University of Hawaii/Institute for Astronomy

Honolulu, Hawaii 96822

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This report covers the period from 1 October 1998 through 30 September 1999, and was compiled in October 1999.

1. INTRODUCTION

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.

More information is available at the Institute's World Wide Web site: http://www.ifa.hawaii.edu/.

2. STAFF

The scientific staff during this report period consisted of Joshua E. Barnes, Ann M. Boesgaard, Wolfgang Brandner, Douglas Burke, Kenneth C. Chambers, Antoinette Songaila Cowie, Lennox L. Cowie, Harald Ebeling, Isabella M. Gioia, J. Elon Graves, Donald N. B. Hall, James N. Heasley, J. Patrick Henry, George H. Herbig, Klaus-Werner Hodapp, Esther M. Hu, David C. Jewitt, Robert D. Joseph, Nick Kaiser, Richard Knabb, Lev Kofman, John Kormendy, Jeffrey R. Kuhn, Barry J. LaBonte, Jing Li, Gerard A. Luppino, Eugene Magnier, Robert A. McLaren (Interim Director), Karen J. Meech, Donald L. Mickey, 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, David B. Sanders, Theodore Simon, Alan Stockton, David J. Tholen, Alan T. Tokunaga, John L. Tonry, R. Brent Tully, William D. Vacca, Richard J. Wainscoat, and Gareth Wynn-Williams.

Postdoctoral fellows included Amy Barger (Hubble Fellow), Nicholas Biver (James Clerk Maxwell Fellow), Renate Kupke, and Gillian Wilson (Parrent Fellow).

Visiting colleagues included Marcelo Emilio, Masatoshi Imanishi, Roland Meier, and Bradford Smith.

3. 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 (NSF); 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, NASA, and UH.

Construction was completed and dedication ceremonies were held for the 8 m Gemini Northern and Subaru Telescopes. Construction continued on the Submillimeter Array (SMA).

This report covers in detail only the UH telescopes.

3.1 2.2 Meter and 0.6 Meter Telescopes

The major new initiative during the report period was the development of a new telescope control system (TCS) for the 2.2 m telescope. The first full integration of the new TCS with the telescope and some associated tests were made during the last week of September 1999. The new TCS is expected to be put into regular use in January 2000. It is based on a PC running Linux and using a Galil three-axis servo-controller (the three axes being controlled are hour-angle, declination, and dome azimuth). It has been designed to allow much more efficient observing, and also to permit remote operation of the telescope.

During the report period, 33 nights of engineering were scheduled. The 2.2 m telescope was shut down during several of the engineering periods for major work involving new wiring.

During the report period, imaging with CCDs remained the most common use of the telescope, accounting for 53% of the observing time and the bulk of the dark-moon observing time. Three-quarters of this was wide-field imaging using the Tektronix 2048 × 2048 CCD at the f/10 focus—this camera continues to be our most popular instrument. Use of the 8192 × 8192 mosaic CCD camera increased to 22 nights—the increase can be mainly attributed to increased efforts to search for near-Earth asteroids, particularly at low solar elongations. High-resolution CCD imaging at the f/31 focus decreased to only 9 nights. The ultraviolet-sensitive Orbit CCD, which has high quantum efficiency in the blue down to the atmospheric cutoff, was used at the f/10 focus for 21 nights for imaging in the ultraviolet.

The use of the 2.2 m telescope for medium-resolution spectroscopy decreased slightly to 15% of the observing time, scheduled mostly during dark and gray periods. Two spectrographs are available on the 2.2 m telescope, the Wide Field Grism Spectrograph (used at the f/10 focus) and the

High Angular Resolution Imaging Spectrograph (used at the f/31 focus with the tip-tilt secondary mirror).

Imaging with the 1024 × 1024 infrared camera (QUIRC) remained steady at 29% of the observing time. About four-fifths of these observations were performed at the f/10 focus, where the camera has a large field of view (3′.2 × 3′.2). The large format of this infrared camera has made it an extremely powerful tool for infrared imaging. This camera was also used at the f/31 focus, where near-diffraction-limited imaging over a 60″ × 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 decommissioned during the report period. New spectrographs soon to be available on other telescopes on Mauna Kea (in particular SpeX on the IRTF) will provide superior capabilities for infrared spectroscopy. Visitor instruments were used on the telescope for 10 nights.

Efforts were made to schedule the telescope with minimal instrument changes. The average length of time an instrument was installed on the telescope was 7.6 nights. There were numerous long periods (up to 20 nights) without instrument changes. The 2.2 m telescope still has many different instrument modes in which it can be used, so further decreases in the number of instrument changes will be difficult without decreasing the number of modes that are made available.

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 and instrument manuals are available there.

Scheduling periods for the telescopes are 6 month semesters. The semesters are: February–July (deadline September 15) and August–January (deadline March 15). The same scheduling periods are used for all the Mauna Kea telescopes.

3.2 Infrastructure and IfA Hilo Building

The MKO summit local area network FDDI was switched to asynchronous transfer mode (ATM). Grants received from NSF by both UH and Gemini will be used to upgrade the Internet connection to DSC3 capacity.

Ground was broken for the Institute for Astronomy Hilo Facility, which will be a state-of-the-art operations base for the Institute's activities on Mauna Kea and will also provide long-awaited expansion space for the Institute's research, instrumentation, teaching, and outreach programs. The 35,000 square foot (3300 m^2) split-level building, designed by Oda/McCarty, Ltd., of Hilo, will be situated on an 8.5 acre (3.4 hectare) parcel at the north end of UH Hilo University Park. The IfA Hilo Facility will have excellent shop and laboratory space for both observatory operations support and for instrument development, together with office space for astronomers, engineers, technicians, and administrative support staff. The facility will be equipped with a high-bandwidth fiber optics link to the telescopes on Mauna Kea for remote observing. The building is expected to be ready for occupancy in spring 2000.

4. HALEAKALA OBSERVATORIES

The administrative staff consists of M. Maberry, D. O'Gara, K. Rhoden, K. Kimura, K. Ventura, and J. Perreira, and the technical staff includes A. Distasio, E. Olson, M. Waterson, R. Coulter, G. Nitta, J. Frey, C. Foreman, L. Hieda, B. Lindsey, S. Rach, and E. Stevenson.

4.1 Mees Solar Observatory

Mees Solar Observatory (MSO) 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*, *Solar and Heliospheric Observatory* (*SOHO*), *Transition Range and Coronal Explorer* (*TRACE*), 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. Plans to update the instruments are discussed in Sec. 10.2.

See Sec. 10, Solar Physics, for information about the research projects at MSO, including Sec. 10.1 for information about the new SOLAR-C project.

4.2 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.

4.3 AEOS-Haleakala Atmospheric Characterization Project

Haleakala Observatories is under contract to the Air Force Research Laboratories to conduct a research program known as the AEOS-Haleakala Atmospheric Characterization (AHAC). This program supports the U.S. Air Force Advanced Electro-Optical System (AEOS) Telescope on Haleakala by providing comprehensive atmospheric characterization and timely prediction of inclement weather conditions at the observatory site. Data are taken nightly on the seeing and meteorological conditions. The instrument suite that supports these site measurements includes a micrometeorological measurement system, a daytime/nighttime optical seeing monitor, and a network of remote meteorological systems linked by radio modems. The optical seeing monitor allows the capture of image data at high frame rates to allow the computation of seeing statistics on 1 s time intervals.

4.4 MAGNUM Telescope Project

The Multi-color Active Galactic NUclei Monitoring (MAGNUM) telescope is a dedicated 2 m telescope to be used for studying the variation of light from active galactic nuclei (AGNs). The project is a collaboration between the University of Tokyo and the University of Hawaii. The main scientific objective of MAGNUM is to measure distances of AGNs and quasars up to $z = 1$. The telescope is in the final phase of construction, and delivery to Haleakala Observatories is expected by the end of 1999. The telescope is designed to be operated remotely and to conduct observations autonomously. The main scientific instrument is a two-detector camera that can obtain images from 0.3 to 3.4 μm.

4.5 Faulkes Telescope

On 26 June 1999, the UH-IfA and the Faulkes Telescope Corporation signed a Memorandum of Understanding to locate a 2 m telescope at Haleakala Observatories. This professional-grade telescope will be the largest in the world dedicated to astronomical education. Access to the telescope in Hawaii will be available to public and private schools and to the science programs of the UH system and other colleges and universities.

The telescope's construction will be financed by the Dill Faulkes Educational Trust of the United Kingdom and will be named in honor of Dr. Martin ''Dill'' Faulkes, the founder of the trust. Plans call for having the instrument operational in 2001. The telescope will be housed in a state-of-the-art facility with an enclosure that will open like a clamshell and that will be capable of exposing the entire telescope to the night sky.

The Faulkes Telescope will be the third in a series of 2 m telescopes being constructed by Telescope Technologies Limited in Birkenhead, Merseyside, in northwest England. The design heritage of these telescopes comes from that of the William Herschel telescope. The first of these instruments will be the Liverpool Telescope, which is scheduled to become operational in the Canary Islands in October 2000.

The initial instrument on the Faulkes Telescope will be a state-of-the-art CCD camera. The IfA plans to add an infrared camera to the instrument complement shortly after the telescope is commissioned. This will allow for daytime observations by schools in Hawaii. The control system will allow observations to be made both interactively over the Internet or by queued robotic operation.

The Faulkes Telescope Project will draw upon the great public interest in astronomy to teach students what science is. Astronomers in Hawaii and the United Kingdom plan to engage students in research projects that will be published in the scientific literature. They will encourage joint projects in which students will collaborate over the Internet with their counterparts halfway around the world.

5. INSTRUMENTATION

5.1 Adaptive Optics

5.1.1 Instrumental Developments

Under the leadership of Graves, most of the effort of the Adaptive Optics Group was put into rebuilding the 36-actuator adaptive optics (AO) system ''Hōkūpaʻa'' (Hawaiian for ''fixed star,'' i.e., North Star) to enable it to operate on the 8 m Gemini Northern Telescope. It required redesigning the transfer optics of the AO system to accommodate the Gemini f/16 beam. Unlike the f/36 beams that Hōkūpaʻa had used in the past, the Gemini f/16 focus does not allow the use of a simple 1:1 transfer system. A more sophisticated ~1:2 transfer system with off-axis mirrors had to be designed. The AO system had to be entirely rebuilt to fit one of the Gemini side ports (the previous system could be mounted only on an on-axis Cassegrain focus). A new deformable mirror was designed and built to compensate for the larger atmospheric deviations produced by the larger telescope aperture. The new deformable mirror is about the same thickness but has a larger 60 mm diameter pupil. The software also had to be modified to support the new environment.

The new Hōkūpaʻa system was installed on the Gemini telescope in May 1999 with the help of Engineering Physicist D. O'Connor and graduate student D. Potter. At that time there were still problems with controlling the telescope primary mirror figure that prevented the AO system from working. Graves and Northcott quickly built a wave-front curvature sensor and used it to control the telescope primary mirror. It allowed the Gemini telescope to produce satisfactory images for the first time. During the first weeks of June, they worked with the Gemini team to produce the compensated images that were released at the telescope dedication on June 25. C. Roddier participated in the data processing. In particular, she produced the image of BD+303639 that appeared in the September 1999 issue of *Physics Today*. These early results clearly demonstrated the potential of ''curvature'' AO systems on 8 m class telescopes.

In addition to mounting Hōkūpaʻa on Gemini, Graves, Northcott, and O'Connor have paved the way for higher-order curvature AO systems. They are now starting the construction of an 85-actuator upgrade for Hōkūpaʻa. To shrink the system size, Northcott has redesigned the control electronics using more modern components. Compact high-voltage amplifiers have already been built and tested, and a new computer interface and wave-front sensor electronics have been designed, but have not yet been tested. Northcott has also spent time modeling the performance of the present 36-actuator Hōkūpaʻa and its 85-actuator upgrade on Gemini. Such simulations will facilitate the observational use of the instrument.

O'Connor has also been working on the conceptual design of the IRTF AO system. He is currently building the deformable mirror and the lenslet array for this project. He has also worked toward the production of smaller lenslet arrays. This technique will be perfected for the IRTF lenslets and then applied to the 85-element Gemini upgrade. Work toward the construction of a solar curvature AO system for Mees Solar Observatory is also in progress. This is in collaboration with the IfA Solar Group. Finally, the AO Group has participated in the design study for the New Planetary Telescope, a potential upgrade to the IRTF, and Northcott has continued to support the operation of the Haleakala site survey instrumentation and has served on the Haleakala Science Committee.

5.1.2 Observations with Adaptive Optics

C. Roddier continued to reduce Neptune data taken with Hōkūpa'a in July 1998 at the CFHT. Not only she was able to detect Larissa, Galatea, and Despina, but she also produced the first ground-based images of Neptune Adams ring arcs. The result is in good agreement with that of similar observations made with the *Hubble Space Telescope* (*HST*) at about the same time. Both results, which were published in the same issue of *Nature* in August 1999, indicate that the ring arcs are near but not within the resonance with Galatea, which calls into question Galatea's sole role in confining the arcs.

Since Hōkūpa'a was no longer available for further observations on the CFHT, IfA astronomers used the CFHT user-instrument PUEO to carry out their ongoing programs. These include observations of T Tauri stars and a NASA-sponsored search for faint companions around nearby stars (C. Roddier and F. Roddier) and around stars in the Uma stream (Tokunaga and Potter). In addition F. Roddier joined the effort of W. Merline (Southwest Research Institute, Boulder, Colorado) and other collaborators in a systematic search for binary asteroids. This search led to the discovery of a companion to (45) Eugenia announced in *Nature* (7 Oct. 1999).

In collaboration with D. Charissoux, a student visiting from Ecole Normale Superieure in Paris, C. Roddier and F. Roddier analyzed the photometric fluctuations of T Tau South in three colors (J, H, K). The color fluctuations were found to be consistent with variable dust absorption in front of a classical T Tauri star. If this interpretation is correct, then the total absorption A_v is in the 20–30 mag range and the mass of T Tau South is of the order of 2.5 $M_\odot$, a much higher value than previously thought.

5.1.3 Application of Adaptive Optics to Interferometry

F. Roddier is now interested in the application of adaptive optics to optical interferometry. With S. Ridgway (National Optical Astronomy Observatories, NOAO) he has analyzed the influence of the dilution factor on the performance of a coherent array of telescopes when photon noise, detector noise, and background noise are present (see PASP, 111, 990, 1999). He also studied the application of curvature adaptive optics to a telescope array (see Proc. of the Dana Conference, ''Working on the Fringe,'' to appear in PASP). A proposal has been submitted to NSF to equip the IOTA interferometer with adaptive optics.

5.2 The Gemini Near-Infrared Imager (NIRI)

Work on the Gemini Near-Infrared Imager (NIRI) is nearing completion. During the report period, most of the mechanical fabrication work was done, and the alignment of the optics began. Two initial cold tests were conducted. They demonstrated adequate cooling of the instrument and the basic functionality of the mechanisms. The control electronics were completed, and the engineering software interface was mostly operational. The first cold test with all the optics and the detectors installed was conducted in September 1999. While a number of minor problems remain to be fixed, the instrument performed well overall. Acceptance testing is planned to begin in January 2000.

5.3 Infrared Camera and Spectrograph (IRCS) for the Subaru Telescope

Tokunaga (PI), Project Scientist N. Kobayashi (National Astronomical Observatory of Japan, NAOJ), and co-investigators Hodapp and Rayner, and Y. Kobayashi, T. Maihara, and T. Nagata (NAOJ) continued their work on the construction of the IRCS, a facility instrument for the 8.2 m Subaru Telescope at Mauna Kea. It will be a high-resolution spectrograph for 1–5 μm (R = 20,000), and a powerful slit-viewing camera. The camera section will have grisms for low to moderate spectral resolution (up to R = 2,000). The instrument will use 1024 × 1024 InSb arrays (the Aladdin arrays), one each for the camera and spectrograph sections. The instrument was shipped to Hilo in March 1999, and final testing of the instrument was underway in October 1999. First light with the instrument on the Subaru Telescope is expected by the end of 1999.

5.4 Optical Detector Development

Tonry has pioneered the development a new type of CCD, the Orthogonal Transfer CCD (OTCCD), which 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 movable optics as is usually done. Prototype devices have been developed by Tonry with Massachusetts Institute of Technology Lincoln Laboratories (MITLL). In fall 1999, the first large devices (2K × 4K) should be delivered to the IfA through the UH-MITLL Consortium, and two devices will be employed on the UH 2.2-m telescope at the bent-Cassegrain focus as a ''hitchhiker camera'' available at all times for synoptic or other time-critical observations. It is also expected that these devices will be used at the European Southern Observatory (ESO) New Technology Telescope and Mt. Stromlo, both sites where high-speed image motion compensation pays big dividends.

5.5 SpeX

SpeX is a medium-resolution 0.8–5.5 μm cryogenic spectrograph being built at the IfA for the NASA IRTF. The NSF is funding the instrument, and NASA Planetary is funding the detector arrays. The primary scientific purpose 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 that adequately separates sky emission lines and disperses sky continuum. This requirement has resulted in an instrument design that uses prism cross-dispersers and gratings to provide spectral resolving powers of R ~ 1000–2000 simultaneously across 0.8–2.5 μm, 2.0–4.2 μm, or 2.4–5.5 μm. Single-order long-slit modes, and a low-resolution prism mode optimized for high-speed (occultation) spectroscopy and solid-state features in small solar system bodies, are also included. SpeX will use an Aladdin 1024 × 1024 InSb array in its spectrograph and an Aladdin 512 × 512 InSb array in its infrared slit-viewer. SpeX is being designed and built by IRTF/UH staff: Rayner (PI), G. Ching (instrument technician), A. Denault (software engineer), P. Onaka (electrical engineer), W. Stahlberger (mechanical engineer), D. Toomey (project engineer), and D. Watanabe (instrument technician).

Fabrication and assembly of the cryostat and array controllers is now complete, and all-up instrument tests using the optically sensitive unhybridized array readouts are underway. Alignment of the optics, including the spectroscopy modes, has proceeded very smoothly and is almost complete. The science-grade detectors will be installed in December 1999. This will be followed by about three months of instrument characterization in the laboratory before shipping to the telescope. The SpeX graphical user interface is now fully functional and is in regular use during instrument laboratory tests. Work continues on the IDL-based online spectral extraction software to produce fully calibrated spectra soon after the observations are obtained.

First light at IRTF is expected in spring 2000, and the first shared-risk observing programs are scheduled for June 2000. Information and quarterly progress reports about SpeX are available on the World Wide Web at http://irtf.ifa.hawaii.edu/Facility/spex/spex.html.

5.6 AEOS Spectrograph

The U.S. Air Force Advanced Electro-Optical System (AEOS) is a 3.63 m aperture telescope now nearing completion on Haleakala. Under contract to the Air Force, the IfA is building a dual-arm visible and near-infrared spectrograph to be installed in one of the AEOS coudé rooms. Institute personnel responsible for this project are Mickey (PI), Stockton, Hodapp, and Luppino.

The spectrograph will utilize large-format array detectors to provide resolving power of at least 50,000 together with wide spectral coverage over the 0.5–2.5 μm wavelength range. The ‘‘optical’’ arm will utilize a 4K × 4K CCD mosaic. The infrared arm will utilize a 2K × 2K HgCdTe array being developed at Rockwell Science Center.

All the system optics have been received or are on order as of fall 1999. Mechanical assemblies have been designed; mechanical detailing and fabrication is underway. The IR detector electronics system design is largely complete and fabrication is in process. The CCD camera is being assembled. Installation of the spectrograph at AEOS is planned to begin in early 2000, as major subassemblies are completed.

6. GALACTIC AND EXTRAGALACTIC ASTRONOMY

Kaiser, Wilson, Luppino, and graduate student H. Dahle have given a detailed description of their ‘‘pipeline’’ for the reduction of images taken with large mosaic CCD cameras like the UH8K and the CFH12K. In a paper submitted to *Publications of the Astronomical Society of the Pacific*, they have described the processing of a set of images of the $z = 0.42$ supercluster MS0302 taken with the UH8K camera at the CFHT. The result of the image processing is a pair of seamless combined *V*- and *I*-band images of the field, catalogs of about 30,000 faint galaxies, and auxiliary data describing the noise properties and the instrumental point-spread function (PSF). The analysis involves the following steps: image preparation; detection of stars and registration to find the transformation from detector to sky coordinates; correction for extinction and/or gain variations; modeling of the PSF; generation of images with a circular PSF; image warping and averaging; modeling of the noise autocorrelation function; and faint object detection, aperture photometry, and shape measurement.

Kaiser, Wilson, Luppino, Kofman, Gioia, M. Metzger (Caltech), and Dahle have now reanalyzed the deep multi-passband images of the $z = 0.42$ supercluster MS0302 using the new improved shear estimator developed by Kaiser and described in the Theory section (11) of this report. Their analysis combines optical photometry, X-ray images and temperature data, and weak gravitational shear from the $\sim$ 30,000 faint galaxies lying behind the supercluster to provide a comparative study of the optical luminosity, hot X-ray emitting gas, and total mass content. They find that the gravitational shear correlates strongly with that predicted from the early-type galaxies if they trace the mass with a mass-to-light ratio, $M/L_B \simeq 250h$. This is a rather surprising result since it is generally thought that early-type galaxies represent strongly positively biased populations; these new results seem to contradict this and would suggest that the early-type galaxies are in fact fair tracers of the mass, a result that has significant implications for estimates of the total matter density of the universe.

Tonry, J. Blakeslee (Caltech), E. Ajhar (NOAO), and A. Dressler (Carnegie) are completing a program of distance determination 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 fluctuation 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 the Hubble constant, infall toward Virgo, and motions toward Centaurus and the ‘‘Great Attractor.’’ In collaboration with former UH student J. Jensen (now at Gemini Northern Telescope), R. Thompson and M. Rieke (Univ. of Arizona), T. Lauer (Kitt Peak), M. Postman (Space Telescope Science Institute, STScI), and R. Weymann (Carnegie Observatory), Tonry is using *HST* NICMOS observations of fluctuations to probe large-scale flows to distances as great as 10,000 km s^{-1}.

Tonry continues a campaign to exploit gravitational lenses to learn about cosmology. With M. Franx (Leiden Observatory) and C. Kochanek (Harvard), he has written several papers on velocities and dispersions from Keck spectroscopy of gravitational lenses. Tonry has begun studies of gravitational lenses with his ‘‘hitchhiker’’ camera on the UH 2.2 m telescope to monitor variations in quasi-stellar object

(QSO) brightness that can be used to determine a time delay, and hence, distance to the lens.

With the ''High-Z Supernova Consortium'' (B. Schmidt, PI, Mt. Stromlo), Tonry has been using type Ia supernovae to measure the geometry of the universe. In recent publications the High-Z team has claimed that the expansion of the universe is actually accelerating, indicating the presence of a cosmological constant. This result was attracted a lot of attention, and was hailed by *Science* as the ''Breakthrough of the Year.'' In 1999 the High-Z team has continued to test and retest this result by obtaining high signal-to-noise spectra of high-redshift supernovae, examining the details of their light curves, and trying to verify this result at yet higher redshift.

Barger, Cowie, and Sanders continued their work on mapping the dusty galaxy populations with the Submillimeter Common User Bolometer Array (SCUBA) to establish the galaxy counts at 850 μm and to show that to a 2 mJy limit these accounted for approximately 30% of the background at these wavelengths. Barger and Cowie, in collaboration with E. Richards (Arizona State), showed using 20-cm-selected samples that most of the 850 μm sources are very faint in the optical with I magnitudes fainter than 25. They used combined radio and submillimeter data to argue that most of these sources lie in the $z = 1-3$ range. At these redshifts the star formation in the obscured submillimeter population exceeds that seen in the optical by almost an order of magnitude.

Songaila, Hu, and Cowie, with R. McMahon (Institute of Astronomy [IoA], Univ. of Cambridge), made the first measurement of the Gunn-Peterson effect in a quasar at redshift > 5. They found that the intergalactic gas was much more ionized than expected at this redshift, which makes a case for a higher level of ionizing sources or for a lower baryon density than is usually assumed.

Hu, McMahon, and Cowie continued their search for $z > 5$ Lyman-α emitters. They reported the discovery of a very luminous galaxy at $z = 5.74$. Using narrowband-filter searches, they are now beginning to turn up substantial samples of such objects. Similar studies of fields lensed by massive cluster galaxies have now yielded the first ground-based detection of a $z = 6.5$ galaxy in the area of the cluster A370.

Cowie, with Wilson, Barger, and Songaila, has been using the Hawaii redshift survey to map the universal star formation seen at ultraviolet wavelengths. The results show that the rise in the star formation rate for objects seen in these wavelengths is much shallower than was previously assumed rising as $(1 + z)^{1.7}$ over the $z = 0-1$ range.

Gioia, Henry, and graduate student C. Mullis are using the deepest region of the *ROSAT* (X-ray satellite) All-Sky Survey, the so-called North Ecliptic Pole (NEP), to produce an X-ray-selected sample of distant clusters. Summer 1999 marked the end of the identification program that used the MKO telescopes for the last 9 years. The completely identified sample will allow them to study the evolution properties of X-ray clusters and to characterize the three-dimensional large-scale structure of the universe by studying the cluster-cluster correlation function. A recent discovery is the presence of a supercluster composed of 20 clusters of galaxies, 15 of which are detected in the NEP region.

Gioia also has an ongoing collaboration with M. Donahue (STScI) that involves the analysis of *HST* images for lensing clusters and distant clusters from the *Einstein* satellite Medium Survey X-ray Sample. Spectroscopic measurements of the arcs redshifts and of the cluster galaxies are being obtained to determine the cluster velocity dispersion. These measurements will be used for the lensing theory that needs to be applied to the *HST* data. *ASCA* (X-ray satellite) and *ROSAT* High Resolution Imager (HRI) observations are also available. The X-ray data will provide the necessary ingredients (temperature and structure of the hot gas) to measure the cluster mass, which will be compared with the mass determined from the lensing.

Barnes and Sanders edited the proceedings of IAU Symposium 186, *Galaxy Interactions at Low and High Redshift*. The symposium brought together the expertise of observers, numerical simulators, and theoreticians to review new ground- and space-based observations of interacting galaxies and to relate these observations to theoretical models. The volume contains 35 major reviews, 25 contributed papers, and nearly 100 poster contributions.

Sanders, in collaboration with D.-C. Kim (Academia Sinica, Institute of Astronomy and Astrophysics, Taiwan) and S. Veilleux (Univ. of Maryland), published their complete sample of long-slit optical ($\lambda\lambda = 3750$–8000 Å) spectra of 108/118 ultraluminous infrared galaxies (ULIGs) in the *IRAS* 1 Jy survey. These new data were obtained with the Gold Cam Spectrograph on the Kitt Peak 2.1 m telescope. These observations show clearly for the first time that the fraction of ULIGs with Seyfert Type 1 and Type 2 spectra increase with increasing infrared luminosity, reaching values of 26% and 23%, respectively, for ULIGs with $L_{\rm ir} > 10^{12.3} L_\odot$, $H_0 = 75$ km s^{-1} Mpc^{-1}. The fraction of LINERs (low-ionization nuclear emission regions) remains large and relatively constant at $\sim$35%.

Sanders, in collaboration with Veilleux and Kim, published their latest results from a near-infrared search for hidden broad-line regions (BLRs) in ULIGs. These data, when combined with previous near-infrared observations, gave a database of 64/118 ULIGs from the 1 Jy sample from which to test for the presence of bona fide hidden QSOs. Nearly all of the optically classified Seyfert 2s show evidence for a hidden BLR at near-infrared wavelengths. In contrast, none of the 41 optically classified LINERs and H II galaxies in the sample show any obvious signs of an energetically important active galactic nucleus (AGN). These results are shown to be consistent with recent mid-infrared spectroscopic surveys carried out with the *Infrared Space Observatory* (*ISO*) if it is assumed that the LINERs are powered primarily by star formation rather than a hidden AGN.

Sanders, in collaboration with A. Evans (Stony Brook), Kim, J. Mazzarella (Infrared Processing and Analysis Center, IPAC), and N. Scoville (Caltech) published new NICMOS (J, H, K) images and millimeter-wave CO(1$\rightarrow$ 0) interferometry observations from the Owens Valley Radio Observatory of the powerful radio galaxy PKS1345+12 (4C12.50). These new data provide support for the idea that the radio activity in powerful radio galaxies is triggered by the merger of gas-rich galaxies. The bulk of the radio power, the near-infrared luminosity, and 3 mm continuum emission comes from the pointlike northwestern nucleus, consistent with its being the site of a buried infrared-excess, radio-loud quasar.

Sanders, in collaboration with Evans, R. Cutri (IPAC), S. Radford (NRAO), J. Surace (Caltech), P. Solomon (Stony Brook), D. Downes (Institut de Radio Astronomie Millimetrique, IRAM), and C. Kramer (Köln, Germany), has obtained upper limits on the molecular gas masses of IRAS 09104+4109 ($z = 0.4$), IRAS 15307+3252 ($z = 0.9$), and the optically selected, infrared luminous QSO PG 1634+706 ($z = 1.3$). Near-infrared spectroscopy of the two *IRAS* galaxies, covering the restframe wavelength range 0.4–1.1 μm, show that the *IRAS* galaxies have Seyfert II-like optical/near-infrared emission-line spectra. The CO and near-infrared observations of the *IRAS* galaxies indicate that their extreme infrared luminosities are most likely to be dominated by reprocessed AGN light.

Sanders and Surace published a near-infrared imaging study of a complete sample of 12 ''warm'' ($f_{25}/f_{60}>0.2$) ULIGs. High-resolution tip/tilt (FWHM ~0.3″–0.5″) images were obtained with the UH 2.2 m telescope at H (1.6 μm) and K' (2.1 μm). Each ULIG was found to have increasing contributions at long wavelengths by a very compact source, which was identified as an AGN. Fully half of the ULIGs were found to have nuclei with dereddened near-infrared luminosities comparable to those of QSOs. All of the ULIGs were observed to have a significant population of circumnuclear star-forming ''knots'' that are also seen at optical wavelengths; however, the total bolometric luminosity of these knots appears to be only a modest fraction of the total bolometric luminosity of the ULIG.

Sanders and Surace submitted a paper summarizing data from high spatial resolution tip/tilt images (FWHM ~ 0.3″–0.8″) of 18 ''cool'' ($f_{25}/f_{60} < 0.2$) ULIGs at B, I, H, K' obtained with the UH 2.2 m telescope. This is a complimentary sample to the *IRAS* ''warm'' ULIGs. All the ''cool'' ULIGs were found to be advanced mergers; extended tidal features (tails, loops, shells, etc.), as well as clustered star formation, were observed in all systems. The observed structures suggested a common progenitor geometry for most of the ULIGs—a plunging disk collision where the disks are highly inclined with respect to each other. The underlying host galaxies have H-band luminosities in the range ~1–2.5 $L*$, very similar to the host galaxies of ''warm'' ULIGs. The nuclear regions of the ''cool'' ULIGs have morphologies and colors characteristic of a recent burst of star formation mixed with hot dust. Based on their optical/near-infrared colors, most of the star-forming knots appear to have very young ages (< 10 Myr). These star-forming knots are insufficiently luminous to provide more than typically 10–20% of the total bolometric luminosity of the system.

Sanders, with N. Trentham (IoA, Cambridge) and Kormendy, published ultraviolet images ($\lambda = 2300$ Å, 1400 Å) of three ''cool'' ULIGs obtained with the Faint Object Camera (FOC) onboard *HST*. These data provide the first look at the shape of the spectral energy distribution (SED) of ULIGs at wavelengths shortward of ~3000 Å. These data are critical for interpreting the observed-frame optical colors of putative high-redshift ULIGs. The measured SEDs drop from the optical to the ultraviolet for all three galaxies, but the magnitude of the drop varies greatly, from a factor of ~3 to a factor of ~100 between $\lambda = 3000$ Å to $\lambda = 1400$ Å. In the former case, such ULIGs seen at high redshift would be sufficiently blue that they would not easily be distinguished from normal field galaxies. In the latter case, such ULIGs would appear to be extremely red or even missing in current deep optical surveys including the Hubble Deep Field. For these latter objects, the implication is that submillimeter surveys may be the only means of properly identifying the majority of ULIGs at high redshift.

Sanders, in collaboration with Y. Taniguchi and Y. Ohyama (Tohoku Univ.), used the published ratios $R_{\mathrm{i-j}} \equiv {}^{12}\mathrm{CO}/{}^{13}\mathrm{CO}$ in both the (i − j) = (1→ 0) and (2→ 1) rotational transitions to determine the excitation properties of the molecular gas in a large sample of luminous infrared galaxies. The anomalously large observed ratios of R_{2-1} and R_{1-0} in those systems with the largest infrared luminosities and the most advanced merger morphologies suggests that either the ^{13}CO is underabundant relative to ^{12}CO, or more likely, that excitation effects, principally due to the large linewidths associated with galactic superwinds, are responsible for the observations.

Sanders, in collaboration with I. Mirabel, O. Laurent, M. Sauvage, M. Tagger, L. Vigroux, P. Gallais, C. Cesarsky (SAp, Saclay), V. Charmandaris (Observatoire de Paris), and D. Block (Univ. of Witwatersrand, South Africa) reported observations in the mid-infrared made with *ISO* and at submillimeter wavelengths obtained with the SCUBA camera at the JCMT. The dust emission from the nuclear regions of Centaurus A reveals a bisymmetric structure with a diameter of 5′ (5 kpc) centered on the AGN. This structure is remarkably similar to that of a barred spiral galaxy with the bar lying in a plane that is tilted ~18° from the line of sight of Cen A.

Sanders reviewed recent results from deep-field submillimeter observations (primarily at 850 μm) using the SCUBA camera on the JCMT for the proceedings of the COSPAR symposium held in Nagoya, Japan, and compared the known observational properties of SCUBA sources with more local ULIGs.

Sanders made ''The Case for AGNs'' as part of ''The Great Debate'' held at the conclusion of a workshop in Ringberg Castle titled ''Ultraluminous Galaxies: Monsters or Babies?'' All of the available observational evidence was gathered together for a small but complete set of the nearest ULIGs. In response to the main topics proposed for the debate, it was found that (1) ULIGs are indeed a key stage in the transformation of merging gas-rich spirals into ellipticals, (2) ULIGs are plausibly the precursors of QSOs, and (3) ULIGs do appear to be local templates of the high luminosity tail of major gas-rich mergers at redshifts ~ 1–4.

7. STAR FORMATION AND INTERSTELLAR MATTER

As reported last year, Herbig and D. McNally (University College London) attempted to determine whether the molecular carrier of the diffuse interstellar band (DIB) spectrum is present in the outflow from the nucleus of a comet. Cometary nuclei are generally regarded as frozen samples of interstellar cloud material, and it is in such clouds that the DIB spectrum is formed. To this end, they observed the spectrum of HD 12895 (B8, V = 8.2) on 3 April 1997 as Comet Hale-Bopp passed in front of the star, at a minimum separation of 31″ from the comet's nucleus. The spectrograms were obtained with the HIRES spectrograph at Keck I under difficult circumstances with respect to air mass and twilight, but clearly show that none of the strong DIBs between 4700 and 6620 Å appeared in absorption in the coma, at a level 3 order of magnitude below that expected from analogy to interstellar OH and HCN. It was concluded that if the DIB carriers were present in the nucleus at all, either they were not carried into Hale-Bopp's coma by the evaporating volatiles, or were modified or destroyed by the solar radiation field while in transit (MNRAS, 304, 951, 1999).

In 1996 Herbig published (AJ, 111, 1241) a description of the peculiar reflection nebula IC 349, only 30″ from the bright star 23 Tauri. The semi-stellar nucleus of this fan-shaped nebulosity was interpreted as an interstellar interloper in the Pleiades, and the nebulosity as dust driven off the nucleus as it dissolves in the radiation field of 23 Tau. High-resolution WFPC2 images of IC 349 have recently been obtained with *HST* at the request of Herbig and Simon. They show a fantastic amount of fine detail in IC 349 that was undetected even on the best 2.2 m telescope f/10 frames. Analysis of this new material has just begun.

There was reason to suspect that the IC 349 nucleus was part of an outlying fragment of the Taurus-Auriga dark clouds, through which the Pleiades cluster is now passing. If so, it raised the possibility that such clouds might contain similar very small condensations, as had been suspected by others largely on radio astronomical grounds. One way to detect such structure would be by changes in the interstellar spectrum of a star moving rapidly with respect to a foreground cloud. Such opportunities are rare, but one is provided by the O9.5 V star AE Aur, moving at about 27 AU yr^{-1} behind the nebulosity IC 405. The only early high-resolution observation of the atomic and molecular interstellar spectrum of AE Aur was by W. S. Adams in the 1940s, but he reported only line velocities, not strengths. Radial velocities of the same lines on the 1998 HIRES spectrogram showed no change over the more than 50 yr interval. The HIRES equivalent widths will be useful when the observation is repeated sometime in the future (PASP, 111, 809, 1999).

Herbig and graduate student S. Dahm are working on *BVRI* and *JHK* photometry of the young cluster IC 5146 and the adjacent clustering around the Ae/Be star BD+46° 3471, supplemented by MOS spectroscopy from CFHT. Some 60 Hα emission stars, as well as two Herbig-Haro objects, have been found in and around the cluster. The cluster is embedded in a large emission/reflection nebula, which causes the background and the extinction to vary over the field, but good color-color and color-magnitude diagrams have been constructed, from which age spread and the distinction between classical and weak-line T Tauri stars can be extracted. These observations are being extended to a number of other young clusters.

Herbig has essentially concluded his attempt to detect interstellar C_{60} (''buckminsterfullerene'') with HIRES. The most sensitive band is observed in the laboratory at about 3280 Å , but the wavelength expected under interstellar conditions ranges from about 3240 to 3306 Å. Despite this uncertainty, a reasonable upper limit on the strength of any interstellar absorption in that interval has been established in the heavily reddened star Cyg OB2/8A. It leads to the conclusion that *neutral* C_{60} cannot be a significant reservoir of interstellar carbon in comparison to the amount of C tied up in CO, CH^+, C_2, and the diffuse band carriers. The C_{60}^+ situation remains to be clarified. There are additional strong C_{60} features known in the satellite ultraviolet, but given the present lack of adequate laboratory information at those wavelengths, a search for those bands is not very promising.

While working on the interstellar C_{60} program, Herbig observed the well-known nearby O-type subdwarf BD+28° 4211. He assumed it could be used as a hot, relatively line-free standard. He found that the (stellar) optical spectrum at the HIRES resolution of 45,000 was not so simple as had been previously believed. In the near ultraviolet there are a number of very narrow absorption lines, mainly of O IV, that are so sharp as to provide an upper limit on $v \sin i$ of about 4 km s^{-1}. A number of emission lines of O IV, O V, and N V are also present, as well as conspicuous emission cores in the stronger lines of H and He II (PASP 111, 1144, 1999).

Herbig has obtained with HIRES a series of excellent spectrograms of the FUors FU Ori, V1057 Cyg, V1515 Cyg, V1735 Cyg, and BBW 76 that cover the region shortward of about 4300 Å. These show a host of interesting features. They also strengthen the proposal that line-doubling in FUors is due to central emission cores, not to rotational splitting by a Keplerian disk. V1057 Cyg has by now returned almost to the minimum brightness that preceded the 1970 outburst, so it is possible to study at high resolution the spectroscopic features that were seen so imperfectly on the single pre-1970 low-dispersion spectrogram. Even at minimum light, massive mass outflow is present at the Balmer lines. It appears that the FUors stand out in this respect from run-of-the-mill T Tauri stars.

Herbig also has under study HIRES spectrograms of the prototype EXor, EX Lupi, obtained by Boesgaard and graduate student A. Stephens during a minor outburst in 1998. The spectrum shows a hot continuum superposed upon that of the M0 dwarf seen at minimum light, and in that respect resembles ultraviolet-excess T Tauri stars like DR Tau. EX Lupi displays many narrow emission lines, mostly of the ionized metals, at the radial velocity of the M dwarf, but also broad shortward-displaced emission components at the Balmer lines that may be part of the hot continuum spectrum. Also present are ''inverse P Cyg'' absorption components of Fe II displaced +320 km s^{-1}. Such structure has been observed in other T Tauri stars and is usually ascribed to infall.

Tokunaga and S. Wada (Univ. of Electro-communications) continued their work on understanding the nature of quenched carbonaceous composite (QCC), a laboratory analogue 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. Laboratory experiments show that QCC also has a 220 nm absorption feature that is similar to that seen in the interstellar medium. Carbonaceous onionlike structures are found in QCC, and these may be the source of the 220 nm feature.

Graduate student M. Cushing, Tokunaga, and N. Kobayashi (NAOJ) have obtained 1.4–2.5 μm spectra of very faint low-mass objects in the ρ Oph dark cloud using the Near-Infrared Camera on Keck I. Spectra of these objects show that 50% of the sources have evidence of water absorption. The other sources appear to be featureless highly reddened sources typical of Type I sources. By estimating spectral types and effective temperatures, they find that three of the sources appear to be substellar and an additional four sources are on the stellar/substellar boundary.

Kobayashi and Tokunaga report the discovery of young stellar objects (YSOs) at the edge of the optical disk of the Galaxy. These apparent YSOs are found in Cloud 2 of the list by S. Digel *et al.* This molecular cloud is located at an estimated distance of 15–19 kpc, and it is one of the most distant from the Galactic Center. The overall distribution of ionized gas, *IRAS* sources, molecular clouds, and near-infrared sources suggests that an early B-type star found near Cloud 2 has triggered the formation of YSOs in Cloud 2.

Brandner joined the IfA star formation and adaptive optics groups in July 1999. He is working on high spatial resolution studies of circumstellar disks using ground-based adaptive optics systems and the *HST*. The first project, a study of the Galactic starburst region NGC 3603 that involved observations with *HST*/WFPC2 and the Infrared Imager and Array Camera at the Very Large Telescope (VLT) of ESO, was completed in September 1999. The main collaborators on the project are E. Grebel (Univ. of Washington), B. Brandl (Cornell), and Y.-H. Chu (Univ. of Illinois at Urbana-Champaign). The deep infrared observations of NGC 3603 with the VLT revealed that low-mass stars with masses down to 0.1 $M_\odot$ can form in the presence of high-mass stars with masses up to 120 $M_\odot$. The emission-line imaging with *HST*/WFPC2 led to the discovery of ionized nebulae of similar morphology and physical properties as the ‘‘proplyds’’ (protoplanetary disks) in Orion.

In September 1999, Brandner, in collaboration with Brandl and E. Gaidos (Jet Propulsion Laboratory, JPL), used the new adaptive optics system at the Palomar 5 m telescope to search for substellar companions to nearby young solar analogues. In addition, they obtained, for the first time, spatially resolved *K*-band spectra of the two components of the 0$''\!.$7 Herbig Ae/Be binary MWC 1080, as well as adaptive optics imaging data in several infrared emission lines. The new data complement data previously obtained with the UH 13- and 36-element curvature sensing adaptive optics systems. The study of MWC 1080 is carried out in collaboration with L. Close (ESO), Tokunaga, and the IfA Adaptive Optics Group.

Graduate student S. Sheppard, Brandner, and Tokunaga started analyzing near-infrared VLT/ISAAC observations of the circumstellar environment of young stars in southern star-forming regions. Complementary *HST*/WFPC2 *R*- and *I*-band observations of some of these sources were obtained in August–September 1999 as part of an ongoing *HST* Cycle 8 snapshot program. The main collaborators on the *HST* snapshot survey are K. Stapelfeldt (PI, JPL) and D. Padgett (IPAC/SSC).

Magnier, who joined the faculty in September 1999, continues to study a sample of ‘‘transitional’’ YSOs, in collaboration with R. Waters (Univ. of Amsterdam), M. van den Ancker (Center for Astrophysics), and N. McCrady (Berkeley). The objects they are studying have flat *IRAS* spectra with optically visible central stars. These objects are close to the transition between the embedded and exposed stages of evolution and will be used to explore the end of accretion and the dispersion of the circumstellar material. The first paper on their optical and near-infrared survey of *IRAS* candidates, in which they identified 28 strong and 22 moderate transitional YSOs, has been accepted. They continue to analyze a large amount of spectroscopic observations of the best of these YSOs.

Sanders and J. Carpenter (Caltech) published their CO(1 $\rightarrow$ 0) study of the Galactic giant molecular cloud (GMC) W51. Both ^{12}CO and ^{13}CO data were obtained with the QUARRY receiver array on the Five College Radio Astronomy Observatory 14 m millimeter-wave telescope. Maps were made using a fully sampled 50$''$ grid covering a 1.4° $\times$ 1.4° region surrounding the W51 H II region complex. These data permit the spatial and kinematic separation of several spectral features observed along the line of sight to W51, and establish the presence of a massive ($1.2 \times 10^6 M_\odot$) and large ($\Delta\ell \times \Delta b = 83$ pc $\times$ 114 pc) gravitationally bound GMC. The W51 GMC is not simply a superposition of unrelated distinct velocity components spread out along an inner spiral arm as has been sometimes proposed in the past. The W51 GMC is among the upper 1% of molecular clouds in the Galactic disk by size and the upper 5–10% by mass; however, the average H_2 column density is not unusual given its size, and the mean H_2 volume density is comparable to that in nearby GMCs. It appears that much of the massive star formation activity in this region has resulted from a collision between the W51 GMC and a massive ($1.5 \times 10^5 M_\odot$) highly elongated molecular cloud at $V = 68$ km s^{-1} along the southern edge of the W51 GMC.

8. STELLAR ASTRONOMY

Boesgaard and a team of collaborators determined the abundance of Be in stars with an array of metal abundances in order to enhance our understanding of the chemical evolution of the Galaxy, cosmic-ray theory, and cosmology. Observations of the Be II resonance lines were made at the Keck telescope with the HIRES spectrometer. From a sample that includes 22 halo dwarfs and 5 disk stars (including the Sun), they found linear relations between Be and Fe and between Be and O. They concluded that Be and Fe increase at the same rate during the course of the evolution of the Galaxy. The Be in the Galaxy increases more rapidly than O by a factor of 8. Traditional models in which energetic cosmic rays interact with ambient CNO nuclei in the interstellar medium to produce Be are consistent with these new findings, as long as certain chemical evolution effects (such as mass outflow from the halo) are taken into account. Models that predict a linear relationship between Be and O, such as those producing Be in the vicinity of Type II supernovae, are less consistent with their result. There is some evidence for an intrinsic spread in Be at a given [Fe/H] or [O/H]. No evidence of a primordial plateau level of Be down to log N(Be/H) = − 13.5 is found in from these data.

Working with J. Crawford and C. Sneden (Univ. of Texas), J. King (STScI), and C. Deliyannis (Indiana), Boesgaard studied the resonance lines of neutral silver appearing at 3280, 3382 Å in the near-ultraviolet spectral region. The lines have been identified on Keck I HIRES spectra of four halo stars with metallicities $-1.3 \geqslant [Fe/H] \geqslant -2.2$. This work represents the first detection in metal-poor stars of an element in the atomic number range $41 \leqslant Z \leqslant 55$. The mean relative silver abundance is $\langle [Ag/Fe] \rangle \simeq +0.2$, with little star-to-star variation. Silver abundance upper limits in three other metal-poor stars are consistent with this mean value. The modest overabundance of silver is similar to the overabundances in this metallicity range exhibited by other neutron-capture elements whose primary nucleosynthesis origin is the *r*-process (such as europium and dysprosium).

In collaboration with E. Brugamyer (Univ. of Texas), Sneden, King, and Deliyannis, Boesgaard worked on new determinations of copper abundances for a sample of seven metal-poor ($-3.1 \geqslant [Fe/H] \geqslant -1.6$) field stars, using two previously little-used Cu I resonance lines in the near ultraviolet. These lines are easily detected on Keck I HIRES spectra that were originally obtained to study beryllium abundances in the target stars. In previous studies, copper abundance ratios have been derived for a large group of relatively metal-poor field stars using higher excitation Cu I lines at 5105 Å and 5782 Å. A large, and possibly linear, decrease in [Cu/Fe] with declining [Fe/H] has been suggested. However, the visible wavelength transitions are usually too weak to be detected in stars having less than ~ -2 dex overall metallicity. Copper abundances for these very metal-poor stars must be determined from intrinsically stronger lines, and their current work represents the first time the near-ultraviolet transitions have been analyzed in their spectra. Isotopic and hyperfine splitting were taken into account in the analysis, and the [Cu/Fe] ratios in our stars were very low, as expected. However, for stars in the sample, [Cu/Fe] was found always to be ~ -1, with little or no trend with [Fe/H].

Graduate student A. Stephens continued his thesis research on the chemical composition of halo stars on extreme orbits. As part of this research, he completed a fine spectroscopic analysis of 11 metal-poor ($-2.15 < [Fe/H] < -1.00$) dwarf stars on orbits that penetrate the outermost regions of the Galactic halo. Abundances for a select group of light metals (Na, Mg, Si, Ca, and Ti), Fe-peak nuclides (Cr, Fe, and Ni), and neutron-capture elements (Y and Ba) were calculated using line strengths measured from high-resolution, high signal-to-noise ratio echelle spectra acquired with the Keck I telescope and HIRES spectrograph. Ten of the stars have apogalactica, a proxy for stellar birthplace, which stretch between 25 and 90 kpc; however, these ‘‘outer halo’’ stars exhibit strikingly uniform abundances. The average, Fe-normalized abundances—$\langle [Mg/Fe] \rangle = +0.23 \pm 0.09$, $\langle [Si/Fe] \rangle = +0.24 \pm 0.10$, $\langle [Ca/Fe] \rangle = +0.22 \pm 0.07$, $\langle [Ti/Fe] \rangle = +0.20 \pm 0.08$, $\langle [Cr/Fe] \rangle = 0.02 \pm 0.07$, $\langle [Ni/Fe] \rangle = -0.09 \pm 0.07$, and $\langle [Ba/Fe] \rangle = +0.01 \pm 0.12$—exhibit little intrinsic scatter; moreover, the evolution of individual ratios (as a function of [Fe/H]) is generally consistent with the predictions of galactic chemical evolution models dominated by the ejecta of core-collapse supernovae. Only $\langle [Y/Fe] \rangle = -0.13 \pm 0.21$ exhibits a dispersion larger than observational uncertainties, which suggests a different nucleosynthesis site for this element. It has been conjectured that stars on high-energy orbits—either those that penetrate the remote halo or ones with extreme retrograde velocities—were once associated with a cannibalized satellite galaxy. Such stars, as shown here, are indistinguishable from metal-poor dwarfs of the inner Galactic halo. The uniformity of the abundances, regardless of kinematic properties, suggests that physically, spatially, and temporally distinct star-forming regions within (or near) the growing Milky Way experienced grossly similar chemical evolution histories.

Stephens and Deliyannis analyzed high-resolution, high signal-to-noise ratio observations of the Li I resonance doublet in a pair of Hg-Mn stars. No record of a lithium detection has been found for this type of chemically peculiar star. The Be abundances in atmospheres of the two program stars (HR 6158 and HR 8915) are among the highest known. While the concentration of Be is several thousand times larger than cosmic $[A(\mathrm{Be})_i \approx 1.27]$ in both stars, lithium (Li) is detected in neither HR 6158 nor HR 8915. The calculated 3 σ upper limits place the maximum Li enhancements at 50 times and 80 times cosmic $[A(\mathrm{Li})_i \approx 3.23]$ for HR 6158 and HR 8915, respectively, or ≈ 100 times smaller than the Be overabundances. These Li upper limits, which argue against a ‘‘nucleosynthesis’’ origin for the Be surfeit, provide yet another means of constraining the physical process (or processes) responsible for the Hg-Mn phenomenon in some A stars.

Simon participated in monitoring the short-term spectroscopic variability in the pre–main-sequence Herbig Ae star AB Aurigae during the Multi-Site Continuous Spectroscopy (MUSICOS) 1996 campaign. The analysis is focused mainly on the He I D3 line, on the Hα line, and on a set of photospheric lines. The star was monitored irregularly for more than 200 hr. The high level of variability of spectral lines in AB Aur was confirmed. The photospheric lines have a profile differing significantly from a classical rotational profile. The dominant features of this abnormal photospheric profile are a blue component, in absorption, whose velocity is modulated with a 34 hr period, and a red component, stable in velocity but of variable intensity, with a possible periodicity near 43 hr. The He I D3 line exhibits two well-defined components: a blue component, always in emission with a velocity modulated with a 45 hr period, and a red component of variable intensity, alternatively in emission and in absorption, occurring at a fixed velocity, with a variable intensity possibly modulated with a 45 hr period. The Hα line, showing a P Cygni profile, also exhibits pseudo-periodic variations of its blue absorption component, but its variability appears more complicated than that of the other lines studied here. The study proposed mechanisms to explain the behavior of the photometric and He I D3 lines.

With G. Duchêne and J. Bouvier (Observatoire de Grenoble), Simon reported on a near-infrared adaptive optics survey of a sample of 66 low-mass members of the pre–main-sequence stellar cluster IC 348. They found 12 binary systems in the separation range 0.″1–8″, excluding 3 probable background projected companions. In the range $\log P = 5.0$–7.9 days, the binary fraction in IC 348 is 19 $\pm$ 5%, similar to the values corresponding to G- and M-dwarfs in the solar neighborhood population. Furthermore, the distribution of orbital periods of IC 348 binaries in this range is consistent with that of field binaries. They concluded that there is no binary excess in IC 348. Substellar companions are found to be rare, or even missing, as companions of low-mass stars in the separation range surveyed. Also, the mass ratio distribution is not peaked at $q \sim 1$ in IC 348, and it is unlikely that an observational bias can account for that. They did not find any evidence for an evolution of the binary frequency with age within the age spread of the cluster of about 10 Myr. Comparing the binary frequency in IC 348 with that of other star-forming regions (SFRs) and young open clusters, they concluded that there is no significant temporal evolution of the binary fraction between a few million years after the formation process and the zero-age main sequence (ZAMS) and field populations. They did find a trend for the binary fraction to be inversely correlated with stellar density, with dense clusters having a binary fraction similar to that of field dwarfs and loose associations exhibiting an excess of binaries. Two scenarios can be suggested to explain these differences: either all SFRs, clusters and associations alike, initially host a large number of binaries, which is subsequently reduced only in dense clusters on a timescale of less than 1 Myr due to numerous gravitational encounters, or specific initial conditions in the parental molecular clouds impact on the fragmentation process leading to intrinsically different binary fractions from one SFR to the other.

Simon collaborated with Duchêne, Bouvier, and Eislöffel to conduct high-angular resolution observing surveys in several young clusters (with ages ranging from 2 to 700 Myr) to determine the binary fraction and other binary properties in various environments. The observed clusters differ from each other in their density and/or stellar content; so far, they have focused on pre–main-sequence solar-type stars (with $M < 1.5 M_{\odot}$). Dense clusters all show low binary fractions, similar to the main-sequence value within statistical errors. On the other hand, a large binary excess is well known in the nearby loose star-forming regions. Although this may reveal the influence of some initial conditions, it may well be due to dynamical evolution of these young clusters, with a much larger number of binaries being disrupted in denser environments. Observations of even younger clusters as well as more massive stars will allow us to distinguish between the two scenarios.

Simon and Ayres have studied the A7 V star α Cephei, which lies in a region of the Hertzsprung-Russell diagram that is generally thought to be devoid of solarlike magnetic activity. The far-ultraviolet spectrum of this star was observed with the Berkeley spectrograph during the 1996 *Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite* (*ORFEUS-SPAS II*) mission. They detected emission lines of Si III, C III, and O VI in the 900–1200 Å interval, spanning formation temperatures of 2×10^4–3×10^5 K. The normalized strengths of these lines, $R_L \equiv f_L/f_{\rm bol}$, are within a factor of 2 of solar values. Lines of two C III multiplets in the *ORFEUS* spectrum yield an electron density estimate, $n_e \approx 10^{9.4\pm0.3}$, at a temperature of $\sim 6 \times 10^4$ K. The corresponding electron pressure, $p \equiv n_e T \sim 10^{14.2\pm0.3}$, is similar to that of the average Sun, but several times smaller than previous estimates made for other late-type G–K stars. At higher temperatures, the normalized flux ratio for coronal soft X-rays is 20 times less for α Cep than it is for the Sun. This greatly reduced X-ray brightness suggests that the outer atmosphere of α Cep differs strikingly from that of the average Sun, being more akin to a low-density ‘‘coronal hole.’’

Simon was part of a team that obtained an 88 kilosecond *ROSAT* HRI exposure of the intermediate-age open cluster IC 4756 with the purpose of detecting stars in the high-luminosity tail ($\log L_X \geqslant 10^{29}$ ergs s^{-1}) of its X-ray luminosity distribution. However, only 1 cluster member (HSS 201) out of the 60 members inside the central high-sensitivity region of the HRI field of view (FOV) was detected. This star has spectral type A8, suggesting a close binary system with a low-mass X-ray emitting companion. They compared the distribution of upper limits for F- and G-type dwarfs in IC 4756 with the X-ray distribution functions of the similarly aged Hyades and Praesepe clusters. The results of this statistical analysis are inconclusive for G-type stars, but suggest that at least F-type stars in IC 4756 are not as X-ray luminous as their Hyades counterparts, thus indicating intrinsic differences between the two clusters. Finally, our data indicate a deficit of very active binaries with respect to both Hyades and Praesepe, and older open clusters.

A helium white dwarf (HeWD) with a nondegenerate companion was reported by Landsman *et al.* (1997, ApJ, 481, L93), who used ultraviolet spectroscopy to identify the low-mass white dwarf companion of the yellow giant S1040 in the open cluster M67. Landsman and Simon reanalyzed the *International Ultraviolet Explorer* spectra of known EUV-quiet white dwarf companions of field late-type stars, and used *Hipparcos* parallaxes to identify possible HeWDs. The white dwarf companion of the star 39 Cet (G5 III–IV) is a certain HeWD, and the system is a near twin of S1040 in M67. Four other stars (56 Per, HR 3643, HD 160538, and HD 165141) are identified as having possible HeWD companions. They considered the feasibility of a empirical determination of the mass-radius relation and envelope mass of these HeWDs.

9. SOLAR SYSTEM STUDIES

9.1 Planetary Atmospheres

Owen continued the analysis of *Galileo* Probe Mass Spectrometer data in collaboration with H. Niemann (NASA Goddard Space Flight Center, GSFC), P. Mahaffy (GSFC), S. Atreya (Univ. of Michigan), A. Bar-Nun (Tel Aviv), and I. De Pater (Berkeley). Careful calibration of the flight instrument by Mahaffy at GSFC has shown that the heavy noble gases argon, krypton, and xenon are enriched by the same factor of 3 ± 1 exhibited by sulfur and carbon. No known solid material in the solar system exhibits this composition. An independent study of the attenuation of the probe radio signal by ammonia indicates that nitrogen is enriched by the same factor. It appears that the only way to account for this common enrichment is to postulate that the icy planetesimals that carried these elements to Jupiter must have formed at temperatures of about 30 K or less. This provides an interesting constraint on models for giant (and supergiant) planet formation.

9.2 Planetary Surfaces

With Bar-Nun, Owen has been studying the origin of water and atmospheres on the terrestrial planets. The source of the water found on Earth and the other inner planets remains an intriguing problem. Evidence available to date suggests that the comets cannot be the sole source of that water because the value of D/H in the three comets measured so far is about twice the value in seawater. Water adsorbed on grains that became the rocks that formed the planets offers an interesting additional source. A test of this hypothesis can be made by looking for evidence of that low D/H water in subsurface rocks from Mars. Unlike Earth, Mars has experienced very little mixing between the crust and the interior. Studies of Martian meteorites have revealed that the lowest values of D/H in water trapped in minerals from these rocks are close to the cometary value, not the terrestrial one. Thus the surface of Mars may be frosted by cometary ice, whereas the interior may contain the primordial water from the inner solar nebula. This test is another interesting goal for Mars sample return.

9.3 Asteroids

Tholen and graduate student R. Whiteley continued a program to search for near-Earth asteroids at small solar elongations. The fourth discovery to result from this work was that of 1999 OW3, which is an Apollo-type object with an estimated diameter of 4.2 km, making it the largest Apollo-type asteroid to be found so far this year.

Tholen's program of asteroid physical observations emphasized planet-crossing asteroids, including primarily near-Earth objects and Kuiper Belt objects. The observations of the former group are being handled primarily by Whiteley as part of his thesis. Several of the Kuiper Belt observations were made simultaneously with infrared observations in the J band at the UKIRT by J. Davies (JAC) and his colleagues. The resulting $V - J$ colors show considerable diversity among the population.

Tholen continued to participate in the Small Bodies Node of the Planetary Data System. Together with the Planetary Science Institute in Tucson, he represents the asteroid subnode, which collects and prepares asteroid data for archiving.

9.4 Comets

Biver has been working on the observations at radio wavelengths of comets as well as carrying out all IfA observations at JCMT. In the fall of 1998, three comets, 21P, C/1998 P1 (Williams), and C/1998 U5 (LINEAR), were detected at CSO and JCMT. The chemical investigation of comet 21P/Giacobini-Zinner, in a quasi-simultaneous observing campaign at CSO, JCMT, IRAM, and Nancay, was presented at the Asteroids, Comets, Meteors (ACM) 1999 meeting. Two other ''new'' comets, C/1998 M5 (LINEAR) and C/1998 T1 (LINEAR), were investigated and detected at JCMT and CSO, respectively. In addition, a worldwide observing campaign was set to follow the activity of the moderately bright comet C/1999 H1 (Lee), which was followed from May to October 1999 at CSO and JCMT, in parallel with observations at the Swedish-ESO Submillimetre Telescope (SEST), the IRAM 30 m telescope, and Nancay. This collaboration involves researchers from Caltech, Paris-Meudon Observatory, and SEST (Chile), as well as astronomers from IfA, JAC, and Johns Hopkins University making observations in the infrared at UKIRT and IRTF. The most striking results of these observations are the detection of an unexpected high HNC/HCN ratio of about 12%, nearly as high as in comet Hale-Bopp, while C/1999 H1 has a 10 times lower CO/CH_3OH ratio. These results were given in International Astronomical Union Circulars 7198, 7201, and 7203, as well as at the ACM and Division for Planetary Sciences (DPS) meetings.

In collaboration with observers from France, Sweden, Chile, and Hawaii, Biver is using SEST for long-term monitoring of comet C/1995 O1 (Hale-Bopp), now beyond Saturn. He is also using CSO and JCMT to search for CO in distant comets, Centaurs, and Edgeworth-Kuiper Belt objects. He gave a talk on the correlation between CO outgassing and visual magnitudes at the Second International Workshop on Cometary Astronomy in August 1999.

Jewitt and H. Matthews (JAC) completed an analysis of SCUBA submillimeter observations of the thermal emission from solid matter in comet Hale-Bopp. They found a dust/gas ratio in Hale-Bopp much in excess of unity. The measured spectral index, 0.6 ± 0.1, in the submillimeter range is similar to the indices measured in the dust disks of young stars. The comets themselves are products of accretion in the Sun's own preplanetary disk, so perhaps this similarity should not be surprising.

Meech has continued her program to search for observable differences in the physical or chemical nature of the periodic comets (old) compared to the Oort comets (comets passing through the inner solar system for the first time) by studying their brightness as a function of heliocentric distance, r. The scientific objectives of this study are (1) to search for physical differences in the behavior of the dynamically new comets (those 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, chemical nature and the evolutionary histories of the two groups of comets.

Observations of approximately 50 comets over a range of r are complete. 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. The analysis will involve using Finson-Probstein dust dynamical models to ascertain the onset and cessation of dust production, the grain properties, ejection velocities, and particle size distributions.

Meech and graduate student J. Bauer have been targeting several comets that are candidates for future space missions. Several sets of observations have been conducted on 81P/Wild 2, the target of the STARDUST mission, which was launched in February 1999. The observations are being added to a 9 yr database of observations. Models have been developed in collaboration with R. Newburn (JPL) to assess the dust hazard for the spacecraft when it flies through the coma to collect dust samples, and a paper has been submitted. Extensive data to study the rotational light curve has also been obtained on comet Wilson-Harrington, the target of the extended Deep Space 1 mission.

9.5 Outer Solar System Objects

Centaurs are probably the transition objects between the Kuiper Belt objects and the short-period comets. The long-term work of Meech on distant comets and short-period (SP) comets has established that SP comets have undergone significant thermal evolution during their residence in the inner solar system. By studying the Centaurs and comparing them to both the SP comets and the trans-neptunian objects, it may be possible to look at an earlier, a more pristine version of the SP comets. For his thesis, Bauer began a comprehensive study of all the Centaur objects to fully characterize their physical properties in the optical and near infrared and to make a sensitive search for activity in these objects. Data have been obtained on several Centaur objects to look at their rotational light curves. Data were presented on 1997 CU26 at the 1999 DPS meeting. It appears that the rotation period of this object is relatively short—near 7.1 or 10.6 hr. In a related project, in collaboration with O. Hainaut (Very Large Telescope, Chile), Meech and Bauer have obtained extensive data on the Kuiper Belt object 1996 TO66. They have established a rotation period of 6.25 hr during three epochs of observation. A dramatic change in the rotational light curve has been interpreted as evidence for possible outgassing or a coma on this object.

Jewitt worked with graduate student C. Trujillo and J. Luu (Univ. of Leiden) on an expanded survey of the Kuiper Belt. They used a 12K $\times$ 8K pixel CCD at the prime focus of the CFHT to image the ecliptic to magnitude 24. This survey is aimed toward understanding the structural properties of the Kuiper Belt, especially the variation in the density of objects with inclination. Initial results support an inference from earlier Mauna Kea data, namely that the Kuiper Belt is extraordinarily thick (half width at half-maximum 30° or more). The thick disk implies a velocity dispersion too large for KBOs to grow at the present time. Therefore, orbits in the Kuiper Belt must have been excited since the epoch of formation, perhaps by gravitational perturbations from Earth-mass planetesimals that were scattered by Neptune.

As a by-product of the survey, three new scattered Kuiper Belt objects (SKBOs) were discovered. One, 1999 CF119, reaches the extraordinary aphelion distance of 200 AU. The SKBOs are a set of objects that may have been scattered outward by Neptune. While rare in the observational sample, the SKBOs may rival the classical and resonant Kuiper Belt populations when account is made for the effects of observational selection. The orbits of SKBOs are eccentric, so that these objects can be detected in magnitude-limited surveys only during a narrow window near perihelion.

Jewitt completed a review of the Kuiper Belt for *Annual Reviews of Earth and Planetary Sciences* and another, with Luu, for the *Protostars and Planets IV*. He also wrote a popular article about the outer solar system for the magazine *Physics Today*.

9.6 Planetary Satellites

Tholen is continuing the reduction and analysis of the Galilean and Saturnian satellite mutual events that occurred in 1997 and 1995, respectively. The events involving Io will be used to make a more precise determination of the satellite's secular acceleration, which can be compared to the amount expected from heat flow measurements. The Saturnian satellite events will be used to improve their ephemerides in support of the Cassini spacecraft mission.

Tholen and Whiteley repeated a search for distant satellites of Uranus and Neptune in the summer of 1998. In addition to recovering the two satellites found in 1997 by Gladman *et al.*, a third object sharing Uranus's motion was found. Observations made in subsequent months indicated hyperbolic motion relative to Uranus, however. Recovery of the object following solar conjunction definitively showed it to be a new Centaur-type asteroid with the smallest known eccentricity of the group, nearly in a 1:1 resonance with Uranus.

9.7 Spacecraft

Tholen was selected by NASA as the U.S. co-investigator for the AMICA instrument (Asteroid Multiband Imaging CAmera) on the Japanese *MUSES-C* spacecraft, the world's first asteroid sample return mission. The spacecraft will be launched in July 2002, arrive at the asteroid (10302) 1989 ML in August 2003, remain there for several months, and then return to Earth, with the sample return capsule parachuting into the Utah desert in June 2006.

Meech is a co-investigator on the Discovery mission *Deep Impact*. This mission will be the first to characterize the interior of a comet by sending a 0.5 ton impactor to excavate a crater on the surface. The investigators will watch the development of the crater, study the surface of the nucleus and the ejecta, and look for changes in the activity of the comet as induced by the impact. The mission will launch during January 2004 for an encounter on 4 July 2005. In preparation for the mission, Meech is coordinating all ground-based observing support for the mission. The goals of the ground-based observing are to fully characterize the nucleus of the comet prior to encounter: its size, albedo, rotation state, and activity level as a function of heliocentric distance. In addition there will be a large-scale multiwavelength Earth- and space-based observing program simultaneous with the encounter. During January and March 1999, Meech and Bauer obtained data on the mission target, P/Tempel 1, to begin to analyze its rotation state. It appears that the comet may be in an excited rotation state with a period at least 4 days in length.

10. SOLAR PHYSICS

The IfA Solar Group had a year of growth, with new faculty, research fellows, and students. The most recent and detailed information on planning, instrumentation, operations, science, and outreach is on the Web at http://www.solar.ifa.hawaii.edu.

10.1 A New Ground Facility: SOLAR-C

Our knowledge of the Sun's corona has advanced enormously since space experiments like *Yohkoh*, *SOHO*, and *TRACE* became operational. The ability to routinely observe the morphology of the corona against the disk (e.g., *Yohkoh*) and to observe the extended corona (in the optical) to many solar radii (e.g., Large Angle and Spectrometric Coronagraph Experiment, LASCO, on *SOHO*) has expanded interest in diverse coronal plasma problems ranging from how coronal mass ejections are formed and accelerated to how photospheric magnetic fields drive the inverted coronal temperature structure. The disappointment borne from the delicacy and intermittency of these space experiments has been heightened by their successes and the lack of comparable developments in ground-based coronal observing capabilities. A new facility for ground observations offers an opportunity to extend measurements of the physical properties of the corona: the Scatter-free Observatory for Limb Active Regions and Coronae (SOLAR-C). Under the direction of Kuhn, the Solar-C instrument is a 0.5 m off-axis coronagraphic reflecting telescope now being built on Haleakala adjacent to the Mees Solar Observatory. This instrument will (1) allow coronal observations that have not been realized, even from space, (2) develop technology that can be used for future satellite observations, and (3) support several long-term coronal observing platforms that extend intermittent coronal space observations.

10.2 Mees Solar Observatory at Max Millennium

Max Millennium is a coordinated program of observations and analysis of solar flares and activity through the present sunspot maximum. Special effort is underway for collaborative operation and science with the *High Energy Solar Spectroscopic Imager* (*HESSI*), a Small Explorer (SMEX) spacecraft scheduled for a mid-2000 launch.

Under the direction of Mickey, major instrument upgrades at Mees are in progress in preparation for *HESSI*. The Imaging Vector Magnetograph (IVM) will receive a dual etalon tunable prefilter, enabling operation over the band 580 to 660 nm. This will permit regular observation of Na D chromospheric vector magnetograms and Hα chromospheric structure and dynamics in sequence with the regular photospheric magnetograms. The Mees CCD imaging spectrograph (MCCD) is undergoing a data system upgrade, with a resulting factor of 25 increase in recorded flux. Commonality with the recently concluded IVM data system upgrade will make the pair of instruments easily operable in combination. The optical train of the MCCD is also being upgraded for a wider field of view, better slit imaging, and an adaptive optics package for more uniform image quality throughout the observing day.

10.3 Global Solar Corona

Research fellow Li has completed her study of the background solar corona during the time of activity minimum in 1996. Using time series of coronal images, she was able to separate the background corona from the short-term effects of active regions. Special attention was paid to the polar coronal holes, where Li found a systematic variation of emission with latitude; the edge of the polar hole is clearly darker than the center. Li was able to construct a model of coronal density as a function of latitude and height that fits the observations inside and outside the polar holes more accurately than previous global coronal models. She is continuing this work with longer time series to understand the coronal structure during the rise toward activity maximum.

10.4 Sunspot Oscillations

Research fellow Kupke is continuing her thesis work on magnetic field oscillations in sunspots. The thesis paper, now submitted for publication, used a polarimeter section on the MCCD, which gave good line profiles but had limited spatial field and resolution. New observations with the IVM have complementary characteristics. Kupke is also directing the optical design of the MCCD optics upgrade.

10.5 Acoustic Imaging

LaBonte has continued his collaboration with D.-Y. Chou (Tsing Hua Univ., Taiwan). They are applying acoustic imaging to the study of the structure of active regions.

11. THEORY

Barnes spent fall 1998 on sabbatical at the University of Tokyo, where he developed a hierarchical N-body code for the GRAPE (GRAvity PipE) special-purpose N-body hardware. By combining the favorable $O(N\log N)$ scaling of hierarchical algorithms with the pipelined arithmetic of the GRAPE, this new code permits the efficient simulation of collisionless systems with $N > 10^6$ particles. Barnes also continued work on a SPH (smoothed particle hydrodynamics) code, implementing improved algorithms for neighbor searching and time stepping. Although not as general as TREESPH, the ''industry standard'' SPH program, the new code is competitive in terms of speed and more than an order of magnitude shorter. Further work to implement feedback-regulated star formation is under way.

Barnes worked with graduate student E. Fulton on the survival of power-law cusp profiles in mergers of spherical galaxies. These studies showed that steep cusps are preserved in equal-mass and unequal-mass mergers, implying that bright ellipticals (which have shallow cusps) can't arise from mergers of faint ellipticals (which have steep cusps). Fulton and Barnes found that remnant shape is correlated with cusp slope; remnants with steep cusps are more likely to be axisymmetric, while those with shallow cusps are more triaxial. They also completed a paper describing a simple and general method of orbit classification in triaxial potentials.

Barnes worked with graduate student G. Bendo on the line-of-sight velocity profiles of simulated merger remnants. This work illustrates how a remnant's line profiles can encode information on the mass ratio and encounter geometry its progenitors. Mergers with mass ratios of 3:1 produce remnants with kinematic features similar to those of S0 galaxies, while equal-mass mergers produce a kinematically diverse population of slowly rotating objects.

Barnes continued work with J. Hibbard (NRAO) and Th. van der Hulst (Kapteyn) on analyzing 21cm observations of NGC 4038/9. With a first paper describing the observations to be submitted shortly, they are now focusing on reproducing the appearance and line-of-sight velocity field of this system with *N*-body models.

Barnes studied the formation of tidal dwarf ''pseudo-galaxies'' by gravitational instability in tidal tails. A large ensemble of simulations was used to characterize the spatial distribution, mass function, and mass–radius relation of such tidal fragments. Formation of tidal dwarfs is primarily governed by stellar dynamics, while gas dynamics plays a supporting role in highlighting newly collapsed systems.

Barnes presented invited review talks on galaxy merging at the 9th Annual October Astrophysics Conference, ''After the Dark Ages: When Galaxies Were Young (the Universe at $2 < z < 5$),'' at the Tenerife Conference, ''The Evolution of Galaxies on Cosmological Timescales,'' and at the XVth Institut d'Astrophysique Meeting, ''Galaxy Dynamics: From the Early Universe to the Present.''

Kaiser has developed the theory of weak gravitational lensing—the detection of dark matter via the miragelike distortion it produces in the images of faint distant galaxies. He has reconsidered the problem of determination of the gravitational shear from galaxy shape measurements. This work was stimulated by failures to generalize earlier methods to properly account for the circularizing effect of the instrumental point-spread function because a central element of the earlier analysis—the second moment of the point-spread function—is physically poorly defined for real telescopes. At the heart of the new approach is a ''finite resolution shear operator'' that, in the absence of noise at least, gives the response of an image to a weak shear applied before the instrumental image degradation. This operator allows a proper calibration of gravitational shear measurements and thus allows quantitative and precise measurements of the dark matter. A further motivation for this analysis was the realization that earlier attempts were flawed in another respect: The simple unweighted averaging of galaxy image shapes used to derive the form of the shear estimator gives results that are biased if, as in any practical study, one attempts to apply a weight based on the signal-to-noise ratio.

The new analysis emphasizes the difference between the response of an individual object and the response of a population of objects. This analysis allows for the first time the construction of an optimal weighting scheme for combining shear estimates from galaxies of various shapes, luminosities, and sizes. One result of this is an objective figure of merit—an inverse shear variance per unit solid angle—that characterizes the quality of image data for shear measurement and allows one to fine tune the measurement process to give optimal performance. The new method was tested with simulated image data. This analysis draws heavily on the properties of real instrumental point-spread functions. In addition to the calibration issue, consideration was given to correction for anisotropy of the point-spread function and a hitherto ignored bias for low signal-to-noise measurements was identified and corrected for.

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Robert A. McLaren, Interim Director

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