PB92-156959

Comet Halley Archive. Summary Volume

Jet Propulsion Lab., Pasadena, CA

Prepared for:

National Aeronautics and Space Administration, Washington, DC

Aug 91

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC INFORMATION

PB92-156959

Report Nos: none

Title: Comet Halley Archive. Summary Volume.

Date: Aug 91

Authors: Z. Sekanina, and L. Fry.

Performing Organization: Jet Propulsion Lab., Pasadena, CA.

Sponsoring Organization: *National Aeronautics and Space Administration, Washington, DC.

Supplementary Notes: Sponsored by National Aeronautics and Space Administration, Washington, DC.

NTIS Field/Group Codes: 54C, 54B

Price: PC A15/MF A03

Availability: Available from the National Technical Information Service, Springfield, VA. 22161

Number of Pages: 337p

Keywords: *Halley's comet, *Archives, Astrometry, Infrared astronomy, Meteor trails, Photometry, Radio astronomy, Spectrophotometry, Spectroscopy, *Comet Halley Archive.

Abstract: Contents: The Organizational History of the International Halley Watch; Operations of the International Halley Watch from a Lead Center Perspective; The Steering Group; Astrometry Network; Infrared Studies Network; Large-Scale Phenomena Network; Meteor Studies Network; Near-Nucleus Studies Network; Photometry and Polarimetry Network; Radio Science Network; Spectroscopy and Spectrophotometry Network; Amateur Observation Network; Use of the CD-ROM Archive; The 1986 Passage of Comet Halley; Recent Observations of Comet Halley.

PB92-156159

THE COMET HALLEY ARCHIVE SUMMARY VOLUME

ZDENEK SEKANINA, *EDITOR*

LORI FRY, *PRODUCTION EDITOR*

AUGUST 1991

INTERNATIONAL HALLEY WATCH

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The Comet Halley Archive Summary Volume

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This publication was prepared by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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PREFACE

The archive for periodic comets Halley and Giacobini-Zinner is being produced in two forms: a digital version, which is stored on compact discs—read only memory (CD-ROMs), and a printed version. The reduced observations of the two comets belong to one of the following networks or disciplines:

Network Number	Network or Discipline
1.	Astrometry
2.	Infrared Studies
3.	Large-Sca[illegible]henomena
4.	Near-N[illegible] Studies
5.	Photometry and Polarimetry
6.	Radio Studies
7.	Spectroscopy and Spectrophotometry
8.	Amateur Observations
9.	Meteor Studies

The Giacobini-Zinner CD-ROM also contains P/Crommelin data, in less refined form.

This summary volume contains chapters describing each of the disciplines or networks. It also includes chapters on the organizational history of the International Halley Watch (IHW), on the IHW's operations, and on the Steering Group. and summary articles detailing Comet Halley's 1986 apparition and recent observations of the comet at large heliocentric distances.

Some of the networks have been organized into subnetworks, as follows:

Infrared Studies Network

Subnetwork 2.1.	Infrared Photometry
Subnetwork 2.2.	Infrared Polarimetry
Subnetwork 2.3.	Infrared Spectroscopy
Subnetwork 2.4.	Infrared Imaging

Photometry and Polarimetry Network

Subnetwork 5.1.	Broadband Photometry
Subnetwork 5.2.	Narrowband Photometry
Subnetwork 5.3.	Polarimetry
Subnetwork 5.4.	Stokes Parameters

Radio Studies Network

Subnetwork 6.1.	Hydroxyl Feature at 18 cm
Subnetwork 6.2.	Spectral Line
Subnetwork 6.3.	Continuum
Subnetwork 6.4.	Occultation
Subnetwork 6.5.	Radar

Amateur Observations Network

Subnetwork 8.1. Visual-Appearance Descriptions
Subnetwork 8.2. Drawings
Subnetwork 8.3. Photographs
Subnetwork 8.4. Spectroscopy

Meteor Studies Network

Subnetwork 9.1. Radar
Subnetwork 9.2. Visual

In the digital version of the Archive, the data, except for the digitized images supplied by the Large-Scale Phenomena Network, are combined into a number of subdirectories. Each of these subdirectories contains one or more files, along with any relevant explanations. One of these subdirectories, called EPHEM, provides geocentric ephemerides (using the equinox and mean equator 1950.0) for midnight Universal Time (U.T.) of each day, covering the intervals of observations for comets Halley and Giacobini-Zinner.

The large-scale images, in both compressed and browse forms, are contained in their own subdirectories, apart from the other data's subdirectories. In addition, the Large-Scale Phenomena Network's browse files are included along with the files for other disciplines, in the main subdirectories.

The digital archive is written in the Flexible Image Transport System (FITS) format.[1] The data appear as part of the FITS headers, in FITS data records, or in table extensions. The FITS headers consist of keywords, some of which were mandatory (as dictated by use of the FITS format or as stipulated by the IHW), while others were selected as needed by the Discipline Specialist Teams and therefore apply only to specific networks. More detailed information on the organizations, indexing, and general use of the digital archive can be found in the chapter by E. Grayzeck, Jr., and D. Klinglesmith III.

In the printed archive, the reduced observations are integrated chronologically by date and by network for each date, with two exceptions: the Meteor Studies Network data are contained in a separate chapter, and no Amateur Observations Network data have been included. The ephemeris in the printed archive is listed with the observations for each date, preceding the data of the first network active on that date.

The evaluation of the submitted observations and their selection for the Archive have primarily been the Discipline Specialist Teams' responsibility. In this summary volume, each Discipline Specialist Team has provided, for its network, an outline and a data-organization description of both the digital and printed versions of the Archive, to expound the process of evaluating, reducing, and formatting the database. This documentation is supplied to orient the Archive's users and to furnish information on the reduction procedures employed to obtain the archived re-

[1] For more information on the FITS format, see Wells, Greisen, and Harten, Astron. Astrophys. Suppl. Ser. 44, 363–370, 1981; Greisen and Harten, Astron. Astrophys. Suppl. Ser. 44, 371–371, 1981; Grosbøl, Harten, Greisen, and Wells, Astron. Astrophys. Suppl. Ser. 73, 359–364, 1988; and Harten, Grosbøl, Greisen, and Wells, Astron. Astrophys. Suppl. Ser. 73, 365–372, 1988.

sults from the measured data. In addition, a table in each network's chapter lists the names, affiliations, and responsibilities of that network's Discipline Specialist Team.

This Archive is a result of major efforts by many individuals, from the observers to the Discipline Specialist Teams to the personnel of the two IHW Lead Centers. Without this Archive, the information provided here either would remain unpublished or would have to be acquired through time-consuming searches in the literature. We therefore request that this Archive be acknowledged in the references of any publications that employ the data presented here.

The decade of the IHW has been one filled with hard work, problems to be solved, fascinating experiences, and, finally, with this publication and release of the CDs, a sense of accomplishment and even triumph. We hope all of you find this archive to be as useful as all of us who worked on it want and expect it to be.

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THE ORGANIZATIONAL HISTORY OF THE INTERNATIONAL HALLEY WATCH

Ray L. Newburn, Jr.
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Jürgen Rahe
University of Erlangen-Nürnberg
Erlangen, F.R.G.

Louis Friedman, then a systems engineer at the Jet Propulsion Laboratory (JPL), originated the concept for some form of internationally recognized organization to coordinate the scientific studies of Comet Halley during its 1986 apparition. While on leave from JPL in 1979, he was working for the U.S. Senate Committee on Commerce, Science and Transportation as an American Institute of Aeronautics and Astronautics (AIAA) congressional fellow. From that position, he saw widespread interest building in P/Halley. That summer, he approached the National Aeronautics and Space Administration (NASA) with the idea for a small study, to be conducted by JPL, to investigate the possibilities of maximizing the scientific return from ground-based and spacecraft studies of the comet through international cooperation and coordination.

Once NASA promised support, Friedman began recruiting help by phone even before returning to JPL. He asked Ray Newburn, an observational cometary astronomer, to concentrate on general ground-based scientific goals of Halley study and the kind of organization that might meet them. Donald Yeomans was recruited for his expertise in astrometry and celestial mechanics, as well as for his enthusiasm for comets and the history of their study. He turned to the task of the cometary ephemeris and geocentric aspects of the upcoming apparition. Astronomer Jay Bergstralh concentrated on Halley studies possible from Earth orbit, using the Shuttle, the Hubble Space Telescope, the International Ultraviolet Explorer, and any other appropriate spacecraft. Friedman himself strongly advocated one or more space missions to Halley, perhaps jointly with the European Space Agency (ESA). He also maintained communications with the study's NASA sponsor, reporting on progress and some of the interesting ideas that began to develop. From the study's first days, the necessity for major international cooperation was obvious, and Newburn immediately dubbed this inquiry the study of an International Halley Watch (IHW).

Long before the IHW study began, John Brandt, a specialist at NASA's Goddard Space Flight Center (GSFC) in the study of cometary ion tails, had recognized a major problem facing research in his field. A substantial ion tail develops only when a comet is at small heliocentric distances, and this usually means the comet is also at a small angular distance from the Sun. Thus, a comet can only be photographed for a short period of time each night from any given site. The continuous coverage needed for the study of an ion tail, which can change considerably in a few hours, can only be obtained by having observing sites scattered in longitude worldwide. Since Halley also goes far south part of the time (to more than 47° south declination), coverage in latitude is mandatory as well. By late 1979, Brandt, Jürgen Rahe (then director of the Astronomical Institute of the University of Erlangen-Nürnberg and on sabbatical at GSFC), Malcolm Niedner (GSFC), and others already had developed a large organization for just such cooperative photography.

After the IHW study team began forming, it communicated regularly with Brandt's team, and, in December 1979, made a trip to GSFC for extended discussions. On January 23, 1980, the IHW team, supported by Brandt, made its first formal presentations to NASA in Washington, D.C. The team suggested that NASA provide financial support for setting up an International Halley Watch to coordinate all ground-based observing of Halley's Comet, as well as coordinating between ground-based studies and such space missions as might be flown. Friedman continued to place great emphasis upon the IHW as an advocacy group encouraging and supporting any scientifically valid means of studying P/Halley (and especially supporting a U.S. mission to Halley).

As a result of the IHW study team's presentations, NASA set up a formal Science Working Group (SWG) to study the concept. The SWG consisted of a broad cross-section of U.S. cometary scientists and study team members, with Brandt as chairman and Newburn as vice-chairman (see Table I).

In the meantime, Friedman had informed ESA, in a letter dated October 17, 1979, of the IHW study. After the very positive response on December 12 from George Haskell of ESA Headquarters, ESA observers were invited to the SWG meetings. Haskell attended the first of these, held March 24–25, 1980, at GSFC.

Friedman also began public advocacy of the IHW. For example, at an AIAA meeting in Pasadena, California, January 14–16, 1980, he gave a paper entitled "A Proposal for a U.S. Initiative: The International Halley Watch." However, the NASA Science Working Group considered this emphasis on a U.S. initiative to be somewhat misplaced: the SWG considered it to be most important that the IHW be made truly international and not be simply an arm of NASA, although the need for NASA's financial support was apparent.

A draft operations plan for the IHW, dated February 28, 1980, already had many of the features that were to appear in the approved IHW:

- The position of Discipline Specialist (DS) as a sort of Principal Investigator (PI) for a given ground-based observational field had been identified.
- A Steering Group of scientists from many nations and from sponsoring organizations was suggested.
- The importance of making good use of the enthusiasm of amateur astronomers was recognized.
- Tie-ins with the flight projects through their project scientists were suggested.
- A Halley Handbook was planned.
- A newsletter for regular communications with all IHW participants was suggested.
- Mass public interest was anticipated, and the importance of a public information office and printed material for the layman was foreseen.
- To avoid a situation such as that in 1910, when much of the Halley data remained unpublished and soon became virtually inaccessible, "The Halley Archive" was planned to contain as much Halley data as was humanly possible.

Table I. The IHW Science Working Group

Michael F. A'Hearn	University of Maryland at College Park, Maryland, U.S.A.
Michael J.S. Belton	Kitt Peak National Observatory, Tucson, Arizona, U.S.A.
John C. Brandt (Chairman)	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
Geoffrey A. Briggs	NASA Headquarters, Washington, D.C., U.S.A.
Donald E. Brownlee	University of Washington, Seattle, Washington, U.S.A.
William E. Brunk	NASA Headquarters, Washington, D.C., U.S.A.
Mark R. Chartrand	American Museum, Hayden Planetarium, New York City, New York, U.S.A.
Armand H. Delsemme	University of Toledo, Toledo, Ohio, U.S.A.
Donald L. DeVincenzi	NASA Headquarters, Washington, D.C., U.S.A.
Bertram Donn (Chairman, IAU Commission 15)	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
Louis D. Friedman (Manager, International Halley Watch Study)	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, U.S.A.
J. Michael Hollis	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
Ray L. Newburn (Vice-Chairman)	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, U.S.A.
Edward P. Ney	University of Minnesota at Minneapolis St. Paul, Minnesota, U.S.A.
Jürgen Rahe	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A., and University of Erlangen-Nürnberg, Erlangen, F.R.G.
Lewis E. Snyder	University of Illinois, Urbana, Illinois, U.S.A.
Edward J. Weiler	NASA Headquarters, Washington, D.C., U.S.A.
Kurt W. Weiler	National Science Foundation, Washington, D.C., U.S.A.
Fred L. Whipple	Harvard University, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, U.S.A.
Donald K. Yeomans (Executive Secretary)	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, U.S.A.

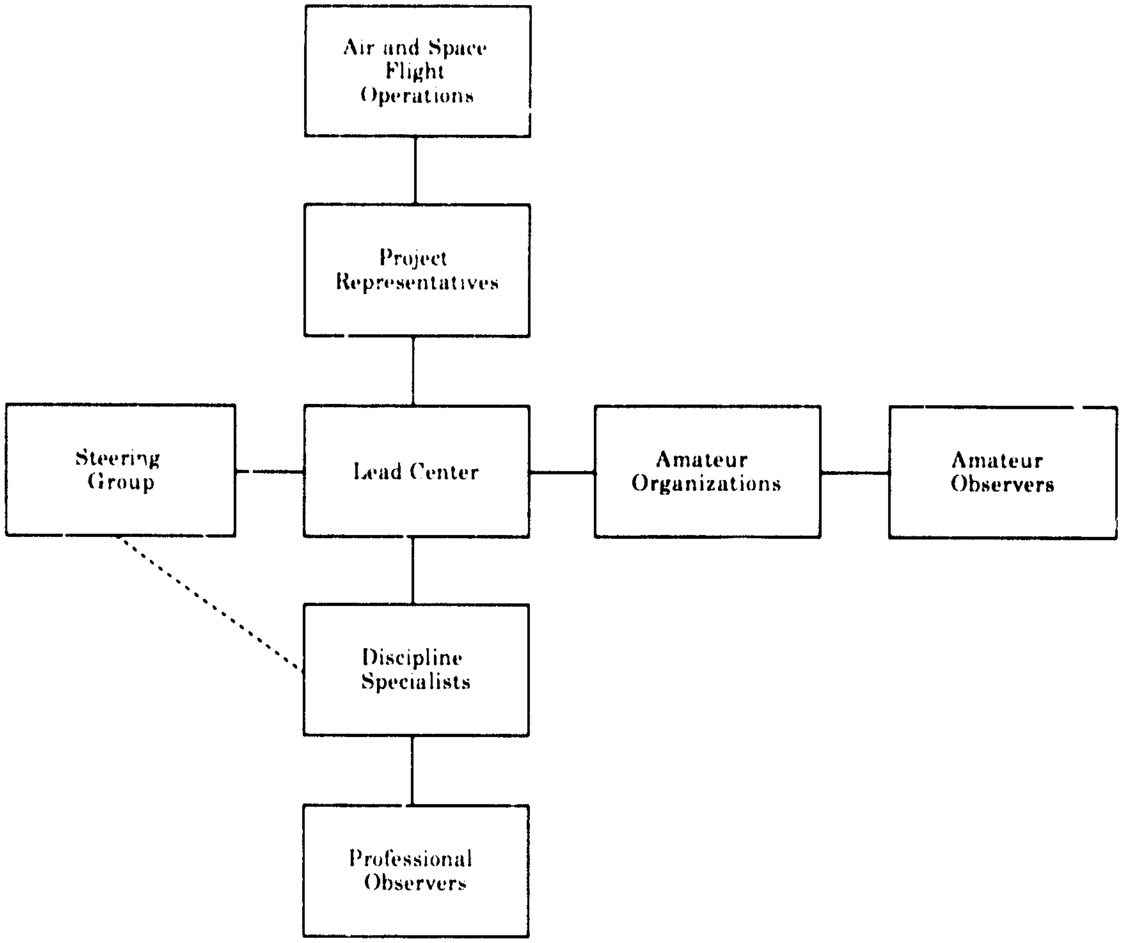

Figure 1. IHW Organization

The March 1980 SWG meeting considered two major topics: how best to accomplish the desirable ground-based science and how best to organize toward that goal. Figure 1 shows the organization chart that was accepted.

Other important occurrences at this meeting included:

- The SWG recommended that a seventh discipline (Near-Nucleus Studies) be added to the six suggested by the original study team.
- A draft of Yeomans' "Halley Handbook" was presented for critiquing.
- Discussion began on two important questions: "What were observers' proprietary rights to their data?" and "What would the probable IHW costs be?"

By the time of the May 1980 SWG meeting, a logical concept for data rights, which was essentially the one ultimately adopted, had evolved: All observers would be encouraged to publish their data in the established journals just as they normally would do. Then they would be encouraged to contribute just the reduced data, with no interpretations, to the archive, which would be simply a database of every type of Halley observation, with the source properly attributed.

The administrative costs for the IHW would be principally for discipline organization and operation and for data handling, but would also include publication and free distribution of "The Halley Archive" to all those contributing to it. These costs were estimated to be $10 million (in 1980 dollars).

On June 24, 1980, Friedman formally recommended to NASA Associate Administrator Tim Mutch that NASA proceed with the IHW. Friedman also announced his intention to "phase out" as IHW leader, following completion of the SWG's final report, "so the cometary scientists can run it." The SWG's final report was published in July 1980 and was reviewed by NASA on August 1.

The months following this final review were a time of some confusion. NASA had indicated its intent to proceed with the IHW, but had not indicated exactly when or how. Nor was it clear until much later whether or not NASA would fly a spacecraft to Comet Halley.

In late fall of 1980, an IHW Lead Center was established at JPL, and Newburn became acting Leader of the IHW. During this period, IHW support was supplied from NASA "pre-project" funds. For fiscal year 1982, IHW support appeared as a "line item" in the U.S. congressional budget for NASA for the first time.

In August 1981, Newburn and Rahe became permanent Co-Leaders for the western and eastern hemispheres, respectively. Each Leader became responsible for all IHW business, including setting agendas and chairing general meetings, in his hemisphere.

The IHW Lead Center at JPL became the western hemisphere Lead Center, while a new Lead Center, supported by the West German government, was established in Bamberg, at the Astronomical Institute, University of Erlangen-Nürnberg.

As soon as the JPL Lead Center had been established, two major tasks were undertaken: selection of the Steering Group (SG) and preparation of a solicitation seeking Discipline Specialists (DSs). After consultation with the Lead Center, NASA issued formal invitations to 20 scientists to join the Steering Group. Newburn invited those who accepted membership to the first SG meeting at GSFC April 30 and May 1, 1981. Table II lists these initial SG members.

Meanwhile, on April 20, 1981, the Lead Center sent out, to more than 4,000 scientists worldwide, an announcement of the competition for DS positions. Proposals were due at JPL on July 20, 1981.

The first SG meeting provided the opportunity to begin an informal dialog between the young IHW administrative arm and its even younger Steering Group. It was recognized that as time passed, it would become more and more difficult to make really fundamental changes in the IHW's structure. Thus, this first meeting's most important work was to discuss everyone's ideas for how the IHW should be organized and should operate.

Everyone present recognized that gaining International Astronomical Union (IAU) sponsorship would be a key to international success. Therefore, two SG members (Bertram Donn and Armand Delsemme) drafted a request to the IAU Executive Council. This request asked that, at the IAU General Assembly's 1982 triennial meeting, the Executive Council recommend recognition by the General Assembly of the IHW as the official international body for coordinating observations of Comet Halley. On August 12, 1981, in a letter to the chairman (Donn) of IAU Commission 15 (Comets, Minor Planets, and Meteorites), the IAU Executive Council "enthusiastically accepted" that recommendation.

Table II. The Original IHW Steering Group

M.K. Vainu Bappu	Indian Institute of Astrophysics, Bangalore, India
Michael J.S. Belton	Kitt Peak National Observatory, Tucson, Arizona, U.S.A.
Jacques Blamont	Laboratoire d'Aeronomie CNRS, Verrieres-le-Buisson, France
Geoffrey A. Briggs	NASA Headquarters, Washington, D.C., U.S.A.
Armand H. Delsemme	University of Toledo, Toledo, Ohio, U.S.A.
Bertram Donn	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
Hugo Fechtig	Max Planck Institut für Kernphysik, Heidelberg, F.R.G.
Ian Halliday	Herzberg Institute of Astrophysics, National Research Council of Canada, Ottawa, Canada
George H. Herbig	University of California, Santa Cruz, California, U.S.A.
Yoshihide Kozai	Tokyo Astronomical Observatory, Tokyo, Japan
Reimar Lüst	Max Planck Gesellschaft, München, F.R.G.
Alla Massevitch	Academy of Sciences of the U.S.S.R., Moscow, U.S.S.R.
Charles Robert O'Dell	NASA Marshall Space Flight Center, Huntsville, Alabama, U.S.A.
Rudeger Reinhard	European Space Research and Technology Center, Noordwijk, The Netherlands
Hans Emil Schuster	European Southern Observatory, Santiago, Chile
Vladimir Vanysek	Charles University, Praha, Czechoslovakia
Joseph F. Veverka	Cornell University, Ithaca, New York, U.S.A.
Kurt W. Weiler	National Science Foundation, Washington, D.C., U.S.A.
George Wetherill	Carnegie Institution of Washington, Washington, D.C., U.S.A.
Fred L. Whipple	Harvard University, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, U.S.A.
Laurel L. Wilkening	University of Arizona, Tucson, Arizona, U.S.A.
Ya.S. Yatskiv	Main Astronomical Observatory, Academy of Sciences of the Ukrainian Republic, Kiev, U.S.S.R.

During the first SG meeting, Hugo Fechtig observed that an international group should have international meetings. Thus, the SG agreed that two of the next four meetings would be held outside of the U.S. The SG also discussed the DS competition in detail and began preparation for evaluating the resulting proposals. This evaluation would be the major task of the second SG meeting, in the fall of 1981.

Also discussed at this first SG meeting were two other topics with major future importance: a trial run and the archive of Halley data. The Lead Center suggested that a brief trial run on some convenient comet during 1984 would be a useful end-to-end t t of the IHW. The SG therefore requested more data on possible targets.

When the discussion turned to the topic of archiving, Joseph Veverka expressed great concern about the long-term survival of the data. Some of the 1910 Halley data had been lost as a result of war, and much more data had been taken, but never published. For the IHW to truly succeed, the widespread dissemination of the 1986 Halley data on some "permanent" medium would be necessary. Since magnetic media (tapes and disks) are impermanent, inconvenient, and expensive, books, because of their durability and their convenience, seemed to everyone to be the best bet for all data that could be presented in tabular form. Images, however, were another problem. Veverka suggested that video discs be used to archive images. This suggestion started a major investigation by Newburn of video disc technology, which would eventually have considerable impact on the IHW.

As a result of the first SG meeting, Jacques Blamont approached COSPAR (an international organization promoting cooperation in space research), suggesting that the IHW might provide a mechanism for promoting better cooperation between the several space missions being planned to study Halley's Comet. However, the four agencies actually planning such missions—NASA, ESA, Japan's Institute of Space and Astronautical Science (ISAS), and the U.S.S.R.'s Intercosmos Council—decided that COSPAR was too large and formal an organization within which to try to accomplish the sort of cooperation that they hoped to bring about. Therefore, a group of representatives from the four agencies (which came to be called the Inter-Agency Consultative Group [IACG]) organized a separate meeting, which was held September 13–15, 1981, at the University of Padova (Padua), Italy, and was hosted by Giuseppe Colombo on behalf of ESA. Newburn and Rahe were invited to discuss the IHW concept, and Yeomans (of the JPL study team and later an IHW astrometry DS) gave a presentation on the Halley ephemeris problem. The flight project agencies recognized the utility of the IHW, especially its proposed astrometry network, for their missions. Therefore, the IACG invited the IHW to participate in their future deliberations. Thus, the IHW actually came to play a part of the role that Friedman had originally conceived for it—helping coordinate the space missions.

By the time of the second SG meeting, the Pasadena Lead Center was fully operational, and Rahe was beginning to build the Bamberg center. Murray Geller had been appointed Deputy Leader of the IHW and Executive Secretary of the SG. Zdenek Sekanina had been named editor of the Halley Archive, and Stephen Edberg the coordinator of work by amateurs. L. William Carls, as IHW administrator, handled such items as contracts and travel. Lori Fry later became the production editor for all IHW documents. Robert Gardner became the computer scientist, but he was replaced, following a serious traffic accident, temporarily by Lee Elson and then permanently by Mikael Aronsson. Soon after the start of the Bamberg Lead Center, Horst Drechsel became Rahe's Deputy and Rudiger Knigge began helping coordinate amateur astronomers in the eastern hemisphere. Only the computer scientist position was ever a full-time one; all others were half-time or less. The IHW was run as a taut and austere project, with used computing equipment and no backup personnel.

As the proposals for the DS jobs arrived at JPL, they were distributed to the SG members to evaluate. At the second IHW SG meeting, held at GSFC November 11–13, 1981, the SG constituted itself as a review panel. A chairman for each proposal type, who had been selected at the first SG meeting, presented each proposal and the collective views of the evaluators of it. The chairman then made his own comments, solicited additional comments from other evaluators, and entertained questions and comments from any SG member. Next, a vote was taken on each proposal, placing it in one of four categories (from "excellent" to "unacceptable"). Only SG members voted (Lead Center personnel were never SG members), and anyone with a personal or institutional relationship to the proposer absented himself or herself during the discussion and voting.

In some cases, the selection was very obvious as soon as the individual votes were taken. In other cases, however, the results were not clear-cut, so additional discussion took place before final voting between the two highest rated proposals in that category. In mid-January 1982, all proposers were notified of the selection procedure's results. Then each DS selected was asked to assemble a team that included members from both sides of the Atlantic Ocean. Table III lists the DS teams as finally constituted in 1982 (plus a 1984 addition, Meteor Studies).

At JPL, March 15–16, 1982, the Discipline Specialists assembled for the first time, for a comprehensive briefing and an exchange of ideas. All the DSs and Lead Center personnel had a chance to express their views about the IHW and how it should operate. During the first months of 1982, the Pasadena Lead Center's major task was to get the DSs who were to be supported by NASA under contract to JPL. A major task for everyone was to prepare for the upcoming IAU meeting.

The IAU held its 18th General Assembly in Patras, Greece, August 16–26, 1982. Every scientist attending the meeting received a copy of the first "IHW Newsletter," which gave a complete description of the IHW organization and its plans for Halley. The newsletter also contained forms to send to the appropriate DS to join the Halley observing networks, as well as forms for free subscriptions to future issues of the "IHW Newsletter."

The General Assembly passed two resolutions supporting the IHW. Figure 2 shows the letter from IAU General Secretary Richard West that officially informed the IHW of the IAU actions. This imprimatur, more than any other action, marked the IHW as an accepted international scientific organization, with duties and responsibilities to astronomy and astronomers worldwide that could not be usurped by any other organization. The IHW had come of age. Although the IHW had been discussed previously at several astronomical meetings, it was not until this time that formal announcement of the IHW and its plans and goals was made to the world press.

Following the IAU General Assembly, the IHW Discipline Specialists and Steering Group members met with each other for the first time, August 28–29, 1982. In addition to the two days of joint meetings, each group had one day of private meetings: the DSs on August 27 and the SG on August 30.

During the joint meetings, the SG expressed concern that the various observing networks might be too independent of each other, competing for observers and for observing time rather than cooperating and coordinating. Therefore, the IHW sent a general letter, including a copy of the IAU resolutions, to observatory directors worldwide. This letter asked for the directors' help and understanding in dealing with the telescope scheduling problem and offered the IHW's help in providing material for the observatories' contacts with the general public. Over the years, though, the concern over competition proved illusory, mainly because the observers did what they always did, and the observatory committees allocated observing time

Table III. The IHW Discipline Specialist Teams

Astrometry

Donald K. Yeomans	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, U.S.A.
R.M. West	European Southern Observatory, Santiago, Chile
R.S. Harrington	U.S. Naval Observatory, Washington, D.C., U.S.A.
B.G. Marsden	Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts, U.S.A.

Infrared Spectroscopy and Radiometry

R.F. Knacke	State University of New York at Stony Brook, New York, U.S.A.
T. Encrenaz	Observatoire de Paris, Meudon, France

Large-Scale Phenomena

John C. Brandt	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
M.B. Niedner	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
Jürgen Rahe	Dr. Remeis Sternwarte, Bamberg, F.R.G.

Meteor Studies

B. McIntosh	Herzberg Institute of Astrophysics, National Research Council of Canada, Ottawa, Canada
P.B. Babadzhanov	Astrophysical Institute, Academy of Sciences of the Tadjik S.S.R., Dushanbe, U.S.S.R.
A. Hajduk	Astronomical Institute, Slovak Academy of Sciences, Bratislava, Czechoslovakia
B. Lindblad	Institute for Astronomy, Lund University, Lund, Sweden

Near-Nucleus Studies

S. Larson	University of Arizona, Tucson, Arizona, U.S.A.
Z. Sekanina	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, U.S.A.
Jürgen Rahe	Dr. Remeis Sternwarte, Bamberg, F.R.G.

Table III. (continued)

Photometry and Polarimetry	
Michael F. A'Hearn	University of Maryland at College Park, Maryland, U.S.A.
Vladimir Vanysek	Charles University, Praha, Czechoslovakia
Radio Studies	
W.M. Irvine	University of Massachusetts, Amherst, Massachusetts, U.S.A.
F.P. Schloerb	University of Massachusetts, Amherst, Massachusetts, U.S.A.
E. Gerard	Observatoire de Paris, Meudon, France
R.D. Brown	Monash University, Clayton, Victoria, Australia
P. Godfrey	Monash University, Clayton, Victoria, Australia
Spectroscopy and Spectrophotometry	
S. Wyckoff	Arizona State University, Tempe, Arizona, U.S.A.
P.A. Wehinger	Arizona State University, Tempe, Arizona, U.S.A.
M.C. Festou	Institut d'Astrophysique, Paris, France

based upon the quality of observer requests, quite independent of the DSs. However, most observatories did heed the IAU resolution and gave far more time to comet observations than they ever had before. A number of countries, including the U.K., France, the People's Republic of China, and the U.S.S.R., set up national Halley organizations to allocate observing time and funds. The IHW always accepted whatever was offered, dealing with national organizations at their request.

At the IAU General Assembly meeting, a special concern had been how the IHW would respond to the sudden pressure when Comet Halley was recovered. The IHW received many useful suggestions, though it could not follow them all, primarily because the actual recovery of Halley occurred only about seven weeks later, on October 16, 1982.

By this time, the IHW did have a press statement ready, with only a few blanks—concerning who made the recovery, when, where, and how—left to be filled in. Thanks to prior contacts with most of the principal groups attempting to recover Halley, the IHW was assured that it would receive word at the earliest possible moment.

In reality, the situation was complicated by the timing of the actual recovery—during the annual meeting of the Division of Planetary Sciences of the American Astronomical Society, in Boulder, Colorado. Newburn found himself being

INTERNATIONAL ASTRONOMICAL UNION

UNION ASTRONOMIQUE INTERNATIONALE

The 18th General Assembly of the International Astronomical Union, in session in Patras, Greece, on August 26, 1982, adopted the following Resolutions:

The International Astronomical Union

recognizing that it is particularly desirable that pre-selected Comet Halley Days for co-ordinated observation over a limited time be supported

recommends that observatory directors and observing program committees give high priority to Comet Halley observation during the interval 1985-1987.

The International Astronomical Union

noting that in order to organise and marshall ground-based observations of Comet Halley throughout its 1986 perihelion passage and to co-ordinate them with space missions, an international program, the International Halley Watch, has been established

and wishing to avoid duplication of effort at the international level and to encourage participation in this program

endorses the International Halley Watch as the international co-ordinating agency for Comet Halley observations.

R.M. West
General Secretary

Figure 2. IAU Resolutions

questioned by reporters in Boulder, while most of the information was in Pasadena, California. The phone lines received much good use that week.

With recognition by the IAU and the recovery of Comet Halley, the IHW's organization was essentially complete. What remained were largely operational problems. However, a few organizational changes occurred over the years that need to be recognized. Until the IACG's second meeting, in Dobogókö, Hungary, November 21–23, 1982, the IACG considered the IHW to be an arm of NASA. Therefore, although Newburn attended the Dobogókö meeting as a member of the NASA delegation, Rahe represented neither NASA nor ESA, so he was not invited! Newburn complained vociferously about this, noting the International Halley Watch's IAU validation as an independent international organization. The IACG accepted this plea and declared November 22 to be IHW Independence Day! Thereafter, the IHW named its own members to IACG meetings, but since the IHW was not a space agency, they were called "representatives," not "delegates," and did not sign official protocols.

In 1983, NASA used a complex series of swing-bys of the Earth and Moon, discovered by Robert Farquhar, to divert the International Sun-Earth Explorer (ISEE-3) to P/Giacobini-Zinner. The mission then became the International Cometary Explorer (ICE).

NASA requested that the IHW observe Giacobini-Zinner (G-Z) during its 1985 apparition. The IHW agreed; G-Z offered an excellent extended second check of the IHW's operational readiness. The first operational check would be a trial run on P/Crommelin, March 25–31, 1984. The Crommelin data would be published in book form late in 1985, while the G-Z data would be used in early 1989 for the IHW's first test of its ability to produce a compact disc—read only memory (CD-ROM).

At the IHW general meeting in Prague, Czechoslovakia, June 20–22, 1984, the IHW officially became independent of NASA. However, the IHW was not totally independent of NASA, since NASA remained its primary funding source. Therefore, the SG could not make changes that would severely impact the budget. However, once the IHW was officially independent, the SG could name its own members. Table IV gives the final list of SG members.

Also at the Prague meeting, the SG strongly recommended that a Meteor Studies Network be added to the IHW as an eighth professional discipline. The Lead Center accepted this recommendation.

The IHW's last general meeting was held at European Southern Observatory (ESO) Headquarters in Garching bei München, Germany, April 21–22, 1989. At this meeting, a major concern was late data sets, some of them very important data sets. Nominally, all data had been due at the Pasadena Lead Center by April 1, 1989. The Lead Center agreed to accept a few additional sets until July 1, 1989. All funding for the DSs ended on that date, although most of the DSs agreed to help correct errors in the data and to provide documentation of their activities as originally contracted.

Fiscal year 1990 provided the last major support for the Pasadena Lead Center to produce the Halley Archive. A small amount of the 1990 funding was carried over into fiscal 1991 to produce this volume and distribute the archive, and some of the funds cut in 1990 were restored in 1991, to assure readiness for production of a printed archive. Following distribution of the archive, the IHW will have completed its job and its decade of activity, and it officially will go out of existence.

Table IV. The Final IHW Steering Group*

W.I. Axford	Max Planck Institut für Aeronomie, Katlenburg-Lindau, F.R.G.
Michael J.S. Belton	Kitt Peak National Observatory, Tucson, Arizona, U.S.A.
Jacques Blamont	Laboratoire d'Aeronomie CNRS, Verrieres-le-Buisson, France
Geoffrey A. Briggs	NASA Headquarters, Washington, D.C., U.S.A.
William E. Brunk	Universities Space Research Association (U.S.R.A.), Washington, D.C., U.S.A.
Armand H. Delsemme	University of Toledo, Toledo, Ohio, U.S.A.
Bertram Donn	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
Hugo Fechtig	Max Planck Institut für Kernphysik, Heidelberg, F.R.G.
Louis D. Friedman	The Planetary Society, Pasadena, California, U.S.A.
Shu Mo Gong	Academia Sinica, Nanjing, People's Republic of China
Ian Halliday	Herzberg Institute of Astrophysics, National Research Council of Canada, Ottawa, Canada
George H. Herbig	University of California, Santa Cruz, California, U.S.A.
Kunio Hirao	Institute of Space and Astronautical Science, Tokyo, Japan
Yoshihide Kozai	Tokyo Astronomical Observatory, Tokyo, Japan
Lubor Kresák	Slovak Academy of Sciences, Bratislava, Czechoslovakia
Reimar Lüst	European Space Agency, Paris, France
Alla Massevitch	Academy of Sciences of the U.S.S.R., Moscow, U.S.S.R.
Charles Robert O'Dell	Rice University, Houston, Texas, U.S.A.
Vernon Pankonin	National Science Foundation, Washington, D.C., U.S.A.

*Over the years, many changes occurred in the Steering Group. The death of our valued friend and colleague Vainu Bappu in 1982 was a special loss. Jack Meadows of the University of Leicester in the U.K. was a great help from 1983–1986.

Table IV. (continued)

Rudeger Reinhard	European Space Research and Technology Center, Noordwijk, The Netherlands
R.Z. Sagdeev	Academy of Sciences of the U.S.S.R., Moscow, U.S.S.R.
Hans Emil Schuster	European Southern Observatory, Santiago, Chile
K.R. Sivaraman	Indian Institute of Astrophysics, Bangalore, India
Vladimir Vanysek	Charles University, Praha, Czechoslovakia
Joseph F. Veverka	Cornell University, Ithaca, New York, U.S.A.
George Wetherill	Carnegie Institution of Washington, Washington, D.C., U.S.A.
Fred L. Whipple	Harvard University, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, U.S.A.
I.P. Williams	Queen Mary College, London, U.K.
Ya.S. Yatskiv	Main Astronomical Observatory, Academy of Sciences of the Ukrainian Republic, Kiev, U.S.S.R.

OPERATIONS OF THE INTERNATIONAL HALLEY WATCH FROM A LEAD CENTER PERSPECTIVE

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Jet Propulsion Laboratory
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University of Erlangen-Nürnberg
Erlangen, F.R.G.

Working on the International Halley Watch (IHW) was a rare privilege, the experience of a lifetime. The IHW saw scientists of many lands really working together for the good of science, just the way it is supposed to happen. Even in that pre-*glasnost* period, scientists from the U.S. and the U.S.S.R. worked together happily and enthusiastically, along with scientists from 50 other countries. The Comet Halley advent was a time of great excitement for the astronomer and for the layperson, building from the comet's recovery on October 16, 1982, to a crescendo during the spacecraft encounters in March 1986. From the fall of 1985 through April of 1986, the Lead Center at the Jet Propulsion Laboratory (JPL) found itself swamped with requests for information, talks, and interviews, just as every other part of the IHW did. As the excitement began to fade, the hard work really began: creation of "The Comet Halley Archive." This publication marks the successful conclusion of the IHW.

Those who have lived through an experience-of-a-lifetime find it almost imperative to tell others about it, to give helpful(?) advice. The most important advice for any multinational cooperative program is to begin at the earliest possible time. The IHW barely got all its organizational pieces assembled in time for the 1982 International Astronomical Union (IAU) meeting, and the IAU clearly is THE organization whose official support is needed for any international astronomical program.

A stable source of funds is needed for administrative activity. There could have been no IHW without the financial support of many governments, especially the U.S. Congress through the National Aeronautics and Space Administration (NASA). A completely volunteer organization, without a sponsor, has little hope of doing more than just limping along, perhaps providing minor, though useful, coordination of efforts. However, the IHW was a volunteer organization in so far as the observing was concerned. All astronomers used their normal funding for their work. Even the IHW would have benefited from additional support. Our old, obsolete computer broke down regularly at the worst possible times, and we never had adequate computing staff to perform many useful, if not absolutely necessary, functions. We always lived in fear that we would lose one of our key personnel, for we had no backups for anyone. Fortunately, we were a healthy, dedicated, nearly accident-free group.

A critical part of maintaining project enthusiasm and coordination, especially in a project with considerable volunteer help, is timely communications. The most widespread form of communication used by the IHW was the printed word, in an "IHW Newsletter" for the professional astronomers and an "Amateur Bulletin" for the amateurs. We did not have the staff to publish these as frequently as we would have liked, but the publications did provide a common forum for all of the IHW. In addition, the individual disciplines had their own newsletters for communication of technical details to their network members. A special IHW electronic mail system was set up to provide more rapid communications between Lead Centers, Discipline Specialists (DSs), and Steering Group Members. Telephone and telex provided the most rapid time-critical communications, used especially by the Astrometry Network. The IHW was just barely too early for fax, which would have been enormously useful at times. There is little doubt, in any case, that the IHW would have benefited from better and more frequent communications. Nothing is more important in maintaining high morale and enthusiasm than keeping everybody well-informed.

It should come as no surprise that most of the operational problems anticipated in early IHW planning proved to be of minor concern or of no concern at all, in part because they were anticipated. There WERE operational problems, however. In the flush of the IHW's successful conclusion, it would be easy to just sweep the problems under the rug. We have decided not to do that, because our thoughts about the problems might help future large-scale cooperative international programs.

The most vexing group of problems throughout a decade of IHW activities occurred in the field of data handling. Part of the trouble was that the IHW took place when all aspects of computer hardware and software were undergoing rapid progress and change. Trying to be up-to-date at the time of publication meant that we often had to make decisions on both hardware and software before international agreements or standardization had been reached. Another difficulty was that the IHW had to deal with people ranging from computer experts to computer illiterates. The technical aspects of the data problem are addressed in another chapter, but a few of the human problems are appropriate for discussion here.

The IHW decided very early that as much data handling as possible should be strictly from computer to computer without direct human manipulation. This was desirable to minimize both the labor involved and the human introduction of errors. Obviously few, if any, amateurs would submit their data electronically or on magnetic tapes or floppy disks, and it is perhaps well that they did not try, because a number of amateurs did not even fill in the printed forms completely and accurately. Much of the amateur data simply had to be discarded because it was incomplete or contained obvious errors. The amateurs have made a valuable contribution to the IHW, but an enormous amount of effort was required to evaluate their data and enter them into the archive. In fact, probably 90% of the valuable data were contributed by 10% of the amateur observers. Depending upon their goals, future astronomical programs involving amateurs could perhaps enrich the data by requiring trial or qualifying observations in order to join the program.

Amateur data problems were anticipated. Problems with professional data were not, though they probably should have been. The personal computer revolution started about the same time as the IHW. Many astronomers of the older generation had professional programmers to handle their mainframe work and have never themselves become comfortable with computers. Therefore, much of the data was submitted as hardcopy, was not submitted in standard Flexible Image Transport System (FITS) format, or was submitted in FITS format, but contained errors. It was the job of the DSs to verify the data and submit them to the Lead Center in correct FITS format. Most did this very well, writing programs to check for format errors and carrying out visual data checks. Contrary to IHW agreements, however, some data were refused by DSs because they were not submitted in FITS format.

Even worse, some data were submitted to the Lead Center unchecked or out of format. Some DSs changed formats that had been formally accepted by the entire IHW, and they did this without any warning to anyone. This caused Lead Center processing-programs to fail regularly. Worst of all, some very fine scientists somehow could not seem to understand, for example, that a format calling for no more than eight characters, left justified, means just that, not nine characters when convenient or six characters centered "because it looks better." Some seemed to feel that the Lead Center should write software that was totally forgiving, anticipating every possible departure from accepted standards and processing the nonstandard submissions correctly anyway. Such artificial-intelligence programming is always difficult to do, especially with limited resources, and is virtually impossible to do in some cases! Then there was the problem with names. A computer, doing any manipulation with names, treats J. Doe, John Doe, J.J. Doe, and Jack Doe as four separate people. Only rarely did such names actually refer to four distinct people, unfortunately. Most commonly, they were all the same person. Any differences in the exact form used for a name required human checking and intervention, to avoid embarrassment. Using 20-20 hindsight, it is possible to say that the Lead Center should have provided certain standard software, such as a FITS writer, a FITS reader, and a FITS format checker, uniformly to all disciplines. A name checker also could have been provided. With the younger generation virtually cutting its teeth on computers, perhaps the human type of computing problems faced by the IHW will mostly go away, but probably not completely.

Because some data were needed by the flight projects at the earliest possible time, the IHW asked that observations be submitted as soon as possible. We worried a great deal about how to protect and preserve the observers' rights in the use of those data. Most physical data on Halley, in fact, came in so slowly and so late that the real problem was the heavy end-loading of all the IHW facilities, not unfair or premature release. Only the Astrometry Network worked in near-real-time, but astrometry specialists were used to working that way and to receiving recognition only in a data line on an "IAU Circular" or a "Minor Planet Circular/Minor Planets and Comets." Those real-time astrometric positions were fundamental to the successful navigation of the spacecraft missions to Halley. Other inputs, on dust and gas production, for example, were given freely to the projects by a subset of network members or were published in preliminary form on "IAU Circulars" for everyone's benefit. In spite of many anguished hours spent worrying about data rights at early IHW meetings, data rights essentially were a nonproblem.

All parts of the IHW spent a great deal of time and care to develop a set of Halley Watch Days, days on which as many observers as possible in each discipline would try to observe Halley. Comets change their appearance and the level of their activity so rapidly that only observations that are virtually simultaneous really can be combined or compared. Lists and charts of Halley Watch Days were circulated widely, and reference was made to them in requests for observing time. It is not clear that this attempt was very successful. Observatory scheduling committees have many boundary conditions placed upon them in assigning telescope time. Even so, most of them cooperated when they were able. Bad weather is always a factor that can defeat the best of schedules. Another problem was the orbit of Halley itself, which placed the comet very far south in the sky of northern observatories during March and April of 1986, when the spacecraft encounters occurred and when the comet was closest to Earth. Overall, evidence exists of some increase in the amount of data taken during Halley Watch Days, but it is not clear that the result was worth the effort. What IS clear is that the average observatory gave an order of magnitude more observing time to comets than normally would have been given, and this provided the IHW with such success as it has achieved. From the IHW, sincere thanks to all the observatory directors and scheduling committees. We could not have done it without you!

Any project in which there is public interest calls for careful early consideration of how that interest will be met. Most scientists have mixed feelings about public interest. It encourages young people to consider careers in science. It can help gain support from a sponsor. It is flattering at times. But it can also be a fearful nuisance. The IHW tried to cope with public interest in Halley in several ways. In advance, the IHW prepared a number of documents giving information on comets in general and Halley in particular, on how to view Halley, on how to photograph Halley, on where to find Halley, and on the IHW. These documents were mailed out in response to a multitude of letters requesting information. The Lead Centers and many DS Centers maintained telephone "hot lines" that were answered by answering machines containing messages updated every day. Most IHW personnel gave many public talks, talks at schools, and interviews to all forms of media, feeling that their message could reach many people at once in this way. The Pasadena Lead Center worked with James Wilson of the JPL Public Information Office to set up a Halley "Museum" that could be visited by school classes or the general public. JPL kept the center staffed for six months. If you are planning a project that will have public visibility and interest, plan well ahead for it, or you will be swamped when you can least afford to be.

Our primary archive is in the form of a set of compact discs—read only memory (CD-ROMs). We also have a complete set of magnetic tapes, but these are unlikely to be maintained or available to anyone for more than a short period of time. A point of considerable debate was whether or not the IHW should also publish a secondary archive in printed form, a set of books. The IHW's goal was to prepare an archive that was readily accessible to all contributors, had archival durability and digital accuracy, and was easy to use. Given only one form of permanent archive, the CD clearly is the medium of choice, a medium that retains the full digital accuracy of all data. Nevertheless, it takes much longer to retrieve one desired number or an analog image from a CD than from a book, and to do the retrieval, it takes several thousand dollars' worth of equipment, equipment that is not available to every interested person in the world. Also, it is not now clear that the archival quality of a CD is nearly as good as that of a book printed on acid-free paper. Discs are guaranteed for only 10 years, although most producers expect them to last much longer. And, on a purely emotional level, the old bibliophiles among us do not get quite the thrill from touching a CD "jewel box" containing "our" work that we do from touching a fine book binding. The Steering Group advised that the CDs be finished first, and then, if sufficient funds were available, a set of books be printed. It now appears that we will be able to provide both CDs and books, and at this writing we plan to do so.

The IHW experience has been extremely positive, positive in scientific results and positive in a social sense, with everyone involved having made many new friends all over the world. It has been an exciting decade. We would not have missed it for anything!

THE STEERING GROUP

Ian Halliday
Herzberg Institute of Astrophysics
National Research Council of Canada
Ottawa, Canada

The initial plans for the International Halley Watch (IHW) recommended that an international group of scientists be appointed as a Steering Group (SG) to review and advise on the plans, activities, and progress of the IHW Leader and the Discipline Specialist (DS) Teams. As described elsewhere in this volume, each discipline was eventually directed by an international team of DSs, and two Lead Centers were established, one for the eastern hemisphere and one for the western. The SG carried out its mandate very much as originally intended.

Early in 1981, the Solar System Exploration Division of the National Aeronautics and Space Administration (NASA) Office of Space Science extended invitations to join the SG. Invitations were sent to recognized comet experts, representatives of space agencies, members of international scientific organizations, and others with an interest in cometary science. A particular effort was made to maintain a broad international membership at all times. During the life of the IHW, some additions and replacements of members on the SG occurred, but a substantial number of members served for the entire nine years of activity by the SG. Between April 1981 and April 1989, the group held fifteen regular meetings, eight in the U.S. and seven in Europe. In October 1988, an additional short meeting was convened to examine technical aspects of the archival process. Held at the western hemisphere Lead Center in Pasadena, California, this meeting was attended by some of the SG members from the U.S. Table I lists the 33 members of the SG who participated at some time in the SG activities.

At the 1982 General Assembly of the International Astronomical Union (IAU), the IHW was affirmed as the sole international body coordinating scientific studies of Comet Halley. Although this status resulted in little change in the SG's operation, it did mean that the SG was free to appoint its own members. The group subsequently defined its terms of reference and its mandate. Also, in 1984, it was decided that the SG should have a Chairman, a decision that led to Ian Halliday's election as Chairman during the January 1985 meeting.

It was natural that the SG's concerns should evolve during the various stages of Comet Halley's apparition. The first major task, in 1981, was to recommend to NASA the selection of DSs from a number of applicants in each discipline and to advise on the membership of each DS team to ensure that they had the appropriate international composition that was considered essential for the IHW's success.

Once the DS teams were well established, the usual procedure at the IHW meetings was to devote a day or more to detailed reports from the various disciplines and from the Lead Centers. The SG then met privately to consider the reports, with special attention given to any potential problem areas. The SG's concerns and recommendations were then presented to the entire group, followed by further discussion. In some cases, the SG's concerns were satisfied at this stage.

The organization of each discipline was a major concern in the years before the comet was bright enough for most networks to begin observations. Did the DS

Table I. The Members of the IHW Steering Group

W.I. Axford	Max Planck Institut für Aeronomie, Katlenburg-Lindau, F.R.G., and Victoria University, Wellington, New Zealand
M.K. Vainu Bappu	Indian Institute of Astrophysics, Bangalore, India
Michael J.S. Belton	Kitt Peak National Observatory, Tucson, Arizona, U.S.A.
Jacques Blamont	Laboratoire d'Aeronomie CNRS, Verrieres-le-Buisson, France
Geoffrey A. Briggs	NASA Headquarters, Washington, D.C., U.S.A.
William E. Brunk	Universities Space Research Association (U.S.R.A.), Washington, D.C., U.S.A.
Armand H. Delsemme	University of Toledo, Toledo, Ohio, U.S.A.
Bertram Donn	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
Hugo Fechtig	Max Planck Institut für Kernphysik, Heidelberg, F.R.G.
Louis D. Friedman	The Planetary Society, Pasadena, California, U.S.A.
Shu-Mo Gong	Academia Sinica, Nanjing, People's Republic of China
Ian Halliday	Herzberg Institute of Astrophysics, National Research Council of Canada, Ottawa, Canada
George H. Herbig	University of California, Santa Cruz, California, U.S.A.
Kunio Hirao	Institute of Space and Astronautical Science, Tokyo, Japan
Yoshihide Kozai	Tokyo Astronomical Observatory, Tokyo, Japan
Lubor Kresák	Slovak Academy of Sciences, Bratislava, Czechoslovakia
Reimar Lüst	Max Planck Gesellschaft, München, F.R.G., and European Space Agency, Paris, France
Alla Massevitch	Academy of Sciences of the U.S.S.R., Moscow, U.S.S.R.
Jack Meadows	University of Leicester, U.K.
Charles Robert O Dell	NASA Marshall Space Flight Center, Huntsville, Alabama, U.S.A., and Rice University, Houston, Texas, U.S.A.

Table I. (continued)

Vernon Pankonin	National Science Foundation, Washington, D.C., U.S.A.
Rudeger Reinhard	European Space Research and Technology Center, Noordwijk, The Netherlands
R.Z. Sagdeev	Academy of Sciences of the U.S.S.R., Moscow, U.S.S.R.
Hans Emil Schuster	European Southern Observatory, Santiago, Chile
K.R. Sivaraman	Indian Institute of Astrophysics, Bangalore, India
Vladimir Vanysek	Charles University, Praha, Czechoslovakia
Joseph F. Veverka	Cornell University, Ithaca, New York, U.S.A.
Kurt W. Weiler	National Science Foundation, Washington, D.C., U.S.A.
George Wetherill	Carnegie Institution of Washington, Washington, D.C., U.S.A.
Fred L. Whipple	Harvard University, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, U.S.A.
Laurel L. Wilkening	University of Arizona, Tucson, Arizona, U.S.A.
I.P. Williams	Queen Mary College, London, U.K.
Ya.S. Yatskiv	Main Astronomical Observatory, Academy of Sciences of the Ukrainian Republic, Kiev, U.S.S.R.

teams have adequate resources to handle the expected volume of data efficiently? Did they have the appropriate geographic distribution of observers for their particular needs? Were standard filters available, and had standard stellar magnitudes been agreed upon? These and a host of other questions occupied the DS and SG teams throughout several meetings.

The test run on Comet Crommelin was a significant event for most disciplines, and the results generally provided confidence in the plans for Comet Halley. The International Cometary Explorer (ICE) mission to Comet Giacobini-Zinner resulted in the inclusion of this comet as a major interest of the IHW in 1985. By 1986, the DS teams were coping with massive amounts of data from Halley itself, and decisions were required on the relative priority of Giacobini-Zinner and Halley data. Somewhat later, the SG was concerned about the DS teams' appropriate division of effort between processing the data already on hand and making a further effort to persuade observers to submit even more observational data.

Once Comet Halley faded beyond the observational threshold for most disciplines, the emphasis shifted again, this time to the archival process. Agreement was reached on the appropriate form for the archival data from each discipline, but delays were encountered in achieving a regular flow of data from the DS teams to the archival center in Pasadena. Other problems concerned the tight schedule imposed by the realities of the financial budget and the vulnerability of the entire archival process to the possible absence of one or two key individuals. Although the pressures involved caused some inevitable tensions, an atmosphere of cooperation and respect always existed between the DS, Lead Center, and SG teams.

One of the SG's peripheral activities was approaching major observatories with requests that special consideration be given to Halley observations when telescope observing schedules were being drawn up. Another was maintaining contact with the space agencies on matters such as membership in the SG. The SG offered its advice on plans for the colloquium on comets, for which the IHW was a sponsor, that was held in Bamberg, F.R.G., in April 1989. On more than one occasion, the SG considered whether the IHW should become involved in what might be considered the social aspects of the Halley apparition. In most countries, special events were organized, including public viewing of the comet, chartered aircraft flights, planetarium shows, and innumerable public lectures and popular articles. In addition, a wealth of special postage stamps appeared in dozens of countries. Should the IHW attempt to arrange for an archival record of these and other activities? After considerable discussion, the SG decided that its mandate should not extend beyond purely scientific activities.

Did the IHW SG play a significant role in the massive effort to study Comet Halley's apparition in the 1980s? It is, of course, best to leave the answer to such a question to those who could observe the entire operation from some distance. However, SG members did devote considerable time and energy to their deliberations. On numerous issues, they reached a consensus only after rather strenuous debate within the group. While the SG's advice may not have been adopted in every case, it was always considered with care. The SG members had the satisfaction of participating in a scientific effort with unprecedented international cooperation, one that is widely acclaimed as a major success. It is the hope of the SG members that their work will be considered as one significant contribution to this achievement.

ASTROMETRY NETWORK

D.K. Yeomans
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California Institute of Technology
Pasadena, California 91109

1. OVERVIEW

Through the dedicated efforts of a great many individuals, the Astrometry Network of the International Halley Watch (IHW) successfully carried out its goal of coordinating astrometric observations of Comet Halley and archiving the collected data. The astrometric data were used to update continually the orbit of Halley's Comet, and the resulting ephemerides were made available to a wide community of researchers to make observations using ground-based, Earth orbital, and interplanetary instruments. Astrometric data were received via telegram, telex, electronic mail message, and computer-to-computer links, as well as via telephone and postal delivery. Many observers went to extraordinary efforts to see that their data were reduced and transmitted to the orbit determination center within the shortest possible time. Some of these observations were less than a day old when received at the data collection center at the Jet Propulsion Laboratory (JPL). These outstanding efforts were most obvious just prior to the spacecraft encounters with Comet Halley in early March 1986. As an example of the personal efforts that made the Astrometry Network a success, we note that an English amateur astronomer often took astrometric photographs, measured the images, reduced the measurements into positional data, and telephoned the information to JPL before finally going to bed.

As of mid-1989, a total of 6475 astrometric observations of Comet Halley, covering the interval from October 16, 1982, through January 9, 1989, had been reported to the Astrometry Network. These observations resulted from efforts by 430 observers working at 148 observatories throughout the world. It is a credit to the IHW Astrometry Network members that 90% of the data received were used in the comet's most recent orbit updates. Lists of the participating observers and observatories are given in Appendices A and B. The members of the Astrometry Network's Discipline Specialist Team are listed in Table I.

2. PREPARATIONS FOR OBSERVING PROGRAMS

In preparation for the extensive observations of Comet Halley, IHW Handbooks were issued, giving observing circumstances, brightness predictions, and ephemeris information (Yeomans 1981, 1983). Updated ephemeris information was distributed to all IHW members in periodic newsletters, and self-contained, two-body ephemeris generation computer software was made available to IHW Discipline Specialists, enabling them to generate accurate ephemeris information from frequently updated orbital elements. Up-to-date orbital elements were maintained in the IHW electronic mail system. Visual stellar occultation predictions were pro-

Table I. Discipline Specialist Team of the Astrometry Network

Team Member	Affiliation	Responsibility
Donald K. Yeomans	Systems Division Jet Propulsion Laboratory California Institute of Technology Pasadena, CA 91109 U.S.A.	Discipline Specialist
Richard M. West	European Southern Observatory D-8046 Garching bei München Federal Republic of Germany	Discipline Specialist
Robert S. Harrington	U.S. Naval Observatory Washington, D.C. 20392 U.S.A.	Discipline Specialist
Brian G. Marsden	Harvard-Smithsonian Center for Astrophysics Cambridge, MA 02138 U.S.A.	Discipline Specialist
Paul W. Chodas	Systems Division Jet Propulsion Laboratory California Institute of Technology Pasadena, CA 91109 U.S.A.	Computer Software Cognizant
Michael S. Keesey	Systems Division Jet Propulsion Laboratory California Institute of Technology Pasadena, CA 91109 U.S.A.	Data Reduction Cognizant
Ravenel N. Wimberly	Sterling Software Palo Alto, CA 94303 U.S.A.	Communications Cognizant

vided by Bowell and Wasserman (1985) and by Dunham (1985a, 1985b). De Pater et al. (1985) provided occultation predictions for radio sources.

In June 1984, R.M. West hosted an Astrometry Network Workshop at the European Southern Observatory. Experts in the field presented papers on modern techniques for making astrometric observations, using star catalogs, reducing plates, and computing orbits. At the conclusion of the workshop, recommendations were made in each of these areas to assist those wishing to make contributions. The Workshop Proceedings were printed and distributed to each Astrometry Network member to serve as a useful guide (Yeomans et al. 1984).

3. FLIGHT PROJECT SUPPORT

The critical nature of astrometric data in support of the various flight projects was recognized at the inception of the IHW, since uncertainties in the comet's ephemeris would dominate spacecraft targeting errors at the encounters with Halley. These ephemeris errors are caused by imperfectly modeled nongravitational forces acting upon the comet's nucleus, systematic offsets between the measured center of light and the comet's (unseen) center of mass, errors in the existing star catalogs used in reducing the data, and nonstandard imaging and data reduction techniques.

It was critically important to provide for the rapid communication of up-to-date Halley astrometric data to the flight project orbit-determination centers at the European Space Operations Centre (ESOC) in Darmstadt, F.R.G., and the Space Research Institute (IKI) in Moscow, U.S.S.R. Accurate spacecraft targeting relied upon the use of recent astrometric data to improve constantly knowledge of the comet's orbital motion. Astrometric data and recent IHW orbit updates were transmitted from JPL to ESOC via a direct computer-to-computer link and these data were, in turn, transmitted to IKI via a direct ESOC—IKI data line. This latter data line was also important for the success of the Pathfinder navigation effort (Munch et al. 1986). Mention must also be made of the considerable help from Dr. B.G. Marsden and D.W.E. Green at the International Astronomical Union (IAU) Minor Planet Center in Cambridge, Massachusetts, for their efforts in immediately relaying astrometric data of Comet Halley, via an electronic mail service, to the IHW orbit-determination center at JPL. Astrometric data and recent orbits were also sent, via telex, from JPL to the Soviet astrometric center in Kiev, U.S.S.R. Y.S. Yatskiv and S.P. Major then forwarded this information directly to Moscow for a redundant flow of information to the VEGA flight project. The astrometric data were used by the Giotto and VEGA Comet Halley flight projects to update existing cometary ephemerides; orbital parameters of Halley's comet provided by the Astrometry Network were used for comparisons with similar efforts by ESOC and IKI. Halley ephemeris data were also provided to the flight projects of the Japanese Sakigake and Suisei spacecraft, as well as to the spacecraft flight projects for the Pioneer Venus Orbiter, the Solar Maximum Mission, and the International Ultraviolet Explorer.

4. DATA REDUCTIONS

Beginning with the work of Marsden et al. (1973), the obvious rocket-like thrusting, or nongravitational effects, affecting the motions of active comets has been successfully represented using a model based upon the sublimation of water ice. Because a solution for nongravitational effects in Comet Halley's motion requires astrometric data from at least three apparitions (Yeomans 1977), an effort was made to improve the existing data from 1835–1836 and 1909–1911, as well as to provide accurate reductions during the current apparition. For this apparition, improved reference star catalogs were generated and all data were reduced to a consistent coordinate system (FK4, equinox 1950.0).

4.1. Improvement of the 1835–1836 and 1909–1911 Astrometric Data

Morley (1983) used the Smithsonian Astrophysical Observatory's (SAO's) star catalog to improve upon the positions taken at Cordoba, Argentina, during 1909–1911, and Vashtova and Latinov (1984) reduced a few 1910 Tashkent observations, using more modern star catalogs. Complete remeasurements and reductions were done by G. Klare, S.F. Roeser, G. Schwehm, and R.M. West (private communication, December 13, 1983) for some of the 1909–1911 Heidelberg plates, and by Bowell (1982) for some of the 1910–11 Lowell Observatory plates that had never been used for astrometric positions. Z.M. Pereyra and R.M. West (private communication, 1984) remeasured approximately 70 plates taken at Cordoba in 1910, and Roeser (1984) and Roeser and T.A. Morley (private communication, 1985) re-reduced many of the 1835–1836 and 1909–1911 visual data on Comet Halley using modern reference star catalogs.

4.2. Star Catalog Improvement

To provide accurate reference stars for the reduction of the astrometric data, special Comet Halley star catalogs were generated and distributed to all Network members. Reference star catalogs were distributed in printed form, on magnetic tape, and on micro computer disks (in 18 different formats and sizes!). R.S. Harrington, of the U.S. Naval Observatory, coordinated all star catalog efforts for the Astrometry Network. For a degree on either side of the comet's celestial path, A.R. Klemola, B.F. Jones, S.P. Francic, E.A. Harlan, and T. Nakajima used plates taken with the Lick Observatory astrograph and compiled a Lick Observatory reference star catalog that required measurements and reductions for 5148 stars, covering the path of Comet Halley from January 1984 until late October 1985. The stars were mostly in the visual magnitude range of 13–14 and all were in the range of 11–15. Their density was approximately 30–40 stars per square degree, the reference catalog used was the AGK3R, and the approximate mean epoch was 1983.2 (equinox B1950). For the period from November 1985 till January 1986, AGK3 stars were used for the Halley catalog that was distributed in advance, and, in early 1986, N. Zacharias and C. de Vegt provided an improved catalog (reduced with respect to the AGK3N) for this same time period. For the critical period just prior to and during the spacecraft encounters (January through mid-March 1986), the U.S. Naval Observatory generated a special supplemental star catalog from transit circle obser-

Table II. Observation Schedule for Comet Halley

Observation Interval	Number of Observations	Number of Observatories	Root Mean Square (rms) Data Noise (arcsec)
October 16, 1982 – January 9, 1989	6475	148	1.0
August 29, 1909 – May 30, 1911	1696	34	1.5 – 3.0
August 21, 1835 – April 15, 1836	158	5	2.0 – 5.5
January 23, 1759 – June 3, 1759	206	5	31.5
August 30, 1682 – September 19, 1682	13	1	35
September 28, 1607 – October 23, 1607	9	3	300

vations, with some additional positions determined from a set of overlapping plates taken with the observatory's twin 20-cm astrograph (Holdenried and Crull 1986).

5. DATA PROCESSING

Comet Halley astrometric data, received by the orbit determination center at JPL, were processed before being archived and sent on to ESOC, F.R.G., and to Kiev, U.S.S.R. The processing included assigning an ephemeris time to the observed UTC time, assigning the observatory's coordinates, and correcting for the small effects of elliptic aberration. On January 1, 1984, the IAU formally switched from using Ephemeris Time (ET) to Terrestrial Dynamical Time (TDT) for the time scale of ephemerides for observations made from the Earth's surface. To the level of the observational accuracy, these two time scales can be considered equal and continuous.

Once verified and weighted, the observations were stored in reverse chronological order on the JPL master data file for use by the orbit determination program. This latter program takes into account the comet's nongravitational perturbations, as well as planetary perturbations, at each time step. The local error allowed at each time step can be inputted, and the time steps of the numerical integration are varied to limit the local error to the input tolerance. The partial derivatives of the observables are integrated numerically along with the comet's equations of motion. To be consistent with the various flight projects to comets Halley and Giacobini-Zinner, the equations of motion also include general relativistic effects by means of the parameterized space-time metric of the Eddington-Robertson-Schiff formalism. The orbit determination program uses a batch-processed, weighted-least-squares technique and can store and employ *a priori* information matrices and map covariance matrices to specified epochs.

6. COMET HALLEY OBSERVATION SETS

The sets of observations used in the various Comet Halley orbit determination solutions are given in Table II. The columns in this table give the time interval covered by the observations, the total number of observations from each apparition used in the computations, the number of observatories contributing observations, and the root mean square (rms) data noise used in the weighting of the data.

The data noise during the 1909–1911 apparition depended not only upon the skill of the observers, but also upon whether the photographic plates had been remeasured (1.5 arcsec of noise) or whether the available observations had only been re-reduced using more modern star catalogs (2.0–3.0 arcsec of noise). For the 1835–1836 apparition, the observations of F.W. Bessel at Konigsberg were assigned a noise value of 2.0 arcsec, of F.G.W. Struve at Dorpat 2.8 arcsec, of T. Maclear at the Cape of Good Hope and of J. Encke at Berlin 4.5 arcsec, and of B. Nicolai at Mannheim 5.5 arcsec. After being re-reduced by Roeser (1984, 1987) and by Roeser and Morley (private communication, 1985), many of the 1835–1836 and 1909–1911 positions were kindly forwarded from ESOC to JPL by Morley. In addition to the 1982–1989 astrometric data, the digital IHW Astrometry archive includes the 1835–1836 and 1909–1911 astrometric data. Although detailed information on the observers and observing conditions is necessarily absent from these early data sets, all data have been re-reduced to be consistent with the 1982–1989 data. In large part, the availability of the 1835–1836 and 1909–1911 data is due to the considerable efforts of Roeser of the Astronomisches Rechen-Institut in Heidelberg.

Observations with orbit residuals smaller than three standard deviations (3-sigma) of the rms residual were given an accept code (A) and employed in the weighted-least-squares differential correction procedure that was used to update the comet's existing orbit. Data with residuals greater than 3-sigma were given a delete code (D) and, if they retained this code during subsequent orbital updates, they were not included in these updates. Data from 1982–1989 with residuals exceeding 10 arcsec were not included in the master data file.

Once verified, the astrometric data were put into the proper format and added to the master data file. The master data file was then used to write the IHW archive on magnetic tapes in the Flexible Image Transport System (FITS) format. These tapes, in turn, were used to generate the digital Astrometry archive on compact disks.

7. ARCHIVING

Once received at JPL, the IHW astrometric data were entered into a master data file in reverse chronological order. This file was updated whenever new data arrived, and the updated files were used to generate a total of 61 orbital solutions using data that spanned the interval from August 21, 1835, through the most current astrometric observation then residing in the file. The five-line format of this master data file is outlined in Tables III, IV, and V. Once the master data file was completed and verified, the data from August 21, 1835, through January 9, 1989, were written in FITS format to a magnetic tape.

Table III. Header Keyword Information

```
Keyword          Content

SIMPLE    =                        T
BITPIX    =                        8
NAXIS     =                        1
NAXIS1    =                     2880
OBJECT    =    'P/HALLEY'
FILE-NUM  =                   102008
DATE-OBS  =    '12/ 8/85'
TIME-OBS  =                  0.88403
DATE-REL  =    '26/ 9/89'
DISCIPLN  =    'ASTROMETRY'
LONG-OBS  =    '116/ 8/24'
LAT--OBS  =    '-32/00/30'
EQUINOX   =    'B1950.0'
SYSTEM    =    '18070000'
OBSERVER  =    'CANDY,M.P ET AL.'
SUBMITTR  =    'WIMBERLY,R.N'
SPEC-EVT  =                        F
DAT-FORM  =    'ASCII    '
COMMENT   ADD. OBS.:          SMITH,P/DOE,J
COMMENT   NOTES:  VERY FAINT IMAGE
END
```

Table IV. Example of Astrometry Data Record

```
2446290.38467          55914.61+19 4 9.3
A 1985 812.88403 552   55914.59+19 4 9.3 323 116.14-362 225     1.0      1.0
  CANDY,M.P ET AL.          PERTH OBSERVATORY, BICKLEY  15.00 99.0
  IAU CENTRAL BUREAU FILE TRANSFER 9-18-85
  ADDITIONAL OBSERVERS: SMITH,P/DOE,J ;!VERY FAINT IMAGE!
```

7.1. Astrometry FITS Header Description and Data Record Format

Each astrometric observation in the FITS format consists of one file that includes header information (36 records of 80 ASCII bytes each) followed by the data

Table V. Five-Line Astrometry Format

Columns	Description
Line 1:	
1 – 13	Julian ephemeris day: xxxxxxx.xxxxx (field length = 13, number of decimal places = 5)
14 – 21	Blank
22 – 30	Right ascension (hr, min, s), hhmmss.ss
31 – 39	Declination (sign, deg, arcmin, arcsec), sddmmss.s
Line 2:	
1	Accept code (A for accept or D for delete)
2	Image quality code
3 – 16	UTC time of observation, yyyymmdd.ddddd
17	Blank
18 – 20	ET-UTC, nnn (552 = 55.2 s)
21	Blank
22 – 30	Right ascension, hhmmss.ss
31 – 39	Declination, sddmmss.s
40	Blank
41 – 43	Observatory code, nnn
44	Blank
45 – 50	East longitude of observatory, ddd.dd
51 – 58	Observatory parallax factors DXY and DZ, snnnsnnn (cf. Note)
59	Blank
60 – 65	Right ascension data RMS in arcsec, ssss.s
66	Blank
67 – 72	Declination data RMS in arcsec, ssss.s
Line 3:	
1 – 2	Blank
3 – 26	Name(s) of observer(s)
27	Blank
28 – 63	Name of observatory
64	Blank
65 – 69	Total visual magnitude estimate, xx.xx
70	Blank
71 – 74	Nuclear magnitude estimate, xx.x
Lines 4 and 5:	
1 – 2	Blank
3 – 80	Supplemental information, character field of width 78

Note: The parallax factors listed on line 2 are denoted DXY and DZ and are used to transform the Earth—Sun vector from a geocentric origin to one that is topocentric:

```
DXY = -426.35E-07 * RHO * cos(LAT),
DZ = -426.35E-07 * RHO * sin(LAT),
```

where 426.35E-07 is the Earth's mean equatorial radius in AU, RHO is the geocentric distance of the observatory in units of mean equatorial radii, and LAT is the geocentric latitude of the observatory.

themselves (another 36 records of 80 bytes each). A hypothetical header is used as an example in Table III.

The header keywords SIMPLE, BITPIX, NAXIS, NAXIS1, OBJECT, DISCIPLN, EQUINOX, SUBMITTR, SPEC-EVT, and DAT-FORM do not change from file to file for the Astrometry Network data. SIMPLE is a logical type (L) and conforms to basic FITS standards. BITPIX, NAXIS, and NAXIS1 are integers (I) denoting, respectively, the number of bits per pixel in the data record, the number of axes in the data record, and the number of pixels in the first axis row. OBJECT is a character field (C) that gives the name of the object. FILE-NUM (I) begins with the integer 1, which identifies the Astrometry Network. The following five digits represent a unique sequential number used to identify the file. DATE-OBS (C) and TIME-OBS (real variable) give, respectively, the UT date (dd/mm/yy) and decimal fraction of a day. DATE-REL (C) is the date when the data were released to the IHW Lead Center, and DISCIPLN (C) denotes the IHW discipline reporting the data.

LONG-OBS and LAT--OBS give the east longitude (ddd/mm/ss) of the observatory and its geographic (geodetic) latitude (sdd/mm/ss). When the geographic latitude was not available, we computed it from the parallax factors listed in each of our observation records. However, the parallax factors carry only enough significant figures to allow the geographic latitude to be computed to a few arcmin, so, in this case, we have rounded off the latitude to the nearest arcmin and placed zeros in the arcsec location. EQUINOX (C) identifies the origin of the equatorial coordinate system used for the astrometric data; for each record, the FK4-1950.0 origin has been abbreviated as B1950.0.

SYSTEM (C) is the system code in which the leading digit (1) identifies the Astrometry Network and the following three digits are a unique code for the reporting observatory (see Appendix A). The trailing four digits are zeros for the Astrometry Network. OBSERVER (C) gives the name(s) of the observer(s), last name first, followed by the initial(s) of the first (and middle) name(s) (see Appendices A and B). The observers are separated by a slash (/), whereas ET AL. indicates that additional observers (ADD. OBS.) are listed after the COMMENTS keyword. Problems with the observation or data reduction process also are identified, after the keyword COMMENTS. SUBMITTR (C) is R.N. Wimberly as the person who prepared the original data archive tape and submitted it to the IHW Lead Center at JPL. The SPEC-EVT (L) keyword is not used in the Astrometry Network. DAT-FORM (C) describes the format of the FITS data record, which, for Astrometry, is to be interpreted as logical records of 80 ASCII characters.

Following each FITS header record are five rows for each astrometric position reported. The first line lists the time (Julian date in ephemeris time) of the observation and the reported right ascension (hr, min, s) and declination (deg, arcmin, arcsec). The first character of the second line is either an A or a D, indicating whether the observation was accepted for or deleted from the final orbital solution. The second column of the second line contains either a blank or a code indicating the image quality. This code—C, D, S, or T—specifies whether the image is centrally condensed, diffuse, stellar, or trailed. An X code indicates that the observation is semi-accurate. The quality code is followed by the reported observation time (calendar date, UTC), by the ET-UTC correction in tenths of a second (Table VI), and by the right ascension and declination corrected for the small effects of elliptic aberration. The right ascension and declination are referred to the mean equator

Table VI. Differences TDT-UTC (ET-UTC)

Date	ET-UTC (s) TDT-UTC (s)
1982 July 1.0	53.18
1983 July 1.0	54.18
1985 July 1.0	55.18
1988 Jan. 1.0	56.18

and equinox of 1950.0. Next on the second line is the observatory code (see Table IV), followed by the observatory's east longitude (deg) and by the parallax factors used to convert the computed geocentric positions to the topocentric observed positions. The last two entries on the second line are the 1-sigma standard deviations of the measurement noise (arcsec) for the right ascension and declination; these values are used to form weights in the orbit determination process. The third line in the data record contains the name(s) of the observer(s), the name of the observatory, and the reported values for the total and nuclear magnitudes. When no magnitude was reported, a value of 99.0 fills this field. The fourth line in the data record begins with a reference that specifies how, or from whom, the data were obtained. The remainder of line 4 and all of line 5 contain further information on the observation, including any problems encountered, as well as additional observers involved whose names were not listed on line 3. An example in Table IV illustrates the five-line Astrometry format, which is described in Table V.

7.2. Observers and Observatories Participating in the Astrometry Network

Observatories that provided astrometric data for Comet Halley are listed in Appendix A. Following the numeric code number of each observatory are its name and the total number of observations received. Under each observatory name is an alphabetical list of the observers and the total number of observations they contributed. In Appendix B, the observers are listed in alphabetical order, followed by the codes of the observatories where they observed and by the total number of observations they made. Differences between the ephemeris time (ET) and the UTC time applied to the observations of Comet Halley are presented in Table VI. The first column shows the date on which the ET-UTC differences changed values by +1 s.

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Appendix A. Observer List by Observatory

Observatory Code	Observatory and Observers	Total Number of Observations At Observatory	By Observer
6	Fabra Observatory Barcelona, Spain	190	
	Cepa, J.		1
	Codina, J.M.		123
	Heras, A.M.		1
	Hernandez, M.		13
	Moreno, M.		11
	Nunez, J.		40
	Sanchez, F.		1
10	CERGA Caussols, France	6	
	Bartheleme, A.		5
	Heudier, J.		5
	Le Fevre, O.		1
	Pollas, C.		6
12	Uccle Observatory Uccle, Brussels, Belgium	30	
	Debehogne, H.		22
	Pauwels, T.		20
17	Hoher List Observatory Hoher List Federal Republic of Germany	36	
	Elst, E.		14
	Geffert, D.		5
	Geffert, M.		21
	Geyer, E.		14
	Haenel, A.		34
20	Nice France	1	
	Benest, D.		1
22	Pino Torinese Torino, Italy	64	
	Ferreri, W.		29
	Massone, G.		35

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
24	State Observatory at Konigstuhl	8	
	Heidelberg		
	Federal Republic of Germany		
	Goerze, M.		1
	Gorze, U.		2
	Kiefer, E.		2
	Kiefer, P.		2
	Madejsky, R.		1
	Mandel, H.		8
	Mandel, U.		1
	Schiffer, H.J.		5
26	Berne-Zimmerwald	20	
	Berne, Switzerland		
	Wild, P.		20
33	Karl Schwarzschild Observatory	25	
	Tautenburg		
	German Democratic Republic		
	Boerngen, F.		25
	Ludwig, F.		13
	Mau, K.H.		12
	Tanzer, G.		10
45	Vienna (since 1879)	33	
	Austria		
	Jackson, P.		33
46	Klet Observatory	283	
	Ceske Budejovice		
	Czechoslovakia		
	Landgraf, W.		6
	Mrkos, A.		267
	Vavrova, Z.		32

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
47	Poznan	25	
	Poland		
	Czelusniak, H.		1
	Gromadzinski, M.		3
	Hurnik, H.H.		2
	Matz, D.		11
	Ochnik, R.		5
	Swierkowska, S.		9
49	Uppsala-Kvistaberg	14	
	Uppsala, Sweden		
	Lagerkvist, C.I.		14
	Oja, T.		14
51	Cape of Good Hope	100	
	South Africa		
	Churms, J.		83
	Roberts, G.		17
56	Skalnate Pleso Observatory	128	
	Skalnate Pleso		
	Czechoslovakia		
	Cervak, G.		110
	Kornos, L.		41
	Rychtarcik, P.		110
	Svoren, J.		47
57	Belgrade	35	
	Yugoslavia		
	Olevic, D.		1
	Protitch-Benishek, V.		34
61	Uzhgorod	88	
	U.S.S.R.		
	Galas, T.Y.		37
	Goroshchak, I.I.		81
	Gvardionov, A.B.		9
	Ignatovich, S.I.		72
	Polishchuk, N.D.		73
	Vorinka, S.I.		27

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations: At Observatory	By Observer
63	Turku-Tuorla Finland	12	
	Haarala, S.		6
	Lappalainen, T.		6
	Niemi, A.		12
	Piironen, J.		6
	Sillanpaa, A.		6
69	Baldone, near Riga U.S.S.R.	70	
	Alksnis, A.K.		26
	Eglitis, I.E.		14
	Grasberg, E.K.		17
	Ozolinya, V.		29
	Platajs, I.K.		23
	Pundure, I.		2
	Rydzinskis, A.		3
	Urgitis, I.I.		16
71	Sofia Bulgaria	114	
	Bonev, T.		21
	Cirova, H.		16
	Georgieva, A.		62
	Ivanova, V.		107
	Kirova, H.		17
	Major, S.P.		5
	Radeva, V.		12
	Shkodrov, V.		98
73	Bucharest Romania	4	
	Alexiu, A.		2
	Bocsa, G.		2
75	Tartu U.S.S.R	4	
	Maazik, M.		4
	Raudsaar, X.		4

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations: At Observatory	Total Number of Observations: By Observer
83	Central Astrophysical Observatory	58	
	Golosseevo-Kiev, U.S.S.R.		
	Golovnya, V.V.		12
	Ivashchenko, Y.N.		10
	Izhakevich, E.M.		13
	Kaltygina, S.V.		1
	Kizyun, L.N.		1
	Ledovskaya, I.V.		7
	Major, S.P.		9
	Safronov, Y.I.		9
	Sereda, E.M.		11
	Shatokhina, S.V.		15
	Sizonenko, Y.V.		5
	Yatsenko, A.I.		1
84	Pulkovo Observatory	40	
	Leningrad, U.S.S.R.		
	Bobylyev, V.V.		3
	Bronikova, N.M.		7
	Kiseleva, T.P.		9
	Kiselyev, A.A.		[illegible]
	Lepeshnikova, S.A.		16
	Narizhnaya, M.V.		3
85	Kiev University Observatory	28	
	Kiev, U.S.S.R.		
	Churyumov, K.I.		5
	Smirnova, K.E.		2
	Telnyuk, V.V.		25
87	Helwan	10	
	Egypt		
	Bagus, B.B.		10
	Bakhtigaraev, N.S.		10
	El-Khilali, Y.		10
	Tovadrus, M.Y.		10

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
89	Nikolaev	194	
	U.S.S.R.		
	Gorel, G.K.		67
	Gudkova, L.A.		21
	Kalinenkov, N.D.		93
	Voronenko, V.I.		128
90	Mainz	5	
	Federal Republic of Germany		
	Landgraf, W.		4
	Riemann, R.		5
91	St. Etienne	14	
	France		
	Chanal, R.		14
92	Torun-Piwnice Observatory	26	
	Poland		
	Antal, M.		19
	Krawczyk, S.		24
	Muciek, M.		20
	Woszczyk, A.		11
93	Skibotn Observatory	37	
	Skibotn, Norway		
	Aksnes, K.		5
	Havnes, O.		18
	Henriksen, K.		17
	Solheim, J.E.		16
94	Crimea-Simeis	25	
	U.S.S.R.		
	Fokanov, S.V.		23
	Merezhina, L.S.		17
	Nagornyuk, S.		5
	Nikolenko, I.V.		6
	Shcherbanovskij, A.L.		13

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
95	Crimea-Nauchnij	293	
	U.S.S.R.		
	Chernykh, L.I.		51
	Chernykh, N.S.		188
	Karachkina, L.G.		114
	Lyukhanov, K.		3
	Pavlenko, E.		56
	Ponomarev, D.N.		19
	Prokofyeva, V.		47
	Smirnova, T.M.		5
	Tarashchuk, V.		56
	Zhuravlyeva, L.V.		67
96	Merate	45	
	Italy		
	Barbieri, C.		3
	Kranjc, A.		3
	Scardia, M.		45
98	Cima Ekar - Asiago Astrophys. Obs.	18	
	Padua, Italy		
	Barbieri, C.		17
	Kranjc, A.		17
	Scardia, M.		18
99	Lahti	3	
	Finland		
	Salmi, J.		3
101	Kharkov	34	
	U.S.S.R.		
	Pavlenko, P.P.		34
102	Zvenigorod	17	
	U.S.S.R.		
	Bakhtigaraev, N.S.		2
	Burg, B.		2
	Osipenko, V.P.		15
	Panferova, V.I.		1

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations: At Observatory	Total Number of Observations: By Observer
105	Moscow	7	
	U.S.S.R.		
	Shokin, Y.A.		7
114	Engelhardt Observatory	171	
	Zelenchuk Station		
	U.S.S.R.		
	Kitkin, V.N.		86
	Rizvanov, N.		8
	Zelishchev, I.E.		85
115	Zelenchukskaya	6	
	U.S.S.R.		
	Karachentsev, I.D.		2
	Nazarchuk, G.K.		4
	Shapovalova, A.I.		3
	Shcherbanovskij, A.L.		3
	Shokin, Y.A.		3
119	Abastuman	34	
	U.S.S.R.		
	Inasaridze, R.Y.		13
	Kiladze, R.I.		2
	Majsuradze, G.A.		19
123	Byurakan	30	
	U.S.S.R.		
	Akhverdyan, L.G.		30
	Ledovskaya, I.V.		14
129	Ordubad	153	
	U.S.S.R.		
	Bobylyev, V.V.		30
	Kiselyev, A.A.		56
	Malkov, A.A.		4
	Novikov, S.B.		2
	Shokin, Y.A.		2
	Tolbin, S.V.		63
	Yagudin, L.I.		44
	Yagudina, E.I.		1

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
136	Engelhardt Observatory Kazan, U.S.S.R.	9	
	Tokhtasyev, S.S.		7
	Zelishchev, I.E.		9
168	Kourovskaya U.S.S.R.	164	
	Barkhatova, K.A.		3
	Blym, M.E.		1
	Kajzer, G.T.		11
	Kalinina, N.D.		36
	Levitskaya, T.I.		113
	Matkin, N.V.		18
	Pyatkes, S.A.		30
	Ryazanov, A.P.		12
	Seleznev, A.F.		24
	Sobolenko, G.M.		15
	Tearo, A.R.		24
	Timofeyev, S.N.		54
	Vasilevskij, A.E.		46
	Yuminova, O.G.		26
	Zhukova, G.A.		12
	Zvonareva, E.V.		40
186	Kitab U.S.S.R.	333	
	Bashtova, L.		22
	Ivanov, Y.		13
	Kadyrova, N.		40
	Kamalov, M.		27
	Khamidov, E.		13
	Khamidov, T.		4
	Lejko, V.		1
	Major, S.P.		37
	Mirmakhmudov, E.		144
	Pattakhov, E.		26
	Rakhmatov, E.		179
	Saidov, G.		23
	Shatokhina, S.V.		32

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations At Observatory	By Observer
188	Majdanak	22	
	U.S.S.R.		
	Bugaenko, O.I.		3
	Novikov, S.B.		22
	Shokin, Y.A.		22
190	Gissar	196	
	U.S.S.R.		
	Gerasimenko, S.I.		196
191	Dushanbe	1	
	U.S.S.R.		
	Churyumov, K.I.		1
	Rspaev, F.K.		1
192	Tashkent	180	
	U.S.S.R.		
	Azizov, S.K.		111
	Baltabaev, Y.		10
	Khamidov, T.		125
	Rakhimov, A.G.		164
	Rakhmatov, A.		16
193	Sanglok	23	
	U.S.S.R.		
	Chernova, G.P.		23
	Gerasimenko, S.I.		23
	Kiselyev. N.N.		23
210	Alma-Ata	47	
	U.S.S.R.		
	Churyumov, K.I.		13
	Gorodetskaja, N.S.		5
	Gorodetskij, D.I.		39
	Meleyev, H.		5
	Mileyev, H.		3
	Rozhkovskij, D.A.		4
	Rspaev, F.K.		1
	Ryabenko, I.B.		3
	Solodovnikov, V.V.		5

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
214	Kazakh Astrophy. Inst. Coronal Sta.	4	
	U.S.S.R.		
	Gorodetskij, D.I.		3
	Ryabenko, [illegible].B.		4
	Solodovnikov, V.V.		1
217	Assah	30	
	U.S.S.R.		
	Churyumov, K.I.		30
	Gorodetskij, D.I.		6
	Meleyev, H.		4
	Rspaev, F.K.		30
219	Japal-Rangapur Observatory	6	
	Japal, India		
	Sanwal, N.B.		6
286	Yunnan Observatory	16	
	Kunming, China		
	Yan, L.S.		15
	Zhang, B.L.		1
293	Burlington (Remote Site)	7	
	New Jersey, U.S.A.		
	Handley, T.		7
302	U. Of The Andes Astronomical Sta.	3	
	Venezuela		
	Ferrin, I.		3
303	Merida	17	
	Venezuela		
	Abad, C.		17
	Contreras, O.		6
	Moreno, F.		9
	Stock, J.		17

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
305	Purple Mt. Observatory Hainan Island Station China	27	
	Ge, Y.L.		27
	Lu, J.H.		27
	Wang, D.C.		27
	Wang, Q.		27
	Wang, S.C.		27
	Wei, S.L.		27
	Yang, J.X.		27
	Zhang, J.X.		27
312	Xisha Islands (Paracel Is.) South China Sea	20	
	Dong, C.Z.		2
	Huei, Y.Q.		2
	Shao, Y.J.		2
	Sun, S.S.		20
	Zhang, B.L.		2
323	Perth Observatory Bickley, Western Australia Australia	548	
	Birch, P.		6
	Candy, M.P.		412
	Harwood, D.		4
	Jekabsons, P.		426
	John, A.		146
	Johnston, J.		39
	Kinnear, G.		55
	Martin, R.		2
	McGrath, A.		372
	Stevens, L.		287
324	Beijing Observatory Shaho Station, China	1	
	Dong, Z.Z.		1
	Hao, X.L.		1
	Tang, D.Y.		1

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
330	Purple Mountain Observatory Nanking, China	149	
	Ge, Y.L.		60
	Li, G.Y.		2
	Lu, J.H.		63
	Luo, G.S.		5
	Wang, D.C.		79
	Wang, Q.		84
	Wang, S.C.		19
	Wang, W.		2
	Wei, S.L.		65
	Yang, J.X.		104
	Yang, J.Z.		6
	Zhang, J.X.		21
334	Qingdao China	176	
	Cheng, L.		11
	Dong, C.Z.		11
	Huei, Y.Q.		111
	Ma, X.Y.		83
	Shao, Y.J.		168
	Song, W.Q.		113
	Sun, S.S.		176
	Wang, Z.L.		102
	Zhang, B.L.		102
337	Zo-Se China	48	
	Zhao, J.L.		48
371	Tokyo-Okayama Japan	5	
	Kosai, H.		3
	Watanabe, E.		2
372	Geisei Japan	22	
	Seki, T.		22

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations: At Observatory	By Observer
378	Murou	2	
	Japan		
	Nakamura, M.		2
379	Hamamatsu	2	
	Japan		
	Tashiro, T.		2
381	Tokyo-Kiso	9	
	Japan		
	Kosai, H.		9
	Yamagata, T.		3
391	Sendai Observatory	134	
	Ayashi Station		
	Ayashi, Japan		
	Koishikawa, M.		134
392	JCPM Sapporo Station	10	
	Sapporo, Japan		
	Kaneda, H.		9
	Watanabe, K.		1
396	Asahikawa	1	
	Japan		
	Tsuchiya, K.		1
397	Sapporo Science Center	30	
	Sapporo, Japan		
	Watanabe, K.		30
399	Kushiro	2	
	Japan		
	Ueda, S.		2
413	Siding Spring Observatory	26	
	New South Wales, Australia		
	Hartley, M.		1
	Russell, K.		25

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations At Observatory	By Observer
414	Mount Stromlo	20	
	A.C.T., Australia		
	Ge, Y.L.		20
	Lu, J.H.		20
	Wang, D.C.		20
	Wang, Q.		20
	Wang, S.C.		20
	Wei, S.L.		20
	Yang, J.X.		20
	Zhang, J.X.		20
415	Kambah (near Canberra)	76	
	New South Wales		
	Australia		
	Herald, D.		76
420	Sydney	3	
	New South Wales		
	Australia		
	Bembrick, C.S.		3
425	Taylor Range Observatory	3	
	Brisbane, Queensland		
	Australia		
	Anderson, P.		3
474	Mount John Observatory	41	
	Lake Tekapo, New Zealand		
	Gilmore, A.C.		40
	Kilmartin, P.		15
482	St. Andrews	14	
	Scotland, United Kingdom		
	Stapleton, J.R.		14
483	Carter Observatory	12	
	Black Birch Station		
	New Zealand		
	Douglass, G.G.		12

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
491	Centro Astronomico De Yebes	44	
	Yebes, Spain		
	Cabanas, C.		44
	De Pascual, M.		44
	Garcia, J.		44
	Martin-Pintado, J.		29
493	Centro Astronomico Hispano-Aleman	114	
	Calar Alto, Spain		
	Birkle, K.		60
	Graser, U.		4
	Groote, D.		4
	Gruen, E.		4
	Hagen, H.J.		4
	Haug, U.		1
	Kohoutek, L.		30
	Lingenfelder, G.		2
	Pauls, R.		4
	Quetsch, A.		1
	Thiele, U.		11
494	Stakenbridge	37	
	England, United Kingdom		
	Manning, B.		37
501	Royal Greenwich Observatory	12	
	Herstmonceux, England		
	United Kingdom		
	Jones, D.H.P.		12
502	Colchester	20	
	England, United Kingdom		
	Hendrie, M.J.		20
503	Cambridge	24	
	England, United Kingdom		
	Argue, A.N.		11
	Shanklin, J.D.		21

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
509	La Seyne Sur Mer	5	
	France		
	Pinson, J.		5
528	Gottingen	3	
	Federal Republic of Germany		
	Landgraf, W.		3
544	Wilhelm Foerster Observatory	2	
	Berlin		
	Federal Republic of Germany		
	Dreyhsig, J.		2
	Leder, N.		2
552	Osservatorio San Vittore	53	
	Bologna, Italy		
	Colombini, E.		24
	Sassi, G.		49
	Vacchi, C.		49
553	Chorzow	36	
	Poland		
	Firszt, T.		1
	Kaminski, R.		1
	Pawicka, B.		1
	Sieron, W.		1
	Stanek, K.		1
	Syroczynski, R.		1
	Szczepanski, M.		3
	Wlodarczyk, I.		27
555	Cracow-Fort Skala	34	
	Poland		
	Kurpinska-Winiarska, M.		6
	Waniak, W.		3
	Winiarski, M.		21
	Zola, S.		4
561	Piszkesteto	5	
	Hungary		
	Toth, I.		5

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations: At Observatory	Total Number of Observations: By Observer
562	Figl Observatory	15	
	Vienna, Austria		
	Schnell, A.		15
	Stockenhuber, H.		11
	Stoll, M.		2
565	Brescia	20	
	Italy		
	Marinello, V.		20
	Quadri, U.		20
567	Chions	3	
	Italy		
	Baur, C.R.		3
	Baur, J.M.		3
568	Mauna Kea	23	
	Hawaii, U.S.A.		
	Alvarez, E.M.		3
	Baudrand, J.		14
	Belton, M.J.S.		3
	Le Fevre, O.		9
	Lecacheux, J.		9
	Lelievre, G.		9
	Lemonnier, D.		9
	Mathez, G.		9
	Meech, K.J.		6
	Piscitelli, J.		1
	Racine, R.		1
	Sicardy, B.		5
571	Cavriana	12	
	Italy		
	Lai, L.		12
	Ronchetti, I.		12
	Ruzza, M.		12
	Vesentini, G.		12
574	Gottolengo	1	
	Italy		
	Mattarozzi, G.		1

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
575	La Chaux De Fonds Switzerland	13	
	Behrend, A.		13
	Behrend, R.		13
576	Burwash England, United Kingdom	16	
	Young, A.		16
577	Metzerlen Observatory Switzerland	3	
	Trefzger, C.F.		3
580	Graz Austria	4	
	Hanslmeier, A.		4
	Ornig, C.W.		4
581	Sedgefield Observatory South Africa	38	
	Hers, J.		38
583	Odessa - Mayaki U.S.S.R.	58	
	Kramer, E.		7
	Shestaka, I.S.		51
586	Pic Du Midi France	2	
	Laffont, E.		2
	Martinez, P.		2
656	Near Victoria British Columbia, Canada	4	
	Newton, J.		4
657	Victoria British Columbia, Canada	18	
	Balam, D.D.		14
	Lowe, T.B.		2
	Tatum, J.B.		10

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations At Observatory	By Observer
662	Lick Observatory Mount Hamilton California, U.S.A.	73	
	Harlan, E.A.		39
	Jones, B.F.		32
	Miller, J.		2
675	Palomar Mountain California, U.S.A.	28	
	Danielson, G.E.		12
	Gibson, J.		14
	Helin, E.		2
	Jewitt, D.C.		12
686	U. Of Minn. Ir. Obs. Mt. Lemmon, Arizona U.S.A.	1	
	Levy, D.		1
	Wisniewski, W.		1
688	Lowell Observatory Anderson Mesa, Arizona U.S.A.	8	
	Bus, S.J.		5
	Gullixson, C.		8
	Skiff, B.A.		3
691	Steward Observatory Kitt Peak, Tuscon, Arizona U.S.A.	11	
	Scotti, J.V.		11
693	Catalina Station Tucson, Arizona, U.S.A.	5	
	Fink, U.		1
	Karkoschka, E.		4
	Schultz, P.		4
	Tyler, A.		5

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
695	Kitt Peak National Observatory	35	
	Tucson, Arizona, U.S.A.		
	Alvarez, E.M.		1
	Baum, S.		2
	Beauchemin, M.		1
	Belton, M.J.S.		11
	Borra, E.		1
	Burks, J.		2
	Bushouse, H.		2
	Butcher, H.		3
	Djorgovski, S.G.		3
	Gallagher, J.		3
	Goad, J.		1
	Heckman, T.M.		2
	Holleran, P.		2
	Howell, S.		2
	Jacoby, G.H.		1
	Junkkarinen, V.T.		3
	Kaluzny, J.		3
	Kennicutt, R.C.		1
	Smith, E.		2
	Spinrad, H.		4
	Szkody, P.		4
	Waller, W.		1
	Wehinger, P.A.		4
	Wyckoff, S.		3
707	Chamberlin Field Station	20	
	Bailey, Colorado, U.S.A.		
	Briggs, J.		19
	Everhart, E.		2
711	McDonald Observatory	27	
	Fort Davis, Texas, U.S.A.		
	Frueh, M.L.		21
	Whipple, A.		6

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
771	Boyeros Habana, Cuba	18	
	Lonal, H.P.		18
	Farinyas, R.		18
	Kulish, A.P.		18
	Nikonov, O.V.		18
	Sid, M.A.		18
	Tolbin, S.V.		18
	Zhilinskij, E.G.		18
781	Quito Ecuador	8	
	Davila, U.		8
	Espin, L.		8
	Kaltygina, S.V.		8
	Sizonenko, Y.V.		8
782	Comet Astrographic Station Quito, Ecuador	4	
	Davila, U.		4
	Espin, L.		4
	Kaltygina, S.V.		4
	Sizonenko, Y.V.		4
788	Mount Cuba Observatory Greenville, Delaware U.S.A.	5	
	Bock, G.		5
	Jackson, S.		5
	Stock, R.F.		5
792	University of Rhode Island Quonochontaug, Rhode Island U.S.A.	11	
	Penhallow, W.S.		11

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations: At Observatory	Total Number of Observations: By Observer
801	Oak Ridge Observatory Harvard, Massachusetts U.S.A.	33	
	McCrosky, R.E.		31
	Schwartz, G..		29
	Shao, C.Y.		27
805	Santiago-Cerro El Roble Chile	273	
	Torres, C.		241
	Wroblewski, H.		143
807	Cerro Tololo Observatory La Serena, Chile	4	
	Meech, K.J.		4
808	El Leoncito Argentina	32	
	Cesco, M.R.		13
	Lopez, C.E.		32
	Sanguin, J.C.		[illegible]3
	Vicentela, J.A.		13
809	European Southern Observatory La Silla, Chile	139	
	Danziger, J.		2
	Debehogne, H.		3
	Ferreri, W.		16
	Louys, L.		15
	Monderen, P.		15
	Pedersen, H.E.		29
	Shaver, P.		2
	West, R.M.		107
820	Tarija Bolivia	23	
	Potter, H.I.		23
821	Cordoba-Bosque Alegre Argentina	16	
	Pereyra, Z.M.		16

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
822	Cordoba	11	
	Argentina		
	Pereyra, Z.M.		11
881	Toyota	3	
	Japan		
	Suzuki, K.		3
889	Karasuyama	1	
	Japan		
	Inoda, S.		1
892	YGCO Hoshikawa and Nagano Stations	2	
	Japan		
	Hayakawa, S.		2
	Kojima, T.		2
893	Sendai Municipal Observatory	5	
	Sendai, Japan		
	Koishikawa, M.		3
	Yusa, T.		5
950	La Palma	1	
	Canary Islands		
	Argyle, R.		1
	Wall, J.V.		1
975	Valencia	15	
	Spain		
	Artes, P.J.		15
	Lopez, G.A.		15
	Lopez, M.R.		15
	Lopez, O.J.A.		15
976	Leamington Spa	3	
	England, United Kingdom		
	Johnstone, G.		3

Appendix A. (continued)

Observatory Code	Observatory and Observers	Total Number of Observations	
		At Observatory	By Observer
978	Conder Brow	9	
	England, United Kingdom		
	Buczynski, D.G.		9
	Greenwood, J.D.		9
979	South Wonston	1	
	England, United Kingdom		
	Arbour, R.W.		1
980	Lancaster	2	
	England, United Kingdom		
	Waddington, W.G.		2
984	Eastfield	15	
	England, United Kingdom		
	Buczynski, D.G.		1
	Ridley, H.B.		15
993	Woolston Observatory	1	
	England, United Kingdom		
	Dykes, M.R.		1
	Waterfield, R.		1
996	Oxford	36	
	England, United Kingdom		
	Waddington, W.G.		36

Appendix B. Observer Index

Observer	Observatory Code(s)	Number of Observations
Abad, C.	303	17
Akhverdyan, L.G.	123	30
Aksnes, K.	93	5
Alexiu, A.	73	2
Alksnis, A.K.	69	26
Alvarez, E.M.	568, 695	4
Anderson, P.	425	3
Antal, M.	92	19
Arbour, R.W.	979	1
Argue, A.N.	503	11
Argyle, R.	950	1
Artes, P.J.	975	15
Azizov, S.K.	192	111
Bagus, B.B.	87	10
Bakhtigaraev, N.S.	87, 102	12
Balam, D.D.	657	14
Baltabaev, Y.	192	10
Barbieri, C.	96, 98	20
Barkhatova, K.A.	168	3
Bartheleme, A.	10	5
Bashtova, L.	186	22
Baudrand, J.	568	14
Baum, S.	695	2
Baur, C.R.	567	3
Baur, J.M.	567	3
Beauchemin, M.	695	1
Behrend, A.	575	13
Behrend, R.	575	13
Belton, M.J.S.	568, 695	14
Bembrick, C.S.	420	3
Benest, D.	20	1
Birch, P.	323	6
Birkle, K.	493	60
Blym, M.E.	168	1
Bobylyev, V.V.	84, 129	33
Bock, G.	788	5
Bocsa, G.	73	2
Boerngen, F.	33	25
Bonev, T.	71	21
Borra, E.	695	1
Briggs, J.	707	19
Bronikova, N.M.	84	7

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Buczynski, D.G.	978, 984	10
Bugaenko, O.I.	188	3
Burg, B.	102	2
Burks, J.	695	2
Bus, S.J.	688	5
Bushouse, H.	695	2
Butcher, H.	695	3
Cabanas, C.	491	44
Candy, M.P.	323	412
Cepa, J.	6	1
Cervak, G.	56	110
Cesco, M.R.	808	13
Chanal, R.	91	14
Cheng, L.	334	11
Chernova, G.P.	193	23
Chernykh, L.I.	95	51
Chernykh, N.S.	95	188
Churms, J.	51	83
Churyumov, K.I.	85, 191, 210, 217	49
Cirova, H.	71	16
Codina, J.M.	6	123
Colombini, E.	552	24
Contreras, O.	303	6
Czelusniak, H.	47	1
Danielson, G.E.	675	12
Danziger, J.	809	2
Davila, U.	781, 782	12
De Pascual, M.	491	44
Debehogne, H.	12, 809	25
Djorgovski, S.G.	695	3
Donal, H.P.	771	18
Dong, C.Z.	312, 334	13
Dong, Z.Z.	324	1
Douglass, G.G.	483	12
Dreyhsig, J.	544	2
Dykes, M.R.	993	1
Eglitis, I.E.	69	14
El-Khilali, Y.	87	10
Elst, E.	17	14
Espin, L.	781, 782	12
Everhart, E.	707	2
Farinyas, R.	771	18

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Ferreri, W.	22, 809	45
Ferrin, I.	302	3
Fink, U.	693	1
Firszt, T.	553	1
Fokanov, S.V.	94	23
Frueh, M.L.	711	21
Galas, T.Y.	61	37
Gallagher, J.	695	3
Garcia, J.	491	44
Ge, Y.L.	305, 330, 414	107
Geffert, D.	17	5
Geffert, M.	17	21
Georgieva, A.	71	62
Gerasimenko, S.I.	190, 193	219
Geyer, E.	17	14
Gibson, J.	675	14
Gilmore, A.C.	474	40
Goad, J.	695	1
Goerze, M.	24	1
Golovnya, V.V.	83	12
Gorel, G.K.	89	67
Gorodetskaja, N.S.	210	5
Gorodetskij, D.I.	210, 214, 217	48
Goroshchak, I.I.	61	81
Gorze, U.	24	2
Grasberg, E.K.	69	17
Graser, U.	493	4
Greenwood, J.D.	978	9
Gromadzinski, M.	47	3
Groote, D.	493	4
Gruen, E.	493	4
Gudkova, L.A.	89	21
Gullixson, C.	688	8
Gvardionov, A.B.	61	9
Haarala, S.	63	6
Haenel, A.	17	34
Hagen, H.J.	493	4
Handley, T.	293	7
Hanslmeier, A.	580	4
Hao, X.L.	324	1
Harland, G.	662	39
Hartley, M.	413	1

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Harwood, D.	323	4
Haug, U.	493	1
Havnes, O.	93	18
Hayakawa, S.	892	2
Heckman, T.M.	695	2
Helin, E.	675	2
Hendrie, M.J.	502	20
Henriksen, K.	93	17
Herald, D.	415	76
Heras, A.M.	6	1
Hernandez, M.	6	13
Hers, J.	581	38
Heudier, J.	10	5
Holleran, P.	695	2
Howell, S.	695	2
Huei, Y.Q.	312, 334	113
Hurnik, H.H.	47	2
Ignatovich, S.I.	61	72
Inasaridze, R.Y.	119	13
Inoda, S.	889	1
Ivanov, Y.	186	13
Ivanova, V.	71	107
Ivashchenko, Y.N.	83	10
Izhakevich, E.M.	83	13
Jackson, P.	45	33
Jackson, S.	788	5
Jacoby, G.H.	695	1
Jekabsons, P.	323	426
Jewitt, D.C.	675	12
John, A.	323	146
Johnston, J.	323	39
Johnstone, G.	976	3
Jones, B.F.	662	32
Jones, D.H.P.	501	12
Junkkarinen, V.T.	695	3
Kadyrova, N.	186	40
Kajzer, G.T.	168	11
Kalinenkov, N.D.	89	93
Kalinina, N.D.	168	36
Kaltygina, S.V.	83, 781, 782	13
Kaluzny, J.	695	3
Kamalov, M.	186	27

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Kaminski, R.	553	1
Kaneda, H.	392	9
Karachentsev, I.D.	115	2
Karachkina, L.G.	95	114
Karkoschka, E.	693	4
Kennicutt, R.C.	695	1
Khamidov, E.	186	13
Khamidov, T.	186, 192	129
Kiefer, E.	24	2
Kiefer, P.	24	2
Kiladze, R.I.	119	2
Kilmartin, P.	474	15
Kinnear, G.	323	55
Kirova, H.	71	17
Kiseleva, T.P.	84	8
Kiselyev, A.A.	84, 129	64
Kiselyev, N.N.	193	23
Kitkin, V.N.	114	86
Kizyun, L.N.	83	1
Kohoutek, L.	493	30
Koishikawa, M.	391, 893	137
Kojima, T.	892	2
Kornos, L.	56	41
Kosai, H.	371, 381	12
Kramer, E.	583	7
Kranjc, A.	96, 98	20
Krawczyk, S.	92	24
Kulish, A.P.	771	18
Kurpinska-Winiarska, M.	555	6
Laffont, E.	586	2
Lagerkvist, C.I.	49	14
Lai, L.	571	12
Landgraf, W.	46, 90, 528	13
Lappalainen, T.	63	6
Le Fevre, O.	10, 568	10
Lecacheux, J.	568	9
Leder, N.	544	2
Ledovskaya, I.V.	83, 123	21
Lejko, V.	186	1
Lelievre, G.	568	9
Lemonnier, D.	568	9
Lepeshnikova, S.A.	84	16

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Levitskaya, T.I.	168	113
Levy, D.	686	1
Li, G.Y.	330	2
Lingenfelder, G.	493	2
Lopez, C.E.	808	32
Lopez, G.A.	975	15
Lopez, M.R.	975	15
Lopez, O.J.A.	975	15
Louys, L.	809	15
Lowe, T.B.	657	2
Lu, J.H.	305, 330, 414	110
Ludwig, F.	33	13
Luo, G.S.	330	5
Lyukhanov, K.	95	3
Ma, X.Y.	334	83
Maazik, M.	75	4
Madejsky, R.	24	1
Major, S.P.	71, 83, 186	51
Majsuradze, G.A.	119	19
Malkov, A.A.	129	4
Mandel, H.	24	8
Mandel, U.	24	1
Manning, B.	494	37
Marinello, V.	565	20
Martin, R.	323	2
Martin-Pintado, J.	491	29
Martinez, P.	586	2
Massone, G.	22	35
Mathez, G.	568	9
Matkin, N.V.	168	18
Mattarozzi, G.	574	1
Matz, D.	47	11
Mau, K.H.	33	12
McCrosky, R.E.	801	31
McGrath, A.	323	372
Meech, K.J.	568, 807	10
Meleyev, H.	210, 217	9
Merezhina, L.S.	94	17
Mileyev, H.	210	3
Miller, J.	662	2
Mirmakhmudov, E.	186	144
Monderen, P.	809	15

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Moreno, F.	303	9
Moreno, M.	6	11
Mrkos, A.	46	267
Muciek, M.	92	20
Nagornyuk, S.	94	5
Nakamura, M.	378	2
Narizhnaya, M.V.	84	3
Nazarchuk, G.K.	115	4
Newton, J.	656	4
Niemi, A.	63	12
Nikolenko, I.V.	94	6
Nikonov, O.V.	771	18
Novikov, S.B.	129, 188	24
Nunez, J.	6	40
Ochnik, R.	47	5
Oja, T.	49	14
Olevic, D.	57	1
Ornig, C.W.	580	4
Osipenko, V.P.	102	15
Ozolinya, V.	69	29
Panferova, V.I.	102	1
Pattakhov, E.	186	26
Pauls, R.	493	4
Pauwels, T.	12	20
Pavlenko, E.	95	56
Pavlenko, P.P.	101	34
Pawicka, B.	553	1
Pedersen, H.E.	809	29
Penhallow, W.S.	792	11
Pereyra, Z.M.	821, 822	27
Piironen, J.	63	6
Pinson, J.	509	5
Piscitelli, J.	568	1
Platajs, I.K.	69	23
Polishchuk, N.D.	61	73
Pollas, C.	10	6
Ponomarev, D.N.	95	19
Potter, H.I.	820	23
Prokofyeva, V.	95	47
Protitch-Benishek, V.	57	34
Pundure, I.	69	2
Pyatkes, S.A.	168	30

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Quadri, U.	565	20
Quetsch, A.	493	1
Racine, R.	568	1
Radeva, V.	71	12
Rakhimov, A.G.	192	164
Rakhmatov, A.	192	16
Rakhmatov, E.	186	179
Raudsaar, X.	75	4
Ridley, H.B.	984	15
Riemann, R.	90	5
Rizvanov, N.	114	8
Roberts, G.	51	17
Ronchetti, I.	571	12
Rozhkovskij, D.A.	210	4
Rspaev, F.K.	191, 210, 217	32
Russell, K.	413	25
Ruzza, M.	571	12
Ryabenko, I.B.	210, 214	7
Ryazanov, A.P.	168	12
Rychtarcik, P.	56	110
Rydzinskis, A.	69	3
Safronov, Y.I.	33	9
Saidov, G.	186	23
Salmi, J.	99	3
Sanchez, F.	6	1
Sanguin, J.G.	808	13
Sanwal, N.B.	219	6
Sassi, G.	552	49
Scardia, M.	96, 98	63
Schiffer, H.J.	24	5
Schnell, A.	562	15
Schultz, P.	693	4
Schwartz, C.	801	29
Scotti, J.V.	691	11
Seki, T.	372	22
Seleznev, A.F.	168	24
Sereda, E.M.	83	11
Shanklin, J.D.	503	21
Shao, C.Y.	801	27
Shao, Y.J.	312, 334	170
Shapovalova, A.I.	115	3
Shatokhina, S.V.	83, 186	47

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Shaver, P.	809	2
Shcherbanovskij, A.L.	94, 115	16
Shestaka, I.S.	583	51
Shkodrov, V.	71	98
Shokin, Y.A.	105, 115, 129, 188	34
Sicardy, B.	568	5
Sid, M.A.	771	18
Sieron, W.	553	1
Sillanpaa, A.	63	6
Sizonenko, Y.V.	83, 781, 782	17
Skiff, B.A.	688	3
Smirnova, K.E.	85	2
Smirnova, T.M.	95	5
Smith, E.	695	2
Sobolenko, G.M.	168	15
Solheim, J.E.	93	16
Solodovnikov, V.V.	210, 214	6
Song, W.Q.	334	113
Spinrad, H.	695	4
Stanek, K.	553	1
Stapleton, J.R.	482	14
Stevens, L.	323	287
Stock, J.	303	17
Stock, R.F.	788	5
Stockenhuber, H.	562	11
Stoll, M.	562	2
Sun, S.S.	312, 334	196
Suzuki, K.	881	3
Svoren, J.	56	47
Swierkowska, S.	47	9
Syroczynski, R.	553	1
Szczepanski, M.	553	3
Szkody, P.	695	4
Tang, D.Y	324	1
Tanzer, G.	33	10
Tarashchuk, V.	95	56
Tashiro, T.	379	2
Tatum, J.B.	657	10
Tearo, A.R.	168	24
Telnyuk, V.V.	85	25
Thiele, U.	493	11
Timofeyev, S.N.	168	54

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Tokhtasyev, S.S.	136	7
Tolbin, S.V.	129, 771	81
Torres, C.	805	241
Toth, I.	561	5
Tovadrus, M.Y.	87	10
Trefzger, C.F.	577	3
Tsuchiya, K.	396	1
Tyler, A.	693	5
Ueda, S.	399	2
Urgitis, I.I.	69	16
Vacchi, C.	552	49
Vasilevskij, A.E.	168	46
Vavrova, Z.	46	32
Vesentini, G.	571	12
Vicentela, J.A.	808	13
Vorinka, S.I.	61	27
Voronenko, V.I.	89	128
Waddington, W.G.	980, 996	38
Wall, J.V.	950	1
Waller, W.	695	1
Wang, D.C.	305, 330, 414	126
Wang, Q.	305, 330, 414	131
Wang, S.C.	305, 330, 414	66
Wang, W.	330	2
Wang, Z.L.	334	102
Waniak, W.	555	3
Watanabe, E.	371	2
Watanabe, K.	392, 397	31
Waterfield, R.	993	1
Wehinger, P.A.	695	4
Wei, S.L.	305, 330, 414	112
West, R.M.	809	107
Whipple, A.	711	6
Wild, P.	26	20
Winiarski, M.	555	21
Wisniewski, W.	686	1
Wlodarczyk, I.	553	27
Woszczyk, A.	92	11
Wroblewski, H.	805	143
Wyckoff, S.	695	3
Yagudin, L.I.	129	44
Yagudina, E.I.	129	1

Appendix B. (continued)

Observer	Observatory Code(s)	Number of Observations
Yamagata, T.	381	3
Yan, L.S.	286	15
Yang, J.X.	305, 330, 414	151
Yang, J.Z.	330	6
Yatsenko, A.I.	83	1
Young, A.	576	16
Yuminova, O.G.	168	26
Yusa, T.	893	5
Zelishchev, I.E.	114, 136	94
Zhang, B.L.	286, 312, 334	105
Zhang, J.X.	305, 330, 414	68
Zhao, J.L.	337	48
Zhilinskij, E.G.	771	18
Zhukova, G.A.	168	12
Zhuravlyeva, L.V.	95	67
Zola, S.	555	4
Zvonareva, E.V.	168	40

INFRARED STUDIES NETWORK

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1. INTRODUCTION

This chapter summarizes activities in the Infrared Studies Network of the International Halley Watch (IHW) during 1982–1989, and describes material in the Infrared Studies portion of the IHW Comet Halley Archive. The archive is self-contained and can be accessed without the material in this chapter.

2. PERSONNEL

The Infrared Studies Network was organized in 1982. Table I lists the personnel. All became members of the project in 1982 except B. McGuinness, who joined in 1985.

The headquarters for the Infrared Studies Network was at the Department of Earth and Space Sciences, State University of New York at Stony Brook. Most of the non-European coordination and organization of Comet Halley observations were carried out there. Coordination of European observations was largely completed at the Observatoire de Paris in Meudon. All of the archiving took place at Stony Brook.

3. CONCEPT

In the early 1980s, infrared study of comets was still a relatively young field, although observations had been made in the previous one-and-a-half decades. These observations included broadband photometric measurements, selected intermediate-resolution spectroscopy (resolving powers of 50 to 100), and some spatial measurements of infrared emission from the coma and tails (Wilkening 1982). The observations had established a base of information on the infrared properties of comets (primarily dust) by 1982, when the IHW was organized. The number of telescopes with infrared capability and of infrared astronomers had increased about tenfold in the previous decade, and infrared instrumentation had dramatically advanced. Thus it was clear that a concerted effort of infrared observations of Comet Halley could help us learn much about comets.

The IHW assigned all observations of the infrared (loosely defined as 1 to 1000 micrometers) to the Infrared Studies Network. This meant that this network had to deal with photometry, spectroscopy, polarimetry, and imaging. Obviously, these areas had somewhat different goals and problems, which were reflected in the organization of the observations and the data archiving.

Relatively few infrared astronomers had observed comets extensively before the IHW's organization. This put demands on them to become familiar with the

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Table I. Discipline Specialist Team of the Infrared Studies Network[a]

Team Member	Affiliation	Responsibility
Roger F. Knacke	Department of Earth and Space Sciences State University of New York Stony Brook, NY 11794-2100 U.S.A.	Discipline Specialist
Therese Encrenaz	Observatoire de Paris Section d'Astrophysique F-92195 Meudon France	Discipline Specialist
Brian McGuinness	Department of Earth and Space Sciences State University of New York Stony Brook, NY 11794-2100 U.S.A.	Software Assistant
Mildred O'Dowd	Department of Earth and Space Sciences State University of New York Stony Brook, NY 11794-2100 U.S.A.	Assistant

[a] T.Y. Brooke and R. Danehy participated in early phases of the project.

issues and methods of cometary science, and sometimes raised questions about observing techniques (fortunately, only rarely after the fact). Of course, it was an objective of the IHW to advocate and encourage comet science, and maybe we succeeded. Probably, however, Comet Halley itself and the accompanying excitement deserve most of the credit for the present interest in comets.

3.1. Photometry

In early discussions about plans for Comet Halley observations, many observers put a high priority on systematic measurements of the infrared fluxes. Objectives included study of the evolution of the coma and tail and study of spectral features such as the silicate emission near 10 micrometers. Several groups organized monitoring programs at major observatories. The larger ones were at the European Southern Observatory (ESO), the Gornergrat Infrared Observatory

(TIRGO), the National Aeronautics and Space Administration (NASA) Infrared Telescope Facility (IRTF), the O'Brien Observatory (Minnesota), the South African Astrophysical Observatory (SAAO), and the United Kingdom Infrared Telescope (UKIRT). Additional programs were organized at Beijing Astronomical Observatory, Cerro Tololo Inter-American Observatory (CTIO), Haute-Provence Observatory (OHP), Kitt Peak National Observatory (KPNO), Sternberg State Astronomical Institute, and Yunnan Observatory. Individual contributions by a number of observers added to the total.

Infrared filters were a difficult issue. Discussions with observers led us to conclude that, for several reasons, it was impractical to arrange for a dedicated infrared filter set for the Comet Halley observations. First, the observatories had their own filters in multipurpose instruments that could not be modified for comet observations. Second, emission lines do not dominate the comet infrared spectrum, so filter passband locations are less critical than in the visible spectral region. Third, sub-percent precision infrared photometry of comets is currently not a high priority. Fourth, the standard (JHKL, etc.) system had been used in previous comet observations. Consequently, we recommended that the standard system be used in the near-infrared observations. Unfortunately, in some instances, filters in the JHKL set differed between observatories, and transformations had to be worked out (cf. Tokunaga 1987; Hanner and Tokunaga 1990). On the other hand, several observatories used nearly identical filters from a set manufactured by the Optical Coating Company and described in the Infrared Stock Filter Catalog (1987). To try to ameliorate the problems caused by nonstandard filters, we have put information, including transmission curves, into the archive (Section 4.3).

A related problem is that of standard stars in the infrared. Here, too, we need more standardization and precision. Hanner and Tokunaga (1990) discuss these issues in a review paper about infrared techniques and comets.

The Infrared Studies Network purchased and distributed long-wavelength filters centered at 18.0, 20.0, and 22.0 micrometers, because bandpass filters at these wavelengths were not available. Sets were sent to CTIO, IRTF, KPNO, Marshall Space Flight Center (MSFC), and the University of Minnesota. Unfortunately, purchasing delays held up the filters until after Halley's perihelion. As far as we are aware, only observers at the IRTF used them to observe Comet Halley. We hope that the filters will be useful in future comet observations.

When we were requested to or when it appeared useful, we supplied observers with ephemerides, comet news, or information on parallel observing programs. We used the electronic mail networks, the Arizona State message board, and written communications, but telephone calls had the most impact.

There was less interest than we expected in coordinating observations with different techniques and at different wavelengths. For example, there was not, as far as we can tell, much coordinated visual and infrared monitoring. It is not clear how much of scientific value was actually lost by this. On the other hand, there was extensive infrared coverage on the Halley Watch Days and near the encounter times of the Giotto and VEGA spacecraft.

Many observatories cooperated with the IHW, awarding large amounts of telescope time for Comet Halley studies. In several instances, we interceded with observatories and allocation committees to advocate observing time for comet programs, probably with mixed success.

While this is not the place to review the scientific results, we wish to mention the appearance of the 10-micrometer silicate emission feature, the evolution of the temperature, the dust size spectrum, composition information, and the gas-to-dust ratio among the many interesting results from photometry. For an overview and introduction to the literature, the reader can consult recent review publications (Grewing et al. 1988; Newburn et al. 1990), references in them, and the other reviews and papers that continue to appear.

3.2. Spectroscopy

Before Comet Halley, the only infrared spectra of comets were circular variable filter (CVF) data longward of 2 micrometers at resolving powers of 50 to 100, and some high-resolution Fourier transform spectra (FTS) shortward of 2 micrometers. Much new spectroscopy was acquired during Comet Halley's apparition. The many spectacular VEGA-1 spectra (with a resolving power of about 50) resulted in the discovery of several new molecules and provided spatial resolution within the coma. Ground-based and airborne observers obtained many spectra with resolving powers ranging from 50 to 500 and extending farther into the infrared than before.

Infrared spectroscopy was in transition during the Halley apparition. Most spectroscopy employed scanning spectrometers, but new array detectors were changing infrared spectroscopy and imaging with enormous sensitivity improvements. Early models of these spectrometers became operational as Halley appeared. Had Halley returned just a few months later, we could have achieved much better sensitivities!

The NASA Kuiper Airborne Observatory (KAO) flew numerous missions to observe Comet Halley, including a special expedition to the southern hemisphere. KAO obtained high-resolution FTS observations (at 2.5 to 3.5 micrometers) and intermediate- (5- to 8-micrometer) to long-wavelength (15- to 60-micrometer) spectra.

There were not many simultaneous photometric and spectroscopic programs, although many observers saw to it that photometry supported specific spectroscopy. It seemed just too hard for observers to coordinate different instruments, telescopes, and observing teams. However, there is photometry near most of the spectroscopy, and in any event, the photometric and spectroscopic observations addressed different questions. Extensive ground-based spectroscopy exists around the spacecraft encounter times.

In hindsight, more spectra in the 10-micrometer region would have been useful, particularly because the spectra that we do have show that the Halley silicates are different from what we expected based on comets Kohoutek and West. Future comets have to be targeted for the 10-micrometer spectroscopy.

3.3. Polarimetry

Infrared polarimetry of comets (at > 1 micrometer) had not been attempted, as far as we are aware, before Comet Halley's apparition. One group carried out a polarization monitoring program over the available range of phase angles at J, H, and K wavelengths. The infrared polarization curves include the negative polarization branch that also appears in the visible.

3.4. Imaging

Comets IRAS-Araki-Alcock, Giacobini-Zinner, and Halley were the first to be imaged in the infrared. Here again, the Halley apparition overlapped the advent of infrared detector array technology. The Wyoming Infrared Observatory (WIRO), IRTF, KPNO, and the Whipple Observatory obtained many beautiful near-infrared and 10-micrometer images.

The infrared maps contain interesting and often unique information on dust albedo, particle sizes, and dust dynamics. The techniques will surely grow in importance in the future.

4. THE ARCHIVE

4.1. The Data

Observers submitted their data for archiving to Stony Brook. In the IHW Comet Halley Archive, all the data accumulated during the 1986 apparition are stored in digital form on compact discs. B. McGuinness created and processed most of the data files for the Infrared Studies Network.

Putting the data into digital form was a major effort that required considerable care, as material came in over several years. Most of the photometric data arrived as handwritten sheets of numbers that had to be entered into the computer. Only imaging data and some spectroscopic data arrived as digital tapes.

Files in the FITS format were created for the data. We worked to achieve a high level of accuracy in this process. After files had been created, we proofread the data file printouts, then sent them to the observers for checking. When the observers returned the data files, we entered recommended changes into the digital files and proofread them again. Finally, we reviewed the completed files for final error checking, format consistency, and cosmetic improvements. The procedure was complex, often taking months (sometimes years) as the data traveled back and forth, were modified, and were corrected. We cannot say exactly how well it worked. A surprising number (perhaps 30%) of the observers did not return checked data sets. We assume that our proofreading sufficed in these cases.

4.2. File Contents

The FITS files consist of observations organized by day. That is, all photometric or polarimetric observations on a given day by a team are in ASCII tables in a single file. Each spectrum and image is in a single file. Appendix A lists the IHW Infrared Studies Network files organized chronologically, while Appendix B sorts them by their file number.

The photometry tables list wavelengths (filters) and comet magnitudes (for all the measurements of a given day), plus auxiliary information such as errors, apertures, and time of observation. COMMENT lines contain additional descriptive material. Generally we tried to err on the side of including too much rather than too little. We assumed that if an observer felt that a comment was important, it probably was.

This could possibly cause some ambiguities. For example, some observers specified that they observed the "nucleus," others specified that they observed "the brightest part of the coma," and still others specified nothing. Probably all three were observing the same thing, but we entered the comments as received. In a few cases, measurements were made that were not centered on the brightest spot of the coma. If so, we specified "origin" or an offset.

Whenever literature references existed, we included them in REFERENCE or COMMENT lines. Table II contains explanations of the FITS and IHW keywords.

Some of the data will probably not appear elsewhere, but much of the material has been published in some form in the scientific literature. However, even for published material, the archive often contains unique data or information. For example, some observers chose to publish averaged magnitudes or fluxes of several observations taken in a night. When the data were available, the archive includes all the measurements rather than just the averaged values. The archive also provides information about apertures, filters, air masses, and miscellaneous material that might not have been published elsewhere.

When photometry data appeared in the literature and the authors submitted nothing to the IHW (a few cases), we entered the published data to make the archive as complete as possible. In all these cases, the archive files contain the references.

Polarimetry files follow the same format as the photometry files, that is, they are ASCII tables with wavelength (filter), polarization magnitude, polarization direction, and ancillary information. Most of the data do not appear in digital form in the published literature.

The spectroscopy and imaging files are usually in the STANDARD format FITS files. Since published spectroscopy and image data appear largely in graphical form, the digital data in the archive are the unique resource in most cases. Many image data sets contain calibration images and comparison-star information.

4.3. Filter Files

To assist in interpretation of photometry and images, we requested detailed information about the filter systems from the observers. The filter information includes, in many cases, filter transmission scans that appear as FILTER files in the archive. In some instances, the observers supplied digital data; in others, we digitized filter transmission charts at Stony Brook. When no other data were available, we included a filter table with information such as the central wavelength and bandwidth. Often the archive includes both tables and transmission curves.

The archive contains, in readily accessible form, an extensive collection of filter information for different observatories. However, in several instances, the filter data either do not exist or were not supplied. Archive users must be cautious when comparing infrared magnitudes at the few-percent precision level, particularly when little filter information exists.

4.4. Completeness

We repeatedly asked (some might say, "harangued") observers to submit data to the archive. We used mailings, personal letters, telephone, fax, electronic mail, and personal conversations to encourage submission of the data. Telephone and

Table II. Keywords in the FITS Primary Headers[a]

Keyword	Description
SIMPLE	Conformity to FITS format (T = yes, F = no)
BITPIX	Number of bits/pixel
NAXIS	Number of axes in array
NAXIS1	Data array size, axis 1
NAXIS2	Data array size, axis 2
EXTEND	Conformity with (new) extension standard (T = yes, F = no)
OBJECT	Name of object
FILE-NUM	File identification number
DATE-OBS	Date of middle of observation (UT) (dd/mm/yy)
TIME-OBS	Time of middle of observation (expressed in decimal days UT)
DATE-REL	Date when observation may be publicly released (dd/mm/yy)
DISCIPLN	IHW Discipline (INFRARED STUDIES)
LONG-OBS	East longitude of observatory (0–360 deg)
LAT--OBS	Latitude of observatory (+ = north, - = south)
SYSTEM	Observing system code 2NNNXXYY, where 2 denotes the Infrared Studies Network, NNN the IAU observatory code (= 500 if not in the IAU list), XX the telescope number as collated by Large-Scale Phenomena Network (if NNN = 500, XX = country code), and YY not used
OBSERVER	Observer(s) name(s)
SUBMITTR	Submitter(s) name(s)
SPEC-EVT	Special event (T = yes, F = no)
DAT-FORM	Form of data: 'STANDARD' if data records conform to FITS standard, 'ASCII' for tables, or 'NODATA' if data were not submitted
DAT-TYPE	Type of data being submitted
OBSVTORY	Name of submitting observatory
LOCATION	Location of submitting observatory
TELESCOP	Telescope identification (size)
INSTRUME	Instrument used
COMMENT	Cols. 9-80 are a comment
HISTORY	Cols. 9-80 are a comment
FILTER	Type of filter used
APERSIZE	Entrance aperture size (arcsec)
AIRM-AVG	Average airmass of observation
RANGE-SP	Approximate spectral range (micrometers)
RESOL-SP	Approximate spectral resolution (micrometers)
DIS-CODE	Filter table number (in filter table files)
BSCALE	Scale factor used to convert tape pixel values to true values (true = tape * BSCALE + BZERO)
BZERO	Offset applied to tape pixel values to convert to true values
BUNIT	Data units
BLANK	Missing pixel filler value

Table II. (continued)

Keyword	Description
CDELTn	Pixel spacing along axis n of data array
CTYPEn	Units along data axis n
CRPIXn	Pixel number of nucleus along axis n
PIXSCALE	Pixel size in arcsec
DATAMIN	Minimum data value in the file
DATAMAX	Maximum data value in the file
END	End of FITS header

[a] Table extension keywords are defined and formatted in each file.

direct conversations were the most effective means of communication. Certainly our IHW mailing list was larger than our readership. In the end, almost everyone who took data submitted them, and the submitted data appear in the archive. We say "almost everyone" because there are some unfortunate gaps.

Some data were never submitted to the IHW. The reasons given for non-submission included pressures of time and lack of funding for preparation of material for the IHW (in fact, no U.S. federal funding was allocated specifically for this task). In other words, priorities lay elsewhere. Still, we are gratified by the cooperation of the great majority of observers and realize that 100% of anything is difficult to achieve.

To make the archive as complete as possible, we created files for those dates when we knew of scheduled observations, even if we could not get the data. These files contain keyword information and references to assist archive users in tracking down material. The amount of missing material known to us is small (a few percent of all the data taken, including photometry, spectroscopy, and imaging). Of course, published material is not lost. However, the data in digital form that the archive contains will be a resource for future researchers. We urge those observers who did not submit their data to consider publishing them in extended form or including them in the NASA Planetary Data System Archive.

At one point, we suggested that people send us photographs that might be interesting for a historical record of the IHW. Only three people did, and we abandoned the idea.

The results of all this effort are nearly 600 files, including the filter files. We estimate, however, that all of it will occupy only about 1% of the space on a compact disc.

4.5. Use of the Archive

When the archive appears, the data may be used by all researchers. Archive users should acknowledge data sources (i.e., the OBSERVERS) and the IHW Comet Halley Archive.

The basic resources for comet infrared data will be the IHW Archive in digital form and the original literature. Both contain unique material. Researchers should always consult the literature in addition to the archive, to get as much information as possible. Only in this way will users be working with primary source material and notice subtleties or potential pitfalls.

In the area of infrared studies, the printed archive should be used only in conjunction with the primary sources, the digital IHW archive, and the literature. We did not submit images or pictures of spectra to the printed archive. The important ones have been or will soon be published, and there is no need to repeat them. The ones that the observers judged to be less immediately significant (or photogenic) and did not publish can be generated from the digital data.

If a researcher insists on having the infrared data in printed form, a viable procedure is to print out the Infrared Studies section of the archive. This is an easy task, and we used it for handling data during creation of the files. Lack of direct access to the necessary computer and compact-disc equipment should not be an insurmountable problem. The equipment exists in many places, and creation of printouts of files or even of the whole Infrared Studies section requires a not-unreasonable effort.

5. ACKNOWLEDGMENTS

It is a pleasure to acknowledge years of association with Mildred O'Dowd, who carried out the secretarial tasks since the beginning of the Halley Watch. She was vital to the project. The Infrared Studies archive also reflects the hard work and dedication of Brian McGuinness. Many others at Stony Brook and Meudon contributed advice and insights, as did people in the IHW organization. We do not quite want to thank those astronomers who did not send their data for archiving, but we do encourage them to make their data available in some other way. Finally, we take pleasure in acknowledging and thanking the many scientists around the world with whom we have worked and interacted during the IHW campaign.

6. REFERENCES

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Appendix A. Chronological List of Files for Infrared Studies

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
220000	15/09/84	0.5130	WILLNER,S	WHIPPLE	PHOTOMETRY	
220001	20/12/84	0.5000	BIRKETT,C/ET AL.	UKIRT	PHOTOMETRY	
220002	18/01/85	0 3000	HANNER,M/ TOKUNAGA,A	NASA IRTF	PHOTOMETRY	
220003	17/02/85	0.2790	BROOKE,T/KNACKE,R	NASA IRTF	PHOTOMETRY	
220004	18/02/85	0.3000	CRUIKSHANK,D/ ET AL.	NASA IRTF	PHOTOMETRY	
220005	20/02/85	0.3000	CRUIKSHANK,D/ ET AL.	NASA IRTF	PHOTOMETRY	
223084	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	IMAGE	
223085	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	IMAGE	
223083	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	IMAGE	
220006	22/03/85	0.2000	TOKUNAGA,A/ET AL.	NASA IRTF	PHOTOMETRY	
220007	10/04/85	0.3000	GREEN,S/GEBALLE,T	UKIRT	PHOTOMETRY	
220008	11/04/85	0.2500	GREEN,S/GEBALLE,T	UKIRT	PHOTOMETRY	
220160	18/08/85	0.6240	GREEN,S/DAVIES,J	UKIRT	PHOTOMETRY	
220161	19/08/85	0.6620	GREEN,S/DAVIES,J	UKIRT	PHOTOMETRY	
220009	23/08/85	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220162	24/08/85	0.6500	MCDONNELL,J/ ZARNECKI,J	UKIRT	PHOTOMETRY	
220010	25/08/85	0.6000	GRIEP,D/ TOKUNAGA,A	NASA IRTF	PHOTOMETRY	
220163	25/08/85	0.6130	ZARNECKI,J/ MCDONNELL,J	UKIRT	PHOTOMETRY	
220164	26/08/85	0.6190	MCDONNELL,J/ ZARNECKI,J	UKIRT	PHOTOMETRY	
220011	04/09/85	0.4200	JOYCE,R	KPNO	PHOTOMETRY	
220012	05/09/85	0.6000	KAMINSKI,C/ET AL.	NASA IRTF	PHOTOMETRY	
220013	06/09/85	0.6000	GOLISCH,W/ KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220165	12/09/85	0.6150	GREEN,S/ MACDONALD,G	UKIRT	PHOTOMETRY	
223060	16/09/85	0.0000	HAYWARD,T	WIRO	IMAGE	HD 18881
223002	16/09/85	0.4920	HAYWARD,T	WIRO	IMAGE	
220014	16/09/85	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220015	21/09/85	0.5930	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
221000	21/09/85	0.5930	BROOKE,T/KNACKE,R	NASA IRTF	POLARIMETRY	
220212	25/09/85	0.4000	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220017	25/09/85	0.6000	KAMINSKI,C/ GOLISCH,W	NASA IRTF	PHOTOMETRY	
220016	26/09/85	0.4000	LE BERTRE,T/ EPCHTEIN,N	ESO	PHOTOMETRY	
220018	26/09/85	0.6000	GOLISCH,W/ KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220019	28/09/85	0.4000	LE BERTRE,T/ EPCHTEIN,N	ESO	PHOTOMETRY	
223061	01/10/85	0.0000	GRASDALEN,G	WIRO	IMAGE	BS 134
223004	01/10/85	0.3600	GRASDALEN,G	WIRO	IMAGE	
223003	01/10/85	0.3600	GRASDALEN,G	WIRO	IMAGE	
223006	01/10/85	0.3690	GRASDALEN,G	WIRO	IMAGE	
223005	01/10/85	0.3690	GRASDALEN,G	WIRO	IMAGE	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
220020	03/10/85	0.0000	TARANOVA,O/ET AL.	STERNBERG	PHOTOMETRY	
220021	04/10/85	0.0000	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
223062	06/10/85	0.0000	HAYWARD,T	WIRO	IMAGE	HD 18881
223007	06/10/85	0.4440	HAYWARD,T	WIRO	IMAGE	
223008	06/10/85	0.4560	HAYWARD,T	WIRO	IMAGE	
223009	06/10/85	0.4670	HAYWARD,T	WIRO	IMAGE	
223010	06/10/85	0.4800	HAYWARD,T	WIRO	IMAGE	
223011	06/10/85	0.4920	HAYWARD,T	WIRO	IMAGE	
220022	14/10/85	0.2000	MONETI,A/ STANGA,R	TIRGO	PHOTOMETRY	
220023	15/10/85	0.1000	MONETI,A/ STANGA,R	TIRGO	PHOTOMETRY	
220024	16/10/85	0.2000	MONETI,A/ STANGA,R	TIRGO	PHOTOMETRY	
220025	17/10/85	0.1000	MONETI,A/ STANGA,R	TIRGO	PHOTOMETRY	
220026	18/10/85	0.1000	MONETI,A/ STANGA,R	TIRGO	PHOTOMETRY	
223063	19/10/85	0.0000	GRASDALEN,G	WIRO	IMAGE	BS 923
223064	19/10/85	0.0000	GRASDALEN,G	WIRO	IMAGE	RHO ORI
220027	19/10/85	0.1000	WHITELOCK,P	SAAO	PHOTOMETRY	
220028	19/10/85	0.3580	GREGORY,B/ET AL.	CTIO	PHOTOMETRY	
223012	19/10/85	0.4420	GRASDALEN,G	WIRO	IMAGE	
223013	19/10/85	0.4530	GRASDALEN,G	WIRO	IMAGE	
223065	20/10/85	0.0000	GRASDALEN,G	WIRO	IMAGE	BS 923
220029	20/10/85	0.0900	MONETI,A/ STANGA,R	TIRGO	PHOTOMETRY	
223014	20/10/85	0.4250	GRASDALEN,G	WIRO	IMAGE	
223015	20/10/85	0.4370	GRASDALEN,G	WIRO	IMAGE	
220030	22/10/85	0.0860	WHITELOCK,P	SAAO	PHOTOMETRY	
220142	23/10/85	0.6000	KAMINSKI,C/ET AL.	NASA IRTF	PHOTOMETRY	
223075	24/10/85	0.0000	HAYWARD,T	WIRO	IMAGE	ALPHA TAU
223073	24/10/85	0.4[illegible]30	HAYWARD,T	WIRO	IMAGE	
223074	24/10/85	0.45[illegible]0	HAYWARD,T	WIRO	IMAGE	
223066	27/10/85	0.0000	HAYWARD,T	WIRO	IMAGE	HD 40335
2230[illegible]	27/10/85	0.4290	HAYWARD,T	WIRO	IMAGE	
223017	27/10/85	0.4410	HAYWARD,T	WIRO	IMAGE	
223018	27/10/85	0.4520	HAYWARD,T	WIRO	IMAGE	
222122	29/10/85	0.5500	KNACKE,R/ET AL.	UKIRT	SPECTROSCOPY	HYA 106
222118	29/10/85	0.5800	KNACKE,R/ET AL.	UKIRT	SPECTROSCOPY	
222119	29/10/85	0.5800	KNACKE,R/ET AL.	UKIRT	SPECTROSCOPY	
223067	30/10/85	0.0000	HAYWARD,T	WIRO	IMAGE	HD 18881
223027	30/10/85	0.2880	HAYWARD,T	WIRO	IMAGE	HD 18881
223028	30/10/85	0.2920	HAYWARD,T	WIRO	IMAGE	HD 18881
223020	30/10/85	0.3150	HAYWARD,T	WIRO	IMAGE	
223031	30/10/85	0.3150	HAYWARD,T	WIRO	IMAGE	
223019	30/10/85	0.3150	HAYWARD,T	WIRO	IMAGE	
223022	30/10/85	0.3260	HAYWARD,T	WIRO	IMAGE	
223021	30/10/85	0.3260	HAYWARD,T	WIRO	IMAGE	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
223023	30/1[illegible]/85	0.3380	HAYWARD,T	WIRO	IMAGE	
223024	30/10/85	0.3380	HAYWARD,T	WIRO	IMAGE	
22302[illegible]	[illegible]/1[illegible]/85	0.3480	HAYWARD,T	WIRO	IMAGE	
2230[illegible]5	[illegible]/[illegible]0/85	0.3480	HAYWARD,T	WIRO	IMAGE	
223[illegible]	[illegible]/[illegible]0/85	0.3480	HAYWARD,T	WIRO	IMAGE	
22302[illegible]	[illegible]/10/[illegible]	0.3570	HAYWARD,T	WIRO	IMAGE	HD 18881
223030	30/1[illegible]/8[illegible]	0.3580	HAYWARD,T	WIRO	IMAGE	HD 18881
220031	30/[illegible]/[illegible]5	0.3720	BOUCHET,P/ ENCRENAZ,T	ESO	PHOTOMETRY	
220032	[illegible]1/11/85	0.5000	KAMINSKI,C/ TOOMEY,D	NASA IRTF	PHOTOMETRY	
2200[illegible]3	03/11/85	0.3600	LE BERTRE,T/ ENCRENAZ,T	ESO	PHOTOMETRY	
220034	03/11/85	0.9610	ROBERTS,G	SAAO	PHOTOMETRY	
220035	04/11/85	0.0000	LE BERTRE,T/ ENCRENAZ,T	ESO	PHOTOMETRY	
220036	04/11/85	0.1000	LORENZETTI,D/ET AL.	TIRGO	PHOTOMETRY	
220237	04/11/85	0.2080	LORENZETTI,D/ET AL.	TIRGO	PHOTOMETRY	
220037	04/11/85	0.2920	LE BERTRE,T/ ENCRENAZ,T	ESO	PHOTOMETRY	
220038	05/11/85	0.4750	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
221001	05/11/85	0.4750	BROOKE,T/ KNACKE,R	NASA IRTF	POLARIMETRY	
222121	05/11/85	0.6000	BROOKE,T	NASA IRTF	SPECTROSCOPY	HYA 106
222125	05/11/85	0.6000	BROOKE,T	NASA IRTF	SPECTROSCOPY	
222124	05/11/85	0.6210	BROOKE,T	NASA IRTF	SPECTROSCOPY	
222123	05/11/85	0.6450	BROOKE,T	NASA IRTF	SPECTROSCOPY	HYA 106
220040	06/11/85	0.5000	GOLISCH,W/ BROOKE,T	NASA IRTF	PHOTOMETRY	
220039	07/11/85	0.0900	LORENZETTI,D/ET AL.	TIRGO	PHOTOMETRY	
220041	08/11/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220145	08/11/85	0.3000	RUSSELL,R/ LYNCH,D	STEWARD	PHOTOMETRY	
220042	09/11/85	0.0380	CATCHPOLE,R	SAAO	PHOTOMETRY	
220166	09/11/85	0.6300	ZARNECKI,J/ CHAKAVEH,S	UKIRT	PHOTOMETRY	
220167	10/11/85	0.4090	ZARNECKI,J/ CHAKAVEH,S	UKIRT	PHOTOMETRY	
220168	10/11/85	0.6280	ZARNECKI,J/ CHAKAVEH,S	UKIRT	PHOTOMETRY	
220043	14/11/85	0.9100	CARTER,B	SAAO	PHOTOMETRY	
220044	14/11/85	0.9600	STANGA,R/TOZZI,G	TIRGO	PHOTOMETRY	
220045	15/11/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220048	16/11/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220046	16/11/85	0.0000	TOZZI,G	TIRGO	PHOTOMETRY	
220049	16/11/85	0.9600	TOZZI,G	TIRGO	PHOTOMETRY	
222116	18/11/85	0.0000	GEBALLE,T	UKIRT	SPECTROSCOPY	
222120	18/11/85	0.4000	GEBALLE,T	UKIRT	SPECTROSCOPY	
223089	18/11/85	0.5000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223086	18/11/85	0.5000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
222117	18/11/85	0.5100	GEBALLE,T	UKIRT	SPECTROSCOPY	HYA 106
220050	19/11/85	0.9830	ROBERTS,G	SAAO	PHOTOMETRY	
220051	21/11/85	0.8720	ROBERTS,G	SAAO	PHOTOMETRY	
221002	22/11/85	0.3210	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
220052	22/11/85	0.3220	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
220053	22/11/85	0.4550	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
221003	22/11/85	0.4580	BROOKE,T/KNACKE,R	NASA IRTF	POLARIMETRY	
220055	23/11/85	0.2650	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
221004	23/11/85	0.2650	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
220056	28/11/85	0.3000	GOLISCH,W/ TOKUNAGA,A	NASA IRTF	PHOTOMETRY	
222146	28/11/85	0.5830	SUTO,H/ET AL.	OAO	SPECTROSCOPY	
220057	01/12/85	0.7500	STANGA,R	TIRGO	PHOTOMETRY	
220144	03/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220058	03/12/85	0.0230	GREGORY,B/ET AL.	CTIO	PHOTOMETRY	
220047	04/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220169	04/12/85	0.2710	MCDONNELL,J/ PANKIEWICZ,G	UKIRT	PHOTOMETRY	
220059	05/12/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220170	05/12/85	0.3340	MCDONNELL,J/ PANKIEWICZ,G	UKIRT	PHOTOMETRY	
220060	06/12/85	0.7140	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
221012	07/12/85	0.2800	PANKIEWICZ,G/ MCDONNELL,J	UKIRT	POLARIMETRY	
220061	07/12/85	0.7050	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220062	08/12/85	0.7310	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220063	09/12/85	0.2000	BROWN,R/GOLISCH,W	NASA IRTF	PHOTOMETRY	
220064	09/12/85	0.5590	QIAN ZHONG-YU/ ZHOU XU	BEIJING	PHOTOMETRY	
220065	09/12/85	0.8130	CARTER,B	SAAO	PHOTOMETRY	
220066	10/12/85	0.2630	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
221005	10/12/85	0.2630	BROOKE,T/KNACKE,R	NASA IRTF	POLARIMETRY	
220067	10/12/85	0.4670	QIAN ZHONG-YU/ ZHOU XU	BEIJING	PHOTOMETRY	
220068	11/12/85	0.5010	QIAN ZHONG-YU/ ZHOU XU	BEIJING	PHOTOMETRY	
220069	11/12/85	0.8000	MONETI,A	TIRGO	PHOTOMETRY	
222131	12/12/85	0.1000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
220070	12/12/85	0.2000	KAMINSKI,C/GRIEP,D	NASA IRTF	PHOTOMETRY	
220071	13/12/85	0.3000	KAMINSKI,C/GRIEP,D	NASA IRTF	PHOTOMETRY	
222002	14/12/85	0.2000	HERTER,T/ET AL.	NASA KAO	SPECTROSCOPY	
222001	14/12/85	0.2000	HERTER,T/ET AL.	NASA KAO	SPECTROSCOPY	
222000	14/12/85	0.2000	HERTER,T/ET AL.	NASA KAO	SPECTROSCOPY	
222159	16/12/85	0.0000	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	MARS
220072	17/12/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
222153	17/12/85	0.1390	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	
222132	17/12/85	0.2000	BREGMAN,J/ET AL.	LICK	SPECTROSCOPY	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
220073	18/12/85	0.8650	BROCKMANN,B/ ET AL.	OHP	PHOTOMETRY	
220074	19/12/85	0.8090	BROCKMANN,B/ ET AL.	OHP	PHOTOMETRY	
220075	20/12/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220076	20/12/85	0.1200	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
221006	20/12/85	0.1200	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
222154	20/12/85	0.1460	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	
220077	20/12/85	0.7710	BROCKMANN,B/ ET AL.	OHP	PHOTOMETRY	
220078	21/12/85	0.7710	BROCKMANN,B/ ET AL.	OHP	PHOTOMETRY	
222183	21/12/85	0.7920	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	
222162	22/12/85	0.0800	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
220079	22/12/85	0.5010	QIAN ZHONG-YU/ ZHOU XU	BEIJING	PHOTOMETRY	
222163	23/12/85	0.1400	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222184	23/12/85	0.3570	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	BETA LEP
222185	23/12/85	0.3780	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	BS 1856
220146	24/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
222164	24/12/85	0.0700	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222165	24/12/85	0.1100	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
220147	27/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220148	28/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220149	28/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220150	29/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220151	30/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
222136	30/12/85	0.0000	DANKS,A/ET AL.	ESO	SPECTROSCOPY	NO DATA
220153	01/01/86	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220154	02/01/86	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
222147	02/01/86	0.3960	SUTO,H/ET AL.	AIRO	SPECTROSCOPY	
223033	02/01/86	0.9950	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223034	02/01/86	0.9950	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223069	03/01/86	0.0000	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 129653
223068	03/01/86	0.0000	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 3029
223054	03/01/86	0.0080	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223053	03/01/86	0.0080	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223035	03/01/86	0.0080	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223036	03/01/86	0.0080	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223038	03/01/86	0.0220	SMITH,J/ MAGRATH,B	WIRO	IMAGE	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
223037	03/01/86	0.0220	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223045	03/01/86	0.0400	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 3029
223046	03/01/86	0.0430	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 3029
223047	03/01/86	0.5900	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 129653
223048	03/01/86	0.5910	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 129653
223049	03/01/86	0.5950	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 129653
223050	03/01/86	0.5970	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 129653
223070	04/01/86	0.0000	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 18881
223040	04/01/86	0.0130	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223056	04/01/86	0.0130	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223055	04/01/86	0.0130	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223039	04/01/86	0.0130	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223042	04/01/86	0.0260	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223041	04/01/86	0.0260	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223051	04/01/86	0.1890	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 18881
223052	04/01/86	0.2000	SMITH,J/ MAGRATH,B	WIRO	IMAGE	HD 18881
223043	05/01/86	0.0740	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
223044	05/01/86	0.0740	SMITH,J/ MAGRATH,B	WIRO	IMAGE	
220080	08/01/86	0.1000	TOKUNAGA,A/ GRIEP,D	NASA IRTF	PHOTOMETRY	
220081	09/01/86	0.0000	GRIEP,D	NASA IRTF	PHOTOMETRY	
220082	09/01/86	0.6510	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220083	10/01/86	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220084	11/01/86	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220085	12/01/86	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220086	13/01/86	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
222126	16/01/86	0.0800	CAMPINS,H	NASA IRTF	SPECTROSCOPY	
220210	17/01/86	0.0820	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220211	18/01/86	0.0130	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220087	21/01/86	0.6510	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
220088	22/01/86	0.8000	EPCHTEIN,N/ LE BERTRE,T	ESO	PHOTOMETRY	
220089	23/01/86	0.8000	EPCHTEIN,N/ LE BERTRE,T	ESO	PHOTOMETRY	
220090	26/01/86	0.8000	EPCHTEIN,N/ LE BERTRE,T	ESO	PHOTOMETRY	
222127	26/01/86	0.9600	EPCHTEIN,N/ LE BERTRE,T	ESO	SPECTROSCOPY	
220091	16/02/86	0.4400	LE BERTRE,T	ESO	PHOTOMETRY	
220092	17/02/86	0.4400	LE BERTRE,T	ESO	PHOTOMETRY	
220180	18/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220181	19/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220182	20/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220183	22/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220184	23/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220185	24/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220186	25/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220093	26/02/86	0.1300	WHITELOCK,P	SAAO	PHOTOMETRY	
220187	26/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220188	27/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220094	28/02/86	0.1300	WHITELOCK,P	SAAO	PHOTOMETRY	
220189	28/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220190	01/03/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220191	02/03/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220206	03/03/86	0.4380	LE BERTRE,T	ESO	PHOTOMETRY	
220207	03/03/86	0.9000	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220095	04/03/86	0.1300	WHITELOCK,P	SAAO	PHOTOMETRY	
220209	04/03/86	0.8510	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220208	05/03/86	0.8610	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220096	06/03/86	0.8500	TOKUNAGA,A/ ET AL.	NASA IRTF	PHOTOMETRY	
220097	12/03/86	0.8400	TOKUNAGA,A/ ET AL.	NASA IRTF	PHOTOMETRY	
223081	13/03/86	0.0000	HAYWARD,T	WIRO	IMAGE	BETA PEG
223076	13/03/86	0.7020	HAYWARD,T	WIRO	IMAGE	
223082	13/03/86	0.7070	HAYWARD,T	WIRO	IMAGE	
223077	13/03/86	0.7090	HAYWARD,T	WIRO	IMAGE	
223078	13/03/86	0.7110	HAYWARD,T	WIRO	IMAGE	
223079	13/03/86	0.7400	HAYWARD,T	WIRO	IMAGE	BETA PEG
223080	13/03/86	0.7430	HAYWARD,T	WIRO	IMAGE	BETA PEG
220098	13/03/86	0.7500	TOKUNAGA,A/ ET AL.	NASA IRTF	PHOTOMETRY	
220099	15/03/86	0.1510	CARTER,B	SAAO	PHOTOMETRY	
222138	15/03/86	0.4550	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
220234	15/03/86	0.4550	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220238	15/03/86	0.7000	CAMPINS,H/ET AL.	NASA KAO	PHOTOMETRY	
222139	16/03/86	0.4120	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
220229	16/03/86	0.4120	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220239	16/03/86	0.7000	CAMPINS,H/ET AL.	NASA KAO	PHOTOMETRY	
220100	17/03/86	0.1490	CARTER,B	SAAO	PHOTOMETRY	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
220213	17/03/86	0.7500	TOKUNAGA,A/ KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220101	18/03/86	0.1470	CARTER,B	SAAO	PHOTOMETRY	
220192	18/03/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220102	19/03/86	0.1300	SPENCER JONES,J	SAAO	PHOTOMETRY	
220156	19/03/86	0.3970	STANGA,R	ESO	PHOTOMETRY	
220103	20/03/86	0.1300	SPENCER JONES,J	SAAO	PHOTOMETRY	
220157	20/03/86	0.3490	STANGA,R	ESO	PHOTOMETRY	
222166	20/03/86	0.7000	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222167	20/03/86	0.7400	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
220104	21/03/86	0.1200	FEAST,M	SAAO	PHOTOMETRY	
220158	21/03/86	0.3710	STANGA,R	ESO	PHOTOMETRY	
222148	21/03/86	0.7500	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
220159	22/03/86	0.3450	STANGA,R	ESO	PHOTOMETRY	
222168	22/03/86	0.6800	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222169	22/03/86	0.7200	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222149	22/03/86	0.7400	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
222150	23/03/86	0.7550	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
220105	24/03/86	0.3440	BROOKE,T/ET AL.	CTIO	PHOTOMETRY	
221007	24/03/86	0.3440	BROOKE,T/ET AL.	CTIO	POLARIMETRY	
222170	24/03/86	0.6500	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222171	24/03/86	0.6800	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222172	24/03/86	0.7100	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222173	24/03/86	0.7300	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222151	24/03/86	0.7500	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
220106	24/03/86	0.8000	KAMINSKI,C/ GOLISCH,W	NASA IRTF	PHOTOMETRY	
222152	25/03/86	0.7190	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
220107	25/03/86	0.8930	CHEN,PEI-SHENG/ ET AL.	YUNNAN	PHOTOMETRY	
222003	26/03/86	0.3650	KNACKE,R/ET AL.	CTIO	SPECTROSCOPY	
222174	26/03/86	0.6400	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222175	26/03/86	0.6600	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222176	26/03/86	0.7000	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222004	27/03/86	0.3510	KNACKE,R/ET AL.	CTIO	SPECTROSCOPY	
220108	27/03/86	0.8990	CHEN PEI-SHENG/ ET AL.	YUNNAN	PHOTOMETRY	
220193	28/03/86	0.2920	DANKS,A/ET AL.	ESO	PHOTOMETRY	
221008	28/03/86	0.3420	BROOKE,T/ET AL.	CTIO	POLARIMETRY	
220109	28/03/86	0.3420	BROOKE,T/ET AL.	CTIO	PHOTOMETRY	
222137	28/03/86	0.3700	DANKS,A/ET AL.	ESO	SPECTROSCOPY	
223091	28/03/86	0.7000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223088	28/03/86	0.7000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
220110	29/03/86	0.1460	BUTLER,J	SAAO	PHOTOMETRY	
222005	29/03/86	0.3650	KNACKE,R/ET AL.	CTIO	SPECTROSCOPY	
223090	29/03/86	0.7000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223087	29/03/86	0.7000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
220111	29/03/86	0.9160	CHEN PEI-SHENG/ ET AL.	YUNNAN	PHOTOMETRY	

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
222133	30/03/86	0.0000	WICKRAMASINGHE,D/ ALLEN,D	AAO	SPECTROSCOPY	NO DATA
222134	31/03/86	0.0000	WICKRAMASINGHE,D/ ALLEN,D	AAO	SPECTROSCOPY	NO DATA
220112	31/03/86	0.1190	BUTLER,J	SAAO	PHOTOMETRY	
220171	31/03/86	0.6650	GREEN,S	UKIRT	PHOTOMETRY	
222135	01/04/86	0.0000	WICKRAMASINGHE,D/ ALLEN,D	AAO	SPECTROSCOPY	NO DATA
220113	01/04/86	0.0070	BUTLER,J	SAAO	PHOTOMETRY	
220114	02/04/86	0.8790	CHEN PEI-SHENG/ ET AL.	YUNNAN	PHOTOMETRY	
220194	03/04/86	0.2920	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220230	03/04/86	0.4300	KAWARA,K ET AL.	CTIO	PHOTOMETRY	
222140	03/04/86	0.4300	KAWARA K/ET AL.	CTIO	SPECTROSCOPY	
220195	04/04/86	0.2920	DANKS,A/ET AL.	ESO	PHOTOMETRY	
222141	04/04/86	0.2980	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
220231	04/04/86	0.2980	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220232	05/04/86	0.3820	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
222142	05/04/86	0.3820	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
220155	06/04/86	0.8750	SHIVANANDAN,K/ ET AL.	KAVALUR	PHOTOMETRY	
220225	07/04/86	0.6000	RUSSELL,R/ET AL.	NASA LEAR JET	PHOTOMETRY	
222143	08/04/86	0.3530	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
220233	08/04/86	0.3530	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
222181	08/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222130	08/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222182	08/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
220226	08/04/86	0.6000	RUSSELL,R/ET AL.	NASA LEAR JET	PHOTOMETRY	
220227	09/04/86	0.6000	RUSSELL,R/ET AL.	NASA LEAR JET	PHOTOMETRY	
222129	10/04/86	0.5000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222180	10/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222179	10/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222178	10/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222177	10/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
220228	11/04/86	0.6000	RUSSELL,R/ET AL.	NASA LEAR JET	PHOTOMETRY	
220196	13/04/86	0.1250	DANKS,A/ET AL.	ESO	PHOTOMETRY	
222160	15/04/86	0.0000	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	MARS
222155	15/04/86	0.6390	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	
220115	15/04/86	0.8270	ROBERTS,G	SAAO	PHOTOMETRY	
222161	17/04/86	0.0000	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	MARS
220117	17/04/86	0.2670	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
221009	17/04/86	0.2670	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
222156	17/04/86	0.6810	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	
220176	17/04/86	0.7900	SKILLEN,I	SAAO	PHOTOMETRY	
220118	17/04/86	0.8520	ROBERTS,G	SAAO	PHOTOMETRY	
223092	19/04/86	0.6000	IANNER,M/ET AL.	AAO	IMAGE	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
220177	19/04/86	0.7280	SKILLEN,I	SAAO	PHOTOMETRY	
220119	19/04/86	0.7750	ROBERTS,G	SAAO	PHOTOMETRY	
220214	20/04/86	0.3000	KAMINSKI,C/ GOLISCH,W	NASA IRTF	PHOTOMETRY	
223093	20/04/86	0.4000	HANNER,M/ET AL.	AAO	IMAGE	
223095	20/04/86	0.5000	HANNER,M/ET AL.	AAO	IMAGE	
223094	20/04/86	0.5000	HANNER,M/ET AL.	AAO	IMAGE	
223096	20/04/86	0.5500	HANNER,M/ET AL.	AAO	IMAGE	
220178	20/04/86	0.8380	SKILLEN,I	SAAO	PHOTOMETRY	
220120	20/04/86	0.8410	ROBERTS,G	SAAO	PHOTOMETRY	
220179	21/04/86	0.8530	SKILLEN,I	SAAO	PHOTOMETRY	
220121	21/04/86	0.8640	ROBERTS,G	SAAO	PHOTOMETRY	
220197	22/04/86	0.0830	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220122	22/04/86	0.3210	GRIEP,D/GOLISCH,W	NASA IRTF	PHOTOMETRY	
220198	23/04/86	0.0830	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220199	24/04/86	0.0830	DANKS,A/ET AL.	ESO	PHOTOMETRY	
222144	25/04/86	0.0000	BAAS,F/ET AL.	UKIRT	SPECTROSCOPY	
220200	25/04/86	0.0000	DANKS,A/ET AL.	ESO	PHOTOMETRY	
222006	25/04/86	0.3230	KNACKE,R/ET AL.	NASA IRTF	SPECTROSCOPY	
220201	26/04/86	0.0000	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220123	26/04/86	0.9480	CARTER,B	SAAO	PHOTOMETRY	
220124	27/04/86	0.2490	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
221010	27/04/86	0.2490	BROOKE,T/ KNACKE,R	NASA IRTF	POLARIMETRY	
220125	27/04/86	0.8220	CARTER,B	SAAO	PHOTOMETRY	
222187	29/04/86	0.2000	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	
222186	29/04/86	0.2000	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	
222188	29/04/86	0.2000	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	
222114	29/04/86	0.3650	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
220126	29/04/86	0.7570	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
222115	30/04/86	0.4170	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
220172	01/05/86	0.3410	ZARNECKI,J	UKIRT	PHOTOMETRY	
222111	01/05/86	0.4170	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
222112	01/05/86	0.4380	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
222113	01/05/86	0.4580	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
220215	02/05/86	0.4000	GOLISCH,W/ GRIEP,D	NASA IRTF	PHOTOMETRY	
222128	03/05/86	0.0000	STACEY,G/ET AL.	NASA KAO	SPECTROSCOPY	
220173	03/05/86	0.3480	ZARNECKI,J	UKIRT	PHOTOMETRY	
223071	06/05/86	0.0000	HAYWARD,T	WIRO	IMAGE	HD 106965
223057	06/05/86	0.1940	HAYWARD,T	WIRO	IMAGE	
223058	06/05/86	0.1940	HAYWARD,T	WIRO	IMAGE	
220127	12/05/86	0.8550	CATCHPOLE,R	SAAO	PHOTOMETRY	
220128	16/05/86	0.7470	CARTER,B	SAAO	PHOTOMETRY	
220129	16/05/86	0.8070	TARANOVA,O/ ET AL.	STERNBERG	PHOTOMETRY	
220130	17/05/86	0.8110	CARTER,B	SAAO	PHOTOMETRY	
220131	18/05/86	0.7510	CARTER,B	SAAO	PHOTOMETRY	

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
222007	19/05/86	0.0000	TOKUNAGA,A/ ET AL.	NASA IRTF	SPECTROSCOPY	
220132	21/05/86	0.8660	LANEY,D	SAAO	PHOTOMETRY	
220133	22/05/86	0.8480	LANEY,D	SAAO	PHOTOMETRY	
220202	23/05/86	0.0000	DANKS,A/ET AL.	ESO	PHOTOMETRY	
223072	23/05/86	0.0000	GRASDALEN,G/ HAYWARD,T	WIRO	IMAGE	HD 105601
223059	23/05/86	0.1870	GRASDALEN,G/ HAYWARD,T	WIRO	IMAGE	
220134	23/05/86	0.8370	LANEY,D	SAAO	PHOTOMETRY	
222145	24/05/86	0.0000	BAAS,F/ET AL.	UKIRT	SPECTROSCOPY	
220135	24/05/86	0.8340	LANEY,D	SAAO	PHOTOMETRY	
220136	25/05/86	0.8370	LANEY,D	SAAO	PHOTOMETRY	
220137	28/05/86	0.1780	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
221011	28/05/86	0.1780	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
220216	28/05/86	0.3000	GRIEP,D/GOLISCH,W	NASA IRTF	PHOTOMETRY	
220217	30/05/86	0.3000	GRIEP,D/KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220138	30/05/86	0.7400	CATCHPOLE,R	SAAO	PHOTOMETRY	
221013	01/06/86	0.2480	MCDONNELL,J	UKIRT	POLARIMETRY	
220203	02/06/86	0.9580	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220218	12/06/86	0.3000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220139	13/06/86	0.7620	CARTER,B	SAAO	PHOTOMETRY	
220204	24/06/86	0.9580	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220205	25/06/86	0.9580	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220140	06/07/86	0.3000	GRIEP,D/KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220141	08/07/86	0.3000	GRIEP,D/KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220143	16/11/86	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220219	24/11/86	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220220	02/12/86	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220221	03/12/86	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220222	20/12/86	0.6000	GRIEP,D	NASA IRTF	PHOTOMETRY	
220223	21/12/86	0.6000	GRIEP,D	NASA IRTF	PHOTOMETRY	
220152	31/12/86	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220175	31/03/87	0.3860	GREEN,S/WALTHER,D	UKIRT	PHOTOMETRY	
220174	09/04/87	0.3910	GREEN,S/SMITH,M	UKIRT	PHOTOMETRY	
220224	01/06/87	0.3000	TOKUNAGA,A/ET AL.	NASA IRTF	PHOTOMETRY	
220235	01/02/88	0.3960	WILLNER,S	WHIPPLE	PHOTOMETRY	
220236	08/04/88	0.3040	WILLNER,S	WHIPPLE	PHOTOMETRY	
228000	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	FILTER CURVE	FILTER
228001	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	FILTER CURVE	FILTER
228002		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228003		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228004		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228005		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228006		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228007		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228008		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228009		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228010		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228011		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
228012		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228013		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228014		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228015		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228016		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228017		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228018		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228019		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228020		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228021		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228022		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228023		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228024		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228025		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228026		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228027		0.0000	JOYCE,R	KPNO	FILTER CURVE	FILTER
228028		0.0000	JOYCE,R	KPNO	FILTER CURVE	FILTER
228029		0.0000	JOYCE,R	KPNO	FILTER CURVE	FILTER
228030		0.0000	PEI-SHENG CHEN	YUNNAN	FILTER CURVE	FILTER
228031		0.0000	PEI-SHENG CHEN	YUNNAN	FILTER CURVE	FILTER
228032		0.0000	PEI-SHENG CHEN	YUNNAN	FILTER CURVE	FILTER
228033		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228034		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228035		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228036		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228037		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228038		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228039		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228040		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228041		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228042		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228043		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228044		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228045		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
229001		0.0000	TOKUNAGA,A	NASA IRTF	FILTERTABLE	FILTER
229002		0.0000	GREGORY,B/ET AL.	CTIO	FILTERTABLE	FILTER
229003		0.0000	EATON,N/ZARNECKI,J	UKIRT	FILTERTABLE	FILTER
229004		0.0000	GREGORY,B	CTIO	FILTERTABLE	FILTER
229005		0.0000	BOUCHET,P/ET AL.	ESO	FILTERTABLE	FILTER
229006		0.0000	BOUCHET,P/ET AL.	ESO	FILTERTABLE	FILTER
229007		0.0000		ESO	FILTERTABLE	FILTER
229008		0.0000	MONETI,A/ET AL.	TIRGO	FILTERTABLE	FILTER
229009		0.0000		OHP	FILTERTABLE	FILTER
229010		0.0000	TARANOVA,O/ET AL.	STERNBERG	FILTERTABLE	FILTER
229011		0.0000	WHITELOCK,P	SAAO	FILTERTABLE	FILTER
229013		0.0000		BEIJING	FILTERTABLE	FILTER
229014		0.0000		TIRGO	FILTERTABLE	FILTER
229015		0.0000	CHEN PEI-SHENG/ ET AL.	YUNNAN	FILTERTABLE	FILTER
229016		0.0000	TOKUNAGA,A	NASA IRTF	FILTERTABLE	FILTER

Appendix A. (continued)

File #	Date	Time	Observer(s)	Observatory	Data Type	Comments
229017		0.0000	WILLNER,S	WHIPPLE	FILTERTABLE	FILTER
229018		0.0000	GEHRZ,R	WIRO	FILTERTABLE	FILTER
229019		0.0000	SHIVANANDAN,K/ ET AL.	KAVALUR	FILTERTABLE	FILTER
229020		0.0000	LYNCH,D	STEWARD	FILTERTABLE	FILTER
229021		0.0000	JOYCE,R	KPNO	FILTERTABLE	FILTER
229022		0.0000	JOYCE,R	KPNO	FILTERTABLE	FILTER
229023		0.0000	LYNCH,D/ET AL.	NASA LEAR JET	FILTERTABLE	FILTER

Appendix B. List of Files for Infrared Studies Sorted by File Number

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
220000	15/09/84	0.5130	WILLNER,S	WHIPPLE	PHOTOMETRY	
220001	20/12/84	0.5000	BIRKETT,C/ET AL.	UKIRT	PHOTOMETRY	
220002	18/01/85	0.3000	HANNER,M/ TOKUNAGA,A	NASA IRTF	PHOTOMETRY	
220003	17/02/85	0.2790	BROOKE,T/KNACKE,R	NASA IRTF	PHOTOMETRY	
220004	18/02/85	0.3000	CRUIKSHANK,D/ ET AL.	NASA IRTF	PHOTOMETRY	
220005	20/02/85	0.3000	CRUIKSHANK,D/ ET AL.	NASA IRTF	PHOTOMETRY	
220006	22/03/85	0.2000	TOKUNAGA,A/ET AL.	NASA IRTF	PHOTOMETRY	
220007	10/04/85	0.3000	GREEN,S/GEBALLE,T	UKIRT	PHOTOMETRY	
220008	11/04/85	0.2500	GREEN,S/GEBALLE,T	UKIRT	PHOTOMETRY	
220009	23/08/85	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220010	25/08/85	0.6000	GRIEP,D/ TOKUNAGA,A	NASA IRTF	PHOTOMETRY	
220011	04/09/85	0.4200	JOYCE,R	KPNO	PHOTOMETRY	
220012	05/09/85	0.6000	KAMINSKI,C/ET AL.	NASA IRTF	PHOTOMETRY	
220013	06/09/85	0.6000	GOLISCH,W/ KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220014	16/09/85	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220015	21/09/85	0.5930	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
220016	26/09/85	0.4000	LE BERTRE,T/ EPCHTEIN,N	ESO	PHOTOMETRY	
220017	25/09/85	0.6000	KAMINSKI,C/ GOLISCH,W	NASA IRTF	PHOTOMETRY	
220018	26/09/85	0.6000	GOLISCH,W/ KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220019	28/09/85	0.4000	LE BERTRE,T/ EPCHTEIN,N	ESO	PHOTOMETRY	
220020	03/10/85	0.0000	TARANOVA,O/ET AL.	STERNBERG	PHOTOMETRY	
220021	04/10/85	0.0000	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220022	14/10/85	0.2000	MONETI,A/STANGA,R	TIRGO	PHOTOMETRY	
220023	15/10/85	0.1000	MONETI,A/STANGA,R	TIRGO	PHOTOMETRY	
220024	16/10/85	0.2000	MONETI,A/STANGA,R	TIRGO	PHOTOMETRY	
220025	17/10/85	0.1000	MONETI,A/STANGA,R	TIRGO	PHOTOMETRY	
220026	18/10/85	0.1000	MONETI,A/STANGA,R	TIRGO	PHOTOMETRY	
220027	19/10/85	0.1000	WHITELOCK,P	SAAO	PHOTOMETRY	
220028	19/10/85	0.3580	GREGORY,B/ET AL.	CTIO	PHOTOMETRY	
220029	20/10/85	0.0900	MONETI,A/STANGA,R	TIRGO	PHOTOMETRY	
220030	22/10/85	0.0860	WHITELOCK,P	SAAO	PHOTOMETRY	
220031	30/10/85	0.3720	BOUCHET,P/ ENCRENAZ,T	ESO	PHOTOMETRY	
220032	01/11/85	0.5000	KAMINSKI,C/ TOOMEY,D	NASA IRTF	PHOTOMETRY	
220033	03/11/85	0.3600	LE BERTRE,T/ ENCRENAZ,T	ESO	PHOTOMETRY	
220034	03/11/85	0.9610	ROBERTS,G	SAAO	PHOTOMETRY	
220035	04/11/85	0.0000	LE BERTRE,T/ ENCRENAZ,T	ESO	PHOTOMETRY	
220036	04/11/85	0.1000	LORENZETTI,D/ET AL.	TIRGO	PHOTOMETRY	

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
220037	04/11/85	0.2920	LE BERTRE,T/ ENCRENAZ,T	ESO	PHOTOMETRY	
220038	05/11/85	0.4750	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
220039	07/11/85	0.0900	LORENZETTI,D/ET AL.	TIRGO	PHOTOMETRY	
220040	06/11/85	0.5000	GOLISCH,W/ BROOKE,T	NASA IRTF	PHOTOMETRY	
220041	08/11/85	0.0000	LYNCH,D/ET AL.	ST[illegible]RD	PHOTOMETRY	
220042	09/11/85	0.0380	CATCHPOLE,R	-	PHOTOMETRY	
220043	14/11/85	0.9100	CARTER,B	SAAO	PHOTOMETRY	
220044	14/11/85	0.9600	STANGA,R/TOZZI,G	TIRGO	PHOTOMETRY	
220045	15/11/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220046	16/11/85	0.0000	TOZZI,G	TIRGO	PHOTOMETRY	
220047	04/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220048	16/11/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220049	16/11/85	0.9600	TOZZI,G	TIRGO	PHOTOMETRY	
220050	19/11/85	0.9830	ROBERTS,G	SAAO	PHOTOMETRY	
220051	21/11/85	0.8720	ROBERTS,G	SAAO	PHOTOMETRY	
220052	22/11/85	0.3220	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
220053	22/11/85	0.4550	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
220055	23/11/85	0.2650	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
220056	28/11/85	0.3000	GOLISCH,W/ TOKUNAGA,A	NASA IRTF	PHOTOMETRY	
220057	01/12/85	0.7500	STANGA,R	TIRGO	PHOTOMETRY	
220058	03/12/85	0.0230	GREGORY,B/ET AL.	CTIO	PHOTOMETRY	
220059	05/12/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220060	06/12/85	0.7140	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220061	07/12/85	0.7050	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220062	08/12/85	0.7310	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220063	09/12/85	0.2000	BROWN,R/ GOLISCH,W	NASA IRTF	PHOTOMETRY	
220064	09/12/85	0.5590	QIAN ZHONG-YU/ ZHOU XU	BEIJING	PHOTOMETRY	
220065	09/12/85	0.8130	CARTER,B	SAAO	PHOTOMETRY	
220066	10/12/85	0.2630	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
220067	10/12/85	0.4670	QIAN ZHONG-YU/ ZHOU XU	BEIJING	PHOTOMETRY	
220068	11/12/85	0.5010	QIAN ZHONG-YU/ ZHOU XU	BEIJING	PHOTOMETRY	
220069	11/12/85	0.8000	MONETI,A	TIRGO	PHOTOMETRY	
220070	12/12/85	0.2000	KAMINSKI,C/GRIEP,D	NASA IRTF	PHOTOMETRY	
220071	13/12/85	0.3000	KAMINSKI,C/GRIEP,D	NASA IRTF	PHOTOMETRY	
220072	17/12/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220073	18/12/85	0.8650	BROCKMANN,B/ET AL.	OHP	PHOTOMETRY	
220074	19/12/85	0.8090	BROCKMANN,B/ET AL.	OHP	PHOTOMETRY	
220075	20/12/85	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220076	20/12/85	0.1200	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
220077	20/12/85	0.7710	BROCKMANN,B/ET AL.	OHP	PHOTOMETRY	
220078	21/12/85	0.7710	BROCKMANN,B/ET AL.	OHP	PHOTOMETRY	

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
220079	22/12/85	0.5010	QIAN ZHONG-YU/ ZHOU XU	BEIJING	PHOTOMETRY	
220080	08/01/86	0.1000	TOKUNAGA,A/ GRIEP,D	NASA IRTF	PHOTOMETRY	
220081	09/01/86	0.0000	GRIEP,D	NASA IRTF	PHOTOMETRY	
220082	09/01/86	0.6510	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220083	10/01/86	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220084	11/01/86	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220085	12/01/86	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220086	13/01/86	0.0000	LYNCH,D/ET AL.	STEWARD	PHOTOMETRY	
220087	21/01/86	0.6510	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220088	22/01/86	0.8000	EPCHTEIN,N/ LE BERTRE,T	ESO	PHOTOMETRY	
220089	23/01/86	0.8000	EPCHTEIN,N/ LE BERTRE,T	ESO	PHOTOMETRY	
220090	26/01/86	0.8000	EPCHTEIN,N/ LE BERTRE,T	ESO	PHOTOMETRY	
220091	16/02/86	0.4400	LE BERTRE,T	ESO	PHOTOMETRY	
220092	17/02/86	0.4400	LE BERTRE,T	ESO	PHOTOMETRY	
220093	26/02/86	0.1300	WHITELOCK,P	SAAO	PHOTOMETRY	
220094	28/02/86	0.1300	WHITELOCK,P	SAAO	PHOTOMETRY	
220095	04/03/86	0.1300	WHITELOCK,P	SAAO	PHOTOMETRY	
220096	06/03/86	0.8500	TOKUNAGA,A/ ET AL.	NASA IRTF	PHOTOMETRY	
220097	12/03/86	0.8400	TOKUNAGA,A/ ET AL.	NASA IRTF	PHOTOMETRY	
220098	13/03/86	0.7500	TOKUNAGA,A/ ET AL.	NASA IRTF	PHOTOMETRY	
220099	15/03/86	0.1510	CARTER,B	SAAO	PHOTOMETRY	
220100	17/03/86	0.1490	CARTER,B	SAAO	PHOTOMETRY	
220101	18/03/86	0.1470	CARTER,B	SAAO	PHOTOMETRY	
220102	19/03/86	0.1300	SPENCER JONES,J	SAAO	PHOTOMETRY	
220103	20/03/86	0.1300	SPENCER JONES,J	SAAO	PHOTOMETRY	
220104	21/03/86	0.1200	FEAST,M	SAAO	PHOTOMETRY	
220105	24/03/86	0.3440	BROOKE,T/ET AL.	CTIO	PHOTOMETRY	
220106	24/03/86	0.8000	KAMINSKI,C/ GOLISCH,W	NASA IRTF	PHOTOMETRY	
220107	25/03/86	0.8930	CHEN,PEI-SHENG/ ET AL.	YUNNAN	PHOTOMETRY	
220108	27/03/86	0.8990	CHEN PEI-SHENG/ ET AL.	YUNNAN	PHOTOMETRY	
220109	28/03/86	0.3420	BROOKE,T/ET AL.	CTIO	PHOTOMETRY	
220110	29/03/86	0.1460	BUTLER,J	SAAO	PHOTOMETRY	
220111	29/03/86	0.9160	CHEN PEI-SHENG/ ET AL.	YUNNAN	PHOTOMETRY	
220112	31/03/86	0.1190	BUTLER,J	SAAO	PHOTOMETRY	
220113	01/04/86	0.0070	BUTLER,J	SAAO	PHOTOMETRY	
220114	02/04/86	0.8790	CHEN PEI-SHENG/ ET AL.	YUNNAN	PHOTOMETRY	

Appendix B. (continued)

File #	Date	Time	Observers)	Observatory	Data type	Comments
220115	15/04/86	0.8270	ROBERTS,G	SAAO	PHOTOMETRY	
220117	17/04/86	0.2670	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
220118	17/04/86	0.8520	ROBERTS,G	SAAO	PHOTOMETRY	
220119	19/04/86	0.7750	ROBERTS,G	SAAO	PHOTOMETRY	
220120	20/04/86	0.8410	ROBERTS,G	SAAO	PHOTOMETRY	
220121	21/[illegible]/86	0.8640	ROBERTS,G	SAAO	PHOTOMETRY	
220122	22/04/86	0.3210	GRIEP,D/ GOLISCH,W	NASA IRTF	PHOTOMETRY	
220123	26/04/86	0.9480	CARTER,B	SAAO	PHOTOMETRY	
220124	27/04/86	0.2490	BROOKE,T/ET AL.	NASA IRTF	PHOTOMETRY	
220125	27/04/86	0.8220	CARTER,B	SAAO	PHOTOMETRY	
220126	29/04/86	0.7570	TARANOVA,O/ SHENAVRIN,V	STERNBERG	PHOTOMETRY	
220127	12/05/86	0.8550	CATCHPOLE,R	SAAO	PHOTOMETRY	
220128	16/05/86	0.7470	CARTER,B	SAAO	PHOTOMETRY	
220129	16/05/86	[illegible]070	TARANOVA,O/ET AL.	STERNBERG	PHOTOMETRY	
220130	17/05/86	0.8110	CARTER,B	SAAO	PHOTOMETRY	
220131	18/05/86	0.7510	CARTER,B	SAAO	PHOTOMETRY	
220132	21/05/86	0.8660	LANEY,D	SAAO	PHOTOMETRY	
220133	22/05/86	0.8480	LANEY,D	SAAO	PHOTOMETRY	
220134	23/05/86	0.8370	LANEY,D	SAAO	PHOTOMETRY	
220135	24/05/86	0.8340	LANEY,D	SAAO	PHOTOMETRY	
220136	25/05/86	0.8370	LANEY,D	SAAO	PHOTOMETRY	
220137	28/05/86	0.1780	BROOKE,T/ET AL.	KPNO	PHOTOMETRY	
220138	30/05/86	0.7400	CATCHPOLE,R	SAAO	PHOTOMETRY	
220139	13/06/86	0.7620	CARTER,B	SAAO	PHOTOMETRY	
220140	06/07/86	0.3000	GRIEP,D/KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220141	08/07/86	0.3000	GRIEP,D/KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220142	23/10/85	0.6000	KAMINSKI,C/ET AL.	NASA IRTF	PHOTOMETRY	
220143	16/11/86	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220144	03/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220145	08/11/85	0.3000	RUSSELL,R/LYNCH,D	STEWARD	PHOTOMETRY	
220146	24/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220147	27/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220148	28/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220149	28/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220150	29/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220151	30/12/85	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220152	31/12/86	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220153	01/01/86	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220154	02/01/86	0.0000	BOUCHET,P/ET AL.	ESO	PHOTOMETRY	
220155	06/04/86	0.8750	SHIVANANDAN,K/ ET AL.	KAVALUR	PHOTOMETRY	
220156	19/03/86	0.3970	STANGA,R	ESO	PHOTOMETRY	
220157	20/03/86	0.3490	STANGA,R	ESO	PHOTOMETRY	
220158	21/03/86	0.3710	STANGA,R	ESO	PHOTOMETRY	
220159	22/03/86	0.3450	STANGA,R	ESO	PHOTOMETRY	
220160	18/08/85	0.6240	GREEN,S/DAVIES,J	UKIRT	PHOTOMETRY	
220161	19/08/85	0.6620	GREEN,S/DAVIES,J	UKIRT	PHOTOMETRY	
220162	24/08/85	0.6500	MCDONNELL,J/ ZARNECKI,J	UKIRT	PHOTOMETRY	

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
220163	25/08/85	0.6130	ZARNECKI,J/ MCDONNELL,J	UKIRT	PHOTOMETRY	
220164	26/08/85	0.6190	MCDONNELL,J/ ZARNECKI,J	UKIRT	PHOTOMETRY	
220165	12/09/85	0.6150	GREEN,S/ MACDONALD,G	UKIRT	PHOTOMETRY	
220166	09/11/85	0.6300	ZARNECKI,J/ CHAKAVEH,S	UKIRT	PHOTOMETRY	
220167	10/11/85	0.4090	ZARNECKI,J/ CHAKAVEH,S	UKIRT	PHOTOMETRY	
220168	10/11/85	0.6280	ZARNECKI,J/ CHAKAVEH,S	UKIRT	PHOTOMETRY	
220169	04/12/85	0.2710	MCDONNELL,J/ PANKIEWICZ,G	UKIRT	PHOTOMETRY	
220170	05/12/85	0.3340	MCDONNELL,J/ PANKIEWICZ,G	UKIRT	PHOTOMETRY	
220171	31/03/86	0.6650	GREEN,S	UKIRT	PHOTOMETRY	
220172	01/05/86	0.3410	ZARNECKI,J	UKIRT	PHOTOMETRY	
220173	03/05/86	0.3480	ZARNECKI,J	UKIRT	PHOTOMETRY	
220174	09/04/87	0.3910	GREEN,S/SMITH,M	UKIRT	PHOTOMETRY	
220175	31/03/87	0.3860	GREEN,S/ WALTHER,D	UKIRT	PHOTOMETRY	
220176	17/04/86	0.7900	SKILLEN,I	SAAO	PHOTOMETRY	
220177	19/04/86	0.7280	SKILLEN,I	SAAO	PHOTOMETRY	
220178	20/04/86	0.8380	SKILLEN,I	SAAO	PHOTOMETRY	
220179	21/04/86	0.8530	SKILLEN,I	SAAO	PHOTOMETRY	
220180	18/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220181	19/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220182	20/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220183	22/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220184	23/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220185	24/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220186	25/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220187	26/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220188	27/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220189	28/02/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220190	01/03/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220191	02/03/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220192	18/03/86	0.4170	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220193	28/03/86	0.2920	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220194	03/04/86	0.2920	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220195	04/04/86	0.2920	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220196	13/04/86	0.1250	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220197	22/04/86	0.0830	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220198	23/04/86	0.0830	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220199	24/04/86	0.0830	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220200	25/04/86	0.0000	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220201	26/04/86	0.0000	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220202	23/05/86	0.0000	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220203	02/06/86	0.9580	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220204	24/06/86	0.9580	DANKS,A/ET AL.	ESO	PHOTOMETRY	

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
220205	25/06/86	0.95[illegible]0	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220206	03/03/86	0.4380	LE BERTRE,T	ESO	PHOTOMETRY	
220207	03/03/86	0.9000	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220208	05/03/86	0.8610	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220209	04/03/86	0.8510	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220210	17/01/86	0.0820	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220211	18/01/86	0.0130	CAMPINS,H	NASA IRTF	PHOTOMETRY	
220212	25/09/85	0.4000	DANKS,A/ET AL.	ESO	PHOTOMETRY	
220213	17/03/86	0.7500	TOKUNAGA,A/ KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220214	20/04/86	0.3000	KAMINSKI,C/ GOLISCH,W	NASA IRTF	PHOTOMETRY	
220215	02/05/86	0.4000	GOLISCH,W/GRIEP,D	NASA IRTF	PHOTOMETRY	
220216	28/05/86	0.3000	GRIEP,D/GOLISCH,W	NASA IRTF	PHOTOMETRY	
220217	30/05/86	0.3000	GRIEP,D/KAMINSKI,C	NASA IRTF	PHOTOMETRY	
220218	12/06/86	0.3000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220219	24/11/86	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220220	02/12/86	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220221	03/12/86	0.6000	GOLISCH,W	NASA IRTF	PHOTOMETRY	
220222	20/12/86	0.6000	GRIEP,D	NASA IRTF	PHOTOMETRY	
220223	21/12/86	0.6000	GRIEP,D	NASA IRTF	PHOTOMETRY	
220224	01/06/87	0.3000	TOKUNAGA,A/ET AL.	NASA IRTF	PHOTOMETRY	
220225	07/04/86	0.6000	RUSSELL,R/ET AL.	NASA LEAR JET	PHOTOMETRY	
220226	08/04/86	0.6000	RUSSELL,R/ET AL.	NASA LEAR JET	PHOTOMETRY	
220227	09/04/86	0.6000	RUSSELL,R/ET AL.	NASA LEAR JET	PHOTOMETRY	
220228	11/04/86	0.6000	RUSSELL,R/ET AL.	NASA LEAR JET	PHOTOMETRY	
220229	16/03/86	0.4120	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220230	03/04/86	0.4300	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220231	04/04/86	0.2980	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220232	05/04/86	0.3820	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220233	08/04/86	0.3530	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220234	15/03/86	0.4550	KAWARA,K/ET AL.	CTIO	PHOTOMETRY	
220235	01/02/88	0.3960	WILLNER,S	WHIPPLE	PHOTOMETRY	
220236	08/04/88	0.3040	WILLNER,S	WHIPPLE	PHOTOMETRY	
220237	04/11/85	0.2080	LORENZETTI,D/ ET AL.	TIRGO	PHOTOMETRY	
220238	15/03/86	0.7000	CAMPINS,H/ET AL.	NASA KAO	PHOTOMETRY	
220239	16/03/86	0.7000	CAMPINS,H/ET AL.	NASA KAO	PHOTOMETRY	
221000	21/09/85	0.5930	BROOKE,T/KNACKE,R	NASA IRTF	POLARIMETRY	
221001	05/11/85	0.4750	BROOKE,T/KNACKE,R	NASA IRTF	POLARIMETRY	
221002	22/11/85	0.3210	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
221003	22/11/85	0.4580	BROOKE,T/KNACKE,R	NASA IRTF	POLARIMETRY	
221004	23/11/85	0.2650	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
221005	10/12/85	0.2630	BROOKE,T/KNACKE,R	NASA IRTF	POLARIMETRY	
221006	20/12/85	0.1200	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
221007	24/03/86	0.3440	BROOKE,T/ET AL.	CTIO	POLARIMETRY	
221008	28/03/86	0.3420	BROOKE,T/ET AL.	CTIO	POLARIMETRY	

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
221009	17/04/86	0.2670	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
221010	27/04/86	0.2490	BROOKE,T/KNACKE,R	NASA IRTF	POLARIMETRY	
221011	28/05/86	0.1780	BROOKE,T/JOYCE,R	KPNO	POLARIMETRY	
221012	07/12/85	0.2800	PANKIEWICZ,G/ MCDONNELL,J	UKIRT	POLARIMETRY	
221013	01/06/86	0.2480	MCDONNELL,J	UKIRT	POLARIMETRY	
222000	14/12/85	0.2000	HERTER,T/ET AL.	NASA KAO	SPECTROSCOPY	
222001	14/12/85	0.2000	HERTER,T/ET AL.	NASA KAO	SPECTROSCOPY	
222002	14/12/85	0.2000	HERTER,T/ET AL.	NASA KAO	SPECTROSCOPY	
222003	26/03/86	0.3650	KNACKE,R/ET AL.	CTIO	SPECTROSCOPY	
222004	27/03/86	0.3510	KNACKE,R/ET AL.	CTIO	SPECTROSCOPY	
222005	29/03/86	0.3650	KNACKE,R/ET AL.	CTIO	SPECTROSCOPY	
222006	25/04/86	0.3230	KNACKE,R/ET AL.	NASA IRTF	SPECTROSCOPY	
222007	19/05/86	0.0000	TOKUNAGA,A/ET AL.	NASA IRTF	SPECTROSCOPY	
222111	01/05/86	0.4170	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
222112	01/05/86	0.4380	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
222113	01/05/86	0.4580	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
222114	29/04/86	0.3650	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
222115	30/04/86	0.4170	AITKEN,D/ET AL.	AAO	SPECTROSCOPY	
222116	18/11/85	0.0000	GEBALLE,T	UKIRT	SPECTROSCOPY	
222117	18/11/85	0.5100	GEBALLE,T	UKIRT	SPECTROSCOPY	HYA 106
222118	29/10/85	0.5800	KNACKE,R/ET AL.	UKIRT	SPECTROSCOPY	
222119	29/10/85	0.5800	KNACKE,R/ET AL.	UKIRT	SPECTROSCOPY	
222120	18/11/85	0.4000	GEBALLE,T	UKIRT	SPECTROSCOPY	
222121	05/11/85	0.6000	BROOKE,T	NASA IRTF	SPECTROSCOPY	HYA 106
222122	29/10/85	0.5600	KNACKE,R/ET AL.	UKIRT	SPECTROSCOPY	HYA 106
222123	05/11/85	0.6450	BROOKE,T	NASA IRTF	SPECTROSCOPY	HYA 106
222124	05/11/85	0.6210	BROOKE,T	NASA IRTF	SPECTROSCOPY	
222125	05/11/85	0.6000	BROOKE,T	NASA IRTF	SPECTROSCOPY	
222126	16/01/86	0.0800	CAMPINS,H	NASA IRTF	SPECTROSCOPY	
222127	26/01/86	0.9600	EPCHTEIN,N/ LE BERTRE,T	ESO	SPECTROSCOPY	
222128	03/05/86	0.0000	STACEY,G/ET AL.	NASA KAO	SPECTROSCOPY	
222129	10/04/86	0.5000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222130	08/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222131	12/12/85	0.1000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222132	17/12/85	0.2000	BREGMAN,J/ET AL.	LICK	SPECTROSCOPY	
222133	30/03/86	0.0000	WICKRAMASINGHE,D/ ALLEN,D	AAO	SPECTROSCOPY	NO DATA
222134	31/03/86	0.0000	WICKRAMASINGHE,D/ ALLEN,D	AAO	SPECTROSCOPY	NO DATA
222135	01/04/86	0.0000	WICKRAMASINGHE,D/ ALLEN,D	AAO	SPECTROSCOPY	NO DATA
222136	30/12/85	0.0000	DANKS,A/ET AL.	ESO	SPECTROSCOPY	NO DATA
222137	28/03/86	0.3700	DANKS,A/ET AL.	ESO	SPECTROSCOPY	
222138	15/03/86	0.4550	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
222139	16/03/86	0.4120	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
222140	03/04/86	0.4300	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
222141	04/04/86	0.2960	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
222142	05/04/86	0.3820	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	
222143	08/04/86	0.3530	KAWARA,K/ET AL.	CTIO	SPECTROSCOPY	

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
222144	25/04/86	0.0000	BAAS,F/ET AL.	UKIRT	SPECTROSCOPY	
222145	24/05/86	0.0000	BAAS,F/ET AL.	UKIRT	SPECTROSCOPY	
222146	28/11/85	0.5830	SUTO,H/ET AL.	OAO	SPECTROSCOPY	
222147	02/01/86	0.3960	SUTO,H/ET AL.	AIRO	SPECTROSCOPY	
222148	21/03/86	0.7500	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
222149	22/03/86	0.7400	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
222150	23/03/86	0.7550	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
222151	24/03/86	0.7500	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
222152	25/03/86	0.7190	SUTO,H/ET AL.	SSO	SPECTROSCOPY	
222153	17/12/85	0.1300	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	
222154	20/12/85	0.1460	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	
222155	15/04/86	0.6390	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	
222156	17/04/86	0.6810	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	
222159	16/12/85	0.0000	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	MARS
222160	15/04/86	0.0000	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	MARS
222161	17/04/86	0.0000	GLACCUM,W/ET AL.	NASA KAO	SPECTROSCOPY	MARS
222162	22/12/85	0.0800	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222163	23/12/85	0.1400	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222164	24/12/85	0.0700	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222165	24/12/85	0.1100	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222166	20/03/86	0.7000	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222167	20/03/86	0.7400	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222168	22/03/86	0.6800	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222169	22/03/86	0.7200	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222170	24/03/86	0.6500	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222171	24/03/86	0.6800	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222172	24/03/86	0.7100	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222173	24/03/86	0.7300	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222174	26/03/86	0.6400	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222175	26/03/86	0.6600	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222176	26/03/86	0.7000	WEAVER,H/ET AL.	NASA KAO	SPECTROSCOPY	NO DATA
222177	10/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222178	10/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222179	10/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222180	10/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222181	08/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222182	08/04/86	0.6000	BREGMAN,J/ET AL.	NASA KAO	SPECTROSCOPY	
222183	21/12/85	0.7920	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	
222184	23/12/85	0.3570	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	BETA LEP
222185	23/12/85	0.3780	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	BS 1856
222186	29/04/86	0.2000	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	
222187	29/04/86	0.2000	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	
222188	29/04/86	0.2000	MAILLARD,J/ET AL.	CFHT	SPECTROSCOPY	
223002	16/09/85	0.4920	HAYWARD,T	WIRO	IMAGE	
223003	01/10/85	0.3600	GRASDALEN,G	WIRO	IMAGE	
223004	01/10/85	0.3600	GRASDALEN,G	WIRO	IMAGE	
223005	01/10/85	0.3690	GRASDALEN,G	WIRO	IMAGE	
223006	01/10/85	0.3690	GRASDALEN,G	WIRO	IMAGE	
223007	06/10/85	0.4440	HAYWARD,T	WIRO	IMAGE	
223008	06/10/85	0.4560	HAYWARD,T	WIRO	IMAGE	
223009	06/10/85	0.4670	HAYWARD,T	WIRO	IMAGE	

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
223010	06/10/85	0.4800	HAYWARD,T	WIRO	IMAGE	
223011	06/10/85	0.4920	HAYWARD,T	WIRO	IMAGE	
223012	19/10/85	0.4420	GRASDALEN,G	WIRO	IMAGE	
223013	19/10/85	0.4530	GRASDALEN,G	WIRO	IMAGE	
223014	20/10/85	0.4250	GRASDALEN,G	WIRO	IMAGE	
223015	20/10/85	0.4370	GRASDALEN,G	WIRO	IMAGE	
223016	27/10/85	0.4290	HAYWARD,T	WIRO	IMAGE	
223017	27/10/85	0.4410	HAYWARD,T	WIRO	IMAGE	
223018	27/10/85	0.4520	HAYWARD,T	WIRO	IMAGE	
223019	30/10/85	0.3150	HAYWARD,T	WIRO	IMAGE	
223020	30/10/85	0.3150	HAYWARD,T	WIRO	IMAGE	
223021	30/10/85	0.3260	HAYWARD,T	WIRO	IMAGE	
223022	30/10/85	0.3260	HAYWARD,T	WIRO	IMAGE	
223023	30/10/85	0.3380	HAYWARD,T	WIRO	IMAGE	
223024	30/10/85	0.3380	HAYWARD,T	WIRO	IMAGE	
223025	30/10/85	0.3480	HAYWARD,T	WIRO	IMAGE	
223026	30/10/85	0.3480	HAYWARD,T	WIRO	IMAGE	
223027	30/10/85	0.2880	HAYWARD,T	WIRO	IMAGE	HD 18881
223028	30/10/85	0.2920	HAYWARD,T	WIRO	IMAGE	HD 18881
223029	30/10/85	0.3570	HAYWARD,T	WIRO	IMAGE	HD 18881
223030	30/10/85	0.3580	HAYWARD,T	WIRO	IMAGE	HD 18881
223031	30/10/85	0.3150	HAYWARD,T	WIRO	IMAGE	
223032	30/10/85	0.3480	HAYWARD,T	WIRO	IMAGE	
223033	02/01/86	0.9950	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223034	02/01/86	0.9950	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223035	03/01/86	0.0080	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223036	03/01/86	0.0080	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223037	03/01/86	0.0220	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223038	03/01/86	0.0220	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223039	04/01/86	0.0130	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223040	04/01/86	0.0130	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223041	04/01/86	0.0260	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223042	04/01/86	0.0260	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223043	05/01/86	0.0740	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223044	05/01/86	0.0740	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223045	03/01/86	0.0400	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 3029
223046	03/01/86	0.0430	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 3029
223047	03/01/86	0.5900	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 129653
223048	03/01/86	0.5910	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 129653
223049	03/01/86	0.5950	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 129653
223050	03/01/86	0.5970	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 129653
223051	04/01/86	0.1890	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 18881
223052	04/01/86	0.2000	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 18881
223053	03/01/86	0.0080	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223054	03/01/86	0.0080	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223055	04/01/86	0.0130	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223056	04/01/86	0.0130	SMITH,J/MAGRATH,B	WIRO	IMAGE	
223057	06/05/86	0.1940	HAYWARD,T	WIRO	IMAGE	
223058	06/05/86	0.1940	HAYWARD,T	WIRO	IMAGE	
223059	23/05/86	0.1870	GRASDALEN,G/ HAYWARD,T	WIRO	IMAGE	

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
223060	16/09/85	0.0000	HAYWARD,T	WIRO	IMAGE	HD 18881
223061	01/10/85	0.0000	GRASDALEN,G	WIRO	IMAGE	BS 134
223062	06/10/85	0.0000	HAYWARD,T	WIRO	IMAGE	HD 18881
223063	19/10/85	0.0000	GRASDALEN,G	WIRO	IMAGE	BS 923
223064	19/10/85	0.0000	GRASDALEN,G	WIRO	IMAGE	RHO ORI
223065	20/10/85	0.0000	GRASDALEN,G	WIRO	IMAGE	BS 923
223066	27/10/85	0.0000	HAYWARD,T	WIRO	IMAGE	HD 40335
223067	30/10/85	0.0000	HAYWARD,T	WIRO	IMAGE	HD 18881
223068	03/01/86	0.0000	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 3029
223069	03/01/86	0.0000	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 129653
223070	04/01/86	0.0000	SMITH,J/MAGRATH,B	WIRO	IMAGE	HD 18881
223071	06/05/86	0.0000	HAYWARD,T	WIRO	IMAGE	HD 106965
223072	23/05/86	0.0000	GRASDALEN,G/ HAYWARD,T	WIRO	IMAGE	HD 105601
223073	24/10/85	0.4530	HAYWARD,T	WIRO	IMAGE	
223074	24/10/85	0.4560	HAYWARD,T	WIRO	IMAGE	
223075	24/10/85	0.0000	HAYWARD,T	WIRO	IMAGE	ALPHA TAU
223076	13/03/86	0.7020	HAYWARD,T	WIRO	IMAGE	
223077	13/03/86	0.7090	HAYWARD,T	WIRO	IMAGE	
223078	13/03/86	0.7110	HAYWARD,T	WIRO	IMAGE	
223079	13/03/86	0.7400	HAYWARD,T	WIRO	IMAGE	BETA PEG
223080	13/03/86	0.7430	HAYWARD,T	WIRO	IMAGE	BETA PEG
223081	13/03/86	0.0000	HAYWARD,T	WIRO	IMAGE	BETA PEG
223082	13/03/86	0.7070	HAYWARD,T	WIRO	IMAGE	
223083	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	IMAGE	
223084	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	IMAGE	
223085	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	IMAGE	
223086	18/11/85	0.5000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223087	29/03/86	0.7000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223088	28/03/86	0.7000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223089	18/11/85	0.5000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223090	29/03/86	0.7000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223091	28/03/86	0.7000	TELESCO,C/ET AL.	NASA IRTF	IMAGE	
223092	19/04/86	0.6000	HANNER,M/ET AL.	AAO	IMAGE	
223093	20/04/86	0.4000	HANNER,M/ET AL.	AAO	IMAGE	
223094	20/04/86	0.5000	HANNER,M/ET AL.	AAO	IMAGE	
223095	20/04/86	0.5000	HANNER,M/ET AL.	AAO	IMAGE	
223096	20/04/86	0.5500	HANNER,M/ET AL.	AAO	IMAGE	
228000	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	FILTER CURVE	FILTER
228001	11/03/85	0.5000	RIEKE,M/ET AL.	STEWARD	FILTER CURVE	FILTER
228002		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228003		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228004		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228005		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228006		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228007		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228008		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228009		0.0000	GREEN,S	UKIRT	FILTER CURVE	FILTER
228010		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228011		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228012		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
228013		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228014		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228015		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228016		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228017		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228018		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228019		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228020		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228021		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228022		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228023		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228024		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228025		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228026		0.0000	TOKUNAGA,A	NASA IRTF	FILTER CURVE	FILTER
228027		0.0000	JOYCE,R	KPNO	FILTER CURVE	FILTER
228028		0.0000	JOYCE,R	KPNO	FILTER CURVE	FILTER
228029		0.0000	JOYCE,R	KPNO	FILTER CURVE	FILTER
228030		0.0000	PEI-SHENG CHEN	YUNNAN	FILTER CURVE	FILTER
228031		0.0000	PEI-SHENG CHEN	YUNNAN	FILTER CURVE	FILTER
228032		0.0000	PEI-SHENG CHEN	YUNNAN	FILTER CURVE	FILTER
228033		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228034		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228035		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228036		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228037		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228038		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228039		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228040		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228041		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228042		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228043		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228044		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
228045		0.0000	HAYWARD,T	WIRO	FILTER CURVE	FILTER
229001		0.0000	TOKUNAGA,A	NASA IRTF	FILTERTABLE	FILTER
229002		0.0000	GREGORY,B/ET AL.	CTIO	FILTERTABLE	FILTER
229003		0.0000	EATON,N/ ZARNECKI,J	UKIRT	FILTERTABLE	FILTER
229004		0.0000	GREGORY,B	CTIO	FILTERTABLE	FILTER
229005		0.0000	BOUCHET,P/ET AL.	ESO	FILTERTABLE	FILTER
229006		0.0000	BOUCHET,P/ET AL.	ESO	FILTERTABLE	FILTER
229007		0.0000		ESO	FILTERTABLE	FILTER
229008		0.0000	MONETI,A/ET AL.	TIRGO	FILTERTABLE	FILTER
229009		0.0000		OHP	FILTERTABLE	FILTER
229010		0.0000	TARANOVA,O/ET AL.	STERNBERG	FILTERTABLE	FILTER
229011		0.0000	WHITELOCK,P	SAAO	FILTERTABLE	FILTER
229013		0.0000		BEIJING	FILTERTABLE	FILTER
229014		0.0000		TIRGO	FILTERTABLE	FILTER
229015		0.0000	CHEN PEI-SHENG/ ET AL.	YUNNAN	FILTERTABLE	FILTER
229016		0.0000	TOKUNAGA,A	NASA IRTF	FILTERTABLE	FILTER
229017		0.0000	WILLNER,S	WHIPPLE	FILTERTABLE	FILTER

Appendix B. (continued)

File #	Date	Time	Observer(s)	Observatory	Data type	Comments
229018		0.0000	GEHRZ,R	WIRO	FILTERTABLE	FILTER
229019		0.0000	SHIVANANDAN,K/ ET AL.	KAVALUR	FILTERTABLE	FILTER
229020		0.0000	LYNCH,D	STEWARD	FILTERTABLE	FILTER
229021		0.0000	JOYCE,R	KPNO	FILTERTABLE	FILTER
229022		0.0000	JOYCE,R	KPNO	FILTERTABLE	FILTER
229023		0.0000	LYNCH,D/ET AL.	NASA LEAR JET	FILTERTABLE	FILTER

LARGE-SCALE PHENOMENA NETWORK

Malcolm B. Niedner, Jr.

on behalf of the
Large-Scale Phenomena Discipline Specialist Team

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Jürgen Rahe

PREAMBLE

The long-awaited arrival of Halley's Comet to the inner solar system in 1985–1986 demanded and received the unabated attention of astronomers around the world, and of the international space agencies. From the ground, aircraft, Earth orbit, and interplanetary space, this most famous of all cometary bodies was (needless to say) more closely scrutinized than any other of its cousin objects, and probably more than any other celestial body of any kind. Of the International Halley Watch (IHW) generally, much has been written elsewhere. This chapter concerns the IHW Large-Scale Phenomena (L-SP) Discipline and is intended to provide not only a history of the discipline's operations and scientific strategy, but also a description of the resulting archive in its various forms and components, particularly the compact disc—read only memory (CD-ROM) (digital) archive.

1. INTRODUCTION TO L-SP STUDIES

1.1. The Scientific Value of L-SP Data

Comets with large gas production rates and typical dust/gas ratios are truly "large-scale objects" in the solar system. Dust tails may reach lengths of 10 million kilometers or more, with their morphology, surface brightness distribution, color, and internal structure (if any) serving as diagnostics of:

- The chemical composition, size distribution, and density of the refractory component of that comet's nucleus.
- The time history of the total gas production over weeks and months.
- The dynamical history of the grains themselves after release from the nucleus.

Typically, due to the low flow speeds and low repulsive accelerations, dust tails are slowly changing and do not require the dense temporal coverage in wide-field imaging that the other major tail type (the ion tail) does for proper study.

Plasma, or ion, tails of comets operate under a completely different force law than do dust tails. Prominent ion tails achieve lengths of several tens of million kilometers (i.e., several tenths of an AU), in a highly time-dependent way as a result of their creation out of the very structured solar wind and interplanetary magnetic field (IMF). The lengths, small- and macro-scale structure, and time-dependence of ion tails are diagnostic of the following:

- The overall strength of the coupling between the solar-wind/IMF and the outflowing cometary ion gas.
- The presence of plasma instabilities operating internally to the bi-lobed magnetic tail and in the sunward magnetic barrier region.
- The interaction of comets with major structures in the interplanetary medium such as high-speed streams, magnetic sector boundaries, and flare-induced shock fronts.

Whereas the typical flow speed in a dust tail (i.e., that of a dust grain) is 1 km/s and an average repulsive acceleration is 0.5–1.0 in units of local solar gravity, in an average ion tail, those numbers are boosted to 50–100 km/s and 50–100, respectively (Niedner 1981; Celnik and Schmidt-Kaler 1987). To put it in more dramatic terms, ion tails are able to undergo rather complete transformation and renewal out to distances of 10 million kilometers in a day or so, and show extremely rapid changes over shorter distances in hours or less (Brandt et al. 1980).

For dust tails, arguably, the two major unsolved problems concern the so-called "striae" and the thin anti-sunward spikes which are occasionally seen emanating from the near-nuclear region. The striae are (relatively) thin rectilinear structures in the dust tails of some comets that do not project into the nuclear zone as do the classical syndynames. They probably reflect a change in the particle size distribution as the grains are convected out into the tail.

Ion tails have, as their major outstanding questions, the production mechanism(s?) of disconnection events (DEs), tail rays, and the entire array of substructures that is seen in almost all examples of this tail type. Moreover, the velocity and acceleration profiles of ions in the tail and the relative abundances of different tail ions are still largely unknown. It is fairly clear that DEs are not an internally generated structure, but rather one caused by changing conditions in the interplanetary medium immediately local to the comet. Magnetic sector boundaries and high-speed stream compression regions appear to be the best candidates, and models invoking magnetic reconnection have been proposed (Niedner and Brandt 1978; Ip 1985; Russell et al. 1986; Niedner and Schwingenschuh 1987).

1.2. On the Need for a Global Approach to L-SP Studies

In the last five to ten years, some advances have been made in our understanding of the structure of cometary plasma tails and of the magnetohydrodynamic (MHD) processes operating in them. This progress has resulted in part from observational studies (including the International Cometary Explorer [ICE] mission to Comet Giacobini-Zinner), theoretical work, and three-dimensional MHD computer modelling, but in all cases it is the conformance of results to real data that is absolutely critical. Without that connection between data and physical models, the models obviously mean very little. Until the return of Comet P/Halley to the inner solar system in 1985–1986, the collected wide-field imaging data were rather sparse for individual comets, despite the existence of some impressive compilations of published data (e.g., Barnard 1913; Bobrovnikoff 1931; Rahe et al. 1969; Jockers 1985; Donn et al. 1986).

Past studies of plasma tails have suffered greatly as a result of the lack of temporal coverage in the imaging data. Except in the relatively rare case of (bright) circumpolar comets, individual observatories are typically able to photograph bright comets for only a few hours each night. The resultant 20- to 22-hour gap between the last image of the previous night and the first one of "tonight" has often destroyed the astronomer's ability to follow the evolution of tail features during times of high activity. In many situations, even when several observatories' data have been combined, it has been impossible to ascertain the place of origin and growth rate of plasma-tail structures, because the earliest phases were not observed.

The proper approach to achieve the required coverage, clearly, is to construct, coordinate, and collect the resultant data from a dense network of observatories around the globe; this has been attempted several times in the past. The 1910 apparition of Halley's Comet stimulated an effort at worldwide coordination and archiving, but was largely unsuccessful (Lankford 1985). More recently, Comet Kohoutek was discovered long enough in advance of perihelion to permit the formation of a National Aeronautics and Space Administration (NASA) project called "Operation Kohoutek" (Maran and Hobbs 1974); the emphasis was less on centralized data collection and archiving, however, than on the advocacy of observing the comet and the analyzing of data obtained at individual sites (cf. the special volume 23 of Icarus, 1974).

2. THE IHW'S LARGE-SCALE PHENOMENA DISCIPLINE

2.1. Rationale, Goals, and Achievements

Much has been written about the rationale behind the IHW's formation. From the point of view of L-SP studies, i.e., studies of the plasma (and dust) tail, no comet in history prior to Halley 1985–1986 had come close to providing the near-hourly resolution in wide-field imaging thought necessary to answer the questions surrounding rapid variability in the plasma-tail environment (DEs, turning tail rays, and helical waves, to give a few examples).

It was hoped that the efforts for the 1985–1986 apparition of Halley would be different from previous attempts if enough effort was made to coordinate a worldwide observational program under the IHW banner. Toward that end, the L-SP Discipline Specialist (DS) Team set a number of ambitious goals in the early 1980s; these are listed in summary form in Table I. Also listed are the actual achievements of the L-SP Discipline and Network; it is quite clear that the goals have been met, if not substantially exceeded, in all areas.

2.2. The L-SP DS Team

Table II lists the L-SP DS personnel who made essentially full-time contributions to the Comet Halley archiving work for a period of a year or more. Their specific accomplishments, as well as the names of other contributors, are given in Appendix A.

Table I. Goals and Achievements of the Large-Scale Phenomena Discipline

Goals (early 1980s)	Achieved (1990)
Construct worldwide network of 75+ observatories	103 observatories contributed imagery to L-SP
Collect and archive 2,500 images of Halley	3,383 images were received and archived
Digitize and deposit on CD-ROMs the 1,000 "best" images	1,612 images were digitized and placed on CD-ROMs
Provide extensive coverage of "Halley Armada Week"	Coverage was excellent: 125 images digitized during this week
Provide coverage of the encounter of the International Cometary Explorer with Comet Giacobini-Zinner	Limited coverage of Comet Giacobini-Zinner was achieved; data were deposited on CD-ROMs
Construct Halley photographic atlas	In production

2.3. The Large-Scale Phenomena Network (LSPN)

2.3.1. *Strategy Behind the Formation of the Network.* Given the above-described (historical) difficulties in interpreting plasma-tail phenomena using sparse data sets, the obvious goals of the newly formed L-SP DS Team in the early 1980s were the formation of as dense a global network as possible (consisting of facilities and observers with wide-field imaging capabilities), and the plugging of any critical holes in the temporal coverage provided by the "fixed-site network," with mobile telescopes and observers to use them.

Starting as early as the late 1970s (pre-IHW), several letters were sent out by the (eventual) L-SP DSs to hundreds of observers and observatories worldwide, soliciting wide-field photographic imagery in support of a hoped-for NASA space mission to Halley's Comet. The response to these early queries, as well as to those which followed in the IHW era, were many and enthusiastic: it was clear that Halley would be well-observed and that astronomers would be willing to submit their data for archiving.

From the very beginning, the L-SP Team analyzed the predicted temporal coverage that its growing network could provide on Halley during periods of critical interest—initial plasma-tail formation in the October–December 1985 time frame, the Halley probe encounters in March 1986, and the close approach to Earth in April 1986—and sent out requests for support in regions where the temporal coverage was seen to be lacking. It is clear from both the size and the temporal coverage

Table II. The Large-Scale Phenomena Discipline Specialist Team

Team Member	Affiliation	Responsibility
Malcolm B. Niedner, Jr.	NASA/Goddard Space Center (GSFC) Greenbelt, MD 20771	Discipline Specialist
John C. Brandt	University of Colorado-Boulder Boulder, CO 80309	Discipline Specialist
Jürgen Rahe	NASA Headquarters Washington, D.C. 20546	Discipline Specialist
Daniel A. Klinglesmith III	NASA/GSFC Greenbelt, MD 20771	Senior Team Member
Archibald Warnock III	ST Systems Corporation (STX) Lanham, MD 20784	Senior Software Specialist
Barbara B. Pfarr	STX Lanham, MD 20784	Archive Manager
Joan E. Isensee	STX Lanham, MD 20784	Data/Software Assistant
Edwin J. Grayzeck	Interferometrics, Inc. Vienna, VA 22180	CD-ROM Specialist
Nancy E. Podger	STX Lanham, MD 20784	Software Assistant
Michael R. Greason	STX Lanham, MD 20784	Microdensitometer Operator
Steven B. Howell	STX Lanham, MD 20784	Software Specialist
Lyla L. Taylor	STX Lanham, MD 20784	Data/Software Assistant

of the current archive that the efforts to create a unique global imaging network were successful. An important component of that network was the so-called "Island Network," which is discussed in the next section.

2.3.2. *The L-SP Island Network*. In about 1983, the writer (M.B. Niedner) developed a software code that quantitatively analyzed the observability of Halley's Comet by the L-SP Network, assuming optimum conditions (excellent weather, etc.). The output of this code was several plots showing, among other things, the visibility windows for each of the participating observatories, and the number of L-SP observatories that could, theoretically, image the comet simultaneously for each minute of a day (overlapping coverage was seen to be essential as insurance against unfavorable weather and other factors). It was clear from these exercises that the post-perihelion branch of the apparition—particularly the first half of March 1986, when the spacecraft encounters were to take place—was at risk if around-the-clock coverage was desired. Analysis quantified the obvious: coverage gaps in the Indian, South Atlantic, and particularly Pacific Oceans were substantial and would greatly limit observations of the comet in early March.

An intense campaign was started by the writer and J.C. Brandt to identify suitable island sites and groups or individuals who might undertake observations there. A detailed description of all our efforts, groups contacted, and so forth is beyond the scope of this chapter, but suffice it say that every effort was made to plug the ocean gaps. In the final analysis, six small, portable Schmidt cameras and complete kits of supplies were placed in five locations favorable for plugging the coverage gaps:

- South African mainland (two instruments)
- British Antarctic Survey (BAS) Faraday Station
- Reunion Island, Indian Ocean
- Tahiti
- Easter Island

Literally hundreds of images, many of them of superb quality, were returned at these locations and are included in the archive; for more details about the L-SP Island Network, the reader is referred to the article by Niedner and Liller (1987).

2.4. General Statistics on the LSPN "Image Yield"

The LSPN observers were extremely productive, and their willingness to ship the DSs unique plate and film material for processing at NASA/GSFC was one of the keys to the assembly of this impressively large, and we think successful, archive. We received over 3,500 images of Halley's Comet taken on more than 100 observatory, instrument, and location combinations. The observers, their affiliations, the equipment used, and the observing sites are listed in Appendix B.

Figure 1 is an image sequence spanning March 8–9, 1986, which shows a spectacular DE in the plasma tail. This sequence is representative of both the image quality of the archive and the temporal completeness of the imagery. Had we wished, we could have constructed a sequence with considerably finer temporal resolution; Figure 1 was designed to show a DE's evolution over a day or so in just four frames (cf. Niedner and Schwingenschuh 1987).

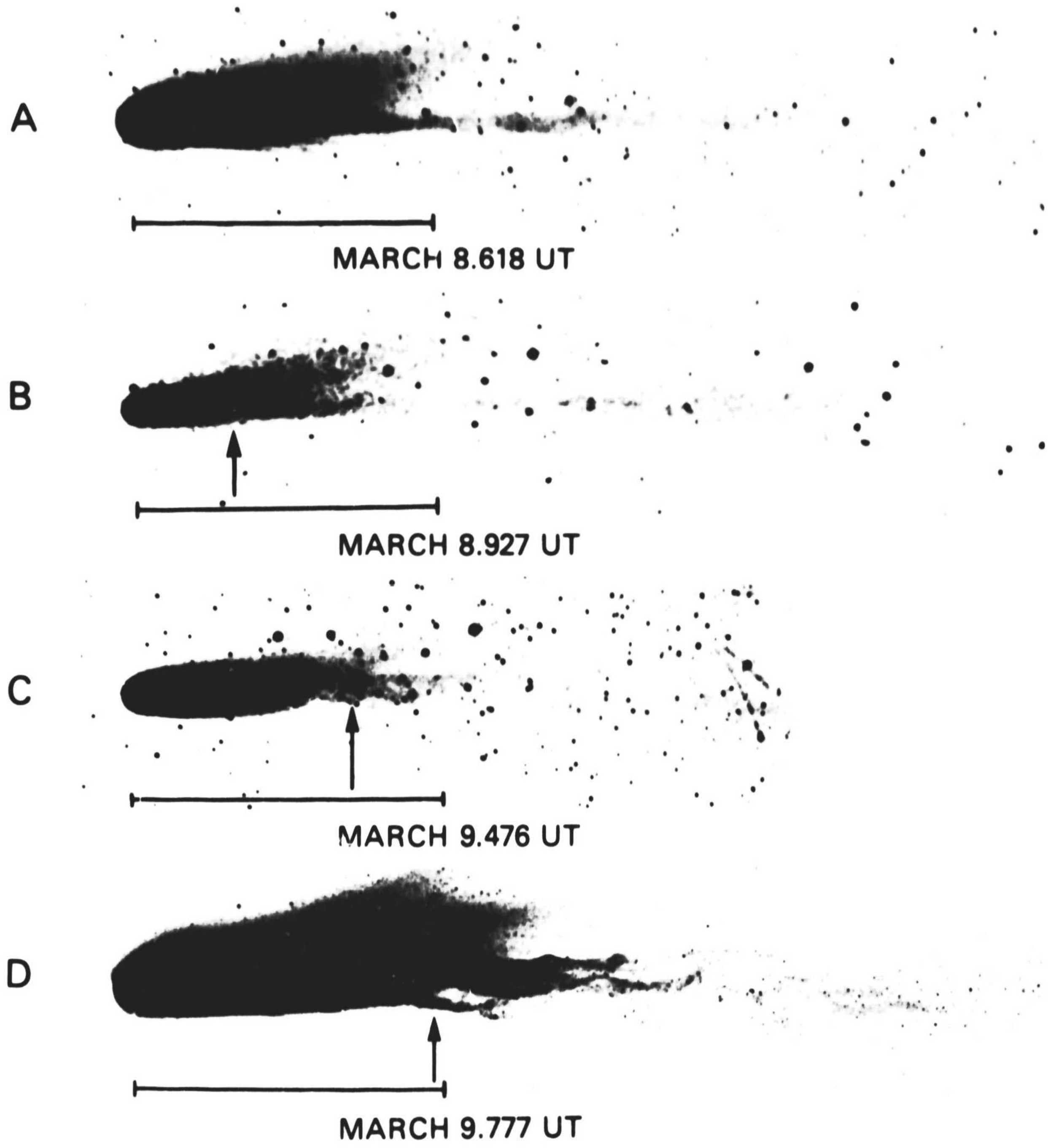

Figure 1. This March 8–9, 1986, photographic sequence shows the development of a disconnection event (DE). The scale bars indicate a linear distance of 5×10^6 km oriented along the prolonged radius vector. The arrows in Figures 1C and 1D point to the detached end of the plasma tail. In Figure 1B, the arrow denotes a bend in the detached tail; the severed end cannot be seen due to strong dust emission near the head. These IHW photographs were taken at, from top to bottom, the Mauna Kea Observatory, Yunnan Observatory, E.E. Barnard Observatory, and Royal Observatory (UK Schmidt, © Royal Observatory).

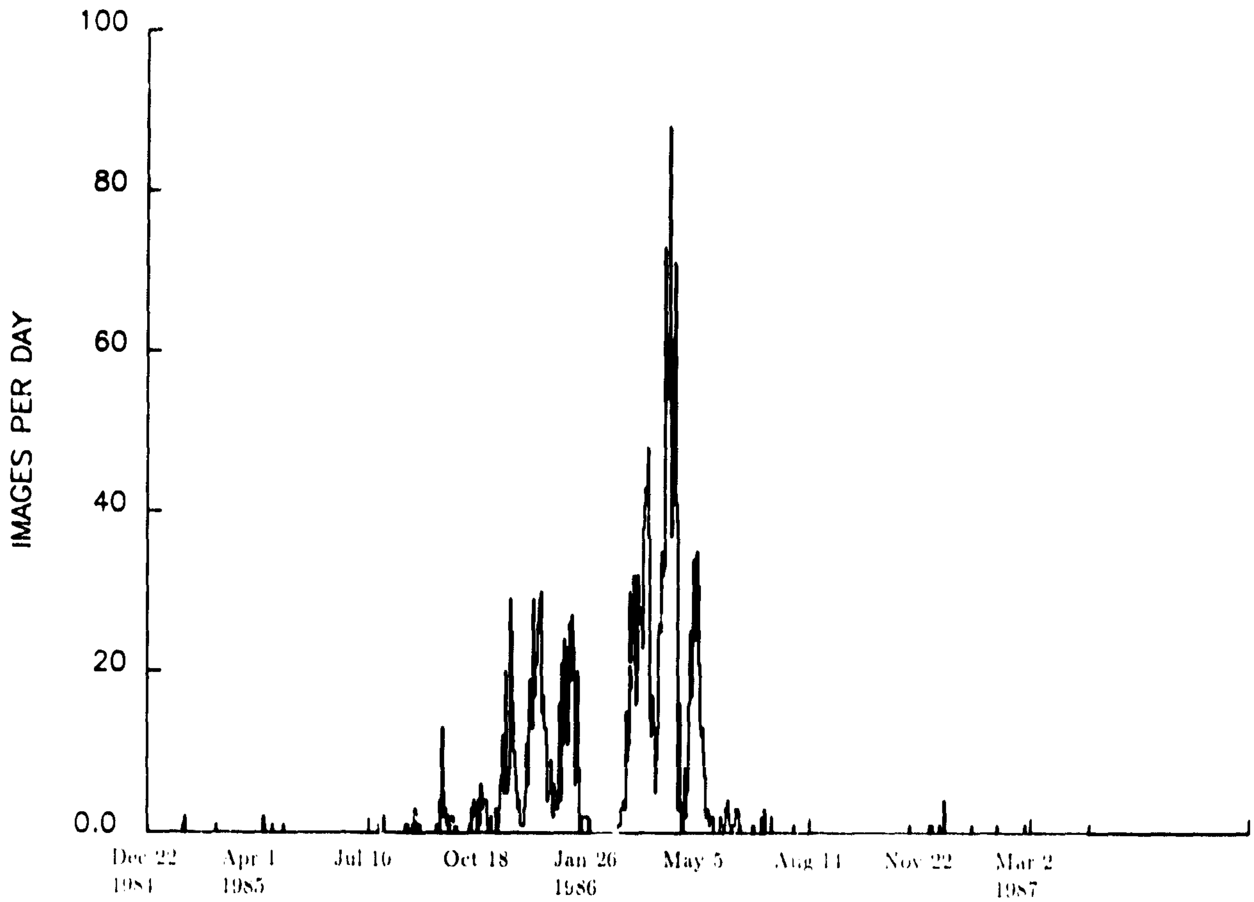

Figure 2. Temporal histogram of the total set of images submitted to the Large-Scale Phenomena Discipline Specialist Team. The time step is one day.

The global LSPN statistics are as follows: A total of 3,383 L-SP images have been archived on the IHW compact discs, either as digital images or as "dataless headers" and listings. A total of 1,612 of the images are in digital form, with 85% having been digitized at NASA/GSFC and 15% having been digitized and provided by a few observers. A slightly larger set of 1,771 images were not digitized, but are listed in several places in the IHW CD-ROM archive. The vast majority of the 1,612 digital images are of Halley (1,439), and the remainder (173) are of various calibration objects. Figures 2 and 3 are histograms of the temporal distribution of the 3,383 total L-SP images and of the 1,439 digitized images of Halley, respectively.

We regret that a small percentage of the images sent to the L-SP DS Team at NASA/GSFC could not be properly archived due to lack of information about the observations, an extremely late submission date to the Discipline Center, or both.

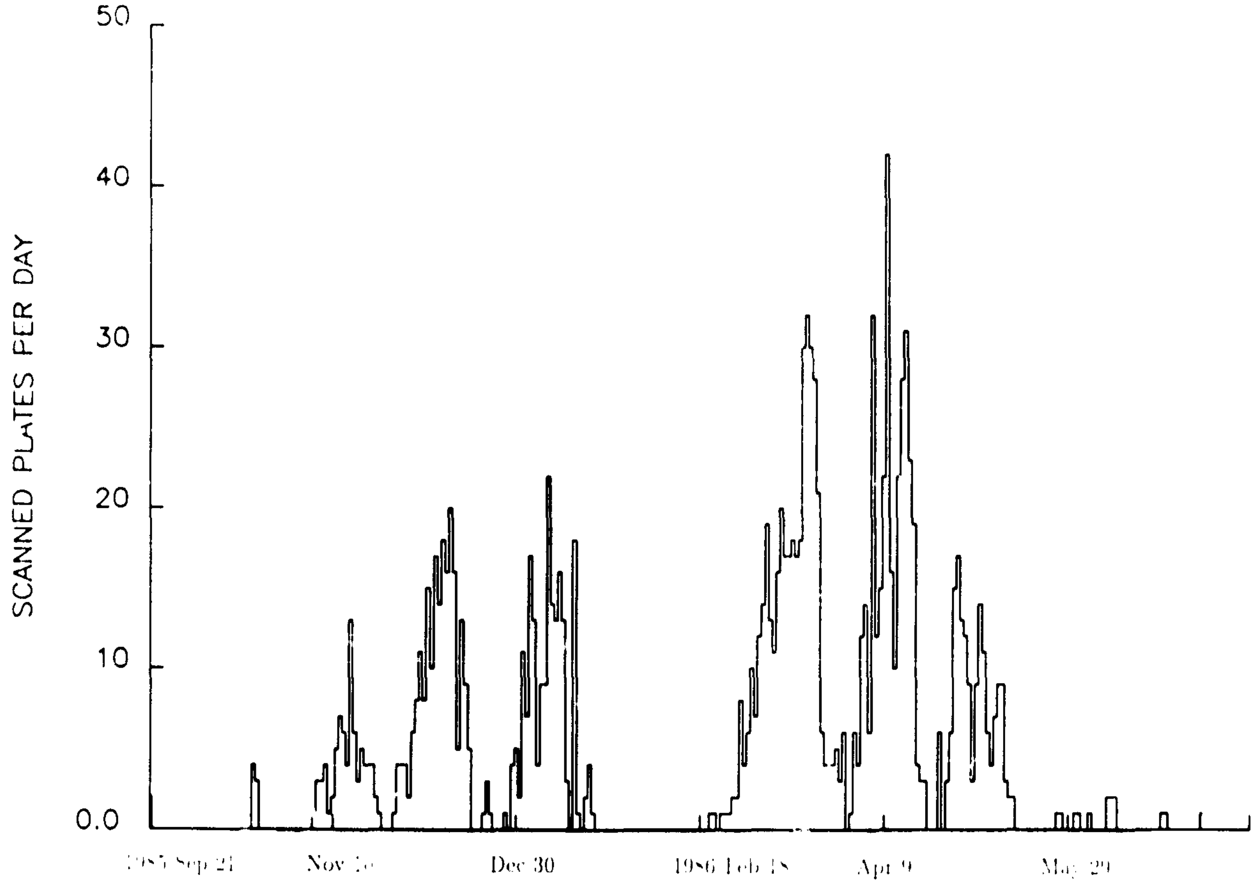

Figure 3. Temporal histogram of the images digitized by the L-SP Team. The time step is one day. Note that 15% of the contributions came from observers who submitted their data in digital, not photographic, form. Also note the adverse influences of perihelion (February 9, 1986) and full-moon intervals.

2.5. The Major L-SP Archive Products: The Digital Data on the CD-ROMs and the Photographic Atlas

In very general terms, the L-SP contribution to the total IHW Archive consists of 18 dedicated volumes (discs) of CD-ROM data containing 1,612 digital images, headers for the undigitized 1,771 images (resident on other CD-ROMs), and a photographic atlas of the best (approximately) 1,000 images. Perhaps the magnitude of 18 CD-ROMs is best judged by considering that the ENTIRE ground-based IHW Archive resides on 23 compact discs. Because of the Atlas' inherent hardcopy format, as well as the extensive documentation on its assembly contained within it, this chapter principally addresses the history of the L-SP Network and the content and structure of the L-SP portion of the CD-ROM archive.

It is, however, important to discuss (briefly) how the CD-ROM archive (the L-SP portion) and the Halley Atlas came into being since both are products of the same IHW Discipline. At the most general level, the flow of original imaging data and data products was as follows: Observers submitted glass plates and films, together with plate log and ancillary information, to NASA/GSFC for initial archiving and digitization. It was at NASA/GSFC that decisions were made (by the writer) about which plates to digitize, and it was here that the actual digitization took place. The principal L-SP image catalog (containing observer, observatory, plate log information, and scanning data) was assembled, maintained, and corrected at NASA/GSFC. Moreover, the creation of magnetic image data tapes (in Flexible Image Transport System [FITS] format) and the shipping of same to the IHW Lead Center at the Jet Propulsion Laboratory (JPL) were NASA/GSFC activities. In other words, the L-SP digital image archive was created at NASA/GSFC, under the direction of M.B. Niedner.

Photographic film copies of the most promising plates—generally those plates that were scanned (see the scanning criteria in Section 4.1)—were made by a NASA/GSFC contractor, and after quality assurance was provided on the resulting film copies, those products were shipped to J.C. Brandt at the University of Colorado-Boulder (UCB). At UCB, paper prints were generated for inspection, measurement, and possible inclusion in the Atlas; Brandt was in charge of this phase of the operation. The reader is referred to the Atlas (Brandt et al. 1991) for specific details about its construction, but the extent to which the NASA/GSFC and UCB operations constituted "one Discipline" is reflected not only in the film flow, but also in the remote use by UCB of the on-line NASA/GSFC L-SP database/catalog in the generation of Atlas tables, figure captions, and the like. Although there are, on the CD-ROMs, digital "browse images" of all scanned L-SP images (see Sections 3.1 and 4.4), we envision that the Halley Atlas will serve as a useful tool to help the CD-ROM user find the images of maximum interest. Also highly useful is the compendium of information on the specific emulsions and filters used by the L-SP Network Observers.

3. ORGANIZATION AND CONTENT OF THE L-SP PORTION OF THE CD-ROM ARCHIVE

3.1. L-SP CD-ROM Data Products

To summarize some of the above discussion (particularly that in Section 2.4), three general categories of L-SP data products are archived on the IHW CD-ROMs:

1. Digital images of Comet P/Halley
   a. Full-resolution compressed images
   b. Subsampled "browse images"
2. Digital images of calibration objects
   a. Compressed images
   b. Browse images
3. FITS headers for images archived, but not digitized

Table III. Locations of the L-SP Data Products on CD-ROMs

	L-SP Discs	Mixed Discs
Compressed Halley images	X	
Compressed calibration images	X	
Browse images of Halley	X	X
Browse images of calibration objects	X	X
Entire set of browse images (Halley and calibration)	Vol. 18	
FITS headers of undigitized images ("dataless headers")		X

Strictly speaking, the "dataless headers" are not data products at all, but contain essentially all the "metadata" associated with images received but not digitized by the L-SP Discipline Team. Every digitized image, be it of Halley or a calibration object, has an associated subsampled browse file, a full-resolution compressed data file, and a FITS header and Planetary Data System (PDS) label for each. Refer to Sections 4.3 and 4.4 for brief details, and to the extensive documentation on the L-SP compressed-image discs for more complete information, on how the data were compressed and browse images created.

3.2. Where the L-SP Data Products Reside on the CD-ROMs

Because of the typically large size of each L-SP digital Halley image, even in compressed form, it was decided to split off the L-SP data from the other eight disciplines' data and deposit the images on separate, dedicated discs (volumes 1–18). A smaller set of multi-discipline discs (volumes 19–23, sometimes called the "mixed discs") contain data from the other disciplines. The rationale was that this split of data would greatly expand the time range associated with each disc containing the remaining disciplines' data, and therefore facilitate multi-discipline studies that did not involve large-scale imagery.

Data compression was used to reduce to 18 (a reduction of about a half) the number of discs required for the L-SP images. The compressed calibration images, as well as the set of browse images, also reside on the L-SP compressed-image discs. All data files on the compressed-image discs are accompanied by the appropriate FITS headers and PDS labels (as separate files). Data compression was used both to reduce project costs and to present the user with a CD-ROM archive of a more manageable size.

Because it was thought important that some representation of ALL disciplines' data be present on the multi-discipline ("mixed") discs, the L-SP browse images have been placed on the CD-ROMs a second time, in the daily data subdirectories of the mixed discs. The FITS headers for undigitized L-SP images also reside on the mixed discs, in the daily subdirectories. Table III shows at a glance where the various L-SP data products reside in the IHW CD-ROM archive.

Note in Table III that the last L-SP CD-ROM, Volume 18, contains the entire set of BROWSE images. They are stored in the separate "volume subdirectories" of the SUMMARY directory of Volume 18; it was hoped that this arrangement would serve as a very useful "image index" to the L-SP discs.

It is worth noting that essentially all the information about the undigitized images also resides on the L-SP discs, but not in header form. The NETLARGE.IDX file in the INDEX subdirectory of the L-SP compressed discs contains essentially all the FITS keywords for all the L-SP images, digitized and undigitized. By downloading NETLARGE.IDX into a database management system (DBMS), the user can perform extremely sophisticated searches of the L-SP archive.

The arrangement of the L-SP compressed-image discs is strictly chronological, both within individual volumes and from volume to volume.

3.3. Supporting Tools for Finding and Using L-SP Data

3.3.1. *General Information, Getting Started.* As indicated in Section 3.2, various index files exist on the L-SP compressed-image discs for assisting the archive user in finding data of interest. Also included on the L-SP discs are a wide variety of explanatory (text) files and software files. The software is concerned mostly with compression and decompression of the L-SP images. Rather than repeat here the detailed descriptions of the contents of the L-SP discs, we refer the archive user to (in particular) the following text files on the compressed-image discs:

- AAREADME.TXT (in the Root directory), which explains the overall layout of the disc.
- CDTREE.TXT (in the DOCUMENT directory), which is a schematic of the directory structure.
- IMAGUIDE.TXT (in the DOCUMENT directory), which is a user's guide to the disc.
- LSPNOBS.TXT (in the DOCUMENT directory), which contains observatory information.
- NETLARGE.TXT (in the DOCUMENT directory), which contains FITS keyword descriptions.
- SOFTINFO.TXT (in the DOCUMENT directory), which describes the software provided.

These text files should suffice to orient the archive user to the contents of the L-SP discs, and if more information on a particular subject is needed, these files refer to additional explanatory files.

The Discipline Appendix for L-SP resides on the mixed discs, along with appendix material for the other IHW Disciplines.

3.3.2. *Printed Archive Table.* One table containing L-SP information resides only on the mixed discs: the so-called "printed archive," which contains chronologically sorted listings of observations across all IHW disciplines. Contained in the Halley printed archive is a one-line table-format summary for each of the images received and archived by the L-SP DS Team. For each image, the following parameters are listed:

Date(UT)	=	Date of the middle of the observation (in Universal Time [UT] days and fractions).
LSPN #	=	Large-Scale Phenomena Network filenumber—a unique number for each observation (the lead digit of "3" indicates that the Discipline is Large-Scale Phenomena). N.B.: This number is not the same as the CD-ROM filename for the corresponding image.
PlateID	=	The identification number provided by the submitting observatory on the original plate jacket or reverse side of the print.
Ap	=	Telescope aperture, in meters.
Scale	=	Scale of the original plate, in arcseconds/millimeter. For copy prints submitted by observers, it is the scale of the original plate, not that of the print, that is listed.
Instrument	=	Type of instrument used.
FOV	=	Field of view (FOV) of the original plate, in degrees. For copy prints submitted by observers, it is the FOV of the original plate, not that of the print, that is listed.
ExpM	=	Exposure time, in minutes.
Emul	=	Type of emulsion used for the original image.
Filter	=	Type of filter used.
Hyp	=	Was the plate hypersensitized? (Y or N)
Cal	=	Did calibration data accompany the image? (Y or N)
St	=	Status of image. "D" (for "digital Halley data") indicates that the image was digitized and deposited on the CD-ROMs. "C" (for "calibration data") indicates that the observation is a calibration image; it is in digital form and was placed on the CD-ROMs. "N" (for "no data") indicates that the (Halley) image was received and archived by the L-SP Team, but was not digitized.
System	=	Observatory System Code (see Appendix B at the end of this chapter, and the text file LSPNOBS.TXT in the DOCUMENT directory of the L-SP compressed-image discs).
Observer(s)	=	Name(s) of the observer(s).

3.3.3. *Discipline Specialist Evaluation of Imagery Science Content.* The file NETLARGE.TXT in the DOCUMENT directory of the L-SP compressed-image discs contains descriptions of the FITS keywords indexed in the NETLARGE.IDX index files. While this index is comprehensive to the point of containing nearly all the L-SP header FITS keywords, a decision was made not to include in NETLARGE.IDX either trivial keywords (such as SIMPLE), or long, relatively unstructured history and comment fields.

The reason for making the point about the comment fields is that the meaning of two of them may be a bit obscure. Unfortunately, they are not well-documented in the FITS headers, nor, because of their non-inclusion in NETLARGE.IDX, were they described in NETLARGE.TXT. Specifically, the history keywords "CMTS-LOG" and (when present) "CMTS-LOG2" provide the evaluation by Discipline Specialist M.B. Niedner of the science content of the plate. An example is the following:

```
HISTORY  CMTS-LOG ='PLASMA TAIL LOOKS HIGHLY TURBULENT, MAY BE DETACHED NEAR'
HISTORY  CMTS-LOG2='THE HEAD.  STRONGEST RAYS STRETCH NEARLY LENGTH OF PLATE.'
```

Because these keywords were not indexed, their use in selecting images of interest will require some work by archive users (namely, extraction of these fields from all headers to a separate file). However, the "special event keyword," SPEC-EVT, has been indexed, and its value (T/F) was set by the DS (Niedner). There is a very high degree of correlation between SPEC-EVT and the science content of the imagery, especially during disturbed intervals (DEs, prominent ray systems, etc.). So we imagine that the FITS keyword SPEC-EVT will be useful to those users wishing to concentrate on the "exciting images."

The second HISTORY keyword needing brief explanation is "CMTS-OBS" (and "CMTS-OBS2", when present). These keywords provide the comments of the observers who took the images. Once again, this is not entirely clear in the FITS headers themselves.

4. PROCESSING OF THE DATA AT THE L-SP DISCIPLINE SPECIALIST CENTER (NASA/GSFC)

4.1. Selection Criteria for Digitization of Images

Because the number of high-quality images received from the Network was large, the set-up and digitization (scanning) time for each image was long, and the project duration was limited, great care had to be exercised in the selection of images for microdensitometry. All decisions concerning which plates would be scanned were made by Discipline Specialist M.B. Niedner. Early in the data submission phase of the project, i.e., late 1985 and early 1986, when the submission rate was slow, the approach was to scan essentially every good-quality plate in which Halley possessed some tail structure, regardless of the plate's temporal relationship to the other plates.

Increased flow of data from the L-SP network observers in the second half of 1986 began a second phase in the microdensitometry effort and it resulted, not unexpectedly, in a significant backlog of high-quality image material for potential scanning. At this point, and for the next two years, consideration was given to the following (unprioritized) factors beyond individual plate quality before a plate was scanned:

- Contribution to the overall temporal coverage of Halley.
- Existence of high levels of activity in the (plasma) tail.
- Depiction of dust-tail evolution.
- Support of a Halley space mission.
- Inclusion of a new observatory's data.

By no means did a plate have to receive a high "score" in all or most areas, nor was the selection process ever fully quantified. For example, plates that depicted a prolonged "quiet interval" in the plasma tail were considered nearly as important in their own way as plates spanning disturbed periods. In addition, lower quality plates were not scanned simply to include a "new" facility's data. The selection process during this second phase of microdensitometry could not be carried out in a completely rigorous way, but much thought was given to it.

The third and fourth phases of microdensitometry were rather different and occurred essentially simultaneously during the last six to nine months of scanning. One effort was directed at re-examining existing plate material for images that could fill gaps in coverage if they were digitized. This effort was rather rigorous in the sense that the L-SP database was examined for all gaps in the (existing) digital imagery greater than a certain maximum allowable duration (typically 6 or 12 hours). Once a list of digital data gaps had been generated, the database was searched a second time for all unscanned images falling within the gaps. These images were then closely scrutinized (a second time) for scientific content and gap-filling potential, and some of them were scanned.

The last phase consisted of identifying outstanding data sets that had not yet been submitted by the observers to the L-SP DS, making additional requests for their submission, and digitizing as many of these high-quality images as possible after their receipt. The primary emphasis here was not so much on filling gaps as supplementing existing coverage with outstanding imagery; some gaps were, however, filled by these plates.

Given Halley's display of "large-scale phenomena" over at least a six-month interval from mid-November 1985 to May 1986, the desired hourly coverage would have required approximately two and a half times the 1,439 Halley images we actually scanned (or received in digital form). What can be said in response to this fact is that the six-week period approximately centered on perihelion (during which the comet was essentially unobservable), the bright moon intervals, and the unavoidable "bunching" of observatories in geocentric longitude were real barriers that could not be completely overcome. On the balance, however, we feel that the record of Halley's Comet contained in this wide-field digital image archive not only is unique, but will also serve its users well.

4.2. Procedures for Digitizing Plates (co-written with A. Warnock)

Most of the submissions to the L-SP Discipline were in the form of photographic plates or films. Original glass plates or film were most desirable for digitizing, but first-generation film copies—submitted by some of the observers—were also acceptable in many instances. All imagery digitized was handled according to the scanning criteria outlined above. In some cases, very small original films (e.g., 35mm) were enlarged on film at the NASA/GSFC Discipline Specialist Center, and the enlarged copy was scanned.

4.2.1. *The Hardware.* All digital images produced by the L-SP DS Team were generated on one of the two Perkin-Elmer PDS 1010A Microdensitometers (PDSs) in the Laboratory for Astronomy and Solar Physics (LASP) at NASA/GSFC, Greenbelt, Maryland.

The PDSs have been modified to enhance performance by replacing the original logarithmic amplifier circuit with a faster one (Anderson et al. 1983), and replacing the original analog-to-digital (A-to-D) converter with one that provides a sample-and-hold circuit in support of the faster log amplifier.

Each PDS is controlled by a DEC PDP-11/23 minicomputer running version 5.1 of the RT-11 operating system. The PDS is interfaced to the computer through a bus converter board that allows the Unibus interface of the PDS to operate on the Q-bus of the PDP-11/23. The control programs were written in a combination of

Fortran IV and PDP-11 assembly language. All scanning was performed with the microdensitometers in density mode.

The optical system of the microdensitometer passes a beam of light through a pre-slit aperture which defines the size of the scanning spot. The beam is focused on the plate, then passes through a post-slit and a Fresnel lens to illuminate a photomultiplier tube. The output voltage from the photomultiplier tube is sent to a logarithmic amplifier, yielding an approximate photographic density. The output voltage from the log amplifier is converted into PDS density units by a 10-bit A-to-D converter.

The plate is scanned by moving the PDS platen, under computer control, in a raster pattern. As the plate is passed through the light beam, the photomultiplier voltage is read at each pixel in real time.

The digital images were written in a PDS line-by-line format to magnetic tape at 1600 bpi on Kennedy 9000-series dual density (1600/800 bpi) tape drives. The PDS-format tapes were converted to FITS format on the IBM 3081 mainframe at Goddard, then checked for readability and accuracy on a VAX 11/750 computer in the LASP before submission to the Lead Center.

4.2.2. *Preliminary Procedures.* Before a plate was scanned, the microdensitometer was used as a measuring engine to produce an astrometric solution for the entire plate. The astrometry program assumes a Schmidt plate geometry, using the transformation equations given by Dixon (1962). The assumption of Schmidt plate geometry yields acceptable results even for plates from other types of telescopes.

Reference stars were selected from the AGK3 catalog for plates north of -5 degrees declination. The Perth-70 catalog was used for southern declinations. Although the SAO catalog is generally unacceptable for astrometric work, it was occasionally used when none of the other catalogs yielded an adequate number of reference stars to get a satisfactory plate solution. The software corrects for proper motions from the catalog date to the plate epoch, and precession may be performed to any desired date. All positions are given in 1950.0 coordinates.

Mean astrometric error depends strongly on the individual plate scales and somewhat on the number of acceptable reference stars available, but is typically less than 10 arcsec (worst case) and frequently is on the order of 2 to 5 arcsec.

The plate solution was used to measure the rotation angle of the North-South meridian passing through the plate center, relative to the Y-axis of the microdensitometer. The coordinates of the comet's head center were also calculated, although this manual measurement provides only a crude location for the nucleus embedded in a highly saturated coma.

4.2.3. *Scanning.* After completion of the astrometry, the region of interest on the plate was scanned. The aperture size was selected to yield roughly the same angular resolution per pixel, regardless of the original plate scale. Typically, an aperture of 40 or 50 μm was used on plates with plate scales around 100 arcsec/mm, and an aperture of 10 or 20 μm was used for plates with scales greater than about 200 arcsec/mm. Spatial resolution of the photographic emulsions limits the smallest usable aperture to 5 or 10 μm in any event. Generally, the step size was equal to the aperture size, so the pixels were contiguous across the scan line with no over-sampling.

Table IV. Observers and Observatories Who Submitted Digital Data

Observatory	System Code
Catalina Observatory	36930300
Catalina Observatory	36930200
Gissar Observatory	31900200
Sanglok Observatory	32000100
Mountain Observatory	35002401
Assah Observatory	35002402
Burakan Observatory	31230400
Burakan Observatory	31230100
Crimean Astrophysical Observatory	35002403
Table Mountain Observatory	36730100
Table Mountain Observatory	36730200
Roque de Los Muchachos Observatory	35001402
European Southern Observatory	38090700

The photomultiplier tube high voltage was set to yield 0 density on clear glass, when clear glass was available. Otherwise, the density was set to around 0.1D on the background fog, primarily to avoid negative density values in the resulting digital image.

The 10-bit A-to-D converter yields integers in the range 0 to 1023. These may be converted to an approximate photographic density by dividing by 200.

4.2.4. *Special Cases: Double Scans and Observer-Provided Digital Imagery.* Because of their large size, both physically and in angular extent, some plates had to be digitized in two pieces or segments. There were several reasons for this from an operational point of view, but the important point is that the archive user should be aware that an image of interest may continue onto another segment (and image file). There are two ways of detecting this situation. The first involves the FITS headers themselves. We inserted a short history keyword at the end of some FITS headers called "CMTS-PRC"; among other things, CMTS-PRC reveals whether an image file is one component of a pair of scans of the same plate. The second method involves searching through the NETLARGE.IDX index: the existence of two files from the same observatory with exactly the same plate number is indicative of our need to perform a double scan on a large plate.

The imagery submitted by some observers was already in digital form (see Table IV), and a major task associated with including these data sets was the reformatting of observer-generated FITS headers so they resembled the DS FITS headers. In some cases, the data had to be rescaled to the same number of bytes as the images digitized at NASA/GSFC (2 bytes per pixel) so our compression software would work correctly. Once again, the CMTS-PRC history keyword indicates processing of this type by the L-SP Team. Table IV lists the observers and observatories who submitted digital data to the L-SP DS Team. More information on these facilities may be found in the individual FITS headers and in the indices NETLARGE.IDX and LSPNOBS.IDX (search on the System Codes given above).

4.3. Compression of the L-SP Digital Imagery

The microdensitometry of more than 1,000 wide-field plates of Halley's Comet at the L-SP Discipline Center, combined with several hundred more images received from observers already in digital form, resulted in the creation of more than 20 gigabytes of L-SP data for the IHW to deposit on the CD-ROMs. In its original uncompressed form—with every pixel being represented by a 2-byte number—this would have required between 35 and 40 discs for the L-SP data alone! Primarily to reduce project costs, but also to create a CD-ROM archive of a size more manageable to the end user, it was decided several years ago that data compression techniques would be used to reduce the number of discs by a substantial factor (two or more).

Following an experimentation period during which several techniques were examined, a previous-pixel algorithm was chosen to accomplish the compression. While not offering the maximum compression factor among all possible techniques (including nesting of techniques), previous-pixel compression does offer the advantages of being extremely simple in concept and of permitting fast, "on the fly" decompression, while at the same time yielding typical compression factors very close to two (2).

The algorithm works as follows: The compressed-image byte stream starts with the byte value 255 (FF hex), followed by the full 2-byte value of the first pixel, with the bytes in standard FITS byte ordering. Thereafter, if the difference between the "i"th pixel and the "i-1"th pixel is less than 127 (absolute), that difference has the value 127 added to it (to avoid negative byte values) and is placed in the compressed byte stream as a single byte value. If, on the other hand, the difference is greater than 127 (absolute), the value 255 is placed in the byte stream, followed by the original 2-byte value for the "i"th pixel. We then proceed to the next pixel as before. Thus, every 2-byte value in the compressed byte stream is prefixed with the flag value 255. Every value without such a prefix is presumed to be a 1-byte difference. The compression was accomplished using the program called PACKER, which was run on an IBM 3081 at NASA/GSFC. The source for the program is in the file PACKER.FOR, located in the SOFTWARE directory of the L-SP compressed-image discs. A decompression algorithm is provided in the DECOMP subdirectory of the SOFTWARE directory, and descriptions of these routines are given in the DECOMP.TXT and PCDECOMP.TXT files of the DOCUMENT directory (of the L-SP compressed-image discs).

4.4. Nature and Construction of the Browse Images

Effective use of the 1,612 digital images contained on the L-SP compressed-image CD-ROMs requires that the user of the discs be able to "browse the data" quickly to find those images and intervals that are of high scientific interest. Because of the long decompression and transfer times of the full-resolution images with current image display hardware, the goal of efficient browsing of the data can be met only if the images are placed on the discs at least a second time, in either subsampled or filtered form, and uncompressed.

This is what has been done in the BROWSE directory of the L-SP compressed-image discs. A set of "browse images" have been generated for which the images are subsampled, uncompressed, and no larger than 256 pixels in either dimension. In addition, the digital data have been scaled into a numerical range of 0 to 255 (1 byte per pixel; the "depth" for most of the original images is 10 bits, or 2 bytes per pixel). Contained in the BROWSE directory of each L-SP compressed-image CD-ROM are data files, headers, and labels for the compressed images on that CD-ROM; this includes images of both P/Halley and calibration objects.

The browse images are actually stored in three places within the total set of IHW CD-ROMs. In addition to the subset of images stored in the BROWSE directory of each L-SP compressed-image CD-ROM, the entire set of 1,612 digital images exists on the last of the L-SP compressed-image discs (Volume 18), in strict time order. And finally, the browse images are interleaved with data from the other IHW disciplines in the daily data subdirectories of the "mixed discs."

The browse images were obtained by taking the "n"th row and column for the original image, starting at row "n/2" and column "n/2." The value for "n" was determined from the larger of the two axes such that the quantity (original length/n) was less than or equal to 256. For the images that were digitized at NASA/GSFC, the original densitometer values ranged between 0 and 1023. These density values were divided by four to compress the density value to a single byte. For those images digitized elsewhere, the density scaling factor was chosen so the "browse density" was less than or equal to 255.

The browsing was accomplished using the program MIDGET, which can be found in the MIDGET.FOR file of the SOFTWARE directory of the compressed-image discs.

5. Some Thoughts on the Veracity of the L-SP Data and Metadata

Every effort has been made by the L-SP DS Team to ensure that its contribution to the final IHW Archive is as clean and free of errors as possible. We realize, however, that in a project of this size and scope, some (nonzero) level of errors will always be present; one can only hope that the errors are few and small in importance.

The microdensitometry effort was done slowly and carefully. Plates that appeared to have been incorrectly scanned the first time were rescanned. The computed astrometric plate solutions, stored in each FITS header, were checked for accuracy by displaying catalog star positions on an image display terminal and comparing the predicted positions with the actual image array.

Arguably the most painstaking aspect of the verification phase was the checking of the metadata, i.e., the "data about the data." Every datum written to the FITS headers that concerned the observatory, observer, and observation was checked against observing logs, correspondence from network observers, and internally generated lists. This was "hand checking" at its most tedious, and it is a fact that all 3,383 archived images were checked at least once in every parameter and keyword. We have done our best.

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Appendix A. Acknowledgments

Malcolm B. Niedner, Jr.

This has been a vast enterprise:

- Setting up a worldwide network of participating observatories with wide-field imaging capability.
- Collecting thousands of the resulting images of Halley's Comet.
- Digitizing a respectable fraction of them with computed astrometry.
- Constructing a database to record all incoming material and track all images while they are being processed.
- Checking all the "metadata" about the imagery against observing logs, letters from observers, and other listings.
- Generating film copies of the best plates for publication in a photographic atlas of the 1985–1986 apparition.
- Running tests on data compression techniques for use on the CD-ROMs.
- Making decisions about the content and format of tables, indices, and text files appropriate for the CD-ROMs.
- Depositing the final data on the CD-ROMs in compressed form.

These were but a few of the things that happened in my laboratory during the 1980s as a result of its involvement in the L-SP Discipline of the IHW. L-SP was a project so large that it nearly defeats any attempt to describe it fully, accurately, and fairly. It is, however, an absolute joy to try, for this is really a tribute to the people I was associated with who helped make this happen, who made the endeavor a success.

First, and very important to state early, thanks go to all the many observers in the Large-Scale Phenomena Network (LSPN) who submitted to us their precious plates, films, and prints of a unique celestial happening, not only for archiving but also for physical and scientific safekeeping. As many of our network colleagues as possible are listed in Appendix B. It sounds terribly trite to say, but I can think of nothing more true than "it wouldn't have happened without you." Thank you for your competence, your dedication, and, in the body of the imagery you submitted to the IHW/L-SP Discipline, your contribution to the advancement of science.

My colleagues and fellow L-SP Discipline Specialists (DSs) JOHN C. ("Jack") BRANDT and JÜRGEN RAHE were highly instrumental in the late 1970s and early 1980s in helping develop the very concept of the IHW and of what turned out to be the "Large-Scale Phenomena Network." Interestingly, a year or two before there was a formal IHW, Jack, Jürgen, and I had sent out letters to hundreds of international observers asking for cooperation in a wide-field network to support any possible NASA mission to Halley's Comet. The mission didn't become reality, but Louis Friedman's idea—the IHW—did. Jack and Jürgen were especially helpful through the years in supplementing whatever efforts I was able to mount to secure important imaging material from the LSPN observers. I wish to take special note of the fact that on several occasions I was "striking out," but either Jack or Jürgen had that "magic touch" and saved the day. Thanks go to both of them for continuing, steadfast support to make the project as successful as it seems to have been. While the digital L-SP archive has been assembled at NASA/GSFC, I have also been involved, and have enjoyed, working with Jack and his colleagues at the University of Colorado on the construction of a wide-field photographic atlas of Halley's Comet, 1985–1986.

There are several remarkable individuals employed by the ST Systems Corporation (STX) in Lanham, Maryland, who worked on the L-SP DS Team as archivists and software specialists, and who deserve much of the credit for whatever success has accompanied this project. BARBARA B. PFARR and ARCHIBALD ("Archie") WARNOCK III have each served as Task Leader on the contract between STX and NASA/GSFC for the L-SP archiving work, and any sane person (which I think I am) would trumpet their accomplishments loudly.

Much of the bedrock structure of our operation at NASA/GSFC either was devised or was heavily influenced by ARCHIE WARNOCK, our Senior Software Specialist. A good example is the code I still find remarkable—that which computes a rigorous astrometric plate solution at the microdensitometer before the plate scan has even commenced! When our team speaks the software elements by name – SETUP and ASTROM—we think of Archie immediately, and for very good reason. Perhaps as much as any other, those pieces of software were the essential core in making our digital data "useful" to the outside community. Archie is also a wizard with personal computers (PCs), CD-ROMs, and database management systems, and I think all of us on the Team have learned a little more in these areas just being around him and absorbing a fraction of what he knows. More important, many of the IHW's good ideas about how to deposit the Halley data on CD-ROMs (in compressed form for L-SP) were first heard from his lips. Regrettably, space (and not my memory) does not permit a listing of all his contributions. Suffice it to say that Archie is an "ideas man" whose expertise in many vital areas went far beyond the boundaries of L-SP work and into the larger arena of the IHW project as a whole. The IHW benefited a great deal.

BARB PFARR, our Archive Manager, took over the Task Leader position from Archie when he became heavily involved with the GHRS experiment on Space Telescope, but the impression would be totally false that Barb was not already a tremendous leader in almost all aspects of the operation. Incredibly, she was a leader at the same time she was keeping herself immersed in the project's most minute details. I would be very hard-pressed indeed to think of an individual more capable than she of keeping a large, complicated project running as smoothly as it did. Thanks to her anticipating possible problems well in advance, many problems were skillfully avoided. When hurdles did come up, Barb didn't simply come to me with them, she presented possible solutions and made recommendations. You name it—the development of high-level code, the skillful assignment of tasks to others (called good management), the constant verification of data quality, the resolution of thorny problems with some of the images, keeping the DS fully informed and, when necessary, "on track"—Barb did it all (digitizing over 200 images herself, by the way), and it still leaves me wondering "How, Barb, how?" How did one person—how COULD one person—do all you did? Working weekends would be the quick answer; being good at what you do AND dedicated is closer to the truth.

I will come back to the STX personnel momentarily. First a word about a NASA/GSFC colleague in Code 684, DANIEL A. KLINGLESMITH III. From time to time during the IHW's long history, we had meetings called "SAM i," where SAM = "Software (and) Archive Meeting" and "i" was a running index (i = I, II,...V,...). It is fair to say that Dan is the "Father of SAM." It was primarily his idea, a long time ago in 1983, that the success of the IHW would depend not only on the amount of data collected by the various disciplines, but also on how we archived the data and deposited them on CD-ROMs. SAM I was held at NASA/GSFC in 1983, and Dan called and chaired that two-day meeting, at which many of our "archiving principles" were established. It was a nice piece of work, and it led to many future SAMs (the final "i" is not known, but is not small). A huge accomplishment of Dan Klinglesmith's, the one for which I will be eternally grateful, has been rather recent. It was he who reasoned out how we were going to take our 1,439 digitized images of Halley, deposited on so many unsorted "archive tapes," and get them "on-line" in one location (an IBM mainframe), compress them, store the compressed images "on-line," and write the images in chronological order to high-density magnetic tapes (all this was required for premastering the L-SP images). If the reader knows how large 20 gigabytes of data are in the context of on-line storage, then perhaps the magnitude of Dan's achievement becomes clear.

No one on this project grew or flourished more than JOAN E. ISENSEE of STX. It is hard to express adequately my admiration for Joan, who went from being my NASA Branch secretary to not only our expert on "Datatrieve" (our database system), but also our top digitizer of Halley images and our most invaluable day-to-day programmer. Joan patiently set up, then scanned, 352 plates of all sizes and descriptions; her plate solutions were consistently as good as anyone's. Having scanned 160 Halley plates myself (and being easily able to remember how tiring it was) makes me really appreciate her dedication and her achievement. As for her programming skills, nearly every time I asked that Datatrieve do something a little better or a little different, Joan took on the job and completed the task with consummate skill. Joan was also the member of our Team who was primarily responsible for monitoring the enormous flow of magnetic tapes associated with converting the original microdensitometer data to FITS format. Along with Barb Pfarr, she was a key person in displaying our scanned images on an image-processing workstation, with particular emphasis on the excellence of the plate solution. I am extremely grateful for all Joan has meant to our success, and wish her well as she begins a promising new career.

EDWIN J. GRAYZECK, of Interferometrics, Inc., has been affiliated with the L-SP Discipline for years and has been a pleasure to work with. Probably Ed's first IHW/L-SP interest was the creation of some scheme by which the many images flowing to the DS Team in 1985–1986 could be "browsed" in an efficient manner, that is, without having to pull plates, films, and prints out of jackets. I remember Ed "frame-grabbing" plates and prints with a charge-coupled device (CCD) camera, depositing them on videotape, and playing them back on a VCR; it was a noble concept that would come to full fruition years later with the "browse images" deposited on the CD-ROMs along with the full-resolution, compressed L-SP images. Bigger and better things were coming as Ed began to get involved in the relatively new technology of CD-ROMs, especially as it related to the IHW. Through sheer force of newly acquired expertise, Ed began to be recognized within the IHW project as a very key player in the assembly of the final CD-ROM archive. As these acknowledgments are being written, Ed is heavily involved in pre-mastering the first of the compressed-image (L-SP) discs. The entire IHW owes him a huge debt of gratitude.

NANCY E. PODGER, who left us in 1988, worked with STX for several years on the L-SP task. "Nanc" really made her mark by taming our database system and making it more relational than it was upon installation. She accomplished this by writing a great number of Fortran programs that allowed the user to perform certain key functions within the "domains" of the system. Well over 3,000 images were eventually entered into our database, and it was Nancy's very well-designed series of menu-driven "log-in pages" that made for an accurate entry of the image metadata onto the computer. The software that writes the so-called "printed archive" was originally written by Nancy, and recent changes to it mostly treat special cases. It was a pleasure having Nancy Podger on our Team, and her good work is felt to this day as we finish the L-SP part of the IHW archive.

MICHAEL R. GREASON, also employed by STX, was the person who kept the microdensitometers running, and he did his fair share of the scanning. Anyone who thinks that a microdensitometer is capable of a 4096 × 4096 (pixel) scan once or twice a day for four years without breakdown is sadly mistaken. The trick is to minimize the "down time" by anticipating breakdowns and replacing parts before they wreak havoc with the machines. Mike really kept on top of things in the "PDS Room," and if the "up time" wasn't quite continuous, it was close enough to being so that we met our goals with something to spare. Back in the very early (pre-data) years of the IHW, we adopted the goal of scanning 1,000 good plates of Halley. In reality, we scanned more than 1,200 images, with several hundred more coming in digital form from a few observers. That we topped 1,200 scans is due in part to Mike keeping us going on numerous occasions when things looked hopeless. Thank you, Mike.

JOHN M. BOGERT III, of NASA/GSFC, worked closely with Dan Klinglesmith on the immense problems associated with storing and manipulating our large images on the IBM 3081 mainframe computer. As I said in Dan's write-up, 20 gigabytes of data pose some daunting challenges if one wants the data to be "on-line" in some sense. John's insight into the world of mainframes (which many of us have drifted from) was a key ingredient in our doing what we wanted with the 1,612 digital data files of Halley and calibration objects. It needs be said loudly that John's programming did not simply move the images around in the IBM archiving system during the various processing steps associated with final preparation of the data; just as important, he wrote the previous-pixel code (PACKER.FOR) that compressed the images. When we reached the critical phase of data preparation in the last months preceding CD-ROM generation, it was comforting to have pros like John and Dan at the helm.

The following individuals made important contributions to the success of the L-SP Team and are thanked here. STEVEN B. HOWELL, then of STX, wrote some code during 1986–1987 that allowed us to display and manipulate images at the workstation level; he was also a regular scanner of images early in our pipeline. WAYNE B. LANDSMAN and other STX employees working on the Ultraviolet Imaging Telescope (UIT) project have developed an extensive image processing system in IDL called "MOUSSE"; much use was made of MOUSSE by the L-SP Discipline after Steve left the project, and it is a pleasure to thank Wayne and the UIT personnel for the use of their software. LYLA L. TAYLOR, also then of STX, worked on our Team during 1988–1989. One of Lyla's major responsibilities was to "Gould-check" the FITS-formatted images for accuracy in the astrometric plate solution. In addition, Lyla probably scanned more images per unit time than anybody, except perhaps Joan Isensee and JANET SINCLAIR. Janet, of the Royal Greenwich Observatory, accompanied her husband, Andrew, to NASA/GSFC during his 1988 summer faculty appointment. Rather than sit in an apartment watching American soap operas, she decided to work, even if it was without compensation. In that one short summer, she scanned 50 images, the oversize difficult ones at that. JINNY RHEE, KANAV BHAGAT, and JENNIFER GAGLIARDI were three summer students who worked with us during the summers of 1987–1989; they were a breath of fresh air as they gladly took on some of the tasks that had the rest of us gasping. CHRISTOPHER A. ("Kit") HARVEL was involved many years ago in thinking through some of the requirements an archive system would have to have to handle our eventual data. WALT BELL, of NASA/GSFC, helped Mike Greason keep the microdensitometers going. Many thanks to one and all of you.

I would like to acknowledge the very substantial contributions of three university colleagues who contributed either data or ideas to the Discipline. WILLIAM LILLER, of the Instituto Isaac Newton in Vina del Mar, Chile, was my closest collaborator in the L-SP "Island Network," a small set of five remote sites around the world that, equipped with portable (8"-class) telescopes in the hands of competent observers, were thought capable of greatly filling in the gaps of coverage caused by the world's great oceans. Bill conducted an incredible post-perihelion campaign from Easter Island, submitting 35mm images of such quality that we digitized a large fraction of them for placement on these CD-ROMs. FREEMAN D. MILLER, of the University of Michigan, secured some of the best and most voluminous plate material we received from any observer. Freeman observed on the Curtis Schmidt at Cerro Tololo Inter-American Observatory (CTIO) during the post-perihelion interval, and, like Bill Liller (who had the pre-perihelion Curtis run, by the way), was possessed of tremendous weather and unbelievable consecutive-nights-with-plates statistics. PETER D. USHER, of the Pennsylvania State University, did not contribute data, but the most detailed thinking yet on an important concept: how to use standard stars in wide-field plates as absolute calibrators of the H & D curve of uncalibrated plates. We hope at some point in the near future to use Peter's techniques to analyze the changing rate of injection of ions into the plasma tail. Many thanks go to these three individuals for their contributions to the L-SP Team.

No acknowledgments would be complete without mentioning the excellent relationship that has existed between my Team and the IHW Lead Center at the Jet Propulsion Laboratory (JPL). To RAY NEWBURN, MO GELLER, ZDENEK SEKANINA, and MIKAEL ARONSSON, I say it's been good fun and we've enjoyed it. Thanks for all your encouragement and support through the years; you've done a good job and should be proud of it.

Last, but most important to me personally, I would like to dedicate whatever contribution I made to this project—whatever share of the success is mine—to the memory of my dear Mother.

Appendix B. Contributing Observatories in the L-SP Network

Malcolm B. Niedner, Jr.

This appendix contains listings of observers, observatories, and instruments that contributed imagery to the Large-Scale Phenomena (L-SP) Discipline of the IHW, and specifically that imagery that is represented in some form on the L-SP compressed-image discs. Unfortunately, due either to the very late arrival of some data to the L-SP Discipline or to the occasional lack of important information about the data, it was not possible to include all submitted images in the present archives. We regret this fact, but do note that almost all imagery submitted by the L-SP Network observers was, in fact, deposited on compact discs, either as actual digital data or as "dataless listings" in some of the indices and tables.

In all, 103 observatory, instrument, and location combinations are listed in Table B-I. Although most of the instruments were site-fixed, some of the smaller, more mobile telescopes were moved to more suitable sites to follow the comet's descent into the southern hemisphere after perihelion. Many of the mobile telescopes are listed more than once because of the substantially different locations at which they were employed; examples are the E.E. Barnard Observatory and the Shanghai Observatory.

Table B-I lists the observatories, instruments, and observers sorted by geographic east longitude (0–360 degrees) of the actual observing sites. The data in this table are also contained in the LSPNOBS.IDX delimited index in the INDEX directory of the L-SP compressed-image discs. Should a search of observatory and telescope combinations satisfying specific criteria be required, it is recommended that LSPNOBS.IDX be downloaded into a database management software (DBMS) package, and the search conducted there. The purpose of this text table is to allow a quick assessment of the L-SP coverage of Halley as well as to permit "quick viewing" of the facility characteristics for a known longitude or system code.

The user of the archive who wishes to access data from particular observatories should note that the System codes below are indexed parameters in both the CALIB.IDX and NETLARGE.IDX indices in INDEX directory of the L-SP compressed-image discs, as well as in the indices by the same names on the mixed discs containing data from the other IHW Disciplines.

Table B-I. Contributing L-SP Observatories Sorted by Geographic East Longitude

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Royal Greenwich Obs. Herstmonceux, ENGLAND SYSTEM = 30000100	Astrograph Ap = 33.0 cm F/ = 10.00 Scale = 60.00 (arcsec/mm)	0.338	50.870	Jones, D
Royal Greenwich Obs. Herstmonceux, ENGLAND SYSTEM = 30000200	Astrograph Ap = 66.0 cm F/ = 10.00 Scale = 30.00 (arcsec/mm)	0.338	50.870	Jones, D
Obs. Haute-Provence Saint Michel, FRANCE SYSTEM = 35110300	Schmidt Ap = 62.0 cm F/ = 3.40 Scale = 98.80 (arcsec/mm)	5.713	43.932	Dossin, F Hutsemekers, D Laugier, A Sause, G
Asiago Astr. Obs. Asiago, ITALY SYSTEM = 30430200	Schmidt Ap = 67.0 cm F/ = 3.20 Scale = 95.90 (arcsec/mm)	11.529	45.862	Barbieri, C Rigoni, L
Asiago Astrophysical Obs. Asiago, ITALY SYSTEM = 30430300	Schmidt Ap = 40.0 cm F/ = 2.50 Scale = 206.30 (arcsec/mm)	11.529	45.862	Rebeschini, M Rigoni, A
K. Schwarzschild Obs. Tautenburg, GERMAN DEM. REP. SYSTEM = 30330100	Schmidt Ap = 134.0 cm F/ = 3.00 Scale = 51.50 (arcsec/mm)	11.712	50.982	Borngen, F Ludwig, F Mau, K Meusinger, H Ziener, R
Catania Astr. Obs. Catania, Sicily, ITALY SYSTEM = 35000702	Schmidt Ap = 41.0 cm F/ = 3.00 Scale = 169.00 (arcsec/mm)	14.975	37.692	Carbanaro, G Coli, A Cristaldi, S Miraglia, M
Project K600/Namibia Sta. Hohenheim-Namibia SOUTH-WEST AFRICA SYSTEM = 35006501	K600 Camera Ap = 10.0 cm F/ = 6.00 Scale = 339.30 (arcsec/mm)	16.400	-23.[illegible]3	Neumann, H

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Comenius Univ. Obs. Bratislava, CZECHOSLOVAKIA SYSTEM = 35003501	Zeiss Refractor Ap = 18.0 cm F/ = 5.60 Scale = 206.20 (arcsec/mm)	17.273	48.374	Kubacek, D Pittich, E Zvolankova, J
Chorzow Observatory Chorzow, POLAND SYSTEM = 35530100	Astrograph Ap = 20.0 cm F/ = 5.00 Scale = 206.00 (arcsec/mm)	18.992	50.292	Wlodarczyk, I
LSPN Island Network Cederberg, SOUTH AFRICA SYSTEM = 35001303	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	19.252	-32.500	Allen, C
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30551100	Photogr. Camera IX Ap = 2.6 cm F/ = 2.00 Scale = 3966.00 (arcsec/mm)	19.827	50.055	Winiarski, M
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30550300	Photogr. Camera I Ap = 2.6 cm F/ = 2.00 Scale = 3966.00 (arcsec/mm)	19.827	50.055	Winiarski, M
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30550200	Twin Astrograph Ap = 14.0 cm F/ = 2.00 Scale = 736.60 (arcsec/mm)	19.827	50.055	Winiarski, M Zola, S
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30551300	Twin Astrograph Ap = 12.0 cm F/ = 5.00 Scale = 343.80 (arcsec/mm)	19.827	50.055	Waniak, W
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30551000	Photogr. Camera VIII Ap = 4.1 cm F/ = 2.00 Scale = 2515.00 (arcsec/mm)	19.827	50.055	Winiarski, M

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30550900	Photogr. Camera VII Ap = 3.4 cm F/ = 1.50 Scale = 4044.00 (arcsec/mm)	19.827	50.055	Winiarski, M
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30550600	Photogr. Camera IV Ap = 2.6 cm F/ = 2.00 Scale = 3966.00 (arcsec/mm)	19.827	50.055	Winiarski, M
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30550400	Photogr. Camera II Ap = 2.6 cm F/ = 2.00 Scale = 3966.00 (arcsec/mm)	19.827	50.055	Winiarski, M
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30550800	Photogr. Camera VI Ap = 2.9 cm F/ = 2.00 Scale = 3556.00 (arcsec/mm)	19.827	50.055	Winiarski, M
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30551200	Photogr. Camera X Ap = 4.2 cm F/ = 2.00 Scale = 2455.50 (arcsec/mm)	19.827	50.055	Winiarski, M
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30550700	Photogr. Camera V Ap = 4.1 cm F/ = 2.00 Scale = 2515.40 (arcsec/mm)	19.827	50.055	Winiarski, M
Jagellonian Univ. Obs. Cracow, POLAND SYSTEM = 30550500	Photogr. Camera III Ap = 2.9 cm F/ = 2.00 Scale = 3556.00 (arcsec/mm)	19.827	50.055	Winiarski, M
Konkoly Obs. Matra Mountain, HUNGARY SYSTEM = 30530100	Schmidt Ap = 60.0 cm F/ = 3.00 Scale = 116.00 (arcsec/mm)	19.898	47.919	Kun, M Lovas, M Toth, I

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Skalnate Pleso Obs. Skalnate Pleso, CZECHOSLOVAKIA SYSTEM = 30560200	Astrograph Ap = 30.0 cm F/ = 5.00 Scale = 138.00 (arcsec/mm)	20.245	49.189	Cervak, G Rychtarcik, P
LSPN Island Network Sutherland, SOUTH AFRICA SYSTEM = 35001302	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	20.811	-32.378	Marang, F Van Wyk, F
Univ. Perugia/S.A.A.O. Sutherland, SOUTH AFRICA SYSTEM = 35001301	Schmidt Ap = 25.0 cm F/ = 3.20 Scale = 257.80 (arcsec/mm)	20.812	-32.378	Butler, C Carter, B Catchpole, R Feast, M Jones, J O'Donoghue, D Roberts, G Whitelock, P
Turku-Tuorla Univ. Obs. Piikkio, FINLAND SYSTEM = 30630100	Schmidt Ap = 70.0 cm F/ = 2.60 Scale = 112.50 (arcsec/mm)	22.447	60.416	Sillanpaa, A
Riga Radio-Ap. Obs. Baldone, near Riga, LATVIAN S.S.R. SYSTEM = 30690100	Schmidt Camera Ap = 80.0 cm F/ = 3.00 Scale = 86.00 (arcsec/mm)	24.400	56.783	Alksnis, A Eglitis, I Jurgitis, I Platajs, I
National Astr. Obs. Rojen, BULGARIA SYSTEM = 35000301	Schmidt Ap = 70.0 cm F/ = 2.80 Scale = 120.00 (arcsec/mm)	24.725	41.717	Ivanova, V Georgieva, A Shkodrov, V
Boyden Observatory Bloemfontein, SOUTH AFRICA SYSTEM = 30740300	Ross-Fecker Camera Ap = 7.6 cm F/ = 7.00 Scale = 395.00 (arcsec/mm)	26.405	-29.038	Jarrett, A Malcolm, G van den Heever, A

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Boyden Observatory Bloemfontein, SOUTH AFRICA SYSTEM = 30740400	Cooke Patrol Camera Ap = 3.8 cm F/ = 8.70 Scale = 625.00 (arcsec/mm)	26.405	-29.038	Malcolm, G
Boyden Observatory Bloemfontein, SOUTH AFRICA SYSTEM = 30740200	Metcalf Triplet Ap = 25.0 cm F/ = 5.00 Scale = 167.00 (arcsec/mm)	26.405	-29.038	Jarrett, A Malcolm, G van den Heever, A
Crimean Astrophys. Obs. Crimea, Ukrainian S.S.R. U.S.S.R. SYSTEM = 35002403	Double Astrograph Ap = 40.0 cm F/ = 4.00 Scale = 129.00 (arcsec/mm)	34.017	44.727	Chernih, N
Byurakan Observatory Armenian S.S.R. U.S.S.R. SYSTEM = 31230100	ZTA-2.6 Ap = 260.0 cm F/ = 3.71 Scale = 21.40 (arcsec/mm)	44.263	40.345	Akhverdyan, L
Burakan Observatory Armenian S.S.R. U.S.S.R. SYSTEM = 31230400	AZT-10 Ap = 100.0 cm F/ = 2.62 Scale = 78.60 (arcsec/mm)	44.263	40.345	Ahverdjan, L
LSPN Island Network Reunion Island, FRANCE SYSTEM = 35007001	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	55.012	-21.250	SAF Observers Berge, P Mahoux, G
Gissar Observatory Tadjik S.S.R. U.S.S.R. SYSTEM = 31900200	Zeiss Refractor Ap = 40.0 cm F/ = 5.01 Scale = 103.00 (arcsec/mm)	68.600	38.510	Borisov, J Gerasimenko, S Kiselev, N Lizunkova, I Masumi, F Pushnin, P

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Sanglok Observatory Tadjik S.S.R. U.S.S.R. SYSTEM = 32000100	1-M RCC Ap = 101.6 cm F/ = 13.29 Scale = 15.28 (arcsec/mm)	69.250	38.300	Kiselev, N Sherbanovsky, A Siklitsky, V Tarasov, K
Shanghai Observatory Mobile Station, PEOPLES REP. CHINA SYSTEM = 35001001	Astrograph Ap = 15.0 cm F/ = 5.00 Scale = 120.00 (arcsec/mm)	76.192	39.400	Lin-Shan, Y
Mountain Observatory Alma-Ata Kasakh S.S.R. U.S.S.R. SYSTEM = 35002401	Maksutov Astrograph Ap = 50.0 cm F/ = 23.79 Scale = 17.34 (arcsec/mm)	76.950	43.188	Gorodetskij, D Rspaev, F
Kodaikanal Obs. Kodaikanal, INDIA SYSTEM = 35000504	Long Focus Camera Ap = 15.0 cm F/ = 15.00 Scale = 91.70 (arcsec/mm)	77.468	10.230	Sivaraman, K
Kodaikanal Obs. Kodaikanal, INDIA SYSTEM = 35000504	Tessar Lens Ap = 4.0 cm F/ = 4.50 Scale = 1160.00 (arcsec/mm)	77.468	10.230	Sivaraman, K
Assah Observatory Alma-Ata Kasakh S.S.R. U.S.S.R. SYSTEM = 35002402	1-M Zeiss Refl. RCC Ap = 100.0 cm F/ = 13.31 Scale = 15.50 (arcsec/mm)	77.878	43.222	Churyumov, K Gorodetskij, D Rspaev, F
Kavalur Obs. Kavalur, INDIA SYSTEM = 35000503	Schmidt Ap = 45.0 cm F/ = 3.00 Scale = 152.80 (arcsec/mm)	78.826	12.576	Sivaraman, K
Yunnan Observatory Kunming, PEOPLES REP. CHINA SYSTEM = 32860500	Tracking Camera Ap = 10.0 cm F/ = 2.50 Scale = 804.90 (arcsec/mm)	102.788	25.025	Zhang, Y

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Shanghai Observatory Mobile Station, PEOPLES REP. CHINA SYSTEM = 35001002	Astrograph Ap = 15.0 cm F/ = 5.00 Scale = 120.00 (arcsec/mm)	109.533	18.200	Lai, W
Perth Observatory Bickley, AUSTRALIA SYSTEM = 33230600	Astrograph Ap = 33.0 cm F/ = 10.00 Scale = 60.00 (arcsec/mm)	116.135	-32.009	Candy, M
Perth/Lowell Obs. Bickley, AUSTRALIA SYSTEM = 33230500	Super Farron Lens Ap = 9.6 cm F/ = 0.80 Scale = 2696.00 (arcsec/mm)	116.135	-32.009	Berg, E Feldstein, B Jansen, S Millis, R Nye, R
Perth/Lowell Obs. Bickley, AUSTRALIA SYSTEM = 33230500	Zenar Lens Ap = 9.2 cm F/ = 4.00 Scale = 562.27 (arcsec/mm)	116.135	-32.009	Berg, E Feldstein, B Jansen, S Nye, R
Univ. Kyoto Obs. Ouda, Nara, JAPAN SYSTEM = 35000801	Schmidt Ap = 40.0 cm F/ = 3.00 Scale = 172.00 (arcsec/mm)	135.956	34.467	Tsujimura, T
Kiso Observatory Kiso-gun, Nagano-ken, JAPAN SYSTEM = 33810100	Schmidt Ap = 105.0 cm F/ = 3.10 Scale = 62.58 (arcsec/mm)	137.628	35.794	Maehara, H
Hidahiko Obs. near Numazu, JAPAN SYSTEM = 35000802	Wide-Field Camera Ap = 20.0 cm F/ = 2.50 Scale = 408.00 (arcsec/mm)	138.860	35.016	Fukaya, T Sakai, Y Sakai, Y
British Astron. Assn. Mt. Stromlo, AUSTRALIA SYSTEM = 34140200	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	149.008	-35.322	Bembrick, C

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Uppsala Southern Sta. Siding Spring, AUSTRALIA SYSTEM = 34140100	Schmidt Ap = 52.0 cm F/ = 3.40 Scale = 120.00 (arcsec/mm)	149.067	-31.277	Magnusson, P
Royal Observatory Siding Spring, AUSTRALIA SYSTEM = 34130200	UK Schmidt Ap = 124.0 cm F/ = 2.50 Scale = 67.14 (arcsec/mm)	149.070	-31.275	UKSTU (= "UK Schmidt Telescope Unit")
LSPN Island Network Papeete, TAHITI, FRANCE SYSTEM = 35006101	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	149.567	-17.533	Malloy, P Spector, M
British Astron. Assn. Meadow Flat, AUSTRALIA SYSTEM = 35002603	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	149.918	-33.477	Bembrick, C
Mt. John Univ. Obs. Mt. John, NEW ZEALAND SYSTEM = 34740700	MPT-300 Camera Ap = 30.0 cm F/ = 1.92 Scale = 358.10 (arcsec/mm)	170.465	-43.987	Sterken, C
Kuiper Airborne Obs. Christchurch, NEW ZEALAND SYSTEM = 35009801	Camera Lens Ap = 10.5 cm F/ = 2.50 Scale = 785.80 (arcsec/mm)	172.667	-43.550	Nicholson, J O'Brien, T Wenger, N
Kuiper Airborne Obs. Christchurch, NEW ZEALAND SYSTEM = 35009801	Camera Lens Ap = 5.8 cm F/ = 1.20 Scale = 2963.60 (arcsec/mm)	172.667	-43.550	O'Brien, T Wenger, N
U.S.N.O. Station Black Birch Mountain, NEW ZEALAND SYSTEM = 34830200	Twin Astrograph Ap = 20.0 cm F/ = 10.00 Scale = 100.00 (arcsec/mm)	173.803	-41.748	Dick, S Douglass, G Loader, B Millington, R

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Mauna Kea Observatory Mauna Kea, HI U.S.A. SYSTEM = 35680400	Schmidt Ap = 30.0 cm F/ = 2.20 Scale = 316.00 (arcsec/mm)	204.528	19.827	Buie, M Cruikshank, D Storrs, A
Lick Observatory Mt. Hamilton, CA U.S.A. SYSTEM = 36620200	Crossley Refl. Ap = 91.4 cm F/ = 5.84 Scale = 38.60 (arcsec/mm)	238.357	37.338	Harlan, E
Lick Observatory Mt. Hamilton, CA U.S.A. SYSTEM = 36620400	Twin Astrograph Ap = 51.0 cm F/ = 7.00 Scale = 55.00 (arcsec/mm)	238.363	37.343	Harlan, E
Table Mountain Obs. Table Mountain, CA U.S.A. SYSTEM = 36730200	Camera Lens Ap = 6.6 cm F/ = 2.80 Scale = 1145.92 (arcsec/mm)	242.320	34.382	Meredith, N Rees, D
Table Mountain Obs. Table Mountain, CA U.S.A. SYSTEM = 36730100	Camera Lens Ap = 6.7 cm F/ = 4.50 Scale = 687.55 (arcsec/mm)	242.320	34.382	Meredith, N Rees, D
Warner and Swasey Obs. Kitt Peak, AZ U.S.A. SYSTEM = 36950600	Burrell Schmidt Ap = 61.0 cm F/ = 3.50 Scale = 97.00 (arcsec/mm)	248.401	31.961	Hill, R Jewitt, D Meech, K
Lowell Observatory Flagstaff, AZ U.S.A. SYSTEM = 36880400	Lowell Astrograph Ap = 33.0 cm F/ = 5.10 Scale = 122.10 (arcsec/mm)	248.464	35.096	Giclas, H
Lowell Observatory Flagstaff, AZ U.S.A. SYSTEM = 36880601	Cogshall Camera Ap = 12.7 cm F/ = 4.50 Scale = 361.80 (arcsec/mm)	248.464	35.096	Giclas, H

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Catalina Observatory Mt. Bigelow, Tucson, AZ U.S.A. SYSTEM = 36930300	58mm Lens Ap = 5.8 cm F/ = 1.00 Scale = 3600.00 (arcsec/mm)	249.268	32.417	DiSanti, M Fink, U Schultz, A
Catalina Observatory Mt. Bigelow, Tucson, AZ U.S.A. SYSTEM = 36930200	4-inch Lens Ap = 10.2 cm F/ = 6.00 Scale = 337.60 (arcsec/mm)	249.268	32.417	DiSanti, M Fink, U Schultz, A
Catalina Observatory Mt. Bigelow, Tucson, AZ U.S.A. SYSTEM = 36930100	Catalina Refl. Ap = 154.9 cm F/ = 16.00 Scale = 66.60 (arcsec/mm)	249.268	32.417	DiSanti, M Fink, U Schultz, A
LSPN Island Network Maunga Orito, Easter Isla CHILE SYSTEM = 35003201	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	250.593	-27.151	Liller, W
J.O.C.R. Socorro, NM U.S.A. SYSTEM = 37020100	Schmidt Ap = 36.0 cm F/ = 2.00 Scale = 298.00 (arcsec/mm)	252.811	33.985	Arnold, G Bair, L Bernick, A Bernick, M Brandt, J Marr, E Moore, E Niedner, M Pirronello, V Stephenson, D
Chamberlin Observatory Bailey, CO U.S.A. SYSTEM = 37070100	Newtonian Refl. Ap = 40.6 cm F/ = 5.50 Scale = 92.20 (arcsec/mm)	254.563	39.427	Briggs, J
E. E. Barnard Obs. Golden, CO U.S.A. SYSTEM = 35001604	Astrograph Ap = 22.5 cm F/ = 4.00 Scale = 229.00 (arcsec/mm)	254.624	39.875	Brandreth, B

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
E. E. Barnard Obs. Golden, CO U.S.A. SYSTEM = 35001604	Astro Camera Ap = 12.0 cm F/ = 2.50 Scale = 688.00 (arcsec/mm)	254.624	39.875	Emerson, G
E. E. Barnard Obs. Golden, CO U.S.A. SYSTEM = 35001604	Schmidt Ap = 30.0 cm F/ = 1.80 Scale = 380.00 (arcsec/mm)	254.624	39.875	Emerson, G
U.S. Air Force Obs. Colorado Springs, CO U.S.A. SYSTEM = 35001605	Cass. Refl. Ap = 61.0 cm F/ = 15.20 Scale = 22.30 (arcsec/mm)	255.125	39.007	Bloomer, R Lewis, D
E. E. Barnard Obs. Terlingua, TX U.S.A. SYSTEM = 35001611	Astro Camera Ap = 7.0 cm F/ = 2.50 Scale = 1178.00 (arcsec/mm)	256.467	29.423	Emerson, G
E. E. Barnard Obs. Terlingua, TX U.S.A. SYSTEM = 35001611	Astrograph Ap = 22.5 cm F/ = 4.00 Scale = 229.00 (arcsec/mm)	256.467	29.423	Emerson, G
A. J. Dyer Observ. Nashville, TN U.S.A. SYSTEM = 35001601	Schmidt Ap = 60.0 cm F/ = 3.50 Scale = 99.00 (arcsec/mm)	273.195	36.053	Heiser, A
Perkins Observatory Delaware, OH U.S.A. SYSTEM = 35001602	Schmidt Ap = 40.6 cm F/ = 2.75 Scale = 184.90 (arcsec/mm)	276.945	40.250	Wahlgren, G
U. S. Naval Observatory Marshall, VA U.S.A. SYSTEM = 37860100	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	282.140	38.863	Chester, G Schmidt, R

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Smithsonian Inst. Marshall, VA U.S.A. SYSTEM = 35001612	Celestron 5 Ap = 14.0 cm F/ = 3.64 Scale = 412.50 (arcsec/mm)	282.140	38.863	Chester, G
Goddard Space Flt. Ctr. Greenbelt, MD U.S.A. SYSTEM = 35001610	Image-Intens. Cam. Ap = 6.1 cm F/ = 1.40 Scale = 2427.00 (arcsec/mm)	283.173	39.021	Grayzeck, E Klinglesmith, D Niedner, M Warnock, A
Goddard Space Flt. Ctr. Greenbelt, MD U.S.A. SYSTEM = 35001610	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	283.173	39.021	Grayzeck, E Niedner, M Schmidt, R
Goddard Space Flt. Ctr. Greenbelt, MD U.S.A. SYSTEM = 35001610	Image-Intens. Cam. Ap = 3.6 cm F/ = 1.40 Scale = 4125.00 (arcsec/mm)	283.173	39.021	Grayzeck, E Klinglesmith, D Niedner, M Warnock, A
Mt. Cuba Astr. Obs. Greenville, DE U.S.A. SYSTEM = 37880100	Baker Camera Ap = 61.0 cm F/ = 4.00 Scale = 85.00 (arcsec/mm)	284.366	39.785	Bock, G Buckley, J Jr Buckley, J III Groski, D King, L Lisansky, T Olena, D Sharp, N Smith, D Uhlenburg, J Watkins, M Westergard, B Wilhelm, R
J.E.R. Gonzales Planet. Medellin, COLOMBIA SYSTEM = 35003301	Zeiss Camera Ap = 5.6 cm F/ = 4.50 Scale = 687.00 (arcsec/mm)	284.428	6.272	Alvear, W

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Cerro el Roble Astr. Sta. Capilla de Caleau, CHILE SYSTEM = 38040100	Maksutov Astrograph Ap = 70.0 cm F/ = 3.00 Scale = 100.00 (arcsec/mm)	288.980	-32.982	Torres, C Wroblewski, H
Univ. Michigan/CTIO La Serena, CHILE SYSTEM = 38070400	Curtis Schmidt Ap = 61.0 cm F/ = 3.50 Scale = 97.00 (arcsec/mm)	289.185	-30.165	Liller, W Meech, K Miller, F
European Southern Obs. Cerro La Silla, CHILE SYSTEM = 38090700	Cass. Reflector Ap = 107.0 cm F/ = 2.80 Scale = 67.60 (arcsec/mm)	289.268	-29.257	Geyer, E Jockers, K Rosenbauer, H
European Southern Obs. Cerro La Silla, CHILE SYSTEM = 38090400	Schmidt Ap = 100.0 cm F/ = 3.00 Scale = 67.00 (arcsec/mm)	289.270	-29.257	Pizarro, G Pizarro, O Schuster, H West, R
Mt. Wilson/Las Camp. Obs. Cerro Las Campanas, CHILE SYSTEM = 33040100	Du Pont Telescope Ap = 250.0 cm F/ = 7.60 Scale = 10.90 (arcsec/mm)	289.297	-29.003	Dressler, A Windhorst, R
Maria Mitchell Obs. Nantucket, MA U.S.A. SYSTEM = 38110100	Cooke Triplet Ap = 19.0 cm F/ = 4.40 Scale = 247.90 (arcsec/mm)	289.895	41.280	Belserene, E
Br. Antarctic Survey Faraday Station, ANTARCTICA SYSTEM = 35000101	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	296.000	-65.000	Clilverd, M Dowson, M
Observ. Highland Park Buenos Aires, ARGENTINA SYSTEM = 35002702	Celestron Schmidt Ap = 20.0 cm F/ = 1.50 Scale = 680.00 (arcsec/mm)	301.307	-34.412	Lopez-Alvarez, M

Table B-I. (continued)

Observatory	Telescope	Long. (deg)	Lat. (deg)	Observer(s)
Amateur Observatory S. Jose do Rio Preto, BRAZIL SYSTEM = 35000204	Nikon EM Ap = 2.8 cm F/ = 1.80 Scale = 4125.30 (arcsec/mm)	310.614	-20.816	Falsarella, N
Amateur Observatory S. Jose do Rio Preto, BRAZIL SYSTEM = 35000204	Pentax K1000 Lens Ap = 2.5 cm F/ = 2.00 Scale = 4125.30 (arcsec/mm)	310.614	-20.816	Falsarella, N
Roque de L. Muchachos Obs. La Palma Island CANARIES, SPAIN SYSTEM = 35001402	Camera Lens Ap = 6.7 cm F/ = 4.50 Scale = 687.55 (arcsec/mm)	342.124	28.760	McWhirter, P Meredith, N
Calar Sta./Nat. Ast. Obs. Calar Alto Mtn., SPAIN SYSTEM = 34930200	Schmidt Ap = 80.0 cm F/ = 3.00 Scale = 86.00 (arcsec/mm)	357.464	37.229	Birkle, K Kohoutek, L

METEOR STUDIES NETWORK

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1. INTRODUCTION

The Meteor Studies Network was established following the recommendation of the International Halley Watch (IHW) Steering Group in Prague, June 1984. Table I lists the Network's Discipline Specialists, who were responsible for the scientific program and coordination of meteor studies in the IHW. The program provided an opportunity to coordinate and combine many different types of observations relating to the Halley meteor showers. The main observing techniques utilized meteor radars and visual recording (naked-eye observations). Very few observations (direct or spectroscopic) were obtained with cameras or photoelectric devices, and none were archived.

2. THE HALLEY METEOR SHOWERS

The Earth makes two close approaches to Comet Halley's orbit, once in early May and again in late October. In common with other comet-produced meteor streams, the dust ejected from Halley is dispersed along the orbit and laterally from the orbit; but, uncommonly in meteor astronomy, the Earth passes twice every year through the band of Halley particles, thus producing the long-known Eta-Aquarid (May) and Orionid (October) meteor showers. In each case, most of the meteor activity is confined to a period of about five days. However, this period is not well defined; shower meteors have been observed over as long as 14 days. Furthermore, the activity is not consistent from year to year—the position in the time of maximum flux shifts significantly, and there are secondary maxima. Hence, an activity curve for one year is not a reliable predictor for the activity in another year. If averaged over many years, a broad, flat curve results, which again is not indicative of annual activity.

Traditional visual observations have never been carried out over sufficiently long intervals of time to clearly define the structure of the stream. Radar observations have contributed to our understanding of the structure, but they are also not without problems. A paper by Hajduk (1970) summarizes visual and radar observations from 1900 to 1969. Earlier observations, from medieval and ancient times, have also been recorded.

The geometric relation between the Earth's orbit and the comet's current orbit suggests that the two showers should not be of equal strength or equal duration,

Table I. The Meteor Studies Discipline Specialist Team

Team Member	Affiliation	Responsibility
P.B. Babadzhanov	Tadjik Astrophysical Institute 734042 Dushanbe U.S.S.R.	Discipline Specialist
A. Hajduk	Astronomical Institute SAV 84228 Bratislava Czechoslovakia	Discipline Specialist
B.A. Lindblad	Lund Observatory, Box 43 S-22100 Lund Sweden	Discipline Specialist
B.A. McIntosh	National Research Council Canada Ottawa Canada K1A 0R6	Discipline Specialist

which is contrary to actual observations. A recent theory (McIntosh and Hajduk 1983; McIntosh and Jones 1988) proposes that the long-term evolution of the comet and dust results in a flat ribbon of particles, so that the Earth's two crossings yield approximately equal-activity, equal-duration showers.

Observationally, the meteors are very fast (V > 65 km/s for both showers), with persistent trains being common. Studies of the physical characteristics and composition of the particles are sparse, but there is no evidence that they are unusual.

The visual rates for the showers may be as high as 30 per hour, depending on the latitude of the observer. The low-declination radiant of the May shower (in Aquarius, at RA = 335.5 deg, DEC = -1.9 deg) rises only a little before sunrise, particularly at high northern latitudes, providing a very limited period for visual or optical observations. More extensive coverage by Southern Hemisphere observers was needed.

The observing period for the Orionids extends through nearly the entire night, because of the radiant's much greater elongation from the Sun (RA = 94.5 deg, DEC = +15.8 deg). The higher declination and time of the year favor Northern Hemisphere observers.

Studies also benefit from observations at many longitudes around the Earth. This is true of the Eta-Aquarids in particular.

3. Scientific Goals

Meteor observations are specifically oriented toward studies of comet-meteor relationships. These observations contribute to comet science mainly in the areas of dust production and dust-particle dynamics. These aspects can be enhanced by:

- Determination of the number density and mass distribution of particles in the showers.
- Determination of the properties and composition of the particles.
- Study of the evolution of the Halley meteor stream.
- Study of the spatial structure of the stream, especially as a function of particle mass.

The IHW program provided an opportunity to coordinate and combine many different observations to determine the stream structure with high resolution and to infer from this the production and dynamical evolution of the larger dust particles. This goal is independent of the current comet passage. No increase in normal meteor shower rates was expected, and none was observed. It was thought that the wider and more rapid dispersal of fine particles might contribute fresh meteors observable on sensitive instruments. These were searched for with the Canadian High-Power Meteor Radar, particularly at the time of the Earth's passage through the comet orbit plane, but the results were negative.

4. Observations

4.1. General

The disintegration of a meteoroid in the Earth's atmosphere produces light and ionization, both of which have a complex relation to the energy (mass and velocity) of the particle. A meteor trail can reflect radio waves, producing "echoes" having measurable parameters such as amplitude and duration that can be related to the properties and energy of the particle. Some radars are able to determine meteor velocity.

The luminous meteor is a point source moving with sufficiently high angular velocity that the human eye is a more sensitive detector than typical lenses and photographic emulsions. However, the eye is not a particularly satisfactory quantitative recorder of brightness and position. The current sensitivity of electronic imaging devices much exceeds that of the human eye.

Spectral measurements are particularly simple because the meteor is a self-produced "slit." However, orientation of the "slit" is not under control and therefore is not always optimum with respect to the spectral dispersion. High-dispersion spectra permit detailed studies of meteoroid composition and thus give valuable information on the solid component of the cometary nucleus.

4.2. Techniques and Methods

To cover as wide a mass range of meteors as possible, a variety of ground-based techniques are required. The resulting data are of many types and in many formats. In general, the data occur in two basic forms: statistical counts and single events. It was established that all statistical counts would be for one-hour intervals. These observations range from a simple count of meteors seen to diversified radar echo counts in multiple interval classes of range (distance) and/or echo duration or echo amplitude.

Details of observing procedures and data formats are given in Sections 5 (Standards) and 6 (Data Formats for Meteor Studies). Information on the forms used for amateur visual observations may be found in the IHW Amateur Observation Network chapter.

It was stressed to all observers that it was important to distinguish carefully between meteors that belonged to the Halley showers and those that were background or other shower meteors. Shower counts are at best slightly higher than background counts and at worst only a small fraction thereof.

Visual observations require an almost instantaneous judgment on a fleeting event, based primarily on extrapolating the trail back to the radiant and secondarily on consideration of the meteor's velocity. The much greater precision of photographs or photoelectric imaging makes distinction easier. Some radars are able to distinguish on the basis of velocity and/or the geometry of the trail, but for others, shower counts are obtained only by subtraction of an assumed background rate.

Although careful counting of shower meteors was deemed paramount, experienced observers were encouraged to estimate magnitudes to the nearest half or whole magnitude. Less importance was attached to ancillary characteristics such as meteor color or train duration.

It was required that radar meteor echo counts be made in standardized class intervals of echo duration and amplitude.

4.3. Periods for Observing

Major activity takes place at solar longitudes 42.5–47 deg (May 3–8) for the Eta-Aquarid shower and 206–210 deg (October 19–24) for the Orionid shower. At least two other relatively stable secondary maxima have been observed in both showers. These secondary maxima are distinctly separated from the main zones at longitudes 38 deg and 50 deg (April 28/29 and May 10/11) and at 203 deg and 215 deg (October 16/17 and 28/29). The maximum at the beginning of each shower is of particular interest, since it is thought to contain particles of the most recent vintage.

As noted earlier, activity extends over as much as 14 days—between solar longitudes 37 and 51 deg (April 27–May 11) and between 202 and 216 deg (October 15–30), with priority being given to the central interval. The lunar phase is significant for visual observations and was reasonably good for the two years of the IHW observations: the new moon occurred on October 28, 1985, and May 9, 1986.

4.4. Results

The suite of data that has been archived consists of radar meteor counts and visual observations. The radar stations that provided data are listed in Section 7. The locations of these stations range from latitude +54 deg to -33 deg and longitude 75 deg W (285 deg) to 69 deg E. Observations of both the Eta-Aquarid and Orionid meteor showers from 1984 through 1988 are included—a total of 5662 hours of data (note that this count includes duplicate hours). Section 8 provides details.

The visual observations of meteors accumulated by the Amateur Observation Network were processed by Dr. A. Hajduk and his colleagues at the Interplanetary Matter Division, Astronomical Institute of the Slovak Academy of Sciences, Bratislava, Czechoslovakia. Based on their considerable experience in processing visual meteor observations, they found that approximately two-thirds of the observation sets were of acceptable quality. The data encompass over 1600 hours of observations of the showers in the years 1984 to 1987, with a few hours also from 1982. Section 8 gives a summary of the data; Section 7 lists the observing sites and observers.

5. STANDARDS

5.1. Time

The time interval for counts—either visual or radar—is one hour. A count for an interval of greater than, or equal to, one-half hour may be prorated to an equivalent hour count. Intervals shorter than one-half hour should be discarded. The tabulated absolute time for a count shall be the beginning of the hour.

5.2. Radar Meteors

5.2.1. *Range class intervals.* The preference is for counts that are given in range class intervals not less than 10 kilometers and not greater than 20 kilometers.

5.2.2. *Duration class intervals.* As a minimum standard, there shall be at least three duration classes:

(1) Counts of long-duration echoes down to the value t_1.
(2) Counts of medium-duration echoes between t_1 and t_2.
(3) Counts of short-duration echoes having durations less than t_2.

In these classes, either t_1 or t_2 shall be 1 s, and the ratio t_1/t_2 shall be > 2.

5.2.3. *Radio magnitudes.* For purposes of standardization, meteor electron line densities q shall be quoted in electrons/m or on a logarithmic magnitude scale M_r, where $M_r = 40 - 2.5 \times \log_{10}(q)$.

5.3. Visual Meteor Counts

Magnitude may be estimated to the nearest half or whole magnitude. A value given as magnitude 3 shall be deemed to lie in the interval 2.5 to 3.5, etc.

6. DATA FORMATS FOR METEOR STUDIES

Flexible Image Transport System (FITS) headers include the standard IHW mandatory keywords. The notes below apply to the keywords as used by the Meteor

Discipline. Table II shows the main header, while an extension header is signalled by the lines shown in Table III.

Data records are specific to a type of observation, a particular observatory, etc., and cannot all be described here. We provide examples for a meteor radar in Appendix A and for visual observations in Table IV. The data in Appendix A are echo counts in class intervals of duration and range in one-hour intervals. Time is included. It should be emphasized that differences exist between the formats set up by the various institutions.

Table II. Main Header

Keyword	Explanation	Format
BITPIX =	8 \ 8-bit characters	
EXTEND =	T \ Yes, a table	
DAT-FORM =	'ASCII '	
OBJECT	Name of meteor shower	'ORIONID' or 'ETA-AQUARID'
FILE NUM =	File number--Beginning with 9 and followed by a unique 5-digit number	
DATE-OBS	UT date of middle of observing period. See notes for shower periods.	'DD/MM/YY'
TIME-OBS	UT time of middle of observation. Not significant for meteor observations and therefore usually given as 0.0.	
DISCIPLN	IHW Discipline	'METEOR STUDIES'
SYSTEM	Key to finding observing system in discipline/station catalog. Institutes with long-standing observing instruments are listed in Section 7	'9uuuccnn'
OBSERVER or SUBMITTR	'Onename,I' or 'Oneperson,J/Otherperson,K' or 'Firstperson,L/ET AL' if more than two	
DAT-FORM	'ASCII ' data are in character form, usually implying tables and BITPIX = 8.	
OBSVTORY	Name of submitting observatory	'Tadjik Astrophy Inst'
LOCATION	Location of submitting observatory	'Dushanbe, USSR'
LIM-SENS	Threshold sensitivity for observations not cataloged by SYSTEM. Given as limiting magnitude (photographic, visual, or equivalent radio magnitude or electron line density).	'+8M radio' '10**14 electron/m'
QUALITY	Estimate of the quality of the observation on a scale of 1 = poor, to 5 = excellent, with 0 = unknown	2

Table III. Extension Header

```
XTENSION    =   'TABLE   '
BITPIX      =                       8 / 8-bit characters
NAXIS       =                       2
NAXIS1      The width (or line length) of the table
NAXIS2      The number of lines in the table - frequently the num-
            ber of hours represented by the observations if they
            are presented as one hour per line
```

6.1. Meteor Radar Observations Data Record

In the following, the first two lines would not appear in the data record; they are entered here to show the headings and column alignment. The third line, a string of 100 ASCII characters, is the actual first line of the data record.

```
                          75     95    115    135    155    175    195    215    235    255    275    295 315 335
 YR MO DA HR TOT >=1 >=8     85    105    125    145    165    185    205    225    245    265    285    305 325 345
 86 10 16 14 304   8   0   0  0  0  4  6 28 20 30 26 22 22 22 24 12 12  6  8  8 14  8  6  6  4  8  2  6  0
```

6.2. Visual Meteor Observations Data Record

Practices and procedures for visual meteor observing may be found in the Amateur Observation Network chapter.

In the following example, the first line would not appear in the data record; it is entered here to show the headings and column alignment. The second line, a string of 40 ASCII characters, is the actual first line of the data record.

```
YR MO   DAY  TME OBS STE  MAG CL SH NS
85  4 17.81   60  66 318  6.6  0  0 25
```

7. SYSTEM CATALOG

The keyword SYSTEM in the Meteor Studies data format is made up as shown in Figure 1.

Of the detailed list of instrument types given in the Meteor Studies Handbook, only that for meteor radars survived. No optical data were received, and for naked-eye visual observations, the site numbers and observer numbers (listed in Table V and Appendix B) are included in each data table.

In Appendix C, the individual visual observers who participated in the Meteor Studies Network activities are listed alphabetically, while in Appendix D, they are listed according to their identification numbers.

Table IV. Example of EXTENSION Header and Data for Visual Meteor Observations

```
XTENSION   =  'TABLE   '              / table extension
BITPIX     =                     8    / bits per character
NAXIS      =                     2    / dimensions of table
NAXIS1     =                    40    / characters per line
NAXIS2     =                   134    / number of lines in the table
PCOUNT     =                     0    / no random parameters
GCOUNT     =                     1    / only one group
TFIELDS    =                    10    / fields per line
EXTNAME    =  'ETA-AQUARIDS85'        / name of table
COMMENT       Description of the table columns.
TTYPE1     =  'YR      '              / year
TBCOL1     =                     3    / starting column
TFORM1     =  'I2      '              / 2-digit integer
TTYPE2     =  'MO      '              / month
TBCOL2     =                     6    / starting column
TFORM2     =  'I2      '              / 2-digit integer
TTYPE3     =  'DAY      '             / UT day & fraction
TBCOL3     =                    10    / starting column
TFORM3     =  'E5.2 '                 / 5-DIGIT 2 DECIMAL PLACES
TTYPE4     =  'TIME      '            / total minute count
TBCOL4     =                    16    / starting column
TFORM4     =  'I3                     / 3-digit integer
TTYPE5     =  'OBS      '             / observer number
TBCOL5     =                    20    / starting column
TFORM5     =  'I3      '              / 3-digit integer
TTYPE6     =  'SITE      '            / site number
TBCOL6     =                    24    / starting column
TFORM6     =  'I3      '              / 3-digit integer
TTYPE7     =  'F-STAR  '              / faintest magnitude visible
TBCOL7     =                    29    / starting column
TFORM7     =  'E3.1      '            / 3-digit 1 decimal place
TTYPE8     =  'CLOUD      '           / cloud cover in %
TBCOL8     =                    33    / starting column
TFORM8     =  'I2      '              / 2-digit integer
TTYPE9     =  'NUM-SH  '              / count shower meteors
TBCOL9     =                    35    / starting column
TFORM9     =  'I3      '              / 3-digit integer
TTYPE10    =  'NUM-NS  '              / count non-shower meteors
TBCOL10    =                    38    / starting column
TFORM10    =  'I3      '              / 3-digit integer
END
```

8. OBSERVATIONS

Table VI lists the results of the radar observations, and Table VII lists those of the visual observations.

Table V. Meteor Radar Stations

SYSTEM	Station	Coord. Long. Lat. (~)	Freq. (MHz)	Peak power (kW)	Pulse repet. freq. (Hz)	Pulse duration (fs)	Min. line. dens. (el/m)	Antenna system (observing method)	Notes, special programs, etc.
95000700	Budrio	11.63 44.55	42.7	200	140	10	1.0 E14	Interferometric; fixed elevation and azimuth	Computer recording; Heights
95002401	Dushanbe	69.0 38.5	37.5	26	500	40	2.0 E13	2 Yagi arrays pointing E and N; fixed elevation	Computer recording; Velocities
95003508	Ondrejov	14.78 49.92	37.5	40	500	10	1.0 E13	6 dipole array at 45 deg elev.; steerable in azimuth	Film speed 3.36m/hr
95005409	Onsala	12.00 57.40	32.6	25	50	10	1.0 E14	Half-wave dipole (Tx), steerable Yagi array (Rx)	Film speed 10.0m/hr
95002110	Ottawa	284.53 45.20	32.7	25	120	20	2.5 E13	Omnidirectional (crossed dipoles)	Film speed 1.25m/hr
95001312	Grahamstown	26.52 -33.30	28	40	500	1000	1.0 E13	Array of half-wave dipoles; fixed elevation and azimuth	Direction of arrival; Doppler shifts (winds)

Table VI. Radar Observations

Object	Source	Number of hours	File number
Eta-Aquarids 1984	Hajduk, Bratislava	70	900201
	Hajduk, Bratislava	14	900202
	Lindblad, Lund	60	900203
	Babadzhanov, Dushanbe	192	900204
	Babadzhanov, Dushanbe	189	900205
Orionids 1984	Hajduk, Bratislava	68	900206
	Hajduk, Bratislava	11	900207
	Cevolani, Budrio	205	900208
	Lindblad, Lund	45	900209
	Babadzhanov, Dushanbe	224	900210
	Babadzhanov, Dushanbe	225	900211
Eta-Aquarids 1985	McIntosh, Ottawa	165	900212
	Lindblad, Lund	59	900213
	Cevolani, Budrio	42	900214
	Hajduk, Bratislava	[illegible]	900215
	Hajduk, Bratislava	38	900216
	Babadzhanov, Dushanbe	267	900217
	Babadzhanov, Dushanbe	265	900218
Orionids 1985	McIntosh, Ottawa	216	900219
	Lindblad, Lund	54	900220
	Hajduk, Bratislava	36	900221
	Hajduk, Bratislava	25	900222
	Poole, Grahamstown	8	900223
	Babadzhanov, Dushanbe	269	900224
	Babadzhanov, Dushanbe	269	900225
Eta-Aquarids 1986 (comet plane crossing)	McIntosh, Ottawa	168	900226
	McIntosh, Ottawa	10	900227
	Cevolani, Budrio	63	900228
	Lindblad, Lund	54	900229
	Poole, Grahamstown	18	900230
	Hajduk, Bratislava	37	900231
	Hajduk, Bratislava	28	900232
	Babadzhanov, Dushanbe	269	900233
	Babadzhanov, Dushanbe	270	900234
Orionids 1986 (comet plane crossing)	McIntosh, Ottawa	193	900235
	McIntosh, Ottawa	10	900236
	Hajduk, Bratislava	23	900237
	Hajduk, Bratislava	12	900238
	Poole, Grahamstown	20	900239
	Cevolani, Budrio	131	900240
	Babadzhanov, Dushanbe	258	900241
	Babadzhanov, Dushanbe	258	900242

Table VI. (continued)

Object	Source	Number of hours	File number
Eta-Aquarids 1987	Poole, Grahamstown	19	900243
	Babadzhanov, Dushanbe	225	900244
	Babadzhanov, Dushanbe	195	900245
Orionids 1987	Poole, Grahamstown	20	900246
	Babadzhanov, Dushanbe	222	900247
	Babadzhanov, Dushanbe	239	900248
Eta-Aquarids 1988	Poole, Grahamstown	17	900249
Orionids 1988	Poole, Grahamstown	20	900250
	Total	5878	50

Table VII. Visual Observations

Eta-Aquarids		Orionids		
Year	Number of Hours	Year	Number of Hours	File Number
		1982	59	900251
1984	134			900252
		1984	368	900253
1985	134			900254
		1985	546	900255
1986	218			900256
		1986	33	900257
1987	93			900258
		1987	39	900259
Totals	579		1045	9
Grand Total		1624		

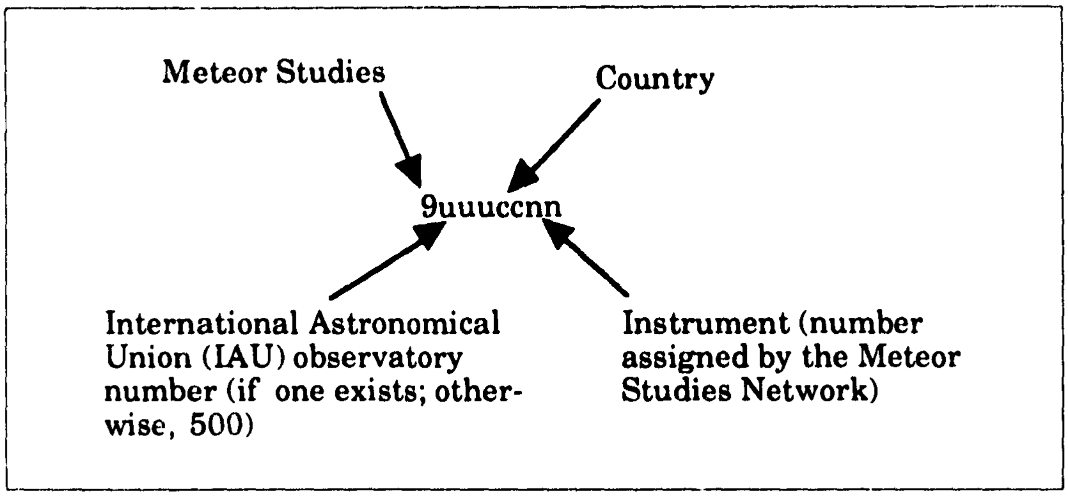

Figure 1. The Keyword SYSTEM in the Meteor Studies Data Format.

9. REFERENCES

Hajduk, A. (1970). Bull. Astron. Inst. Czech. 21, 37.
McIntosh, B.A., and Hajduk, A. (1983). Mon. Not. R. Astron. Soc. 205, 931.
McIntosh, B.A., and Jones, J. (1988). Mon. Not. R. Astron. Soc. 235, 673.

Appendix A. Example of EXTENSION Header and Data for Meteor Radar Observations

```
XTENSION  =  'TABLE   '            / table extension
BITPIX    =                     8  / bits per character
NAXIS     =                     2  / dimensions of table
NAXIS1    =                   100  / characters per line
NAXIS2    =                   193  / hours of observations
PCOUNT    =                     0  / no random parameters
GCOUNT    =                     1  / only one group
TFIELDS   =                    35  / fields per line
EXTNAME   =  'ORIONIDS 86'         / name of table
COMMENT      Description of the table columns.
COMMENT      There is one space between each field.
TTYPE1    =  'YR      '            / year
TBCOL1    =                     1  / starting column
TFORM1    =  'I2      '            / 2-digit integer
TTYPE2    =  'MO      '            / month
TBCOL2    =                     4  / starting column
TFORM2    =  'I2      '            / 2-digit integer
TTYPE3    =  'DA      '            / UT day
TBCOL3    =                     7  / starting column
TFORM3    =  'I2      '            / 2-digit integer
TTYPE4    =  'HR      '            / UT hour
TBCOL4    =                    10  / starting column
TFORM4    =  'I2      '            / 2-digit integer
TTYPE5    =  'TOTAL       '        / total hour count
TBCOL5    =                    13  / starting column
TFORM5    =  'I3      '            / 3-digit integer
TTYPE6    =  '>=1sec  '            / count for durations >=1 s
TBCOL6    =                    17  / starting column
TFORM6    =  'I3      '            / 3-digit integer
TTYPE7    =  '>=8sec  '            / count for durations >=8 s
TBCOL7    =                    21  / starting column
TFORM7    =  'I2      '            / 2-digit integer
TTYPE8    =  ' 75     '            / count in 10-km range class 70-80 km
TBCOL8    =                    24  / starting column
TFORM8    =  'I1      '            / 1-digit integer
TTYPE9    =  ' 85     '            / count in 10-km range class
TBCOL9    =                    26  / starting column
TFORM9    =  'I2      '            / 2-digit integer
TTYPE10   =  ' 95     '            / count in 10-km range class
TBCOL10   =                    29  / starting column
TFORM10   =  'I2      '            / 2-digit integer
TTYPE11   =  '105     '            / count in 10-km range class
TBCOL11   =                    32  / starting column
TFORM11   =  'I2      '            / 2-digit integer
TTYPE12   =  '115     '            / count in 10-km range class
TBCOL12   =                    35  / starting column
TFORM12   =  'I2      '            / 2-digit integer
TTYPE13   =  '125     '            / count in 10-km range class
TBCOL13   =                    38  / starting column
TFORM13   =  'I2      '            / 2-digit integer
TTYPE14   =  '135     '            / count in 10-km range class
TBCOL14   =                    41  / starting column
TFORM14   =  'I2      '            / 2-digit integer
TTYPE15   =  '145     '            / count in 10-km range class
TBCOL15   =                    44  / starting column
```

```
TFORM15  = 'I2      '          / 2-digit integer
TTYPE16  = '155     '          / count in 10-km range class
TBCOL16  =                  47 / starting column
TFORM16  = 'I2      '          / 2-digit integer
TTYPE17  = '165     '          / count in 10-km range class
TBCOL17  =                  50 / starting column
TFORM17  = 'I2      '          / 2-digit integer
TTYPE18  = '175     '          / count in 10-km range class
TBCOL18  =                  53 / starting column
TFORM18  = 'I2      '          / 2-digit integer
TTYPE19  = '185     '          / count in 10-km range class
TBCOL19  =                  56 / starting column
TFORM19  = 'I2      '          / 2-digit integer
TTYPE20  = '195     '          / count in 10-km range class
TBCOL20  =                  59 / starting column
TFORM20  = 'I2      '          / 2-digit integer
TTYPE21  = '205     '          / count in 10-km range class
TBCOL21  =                  62 / starting column
TFORM21  = 'I2      '          / 2-digit integer
TTYPE22  = '215     '          / count in 10-km range class
TBCOL22  =                  65 / starting column
TFORM22  = 'I2      '          / 2-digit integer
TTYPE23  = '225     '          / count in 10-km range class
TBCOL23  =                  68 / starting column
TFORM23  = 'I2      '          / 2-digit integer
TTYPE24  = '235     '          / count in 10-km range class
TBCOL24  =                  71 / starting column
TFORM24  = 'I2      '          / 2-digit integer
TTYPE25  = '245     '          / count in 10-km range class
TBCOL25  =                  74 / starting column
TFORM25  = 'I2      '          / 2-digit integer
TTYPE26  = '255     '          / count in 10-km range class
TBCOL26  =                  77 / starting column
TFORM26  = 'I2      '          / 2-digit integer
TTYPE27  = '265     '          / count in 10-km range class
TBCOL27  =                  80 / starting column
TFORM27  = 'I2      '          / 2-digit integer
TTYPE28  = '275     '          / count in 10-km range class
TBCOL28  =                  83 / starting column
TFORM28  = 'I2      '          / 2-digit integer
TTYPE29  = '285     '          / count in 10-km range class
TBCOL29  =                  86 / starting column
TFORM29  = 'I2      '          / 2-digit integer
TTYPE30  = '295     '          / count in 10-km range class
TBCOL30  =                  89 / starting column
TFORM30  = 'I2      '          / 2-digit integer
TTYPE31  = '305     '          / count in 10-km range class
TBCOL31  =                  92 / starting column
TFORM31  = 'I1      '          / 1-digit integer
TTYPE32  = '315     '          / count in 10-km range class
TBCOL32  =                  94 / starting column
TFORM32  = 'I1      '          / 1-digit integer
TTYPE33  = '325     '          / count in 10-km range class
TBCOL33  =                  96 / starting column
TFORM33  = 'I1      '          / 1-digit integer
TTYPE34  = '335     '          / count in 10-km range class
```

```
TBCOL34    =                   98   / starting column
TFORM34    =  'I1      '            / 1-digit integer
TTYPE35    =  '345     '            / count in 10-km range class
TBCOL35    =                  100   / starting column
TFORM35    =  'I1      '            / 1-digit integer
END
```

Appendix B. Visual Sites

Site	No.	Long. (deg, arcmin)	Lat. (deg, arcmin)	Elev. (m)
POTSDAM	102	13 01	52 23	34
RADEBEUL	103	13 38	51 06	180
ARNSTADT	104	10 54	50 48	
CARLSFELD	105	12 35	50 26	
BERLIN	106	13 34	52 25	
LIMBACH	107	12 46	50 50	
KARL-MARX-STADT 1	108	12 57	50 52	
WEISSWASSER	109	14 38	51 29	160
MARSASCALA	110	14 34	35 52	56
AROSIO	111	9 38	46 42	1500
DEMEN	112	11 26	53 23	
DRESDEN	113	13 48	50 58	
GOLM	114	12 57	52 24	35
KARL-MARX-STADT 2	115	12 54	50 48	250
SCHNEEBERG	116	12 38	50 36	
SOHLAND	117	14 25	51 01	
HAVDRUP	118	12 07	55 32	
KLOVBORG	119	9 28	55 55	
HADERSLEV	120	9 35	55 17	
CAMBRIDGE	121	357 39	51 45	
BOLY	122	18 32	45 52	128
BAJA	123	18 57	46 11	
FOT	124	19 12	47 39	
LAJOS FORRAS	125	19 00	47 45	550
SULYSAP	126	19 32	47 27	200
TATA	127	18 24	47 40	200
KAJDACS	128	18 37	46 34	
MEZOBERENY	129	21 00	46 48	
OROSHAZA	130	20 41	46 34	
VASAS	131	16 46	47 05	
ZALAEGERSZEG	132	16 50	46 50	
SATU-NOU	133	24 38	47 08	
TAMPERE	135	23 37	61 30	150
RAUMA	136	21 29	61 08	
PARTALANKOSKI	137	25 05	61 53	
HELSINKI	138	25 11	60 11	2
HEGGEDAL	139	10 24	59 47	
KONGSBERG	140	9 36	59 42	
VIBY	141	10 42	55 30	
RONNE	142	14 43	52 09	
BRONDBY	143	12 25	55 39	
ULM	144	10 02	48 27	

Appendix B. (continued)

Site	No.	Long. (deg, arcmin)	Lat. (deg, arcmin)	Elev. (m)
NEAR FISCHEN	145	10 13	47 29	
GROSS WOKERN	146	12 29	53 45	
PAPA	147	17 27	47 22	
GUSTROW	149	12 09	53 47	
BASDORF	150	13 27	52 43	50
CATANZARO	151	16 36	38 54	
COMO	152	9 3	45 49	
FGURA	153	14 31	35 52	47
ZURRIEG	154	14 25	35 51	30
MOSTA	155	14 26	35 54	
MSIDA	156	14 50	35 54	
ZAVADA	157	19 44	48 32	
VARTOVKA	158	19 09	48 43	
DELHI	201	77 20	28 40	
ARUYAMA	202	136 06	35 09	100
HOSHINOKITSUSASHITSU	203	141 08	39 28	71
MUROH-NARA	204	136 01	34 34	400
KINOE-CHO HIROSHIMA	205	132 55	34 13	2
MT. TSUKUBA	206	140 08	36 12	360
KANAYA TOYAMASHI	207	137 10	36 41	15
KITAJIMA TAINOHAMA	208	134 33	34 07	2
SAYAMA OBS.	209	139 28	35 51	46
KAWAUCHI KIRYU	210	139 20	36 10	55
MATSUE	211	133 07	35 26	
OHCHI-GUN	212	132 27	34 53	
KAWASAKI OBS.	213	135 23	34 23	75
KAWATANA	214	129 50	33 04	10
KAMI TOWN	215	134 53	35 06	
FUKUMITMACHI TOYA	216	136 54	36 33	72
KITAOJI OTSU	217	135 53	34 58	233
HIGASHI-SON, OKINAWA	218	128 13	26 38	100
SHIROYAMA	219	137 14	34 54	136
NEAR FUJINOMIYA	220	138 48	35 20	1455
CARTER OBS.	301	174 46	-41 17	
BROWN OWL OBS.	302	175 06	-41 06	140
MANA OBS.	303	174 52	-41 05	
GLENEAGLE	304	116 25	-32 20	
DRYANDRA	305	117 11	-32 49	
DARKES FOREST	306	150 50	-34 13	
BUNDABERG	307	152 21	-24 50	
KARNET	308	116 05	-32 31	
THORNLIE	309	115 58	-32 02	

Appendix B. (continued)

Site	No.	Long. (deg, arcmin)	Lat. (deg, arcmin)	Elev. (m)
BYFORD	310	116 01	-32 15	
BLACK BIRCH	311	173 48	-41 48	
AUCKLAND	312	174 47	-36 51	
GAWLER	314	138 45	-34 36	
KALAMUNDA	315	116 04	-31 59	
YORKRAKINE	316	117 35	-31 26	
BELMONT	317	151 35	-33 00	
BALLAJURA	318	115 50	-31 49	
RIVERVALE	319	115 56	-31 56	
ROLEYSTONE	320	116 05	-32 07	
GIDGEGANUP	321	116 17	-31 42	
BAROSSA VALLEY	322	138 56	-34 34	
COOTAMUNDRA	323	148 03	-34 41	
PAVAVTANANUI FIELD S	324	174 56	-41 08	
TOODYAY	325	116 28	-31 35	
JARRAHDALE	326	116 05	-32 20	
COLO	327	149 36	-31 55	
COONABARRAN	328	149 30	-31 06	
BROOME	329	122 12	-18 00	
PERTH	330	116 00	-32 00	
EWA BEACH	401	201 59	21 20	
BARBERS POINT	402	201 57	21 20	
KIPAPA GULOH	403	201 59	21 26	
PEARL HARBOR	404	202 05	21 25	
DALLAS	405	263 21	32 43	
MC KENDREE	406	283 22	38 47	
ROSEBURG	407	237 13	43 22	
WHITTAKER PEAK	408	241 18	34 34	914
SAN DIEGO	409	242 59	32 42	
NEAR BELLEFONTE	410	282 05	40 55	
NUGGET	411	247 26	53 08	
POLISH SETTLEMENT	413	247 11	53 53	
ELK ISLE	414	247 09	53 31	
HALIFAX	415	296 23	44 39	
VALSAYN	416	298 36	10 38	
SEBRING	417	278 40	27 20	
WORCESTER	418	285 16	42 35	640
WEAVERS NEEDLE	419	248 34	33 24	
PHILADELPHIA	420	284 51	39 56	
CLARION PA	421	280 37	42 12	460
MIQUELON	422	247 05	53 14	
WINNIPEG	423	262 36	49 54	232

Appendix B. (continued)

Site	No.	Long. (deg, arcmin)	Lat. (deg, arcmin)	Elev. (m)
ALPINE	424	243 22	32 50	885
CABRERA	425	249 03	31 19	1220
UPN	426	249 02	31 20	1240
LAIE	427	202 04	21 39	
PUNTA ARENAS	428	275 06	9 54	
FT. DAVIS	429	256 03	30 36	
LA SALLE STATE PARK	430	272 32	41 04	
BELO HORIZONTE	501	315 10	-20 43	997
PORTO ALEGRE 1	502	308 50	-29 55	4
PORTO ALEGRE 2	503	308 48	-30 03	4
PORTO ALEGRE 3	504	308 30	-30 14	200
LA PAZ 2	506	291 55	-16 32	3360
LA PAZ 1	507	291 52	-16 31	3580
BRAZILIA	508	312 20	-15 55	1100
ARAMBARE	509	308 30	-30 55	
PORTO ALEGRE 4	510	308 33	-30 55	
PORTO ALEGRE 5	511	309 00	-30 23	4
PORTO ALEGRE 6	512	308 51	-30 04	
IRAI	513	306 37	-27 21	522
PORTO ALEGRE 7	514	308 49	-30 05	295
PORTO ALEGRE 8	515	309 06	-29 51	30
PORTO ALEGRE 9	516	309 17	-30 12	15
FORTALEZA	517	321 00	-3 34	
SANTA ANA, TARIJA	518	295 29	-21 37	1900
VILLA ELISA	519	301 57	-34 50	20
ABAGAZA, ZARATE	520	300 58	-34 07	26
PORTO ALEGRE 10	521	309 52	-29 48	
PORTO ALEGRE 11	522	350 50	-30 03	6
PORTO ALEGRE 12	523	308 49	-30 05	
SAO PAOLO	524	313 17	-23 32	780

Appendix C. Visual Observers Listed Alphabetically

Observer	No.	Observer	No.
ABELA S.	222	DE ABREU E.R.	070
ADIB C.A.	158	DE ARAUJO L.	268
ALCARAZ D.	229	DECONINCK M.	013
ALDRICH P.T.	001	DIETEL F.	014
ALMEIDA L.D.	159	DOCKING G.	200
ANDERSON C.	003	DOHRMANN M.	192
ANDRESEN B.	002	DOMENY G.	130
ANTHONY D.	004	DOUGHTY S.	015
AOTA T.	185	DURHAM D.	016
AQUILINA J.	220	DYMOVA G.	213
ARAUJO P.	265	ESPINOZA E.	112
ARCE M.	233	EVANS S.	017
ARCE V.	234	FARKAS E.	082
ARLT R.	005	FERDINANDO D.	018
AZEVEDO C.	157	FETTIG S.	144
AZOFEIFA D.E.	246	FITZGERALD P.	019
BABNIC S.	208	FODOR A.	086
BALDACCHINO G.	091	FOLDESI F.	089
BALDAUF P.	094	FOLEY C.	240
BALL J.	198	FORTUNATO H.	272
BARATA P.	274	FROTA L.M.	116
BARKAT S.	006	FUJITA Y.	179
BARROW R.	148	FUNANO K.	190
BEAZLEY I.	250	GHISOLFI E.S.	201
BERKO E.	132	GILROY J.	021
BOSCHAT M.E.	147	GOLDSMITH J.	022
BROWN P.	261	GOODKNECHT R.	140
BURROWS J.	199	GOODMAN D.	023
BUSSON A.	110	GRAY M.	024
CAKE D.	007	GUHL K.	193
CARLOS F.	117	GYARMATI L.	084
CLARK M.	239	HAAGH N.	029
CLAY M.	008	HALMI G.	133
COCKERAM L.	009	HARADA S.	181
COCKERAM M.	010	HARNISCH T.	030
COMOS G.	210	HARVEY N.	224
COOK A.	145	HASHIMOTO T.	248
CORONEOS M.	228	HAYS R.	114
COWIE F.	196	HILLESTAD T.E.	031
CSABAI I.	127	HINTON C.	275
CZESCIK C.	011	HINZ W.	032
DALAVIA O.D.	152	HIRAGA E.	189
DARVANN T.	012	HIROE T.	176
DA SILVA L.A.	153	HOLLOSY T.	128

Appendix C. (continued)

Observer	No.	Observer	No.
HOTOKINEN	076	MITCHELL K.	258
INOUE M.	187	MONTEON R.	230
INOUE S.	186	MOORE R.	141
INWOOD N.	034	MORAIS D.	244
ITO O.	168	MORENO G.	270
JAASKELAINEN P.	071	MORITZ S.	097
JENKINSON C.	033	MORROW M.J.	041
KAALZ A.	095	MUDGE R.	255
KADLCIK M.	194	MULLER K.	042
KAWASAKI Y.	177	MUNOZ S.	107
KEIICHI F.	171	MUROTA M.	180
KERR S.	025	MUSCAT T.	221
KESZTHELYI S.	134	NATOLI C.	043
KITAHATA K.	184	NEGISHI M.	175
KNOEFEL A.	108	NELSON J.	257
KOCH B.	026	NERY M.D.	154
KOSCHACK R.	027	NETO V.F.	151
KRAWIETZ A.	098	NOLLE M.	044
KRISTENSEN G.M.	028	NOSAL I.	211
KUROKAWA T.	173	NOUSIAINEN M.	080
LAM H.	035	NUNES H.	271
LEPORI B.	216	OCENAS D.	204
LEVAI R.	069	OCHIAI T.	174
LINKE P.	202	OKA Y.	188
LOCKHART J.A.	149	OLESEN J.O.	045
LOHVINENKO T.W.	195	OLSSEN S.	264
LOWE D.	036	OTTO F.	096
LUNSFORD R.	146	PAGE B.	263
MACAULEY B.	037	PARADOWSKI M.	115
MACHADO L.A.	245	PARKER J.	047
MAKELA V.	075	PATAK A.	135
MALONE J.	238	PAYNE J.	262
MARAZITI A.	218	PEDERSEN V.T.	121
MARTIKAINEN M.	079	POSZTOBANY K.	087
MARUYAMA T.	172	PRICE R.	243
MATSUOKA K.	183	QUAN H.	048
MCATEE W.	241	RADANOVIC V.	259
MCKINLAY G.	038	RAJALA R.	073
MCLOUGHLAN R.	242	RAMBERG P.	074
MCMULLEN M.	039	RANNERIES	122
MELANDRI F.	040	RAPAVY P.	205
MELGAREJO M.	120	RAPHAEL W.	235
MEOLI F.	215	RASMUSSEN A.	123
MERING G.	203	RAVISCH I.	106

Observer	No.	Observer	No.
RAWLINGS P.	049	SWANN D.	059
RENDTEL I.	050	SWAVELY M.	160
RENDTEL J.	051	SZABO J.	212
RENNER G.K.	155	SZABO S.	125
RIDDLE D.	052	TABORI S.	136
RITZL F.	126	TACHIHARA Y.	182
ROBLER S.	273	TAIBI R.J.	060
ROCHA E.	267	TAKACS R.	209
RODRIGUEZ G.	231	TAME J.	061
ROLDAN R.	232	TARNAY K.	129
RUDD I.	251	TEPEL S.	105
RUTLEY J.	260	TEPLICZKY I.	081
SAARENPURO M.	072	TIZZARD K.	249
SAJTZ A.	137	TOMIHIRO H.	170
SAKATA Y.	191	TOTH J.	131
SALAS J.	138	TREASSURE M.	197
SALM H.R.	053	TRINH N.	227
SANCHEZ A.	236	UEDA K.	247
SANTANA E.	266	UEDA M.	169
SASSI A.	217	VALDENASSI E.	062
SCHEMBRI A.	092	VALJUS P.	077
SCHREYER T.	103	VELLA I.	093
SCHROETER T.	104	VENTURA F.	090
SCHUTT S.	254	VILLA R.	237
SCLOVSKY L.	156	WAKE S.	166
SEARS K.	142	WATERS B.	139
SEARS P.	143	WHITNEY A.	063
SEIFERT H.	102	WHITNEY J.	064
SEIPELT H.	109	WIBLIN B.	065
SENTDORDIOVA I.	214	WIRTANEN P.	078
SHANKLIN J.	124	WITZSCHEL H.	101
SHAVER J.	150	WITZSCHEL S.	099
SHEPHERD A.	054	WOOD J.	066
SHIBU Y.	118	YABU Y.	167
SIMPSON D.	253	YAKIWARA H.	178
SINGH B.	119	YAMAGUCHI W.	111
SKJAERAABEN O.	055	ZALCIK M.	067
SOMMER C.	269	ZALLES R.	113
SPANYI P.	085	ZIMNIKOVAL P.	207
STACEY P.	056	ZNASIK M.	206
STEPHAN C.	057	ZSCHOCHE M.	100
SULE G.	083	ZUTHER O.	068
SULLIVAN S.	058		

Appendix D. Visual Observers Listed by Identification Number

Observer	No.	Observer	No.
ALDRICH P.T.	001	PARKER J.	047
ANDRESEN B.	002	QUAN H.	048
ANDERSON C.	003	RAWLINGS P.	049
ANTHONY D.	004	RENDTEL I.	050
ARLT R.	005	RENDTEL J.	051
BARKAT S.	006	RIDDLE D.	052
CAKE D.	007	SALM H.R.	053
CLAY M.	008	SHEPHERD A.	054
COCKERAM L.	009	SKJAERAABEN O.	055
COCKERAM M.	010	STACEY P.	056
CZESCIK C.	011	STEPHAN C.	057
DARVANN T.	012	SULLIVAN S.	058
DECONINCK M.	013	SWANN D.	059
DIETEL F.	014	TAIBI R.J.	060
DOUGHTY S.	015	TAME J.	061
DURHAM D.	016	VALDENASSI E.	062
EVANS S.	017	WHITNEY A.	063
FERDINANDO D.	018	WHITNEY J.	064
FITZGERALD P.	019	WIBLIN B.	065
GILROY J.	021	WOOD J.	066
GOLDSMITH J.	022	ZALCIK M.	067
GOODMAN D.	023	ZUTHER O.	068
GRAY M.	024	LEVAI R.	069
KERR S.	025	DE ABREU E.R.	070
KOCH B.	026	JAASKELAINEN P.	071
KOSCHACK R.	027	SAARENPURO M.	072
KRISTENSEN G.M.	028	RAJALA R.	073
HAAGH N.	029	RAMBERG P.	074
HARNISCH T.	030	MAKELA V.	075
HILLESTAD T.E.	031	HOTOKINEN	076
HINZ W.	032	VALJUS P.	077
JENKINSON C.	033	WIRTANEN P.	078
INWOOD N.	034	MARTIKAINEN M.	079
LAM H.	035	NOUSIAINEN M.	080
LOWE D.	036	TEPLICZKY I.	081
MACAULEY B.	037	FARKAS E.	082
MCKINLAY G.	038	SULE G.	083
MCMULLEN M.	039	GYARMATI L.	084
MELANDRI F.	040	SPANYI P.	085
MORROW M.J.	041	FODOR A.	086
MULLER K.	042	POSZTOBANY K.	087
NATOLI C.	043	FOLDESI F.	089
NOLLE M.	044	VENTURA F.	090
OLESEN J.O.	045	BALDACCHINO G.	091

Appendix D. (continued)

Observer	No.	Observer	No.
SCHEMBRI A.	092	TABORI S.	136
VELLA I.	093	SAJTZ A.	137
BALDAUF P.	094	SALAS J.	138
KAALZ A.	095	WATERS B.	139
OTTO F.	096	GOODKNECHT R.	140
MORITZ S.	097	MOORE R.	141
KRAWIETZ A.	098	SEARS K.	142
WITZSCHEL S.	099	SEARS P.	143
ZSCHOCHE M.	100	FETTIG S.	144
WITZSCHEL H.	101	COOK A.	145
SEIFERT H.	102	LUNSFORD R.	146
SCHREYER T.	103	BOSCHAT M.E.	147
SCHROETER T.	104	BARROW R.	148
TEPEL S.	105	LOCKHART J.A.	149
RAVISCH I.	106	SHAVER J.	150
MUNOZ S.	107	NETO V.F.	151
KNOEFEL A.	108	DALAVIA O.D.	152
SEIPELT H.	109	DA SILVA L.A.	153
BUSSON A.	110	NERY M.D.	154
YAMAGUCHI W.	111	RENNER G.K.	155
ESPINOZA E.	112	SCLOVSKY L.	156
ZALLES R.	113	AZEVEDO C.	157
HAYS R.	114	ADIB C.A.	158
PARADOWSKI M.	115	ALMEIDA L.D.	159
FROTA L.M.	116	SWAVELY M.	160
CARLOS F.	117	WAKE S.	166
SHIBU Y.	118	YABU Y.	167
SINGH B.	119	ITO O.	168
MELGAREJO M.	120	UEDA M.	169
PEDERSEN V.T.	121	TOMIHIRO H.	170
RANNERIES	122	KEIICHI F.	171
RASMUSSEN A.	123	MARUYAMA T.	172
SHANKLIN J.	124	KUROKAWA T.	173
SZABO S.	125	OCHIAI T.	174
RITZL F.	126	NEGISHI M.	175
CSABAI I.	127	HIROE T.	176
HOLLOSY T.	128	KAWASAKI Y.	177
TARNAY K.	129	YAKIWARA H.	178
DOMENY G.	130	FUJITA Y.	179
TOTH J.	131	MUROTA M.	180
BERKO E.	132	HARADA S.	181
HALMI G.	133	TACHIHARA Y.	182
KESZTHELYI S.	134	MATSUOKA K.	183
PATAK A.	135	KITAHATA K.	184

Appendix D. (continued)

Observer	No.	Observer	No.
AOTA T.	185	ROLDAN R.	232
INOUE S.	186	ARCE M.	233
INOUE M.	187	ARCE V.	234
OKA Y.	188	RAPHAEL W.	235
HIRAGA E.	189	SANCHEZ A.	236
FUNANO K.	190	VILLA R.	237
SAKATA Y.	191	MALONE J.	238
DOHRMANN M.	192	CLARK M.	239
GUHL K.	193	FOLEY C.	240
KADLCIK M.	194	MCATEE W.	241
LOHVINENKO T.W.	195	MCLOUGHLAN R.	242
COWIE F.	196	PRICE R.	243
TREASSURE M.	197	MORAIS D.	244
BALL J.	198	MACHADO L.A.	245
BURROWS J.	199	AZOFEIFA D.E.	246
DOCKING G.	200	UEDA K.	247
GHISOLFI E.S.	201	HASHIMOTO T.	248
LINKE P.	202	TIZZARD K.	249
MERING G.	203	BEAZLEY I.	250
OCENAS D.	204	RUDD I.	251
RAPAVY P.	205	SIMPSON D.	253
ZNASIK M.	206	SCHUTT S.	254
ZIMNIKOVAL P.	207	MUDGE R.	255
BABNIC S.	208	NELSON J.	257
TAKACS R.	209	MITCHELL K.	258
COMOS G.	210	RADANOVIC V.	259
NOSAL I.	211	RUTLEY J.	260
SZABO J	212	BROWN P.	261
DYMOVA G.	213	PAYNE J.	262
SENTDORDIOVA I.	214	PAGE B.	263
MEOLI F.	215	OLSSEN S.	264
LEPORI B.	216	ARAUJO P.	265
SASSI A.	217	SANTANA E.	266
MARAZITI A.	218	ROCHA E.	267
AQUILINA J.	220	DE ARAUJO L.	268
MUSCAT T.	221	SOMMER C.	269
ABELA S.	222	MORENO G.	270
HARVEY N.	224	NUNES H.	271
TRINH N.	227	FORTUNATO H.	272
CORONEOS M.	228	ROBLER S.	273
ALCARAZ D.	229	BARATA P.	274
MONTEON R.	230	HINTON C.	275
RODRIGUEZ G.	231		

NEAR-NUCLEUS STUDIES NETWORK

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1. THE STUDY OF NEAR-NUCLEUS PHENOMENA

1.1. Goals

In the broadest sense, the goal of near-nucleus studies is to understand the processes taking place in the coma as they relate to the physical nature of the cometary nucleus. Assuming that the observed coma distribution results from the ejection of material from a possibly inhomogeneous, rotating nucleus, coma anisotropy can be used as a tracer of nucleus activity and motion. By measuring the motions of coma features and extrapolating back to the time of ejection, it is possible to locate the active areas on the nucleus and, by observing a sufficient number of features over time, to determine or constrain the nucleus rotational motion. Knowledge of the distribution and evolution of active areas may provide important clues about the internal structure of the nucleus and about the comet formation environment. To fulfill these goals for Comet Halley, the Near-Nucleus Studies Network (NNSN) was designed to obtain data on the spatial and temporal distribution of matter in the coma at the highest possible resolution, especially during the period of maximum activity in 1985–1986.

1.2. Historical Perspective

When the International Halley Watch (IHW) was formed, cometary near-nucleus study was an immature field with little quantitative foundation, based largely on descriptive reports of primarily visual observations of coma morphology. One of the most extensive of these reports was Bobrovnikoff's (1931) monograph on the 1910 apparition of Comet Halley. The potential of such studies was underscored with the publication of the Atlas of Cometary Forms by Rahe et al. (1969), which illustrated some of the interesting coma patterns in Comet Halley observed over the previous two apparitions. The application of modern photographic emulsions in recording the spectacular spiral jets in Comet Bennett (1970 II) (Larson and Minton 1972), the analysis by Whipple (1978, 1980) of expanding halos to estimate nucleus rotation periods, and the quantitative modeling by Sekanina (1979,1981a, 1981b) of fans and jets provided further justification for a dedicated network to observe the expected changing coma pattern of Comet Halley. From the onset, it was clear that the NNSN strategy for obtaining data would be similar to that of the Large-Scale Phenomena Network (LSPN), but that details, such as optimum detectors, plate scales, temporal coverage, and acquisition of telescope time, needed to be defined.

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2. STRUCTURE AND FORMATION OF THE NEAR-NUCLEUS STUDIES NETWORK

2.1. Organization

The Discipline Specialists (DSs) selected to manage the western and eastern hemisphere efforts for the NNSN were Zdenek Sekanina (Jet Propulsion Laboratory [JPL], California Institute of Technology, Pasadena, California, U.S.A.) and Jürgen Rahe (Dr. Remeis Sternwarte, Bamberg, F.R.G.), respectively. Stephen M. Larson (Lunar and Planetary Laboratory [LPL], University of Arizona, Tucson, Arizona, U.S.A.) was selected to be a Deputy DS to assist Sekanina, but after the first year, Larson was appointed to be a DS. Because of the extent of Rahe's responsibilities as co-leader of the IHW, as DS of the LSPN, and in his position at National Aeronautics and Space Administration (NASA) Headquarters and of Sekanina's responsibilities as Archive Editor and co-investigator on two Giotto experiments, it was decided that Larson would carry out the NNSN's day-to-day tasks, at LPL. There, J. Gotobed initially provided volunteer computer and programming assistance, N. Connaro supplied part-time clerical and data input assistance, and B. Smith (LPL) and R. Lynds (National Optical Astronomy Observatories [NOAO]) made available, on a limited basis, the Space Telescope Wide Field/Planetary Telescope DEC VAX-780 computer housed in the Tucson NOAO offices. In mid-1985, D. Levy was hired part-time to assist with all NNSN activities. With the influx of data, part-time undergraduate students assisted in various times with the archiving: S. Movafagh wrote and integrated archiving software, and M. Guengerich and M. Garlick assisted in the tedious data input and tape handling chores. Table I lists the NNSN personnel.

2.2. Recruiting

The effort to recruit observers started in mid-1982 with the first NNSN Circular letter. Over the next two years, more than 200 responses, ranging from general interest to specific plans to monitor Comet Halley, were received from 50 countries. The second mailing included a questionnaire inquiring about anticipated observing plans and equipment and a detailed technical note on imaging techniques and standardization. The evolving mailing list remained at about 250 through 1986, with the understanding that fewer than half of these people were potential contributors. Subsequent NNSN Circulars were issued about every six months and contained general information on the behavior of P/Halley, news of the trial run on P/Crommelin, information about the P/Giacobini-Zinner Watch, technical notes about imaging techniques, ephemeris information supplied by D.K. Yeomans, and the results of our study of the 1910 photographs of P/Halley (see Section 2.3). We also provided information of a somewhat more general nature to the IHW newsletters published and distributed by the Lead Center at JPL. We tried to respond rapidly to individual inquiries, which usually dealt with details of observing techniques.

2.3. Study of the Photographs of Comet Halley From 1910

In 1983, Sekanina and Larson initiated a study of the high-resolution photographs of P/Halley taken in 1910. The aims were:

Table I. Discipline Specialist Team of the Near-Nucleus Studies Network

Team Member	Affiliation	Responsibility
Stephen M. Larson	Lunar and Planetary Laboratory University of Arizona Tucson, Arizona 85721 U.S.A.	Discipline Specialist
Zdenek Sekanina	Earth and Space Sciences Division Jet Propulsion Laboratory California Institute of Technology Pasadena, California 91109 U.S.A.	Discipline Specialist
Jürgen Rahe	Dr. Remeis Sternwarte Universitat Nurnberg-Erlangen D-8600 Bamberg Federal Republic of Germany	Discipline Specialist
David H. Levy	Lunar and Planetary Laboratory University of Arizona Tucson, Arizona 85721 U.S.A.	Assistant Discipline Specialist 1985–1989
Marilyn Guengerich	Lunar and Planetary Laboratory University of Arizona Tucson, Arizona 85721 U.S.A.	Archiving Assistant 1988–1989
Shahin Movafagh	Lunar and Planetary Laboratory University of Arizona Tucson, Arizona 85721 U.S.A.	Programmer 1988–1989

(1) To develop image-processing methods for enhancing the low-contrast coma features and for measuring them more reliably.
(2) To characterize the time scale of changes in the features.
(3) To better understand the coma pattern evolution.
(4) To quantitatively study processes of coma pattern formation.
(5) To investigate the predictability of jets to aid the flight projects.
(6) To provide a basis for more intelligent design of ground-based imaging experiments.

The first result was a new image-processing algorithm designed to enhance density discontinuities in radial outflow from a rotating nucleus (Larson and Sekanina 1984). The enhanced images made it possible to identify and measure discrete jets evolving into expanding envelopes over several days, which enabled quantitative particle trajectory modeling using the code developed by Sekanina during previous years. It was then possible to find a self-consistent model for the ejection of dust from discrete sources on the sunward side of the rotating nucleus under the influence of solar radiation pressure (Sekanina and Larson 1984). The additional images (Larson and Sekanina 1985) and further modeling (Sekanina and Larson 1986) resulted in a map of active areas on a spherical nucleus with a simple rotation period of 2.2 days. The limited number of images and short time span precluded determination of a unique spin vector solution, but established the fact (well before the spacecraft flybys) that most of the dust was ejected from discrete vents on the sunlit side of the nucleus.

The 1910 photographs revealed an emission phenomenon that produced spherical shells of gas and dust followed by an expanding tailward jet. From the June 2, 1910, event, the gas and dust expansion velocities were measured at 1.4 and 0.4 km/s, respectively. Giving the appearance of a bright, secondary (sometimes multiple) nucleus before extending tailward by solar radiation pressure, this type of phenomenon appears to differ from the usual sunward emission mechanism and is not yet understood.

The study of the 1910 photographs established the need for images at a rate of 2–3 per day for the major dust jets, and more if higher resolution showed smaller, overlapping jets. Ideally, the images needed to be scaled and exposed to resolve the nuclear condensation (defined by the terrestrial atmospheric seeing) and the outer envelopes up to some 100,000 km from the nucleus.

2.4. Standard International Astronomical Union (IAU) Cometary Filters for Imaging

Standard filters for isolating the principal cometary spectral emissions of CN, C_3, C_2, CO^+, H_2O^+, and three continuum bands in the visible region were defined by a special working group of Commission 15 at the IAU's Montreal meeting in 1979. These were selected as a means of determining production rates with standard-aperture photometers. The originally distributed 25-mm-diameter filters were too small and of questionable optical quality to be used for imaging studies of the spatial distribution of the gas coma species. With support from the Lead Center, an order was placed for 15 sets of 38-mm-diameter optical-quality filters that would be purchased or borrowed by observers. The transmission specifications were identical to those of the photometric filters (see the discussion and curves in the Photometry and Polarimetry Network chapter), the filters all had the same optical thickness (no refocusing for achromatic input), and the size was a compromise between detector size (field) and cost. After much delay in delivery from the manufacturers, all the filters were traced in Tucson to confirm their blocking and bandpass characteristics, then distributed to the groups requesting them in 1984. These filters proved valuable for those observers having good tracking capability over the long exposures needed to produce adequate signal.

2.5. Interaction With the Flight Projects

The Inter-Agency Consultative Group (IACG) was formed to create a mechanism for coordination between the several flight projects to maximize the science return (Reinhard 1986). The IACG consisted of delegations from the European Space Agency (ESA) (the Giotto spacecraft), Intercosmos (the two VEGA spacecraft), the Institute of Space and Astronautical Science (ISAS) (the Sakigake and Suisei spacecraft), NASA (the International Cometary Explorer [ICE] spacecraft), and the IHW. The flight projects needed as much near-real-time ground-based input as possible, especially from the Astrometry Network as part of the Pathfinder Project for spacecraft targeting (see the Astrometry Network chapter). A subgroup (which included R.L. Newburn, Z. Sekanina, J. Rahe, and D.K. Yeomans of the IHW) worked on modeling the cometary dust environment that the spacecraft would fly through (Divine et al. 1986). By 1984, it became clear that the NNSN dust jet study might help provide information on dust jet configurations and the dust impact hazard, and S.M. Larson was added to the IHW delegation to brief the IACG on our study of the 1910 photographs and to explore the possibility of providing the flight projects with real-time data on the locations of dust jets. A computer link was established between Tucson and the European Space Operations Center (ESOC), and a format for data transmission was established to allow ESA and Intercosmos to predict the location of jets during the flybys, given jet source locations derived from ground-based images. The concept proved overly optimistic, considering that our understanding of the spin vector was limited and that the mechanism for rapid image transmission, enhancement, measurement, and analysis required much more time and many more resources than were available. Such information might not have influenced the flight profile, given the high encounter velocity and short encounter time, but it would have been useful in helping interpret the spacecraft data. The most that could be provided was a correct qualitative prediction of relative jet activity during the three encounters, given the roughly two-day cycle of activity observed at the Boyden Observatory two weeks before the VEGA-1 encounter. Despite only limited input by the NNSN, the IACG experience represented a milestone in international cooperation and data exchange on many levels and helped usher in a new era of openness. This spin-off may, in the long run, become recognized as one of the most meaningful benefits of this return of Comet Halley.

3. NNSN DATA PROCESSING

The primary goal of the archiving task was to make sure that all the necessary data were accurately included with the images as Flexible Image Transport System (FITS) headers in the form prescribed by the Lead Center. Image array data have always presented special problems due to their sheer volume, which must be reduced to one form or another. Most first-time charge-coupled device (CCD) observers found themselves overwhelmed with the flat-field and photometric reduction tasks. The result of underestimating the problem caused most of the data to be submitted near the deadline, without the prescribed headers, and without photometric calibration in most cases.

3.1. Data Requirements

We requested that observers send their data in the FITS format, with additional header keywords specific to NNSN data. In practice, less than 20% of ob servers were able to generate the full NNSN headers; many images were submitted in unusual formats produced by local image-processing packages. Likewise, we requested 16-bit integer data, but often received 32-bit integer and 32-bit real data numbers. Most of our original requests stemmed from our own specialized and limited image-handling software, which was later replaced by more general software. Although photometric calibration was encouraged, it was not a requirement.

3.2. Data Flow

After much experimentation and many false starts, we adopted the following data-handling procedure, much of which was dictated by available hardware. Upon receiving a tape, we opened a folder to hold correspondence and any accompanying hardcopy. The data set was entered on a job status board that included boxes that would be checked off at appropriate milestones. The tape was then read into the Space Telescope's VAX-780 computer at NOAO using the program DOMAIN, and each image was inspected, selected, and graded; had its orientation determined; and had its comet maximum and sky background level measured. At LPL, permanent file numbers and system codes were assigned to the images selected for inclusion in the archive. Unique system codes were entered in a file for all combinations of data related to the observatory, telescope, detector, array size, filter, and observers. This minimized the times these data had to be entered for each of 250 configurations used. The file number, date, time (either beginning or mid-time), system code, exposure, filter, observer(s), orientation, quality, comet maximum, sky background, and comments were then entered into the INFORMIX database program in a Charles River Data Systems Computer. The database program had 50 fields per record, including all of the FITS keyword entries. After all of the entries for a data set were in the database, a chronological report was written with the most critical entries arranged on one line for easy proofreading. After proofreading, a program was run that searched by file number and utilized the database entries and system code file to run D.K. Yeomans' two-body comet ephemeris generating program to calculate the location of the comet and the airmass using the observatory coordinates. The program used the osculating elements most appropriate for the time of observation and placed the selected computed values in the remaining database fields. The program also ran an error check on the few redundant entries in the system code file and the database. With the database fields completed, a report was written that had the precise form of the required headers. The headers were then printed out and proofread before being transmitted by modem (twice for error checking) to the VAX and combined with the renamed images for transmission on magnetic tape to JPL. This seemingly orderly procedure was usually interrupted by the need to obtain some missing information from the observers or to manage limited disc space. The adopted procedure was in place and operational only during the last year, when all of the images were prepared for the archive. Previous attempts to edit headers were simply not accurate enough, and program debugging took much of one year prior to the final production run.

3.3. Data Selection

The NNSN data are of uneven quality for many possible reasons, and substandard images were often included when no other data existed. The rationalization for including substandard images is that it may be possible, with future sophisticated image reconstruction software, to compensate for imperfect focus or guiding that currently limit the value of these images. It was felt that a present-day archivist cannot accurately predict what data may be useful in the future as far as the next apparition of Comet Halley. In some cases, the images are very weak, but these were usually the only narrowband images available. In most cases, information on identified defects is included in the header comments. Discussion of the quality ratings can be found in Section 7.1.

4. THE CONTRIBUTED DATA

Correspondence indicated the existence of about 4000 images that might qualify for the archive, and about 3700 were received. Most observers had done a good job of filtering out the unusable data, and 3540 images were cataloged and reformatted for the archive. Digital CCD images comprise 98% of the collection. Many observers, faced with the task of flat-fielding large numbers of CCD images for the first time, submitted images up until the deadline. With the exception of 65 photographs digitized at the NNSN Center, only reduced data were accepted. It was assumed that the observers were the best qualified and equipped properly to flat-field their images. Improved detectors, more telescopes, and dedicated observers overcame the poor observing circumstances of Comet Halley's 1986 apparition to obtain some truly remarkable images that show much finer detail than the best images taken during the very favorable 1910 apparition. This, and the fact that there is nearly continuous coverage for 2 months both pre- and post-perihelion, provides an unprecedented data set for the study of near-nucleus phenomena for any comet.

It should be noted that the jet structure is typically of low contrast superimposed on a steep intensity gradient radial to the central condensation, and as such, spatial filtering algorithms usually must be applied to enhance the visibility of these features. A number of image-processing packages in use have adequate utilities to enhance the digital images in this archive.

4.1. Time Distribution of Images

The Halley Archive contains 3540 NNSN images, which range in time from recovery in 1982 through the 1989 observing season. The number of images is near the middle of our range of early estimates. The majority of images (about three-quarters) were taken from mid-October 1985 through May 1986, during the period of major jet activity, when the comet was within 2 AU of the Sun. The coverage (see Table II) was excellent during the spacecraft encounters. There are some gaps during full-moon periods pre-perihelion, as well as during the solar conjunction from January 29 through February 27, 1986.

Table II. Daily Number of NNSN Images From October 18, 1985 to May 18, 1986

Day of month	1985 Oct.	Nov.	Dec.	1986 Jan.	Feb.	Mar.	Apr.	May	Day of month
1		3	2	0	0	19	20	21	1
2		4	2	26	0	0	8	19	2
3		11	1	11	0	18	16	4	3
4		4	2	44	0	26	21	6	4
5		0	2	29	0	23	35	4	5
6		0	0	38	0	40	52	13	6
7		4	20	36	0	41	30	20	7
8		5	17	50	0	52	11	18	8
9		5	12	11	0	29	22	11	9
10		20	10	6	0	12	15	7	10
11		11	12	23	0	45	19	0	11
12		10	61	6	0	40	16	2	12
13		9	5	28	0	49	3	0	13
14		24	17	5	0	32	33	8	14
15		2	23	0	0	12	41	4	15
16		12	15	5	0	5	29	3	16
17		5	10	11	0	9	21	16	17
18	15	53	2	1	0	13	13	10	18
19	16	7	4	8	0	6	15		19
20	4	7	25	7	0	6	5		20
21	2	36	7	1	0	16	7		21
22	18	1	5	2	0	26	14		22
23	15	1	1	2	0	55	34		23
24	14	1	5	1	0	23	20		24
25	0	0	2	1	0	31	9		25
26	0	0	9	1	0	9	19		26
27	0	0	5	0	18	17	24		27
28	2	1	7	2	31	23	41		28
29	2	1	2	0		0	30		29
30	2	2	1	0		12	12		30
31	5		1	0		19			31

4.2. Source Distribution

Images obtained by 80 observers in 25 groups working at 23 observatories in 10 countries are represented in the archive (Table III). Several observers used equipment at more than one observatory during the apparition. Apertures from 0.3 to 5 meters were employed at most of the major observatories. The largest longitude gap was between the European and Chilean observatories.

Table III. Observatories and Observers Contributing to the NNSN IHW Archive

Observing Station			Elev.	Aper.	
E Long	Lat	Observatory	(m)	(m)	Observers
0244500	+414200	BNAO-ROZHEN	1750	0.7	SHKODROV,V/IVANOVA,V/BONEV,T/BELLAS,Y
0262418	-290218	BOYDEN OBS.	1378	1.5	TAPIA,S/SENAY,M/LARSON,S
0344548	+303548	WISE OBS.	900	1.0	SCARROTT,S/WARREN-SMITH,R
0691500	+381800	SANGLOK	2302	1.0	KISELEV,V/SIKLITSKY,V/CHERNOVA,G/AMIRKHANJAN,V
0724300	+243900	GURUSHIKAR OBS.	1700	0.4	CHANDRASEKHAR,T/DEBIPRESAD,C/ASHOK,N
1160806	-320029	PERTH OBSERVATORY	407	0.6	A'HEARN,M/HOBAN,S/BIRCH,P/CANDY,M/MARTIN,R
1310445	+311500	KAGOSHIMA SP. CTR.	228	0.6	TAKAGISHI,K/TOMITA,K/WATANABE,J/EIRAKU,M
1333606	+343426	OKAYAMA AST. OBS.	372	1.9	WATANABE,J/KAWAKAMI,H/KINOSHITA,H/NAKAMURA,T/NORIMOTO,Y/OKITA,K/SHIMIZU,M/TOMITA,K
1391141	+360021	DODAIRA AST. OBS.	879	0.9	WATANABE,J/AOKI,T/HIRAYAMA,T/KAWAKAMI,H/MURATA,Y/NAKAMURA,T
1393229	+354021	TOKYO AST. OBS.	59	0.7	HATANAKA,Y
1490358	-311637	ANGLO-AUSTRALIAN	1164	3.9	GREEN,S/HUGHES,D
1702754	-435915	MT. JOHN	1029	0.6	GILMORE,A
2043140	+194934	MAUNA KEA	4214	2.2	STORRS,A/BUIE,M/GOGUEN,B/CRUIKSHANK,D/LARK,N/HAMMEL,H/BELTON,M/MEECH,K/ALVAREZ,L
2043140	+194935	MAUNA KEA	4215	3.6	GOLDBERG,B/HALLIDAY,I/AIKMAN,C
2430810	+332122	PALOMAR	1706	5.1	JEWITT,D/DANIELSON,G
2430829	+332056	PALOMAR	1706	1.5	PORTER,A/SELMAN,I
2482006	+351214	LOWELL OBSERVATORY	2204	0.6	A'HEARN,M/HOBAN,S/WANG,Z/SCHLEICHER,D/FEIERBERG,M/LUTZ,B/SAMARASINHA,N

Table III. (continued)

Observing Station			Elev.	Aper.	
E Long	Lat	Observatory	(m)	(m)	Observers
2482408	+315729	KITT PEAK NATIONAL	2096	2.1	JEWITT,D/MEECH,K/BELTON,M/ALVAREZ,L/WEHINGER,P/MCCARTHY,D
2482402	+315750	KITT PEAK NATIONAL	2120	4.0	MEECH,K/JEWITT,D/DJORGOVSKY,S/SPINRAD,H/WILL,G/BELTON,M
2485940	+321248	TUMAMOC	0950	0.5	LEVY,D/LARSON,S/MAGEE,M
2491243	+322633	MT. LEMMON	2790	1.5	FINK,U/LEVY,D/WISNIEWSKI,W
2491605	+322501	CATALINA	2510	1.5	LARSON,S/LEVY,D/HOBAN,S/FINK,U/DISANTI,M/SCHULTZ,A/MARCIALIS,R/FINK,R
2885850	-325854	CERRO EL ROBLE	2220	0.7	TORRES,C
2891106	-300956	CERRO TOLOLO	2225	1.5	LARSON,S/TAPIA,S
2891106	-300956	CERRO TOLOLO	2225	1.5	MEECH,K/JEWITT,D
2891605	-291518	EUROPEAN SOUTHERN	2347	1.5	FRANDSEN,S/REIPURTH,B/GAMMELGAARD,F PEDERSEN,H/WEST,R/JOERGENSEN,H/KJAERGAARD,P/HAEFNER,O
2891802	-290023	U. TORONTO S. OBS.	2276	0.6	LARSON,S/TAPIA,S/SHELTON,I

5. IN RETROSPECT

The operation of the NNSN was an experiment in many ways. Vastly improved technology and communications since 1910 provided new tools as well as new challenges. The NNSN was started just as CCDs began replacing the photographic emulsion as the areal detector of choice in astronomy. Because of this changeover, it was difficult to predict and plan for the outcome. Most observers severely underestimated the time and effort needed to decalibrate their CCD images, and financial support diminished after the excitement of the flybys. The details of preparing the data for the archive changed many times during the course of the campaign, and most of it was learned and designed as we went. The trial runs were invaluable in providing experience with the new detectors at the telescopes, as well as demonstrating the inadequacies of our early concepts of data handling.

With the advantage of hindsight, it is probable that the IHW would have been more efficient over its lifetime if the networks could have used the same computer hardware and shared the same data-handling software developed by one group (say, at the Lead Center). As it was, the personnel of each network implemented their own systems to the same end, with considerable duplication of effort. On the other hand, such a strategy requires definitions of the needs well in advance and may restrict flexibility for later changes.

The NNSN solicited data from anyone who might have had the capability to acquire images, even as an adjunct to other programs, but a look at the statistics of the NNSN shows that the bulk of the data came from relatively few people using dedicated systems on moderate-aperture telescopes. The lesson may be that future imaging networks would best spend their resources contracting with a few observers who have easy access to telescopes and can dedicate more time to the task.

The Halley Archive does not contain all of the useful images available for near-nucleus studies, since some observers were not able to prepare their images by the time of our deadline. Had the NNSN continued for another year, perhaps 10%–15% more data could have been archived, and the data set still would not have been complete. A few years from now, future investigators may find that the NASA Planetary Data System contains additional Comet Halley images.

6. SCIENCE HIGHLIGHTS

The science results obtained from NNSN data are too numerous to summarize completely here, so we mention only a few of the highlights:

- Nucleus spin vector—The observed dust jet curvature indicates that the nucleus rotates in a prograde sense and that the sources have an instantaneous apparent period of around two days. The dust jet morphology repeats quite accurately with the 7.4-day light curve (Millis and Schleicher 1986; Larson and Sekanina 1987), indicating that the nucleus orientation in space repeats with that frequency. This implies complex rotation, for which a unique solution had not been identified as of December 1989.
- Dust jets—Measured outward projected velocities of dust in the jets range from 0.2 to 0.6 km/s (Larson et al. 1987). There is evidence for variable size distribution in the dust jets (Hoban et al. 1989).
- Gas jets—Discrete jets of gas (CN, C_2, and C_3) were observed for the first time in a comet (A'Hearn et al. 1986a, 1986b), but they do not correlate well with the dust jets (Larson et al. 1987; Larson and Sekanina 1987). The exact origin and mechanism of the gas jets are still debated (Larson 1988).
- Similarity with 1910—The type of coma morphology in 1910 and 1986 was very similar, including the straight "tailward" jets (Larson et al. 1987).

7. THE NNSN ARCHIVE

This section is intended to assist investigators in the use of the NNSN images contained in the archive by defining and explaining the network-specific FITS header keywords, index entries, and filter bandpasses, and any peculiarities in specific data sets. There is also information on known data sets that, for various reasons, could not be included in this archive.

The 3540 uncompressed NNSN images in the archive are arranged chronologically on the compact disc—read only memory (CD-ROM) discs, together with the other non-LSPN data, and are accessed as FITS files in the same manner as the other data on the discs. Each image is accompanied by a FITS header intended to provide nearly all of the information a user needs to know about the image. Every effort was made to ensure accuracy of the entries, but users are advised that the source of any apparent inconsistency should be investigated by them. Mistakes could have been made anywhere from the observers' logs through the NNSN database entry and even perhaps in the CD-ROM mastering process. The submitting institution and observer's names should allow users to track down and resolve apparent inconsistencies.

No calibration frames are included in the archive. Calibration information, such as step wedge input intensities and output counts, are included in the HISTORY or COMMENT lines. In some cases, there might be conversion factors from counts to magnitude or flux units. In other cases, total counts, times, and exposures of standard stars are given.

7.1. The NNSN FITS Header

The headers that accompany the images begin with the five mandatory FITS keywords plus 35 additional entries. Table IV lists the header keywords.

The 250 system codes are specific to any detector, array size, telescope, optical configuration, and filter, and are of the form 4NNNXXYY, where 4 denotes the NNSN, NNN is the IAU observatory code, XX is the telescope, and YY is the filter/scale/array size configuration. A list of observers is associated with each system code, so more than one observer group may share a system code.

The quality rating is only a rough, qualitative guide that includes the effects of seeing, focusing, guiding, the signal-to-noise ratio, and decalibration. The four rating categories are excellent, good, fair, and poor: "excellent" refers to images with no obvious flaws, and "poor" denotes images included only because of the lack of better ones on that day. The user will have to gain some experience to know what to expect from the different grades.

The airmass at mid-exposure (AIRM-MID) is calculated from current epoch topocentric comet coordinates (RA, DEC) and observatory coordinates (LONG, LAT) as:

```
AIRM-MID = sec Z - 0.0018167 (sec Z - 1) - 0.002875 (sec Z - 1)**2
           - 0.0008083 (sec Z - 1)**3,
```

where the zenith distance Z follows from:

```
sec Z = 1/[sin(LAT)*sin(DEC) + cos(LAT)*cos(DEC)*cos(local hour angle)].
```

Table IV. The NNSN Header Keywords

Keyword		Content	
SIMPLE	=	T	/T conforms to standard FITS format
BITPIX	=	16	/16 (or 32)-bit data
NAXIS	=	2	/number of axes in array
NAXIS1	=	_____	/number of pixels in X axis (samples)
NAXIS2	=	_____	/number of pixels in Y axis (rows)
OBJECT	=	'P/HALLEY'	/object name
FILE-NUM	=	4_____	/file number
DATE-OBS	=	'__/__/__'	/mid-UT date of observation (dy/mo/yr)
TIME-OBS	=	.______	/mid-UT decimal part of day
DATE-REL	=	'__/__/__'	/date released to archive (dy/mo/yr)
DISCIPLN	=	'NEAR NUCLEUS'	/IHW network
LONG-OBS	=	'___/__/__'	/observatory east longitude (deg/min/sec)
LAT--OBS	=	'___/__/__'	/observatory latitude (+-deg/min/sec)
SYSTEM	=	'4________'	/observing system code
OBSERVER	=	'__________________'	/observer's names (see ADD. OBS.:in COMMENT)
SUBMITTR	=	'__________________'	/submitter's names
SPEC-EVT	=	_	/T if jets present (10/85-6/86)
DAT-FORM	=	'STANDARD'	/type of data
OBSVTORY	=	'__________________'	/observatory name
ELEV-OBS	=	____	/elevation of observatory in meters
TELESCOP	=	'__________________'	/telescope used
APERTURE	=	_.__	/telescope aperture in meters
TELEFL	=	_.___	/effective focal length in meters
PLTSCALE	=	__.__	/plate scale in arcsec per mm
CROTA1	=	___._	/position angle of sample axis, north -> east
SENSE	=	_	/PA counterclockwise (T) or clockwise (F)
DETECTOR	=	'__________________'	/detector used
DIGITIZE	=	'__________________'	/type of digitizer used if not detector
APSIZE	=	_.___	/original pixel size of detector/digitizer
FILTER	=	'______ '	/filter used (see Table VI)
EXPOSURE	=	____._	/exposure duration in seconds
AIRM-MID	=	_.___	/calculated airmass at mid-exposure
QUALITY	=	'__________'	/general quality of image
DATE-WRT	=	'__/__/__'	/date this file written
ORIGIN	=	'__________________'	/institution sending data to NNSN
BUNIT	=	'__________________'	/intensity units (note that BSCALE=1, BZERO=0)
COMETMAX	=	______	/approximate maximum value in comet image
SKYMIN	=	______	/approximate background sky brightness
COMMENT	(a y comments relating to the contents of the image and additional observers)		
HISTORY	(any comments relating to the reduction process)		
END			

The airmass at the zenith is 1, so it does not include a correction for the local elevation. Also note that there is no correction for apparent and true zenith distance.

7.2. NNSN Index Entries

For each image in the digital archive, there is an entry in the NNSN index that includes useful information the users will need in order to determine if that image may satisfy their needs. All items are derived from the NNSN extended FITS headers. Each entry item is described in Table V.

Table V. List of Index Entries

Heading	Description
Date(UT)	Date (day and fraction of day) of middle of observation
NNSN#	Near-Nucleus Studies Network file number
Filter	Filter used (see Table VI)
Detector	Detector used
Field	Angular field of axes (arcminutes) derived from the array size and the plate scale. The field may actually be smaller due to field stops or vignetting.
PAX	Position angle (N through E) of NAXIS1 (degrees)
ExpS	Exposure duration (seconds)
Pixl	Angular scale of picture element (arcseconds)
Ap	Telescope aperture size (meters)
Scale	Effective plate scale at the detector (arcseconds per millimeter)
System	Observing system code (see Section 7.1)
Observer(s)	Name(s) of the observer(s)
Notes	Notes from HISTORY or COMMENT keywords, footnotes

7.3. Printed Archive Images

The printed archive contains one representative halftone image every few days to give the user a general idea of the appearance of the comet. The images are reproduced with the same orientation (north up, east to the left) and have a scale of 150,000 km per (75mm) side during the interval of November 1, 1985, to May 1, 1986, and 2 arcmin per side at other times. This allows more convenient comparison of coma size and structure during the more active period, while providing better visibility of the faint images when the comet was farther from the Sun. To permit greater visibility of the near-nucleus region as well as some of the outer coma, the base 10 logarithm of the counts is displayed. The final prints have similar densities and contrasts to maximize visibility of the comet, but the halftone process may degrade the dynamic range further. For detailed study, the user should use images from the digital archive.

7.4. Filters

Table VI lists the filters used and their wavelengths at 50% (and, for some, also at 10%) of maximum transmission. These numbers do not take into account detector responses or atmospheric extinction. For more information on transmission characteristics, the observers should be contacted directly. There are five general categories of filters:

(1) Four standard broadband photometry filters sets are not specifically intended to isolate cometary emissions. During the period of maxi-

Table VI. Characteristics of Filters Used for NNSN Images

Category		Cut-On (nm)		Central Wavelength (nm)	Cut-Off (nm)	
IHW Name	Other Name	10%	50%		50%	10%
Standard Broadband						
B	Johnson B		386	440	494	
V	Johnson V		491	548	605	
R	Johnson R		585	650	715	
I	Johnson I		729	825	921	
Gunn G			458	493	528	
Gunn R			610	655	700	
Gunn I			690	780	880	
Mould B			386	442	498	
Mould V			501	546	591	
Mould R			585	647	708	
Mould I			732	829	927	
Cousins B			390	440	530	
Cousins V			500	550	600	
Cousins R			620	640	700	
Cousins I			700	790	900	
Wide B			400	450	500	
Wide R		550	560	-	-	-
Schott Glass						
GG7		475	460	-	-	-
GG11		420	480	-	-	-
GG13		440	490	-	-	-
GG455		450	455	-	-	-
GG495		490	495	-	-	-
OG530		525	530	-	-	-
RG1		600	610	-	-	-
RG610		600	610	-	-	-
RG665		660	665	-	-	-

Table VI (continued)

Category: IHW Name	Category: Other Name	Cut-On (nm): 10%	Cut-On (nm): 50%	Central Wavelength (nm)	Cut-Off (nm): 50%	Cut-Off (nm): 10%
IHW/IAU Comet Imaging						
309OH		305	306	309	313	314
365BC		360	362	365	368	370
387CN		384	386	387	390	401
406C3		401	402	406	409	410
426CO+		422	423	426	429	430
485MC		481	482	485	487	489
514C2		507	508	514	519	520
684RC		678	679	684	688	689
703H2O+		689	691	703	713	714
Giotto Multicolor Camera						
314OH	C10	293	295	298	323	336
408C3	C11	399	403	410	419	422
HMCB	C5	320	336	395	488	489
450BC	C8	441	443	453	457	458
509C	C12	499	502	511	520	524
HMCO	C4	578	585	652	702	714
731RC	C9	715	718	728	743	746
HMCR	B/C3	695	705	-	-	-
Special Bandpasses						
315OH			310	315	320	
457CO+			454	457	459	
598NH2			596	598	600	
600HN2			580	600	620	
619H2O+			617	619	621	
625CONT			624	625	625	
630OI			628	630	632	
630TLT			627	629	631	
H ALPHA			646	656	666	
701RC			691	701	711	
852CONT			826	852	878	
860CONT			854	860	866	
910CN			900	910	920	
918CN			912	918	924	

mum activity (January–April 1986), the dominant source was dust, but the V and B bands have sizable contributions from C_2 and CN emissions. Some filter data were obtained from Thuan and Gunn (1976) and from Bessell (1979).

(2) Schott glass filters were used primarily as short-wavelength cut-off filters. The table indicates the 10% and 50% cut-off wavelengths, while the effective peak and the long-wavelength cut-offs were defined by the detectors.

(3) IHW/IAU cometary filters are imaging-quality versions of the standard photometry bandpasses. The values in the table are the mean of all those measured and are correct to 1 nm. Further details can be found in the Photometry and Polarimetry Network chapter. Our IHW filter names are intended to indicate the effective peak wavelengths (in nm) and the emissions they should isolate. The continuum bands are indicated by BC (blue continuum), MC (mid-continuum), and RC (red continuum).

(4) Giotto Halley Multicolor Camera filters were used to provide ground-based calibration during the flyby. The filter characteristics are taken from Keller et al. (1982).

(5) Special bandpass filters are the remaining miscellaneous filters that observers usually selected to investigate special spectral features. A particularly useful example is the 619H2O+, which isolates the (0,8,0) emission of H_2O^+ and provides excellent images of the ion tail.

7.5. Notes on Specific Data Sets

Listed below are some features of some specific data sets that the user should be aware of.

The Wise Observatory polarization images of Eaton (402601-21) are broken into separate fields separated by blank spaces.

The COMETMAX and SKYMIN values for the images taken when Comet Halley was at large heliocentric distances (400001–012, 403801–950, 406001–124) are only guideline values to produce a good display, since the comet is sometimes only a few counts above the background.

The photographs from Mt. Johns Observatory and Cerro El Roble (402501–546, 402551–566) were digitized using an LPL CCD camera and macro lens adjusted to give an appropriate scale. When there is sensitometric calibration, the digitized step values and their relative input intensities are given in the header comments. The Cerro El Roble films had multiple exposures, so when there are two images per field, the time and exposure of the faintest image are given in the header comment. The user should be aware that there will be two sets of field stars in these images.

8. ADDITIONAL DATA SETS

Table VII lists the data sets that for various reasons do not appear in the archive, but that might be potentially useful for future near-nucleus studies. Some

Table VII. Data Sets Not Listed in the Archive

Institution	Observer	Observatory	Aperture (m)
Univ Beijing	Liu, Z.	Yunnan	1.0
Univ Calif	Spinrad, H., et al.	Lick	3.0, 0.5
Univ Catania	Cristaldi, S.	Catania Obs.	0.3
U Coll London	Rees, M., et al.	Table Mt (JPL)	0.6
Univ Hamburg	Kohoutek, L.	ESO	2.2
Klet	Mrkos, A.	Klet	0.6
Univ Kyoto	Akabane, T.	Hida	0.6
Univ Liege	Dossin, F., et al.	Haute-Provence	0.6
Notre Dame Univ	Rettig, T.	AAO	2.3
Meudon	Kohl, J., et al.	Haute-Provence	1.9
Meudon	Lecacheux, J., et al.	Pic-du-Midi	2.0
Osmania Univ	Kilambi, G., et al.	Japal	1.3
Univ Padova	Barbieri, C., et al.	Mt Ekar	1.8
SAAO	Mack, P., et al.	SAAO	1.9
Univ Texas	Barker, E., et al.	McDonald	2.1, 0.9
US Naval Obs	Luginbuhl, C., et al.	USNO Flagstaff	1.5

images in the Large-Scale Phenomena Network, digitized to about 4 arcseconds per pixel, might also be useful in studying evolved coma features.

9. ACKNOWLEDGMENTS

The contribution of the Near-Nucleus Studies Network to the Halley Archive was made possible by the many dedicated observers worldwide and their unselfish cooperation. Participation in the NNSN has been strictly voluntary. The results benefit cometary and space science and have helped foster international cooperation. We thank Ya. Yatskiv (Ukrainian Academy of Sciences) and I. Williams (Queen Mary College, University of London) for organizing and transmitting data from observers in their countries. We thank B.A. Smith (LPL) and R. Lynds (NOAO) for use of the Space Telescope's VAX-780 computer at NOAO. E. O'Neil (NOAO), S. Movafagh (LPL), and J. Gotobed (LPL) provided assistance with the VAX. M. Aronsson of the Lead Center provided helpful suggestions and assistance. M. Guengerich (LPL) did an extraordinary job with data entry in our database and constructing the FITS headers.

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PHOTOMETRY AND POLARIMETRY NETWORK

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1. INTRODUCTION AND PERSONAL VIEW OF THE NETWORK'S HISTORY

The Photometry and Polarimetry Network of the International Halley Watch (IHW) has been heavily influenced by my long-standing interest in coordinated narrowband photometry of comets. Many years ago, Bob Millis and I initiated a program of narrowband photometry to investigate chemical abundances in a large number of comets. We had already realized that narrowband photometry of comets was totally without standardization. Broadband photometry had been well standardized by the stellar photometrists, but was not very diagnostic for active comets. Some types of narrowband photometry had also been standardized by the stellar spectroscopists, but these systems were almost entirely useless for cometary purposes. Since very large discrepancies in the literature existed regarding the fluxes from comets, and since the results had been derived from a wide variety of techniques and using a variety of models of the emission, it was very difficult to disentangle the real variations from the variations due to technique. We recognized very early that studies of both the long-term and the short-term variability of comets would require data from more than one site, preferably in a common photometric system, and therefore we ordered several nominally identical sets of narrowband filters. We soon enlisted Peter Birch to carry out observations from the southern hemisphere to follow comets as they move from one hemisphere to the other. We used these filters to study a number of comets in the 1970s and published what we believe to be the largest systematic survey to that date of molecular abundances with a common technique (A'Hearn and Millis 1980). This program has continued to the present day and still provides a useful complement to the other major surveys carried out spectrophotometrically because the photometric technique has a much larger field of view than does the spectrophotometric technique. It was the recognition of the value of a coordinated program using the same filters at many sites, particularly for studying temporal variability, that led me to propose to the IHW that I be the Discipline Specialist for Photometry.

Prior to the IHW's creation, the need for a standardized system of filters had been recognized when Commission 15 of the International Astronomical Union (IAU), at the Montreal General Assembly in 1979, appointed a working group to establish a standardized system of filters and to seek funding to distribute standardized filters. I was the chairman of this Working Group and my subsequent co-Discipline Specialist in the IHW, V. Vanysek, was also a member of the Working Group. The Working Group established the desired characteristics of a preliminary set of filters and obtained funding from the U.S. National Science Foundation (NSF) to purchase the filters. At about this time, the IHW was created by the National Aeronautics and Space Administration (NASA) through the Jet Propulsion Laboratory (JPL) and, when I was selected as a Discipline Specialist for Photometry and Polarimetry, the two activities merged under the auspices of the IHW. The IHW also, of course, merged the activities in polarimetry and broadband photometry with those of narrowband photometry.

One of our early philosophical decisions regarding the approach was the one to use students for most of the data entry and data reduction work, and even for much of the programming, rather than hiring full-time personnel. Even the Assistant Discipline Specialist, who supervised the work of the students and dealt with the details of many of the technical issues that arose, was only a part-time employee of the IHW. There are some significant advantages to using students: they are relatively inexpensive to hire and one has the satisfaction of getting students involved in research, albeit at a limited level, at a very early stage in their careers. On the other hand, there is one significant disadvantage for a project, such as the IHW, that lasts much longer than the typical academic career of undergraduates and longer even than the careers of most graduate students: on[illegible]s to continuously train replacement students to do the routine tasks. Natu[illegible] with students, one also does not have the luxury of screening the applicants as thoroughly as one would screen applicants for a permanent job. This results in numerous highs and lows in the rate of progress and certainly kept the job of Discipline Specialist from being a dull one. All in all, I believe that this was the right decision, although it was certainly not the most efficient way to get the job done.

The personnel who worked directly for the network are all listed in Table I. Although it is a lengthy list, the only individuals, other than myself and my co-Discipline Specialist V. Vanysek, who were associated with the Photometry and Polarimetry Network throughout its existence were Maggie Berry, who provided all the secretarial and clerical support as well as much of the administrative support for the network, and Marek Wolf, who was the Assistant Discipline Specialist in Prague for the IHW's duration. All the other personnel either entered the project after it was well under way or left the project, either at the completion of their schooling or to take other jobs or for a variety of other reasons. Some were even 'stolen away' by other networks in the IHW when they graduated and wanted a 'real' job. Many of those who did leave happily returned on an occasional basis to clear up subsequent problems. It was fascinating working with this wide group of people with talents in many different areas.

In addition to the personnel who worked directly for the network, I would be remiss if I did not point out that several other individuals carried out programs specifically to benefit the network as a whole. This includes, in particular, Peter Birch and Hugo Moreno, both of whom, at our request, organized programs to establish the standard stars in the southern hemisphere. Several other individuals provided help in understanding and calibrating the narrowband filters, in providing both measurements of the transmission curves and spectra for use in calibrating the photometric system. These included personnel in the Chemistry Department at the University of Maryland, John Osantowski and Charlie Fleetwood at Goddard Space Flight Center (NASA/GSFC), and several observers in the network, particularly the group at McDonald Observatory. None of these individuals received any reimbursement from the IHW.

2. FILTERS FOR PHOTOMETRY AND POLARIMETRY

Within the Photometry and Polarimetry Network, we decided to encourage observers to use the existing broadband photometric systems when comets were in-

Table I. Discipline Specialist Team for the Photometry and Polarimetry Network

Team Member	Affiliation	Responsibility
Michael F. A'Hearn	Astronomy Program University of Maryland College Park, MD 20742 U.S.A.	Discipline Specialist
Vladimir Vanysek	Department of Astronomy Charles University CZ-15000 Prague 5 Czechoslovakia	Discipline Specialist
Humberto Campins	Astronomy Program University of Maryland	Assistant Discipline Specialist 1982–1984
Michael A. Feierberg	Astronomy Program University of Maryland	Assistant Discipline Specialist 1984–1986
Uri Carsenty	Astronomy Program University of Maryland	Assistant Discipline Specialist 1986–1989
Marek Wolf	Department of Astronomy Charles University	Assistant Discipline Specialist
Wayne Osborn	Physics Department Central Michigan University Mount Pleasant, MI 48859 U.S.A.	Standard Star Coordinator
David Edsall	Astronomy Program University of Maryland	Programmer
Jason Meyer	Astronomy Program University of Maryland	Programmer
Anne Raugh	Astronomy Program University of Maryland	Programmer
Donald Ingram	Astronomy Program University of Maryland	Technician
Edward Colon	Astronomy Program University of Maryland	Data Processing and Archiving Assistant

Table I. (continued)

Team Member	Affiliation	Responsibility
Clare Ewald	Astronomy Program University of Maryland	Data Processing and Archiving Assistant
John Macuk	Astronomy Program University of Maryland	Data Processing and Archiving Assistant
Mikail Shams	Astronomy Program University of Maryland	Data Processing and Archiving Assistant
Edith Stahl	Astronomy Program University of Maryland	Data Processing and Archiving Assistant
Lyla Taylor	Astronomy Program University of Maryland	Data Processing and Archiving Assistant
Melisa Walter	Astronomy Program University of Maryland	Data Processing and Archiving Assistant
Margaret S. Berry	Astronomy Program University of Maryland	Administrative and Secretarial Assistant

active, e.g., for studies of the 'bare' nucleus at large distances from the Sun and whenever the comets were so faint that every photon was needed. On the other hand, it was clear that polarimetric measurements, to be made primarily when the comet was active, would benefit considerably from using filters that cleanly separated emission bands from the continuum. For this reason, we decided that we would encourage the polarimetric observers to use the standard narrowband filters.

2.1. Broadband Filters

The broadband filters that were used by many observers were obtained by the individual observers, usually from locally available sets of filters in the standard photometric systems. The two standard photometric systems that were widely used were UBVRI and the v, g, r, and i filters of the Thuan-Gunn (1976) and Wade et al. (1979) systems. These two systems are indicated in the 'Filter' column of the data tables of the archive as U B V R I and VT RT GT IT, respectively. A variety of other bandpasses that do not belong to standard systems were also used. In general, these nonstandard filters have no designation in the 'filter' column of the tables, but the peak wavelength and half-power bandwidth are given.

The only other broadband filter designated by name in the tables is 'FES', which refers to the Fine Error Sensor (the acquisition and tracking camera) on the

International Ultraviolet Explorer (IUE) satellite. This camera uses an unfiltered S-20 photocathode with measured half-power points at roughly 3800 and 6300 Å (Sonneborn et al. 1987). Although never intended to be used as a photometer, the instrument first proved its usefulness for studying cometary variability during the apparition of Comet IRAS-Araki-Alcock and since then has been used routinely on all comets. Because of gradual degradation of the photocathode, sensitivity to focus, and other variable properties, the absolute calibration is not reliable and the data must be treated with caution. All reported magnitudes, the scale of which has an arbitrary zero point, refer to a cross-shaped region centered on the photocenter of the comet, with the arms of the cross being 12.6 arcsec wide and 23.4 arcsec long. See the IUE Observer's Guide by Sonneborn et al. (1987) for more information.

We have made no attempt to reduce broadband magnitudes from one filter system to another because all such transformations are strongly dependent on the spectrum of the object being studied. Although empirical transformations exist for stellar spectra, they are totally inappropriate for cometary spectra. At times when the comet was inactive, the transformations may be approximately valid, although even then the procedure will not be very precise since reddening of the solar continuum by the cometary nucleus and/or dust is not equivalent to changing the spectrum to that of a cooler star.

2.2. Narrowband Filters

The process of acquiring the narrowband filters was far lengthier and more time-consuming than I could have imagined at the time I began the process. We purchased the first filters for the original sets of five bandpasses (to isolate the emission bands of CN, C_2, and C_3 as well as two bands in the continuum) from MicroCoatings, Inc., and began distribution using both the original NSF funding for the effort sponsored by the IAU Working Group and additional funding from the IHW. After lengthy disputes with MicroCoatings, Inc., based on extensive tests and measurements of transmission curves of the filters in Maryland, we completed the purchase of the originally defined set of filters from Andover Corp.

Meanwhile, we sought bids for the sets of filters to measure ions (CO^+ and H_2O^+) and the red continuum. These sets were purchased from Barr Associates, Inc. Finally, we sought bids for a smaller number of filters to isolate the $\Delta v = 0$ emission band of OH near the atmospheric cutoff; these filters we purchased from Spectro-Film, Inc. Thus, the narrowband filters that were distributed to both photometrists and polarimetrists came from several different manufacturers. Although the manufacturers tried to maintain uniformity among the filters, they were not entirely successful. Since the transformations from measured magnitudes to fluxes depend on the actual profiles of the filters, the differences between the transmission profiles of the different filters are discussed here.

It should be kept in mind that the characteristics of the bandpasses of interference filters change with time, some much more than others. All measurements reported here are based on data taken prior to distribution of the filters, that is, around 1982–1983, except for the profile of the OH filter, which was remeasured in 1988, and the profiles of the NH filters, which were measured by the manufacturer in 1979. We are aware of some changes in the bandpasses since some observers measured the bandpasses themselves and reported problems to us. At least one of the OH filters has had a significant shift in the bandpass reported to us and several

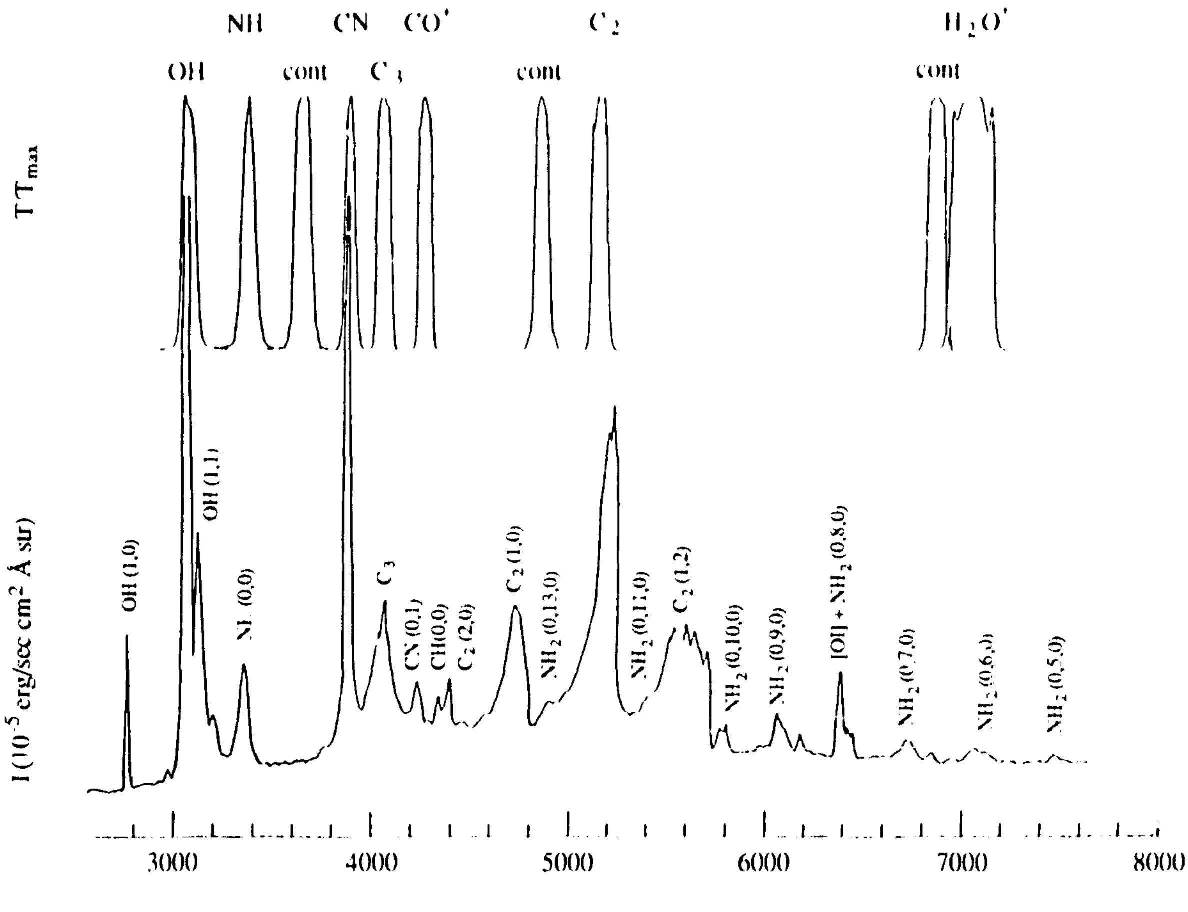

Figure 1. Spectrum of Comet P/Tuttle with the profiles of the inference filters used in the IHW narrowband photometric program.

of the CN filters (so far, all from the batch manufactured by MicroCoatings, Inc.) have shown a significant (5–10 Å) shift toward longer wavelengths. These changes will have rather little effect on the observations of stars, other than for the linearization of the extinction for the OH filter, but they will have drastic effects on the transformation of cometary magnitudes to fluxes. Any observers planning to continue to use the filters in the future should take care to have the bandpass remeasured regularly. At the time of this writing, we are in the midst of a program to have several complete sets of filters remeasured in collaboration with John Osantowski and Charlie Fleetwood of the optical physics group at NASA/GSFC.

To provide an overview of the filters, Figure 1 shows the transmission curves of representative filters of each type, together with a spectrum of Comet P/Tuttle kindly provided by S. Larson. The spectrum is a combination of ground-based data and data obtained with the IUE satellite. The two sets have been scaled to approximately take into account the instruments' different fields of view. The species being measured are indicated in the figure.

Table II. Transmission Curve of the OH Filter 3085/75 (#S2)

Lambda	Trans.	Lambda	Trans.	Lambda	Trans.	Lambda	Trans.
2920	0.000020	3090	0.36125	3270	0.0001375	3580	0.002850
2930	0.0000285	3100	0.33125	3280	0.000110	3590	0.00275
2940	0.000050	3110	0.24125	3290	0.0000975	3600	0.00255
2950	0.0001075	3120	0.12125	3300	0.00008	3620	0.002275
2960	0.000225	3130	0.0500	3320	0.000055	3640	0.002100
2970	0.000485	3140	0.02125	3340	0.0000475	3660	0.0020875
2980	0.00095	3150	0.010	3360	0.0000375	3680	0.0020
2990	0.0020	3160	0.00570	3380	0.00003375	3700	0.0018625
3000	0.0045	3170	0.00325	3400	0.0000325	3720	0.0016625
3010	0.01125	3180	0.002025	3420	0.0000375	3740	0.001375
3020	0.03	3190	0.001325	3440	0.000050	3760	0.0010375
3030	0.095	3200	0.000925	3460	0.0000925	3780	0.000750
3040	0.25	3210	0.00065	3480	0.0001025	3800	0.0004875
3050	0.385	3220	0.000473	3500	0.000275	3820	0.0002875
3054	0.3950	3230	0.000360	520	0.0005375	3840	0.00015
3060	0.38875	3240	0.000285	3540	0.0012125	3860	0.0000575
3070	0.3775	3250	0.000215	3560	0.0022875	3880	0.000015
3080	0.37375	3260	0.000175	3570	0.0027375	3900	0.0000025

Because, in the following write-up, the OH and NH filters are treated differently from the remainder, the tabular data for the OH and NH filters are included in the section with the write-up. For the remaining filters, the tabular data are all at the end of this section. All filters are identified by the nominal central wavelength [Å], the nominal full-width-half-maximum (FWHM) [Å], and a serial number consisting of a letter indicating the manufacturer plus a sequential number.

2.2.1. *OH (3085 Å)*. This filter was designed to measure the 0-0 band of the A $^2\Sigma$ - X $^2\Pi$ system of OH. Although the 1-1 band is in the wing of the filter, it does not contribute a large fraction of the total light. The formula for flux in Section 4.2 gives the flux in the 0-0 band alone. These filters were all manufactured by Spectro-Film, Inc., of Winchester, Massachusetts, and are, in a sense, a special case because the primary bandpass is centered near 3075 Å with a FWHM = 80 Å, but there is also a secondary bandpass near 3580 Å, which is lower in transmission by more than two orders of magnitude but wider by about one order of magnitude. It thus transmits, for a flat spectrum, a flux of a few percent of the primary bandpass' flux. This secondary bandpass, however, is the dominant source of light at large airmasses because the atmospheric transmission is so much greater at the wavelength of the secondary bandpass than at the wavelength of the primary bandpass. Data were received from only a few observers using these filters, and the data shown in Table II, which are for the filter used by the group from Lowell Observatory, can be considered representative. Spectro-Film, Inc., made the filters in two separate

Table III. Transmission Curves of the NH Filters 3365/70

	Transmission		
Lambda [Å]	Filter #S1	Filter #S2	Filter #S3
3200	0.002	0.002	0.001
3225	0.002	0.002	0.002
3250	0.003	0.003	0.002
3275	0.005	0.005	0.003
3300	0.012	0.010	0.010
3325	0.088	0.082	0.058
3350	0.310	0.300	0.265
3375	0.375	0.368	0.332
3400	0.225	0.240	0.290
3425	0.045	0.050	0.080
3450	0.010	0.011	0.013
3475	0.004	0.003	0.003
3500	0.002	0.002	0.002

evaporation runs, and it appears that filters are very well matched within a single evaporation run, but that there are some noticeable differences between the two evaporation runs.

2.2.2 *NH (3365 Å)*. The filters for NH were not distributed as part of the IHW effort, but several older filters were available from previous programs. These filters were used at Lowell Observatory, Cerro Tololo Inter-American Observatory, and Perth Observatory. They were chosen to measure the $\Delta v = 0$ sequence of the $A\ ^3\Pi_i - X\ ^3\Sigma^-$ system of NH. Although the entire sequence is in the bandpass, virtually all of the light is from the 0-0 band, because the Franck-Condon factors are low for the other bands. These filters were also manufactured by Spectro-Film, Inc., although many years before the OH filters. Since the NH filters are not very well matched, the only way to characterize them is to present the transmission curve for each of them (see Table III).

2.2.3. *Continuum 3650 Å*. The early filters of this type were produced by MicroCoatings, Inc., of Burlington, Massachusetts, while the later ones were produced by Andover Corp. of Lawrence, Massachusetts. Approximately 75 were distributed. Since the two companies used different techniques to manufacture the filters, the characteristics came out rather different. Although the filter is intended for the continuum, there are some weak ionic bands present in the wings of the filter. Preliminary calculations show that the contamination by these ions (CO^+ and CO_2^+) is not significant.

2.2.4. *CN (3871 Å)*. This filter is intended to measure the $\Delta v = 0$ sequence of the $B\,^2\Sigma^+ - X^2\Pi$ system of CN. Like the 3650-Å filters, the early filters were made by MicroCoatings, Inc., and the later ones by Andover Corp. The entire $\Delta v = 0$ sequence is included, but since the 1-1 band is weaker than the 0-0 band by a full order of magnitude, the flux is 90% due to the 0-0 band. The reduction formulae discussed in subsequent sections give the flux in the complete $\Delta v = 0$ sequence.

2.2.5. *C_3 (4060 Å)*. This filter is intended to measure a portion of the A-X Swings system of C_3 which extends over approximately 150 Å in this region. The filter was chosen to measure that portion of the emission band that is least contaminated by other features (which are due, e.g., to bands of CO^+ at the short wavelengths). The reduction formulae in Section 4.2, however, are for the flux integrated over the entire band, based on published profiles that are assumed to remain the same in all comets. These filters were also manufactured by both MicroCoatings, Inc., and Andover Corp.

2.2.6. *CO^+ (4260 Å)*. Since the strongest band of CO^+, the 3-0 band, is inextricably involved with the C_3 band, this filter was chosen to cover the 2-0 band of the $A\,^2\Pi - X\,^2\Sigma^+$ system. These filters were all made by Barr Associates, Inc., of Westford, Massachusetts. Our results indicate a strong sensitivity to the subtraction of the continuum relative to which the emission band is weak except in distant parts of the ion tail.

2.2.7. *Continuum 4845 Å*. This region of the continuum is noticeably contaminated by the high vibrational and rotational components of the $\Delta v = 0$ sequence of the Swan system of C_2, the strongest bands of which occur predominantly at longer wavelengths. Our standard reduction applies a correction for this contamination. The filters were manufactured by MicroCoatings, Inc., and by Andover Corp.

2.2.8. *C_2 (5140 Å)*. This filter measures the $\Delta v = 0$ sequence of the Swan ($d\,^3\Pi_g - a\,^3\Pi_u$) system of C_2. The filters were manufactured by both MicroCoatings, Inc., and Andover Corp.

2.2.9. *Continuum 6840 Å*. This filter measures a relatively 'clean' region of the continuum. There is some weak emission by NH_2 in this region, but it does not appear to be a significant contributor. Because this band includes the Fraunhofer line B, which is due to telluric oxygen, there is a possibility that atmospheric extinction in this band might be affected by curve-of-growth effects. No allowance has been made for this in our reductions. The most obvious alternative location for a red continuum filter would involve interference from the telluric water vapor absorption, which would cause greater problems because of the variation of absorption with humidity. These filters were all manufactured by Barr Associates, Inc.

2.2.10. *H_2O^+ (7000 Å)*. This filter was chosen to isolate the (0,6,0)-(0,0,0) band of H_2O^+. Because this band is very broad and the filter was designed to encompass all of it, the bandpass tends to be dominated by the continuum in the heads of many comets and the deduced flux is therefore sensitive to the precision of the subtraction of the continuum. There is also some contamination by an emission band of NH_2.

Table IV. Average Characteristics of the IHW Narrowband Filters

Filter [Å]/[Å]	Lambda [Å]	Trans.	Width (80%) [Å]	Width (50%) [Å]	Width (10%) [Å]	Width (1%) [Å]
3650/80						
Mic.	3650.1(5.5)	0.368(.050)	57.7(4.3)	82.5(3.4)	126(4.8)	191(6.5)
And.	3644.2(4.1)	0.295(.029)	68.3(1.3)	88.1(1.7)	125(2.9)	180(4.0)
3871/50						
Mic.	3871.6(2.7)	0.264(.030)	31.3(4.4)	44.2(3.9)	70(5.6)	115(8.4)
And.	3870.2(2.3)	0.312(.031)	30.4(0.6)	42.4(1.4)	64(2.2)	92(1.2)
4060/70						
Mic.	4057.9(2.0)	0.458(.009)	62.6(1.9)	76.7(2.0)	100(3.5)	137(5.0)
And.	4054.1(1.8)	0.487(.020)	59.1(3.5)	70.5(2.9)	91(1.3)	117(2.3)
4260/65						
Barr	4259.8(5.8)	0.445(.009)	62.1(1.4)	69.8(0.4)	76(0.5)	79(1.6)
4845/65						
Mic.	4848.1(5.6)	0.721(.009)	56.9(1.9)	71.7(1.0)	100(1.6)	143(2.8)
And.	4849.0(1.1)	0.739(.008)	52.4(1.0)	65.0(0.6)	90(0.4)	5140/90
Mic.	5140.4(5.2)	0.629(.010)	74.2(3.5)	85.3(2.2)	108(1.7)	142(3.3)
And.	5141.3(4.5)	0.739(.017)	71.3(2.7)	82.6(4.2)	106(5.4)	155
6840/90						
Barr	6840.3(15.)	0.788(.016)	79.9(4.9)	90.9(4.4)	114(4.2)	146(5.4)
7000/175						
Barr	7025.9(3.6)	0.791(.013)	215(1.3)	228(1.2)	259(2.2)	311(2.7)

The filters were all manufactured by Barr Associates, Inc. If I had it to do over again, this filter would be designed to be much narrower, to better isolate the ions from the continuum.

Characteristics of all the filters except those for OH and NH are given in Table IV. Each filter is identified by its peak wavelength, its FWHM (following a slash), and the manufacturer. Listed are the mean wavelength of the peak transmission, the peak transmission, and the full widths at 80%, 50%, 10%, and 1% of peak transmission. Each value is followed in the parentheses by the root-mean-square (rms) scatter of that parameter from filter to filter. Table V presents the widths for several actual filters—the overall narrowest one (Nr.), an average one (Av.), and the widest one (Wd.). The numbers in the parentheses are the most extreme values found. Appendix A shows the complete profile for one filter of each type. In Table V and Appendix A, the individual filters are identified by the manu-

Table V. Characteristics of Filters—Narrowest, Average, and Widest

Filter [Å]/[Å]	Desc.	Ident.	Width (80%) [Å]	Width (50%) [Å]	Width (10%) [Å]	Width (1%) [Å]
3650/80	Nr.	M32	54(49)	79	123(121)	184(182)
	Av.	M3	57	81	125	
	Wd.	M37	67	88(89)	128(137)	201
	Nr.	A36	66(65)	88(86)	126(114)	169
	Av.	A30	68	87	124	181
	Wd.	A34	68(72)	90(92)	127(129)	183(184)
3871/50	Nr.	M30	28(21)	41(38)	63(62)	98
	Av.	M41	31	44	71	118
	Wd.	M43	35(46)	49(50)	77(82)	125(127)
	Nr.	A26	30(29)	42(40)	62(61)	90
	Av.	A17	30	42	64	92
	Wd.	A13	31	42	73	(94)
4060/70	Nr.	M49	60(58)	72	92	130
	Av.	M25	63	77	101	
	Wd.	M38	64(65)	78(80)	104	144(146)
	Nr.	A33	53	59	89	116(111)
	Av.	A22	59	70	91	117
	Wd.	A14	64	74	92(93)	(120)
4260/65	Nr.	B10	61	69	76(75)	78(77)
	Av.	B4	63	70	76	78
	Wd.	B25	63(64)	70	76	83
4845/65	Nr.	M25	51	70(69)	99(98)	(139)
	Av.	M21	57	73	100	143
	Wd.	M33	59(60)	73	101(109)	148
	Nr.	A22	51	64	91	
	Av.	A12	52	65	90	
	Wd.	A17	52(54)	66	90(91)	
5140/90	Nr.	M14	56	80	104	(137)
	Av.	M41	74	86	108	141
	Wd.	M36	79	90	113	148
	Nr.	A14	68	80	103	
	Av.	A20	71	81	104	
	Wd.	A29	77	92	118	155

Table V. (continued)

Filter [Å]/[Å]	Desc.	Ident.	Width (80%) [Å]	Width (50%) [Å]	Width (10%) [Å]	Width (1%) [Å]
6840/90	Nr.	B23	68	83	110	141
	Av.	B21	80	92	115	148
	Wd.	B54	94	95	120	152
7000/175	Nr.	B 3	215(211)	227	256	307
	Av.	B51	216	229	258	309
	Wd.	B15	217	229(232)	260(263)	320

facturer (M = MicroCoatings, Inc.; A = Andover Corp.; B = Barr Associates, Inc.) and its assigned number.

2.3. Filters for Imaging

When Steve Larson was planning the activities of the Near-Nucleus Studies Network, he realized that many observers with charge-coupled devices (CCDs) would want to image the comet in narrow bandpasses and that this would be very valuable for understanding the processes of ejection from the nucleus and of formation of the observed species from their generally unknown parent species. He therefore arranged to have larger, image-quality filters made which duplicated the bandpasses of the filters used by the Photometry and Polarimetry Network. While our filters were 25 mm in diameter, his were 38 mm. Furthermore, he specified the flatness and parallelism of the surfaces of the filters and required that all filters have the same optical thickness (to maintain constant focus from filter to filter). The specifications for the bandpasses were identical to ours. All of his filters were purchased from Barr Associates, Inc.

Although the specifications for the bandpasses were identical between the photometric and imaging sets, the fact that they were not made in the same evaporation runs and in some cases were even made by different manufacturers (and thus to different detailed designs) implies that the actual bandpasses are not identical. We have not examined the bandpasses in detail to ascertain whether the actual photometric calibration is different. Because of some urgency for scientific reasons, we have examined the imaging OH filter that I used in my own CCD system and found that although the primary bandpass is nearly identical to that of the photometric filters, the secondary 'red' leak at λ 3580 of the photometric filter for OH is considerably suppressed and possibly totally absent in the imaging filters. This means that photometric reduction of OH from the observations with CCDs must be handled differently from the photometric reduction of OH from observations with photometric filters, which is discussed in a later section.

3. STANDARD STARS

3.1. Standards for Broadband Photometry

No special efforts were made to establish any standards for broadband photometry since the commonly used systems already have extensive networks of standard stars. In the individual Flexible Image Transport System (FITS) files for each set of observations, we have included, for those cases in which we had the information, a HISTORY keyword, which lists the standard stars that were used in the observational program. We have not always had available the actual magnitudes used for the standard stars and, in any case, different observers tend to use slightly different standard values for the same star. For those reasons, we have not provided a complete table of the broadband magnitudes of the standard stars. In those cases in which we know the values used by the observers, we have included those values in the FITS files under the HISTORY keyword.

3.2. Standards for Narrowband Photometry

All of the early photometric observations of comets with narrowband filters were carried out using ad hoc standards observed for a specific comet and a few specific filters. When Bob Millis and I undertook our first survey of comets in the mid-1970s using narrowband photometry, we realized that it would be essential to have a set of standard stars that were distributed around the sky and that had been measured with the same set of filters. We also realized that stars of early spectral types would be the best standards for calibration of fluxes since they had the fewest spectral features and would be least sensitive to slight shifts in the bandpasses of the filters. For that reason, we initially observed, during our cometary program, a set of standards of spectral types O9 to B3 distributed along the celestial equator. We subsequently realized the need for solar analogs to better subtract the continuum underlying the emission bands of comets, and we added several of those stars. We therefore had an evolving set of standards for which the precision gradually improved.

When the IHW was begun and it was obvious that the new system of filters would require newly observed standard stars, the Lead Center issued a contract to Ben Zellner and Wieslaw Wisniewski to observe a suitable set of standards with the filters then available, basically the original set of five filters. An extensive program of observations over more than a year (to close the loop in right ascension) led to a very precisely determined set of standards. Unfortunately, the timetable for purchasing the filters for the other bandpasses slipped due to the manufacturing problems with the original filters, whereas the observing program for standard stars was tied to the timetable of a specific contract, so it was not possible to incorporate the remaining filters into the program of Zellner and Wisniewski. The results of their program to establish standards have been published (Wisniewski and Zellner 1985) and, except for an arbitrary shift of the zero point, are in excellent agreement with our own results where there is overlap.

To remedy the lack of several filters in the work of Zellner and Wisniewski, we undertook our own program of standardization. Primary standard stars were chosen to be of two types: solar analogs and stars of spectral types O9–B3. These stars were essentially the same ones that Bob Millis and I had used in our previous work. The early-type stars were chosen to have the most line-free spectra and to be distributed along the celestial equator, while the solar analogs were chosen to be those most nearly like the Sun in the work of Hardorp (1978, 1980a, 1980b, 1982). The solar analogs were used to determine the continuum underlying the emission bands of the comet and are marked in Appendix B. Secondary standards were chosen in other parts of the sky, particularly near the path of P/Halley.

We initiated these observations ourselves, interspersing the observations of standard stars among the cometary observations made by myself, the co-Discipline Specialist V. Vanysek, and various collaborators (primarily Millis, Birch, Schleicher, and Wolf), but it soon became clear that we would require a program dedicated to just standard stars similar to that of Zellner and Wisniewski. We arranged with Wayne Osborn to complete the establishment of these standard stars, including arranging new observations of the standard stars and consolidating the existing data. We also arranged with Dr. H. Moreno of the Universidad de Chile to carry out a program of observations of standard stars from the southern hemisphere, while our long-term collaborator Peter Birch of Perth Observatory also observed a number of the southern standards. This program was carried out in parallel with the actual cometary observations, with the result that all the observations of Comet P/Giacobini-Zinner, as well as the early observations of Comet P/Halley, could not be reduced to final form until well into P/Halley's apparition. Ultimately, many of the individual observations of the standard stars were discarded (including, to my embarrassment, most of those that I obtained), to obtain the highest quality for the standard magnitudes. Some of these other observations have been published separately (e.g., Wolf and Vanysek 1987).

The observations from the various sites with various instruments were synthesized by W. Osborn to establish the standard magnitudes. Although our original zero point had been defined differently, the final zero point of the system was arbitrarily set to be m = 5.88 for all filters for the star 53Psc = HD3379 (V = 5.88). Based on our subsequent reduction of observations by all observers, there appears to be nothing more than a zero-point shift between instrumental magnitudes and the standard magnitudes in nearly all cases. In a few cases—that is, for certain sets of filters—the zero-point shift of the CN filter is slightly different for G-stars and for B-stars and presumably, therefore, for comets. For a more complete discussion, see the paper by Osborn et al. (1990). The results of the program are summarized in Appendix B and Table VI.

3.3. Standards for Polarimetry

Both highly polarized stars (POL-STD in the FITS HISTORY keyword) and unpolarized stars (UNPOL-STD in the FITS HISTORY keyword) are needed to calibrate polarimetric measurements. The standard values were taken from the literature by the individual observers. In some cases, the observers did not provide us with information about which standard stars were used for the calibration, but the information is included under the HISTORY keyword when the information is available. References for standard values were also not always provided. One known reference was Hsu and Breger (1982).

Table VI. Solar Analog Colors

Monochromatic Magnitude at Wavelength [Å] Relative to 4845 Å

HD#	3085	3365	3650	3871	4060	4260	5140	6840	7000
28099	2.267	1.594	1.183	1.459	0.863	0.733	-0.052	-0.854	-0.884
29461	2.211	1.596	1.167	1.432	0.854	0.730	-0.047	-0.873	-0.919
30246	2.276	1.585	1.182	1.468	0.871	0.755	-0.046		-0.905
44594	2.221	1.607	1.162	1.430	0.837	0.724	-0.057	-0.878	-0.912
105590	2.224	1.586	1.155	1.452	0.859	0.749	-0.052	-0.893	-0.925
186427	2.287	1.601	1.179	1.454	0.858	0.748	-0.041	-0.876	-0.857
191854	2.311	1.603	1.193	1.463	0.868	0.762	-0.030	-0.858	-0.854
Mean	2.257	1.596	1.174	1.451	0.859	0.743	-0.046	-0.872	-0.894
Sigma	0.038	0.008	0.013	0.015	0.011	0.014	0.009	0.014	0.029

4. REDUCTION OF NARROWBAND PHOTOMETRY

Our original plan for archiving the data had been based on the assumption that the best results would be obtained if the individual observers reduced their own data and submitted reduced data to us. Whether or not this would be true, it was by far the most cost-effective approach from our point of view. On the other hand, we anticipated that the standard stars might not be well enough calibrated to submit fully reduced data and we therefore recommended that observers submit magnitudes of the comet and the standard stars reduced to outside the atmosphere. While we were archiving the data on Comet P/Giacobini-Zinner together with the earliest received data on Comet P/Halley, the largest source of inhomogeneity was expected to be the evolution of the system of standard magnitudes as we improved the standardization. Although we distributed to all observers interim lists of standard magnitudes, we knew ourselves and warned the observers that these magnitudes were not final. The interim magnitudes were sufficiently precise that interesting scientific conclusions could be drawn from the data reduced with the interim magnitudes, but the final archive would clearly require re-reduction using the final magnitudes of the standards, to ensure homogeneity and allow different data sets to be combined. As noted above, we had anticipated this problem and had originally requested that observers submit to us instrumental magnitudes of both the comet and the standard stars reduced to outside the atmosphere. We had then planned to apply the 'best' system of magnitudes for the standard stars and the 'best' version of the calibration formulae.

However, we also found that various observers used different criteria for discarding 'bad' observations, different formulae for the airmass, and so on. In fact, one of the things that we found quite surprising was the wide variety of approaches used by different observers in obtaining and reducing their data. In most cases, therefore, we have carried out the complete reductions from counting rates or instrumental magnitudes. A very few observers who had already reduced their data found it difficult to back up and submit the unreduced data, and in one such case (Wieslaw Wisniewski), we did not reduce the data ourselves, as we had confidence in our understanding of his reductions. In some other cases, observers provided us with partially reduced data (as we had originally requested!) and with sufficient information about atmospheric extinction and airmass that we were able to unreduce their data back to actual instrumental magnitudes. We were then able to reduce the data ourselves using a standard formula for airmass and other standard procedures. There is still a certain amount of inhomogeneity in the results due to varying reduction procedures, but we believe the effects due to this are small compared with other uncertainties in the results. The remaining inhomogeneities in the data are probably due primarily to differences between the interference filters used.

The rest of this section describes the methods and formulae used at the University of Maryland to reduce the narrowband photometric data. Significant deviations from these procedures are noted in the archive as comments for the relevant observations.

4.1. Atmospheric Effects and Reduction to Standard Magnitudes

The most basic data with which we could begin reductions consisted of Universal Times (UTs) and counting rates on the various objects and on the sky. In the case of measurements with direct-current (d.c.) systems rather than pulse-counting systems, the most basic data would consist of readings from the d.c. amplifier and UTs. Some observers submitted data in various stages of reduction beyond these most basic data, and in general, we do not know the details of the reductions applied by such observers. We will describe here the complete reduction from the most basic data as we carried it out.

Instrumental magnitudes were derived by first correcting all counting rates for the dead-time of the amplifier using the formula

$$n = n_{obs}/[1.0 - n_{obs} \times \tau]$$

where τ is the dead-time of the amplifier and n and n_{obs} are the 'true' and observed counting rates, respectively. These counting rates were converted to instrumental magnitudes by choosing an appropriate counting rate n_{sky} for the sky brightness (by interpolation where appropriate and possible) and using

$$m = 20.00 - 2.5 \times \log [n - n_{sky}]$$

Airmasses were calculated for each observation in the following manner, beginning with the coordinates of the observatory and the coordinates (current epoch) of the object. The equation for the true zenith distance, Z, is:

$$\sec Z = [\sin (lat) \times \sin (dec) + \cos (lat) \times \cos (dec) \times \cos (LHA)]^{-1}$$

The equation for the apparent zenith distance, Z_{app}, is:

$$Z_{app} = Z - [60.4 \times \tan (Z) - 0.06688 \times \tan^3 (Z)]$$

where the term in brackets is in arcsec. The airmass, X, is then:

$$X = \sec Z_{app} - 0.0018167 \times [\sec Z_{app} - 1] - 0.002875 \times [\sec Z_{app} - 1]^2 - 0.0008083 \times [\sec Z_{app} - 1]^3$$

Although atmospheric attenuation is normally linear with airmass as defined above, this is not the case for observations with the OH filters because the monochromatic attenuation varies drastically across the bandpass. To simplify the reductions, particularly when only limited data were available, the nonlinearity of the atmospheric attenuation was modelled by defining an effective airmass, X_{eff}, such that attenuation would be linear in this variable. Unfortunately, the nonlinearity varies from one site to another and even with time at a single site due to differences in the amount of atmosphere above the site (changing the Rayleigh component), in the amount of aerosol at the site, and in the amount of ozone above the site. Furthermore, the nonlinearity depends on the actual spectrum of the source being observed. Fortunately, we are interested only in three types of sources—B-stars, solar analogs, and cometary emission bands. We can therefore define effective airmasses separately for each of the three cases.

The details of the atmospheric modelling will be described elsewhere, but our general approach, based on that of Hayes and Latham (1975), was to use a three-component model for the atmosphere (Rayleigh, aerosol, and ozone) to calculate the monochromatic extinction. The altitude of the observatory defines the Rayleigh component (we ignore barometric variations), whereas the aerosol and ozone components are allowed to vary within ranges expected for a given site. The monochromatic extinction for various airmasses is then multiplied by the spectral distribution of a B-star, a G-star, and a cometary emission band, and the resultant flux is multiplied by the transmission curve of the filter, yielding magnitudes as a function of airmass. The resultant theoretically calculated magnitudes are compared with whatever observations are available, usually a large set of observations of the B-stars observed over a wide range of airmasses during a single observing run. The two free parameters (ozone column density and aerosol abundance) are varied until the observed data are reproduced by the model. (Usually only the ozone abundance needs to be varied significantly, and it turns out that, in the cases studied so far, this remains within the ranges expected for a given latitude and season.) We then use the calculated variation of magnitude with airmass to define the effective airmass, X_{eff}, such that the extinction is linear. It appears adequate to use a quadratic polynomial:

$$X_{eff} = X + a \times X^2$$

where a is, in principle, different for every site (conceivably, for every observing run, due to seasonal effects in ozone abundance) and different for B-stars, G-stars, and comets.

Since, in practice, extinction is determined only from B-stars or only from B- and G-stars, it is also necessary to know the ratio of extinction coefficients for the three classes of objects once they have all been linearized by the above formulae. This ratio is also derived from the model. Results from the models for a few obser-

Table VII. Coefficients for Extinction with the OH Filter

Parameter	Lowell	Mauna Kea	Cerro Tololo
a(B)	-0.0455	-0.0726	-0.0482
a(G)	-0.0796	-0.1000	-0.0824
a(C)	-0.00929	-0.0273	-0.00754
k(G)/k(B)	0.973	0.930	0.973
k(C)/k(B)	0.924	0.923	0.900

vatories, as used in our reductions, are given in Table VII, where the letters B, G, and C in parentheses refer to the values of the parameters for B-stars, G-stars, and comets, respectively. More recent calculations lead to slightly different values for the coefficients, but the ones in the table are those that were used for our reductions. It can be seen that the curvature of the extinction is larger at Mauna Kea than at the sites at lower altitudes. It is also the case that, at these wavelengths, the extinction at Mauna Kea is as large as it is at good sites at lower altitudes. This is presumably due to a greater column of ozone over Mauna Kea at the time these measurements were taken than over the other sites at lower elevations. Indeed, the model of the extinction does require a greater column of ozone.

Given a set of observations of standard stars, extinction coefficients were determined in a variety of ways. In most cases, we determined atmospheric extinction for each night by two methods: conventional fitting by least squares of magnitude vs. airmass for individual stars and also a global least squares solution using all standards, in which we solved simultaneously for the extinction coefficient and the zero-point shift from instrumental magnitude to standard magnitudes. The result of the global solution was normally used unless the solutions for individual stars suggested hemispheric asymmetries and/or temporal variations during the night. In these cases, we then solved separately for different hemispheres and/or parts of the night. In some cases, we also averaged several nights together to define average extinction coefficients either when too few data existed on a particular night to determine extinction or when the scatter from night to night was no larger than expected from the errors in the results of the individual nights. Different types of extinction fitting are noted as comments in the archive. When global solutions for extinction were not used, magnitudes were transformed to the standard system by a least squares solution for the zero-point shift with no color terms.

It was at this point that a certain amount of discretion was exercised in our operation. If individual observations or even all the observations of a single object seemed discrepant, and if we were able to identify a physically plausible mechanism for producing the discrepancy, we often discarded those observations. In a few cases, we even discarded the data from entire nights at this point. We should point out that, in some cases, the observers had already advised us that the data were of poor quality, but we had requested that they submit everything in the hope that we could salvage some marginal data if they turned out to be critical for filling in a significant gap in the light curve. The subjective comments of the observers were of great help in understanding the effects of atmospheric extinction.

4.2. Conversion to Fluxes

The following procedures were used to derive fluxes in the continuum bandpasses. These procedures are rather sensitive to the actual shape of the bandpass of the filter since they involve integrating the product of the filter transmission curve and the emission profile. These steps are, therefore, the steps that will rapidly become incorrect if the bandpass of a filter shifts with age. We first applied a correction due to the fact that the filter at 4845 Å, nominally a continuum filter, also includes a weak tail of emission from the $\Delta v = 0$ sequence of the Swan system of C_2, which is measured by the filter at 5140 Å. This correction was done in magnitude units using

$$m_{cont}(4845) = m_{4845} + 0.012 \times [m_{4845} - m_{5140}].$$

The coefficient 0.012 was derived on the basis of theoretical spectra of the Swan bands from A'Hearn (1978). Actual spectra of Comet P/Halley from Lowell Observatory (courtesy of Dave Schleicher) and of other comets from both Lowell Observatory and Lick Observatory (courtesy of Hy Spinrad) suggest that the coefficient should be somewhat larger than this, perhaps as large as 0.03. In any case, the correction does not change the continuum flux drastically.

The conversion from magnitudes in the standard system to fluxes in the continuum is straightforward. To generalize for future use, we arbitrarily define

$$m_{cont}(6840) = m_{6840}$$
$$m_{cont}(3650) = m_{3650}$$

and

$$F_{cont}(\lambda) = 10^{-0.4 \times m_{cont}(\lambda)}$$

The flux per unit wavelength [erg cm^{-2} s^{-1} Å^{-1}] is then given by

$$F_\lambda(3650) = (8.22 \pm 0.13) \times 10^{-9} \times F_{cont}(3650)$$
$$F_\lambda(4845) = (5.10 \pm 0.30) \times 10^{-9} \times F_{cont}(4845)$$

and

$$F_\lambda(6840) = (1.65 \pm 0.02) \times 10^{-9} \times F_{cont}(6840)$$

The 'errors' given with the coefficients are a measure of the variation in the flux transformation from one filter to another and, for a given filter, with temperature over the range - 20° C to + 20° C. These errors do not include the uncertainties in the stellar spectra (some published, others from unpublished material obtained by myself and Dave Zipoy) that were used in the calibration.

Derivation of fluxes in emission bands is somewhat more complicated. The first step is to remove the continuum that underlies the emission band and that is also detected through the filters. This is done using the solar analogs' colors (Table VI) and measurements of the comet in any two continuum bandpasses—(3650, 4845), (3650, 6840), or (4845, 6840). For each pair of filters, we interpolate (or extrapolate) the magnitudes of the solar analogs to the wavelength of an emission-band filter and determine the difference between the measured magnitude and the interpolated magnitude, B. For the comet, we then interpolate the magnitudes in the same two continuum filters and add B to estimate the continuum contribution to the measured magnitude. This procedure is accurate if the cometary continuum in magnitudes is redder (or bluer) than the Sun linearly with wavelength. If there is curvature or structure in the continuum reflectivity of the cometary grains, then this procedure is not adequate. The general form of the equation is

$$m_{cont}(i) = A \times m_{cont}(1) + (1 - A) \times m_{cont}(2) + B(i)$$

where i refers to the ith emission band designated by its wavelength, A and (1 - A) are the coefficients for the linear interpolation which depend only on the wavelengths of the three filters, and B(i) is as described above. In Table VIII, we give the coefficients for the continuum correction for each emission band filter and for each of the three possible pairs of continuum bandpasses. We also give an error in B that is a measure of the scatter from one solar analog to another.

In reducing the data, we often had a choice of which continuum bandpasses to use for the continuum subtraction. We always chose interpolation over extrapolation and then the shorter of the two possible baselines. To define the fluxes in the emission bands, we first define

$$F(i) = 10^{-0.4 \times m(i)}$$

and

$$F_{cont}(i) = 10^{-0.4 \times m_{cont}(i)}$$

where we will denote the individual emission bands, i, by their wavelengths [Å].

The true fluxes in the emission bands [erg cm^{-2} s^{-1}] are then given by

$$F(OH) = (Y_1 - 0.0015T) \times 10^{-6} \times [F(3085) - F_{cont}(3085)]$$
$$F(NH) = Y_2 \times 10^{-7} \times [F(3365) - F_{cont}(3365)]$$
$$F(CN) = (Y_3 - 0.0021T) \times 10^{-6} \times [F(3870) - F_{cont}(3870)]$$
$$F(C_3) = (1.381 - 0.003T) \times 10^{-6} \times [F(4060) - F_{cont}(4060)]$$
$$F(CO^+) = (5.90 - 0.005T) \times 10^{-7} \times [F(4260) - F_{cont}(4260)]$$
$$F(C_2) = 6.81 \times 10^{-7} \times [F(5140) - F_{cont}(5140)]$$
$$F(H_2O^+) = 3.58 \times 10^{-7} \times [F(7025) - F_{cont}(7025)]$$

where T is the temperature (in degrees Celsius) of the filter. The coefficients Y_1, Y_2, and Y_3 must be tabulated. Y_2 varies from one filter to another because the filters for NH (which are not widely distributed) are much older than the filters distributed by the IHW and they are not nearly as well matched to each other. For filter #S1, $Y_2 = 8.079 + 0.0080T$; for filter #S2, $Y_2 = 8.240 + 0.0095T$; for filter #S3,

Table VIII. Coefficients for Continuum Subtraction

Filter		cont1/cont2		
		3650/4845	4845/6840	3650/6840
OH (3085)	A	1 4728	1.8822	1.1771
	B	0.528	1.488	0.721
	σ(B)	0.040	0.037	0.038
NH (3365)	A	1.2385	1.7419	1.0893
	B	0.142	0.949	0.239
	σ(B)	0.018	0.013	0.015
CN (3871)	A	0.8151	1.4882	0.9307
	B	0.494	1.025	0.419
	σ(B)	0.018	0.015	0.018
C_3 (4060)	A	0.6569	1.3935	0.8715
	B	0.088	0.516	-0.052
	σ(B)	0.014	0.011	0.015
CO^+ (4260)	A	0.4395	1.2932	0.8088
	B	0.168	0.487	-0.040
	σ(B)	0.015	0.014	0.016
C_2 (5140)	A	-0.2469	0.8521	0.5329
	B	0.244	0.083	-0.264
	σ(B)	0.010	0.008	0.012
H_2O^+ (7000)	A	-1.8033	-0.0802	-0.0502
	B	1.223	0.048	0.083
	σ(B)	0.037	0.030	0.030

$Y_2 = 9.040 + 0.0150T$. The coefficients Y_1 and Y_3, on the other hand, vary with the comet's heliocentric radial velocity, $\dot{r}$, because of the very large Swings effect on the bands of OH and CN. These coefficients are tabulated in Table IX.

4.3. Errors

Errors were not always treated consistently. For the polarimetry, we simply used the errors provided by the observers, who had been asked to supply the stan-

Table IX. Transformation Coefficients Y_1 for OH and Y_3 for CN

i	Y_1	Y_3	*i*	Y_1	Y_3	*i*	Y_1	Y_3	*i*	Y_1	Y_3
-60	1.080	0.5277	-30	1.099	0.5188	1		0.5230	31		0.5267
-59		0.5273	-29		0.5214	2	1.189	0.5238	32	1.100	0.5270
-58	1.086	0.5276	-28	1.112	0.5247	3		0.5245	33		0.5272
-57		0.5284	-27		0.5272	4	1.161	0.5251	34	1.117	0.5271
-56	1.093	0.5304	-26	1.128	0.5287	5		0.5257	35		0.5268
-55		0.5329	-25		0.5289	6	1.147	0.5263	36	1.136	0.5263
-54	1.101	0.5358	-24	1.132	0.5288	7		0.5267	37		0.5258
-53		0.5378	-23		0.5286	8	1.151	0.5274	38	1.134	0.5255
-52	1.106	0.5380	-22	1.119	0.5280	9		0.5282	39		0.5254
-51		0.5362	-21		0.5268	10	1.140	0.5289	40	1.118	0.5258
-50	1.111	0.5333	-20	1.105	0.5248	11		0.5291	41		0.5261
-49		0.5306	-19		0.5229	12	1.113	0.5288	42	1.094	0.5263
-48	1.128	0.5285	-18	1.112	0.5214	13		0.5285	43		0.5265
-47		0.5273	-17		0.5210	14	1.092	0.5289	44	1.069	0.5267
-46	1.156	0.5269	-16	1.121	0.5214	15		0.5214	45		0.5269
-45		0.5270	-15		0.5223	16	1.087	0.5290	46	1.057	0.5274
-44	1.170	0.5277	-14	1.108	0.5234	17		0.5275	47		0.5277
-43		0.5287	-13		0.5244	18	1.095	0.5275	48	1.052	0.5275
-42	1.146	0.5300	-12	1.111	0.5261	19		0.5290	49		0.5277
-41		0.5309	-11		0.5292	20	1.090	0.5307	50	1.050	0.5286
-40	1.126	0.5307	-10	1.154	0.5336	21		0.5312	51		0.5304
-39		0.5299	- 9		0.5372	22	1.074	0.5309	52	1.05[illegible]	0.5320
-38	1.120	0.5287	- 8	1.235	0.5395	23		0.5307	53		0.5327
-37		0.5275	- 7		0.5402	24	1.059	0.5309	54	1.057	0.5323
-36	1.108	0.5263	- 6	1.236	0.5394	25		0.5310	55		0.5312
-35		0.5250	- 5		0.5371	26	1.054	0.5305	56	1.061	0.5296
-34	1.089	0.5232	- 4	1.215	0.5332	27		0.5292	57		0.5282
-33		0.5208	- 3		0.5290	28	1.061	0.5277	58	1.064	0.5269
-32	1.088	0.5186	- 2	1.202	0.5256	29		0.5267	59		0.5256
-31		0.5179	- 1		0.5236	30	1.078	0.5266	60	1.067	0.5243
			0	1.208	0.5228						

dard deviation of the final answer, for both the percent polarization and the position angle or for the Stokes parameters.

For the narrowband photometry, we normally calculated the errors ourselves by propagating the errors through each step of the reduction. In some cases, however, we did not know the uncertainties, e.g., in the raw count rates, and we had to guess these errors. Wherever possible, we checked the scatter between different measurements to ensure that this was consistent with the expected error in an individual measurement. If they were not consistent, we always chose the larger error. This typically occurred when we derived the zero-point shift to the standard magnitude system. The scatter in zero-point shift from one standard star to another was often greater than one would expect from the uncertainties in the raw counting rates and in the extinction determinations. The resultant errors, when propagated through to the fluxes, represent only the photometric uncertainty. They do not include uncertainties in the transformation equations given above, nor do they include uncertainties due to the scatter in characteristics between the different filters, nor do they include the errors in the flux-calibrated spectra of the standard stars that were used to derive the transformation coefficients.

We do know that we have neglected one significant source of error. As noted above, our algorithm for removing the continuum from the measurements of emission bands will only work if the reddening (in magnitudes) is linear with wavelength. Empirically we have found that frequently the flux of CO^+ turns out to be negative. We have looked into the contamination of the continuum bandpasses by emission bands and have concluded that this is not the source of the problem. We suspect that the real problem is due to nonlinearity in the reddening of the solar continuum by the cometary grains, but we have no way of adequately dealing with this. The effect is most pronounced for CO^+ because the band is very weak compared with the continuum near the nucleus, but the problem is presumably present, to a lesser degree, for all emission bands.

Other than the uncertainty due to the varying reflectivity of cometary grains, we believe that the photometric uncertainty is the largest uncertainty in the results presented here and that the quoted errors are reasonably realistic. We note that although the CO^+ feature is frequently negative, it is virtually never more than 3-σ negative. In the data tables, our general policy has been to quote 1-σ errors. If the result is less than 3-σ, we have usually quoted a 3-σ upper limit, but in a few cases we have included results between 2-σ and 3-σ, together with the errors.

5. CONTENTS OF THE ARCHIVE

5.1. The Data

To provide an overview of the archive's contents, Table X offers a chronological summary of the data. Listed are the calendar month and the number of observations archived for each of three different types—magnitudes, fluxes, and polarizations. Note that several sets of data taken with the narrowband filters were archived as magnitudes rather than as fluxes because we thought that conversion to fluxes either was too uncertain or would involve only a small subset of the data. If these narrowband data were thought to be useful in the form of magnitudes, because they formed either useful maps or useful time-series, we archived them in that form. Note also that the polarimetric measurements came in two forms, although they are combined in Table X.

The data were taken by 116 different observers using 53 different instruments. The observers are listed in Appendix C, together with their affiliations. In some cases, we have given the observer's affiliation as his or her home institution and in other cases as the observatory at which he or she observed, depending on the information available to us. We have made no attempt to update affiliations or countries to the present. An examination of Appendix C shows that the observers came from 16 different countries (additional countries were also represented in the data we were unable to archive). An examination of the observing sites shows data from observatories in at least 14 countries that only partially overlap the set of countries in which the observers were based.

Table X. Chronological Listing of the Data

Date (UT Year/Month)	Number of Observations: Magnitudes	Fluxes	Polarizations
1981 December	3 (limits)	--	--
1982 October	4	--	--
1982 November	2	--	--
1982 December	2	--	--
1983 January	1	--	--
1983 February	2	--	--
1984 January	36	--	--
1984 February	9	--	--
1984 March	1	--	--
1984 October	13	--	--
1984 November	14	--	--
1984 December	73	--	--
1985 January	30	--	--
1985 February	14	--	--
1985 March	16	--	--
1985 April	4	--	--
1985 August	31	8	--
1985 September	217	440	14
1985 October	149	235	58
1985 November	340	1,948	178
1985 December	175	941	195
1986 January	24	363	60
1986 February	--	27	1
1986 March	132	1,671	76
1986 April	53	7,094	188
1986 May	53	2,921	114
1986 June	43	404	--
1986 July	14	32	--
1987 January	8	21	--
1987 February	4	--	--
1987 March	255	51	--
1988 April	27	--	--
1988 May	26	--	--

Total interval: 7 years, 5 months

Total number of observations: 1,775 magnitudes, 16,156 fluxes, and 884 polarizations.

5.2. The FITS Files (Digital Archive)

The data from the Photometry and Polarimetry Network are stored using the Tables Extension of FITS ('EXTEND = T'). Some of the important parameters of the data are given in the standard FITS header, while the remainder are given in the tables. Regardless of the type of data, the information in the FITS header is the same. The logically grouped content of the various keywords in the header is given in Table XI. Note that some values, particularly 'TIME-OBS', have been truncated in some cases to the number of digits meaningful for all entries in the file, since the times of each individual observation are given on each line of the actual tables of data. Furthermore, the accuracy of the entries varies, particularly for the coordinates of the observatory, since the coordinates were obtained from a variety of sources, often the observers themselves. In some cases, values were not available for certain parameters that appear either in the FITS header or in the FITS Table. In cases where the parameter was thought to be necessary to understand the data, we nearly always were able to ultimately obtain the relevant values, although in other cases, where the values were not thought to be critical, I decided that the effort to obtain the value would not be worthwhile, since we had so many other tasks to be performed in the archiving process.

The FITS tables can take any of four different formats, depending on the type of data in the table. The types of tables are known by the following values for the FITS 'DAT-TYPE' keyword: 'BROADBAND', 'NARROWBAND', 'POLARIMETRY', and 'STOKES'. Note that the value 'BROADBAND' is an historical artifact actually used to indicate results given in magnitudes rather than fluxes. It is independent of the actual bandwidth of the filters used. The first few columns in the tables are identical for all types of data and are listed in Table XII. The additional entries for DAT-TYPE = 'BROADBAND' are in Table XIII, for DAT-TYPE = 'NARROWBAND' in Table XIV, for DAT-TYPE = 'POLARIMETRY' in Table XV, and for DAT-TYPE = 'STOKES' in Table XVI. The format of the printed archive and the index table are described in Table XVII.

6. SYSTEM CODES

The observers in our network used a wide variety of instruments and, not surprisingly, provided us with a wide variety of information. The system codes in the FITS headers are meant to uniquely identify telescope-instrument combinations. The general structure used in constructing the codes is as follows: digit 1 = 5 (indicating this network); digits 2–4 = an observatory code, normally from the IAU list of observatory codes, but see the complete list of codes given elsewhere in this volume; digits 5–6 = a telescope code, normally a sequential number in order of decreasing telescope size at a given site; digits 7–8 = a unique number indicating (when used in conjunction with the previous digits) the equipment used. Normally we have used 1 to indicate photoelectric photometers, 2 to indicate CCDs, and 6 to indicate polarimeters. Where different instruments of the same type were used on a particular telescope, other numbers could be used.

Details of particular instruments, to the extent that they are known to us, are given in Appendix D. Under comments, we have also given the format in which we received the data in some cases, to indicate, e.g., that the observer might have already taken into account the dead-time of a photomultiplier so we did not need that

Table XI. FITS Header Keywords

Item	FITS Keyword	Format	Value/Explanation
Comet Name	OBJECT	string	'P/HALLEY' for all files in this archive.
File Number	FILE-NUM	I6	'56xxxx' 5 ==> Photometry/Polarimetry Network 6 ==> P/Halley xxxx = running number, not in chronological order
Date	DATE-OBS	dd/mm/yy	Date of the observations
UT Time	TIME-OBS	F6.5	Decimal fraction of the day at the midpoint of the observations in the table
Our Network	DISCIPLN	string	'PHOTOMETRY' for this Network
Observatory	OBSVTORY	string	Name of observatory
Longitude	LONG-OBS	ddd/mm/ss	Positive, eastward from Greenwich
Latitude	LAT--OBS	sdd/mm/ss	s = '+' or '-' for North or South
Elevation	ELEV-OBS	I4	[m]
System	SYSTEM	I8	See Section VII.
Telescope	TELESCOP	string	A unique identification of the telescope by name or size
Type of data	DAT-TYPE	string	'POLARIMETRY', 'STOKES', 'BROADBAND', or 'NARROWBAND'. Note that in Table IX, 'Fluxes' refers to 'NARROWBAND' and 'Magnitudes' refers to 'BROADBAND'.
Observer(s)	OBSERVER	string	Name(s) of observer(s) (omitted for FES observations with IUE; large team headed by Feldman and Festou)
Submitter	SUBMITTR	string	Person who submitted data to the DS. A blank usually means data were taken from the literature.
Comments	COMMENT	string	All comments are character strings (line = 80 characters) following the keywords 'COMMENT' and 'HISTORY' and in some cases the following secondary keywords: 'LIT.' => reference from literature; 'NOTE' => footnote to table; 'NOTExx' => footnote to line xx; 'ADD. OBS.' => names of additional observers beyond those above.

Table XI. (continued)

Item	FITS Keyword	Format	Value/Explanation
	HISTORY	string	Comments relevant to calibration: 'STDSTARS' => list of standard stars used in the reduction. In the case of polarimetry standard stars, POL-STD refers to highly polarized stars, and UNPOL-STD to unpolarized stars.

Table XII. Columns Common to All Types of Data

Item	Format	Columns	Explanation
Date and time (UT)	F8.5	1 – 8	Day of month and decimal fraction at midpoint of observation
Serial number	I2	10 – 11	Line number in the table; occasional numbers are skipped
Filter name	A4	13 – 16	Shorthand name
wavelength	I4	18 – 21	Central wavelength [Å]
width	I4	23 – 26	FWHM [Å]

information. We have also given the approximate number of FITS files based on the use of each instrument, although the exact number may be slightly different due to editing in the last stages of preparing the archive.

7. ERRATA AND ADDENDA

In any project as large as this, errors are bound to creep in. I have been amazed at some of the errors that have crept in and have already been found. We, of course, attempted to catch errors before the data left Maryland, but were not completely successful. Various format checks on the data by Mikael Aronsson at the Lead Center turned up several errors, some of which were just format errors, but others of which were indicative of more substantive errors. Subsequent examination of the data by several people (particularly Dan Klinglesmith, Mal Niedner, Ed Grayzeck, and myself) while the data were at NASA/GSFC for premastering of the compact disc—read only memory (CD-ROM) discs turned up numerous additional errors, not only in the photometry, but also in the data of most other networks. Additional checking of a test CD-ROM by several working scientists outside the IHW was sponsored jointly by the IHW and the Small Bodies Node of the Planetary

Table XIII. Columns for Magnitudes (DAT-TYPE = 'BROADBAND')

Item	Format	Columns	Explanation
Upper limit code	char	28	'<' indicates that the result in the following field is a 3-σ limit
Magnitude	F7.3	30 – 36	Reduced magnitude
error	F5.3	38 – 42	One (1) σ [mag]; omitted if previous field is a limit
Aperture size	F5.1	44 – 48	Diameter [arcsec]
Radial offset	I4	50 – 53	Radial distance between the center of the aperture and the peak brightness of the comet [arcsec]
Offset direction	I3	55 – 57	Angular direction [deg] (eastward from north) of the radius vector to the center of the aperture from the peak in brightness
Integration time	I4	59 – 62	Integration time [s]
Airmass	F5.3	64 – 68	Airmass at the midpoint in time, usually as quoted by the observer

Table XIV. Columns for Fluxes in Narrowband Filters (DAT-TYPE = 'NARROWBAND')

Item	Format	Columns	Explanation
Upper limit code	char	28	'<' indicates that the result in the following field is a 3-σ limit
Log (Flux)	F7.3	30 – 36	Logarithm (base 10) of the flux (see Section IV for details)
error	F5.3	38 – 42	Error of $\log_{10}$ of flux
Aperture size	F5.1	44 – 48	Diameter [arcsec]
Radial offset	I4	50 – 53	Radial distance between the center of the aperture and the peak brightness of the comet [arcsec]
Offset direction	I3	55 – 57	Angular direction [deg] (eastward from north) of the radius vector to the center of the aperture from the peak in brightness
Integration time	I4	59 – 62	Integration time [s]
Airmass	F5.3	64 – 68	Airmass at the midpoint in time

Table XV. Columns for Polarimetry in Percent (DAT-TYPE = 'POLARIMETRY')

Item	Format	Columns	Explanation
Polarization type	A2	28 – 29	'CR' => right circular, 'CL' => left circular, 'LN' => linear
Polarization value	F5.2	31 – 35	Degree of polarization [%]
error	F5.2	37 – 41	One (1) σ [%]
Position angle	F5.1	43 – 47	For linear polarization, the position angle of the electric vector [deg] clockwise from the plane of scattering (- 45 to + 135)
error	F4.1	49 – 52	One (1) σ
Aperture size	F5.1	54 – 58	Diameter [arcsec]
Radial offset	I4	60 – 63	Radial distance between the center of the aperture and the peak brightness of the comet [arcsec]
Offset direction	I3	65 – 67	Angular direction [deg] (eastward from north) of the radius vector to the center of the aperture from the peak in brightness
Integration time	I4	69 - 72	Integration time [s]
Airmass	F5.3	74 – 78	Airmass at the midpoint in time, usually as quoted by the observer

Data System (PDS), and this turned up still more omissions and errors. With this repeated checking by different individuals, we have found and corrected many errors, but no doubt there are still more that we have not found. We welcome reports of anomalies in the data reported here, since anomalies may be indicative either of errors or of physically interesting events.

In addition to the data included in this archive, many other observers submitted data that we have not been able to include because the press of time near the completion of the archive did not allow us enough time to reduce the data from all observers. The choice of which data sets to include was based largely on practical considerations. We worked first on the largest, most readily processed data sets, adding, as time permitted, smaller data sets and data sets that were more difficult to process.

Although the IHW is passing out of existence as an organization, the data themselves will be archived with the PDS, which will provide a continuing base for correcting and updating the data. We hope that the additional data sets not included in this archive will be reduced and 'published' through the PDS, as will any necessary errata.

Table XVI. Columns for Stokes Vectors (DAT-TYPE = 'STOKES')

Item	Format	Columns	Explanation
Q/I	F7.4	28 - 34	Normalized Stokes parameter Q/I, positive for the electric vector perpendicular to the plane of scattering, negative for the electric vector parallel to the plane [dimensionless]
error	F6.4	36 - 41	One σ
U/I	F7.4	43 - 49	Normalized Stokes parameter U/I, positive for the electric vector 45 degrees counterclockwise from positive values of Q, negative for 45 degrees clockwise [dimensionless]
error	F6.4	51 - 56	One σ
V/I	F7.4	58 - 64	Normalized Stokes parameter V/I, positive for left-handed as seen by the observer, negative for right-handed as seen by the observer [dimensionless]
error	F6.4	66 - 71	One σ
Aperture size	F5.1	73 - 77	Diameter [arcsec]
Radial offset	I4	79 - 82	Radial distance between the center of the aperture and the peak brightness of the comet [arcsec]
Offset direction	I3	84 - 86	Angular direction [deg] (eastward from north) of the radius vector to the center of the aperture from the peak in brightness
Integration time	I4	88 - 91	Integration time [s]
Airmass	F5.3	93 - 97	Airmass at the midpoint in time, usually as quoted by the observer

8. ACKNOWLEDGMENTS

The extensive program to establish a network of standard stars for the narrowband photometric system would have been impossible without the assistance to the Discipline Specialist Team from P.V. Birch (Perth Observatory, Australia), A. Gutierrez-Moreno (Universidad de Chile, Chile), R.L. Millis (Lowell Observatory, U.S.A.), H. Moreno (Universidad de Chile, Chile), D.G. Schleicher (Lowell Observatory, U.S.A.), and E. Wenderoth (Universidad de Chile, Chile).

The Discipline Specialist Team would like to particularly thank all the observers listed in Appendix C for their efforts to make this archive a success. In nearly all cases, their efforts were totally voluntary, unsupported financially by the

Table XVII. Format of the Printed Archive and the Index Table

Header	Value/Explanation
GENERAL SECTION	
Date(UT)	Date of the middle of observation (in UT days and fractions)
PPN#	Photometry and Polarimetry Network number—a unique number for each FITS file
Filter	Filter name
λ	Central wavelength of filter [Å]
$\Delta\lambda$	FWHM of filter [Å]
ApDia	Aperture diameter [arcsec]
ExpS	Integration time [s]
FLUXES (NARROWBAND PHOTOMETRY)	
LogFlux	Logarithm (base 10) of the flux and uncertainty; '<' indicates a limit
POLARIMETRY	
Type	Polarization type, 'CL' => left circular, 'CR' => right circular, 'LN' => linear.
Polar	Degree of polarization [%] and uncertainty (one σ)
Angle	For linear polarization, the position angle of the electric vector [deg] clockwise from the plane of scattering and its 1-σ uncertainty
MAGNITUDES (BROADBAND AND NARROWBAND PHOTOMETRY)	
Mag	Magnitude in a photometric system and uncertainty; '<' indicates a 3-σ limit
STOKES (POLARIMETRY)	
Q/I	Normalized Stokes parameter normal to scattering plane and uncertainty (one σ); '<' indicates a 3-σ limit
U/I	Normalized Stokes parameter at 45 degrees to scattering plane and uncertainty (one σ); '<' indicates a 3-σ limit
V/I	Normalized Stokes parameter for circular polarization and uncertainty (one σ); '<' indicates a 3-σ limit

Table XVII. (continued)

Header	Value/Explanation
GENERAL SECTION (CONT.)	
Offset rho	Radial distance between the center of the aperture and the peak brightness of the comet [arcsec]
Offset theta	Angular direction [deg] (eastward from north) of the radius vector between the peak brightness and the center of the aperture.
Airm	Airmass at the midpoint of the observation.
System	System codes '5oooxxyy'. See Section VII.
Observer	Name(s) of observer(s)
Notes	Comment notes

IHW. In addition, several individuals also contributed by enlisting other observers and by collecting data. Particularly noteworthy was N. Kiselev, who collected, organized, and submitted data from nearly all observatories in the U.S.S.R. in addition to carrying out his own observational program both in the U.S.S.R. and in Bolivia.

Finally, I would like to personally thank the many individuals who worked directly for me during the existence of the IHW for their many efforts.

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Appendix A. Transmission Curves of Actual Filters

Lambda [Å]	Trans.	Lambda [Å]	Trans.	Lambda [Å]	Trans.	Lambda [Å]	Trans.
			Filter: 3650/80; M30				
3522	0.00152	3587	0.08181	3652	0.3030	3717	0.0237
3527	0.00167	3592	0.1169	3657	0.3030	3722	0.0130
3532	0.00200	3597	0.1515	3662	0.3030	3727	0.0079
3537	0.00222	3602	0.2030	3667	0.3006	3732	0.00303
3542	0.00242	3607	0.2424	3672	0.2912	3737	0.00285
3547	0.00258	3612	0.2783	3677	0.2424	3742	0.00278
3552	0.00303	3617	0.2912	3682	0.20907	3747	0.00248
3557	0.00576	3622	0.2936	3687	0.1515	3752	0.00222
3562	0.00788	3627	0.29827	3692	0.1224	3757	0.00217
3567	0.00939	3632	0.3013	3697	0.0821	3762	0.00203
3572	0.02275	3637	0.3013	3702	0.0559	3767	0.00192
3577	0.02908	3642	0.3030	3707	0.0297	3772	0.00152
3582	0.0303	3647	0.3030	3712	0.0266		
			Filter: 3871/50; A16				
3802	0.00033	3842	0.03343	3882	0.3316	3922	0.04072
3807	0.00078	3847	0.08311	3887	0.3343	3927	0.02804
3812	0.00147	3852	0.1327	3892	0.3289	3932	0.02117
3817	0.00207	3857	0.1932	3897	0.3049	3937	0.00669
3822	0.00289	3862	0.2474	3902	0.2675	3942	0.00319
3827	0.00613	3867	0.2835	3907	0.2163	3947	0.00215
3832	0.01297	3872	0.3129	3912	0.1488	3952	0.00152
3837	0.02609	3877	0.3236	3917	0.09772	3957	0.00078
						3962	0.00033
			Filter: 4060/70; A22				
3972	0.00026	4012	0.1592	4052	0.512	4092	0.2326
3977	0.00038	4017	0.256	4057	0.5079	4097	0.1335
3982	0.00051	4022	0.3911	4062	0.5038	4102	0.0512
3987	0.00187	4027	0.4628	4067	0.49152	4107	0.02638
3992	0.00359	4032	0.4833	4072	0.49152	4112	0.00512
3997	0.00512	4037	0.4997	4077	0.49152	4117	0.00051
4002	0.02638	4042	0.5079	4082	0.45056	4122	0.00038
4007	0.0512	4047	0.512	4087	0.3873	4127	0.00026

Appendix A. (continued)

Filter: 4260/65; B4

Lambda [Å]	Trans	Lambda [Å]	Trans.	Lambda [Å]	Trans.	Lambda [Å]	Trans.
4200	0.001	4230	0.390	4260	0.445	4290	0.351
4205	0.002	4235	0.393	4265	0.439	4295	0.199
4210	0.007	4240	0.404	4270	0.430	4300	0.071
4215	0.021	4245	0.427	4275	0.422	4305	0.022
4220	0.084	4250	0.412	4280	0.415	4310	0.008
4225	0.261	4255	0.417	4285	0.405	4315	0.003
						4320	0.001

Filter: 4845/65; M21

Lambda [Å]	Trans	Lambda [Å]	Trans.	Lambda [Å]	Trans.	Lambda [Å]	Trans.
4714	0.00042	4779	0.02952	4844	0.6833	4909	0.04197
4719	0.00048	4784	0.03959	4849	0.6778	4914	0.03557
4724	0.00052	4789	0.04726	4854	0.6669	4919	0.02459
4729	0.00056	4794	0.06087	4859	0.6505	4924	0.01342
4734	0.00066	4799	0.1084	4864	0.6450	4929	0.00664
4739	0.00104	4804	0.2317	4869	0.6286	4934	0.00374
4744	0.00194	4809	0.3178	4874	0.5739	4939	0.00282
4749	0.00274	4814	0.4677	4879	0.4481	4944	0.00200
4754	0.00425	4819	0.5849	4884	0.3178	4949	0.00131
4759	0.00508	4824	0.6395	4889	0.2287	4454	0.00100
4764	0.00629	4829	0.6559	4894	0.1084	4459	0.00076
4769	0.01140	4834	0.6724	4899	0.06320	4464	0.00066
4774	0.01781	4839	0.6833	4904	0.05039	4969	0.00044
						4974	0.00042

Filter: 5140/90; M5

Lambda [Å]	Trans	Lambda [Å]	Trans.	Lambda [Å]	Trans.	Lambda [Å]	Trans.
5030	0.00017	5099	0.3945	5144	0.6109	5189	0.1660
5034	0.00020	5104	0.5649	5149	0.6039	5194	0.08551
5044	0.00030	5109	0.5598	5154	0.6067	5204	0.02393
5054	0.00054	5114	0.5408	5159	0.6166	5214	0.00724
5064	0.00137	5119	0.5546	5164	0.6295	5224	0.00254
5074	0.00521	5124	0.5875	5169	0.6194	5234	0.00122
5084	0.02786	5129	0.6166	5174	0.5623	5244	0.00065
5089	0.07112	5134	0.6310	5179	0.4446	5254	0.00041
5094	0.1862	5139	0.6237	5184	0.2858	5264	0.00027
						5271	0.00021

Lambda [Å]	Trans.	Lambda [Å]	Trans.	Lambda [Å]	Trans.	Lambda [Å]	Trans.
				Filter: 6840/90; B21			
6750	0.00000	6795	0.43956	6840	0.81500	6885	0.45000
6755	0.00400	6800	0.65919	6845	0.81100	6890	0.25000
6760	0.00600	6805	0.77105	6850	0.80700	6895	0.11985
6765	0.00800	6810	0.79502	6855	0.79901	6900	0.05990
6770	0.02000	6815	0.79901	6860	0.79303	6905	0.03196
6775	0.02796	6820	0.79901	6865	0.79102	6910	0.01598
6780	0.05992	6825	0.80700	6870	0.79000	6915	0.08000
6785	0.08000	6830	0.81100	6875	0.77000	6920	0.00400
6790	0.23970	6835	0.81200	6880	0.66000	6925	0.00023
						6930	0.00000
				Filter: 7000/175; B7			
6850	0.003	6940	0.746	7030	0.826	7120	0.791
6855	0.004	6945	0.748	7035	0.825	7125	0.752
6860	0.005	6950	0.756	7040	0.825	7130	0.610
6865	0.007	6955	0.770	7045	0.826	7135	0.418
6870	0.010	6960	0.783	7050	0.827	7140	0.249
6875	0.015	6965	0.794	7055	0.825	7145	0.142
6880	0.022	6970	0.801	7060	0.823	7150	0.080
6885	0.036	6975	0.806	7065	0.820	7155	0.048
6890	0.060	6980	0.808	7070	0.809	7160	0.029
6895	0.102	6985	0.809	7075	0.793	7165	0.018
6900	0.177	6990	0.812	7080	0.773	7170	0.011
6905	0.300	6995	0.814	7085	0.748	7175	0.008
6910	0.475	7000	0.816	7090	0.726	7180	0.006
6915	0.475	7005	0.819	7095	0.711	7185	0.004
6920	0.753	7010	0.822	7100	0.706	7190	0.003
6925	0.780	7015	0.823	7105	0.715	7195	0.002
6930	0.769	7020	0.824	7110	0.735	7200	0.001
6935	0.754	7025	0.825	7115	0.772		

Appendix B. The Set of Standard Stars for Narrowband Photometry

HD#	R.A. (1950)	Decl	3085	3365	3650	3871	4060	4260	4845	5140	6840	7000	Spectrum	
			Monochromatic Magnitude at Wavelength [Å]											
3379	00 34 10.8	+14 57 24	5.880	5.880	5.880	5.880	5.880	5.880	5.880	5.880	5.880	5.880	B2.5IV	*
10126	01 36 45.6	27 51 22	10.497	9.768	9.304	9.727	8.978	8.863	8.011	7.999	7.11	7.09	G8V	
13974	02 13 59.6	33 59 48	7.069	6.494	6.141	6.252	5.902	5.811	5.130	5.096	4.290	4.25	G0V	
16397	02 35 30.9	30 36 24	9.532	8.943	8.559	8.683	8.340	8.265	7.596	7.546	6.81	6.87	G1V	
16908	02 40 30.7	27 29 44	4.735	4.742	4.725	4.677	4.676	4.677	4.668	4.665	4.626	4.641	B3V	
18803	02 59 27.7	26 24 56	9.349	8.600	8.149	8.565	7.826	7.704	6.898	6.864	6.033	6.005	G8V	
22951	03 39 12.0	33 48 22	4.925	4.932	4.893	5.107	5.161	5.146	5.017	5.023	4.862	4.892	B0.5V	
23464	03 43 15.2	22 58 28	11.08	10.46	10.011	10.196	9.723	9.598	8.960	8.892		8.11	G0V	
24760	03 54 29.4	39 52 03	2.433	2.529	2.549	2.807	2.933	2.948	2.885	2.952	2.885	2.95[illegible]	B0.5V	
25680	04 02 22.4	21 52 32	8.289	7.665	7.277	7.484	6.987	6.868	6.163	6.108	5.340	5.326	G5V	
26736	04 11 32.2	23 27 02	10.581	9.896	9.472	9.732	9.178	9.055	8.318	8.269	7.433	7.360	G3V	
26912	04 12 49.0	08 46 07	4.669	4.593	4.539	4.411	4.404	4.399	4.329	4.317	4.202	4.202	B3IV	*
28099	04 23 47.7	16 38 07	10.631	9.958	9.547	9.823	9.227	9.097	8.364	8.312	7.51	7.48	G6V	+
29461	04 36 07.6	14 00 29	10.454	9.839	9.410	9.675	9.097	8.973	8.243	8.196	7.370	7.324	G5V	+
30246	04 43 38.9	15 22 59	10.861	10.170	9.767	10.053	9.456	9.340	8.585	8.539		7.68	G5V	+
30455	04 45 46.3	18 37 40	9.16	8.69	8.297	8.464	8.004	7.921	7.218	7.160	6.36	6.32	G2V	
31966	04 57 43.5	14 18 36		8.66	8.245	8.476	7.895	7.781	7.038	6.979	6.15	6.10	G2IV-V	
36351	05 28 37.0	03 15 21	5.187	5.229	5.248	5.383	5.426	5.439	5.419	5.444	5.436	5.452	B1.5V	
41753	06 04 42.9	14 46 34	4.43	4.41	4.408	4.382	4.393	4.405	4.403	4.410	4.404	4.426	B3V	
44594	06 18 47.1	-48 42 50	9.110	8.496	8.051	8.319	7.726	7.613	6.889	6.832	6.011	5.977	G2V	+
[illegible]7032	06 34 07.4	04 44 14	9.776	9.57	9.396	9.577	9.594	9.516	9.116	8.984	8.303	8.260	B2	
52266	06 57 53.9	-05 45 21	7.053	7.075	7.037	7.327	7.415	7.404	7.240	7.256	7.040	7.048	O9V	*
74280	08 40 36.7	03 34 46	4.196	4.206	4.198	4.240	4.265	4.283	4.275	4.293	4.296	4.324	B4V	*
76151	08 51 50.1	-05 14 39	8.525	7.898	7.462	7.810	7.152	7.044	6.291	6.238	5.404	5.371	G3V	
84971	09 46 12.4	-02 28 50	8.579	8.597	8.583	8.620	8.665	8.679	8.629	8.660	8.612	8.631	B2.5V	
88725	10 11 32.1	03 24 19	9.970	9.413	9.003	9.145	8.791	8.720	8.020	7.963	7.152	7.117	G1V	
89688	10 18 27.1	02 32 31	6.838	6.802	6.756	6.734	6.766	6.761	6.671	6.682	6.584	6.596	B2.5IV	*
96700	11 05 31.5	-29 54 07	8.815	8.242	7.845	7.995	7.569	7.480	6.803	6.733	5.949	5.917	G2V	
97991	11 13 38.6	-03 11 57	6.943	7.038	7.055	7.283	7.348	7.374	7.355	7.401	7.421	7.446	B1V	
99171	11 21 58.1	-42 23 39	5.924	5.989	5.975	6.087	6.118	6.132	6.115	6.141	6.129	6.152	B2V	
104337	11 58 17.5	-19 22 50	4.955	5.019	5.026	5.193	5.256	5.277	5.240	5.283	5.283	5.312	B1.5V	
105590	12 06 53.2	-11 34 36	9.365	8.727	8.296	8.593	8.000	7.890	7.141	7.089	6.248	6.216	G2V	+
112185	12 51 50.1	+56 13 51	3.23	3.02	2.84	2.10	1.98	1.93	2.00	1.89	1.59	1.65	B2	
120086	13 44 44.2	-02 11 40	7.653	7.697	7.695	7.813	7.855	7.862	7.845	7.873	7.867	7.888	B3III	*

Appendix B. (continued)

HD#	R.A. (1950)	Decl	3085	3365	3650	3871	4060	4260	4845	5140	6840	7000	Spectrum
			Monochromatic Magnitude at Wavelength [Å]										
120315	13 45 34.3	49 33 44	1.89	1.90	1.91	1.90	1.91	1.91	1.94	1.94	1.86	1.89	B3V *
121849	13 55 42.9	-33 45 15	10.743	10.024	9.614	9.874	9.339	9.256	8.466	8.421	7.542	7.506	G5V
122980	14 02 59.0	-40 56 28	4.159	4.161	4.188	4.301	4.325	4.334	4.342	4.358	4.365	4.386	B2V
124580	14 12 27.6	-44 46 00	8.593	8.014	7.644	7.769	7.390	7.285	6.624	6.550	5.773	5.745	G1V
133955	15 05 27.9	-45 05 20	4.054	4.017	4.035	4.062	4.060	4.066	4.075	4.065	4.049	4.054	B3V
136352	15 18 25.2	-48 08 06	8.062	7.425	7.012	7.221	6.754	6.673	5.944	5.896	5.066	5.033	G2V
137432	15 24 05.5	-36 35 37	5.600	5.570	5.561	5.504	5.472	5.475	5.492	5.455	5.416	5.437	B4V
148045	16 24 27.7	-56 34 03	10.83		10.07	9.86	9.61	9.48	9.06	8.94	8.32	8.31	G0V
149363	16 31 47.9	-06 01 59	7.770	7.752	7.706	7.938	8.027	8.007	7.818	7.823	7.590	7.600	B0.5III*
149438	16 32 45.9	-28 06 51	2.26	2.281	2.340	2.656	2.767	2.801	2.780	2.820	2.84	2.89	B0V
164852	18 00 14.7	20 49 57	5.443	5.398	5.372	5.337	5.323	5.317	5.292	5.269	5.186	5.208	B3V *
165185	18 03 00.9	-36 01 32	8.207	7.648	7.245	7.381	6.988	6.874	6.212	6.139	5.374	5.352	G5V
166197	18 07 36.8	-33 48 40	5.903	5.956	5.932	6.104	6.184	6.190	6.113	6.154	6.081	6.106	B1V
175191	18 52 09.9	-26 21 38	1.955	1.95	1.955	2.02	2.045	2.065	2.09	2.09	1.92	1.95	B2.5V
186427	19 40 32.0	50 24 03	8.779	8.093	7.671	7.946	7.350	7.240	6.492	6.451	5.616	5.635	G5V +
189340	19 57 04.3	-10 05 25	8.094	7.518	7.170	7.249	6.882	6.768	6.138	6.075	5.315	5.296	G0V
191263	20 06 15.1	10 34 44	6.430	6.410	6.390	6.366	6.365	6.364	6.347	6.346	6.302	6.328	B3IV *
191639	20 08 27.5	-08 59 30	6.099	6.159	6.153	6.394	6.486	6.495	6.423	6.475	6.432	6.463	B1V
191854	20 08 33.7	43 47 43	9.982	9.274	8.864	9.134	8.539	8.433	7.671	7.641	6.813	6.817	G1 +
193901	20 20 38.8	-21 31 05	10.573	10.028	9.723	9.775	9.585	9.494	8.903	8.827	8.072	8.049	G3V
198188	20 46 21.9	-20 48 51	10.428	9.819	9.438	9.609	9.153	9.053	8.394	8.325	7.559	7.543	G0V
214680	22 37 00.7	38 47 22	4.268	4.349	4.381	4.716	4.834	4.858	4.811	4.880	4.898	4.921	B2
218687	23 07 27.5	14 09 22	8.793	8.211	7.846	7.984	7.586	7.475	6.821	6.760	6.003	5.976	G0V
219188	23 11 28.0	04 43 29	6.675	6.723	6.727	6.992	7.100	7.102	7.001	7.062	6.992	7.023	B0.5III*

* Primary flux standards (equatorial).
\+ Primary solar analogs.

Appendix C. List of Observers and Their Affiliations

Observer	Affiliation
M.F. A'Hearn	University of Maryland, U.S.A.
E. Alvarez	Kitt Peak National Observatory, U.S.A.
P.J. Andrews	Royal Greenwich Observatory, U.K.
J. Arnaud	Observatoires du Pic du Midi et de Toulouse, France
G.A. Baratta	Citta Universitaria, Catania, Italy
E.S. Barker	McDonald Observatory, U.S.A.
P. Bastien	Universite de Montreal, Canada
J. Baudrand	Observatoire de Paris, Meudon, France
M.J.S. Belton	Kitt Peak National Observatory, U.S.A.
P.V. Birch	Perth Observatory, Australia
N. Brosch	Wise Observatory, Israel
H. Butcher	Kitt Peak National Observatory, U.S.A.
F.A. Catalano	Citta Universitaria, Catania, Italy
G.P. Chernova	Institute of Astrophysics, Dushanbe, U.S.S.R.
A. Chevillot	Observatoire de Paris, Meudon, France
K.I. Churyumov	T. G. Shevchenko Kiev University, U.S.S.R.
J.J. Claria	Observatorio Astronomico, Cordoba, Argentina
M. Combes	Observatoire de Paris, Meudon, France
D. Cruissaire	Observatoire de Paris, Meudon, France
G.E. Danielson	California Institute of Technology and JPL, U.S.A.
A. Dollfus	Observatoire de Paris, Meudon, France
L. Drissen	Universite de Montreal, Canada
Y.S. Efimov	Crimean Astrophysical Observatory, U.S.S.R.
M.A. Eritzian	Byurakan Astrophysical Observatory, U.S.S.R.
P. Felenbok	Observatoire de Paris, Meudon, France
A. Fitzsimmons	University of Leicester, U.K.
E. Gerard	Observatoire de Paris, Meudon, France
S.I. Gerasimenko	Institute of Astrophysics, Dushanbe, U.S.S.R.
S.Y. Gorda	Kourovskaya Observatory, U.S.S.R.
J. Guerin	Observatoire de Paris, Meudon, France
H.H. Guetter	U.S. Naval Observatory, Flagstaff, U.S.A.
A.L. Guralchuk	Tarija expedition, U.S.S.R.
H.B. Hammel	University of Hawaii, U.S.A.
D. Jewitt	California Institute of Technology and Massachusetts Institute of Technology, U.S.A.
A. John	Perth Observatory, Australia
J. Johnston	Perth Observatory, Australia
H.E. Jorgensen	University Observatory, Copenhagen, Denmark
V.V. Kayumov	Institute of Astrophysics, Dushanbe, U.S.S.R.
S. Kikuchi	Tokyo Astronomical Observatory, Japan
G.C. Kilambi	Osmania University, Hyderabad, India
R. Killinger	Ruhr Universitaet, Bochum, F.R.G.
N.N. Kiselev	Institute of Astrophysics, Dushanbe, U.S.S.R.
P. Kjaergaard	University Observatory, Copenhagen, Denmark

Appendix C. (continued)

Observer	Affiliation
P.P. Korsun	Main Astronomical Observatory, Kiev, U.S.S.R.
V.P. Kozhevnikov	Kourovskaya Observatory, U.S.S.R.
A.V. Krivtsov	Assah Observatory, U.S.S.R.
K.S. Kuratov	Assah Observatory, U.S.S.R.
E. Lapasset	Observatorio Astronomico, Cordoba, Argentina
N. Lark	University of the Pacific, U.S.A.
J.F. Le Borgne	Observatoires du Pic du Midi et de Toulouse, France
J. Lecacheux	Observatoire de Paris, Meudon, France
E.M. Leibowitz	Tel-Aviv University, Israel
G. Lelievre	Canada-France-Hawaii Telescope, U.S.A.
J.P. Lemonnier	Canada-France-Hawaii Telescope, U.S.A.
J.L. Leroy	Observatoires du Pic du Midi et de Toulouse, France
A.V. Loktin	Ural State University, U.S.S.R.
D.F. Lupishko	Astronomical Observatory, Kharkov, U.S.S.R.
J. Manfroid	Universite de Liege, Belgium
L. Martin	Lowell Observatory, U.S.A.
F. Martin	Perth Observatory, U.S.A.
P. McCarthy	University of California, Berkeley, U.S.A.
K.J. Meech	Massachusetts Institute of Technology and University of Hawaii, U.S.A.
F. Menard	Universite de Montreal, Canada
Y. Mikami	Tokyo Astronomical Observatory, Japan
R.L. Millis	Lowell Observatory, U.S.A.
A.S. Miroschnichenko	Main Astronomical Observatory, Pulkovo, U.S.S.R.
H. Moreno	Universidad de Chile, Chile
A.V. Morozhenko	Main Astronomical Observatory, Kiev, U.S.S.R.
D.B. Mukanov	Assah Observatory, U.S.S.R.
R. Nadeau	Universite de Montreal, Canada
I.V. Nosov	Astrophysics Institute, Kazakhstan, U.S.S.R.
C.B. Opal	McDonald Observatory, U.S.A.
H. Pedersen	European Southern Observatory, Chile
W. Pfau	Friedrich-Schiller-Universitat, G.D.R.
J.P. Picat	Observatoire du Pic du Midi, France
D.J. Piscitelli	University of Hawaii, U.S.A.
J.I. Polevaya	Institute of Astrophysics, Dushanbe, U.S.S.R.
T.S. Polyshina	Ural State University, U.S.S.R.
C.L. Presti	Citta Universitaria, Catania, Italy
V.Y. Rakhimov	Institute of Astrophysics, Dushanbe, U.S.S.R.
G.R. Ricker	Massachusetts Institute of Technology, U.S.A.
D.I. Rodetsky	Assah Observatory, U.S.S.R.
K.I. Rspayev	T. G. Shevchenko Kiev University, U.S.S.R.
N. St. Louis	Universite de Montreal, Canada
M.B.K. Sarma	Osmania University, Hyderabad, India
D.G. Schleicher	Lowell Observatory, U.S.A.

Appendix C. (continued)

Observer	Affiliation
N.M. Shakhovskoy	Crimean Astrophysical Observatory, U.S.S.R.
V.G. Shevchenko	Institut Kosmicheskiikh Issledovaniikh, U.S.S.R.
T. Siklitsky	Institute of Astrophysics, Dushanbe, U.S.S.R.
R.F. Sistero	Observatorio Astronomico, Cordoba, Argentina
H. Spinrad	University of California, Berkeley, U.S.A.
B. Stecklum	Friedrich-Schiller-Universitat, G.D.R.
C. Sterken	Vrije Universiteit, Brussels, Belgium
R.P.S. Stone	Lick Observatory, U.S.A.
A.D. Storrs	University of Hawaii, U.S.A.
G. Strazzulla	Citta Universitaria, Catania, Italy
J.L. Suchail	Ecole Normale Superieure, Paris, France
K.V. Tarasov	Institute of Astrophysics, Dushanbe, U.S.S.R.
D.J. Tholen	University of Hawaii, U.S.A.
D.T. Thompson	Lowell Observatory, U.S.A.
L.I. Tsvetkov	Institute of Astrophysics, Dushanbe, U.S.S.R.
F.A. Tupieva	Institute of Astrophysics, Dushanbe, U.S.S.R.
R.A. Vardanian	Byurakan Astrophysical Observatory, U.S.S.R.
F.P. Velichko	Astronomical Observatory, Kharkov, U.S.S.R.
P. Vivekananda Rao	Osmania University, Hyderabad, India
F.J. Vrba	U.S. Naval Observatory, Flagstaff, U.S.A.
R.L. Walker	U.S. Naval Observatory, Flagstaff, U.S.A.
L. Walsh	Perth Observatory, Australia
P.A. Wehinger	Arizona State University, U.S.A.
E. Wenderoth	Universidad de Chile, Chile
R.M. West	European Southern Observatory, F.R.G.
I.P. Williams	Queen Mary College, U.K.
W. Wisniewski	University of Arizona, U.S.A.
S. Wyckoff	Arizona State University, U.S.A.
R.V. Yudin	Main Astronomical Observatory, Pulkovo, U.S.S.R.
N.Y. Yutanov	Main Astronomical Observatory, Pulkovo, U.S.S.R.

Appendix D. System Codes

Code	Observatory	# Files	Telescope	Comments
50050106	Meudon	1	1.00 m	Meudon PPHR; rotating 1/2-λ plate
50320101	Jena	21	0.90 m	data as M_0, used reported values of k to re-reduce the data
50940101	Crimea	17	1.25 m	
50940106	Crimea	10	1.25 m	
50970101	Wise	16	1.00 m	
51010101	Kharkov	3	0.7 m	
51230206	Byurakan	5	0.5 m	
51680101	Kourovskaya	3	0.5 m	
51900101	Hissar	10	0.7 m	
52000101	Mt. Sanglok	209	1.0 m	photomultiplier; dc mode
52000106	Mt. Sanglok	34	1.0 m	photomultiplier; dc mode
52170101	Assah	1	1.0 m	
52170106	Assah	13	1.0 m	
52190101	Japal-Rangapur	25	1.20 m	EMI 9658R; Ortec counter; assumed $\tau = 3.0 \times 10^{-8}$ s but all rates low therefore τ irrelevant; unknown number of observations had integration time = 15 s instead of 12 s.
53040206	Las Campanas	31	0.6 m	Minipol; rotating half-wave-plate
53230101	Perth	148	PlanetPatrol	Lowell-style photometer; dc mode
53870106	Dodaira	23	0.91 m	f/18; 8-channel polarimeter
54740101	Mt. John	196	0.61 m	Mt. John photometer data as Mi via E-mail
55001301	South African	32	0.50 m	data as Mi
55002106	Mt. Megantic	10	1.6 m	Rotating 1/4-wave plate + Pockels
55009910	IUE	52	0.45 m	Reported lat/long are fictitious. Reported magnitudes obtained with Fine Error Sensor (FES), image dissector tube which scans focal plane in cross pattern. Conversion to magnitudes done using methods described in IUE manuals.
55110102	Haute Provence	7	1.93 m	f/5 Newtonian focus, RCA CCD
55590101	Catania	256	0.91 m	data as Mi
55680203	Mauna Kea	21	CFHT	f/4.2-prime focus; electronographic camera

Appendix D. (continued)

Code	Observatory	# Files	Telescope	Comments
55680301	Mauna Kea	5	UH-88	Tholen's photometer; data as Mi "Tinsley" photometer, RCA C31034 LeCroy MVL100 pulse-amp/discrim
55680701	Mauna Kea	79	AirForce-24	Tholen's photometer; data as Mi "Tinsley" photometer, RCA C31034 LeCroy MVL100 pulse-amp/discrim
55860106	Pic du Midi	18	1.0 m	
55860202	Pic du Midi	2	2.0 m	f/5 Strand focus, RCA CCD
56620301	Lick	5	0.60 m	data in Mi
56750102	Palomar	7	Hale	prime focus, Pfuei + TI CCD
56860101	Mt. Lemmon	14	1.50 m	data as M(std); RCA C31034
56880101	Lowell	9	Perkins	Lowell blue Photometer; EMI 6256 Pacific Photometric Counter $\tau = 6.0 \times 10^{-8}$
56880104	Lowell	9	Perkins	Lowell Blue photometer; EMI 6256 Ortec counter, $\tau = 1.0 \times 10^{-7}$
56880106	Lowell	1	Perkins	VATPOL polarimeter
56880201	Lowell	29	JSHall-42	Lowell blue photometer; EMI 6256 Pacific Photometric Counter $\tau = 6.0 \times 10^{-8}$; f/16
56880204	Lowell	1	JSHall-42	Lowell blue photometer; EMI 6256 Ortec counter $\tau = 1.0 \times 10^{-7}$; f/16
56880501	Lowell	12	JSHall-42	Lowell blue photometer; EMI 6256 Pacific Photometric Counter $\tau = 6.0 \times 10^{-8}$; f/8
56890106	USNO-Flagstaff	19	1.0 m	VATPOL polarimeter
56900101	Lowell	2	Morgan-24	Blue Photometer, EMI 6256 at 1220v Pacific Photometric Counter $\tau = 6.0 \times 10^{-8}$
56900104	Lowell	0	Morgan-24	Blue Photometer, EMI 6256 at 1300v Ortec counter, $\tau = 1.0 \times 10^{-7}$ s
56950102	Kitt Peak	4	4.0 m	prime focus, cryogenic CCD
56950202	Kitt Peak	10	2.1 m	f/7.5 RCA #1 CCD
56951102	McGraw-Hill	7	1.3 m	f/13.5 MASCOT CCD
57110102	McDonald	3	2.72 m	RCA CCD
58070301	Cerro Tololo	480	Yale-40	ASCAP (Automatic Single-Channel Aperture Photometer)

Appendix D. (continued)

Code	Observatory	# Files	Telescope	Comments
58070801	Cerro Tololo	577	PlanetPatrol	Lowell Blue photometer; EMI6256 at 1220v (occ. 1225 or 1300) Pacific Photometric counter, $\tau = 6.0 \times 10^{-8}$
58090106	ESO	8	1.52 m	Meudon PPHR; rotate 1/2-λ plate
58090302	ESO	6	Danish-1.5 m	RCA SID53612 CCD
58090501	ESO	72	0.50 m	
58200101	Tarija	47	0.60 m	data in Mi
58200106	Tarija	19	0.6 m	
58210101	Bosque Alegre	66	1.54 m	data as M0, used reported k's to re-reduce the data. Errors much larger than random scatter among measures on a given night because all such points were taken in a short time interval and dm and extinction were poorly determined.
59500301	La Palma	400	J.Kapteyn	$\tau = 0.96 \times 10^{-7}$ s; data as Mi; E-mail; 2-channel photometer with filters, one channel = (OH, UCNT, CN, C_3, CO^+), other = (BCNT, C_2, RCNT, H_2O^+). Two channels view different parts of sky, separated by 177". Telescope offsets used to position the two different channels on particular positions at different times. In March 1986 a beam-splitter joined both channels. Data subject to quantization errors at low signal levels. Arbitrarily assumed ± 0.5 counts for errors. Errors may be underestimated at some locations, particularly far from nucleus where continuum is very uncertain.

RADIO SCIENCE NETWORK

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1. INTRODUCTION

Radio astronomy is a new technique developing for the study of comets. In some areas, such as observations of the OH radical via its 18-cm transitions, the observational procedures and analysis are well-developed. Studies in these areas have proved their value, since they provide both new probes of important physical processes and a window on physical processes that are less well known and less accessible to study by other techniques. In many other areas, however, the study of comets at radio wavelengths continues to be primarily an exploratory endeavor. In recognition of this fact, the International Halley Watch (IHW) Radio Science Discipline Specialist team (see Table I) felt that it was important to attempt many different kinds of observations during the Comet Halley campaign, since each observation has scientific merit as an exploration. Thus, we have been careful to document and include all data submitted to this archive by radio observers.

The Comet Halley Archive contains data from 36 different observing groups, representing a range of techniques. The majority of the observational data comes in the well-developed area of 18-cm OH observations. However, many other projects were attempted as well. Approximately 75% of the groups known to have obtained useful data on the comet have submitted them to the archive, and we are grateful to these people for their contributions.

In this chapter, we describe the format of the data contained in the Radio Science archive of observations of P/Halley. In Section 2, we present a detailed description of the Flexible Image Transport System (FITS) files, which contain the data. Section 3 contains a description of the Radio Science Index to the compact disc—read only memory (CD-ROM). Section 4 provides a description of the printed archive format, which may also be used as an index to the data under some circumstances. The units adopted by the Radio Science Network are given in Section 5, and the calibration of data is discussed in Section 6. Finally, in Section 7, we acknowledge those who have been so helpful to us in the construction of this archive.

2. THE RADIO SCIENCE FITS FORMAT

2.1. FITS Header Description

The IHW Radio Science archive is written in FITS format, following the standard for all networks within the IHW. FITS files are a standard for the interchange of astronomical data. These files consist of one or more 2880-byte header records, which contain the documentary information about the observations, followed by 0 or

Table I. Discipline Specialist Team of the Radio Science Network

Team Member	Affiliation	Responsibility
William M. Irvine	Astronomy Program University of Massachusetts Amherst, MA 01003 U.S.A.	Discipline Specialist
F. Peter Schloerb	Astronomy Program University of Massachusetts Amherst, MA 01003 U.S.A.	Discipline Specialist
Eric Gerard	Departement de Radioastronomie Observatoire de Meudon F-92190 Meudon France	Discipline Specialist
Ronald D. Brown	Department of Chemistry Monash University Clayton, Victoria 3168 Australia	Discipline Specialist 1981–1985
Peter D. Godfrey	Department of Chemistry Monash University Clayton, Victoria 3168 Australia	Discipline Specialist 1981–1985
Wayne M. Kinzel	Astronomy Program University of Massachusetts Amherst, MA 01003 U.S.A.	Archive Manager

more 2880-byte data records in the format specified by the FITS header. In the IHW archive, these two parts of a FITS file—the header records and the data records—are presented in two different files to facilitate their use by a wide range of analysis software. However, we note that users who require FITS format files have only to concatenate the header and data files to make a standard FITS file.

The FITS header is meant to provide a description of the structure and format of the FITS data records that follow it and to offer any auxiliary information necessary for their interpretation. For the Radio Science FITS header, we have defined several FITS keywords that specify observational parameters necessary to interpret the data. Section 2.1 presents a detailed description of the complete Radio Science FITS header. In general, the Radio Science Network has tried to conform to

Table II. Keyword Block I

Keyword	Type	Description
SIMPLE	L	Conformity to basic FITS standards
BITPIX	I	Bits per pixel in the data record
NAXIS	I	Number of axes in the data record; if NAXIS = 0, then there is no data record
NAXIS1	I	Number of pixels in the row along the first axis; if NAXIS1 = 0, then this is Extended FITS Format and GROUP data are present
NAXISn	I	Number of pixels along the n-th axis in the image

standards commonly used in FITS and adopted by the IHW. The characteristics of the observation are described by assigning values to the "keywords" that are listed in Tables II, III, and IV. We note that the special keywords we have defined have been selected to specify information vital to the interpretation of the data, such as specification of the observing frequency or telescope parameters. At another level, under FITS HISTORY keywords, we present information about how the data were obtained, including calibration and orbital tracking information. The distinction between these groupings is admittedly somewhat arbitrary and has been made primarily to limit the number of new FITS keywords defined by our network.

In an exploratory program such as the Radio Science Network, it is to be expected that many observations will fail to detect the comet, and the data to be archived are best described as an upper limit rather than as a thorough presentation of a spectrum or image. In recognition of this fact, the IHW permits FITS files to be created without any data records at all, and in this case, the "data" are presented as a summary in the FITS HISTORY section of the Radio Science header. FITS files of this type may be recognized because they have the NAXIS keyword set equal to 0 and the DAT-TYPE keyword set equal to the character string 'NODATA '.

Where possible, even when actual data exist, we have attempted to describe them by presenting the results of a model fit to the data. In spectral line work, for example, a line is often described in terms of its peak intensity, the velocity of the peak, the line width, the integrated area under the line, and the mean velocity of the emission. We have provided these values in FITS HISTORY keywords by fitting a Gaussian line shape model to the data.

2.1.1. *Keyword Block I: Basic FITS Keywords.* This block of keywords is required for FITS tapes. See Table II for details.

2.1.2. *Keyword Block II: IHW Keywords.* These keywords have been agreed upon for use by the entire IHW and are listed in Table III.

2.1.3. *Keyword Block III: Radio Science Keywords.* These keywords are designed to be directly read by computers in the normal manner of FITS header keywords. Some attempt has been made to choose keyword names already in use by the astro-

Table III. Keyword Block II

Keyword	Type	Description
OBJECT	C	Name of the object Examples: 'P/CROMMELIN' 'P/HALLEY' 'P/GIACOBINI-ZINNER'
FILE-NUM	I	6NNNNV - a unique, sequential number to identify files sent to the IHW Lea Center. Format description: 6 = denotes the Radio Science Network NNNN = a unique 4-digit ID number assigned to each observation V = version number (used to keep track of resubmissions)
DATE-OBS	C	'DD/MM/YY' - UT date of the middle of the observation. If observations were made during several intervals, then these intervals will be specified in the HISTORY fields described below
TIME-OBS	R	the UT time of the middle of the observation, expressed in decimal days
DATE-REL	C	'DD/MM/YY' - the date when observations may be publicly released
DISCIPLN	C	'RADIO STUDIES' - the Network identification
LONG-OBS	C	'DDD/MM/SS' - the east longitude of the observatory (0-360 deg)
LAT--OBS	C	'sDD/MM/SS' - the latitude of the observatory
SYSTEM	C	'6OOOCCTT' - the system code, formatted as follows: 6 = the Radio Science Network OOO = the IAU number for the observatory (OOO = 500 for radio observatories, since no IAU number exists) CC = identifies the country according to the Large-Scale Phenomena Network (LSPN) Code TT = identifies the radio telescope
OBSERVER	C	Name of the observer Format : 'LASTNAME,I' - 1 author 'LASTNAME,I/NEXTNAME,J' - 2 authors 'LASTNAME,I/ET AL.' - > 2 authors For more than 2 observers, the names of all additional observers are given in special ADD. OBS. comments
SUBMITTR	C	Name of the submitter of data
SPEC-EVT	L	Flag for special events as designated by the Discipline Specialist
DAT-FORM	C	Describes the format of the FITS data records 'NODATA ' no FITS data records written 'STANDARD' - data records conform to FITS standard 'ASCII ' - data records are to be interpreted as logical records of 80 ASCII characters (not FITS standard) 'HARDCOPY' - data submitted as hardcopy

nomical community. These keywords are used to describe information vital to data interpretation or potentially useful for searches of the database (see Table IV).

2.1.4. *Keyword Block IV: Special Keywords for the Printed Archive.* This group of COMMENT lines gives additional information to be used in the production of the IHW printed archive.

The ADD. OBS. comment gives the names of the full observing team when more than two observers carried out the observations. More than one ADD. OBS. comment may be used to specify teams with many members or long names. The format of the ADD. OBS. comment is:

```
COMMENT   ADD. OBS.   NAME,I/NAME2,I/NAME3,I
```

The NOTE comment provides information to be printed in the following format as a footnote in the printed archive:

```
COMMENT   NOTE   THIS IS A TEST
```

2.1.5. *Keyword Block V: Radio Science Data History Section.* This block of FITS HISTORY keywords is provided to incorporate additional information about the observation, such as descriptions of calibration methods and sources, details about observing procedures, and comments by the observer and the IHW Discipline Specialist. Another important use of the HISTORY lines is to provide a summary of the data obtained or, in the case of FITS files with no data records, the actual data values reported by the observer. The general format of the HISTORY lines is:

```
column
1          11          21
HISTORY     SUBKEY__    VALUES....
```

where 'VALUES' is a list of values associated with this subkey. In most cases, the value lists are in a fixed format to simplify their use.

2.1.5.1. *Data summary section.* To transmit upper limits or a summary of the data appropriate for tabular presentation in the printed archive, we utilize one of the following HISTORY keyword formats. Such data summaries will always be contained in the first part of the HISTORY keyword section; the presence of such a summary shall be indicated in the DAT-TYPE keyword discussed above. When FITS data records accompany the header, **users of the archive are cautioned that the summary values are meant only to describe and characterize the data, not to replace them.**

All summary lines follow the same general form:

```
HISTORY   SUBKEY   ################   'UNITS    '
```

where the # field is a right-justified floating-point number.

Table IV. Keyword Block III

```
Keyword   Type  Description

DIS-CODE  C     'TFESEWEABENC'-describes parameters of the telescope/instrument
                T : Telescope type
                     S = single antenna
                     I = interferometer
                     U = unknown/unclassified
                FE: Frequency (Center Frequency or Rest Frequency)
                     FE=> frequency = F x 10**(E) MHz
                     00=  unknown
                SE: Spectral resolution
                     SE=> spectral resolution = S x 10**(E) Hz
                     00=  unknown
                WE: Bandwidth
                     WE=> bandwidth = W x 10**(E) Hz
                     00=  unknown
                A : Beam description
                     C = circular
                     E = elliptical
                     O = other
                     U = unknown
                BE: Beam size (geometric mean)
                     BE=> beam size = B x 10**(E) arcsec
                     00= unknown
                N : Noise estimate
                     N => RMS noise = 10**(N) microjanskys/beam
                     0 = unknown
                C : Information provided by the observer to the Discipline
                    Specialist is complete
                     T = TRUE
                     F = FALSE
DAT-TYPE  C     'NNSTHP' - describes the data format in the Header and Data
                Records
                NN: Subnetwork
                    OH= OH Subnetwork
                         Spectral line observations of 18-cm OH
                    SL= Spectral Line Subnetwork
                         Spectral line observations (other than 18-cm OH)
                    CN= Continuum Subnetwork
                         Broadband continuum observations
                    OC= Occultation Subnetwork
                         Observation of occultation events
                    RD= Radar Subnetwork
                         Active experiments
                S : Search/detection status
                     S = search - implies nondetection (< 3 sigma)
                     D = detection - implies detection (> 3 sigma)
                     M = marginal - implies marginal detection (approx. 3 sigma)
                T : Type of data in FITS Data Records
                     N = no FITS Data Records
                     S = Spectrum => intensity vs frequency
                     C = Continuum scan => intensity vs space
                     T = Time series => intensity vs time
                     I = Image => spatial - spatial image
```

Table IV. (continued)

Keyword	Type	Description
		D = Dynamic spectrum => frequency - time image
		F = SV image => frequency - spatial image
		V = Visibility Function Data
		H : Summary of Data in Header?
		T = Summary of data exists in Header History Section
		F = No summary of data in Header History Section
		P : Polarization status
		I = Intensity data only
		P = Polarization data format used
OBSVTORY	C	Abbreviation for the observatory
TELESCOP	C	Telescope identifier - usually gives aperture size in meters
LOCATION	C	Location of the observatory as given in American Ephemeris
INSTRUME	C	'FRONT/BACK' - describes "frontend" and "backend" of receiver
		FRONT: Receiver Front End
		MASER = Maser Amplifier
		FET = Field Effect Transistor Amplifier
		PARA = Parametric Amplifier
		MIXER = Mixer
		SPEC = Special Front End
		UNK = Unknown Front End
		BACK : Receiver Back End
		FB = Filterbank
		SEFB = Filterbank With Spectrum Expander
		AC = Autocorrelator
		CONT = Broadband Continuum Receiver
		SPEC = Special Back End
		AOS = Acousto-Optical Spectrometer
		UNK = Unknown Back End
CENTFREQ	R	Center frequency of the observed bandwidth (Hz)
BANDWIDT	R	Total bandwidth (Hz)
BEAMSIZE	R	Geometric mean of the major and minor axes of the Elliptical Gaussian Beam (deg)
BEAMELON	R	Ratio of the major beam axis to minor beam axis
BEAMROTA	R	Position angle of the major beam axis (deg)
BEAMEFF	R	Beam efficiency - the fraction of power received that is in the Gaussian Main Beam (BEAMEFF = 0.0 if unknown or unspecified)
MOLECULE	C	Chemical formula for the molecule (follows the convention of the NBS interstellar-line list)
TRANSITN	C	Quantum numbers for the transition (follows the convention of the NBS interstellar-line list)
RESTFREQ	R	Rest frequency of the line used by the observer (Hz)
RES-SPEC	R	Spectral resolution (Hz) - the true spectral resolution of the spectrometer, NOT the channel spacing
EQUINOX	R	Equinox of the RA-DEC information presented in this file
RAOFF	R	Pointing offset in the RA direction DELTA(RA)*COS(DEC) (deg)
DECOFF	R	Pointing Offset in the Dec direction DELTA(DEC) (deg)
DATE-BEG	C	'DD/MM/YY' - UT date on which observations began
DATE-END	C	'DD/MM/YY' - UT date on which observations ended

The format for upper limits is:

```
COMMENT                *SUMMARY OF DATA - UPPER LIMIT
HISTORY    LIMIT                   0.5   'JY/BEAM '
```

Upper limits in the Radio Science Network are always given as 3-standard-deviation upper limits.

The for..at for spectral lines is:

```
COMMENT                   *SUMMARY OF DATA - SPECTRAL LINE
HISTORY    LINEPEAK                     0.5   'JY/BEAM '
HISTORY    ERR-PEAK                     0.1   'JY/BEAM '
HISTORY    LINE-VEL                    10.0   'M/SEC   '
HISTORY    ERR--VEL                   200.2   'M/SEC   '
HISTORY    LINE-WID                  2532.0   'M/SEC   '
HISTORY    ERR--WID                   130.2   'M/SEC   '
HISTORY    LINEAREA                  1243.1   'JY/B*M/S'
HISTORY    ERR-AREA                   143.6   'JY/B*M/S'
HISTORY    LINEMEAN                    32.1   'M/SEC   '
HISTORY    ERR-MEAN                    10.2   'M/SEC   '
```

The spectral line summary values LINEPEAK, LINE-VEL, and LINE-WID are determined from Gaussian fits to the line profiles. If one or more parameters were fixed in a fit to the data, the assumed values are listed with no errors. Spectral lines with hyperfine structure (e.g., HCN) are fitted on the assumption that all hyperfine components have their nominal intensity ratios.

The format for continuum observations is:

```
COMMENT                   *SUMMARY OF DATA - CONTINUUM
HISTORY    CONTFLUX                     0.5   'JY/BEAM '
HISTORY    ERR-FLUX                     0.1   'JY/BEAM '
```

The format for radar observations is:

```
COMMENT                   *SUMMARY OF DATA - RADAR
HISTORY    XSECTION                    30.0   'SQUARE KILOMETERS'
HISTORY    ERR-XSEC                     6.0   'SQUARE KILOMETERS'
```

2.1.5.2. *Observing window section.* Since many radio observations take place over several days, we include the precise observing windows in the HISTORY section, according to the format:

```
COMMENT                   *OBSERVING WINDOW SPECIFICATION
HISTORY    N-WINDOW                       #
HISTORY    WINDOW         'DD/MM/YY' #######     'DD/MM/YY' #######
HISTORY    WINDOW         'DD/MM/YY' #######     'DD/MM/YY' #######
```

where N-WINDOW gives the total number of windows for observations and subsequent window lines give the date and time (in decimals, as in TIME-OBS) of the beginning and end of the observing window. The time fields are right-justified floating-point numbers.

2.1.5.3. *Orbital elements section.* Radio observers track the comet "blind," and it is important to know the precise position on the sky that they were tracking. We include a provision in the HISTORY section to specify the two-body elements and observatory position data used to produce the topocentric ephemeris for tracking.

```
COMMENT                    *ORBITAL ELEMENT SPECIFICATION
HISTORY   ORBELEM                     T       - T if orbital elements are provided
HISTORY   LONGEAST         243.11046715       - east longitude of the observatory
                                                (deg)
HISTORY   RHO--COS         0.8159113419       - radius*cos(lat) for the observatory
                                                (units of Earth equatorial radius)
HISTORY   RHO--SIN         0.5765085118       - radius*sin(lat) for the observatory
                                                (units of Earth equatorial radius)
HISTORY   ET-UT                53.18439       - Ephemeris time - UT correction (s)
HISTORY   JD              2446471.16128       - Time of perihelion passage (ET)
HISTORY   Q                   0.5870959       - Perihelion distance (AU)
HISTORY   E                   0.9672671       - Eccentricity
HISTORY   SOMEGA              111.85336       - Argument of perihelion (deg)
HISTORY   LOMEGA               58.15313       - Longitude of the ascending node
                                                (deg)
HISTORY   I                   162.23779       - Inclination (deg)
```

2.1.5.4. *Antenna tracking section.* This HISTORY keyword specifies the antenna root-mean-square (rms) pointing errors

```
COMMENT                *RMS POINTING ERROR OF TELESCOPE
HISTORY   POINTERR     ################ 'UNITS    '
```

2.1.5.5. *Calibration section.* This group of keywords provides information on details of the calibration process.

```
COMMENT                *CALIBRATION METHOD INFORMATION
HISTORY   CALMETH      'DESCRIPTION OF CAL METHOD'
```

If the calibration method is unknown, no line appears. Current possible values are 'CHOPPER WHEEL', 'NOISE TUBE', 'STANDARDS', and 'ABSOLUTE'.

```
COMMENT                *CALIBRATION STANDARD INFORMATION
HISTORY   CALSRCE      'SOURCE NAME'    ########## 'UNITS    '
```

'SOURCE NAME' is the source (or sources) used to provide principal calibration. The # field is a right-justified floating-point number. When planets are the calibrators, the assumed brightness temperature is given; otherwise, the calibrator flux density is given in janskys. There may be more than one CALSRCE HISTORY line.

```
COMMENT                *SYSTEM TEMPERATURE ETC.
HISTORY   TSYSTEM      ############### '_SB     '
HISTORY   TRCVR        ############### '_SB     '
```

'TSYSTEM' represents the total system temperature, while 'TRCVR' represents the noise temperature of the receiver alone. '_SB   ' allows single sideband measurement ('SSB   ') or double sideband measurement ('DSB   ') to be indicated. The # field is a right-justified floating-point number.

```
HISTORY   TAUZENTH   ###############
```

This line indicates the atmospheric opacity at zenith. The # field is a right-justified floating-point number.

2.1.5.6. *Observer's comment section.* This block of HISTORY lines contains any extra comments about conditions, data quality, etc. sent to the Discipline Specialist by the observer. Generally, fewer than eight such comment lines are given.

```
COMMENT              *OBSERVER COMMENTS
HISTORY   OBSCOMM    ROOM TO REPORT OBSERVER COMMENTS
HISTORY   OBSCOMM    ...
HISTORY   OBSCOMM    ...
HISTORY   OBSCOMM    MORE ROOM FOR OBSERVER COMMENTS
```

2.1.5.7. *Discipline Specialist's comment section.* This block reports comments by the Discipline Specialist team on this observation. Generally, fewer than eight such comment lines are given.

```
COMMENT             *DISCIPLINE SPECIALIST COMMENTS
HISTORY   DSCOMM    ROOM TO REPORT DISCIPLINE SPECIALIST COMMENTS
HISTORY   DSCOMM    ...
HISTORY   DSCOMM    ...
HISTORY   DSCOMM    MORE ROOM FOR DISCIPLINE SPECIALIST COMMENTS
```

2.1.6. *Keyword Block VI: Standard FITS Keywords.* These keywords describe the FITS data records. They are all standard and are summarized in Table V.

2.1.7. *Keyword Block VII: End Statement.* This keyword is required by FITS to terminate the header:

```
END
```

2.2. Types of Data in the Comet Halley Archive

Several distinct types of data were obtained during the International Halley Watch, and each data type required the use of a slightly different type of FITS format. In this section, we review the individual data types and any special steps taken in formatting data of this type.

2.2.1. *Upper Limits.* As stated above in the description of the FITS format, upper limits are reported in the HISTORY section of the FITS header in the HISTORY LIMIT keyword. The detection status of a particular observation is summarized in the third character of the DAT-TYPE keyword. An 'S' implies that the observation did not yield a detection and is reported as a limit. However, in some cases, marginal results, designated by an 'M' in the DAT-TYPE keyword, have also been reported as limits.

2.2.2. *OH Spectral Line Observations.* The principal type of data is the 18-cm OH observations. These data are archived in FITS format as one-dimensional spectra of

Table V. Keyword Block VI

Keyword	Type	Description
BSCALE	R	Scale factor data = tape * BSCALE + BZERO
BZERO	R	Zero value
BUNIT	C	Units of data 'JY/BEAM ' - for line and continuum data 'STANDARD DEVIATIONS' - for radar data
BLANK	I	Value for out-of-range data
CRVALn	R	Value of the physical coordinate of the nth axis at the reference pixel
CRPIXn	R	Array location of the reference pixel for the nth axis
CDELTn	R	Increment in the physical coordinate along the nth axis
CTYPEn	C	Type of physical coordinate 'VELO-COM' - the frequency coordinate for line work in m/s, defined to be the velocity relative to the comet 'VELO-GEO' - the velocity defined relative to the center of the Earth 'FREQUENCY' - the frequency offset of the radar echo from the expected value, in units of Hz 'CIRCULAR POLARIZATION' - the axis used to define different states of circular polarization: -1 = LHC; -2 = RHC 'LINEAR POLARIZATION' - the axis used to define the linear polarization position angle 'ECHO POLARIZATION' - the axis used to define the polarization of the radar echo 'RAOFF ' - the spatial coordinate for maps (deg) 'DECOFF ' - the spatial coordinate for maps (deg) 'RA ' - the coordinate used for drift scans (deg) 'MAP-TYPE' - the coordinate to indicate the type of drift scan map: 0 = map with the comet in the beam; 1,2 = maps of the galactic background only
CROTAn	R	Rotation angle of the physical coordinate axis n

the comet's flux density as a function of the line-of-sight velocity. For most OH observations, the line-of-sight velocity is given with respect to the observer, although some observers transmitted their results to us in terms of the geocentric velocity.

Many OH line observations were conducted using two receivers having orthogonal polarizations. To preserve this information, we have presented the polarized spectral data in a two-dimensional format with a second axis to designate which polarization applies. These spectra have the NAXIS keyword set equal to 2, and the second axis is labeled either 'CIRCULAR POLARIZATION' or 'LINEAR POLARIZATION', as shown in Table V. This method for designating polarization is similar to the convention used in many FITS formats, where a separate axis (often labeled 'STOKES') is used to give the full Stokes parameters of the data. However, full Stokes parameters have not been measured in this archive, so we have defined these new polarization axes to handle this situation.

2.2.3. *Interferometric Ultraviolet (UV) Data.* Radio interferometers measure a source's visibility function, which is the Fourier transform of the source brightness distribution. In aperture synthesis imaging, a set of measurements of the visibility function are Fourier transformed to obtain an image of the source brightness distribution. Unfortunately, the processing steps required to make a map force the observer to specify many parameters that determine how the visibility data will be transformed to make the image. The specification of these parameters and the Fourier transformation of the data, in our view, constitute an interpretation of the data, and run counter to the philosophy of a data archive. Thus, we have preserved the actual visibility data in this archive.

The visibility data are presented in the extended FITS GROUP data format. This is the format currently used for visibility data by many of the world's interferometers, and FITS readers for visibility data should be able to directly read the files prepared for the IHW archive. We have tested the files in the Astronomical Image Processing System (AIPS), which is the data reduction program for the U.S. National Radio Astronomy Observatory (NRAO), and, in fact, the files are quite similar to the UVFITS format of AIPS. For spectral line data, AIPS cannot Fourier transform more than eight spectral line channels at a time. Therefore, following the style of the NRAO Very Long Array (VLA), we have taken the 32-channel data that were typically obtained and archived the data in 4 separate FITS files with 8 channels in each file. A fifth file usually accompanies these data and contains the broadband continuum data recorded at the same time as the spectral line data.

2.2.4. *Radar data.* Radar observations of Halley's Comet were carried out only at the Arecibo Observatory during November 1985. We have recorded in a single FITS file the average echo obtained during this experiment. The radar observation was made by transmitting a single frequency tone in one circular polarization toward the comet and observing the echo in both polarizations. The echo was observed in spectral line mode, and a detection was sought at the correct Doppler-shifted frequency given by the ephemeris of the comet. Thus, since this data type is identical in most respects to a spectral line observation, the data are recorded in a similar format. For a specular reflection, the echo is expected to be polarized in the sense opposite to that of the transmitted signal. However, real surfaces often contain significant power in the same sense as that transmitted, perhaps due to multiple reflections on the target. We have treated the echo polarization in the same manner as the orthogonal polarizations in the OH experiments, but with a special key to designate the "same' and the "opposite" senses of polarization.

2.2.5. *Occultations.* Many types of occultation experiments were carried out during the Halley campaign. Unfortunately, relatively few were reported to the IHW for inclusion in this archive. In the occultation observations presented here, the Milky Way was itself employed as a background source and comparison was made of the data along a track across the sky with and without the comet in the beam. When carried out as a spectral line experiment, these observations result in a two-dimensional data type with spectra taken at many positions along a track on the sky. We have attempted to preserve the raw data here by saving these two-dimensional images in the FITS file. Thus, a typical file contains: (1) the data with the comet in the beam, and (2) one or more maps, which were obtained on a different day, with the comet out of the beam. We have chosen to present these different maps as a three-dimensional "cube" of data, with NAXIS = 3. The first axis is the frequency dimension of the spectra. The second axis is the position of the spectrum in RA. Finally, the third axis, labeled 'MAP-TYPE', defines which map is being presented. 'MAP-TYPE = 0' is the data with the comet in the beam, and MAP-TYPE not equal to 0 gives the map of the galactic background alone on one or more days of observation. Users are advised to check the individual FITS headers for further information on the definition of MAP-TYPE for specific dates of observation.

3. THE RADIO SCIENCE NETWORK INDEX TO THE CD-ROMS

The IHW provides various indices to help users of the archive find the data they want. For the Radio Science Network, the IHW has provided two indices that users will find useful: the quick-look index and the printed archive index (see Section 4 for a description), both of which contain information on all observations in the archive. The Radio Science Network provides a third, discipline-specific index, which contains much more detailed information about the radio observations than the other indices do. In selecting the information to be included in the Radio Science index, we have attempted to include all relevant data from the FITS headers, within limitations imposed by the standards set by the IHW. Table VI gives the detailed format of the Radio Science index.

4. THE RADIO SCIENCE NETWORK PRINTED ARCHIVE

The printed archive provides another format in addition to the FITS presentation of the Radio Science Network data. This additional format provides most of the information necessary to make use of the data, as well as the "data summary" information included in the FITS headers, such as the line peak intensity and width for spectral line observations. The format of the printed archive for the Radio Science Network is described below.

4.1. Printed Format I: OH Subnetwork and Spectral Line Subnetwork

Since the OH Subnetwork and the Spectral Line Subnetwork contain the same data type, it is most economical to print both subnetworks together in the same subsection of the Radio Science part of the archive. Table VII provides a detailed description of this format.

4.2. Printed Format II: Continuum Subnetwork

The data in the Continuum Subnetwork are fundamentally different from the spectral line data in the previous section. Thus, these data require another format, as listed in Table VIII.

Table VI. IHW Radio Science Network Index Format

Field	Keyword	Type	Format	Notes
1	Path:Volume	C	TBD by LC	Path to file on CD-ROM
2	Path:Year SubDirect	C	A4	Ditto
3	Path:Mon. SubDirect	C	A3	Ditto
4	Path:Day SubDirect	C	A2	Ditto
5	Filename	C	A11	E.g., filename.ext
6	OBJECT	C	A20	
7	FILE-NUM	N	I6	
8	DATE-OBS	D	A8	IHW date format
9	TIME-OBS	N	F5.3	
10	LONG-OBS	C	A9	
11	LAT-OBS	C	A9	
12	SYSTEM	C	A8	
13	OBSERVER	C	A30	
14	COMMENT ADD. OBS.	C	A60	May exclude some observers
15	SUBMITTR	C	A30	
16	SPEC-EVT	L	L1	
17	DAT-FORM	C	A8	
18	DIS-CODE	C	A12	
19	DAT-TYPE	C	A6	
20	OBSVTORY	C	A10	
21	TELESCOP	C	A10	
22	LOCATION	C	A30	
23	INSTRUME	C	A20	
24	CENTFREQ	N	F11.4	In MHz
25	BANDWIDT	N	F11.4	In MHz
26	BEAMSIZE	N	F6.4	
27	BEAMELON	N	F6.3	
28	BEAMROTA	N	F6.1	
29	BEAMEFF	N	F6.3	
30	EQUINOX	N	F8.3	
31	RAOFF	N	F7.4	
32	DECOFF	N	F7.4	
33	MOLECULE	C	A10	
34	TRANSITN	C	A20	
35	RESTFREQ	N	F11.4	In MHz
36	RES-SPEC	N	F11.4	In kHz
37	HISTORY LIMIT	N	F11.4	In Jy/beam
38	HISTORY LINEPEAK	N	F11.4	In Jy/beam
39	HISTORY ERR-PEAK	N	F11.4	In Jy/beam
40	HISTORY LINE-VEL	N	F11.4	In m/s
41	HISTORY ERR--VEL	N	F11.4	In m/s
42	HISTORY LINE-WID	N	F11.4	In m/s
43	HISTORY ERR--WID	N	F11.4	In m/s
44	HISTORY LINEAREA	N	F11.4	In Jy/beam * m/s
45	HISTORY ERR-AREA	N	F11.4	In Jy/beam * m/s
46	HISTORY LINEMEAN	N	F11.4	In m/s
47	HISTORY ERR-MEAN	N	F11.4	In m/s
48	HISTORY CONTFLUX	N	F11.4	In Jy/beam

Table VI. (continued)

Field	Keyword	Type	Format	Notes
49	HISTORY ERR-FLUX	N	F11.4	In Jy/beam
50	DATE-BEG	D	A8	Date format
51	DATE-END	D	A8	Date format
52	HISTORY NWINDOW	N	I1	
53	HISTORY WINDOW (1)	D	A8	Start Date of 1st Window (Date Fmt)
54	HISTORY WINDOW (1)	N	F5.3	Start Time of 1st Window
55	HISTORY WINDOW (N)	D	A8	End Date of Last Window (Date Fmt)
56	HISTORY WINDOW (N)	N	F5.3	End Time of Last Window
57	HISTORY POINTERR	N	F10.2	In arcsec
58	HISTORY CALMETH	C	A20	
59	HISTORY CALSRCE (1)	C	A15	Name of Cal Source 1
60	HISTORY CALSRCE (1)	N	F10.3	Value of Cal Source 1
61	HISTORY CALSRCE (1)	C	A15	Units of Cal Source 1
62	HISTORY CALSRCE (2)	C	A15	Name of Cal Source 2
63	HISTORY CALSRCE (2)	N	F10.3	Value of Cal Source 2
64	HISTORY CALSRCE (2)	C	A15	Units of Cal Source 2
65	HISTORY TSYSTEM	N	F7.1	Value Only
66	HISTORY TRCVR	N	F7.1	Value Only
67	HISTORY TAUZENTH	N	F4.2	
68	BITPIX	N	I2	
69	NAXIS	N	I3	
70	BSCALE	N	F15.9	
71	BZERO	N	F10.4	
72	BUNIT	C	A15	
73	BLANK	N	I6	
74	DATAMAX	N	F10.4	
75	DATAMIN	N	F10.4	
76	NAXIS1	N	I4	
77	CDELT1	C	A15	
78	CRPIX1	C	A15	
79	CRVAL1	C	A15	
80	CTYPE1	C	A25	
81	NAXIS2	N	I4	
82	CDELT2	C	A15	
83	CRPIX2	C	A15	
84	CRVAL2	C	A15	
85	CTYPE2	C	A25	
86	NAXIS3	N	I4	
87	CDELT3	C	A15	
88	CRPIX3	C	A15	
89	CRVAL3	C	A15	
90	CTYPE3	C	A25	

Table VII. Printed Format I

Col.	FITS Keywords	Field Format	Field Header	Notes
1	DATE-OBS,TIME-OBS	DD.TTTTT	Date(UT)	
10	FILE-NUM	I6	RSN#	
17	MOLECULE	A5	Mol	
23	DAT-TYPE (4th character)	A1	DT	Denotes Subnetwork
25	RESTFREQ (MHz)	I6	Freq	
32	RES-SPEC (MHz)	I4	Res	
37	HISTORY TSYSTEM (K)	I5	Tsys	
43	BEAMEFF (percent)	I2	BE	
46	BEAMSIZE (arcsec)	I4	HP	
51	DIS-CODE (8th character)	A1	BS	Denotes beam shape
53	Radial Offset of Beam From Nucleus (arcsec)	I4	rho	
58	Position Angle of Radial Offset (deg)	I3	PA	
	For Limits:			
62	A "<" symbol	A1		
63	HISTORY LIMIT (Jy/beam)	F6.1 or F6.3	Line Peak	If value > 10 Jy/beam If value < 10 Jy/beam
80	A "-" symbol	A1	Width	
91	A "-" symbol	A1	Velocity	
	For Detections:			
63	HISTORY LINEPEAK (Jy/beam)	F6.1 or F6.3		If value > 10 Jy/beam If value < 10 Jy/beam
69	A "plus or minus" symbol	A1	Line Peak	
70	HISTORY ERR-PEAK (Jv/beam)	F5.1 or F5.3		If value > 10 Jy/beam If value < 10 Jy/beam
76	HISTORY LINE-WID (km/sec)	F4.2		
80	A "plus or minus" symbol	A1	Width	
81	HISTORY ERR--WID (km/sec)	F4.2		
86	HISTORY LINE-VEL (km/sec)	F5.2		
91	A "plus or minus" symbol	A1	Velocity	
92	HISTORY ERR--VEL (km/sec)	F4.2		
	For All:			
97	SYSTEM	A8	System	
106	OBSERVER	A23	Observer	
130	COMMENT NOTE	A2	Note	

Table VIII. Printed Format II

Col.	FITS Keywords	Field Format	Field Header	Notes
1	DATE-OBS,TIME-OBS	DD.TTTTT	Date(UT)	
11	FILE-NUM	I6	RSN#	
18	DAT-TYPE (4th character)	A1	DT	Denotes Subnetwork
20	CENTFREQ (MHz)	I6	Freq	
27	BANDWIDT (MHz)	I4	Res	
34	HISTORY TSYSTEM	I5	Tsys	
40	BEAMEFF (percent)	I2	BE	
43	BEAMSIZE (arcsec)	I4	HP	
48	DIS-CODE (8th character)	A1	BS	Denotes beam shape
50	Radial Offset of Beam From Nucleus (arcsec)	I4	rho	
55	Position Angle of Radial Offset (deg)	I3	PA	
	For Limits:			
60	A "<" Symbol	A1		
61	HISTORY LIMIT (Jy/beam)	F6.1 or F6.3	Flux Density	If value > 10 Jy/beam If value < 10 Jy/beam
	For Detections:			
61	HISTORY CONTFLUX (Jy/beam)	F6.1 or F6.3		If value > 10 Jy/beam If value < 10 Jy/beam
67	A "plus or minus" symbol	A1	Flux Density	
68	HISTORY ERR-FLUX (Jy/beam)	F5.1 or F5.3		If value > 10 Jy/beam If value < 10 Jy/beam
	For All:			
75	SYSTEM	A8	System	
84	OBSERVER	A30	Observer	
116	COMMENT NOTE	A2	Note	

4.3. Printed Format III: Occultation Subnetwork

Since the occultation data in this archive are of the same type as the data from the OH and Spectral Line Subnetworks, they are presented in the same format. Table IX provides a detailed description of this format.

Table IX. Printed Format III

Col.	FITS Keywords	Field Format	Field Header	Notes
1	DATE-OBS,TIME-OBS	DD.TTTTT	Date(UT)	
10	FILE-NUM	I6	RSN#	
17	MOLECULE	A5	Mol	
23	DAT-TYPE (4th Character)	A1	DT	Denotes Subnetwork
25	RESTFREQ (MHz)	I6	Freq	
32	RES-SPEC (MHz)	I4	Res	
37	HISTORY TSYSTEM (K)	I5	Tsys	
43	BEAMEFF (percent)	I2	BE	
46	BEAMSIZE (arcsec)	I4	HP	
51	DIS-CODE (8th Character)	A1	BS	Denotes beam shape
53	Radial Offset of Beam From Nucleus (arcsec)	I4	rho	
58	Position Angle of Radial Offset (deg)	I3	PA	
	For Limits:			
62	A "<" symbol	A1		
63	HISTORY LIMIT (Jy/beam)	F6.1 or F6.3	Line Peak	If value > 10 Jy/beam If value < 10 Jy/beam
80	A "-" symbol	A1	Width	
91	A "-" symbol	A1	Velocity	
	For Detections:			
63	HISTORY LINEPEAK (Jy/beam)	F6.1 or F6.3		If value > 10 Jy/beam If value < 10 Jy/beam
69	A "plus or minus" symbol	A1	Line Peak	
70	HISTORY ERR-PEAK (Jy/beam)	F5.1 or F5.3		If value > 10 Jy/beam If value < 10 Jy/beam
76	HISTORY LINE-WID (km/sec)	F4.2		
80	A "plus or minus" symbol	A1	Width	
81	HISTORY ERR--WID (km/sec)	F4.2		
86	HISTORY LINE-VEL (km/sec)	F5.2		
91	A "plus or minus" symbol	A1	Velocity	
92	HISTORY ERR--VEL (km/sec)	F4.2		
	For All:			
97	SYSTEM	A8	System	
106	OBSERVER	A23	Observer	
130	COMMENT NOTE	A2	Note	

Table X. Printed Format IV

Col.	FITS Keywords	Field Format	Field Header	Notes
1	DATE-OBS,TIME-OBS	DD.TTTTT	Date(UT)	
10	FILE-NUM	I6	RSN#	
18	DAT-TYPE (4th character)	A1	DT	Denotes Subnetwork
20	CENTFREQ (MHz)	I6	Freq	
27	BANDWIDT (MHz)	I4	Res	
34	HISTORY TSYSTEM	I5	Tsys	
40	BEAMEFF (percent)	I2	BE	
43	BEAMSIZE (arcsec)	I4	HP	
48	DIS-CODE (8th character)	A1	BS	Denotes beam shape
50	Radial Offset of Beam From Nucleus (arcsec)	I4	rho	
55	Position Angle of Radial Offset (deg)	I3	PA	
61	HISTORY XSECTION	F6.1		
67	A "plus or minus" symbol	A1	Cross Sect.	In units of km**2
68	HISTORY ERR-XSEC	F5.1		
75	SYSTEM	A8	System	
84	OBSERVER	A30	Observer	
116	COMMENT NOTE	A2	Note	

4.4. Printed Format IV: Radar Subnetwork

The archive contains only one radar observation, but, for consistency, we have made a printed format for it. The format follows the Continuum Subnetwork format and is described in Table X.

5. UNITS IN THE RADIO SCIENCE ARCHIVE

We have attempted to use a fixed set of standard units for the values given in the IHW archive. These units are given in Table XI. Where these units are not used, as in the printed archive, in the index tables, or in certain values in the HISTORY section of the FITS headers, attention is explicitly called to the change of units.

The adoption of the flux density unit, janskys (Jy) per beam, deserves some additional comment. This unit is well-defined: the signal is described in terms of the flux density of a point source that would produce the same signal observed from the comet. The explicit use of "per beam" in the unit acknowledges that the coma is possibly resolved by the beam to an unknown extent. Some observatories, such as the VLA, have naturally already adopted this choice of units, since they use celestial point sources to calibrate the instrument. All continuum observations also use jan-

Table XI. IHW Radio Science Units

Angle	Degrees
Length	Meters
Time	Seconds
Frequency	Hertz
Velocity	Meters/Second
Flux Density	Janskys/Beam*
Radar Cross-Section	Square Kilometers

* 1 jansky = 1.0×10^{-26} watts per square meter per hertz

skys to express their results, regardless of how the data are actually internally calibrated. Thus, in both of these cases, the jansky is the obvious choice of units. For spectral line work on large single antennas, however, results are typically expressed in "antenna temperature," since they are calibrated by comparing the observed signal with a calibration signal of known noise temperature. In recent years, this unit has become rather confusing as a result of efforts to convert a relatively well defined observed quantity into a more physically meaningful unit that gives an approximation to the true brightness temperature of the source. Thus, various forms of "corrected" antenna temperature are in use at different observatories, and it is often not clear which corrections have been made to the data. We therefore favor a system in which the calibration is achieved by direct comparison of the cometary signal to celestial sources of known flux density, and the natural unit for such a comparison is the unit of flux density, the jansky. Thus, all observations in the archive have been converted to these units, using data provided by the observers.

6. CALIBRATION

Although we have converted the data in the archive to a common unit of flux density, we have made no attempt to recalibrate data to a common flux density scale. The calibration scale for radio astronomy is well-established at centimeter wavelengths, and, in general, well-known standard sources were used by the network observers. For wavelengths shorter than about 1 cm, however, the calibration becomes less precise as atmospheric attenuation becomes significant in the observations. In most cases, comparisons to celestial sources are more indirect, and observers rely on absolute calibration schemes as their primary method. Ultimately, though, even these techniques use known sources, such as the planets, to calibrate the system, and we have attempted to archive information about these calibration sources with each observation.

Calibration information supplied to us by the observer is given in the HISTORY section of the FITS header. The HISTORY CALMETH keyword provides an ASCII string with a brief description of the calibration method used. Four methods are commonly used: (1) 'STANDARDS' indicates that the data were calibrated through direct comparison to standard sources, (2) 'NOISE TUBE' indicates that the data were primarily calibrated by injecting power from a noise source into the receiver, (3) 'CHOPPER WHEEL' indicates that the "chopper wheel" method was used, and (4) 'ABSOLUTE' calibration is used for the radar observations presented in this archive and is based on measurements of antenna and transmitter properties rather than on astronomical standards. This latter method uses the comparison of the noise power from an ambient temperature load to that produced by the sky emission to make an estimate of the optical depth of the atmosphere, and it is commonly used at millimeter wavelengths.

Even in the cases of 'NOISE TUBE' and 'CHOPPER WHEEL' calibration, where celestial sources are not initially used to calibrate the data, the final calibration is generally made with celestial sources. Whenever a standard source is used for this purpose, its name and assumed flux density are given in the HISTORY CALSRCE keywords. More than one of these keywords may exist in the header if more than one calibration source is used. For planetary sources, the assumed brightness temperature is given rather than the flux density, since planetary flux densities vary with distance to the object. Finally, the system temperature (defined to be the total system noise temperature, including receiver noise and atmospheric and ground pickup) and the receiver temperature (defined to be the noise temperature of the receiver alone) are given in the HISTORY TSYSTEM and HISTORY TRCVR keywords; the atmospheric opacity at zenith is given in the HISTORY TAUZENTH keyword where appropriate.

7. THE OBSERVERS

Many people have made substantial contributions to the success of the Radio Science Network of the IHW. First of all, we wish to thank the observers who have submitted data to the archive, since if it were not for their interest and assistance, there would be no archive at all. These observers are listed in Appendix A. We also appreciate those who attempted to observe Comet Halley, even if they did not get useful data. In many cases, these early attempts paid off in our later studies of the comet.

8. ACKNOWLEDGMENTS

We, F.P. Schloerb and W.M. Irvine, as leaders of the radio astronomy effort, have been aided in our effort by a number of students, post-doctorate students, and secretaries at the University of Massachusetts during the course of our involvement with the IHW. We gratefully acknowledge the efforts of R. Bassett, M. Claussen, C. Clemens, R. Molloy, G. Moriarty-Schieven, D. Swade, and L. Tacconi-Garman, who have provided assistance to the project at various times throughout its duration.

As leaders of the Radio Science effort, we would also like to especially acknowledge two of the other members of the Discipline Specialist Team listed in Table I. W.M. Kinzel, the manager of the Radio Science Archive, has made a substantial and noteworthy contribution of time and effort to the actual archiving of the data while serving as a graduate student at the University of Massachusetts. The archive that exists today would have been impossible to complete without his participation in the project. Finally, we would like to thank particularly our Co-Discipline Specialist E. Gerard for his continued leadership in the field of cometary radio astronomy, his enthusiastic support of the International Halley Watch, and his efforts on our behalf.

Appendix A. IHW Radio Science Observers

Observer	Affiliation
Abraham, Z.	Instituto de Pesquisas Espaciais, Brazil
Altenhoff, W.	Max Planck Institut fur Radioastronomie, F.R.G.
Andersson, Ch.	Onsala Space Observatory, Sweden
Arnal, E.	Instituto Argentino de Radioastronomia, Argentina
Bajaja, E.	Instituto Argentino de Radioastronomia, Argentina
Batelaan, P.	Jet Propulsion Laboratory, U.S.A.
Batrla, W.	University of Illinois, U.S.A.
Baum, S.	University of Maryland, U.S.A.
Berulis, J.	Lebedev Physical Institute, U.S.S.R.
Biggs, J.	University of Sydney, Australia
Bird, M.	Universitat Bonn, F.R.G.
Bockelee-Morvan, D.	Observatoire de Paris-Meudon, France
Boriakoff, V.	Cornell University, U.S.A.
Botti, C.	Instituto de Pesquisas Espaciais, Brazil
Bourgeois, G.	Observatoire de Paris-Meudon, France
Bretas Filhd, F.	Instituto de Pesquisas Espaciais, Brazil
Butner, H.	University of Texas, U.S.A.
Bystrova, N.	Special Astrophysical Observatory, U.S.S.R.
Campbell, D.	National Astronomy and Ionosphere Center, Puerto Rico
Cancoro, A.	Instituto de Pesquisas Espaciais, Brazil
Cersosimo, J.	Instituto Argentino de Radioastronomia, Argentina
Claussen, M.	University of Massachusetts, U.S.A.
Cohen, J.	University of Manchester, U.K.
Colom, P.	Observatoire de Paris-Meudon, France
Colomb, F.	Instituto Argentino de Radioastronomia, Argentina
Comoretto, G.	Osservatorio Astrofisico Arcetri, Italy
Cordes, J.	Cornell University, U.S.A.
Crovisier, J.	Observatoire de Paris-Meudon, France
de Pater, I.	University of California, Berkeley, California, U.S.A.
Del Ciampo, L.	Instituto de Pesquisas Espaciais, Brazil
Despois, D.	Universite de Bordeaux, France
Destombes, J.	Universite de Lille, France
Duncan, R.	CSIRO Division of Radiophysics, Australia
Ekelund, A.	Onsala Space Observatory, Sweden
Ekelund, L.	Onsala Space Observatory, Sweden
Encrenaz, P.	Observatoire de Paris-Meudon, France
Falchi, A.	Osservatorio Astrofisico Arcetri, Italy
Forster, R.	CSIRO Division of Radiophysics, Australia
Forveille, T.	Universite de Grenoble, France
Frerking, M.	Jet Propulsion Laboratory, U.S.A.
Friehe, K.	Instituto de Pesquisas Espaciais, Brazil
Gagliardi, L.	Osservatorio Astrofisico Arcetri, Italy
Galt, J.	Dominion Radio Astrophysical Observatory, Canada
Gaylard, M.	Hartebeesthoek Radio Astronomy Observatory, South Africa

Appendix A. (continued)

Observer	Affiliation
Gerard, E.	Observatoire de Paris-Meudon, France
Gossachinskij, I.	Special Astrophysical Observatory, U.S.S.R.
Gulkis, S.	Jet Propulsion Laboratory, U.S.A.
Harmon, J.	National Astronomy and Ionosphere Center, Puerto Rico
Haschick, A.	Haystack Observatory, U.S.A.
Hasegawa, T.	Nobeyama Radio Observatory, Japan
Hoban, S.	University of Maryland, U.S.A.
Huchtmeier, W.	Max Planck Institut fur Radioastronomie, F.R.G.
Irvine, W.	University of Massachusetts, U.S.A.
Judaeva, N.	Special Astrophysical Observatory, U.S.S.R.
Kaifu, N.	Nobeyama Radio Observatory, Japan
Kaufmann, P.	Instituto de Pesquisas Espaciais, Brazil
Kinzel, W.	University of Massachusetts, U.S.A.
Kitamura, Y.	Nobeyama Radio Observatory, Japan
Klein, M.J.	Jet Propulsion Laboratory, U.S.A.
Krevsa, E.	Max Planck Institut fur Radioastronomie, F.R.G.
Kuiper, T.	Jet Propulsion Laboratory, U.S.A.
Lewis, M.	National Astronomy and Ionosphere Center, Puerto Rico
Losovski, B.	Lebedev Physical Institute, U.S.S.R.
Madden, S.	University of Massachusetts, U.S.A.
Malzoni, M.	Instituto de Pesquisas Espaciais, Brazil
Martin, C.	Instituto Argentino de Radioastronomia, Argentina
Matthews, H.	Herzberg Institute of Astrophysics, Canada
Mazzaro, R.	Instituto Argentino de Radioastronomia, Argentina
Melad, I.	Instituto de Pesquisas Espaciais, Brazil
Mirabel, I.	University of Puerto Rico, Puerto Rico
Montiero do Vale, J.	Instituto de Pesquisas Espaciais, Brazil
Morras, R.	Instituto Argentino de Radioastronomia, Argentina
Nelson, G.	CSIRO Division of Radiophysics, Australia
Norris, R.	CSIRO Division of Radiophysics, Australia
Ohishi, M.	Nobeyama Radio Observatory, Japan
Olalde, J.	Instituto Argentino de Radioastronomia, Argentina
Palagi, F.	Osservatorio Astrofisico Arcetri, Italy
Palmer, P.	University of Chicago, U.S.A.
Persson, G.	Onsala Space Observatory, Sweden
Petroni, M.	Instituto de Pesquisas Espaciais, Brazil
Pickett, H.	Jet Propulsion Laboratory, U.S.A.
Poppel, W.	Instituto Argentino de Radioastronomia, Argentina
Reynolds, J.	University of Sydney, Australia
Scalise, E.	Instituto de Pesquisas Espaciais, Brazil
Schaefer, M.	Jet Propulsion Laboratory, U.S.A.
Schloerb, P.	University of Massachusetts, U.S.A.
Schmidt, J.	Max Planck Institut fur Radioastronomie, F.R.G.
Schraml, J.	Max Planck Institut fur Radioastronomie, F.R.G.

Appendix A. (continued)

Observer	Affiliation
Sestokas, B.	Instituto de Pesquisas Espaciais, Brazil
Shang, Q.	Yunnan Observatory, People's Republic of China
Shapiro, I.	Harvard-Smithsonian Center for Astrophysics, U.S.A.
Silva, A.	Instituto Argentino de Radioastronomia, Argentina
Snyder, L.	University of Illinois, U.S.A.
Sorochenko, R.	Lebedev Physical Institute, U.S.S.R.
Stumpff, P.	Max Planck Institut fur Radioastronomie, F.R.G.
Suzuki, H.	Nobeyama Radio Observatory, Japan
Swade, D.	University of Massachusetts, U.S.A.
Tateyama, C.	Instituto de Pesquisas Espaciais, Brazil
Terasranta, H.	Helsinki University of Technology, Finland
Terzian, Y.	Cornell University, U.S.A.
Thum, C.	Institut de Radioastronomie Millimetrique, Spain
Tofani, G.	Osservatorio Astrofisico Arcetri, Italy
Tolmachev, A.	Lebedev Physical Institute, U.S.S.R.
Turner, B.	National Radio Astronomy Observatory, U.S.A.
Urpo, S.	Helsinki University of Technology, Finland
Vilas Boas, J.	Instituto de Pesquisas Espaciais, Brazil
von Kap-Herr, A.	Max Planck Institut fur Radioastronomie, F.R.G.
Walmsley, M.	Max Planck Institut fur Radioastronomie, F.R.G.
Wang, J.	Yunnan Observatory, People's Republic of China
Wannier, P.	Jet Propulsion Laboratory, U.S.A.
Webber, J.	Haystack Observatory, U.S.A.
Winnberg, A.	Onsala Space Observatory, Sweden
Wootten, A.	National Radio Astronomy Observatory, U.S.A.
Zimmermann, P.	Universitat zu Koln, F.R.G.
Zinchenko, I.	Lebedev Physical Institute, U.S.S.R.

SPECTROSCOPY AND SPECTROPHOTOMETRY NETWORK

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1. INTRODUCTION

Between 1983 and 1988, the Spectroscopy and Spectrophotometry Network (SSN) of the International Halley Watch (IHW) was responsible for coordinating, collecting, and archiving a wide diversity of spectroscopic observations of periodic comets Halley, Giacobini-Zinner, and Crommelin. Table I lists the SSN Discipline Specialist Team personnel for 1982 to 1989. The spectral domain covered the ultraviolet (UV) and visible regions, from about 1100 Å to 10,000 Å; the ground-based data, covering 3000 Å to 10,000 Å, represent the bulk of the spectra. Cometary spectra obtained in the wavelength regions longer than 10,000 Å (1 μm) have been archived by the Infrared Studies Network.

The spectra of Comet Halley taken from Earth have spatial resolutions of about 400 km at best. Such spectra obtained remotely arise from three distinct sources in the coma: sunlight scattered by the coma dust, neutral gas, and ionized gas. Solar radiation reflected directly from a comet's nucleus contributes negligibly to the spectrum observed from Earth, except when the comet is at relatively large heliocentric distances (> 5 AU), and/or has a very low gas production rate. UV and optical spectra in the IHW Archive obtained with the instrument aperture centered on the brightest part of the coma are generally dominated by the neutral molecular spectrum of the coma. Spectra offset from the nucleus region to projected distances > 100,000 km toward the tail (anti-solar direction) are generally dominated by molecular ions that populate the plasma tail of the comet.

Both the coma and plasma tail spectra are composites with an underlying continuous spectrum contributed by the solar radiation scattered by the comet dust. Thus, when the gaseous component of the spectrum is analyzed, the dust-reflected solar continuum is usually subtracted from the composite spectrum. The spectra of Comet Halley presented in this archive can be found in various forms, both with and without the correction for the solar background continuum. The extent of processing of each archive spectrum can generally be determined by reading its Flexible Image Transport System (FITS) header. Some observers have submitted spectra of Solar-System objects or scattered twilight to provide a solar spectrum taken with the same instrument used to observe the comet. These spectra have been archived with the Halley spectra and can be used to subtract the background solar spectrum from the comet spectrum. Also included in this archive, as appendices, are two high-resolution spectra obtained directly of the Sun (A'Hearn, Ohlmacher, and Schleicher 1983; Kurucz et al. 1984), which, when convolved with the appropriate instrument profile and corrected for the scattered light wavelength dependence ($1/\lambda$), can be used to correct the composite comet spectra for scattered sunlight.

The Comet Giacobini-Zinner Spectroscopic Archive contains 433 spectra, while the Comet Halley Archive includes more than 3,500 spectra. The spectra of

Table I. Discipline Specialist Team of the Spectroscopy and Spectrophotometry Network

Team Member	Affiliation	Responsibility
Susan Wyckoff	Physics-Astronomy Department Arizona State University Tempe, Arizona 85287-1504 U.S.A.	Discipline Specialist
Peter A. Wehinger	Physics-Astronomy Department Arizona State University	Discipline Specialist
Anthony J. Ferro	Physics-Astronomy Department Arizona State University	Data Archivist and Scientific Programmer
Beverly Dunlap	Physics-Astronomy Department Arizona State University	Data Acquisition Specialist
Michel C. Festou	Observatoire de Besancon F-2544 Besancon Cedex France	Discipline Specialist
Barbara Boothman	Physics-Astronomy Department Arizona State University	Computer System Manager and Scientific Programmer
David Reisinger	Physics-Astronomy Department Arizona State University	Scientific Programmer
David Schleicher	Physics-Astronomy Department Arizona State University	Post-Doctoral Fellow
R. Mark Wagner	Physics-Astronomy Department Arizona State University	Post-Doctoral Fellow
Uri Carsenty	Physics-Astronomy Department Arizona State University	Post-Doctoral Fellow
Marvin Kleine	Goodyear Aerospace Corp. Litchfield Park, Arizona U.S.A.	Software Consultant
Tobias Kreidl	Lowell Observatory Flagstaff, Arizona 86001 U.S.A.	Software Consultant

Table I. (continued)

Team Member	Affiliation	Responsibility
Patricia Monger	Astronomy Department University of California Berkeley, California 94720 U.S.A.	Software Consultant
Kyle Baird	Physics-Astronomy Department Arizona State University	Student Assistant
Lisa Engel	Physics-Astronomy Department Arizona State University	Student Assistant
Ichishiro Konno	Physics-Astronomy Department Arizona State University	Student Assistant
Carla Landenburger	Physics-Astronomy Department Arizona State University	Student Assistant
Thomas Larson	Physics-Astronomy Department Arizona State University	Student Assistant
Eric Lindholm	Physics-Astronomy Department Arizona State University	Student Assistant
Gregory Loper	Physics-Astronomy Department Arizona State University	Student Assistant
Steven Tegler	Physics-Astronomy Department Arizona State University	Student Assistant
Jill Theobald	Physics-Astronomy Department Arizona State University	Student Assistant
Maria Womack	Physics-Astronomy Department Arizona State University	Student Assistant
Carol Taylor	Physics-Astronomy Department Arizona State University	Secretary and Word Processor
Loretta McKibben	Physics-Astronomy Department Arizona State University	Secretary and Word Processor

P/Crommelin were originally published in the *Archive of Observations of Periodic Comet Crommelin Made During Its 1983–84 Apparition* (Sekanina and Aronsson 1985). In addition, the P/Crommelin spectra in digital format were included on the P/Giacobini-Zinner 5.25-inch compact disc—read only memory (CD-ROM). The digital archives of P/Giacobini-Zinner and P/Halley contain significantly more spectra than originally expected. The bulk of the Comet Halley spectra was received and archived between 1987 and 1989. The overall effort involved contributions from approximately 150 observers in 16 countries, at more than 80 observatories or astronomical institutes. The response of the astronomical community to the IHW archive was most positive and cooperative. We owe a great debt of thanks and appreciation to our colleagues, scattered around the world, who very kindly provided copies of their spectra for the archive. The following sections provide a brief description of the spectroscopic archive.

The spectroscopic portion of the digital version of the Halley archive contains the following files:

DESCRIPT.TXT	A description of the FITS keywords used in the spectroscopy files.
DISCODES.TAB	A table giving the translations for the spectroscopy keyword 'DIS-CODE'. This is a delimited file and can be read into most database programs.
HISTO.DAT	A data file with (X,Y) pairs, giving the number of observations in the spectroscopic archive and the Julian date.
NOTES.TXT	Various notes regarding the archive, including warnings, hints, and kinks.
SOLAR	A directory containing two solar atlases in FITS format.

2. SPECTROSCOPIC DATA ARCHIVE

The spectroscopic archive for Comet Halley consists of data obtained by a wide variety of observers, instruments, and techniques. The range of observation sites spans the globe and includes the upper atmosphere and satellites in Earth orbit. The spectroscopic observations of Comet Halley were monitored, but not coordinated, by the Spectroscopy Center at Arizona State University. Various individual observing programs were planned and executed in their entirety by the observers who contributed data to the archive. Occasionally, the observations were made by observers who had no expertise in cometary spectroscopy. Fortunately, there was such an overwhelmingly universal interest in Comet Halley that virtually every large-aperture telescope in the world that was equipped with spectroscopic instrumentation obtained at least a few spectra of the comet. Thus, the spectroscopic archive is composed of data obtained with a very diverse array of state-of-the-art instruments and detectors in the years 1985 to 1986 and represents a unique set of observations of Comet Halley. In 1910, the state-of-the-art detector was the photographic plate. The present archive includes a small percentage (< 0.5%) of spectra digitized from photographic plates, which is a testimony to the technological advances made in astronomical detectors during the past 76 years, in the 1970s and 1980s. Our task to archive this diverse data set was a challenging one. Because of the data's diversity, our policy, as editors of the Spectroscopic Archive, was not to alter any data, and to include all scientifically useful spectra.

Our standard keywords, listed in Appendix A, were used to describe the wide variety of different data types, but because we had a finite set of descriptors, limitations arose in the extent to which the FITS headers could completely describe the spectra. For example, in the case of the International Ultraviolet Explorer (IUE) satellite, the site location (in a geosynchronous orbit) could not be described in terms of latitude, longitude, and elevation, since these values were constantly changing. In this case, we entered mean values for the latitude and longitude of the satellite's position projected onto the Earth, and used a negative value for the elevation as a flag noting that this elevation was inherently variable.

The spectroscopic data in the Comet Halley Archive consist of two basic types: one-dimensional and two-dimensional spectra. In the case of one-dimensional spectra, the data are measurements of flux vs. the wavelength from the comet within a solid angle determined by the size of the spectroscopic instrument aperture projected at the comet. For the two-dimensional spectra, a spatial dimension is added, covering the length of the slit projected at the comet. Thus, a two-dimensional spectrum contains flux information for a set of points, determined by the slit length used. For processing and displaying, the two-dimensional spectra can be treated as a normal image.

Because of our editorial policy of not altering the data submitted to the archive, we did not calibrate the spectra, which were submitted in unreduced form. Instead, we included calibration spectra in the archive, so users can perform the calibrations if desired.

Valid arguments exist on both sides of the issue of whether submitted data should have been reduced or left in their raw form. Future workers may have better reduction techniques, and the original observer may not be interested in doing the full reduction or may not have experience in reducing cometary spectra. On the other hand, the observer, who is familiar with the instrument used, probably knows his or her data best and is in the best position to make judgements as to what reduction techniques are proper. We have taken the position that fully reduced data (flux- and wavelength-calibrated) are the norm, but we have archived what was received. Most of the data in the archive are fully reduced, or as fully reduced as possible (in some instances, such as with high spectral resolution data, flux calibration may not be possible). In some sets, the data are raw, essentially as observed. Other calibration data may have been included with the raw data sets, although this is not always the case. When calibration frames are available, their type should be clear from the OBJECT keyword. The type of data presented can be determined from DAT-TYPE. Data and calibration frames should be correlated, based on time and date of observation, observer, and observatory.

A major source for information regarding observatories (e.g., location, name, and elevation) was the Astronomical Almanac, published annually by the U.S. Printing Office. This almanac was used only when the observer did not furnish exact information, such as the latitude and longitude of the observatory.

As described in Appendix A, the OBSERVER and SUBMITTR keywords contain the name of the first observer or submitter. If there are more than two names, all but the first name go into a special COMMENT ADD. OBS. field. Most names are generally not a problem. However, the FITS conventions may have difficulties with names that contain an apostrophe. For example, OBSERVER = 'A'HEARN,M' is valid (the apostrophe after A is within the minimum eight characters for the keyword value), but OBSERVER = 'FELDMAN,P/A'HEARN,M' is not valid (it would likely be read in as OBSERVER = 'FELDMAN,P/A'). We have tried the solution of replacing the apostrophe with a blank. Thus, we have OBSERVER = 'FELDMAN,P/A HEARN,M'. This may present a slight problem when a search is made spelling the name "A'Hearn" properly.

The airmass of the observation was not always submitted to us. When we were given hour angles, we calculated the airmass. However, in many submissions, the observer gave neither the airmass nor the hour angle. The proper airmass, if needed, can be obtained from the comet ephemeris for that time and the location of the observatory.

At present, no standard ways exist for describing the position of the spectrograph slit with respect to the comet. To describe the location of the slit, we chose three measurements:

(1) The distance between the center of brightness of the comet and the center of the slit, measured in arcseconds (SEPNUC).
(2) The angle, measured in degrees from north through east, to the center of the slit (ORIENT).
(3) The angle, measured in degrees from north through east, of the beginning of the slit (POSANG).

Unfortunately, most observers did not use these exact measurements. Often, the only measurement that observers submitted referred to the number of arcseconds sunward or tailward of the comet's light center. We have tried to convert the pointing angles given to our three parameters as accurately as possible. Often we used the comet's ephemeris for converting from tailward-sunward coordinates to those used in the archive. It is a general convention that if the nucleus is in the data frame, the slit is "on the comet," even though, strictly, SEPNUC is not zero, but is very small.

3. TRIAL RUNS OF 1983 TO 1985: RECOVERY, SPECTROSCOPIC HIGHLIGHTS, AND LESSONS LEARNED

The first trial-run observations and archiving campaign centered on periodic Comet Crommelin, which was recovered August 11, 1983, by L. Kohoutek at the Calar Alto Observatory in Spain and independently by S. Wyckoff and P. Wehinger at the Kitt Peak National Observatory (KPNO) in Arizona. At this time, the comet's total V magnitude was 19.7. While P/Crommelin only reached a maximum total brightness of 7.5 mag, spectroscopically it was very rich in NH_2.

One of the lessons learned in this trial run was that the range of dates selected for coordinated observations was not optimized for best coverage, i.e., it was not optimized for the largest elongation from the Sun and the maximum brightness. Also, since limited advance notice of the coordinated observations was given, only a small number of observers participated in the P/Crommelin campaign.

The second trial run involved periodic Comet Giacobini-Zinner. Pre-recovery images were obtained with charge-coupled detectors (CCDs) in May 1984 by H. Spinrad and M. Belton using the KPNO 4-m telescope; on January 28, 1985, by

R.M. West using the European Southern Observatory (ESO)/Danish 1.5-m telescope; and on March 28, 1985, by M. Belton and P. Wehinger using the KPNO 0.9-m telescope. Subsequently, on April 10, 1989, S. Djorgovski, H. Spinrad, G. Will, and M. Belton recovered P/Giacobini-Zinner with the KPNO 4-m reflector, when the comet's total brightness was 22.5 mag. P/Giacobini-Zinner was the first comet to be visited by a spacecraft, when the National Aeronautics and Space Administration (NASA) International Cometary Explorer (ICE) passed through the plasma tail of this comet, 7,800 km from the nucleus, on September 11, 1985, at 11:02 GMT.

What lessons were learned in this case? Here, the encounter was well-timed for coordinated simultaneous ground-based observations in the predawn hours in the U.S. southwestern desert (11:02 GMT = 04:02 MST). However, very limited information was provided by NASA's Mission Control to ground-based observers prior to the ICE encounter. Details were not available about such things as ICE's track orientation through the tail of the comet and the rate of motion across the tail. Only about 5% as much data was acquired on P/Giacobini-Zinner as on P/Halley. Perhaps there was too little publicity to the comet community of plans to create a digital archive of P/Giacobini-Zinner data.

One general remark should be made about all three periodic comets with regard to their recoveries. P/Crommelin, P/Giacobini-Zinner, and P/Halley were all recovered during the new moon, using telescope time actually scheduled for quasar imaging with CCDs. Since the comets' orbits were well-established, the CCDs' relatively small fields were successful in the recovery efforts. The situation was different for the recovery of P/Brorsen-Metcalf. Non-gravitational forces neglected since this comet's last apparition (in 1919) caused the comet's predicted position to be approximately 15 degrees away from its actual position.

Prior to P/Halley's 1980s return, bright comets of special interest included: P/Humason 1962 VIII, C/Bennett 1970 II, C/Kohoutek 1973 XII, C/West 1976 VI, and C/IRAS-Araki-Alcock 1983 VII. After P/Halley, bright comets from 1987 to 1990 included: C/Wilson (May 1987), m1 (total magnitude) = 5.0 mag; P/Brorsen-Metcalf (August 1989), m1 = 5.6 mag; C/Okazaki-Levy-Rudenko (December 1989), m1 = 5.8 mag; C/Austin (May 1990), m1 = 5.0 mag, and C/Levy (September 1990), m1 = 4.0 mag (estimated). P/Brorsen-Metcalf has a period of 70 years, similar to that of P/Halley, but P/Brorsen-Metcalf is in a prograde orbit, not a retrograde one.

4. RECOVERY OF PERIODIC COMET HALLEY

P/Halley was recovered October 16, 1982, by David Jewitt and others (see below) using the Palomar Observatory 5-m telescope. We wish to point out that Alan Dressler's suggestion to mask bright stars in the CCD's field of view was crucial in leading to the recovery of Comet Halley in October 1982. Dressler suggested that Jewitt make use of an occulting mask to suppress the scattered light from an 8-magnitude star close to the predicted track of P/Halley on October 16, 1982. Without the occulting mask, the 25.9-magnitude comet would have been lost in the 8-magnitude star's scattered light. Others who contributed to the recovery at Palomar included Maarten Schmidt, who gave up some of his time (scheduled for work on quasars); Edward Dennison, James Westphal, and James Gunn, who were essential in making the CCD system work; and Barbara Zimmerman, who provided software expertise. Finally, the ephemeris computed by Donald Yeomans, based on observations from the 1835 and 1910 apparitions, was also essential.

With the long-term future in mind, it is conceivable that this past apparition of P/Halley was the last time that this comet will be recovered in such a way. With the advent of larger ground-based and space-based telescopes, P/Halley may never be lost again as it heads out to aphelion beyond the orbit of Neptune.

Prior to P/Halley's actual recovery, numerous attempts were made over a five-year period, starting in 1977. Early efforts of note were those of M. Belton and H. Butcher at KPNO, using the 4-m telescope with the cryogenic camera, a CCD mounted in a semi-solid Schmidt camera cooled to liquid-nitrogen temperatures. Part of the difficulty in recovering P/Halley was the comet's location close to the galactic plane with densely populated Milky Way fields.

Even the early spectroscopic observations of P/Halley were hampered by the comet's being located in rich Milky Way fields from October 1983 to February 1985. All spectra of the comet acquired prior to February 1985 were obtained using blind offsets with the slit oriented along the position angle of the comet's predicted track. Precise coordinates, determined to an accuracy of 0.3 arcsec, were ascertained using Smithsonian Astrophysical Observatory (SAO) stars and, from them, secondary astrometric standards were established. Then, using blind offsets from these secondary standards, the slit was positioned and rotated to the proper position angle. For each observation on a given night, about a day's work was involved in setting up the astrometric standards, which were measured from glass copies of the National Geographic Society—Palomar Sky Survey (1955 edition). In the case of KPNO's 4-m spectra, a slit width of 3 arcsec and a slit length of 4.5 arcmin were employed.

5. SPECTRA ON THE INBOUND JOURNEY: HELIOCENTRIC DISTANCES FROM 7 TO 4 AU

The IHW Spectroscopy Network served as a catalyst to help observers acquire key data sets in the course of the eight years centered on Comet Halley's 1986 apparition. In this Halley campaign, the first phase of spectroscopic observations, from 1983 to 1984, can be described as a pre-sublimation phase. The level of detection was so faint in these years (the total magnitude was fainter than 23) that no well-defined color or color index could be derived prior to early 1985, when sublimation had begun. During most of the pre-perihelion phase (1982 to 1985), P/Halley was located in a relatively crowded Milky Way field, making it difficult to acquire the comet and obtain reliable spectra at very low light levels.

The first non-spectroscopic evidence of the developing coma was CCD images obtained on September 27, 1984, by S.G. Djorgovski and H. Spinrad, using the KPNO 4-m telescope. A 6-arcsec coma was detected in the red region (6000 to 7000 Å). Subsequently, in November 1984, A. Crotz acquired additional CCD images with the KPNO 4-m, showing a similarly extended coma. Spectra obtained from October 1984 to January 1985 showed no spectroscopically detectable emission features. Some observations, particularly in the United States, were hampered by cloudy weather at this time. However, the increasing intrinsic light of the comet was the first evidence of a developing coma.

Between October 1983 and March 1984, a team at KPNO (M. Belton, H. Spinrad, P. Wehinger, and S. Wyckoff) used the 4-m telescope with a grism spectrograph and CCD to obtain low-resolution spectra (12 to 15 Å). All observations from 1983 to 1984 were acquired using blind offsets from stars near the comet's predicted track, with the slit oriented along the comet's track on the sky and the telescope tracking at the comet's rate in right ascension and declination. During these years, the comet's total light was fainter than magnitude 22. The low signal-to-noise spectra showed a reflected solar continuum. None of the 1983 to 1984 spectra showed any emission features indicative of the comet's gas production. Spectra of P/Halley obtained in October 1984 were collapsed to one dimension. The cross-cut spectra first appeared to show evidence suggestive of an extended coma. However, later very careful astrometry by Belton showed that the "coma" was due to faint Milky Way field stars. The early interpretation suggesting a developing coma was reported by Belton (1985) in his review, "Comet Halley: The quintessential comet." In the future, one should be cautious of early detection of the coma, unless, of course, in situ measurements are made from a spacecraft.

By February 17, 1985, the first spectroscopic evidence for the onset of sublimation was detected, by Spinrad observing with the KPNO 4-m telescope and by Wyckoff observing with the 4.5-m Multiple-Mirror Telescope (MMT). Spinrad observed the [O I] 6300-Å line (cf. Belton 1985), while Wyckoff et al. (1985) detected the CN(0,0) violet system at 3880 Å. E. Barker, A. Cochran, and W. Cochran at the McDonald Observatory detected CN with the 2.7-m reflector on the same night.

Later, on August 23, 1985, Spinrad detected the C_2 Swan system using the Lick Observatory 3-m telescope. From October 17 to 20, 1985, E.M. Burbidge at Lick, S. Wyckoff at the MMT, and B. Peterson at the Anglo-Australian Telescope all detected the H_2O^+ (8,0) band, while the comet was 2.2 AU from the Sun, nearly twice as distant as any previous H_2O^+ detection in a comet.

6. SPECTRA ON THE OUTBOUND JOURNEY: HELIOCENTRIC DISTANCES FROM 4 TO 8 AU

On the outbound journey, the last emission band detections were those of CN(0,0) and C_3 (4040 Å) on January 30, 1987, at 5.0 AU by Belton and Wehinger, who used the Cerro T[illegible]lo Interamerican Observatory (CTIO) 4-m telescope. The outbound production rates were 15 times greater than the inbound rates. The extent of the coma from the long-slit spectra obtained by Belton and Wehinger was 32 arcsec in diameter. Other evidence—for example, the CCD imaging data acquired by R.M. West and his team at ESO—for the apparent inertia in the comet's outgassing processes also exists. Attempts to detect the last emission due to the CN violet system were made in February 1988 by S. Tegler, S. Wyckoff, and P. Wehinger, using the KPNO 2.2-m telescope; only a scattered solar continuum was detected. West found a coma of more than 30 arcsec in diameter in April 1988 at 8.6 AU and more than 10 arcsec in January 1989 at 10.1 AU. Finally, in February 1990, West (1990) reported no detectable coma in the visible at a level of 29 mag/arcsec^2. See Table II for a list of the major spectroscopic developments as a function of time and heliocentric distance.

Table 11. Major Spectroscopic Developments as a Function of Time and Heliocentric Distance (r)

r = 8–5 AU	Extended dust continuum develops (1984).
r = 6.5 AU	Photometric detection of the development of the coma (1984).
r = 4.8–4.5 AU	Onset of sublimation in CN(0,0) 3883, C_3 4040, [O I] 6300 (February to April 1985).
r = 4.2–2.6 AU	Comet lost in the Sun's glare, inbound (May to July 1985).
r = 2.4 AU	Neutral coma develops; C_2 Swan system detected (August to September 1985).
r = 2.2 AU	H_2O^+ plasma tail detected (October to November 1985).
r = 1.2–0.8 AU	Brightest pre-perihelion phase (January 1986).
r < 0.7 AU	Comet lost in the Sun's glare.
r = 0.5 AU	Comet reaches perihelion (February 9, 1986).
r = 0.8–1.0 AU	Brightest post-perihelion phase; spacecraft—VEGA-1, VEGA-2, Suisei, Sakigake, Giotto, and ICE—encounter the comet (March 6–14, 1986).
r = 1.2 AU	Highest spectral resolution spectra acquired of neutral species: CN(0,0) R-branch, C_2(1,0), and C_2(0,0) rotational lines. Identification of $C^{13}N^{14}$ in CN(0,0) violet system R-branch lines (April 4–7, 1986).
r = 1.4 AU	Highest signal-to-noise spectra of the plasma tail were acquired with the CTIO 4-m telescope (April 12–15, 1986).
r = 2.46 AU	Neutral molecular spectrum continues (June 30, 1986).
r = 2.5–4.4 AU	Comet lost in the Sun's glare, outbound (July to October 1986).
r = 4.5 AU	Neutral coma continues (December 1986).
r = 4.8 AU	Neutral molecular species still detected, including CN(0,0), C_3 4040, and very weak C_2 Swan system (January 30, 1987). CN band strength 15 times greater than at 4.8 AU pre-perihelion.
r = 6.5 AU	Dust continuum 32 arcsec in diameter detected spectroscopically (February 1988); no emission features.
r = 10.5 AU	Imaging shows continued existence of dust coma 20 arcsec in diameter (May 1989).
r = 12.5 AU	Imaging shows no further evidence of a coma down to 29 mag/arcsec^2 (February 21–24, 1990).

7. COORDINATION AND COMMUNICATIONS

At the start of the IHW campaign, communications were limited to telephone, telex, and air mail. By 1985, electronic mail was first becoming available to more than half of the observers, and by the end of the campaign (1989), more than 90% of the observers had access to some form of electronic mail. From April 1985 to early 1987, an electronic bulletin board was operated for the IHW at Arizona State University. By October 1985, the Halley Hotline was linked to GTE's Telenet, the largest public data network in the United States. Observers could leave messages and read current updates in five subdirectories, including spectrophotometry, imaging, astrometry, space missions, and ephemerides.

From November 1985 to June 1986, some 3,000 log-ons were recorded by observers, space scientists, laboratory spectroscopists, and other interested parties, representing 22 states in the United States, and 12 other countries. These countries were the United Kingdom, France, the Federal Republic of Germany, the Netherlands, Belgium, Italy, Spain, Austria, Canada, Japan, Chile, and Australia. Access within the United States was provided by a corporate gift of GTE Telecommunications, who provided free access to Telenet. Overseas users paid the transoceanic charges through their countries' post, telephone, and telex companies to access the Halley Hotline.

8. REMARKS ABOUT GLOBAL COMMUNICATIONS

From a historical perspective, the period 1982 to 1990 was a time of major technological advancement with regard to digital computers, local- and wide-area computer networks, and national and global computer links. When the IHW began, we used the conventional postal system, the telephone, and the telex. The telex provided the widest possible link for communications, though it was slow and sometimes unreliable in some countries and it was not available in others. Sometimes no replies came through for months after a telex had been sent.

In terms of the technology of our times, the common modes of communication from 1982 to 1985 included airmail (2 to 15 days in transit); international telex (immediate, 110 baud) used in most countries, but not widely used in the United States; and telephone (immediate, voice communication, expensive). By 1985, electronic mail via Bitnet was coming into use. Bitnet, a system of store and forward from computer to computer, was promoted by IBM, including IBM's support of a trans-Atlantic link from the United States to western Europe. This first electronic mail system was free to the user and grew rapidly. The typical transit time, for example, for a one-page letter from Arizona to France, was 2 to 3 minutes when all intermediate nodes were operating, though it was longer at times of heavy traffic.

At the same time, the Committee Consultatif International de Telex et Telephone (CCITT) had already set up the X.25 standards for transferring ASCII files over international telephone networks. The X.25 protocol uses a mode of packet assembly and disassembly (PAD) software that enables files to be transferred in a machine-independent manner at a rate of 9600 baud with error-checking routines. GTE Telenet Corporation, which operated the largest public-data network in the United States from 1985 to 1986, used X.25 protocol for the transfer of files, for remote log-ons, and for links to international communications networks. The X.25 protocol provided a much faster and direct link from node to node than Bitnet's slower store and forward system.

9. SPECTROSCOPIC DATA: MAGNETIC STORAGE MEDIA

When the first IHW General Meeting was held in August 1982 in Patras, Greece, in conjunction with the International Astronomical Union (IAU) General Assembly, some members of the IHW Steering Committee expressed concern that a significant percentage of the spectroscopic data would be recorded on photographic plates and would require subsequent digital scanning with a microdensitometer. Our early estimates were that the majority (70% to 80%) of the spectra would be recorded in digital format. In fact, virtually all the spectroscopic data that we received were in digital format. A small percentage of spectra originally recorded on photographic plates were scanned with digital microphotometers by observers at their institutes and were submitted on magnetic tape. At the time the IHW was organized, photographic plates were no longer the preferred detector in astronomy. Nearly all observatories that had instrumentation to record useful slit spectra of Comet Halley also had some kind of digital detector system.

10. FITS FORMAT

To standardize the data documentation and calibration, we provided observers with detailed flux standard star calibration data using existing compilations by K. Strom from KPNO and with guidelines to creating FITS headers, based on the FITS definitions established by Wells, Greisen, and Harten (1981) and by Greisen and Harten (1981). The initial motivation for creating FITS-formatted data tapes was driven by radio astronomers, who wished to intercompare and/or combine data sets obtained with different radio telescopes. The IHW disciplines have introduced additional FITS keywords to describe various aspects of their data so the archive could be properly documented. Efforts have been made to coordinate common keywords between various disciplines. During the 1980s, FITS format became an international standard used by ultraviolet, optical, infrared, and radio astronomers. In addition, public-domain data reduction and data analysis packages, such as IRAF, STSDAS, AIPS, and MIDAS, have been designed and written to handle data written in FITS format.

The FITS standards were initially established to read and write data on magnetic tape in a machine-independent format. Since then, various types of more compact data-storage media have been developed. The medium selected for recording the IHW archive is 5.25-inch-diameter CD-ROMs; each CD-ROM holds approximately 650 megabytes. FITS standards have been modified to handle data recorded on CD-ROMs. With the advent of CD-ROMs, another, very similar machine-independent formatting system was established by space scientists who are primarily involved in the collection and archiving of spacecraft data on missions within the solar system. This formatting system is called the Planetary Data System (PDS). Routines have been written to convert data from FITS to PDS format and from PDS to FITS format for use with different software packages and different applications.

11. SSN FITS KEYWORDS

Appendix A describes the keywords used in the FITS headers of the SSN data. Each keyword is listed in capital letters, followed by an initial indicating whether the variable is a logical (L), integer (I), floating point (F), or character string (C).

Table III. International Distribution of Halley Spectroscopic Contributions

Australia	Italy	United States (cont.)
Belgium	Japan	Hawaii
Brazil	South Africa	Maryland
Canada	Soviet Union	Massachusetts
Chile	Spain	New Mexico
China (People's Republic)	United Kingdom	Pennsylvania
France	United States	Texas
Germany	Arizona	Wisconsin
India	California	

For several FITS keywords, several forms of the keyword exist, usually relating to various axes. In these cases, the keyword is listed as XXXXn, where n is the number of the axis the keyword describes.

12. SSN OBSERVERS AND SUBMITTERS

Appendix B alphabetically lists the observers and submitters participating in the SSN activities, and Table III shows a brief statistical distribution of the contributing countries. The institutional affiliation given for each observer may be different from the institution where he or she originally acquired the data. Also, as of 1989, the Royal Greenwich Observatory has moved from Hailsham, East Sussex, to Cambridge. Some effort has been made to retain the names of observatories for the western European languages (French, German, Spanish, Portuguese, and Italian), while other observatory names have been translated into English.

13. SPECTROSCOPIC SOLAR ATLASES

This archive presents two high-resolution integrated disk solar spectra compiled from a variety of sources. One was contributed by A'Hearn, Ohlmacher, and Schleicher (1983) and the other by Kurucz et al. (1984). The A'Hearn et al. solar spectrum, which is found in one file, AHEARN.FIT, is given in vacuum wavelengths (Å), calibrated in flux units (erg/cm^2/s/Å) covering the wavelength range 2245 Å to 7000 Å in steps of 0.005 Å. The Kurucz et al. solar spectrum, which is found in two files, KURUCZ1.FIT and KURUCZ2.FIT, is given in air wavelengths (Å), calibrated in flux units (erg/cm^2/s/Å). KURUCZ1.FIT covers a wavelength range of 2960 Å to 8000 Å in steps of 0.005 Å, while KURUCZ2.FIT covers the wavelength range of 8000 Å to 13,000 Å in steps of 0.01 Å. We note a wavelength shift between the two solar spectra of approximately 0.03 Å in the sense A'Hearn minus Kurucz. We therefore caution users of these files requiring wavelength accuracies better than this difference to first assess and correct the wavelengths of the solar spectra to the rest frame.

14. REFERENCES AND BIBLIOGRAPHY FOR COMETARY SPECTROSCOPY

Listed below are the references and a few key review papers on cometary physics and spectroscopy that may serve as an introduction for interested observers who are just getting started in the field. These papers are listed simply as a guide and a starting point for future investigators.

A'Hearn, M.F. (1982). "Spectrophotometry of comets at optical wavelengths." In *Comets*, L.L. Wilkening (ed.), University of Arizona Press, Tucson, pp. 433–460.

A'Hearn, M.F. (1988). "Observations of comet nuclei." Ann. Rev. Earth Planet. Sci. 16, 273–293.

A'Hearn, M.F., Ohlmacher, J.T., and Schleicher, D.G. (1983). Technical Report TR AP83-044, University of Maryland, College Park, Maryland.

Belton, M.J.S. (1985). "Comet Halley: The quintessential comet." Science 230, 1129.

Feldman, P.D. (1982). "Ultraviolet spectroscopy of comets." In *Comets*, L.L. Wilkening (ed.), University of Arizona Press, Tucson, pp. 461–479.

Greisen, E.W., and Harten, R.H. (1981). "An extension of FITS (Flexible Image Transport System) for groups of small arrays of data." Astron. Astrophys., Suppl. Ser. 44, 371–374.

Grewing, M., Praderie, F., and Reinhard, R., eds. (1988). *Exploration of Halley's Comet*, Springer, Berlin, pp. 1–984. See also Astron. Astrophys. 187, 1–936 (1987).

Huebner, W.F. (1985). "The photochemistry of comets." In *The Photochemistry of Atmospheres, Earth, the Other Planets and Comets*, Academic Press, New York, pp. 437–508.

Krishna Swamy, K.S. (1986). *Physics of Comets*, World Scientific Publishing Company, Singapore.

Kurucz, R.L., Furenlid, I., Brault, J., and Testerman, L. (1984). *Solar Flux Atlas From 296 to 1300 nm*, Harvard University, Cambridge, Massachusetts.

Mendis, D.A. (1988). "A post-encounter view of comets." Ann. Rev. Astron. Astrophys. 26, 11–49.

Mendis, D.A., Houpis, H.L.F., and Marconi, M.L. (1985). "The physics of comets." Fundamentals of Cosmic Physics 10, 1–353.

Sekanina, Z., and Aronsson, M. (1985). *Archive of Observations of Periodic Comet Crommelin Made During Its 1983–84 Apparition*. JPL Publication 86-2, Jet Propulsion Laboratory, Pasadena, California.

Spinrad, H. (1987). "Comets and their composition." Ann. Rev. Astron. Astrophys. 25, 231–269.

Wells, D.C., Greisen, E.W., and Harten, R.H. (1981). "FITS: A flexible image transport system." Astron. Astrophys., Suppl. Ser. 44, 363–370.

West, R.M. (1990). "Periodic Comet Halley (1986 III)." IAU Circular 5059.

Whipple, F.L., and Huebner, W.F. (1976). "Physical processes in comets." Ann. Rev. Astron. Astrophys. 14, 143–172.

Wyckoff, S. (1982). "Overview of comet observations." In *Comets*, L.L. Wilkening (ed.), University of Arizona Press, Tucson, pp. 3--55.

Wyckoff, S. (1983). "Interaction of cometary ices with the interplanetary medium." J. Phys. Chem. 87, 4234–4242.
Wyckoff, S. (1990). "Comets: Clues to the early history of the solar system." Earth Sci. Rev., in press.
Wyckoff, S., Wagner, R.M., and Wehinger, P.A. (1985). "Onset of sublimation in Comet P/Halley (1982i)." Nature 316, 241–242.

Appendix A. Keywords for SSN FITS Headers

Keyword	Initial	Description
SIMPLE	L	Does the file conform to the FITS format? If yes, the keyword is set to T. Otherwise, the keyword is F. This keyword should be set to T (true) for all SSN files.
BITPIX	I	Keyword contains the number of bits in each picture element. This value is either 16 or 32 for SSN data.
NAXIS	I	Keyword contains the number of axes in the data. One-dimensional spectra have a value of 1. Two-dimensional spectra have a value of 2.
NAXISn	I	n is a number in the range of 1 to NAXIS. Keyword contains the length of axis. NAXIS1 is the dimension of the fastest varying axis in the data, NAXIS2 is the second fastest varying axis, etc.
EXTEND	L	Does the file contain extensions conforming to the FITS standards? If yes, the keyword is set to T. Otherwise, the keyword is F. For all SSN data files, EXTEND = F.
OBJECT	C	Keyword contains the name of the object of the data.
FILE-NUM	I	This is a running number of the files sent to the archive. All values have six places and, for the SSN, begin with 7. For P/Halley, the SSN file numbers are in the range of 701000 to 709999.
DATE-OBS	C	Universal Time (UT) date of the middle of data acquisition. Date is given in the FITS standard of day, month, year (DD/MM/YY).
TIME-OBS	F	Fractional part of a day, indicating the UT time of the middle of data acquisition. The keyword has a value ranging from 0.0 to 0.99999.
DATE-REL	C	Date the submitter or submitters agree to release their data to the public.
DISCIPLN	C	IHW Discipline. For the SSN, the value is always SPECTROSCOPY.
LONG-OBS	C	East longitude of the observation station. Keyword value range is from 00/00/00 to 359/59/59.
LAT--OBS	C	Latitude of the observation station. Degrees north or south are indicated by a preceding '+' or '-', respectively; 0 deg has no sign.
SYSTEM	C	Station system code. Keyword is a number of the form 7nnnttii, where: 7 = Discipline number (SSN) nnn = IAU Observatory Number tt = Telescope Number, as assigned by the IHW Large-Scale Phenomena Network (LSPN) ii = Instrument/Detector Number, as assigned by the SSN. This number corresponds to DD in the DIS-CODE keyword.
OBSERVER	C	Name of observer. If there are more than two observers, the first observer is listed, followed by 'ET AL.' Additional observers are listed in the COMMENT ADD. OBS. keyword.
SUBMITTR	C	Name of the person or persons who submitted the data to the IHW SSN.
SPEC-EVT	L	If true, some special event occurred during observation. See COMMENT and HISTORY fields for more information.
DAT-FORM	C	Form of the data. Either ASCII, STANDARD, HARDCOPY, or NODATA.
DAT-TYPE	C	Type of data being submitted. Either UNKNOWN, REDUCED DIGITAL, RAW DIGITAL, PHOTOGRAPHIC, OBJECTIVE PRISM, INTERFEROMETRIC, or SPACE BORNE.
DIS-CODE	C	This keyword contains a 9-digit integer of the form DDCCWWWRQ, where: DD = Detector/Instrument combination. This is a unique number for each combination and has been assigned by the SSN. This value is the same as ii in the SYSTEM code.

Appendix A. (continued)

Keyword	Initial	Description
		CC = Configuration (grating, grating tilt, filter, aperture size, order, etc.) for a given telescope and detector/instrument combination.
		WWW = Wavelength range (in Å), included in the data. A binary coding scheme is used to specify a unique number for a unique set of wavelength regions. The number is the sum of all defined values for each spectral region in which data are submitted: 1 = < 3000 2 = 3000–3499 4 = 3500–3999 8 = 4000–4999 16 = 5000–5999 32 = 6000–6999 64 = 7000–7999 128 = 8000–10,000 256 = > 10,000 Example: A range of 3700–6400 Å would be 4+8+16+32=60.
		R = Resolution. This parameter is based on the spectral resolution (full width half maximum [FWHM] in Å). 1 = < = 0.05 2 = > 0.05–0.2 3 = > 0.2–1 4 = > 1–5 5 = > 5–10 6 = > 10–20 7 = > 20–50 8 = > 50–100 9 = > 100
		Q = Quality of the data. We adopted a qualitative judgement for this parameter, and the values are the same as for the QUALITY keyword. 0 = Unknown 1 = Excellent 2 = Very Good 3 = Good 4 = Fair 5 = Poor
OBSVTORY	C	Name of the observatory from which the data were obtained.
ELEV-OBS	F	Elevation of the observing station (in m).
TELESCOP	C	Telescope used for the observation. Where possible, the telescope name as listed by the Astronomical Almanac has been used.
INSTRUME	C	Instrument and detector used for obtaining data.
RESOL-SP	C	Approximate spectral resolution of data (in Å).
RANGE-SP	C	Approximate spectral range of data (in Å).
EXPOSURE	F	Exposure or integration time (in s).
APERSIZE	C	Entrance aperture size, or slit width and length of instrument or detector (in arcsec).

Appendix A. (continued)

Keyword	Initial	Description
Airmass	F	One of the following: AIRM-BEG = Airmass at the beginning of the observation. AIRM-END = Airmass at the end of the observation. AIRM-MID = Airmass at the midpoint of the observation. AIRM-AVE = Average of the airmass of the observation.
SE[illegible]	F	Separation between the comet nucleus and the center of the slit or aperture (in arcsec); see Figure 1.
O[illegible]NT	F	Position angle of the slit or aperture center with respect to the comet nucleus, measured north through east (in deg), ranging from 0 to 360 degrees; see Figure 1.
POSANG	F	Position angle of the slit measured from north through east (in deg), ranging from 0 to 360 degrees. Two-dimensional spectra only. See COMMENT and HISTORY sections for observers' variations of this definition.
PIXSCALE	F	Image scale at the detector in arcsec per pixel. Two-dimensional spectra only.
QUALITY	I	A subjective, qualitative estimate of the data. Values used are UNKNOWN, EXCELLENT, VERY GOOD, GOOD, FAIR, and POOR.
CTYPEn	C	n is a number between 1 and NAXIS. Name of the independent variables: LAMBDAA = Wavelength (in Å). VELOCITY = Velocity (in km/s). PIXELS = Pixel number. RHO = Projected distance (in arcsec). OTHER = Described in a comment.
BUNIT	C	Name of dependent variable: FLAMBDA = Flux per wavelength (in erg/cm^2/s/Å). FNU = Flux per frequency (in erg/cm^2/s/Hz). RAYLAMBDA = Flux per wavelength (in rayleighs/Å). RELINS = Relative intensity. COUNTS = Counts or count rate (in counts/s). DENSITY = Photographic density. OTHER = Described in a comment.
CRVALn	F	Reference point for CTYPEn.
CRPIXn	F	Reference pixel location corresponding to CRVALn.
CDELTn	F	Increment in CTYPEn per pixel.
HISTORY DATE-REC	C	Date the file was received by the IHW SSN.
HISTORY DATE-CMP	C	Date the file archiving was completed.
HISTORY REDUCED	C	Known data reduction steps.
HISTORY	C	Other history, if known.
COMMENT ADD. OBS.	C	Additional observers.
COMMENT NOTE	C	Some important note on the data extracted from COMMENT or HISTORY fields.

Appendix A. (continued)

Keyword	Initial	Description
COMMENT PROC FILE and ORIG. FILE	C	Comment regarding the original file identification of the submitted file. Often the file name consists of the position of the file on the original submission tape. Used for SSN archiving.
COMMENT REPLACE	C	A note that this file supersedes another file (the previous file would have been deleted from the archive).
COMMENT	C	Additional comments about the data.
DATAMAX	F	Maximum value of the dependent variable.
DATAMIN	F	Minimum value of the dependent variable.
BSCALE	F	Scale factor to convert the FITS pixel values to true values. Used to convert FITS data to the original data values. DataValue = BZERO + BSCALE * FileDataValue
BZERO	F	Offset applied to true pixel values.
END		Signals the end of the FITS header.

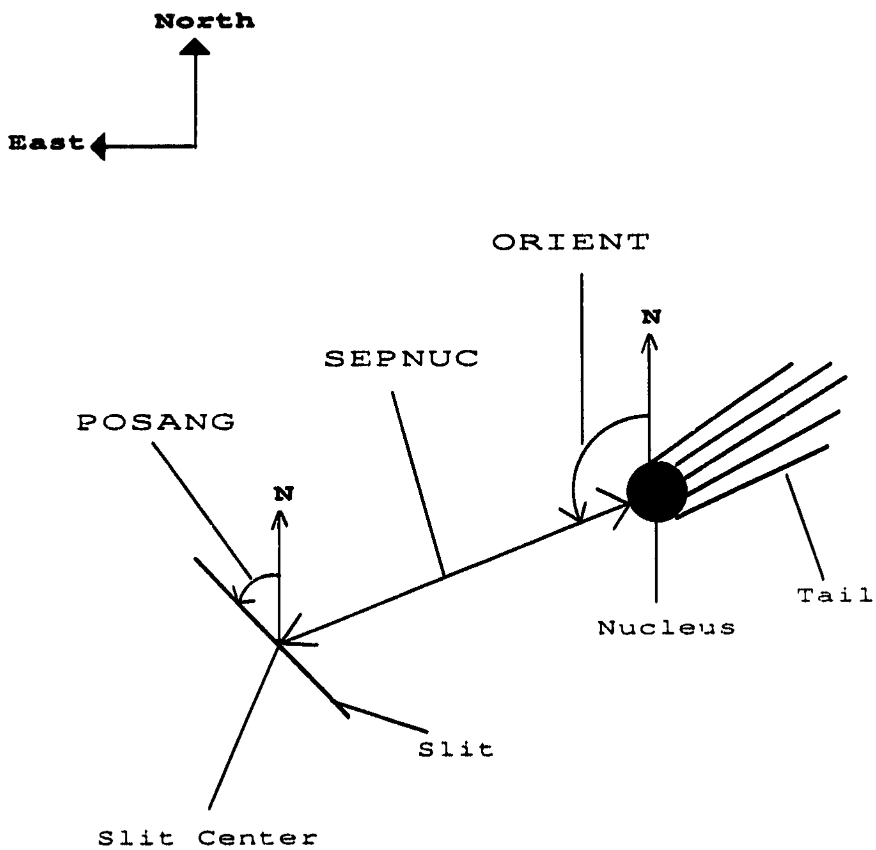

Figure 1. Definition of angles, POSANG, SEPNUC, and ORIENT.

Appendix B. List of SSN Observers and Submitters

Observer/Submitter	Institute (City, State, Country)
M.F. A'Hearn	University of Maryland, College Park, Maryland, U.S.A.
I. Appenzeller	Landessternwarte, Heidelberg, F.R.G.
C. Arpigny	Universite de Liege, Cointe-Ougree, Belgium
E.S. Barker	McDonald Observatory, University of Texas, Austin, Texas, U.S.A.
J.E. Beckman	Universidad de La Laguna, Tenerife, Canary Islands, Spain
M.J.S. Belton	National Optical Astronomy Observatories, Tucson, Arizona, U.S.A.
J.H. Black	University of Arizona, Tucson, Arizona, U.S.A.
G. Branduardi	Roque de los Muchachos Observatory, Canary Islands, Spain
M. Breare	Roque de los Muchachos Observatory, Canary Islands, Spain
M.W. Buie	Space Telescope Science Institute, Baltimore, Maryland, U.S.A.
E.M. Burbidge	University of California, San Diego, California, U.S.A.
P.S. Butterworth	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
L. Castinel	European Southern Observatory, La Silla, Chile
M. Chester	Pennsylvania State University, University Park, Pennsylvania, U.S.A.
K.I. Churyumov	Kiev State University, Kiev, Goloseevo, U.S.S.R.
K. Chuvaev	Crimean Astrophysical Observatory, Nauchny, Crimea, U.S.S.R.
K.K. Chuvayev	Kiev State University, Kiev, Goloseevo, U.S.S.R.
A. Cochran	McDonald Observatory, University of Texas, Austin, Texas, U.S.A.
W.D. Cochran	McDonald Observatory, University of Texas, Austin, Texas, U.S.A.
S.J. Codina-Landaberry	Observatorio Nacional, Sao Cristovao, Rio de Janeiro, Brazil
C. Corbally	Steward Observatory, University of Arizona, Tucson, Arizona, U.S.A.
C. Cosmovici	Instituto di Astrofisico Spatiale, Frascati, Roma, Italy
I. Coulson	South African Astronomical Observatory, South Africa
D.P. Cruikshank	NASA Ames Research Center, Moffett Field, California, U.S.A.
A. Danks	Applied Research Corporation, Landover, Maryland, U.S.A.
M.S. Dementyev	Main Astronomical Observatory, Kiev, Goloseevo, U.S.S.R.
M. DiSanti	University of Arizona, Tucson, Arizona, U.S.A.

Appendix B. (continued)

Observer/Submitter	Institute (City, State, Country)
S. Djorgovski	California Institute of Technology, Pasadena, California, U.S.A.
A.N. Dovgopol	Main Astronomical Observatory, Kiev, Goloseevo, U.S.S.R.
T. Encrenaz	Observatoire de Paris, Meudon, France
L. Engel	Arizona State University, Tempe, Arizona, U.S.A.
A.P. Fairall	University of Capetown, Rondebosch, South Africa
R. Falciani	Osservatorio Astrofisico di Arcetri, Firenze, Italy
R. Falciani	Bologna University Observatory, Loiano, Italy
D. Faria	Observatorio Nacional, Sao Cristovao, Rio de Janeiro, Brazil
P.D. Feldman	Johns Hopkins University, Baltimore, Maryland, U.S.A.
A.J. Ferro	Arizona State University, Tempe, Arizona, U.S.A.
M. Festou	Observatoire de Besancon, Besancon, France
A.V. Filippenko	University of California, Berkeley, California, U.S.A.
U. Fink	University of Arizona, Tucson, Arizona, U.S.A.
R.F. Garrison	David Dunlap Observatory, Richmond Hill, Ontario, Canada
R. Gilmozzi	Astrophysics Institute, Frascati, Italy
R. Goodrich	Lick Observatory, Mt. Hamilton, California, U.S.A.
D.I. Gorodetskij	Kiev State University, Kiev, Goloseevo, U.S.S.R.
J. Green	McDonald Observatory, University of Texas, Austin, Texas, U.S.A.
R. Haefner	Universitatssternwarte, München, F.R.G.
E.A. Harlan	Lick Observatory, Mt. Hamilton, California, U.S.A.
D. Harmer	Royal Greenwich Observatory, Cambridge, U.K.
G.H. Herbig	University of Hawaii, Honolulu, Hawaii, U.S.A.
S. Ibadov	Institute of Astrophysics, Dushanbe, U.S.S.R.
W. Jaworski	University of Victoria, Victoria, British Columbia, Canada
V. Jesipov	Institute of Astrophysics, Dushanbe, U.S.S.R.
D. Jewitt	University of Hawaii, Honolulu, Hawaii, U.S.A.
M. Kane	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
P. Kelton	McDonald Observatory, University of Texas, Austin, Texas, U.S.A.
M. Kidger	Universidad de La Laguna, Tenerife, Canary Islands, Spain
D. Kilkenny	South African Astronomical Observatory, South Africa
V.M. Klimenko	Main Astronomical Observatory, Kiev, Goloseevo, U.S.S.R.
P.P. Korsun	Main Astronomical Observatory, Kiev, Goloseevo, U.S.S.R.
S. Koutchmy	National Solar Observatory, Sunspot, New Mexico, U.S.A.
P.L. Lamy	Laboratoire d'Astronomie Spatiale, Marseille, France

Appendix B. (continued)

Observer/Submitter	Institute (City, State, Country)
R. Las Casas	Observatorio Nacional, Sao Cristovao, Rio de Janeiro, Brazil
E. Lindholm	Arizona State University, Tempe, Arizona, U.S.A.
T. Lloyd-Evans	South African Astronomical Observatory, South Africa
G. Loper	Arizona State University, Tempe, Arizona, U.S.A.
B.L. Lutz	Lowell Observatory, Flagstaff, Arizona, U.S.A.
L. MacFadden	University of Maryland, College Park, Maryland, U.S.A.
P. Mack	McGraw-Hill Observatory, c/o National Optical Astronomy Observatories (NOAO), Tucson, Arizona, U.S.A.
K. Magee-Sauer	University of Delaware, Newark, Delaware, U.S.A.
P. Malburet	European Southern Observatory, La Silla, Chile
C. Malivoir	Observatoire de Haute-Provence, St. Michel de l'Observatoire, France
M. Malkan	University of California, Los Angeles, California, U.S.A.
O. Mamadov	Institute of Astrophysics, Dushanbe, U.S.S.R.
J. Manfroid	Universite de Liege, Cointe-Ougree, Belgium
F. Marang	South African Astronomical Observatory, South Africa
R. Marcialis	Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, U.S.A.
R. Martin	Royal Greenwich Observatory, Cambridge, U.K.
Y. Matsuguchi	Okayama Astrophysical Observatory, Okayama, Japan
M. Matsumura	Okayama Astrophysical Observatory, Okayama, Japan
P. McCarthy	University of California, Berkeley, California, U.S.A.
J.S. Miller	Lick Observatory, Mt. Hamilton, California, U.S.A.
A. Miyashita	National Astronomical Observatory, Mitaka-Shi, Tokyo, Japan
E. Muers	Roque de los Muchachos Observatory, Canary Islands, Spain
P. Murdin	Royal Greenwich Observatory, Cambridge, U.K.
C. Nitscheim	Observatoire de Haute-Provence, St. Michel de l'Observatoire, France
C.R. O'Dell	Rice University, Houston, Texas, U.S.A.
R. Oliversen	Kitt Peak National Observatory, Tucson, Arizona, U.S.A.
C. Opal	McDonald Observatory, University of Texas, Austin, Texas, U.S.A.
J. Pacheco	Observatorio Nacional, Sao Cristovao, Rio de Janeiro, Brazil
P. Patriarchi	Osservatorio Astrofisico di Arcetri, Firenze, Italy
B. Peterson	Mount Stromlo and Siding Spring Observatories, Canberra, Australian Capital Territory, Australia
M. Prieto	Roque de los Muchachos Observatory, Canary Islands, Spain

Appendix B. (continued)

Observer/Submitter	Institute (City, State, Country)
D.A. Ramsay	National Research Council of Canada, Ottawa, Ontario, Canada
L. Ramsey	Pennsylvania State University, University Park, Pennsylvania, U.S.A.
N. Reid	Roque de los Muchachos Observatory, Canary Islands, Spain
R.J. Reynolds	University of Wisconsin, Madison, Wisconsin, U.S.A.
F. Roesler	University of Wisconsin, Madison, Wisconsin, U.S.A.
E. Roettger	Johns Hopkins University, Baltimore, Maryland, U.S.A.
T. Santos	Observatorio Nacional, Sao Cristovao, Rio de Janeiro, Brazil
W. Sargent	Palomar Observatory, California Institute of Technology, Pasadena, California, U.S.A.
S. Sawyer	McDonald Observatory, University of Texas, Austin, Texas, U.S.A.
F. Scherb	University of Wisconsin, Madison, Wisconsin, U.S.A.
D.G. Schleicher	Lowell Observatory, Flagstaff, Arizona, U.S.A.
A. Schultz	Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, U.S.A.
V. Shavlovski	Main Astronomical Observatory, Kiev, Goloseevo, U.S.S.R.
K.R. Sivaraman	Indian Institute of Astrophysics Bangalore, India
L.A. Smaldone	Dipartimento di Fisica, Napoli, Italy
H. Spinrad	University of California, Berkeley, California, U.S.A.
M. Strauss	University of California, Berkeley, California, U.S.A.
M. Takada-Hidai	Tokai University, Hiratsuka-Shi, Kanagawa, Japan
H. Tanabe	National Astronomical Observatory, Mitaka-Shi, Tokyo, Japan
Y. Taniguchi	Kiso Observatory, Kiso-Gun, Nagano-Ken, Japan
V.P. Tarashchuk	Kiev State University, Kiev, Goloseevo, U.S.S.R.
J.B. Tatum	University of Victoria, Victoria, British Columbia, Canada
S. Tegler	University of Florida, Gainesville, Florida, U.S.A.
R. Terlevich	Royal Greenwich Observatory, Cambridge, U.K.
J. Theobald	Arizona State University, Tempe, Arizona, U.S.A.
G.P. Tozzi	Osservatorio Astrofisico di Arcetri, Firenze, Italy
S. Unger	Royal Greenwich Observatory, Cambridge, U.K.
W. van Breugel	University of California, Berkeley, California, U.S.A.
C. Vanderriest	Observatoire de Paris, Meudon, France
R.M. Wagner	Lowell Observatory, Flagstaff, Arizona, U.S.A.
M. Wallis	University College Cardiff, Wales, U.K.
J. Watanabe	Tokyo National Observatory, Tokyo, Japan
H. Weaver	Space Telescope Science Institute, Baltimore, Maryland, U.S.A.
P.A. Wehinger	Arizona State University, Tempe, Arizona, U.S.A.

Appendix B. (continued)

Observer/Submitter	Institute (City, State, Country)
M. Womack	Arizona State University, Tempe, Arizona, U.S.A.
T. Woods	Johns Hopkins University, Baltimore, Maryland, U.S.A.
Wu Guangjie	Yunnan Observatory, Kunming, People's Republic of China
S. Wyckoff	Arizona State University, Tempe, Arizona, U.S.A.
F. Wyk	South African Astronomical Observatory, South Africa
Y.S. Yatskiv	Main Astronomical Observatory, Kiev, Goloseevo, U.S.S.R.
D.K. Yeomans	Jet Propulsion Laboratory, Pasadena, California, U.S.A.
J.-M. Zucconi	Observatoire de Besancon, Besancon, France

AMATEUR OBSERVATION NETWORK

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1. SUMMARY

The rationale for including amateur observations in the International Halley Watch (IHW) activities was described in the original IHW report by Brandt et al. (1980). The goal was to ensure that amateur observations would be as scientifically useful as possible. With that in mind, the IHW Amateur Observers' Manual (Edberg 1983) was written. The philosophy was to provide detailed instructions that observers with some experience could follow. The Manual was not intended to teach neophyte amateur astronomers how to begin the hobby, though it was available early enough that a novice wishing to learn how to make amateur astronomical observations in general and observations of comets in particular would have enough time and could find enough general references to learn the necessary techniques.

To gather participants in the amateur network, announcements were made in various publications. Seeking scientific assistance from amateur astronomers via the public news media had its pros and cons. Filling in observational gaps in professional coverage of the comet, for the Large-Scale Phenomena Network and Spectroscopy and Spectrophotometry Network, to name two examples, and supplying numerous visual observations were genuine, positive contributions to the IHW. On the other hand, the potentially large number of contributors and observations could easily have overwhelmed efforts to manage and then prepare the data for inclusion in the archive. Estimates of numbers of amateur astronomers in the U.S. and Canada alone reached as much as 300,000.

To ameliorate the problem, amateurs planning to register with the Amateur Observation Network were encouraged, via the Observer Index registration form, to first read portions of the IHW Amateur Observers' Manual to confirm their interest not just in joining the IHW, but also in actually participating by making observations useful to the scientific community. Ultimately, the numbers of participants and observations proved manageable. There were 1,575 registrations, and of these, only 873 actually submitted observations of P/Halley. (The latter figure includes submitters who did not register with the amateur network: their observations simply arrived in the mail.)

2. REGISTRATION AND PREPARATION

The Observer Index form was designed so that the observer's address and observing site particulars could be entered into computer files for later use. The information requested on telescopes, cameras, and other observing hardware, while not necessary at the time of registration (but required for observations), later proved useful on numerous occasions when ambiguities of various types appeared in observation reports. Even the signature permitting use of the data in the archive was helpful at times.

Registrants received a letter of acknowledgment and, later, letters timed appropriately for the P/Crommelin trial run and the P/Giacobini-Zinner (G-Z) campaign. Registrants were encouraged to request a free subscription to the IHW Amateur Observer's Bulletin (published for the IHW by the Planetary Society) so they would be informed about IHW activities.

Later, a short questionnaire requesting more details on each observer's past cometary and general astronomical experience was sent to all submitters for whom addresses were available. (Some observations were sent without the submitter's address and other observers moved without sending an address update.) Staff and time limitations prevented the inclusion of the ancillary Observer Index data and the questionnaire data in computer files, but the paper files will stay with the IHW archives for any future use, including sociological studies.

The observing site coordinates listed with the observations in the archives are mostly those supplied by the observer. Appended to these coordinates is a subjective estimate of the accuracy of that position. Occasionally, observers listed additional sites for which they may not have supplied coordinates. For these sites, any evidence available was used to supply very approximate geographic coordinates, and a very large position uncertainty estimate, sometimes as large as a whole country, was attached to them.

The large number of observing sites that many individuals would use was not anticipated. Observers selected sites based on such characteristics as atmospheric conditions and weather, distance from home, altitude and darkness of the horizon, and the comet's azimuth, among others.

The observation report forms in the Manual (as later modified and published in the IHW Amateur Observer's Bulletin and in letters to observers) were patterned on report forms used by various amateur astronomy organizations. Occasionally there is redundancy on the forms: this sometimes proved very helpful in preparing the data for input. The forms were as self-explanatory as possible, even though the Manual provided a complete glossary explaining the forms. The report forms were formulated such that a selected parameter was the same for all observations reported on that form: for magnitudes, the parameter was the comet observed; for drawings, photoelectric photometry, and meteor counts, it was the date; and for all observations using photography, it was photographic emulsion. Unfortunately, some observers did not follow the formulations, creating significant additional work to prepare mixed observations for entry in the archive.

The preparation of thousands of observations for entry in the archive leads to the following conclusion: the organizer of any activity of this nature must be prepared for the unexpected and irrational. Sometimes people just do not follow instructions, and the data system must have built-in flexibility and adaptability.

3. MAGNITUDE OBSERVATIONS

After discussions with the staff of the International Comet Quarterly (ICQ), the ICQ observation report form was adopted with added columns for further data relevant to the analysis and understanding of the large number of magnitude estimates in the archive. It was a mistake not to ask for the comet's name on the report form: some observers sent in their data on P/Giacobini-Zinner and on P/Halley on separate forms, but in the same mailing. Some G-Z observations were found mixed with Halley observations during the final Halley proofreading, when it was too late to add them to the G-Z archive. Another minor problem, fortunately made obvious by the observers, was that observations of brighter "comets of opportunity" discovered in 1985 were sometimes submitted with Halley observations on the same report form (this occurred with drawings as well).

The Universal Time (UT) Date was usually understood by observers, but the time of observations was sometimes not correctly computed or not attached to the correct data. Some observers, responding to an IHW request, submitted their times as decimals of a day. A number used the table distributed in the acknowledgment letter and IHW Amateur Observer's Bulletin (No. 11) incorrectly. Ambiguous dates or times were discarded. With very few exceptions, decimal dates had to be specified to two or more decimal places for inclusion in the archives.

To better standardize the magnitude estimates, comparison star charts were provided in Part II of the IHW Amateur Observers' Manual. These charts included reduced-size AAVSO Variable Star Atlas charts (Scovil 1980) with their V and visual magnitudes and portions of the B.A.A. Star Atlas charts (Tirion 1981) that had AAVSO Atlas magnitudes transferred to them. In addition, selected AAVSO variable star comparison charts, some checked photoelectrically by Richard Stanton (private communication), were mailed to registered observers. In spite of this effort, the Amateur Network appendix to the archive lists dozens of reference sources used by the observers. It is incumbent on any archive user to decide which set(s) of comparison charts are acceptable for research.

Some observers reported magnitudes made with the same instrument, but with different magnifications on the same data line. These were discarded.

The Dark Adapted column asked for a simple yes/no response. The actual time spent dark adapting would have been a more useful datum.

The criteria for the retention of magnitude data in the archive were extensively debated. The extremes ranged from keeping the data from only a few, selected, experienced observers to keeping virtually all of the data. The only criterion enunciated that seemed valid originated with Charles Morris (private communication): Exclude observers who made less than a specified number of observations (e.g., 1 observation per month on the average) during the prime 1985–1986 observing period. This number can be selected so that the criterion tends to filter out inexperienced observers and so that there is sufficient data from the remaining observers to make meaningful intercomparisons.

The archive actually includes all those data that, based on each observer's report itself, appear to have been made in the Manual-prescribed manner. This allows researchers the option of applying Morris' criterion. Even this approach to data inclusion still resulted in the discard of roughly one-quarter of the submitted observations.

This data set will allow many more studies of interest—some of the observers perhaps, as well as of the comet—than would have been possible had a much more limited archive been produced. Workers interested in using experience as a selection criterion are referred to Appendix A, kindly supplied by Daniel Green (private communication), which lists observations by those whose data are in the ICQ files. Users are also referred to Green (1986) for additional data on ICQ observers of

P/Halley. Green (1986) lists both the most active ICQ observers of P/Halley and the most active observers of all comets in the ICQ archives.

Throughout the archive, observers' notes are usually reproduced as written by the observer, especially in the cases of observers whose first language is not English. This can make for rough reading and ambiguity at times, but it allows archive users to make their own judgments. Some observers supplied extensive notes not directly related to the comet or the observations. A few of these are scattered through the archive to supply a little color and context to the data and the times.

4. DRAWINGS

The discerning eyes and skilled hands of astronomical illustrators have historically provided images of comets. Drawings of P/Halley in this age of photographic and electronic imaging help place the comet's 1986 apparition in the context of earlier apparitions. In addition, the large number of drawings on file offers investigators the opportunity to better understand eye-brain detector variations among observers, especially when the drawings are compared with images from the Near-Nucleus Studies Network that were made by impersonal detectors (though later processing by archive users will insert personal bias into these images).

Some observers' reports of magnification used were ambiguous. For example, an observer may have indicated 58-271, listed in the archive as 58,271. It is not clear if the observer used an unspecified intermediate power.

The intent in asking for UT Start/End was to determine how long it took the observer to make the drawing, since it could not be made instantaneously. In a few cases, a single time was given with the drawing, but not in the space provided for Start/End. In such cases, an editor's note was inserted and any evidence available, including other drawings or magnitude estimates, was used to suggest in the note whether the supplied time was for the start or the end or the middle of the observation.

Today, unfortunately, in this age of photographic and electronic detectors, few professional or amateur astronomers have the artistic skill and accuracy that were once the common tools of many astronomers.

5. PHOTOGRAPHY

The photography report form, updated in IHW Amateur Observer's Bulletin No. 6 from the version in the Manual, was designed with intentionally redundant entries. This was occasionally helpful in interpreting an observer's report.

Images listed in the archive are those for which a quick visual inspection without magnification suggested that the image could have use to someone studying the appearance of the comet. When an image is of doubtful quality, it is nevertheless listed, consistent with the philosophy that it is better to let archive users be aware of the availability of that image. Roughly one-eighth of the photos submitted were not included in the archive, and neither were the numerous reports of photos taken for which no copy was included. The quality of the images in the files ranges from barely useful to superb, professional-level work.

The times listed in the archive were converted from exposure start and duration to mid-exposure time. Often the photographer gave the starting time to greater precision (in hours:minutes:seconds) than is indicated by the decimal conversion.

In the archive listing, telescopes used for photography commonly have the focal length, focal ratio, and aperture all (redundantly) specified. When camera lenses were used, only the focal length and focal ratio are listed. The focal ratio listed for a camera lens is that used for the photograph, which may not be the widest-open aperture (lowest focal ratio) possible with the lens.

Auxiliary lenses are sometimes used on telescopes and cameras to increase or decrease the focal length. When reimaging is not involved and a negative lens is used to increase the telescope's effective focal length, these lenses are commonly called telextenders or teleconverters (or Barlow lenses when used visually). A telecompressor or focal reducer shortens the effective focal length without reimaging.

The ISO (ASA/DIN) speed of the emulsion is given as supplied by the observer or manufacturer. Some emulsions do not have a speed (in the usual sense of the word) determined for them, so for these and for emulsions that have been hypersensitized or push-processed, this column is left empty. For an emulsion for which different speeds are available by manufacturer's design and recommended processing, the speed as given by the observer is used.

Gas hypersensitizing and emulsion cooling both serve to increase the sensitivity or mitigate the effects of low-intensity failure of the reciprocity law for photographic emulsions. Gas-hypersensitized emulsions are available commercially (Lumicon and University Optics are two such suppliers) and are also prepared by observers themselves.

Considering the psychology and worldwide locations of astrophotographers, it would be impossible to standardize photographic emulsions and processing. These details are provided with the archive listing.

Kodak developer D-19b is commonly used by European astrophotographers. It is an X-ray emulsion developer that is rather radically different in composition from its high-contrast American namesake, D-19. Contact Eastman Kodak Co., Dept. 841-S, 343 State St., Rochester, NY 14650-0811, U.S.A., for details. Kodak also can provide details on the spectral transmission of its gelatin Wratten filter series (see the *Kodak Filters for Scientific and Technical Uses* manual); many of these designation numbers have been adopted for equivalent glass filters made by other manufacturers.

There were variations in the way observers indicated the dilutions of their developers: for example, both 1 + 4 and 1 : 4 were used.

It seemed likely that original negatives or positives of the comet would be too precious for observers to want to give up. While there are some originals in the files, the archive largely lists copies of one of the following types:

Contact Prints	Positive images on paper made by placing the original negative in contact with the photographic paper.
Negatives	May be originals or copies. Some are mounted in slide frames.
Prints	These are usually enlargements from the original; occasionally, they are halftone or xerographic (often of poor quality) copies. Composite prints are so noted, but are listed as a single entry with a mid-time determined as

	being halfway between the initial opening of the shutter and its final closing, no matter what the individual exposure times and their separations were. Rarely, negative prints were submitted.
Slides	135-size positive black-and-white or color transparencies mounted in standard frames.
Transparencies	Positive images on film, unmounted, of 135-size or larger. Standard sizes are 135, providing an image area of approximately 24 × 36 mm, and 120, with an area of approximately 6 × 6 cm (sometimes 6 × 7 cm). Rarely, other, larger films were used.

The data files contain hardcopy images ranging in size from individual 135-size images to oversize prints.

For the purpose of standardization, the IHW Amateur Observers' Manual instructed observers to obtain calibration photos of M31, M83, and Orion's belt. Only a handful of observers cooperated. Calibration photos are stored with the comet photos, but are not listed in the archive.

6. ASTROMETRY

A few amateur astronomers have been contributing much-needed astrometric observations of comets for many years. These astronomers worked directly with the IHW Astrometry Network. Several other amateur astrometrists sent their measurements to the Amateur Observation Network. Astrometry network Discipline Specialist Don Yeomans analyzed these data and, unfortunately, found them unacceptable. These observers were encouraged to continue improving their technique.

7. SPECTROSCOPY

Reports of spectroscopic observations were made on a form closely matching the photographic report form (both in the original and updated versions). The principal differences were the information requested on the type of telescope and spectroscopic system used and on disperser characteristics. The archive listings indicate camera lens specifically with a "CL", and a camera lens may also be inferred, as in the photographic listings, by the empty column listing for aperture.

Observer W. Tom Buchanan's spectrograph has an unusual design. It is basically an objective grating spectrograph using a camera lens. He has added a complex optical system that allows wavelength reference marks to be placed on the film with the target spectrum. His detailed description is on file with his spectra.

8. PHOTOELECTRIC PHOTOMETRY

Only one observer submitted photometric observations to the Amateur Network, on his own report form (with the comment that the form in the Manual was inadequate). These were forwarded to the professional Photometry and Polarimetry Network for disposition.

9. METEOR OBSERVATIONS

At the time the IHW was being organized, a professional network of meteor observers was not planned. Amateur meteor observations were solicited to ensure that at least some meteor data would be included in the archives, especially since this is a subject easily and traditionally studied by amateurs.

With much already known about these meteor showers, hourly counts, photography, and spectrophotography were emphasized. Halley Meteor Days were set from 1982–1987 for May 2–6 and October 20–24.

Visual hourly counts were emphasized initially (in the Manual), but with the encouragement and assistance of David Meisel of the American Meteor Society (AMS), radio counts were later added to the program. Mike Morrow and Ruthi Moore, the IHW Meteor Recorders, designed an improved Visual/Radio Meteor Observation Report form, which was distributed and explained in the acknowledgment letter to observers and in IHW Amateur Observer's Bulletin No. 5.

Well over a thousand meteor reports were received from several hundred observers. The majority of them observed only over one or two of the standard one-hour-long observation periods, rather than the more desirable multiple one-hour-long periods.

Efforts in meteor photography were minimal. Only three direct photos were submitted (one Eta Aquarid, one Orionid, and one sporadic meteor) and no spectra. The meteor photography report form was updated in parallel with those of photography and spectroscopy.

On the advice of the IHW's Steering Group, a professional Meteor Studies network was created and announced in IHW Newsletter No. 7 (June 18, 1985). With this network organized, all the amateur observations were forwarded to Discipline Specialist Anton Hajduk at the Astronomical Institute of the Slovak Academy of Sciences for inclusion in the meteor archive. Copies of all these data are also with the paper files of the amateur archive.

10. FLEXIBLE IMAGE TRANSPORT SYSTEM (FITS) HEADERS

The amateur data are computer-archived according to the standard, extended FITS format. The visual data use a header with a table extension format, while all the other types include all the data in the primary header. To maintain consistency in the magnitude data, the header plus extension format is used for the archives containing P/Crommelin, P/Giacobini-Zinner, and P/Halley data, even though it would have been more efficient to include all the magnitude data in the primary header.

11. CONCLUSIONS

Halley's Comet inspired amateur astronomers worldwide to contribute useful data to the IHW archive. Halley is special, though, and the numbers of participants for any other comet or other significant astronomical event would probably be only a small fraction of this number. (One need only contemplate the small number of participants for the IHW-sponsored watches on P/Crommelin and P/Giacobini-Zinner to reach the same conclusion.) In another aspect of completeness, there are certainly numerous high-quality photographs taken by amateurs that were not reported to the IHW. This is an unfortunate loss, as are the photos reported without copies submitted.

It was heartening to find that the majority of those participating took their efforts seriously enough to submit useful data. It was interesting to find that the observers new to the field of cometary observations followed directions better than the more experienced observers did.

Future organizers of observational campaigns should certainly include amateur astronomers in their efforts. The talent available is a valuable resource that should be tapped. Do not expect even the most careful and lucid instructions to be followed rigorously, however. Even professional astronomers can be willful on occasion, and amateurs additionally often lack the insight to appreciate the importance of standardizing observing techniques.

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Appendix A. The Most Active ICQ Observers

The top 24 active observers of all comets in the ICQ archive as of January 4, 1990, are listed in Table A-I. The columns list the observer's name, number of positive observations, and number of negative observations (i.e., those observations in which the comet was not detected). Here, an observation is defined as a single ICQ-format 80-character data listing; in the ICQ archive, there is often more than one observation per observer per comet per night, since observers use different methods and different instruments to determine the total visual magnitude. The vast majority of observations (> 95%) contain some sort of magnitude estimate, while the remainder report only other aspects of the visual appearance.

Table A-I. Top Active Observers of All Comets in the ICQ Archive

Observer	Number of Positive Observations	Number of Negative Observations
John E. Bortle	1,952	74
Albert Jones	1,942	1
Charles S. Morris	1,799	36
Reinder Bouma	914	8
Daniel W.E. Green	863	3
Andrew Pearce	801	43
Alan Hale	682	280
Graham Keitch	775	1
Jonathan Shanklin	657	18
Warren Morrison	622	--
David Seargent	618	1
Richard Keen	607	--
Chris Spratt	596	--
Michael Moeller	533	--
Maurice Clark	503	--
Jean-Claude Merlin	480	19
Don Machholz	463	4
Eric Jacobson	391	20
Richard Fleet	354	5
Georg Comello	330	1
Kiyotaka Kanai	329	--
Werner Hasubick	327	2
E.P. Bus	326	--
Akimasa Nakamura	316	--

USE OF THE CD-ROM ARCHIVE

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1. BACKGROUND

The Comet Halley Archive compact discs contain observations of Comet Halley's apparition in 1981–1989 obtained as part of the International Halley Watch (IHW) campaign to observe the comet. The collection of data spans the wavelength range from ultraviolet through radio and is augmented by a large fraction of the in situ (spacecraft) measurements. The IHW observations were divided into nine ground-based disciplines: Astrometry, Infrared Studies, Large-Scale Phenomena, Meteor Studies, Near-Nucleus Studies, Photometry and Polarimetry, Radio Studies, Spectroscopy and Spectrophotometry, and Amateur Observations. Data evaluation and selection for the Archive have been the responsibility of the discipline specialist teams for each network, in cooperation with the IHW Lead Center. The Halley database contains over 37,000 observational files, constituting 23 gigabytes (uncompressed) of information, to be presented on 25 compact discs—read only memory (CD-ROMs), according to the production plan well under way at the time of this writing. The complete archive is expected to include 18 discs of compressed large-scale images, 5 discs of other chronologically ordered data types, and 2 discs of spacecraft measurements (plus 1 disc of data on comets Giacobini-Zinner and Crommelin).

As the IHW became a reality during 1980–1981, it became obvious that the distribution of images in any digital form would be a problem because of the enormous amount of data involved. Since what the IHW would be producing was an archive, there was no need to use a medium that could be overwritten. The required features were longevity, accuracy, speedy access, and a standardized format for which inexpensive playback equipment was readily available. Cost and ease of production were also clearly factors.

For storage purposes, the IHW considered both large-size experimental digital laser discs and the compact discs (CDs) being promoted for the audio market. In the production of audio CDs, Philips and Sony had reached an agreement on the discs' physical structure. The so-called Red Book described the size of the disc, placement of center hole, usable area, and encoding of the data. Sony and Philips also realized the potential for this medium to store other digital data for distribution if the error correction could be improved. Using a layered Error Detection Code/Error Correction Code (EDC/ECC) scheme to improve upon the standard error correction code (called the Cross Interleaved Reed-Solomon Correction [CIRC]) by

10,000 times meant that character, tabular, and image data could be archived on CD-ROMs. Eventually, a so-called Yellow Book was promoted to describe the physical encoding of these data; this coding had the same structure as that for audio CDs, i.e., 2,048-byte blocks with 304 bytes for housekeeping. Typical error rates indicate only one lost bit per 2,000 discs.

The use of the Continuous Linear Velocity (CLV) recording format provides maximum data packing, but has the disadvantage of slow access times when compared with media using the Continuous Angular Velocity (CAV) approach. Access time usually includes the changing speed for the disc; the radial movement of the laser diode, which requires a settling time; and the location procedure, which often demands a full rotation of the disc. Current CD-ROM players have reduced the access times to under 400 msec, or a factor of 4 slower than the access times for typical magnetic hard disks. Coupled with the low transfer rates set by the audio requirements (150 kilobytes/s of useful data), this means that data placement on CD-ROMs requires a strategy for efficient use. However, these disadvantages are outweighed by this medium's low cost and its longevity as an archiving tool.

When the CD-ROM technique became accepted as a digital storage medium, a number of vendors attempted to write application software, primarily for IBM Personal Computers (PCs) and compatibles. This resulted in proprietary formats, which quickly became nonstandard. At about this time, Microsoft organized an informal working group that developed a logical structure then called the High Sierra proposal. Eventually, this resolution was modified and has been documented as the International Standards Organization (ISO) 9660 format. At this writing, even those vendors with proprietary formats, such as DEC (UNIFILE) and Apple (HFS), have announced their support of that standard. In the PC market, Microsoft has supported an extension to MS-DOS which is supplied in its 4.0 operating system.

The main advantage of this logical structure is that it has well-defined rules for volume descriptors, placement of files, and record structures. Descriptors in the data area identify the volume, establish a character set, locate the path table, and indicate the presence of boot records. Data are located by logical sectors (2,048-byte blocks) or by a finer division into logical blocks (512 bytes minimum). The path table provides a quick means to point at data, since the structure is hierarchical as in MS-DOS. Finally, Extended Attribute Records (XARs) may be used to carry associated information about the record structure, key dates, global permission, and hidden files. The key to this standard is its three levels of interchange, which span various machines and operating systems. In the lowest level, a file is a continuous byte stream spanning only one sector. Directory and file names are restricted to 8 characters, with a 3-character file extension allowed. This level is designed for PC-style machines, but must be acceptable to drivers for higher levels.

The advent of these standards has proved to be a major advantage to archivists. The low cost of the media and players, and their widespread applications insure that the data can be widely distributed; the longevity for optical media is considerably greater than that for more volatile magnetic storage and could rival such media as photographic plates. But there are also disadvantages to the CD-ROM approach. The CD-ROM is really a "publishing" medium. In the data preparation phase, an archivist has complete control over the integrity and structure. However, to produce the CD-ROM, the data must be shipped to a commercial vendor for the actual replication. To insure that the data's organization follows the archivist's standards, the "premastering" phase is often done in-house. In this way, the directories, path table, and layout of the disc, as well as any customized application programs, can be tested on the complete data set. Once the data's integrity is secure, then final tapes in the ISO format are sent to a mastering facility. There the actual EDC/ECC is supplied, along with synchronization information to complete the premastering phase.

Creation of the IHW Archive has required several advances in data formatting and handling. Astronomical data transfer began to be standardized with the acceptance by the International Astronomical Union (IAU) of a system called the Flexible Image Transport System (FITS). The IHW adopted this format, including an extension to FITS generated for tabular material. The IHW is using a further extension for compressed data that is nonstandard. Meanwhile, the Planetary Data System (PDS) has developed an independent system of formatting data that has some advantages over the FITS format. Therefore, the IHW and the PDS have cooperated by including detached PDS labels for the Archive so that data can be accessed using either format. The techniques for indexing CD-ROMs have been developed by the National Space Science Data Center (NSSDC) and IHW for the database composed of the Comet Giacobini-Zinner and Comet Halley archives. The software required to read CD-ROM stored data has been continuously developed by the PDS and has been made available to the IHW and NSSDC.

2. THE COMET GIACOBINI-ZINNER TEST DISC

To produce the Comet Giacobini-Zinner Archive test disc, we brought the archive data files to the NSSDC and transferred them to the CD premastering workstation via 9-track magnetic tape. Then we modified the initial directory structure to include International Cometary Explorer (ICE) data, BROWSE images, and COMPRESS data. Also, so we could tailor the disc to a convenient layout, we refined the actual premastering process for batch-mode processing. We sent the premastered tapes to Disctronics, a vendor chosen by the IHW Lead Center (IHW-LC), located in Pasadena, California, at the Jet Propulsion Laboratory (JPL).

In April 1989, the IHW-LC officially released the test disc and accompanying software. The Beta release included not only the CD-ROM, but also a floppy disk with modified IMDISP code (IMDISP is image-handling software developed by the PDS), a user shell, and a guide that could be printed as ASCII text. The user shell was designed to be flexible, i.e., to make use of existing astronomy software packages.

To help recipients of the test disc evaluate it, we designed a written questionnaire and included it with the CD-ROM distribution. As a follow-up, a poster presentation at the American Astronomical Society meeting in June 1989 demonstrated the search capability of database management system (DBMS) indexes. In addition, a CD-ROM Workshop was held, also in June 1989, at the NSSDC.

This workshop focused on the use of the premastering workstation at the NSSDC. Through a series of talks, the entire premastering process was outlined and procedures for the workstation's use were proposed. In addition, the workshop participants discussed the general topic of guidelines, in the ISO format and even in the label art. The summary document from this first CD-ROM Workshop in the National Aeronautics and Space Administration (NASA) environment (King and

Grayzeck 1989) could be used as a paradigm by other technical and government agencies for producing CD-ROMs.

Finally, the workshop participants shared experiences from many different projects involving data types and formats that would be used in the future. It became clear that the test disc format had to be modified slightly so the Comet Halley Archive would follow the NSSDC guidelines. A subsequent meeting, attended only by IHW participants, took place immediately after the CD-ROM Workshop. The minutes from that session have formed the guidelines for the current design of the full Comet Halley Archive, which include some additional background steps leading up to the eventual premastering of the compressed-image discs.

The most important changes were the choice of new file names, to reflect the files' disciplines and subnetworks, and the decision to keep a chronological running count of the number of files throughout the Archive. Using this new design, the IHW has republished the data from comets Crommelin and Giacobini-Zinner as part of the Halley Archive, on a disc named HAL_0024.

3. PRODUCTION OF THE LARGE-SCALE PHENOMENA NETWORK (LSPN) COMPRESSED-IMAGE CD-ROM SET

Initial work on these compressed-image CD-ROMs (the first 18 discs of the Comet Halley Archive) included definition of the method for producing the CD-ROM set for a wide variety of platforms. We developed expertise in using SUN, MicroVAX, Macintosh, and PC computers to access the CD-ROM data. To develop a working knowledge of the ISO constraints and a testbed of systems for evaluating the first CD-ROMs, we swapped a large number of types of CD-ROM readers (e.g., SCSI, Q-bus, and PC-bus) between machines. An immediate concern was the current implementation of XARs to describe variable-length files in the DEC environment, a problem that still exists. We concluded that for the IHW CD-ROMs, no XARs would be included, but that the text and data would be presented in a fixed-length format with instructions on the conversion procedure for a compressed image.

In designing these first Comet Halley CD-ROMs, we strove to be aware of the constraints for the complete set of data, including non-image data. Therefore, we decided that the file numbering would be consecutive and unique, including Comet Halley data that had been digitized as well as those data only catalogued. A separate identifier for the calibration images would be constructed; these data would be in a separate subdirectory, as had been proposed for the Comet Halley Archive and had been illustrated in the Comet Giacobini-Zinner test disc. We developed a plan that would divide the data into convenient units for premastering, yet would preserve the chronology of the data. We also composed the necessary programs to load the data from tape as batch routines for each disc.

In February 1990, a new "low-bid" vendor mastered the first compressed-image disc. However, tests proved this disc to have an unacceptably high read-error rate. Therefore, another vendor was chosen and a new test disc made. The first real test of our new techniques as well as of this vendor, the new disc used a set of selected images from the time period of March 6–14, 1986, when an "armada" of spacecraft encountered Comet Halley. Unlike the Comet Giacobini-Zinner test disc project, which showcased the design, this project was intended to streamline the process of both reformatting the data and describing them by adequate metadata. We made a number of critical discoveries as part of the review process: first, we did not need to build the premaster tape through an MS-DOS image if we thoroughly verified the input tapes; second, we needed to ensure that overlapping plates of the same area did not split across disc boundaries; and third, we needed to keep modification of the metadata to a minimum. One consequence of metadata modification was that this second test disc had some errors in labels and text files, but such problems were acceptable for this disc. From this point on, however, we made a conscious effort to create all files (labels, index, and text) in such a way that once we corrected the set, only minor changes took place. Specifically, we assembled the BROWSE and CALIB files on tapes and split them according to the disc chronology. Similarly, we made the PDS labels as a set, corrected them, and held them on floppy disks for each CD-ROM volume. The text files that did not change were held on a master floppy disk; we updated only three files (AAREADME, CDTREE, and VOLUME) from a master table composed in the IHW log. Only those index files specific to each volume (CDSTRUCT, EPHEM, NETLARGE, and PATHTABL) changed, and we took care to correctly reflect these changes in the FITS headers accompanying those files.

The production schedule instituted called for roughly two discs to be composed per week of scheduled premastering time. We began this process immediately after reformatting the test run of selected images for the Armada Week. We checked each disc in three steps: by the display of all BROWSE images, by a random check of the compressed comet images as well as the calibration images, and by a file count for each disc that was kept and verified before the tapes were written. We composed a set of structure files, namely CDSTRUCT, to provide a listing of the physical locations of each data file. We constructed these structure files at the very end of the premastering process and inserted them into the "CD-ROM" image. This output was essential to providing the path and file names for the Standard Format Data Units (SFDU) inventory file termed VOLDESC.SFD, which we will describe later.

By July 1990, we had premastered the LSPN compressed-image set of 18 discs at the NSSDC, and the disc vendor mastered one disc that October. New options in this project included splitting the storage space into separate ISO partitions to increase speed, and building a master index disc (HAL_0018) in the background while continuing the production run. New ideas that came to fruition for this index disc were a full SUMMARY presentation of the subsampled images; a full PATHTABL index for each data file in the entire set; and a complete listing of errata, including replacement HEADER and LABEL files. After it became clear that the index disc would have extra storage capacity, we decided to build it slowly and try out designs for the SUMMARY and PATHTABL index. It was prudent not only to include the full set of subsampled data (1,612 BROWSE files), but also to present all the calibrations together (173 CALIB files). This led to a review of the entire data set, which uncovered a few corrigenda, which we put into a summary file (SUMINFO.TXT). It also uncovered some erroneous HEADERS (and LABELS), where the OBJECT was not the comet, but a calibration field. Since these metadata were split off from the data, it was easy to provide replacement files. In doing this review, we found that a method to search all discs via the PATHTABL index was useful. In the final SUMMARY section of the disc, we have provided such a full index as a MASTER index for the volume set.

As this project progressed, we developed software to construct various levels of metadata, beginning with the PDS labels and including SFDU pointers to specific reference documentation. Following guidelines provided by the PDS and Consultative Committee on Space Data Systems (CCSDS), we created a VOLDESC.SFD inventory file for each disc, including the final summary volume. Working with the NASA Office of Standards and Technology (NOST), we developed a procedure to design reference files to self-document the disc and then provide an inventory of the pointer files for the data. We developed the original code using C on a mainframe computer, then transferred the code to the premastering workstation. After a number of iterations and modifications, a series of steps to provide this inventory was streamlined into a software package now available at NOST.

We premastered the entire set of compressed-image discs according to the standards proposed by the NSSDC for disc structure (including subdirectories), in conformance with the ISO 9660 standard (Volume Descriptor table) and disc art, e.g., full VOLUME identification. As mentioned earlier, many of these guidelines were introduced at the CD-ROM Workshop in June 1989; a follow-up meeting took place recently to discuss unresolved questions. At these meetings, CD-ROM manufacturing processes were scrutinized, as was the longevity of this medium as an archive product. During the early testing phases of the IHW CD-ROM project, we defined procedures to inspect the quality of test discs, as described in Section 4. Mal Niedner of Goddard Space Flight Center (GSFC) has overseen the production and quality checks applied to these discs.

4. COMET HALLEY TEST DISC

The IHW collected FITS-formatted data files from each of the nine disciplines (Astrometry, Infrared Studies, Large-Scale Phenomena, Meteor Studies, Near-Nucleus Studies, Photometry and Polarimetry, Radio Studies, Spectroscopy, and Amateur Observations). Some disciplines have been further split into subnetworks, as follows:

Infrared Studies Network

Subnetwork 2.1. Infrared Photometry
Subnetwork 2.2. Infrared Polarimetry
Subnetwork 2.3. Infrared Spectroscopy
Subnetwork 2.4. Infrared Imaging

Photometry and Polarimetry Network

Subnetwork 5.1. Broadband Photometry
Subnetwork 5.2. Narrowband Photometry
Subnetwork 5.3. Polarimetry
Subnetwork 5.4. Stokes Parameters

Radio Studies Network

Subnetwork 6.1.	Hydroxyl Feature at 18 cm
Subnetwork 6.2.	Spectral Line
Subnetwork 6.3.	Continuum
Subnetwork 6.4.	Occultation
Subnetwork 6.5.	Radar

Amateur Observations Network

Subnetwork 8.1.	Visual-Appearance Descriptions
Subnetwork 8.2.	Drawings
Subnetwork 8.3.	Photographs
Subnetwork 8.4.	Spectroscopy

For the mixed-data discs, there will be on the order of 300 megabytes of information from the FITS headers alone (and an equivalent amount from the PDS labels). The total amount of data will be approximately 2.3 gigabytes.

After the IHW Lead Center received the data, time-ordered on magnetic tapes, from each of the disciplines, it sorted the data by date and time across all of the disciplines. The on-line storage capacity at Goddard Space Flight Center (GSFC) could handle this entire data set in its Mass Storage System associated with Code 930's IBM 3081 computer complex. So the IHW LSPN transferred the set of files to this storage system and in the process created a catalog of all of the files, containing the file names, date, time, network, subnetwork, object, and data size. Using this catalog, we could produce a chronologically sorted data set that could be used to pass the correct files over to the premastering workstation in the proper order.

In the process of storing the data in the Mass Storage System, we did an initial check on the size of each data set. We found 101 files that did not have the amount of data expected from the parameters within the FITS header. Out of 22,696 files, 101 files is not a high failure rate, but finding this problem started us looking at other potential problems; hence, we adopted quality assurance steps as described below.

4.1. Step 1: Internal Consistency of the Header Keywords

Several checks can be made across the entire mixed-data disc set as well as on the individual networks themselves. At the time of this writing (May 1991), we plan to implement the following checks:

Across all the networks:

- Check that the data file size agrees with the header axis information (naxisn × bitpix/8).
- Check for duplicate keyword values for FILE-NUM.
- Check that the FITS header is complete and look for Keyword = END.

For the individual networks:

- Check the consistency of the independent variable (naxis1).
- Check the consistency of any additional variable (e.g., naxis2, naxis3, and naxis6).
- Check the consistency of the dependent variable (BUNIT) description.
- Check the consistency of DAT-TYPE with INSTRUME.
- Check the consistency of SYSTEM with OBSVTORY.
- Check the consistency of TIME-OBS with other time parameters (e.g., EXPOSURE).

For specific networks, we will inspect physical parameter keywords, such as the following for Spectroscopy:

- The consistency of LAMBDA and VELOCITY.
- The consistency of the PIXEL and RHO (separation) description.
- The consistency of the units for the dependent variable (BUNIT).
- The meaningful position angle keywords (POSANG, ORIENT, and SEPNUC).

4.2. Step 2: File-Naming Conventions

Once all of the files from an individual network have been copied from tape and catalogued on the IBM 3081 Mass Storage System, they can each be given a unique running number file name and extension type. These are the files names and extensions that will be used on the CD-ROMs. The accepted conventions to be used have been spelled out in an internal memorandum ("Processing Steps at GSFC for Generating the Mixed CD-ROM File Names") by Dan Klinglesmith. These conventions are a combination of the information from Mikael Aronsson (at the IHW-LC) and that from Ed Grayzeck (of the PDS Small Bodies Node [PDS-SBN]).

4.3. Step 3: Directory Structure and Size

On the CD-ROMs, it is desirable to limit the size of any one level of subdirectory to less than 255 files. Each data file to be stored on the CD-ROMs may have two associated files: a PDS label file and a FITS header file. Therefore, we are limited to 84 data files per subdirectory.

The naming convention of the lowest level subdirectory is as follows:

Y19yy\Mmm\Ddd\Hhh\NETNfile.ext

where yy ranges between 81 and 89, except for the early Astrometry files, where the Y19yy is replaced with the year value AST_HIST\Yyy, and Meteor data, which are stored separately; mm ranges between 01 and 12; dd ranges between 01 and 31; and hh ranges from 00 through 21, in increments of 03. Exceptions to this scheme have been kept to a minimum; only Astrometry and Amateur Observations data have been placed in a lower directory. These latter paths may appear as follows:

Y19yy\Mmm\Ddd\Hhh\ASTROM\ASTRfile.ext

Y19yy\Mmm\Ddd\Hhh\AMDRAW\AMDRfile.ext

Y19yy\Mmm\Ddd\Hhh\AMPHOTO\AMPGfile.ext
Y19yy\Mmm\Ddd\Hhh\AMSPECTR\AMSPfile.ext
Y19yy\Mmm\Ddd\Hhh\AMVIS\AMVfiles.ext

4.4. Step 4: Contents of the Text Files and Other Assorted Files

Each of the CD-ROMs contains numerous text files that describe the contents and format of the data structures on that particular disc. These files will be checked for accuracy both in typing and content, through proofreading checks done at both GSFC and JPL.

4.5. Step 5: Readability of a Statistical Sample of the Completed CD-ROMs

From the initial set of discs replicated by the vendor, a sample of 30 will be chosen for review. This review will have three stages:

1. A single disc may be sent to Helgerson Associates for measurement of the physical parameters such as Bit Linear Error Rate (BLER), Radial Noise, and Cross-Talk.
2. A separate disc will be chosen for some random samples by single-beam players available at GSFC; machines from at least two manufacturers (NEC and DEC) will be involved.
3. A third disc will be used to open every file (via a batch program) on another single-beam player (manufactured by LMSI) available at the NSSDC.

The quality check of the data covered three stages: first, an internal review; second, the assembly of a selected data sample for a single CD-ROM; and third, the actual review of the disc's contents. Dan Klinglesmith of the IHW LSPN pioneered the on-line archive at GSFC using the Mass Storage System. He developed a series of catalogues that were tested for consistency in size as well as FITS attributes. From this, we determined that the data content needed to be evaluated and levels of ERRATA developed. Working with Ed Grayzeck, the NSSDC, and the PDS-SBN, Dan produced a test disc of Halley data covering the range termed the "Armada" period, as described earlier. We assembled only FITS files, but in their split forms (that is, with detached headers), to test out new File Transfer Protocol (FTP) procedures to electronically transfer data to the CD premastering workstation. We also created a simple QUIK index file, but with a full path. We provided 30 copies of the disc to individual scientists, who were later polled by Mal Niedner of the IHW LSPN. A number of suggestions were received and summarized via a mid-January 1991 review. The PDS-SBN was particularly active in investigating inconsistencies in the spectroscopic data. Specifically, we invited an International Ultraviolet Explorer (IUE) expert, M. Festou, to GSFC to review the data and help establish ground rules for "fixing" the files. In addition, we contacted the authors of particular data sets and invited them to provide insight as to the integrity of their data based on the FITS documentation. In December 1990, we outlined these corrections to the IHW-LC, along with recommendations for the overall CD-ROM design. All corrections were completed by February 1991, with subsequent updates terminating in April 1991.

Table I. Disc Splits

Disc	Start Directory/ Stop Directory	Per Disc Megabytes	Files	Directories
19	\Y1981\ \Y1985\M12\D08	480	10,902	679
20	\Y1985\M12\D09\ \Y1986\M02\D09\	421	8,885	452
21	\Y1986\M02\D10\ \Y1986\M04\D13\	535	8,820	470
22	\Y1986\M04\D14\ \Y1987\M04\D03\	512	8,416	624
23	\Y1987\M04\D04\ \Y1989\M04\	429	692	87

5. GENERATION OF THE MIXED-DATA CD-ROMS

The amount of information for the mixed-data discs is so great that we will require five CD-ROMs, containing 37,844 files, to hold all of the data. We will need to create these discs one at a time, in time order. Table I shows how the files will be split between the discs. Since the files can also be separated into nine disciplines, Table II shows the distribution by discipline.

The actual number of files will be about three times larger than the figure of 37,844, because that figure does not include the header and PDS label files. There will be 5,468 dataless headers, so the total data-related file count will be $[(2 \times 5{,}468) + (3 \times 32{,}247)] = 107{,}677$. Note that the directory files are not included in these counts.

We can, in turn, separate the FITS data sets into a header file and a data file. In addition, each of the FITS data sets will have an associated "PDS" label file on the CD-ROMs. This means that we will be dealing with over 100,000 file names in the course of generating the five CD-ROMs.

To put the data on the CD-ROMs in the correct chronological order, we must generate a catalog of all 37,844 files, sorted first by date and time and then by CD-ROM name. The three exceptions to this chronological pattern are:

- The astrometry data sets (the 1835 and the 1910 apparitions). These will also be stored in separate subdirectories.
- The infrared filter sets. The filter curves and tables used for calibration purposes do not carry a time tag and so are stored separately.
- The meteor data sets.

Table II. Number of Files for Each IHW Discipline

Discipline ID	Discipline	Number of Files
1.	Astrometry	6,477
2.	Infrared Studies	498
3.	Large-Scale Phenomena	3,383
4.	Near-Nucleus Studies	3,523
5.	Photometry	3,436
6.	Radio Studies	1,950
7.	Spectroscopy	3,368
8.	Amateur Observations	15,150
9.	Meteor Studies	59
TOTAL		37,844

To start generating the chronological sort, we first sorted the files by discipline. We then combined these files into one file and sorted them according to the year, month, day, time, and CD-ROM name. We used the resultant chronologically sorted file to generate a list of what would be on which disc according to the directory structure.

6. DATA AND SUPPLEMENTAL DIRECTORIES

Table III schematically gives the structure for the mixed-data discs. Most ground-based data are located in chronological subdirectories whose names are based on date. We attempted to restrict subdirectories to a reasonable size, while allowing enough information for useful browsing. For the years 1981 through 1984, the number of files per year was small. All files from any of these years have been grouped together in one subdirectory per year, e.g., all the files from 1981 can be found in the subdirectory Y1981. As the number of files per year increased, we had to split the subdirectories into shorter intervals. The average number of files in a directory is fewer than 100. When possible, we grouped all files from a particular month together in one subdirectory, e.g., all files from January 1985 can be found in the subdirectory Y1985\M01. Starting with the August 1985 files, most files were grouped in daily subdirectories, e.g., Y1985\M08\D01 contains all data from August 1, 1985. In some cases, we had to split a day into two or more parts, e.g., November 12, 1985, was split into two half-days, with the subdirectory names Y1985\M11\D12\H00 and Y1985\M11\D12\H12, respectively. When necessary, the number of parts that a day was split into was increased to four (H00, H06, H12, and H18) or eight (H00, H03, H06, H09, H12, H15, H18, and H21). The average subdirectory size is less than 10.0 megabytes. No subdirectories were created for days on which data were not submitted.

Table III. The Structure for the Mixed Data Discs

```
I--AAREADME.TXT
I--AST_HIST-- A1835_36.*
              A1909_11.*
I--BROWSE   -- LSPN*.*
I--CALIB    -- IR, LSPN, SPEC*.*
I--DOCUMENT-- APPENDIX   -- *.APX
            -- *.TXT
I--EPHEM    -- EPHEM.*
I--INDEX    -- *.IDX
            -- NETABLES-- *.IDX
I--IR_FILTR--IRFC, IRFT*.*
I--METEOR   --MSNRDR, MSNVIS*.*
I--SOFTWARE-- *.*
I-- SUMMARY-- ERRATA, *.TXT
I-- VOLDESC.SFD
I-----Y1981----EPHEM.*
I              PMAG0001.*
I              PMAG0002.*
:
I-----Y1982----I--ASTROM-----ASTR0001.*
:              :                 :
I              I--EPHEM.*
I                 NNSN0001.*
:
I                 PMAG0008.*
I
I-----Y1983----I--ASTROM-----ASTR0022.*
:              :                 :
I              I             ASTR0028.*
I              I
I              I--EPHEM.*
I                 SPEC0001.*
I                 SPEC4001.*
I
I-----Y1984----I--M01--------I--ASTROM-----ASTR0029.*
:                            :
I                            I
I                            I--EPHEM.*
I                               IRDN0001.*
I                               LSPN0001.*
I
```

Table III. (continued)

```
I-----Y1985----I--M01--------I--AMVIS------*.*
|              |
I              I--M12--------I--ASTROM-----*.*
:                            :
I                            I--D16--------1--H00--------*.*
I                            I             I--H12--------*.*
:                            :
I                            I--D31--------*.*
I
I-----Y1986----I--M01--------I--D01--------*.*
:              :             :
I              I--M12--------I
I                            |
I                            I--D31--------*.*
I
I-----Y1987----I--M01--------I--D01--------*.*
I              I
I              I--M12--------*.*
I
I-----Y1988----I--M01--------*.*
:              :
I              I--M10--------*.*
I
I-----Y1989----I--ASTROM-----ASTR6457.*
:              :                 :
I              I             ASTR6475.*
:              :
I              I--NNSN3523.*
```

In an effort to reduce the space requirements for the full Halley Archive, we have applied data compression to the LSPN images, which are found on discs 1–18. We have employed an algorithm based on the successive differences between pixels (the Previous Pixel algorithm) to reduce the digital images from the LSPN to a coded byte stream of 8-bit data. The compression yields files roughly 50% the size of the original images. The file FITSCOMP.TXT in the DOCUMENT directory contains details of the algorithm and the accompanying FITS proposal. Because CD-ROM transfer rates are low for full-resolution data, subsample images (browse images) are also supplied. These images are restricted to a maximum of 256 pixels on a side and preserve the original sampling geometry. In addition, the original 10-bit data has been rescaled to 8 bits. These "quick-look" images are especially important for reviewing the larger set of 1,439 images of Comet Halley and have been included in the chronological directories.

Some networks have submitted supplemental data, including filter tables, non-comet images, flat fields, and laboratory spectra. These data are in CALIB or IR_FILTR subdirectories; these files use the same network/subnetwork codes as the other files, but their running numbers start at 4001 in the file-naming scheme (see Section 7 for more on this scheme).

Three directories (DOCUMENT, INDEX, and SOFTWARE) on the CD-ROMs contain supplementary files. In addition, to correlate the chronological observations with the comet's apparent location, we have included an ephemeris and an interpolation procedure, in the subdirectory EPHEM. The DOCUMENT subdirectory contains text files that give the background to this CD-ROM project, present a general guide to use of these CD-ROMs, and detail experience with previous CD-ROM products, including those for observations of comets Crommelin and Giacobini-Zinner, which were also archived by the IHW. We have collected tables of useful index information in various forms to allow for automated searching of the data. These files can be found in the INDEX subdirectory. The QUIK* tables contain a selected set of mandatory FITS keywords from all disciplines. In the NETABLES subdirectory, a set of tables contains the data from the proposed printed archive, organized by network and subnetwork. Finally, some additional "NET" tables list a complete set of keywords as specified by some disciplines. The SOFTWARE subdirectory contains program code for a few utilities, in this case, decompression of images and the interpolation of ephemeris tables for the comet.

7. DATA DESCRIPTIONS

Early on in the archive project, the IHW disciplines and Lead Center agreed that all data would be submitted from the individual disciplines to the Lead Center using the FITS format. When the decision was made to distribute this information on CD-ROMs, it was determined that the data had to have even broader accessibility. For this reason, the original FITS files, with contiguous headers and data records, were split into separate files, preserving the 2,880-byte (or integer multiples thereof) record sizes. The original FITS byte stream could then be recovered by concatenating the appropriate header and data files. In addition, detached PDS labels were constructed to allow parallel definition of the data files for the Planetary Data System.

The IHW Lead Center proposed a convention for naming files on the CD-ROMs to include a unique data qualifier for the data. A specific set of rules was established to identify the network/subnetwork for each discipline, using a letter code. A CD-ROM running number relates the information contained in the various indexes to the files containing the actual data. Table IV lists these conventions ordered by the IHW discipline number and FITS parameter NAXIS.

Note that the letter coding (explained in Section 4.2) is one way to distinguish the file extension and content. Additions to this statement are the calibration files, which start at XXXX4NNN for IRIM, IRSP, LSPN, and SPEC. In the case of a header file that is not followed by a data record (i.e., DAT-FORM = NODATA), the PDS object indicates that the LABEL is in FITS form, that is, in 2,880-byte records.

The file extensions follow suggestions by the Planetary Data System (Martin et al. 1988) for tabular and image data. In addition, for the IHW FITS files, the original headers and data have been split into separate files, with file-name extensions as follows:

.DAT	Other non-image or non-table data
.HDR	FITS header records
.IBG	Data records for subsampled browse images

Table IV. CD-ROM Naming Conventions

PDS Object (Description)	FITS NAXIS =	Discipline	Letter Code	File Extensions		
text	1	Astrometry	ASTR	.dat	.hdr	.lbl
FITS_LABEL (no data)	0	Infrared Studies	IRSP		.hdr	.lbl
table (filter)	0, 2	Infrared Studies	IRFT	.tab	.hdr	.lbl
table (photometry)	0, 2	Infrared Studies	IRPH	.tab	.hdr	.lbl
table (polarimetry)	0, 2	Infrared Studies	IRPOL	.tab	.hdr	.lbl
spectrum (filter)	2	Infrared Studies	IRFC	.dat	.hdr	.lbl
image	2	Infrared Studies	IRIM	.img	.hdr	.lbl
spectrum	2	Infrared Studies	IRSP	.dat	.hdr	.lbl
FITS_LABEL (no data)	0	Large-Scale Phenomena	LSPN		.hdr	.lbl
image (browse)	2	Large-Scale Phenomena	LSPN	.ibg	.hdr	.lbl
image	2	Near-Nucleus	NNSN	.img	.hdr	.lbl
table (broadband)	0, 2	Photometry and Polarimetry	PFLX	.tab	.hdr	.lbl
table (narrowband)	0, 2	Photometry and Polarimetry	PMAG	.tab	.hdr	.lbl
table (polarization)	0, 2	Photometry and Polarimetry	PPOL	.tab	.hdr	.lbl
table (Stokes parameters)	0, 2	Photometry and Polarimetry	PSTOKE	.tab	.hdr	.lbl
FITS_LABEL (no data)	0	Radio Studies	RSCN		.hdr	.lbl
FITS_LABEL (no data)	0	Radio Studies	RSSL		.hdr	.lbl
spectrum	1	Radio Studies	RSCN	.dat	.hdr	.lbl
spectrum	1	Radio Studies	RSOH	.dat	.hdr	.lbl
spectrum	1	Radio Studies	RSSL	.dat	.hdr	.lbl
spectrum (multiple)	2	Radio Studies	RSOH	.dat	.hdr	.lbl
spectrum (multiple)	2	Radio Studies	RSSL	.dat	.hdr	.lbl
spectrum (multiple)	2	Radio Studies	RSRDR	.dat	.hdr	.lbl
image (multiple)	3	Radio Studies	RSOC	.img	.hdr	.lbl
spectrum (visibility)	6	Radio Studies	RSOH	.dat	.hdr	.lbl
spectrum	1	Spectroscopy	SPEC	.dat	.hdr	.lbl
spectral image qube	2	Spectroscopy	SPEC	.dat	.hdr	.lbl
image (spectrum)	2	Spectroscopy	SPEC	.img	.hdr	.lbl
FITS_LABEL (no data)	0	Amateur Studies	AMDR		.hdr	.lbl
FITS_LABEL (no data)	0	Amateur Studies	AMPG		.hdr	.lbl
FITS_LABEL (no data)	0	Amateur Studies	AMSP		.hdr	.lbl
table (magnitude)	0, 2	Amateur Studies	AMV	.tab	.hdr	.lbl
table (visual)	0, 2	Meteor Studies	MSNRDR	.tab	.hdr	.lbl
table (radar)	0, 2	Meteor Studies	MSNVIS	.tab	.hdr	.lbl

.IMG	Image data records
.LBL	Detached PDS stream format files
.TAB	Table data records (as ASCII files)

The archive contains five fundamental PDS classes: FITS_LABEL, IMAGE, TABLE, TEXT, and SPECTRUM. Our aim was to construct a basic PDS label for each data file on the CD-ROMs as defined in the next section. Files that remain in their original FITS form (.FIT) do not have PDS labels; such files occur only on disc HAL_0024, as DOCUMENT files and data files for Comet Crommelin.

The PDS labels are metadata, that is, headers describing data submitted to the archive. No effort has been made to duplicate the documentation contained in the full FITS headers because the PDS and FITS headers for a given data file differ only in the file-name extension. Instead, we have attempted to use the power of the PDS label syntax to describe the data structures fully and thus gain access to PDS software. The primary reference for the Object Description Language (ODL) necessary to create the PDS labels was *SPIDS v1.1: Standards for the Preparation and Interchange of Data Sets* (Martin et al., 1988). In addition, R. Borgen and M. Martin, PDS Central Node, assisted the IHW with version 2.0 of the ODL implementation for SPECTRUM.

The SPIDS document explains the basic PDS descriptors such as SFDU_LABEL, RECORD_TYPE, RECORD_BYTES, and FILE_RECORDS. The RECORD_TYPE for all data files is FIXED_LENGTH. The PDS labels have been formed as fixed-length records of 78 bytes plus an embedded <carriage return> and <line feed>.

7.1. FITS_LABEL

We have conformed to the PDS definition of a specific keyword to indicate the presence of a FITS "HEADER" (the keyword TYPE = FITS) when the "data" object is another FITS_LABEL (.HDR). In FITS, if NAXIS = 0, then no data records need follow, as is the case for an upper limit. The "dataless" headers can be recognized by the NAXIS value or the IHW keyword DAT-FORM = NODATA in the FITS header. The PDS label (with the same file name but a different extension) points at the header file as its data object.

7.2. IMAGE

In the case of images, we have included a new keyword that describes the byte ordering of the data (MSB_INTEGER) required by FITS. In the PDS format, images (.IMG and .IBG) are in terms of LINES (FITS keyword NAXIS2) and SAMPLES (FITS keyword NAXIS1), given knowledge of the SAMPLE_BITS (FITS keyword BITPIX), and are easy for the split files. The final form of the label for compressed images is still under active discussion at the time of this writing. For our project, unlike previous PDS efforts with compressed images, we chose not to compress the header (or label) and thus have included a keyword to describe the type of compression (ENCODING_TYPE = "PREVIOUS PIXEL") used. The label for compressed images also contains information to permit software to skip over the data if the decoding algorithm is unknown (ITEMS, ITEM_TYPE, and ITEM_BITS). We use the ODL to indicate various subclass structures for the data objects. An example of this is the DIFFERENCE modifier applied to IMAGE, yielding the keyword DIFFERENCE_IMAGE, which indicates that a processing step was applied to the original image.

7.3. TABLE

In creating the TABLE descriptions, we have found a good correspondence between the FITS and PDS syntax. For tables, the value of NAXIS2 = ROWS, TFIELDS = COLUMNS, and NAXIS1 = ROW_BYTES; in both the FITS and PDS formats, the default format is ASCII. We choose not to describe the values in each column here, as this is done fully in the FITS header file and the data themselves follow the FITS record format (i.e., the records contain ASCII characters with no delimiters and are padded to multiples of 2,880 bytes). The FITS data structures are currently supported by public-domain software that is being distributed with the archive.

7.4. TEXT

The TEXT object (which is used for the Astrometry Discipline's data with extension .DAT) is an 80-byte fixed-length record that contains only ASCII values. In the FITS formulation, the 80-byte records are strung together, typically as five "card" images with no delimiters and padded to fill the 2,880-byte record structure. The TEXT object can be recognized in the FITS formulation by the NAXIS = 1 statement, which indicates that a byte stream follows, usually one that carries a "text" description.

7.5. SPECTRUM

The IHW has refined the SPECTRUM class description by working closely with the PDS group to ensure the definition of data groups that included both uniformly spaced data (as a single array) and ordered groups of observations. Using the guidelines for dealing with the SPECTRUM data structure, we treat the spectra as tabular data (using COLUMN, NAME, DATA_TYPE, START_BYTE, and BYTES), which are binary. The independent variable (e.g., WAVELENGTH) is described by the following keywords:

SAMPLING_PARAMETER_NAME
MINIMUM_SAMPLING_PARAMETER
SAMPLING_PARAMETER_INTERVAL
SAMPLING_PARAMETER_UNIT

(Special cases for radio or infrared data use Doppler VELOCITY, FREQUENCY, or FREQUENCY_OFFSET.) Another case, from the Infrared Studies Network, is a table of ordered triples of data, in which we interpreted the column of signal-to-noise ratios as an associated ERROR. A NOTE about this nonstandard use is included in the labels for the appropriate data sets. We have also attempted to use the NOTE keyword to identify the contributing IHW discipline, the subnetwork, and generic comments about the data. As with multiple images, we have subclasses for the spectra indicated by a modifier, e.g., LHC_POLARIZATION_SPECTRUM.

Inclusion of the PDS labels allows the use of CD-ROM imaging software already available from JPL. The PDS labels are text files, with lines terminated by the <carriage return>, <line feed> characters. The total sizes of the files are maintained in the required SFDU_LABEL.

8. GUIDE TO THE USE OF THE HALLEY CD-ROMS

The software distributed on the CD-ROMs includes IMDISP, a modified image display program from JPL and PDS that runs on MS-DOS machines, and FTB, a FITS table browser from GSFC, likewise for MS-DOS machines. Also included are utilities (FITS2TXT, TXT2FITS, FITSXTND, and FITSUTIL) written to develop various test discs for the IHW and the documentation associated with these programs. Each of the programs can stand alone. The following text describes a user approach to accessing the data on the CD-ROMs. The main philosophy has been to work with existing code, in particular, IMDISP, and write C modules that handle the special cases of the IHW data.

The CD-ROMs provide multiple access routes to the data, but the best approach in answering scientific questions is to use the index tables to search and then browse the data on a PC or other suitable workstation, and perform subsequent data analysis as needed. The last stage could be done by specialized software on a PC or other workstation, but, at this writing, it is more likely to be performed with an image processing package (e.g., AIPS, IRAF, or MIDAS). Work off-line is also expected for the compressed data, for which various decompression modules are provided but specialized I/O is not.

After the setup stages, we anticipate that the user will search the data via indexes: CALIB*, EPHEM, NETABLES, OBSCODES, PATHTABL, or QUIK*. Each index is provided in a delimited form for import to DBMSs such as dBase. Experience with both dBase III+ and dBase IV indicates that the following steps would be generically useful:

1. The user should first set up for the type of index preferred at this point, then display the structure so he can see the column headings.
2. Next, the user should get the provided .IDX file and place it into the provided "dummy" dBase file of the same name (with the extension .DBF).
3. The List command or equivalent will give columns of interest for various conditions that depend on the range and type of search.

The typical Sort function will permit the choosing of ranges by Boolean conditions. Other database packages have similar commands that can be applied once the data have been imported using the structure file (or FITS header or PDS label) to correctly recognize the fixed-width format of the fields.

To find the data, the user must search the index or chronological directory. We have assumed that for typical operation, the user has a "report" or file that contains the file names of interest. After deciding on the content of the set of files (extensions such as .DAT, .TAB, .IMG, or .IBG), the user must choose the manipulation program. The simplest case is for all two-dimensional data (.IMG and .IBG) for which IMDISP is fully implemented in both the FITS and the PDS options (see the IMDISP.DOC file). If the data are appropriate, i.e., if they can be displayed quickly, the Browse set of commands can be used. We have constructed a set of subsampled images with this purpose in mind. The Browse command can be used on any two-dimensional data, but files larger than a browse image (a 256 × 256, 1-byte image) will require additional display time (typically 20 s for a 512 × 512, 1-byte image). Also, radio data that contain multiple images can be displayed simply by pointing at the PDS label. In all cases, the display time is dramatically improved if the PDS label is used rather than the FITS option (which requires the original [embedded] data structure).

If the data file has the extension .DAT, then it can be displayed by applying the IMDISP program using "plot," as described in the on-line help. The detached PDS objects may read a two-dimensional spectrum (SPECTRAL_IMAGE_QUBE), a spectrum with ordered values or a multiple-column matrix (SPECTRUM), and a spectrum with a qualifier (LHP_POLARIZATION_SPECTRUM). The FITS option requires that the data be in the original form, i.e., embedded headers with data. Consequently, FITSUTIL was developed to concatenate files in an MS-DOS environment (as well as to split data for assembling the compact discs). Therefore, at this point, the user should branch to FITSUTIL and work on those files he chose to save on his hard disk or create a new work area. (Note that the program does not overwrite data, so the user can check for consistency; however, this means that storage space will get used quickly as file copies appear.) A full-scale plot should be used. Since the data range can be very large normally, the user can perform a zoom query to pick a restricted range, applying the normal cursor commands in IMDISP. Multiple spectra can also be plotted. Figure 1 shows the basic data flow.

All descriptive "textual" information can be displayed on the screen using various commands, such as LABEL within IMDISP. Although the Astrometry data are identified by the PDS object TEXT, they are continuous byte streams (as required by FITS) without the normal end-of-line characters (a carriage return, a line feed, or both). The data could be broken up into 80-byte chunks (card images) for further use, but the derived orbital elements have been provided as a complete ephemeris table.

In addition, the FITS data loaded in the extended "tables" format can be accessed much as the Astrometry data can be. FTB, which is one of the programs supplied on the CD-ROMs and which was written by GSFC's Astronomical Data Center, parses this "byte stream" of ASCII characters into a "tabular display." However, to run the FTB program, the file must be concatenated back into its original form, i.e., the .HDR and .TAB files must be combined into a .FIT file while preserving the 2,880-byte record format.

9. REFERENCES

King, J.H., and Grayzeck, E.J. (1989). "Minutes of the CD-ROM Workshop," June 19–20, 1989, NSSDC 89-11.

Martin, T., Martin, M., Braun, M., Johnson, T., Davis, R., and Mehlman, R. (1988). *SPIDS v1.1: Standards for the Preparation and Interchange of Data Sets*, JPL D-4683 (internal document), Jet Propulsion Laboratory, Pasadena, California, October 3, 1988.

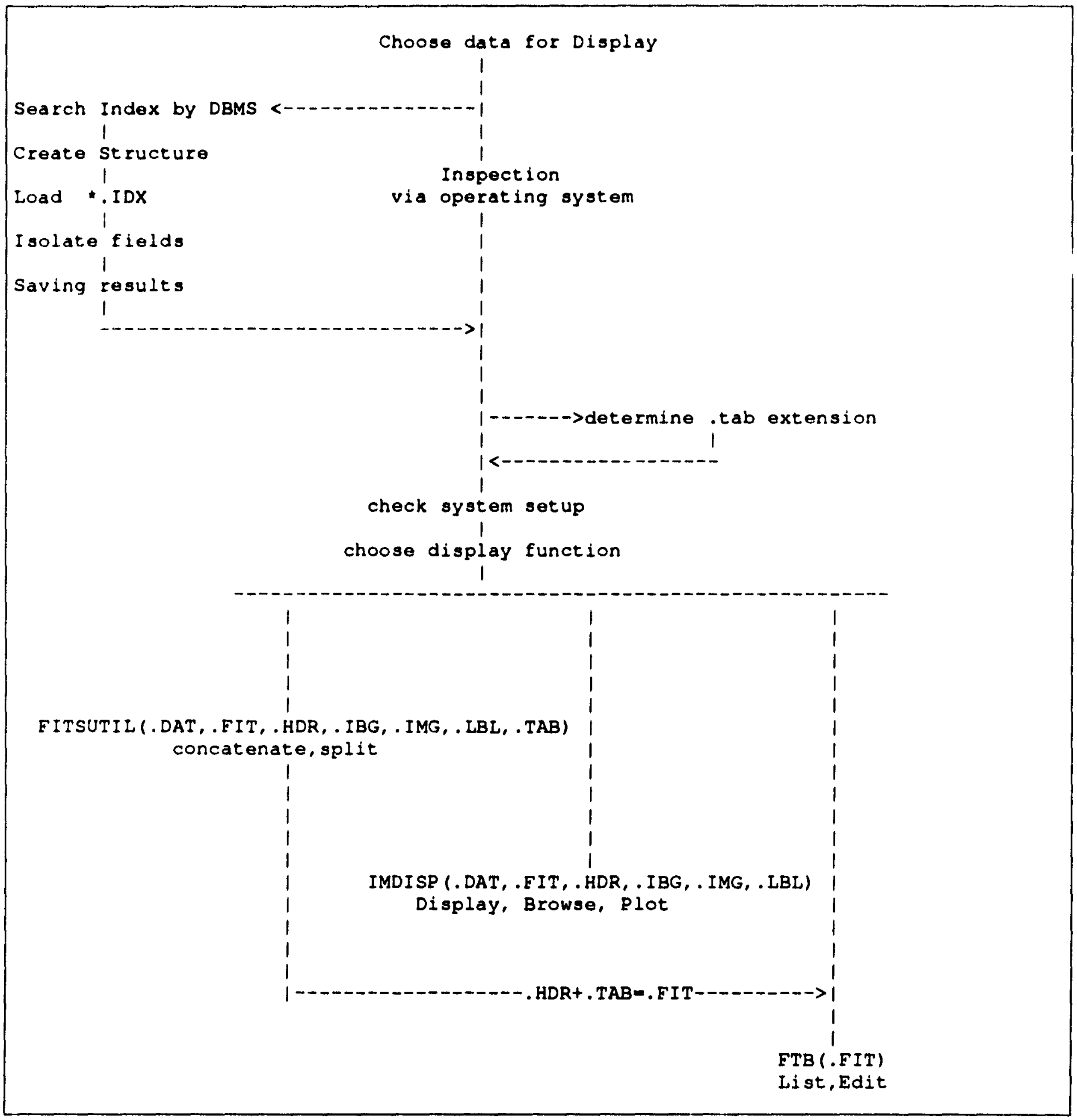

Figure 1. The Basic Data Flow

THE 1986 PASSAGE OF COMET HALLEY

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1. INTRODUCTION

Comet Halley has repeatedly played an important role in astronomy: each of its returns has added to our knowledge more than the apparitions of any other comet have. As soon as Edmund Halley identified its 1682 passage with the return of the object of the 1607 and 1531 passages, Comet Halley became the first known example of a new kind of heavenly body—namely, a small object bound to the Sun, with an aphelion lying much further away than the orbits of the planets known at that time. The significance of such a discovery can be better appreciated if we are reminded that only a few years earlier, Sir Isaac Newton had established for the first time that a parabola fitted the observed trajectory of a comet (namely, that of the Great Comet of 1680) much better than did the straight line assumed previously by Johannes Kepler.

Comet Halley's 1759 return played a different, but no less important, role: it was instrumental in the wide acceptance of Newton's law of gravitation. Using for the first time the existence of planetary perturbations to correct the comet's orbit, Clairaut (1758) predicted the 1759 perihelion passage with an approximation of one month. The timely appearance of Comet Halley according to Clairaut's prediction was taken in Europe to be a triumph of Newton's law of gravitation that suddenly relegated René Descartes' (1792) still-popular "eddies" (vortices) to the status of an historical aberration.[1]

By Comet Halley's 1835 return, improvements in optical instruments revealed for the first time the existence of physical phenomena taking place in a comet's head. In particular, Friedrich Bessel's drawings show jets, rays, and fans that seem to be ejected sunwards before being repelled away from the Sun. Bessel interpreted his drawings by his now-classical fountain model, already suggestive of vaporizing gases dragging dust away on the sunside of the nucleus. This looked like a confirmation of Laplace's (1803) ideas about the existence of a solid frozen nucleus. Laplace had written: "the nebulosities that surround [the comets] are the result from the vaporization...at their surface; the cooling off that follows diminishes the excessive heat coming from their proximity to the Sun."

The development of photography and spectroscopy gave an entirely different flavor to the 1910 passage. Several national committees tried to promote international cooperation concerning observations of the comet, but the effort failed. The plan of reproducing the best photographs was later abandoned, chiefly because of the abundance of material. Bobrovnikoff (1931) saved part of this effort by under-

[1]It is worth mentioning that Descartes' eddies were part of a field theory conceptually similar to those that have now invaded physics: the field lines, as well as the eddies, replace the mysterious action at a distance that had remained repugnant even to Newton. Of course, Descartes was much too early and was never able to express his field visualization into any quantitative theory.

taking a major monograph of the 1910 passage, in which he used 709 photographs and a few scores of spectrograms. The radicals and ions that had been identified at that time in cometary heads and tails contained only three elements: carbon, nitrogen, and oxygen. Comet Halley's 1910 passage added hydrogen to this list because of Bobrovnikoff's probable identification of the Fortrat band of CH near 4300 Å. Nicolet (1938) removed any doubt about the identification. Bobrovnikoff (1942) assumed that the four identified elements (H, C, N, and O) came from three volatile "parent" molecules—namely, carbon dioxide (CO_2), ammonia (NH_3), and water (H_2O)—that were vaporizing from the nucleus. Fragmentation and ionization of these three molecules were enough to explain the observed spectra: CN, C_2, C_3, CH, OH, NH, NH_2, and the ions CH^+, OH^+, N_2^+, CO^+, and CO_2^+, as they were identified in the 1940s. These data would be the baseline upon which Whipple (1950) would build his icy conglomerate model of the nucleus.

Like Comet Halley's earlier passages, its 1986 passage has played an important role in astronomy. Thanks to better preparations, this passage has undoubtedly been more fruitful than the last one. In fact, with the help of space endeavors, this passage has brought such a wealth of information that, more than two years later, a large fraction of this information has not yet been properly interpreted. Most of this information might have remained scattered in obscure places for a long time, at the risk of duplicating the story of the 1910 passage, if the International Halley Watch (IHW) had not been organized and supported by the National Aeronautics and Space Administration (NASA) and internationally sponsored by the International Astronomical Union (IAU). The data collected during this passage's vast endeavor have been preserved in the Comet Halley Archive, which is stored on the compact discs that accompany this summary volume.

The IHW's Steering Group asked me to give an outline of the 1986 passage's results, as a chapter in this book. Having been the first chairman of the Steering Group (from 1984 to 1985), I could not refuse, but I accepted without measuring the immensity of the task. Of course, I will not speak about the interpretations of the contents of the Comet Halley Archive, since most of the contents are still unknown to me while I am writing these lines. All I can do is present a partial and probably biased outline describing the gist of what has already been published in the literature. The following sections contain this outline, which I see as a preliminary baseline that the next generation will criticize, amend, modify, or completely overhaul.

2. ELEMENTAL ABUNDANCES IN COMET HALLEY

2.1. Mean Composition of the Volatile Fraction

I have published an extensive discussion (Delsemme 1988) comparing all available data for Comet Halley with the average elemental abundances for a few recent bright comets, namely, comets Arend-Roland 1957 III, Seki-Lines 1962 III, Bennett 1970 II, Kohoutek 1973 XII, and West 1976 VI. Table I outlines this comparison. Taking into account the existence of large error bars, wide differences from comet to comet have not been revealed. For this reason, notwithstanding Comet Halley's retrograde orbit, it seems reasonable to use Halley's volatile fraction as a logical sample representing the volatile fraction of any bright comet.

Table I. Mean Ratios of Atom Numbers in the Volatile Fraction of Light Elements in Some Bright Comets

Element	Bright Comets (Delsemme 1985)	Comet Halley (Delsemme 1988)
H/O	1.8 ± 0.4	1.9 ± 0.4
C/O	0.20 ± 0.10	0.20 ± 0.05
N/O	0.10 ± 0.05	0.10 ± 0.05
S/O	0.003 ± 0.0015	0.01 ± 0.005

2.2. Mean Composition of the Refractory Fraction

For the first time in any comet, the mean elemental composition of dust has been established (Krueger and Kissel 1987). The results, given in Table II, have been derived from the mass spectrometry of a minimal number of dust grains (about 80 particles) collected at high velocity and vaporized by impact during the VEGA-1 and Giotto flybys of Comet Halley.

2.3. Dust-to-Gas Ratio

To find the total elemental abundances, the volatile fraction and the refractory fraction must be added together in the proper ratio. However, this ratio has not been satisfactorily established for Comet Halley. The mean ratio inside the nucleus is difficult to derive using the production rates of gas and dust coming from surface vaporizations. In addition, these production rates showed wide fluctuations at the time of the spacecraft flybys, as established by a Finson-Probstein analysis of the dust tail isophotes (Fulle 1987; Fulle, Barbieri, and Cremonese 1987). If we call M the dust-to-gas mass ratio, the mean M averaged over a long time approximates the ratio of refractory-to-volatile fractions inside the nucleus, in the reasonable assumption of radial homogeneity (see the circumstantial evidence given in Delsemme 1982).

Low values of M (0.1 to 0.3) were found during the Comet Halley flybys (Sagdeev et al. 1986). These values could be consistent with the buildup of an outgassed mantle of dust on the nucleus, as would be expected with the subsiding of vaporizations after perihelion. But these values are irrelevant for the steady state, implying a much larger value than 0.3 for the mean M. The existence of a large number of massive grains, otherwise undetectable but deduced from the discrete data of the Dust Impact Detection System (DIDSY) experiments and confirmed by radar observations (Campbell, Harmon, and Shapiro 1989), suggests that the steady-state ratio could be anywhere from M = 0.5 to M = 2 (McDonnell et al. 1986; McDonnell, Lamy, and Pankiewicz 1990). A lengthy discussion (Delsemme 1990) shows that the only way to go further is to assume that all comets are essentially similar (see arguments given in Delsemme 1987) and use M = 0.8, as suggested by comets Arend-Roland 1957 III (0.8 ± 0.2) and Bennett 1970 II (0.6 ± 0.4) (Delsemme 1982).

Table II. Comparison of Elemental Abundances in the Sun, in C I Chondrites, and in Comet Halley. Normalized in Log Atom Numbers, With Log N_H = 12.00 in the Sun.

Element	Sun (Anders and Grevesse 1989)	CI Chondrites[a]	Comet Halley (see text)		
			Dust Only	Gas Only	Gas + Dust
1 H	12.00	7.64 ± 0.09	8.89 ± 0.08	9.22 ± 0.15	9.39 ± 0.12
6 C	8.56 ± 0.04	7.40 ± 0.13	8.49 ± 0.08	8.25 ± 0.20	8.69 ± 0.14
7 N	8.05 ± 0.04	6.24 ± 0.04	7.20 ± 0.12	7.95 ± 0.22	8.02 ± 0.22
8 O	8.93 ± 0.04	8.42 ± 0.02	8.53 ± 0.05	8.95 ± 0.15	9.09 ± 0.10
11 Na	6.33 ± 0.03	6.31 ± 0.03	6.58 ± 0.20	---	6.58 ± 0.20
12 Mg	7.58 ± 0.05	7.58 ± 0.02	7.58[b]	---	7.58[b]
13 Al	6.47 ± 0.07	6.48 ± 0.02	6.41 ± 0.10	---	6.41 ± 0.10
14 Si	7.55 ± 0.05	7.55 ± 0.02	7.85 ± 0.04	---	7.85 ± 0.04
16 S	7.21 ± 0.06	7.27 ± 0.05	7.44 ± 0.12	6.48 ± 0.26	7.48 ± 0.24
19 K	5.12 ± 0.13	5.13 ± 0.03	4.88 ± 0.18	---	4.88 ± 0.18
20 Ca	6.26 ± 0.02	6.34 ± 0.03	6.38 ± 0.11	---	6.38 ± 0.11
22 Ti	4.99 ± 0.02	4.93 ± 0.02	5.18 ± 0.18	---	5.18 ± 0.18
24 Cr	5.67 ± 0.03	5.68 ± 0.03	5.53 ± 0.09	---	5.53 ± 0.09
25 Mn	5.39 ± 0.03	5.53 ± 0.04	5.28 ± 0.15	---	5.28 ± 0.15
26 Fe	7.67 ± 0.03	7.51 ± 0.01	7.30 ± 0.07	---	7.30 ± 0.07
27 Co	4.92 ± 0.04	4.91 ± 0.03	5.06 ± 0.22	---	5.06 ± 0.22
28 Ni	6.25 ± 0.04	6.25 ± 0.02	6.19 ± 0.18	---	6.19 ± 0.18

[a] For the CI chondrites, the abundances of H, C, N, and O are from Mason (1971); the other elements are from the revised values of Anders and Grevesse (1989).

[b] Comet Halley's abundances are normalized for Mg = 7.58; the dust-to-gas mass ratio is 0.8 and the error bars include a variation of this ratio from 0.6 to 1.0.

2.4. Elemental Abundances Are Quasi-Solar

Table II assumes that the dust-to-gas mass ratio is M = 0.8 ± 0.2 for Comet Halley. The elements' final error bars include the possible variation from 0.6 to 1.0. The table compares the elemental abundances of Comet Halley with those in the solar photosphere and in the C I chondrites. This comparison demonstrates an important fact (shown graphically in Figure 1): In Comet Halley, elemental abundances are very close to solar abundances, except for the abundance of hydrogen, which is depleted by several orders of magnitude in the comet. Presumably, the only other elements that could also be deeply depleted are most of the noble gases (though none of them has been detected yet in Comet Halley). It must be emphasized that most of the detected metals, but also C, N, and O, are present in solar

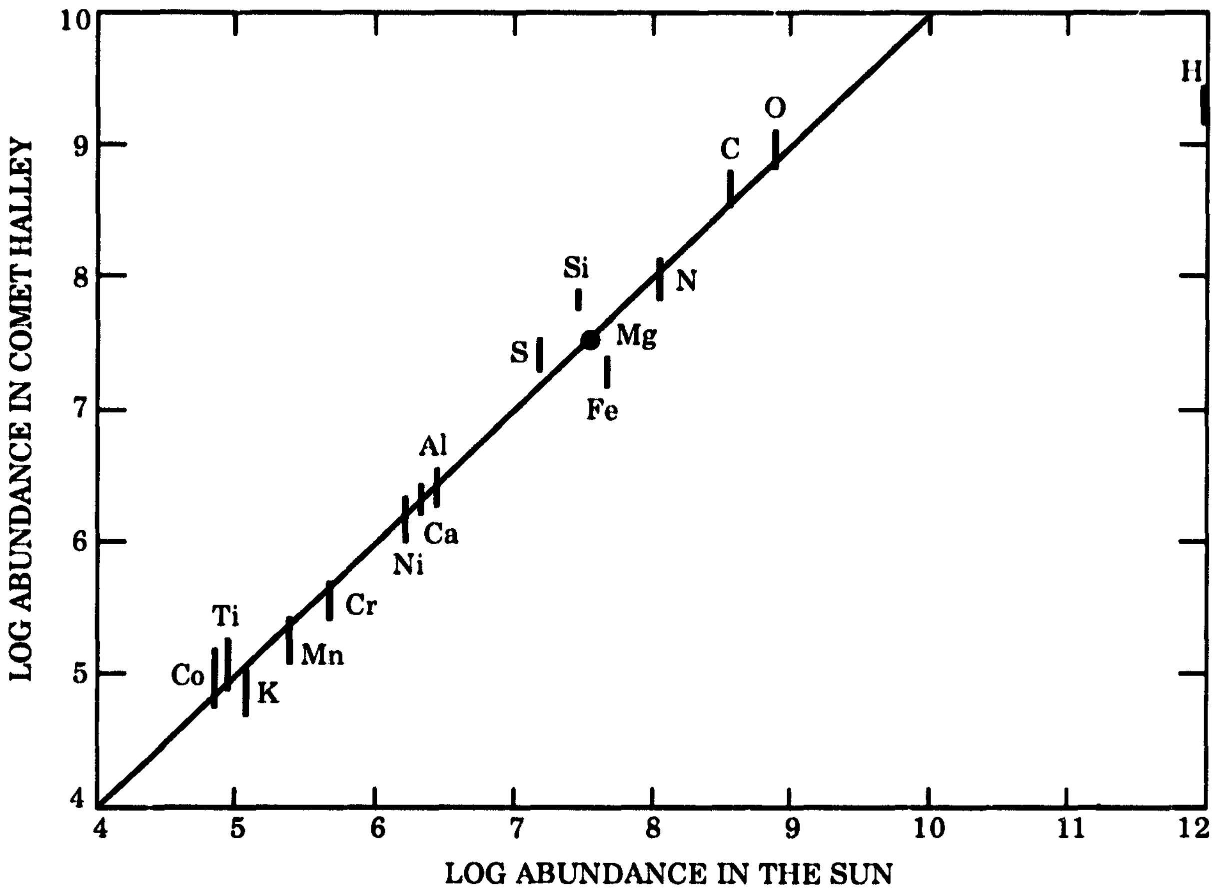

Figure 1. The elemental abundances known in Comet Halley (the sum of gas and dust) are compared with those in the Sun. The units are those used in astrophysics, with log N = 12 for the Sun. The data come from Table II. The (vertical) error bars are those for Comet Halley and include the uncertainty for the dust-to-gas mass ratio. The 45° line, which represents solar abundances for Comet Halley, passes practically through all the error bars, except for that of hydrogen; hydrogen is depleted by a factor of about 500. The exception represented by Fe and Si is discussed in the text.

abundances, within the error bars (Section 2.5 discusses a small, but interesting, exception). If it is now <u>assumed</u> that solar abundances are indeed reached for C, N, and O in Comet Halley, a least-squares fit with M as an independent variable yields a mass ratio of M = 0.64 ± 0.30, in agreement with the ratios deduced previously for the other two comets. This is another way to assess the uncertainty in M.

2.5. The Iron-Over-Silicon Ratio

The exception mentioned in Section 2.4 is the nominal Fe/Si ratio: it is only 25% solar. This can be seen in Figure 1, where Fe is <u>twice</u> as abundant as it is in the Sun, and Si is <u>one-half</u> as abundant. Such results could easily be dismissed as a fluke in the results coming from the small number and microscopic mass of dust grains used in the VEGA mass spectrometry experiment. However, for two reasons, I am willing to take the risk here of not dismissing this odd ratio. First, in the same microscopic sample, twelve other elements, including trace elements such as cobalt, titanium, and potassium, are, within their error bars, in strict solar abundances. It would be surprising that a fluke would affect only two major metals. Second, this unexpected ratio is highly suggestive of the same type of anomaly abundantly documented in the different types of carbonaceous chondrites, where the Fe/Si ratio varies from 25% to 75% solar. These primitive meteorites also contain many other metals (more than 50) in strict solar abundances. Moreover, chondrites and comets probably have a similar origin, with only a slightly different thermal history (Delsemme 1990). The composition of the terrestrial planets also suggests that a variable iron deficiency exists in the inner Solar System (Delsemme 1990).

2.6. The Carbon Depletion Puzzle Has Disappeared

I have previously observed that the volatile fraction of comets lacks at least two-thirds of the cosmic carbon (Delsemme 1982). I proposed that this missing carbon could be hidden in the dust grains. However, this conjecture looked rather odd, because no bodies—not even primitive bodies—were then known to contain more than 5% to 7% carbon. At that time, the only signatures found in cometary dust were the silicate infrared bands; the dark albedo of dust could have been easily explained by a minimal amount of carbon, as in chondrites. However, it happens that my conjecture has been substantiated in Comet Halley, since its dust contains most of its carbon (see Table II).

3. MOLECULAR COMPOUNDS IN COMET HALLEY

3.1. Volatile Molecules, Radicals, and Ions

All chemical species identified in the heads or tails of previous comets, plus a few more species, have been observed in Comet Halley during its 1986 passage. These observations used numerous techniques: they were taken either from the ground or from satellites or spacecraft, and they used spectroscopy in the visual, ultraviolet, infrared, or radio domains, as well as using mass spectrometry during the spacecraft flybys. Table III lists the chemical species found.

3.2. Less-Volatile and Refractory Molecules

The dust-impact mass spectrometer PUMA on the VEGA-1 flyby provided the most detailed information on Comet Halley's dust composition (Kissel et al. 1986; Krueger and Kissel 1987). Table IV gives the mean composition of the average of icy and dusty particles collected between 10,000 and 60,000 km from the nucleus.

Table III. Chemical Species Identified in the Cometary Head[a]

1. BY VISUAL, ULTRAVIOLET, INFRARED, AND RADIOWAVE SPECTROSCOPY

ORGANIC:

Hydrocarbons: C, C_2, C_3, CH (isotope ratio $^{12}C/^{13}C$; Wehinger et al. 1986)
With nitrogen: CN, HCN, CH_3CN (isotope ratio $^{14}N/^{15}N$; Wehinger et al. 1986)
With oxygen: HCO, (H_2CO), CO_2 (Combes et al. 1986)

INORGANIC:

Ammonia group: NH, NH_2, (NH_3), (NH_4)
Water group: H, O, OH, H_2O (ortho/para in H_2O; Mumma, Weaver, and Larson 1987)
Sulfur group: S, S_2

METALS:

Na, K, Ca, V, Mn, Fe, Co, Ni, Cu (Sun-grazing comets)

IONS:

Organic: C^+, CH^+, CO^+, CO_2^+
With N: N_2^+
With O: OH^+
With S: H_2S^+
Metal: Ca^+

2. FROM PEAKS IN MASS SPECTRA DURING SPACECRAFT FLYBY

H_3O^+ (Gringauz et al. 1986; Balsiger et al. 1986; Korth et al. 1986)

$(H_2CO)_n$ (from ionic fragments; Huebner 1987)

NH_4^+, NH_3^+; CH_4^+, CH_3^+; S_2^+, CS^+, CS_2^+ (Allen et al. 1987)

$C_3H_3^+$ (Korth et al. 1986)

HCO·OH and H_2CO in CHON grains (Kissel and Krueger 1987)

[a] References for post-1985 discoveries only; prior to that, see Delsemme (1985).

Table IV. Mean Chemical Composition (in Mass Percent) of Dust in Comet Halley[a]

Organic 33%		Inorganic 67%	
Unsaturated hydrocarbon	16.0%	Silicates	51.5%
H, C, + O	5.2%	FeS (Troilite)	6.0%
H, C, + N	4.5%	C (Graphite)	3.0%
H, C, + S	1.8%	S (Sulfur)	1.0%
Water	5.5%	Water	5.0%

[a] Interpreted from Krueger and Kissel (1987).

3.3. Quantitative Analysis of the Volatile Fraction

I have tried to quantitatively assess the chemical composition of the gases vaporizing from the nucleus and from the icy grains (Delsemme 1990). Table V, which lists the results, qualitatively agrees with all the by-products of photodissociation and photoionization given in Table III. Table V also quantitatively agrees with Comet Halley's atomic ratios given in Table I. However, Table V's apparent accuracy must not, of course, be taken at face value, since the error bars remain large.

3.4. Existence of an Extended Halo of Vaporizing Icy Particles

The icy halo has been detected up to 20,000 km away from the nucleus by its production of CO (Eberhardt et al. 1987). Formaldehyde (H_2CO) and formic acid (HCO·OH) have both been detected in the CHON grains (see Table III). Since these two molecules seem to be the major oxygen-bearing molecules, they must provide the major extended source of CO. Originally contained in icy grains, they are released into space by their vapor pressure, and their photodissociation into CO, by ultraviolet, occurs with a half-life consistent with the extent of the halo. Because their vapor pressure is in the same range as that of water, these molecules are counted in the volatile fraction and appear in Table V. It is interesting to remember that a vaporizing icy halo has been studied earlier, in Comet Burnham 1960 II (Delsemme and Miller 1971). Therefore, this halo does not seem to be an odd peculiarity of only Comet Halley.

3.5. Scatter of Grain Composition

The fact that the average of 80 microscopic grains has elemental abundances in quasi-solar proportions makes it even more surprising that the variation in individual grains' elemental composition is considerably larger than that in submicrometer volumes of meteoric and interplanetary particles (Brownlee et al. 1987). For

Table V. Chemical Composition (in Atom Numbers) of the Volatile Fraction of Comet Halley[a]

Molecules Containing Oxygen		Molecules Containing Nitrogen		Hydrocarbon Molecules		Molecules Containing Sulfur	
78.5%	H_2O	2.6%	N_2	1.5%	C_2H_2	0.1%	H_2S
4.5%	HCO·OH	1.0%	HCN	0.5%	CH_4	0.05%	CS_2
4.2%	H_2CO	0.8%	NH_3	0.2%	C_3H_2	0.05%	S_2
3.5%	CO_2	0.8%	N_2H_4				
1.5%	CO	0.4%	$C_4H_4N_2$				
92%	Total	5.6%	Total	2.2%	Total	0.2%	Total

[a] This table has tried to incorporate many discordant data, and it will remain controversial. Although it is consistent with all elemental abundance ratios established for the volatile fraction, it is prudent to take this table with a grain of salt.

instance, the distribution of the ratio Fe/(Fe + Mg) in a chondrite matrix is narrow: roughly from 0.3 to 0.7, with a strong peak at 0.5. In Comet Halley's grains, the same distribution ranges from 0.0 to 1.0, with no central peak. Jessberger et al. (1988) distinguish four families by cluster analysis of their elemental abundances in their mass spectra. The abundance dispersions are very large, but on the average, the families contain the following proportions (Jessberger, Christoforidis, and Kissel 1988):

Group A (carbon-rich): mean 54% C, 12% O, 10% metals (37 grains)
Group B (oxygen-rich): mean 54% O, 10% C, 15% metals (18 grains)
Group C (Mg-Si-rich): mean 81% metals (but 5% Fe), 2% C, 2% O (10 grains)
Group D (iron-rich): mean 33% Fe, but 9% Mg, 5% Si, 8% C, 4% O (11 grains)

These results can be interpreted by saying that cometary dust is an extreme example of the same kind of sedimentation that has produced the microscopic grains compressed in the matrix of chondrites. The very large variability in the cometary grains suggests the total absence of alteration or metamorphism. The absence of any thermal processing in comets is also demonstrated by the outgassing that takes place in the nucleus as soon as the surface temperature reaches 180 K.

Although the two metal-rich families C and D may contain silicates (Jessberger, Christoforidis, and Kissel 1988), they do not seem to contain enough oxygen to make large amounts of silicates or metallic oxides. In fact, groups A, C, and D appear to contain much reduced carbon or metals, whereas group B seems to be formed of completely oxidized particles.

The validity of the anomalous Fe/Si ratio mentioned in Section 2.5 is greatly reinforced by the existence of group C, where the large depletion of Fe/Si reaches extreme values that could not come from instrumental uncertainties alone. This group's grains seem to have required a high-temperature fractionation (typically 1500 to 1600 K) before their sedimentation with the other groups, which have different thermal histories. I have tried to interpret this fractionation (Delsemme 1990) in the context of the scenario describing the origin of comets in the pre-solar accretion disk, but this is outside the scope of the present discussion.

3.6. Isotopic Ratios

Before Comet Halley's 1986 passage, the only isotopic ratio measured in comets was the $^{12}C/^{13}C$ ratio measured from the (1-0) band of the C_2 radical. The results looked somewhat unreliable because of the blend of the C_2 band with NH_2. Published ratios went from 70 to 140 or even beyond, but it was generally assumed that the ratio was consistent with the terrestrial value of 89 (Lambert and Danks 1983) rather than with the interstellar ratio. This interstellar ratio, measured optically in the CH^+ band by Hawkins and Jura (1987), is 43 ± 4 and seems to be constant within 12% in four different lines of sight.

The traditional explanation for the high Solar-System value of 89 is that five billion years ago, 89 was the interstellar value in the solar neighborhood, and this ratio was set in the Solar System during its formation. Since that time, young Population I stars in the solar neighborhood have enriched interstellar space in ^{13}C, because these stars use the CNO cycle in thermonuclear burning (Truran 1985). However, this gradual enrichment is not unanimously accepted (Schramm 1985). Also, the interstellar value varies with the carbon compound considered, in particular because of the different fractionation mechanisms which depend on the different histories of the ions or radicals.

Wyckoff et al. (1989) have resolved the ^{13}CN rotation lines in Comet Halley and deduced an isotopic ratio of 65 ± 9 for the CN radical. As in interstellar space, different fractionation effects may be present for the ^{13}C in C_2 or in CN when these radicals are detected after vaporization in the coma. When different molecules are considered, the interstellar ratio also varies from 40 to 90 (Wannier 1980). On the other hand, the slight isotopic anomaly of CN in Comet Halley could have the same origin as the larger anomalies (in this case, the ^{13}C enhancements) found in particular grains of carbonaceous chondrites (Swart et al. 1983; Niederer, Eberhardt, and Geiss 1985). Although quantitative measurements of ^{13}C were also attempted by mass spectrometry in Comet Halley, the mass spectra blended the ^{13}C peak with that of abundant CH, making the measurement difficult. Nonetheless, Jessberger et al. (1987) reported that some grains had anomalously high $^{12}C/^{13}C$ ratios.

Other isotopic abundances in Comet Halley have also been reported. In particular, Eberhardt et al. (1986) found the D/H ratio for water to be between 60 and 480 parts per million (ppm). This ratio is consistent with the 150-ppm value of sea water and is definitely higher than the 20-ppm value of the interstellar medium, in agreement with a possible cometary origin of sea water (Delsemme 1990). Eberhardt et al. (1986) also reported that $^{18}O/^{16}O = (23 \pm 6) \times 10^{-4}$ for Comet Halley. This is in agreement, within the error limits, with the value of 20×10^{-4} for sea water and for elsewhere in the Solar System.

All isotopic ratios found in Comet Halley remain rather consistent with the hypothesis that all cometary material has come from the same original reservoir as the rest of the Solar System. The very fact that some isotopic anomalies have been preserved in Comet Halley's dust grains, as well as in numerous microscopic grains of carbonaceous chondrites, must then be interpreted. A possible explanation is that the original material of the Solar System has been coming directly from a molecular cloud. Later in its evolution, primitive objects such as chondrites and comets have kept the diversity of interstellar grains more or less intact until now, which also explains the scatter in grain composition discussed in Section 3.5.

4. CONCLUSIONS

4.1. Range of This Review

This paper has thus far been limited to a few topics for which fundamental advances seem to have been made thanks to Comet Halley's 1986 passage. Many advances have also been made in other directions, including the morphology of the nucleus, its relationship with the inner coma, the identification of the photodissociation and photoionization mechanisms of molecular fragments, the interaction with the solar wind in all its complexity, and the plasma and dust tail morphology and development. However, in my opinion, the 1986 passage of Comet Halley will mostly be remembered for having brought a considerable advance in our understanding of the chemistry of the cometary nucleus and its interconnections with interstellar matter. This understanding shows the way towards a unified approach in studying comets and carbonaceous chondrites as those primitive bodies whose chemistry can help unravel, on an empirical basis, the origin of the Solar System.

4.2. Summary of Major Results

4.2.1. *Elemental Composition.* The elemental abundances of C, N, O, S, and twelve major metals are in solar proportions. Only H is depleted, by a factor of about 500 with respect to the Sun.

4.2.2. *Fe Depletion.* An interesting exception to the statement in Section 4.2.1 is the Fe/Si ratio, which is only 25% solar. If this ratio is not dismissed as a fluke, it can be compared with the Fe/Si ratios of different chondrites. These latter ratios are abundantly documented and vary from 25% to 75% solar, depending on the chondrite type. The 25% cometary Fe/Si ratio can also be compared with the Earth's composition, in which Fe/Se (assumed to be homogenized globally) is less than 50% solar (Delsemme 1990).

4.2.3. *No Carbon Depletion Puzzle.* Only one-third of the solar carbon abundance is present in Comet Halley's gaseous fraction, but the other two-thirds are in its dust. Adding the gas and dust together brings carbon exactly to its solar abundance.

4.2.4. *Scatter in Dust-Grain Composition.* Cluster analysis of the elemental abundances in dust reveals four different families of particles: carbon-rich (group A), oxygen-rich (group B), Mg-Si–rich (group C), and iron-rich (group D). This suggests that individual interstellar grains coming from different stellar environments have been mixed together and preserved in these primitive bodies that we call cometary nuclei.

4.2.5. *Halo of Vaporizing Grains.* Grains of groups C and D are mostly metallic, but grains of groups A and B have been dubbed "CHON particles" because they contain mainly molecules built up with C, H, O, and N atoms. A fraction of these CHON particles are refractory organic polymers, but there is also a volatile fraction, which is likely to release formaldehyde and formic acid, because these two molecules' vapor pressures are very close to that of water ice. The two molecules can both vaporize and photodissociate into CO, forming the source of an extended CO halo surrounding the nucleus up to 20,000 km.

4.2.6. *Isotopic Ratios.* Isotopic anomalies seem to have been preserved in some of Comet Halley's dust grains, and the carbon isotopic ratio appears to depend on the organic radical involved in the measurement. Some isotopic anomalies have also been found in microscopic grains from the matrix of chondrites, suggesting that chondrites, as well as comets, have preserved interstellar grains intact. Otherwise, the deuterium and the oxygen isotopic ratios are those of sea water and more generally those of the Solar System. This suggests that Comet Halley comes from the same original material as the rest of the Solar System.

4.3. Concluding Remarks

Most of the fundamental advances described here relating to Comet Halley's 1986 passage throw a new light on the origin of comets. The elemental composition reveals the same origin as that of the rest of the Solar System, whereas the scatter in dust-grain composition, as well as some isotopic anomalies, suggests that individual interstellar grains coming from different stellar environments have been collected together and preserved in their pristine form in those primitive bodies that we call comets. Hence, the new data bring new constraints and new prospects for the models describing the Solar System's origin.

A particularly puzzling result of these new advances is the very low Fe/Si ratio. If not dismissed as a fluke in the experiments, it will have to be explained by a mechanism depleting iron in silicate grains during the evolution of the accretion disk surrounding the proto-Sun.

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RECENT OBSERVATIONS OF COMET HALLEY

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Comets are some of the most famous actors on the vast celestial stage. They make their striking entrées from the dimly lit wings, they spellbind us during a brief period of glory, and all too soon they exit into the shadows. Some of them perform better than most and are applauded by a fascinated audience, while the radiation of others seems to fade after a promising overture.

It is the art of comets, like all good actors, to imitate personalities that are not necessarily their own. Sure enough, through the binoculars we can see them perspire in the glaring limelight and we sense the heavy breathing that follows a particularly dramatic outburst. But if we want to learn more about their real nature, we must also watch them when their performance is over and they retire from the stage. Unless we keep an eye on their secluded life in the quarters where they rest between their brief and spectacular appearances, we may never fully understand them.

And this is why it is so desirable to continue observations of Comet Halley, that most famous and regular performer of them all, long after its fine display in early 1986. Although such observations at ever-increasing heliocentric distances are rather time-consuming, they are well-justified and provide an important complement to the enormous efforts that went into space- and ground-based studies when Halley was closest to the Sun.

In early 1987, one year after the perihelion passage, the outgassing from Comet Halley's "dirty snowball" nucleus had ceased at 5 AU from the Sun. The spectrum no longer showed the characteristic emission lines from the CN molecule, and from then on, the visible coma most likely consisted only of dust. The last remnants of a tail disappeared a few months later. Somewhat surprisingly, however, the coma turned out to be much more persistent than expected. This was bad news for those observers who had hoped to make an easy determination of the nucleus' rotation period using the observed light variations of that body: since the nucleus continued to be shrouded by surrounding dust, accurate intensity measurements were not possible.

It was for this reason that we delayed the first post-perihelion observations of Comet Halley from the European Southern Observatory (ESO) until early 1988, when Halley was at the heliocentric distance of 8.5 AU. Hoping that the mist had cleared in the meantime, so we could directly measure the changing amount of sunlight reflected from the tumbling nucleus, we observed Halley during 21 nights in April and May 1988. We were astonished, though, to register the presence of a stable coma with enormous dimensions, more than 500,000 kilometers across. By advanced image processing, we could separate the light of the nucleus from that of the coma and measure variations of about 1.2 magnitudes. But the rotation period continued to remain elusive, even when this extensive observational material was compared with pre-perihelion measurements.

We repeated the observations during six nights in January 1989, and we accumulated a total of more than 14 hours of integration time. Rather unexpectedly, we found that the size and structure of the coma were very similar to what had been seen in 1988. In particular, the dust density was virtually unchanged, proving that the nucleus was still spewing dust out into the surrounding space at 10.1 AU from the Sun. It was even possible to discern what looked like a straight "jet" in the coma, with a morphology similar to those jets that had been observed from spacecraft and from the ground in 1986.

The picture in February 1990 was completely different. Despite the deepest series of charge-coupled device (CCD) exposures ever made of any comet, we could perceive no coma at all, even at the level of 29 magnitudes/arcsec^2, i.e., at a level almost 1,000 times fainter than the night sky background. Now, at 12.5 AU from the Sun, Halley seemed to have finally become quiescent, so that the activity on the nucleus had ceased and no more dust was escaping from it. Halley was declared asleep, quite a bit too late according to current theories about the structure and composition of the nucleus, but, after all, asleep.

Astronomy is a beautiful science for many reasons. One of these is that it not infrequently presents its supporters with completely unexpected observational facts. A routine "inspection" of Comet Halley with the Danish 1.54-m telescope at the ESO La Silla Observatory on February 12, 1991, took the astronomers by complete surprise: instead of a 25.3-magnitude, hardly visible light point representing the reflected sunlight from the frozen nucleus, they saw a 20-arcsec-wide cloud of magnitude 19. Follow-up observations at ESO, and also at Mauna Kea and Pic du Midi, confirmed that Halley had indeed had a dramatic outburst, more than 14.3 AU from the Sun. The comet was now about 300 times brighter than expected. And even more was yet to come: that outburst was not a brief flash. One month later, seven nights of observations with the same telescope at ESO (now 26 hours of integration) proved that the outburst was still going on and that vast amounts of dust continued to be transferred to a coma measuring an incredible 500,000 kilometers across.

Only two comets have ever been observed at such a large distance from the Sun before, and no cometary outburst has ever been seen so far away, at such a low ambient temperature. At this moment, we can only provide educated guesses about the mechanism responsible for this dramatic event. A collision with a small body is statistically unlikely, and it would probably lead to a rapid fall-off of the activity soon after the initial burst. Heating by the solar wind, even at the time of the current solar maximum, would probably not be able to provide enough energy. There remains the possibility of a release of internal energy, stored inside the nucleus since the perihelion passage, opening a crack (a vent) in the otherwise frozen surface. But what kind of energy storage? Chemical, mechanical, or thermal? Nobody knows at this time.

The present outburst may be an isolated event, unique to Comet Halley. Or it may signify that comets in general are more active at large heliocentric distances than previously thought. Whatever the case, it implies that our knowledge about comets is still far from complete. Thanks to Halley, we must now reconsider our models of the cometary nucleus and we must endeavor to observe other distant comets in greater detail and at more regular intervals than we have done before.

Perhaps we shall then learn more about the true nature of these distinguished celestial actors.