University of Rochester
C. E. Kenneth Mees Observatory

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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, 1996 to September 30, 1997.

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, 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 the Division of Astronomical Sciences at the National Science Foundation, holds an adjunct professor position in the Department of Physics and Astronomy, and visits to work with his former faculty colleagues and students approximately monthly.

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, and completed her term as a member of the NRAO Visiting Committee in spring 1997. She began terms as members of the Gemini Board and the NASA Astrophysics Working Group, the AAS Tinsley Prize Committee, as well as the SOFIA Science Council. The Advisory Committee for the AAS study ''Examining Graduate Education in Astronomy'' completed their work this year: Pipher was a member.

Thomas completed his two-year term as chair of the AAS Solar Physics Division in June 1997, then becoming vice-chair for a year. He 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. In August 1997 he was appointed to a four-year term on the AURA/NOAO Observatories Visiting Committee.

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.

Babar Ali and Bill Glaccum continued post-doctoral appointments in the Near IR group, with Ali working on Forrest's ISO project to search for brown dwarfs, and Glaccum assuming responsibility for the SIRTF IRAC detector array work. Jian Wu continued as an Engineer with the Near Infrared Group until August 1997; he left to assume a position in CCD research at Kodak, and completed his Ph.D. under Forrest's direction in September 1997. Sheldon Weng has been hired as a laboratory engineer to replace Wu, and will assume responsibility for the HgCdTe detector development programs. Brendan White is senior programmer/analyst with the Near IR group.

Working with Ninkov at RIT are post-doctoral fellows Robert Slawson and Elliott Horch. In addition Min-Ming Wu provides engineering support to the group while Gerrutt Lubberts supports activities in device fabrication and design.

Public tours were conducted at the C. E. K. Mees Observatory from mid-May until the end of August by several undergraduate employees, Matthew Barczys, Marianne Vieira and senior guide Andi Sarafinas. We are indebted to Marilee Montanaro for her nine years of service with the Astronomy group, most recently as an administrative assistant: she has taken a position with the University Budget office. Deborah Tedrick has assumed the administrative assistant position. 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 is the undergraduate advisor for astronomy majors.

Undergraduates Matthew Barczys and Andi Sarafinas worked with the Near IR group this summer. Andi continued work under Forrest's direction on image reduction of images of brown dwarf candidates, and Matthew reduced IR data on Comet Hale-Bopp obtained in May 1997 with the UR camera at Mt. Lemmon Observatory, Tucson.

Jen Hoffman completed her senior thesis, entitled ''3.28 μm Dust Feature as a Diagnostic of Massive Star Formation in Galaxies,'' under Pipher's direction. She went on to graduate work in Mechanical Engineering at Michigan.

Danial Haug completed his undergraduate thesis requirement in the Center for Imaging Science (RIT) on developing IDL software for modeling point spread functions for stars and comparing theoretically expected functions with data collected at the Mees Observatory and in Hawaii. His results were reported at the spring meeting of the CIS Industrial Associates. Chitra Sivanandam has begun a senior thesis project with Ninkov on comparing lunar images obtained with the Lunar Orbiter spacecraft in the 1960s and those gathered with the Clementine mission in the 1990s.

3. GRADUATE EDUCATION

Steve Solomon (in absentia), Bob Benson, Jian Wu, Jennifer Goetz, and Carl Welch have been graduate students in Forrest and Pipher's Near Infrared Group for the past year. Kristin Nelson has joined the group in September, 1997 as an incoming student, and is beginning to work on infrared imaging of extragalactic sources. Nick Raines, John Bloomer and Matt Guptill have been graduate student's in Watson's Far Infrared group.

Wu completed the requirements for his Ph.D. degree in EE in September, 1997, under Forrest's direction: his thesis is entitled ''Development of Infrared Detectors for Space Astronomy.'' He assumed an engineering position with Kodak in August 1997.

Solomon had been active in detector development for SIRTF while in residence. He is now working at SBRC, Santa Barbara CA, on detector array development while completing his Ph.D. thesis under Forrest's direction in absentia. His thesis will be concerned with the dual topics of 3.3 μm imaging of the reflection nebula NGC 2023, and on detector physics.

Goetz has been analyzing broad-band IR and Fabry Perot spectral images of the high mass, heavily obscured star formation region Cep A, and has begun work on S88B. She has submitted a paper for publication on Cep A, which compares radio images (of ionized hydrogen, NH_3 and CO emission) with IR images of line emission from [FeII] and H_2, as well as broad band images, in order to develop a model of the region. She passed the Ph.D. Qualifying Exam this year.

Welch has commenced an IR study of planetary and proto-planetary nebulae, and is concentrating on images of shocked line emission as well as broad-band images. He passed the Ph.D. Preliminary Exam this year.

Benson has begun characterization of SIRTF InSb detector arrays, and in particular has completed an extensive latent image study experiment.

Raines, working under Watson's direction, is studying high-velocity outflow sources with imaging near-infrared spectroscopy, and is continuing his research in Watson's NASA-supported far-infrared detector development program.

Bloomer is using near infrared imaging and slit spectroscopy in a study of the interaction of young stellar objects associated with compact or ultracompact H II regions, with their molecular-cloud environment. Watson is his thesis adviser.

Guptill continues his graduate thesis work on far-infrared impurity band conduction detectors at Boeing, in absentia.

In the astrophysics theory group, headed by Frank and Thomas, the graduate students included Guy Delamarter, Tom Gardiner, Andrew Markiel, Colin Roald, Don Stanchfield, and Tim Collins.

Collins completed and defended his Ph.D. dissertation entitled ''Accretion Disk Boundary Layers,'' under the direction of Profs. Helfer and Van Horn. He subsequently joined the computational plasma physics group at the UR Laboratory for Laser Energetics.

Delamarter works on hydrodynamic collimation of young stellar object jets. He presented a poster with Frank at the Summer 1997 AAS meeting entitled ''Evolution of Outflows in Collapsing Filaments.'' Presently Delamarter is adding rotation, gravity, and molecular cooling to his hydrodynamics code for use in more accurate calculations.

Gardiner joined the theory group in September 1997, and plans to work with Frank on problems of magnetohydrodynamic collimation in young stellar objects. He is currently researching that problem and the numerical simulation methods he will apply.

Andrew Markiel continued his research with Thomas and Van Horn on the generation of stellar magnetic fields. His work focuses particularly on models of the solar dynamo incorporating the solar differential rotation profile as determined from recent advances in helioseismology.

Colin Roald spent 6 months at the High Altitude Observatory (HAO), NCAR, in Boulder, Colorado under the terms of his Newkirk Fellowship from HAO. He continued his research on nonlinear solar and stellar dynamos, supervised by Thomas. Roald won the 1996 Graduate Student Prize of the Astronomical Society of New York for his recent paper on this subject (Roald and Thomas 1997).

Don Stanchfield continued his investigation of the relation among p-modes, acoustic emission, and solar magnetic fields using a data set from observations of a developing pore region taken by Thomas in October 1995. In June 1997, he assisted B. W. Lites and R. Casini (HAO/NCAR) in carrying out observations of prominences and filaments in Hα and He D3 using the Vacuum Tower Telescope at the National Solar Observatory, Sacramento Peak.

Brian Backer, Dan Kavaldjiev, George Lungu, Albert Piterman and Alina Gorcea have been graduate students of Zoran Ninkov at the Center for Imaging Science at RIT.

Backer has been studying charge injection device performance and developed a tip-tilt imaging system based on a 512 x 512 CID array. This area will be the subject of his Ph.D. thesis which he is completing in absentia while working at Lockheed Martin IR Imaging Systems in Lexington. Kavaldjiev has been measuring sub-pixel sensitivity variations on a CCD (Kavaldjiev and Ninkov 1997) and studying the implications of such variation on photometry. Lungu is involved in the modeling, fabricating and testing of CMOS sensors principally using the RIT fabrication facility. Piterman has begun work on sensor testing and Gorcea has been involved in data reduction and analysis of CCD images.

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 T. Collins, G. Delamarter, T. Gardiner, A. Markiel, C. Roald, and D. Stanchfield. The group's research interests are mostly in the areas of astrophysical fluid dynamics and magnetohydrodynamics.

4.1.1 The Sun

Thomas and B. Montesinos (LAEFF, Madrid) completed work on an improved siphon-flow model of the Evershed flow in sunspots (Montesinos and Thomas 1997). The results of their model are in excellent agreement with the new observations of Westendorp Plaza *et al.*, which shows the downward component of the flow near the outer boundary of the sunspot penumbra.

4.1.2 Solar and Stellar Dynamos

Roald and Thomas (1997) examined a nonlinear solar dynamo model with dynamically variable α and ω effects. The dynamo equations were solved by means of a truncated Fourier-Galerkin expansion, and the expansion was carried to high enough order to yield convergence of the behavior of the system. The bifurcation structure of the system was mapped out in considerable detail. The nonlinear quenching of the α and ω effects affect the dynamo in quite different ways, with ω-quenching producing periodic solution more like the Sun's dynamo.

Roald (1998) has extended the dynamo model described above to a two-layer interface dynamo operating near the base of the convection zone. In order to keep the model one-dimensional (radially averaged), turbulent diffusion between the two layers is represented by an approximation equivalent to Newton's law of cooling. The two-layer model has recognizable similarities to, but also significant differences from, the one-layer model described above. The interface scheme does produce much stronger magnetic fields in the core than in the envelope, as desired.

Markiel, Thomas, and Van Horn continued their investigation of the dynamo generation of stellar magnetic fields. Markiel completed the development of a 2-D finite difference code for solving the dynamo equations in a spherical shell. He has applied this code to the solar dynamo problem, considering interface models where the production of poloidal and toroidal fields are separated into two layers coupled by diffusion. The inclusion of a realistic solar differential rotation profile leads to different kinds of solutions than those found from simple analytical models. Markiel is working to identify the types of solutions that can occur and find models which reproduce the solar activity cycle.

4.1.3 Shock Waves in Molecular Clouds

The collaboration continued between Raines and Delamarter to develop a model relevant for shocks observed in Cep A.

4.1.4 Accretion Disks

Collins, Helfer, and Van Horn have finished an investigation of the the thermal structure and stability of the disk and boundary-layer region (BL) of accretion disk models for non-magnetic cataclysmic variables, using OPAL opacities, a Shakura-Sunyaev turbulent viscosity, and including the radial viscous force. The continuous spectrum of the steady state disk is the same as that calculated using simple electron scattering opacity. However, the BL luminosity calculated using OPAL opacities is about a factor of two larger than the electron scattering models, enhancing the spectum below 300A. (See Collins, Helfer, and Van Horn 1977a,b)

A linear local stability analysis shows that the disk and BL are unstable to short wavelength oscillations when the turbulent viscosity term is small; using conventional values of the turbulent viscosity stabalizes the disk. The BL exhibits unstable large scale azimuthal modes, (*e.g.* $m=1,2$), with characteristic periods of about 20s, similar to the periods of the quasi-periodic oscillations observed in many dwarf novae; a beat frequency, $\sim$1 Hz, between two of the most unstable modes, should be present. This material is being prepared for publication. Details can be found in Collins (1997).

4.1.5 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 simutaneous calculation of the gas microphysics. In Mellema and Frank (1997), hydrodynamic collimation models with radiative cooling were presented. Delamater and Frank are extending this study to include the effect of more realistic initial conditions for a collapsing cloud filament. Gathier and Frank are working to include the effect of magnetic fields on the collimation process. These models will include the calculation of microphysical quantities such as the molecular hydrogen fraction. Knowing the micro-state of the gas allows for the production of ''synthetic'' observations of the model for detailed comparison with what is seen on the sky.

Frank is also working on magneto-gasdynamic models of YSO jets. In Frank *et al.* (1997), simulations of magnetized radiative jets were presented which demonstrate the effect of strong magentic fields on the propagation characteristics of the jet beams and bow shocks.

Basic research on magneto-gasdynamical instabilities are also being conducted. Along with collaborators in Minnesota and Korea, 2-D and 3-D simulations of magnetized shear (Kelvin-Helmholtz) instabilities have performed and analyzed (Jones *et al.* 1997), Ryu, Jones and Frank 1998)

Delamarter completed preliminary simulations which showed that a spherically symmetric wind is strongly collimated by the collapsing filament initial condition taken from Hartmann, Calvet and Boss (1996). The azimuthally symmetric hydrodynamics code used in the calculations included the effects of atomic radiative cooling, but did not track the effects of molecular cooling, destruction, or formation, and left out gravity and rotation. Presently Delamarter is adding and testing these additional effects. Meanwhile, he is using the existing code to investigate hydrodynamic collimation via the evaporation of accretion disks.

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 KPNO 2.1m, the MLOF 1.5m, and the WIRO 2.3m telescopes. Optical observations have been carried out by RIT at the WIYN telescope, and at the University of Toronto Las Campanas telescope.

4.2.1 The Sun

Thomas, in collaboration with B. W. Lites and T. J. Bogdan (HAO/NCAR) and P. S. Cally (Monash U.), studied magnetic field variations associated with umbral oscillations in sunspots, using a data set of exceptionally high quality obtained with the HAO/NSO Advanced Stokes Polarimeter (ASP) at the Vacuum Tower Telescope, NSO/ Sacramento Peak (Lites *et al.* 1998). These magnetic field variations are shown to be very weak, at most a few G, and results are shown to be completely consistent with theoretical expectations. This work thus settles a long-standing controversy.

Using the same data set mentioned above, Thomas, Bogdan, D. Braun (HAO/NCAR), and Lites have shown that the five-minute oscillations at the umbra-penumbra boundary in a sunspot lag those at the center of the umbra by about one minute (Bogdan *et al.* 1998). This result has significant implications for time-distance helioseismology of sunspots and in fact casts doubt on some previously reported evidence for downflows in and around sunspots. The result is interpreted in terms of the travel times of upward-propagating slow magneto-atmospheric waves in the sunspot.

Stanchfield and Thomas are analyzing another ASP data set, related to the suppression of p-mode power and enhancement of power at higher frequencies (above the acoustic cutoff frequency) due to magnetic fields. These observations, which also include Ca II K filtergrams, show the connection between the halos of enhanced high-frequency power in the photosphere and in the chromosphere.

4.2.2 The Solar System

Meisel continues his collaboration with the Communications and Space Science Laboratory of the Electrical Engineering Department at Penn State University using the Arecibo radar for micrometeor detection (Mathews *et al.* 1997). A number of the particles have strongly hyperbolic velocities and these are being followed up by Meisel and his students. The dynamical characteristics of these particles during ablation indicate a possible link to the small interstellar particles now being found in meteorites.

Meisel and his students will be participating in a NASA student rocket launch in 1999 May from Wallops Island, VA to study the temperature structure of the mesosphere where most of the micrometeors are seen. The SUNY-Geneseo instrument to be flown is a solid Fabry-Perot etalon with holographic transformer and UV diode detectors. High resolution spatial measurement of the OH rotational/vibrational temperatures will be attempted along with the band intensities of OH and OH^+. As a part of the instructional effort of this collaboration, Meisel and J.D. Mathews offered an introductory plasma physics course to its seniors via a two-way television hookup between Geneseo and Penn State. While the courses on the two campuses are separate for credit and administrative purposes, the television connection allowed a sharing of material and demonstration resources.

4.2.3 Saturn

Hubbard *et al.* (1997) deduce the structure of the Saturnian stratosphere from an extensive optical and infrared data set of the immersion and emersion lightcurves of the occultation of 28 Sgr by Saturn's atmosphere on 3 July 1989, and find agreement with Voyager and Pioneer 11 data.

4.2.4 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 Ali, in collaboration with Stauffer (SAO) and Leggett (Hawaii), are conducting an ISO search for Brown Dwarfs in the Hyades. Undergraduate student Sarafinas has begun analysis of images obtained from ground-based cameras on brown dwarf candidates in Taurus.

4.2.5 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, we have 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. Images in the feature and the nearby continuum as well as the J,H,K bands are being analyzed for Solomon's Ph.D. thesis. The NGC 7023 images show a very strong 3.29 μm dust feature in narrow filaments to the NE of the exciting HD star. The 3.4 μm dust feature is also quite strong. Undergraduate Hoffman began study of several galaxies in this feature last year, and graduate student Nelson is continuing that work. 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.

Utilizing the 3rd generation Rochester Infrared Camera, we 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 3.28 μm PAH emission feature to explore PDR regions; and *(v.)* imaging at broadband J, H, K, L$''$, and M$'$ (to probe reflection nebulosity, thermal dust emission, and to obtain crude photometry and reddening of associated point sources). Howard *et al.* (1997a) and Goetz *et al.* (1997) have exploited many of these techniques in detailed studies of NS14 and Cep A East respectively. Raines *et al.* (1997, in preparation) and Bloomer *et al.* (1997, in preparation) have also exploited many of these techniques in studies of GGD37 (Cep A West) and NGC 7538 respectively. Images of the Herbig-Haro (H-H) objects in GGD 37 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.

In Cep A East ''artillery shells,'' such as those observed in Orion (Allen and Burton 1993), are observed with [FeII] emission at the tip of the shell, one side of which is outlined in H_2 emission along the string of the southern radio continuum sources HW 7. The proposed Herbig-Haro object HW7c(ii), a radio compact source which shows a transverse motion of 300 – 400 km/s away from the exciting cluster in HW2/3, is interpreted as the Mach disk in this region (Goetz *et al.* 1997). On the other hand, line emission associated with the northern HW 6 radio sources in Cep A East is modeled by a series of shocks which ablate a dense clump associated with HW 6, and which give rise to superposed oblique shocks or bow shocks along the periphery of the molecular cloud Cep A-2.

Bloomer has continued work on probable shock structures, imaged in [Fe II] and H_2 line emission, surrounding the cometary, compact H II region NGC 7538 IRS 2 (Bloomer *et al.* 1996). In an effort to ascertain the physical conditions and excitation mechanisms at work across this region, J, H, and K band slit spectra have been obtained with ONIS at the KPNO 2.1m telescope. An imaging survey of similar cometary, compact H II regions (a subset of those catalogued by Garay, Rodriguez, Moran, and Churchwell 1993) has been begun to search for high levels of [Fe II] line emission and leading-edge bow-shaped structures, both of which would lend credence to the ''stellar wind bow shock'' theory (Van Buren, Mac Low, Wood, and Churchwell 1990). Imaging observations have been carried out with the Rochester array camera at the MLOF 1.5m and the WIRO 2.3m telescopes.

Howard, Pipher and Forrest (1997a) report broad-band J, H and K as well as 3.29 μm and $Br\gamma$ imaging of NS14, a bipolar nebula. A two component source for the $Br\gamma$ emission includes an ionizing wind source, as well as a traditional HII region. Reflection nebulosity surrounding a central 'trapezium' of exciting stars forms the bipolar structure, also seen in the 3.29 μm dust emission feature. Since there is limb brightening of the dust feature emission, a central evacuated region in the bipolar structure is postulated.

Howard, Pipher and Forrest (1997b) report formation of a stellar cluster in S255-2. These results derive from broad-band, H_2, Brackett line, and 3.29 μm dust emission images, as discussed in more detail in last year's report.

4.2.6 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 observation 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, M82 and NGC 1614. In NGC 7469 a ring of emission around the nucleus is seen.

Greenhouse *et al.* (1997) present extinction-corrected [FeII] 1.64 μm images of M82, and conclude that the [FeII] sources trace out a supernova population considerably older than those revealed on 6-cm radiographs. The [FeII]/Brγ line ratio correlates with the age of the starburst as reflected by the photospheric emission from the stars in M82 (Satyapal *et al.* 1996). Thus, the [FeII] emission regions are co-located with a post main-sequence population.

Satyapal *et al.* (1997, in preparation) utilize hydrogen recombination images, broad-band IR images, and 3.29 μm dust feature images of the Arp 299 system (NGC 3690) to deduce that a purely starburst model for the galaxy is appropriate to explain these results, despite a putative AGN source in one of the components.

4.2.7 Planetary Search

Ninkov continues as a participant in the international TEP (Transits of Extrasolar Planets) network. This world wide collaboration has continued monitoring of the eclipsing binary CM Dra in an effort to detect photometric variations attributable to the transit of a planet (or planets) in the system. The results of data obtained between 1994 and 1996 are presented in (Deeg *et al.* 1997). The group is also investigating accurate timing of eclipse minimum in low mass eclipsing binary system as another means for detection of planetary objects (Doyle *et al.* 1997).

4.2.8 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. The CCD is used therefore not only as a detector but as an analog storage register. The advantages of such a system are high quantum efficiency and relatively low noise as the CCD is readout slowly only when it is full of speckle images. Initial results are very encouraging when compared to the work of other speckle observers (Horch, Ninkov and Slawson 1997). In addition this system has been used, in collaboration with Bill van Altena at Yale, at the WIYN telescope. Preliminary efforts have been made at comparing the performance of this CCD based system versus an existing MAMA system. Diffraction limited performance speckle imaging has been achieved at WIYN using both systems (Horch, Ninkov, van Altena, Meyer, Girad and Timothy 1997).

4.2.9 Multi-Spectral Imaging

Slawson and Ninkov have utilized a tunable liquid crystal filter (LCF) from CRI of Cambridge MA in front of a cooled, large format CCD to obtain multi-spectral images of clusters of stars. The filter has a tuning range of 400 - 720 nm with an instantaneous passband of 5 nm. The series of images at different wavelengths are normalized to a known spectra, for at least a single star in the field. Low resolution spectra of all stars in the field can then be recovered. Initial results from data obtained at the University of Toronto's Southern Observatory at Las Campanas, Chile of the Jewel Box cluster are very encouraging (Slawson and Ninkov 1997).

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, 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 sensor development has taken place at RIT.

4.3.1 CMOS Active Pixel Developments

Ninkov and his group continue to investigate and test sensors fabricated in silicon that will be successors for CCDs. This activity has focussed on the development of Active Pixel Sensors that utilize amplifiers and switches within each pixel. In many respects that are similar to the multiplexers bonded to suitable detector materials for IR imaging. Devices for the visible region are intended to be monolithic and need excellent fill factors. The group at RIT this year has designed, modeled and fabricated their own small, but working, APS devices. A 128 x 128 device has now completed design and will be fabricated both at RIT and using a commercial facility, namely Orbit. These devices utilize a two MOS capacitor per pixel store and sense architecture, and an injection (lateral or vertical) for reset - similar to existing CID devices. This work is supported with funding from the New York State Center for Advanced Technology Program and NASA.

4.3.2 Near Infrared Array Detector System Development

Forrest and Pipher and their group continue to develop infrared arrays for space application using the flexible, programmable array controller utilizing DSPs described in previous reports. This year they have concentrated on 256$\times$256 InSb arrays mounted on CRC 744 multiplexers (muxes). Following Rochester tests of lot splits of bare muxes, two candidate materials were chosen. InSb arrays mounted to the best muxes exhibit very low noise at 13 – 17K (5 e^- with multiple sampling), low dark current ($<$ 0.2 e^-/s), high quantum efficiency ($>$ 85%), and as well are robust under proton and gamma ray irradiation (Wu *et al.* 1997). Problems encountered this year include: an area of degrading quantum efficiency with lower temperature, found to be attributable to the array back surface (a new passivation has eliminated the problem); glows associated with both the mux unit cell, and a clamp circuit; image latency with the present frontside passivation. Forrest and Pipher, in collaboration with SBRC, are funded under a NASA ISR grant to develop large format InSb arrays for NGST that exceed present performance capabilites.

In addition, Pipher and Forrest, with engineer/ graduate student Wu, 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 an NSF GOALI grant (which began June 1996). There has been considerable progress in this area of research (Wu, 1997), and Pipher and Forrest have participated in the NGST study partially in order to advance this detector work. A report on progress to date was presented at the NGST Technology Challenge Review in April 1997, and the review can be found on the NGST WWW page.

4.3.3 Near Infrared Astronomical Instrumentation

One of the SBRC InSb CRC 744 arrays, SCA 40716, 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.

4.3.4 Far Infrared Detector Development

Watson has received NASA ISR funding to develop Ge:Ga IBC detectors for space astronomy.

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