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NASA GRANT NAGW-3875

OPERATION OF THE UNIVERSITY OF HAWAII 2.2M TELESCOPE ON MAUNA KEA

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FINAL REPORT

October 5, 1993–October 31, 1997

Technical Officers
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During the period October 5, 1993–October 31, 1997, operation of the University of Hawaii's 2.2-meter telescope was partially funded by grant NAGW-3875 from the NASA Planetary Astronomy Program. This grant provided $651,200 during this period.

During the initial 3-year period of the grant, NAGW-3875 provided approximately 20% of the operating budget of the telescope. The remainder of the operating budget was funded by the State of Hawaii, through the University of Hawaii. A no-cost extension was granted until October 31, 1997. During the grant period, the fraction of observing time devoted to studies of solar system objects (e.g., planets, planetary satellites, asteroids, and comets) was approximately 24% (i.e., it exceeded the fractional funding provided by this NASA grant). The number of nights allocated to planetary observing time is summarized below:

Period	Planetary	Other science	Engineering	Planetary fraction
Nov 1993–Oct 1994	74	229.5	61.5	24.4%
Nov 1994–Oct 1995	69.9	248.1	47	22.0%
Nov 1995–Oct 1996	80.7	262.3	23	23.5%
Nov 1996–Oct 1997	86.5	252.5	26	25.5%

Proposals for use of the solar system observing time coming from within and outside the University of Hawaii competed for this observing time on an equal basis; applications were judged on scientific merit by a time allocation committee at the University of Hawaii.

TELESCOPE AND INSTRUMENTATION

During the grant period, many very substantial improvements to the telescope and its instrumentation were made. These include:

HIGH RESOLUTION IMAGING AND TIP-TILT SECONDARY

The 2.2-meter telescope has a high quality f/31 secondary mirror shaped to match the excellent figure of the primary, and deliver a two-mirror enclosed energy of 80% in 0.2 arcsec (compared to 0.4 arcsec for the f/10 system). A piezo-driven momentum-compensated tip-tilt driver, specially designed for this 8-inch diameter mirror, was brought into routine operation during the grant period. Successful tip-tilt guiding was first performed in July 1994 for the impact of Comet Shoemaker-Levy 9 with Jupiter.

Tip-tilt guiding is now performed during nearly all observations with the f/31 secondary mirror. Images with full-width half-maximum (FWHM) of 0.25″ in the K' passband have been obtained over periods of several nights. Images with FWHM of 0.20″ in the H passband have also been achieved.

NEAR-INFRARED IMAGING

At the start of the grant period, a high QE, low-noise HgCdTe 256 × 256 array (NICMOS-3) was the principal IR detector on the 2.2-meter telescope. This remained the IR imager of choice until July 1994, when the first 1024 × 1024 HgCdTe "HAWAII" array was used to record the impact of Comet Shoemaker-Levy 9 with Jupiter. This array is installed in a camera named QUIRC (QUick InfraRed Camera).

Since then, numerous improvements in the array fabrication have been made, and the array was replaced several times with newer, cosmetically and electrically superior arrays.

This camera was an extremely powerful and popular instrument, and was used on the telescope for a major fraction of the observing time during the grant period (and during the bulk of the bright observing time).

OPTICAL IMAGING AND SPECTROSCOPY

During the grant period, the Tektronix 2048×2048 CCD (thinned, back-side illuminated) remained the principal detector for imaging and spectroscopy at visible light wavelengths.

NEAR-INFRARED SPECTROSCOPY

The near-infrared spectrograph (KSPEC) was upgraded with a 1024×1024 HAWAII array in 1995. KSPEC also has a 256×256 NICMOS-3 array that images the reflection from the slit (at 2 microns)—this is especially powerful for placing infrared targets on the slit.

KSPEC produces spectra in the J, H, and K atmospheric windows simultaneously, with a resolution of $R \approx 750$ for a slit of $0.96''$; higher resolutions are possible with narrower slits. The sensitivity of this instrument has made it ideally suited to studies of faint solar-system objects (such as planetary satellites, asteroids, and comets).

WIDE-FIELD IMAGING

A mosaic CCD camera, with eight 4096×2048 CCDs (total imaging area 8192×8192 pixels) was brought into operation at the 2.2-meter telescope in 1995. This camera proved to be an extremely powerful tool for the discovery of Kuiper Belt Objects.

FIBER-OPTIC LINK TO HALE POHAKU

A bi-directional fiber-optic audio-video link to Hale Pohaku was installed in 1995. This link permits clear audio and video communications between the control room and 2.2-meter telescope office at Hale Pohaku. It permits remote participation in observations from Hale Pohaku, and facilitates improved communication between Hale Pohaku and the day crew during the day time.

NEWSLETTER AND DOCUMENTATION

A newsletter was distributed to all planetary astronomers in the United States who had expressed an interest in receiving it. It was distributed in both electronic form (for speed) and through hardcopy (regular mail). The newsletter contained information about instruments, including their sensitivities, and discussed recent changes and developments at the telescope. The newsletter was distributed three times per year, before each proposal deadline.

A major update of the telescope user manual was completed April 1996. Detailed user manuals were also maintained for the major instruments.

Documentation relating to the 2.2-meter telescope was made available on the World Wide Web beginning in July 1994. This documentation has been maintained and updated regularly.

SCHEDULING PERIODS

Beginning August 1997, the telescope scheduling period was changed from four-month trimesters to six-month semesters. This change was made to coordinate the scheduling period with the scheduling periods of all the other telescopes on Mauna Kea. Associated with this change, about 10–15 nights per semester were held back for allocation later in the semester. Some preference in the allocation of these additional nights will be given to target of opportunity observations, and to observers who lose all or a large part of their observing time to weather or instrument failures.

SCIENTIFIC HIGHLIGHTS

A sample of the many scientific programs performed on the 2.2-meter telescope during the grant period are described below.

THE OUTER SOLAR SYSTEM—TRANS-NEPTUNIAN OBJECTS AND THE KUIPER BELT

Undoubtedly the major contribution to planetary science coming from the UH 2.2-meter telescope during the grant period was the exploration of the outer solar system by Jewitt, Luu and collaborators. At the start of the grant period, 6 trans-Neptunian Objects were known (4 of which had been discovered using the 2.2-meter telescope). By the end of the grant period, 60 trans-Neptunian objects had been discovered; 36 of these (60%) were discovered with the 2.2-m telescope. Discoveries included 1996 TL_{66} with a orbit dramatically different from the other objects.

The cumulative sky-plane surface density of these Kuiper Belt Objects reaches about 1 per square degree at magnitude 23. Brighter objects are comparatively rare, demanding observing strategies different from those employed in previous surveys. Accordingly, D. Jewitt and collaborators are conducting a new wide field survey with the UH 8192×8192 pixel CCD camera that is designed to assess the abundance of bright (red magnitude $m_R < 23$) KBOs. This survey serves two main scientific functions. First, it allows them to determine the size distribution to diameters intermediate between those of the established KBOs and Pluto. Second, it provides a sample of KBOs bright enough for detailed physical observations to be obtained. For example, it is very difficult to obtain spectra of a KBO with $m_R = 23$ even with the Keck telescopes. However, it is relatively straightforward to obtain the spectrum of a KBO with $m_R = 21$. This is an excellent example of the synergy between a smaller telescope like the UH 2.2-meter and larger ones such as the Kecks. The UH 2.2-meter telescope has a large field-of-view and thus can search large areas of the sky very efficiently. By searching a large enough area, brighter objects are found, and their spectra can efficiently be obtained with the large telescopes.

Initial results of this survey include the discovery of the extraordinary trans-Neptunian object 1996 TL_{66}. TL_{66} is distinguished from other Kuiper Belt objects by its eccentric orbit, which carries it from 35 AU at perihelion to 150 AU at aphelion (eccentricity = 0.6). It moves far beyond the previously established outer boundaries of the "classical" Kuiper Belt. From the limited sky area so far surveyed, Jewitt and collaborators believe that TL_{66} is one of about 8000 similar, 500 km diameter objects moving in eccentric orbits beyond Neptune. The total mass of such bodies may exceed that in the classical Kuiper

Belt, approaching 1 Earth Mass. Dynamical studies suggest that such objects may have been produced by gravitational scattering in the early phases of the solar system.

The steady access to the telescope guaranteed by NASA's support was central to the success of this project.

COMET SHOEMAKER-LEVY 9

Extensive studies of Comet Shoemaker-Levy 9 were undertaken in 1994. These studies contributed extensively to identification and astrometry of the comet fragments in the months leading up to the impact with Jupiter. The observations culminated in a two week observational study during the impact period in July 1994. Both CCD imaging and near-infrared imaging were performed. The tip-tilt secondary was used for the first time for observations of Jupiter during this period. By using Io as the tip-tilt guide source, Hodapp and collaborators were able to obtain the highest resolution ground-based image of Jupiter during this period (using the newly completed 1024×1024 near-infrared camera). The last part of the impact period was lost due to bad weather on Mauna Kea caused by a hurricane passing close to Hawaii.

PLUTO-KUIPER EXPRESS MISSION SUPPORT

Jewitt and UH graduate student Chad Trujillo started a survey in support of NASA's Pluto-Kuiper Express mission. The objective is to identify Kuiper Belt objects which will pass near the post Pluto-encounter flight path of Pluto-Kuiper Express, and with which the spacecraft may rendezvous. The Pluto-Kuiper Express Science Definition Team (of which Jewitt and Tholen are members) endorsed the concept of a post-Pluto Kuiper Belt encounter in its 1995 Report, and is interested in elevating this encounter to a primary mission goal. The wide field capability of the 8k array on the UH telescope represents the best route by which suitable objects might be identified. The field of view on the Keck telescope, for example, is limited by the reimaging optics to a maximum of $6' \times 8'$, whereas at the 2.2-meter telescope, the field of view is $19' \times 19'$.

COMET HALE-BOPP

Extensive observations of comet C/1995 O1 Hale-Bopp by Meech and collaborators, highlighted the development of intricate structures in the inner coma of the comet, starting in about 8/96. In addition, extensive data were obtained during 6/96 to look at the rotation of the nucleus, and more recently, narrow-band data were obtained during 4/97 (using the NASA Hale-Bopp filter set) to investigate the production of CN to see if it was correlated with the dust jets as was the case with P/Halley.

A concerted campaign is planned to follow comet C/1995 O1 Hale-Bopp outbound as far as possible to monitor for activity at large *r* and if possible get more information on its nucleus properties.

NEAR-EARTH ASTEROIDS

Tholen performed physical studies of near-Earth asteroids. His observations included photometry and astrometric followup. We attempted to provide flexible scheduling for these observations—there is often very little time between discovery and closest approach, so these observations cannot easily be accommodated in the conventional semester proposal system. We have been able to support some observations of newly discovered near-Earth asteroids by giving access to engineering nights.

Graduate student R. Whiteley made heavy use of the 2.2-meter telescope for work on asteroid compositions, and has performed searches for asteroids in dynamically new locations (e.g., Earth, Venus and Mars Trojans, Atens). He used the 2k CCDs for colorimetry and the 8k CCD for searches.

ASTROMETRY AND PHOTOMETRY

Tholen obtained numerous astrometric and photometric observations, many of which were in support of NASA planetary missions. These include:

- physical and astrometric observations in support of the Galileo encounter with Ida;
- high speed photometry of Saturn satellite mutual events to support Cassini ephemeris requirements;
- physical and astrometric observations in support of the Clementine encounter with Geographos;
- attempts to recover Rosetta target P/Wirtanen;
- astrometry of SL9 fragments in support of impact time prediction efforts, including the very last positions for the tail of the train after the head of the train had already started impacting;
- high speed photometry of SL9 impacts to look for flash events;
- discovery of a second very red object among the Centaurs (1993 HA2); and
- astrometry of Kuiper Belt objects;
- recovery of lost objects such as the metal-rich near-Earth asteroid 1986 DA; and
- photometry and astrometry of planet crossing asteroids.

ASTEROID FAMILIES

M. Gaffey and M. Kelley (Rensselaer Polytechnic Institute) have obtained low-resolution optical spectra of asteroids, and conducted a parallel program with the NASA IRTF to obtain near-infrared spectra. They will use their spectra to reconstruct the internal structure and constrain the thermal evolution of their parent bodies, and to investigate collisional evolution in the asteroid belt.

DISCOVERY MISSION SUPPORT: 3200 Phaethon

Meech undertook an extensive observing program to characterize the nucleus of object 3200 Phaethon, a proposed future NASA Discovery Mission target. Phaethon is a Near Earth Object (NEO) discovered in 1983 by IRAS, which has been determined unambiguously to be the parent of the Geminid meteor stream. No cometary activity has ever been detected on Phaethon, yet our accepted paradigm for the source of meteor streams is cometary activity. It is highly probable that Phaethon may be an example of an extinct or inactive cometary nucleus, and as a potential target for a Discovery mission, may be our first opportunity to study in detail the process of cometary evolution in-situ. If extinct/inactive comets still retain significant volatile material, they could become an important resource for NASA in near-Earth space. Meech's observing campaign made extensive use of UH 2.2-meter observations. From this work they determined the rotation period of Phaethon (3.604±0.0011 hrs), which shows unequal maxima which may be the result of albedo features on the surface.

GALILEO MISSION SUPPORT

Orton and collaborators from JPL have been conducting an extensive imaging campaign in support of the Galileo mission, using the University of Hawaii 2.2-meter telescope. Their observations consist of mapping Jupiter's cloud albedo fields at different wavelengths and at gaseous CH_4 absorptions. The most important mission critical function of this work was to provide direct real-time support for the Galileo atmospheric investigation, particularly for the Solid State Imager (SSI) and Near-Infrared Mapping Spectrometer (NIMS) experiments, verifying their photometric calibration, and characterizing the time history of atmospheric features targeted for intense study. This provided SSI and NIMS comparisons with other regions during spacecraft encounters, and the broader coverage characterized processes outside the very limited fields of view of these instruments for phenomena, such as injection of energy or momentum into the area being observed.

APPENDIX 1: Partial list of recent publications resulting from observations on the 2.2-meter telescope

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