University of Rochester
C. E. Kenneth Mees Observatory
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[S0002-7537(90)05401-4]

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, 1998 to September 30, 1999.

1. STAFF

The Astronomy faculty at the University of Rochester includes 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 (on sabbatical until mid-July 2000 at the Communications and Space Sciences Laboratory (CSSL), Department of Electrical Engineering, Penn State University) and Z. Ninkov, Rochester Institute of Technology. H. W. Fulbright, Emeritus Professor of Physics, remains active in the Department and at the Observatory. H.M. Van Horn, Director of Astrophysics at the NSF, 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. The Astronomy group is delighted to welcome Eric Blackman as an 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 Gemini Board, of the AAS Pierce and Warner Prize Committees, as well as the SOFIA Science Council. She served on the organizing committee for the SIRTF Legacy Science Conference, ''Galactic Science and the Interstellar Medium'' to be held in the Grand Tetons in May 2000, and as well as chair of the LOC for the June 2000 AAS meeting (to be held in Rochester). Pipher gave a public and a technical talk at Georgian Court College as part of the AAS Shapley program.

Forrest participated in the MIDEX review run by NASA Langley. He also was on the team reviewing the NASA, ESA, and CSA studies of the Integrated Science Module for NGST.

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.

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. Meisel continues as a Visiting Lecturer for the AAS Shapley Lecture Series.

Thomas continues to serve as a Scientific Editor of *The Astrophysical Journal* and as an affiliate scientist at the High Altitude Observatory, National Center for Atmospheric Research. He is a member of the executive committee of the AAS Solar Physics Division (SPD), and he wrote an article on the history of the SPD for the AAS centennial volume (Thomas 1999a). Thomas also serves on the AURA Observatories Visiting Committee and the Solar Astronomy Panel of the NRC Astronomy and Astrophysics Survey Committee.

Van Horn continues to serve as Director of the Division of Astronomical Sciences at the National Science Foundation. In addition, he has been reappointed as Adjunct Professor of Physics and Astronomy at the University of Rochester through 30 June 2002.

Bill Glaccum continues his post-doctoral appointment in the Near IR group, and has assumed responsibility for the SIRTF IRAC detector array work. Sheldon Weng, Senior Research Engineer, has responsibility for the Near IR group's HgCdTe detector development programs. Ryan Overbeck has been programmer/analyst for the Near IR group since summer 1998. Babar Ali continued his post-doctoral appointment until mid-June 1999. He has assumed a position at IPAC. Ali is responsible for ISOcam support at IPAC. He will be investigating the efficacy of the analysis method developed at Rochester to improve the sensitivity and reliability of other ISOcam observations.

Working with Ninkov at RIT is post-doctoral fellow Robert Slawson.

In addition Gerrutt Lubberts provides support for the group's activities in fabricating detector arrays in the RIT silicon foundry.

Public tours were conducted at the C. E. K. Mees Observatory from mid-May until the end of August by several undergraduate employees: Aaron Reichman, Mike Thomas, Brian Goss, Jenn Witkowsky, Peter Allen, and Rich Sarkis. We are indebted to Deborah Tedrick, administrative assistant for the group, who left the area in August 1999. Deborah Shannon is her very able replacement. Finally, Kurt Holmes, carries on in his father's fine tradition as Observatory Supervisor.

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. Pipher was the undergraduate advisor for physics and astronomy majors during most of this period, and was replaced by Watson in July 1999. 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 and Matthew Barczys worked with the Near IR group in winter 1999, and Reichman, Brian Goss, and Peter Allen worked with the Near IR group this summer. Brian and Peter worked on providing visible light response data on InSb detector arrays, for NGST consideration. This project involved Rochester faculty Forrest and Pipher and RIT faculty Ninkov, as well as collaborators from UBC. Reichman began work on design of a fanout board for NGST InSb arrays: he continued this work Fall 1999 with Brian Goss. Matthew Barczys completed his senior thesis under Pipher's supervision, ''A Near Infrared Study of the Star Formation Region L988e.'' A paper on this work, to be submitted to either AJ or ApJ, is in preparation. Barczys is now a graduate student at UCLA.

Marianne Vieira completed an undergraduate senior thesis entitled ''Numerical Simulations of the Protoplanetary Nebula CRL 2688 (Egg Nebula)'' under Frank's direction.

Mike Thomas, now in his junior year, has worked since joining the University in Watson's research group, and is involved in detector and optical materials characterization efforts for SIRTF as well as NASA-supported development of far-infrared detector arrays.

Meghan Canning completed a senior project entitled ''Study of the Red Rectangle.''

Katherine Hoheusle has begun a senior project involved with reducing images obtained with a tunable liquid crystal filter + CCD.

Laurie Tuttle has also started a senior project that involves designing a focal reducer for the Mees Telescope using the Oslo Design Package.

Meisel and a team of Geneseo students have been making preparations for a student rocket launch (called SPIRIT, Student Projects Involving Rocket Investigation Techniques) from the NASA Wallops Flight Center. Their experiment is to measure the daytime UV OH airglow intensity and temperature using an array of 16 photodiodes. The launch, in collaboration with Penn State undergraduate engineers, is scheduled for late 1999. The SUNY project is partially funded by funds from the New York Space Grant consortium.

3. GRADUATE EDUCATION

Bob Benson, Jennifer Goetz, Carl Welch, Dawn Peterson and Kristin Nelson have been graduate students in Forrest and Pipher's Near Infrared Group for the past year. First year student Candice Bacon joined their detector development group this past summer.

Goetz completed her PhD thesis work, and submitted her thesis entitled ''An Infrared Study of Three Massive Star Forming Regions: Cep A East, S88 B, and S235 A/B.'' She assumed a faculty position at the College at Wooster, and successfully defended her thesis in early October. She studied the interactions of the forming stars with their environments, and determined cluster ages by several methods.

Welch successfully defended his Admission to Candidacy exam with a research brief on an IR study 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 has continued research on 3.3 μm imaging of active galaxies.

Benson has continued latent image characterization of SIRTF InSb detector arrays, and has begun observational studies of reflection nebulae and young stellar objects (YSOs).

Nelson continued her work on a spectrometer optical design which comprised the research brief for her Admission to Candidacy exam. She was successful in obtaining a Smithsonian Predoctoral Fellowship, and will work at CfA under Willner's direction (Pipher, home advisor) on a study of 3.3 μm and mid-IR feature emission from interacting galaxies.

Matt Guptill and Nick Raines are graduate students in Watson's Far-Infrared group. Guptill continues far-IR detector development, in absentia at Boeing, and Raines is completing his thesis work on shocks in massive YSO complexes.

Tom Gardiner is has developed a new magnetohydrodynamics (MHD) code and is applying it to jet propagation in YSOs.

Guy Delamarter continues study of hydrodynamic interaction of youg stellar object winds and infall. A paper on this topic has been accepted for publication. Using the Cashmere system developed in the University of Rochester Computer Science Department (Dwarkadas, 1999), he has written a parallel version of a hydrodynamic code to increase the speed and resolution of interaction simulations.

Alexi Puludenko has begun work on the development of an Adaptive Mesh Refinement code for use in wind-cloud collisions.

Andrew Markiel completed and defended his dissertation entitled ''Solar and Stellar Dynamo Models'' under the supervision of Thomas and Van Horn and subsequently took up a postdoctoral research position at the University of Washington.

Al Piterman continues his graduate thesis work on CID/APS detector characterization with Ninkov.

George Lungu also continues with his PhD thesis work in fabrication of silicon based Active Pixel Sensors (APS).

Kevin Kearney continues his graduate research in the development of digital micromirror devices for use as digital masks for multi-object spectroscopy (Kearney and Ninkov [1998]).

Danial Ma is a new graduate student involved with detector fabrication at RIT.

New University of Rochester graduate students in astrophysics include: Robert Selkowitz, Adam Kubik, Marian Ghilea, Jeong-Hoon Yang and Jayanthi San. All are presently TAs in the department.

4. RESEARCH

4.1 Theoretical Astrophysics

Rochester's theoretical astrophysics group consists of 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. Markiel, A.

Ivanov and A. Poludnenko. The group's research interests are mostly in the areas of astrophysical fluid dynamics and magnetohydrodynamics.

4.1.1 The Sun

Markiel and Thomas (1999) studied interface models for the solar dynamo incorporating a realistic internal solar rotation profile as determined from helioseismology. They found that the latitudinal gradient of rotation has a significant effect, generally suppressing oscillatory modes and driving steady modes. A solar-like interface dynamo seems possible only if the alpha effect is somehow confined to a band about the equator.

4.1.2 Accretion Disks

T. Collins (Laboratory for Laser Energetics, University of Rochester), Helfer, and Van Horn completed two papers concerned with the oscillations of accretion disks and boundary layers in cataclysmic variable systems (CVs). The two papers have been submitted for publication as companion papers in the *Astrophysical Journal*. The first paper (Collins, Helfer, and Van Horn 1999a) describes unperturbed, steady-flow models for the disks and boundary layers in CVs. These serve as unperturbed models for the local, linear stability analysis discussed in the second paper (Collins, Helfer, and Van Horn 1999b). The results demonstrated the existence of oscillatory instabilities with periods of order seconds. The beating of these modes produces oscillations with periods of order 20s to several hundred seconds, just in the range in which oscillations have been observed. A search for the underlying, shorter periods predicted by this model may allow an observational test. A study of coronal wind models to complement these disk models has been initiated.

4.1.3 Bipolar Outflows and Highly Collimated Jets

Frank's research focuses on bipolar outflows and highly collimated jets which are nearly ubiquitous features associated with stellar mass loss. From Young Stellar Objects (YSOs) to Luminous Blue Variables (LBVs) 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 extended 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 parent stars.

The principal goal of Frank's research program is to develop and refine theories of collimated stellar outflows by detailing the basic physics which drives the collimation process. Frank's approach to these problems relies on numerical gasdynamic and magneto-gasdynamic simulations with simultaneous calculation of the gas microphysics (Ryu *et al.* 1999).

Recent work in the field of Young Stellar Objects includes a study of hydrodynamic collimation in models of collapsing sheets by Delamarter, Frank, & Hartmann (1999). This work was begun on time-dependent wind models for YSOs where the mass loss rate for the wind varies in a manner similar to what is seen in FU Ori stars. In the domain of evolved stars Frank's group continues their studies of outflow collimation in Planetary Nebulae (Welch *et al.* 1999). An ongoing numerical study of CRL 2688 (the Egg nebula) has revealed the limitations of the popular *interacting winds* model indicating that fully collimated jets may be required to form close to the star (Delamarter *et al.* 2000). Frank explored new models for collimation in PNe in a presentation at the Aspherical PNe conference at MIT this year (Frank 2000). This year Frank also completed an invited review of bipolar outflows for New Astronomy (Frank 1999).

Frank's group also has an active program studying magneto-gasdynamic models of YSO jets. This year a project was completed focusing on the role of ambipolar diffusion in YSO jets (Frank *et al.* 1999). In addition, the first study of pulsed MHD jets was completed (Gardiner *et al.* 2000). The use of *ad hoc* initial conditions is a problem which plagues many jet simulations, especially MHD jets. To address this issue Frank's team has begun using jet profiles calculated from detailed models of magneto centrifugal jet launching from an accretion disk (Lery & Frank 1999, Frank *et al.* 1999). In two papers the stability properties and the propagation characteristics of these jets were studied. The results show that jets from different classes of magnetic rotators can have quite different propagation characteristics. These simulations may be useful in helping distinguish between different jet lauching mechanisms.

Frank's group is also involved in science outreach efforts. The Astroflow program developed by the group is an integrated software environment which allows users to simulate and visualize their own astrophysical fluid experiments. Designed for classrooms, planetaria and web-based applications, users can create their own supernovae, hypersonic jets, and planetary nebulae. This project is ongoing and is funded via the NSF and NASA.

4.2 Observational Astrophysics

In the past year, observational astrophysics at the University of Rochester has included studies of star formation regions, 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, and the WIRO 2.3m telescopes. GTO planning for SIRTF has occupied the three SIRTF team members most of this year.

4.3 The Sun

Thomas reviewed the scientific case for high resolution in solar observations in his keynote talk at the NSO/Sacramento Peak Workshop on High-Resolution Solar Physics (Thomas 1999b), and he summarized the highlights of this workshop in a News & Views article in *Nature* (Thomas 1998).

4.3.1 The Solar System

Meisel continues his intensive collaboration with Penn State Electrical Engineering Communications and Space Sciences Laboratory (CSSL) and is on sabbatical there Fall

1999-Summer 2000. In addition he has collaborated with the Meteor Observatory staff of the Kazan State University on a number of projects.

He was lead or co-author on several published and presented papers in the area of meteor science (Meisel *et al.* 1999a, 1999b; Mathews *et al.* 1998a, 1998b, 1999a, 1999b; Janches 1999a, 1999b; Karpov *et al.* 1999; Richardson *et al.* 1999). In addition, he continued work on a payload for a student NASA sounding rocket experiment to be launched in December 1999.

4.3.2 Brown Dwarfs and Low Mass Stars

The Near Infrared group continues to monitor brown dwarf candidates projected on the Taurus cloud (Forrest *et al.*, 1990) for variability. Forrest and former post-doc 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. These data are being analyzed.

4.3.3 Observations of Star Formation Activity

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.

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 H_2 (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 M′ broadbands (to probe reflection nebulosity, thermal dust emission, and to obtain photometry and reddening of associated point sources). Goetz *et al.* (1998, 1999) and Bloomer *et al.* (1998) have exploited many of these techniques in detailed studies of Cep A East, S88B, and NGC 7538. Goetz's PhD thesis investigated Cep A East, S88B, and S235 A/B. In addition to addressing the above goals, Goetz has utilized her broad-band data to characterize the stellar clusters in the regions: specifically, she de-reddens the J, H, K -band photometry, and interprets a K vs. [J - K] HR diagram using the models and prescriptions of d'Antona and Mazitelli (1994) and Luhman and Rieke (1998). Barczys *et al.* (1999) apply the same models to the L988e cluster. Goetz attempts to classify these massive star formation regions with a scenario based on the Class 0/I/II/III models for low-mass YSOs. Raines *et al.* (1999, submitted) have imaged the Herbig-Haro (H-H) objects in GGD 37 (Cep A West) and show that the H_2 emission forms arcs exterior to the [Fe II] emission; the morphology is similar to that of the H_2/[S II] images of Hartigan, Carpenter, Dougados, and Skrutskie (1996). The peak H_2 and [Fe II] line emissions for several of the H-H objects are clearly separated relative to one another, suggestive of multiple shocks. Raines is currently modifying Delamarter's model of the structure of C* and J shocks in H_2 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. Among their more recent findings is 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. Both are visible also in the 6 and 20 cm VLA maps of this region by Garay *et al.* (1996), one northeast of their source W3 and one coincident with their source W2. The first of these, located 3.62″ W, 1.44″ N of W3 in 1993, has derived proper motions of $\mu_\alpha \cos \delta = -0.25 \pm 0.03''$/yr, $\mu_\delta = 0.02 \pm 0.04''$/yr, which corresponds to a tangential velocity of 850 $\pm$ 200 km s^{-1} at position angle PA = 334deg $\pm$ 6deg. The directions are consistent with motions measured for others of the GGD 37 H-H objects, but the transverse velocities are much greater.

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 PdSnTe: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.* (1999).

4.3.4 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 has begun a study of these phases, including the Egg Nebula, M1-92, Hubble 12, NGC 7027, and BD 30 $+^{o}$ 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 H_2 PDR hourglass. A young planetary nebula is seen at the vertex. They explored two current models: that the loops represent the inner shock of the fast wind, or that they are evidence of a second episode of mass ejection.

4.3.5 Observations of Active and Starburst Galaxies

Following the interesting results on the distribution of the 3.29 μm dust emission in the starburst galaxy NGC 253 described in the 1991 Mees report, a program of observations of this feature in other starburst galaxies is being carried out using the infrared cameras of the University of Rochester equipped with 1% resolution CVFs. In a wide variety of galaxies, the 3.29 μm dust emission feature carries approximately 0.1% of the total dust luminosity, which is predominantly in the far-infrared. This feature is believed to result from extremely small grains heated temporarily to high temperatures by single ultraviolet photons. Thus, it is believed to be a good tracer for star-formation activity. With our cameras we can achieve 1″ resolution and locate and explore the regions of active star formation in distant galaxies. To date the (red-shifted) feature has been clearly detected in images of NGC 3690, NGC 7469, NGC 4194, M82 and NGC 1614. In NGC 7469 a ring of emission around the nucleus is seen.

4.3.6 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 between 1993 and 1996 is presented in the paper Deeg *et al.* (1998). 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]).

4.3.7 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). An adaption to this system that uses a piezo-mirror to allow use of the CCD as a two dimenional storage register is now being developed. The system is also being used at WIYN to observe proposed Space Interferometry Mission reference grid stars.

4.3.8 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.

4.4 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, improvements to the Rochester third generation ground-based camera, development of near and far IR Fabry Perot interferometers, and continued design of a near IR echellette spectrometer for ground-based application. Optical CCD, CID, and Active Pixel Sensor development has taken place at RIT.

4.4.1 Near Infrared Array Detector System Development

Forrest and Pipher and their group (particularly Glaccum, research associate) 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 array candidates for selection for mounting on the flight mounts. There has been active participation of the UR group with the GSFC group, who are responsible for flight array testing. Latent images are a problem for astronomy. The UR group devised data-taking modes which minimize the effect of image latency for SIRTF.

Forrest and Pipher, in collaboration with SBRC /Raytheon, are funded under a NASA ISR grant to develop large format InSb arrays for NGST that exceed present performance capabilites. The array requirements include: QE $>$ 80% 0.5-5μm, pixel dark current $<$ 0.02 e^-/s, pixel read noise $<$ 3 e^-, 1024 $\times$ 1024 format buttable to 4k $\times$ 4k, power dissipation $<$ 2 mW per 1k $\times$ 1k module, operation near 30K (passive cooling). NGST will require 80 1k $\times$ 1k module 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. Test cryo-CMOS multiplexers have been produced at Raytheon. Based on this experience the first NGST-optimized 1k $\times$ 1k readout has been produced at Orbit (now Supertex). Al Fowler (NOAO) is aiding in this effort. Reports on this work include that by Garnett *et al.* (1999) at the AAS meeting, as well as a demonstration model at an NGST workshop Fall 1999.

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 (Bailey *et al.* 1998a, 1998b). Most recently, HgCdTe arrays, with cutoff wavelengths of 9.0 and 11.0 μm, mounted on two different muxes, are being characterized and optimized in our lab.

4.4.2 Near Infrared Astronomical Instrumentation

One of the SBRC InSb CRC 744 arrays (not 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 $\sim$ 1 - 2% resolution. The Third Generation 256 $\times$ 256 InSb array camera has been used in ever-improved form since October, 1992 at WIRO and MLOF.

For several years now, we have obtained spectral images by combining warm NRL/GSFC Fabry Perot interferometers with the Rochester Third Generation camera. The resultant resolution ($\sim$ 800) has allowed our groups to obtain spectacular line emission images, referred to in the observational section above.

A near IR echellette spectrometer has been designed and will be built in collaboration with Universities of Wyoming and Minnesota for use at WIRO. The slit size will be 1″ $\times$ 10″ and the resolution will be $\sim$ 1000. The complete 1 - 2.5 μm spectrum or the complete 3 - 5 μm spectrum will fill the InSb array.

4.4.3 Far Infrared Detector Development

Watson has received NASA ISR funding for the development of extrinsic germanium blocked-impurity-band (BIB) detector arrays for far-infrared astronomy. His collaborators in this venture are J.E. Huffman (Lawrence Semiconductor Research Laboratories) and M.T. Guptill (Boeing North American). This year's cycle of fabrication will consist of at least nine process-evaluation (1x5) test arrays and four larger test arrays (6x6, 4x16 or 4x32). The process-evaluation arrays will be provided with a BNA six-channel, silicon NMOS source-follower per detector readout chip, designed for this purpose, that has been shown at UR to perform at 1.5 K adequately for all of our test purposes. Evaluation of the larger arrays will initially involve the off-chip cryogenic readout built into the UR array test system.

4.4.4 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 128x 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.

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