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I. STAFF

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. On October 1, 1988, Meisel was named Associate Director of the Observatory. H. W. Fulbright, a member of the Physics faculty, has been devoting much of his teaching and research time to astronomical activity. He became an Emeritus Professor of Physics on July 1, 1989; Prof. Fulbright plans to remain active in the Department and at the Observatory.

James Garnett began his second year as a Research Associate in the Near-Infrared Group in December, 1988. He is participating in both detector array development and ground-based application of the arrays. Hao Chen joined the Near-Infrared Group as an Engineer in January 1989. He recently completed his M.S. in Electrical Engineering at the University of Arizona and comes to us with considerable experience in detector array engineering, completing his thesis research on theoretical and experimental analysis of dark current in InSb arrays at Kitt Peak National Observatory.

Gilles Chabrier completed his second year as a Research Associate in Physics and Astronomy and returned to France at the end of December, 1988. He currently holds a tenured position at the École Normale Supérieure in Lyon. He is continuing to collaborate with Saumon and Van Horn on investigations of the equation of state of extremely dense hydrogen and applications to models of "brown dwarf" stars, and he returned briefly to Rochester for that purpose in March and again during the summer of 1989.

Erlend Østgaard, of the University of Trondheim, in Norway, spent the month of June 1989 as a Visiting Scientist in the Department of Physics and Astronomy. He collaborated with Wendell, Strohmayer, and Van Horn in research on the equation of state of "magnetic matter" at the surfaces of strongly magnetic neutron stars. Similar calculations have recently been published by Fusihiki *et al.* (1989). These calculations will be used to extend earlier studies by our group of the oscillation spectrum of magnetic neutron stars. Wendell and Østgaard are also collaborating on an investigation of magnetic flux-trapping by the non-superconducting cores of neutron stars.

Forrest serves as a member of the Kitt Peak User's group. He has given invited talks on his brown dwarf discoveries, (see §B.1 below) at the 26th Yamada Conference on strongly coupled plasmas (Japan), U. Minnesota, the Naval Research Laboratory, NASA GSFC, and LLNL. Helfer is on the Board of Directors of the New York Astronomical Corporation. Pipher completed her terms on the NOAO Visiting Committee, and the IAU USNC committee in spring 1989. She continues on the Kitt Peak Telescope Allocation Committee, the Warner/Pierce Prize Committee of the AAS (Chair, 1989) and as Chair of the Astronomical Society of New York Student Prize Committee. Pipher has been named as a member of the Infrared Panel of the Bahcall Astronomy and Astrophysics Survey Committee, chaired by F. C. Gillett and J. R. Houck. 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. With D. Meisel, Van Horn also served as a member of the organizing committee for the meeting of the New York State Section of the American Physical Society on "The Life Cycle of a Star," which was held at SUNY - Geneseo on April 7 - 8, 1989. He also served as a member of the International Advisory Board for the "Yamada Conference on Strongly Coupled Plasma Physics," which took place in Japan from August 28 - September 2, 1989. In collaboration with H. E. DeWitt (LLNL) and J. Callaway (LSU), Van Horn also organized a research program on "Atoms and Ions in Dense Plasmas," which is being held at the Institute for Theoretical Physics in Santa Barbara from September through December of 1989. Thomas has been given a joint appointment as an Affiliate Scientist at the High Altitude Observatory, National Center for Atmospheric Research, in Boulder, Colorado. He serves on the U. S. Scientific and Technical Working Group for the proposed Large Earth-Based Solar Telescope (LEST).

Watson was honored with a Presidential Young Investigator award by the National Science Foundation. This fellowship will cover the years 1989-1994, and will be supported by funds from the NSF and the Xerox Corporation.

Public tours were conducted at the Observatory from mid-May until the end of August by two under-graduate employees, Linda Marchese and Bruce Pirger. Rosemary Dow left the Astronomy group as secretary in January 1989, in order to complete her education. We are indebted to her for her years of handling so well the tour arrangements. Barbara Merkel now handles tour arrangements and public relations for the Observatory, and Roberta Montanaro and Marilee Fannon are sharing secretarial duties for the group.

II. UNDERGRADUATE EDUCATION

The undergraduate program 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.

John Noto completed his senior thesis under the direction of J. Pipher, on analysis of high resolution IR images of the BN-KL region. Forrest supervised David Chappell's senior thesis on analysis and interpretation of IR images of M82. Peter Owings completed his senior thesis a year ago under S. Sharpless' direction, but submitted it this year, winning the Department Stoddard Prize for the best senior thesis. He was a "Take-Five" student; this is a program offered by the University of Rochester in which a free fifth year is offered so that students may explore other areas of interest outside their discipline. Van Horn served as the faculty adviser for Thomas Krawczyk's senior thesis project, which consisted of computing the Madelung energies for random distributions of C and O nuclei on a lattice. The object of the investigation was to explore the possibility that "super" lattices may have lower energies than random mixtures of carbon and oxygen for some C/O ratios. If this does occur, it may have significant implications for C/O phase separation in white dwarfs. The best existing calculations (Barrat *et al.* 1988, Ichimaru *et al.* 1988), which assume that C/O mixtures freeze into a random alloy, find that significant phase separation does *not* occur and that the ages of the oldest white dwarfs are at most ~ 0.5 Gyr longer than given by cooling calculations that neglect phase separation. Unfortunately, Krawczyk's results were not sufficiently extensive to demonstrate whether or not any such hypothetical "super" lattices exist.

Undergraduate Bruce Pirger has continued to work with the Near-Infrared Group. Pipher, Forrest, Watson and Helfer participated in the PEW Foundation Program this summer; two undergraduate students from Wabash College and Earlham College (Eric Burgess and Ida Chan, respectively) worked for two months this summer on research programs in the two infrared groups and in theory respectively.

Van Horn served as one of the Harlow Shapley Visiting Lecturers (to undergraduate institutions) for the American Astronomical Society in 1989. He visited Auburn University at Montgomery, Alabama, where he spoke on "The Search for Extraterrestrial Life... Other Stars, Other Worlds, Other Life?".

Meisel, with grants from SUNY-Geneseo, continues development of astronomy laboratory materials for non-majors courses centering around an Appletalk network of Macintosh computers. Software development centers around Hypercard and will include exercises in image-processing of astronomical images.

Undergraduate students in the Advanced Laboratory course continue to work with the optical spectrograph at the Mees Observatory. The linear CCD detector system has been improved in two respects:

(1) a charge injection effect which had limited integration times to a few minutes has been traced to a particular internal structure of the CCD. It has been virtually eliminated by automatically reducing an associated voltage by about 25% during integration, allowing use of integration times longer than 20 minutes (which could be extended further by lowering the operating temperature); (2) computer programs have been improved to permit more convenient operation and data handling and the use of more powerful methods of data reduction and presentation. Professor Fulbright and two students, N. Cowan and J. Geremia, have built a two-dimensional CCD system intended for use at Mees. It incorporates a small, inexpensive CCD element (TI211, 192×165 pixels), a thermoelectric cooler, and a mechanical shutter, with operation and data acquisition under computer control. Recently, after satisfactory bench tests, a trial at a 14-inch on-campus telescope showed that minor changes should be made. The vacuum chamber and the shutter were made big enough to accomodate a larger CCD.

III. GRADUATE EDUCATION

Steve Solomon, Paula Turner and Gordon Brown are graduate students working in the Near-Infrared group with Forrest. In addition, two incoming students, Eric Howard and Nick Raines, joined Forrest's and Pipher's group for the summer. Howard continues to work in the Near-Infrared Group. Scott Libonate, an advanced student past the preliminary exam, has recently transferred from High Energy Physics to Near-Infrared Astronomy. Solomon and Turner have completed their preliminary examinations; Turner has completed analysis of infrared images of Centaurus A for her qualifying research brief, and Solomon is beginning work on NGC 253. Both students are working on hardware and software development projects within the Near-Infrared Lab.

Four graduate students — Matthew Guptill, Uwe Peppel, Nick Raines and Shobita Satyapal — have joined the new Far-Infrared Astrophysics Laboratory to work with Dan Watson. Their thesis work will presumably involve development of mid-infrared and far-infrared detector arrays and instrumentation, and observational studies of star formation and galactic structure and evolution using the instruments they build.

Didier Saumon, in close collaboration with Chabrier and Van Horn, will complete his Ph.D. thesis investigation of the equation of state of dense hydrogen during the present academic year. Charles Wendell, who will also 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 will continue his thesis investigation of the coupling between non-radial oscillations of neutron stars and models for the pulsar emission process. The purpose of the latter research is to investigate the potential observability of neutron star oscillations. All three 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 solar system studies, studies of the equation of state of dense hydrogen, white dwarfs, neutron stars, high energy particles in the interstellar medium, and properties of astrophysical jets and active galactic nuclei.

1. Solar 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 adiabatic flows (Montesinos and Thomas 1989) and calculations of the equilibrium path of a thin magnetic flux tube in a stratified atmosphere in cases where the tube contains a siphon flow (Thomas 1989; Thomas and Montesinos 1989b). The siphon flow affects the arched equilibrium path of the flux tube by altering the magnetic field strength and by introducing an inertial (centrifugal) force due to flow along curved streamlines. Siphon flows offer a possible mechanism for producing intense magnetic flux concentrations in the solar photosphere (Thomas and Montesinos 1989a).

2. Planetary Physics

Helfer has examined some peculiarities in the cratering of the northern Martian plains. He concludes that these plains were the sites of ancient oceans 2 to 3.5 Gyrs ago, with a calculable water depth > 0.7 km, based on the absence of extensive cratering on these plains. Further it has been found possible to interpret the crater density counts for Chryse and the highlands as implying that Mars had a fairly dense atmosphere until 1.5 ± 0.7 Gyrs ago. This work has been submitted for publication.

3. Equations of State for Dense Hydrogen and Cold Dense Plasmas

Chabrier (1989) has developed a two-fluid plasma model including local field corrections for dense, fully-ionized hydrogen. Comparison of the thermodynamic properties computed from this model to the results of much more detailed quantum two-component plasma calculations for hydrogen (*c.f.* Ichimaru, Iyetomi, and Tanaka 1987, and references therein) shows the simpler model to provide surprisingly good results, even in circumstances where the plasma is only weakly degenerate. These calculations were subsequently employed by Saumon and Chabrier (1989a) in detailed equation-of-state calculations for hydrogen under conditions appropriate to low-mass stars, brown dwarfs, and giant planets.

Saumon and Chabrier (1989b) and Chabrier and Saumon (1989) have recently 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 (*c.f.* Van Horn 1989a 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," where the phase transition must terminate. Some of these calculations will comprise part of Saumon's Ph.D. thesis. Saumon and Chabrier (1988) have briefly explored the effects of the postulated plasma phase transition upon the thermal structure of giant planets and have verified that if it exists the PPT will have significant consequences for our understanding of the internal temperature and evolution of these objects.

In connection with their research on the equation of state of dense, molecular hydrogen, Saumon, Chabrier, and Weis (1989) have developed a new and more accurate form of fluid perturbation theory for binary mixtures at high temperature. It is based on a new method of splitting the intermolecular potentials into a repulsive core and an attractive part, and it permits rigorous additivity of the hard sphere diameters. Comparisons with detailed Monte Carlo calculations show that the new method is accurate to a few percent even in cases where earlier forms of fluid perturbation theory are in error by as much as 50% or even fail to converge.

Van Horn (1989a) has recently reviewed the wide variety of phase transitions that may occur in dense, fully ionized astrophysical plasmas. These include the freezing of matter in white dwarfs cores and neutron star crusts and phase separation in C/O, Fe/H, or H/He mixtures, as well as the hypothetical "plasma phase transition."

Helfer is continuing a long term collaboration with R.M. McCrory to evaluate the free energy of cold dense plasmas by Monte Carlo calculations. Previous work is being extended to handle binary mixtures.

4. White Dwarfs

Van Horn (1989b) has recently reviewed the current understanding of the white dwarf and hot subdwarf stars. Of particular interest are the recent discovery from the "Whole Earth Telescope" (*c.f.* Nather 1989) that the unseen companion of the white dwarf G29-38 may be a neutron star and 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.

Van Horn, Winget, and Hansen (1989) are preparing a detailed review of the current state of theory and observations of the various classes of pulsating white dwarfs.

5. Neutron Stars

McDermott *et al.* (1988) have completed a detailed investigation of the non-radial oscillations of non-magnetic, non-rotating, spherical neutron stars. This study found a wealth of adiabatic pulsation modes, including surface and core g-modes, p-modes, interfacial modes at the top and bottom surface of the crust, and torsional oscillations of the solid crust. The mode periods range from tenths of milliseconds to some tens of seconds.

Wendell (1988a) has carried out a careful computation of the minimum energy configurations of magnetic flux tubes in neutron star cores, assuming that they are pinned at the base of the crust. Interestingly, he finds that the flux tubes closest to the center of the star remain trapped there, because the energy gain from buoyancy is not sufficient to overcome the magnetic tension of the pinned flux tube. However, the minimum energy state for the majority of flux tubes is that in which the pinned tube deforms and rises buoyantly until it is plastered along the underside of the crust. These results together provide a natural explanation for observations which suggest that the 10^{12} gauss fields in pulsars decay on the crustal timescale to residual levels of 10^9 to 10^{10} gauss. In more recent work, Wendell (1988b) has performed a preliminary computation of the dynamic evolution of a buoyant flux tube pinned to the crust at both endpoints. The results confirm the relatively rapid rise of tubes located at some distance from the magnetic axis and verify that tubes close to the axis remain trapped there.

6. High Energy Particles in the Interstellar Medium

Helfer and Savedoff have continued their study of production of antiparticles in shocked small interstellar clouds (*c.f.* Helfer and Savedoff 1989). Following work by Blandford and Cowie (1982), it is assumed that in the compressed shocked clouds, the *in situ* cosmic ray protons are trapped and accelerated by magnetic field fluctuations and turbulence associated with the shock front's passage. Because of the higher energy of the bombarding protons, the effective production cross-sections for anti-protons or positrons are enhanced by a factor of 30–100, depending upon the amount of compression produced by the shock front. In addition, the number density of target interstellar hydrogen atoms is higher in compressed shocked clouds, compared to normal unshocked clouds, and the trapped accelerated cosmic ray primaries have a longer dwell time in such compressed regions. In order to explain the observed antiproton to proton ratio at energies of 2–10 Gev, a volume filling factor of $f_{shock} \simeq 10^{-7} \cdot (s/100)^{-1.33}$ (where s is the compression) for the shocked clouds is needed, assuming that a typical shock velocity is 100 km/s and that the volume filling factor for normal clouds is $f \sim 0.01$. The value of f_{shock}/f can also be expressed in terms of the porosity factor, Q, of Cox and Smith (1974); for $Q \sim 0.03$, one requires an average compression $s \sim 20$. A paper on this work is in preparation.

7. Astrophysical Jets and Active Galactic Nuclei

Koupelis and Van Horn (1988a) have developed a simple "helix model" for astrophysical jets. The basic concept is that the plasma in a jet is tied to a central massive object (the source of the jet flow) by the magnetic field which threads both. If the source is rotating, the magnetic field between it and the plasma blob is twisted, and the resulting gradient of $\mathbf{B}_\phi$ accelerates the plasma along the jet. For models in which the central object is a black hole or a neutron star, terminal velocities close to c are obtained, while for conditions typical of those in protostars the injection speed is not greatly increased. Koupelis (1988) and Koupelis and Van Horn (1988b, 1989) have further extended these calculations by considering a "narrow jet" approximation, in which the full set of MHD equations for a rotating, magnetic flow is projected onto the jet axis. The resulting system of one-dimensional equations bears a similar relation to the full magnetohydrodynamic problem as the "thin disk" approximation does to a complete accretion disk calculation. Application to a model for an active galactic nucleus indicates acceleration to $\sim 0.3c$ within 100 AU, while parameters appropriate to SS 433 yield velocities $\sim 0.96c$ at a distance of 1.6×10^{10} cm from the neutron star.

Zaninetti and Van Horn (1988) have conducted geometrical simulations of the patterns of jets emitted by moving galaxies when the source of emission is precessing, an attempt to trace the transition from C- to S-shaped sources. In particular, the effect of ram pressure bending of the jet flow has been used to investigate beam trajectories in the intracluster medium of a cluster of galaxies. Alternatively, the velocity decrease of a freely expanding jet can provide a natural way to understand the production of a "head-tail" radio jet even without the presence of a surrounding medium.

Zaninetti and Siah (1988), in work begun while both were visitors in the Department of Physics and Astronomy during the summer of 1986, explored the problem of electron acceleration in a non-homogeneous medium, as applied to the extragalactic radio sources. In their model, the magnetic field is stronger in discrete clouds, and both the Fermi acceleration and synchrotron losses affect the asymptotic spectrum, for which they develop a recursive relation.

Zaninetti (1988) has also investigated radio emission from spiral galaxies as a percolation problem. The results give encouraging consistency with observations.

M. P. Savedoff, E. Wolf (Physics), and D. James (Institute of Optics) have considered possible coherence mechanisms for producing non-kinematic wavelength shifts. Recently, a mechanism involving scattering from susceptibility fluctuations in space and time has been explored which for a certain geometry produces displacements with $\lambda'/\lambda =$ constant. Preliminary discussion appeared in Savedoff (1989). A paper describing the mechanism and its compatibility with conditions in active galactic nuclei will be submitted to the *Astrophysical Journal*. Other aspects of applications of coherence theory to interferometry and astrophysics are under study.

B. Observational Astronomy

The observational astronomers are involved in instrument development for space experiments (see, *e.g.* Pipher and Werner 1989) and for ground-based astronomy. Members of the Near-Infrared Group have used their instrumentation to study brown dwarfs, the Galactic center, galactic nebulae and external galaxies. Solar system studies have been conducted both by the near-infrared group and by Thomas.

1. Brown Dwarfs and Low Mass Stars

Forrest, Garnett, M. Shure, M. Skrutskie, Z. Ninkov, and Burton Jones have identified approximately 10 strong brown dwarf candidates believed to be members of the Taurus-Auriga star-forming association. A preliminary report was given at the June 1989 AAS meeting in Ann Arbor (Forrest *et al.* 1989a). The work is based on a 2 μm survey conducted with the 58 x 62 Rochester Infrared Camera on the IRTF in September, 1988. Confirmation of Taurus membership comes from the proper motion studies of Jones. The masses are inferred to be *circa* 0.01 $M_\odot$, *i.e.* low mass brown dwarfs. The total number of such objects in Taurus could be as high as $10^4 - 10^6$. Work is proceeding to test these conclusions further. Spectroscopy will be obtained in October and November. If the objects are young brown dwarfs rather than reddened background stars, the spectra should show molecular absorptions characteristic of cool temperatures. Skrutskie has performed a more extensive survey in Taurus using the Wyoming Infrared Observatory's new 64 x 64 camera at J, H, and K. Further infrared surveying will be made in November and December using the IRTF and the Observatorio Astronomico de San Pedro Martir in Baja California. A survey for dim, red variable stars is being performed using the U. Minnesota automatic plate scanner and multi-epoch red plates from the Palomar Schmidt telescope. This work is in collaboration with John Stauffer and Roberta Humphreys.

Forrest, M. Skrutskie, and M. Shure, are continuing work on the near-infrared spectra of the lowest mass stars and high mass brown dwarf candidates such as Gliese 569B (Forrest, *et al.*, 1988). The aim is to provide a basis for a more accurate determination of the effective temperatures, in order to compare their positions on the H-R diagram with the theoretical predictions.

2. The Galactic Center

Forrest, Garnett, M. Simon, and W.P. Chen, (Simon *et al.*, 1989) of SUNY Stony Brook have observed lunar occultations of the Galactic Center at 2 μm. The observations with the Rochester Infrared

Camera have demonstrated the utility of imaging information when observing such events through thin cirrus or bad seeing. Most of the named sources in the vicinity of Sgr A*/ IRS 16 were found to be compact, <55 mas diameter, and therefore probably single stars, suggesting these may be responsible for the ionization and heating of the central regions of Sgr A. IRS 1W and 13 were resolved into pairs of sources; they are probably the stars that excite these H II regions.

Images of an infrared cluster of sources near the Galactic center were obtained with the Rochester IR camera by Pipher, Woodward and Shure in collaboration with T. Nagata (Kyoto Univ.). Nagata *et al.* (1989) show that cluster members have a luminosity comparable with bright giants or supergiants; they may be luminous YSOs.

3. Galactic Nebulae

Woodward *et al.* (1989a) show the spatial relationship between the ionized gas emission and the 3.28 μm infrared dust feature emission in NGC 7027, via infrared images obtained with the Rochester IR camera at the IRTF at 0.4″/pixel resolution. The dust is more spatially extended than the gas; however, dust emission is terminated close to the star, even though there is still gas emission. Constraints on feature excitation are derived from these data.

Hayward *et al.* (1989) have combined images of the W3A region derived from single-channel fast-mapping at wavelengths from 1.65 to 20 μm with 2.23 and 3.75 μm images obtained with the Rochester IR camera at the WIRO at 0.6″/pixel resolution. A variety of new sources have been identified; they range from dusty compact objects to reddened stars. Maps of the dust material are used to verify and expand upon the Champagne-flow model previously proposed for this nebula.

Woodward *et al.* (1989b) have analysed 1″images of the bipolar nebula associated with the late-type star/OH source OH 0739-14 and have identified the extent of the disk as well as the unusually red colors of the scattering lobes. They propose a number of testable alternative mechanisms for this radiation. Higher resolution imaging of the region (0.4″/pixel) reveals that the lobes have considerable structure (Shure *et al.* in preparation).

4. Active Galactic Nuclei

Turner, Forrest, Pipher and Shure have imaged Centaurus A (NGC 5128) and M83 at 0.4″/pixel. Centaurus A exhibits a point-like nucleus at 3.3 μm, and is successively more extended in the nuclear regions as the wavelengths decrease; at J (1.25 μm) there is evidence for an extension that is perpendicular to the dust lane and roughly aligned with the inner radio synchrotron jet. The colors of the nuclear regions (as revealed by the 3.3 μm image) are quite red, consistent with substantial reddening (> 10 magnitudes in the visual). A preliminary report of these observations (Turner 1989) will be expanded upon (paper in preparation). M83 exhibits unusual structure at 2.23 μm; further observations are planned at other wavelengths.

5. Gravitational Lens Galaxies

Forrest, Pipher, Ninkov, Garnett, D. Nadeau (U. Montreal), and H. Yee (U. Toronto) have obtained near-infrared images of 2237 + 030 using the Rochester Camera and the CFHT in July 1988. The brightness ratios of the A, B, C, and D quasar images are similar to those found a year earlier by Yee (1988). Irwin *et al.* (1989) found a brightening of A in August and September of 1988 while Yee saw a return to nearly normal levels by November of 1988. Combining these data into a light curve indicates that a micro-lensing event has been observed, with a rise time of order 27 days and a total duration of 120 days. The former indicates that the quasar emitting region is circa 1 light day in size. The latter sets limits on the mass of the lensing object to be $< 0.008 M_{\odot}$, *i.e.*, a low mass brown dwarf (Nadeau *et al.* 1989). Further observations of this and other "cloverleaf-" shaped lenses are proceeding.

6. Solar System Astronomy

In collaboration with J. Harrington and E.W. Dunham (MIT), Forrest and Pipher obtained a partial lightcurve of the 1989 July 3 occultation of 28 Sgr by Saturn using the Rochester IR camera (Harrington *et al.* 1989). Analysis of this dataset is currently in progress.

7. Solar Astronomy

In collaboration with Bruce Lites, Timothy Brown, and Thomas Bogdan (all at the High Altitude Observatory, NCAR), Thomas is carrying out a program of observations of the interaction of solar p-modes with sunspots in order to probe the subsurface structure of the sunspots ("sunspot seismology"). These observations are made simultaneously with the vacuum tower telescope at NSO/Sunspot and with the HAO/NSO Fourier tachometer in Tucson. Several good data sets were obtained in March 1989, and current efforts are directed toward the reduction and interpretation of these data.

C. Instrumentation

1. Infrared Array Detector Development

Watson is a member of the SIRTF Spectroscopy Team (J.R. Houck, Cornell, PI), and has responsibility for the development of the 30-200 μm detector arrays for the SIRTF spectrometer. He and his students have completed the first phase of a new laboratory dedicated to far-infrared detector array and instrumentation development. The lab has extensive facilities for characterization of far-infrared detectors and arrays, and for detailed characterization of the semiconductor materials out of which the detectors are made. Evaluation of a new generation of extrinsic germanium blocked-impurity-band (BIB) detectors, under the auspisces of the SIRTF spectroscopy program, is now taking place using this new equipment.

Dan Watson, J.E. Huffman (Rockwell International Science Center) and T.N. Krabach (Jet Propulsion Laboratory) have produced the first monolithic arrays of Ge:Ga BIB detectors. The initial arrays are modest in size (1 x 8 and 6 x 6), but their pixels have been shown to match or outperform the best individual conventional detectors (Ge:Ga photoconductors) in the $100 - 200$ μm range in terms of responsivity, responsive quantum efficiency and dark current. The high-energy particle immunity of the Ge:Ga BIBs should be orders of magnitude better than that of conventional photoconductors. Overall, the present generation of Ge:Ga BIBs comes close in performance to the goals established for the SIRTF/IRS detector arrays. Work is now under way on larger formats, higher-purity epitaxy and compatible cryogenic multiplexers.

The Near-Infrared group (Forrest and Pipher) conducts a vigorous program of infrared array development both for SIRTF and for ground-based application (Forrest *et al.* 1989b). Forrest is a member of the SIRTF Spectroscopy team, and Pipher and Forrest are members of the SIRTF Array Camera team (G. Fazio, SAO; PI). The low-doped Santa Barbara Research Center 58 x 62 InSb arrays, sensitive from 1 - 5 μm, developed under the auspices of the SIRTF program to operate at temperatures near 10K (negligible dark current, <10 electrons/sec) but with good quantum efficiency (near 50%), also have been optimized to provide low read noise (200 electrons). A camera exploiting a SIRTF array has been successfully used on the IRTF and CFHT telescopes in Hawaii. The next generation InSb array will be of 256 x 256 format, with much lower pixel capacitance, hence lower read noise (approximately 50 electrons). SIRTF development to improve low temperature quantum efficiency is underway. Additional array types will be investigated in the next year – including Impurity Band Conduction (IBC) arrays sensitive from 5 to 26 μm – and 4.5 μm cutoff HgCdTe arrays. In order to facilitate these diverse projects, the near-infrared group is designing and building flexible and programmable drive and signal processing electronics based on Motorola 56001 DSPs, in conjunction with Dan Briotta, Ithaca College.

D. Meisel under a grant from the Fund for Astrophysical Research, titled "1988 Theodore Dunham, Jr. Grant for Research in Astronomy", is refurbishing the Vaughn Fabry-Perot interferometer which will be used to continue study of the Helium 10830 Å line in early type stars, as well as to start observations of other objects with Savedoff and Helfer.

REFERENCES

Barrat, J. L., Hansen, J. P., and Mochkovitch, R. 1988, *Astron. Ap.* **199**, L15.

Blandford, R.D. and Cowie, L.L. 1982, *Ap.J.*, **260**, 625.

Büttgenbach, T.H., Miller, R.E., Wengler, M.J., Watson, D.M. and Phillips, T.G., 1988, *IEEE Trans. Microwave Theory and Techniques*, **36**, *1720.*

Chabrier, G. 1989, *Phys. Letters A*, **134**, 375.

Chabrier, G., and Saumon, D. 1989, in *Proc. Yamada Conference on Strongly Coupled Plasma Physics*, ed. S. Ichimaru (Elsevier Publ. B.V.: Amsterdam).

Cox, D.P. and Smith, B.W. 1974, *Ap. J. Lett.* **89**, L105.

Forrest, W. J., Skrutskie, M. F., Shure, M., 1988, *Ap. J.*, **330**, L119.

Forrest, W. J., Garnett, J. D., Shure, M., Skrutskie, M., Ninkov, Z. and Jones, B., 1989a, *Bull.A.A.S.*, **21**, 795.

Forrest, W. J., Ninkov, Z., Garnett, J., Pipher, J. L. McKelvey, M. E., Moss, N. N., Savage, M. L., McCreight, C. R., 1989b, *Bull.A.A.S.*, **20**, 1004.

Fusihiki, I., Gudmundsson, E. H., and Pethick, C. J., 1989, *Ap. J.*, **342**, 958.

Harrington, J., Dunham, E. W., Forrest, W. J., Pipher, J. L., 1989, *DPS Abstracts*, in press.

Hayward, T. L., Grasdalen, G. L., Woodward, C. E., Hackwell, J. A., Gehrz, R. D., and Pipher, J. L., 1989, *Ap. J.*, **345**, 894.

Helfer, H.L. and Savedoff, M.P. 1989 *News Letter of the Astronomical Society of New York* Vol. III, No. 6, 25.

Ichimaru, S., Iyetomi, H., and Tanaka, S. 1987, *Phys. Rep.*, **149**, 91.

Ichimaru, S., Iyetomi, H., and Ogata, S. 1988, *Ap. J.*, **334**, L17.

Irwin, M. J., Webster, R. L., Hewett, P. C., Corrigan, R. T., and Jedrzejewski, R. I., 1989, *Ap. J.*, in press.

Koupelis, T. 1988, Ph. D. thesis, University of Rochester

Koupelis, T., and Van Horn, H. M. 1988a, *Ap. J.*, **324**, 93.

Koupelis, T., and Van Horn, H. M. 1988b, in *Active Galactic Nuclei*, ed. H. R. Miller and P. J. Wiita (Springer-Verlag: Berlin), p. 375.

Koupelis, T., and Van Horn, H. M. 1989, *Ap. J.*, **342**, 146.

McDermott, P. N., Van Horn. H. M., and Hansen, C. J. 1988, *Ap. J.*, **325**, 725.

Montesinos, B., and Thomas, J. H. 1989, *Ap. J.*, **337**, 977.

Nagata, T., Woodward, C. E., Shure, M., Pipher, J. L. and Okuda, H., 1989, *Ap. J.*, in press.

Nadeau, D., Yee, H. K. C., Forrest, W. J., Garnett, J. D., Ninkov, Z. and Pipher, J. L., 1989, Presented at the Toulouse Workshop on Gravitational Lensing.

Nather, R. E. 1989, in *Proc. IAU Colloq. No. 114: White Dwarfs*, ed. G. Wegner (Springer-Verlag: Berlin), p. 109.

Park, I. S., Haller, E. E., Grossman, E. N., and Watson, Dan M., 1988, *Appl. Optics* **27**, 4143.

Pipher, J. L. and Werner, M. W., 1989, *Comments Astrophys.*, Vol. 13, No. 5, 295-302.

Saumon, D., and Chabrier, G. 1988, *Bull.A.A.S.*, **20**, 1072.

Saumon, D., and Chabrier, G. 1989a, in *Proc. IAU Coll. No. 114: White Dwarfs*, ed. G. A. Wegner (Springer-Verlag: Berlin), p. 300.

Saumon, D., and Chabrier, G. 1989b, *Phys. Rev. Letters*, **62**, 2397.

Saumon, D., Chabrier, G., and Weis, J. J. 1989, *J. Chem. Phys.*, **90**, 7395.

Savedoff, Malcolm P. 1989, *News Letter of the Astronomical Society of New York*, **3**, 22.

Simon, M., Chen, W. P., Forrest, W. J., and Garnett, J. D., 1989, *Bull.A.A.S.*, **21**, 764.

Storey, J.W.V., Harnett, J.I., Crawford, M.K., Lugten, J.B., Watson, D.M. and Genzel, R., 1989, *M.N.R.A.S.*, **237**, 1001.

Thomas, J. H. 1989, in *The Physics of Magnetic Flux Ropes*, ed. C. T. Russell, E. R. Priest, and C. Lee (Washington: American Geophysical Union), in press.

Thomas, J. H., and Montesinos, B. 1989a, in *Proc. IAU Symp. No. 138, Solar Photosphere: Structure, Convection, and Magnetic Fields*, ed. J. O. Stenflo (Dordrecht: Reidel), in press.

Thomas, J. H., and Montesinos, B. 1989b, submitted to *Ap. J.*

Turner, P., 1989, *News Letter of the Astronomical Society of New York*, **3**, 6.

Van Horn, H. M. 1989a, in *Proc. Yamada Conference on Strongly Coupled Plasma Physics*, ed. S. Ichimaru (Elsevier Publ. B. V.: Amsterdam).

Van Horn, H. M. 1989b, in *Frontiers of Stellar Evolution*, ed. D. Lambert, to be published as a special issue of *Publ. Astron. Soc. Pacific.*

Van Horn, H. M., Winget, D. E., and Hansen, C. J. 1989, invited article for *Revs. Mod. Phys.*

Watson, D.M. and Huffman, J.E., 1988, *Appl. Phys. Lett.*, **52**, 1602.

Wendell, C. E. 1988a, *Ap. J. Letters*, **333**, L95.

Wendell, C. E. 1988b, *B.A.A.S.*, **20**, 1048.

Wigner, E., and Huntington, H. B. 1935, *J. Chem. Phys.*, **3**, 764.

Woodward, C. E., Pipher, J. L., Shure, M., Forrest, W. J., and Sellgren, K., 1989a, *Ap. J.*, **342**, 860.

Woodward, C. E., Forrest, W. J., Pipher, J. L., Moneti, A., and Shure, M. A., 1989b, *Ap. J.*, **337**, 754.

Yee, H., 1988, *A. J.*, **95**, 1331.

Zaninetti, L. 1988, *Astron. Ap.*, **190**, 17.

Zaninetti, L., and Siah, M. J. 1988, *Astron. Ap.*, **201**, 21.

Zaninetti, L., and Van Horn, H. M. 1988, *Astron. Ap.*, **189**, 45.