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The Institute for Astronomy (IfA) is the astronomical research organization of the University of Hawaii (UH). Its headquarters is located in Honolulu on the island of Oahu near the University of Hawaii at Manoa, the main UH campus. The IfA is responsible for administering and maintaining the infrastructure for Haleakala Observatories on the island of Maui and for Mauna Kea Observatories (MKO) on the island of Hawaii. This report covers the period from 1 October 1995 through 30 September 1996. More information about the IfA is available at the Institute's World Wide Web site: http://www.ifa.hawaii.edu/.

## 1. STAFF

The scientific staff during this report period consisted of Timothy M. C. Abbott, Joshua E. Barnes, Richard L. Baron, Ann M. Boesgaard, Richard C. Canfield, John Carpenter (James Clerk Maxwell Telescope Fellow), Kenneth C. Chambers, Laird M. Close, Antoinette Songaila Cowie, Lennox L. Cowie, Christophe Dumas, Harald Ebeling, Fred Forbes (visitor), Isabella M. Gioia, J. Elon Graves, Thomas P. Greene, Olivier R. Hainaut (postdoctoral fellow), Donald N. B. Hall (Director), James N. Heasley, J. Patrick Henry, George H. Herbig, John Hibbard (Hubble Fellow), Klaus-Werner Hodapp, William Hoffman (visitor), Joseph L. Hora, Esther M. Hu, Hugh Hudson, David C. Jewitt, Robert D. Joseph, Lev Kofman, John Kormendy, Barry J. LaBonte, Sandra Leggett, Gerard A. Luppino, Alexander N. McClymont, Robert A. McLaren, Karen J. Meech, Thomas R. Metcalf, Mark Metzger (postdoctoral fellow), Donald L. Mickey, Satoshi Miyazaki (visitor), Malcolm J. Northcott, Kouji Ohta (visitor), Tobias C. Owen, Aleksei Pevtsov (postdoctoral fellow), Andrew J. Pickles, Narayan S. Raja, John T. Rayner, Pui Hin W. Rhoads, A. Kathleen Robertson, Claude Roddier, François J. H. Roddier, Katherine Roth (Hubble Fellow), David B. Sanders, Theodore Simon, Bradford Smith (visitor), Alan Stockton, Tjet Sun, David J. Tholen, Alan T. Tokunaga, R. Brent Tully, William D. Vacca (Parrent Fellow), Richard J. Wainscoat, Jean-Pierre Wülser, Gareth Wynn-Williams, and Michitoshi Yoshida (visitor).

## 2. MAUNA KEA OBSERVATORIES

The telescopes in operation during the report period were the UH 2.2 m telescope and the UH 0.6 m telescope; the 3 m NASA Infrared Telescope Facility (IRTF), operated by the UH under a contract with NASA; the 3.6 m Canada-France-Hawaii Telescope (CFHT), operated by the Canada-France-Hawaii Telescope Corporation on behalf of the National Research Council of Canada, the Centre National de la Recherche Scientifique of France, and the University of Hawaii; the 3.8 m United Kingdom Infrared Telescope (UKIRT), operated in Hawaii by the Joint Astronomy Centre (JAC) based in Hilo on behalf of the Particle Physics and Astronomy Research Council of the United Kingdom; the 15 m James Clerk Maxwell Telescope (JCMT), a submillimeter telescope operated by the JAC on behalf of the United Kingdom, Canada, and the Netherlands; the 10.4 m Caltech Submillimeter Observatory (CSO), operated by the California Institute of Technology for the National Science Foundation; the Hawaii antenna of the Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory (NRAO); and the 10 m Keck I telescope of the W. M. Keck Observatory, which is operated by the California Association for Research in Astronomy for the use of astronomers from the California Institute of Technology, the University of California system, and UH.

The 10 m Keck II telescope was officially dedicated in May, and was scheduled to become operational on 1 October 1996. Construction continued on the 8 m Subaru and Gemini Telescopes and on the Submillimeter Array.

This report covers in detail only the UH telescopes.

### 2.1 2.2 Meter and 0.6 Meter Telescopes

The report period was characterized by steady, productive observing and stable operation. The number of engineering nights was reduced to 24, making more nights available for scientific research. The f/31 tip-tilt secondary mirror was in routine operation—it is very easy to use—and was used in most of the observations involving this secondary mirror.

During the report period, imaging with CCDs remained the most common use of the telescope, accounting for 39% of the observing time and the bulk of the dark-moon observing time. This comprised mainly wide-field imaging using the Tektronix 2048 $\times$ 2048 CCD at the f/10 focus.

Twenty-seven nights were scheduled with the new 8192 $\times$ 8192 mosaic CCD camera (see § 4.4). This camera has a field of view of $19' \times 19'$. A field-flattener was designed and installed (it serves as the dewar window).

Imaging with QUIRC, the 1024 $\times$ 1024 infrared camera, was performed for 34% of the observing time, which was evenly split between wide-field imaging at the f/10 focus and high-resolution infrared imaging at the f/31 focus. The large format of this infrared camera has made it an extremely powerful tool for imaging. This camera was in high demand during the report period, and it was heavily used during each bright-moon period.

The near-infrared spectrometer KSPEC was upgraded with a 1024 $\times$ 1024 array, and was used for 17% of the observing time. Low-resolution optical spectroscopy was performed for 9% of the observing time. The coudé spectrograph was little used (only 2 nights); the remaining 1% of the observing time involved visitor instruments.

A 25 cm telescope was mounted on top of the 1024 $\times$ 1024 camera and attached on the counterweight side of the 0.6 m telescope. This telescope was brought into remote operation during May 1996. Work continued through the report period to further improve this remote operation.

A major revision of the telescope user manual was completed in April. Further progress was made in making documentation available via the World Wide Web. The URL for information relating to the 2.2 m telescope is http://www.ifa.hawaii.edu/88inch. The user manual, instrument manuals, and a telescope newsletter are available at this URL.

Scheduling periods for the telescope are currently four-month trimesters: December–March (deadline October 1); April–July (deadline February 1); and August–November (deadline June 1).

### 2.2 Site Characteristics

The National Radio Astronomy Observatory completed its measurements of atmospheric transparency and radio ''seeing.'' These were carried out from a location near the VLBA antenna at an elevation of 3220 m and were part of NRAO's program to evaluate potential sites for the proposed Millimeter Array (MMA). Results are available at the MMA site on the World Wide Web, http://www.tuc.nrao.edu/mma/mma.html.

The Federal Aviation Administration, the National Weather Service, and the Department of Defense are engaged in a joint program to install a new generation of powerful Doppler weather radars throughout the United States. The program is called the Next Generation Weather Radar (NEXRAD). The NEXRAD closest to the IfA's observatory sites is located in the Kohala district on the island of Hawaii, 48 km (30 miles) northwest of Mauna Kea and 80 km (50 miles) southeast of Haleakala, in direct line of sight to both. The Kohala NEXRAD was installed in August. In accordance with an agreement between IfA and the NEXRAD Program Office, spot blanking has been implemented. Spot blanking involves turning off the radar transmitter when the antenna's main lobe is pointed at the mountain summits. With the blanking, power density levels at the observatories are below 1 mW $m^{-2}$. Without it, they would be $\sim$1 W $m^{-2}$ and a major source of radio frequency interference.

### 2.3 Infrastructure

The IfA has a 10 year Network Services Agreement with GTE Hawaiian Tel to provide high-bandwidth fiber optics communications for MKO. Based on SONET OC-12 (622 Mbit $s^{-1}$) technology, the system will provide 11.5 DS-3 (45 Mbit $s^{-1}$) circuits between summit observatories and base facilities in Hilo and Waimea. During the summer, Hawaiian Tel installed fiber optic cable on existing utility poles from its Humuula relay station in the saddle between Mauna Kea and Mauna Loa up to the MKO mid-level facility at Hale Pohaku, where the new cable connects to the existing underground fiber optic trunk to the summit. The fiber across the saddle to Hilo and Waimea is scheduled to be in place by the end of 1996, with the new service available early in 1997.

The Submillimeter Array (SMA) Project, as part of its site work, completed a major upgrade of the underground power and communications duct system at the summit. The ducts for the primary electrical feeders have been extended from their previous terminus at the base of the summit switchbacks to a new endpoint near the SMA site. Two new fused switches will be installed at this location. New ducts for fused feeders extend up slope from the switches to join the existing ducts at Subaru, thereby completing the power distribution loop. These improvements will double the electrical capacity and provide considerable redundancy. New communications ducts have been installed alongside the electrical ones, closing that loop as well.

The IfA has contracted with a local survey firm to obtain new aerial photography of the Mauna Kea Science Reserve and new photogrammetric mapping of the inner portions of the Reserve. The photography was completed in September. The purpose of this mapping project is to document the current development in the Science Reserve and to provide the basic topographical data needed to begin planning any future development. The map is also a key element of the Historic Preservation Management Plan, in that the location of approximately 60 sites of historic and cultural significance (mostly rock shrines) will be recorded. The map will be produced in computer-readable format.

At Hale Pohaku, there is a long-term construction camp available to telescope projects that wish to have their workers reside on the mountain during work shifts. Over the past year, the camp was used by Subaru and SMA.

## 3. HALEAKALA OBSERVATORIES

W. Lu is the assistant director, Haleakala Division, UH IfA, and is based at the IfA Maui headquarters office located in Kula.

### 3.1 Mees Solar Observatory

The observatory staff consisted of A. Distasio, superintendent; J. Frey and L. Hieda, electronics technicians; E. Kiernan, software engineer; K. Kimura, secretary; G. Nitta, solar observer; K. Rhoden, fiscal administrator; and M. F. Waterson, electronics engineer.

During the report period, the Mees staff carried out programs in support of IfA scientists and the *Yohkoh* mission.

Major instruments at the Mees Solar Observatory include the Imaging Vector Magnetograph, the Photometric Oscillation Imager, and the White-Light Solar Imaging Telescope System.

### 3.2 LURE Observatory

LURE is a lunar- and satellite-ranging facility. Currently, LURE tracks 16 satellites in orbits from 400 to 20,000 km high. The missions of the target satellites include monitoring of Earth resources and climate parameters, measurements of ocean level and temperature changes, measurement of tectonic plate movement, and improvement of the Global Positioning System (GPS). These satellites were developed by the United States (Topex/Poseidon, TIPS, GPS35, GPS36, and Lageos1), European Space Agency (ERS1 and ERS2), Japan (Ajisai), Russia (Etalon1, Etalon2, and Glonas), France (Stella and Starlette), Germany (GFZ1), and Italy (Lageos2). The observatory staff consisted of Project Manager D. O'Gara; Systems Engineer R. Zane; Observatory

Foreman M. Maberry; Laser Ranging Technicians C. Foreman, K. Rehder, and T. Georges; and Research Associate K. Hollman.

## 4. INSTRUMENTATION

### 4.1 Adaptive Optics

During the report period, most of the effort of the Adaptive Optics (AO) Group focused on obtaining and analyzing high angular resolution astronomical data. Data were taken through the UH adaptive optics system mounted at the f/35 Cassegrain focus of the CFHT, with both a 1024 × 1024 HgCdTe infrared camera (35″ field of view), and a 1024 × 1024 CCD camera (25″ field of view). In both cases the field of view was found to match quite well the isoplanatic patch size for adaptive optics compensation with a loss of about 10% in Strehl ratio at the edge of the field. Imaging was done mostly through standard $J$, $H$, and $K$ filters with simultaneous optional imaging through a narrowband filter in the $I$ band. The use of a narrowband filter still allows use of most of the light shortward of 1 $\mu$m for wave-front sensing. Two main programs have been pursued, one on young stars (see § 7) and one on solar system objects (see § 8).

Northcott and Graves worked on instrument improvements and installed new features, including polarization measurement capabilities for the infrared camera, improved scanning speed for the guide source offset, maximum offset increased from 20″ to 35″, coatings changed from aluminum to protected silver for improved throughput, integration of the AO system (both cameras, and remote controls) into a central control workstation, and absolute position Hall sensor installed on the infrared camera focus stage to reduce the prerun setup time.

In addition, Graves pursued improvements in bimorph mirror technology. Using a new fabrication process (patent pending), he was able to produce a 13-actuator mirror with very high performance. Compared to mirrors used before, the stroke of the new mirror is larger by more than a factor of 2, and its optical quality is excellent. It is coated with protected silver and uses only 2% of its stroke to flatten itself. This new mirror was first used during an observing run at the CFHT in July. The improved stroke was easily able to handle all the changes in telescope collimation, focus drifts, and atmospheric disturbances. (The previous mirror saturated on 0.75″ seeing, and on many occasions had fixed telescope aberrations.) Because of the success of this mirror the AO group can proceed confidently with the fabrication of a 36-actuator mirror if funds become available.

### 4.2 The Gemini Near-Infrared Imager (NIRI)

The 8 m Gemini North Telescope, now under construction on Mauna Kea, is designed to achieve unprecedented image quality and is unique in its optimization for low telescope emissivity. It is expected that these design features, together with the quality of the observing site, will make the Gemini North Telescope the best ground-based telescope for observations in the thermal infrared.

NIRI will be the main infrared imaging instrument on Gemini North. Its first task will be the commissioning of the telescope and a characterization of its performance. NIRI is therefore required to allow a detailed evaluation of telescope performance.

While the tip-tilt and fast-focus system is expected to be operational at the start of science observations, the adaptive optics system will become available only later. NIRI must therefore allow efficient scientific observations with the image quality expected from tip-tilt and focus correction alone.

NIRI will provide three pixel scales for scientific observations, the finest (0.02 arcsec pixel$^{-1}$) has been chosen to sample properly the expected image quality delivered by the adaptive optics system; the middle one (0.05 arcsec pixel$^{-1}$) is best matched to the image quality expected from tip-tilt corrected images on the best nights; and the widest field (0.12 arcsec pixel$^{-1}$) fills almost the whole unvignetted science field of the telescope. Produced by the Hughes Aircraft Santa Barbara Research Center (SBRC) under contract from Gemini, the science detector array will be a 1024 × 1024 Aladdin array with 27 $\mu$m pixels. The NIRI science array control electronics are being built by National Optical Astronomy Observatories to benefit from their experience with testing of the initial Aladdin arrays and to ensure commonality between NIRI and the other near-infrared instrument for Gemini North, the Gemini Near-Infrared Spectrograph. Besides basic imaging, NIRI will provide the capability for grism spectroscopy at low to moderate spectral resolutions (600 and 2000 for $J$, $H$, and $K$, and 1500 for $L$), the capability to obtain coronographic imaging data, and the capability for polarimetric observations using a Wollaston prism with 1″ beam separation.

NIRI will be equipped with an internal on-instrument wave-front sensor (OIWFS) to keep differential flexure between the science channel and the OIWFS within acceptable limits. Optical wave-front sensors perform well almost everywhere in the sky, but an important class of scientific projects, studies of deeply embedded very young stars in nearby molecular clouds, is not able to utilize such a system. For this reason, and in light of recent advances in the noise performance of near-infrared detector arrays, the NIRI OIWFS will be a HAWAII (HgCdTe Astronomical Wide Area Infrared Imager) 1024 × 1024 HgCdTe array.

As a tool for the characterization of telescope performance, in particular telescope emissivity, NIRI will be equipped with a pupil viewer, allowing users to direct a high-resolution image of the telescope pupil onto the science detector array. It is expected that this capability will also be useful in setting the instrument up for certain scientific programs, e.g., to check proper apodization of the pupil mask for coronographic observations.

### 4.3 Infrared Camera and Spectrograph for Subaru (IRCS)

Tokunaga (PI), Project Scientist N. Kobayashi, and co-investigators Hodapp, Rayner, and Hora (IfA), and Y. Kobayashi, T. Maihara, and T. Nagata (Japan) received approval from the Subaru Project Office to begin construction of the IRCS, a facility instrument for the Subaru Telescope. It will be a high-resolution spectrograph for 1–5 $\mu$m (R = 20,000) and a powerful slit-viewing camera. The camera section will have grisms for low to moderate spectral resolution (up to R = 2000). The instrument will use 1024 × 1024 InSb Aladdin arrays, one each for the camera and spectrograph sections. The final design will be completed by December 1996, with fabrication to begin in January 1997. The planned completion date is December 1998.

### 4.4 8K CCD Mosaic Camera

During the report period, the camera was used extensively by UH astronomers for wide-field projects in weak gravitational lensing, the study of the faint galaxy luminosity function in clusters, and the search for solar system comets, asteroids, and Kuiper Belt objects.

This camera, developed by the IfA, is the world's largest astronomical CCD camera—a mosaic focal plane with 8192 × 8192 pixels. The mosaic is a close-packed (gaps$\lesssim$1 mm), 4 × 2 array of three-edge-buttable 2048 × 4096 Loral CCDs with 15 $\mu$m pixels. The camera was designed primarily for use at the prime focus of the CFHT, where it offers an unprecedented combination of wide field of view (0.47° × 0.47° or 0.22 deg$^2$) with optimal sampling (0.21 arcsec pixel$^{-1}$) of the best Mauna Kea seeing (0.5″). In addition, with the use of a field-flattener, the camera can also be used at the f/10 RC focus of the UH 2.2 m telescope, where the image scale is 0.14 arcsec pixel$^{-1}$ and the field of view is 0.31°×0.31° (0.1 deg$^2$).

The UH 8K Mosaic camera has obtained impressive data so far. On the CFHT, 0.5″ images were achieved over the entire mosaic field. Work is currently underway to upgrade the CCDs in the UH 8K mosaic camera with higher-sensitivity thinned devices, and to build an 8 × 10K CCD mosaic camera for permanent use at the CFHT.

The optical detector group is also leading aggressive programs to develop new, state-of-the-art CCDs optimized for astronomical observations. One such UH-led effort involving six world-class observatories is developing a 2K × 4K, three-edge buttable CCD with MIT Lincoln Laboratory. The goals of this program are to produce an extremely low-noise ($<$1.5 electrons), high-speed, deep-depletion CCD with enhanced near-infrared (700 nm to 1 $\mu$m) response and minimal interference fringing.

### 4.5 SpeX

SpeX, a medium-resolution, 0.8–5.5 $\mu$m spectrograph is being built at the IfA for the IRTF. Funded by the National Science Foundation in July 1994, it is scheduled for first light during 1999. The UH is contributing matching funds. Project staff include Rayner (PI), D. Toomey (cryostat), P. Onaka (electronics), T. Denault (software), V. Stahlberger (mechanical engineer), and D. Watanabe (instrument technician).

SpeX will use an Aladdin II 1024 × 1024 InSb array from Hughes SBRC, and it will get first choice of arrays being built for the NASA Planetary Astronomy InSb Detector Array Infrastructure Project. All being well, SpeX will use a science-grade 1024 × 1024 (four quadrant) device in the spectrograph and a 512 × 512 (one working quadrant) device in the infrared slit-viewer.

The primary scientific driver of the instrument is to provide maximum simultaneous wavelength coverage at a spectral resolving power that is well-matched to many planetary, stellar, and Galactic features, and at resolving power that adequately separates sky emission lines and disperses sky continuum. This requirement has resulted in an instrument design that provides spectral resolutions of R ~ 1000–2000 across 0.9–2.5 $\mu$m and 2.4–5.5 $\mu$m, using prism cross-dispersers. An autonomous infrared imager is provided for guiding and high-quality imaging. If funding permits, long-slit modes and a low-resolution prism mode will also be built. Design review was scheduled for early October 1996, with fabrication to begin shortly thereafter.

Briefly, the instrument will consist of a large box-shaped cryostat that contains the cold instrument optics and detector arrays. Cooling will be accomplished using one CTI 1050 cryo-cooler to sink most of the radiation load from the large vacuum jacket and liquid nitrogen to sink the remainder of the load and to clamp the temperature of the optics box. The cryostat will be mounted to the telescope by a rigid interface box, into which a spectral calibration unit will be built. An IRTF-designed array controller will run both the spectrograph and imaging arrays. The VME64-based controller will use multiple DSPs and a single-board computer. A smaller instrument computer mounted on the mirror cell will be used for motor and temperature control and for monitoring tasks. Cryostat-mounted electronics, consisting of preamps, A/Ds, clock, and bias boards, will be fiber optically coupled to the array controller, which will reside in the control room. The user interface will run on a UNIX workstation connected to the array controller and instrument computer by Ethernet. A quick-look data reduction package will provide observers with near-real-time extracted spectra corrected for flat-field and telluric features.

## 5. GALACTIC AND EXTRAGALACTIC STUDIES

Chambers is interested primarily in observational cosmology and cosmogony, with concentration on the properties of galaxies and active galactic nuclei (AGNs) at high redshift. He continues to pursue his technique of selecting radio sources by their ultrasteep radio spectrum with a two-pronged approach to investigate the nature and origin of the relationship between the radio source and optical/infrared continuum.

The first approach involves detailed studies of high-redshift ($1<z<5$) radio galaxies and the fields surrounding them. Radio studies include multifrequency radio imaging and polarimetry to determine the details of the radio morphology, radio color, and radio depolarization asymmetry, all of which help to constrain the magnetic field and electron density, and provide clues into the orientation of the radio source. Optical and infrared studies include deep multicolor broad- and narrowband imaging, producing, for example, five-color spectral energy distributions (SEDs) of 117 objects in the 1′ field around 4C23.56. Optical and infrared polarimetry provides important clues into the nature of the extended continuum around high-redshift radio galaxies. Working with Chambers, graduate student G. Knopp is studying a sample of 10 $z>2$ radio galaxies with multicolor optical and infrared polarimetry. These observations have led to new constraints on the dust content and the nature of the continuum emission from early epoch galaxies.

The second approach comprises surveys for new identifications. Chambers nearly completed an optical/infrared survey of 33 faint ultrasteep spectrum (USS) objects, with radio fluxes about 30 times less than the 4C sample of USS, to obtain identifications and spectroscopic redshifts when possible. Using the 8K CCD mosaic camera on the CFHT, Chambers also began a wide-field study of deep radio survey fields to investigate a homogeneous sample of radio sources down to $\sim 75\ \mu$Jy. Both of these samples are designed to probe the radio luminosity and redshift dependence of the peculiar properties of high-redshift radio galaxies and their companion galaxies.

L. Cowie, A. Cowie, and Hu continued studies of galaxy evolution in the Hawaii Survey fields. They used a combination of deep multicolor imaging from the optical through the infrared with deep multiobject spectroscopy on the Keck telescope. These investigations emphasize obtaining complete, magnitude-limited samples in each color ($B$, $I$, $K$), and in particular, using samples selected in the near-infrared ($K$ band) to probe galaxy populations to very high redshifts. The $K$-selection minimizes the biases present in optically selected samples, where large and uncertain K-corrections (which also depend on morphological type) are present even by redshift $z\sim 1$. The present samples reach complete coverage at $B<24.5$, $I<23$, and $K<20.5$, with some additional identifications at fainter magnitudes.

The datasets have been used to construct a ''fundamental plane'' to describe the star-forming properties of galaxies and their evolution with redshift, where the $K$-band light may be used as an estimator of mass in stars and where the rest-frame ultraviolet–infrared colors, or equivalently, the [O II] emission-line strengths, can be used as a measure of star-forming activity. Star formation rates peaked between $1<z<2$, with many rapidly star-forming and massive (spiral) galaxies present at $z\sim 1$. Deep *Hubble Space Telescope* (*HST*) Wide Field Planetary Camera 2 (WFPC2) imaging studies of the Hawaii Survey fields show that these high-redshift ($z>1$) galaxies have unusual, and in several instances, chainlike morphologies.

The complete nature of the survey identifications makes these redshift determinations useful for investigating the correlation properties of field galaxies, and this has been addressed in a program of collaboration with R. Carlberg (Toronto). Correlation amplitudes are shown to be significantly larger among galaxies with redder ultraviolet–infrared colors, and clustering of weak C IV lines in quasar absorption spectra ($2.66<z<3.62$ and $N_{\rm H\,I}>10^{12}$ cm$^{-2}$) are less clustered than the trend for galaxy correlations.

In a program of study with former IfA graduate student E. Egami (now at Max-Planck-Institut für Extraterrestrische Physik) that uses the CGS4 spectrograph on UKIRT, the emission-line diagnostics for high-redshift objects are being extended to measurements in the infrared. This work has been particularly useful for identifications of the $z>1.7$ objects where the signature lines have moved outside of the optical band. From the infrared Hubble diagram, which can now be constructed out to redshifts $z\sim 3.5$ in the field samples, it may be seen that the typical galaxy at any redshift is a sub-$L_*$ object—at high redshift, galaxies were not particularly luminous objects.

L. Cowie, Hu, A. Cowie, Hodapp, and graduate students E. Fulton and D. Clowe have conducted field galaxy investigations of the Hubble Deep Field (HDF). They use the large format of the 1024 × 1024 Rockwell HAWAII infrared arrays to perform infrared imaging with the UH QUIRC camera at CFHT and at the UH 2.2 m telescope to cover the entire HDF at high image quality. For deep samples that reach very high redshift populations, it is possible to construct six-color (optical–IR) color-estimated redshifts that are in fair agreement with spectroscopically determined redshifts measured on Keck.

Hu and R. McMahon (Institute of Astronomy, Cambridge) have been studying very high redshift ($z>4.5$) galaxies. They use targeted searches around $z>4$ quasar fields to identify candidates that show emission in the strong Ly$\alpha$ line of hydrogen at the redshift of the quasar. This technique has proved successful in identifying the highest redshift galaxies now known. It relies on the fact that galaxies cluster to use distant quasars as markers to find much fainter, normal star-forming galaxies at the redshift of the quasar. Hu and McMahon have found two such distant galaxies at $z\sim 4.7$ at separations $\sim 10$ kpc from the quasar BR1202−0725, and they have investigated it using a combination of *HST* WFPC2 images, ground-based emission-line and multicolor imaging, and deep spectroscopy at the Keck telescope. Two additional $z\sim 4.55$ galaxies have been discovered in the field of the quasar BR2237−0607. Both objects are well separated from the quasar ($\sim 700$ kpc) and thus cannot be excited by it. Instead, these appear to be galaxies in their first burst of star formation, prior to the formation of a substantial generation of stars providing continuum light and before substantial chemical enrichment and dust formation have taken place.

Investigation of the gaseous component of the high-redshift universe is underway through quasar absorption-line observations being conducted by A. Cowie, L. Cowie, Hu, and graduate student T.-S. Kim. At redshifts $z>2.5$ a substantial portion of the baryonic material of the universe is contained in ''Ly$\alpha$ forest'' clouds, and recent advances in theoretical modeling of galaxy formation and simulations of the forest have made these high S/N, high-resolution observations from the Keck HIRES spectrograph the subject of intense interest. From these data they found that roughly half the Ly$\alpha$ forest clouds with $N_{\rm H\,I}\geqslant 3\times 10^{14}$ cm$^{-2}$ have measurable C IV lines with $N_{\rm C\,IV}>10^{12}$ cm$^{-2}$, and that the ratio median C IV column density to median H I column density corresponds to roughly $10^{-2}\times$ solar metallicity—a value comparable to the metallicity of our Galactic halo.

Kim is studying the evolution of the Ly$\alpha$ forest clouds with redshift and finds that although the distribution function of forest clouds is well-described by a power law at low column densities, high-column-density clouds deviate from this distribution, and at higher redshifts, this deviation occurs at higher column densities.

Further studies by A. Cowie and L. Cowie of the evolution of ionization and metallicity toward quasars in the redshift $3 \rightarrow 4$ range show that C IV can be found in nearly all forest clouds, with a detection fraction determined by the hydrogen column density (and thus the sensitivity of detections), and that the C IV/H I ratio has a remarkably small dispersion for clouds in the studied column density range of $10^{15} \lesssim N_{\mathrm{H\,I}} \lesssim 3 \times 10^{16}\ \mathrm{cm}^{-2}$. These data suggest that Lyman forest clouds are ubiquitously metal enriched, at a metallicity value very close to the average seen in our own Galactic halo, and this strongly favors pre-galactic enrichment by an early generation of stars (e.g., Population III). Using the lines of silicon, carbon, and nitrogen as ionization diagnostics, A. Cowie and L. Cowie also find evidence for changes in the background ionizing flux with redshift, with an increase in the Si IV/C IV ratio above redshifts $z \sim 3.2$. Such an effect might reflect either the epoch at which quasars take over from star formation as the dominant ionizing source or the transition point at which the intergalactic gas becomes transparent to He II ionizing photons (reionization).

Graduate student C. Dudley and Wynn-Williams completed their mid-infrared (10 and 20 $\mu$m) study of the ultraluminous infrared galaxy IRAS 08572+3915. The 10 $\mu$m spectrum reveals a deep silicate absorption feature, while the 20 $\mu$m spectrum shows no clear evidence for an 18 $\mu$m silicate absorption feature. An interstellar extinction curve is fitted to IRAS 08572+3915 and two other deep silicate infrared galaxies, NGC 4418 and Arp 220.

Dudley and Wynn-Williams found that pure extinction cannot explain the spectral energy distributions of these sources, but both the strength of the silicate absorption and the overall spectral energy distributions of the three galaxies agree well with scaled-up models of Galactic protostars. From this agreement, they conclude that the infrared emission comes from an optically thick dust shell surrounding a compact power source. The size of the power source is limited to less than a few parsecs; therefore, accretion onto a supermassive black hole, rather than a burst of star formation, is more likely to be the power source.

Gioia and Henry used the UH 2.2 m telescope and the CFHT to identify and study the X-ray sources of the NEP (North Ecliptic Pole) region of the All-Sky Survey of the *ROSAT X-ray Astronomy Satellite*. The goal of this program is to use the deepest region of the All-Sky Survey to investigate the evolution of the X-ray luminosity function of clusters. This evolution was first detected in the *Einstein Observatory* data and is still a matter of debate. Among the serendipitous discoveries worth mentioning is the most distant cluster of galaxies yet found in the NEP at $z = 0.82$.

During the report period, Gioia and Luppino completed a survey to search for arcs and arclets in a sample of 40 X-ray luminous ($L_x > 2 \times 10^{44}$ ergs s$^{-1}$) and distant ($0.15 < z < 0.83$) clusters of galaxies. The program used both the UH 2.2 m telescope and the CFHT. The main results indicate that (1) high X-ray luminosity does indeed identify the most massive clusters, and thus X-ray selection is the preferred method for finding rich clusters at intermediate and high redshifts; (2) there is evidence for compact cluster mass density profiles; and (3) the geometry of the arcs suggests the presence of mass substructure in the central 0.5 Mpc cluster cores. *HST* data have been obtained for two clusters with the most complex arc configurations. Spectroscopic measurements of the arcs redshifts and of the cluster galaxies to determine the cluster velocity dispersion are now crucial for the lensing theory that needs to be applied to the *HST* data. For these two clusters and other X-ray selected clusters, *Advanced Satellite for Cosmology and Astrophysics* (*ASCA*) and *ROSAT* High Resolution Imager (HRI) observations have also been awarded. The X-ray data will provide the necessary ingredients (temperature and structure of the hot gas) to measure the cluster mass, which will be compared with the mass determined from the lensing. An ongoing program with N. Kaiser (now at IfA), Metzger, and Clowe will image a number of X-ray clusters selected to cover a range in redshift. The goal of this ongoing program is to measure the weak gravitational distortion of faint background field galaxies behind rich clusters at large radii.

Stockton and former graduate students S. E. Ridgway (now at Oxford) and M. Kellogg (now at Caltech) completed an imaging and spectroscopic study of the $z = 1.132$ radio galaxy 3C 368, often taken to be the prototype of powerful radio galaxies at high redshift. They confirmed a previous suggestion that what was long thought to be the nucleus of this galaxy is actually a projected Galactic M-dwarf star, and they obtained high-resolution imaging in an H+K filter with the 2.2 m telescope tip-tilt secondary (FWHM = 0.32″) showing what is apparently the true nucleus about 1.5″ N of the star. Spectroscopy obtained with the Low-Resolution Imaging Spectrometer (LRIS) on the Keck I telescope shows a wide range of ionization conditions in various regions along the optical structure aligned with the radio source, as well as a very complex velocity field. The main results of the spectroscopic work are that (1) there is an apparent correlation between emission-line strength and velocity width, (2) in the most luminous emission-line region, about 80% of the continuum shortward of the Balmer limit is due to nebular thermal emission, and (3) the high velocities in the emission-line gas tend to be one sided with respect to the local standard of rest and are probably due to the interaction of cloudlets entrained in the radio jet with ambient material.

Ridgway completed her Ph.D. work on ground-based and *HST* imaging of a complete sample of $z \sim 1$ 3CR quasars and radio galaxies, and a paper on this work has been submitted for publication by Ridgway and Stockton. The main data comprise deep *HST* WFPC2 images at restframe 0.33 $\mu$m of the sample of five quasars and five galaxies, and deep Keck Near-Infrared Camera images of the sample at $K'$ (restframe $\sim 1$ $\mu$m). Some form of extended optical continuum structure was seen around each of the quasars, and four of the five showed structure aligned with the radio axis. However, in at least three of these cases, the aligned component shows very strong point-to-point correspondence with the radio structure and is almost certainly optical synchrotron radiation. The luminosities of the quasar hosts are consistent with those of the radio galaxies to within the observed dispersion of the sample, and this similarity supports the unification of Fanaroff-Riley class II radio galaxies and quasars. Some specific objects of special interest were found: 3C 212 not only shows an optical jet that matches perfectly the radio jet seen in a 3.6 cm Very Large Array map, but it also shows apparent aligned continuum structure well *beyond* the detectable radio lobes, and 3C 280 shows an arclike extension that may be either a tidal tail or the trace of a greatly foreshortened precessing jet.

Graduate student G. Canalizo and Stockton have been obtaining spectra of apparent close companions to low-redshift QSOs. So far, one shows a late-type composite stellar spectrum near the QSO redshift; one shows an E + A spectrum, again near the QSO redshift; and one is a Galactic star.

Tully, E. J. Shaya (Maryland), and P. J. E. Peebles (Princeton) have continued attempts to model the formation of the Local Supercluster using the Least Action methodology. A first paper published in *The Astrophysical Journal* describes the method and provides preliminary results based on 300 distance estimates. Since that publication, the procedure has been extended to use 900 distance estimates, and comparisons have been made with N-body simulations. Present estimates of the density parameter are in the range $0.15<\Omega_0<0.35$.

Tully, Wainscoat, graduate student J.-S. Huang, M. J. Pierce (Indiana), and M. A. W. Verheijen (Groningen) wrote a paper accepted by *The Astronomical Journal* that provides photometry at $B,R,I$, and $K'$ for 79 galaxies in the nearby Ursa Major Cluster of galaxies, including all 62 galaxies brighter than $M_B=-16.5^m$. Tully and Verheijen have submitted a paper that speculates on a possible bimodality of the distribution of disk surface brightnesses for the members of this sample.

## 6. STAR FORMATION AND INTERSTELLAR MATTER

John Carpenter and collaborators have completed a near-infrared and spectroscopic survey of the MonR2 stellar cluster. They found that MonR2 contains over 300 stars within a region a few tenths of a parsec in size, making MonR2 one of the richest and densest clusters in the solar neighborhood. However, the properties of the individual stars, including the gross shape of the initial mass function, are consistent with that found in other nearby star-forming regions regardless of the stellar density or the local conditions.

Carpenter and Deane completed the molecular line observations of a sample of ultracompact regions. The analysis of these data will reveal the physical conditions of the molecular gas in a wide range of star-forming environments. Carpenter and T. Bergin (Center for Astrophysics) are analyzing strip maps of several molecular transitions in the M17 cloud to test the predictions from chemical models in photodissociation regions. Sanders and Carpenter are continuing their Galactic plane survey in the $2\rightarrow1$ and $3\rightarrow2$ transitions of $^{12}CO$ and $^{13}CO$. The $2\rightarrow1$ observations are complete, and the $3\rightarrow2$ observations will be conducted with the new 345 GHz receiver at the JCMT. Carpenter, and Heyer and Snell (both Five College Radio Astronomy Observatory) have imaged 43 *IRAS* point sources in W3/W4/W5 in the near-infrared. Many of these *IRAS* point sources are located along shells of molecular gas, and the near-infrared images showed that over half of these represent an embedded cluster of stars. Carpenter has developed a three-dimensional Monte Carlo radiative transfer code for clumpy molecular clouds. This model will be compared with molecular line observations to place constraints on the density and filling factor of clumps in molecular clouds.

Greene and C. Lada (Smithsonian Astrophysical Observatory [SAO]) completed their near-IR spectroscopic survey of over 100 young stellar objects (YSOs) and MK standards using the UH KSPEC spectrometer. This pioneering study demonstrated that the shapes, absorption spectra, and emission spectra of YSOs can yield key details of their extinctions, veilings, and circumstellar environments. The entire $\rho$ Ophiuchi YSO population was surveyed down to $K\sim10.5$, and this magnitude-limited sample was key for relating observed IR spectroscopic properties to the evolutionary status of YSOs. In general, Greene and Lada found that the shapes of YSO spectra are correlated with SED class such that the most embedded objects generally have the steepest IR spectra. The veiling of stellar absorption spectra was found to increase from near zero for (diskless) Class III YSOs to the pre–main-sequence (PMS) Class II YSOs to the flat-spectrum and Class I protostars that have very high IR veilings ($r_k\geqslant5$). These measured veilings were quantitatively related to mass accretion rates via disk and infalling envelope models. Analysis of $K$-band absorption spectra shows that most Class II and III YSOs have surface gravities intermediate between dwarf and giant MK stellar standards, while the $\rho$ Oph flat-spectrum YSOs have lower surface gravities, similar to giant stars. Thus surface gravity increases as YSOs evolve from protostars to PMS stars to main-sequence stars. FU Ori stars have surface gravities similar to giant or supergiant stars, suggestive of line formation in disks rather than stellar photospheres. The FU Ori type stars and a few other YSOs show deep and broad $H_2O$ absorptions, indicative of cool ($T\leqslant3000$ K) disks or stellar photospheres. Many Class I and Class II objects show relatively strong H I emission lines that probably originate in a partially ionized circumstellar region. However, mostly Class I objects show detectable $H_2$ emission lines.

In collaboration with H. Chen (SAO), Greene has used the IRTF and other Mauna Kea telescopes to observe the molecular outflow source IRAS 20050+2050. They have found that a number of embedded YSOs associated with the outflow are grouped in a small cluster and have identified the YSO that drives the flow. This object is nearly invisible in the $K$ band, but IRTF imaging with NSFCAM reveals that it is one of the brightest sources in the cluster at $L$- and $M$-band wavelengths.

Hora, with D. Kelly (Wyoming) and W. Latter (NASA/Ames), used CSHELL at the IRTF to measure velocities and strengths of $H_2$ and Fe II emission lines in seven planetary nebulae (PN). These lines are excited by shocks or by UV-fluorescence. Spectra were obtained at many positions in the PN to attempt to understand their structure and dynamics. In the Egg nebula (AFGL 2688), evidence of an expanding, rotating ring in the equatorial plane was observed. Along the poles of the nebula was a fast wind that terminates in bright knots of $H_2$ emission. In M 2-9, $H_2$ and Fe II emission was measured along the N lobe from the central source to the N knot. The $H_2$ is in a slowly expanding shell around the outside of the lobe, and the Fe II emission is from rapidly moving gas that is streaming along the polar axis and forming a shock front at the N knot. The data will be analyzed in conjunction with near-IR imaging and other spectral data to understand the geometry and evolution of the PN and to constrain shock and photoexcitation models.

Tokunaga and S. Wada (Univ. of Electro-communications) continued their work on understanding the nature of quenched carbonaceous composite (QCC), a laboratory analog to the carbonaceous material in the interstellar medium. This material is produced from a hydrocarbon plasma, and it has a 220 nm absorption that is close in wavelength to that seen in the interstellar medium. In addition, it has infrared emission features corresponding to that seen at 3.29, 6.2, 7.7, 8.6, and 11.3 $\mu$m in the interstellar medium. These properties make it an attractive alternative to the PAH hypothesis as an explanation of the infrared emission features. A paper summarizing the properties of QCC was presented at the thirty-first meeting of Committee on Space Research (COSPAR) in Birmingham, England, in June.

Wynn-Williams wrote a review ''Interstellar Dust,'' for volume 3 of the series *Advanced Mineralogy*.

## 7. STELLAR ASTRONOMY

With B. Wilking (Missouri St. Louis), M. Meyer (Max-Planck-Institut für Astronomie, Heidelberg) and Carpenter, Greene has been obtaining moderate-resolution (R $\sim$ 500) near-IR spectra of low-mass stars and brown dwarf candidates in the $\rho$ Oph embedded cluster with the IRTF and UH 2.2 m telescope on Mauna Kea. These observations should determine whether the cluster mass function turns over, is flat, or increases toward the low-mass end. At the close distance (160 pc) and young age ($t<10^6$ yr) of Ophiuchus, even substellar objects are expected to be relatively bright and within the range of near-IR spectroscopic observations ($K\sim14$). Thus far only one low-mass cluster candidate has been found to be a background giant, and a number of candidates have spectra that indicate that they are very low mass dwarfs, at or perhaps below the minimum hydrogen-burning mass.

Simon, with collaborators S. L. Hawley (Michigan State) and G. H. Fisher (California, Berkeley), published an analysis of two long-lived flares of the dMe star AD Leo from March 1993 that were detected at high energies with the *Extreme-Ultraviolet Explorer* (*EUVE*) spacecraft and also from the ground at optical wavelengths. These events mark the first time that the Neupert Effect, considered to be the characteristic signature of particle beams in solar flares, has been detected in a stellar flare. Analysis of the EUV coronal spectra of AD Leo, taken in quiescence and also over the duration of both flare events, continues in collaboration with graduate student S. L. Cully (California, Berkeley). A second AD Leo observing campaign, organized around simultaneous observations with *EUVE* and the *ASCA* X-ray observatory, was completed successfully in May 1996. Two powerful flares were detected by both spacecraft. The flares were also detected and monitored in white light from the ground. Analysis of the *EUVE*/DS and X-ray light curves has begun. The results will be used to test and refine the flare model that was devised to interpret the March 1993 flares.

Continuing their investigation of the coronal activity of intermediate-mass main-sequence stars, Simon, S. A. Drake (NASA/Goddard and University Space Research Association), and undergraduate student and summer research assistant P. D. Kim (MIT) published their survey of *ROSAT* X-ray observations of A-type stars. Simon and Drake, in collaboration with K. P. Singh (Tata Institute of Fundamental Research, India) and N. E. White (NASA/Goddard), published an analysis of the first ionization potential (FIP) effect from *ROSAT* Position Sensitive Proportional Counter (PSPC) spectra of a select group of chromospherically active late-type stars. Models with a range of elemental abundances, from solar to substantially subsolar, were shown to produce acceptable fits to PSPC spectra, emphasizing the need for higher spectral resolution in studies of the FIP effect.

With collaborators C. F. Prosser and J. R. Stauffer (Harvard-Smithsonian Center for Astrophysics), and S. Randich and J. H. M. M. Schmitt (Max-Planck-Institut für Extraterrestrische Physik, Germany), Simon completed work on a *ROSAT* survey of coronal X-ray emission from late-type stars in the Alpha Persei open cluster. Sixty sources having optical counterparts that could not be identified with known members of the cluster were found in three deep PSPC pointings. Of these, nearly half (30 stars) are considered to be likely new members of the cluster, based on supporting optical data acquired as part of this study. The results will appear in future issues of *The Astronomical Journal.*

Simon and W. Landsman (NASA/Goddard and Hughes STX) completed a detailed investigation of the ultraviolet spectral energy distributions of A-type stars, based on a study of TD-1 photometry and *IUE* spectroscopy. They find no evidence to support earlier claims made by other investigators that normal main-sequence A stars divide into two different effective-temperature sequences, (1) a high-temperature branch composed of slowly rotating convective stars, and (2) a low-temperature branch consisting of rapidly rotating radiative stars. They do find, however, a large scatter in the ultraviolet colors of the chemically normal A-type stars, a large part of which they show originates from a dispersion in stellar luminosity and metallicity.

Simon (PI) and the UH 2.2 m telescope took part in the Multi-Site Continuous Spectroscopy (MUSICOS) 1992 observing campaign. A number of papers stemming from the campaign were submitted and accepted for publication during the past year. Among the notable results was the first detection of rotationally modulated variability in the photospheric spectral line profiles of the PMS Ae star, AB Aurigae. This discovery suggests that the previously observed azimuthal structures observed in the chromosphere of this star may be rooted in magnetic features in the stellar photosphere. Direct tests of this idea were planned for the next MUSICOS campaign, scheduled for November 1996.

The presence of stars apparently of high luminosity far above the Galactic plane, and hence distant from conventional sites of star formation, has long posed an interesting puzzle. Some high-latitude F supergiants are now believed to be old, post-AGB stars, and some OB stars are probably high-velocity ejecta from distant associations, while the faint blue stars at high latitudes are now thought to be old, subluminous halo objects. But at lower luminosities, the question becomes whether such stars could form at high latitudes, particularly in the high-latitude CO clouds that are now known to exist. The issue therefore is whether recognizable PMS stars can be found therein. In 1992, M. Kun reported the discovery of about 100 stars having H$\alpha$ in emission—and hence possibly T Tauri stars—associated with high-latitude CO. Since 1993 Herbig has been observing the brighter Kun stars with the f/10 and f/31 faint object spectrographs at the UH 2.2 m telescope. It became obvious that few of these stars really had strong H$\alpha$ emission; what had been detected on objective-prism spectrograms were actually the TiO band heads of M-type spectra. No recognizable T Tauris have been found among the 20-odd Kun stars and *IRAS* sources examined. This same result has also been obtained by two similar but quite independent investigations of the same issue that have now appeared, by Martin and Kun (1996) and by Magnani, Blitz, and Speck (1996). Since the Mauna Kea material is of lower resolution than those other studies, and contributes little additional new information, there are no plans to publish the details, but the conclusion stands: a small number of what appear to be PMS stars are known to exist far from recognizable molecular clouds, and at moderately high-latitude in the Gould Belt, but no convincing cases are known to exist in association with the high-latitude CO.

## 8. SOLAR SYSTEM STUDIES

### 8.1 Comets

T. Y. Brooke (Jet Propulsion Laboratory), Tokunaga, and co-investigators H. Weaver (Johns Hopkins), J. Crovisier and D. Bockelée-Morvan (Observatoire de Paris-Meudon), and D. Crisp (JPL), reported the detection of $C_2H_2$ (acetylene) in comet Hyakutake. The abundance ratio of acetylene to water was found to be 0.3–0.9%. This abundance ratio is consistent with some models of the solid phase abundances in molecular clouds, but it is not consistent with a solar abundance mixture of gases in thermal equilibrium. It therefore suggests that the acetylene in comet Hyakutake could have been incorporated directly into the nucleus from the interstellar grains.

Jewitt, graduate student M. Senay, and H. Matthews (Joint Astronomy Centre) detected prodigious outgassing of CO from comet Hale-Bopp at 6 AU using the JCMT. This observation showed clearly that outgassing from this comet was initially controlled by CO rather than by the more familiar water sublimation. Monitoring of the CO production curve continues.

Meech continued a long-term program of comet observations. The objectives of this study are (1) to search for physical differences in the behavior of the dynamically new comets (those entering the solar system for the first time from the Oort cloud) and the periodic comets, and (2) to interpret these differences, if any, in terms of the physical, chemical nature and the evolutionary histories of the two groups of comets.

The differences in activity levels seen between the comet classes are almost certainly due to evolutionary or aging effects. An important result of the work is that the brightness limits for the Oort cloud comets suggest that the nuclei are relatively small, and that they are not the giant nuclei that some have suggested. Work is continuing on placing these distant comet observations into the context of the formation of the early solar system material.

Observations of the possible extinct comet nucleus 3200 Phaethon were made during January 1995 at its minimum geocentric distance to place stringent limits on any possible activity. The rotational period has been measured. Simultaneous near-IR and optical observations were obtained during February in collaboration with M. A'Hearn and C. Lisse (Maryland) to both search for color variations with phase and to combine the light curve with previous light curves to solve for the rotational pole.

An observing campaign to follow 2060 Chiron through its 1996 perihelion was successful. Meech used both the UH 2.2 m and the KPNO 0.9 m telescopes. The goal was to get nearly nightly observations of Chiron to look both at its long- and short-term brightness variations and coma extent, to be able to coordinate this with deep Faint Object Camera Observations made with the *Hubble Space Telescope* during spring 1996.

Graduate student T. Farnham (in collaboration with Meech) completed his thesis work to model the development and dynamics of cometary dust tails. This work is an analysis of the dust tail structure and morphology being used to infer properties of the dust and the mechanisms of dust production on active comets. The models expand upon the dust tail model originally developed by M. Finson and R. Probstein nearly 30 years ago. Farnham's modifications, in addition to orbital mechanics improvements and the use of multiple images spaced in time, include the use of realistic scattering functions of the dust. The goal is to be able for the first time to make inferences about comet dust grain structure, something previously possible only with in-situ spacecraft observations.

Meech and Hainaut continued an extensive program of distant comet recovery using the new UH 8K CCD mosaic camera (see § 4.4). Their goal is to recover periodic comets much earlier than is typical (usually after they are active, near 23 AU) to better understand the onset of activity in comets. This should address a major observational selection effect in the study of comet activity as a function of distance from the Sun. They have now had four successful runs using the UH 2.2 m telescope and CFHT. They have recovery data for 13 comets, and have recovered 5 of them (although data analysis continues). Hainaut has been developing neural networking algorithms for automated searches for faint moving objects in these large images.

Together with Bockelée-Morvan, D. Gautier (Observatoire de Paris-Meudon), Matthews, and several other collaborators, Owen analyzed the abundance of HDO in comet Hyakutake. The preliminary results indicate that this comet, like Halley, has a value of D/H that is about twice the value in sea water. Unless other comets are found to be very different from these two, it appears that comets were not the only source of the water in the Earth's oceans. Water adsorbed from the solar nebula by grains that accreted to form the inner planets may produce the correct mixture of isotopes.

### 8.2 Kuiper Belt

Jewitt and J. Luu (Harvard) have continued their long-term deep optical survey of the Kuiper Belt. Major results include a determination of the size distribution (an inverse cube power law) and absolute abundance (70,000 objects larger than 100 km diameter in the distance range 30 to 50 AU) of Kuiper Belt objects (KBOs). The total mass of KBOs is of order 0.1 Earth masses.

Jewitt, Luu, and graduate student J. Chen have also measured the surface density of Centaurs (objects moving in short-lived orbits in the vicinity of the gas giant planets). This density is 50 times larger than predicted based on the expected lifetimes of the Centaurs, presenting a puzzle for the origin and survival of the Centaurs. The latter are believed to be escapees from the Kuiper Belt and some will, ultimately, reach the inner solar system and be observed as comets. The large number of Centaurs suggests that the total mass flux through this region in the age of the solar system exceeds 1 Earth mass.

Broadband photometry with the Keck telescope has been used to measure the reflectance properties of the KBOs. The main result is that the KBOs exhibit a wide range of optical colors, from nearly neutral to very red. The same color diversity is evident among the Centaurs, with Chiron being spectrally neutral and Pholus being one of the reddest known objects in the solar system. They interpret the color diversity as a possible result of a competition between reddening due to cosmic ray bombardment and resurfacing due to collisions.

### 8.3 Planets and Rings

Baron in collaboration with Owen, J. Connerney, and T. Satoh (both NASA/Goddard) continued his studies of the magnetosphere and upper atmosphere of Jupiter. He uses the high spatial resolution imaging capability of the IRTF to record detailed images of the $H_3^+$ aurora. These images act as a probe of the magnetosphere, since high-energy particles following magnetic lines-of-force precipitate in the ionosphere to produce an image much the same as a photographic plate produces an image. Each point of the aurora can be traced or mapped along a line-of-force to some distant point in the magnetosphere. Thus the auroral illumination acts as a probe or indicator of magnetospheric activity and processes. The original work was published in *Nature*.

A major discovery is the imaging of the instantaneous Io flux tube foot. The foot, a small spot of illumination (not spatially resolved with the IRTF) moving with respect to the surface of Jupiter and in phase with the rotation of Io about Jupiter, is now used to study the interaction of Io with the magnetosphere. This has already resolved a long-standing ($\sim$20 yr) question as to the correct model describing the electrical circuit produced as the conductive body of Io cuts through magnetic lines of force. This monopole electrical generator produces a current of $\sim 10^6$ amperes.

The first study to demonstrate a high degree of correlation of auroral intensity with solar wind ram pressure was published in *Icarus*. This work used solar wind data monitored by the *Ulysses* spacecraft as it was on its way to polar orbit of the Sun.

Owen pointed out at a COSPAR Mars symposium (July 1996) that the determinations of D/H in water from minerals in SNC meteorites never reach a minimum value below 2 times terrestrial, the cometary number. He interpreted this to mean that the Martian surficial water reservoir has been contributed primarily by comets, with little mixing between the surface and the interior. The latter conclusion is in agreement with results from other investigations.

With collaborators D. Cruikshank (NASA/Ames), T. Geballe (JAC), and C. de Bergh (Observatoire de Paris), Owen recorded near-IR spectra of the icy inner satellites of Saturn with CGS4 at UKIRT. These spectra have both higher resolution and higher signal-to-noise than any previously published observations. They show only absorptions from water ice, unlike some previous work that suggested the presence of additional absorbers on these objects. However, the ice absorptions on Mimas and Enceladus reveal a structure that is unlike the spectra of the other satellites and also different from the low-temperature spectra of ice recorded in the laboratory. The cause of this apparent anomaly is under investigation.

The same group of collaborators studied the spectrum of Pluto over the full rotation of the planet. Contrary to expectation, no radical changes in the absorptions of the volatiles frozen on the planet's surface were observed to occur as the light curve varied from maximum to minimum. The dark regions of Pluto evidently do not correspond to some kind of ''exposed bedrock,'' but may instead imply an uneven distribution of dark, overlying material of the type seen in the wind streaks on Triton.

Owen and A. Bar-Nun (Tel Aviv) continued their investigation of the role played by comets in the delivery of volatiles to the inner planets and to the forming cores of the outer planets. Results from the Galileo probe appear to support this model, with the confirmation of previous determinations of a 3 times solar abundance of carbon and the discovery of an over-solar abundance of sulfur. Owen is continuing to investigate the probe results as a member of the mass spectrometer team and as an interdisciplinary scientist.

C. Roddier continued analysis of data taken at the CFHT with the adaptive optics system in August 1995, as Earth was crossing the Saturn ring plane. Bright satellites such as Dione and Tethys were used as natural guide stars to sense the wave-front. Several hundred exposures of 15, 30, and 60 s were obtained each night in the $J$, $H$, and $K$ infrared bands. Average resolution is 0.15″ in the $H$ band. Remarkably, all the known close satellites of Saturn have been detected and identified except Pan. These include: Saturn X (Janus), XI (Epimetheus), XII (Helene), XIII (Telesto), XIV (Calypso), XV (Atlas), XVI (Prometheus), and XVII (Pandora). Up to ten additional faint objects were found to orbit Saturn, all of them at the distance of the F ring. Two of them have their estimated orbit consistent with *HST* objects S5 and S7. *HST* object S6 was too close to Saturn to be seen during these observations. During the same observing run, a few frames of Neptune, using Triton as a guide source, were also recorded. The images made in the *K* band show high contrast cloud structures on Neptune. On these images they were able to make the first ground-based observation of Proteus. Its position was found to be in perfect agreement with that expected from *Voyager* data. These observations were made in cooperation with A. Brahic (Observatoire de Paris).

## 9. SOLAR PHYSICS

Graduate student K. Blais continued a multiwavelength study of 31 solar flares using data from the Mees Imaging Spectrograph, Mees K-Line CCD, Compton Burst and Transient Source Experiment (BATSE), and *Geostationary Operational Environmental Satellite* (*GOES*) soft X-ray instruments. The purpose of the research is to determine whether optical proxies for high-energy emission in solar flares exist, and if so whether they are similar to the suggested proxies that have been observed in stellar flares. Preliminary results show that Ca II K is typically a good temporal proxy for soft X-rays, on timescales longer than 10 minutes. A linear relationship was found to exist between the change in the Ca II K line flux during a hard X-ray burst and the log of the maximum hard X-ray counts. Comparison of the Ca II K and H$\alpha$ light curves reveals a high degree of correspondence in their time evolutions.

Canfield worked with J. Li and Metcalf on a study of the spatial relationship between hard X-ray emission during flares and photospheric current systems. The study confirms that hard X-ray emission normally occurs at the edges of photospheric currents.

Canfield, with Pevtsov and McClymont, studied transequatorial active region interconnections. Their investigation shows that active regions whose magnetic fields are twisted in the same sense (left- or right-handed) tend to connect with one another, while those with the opposite sense do not. They explain the phenomenon in terms of the closure of coronal current systems.

The solar corona exhales almost continuously—the solar wind—and occasionally hiccups. The hiccups—coronal mass ejections, or CMEs—are of interest from the point of view of the magnetohydrodynamic (MHD) development of the magnetic corona. Hudson has studied the signatures of CMEs in soft X-ray images obtained by *Yohkoh*, with special emphasis on the relationship of CMEs to solar flares. On the basis of these observations, he now believes that there is a much closer relationship than heretofore suspected, and that the instability responsible for the mass ejection almost universally also heats coronal plasma to million-degree (X-ray) temperatures.

Graduate student L. Jiao continued work on the reconstruction of the three-dimensional coronal magnetic field from photospheric boundary data by solving the nonlinear force-free MHD equations and comparing the coronal structure deduced in this way to soft X-ray images from the *Yohkoh* Soft X-ray Telescope (SXT). He automated the production of ambiguity-resolved vector magnetograms from raw Stokes polarimetry data and developed software tools for merging magnetograms to form boundary data suitable for coronal field computation, and for comparing the computed fields to SXT images. Jiao also applied the pixon image reconstruction method (see below) to enhance the SXT images.

Jiao, with McClymont and Z. Mikic (Science Applications International Corporation [SAIC]), applied these methods to active region NOAA AR 7222/7220. Computed field lines show excellent agreement with soft X-ray features. This active region will be studied further with a view to understanding the effects of spatial resolution and data errors. They also began work on computing the coronal field of active region AR 6919 using measured currents as boundary conditions only over the preceding polarity.

Graduate student R. Kupke continued development of a wave-front sensor for extended objects (with the aim of application to solar granulation). The wave-front sensing technique is an extension of the curvature sensing technique used on point sources. It compares the Fourier power and phase of oppositely defocused images to obtain the wave-front information. Kupke has nearly completed the computer simulations of this technique, and assisted by D. Mickey, she will next perform laboratory tests. A paper on the technique is in preparation.

Kupke has also equipped the Mees Imaging Spectrograph for a study of waves in magnetic flux tubes. She will use the Imaging Spectrograph with polarization-analyzing optics to detect oscillatory motions on magnetic field lines in the photosphere. The instrumentation effort for this project, including an upgrade to install a slit-jaw camera and the temporary addition of polarization optics, is complete and tested.

McClymont, working with I. Craig (Waikato, New Zealand), concluded a study of the effects on magnetic reconnection of gas pressure and nonlinear amplitudes. In the absence of gas pressure, magnetic reconnection at an X-type neutral point is ''fast'' even for large-amplitude perturbations. However, the presence of any appreciable gas pressure quickly quenches the reconnection, as the pressure of gas swept into the current sheet halts the collapse. The trapped gas is subsequently ejected at the local sound speed, but it is not certain whether this leads to eventual fast reconnection.

McClymont and Craig also studied the dissipation of shear waves at magnetic neutral points. These waves appear attractive for the purpose of achieving fast reconnection since they do not compress the plasma—but they do not compress the magnetic field either, which turns out to be essential for fast reconnection. They show that the apparent fast decay of shear waves found by previous authors is a result of energy propagating out of the volume, not of ohmic dissipation.

Using numerical solution of the nonlinear force-free MHD equations, McClymont, with Jiao and Mikic, prepared a paper reviewing the state of the art in the reconstruction of the three-dimensional coronal magnetic field from photospheric boundary data. These techniques were applied to several active regions for comparison with soft X-ray coronal images (see above). McClymont also began a collaboration with Mikic and J. Lee (Maryland) to compare microwave images of the corona with the reconstructed coronal magnetic field.

Metcalf continued the development of a new technique for synthesizing hard X-ray images from *Yohkoh* Hard X-ray Telescope data. The technique uses pixons to minimize the number of degrees of freedom used in the reconstruction. Comparisons with maximum entropy reconstructions indicate that the new algorithm is superior because it gives better photometry and noise suppression. With D. Alexander (Lockheed Martin ATC), Metcalf applied the method to the 13 January 1992 flare.

Metcalf also worked with G. Fisher and D. Longcope (California, Berkeley) on a statistical study of hundreds of Mees vector magnetograms and *Yohkoh* SXT images to investigate the mechanisms of active region coronal heating.

Mickey, with B. LaBonte and K. D. Leka (High Altitude Observatory), published a description of the Imaging Vector Magnetograph (IVM) currently in operation at Mees Solar Observatory. Included are details of its hardware design, capabilities and operating characteristics, plus a discussion of its sensitivity and sources of error. In the evaluation of sensitivity, it became clear that image distortions due to atmospheric seeing are the principal source of errors in polarization measurements. Mickey has developed a technique for using the second, broadband, camera in the IVM to characterize the seeing at each instant. A simple model based on the spatial structure in the broadband image is constructed, then used to correct for distortion and blurring in the narrowband images used in the polarization measurement. The technique appears to reduce the amplitude of spurious polarization by up to a factor of 10 in high-contrast features.

Mickey and J.-P. Wülser used the IVM to measure the vector magnetic field in polar regions of the Sun, in conjunction with a *Solar and Heliospheric Observatory* (*SOHO*) campaign to study polar plumes. Magnetograms were obtained every few minutes over a period of several hours during each of three campaigns. In reducing these data, the seeing-compensation technique was used successfully to improve the instrument sensitivity. Preliminary results indicate that the photospheric field under polar plumes is nearly radial: more detailed analysis including temporal evolution is underway.

Mickey and Metcalf continued work on IVM observations of linear polarization in H$\alpha$ obtained in several flares in 1992. Such polarization could occur as a result of a low-energy proton beam impacting the chromosphere during a flare. The observations show areas—coincident with the flare kernels—that appear to have several percent linear polarization at H$\alpha$ line center, at the time of the impulsive phase of the flare. The IVM is well suited for these observations in the sense that it observes an entire active region at once and can be run at a few-second cadence. However, evaluation of the noise levels in these data is made difficult by the high contrast in H$\alpha$ images compared to photospheric images, especially at the flare kernels. At the time of the observations, the broadband camera in the IVM was not in operation, so there is no way of measuring the spurious seeing-induced polarization. Definitive results may have to wait for more flare observations with adequate simultaneous seeing measurements.

Pevtsov, with Canfield and G. Glatzmaier (Los Alamos National Laboratory), studied the signature of convection in the helicity of photospheric magnetic fields. The Coriolis force is expected to induce a strong hemispheric antisymmetry in the helicity of photospheric magnetic fields. Using Haleakala Stokes Polarimeter vector magnetograms and *Yohkoh* soft X-ray images, they show that in fact the asymmetry is rather weak. They also find that some areas on the Sun have the same sign of helicity for several successive solar rotations even when the sign disagrees with the hemispheric rule. They speculate that this may be a signature of a long-lived pattern of solar convection, and they propose a simple cartoon model of the convective flows.

Pevtsov, Canfield, and H. Zirin (California Institute of Technology) studied the role of magnetic reconnection and helicity in the *Yohkoh* flare of 8 May 1992 in AR 7154. This eruptive flare shows a dramatic twisted loop that formed just before the eruption and disappeared after it. Analyzing the helicity of the loop, they interpret the eruption in terms of the MHD kink instability.

Pevtsov, with Canfield, McClymont, and L. Acton (Montana State), studied the correlation between photospheric and coronal measures of magnetic helicity. Using photospheric vector magnetograms and coronal X-ray images, they compared the magnetic helicity density in the photosphere ($\alpha_p$) and corona ($\alpha_c$) of 140 active regions. In active regions whose photospheric helicity is predominantly of one sign, the average values of $\alpha_c$ and $\alpha_p$ are well correlated. They are not well correlated in active regions in which both signs of $\alpha$ are well represented. They conclude that the shear of coronal loops reflects the presence of coronal electric currents that are of subphotospheric origin.

A Web site (http://www.solar.ifa.hawaii.edu) was developed by the Solar Group for use in planning observations, accessing observing records and quick-look data, and evaluating instrument performance.

A number of Solar Group members left IfA for Montana State University, Solar Physics Research Corporation, and Lockheed Martin ATC during the report period.

## 10. THEORETICAL STUDIES

### 10.1 Cosmological Theory

Kofman studied reheating after inflation. It is assumed that the universe initially expands quasi-exponentially in a vacuumlike state with a vanishing entropy and particle number density. During the inflation stage, all energy was concentrated in a classical slow-moving inflaton field. Soon after the end of inflation, when the observable universe was the size of a dime, the inflaton field began to oscillate near the minimum of its effective potential. An almost homogeneous inflaton field coherently oscillated with a very large amplitude of the order of the Planck mass. The interaction of the inflaton field with other elementary particles led to creation of many ultrarelativistic particles from the classical inflaton oscillations. Gradually, the inflaton field decayed and transferred all its energy nonadiabatically to the created particles.

They interacted with each other and came to a state of thermal equilibrium at some temperature $T_r$, which was called the reheating temperature. Recently, Kofman and collaborators found new effects in particle creation that arise beyond perturbation theory. These effects significantly alter the reheating scenarios. Bosons produced at that stage are far away from thermal equilibrium and have enormously large occupation numbers. This leads to cosmological phase transitions of a new type, which may result in a copious production of topological defects and in a secondary stage of inflation after reheating.

Kofman and collaborators have investigated the statistics of illumination from two- and three-dimensional gravitational microlensing. The propagation of light from distant sources through a distribution of clumpy matter, acting as point mass lenses, produces multiple images that contribute to the total brightness of the observed macroimages.

In the two-dimensional case, the probability distribution of macroimage magnification, $P(A)$, is derived at high magnification ($A-1 \gg \tau^2$) for a low optical depth ($\tau \ll 1$) lens distribution by modeling the illumination pattern as a superposition of the patterns due to individual ''point mass plus weak shear'' lenses. A point mass lens perturbed by weak shear $S$ produces an astroid-shaped caustic. It is shown that the magnification cross-section $\sigma(A|S)$ of the point mass plus weak shear lens obeys a simple scaling property and provides a useful analytic approximation for the cross-section. By convolving this cross-section with the probability distribution of the shear due to the neighboring point masses, a caustic-induced feature in $P(A)$, which also exhibits a simple scaling property, is also obtained. This feature results in a 20% enhancement in $P(A)$ at $A \approx 2/\tau$.

In the low magnification ($A-1 \ll 1$) limit, the macroimage consists of a single bright primary image and a large number of faint secondary images formed close to each of the point masses. The magnifications of the primary and the secondary images can be strongly correlated. Taking into account the correlations, $P(A)$ is derived for low magnification and it is found that a peak of amplitude $\sim 1/\tau^2$ at $A-1 \sim \tau^2$. The low magnification distribution matches smoothly the high magnification distribution in the overlapping regimes $A \ll 1/\tau$ and $A-1 \gg \tau^2$.

Finally, after a discussion of the correct normalization for $P(A)$, combining the high and low magnification results and a practical semi-analytic expression for the macroimage magnification distribution, $P(A)$ is obtained. This semianalytic distribution is in qualitative agreement with the results of previous numerical simulations, but the latter show stronger caustic-induced features at moderate $A$ for $\tau$ as small as 0.1. This discrepancy is resolved by reexamining the criterion for low optical depth. A simple argument shows that the fraction of caustics of individual lenses that merge with those of their neighbors is approximately $1-\exp(-8\tau)$. For $\tau = 0.1$, the fraction is surprisingly high: $\approx 55\%$. For the purpose of computing $P(A)$ in this manner, low optical depth corresponds to $\tau \ll 1/8$.

A similar program was realized for the three-dimensional case.

Kofman and collaborators described the physics behind the formation of a network of filaments in hierarchical clustering models of structure formation. At a given snapshot in time, as the density threshold drops from high values, the regions that first emerge are clusters, then arms stretching from the clusters, which ultimately join to form the predominantly filamentary network: the first pattern to percolate is filamentary, and it is that that the eye picks out. The same sequence follows from nonlinear dynamics, even from the simplified Zeldovich approximation, with the filaments arising from ''correlation bridges'' between neighboring cluster-scale peak-patches that exist in the initial conditions—provided the clusters are not too far apart ($\lesssim 40\ h^{-1}$ Mpc for Abell clusters) and their shear tensors are not too misaligned. Walls are identified with the expanding boundaries of rare minima and their connecting ''correlation trenches''; voids are identified with the interiors.

It is shown explicitly that the final state filaments exist in a fattened form in the initial conditions. Choosing from a list rank-ordered by mass, they have constructed mean linear fields subject to the constraints of having the measured linear density, anisotropic shear tensor, and velocity of the rarest peak-patches and/or void-patches. With only a handful of peaks they accurately have reconstructed the filamentary structure of the full Zeldovich-mapped fields. They have found that adding rare voids to the constraint mix is not as important as adding less rare peaks for sharpening the filamentary design, but also find that rare voids help define where less rare peaks must be.

## 10.2 Extragalactic Theory

Barnes gave nine lectures on Dynamics of Galaxy Interactions at the 1996 Saas-Fee Advanced Course, ''Galaxies: Interactions and Induced Star Formation.'' These lectures were attended by over one hundred advanced students—the largest Saas-Fee course to date. Preparing and writing up these lectures was the major focus of work over the past year.

Barnes conducted tests to study the reliability of N-body simulation of collisionless systems. These tests were aimed at explicitly demonstrating that trajectories converge to the continuum limit as the number of particles $N$ is increased. Test particles were included in a head-on collision and merger of two Hernquist models, simulated with a total of $N = 4096, 8192, \ldots\ 262144$ massive particles. The expected convergence was seen as $N$ increased, but even for the largest values of $N$ the trajectories of particles more tightly bound than the median showed considerable variation due to repeated scatterings off the central cusps of the models employed.

Barnes designed and conducted a new suite of encounters and mergers between equal-mass bulge/disk/halo galaxies. These experiments doubled the coverage of parameter space for parabolic encounters available from previous studies. They complement the ensemble of three-to-one encounters performed last year. A key result, presented at Saas-Fee, is that the merger remnants typically have fairly small kinematic misalignments; for most of the ensemble, the angle between the spin and minor axes is $\lesssim 15°$.

Barnes developed a new scheme for classifying orbits in N-body systems. Whereas previous schemes typically combined a number of ad hoc criteria, the new scheme works entirely from a record of the crossings of coordinate planes as the orbit is integrated. In addition to recognizing the major tube orbits in triaxial systems, the new scheme can reliably discriminate among the various families of ''boxlet'' orbits that occur in systems with deep central potential wells. The scheme is easily generalized to three dimensions, and when applied to simulated merger remnants, indicates several new kinds of orbits, including ''y-fish,'' which are fish-shaped when viewed along the intermediate axis, and ''hyper-pretzels,'' which are true three-dimensional resonances.

Barnes and Hibbard, using velocity data previously taken by Hibbard and others, developed a self-consistent N-body model for ''The Mice'' (NGC 4676). The appearance and velocity field of this system are well reproduced by the product of a parabolic encounter between two equal-mass bulge/disk/halo galaxies.

Barnes was the chief organizer for the 1996 Aspen Summer Astrophysics Workshop, ''Galaxy Interactions at Low and High Redshift.'' This two-week workshop attracted over fifty participants from the United States and abroad. One of the most exciting topics discussed at this workshop was the formation of star clusters in merging starburst galaxies. Barnes and Sanders are developing a combined observational-numerical approach to test the hypothesis that such clusters result when pre-existing molecular clouds are imploded by overpressure of hot gas produced in a violent starburst.

Barnes presented a review of work on the nature and dynamics of compact groups at the Second Stromlo Symposium, ''The Nature of Elliptical Galaxies.'' While existing surveys of compact groups probably contain a wide variety of systems, there is good evidence that a substantial fraction are truly compact and dynamically evolving. Such evidence includes the detection of complex neutral hydrogen velocity fields, extended halos of hot (X-ray) gas, diffuse optical light, and shell-like features associated with compact-group galaxies.

## 11. LIBRARY

During the report period, LIBCAT, the online public access catalog (OPAC) for the IfA library, was added to the library's electronic menu, which already included databases of preprints, journal articles, and Internet/Web resources. LIBCAT provides access to the library's book and journal collections. Robertson, the IfA librarian, oversaw the record conversion project that rendered the information from the catalog cards into machine readable records, the database design, and the loading of the records into the database. LIBCAT and other menu options are available at researchers' desktops via the IfA's local area network.

## PUBLICATIONS

The following articles and books were published during calendar year 1995:


Ayres, T. R., *et al.* (including T. Simon). 1995. The RIASS Coronathon: Joint X-Ray and Ultraviolet Observations of Normal F–K Stars. ApJS, 96, 223–59.

Briel, U. G., and J. P. Henry. 1995. Search for X-ray Filaments between Galaxy Clusters. A&A, 302, L9–L12.

Clowes, R. G., L. E. Campusano, S. K. Leggett, & A. Savage. 1995. Discovery and Environment of Five Ultraluminous IRAS Galaxies. MNRAS, 275, 819–27.

Connerney, J. E. P., T. Satoh, R. Baron, & T. Owen. 1995. The Infrared Signature of the Io Interaction Is Detected in Jupiter's Atmosphere. EOS, 76, No. 8, 73, 81.

Cowie, L. L. 1995. Quasar Absorption-Line Studies at High Redshift: Measurements of the Microwave Background and Molecular Hydrogen. In The Physics of the Interstellar Medium and the Intergalactic Medium, ed. A. Ferrara, *et al.* ASP Conf. Ser. 80 San Francisco: ASP, pp. 463–67.

Cowie, L. L., E. M. Hu, & A. Songaila. 1995. Detection of Massive Forming Galaxies at Redshifts $z>1$. Nature, 377, 603–605.

Cowie, L. L., E. M. Hu, & A. Songaila. 1995. Faintest Galaxy Morphologies from *HST* WFPC2 Imaging of the Hawaii Survey Fields. AJ, 110, 1576–83.

Cowie, L. L., & A. Songaila. 1995. Astrophysical Limits on the Evolution of Dimensionless Physical Constants over Cosmological Time. ApJ, 453, 596–98.

Cowie, L. L., A. Songaila, T.-S. Kim, & E. M. Hu. 1995. The Metallicity and Internal Structure of the Lyman-Alpha Forest Clouds. AJ, 109, 1522–30.

de La Beaujardiere, J.-F., R. C. Canfield, H. S. Hudson, J.-P. Wülser, L. Acton, T. Kosugi, & S. Masuda. 1995. The 1991 October 24 Flare: A Challenge for Standard Models. ApJ, 440, 386–93.

Deliyannis, C. P., A. M. Boesgaard, & J. R. King. 1995. Evidence of Higher Primordial Lithium from Keck Observatories of M92. ApJL, 452, L13–L16.

Doyon, R., D. Nadeau, R. D. Joseph, J. E. Goldader, D. B. Sanders, & N. Rowlands. 1995. Near-Infrared Imaging and Spectroscopy of the Bright *IRAS* Galaxy VV114. ApJ, 450, 111–21.

Egami, E. 1995. Deep Survey of Fields around $z>4$ Quasars. In Wide-Field Spectroscopy and the Distant Universe, ed. S. Maddox. Singapore: World Scientific, pp. 380–87.

Fludra, A., J. G. Doyle, T. Metcalf, J. R. Lemen, K. J. H. Phillips, J. L. Culhane, & T. Kosugi. 1995. Evolution of Two Small Solar Flares. A&A, 303, 914–26.

Foing, B. H., *et al.* (including T. Simon). 1995. Surface Structures and White-Light Flares on HR 1099: Review of MUSICOS 1989 Results. In Proceedings of the Fourth MUSICOS Workshop: Multi-Site Continuous Spectroscopy, held at Beijing, China, June 19–24, 1994, ed. L. Huang, *et al.* Beijing: Beijing Astronomical Observatory, pp. 131–41.

Friedson, A. J., *et al.* (including J. L. Hora). 1995. Thermal Infrared Lightcurves of the Impact of Comet Shoemaker-Levy 9 Fragment R. Geophys. Res. Lett., 22, 1569–72.

Génova, R., S. Bowyer, S. Vannes, R. Lieu, J. P. Henry, & I. Gioia. 1995. An Optical and Far UV Study of the Field of the Source EUVE J1027+323. AJ, 110, 788–93.

Gioia, I. M., J. P. Henry, G .A. Luppino, D. I. Clowe, *et al.* 1995. Discovery of a Large Gravitational Arc in the X-ray Cluster A2280. A&A, 297, L75–L78.

Goldader, J. D., R. D. Joseph, R. Doyon, & D. B. Sanders. 1995. Spectroscopy of Luminous Infrared Galaxies at 2 Microns. I. The Ultraluminous Galaxies ($L_{IR} \gtrsim 10^{12} L_{\odot}$). ApJ, 444, 97–112.

Gomez, D. O., E. E. DeLuca, & A. N. McClymont. 1995. Nonlinear Energy Transfer in Solar Magnetic Loops. ApJ, 448, 954–62.

Greene, T. P., & M. R. Meyer. 1995. An Infrared Spectroscopic Survey of the $\rho$ Ophiuchi Young Stellar Cluster: Masses and Ages from the H-R Diagram. ApJ, 450, 233–44.

Hall, D. N. B. 1995. University of Hawaii, Institute for Astronomy. BAAS, 27, 160–78.

Hainaut, O., R. M. West, B. G. Marsden, A. Smette, & K. J. Meech. 1995. Post-Perihelion Observations of Comet P/Halley. A&A, 293, 941–47.

Hammer, F., I. Gioia, O. LeFevre, & G. Luppino. 1995. Giant Luminous Arcs. In Relativistic Astrophysics and Cosmology, ed. H. Böhringer, *et al.* New York: New York Academy of Sciences, pp. 568–72.

Hanner, M. S., T. Y. Brooke, & A. T. Tokunaga. 1995. 10 Micron Spectroscopy of Young Stars in the $\rho$ Ophiuchi Cloud. ApJ, 438, 250–58.

Hawley, S. L., *et al.* (including T. Simon). 1995. Simultaneous *Extreme-Ultraviolet Explorer* and Optical Observations of AD Leonis: Evidence for Large Coronal Loops and the Neupert Effect in Stellar Flares. ApJ, 453, 464–79.

Henry, J. P., I. M. Gioia, *et al.* 1995. Groups of Galaxies in the *ROSAT* North Ecliptic Pole Survey. ApJ, 449, 422–30.

Herbig, G. H. 1995. IC 349: Barnard's Merope Nebula. AJ, 111, 1241–51.

Herbig, G. H. 1995. The Diffuse Interstellar Bands. ARA&A, 33, 19–73.

Hibbard, J. E., & J. C. Mihos. 1995. Dynamical Modeling of NGC 7252 and the Return of Tidal Material. AJ, 110, 140–55.

Hodapp, K.-W., J. L. Hora, D. N. B. Hall, L. L. Cowie, M. Metzger, E. Irwin, T. Keller, K. Vural, L. J. Kozlowski, & W. Kleinhans. 1995. Astronomical Characterization of 1024x1024 HgCdTe HAWAII Detector Arrays. Proc. SPIE, 2475, 8–14.

Hodapp, K.-W., J. L. Hora, D. N. B. Hall, L. L. Cowie, M. Metzger, E. Irwin, T. Keller, K. Vural, L. J. Kozlowski, & W. Kleinhans. 1995. Astronomical Characterization of 1024x1024 HgCdTe HAWAII Detector Arrays. In Scientific & Engineering Frontiers for 8–10 M Telescopes, ed. M. Iye & T. Nishimura. Tokyo: University Press, pp. 145–47.

Hodapp, K.-W., & Ladd, E. F. 1995. Bipolar Jets from Extremely Young Stars Observed in Molecular Hydrogen Emission. ApJ, 453, 715–20.

Hora, J. L., K.-W. Hodapp, E. Irwin, T. Keller, & T. Young. 1995. Design of the Near-Infrared Camera for the Gemini Telescope. Proc. SPIE, 2475, 308–317.

Hu, E. M. 1995. The Future of CFHT—An Unofficial UH SAC View. In Proceedings of the Fourth CFHT Users Meeting, ed. M. Azzopardi. Kamuela, Hawaii: Canada-France-Hawaii Telescope Corp., pp. 193–98.

Hu, E. M., T.-S. Kim, L. L. Cowie, & A. Songaila. 1995. The Distribution of Column Densities and *b* Values in the Lyman-Alpha Forest. AJ, 110, 1526–43.

Huang, J.-S., A. Songaila, L. L. Cowie, & E. B. Jenkins. 1995. Detection of Hot Gas in the Interstellar Medium. ApJ, 450, 163–78.

Iwamuro, F., T. Maihara, H. Tsukamoto, S. Oya, D. N. B. Hall, & L. L. Cowie. 1995. Near-Infrared Spectrophotometry of IRAS FSC 10214+4724. PASJ, 47, 265–70.

Jewitt, D. C. 1995. Pre-Impact Observations of P/Shoemaker-Levy 9. In Proceedings of the European SL-9/Jupiter Workshop, ed. R. West & H. Boehnhardt. Munich: European Southern Observatory, pp. 1–4.

Jewitt, D. C., & J. X. Luu. 1995. The Solar System beyond Neptune. AJ, 109, 1867–76.

Joseph, R. D. 1995. NASA Infrared Telescope Facility. BAAS, 27, 204–7.

Kalas, P., & Jewitt, D. 1995, Asymmetries in the Beta Pictoris Dust Disk. AJ, 110, 794–804.

Khan, J. I., L. Harra-Murnion, H. S. Hudson, J. R. Lemen, & A. C. Sterling. 1995. Yohkoh Soft X-Ray Spectroscopic Observations of the Bright Loop-Top Kernels of Solar Flares. ApJL, 452, L153–L156.

Kim, D.-C., D. B. Sanders, & B. T. Soifer. 1995. Optical Spectroscopy of Luminous Infrared Galaxies. I. Nuclear Data. ApJS, 98, 129–70.

King, J. R., & A. M. Boesgaard. 1995. Stellar Oxygen Abundances. IV. Systematic Effects on Oxygen Abundances Derived from the 6300 Å [O I] and 7774 Å O I. AJ, 109, 383–95.

Kodaira, K., T. Greene, & A. T. Tokunaga. 1995. On the Stellar Nature of an Infrared Object, Kodaira 1. PASP, 47, 27–29.

Krismer, M. L., R. B. Tully, & I. M. Gioia. 1995. The IC 342/Maffei Group of Galaxies and Distances for Two of Its Members. AJ, 110, 1584–87.

LaBonte, B. J., R. Ronan, & R. Kupke. 1995. Solar Phys., 158, 1–10.

Landsman, W., T. Simon, & P. Bergeron. 1995. The High Mass White Dwarf in HR 8210. In Proceedings of the Ninth European Workshop on White Dwarfs, ed. D. Koester & K. Werner. Berlin: Springer-Verlag, pp. 191–95.

Latter, W. B., D. M. Kelly, J. L. Hora, & L. K. Deutsch. 1995. Investigating the Near-Infrared Properties of Planetary Nebulae I. Narrowband Imaging. ApJS, 100, 159–67.

Lauer, T. R., *et al.* (including Y.-I. Byun & J. Kormendy). 1995. The Centers of Early-type Galaxies with *HST*. I. An Observational Survey. AJ, 110, 2622–54.

Lu, E. T. 1995. Avalanches in Continuum Driven Dissipative Systems. Phys. Rev. Lett., 74, 2511–14.

Lu, E. T. 1995. Constraints on Energy Storage and Release Models for Astrophysical Transients and Solar Flares. ApJ, 447, 416–19.

Lu, E. T. 1995. The Statistical Physics of Solar Active Regions and the Fundamental Nature of Solar Flares. ApJL, 446, L109–L112.

Luppino, G. A., & I. M. Gioia. 1995. Constraints on Cold Dark Matter Theories from Observations of Massive, X-ray Luminous Clusters of Galaxies at High Redshift. ApJL, 445, L77–L80.

Marten, A., *et al.* (including T. Owen & D. B. Sanders). 1995. The Collision of Comet Shoemaker-Levy 9 with Jupiter: Detection and Evolution of HCN in the Stratosphere of the Planet. Geophys. Res. Lett., 22, 1589–92.

Meech, K. J., & H. A. Weaver. 1995. Unusual Comets (?) as Observed from the Hubble Space Telescope. Earth, Moon and Planets, 72, 119–32.

Meech, K. J., G. Knopp, T. L. Farnham, & D. Green. 1995. The Split Nucleus of Comet Wilson (1987 VII). Icarus, 116, 46–76.

Metcalf, T. R., L. Jiao, A. N. McClymont, R. C. Canfield, & H. Uitenbroek. 1995. Is the Solar Chromospheric Magnetic Field Force-Free? ApJ, 439, 474–81.

Miller, S., *et al.* (including R. D. Joseph). 1995. The Effect of the Impact of Comet Shoemaker Levy-9 on Jupiter's Aurorae. Geophysics Research Letters, 22, 1629–32.

Mullis, C. R., M. C. Begam, & P. A. Ianna. 1995. The Mistaken Identities of LHS 2067 and LHS 2068. PASP, 107, 742–43.

Orton, G., *et al.* (including D. Jewitt, J. Hora, R. Joseph, J. Rayner, M. Shure, W. Golisch, D. Griep, & C. Kaminski). 1995. The NASA Infrared Telescope Facility Investigation of Comet Shoemaker-Levy 9 and Its Collision with Jupiter: Preliminary Results. Science, 267, 1277–82.

Owen, T., D. Cruikshank, & T. Geballe. 1995. Dark Matter in the Outer Solar System. Adv. Space Res., 16, no. 2, 41–49.

Palumbo, M. E., A. G. G. M. Tielens, & A. T. Tokunaga. 1995. Solid Carbonyl Sulphide (OCS) in W33A. ApJ, 449, 674–80.

Pevtsov, A. A., R. C. Canfield, & T. R. Metcalf. 1995. Latitudinal Variation of the Helicity of Photospheric Magnetic Fields. ApJL, 440, L109–L112.

Raulin, J.-P., M. R. Kundu, N. Nitta, H. S. Hudson, & A. Raoult. 1995. Metric Type III Bursts Associated with Soft X-Ray Jets. ApJ, 444, 922–28.

Robertson, K. 1995. CD-ROMs in Astronomy. In Library and Information Services in Astronomy II (LISA II), European Southern Observatory, 10–12 May 1995, ed. by F. Murtagh, *et al.* Vistas Astron., 39, 167–71.

Roddier, F. 1995. Error Propagation in a Closed-Loop Adaptive Optics System: A Comparison between Shack-Hartmann and Curvature Wave-Front Sensors. Optics Commun., 113, 357–59.

Roddier, F. 1995. Prospects for Imaging Interferometry, Invited Paper Presented at the NASA Conference on Planetary Systems, Formation, Evolution, and Detection Held in Waikoloa (Hawaii), December 12, 15, 1993. Ap&SS, 223, 109–18.

Roddier, F., C. Roddier, J. E. Graves, K. Jim, & M. J. Northcott. 1995. Adaptive Optics Imaging at the CFHT. In the Proceedings of the Fourth CFHT Users Meeting, ed. Marc Azzopardi. Kamuela, Hawaii: Canada-France-Hawaii Telescope Corp., pp. 125–31.

Roddier, F., C. Roddier, J. E. Graves, & M. J. Northcott. 1995. Adaptive Optics Imaging of Protoplanetary Nebulae: Frosty Leo and the Red Rectangle. ApJ, 443, 249–60.

Ruiz, M.-T., P. Bergeron, S. K. Leggett, & C. Anguita. 1995. The Extreme Low-Luminosity White Dwarf ESO 439-26. ApJL, 455, L159–L162.

Sakata, A., S. Wada, A. T. Tokunaga, & T. Narisawa. 1995. Comparison of the Absorption Curves of Soots, Pitch Samples, and QCCs to the Interstellar Extinction Curve. Plan. & Space Sci., 43, 1223–26.

Sanders, D. B., E. Egami, S. Lipari, I. F. Mirabel, & B. T. Soifer. 1995. The *IRAS* Bright Galaxy Survey–Part II: Extension to Southern Declination $\delta \lesssim -30$), and Low Galactic Latitudes ($5 < |b| \leqslant 30°$). AJ, 110, 1993–2008.

Satoh, T., J. E. P. Connerney, & R. Baron. 1995. Emission Source Model of Jupiter's $H_3^+$ Aurorae. In Proceedings of the 28th ISAS Lunar and Planetary Symposium. Tokyo: Institute for Space and Astronautical Science.

Shaya, E. J., P. J. E. Peebles, & R. B. Tully. 1995. Action Principle Solutions for Galaxy Motions within 3000 Kilometers per Second. ApJ, 454, 15–31.

Simon, T., S. A. Drake, & P. D. Kim. 1995. The X-Ray Emission of A-Type Stars. PASP, 107, 1034–41.

Songaila, A., E. M. Hu, & L. L. Cowie. 1995. A Population of Very Diffuse Lyman-$\alpha$ Clouds as the Origin of the $He^+$ Absorption Signal in the Intergalactic Medium. Nature, 375, 124–26.

Spencer, J. R., *et al.* (including D. J. Tholen). 1995. The Lightcurve of 4179 Toutatis: Evidence for Complex Rotation. Icarus, 117, 71–89.

Stockton, A., M. Kellogg, & S. E. Ridgway. 1995. The Nature of the Stellar Continuum in the Radio Galaxy 3C 65. ApJL, 443, L69–L72.

Svestka, Z., F. Farnik, H. S. Hudson, Y. Uchida, P. Hick, & J. R. Lemen. 1995. Large-Scale Active Coronal Phenomena in Yohkoh SXT Images. I. Post-Flare Giant Arches Rising with Constant Speed: Solar Phys., 161, 331–63.

Tokunaga, A. T., K.-W. Hodapp, J. L. Hora, J. T. Rayner, *et al.* 1995. Infrared Camera and Spectrograph for the Subaru Telescope. In Scientific & Engineering Frontiers for 8–10 M Telescopes, ed. M. Iye & T. Nishimura. Tokyo: University Press, pp. 263–66.

Trentham N. 1995, How Much of the Extreme Luminosity of IRAS F10214+4724 Can Be Attributed to Gravitational Lensing. MNRAS, 277, 616–26.

Tully, R. B., J. Morse, & P. Shopbell. 1995. Dissecting Cosmic Explosions. S&T, July.

Tully, R. B. 1995. Observations of Extragalactic Objects with the Hawaii Imaging Fabry-Perot Interferometer (HIFI). In Tridimensional Optical Spectroscopic Methods in Astrophysics, IAU Colloq. 149, ed. G. Comte & M. Marcelin. ASP Conf. Ser. 71. San Francisco: ASP, pp. 107–12.

Tully, R. B., P. J. E. Peebles, & E. J. Shaya. 1995. Variational Principle Analysis of Orbits in the Local Supercluster. Ap. Lett. & Commu., 31, 329–35.

Vacca, W. D., C. Robert, C. Leitherer, & P. S. Conti. 1995. The Stellar Content of 30 Doradus Derived from

Spatially-Integrated Ultraviolet Spectra: A Test of Spectral Synthesis Models. ApJ, 444, 647–62.
Veilleux, S., D.-C. Kim, D. B. Sanders, J. M. Mazzarella, & B. T. Soifer. 1995. Optical Spectroscopy of Luminous Infrared Galaxies. II. Analysis of the Nuclear and Long-Slit Data. ApJS, 98, 171–217.
Weaver, H., & D. Jewitt. 1995. The String of Pearls. In The Great Comet Crash, ed. J. Spencer & J. Mitton. Cambridge: Cambridge University Press, pp. 45–54.
Weaver, H. A., *et al.* (including K. J. Meech). 1995. The Hubble Space Telescope Observing Campaign on Comet P/Shoemaker-Levy 9. Science, 267, 1282–88.

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