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 (formerly an Associate of the C.E.K. Mees Observatory), 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 member of the Physics faculty, has been devoting much of his teaching and research time to astronomical activity.

Zoran Ninkov began a two year appointment as a Research Associate in Astronomy in November 1985 with the Infrared Group. Before coming to Rochester, he was employed by the Western Australian Institute of Technology. He completed his PhD in July 1985 with Professor G.A.H. Walker, at the University of British Columbia. His thesis research concerned observations and interpretation of the X-ray binary Cygnus X-1. Mark A. Shure continues as a Research Associate in Astronomy with the Infrared Group.

Gilles Chabrier joined the theoretical astrophysics group on 1 August 1986 as a Research Associate. He holds a NATO Fellowship. His doctoral research with Professor J.-P. Hansen in Paris was concerned with the properties of molten salts; in Rochester he will be collaborating in research on the properties of dense astrophysical plasmas.

Lorenzo Zaninetti, on leave from the Istituto Fisica Generale in Torino, Italy, began a one-year appointment as Visiting Senior Research Associate on 15 April 1986. His area of research is the theory of astrophysical jets.

In the summer 1986, Bradley W. Carroll and M. Javad Siah joined the theory group as temporary visitors. Carroll, from Weber State College in Ogden, Utah, conducted research on the problem of the coupling between neutron star oscillations and the pulsar emission mechanism. Siah, from Villanova University, continued his investigations of the properties of astrophysical jets.

In the fall 1986, Tetsuya Nagata, University of Hawaii, joined the infrared group to collaborate on interpretation of observations of Halley's Comet obtained on the Infrared Telescope Facility with the Rochester Infrared Array Camera. During the summer 1986, Andrea Moneti, Osservatorio Astrofisicio Arcetri, Italy, collaborated with the infrared group on several projects, including analysis of the starburst galaxy M82 and the bipolar star formation region L1551-IRS5.

Van Horn completed his sixth year as Chairman of the Department of Physics and Astronomy on 30 June 1986 and has returned to full-time research and teaching. He is on leave for the 1986-87 academic year, spending the fall 1986 semester in Rochester and the spring 1987 semester in the Department of Astronomy at the University of Texas (Austin). In the fall of 1985 he became a consultant to Lawrence Livermore National Laboratory. He and Helfer were appointed Senior Scientists at the University's Laboratory for Laser Energetics in addition to their regular appointments of Professors of Physics and Astronomy.

On 1 July 1986, Van Horn also became Chairman of the NSF Advisory Committee for the Astronomical Sciences, succeeding Professor Martha Haynes of Cornell University in that capacity. He served as a member of the Organizing Committee for the Workshop on Strongly Coupled Plasma Physics, which was held at the University of California at Santa Cruz on 4-9 August 1986. He was also a member of the Visiting Committee for the Department of Physics at Villanova University on 11-13 June 1986.

Pipher continues to serve on the NNTT Infrared Instrumentation Committee, and on 1 October 1986 began a three year membership on the NOAO Observatories Visiting Committee. She was nominated to the U.S. National Committee for the International Astronomical Union (USNC-IAU), Category I; the appointment will be effective 1 January, 1987.

Van Horn and Pipher served as Harlow Shapley Visiting Lecturers. Van Horn visited Andrews University on 26-27 March 1986. His Shapley Lecture was entitled "Exploration of the Solar System." He also spoke on the topic: "From the Depths of Space: the Return of Halley's Comet." Pipher visited the neighboring institutions Wabash College and DePauw University on 20-22 November 1985 and Hartwick College 29 April 1986 under this program. Her Shapley Lectures were entitled "Energetic Winds from Newly Born Stars" and "Probing Dark Clouds to Unveil Newly Born Stars" respectively. She also spoke to a more advanced audience on "Infrared Observations of the Galactic Center".

John H. Thomas, whose primary appointment is Professor of Mechanical and Aerospace Sciences, was appointed in addition Professor of Astronomy by the Department of Physics and Astronomy. Thomas also serves on the User's Committee of the National Solar Observatory.

Meisel presented a number of talks on Comet Halley to various groups and astronomical societies and held 15 public openhouse sessions at SUNY-Geneseo with an estimated total of 400 persons in attendence.

Public and special tours were conducted at the Observatory from mid-May until the end of August by graduate students, faculty, research associates and two undergraduate employees of the Observatory, Scott Barbaritz and Dan LaSota. Rosemary Dow, the Astronomy group secretary, continues to be an effective public relations interface 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 1986 summer session Astronomy 102 was offered, and taught by Meisel.

James Lauroesch completed a senior thesis in Astronomy under the direction of Forrest, and won the coveted departmental Stoddard Prize for the best senior thesis in Physics or Astronomy.

Meisel with K. F. Kinsey (S.U.N.Y.-Geneseo) wrote and distributed an Apple IIe data entry and analysis program, DATASHEET, which is to be used by undergraduate physics and astronomy students in a variety of laboratory situations. This program is in the public domain, is menu driven in a spread-sheet format with graphics available, and is easily mastered within a few hours by non-science students. Requests for copies for non-commercial use by the astronomical community can be made to D. Meisel, SUNY, Geneseo, NY 14454.

The Advanced Physics Laboratory Course, normally taken by seniors in the Department of Physics and Astronomy, will shortly offer 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.

III. GRADUATE EDUCATION

Theodoros Koupelis is carrying out his Ph.D. research on the process of acceleration in astrophysical jets. Didier Saumon is investigating the equation of state of dense hydrogen for application to calculations of the evolution 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.

Charles E. Woodward is completing his PhD thesis research on the nature of interstellar dust, particularly that responsible for 'unidentified feature emission,'and its relation to the interstellar gas through analysis of infrared, optical, VLA and IUE observations. He won the Astronomical Society of New York (ASNY) graduate student prize for his research on M8, and presented the prize winning lecture 1 November 1986 at the fall ASNY meeting.

Tod Strohmeyer, Karl Helmer (second year students) and Steve Solomon (first year student) are all working with the infrared group. Paula Comiski an entering graduate student, is a teaching assistant in Astronomy.

IV. RESEARCH

A. Theoretical Astrophysics

1. Neutron Star Oscillations

McDermott *et al.* (1985, 1986) have performed detailed numerical computations of the non-radial oscillations of warm neutron stars. With a surface fluid "ocean" of molten crustal material, solid crust, and superfluid core, these stars can sustain rich spectra of both spheroidal and toroidal oscillations. McDermott, now a postdoc with R. E. Taam at Northwestern University, has since extended this work to X-ray bursters; McDermott and Taam (1985) find that near the peak of the He-shell flash, the g_1-mode which is trapped in the "ocean" is excited by the thermonuclear burning and has a period $\sim$ 10 ms, quite comparable to the quasiperiodicities observed in XB1728-34 and 1H 1909+096.

In another extension of McDermott's work, Carroll *et al.* (1985a, 1986a) have studied the effects of strong magnetic fields at the surface of a pulsar upon the oscillation spectra of the neutron star. They have shown that most of the oscillation modes are relatively insensitive to the field. The spheroidal "ocean" g-modes, however, are transformed into magneto-gravity (m/g-) modes with periods $\lesssim$ 10 nanoseconds for $B = 10^{12}$ gauss. In the toroidal mode spectrum, a new class of Alfvén (a-) modes appears, which are essentially the orthogonal polarization of the m/g- modes and which have similar periods. Many of the modes, especially the m/g- and a-modes, appear to be strongly damped by the emission of electromagnetic radiation (Carroll *et al.* 1985b).

2. Magnetic Field Evolution in Degenerate Stars

Wendell *et al.* (1986) have studied the evolution of magnetic fields in a contracting pre-white-dwarf star. They have found that in the early, pre-degenerate models even simple initial field configurations develop complex mixtures of decay overtones because of the changing mass and electrical conductivity distributions. Toward the end of the white dwarf cooling phase, however, the internal temperatures of the stars become so low that the electrical conductivity becomes extremely large. Under these conditions, the decay timescale is much longer than the age of the star, and further evolution of the magnetic field effectively ceases.

In his Ph.D. thesis research, Wendell is currently investigating the dynamics of magnetic vortex lines in the superfluid interiors of neutron stars. The motivation for this work is provided by the strong observational suggestion that magnetic fields in pulsars decay in $\sim 10^6$-10^7 years, approximately the crustal decay timescale (cf. Taylor and Stinebring 1986). However, if pulsars are formed with magnetic field lines threading the core, there is not sufficient time for the Meissner effect to exclude the field as the neutron star cools, and the field lines become trapped in the core, being slowly excluded on the very long core field dissipation timescale (Baym and Pethick 1979). Recently, Muslimov and Tsygan (1985) have questioned this, suggesting that magnetic bouyancy can cause the flux tubes to rise. Wendell is carrying out a careful investigation of this suggestion.

3. Accretion Disks and Astrophysical Jets

Carroll *et al.* (1986b) have carried out a short-wavelength analysis of a self-consistent, two-dimensional accretion disk model. Two of the modes correspond to high-frequency (p-mode) oscillations. Two more share characteristics of internal gravity waves (g-modes) and inertial waves and have characteristic frequencies intermediate between the Brunt-Väisälä frequencies and the Solberg-Hoiland frequency.

Van Horn (1986a) has recently suggested that the quasiperiodicities observed in FU Orionis stars may represent non-radial stellar oscillations driven by disk-fed accretion, as in the cataclysmic variables.

Members of the theory group also have carried out a substantial amount of work on the properties of astrophysical jets. Zaninetti (1986a,b,c,d,e) and Turolla and Zaninetti (1986) have completed a program of research on Kelvin-Helmholtz instabilities in axisymmetric jets. More recently he has begun a series of computations to simulate the shapes of extragalactic radio sources, including the combined effects of instabilities, precession of the jet, and aspect angle of observation (Zaninetti and Van Horn 1986a,b). Zaninetti and Siah (1986) have also explored the process of electron acceleration in a non-homogeneous medium, in which the magnetic field is stronger in discrete clouds, and in which Fermi acceleration and synchrotron losses both affect the asymptotic spectrum.

Siah has also begun research on the nature of the electromagnetic instabilities produced during the passage of a cold, relativistic beam of electrons through a thermal plasma. The aim of this project is to investigate the effects of the instabilities on the collimation and deceleration of the beam in an effort to understand the lack of observed enhanced brightness at the bends of the relativistic beams emerging from quasars and other strong extragalactic radio sources.

Koupelis and Van Horn (1985, 1986a,b) have continued their investigation of the acceleration mechanisms in the jets originating from active galactic nuclei, neutron stars (SS433), and proto-stars (producing Herbig-Haro objects). Preliminary calculations with a simple kinematic model suggest that the helical magnetic fields produced by differential rotation between the source of the jet and a "blob" of plasma in the jet can accelerate matter ejected from neutron stars or galactic nuclei to relativistic speeds. Current work is focusing on separable MHD solutions for "narrow" jets and on improved calculations of the forces exerted on discrete plasma blobs within such a jet.

4 Equations of State for Dense Matter

In an extension of earlier work, Helfer, McCrory, and Van Horn (1986) are investigating the properties of a dense plasma in which the electrons form a responding background rather than a rigid background, as in the hypothetical one-component plasma" (OCP). These calculations indicate that the additional screening lowers the energy of the plasma relative to the OCP and reduces the amplitude and increases the typical spacing in the pair correlation function. Chabrier has joined this effort, bringing to bear his expertise on the statistical physics of metal-molten salts, and H. E. DeWitt from Lawrence Livermore National Laboratory has become an active collaborator as well.

H. L. Helfer and R. L. McCrory are continuing their Monte Carlo studies of plasmas with densities in the range, $N_e = 10^{22}$ to 10^{28} cm^{-3}. A paper, Thermodynamic Properties of a Polarized OCP, was given at the August 1986 Santa Cruz meeting on Strongly Coupled Plasmas, and will be published in the conference proceedings. The departures of the excess internal energy and pressure terms from the standard OCP (with a uniform electron background) are significant at lower densities and cannot be ignored. The pair correlation functions can also depart appreciably from the standard OCP forms. The detailed results are being prepared for publication. Following an approach suggested by Ashcroft and Stroud, a careful derivation of the expression for the partition function has shown the presence of some terms which have been neglected in previous work. For high density plasmas these terms give minor contributions to the internal energy and pressure. Further numerical calculations are in progress to access their contributions for lower density plasmas.

In the first stage of his Ph.D. thesis research, Saumon has undertaken a critical recalculation of the equation of state of dense, molecular H_2 (see Saumon and Van Horn 1986). This work has shown good agreement with the Los Alamos equation of state calculations for D_2 (Holian 1984) but less good with the Los Alamos tables for H_2, which were obtained by them using simple density scaling from the D_2 calculations. Comparison with the Livermore calculations for H_2 (cf. Graboske and Wong 1980) showed even poorer agreement, revealing difficulties in some parts of these tables, which more recent Livermore calculations have corrected. These and other equation of state calculations have recently been reviewed by Van Horn (1986b).

5. SS433

Helfer and Savedoff are continuing their study of SS433. Some thermal properties of the jet and some effects of the jet's interaction with the surrounding medium seem to preclude adoption of any of the proposed models for the production of the narrow γ-ray lines that have been detected. (See Helfer and Savedoff, 1986.) They are presently exploring mechanisms for production of large amounts of ^{24}Mg in the throat of the central engine. In a separate problem they are also examining the interaction of the beam electrons with Alfvén wave fluctuations.

6. Solar Physics

Thomas and Toufik Abdelatif (University of Chicago) have studied a simple theoretical model for the interaction of solar p-modes with a sunspot magnetic flux tube (Abdelatif and Thomas 1987). The transmission of wave energy into the sunspot involves two important effects: the energy is shifted to longer horizontal wavelengths in the sunspot, and the transmission coefficient varies in an oscillatory manner with horizontal wavelength. These two effects are evident in observations of five-minute oscillations in a sunspot (Abdelatif, Lites, and Thomas 1986; see also Thomas, Lites, and Abdelatif 1986).

B. Observational Astronomy

1. Infrared Imaging

Forrest, Pipher, Shure 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 fully described in Forrest *et al.* (1985), and recently has been upgraded. In the past year, the 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.

2. The Galactic Center

Imaging of the Galactic Center with the Rochester infrared array camera has been extended to include observations in the Brα line. These images reveal structure that is generally similar to recent 5 and 15 GHz high resolution radio maps of the region (Lo and Clausen 1983; Yusef-Zadeh, private communication). By comparing the Brα and radio structures, the location of the non-thermal radio source Sgr A* is more accurately located with respect to the infrared sources observed at 1.25, 2.23, 3.76 and 4.7 μm. There is no discrete infrared counterpart to the non-thermal source, which, by this technique, is 0.3" south of the position suggested by Forrest *et al.* (1986). There are certain unusual Brα sources with no radio counterparts. Forrest presented a poster paper on these observations at the Townes Symposium on the Galactic Center in Berkeley, CA in October 1986.

3. Comet Halley

Images of Comet Halley obtained with the Rochester infrared array camera at the IRTF in March and April 1986 are quite dissimilar. In March (comet 1.1 AU from the earth), the coma was non-spherical, and the structure and brightness were variable, while in April (comet 0.4 AU from the earth) the images were spherically symmetric. A comparison of the 2.23 μm and 3.81 μm images showed marked variation in dust grain properties within the coma to the anti-sunward side of the nucleus. These results (obtained in collaboration with T. Nagata and A. T. Tokunaga, Hawaii) were presented at the 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, W. Germany, October 1986.

4. Brown Dwarfs

Collaborative searches (with W. Stein and M. Skrutskie) for brown dwarf companions using the Rochester infrared array camera have been unsuccessful. An observation of particular interest is that of Van Biesbroeck 8 (VB 8), the low mass star suggested by McCarthy, Probst and Low (1985) to have a binary substellar companion. Direct imaging of this possible system at 2.23 μm and 3.76 μm shows no evidence for a brown dwarf companion 1" away from VB 8: instead, a faint nebulosity around VB 8 may be present (Skrutskie, Forrest and Shure 1986a,b).

5. 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 has been observed, and those associated with late type stars with high mass loss. Forrest and Shure (1986) report 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. These bubbles are interpreted as the outline of a nearly spherical cavity along the outflow axis. Königl (1982) has demonstrated that an initially spherically symmetric wind will blow a bubble to one side of a star if there is an appropriate density gradient in the ambient medium. Scattering off the bubble edge is shown to be the cause of the observed emission at 1.65 and 2.23 μm, and the presence of a density gradient in AFGL 2591 is demonstrated. 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.* 1986).

Woodward *et al.* (1986a) 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 scattering regions north and south of the disk are seen, as is one of the Herbig Haro objects identified by Cohen *et al.* (1985).

6. 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 3m. 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 originates beyond the sharp ionized boundary. Extinction maps of NGC 7027 show considerable extinction to the strong radio lobes.

These data on the spatial location of 3.28 μm emission in ionized nebulae, complement previously obtained data on the HII region M8, which was studied with single detector systems in the infrared, and at the VLA, in the optical and also the UV (Woodward *et al.* 1986b). Woodward has been analysing these results as part of his doctoral research; the M8 project has extended over several years, and has involved Sharpless, Helfer and Pipher from Rochester, as well as external collaborators, including Herter (Cornell) and Willner (SAO). A model for M8 was developed incorporating the various observations. In that model the 3.28 μm radiation emanates from the HII/ molecular cloud interface, and an unusual extinction law is required to explain the observations.

Images of M8 were obtained with the Rochester infrared array camera on the KPNO 4-m telescope. A number of point-like sources were discovered for the first time in the core of the Hourglass; Woodward *et al.* (1985) suggested that M8 may contain a Trapezium-like cluster of hot stars and/or forming stars.

Pipher and Helfer are writing up final results of their abundance gradients study via measurements of infrared fine structure lines from galactic HII regions. With Herter, Cornell University, they are analysing data on the ArII/ArIII ratio in HII regions to determine indirectly the neutral helium fraction HeI/He.

7. Solar Astronomy

Thomas and Bruce W. Lites (High Altitude Observatory, NCAR), Joseph B. Gurman (NASA Goddard), and Edwin F. Ladd (Williams College) have reported the results of their simultaneous space and ground-based observations of umbral oscillations in a sunspot (Thomas, Lites, Gurman, and Ladd 1987). Oscillations were measured simultaneously in photospheric and chromospheric spectral lines (with the tower telescope at NSO/Sunspot) and in a UV transition-region spectral line (with the UVSP instrument aboard the Solar Maximum Mission satellite). Coherent modes of three-minute umbral oscillation were detected, extending from the photosphere up into the chromosphere. These measurements of amplitude and phase of the waves at different heights provide a new means of measuring the vertical temperature distribution in a sunspot atmosphere.

Thomas, Lites, and Timothy Brown (High Altitude Observatory, NCAR) have begun a program of observations of five-minute oscillations in sunspots and their surroundings as a means of probing the structure of a sunspot below the solar surface (i.e., "sunspot seismology"). Five-minute p-mode oscillations are measured in a sunspot and in its surroundings. Observations with the tower telescope and universal birefringent filter at NSO/Sunspot will concentrate on the high wavenumber range, while observations with the HAO Fourier tachometer in Tucson will concentrate on the low wavenumber range. Preliminary observations at both sites were obtained in August 1986. The theoretical work necessary to interpret these observations is also proceeding.

Meisel with A. Young and B. Saunders of RIT used the Mees 0.6m telescope to obtain photographs of Comets Giacobini-Zinner and Halley at 4000-5000Å, 5000-7000Å, and 7000-9000Å. These are presently being analyzed at the RIT Digital Imaging Laboratory with emphasis on the enhancement of coma jet structures. Eventually the images will be deposited in the IUW photo archives at JPL.

Meisel continued efforts to set up a time-series model of meteoroid flux using meteor radar observations in collaboration with R. Roper of Georgia Tech.

C. Instrumentation

1. Infrared Array Detector Development

Forrest, Shure and Pipher have modified the infrared array camera described in last year's Observatory Report and in Forrest *et al.* (1985). Using a similar imaging system based on an InSb 32 x 32 detector array with CCD readout, they have designed, built and tested a new dewar that attains a lower more stable operating temperature. In addition, two circular variable filter wheel sections, with approximately 1% resolution between 1.9 and 4.5 μm, have been added to their complement of broad band filters. This new system has been tested extensively on several telescopes. They have found that as the temperature was lowered from 53K to 47K the dark current dropped as expected, but at the same time, the responsivity of the InSb began to fall. A compromise temperature of 51 K has been adopted for best telescope performance.

Forrest, Ninkov and Pipher have acquired a 58 x 62 InSb engineering array from SBRC with direct, switched MOSFET readout. They expect to receive from SBRC a final array in this program, as well as specially low doped InSb arrays for evaluation for SIRTF experiments, and an alternate technology array of Si:In. This device uses the same type of switched-MOSFET readout as the InSb arrays. They have developed for this project interfaces to the SBRC supplied electronics, and 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.

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). The Definition Phase is likely to begin in early December.

2. Radio Astronomy

Fulbright spent the summer at the Green Bank Radio Astronomy Observatory helping plan and prepare equipment for a holographic determination of the shape of the 140' diameter radio telescope dish. He will return to Green Bank in November for the observations, which will involve 12 GHz signals from geostationary communication satellites.

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