University of Rochester
C. E. K. Mees Observatory
Rochester, NY 14627-0171

1. STAFF

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, 1994 to September 30, 1995. The Astronomy faculty at the University of Rochester includes W. J. Forrest, H. L. Helfer (Emeritus), J. L. Pipher, M. P. Savedoff (Emeritus), S. L. Sharpless (Emeritus), J. H. Thomas, H. M. Van Horn (on leave), M. Wardle, and D. M. Watson. D. Meisel, SUNY at Geneseo, and Z. Ninkov, Rochester Institute of Technology, are Associates of the C. E. K. Mees Observatory. Meisel acted as Associate Director of the Observatory until July 1995: we thank him for his many years of dedicated service on behalf of the Observatory. Z. Ninkov is the new Associate Director. H. W. Fulbright, Emeritus Professor of Physics, remains active in the Department and at the Observatory.

Forrest reviewed the conceptual design for the Gemini near infrared camera, being constructed by the U. of Hawaii for the NSF. In December he gave several lectures on the operation of infrared array cameras at a workshop at IUCCA in Pune, India.

Pipher completed her term on the Space Studies Board of the NRC in June, 1995, and continues on the Board's Joint Committee on Technology, which has just completed the ''Future of Space Science: Technology'' study. She was a member of the so-called McCray committee, a subcommittee of the NAS Board of Physics and Astronomy commissioned to recommend a strategy for observational astronomy in the US to the NSF. She also served as a member of the Gemini Director Search Committee, the NSF review of the Sloan Survey, the AUI NRAO Visiting Committee and the CfA Visiting Committee. Following Helfer's retirement in October of 1995, she assumed the position of Rochester's representative to the Board of Directors of the New York Astronomical Corporation. Pipher completed her final year on NASA's IR/SubMM/Radio Management and Operations Working Group, and is now a member of NASA's 2MASS external review committee.

Watson served as chair of the NSF Graduate Fellowship review panel.

Forrest, Pipher and Watson are members of the instrument teams for the NASA Space Infrared Telescope Facility (SIRTF), and are responsible for a substantial amount of the 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.

Thomas began a two-year term as chair of the AAS Solar Physics Division in June 1995. He continues to serve as an Associate Editor of *The Astrophysical Journal* and as an affiliate scientist at the High Altitude Observatory, National Center for Atmospheric Research. He gave two invited lectures at the NATO ASI on ''Solar and Astrophysical MHD Flows'' in Crete in June 1995.

Van Horn continues to serve as Director of the Division of Astronomical Sciences at the National Science Foundation (NSF), in Washington, DC, on extended leave from the University of Rochester. He also continues to serve as a member of the Publications Board of the American Astronomical Society (AAS). In addition, He completed a five-year term as a member of the AAS Advisory Committee for the Annie Jump Cannon Award for young women in astronomy. He served as a member of the International Scientific Committee for the *International Conference on the Physics of Strongly Coupled Plasmas*, held in Binz/Rügen, Germany, in September 1995, and he has just agreed to serve as a member of the Scientific Organizing Committee for the Tenth European Workshop on White Dwarfs, to be held in Blanes, Spain, in summer 1996.

Van Horn presented several invited lectures in 1994-95. Most concerned NSF matters. Included among these were presentations to the National Research Council's (NRC's) Committee on Planetary and Lunar Exploration, to NRC's Space Studies Board, and several presentations to NRC's Committee on Astronomy and Astrophysics. In addition, Van Horn made presentations to NASA's ISRMOWG, to the Mathematical and Physical Sciences Directorate's Advisory Committee, to the AAS Division for Planetary Astronomy, and to an international conference on the Evaluation of Scientists, Research Projects, and Institutions, held in Warsaw, Poland. Science talks included a presentation on ''Neutron Star Seismology'' to the Washington Area Astronomers Meeting and a talk on ''Brown Dwarfs, White Dwarfs, and Neutron Stars'' and a Harlow Shapley Visiting Lecture entitled ''Exploration of the Solar System'' at Gustavus Adolphus College, in St. Peter, Minnesota.

H.L. Helfer completed his teaching obligations as of January 1,1995. He continues active participation in graduate instruction.

Helfer and Meisel served on the Board of Directors of the New York Astronomical Corporation.

Ninkov serves as a member of the Instruments/MEMS Integrated Product Development Team for the NASA Millennium Program.

Brendan Fisher assumed the position of Instructor/Fellow in the Near Infrared Group in February, 1995, with responsibility for reduction and analysis of the several thousand Jupiter/Shoemaker-Levy9 images obtained in July 1994 in collaboration with the Universities of Wyoming and Minnesota. Jian Wu completed his third year as Engineer with the Near Infrared Group. Wu's primary interest has been detector array development for space and ground-based application, and he is completing a PhD thesis under Forrest's supervision in Electrical Engineering on development of space astronomical mid-IR HgCdTe detectors. Kevin McFadden is senior Programmer/Analyst with the Near IR group.

During the 1994-5 school year, Alexander G. Muslimov continued as an Instructor/Fellow with the theory group, and taught a course each semester in the Department. He left to assume a prestigious Alexander von Humboldt Fellowship at

the Institut fur Astrophysik und Extraterristrische Forshung in Bonn, Germany.

Public tours were conducted at the Observatory from mid-May until the end of August by several undergraduate employees: Rob Armstrong, Suzanne Galayda, and Ronian Siew.

We are indebted to Marilee Montanaro, Administrative Assistant, for her excellent handling of the many administrative tasks for the group and tour arrangements and public relations for the Observatory, and to Kurt Holmes, carrying 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 sequence in astronomy. Pipher is the advisor for undergraduate majors.

Undergraduate Suzanne Galayda was a Bausch and Lomb Scholar working with the Near IR group this summer: she has been reducing images on the star formation region L988e, and will continue this work, completing a senior thesis in the Spring under Pipher's supervision.

Undergraduate Cherie Miskey, RIT, under the aegis of the Rochester REU program, worked with Fisher on reduction of the Jupiter/Shoemaker Levy 9 images.

Undergraduates Ali and Abbas Tahir, EE majors, worked on wiring a dewar, and optical ray-tracing respectively for the Near IR group, under Forrest's supervision. Abbas has nearly completed optimization of the design of a resolution 1000, cryogenic echellette spectrometer, sensitive from 1 - 2.5μm, and 3 - 5μm, to be built in collaboration with the Universities of Wyoming and Minnesota.

Undergraduate Rob Armstrong worked in the Near IR Lab, and analyzed images of brown dwarf candidates under Forrest's supervision.

Senior undergraduate Tammy Middleton has been working with Raines and Watson on characterization of far-infrared detectors and arrays.

Michael Zingale was a Bausch & Lomb Scholar working with Wardle over the summer on calculations of magnetohydrodynamic wave support of molecular clouds. This and continuing work forms the basis of a senior thesis to be completed in the Spring.

Undergraduate Al Pieterman, from Ninkov's group at the RIT Imaging Science Program, spent the summer analyzing images of southern OB clusters obtained in Chile by Scott Wolk of SUNY Stonybrook.

3. GRADUATE EDUCATION

Jennifer Goetz, Eric Howard, Scott Libonate, David May, Steve Solomon, Paula Turner, and Jian Wu, are graduate students in Forrest and Pipher's Near Infrared Group.

Goetz has been analyzing Fabry Perot IR images of the high mass, heavily obscured star formation region Cep A. She is analyzing images in the 1.64μm [FeII] line, and the 2.12μm H_2 line, which identify shocks in the complex outflow and identify the location of the exciting source.

Howard has been continuing his work on high mass star formation, and has completed work on several regions, including K3-50 and MonR2, as well as NS14 and S255. He observed M3-50A with the Owens Valley Millimeter Array earlier this year and is analyzing and modeling the dense molecular gas cloud surrounding this region. His paper, entitled ''A Near Infrared Study of the K3-50 Region of High Mass Star Formation,'' was accepted for publication in the April 1, 1996 issue of ApJ. He plans to submit his thesis this year. Howard is also System Manager for the Near Infrared Group's Sun network.

Libonate completed the requirements for his PhD degree in December, 1994 under the direction of J. L. Pipher; his thesis is entitled ''Identification of the Dominant Luminosity Sources at the Galactic center through Infrared Imaging and Spectroscopy.'' He assumed a postdoctoral position at RIT for six months, then began work at Loral, in Lexington MA, where he continues to work on IR detector array applications begun at Rochester for SIRTF.

May has been analyzing IR images of the high mass star formation region S106. He has obtained a one year leave of absence starting September, 1995.

Solomon had also been active in detector development for SIRTF: he is working at SBRC, Santa Barbara CA, on detector array development. He will be completing his PhD thesis in absentia, on topics of the hot-dust emission, including the 3.3 and 3.4μm features, from NGC 2023, NGC 7023 and NGC 253, and on his research in the area of detector physics.

Turner is Assistant Professor of Astronomy, Kenyon College, and successfully defended her thesis in September, 1995 under the direction of W. J. Forrest. Turner's thesis is entitled: ''Near Infrared Observations of Merging Galaxy Systems NGC 520, NGC 1614, and NGC 5128.''

Jian Wu has developed the techniques necessary to test and evaluate LWIR HgCdTe photodiodes at low temperatures and backgrounds, appropriate for space experiments. Individual diodes are wire bonded to pixels on a NICMOS3 multiplexer by Rockwell. For measuring small currents, the mux is read out in the normal integrating mode. For higher currents, the clock is stopped on one pixel and data is taken as the diode discharges. From these data, the I-V curves are reconstructed. The diode performance is being compared to the theory of Generation-Recombination and tunneling dark current mechanisms. Surface leakage is believed to be negligible in these devices because the small band gap junction is buried under a larger bandgap layer (heterostructure). The first device, using LPE material with 14μm cutoff, was successfully tested over the temperature range 20-40K. Succeeding devices will employ MBE growth methods.

John Bloomer, Matt Guptill, Nick Raines and Shobita Satyapal are graduate students in the Far Infrared Group, working with Watson on far-infrared detector development for SIRTF, imaging far-infrared spectrometer development, and infrared and millimeter-wave spectral-line imagery of galaxies and Galactic star-formation regions.

Guptill has been spear-heading the detector development at Rockwell, Anaheim with collaborator James Huffmann. At Rockwell he is involved in the epitaxial growth and process-

ing of Ge:Ga BIB far-infrared detector arrays, under Jim Huffman's direction. His presence at Rockwell has boosted considerably the detector fabrication activities of the Rochester-Rockwell-JPL collaboration responsible for the development of these devices for SIRTF, and has provided him the opportunity of including every aspect of building, testing and using the arrays in his thesis.

Satyapal successfully defended her PhD dissertation, entitled ''Probing the Dust-Enshrouded Nuclei of the Starburst Galaxy Systems M82 and Arp 299: High Spatial Resolution Near Infrared Fabry Perot Imaging Observations,'' in September 1995 under the direction of D. Watson. She has assumed a Smithsonian Institution Postdoctoral Fellowship at the Laboratory for Astrophysics, Smithsonian National Air and Space Museum.

UR graduate student Mark Swain has completed his thesis work in residence at the National Radio Astronomy Observatory in Charlottesville, under the direction of Dr. Alan Bridle. Van Horn and Watson act as Swain's internal advisers. Swain will assume a postdoctoral position at Cornell University in Fall 1995.

Graduate students Tim Collins, Guy Delamarter, Andrew Markiel, Anthony Perez-Miller, Colin Roald, and Don Stanchfield, work in the astrophysics theory group with Thomas, Wardle and Van Horn.

Collins has continued his thesis research on the structure and stability of accretion disk boundary layers in cataclysmic variables. Last year he constructed steady-state boundary layer and disk models in the fashion of both Lightman (1974) and Lioure and Le Contel (1994). This year he began a study of the stability of boundary layers using these models. Collins has also investigated other aspects of boundary layers: the importance of bulk viscosity, and thermal boundary layer vertical structure and spectra.

Delemarter continued his work with Wardle on C*- and J-type shock stability, and anticipates taking his PhD qualifying examination in the Fall.

Markiel continued his PhD thesis research with Thomas and Van Horn, studying dynamo models in the Sun, white dwarfs, and giant planets. These investigators published a paper (Thomas, Markiel, and Van Horn, 1995) which indicates that significant dynamo activity comparable to that inferred from observations of the white dwarf GD 358 (Winget *et al.*, 1994) can be expected for a wide range of white dwarf parameters. Markiel is currently developing a code to calculate 2-D dynamo models, which will be able to determine the spatial structure of the generated magnetic fields.

Perez-Miller began an investigation of magnetic field diffusion in protostellar disks.

Roald continued his research into nonlinear 1- dimensional α-ω solar dynamo models after passing his qualifying examination in April 1995. Working with Thomas, he is exploring a family of simple models with dynamically variable α and/or ω effects. Preliminary results of this project were presented in a poster session at the NATO ASI ''From Finite to Infinite Dimensional Dynamical Systems'' (Cambridge, UK) in August 1995. He was awarded a University of Rochester Messersmith Fellowship in May 1995.

Stanchfield, with Thomas, completed an analysis of the jump conditions associated with standing tube shocks in siphon flows. He presented the results of this work at a poster session at the 26th meeting of the Solar Physics Division of the AAS at Rhodes College (Memphis, TN) on 7 June 1995. Currently he is analyzing data sets from observations of dynamical phenomena in sunspots with Thomas and B. Lites (HAO/NCAR, Boulder).

David Bretz, RIT, completed his Master's Dissertation on the investigation if the initial mass function of the central region of IC1805. He has taken a position at NASA, Marshall Space Flight Center, Huntsville, AL.

4. THEORETICAL ASTROPHYSICS

Rochester's theoretical astrophysics group consists of H. L. Helfer, J. H. Thomas, H. M. Van Horn (on leave), and M. Wardle, along with current graduate students T. Collins, G. Delamarter, A. Markile, A. Perez-Miller, C. Roald, and D. Stanchfield. The group's research interests lie mostly in the general area of astrophysical fluid dynamics and megnetohydrodynamics.

4.1 The Sun

Thomas and B. Montesinos (LAEFF, Madrid) are continuing their theoretical modeling of siphon flows in solar magnetic flux tubes. Recent work includes detailed modeling of the spatial distribution of the Evershed flow in a sunspot.

4.2 Planetary Physics

Saumon, Chabrier, and Van Horn (1995) completed a detailed paper on the equation of state for hydrogen/helium mixtures at the relatively high densities and low temperatures that exist in low-mass stars and giant planets.

4.3 Dynamo Models

Markiel and Thomas have investigated the dynamo generation of magnetic fields in the Sun and white dwarfs, motivated by the evidence for a weak, $\sim 10^3$ G magnetic field in the DB (He-atmosphere) white dwarf GD 358 from analysis of the splittings of g-mode oscillations in the star (Winget *et al.* 1994). Thomas *et al.* (1995) calibrated a time-dependent dynamo model to the Sun and then applied the model to white dwarf convection zone models, and demonstrated that dynamo generated magnetic fields can be expected in white dwarfs for a wide range of parameters, including for DA (H-atmosphere) white dwarfs at a luminosity where the star is unstable to g-mode oscillations, which could in principle be detected in the same manner as the field in GD 358. Markiel has extended the model to include the latitudinal structure of the dynamo field and reproduced the butterfly structure of sunspots on the solar surface. He is currently developing a code to calculate the 2-D (latitudinal and radial) structure of the field. This code will be applied to new helioseismological data on the internal rotation of the Sun, and will also compute the structure of fields in white dwarfs which can be used with pulsation calculations to pro-

vide a better match to the observational data. The code will also be applicable to other astrophysical bodies, including main sequence stars and giant planets.

4.4 Properties of Dense Matter

Kurilenkov and Van Horn (1994) described some research on radiative transfer near the plasma frequency in strongly coupled plasmas.

Van Horn (1994) also presented a general summary of equations of state in stellar structure and evolution.

Saumon, Chabrier, and Van Horn (1995) completed a detailed paper on the equation of state for hydrogen/helium mixtures at the relatively high densities and low temperatures that exist in low-mass stars and giant planets.

4.5 Waves in Molecular Clouds

Delamarter and Wardle have calculated the steady structure of oblique, J- and C*-type shocks. A global linear stability analysis of these shock structures is underway. Preliminary results indicate that these shocks are unstable in a manner similar to C-type shocks, and that the growth rate increases with increasing shock speed.

Wardle and Perez-Miller have investigated the effect of dust grains on the structure of oblique C-type shock waves. The limiting shock speed found by Pilipp and Hartquist (1994) applies only to intermediate shock waves, and fast C-type shock solutions have been found for a wide range of velocities. Intermediate shock structures have also been found for the standard ambipolar diffusion case. These structures will provide useful test problems for multidimensional MHD simulations.

Zingale and Wardle are examining the support of molecular clouds by MHD waves. They are calculating the effect of waves on the density profile of a self-gravitating slab of gas. The calculation is self-consistent in that the time-averaged density profile determines the propagation of the waves.

4.6 Development of Fluid Shocks

H. L. Helfer is continuing studies in fluid turbulence and in non-linear mode interactions. He has developed a new approximate solution to Burgers' equation, which is in very good agreement with numerical solutions for the case of low viscosity. The approach uses the feature that the distortion of the velocity profile results from the fact that the phase velocity is amplitude dependent. He is trying to extend the technique to more complicated non-linear fluid problems.

4.7 White Dwarfs

Thomas, Markiel, and Van Horn (1995) completed a relatively extensive paper on the dynamo generation of magnetic fields in white dwarfs.

Muslimov, Van Horn, and Wood (1995) also studied magnetic field evolution in white dwarfs, concerning themselves in particular with the Hall effect and the complexity of the field.

4.8 Neutron Stars

Muslimov and Van Horn (1994) considered magnetic field decay in the non-superfluid regions of neutron stars.

Lee, Collins, Epstein, and Van Horn (1994) discussed the effects of superfluidity on spheroidal oscillations of neutron stars.

Van Horn, Lee, Epstein, and Collins (1995) discussed global oscillations of neutron stars as potential probes of the microscopic physics of matter at ultrahigh densities.

4.9 Accretion Disks

Collins, Van Horn, and Wardle continued their study of the boundary layer between the white dwarf and accretion disk in cataclysmic variables. The main thrust of their research has been a search for instabilities which might result in observed quasiperiodic oscillations thought to originate in the inner disk or boundary layer. To this end a local analysis was performed, yielding a shear instability with rise times comparable to the dynamical time in the boundary layer. A global stability analysis is currently underway.

Collins and Wardle have investigated the effects of bulk viscosity on boundary layer structure. They found that the bulk viscosity has as important an effect as the shear viscosity on the dynamical structure, but little effect on the thermal structure.

Wardle, in collaboration with A. Königl (U. Chicago), has calculated the vertical structure of magnetized protostellar accretion disks for the density regime in which dust grains are the dominant charge carriers, appropriate to a distance of roughly 1 AU from the central protostar. They have also found solutions appropriate to the ionization levels when dust grains are absent (because, for example, grains have settled to the disk midplane). In these solutions, the conductivity of the bulk of the disk material is too small to couple to the magnetic field. The conductivity rises near the disk surfaces, and the coupling between the disk material and magnetic field becomes sufficient to initiate a disk wind.

Perez-Miller and Wardle are examining the implications of the vertical structure calculations for the global evolution of the magnetic field in protostellar disks. If the surface density and surface magnetic field are specified, then the local vertical structure solutions determine the accretion rate, the mass flux from the disk surface, and the drift of the field lines within the disk. The relationship between these quantities is being explored with the goal of providing boundary conditions for numerical MHD simulations of disk-driven winds.

5. OBSERVATIONAL ASTRONOMY

Rochester's infrared astronomy groups continue to work with groups at the Smithsonian National Air and Space Museum (NASM), the Naval Research Laboratory (NRL), and the Wyoming Infrared Observatory (WIRO) on infrared spectral-line imaging of Galactic star-formation regions and starburst and Seyfert galaxies. Their observations involve the use of the Rochester Third Generation Near-Infrared Array Camera, with a 256x256 InSb/DRO detector array, along with scanning Fabry Perot spectrometers belonging to

NASM and NRL, on the 2.3 meter WIRO telescope. The Infrared Spectroscopic Imaging (ISI) team includes J. Bloomer, W.J. Forrest, E. Howard, S. Libonate, J.L. Pipher, S.N. Raines, S. Satyapal and D.M. Watson (Rochester), M.A. Greenhouse and H.A. Smith (NASM), J. Fischer and M. Luhman (NRL) and T. Hodge, C.R. McMurtry and C.E. Woodward (WIRO).

J. H. Thomas collaborates with B. W. Lites (HAO/NCAR) in carrying out high-resolution observations of dynamical phenomena in sunspots and solar active regions at the Vacuum Tower Telscope at the National Solar Observatory/Sacramento Peak.

5.1 The Sun

Stanchfield, Thomas, and B. Lites (HAO/NCAR, Boulder) are analyzing their observational data on the vector magnetic field and motions in a sunspot, taken with the Advanced Stokes Polarimeter at the Vacuum Tower Telescope at NSO/Sacramento Peak. Preliminary results confirm the elevated nature of the flux tubes carrying the Evershed flow in the penumbral photosphere.

5.2 The Solar System

The Comet Shoemaker-Levy 9 impacts with Jupiter in July 1994 provided an unprecedented probe of the Jovian atmosphere. A world-wide network of observers, using a variety of techniques and instruments, were integrated together to assure complete coverage of this once-in-a-lifetime event. The Jupiter/SL9 encounter observations utilized the University of Rochester near infrared camera (described below), and observations were obtained in collaboration with our colleagues at the University of Wyoming (Woodward and Howell), and University of Minnesota (Gehrz) on the 2.3m telescope at the Wyoming Infrared Telescope Facility (WIRO).

Our 2-2.5μm and 1.6-1.8μm dataset can be considered complementary to the large number of datasets in this band collected world-wide. Spectral images in the 3 - 4μm waveband are crucial, and since temporal observations are extremely important, it is clear that our dataset is valuable because the worldwide coverage in this band is quite limited.

Atmospheric modeling analysis is being conducted in collaboration with Phil Nicholson's group at Cornell, using a code developed by Cornell and Conrath, GSFC.

The spectra of certain impact sites as they evolved in time give crucial information concerning the chemistry from earliest acquisition of an impact site. For example, we have observed (Fisher *et al.*, in preparation) a *very* strong emission feature near 3.3–3.4μm in the Q1 spot 3–4 hours after impact. We are studying the Q1 spot's temporal history in this band, and are searching for similar emission features in other young spots. Roos-Serote *et al.* (1995) have discovered transient emission lines of Na, Fe, Ca, Li, and K within the first few hours of the Q1 and L impacts which they deduce were released from cometary refractory material. Rapid cooling of the hot gas (methane), observed by Encrenaz *et al.* (1995) and Maillard *et al.* (1995) for other young impact sites may be a related phenomenon. Carlson *et al.* (1995) report a 3.25μm measurement from Galileo that appears to be much stronger than expected during the fireball phase for impact G. They postulate a methane or hydrocarbon by-product perhaps produced through entry shock-wave heating at high altitudes, causing the presumed C-H stretch emission.

5.3 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. In addition, with the advent of the 256×256 InSb camera a larger region around known Taurus members has been surveyed at J, H, and K. The star counts there will be compared to ''blank'' fields at the 3 galactic-conjugate positions, to see if there is an excess of faint stars in Taurus. Forrest, in collaboration with Stauffer (SAO), and Leggett (IRTF) have been granted 26 hours of ISOcam prime time to search for low mass Brown Dwarfs in the Hyades. Forrest spent one week in June at IPAC laboriously entering the complex observing program for this search. The survey areas will be followed up with our Near IR camera as well.

5.4 Galactic Star Formation Activity

In support of the use of the 3.29μm 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 PhD thesis.

We have been studying 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 PDR regions; and (*v.*) imaging at broadband J, H, K, L', and M' (to probe reflection nebulosity and thermal dust emission). Howard *et al.* (1994, 1995) have exploited many of these techniques in detailed studies of MonR2, and K3-50 respectively: further observations of Orion BNKL, Cep A and GGD37 (Cep A west), S255, NS14, NGC 7538, DR 21 and L988e are in various stages of reduction. Of particular interest are the molecular shocks associated with outflows from the young stellar objects. We are investigating the effects on ongoing star formation of injection of the outflow's energy and momentum into the surrounding molecular cloud. For example, through imaging in H_2 (which traces non-dissociative) magnetically supported, C-type shocks in the accelerated cloud material), and in [FeII] (which traces dissociative, gas-dynamic, J-type shocks in the decelerated wind), the shocked emissions are clearly separated in GGD37. In Cep A, ''artillery shells'' such as those observed in Orion (Allen and Burton 1993), are observed (Goetz, 1995), with [FeII] emission at the tip of the shell outlined in H_2 emission co-aligned with the radio con-

tinuum sources HW 7. Shocks in other star formation regions including NGC 2264/HH124 and L1448 (Piche *et al.* 1995; 1993) are being probed by H_2 line emission.

5.5 Interacting, Active and Starburst Galaxies

Following the interesting results on the distribution of the 3.29 μm dust emission feature in the starburst galaxy NGC 253 described in the 1991 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 CVF's. In a wide variety of galaxies, the 3.29μm 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 Arp 299, NGC 7469, NGC 253 and M82. Spectral images of NGC 4102, NGC 4194, NGC 1614, and NGC 1068 are being investigated for the presence of this feature. The observations have been carried out at the IRTF 3m, the MLOF 1.5m and the WIRO 2.3m telescopes. For the objects with well-determined extinction, Arp 299, M82 and NGC 1614, the ratio of total dust luminosity to the extinction-corrected power in the 3.29μm feature is 1500 $\pm$ 200. In the cases of M 82 and the 3 components of Arp 299, the 3.29 μm feature is a far better tracer of total infrared luminosity than the K-band images or the (extinction corrected) Brγ line emission.

Turner has studied several merger galaxies, NGC 1614, Cen A and NGC 520, for her PhD thesis. These were selected to bridge the range from pre-(NGC 520) to post-(Cen A) merger phases. Broad-band images in the 1-5μm as well as extinction-free images of the 2.3μm CO bandhead strength are used to investigate the central regions of these galaxies. In Cen A, the AGN can only be seen clearly at wavelengths beyond 3μm. Follow-up observations at the IRTF, conducted by M. Shure, confirm the nuclear variability reported earlier by Turner *et al.* (1992) and require a source size of at most 2pc. Small-beam measurements at 450-1300μm from the JCMT were unable to distinguish between synchrotron and other possible emission mechanisms for the near infrared nuclear emission. The nuclei of NGC 1614 and NGC 520 have been resolved spatially. The emitting region in each is about 300 pc across, somewhat bigger than the starburst region in M 82. There is no evidence for an AGN in either galaxy. The data from NGC 1614 can be understood as a starburst similar to that in M 82, but about 10 times bigger. Anomalous J-H, H-K colors in both NGC 1614 and NGC 520 may indicate significant hot-dust emission in the central few kpc of each galaxy.

In one publication (Satyapal *et al.* 1995) and in Shobita Satyapal's (1995) PhD dissertation, the ISI team combined near-infrared spectroscopy of Paβ, Brγ, 2.3μm CO and the 3.3μm dust feature with high spatial resolution imaging to probe the dust enshrouded nuclei of two starburst galaxy systems, M82 and Arp 299 (NGC 3690 + IC 694). A starburst model was constructed and compared to observations to infer the properties of the starburst episodes, such as the age and initial mass function (IMF) of the stellar population. Our analysis implies that the starburst in both galaxies is approximately 10^7 years old. This is a typical age derived for starburst galaxies; examination of the evolution of our model quantities reveals the inherent selection effect that is taking place. In addition, our high spatial resolution observations of M82 indicate that there is an age dispersion within the M82 starburst complex that is correlated with the projected radius from the center of the galaxy. This suggests that the starburst in M82 is propagating outwards from the nucleus. The inferred age dispersion is 6×10^6 years, corresponding to a speed of propagation of 50 km/s. Our high spatial resolution recombination-line data have allowed us to obtain the most accurate extinction-corrected colors and luminositites to date toward the starburst region in M82. Our extinction-corrected K magnitude, the most stringent constraint on the IMF of the starburst population in M82, is -22.0, substantially fainter than previous values adopted. This difference substantially weakens the arguments made previously for a low mass-deficient IMF for the starburst region in M82. A quantitative analysis reveals that the observed properties of M82 can be accommodated by a solar-neighborhood IMF if we assume that 30% of the total dynamical mass within the central 450 pc is in the burst population, leaving more than 60% of the mass for a pre-existing population.The observations of the Arp 299 system can be explained entirely by a starburst model. The putative AGN in IC 694 does not dominate the properties of this source. We see no evidence of broad recombination lines. In addition, the ratio of feature to far-infrared luminosity is consistent with that observed in most starburst galaxies, suggesting that the large far-infrared luminosity from this source can be completely attributable to starburst activity. The starburst in NGC 3690 is older than that in IC 694, and the off-nuclear source C, near NGC 3690, is the youngest starburst region present. IC 694 appears to have a smaller upper mass-cutoff than NGC 3690, which explains the larger ratio of far-infrared luminosity to ionizing flux observed from this source. Source C, furthermore, has a very unusual color that cannot be ascribed to extinction from any assumed dust geometry. The unusual color of this source may be the result of a population of Wolf-Rayet stars.

Watson has continued a program of molecular observations of polar ring galaxies, and has detected and partially mapped eight of a sample of ten of these objects in the CO J = 2-1 line, using the Caltech Submillimeter Observatory, and the brightest of these, NGC 2685, using the millimeter array at the Owens Valley Radio Observatory. In each case the molecular component of the polar ring is substantial, comprising $1-20\times10^8$ solar masses, and in some cases the molecular component outweighs the neutral atomic component. All of the galaxies detected show low to moderate star formation efficiency indices (0.1-10 $L_\odot/M_\odot$), much lower than that of other galaxy-interaction remnants such as starburst galaxies (typically 200 $L_\odot/M_\odot$).

5.6 The Galactic Center

F. Yusef-Zadeh (Northwestern) and Wardle have mapped the rotation measure towards one of the Galactic Center nonthermal filaments, G359.54+0.18. The intrinsic polarization of the emission confirms that a magnetic field runs along the filament. The large value of the rotation measure, typically several thousand μG cm^{-3} pc, and the large variations on a scale of a few arcseconds suggest that the Faraday screen lies close to the Galactic center.

Yusef-Zadeh, Wardle and D. Roberts (U. Illinois) carried out a search at 3.6 cm for continuum emission from a small sample of OH/IR stars near the Galactic Center. The aim was to detect emission from the outer parts of the stellar winds that have been externally-ionized by the intense UV radiation within the inner hundred parsecs of the Galaxy. Emission from one OH/IR star was detected at a level consistent with estimates of the UV field in the region. The emission should be optically thin, becoming optically thick below a few hundred MHz. In principle the transition frequency is a measure of the ambient UV flux.

Libonate *et al.* (1995) report evidence for a cluster of compact stellar wind sources at the Galactic Center, utilizing long-slit, H and K-band spectra of the central regions of the Galactic Center obtained with the 2.1m telescope at the KPNO, as well as the CRSP facility spectrometer. Krabbe *et al.* (1991) had previously investigated the He I emission from stars at the Galactic Center. Libonate *et al.* identify many of the sources as LBV or WN9/Ofpe stars, and others as early-type emission line stars. The nine wind sources contribute a significant fraction of the total luminosity of the central few parsecs of the Galaxy. Rieke, Rieke, and Paul (1989) suggested that unresolved clusters of hot stars may dominate the IRS 16 complex. Libonate (1994, PhD thesis) concludes from a study of high resolution near IR stellar distribution images of the Galactic Center that a black hole more massive than $6 \times 10^5 M_\odot$ is not consistent with our data.

5.7 Stellar Cluster Studies

Ninkov *et al.* (1995) and Deeg and Ninkov (1995) have examined the initial mass function of the central regions of OB associations to lower mass limits than previously available. It is observed that sections of the IMF are significantly steeper, or flatter, than the average. Similar ''dips'' may have led to steep IMFs over narrow mass ranges as reported in the literature for other clusters.

6. INSTRUMENTATION

This year, infrared instrumentation development has centered on the groups' near infrared and far infrared detector development, improvements to the Rochester third generation ground-based camera, development of near and far IR Fabry Perot interferometers, and design of a near IR echellette spectrometer. Ninkov continued CID development.

6.1 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 256×256 InSb arrays, mounted on both CRC 463 and CRC 744 multiplexers. They have achieved 6.5e- of read noise with an InSb array utilizing the CRC 744 multiplexer down to and below 10 K.

In addition, Pipher and Forrest are continuing work with Rockwell Science Center to develop mid-wave HgCdTe detector arrays as an alternate technology for Space Astronomy, under a NASA contract.

6.2 Near Infrared Astronomical Instrumentation

One of the SBRC InSb CRC 463 arrays, FPA 131, 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 and M' bands, and in addition, three CVFs (circular variable filters) over the usable 1 - 5μm 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.

For several years now, we have obtained spectral images by combining warm NRL/NASM Fabry Perot interferometers with the Rochester Third Generation camera. The resultant resolution (~ 800) has allowed our groups to obtain spectacular line emission images.

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″×10″, and the resolution will be ~ 1000. The complete 1 - 2.5μm spectrum or the complete 3 - 5μm spectrum will fill the InSb array. The spectral region is selected via a stepper motor.

6.3 Visible Sensor Development

Ninkov and his group continued to pursue the development of charge injection devices. Devices that use pre-amp per row and pre-amp per pixel architecture are being investigated. Mass manufacture and device fabrication are proceeding both at commercial foundrys and using the RIT 2.5 μ CMOS facility. The array development work proceeds in cooperation with CIDTEC of Liverpool, NY.

The randomly addressable CID arrays are also being integrated into a photon counting visible system that will provide a significant improvement in dynamic range over CCD based systems. This work is proceeding in cooperation with Peter Chen (CSC) and Randy Fimble (NASA) at Goddard.

In addition, CID devices will be used in a single array tip-tilt image correction and acquisition system (Backer, Ninkov and Cirillo, 1995)

6.4 Ge:Ga BIB detector arrays

Dan Watson and his group, with J.E. Huffman (Rockwell) and T.N. Krabach (JPL), continue to develop germanium

blocked-impurity-band (BIB) detector arrays, a radiation-hard planar detector technology developed for use in the 50-200 micron channels of SIRTF. Currently 6x6 and 4x16 arrays are produced, and achieve peak quantum efficiency up to 20% and dark current below 100 e/s, suiting the requirements of the SIRTF instruments. Work this year has focused on improvement in the photoresponse time constant of the detectors, which have hitherto been rather slow at low backgrounds, and upon modeling of the long-wavelength response and optimization of the structure and doping.

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