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# COMETS: GASES, ICES, GRAINS AND PLASMA

## IAU COLLOQUIUM NO. 61

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COMETS: GASES, ICES, GRAINS AND PLASMA

IAU Colloquium No. 61

FINAL PROGRAM

All Scientific Sessions are in the Williamsburg Room

| | March 10 Tuesday | March 11 Wednesday | March 12 Thursday | March 13 Friday | March 14 Saturday |
|---|---|---|---|---|---|
| MORNING | | 0845 Introduction<br>0900 Nucleus | 0830 Dust | 0830 Coma | 0830 Ion Tails<br>0915 Origins and Connections |
| AFTERNOON | | 1400 Nucleus | 1400 Dust and Radio Obs. | 1330 Coma<br>1530 Ion Tails | 1200 Field Trip to KITT PEAK |
| EVENING | 1930 Halley Watch Meeting (Newburn) Mt. Vernon Room | 1930 Working Group on Standardized Filters (A'Hearn) Mt. Vernon Room<br>1930 Keller Mtg. (Keller) Williamsburg Room | 1800 No host bar<br>1900 Western Barbeque (Pool Side)<br>2000 B. Marsden* Williamsburg Room<br>2045 D. Yeomans*<br>2130 G. Briggs* | 1930 Keg Session<br>2000 Comet Mission Poster Talks Hermitage Room | |

*B. Marsden - Serendipity in Cometography

*D. Yeomans - Comet Halley and Some Dubious Achievement Awards

*G. Briggs - NASA Funding Status Report

COMETS: GASES, ICES, GRAINS AND PLASMA

FINAL PROGRAM - SCIENTIFIC SESSIONS

R=Review (15 min.), C=Contributed (10 min.)
P=Poster Talk (10 min.), E=Exhibit, T=Title Only

A maximum 5 minutes discussion is allotted for each R, C, and P paper. Discussion of related papers may be combined at the session chair's discretion.

## WEDNESDAY

0845 WELCOME and INTRODUCTION — A.R. Kassander, Jr. Vice-President for Research, University of Arizona; L.L. Wilkening, Chair, Organizing Committee

### NUCLEUS Chair: W. Irvine

| | | | |
|---|---|---|---|
| 0900 | Delsemme, A., Donn, B. and Rahe, J. | (N.1R) | Structure and Origin of Cometary Nuclei |
| | Sekanina, Z. | (N.2R) | The Problem of Split Comets in Review |
| | Whipple, F. L. | (N.3R) | Rotation of Comet Nuclei |
| 1010 | BREAK - Gehrels, T. et al. | (N.26P) | Spacewatch Camera |
| 1030 | Hellmich, R. and Keller, H.U. | (N.4C) | On the Visibility of Cometary Nuclei |
| | Tedesco, E.F. and Barker, E.S. | (N.5C) | Photometric Function of the Periodic Comet Tempel-2 During Its 1978-79 Apparition |
| | Stauffer, J.R. and Spinrad, H. | (N.6C) | Behavior of the Red Nuclear Continuum of P/Comets with Heliocentric Distance |
| | Degewij, J. and Chapman, C.R. | (N.7C) | Spectrophotometric imagery of P/Schwassmann-Wachmann 2 |
| | Degewij, J., Hartmann, W.K. and Cruikshank, D.P. | (N.8C) | P/Schwassman-Wachmann 1 and Chiron: Near IR Photometry |
| | Hartmann, W.K., Cruikshank, D.P. and Degewij, J. | (N.9C) | Surface Materials on Remote Comets: Theoretical and Observational Indications |
| | A'Hearn, M.F., Dwek, E. and Tokunaga, A.T. | (N.LT) | Where is the Ice in Comets? |
| | Jamar, C. and Malaise, D. | (N.10C) | Study of the Nuclear Region of Comets by the Observations of Eclipsed Stars |
| | Hobbs, R.W., Brandt, J.C., Maran, S.P. and Hollis, J.M. | (N.11C) | Millimeter-Wave Radiometry of Cometary Nuclei |
| 1230 | LUNCH | | |

### NUCLEUS Chair: D. Cruikshank

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| 1400 | Kamoun, P., Pettengill, G.H. and Shapiro, I.I. | (N.12C) | Radar Detectability of Comets |
| | Weissman, P.R. and Kieffer, H.H. | (N.13C) | Thermal Modeling of Cometary Nuclei |

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| | Smoluchowski, R. | (N.14C) | Heat Content and Evolution of Cometary Nuclei |
| | Klinger, J. | (N.15C) | Some Consequences of a Phase Transition of Water Ice on the Heat balance of Comet Nuclei |
| | Fink, U. and Sill, G. | (N.16R) | Infrared Spectra of Condensed Volatiles |
| | Hapke, B., Wagner, J., Wells, E. and Partlow, W. | (N.17E) | Vacuum UV Reflectance of $NH_3$, $H_2O$, $CO_2$, and $SO_2$ Ices |
| | Moore, M. and Donn, B. | (N.18C) | Proton Irradiation of Cometary Type Mixtures: Cosmic Ray Effects on Comets in the Oort Cloud |
| | Foti, G., Pirronello, V. and Strazzulla | (N.LT) | Experimental Rates of Frozen Gas Erosion by KeV-MeV Light Ions |
| | Johnson, R.E. and Lanzerotti, L.J. | (N.19E) | Charge Particle Erosion of Frozen Volatiles in Comets |
| 1535 | BREAK - ReVelle, D.O. | (N.22P) | Identification of Meteoritic Fireballs Using the Theoretical Light Curve Technique |
| 1555 | Wetherill, G.W. and ReVelle, D.O. | (N.20R) | Relationships Between Comets, Large Meteors, and Meteorites |
| | Drummond, J. | (N.21C) | Earth Orbit Approaching Comets and Their Theoretical Radiants Using the Theoretical Light Curve Technique |
| | Williams, I. and Hughes, D.W. | (N.LT) | The Connection Between Meteor Streams and Comets |
| | Tedesco, E.F. and Gradie, J.C. | (N.23C) | Compositions of Outer-Belt Asteroids: Implications for Comets |
| | Wilkening, L.L. | (N.24C) | Composition of the Material Which Initially Accreted in Comets |
| | Ponnamperuma, C. | (O.12R) | Comet Implications for the Origin of Life |

## THURSDAY

### DUST Chair: J. Burns

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|---|---|---|---|
| 0830 | Fechtig, H. | (D.1R) | Cometary Dust in Space |
| | Fraundorf, P., Brownlee, D.E. and Walker, R. | (D.2R) | Laboratory Studies of Interplanetary Dust |
| | Wagstaff, J. and King, E.A. | (D.3C) | Search for Possible Cometary Dust in Antarctic Ice Cores |
| | Grün, E., Fechtig, H., Kissel, J. and Pailer, N. | (D.4C) | Interrelation of Interplanetary and Cometary Dust as Observed by the Helios Micrometeroid Experiment |
| | Fraundorf, P., Freeman, J.J. and Patel, R. | (D.5C) | Infrared Spectroscopy of Interplanetary Dust in the Laboratory |
| | Ney, E. P. | (D.6R) | The Optical and Infrared (.5 to 20μ) Broad Band Observations of Bright Comets |
| 1015 | BREAK - Van Flandern | (C.25P) | Do Comets Have Satellites? |

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| 1035 | Campins, H., Lebofsky, M. and Rieke, G. | (D.7C) | The Thermal Properties of Dust in Periodic Comets |
| | Hanner, M. S. | (D.8C) | Interpreting the Infrared and Optical Emission from Comet Dust |
| | Michalsky, J.J. Jr. | (D.9C) | Optical Polarimetry of Comet West 1976 VI |
| | Isobe, S. | (D.10C) | Interpretation of the Polarization Distribution of Comet West |
| | Saito, K., Isobe, S. Kimihiko, N. and Tatsuro, I. | (D.11C) | Substances of Cometary Grains Estimated from Evaporation and Radiation Pressure Mechanisms |
| | Hughes, D.W. | (D.12R) | Cometary Dust Models |
| | Wallis, M. K. | (D.13R) | Dusty Gas Dynamics in Real Comets |
| 1230 | LUNCH | | |

DUST and RADIO OBSERVATIONS Chair: R. Newburn

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|---|---|---|---|
| 1400 | Schwehm, G.H. and Kneissel, B. | (D.14C) | Dust Production Rates of Comet Halley: Models for the ESA Giotto Comet Halley Probe |
| | Consolmagno, G. | (D.15C) | Diffusion of Cometary Dust by Electromagnetic Scattering |
| | Mendis, D.A. | (D.16C) | On the Electrostatic Charging of the Distant Cometary Nucleus |
| | Sekanina, Z. | (D.17C) | Mapping of Active Areas on the Nucleus of the Perseid Comet from Observations of Dust Phenomena |
| | Gustafson, B. A. S. and Misconi, N. Y. | (D.18C) | The Observed Position of the Symmetry Plane of Interplanetary Dust and Its Possible Relation to Dust from Comet Encke |
| | Yeomans, D.K. | (D.19C) | Comet Tempel-Tuttle and the Leonid Meteors |
| 1530 | BREAK - Irvine, W., Schloerb, P. and Yngvesson, S. | (M.11P) | Direct Detection of the $H_2O$ molecule in the Coma by Using Submillimeter Waves from Spacelab. |
| 1550 | Singer, S.F. | (D.20C) | Lifetime and Origin of Submicron Particles |
| | Stanley, J.E. | (D.21C) | Submicron Particles in the Solar System |
| | Farrell, J.A. and Sekanina, Z. | (D.22C) | Motion of Structures in the Dust Tail of Comet West 1976 VI |
| | Kiselev, N.N. Chernova, G.P. | (D.23C) | Phase Function of Polarization and Brightness and the Nature of Cometary Atmospheres |
| | Gibson, D.M. and Hobbs, R.W. | (D.24C) | Microwave Continuum Observations of the Icy Grain Halo |
| | Snyder, L. E. | (C.1T) | Outstanding Problems in Radio Observations of Comets |
| | Bockelée-Morvan, D., Crovisier, J., Gerard, E. and Kaže, I. | (C.2C) | Observations of the OH Radical in Comets at 18 cm Wavelength |
| | Ekelund, L., Andersson, C., | (C.3C) | Searches for Millimeter-Wave Emission from HCN, CS, and $CH_3OH$ in Comet |

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| | Irvine, W.M., Schloerb, F.P. and Robinson, S.E. | | Bradfield (1979ℓ) |

## FRIDAY

### COMA Chair: J.C. Brandt

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| 0830 | Meisel, D.D. and Mees, C.E.K. | (C.4R) | Comet Photometry: Past, Present, and Future |
| | Neff, J.S. | (C.5C) | Filter Photometry of Comets |
| | Millis, R.L., Thompson, D.T. and A'Hearn, M.F. | (C.6C) | Narrowband Photometry of Comet P/ Stephan-Oterma |
| | A'Hearn, M.F. | (C.7E) | Standardized Filters for Cometary Photometry |
| | A'Hearn, M.F. | (C.8R) | Spectroscopy and Spectrophotometry of Comets at Visible Wavelengths |
| | Cochran, W.D., Cochran, A.L. and Barker, E.S. | (C.9C) | Spectrometric Observations of Comet Bradfield (1980t) |
| | Barker, E.S. | (C.10C) | Spatially Resolved Observations of the Inner Coma of Bradfield (1979ℓ) |
| 1010 | BREAK - Malaise, D. and Cucchiaro, A. | (C.15P) | Detection of the Proper Glow of Comet Bennett |
| 1030 | Larson, S. | (C.11C) | Recent Spectroscopic Observations of Comets |
| | Cochran, A.L. and Barker, E.S. | (C.12C) | Spectrometric Observations of Comets Stephan-Oterma and Encke During Their 1980 Apparitions |
| | Johnson, J.R., Turek, P., Fink, U., Larson, S., Smith, B.A. and Reitsema, H.J. | (C.13C) | Recent Results of CCD Comet Spectroscopy |
| | Newburn, R., Jr., Spinrad, H. and Stauffer, J. | (C.14C) | Spectrophotometric Evidence on the Origin of Cometary $C_2$ and CN |
| | Feldman, P. D. | (C.16R) | Ultraviolet Spectroscopy of Comae |
| | Festou, M.C., Feldman, P.D. and Weaver, H.A. | (C.17C) | Ultraviolet Bands of $CO_2^+$ in Comet Bradfield (1979ℓ) |
| | Weaver, H.A., Feldman, P.D., Festou, M.C., A'Hearn, M.F., and Keller, H.U. | (C.18C) | Observations of Faint Comets with IUE |
| 1225 | LUNCH | | |

### COMA Chair: P. Feldman

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|---|---|---|---|
| 1330 | Huebner, W.F., Giguere, P.T. and Slattery, W.L. | (C.19R) | Photochemical Processes in the Inner Coma |
| | Jackson, W.M. | (C.21R) | Laboratory Studies of Photochemistry and Spectroscopy Applied to Comets |
| | Huntress, W.T., Jr. | (C.22T) | Laboratory Studies of Ion Chemistry in Cometary Atmospheres |

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| | Spinrad, H. and Stauffer, J.R. | (C.23C) | Production Rates of [OI] in Recent Comets |
| | Cucciaro, A. and Malaise, D. | (C.24C) | Dynamical Coma Models for Comet Bennett |
| | Swift, M.B. and Mitchell, G.F. | (C.25C) | Models of the Cometary Coma in Which Abundances of Observed Species are Calculated for Various Heliocentric Distances |
| | Prasad, S.S., Huntress, W.T., Neugebauer, M.M., and Mitchell, G.F. | (C.26C) | Chemical Composition in Cometary Comae |
| 1510 | BREAK Schleicher, D. and A'Hearn, M.F. | (C.20P) | OH Fluorescence in Comets |

ION TAILS Chair: P. Feldman

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| 1530 | Brandt, J.C. | (I.1R) | Observations and Dynamics of Ion Tails |
| | Ip, W-H., Axford, W.I., and McKenzie, J.F. | (I.2R) | Theories of Physical Processes in Cometary Ion Tails |
| | Schmidt, H.U. and Wegman, R. | (I.3R) | Plasma Flow and Magnetic Fields in Comets |
| | Mendis, D.A. and Houpis, H.L.F. | (I.4C) | The Cometary Ionosphere |
| | Beard, D. | (I.5C) | Cometary Molecular Densities and the Production of Type I Tail Rays |
| | Krishan, V. and Sivaraman, K.R. | (I.6C) | Peculiarities in the Ionic Tail of Comet Ikeya-Seki (1965f) |
| | Jockers, K. K. | (I.7C) | Plasma Dynamics in Comet Kohoutek 1973 XII |
| | Miller, F.D. | (I.8T) | Configurations of Evolving Plasma Tail Rays |
| | Ershkovich, A. I. | (I.9C) | On the Folding Phenomenon of Comet Tail Rays |
| | Niedner, M. B., Jr. | (I.10C) | Connections Between the Solar Wind and the Large-Scale Properties of Cometary Plasma Tails - The Role of Magnetic Reconnection |

FRIDAY NIGHT

COMET MISSIONS

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|---|---|---|---|
| 2000 | Arduini, M. et al. | (M.1P) | IR Space Experiment on Soviet Spaceprobe to Comet Halley |
| | Delsemme, A.H. and Degewij, J. | (M.2P) | Physical Observations of Comets with the Infrared Astronomical Satellite |
| | Bender, D.F. | (M.3P) | Observation/Mission Planning Aids for Periodic Comets |
| | Zerull, R.H., Giese, R.H., and Kneissel, B. | (M.4P) | A Light Scattering Experiment for the Measurement of Cometary Dust |
| | Levassuer-Regourd, A. | (M.5P) | In-Situ Optical Observations on |

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| | C., et. al. | | board Giotto Probe |
| | McDonnell, J.A.M., Evans, G. and Grun, E. | (M.7P) | In-situ Evaluation of a Cometary Dust Efflux: DIDSY on board ESA's Comet Halley Giotto Mission |
| | Neugebauer, M., Goldstein, B.E. Goldstein, R. and Clay, D.R. | (M.8P) | An Ion Mass/Velocity Spectrometer for a Comet Mission |
| | Curtis, C.C., Fan, C. Y. and Hsieh, K. | (M.9P) | Some problems and Some Solutions to in situ Investigation of Neutral Atmosphere on a Fast Fly-by Mission |
| | Dobrovolsky, O.V. and Ibadov, S. | (M.10P) | Artificial Meteors in the Atmospheres of Comets and other Celestial Bodies as Research Tools |
| | Smith, P.L., Black, J.H. and Oppenheimer, M. | (M.12P) | Ultraviolet Absorption Studies of Atoms and Molecules in Comet Halley with Space Telescope |

## SATURDAY

### ION TAILS (con't) Chair: M.J.S. Belton

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| 0830 | Goldstein, B. E. | (I.11C) | Constraints on Magnetic Merging and Particle Acceleration in Cometary Tails |
| | Buti, B. | (I.12C) | Role of High-Frequency-Turbulence in Cometary Plasma Tails |
| | Russell, C.T., Luhmann, J.G. and Elphic, R.C. | (I.13C) | Solar Wind Interaction with Comets: Lessons from Venus |

### ORIGIN, EVOLUTION AND INTERRELATIONS Chair: M.J.S. Belton

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| 0915 | Bhandari, N., Lal, D. and Rao, H.N. | (O.11C) | Planetary Atmospheres: Cometary contribution |
| | Greenberg, J. | (O.1R) | Evolution of Comets from Interstellar Matter to Interplanetary Matter |
| | Irvine, W. M. | (O.2C) | The Increasing Chemical Complexity of Cold, Dark Interstellar Clouds |
| 1005 | BREAK | | |
| 1020 | Weissman, P. R. | (O.3R) | Dynamical History of the Oort Cloud |
| | Scholl, H., Cazenave A. and Brahic, A. | (O.4C) | The Effect of Star Passages on Cometary Orbits in Oort's Cloud |
| | Everhart, E. | (O.5R) | Evolution of Long and Short Period Orbits |
| | Fernandez, J. and Ip, W.-H. | (O.6C) | Dynamical Evolution of a Cometary Swarm in the Outer Planetary Region |
| | Froeschle, C. and Rickman, H. | (O.7C) | A New Method to Estimate Perturbations of Jupiter on Cometary Orbits |
| | Carusi, A., Valsecchi, G.B. and Kresak, L. | (O.8E) | Orbital Patterns at Close Planetary Encounters |
| | Degewij, J. and Tedesco, E. | (O.9R) | Do Comets Evolve into Asteroids or Satellites? The Physical Evidence |
| | Levin, B.J. and Simonenko, A.N. | (O.10T) | On the Implausibility of Cometary Origin of Most Apollo-Amor Asteroids |

N.1R

## THE STRUCTURE AND ORIGIN OF COMETARY NUCLEI

A.H. Delsemme, B. Donn
and J. Rahe

The primary concern of this review is the structure of the nucleus. The relation between origin, structure and composition is also treated. In order to develop a consistent model, basic observational properties are summarized. These are mass, radius, albedo, composition, and behavior both throughout the orbit and with "age". More detailed discussions of most of these subjects are presented by other authors. Proposed models for the nucleus are described and examined. Some variation of Whipple's icy-conglomerate nucleus appears to be the most suitable working hypothesis. We do not attempt to derive a definitive model as current knowledge about comets is not sufficient. Our aim is to present an interim model which will serve as a sound basis for further research.

The origin of the adopted model by accumulation in a primordial solar nebula or interstellar cloud is discussed. The further evolution of cometary nuclei through their residence in the Oort Cloud to their appearance as short period comets and their ultimate demise is also considered.

N.2R

## THE PROBLEM OF SPLIT COMETS IN REVIEW

Z. Sekanina

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California Institute of Technology
Pasadena, California 91109

Recent progress in the investigation of cometary splitting is reviewed from the dynamical and physical standpoints. The clue to the understanding of relative motions of fragments of a comet is the fact that their rate of separation is determined by the momentum from outgassing, the net differential force thence being of the same nature as the nongravitational perturbations detected in the motions of most short-period comets and some nearly-parabolic ones. The differential repulsive acceleration $\gamma$ (assuming that the radial component is dominant) and the time of splitting are the only parameters of this simple model, which successfully represents the positional observations of nearly all of the 21 known split comets. The time difference between splitting and final observation, weighted by heliocentric distance, is termed the endurance. It provides a lower limit to each fragment's normalized lifetime and measures its relative mass loss. The endurance is found to be highly correlated with $\gamma$ and either quantity can serve to classify secondary nuclei of split comets into three categories: persistent companions, short-lived companions, and minor fragments. A test of splitting, based on this model, has been devised to establish whether or not an allegedly multiple comet has in fact split. It turns out that virtually all reports of unconfirmed observations of comet multiplicity are erroneous. - The acceleration $\gamma$ varies between $10^{-5}$ and several times $10^{-3}$ the solar attraction, the endurance between a few and several hundred equivalent days. The points of splitting have a random distribution, the record heliocentric distance being 9 A.U. (!) before perihelion. Only for the extensively observed split comets the model need incorporate also the initial velocity of separation, which is never greater than a few meters per second. The interpretation of the separation velocity is complicated by the gravitational interaction of the fragments for some time after breakup. The calculations show that in the absence of a net differential nongravitational force (an idealized case of identical fragments), the existence of gravitationally locked multiple nuclei is at least remotely possible. - In several cases the calculated time of splitting coincides either with a flare-up in the visual and/or infrared brightness or with an outburst detected as an isolated streamer in the dust tail. Comet West 1976 VI is the best example of this correlation of events. Although the time of breakup derived from the observed motions of the fragments refers probably to the time of termination of their appreciable attraction, the coincidence of events suggests that the "dynamical separation" follows the splitting with little time lag. - Light variations of fragments are unpredictable and their average amplitude appears to be correlated with the companion category: short-lived fragments display greater amplitudes than persistent companions and show physical similarities with the behavior of a small class of comets that have dissipated literally before the eyes of observers. - The identification of the breakup mechanism, the most difficult part of the investigation of split comets, is briefly addressed and a few proposed candidates (rotational breakup, radioactive heating) discussed. - This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract Number NAS 7-100, sponsored by the National Aeronautics and Space Administration, Planetary Atmospheres Program, Office of Space Sciences.

N.3R

## Rotation of Comet Nuclei

Fred L. Whipple
Smithsonian Astrophysical Observatory
Cambridge, Massachusetts

The miniscule history of spin-vector research on comet nuclei is reviewed. Major emphasis is placed on actual determinations of rotation period and of spin-axis orientation. The latter is indicated by asymmetrical comae (Sekanina, Icarus, 37, 420-442, 1979, and Whipple, Astron. J., 85, 305-313, 1980) and by the directions of near-nucleus jets (Sekanina, in press, 1981). The spin axis is known for six short-period comets, including P/Encke for which a rapid precession of the spin axis has been established by Whipple and Sekanina (Astron. J., 84, 1894-1909, 1979).

Rotation periods can be measured by photometry (as for asteroids), by near-nucleus jets and by halo diameters (see Whipple, The Moon and Planets, 19, 305-315, 1978). The halo method has been by far the most prolific. The spin periods (P) for 45 comets, almost all new determinations, are presented and compared with those of 41 small asteroids of diameter ≤40 km. The median P for the comets is 15.0 hr. versus 6.8 hr. for these asteroids. The preliminary distribution curve of log P for comets is flatter than gaussian and for asteroids. Slow accumulation at low relative velocities is suggested. The shortest period is 4.1 or 4.6 hr, consistent with near stability for a low mean density. The period increases statistically with absolute brightness (at the 2.5 $\sigma$ level). No proof of sublimation spin-up is yet established.

## N.4 ON THE VISIBILITY OF COMETARY NUCLEI

R. Hellmich, H.U. Keller

Scattered light from dust in the inner coma can deteriorate the visibility of the cometary nucleus. For a given particle size distribution and production rate the screening effect depends on the details of the number distribution of the dust grains in the very vicinity of the nuclear surface. Based on the results of a generalized Probstein gas-dust interaction model (Hellmich, 1981) the contributions of radiation scattered by dust are estimated for Newburn's dust models of comet Halley using a single scattering approach. The degradation of the visibility of the nucleus (particularly in contrast) can be neglected for Newburn's extreme low case and reaches complete obscuration for the extreme high case.

Ref.: Hellmich, R.: 1981, The Influence of Radiation Transfer in Cometary Dust Haloes on the Production Rates of Gas and Dust, Astron. Astrophys., in press.

## N.5 Photometric Phase Function of the Periodic Comet Tempel-2 during its 1978-1979 Apparition

by

Edward F. Tedesco, Lunar and Planetary Lab., The University of Arizona
and
Edwin S. Barker, McDonald Observatory, University of Texas at Austin

Photometric observations of P/Tempel-2 were obtained by four different groups in late 1978 and early 1979. These data show that between 28 October and 29 December 1978 Tempel-2 exhibited an asteroid-like phase function with a slope of 0.04 $\pm$ 0.05 mag/deg. During this time the heliocentric distance, r, increased from 2.66 to 3.02 AU and the apparent visual magnitude went from 19.0 to 19.4. Between 24 January and 24 February 1979 ($3.16 \leq r \leq 3.31$ AU) a sharp increase in brightness was observed, reaching a peak on 29 January at which time the comet was ~2.7 mag brighter than it was at a similar phase angle in late October. Since the heliocentric distance at the time of this outburst was ~¼ AU greater than it was in October the outburst cannot be attributed to heating of the nucleus as the comet approached the sun. Since an upper limit of $V(1,\alpha) \sim 16.4$ was deduced from observations made on 24 March the comet had returned to its pre-outburst brightness by this date. Hence an upper limit of 85 days can be placed on the period of time during which significant activity was displayed. The fact that the $V(1,\alpha)$ on 28 October and 24 March differ by about ¼ mag is consistent with the uncertainties of measurement and the fact that Tempel-2 displays a rotational amplitude on the order of ¼ mag [Barker and Rybski (1979, BAAS 12, 436)]. If we assume that the October, December, and March observations were not affected by cometary activity, i.e., that a "bare nucleus" was being observed then the phase coefficient of 0.11 $\pm$ 0.07 mag/day obtained from these data should be consistent with those observed for asteroids. Indeed, within the large uncertainty, such is the case since asteroid phase coefficients vary between 0.02 and 0.05 mag/deg with asteroids of lower albedo having larger phase coefficients. The absolute magnitude, $V(1,0)$, of the bare nucleus is therefore 14.5 $\pm$ 0.5. The spectra obtained by Spinrad et al. (1979) are similar to those of the low albedo asteroids found in the outer parts of the asteroid belt (Tedesco and Gradie, this conference) as well as to the more common S-type asteroids. Since these asteroids have geometric albedos ranging from 0.02 to 0.20 it is not unreasonable to suppose that the albedo of Tempel-2 also lies in this range. (This, of course, assumes that the comet's bare nucleus was actually observed.)

### Conclusions

1) Photometric observations of faint comets using different observational techniques can be successfully combined.

2) Tempel-2 can undergo outbursts of activity at heliocentric distances in excess of 3 AU.

3) The absolute (V) nuclear magnitude of Tempel-2 is 14.5 $\pm$ 0.5.

4) If the bare nucleus was actually observed it may be as large as 15 km in diameter. If the bare nucleus was not observed then this value represents a strict upper limit on the size of the true nucleus.

## N.6 "The Behavior of the Red Nuclear Continuum of P/Comets with varying Heliocentric Distance"

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Our Lick IDS scans isolate the red continuum from the photometric nuclei of several 1980 P/Comets in spectral "windows" almost entirely free of emission (on either side of the red [OI] lines, mostly avoiding the $NH_2$ bands).

The red region continuum magnitudes of these comets are quite faint; P/Encke was observed at r = 1.89 A.U. at continuum mag. 19.0; however its continuum then quite strong compared to the emission lines. As Encke approached the sun, its continuum did not brighten; if anything, it faded slightly. We present rough power-law descriptions of the reduced continuum brightness variation of P/Encke (positive exponent) and P/Tuttle and P/Stephen-Oterma for their 1980 apparitions. Tuttle and Stephen-Oterma both show the expected negative exponential dependence upon the cometary heliocentric distance.

These changes are cautiously inserted into the context of an icy-grain photometric nuclear model. In the case of P/Encke, no solid body nucleus exceeding a half-km radius is photometrically possible, unless its albedo is lower than 0.05! More likely r < 0.5 km if any icy-grains survive in the halo at r ≈ 0.8 A.U.

N.7 Spectrophotometric imagery of P/Schwassmann-Wachmann (2)

Johan Degewij (Jet Propulsion Laboratory) and Clark R. Chapman (Planetary Science Institute, Tucson).

We are trying to obtain spatially resolved colorimetry (0.40 - 0.85 µm) of faint comets using the Video Camera on the 84-inch telescope of the Kitt Peak National Observatory. Two filters centered at the CN(0,0) and $C_2$(0,0) bands are used plus six filters at wavelengths less affected by gaseous emissions. This approach allows us to obtain spectral reflectivity points for the central condensation and the dust/gas cloud. In particular for faint ($V \gtrsim 15$ mag) and distant $r \gtrsim 2$-3 AU) comets, the coma is relatively faint compared with the core, and we can expect that most of the light may be reflected from the surface of the nucleus.

On 10 Jan. 1981 UT, we tested our approach on P/Schwassmann-Wachmann (2). It was at 2.2 AU from the sun and 1.2 AU from the earth. We measured the total integrated magnitude to be V=14.9 and the magnitude of the central condensation to be V=15.9. The colors of the central knot (diameter 2.2 arcsec) are similar to that of the S-type asteroid 433 Eros. The annuli further out tend to have 10-20% larger reflectances near 0.8 µm and also they seem brighter at 0.42 µm. The magnitude of the central condensation at unit distance to Earth and Sun is $V(1,\alpha)$= 12.7 and this is consistent with an observation at r=5.5 AU by Dr. E. Roemer (Kresak 1973) providing $B(1,0) \sim 14.1$ or $V(1,0) \sim 13.3$. The corresponding diameter would be somewhere between 2 km ($p_V$=0.6) and 7 km ($p_V$=0.05). This photometric diameter estimate and the similarity of the stellar and comet seeing disk intensity profiles, are consistent with a major fraction of the light being reflected by a solid body, not obscured by an optically thick dust cloud. Most of the distant asteroids in the solar system beyond 4-5 AU, including Chiron, have neutrally colored spectra. P/S-W (2) was captured by Jupiter in 1926 from q=3.55, and it would be a surprise if this body, with an origin presumably in the Oort cloud, had S-type colors. It is not excluded, however, that the central condensation is actually a cloud of neutral-colored particles with a size distribution such that a reddish S-type spectrum is generated. More observations of comets are needed, with a variety of magnitudes and distances from the sun.

N.8 P/Schwassman-Wachmann 1 and Chiron: Near-Infrared Photometry

J. Degewij (Jet Propulsion Lab.), W. K. Hartmann (Planetary Sciences Institute), and D. P. Cruikshank (Inst. for Astronomy, Univ. Hawaii).

In a program of visible band and near-infrared photometry of distant comets aimed at the detection of a cometary nucleus in the absence of a coma, we have obtained VJHK photometry of P/Schwassman-Wachmann 1 during a period of very low or absent comatic activity. When plotted in a JHK color diagram, P/S-W 1 lies near the field occupied and defined by rocky objects such as asteroids and planetary satellites of low albedo. The V-J color of the comet is very red and comparable to the RD asteroids. The JHK colors of P/S-W 1 are distinctly different from those of four other comets, most with extensive comae, measured by M. Ahern and A. Tokunaga. We have also measured the JHK colors of asteroid 2060 Chiron with the goal of ascertaining if it has a surface of rocky/dusty material or of exposures of water ice. In the JHK color diagram Chiron falls within the boundaries of the rocky/dusty objects of low and intermediate albedo. The possibility that Chiron is an extinct cometary nucleus remains open because of the growing body of evidence that extinct or weakly active nuclei, and even well-developed comae, show JHK signatures indicative of the spectral reflectance of dust with no significant gaseous emissions in the spectral region 1-2.5 µm.

N.9 **SURFACE MATERIALS ON REMOTE COMETS: THEORETICAL AND OBSERVATIONAL INDICATIONS,**

W.K. Hartmann (Planetary Science Institute), D.P. Cruikshank (University of Hawaii) and J. Degewij (Jet Propulsion Laboratory)

Cruikshank, Degewij, and Hartmann have pursued a program of infrared JHK photometry of outer solar system (OSS) asteroids and small satellites, showing that JHK colors discriminate bright icy from dark stony surfaces. Objects in Jupiter's region formed from a mixture of $H_2O$ ice and carbonaceous stony material, and developed very dark surfaces by a cratering process (selective vaporization of ice). Objects further out may have less initial stony component and may have darkened less by cratering. If comets contain a substantial stony component of carbonaceous dust or rock, they may develop dark surfaces in the OSS either by the cratering process or by fallback of stony material as the last ices vaporize on the way toward aphelion. These two processes would produce dark soil surfaces on remote, inactive comets if they had a substantial initial dust component. These conclusions are supported by observations since November 1980 by M. A'Hearn and his colleagues, and by us. A'Hearn et al. obtained JHK colors of four moderately active comets at solar distances of 1.2 to 5.6 A.U., placing all four in the JHK region of dark, stony surfaces. We obtained JHK colors of comet Schwassmann-Wachmann (1) in a quiescent state and object 2060 Chiron, at solar distances 6.3 and 17.1 A.U., respectively, with similar preliminary results. Reflecting surfaces and comas in these objects may be primarily dark, carbonaceous, dusty debris. Further observations are in progress and will be discussed.

N.L **Where is the Ice in Comets?**

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and

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**ABSTRACT**

JHK photometry of Comets P/Tuttle, Meier (1980q), P/Stephan-Oterma, and Bowell (1980b) has yielded J-H and H-K colors, uncontaminated by thermal emission, which are nearly identical for all 4 comets. The colors are inconsistent with the reflection spectrum from a cloud of icy particles if the particles are composed primarily of any of the ices ($H_2O$, $CO_2$, $CH_4$, or $NH_3$) commonly assumed to be present in the nuclei of comets. CVF spectra of Comet Stephan-Oterma confirm the absence of any absorption features due to these ices. The reflection spectra of these comets appear most like those of C- and S- type asteroids and the ring of Jupiter.

N.10 STUDY OF THE NUCLEAR REGION OF COMETS BY THE OBSERVATION OF ECLIPSED STARS

Jamar, C. and Malaise, D.

The most important part of the comet is the nucleus which was never observed on account of its small size. In the immediate vicinity of the nucleus, there is a dense cloud of dust in which takes place the chemical transformation of the nuclear species into the radicals observed in the head. It is shown that important properties of this crucial part of the comet can be studied by high speed photometry of stars eclipsed by the central part of the comet. Latest developments in photon-counting detectors allows the development of the instrument needed for such a study. The instrument and program of observations are presented.

N. 11

## MILLIMETER-WAVE RADIOMETRY OF COMETARY NUCLEI

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### ABSTRACT

Predicted brightness temperatures for a variety of cometary nucleus models consisting of homogenous layers comprised of mixtures of water ice and refractory grains, are presented as a function of wavelength. These spectra are computed using simple radiative transfer techniques adapted from modelling of terrestrial ice and snow fields.

The millimeter wave spectra so computed are sensitive to the values of physically significant model parameters such as crust thickness, the subsurface temperature gradient, and the boundary temperature of the sublimating surface. It appears that mm-wave sensing of these thermal spectra from an interplanetary spacecraft is a most effective means for distinguishing between alternate models of the nucleus and for evaluating the physical state of substrata; modern theories on the nature of the nucleus indicate that sublimation from these substrata provides the gas phase cometary volatiles that are actually observed from ground-based and/or earth orbit instruments.

In addition, antenna beam dilution has been a major obstacle for ground-based molecular spectral line radio observations (e.g., water and ammonia) of comets but a suitable millimeter wave radiometer system in the near vicinity of the comet is capable of completely circumventing this problem. Thus, a system with spectral line capability in the millimeter region will allow unambiguous searches for several possible parent molecules in the gas phase as well as the investigation of inner coma physics which determines the excitation of any molecules detected.

N.12

## Radar Detectability of Comets

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### Abstract

Aside from the close encounter of a spacecraft with a comet earth-based radar observations appear to offer the only way to obtain direct data related to the central condensation of a comet. We evaluate the capability of radar to yield information on the size, rotation rate and albedo of the nucleus, the particle density in the coma and the cometary orbit itself. So far very few attempts with radar to detect cometary nuclei have been made, mostly because the needed radar capability is not available. We treat the general problem of the detectability of a comet (nucleus, coma, and tail), considering the backscattering properties of a comet, as expected from Whipple's model, and the parameters of the available radar systems. We also evaluate the best opportunities for the ground-based radar detection of a comet in the period 1981-1991; this study is based on the best estimates of orbital elements, nuclei sizes and rotation rates available. We discuss in detail comet P/Encke, the first to return a detectable radar echo, including the experimental procedure used at the Arecibo Observatory in November 1980 for this detection. The radar echoes are consistent with scattering by a uniformly bright sphere of limb-to-limb bandwidth $f_{LL}$=7.0±1.0Hz. Using the current estimates of rotation period (6 1/2 hrs) and pole position ($\lambda$=183°, $\beta$=-11°), we deduce a nuclear radius R=1.3±0.2 km. Reception was made in the rotational sense of circular polarization opposite to that transmitted and yielded a radar cross-section of (0.22±0.12)$\pi R^2$ (with R=1.3km).

N.13 THERMAL MODELING OF COMETARY NUCLEI

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A new model of the sublimation of volatile ices from a cometary nucleus has been developed which includes the effects of diurnal heating and cooling, rotation period and pole orientation, and thermal properties of the ice and subsurface layers. The program also includes the contribution from coma opacity, scattering, and thermal emission, where the properties of the coma are derived from the integrated rate of volatile production by the nucleus. The model is based on an earlier program by Kieffer et al. (1977) used to interpret data from the IRTM experiment on the Viking Orbiters. Modular software design allows any volatile ice to be substituted for water if so desired.

The model is applied to the specific case of the 1986 apparition of Halley's Comet. Newburn's (1979) nominal model for Halley is used as the baseline for the cases run. It is found that the generation of a cometary dust coma actually increases the total energy reaching the Halley nucleus. This results because of the significantly greater geometrical cross-section of the coma as compared with the bare nucleus, and because the coma provides an isotropic source of scattered sunlight and thermal emission over the entire nucleus surface. For Halley the calculated coma opacity is approximately 0.1 at 1 AU from the sun, and 0.7 at perihelion (0.59 AU). At 1 AU this has little effect on dayside temperatures (maximum ~195°K) but raises nightside temperatures by about 20°K. At perihelion the higher opacity results in a nearly isothermal nucleus with only small diurnal and latitudinal temperature variations. The general surface temperature is 203°K with a maximum of 208°K at local noon on the equator. Results for volatile production rates are in good agreement with earlier models and with observations of Halley.

Input values for the cases run were: nucleus radius 2.5 km; surface albedo, 0.3; surface thermal inertia, 0.003; rotation period, 10.3 hrs; rotation pole obliquity, 20°; dust to gas ratio, 0.5; physical density of coma dust, 1.0 g/cm$^3$; dust particle radius, 1.5μ. This work was supported by the NASA Planetary Geophysics and Geochemistry Program.

References

Kieffer, H.H., et al., J. Geophys. Res., 82, 4249, 1977.

Newburn, R.L., in "Comet Halley Micrometeroid Hazard Workshop," Eur. Space Agency SP-153, 35, 1979.

N.14 HEAT CONTENT AND EVOLUTION OF COMETARY NUCLEI

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It has been shown recently (1) that new water-ice cometary nuclei, which are almost certainly amorphous, begin to crystallize rapidly at 5.5 AU for a fixed subsolar point and at 2.7 AU in the so-called "isothermal" case. The ensuing very rapid evaporation of water leads to an outburst which is larger for less porous ices. In the present extension of this study the rate of heat diffusion into the nuclei and their heat content has been calculated in order to investigate their influence on the subsequent evolution of comets. The heat flux into the nucleus turns out to be surprisingly large and, for zero porosity, it can be of the order of 20 to 30 percent of the incident solar flux for heliocentric distances between 3 and 8 AU dropping to 1 to 2 percent for 90 percent porosity which is typical of fresh non-compacted snows. During subsequent passages near the Sun the porous ices become compacted ("constructive metamorphism") and the bonding strength increases through molecular diffusion; as a result the heat flux into the nuclei increases so that, for the same heliocentric distances, the temperature and the rate of evaporation becomes progressively lower. The considerable heat content of the nuclei leads to thermal inertia so that, for the same distances from the Sun, the temperature is lower before than after the perihelia. The behavior of other ices, of dust and of more complicated molecules has been also investigated.

(1) R. Smoluchowski, Astroph. J. Lett., March 1, 1981 (in press).

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N.15 Some Consequences of a Phase Transition of Water Ice on the Heat Balance of Comet Nuclei
(Abstract)

We consider a sphere of water ice of about 1 km in radius orbiting sufficiently far from the sun that evaporation can be neglected.

Numerical calculations of the surface temperature are done for two cases :

1) the sphere is composed of amorphous ice with a heat conduction to the interior supposed to be negligeable.

2) the sphere is composed of compact hexagonal ice with a heat conduction coefficient given by an empirical law from ref. (1) :

$$\lambda = \frac{5,67}{T} \frac{W}{cmK}$$

The variations of the surface temperature during one period are smoothed in case 2 with respect to case 1. The amount of the smoothing depends on the orbital parameters. The surface temperature of the hexagonal ice sphere shows a phase angle of about $\frac{\pi}{4}$ with respect to aphelion and perihelion. The difference between cases 1 and 2 fixes the upper limit of the influence of a phase transition from amorphous to crystalline ice in a celestial body containing $H_2O$ as a major component.

Ref.
(1) J. Klinger : Influence of a Transition of Ice on the Heat and Mass Balance of Comets, Science, 209, 11 July 1980 pp.271-272.

## N.16R The Infrared Spectral Properties of Frozen Volatiles

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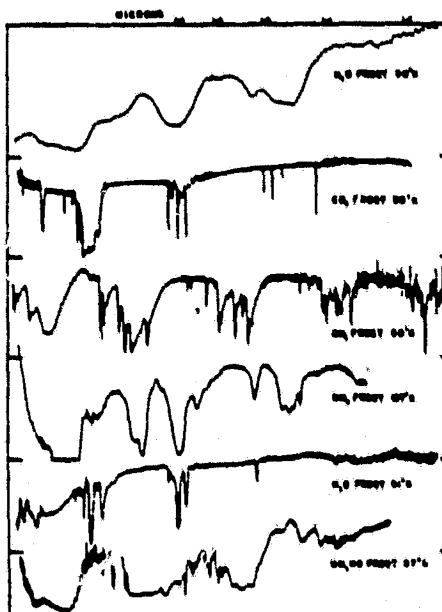
Although the nuclei of comets have not been directly observed, it is generally believed that the nuclei contain condensed volatiles. Whipple's "dirty snowball" model of comet nuclei depends on the role of volatile ices in explaining cometary phenomena. Since most frozen volatiles are white, it is difficult to identify an ice by examining its visible reflected light. It is in the infrared reflected radiation that these materials reveal their identities. Vibrational modes unique to each molecular species modify the spectral energy reflected.

We have pursued near IR laboratory reflectance studies of molecules that are potential candidates for frozen volatiles in the solar system, viz. solid $H_2O$, $CO_2$, $SO_2$, $CH_4$, $NH_3$, $H_2S$, CO, $NH_4HS$, and $NH_3 \cdot H_2O$. We have also measured the IR transmission spectra of thin films of these ices and derived optical constants in the infrared from 1 to 100um for most of these. We present both our own work and that existing in the literature. We also review the ices that have so far been detected on solar system bodies: $H_2O$ ice on Europa, Ganymede and Callisto; the rings of Saturn, the satellites of Saturn; $CO_2$ ice on Mars; $SO_2$ ice on Io. When we are able to view the nuclei of comets, before they develop extensive comas, or at close range, it is hoped that this data will help to identify the ices in the "dirty snowball."



Reflection spectra of various frosts in the near IR, 1.2-4.0μm

**ORIGINAL PAGE IS OF POOR QUALITY**

N.17E VACUUM UV REFLECTANCE SPECTRA OF $NH_3$, $H_2O$, $CO_2$ AND $SO_2$ ICES

B. Hapke, J. Wagner, E. Wells and W. Partlow

The reflectance spectra of ices of several volatiles of interest for comet nuclei and outer solar system objects have been measured over the range 5-10.5eV (1200-2500Å). In this region all the spectra have distinctive features which could allow their identification by UV spectroscopic remote sensing. $NH_3$ is bright at energies below about 6.0eV, where the reflectance drops precipitously, and is low at higher energies. $H_2O$ has a minimum at about 7.75eV and a maximum at 9.5eV. $CO_2$ has minima near 6.0, 7.0 and 10.0eV and maxima at 6.5, 9.25 and 10.5eV. The spectrum of $SO_2$ is very black throughout the entire range measured, but has a minimum at about 6.75eV and a maximum near 9.5eV.

N.18 PROTON IRRADIATION OF COMETARY TYPE ICE MIXTURES

The infrared absorption features of cometary type ice mixtures are analyzed at low temperatures before and after proton irradiation. The ice mixtures consist of combinations of the molecules: $H_2O$, $NH_3$, $CH_4$, $C^{13}H_4$, $N_2$, CO, $CO_2$. The temperature of the ice is maintained near 15K while the incident 1 Mev proton fluence ranges from $10^{12}$-$10^{15}$ Mev/cm$^2$(simulating 1/10,000 to 1/10 the estimated cosmic ray accumulation in the top 10 cm of a cometary nucleus in $10^9$ years).

All experiments support the idea that new molecular species are synthesized in the solid phase mixture at 15 K. Long chained hydrocarbons along with nitrogen and carbon oxides are identified spectroscopically; their absorption strengths are proportional to proton fluence. After irradiation, the ice is very volatile around 20K as indicated by pressure bursts. From 20-40K, chemi-luminescence with enhancement of volatility is observed and thermal luminescence is observed around 150K. Gas chromatographic analysis of volatiles liberated from the ice during warm-up confirms the presence of $C_2H_6$ or $C_2H_4$ and $C_3H_8$. A colored room temperature residue is also produced. Preliminary analysis of the residue indicates a variety of organic compounds.

These experiments give direct results concerning the expected nature of cometary ices after $10^9$ years of radiation synthesis. It is suggested that the albedo and volatility of the nuclear ice are affected by the presence of synthesized products. Application of these experiments to cometary models is presented.

Marla H. Moore and Bertram Donn

(N.LT) Experimental Rates of Frozen Gas Erosion by KeV-MeV Light Ions.

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Laboratory measurements of $H_2O$ ice erosion induced by energetic ions have been performed at low temperature (77K) using the ion implanter of the Catania University.

Ejected particles have been analyzed with a quadrupole mass spectrometer. This analysis has shown that the particles lost by the target are substantially molecules: infact, during steady state erosion almost only $H_2$, $O_2$ and $H_2O$ partial pressures considerably increased.

This fact could be of some relevance in problems connected with particles release by parent molecules in comets at large distance from the Sun where the effect of UV photons is less important.

N.19E **Charged Particle Erosion of Frozen Volatiles in Comets**

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Recent laboratory data shows that charged particles very effectively erode frozen volatiles.[1,2] Further, the erosion yields for different volatiles vary enormously with water ice having the lowest yields. These results, therefore, have a bearing on the competition between collection and loss of volatiles by comets at very large distances from the sun, hence on the 'pristine' nature of the surface composition. In addition to affecting the molecular composition, there is also evidence that changed particles change the nature of the frozen surfaces, as dendritic growth has been observed on the surface of amorphous water ice eroded by ions and the yields for $CO_2$ depend on the thermal history during erosion. The erosion results also are relevant in estimating lifetimes of ice grains produced as comets approach within observational distances of the earth. For instance, water ice grains of the order of 20μm have been shown to be eroded more effectively by solar wind ions than by sublimation at distances greater than 1.5AU from the sun[3]. This paper will review the state of knowledge and the status of laboratory measurements on the erosion of volatiles ($H_2O$, $CO_2$, $SO_2$, $NH_3$, $CH_4$, Ar and Ne) with application to a few cometary problems.

This work is supported in part by a grant from the National Science Foundation, AST79-12690.

1) W. L. Brown, W. M. Augustyniak, E. Brody, B. Cooper, L. J. Lanzerotti, A. Ramirez, R. Evatt, and R. E. Johnson, Nuclear Inst. and Methods 170, 321 (1980).

2) R. E. Johnson, L. J. Lanzerotti, W. L. Brown, and T. P. Armstrong, Science February (1981).

3) L. J. Lanzerotti, W. L. Brown, J. M. Poate, and W. M. Augustyniak, Nature, 272 431 (1978).

N.20R **Relationships between comets, large meteors, and meteorites**

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The link between comets and small meteors is well known. The greater value of data from very bright meteors (fireballs brighter than -5 Mag., >100g) is less recognized. This value is a consequence of their deeper atmospheric penetration, thus permitting "natural experiments" that test the properties of the meteoroids under a range of physical conditions. The longer flight path provides more useful deceleration and photometric data. In some cases, survival of atmospheric entry permits a connection with meteorites studied in the laboratory. The heliocentric orbits of large meteors are more stable, and more diagnostic of origin, because of the relatively small importance of non-gravitational forces, such as Poynting-Robertson effect and radiation pressure.

The ~300 fireballs for which data are available (1-3) exhibit a wide range of physical and orbital characteristics, classified (4) into three types:

(I) Strong survivable bodies, similar to ordinary chondrites

(II) Weaker or less dense objects, tentatively identified as carbonaceous chondrites.

(III) Very weak objects [illegible]

Although the statistical sample is not good, the three types appear to be comparable in number.

In the present work these distinctions have been explored further and somewhat modified in a number of ways by use of deceleration data, improved entry modelling (5) and evidence from the recovered Innisfree fireball.

N.20R (continued)

From this and earlier work the following conclusions can be drawn:

(1) Many fireballs (as large as 10 tons or more) are associated with meteor streams and hence comets, despite deliberate selection against such objects in reduction of Prairie Network data.

(2) Steady-state mass balance shows that almost all cometary fireballs fail to survive the $\sim 10^4$ years required to evolve into random orbits, presumably because of low mechanical integrity. These objects break up completely at aerodynamic pressures of .01 to 1 atmosphere, seem to have some ability to partially penetrate the atmosphere, but are unlikely to be represented in museum meteorite collections, even as C1 chondrites.

(3) Fireballs similar to the above are sometimes found in orbits with aphelia <2.5 A.U. Survival of such intangible objects for the $10^6$-$10^7$ yr required for this orbital evolution is unlikely, and hence this is good evidence for existence of extinct comets in the inner solar system.

(4) Some fireballs with aphelia beyond Jupiter, presumably of cometary affinity, have sufficient strength to survive passage through the atmosphere. One of these is indistinguishable in mechanical properties from ordinary chondrites. Others appear weaker, but nevertheless are likely to be represented in meteorite collections.

(5) The large number (~25%) of fireballs with physical properties similar to recovered meteorites are less likely to be products of active comets, but could be derived from Apollo objects of cometary origin (6).

REFERENCES
(1) McCrosky et al SAO preprint 665, Meteoritika 37, 44-59 (1978)
(2) McCrosky et al SAO preprint 721, Meteoritika 38, 106-156 (1979)
(3) Ceplecha Z, Bull. Astron. Inst. Czech. 28, 328-340 (1977)
(4) Ceplecha and McCrosky, J. Geophys. Res. 81, 6257-6275 (1976)
(5) ReValle, D.O., J. Atmos. Terr. Phys. 41, 453-473 (1979)
(6) Wetherill, G.W., Geochim. et Cosmochim Acta 40,1297-1317 (1976)

## N.21 Earth Orbit Approaching Comets and Their Theoretical Radiants

by Jack Drummond

Abstract

There are sixteen comets which produce recognizable meteor showers found in Cook's (1973) list. Of these, five are long period, including one in a parabolic and one in a hyperbolic orbit. The largest earth-comet orbit miss distance is 0.20 AU for comet Encke and the daytime β Taurids. Using this as an upper limit for meteor showers from comets, all comets which approach the earth's orbit to within 0.20 AU were extracted from "The Catalogue of Cometary Orbits", 3rd ed (Marsden 1979). A compilation of all such comets is presented by date of minimum approach, along with the distance of closest approach and the theoretical geocentric radiants and velocities of possible associated meteor showers. Both pre- and post-perihelion encounters with the earth's orbit are considered.

There are 240 entries for 178 long period comets, and 36 for 28 short period comets. It is noted that all short period comets that have approached the earth's orbit to within 0.08 AU have produced meteors, except P/Lexell, P/Finlay, P/Denning-Fujikawa, and P/Grigg-Skjellerup. Other pertinent facts are discussed as an aid for those who wish to model meteor production from comets.

N.LT

# THE CONNECTION BETWEEN METEOR STREAMS AND COMETS

IWAN P.WILLIAMS and DAVID W.HUGHES.

It has long been suggested that the break up of a cometary nucleus gives use to a meteor stream. However, the gravitational perturbations of the planets can considerably modify the mean orbit of the meteor streamso that the current observed steam orbit may bear no obvious relationship to the original cometary orbit. We have investigated these perturbations for the quadrantid stream and obtain excellent agreement between observed parameters and predicted ones (including mass segregation). Extending the work back in time indeed leads to an orbit vastly different from the current one. A similar calculation has been carried out for the Gemenids and an interesting problem arises. As expected, the calculations give a retrogression rate for the ascending node where observations show a progression. Thus, gravitational perturbation by the planets is not the dominant perturber of the Geminid orbit. We will indicate other possibilities.

N.22P

# Identification of Meteoritic Fireballs Using the Theoretical Light Curve Technique

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The relative shape of the light curve of fireballs can be used as a diagnostic tool in combination with other approaches in order to quantify differences in fireball behavior. Using procedures developed in McKinley (1961) and Hughes (1978) a theoretical fireball light curve equation has been derived. In contrast to earlier work the new result allows for a contribution to the light from fireball deceleration (ReVelle and Rajan, 1979) as well as from the ablation products directly. It also incorporates a height variable velocity into the result. The quantities needed to evaluate the light curve equation include the observed initial velocity and subsequent values including the value at the point where the maximum magnitude occurs and the observed magnitude values at all points along the trail at their corresponding altitudes of occurence. Two additional quantities are also needed in order to evaluate the light curve equation. These are $\sigma$, the average ablation parameter and n, the constant power law exponent of the velocity in the assumed luminous efficiency function. Although representative values of 0.02 $sec^2/km^2$ for $\sigma$ and 7.5 for n are currently being suggested by the author, the results are not very sensitive to these values. This is especially the case for n such that the difference between using n = 1 and 7.5 in the computed light curve is only perceptable at the lowest altitudes, very near the observed end height. Application of this new equation to the three photographed and recovered meteorites, Pribram, Lost City and Innisfree yields very good agreement between the observed and computed light curves. Work is proceeding with Ceplecha with some additional new results to apply this equation to the Prairie Network fireballs photographed through 1976 by McCrosky and co-workers. Although agreement is good in a number of cases, there are some fireballs which do not follow this new relation even in an approximate manner. These fireballs are the suspected "nonmeteoritic" types, a suspicion which can be tested via other approaches such as dynamical treatments, etc..

N.23

## Compositions of Outer Belt Asteroids: Implications for Comets

by

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and
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We report on recent broad band (0.32 to 1.03 $\mu m$) photometry, and 10 and 20 $\mu m$ radiometry of asteroids in the outermost parts of the asteroid belt. Our observations establish that these asteroids, belonging to the Hilda group (semimajor axes, $a$, near 4 AU) and Trojan groups ($a$ near 5.2 AU) form a compositionally distinct population compared with main belt asteroids. In particular there are apparently no *C*-type asteroids among the Trojans while no more than 25% of the Hilda asteroids observed to date could be classified as *C*-type. This is in contrast to the outer main belt population ($3.1 \leq a \leq 3.5$) 90% of which are believed to be *C*-type [Zellner, 1979 in *Asteroids* (T. Gehrels, ed.), pp. 783-806]. In addition to the *C* and *RD*-types previously recognized among the Hilda and Trojan groups there are present at least one, and perhaps two, new taxonomic types. All members of these two groups are low albedo objects ($p_v \leq 0.04$). We discuss the suggestion by Gradie and Veverka (1980, *Nature* 283, 840) that the very low albedos and red spectra of these outer belt asteroids can be explained by the presence of kerogen-like organic compounds on their surfaces and that these compounds may have been the primary rocky condensate in the outer Solar System and may therefore be typical of the rocky component of comet nuclei. We also discuss observations of dusty comets whose reflection spectra resemble those of outer belt asteroids leading us to think that "bare" cometary nuclei may rarely, if ever, be observable.

N.24 Composition of the Material Which Initially Accreted in Comets

L.L. Wilkening, Univ. of Arizona

What is known about the composition of the silicate component of the nucleus has been learned from the study of dust tails and interplanetary dust. From infrared studies it is known only that the dust in tails bears some resemblence to interstellar dust. The best analogs to this material are CI or CM chondrites or synthetic vapor-deposited amorphous silicates. The study of interplanetary dust recovered from the stratosphere shows it is diverse and complex in its mineralogy. If all interplanetary dust is from comets, then comets may be more complex than in their origin and evolution than originally suspected. Alternatively there may be more than one source of interplanetary dust.

It has been clearly demonstrated by several groups that the mineralogy of CI and CM chondrites is the result of the action of liquid $H_2O$ upon the original minerals which constituted the carbonaceous chondrite parent bodies. Two important questions bear on the origin and evolution of the silicate portion of comets if this material resembles CI or CM meteorites. (1) Are hydrated silicates a probable primary accretionary material? (2) If carbonaceous chondrite parent bodies were comets, could cometary nuclei have ever reached the melting point of $H_2O$?

N.25P

## DO COMETS HAVE SATELLITES?

T. C. Van Flandern

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The recent rush of evidence that many minor planets may have satellites, together with the known physical, chemical, and lightcurve similarities between minor planets and comets, lead naturally to the question, "Might comets have satellites too?" This paper explores six puzzling features of comets which are presently poorly understood, but which can be elegantly explained if it is assumed that comets do indeed have dust, debris, and satellites in orbit around their nuclei.

N.26P

# THE SPACEWATCH CAMERA

T. Gehrels[a], E. Shoemaker[b], H. Boesgaard[c], J. Degewij[b], J. Frecker[a], R. McMillan[a], K. Serkowski[a], C. Stoll[a], W. Stone[a], and P. Strittmatter[a].

The Spacewatch Camera is presently in a design phase with support from NASA's Solar System Exploration Division (Office of Space Sciences). It is a 1.8 m reflector for the detection of asteroids and cometary cores that occasionally approach the earth. A CCD array is used at prime focus (F/2.2) to scan 20° in right ascension and 0°3 in declination during two consecutive scans of five minutes each. A computer system compares the two scans in real time in order to find moving objects. The limiting magnitude is V~19.4. The Camera and computers will be installed in an existing dome of the University of Arizona Observatories on Kitt Peak. A ten-year program of searching should discover a substantial fraction of earth-approaching asteroids that are larger than ~0.6 km in diameter. Photometry and radiometry will be done for many of them, with emphasis on the distinction of spectral types and on the difference between asteroids and extinct cometary nuclei.

[a]University of Arizona; [b]Jet Propulsion Laboratory; [c]University of Hawaii

D.1R **Cometary Dust in the Solar System**

Review Paper by H. Fechtig, Max-Planck-Institut für Kernphysik, Heidelberg, Germany

By two basic methods, namely studies of microcraters on lunar samples and in situ dust experiments, information has been obtained on cometary dust in the solar system. The diameter to depth ratios of lunar microcraters are primarily determined by the densities of the projectiles. Up to 25% of all lunar microcraters are produced by low density projectiles. The results from the HEOS-2 dust experiment showed the existence of socalled "swarms", which are bursts of particles produced shortly before observation. Since these swarms are observed within 10 Earth radii, their production probably results from electrostatic fragmentation within the auroral plasma region. The fluxes of the parent bodies are estimated to be roughly 30% of the fluxes of these parent bodies travelling through these region. However, less than 50% of the observed dust particles are of this type. Observational results of the Helios experiment clearly show the existence of low density particles. This could be derived from the differences in events of the two Helios-sensors.

All these informations indicate the existence of low density particles in the solar system which are most likely of cometary origin. Only less than 30% are of this low density type. This fact in combination with the low dust production rate of comets either show that there are other dust sources in the solar system or we do not understand what cometary dust in particular or comets in general look like. To explore the nature of cometary dust particles within the coma of Halley is another important reason to have a cometary mission.

D.2R **LABORATORY STUDIES OF INTERPLANETARY DUST**

Fraundorf, P.[1], Brownlee, D.E.[2], and Walker, R.[1]
(1) Washington University, (2) University of Washington; Caltech.

Dust particles in the size range 2μ to 50μ, collected above 65,000 ft. in the earth's atmosphere, fall into several categories; some, eg. ($AL_2O_3$) spherules) are clearly terrestrial contaminants, others are extraterrestrial in origin, and for still others the issue is not settled. The extraterrestrial origin of one subset of particles dubbed "chondritic aggregates" has been established by several observations. For one, as suggested by their name, the abundances of major elements, C, Na, Mg, Al, Si, S, Ca, Fe, and Ni and minor and trace elements Ir, Sc, Mn, Co and Zn are similar to those found in primitive, carbonaceous chondrites. The particles have also been found to contain large concentrations of the noble gases He, Ne and Ar in proportions consistent with a solar wind implantation origin. The abundance of Ne with respect to Ar is close to the photospheric abundance and differs by an order of magnitude from the terrestrial atmospheric value. The $^{40}Ar/^{36}Ar$ value is also distinctly lower than the atmospheric value. This solar type noble gas component could be due to a recent solar wind irradiation of the particles in space or it could be due, as in gas-rich meteorites, to an ancient solar irradiation of the individual constituents that make up the particles. In spite of their extraterrestrial origin and apparently primitive nature, none of the particles so far studied show large anomalies in the isotopes of Mg although possible deviations from terrestrial standards at the level of ~ 4 per mil have been observed. Nor do the crystals in the aggregates exhibit solar flare track densities that would be expected if previously calculated lifetimes for small particles were correct. Possibly the particles were once parts of much larger aggregates prior to entry; heating during entry may also have erased many of the tracks.

D.2R (continued)

Although the particles often contain minerals that are common in meteorites, namely, olivine, clinoenstatite and iron sulfides, the manner in which these mineral assemblages occur sometimes appears to be very different than in meteorites. Typically the minerals in a given particle are very fine-grained and are covered and cemented together by noncrystalline, probably carbonaceous, material. Examination of the particles by electron beam techniques demonstrate that the particles differ considerably one from the other and reflect a variety of processes that led to their formation. One contains some spherical crystals that came together when they were partially molten. Some consist mostly of a noncrystalline "chondritic" material. Still other contain crystals whose morphologies possibly reflect a collision and comminution history. Some aggregates are clearly not thermal equilibrium assemblages, and some crystals have apparently been quenched from high temperature. Optical spectroscopic measurements show the presence of a prominent 10μ absorption band and are thus consistent with a cometary origin for the particles. The friable and fluffy nature of many of the aggregate particles are consistent with what has been inferred for the properties of meteors, some of which are known to be associated with comets. At this point in time, a cometary origin for the particles appears to be a viable working hypothesis.

Interplanetary particles much larger than those collectable in the stratosphere have been recovered from the sea floor. These particles range in size from 100μm to 3mm and are of particular interest because they are samples of the sizes of meteoroids which have been studied for many years as visual and radar meteors. These large particles melted during atmospheric entry but to a large extent their elemental and isotopic composition remained unaltered. Analyses of a large number of these particles has produced what is probably the best determination of the composition of cometary solids.

References: Fraundorf, P. and Shirek, 1979, Proc. Lunar Planet. Sci. Conf. 10th, p. 951; Brownlee, D.E. 1979, Rev. of Geophys. and Space Phys. 17, p. 1735.

## D.3 SEARCH FOR POSSIBLE COMETARY DUST IN ANTARCTIC ICE CORES

Jerry Wagstaff and Elbert A. King

ABSTRACT Particles of probable extraterrestrial origin have been recovered from Antarctic ice cores in which they may occur in concentrations of as much as one particle in ten thousand. The ice cores offer the possibility for time-stratigraphic control, selection of intervals with low total particle concentrations and preindustrial age samples. We presently are searching for a distinctive population of particles associated with the spectacular Leonid meteor display of 1833. This interval of core was selected because of its low total particle, hence low terrestrial particle, concentration and because it is bracketed by large volcanic ash falls that may be used as stratigraphic markers. Our efforts are focused primarily on the less than 3 micrometer size fraction as this size class has the possibility to enter the Earth's atmosphere and settle to the surface with only minor particle alteration. Particles are imaged with a Cambridge S4-10 Stereoscan scanning electron microscope and analyzed with an EDAX SW 9160 program on an EDAX 9100 system. Particles believed to be extraterrestrial in origin include Fe-S and Fe-O spheres and also irregular particles with various proportions of Si-Mg-Fe-Ni-S-P-Al-O and Fe-Cr-Ni-S-O with morphologies similar to particles collected with airborne systems by other workers. In addition, populations of particles characterized by an abundance of low atomic number elements and minor amounts of Fe-Ni-Cu or inhomogeneously distributed Si-Ca-Mg-Fe-Zn-Cu-Ni-S may be of extraterrestrial origin. Work is continuing to characterize the particle populations of various stratigraphic intervals in the cores. We will attempt to determine whether or not it is feasible to make a stratigraphic/statistical argument for the cometary origin of any specific extraterrestrial particle population. However, this will require the investigation of many hundreds of thousands of particles.
This research is supported by the National Science Foundation, Division of Polar Programs.

D.4 **Interrelation of Interplanetary and Cometary Dust as Observed by the Helios Micrometeoroid Experiment.**

E. Grün, H. Fechtig, J. Kissel, and N. Pailer, Max-Planck-Institut für Kernphysik, Heidelberg, W. Germany

The micrometeoroid experiment on board Helios observes interplanetary dust particles between 0.3 AU and 1 AU distance from the sun. It detected several hundreds of micrometeoroids in the mass range from $10^{-16}$g to $10^{-7}$g. Approximate orbits are obtained for these particles from the measured impact speed and flight directions. It is shown that many particles ($\gtrsim$ 50 %) move on high eccentricity orbits ($e > 0.5$). From a comparison of the countrates at two sensors - one covered by a thin entrance film, the other with an open aperture - limits for the particle density can be derived. 10 to 30 % of all observed micrometeoroids have bulk densities $\rho < 1g/cm^3$, most of them have also high eccentric orbits.
High eccentricities and low bulk densities are known characteristics of meteor stream particles and sporadic meteors which are directly related to comets. This similarity suggests a recent cometary origin of at least 10 to 30 % of the dust particles detected by Helios.

D.5 INFRARED SPECTROSCOPY OF INTERPLANETARY DUST IN THE LABORATORY.

P. Fraundorf, J. J. Freeman*, and R. I. Patel, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130; *Monsanto Co., Corp. Research Dept., 800 N. Lindbergh Blvd., St. Louis, MO 63166.

Interplanetary dust is likely to be in part of cometary origin, and comets in turn provide a most promising reservoir for unaltered samples of material present during the formation of our solar system. The recent availability in the laboratory of interplanetary dust collected in the stratosphere (1), albeit in small quantities, represents an important opportunity to relate the optical properties of such dust to knowledge of composition and structure only obtainable by "hands-on" examination. Transmission electron microscope (TEM) work on stratosphere-collected interplanetary dust particles (IDPs) with compositions similar to those of chondritic meteorites has shown that, in spite of outward similarities (e.g. reentrant structures; "primitive" compositions), they exhibit a rich variety of internal structures which undoubtedly contain information on differences in origin from one particle to the next, as well as signs of alteration during atmosphere entry (2). In this paper, we report results on the study of infrared absorption features in such particles.

First, transmission spectra using macroscopic amounts of minerals which have already been shown to be common in collected IDPs have been obtained to provide a point of reference in interpreting spectra from microscopic samples. Of the minerals olivine, pyroxene, magnetite, and pyrrhotite, only the first two (the silicates) have strong absorption features between 5 and 20 µm. At least two common constituents of collected IDPs, a carbonaceous component and a non-crystalline "chondritic" material (2,3,4), remain essentially uncharacterized, and hence no macroscopic analogs have been examined for them. Secondly, data from samples only 1 to 10 ng in mass has been obtained: spectra of olivine, pyroxene, and an improved spectrum from 3 crushed IDPs (5). The dominant absorption feature between 9 and 11 µm in the $10^{-9}$ g IDP sample is clearly different from that of olivine. With these spectra, the ability to obtain diagnostic spectra from the quantity of material found in large (e.g. 15 µm) IDPs will be demonstrated. Subsequent TEM work on these IDPs will be attempted to relate observed optical properties to the underlying IDP structures.

D.5 (continued)

Finally, initial attempts at examining subnanogram quantities of material suspended in carbon films on TEM grids have been made. In particular, two of eleven IDPs already examined in the TEM consisted mostly of a noncrystalline "chondritic" material. These particles are interesting because they did not exhibit magnetite decoration, which may be a sign of alteration on atmospheric entry (6), and because astrophysical observations of the interstellar feature near 10 μm suggest that noncrystalline silicates may be common in dust outside the solar system (7). Although signal-to-noise problems are too severe to allow any inferences about its shape, transmission spectra of mounts made from one of these IDPs indicate that this noncrystalline material does exhibit a 10 μm absorption feature.

REFERENCES: (1) D.E. Brownlee et al. (1976) NASA TM X-73,152; (2) P. Fraundorf (1980) Geochim. et Cosmochim. Acta, in press; (3) P. Fraundorf and J. Shirck (1979) Proc Lunar Planet. Sci. Conf. 10th, 951-976; (4) P. Fraundorf (1981) Lunar and Planet. Sci. XII Abstracts, submitted; (5) P. Fraundorf et al. (1980) Nature 286, 866-868; (6) D.E. Brownlee et al. (1975) J. Geophs. Res. 80, 4917-4924; (7) T.J. Millar and W.W. Duley (1980) Mon. Not. R. Astr. Soc. 191, 641-649.

## D.6R Optical and Infrared (.5μ to 20μ) Observations of Bright Comets

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Since 1965 infrared observations have been obtained on 7 bright comets and p. Encke. Five comets were dusty with pronounced Type II tails. These were Bennett 1969i, Kohoutek 1973f, Bradfield 1974b, West 1975n, and Bradfield 1980t. All of these dusty comets showed a silicate signature at 10 and 18 microns indicating the presence of small ($r < 5\mu$) refractory grains in the comae and tails of these comets. The anti tail of Kohoutek did not have the silicate feature suggesting the presence of large particles. Comet Kobayashi-Berger-Milon 1975h and Coemt Ikeya 1965f had Type I tails. Detailed study of 1975h indicated thermal emission from large grains. Measurement of coma colors from visual to infrared wavelengths allows determination of the grain temperature and of the albedo and its dependence on scattering angle. Both 1975n and 1980t passed between the earth and the sun allowing observations at scattering angles as small as 30°. Both comets show strong forward scattering as expected for dielectric grains of radius about a micron. The nature of the size distribution can change abruptly on an individual comet. The visual and infrared brightness of 1974b decreased in a few days, the silicate feature disappeared and the visual albedo dropped. The dependence of the comet brightness on diaphragm diameter (brightness proportional to diameter) suggests a model for the dust in which the number of grains satisfies the continuity equation. Plots of $(\lambda F_\lambda)_{max}$ show that the total energy radiated by the coma varies as $R^{-n}$ with an exponent n between 3 and 5 when R is less than 1 a.u. The infrared observations allow estimates of the mass rjected in silicate grains and these are consistent with a quantity comparable to the mass of water ejected (as determined by the OH and H abundances).

D.7 THE THERMAL PROPERTIES OF DUST IN PERIODIC COMETS

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University of Arizona

We present nearly simultaneous photometric observations between 1 and 20 μm of four periodic comets including comet Encke. Our observations are the first to include the thermal and reflected portions of the infrared spectrum of any periodic comet. The properties of the cometary dust as derived from these observations are discussed, as well as the peculiar behavior of comet Encke relative to that of other periodic and non-periodic comets.

D.8 INTERPRETING THE INFRARED AND OPTICAL EMISSION FROM COMET DUST

Martha S. Hanner*
Jet Propulsion Laboratory

The infrared emission from cometary dust grains is being modeled in order to infer the composition and dominant size range of dust emitted from comets. The models are based on measured refractive indices for minerals expected to be present in cometary material - silicates, magnetite, carbon, ices. The observed shape of the 10 μm emission and the relative 10 μm/18 μm emission can be fit by amorphous olivine, whereas the underlying thermal emission requires the presence of hot absorbing grains. Icy grains may also be present; they can enhance the optical scattering without contributing to the infrared brightness. The effect of these three dust components on the optical scattering and derived albedo will be discussed. Desirable observations of future comets will be suggested.

D.9 OPTICAL POLARIMETRY OF COMET WEST 1976 VI

J.J. Michalsky Jr.

ABSTRACT

The polarization of the continuum of Comet West 1976 VI was measured in four narrowband filters spanning the wavelength range from 440-850 nm. The post-perihelion observations indicated wavelength independent polarization on each of the three occasions on which it was measured. The wavelength independence is in agreement with other polarization measurements of this comet from the visible to the near-infrared, but it counters the general tendency in comets for the polarization to increase with wavelength. The magnitude of the polarization as a function of scattering angle, the wavelength independence, and the infrared and optical photometric properties suggest that dirty silicates ($n_i \sim 0.5$) smaller than 5μm but approaching this size may be responsible. No circular polarization was detected.

D.10 Interpretation of the Polarization Distribution of the Comet West

S. Isobe

Polarization distribution with a high spatial resolution was obtained in the central 3' region of the Comet West by Isobe et al. (1978). We interpret this observation in the way that large icy grains including small silicate and graphite grains in it evaporate by the solar radiation keeping smooth surface in the region of anti-solar direction but have rough surface by atomic collisions in the region of solar direction.

D.11 **Substances of Cometary Grains Estimated from Evaporation and Radiation Pressure Mechanisms.**

by Keiji Saito, Syuzo Isobe, Kimihiko Nishioka, and Tatsuro Ishii.
Tokyo Astronomical Observatory

**Abstract**

Intensity distribution of tails for several big comets are estimated on the basis of grain properties in the solar radiation field. The following results are obtained.

1). Value of the maximum radiation pressure acting on dust grains in any cometary tails is found to be less than 2.5 normalized to the unity for gravitational force. This claims the condition that grains such as graphite particles of size range between 0.02 and 0.2 micron did not exist in them, because the particles suffer big force beyond 2.5.

2). Tail substances supplied arround the time of perihelion passage for two sun grazing comets Ikeya-Seki (1965VIII) and Seki-Lines (1962 III) were composed of the particular grains which have the values of radiation pressure force less than 1.0. Therefore, it is concluded that the substance was composed of silicate grain only, since iron grains had sublimated and there were no graphite particles.

D.12R COMETARY DUST MODELS

D.W. Hughes

This paper reviews our knowledge of cometary dust both when it is in the cometary nucleus and when it has been expelled from that nucleus by gas pressure. The production and break up of the dusty insulating layer that surrounds the nucleus is considered. The basic properties of the dust, such as density, mass distribution, index, shape, strength, charge and composition are reviewed. Special emphasis is given to the way that some of these properties vary as a function of particle size.

The problems of observational selection are also stressed. Dust can be detected in the inner coma, in the dust tails and as meteoroids in meteor streams. The relationships between these three groups of particles are investigated.

The orbits of the dust particles after ejection from the nucleus vary drastically as a function of particle size, this being due to the relative importance of solar gravitation, radiation pressure and solar wind. Models of dust distribution around the nucleus and the dust hazard to spacecraft in the vicinity of the comet are reviewed.

Consideration is also given to the way the cometary dust decays into the solar system dust cloud, the effect of nuclear spin on the dust distribution and evidence for non perihelion emission and the contribution of outbursts to the dust population.

D.13R

# Dusty Gas Dynamics in Real Comets (invited review)

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Two-phase hydrodynamics is used to model the combination of solid grains in outstreaming cometary gas. Evaporation of the grains can be included by allowing mass and energy exchanges. In the space environment, radiative heating of submicron grains is also important.

Radially-symmetric flow is described by a set of ordinary differential equations with a singular point at Mach number $M = 1$. Appropriate solutions for a single size of grain (Probstein, 1969), having in general subsonic Mach number $M_0$ at the nucleus, require calculation as a two-point boundary problem through the X-type singular point. Values of $M_0$ and the terminal speed $v_\infty$ for the adiabatic case (Probstein) and for heated grains (Shul'man, 1972) depend mainly on the dust-gas ratio and grain-gas coupling parameters.

In real comets the dust particle size spectrum is also important. To again model by ordinary differential fluid equations, a number of discrete grain sizes are chosen. Sample solutions given show dependence of $M_0$ and $v_\infty$ on the size distribution. Effects of comet gravity, ice grain sublimation and radiative exchanges of the gas are modelled by additional source or loss terms. Qualitatively it is seen that gravity, increased grain drag and sublimation reduce $M_0$ and extend the subsonic region, while gas cooling (via collisional excitation of molecular rotational modes) tends to counteract these changes.

Visible dust halos would not be produced in steady outgassing, but need describing by an unsteady source giving outwardly propagating shocks. Radial symmetry is not an appropriate assumption for jet-like gas and dust sources, nor for flows within a few radii of the nucleus where there is condensation on the shaded side. The difficulty of treating the partial differential equations for 2 or 3 dimensional flow with a free boundary surface suggests more direct computational approaches.

Probstein, R F, 1969 *Problems of hydrodynamics and continuum mechanics*, (ed. M A Lavrent'ev) p.568, SIAM, Philadelphia.

Shul'man, L M, 1972 *Dynamika kometnikh atmosfer - neitralnii gaz*, Ch.3, Kiev.

Wallis, M K, 1979 *Cometary Missions*, Remeis Sternwarte, Bamberg, 12 (132), p.127

D.14 Dust Production Rates Of Comet Halley: Models For The ESA GIOTTO Comet Halley Probe.

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The spatial distribution and velocities of dust particles in the coma of Comet Halley have been derived. For the emission of ice particles from the comet and their distribution in the coma a modified fountain-model is used, which takes into account the finite lifetimes of the ice particles due to sublimation.Based on these results we discuss the anticipated flux encountered by the GIOTTO probe,to get an estimate of the expected count rates of the Meteoroid Shield Penetration Flash Detector(MSF),which is part of the Dust Impact Detection System(DIDSY).The results are compared with the count rates derived from the Newburn-Divine model.

For selected particle size ranges the influence of the sublimation of the ices on the measurements of the Particle Impact Analyzer (PIA)- Experiment on the GIOTTO-S/C will be discussed.

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D.15 DIFFUSION OF COMETARY DUST BY ELECTROMAGNETIC SCATTERING.

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Interplanetary dust, presumably from comets, is subjected to a large number of small forces, most of them negligible for most particles. For dust in the size range 1 mm – 1 μ, the Poynting-Robertson effect is the most important secular force; radiation pressure is comparable to the sun's gravity for particles 1 – ≲ 1 μ; electromagnetic forces will tend to carry smaller particles out of the solar system with the solar wind. In addition to these secular effects, electromagnetic forces will also tend to act randomly on all particles, and this can lead to a scattering of particles as large as 10 μ from their original orbits on a timescale similar to the Poynting-Robertson timescale, in a manner first outlined by Parker (1964, Ap J 139, 951) and described at length elsewhere (c.f. Morfill and Grün, 1979, Planet Space Sci 27, 1269; Consolmagno, 1979, Icarus 38, 398).

The most complete description of how this scattering works was given in Consolmagno (1980, Icarus 43, 203) who gave the following equations for the mean square changes in dust orbital elements:

$$\frac{\langle \Delta a^2 \rangle}{\Delta t} = \frac{4 a q^2 \Omega^2}{\mu m^2 [\text{illegible}]} \{ [1/r_e + A_1] \sin^2 i P_{rr} + (A_2 + A_3) \cos^2 i P_{\theta\theta} \}, \quad (1)$$

where the terms $A_1$ through $A_4$ are defined by

$$A_1 = \frac{\mu e^2 (4 + e^2)}{16 a r_{rr} [\text{illegible}] (1 - e^2)^{5/2}},$$

$$A_2 = \frac{16 + 7e^2}{32 (1 - e^2)^{3/2}},$$

$$A_3 = \frac{\mu (4 + e^2)}{8 a r_{rr} [\text{illegible}] (1 - e^2)^{3/2}},$$

$$A_4 = \frac{2 + e^2}{2 (1 - e^2)^{3/2}}$$

$$\frac{\langle \Delta e^2 \rangle}{\Delta t} = \frac{[\text{illegible}]\, q^2 \Omega^2}{a \mu m^2 [\text{illegible}]} \{ [E_1 + E_2 + E_3] \sin^2 i P_{rr} + (E_4 + E_5) \cos^2 i P_{\theta\theta} \}, \quad (2)$$

where the terms $E_1$ through $E_5$ are defined by

$$E_1 = \frac{\mu (4 + e^2)}{16 a r_{rr} [\text{illegible}] (1 - e^2)^{[\text{illegible}]}},$$

$$E_2 = [\text{illegible}]$$

$$E_3 = \frac{(1 - e^2)^{[\text{illegible}]} - 1}{2e^2},$$

$$E_4 = 2E_{[\text{illegible}]}$$

$$E_5 = \frac{e^2 + 2(1 - e^2)^{1/2} - 2}{2e^2}$$

$$\frac{\langle \Delta i^2 \rangle}{\Delta t} = \frac{q^2}{\mu m^2 [\text{illegible}] (1 - e^2)} \{ [I_1 + I_2 + I_3] P_{rr} + I_4 P_{\theta\theta} \}, \quad (3)$$

where

$$I_1 = \frac{\mu (2 + e^2)}{2 a [\text{illegible}] (1 - e^2)^{[\text{illegible}]}},$$

$$I_2 = [\text{illegible}] \cos^2 i (1 - e^2),$$

$$I_3 = [\text{illegible}]$$

$$I_4 = 0.5\, \Omega^2 \sin^2 i$$

In these equations, $a$ is the semimajor axis, $q$ the charge on the grain (in esu), $\Omega$ the spin rate of the Sun, $\mu$ the Keplerian constant (gravitational constant times the mass of the Sun), $m$ the mass of the dust particle, $c$ the speed of light, $i$ the inclination of the particle orbit, $e$ the eccentricity of that orbit, $v_{sw}$ the solar wind velocity, and $P_{rr}$ and $P_{\theta\theta}$ the radial and azimuthal (respectively) power spectral densities of the solar wind at 1 AU. These terms and their units are defined at some length in Consolmagno (1979).

COMPOSITION EFFECTS: The amount of scattering depends on $q^2/m^2$; thus a root mean square change varies as $q/m$, which for spherical particles depends linearly on the voltage, V, and the inverse of the radius squared. No hard data exist on the charge state of dust in interplanetary space. Theoretical calculations suggest that a potential of 10V should be expected from the balance of solar UV-induced emission of electrons versus solar wind particle impact. It is possible that materials whose optical properties are dominated by carbon may have substantially lower photoemissivities and consequently lower voltages. In addition, if the mean size of the dust is a function of its composition (e.g. if more friable carbonaceous material makes finer dust) then this could lead to further sorting of cometary dust.

DIFFUSION: The mean square change terms given above are like diffusion coefficients...dust particles will "diffuse" away from their original orbital paths. The rate of diffusion will depend on particle size and charge (hence, composition) and on its position in space. These terms are symmetric about the ecliptic (solar equator) plane; thus we would expect dust to be distributed in a regular way above and below the plane. The shape of the distribution will depend on the sources and sinks. We can use these terms to set up a Fokker-Planck equation to describe the evolution of the distribution function of the dust. If we assume a steady state, such an equation will tell us how the source/sink term varies in space.

A simplified example may illustrate this. Assume the dust is in circular orbits, so that $\langle \Delta a^2 \rangle/\Delta t = \langle \Delta r^2 \rangle/\Delta t$, and this is proportional to the diffusion coefficient. Assume the dust is observed to vary in space as $n = n_0 r^{-1}$. Then, in the diffusion equation $\frac{\partial n}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D \frac{\partial n}{\partial r}\right) + S$, (4)

the source term S in a steady state must vary as $r^{-2}$, consistent with the release of dust from comets increasing with the solar insolation as they come closer to the sun.

In addition, assume that rocky or metallic dust is on average 3 μ in radius with a 10V potential, while carbonaceous dust is 1 μ large, and charged to 1V. This leads to a difference of two orders of magnitude in the diffusion coefficient. The dust which diffuses faster reaches its sinks faster; thus carbonaceous dust would dominate in space, even though it may make up only a small fraction of the dust released by comets.

Finally, note that scattering in inclination is strongest when the inclination is 0, while scattering in semimajor axis increases as the inclination increases. Thus dust in the plane of the ecliptic will be scattered out of the plane first, then towards or away from the sun (and into its sinks), while dust originating in highly inclined orbits will tend to stay in those inclined orbits, and be lost more quickly. One thus ought to be able to calculate the angle from the plane where the maximum dust density should occur. To test, and use, these calculations, one needs both ground and in-situ observations of the distribution of dust as a function of size, composition, and location in space.

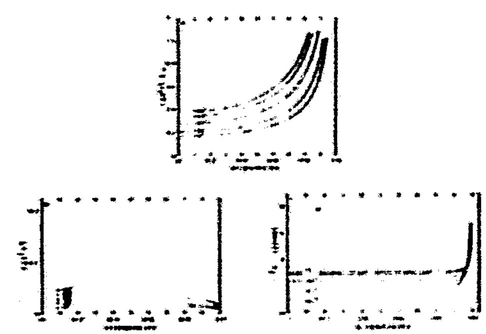

FIG. 1. (a) The root mean square change in semimajor axis for a 1 μm particle charged to 10 V whose original semimajor axis was 1 AU is plotted as a function of original eccentricity [illegible]

D.16 ON THE ELECTROSTATIC CHARGING OF THE DISTANT COMETARY NUCLEUS

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ABSTRACT

The direct interaction of the solar wind and the ultraviolet solar radiation with the cometary nucleus, when it is sufficiently distant from the sun ($d \geq 5AU$) is discussed. It is shown that, while much of the sunlit hemisphere attains significant positive electrostatic potentials ($\approx 5$ V) as a result, the dark hemisphere attains numerically large negative potentials ($\approx -1$ kV). As a result of these surface potentials and associated electric fields, any loose, fine dust that may exist on the surface will levitate above the surface and the smallest grains ($R_g \lesssim 0.1\ \mu$) will be completely "blown off." Consequently at large heliocentric distances a comet could lose a portion of any dusty mantle it may possess without the assistance of any outflowing gases.

D.17 MAPPING OF ACTIVE AREAS ON THE NUCLEUS OF THE PERSEID COMET FROM OBSERVATIONS OF DUST PHENOMENA

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Abstract

Because of its dynamical behavior, dust plays a major role in studies aimed at large-scale surface mapping of cometary nuclei. In contrast to gas, dust motions in comets are highly organized and initial impulses the particles are subjected to are well preserved for some time after ejection. Quantitative analysis of the dynamical evolution of distinct dust phenomena (such as jets, envelopes, etc.) in the coma allows us to trace particle motions back to the nucleus and thus to identify discrete sources of emission on or below the surface. As a byproduct, the analysis also yields information on the rotational properties of the comet, on the ejected dust itself, and on the gas flow that gives rise to the dust emission. - The proposed dynamical approach has been applied to Periodic Comet Swift-Tuttle, the parent comet of the Perseid meteor stream. The results show that the comet's jet activity was a product of brief bursts of dust (duration less than 3 hours) from eight isolated active areas on the nucleus and that 75% of the bursts took place in the cometary "afternoon". Only one of the eight emission areas was demonstrably active throughout the nearly two months of observation; the others were short-lived phenomena. Their distribution over the nucleus was strongly lopsided in cometocentric longitude, indicating that the structure of the surface layer was profoundly heterogeneous. Five of the active regions clustered to form a large ring-shaped feature, perhaps a prominent fault. The comet's rotation period is found to be 66.5 hours and the obliquity $80^{\circ}$. The spin axis made an angle of $60^{\circ}$ with the direction to the sun at the time of perihelion passage. - This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract Number NAS 7-100, sponsored by the National Aeronautics and Space Administration, Planetary Atmospheres Program, Office of Space Sciences.

D.18 GUSTAFSON, BO Å. S. and NEBIL Y. MISCONI (Space Astronomy Laboratory, University of Florida, Gainesville). <u>The Observed Position of the Symmetry Plane of Interplanetary Dust and Its Possible Relation to Dust from Comet Encke</u>.

The dynamical evolution of dust injected into the interplanetary medium by comet Encke in its early stages is investigated on the basis of both long-term gravitational perturbations by planets (Venus, Earth, Mars and Jupiter) on the dust and solar wind electromagnetic forces on the dust. The present location of the dust as deduced from these calculations is compared to the position of the plane of maximum dust density ("symmetry plane") of interplanetary dust.

D.19 Comet Tempel-Tuttle and the Leonid Meteors

D.K. Yeomans

The distribution of dust surrounding periodic comet Tempel-Tuttle has been mapped by analyzing the associated Leonid meteor shower data over the 902-1969 interval. The majority of dust ejected from the parent comet evolves to a position lagging the comet and outside the comet's orbit. The outgassing and dust ejection required to explain the parent comet's deviation from pure gravitational motion would preferentially place dust in a position leading the comet and inside the comet's orbit. Hence it appears that radiation pressure and planetary perturbations, rather than ejection processes, control the dynamic evolution of the Leonid particles. Significant Leonid meteor showers are possible roughly 2500 days before or after the parent comet reaches perihelion but only if the comet passes closer than 0.025 AU inside or 0.010 AU outside the earth's orbit. Although the conditions in 1998-99 are optimum for a significant Leonid meteor shower, the event is not certain because the dust particle distribution near the comet is far from uniform. As a by-product of this study, the orbit of comet Tempel-Tuttle has been redetermined for the 1366-1966 observed interval.

D.20 <u>Lifetime and Origin of Submicron Particles</u>

S. Fred Singer, Univ. Virginia

Submicron particle enhancements are observed for meteor streams associated with Encke but not with Halley's Comet. This suggests a "lifetime" in the meteor stream orbit of 2-5 years. Such a value can be roughly calculated if the particles' electrostatic potential in interplanetary space is about 3 volts. To prevent ejection by radiation pressure, $\beta$ (=radiation pressure/gravitational force) must not exceed $\sim$0.08. This sets close limits on the physical nature of the particles. An LDEF experiment during 1984-1986 should reveal the detailed dynamics of injection due to Halley's Comet, and the subsequent dispersal of particles.

D.21 **Submicron Particles in the Solar System**

John E. Stanley, Univ. of Virginia

Near-earth observations by the Explorer XLVI satellite have revealed the existence of particles of mass $\sim 10^{-16}$ gm. We observe very strong enhancements during certain meteor streams. This had not been seen by previous experiments. It suggests that comets are the source of these particles. A forthcoming LDEF experiment will have a particle event rate 10 times greater than any previous experiment, and permit better time resolution, as well as angular resolution.

D.22 THE MOTIONS OF STRUCTURES IN THE DUST TAIL OF COMET WEST 1976 VI

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Abstract

The dust tails of comets, which are usually smooth and featureless, occasionally show structures which are caused by the fragmentation of relatively large particles. Two types of structures have been observed in the dust tail of Comet West which have been explained by a simple model (Sekanina and Farrell, 1978, Astron. J. 83, 1675; 1980, Astron. J. 85, 1538): streamers or synchrones caused by explosive events at the nucleus, and striae which are caused by particles released from the nucleus during these explosive events that subsequently fragment in the tail. The development of these structures is depicted in a computer-generated motion picture using the parameters derived from fitting the observational data. This work was performed under the auspices of the U.S. Department of Energy. The second author acknowledges support from NASA Planetary Atmospheres Program under Contract NAS 7-100 to the Jet Propulsion Laboratory.

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# PHASE FUNCTION OF POLARIZATION AND BRIGHTNESS AND THE NATURE OF COMETARY ATMOSPHERE PARTICLES

By N.N.Kiselev and G.P.Chernova

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A good deal of information on dust particles properties may be gained from studing the cometary atmosphere brigtness and polarization dependency on the phase angle $\alpha$ . Observations of such a kind of five comets - 1975n West, Schwassmann-Wachmann 1, 1977l Chernykh, 1977g Ashbrook-Jackson, 1978f Meier - were performed in 1976-1980.

Our present investigation and an analysis of previous years observations enable us to make a conclusion that for a typical dusty cometary coma the phase dependency of polarization has a positive polarization maximum as high as 20-30% at $\alpha = 90^\circ$, an inversion angle near $20^\circ$ and a negative polarization branch at $\alpha \leqslant 20^\circ$ with a polarization minimum several percent deep.

For comets 1977g Ashbrook-Jackson and 1978f Meier an opposition effect is found.

The phase dependencies of polarization and the opposition effect of cometary atmospheres showed a striking resemblance to analogous dependencies for minor planets and Zodiacal light.

Mie theory calculations show that in general the inversion of the polarization sign and the opposition effect are characteristic for particles of dielectric nature and of dimensions greater than a few microns. Taking into account these circumstances it is not surprising that one observe a community of particle properties in cometary atmospheres, on the surfaces of minor planets and in the Zodiacal cloud as the particle dimensions in the last two particle assemblies are known to be of the order of several tens of microns.

D.24 Microwave Continuum Observations of the Icy Grain Halo

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and

R.W. Hobbs, Goddard Space Flight Center

A comparison of microwave continuum data for comets with theoretical models of their icy grain halos (IGH) reveals both consistencies and inconsistencies. For example, observations of the six comets made to date (two detections and four upper-limits) can be reconciled with IGH theory provided the gas production rate is allowed to vary about its nominally accepted mean value by about a factor of four. However, the data for Comet Kohoutek (1974f) suggests the grains may not be clathrates but instead have a very substantial refractory component. The present data are probably too sparse to give any more than hints as to the true nature of the IGH. However, future observations with interferometers such as the VLA should provide the most sensitive ground-based data available for studying this region.

C.1R Outstanding Problems in Radio Observations of Comets

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Three general techniques of radio science have been applied to attempt to observe comets: spectral line, continuum and radar observations. Of these, only radio spectral line observations have achieved a degree of success but, even here, the results have been negative more often than positive. Hence a summary of radio observations must take into account our understanding of why radio searches can fail.

Cometary radio spectroscopy is reviewed, starting from the earlier article of Snyder (1976), with particular emphasis placed on current searches for large cometary molecules such as glycine, the simplest amino acid. A brief summary is given of those observational programs which were designed to aid in discriminating between current theories of terrestrial biological evolution (e.g., the Haldane-Oparin theory versus the Hoyle and Wickramasinghe (1977) interstellar virus-infested cometary debris).

Hoyle, F., and Wickramasinghe, C. 1977. Does epidemic disease come from space? New Scientist 17: 402-404.

Snyder, L.E. 1976. Radio detections of cometary molecular transitions: a review. In The Study of Comets, Part 1 (IAU Colloq. No. 25), eds. B. Donn, M. Mumma, W. Jackson, M. A'Hearn, and R. Harrington (NASA Special Publications 393), pp. 232-252.

## C.2 Observations of the OH Radical in Comets at 18 cm Wavelength.

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**Abstract :**

We present a progress report on the observations of the OH radical at $\lambda$ 18 cm in comets with the Nançay radio telescope. Recent observations include comets Meier (1978 XXI), Bradfield (1979 l), Meier (1980 q) and Encke (1980).

The analysis of the OH radio line shape is a powerful tool to study the kinematics of the coma. The expansion velocity of the OH molecules is found to be $\sim 1.5$ km s$^{-1}$ at $r_h = 1$ AU and decreasing with increasing heliocentric distance. The line profile is generally asymmetric, which demonstrates the Greenstein effect on the fluorescent excitation mechanism and/or anisotropic outgassing of the nucleus. In several cases, and especially for comet Meier (1978 XXI), an asymmetry is also found in the East-West brightness distribution of the OH line, showing again Greenstein effect and/or anisotropic outgassing.

An excitation model by UV pumping and fluorescence of the OH radical - which agrees with the observations at least in the first order - and the application of Haser's model lead to the production rate of the parent molecule of OH. There is a close correlation between this gas production rate and the visual brightness of the comets. Our estimates of gas production rates, however, are smaller than or equal to those obtained from UV measurements.

## C.3 SEARCHES FOR MILLIMETER-WAVE EMISSIONS FROM HCN, CS, AND $CH_3OH$ IN COMET BRADFIELD (1979 l)

L. Ekelund, Ch. Andersson,
W.M. Irvine
and
F.P. Schloerb and S.E. Robinson

**Abstract**

We have searched for and not detected emission in the following pure rotational transitions from Comet Bradfield (1979 l):

HCN, $J=1\rightarrow0$; CS, $J=1\rightarrow0$; $CH_3OH$, $1_0\rightarrow0_0$ $A^+$ and $1_0\rightarrow0_0$ E.

We also did not detect the unidentified lines U 86247 and U 89010 reported in Comet Kohoutek (1973 f) by Buhl, Huebner and Snyder. We estimate an upper limit on the HCN production rate considerably below that determined for Comet Kohoutek and probably below the observed CN production rate.

C.4R COMET PHOTOMETRY: PAST, PRESENT, AND FUTURE

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Until the last decade, studies of the photometric properties of the comet coma depended heavily on visual or photographic estimates of "total" brightness. Because of large systematic and random observational errors, most early investigations of comet brightness were of an empirical or statistical nature with little real physical, chemical, or thermodynamical theoretical basis. The introduction of photoelectric techniques have greatly reduced many of the random errors inherent in earlier methods. Although some systematic effects still remain, it is now becoming possible to relate the photoelectric work to both the "classical" methodologies and to realistic models of comet comae. Recent developments in image processing and spectral analysis of time-series data, the greater availability of sophisticated instrumentation for comet studies, and a coordinated effort on the part of all observers hold great promise for future studies of comet brightness and its relationship to the physical and chemical evolution of the comet coma.

C.5 Filter Photometry of Comets.

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Surface photometry of several comets has been obtained with a photometric system employing five intermediate bandpass interference filters. The photometric system was designed for the physical study of comets and is a preliminary version of the proposed standard system developed by the filter committee of Commission 15. The filters were selected to measure the continuum in the ultraviolet at a wavelength of 3650A and in the blue at a wavelength of 4850A. The other filters were centered on the CN band at 3880A, the blend of C3 and CO+ at 4050A, and the C2 band at 5100A.

The filters were used in a computer controlled area scanning photometer. The observations consisted of a set of one dimensional scans, one for each filter centered on the apparent nucleus of the comet. In addition at a few wavelengths two dimensional maps of surface brightness were obtained for each comet. Flux standard stars were observed and extinction coefficients determined so that the intensity profiles and contour levels can be calibrated in absolute units.

Data presently are available for P/Comet Encke, P/Comet Stephan-Oterma, and P/Comet Tuttle. It is possible that data will be available for other comets by the time of the meeting.

## C.6 NARROWBAND PHOTOMETRY OF COMET P/STEPHAN-OTERMA

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Lowell Observatory

and

M. F. A'Hearn
Astronomy Program
University of Maryland

The 1980/81 apparition of Comet P/Stephan-Oterma has provided an excellent opportunity to study this comet's photometric properties. Not only was the object well placed and moderately bright for more than six months, but it also covered a wide range of solar phase angles, reaching a minimum of 2°4 on 14 December 1980. In this paper we present the results of extensive narrowband filter photometry conducted between September 1980 and March 1981 at Lowell Observatory and Mauna Kea Observatory. The production rates of OH, CN, $C_2$, and $C_3$ as a function of heliocentric distance will be discussed. A pronounced brightening of the continuum observed at small phase angles will be considered in terms of the scattering characteristics of dust in the coma.

## C.7E Standardized Filters for Cometary Photometry

Michael F. A'Hearn

The Working Group on Standardized Filters, appointed by IAU Commission 15 at the last General Assembly, has established a set of standardized filters for use in cometary photometry. Funding from the U.S. National Science Foundation has enabled us to order 50 matched sets of the filters. Filters will be available on either a sale basis or a loan basis depending on the needs of the user. The characteristics of the filters and future activities of the Working Group will be discussed.

C.8R Spectroscopy and Spectrophotometry of Comets

at Visible Wavelengths

Michael F. A'Hearn
Astronomy Program
University of Maryland

ABSTRACT

The techniques of spectroscopy and spectrophotometry will be reviewed with emphasis on measurements of absolute or relative intensities as a function of wavelength. This type of data gives us much information about the physical nature of comets which will also be reviewed. Examples of the information which can be derived from spectrophotometric data and which will be discussed include isotope ratios, column densities of various species, which can then be related to production rates and vaporization rates, population distributions among levels which can be related to production mechanisms and excitation mechanisms of the relevant species, reflectivity curves for the solid particles in the coma and tail, and even the velocity distribution of certain species in the coma.

C.9 Spectrometric Observations of Comet Bradfield (1980t)

by

W. D. Cochran, A. L. Cochran, E. S. Barker

The passage of the bright comet Bradfield (1980t) afforded us the opportunity to study at high resolution the $^1P$ - $^1D$ transition of [O I]. On 16 January, 1981 UT, we obtained spectra at 0.4A resolution of the 6300 and 6363A [O I] lines using the Digicon detector on the coude spectrograph of the 2.7 m telescope at McDonald Observatory. The spectra were of a region 1.4 arcsec X 1.6 arcsec on the central condensation. This spectral resolution enabled us to clearly resolve the cometary [O I] lines from the night sky emission lines. Independent spectra of the night sky [O I] emission lines were also obtained.

On 10 January, 1981 UT, we also obtained lower resolution (11A) spectra on this comet covering the range from 3400 to 6100A using the Intensified Dissector Scanner (IDS) spectrograph on the 2.7 m telescope. Spectra were taken on the central condensation, in various places around the coma, and 300 arcsec north of the central condensation. These IDS spectra show a very large ratio of $C_2$ to CN emission.

Relative production rates of the various species will be presented.

C.10 Spatially Resolved Observations of the Inner Coma of Bradfield (1979l)

E. S. Barker

During January 1980 Comet Bradfield (1979l) passed near the earth at a distance of 0.24 AU affording high spatial resolution on the inner coma. The Tull coudé scanner on the 2.7 m telescope at McDonald Observatory was used to obtain spectra in the range 3-6000 Å with a RCA 31034A photomultiplier at 11 Å resolution and the 6-11200 Å region with a Varian 164A photomultiplier at 16 Å resolution.

Five different regions, on the central coma condensation of 5 arcsec (915 km) and regions 12 arcsec away, were sampled between 3000 and 6000 Å using a spectrograph slot of 7 x 14 arcsec (1280 x 2600 km). The spatial distribution of the flux within the inner 30 arcsec coma (5500 km) arising from the various molecular emission bands (OH, CN, $C_2$, $C_3$) and the continuum will be presented.

In addition, spectra of photometric quality and centered on the central coma were taken on the 29 and 30th of January in the red spectral region. The red system CN bands (0-0) at 10925 Å and (1-0) at 9141 Å were detected above the level of the night sky emission. The red CN system band fluxes will be compared to the violet system CN band fluxes from the (0-0) at 3883 Å and (0-1) at 4215 Å.

C.11 Recent Spectroscopic Observations of Comets, S. M. LARSON, Lunar and Planetary Laboratory, University of Arizona - The recent 0.30-0.56μm spectral characteristics of several comets are reviewed. Periodic comets Tuttle and Encke had high gas-dust ratios and well developed emissions from OH, NH, CN, $C_3$, CH and $C_2$. The coma of comet Tuttle was symmetric and diffuse, but comet Encke developed a short dusty sunward fan. Comet Stephan-Oterma (1980g) had a relatively low gas-dust ratio and emissions of OH, NH, CN, $C_3$ and $C_2$. The changes in relative production rates over six months centered on perihelion (1.85-1.53AU) are noted. Comet Bowell (1980b), approaching perihelion next year in a hyperbolic orbit has shown only reflected solar continuum from 7.2 to 5.4 AU. P/Schwassmann-Wachmann 1, displaying $CO^+$ emissions during and between brightness outbursts in 1979 and early 1980 had only a reflection spectrum in mid and late 1980.

C.12 **Spectrometric Observations of Comets Stephan-Oterma and Encke During Their 1980 Apparitions**

A. L. Cochran and E. S. Barker

We obtained Intensified Dissector Scanner (IDS) spectra of the periodic comets Stephan-Oterma and Encke using the 2.7 m telescope of McDonald Observatory. The spectra cover the range from 3400 Å to 6100 Å at 11 Å resolution. The spectra of Stephan-Oterma were obtained in the period from July 1980 to January 1981 and cover a range of heliocentric distances from 2.3 AU pre-perihelion to 1.64 AU post-perihelion. Extensive study of the spatial distribution of the gases in the coma was made.

The spectra of Encke were obtained from July 1980 to October 1980 with narrowband filter photometry after this time to supplement the spectrometry. The spectra cover the heliocentric range from 2.25 AU to 1.20 AU pre-perihelion. Some spatial study was done.

The spectra were first converted to fluxes using standard spectrophotometric techniques and production rates were determined for the various molecular species. Some preliminary models for the chemical structure of these comets have been calculated.

C.13 **Recent results of CCD comet spectroscopy**

J.R. Johnson, P. Turek, U. Fink, S. Larson, B.A. Smith, and H.J. Reitsema

Abstract: Spectra of four comets (Tuttle, Bowell, Stephan-Oterma and Brooks 2) were obtained during November, 1980 using the LPL-CCD spectrograph at the University of Arizona 61 inch Catalina telescope. The spectral coverage extended from 5700Å to 10400Å at ∿ 20Å resolution. Molecular band emissions, of $NH_2$, CN, $C_2$ and $H_2O+$, are identified and their relative intensities are tabulated. Radial intensity distributions across the coma are determined for selected emissions and continuum features. Future observations utilizing the CCD's high quantum efficiency, should enable us to obtain comet spectra at large heliocentric distances possibly revealing information concerning nuclear composition.

This research was supported by NASA grants NSG 7070, NGL 05-002-003 and NASA contract NAS5-25451. The CCD detector system was built at Caltech for groundbese training of the Space telescope Wide Field/ Planetary Camera Team.

C.14 SPECTROPHOTOMETRIC EVIDENCE ON THE SOURCES OF COMETARY $C_2$ AND CN

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We have measured the fluxes in the λ5165 Swan band of $C_2$ and the λ3883 violet band sequence of CN in comets Kohoutek (1973 XII), Stephan-Oterma (1980 g) and Tuttle (1980 h) as a function of distance from the nucleus at various heliocentric distances. These flux profiles and comparisons with similar continuum data place significant limits on the possible sources of the observed radicals.

* Newburn's contribution to this work represents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract Number NAS 7-100, sponsored by the National Aeronautics and Space Administration, Planetary Astronomy Program Office, Office of Space Science.

C.15P DETECTION OF THE PROPER GLOW OF COMET BENNET

Malaise, D. and Cucchiaro, A.

High dispersion spectra of comet Bennet, compared with solar high dispersion spectra obtained with the same instrument, indicate that, superimposed to the normal reflected fraunhofer spectrum, there is a weak but conspicuous glow of the nuclear region on the comet. The nature of this glow, observed for the first time, is unknown.

C.16R ULTRAVIOLET SPECTROSCOPY OF COMAE

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Ultraviolet spectroscopy is a very powerful tool for the study of cometary atmospheres since the four elemental cosmic species, H, C, N, and O, as well as several simple molecules made from these species have their strong resonance transitions in the ultraviolet region of the spectrum. However, due to the opacity of the atmosphere to ultraviolet, these observations must be made from space, and it was not until 1970 that the extensive HI Lyman α envelope, produced by the scattering of solar Lα photons from hydrogen resulting from the photodestruction of cometary water molecules, was discovered in comets Tago-Sato-Kosaka and Bennett. Atomic carbon and oxygen were discovered in rocket observations of comet Kohoutek in 1974, but comprehensive spectra spanning the wavelength range from 1150-3100 Å have been obtained only for comets West (1976 VI), Seargent (1978 XV) and Bradfield (1979 X). The observations of comet Bradfield, made with the orbiting International Ultraviolet Explorer, were the first to span a wide range of heliocentric distance (0.7 to 1.5 a.u.). More recently, several faint comets, including periodic comets Encke, Tuttle and Stephan-Oterma were observed by IUE and their ultraviolet spectra were found to be remarkably similar to those of the previously observed comets. The results of these observations and their interpretation will be reviewed in terms of their contribution to our understanding of both the chemistry and physics of the coma and the composition of the cometary ice.

C.17 THE ULTRAVIOLET BANDS OF $CO_2^+$ IN COMET BRADFIELD (1979L)

M. C. Festou , P. D. Feldman and H. A. Weaver

The ultraviolet spectra of comet Bradfield in the 2200-3300Å region obtained with the I.U.E. spectrograph reveal the presence of important amounts of $CO_2^+$ ions while $CO^+$ ions are not detected.

Spatial information on the ultraviolet doublet at 2883-2906Å have been obtained. New bands of the Fox-Duffenback-Barker band system (sequence Δv=2 of the (v', o, o) → (v'', o, o) transition) have been identified in the present observations as well as in earlier spectra of comets Kohoutek and West obtained from the ground.

The production and loss processes of $CO_2^+$ ions are discussed. The implications for the $CO_2/H_2O$ ratio are examined.

C.18 OBSERVATIONS OF FAINT COMETS WITH IUE

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The ultraviolet spectra of four faint comets (p/Encke, p/Stephan-Oterma, p/Tuttle, and Meier (1980q) ) were obtained using the IUE satellite during October-December 1980. The spectra are compared with each other and with spectra of comet Bradfield (1980 X) which was observed earlier in the year with IUE. All spectra are quite similar which may indicate a common composition and origin for these comets. Comet p/Stephan-Oterma is distinguished from the others by a relatively high dust/gas ratio. Water production rates are derived for all of the observed comets. Brightness maps were obtained for comet Encke and compared to model predictions. The water production rate derived for comet Encke ($Q_{H_2O} \sim 8 \times 10^{27}$ mol/sec for r = 1 a.u.) is considerably higher than the value derived by Bertaux et al. (1973) from OGO-5 measurements of Lyman α emission from p/Encke made in 1970.

C.19R Photochemical Processes in the Inner Coma

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Very little evidence exists about the physical structure and chemical composition of a comet nucleus. Thus, one purpose of modeling the coma is to characterize the chemical and physical properties of the nucleus by fitting coma model calculations to coma observations.

Models for inner coma chemistry are reviewed. In the most advanced, recent models over one hundred species undergo time-dependent chemical kinetics with many hundreds of chemical and photolytic reactions in an outstreaming, constantly diluting coma gas. Solar ultraviolet radiation and opacity of the coma, fluid dynamic flow--going over into free particle flow in the outer coma--and chemical kinetics must be linked intimately in a realistic model.

The physics relevant to the chemistry in the coma is summarized. The interaction of solar radiation with the coma and the photolytic and chemical processes are described in the context of a chemical reaction network. As specific examples, the formation and destruction of a few observed species are traced through such a network. Parallel reaction paths, i.e., different reactions that lead to one and the same end product are very important: (1) The uncertainty of the final product abundance tends to be smaller than would be predicted from the uncertainty of the rate coefficients from any one of the reaction paths, (2) Different reaction paths dominate in different parts of the coma or at different heliocentric distances of the comet. This second reason also indicates that it may not be possible to greatly simplify reaction networks.

Compositions based on an origin of comets in the presolar nebula or in a companion fragment thereof yield abundances of $C_2$, $C_3$, and CN that are in good agreement with observations, both in heliocentric distance of the comet as well as with respect to distance into the coma. This is not the case (with present models) if the composition is nearer to chemical equilibrium as would be expected if the origin of comets were in the neighborhood of the giant planets. Comparison of model results with observations also indicates some severe restrictions on the composition of the nucleus. The ratio of $CO^+$ to $H_2O^+$ column density is still not in agreement with the only observation that has been reduced. Some alternatives are discussed. A list of physical and chemical processes that will improve the models is presented at conclusion.

C.20P

## OH Fluorescence in Comets

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Astronomy Program
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We have carried out calculations of the fluorescence equilibrium of OH in the solar radiation field as a function of heliocentric radial velocity. The fluorescence efficiency for the 0-0 band ($A^2\Sigma - X^2\Pi$) varies by a factor of 5 for radial velocities between -60 and +60 km $s^{-1}$. Relative intensities of the 1-1 and 1-0 bands also vary with velocity. Comparison of detailed band profiles with observed, high-resolution spectra of all 3 bands in Comet Bradfield (1979ℓ) shows good agreement. In some comets, collisions can modify the populations of levels within the ground states sufficiently to significantly change both the band profile and also the fluorescence efficiency. Comparison of spectra on and off the nucleus of Comet Seargent (1978m) shows the effect of collisions in the region near the nucleus. We have also calculated theoretical spectra for a combination of two populations, one in collisional equilibrium and one in fluorescent equilibrium, for a variety of radial velocities. These will enable us to estimate the importance of collisions in comets for which the radial velocity is such that the population in fluorescent equilibrium is quite different from that in collisional equilibrium.

C.21R

## LABORATORY STUDIES OF PHOTOCHEMISTRY AND SPECTROSCOPY APPLIED TO COMETS

William M. Jackson

Our basic understanding of comets has been obtained from remote observations of the electromagnetic radiation emitted by these bodies. These observations have consisted of identifying the atom, ions and radicals responsible for the spectral lines that extend from the vacuum ultraviolet region to the radio region of the spectra. Once the species responsible for the emissions have been identified, detailed studies can be made of the intensities of these lines, both as a function of the heliocentric distance, and as a function of the radial distance from the center of the cometary nucleus. To interpret these spatial studies, one needs a detailed knowledge of the spectroscopy of the species that have been observed in the cometary coma. This detailed knowledge can only be obtained from laboratory studies. The laboratory information that is needed is the lifetime of the appropriate excited states and the branching ratios from a given excited state to various levels of the lowest state. The first part of the review will cover these aspects of the spectroscopy of the identified species in comets and point out what new additional information is required for interpreting cometary data.

Since most of the species that have been observed in comets are unstable radicals, ions, and atoms which cannot be stored in the icy cometary nucleus, we must have some mechanism for producing them in the coma. Currently, the photodissociation and photoionization of parent molecules are the theories that have had the most success in explaining the observed species in comets. The second part of this review will cover the details of these photodissociation and photoionization mechanisms that are presumed to be responsible for the observed cometary species. In each case the dynamics of the photochemical processes will be reviewed in an effort to define how the excess available energy is partitioned between the fragments. This information is important if one is to understand the spatial profiles of the various spectral emissions taht are observed in comets.

C.22T LABORATORY STUDIES OF ION CHEMISTRY IN COMETARY ATMOSPHERES

We have obtained laboratory data on the product distribution and rate constants for the following ion-molecule reactions in cometary atmospheres:

1) $OH^+$, $H_2O^+$ reacting with $CH_4$, CO, $CO_2$, $H_2$, $O_2$, NO, HCN
2) $NH_2^+$, $NH_3^+$ reacting with CO, $CO_2$, $N_2$, HCN
3) $CO^+$ reacting with $H_2O$, $CH_4$, $CO_2$, $NH_3$, $H_2S$, $O_2$, HCN
4) $CO_2^+$ reacting with $H_2O$, $CH_4$, $NH_3$, $H_2S$, $O_2$, HCN
5) $CH_4^+$ reacting with CO, $CO_2$, HCN
6) $N_2^+$ reacting with $H_2O$, CO, $CO_2$, $CH_4$, $NH_3$, $H_2S$, HCN
7) $CN^+$, $HCN^+$ reacting with $H_2O$, CO, $CO_2$, $CH_4$, $NH_3$, $N_2$, HCN

All the above ions are major products of photoionization (or electron-impact ionization) of suspected parent cometary volatiles. The neutral species on the right together make up a list of potential parent volatiles. This set of reactions supplements the data set of major ionic reactions for comets published earlier [Astrophys. J. Suppl. Ser. 33, 495 (1977)]. Models of the chemistry occurring in a water-dominated cometary coma inside the contact surface have been constructed using these data [Mitchell, Prasad and Huntress, Astrophys. J. 244, in press].

C.23 1. "The Production Rates of [OI] in Recent Comets"

Hyron Spinrad
John R. Stauffer
Dept. of Astronomy, Univ. of California, Berkeley

We have measured the fluxes of the forbidden red auroral lines of oxygen in eight comets, to a maximum heliocentric distnace of 2.04 A.U.

For all those comets the scale length for the λ6300 lines are very short, probably under $10^4$ km. In 1980, P/Encke's [OI] 'D production rate went from $2 \times 10^{26}$ oxygen atoms $s^{-1}$ at r = 1.89 A.U., to ~ $2 \times 10^{27}$ atoms $s^{-1}$ at r = 0.83 A.U. This production change corresponds to a power law index of -2.8 in r.

The ratio of CN (0,0)/[OI] at the cometary photometric nucleus appears to vary considerably in the sample of comets so far scanned at Lick.

We will also discuss the total volatile production rates extrapolated from the [OI] 'D lines in terms of absolute cometary mass-loss.

C.24 DYNAMICAL COMA MODELS FOR COMET BENNET

Cucchiaro, A. and Malaiso, D.

For the first time, we have introduced the effect of time and space variations of the source function of the gas at the nucleus of comets. These variations are normally observed as outbursts and jets in many comets, and have been measured on photometric profiles obtained by the author for comet Bennet. Several models are given to compare with the observations. Namely: monocinetic with Gaussian distribution, Maxwellian with cosine distribution, and monocinetic with cosine distribution. These bursts decay exponentially with various time constants and are directed towards the sun or towards the tail. It is shown that a burst towards the sun modifies the so-called "scale length" on the sun's side of the nucleus, but does not affect the photometric profile on the tail's side. The number of molecules contained in a single burst compares with the total content of the head.

C.25 **MODELS OF THE COMETARY COMA IN WHICH ABUNDANCES OF OBSERVED SPECIES ARE CALCULATED FOR VARIOUS HELIOCENTRIC DISTANCES**

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One-dimensional radial models of the chemistry in cometary comae have been constructed for heliocentric distances ranging from 3 AU to 0.25 AU using a network of reactions consisting of 1051 gas phase reactions and 111 photolytic reactions. The coma's opacity to solar radiation is included and photolytic reaction rates are calculated for solar minimum flux and for solar maximum flux. Model abundances of $C_2$, $C_3$, CN, CH, $NH_2$, and OH are compared with abundances derived from observations of these species. We find that a parent volatile mixture similar to that found in interstellar molecular clouds gives the most satisfactory agreement with observed coma abundances.

C.26 CHEMICAL COMPOSITION IN COMETARY COMAE*

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and

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One-dimensional radial models of the chemical composition of cometary comae have been constructed in order to infer the composition of volatiles in the nucleus using observations of the daughter products. These models consider both photochemistry and the comet-solar wind interactions. If the latter is similar to Venus-solar wind interactions, then the electrons may be heated by Joule heating or by the absorption of whistler waves generated in the plasma sheath. Hot electrons would affect the chemical composition through the temperature dependence of dissociative recombinations and through increased population of excited and reactive species.

The model under development includes the use of a large library of photochemical reactions. The computer code scans the library at frequent intervals of distance from the nucleus, and determines the important production and loss mechanisms for individual species from the library of reaction. This approach is useful for deriving the composition of the nucleus from the observed composition of the comae, because this derivation could involve a large number of trials with various assumed nuclear compositions.

Early results from this model suggest that a mixture of parent volatiles derived by assuming the comet to originate from a gas with composition similar to that found in the interstellar medium is successful in accounting for the observed comae column abundances of $C_2$, $C_3$, CN, CH, OH and $NH_2$.

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*This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract Number NAS7-100, sponsored by the National Aeronautics Space Administration.

I.1R **OBSERVATIONS AND DYNAMICS OF ION TAILS**

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**Abstract**

Photographs of comets reveal a constantly changing array of structural features such as rays, streamers, knots, kinks, helices, condensations and disconnected tails. Historically, the physical emission of the $CO^+$ molecule has been used to indicate the location of the magnetized cometary plasma. The observational situation and the suggested physical explanations are briefly reviewed. Until recently, however, the general approach to the structure in cometary plasma tails has not generally concentrated on the connection between the various features.

There are signs of maturity in this subject because recent work on structure and evolution has tended toward regarding it as regular phenomena with (hopefully) a specific physical cause. A tentative morphology of plasma tail evolution has been developed, and it can be interpreted as the interaction of the comet with sector boundaries in the solar wind (utilizing magnetic reconnection). Thus, there appears to be a regular "forcing function" which produces the systematic evolution of the plasma tail.

The study of plasma tail evolution is greatly hampered by the general lack of continuous coverage of one week or more. Some extended coverage was possible in 1908 with comet Morehouse (because of its high declination) and isolated time sequences have been obtained. Nevertheless, the foundation of our morphological view of the plasma tail is based on fragmentary data. The appearance of Halley's Comet in 1985-86 presents an unparalleled opportunity to obtain extensive coordinated sequences of photographs which should place our understanding of basic cometary plasma morphology on a sound observational footing.

I.2R Theories of Physical Processes in the Ion Tails

W.-H. Ip, W.I. Axford, J.F. McKenzie

(Abstract)

The solar wind interaction with a cometary atmosphere has many of the physical ingredients observed in planetary magnetospheres. As far as global dynamics are concerned, these include the occurrence of a shock in the solar wind upstream of the comet and the generation of a large-scale current system resulting in the formation of a long magnetotail. Some of the activity observed in ion tails may be interpreted in terms of physical phenomena known to take place, for example, in the magnetospheric environments of the Earth and Venus and in laboratory simulation experiments. Cases in point which will be discussed are the occurrence of Kelvin-Helmholtz instability in the ion tail and magnetic field reconfiguration as a result of disruption of the tail current system.

1.2R (continued)

The comet-solar wind interaction is dominated by the penetration of the solar wind plasma into the neutral cometary atmosphere and the subsequent pickup of the cometary ions by the plasma flow. As a consequence, the solar wind tends to be heated due to the assimilation of cometary protons from the hydrogen coma; heavy ions such as $C^+$, $O^+$, $OH^+$ and their corresponding parent molecules ($H_2O^+$, $CO^+$, and $CO_2^+$) would first appear as very energetic. Thermalization of these suprathermal ions in the dayside coma is expected to be associated with plasma instabilities. The tailward flow of the cometary plasma is in part affected by the charge exchange, ionization and ion-neutral reactions in the coma and the resulting chemical composition of the ion tail will be discussed. In addition to the large-scale "steady state" configuration (with a length scale $l \gtrsim 10^5$ km) the importance of small-scale spatial structures ($l \lesssim 10^4$ km) as well as temporal variations of the ion tail will also be stressed. Though theoretical in nature, the discussions in this review will follow closely morphological studies obtained from observations.

## I.3R Plasma Flow and Magnetic Fields in Comets

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As a comet in the interplanetary medium seeds heavy molecular ions over an extended area the flow of the solar wind is changed to subsonic at a distance from the nucleus where the mass flow of cometary ions can compete with the mass flow in the solar wind. This estimate is confirmed by a hydrodynamic model. For typical stationary conditions the bow shock can be calculated as a rotationally symmetric free surface with a standoff distance of order $10^6$ km for a gas production of order $10^{30}$ molecules per second. In the subsonic domain the plasma flow is further braked and the imbedded transverse magnetic field amplified till at about 30 000 km from the nucleus the magnetic stresses enforce a limited asymmetry in the flow parallel and perpendicular to the field. This asymmetry affects all flow parameters including the density of cometary ions. It can be calculated for a stationary magnetohydrodynamic model with an explicit three-dimensional code for a suitable grid. The total delay of an interplanetary magnetic field line passing through the cometary coma comes out to be of order 10 hours. As the transverse interplanetary magnetic field changes its direction within hours abruptly and drastically the asymmetric nature of the flow should become visible as fine structure similar to the observed envelopes and streamers. A suitable superposition of the stationary threedimensional models allows a prediction of this fine structure.

I.4

## THE COMETARY IONOSPHERE

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The interaction of the solar wind and solar radiation with a comet, as the comet moves around the sun, is discussed. It is shown that the nature of this interaction is highly variable. It is also shown that the cometary neutrals play a dominant role in standing-off the solar wind, particularly during "quiet" conditions in the solar wind. Consequently the cometary ionosphere is generally highly incompressible, although it can be highly inflated subsequent to its interaction with a high speed solar wind stream.

The generally prevailing view, that the solar wind is gradually decelerated ahead of the outer shock front due to its contamination with heavy cometary ions, is shown to be not universally true. In certain circumstances the cometary neutrals cannot penetrate the ionopause to interact with the solar wind ahead of it. Then the solar wind is decelerated via a strong shock ($M \approx 10$) rather than the weak one ($M \approx 2$) present at other times.

At all times the outflowing cometary ions are decelerated and diverted into the tail by a strong "inner" shock which is also of a variable nature. When the cometary neutrals cannot penetrate the ionopause, this inner shock is of a special type. It becomes a hybrid "ion-neutral" shock, wherein not only the ions but also the neutrals are decelerated and diverted into the tail.

Strong outer shocks and ion-neutral inner shocks are present only when the comet is sufficiently close to the sun ($d \leq d_c$). For an "average" ($R_n \approx 1$ km) comet dominated by $H_2O$ $d_c \approx 0.75$ AU, whereas for such a comet dominated by $CO_2$ or $CO$, $d_c \gtrsim 2$-$3$ AU.

I.5

## Cometary Molecular Densities and the Production of Type 1 Tail Rays

David Beard, U. Kansas

Type 1 tail rays are (i) energetic having observed kinetic energies of tens of electron volts perion, (ii) highly ionized having observed ion densities of up to 300 ions/cm$^3$, (iii) produced in a region deduced from the narrow width of the rays to be less than 1000 km thick. The sharp discontinuity and copious supply of energetic electrons required for the observed phenomena can occur only in a strong magnetohydrodynamic shock. This shock will not occur unless the gradient of cometary molecular density is steep. A gradual decrease of density ($n \sim r^{-2}$) will result in gentle slowing of the solar wind because of ionization by charge exchange in the solar wind and solar photoionization far out in front of the comet. An appropriate much steeper decrease in density ($n \sim r^{-4}$) will result from solar radiation pressure on the CO molecules in the cometary atmosphere. We suggest a scale length of about $10^4$ km due to the unmeasured resonance fluorescence of CO over the entire solar spectrum and the adiabatic cooling of evaporated CO molecules in the collision dominated region close to the comet nucleus.

## I.6 PECULIARITIES IN THE IONIC TAIL OF COMET IKEYA SEKI (1965f)

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Direct photographs of Comet Ikeya Seki (1965f) obtained on four consequetive days from October 29 to November 1, 1965 are used for an analysis of the multiple helical structures in the ionised tail material. The formation of these structures is explained on the basis of plasma instabilities excited in the tail containing twisted magnetic fields. The growth rate of the modes excited at the mode rational surface agrees well with the observed results. This model also accounts for the presence of harmonic structures seen in this Comet.

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*Abstract:*

*Photographs of the tail of Comet Kohoutek 1973 XII, taken between 8 and 24 of January 1974, were collected from all over the world. These pictures allow to study the kinematics of the ion tail of the comet with respect to solar wind measurements corotated to the location of the comet.*
*The observations are discussed in the light of present theories of ion tail formation and compared with similar observations of other comets. Particular attention is drawn to some large disturbances of the cometary plasma which partly have already been discussed in the literature. It appears that we are still far from understanding their physical nature.*

I.8T CONFIGURATIONS OF EVOLVING PLASMA TAIL RAYS

Freeman D. Miller

Geometrical and kinematical properties of systems of plasma tail rays intermediate between the classical collapsing parabolic envelopes and long straight rays are under study. For comparison with theories of ray evolution, the forms of "young", relatively short, curved rays have been evaluated, using Michigan Schmidt plates of Comets 1969 IX and 1970 II. On four nights, two or more plates permit measurements of changes in ray configurations.

Five examples of outbursts of ray formation resulting in groups of several closely spaced rays (Comet 1957 V, two ; Comets 1969 IX, 1970 III, and 1979f, one each) appear to be the result of repeated pulses of plasma ejection. If these rays are truly tube-like in cross-section, the structure of such a group appears to require that the velocity vectors of successive plasma injections were confined to very nearly the same plane. A contrary view is that a ray is, in fact, a thin plasma sheet lying on a surface of revolution about the tail axis, and visible because that part of the surface occupied by plasma intersects, or nearly intersects, the plane of the sky. This hypothesis relaxes the severe restriction on the ejection velocity vectors implied by the ray-tube model.

I.9 ON THE FOLDING PHENOMENON OF COMET TAIL RAYS

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and

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Abstract

The mechanism of ray closure due to convectional electric fields is proposed. The ray closure is shown to be described by means of the Chew-Goldberger-Low quasihydrodynamics and obeys the Ferraro's isorotation law. Both the magnetic field and the plasma conductivity in the tail can be obtained by means of the observations of the folding phenomenon. The magnetic field B of about 30-40$\gamma$ in the coma and $1\gamma < B \lesssim 10\gamma$ in the distant tail (at 1 AU) is estimated for a "Venus-like" interaction. If the bow shock is not formed the magnetic field $B \lesssim 10\gamma$ (at 1 AU) is expected both in the coma and in the tail.

I.10 CONNECTIONS BETWEEN THE SOLAR WIND AND THE LARGE-SCALE PROPERTIES OF COMETARY PLASMA TAILS--THE ROLE OF MAGNETIC RECONNECTION

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For nearly 100 years, cometary plasma (type 1) tails have been known to undergo remarkable transformations and outbursts, comet Morehouse 1908c unquestionably being the most outstanding and well known example. At the heart of most of these disturbances is the disconnection of the plasma tail, or disconnection event (DE). In several instances, sudden brightness surges in the head and plasma tail have been observed at the time a DE was taking place, which implies that the disconnection mechanism is also capable of enhancing the ionization rate of the cometary neutrals.

A current explanation of these traditionally puzzling phenomena invokes Alfvén's (1957) theory of plasma tails and the interaction of comets with the sector structure of the solar wind. The physical process which disconnects the tail and provides the energy for the ionization surge is magnetic reconnection, which is strongly forced when impinging magnetic fields past a sector boundary are pushed into oppositely-polarized fields already captured into the head region from the previous magnetic sector.

The purpose of the talk is to discuss the fundamental conditions under which reconnection is likely to occur in the heads of comets at interplanetary sector boundary crossings. Specific problems of interest are the duration of reconnection during the "pre-disconnection phase" of a DE, the reconnection rate, the possible operation of plasma micro-instabilities in the neutral sheet region, the dimensions of the diffusion region, and ionization time scales associated with the reconnection process.

I.11 Constraints on Magnetic Merging and Particle Acceleration in Cometary Tails

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Abstract

High energy particles are produced by magnetic merging in the tail of the Earth's magnetosphere, and the question arises as to whether such a process might operate in a cometary tail. For example, Hill and Mendis (1980) have suggested that beams of 1 KeV to 10 KeV electrons in cometary ionospheres might lead to disruption of dust grains far down the tail. Also, Ip and Mendis (1976) have suggested that resistive instabilities in the cometary tail might divert currents through the inner coma and cause rapid ionization in this region. However, in the case of a cometary tail the high ion density and weak magnetic fields result in low Alfven speeds and therefore limit the particle acceleration that might be caused by either transient or time independent electric fields (Tsurutani et al., 1976). For time independent merging the maximum reconnection electric field is determined by the Alfven velocity; for transient electric fields due to instabilities the condition $dB/dt = \text{curl } E$ results in a limit for the product $E\,t$ (where $t$ is the duration of the transient) determined by the width of the region over which magnetic field is being annihilated. For a cometary tail of $10^4$ m width, an ion density of 100 $cm^{-3}$, an average mass of 28 AMU, and a magnetic field within the comet tail of 2 gamma (by theory and analogy to Venus), the maximum steady state merging electric field is $1.65 \times 10^{-4}$ v/m and the cross tail potential is 165 volts. If transient electric fields are caused by the rapid growth of an instability in the neutral sheet

I.11 (continued)

region, the condition that t must be long enough for the particle to cross the length of the acceleration region and the condition that the width of the acceleration region be no greater than an electron gyroradius (the thickness of the region over which the electrons are the dominant current carriers) leades to the conclusion that electron energies can be increased by no more than the electron thermal energy; for most electrons the energization will be much less. Alternatively, if an instability (for example, an ion drift mode, Huba et al., 1978) grows over an extended region in space the heating may be estimated from the free energy that is available. In this case, if all available magnetic field energy density is used to heat electrons, the average energy increase of an electron would be 0.1 eV. Some electrons could be heated to much higher energies, but energy conservation would require that the fraction of such electrons be very small. We conclude that magnetic merging and/or resistive heating due to plasma instabilities in the tail neutral sheet can not lead to significant ionization of cometary material or disruption of dust.


Hill, J.R., and D.A. Mendis, The Sudden Disruption of Dust in Cometary Tails, EOS, Trans. Amer. Geophys. Union, 61, 1022, 1980.

Ip, W.H., and D.A. Mendis, The Generation of Magnetic Fields and Electric Currents in Cometary Plasma Tails, Icarus, 29, 147, 1976.

Tsurutani, B.T., B.E. Goldstein, and A. Bratenahl, Acceleration of Energetic Particles of the Outer Regions of Planetary Magnetospheres: Inferences From Space and Laboratory Experiments, Planet. Space Sci., 24, 995, 1976.


## I.12 ROLE OF HIGH-FREQUENCY-TURBULENCE IN COMETARY PLASMA TAILS


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There have been some attempts to explain the wavy structure, observed in the plasma-tails of some of the comets, in terms of the nonlinear Kelvin-Helmholtz instability which arises due to the interaction of solar wind with the cometary plasma. These models, however, do not try to explain as to why these structures do not appear throughout the length of the tail. This can be easily explained if one considers the solar wind - cometary tail interaction in the presence of high-frequency Langmuir turbulence which has been observed in the interplanetary space by recent satellites. Nonlinear Langmuir waves with frequencies $\omega < \omega_p$ ($\omega_p$ being the plasma frequency) can propagate in a collisionless plasma column without an appreciable damping but waves with $\omega > \omega_p$ however are strongly Landau-damped. These nonlinear Langmuir waves drastically affect the growth rate of the Kelvin-Helmholtz instability, so much so that the latter can even be suppressed. If one accounts for the density inhomogeneity in the tail plasma, one can show that only at a distance greater than some critical distance $R_c$ from the comet-head, this instability can grow. Nonlinear saturation in the growth rates can then reasonably account for the observed wavy structure in the tail.

I.13 SOLAR WIND INTERACTION WITH COMETS: LESSONS FROM VENUS, C.T. Russell, J.G. Luhmann and R.C. Elphic, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024.

The in-situ measurements of the Pioneer Venus orbiter provide some guidance to our understanding of the interaction of the solar wind interaction with comets. Although Venus does not possess an intrinsic magnetic field of sufficient strength to aid in the deflection of the solar wind flow, the upper atmosphere of Venus is only weakly coupled to the solar wind. The decoupling occurs because the magnetized solar wind plasma does not typically penetrate the Venus ionosphere but rather forms a magnetic shield above the ionosphere which remains free of any large scale field. The ionosphere thus forms a "hard" obstacle to the solar wind and a bow shock forms in front of Venus to divert the supersonic flow of the solar wind. This bow shock is somewhat weaker than the terrestrial shock, presumably due to the removal of solar wind ions from the flow by charge exchange downstream from the bow shock. A comet's weaker gravitational pull would allow the same type of charge exchange process to much greater distances possibly even upstream from the bow shock.

Venus has a sizeable magnetotail, in part because of mass loading of field lines draped over the dayside by photoionization of the neutral upper atmosphere. These "hung-up" field lines move slowly over the dayside ionosphere while their ends are pulled far behind the planet by the solar wind. For comets this mass loading is expected over a much larger scale and to lead to even more extensive magnetic tails than at Venus. The orientation of the field in the Venus magnetotail is determined by the direction of the interplanetary magnetic field. Variations in the direction of the IMF lead to the reconstruction of a new magnetic tail possibly with reconnection of magnetic fields playing a role.

Finally, the ionosphere of Venus is not always field free. Occasionally when the solar wind dynamic pressure is high, part of the ionosphere becomes highly magnetized apparently with the geometry of a circumferential belt. Even when the solar wind pressure is low what appear to be thin twisted filamentary magnetic structures or "flux ropes" occur throughout the ionosphere. Similarly the cometary solar wind interaction should be sensitive to the solar wind pressure varying both with radial distance and with the azimuthal stream structure of the solar wind.

O.1R Evolution Of Comets From Interstellar Matter To Interplanetary Matter

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This paper will present a brief but critical theoretical and observational evaluation of theories and laboratory studies of interstellar dust as a key ingredient of the primordial comet material. This will include among others, our recent work on ultraviolet processing of grains and the formation of complex organic molecules. Following this I will review recent developments on theories of condensation of comets from interstellar clouds. The next section is a summary of detailed calculations which are now in progress here on the thermal evolution of bodies of cometary size. (A preliminary report was presented by D'Hendecourt at the Garching Comet Workshop in March.) This is a study, in depth, of the possible evolutionary tracks of various bodies as a function of size, time of formation, initial chemical composition, initial heat sources such as $^{26}Al$. The aim is to predict ultimate surface properties and to what depth in the comet. They apply albedo, chemical composition, atomic and molecular abundances are deduced where possible. Inferences will be drawn of the relationship of surface properties to the formation of dust (of what kind) and how this is connected with the solid particles detected in the solar system by zodiacal light, in situ measurements such as those of Fechtig et. al., lunar rock cratering, and particle collections in the upper atmosphere as by Brownlee.

0.2

## The Increasing Chemical Complexity of Cold, Dark Interstellar Clouds

William M. Irvine

ABSTRACT

It has been suggested by several investigators that comets may be frozen conglomerates of interstellar volatiles and grains, formed during the collapse of the molecular cloud which ultimately formed the sun and planets. Available data on cometary parent molecules and dust grains are consistent with this view. It therefore becomes important to determine the chemical composition of interstellar molecular clouds. The cold, dark clouds in Taurus, which are relatively nearly the solar system, are possible formation sites for solar mass stars. Knowledge of their chemical complexity has increased markedly in recent years, with the identification of the cyanopolyynes (H (C≡C)$_i$CN, i = 1, , 4), which are chemically related to the carbynes which have been found in meteorites and suggested as constituents of interstellar grains.

High spatial and spectral resolution studies of Taurus Molecular Clouds One and Two have been carried out in 1979-80 at the Onsala Space Observatory, and have resulted in the first detection in such regions of SO and the radical $C_3N$. We report here the detection of two additional organic molecules in TMC-1, for one of which this marks the first detection in the interstellar medium. Relative abundances of possible precursers to the observed cometary molecules $C_2$ and $C_3$ will be tabulated.

0.3R

## DYNAMICAL HISTORY OF THE OORT CLOUD

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The hypothesis of a cloud of comets surrounding the solar system and extending out to interstellar distances as suggested by Oort (1950) has been very successful in explaining the observed distribution of orbits of the long-period comets. Oort demonstrated that the motion of comets in the cloud is controlled by perturbations from random passing stars. Recent numerical studies employing Monte Carlo techniques have further expanded our understanding of the dynamics of comets in the Oort cloud. It is shown that the population of the cloud has been depleted over the history of the solar system. If comets formed in orbits near the outer planets and were subsequently ejected to the cloud, then only about 15% of the original population still remains. However if comets formed further from the sun in satellite fragments of the primordial solar nebula, then the depletion is less severe with possibly up to 70% of the initial population surviving. Estimates of the current cloud population range between 1.1 and 2.0 x $10^{12}$ comets, roughly an order of magnitude greater than Oort's original estimate. Loss mechanisms from the cloud are: diffusion of cometary perihelia into the planetary region where planetary perturbations will eject the comets from the solar system; diffusion of cometary aphelia to distances beyond the Sun's sphere of influence (~2 x $10^5$ AU); and direct ejection due to close encounters with passing stars.

0.3R (continued)

The numerical simulations are used to examine the relative fraction of comets going into each end-state or surviving, as a function of the initial perihelion and aphelion distances of the comet orbits, and the total magnitude of the random stellar perturbations. Weissman (1980) has shown that the r.m.s. perturbation of the comet aphelion velocities by passing stars is $\sim$113 m/s over the history of the solar system, equivalent to the escape velocity at $1.4 \times 10^5$ AU from the sun, or the circular orbit velocity at half that distance. Thus the limit on the radius of the Oort cloud is on the order of $10^5$ AU. Marsden et al. (1978) have shown that the mean aphelion distance of new comets entering the planetary region from the cloud is $4.32 \pm 0.12 \times 10^4$ AU. The effect of the stellar perturbations is largely to randomize the orbits of comets in the cloud, leaving little evidence of the initial formation site of the comets.

In addition, the numerical models are used to find the distributions of perihelia and energy for comets in the present Oort Cloud. This work was supported by the NASA Planetary Geophysics and Geochemistry Program.

References

Marsden, B.G., Sekanina, Z., and Everhart, E., Astron. J., 83, 64, 1978.

Oort, J.H., Bull. Astron. Inst. Neth., 11, 91, 1950.

Weissman, P.R., Nature, 288, 242, 1980.

## 0.4 The Effect of Star Passages on Cometary Orbits in Oort's Cloud

by H. Scholl, A. Cazenave, A. Brahic

ABSTRACT

We investigate with two independent numerical methods the dynamical evolution of cometary orbits under the gravitational influence of passing stars in a three-dimensional model Sun-Comet-Star, where both star and comet move. The parameters of the model are minimum distance between passing star and comet, relative velocity between star and Sun, and all the orbital elements of a cometary orbit.

We particularly investigate dynamical configurations which yield strong decreases in perihelion distances. The most favorable cases for the delivery of these "observable" long-period comets are obtained if the cometary orbital plane is perpendicular to the star's orbital plane and if an additional particular geometrical configuration is given. After such an event, the direction of the semi-major axis of the cometary orbits coincides with the line of conjunction Sun-Comet-Star.

The result of our calculations can serve as a basis for a tentative search for families of long-period comets which were perturbed into their present orbits by the same passing star. In addition, these results provide empirical rules for the changes of cometary orbits due to a passing star.

0.5R EVOLUTION OF LONG AND SHORT PERIOD ORBITS

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The orbits of short period comets belong to the class of "chaotic" orbits. This type, always of inclination less than 35°, includes near-parabolic orbits with perihelia near Jupiter's orbit or beyond, near-circular orbits at Jupiter or Saturn's distance, some unstable Trojan and horseshoe orbits, and the visible short period comet orbits. There are frequent changes from one of these forms to another. The "long period" orbits, extending that term to include long period and intermediate period orbits of any inclination with small enough perihelia for the comet to be visible, do not interact with the chaotic orbits. We trace the separate evolution of these two types of orbits from Oort's cloud via stellar and planetary perturbations.

0.6 J.A. Fernandez and W.-H. Ipp

Title: Dynamical Evolution of a Cometary Swarm in the Outer Planetary Region

Consideration will be given to the dynamical evolution of hypothetical comets originally orbiting in the outer planetary region ( say between Uranus and Neptune ). We will attempt to reach conclusions about lifetimes of such comets against scattering and the incidence of a residual cometary swarm as a possible source of intermediate and short-period comets. This work is a continuation of previous studies of both authors related to the dynamics of particles in the outer planetary region and their connection with comets ( Refs (1) and (2) ).

References

(1) Ip W-H. 1977. On the early scattering process of the outer planets. In Comets, Asteroids, Meteorites. Interrelation, Evolutions and Origins, ( A.H. Delsemme, ed. ). Univ. of Toledo, 485-490.
(2) Fernández J.A. 1978. Mass removed by the outer planets in the early solar system. Icarus, 34, 173-181.

0.7 A NEW METHOD TO ESTIMATE PERTURBATIONS OF JUPITER ON COMETARY ORBITS.

by C. FROESCHLE and H. RICKMAN

A new fast method is developed and tested to estimate perturbations of Jupiter (or planets) on cometary orbits. This method not only allows to maximize the amount of informations in the building of a sample of perturbations used in Monte Carlo simulation (rejection procedure) but also yields a good approximation of the perturbation sample. We compare the perturbations obtained by the new estimator with the results of numerical integration of regularized equations of motion for the same dynamical model: the three-dimensional, elliptic restricted three body problem (Sun - Jupiter - Comet).

0.8E

## ORBITAL PATTERNS AT CLOSE ENCOUNTERS

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The poster presents Jovicentric trajectories of 180 objects experiencing low-velocity close approaches to Jupiter. The first group of diagrams represents a chain of 80 fictitious objects supposed to move along the orbit of P/Oterma before its encounter with Jupiter in 1934-1939. The chain covers 10° in the mean anomaly of the initial orbit; except for the wings, a uniform spacing of 0.1° is adopted. The second group of diagrams refers to a semi-random sample of 100 fictitious comets with initial orbits nearly tangent to that of Jupiter. The occurrence rates of some major events (temporary satellite captures, change of perihelion into aphelion and vice versa) for these two samples are also indicated.

0.9R

## Do Comets Evolve into Asteroids or Satellites?: The Physical Evidence

Johan Degewij (Jet Propulsion Lab.) and Edward F. Tedesco (Lunar and Planetary Lab. Tucson).

In this paper we discuss the evidence for the suspected interrelation between comet nuclei, asteroids, and small satellites, as inferred from their optical and near-infrared reflection spectra. Several teams have obtained interesting results from spectrophotometric observations of faint comets.

At optical wavelengths, Chapman (priv. comm.) obtained an RD-type spectrum for P/Arend-Rigaux, Spinrad et al. (PASP,91,707) obtained a reddish (S-type?) spectrum for P/Tempel (2), confirmed by Barker and Smith(1980, McDonald Obs. report to JPL). Degewij and Chapman (this conf.) obtained an S-type spectrum for the seeing disk condensation of P/Schwassmann-Wachmann (2). Tedesco (this conf.) obtained RD-type colors for P/Stephan-Oterma. At near-infrared wavelengths, A'Hearn et al. (1981, reprint) fail to see any absorption caused by icy particles in the comae of bright comets. Degewij et al. (this conf.) report about rocky/dusty JHK colors for P/Schwassmann-Wachmann (1) during very low activity.

Extensive progress has been made with the acquisition of physical parameters of asteroids in the far outer zones (≳5 AU) of the main belt (Degewij and van Houten 1979, "Asteroids", T.Gehrels ed. Univ. of Ariz. p.417; Tedesco and Gradie, this conf.), suspected to be one of the reservoirs of extinct cometary nuclei. Only very dark objects have been found here, having optical spectra with a neutral and sometimes very reddish signature. Degewij, Hartmann, and Cruikshank (this conf.) report about rocky/dusty near-infrared colors for Chiron. Of interest is the suggestion by Gradie and Veverka(1980, Nature 283, 840) that the reddish and dark surfaces can be explained by the presence of Kerogen-like organic compounds, possibly typical of the rocky component in cometary cores.

If, as has been suggested, a significant fraction of the earth approaching asteroids are extinct cometary nuclei, then physical observations suggest that these cores are not compositionally distinct of main belt asteroids with one or two possible exceptions.

The fact that no neutrally colored faint comet continuum has as yet been observed, may indicate that either the (C-type?) core is partially shielded by a dustcloud of C-type particles with a size distribution such that reddish S-type colors are generated, or we indeed observe S-type cores. More optical and infrared observations of faint and distant comets are urgently needed.

0.10 On the Implausibility of cometary origin of most Apollo-Amor asteroids

B.J. Levin and A.N. Simonenko

As the rate of replenishment of short-lived Apollo-Amor asteroids from the main belt seems to be insufficient to compensate their losses, the idea was put forward that most of them are deactivated cometary nuclei. However observational and theoretical evidence for the possibility of transformation of cometary nuclei into asteroid-like objects is inconclusive. This is good evidence that Apollo-Amor asteroids represent last parent bodies or most or even all meteorites. But meteorites cannot be formed within cometary nuclei with a constitution according Whipple's classical model, while alternative models seem to be unsatisfactory. Therefore is it concluded that the cometary origin of most Apollo-Amor asteroids is implausible, and they are genuine asteroids coming from the main belt. The process of their replenishment must be studied further.

0.11 Planetary Atmospheres: Cometary Contribution

N. Bhandari, D. Lal, M.N. Rao

The volatile components in the terrestrial atmosphere are largely due to the late influx of carbonaceous chondrite (C.C.) - like materials on the accreting earth's surface. The compositional relation between comets and the C.C. - type materials will be discussed with regard to physicochemical processes operating in the generation of planetary (terrestrial) atmospheres. Relevant lunar chemical data will be used. The focus will be on the chemical aspects of planetary atmospheres.

0.12R COMET IMPLICATIONS FOR THE ORIGIN OF LIFE

C. Ponnamperuma

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M.1P IR Space Experiment on Soviet Spaceprobe to Comet Halley

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An infra-red spectrophotometer (wavelength range 4 to 20 microns) will be flown on the Soviet spaceprobe to Comet Halley to study the molecular coma and the nucleus. Its scientific objectives are: (I) to measure the size and temperature of the nucleus (II) the abundance and temperature of the parent molecules and (III) the abundance and temperature of the dust particles surrounding the nucleus.

M.2P

PHYSICAL OBSERVATIONS OF COMETS WITH THE INFRA-RED ASTRONOMICAL SATELLITE

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The number of comets observable in 1982-1984 by IRAS, amounts to ten; a very favorable signal to noise ratio is however not to be expected for more than one third of them. This number will probably be more than doubled by unexpected long period comets.
Anticipated scientific results are: a) nuclear temperature and albedo; b) silicate signature of the nucleus; c) presence or absence of a dusty halo; d) silicate signature of the dust; e) temperature of the dust; and f) mass loss rate of the grains.

M.3P OBSERVATION/MISSION PLANNING AIDS FOR PERIODIC COMETS

by David F. Bender, Mission Design Section, Jet Propulsion Laboratory

Two forms of presenting future short period comet orbital position data are given which can be of use to those planning observing programs or to those interested in comet missions. The first is simply an approximate ephemeris for ± 200 days around each expected perihelion for the next ten years (through 1991). The second is a list of these expected perihelia for the next twenty years and a plot for each comet showing its motion in the Solar system and its motion relative to the Earth (a bipolar plot). The data are to be considered only as approximate since in most cases the orbits used are Keplerian extensions of recent or predicted osculating elements.

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" A Light ScatteringExperiment for the Measurement of Cometary Dust "

The scattering properties of cometary dust particles are closely related to the physical properties of these particles. It will be shown, that especially in situ-measurements of single particles can provide detailed information concerning shape, refractive index, velocity, size distribution, and spatial distribution of cometary dust. Appropriate instrumentation will be presented. Furthermore scattering results of models of cometary dust particles, obtained in the microwave laboratory, will be compared to the empirical scattering functions derived from optical measurements of comets.

M.5P - In-situ optical observations on board Giotto probe -

A.C. Levasseur-Regourd (P.I.)
J.L. Bertaux, R. Dumont, M. Festou, R.H. Giese, F. Giovane,
P. Lamy, A. Llebaria, D.W. Schuerman, J.L. Weinberg (Co-I)

The Halley Optical Probe Experiment H.O.P.E. has recently been approved by ESA for the cometary probe Giotto.

The Optical Probe technique (see Levasseur-Regourd et al, Space Research XXI, 1981) is a unique method for making optical in-situ observations. It is based on photopolarimetric measurements made parallel to the direction of motion through the dust and gas coma ; the rapid motion of the spacecraft allows measurements to be differenced such that the brightnesses and polarizations only refer to a small local volume, of about 140 km in length by 7 km in diameter.

The measurements unequivocally determine the spatial distribution of the dust number density and of some gaseous emissions, some changes in the grains size distribution, and the ratio of gaseous emission / dust scattering. These parameters forge the link between in-situ and past or future remote optical observations.

Out of the 8 channels of the spectral photopolarimeter, 4 will be devoted to continuum, i.e. dust and 4 to discrete emissions, i.e. gas. Polarization will be determined by the spinning spacecraft rotation of the analyzer. The net result should be an extremely light and reliable instrument with no moving parts.

M.7P

# In-situ Evaluation of a Cometary Dust Efflux: DIDSY† on board ESA's Comet Halley Giotto Mission

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An integrated system comprising an array of independent dust impact sensors has been selected as an experiment on the ESA Comet Halley Mission. Using the entire front surface of the Halley Probe Meteoroid Shield, the system measures the particulate mass efflux from a comet and its mass distribution over the range $10^{-17}$g to $10^{-3}$g or even larger; this upper limit is dependent only on the maximum mass of particle intercepted by the probe during fly-by.

Instrumentation selected for the mission comprises (i) an impact plasma, micro-perforation and momentum sensing array which determines the mass, penetration properties, density and ionisation of impacting particles from $10^{-17}$g to $10^{-11}$g (IPPM); (ii) a meteoroid shield momentum array which determines the impact position and momentum exchange of the entire probe (MSM); (iii) a penetration initiated capacitor discharge array for determining the impacting flux at three precisely defined masses which are chosen to be $10^{-3}$, $10^{-6}$ and $10^{-9}$ times the critical meteoroid shield penetration mass (CPD); and (iv) a sensor which determines and measures impact perforations in the Probe meteoroid shield (MSF).

The paper will discuss measurement principles and, in particular, how in-situ flux measurements will relate to cometary science and the interplanetary environment.

† Dust Impact Detection System

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M.8P

## An Ion Mass/Velocity Spectrometer for A Comet Mission

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For the past two years, we have been developing and testing a new type of ion spectrometer capable of obtaining three-dimensional velocity distribution functions with unusually high mass resolution ($\frac{m}{\Delta m} \sim \frac{600\ AMU}{m}$). This instrument distributes ions on two-dimensional detectors, with one dimension a measure of mass/charge and the other dimension a measure of the elevation angle of the ion's velocity vector. Azimuth angle is mapped by the spacecraft spin or mirror scan motion and the energy distribution is determined by variation of the voltages applied to the instrument. The basic components are: (1) An electrostatic mirror which can withstand the expected dust flux and reflects ions into the rest of the instrument which is shielded from dust; (2) A pair of grids with variable applied voltage to accelerate or decelerate the incident ions before they enter the analysis part of the instrument; (3) A sector magnet which serves as a momentum/charge filter with a very wide angular acceptance; (4) An electrostatic deflector which spreads the momentum-analyzed beam according to energy/charge (equivalent to mass/charge); (5) Two microchannel plate detectors with position sensitive readout; and (6) The electronics needed for signal processing, instrument control, and high voltage generation.

M.9P

## SOME PROBLEMS AND SOME SOLUTIONS TO IN SITU INVESTIGATION OF NEUTRAL ATMOSPHERE ON A FAST FLY-BY MISSION

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Flying through a dusty environment at a speed 50-70 km $s^{-1}$, the task of *in situ* chemical analysis of the neutral atmosphere with sufficient spatial resolution becomes a non-trivial one. The positive and negative features of existing techniques will be discussed. Two complementary ionization schemes using identical mass analyzers seems to provide some of the needed solutions.

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11.10P ARTIFICIAL METEORS IN THE ATMOSPHERES OF COMETS AND OTHER CELESTIAL BODIES AS RESEARCH TOOLS

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Calculation of cometary coma interaction with interplanetary medium solid particles reveals new possibilities for studying of comets on the basis of meteor phenomena (Dobrovolsky and Ibadov, 1980; Ibadov, 1980). However sufficiently bright ( $\lesssim 0^m$ ) natural meteors may appear even in the atmospheres of bright comets at a too small rate ( $<1$ meteor/hour ) to be used for studying of comets especially those with retrograde motion like comet Halley.

The injection of small bodies from space vehicle into the atmospheres of comets and other celestial bodies allows to get bright meteors. The observation of such artificial meteors from space is of interest for studying the gas production rate of the nucleus and the law of molecule distribution in the cometary comas and also for widening the range of registerable electromagnetic information from the meteor region and for better understanding the proper meteor processes such as the meteor body fragmentation in the earth's atmosphere.

References:

Dobrovolsky, O.V., and Ibadov, S., 1980, Report presented to the Workshop of the IAU Commission No. 15, Greenbelt, 1980, oct.22-24.

Ibadov, S., 1980, Komety i Meteory, USSR, No. 29, 49.

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M.11P Authors: William M. Irvine, F. Peter Schloerb, and K. Sigfrid Yngvesson

Title: Direct Detection of Water Vapor in the Coma Using a New Spacelab Submillimeter Telescope


ABSTRACT:

The direct detection of $H_2O$ in the coma of a comet is very desirable in order to put production rates and molecular life-times on a firm basis. Earlier efforts to use ground-based radio-telescopes for detection of the 22 GHz water line have not been successful, except for a possible detection in Comet Bradfield.

The SINTOX group at the University of Massachusetts has recently finished its definition phase study, which shows the feasibility of constructing a telescope which can operate at the frequency of the 557 GHz transition of $H_2O$. The instrument is designed for operation from Spacelab. It is a Cassegrain telescope with a main reflector diameter of 3.4 meters. The half-power beamwidth of the telescope will be about 40" at 557 GHz, corresponding to a region with diameter of $2.8 \cdot 10^4$ km at a distance of 1 AU, i.e. of the same order as the diameter of the $H_2O$-containing portion of the coma.

We have calculated the expected signal strength and find that production rates of the order of $10^{27}$ molecules per second are detectable, whereas expected production rates for Comet Halley are about two orders of magnitude greater than this limit. Detection of $H_2O$ thus is assured. Follow-on projects of this type to detect other parent molecules (HCN, $CH_3CN$) or isotopic species of these also look very attractive.


M.12P ULTRAVIOLET ABSORPTION STUDIES OF ATOMS AND MOLECULES IN COMET HALLEY WITH SPACE TELESCOPE

Peter L. Smith, John H. Black & Michael Oppenheimer


The possibility of studying the ultraviolet absorption spectrum of a comet, by using a hot star as a background continuum source, is examined. The advent of the Space Telescope and the forthcoming apparition of comet Halley will provide a unique opportunity for observations of this kind. We have used a Haser model to estimate the molecular column densities and predicted equivalent widths for lines of $H_2O$, OH, and CO as functions of time and angular distance from the comet. We have considered the capabilities of the High Resolution Spectrograph on the Space Telescope and determined the minimum detectable equivalent widths and, therefore, the maximum angular separation from the comet at which $H_2O$, OH, and CO could be studied. Because the ephemeris of comet Halley is, at present (3/81), uncertain by about one arc min, it is not possible to demonstrate that Halley will occult particular, suitable background sources, such as A0 stars of about 9th magnitude or brighter. However, a conservative, statistical estimate shows that Halley should pass near enough to $3 \pm 1.5$ such stars, primarily during its crossing of the galactic plane in April of 1986, and that lines of the $\tilde{C}$-$\tilde{X}$ band of $H_2O$ (1240 Å) and the 4th positive system of CO (1400-1600 Å) could be observed. Estimated equivalent widths for OH and the resonance lines of C and O indicate that these species may also be detected. Such observations could provide the first optical detection of $H_2O$, the fundamental parent molecule in comet comae, and give direct measures of molecular level populations.