

University of Hawaii
Institute for Astronomy
Honolulu, Hawaii 96822

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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 1996 through 30 September 1997, and was compiled in October 1997. 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, Amy Barger (NICMOS postdoctoral fellow), Richard L. Baron, Ann M. Boesgaard, Peter M. Bryant, John Carpenter (James Clerk Maxwell Telescope Fellow), Kenneth C. Chambers, Laird M. Close, Antoinette Songaila Cowie, Lennox L. Cowie, Christophe Dumas, Harald Ebeling, Jochen Eisloffel (visitor), Isabella M. Gioia, J. Elon Graves, Thomas P. Greene, Olivier R. Hainaut (postdoctoral fellow), Donald N.B. Hall, James N. Heasley, J. Patrick Henry, George H. Herbig, John Hibbard (Hubble Fellow), Klaus-Werner Hodapp, Joseph L. Hora, Esther M. Hu, David C. Jewitt, Robert D. Joseph, Nick Kaiser, Naoto Kobayashi (visitor), Lev Kofman, John Kormendy, Barry J. LaBonte, Gerard A. Luppino, Alexander N. McClymont, Robert A. McLaren (Interim Director), Karen J. Meech, Roland Meier (NICMOS postdoctoral fellow), Donald L. Mickey, Satoshi Miyazaki (visitor), Guillaume Molodtsov (visitor), Malcolm J. Northcott, Tobias C. Owen, 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, David J. Tholen, Alan T. Tokunaga, John L. Tonry R. Brent Tully, William D. Vacca (Parrent Fellow), Richard J. Wainscoat, and Gareth Wynn-Williams.

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 and Keck II telescopes 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.

Construction continued on the 8 m Subaru and Gemini Telescopes and on the Submillimeter Array (SMA).

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. No new instruments were commissioned on the 2.2 m telescope. This allowed us to reduce the number of engineering nights to 20, making more nights available for scientific research.

The primary mirror of the 2.2 m telescope was aluminized in September 1997. It had been 3 yr since this mirror was aluminized. Aluminizing had not been performed in the previous years because of the heavy construction adjacent to the 2.2 m dome, where the northern Gemini telescope is being built.

During the report period, imaging with CCDs, which accounted for 50% of the observing time and the bulk of the dark-moon observing time, remained the most common use of the telescope. A little under half of this was wide-field imaging using the Tektronix 2048×2048 CCD at the f/10 focus. Use of the new 8192×8192 mosaic CCD camera increased markedly, with 38 nights scheduled in four separate runs. Access to this camera was limited somewhat by heavy usage of the camera on the CFHT—use on the 2.2 m telescope would have been higher if it had been more available. The 8192×8192 camera has a field-of-view of 19' × 19'. A field-flattener is installed as the dewar window when it is used at the f/10 focus of the 2.2 m telescope. High-resolution CCD imaging at the f/31 focus accounted for about one quarter of the CCD imaging, and the remainder of the CCD imaging used ultraviolet-sensitive CCDs. The Orbit 2048×2048 CCD was successfully used during the report period. This CCD has high quantum efficiency in the blue down to the atmospheric cutoff.

Imaging with the 1024×1024 infrared camera (QUIRC) was performed for 26% of the observing time. The bulk of these observations were performed at the f/10 focus, where the camera has a 3.2' × 3.2' field-of-view. The large format of this camera has made it an extremely powerful tool for infrared imaging. It is in particularly high demand for deep, wide-area infrared imaging surveys of distant galaxies.

QUIRC was also used at the $f/31$ focus, where near-diffraction-limited imaging over a $60'' \times 60''$ field-of-view is possible in good conditions with a suitable guide star for the tip-tilt system.

The near-infrared spectrometer KSPEC was used for 8% of the observing time. Low-resolution optical spectroscopy was performed for 10% of the observing time. The UH adaptive optics system was used for a 12 night run in November–December 1996, but the weather was very poor. The remaining 3% of the observing time was used by visitor instruments. The coude spectrograph was not used during the report period.

Scheduling of the telescope focused on minimizing instrument changes. During the report period, the average length of time an instrument was installed on the telescope was 6.4 nights. Problems with instruments most commonly occur after a change, so by minimizing the number of changes, observing efficiency was improved.

QUIST—a 25 cm telescope mounted on top of the 1024×1024 camera and attached on the counterweight side of the 0.6 m telescope—was heavily used during the report period. This telescope provides a field-of-view of $29' \times 29'$, with pixels of $1.7''$. This telescope is normally used remotely from Manoa. Observers normally execute their observations by means of a script, and the telescope performs them robotically; the observer checks progress periodically. QUIST was oversubscribed during the report period—its usage was limited primarily by availability of the 1024×1024 camera. QUIST was used mostly on the 0.6 m telescope during dark time. During bright time, the 1024×1024 camera was used on the 2.2 m telescope or CFHT. Work continued through the report period to further improve the remote operation.

Further progress was made in making documentation for the telescopes available via the World Wide Web. The URL for information relating to the 2.2 m and 0.6 m telescopes 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 telescopes were changed to 6 month semesters. The semesters were chosen to match the scheduling periods common to all the other Mauna Kea telescopes. The semesters are February–July (deadline September 15) and August–January (deadline March 15).

2.2 Infrastructure

High-bandwidth fiber optics communications is now available from GTE Hawaiian Tel. Based on SONET OC-12 (622 Mbit s^{-1}) technology, the system provides DS-3 (45 Mbit s^{-1}) circuits between summit observatories and base facilities in Hilo and Waimea. Even higher capacity circuits will be available when a new communications equipment room is completed early in 1998.

A new photogrammetric mapping of the inner portions of the Mauna Kea Science Reserve was completed. It is based on aerial photography obtained in September 1996. The mapping serves the dual purpose of documenting the current development and providing the basic topographical data needed for planning any future development. The map is also a key element of the Historic Preservation Management Plan

for the Science Reserve, in that the locations of approximately 60 sites of historic and cultural significance (mostly rock shrines) are accurately recorded. The map was 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. The camp saw considerable use by Subaru and SMA during the first half of the year, but this tapered off in the second half and the camp was shut down in July.

3. HALEAKALA OBSERVATORIES

The administrative staff consisted of M. Maberry, D. O'Gara, K. Rhoden, K. Kimura, K. Ventura, and J. Perreira, and the technical staff included A. Distasio, E. Olson, M. Waterson, R. Zane, G. Nitta, J. Frey, C. Foreman, L. Hieda, and K. Rehder.

3.1 Mees Solar Observatory

Mees Solar Observatory supports IfA solar scientists in data acquisition by running diverse observational programs with its seven telescopes. The observatory regularly co-observes with the satellites *Yohkoh* and *Solar and Heliospheric Observatory (SOHO)* and also participates in support of special satellite and ground-based observatory campaigns. One of the unique observational capabilities at Mees is the ability to perform measurements of the temporal evolution of photospheric vector magnetic fields.

The observatory's complement of instruments includes the Imaging Vector Magnetograph, Haleakala Stokes Polarimeter, Mees CCD Imaging Spectrograph, Mees White Light Telescope, K-Line Imager, Coronal Limb Imagers, and a second K-line Imager.

3.2 LURE Observatory

LURE is a satellite laser ranging (SLR) observatory. LURE utilizes a high-powered pulsed laser to obtain distance measurements to satellites in Earth orbit. LURE is funded by the Space Geodesy and Altimetry Projects Office (SGAPO) of NASA Goddard Space Flight Center. The missions of the target satellites include monitoring of Earth resources and climate parameters, measurements of ocean levels and temperatures, plate tectonics, improvement of the Global Positioning System (GPS), as well as special missions on the physics of tethered satellite systems. LURE provides range data to NASA 7 days a week, and improvements to the computer system and to the operational procedures will soon allow LURE to operate on a 24 hr schedule. LURE continues to be a top data producer in the worldwide network of cooperating SLR observatories.

3.3 Haleakala Atmospheric Characterization Project

During 1996–97, Haleakala Observatories has been under contract to Boeing's Rocketdyne Technical Services Company to conduct a research program known as the Haleakala Atmospheric Characterization (HAC). This program ulti-

mately supports the U.S. Air Force Advanced Electro-Optical System (AEOS) Telescope on Haleakala.

The instrument suite that supports these site measurements includes a micrometeorological measurement system (MMS), a daytime/nighttime optical seeing monitor, a sound-powered radar system, and a small standard meteorological system. IfA is acquiring data on the atmospheric seeing and optical quality of this site.

4. INSTRUMENTATION

4.1 Adaptive Optics

Over the last year we have both expanded our adaptive optics observation program, and worked on the development a more advanced system.

The 13-actuator UH Adaptive Optics (AO) system was awarded observing time on the CFHT from 22 to 29 October 1996 and from 11 to 17 July 1997, and on the UH 2.2 m telescope from 26 November to 8 December 1996. An increasing fraction of the telescope time was awarded to IfA staff members other than the AO team, and to astronomers from other institutions. Results from these observations will be found elsewhere in this report. The AO team focused its efforts on two main programs: a study of the environment of young stars by Close (see sec. 6), and observations of solar system objects by C. Roddier and F. Roddier (see sec. 8).

A new 3 yr NSF grant was awarded to the UH team for the development of a 36-actuator AO system. A first version of this new system is scheduled to operate at the CFHT from 7 to 17 November 1997. In addition to providing higher compensation performance, the system will be equipped with new actively quenched avalanche photodiodes from EG&G that will provide a factor of 2 improvement in photon detection efficiency and allow the use of natural guide stars as faint as mag 18. In the following years an infrared wave-front sensor based on a Rockwell detector array will be built. It will allow almost full sky coverage to be obtained in the Galactic plane. A new type of stellar coronagraph will also be implemented (see PASP, 109, 815).

Since last year, Northcott and Graves worked on the construction of the new system, which required a number of important technical developments: (1) computer simulation and design optimization of the new system; (2) development of more versatile control software able to operate with any number of sensors or actuators; (3) design, fabrication, and testing of new control electronics based on new Sparc 5 processors for control loop and communications; (4) fabrication of a 36-actuator deformable mirror (Laplacian Optics design); (5) in-house fabrication of lenslet arrays with a computer-controlled milling machine; (6) in-house fabrication of a new wave-front curvature sensor; and (7) reconfiguration of the optical bench and transfer optics. In addition, a possible extension of our current deformable mirror technology to a large number of actuators (100 to 1000) was explored via computer simulations to allow the correction of telescope aberrations in space.

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. Hodapp is principal investigator for NIRI.

NIRI will provide three pixel scales for scientific observations. The finest ($0.02 \text{ arcsec pixel}^{-1}$) has been chosen to sample properly the expected image quality delivered by the adaptive optics system; the middle one ($0.05 \text{ arcsec pixel}^{-1}$) is best matched to the image quality expected from tip-tilt corrected images on the best nights; and the widest field ($0.12 \text{ arcsec pixel}^{-1}$) 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 will be a 1024×1024 Aladdin array with $27 \mu\text{m}$ pixels. 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 coronagraphic 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.

Throughout the report period, the NIRI design was detailed out, the optical design performance was analyzed, and prototype cryogenic mechanisms were tested. NIRI successfully passed the critical design review in May 1997 and is now in the fabrication phase.

4.3 Camera and Spectrograph for Subaru

Tokunaga (principal investigator), Project Scientist N. Kobayashi (Japan), and coinvestigators Hodapp, Rayner, Hora (IfA), Y. Kobayashi, T. Maihara, and T. Nagata (Japan) have started the construction of the Infrared Camera and Spectrograph (IRCS), a facility instrument for the 8.2 m Subaru telescope on Mauna Kea. It will be a high-resolution spectrograph for $1\text{--}5 \mu\text{m}$ ($R = 20,000$), 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 arrays (the ALADDIN arrays), one each for the camera and spectrograph sections. Major components have been purchased or constructed, and

testing of hardware is planned for December 1997. The planned completion date is January 1999, with the first test observations to be made about three months later.

4.4 Optical Detector Development

The optical detector group is leading aggressive programs to develop CCD instruments and new CCD detectors optimized for astronomical observations.

One area of specialty is the construction of large CCD mosaic focal planes. The IfA has constructed one of the world's largest CCD focal planes, a mosaic with 8192×8192 pixels. This camera was commissioned in 1995 and was the first large mosaic to go into regular use. The CCD mosaic is a close-packed (gaps ≤ 1 mm), 4×2 array of three-edge-butable 2048×4096 Loral CCDs with $15 \mu\text{m}$ 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 ($0.47^\circ \times 0.47^\circ$ or 0.22 deg^2) with optimal sampling ($0.21 \text{ arcsec pixel}^{-1}$) of the best Mauna Kea seeing ($0.5''$). In addition, with the use of a field-flattener, the camera can be used at the $f/10$ RC focus of the UH 2.2 m telescope, where the image scale is $0.14 \text{ arcsec pixel}^{-1}$ and the field of view is $0.31^\circ \times 0.31^\circ$ (0.1 deg^2).

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. 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 with higher-sensitivity thinned devices, and to build an $8K \times 12K$ CCD mosaic camera for permanent use at the CFHT.

In addition, the optical detector group is developing new, state-of-the-art CCDs. One example is a UH-led effort involving six major observatories that are developing a $2K \times 4K$, three-edge butable CCD with Massachusetts Institute of Technology Lincoln Laboratory (MITLL). The goal of this program is to produce an extremely low-noise (< 1.5 electrons), high-speed, deep-depletion CCD with enhanced near-infrared (700 nm to $1 \mu\text{m}$) response and minimal interference fringing. The first thinned devices from this project have been produced. They work as expected; $1 e^-$ noise has been achieved, and increased red quantum efficiency has been realized from the deep depletion technology. This work with MITLL is continuing.

The optical detector group has been substantially augmented with the arrival of Tonry. He has pioneered the development of a new type of CCD—the Orthogonal Transfer CCD (OTCCD)—that is capable of transferring charge in two directions. With such a detector, one can accomplish tip-tilt image-motion compensation “on chip” rather than with moveable optics as is usually done. The first of these devices were developed by Tonry with MITLL. Further work in this area, including the production of large devices, will now be done at IfA through the UH-MITLL Consortium.

4.5 SpeX

Rayner is principal investigator for SpeX, a medium-resolution $0.8\text{--}5.5 \mu\text{m}$ spectrograph and imager being built at the IfA for the NASA IRTF. 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 uses prism cross-dispersers to provide spectral resolutions of $R \sim 1000\text{--}2000$ across $0.8\text{--}2.5 \mu\text{m}$ and $2.0\text{--}5.5 \mu\text{m}$.

SpeX was funded by the National Science Foundation (NSF) in July 1994. First-light is expected in 1999. SpeX will get first choice of an array from the NASA Planetary Astronomy InSb Detector Array Infrastructure Project (PAIDAI). The PAIDAI Project is funding a foundry of 1024×1024 detector arrays at Hughes SBRC. Work at SBRC started in October 1996 and is expected to last about 18 months. All being well, SpeX will use a science-grade 1024×1024 InSb array in the spectrograph and a 512×512 InSb array in the infrared slit-viewer.

SpeX is being designed in-house, but all optical, electronic, and cryo-mechanical parts are being procured and fabricated by outside vendors. Assembly and testing will be done at the IfA in Honolulu. In October 1997, the array controller was undergoing testing, and delivery of the large cryostat vacuum jacket is imminent. All major optical components are scheduled to be delivered by the end of 1997, and all major cryo-mechanical components by mid-1998. The other IRTF/UH personnel working on SpeX include D. Toomey (project engineer), P. Onaka (electrical engineer), V. Stahlberger (mechanical engineer), T. Denault (Software engineer), and D. Watanabe (instrument technician).

4.6 AEOS Spectrograph

Mickey (PI) and coinvestigators Hodapp, Stockton, and Luppino began design work on a high-resolution optical/SWIR spectrograph for the U.S. Air Force AEOS telescope on Haleakala. The 3.6 m AEOS telescope will be available a significant fraction of the time for astronomical observations. The UH spectrograph, funded by an Air Force contract, will make use of large-format detectors to provide both high resolution and wide spectral coverage.

The spectrograph will consist of two separate arms, one for “visible” wavelengths (0.5 to $1.0 \mu\text{m}$) and another for the range 1.0 to $2.5 \mu\text{m}$. Both will be cross-dispersed echelle spectrographs that use “white pupil” layouts to control the size of the camera optics. Tentative plans call for slit widths of $0.15''$ and resolving powers of 50,000 on both arms. The visible spectrograph will use a $4K \times 4K$ CCD mosaic covering the full wavelength range in two settings. The SWIR arm is designed to use a $2K \times 2K$ HgCdTe array currently under development. It will obtain full coverage of the *J* or *H* band in a single grating setting, and the *K* band in two settings. A dichroic will permit simultaneous use of both arms; tip-tilt image stabilization will be provided using an active

fold mirror and centroid measurement with a slit monitor camera.

5. GALACTIC AND EXTRAGALACTIC STUDIES

Gioia, Henry, and graduate student C. Mullis used the deepest region of the *ROSAT* (X-ray astronomy satellite) All-Sky Survey, around the North Ecliptic Pole (NEP), to produce an X-ray-selected sample of distant clusters. With this sample, they will study the evolution of the cluster X-ray luminosity function. The *ROSAT* NEP sample is from a contiguous region, so they will also be able to characterize the three-dimensional large-scale structure of the universe by studying the cluster-cluster correlation function. So far they have identified about 80% of the 465 X-ray sources in the sample. There are 50 clusters of galaxies so far with redshifts extending beyond 0.8; there are 16 clusters with $z > 0.3$.

A recent discovery is a cluster at $z = 0.82$ with a filamentary optical structure. The cluster has a high velocity dispersion. X-ray maps obtained with the High Resolution Imager (HRI) onboard *ROSAT* show the presence of hot gas in the same region as the optical filaments. This is reminiscent of the initial formation of protoclusters described as matter flowing along filaments: a process that may be occurring in this distant cluster. The *Advanced Satellite for Cosmology and Astrophysics* (*ASCA*) temperature is characteristic of hot low-redshift clusters.

As recipient of a Humboldt Research Award from the Alexander von Humboldt Foundation, Kormendy visited the observatory of the Ludwig Maximilians University, Munich, Germany, in July–October 1996 and July–August 1997. The purpose was to work with R. Bender on several papers on the search for supermassive black holes (BHs) in galaxy nuclei. A paper was completed on the discovery of a $6 \times 10^8 M_{\odot}$ central dark object, probably a BH, in NGC 4486B, a dwarf elliptical companion of M87. The detection is remarkable (1) because NGC 4486B is the second galaxy known to have a close double nucleus, suggesting that double nuclei and BHs are connected, and (2) because the above mass is an unprecedentedly large fraction (7%) of the mass in stars. *Hubble Space Telescope* (*HST*) STIS observations of NGC 4486B are scheduled to check the BH detection. Kormendy and Bender also are analyzing CFHT SIS spectroscopy of M31; these greatly strengthen the case for a central BH and are consistent with the predictions of Tremaine's model of the double nucleus as an eccentric disk of stars orbiting in the potential of the BH.

Kormendy, Bender, former graduate student A.S. Evans (now at the California Institute of Technology), and D. Richstone (Univ. of Michigan) completed a paper on the discovery of a $2 \times 10^8 M_{\odot}$ central dark object, again probably a BH, in the normal E5 galaxy NGC 3377.

Kormendy continued work on *HST* photometry and kinematic measurements of the central parts of early-type galaxies, as part of a team including E. Ajhar (Kitt Peak National Observatory [KPNO]), Bender, G. Bower (National Optical Astronomy Observatories [NOAO]), A. Dressler (Carnegie Observatories), S.M. Faber (Univ. of California, Santa Cruz), C. Grillmair (Jet Propulsion Laboratory [JPL]), K. Gebhardt (Univ. of Michigan), R. Green and T.R. Lauer (KPNO), J.

Magorrian (Canadian Institute of Theoretical Astrophysics [CITA]), Richstone (PI), and S. Tremaine (CITA). Papers were completed on core fundamental plane parameter scaling relations, the discovery of a double nucleus in NGC 4486B, the detection of a supermassive black hole in NGC 3379, and black hole demographics.

Kormendy and K.C. Freeman (Mt. Stromlo Observatory) are preparing a paper on dark matter (DM) halo scaling relations, i.e., observed correlations between halo central density, halo core radius, halo velocity dispersion, and total galaxy luminosity. These provide constraints on our understanding of galaxy formation, and they suggest that there may be a significant population of undiscovered, essentially empty DM halos that are like the halos of the dwarf spheroidal galaxies Draco and UMi.

L. Cowie, A. Cowie, and Hu continued studies of galaxy evolution in the Hawaii Survey fields—a reference sample for which deep optical and near-infrared multicolor imaging data are available, with now near-complete, magnitude-limited (in *B*, *I*, *K*) spectroscopic identifications from deep multiobject spectroscopy on the Keck telescope. Recent work has focused on completing spectroscopic identifications of the $1.7 < z < 2.8$ sample galaxies using a combination of rest-frame ultraviolet absorption-line spectroscopy with LRIS on Keck II at blue wavelengths, together with infrared spectroscopy using the CGS4 spectrograph on UKIRT for rest-frame optical emission-line features. In collaboration with E. Egami (Max-Planck-Institut für Extraterrestrische Physik) these data have been used to study the evolution of the galaxy formation function with redshift.

Graduate student J. Huang, with L. Cowie, Hu, A. Cowie, Wainscoat, and J. P. Gardner (Univ. of Durham), completed a bright *K*-band survey designed to determine the local end of the galaxy luminosity function. Huang, Cowie, and Lupino have also used the UH 8K mosaic CCD camera to perform morphological classification on the bright multicolor (*B*, *I*, *K*) sample.

L. Cowie, Barger, graduate student N. Trentham (now at Institute of Astronomy [IoA], Cambridge), graduate student E. Fulton, Hu, and A. Cowie continued with deep wide-field multicolor imaging of the Hubble Deep Field (HDF). A. Cowie has constructed an active catalog of summary spectroscopic/imaging data on the Hawaii HDF observations for interactive Web access at <http://www.ifa.hawaii.edu/~cowie/tts/tts.html>.

Sanders, L. Cowie, Joseph, Wynn-Williams, and Chambers, in collaboration with Y. Taniguchi (PI) and Y. Sato (Tohoku Univ.), K. Kawara (Tokyo Astronomical Observatory), H. Okuda (Institute of Space & Astronautical Science, Tokyo) and Y. Sofue (Institute of Astronomy, Univ. of Tokyo), T. Matsumoto and H. Matsuhara (Nagoya Univ.), K. Wakamatsu (Gifu Univ.), and F.X. Désert (Institut d'Astrophysique Spatiale), have used the *Infrared Space Observatory* (*ISO*) satellite to conduct a deep $7 \mu\text{m}$ ISOCAM and 90–175 μm ISOPHOT survey of the Lockman Hole, a region of very low Galactic HI column density that is suitable for deep mid- and far-infrared searches for high-*z* reddened galaxy populations. This is currently the deepest mid- and near-infrared survey of this type. Follow-up infrared,

submillimeter, and millimeter investigations will be directed toward those sources with no near-infrared counterparts, and those that are candidates for previously undetected highly reddened galaxy populations.

Wynn-Williams, together with G.P. Knapp (Princeton), M.P. Rupen (NRAO), M. Fich (Univ. of Waterloo), and D.A. Harper (Yerkes Observatory), used the ISOCAM instrument on *ISO* to study the infrared emission from a number of elliptical galaxies. Observations at 4.5 and 15 μm of the first of these, NGC 3998, show extended emission from the bulge stars and strong point-source emission from the nucleus. The inner regions of NGC 3998 appear to contain a few thousand solar masses of warm (~ 200 K) dust, probably associated with the active galactic nucleus (AGN).

Hu and R. McMahon (IoA, Cambridge) have been continuing their studies of very high redshift ($z > 4.5$) galaxies targeted in $z > 4$ quasar fields by strong Lyman- α line emission. This program is being extended to a sample of $z > 4.5$ quasars that will be studied with deep *HST* imaging in the optical and infrared to identify high-redshift galaxies by their colors. Supporting observations on these fields will be taken using telescopes on Mauna Kea. European collaborators on this program, S. D'Odorico (ESO), Egami, A. Fontana and E. Giallongo (Rome Observatory), and S. Cristiani (Padua), will use telescopes at ESO.

Graduate student G. Canalizo and Stockton completed a project on close companions of three low-redshift QSOs. One proved to be a star, but the companion of PG 1700+518 turned out to be particularly interesting. Using a simple two-component model, Canalizo and Stockton were able to achieve a satisfactory fit to the spectrum with a combination of a 10^8 yr old population with one with an age of $\sim 1.2 \times 10^{10}$ yr. These observations have been followed up with additional Keck spectroscopy of QSO companions and host galaxies, with a particular focus on objects that lie in the transition region between ultraluminous infrared galaxies and the classical QSO population in the far-infrared two-color plot.

In a related project, Stockton, Canalizo, and Close used the UH Adaptive Optics system on CFHT to image the QSO PG 1700+518 in the *H* band. The resulting image has a FWHM of 0.25", and the object on the N edge of the QSO is clearly seen to be a discrete companion with an arclike, presumably tidal, tail.

Stockton and S. Ridgway (Oxford) continued their investigations of various complete subsamples of 3C radio sources with $z \sim 1$. They have begun to obtain WFPC2 images from their Cycle 6 *HST* imaging program, which extends their recently published *HST* Cycle 4 quasar sample to higher redshifts. A detailed spectroscopic study of the environment of the quasar 3C 212 has been completed. This quasar is of special interest because of the complex apparent alignment of features with the radio axis, both within and beyond the radio lobes. One important result of the spectroscopic work has been to show that a component just beyond the NW radio lobe, which seemed to have a close morphological connection with the radio structure, is most likely instead a chance foreground projection. The quasar itself appears to be in a loose group rather than in a rich cluster.

Stockton, Canalizo, and Ridgway continued a program of searching for old stellar systems at $z \sim 1.5$ in the form of companions to QSOs. A sieve procedure is used to identify likely candidates. First, short K' images are obtained with the IRTF, and fields having galaxies with $18.0 < K' < 19.5$ within a 30" radius of the QSO are identified. For these, *J*-band images are obtained, and fields with objects with $J - K \sim 2$ are noted. These fields are observed in a 0.9 μm filter in bright time on Keck, and a two-color plot is constructed and compared with models for stellar populations of different ages. Finally, deep *R*-band imaging is obtained to look for consistency with the indicated age. For the best candidates surviving this selection process, deep Keck spectroscopic observations are obtained to determine an age from diagnostic lines in the near-ultraviolet. About 160 fields have been examined so far, and several candidates have been identified, although spectroscopic confirmation has been hampered by weather.

Tonry, J.P. Blakeslee (MIT), Ajhar, and A. Dressler (Carnegie Observatories) are completing a program of distance determinations to nearby elliptical and S0 galaxies using the method of surface brightness fluctuations formulated by Tonry. While the surface brightness of a galaxy is invariant with distance, the rms fluctuations about this mean will depend on the number of unresolved stars sampled by each detector pixel, and will be inversely proportional to the distance of the galaxy. This method is being applied to make an estimate of infall towards Virgo. At larger distances, Tonry, Ajhar, Dressler, M. Postman (Space Telescope Science Institute [STScI]), Lauer, and J. Holtzman (New Mexico State Univ.) are using surface brightness fluctuations in *HST* WFPC2 far-red optical data to determine distances and peculiar velocities toward the local "Great Attractor." This method is also being applied by Tonry, graduate student J. Jensen, R. Thompson and M. Rieke (Univ. of Ariz.), Lauer, Postman, and R. Weymann (Carnegie Observatories).

6. STAR FORMATION AND INTERSTELLAR MATTER

Tokunaga and S. Wada (Univ. of Electrocommunications) continued their work on understanding the nature of quenched carbonaceous composite (QCC), a laboratory analog to the carbonaceous material in the interstellar medium. As an amorphous material containing aromatic hydrocarbons, QCC provides an alternative to the polycyclic aromatic hydrocarbon (PAH) hypothesis as an explanation of the infrared emission features observed at 3.29, 6.2, 7.7, 8.6, and 11.3 μm . Tokunaga provided a review of the emission features, including the 21 and 30 μm features, at a meeting of the Infrared Telescope Satellite in Tokyo, Japan, during November 1996. The main conclusion is that these emission bands can be roughly divided into three types, named A, B, and C, following Geballe. Type A is the most common and is typical of most H II regions and planetary nebulae. Type B is frequently seen in late-type stars that are in the transition phase to becoming planetary nebulae. These objects typically have the 21 and 30 μm emission features. Type C is very rare, and objects of this class show a unique set of emission bands at 3.43 and 3.51 μm .

Herbig's search for interstellar C_{60} in the 3200 Å region, in spectra of reddened OB stars obtained with the HIRES spectrograph at Keck I, has so far shown no positive results. Interstellar C_{60}^+ is expected to occur near 9500 Å, and has indeed been reported by a French group, from Observatoire Haute Provence and CFHT spectra. Herbig also has observed a large number of reddened and unreddened OB stars in this region, but heavy atmospheric H_2O structure (even on dry nights on Mauna Kea) make the reductions difficult.

In an effort to determine whether the carriers of the diffuse interstellar bands (DIBs) may be present in the material evaporated from the nucleus of a comet when it nears the Sun, Herbig and D. McNally (Univ. College London) observed the spectrum of the B-type star HD 12895 as comet Hale-Bopp passed almost over it on 3 April 1997. The observations were made with Keck HIRES at very low altitude, under difficult conditions, but good spectra were obtained. It was necessary also to observe with the same instrumental setup an adequate number of stars having strong DIBs. Those spectra were obtained by Herbig on a subsequent run at HIRES.

It has been suggested that the DIBs might occur in emission in a reflection nebula illuminated by a hot star. Herbig obtained low-resolution spectra of two reflection nebulae (NGC 1788 and NGC 2068) at the 2.2 m telescope, but there was no indication that any of the stronger DIBs were present in emission. This suggests that these DIBs are not produced by a scattering process.

Herbig now completed his investigation of IC 348, a small cluster that is part of the Per OB2 association. CCD photometry was obtained in *BVRI* (at the 2.2 m) for about 260 stars in and around IC 348, and CFHT multiobject spectroscopy for about 80. A somewhat larger region was surveyed for stars having $H\alpha$ in emission, and over 110 emission-line stars brighter than about $R = 19$ were discovered. Because $H\alpha$ emission could be detected to a limit near $W = 3 \text{ \AA}$, division into weak-line (WTTS) and classical T Tauris (CTTS) was possible on purely spectroscopic grounds. There is a steep rise in the number of emission-line stars below $W(H\alpha) = 10 \text{ \AA}$; the proportion of WTTS:CTTS in the area surveyed is 59:51. *ROSAT* detected about 58% of the spectroscopic WTTS and about 65% of the CTTS, although these numbers are sensitive to the spectroscopic and X-ray survey thresholds. The ages of about 100 stars, read off the theoretical tracks of D'Antona & Mazzitelli, mostly scatter between about 0.5 and 12 Myr, but the emission-line stars, which are most likely to be members of IC 348, have a mean age of 1.3 Myr. Allowance for unresolved binaries would increase this age somewhat, but there is a firm upper limit at 2.95 Myr. There is no indication that the ages of the emission-line stars depend upon $W(H\alpha)$: the IC 348 WTTS as a population are not systematically older than the CTTS, but there is a tendency for the WTTS to be concentrated toward the center of IC 348, while the CTTS are more widely distributed. There is a scattering of emission- $H\alpha$ stars over the entire area surveyed. There are too many to be explained as low-mass members of an earlier generation of star formation in Per OB2. The expected number of foreground dMe stars is also too small. The mass frequency function,

based on some 125 stars fitted to theoretical tracks, rises from $1.5 M_{\odot}$ to about $0.2 M_{\odot}$, with a slope very much like that of the Scalo initial mass function. The optical cluster IC 348 radius is about $4.0'$, or 0.37 pc. The total mass of optically detectable stars in this volume is $57 M_{\odot}$, while the mean space density is about $520 \text{ stars pc}^{-3}$. The amount of interstellar material remaining within the cluster is small in comparison. Star formation in the Per OB2/IC 348 region cannot be characterized by one unique age; it appears that stars have been forming in the region now occupied by the association for 10–20 Myr.

Close continued to probe the early stages of stellar and planetary formation with the new technique of adaptive optics. During the last year, Close has utilized the UH Adaptive Optics (UHAO) system at the CFHT to produce the first high-resolution polarimetry images with adaptive optics of the nebulae around young stars. These infrared imaging polarimetry maps obtained $0.2''$ resolutions and proved that Hubble's Variable Nebula is produced by light from the central young Herbig Ae/Be star R Mon (see *ApJ*, vol. 489). Close also imaged the accretion disk around the young star HL Tau at the highest resolutions to date at J , H , and K' with UHAO. These images showed how the outflow from a young star is perpendicular to the disk and clears away the dust above and below the disk. In addition, he obtained diffraction-limited $0.1''$ images of the accretion disk around the classical T Tauri binary UY Aur at J , H , and K' . It was found that the dust particles in such circumbinary disks are not larger than $0.6 \mu\text{m}$. It was also found that material from circumbinary disks seems to feed the inner, smaller, circumstellar disks. He also utilized UHAO at the UH 2.2 m with M. Simon (State Univ. of New York at Stony Brook) to produce the largest AO image ever taken (6 continuous arc-min²) with $0.25''$ resolutions of the Trapezium cluster in Orion. This large, high-resolution map showed the fraction of binaries in Orion is the same as that in the solar neighborhood.

Hodapp continued the project of deep imaging of Class 0 outflow sources in K and the $2.12 \mu\text{m}$ S(1) line filter. In IC 1396 W and B335, molecular hydrogen emission and continuum nebulosity associated with embedded Class 0 sources were found.

Hodapp also continued to monitor the photometric evolution of the deeply embedded outburst star (DEOS) discovered in the Serpens molecular cloud in July 1995. Its brightness is slowly declining, suggesting a light curve somewhere between the fast declines of typical EXor and the slower decline of typical FUor stars.

Carpenter has completed a molecular line and radio continuum survey of ultracompact regions. The data will be used to determine the masses and densities of the dense cores where massive stars form. Molecular line and continuum data have also been obtained for a sample of cores in Orion to search for depletion of the molecules onto the grain surfaces. These data will examine the ratio of the gas to dust column densities over a range of gas temperatures to determine if there is a critical temperature at which molecules begin to freeze onto grains. He has also completed a near-infrared imaging and spectroscopic study of the MonR2 stel-

lar cluster (see AJ, 114, 198). The MonR2 cluster is shown to constitute one of the richer dense stellar clusters in the solar neighborhood.

7. STELLAR ASTRONOMY

Boesgaard continued research on the abundances of the light elements aimed both at a determination of the primordial (Big Bang) production of Li and at an understanding of internal stellar structure of solarlike stars. J. King (STScI), C. Deliyannis (Yale), and Boesgaard have determined the lithium (Li) abundance in the halo star BD+23 3912 ($[Fe/H] = -1.5$) to be a factor of 2–3 above the Li plateau found for the field halo stars. This remarkable difference could reflect either (1) less-than-average stellar Li depletion from a higher primordial Li abundance (as predicted by the Yale rotational stellar evolutionary models), which may have interesting implications for Big Bang nucleosynthesis, or (2) the extraordinary action of Galactic Li production mechanisms. (It is also possible that both processes have acted.) They used high-resolution, high signal-to-noise Keck HIRES spectra to determine the s-process element abundances and the ${}^6\text{Li}/{}^7\text{Li}$ ratio in this star. These values serve as signatures for two possible Li production scenarios: the ${}^7\text{Be}$ transport mechanism in asymptotic giant branch (AGB) stars and cosmic ray interactions with the interstellar medium. The unremarkable abundances of yttrium, zirconium, barium, lanthanum, neodymium, and samarium that they derived argue against a significant contribution to this star's excess Li from AGB production mechanisms carrying an s-process signature. Since halo subgiants like BD+23 3912 are expected to be particularly good ${}^6\text{Li}$ preservers, their conservative upper limit of ${}^6\text{Li}/{}^7\text{Li} < 0.15$ (compared to 0.25–0.30 expected from cosmic ray production) argues against cosmic ray + ISM interactions as the source of the excess Li, unless Li depletion from an even higher Li has occurred with preferential ${}^6\text{Li}$ depletion. Highly speculative red giant branch production scenarios also seem unlikely given the normal sodium and aluminum abundances they found and the normal carbon and oxygen abundances found by others. The totality of Li data on halo subgiants argues against possible diffusion scenarios, in which all such stars dredge up Li that diffused during the main-sequence lifetime. The high Li abundance is consistent with that expected from Yale rotational models having lower-than-average initial angular momentum.

In another approach to the determination of the primordial Li abundance, Boesgaard, with Deliyannis, graduate student A. Stephens, and King, made observations of Li in turn-off stars in one of the oldest and most metal-poor globular clusters, M92. They made Keck I/HIRES observations at $R = 45,000$ ($= 3$ pixels) of six stars near the turnoff; for three of these stars they have a signal-to-noise ratio of 40 (per pixel), while the other three are ~ 20 . They found that star 18 has a Li abundance that is about a factor of 2–3 larger than that in stars 21 and 46. The Li abundance in star 18 is high compared to the halo field star plateau and is similar to that in the remarkable Li-rich halo star BD+23 3912. They have attempted to determine whether the excess Li in star 18 is due to less-than-average Li depletion in this star from an even higher initial abundance, as predicted by the Yale rota-

tional models, or to the extraordinary action of Li production mechanisms in the material that formed this star. They found no convincing evidence that favors Li production. Stars 18, 21, and 46 have identical Ba abundances, which argues against Li production carrying an s-process signature. These three stars have indistinguishable calcium, chromium, iron, and titanium, which argues against supernova Li production. They considered ν -process production of Li and found no convincing observational evidence for this from the strengths of the magnesium, Ca, and Fe lines. The similarity in age of these cluster stars argues against cosmic-ray Li production that requires age differences of billions of years. At present, the most likely explanation is differential Li depletion from a (possibly significantly) higher primordial Li abundance.

Stephens, together with Boesgaard, Deliyannis, and King studied the element beryllium in stars known to be deficient in Li. These observations were made at the CFHT in the ultraviolet region near 3130 Å of the Be II doublet in lithium-deficient F and G dwarfs. They also made revised Li abundance estimates for the entire sample using updated, consistently calculated stellar parameters with previously published equivalent widths. Abundances derived from LTE analyses of the Li and Be line-forming regions confirmed the suspicion that F stars that deplete Li by factors of 10–200 may also be Be-deficient. Photospheric Be concentrations ranged from near meteoritic levels in G dwarfs to factors of 10–100 below this assumed initial abundance in hotter stars. Moreover, significant Be deficiencies were found in stars that populate a 600-K-wide effective temperature window centered on 6500 K. This Be abundance gap is reminiscent of the Li gap observed in open clusters. They also discovered 12 new stars that are like 110 Her: objects that exhibit a depleted, *but detected*, surface concentration of both Li and Be. These provide a powerful means of differentiating between the possible physical processes responsible for observed light-element abundance patterns. Indeed, their Be results, in conjunction with the newly calculated Li abundances, led to the following conclusions regarding the hypothesized light-element depletion scenarios: (1) Mass loss cannot account for stars with severely depleted (but detected) Li and moderate Be deficiencies. (2) The predicted timescales for surface depletion due to microscopic diffusion are too long for significant Li and Be deficiencies to develop in cool ($T_{\text{eff}} \leq 6200$) stars; nevertheless, underabundances are observed in these stars. (3) Diffusion theory also predicts Li and Be depletion rates to be comparable, but it is evident that Li and Be depletion proceed at different speeds. (4) Models of mixing induced by internal gravity waves cannot explain mild Be deficiencies in cool dwarfs. (5) A key meridional circulation prediction regarding the efficiency and severity of Li and Be dilution was shown to be fallible. (6) However, rotationally induced mixing, a turbulent blending of material beneath the surface convection zone due to the onset of instabilities from superficial angular momentum loss, predicts both the observed light element depletion morphology as well as the existence of 110 Her analogs. These “Yale” mixing models provide, therefore, the most plausible explanation of those presented for the observed Li and Be abundances.

In a related study, Boesgaard, with Deliyannis, Stephens, and D. Lambert (Univ. of Texas), studied boron in Li- and Be-deficient stars. The Goddard High Resolution Spectrograph (GHRS) was used with the *HST* to observe the B I region at 2497 Å in nine F and G dwarfs of approximately solar metallicity. The stars were selected because they have a variety of Li and Be deficiencies. Most of the nine stars were also newly observed at high spectral resolution and high signal-to-noise ratios at the Keck I telescope, the CFHT, and the UH 2.2 m telescope at 3131 Å for Be II and at 6708 Å for Li I. With spectrum synthesis they determined the abundances of B in nine program stars and in five other stars from the *HST* archive. The stellar parameters used were determined in a self-consistent way for the program stars and the archive stars. Spectrum synthesis was also used to determine the Li and Be abundances or upper limits. Corrections to the B and Li abundances due to non-LTE effects were applied.

The stars originate from the region on the zero-age main sequence (ZAMS) of the Li (and Be) dip. In spite of large deficiencies in Li and Be, they found a striking uniformity in the B abundances, i.e., there is no B dip. In all cases the Li deficiency is greater than the Be deficiency. For the coolest and most evolved star in the sample, ζ Her A, the B abundance is 0.5 dex lower than the mean for the other stars. This star also has the largest Be deficiency (more than a factor of 60) and the largest Li deficiency (more than a factor of 500). These data, together with other studies of the Li dip, argue strongly against diffusion and mass loss, and in favor of slow mixing as the cause of the Li and Be dip and the absence of a B dip.

Six stars with [Fe/H] from -0.75 to $+0.15$ have Be abundances ranging from the maximum of the sample to a factor of 4 below the maximum, yet these stars have a B/Be ratio that is constant to within ± 0.10 dex and that is close to the predictions of Galactic cosmic-ray spallation of 10–15. The Be range for four stars with solar metallicity is still a factor of 2, and yet the B/Be ratio is constant to within ± 0.03 dex. These results imply that the Galactic cosmic-ray production of B and Be is not uniform relative to the production of elements such as Fe by stellar nucleosynthesis.

Boesgaard and colleagues also studied the abundances of Li and Be in solar twins and solar analogs, in particular the visual double stars 16 Cyg A and B and α Cen A and B. Research on Li in these two pairs by King, Deliyannis, D. Hiltgen (Univ. of Texas), Stephens, K. Cunha (National Observatory Brazil), and Boesgaard showed that the two components in each pair have very different Li abundances. Their observations are high resolution ($R \sim 45,000$ – $70,000$) and very high S/N ($\sim 1,000$) spectroscopy of the Li I 6707 Å region in each component of the binary solar twins 16 Cyg A and B, the solar analog α Cen A, and α Cen B. Spectra of 16 Cyg were obtained with the UH 2.2 m, McDonald Observatory 2.1 m, and Keck telescopes, and were reduced independently. Comparison of spectral synthesis with the 16 Cyg data and similarly obtained solar data, yielded ${}^7\text{Li}$ abundances that show excellent concordance between the various datasets. Despite differing in T_{eff} by only 35–40 K, the Li abundances of 16 Cyg A and B differ by a factor of ≥ 4.5 .

The solar photospheric abundance is intermediate between the two values. This intermediacy indicates that the Sun, whose highly depleted photospheric Li abundance is in gross conflict with standard stellar models, is not an isolated anomaly in its Li abundance evolution. A similar conclusion is reached via comparison of α Cen A and metal-rich Hyades dwarfs. The difference in the 16 Cyg components' abundances suggests, though does not directly establish, a slow (possibly rotationally induced) mixing mechanism operating below the surface convection zone in these stars. Indeed, the Li abundance difference can be viewed as an analog to the Li abundance dispersion seen in cool stars of similar T_{eff} in open and globular clusters, and in Galactic field halo stars. It is possible, in principle, that the low Li abundances of the Sun and 16 Cyg B with respect to 16 Cyg A may be related to the presence of a planetary companion; extant Li abundances of 47 UMa, 51 Peg, and HD 114762 might further support such a connection between planets/disks, angular momentum evolution, and photospheric Li abundances. Because of a variety of uncertainties, however, any conclusions remain tenuous and speculative at this time.

The Be study was a joint project of King, Deliyannis, and Boesgaard. At the Cerro Tololo Inter-American Observatory (CTIO) 4 m telescope, they obtained high-resolution, high-S/N spectra of the Be II 3131 Å region in the metal-rich solar analog α Cen A and its companion α Cen B. Be abundances were derived relative to the Sun in a consistent fashion via spectrum synthesis. For α Cen A, they found $[\text{Be}/\text{H}] = +0.20 \pm 0.15$ where the error reflects random uncertainties at the 1σ confidence level; systematic errors of ~ 0.1 dex are also possible. Analysis of α Cen B is more uncertain since inadequacies in the line list, which was calibrated with solar data, may manifest themselves in cool metal-rich dwarfs. Their analysis suggests $[\text{Be}/\text{H}] \leq +0.05$, which is lower than the value of A, but not significantly so given the uncertainties in the A determination alone. They also considered uncertainties in the solar photospheric and meteoritic Be abundances and concluded that it is likely that the former value is depleted relative to the latter by 0.1–0.5 dex. Even a slight real depletion in solar photospheric Be coupled with the observed Li depletion of ~ 2 dex would favor a slow (possibly rotationally induced) mixing mechanism in addition to standard model burning at the base of the convection zone. If the difference in the Be abundances of α Cen A and B is real, it too would strongly suggest the action of additional nonstandard mixing mechanisms. They concluded that the light element abundances of the Sun and α Cen A (and other solar analogs) are not grossly dissimilar. The idea that standard models and the current solar photospheric Li and Be abundance are discrepant because the Sun is a lone “odd-ball” is doubtful.

Simon, along with collaborators S.L. Cully and G.H. Fisher (Space Sciences Laboratory, Berkeley), and S.L. Hawley (Michigan State), completed their analysis of spectra of the flare star AD Leo, taken by the *Extreme Ultraviolet Explorer (EUVE)* spacecraft during the March 1993 flare of this star. The EUV spectra are dominated by iron lines from a hot coronal plasma. A novel version of the regularized inversion technique was developed to take account of infor-

mation in the plasma emissivities as well as the S/N ratio of the spectrum. The method was applied to AD Leo to derive a differential emission measure distribution for the flare and for the quiescent corona of this star. The emission measure during the flare is strongly peaked at temperatures above 10^7 K, and it declines to lower values during the decay phase of the flare. The results of the spectral analysis are consistent with the tall loop model developed by the same authors in an earlier study, based on their analysis of the EUV light curve taken by the *EUVE* Deep Survey instrument during the same flare in 1993. In May 1996, a moderate-size flare of AD Leo was observed at X-ray wavelengths with the *ASCA* satellite by the same investigators. A preliminary analysis of the SIS light curve reveals a strong Fe/H deficiency in the coronal spectrum during quiescence (the so-called first ionization potential effect), which vanishes during the flare as the Fe/H ratio rises to very nearly the photospheric value.

Simon and W. Landsman (NASA Goddard and Hughes STX) used the GHRS aboard the *HST* to detect N V 1239 Å emission in spectra of Altair and α Cep. This is the first time $1-3 \times 10^5$ K transition material has been observed in the spectrum of any normal A star. They also reported the detection of Si III 1206 Å and Lyman- α 1216 Å emission in the GHRS spectrum of the middle A star, τ^3 Eri, making this star the hottest main-sequence A star known to have a chromosphere and a convection zone. Simon obtained a well-exposed 900–1200 Å spectrum of α Cep during the 19 November to 7 December 1996 flight of the space shuttle *Columbia* as part of the ORFEUS-SPAS II guest investigator program on STS-80. Emission lines of C III 977 Å and 1176 Å are present, as are those of O VI 1032 Å and Si III 1206 Å. Simon and J.-C. Bouret and C. Catala (Laboratoire d'Astrophysique de Toulouse, France) observed the pre-main-sequence Ae star AB Aurigae with the GHRS on *HST* and detected emission at N V 1239 Å. This observation provides evidence for the presence of material at much higher temperatures than 17,000 K, the hottest chromospheric temperature previously established from the ultraviolet lines of C IV. The N V emission is modeled in terms of hot clumps ($\sim 150,000$ K) that form as fast-streaming gas overtakes and collides with slow-moving gas in the wind of this star.

Simon and C. S. Jeffery (Armagh Observatory, Northern Ireland) published their study of an *International Ultraviolet Explorer* (*IUE*) eclipse light curve of HD 185510 (= V1379 Aql), a double-lined binary containing a K0 III/IV primary of the RS CVn class and a hot, subluminescent secondary star. The light curve resolves the ingress and egress phases of the secondary eclipse. Also analyzed were a high-dispersion *IUE* spectrum in the vicinity of 1300 Å and the Lyman- α profile of the companion star. The spectroscopic analysis favors the identification of the secondary as a helium white dwarf, while the orbital solution points instead to a sdOB classification. A fit to the spectral energy distributions of both stars succeeds only if the primary is moderately deficient in metals.

Simon took part in the Multi-Site Continuous Spectroscopy (MUSICOS) 1996 campaign at the CFHT in November 1996. Using Zeeman-Doppler tomography, the campaign focused on variability in the wind of the O star ξ Per, on the

surface and wind magnetic structure of the pre-main-sequence Ae star AB Aur, and on star-disk magnetic interactions in the T Tauri variable SU Aur. The campaign was beset by unusually poor weather on Mauna Kea.

Simon and S. Wolff (NOAO/KPNO) measured rotational velocities for a large sample of field A and F stars, based on high signal-to-noise CCD spectra taken at the coude feed telescope of the KPNO. A comparison was made with mean velocities published for young stars in the Orion, α Persei, Pleiades, and Hyades clusters. The study shows that stars more massive than $1.6 M_{\odot}$ experience little or no change in rotation within the main-sequence band, while stars between 1.6 and $1.3 M_{\odot}$ show little decline in rotation on the main sequence and at most a factor of 2 decrease as they evolve off the main sequence. They concluded that the overall decline in rotation speed along the main sequence among the A and early F-type stars is imposed during the pre-main-sequence phase of evolution, and that the pattern changes relatively little during the main-sequence evolution of intermediate-mass stars. This suggests a very limited role for magnetic braking in the rotational histories of these stars.

Heasley continued his work on photometric studies of Galactic globular clusters. The main thrust of this work is to establish the chronology of the globular clusters located in the vicinity of the Galactic center. This includes both clusters in the metal-rich thick disk population and several metal-poor clusters located within 2–3 kpc of the Galactic center. The primary observations for the program have been obtained with the *HST*, with supporting data obtained at the CFHT, the UH 2.2 m telescope, and the Kitt Peak 0.9 m telescope. Collaborators in this work are K. Janes (Boston Univ.), P. Demarque and R. Zinn (Yale), and G. Da Costa (Mount Stromolo Observatory).

The metal-rich thick disk clusters being studied include NGC 6624 and NGC 6637 (from the *HST*) and M71 (from the ground). Preliminary color-magnitude diagrams have been obtained for all three of these clusters using subsets of the available observations. From a direct comparison of their color-magnitude diagrams, both NGC 6624 and NGC 6637 appear to be identical in age within the uncertainties of the data. The difference in color between the main-sequence turnoff and lower giant branch suggests that M71 is somewhat younger than the other two clusters. If this result holds, it suggests that the thick disk of metal-rich clusters formed over an extended period of time, perhaps on the order of several billion years.

Heasley has also developed color-magnitude diagrams for the metal-poor globulars NGC 6293 and NGC 6333. Both of these clusters are located near the Galactic center, but have metallicities typical of the metal-poor clusters in the Galactic halo. New estimates of the metallicities of both clusters obtained by Da Costa confirm the low metal abundances. The color-magnitude diagrams for these clusters have been compared with a new (V , $V-I$) color-magnitude diagram for M92 derived from CFHT and UH 2.2 m observations. The clusters appear to be identical in age to each other and to M92. If the orbits of NGC 6293 and NGC 6333 are indeed confined to the inner halo, this suggests this region of the Galaxy formed at the same time as the outer halo. This result

is in conflict with suggestions by Y. W. Lee (Yonsei) that the oldest metal-poor stars near the Galactic center are older than halo clusters like M92.

In collaboration with A. Sarajedini (NOAO), Heasley began an investigation of the outer halo globular NGC 5024. *BVI* observations of the cluster obtained with the Kitt Peak 0.9 m telescope are being used to develop color-magnitude diagrams for stars extending out to the tidal radius of the cluster.

Abbott continued his research into cataclysmic variables and their progenitors with the report of observations taken at ESO of a *ROSAT*-discovered cataclysmic variable, RX J2353.0-3852. The optical spectrum shows strong, double-peaked Balmer emission, embedded in absorption troughs from $H\beta$ onward and similarly doubled He I and Fe II emission; He II $\lambda 4686$ is not seen. Optical light curves show a periodicity at 5246 s with its first three harmonics, and another at 2282 s. These periodicities were not present in further observations made in September 1994. A pointed observation in 1994 with *ROSAT* yielded a spectrum consistent with a dwarf nova with a low-mass transfer rate (see A&A, 318, 134).

With J. Patterson (Columbia) and others, Abbott studied the recent outburst of the SU UMa star AL Com. The overall eruption light curve was striking, suggestive of two superoutbursts in rapid succession. During the first week of eruption, the light curve sported a period of 81.63 ± 0.07 min. This signal declined quickly in amplitude, and was replaced by a stronger signal at 82.55 ± 0.03 min. The latter bears all the earmarks of a “common superhump,” a feature usually seen in SU UMa-type dwarf novae in superoutburst. This superhump endured at least 40 days, with no secular period change.

The quiescent light curves were reexamined to search for a stable photometric signal that might signify the true binary period. They found a stable double-humped waveform with a fundamental period of 81.6025 ± 0.0001 min—the shortest period yet seen among dwarf novae, and probably very nearly the shortest period attainable by any binary star with a hydrogen-rich secondary. In orbital period and quiescent light curve, as well as in the eruption light curve, the star is a virtual twin of WZ Sge. There are also large-amplitude waves with a period in the range of 83–90 min; these “quiescent superhumps” are rarely found in cataclysmic variables, and require an origin somewhat different from that of the common superhumps characteristic of SU UMa stars in eruption. We speculate that they arise from instability at the 2:1 orbital resonance in the accretion disk and that the secondary has been whittled down to $<0.04 M_{\odot}$ (see PASP, 108, 748).

Observations of the old nova HZ Puppis, also at ESO, reveal it to be an intermediate polar whose light curve displays an exceptionally rich selection of photometric periodicities arising from spin and orbital variations and beating between these two. This system is a candidate for the new class of diskless intermediate polars.

With F. Ringwald (Pennsylvania State Univ.), Abbott is engaged in a program to study composite spectrum binaries as possible survivors of common envelope evolution. This

program involves high-resolution imaging with the adaptive optics bonnet at CFHT to identify those binaries that are not optically evolved and are therefore possible common envelope evolution remnants. Low-resolution spectroscopy of other candidates has been obtained at the Dominion Astrophysical Observatory. Results include the identification of a long-period eclipsing system that may help to define the long-period limit of the common envelope phase.

With C. Haswell (Univ. of Sussex, UK), and using the KSPEC spectrograph on the UH 2.2 m telescope, Abbott is obtaining near-infrared spectroscopy of cataclysmic binaries and low-mass X-ray binaries to dissect the accretion geometry of these objects.

8. SOLAR SYSTEM STUDIES

Dumas worked with Owen on adaptive optics observations of solar system objects (asteroids, satellites, giant planets, rings) and near-infrared spectroscopy of primitive solar system objects. He used telescopes worldwide that are equipped with adaptive optics systems, including those at ESO, Mount Wilson, and Mauna Kea. He obtained some very high resolution of the asteroids Vesta, Ceres, and Pallas with the aim to map the surface of these minor bodies through selected narrowband filters that match the spectral features of the minerals present in their regoliths. Dumas’s work on Vesta consists of measuring the abundances of the diogenites and eucrites at the surface of Vesta to constrain the existing models of differentiation of this asteroid. The purpose of the adaptive optics observations of the large C-class asteroids like Ceres and Pallas is to search for the presence of bound water on their surfaces and determine if there are polar caps on Ceres.

Dumas was also involved in other programs using adaptive optics systems, including searching for satellites of asteroids and monitoring the volcanic activity of the Jupiter-facing hemisphere of Io during Io’s eclipses. The resolution obtained on Io from the ground is at least comparable with the Io infrared images obtained with NIMS, the Near-Infrared Mapping Spectrometer aboard the *Galileo* spacecraft.

Dumas’s interest is also oriented toward the surface composition of the most primitive objects of the solar system. He obtained a collection of near-infrared spectra of dark asteroids, mainly P- and D-type asteroids, to search for the presence of organic compounds on their surfaces. He is also involved in projects to obtain infrared spectra of Kuiper Belt objects and Centaurs using large telescopes.

Graduate student J. Bauer completed work on a master’s thesis project started at the State University of New York at Stony Brook in collaboration with J. Lissauer (NASA Ames) and M. Simon (Stony Brook). The thesis involved the analysis of 1995 Saturn ring-plane-crossing data obtained at the IRTF that yielded near-infrared photometry of the faint E and G rings and several small moons.

Meech continued her 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 which are entering the solar system from the Oort cloud for the first time) and the periodic comets, and (2)

to interpret these differences, if any, in terms of their physical and chemical nature, and the evolutionary histories of the two groups of comets. Observations of approximately 50 comets over a range of heliocentric distances have been continuing for several years and are nearing completion. The data will be compared to models of the level of activity (brightness and extent of coma) as a function of distance to interpret the observations in terms of possible evolutionary or aging processes, or as differences in primordial source regions. Highlights are as follows:

Observations of cometary comae at large heliocentric distances is now routine for the dynamically new comets, and this clearly indicates that there is a strong difference in the brightness curves of the Oort comets compared to the periodic comets. The dynamically new comets and the short-period comets are believed to have formed in different regions, with the short-period comets forming at lower temperatures. The differences in activity levels seen between the comet classes are almost certainly due to evolutionary or aging effects. *HST* observations of five Oort comet nuclei by Meech and Hainaut have yielded upper limits to the sizes of the nuclei that are small and comparable to the sizes of the known short-period nuclei. This has important implications for the extreme activity levels in these comets as well as for models of the outer solar system that suggest the Oort comet size distribution should be primordial, but the short-period comets are probably collisional fragments from the Kuiper Belt.

An observing campaign to follow 2060 Chiron through its 1996 perihelion was successful. Both the UH 2.2 m and the KPNO 0.9 m telescopes were used. The goal was to get nearly nightly observations of Chiron to look both at its long- and short-term brightness variations and coma extent, and to be able to coordinate this with deep Faint Object Camera (FOC) observations made with *HST* during spring 1996. The set of observations is being used to interpret the structure of the bound dust coma seen in cycle 2 *HST* observations by Meech, M. Buie (Lowell), and M. Belton (KPNO). There is a straightforward relationship between the extent of this bound atmosphere (the exopause), the size of the dust grains in the coma, and the size of Chiron's nucleus and its mass, and the *HST* observations imply a very low nucleus density for Chiron. Because of recent occultation measurements that give a good estimate of Chiron's size, for the first time it is possible to estimate the density of a comet nucleus, which has fundamental implications for the condensation processes in the early solar nebula.

In addition, Bauer and Meech, in collaboration with Belton and others, are planning to begin development of a sophisticated bound atmosphere model. Monitoring the color of the coma dust in an attempt to correlate this with the level of activity has continued through the spring of 1997, and several runs were devoted to getting the 1995–96 observations calibrated on the same photometric system so that a grand light curve can be constructed to examine the long-term activity.

Meech and Hainaut continued their program of distant comet recovery using the UH 8K CCD mosaic camera. The goal is to recover periodic comets much earlier than is typi-

cal (which is usually 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. As this will be done primarily in the ecliptic and the images will go deep, it is likely that many new Kuiper Belt members will also be found. During four successful runs using the UH 2.2 m telescope and the CFHT, recovery data for 13 comets was obtained, and five were recovered (although data analysis was continuing). Hainaut finished the development and testing of a neural networking algorithm to make automated searches for faint moving objects in these large images, and this work is being written up for publication.

Comet 55P/Tempel-Tuttle, the parent of the Leonid meteor stream, was recovered by Meech and her group using the Keck telescope. This is the first physical data on the comet nucleus since the comet was discovered in 1865 (the only other data being three astrometric data points obtained in 1965). Observations from 10.8 to 3.5 AU showed no activity from the 1.8 km nucleus. An observing campaign has been planned to characterize the comet before the 1998–99 meteor showers, which may be significant.

Meech, Hainaut, and Bauer observed three comets that are candidates for future space missions. For premission planning and a successful encounter, one needs to know the rotation, the pole of rotation, the size, albedo, and characteristics of the dust environment around the comet. Observations continued to obtain the rotational light curve of 3200 Phaethon. This is part of a long-term campaign to characterize the nucleus of this object, the progenitor of the Geminid meteor stream, which is believed to be an extinct or dormant comet nucleus, and may be the target of a future space mission. The current goals of the campaign are to observe the rotational light curve, which has a period of 3.6 hr, at several different epochs in order to fit for a pole solution. The data is currently being analyzed. A large visible-infrared-radio campaign was planned for fall 1997 during Earth's close approach to Phaethon.

Observations of the Rosetta target, comet 49P/Wirtanen, were made during August 1996 with the UH 2.2 m telescope. Analysis of this data was completed, and they found a rotation period near 7.6 hr with a minimum axis ratio of 1.7. With observations at 3 epochs they were able to watch the development of the coma, and have inferred that activity began between 3.5 and 4.5 AU from the Sun. A comparison with *HST* data suggests that the albedo of the nucleus is very low, near 0.04.

Observations have been ongoing through the perihelion of 81P/Wild 2, the target of the NASA STARDUST mission, which will send a spacecraft within 150 km of the nucleus to collect samples of the dust coma in aerogel for return to Earth. Success of this mission will depend on careful modeling of the dust environment in the inner coma. Observations obtained during this past year are being added to a 9 yr database of observations. The analysis of the database has shown that the nucleus has a radius of 2 km. Detailed dust models are being developed in collaboration with R. Newburn (JPL) to assess the probabilities of impact from millimeter-size dust near the nucleus.

As part of the guaranteed observing time with the NICMOS instrument development team, Smith, Meier, and Owen have been preparing numerous observing runs for NICMOS, the new infrared camera aboard the *HST*. The planetary program involves narrowband and wideband photometry as well as low-resolution spectroscopy of various satellites and planetary rings in our solar system. Additional targets are dust disks around selected main-sequence stars. First observations will be completed in mid-October 1997.

Owen and Meier, in collaboration with Jewitt and Tokunaga, also conducted an intense observing campaign in the infrared and submillimeter to search for rare isotopes and new molecules in comet Hale-Bopp during its peak activity. Highlights of this program were the detection of deuterated water and the discovery of DCN, the first deuterated species found in a comet that does not belong to the water group. The D/H in water suggests that comets cannot be the only source for Earth's ocean, while the high D/H ratio in HCN supports the pristine nature of comets.

C. Roddier and F. Roddier continued analysis of images of the Saturn ring system taken using the adaptive optics system in August 1995, as Earth was crossing the ring plane. Evidence was found for nine additional clumps in the F ring that escaped *HST* observations (IAU circular 6515). Evidence was also found for particles on a tadpole orbit ahead of Enceladus (IAU circular 6697). Images of Neptune and Proteus taken in 1995 were also analyzed (Planet Space Sci., 45, 1031).

They also participated in several other solar system projects that used the adaptive optics system: In cooperation with Owen, new images of Neptune were taken both in November 1996 and July 1997. These images will help to keep track of the stratospheric cloud activity and determine wind velocities at these altitudes. In cooperation with Owen and Tholen, they obtained narrowband images of Pluto and Charon that show clear differences in the surface composition of these two objects. Narrowband images of Titan were taken by graduate student B. Han as part of his Ph.D. thesis research.

Tholen pursued high-speed photometric observations of Galilean satellite mutual events, which occur near each Jovian equinox about six years apart. The latest series of events occurred in 1997. A principal goal of these observations is an improved measurement of the secular acceleration of Io's orbit, which depends on both the energy being dissipated by Io's volcanoes and the tidal acceleration. The former would cause Io to spiral inward, while the latter does the opposite, because Jupiter rotates faster than Io revolves.

Tholen and graduate student R. Whiteley continued to survey ecliptic regions at small solar elongations to look for Aten asteroids with aphelia close to 1 AU. Such objects represent a potential impact hazard, yet the probability of their discovery by opposition search techniques is very small. To compensate for phase losses, a larger aperture telescope (the 2.2 m) is being employed, and to compensate for the small field of view normally provided by such a long-focal-length instrument, the 8K CCD mosaic camera was chosen as the detector. Approximately 13 deg^2 of sky have been imaged so far. Although no Aten asteroids have been discovered to

date, the Apollo asteroid 1997 QK1 was discovered by this program on 27 August 1997. This object has a perihelion distance very close to 1 AU and ranks in the top 50 objects that pass close to Earth's orbit. It is also substantially larger (about 0.5 km estimated diameter) than many of the objects that pass closer.

The eccentricity of Charon's orbit continued to be a subject of study by Tholen. Attempts were made during the reporting period to combine the *HST* data obtained by Tholen and Buie with those obtained by G. Null (JPL) and Owen, in hopes of improving the overall orbit solution. The principal difficulty is ensuring that the image scale and position angle calibrations are consistent between the two data sets. Tholen has also been investigating with Buie the possibility of using the *HST* FOC images of Pluto to determine better offsets between the center of light and the center of body. Such information has a significant effect on the orbital eccentricity solution. Work is progressing on both fronts. Ultimately, it is hoped that ground-based observations can be included in the orbit solution process.

Tholen continues to participate in the Planetary Data System Small Bodies Node. A significant effort in 1997 was directed toward helping the 2MASS infrared sky survey project identify asteroids in the scans. It is hoped that over the lifetime of the survey, several thousand asteroids will be homogeneously observed at *JHK* wavelengths.

Whiteley continued physical observations of near-Earth asteroids under the supervision of Tholen. In collaboration with J. Bell (UH Planetary Geosciences), a filter wheel and a new set of infrared filters were procured to permit observations of fainter near-Earth asteroids in the 0.8–2.5 μm wavelength range at the IRTF. The first observations with this new system were made in late 1997.

Jewitt continued a highly successful program to discover objects in the Kuiper Belt beyond Neptune in collaboration with J. Luu (Harvard-Smithsonian Center for Astrophysics) and assisted by graduate students J. Chen and C. Trujillo.

Jewitt also embarked on a systematic effort to observe comet Hale-Bopp at submillimeter wavelengths at approximately weekly intervals while it remained far enough north to observe from Mauna Kea. The observational effort was shared with recent IfA graduate M. Senay (now at Univ. of Massachusetts, Amherst), H. Matthews (Joint Astronomy Centre, Hilo), and K. Berney.

H. Weaver (Johns Hopkins), T. Brooke (JPL), M. DiSanti, M. Mumma, G. Chin, and C. Lisse (NASA Goddard), and Tokunaga and Owen reported observations of the methane abundance in comet Hyakutake. Seven lines of the ν -3 fundamental of the methane at 3.3 μm were observed, and the methane abundance relative to water was found to be about 1% with an uncertainty of a factor of 2. This abundance is consistent with observations of the methane-to-water abundance in dark molecular clouds. The rotational temperature derived from the line intensity ratios indicates that the rotational temperature varied approximately inversely with heliocentric distance.

9. SOLAR PHYSICS

9.1 Coronal Temperature Measurement

LaBonte and K. Reardon (Osservatorio Astronomico di Capodimonte) developed a novel technique that uses the *Yohkoh* Soft X-ray Telescope (SXT) data, to measure coronal temperatures from the average energy of photons received through single filters. Individual X-ray photons in the keV energy range produce hundreds of photoelectrons in a single pixel of a CCD array detector. The number of photoelectrons produced is a linear function of the photon energy, allowing the measurement of spectral information with an imaging detector system. The *Yohkoh* SXT uses a CCD in an integrating mode and makes temperature estimates from multiband filter photometry. LaBonte and Reardon showed how the SXT can be used in a new way to perform a limited type of photon spectroscopy. By measuring the variance in intensity through a single filter of an X-ray source on repeated SXT images, the mean energy per detected photon can be determined. This value is related to the underlying coronal spectrum, and hence can be used to deduce the plasma temperature. They compared the results of the temperatures derived using this new technique on a series of SXT images of a post-flare loop system with the temperatures derived using the standard flux-ratio method. The comparison demonstrated that the bright postflare loops really are cooler than the surrounding material, as shown via the flux-ratio method by Tsuneta and collaborators. Given the large dynamic range of the soft x-ray flux observed from the Sun, they were able to describe the requirements for a future instrument that would take advantage of photon spectroscopy.

9.2 Isolated Active Regions

LaBonte, H. Hudson (Space Physics Research Center), A. Sterling (Naval Research Laboratory), and T. Watanabe (National Astronomical Observatory of Japan) worked on the isolated active regions AR 7978/7981 from July and August 1996. This region is very interesting because its appearance on an otherwise blank Sun makes it a “test particle” for understanding the nature of its activity and its effects on the global corona. Statistical study of the soft X-ray events is the primary focus of this study. The flares of this region show no indication of obeying a relaxation oscillator. During its second disk passage as AR7981, the decay of sunspots and magnetic complexity was accompanied by an increase in the flare rate and flare sizes. The effects of this region in energizing an entire hemisphere of the corona are dramatically seen in the SXT images for the July 1996 time period.

9.3 Multiwavelength Study of Solar Flares

Graduate student K. Blais successfully defended her Ph.D. thesis, “A Search for Optical Proxies for High Energy Emissions from Solar Flares.” Combining optical observations of the strong Ca II K line and H I Balmer α lines taken at Mees Solar Observatory with hard X-ray burst data from GRO/BATSE (Gamma-Ray Observatory/Burst and Transient Source Experiment) and soft X-ray light curves from the *Geostationary Operational Environmental Satellite*

(*GOES*) spacecraft, she was able to quantitatively test whether optical lines in solar flares are reliable proxies of coronal emissions. Her study is unique in providing quantitative values for the optical fluxes integrated over space and wavelength, and in its focus on flares of small total flux. She found that several temporal correlations exist between the optical and X-ray emissions. Despite the selection of the flares as hard X-ray emitters, the flux ratio of K and Balmer α and the temporal behavior demonstrate that the nonthermal beam is stopped in the transition region, producing flares that should be EUV bright.

9.4 Estimation of Coronal Magnetic Field Structure

Graduate student L. Jiao continued his thesis work on three-dimensional reconstruction of solar coronal magnetic fields. Working with A. McClymont, R. Canfield (Montana State), and Z. Mikic (Science Applications International Corporation), he found that analysis of active region AR7220/7222 has revealed some remarkable features of the solar coronal magnetic field: The region of bright X-ray loops is bounded by separatrix surfaces and restricted to regions of short field lines. Surrounding areas conspicuously lacking in soft X-ray emission are connected by long field lines to distant opposite polarity. The force-free field lines align well with observed coronal loops and agree better than potential field lines do. The footpoints of the brightest set of loops lie in a photospheric flux tube that has a very distinct sheath of return current. Furthermore, the bright loops appear to have both ends rooted in quite strong magnetic fields. The separatrix surfaces do not seem to contribute to heating of the loops; the lengths of the field lines and field strength at the footpoints seem to be the most significant factors.

These findings stimulate the investigation of the physics of loop heating in other active regions. They reconstructed the coronal magnetic field of AR6919 from a series of three magnetograms that span the 15 November 1991 flare event. They also compared coronal fields of AR6919 computed from two kinds of boundary conditions: one with the α specified everywhere, the other with α specified only over one polarity. They expanded their study of loop heating by computing loop brightnesses based on heating fluxes dependent on the footpoint magnetic field strength, applying the coronal loop scaling law to determine temperature and density, and mapping those onto the computed field lines. They can then compute the X-ray flux and integrate along the line-of-sight to obtain two-dimensional images.

Jiao continued his work on the numerical characteristics of three-dimensional reconstruction of solar coronal magnetic fields based on Mees Stokes vector magnetic field data. He found the ambiguity resolution of the magnetogram sometimes plays an important role in leading to the stable state. The ambiguity correction method relies to some extent on comparing the measurements with the computed potential field or linear force-free field, which is not good in case the fluxes do not balance within the magnetogram field of view. He is now testing on how to improve the stability of the method. When applying methods such as embedding a small field-of-view Mees Stokes vector magnetogram into a larger

field-of-view Kitt Peak magnetogram to balance flux, some spurious currents are introduced around the edges of the intersection.

9.5 Polar Plumes

Mickey and J.-P. Wülser (Lockheed) continued work on the analysis of the March 1996 polar plumes data. The principal question is the determination of the orientation of the photospheric magnetic fields with respect to the overlying coronal structures. The vector magnetic field observations taken with the Imaging Vector Magnetograph (IVM) provide the opportunity to follow the field orientations to the surface level.

9.6 Image Reconstruction for Stokes Polarimetry

The IVM at Mees Solar Observatory is designed to measure the magnetic field vector over active-region-size areas of the Sun. The first step in that process is the correction of the raw data for all known systematic effects introduced by the instrument and Earth's atmosphere. LaBonte, Mickey, and K.D. Leka (Space Environment Laboratory) have completed the first functional model of the *atmosphere/instrument* system and measured the corrections for the degradation introduced by each component of the model. Particularly important is the use of the second channel of images, taken in the unpolarized continuum, to measure and remove the effects of differential seeing and image motion. The corrections are applied to standard observations, and reductions of the spurious polarization induced by atmosphere and instrument by up to a factor of 10 are found.

9.7 Polarimeter Intercalibration

LaBonte, Mickey, and Leka compared the Stokes spectra taken with the IVM and the High Altitude Observatory's Advanced Stokes Polarimeter. These two instruments represent the state of the art in vector magnetography, but have radically different designs. After correction for known instrumental properties, preliminary data indicate a better match than any of the previous magnetograph intercalibrations. Improved methods for deriving the field parameters from the Stokes spectra are being tested to make the analysis more model independent.

9.8 Ambient Acoustic Imaging

LaBonte collaborated with H.-K. Chang and D.-Y. Chou (Tsing Hua Univ.) in demonstrating a new method for observation of magnetic and other structures below the solar surface. Analogous to our viewing of objects via ambient light, structures inside the Sun can be observed with ambient sound. The ability to follow magnetic structure below the surface is an important counterpart of the observation of structure above the surface and can help decide issues of flux emergence and connectivity. Initial results show that field sunspots can be traced up to 30 Mm below the surface.

9.9 Magnetic Field Reconnection

A. McClymont and I. Craig (Waikato) continued their study of the mechanisms of magnetic reconnection and energy release in flares. Most studies of magnetic reconnection have assumed a two-dimensional geometry. Gas swept into the current sheet halts the collapse to the near-singularity required to effectively dissipate magnetic energy. The gas is squeezed out of the current sheet along the separatrices at the local sound speed. Although this allows collapse to proceed (at a slower pace), it is not yet clear whether all the gas can be removed, particularly in a closed system. Therefore it is of interest to examine how relaxing invariance along the third dimension might allow escape of gas from the current sheet and reconnection to proceed at an explosive rate. Uchida and Sakurai have examined the possibility of reconnection rate enhancement by the three-dimensional interchange instability. Some three-dimensional analyses have assumed analytic forms of solution that preclude many outcomes. Another three-dimensional simulation assumes a strong magnetic field along the current sheet. McClymont and Craig are investigating ideal instabilities and other phenomena that might allow gas to escape more effectively from the current sheet and enhance the reconnection rate.

9.10 Wave-front Sensing for Solar Adaptive Optics

Extended objects such as the Sun present a difficult problem for adaptive optics systems. Wave-front sensing must be performed on a low-contrast, partially resolved, evolving target. Graduate student R. Kupke, working with F. Roddier, studied the properties of curvature sensing techniques for application to the solar case. She found that the technique works well and is robust against various noise sources.

9.11 Instrument for Stokes Spectropolarimetry Time Series

Kupke, working with Mickey, designed and constructed a polarimeter section in the coudé feed telescope at Mees Observatory. This permits the Mees CCD Imaging Spectrograph to function as a spectropolarimeter for high time cadence observations. Tests show the system to be quite clean in its polarimetric properties, with a calibration matrix that is highly diagonal dominant. Observations of fluxtube oscillations are the primary science goal for this instrument.

10. THEORETICAL STUDIES

10.1 Cosmological Theory

Kaiser explored the dependence of weak lensing phenomena on the parameters of the background cosmology, with particular emphasis on measurement of the power-spectrum of galaxy distortions. Using empirical predictions for the distortion power based on galaxy clustering observations (normalized to cluster abundance or bulk-flows), the predicted distortions for sources at $z \sim 1-3$ are only weakly dependent on the cosmological background. However, the growth of the distortion signal with source redshift in this range is quite cosmology dependent; it is stronger in low-density models in general and in Λ -dominated models in particular. This sug-

gests that coupling weak lensing observations of supercluster-scale mass fluctuations with crude redshift information from broadband photometry may provide a way to constrain the parameters of the cosmological world model.

Kaiser and A. Jaffe (CITA) studied the statistical properties of light rays propagating through a random sea of gravity waves and compared them with the case for scalar metric perturbations from density inhomogeneities. For scalar fluctuations the deflection angle grows as the square root of the path length D in the manner of a random walk, and the rms displacement of a ray from the unperturbed trajectory grows as $D^{3/2}$. For gravity waves, the situation is very different. The mean square deflection angle remains finite and is dominated by the effect of the metric fluctuations at the ends of the ray, and the mean square displacement grows only as the logarithm of the path length. In terms of power spectra, the displacement for scalar perturbations has $P(k) \propto 1/k^4$, while for gravity waves the trajectories of photons have $P(k) \propto 1/k$, which is a scale-invariant or “flicker-noise” process. Departures from rectilinear motion are suppressed, relative to the scalar case, by a factor of $\sim(\lambda/D)^{3/2}$, where λ is the characteristic scale of the metric fluctuations and D is the path length. This result casts doubt on the viability of some recent proposals for detecting or constraining the gravity wave background by astronomical measurements (see ApJ, vol. 484).

Kofman, Kaiser, M. H. Lee (Queen’s Univ., Canada), and A. Babul (New York Univ.) have developed analytic results for the probability of amplification from microlensing in the limit of low optical depth. An important result of these calculations is the caustic induced feature at amplifications $A \sim 1/\tau$. The results are presented in a pair of papers to be published in *The Astrophysical Journal* (vol. 489); the first deals with lensing by a single screen of point masses, while the second extends the analysis to a three-dimensional distribution of lenses.

Kofman, A. Linde (Stanford), and A. Starobinsky (Landau Institute for Theoretical Astrophysics, Moscow) studied reheating after inflation. This effect occurs due to particle production by the oscillating inflaton field. In a paper published in *Physical Review* (vol. D56), they briefly describe the perturbative approach to reheating, and then concentrate on effects beyond the perturbation theory. These are related to the stage of parametric resonance, which they called *preheating*.

Lev Kofman, together with graduate student P. Greene (UH Physics), Linde, and Starobinsky considered preheating in the theory $\frac{1}{4}\lambda\phi^4 + \frac{1}{2}g^2\phi^2\chi^2$, where the classical oscillating inflaton field $\phi(t)$ decays into χ -particles and ϕ -particles. The parametric resonance that leads to particle production in this conformally invariant theory is described by the Lamé equation. It significantly differs from the resonance in the theory with a quadratic potential. The structure of the resonance depends in a rather nontrivial way on the parameter g^2/λ . They find an “unnatural selection” rule: the most effective creation of particles occurs not for particles that have the strongest coupling to the inflaton field, but for those that have the greatest characteristic exponent μ . They construct the stability/instability chart in this theory for arbi-

trary g^2/λ . They give simple analytic solutions describing the resonance in the limiting cases $g^2/\lambda \ll 1$ and $g^2/\lambda \gg 1$, and in the theory with $g^2 = 3\lambda$, and with $g^2 = \lambda$. From the point of view of parametric resonance for χ , the theories with $g^2 = 3\lambda$ and with $g^2 = \lambda$ have the same structure, respectively, as the theory $\frac{1}{4}\lambda\phi^4$, and the theory $\lambda/4N(\phi_i^2)^2$ of an N -component scalar field ϕ_i . They show that in some of the conformally invariant theories such as the simplest model $\frac{1}{4}\lambda\phi^4$, the resonance can be terminated by the backreaction of produced particles long before $\langle\chi^2\rangle$ or $\langle\phi^2\rangle$ become of the order ϕ^2 . They analyze the changes in the theory of reheating in this model that appear if the inflaton field has a mass m . In this case the conformal invariance is broken, and the resonance may acquire the features of stochasticity and intermittency even if the mass is very small, so that $m^2/2\phi^2 \ll \lambda/4\phi^4$. They give a classification of different resonance regimes for various relations between the coupling constants, masses, and the amplitude of the oscillating inflaton field ϕ in a general class of theories $\pm m^2/2\phi^2 + \lambda/4\phi^4 + g^2/2\phi^2\chi^2$.

Kofman and collaborators show that during preheating after inflation, parametric resonance rapidly amplifies quantum fluctuations of bosons. The fluctuations of scalar and vector fields produced at this stage are much greater than they would be in a state of thermal equilibrium. They show that in the models with breaking symmetry this effect may lead to a copious production of nonthermal topological defects, with and even without phase transitions. They argue that the Hartree approximation to the fully nonlinear self-consistent dynamics is not sufficient to investigate the formation of the topological defects. In the context of preheating when the scalar fields have large occupation numbers, it can be done in the approximation of classical waves, which incorporates all the backreaction effects in an expanding universe. It allows one to use the lattice simulation to model the self-consistent dynamics.

Lev Kofman with D. Bond and D. Pogosyan (CITA) studied large-scale structure. They describe the physics behind the formation of a network of filaments and membranes in a hierarchical clustering scenario 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. The latter 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 large-scale nonlinear dynamics, with the filaments arising from “correlation bridges” between neighboring cluster-scale peak-patches that exist in the initial conditions. Thus the final state filaments exist in a fattened form in the initial conditions. They construct mean linear density fields subject to the constraints of having the measured linear density. It is found that the anisotropic shear tensor at the peak patches is primarily responsible for the long-range filamentary structures, provided the clusters are not too far apart ($\lesssim 40h^{-1}$ Mpc for Abell clusters) and their shear tensors are not too misaligned. They show that the mean density field constrained at multiple peaks is reduced to the simple superposition of the (analytic)

density field constrained at each single peak. This superposition rule greatly oversimplifies the study of how the geometry of the gaussian field is assembled, and shows where and which moderate-density (of several $\bar{\rho}$) filaments and low-density (of a few $\bar{\rho}$) membranes between them are forming.

When applying this to the observed large-scale structure, they interpret the stretched superclusters of galaxies (Persius-Pisces) as the evolved primordial overdensity ridges (ribbon-like filaments) between aligned clusters. The rich wall-like structures around Coma or Virgo clusters are interpreted as the membrane-rich webbing between the filaments stretching from the clusters. A similar picture is expected for structures at higher redshift, with corrections due to the rescaling of the length of the nonlinearity and change of the effective spectrum index of density fluctuations.

10.2 Extragalactic Theory

Barnes completed a major review article, "Dynamics of Galaxy Interactions," based on lectures presented at the 1996 SAAS-FEE Advanced Course, "Galaxies: Interactions and Induced Star Formation." It includes new results on orbit decay, dynamics of merging, remnant structure, and dynamics of both cool and hot interstellar gas. Together with companion articles by F. Schweizer (Carnegie Institution of Washington) and R. Kennicutt (Univ. of Arizona), this review will be published in early 1998 by Springer-Verlag.

Barnes constructed self-consistent models of interacting galaxies with massive halos to show that tail length constrains potential well depth but does not limit halo mass as such. Halo models with density profiles falling off as $\rho \propto r^{-3}$ at large radii have logarithmically divergent masses but produce potential wells of finite depth. When galaxies incorporating such halos collide, well-developed tails result even when the dark mass is as much as 20 times the mass of the luminous component. This counters published claims, already enshrined in at least one popular textbook, that long tails imply halo masses of no more than 10 times the luminous mass.

Barnes studied mergers of spherical galaxies with power-law central density profiles to determine the likely outcome of mergers between "cuspy" elliptical galaxies. Preliminary results indicate that steep cusps are robust to merging; if bright ellipticals having shallow cusps are to be built by mergers of faint ellipticals, which have steep cusps, then some additional dynamical mechanism is required to reduce the cusp slope.

Graduate student E. Fulton and Barnes used a general orbit-classification algorithm to study orbits in 2-D and 3-D potentials. The algorithm efficiently recognizes boxlet orbits produced by resonant motions in two or three coordinates; it is faster, less complex, and more robust than other methods. This work illustrates how boxlet population depends on the shape and core radius of a triaxial potential, and offers some constraints on the shapes of self-consistent triaxial systems.

Graduate student G. Bendo and Barnes studied line-of-sight velocity profiles in simulated merger remnants. From models of both equal-mass and unequal-mass merger remnants, they derived fairly accurate values of h_3 and h_4 , which respectively parameterize the skewness and peaked-

ness of the velocity profile. Unequal-mass mergers in which the larger disk is incompletely disrupted produce distinctively skew line profiles. These results may be useful in interpreting the growing body of line-profile measurements for E and S0 galaxies.

11. LIBRARY

The IfA Library's catalogue databases became accessible from the IfA Web home page via STARweb. Also, the circulation module of STAR, the library software application, was released for Institute-wide use. This makes information on the circulation status of library materials available to IfA researchers on their desktop computers.

PUBLICATIONS

The following articles and books were published during calendar year 1996:

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