NASA Infrared Telescope Facility
University of Hawaii, Institute for Astronomy
Honolulu, Hawaii 96822

This report covers the year from 1 July 1995 through 30 June 1996. The NASA Infrared Telescope Facility (IRTF) is a 3.0 m infrared telescope located at an altitude of 14,000 feet on the summit of Mauna Kea in Hawaii. It was established by NASA in 1979 primarily to provide infrared observations in support of NASA's programs and is the only U.S. national telescope dedicated to infrared observations. The IRTF is managed and operated by the University of Hawaii (UH) Institute for Astronomy (IfA) under a contract between NASA and UH. Under this agreement NASA provides the costs of operation; NSF provides support for new focal plane instrumentation based on individual grant applications from IRTF support astronomers to the NSF. Observing time is open to the entire astronomical community, and 50% of the IRTF observing time is reserved for studies of solar system objects.

1. PERSONNEL

During this period, NASA awarded UH a new 5 year contract to operate the IRTF. Robert D. (Bob) Joseph was the IRTF Division Chief during the period, and support astronomers were Tom Greene (Deputy to the Division Chief), Richard Baron, Sandy Leggett, and John Rayner (15% FTE). Mark Shure left the IRTF staff in the early part of this period to join the faculty of Georgia State University. Don Hall is the P.I. and IfA Director.

On the telescope Day Crew, Paul Jensen is the IRTF Telescope Superintendent, and George Koenig is the Foreman. Other members of the Day Crew are Lars Bergknut, Danlee Lee, Imai Namahoe, and Sammy Pung. Telescope Operators are Bill Golisch, Dave Griep, and Charlie Kaminski. Marie-Claire Hainaut was employed as a temporary telescope operator during the Comet Hyakutake observing campaign.

Engineering/technical staff included Doug Toomey, instrumentation engineer, Peter Onaka, electronics engineer, Darryl Watanabe, electronics and instrument technician, and Tony Denault, Eric Pilger, Steve Smith, and Jim Harwood (50% FTE) software engineers.

Karan Hughes is the IRTF secretary, and Lorrie Kuwata is the clerk-typist in the IRTF office. Gale Yamada and Chris Kaukali were the IRTF fiscal officers. Art Monteville is assistant to the Division Chief. The total IRTF staff numbered 24 full-time equivalent.

The NASA Management and Operations Working Group (MOWG) for the IRTF was chaired this year by Michael Belton (NOAO). Other members were: Michael A'Hearn (Maryland), Bernard Burke (MIT), Martha Hanner (JPL), Dan Lester (Texas), and Yervant Terzian (Cornell). Ex-officio members were Morris Aizenman (NSF), Edwin Barker (NASA), and Jürgen Rahe (NASA).

William Keel (University of Alabama), John Spencer (Lowell), and Bruce Wilking (University of Missouri St. Louis) served on the six member IRTF Time Allocation Committee during the entire period. Heidi Hammel (MIT), David Latham (Harvard/SAO), and Gordon Bjoraker (NASA GSFC) also served during the fall 1995 semester, while Kevin Baines (NASA JPL), Bruce Carney (UNC), and Harold Weaver (Applied Research Corp.) also served during the spring 1996 semester. The TAC was chaired by Bob Joseph.

2. USAGE OF THE IRTF

Observing time on the IRTF is open to the entire astronomical community. Fifty percent of the observing time is reserved for studies of solar system objects, and 50% is allocated to studies outside the solar system. The semesters are February – July and August – January inclusive. Deadlines for observing proposals are 1 October for February – July and 1 April for August – January.

The IRTF received 192 applications for observing time during this year. The oversubscription was a factor of 2.4 for solar system programs and 2.8 for non-solar system programs. The scheduled programs involve over 200 U.S. and foreign astronomers each semester. About 24% of the scheduled observing time was lost to bad weather, and 5% to IRTF instrumentation and other facility problems.

3. THE TELESCOPE

3.1 Image quality

We continue to characterize and improve the image quality of the IRTF. Scientific, technical, and operations (day crew) staff all participate in this effort. The intrinsic telescope image quality is now generally reproducible and is nearly diffraction-limited (FWHM $< 0\farcs3$ FWHM at 2.2 μm) over much of the viewable sky (best in the west and south). Image quality is regularly measured each semester by acquiring short exposure (typically 0.1 s or less) NSFCAM images which are shifted and added in real time. We have also correlated image quality with displacements of the primary mirror in its cell. Thus image quality problems can be detected and diagnosed by daytime mirror movement tests which do not require any observing time.

The IRTF Phase II Facility Upgrade to improve the dome cooling began in 1994. This upgrade includes a new dome air conditioning and circulation system for use during the daytime, extra dome insulation, a low emissivity outer dome coating, and a large throughput exhaust tunnel and fan capable of circulating outside air through the dome during the night at a rate of several dome volumes per hour. A computerized system will control all air conditioning to maintain the dome air at a non-stratified ideal temperature (equal to that of the outside air at midnight). The performance of this system was improved during this period, but it was still not optimized much of the time.

The IRTF proposal to install ''tip-tilt'' active optics on the IRTF received funding from NASA in mid-1992. Richard Baron is the Project Scientist, and Don Hall is the P.I. Since the diameter of the telescope is less than four times the Fried parameter in the infrared on Mauna Kea, tip-tilt techniques will correct most of the image degradation introduced by the atmosphere. The error budget for this project suggests that under median atmospheric conditions the IRTF will achieve image quality of $\sim 0\farcs25$ FWHM at $1-2.5\ \mu$m, and diffraction-limited images at longer wavelengths. The IRTF system features a very lightweight ($\sim$ 800 g) SiC secondary mirror which is used as the tip- tilt optical element. The tip-tilt error sensor is a CCD camera built around an 800×800 pixel CCD; this camera also functions as a wavefront curvature sensor via remotely selectable extrafocal lenses. This camera system is attached to IRTF facility instrumentation and is fed a $1'$ on-axis field via a dichroic inside the IR instrument. The secondary and fast tip-tilt actuator are mounted on a hexapod which provides five degrees of freedom for alignment, collimation, and focus. The system was first installed on the telescope in October 1995, and it has demonstrated good engineering performance.

The existing IRTF focal plane instruments incorporating two dimensional detector arrays (NSFCAM and CSHELL; see ß 4.1) incorporate plate scales which take full advantage of these recent and anticipated image quality gains. These instruments also have integral dichroics which split off the visible light from the target object or a nearby guide star to provide the error signal for the tip-tilt sensor. SpeX, the new medium-resolution spectrograph now under development (ß 4.2), is also designed to fully exploit the image quality and stabilization provided by the tip-tilt system.

3.2 Telescope Control System (TCS)

The IRTF still operates with its original telescope control system (TCS), now more than 16 years old. A project to replace the TCS with a modern VME-based computer system has been established, and Peter Onaka, the IRTF electronics engineer, is responsible for this development. The project has been given lower priority the past two years while Onaka developed the electronics for the tip-tilt system. However a new master telescope control console has been built and will be installed at the summit during the coming year. A Unix and X Windows interface to the current TCS has been developed and in use by the telescope operators for the past 2 years. A barcode system for encoding the dome position has also been installed and is working very reliably.

3.3 Multiple Instrument Mount (MIM)

A new mounting concept in which all three major IRTF instruments and the associated electronics are semi-permanently mounted and cabled on the telescope was developed several years ago. This Multiple Instrument Mount (MIM) was installed on the telescope just before the Comet Shoemaker-Levy 9 impacted Jupiter in July 1994. Using a railroad roundhouse concept, the selected instrument is slid along mounting rails from its stow position to the focal position. MIM allows instruments to be easily selected without inserting any extra surfaces into the optical beam, thus incurring no emissivity penalty. A telescope operator can change instruments in 15 minutes, allowing multiple instruments to be used for one or more observing programs each night. It continues to be a huge success after 2 years of operation and is the single most important operational enhancement at the IRTF in recent history.

3.4 Telescope Emissivity

A program to reduce the thermal background radiated by the telescope was instituted three years ago. Doug Toomey is the Project Leader. One of the major achievements has been the reduction of telescope emissivity to 6%. The primary mirror was re-aluminized in late 1992, and since that time has been cleaned using a new CO2 snow technique approximately once a month. This procedure is working very well in maintaining the primary mirror coating and the low telescope emissivity.

4. SCIENTIFIC FOCAL PLANE INSTRUMENTATION

4.1 Instruments Presently Available

The present complement of IRTF instruments covers the $1-30\ \mu$m spectral range. It includes two InSb single detector photometers (with CVF spectrometers), a bolometer photometer for the mid-infrared, and two state-of-the-art instruments incorporating 256×256 pixel SBRC InSb detector arrays for the $1-5.5\ \mu$m region, CSHELL and NSFCAM.

CSHELL covers the $1-5.5\ \mu$m spectral range with $0\farcs20$ pixels. It has a $30''$ long slit and can also image a $30''\times30''$ area for easy object acquisition. Slits from $0\farcs5$ - $4\farcs0$ wide can be selected, and the $0\farcs5$ slit provides a spectral resolution R = 43,000. An internal science-grade CCD is used for guiding. One outstanding problem has been that the order-sorting Circular Variable Filters produce interference fringes which are difficult to remove from CSHELL spectra. New CVFs have been designed by Tom Greene to eliminate this and other problems, and they will be installed in late 1996 or early 1997.

The facility IR camera, NSFCAM, has become a workhorse IRTF instrument. It is scheduled for up to 50% of all observing time. It has three selectable image scales of $0\farcs06$, $0\farcs15$ and $0\farcs30$ pixel^{-1} and a multitude of selectable filters. CVFs also provide 1-2% spectral resolution from $1-5\ \mu$m. A warm waveplate rotator assembly has been installed on the top of the dewar so that linear polarization measurements may be obtained. NSFCAM also features two grisms which provide long-slit spectroscopy. One covers the $0.9-1.8\ \mu$m range at a resolution of R = 100, while the other works in the H, K, or L bands at R = 300 (double sampled). The DSP-based array controller, developed by the IRTF staff, provides real-time shift-and-add for image sharpening (typically achieving Strehl ratios up to 0.30 in the K band), and a movie-mode for high duty cycle short exposure observations such as occultations. Precise timing (for occultations) is provided via a GPS receiver.

A unique strength of the IRTF is the large number of visitors' instruments which are used on the telescope. Almost all of these are mid-infrared cameras or spectrometers. The

IRTF has encouraged the collaborative use of these instruments by advertising them regularly on our WWW site, in the newsletter, and in the semiannual announcement of observing time. Programs using visitor instrumentation accounted for 21% of the observing time awarded.

4.2 Instruments Under Development

Under a unique agreement between NASA and NSF, NASA supports the operating costs of the IRTF but provides no funding for focal plane instruments. New instruments are funded by the NSF based on peer review of proposals submitted by IRTF staff astronomers.

In 1994 the NSF granted funding for the development of the next IRTF facility instrument, a medium-resolution array spectrograph. John Rayner is the PI for this instrument (named SpeX), and he was awarded additional funding from the University of Hawaii for its construction. SpeX is designed around a 1024×1024 InSb detector array and will cover the $0.8 - 5.5$ μm region. The plate scale will be $0\rlap{.}''15$ pixel^{-1}, and a variety of slit widths and lengths will be available. A full spectrum over either $0.9 - 2.5$ μm or $2.7 - 5.5$ μm will be obtained in a single exposure at a resolving power of up to $R = 2000$ (double sampled) with a $15''$ long slit. A low resolution, high throughput, fast readout, long-slit spectrum covering $0.8 - 2.5$ μm at $R = 150$ is another mode. Additional $1'$ single-order long-slit modes are also included in the SpeX design. There will be an internal image rotator and an infrared slit viewer. The instrument is designed to interface with the CCD error sensor of the IRTF tip-tilt system to take full advantage of the image size and stability provided.

4.3 Computing

The standard design for instrument control and data acquisition of all IRTF array-based instruments features an X Windows graphical user interface for instrument control (XUI) and real-time ‘‘quick-look’’ data analysis (VF). Therefore both NSFCAM and CSHELL interfaces have a similar look and feel, making it relatively easy for IRTF users to observe with either instrument. The user feedback on this interface has been very positive, and several institutions and instrument P.I.s have adopted this software.

There are now two SPARC-based Unix workstations at the summit for observers, Herschel and Planck. These machines have over 10 GB of disc capacity mounted, much of which is used in a 4 GB Level 1 RAID. Another workstation, Wien, is in the IRTF / U.H. communications room at Hale Pohaku. Both 4 mm (DAT) and 8 mm (Exabyte) drives are available at Hale Pohaku. Data are typically archived onto tape after the end of a night or run via the FDDI optical fiber link to the summit machines. CSHELL observers also regularly acquire arc lamp exposures in the afternoon from Hale Pohaku, saving some observing time each night. This also allows observers to become familiar with the instrument before their first observing session.

The system of automatic guest accounts for visiting observers is now central to IRTF operations, and observers run both CSHELL and NSFCAM from their guest accounts. Visiting observers can also access Hawaii weather information via the WWW from their guest accounts. The IRTF World Wide Web site (http://irtf.ifa. hawaii.edu/) provides convenient access to the IRTF anonymous ftp site, allowing the easy retrieval of public IRTF data (such as from the Galileo Jovian monitoring program), IRTF photometric catalogs, observing time application forms, instrument and telescope manuals, the telescope schedule, issues of the IRTF newsletter, and a gallery of images obtained with IRTF instruments. It is accessed over 3,500 times a week. IRTF policy is that the definitive and most up-to-date version of all IRTF documents is the one in electronic form on our WWW site.

5. IRTF DOME AND BUILDING UPGRADES

We have been working with the NASA Facilities Engineering Division (Code JX) on three major modernization and rehabilitation projects for the observatory building on the summit of Mauna Kea. These upgrades are therefore outside the IRTF operating budget and do not come from NASA funds for planetary astronomy.

The Phase I facility upgrade was completed in 1993, and the Phase II Upgrade construction work began in January ’94. This project is managed for NASA by the Pacific Ocean Division of the U.S. Army Corps of Engineers, as was the Phase I upgrade. The major objective of this upgrade is to control the dome thermal environment so that the dome makes a negligible contribution to seeing at the IRTF. This includes additional insulation on the dome interior, installation of air conditioning and air handling ducts and fans throughout the dome, and provision of a large throughput exhaust fan outside the IRTF building, and the associated tunnel from the dome to the fan room, for circulating outside air through the dome during the night at a rate of several dome volumes per hour. A significant number of other upgrades to the facility were also included, several of which were focused on improving the safety of working conditions for the Day Crew. The project is complete except for some aspects of the measuring and control system. The system was tuned up to deliver good performance in June of 1996 and appears to be working adequately (keeping the day time dome air at or below the midnight outside air temperature). We expect that the Army Corps and the contractor will complete the commissioning of this system in the very near future.

A study and inspection of the IRTF dome shutter recommended increasing the safety margins in the designs of the shutter drive and braking system. The IRTF proposal to carry out this renovation, the Phase III Upgrade, has been approved by Facilities Engineering at NASA Headquarters. The new drive and braking system has been designed, and contractors have been selected. This new system is scheduled for installation during the summer of 1997 and will require a 45 day stand-down of the telescope. We have requested that this work be scheduled so that it does not interfere with periods of Galileo support or Comet Hale-Bopp observations.

6. SCIENTIFIC HIGHLIGHTS

The following results from recent IRTF observing programs are examples of the science conducted on the IRTF.

6.1 Comet Hyakutake

Comet 1996 B2 Hyakutake was the subject of two major observational efforts at the IRTF this year. After its discovery in late January, five target-of-opportunity (ToO) proposals were accepted and scheduled to observe the comet from mid-March through mid-April. These observations showed that the comet was truly spectacular, so NASA convened a 10 member science team which continued to observe the comet during daytime through May 25, except for a two week period near perihelion.

CSHELL, NSFCAM, and MIRAC (Mid-IR Array Camera; W. Hoffmann of U. Arizona is P.I.) were the primary instruments used to observe the comet. CSHELL yielded conclusive detections of CH_4 (methane), C_2H_6 (ethane), and C_2H_2 (acetylene) for the first time ever in a comet. NSFCAM and MIRAC yielded 1 – 20 μm images of the comet, and its nucleus was directly detected in 20 μm MIRAC images (also a first for a comet). The comet was monitored for temporal changes and the entire 3 – 5 μm near-IR region was scanned with CSHELL during the extended observing campaign. Many unidentified features were found, and HCN, CH_3OH, H_2CO, CO, and H_2O were also detected. These observations indicate that the chemical abundances of Comet Hyakutake are anomalous, and this may have arisen from chemistry occurring on interstellar grains before they underwent cold accretion onto the comet.

6.2 Other Solar system

Jupiter and Io were monitored nearly daily during September, October, and June for about 1 hour each night in support of the Galileo spacecraft's encounter with the planets. Jupiter was also observed extensively before, during, and after the Galileo probe entry into the planet's atmosphere. IRTF observations showed that the probe entered a relatively dry, cloud-free region. A strong new volcanic outburst on Io was discovered in June after six months of inactivity. These monitoring observations in support of Galileo will continue throughout the duration of the mission.

6.3 Non-solar System

Components of close ($\sim 1''$ or 150 AU separation) binary pre-main-sequence stars were observed for T Tauri activity. It was found that either both components or else neither component of these close systems showed such activity; no mixed pairs were found. Thus T Tauri activity appears to be related to a common circumstellar environment shared by both components of these close systems. Magnetic fields were measured in a group of active low-mass stars (K and M dwarfs) using observations of Zeeman broadening of IR Ti lines with CSHELL. The results show that as much as 60% of the surface areas of some stars are covered by constant magnetic fields (due to flare activity), while other stars have spectra which are not consistent with single-component magnetic fields. Finally, several high mass pre-main-sequence stars in the M17 and N2024 clusters were observed to have near-IR first overtone CO emission with bandhead velocity profiles consistent with arising in circumstellar disks undergoing Keplerian rotation. This indicates that circumstellar disks around high mass stars may survive longer than first predicted by protostellar evolution theory, and near-IR CO emission is a particularly good tracer of such disks around young high-mass stars.

Thomas P. Greene
Robert D. Joseph