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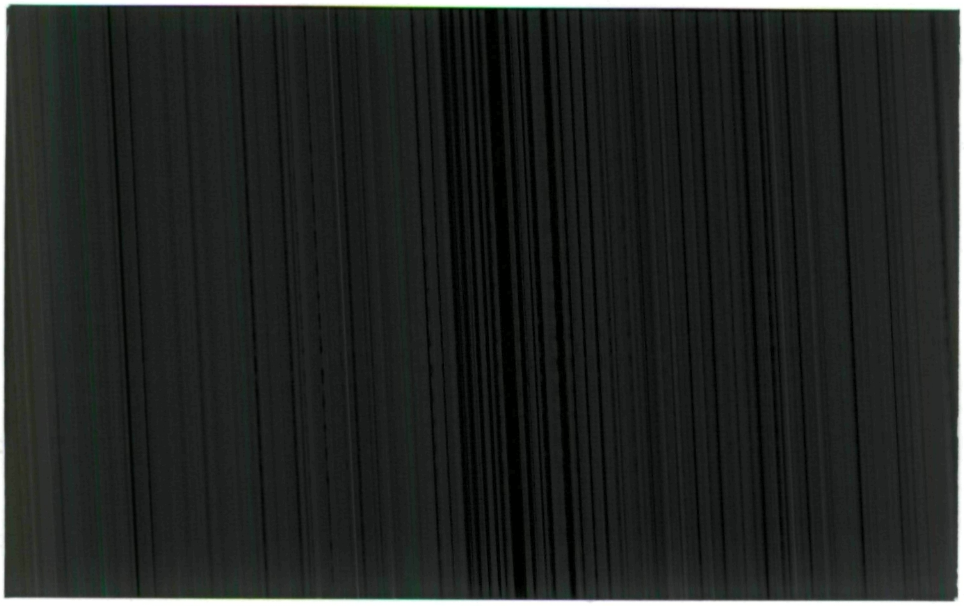
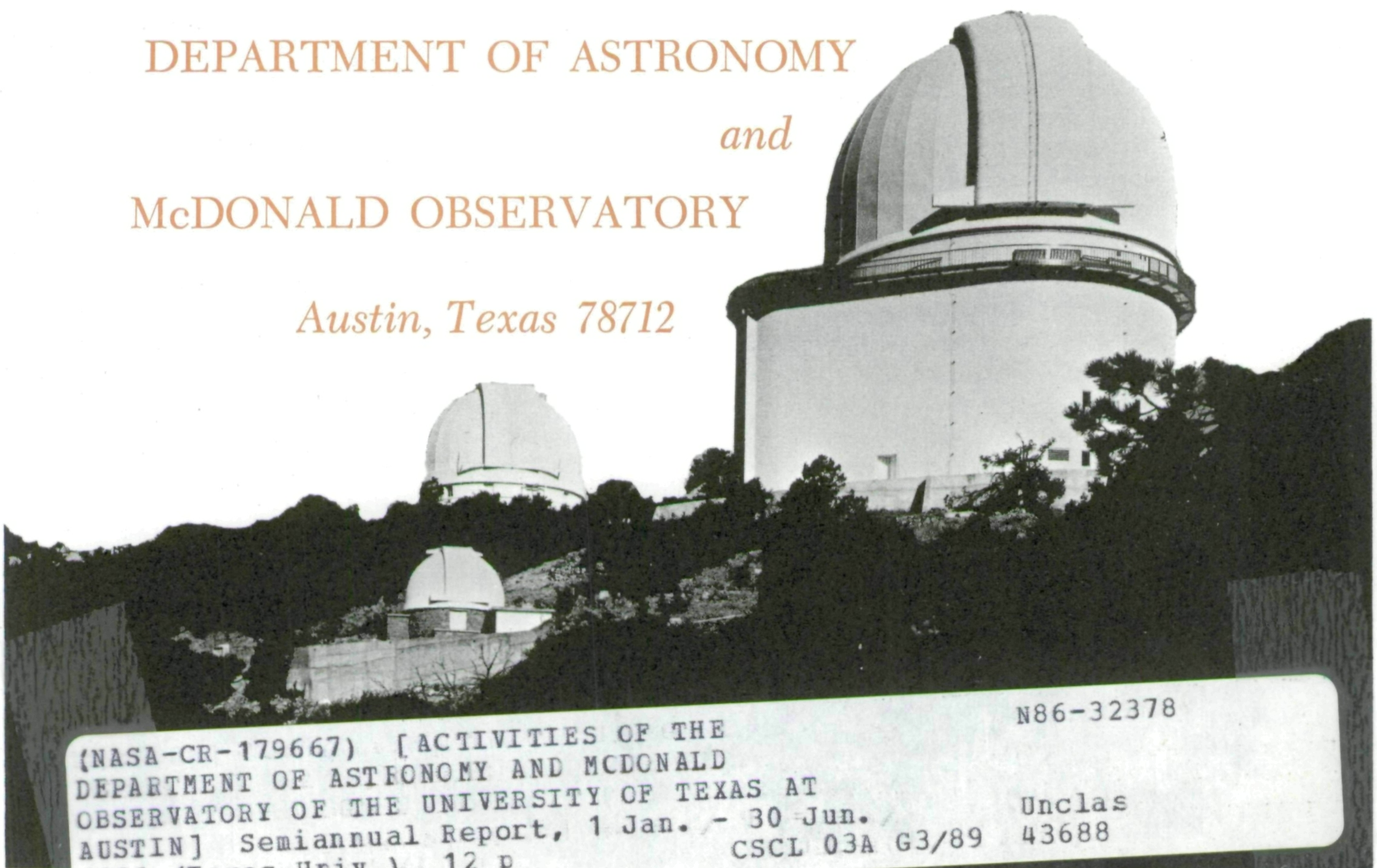


DEPARTMENT OF ASTRONOMY

and

McDONALD OBSERVATORY

Austin, Texas 78712



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The University of Texas at Austin

McDonald Observatory

and

Department of Astronomy

NASA Grant NGR 44-012-152

SEMIANNUAL REPORT #25

Period January 1, 1986 to June 30, 1986

Submitted:

Harlan J. Smith

I. Personnel working on this Grant during this reporting period

Dr. Harlan Smith (Principal Investigator, not charged to grant)
Dr. William Cochran (Co-Investigator, two months)
Dr. Laurence Trafton (Co-Investigator, five months)
Dr. Edwin Barker (Co-Investigator, two months)
Dr. Robert Tull (Senior Research Scientist, not charged to grant)
Dr. Anita Cochran (Res. Sci. Assoc. III, two months)
Dr. Brenda Young (Res. Sci. Assoc. IV, not charged to grant)
Richard Binzel (Grad. Res. Asst. II, not charged to grant)
Jacklyn Green (Grad. Res. Asst. II, not charged to grant)
Kam Sun (Lab Research Asst. II, half time)
Scott Sawyer (Grad. Res. Asst. I, not charged to grant)
Wang Hong-Yu (Grad. Res. Asst. I, half time, five months,)
Carol Mundorff (Admini. Sec., 30% time)

Peripheral activities and events relevant to this grant

R. P. Binzel has completed the requirements for his Ph.D. and received his degree in May 1986. His dissertation is entitled *"Collisional Evolution in the Asteroid Belt An Observational and Numerical Study"*. He will remain with the Texas Planetary group during the summer and fall 1986.

S. R. Sawyer has completed the requirements for his Masters degree. His Masters Thesis was entitled *"Time Resolved Spectrophotometry of Pluto"*.

L. Trafton was elected Fellow of the American Association for the Advancement of Science on 29 May, 1986.

E. Barker and A. Cochran spent considerable time during this reporting period year giving public presentations and interviews to the press about Halley's comet. The press interviews given numbered between 75 and 100 (46 interviews were given in one week when a press release announced their willingness to give interviews from McDonald Observatory). The public talks were given to groups as diverse as Discovery Hall Science Center, the Texas Junior Science, Humanities and Engineering Competition and school groups to business people, state and national legislators and the general public during visitor's night at McDonald Observatory. Around 100 talks were given.

II. Overview and Summary

We obtained extensive observations of comet Halley during this reporting period. This comet exhibited large variability; moreover, its variability was much more rapid than can be accounted for by water vaporization as the sole controller of activity.

Io's atmosphere is distended by more than the equilibrium scale height but less than for unimpeded streaming into space. The atmosphere is at least temporarily bound to Io.

Uranus' (3-0) H_2 quadrupole line shapes require a modification of Baines and Bergstralh's standard model (*Icarus* **65**, 406, 1986) which incorporates a high altitude, absorbing haze in addition to the lower haze layer. A fraction of normal H_2 equal to 0.25 ± 0.10 is derived, in good agreement with the standard model. This result is unchanged when the preliminary temperature structure derived by the Voyager Radio Occultation Experiment is used instead of Appleby's model c.

Out of the six Pluto-Charon mutual events we attempted to observe this year, we obtained data on four. Preliminary analysis is yielding improved estimates for the diameters, masses, densities, and albedos of these objects.

III. Observational Research Program

A. NASA-Texas Observing Runs

Dates (Civil)	Possible Hours[1]	Unobservable Hours[2]	Observed Hours[3]	Telescope	Focus
6 Jan - 8 Jan[4]	9	8	1	2.7m	Cassegrain
14 Jan	5	3	2	2.1m	Cassegrain
16 Jan - 19 Jan	48	24	24	2.7m	Coudé
30 Jan	4	2	2	2.1m	Cassegrain
15 Feb	9	4	5	2.1m	Cassegrain
20 Feb - 28 Feb	31	7 1/2	23 1/2	2.7m	Coudé
10 Mar - 14 Mar[4]	10	10	0	2.7m	Cassegrain
15 Mar - 18 Mar	28	14 3/4	13 1/4	2.7m	Coudé
19 Mar	9	5	4	2.1m	Cassegrain
15 Mar - 23 Mar[4]	18	9 1/4	8 3/4	2.7m	Cassegrain
4 Apr	9	4	5	2.1m	Cassegrain
5 Apr - 10 Apr	54	48 1/2	5 1/2	0.9m	Cassegrain
7 Apr - 11 Apr[4]	15	12 3/4	2 1/4	2.7m	Cassegrain
22 Apr - 26 Apr	47 1/2	31 1/2	16	2.7m	Coudé
28 Apr - 2 May[4]	17 1/2	14	3 1/2	2.7m	Cassegrain
1 May - 8 May	28	15	13	2.1m	Cassegrain
2 May - 4 May	18	15	3	0.8m	Cassegrain
6 May	9	4 1/2	4 1/2	8.1m	Cassegrain
8 May - 11 May[4]	15	7	8	2.7m	Cassegrain
24 May-26 May	25 1/2	25 1/2	0	2.7m	Coudé
27 May - 1 Jun	51	51	0	2.7m	Coudé
31 May - 2 Jun	12	12	0	0.8m	Cassegrain
1 Jun	3	3	0	2.7m	Cassegrain
1 Jun - 3 Jun[4]	7 1/2	6	1 1/2	2.7m	Cassegrain
13 Jun - 22 Jun[5]	80	50 1/2	29 1/2	2.7m	Coudé

[1] Possible Hours = Hours during which objects of interest were available minus laser runs minus time shared with nonplanetary observers.

[2] Unobservable Hours = Hours during which observations were not made due to inclement weather or equipment failure.

[3] Observable Hours = Hours of actual observation or calibration.

[4] Planetary Science was assigned partial telescope nights during these runs.

[5] In collaboration with W. H. Smith and W. Schempp of Washington University.

B. Other Planetary Observing Runs

Dates (Civil)	Observer	Institution	Telescope	Focus
19 Feb - 22 Feb	A. Potter	JSC	2.7m	coudé

13 Jun - 22 Jun	J. Bergstralh and J. Neff	JPL U. Iowa	2.1m	cassegrain

C Observations Made During This Reporting Period.

Mercury, Venus, Mars

No observations were made during this reporting period.

Jupiter

A partial survey of the disk at 1.95 - 2.30 microns was accomplished at the IRTF with our Infrared Spectrometer. No northern auroral emission at the wavelength of the $S_1(1)$ H_2 quadrupole line was found, controverting the predictions of Kim and McGuire. Our earlier discovery of marked spatial variations in the pressure-induced H_2 absorption was confirmed and these spectral variations were mapped.

Saturn

Spectra from 1.95 to 2.30 microns were obtained at the IRTF along the central meridian with the Infrared Spectrometer. Larger changes in the H_2 spectrum occur at Saturn's north pole than at Jupiter's. We will interpret these in terms of a polar hood.

Three spectra of the HD (5-0) band were observed for comparison of deuterium abundances with the other outer planet atmospheres.

Uranus

We attempted once again to use the Washington University CCD to obtain high spectral resolution line profile measurements of the H_2 quadrupole (3-0) band lines. Unfortunately, the CCD computer system was damaged in shipment to McDonald Observatory. After replacement parts were received, poor weather prevented our obtaining any data.

Reticon spectra of the (5-0) band of HD lines were obtained. These spectra are for a comparison of the deuterium abundances of the outer planets.

Pluto

Out of six Pluto-Charon mutual events which we attempted to observe this year with the McDonald 82-inch telescope, we obtained photometry on four. Preliminary analysis of the 1986 observations are already yielding improved estimates for the diameters, masses, densities, and albedos of these objects.

Titan

Several Digicon spectra were obtained of the spectral region of the solar Ca II H and K lines in an attempt to search for possible Raman scattering in the atmosphere of Titan.

Io

No observations were made during this reporting period.

Comets

Halley - Coudé Observations

A total of 17 coudé Digicon spectra, taken over 3 nights, were obtained of the NH feature at 3360 Å. We observed this feature because in low resolution spectra of other comets, it has a spatial intensity profile similar to ionic species. We wished to observe the rotational line structure of the band to determine if this really is NH, an ionic species, or a blend of both. The spectra clearly show six rotational lines which can all be attributed to low J lines of NH.

Coudé Digicon spectra were obtained of the violet CN band (3883Å) at several positions within the coma. The spectra are at sufficiently high resolution to resolve the individual rotational lines of the R branch of the band. Spectra taken centered on the "nucleus" will be used to test fluorescence calculations of the Swings effect. We will then use the spectra taken at different locations in the coma to measure the differential Swings effect (Greenstein effect) arising from the gas outflow in the coma.
The goal is to measure the CN outflow velocity. We are collaborating with David Schleicher of Lowell Observatory in the analysis of these data.

We have obtained 11 high dispersion spectra of the CH band near 4300 Å. Although this band is very weak, our chemical models have shown CH to be a very important species. The lifetime of CH is very short, and the oscillator strength of this band is very small. Thus any detectable CH implies a large parent abundance.

Halley - Cassegrain Observations:

The Cassegrain observations of comets obtained during this period were entirely of comet Halley. Since the comet was available only part of the night, we shared telescope time with several 2.7m observers.

The Halley observations were obtained with three different instruments. The Intensified Dissector Spectrograph (IDS) was used on the 2.7 m telescope for some of the spring observing runs and was supplemented by the new McDonald Large Cass Spectrograph (LCS), also on the 2.7 m telescope, which uses a CCD in long slit mode as the detector. There were 7 spectra of Halley obtained with the IDS during this time. Each of these spectra has 2 slits and, thus, generally represents 2 positions within the coma. There were 70 LCS spectra obtained, each covering ~140 arcsec of the coma.

The third instrument used was a CCD area photometer coupled with the IAU/IHW filters. This enabled us to get 2 dimensional profiles of the comet studying various molecular emissions. Unfortunately, our luck with the weather was not very good. However, we managed to get 27 images during this reporting period.

Extra-Solar Planet Search

The high precision radial velocity interferometer was used for several short observing runs during the winter and spring of 1986. A large amount of test data on three bright stars has been gathered. These stars were monitored in a several hour time sequence of short exposures to attempt to detect short period stellar oscillations which might mask the radial velocity signal from planets in orbit around the star.

Support of NASA Missions

IDS observations of Comet Halley were obtained on 13 March 1986 in support of the Giotto mission as requested by The International Halley Watch.

IV Instrumentation

Infrared Spectrometer

This instrument has been used successfully on several observing runs and needs only minor modifications to become a general-use instrument.

Installation of MicroVAX for CCD image processing

A special equipment augmentation to this NASA grant for $20K was approved in late December 1985, matched with an equal amount from The University of Texas College of Natural Sciences equipment funds, for the purchase of a MicroVAX workstation for the acquisition and reduction of CCD data at McDonald Observatory. A basic DEC VAXstation II system consisting of a MicroVAXII CPU with 5 MByte of memory, graphics workstation, Ethernet interface, 71 MByte Winchester disk, dual floppy drive, and cartridge tape in a 12-slot chassis was ordered in late January. An additional disk, an 8-channel terminal multiplexer, 4 MByte additional memory, and Image Analytics display board, and various accessories such as a small printer and Ethernet hardware were also ordered. The computer was installed by DEC in early June. Chet Opal has installed the display board, multiplexer, and additional memory, but is still waiting for the disk and several other items. Software purchased included an 8-user VAX/VMS license, Fortran, Interactive Data Language (IDL), and device drivers for the image display. The computer is temporarily located in the Austin CCD detector lab near the CCD data acquisition system during the software development phase. In addition to the workstation display and other terminals in the lab, four terminal lines connected to the department MICOM system are available for software development by users.

Existing data reduction programs have been converted to use the new display and are working very well: for example, it takes only three seconds to load a 352x512 CCD image from disk to the display. We have succeeded in transmitting data packets over the Ethernet interface with the NOVA CCD control computer and are in the process of developing a protocol which will allow the NOVA to transmit images directly to files on the microVAX. We anticipate that a prototype system which uses the microVAX for operator control and the NOVA for running the CCD will be demonstrated by year end.

High-Precision Radial Velocity Interferometer

Several problems were identified during test observing-runs with this instrument this year and were corrected: The mechanical support system was improved to give increased stability. The folding diagonal flat mirrors have been replaced.

V. Data Reduction

Reduction of our observations of the 27 Aug 1985 eclipse of JII by Io are now complete. The solar and telluric H_2O lines have been successfully removed and the equivalent widths of the NaD absorptions in Io's atmosphere measured and plotted. Some miscancellation of the core of the D_2 line sometimes occurred, suggesting the presence of background light from Io's spectrum while observing JII during the eclipse. We modeled this roughly by allowing for a small constant background subtraction before the division by the lunar spectra. It was necessary to employ fractional shifts in the ratio spectra to cancel the unwanted features.

The coudé spectra of comet Halley have all had nominal reductions completed. They have had dispersion curves calculated, are flat fielded, and have bad pixels edited out The CN spectra have been sent to David Schleicher at Lowell Observatory so that he may compare them with his CN fluorescence models.

The IDS spectral reductions are complete for the purpose of providing measured emission line intensities for all observations except those obtained in June.

The Halley CCD photometry data through March 1986 have been flat fielded and intensity calibrated. The reduction is still in progress. This data reduction has been carried out by Jacklyn Green. As part of his second year project, Chris Matney will compare intensity profiles obtained with the LCS and the CCD camera.

The LCS data reduction is largely unstarted since this is a new instrument with a data format which is incompatible with existing University of Texas software. We have just received and ported the NOAO reduction package IRAF. This should be capable of handling our LCS data. We have only made preliminary attempts to use this program so far. We will probably have all of the LCS data reduced to intensities by the end of the fall. Chris Matney, a second year graduate student, will be reducing the LCS data as a part of his second year project.

We are in the process of writing data reduction software for the high precision radial velocity interferometer. We are using the IBM PC/AT microcomputers we have received from Project Quest. We have completed the first step of writing a system to do standard preliminary processing of the Octicon data. This step includes flat fielding, dark subtraction, and video line normalization. We are now in the process of writing the cross-correlation software for determining the Doppler shifts of the spectra.

VI. Analysis and Theoretical Studies

A paper is in preparation on comet Giacobini-Zinner. Giacobini-Zinner turns out to have been depleted in C_2 and C_3 relative to CN.

The 27 Aug 1985 eclipse of JII by Io implies a sodium atmosphere for Io which is distended by more than the equilibrium scale height, but less than for unimpeded streaming into space. The atmosphere is at least temporarily bound to Io. The measured ratio of the D_2 line remains less than 2 near Io, indicating that the sodium atmosphere is optically thick in the D lines.

The spectral intensities derived from the IDS observations of Comet Halley have been converted to column densities and Haser models and non-equilibrium chemical models have been run. The preliminary model results are that Comet Halley was quite variable, with a time scale of less than a day, and the variability is not controlled solely by water vaporization. The outflow velocity found by the Vega and Giotto spacecraft is confirmed by our data and does not follow the previous laws for outflow velocity.

Analysis of the 1978-1980 data on Uranus' (3-0) H_2 quadrupole line shapes has been completed and a paper is in preparation. These 0.1 A resolution profiles require a modification of Baines and Bergstralh's standard model (*Icarus* **65**, 406, 1986) which incorporates a high altitude, absorbing haze in addition to the lower haze layer. A fraction of normal H_2 equal to 0.25 ± 0.10 is derived, in good agreement with the standard model. This result is unchanged when the preliminary temperature structure derived by the Voyager Radio Occultation Experiment is used instead of Appleby's model c. The CH_4/H_2 ratio deep in the atmosphere cannot be constrained further by our data without accurate values of the CH_4 absorption coefficients at low temperature at the wavelengths of these lines.

Wang and Cochran have analyzed ultraviolet limb darkening profiles of Saturn. The data used were CCD images of Saturn taken in 1983 through a set of filters at continuum wavelengths between 3400Å and 5000Å. First, a geometrical reduction of the images was used to determine the planet center and orientation, as well as the image scale. The data were then reduced to reflectivities assuming previously published photometric calibrations Limb darkening profiles were then extracted from the data for several latitudes. These data showed some very interesting differences of the various latitudes. In particular, the equatorial region was very bright at 5000Å, but was quite dark at 3600Å. The polar regions were the opposite of the equator; they were bright in the UV, but dark in the visual. The data on a bright zone centered at 9 degrees S and darker belt at 30 degrees S were modeled using a doubling-adding code. The baseline model was that derived by Tomasko and his coworkers from analysis of Pioneer images of Saturn. Models of these data are particularly sensitive to the distribution of upper atmospheric aerosols, sometimes referred to as "Axel dust". The nominal model of a thin clear gas layer above a mixed aerosol, gas, and cloud region was able to fit the data at 4500 and 5000 Å, but gave too little limb brightening at 4000 Å and shortward. A possible solution is to increase the depth of the clear gas region, and to place a thin aerosol haze at the top of the atmosphere. A haze with optical thickness approximately independent of wavelength, and a single scattering albedo which drops sharply in the ultraviolet seems to fit the data well. In fact, the same high altitude haze properties may be used to model both the belt and the zone areas. The major difference between the two areas is the photon mean free path in the deeper cloudy areas of the atmosphere. The model is still being refined, and the results will be submitted for publication this fall.

Sawyer has completed his Masters Thesis analyzing time resolved spectrophotometry of Pluto. The Thesis was supervised by H. Smith and W. Cochran. The data consisted of a series of spectra of Pluto in the 0.74 to 1.02 micron range taken in 1983 and 1984. The data were reduced to geometric albedos using the nightly standard star and extinction star observations. The strength of the CH_4 absorption bands did not discernibly vary during either observing run. A model was constructed to investigate whether the absorption arises from CH_4 frost or CH_4 gas. The 30% brightness variation of Pluto with rotational phase was modeled by the two spot model of Marcialis (1983, Masters Thesis, Vanderbilt University). The surface frost was modeled using the bidirectional reflectance spectroscopy theory of Hapke (1981, *J.G R* **86**, 3039). The gas absorption was modeled with a random band model. Pure frost models which limited the CH_4 frost to the bright (unspotted) surface areas did not produce good fits to the observed data. They were unable to simultaneously fit the strong and weak bands and they required unrealistically large frost particle diameters (greater than 1 cm). They also showed a high degree of phase variation. The phase variation could be removed by allowing CH_4 frost to be present on both the bright and dark areas of the surface, and by assuming nearly identical particle sizes for the two regions. However, particle sizes greater than 5 mm were required, and the strong and weak CH_4 bands still could not be fit simultaneously. Pure gas models were able to fit simultaneously all of the observed bands and did not exhibit phase variations. Column abundances of 15-20 m-am of CH_4 gas were required. The best fit assumed a CH_4 frost with particle diameter of 1.0 mm and CH_4 gas with a column abundance of 15 m-am. The resulting estimate for the column abundance of CH_4 gas on Pluto is 15 ± 5 m-am.

A major advancement towards our understanding of the origin of the Kirkwood gaps was achieved by the first observational survey of physical properties of near-resonance asteroids. The results of observations of rotation rates (rotational angular momenta) and shapes of resonance and non-resonance asteroids show no evidence for enhanced collisions in the vicinity of the 3:1 resonance. Therefore the origin of the gaps may be attributed entirely to gravitational processes.

A comparison of the distribution of rotation rates and shapes in the Eos and Koronis dynamical families with computer models of collisional evolution shows that the two families may have distinctly different relative ages. The origin of the Eos family probably dates back to the early solar system while the Koronis family may have formed more recently. The new observations confirm that these two families were formed by the collisional disruption of large parent bodies.

We have studied the abundances of CN, C_2 and C_3 in a large number of comets in order to determine whether correlations between the species exist. We have re-reduced the data of A'Hearn and Millis (*A J.*, **85**, 1528, 1980) and Newburn and Spinrad (*A. J.*, **89**, 289, 1984) onto a common system of parameters with our data. We find that C_2 and C_3 Haser model production rates are correlated with CN production rates. This study confirms and strengthens the conclusions of A'Hearn and Millis.

VII. Publications and Presentations

A. Published Papers

1. "Spectroscopy of Asteroids in Unusual Orbits" W. D. Cochran, A L. Cochran, and E. S. Barker in "Asteroids, Comets, Meteors II", (C.-I. Lagerkvist, B. A. Lindblad, H. Lundstedt, and H. Rickman Eds.) Uppsala Universitet Reprocentralen, p. 181, 1986.

2. "Brightness Asymmetry in Comet Kopff" A. L. Cochran, in *"Asteroids,Comets, Meteors II"*. (C.-I. Lagerkvist, B. A. Lindblad, H. Lundstedt, and H. Rickman Eds.) Uppsala Universitet Reprocentralen, p. 137, 1986.

3. "Photometric and Spectrophotometric Activity of P/Halley During 1984-85" E. S. Barker and C. B. Opal, in *"Asteroids, Comets, Meteors II"*. (C.-I. Lagerkvist, B. A. Lindblad, H. Lundstedt, and H. Rickman Eds.) Uppsala Universitet Reprocentralen, p. 481, 1986.

4. "Comet Kopff: A Case for Mantle Development" A. L. Cochran, *A. J.* **91**, 646, 1986.

5. "Chaotic Rotation of Hyperion?", R.P. Binzel, J.R. Green, C.B. Opal, *Nature* **320**, 511, 1986 .

B. Submitted Papers

1. "The Role of Collisions in Clearing the Kirkwood Gaps", R.P. Binzel, *Science.*

C. Presentations and Abstracts

1. Colloquium presented April 14, 1986 to Department of Physics and Astronomy, Kansas University: "Ground and Space Based Observations of Comet Halley", E. S. Barker.

2. Colloquium presented June 4, 1986 to Laboratory for Atmospheric and Space Physics, University of Colorado: "In Search of Extra-Solar Planets", W. Cochran.