**C. E. Kenneth Mees Observatory**
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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, J. H. Thomas, and H. M. Van Horn. In addition, D. D. Meisel, SUNY at Geneseo, and R. W. Boyd, Institute of Optics, are Associates of the C. E. K. Mees Observatory. H. W. Fulbright, a long-time member of the Physics faculty, has recently transferred to the astronomy group as well.

Mark A. Shure completed two years as a Research Associate with the Infrared Group. While at Rochester, he added spectral capability to the Rochester Array Camera, participated in many observing trips and co-authored a number of papers. Mark began a position as Assistant Astronomer at the Institute for Astronomy, University of Hawaii on 1 July 1987.

Zoran Ninkov is continuing for a third year as Research Associate with the Infrared Group, and has been actively developing infrared arrays for our SIRTF (Space Infrared Telescope Facility) experiments.

Lorenzo Zaninetti completed his year as a Visiting Senior Research Associate on 15 April 1987 and returned to the Istituto Fisica Generale in Torino, Italy. During his stay in Rochester he completed several papers on astrophysical jets, attended a conference in Green Bank on the intracluster medium, and initiated an investigation of radio emission from spiral galaxies as a percolation problem.

Gilles Chabrier completed the first of two years as a Research Associate in Physics and Astronomy, during which he has been supported as a NATO Fellow. He is collaborating with Saumon and Van Horn on an investigation of the equation of state of extremely dense hydrogen.

Pipher continues to serve on the NOAO Visiting Committee, the IAU USNC committee, and the NNTT Infrared Instrumentation Committee, and will begin a two year term on the Kitt Peak Telescope Allocation Committee, Fall 1987. She was on the Organizing Committee for the Workshop on "Ground-based Astronomical Observation with Infrared Array Detectors," held in Hilo, Hawaii March, 1987 and was an invited participant at a workshop on Origins of the Solar System, held at the Aspen Institute in December, 1986.

Forrest was appointed to the KPNO Users Group, with an emphasis on the new infrared detector array developments. He gave invited review talks at the March 1987 Hilo, Hawaii workshop on "Ground Based Astronomical Observations with Infrared Detector Arrays" and the June 1987 27th Liège International Astrophysical Colloquium "Observational Astrophysics with High Precision Data" (Forrest, 1987a,b).

Van Horn returned from his academic leave at the University of Texas (Austin) on 1 July 1987 to resume his normal research and teaching duties. He also completed his tenure as chairman of the NSF Advisory Committee for the Astronomical Sciences on that date and was succeeded in that capacity by Prof. A. B. C. Walker, Jr., of Stanford. In the fall of 1986, Van Horn was elected to the Executive Committee of Associated Universities, Inc., an organization of which he has been a Trustee since 1983. He has also been asked to join the Organizing Committee for the IAU Colloquium on "White Dwarfs and Cataclysmic Systems," to be held at Dartmouth College in August 1988, and to become a member of the International Advisory Board for the "International Workshop on Strongly Coupled Plasma Physics," to take place in Tokyo in August 1989.

Thomas presented a talk on "Sunspot Seismology" on behalf of the National Solar Observatory at the annual review of the National Optical Astronomy Observatories at NSF headquarters in May 1987. He serves on the Users Committee of the National Solar Observatory. Thomas is on academic leave during 1987-88 academic year, as a visiting fellow of Worcester College and visiting scientist in the Department of Theoretical Physics, University of Oxford.

Fulbright gave an invited talk at Yale in March entitled: "Teaching Experimental Physics."

Public and special tours were conducted at the Observatory from mid-May until the end of August by graduate students, faculty and three undergraduate employees of the Observatory, Scott Barbaritz, David Chappell and Anthony Imperial. Rosemary Dow, the Astronomy group secretary, continues to be an effective informational link with the public.

## 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. In the 1987 summer session Astronomy 102 was offered, taught by Meisel.

The Advanced Physics Laboratory Course, normally taken by seniors in the Department of Physics and Astronomy, now offers students the possibility of making simple radio astronomy observations. Fulbright and past seniors have constructed a computer-controlled, steerable 8' diameter dish antenna (which was originally used for weather satellite work) along with a sensitive low-noise microwave receiver, a Dicke switch unit etc.

A linear CCD detector (1024 or 2048 pixels) has been mounted on the spectrograph of the Mees Observatory telescope. It operates in a vacuum, cooled by thermoelectric refrigeration. It works well in bench tests. Computer interfacing and programming are still under development. A simple two-dimensional CCD (192 by 165 pixels) has just been obtained and plans are being made for constructing the equipment which will be required for its use at Mees. These two CCD

projects are being carried out by Fulbright, David Saroff (a graduate student in Physics) and several undergraduate students.

Meisel continued the development of astronomy laboratory instructional materials for Apple IIe and IIGS computers. Monochrome video tapes made with the Mees telescope of the Moon, Jupiter, Saturn, Uranus and selected binary stars as well as low-dispersion, prismatic spectra of bright stars have been successfully digitized to a 256 x 256 pixel array with an 8 bit gray scale using an Imageworks™ (Redshift Limited) system. Captured images can be manipulated as is, or can be transferred in bilevel form to the normal Apple II 'hires' graphic screens for further measurement and processing. Because of its low cost and simplicity, this system will be used to introduce certain techniques of modern astronomical image processing into elementary courses.

## III. Graduate Education

Theodoros Koupelis is completing his Ph.D. research on the mechanism of acceleration of astrophysical jets. Didier Saumon, in close collaboration with Chabrier and Van Horn, is continuing his investigation of the equation of state of dense hydrogen. When completed later this year, these results will be used to construct new models of brown dwarf stars. Charles Wendell is studying the dynamics of magnetic vortices in the superfluid interiors of neutron stars in order to explore the process of flux expulsion from a neutron star core. All three are working with Van Horn, and Koupelis and Saumon accompanied him on leave to the University of Texas. Both Koupelis and Saumon participated in fast photometric observations of pulsating white dwarfs and cataclysmic variables at McDonald Observatory while at the University of Texas.

Tod Strohmeyer completed a summer research program classifying late-type stars on the basis of IRAS low resolution spectroscopy with Dr. Irene Little-Marenin at AFGL, Cambridge, MA and is a teaching assistant in the Department this semester.

Charles E. Woodward completed his Ph.D. dissertation under the primary direction of Pipher in April, 1987. His thesis was entitled "High Spatial Resolution Observations of Dust and Gas in NGC 7027 and the M8 Hourglass." He is now employed as a Research Associate at the University of Wyoming.

Steve Solomon and Paula Comisky Turner are graduate students working with the Infrared Group. Uwe Peppel, an incoming student Fall 1987, received a Sproull Fellowship, and worked with the Infrared Group over the summer. Mike McGovern, an incoming graduate student Fall 1987, is a teaching assistant for the astronomy courses.

## IV. Research

### A. Theoretical Astrophysics

In the past year, research in theoretical astrophysics at the University of Rochester has included studies of white dwarfs, the properties of astrophysical jets, equations of state for dense matter, neutron stars, galaxies, the properties of plasmas, and solar astrophysics.

#### 1. White Dwarfs

Winget *et al.* (1987) have demonstrated a new method for determining the age of the Universe. The method is based on the observed deficiency of faint, cool white dwarfs. The authors point out that the most natural explanation for this is that these stars have simply not had sufficient time to cool further than the observed limit of $\log L/L_\odot = -4.5$. The best current models for cooling white dwarfs give the age of the Galactic disk as about 9 Gyr and, with an assumed duration of the pre-galactic era of about 1 Gyr, give the age of the Universe as 10 Gyr. These results conflict with some other estimates of the age of the Universe and of the globular clusters, but they are also consistent with other values for the Hubble constant and with recent results of nucleocosmochronology. In an effort to assess the reliability of white dwarf model ages, Winget and Van Horn (1987) have investigated the physics of cool white dwarfs. In particular they have found that, when corrected to the same choices of input physics, all of the recent model calculations which have attempted to treat the microscopic physics accurately give ages which are mutually consistent to within about 6 percent. One set of models used in this assessment was that constructed by Wood *et al.* (1987). These have pure O cores, complementing the pure C core models constructed earlier by Winget *et al.* (cf. Winget 1981), and representing a compositional extreme which is made more plausible by recent changes in the thermonuclear reaction rates (cf. Mazzitelli and D'Antona 1986).

Wendell *et al.* (1987) have recently recomputed the evolution of magnetic fields in white dwarfs, using new expressions for the electrical conductivity of matter at high densities. They found that the conductivity increases so rapidly as the star cools that the field can never decay completely, in contrast to earlier findings by Fontaine, Thomas, and Van Horn (1973), which were based on a more approximate expression for $\sigma$. Wendell *et al.* also found that internal mass motions associated with the evolution of the pre-white-dwarf star cause changes in the structure of the magnetic field, because the field is very nearly frozen into the matter. Thus even a calculation of field evolution which is started from the lowest decay eigenmode of the initial model develops higher overtones, which decay more rapidly, as the evolution proceeds.

Koupelis and Winget (1987) have carried out new observations of the pulsations of the hot pre-white-dwarf star PG1159-035. Quite surprisingly, at least four new period bands appeared in the optical light curve. The new modes, however, still appear to fit the form of the oscillation spectrum suggested by Kawaler (1987). Thus the mass of 0.6 $M_\odot$ inferred by Kawaler for this star remains secure.

#### 2. Accretion Disks and Astrophysical Jets

Koupelis and Van Horn (1986) have considered electromagnetic mechanisms for the acceleration of plasma blobs in astrophysical jets. These ideas have been expanded by Koupelis and Van Horn (1987), who have developed a simple "helix model"

for the 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 $B_\phi$ 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. As a part of his Ph.D. thesis research, Koupelis (1987) is further extending 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.

In a short paper, Van Horn (1987) has suggested the possibility that accretion disk oscillations may be detectable in FU Orionis stars, in analogy with the case of cataclysmic variable stars. This follows the proposal by Hartman and Kenyon (1985) that accretion disks may be responsible for much of the emission from these systems.

Zaninetti completed work (1987a) on Kelvin-Helmholtz instabilities in axisymmetric configurations, continuing previous work. In addition, Zaninetti (1987b) and Zaninetti and Van Horn (1986, 1987) 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.

## 3. Equations of State for Dense Matter

Chabrier (1986a,b, 1987a,b), Chabrier and Hansen (1987), Chabrier *et al.* (1986), and Chabrier and Joanny (1987) have carried out several calculations on the properties of mixtures of metals and molten salts. These studies are extensions to more realistic cases of prior work on the properties of the hypothetical one-component plasma. They also have provided a solid foundation for a new study of the equation of state (EOS) of dense hydrogen, which Chabrier is pursuing in collaboration with Saumon and Van Horn. Chabrier has recently completed a calculation of the properties of fully ionized H in a responding electron background based on solutions of the so-called "hypernetted chain" (HNC) equation. His results compare very well with previous Monte Carlo calculations by Totsuji and Tokami (1984) and by Helfer and McCrory (1987). Saumon is completing a calculation of the dissociation and ionization of $H_2$, using modern hard-sphere fluid perturbation theory, which he has extended by incorporating the theory of Hummer and Mihalas (1987) to treat the internal partition functions. A preliminary report on the latter work has been given by Saumon and Van Horn (1987). These calculations will comprise part of Saumon's Ph.D. thesis, where they will be applied to computations of the structure and evolution of brown dwarf stars.

Helfer and McCrory are continuing their studies of the thermodynamic properties of partially degenerate plasmas. A report summarizing the results for the excess internal energy, excess pressure, and pair correlation functions for $n = 4 \times 10^{28}$ to $7 \times 10^{22}$ cm$^{-3}$ and $\Gamma = 1$ to 150 has been published (Helfer and McCrory 1987). A manuscript giving details of the calculation is in preparation.

Van Horn (1986) has also presented a discussion of the physics of dense matter, with particular reference to brown dwarfs, white dwarfs, and neutron stars.

## 4. Shocks in Collisionless Plasmas

Helfer and Savedoff are exploring some problems involved in the production of non-thermal particles in very strong plasma shocks. Others have noted the importance for the radio spectrum of supernovae and galaxies of the production of relativistic electrons in supernova generated shocks. Prediction of the power radiated by the electrons and of the absorption of energy and momentum by non-thermal electrons and ions is needed for a better description of the energetics of these shocks. They have started to determine the limitations on the diffusive acceleration process by doing a quasi-steady state calculation which self-consistently treats the effects of the non-thermal gas on the shock. The assumption that all particles with momentum exceeding $p_o$ are converted into a non-thermal (power-law) fluid component, allows them to explore the relations among the Mach number, power-law index, and flux of non-thermal particles. Inclusion of the non-thermal particles' energy and momentum appears to eliminate run-away amplification: the singular indices in the power law spectra are self-limited even in steady state calculations. They are also investigating the motions of individual electrons and ions in the electron dissipative region (the "ramp") and in the diffusive regions in order to model radiative losses, determine threshold energies for injection into the non-thermal distribution, and the time evolution of this distribution.

## 5. Neutron Stars

McDermott *et al.* (1987) have completed work on the non-radial oscillations of non-magnetic, non-rotating, spherical neutron stars. This study, which comprises much of McDermott's (1985) Ph.D. thesis, found a wealth of adiabatic pulsation modes, including surface and core g-modes, p-modes, interfacial modes at the top and bottom surfaces of the crust, and torsional oscillation modes of the solid crust. The mode periods range from tenths of milliseconds to some tens of seconds. Recently McDermott and Taam (1987) have carried out a study of the surface g-mode pulsations in X-ray burst sources, and they have concluded that some of the lower-lying modes can be excited by the $\varepsilon$-mechanism driven by the $3\alpha$ reaction during the peak of some outbursts.

Wendell has been investigating the evolution of magnetic flux tubes in the superconducting

cores of neutron stars as part of his Ph.D. thesis research. He has carried out a careful analysis of the forces acting on a flux tube, extending an earlier analysis by Bardeen and Stephen (1965) for laboratory superconductors. His results are very similar to those of Jones (1987). Both agree that there are errors in the earlier calculation of Muslimov and Tsygan (1985), but both agree with these authors that the rise time of a buoyant flux tube is less than or of the order of $10^6$ to $10^7$ years. The mechanism of pulsar turnoff thus can indeed be the decay of field trapped in the crust, as has been suggested by pulsar observers for some time.

Wendell (1987) has also 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 the recent 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.

### 6. Galaxies

Zaninetti and Siah (1987) 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 Fermi acceleration and synchrotron losses affect the asymptotic spectrum.

Zaninetti (1987) has also begun an investigation of radio emission from spiral galaxies as a percolation problem. Preliminary results give encouraging consistency with observations.

### 7. Solar Physics

Thomas and Toufik Abdelatif (Queen Mary College, London) have developed simple theoretical models for the interaction of solar p-mode oscillations with a sunspot (Abdelatif and Thomas 1987). These models reproduce the two important effects seen in their earlier observations (Abdelatif, Lites, and Thomas 1986), namely, that oscillation energy is shifted to longer wavelengths in the sunspot, and that the sunspot acts as a selective filter in preferentially admitting certain frequencies of oscillation. Thomas is continuing his work on theoretical models for "sunspot seismology," the use of solar p-modes as a probe of the subsurface structure of a sunspot (see Thomas, Lites, and Abdelatif 1987).

Thomas has continued his study of flows in isolated magnetic flux tubes by performing numerical calculations of both isothermal and adiabatic flows. This work differs from previous work on siphon flows in embedded magnetic flux tubes, in the sense that the magnetic field strength and the cross-sectional area of the flux tube are allowed to vary in response to internal pressure changes induced by the flow. This work has direct application to the Evershed flow in sunspot penumbras.

## B. Observational Astronomy

Forrest, Pipher, Shure, Ninkov and Woodward are continuing a program of astronomical imaging with the Rochester Infrared Array Camera. The camera utilizes a 32 x 32 InSb array coupled to a silicon CCD readout, and is sensitive from 1-5 μm. The instrument is described in Forrest *et al.* (1985), but was upgraded over that description as noted in last year's Observatory Report. Forrest (1987a,b) has given review papers outlining the use and performance of this and other arrays for ground-based observation. In the past year, the Infrared group has been engaged in an observational program at the Wyoming Infrared Observatory, Kitt Peak National Observatory (KPNO) and the NASA Infrared Telescope Facility (IRTF) in Hawaii. Some of the scientific programs are detailed below. In addition, Helfer and Woodward have obtained radio observations of nebulae, Ninkov and collaborators have obtained optical observations of stars, and Thomas and collaborators have obtained optical solar observations.

### 1. The Galactic Center

In a collaboration with Nagata and Okuda, Woodward, Shure and Pipher have imaged an infrared quintuplet source near the Galactic center radio arc. Five very red objects were found in images obtained at 2.23, 3.75 and 4.67 μm; these data are presented along with 10.2 μm maps of the region. Nagata *et al.* (1987) show that the quintuplet is probably located near the Galactic center. To date, they have not identified what type(s) of objects these sources are.

Imaging of the Galactic center in and out of the CO band has been initiated on the KPNO 1.3-m and on the IRTF by the Infrared group. Further observations are planned. They hope to identify the background giant component, the supergiants, and the extent of the anomalous blue region near IRS 16. Second epoch Brα images were obtained in 1987. These will be compared to the 1986 images (Forrest *et al.* 1986) to search for variable sources. Yearly imaging in the K band (2.23μm) extending back to 1984 (Forrest *et al.* 1986) and 1985 (Forrest 1987b) will be used to search for variable sources.

### 2. Starburst Galactic Nuclei

The prototypical starburst galaxy, M82, has been imaged in the near infrared at spatial scales of 2.5"/pixel, 0.98"/pixel and 0.38"/pixel (Pipher *et al.* 1987). In the latter observations, on a night of excellent seeing, they resolved the nuclear regions into a number of compact sources. For the first time, it has been demonstrated that there is correspondence of some of the radio compact non-thermal sources (presumably SNRs) with infrared compact sources. They conjecture that the infrared compact sources may either represent a cluster of supergiant and giant stars, similar to the 'blue globulars' reported in other galaxies, and that coincidences of infrared clusters with a SNR might be expected, since the most massive stars would have

gone through the supernova stage. Another possibility is that a supernova has been observed in the infrared; temporal observations at high spatial resolution are planned to investigate this possibility. The extinction (discerned through H-K colors) is quite patchy, but substantial.

## 3. Stars and Brown Dwarfs

Collaborative searches (with W. Stein, J. Gaustad and M. Skrutskie) for brown dwarf and low mass companions to nearby stars, using the Rochester infrared array camera, have been conducted. Near-infrared imaging of 61 stars in the solar neighborhood and the Pleiades revealed one previously unknown companion (Skrutskie, Forrest and Shure 1987). This object, in common proper motion with Gliese 569, is somewhat redder than the previously reddest known main sequence stars VB 10 and LHS 2924. On the other hand, it is brighter in the K-band (2.23μm) by about 0.5 mag. Therefore it may be a bona-fide star with a peculiar red spectral distribution or, possibly, a young brown dwarf in the process of cooling. Gaustad *et al.* (1987) find that the R CrB star V482 Cyg is a member of a quadruple star system. They conclude that the absolute magnitude is a little fainter than other R CrB stars, and that the fours stars observed are a physical system, and may be the brightest members of an obscured cluster. If confirmed, this association could lead to improved estimates of the mass, age, and luminosity of the R CrB variables.

## 4. Bipolar Nebulae

Two types of bipolar nebulae have been observed with the Rochester infrared array camera, those associated with star formation regions where high velocity molecular outflow have been observed, and those associated with late type stars with high mass loss. Forrest and Shure (1986) had reported on the peculiar uni-polar bubbles discovered near the central young stellar objects S140 and AFGL 2591 by imaging at 1.65, 2.23, 3.76 and 4.67 μm. Other interesting objects now studied include the unusual region Cep A (Shure *et al.* 1987). This molecular hotspot in the Cep OB3 association contains many signposts of star formation. The IR group has discovered several point sources, including an extremely red source (H-K ~ 4 mag.), and highly structured nebulosity. Infrared imaging of the lower luminosity object L1551-IRS5 reveals the disk collimating the bipolar flow via scattering, and in addition a partial segment of a bubble on the blue-shifted side (Moneti *et al.* 1987). Other objects currently under investigation include AFGL 2136, NGC 2170, NGS 7538, W33A, M8E and S255.

Woodward *et al.* (1987) show that the bipolar nebula associated with the M9III star in the source OH0739-14 is due to scattering off expelled material. Evidence for a very thick equatorial disk extending 2" north and south of the equator is given. Two moderately blue regions north and south of the disk are seen, as is one of the Herbig Haro objects identified by Cohen *et al.* (1985). These regions are, however, redder than expected if the radiation is scattered light by a 'bare' M9III star. Possible explanations are advanced. In addition Shure *et al.* (1987) report imaging of this object at 0.42"/pixel at 1.65, 2.23, and 3.75 μm as well as through the 3.08 μm ice feature at 1% spectral resolution. The ice feature images clearly depict the extinction disk, while the high spatial 2.23 μm images show three string-like extensions from the bright northern lobe of the bipolar nebula, and terminating in the northern Herbig Haro object. Perhaps these are trails of material entrained in the flow which created the Herbig Haro object.

## 5. Emission Nebulae

Infrared images of the planetary nebula NGC 7027 have been obtained with the Rochester infrared array camera on the KPNO 1.3-m and 4-m telescopes as well as the IRTF 3-m. The latter images, in Brα and γ, as well as in the 3.28 μm feature show clearly that the unidentified feature emission at 3.28 μm is found beyond the sharp ionized boundary (Woodward, 1987; Woodward *et al.* 1987). Brα/Brγ images of NGC 7027 show considerable extinction to the strong radio lobes. Images in the $H_2$ emission band head at 2.4 μm have been obtained; the data are not fully reduced, but apparently the emission primarily emanates from lobes just beyond the 3.28 μm peaks.

Woodward and Helfer have obtained H76α recombination line high-resolution (2.5" x 3" FWHM) VLA maps of the Hourglass region of M8 and of G25.4-0.2, previously studied in the continuum at 5 GHz (Woodward *et al.*, 1985; Woodward *et al.*, 1986). The two central features of the northern lobe of the Hourglass each seem to show extended velocity profiles, perhaps indicative of expansion. The velocity field of the G25.4-0.2 source is very complicated; the complex seems to be composed of several spacially separated components, each with different velocity profiles. Analyses of these data are underway.

## 6. The Sun

Thomas, together with Bruce Lites and Timothy Brown (High Altitude observatory, NCAR), are engaged in a program of observations of the interaction of five-minute solar p-modes with a sunspot, as a means of probing the subsurface structure of sunspots ("sunspot seismolgy"). Observations at high horizontal wavenumber are carried out with the vacuum tower telescope and universal birefringent filter at NSO/Sunspot, while observations at low horizontal wavenumber are carried out with the HAO/NSO Fourier tachometer in Tucson. Observations have now been obtained at both sites, and analysis of the data is proceeding.

## 7. Early Type Stars

Ninkov, together with Gordon Walker and Stephenson Yang (University of British Columbia), completed two papers based on observations of Cygnus X-1 contained in Ninkov's Ph.D. thesis: "The Primary Orbit and Absorption lines of HDE 226868 (Cygnus X-1)" and "The HeII λ4686 and Hα Emission Lines of Cygnus X-1." A paper is in preparation with L. Stella of ESA on EXOSAT observations of Cygnus X-1 obtained near phase zero on the 294 day X-ray period. Ninkov with Walker, Yang and Hill (University of British Columbia) have also reported on two previously unknown emission lines at 6667A and 6700 A in the

spectra of O and Of stars. While no positive identification can be made for these lines, their behavior mimics that of the unidentified lines at 4486Å and 4504Å. Yang, Ninkov, and Walker have submitted a paper on rapid spectroscopic variations seen in the Be star γ Cas. These variations are interpreted as being the result of nonradial pulsations in the atmosphere of this star.

## C. Instrumentation

### 1. Infrared Array Detector Development

Forrest, Ninkov and Pipher have acquired several 58 x 62 InSb arrays from SBRC with direct, switched MOSFET readout; these include a 'standard' doped array, as well as specially low doped InSb arrays for evaluation for SIRTF experiments. As well, they have acquired a Si:In array mated to the same type of readout. The Rochester group has developed interfaces to the SBRC supplied electronics, and to the LSI 11-73 computer employed, as well as other peripherals. Mike Myers, the student programmer for the infrared group, has been developing required software. Testing of these arrays, and evaluation of alternate technologies are well under way. Ninkov, Forrest and Pipher (1987) have reported on the testing of the engineering InSb array.

Forrest and Pipher are team members of the SIRTF Imaging Team (Fazio, SAO, principal investigator), and Forrest is a team member of the SIRTF Spectroscopy Team (Houck, Cornell, principal investigator). Presently, these experiments are near the end of the first of four years of the Definition Phase. Instrument development is under study; crucial areas, such as a suitable detector array technology, are under active investigation as described above.

### 2. Radio Astronomy

Fulbright recently spent several weeks at Green Bank, continuing a collaboration with Ron Maddalena and other staff members on a project to improve the figure of the 43 meter dish antenna. Holographic measurements, for which the required equipment had been built the previous summer, were made alternately with panel adjustments. The result, according to preliminary observations made on standard sources, was a substantial improvement in antenna efficiency. According to one estimate the time required for an observation at 24 GHZ has been reduced by a factor of two or three.

## REFERENCES


Abdelatif, T. E., Lites, B. W., and Thomas, J. H. 1986, *Ap. J.*, **311**, 1015.

Abdelatif, T. E., Thomas, J. H. 1987, *Ap. J.*, **320**, in press.

Bardeen, J., and Stephen, M. J. 1965, *Phys. Rev.*, **140**, A1197.

Chabrier, G. 1986a, *J. Phys. C*, **20**, 357.

Chabrier, G. 1986b, in *Strongly Coupled Plasma Physics*, ed. F. J. Rogers and H. E. DeWitt (Plenum Press: New York), p. 45.

Chabrier, G. 1987a, *J. Electrochem. Soc.*, in press.

Chabrier, G. 1987b, *J. Electrochem. Soc.*, in press.

Chabrier, G., and Hansen, J. P. 1987, *Mol. Phys.*, **59**, 1345.

Chabrier, G., Hansen, J. P., and Joanny, J. F. 1986, *J. Phys. C*, **19**, 4443.

Chabrier, G., and Joanny, J. F. 1987, *J. Phys. C*, **20**, 1987.

Cohen, M., Dopeton, M., Schwartz, P., and Tielens, A. 1985, *Ap. J.*, **297**, 702.

Fontaine, G., Thomas, J. H., and Van Horn, H. M. 1973, *Ap. J.*, **184**, 911.

Forrest, W. J., Moneti, A., Woodward, C., Pipher, J. L., and Hoffman, A. 1985, *Pub. Astr. Soc. Pac.*, **97**, 183.

Forrest, W. J., Pipher, J. L., and Stein, W. A. 1986, *Ap. J. (Letters)*, **301**, L28.

Forrest, W. J., Shure, M. A., Pipher, J. L., and Woodward, C. E. 1987, A.I.P. Conf. Proc. 155: *The Galactic Center*, p. 153.

Forrest, W. J. 1987a, in *Infrared Astronomy with Arrays*, ed. C. G. Wynn-Williams and E. E. Becklin (IfA, U. Hawaii: Honolulu), p. 171.

Forrest, W. J. 1987b, Review paper, 27th Liège International Astrophysical Colloquium: "Observational Astrophysics with High Precision Data" (in press).

Forrest, W. J., and Shure, M. A. 1986, *Ap. J. (Letters)*, **311**, L81.

Gaustad, J., Stein, W. A., Forrest, W. J., and Pipher, J. L. 1987, submitted to *Pub. Astr. Soc. Pac.*

Hartman, L., and Kenyon, S. J. 1985, *Ap. J.*, **299**, 462.

Helfer, H. L., and McCrory, R. L. 1987, in *Strongly Coupled Plasma Physics*, ed. F. J. Rogers and H. E. DeWitt (Plenum Press: New York), p. 41.

Hummer, D. G., and Mihalas, D. 1987, *Ap. J.*, submitted.

Jones, P. B. 1987, *Mon. Not. R. Astr. Soc.*, **228**, 513.

Kawaler, S. D. 1987, in IAU Symposium No. 123: *Advances in Helio- and Asteroseismology*

Koupelis, T. 1987, Ph.D. thesis, in preparation, University of Rochester.

Koupelis, T., and Van Horn, H. M. 1986, *Newsletter Astron. Soc. N. Y.*, **2**, #10, 13.

Koupelis, T., and Van Horn, H. M. 1987, *Ap. J.* (in press).

Koupelis, T., and Winget, D. E. 1987, in Proc. IAU Coll. No. 95: *The Second Conference on Faint Blue Stars*, ed. A. G. D. Philip, D. S. Hayes, and J. W. Liebert (L. Davis Press: Schenectady) (in press).

Mazzitelli, I., and D'Antona, F. 1986, *Ap. J.*, **308**, 706.

McDermott, P. N. 1985, Ph.D. thesis, University of Rochester.

McDermott, P. N., and Taam, R. E. 1987, *Ap. J.*, **318**, 278.

McDermott, P. N., Van Horn, H. M., and Hansen, C. J. 1987, *Ap. J.* (in press).

Moneti, A., Forrest, W. J., and Pipher, J. L., and Woodward, C. E. 1987, in press.

Muslimov, A. G., and Tsygan, A. I. 1985, *Ap. Space Sci.*, **115**, 43.

Nagata, T., Woodward, C. E., Shure, M. A., Pipher, J. L., and Okuda, H. 1987, in preparation.

Ninkov, Z., Forrest, W. J., Pipher, J. L. 1987,

in *Infrared Astronomy with Arrays*, ed. C. G. Wynn-Williams and E. E. Becklin (IfA, U. Hawaii: Honolulu), p. 37.
Ninkov, Z., Yang, S., Hill, G., Walker, G. A. H. 1987, *Pub. Astr. Soc. Pac.*, **99**, 284.
Ninkov, Z., Walker, G. A. H., Yang, S. 1987, *Ap. J.*, **321**, 425.
Ninkov, Z., Walker, G. A. H., Yang, S. 1987, *Ap. J.*, **321**, 438.
Pipher, J. L., Moneti, A., Forrest, W. J., Woodward, C. E., and Shure, M. A. 1987, in *Infrared Astronomy with Arrays*, ed. C. G. Wynn-Williams and E. E. Becklin (IfA, U. Hawaii: Honolulu), p. 326.
Saumon, D., and Van Horn, H. M. 1987, in *Strongly Coupled Plasma Physics*, ed. F. J. Rogers and H. E. DeWitt (Plenum Press: New York), p. 173.
Skrutskie, M., Forrest, W. J., Shure, M. A. 1987, preprint.
Thomas, J. H., Lites, B. W., and Abdelatif, T. E. 1987, in Proc. IAU Symp. No. 123, *Advances in Helio- and Asteroseismology*, ed. J. Christensen-Dalsgaard (Dordrecht: Reidel), in press.
Totsuji, H. and Tokami, K. 1984, *Phys. Rev.*, **30**, 3175.
Van Horn, H. M. 1986, *Mitt. der Astron. Gesellschaft*, **67**, 63.
Van Horn, H. M. 1987, *Astrophys. Letts. and Commun.* (in press).
Wendell, C. E. 1987, submitted to *Ap. J.*
Wendell, C. E., Van Horn, H. M., and Sargent, D. 1987, *Ap. J.*, **313**, 284.
Winget, D. E. 1981, Ph.D. thesis, University of Rochester.
Winget, D. E., Hansen, C. J., Liebert, J., Van Horn, H. M., Fontaine, G., Nather, R. E., Kepler, S. O., and Lamb, D. Q. 1987, *Ap. J.*, **315**, L77.
Winget, D. E., and Van Horn, H. M. 1987, in Proc. IAU Coll. No. 95: *The Second Conference on Faint Blue Stars*, ed. A. G. D. Philip, D. S. Hayes, and J. W. Liebert (L. Davis Press: Schenectady) (in press).
Wood, M. A., Winget, D. E., and Van Horn, H. M. 1987, in Proc. IAU Coll. No. 95: *The Second Conference on Faint Blue Stars*, ed. A. G. D. Philip, D. S. Hayes, and J. W. Liebert (L. Davis Press: Schenectady) (in press).
Woodward, C. E. 1987, Ph.D. thesis, University of Rochester.
Woodward, C. E., Helfer, H. L., and Pipher, J. L. 1985, *Astron. Ap.*, **147**, 84.
Woodward, C. E., Pipher, J. L., Helfer, H. L., Sharpless, S. L., Moneti, A., Kozikowski, D., Oliveri, M., Willner, S. P., Lacasse, M., and Herter, T. 1986, *A. J.*, **91**, 870.
Woodward, C. E., Pipher, J. L., Forrest, W. J., Shure, M. A., Sellgren, K., Nagata, T. 1987, in *Infrared Astronomy with Arrays*, ed. C. G. Wynn-Williams and E. E. Becklin (IfA, U. Hawaii: Honolulu), p. 299.
Yang, S., Ninkov, Z., Walker, G. A. H. 1987, submitted to *Pub. Astr. Soc. Pac.*
Zaninetti, L. 1987a, *Phys. Fluids*, **30**, 612.
Zaninetti, L. 1987b, submitted to *Astron. Ap.*
Zaninetti, L., and Siah, M. J. 1987, submitted to *Ap. J.*
Zaninetti, L., and Van Horn, H. M. 1986, in *Proc. Green Bank Workshop on Clusters of Galaxies* (in press).
Zaninetti, L., and Van Horn, H. M. 1987, *Astron. Ap.* (in press).
Zaninetti, L., and Van Horn, H. M. 1986, submitted to *Astron. Ap.*