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John T. Jefferies, Principal Investigator

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For the Periods
January - June 1981
and
July - December 1981

TABLE OF CONTENTS

I. PERSONNEL

This report includes two semi-annual reports for the periods January-June and July-December 1981. Scientific personnel engaged in planetary research who were supported fully or in part by this grant during the period are as follows:

W. M. Sinton	D. Morrison	C. B. Pilcher
D. P. Cruikshank	J. Goguen	R. R. Howell

In addition, graduate students, A. Colucci, J. F. Morgan, M. Pierce, and E. Shaya received salary support on research assistantships. Those students who received nonsalary support for their participation in various projects are J. F. Bell, R. H. Brown, D. Backman, and J. H. Fertel.

Dr. J. Goguen, a graduate of Cornell University under Joseph Veverka, joined the staff as a post-doctoral scientist in 1981. David Morrison returned to residence in Honolulu in November 1981, after a leave at NASA Headquarters and at the Jet Propulsion Laboratory.

II. THE RESEARCH PROGRAMS

A. Highlights

1. Observation of a decrease in the near-infrared brightness of Neptune in 1981, amounting to approximately one magnitude in the K band.
2. Acquisition of CCD images of Uranus with the new CCD system on the 2.2-m telescope.
3. Observations and analysis of the dark side of Iapetus, showing its lack of reflectance similarity with Phoebe and the intriguing resemblance to dark reddish residue from C2 carbonaceous chondrites.
4. Production of a movie illustrating the structural variation of Jupiter's SII plasma torus with magnetic longitude.
5. Acquisition and analysis of high-quality near-infrared spectra of the Uranian satellites, confirming water frost as a primary constituent and showing sensible differences among the four satellites observed.
6. Acquisition and preliminary analysis of a high-quality spectrum of Triton, confirming the presence of the 2.3-μm feature.
7. Acquisition and analysis of a high-quality near-infrared spectrum of Hyperion, confirming the presence of water frost, but showing that the satellite's reflectance is different from other ice-bearing satellites.
8. Confirmation of the low-albedo of 2060 Chiron from VJHK photometry.
9. Acquisition of high-quality 3-μm spectra of asteroids showing the presence of bound water in the surface mineral structures.
10. Discovery of variability of the 5-μm flux from Io on a time scale of 30 seconds, which is termed "flickering."
11. Analysis of 4 out of 8 probable or definite 5-μm outbursts of Io yielding a picture of an initial high temperature phase (800 K) of small area that quickly cools (to 300 K) and spreads to a large area (10^4 km^2).
12. Determination of an apparent dependence of the 5-μm Io flux on its Zenographic magnetic longitude.
13. The discovery of the first evidence in the Io torus emission for corotating magnetospheric convection.
14. Recalibration of the asteroid radiometric diameter scale to a precision of 5%, based on independently determinated diameters.

B. The Major Planets

1. Jovian Magnetospheric Studies

One of the major advances in our understanding of the Jovian emission nebulae during the report period involved the production of a movie of the Io torus in the light of S^+ at 6731A. The data were acquired by Pilcher during a 7-1/2 hour period on the night of 1981 March 13 UT. He acquired 24 ten-minute exposures of the S^+ torus at a fixed position on the sky relative to Jupiter. The instrumentation used was the same optical/image-tube/photographic system used in previous studies. The data were digitized at the Institute by Research Associate Jeanne Fertel and then, working with Charles C. Avis at JPL's Image Processing Laboratory, Pilcher and Morgan combined the 24 "snapshots" into a movie that reveals a great deal about the structure of the plasma torus. Images acquired on two preceding nights and on numerous other occasions during the last two years provide a measure of the temporal variation of this strucutre.

Some of the individual images are shown in Figures 1-5. In Figure 1 we show frame 6 of the movie, corresponding to Jovian magnetic longitudes centered on 106° [System III (1965)]. (In this coordinate frame the north magnetic pole is at 200°. The longitudes given for each image refer to the central longitude of the portion of the torus observed, i.e., the longitude on that side of Jupiter approximately in the plane of the sky.) The graphics in Figure 1 show Jupiter with magnetic longitude markings, a ring of radius 5.7 R_J in the centrifugal equator, and dipolar field lines at the longitudes of the two magnetic poles. The data shown in this figure are typical of the data acquired at longitudes between 60° (the beginning of this sequence) and $\sim$140°. The emission is fairly weak and in the form of a thin ring of radius $\sim$5.1 R_J. (This determination of the ring radius comes from a measurement of the position of the intensity maximum in each of these images relative to Jupiter. We have assumed that the intensity maximum is at the position of the ring ansa.)

At 151° (Figure 2) a brighter maximum at 5.7 R_J becomes apparent. We believe that this maximum, which we call the field-aligned-feature (FAF) because of its elongation in the direction of the magnetic field lines, corresponds to the total charge density maximum observed at 5.7 R_J by both the Voyager 1 plasma science and planetary radio astronomy

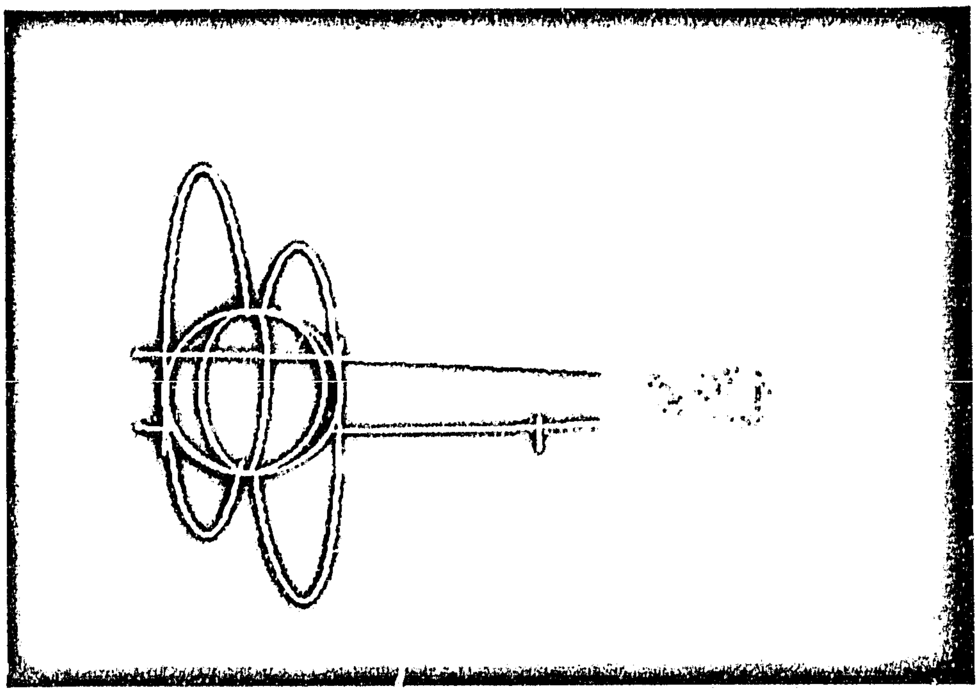

Fig. 1. Frame 6, data and graphics, effective magnetic longitude System III (1965) = 106°. The graphics show Jupiter with magnetic longitude markings every 90° beginning at 0°, a ring of radius 5.7 R_J in the centrifugal equator with tic marks every 90° beginning at 0° magnetic longitude, and dipolar field lines at the longitudes of the two magnetic poles (north: 200°; south: 20°). The data show weak [SII] λ6731 emission with an intensity maximum near 5.1 R_J.

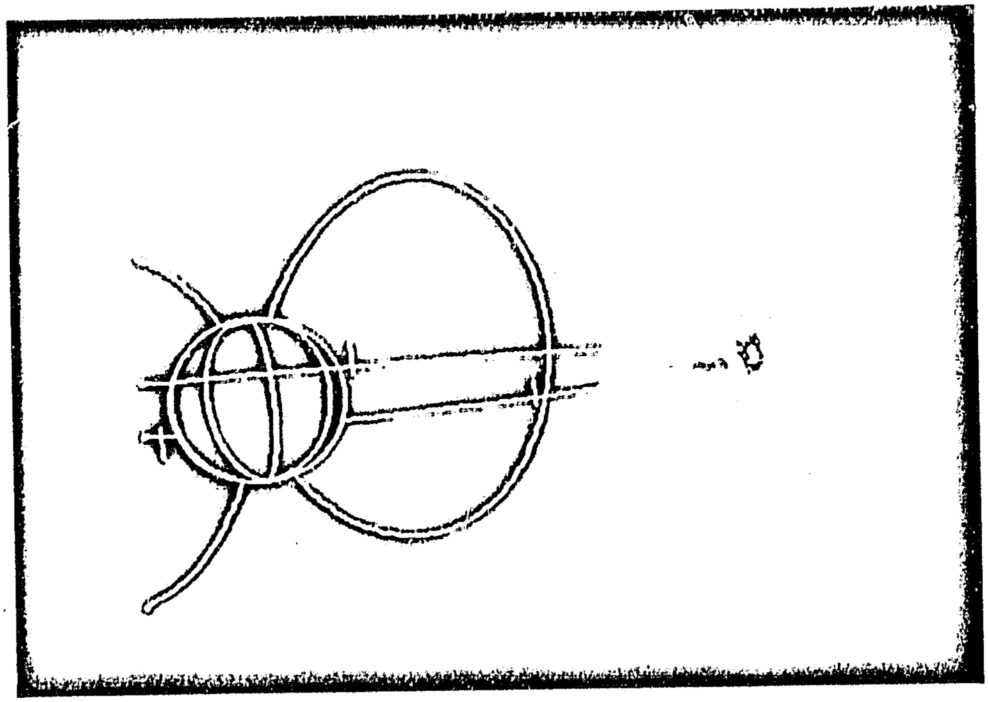

Fig. 2a. Frame 10, data and graphics, effective magnetic longitude 151°.

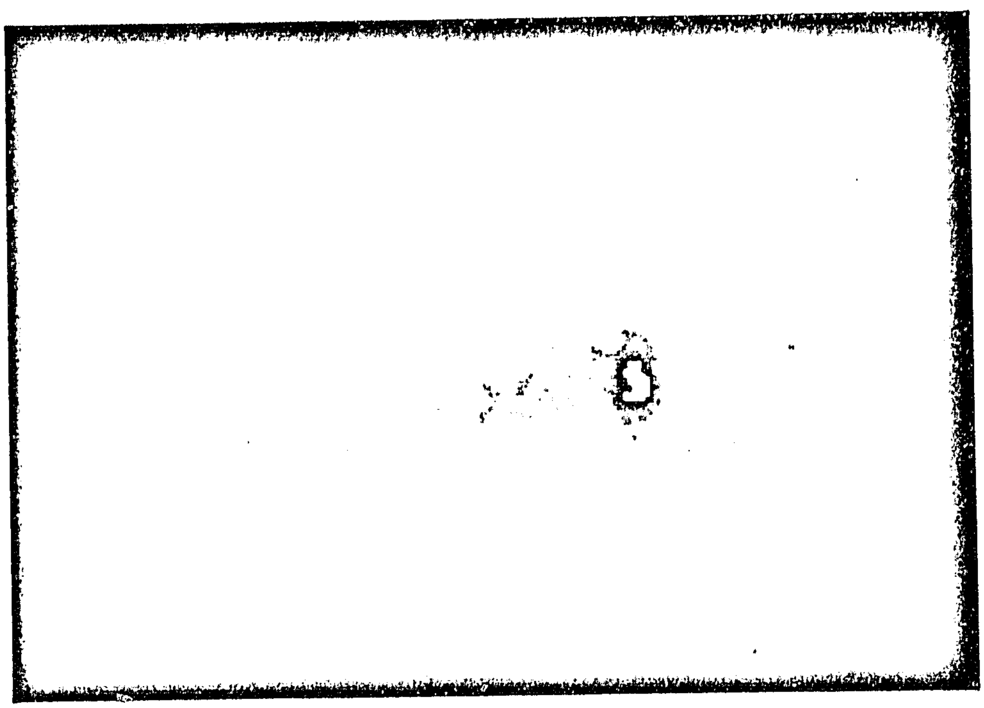

Fig. 2b. Frame 10, data only.

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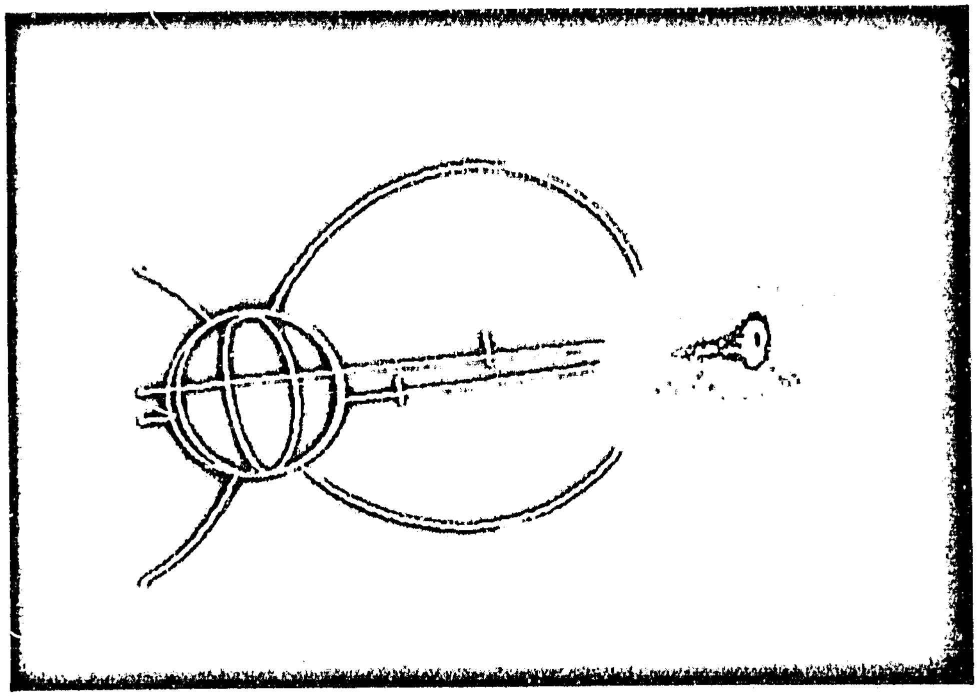
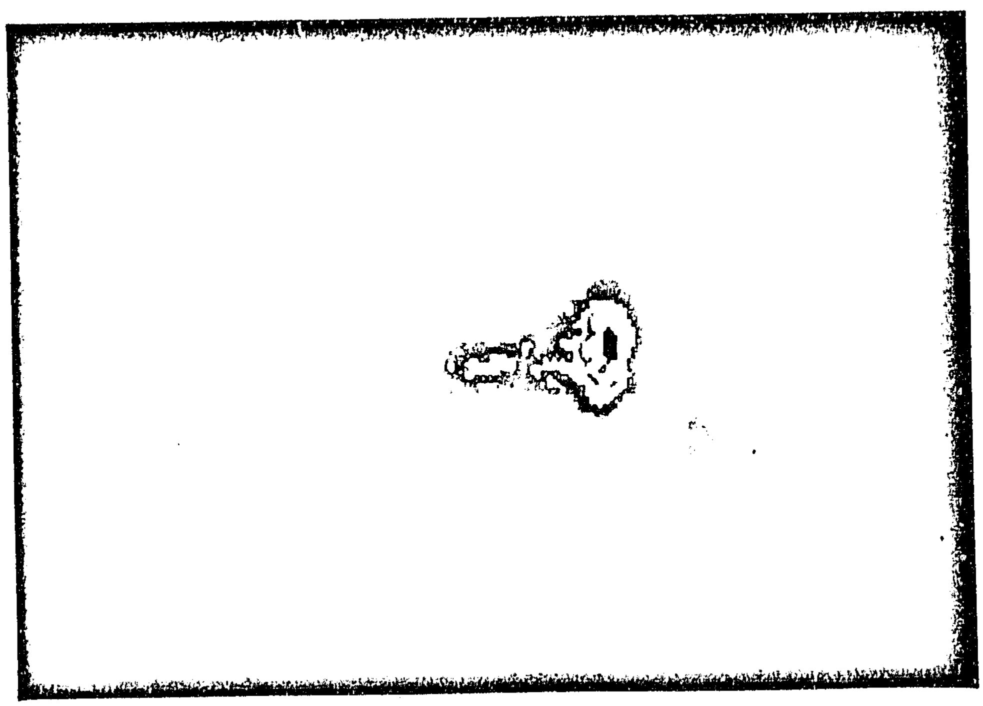


Fig. 3a. Frame 11, data and graphics, effective magnetic longitude 168°.



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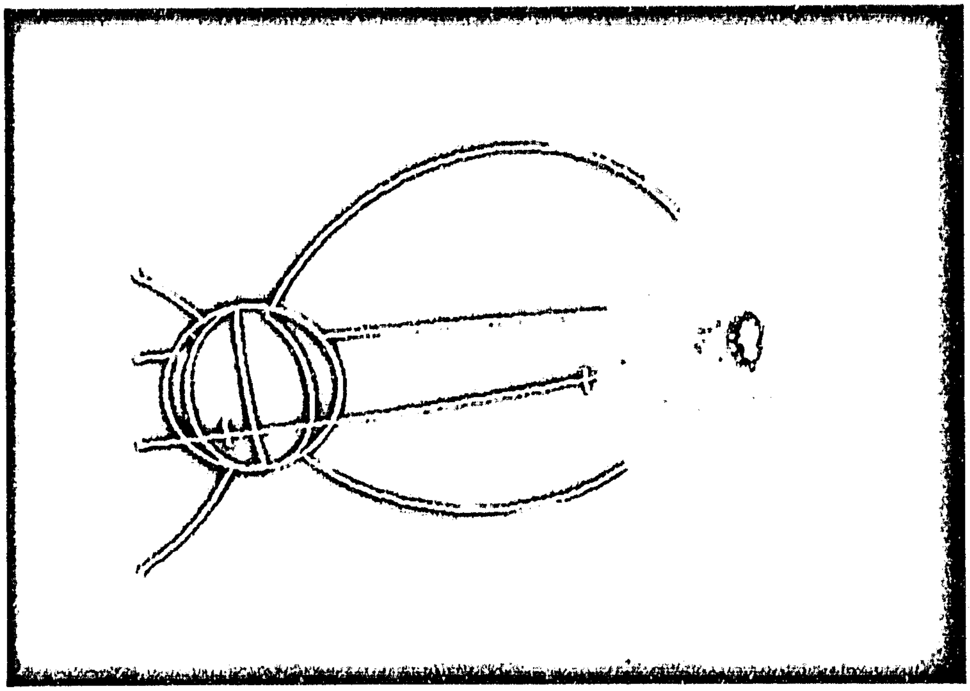

Fig. 4a. Frame 16, data and graphics, effective magnetic longitude 228°.

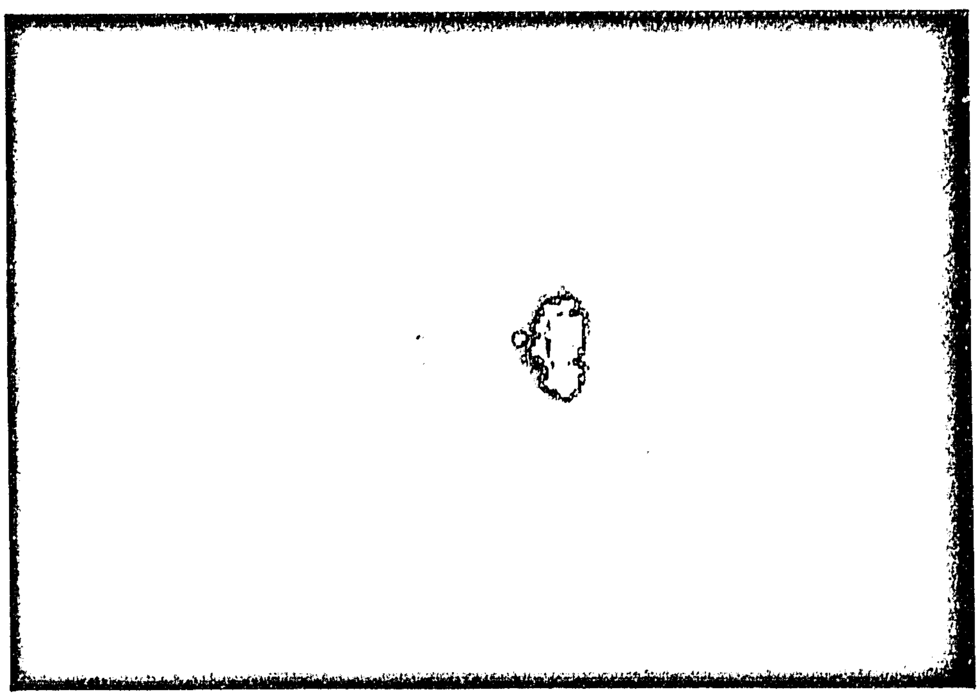

Fig. 4b. Frame 16, data only.

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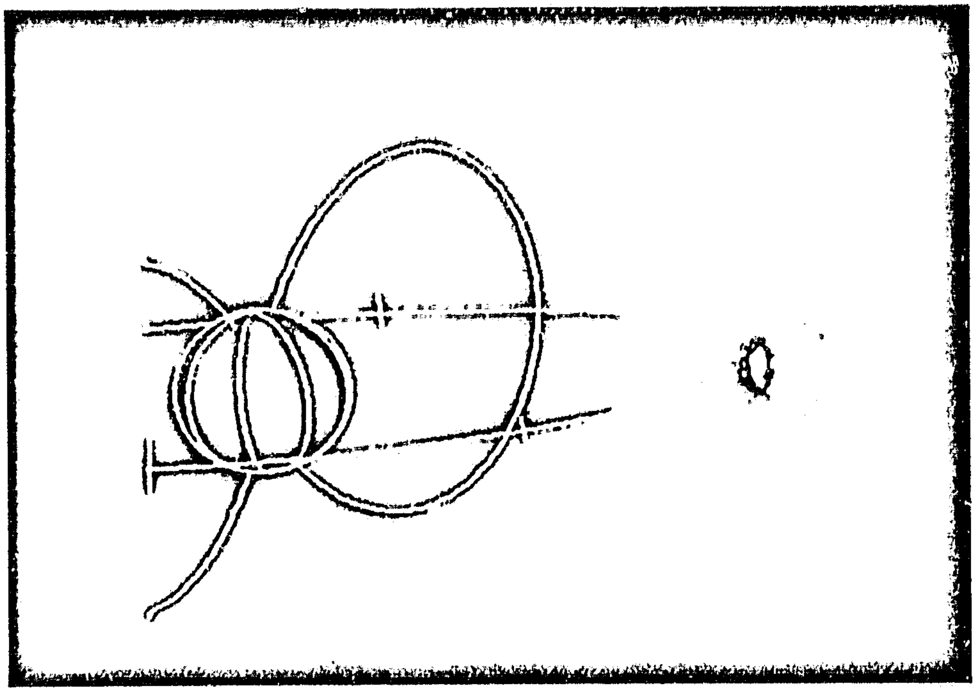


Fig. 5a. Frame 18, data and graphics, effective magnetic longitude 263°.

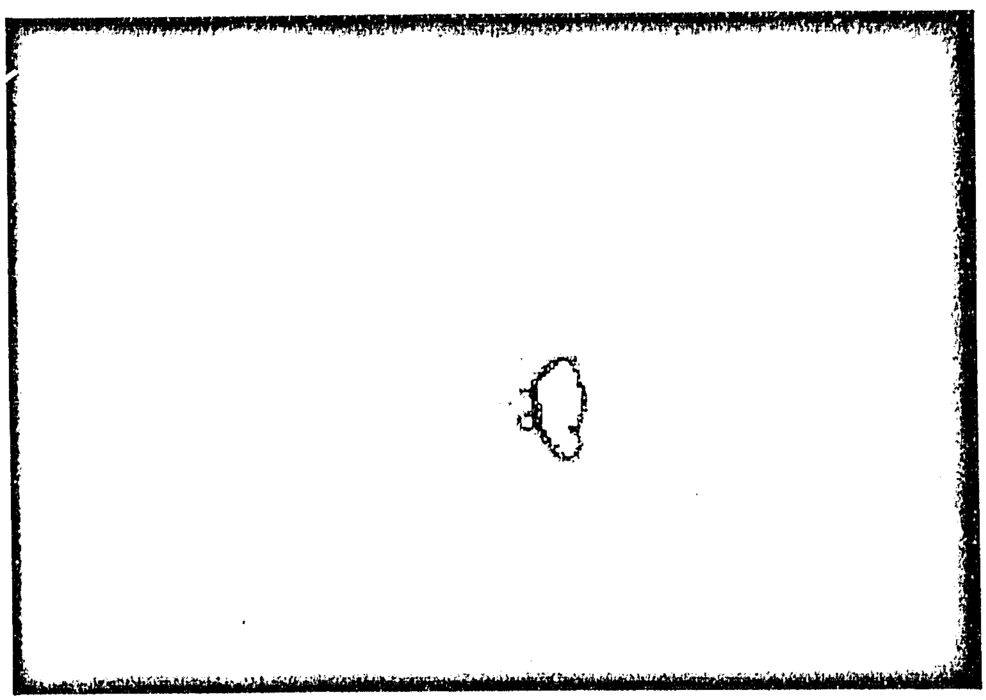


Fig. 5b. Frame 18, data only.

instruments (see Figure 6). At 168° (Figure 3) both maxima are present, with the FAF essentially at the maximum intensity observed during the entire sequence. By 228° (Figure 4) the maximum at 5.1 R_J has begun to diminish, and by 263° (Figure 5) it is totally absent. (We see no indication in this sequence of the 5.1 R_J maximum between ∿245° and ∿325°, the latter corresponding to the highest longitudes covered.) The data of Figures 4 and 5 show that at these longitudes the torus volume emitting this SII line is basically a "doughnut" centered at 5.6-5.7 R_J.

In images in which the FAF is present, the emission extends out to ∿7.5 R_J, substantially beyond the outer limit observed early in the sequence. Since SII has only a ∿30 hour lifetime in the hot plasma beyond Io's orbit, we interpret this as indicating rapid outward transport of plasma from the region of high plasma density corresponding to the FAF. The thin ring at ∿5.1 R_J is believed to be the result of slow inward diffusion and cooling of the plasma. Its absence beginning at longitude ∿245° and extending to at least ∿325°, coupled with the presence of the FAF and the indication of rapid outward motion of the plasma at these longitudes, suggests to us one-way motion of the plasma, i.e., over this range of longitudes the dominant motion of the emitting SII plasma is outwards. This is consistent with the pattern of corotating magnetospheric convection discussed by Hill, Dessler, and Maher (1981) submitted to J. Geophys. Res. in connection with the magnetic anomaly model.

We have a great deal of evidence that the structure of the plasma on the night these data were acquired was not unusual. Similar structure was observed in some of our very first images obtained nearly two years ago and on many occasions since. The Voyager 1 plasma science data, which were obtained almost entirely at longitudes where the FAF is prominent (while inside of Io's orbit, the Voyager 1 spacecraft traversed only the longitude range ∿200° to ∿325°), are in excellent agreement with the corresponding images in the movie sequence. The perplexing question is why is there no indication of a similar variation of plasma properties with magnetic longitude in the extensive Voyager ultraviolet spectrometer (UVS) data?

Although the plasma structure described above is not unusual, it is also not the only configuration of the plasma observed. A month after

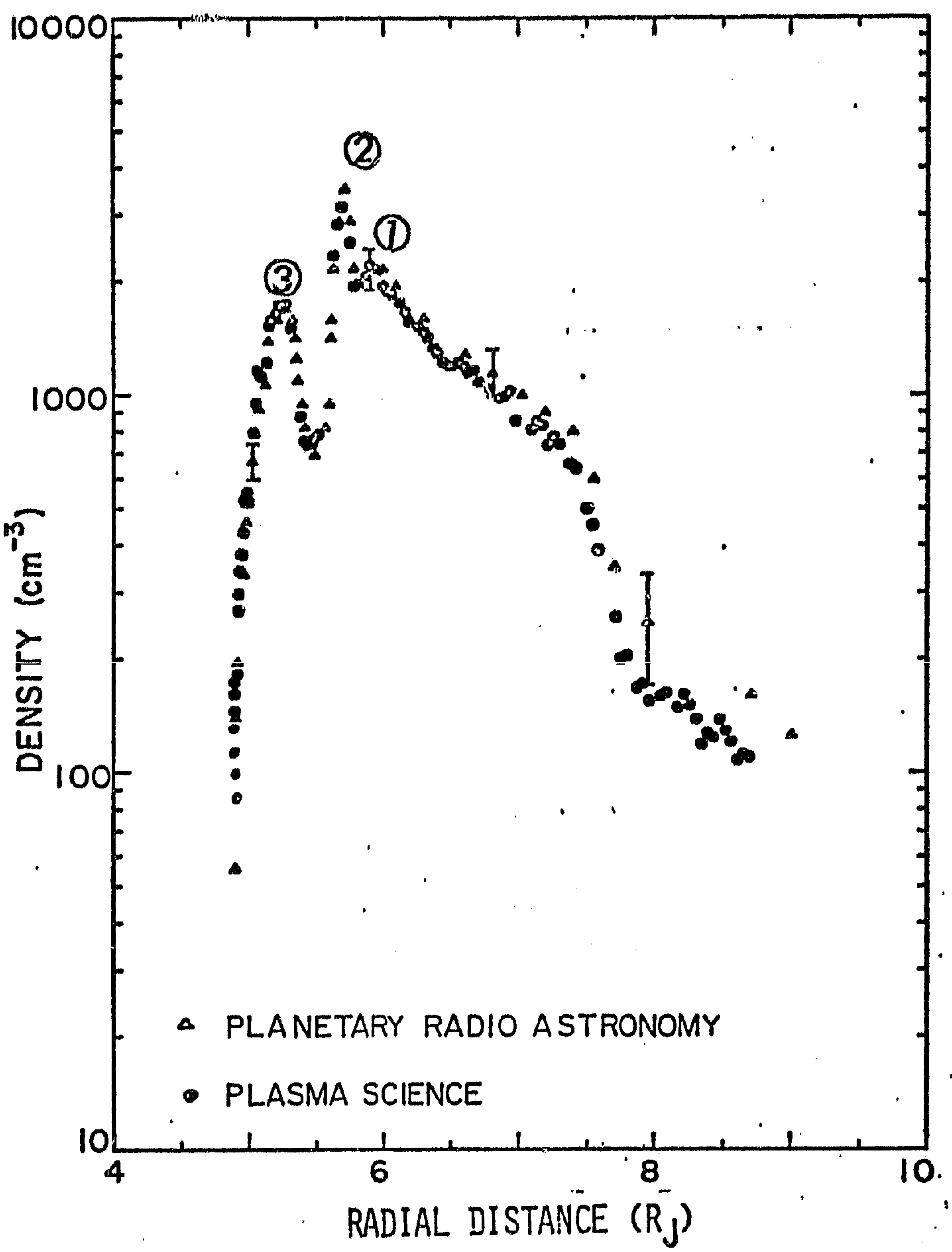
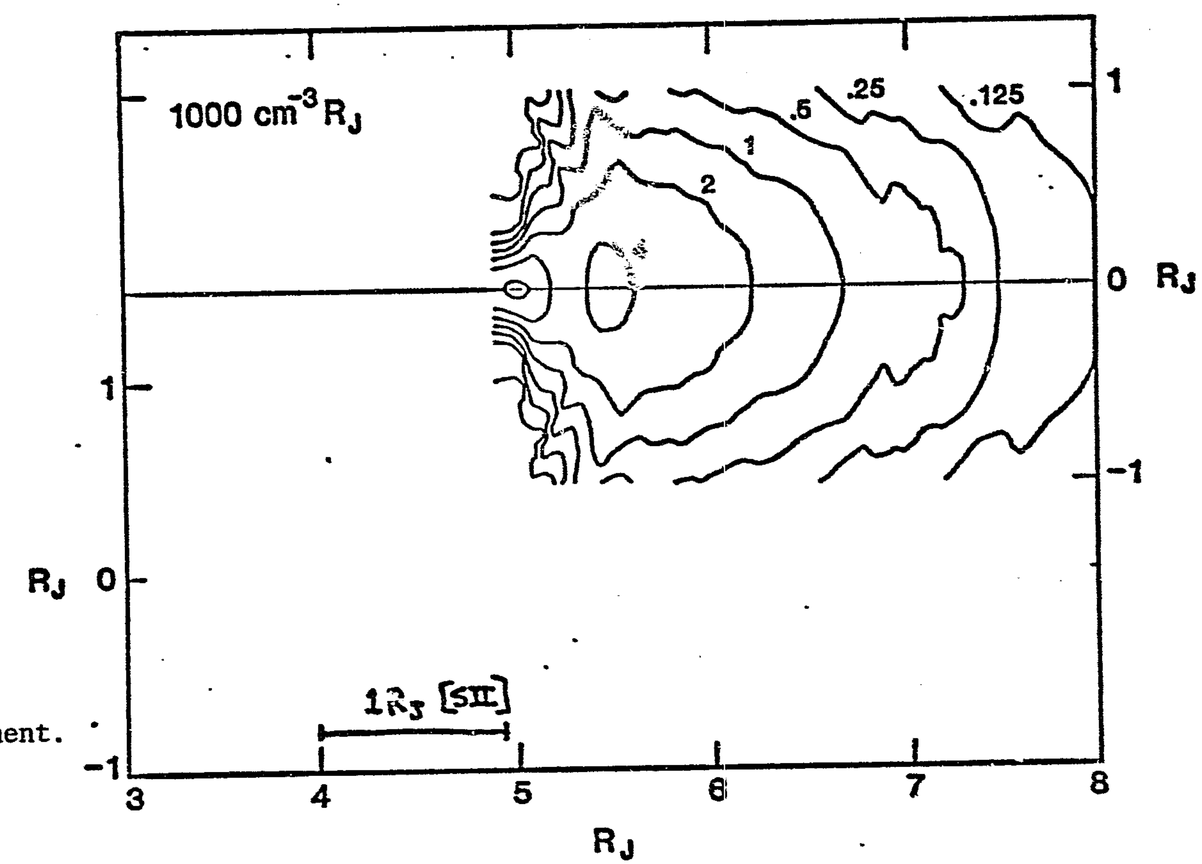


Figure 6. Radial profile of in situ measurements of charge density. The plasma science measurements (●) are of the positive charge derived from fits to positive ion energy per charge spectra. The Planetary Radio Astronomy data (Δ) from Birmingham et al. (1981) are electron density determined from the cut off frequency of plasma wave modes (typical uncertainties in the PRA determinations are shown by vertical bars).

SII column
density from
Voyager plasma
science experiment.



KD 14796
$\lambda_{III} \approx 190°$
[SII]λ6731
Intensity contours

Figure 7(a)

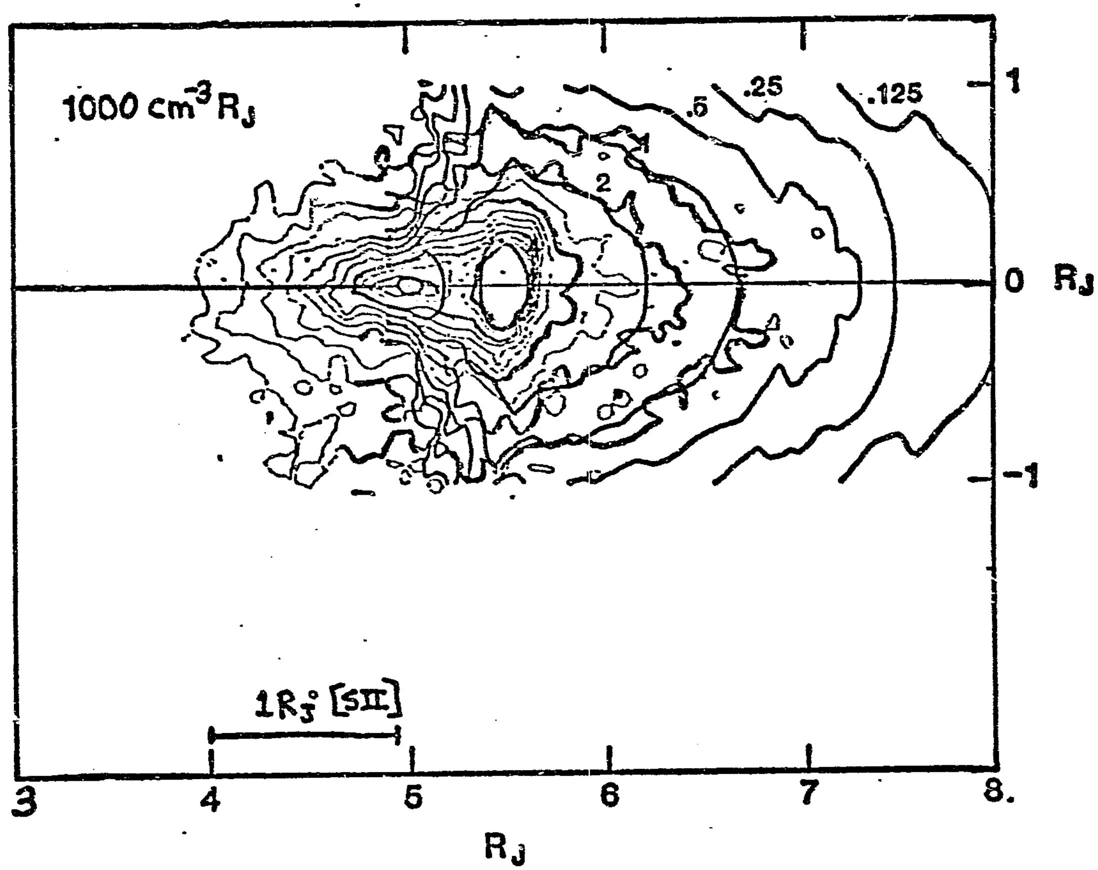


Figure 7(b): The data of Fig. 7(a) shown superimposed.

the data presented here were acquired, the plasma showed much less structure in [SII] images and a considerably weaker FAF. Our original images (Pilcher 1980a, Science, 207, 181) indicate that the FAF may develop in as little as 24 hours. If our interpretation of the FAF as a region of enhanced plasma density is correct, then this development would correspond to the "turning on" of a plasma source. Such time variable models have been considered in the interpretation of the Voyager plasma science data (Richardson et al. 1980, GRL, 1, 31), and remain an important area of study.

In connection with his magnetospheric research, Pilcher coauthored two major review papers on Jovian magnetospheric phenomena. The first, by Pilcher and Voyager UVS Co-Investigator Darrell F. Strobel, is a summary of the ground-based and spacecraft extreme ultraviolet (EUV) measurements. One of the goals of the authors was to resolve a number of apparent discrepancies within each data set. For example, it was shown that apparent disagreement between various ground-based determinations of the electron density were largely due to differences in assumptions or in atomic parameters used in the analyses. Uncertainties in atomic parameters were also found to be important in the interpetation of the EUV data and may, in particular, account for differences between IUE and Voyager UVS measurements.

The second review paper, by astronomer Robert A. Brown of the University of Arizona, Pilcher and Strobel, draws on the first review and includes discussions of important collisional processes that had not previously been considered in relation to the torus. One of these is elastic collisions between corotating ions and neutrals in the circum-Io clouds that result in lifetimes of ∿100 hours for neutral sulfur and oxygen and as little as ∿20 hours for sodium and potassium. Another is charge-exchange collisions that may compete effectively with electron impacts as an ionization mechanism.

Additional work on the Jovian magnetospheric emissions has been carried out by Morgan in fulfillment of his dissertation requirements. Approximately 300 slit spectra of the Io torus were acquired in 1981 by means of the order overlap technique which we have discussed in past reports. Basically, this technique allows the simultaneous measurement of 7 forbidden emission lines of SII, SIII, and OII that are diagnostic of the electron temperature and density within the nebula.

These measurements are complementary to the imaging discussed above in that they provide measurements of the density of the nebula, a parameter that could only be inferred from the images. Of particular importance is the question of whether or not bright regions in the nebula are associated with high density or large optical path lengths. The answer to this question is the key to proper interpretation of these images. Preliminary analysis of a portion of the data has shown that order of magnitude density variations can be found on a single spectrum, with at least some of these variations being longitudinal rather than radial in nature. This preliminary work also suggests that the brightness of the SII emission is not correlated with the density of the plasma, but a resolution of this question awaits analysis of the complete data set.

These spectra continue to be the only ground-based means we have of studying the distribution of oxygen in the torus. This new data set confirms our previous conclusion that the oxygen distribution is different from the sulfur distribution. It confirms the fact that OII is found at higher magnetic latitudes than SII, but an understanding of the longitudinal OII distribution also awaits a complete analysis.

Spatial variation in the [SIII]λ3722 line intensity has been seen in these data. Voyager UVS data has shown the hot, outer torus to be fairly uniform and constant in nature. And yet ground-based studies have shown that the cool, inner torus has large longitudinal variations. Light from the outer torus is dominated by UV emissions from SIII, SIV, and OIII, while the cool inner torus emits optical radiation primarily from SII and OII. The [SIII]λ3722 line is a link between these two different regions of the torus since it comes from an ionization state associated predominantly with the hot outer torus and yet is "cool" optical radiation that exhibits spatial variability associated with the cool inner region. It is hoped that by further study of the spatial variability of this line we can begin to answer the question of how the cool inner torus can exhibit such large spatial variability without this being reflected in the hot outer torus.

These findings, based on an analysis of 20 spectra, were reported in October by Morgan at the DPS meeting held in Pittsburgh and at the conference on Physics of the Jovian and Saturnian Magnetospheres held at the Applied Physics Laboratory of the Johns Hopkins University in Maryland. Morgan has also recently finished automating the data reduction of the spectra which will allow the remaining (∿280) spectra to be analyzed in a reasonable amount of time. He hopes to be completed with this analysis by May 1982 and finish his dissertation by September.

2. The Atmosphere of Neptune

Howell and Cruikshank have continued the program of J-K color measurements of Neptune begun by Cruikshank and Brown. The K bandpass corresponds to a strong CH_4 band in the atmosphere, while the J bandpass corresponds to the "continuum." Therefore the K filter sees only the light reflected from high altitude haze, above the CH_4 absorbing region. During 1980 Brown and Cruikshank found a regular 17.7 hr. variation in the color having an amplitude of 1.5 magnitudes, corresponding to a factor of 4 difference in optical depth of the haze in opposite hemispheres. In previous years the variation had been more chaotic.

Our observations from 1981 have been partially analyzed. They show a similar amplitude variation, but a K brightness at both maximum and minimum which is 1 magnitude fainter. In addition to the K variation, a smaller periodic variation in the J brightness was observed. However, the average J magnitude is similar to that one of a year ago. The nature of the haze and the reasons for its variability remain uncertain. Because of the decrease in brightness, we were not able to obtain with the 2.2-m the near-infrared spectra that we hoped would clarify this matter.

An exact determination of the period, and the search for proposed "secondary" periods in the light curve, have also been made impossible by e decrease in brightness. Neptune is currently located in the Galactic Plane in Scorpius. The region is filled with stars 14th magnitude and brighter at K, many of which cannot be seen in the visible because of their large reddening. Since they cannot be seen on the acquisition TV and at this brightness level they are not immediately evident on the strip chart, they can only be found by slow searching along the path Neptune will follow. The density of such stars is great enough that significant parts of the night are lost while Neptune is near the brighter ones, and errors of 10% or more may be caused by the unnoticed ones. This be the explanation for past observations of short "outbursts" at 2 μm.

Although detailed measurement of the light curve are impossible, changes in average brightness can be followed. We intend to obtain data as early as possible this year to follow the long period variations. In addition, Pilcher and Howell plan to observe Neptune and Uranus with the CCD, using CH_4 band and continuum filters. At these visible wavelengths it should be possible to measure the light curve, and during periods of good seeing, to resolve spatial structure.

3. CCD Imaging of Unraus

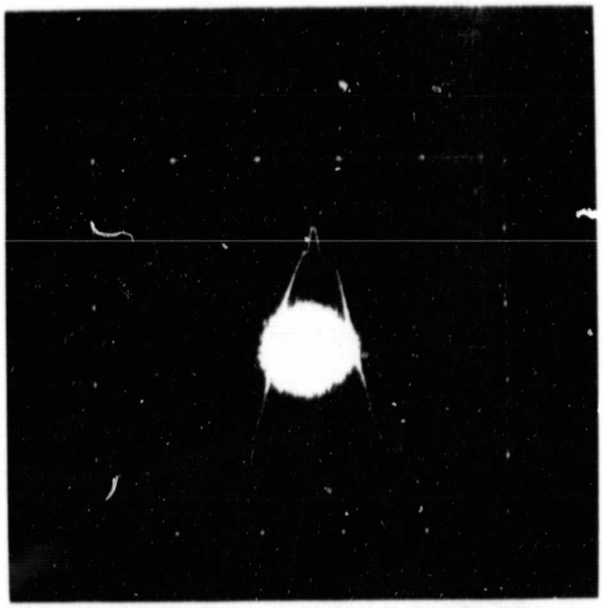
During the summer and fall, Howell developed data acquisiton software for the Galileo/Institute for Astronomy Charge-Coupled Device system and participated with Pilcher and Hlivak in that instrument's first use at the telescope. Most of the planetary observations cannot begin until the apparitions of the outer planets this spring, however, some data were obtained during the initial testing of the instrument. Figure 8 shows two Uranus images obtained through narrow-band filters in the CH_4 band at 7250 A and in the continuum at 3600 A. Also shown are traces through the centers of images. These clearly show differences in limb darkening between wavelengths. The CH_4 band data, when seeing effects are removed, should actually show limb brightening. The data are now being reduced so that they can be compared with slit scans at the same wavelengths (Pilcher et al. 1979), which indicate the absence of a high altitude haze layer with $\tau > 0.1$.

C. Satellites

1. Dark Side of Iapetus

The study of the dark hemisphere of Saturn's satellite Iapetus has been a topic of special interest to planetary scientists at the Institute for Astronomy for over a decade. In 1971, Murphy, Cruikshank, and Morrison made the keystone observations of the thermal emission of this satellite that established the albedo of the dark hemisphere and confirmed that Iapetus is indeed a spherical body with two distinct hemispheres. This was further developed by Morrison, Jones, Cruikshank, and Murphy in a more detailed study.

In the last two years we have engaged in a broad range of observations of the reflectance of the dark hemisphere of Iapetus using the large telescopes available to us at Mauna Kea Observatory. Cruikshank has taken the lead in this work and has enlisted the collaboration of students



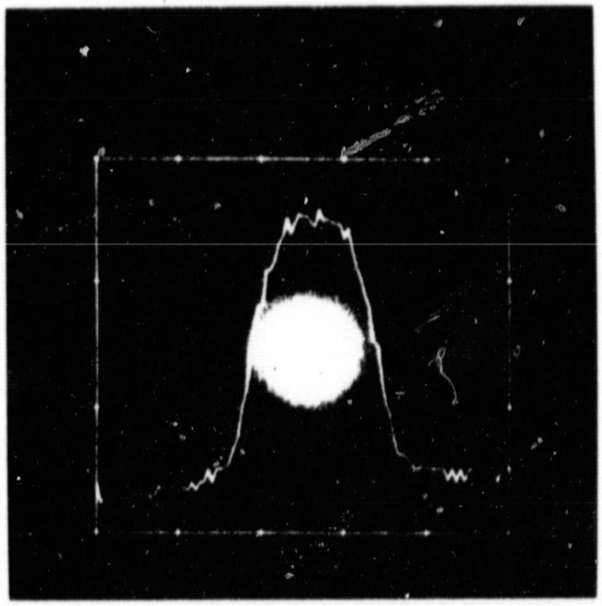


Fig. 8. CCD images of Uranus. Left: image in the spectral continuum. Right: image in the 7250-Å CH_4 absorption band. The intensity profiles superimposed are derived from the images themselves.

J. F. Bell, R. H. Brown, and C. Beerman, and colleagues Howell, Gaffey, Rognstad. A large paper has just been submitted for publication. This work presents new photometry in the UBV and JHK filter bands, new spectrophotometry from 0.3 to 3.75 μm (see Figure 9), and an analysis. The highlights of the analysis show that the color of the dark hemisphere is distinctly different from that of the outermost known satellite, Phoebe, and that the carbonaceous residue from the Murchison C2 carbonaceous chondrite provides quite a good match to the spectrum in the range 0.3-2.5 μm (Figure 10). This comparison is significant because the spectrum of the Iapetus dark hemisphere is unusually red and is similar to the darkest and reddest of the asteroids (RD type).

In models developed largely by Bell, the above work shows that the best evidence supports the contention that debris from Phoebe or other unknown outer satellite of Saturn impacts the dark hemisphere as Poynting-Robertson drag causes the debris to spiral toward Saturn. The high-velocity impacts preferentially remove ice from the satellite's surface, causing enrichment of included carbonaceous material intrinsic to Iapetus. The difference in the reflectances of Phoebe and the dark hemisphere suggest that relatively little Phoebe debris lies on the satellite. There remains the possibility that the impacting debris debris originates from another body of composition similar to the Murchison residue and that this material is exposed on the surface of Iapetus.

Observational work on the dark hemisphere will continue through the opportunities in early 1982 with an attempt to improve the quality of the spectral data and to extend the wavelength coverage. We will continue this work in collaboration with individuals at HIG Planetary Geosciences.

2. Distribution of SO_2 on Io

During early 1981, Howell modified the InSb CVF spectrometer used at the 2.2-m telescope, increasing its sensitivity at short wavelengths ($\lambda \sim 2$ μm) by a factor of 2. The wheel holding the discrete filters was placed under computer control for more efficient operation, and programs were rewritten to use the new CAMAC models in place of older, less reliable hardware.

This instrument was used by Howell with the assistance of graduate students Brown, Morgan, and Shaya to obtain 2.5-4.2 μm spectra of Io and

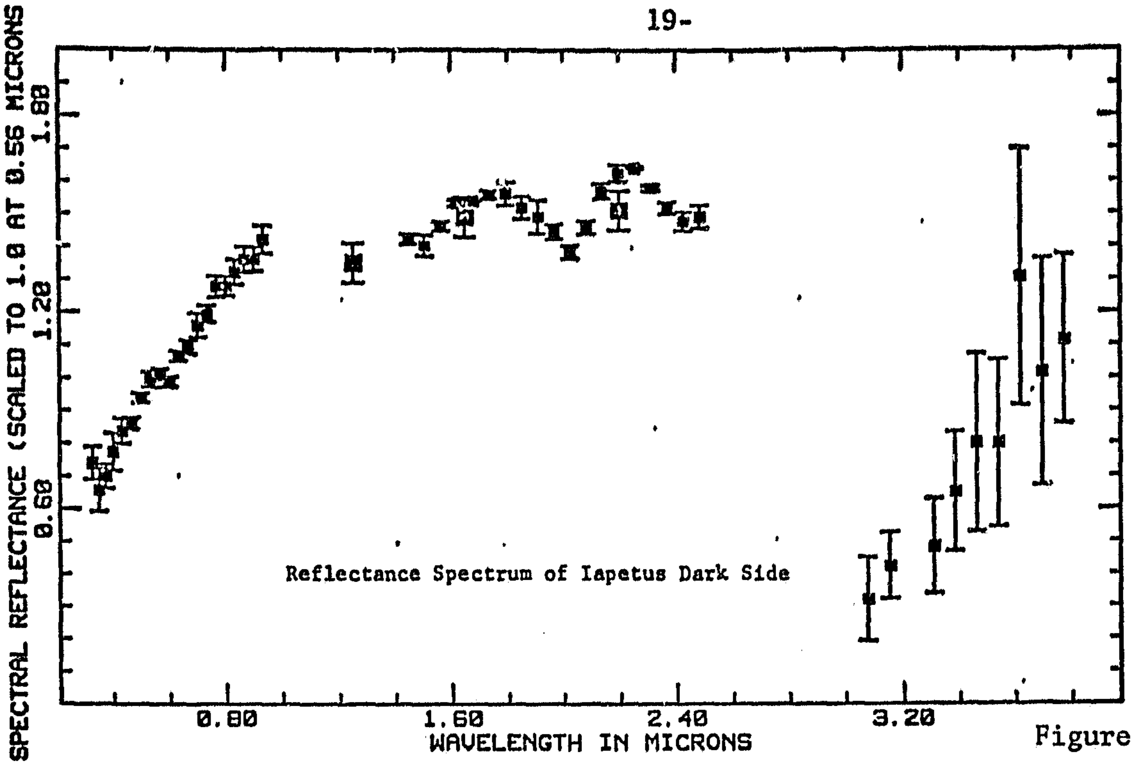


Figure 9

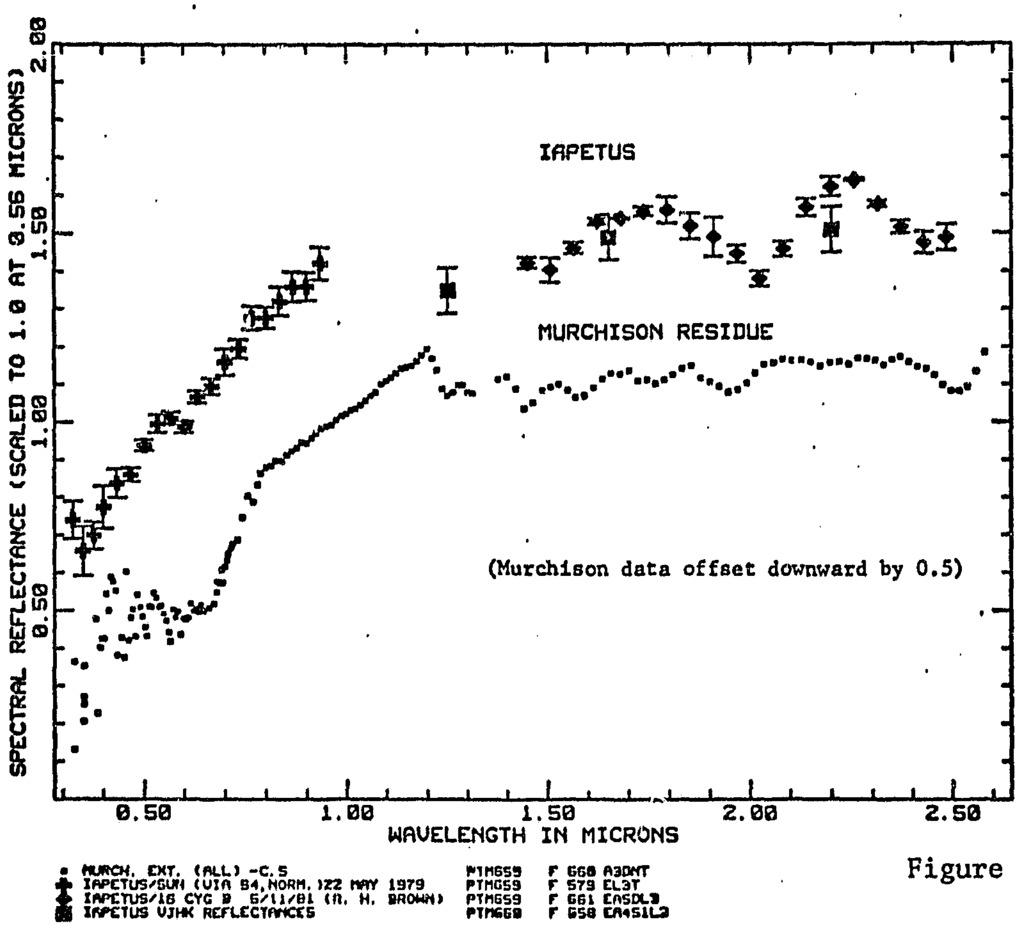


Figure 10

JK photometry of Neptune. The Io data is part of a continuing program by Howell and Cruikshank to measure spatial and temporal variations in the amount of SO_2. Those data Figures 11 and 12 have been analyzed and were presented at the 1981 DPS meeting in Pittsburgh.

Figure 11 shows spectra obtained on adjacent nights in February with the United Kingdom Infrared Telescope. Clearly there is less SO_2 in the hemisphere centered at 270° than in the opposite one. This difference in the band depth is not a result of thermal radiation filling in the band because observations at the 2.2-m telescope (Figure 12) obtained three months later show a virtually identical result. Observations at a number of orbital phase angles confirm this hemisphere asymmetry first seen in IUE data (Nelson et al. 1980). This is consistent with either SO_2 frost being the main constituent of the white plains unit common except at 270°, or SO_2 gas being preferentially absorbed by some other high albedo (and therefore cold) material making up the white plains unit.

In addition to spatial variations, temporal variations may exist. During the interval between the Voyager 1 and 2 flybys marked changes occurred in the region around 270° longitude. However, as Morrison has pointed out, the visible rotation light curve has not changed significantly over the past several decades. This may indicate some global pattern to the volcanism with short-term fluctuations in local rates. We have found no significant variations in SO_2 abundance over a times scale of a few months. In addition, comparison of 1976 observations from Mauna Kea with the recent data shown on significant change in the leading hemisphere (i.e., 1 = 90°). However, there may have been a change in the trailing hemisphere. The 1976 observations at 234° show considerably more SO_2 than the 1981 observations at 277°. This could however represent sharp longitudinal variation rather than a temporal one. During the coming year we will attempt to obtain spectra at precisely the same longitude as the 1976 observations to investigate this possibility.

A final question concerning the SO_2 is its exact form. Both frost and adsorbed gas have been proposed, and resolving this question is important for understanding the nature of the possible transient atmosphere and the global migration of the SO_2. It appears that the wavelength of the band is different for adsorbed gas and frost, although the various

Figure 11

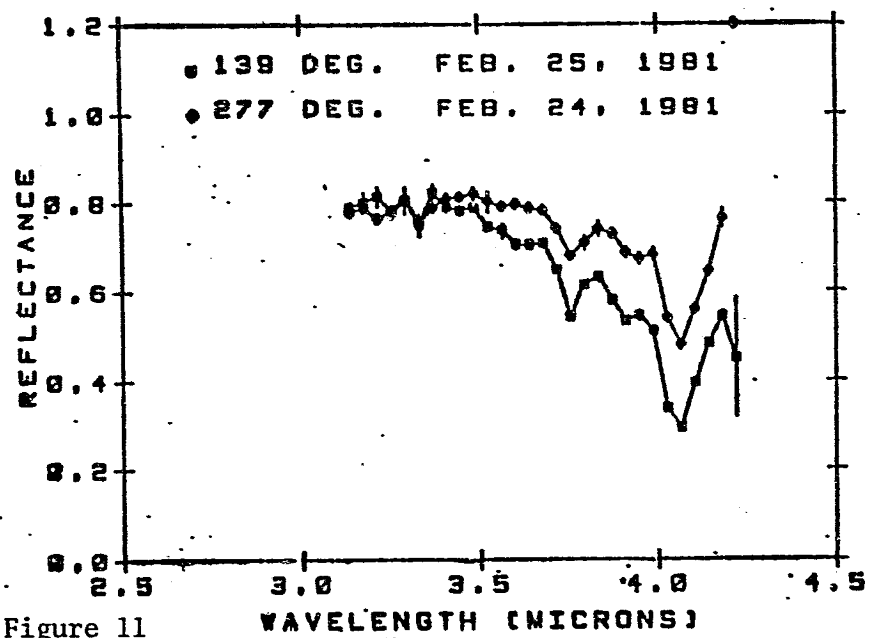


Figure 11

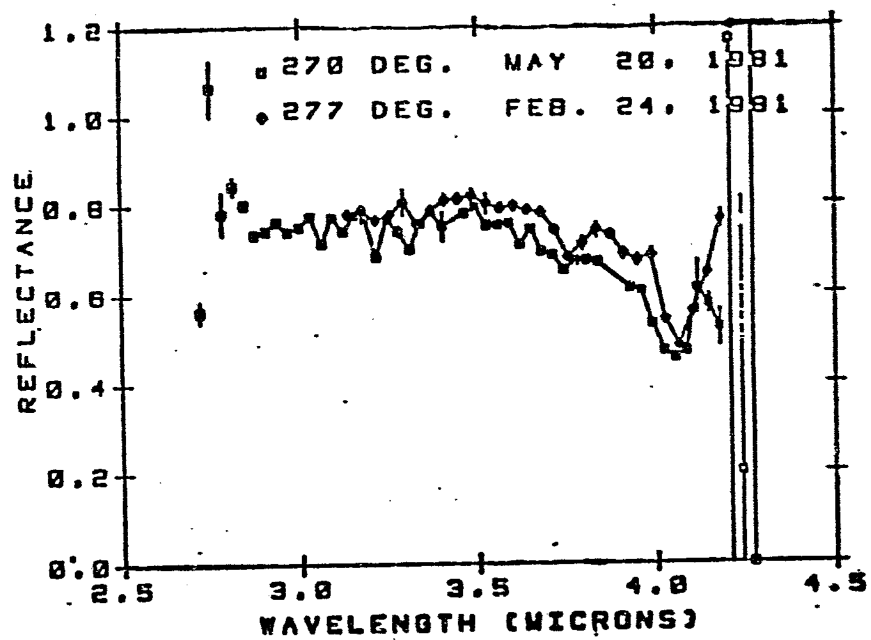


Figure 13

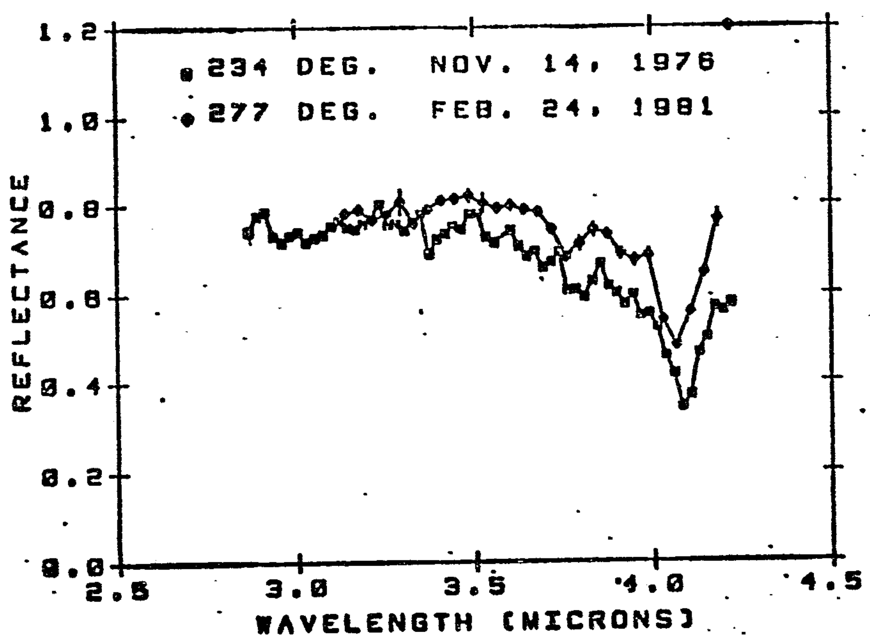


Figure 12

measurements have been made with different instruments, few of which have precise wavelength calibrations. We are preparing to recalibrate our data by observing objects with Br α emission at 4.05 μm. This is at virtually the same wavelength as the feature of interest which will eliminate the errors in calibration introduced by the CVF's nonlinearity (in central wavelength vs. position). Figure 13 illustrates the problem.

3. Thermal Studies of Io

During the 1980 apparition of Jupiter, Io's near IR flux at 2.2, 3.8, and 4.8 μm was monitored on 21 nights using the IRTF, 2.2-m, and 0.6-m telescopes. In addition to these data, earlier measurements by C. Lonsdale and T. J. Lee at the UKIRT telescope, and those made by Sinton in June 1979, have been analyzed by Sinton and graduate student D. Lindwall. Eleven nights of high quality data that were obtained during 1981 with the 2.2-m telescope, the IRTF and the UKIRT have been added to the analysis. Reduction of the new data has been carried out by an undergraduate student (W. Tittemore). A paper is in an advanced state of preparation and makes the following conclusions:

a. At 2.2 μm flux from Io is essentially reflected sunlight, and may be treated in a conventional way. The linear solar-phase-angle coefficient is 0.025 mag deg^{-1} and is not significantly different from the visual phase effect. The rotation phase curve is similar to the visual phase curve, but the geometric albedo is greater at 1.00 ± 0.03 at the maximum of the curve.

b. There is a definite intrinsic scatter to the 3.8- and 4.8-μm photometry which is subtantially larger than the observational errors. The large scatter made it impossible to determine the solar-phase-angle effect at 4.8 μm, at either apparition but it was possible to determine this effect at 3.8 μm with the 1980-81 data. The value found was close to 0.025 mag deg^{-1}. This value, if used for the 4.8- μm data also reduces the scatter in a least squares sense. In L and M the trailing hemisphere is generally brighter than the leading side. These differences may be due to either albedo differences or to greater volcanic activity on the trailing side.

c. A number of period-finding techniques were employed by Lindwall to search for harmonic components. All of these were unproductive, presumably because of the large intrinsic scatter. Clearly, the 42.5-

hour rotational period is present in the 4.8-μm data, and a least-square fitting of a sine wave of this period does not give a significant (at about 5σ) component. We next tried least-square fitting of sinusoidal components at the Jovian magnetic longitude (System III [1965]) and its first overtone (periods of 13 and 6.5 hours) Figure 14. From the 1979-1980 data, the fundamental appeared to be marginally significant, while the overtone may not be significantly present. We have tried this again with the 1980-1981 data, and we find that the fundamental is once more marginally significant, and moreover the values found for the amplitude and phase agree with those found from the earlier data Figure 15. The overtone, by itself, was again not significant, but it generally agrees with the earlier determination. This has been a most unexpected result, for it seems to confirm the hypothesis of T. Gold (1979, Science, 206, 1071-1073), whose electrical theory of the origin of the volcanism is not generally held in high esteem. But if this dependence of Io's activity on the magnetic longitude continues with future data, it is an extremely important result which demands an explanation. Our own view is that the exact mechanism proposed by Gold is not sufficient to produce the volcanic activity as he proposed, but that an electrical or magnetic effect may trigger the volcanic eruptions. We have in the Jupiter-Io system a most unusual and exceedingly complex geophysical system, considering all of the phenomena that have been observed and a majority of which appear to be related to one another. A magnetic longitude dependence of the volcanism will add another relation to those already found.

d. A total of eight definite or probable outbursts have been identified. Besides a major outburst of 11 June 1979, which is attributed to the formation of Surt, we believe there were minor outbursts on 12 June 1979, 13 December 1979, 20 December 1979, 24 February 1981, and 25 February 1981. In addition we place events on 8 February 1980, and 2 March 1980 in a probable outburst category because these were observed at a low S/N ratio with the 0.6-m telescope. At four of the minor outbursts, elevations in L as well as M were observed on 13, 20 December 1979, 24, and 25 February 1981. In all four of these events the excess flux at L decayed very rapidly in the first hour of observation, while

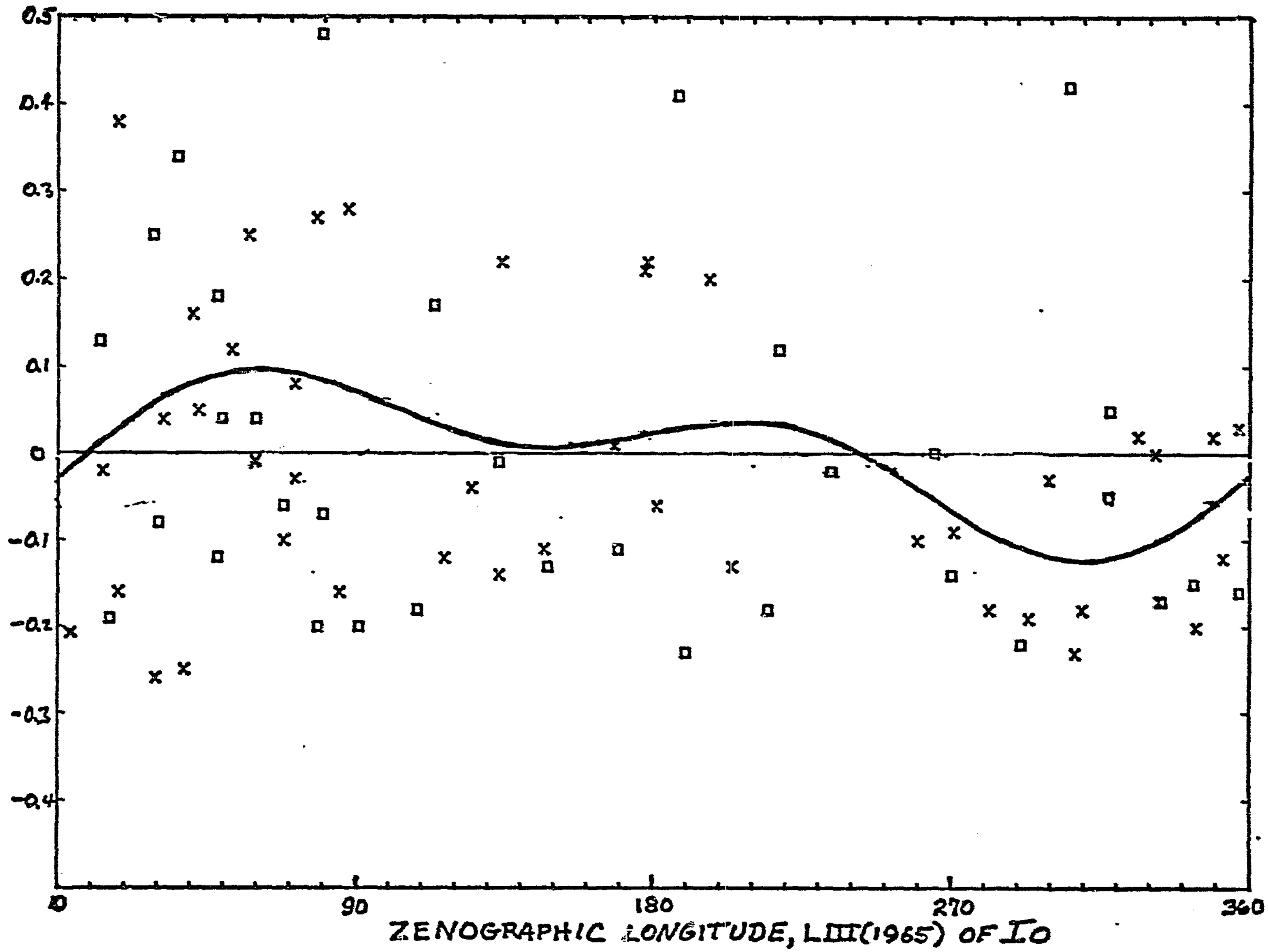


Fig. 14. Residual deviations (after removal of phase and rotation effects) 4.8 μm data plotted against the System III longitude of Io. The curve is obtained from a least-square fitting of the fundamental and first overtone to the data.

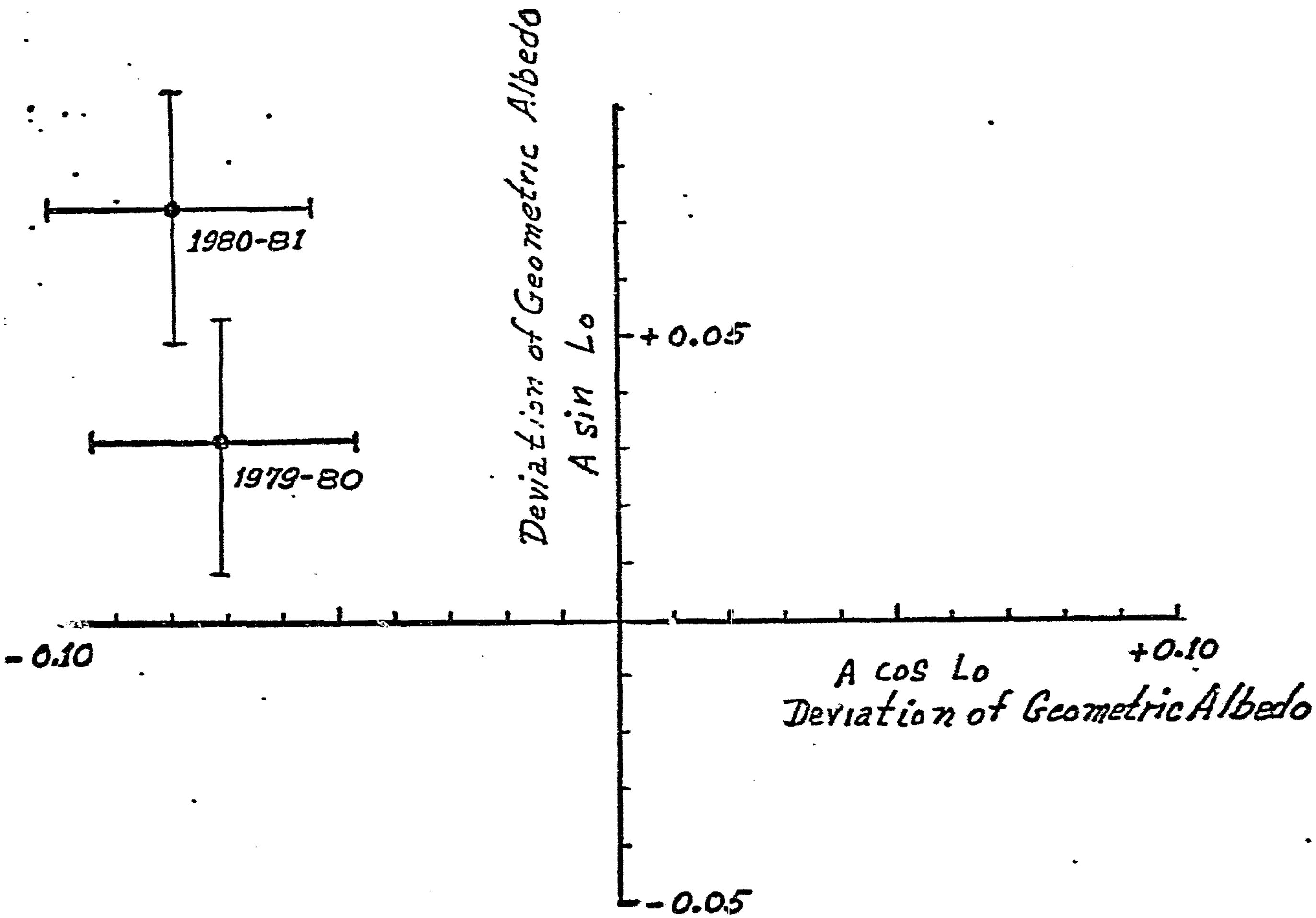


Fig. 15. The amplitude A and phase, Lo, of the System III fundamental component of residual deviations of geometric albedo for the two seasons of 4.8 μm data.

the excess M flux persisted, generally with a slight decay, through the remainder of the observations. These four events all seemed very similar and so they have been averaged together to obtain a mean behavior. The color temperature at the beginning appears to be in the vicinity of 800K with an equivalent area of $\sim$100 km^2. The color temperature quickly decays to 300K and the area expands to $\sim 10^4$ km^2. The increase in area leads us to believe that these outbursts were the result of eruptions that led to extensive lava flows.

These minor outbursts, which have a 20 to 50% enhancement of the 4.8 μm flux, occur about 20% of the time on Io. The major outbursts, of which we have only seen one, certainly are a lot less frequent.

During the spring of 1981, a new phenomenon was found. It was discovered that Io "flickers" at 4.8 μm. Figure 16 shows this flickering as observed with the IRTF at high S/N ratio. A number of stars (the data from two are shown in the figure) were also observed for comparison. The time scale of the flickering is $\sim$30 seconds. Thus far efforts to determine the power spectrum of the flickering have been unsuccessful. At times the amplitude of the flickering reached 10% of Io's flux, while at other times the flickering is undetectable. The phenomenon has been searched for at 10 μm as well. No flickering has yet been observed at this wavelength, and the flux from Io has been stable to better than 1%.

The apparent spreading and cooling of flows as shown by Figure 17 led Sinton to consider models that consist of a pahoehoe-like flows. Numerous examples of such flow constructs are found on the Voyager pictures (Carr et al., 1979, Nature, 280, 729-733). The models assume a steady state of formation, cooling off, and eventual obliteration by resurfacing of these flows. In addition to the "old" cooling-off flows, the model contains currently active sources at $\sim$600K which contribute most to the 5-μm emission. With only three free parameters, the model "explains" the eclipse spectrum found by Morrison and Telesco. One of the parameters is the resurfacing cut-off temperature of emission by the cooling flows. The temperature at which cut-off occurs is set at about 175K by a nominal 0.1 cm yr^{-1} resurfacing rate. This temperature is close to the best value required to fit the observed spectrum (the assumed cut-off temperatures are used to label the curves in Figure 18).

The aforementioned "flickering" also fits in with this model. The

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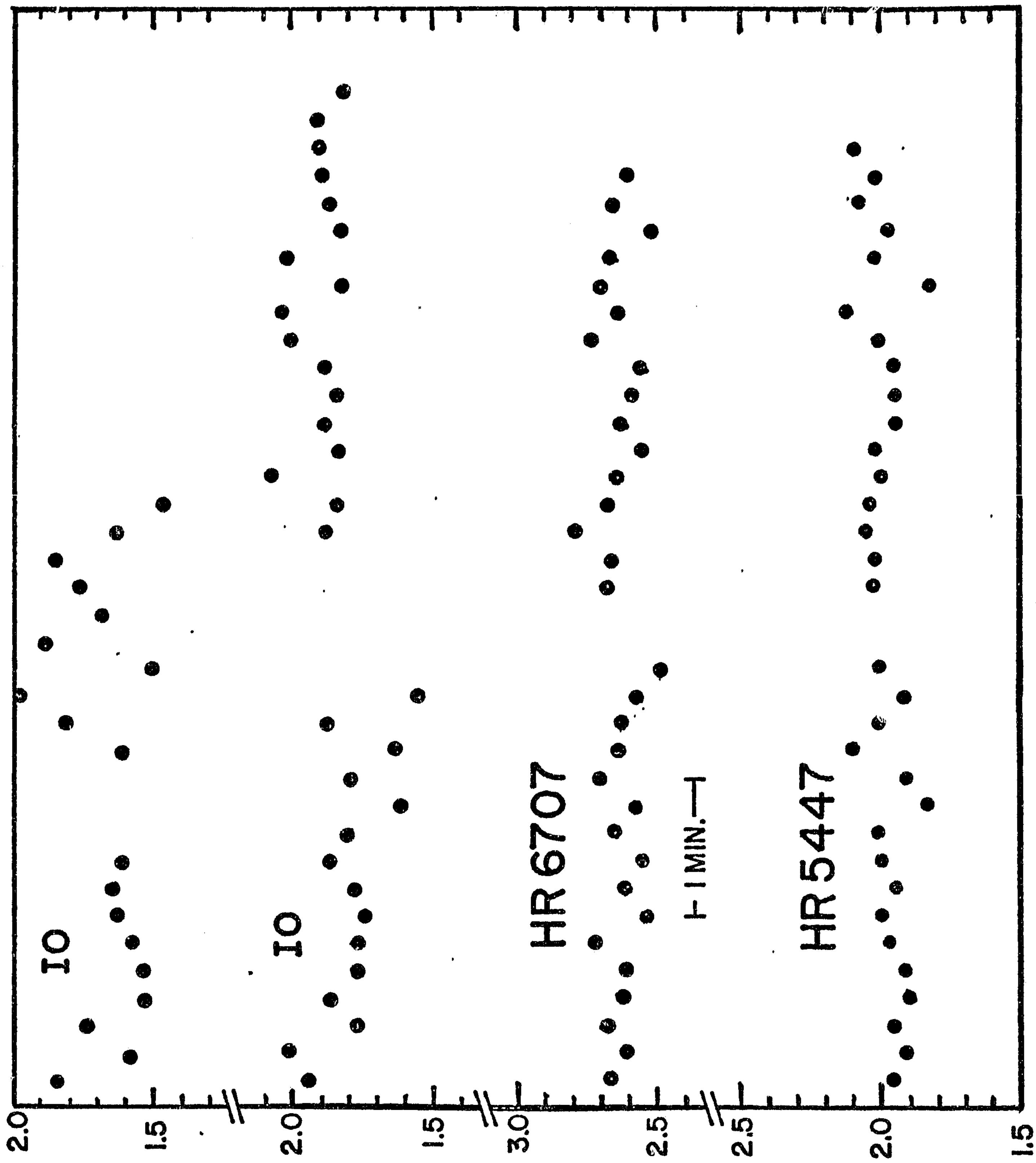


Fig. 16. Time-series 4.8 μm measurements of Io and 2 stars of nearly the same magnitude obtained with the IRTF. The fluctuation of Io is often greater than that observed for stars.

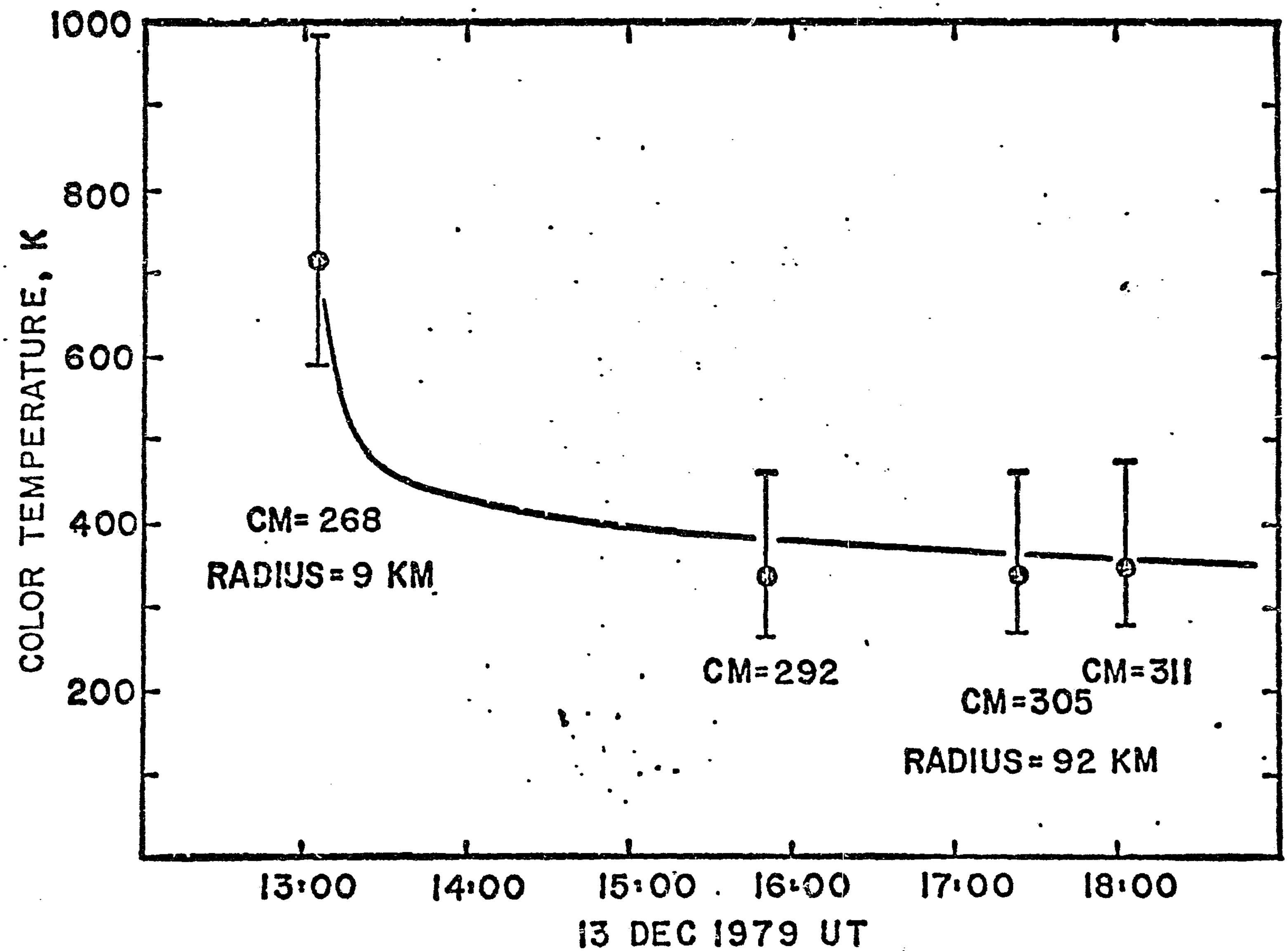


Fig. 17. The minor outburst of 13 Dec 1979 from 3.8 μm and 4.8 μm data temperatures and apparent radius of the source of emission are shown as a function of time. Similar behavior has been found for three other minor outbursts.

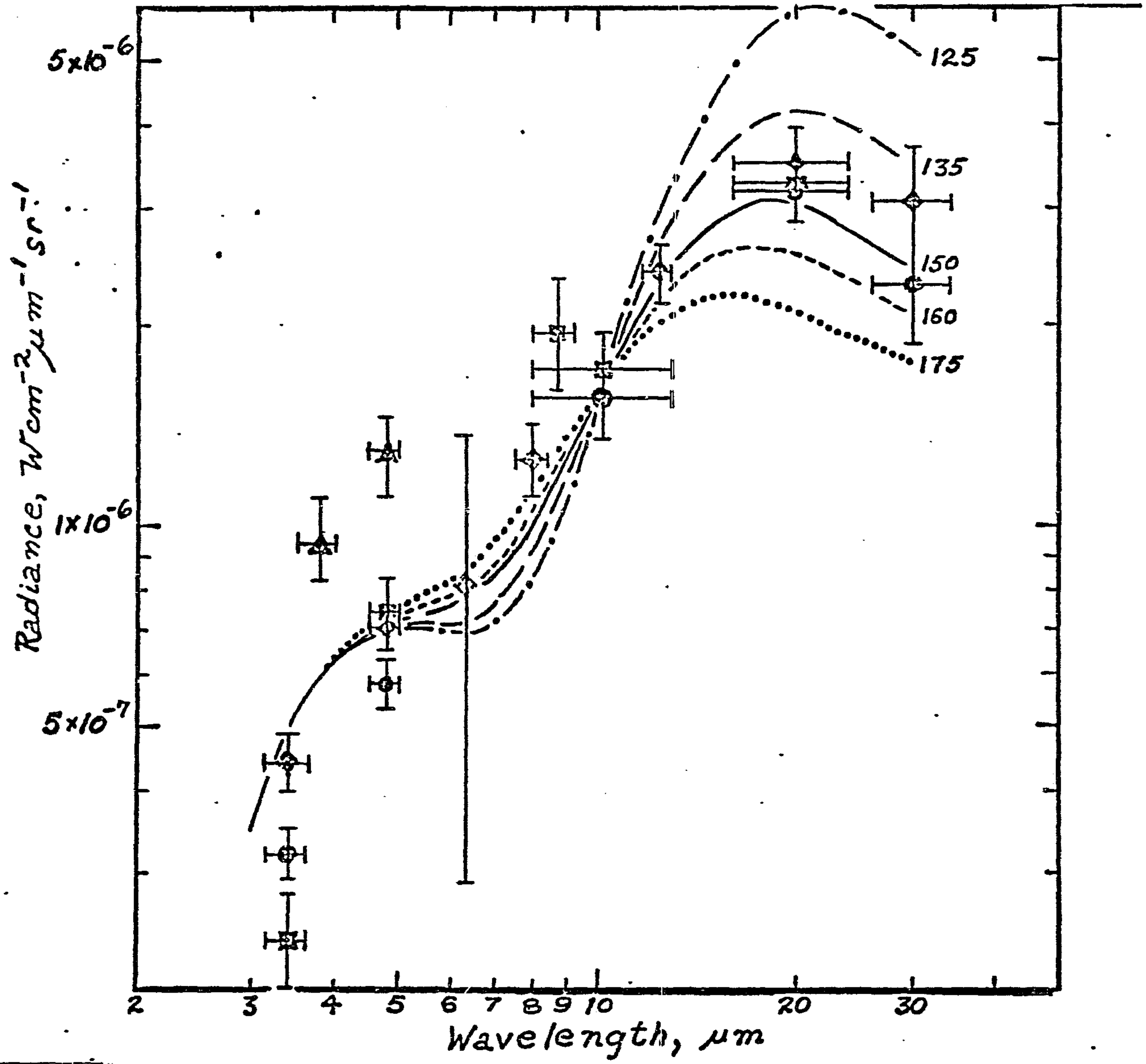


Fig. 18. Model curves for various flow models compared to data obtained during the total phase of a number of eclipses. The model curves include the background emission which includes the emission of 5% of the surface covered by calderas with 10% albedo. The numbers labeling the various curves are the temperatures of the various models at which resurfacing causes cessation of emission. The models are fitted to the 4.8 μm and 10 μm mean fluxes.

active sources would be expected to vary as the volume or temperature of the flow varies. On the other hand the cooling off flows are not expected to flicker. Since, in the model, most of the 10-μm flux comes from these old flows, the 10-μm flux is not expected to fluctuate. Indeed, this has been observed to be the case thus far.

In April 1980, Morrison and C. Telesco used the IRTF to make the first measurement during an eclipse of the thermal emission from Io over the full spectral range 3-30 μm. Their analysis of these observations yielded an average surface heat flux of (1.5 ± 0.5) W cm^{-2}, corresponding to an internal luminosity for Io of $(6 \pm 2) \times 10^{13}$ watts. The value of 6×10^{13} watts is near the upper limit calculated by Yoder for the dynamical heating of Io. Sinton has continued these eclipse measurements; several eclipses were observed with the IRTF in 1981. The fluxes that he has found at 10, 20, and 30-μm are in excellent agreement with those found by Morrison and Telesco. In addition, he has made narrow-band measurements at 6.3, 8.9, and 12.5 μm as well as the shorter wavelengths of 3.5 and 4.8 used by Morrison and Telesco. The aim of these narrow-band measurements is to make a better determination of the spectrum of the hot spot emission for comparison to the models mentioned above.

A problem that occurs in determining an accurate value for the heat flux from Io is the accurate determination of the residual flux from the cooling background surface of Io. To this end Sinton and Tittemore have computed numerous models of the eclipse cooling of Io. For all the the computed models the disk of Io has been divided into 20 areas arranged by circular zones and sectors. For each area a complete temperature curve is combined for an Ionian day before the eclipse in order that during the eclipse calculations the correct subsurface temperature gradients are used. Models that have been calculated are three types: homogeneous, vertically inhomogeneous, and horizontally inhomogeneous. With the addition of the subsurface gradients, the homogeneous model could not be made to fit, which constrasts with that found by Morrison and Telesco who did not use subsurface gradients. We feel that the most applicable model was the horizontally inhomogeneous model which incorporated the known calderas of Io at 5% of the surface and which had an average albedo of 10%. These modelled calderas were given the properties of amorphous sulfur. This model gave an excellent fit to M and T as well as our data. It however leads to a somewhat lower background flux during eclipse than that used by M and T. Hence we find a somewhat greater heat flux from Io and our value is again close to 2 Watts m^{-2}.

We have determined new flow models to fit the revised background estimate found from the horizontally inhomogenous model mentioned above. The result of the new flow models combined with the eclipse cooling background is shown in Figure 18 and one of these curves is an excellent fit to all observations at wavelengths at 8 μm and longer. Shortward of 8 μm Io is known to vary from eclipse to eclipse, presumably because of the variability of the current activity discussed above. We have then also computed different models in which only the area of 600K sources was varied to fit each eclipse measurement at 4.8 μm, while keeping the best fitting flow model. These models are shown in Figure 19 and the models verify that the short wavelength data can be fit by changes in the 600K source area while still fitting the constancy of the data obtained at 10 μm and longer. Thus, there does not appear to be any significant change in the long wavelength flux from Io. Since most of Io's heat flux occurs at these long wavelenghts, no appreciable variation of the total heat flux from Io has been found.

4. Composition of the Uranian Satellites

Cruikshank is collaborating with R. H. Brown on the latter's observational work for a Ph.D. dissertation on the composition and other physical properties of the satellites of Uranus. During this report period the observations of a few months earlier were analyzed, mostly by Brown. The new data set consists of high-quality CVF spectra of Ariel, Titania, Oberon, and Umbriel obtained with the 5-percent bandpass filter on the UKIRT and the NASA IRTF. The data far surpass in quality those obtained by Cruikshank earlier with the KPNO 4-m telescope, and in particular show the spectrum right through the strong telluric water vapor band at 1.95 μm. Only at Mauna Kea is it possible to work through this band with photometric precision, and in the case of solar system bodies with ice signatures in their spectra, it is very important to have the additional data. The new spectra, ratioed to a solar-type star, are shown in Figure 20. The comparison object is Iapetus with some H_2O ice revealed.

The discovery of water ice made earlier by Cruikshank is neatly

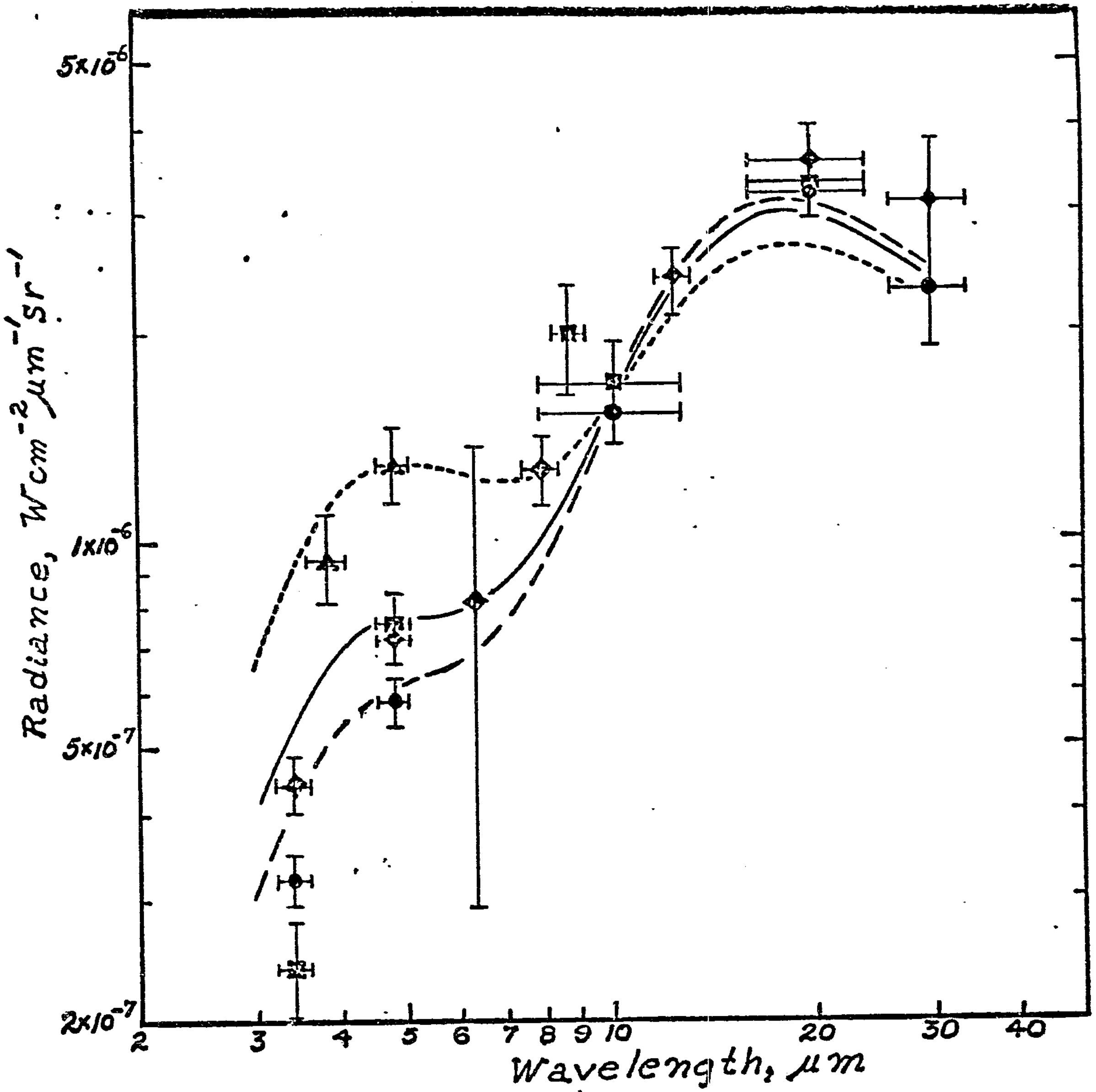


Fig. 19. Model curves for various flow models compared to data obtained during the total phase of a number of eclipses. The model labeled 150 in Fig. 18 is adopted, and the area of 600K is varied to fit the 4.8-μm emission observed at different eclipses.

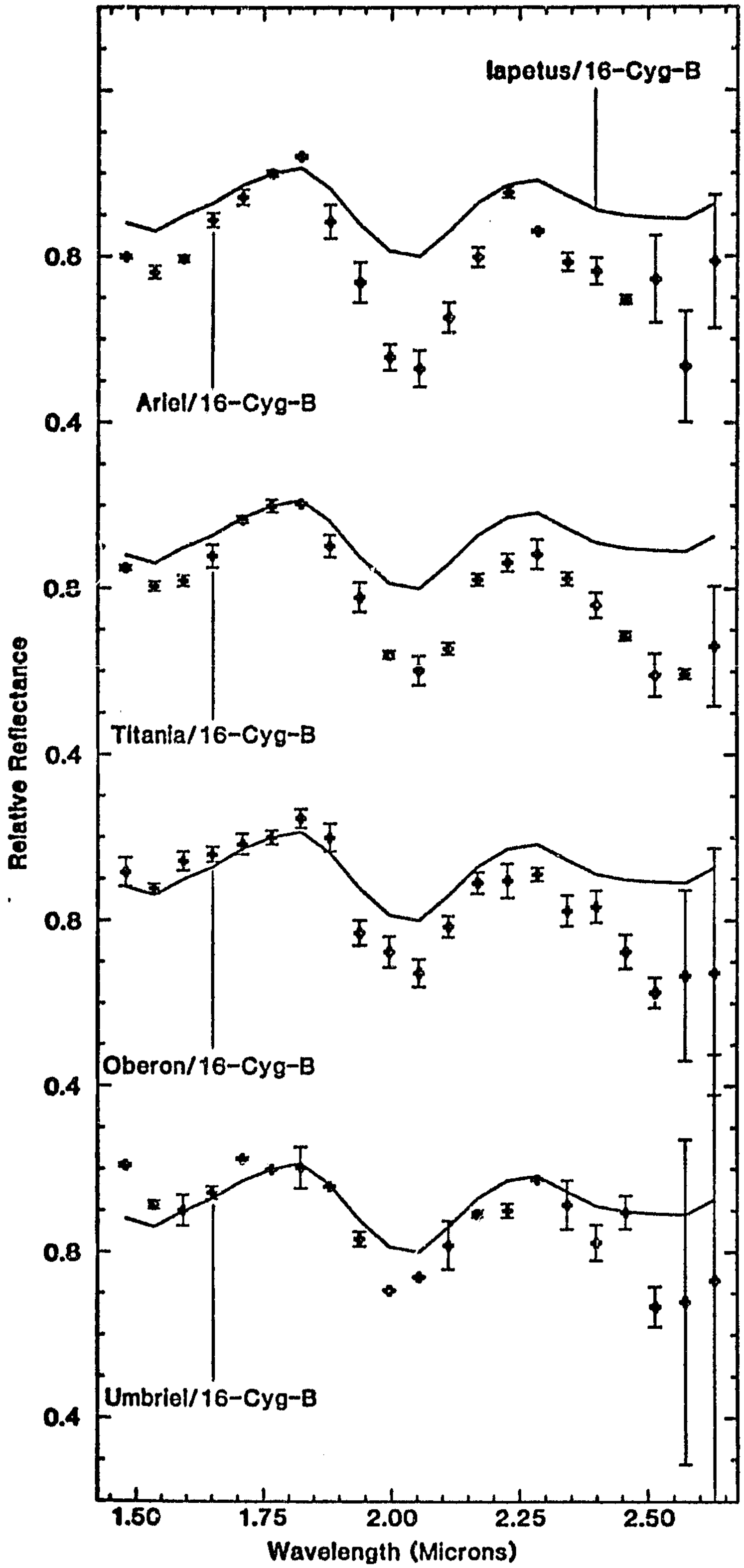


Fig. 20.

Spectra of the Uranian satellites by Brown and Cruikshank, 1981. Solid line represents spectrum of Iapetus at an intermediate rotational phase. (Note ice bands.)

confirmed in the new spectra, and Brown has begun a detailed analysis of the satellite spectra in comparison with laboratory data taken by R. Clark and by Brown with the HIG Planetary Geosciences facility.

Some of the new ice and frost spectra obtained by Brown for his study of the Uranian satellite spectra have been made with an environmental chamber specially designed for this purpose. The chamber contains a sample cup that can be maintained at T = 60K or heated up to any required temperature at which the ice will remain frozen. The chamber can also be used for ices of other substances, and will be used for methane ice observations in conjunction with the Triton analysis described elsewhere in this report. The chamber was built largely with funds on this grant, and can be used with either the HIG Planetary Geosciences spectrogoniometer or spectrometers at the Institute for Astronomy.

5. Europa

Because of the mutual coupling of the orbits of Io, Europa, and Ganymede, Europa also has forced eccentricity and consequently tidal dissipation analogous to Io. Cassen, Peale, and Reynolds have estimated that the combined radiogenic and tidal heating of Europa will amount to 1% of that of Io, but that convection and conduction may be adequate to remove this heat without geothermal activity.

Sinton, with collaboration of A. Tokunaga and I. Gatley, have sought to detect such geothermal activity by observing Europa during eclipses by Jupiter in a method analogous to that used on Io. Some conflicting and indefinite results have been obtained. Reappearances from eclipse were observed on 21 April, 16 May, 23 May, and 12 July 1981. The 16 and 23 May eclipses were observed simultaneously with the IRTF and UKIRT telescopes. On several eclipses (16 and 23 May) 5-μm data were obtained. A positive detection at 5 μm during a total eclipse would constitute a definitive indication of geothermal activity since emission from the background is insignificant at this wavelength. At the 16 May eclipse, Europa was detected. However, with much greater sensitivity, it was not detected at the 23 May eclipse at both telescopes. A difference between the two observations was that a bolometer was used on 16 May while InSb detectors were used on 23 May. It is possible, but not proven, that the 5-μm filter in the bolometer system has a minute leak at 38 μm which could account for the detection. Observations were obtained in the 10, 20, and 30-μm atmospheric windows on three eclipses. Figure 21 shows all 10 and 20-μm data which were obtained during the total and recovery phases of the eclipses. The model curves in the figure are of a homogeneous model that is fit to the 20-μm data. The model calculations include integration of the fluxes over the bandwidth of the filters, an important consideration. The 10-μm data obtained during eclipse are significantly above the 10-μm model curve which is expected if there are hot spots. Yet we feel that this is not a positive detection because of possible inadequacies of the model and uncertainties in accounting for the width bandwidth of the 10-μm filter. In the observations made on 12 July, we used 8.7 and 12.5-μm narrow band filters. Europa was not detected at 8.7-μm during eclipse and only marginally detected at 12.5 μm.

From careful analysis of the 10-μm data we feel that the best indication from the data is that although Europa may have a hot spot flux 1% of Io, uncertainties in modelling the background flux make it safer to say that we have set an upper limit to Europa hot spot flux at 3% of the Io flux.

6. The Infrared Spectrum of Triton

Using the 5-perfect CVF on the IRTF, Cruikshank with the assistance of R. H. Brown obtained a spectrum of Neptune's satellite Triton having the highest signal precision of any data yet acquired. The data cover the region 0.5-2.5 μm and are shown, ratioed to a solar-type, in Figure 22. Superimposed on the Triton data (points with error bars) is a solid line representing a model methane atmosphere computed by J. Apt (JPL) who is collaborating in this work. The methane atmosphere consists of 500 m-agt of methane at $P = 10^{-3}$ bar and T = 55K. While the gas fits the spectrum fairly well in the band at 2.3 μm, there is a distinct failure of the fit at 1.7 μm and an additional feature shows up in the Triton spectrum at 2.15 μm.

Work is in progress with Apt to explain the Triton spectrum, and at the same time we are planning for new observations with the complementary high transmission CVF (0.8-1.6 μm) presently on order.

The resolution of the problem of the atmosphere and/or surface composition of Triton is of special interest in view of pending Voyager 2 observations of the Neptune system. It seems that this problem can be

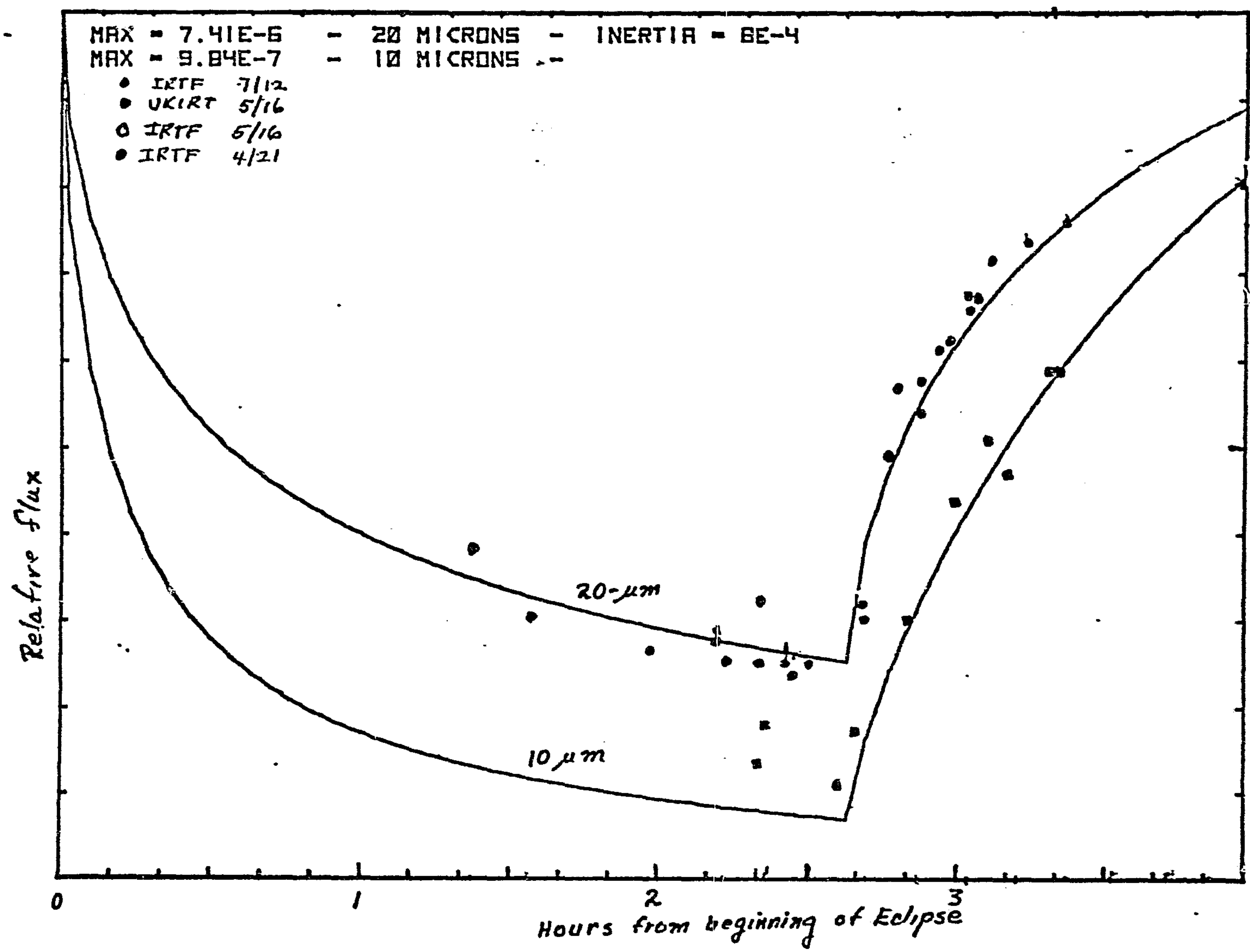
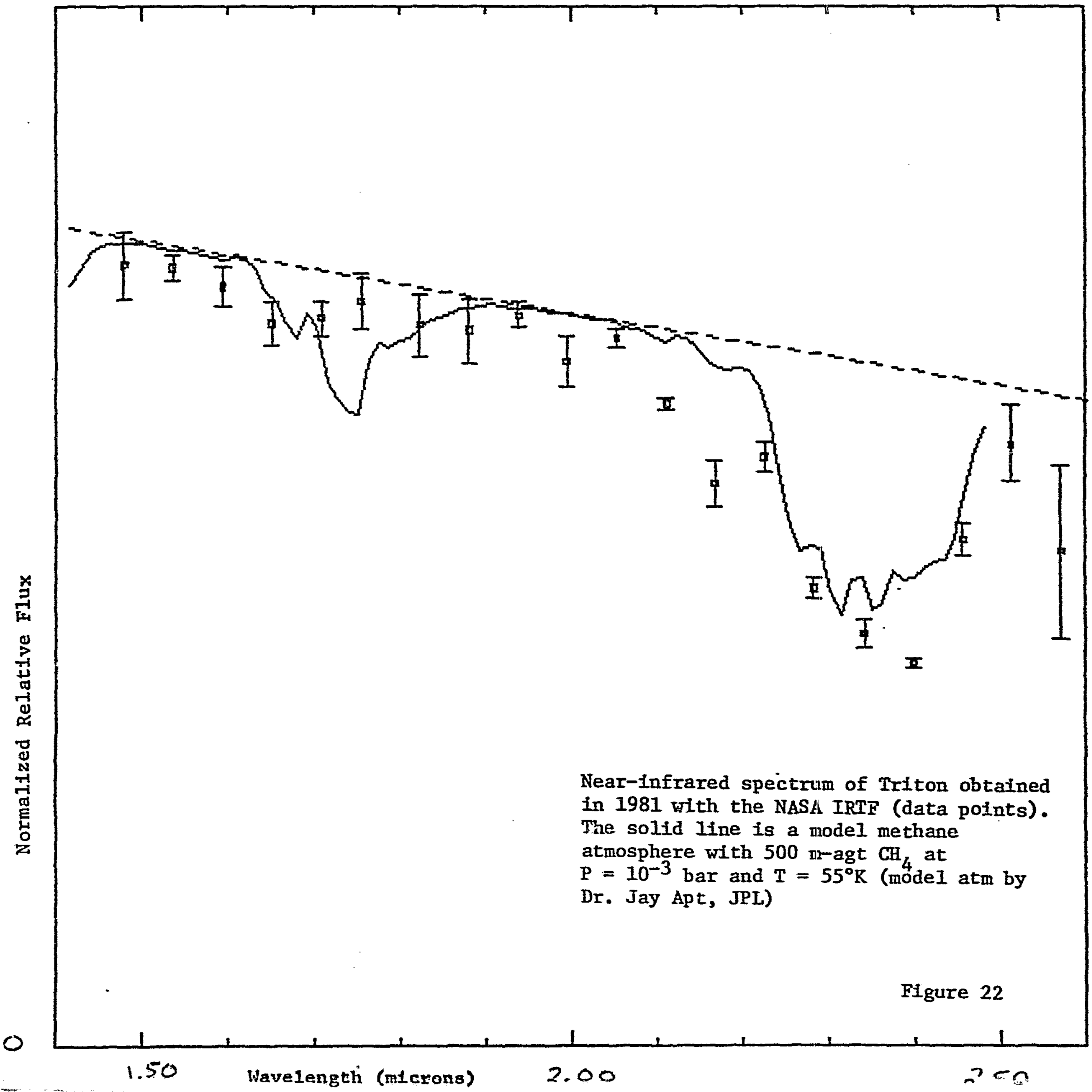


Fig. 21. Observations of eclipses of Europa at 10 and 20 μm. The curves are calculations of a model that best fits the 20 μm data. ~~The fact~~ that the 10 μm data in the total phase (near to 2.5 hours) lie above the model curve is an indication of possible hot spot activity on Europa.



Near-infrared spectrum of Triton obtained in 1981 with the NASA IRTF (data points). The solid line is a model methane atmosphere with 500 m-agt CH_4 at $P = 10^{-3}$ bar and T = 55°K (model atm by Dr. Jay Apt, JPL)

Figure 22

solved from ground-based observations, but a broader wavelength region must be studied and with moderate spectral resolution. At the present time, this can be done only with CVF systems on the largest telescopes.

Note in the new Triton spectrum that it was possible to observe through the strong telluric water vapor band at 1.9 μm because of the conditions of low humidity and consequent high transmission at Mauna Kea Observatory. This region cannot be studied so well from any other observatory on the ground.

7. Surface Composition of Hyperion

In a collaborative project with R. H. Brown, Cruikshank has continued the study of the near-infrared reflectance spectrum of Hyperion in an analysis of the surface composition of this satellite of Saturn. The work takes on particular significance in view of the Voyager 2 images of the object showing it to be highly irregular in shape. Following on Cruikshank's earlier discovery of water ice on this satellite, he and Brown obtained new low-resolution CVF spectra (using the 5-percent bandpass filter) on the NASA IRTF and the UKIRT telescopes on Mauna Kea. The new data, shown in Figure 23 confirm the presence of the strong ice bands at 1.55, 1.95, and 2.4 μm.

While a superficial resemblance to the spectrum of Ganymede appears in the Hyperion data, when the Ganymede spectrum is reduced in resolution to the approximately 5-percent of that of Hyperion, differences become apparent. In fact, as will be shown in a later analysis, the spectrum of Hyperion resembles the spectra of the Uranian satellites more closely than the icy satellites of Saturn or Jupiter. The differences occur in the shapes and depths of the ice bands and in the shape of the continuum. These differences are in the same sense as the photometric differences identified by Cruikshank, Pilcher, and Morrison (1977, Ap.J., 217, 1006) and are presently not understood. Brown is working on the Uranian satellite data for his Ph.D. dissertation and may uncover the reason for the spectral peculiarities of these objects and Hyperion in his analysis. This will be discussed in a future report, and the results will be published in the open literature.

We note that spectra of faint bodies such as Hyperion and the Uranian satellites with existing telescopes would not be possible if it were not for high transmission of the 5-percent CVF filter that was

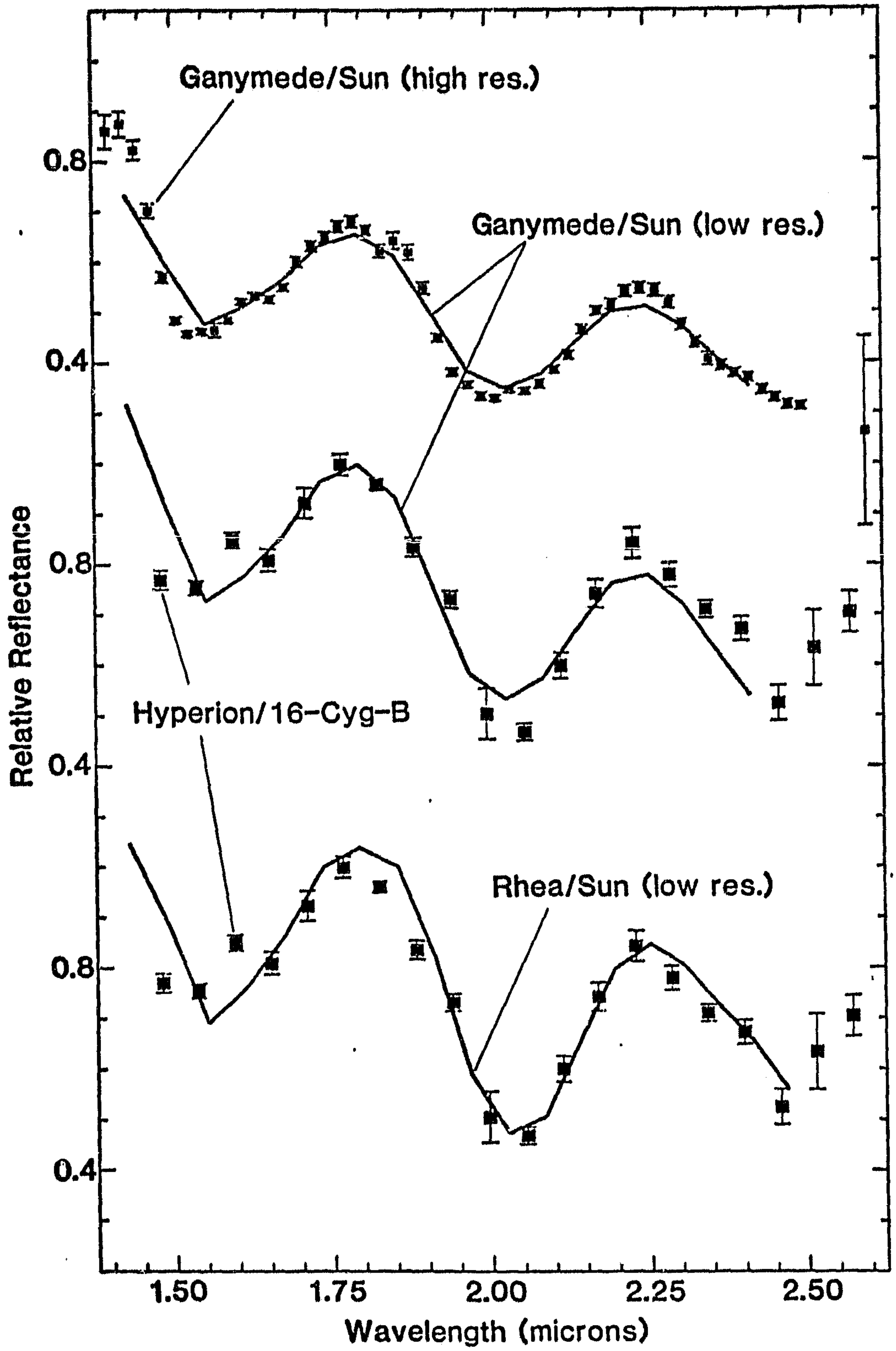

Ganymede/Sun (high res.)
Ganymede/Sun (low res.)
Hyperion/16-Cyg-B
Rhea/Sun (low res.)
Relative Reflectance
0.8
0.4
0.8
0.4
0.8
0.4
1.50
1.75
2.00
2.25
2.50
Wavelength (microns)

Figure 23

purchased with NASA support. We look forward to similar observations in the complementary spectral region, 0.8-1.6 μm, with a new filter of similar high transmission presently on order from Optical Coating Laboratories, Inc.

8. Saturn's Rings: The Division in the Outer Part of Ring A

In collaboration with D. E. Osterbrock (Lick Observatory), Cruikshank is engaged in a historical study of the narrow gap in the outer portion of Saturn's Ring A. This has been called Encke's Division in the context of new Voyager observations of the Division, but as Osterbrock and Cruikshank have shown, Encke's "Division" found by Encke in 1837 with a 9-inch telescope, is really a broad intensity dip in the center of the A Ring; the division now observed so well by Voyager could not possibly have been seen by Encke with a small telescope.

The division now seen in Ring A was, in fact, first observed in 1888 and reported by J. E. Keeler, then working at Lick Observatory and observing with the 36-inch refractor on Mt. Hamilton. He reported his work in several journals, including the Sidereal Messenger, 1888, 8, 79. The discovery was confirmed by his colleague E.E. Barnard, and much later by B. Lyot and A. Dollfus.

Osterbrock and Cruikshank are preparing an article about this work so that Keeler can get proper credit for the discovery he made and so that the error of calling the gap in Ring A after Encke will be corrected.

D. Asteroids and Comets

1. Asteroids of the Outer Solar System and Distant Comets

Cruikshank has continued his collaboration with J. Degewij (JPL, now Leiden Observatory) and W. K. Hartmann (PSI, Tucson) on distant comets and the asteroidal bodies of the outer solar system. During this report period they made confirmatory observations of the colors of 2060 Chiron with the NASA IRTF, observed a number of distinct asteroids of the RD, C, and DM types, and made color measurements of several faint comets, some with comatic activity and others with no detectable activity. An analysis of the existing data is well along, and new observations are planned for the early months of 1982 when certain important comets can be reobserved. A particular candidate is P/Schwassmann Wachmann I.

We have been particularly careful in this work to inlcude V photometery as well as the JHK photometry in order to expand the wavelength base of the data to permit a more useful differentiation of objects by reflectance type. This inclusion of the V data has made the work slower and more complicated than it might otherwise have been, but is of prime importance in the interpretation of the data both for solid objects and the comets.

The Chiron work, now in press (jointly with R. W. Capps), shows that the VJHK colors of Chiron are consistent with other objects in the outer solar system known to have low-albedo surfaces. If we then infer that Chiron itself has a very dark surface, we can calculate that its diameter is between 310 and 400 km, making it larger than all but four of the thousands of known asteroids, as well as several planetary satellites. We do not conclude that Chiron is necessarily a rocky body, but only that its surface contains a significant amount of opaque mineral dust.

The work on comets in comparison with asteroidal bodies of various types will be discussed thoroughly in our next report, as the analysis is still in an early stage.

2. Asteroid Spectra in the 3-μm Region

Howell and Cruikshank have continued the study of their asteroid spectra obtained with the UKIRT in the 3-μm region. An example of the one of the spectra is shown in Figure 24. The thermal contribution to the spectrum is not removed in this figure, but the discontinuity across the region from 2.5 μm to 3.0 μm is clearly due to water of hydration in the minerals lying on the surface of 1 Ceres. This confirms an earlier photometric result by Lebofsky and now shows the band in considerable detail. Lebofsky and colleagues obtained data similar to ours from Mauna Kea at the same time we were observing; in his report of the work he calls attention to a small spectral feature at about 3.05 μm which he attributed to water ice in the regolith of the asteroid. We confirm the presence of this spectral feature, through reserve judgement on the interpretation.

We find the general 3-μm absorption band at various strengths depending upon asteroid type. 1 Ceres (C), 2 Pallas (U), and 511 Davida (C) show 10-20 percent absorption, while 3 June, 4 Vesta, and 97 Klotho (M) show no obvious absorption after correction for thermal emission of the bodies themselves.

The new data show that on the best nights at Mauna Kea, spectrophotometry can be obtained through the 2.7-μm telluric water vapor

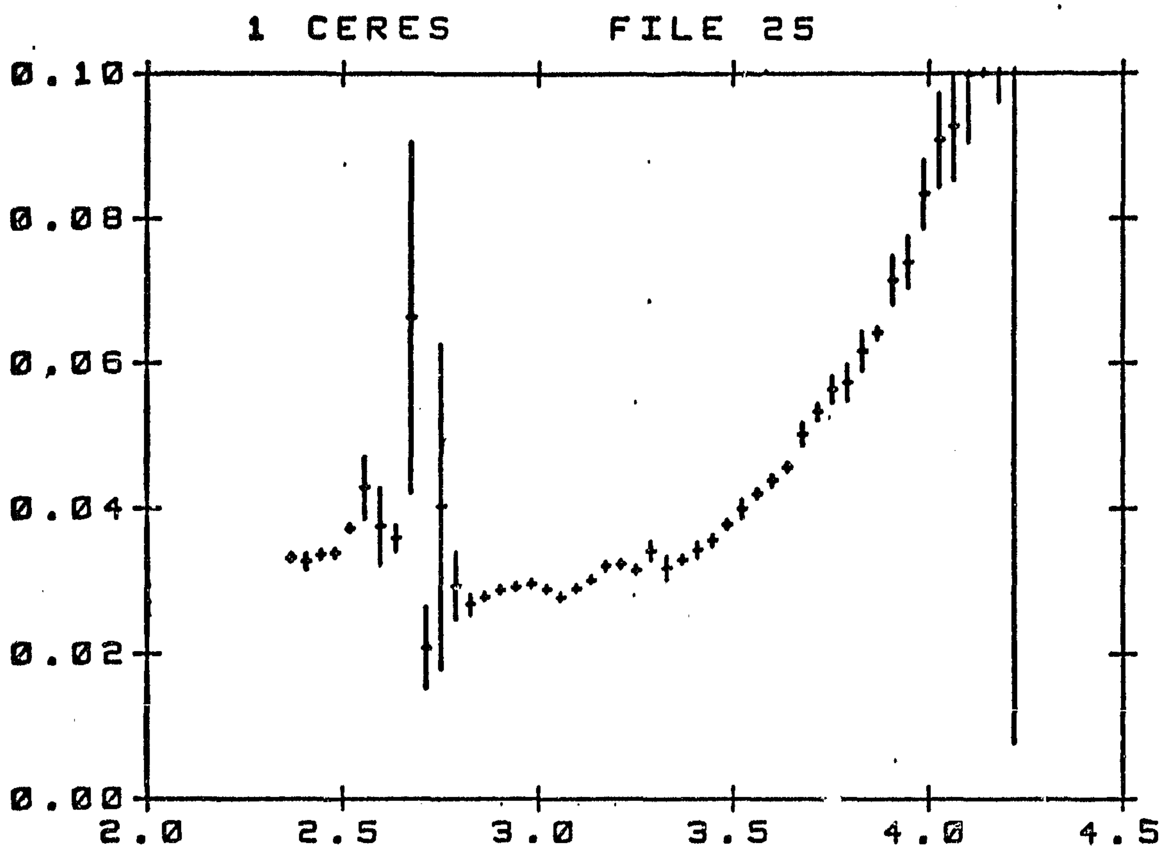


Figure 24. Spectrum of 1 Ceres, obtained with the UKIRT, 1981.

giving hope that features due to OH, water of hydration, and water ice can be distinguished from one another for eventual improvement in our understanding of asteroid and satellite surface compositions.

3. Asteroid Radiometry

Morrison and Brown, working in collaboration with C. Telesco of the IRTF staff and W. Brunk of NASA Headquarters, completed their recalibration of the radiometric scale for determining the diameters and albedos of asteroids. The standard calibration used in the past was derived indirectly, and its estimated uncertainties have been $\sim$10% in diameter and $\sim$20% in albedo. The new calibration represents a significant improvement because it is based on directly measured diameters: for 2 Pallas and 3 Juno from stellar occultations, and for Callisto (J4) from Voyager.

New observations obtained at the IRTF were used to determine the infrared brightness (10 and 20 μm) of the calibration objects and of several additional large asteroids, including 1 Ceres. A comparison of the new results suggests that the standard TRIAD (Tucson Revised Index of Asteroid Data) diameters are about 5% to large, and the albedo $\sim$10% too low. It is argued that this new calibration is accurate to $\sim$5% in the diameters. We plan to use this new calibration in a full readjustment of the TRIAD files of diameter and albedo values in the near future.

Additional radiometric observations have been made at the IRTF of previously unobserved asteroids, primarily those with ambiguous classifications based on UBV colors alone. Observations were also made of 4 Earth-approaching asteroids. These new data will be reduced in the near future and added to the TRIAD file. With the addition of our new radiometric observations and those (also obtained with the IRTF) by J. Gradie (Cornell) and E. Tedesco (Arizona), the total number of asteroids with measured diameters and albedos will be approximately doubled, thus greatly strengthening the data base for physical and taxinomic studies of the asteroid population.

4. Stellar Occultation by 18 Melpomene

The August 7th, 1981 occultation of SAO 145972 by the minor planet 18 Melpomene was observed by Pilcher, Howell, Hlivak, and Colucci during a test of the new Galileo/IFA CCD system. This asteroid is suspected of being a binary system, although our results fail to confirm this.

The CCD system was continuously read, line by line, at 0.1 sec intervals, but owing to atmospheric seeing constraints a photometric time resolution of about 1 sec was obtained. The resulting signal of both the star and minor planet were then summed, resulting in the classical photometric light curve for the system. Although the signal was rather noisy, it is clear that the occultation occurred, lasting 21 ± 1 sec, in good agreement with the predictions of 23 sec.

The chord length across 18 Melpomene can be inferred from the velocity and distance of the asteroid at the time of the occultation. A cubic interpolation of Ephemeris points yields a projected velocity of 6.3 km/sec. An occultation of 21 ± 1 seconds thus corresponds to a chord of length 132 ± 6 km. This is consistent with the diameter of 162 km published by Morrison and Zellner in Asteroids (ed. T. Gehrels, University of Arizona Press, 1979).

The data were analyzed by graduate student M. Pierce.

5. A Search for Comet Halley

In December, Pilcher and Howell conducted a search for Comet Halley using the Galileo/IFA CCD system. Participating in the observations was M. Belton of KPNO, who provided the necessary finding charts and other information. Since the comet's apparent motion on the sky (due entirely to the motion of the earth) was 13 arcsec/hour, the observers set the telescope to track the comet during the 45-minute exposures. On the one clear night of the three night observing run, three good images of the comet field were obtained. The comet was not apparent in any of these images, but a careful study of the data is being carried out to determine if a weak detection may have been made. If the comet proves not to be present in our images, we will be able to set an upper limit to the comet's brightness under the assumption that its position fell within our 70 arcsec field. Although we have not yet determined an upper limit to the comet's brightness, it seems likely that the comet is either dimmer than predicted or not in the location predicted.

E. Other Research Activity

1. Stellar Eclipse by Possible Protoplanetary System

The F0 Ia supergiant ε Aurigae is eclipsed every 27 years by an object whose nature is mysterious. The eclipse is "grey" (wavelength independent) over at least the range of λ available during the last eclipse in 1956-1957. (1) The duration and depth of the eclipse are inconsistent with the passage of any solid body with a circular cross-section across the primary. Astronometry (2) reveals that the eclipsing body is associated with a mass of about 10 $M_\odot$ and extends about 4 AU along its orbit, which is 30 AU in radius.

Speculation has centered about two possibilities for the nature of the obscuring material: (a) a swarm of solid particles orbiting a massive but under-luminous secondary (3), and (b) a disk or shell of ionized gas connected with an early-type main sequence star (4). In both cases, the secondary object is presumed to be much fainter than the primary ($M_r = +3$).

The next eclipse will commence in June, 1982 and will continue for ∿2 years following. We are making observations before the eclipse to establish a baseline. In particular, IR observations may be able to distinguish between the two models above in terms of the characteristic emissions of hot, solid material versus dense plasma.

We have begun broad-band IR measurements from 1-20μ. These are crucial for establishing the overall energy distribution in the light from this system and checking the wavelength dependence of the eclipse.

We will also be making baseline medium-band observations at 5 wavelengths acrosss the 10 μm silicate feature, which will be a very important diagnostic once the eclipse commences. The medium-based observations required the use of the 2.2-m telescope in order to achieve an adequate S/N (at least 10 on the star and several standards. We are in part repeating measurements made in the last two winters. There is indication of episodes of small magnitude and color changes in the years immediately before and after previous eclipses, so repetition is necessary for the establishment of a baseline. Also, we were unable to make accurate 20 μm broad-band or 10 μm narrow-band measurements last winter, due in part to RF interference from the U.S. Geologic Survey "repeaters" on the summit.

2. Equipment Improvement

Goguen has taken prime responsibility for improvements and modernization of the old Tinsley photometer. Modifications include a new cold-box, quartz Fabry lens and window, a high-responsivity, gallium-arsenide phototube and a fast pulse pre-amplifier/ discriminator IC. Output pulses will be counted and recorded using the existing 2.24-m telescope data system. This improved instrument will be capable of high-time resolution (~50 MHz bandwidth) photometry and suitable for observations of occultations and other rapid brightness variations. UV sensitivity down to ~0.20 μm is maximized to take advantage of the high atmospheric transparency at MKO. The broad spectral response (0.2-0.9 μm) allows colors to be determined adequately, for example, to assign asteroids to a taxonomic class. Additional improvements consist of stepper-motor control of the filter wheel and field viewing flip-mirror plus adaptation of a Quantex TV camera to the eyepiece, enabling the instrument to be operated efficiently from the control room. The upgraded photometer will be used for UV photometry of Io to monitor changes in SO_2 absorption, determination of the rotational light curves of Trojan asteroids, measurements of the rotational and phase angle brightness variations of 1862 Apollo and other asteroids, asteroid occultations of stars and by the Moon, as well as for photometry of non-solar system objects by other members of the IFA staff and visiting astronomers. First use is scheduled for February 16, 1982.

3. Satellites of Jupiter

Morrison has continued his work as Editor of the University of Arizona Press book Satellites of Jupiter, based in part on the invited papers from IAU Colloquim No. 57 of the same name, held in Kailua-Kona in 1980. The book will have 24 chapters and be about 800 pages in length. There is every reason to expect that it will be the definitive volume on these objects until Galileo, and that it will find a place on the bookshelves of most planetary scientists. During this report period, all of the chapter manuscripts were completed and edited, and all but four typeset. Morrison has written an introductory chapter and completed the glossary, index, and other endpaper material. The book should be available in the spring of 1982.

III. OTHER TOPICS

Sinton presented a paper on his Io research at the Hawaii Science Fair in Hilo in May. In July he also gave a popular talk for the Mauna Kea Astronomical Society, an amateur group based in Hilo.

Since a number of observational astronomers have adopted the HP 41 C as their personal calculator, Sinton has made available to other astronomers a number of routines that he has written. A program that predicts offsets from one Galilean satellite to another has been made available to other astronomers at the Institute and elsewhere. Several of his programs have been accepted into the Hewlett Packard Users Library. These include programs for thermophysical calculations and for color temperature and emissivity calculations.

Those who had teaching obligations during the report period are Sinton, Cruikshank, and Pilcher.

Cruikshank continued on the Editorial Board of Icarus, as a member of the Board of Directors of the Canada-France-Hawaii Telescope Corp., and as a member of the MOWG for Airbone Science of NASA.

During the first half of the report year Morrison was on leave of absence from the University to serve at NASA Headquarters as the Acting Deputy Associate Administrator for Space Science, so he was forced to defer much of his planned research activity, supported by this grant, until his return to Hawaii following the Voyager 2 Saturn encounter.

Morrison was appointed to the NASA Solar System Exploration Committee, a Subcommittee of the NASA Council, which is charged with developing a plan for solar system missions for the rest of the century. In September, he was asked to serve as Chairman of the SSEC Working Group in asteroid and comet missions.

During most of the report period, Morrison served as Chairman of the Division for Planetary Sciences of the American Astronomical Society. In October he was succeeded as Chairman by M. J. S. Belton of Kitt Peak, but continued to serve on the Division Committee.

Morrison organized, chaired, and presented a paper in a special session on planetary science at the American Astronomical Society Meeting in June in Calgary.

In November, Morrison was elected Vice-President and President-Elect of the Astronomical Society of the Pacific, a professional organization with more than 5,000 members. His term as President will be from Fall 1982 through Fall 1984.

During this report period asteroid number 2410 was named for Morrison.

Morrison was selected a member of the Organizing Committee for the University of Arziona meeting on Saturn to be held in May 1982, and he became Co-chairman (with J. Burns of Cornell) of a preliminary Organizing

Committee for a summer 1983 meeting on planetary satellites.

During August and September, Morrison and Cruikshank participated in the Voyager 2 encounter with Saturn, as members of the Imaging Team and IRIS Team, respectively. Both hope to be similarly involved in the Voyager encounter with Uranus in 1986.

Morrison was selected to participate with representatives of NASA Headquarters and the U.S. science community as a member of the Joint U.S./U.S.S.R. Working Group on Planetary Exploration which met for a week in San Francisco in October. Earlier, in January, Morrison made a 10-day trip to Russia at the invitation of the U.S.S.R. Academy of Sciences to present a series of lectures in Moscow and Leningrad on Voyager Saturn results.

Pilcher chaired a session at the Pittsburgh DPS meeting in October. He and Morgan presented papers on their Jovian magnetospheric results at both the DPS meeting and at the Third Annual Conference on the Jovian and Saturnian Magnetospheres held the following week at Johns Hopkins.

Pilcher presented an invited review paper at the session on "Frontiers in Planetary Astronomy" organized by Morrison at the Calgary AAS meeting in June.

Pilcher was elected by the DPS membership to the position of Committee Member, a post he will hold for three years.

Pilcher contined his participation in the Galileo Project as a member of the Imaging Science Team.

IV. BOOKS AND PAPERS PUBLISHED DURING THE REPORT PERIOD

1. Books and Papers Published in 1981 (excluding Abstracts)

Brown, R.A., Pilcher, C.B., & Strobel, D.F. 1981. Spectrophotometric studies of the Io torus. In Physics of the Jovian Magnetosphere, A.J. Dessler, ed., (London: Cambridge University Press), in press.

Brown, R.H., Cruikshank,D.P., & Tokunaga, A.T. 1981. The rotation period of Neptune's upper atmosphere. Icarus 47:159-165.

Brown, R.H., Morrison, D., & Telesco, C.M. 1982. Calibration of the radiometric asteroid scale using occultation diameters. Icarus submitted.

Cruikshank, D.P. 1981. The satellites of Uranus. In Uranus and the Outer Planets, G.E. Hunt, ed. (London: Cambridge University Press), in press.

Cruikshank, D.P., Bell, J.F., Gaffey, M.J., Brown, R.H., Howell, R., Beerman, C., & Rognstad. 1982. The dark side of Iapetus. Icarus submitted.

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Cruikshank, D.P., Degewij, J., & Zellner, B.H. 1981. The outer satellites of Jupiter. In The Satellites of Jupiter, D. Morrison, ed. (Tucson: Univ. of Arizona Press), in press.

Degewij, J., Cruikshank, D.P., & Harmann, W.K. 1981. Near-infrared colorimetry of J6 Himalia and S9 Phoebe: A summary of 0.3 to 2.2-μm reflectances. Icarus 44:541-547.

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Hanel, R + 12 other authors (including D.P. Cruikshank). 1981 Infrared observations of the Saturnian system from Voyager 2. Science in press.

Hartmann, W.K., Cruikshank, D.P., Degewij, J., & Capps, R.W. 1981. Surface materials on unusual planetary object Chiron. Icarus 47:333-341.

Howell, R.R., McCarthy, D.W., & Low, F.J. 1981. One-dimensional infrared speckle interferometry. Ap.J.Letters in press.

Millis, R.L. + 37 other authors (including D.P. Cruikshank & D. Morrison). 1981. Diameter of Juno from its occultation of AG+0°1022. Astron. J. 86:306-313.

McCord, T.B., & Cruikshank, D.P. 1981. Spectrophotometric remote sensing of planets and satellites. In Infrared Astronomy, C.G. Wynn-Williams & D.P. Cruikshank, eds. (Dordrecht: Reidel Publ. Co.), pp. 57-87.

Morgan, J.S., & Pilcher, C.P. 1981. Plasma characteristics of the Io torus. Astrophys. J. in press.

Morrison, D. 1981. Thermal studies of planetary surfaces. In Infrared Astronomy, IAU Symp. No. 96, Kona, Hawaii, 23-27 June 1980, C.G. Wynn-Williams & D.P. Cruikshank, eds. (Dordrecht: Reidel Publ. Co.), pp. 223-236.

Morrison, D. 1981. Introduction to the satellites of Jupiter. In Satellites of Jupiter, D. Morrison, ed. (Tucson: Univ. of Arizona Press), in press.

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Morrison, D., & Cruikshank, D.P. 1981. The outer solar system. In The New Solar System, B. O'Leary, J.K. Beatty, & A. Chaikin, eds. (Cambridge: Sky Publ. Co.), pp. 167-1976.

Pearl, J.C., & Sinton, W.M. 1981. Hot spots of Io. In Satellies of Jupiter, D. Morrison, ed. (Tucson: Univ. of Arizona Press), in press.

Pilcher, C.B., & Strobel, D.F. 1981. Emission from neutrals and ions in the Jovian magnetosphere. In The Satellites of Jupiter, D. Morrison, ed. (Tucson: Univ. of Arizona Press), in press.

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Sinton, W.M. 1981. Io: A volcanic flow model for the hot spot emission spectrum and a thermostatic mechanism. Icarus in press.

Smith, B.A. et al. (including D. Morrison). 1981. Encounter with Saturn: Voyager 1 imaging science results. Science 212:163-191.

Smith, B.A. et al. (including D. Morrison). 1981. Voyager 2 imaging results at Saturn. Science in press.

Wynn-Williams, C.G., & Cruikshank, D.P. Editors. 1981. Infrared Astronomy IAU Symp. 96, (Dordrecht: Reidel Publ. Co.) pp. 376.

Veverka, J., Simonelli, D., Thomas, P., Morrison, D., & Johnson, T.V. 1981. Voyager search for post-eclipse brightening on Io. Icarus 47:60-74.

Veverka, J., Thomas, P., Davies, M., & Morrison, D. 1981. Amalthea: Voyager imaging results. J. Geophys. Res. 86:8675-8682.

OPERATION OF THE 2.24-M TELESCOPE

A. Telescope Utilization

Statistics relating to the usage of the 2.24-m telescope are presented in the two tables on the following page. During 1981, the telescope was used for observations during 77% of the available night time hours. Only 1.5% of the potential observing time was lost to failure of the telescope, data acquisition computers, or other systems maintained by observatory staff. This level of reliability is particularly noteworthy since electronics technicians are normally not available during nights or weekends to make repairs.

During 1981, slightly more than 41% of the observing time was devoted to planetary programs. Half of those observations were carried by members of the Institute for Astronomy staff. The remaining planetary time was used by members of T. B. McCord's group at the University of Hawaii's Institute for Geophysics and by visitors from such institutions as Cornell, Brown, Lowell and JPL.

B. Progress Report -- 2.24-m Telescope

During the past year, we have made very substantial progress in developing electronic detector systems for the 2.24-m telescope. Indeed, in the past 12 months, we have successfully tested and used the three most promising new techniques. An intensified Reticon system, which is well suited for spectroscopy of faint objects, is now in regular use. This system was constructed at the Institute for Astronomy with support from NSF and the State of Hawaii. There have been several observing runs with the Galileo CCD system, and sub-arcsecond images have been obtained of objects as faint as R(mag)=25. The testing and operation of this detector are supported jointly by NASA and the State of Hawaii. Finally, we have tested, and hope soon to have in regular use, the multi-anode microchannel array detectors developed by Gethyn Timothy with NASA support.

We have continued to develop software for the 2.24-m telescope control system and to upgrade the data acquisition system. After a year with no programmer on the staff, we have hired a support scientist (W. Heacox) to take responsibility for the development of software. We have improved the computer slew, raster scanning, offset, and beamswitch capabilities of the 2.24-m telescope. At the present time, we are developing a CAMAC-based data acquisition system with software that will appear to the user to be identical to that now in use at the IRTF. With NSF support, we have acquired a tape drive and a Winchester-type fixed disk for the data acquisition system. We hope soon to replace the LSI 11 in the data acquisition system with an LSI 11/23. The expansion in memory from 28K to 256K that this change would permit is essential to allow on-line processing of data obtained with array detectors.

TABLE 1

USE OF THE 2.24-M TELESCOPE
(January-December 1981)

Month	Hours Lost Due To Weather Conditions	Hours Lost Due To Observatory Systems Failure	Total Scheduled Hours	Scheduled Time Used For Observations	
January	109.5	4.0	341	227.5	(67%)
February	109	4.0	308	195.6	(64%)
March	44.5	2.3	341	294.2	(87%)
April	70.5	4.5	315	240.0	(76%)
May	57.0	1.8	325.5	266.7	(82%)
June	77.5	5.0	300	217.5	(73%)
July	20.5	2.0	310	287.5	(93%)
August	68.5	4.8	325.5	252.2	(77%)
September	96.5	6.0	315	212.5	(67%)
October	41.5	0.2	325.5	283.8	(87%)
November	83.5	11.9	330	234.6	(71%)
December	67.5	10.9	341	262.6	(77%)
TOTAL	846.0	57.4	3877.5	2976.9	(77%)

TABLE 2

VISITOR/STAFF AND PLANETARY/NON-PLANETARY USE
2.24-M TELESCOPE (January-December 1981)

Program Area	Staff Use (Nights/Percentage of Scheduled Time)	Visitor Use (Nights/Percentage of Scheduled Time)	Total
Planetary Research	73 (20%)	76 (21%)	149 (41%)
Non-Planetary Research	167 (47%)	42 (12%)	209 (59%)