**University of Rochester**  
**C. E. Kenneth Mees Observatory**  
*Rochester, New York 14627-0171 USA*  

This year’s “Report of the C.E.K. Mees Observatory” covers activities of the faculty, staff and students at the University of Rochester, as well as of the Mees Associates, during the period October 1, 1999 to September 30, 2000.

1. **STAFF**

The Astronomy faculty at the University of Rochester includes E. Blackman, A. Frank, W. J. Forrest, H. L. Helfer (Emeritus), J. L. Pipher, M. P. Savedoff (Emeritus), S. L. Sharpless (Emeritus), J. H. Thomas, and D. M. Watson. Associates of the C. E. K. Mees Observatory include D. Meisel, SUNY at Geneseo and Z. Ninkov, Rochester Institute of Technology (RIT). H.M. Van Horn, Director of the Division of Astronomical Sciences at the NSF until June 2000, holds an adjunct professor position in the Department of Physics and Astronomy, and visits approximately monthly to work with his former faculty colleagues and students; in addition, he has been in residence at the University of Rochester since mid-June on a sabbatical. The Astronomy group was delighted to welcome Eric Blackman as a new Assistant Professor in January, 2000.

Pipher continues in the position of Rochester representative to the Board of Directors of the New York Astronomical Corporation, as a member of NASA’s 2MASS External Review Committee, of the AAS Pierce and Warner Prize Committees, as well as the SOFIA Science Council, and has been named Chair as of 10/00. She served on the organizing committee for the SIRTF Legacy Science Conference, “Galactic Science and the Interstellar Medium” held in the Grand Tetons in May 2000, and as well was chair of the LOC for the June 2000 Rochester AAS meeting. Pipher (with Michael Bicay, SIRTF Science Center) organized and chaired a special SIRTF topical session at the AAS meeting. Her term on the Gemini Board was completed in November, 1999. She became a member of the NRC CAA - Committee on Astronomy and Astrophysics - in August, 2000, and served on an adhoc committee chaired by Craig McCreight (NASA Ames) to define detector array properties for NGST. Pipher gave invited talks at the STScI meeting “From X-Rays to X-band” in June, 2000 and at the San Diego SPIE meeting in July, 2000.

Forrest, Pipher, and Watson are members of instrument teams for the NASA Space Infrared Telescope Facility (SIRTF), and are responsible for substantial detector array development for these experiments. Forrest and Pipher are members of the SIRTF Infrared Array Camera (IRAC) team, and Forrest and Watson belong to the SIRTF Infrared Spectrograph (IRS) consortium. They have been involved in Guaranteed Time Observations (GTO) SIRTF planning for the last year.

Frank served as the head of the Astronomy Advisory Committee for the Department of Physics and Astronomy and also chairman of the Rochester Astrophysics Consortium. Frank served as a consultant to NASA’s High Performance Computation and Communications program. In addition to his research activities Frank continues his outreach work as science writer for various popular magazines including Astronomy and Discover. This year Frank was named to the Editorial Advisory Board of Astronomy magazine.

Meisel presently serves as a member of the Arecibo Users and Scientific Advisory Board (AUSAC) for a three-year term as well as an affiliate director of the New York Space Grant Consortium.


Van Horn served as Director of the Division of Astronomical Sciences at the National Science Foundation until June 2000. Since then, he has been on a year-long sabbatical, dividing his time between the University of Rochester and the Department of Terrestrial Magnetism, at the Carnegie Institution of Washington, in Washington, DC. In addition, he has been reappointed as Adjunct Professor of Physics and Astronomy at the University of Rochester through 30 June 2002. When he returns to NSF in June, 2001, he will serve as Senior Science Advisor for the Directorate of Math and Physical Sciences.

Bill Glaccum continues his post-doctoral appointment in the Near IR group, and assumed responsibility for the SIRTF IRAC detector array work as liaison to the IRAC project at GSFC. Sheldon Weng, Senior Research Engineer, had responsibility for the Near IR group’s HgCdTe detector development programs, and left to take a job in industry in August, 2000. In mid-October 2000, Craig McMurtry will arrive as his replacement. Ryan Overbeck had been programmer/analyst for the Near IR group since summer 1998, and left in January, 2000 to take a position with the X-ray group at SAO. His successor, Rich Sarkis, began in May.

Working with Ninkov at RIT is post-doctoral fellow Robert Slawson. In addition Gerritt Lubberts provides support for the group’s activities in fabricating detector arrays in the RIT silicon foundry.

The astronomy faculty at the University of Rochester and Rochester Institute of Technology (RIT) have combined forces to form the Rochester Astrophysics Consortium (RAC). RAC has collaborated on seminars for the past year, co-hosted the June AAS meeting, and RAC faculty have begun further scientific collaborations. In addition to Ninkov (who is a Mees Associate), RIT faculty include Anne Young,
Roger Easton, Jim Kern, Michael Richmond, Elliott Horch, Joel Kastner, and Ian Gatley.

Public tours were conducted at the C. E. K. Mees Observatory from mid-May until the end of August by several undergraduate employees: Mike Thomas, Jenn Witkowsky, Dan Licht, Dan Berdine, Kim Krieger and Rich Sarkis. We are indebted to Deborah Shannon, our very able administrative assistant. Finally, Kurt Holmes, carries on in his father’s fine tradition as Observatory Supervisor. A long-awaited upgrade (computer control) to the observatory was completed Spring, 2000 by DFM Engineering. The Observatory is now used more extensively in undergraduate education.

2. UNDERGRADUATE EDUCATION

The undergraduate program at the University of Rochester includes the option of both a B.A. and B.S. in Physics and Astronomy. A flexible advanced program is offered, in addition to the two-semester introductory freshman-sophomore sequence in astronomy. Watson is the undergraduate advisor for physics and astronomy majors. The University of Rochester began a transitional period of cross-listing courses for undergraduates and graduate students at the University of Rochester and RIT.

Undergraduates Aaron Reichman, Brian Goss, John Vernaleo and Peter Allen worked with the Near IR group during the last academic year. Reichman began work on design of a fanout board for NGST InSb arrays in summer 1999: he continued this work during the past academic year with Brian Goss. Their work has been partially sponsored by an annual donation provided by a former Rochester undergraduate, and Mees Observatory student, Steve Varlese, now at Ball Brothers. Vernaleo worked with Near IR Lab engineer Weng on HgCdTe detector array testing analysis, and continues this academic year. Reichman and Allen reduced infrared images obtained by the near infrared group’s graduate students. Allen completed his senior thesis entitled “Molecular Hydrogen Emission in AFGL 437,” and Reichman completed his senior thesis entitled “Near Infrared Line Imaging of the Starburst Ring in NGC 7771” ; both theses were under Pipher’s direction. Allen is a graduate student at U. Penn., and Reichman is employed by Kodak. Matthew Barczys’ senior thesis (1999) “A Near Infrared Study of the Star Formation Region L988e” won the Astronomical Society of New York undergraduate prize in spring 2000. Pipher was his advisor. Barczys is now a graduate student at UCLA. Pratap Ranade is working with Forrest on optimization of AR coatings for InSb, as part of our NGST project.

Mike Thomas has worked since joining the University in Watson’s research group, and is involved in detector and optical characterization efforts for SIRTF and other NASA-supported development of far-infrared detector arrays. He was joined recently by brand-new freshman Joe Gester. Mika Edmondson (Hampton College) visited Watson’s group for the summer of 2000 as a McNair Fellow, and worked with Watson and graduate student Joel Green on simulations of spectral-scanning observing modes of the SIRTF Infrared Spectrograph.

Sean Hartnoll from Cambridge University completed a summer REU project calculating the theoretically predicted fluorescent iron line profiles from AGN accretion disks around black holes under Blackman’s supervision.

A number of undergraduates have worked in Frank’s research group last year. Rich Sarkis completed a honors project studying the effect of magnetic fields in wind blown bubbles. Russ Bent, Josh Oleksyn, Zeb Forney and Sam Hathaway worked with Frank developing numerical tools that could be used in both classroom settings and planetaria. Currently Bent is a graduate student at Brown in Computer Science.

The UV photometer experiment to measure daytime OH airglow built by a team of SUNY-Genesee students and directed by Meisel was successfully launched May 17, 2000 from the NASA Wallops Flight Center in collaboration with Penn State undergraduate engineers (Mitchell et al., 1999). The SUNY project is partially funded by funds from the New York Space Grant consortium. The filters for the project were deposited in the University of Rochester Nuclear Structure Laboratory target preparation facility. Initial data reduction accomplished in July-August 2000 show usable signals in 16 of 21 channels. Further analysis is presently being carried out by Geneseo physics and astronomy students.

Katherine Hoheusle (RIT) completed a senior project involving with reducing images obtained with a tunable liquid crystal filter and CCD.

Laurie Tuttle (RIT) completed a senior project that involves designing a focal reducer for the Mees Telescope using the Oslo Design Package.

3. GRADUATE EDUCATION

Bob Benson, Carl Welch, Dawn Peterson, Candice Bacon and Kristin Nelson have been graduate students in Forrest and Pipher’s Near Infrared Group for the past year. Welch has taken a leave of absence as of August 2000. First year student Rot Gutermuth joined their group this fall, and second year student Marian Ghilea joined the group this summer.

Welch has been conducting an IR study of stars from the asymptotic giant branch (AGB) phase through the planetary nebula phase. This study is done by imaging line emission and broadband emission in objects in post-AGB phases of stellar evolution.

Peterson successfully completed the preliminary exam, and is beginning work on young star clusters, working closely with Tom Megeath of SAO. These studies are a prelude to SIRTF observations of the same objects. First year student Gutermuth is beginning to assess 2MASS data on the SIRTF cluster objects.

Benson has completed latent image characterization of SIRTF InSb detector arrays, and presented a paper on this at the San Diego SPIE meeting this summer. He has begun observational studies of reflection nebulae and young stellar objects (YSOs).

Ghilea continued the work begun by the undergraduates on designing a fanout board for the SB 226 multiplexer, and completed the design summer 2000. The fanout board has been fabricated, and the dewar will shortly be assembled for testing of the SB 226 bare muxes.
4. RESEARCH

4.1 Theoretical Astrophysics

Rochester’s theoretical astrophysics group consists of E. Blackman, A. Frank, H.L. Helfer (emeritus), M.P. Savedoff (emeritus), J.H. Thomas, and H.M. Van Horn (adjunct), along with current graduate students G. Delamarter, T. Gardiner, A. Poludnenko, R. Selkowitz and Jeong-Hoon Yang. The group’s research spans a wide range, from astrophysical fluid dynamics and magnetohydrodynamics to relativistic and high energy astrophysics. Research has also focused on a broad variety of astrophysical settings, from stars to active galactic nuclei. A diverse set of techniques are utilized, including massively parallel numerical computations. Interactions with the University’s Laboratory for Laser Energetics give students access to high performance computational tools and opportunities to study plasma astrophysics in both theoretical and laboratory settings.

4.1.1 Gamma-Ray Bursts

Blackman has continued to study Poynting flux driven outflows from magnetized rotators as a plausible explanation for the mysterious engines of gamma-ray bursts (GRB). Of the many models that have been proposed to explain gamma-ray bursts only a few have survived the increasing number of observational constraints. The magnetized rotator model is one of them. Lyutikov and Blackman (2000) have suggested a new possibility for how such relativistic Poynting flux outflows might transfer energy into radiating particles, arguing that the Poynting flux drives non-linearly unstable large amplitude electromagnetic waves (LAEMW) which “break” at radii where the MHD approximation becomes inapplicable. Particles are accelerated to ultrarelativistic energies which then radiate in turbulent electromagnetic fields. The emission properties are similar to synchrotron radiation, with a typical cooling time $\sim 10^{-4}$ sec. This mechanism can account for the universality of the characteristic gamma-ray burst frequency of 0.5 MeV, and can supply the large magnetic fields required in the afterglow external shocks.

4.1.2 Magnetic Dynamo Theory

Mean field dynamo theory is the leading explanation to explain large scale fields of stars and Galaxies. However, it has been controversial because the role of MHD turbulence and the role of the backreaction of the growing field on the turbulent motions driving the growth is not well understood. Blackman and G. Field (Harvard), have recently made significant progress on this question.

Blackman & Field (2000a) showed that the expulsion of magnetic helicity is a fundamental requirement for astrophysical magnetic dynamos to function. This potentially resolves some long standing conflicts in mean field dynamo theory. In particular, it reveals that open boundary conditions must be included in numerical simulations when testing for dynamo suppression in real astrophysical systems. They showed that the suppression observed in a number of previous simulations may be explained by the choice of periodic boundary conditions. Such boundary conditions do not allow magnetic helicity to escape. This restriction means that what
appeared to by a dynamical catastrophic effect of the mag-
netic backreaction may be merely an apparent suppression,
dictated by the initial boundary conditions. Blackman &
Field (2000b) have also shown that all systems which harbor
a mean field dynamo must have an active corona shedding
magnetic field in dynamo theory. This is motivated by planet
formation studies. There has been some difficulty in under-
standing how planetessimals grow from the centimeter sized
grains to the scale of meters whence gravitational instability
can take over. Previous work had considered only how ex-
isting vortices in protostellar disks may help concentrate
dust particles to the extent required, but had not discussed
the origin of the vortices. Blackman has shown analytically
that vortices can be produced in accretion disks, with the
necessary properties. More work will be needed to verify this
for more sophisticated computational treatments.

4.1.3 Accretion Disks, Vorticity and Planet Formation

Blackman (2000) has considered the growth of large scale
vortices in accretion disks by analogy to the growth of mag-
netic field in dynamo theory. This is motivated by planet
formation studies. There has been some difficulty in under-
standing how planetessimals grow from the centimeter sized
grains to the scale of meters whence gravitational instability
can take over. Previous work had considered only how ex-
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that vortices can be produced in accretion disks, with the
necessary properties. More work will be needed to verify this
for more sophisticated computational treatments.

4.1.4 Active Galactic Nuclei

With REU student Sean Hartnoll (Cambridge UK), Black-
man continued an investigation of Iron line profiles in AGN.
Fluorescent iron lines in AGN result from X-rays impinging
onto cold gas and being re-radiated. The line shape is deter-
mained by Doppler and gravitational effects. These line pro-
files represent one of the very few pieces of observable evi-
dence for the strong gravity regime of General Relativity.
Standard models have considered the cold material to be in a
flat thin accretion disk. Hartnoll & Blackman (2000ab) have
been considering alternative well motivated geometries to
benchmark against the standard theory. The study is moti-
vated by certain inconsistencies and resolution issues for ex-
isting X-ray data from Seyferts when compared to flat disk
models, as well as by theoretical models of alternative accre-
tion disk geometries. Hartnoll & Blackman (2000ab) consid-
ered line profiles from warped relativistic disks and from
dense clouds immersed in otherwise optically thin geometri-
cally thick accretion engines (such as Advection Dominated
Accretion Flows (ADAFs)). They found that these alterna-
tive disks can account for the observations as well as flat
disks in many cases, and may help alleviate some of the
problems with the flat thin disk model fits.

4.1.5 YSO Jets and Pulsed Outflows

Bipolar outflows and highly collimated jets are nearly
ubiquitous features associated with stellar mass loss. From
Young Stellar Objects (YSOs) to Luminous Blue Variables
(LBV$s$) and Planetary Nebulae (PNe)—the stellar cradle to
the grave—there exists clear evidence for collimated gaseous
flows in the form of narrow high velocity streams or ex-
tended bipolar lobes. In YSOs, LBVs and PNe collimated
highly supersonic outflows are observed to be transporting
prodigious amounts of energy and momentum from a central
star - enough to constitute a significant fraction of the total
budgets of the entire system. Thus outflows and jets must
play a significant dynamical role in the evolution of the par-
ent stars.

Frank’s group produced a number of numerical gasdy-
namic and magneto-gasdynamic simulation studies of these
outflows. Projects include studies of magneto-gasdynamic
YSO jets. In Frank et al. (2000) the effects of magnetic fields
on MHD jets from Keplerian rotators were explored. Lery &
Frank (2000) also investigated the stability of these jets.
These works showed that jets from different classes of mag-
netic rotators can have quite different propagation character-
istics. These simulations may be useful in helping distinguish
between different jet launching mechanisms. In Gardiner &
Frank (2000) the effects of magnetic geometry of pulsed jets
were studied. The results showed that distinctive magnetic
signatures of pulsing are likely to exist if the fields have a
large enough initial magnitude.

In Delamarter Frank & Hartmann (2000) used a hydrody-
namic simulation code to study the effects of time-dependent
winds by driving them into realistic collapsed filament envi-
nvironments. These simulations have shown that hydrodynamic
collimation effects can be strengthened by variability in a
wind.

4.1.6 Planetary Nebulae

Magnetic shaping of the wind from the progenitor star has
been shown to be an effective mechanism for producing el-
liptical or bipolar planetary nebulae. Blackman, Frank,
Markiel, Thomas, and Van Horn (2000) have shown that the
magnetic field can have its origin in an alpha-omega dynamo
during the AGB phase of the central star. Events analogous
to solar coronal mass ejections can produce the ejected knots
or bullets seen in some planetary nebulae. Besides shaping
the planetary nebula, the dynamo-generated magnetic field
will eventually slow the rotation rate of the condensed core
of the AGB star. This model offers a self-consistent para-
digm for planetary nebula formation, beginning with the
AGB stage and ending with a slowly rotating white dwarf.

Blackman, Frank and Welch (2000) have considered the
role of magnetized disk and stellar winds in powering the
remarkable bipolar outflows from planetary nebulae ob-
served by HST. They have shown that not only can the mag-
netized winds power the planetary nebulae, but the combina-
tion of MHD disk + stellar winds may lead to the mulipolar
multi-axis morphology of planetary nebulae when the central
post AGB star is rapidly rotating and the stellar and disk axes
are misaligned.

4.1.7 Solar and Stellar Physics

Thomas and B. Montesinos (LAEFF, Madrid) have stud-
ed dynamo generation of magnetic fields in lower main se-
quence stars. They have re-examined the relationship among
chromospheric Ca II H and K emission, dynamo number,
and Rossby number for stars in the Mt. Wilson stellar activ-
ity record, in the context of a solar-like interface dynamo
model. The tight correlation between observed chromo-
spheric activity and Rossby number provides restrictions on
the internal differential rotation in these stars.
4.2 Observational Astrophysics

In the past year, observational astrophysics at the University of Rochester has included studies of star formation regions and stellar clusters, planetary and proto-planetary nebulae, active and starburst galaxies, brown dwarf candidates, and the Sun. The IR imaging observations have been carried out at the MLOF 1.5m, the Mt. Hopkins 1.2m, and the WIRO 2.3m telescopes. GTO planning for SIRTF has occupied the three SIRTF team members most of this year.

4.2.1 The Sun

Thomas and Stanchfield (2000) observed fine-scale magnetic effects on solar p-modes and higher-frequency acoustic waves, using the Dunn Solar Telescope at NSO/ Sacramento Peak. These effects include the suppression of p-mode power by the magnetic field and enhancement of power at higher frequencies (above the acoustic cutoff) in “‘halos” around intense magnetic fields. They found seismic evidence of an emerging pore before it was visible in continuum intensity at the solar surface.

4.2.2 Comet Hale Bopp

A paper “Near-Infrared Imaging Spectrophotometry of Comet C/1995 O1 (Hale-Bopp) Near Perihelion” (Harker et al. 2000) describes 1 – 5 μm broadband and CVF images taken 49 days before perihelion. The images display a non-spherical coma, with a bright ridge in the direction of the dust tail. Inferred grain sizes responsible are <0.4 μm, the smallest yet noted in a comet. Variation in integrated surface brightness with radial distance from the coma can be interpreted in terms of comet dust ablation. The colors along the tail are not constant, suggesting varying dust properties.

4.2.3 Micrometeors

Meisel continues his intensive collaboration with the Penn State Electrical Engineering Communications and Space Sciences Laboratory (CSSL). While on sabbatical there last year, a number of papers (Mathews et al., 1999a,b; Janches et al., 2000a,b,c; and Meisel et al., 2000) were produced detailing the physical properties of micrometeors (masses on the order of a microgram) detected with the Arecibo 430 MHz UHF radar.

From the nearly 9000 micrometeors observed so far, about 1200 show deceleration and can have their sizes directly estimated. Out of a sample of 600 “‘best” orbits approximately 70 are on truly hyperbolic paths. All but 11 of the hyperbolic ones seem to be coming from the vicinity of Jupiter and Saturn with the remainder appearing to be related with the Geminga supernova explosion (Meisel et al. 2000). This sample of solar system dust particles also includes a number of the so-called beta particles as well as a number of electromagnetically trapped particles with perihelia quite close to the sun. This work is funded by the National Science Foundation.

Meisel is continuing his collaboration with the Meteor Observatory staff of the Kazan State University on a number of projects, including forward scatter and backscatter observations of meteors.

4.2.4 Brown Dwarfs and Low Mass Stars

Forrest and former post-doc B. Ali, in collaboration with Stauffer (SAO) and Leggett (Hawaii), have conducted an ISOcam search for Brown Dwarfs in the Hyades. They developed an innovative technique to analyze the data, and have identified several candidate brown dwarfs. Deep K-band imaging of the best candidates has been obtained via UKIRT service observing. Preliminary analysis shows that two of the objects have R, K, [6.7 μm] magnitudes and colors consistent with the methane brown dwarf Gl229B at the distance of the Hyades. These objects would be consistent with 0.03 M⊙ brown dwarfs at the age (1 Gyr) and distance of the Hyades. J and H band observations indicate red J, H, K colors more consistent with L-dwarfs 300pc distant.

4.2.5 Planetary Search

Ninkov continues as a participant in the international TEP (Transits of Extrasolar Planets) network. This worldwide collaboration has continued monitoring of the eclipsing binary system CM Dra in an effort to detect photometric variations attributable to the transit of a planet (or planets) in the system. The result of the data obtained is presented in Deeg et al. (1998) and Deeg et al. [2000]. The group is also investigating accurate timing of eclipse minima in low mass binary systems as another means for detection of planetary objects (Doyle et al. [1997]).

4.2.6 Observations of Star Formation Activity

Utilizing the 3rd generation Rochester Infrared Camera, the groups continue to study massive star formation regions via: (i.) imaging in hydrogen recombination lines (to probe excitation and extinction); (ii.) imaging in lines of H₂ (to probe molecular shock excitation); (iii.) imaging in [FeII] lines (to probe molecular shocks); (iv.) imaging in the 3.29 μm PAH emission feature (to explore PDRs) and (v.) imaging at J, H, K, L’’, and L’’’ broadbands (to probe reflection nebulosity, thermal dust emission, and to obtain photometry and reddening of associated point sources). Raines et al. (in preparation) have imaged the Herbig-Haro (H-H) objects in GGD 37 (Cep A West) and show that the H₂ emission forms arcs exterior to the [Fe II] emission; the morphology is similar to that of the H₂/S II images of Hartigan, Carpenter, Dougados, and Skrutskie (1996). The peak H₂ and [Fe II] line emissions for several of the H-H objects are clearly separated relative to one another, suggestive of multiple shocks. Delamarter’s model of the structure of C* and J shocks in H₂ has been modified to include other important coolants such as [Fe II], in order to compare the separation of the shocked emissions to those seen in GGD 37.

The detection of very large proper motion in two compact H-H objects close to the putative outflow source in GGD 37, in [Fe II] 1.64 micron images taken in 1993, 1996, and 1998 is discussed by Raines et al. (2000). Both objects are visible also in the 6 and 20 cm VLA maps of this region, one northeast of their source W3 and one coincident with their source W2. The directions of the proper motions are consistent with motions measured for others of the GGD 37 H-H objects, but the transverse velocities are much greater.
4.2.7 Observations of Late Phases of Stellar Evolution

The late stages of low- to intermediate-mass stellar evolution include mass loss stages during the AGB evolution, and development of protoplanetary and planetary nebular phases. Welch is well into an observational study of these phases, including the following objects: Egg Nebula (AFGL 2688), M1-92, Hubble 12, NGC 7027, NGC 2392, NGC 2440, NGC 2371, NGC 6826, NGC 7662, IRAS 22272, Abell 79, and BD + 30° 3639. He has found evidence for the action of a substantial dusty disk at all stages: in M1-92 his J - K images depict the disk clearly, while in Hubble 12 (Welch et al. 1999), he observed small, shocked FeII hourglass outflow loops on either side of the equatorial disk, within a larger H2 PDR hourglass. A young planetary nebula is seen at the vertex. At the conference “Asymmetrical Planetary Nebulae II: from Origins to Microstructures” (Welch et al. 2000) he showed that BD + 30° 3639 may represent a more evolved form of Hubble 12, while NGC 7027 likely has a more massive central star.

4.2.8 Active and Starburst Galaxies

In support of the use of the 3.29 μm dust feature as a probe of star formation in galaxies, the group has extensively investigated this feature in galactic sources. The intent is to gain a better understanding of the astrophysics underlying its generation. To this end, we have imaged the well-known reflection nebulae NGC 2023 and NGC 7023 with approximately 1” resolution. Graduate students Nelson and Peterson are investigating various extragalactic sources in these features. Images in the 3.29 μm dust feature of NGC 7469 show strong circumnuclear emission. Work is in progress on 3.29 μm images of NGC 1614 (which is at the same distance as NGC 7469) and with special emphasis on NGC 4194. Satyapal et al. (1999) present images in 3.29 μm dust feature emission as well as in Paβ and Brγ hydrogen recombination line emission of the Arp 299 interacting galaxy system. The observations obtained are completely consistent with a starburst model, and the 3.29 μm dust feature flux to total luminosity ratio is consistent with that of other starburst galaxies. Starburst ages of ~6 Myr, 8 Myr, and 4 Myr are derived for components A, B and C respectively.

4.2.9 Speckle Imaging

Horch and Ninkov have utilized a slow scan CCD for speckle imaging by using the CCD to detect the image and then executing a fast row transfer prior to the next speckle image (Horche et al. [1997]). The CCD is therefore not only used as a detector but as an analog storage register. Initial results have been very encouraging when compared to other speckle observers. The results of the first year of using this system at the WIYN telescope (in collaboration with William van Altena of Yale) are reported on in Horch et al. (1999) and Horch et al. [2000]. An adaption to this system that uses a piezo-mirror to allow use of the CCD as a two dimensional storage register is now being developed. The system is also being used at WIYN to observe proposed Space Interferometry Mission reference grid stars.

4.2.10 Multispectral Imaging

Slawson & Ninkov (1999) have demonstrated that wide-area spectrophotometry is possible using a liquid-crystal tuneable filter and a CCD camera. Multiple images of the central region of the open cluster NGC 4755 were acquired covering the wavelength range from 435 to 720 nm with a 10 nm passband in 5 nm steps. Magnitudes were measured for all stars in the images by PSF fitting photometry. A simple calibration was adopted by assuming that a spectrophotometric scan from an atlas for a B1 V star matched the intrinsic spectrum of a star classified as B1 V in the cluster. A differential correction was computed between the atlas scan and this adopted local standard star and then applied to all the other stars on a frame by frame basis. Spectra for stars were extracted from the data set and with these it was possible to demonstrate that broad features, such as molecular bands, are detectable as well as the overall shape (slope) of the continuum. Studies of more dense stellar regions are planned.

Development of a digital micromirror based multiobject spectrograph continues as part of Kevin Kearney’s thesis work. Initial results on scattering from these mirrors are presented in Kearney and Ninkov [2000].

4.3 Instrumentation

This year, infrared instrumentation development at the University of Rochester has centered on the groups’ near infrared and far infrared SIRTF detector developments, HgCdTe and InSb development for future space missions, innovative far-infrared detectors, and improvements to the Rochester third generation ground-based camera. Optical CCD, CID, and Active Pixel Sensor development has taken place at RIT.

4.3.1 Near and Mid-Infrared Array Detector System Development

Forrest and Pipher and their group (Glaccum, Weng, Benson, Bacon) continue to develop infrared arrays for space application using the flexible, programmable array controller utilizing DSPs described in previous reports. This year they have characterized latent image performance for a wide variety of InSb arrays (Benson et al. 2000), and have studied the 30K performance of SIRTF-like arrays. In addition, Rochester has been heavily involved in test result interpretation of flight-mounted InSb arrays in the IRAC experiment at GSFC (Pipher et al. 2000; Hora et al. 2000). There has been active participation of the UR group with the GSFC group, who are responsible for flight array testing.

Forrest and Pipher, in collaboration with Raytheon, are funded under a NASA ISR grant to develop large format InSb arrays for NGST that exceed present performance capabilities. The array requirements include: QE >80% 0.5-5 μm, pixel dark current <0.02 e⁻/s, pixel read noise <3 e⁻, 1024×1024 format buttable to 4k × 4k, power dissipation <2 mW per 1k × 1k module, operation near 30K (passive cooling). NGST will require 80 1k × 1k modules in its focal planes. Work at Rochester (Wu et al., 1997), NOAO, and SBRC/Raytheon shows that InSb photodiode arrays can meet the detector requirements. The chief challenges are in
the Si multiplexer circuit, which determines the read noise, and in achieving a yield consistent with producing more than 80 flight-quality parts. Measurements of the FET noise power spectra and analysis and measurement of the resulting pixel read noise indicate that the noise requirement can be met using multiple, non-destructive, Fowler sampling or a variant on the sample up the ramp routine. Pipher and Forrest worked with the NGST group on Up-the-Ramp-Sampling with cosmic ray rejection (Offenberg et al., 2000 submitted).

In this paper radiation data obtained on SIRTF-like detector arrays were analyzed by the Fixsen method of up-the-ramp sampling with on-the-fly cosmic ray identification and mitigation (Fixsen et al. 2000).

Test cryo-CMOS multiplexers have been produced at Raytheon. Based on this experience the first NGST-optimized 1k × 1k readout has been produced at Orbit (now Supertex). Al Fowler (NOAO) is aiding in this effort. Reports on this work include that by Love et al. (2000) at the Munich SPIE meeting, as well as a demonstration model shown by J. Garnett at an NGST workshop August 1999. Bare muxes of several lot splits have been delivered to the University of Rochester, and have also been distributed to our collaborators at NOAO and NASA-Ames. Forrest’s student Ghilea has designed and had manufactured the fanout board for this array, and testing of the bare mux will proceed shortly.

In addition, Pipher and Forrest, with research engineer Weng, are continuing work with Rockwell Science Center to develop mid-wave HgCdTe detector arrays as an alternate technology for space astronomy under a NASA ISR grant (which began in April 1997) and a NASA SOFIA/Explorer grant (which began August 1999). There has been considerable progress in this area of research. Most recently, HgCdTe arrays, with cutoff wavelengths of 7.0 and 9.0 μm, mounted on NICMOS muxes, have been characterized and optimized in our lab. Dark currents of <100 e−/s have been obtained on a relatively modest fraction of the 256 × 256 pixels in a given array. James Garnett is now in charge of our program at Rockwell, and he has several “advanced process diode” mid-IR arrays in process. We anticipate a much better yield of low dark-current arrays.

4.3.2 Near Infrared Camera

One of the SBRC InSb CRC 744 arrays (not a flight array) is utilized in the Rochester Third Generation camera, developed under a grant from the NSF. It now has a complement of fixed filters at the J, H, K, L′, 3.26 μm and M′ bands, and in addition, three CVFs (circular variable filters) over the usable 1 - 5 μm waveband with ~1 - 2% resolution. The Third Generation 256 × 256 InSb array camera has been used in ever-improved form since October, 1992 at WIRO and MLOF.

4.3.3 Far Infrared Detector Development

In collaboration with Jim Huffman (LSRL) and grad students Matt Guptill (UR and Boeing) and Joel Green (UR), Watson continues to develop extrinsic germanium blocked-impurity-band detector arrays, with support from NASA. The current ten-wafer batch, in progress, has several splits intended to solve for good and all the trade-off among majority impurity concentration, active layer thickness, dark current, and threshold wavelength. The wafers will be processed into numerous 41 × 32 and 6 × 6 arrays.

As part of a NATO-funded collaboration, Professor D.R. Khokhlov (Moscow State University) paid a visit to Rochester in January and February to work with Raines, Watson and Pipher on characterization of PsSnTe:In photodetectors fabricated in Russia by Khokhlov and I.I. Ivanchik (MSU) and their co-workers. The performance of single-element PbSnTe:In detectors were compared with that of state-of-the-art single elements of Si:As BIBs and Ge:Ga photoconductors in the same cryogenic optical system in the wavelength range 14-120 microns. Results show PbSnTe:In to be quite competitive with these conventional detectors, especially at the shorter wavelengths. These devices are quite novel in the sense that they exhibit persistent photoconductivity, and thus can be said to “integrate internally” without the benefit of switched-gate electronics. They can be reset by microwave or thermal pulses. Details of the results can be found in Khokhlov et al. (2000).

4.3.4 CMOS Active Pixel Developments

Ninkov, Lubberts, Lungu and Fuller (RIT Microelectronics) continue to investigate and test sensors fabricated in silicon that will be successors for CCDs. This activity has focused on the development of Active Pixel Sensors that utilize amplifiers and switches within each pixel. In many respects these devices are similar to the multiplexers bonded to suitable detector materials for IR imaging. The group at RIT has designed a 128 × 128 APS device that is in fabrication at a commercial foundry (Lungu et al. [1999]). In addition an enhanced larger format version of this device is being fabricated in the RIT Foundry facility. Finally, a separate version of a related device is being fabricated using silicon-on-quartz material in order to develop a back-illuminated APS device.

Characterization of the performance of visible focal plane arrays continues at RIT. Recent emphasis has been on measuring the sensitivity variations within pixels of a CCD (Piterman and Ninkov [2000]) and studying the resulting effect on centroiding and photometry accuracy (Kavaladgiev and Ninkov [2000]). Also the performance of CID arrays in a harsh radiation environment has been investigated (Marshall et al. [2000]).

PUBLICATIONS


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