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C. E. Kenneth Mees Observatory
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I. STAFF

This year's "Report of the C.E.K. Mees Observatory" covers activities of the faculty, staff and students at the University of Rochester, as well as of the Mees Associates, during the period October 1, 1991 to September 30, 1992. The Astronomy faculty at the University of Rochester includes W. J. Forrest, H. L. Helfer, J. L. Pipher, M. P. Savedoff (Emeritus), S. L. Sharpless (Emeritus), J. H. Thomas, H. M. Van Horn, and D. M. Watson. On 1 July, 1992, Helfer elected early retirement, becoming Professor Emeritus as well as Senior Scientist at the Laboratory for Laser Energetics. He continues teaching with the Department of Physics and Astronomy and as a Faculty Senior Associate. D. D. Meisel, SUNY at Geneseo, and Z. Ninkov, Rochester Institute of Technology, are Associates of the C. E. K. Mees Observatory. Meisel acts as Associate Director of the Observatory. Ninkov, Assistant Professor in the Center for Imaging Science at the Rochester Institute of Technology, and previously a Research Associate in the University of Rochester's Near Infrared Group, became Mees Associate on 1 January, 1992. H. W. Fulbright, Emeritus Professor of Physics, remains active in the Department and at the Observatory.

Pipher continues on the Kuiper Airborne Observatory proposal review committee, this year as chair. She is also a member of the Board of Editors of the PASP, and continues as Chair of the New York Astronomical Corporation Student Prize Committees. Pipher has been selected to serve on NASA's IR/SubMM/ Radio Management and Operations Working Group, beginning this Fall, for a three year term. She also participated in a review of the South Pole CARA NSF Center, and in a review of the NICMOS HST program.

Watson continues to serve on the NSF/NRC Graduate Fellowship Review Panel.

Forrest, Pipher and Watson are members of instrument teams for the NASA Space Infrared Telescope Facility (SIRTF), and are responsible for a substantial amount of the detector array development for these experiments. Forrest and Pipher are members of the SIRTF Infrared Array Camera (IRAC) team, and Forrest and Watson belong to the SIRTF Infrared Spectrograph (IRS) consortium.

James Garnett, Research Associate in the Near Infrared Group since December, 1987, left the University in late August to enter Law School at Case Western Reserve University. After one semester, he came back to the University to continue his professional astrophysics career. Hao Chen is in his fourth year as an Engineer with the Near Infrared Group: he was promoted to Senior Laboratory Engineer this past summer. He is training Bradley Marazas, a new Engineer who joined the group in September, 1992. Garnett and Chen's primary interest has been in detector array development for space and ground-based application, although Garnett spends increasingly more time on astronomy. Nat Cowen, programmer/analyst with the Near IR group has left to attend graduate school. He has been replaced by Kevin McFadden, a former Rochester undergraduate.

Thomas completed a two-year term on the executive committee of the Solar Physics Division of the American Astronomical Society (AAS) in June 1992. He was recently appointed as a Shapley Lecturer by the AAS. Thomas holds a joint appointment as an affiliate scientist at the High Altitude Observatory, National Center for Atmospheric Research, in Boulder, Colorado. He and N. O. Weiss (University of Cambridge) were co-directors of the NATO Advanced Research Workshop on "The Theory of Sunspots," held in Cambridge in September 1991, and they are also co-editors of the proceedings, published by Kluwer in July 1992 (Thomas and Weiss 1992a). Thomas gave invited review talks on sunspot seismology at the 25th anniversary meeting of the Astronomical Society of New York in April, 1992 (Thomas 1992), and at IAU Colloquium No. 141 in Beijing, China in September 1992.

In the fall of 1991, Van Horn was elected to the post of Chair-Elect of the Section on Astronomy of the American Association for the Advancement of Science. In July 1992, he was also named Acting Chair of the Department of Physics and Astronomy for the year ending 30 June 1993. In addition, he continued to serve as one of the Harlow Shapley Visiting Lecturers for the American Astronomical Society. He also served as chairman of the Scientific Organizing Committee for the International Conference on the Physics of Strongly Coupled Plasmas, which was held at the University of Rochester from 17-21 August 1992. With Prof. S. Ichimaru of the University of Tokyo he is currently editing the proceedings of that conference, which will be published by the University of Rochester Press. Van Horn also continues to serve on the Board of Trustees of Associated Universities, Inc., an organization of which he has been a member since 1983, and to serve as a member of the AXAF Senior Review Board established by the Eastman Kodak Company, one of the three members of the industrial team that is building the Advanced X-ray Astrophysics Facility.

In addition, he served the third year of a five-year term as a member of the Annie J. Cannon Award Advisory Committee for the AAS, and he continues to serve as a member of the Publications Board of the AAS.

Thomas and Van Horn continued in the second year of their NASA Theory Grant, on "The Seismology of Rotating, Magnetic Stars," which supports the research of their joint astrophysics theory group. The research program of this group includes investigations of oscillations and other physical properties of the Sun, giant planets, "brown dwarfs," white dwarfs, accretion and "excretion" disks, neutron stars, and astrophysical jets.

Theo Koupelis, who has spent the past year as a Visiting Scientist with the astrophysics theory group, left in August 1992 to take a faculty position at the University of Wisconsin-Marathon Center. During this period, he continued his work on theoretical modeling of astrophysical jets using the ideal MHD equations, and he studied the specific cases of the jets in M87 and SS433.

In July 1992, Umin Lee began his second year as a Research Associate with the group. During the past year, Lee has investigated the high- and low-frequency global oscillations of Jupiter. Currently, he is also interested in forced oscillations of massive main-sequence stars in close binary systems. Because of radiative dissipation near the surface of the star, the forced oscillations may play a role in exchanging angular momentum between orbital motion and the stellar rotation. In addition, Lee is interested in calculating nonadiabatic oscillations of white dwarfs, in order to determine the locations of the blue edges of the pulsational instability strip.

Also in July 1992, Alexander G. Muslimov, formerly of the A. P. Ioffe Institute in St. Petersburg, Russia, and the University of Sussex in England, joined the group as an Instructor/Fellow in Astronomy. He is supported by a grant from NSF, and he is studying the effects of cooling on the evolution of magnetic fields in neutron stars.

In September 1991, Shuji Ogata also joined the group for a three-month period as a Visiting Scientist. A member of Prof. S. Ichimaru's research group in the Physics Department at the University of Tokyo, Ogata was the first scientist to visit Rochester for an extended period as part of the collaborative research program organized by Ichimaru and Van Horn to study phase transitions in dense astrophysical plasmas. Ichimaru himself visited Rochester for a two-week period in September 1991; Van Horn spent two weeks in Japan in January 1992; and Ogata returned to Rochester again for another six-week stay in September 1992. This program is supported by grants from NSF and from the Japan Society for the Promotion of Science.

Savedoff served this year on the NRC Associate Review Panel.

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

In September, 1992, Ninkov and collaborators at the University of Rochester (the Institute of Optics, the Department of Physics and Astronomy, and the Electrical Engineering Department) and from Rochester Institute of Technology, were awarded one of only four NSF- State-Industry University Research Centers (from the NSF Directorate for Engineering) to conduct research in Electronic Imaging. Ninkov's research will concentrate on improvements in low light imaging techniques, instrumentation and data reduction. In addition, in July 1992, Ninkov and collaborators at RIT were awarded a NSF ILI grant to establish a remote, robotic observatory. Such a 16″ telescope supplied by Autoscope of Tucson will be installed in the summer of 1993 in the vicinity of RIT. The observatory will be connected by an optic fiber to workstations in the laboratory to allow for automated real time observing and data reduction.

Meisel has given several talks to local amateur astronomy groups including the Buffalo Astronomical Society. He also has held public observation sessions with the Geneseo 0.5m Celestron telescope. Meisel has obtained an NSF ILI grant to build small portable CCD camera systems for use in introductory astronomy courses and laboratories. Meisel continues as the executive director of the American Meteor Society and attended the International Astronomical Symposium, "Meteoroids and their Parent Bodies" held at Smolenice Castle, Slovakia. At this meeting, Meisel participated in IAU Commission 22 (meteors) working group "Professional-Amateur Cooperation."

Public tours were conducted at the Observatory from mid-May until the end of August by several undergraduate employees: Chad Engelbracht, Heidi van Tassell, Andrea La Barbera, Leah Buccholz , Christopher Mason, and Mike Thrapp. We are indebted to Barbara Warren for her excellent handling of tour arrangements and public relations for the Observatory, and to Kurt Holmes, carrying on in his father's fine tradition as Observatory Supervisor.

Marilee Montanaro, Administrative Research Coordinator for Astronomy, has handled efficiently the many administrative tasks for the group.

II. UNDERGRADUATE EDUCATION

The undergraduate program at the University of Rochester includes the option of both a B.A. and B.S. in Physics and Astronomy. A flexible advanced program is offered, in addition to the two-semester introductory freshman sequence in astronomy. Helfer is the undergraduate advisor for majors.

Undergraduate Chad Engelbracht continued to work with the Near Infrared Group for two months following his graduation in May, before entering graduate school at Arizona. He completed a senior thesis under the direction of Pipher, entitled "Infrared Images of the Galaxy M82," and was awarded the Department's prestigous Stoddard Prize for the best senior thesis. Chad also presented his results at the Rochester Symposium for Physics Students, a symposium held annually for some 25 schools in the region.

Andrea LaBarbera joined the Near IR Group this summer, taking over many functions formerly handled by Engelbracht. She will begin a senior thesis comparing IR images of M82 taken at different epochs in order to search for IR supernovae under Pipher's direction in September.

Heidi Van Tassel also began work in the same group this summer as a Bausch and Lomb Fellow. She will continue work during the year, taking over LaBarbera's duties this summer and next year.

Leah Buchholz joined the Far-IR group this summer, and will be writing a senior thesis on millimeter and submillimeter line observations of polar ring galaxies, under Watson's direction.

During the spring of 1992, undergraduate Sigrid Horoschak joined the astrophysics theory group to work on the construction of models for the surface He convection zones of white dwarfs. She left in May to begin graduate study in physics at the University of Texas (Austin).

Don Stanchfield, an undergraduate physics major, is currently working with the astrophysics theory group. For his senior thesis, he is doing research on the variation of sunspot properties with the solar cycle.

In January 1992, Mike Thrapp took a leave of absence from his B.Sc. studies at the University of Rochester. He is presently serving as the staff computer operator for the astrophysics theory group. His work has mainly involved numerical integration, curve fitting, and extensive graphical work in the area of the solar wind and solar oscillations.

Meisel continued to work with the use of computers in astronomy and physics education with a total of five presentations at various meetings including an invited presentation at the special Education session at the ASP meeting in Madison, Wisconsin. Also during the year he worked to modify the 2nd year modern physics course incorporating MathCad as a student problem solving environment. All materials developed for the Macintosh at Geneseo are available via anonymous ftp over INTERNET at anonymous@UNO.Geneseo.cc.edu in the subdirectory ASTRO. These materials can also be obtained by sending 4 high density 3.5inch diskettes to Meisel at Department of Physics and Astronomy, SUNY Geneseo, Geneseo, NY 14454.

Meisel delivered a Shapley lecture "Technology in Astronomy" to undergraduates at the University of the South, Swanee, Tennesee. In April, 1992, Van Horn visited the University of Wisconsin at La Crosse, where he presented a Shapley lecture entitled "Other Worlds, Other Stars, Other Life?"

Three SUNY Geneseo Undergraduates – Fred Huebner, William Dykstra, and Frederick Schulitz presented poster papers at the 25th anniversary meeting of ASNY held at Cornell in April 1992.

III. GRADUATE EDUCATION

Steve Solomon, Paula Turner, Scott Libonate, Eric Howard and Alexei Helmbock are graduate students in Forrest and Pipher's Near Infrared Group. Solomon and Libonate completed their Admission to Candidacy Exams this year, with research topics centering on IR imaging of the galaxy NGC 253, and Brα imaging of the Galactic Center, respectively. Solomon and Libonate have been active in detector development for SIRTF: Solomon is in his second year of a NASA Traineeship for his work characterizing trapping in near IR detector array materials. Turner is writing her Ph.D. thesis: she has left Rochester to assume the position of Assistant Professor of Astronomy, Kenyon College. Howard is preparing to take his Admission to Candidacy exam this year: he is working on imaging of the high luminosity bipolar outflow source MonR2. Howard is also System Manager for the Near Infrared Group's Sun network. Entering graduate student Diana Johnson has joined the group this semester.

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

UR graduate student Mark Swain will be carrying out his thesis work in residence at the National Radio Astronomy Observatory in Charlottesville, under the direction of Dr. Alan Bridle. Van Horn and Watson act as Swain's internal advisers. His thesis work will involve multifrequency VLA observations of the radio galaxy 3C 253.

Tod Strohmayer completed his thesis research, supervised jointly by Van Horn, J. M. Cordes (Cornell), and Thomas, on theoretical and observational investigations of non-radial oscillations of neutron stars. The purpose of his research was to investigate the potential observability of neutron star oscillations. The last two years of Strohmayer's work were supported by one of the highly competitive NASA Graduate Student Researchers grants, which was awarded for his proposal entitled "Neutron Stars in Low-Mass X-Ray Binaries and Pulsars." Strohmayer was also the winner of the 1992 Graduate Student Prize awarded by the Astronomical Society of New York for his paper entitled "Light Curves of Rotating, Oscillating Neutron Stars" (Strohmayer 1992b). He left in August 1992 to take a postdoctoral position at Los Alamos Scientific Laboratory.

Tim Collins continued his research on the effects of superfluidity on nonradial spheroidal oscillations of neutron stars, in collaboration with Van Horn and Richard Epstein (Los Alamos). Preliminary results of this investigation were presented at the 180th meeting of the American Astronomical Society (Collins *et al.* 1992).

J. Andrew Markiel joined the group in summer 1992. With Thomas and Van Horn, he is studying time-dependent dynamo models operating in the convective He envelopes of white dwarfs, in an effort to determine whether this process can generate magnetic fields with the strength and variability timescale which are suspected from the observations of GD 358 (Winget 1991). The preliminary results appear very promising, and the three investigators are currently preparing a short paper for submission as a companion to an observational paper by the Texas group.

Matthew Rave, a second-year graduate student supervised by Thomas, is doing his research on sunspot seismology. He spent part of the summer at the High Altitude Observatory in Boulder, Colorado, reducing sunspot seismology data obtained earlier by Thomas and Bruce Lites (HAO), and he is continuing the data reduction and analysis in Rochester.

Rochester Institute of Technology graduate students, supervised by Ninkov and involved with optical CCD observations at the C.E.K. Mees Observatory, are David Bretts (O star systems), Chen Tang (monitoring He I 10830 line), Brian Backer (CID Imaging) and Ultan Carroll.

IV. RESEARCH

A. Theoretical Astrophysics

1. Solar System Physics

Thomas and Benjamin Montesinos (University of Oxford) are continuing their work on the theory of siphon flows in isolated magnetic flux tubes. Their prediction (Thomas and Montesinos 1991) of the observational signature of a siphon flow operating in an intense arched magnetic flux tube in the solar photosphere was recently confirmed by the observations of Rüedi, Solanki, and Rabin (1992). The calculations of siphon flows have now been extended to include the effects of variable ionization and radiative transfer between the flux tube and its surroundings (Montesinos and Thomas 1993). In related work, Thomas and Montesinos (1992, 1993) have produced a siphon-flow model of the photospheric Evershed flow in a sunspot.

Thomas and N. O. Weiss (University of Cambridge) wrote an extensive review chapter on the theory of sunspots for the proceedings of their NATO Advanced Research Workshop (Thomas and Weiss 1992a, b).

2. Planetary Physics

Saumon *et al.* (1991, 1992) have recently applied their new equation of state for dense hydrogen to investigate the evolution of the giant planets. If the so-called "plasma phase transition" (PPT) actually exists, the thermal energy content of Jupiter and Saturn may be large enough so that H/He phase separation is not needed to account for the age of Saturn.

Lee (1992a) and Lee, Strohmayer and Van Horn (1992) calculated inertial mode oscillations of Jupiter. Since inertial oscillations are rotationally induced modes which propagate in isentropic regions, and since the giant planet Jupiter is believed to be fully convective and therefore isentropic, Jupiter is expected to exhibit such inertial oscillations. The authors found that the frequency spectrum of inertial oscillations is sensitive to the existence or non-existence of the density discontinuity associated with the PPT in dense hydrogen. If inertial modes are detected in Jupiter, they may thus provide a sensitive test for the existence of the PPT.

Lee (1992b, 1993) also calculated the frequency spectrum of acoustic (p-mode) oscillations of Jupiter, taking into account the second-order effects due to the rapid rotation of Jupiter; that is, the effects of the centrifugal force and the deformation of the equilibrium structure. It is well known that to produce accurate frequency spectra for the p-modes of rotating bodies it is essential to include these effects. Lee gave several echelle diagrams for p-mode frequencies of Jupiter and showed that it is in principle possible to determine whether or not the PPT really exists, if it is possible to obtain good observations of precise p-mode frequencies for Jupiter.

3. Massive and Close Binary Stars

In addition to the studies mentioned above, Lee is also interested in nonradial pulsations of rapidly rotating massive stars. Lee, Jeffery and Saio (1992) calculated the line profile variations caused by low-frequency g- modes excited by overstable convective modes. Comparisons indicate that the theoretically calculated line profile variations are consistent with those observed. Lee and Saio (1992a, b) also examined the mechanism of angular momentum transfer in rotating stars by low-frequency g-modes excited by overstable convective modes. They showed that the g-modes so excited can transfer angular momentum from the convective cores to the surfaces of rotating, massive, main-sequence stars. The transferred angular momentum may produce a viscous "excretion" disk around a rapidly rotating massive main sequence star, and this process was proposed as an explanation for the existence of circumsteller disks around Be stars (Lee, Saio and Osaki 1991).

Currently, Lee is interested in *forced* oscillations of massive main-sequence stars in close binary systems. Because of radiative dissipation near the surface of the star, the forced oscillations may play a role in exchanging angular momentum between the orbital motion and the stellar rotation in such systems. This process is of direct interest for studies of the evolution of binary systems that include massive main sequence stars. In fact, there are some eccentric binary systems which contain both a Be star and a neutron star. Forced oscillations may also contribute to the formation of an "excretion" disk in such a system.

Muslimov and Sarna (1992) have recently proposed an evolutionary scheme that results in the formation of a low-mass binary consisting of a red dwarf of mass less than 0.3 $M_\odot$ together with a rapidly rotating neutron star having a spin period of a few milliseconds and a surface magnetic field less than 10^9 Gauss. Evolutionary sequences have been computed for cases in which the donor star either has mass 1 $M_\odot$ or 0.5 $M_\odot$, and the orbital period of the system is either $9.^h4$ or $4.^h5$, respectively, at the beginning of mass transfer.

4. *Properties of Dense Matter*

Van Horn (1992) has recently shown that the Rosseland mean opacity in dense plasmas can be appreciably modified by plasma dispersion when $\hbar\omega_p/kT >$ 1. Although this result in itself is not new, there has been disagreement in the community concerning the correct way to incorporate the plasma cutoff into calculations of the Rosseland mean opacity. The new derivation provides a clear prescription for the proper procedure. It seems appropriate that these dense plasma effects should be properly included in the next generation of astrophysical opacity calculations which are now in progress.

New calculations have also been performed for nuclear reaction rates at high densities. Ichimaru, Ogata, and Van Horn (1992) have recently extended the calculation of *pycno*nuclear (density-induced, $T = 0$) reaction rates to the case where the reacting ions are of different species. Such a mixture is termed a "binary ionic mixture" (BIM). The formula obtained by Ichimaru *et al.* generalizes the previous expression obtained by Ogata, Iyetomi and Ichimaru (1991) for C-O pycnonuclear reactions to arbitrary mixtures. Still more recently, Ogata *et al.* (1992) have similarly extended the results of Ogata *et al.* (1991) to the general calculation of strong screening of *thermo*nuclear reaction rates in BIMs. The detailed Monte Carlo calculations on which these new rates are based show that the enhancement of nuclear reaction rates may be significantly larger or smaller than previous results, depending upon the relative concentrations of the ions with larger and with smaller nuclear charges.

Ogata (1992) performed Monte Carlo (MC) simulations for rapidly supercooled one-component plasmas, appropriate to the outer crusts of neutron stars, using $\sim$ 1500 MC particles under periodic boundary conditions. The final configurations thus obtained are monocrystalline solids with admixtures of a few defects, in contrast to the glassy states obtained for previous cases using $\sim$ 500 particles. Ogata (1992) and Ogata and Ichimaru (1992) discussed the role of the MC periodic boundary conditions in conjunction with the number of MC particles.

Iyetomi, Ogata, and Ichimaru (1992a) extracted bridge functions, the neglected terms in the hypernetted-chain theory of classical fluids, from the Monte Carlo simulation data for classical one-component plasmas, using the exact short-range expansion and long-range boundary conditions arising from the compressibility sum rule. The bridge functions will be useful in the improving the equations of state for ionic fluid mixtures.

Intending application to the deep interiors of white dwarfs, Iyetomi, Ogata and Ichimaru (1992b) calculated quantum corrections for the free energies of the solid phases in one-component plasmas by a quantum Monte Carlo method. The quantum effects begin to change the classical melting temperature beyond a critical density of 2×10^8 g cm^{-3} in a carbon plasma. The evolution of white dwarfs may therefore be influenced by the quantum effects, as reflected in the changed melting temperature.

5. *Phase Transitions in White Dwarfs*

In the past five years, the cooling times of the white dwarfs have given us a new estimate of the age of the disk of our Galaxy. The result, $\sim$ 9 Gyr, is much shorter than the 11 – 17 Gyr ages of the globular clusters. If correct, this result suggests a need for a new theory of galaxy formation. Alternatively, there may be some additional energy source that prolongs the cooling times of the white dwarfs, thus lengthening their ages. One possibility that has been suggested is separation of C from O or of heavier elements from C/O in the core of a white dwarf.

Xu and Van Horn (1992) have computed the energy released in a postulated separation of primordial Fe from C. They have shown that this process alone can only lengthen the cooling times by $\sim$ 0.6 Gyr but that three-component calculations are necessary in order to determine whether C/O, Ne/(C+O), and Fe/(C+O) can occur sequentially, a sequence that *would* significantly lengthen the ages.

Motivated by these results, Ogata *et al.* (1992) have computed accurate, new equations of state and phase diagrams for binary ionic mixtures (BIMs) and ternary ionic mixtures (TIMs) of astrophysical interest. Specifically, they have computed new phase diagrams for C-O, C-Ne, C-Fe, and O-Mg BIMs. The C-O phase diagram is azeotropic, as previously found by Ichimaru, Iyetomi, and Ogata (1988). The other phase diagrams are significantly more complicated, and all lead to the conclusion that the onset of freezing is very likely to be accompanied by the precipitation of a nearly pure heavy-element core. A preliminary TIM calculation for a C-O-Ne plasma supports this conclusion.

6. *Neutron Stars*

Epstein (1988) has previously discussed the effects of superfluidity upon the oscillations of neutron stars, using a short-wavelength approximation for his calculations. Van Horn and Epstein (1990) subsequently extended this work to include the global nonradial toroidal oscillation modes, which are generalizations of Epstein's transverse waves. Superfluidity increases the propagation speed of transverse waves, and this increases the toroidal oscillation frequencies significantly over the results obtained neglecting superfluidity. At the 180th meeting of the AAS, in June 1992, Collins, Van Horn, and Esptein (1992) presented newly calculated toroidal modes which take into account additional effects not considered by Van Horn and Epstein (1990). Also presented at the 180th meeting of the AAS were the oscillation equations for the spheroidal modes with superfluidity. T. Collins continues his investigation of the effects of superfluidity, with the goal of numerically calculating the new spheroidal oscillation modes.

Strohmayer (1991) has employed a perturbation method to investigate the effects of rotation on the nonradial oscillations of neutron stars. He finds that it is often necessary to include as many as 30 to 50 overtones in order for this technique to yield "converged" results for the eigenfunctions, depending upon the mode being corrected. The Coriolis force also couples modes with spherical harmonic index l to those with index $l \pm 1$. For those modes which were purely toroidal in the non-rotating star, this rotational coupling produces non-vanishing radial components, the existence of which modifies both the neutrino- and electromagnetic-damping rates for these modes.

Strohmayer (1992a, b) has also investigated the light curves that can be produced by a rotating, oscillating neutron star whose emission is confined to circular magnetic polar cap regions, as might be produced in pulsars and x- ray binaries. The theory includes the effects of general relativity on the photon trajectories and assumes homogeneous emission from the neutron star surface. Non-isotropic emission is taken into account through the use of a beaming function (Pechenick *et al.* 1983). A gaussian beaming function is used to simulate the narrow pulse profiles of pulsars, and to investigate a simple model of subpulse drift in pulsars. Simulations of x-ray observations with AXAF and XTE are used to estimate the sensitivity for detecting neutron star oscillations in x-ray burst sources and x-ray pulsars with these observatories.

Strohmayer (1992c) has also investigated the effects of the density discontinuities associated with composition changes in the surface layers of a neutron star upon the g-mode spectrum of such a star. This work extends the previous zero-temperature calculations of Finn (1987) and McDermott (1990) to neutron stars with finite temperatures and thus with surface fluid "oceans." Strohmayer finds that the presence of a composition discontinuity within the "ocean" can substantially alter the g-mode spectrum.

7. *Astrophysical Jets*

Koupelis (1992a) extended his theoretical studies of astrophysical jets to include the case where the winding direction of the magnetic field lines at the origin of the flow is opposite to the source's rotation. Such a configuration is not allowed if the assumption of time independence and infinite conductivity are to be strictly followed, but – for the case of jets with constant opening angles – it is the only configuration which allows a wind-type outflow. In light of this result, he examined the dependence of the type of the flow (wind- *vs.* breeze-type) on the winding of the field lines at the origin. As the conditions close to the source continuously change, a result of accretion, the flow may go through cycles of breeze/wind types. These "cycles" may explain the cases where the counter-jet is not observed, or where only remnants of it seem to exist. This may especially apply to the cases where the remnants are well defined and almost symmetrical to the morphology of the observed jet, since in the latter case one cannot use relativistic beaming arguments. Koupelis (1992b, c) also studied the specific cases of the M87 and SS433 jets. By applying to these cases the narrow-jet model (in which the ideal MHD equations are projected onto the jet axis), he found that the ranges of allowed values of the parameters describing the flow at the origin (close to the source) are very restrictive. Such studies, for the moment limited to jets with constant opening angles, may ultimately give us a better understanding of the physical conditions of the region surrounding a central source.

8. *High Energy Particles in the Interstellar Medium*

Helfer and Savedoff have extended their work on antiproton production by accelerated cosmic ray protons in shocked interstellar clouds (Helfer and Savedoff, 1992) to examine pion production. The same model parameters used to successfully produce the observed 1 - 10 GeV antiproton spectrum overproduces positrons in the 3 - 20 GeV range by a factor of 3-4, though the observed spectral slope is obtained. It appears as if considerable attenuation in the source region (most likely by bremsstrahlung) is needed.

Dogiel and Sharov (1990) have found a similar positron overproduction in their models. We have examined their models, and our preliminary analysis indicates that their putative second-order Fermi-mechanism requires physically improbable microscale turbulence. Also they need different interstellar cloud parameters for positron and antiproton production, resulting in a somewhat inconsistent picture. Their model for diffusion in the intercloud region and into an extended halo is inconsistent with the estimates of the cosmic ray age determined by the ^{10}B.

Helfer and Savedoff's model underestimates the positron-electron ratio observed at energies < 1 GeV by a factor up to ~ 3 at 0.1 GeV, but this need not be a flaw in their model. For one thing, the standard charge-independent corrections for solar modulation are in severe doubt (see, *e.g.* Tuska *et al.* 1991), and the local interstellar positron-electron ratio at low energies cannot be established. For another, the local interstellar electron spectrum used in the calculation is that derived by Webber, Simpson, and Cone (1980; hereafter, WSC) and this may be overestimated at low energies by a factor $\gtrsim 3$ (see Cummings (1973); Rockstroh and Webber (1978)). [WSC derived the low-energy electron spectrum from a radio brightness spectrum for the north polar region which utilized wide angle observations below 5 MHz. The optical depth they derived at 1 MHz is too large by a factor of $\sim$ 4 compared to that inferred from the $H\alpha$ observations of Reynolds (1984, 1989)] A convection-diffusion model for the halo is being developed to see if one can produce the north polar radio spectrum, assuming the local interstellar electron spectrum is similar to that of Rockstroh and Webber.

B. Observational Astronomy

In the past year, observational astronomy at the University of Rochester has included studies of nebulae, active and gravitational lens galaxies, the galactic center, pulsars, brown dwarf candidates, and the Sun.

1. The Solar System

Thomas continues his collaboration with Bruce Lites, Timothy Brown, and Thomas Bogdan (all at the High Altitude Observatory, NCAR) on observations of the interaction of solar p-modes with sunspots ("sunspot seismology"). These observations are obtained with the vacuum tower telescope, universal birefringent filter, and multi-diode array at the National Solar Observatory (Sacramento Peak). These observations now confirm the absorption of p-modes by sunspots, which was discovered by Braun, Duvall, and LaBonte (1987), but with some significant differences concerning the dependence of the absorption on wavenumber (Bogdan, *et al.* 1993). The high signal-to-noise ratio of the data allow a determination of the absorption as a function of mode degree along individual p-mode power ridges. The absorption shows a sinusoidal-like modulation along the ridges, which provides important clues about the absorption mechanism and the subsurface structure of a sunspot.

In related work with the same data, it was found that a small fraction of the solar surface emits a disproportionate amount of acoustic energy in the frequency range 5.5 - 7.5 mHz, just above the minimum acoustic cutoff frequency (Brown, *et al.* 1992). These regions of excess high-frequency emission consist of patches a few arc seconds across that are near, but not coincident with, the regions of strongest magnetic field in the photosphere. These regions may be the surface signature of the subsurface sources of acoustic energy that are driving the solar p-modes.

Meisel, in cooperation with Robert Desourdis of SAIC, is continuing to investigate various aspects of radiometeor research including the use of amateur astronomers as monitors of meteor activity.

2. Pulsars

Strohmayer, Cordes, and Van Horn (1992) have recently examined the coherence of microstructure in PSR 2016+28 in an attempt to determine whether or not the quasiperiodic micropulses, first observed by Boriakoff (1976) can be attributed to oscillations of the underlying neutron star. A Fourier cross-spectral analysis of 2000 consecutive pulses from this pulsar confirms that the micropulse quasiperiods are *not* coherent across individual pulses of this pulsar. A Q-value of $\approx$ 6 is deduced from the width of the quasiperiodic micropulse feature which is seen in the average power spectrum of the individual pulses. Identical analysis of fully random, simulated pulsar signals, supports the notion that the quasiperiodicities are probably *not* associated with high-Q oscillations of the star. In contrast, the drifting subpulses which are seen in this pulsar (Backer 1973), *do* show evidence for coherence across several pulse periods. Analysis of the cross spectrum in the subpulse separation feature (P_2) indicates coherence across 4 - 5 pulse periods and a Q-value of $\approx$ 90. Analysis of simulated pulses indicates that these results are consistent with a model which allows for variable subpulse drift about a mean drift rate.

In his Ph.D. thesis, Strohmayer (1992d) has extended the theory of neutron star oscillations to conditions applicable to the magnetic polar caps of pulsars and has performed further analyses of pulsar observations. On the theoretical side, he first derived the rotational corrections for various neutron star oscillation modes (see also Strohmayer 1991), discussed the effects of gravitational lensing on the light curves of rotating, pulsating neutron stars (see also Strohmayer 1992a, b), and then extended the theoretical model first developed by Fawley, Arons, and Scharlemann (1977) to include time-dependent perturbations of a pulsar magnetosphere. Turning to observations, he next investigated in detail the time-series for PSR 2016+28 in an effort to determine whether or not periodic variations exist in these data (see also Strohmayer, Cordes, and Van Horn 1992). Finally, he extended this type of analysis to the pulsars PSR 1133+16 and PSR 0950+08, neither of which has been found to exhibit coherent periodicities.

3. Brown Dwarfs and Low Mass Stars

The Near Infrared group continues to monitor brown dwarf candidates projected on the Taurus cloud (Forrest *et al.*, 1990) for variability. In addition, with the advent of the 256 $\times$ 256 InSb camera a larger region around known Taurus members has been surveyed at J, H, and K. The star counts there will be compared to "blank" fields at the 3 galactic-conjugate positions, to see if there is an excess of faint stars in Taurus.

3. Observations of Star Formation Activity

The research on Hubble's Variable Nebula (by Meisel and Ninkov) using the RIT Kodak CCD array continues. Preliminary results were presented in poster form at the 180th AAS meeting in Columbus, Ohio. This research is continuing with further exposures planned from Mees Observatory during the fall and winter 1992-93.

As part of an infrared survey of bipolar nebulae ranging from low to high luminosity, Howard (1992) has analyzed images obtained at the Mt. Lemmon Observatory at wavelengths centered at 1.25, 1.65, 2.23, 3.76, 3.3 μm broad-band filters, as well as at 1% resolution in the 3.29 and 3.4 μm dust emission features, in the Br γ and α hydrogen recombination lines, in a line of H_2, and at associated continuum wavelengths. He is separating out the extensive, patchy extinction, as well as the role played by different constituents in this complex region. Van Tassel is analyzing a nearby region, MonR2 E. Garnett plans to analyze other results from this survey, which has focussed on the Fukui (1985) list of bipolar sources, culled from CO observations.

Following the interesting results on the distribution of the 3.29 μm dust emission in the starburst galaxy NGC 253 described in last year's report, a program of observation of this feature in other starburst galaxies is being carried out using the infrared cameras of the University of Rochester equipped with 1% resolution CVF's. In a wide variety of galaxies, the 3.29 μm dust emission feature carries approximately 0.1% of the total dust luminosity, which is predominantly in the far-infrared. This feature is believed to result from extremely small grains heated temporarily to high temperatures by single ultraviolet photons. Thus it is believed to be a good tracer for star-formation activity. With our cameras we can achieve $1''$ resolution and locate and explore the regions of active star formation in distant galaxies. To date the (red-shifted) feature has been clearly detected in images of NGC 3690, NGC 7469, and M82. Spectral images of NGC 4102, NGC 4194, NGC 1614, and NGC 1068 are being investigated for the presence of this feature. The observations have been carried out at the IRTF 3m, the MLOF 1.5m and the WIRO 2.3m telescopes.

In support of the use of the 3.29 μm dust feature as a probe of star formation in galaxies, we have started a program of investigation of this feature in galactic sources. The intent is to gain a better understanding of the astrophysics underlying its generation. To this end we are imaging the well-known reflection nebulae NGC 2023 and NGC 7023 with approximately $1''$ resolution. Images in the feature and the nearby continuum as well as the J,H,K bands and, ultimately, the molecular hydrogen lines. We hope to be able to distinguish between thermal grain emission and scattering and to locate the regions of survival of the feature-emitting grains and continuum-emitting grains. The images of these sources are surprisingly complex and thus interesting. The reflection nebulae were selected for their simplicity, but we are also imaging well known HII regions, such as M 42 and Mon R2 (see above), in order to enhance our understanding of the feature emission.

4. The Galactic Center

Libonate (1992) has reduced a second epoch of Brα observations of the Galactic center to search for variability of the unusual Brα sources (with no corresponding free-free radio emission) discovered by Forrest *et al.* (1987), and has identified several other unusual Brackett line-emitting sources. These unusual sources were suggested by Forrest *et al.* (1987; 1992) to be wind sources, resembling Wolf-Rayet stars, Be stars, or O supergiant/LBV stars. Herbst *et al.* (1992) followed up on this earlier work to obtain velocity-resolved Brγ observations of the central parsec of the Galaxy, utilizing the Rochester Array Camera and the Cornell Fabry-Perot Spectrometer. In addition to characterizing the overall dynamics at the Galactic Center, stellar wind sources were identified. These include the brightest of the the unusual Brα sources, and most notably, IRS 1 and IRS 13, located on either side of the nonthermal radio source SgrA* and IRS 16, the complex close to the dynamic center and SgrA*.

Subsequently, Libonate *et al.* (1992) obtained long-slit, near-infrared spectra of the central regions of the Galactic Center using the 2.1m telescope at the Kitt Peak National Observatory, as well as the CRSP facility spectrometer to identify morphological types of objects at the Galactic Center. Libonate is currently reducing these observations: they will complement those of Krabbe *et al.* (1991), who have investigated the He I emission from stars at the Galactic Center. There is substantial evidence that wind sources are prominent at the Galactic Center, may dominate the energetics, and even affect the dynamics. Rieke, Rieke, and Paul (1989) have suggested that unresolved clusters of hot stars may dominate the IRS 16 complex. Further high spatial/spectral resolution spectroscopic studies are planned, since the ***starburst vs. black hole*** controversy of the Galactic Center excitation seems to be close to resolution.

5. Extragalactic Objects

Turner *et al.* (1992) report near infrared images of the central regions of the Galaxy NGC 5128, Centaurus A. It is a double-lobed radio source, with two optical components—a luminous giant elliptical bisected by a warped dark lane of gas, dust, younger stars and HII regions, suggesting a probable merger. The infrared observations identify a red, variable compact object (the probable nucleus) and show that the optical hotspot is not the nucleus but rather a hole in the extinction. Turner has observed a variety of other merger galaxies in order to generally characterize the interaction.

Guptill and Watson, using the Caltech Submillimeter Observatory, detected CO J = 2-1 (230 GHz) line emission from polar ring material in the galaxies NGC 2685 and NGC 4650A. It appears from these observations that the distribution of molecular matter (in space and velocity) in these archetypical polar rings is similar to that of neutral atomic gas, but that the gas is relatively poor in molecules ($M[H_2]/M[H] \lesssim 0.1$), consistent with origin in encounters which involved the very outermost parts of the disk of the galaxies which contributed the polar ring material.

Satyapal and Watson have analyzed infrared continuum and spectral line images, which they obtained with the Palomar 5m telescope, of the starburst galaxy M82. They find evidence that the ultraviolet extinction across the central 150 pc starburst region is relatively small, since large HII complexes are seen in the Brγ recombination line which have no association with bright stellar clusters or nonthermal radio sources. Since this implies small extinction at visible and infrared wavelengths as well, the finding lends further support to the idea that most of the patchy extinction toward the nuclear region is due to dusty material lying outside this region. The extinction toward the young stellar clusters can therefore be measured by measuring the extinction toward the nuclear region's ionized gas (using infrared hydrogen recombination-line intensity ratios). This removes a major source of uncertainty in the determination of the colors and luminosities of these clusters, and in particular rules out large values of local extinction inferred from infrared spectroscopic observations in single, large beams.

C. Instrumentation

This year, infrared instrumentation development has centered on the groups' near infrared and far infrared SIRTF detector developments, and on the development of a third generation ground-based camera exploiting state-of-the-art 256 × 256 InSb arrays.

1. Near Infrared Array Detector System Development

Forrest and Pipher and their group continue to develop infrared arrays for Space Application. The flexible, programmable array controller and signal processor described in previous reports is fully operational. It has been used to operate CE 64×64, CE/VO 256×256, CRC 228 58 × 62, CRC 463 256 × 256, and CRC 590 256 × 256 infrared detector arrays and multiplexers. Using our flexible wiring system, a change from one detector type to another is accomplished in one day. The maximum readout speed with the CRC 463 256 × 256 array is 25 Hz, which is sufficient for ground-based imaging in the L′ (3.8 μm) and M′ (4.67 μm) bands. The multiple non-destructive readout scheme described by Fowler and Gatley (1990, 1991) sampling has been implemented. A read noise of 12 electrons has been achieved with a CRC 463 256 × 256 InSb array operated at 29K. The new low-temperature muxes from Hughes Technology Center (the CRC 590 and 644) have somewhat higher read noise ($18e^-$) at these temperatures, but exhibit no freezeout and maintain a reasonably low read noise ($27e^-$) down to 6 K, the lowest temperature sampled. All previous muxes tested by this group (the CRC 228 and 463 and the Valley Oak/NASA 256 × 256) have shown large increases in read noise at low temperature, amounting to several hundred electrons.

256 × 256 InSb arrays from SBRC and Cincinatti Electronics have been tested and evaluated for QE, dark current, read noise, and anomolous behavior. These include FPA 48, FPA 41, and FPA 84 from SBRC and one array using the Valley Oak/NASA mux from CE. We have found the pure InSb, developed for space applications for NASA, of FPA 84 was superior for low temperature QE, but the commercial-grade InSb of FPA 41 and 48 gave excellent QE (greater than 80%) at temperatures above 25K. We found that the new gateless passivation (Si_3N_4) used in FPA 41 and 48 is much superior in the area of latent images. The latent images were undetectable from these arrays, both in the lab and on the first observing run described above. In contrast, FPA 84, which uses a gate to bring the surface into flatband, showed the usual long-lived latent images we have seen in the past from these types of arrays. The dark current of FPA 84 was very low, less than 0.5 e^-/s at 26K. The measurement of dark current in FPA 48 and 41 has been hampered by glow believed to originate in the multiplexer or perhaps the SBRC temperature diode. Episodes of low dark current (2 e^-/s and less) have been seen, but a more usual value is 40 e^-/s. Evaluation of the CE InSb array was hampered by a large glow believed to originate in the Valley Oak/NASA multiplexer.

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

2. 256 × 256 IR Camera

A camera based on the 256 × 256 InSb arrays from SBRC (described below) has been constructed and used for the first time at the WIRO 2.3m telescope for 10 nights in October, 1992. The array, FPA 48, has gateless InSb passivation and is AR coated for high QE. The detector's QE is greater than 80% at 3.3 μm and the read noise is 12 electrons using multiple non-destructive sampling. The flat field of this array is very flat and there are almost no bad pixels in the central 98% of the array. The camera and the WIRO telescope worked very well and amazing images of a wide variety of objects were obtained. For over half of the nights, star images were 0.75″ FWHM, probably limited by residual astigmatism in the telescope. The other nights, seeing of 1 to 1.5″ was experienced. The telescope emissivity was relatively low, enabling work in the L′ band (3.8 μm) even with relatively high outside air temperatures (50°F). The images at WIRO were superior to any this group has obtained previously with earlier generation cameras and other telescopes.

3. Far-Infrared Detector Array Development

Great progress continues to be made on the development of Ge:Ga and Si:Sb blocked-impurity-band (BIB) arrays, which will be of benefit to instruments intended for airborne and ground-based observations as well as SIRTF. Watson, Guptill, Raines and Satyapal, with J.E. Huffman (Rockwell) and T.N. Krabach (JPL) have produced 6x6 Ge:Ga BIB arrays which meet the SIRTF Infrared Spectrograph performance goals — at present, these devices are the largest and best detectors in existence for the 80 – 200 μm band, and represent the only monolithic array technology useful at far-infrared wavelengths. Quantum efficiency, especially at short wavelengths, and pixel count continue to improve, with a working goal of 16x32 arrays. Guptill, Raines and Watson are currently constructing a tandem Fabry-Perot spectroscopic camera, using the 6x6 Ge:Ga BIB arrays in the focal plane; this instrument will be the first to use the new arrays for far-infrared astronomy.

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