University of Rochester
C. E. Kenneth Mees Observatory
Department of Physics and Astronomy
Rochester, New York 14627-0011

I. 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, 1989 to September 30, 1990. The Astronomy faculty at the University of Rochester includes W. J. Forrest, H. L. Helfer, J. L. Pipher, M. P. Savedoff, S. L. Sharpless (emeritus), J. H. Thomas, H. M. Van Horn, and D. M. Watson. In addition, D. D. Meisel, SUNY at Geneseo, is an Associate of the C. E. K. Mees Observatory. H. W. Fulbright, emeritus Professor of Physics, remains active in the Department and at the Observatory. Professor Vern Easterling, Wabash College, visited the two infrared groups this summer to join in research under the auspices of the PEW Foundation Faculty Fellowship program. He completed a project to measure lateral collection in InSb detector arrays as a function of a number of physical parameters.

James Garnett began his third year as a Research Associate in the Near Infrared Group in December, 1989. Hao Chen is in his second year as an Engineer with the Near Infrared Group. Their primary interest is in detector array development for space and ground-based application. The Near IR group's programmer, Mike Myers, has taken a new position as System Manager for the Physics and Astronomy department. Nat Cowen replaces Mike as programmer with the Near IR group.

Forrest serves as a member of the Kitt Peak User's group.

Helfer is on the Board of Directors of the New York Astronomical Corporation.

Pipher completed her terms on the Kitt Peak Telescope Allocation Committee and the Warner/Pierce Prize Committee of the AAS, of which she was chair, in spring 1990. She participated on the Infrared Panel of the Bahcall Committee, charged with the Decade Review of Astrophysics for the NAS. Pipher served on NSF panels to evaluate proposed Large Telescope projects (the NOAO 8-m telescopes, and the University of Chicago South Pole Center). Pipher began a three year term as a member of the Board of Editors of the PASP in January, 1990. She continues as Chair of the New York Astronomical Corporation Student Prize Committees.

Forrest, Pipher and Watson are members of 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.

Van Horn continues to serve on the Board of Trustees of Associated Universities, Inc., an organization of which he has been a member since 1983. He also continues to serve as a member of the Visiting Committees for the Department of Physics and Astronomy and for the Bartol Research Institute, both at the University of Delaware, responsibilities he assumed in 1984 and 1987, respectively. In addition, he has been a consultant to Lawrence Livermore National Laboratory since 1985, and he has just become a member of the AXAF Senior Review Board established by the Eastman Kodak Company, one of the three members of the industrial team that is building the Advanced X-ray Astrophysics Facility. He has also begun a five-year term as a member of the Annie J. Cannon Award Advisory Committee for the American Astronomical Society. In addition, during 1990 he served as a member of the NSF site visit committee for the GONG project at the National Optical Astronomy Observatories in Tucson. He also presented an invited summary lecture at *IAU Symposium 145 — Evolution of Stars: The Photospheric Abundance Connection*, in Druzba, Bulgaria.

Meisel was Chair of the Professional-Amateur Relations Subcommittee of Commission 22 (Meteors) of the International Astronomical Union. The Subcommittee will prepare recommendations for IAU General Assembly.

Thomas holds a joint appointment as an affiliate scientist at the High Altitude Observatory, National Center for Atmospheric Research, in Boulder, Colorado. He is a member of the U. S. Scientific and Technical Working Group for the Large Earth-based Solar Telescope (LEST), to be built in the Canary Islands, and an associate scientist for the NASA Orbiting Solar Laboratory.

Public tours were conducted at the Observatory from mid-May until the end of August by three undergraduate employees, Linda Marchese, Bruce Pirger and John Geremia. We are indebted to Barbara Merkel for her excellent handling of tour arrangements and public relations for the Observatory, and to Kurt Holmes, carrying on in his father's fine tradition as Observatory Supervisor.

Marilee Fannon was promoted to Administrative Research Coordinator from Secretary, and is now additionally responsible for budgets of the group, as well as for other administrative tasks.

II. 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.

Undergraduate Bruce Pirger has continued to work with the Near Infrared Group, and will begin a senior thesis under the direction of Pipher this spring. Anthony Imperial completed a senior thesis entitled "Performance of a CCD System used with an Astronomical Spectrograph" and John Geremia completed a senior thesis on the development of a two-dimensional CCD camera and its use at the Observatory, both under the direction of Fulbright.

Van Horn continued to serve as one of the Harlow Shapley Visiting Lecturers for the American Astronomical Society. In March, 1990 he visited Northern Michigan University in Marquette, Michigan, where he presented a talk entitled "From Mercury to Neptune: The Exploration of the Solar System."

Meisel was also a Harlow Shapley Visiting Lecturer of the American Astronomical Society (he visited Penn State at DuBois and University of Nebraska at Omaha.) Lectures on technology in astronomy, and comets and meteors were presented.

Meisel continued development of public-domain Hypercard modules for undergraduate astronomy laboratories. At the present time, finished stacks do least-squares binary orbit analysis, aid H-R diagram construction, perform distance modulus solutions, enable measurements of digitized, frame-captured images, and control of Houston DMP-29 plotters for making digitized position measurements on photographs. He published "Astronomy at Geneseo" presented at Spring meeting of Astronomical Society of New York, April 28, 1990 at Alfred University.

III. GRADUATE EDUCATION

Steve Solomon, Paula Turner, Scott Libonate and Eric Howard are graduate students in Forrest and Pipher's Near Infrared Group. Turner completed her Admission to Candidacy exam under Forrest's direction, and presented an analysis of near IR imaging of the galaxy Centaurus A for her research brief. Solomon and Libonate expect to complete their Admission to Candidacy Exams in December 1990, with research topics centering on IR imaging of the galaxy NGC 253, and Brackett alpha imaging of the galactic center, respectively. Solomon and Libonate have been active in detector development for the Space Infrared Telescope Facility (SIRTF). Howard has been reducing images of candidate brown dwarf fields with Forrest.

Shobita Satyapal, Uwe Peppel, Matt Guptill, Mark Swain and Nick Raines 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 spectral-line imagery of starburst galaxy nuclei. The former three students have passed the department preliminary examination during the past year.

Didier Saumon, working in close collaboration with former research associate G. Chabrier and Van Horn, completed his Ph.D. thesis investigation of the equation of state of dense hydrogen during the past academic year (Saumon 1989). Charles Wendell, who will complete his Ph.D. thesis this year, is studying the dynamics of magnetic flux tubes in the superfluid interiors of neutron stars in order to explore the process of flux expulsion from a neutron star core. Tod Strohmayer continued his thesis investigation of the coupling between non-radial oscillations of neutron stars and models for the pulsar emission process. The purpose of this research is to investigate the potential observability of neutron star oscillations. Strohmayer was awarded one of the highly competetive NASA Graduate Student Researchers grants for his proposal entitled "Neutron Stars in Low-Mass X-Ray Binaries and Pulsars." He also attended *IAU Colloq. No. 128: The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars* in Łagów, Poland, where he presented a paper on some of his recent research. Gordon Brown joined the group in the early spring; he is studying a model for accretion disk instabilities as a possible explanation for the observed quasiperiodic oscillations (QPOs) in low-mass X-ray binaries. Zhi We Xu joined the group in summer 1990, and he is currently carrying out a preliminary investigation of phase transitions in degenerate stars and planets. All four students are working with Van Horn.

IV. RESEARCH

A. Theoretical Astrophysics

In the past year, research in theoretical astrophysics at the University of Rochester has included studies of the equation of state of dense hydrogen, phase transitions in dense astrophysical plasmas, white dwarfs, and neutron stars, high energy particles in the interstellar medium, astronomical applications of coherence theory, as well as solar and planetary astrophysics.

1. Solar Physics and Planetary Physics

Thomas, in collaboration with Benjamin Montesinos (University of Oxford), has extended his theoretical studies of siphon flows in isolated magnetic flux tubes to include calculations of the equilibrium path of the flux tube in the external atmosphere (Thomas and Montesinos 1990a,b) and calculations of the strength and position of standing "tube shocks" in critical siphon flows (Thomas and Montesinos 1990c). These siphon flows offer a mechanism for producing some of the intense magnetic flux concentrations observed in the solar photosphere (Thomas 1990), and may also be related to the Evershed flow in a sunspot penumbra.

A paper on the probable presence of an extensive Martian atmosphere, up to $\sim$ 1.5 Gyr ago, and of an extensive deep Martian ocean, up to $\sim$ 2 Gyr ago, was published by Helfer (1990).

2. Properties of Dense Matter

G. Chabrier (1990) has recently discussed his calculations of the equation of state (EOS) of dense, fully-ionized hydrogen. His model includes the effects of the increasingly strong polarization of the electron fluid as the density is lowered toward ~ 1 g cm^{-3}. These calculations were previously used by Saumon (1989) in his detailed computations of the EOS of partially ionized hy-

drogen under conditions appropriate to low-mass stars, brown dwarfs, and giant planets. Chabrier and Saumon (1990) have also published a summary of their calculations of the hypothetical "plasma phase transition" (PPT) in dense hydrogen. As first suggested by Wigner and Huntington (1935), and more recently explored by several other groups (*cf.* Van Horn 1990a and references therein), this first-order metal-insulator phase transition is postulated to take place as insulating, molecular hydrogen undergoes the transition to the conducting, monatomic metallic state with increasing pressure. If such a phase transition exists, the calculations in the cited papers by Chabrier and Saumon provide the most accurate values obtained to date for the location of the coexistence curve and the "second critical point," at which the phase transition must terminate.

Van Horn (1990a) has also reviewed the wide variety of phase transitions that may occur in dense, fully ionized astrophysical plasmas. These include the freezing of matter in the cores of white dwarfs and the crusts of neutron stars, as well as phase separation in C/O, Fe/H, or H/He mixtures, and the hypothetical "plasma phase transition."

3. White Dwarfs

Van Horn (1990b) also has recently reviewed the current understanding of the white dwarf and hot subdwarf stars. One item of particular interest is the theoretical prediction that large numbers of halo white dwarfs, perhaps sufficient to solve the problem of the "missing mass," may be present at luminosities just below the currently observed cutoff in the white dwarf luminosity function. The launch of the Hubble Space Telescope within the past year offers a real possibility that this prediction may be tested within the near future.

Verdon *et al.* (1990), in a collaboration between astronomers in the Department of Physics and Astronomy and scientists in the University's Laboratory for Laser Energetics, have begun radiation-hydrodynamic calculations to study the effects of UV radiation from hot white dwarfs upon their rate of accretion of interstellar hydrogen. The goal of this work is to investigate whether ionization of the hydrogen can significantly reduce the accretion rate; a reduction by several orders of magnitude below the classical Bondi-Hoyle rate is necessary in order to explain the absence of any detectable hydrogen in white dwarfs with 70,000 K$\gtrsim T_{\rm eff} \gtrsim$ 12,000 K. Preliminary results reported at the *7th European Workshop on White Dwarfs*, appear promising, and this research is continuing.

Van Horn, Winget, and Hansen (1990) are currently finishing a detailed review of the current state of theory and observations of the various classes of pulsating white dwarfs. In addition, Van Horn and J. W. Liebert are preparing a book about the white dwarf stars, which they hope to complete within the coming year.

4. Neutron Stars

Epstein (1988) has previously discussed the effects of superfluidity upon the oscillations of neutron stars, using a short-wavelength approximation for his calculations. Van Horn and Epstein (1990) have now extended this work to include the global nonradial toroidal oscillation modes, which are generalizations of Epstein's transverse waves. Superfluidity increases the propagation speed of transverse waves, and this increases the toroidal oscillation frequencies significantly over the results obtained neglecting superfluidity. Van Horn and Epstein are continuing this study to investigate the effects of superfluidity on global spheroidal oscillation modes as well.

Strohmayer (1990a, b) has employed a perturbation method to investigate the effects of rotation on the nonradial oscillations of neutron stars. He finds that it is often necessary to include as many as 30 to 50 overtones in order for this technique to yield "converged" results for the eigenfunctions, depending upon the mode being corrected. The Coriolis force also couples modes with spherical harmonic index l to those with index $l \pm 1$. For those modes which were purely toroidal in the non-rotating star, this rotational coupling produces non-vanishing radial components, the existence of which modifies both the neutrino- and electromagnetic-damping rates for these modes.

Strohmayer *et al.* (1990) have recently carried out the first *ab initio* calculations of the shear modulus of a neutron star crust and have conducted a preliminary study of the effects of the new shear modulus on neutron star oscillations. It is generally believed that the crust of a neutron is a *bcc* crystalline solid. Because neutron stars cool very rapidly, however, it is possible that the crust may be glassy instead. The new shear modulus calculations by Strohmayer *et al.* have been computed for both crystalline and glassy crusts. Except near the surface of the solid crust, where thermal effects are large, the results are quite similar, although both are significantly less than the Fuchs value used previously. Not surprisingly, those oscillation modes which are most sensitive to the crustal properties – such as the toroidal oscillation modes – have significantly shorter periods when calculated using the new shear moduli.

5. High Energy Particles in the Interstellar Medium

Helfer and Savedoff have finished their study of antiproton ($\bar{p}$) production in shocked interstellar clouds, and the results are being submitted for publication. They found that the efficiency of $\bar{p}$ production in interstellar clouds is increased by a factor $\gtrsim 50$ when the engendering cosmic ray protons (CRs) experience diffusive acceleration by shocks. One can represent the $\bar{p}/p$ observations by a conventional multi-phase model of the interstellar medium in which the volume filling factor for shocked clouds is $\leq 1\%$ of that for all clouds. The $\bar{p}/p$ ratio will reach a maximum value at an energy which depends upon a typical cloud size; the present observations give this size to be $\gtrsim 2$ pc. If individual cloud sizes do not get very much larger than this, then the $\bar{p}/p$ value may have actually reached its maximum and will decrease at an energy slightly larger than the present limit of useful observations, ~ 10 GeV. Also, the porosity factor is limited ($Q \gtrsim 1/6$). One need not assume

that an old CR population exists in order to explain the $\bar{p}$ observations.

Helfer has studied a large class of CR confinement models, using the diffusion-advection model of Jokipii & Higdon (1979) to examine whether any of the production of $\bar{p}$s could be by an old CR population. He uses a Green's function approach and adopts a partially reflecting boundary at the interface between the halo and intergalactic space. He finds that if such an old population is present, with the properties normally assumed in the literature (see *e.g.* Stephens & Golden (1987), it too will produce $\bar{p}$s primarily in shocked clouds near the galactic plane. Also, one needs to postulate a very high reflectivity, $\sim 95\%$, at the interface and that the interface is at a fairly low height above the galactic ≤ 3 kpc, to get the assumed properties. A stationary reflecting interface, such a bow shock bounding a diffusive halo with streaming motions in it, seems to provide an efficient first order Fermi mechanism for acceleration of very high energy ($> 10^4$ GeV) particles. This work is continuing.

6. Astronomical Applications of Coherence Theory

Savedoff is collaborating with E. Wolf and D. James on astronomical applications of coherence theory. James, Wolf and Savedoff (1990) describe a mechanism which produces $\lambda'/\lambda =$ constant wavelength shifts by scattering off a medium with space-time fluctuations characterized by an anisotropic generalized dielectric susceptibility correlation. Contemporary discussion of AGNs provide parameters which suggest that the relevent scales needed may be present. An isotropic correlation function which generate such shifts was found by James and Wolf (1990), but these are expected to be less intense.

James and Wolf also showed that spectral analysis, rather than fringe visibility measurements can be used to determine correlation properties of the field. Using this result they formulated a new principle, according to which a trade-off can be made between the length of the base line and the frequency at which measurements are made in many interferometric measurements. This principle is a rigorous generalization of the so-called space-frequency equivalence theorem for two antenna detection systems, and it applies to radiation from a broader class of sources than previously considered.

B. Observational Astronomy

In the past year, observational research has focussed on the Sun, the interstellar medium, brown dwarf and low mass stars, the galactic center and active galaxies.

1. The Sun

Thomas is continuing his collaboration with Bruce Lites, Timothy Brown, and Thomas Bogdan (all at the High Altitude Observatory, NCAR) in a program of observations of the interaction of solar p-modes with sunspots as a means of determining the subsurface structure of the sunspots ("sunspot seismology"). These observations are made simultaneously with the vacuum tower telescope at NSO/Sunspot and the HAO/NSO Fourier tachometer in Tucson. Current efforts are directed toward the analysis of several good data sets.

2. Brown Dwarfs and Low Mass Stars

Stauffer *et al.* (1990) have obtained low dispersion optical and near infrared spectra of 6 of the candidate brown dwarfs in Taurus reported by Forrest *et al.* (1990). None of the candidates showed the strong molecular absorption features which were expected based on the low temperatures predicted theoretically for such low mass objects. The spectra would be consistent with distant, reddened, field stars, but such stars would not show the proper motions reported by Forrest *et al.* (1990). Infrared photometry of the Lk Ca 4 "companions" in December 1989 using the San Pedro Martir 2m telescope indicates the closer companion (9″from Lk Ca 4) had dimmed by 0.5 magnitudes from its brightness in September 1988. The photometry is being compared to data taken with the IRTF's Proto-cam in November 1989.

3. Galactic Nebulae

Woodward *et al.* (1990a) present 0.38″/pixel images of the Hourglass region in M8 in the H (1.65 μm), K (2.23 μm), L′ (3.75 μm) filters. They have identified several compact objects, which are probably early B stars, and a pre-main sequence object. Elias 1, a highly obscured variable Ae star, illuminates the faint nebula IC 350 in the Taurus dark cloud. Thornley *et al.* (1990) present infrared images of the system in several broaad band filters, which revealed a second source (Elias 1B), 4″ away at a position angle of −25.8 degrees from Elias 1A, with similar energy distribution. As well, images at the wavelength of the 3.28 micron dust feature were obtained. The feature emission (vicinity of Elias 1A) was not extended. High spatial resolution, near-IR images of the bright HII region in the W42 complex, G25.4-0.2S, were obtained on the NOAO 1.3-m telescope and on the IRTF 3-m telescope (Woodward *et al.* 1990b). These data were compared with optical and radio (H76α) maps of the region. Over 20 sources were detected at [H] and [K], and apparently comprise a massive OB cluster exciting the region. Two of the sources are coincident with the radio emission.

4. The Galactic Center

Nagata *et al.* (1990) present infrared imaging observations of AFGL 2004, a peculiar group of sources along the line of sight to the Galactic Center radio arc. The sources have luminosities comparable to bright giants and supergiants if at the distance of the Galactic Center, but, from the absence of photospheric features and associated Brackett emission, are probably not supergiant stars. Since they illuminate nebulosity in the surroundings, they may be a cluster of YSOs. Simon *et al.* (1990) have obtained subarcsecond spatial resolution observations at [K] of the central parsec of the Galaxy obtained during four lunar occultations. From sizes so ascertained, the authors identify a number of

the IRS16 components with stars, and the diffuse component with an unresolved stellar cluster. Scott Libonate is reducing a second epoch of Brackett α observations of the Galactic center to search for variability of the unusual Brackett α sources discovered by Forrest *et al.* (1987). Variability is the signature of the source responsible for the 511 keV positron annihilation line (Sternberg 1986) at the Galactic center.

5. Extragalactic Nuclei

Turner *et al.* (1990) report near infrared images of the central regions of the Galaxy NGC 5128, Centaurus A. It is a double-lobed radio source, with two optical components—a luminous giant elliptical bisected by a warped dark lane of gas, dust, younger stars and HII regions, suggesting a probable merger. The infrared observations identify a red, variable compact object (the probable nucleus) and show that the optical hotspot is not the nucleus but rather a hole in the extinction. Nadeau *et al.* (1990) present infrared and visible images of the gravitational lens system 2237+030. In addition to identifying extinction in the distant galaxy, and the energy distribution of the quasar emission, the data constrain the suggested microlensing event of August-September 1988 to a timescale of 100 days, implying a mass of planetry size for the microlens. Steve Solomon is anaysing infrared images of the starburst galaxy NGC 253; the near infrared group has previously worked on the prototypical starburst galaxy, M82 as well as other starburst galaxies.

C. Instrumentation

In the past year, research in instrumentation has included technological development of both near and far IR detector systems for SIRTF and ground-based use, as well as implementation of an optical CCD Fabry Perot interferometer.

1. Near Infrared Array Detector System Development

Forrest and Pipher and their group continue to develop infrared arrays for two SIRTF experiments, IRAC (the Infrared Array Camera) and IRS (Infrared Spectrometer). They have been concentrating in the past year on testing composite arrays, bonded to a CRC228 multiplexer, developed by SBRC for IRAC to ascertain appropriate detector material selection, the effects of lateral collection, octagonal *vs.* square diode junctions, and variable gate overlap. Noise reduction schemes have been implemented, and radiation testing (gamma- and proton-) has been evaluated. In addition, the effects of latent images, and a droop in signal rate at low signal levels have been studied. The group has been working with SBRC on the development of 256 × 256 InSb arrays for the next phase. At the same time, a flexible, programmable, array controller and signal processor has been developed for use with this array, and other format arrays as they become available. The controller/processor has been developed with the assistance of Prof. Dan Briotta, Ithaca College and Cayuga Microprocessor Services, and George Gull, Electromechanical Design, and Russell Wallace, Wallace Instruments. Nat Cowen (programmer) and Bruce Pirger (undergraduate) have been heavily involved in the program, as have Jim Garnett and Hao Chen. Bill Forrest has directed the program. The group continues to use their state of the art InSb arrays for ground-based Astronomy.

2. Far-Infrared Detector Array Development

During the past year, Watson, J.E. Huffman (Rockwell International Science Center, Anaheim) and T.N. Krabach (Jet Propulsion Laboratory) have produced monolithic Ge:Ga blocked-impurity-band (BIB) detector arrays for the 30 – 200 μm band, and have achieved performance which meets the goals for the SIRTF Infrared Spectrograph long-wavelength arrays. Two arrays now exist for which the peak quantum efficiency is 15%, substantially better than the best conventional stressed Ge:Ga photoconductors used in far-infrared astronomy. Peak responsivities of nearly 20 A/W and dark currents below 200 carriers/s are observed in these devices, which work best in the 60 – 210 μm range. Other advantages of the new Ge:Ga BIB arrays over far-infrared extrinsic photoconductors (eg. the *IRAS* detectors) include much better high-energy particle immunity and the fact that they can be made in the form of two-dimensional monolithic arrays. They also respond at wavelengths longer than 115 μm without the mechanical stress necessary for long-wavelength response in germanium photoconductors. Measurements on these detectors have done much to elucidate the processes responsible for the extended-wavelength response of BIB detectors, and provide a very detailed account of the density of states as a function of energy in Ge:Ga which is very close to the metal-insulator transition. Two papers, describing the detector array performance and the details of the blending of impurity states at high doping densities, are in preparation, and work has begun on an imaging high-resolution Fabry-Perot spectrometer which would employ these devices. More devices in the present 1 × 3, 3 × 3, 2 × 8 and 6 × 6 formats are in preparation, with several different photolithographic techniques, in an effort to improve the low yield of the current fabrication process. J.R. Rosenberg (Jet Propulsion Laboratory) has recently joined the project, and is contributing his considerable expertise in the fabrication of germanium MOSFETs and photodiodes, which require processing similar to that needed for the Ge:Ga BIB arrays.

3. Optical Interferometer

Meisel continued work on the Vaughan Fabry-Perot interferometer upgrade with a germanium photodiode. Initial experiments on the Mees telescope indicate that it will be necessary to run the device with beam chopping in order to achieve the desired signal/noise ratio. The photodiode was obtained under a Theodore Dunham, Jr. Award from the Fund for Astrophysical Research. Savedoff and Helfer are co-investigators on this project to study the helium λ 10830 line in various celestial objects.

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