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CHAPTER 5
FOCUS ON THE FUTURE

prepared by M. Hanner
with contributions from Panel Members and the Organizing Committee

INTRODUCTION

The third morning of the Workshop was devoted to a panel discussion (followed by general discussion) to assess what we have learned from Halley and to recommend future directions for infrared studies of comets and supporting laboratory investigations. Panel members were L. Allamandola, T. Encrenaz, R. Gehrz, M. Mumma and M. Hanner (moderator). The panelists were asked to address the following issues:

1. What steps can be taken to achieve consistent interpretation of Halley infrared data?
2. How successful has the Halley Watch been for infrared studies? Should some functions be extended to other comets?
3. What supporting laboratory research is needed?
4. What are the key infrared observations needed for future comets? Is new instrumentation required?
5. How do current and future NASA programs relate to comet studies?

1.0 ACHIEVING A CONSISTENT INTERPRETATION OF HALLEY DATA

1.1 Comparing Observations

- Observers should publish full details of their photometric system and calibration. Infrared photometric systems are not standardized among observatories; even "standard" infrared filters may have different effective wavelengths.
- Several groups carried out extensive photometric monitoring programs (Table 1-1). Efforts should be made to bring these basic data sets onto a common photometric system, so that they can be combined to give a synoptic history of the comet activity.
- Differences in beam size and sky chop amplitude have to be considered when comparing data sets. When jets were present in the coma, the brightness did not necessarily decrease inversely with distance from the nucleus.
- Whenever possible, intercomparisons should be done by the observers themselves.

1.2 Temporal Variability

- From November '85 through April '86, Halley displayed extreme variability. Not only did the amount of dust in the inner coma vary on timescales of a few hours, but also the size distribution apparently varied, so that the average optical properties changed.
- Thus it can be dangerous to combine data taken at different times (for example to extend spectral coverage) without taking this variability into account.
- Synoptic observations in the visible and ultraviolet spectral regions may be useful in charting the variability.
- Observers should *always* publish the UT times of their measurements.

1.3 Applying Models

- When interpreting data, it is a good idea to talk with the observers first!
- A complete, rigorous treatment of the scattering and emission from inhomogeneous, irregular grains does not exist; however, there are approaches to treat specific aspects of the problem.
- The limitations of the analytical methods for treating irregular particles have to be kept in mind when analyzing Halley data.
- Where high accuracy and detailed spectral fitting are not required (for example, estimating dust production rate and total emitting cross-section) the Q_{abs} computed from Mie theory may be adequate.
- The silicate grains in the coma may exhibit differing degrees of crystallinity. Structure in the spectral features will show up in the $10\mu m$ stretching mode for a lesser degree of crystallinity than in the $20\mu m$ bending mode vibration.
- Possible changes in grain properties during outburst need to be evaluated.
- Infrared data should not be interpreted without reference to data at other wavelengths.

2.0 INTERNATIONAL HALLEY WATCH/INFRARED NET

The International Halley Watch was established to advocate and coordinate worldwide observations of Halley and, thereafter, to prepare a permanent data archive. These roles were discussed specifically for the Infrared Net.

2.1 Coordination

Participants agreed that planning and coordination have been helpful:

- Many observers from other disciplines were encouraged to participate.
- Publicity from IHW facilitated allocation of observing time at large telescopes.
- Compiling and distributing observing schedules allowed observers to be aware of concurrent observations.
- Electronic hotline and mail system were useful for posting new observations and exchanging information quickly.

It was agreed that a permanent "comet hotline" for the purpose of exchanging observing schedules and new results would be useful.

However, a few desirable results were not realized:

- The 8-$13\mu m$ spectral region was poorly observed, despite the fact that this could have been done from the ground with CVFs available at several telescopes.
- A common photometric system among observatories (filters, photometric standards) was not achieved, reflecting the larger problem of standardization in infrared astronomy.
- Coordination of KAO and ground-based observations proved to be difficult.
- In some cases, the Infrared Net has not been notified whether planned observations were actually obtained.

Participants expressed frustration over the dollars spent for coordination compared to the support available for actually carrying out the observations. However, most agreed that a continued, low-cost coordination effort for comet observations is desirable, and that this effort should include recommending the observations most needed. Some observers stated that they are now experiencing more difficulty than ever in obtaining telescope time for comet observing, and they feel that there is a "backlash" resulting from the Halley effort.

2.2 The Archive

Software specialist B. McGuinness gave a status report on the archive for the infrared net (appended to this chapter). The Halley archive is designed to be a permanent, long-term database containing the original observations, without interpretation, and with sufficient information on instrument parameters that they can be re-evaluated by future researchers. Both an accessible CD-ROM and a printed version will be created. In addition, an archive is being prepared for Giacobini-Zinner.

Obviously, if the archive is to serve its purpose, all observers need to submit their data promptly. Final date for submission to the infrared net is June 30, 1988. All those who have contributed data will be offered a free copy of the completed archive.

The information to be placed in the header with each data set was discussed. In addition to instrument parameters such as beam size and chopping throw, comments on the weather and data quality should be included. An example of the header format is shown in Figure 5.1.

It was recommended that a bibliography of published papers related to the observations be appended to the archive.

Concern was expressed as to how the archive will be used after the considerable resources expended to create it. The recommendation was made that small grants be made available for utilizing the Halley and GZ data base.

Target publication dates are:

GZ printed archive - November 1988

GZ CD-ROM archive - May 1990

Halley printed archive - October 1989

Halley CD-ROM archive - July 1990

**** Final date for submitting data is June 30, 1988 ****

3.0 SUPPORTING LABORATORY STUDIES

This section draws on an evening of discussion by the laboratory investigations subgroup, as well as the discussions during Sessions III, IV and V.

Laboratory investigations can contribute to our understanding of comet grains in several ways, including:

- interpreting optical and infrared spectra obtained from Halley and other comets;
- supporting instrument design and measurement strategy for the CRAF mission;
- analyzing interplanetary dust particles;
- investigating the physical and chemical processes taking place on the nucleus and in the coma, as well as the processing of grains since their initial formation in the ISM.

Recommendations for specific measurements in these areas, directed toward the topics covered in this workshop, are summarized below.

3.1 Interpret Existing Infrared Observations

What types of silicates are present in comet dust and how do they compare to interstellar silicate grains?

What types of organic material are present in the grains?

```
NUMBER:                                  DATE:
PREPARER:                                RECD:
FILE-NUM:                                DISPOSITION:


OBSERVERS:

ADDRESSES:


TEL:

COMMENTS:   Information above will not be archived.
--------------------------------------------------------------------------------------------
SIMPLE   =                        T: ]
BITPIX   =                        8: ]  Set by DS
NAXIS    =                        0: ]
EXTEND   =                        T: ]

OBJECT   =:   comet e.g. "P/Halley," "P/Giacobini-Zinner
FILE-NUM=               : set by PS
DATE-OBS=:    Midpoint of observation (day/month/year)
TIME-OBS=                 :  Midpoint of observation (decimal fraction of a day)
DATE-REL=:    Date observers allow data to be released to the public
DISCIPLN= 'IR STUDIES':
LONG-OBS=:    Longitude of observatory deg/min/sec
LAT--OBS=:    Latitude of observatory ± deg/min/sec
SYSTEM   =:   Set by DS
OBSERVER=:    Names of observers (see COMMENT ADD. OBS. below)
SUBMITTR= 'KNACKE    ':
SPEC-EVT=                       : Observation of a special event? - Yes (T) or No (F)
DAT-FORM= 'STANDARD':

DAT-TYPE=:    "Photometry, Filter Table, Spectroscopy, Polarimetry, Image"
OBSVTORY=:    Name of observatory
LOCATION=:    Location of observatory
TELESCOP=:    Telescope size in meters
INSTRUME=:    Instrument used to observe the comet, e.g. "InSb photometer," "2-banger
                   photometer," "Bolometer," etc.


COMMENT                  General comments
COMMENT     ADD.OBS.     If more than 2 observers, all names after the first are placed here.
COMMENT     NOTE         Notes pertaining to rows in the table below
COMMENT     OBSVRUN      Observing period
COMMENT     ORIGIN       Location of beam center:  coma, peak signal point, etc.
COMMENT     REFERENC     Reference to a published paper
COMMENT     SEEING       Seeing in arcseconds
COMMENT     WEATHER      Weather conditions during the observation, e.g. cloudy, clear, marginal
                            etc.
HISTORY     STDSTARS     Stars used as brightness standards


NLINES   =                        :
END
  Filt    Mag    Err  ApDiam TmUT InUT Airm ChpThrw BeamOffOrigin Or Filt CommNotes
                      arcsec hhmm hhmm  Avg arcsec  rho arcsec th     Tabl
:       :         :    :      :    :    .    :   :   :                 .   .   :

:       :         :    :      :    :    :    :   .                     :   .   :
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Figure 5.1 - Sample Header Format for Halley Archive Infrared Net

Figure Explanation

TmUT: Time of midpoint of observation.

InUT: Duration of observation.

Beam Off Origin: Distance of beam from origin specified in comment.

Or: Number identifying one of the "origin" comments.

Filter Table: Number of specific table describing filter characteristics.

Comm Notes: Letter identifying one of the "Note" comments.

What is the carrier of the 3.36μm emission feature and what is the excitation mechanism?

Recommended Measurements

1. 10μm band shape versus physical and chemical properties of silicates (anhydrous/hydrated; degree of crystallinity; grain size and shape).
2. 20μm band shape and 10 to 20μm band strength ratio in silicates.
3. Temperature effects in spectral features.
4. Complete spectra to 50μm, and selected spectra to 200μm.
5. Spectra of appropriate organic materials, including PAHs and various forms of hydrogenated carbon.
6. Optical constants for appropriate organic material in the 3μm region.
7. Effects of grain size, from large molecules to small grains to grain aggregates.
8. Resonant and non-resonant fluorescence - is this a viable excitation mechanism in solid grains?
9. Microwave scattering on grain analogs: phase function, polarization, and Q_{scat}.

(Spectral resolution of $\sim 5\text{cm}^{-1}$ is needed to support future comet observations.)

3.2 Provide Database in Support of CRAF

What are the most important wavelength bands to sample?

What gas/grain interactions take place in the inner coma?

What are the structural properties of the nucleus?

Recommendations

1. Identify and study position and width of spectral features to determine the required filters.
2. Study isotope effects, especially in CO_2 and ice bands, to define instrument and filter requirements.
3. Measure ions/radicals coming off well-defined surfaces to plan for measurements of the near-nucleus environment.
4. Study structural properties of ices, in preparation for penetrator experiment.

3.3 Analyze Interplanetary Dust Particles

What can the composition and structure of IDPs tell us about their origin and processing history?

What carbon compounds are present?

Can isotope anomalies identify remnant interstellar grains?

What are the optical properties of IDPs?

How do their infrared emission spectra compare with comet spectra?

Recommendations

1. Study the composition and mineralogy of units within grains to identify high and low temperature phases.
2. Identify the carbon-bearing materials within grains.

3. Measure key isotopes ratios, such as D/H, carbon.
4. Measure optical and infrared properties, if possible emission spectra.

3.4 Study Physical and Chemical Processes

How do grains form and how do they aggregate?

What dust structures result during the process of sublimation from the nucleus?

What are the structural properties of the nucleus?

Are there isotope fractionation effects during condensation and vaporization?

Is the hydrogen ortho/para ratio primordial?

How are cometary materials altered by irradiation?

Recommended Investigations

1. Structural properties of ices and heat conductivity.
2. Irradiation effects on simulated cometary nuclear surfaces.
3. Composition of residues produced by irradiation of ices, and their C:H:O ratio.
4. Outgassing of CN and other radicals from grains.
5. Isotope effects - fractionation during condensation and sublimation.
6. Ice sublimation and the expected ortho/para ratio.
7. Formation of dust structures, including clusters and "bucky- balls."
8. Energy storage mechanisms to drive outbursts and jets.

4.0 STRATEGY FOR FUTURE COMET OBSERVATIONS

4.1 Lessons from Halley

The infrared spectral region is the key to remote study of comet dust composition, as evidenced by the list of spectral features detected in Comet Halley (Table 1-2). Thus, infrared spectroscopy will be extremely important for future comet studies. However, without basic photometry to define the spectral energy distribution, the spectroscopy is often difficult to interpret; thus, coordinated programs covering a broad spectral range are vital.

Participants all agreed that the most serious omission from the Halley campaign is the lack of spectra across the 10-micron silicate feature. Moreover, only one spectrum of the 16-24μm region was obtained – at 1.3 AU pre-perihelion. It is not known whether the lack of identifiable silicate peaks in this spectrum was characteristic of the grains or was simply a result of temporal variability.

The Kuiper Airborne Observatory played a vital role in the Halley observations, providing the first ever cometary spectra at 5-8μm, 16-24μm, and 20-68μm, as well as direct detection of H_2O and upper limits to other parent molecules. It is crucial to cometary studies that NASA keep this facility operational.

The Lear jet observatory telescope can also be a valuable tool for comet observations, as evidenced by its role in the Halley program.

4.2 Science Rationale

As is often the case, new discoveries have created new puzzles about the nature of the material in comets. Scientific questions to be addressed by future observations include:

- How typical is Halley? Are the same spectral features, implying similar composition, seen in all comets, both new and evolved?
- What kinds of silicates are present in comets? Are hydrated silicates present as well as anhydrous forms (olivine, pyroxene)? Why did Halley show distinct peaks in the $10\mu m$ feature, indicative of crystalline grains while other astronomical sources do not? Where is the silicate bending mode vibration near $20\mu m$?
- How common is the $3.36\mu m$ emission in comets? What is the excitation mechanism, and are the carriers molecules or grains? Why is the strongest emission at $3.36\mu m$ in the comet and at $3.29\mu m$ in interstellar sources? Are there any emission features from organic material at longer wavelengths?
- What gaseous species originate from grains in the coma?
- What is the origin of the $12.2\mu m$ emission feature in Comet Wilson? Why was it not evident in Halley?
- Are emission features at $\lambda > 24\mu m$ present in other comets? What is their origin?
- How do the various spectral features vary with heliocentric distance, and what can this tell us about their excitation mechanism?
- Finally, how are cometary grains related to interstellar grains? Can we infer anything about their processing history?

4.3 Recommendations for Future Infrared Observations

The following recommendations for future observing of moderately bright comets were agreed upon:

- The 10 and $20\mu m$ silicate features should be observed with good spectral resolution ($\sim 1\%$) and with good temporal coverage.
- Synoptic 1-$20\mu m$ filter photometry should be carried out with small or moderate-sized telescopes (≥ 75 cm), ideally telescopes dedicated for that purpose. Observations of bright comets at small angular distance from the sun are very desirable.
- The 2.7-$5\mu m$ region should be observed with the maximum possible spectral resolution, not only to study the 3.29 and $3.36\mu m$ features, but also to confirm the presence of several other features tentatively detected in Halley spectra.
- Complete 5-$13\mu m$ spectra and/or both 10 and $20\mu m$ spectra should be obtained during a KAO flight, in order to define the continuum level and to correlate spectral features. Lack of such coverage has complicated the interpretation of Halley data.
- The $2.65\mu m$ transition in the H_2O molecule should be observed in other comets, as a direct means of measuring the H_2O production rate and ortho/para ratio. Other parent molecules can also be searched for via their infrared transitions (e.g., HDO,$H^{18}OH$, CH_4, CO_2, H_2CO, CO); for this purpose, instrument sensitivities should be improved to permit detections at 1% of H_2O.
- The spectral region beyond $20\mu m$ needs further study, to confirm and identify the weak emission features discovered in Halley.
- Coordinated observations in different wavelength regions are needed, to correlate spectral variations and identify common carriers. For this purpose, two telescopes at the same site are very desirable, as is coordination of KAO, LJO, and ground-based measurements.
- Because bright comets appear unpredictably and often without sufficient warning to apply for observing time, let alone plan a coordinated campaign, we recommend that major observing facilities, including the KAO, have a target of opportunity plan,

whereby some observing time can be allocated on relatively short notice, to obtain key observations of new comets. Such a program already functions well on the IUE.

Comet P/Brorsen-Metcalf, with P = 70 years and q = 0.48 AU, has a favorable apparition in 1989, passing 0.4 AU from Earth about six weeks pre-perihelion. In contrast to Halley and Wilson, it will be favorably placed for Northern Hemisphere observers. An ephemeris for planning purposes is given in Table 5-1. Although brightness estimates are uncertain, it will be among the brighter periodic comets.

- We recommend that a coordinated program of ground-based and airborne observations be initiated to study P/Brorsen-Metcalf, during July - September 1989.
- There is also a need to study the class of fainter, short-period comets, to support NASA's CRAF mission.

4.4 Instrumentation

Specialized instrumentation for cometary observations is not required. Several new instruments under development for ground-based and airborne spectrophotometry and/or imaging will benefit cometary studies. Instruments which can operate in more than one spectral region are desirable, for the reasons discussed above.

5.0 RELATION TO NASA PROGRAMS

NASA-supported projects are an essential ingredient of infrared studies, since much of the infrared spectrum is accessible only from high altitude or from space. In the future, we can look forward to infrared spectroscopy with improved spatial and spectral resolution from several NASA projects. However, we stress that excellent science can be conducted with existing NASA facilities.

5.1 Ground-Based Support

- Grants to observers from NASA's Planetary Astronomy Program are needed to carry out the observational program outlined in Section 4.
- The large aperture and excellent sky at NASA's Infrared Telescope Facility (IRTF) on Mauna Kea make possible high-resolution spectroscopy of comets in the 3 and 10μm atmospheric windows and also allow faint comets to be detected and bright comets to be followed over a wide range in heliocentric distance. Several of the 3μm spectra of Halley and Wilson and one 10μm spectrum were obtained at the IRTF with facility instruments.

5.2 Airborne Facilities

- The Kuiper Airborne Observatory will continue to be an important facility for comet observations. Many of the emission features detected for the first time in Halley spectra need to be confirmed in other comets and observed over a range in heliocentric distance to help identify their origin and excitation mechanism. Detection of emission bands from organic materials at 5 - 8μm would greatly aid identification of the 3.36μm carrier. Other parent molecules may be detected via infrared transitions. It is crucial that NASA keep the KAO flying, with a full schedule, and that comet observations be considered a bona fide part of the science program.
- The Lear Jet Observatory, equipped with a 30-cm telescope, complements the 91-cm KAO; both fly at similar altitude. The LJO, with its shorter flight times and more flexible schedule, is particularly suited for monitoring variability in the comet spectrum; a large dust outburst in Halley in April 1986 was successfully observed in this way. The telescope can point to elevations 0-30 degrees above the horizon; thus, comets can be followed near the sun. Simultaneous LJO and KAO flights can achieve desirable correlated observations in different spectral regions.

Table 5-1

EPHEMERIS (WITH PERTURBATIONS) FOR P/BRORSEN-METCALF - ORBIT BY D.K. YEOMANS

YR	MN	DY	HR	J.D.	R.A. 1950.0		DEC.		DELTA	DELDOT	R	ROOT	TMAG	NMAG	THETA	BETA	MOON	PSANG	PSAMV
1989	4	4	.0	2447620.5	21	37.371	-15	41.64	3.4876	-41.2045	2.9609	-21.1910	.0	22.5	52.2	15.4	21.9	250.0	238.0
1989	4	9	.0	2447625.5	21	43.371	-15	2.99	3.3672	-42.0976	2.9194	-21.3911	.0	22.3	55.5	16.4	95.6	249.9	237.9
1989	4	14	.0	2447630.5	21	49.379	-14	22.97	3.2445	-42.8739	2.8573	-21.5979	.0	22.1	58.9	17.5	160.7	249.7	237.9
1989	4	19	.0	2447635.5	21	55.396	-13	41.49	3.1197	-43.5445	2.7946	-21.8115	.0	21.9	62.1	18.5	141.0	249.6	237.7
1989	4	24	.0	2447640.5	22	1.427	-12	58.42	2.9931	-44.1192	2.7313	-22.0324	.0	21.7	65.4	19.6	82.6	249.4	237.7
1989	4	29	.0	2447645.5	22	7.474	-12	13.62	2.8650	-44.6025	2.6674	-22.2611	.0	21.5	68.6	20.6	19.6	249.2	237.6
1989	5	4	.0	2447650.5	22	13.541	-11	26.94	2.7356	-44.9870	2.6027	-22.4979	.0	21.3	71.8	21.6	50.9	249.0	237.5
1989	5	9	.0	2447655.5	22	19.629	-10	38.21	2.6053	-45.2541	2.5374	-22.7433	.0	21.1	74.9	22.6	122.0	248.8	237.4
1989	5	14	.0	2447660.5	22	25.745	- 9	47.17	2.4743	-45.4045	2.4713	-22.9979	.0	20.9	78.0	23.6	176.4	248.6	237.3
1989	5	19	.0	2447665.5	22	31.901	- 8	53.52	2.3431	-45.4515	2.4045	-23.2620	.0	20.7	81.1	24.6	118.7	248.4	237.2
1989	5	24	.0	2447670.5	22	38.114	- 7	56.85	2.2119	-45.4040	2.3370	-23.5364	.0	20.4	84.2	25.5	58.0	248.2	237.1
1989	5	29	.0	2447675.5	22	44.401	- 6	56.70	2.0809	-45.2533	2.2686	-23.8215	16.9	20.1	87.1	26.5	8.0	247.9	237.0
1989	6	3	.0	2447680.5	22	50.782	- 5	52.49	1.9506	-45.0152	2.1994	-24.1180	16.6	19.9	90.1	27.5	78.6	247.7	236.9
1989	6	8	.0	2447685.5	22	57.283	- 4	43.50	1.8211	-44.6451	2.1293	-24.4264	16.2	19.6	92.9	28.4	145.5	247.4	236.8
1989	6	13	.0	2447690.5	23	3.966	- 3	28.77	1.6928	-44.1596	2.0582	-24.7474	15.8	19.3	95.7	29.4	155.7	247.0	236.8
1989	6	18	.0	2447695.5	23	10.828	- 2	7.03	1.5661	-43.5667	1.9863	-25.0814	15.4	19.0	98.3	30.4	97.2	246.7	236.7
1989	6	23	.0	2447700.5	23	18.005	- 0	36.66	1.4413	-42.8679	1.9134	-25.4291	15.0	18.6	100.8	31.4	33.3	246.2	236.6
1989	6	28	.0	2447705.5	23	25.577	+ 1	4.47	1.3186	-42.0491	1.8394	-25.7908	14.6	18.2	103.2	32.6	34.6	245.7	236.6
1989	7	3	.0	2447710.5	23	33.650	+ 2	59.14	1.1966	-41.0770	1.7644	-26.1065	14.1	17.9	105.3	33.8	102.3	245.1	236.6
1989	7	8	.0	2447715.5	23	42.515	+ 5	11.17	1.0816	-39.9201	1.6892	-26.5561	13.6	17.4	107.1	35.1	163.4	244.5	236.6
1989	7	13	.0	2447720.5	23	52.364	+ 7	45.36	.9662	-38.5448	1.6110	-26.9583	13.0	17.0	108.5	36.8	139.7	243.7	236.7
1989	7	18	.0	2447725.5	0	3.751	+10	50.53	.8592	-36.8569	1.5325	-27.3730	12.5	16.5	109.3	38.7	80.4	242.8	236.9
1989	7	23	.0	2447730.5	0	17.343	+14	35.24	.7555	-34.8278	1.4528	-27.7956	11.8	16.0	109.3	41.3	16.9	242.0	237.4
1989	7	28	.0	2447735.5	0	34.346	+19	13.42	.6557	-32.1491	1.3720	-28.2213	11.2	15.5	108.2	44.7	50.7	241.3	238.4
1989	8	2	.0	2447740.5	0	55.311	+25	1.12	.5708	-28.4933	1.2898	-28.6414	10.4	14.9	105.4	49.3	108.8	241.2	240.4
1989	8	7	.0	2447745.5	1	23.450	+32	11.18	.4955	-23.3444	1.2065	-29.0415	9.7	14.3	100.4	55.8	155.0	242.6	244.2
1989	8	12	.0	2447750.5	2	16.051	+40	30.99	.4380	-16.1063	1.1221	-29.3979	9.0	13.7	92.6	64.4	145.9	247.4	251.9
1989	8	17	.0	2447755.5	3	29.741	+48	30.59	.4047	-6.5930	1.0368	-29.6717	8.3	13.2	82.0	75.2	99.7	258.3	266.7
1989	8	22	.0	2447760.5	5	12.202	+52	49.58	.4012	4.1805	.9509	-29.7980	7.7	12.8	69.8	86.8	50.7	276.7	290.3
1989	8	27	.0	2447765.5	6	55.930	+51	11.57	.4282	14.2603	.8650	-29.6674	7.2	12.5	58.2	96.9	25.0	295.7	317.0
1989	9	1	.0	2447770.5	8	11.766	+45	40.86	.4616	22.3976	.7800	-29.0947	6.8	12.3	45.7	103.7	56.8	308.1	339.3
1989	9	6	.0	2447775.5	9	1.273	+39	12.63	.5557	28.6697	.6977	-27.7661	6.4	12.2	41.6	106.5	101.0	313.8	355.3
1989	9	11	.0	2447780.5	9	34.931	+33	1.32	.6460	33.6864	.6209	-25.1716	5.9	12.0	36.5	105.2	149.9	315.1	4.7
1989	9	16	.0	2447785.5	10	.092	+27	18.38	.7494	37.8364	.5542	-20.5788	5.5	11.8	32.9	99.8	139.4	313.7	6.8
1989	9	21	.0	2447790.5	10	21.213	+21	55.69	.8635	40.9424	.5047	-13.2715	5.2	11.7	30.2	90.5	75.0	310.9	2.3
1989	9	26	.0	2447795.5	10	40.749	+16	44.98	.9842	42.3489	.4801	-3.3721	5.2	11.6	27.9	78.2	17.9	307.1	354.0
1989	10	1	.0	2447800.5	10	59.617	+11	45.30	1.1059	41.6522	.4860	7.3296	5.5	12.1	26.1	64.8	38.6	302.8	345.7
1989	10	6	.0	2447805.5	11	18.526	+ 7	2.30	1.2232	39.4069	.5208	16.3678	6.2	12.6	24.6	52.9	91.3	298.3	339.4
1989	10	11	.0	2447810.5	11	36.555	+ 2	42.12	1.3330	36.6269	.5777	22.5963	7.1	13.2	23.6	43.7	150.2	293.7	335.1
1989	10	16	.0	2447815.5	11	53.631	- 1	12.77	1.4348	33.9504	.6489	26.3402	8.0	13.9	23.1	37.1	140.5	289.3	332.3
1989	10	21	.0	2447820.5	12	9.600	- 4	43.13	1.5293	31.5451	.7282	28.3828	8.9	14.5	23.2	32.5	74.0	285.5	330.3
1989	10	26	.0	2447825.5	12	24.661	- 7	51.34	1.6172	29.3808	.8118	29.3769	9.7	15.1	23.7	29.5	16.5	282.4	328.8
1989	10	31	.0	2447830.5	12	38.699	-10	40.16	1.6991	27.3898	.8973	29.7565	10.4	15.7	24.6	27.4	38.5	280.0	327.7
1989	11	5	.0	2447835.5	12	51.858	-13	12.22	1.7755	25.5132	.9833	29.7735	11.1	16.2	25.8	26.1	95.6	278.2	326.9
1989	11	10	.0	2447840.5	13	4.217	-15	29.90	1.8465	23.7095	1.0690	29.5818	11.8	16.6	27.4	25.2	160.0	277.0	326.2
1989	11	15	.0	2447845.5	13	15.847	-17	35.22	1.9124	21.9431	1.1540	29.2710	12.3	17.0	29.2	24.7	127.6	276.2	325.6
1989	11	20	.0	2447850.5	13	26.810	-19	29.95	1.9733	20.1800	1.2380	28.8947	12.9	17.4	31.1	24.4	62.8	275.7	325.1
1989	11	25	.0	2447855.5	13	37.152	-21	15.52	2.0290	18.4145	1.3209	28.4849	13.3	17.7	33.3	24.3	7.9	275.5	324.7
1989	11	30	.0	2447860.5	13	46.905	-22	53.14	2.0796	16.6548	1.4025	28.0615	13.8	18.1	35.7	24.2	52.0	275.4	324.4
1989	12	5	.0	2447865.5	13	56.089	-24	23.84	2.1252	14.9134	1.4829	27.6362	14.2	18.3	38.3	24.3	113.1	275.6	324.1

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- SOFIA, a proposed 3-meter airborne telescope, would greatly aid the identification of fainter emission features in comet spectra, particularly those at $\lambda > 24\mu m$ and potentially other signatures of organic materials in the 5 - 8 μm region. It would bring into view a larger number of comets, over a wider range of heliocentric distance, including the important class of new comets, such as Bowell and Cernis, with perihelion at ~ 3 AU. Spatially resolved spectral observations would also be possible.

5.3 Telescopes in Earth Orbit

- The Infrared Astronomy Satellite (IRAS) observed at least 17 known comets in four bandpasses extending to $120\mu m$ during its 1983 sky survey. Many more comets are doubtless included in the asteroid catalogue. The high sensitivity, large field of view, and wide-wavelength coverage of the IRAS instrument affords an infrared view of comets, both spatially and spectrally, that will not be repeated within the next decade. Of particular interest are the dispersal of dust grains in the tail, the existence of dust comae at large heliocentric distance, and the formation of debris trails, such as that of Tempel 2. We recommend that NASA continue to support analysis of the IRAS comet data.
- The Space Infrared Telescope Facility (SIRTF) is a new space observatory in the planning stages. The present design goals are:

  Facility lifetime: five years, with ten-year goal.

  Spectral range: 1.8 to $700\mu m$

  Aperture: 85 cm

  Field of view 7 arcmin

  Sensitivity: natural background-limited, 2 to $200\mu m$

  Image quality: diffraction-limited for $\lambda > 5\mu m$

Three instruments have been selected for SIRTF, to provide photometric, imaging, and spectroscopic capability with the utmost sensitivity for infrared wavelengths. They are:

Infrared Array Camera -	PI: G. Fazio, SAO
Multiband Imaging Photometer -	PI: G. Rieke, Arizona
Infrared Spectrograph -	PI: J. Houck, Cornell

These instruments will have the following capabilities:

Photometry with diffraction-limited beams from 2 to $700\mu m$ (beamsize 3 arcsec at $10\mu m$).

Low-resolution dispersive spectroscopy from 2.5 to $120\mu m$ (resolving power ~ 100).

Moderate resolution dispersive spectroscopy from 4 to $120\mu m$ (resolving power ~ 2000).

Wide-field and diffraction-limited imaging, mapping, and surveying at 2.5 to $200\mu m$, using arrays with at least 128 x 128 pixels.

Polarimetric capability for use in conjunction with both the imaging and photometric instrumentation.

SIRTF will provide unprecedented spectral coverage and sensitivity for the study of comets. Complete spectra can be obtained from 2.5 to $200\mu m$ at resolutions of 100 to 2000. With the continuum from $13\text{-}16\mu m$ defined, the silicate features in the $16\text{-}24\mu m$ region can be identified. Weak features at longer wavelengths can also be confidently detected. In addition, SIRTF will allow study of the shape of the $10\mu m$ silicate band without interference from the 9.7μm ozone absorption, which now causes uncertainty in the definition of the peak near 9.8μm. The coma can be spatially mapped in individual spectral features. The inactive nuclei of many short-period comets should be detectable in the thermal infrared.

- The Infrared Space Observatory (ISO) is a fully approved and fully- funded mission of ESA, which is scheduled for launch in 1992 - 1993. The expected lifetime is 18 months. ISO consists of a 60-cm telescope, cooled with a helium cryogenic system, and four focal plane instruments presently being built by European consortia. These instruments are summarized in Table 5-2. ISO is designed to be an observatory for the whole astronomical community. Two-thirds of the observing time will be made available to this community via submission and selection of proposals.
- We strongly recommend that NASA support guest investigators for comet studies on ISO.
- The Planetary telescope now under study in collaboration with FRG could greatly aid comet research. We strongly recommend that infrared instruments be considered for the payload.

6.0 THE COMET RENDEZVOUS/ASTEROID FLYBY MISSION

While there is much to be learned from remote sensing and laboratory studies, there are some questions that can only be answered with direct sampling. The Comet Rendezvous/Asteroid Flyby mission (CRAF) has the exciting prospect of sampling the composition of the solid grains with a variety of analysis techniques throughout the perihelion passage of the target comet.

Key element ratios can be measured, for comparison with meteorites, IDPs and the interstellar medium. Isotope anomalies that are tracers of interstellar grains can be detected, such as the D/H and $^{13}C/^{12}C$ ratios. The mineralogy of silicates can be studied and the composition of the organic material can be investigated.

Three dust analysis experiments have been selected for the payload:

The Cometary Matter Analyzer (COMA) will use secondary ion mass spectroscopy to measure the elemental and isotopic composition of the dust. The measurement technique is similar to that of the PIA/PUMA instrument on the Halley probes. (PI: J. Kissel FRG).

The Scanning Electron Microscope and Particle Analyzer (SEMPA) is a miniature scanning electron microscope with an energy-dispersive x-ray spectrometer. SEMPA will measure the elemental composition, dimensions, and surface morphology of individual micron-sized grains, from which the mineralogy and crystal form can be deduced. (PI: A. Albee).

The Cometary Ice and Dust Experiment (CIDEX) uses the techniques of x-ray fluorescence spectrometry and gas chromatography. The XRF can determine the bulk elemental composition of the dust (15 to 25 elements). The GC can study light gases, organics, and polar molecules; the volatiles can be released and analyzed stepwise at a series of temperatures from -90 to +1000 deg C. (PI: G. Carle).

In addition, the spacecraft will carry a complement of remote sensing instruments, gas mass spectrometers to measure the gas composition, and particles and fields instrumentation. Of particular relevance to this Workshop, a visual and near-infrared mapping spectrometer (VIMS) will survey the wavelength range from 0.35 to 5.2μm, with a spectral resolution of 0.011- 0.022μm, while a thermal infrared radiometer (TIREX) will measure the emission from the coma and the nucleus through various filters at $\lambda \geq 5\mu$m.

- **We strongly recommend that NASA fully support this important mission with a timely New Start and adequate funding.**

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Table 5-2
Instrument Payload for ISO

	Main Function	Wavelength (Microns)	Spectral Resolution	Spatial Resolution	Description
ISOCAM	Camera and Polarimetry	3 - 17	Broad-band, Narrow-band, and Circular Variable Filters	Pixel f.o.v.'s of 3,6 or 12 arc/seconds	Two channels each with a 32x32 element array.
ISOPHOT	Imaging Photo-polarimeter	3 - 200	Broad-band and Narrow-band Filters. Near IR Grating Spectrometer with R=100	Variable (Diffraction - limited and wide beam)	Four sub-systems: .Multi-band, Multi-aperture Photo-polarimeter .Far-Infrared Camera .Spectrophotometer .Mapping Arrays
SWS	Short-wavelength Spectrometer	3 - 45	1000 across wavelength range and $3x10^4$ from 15-30 microns	14 and 20 arc sec.	Gratings, and Fabry-Pérot Interferometers
LWS	Long-wavelength Spectrometer	45 - 180	200 and 10^4 across wave-length range	1.65 arc minutes	Grating and Fabry-Pérot Interferometers