University of Rochester
C. E. K. Mees Observatory

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1 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 1 October 1993 to 30 September 1994. The Astronomy faculty at the University of Rochester includes Kaiyou Chen, W. J. Forrest, H. L. Helfer (Emeritus and Faculty Associate), J. L. Pipher, M. P. Savedoff (Emeritus), S. L. Sharpless (Emeritus), J. H. Thomas, H. M. Van Horn, M. Wardle and D. M. Watson. H. W. Fulbright, Emeritus Professor of Physics, remains involved in the Observatory.

D. Meisel (SUNY 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. Forrest was appointed Director of the C.E.K. Mees Observatory 1 June 1994.

Pipher completed her term as a member of the Board of Editors of the PASP in early 1994. She is in the third year of a three year term on NASA's IR/SubMM/ Radio Management and Operations Working Group. Pipher is in her second year of a three year term as member of the AAS council, and is a member of the Space Studies Board (SSB) of the National Research Council (NRC). As part of her duties on the SSB, she is a member of the Joint Committee on Technology for Space Science and Aeronautical Engineering, which has embarked on a study requested by Congress, "The Future of Space Science". Pipher served on a subcommmittee of the NRC Committee for Astronomy and Astrophysics, the so-called "Panel on Ground-based Optical and Infrared Astronomy". The panel, chaired by R. McCray, JILA, was charged with recommending a strategy for NSF support of ground-based optical and infrared astronomy in the Gemini era. She also served on the Gemini Director Search Committee, chaired by J. Huchra (SAO). Among her proposal review activities, she served on the NASA 2MASS Survey review committee, and the NSF SDSS review committee. Pipher is also a member of the NRAO Visiting Committee for the next three years. She gave two Shapley lectures at St. Lawrence University and participated in an astronomy class.

Watson continues to serve on the NSF Graduate Fellowship review panel, and served on the astronomy review panel for the NSF Young Investigator Program.

Forrest, Pipher and Watson are members of the 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.

Kaiyou Chen completed one year as visiting assistant professor and returned to Los Alamos National Laboratory. During the summer of 1994, Chen presented invited lectures at several institutes in China, including Nanjing University, the Institute of High Energy Physics, and the China Center for Advanced Science and Technology.

Thomas was on academic leave during 1993-94 with the support of a Guggenheim Fellowship. He spent one month at LAEFF in Madrid working with B. Montesinos, one month at the Max-Planck-Institute for Astrophysics in Garching (Munich), and also visited the Observatoire du Pic du Midi and the Observatoire de Paris (Meudon). He gave an invited talk on "The Cause of the Evershed Effect in Sunspots: Flows or Waves" at the NATO ARW on Solar Surface Magnetism in Soesterberg, The Netherlands in November 1993, and an invited talk on "Siphon Flows in Photospheric Magnetic Flux Tubes" at the meeting on Current Trends in Solar and Astrophysical Magnetohydrodynamics in Boulder, Colorado in July 1994.

In June 1994, Thomas was elected vice-chair and chair-elect of the Solar Physics Division of the AAS. He will serve as vice-chair in 1994-95, as chair in 1995-97, and again as vice-chair in 1997-98. Thomas continues to serve as an associate editor of *The Astrophysical Journal.*

Van Horn took a two-year leave of absence from the University of Rochester, beginning in July 1993, to serve as Director of the Division of Astronomical Sciences at the National Science Foundation, in Washington, DC. In an effort to improve communication between NSF and the US astronomical community, he has begun regular contributions to the *AAS Newsletter*; to date he has contributed six columns. Van Horn also was elected to chair the Publications Board of the American Astronomical Society (AAS), assuming this position following the June, 1993 meeting of the AAS. He served in this capacity for one year, resigning in May 1994 to concentrate his full attention at NSF. He remains a member of the AAS Publications Board, however. He also served the fourth year of a five-year term as a member of the AAS Advisory Committee for the Annie Jump Cannon Award for young women in astronomy. On 22 March 1994, he participated in a program at Wesley College in Dover, DE, at which Dr. Barbara Welther of Harvard was awarded the Annie Jump Cannon Medal by that institution. In addition, during the 1993-94 academic year he served as Chair of the Astronomy Section of the American Association for the Advancement of Science (AAAS). He has also agreed to serve as a member of the

International Scientific Committee for the *International Conference on the Physics of Strongly Coupled Plasmas*, to be held in Binz/Rügen, Germany, in September 1995.

Van Horn presented several invited lectures in 1993-94. He spoke on "Equations of State in Stellar Structure and Evolution" at IAU Colloquium 147, in St.Malo, France, on 14 June 1993 (Van Horn 1994), on "The Physics of White Dwarfs" at the 9th APS Topical Conference on Atomic Processes in Plasmas, in San Antonio, TX, on 20 September 1993, and on "Global Oscillations of Neutron Stars as Potential Probes of Microscopic Physics at Ultra-High Densities" at the International Oji Seminar, in Tomakomai, Japan, on 28 June 1994 (Van Horn *et al.* 1994).

Thomas and Van Horn completed the third 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.

Wardle joined the faculty effective July 1993, but remained at Northwestern University on leave during the fall semester of 1993. He moved to Rochester in January 1994. While at Northwestern he continued collaborations with F. Yusef-Zadeh and A. Königl (U. Chicago). In addition to their collaborative research, Wardle and Yusef-Zadeh are co-writing a book about the Galactic Center for Cambridge University Press.

Helfer officially retired as of 1 July 1992 but remains active in the Department. He served as Rochester's representative on the Board of Directors of the New York Astronomical Corporation.

Ninkov continues studies into the development of charge injection devices under the auspacies of a National Science Foundation Industry University Co-operative Research Center (IUCRC) and a New York State Center for Advanced Technology (CAT) grant which supports the activities of faculty participants in the Institute of Optics, Department of Electrical Engineering, Department of Physics & Astronomy, and the Center for Imaging Science at RIT.

In November, 1993, postdoc Umin Lee left the University of Rochester to accept a position at the Ecole Normale Superieure, in Lyon, France. Dr. Lee is continuing his collaboration with Rochester astronomers, completing a study with Van Horn of the global oscillation modes potentially excitable during the impacts of fragments of Comet Shoemaker-Levy 9 with Jupiter. In addition, he is currently finishing work on the effects of superfluidity upon the global oscillation modes of neutron stars in collaboration with Richard Epstein (Los Alamos), Tim Collins (Rochester), and Van Horn.

Research Associate François Piché left the near IR group in June 1994 after a 1 1/2 year stay. He has taken a position at the University of Cambridge, UK and will be developing new instrumentation to avoid the OH emission bands in the near IR. He continues to collaborate with the near IR group in his studies of the outflows from Young Stellar Objects, such as L1157.

Alexander G. Muslimov completed his second year as a research associate and instructor in July 1994, with support from an NSF grant. During the academic year 1994-95 he will continue as Assistant Professor. In June 1995 he will move to the Institut für Astrophysik und Extraterrestrische Forschung der Universität, Bonn (Germany) with the support of a Humboldt fellowship.

Jian Wu, a doctoral candidate in the EE department, completed his first year with the near IR group this past year as a part time engineer and scientist. He is responsible for the test and evaluation of 5 micron cutoff HgCdTe 256×256 arrays from Rockwell Thousand Oaks Science Center.

Bradley Marazas is in his third year as Engineer with the group.

Hans Deeg joined the detector group at RIT in September 1993 after completing his PhD in Astrophysics at the University of New Mexico. He is stuyding the performance of CCD arrays and the IMF of young clusters.

William Cirillo joined the detector group at RIT as an Associate Scientist with principal responsibilities being the development of camera control software.

Peter Wilson (University of Sydney) was a visiting scientist in the department in August 1994, working on problems in helioseismology and the solar cycle with Thomas.

Charles Gammie (U. Virginia) visited for two weeks in June 1994, working on aspects of ambipolar diffusion in the interstellar medium with Wardle.

Kevin McFadden is in his third year as Programmer/Analyst with the Near IR group.

Public tours were conducted at the Observatory from June until the end of August by several undergraduate employees: Rob Armstrong, Ronian Siew, Tammy Middleton, and Craig McMurtry. We are indebted to Marilee Kaye Montanaro 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 Kaye Montanaro, Administrative Research Coordinator for Astronomy, has efficiently handled the many administrative tasks for the group.

2 Undergraduate Education

In the second year of an NSF ILI grant, Meisel continued work using portable CCD cameras in elementary astronomy laboratories. A paper describing the first year results was given in the Education session of the American Astronomical Society meeting in Washington D.C., January 1994 (Meisel, Showers, Lang, *et al.* 1994). This in turn led to an invitation to do a 1/2 hour presentation before the National meeting of the American Association of Physics Teachers at Notre Dame in August '94. The project has also led to the collaborative development of astronomy laboratory exercises with two observatories and others are expected in the future.

James Muzerolle worked with the far-infrared astronomy group this year, and wrote a senior thesis entitled "Infrared spectroscopy of shocks in the DR21 and Cepheus A molecular outflows," under Watson's direction. On the strength of this work he was runner-up in our department's annual Stoddard Prize competition.

Senior undergraduate Tammy Middleton joined Watson's group in the summer of 1994. She has been working with Raines and Watson on characterization of far-infrared detectors and arrays.

Craig McMurtry completed his senior thesis "Near Infrared Observations of the Star Formation Region AFGL 6336 S" under Forrest. It was based on near IR images acquired at the 1.5m Mount Lemmon Observing Facility. He has begun graduate work in the Physics Department at U. Wyoming and is working for C.E. Woodward there. He continues to collaborate with the IR group during observing runs at the 2.3m Wyoming Infrared Observatory.

Bernie Sklanka completed his senior thesis "A Near Infrared Study of the BFS 56 Star Formation Region" under Forrest. He also wrote "An Overview of Observational Techniques for C.E. Kenneth Mees Observatory and the Santa Barbara Instrumentation Group ST-6 CCD Camera" which described his experiences imaging the S 106 in the Hα line. He has gone to graduate school in Engineering at Penn State.

Craig McMurtry, Bernie Sklanka, Abbas Tahir, Rob Armstrong, and Ronian Siew worked in the near IR lab over the summer of 1994. They helped develop new IR instrumentation and organized the IR observational data base. McMurtry and Sklanka also took part in the testing and evaluation of 256×256 InSb and HgCdTe arrays under the supervision of Brad Marazas and Jian Wu. Abbas began the design in Zemax and AutoCAD of the cross-dispersed 1-5 micron echelette spectrometer (Xchel).

Undergrads Armstrong and Siew, along with grad students Jennifer Goetz and David May used the upgraded ST-4X SBIG CCD camera at the 14" Wilmot observatory to record the appearance of Jupiter in red, green, and blue bands during its collision with comet Shoemaker/Levy in July 1994. Dark spots corresponding to impact sites were detected.

Al Pieterman spendt the summer of 1994 using the RIT 2k$\times$2k CCD camera at the Mees Observatory studying the limits to accurate photometry of selected fields. He is continuing his efforts in his senior year at the Center for Imaging Science at RIT.

3 Graduate Education

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.

Matt Guptill has taken a year's leave from his NASA Graduate Researchers Fellowship in Watson's group in order to spend a year working at Rockwell (Anaheim). At Rockwell he is involved in the epitaxial growth and processing of Ge:Ga BIB far-infrared detector arrays, under Jim Huffman's direction. His presence at Rockwell has boosted considerably the detector fabrication activities of the Rochester-Rockwell-JPL collaboration responsible for the development of these devices for SIRTF, and has provided him the opportunity of including every aspect of building, testing and using the arrays in his thesis.

Tim Collins completed his research on the effects of superfluidity on nonradial spheroidal oscillations of neutron stars, in collaboration with Van Horn, Lee, and R. Epstein (Los Alamos). He presented a poster paper on this work at the 184th meeting of the AAS (Collins *et al.* 1994). Collins also began his Ph.D. thesis research, investigating the boundary layers of accretion disks around white dwarfs in cataclysmic binaries. This research examines the possibility that quasiperiodic oscillations and dwarf-nova oscillations might both be driven by instabilities in the boundary layer. To this end he has created steady-state boundary layer and disk models in the fashion of both Lightman (1974) and Lioure and Le Contel (1994), and is currently investigating the stability of the boundary layer. This work is being supervised jointly by Van Horn and Wardle.

Guy Delamarter completed his first year of graduate study and his work with Van Horn on core formation in terrestrial planets. He is now working with Wardle on shock waves in molecular clouds.

J. Andrew Markiel is conducting his Ph.D. thesis research with Thomas and Van Horn, studying time-dependent dynamo models operating in the surface convection zones of white dwarfs. The goal of this research is to determine the conditions under which this process can generate magnetic fields with the strength and variability timescale, *e.g.*, which are inferred from the observations of GD 358 (Winget *et al.* 1994). The preliminary results appear very promising, and the three investigators have recently published a short paper describing them (Markiel, Thomas, and Van Horn 1994) as a companion to the observational paper by the Texas group.

Anthony Perez-Miller completed his first year of graduate study and is now working with Wardle, studying the effects of dust grains on shocks in molecular clouds.

Colin Roald continued his research into nonlinear aperiodic solar dynamo models after passing his preliminary examination in September 1993. Working with Thomas, he is developing a simple model with the dynamo number and the magnetic Reynolds number as free parameters. Currently he is attempting to map out the bifurcation boundaries in this two-dimensional parameter space. Intermediate results of this project were presented at a poster session at the MHD94 conference at HAO (Boulder, Colorado) in August. He received his M.A. in May, 1994.

Don Stanchfield returned to the astrophysics theory group in the summer of 1994 after a leave of absence in the spring. With Thomas, he is analyzing the jump conditions associated with standing tube shocks in siphon flows.

Eric Berton, a second-year graduate student in mechanical engineering, joined the theoretical astrophysics group in September 1994. He is working with Thomas on magnetohydrodynamic problems associated with sunspots.

Mark Swain is conducting his Ph.D. thesis research on radio observations of the jets of galaxy NGC 353 under the direction of Dr. Alan Bridle at the Charlottesville, Virginia, headquarters of the National Radio Astronomy Observatory. His internal (University of Rochester) advisers are Van Horn and Watson.

Scott Libonate, Eric Howard, Jennifer Goetz, and David May are graduate students in Forrest and Pipher's Near Infrared Group.

Jennifer Goetz and David May have completed the first year of graduate school and begun investigations of star formation regions through observations of characteristic spectral lines of [FeII], ionized hydrogen, and molecular hydrogen.

Libonate has completed his PhD thesis and will be defending in November 1994. The thesis describes his analysis of near IR spectra and images of galactic center sources and his design of a cross-dispersed echelette spectrometer for use with the excellent 256×256 InSb arrays available in the Near IR lab.

Howard is continuing observations and analysis of the high mass star formation regions MonR2, K3-50a, NS14, S255-2 and S106. He is co-System Manager for the Near Infrared Group's Sun network and is supporting a WWW mosaic home page for the NIR group. The page may be accessed through the URL: http://sherman.pas.rochester.edu/URNIRhome.html.

Steve Solomon is writing his Ph.D. thesis *in absentia* on both his detector studies and on his study of the physical conditions leading to excitation of the 3.28 μm dust emission feature in galactic and extragalactic objects. He is a research physicist in the detector division of Santa Barbara Research Center. Paula Turner is also writing her Ph.D. thesis *in absentia*, on the topic of galaxy-galaxy interactions: she is Assistant Professor of Astronomy at Kenyon College.

David Bretz continued his MS research at the Center for Imaging Science (RIT) into determining the initial mass function for the young cluster IC1805. Brian Bacher is conducting his PhD research into the performance of CID arrays and their use in a tip-tilt image correction system for astronomy.

4 Theoretical Astrophysics

4.1 Solar Physics

Thomas and B. Montesinos (LAEFF, Madrid) continued their theoretical work on siphon flows in solar magnetic flux tubes. Recent observations by T. Rimmele support their siphon-flow model for the Evershed flow in a sunspot (Montesinos and Thomas 1993,Thomas and Montesinos 1993). This model has now been improved to allow for flux tubes extending beyond the penumbral boundary into the surrounding photosphere. In a review of work on the Evershed effect, Thomas (1994) concluded that proposed mechanisms based on small-scale waves are not tenable and that the siphon-flow mechanism offers the best explanation of the observations.

Stanchfield and Thomas are investigating the structure of tube shocks in flows in magnetic flux tubes. They have studied the one-dimensional jump conditions for these shocks and have also shown that the thickness of these shocks is on the order of the flux tube diameter.

4.2 Planetary Physics

Van Horn and Lee (1993) and Lee and Van Horn (1994) extended earlier calculations by Lee and his collaborators on the global oscillation spectrum of the giant planet Jupiter to estimate the amplitudes of the oscillation modes excited during the July 1994 collision of Comet Shoemaker-Levy 9 with Jupiter. They are currently awaiting the analyses of these data to see whether or not any of the global modes were excited during this event. If so, they expect the mode spectrum to contain evidence for or against the existence of a first-order "plasma phase transition" from the neutral molecular H_2 surface layers to the ionized, metallic hydrogen interior.

4.3 Low-Mass Binary Stars

Muslimov has been studying the evolution of low-mass binaries with neutron stars, and mechanisms of Gamma-ray production by newly discovered Gamma-ray pulsars. Muslimov and Sarna (1993) have computed evolution of the low-mass binary with 1.4 $M_\odot$ neutron star as a compact companion and 1 $M_\odot$ red dwarf as a donor star. They have found that at the late stage of evolution, before the donor star reaches the minimum mass $\sim 0.2\ M_\odot$ and shrinks within its Roche lobe, the donor star undergoes 4-5 relatively short stages of episodic mass loss with approximately the Eddington rate. The detailed analysis of this effect of episodic mass loss in low-mass binaries is in progress.

Sarna, Lee, and Muslimov (1993, 1994) have investigated the pulsations of the red-dwarf companion of the neutron star in a low-mass binary. The illumination of the donor star by the pulsar's high-energy, non-thermal radiation and relativistic wind may substantially affect its internal structure and, *e.g.*, result in the oscillation spectrum qualitatively different from that of its ZAMS counterpart. They have calculated tidally forced gravity modes for the different degrees of the non-sunchronization between the orbital rotation and spin rotation of the red-dwarf component. These investigators have suggested that the tidally induced oscillations may trigger the Roche-lobe overflows and sudden mass loss by the donor star, and that this effect may be relevant to the γ- and X-ray bursting activity in low-mass binaries. Muslimov has suggested that the electrodynamics of pulsar polar cap regions incorporating the effect of *dragging of inertial frames of reference* on the accelerating electric field may help to advance our study of the mechanisms of γ-ray production by Vela-type pulsars. He has illustrated the idea for a neutron star, such as in PSR 1706-44, with the the rotation period 0.1 s and surface magnetic field 3×10^{12} G. His preliminary estimates appear very promising, and he reported them at the Aspen Winter Conference on Millisecond Pulsars (see Muslimov 1994c).

4.4 Properties of Dense Matter

Van Horn and Ichimaru (1993) have published the proceedings of an August 1992 conference on the physics of dense matter held at the University of Rochester. Van Horn (1994) has more recently published a discussion of dense matter equations of state in calculations of stellar structure and evolution.

Van Horn and Yu. K. Kurilenkov have begun a collaboration to apply the results of laboratory investigations of the optical properties of dense matter to astrophysical applications. Several poster papers have already been presented (Kurilenkov and Van Horn 1994a, b; Kurilenkov, Van Horn, and Skowronek 1994), and a number of longer papers are currently in preparation (*c.f.* Van Horn and Kurilenkov 1994). The goal of this work is to investigate the effects of plasma dispersion upon the transfer of radiation in dense plasmas, to calculate the Rosseland mean opacity under conditions where $\hbar\omega_p/kT > 1$, and to include the effects of the modified atomic energy level structures in dens plasmas upon the Rosseland mean opacity.

New calculations have also been performed for nuclear reaction rates at high densities. Ogata, Ichimaru, and Van Horn (1993) have extended results by Ogata, Iyetomi and Ichimaru (1991) to the general calculation of strong screening of thermonuclear reaction rates in binary ionic mixtures (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 *et al.* (1993a, b) have also computed new phase diagrams for dense, multi-ionic matter. This work was motivated by an interest in the energetic consequences of phase separation for the ages of the coolest white dwarf stars. Without the energy released during phase spearation, the best estimates for the ages of these stars are ~ 9 Gyr, much less than other estimates for the age of the Milky Way Galaxy. The new calculations indicate that phase separation, especially of Ne from C in the dense core of a white dwarf, can prolong the cooling time by as much as ~ 6 Gyr. Whether this large an increase can occur in the *multi*-ionic plasma within a real white dwarf remains to be seen, however.

4.5 White Dwarfs

Winget *et al.* (1994) have discovered that the oscillation spectrum of the prototypical He-atmosphere white dwarf GD 358 exhibits evidence for weak, $\sim 10^3$ G magnetic fields, which appear to vary on a timescale $\sim$ months. This clearly suggests that a dynamo process may be operating in the surface convection zone of this star. Markiel *et al.* (1993, 1994) have demonstrated that a time-dependent dynamo can indeed operate in a white-dwarf convection zone, producing fields strengths as large as $\sim 10^4$ G, with a dynamo cycle period $\sim$ years. More extensive theoretical investigations are currently in progress as part of Markiel's Ph.D. thesis.

Muslimov, Van Horn, and Wood (1994) have recently extended earlier calculations of magnetic-field evolution in white dwarfs to include the Hall effect. In particular, they have explored the simplest case in which the Hall effect changes the time-evolution of the field: the case of a cooling white dwarf possessing a strong ($\sim 10^9$ G) internal toroidal magnetic field as well as poloidal dipole and quadrupole components. Due to the Hall effect the equations describing magnetic field evolution depend non-linearly upon the field strength. This in turn couples the field-decay modes. Muslimov *et al.* have found that under these conditions, the evolution of the poloidal field is strongly affected by the presence of the postulated strong toroidal field.

4.6 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. Lee *et al.* (1994) and Collins *et al.* (1994a, b) have now extended these results to include the effects of superfluidity on the global spheroidal oscillation modes of neutron stars, and Van Horn *et al.* (1994) have discussed possible future uses of observations of neutron-star oscillations as potential probes of the microscopic physics of matter at ultra-high densities.

Haensel, Urpin, and Yakovlev (1988) showed that in the high magnetic fields $\mathbf{B}$ at the surfaces of pulsars, the generalized "Ohm's Law" that governs fields decay depends nonlinearly on $\mathbf{B}$. As a result, the timescale for field dissipation may be only $\sim 10^6$ years, rather than exceeding the Hubble time. Muslimov and Van Horn (1994) have recently explored this process using a more detailed model than that employed by Haensel *et al.* They find that the combination of the nonlinear field-dependence and the temperature sensitivity of the transport coefficients indeed leads to rapid dissipation of *poloidal* magnetic fields, with a timescale $\sim 10^5$ years, if the rapid cooling produced by the *direct* Urca process actually occurs.

Muslimov (1994a) has extended his previous study of the magnetic field evolution in neutron stars to include the Hall effect and complexity of the magnetic field. He has found that the Hall effect may substantially affect evolution of the poloidal components of the magnetic field in neutron stars. Recently, he has also proposed (Muslimov 1994b) one of the possible schemes for the evolution of the magnetic field in millisecond pulsars. He has assumed that the magnetic field initially occupies the neutron star crust and outer core with superconducting nucleons, and that the magnetic field in a superconducting core is organized in a form of flux tubes. Also, he has assumed that there is "strong" interaction between neutron and proton vortices in a core of a neutron star. He has calculated evolution of the surface value of the magnetic field strength and has shown that it declines approximately 10 times during the first ~ 100 Myr, then it rapidly decays by a factor of $10^2 - 10^3$ and at $t \geq 1$ Gyr enters a residual value ranging from 10^{-4} to 10^{-3} times the initial value of the magnetic field strength.

4.7 Pulsars

Chen studied radio pulse properties of millisecond pulsars. He proposed that radio emission of a millisecond (ms) pulsar consists of two components, a narrow one and a broad one, according to the observed pulse width. The former is associated with the fastest ms pulsars, and the latter dominates the radio emission of relatively slower pulsars. It seems that the morphology of the radio pulse profile correlates with a pulsar's magnetic field at light cylinder. The broad component appears to originate at $\sim 1/3 - 1/4$ of the light cylinder ($r_{lc} = cP/2\pi$), where the local magnetic field is $\sim 10^{5-6}$ G, which is similar to that associated with the conal components of canonical radio pulsars. Chen noted that the magnetic fields at the light cylinder of the disk-populated ms pulsars with dominant broad components tend to be a constant, *e.g.*, $B_{lc} = 10^{4.2\pm0.1}$ G. This empirical law may be used to estimate magnetic field strengths of ms pulsars in globular clusters which have similar radio pulses.

Chen and S. Colgate (Los Alamos) have studied the observed circumstellar rings around the famous SN 1987A. This circumstellar ring is extraordinarily symmetric, localized in space and in velocity. They postulate that this degree of localization in phase space could most likely happen by the merger of two massive binary stars forming the progenitor of the supernova. The formation of a neutron star with a period as short as few milliseconds is then a natural consequence of the core collapse.

4.8 Accretion Disks

Wardle is continuing his collaboration with A. Königl (U. Chicago) to calculate the structure of magnetized protostellar accretion disks that may power centrifugally driven outflows (Wardle and Königl 1993). The regime in which dust grains are the dominant charge carriers is currently under investigation. In this case the bulk of the disk material is magnetically passive because it is unable to support a significant current. Close to the disk surfaces, where the gas density (and resistivity) is lower, the coupling between the disk material and magnetic field is sufficient to initiate a disk wind as before. An exploration of parameter space is currently underway.

MacLow, Norman, Königl and Wardle (1994) have incorporated ambipolar diffusion into the ZEUS mhd code and run some numerical tests: the gravitational collapse of a magnetized slab, the formation and steady structure of an oblique C-type shock, and the development of the Balbus-Hawley mechanism in a magnetized, weakly-ionized accretion disk.

Wardle is carrying out a linear analysis of the Balbus-Hawley instability in a weakly-ionized accretion in the case that the magnetic and thermal pressures are comparable at the disk midplane. He is also investigating the stability of the disk-wind solutions found with Königl.

Collins, Van Horn, and Wardle continued their study of the boundary layer between the white dwarf and the accretion disk in cataclysmic variables. The investigation has included an analytical and numerical study of local instabilities in the Keplerian part of the disk and in the boundary layer, identifying instabilities which may be responsible for the quasiperiodic and dwarf-nova oscillations observed in many cataclysmic variables. They have also created state-of-the-art alpha disk models in the manner of Lightman (1974) and boundary layer models similar to those of Lioure and Le Contel (1994). This will allow a global numerical stability analysis of the boundary layer.

4.9 The Galactic Center

Yusef-Zadeh, Cotton, Wardle, Melia and Roberts (1994) presented VLA $\lambda 20$ cm observations of the angular broadening of Sgr A* at the Galactic Center. The scatter-broadened image shows an East-West elongation with an axial ratio of 0.56 ± 0.22, consistent with VLBA measurements at shorter wavelengths. They suggest that scattering arises from anisotropic MHD turbulence in the thin ionized skins of clouds lying within 100 pc of the galactic center. The thickness of the layers, $10^{-3.5}$ pc, provides an outer turbulent scale much less than the pc scale usually assumed and allows the scattering medium to lie much closer to the Galactic Center without violating the constraints of free-free emissivity or absorptivity.

In a related investigation, Yusef-Zadeh (Northwestern) and Wardle are examining the spatial variation of rotation measure along one of the Galactic Center nonthermal filaments. The aim of this study is to relate the statistical properties of the rotation measure to the fluctuations in magnetic field and electron density close to the Galactic Center.

4.10 Shock Waves in Molecular Clouds

Delamarter and Wardle have calculated the steady structure of oblique, J-type shocks. A global stability analysis will determine whether the precursors of these shocks are susceptible to the instability known to exist in C-type shocks.

Perez-Miller and Wardle have investigated the effect of dust grains on the structure of oblique C-type shock waves. A recent paper by Pilipp and Hartquist (1994) shows that such shocks are not coplanar. Equations describing the shock structure have been derived for an arbitrary number of charged fluids (*e.g.* ions, electrons and grains), and solutions will be found for shock waves propagating in diffuse and dense interstellar clouds for different grain populations.

4.11 Positron Production in Shocked Interstellar Clouds

Helfer is constructing a model for positron production in shocked interstellar clouds following the development of a sucessful model for antiproton production by Helfer & Savedoff (1992). That model used diffusive acceleration of primary CR protons by shocks in such clouds. The accelerated protons produce positrons from pion decay in excess of the observed 1 - 10 GeV positron flux by a factor of up to four. Most probably, this excess results from ignoring bremsstrahlung losses in the shocked cloud. A model allowing for energy-dependent storage times and radiative losses within the shocked cloud residue is being developed. It is necessary to include the rapid decay of very short scale magnetic field fluctuations in the clouds (see Kulsrud & Pearce 1969; Helfer 1993). Estimates of the frequencies of occurances of intermediate-scaled fluctuations in the post shocked clouds are underway in a separate investigation.

The 'observed' positron flux in the 0.2 - 1 GeV range cannot be matched; however we note that, for this energy range, the positron flux directly inferred from CR lepton observations uses a large (and uncertain) correction for solar modulation effects and the lepton flux inferred from galactic low frequency radio radiation is suspect because of the use of inapropriate antenna patterns.

5 Observational Astronomy

There are two observational infrared astronomy groups at the University of Rochester, the near infrared group (faculty supervisors: Forrest and Pipher) and the far infrared group (faculty supervisor: Watson). The near infrared group has been developing InSb detector arrays for SIRTF, and exploits them in a near IR 256 $\times$ 256 InSb camera in ground-based activity. The camera has fixed filters covering the 1 - 5.5 μm range, as well as CVF (circular variable filter) sections at resolutions of 1 - 2%. Primary studies at the WIRO 2.3-m telescope and the Mt. Lemmon 1.5-m telescope include an investigation of the nature of young stellar objects, and of extragalactic nuclei and starburst regions. Rochester's infrared astronomy groups continue to work with groups at the Smithsonian National Air and Space Museum (NASM), the Naval Research Laboratory (NRL), and the Wyoming Infrared Observatory (WIRO) on infrared spectral-line imaging of Galactic star-formation regions and starburst and Seyfert galaxies. Their observations involve the use of the Rochester Third Generation Near-Infrared Array Camera, with a 256x256 InSb/DRO detector array, along with scanning Fabry-Perot spectrometers belonging to NASM and NRL, on the 2.2 meter WIRO telescope. This Infrared Spectroscopic Imaging (ISI) team includes W.J. Forrest, E. Howard, S. Libonate, F. Piché, J.L. Pipher, S.N. Raines, S. Satyapal and D.M. Watson (Rochester), M.A. Greenhouse and H.A. Smith (NASM), J. Fischer and K.L. Thompson (NRL) and T. Hodge, C.R. McMurtry and C.E. Woodward (WIRO).

In addition to this activity, Thomas conducts solar observations at the NOAO Sac Peak Observatory, and Mees Associates Ninkov and Meisel conduct optical CCD observations at the C.E.K. Mees Observatory, in Hawaii, and at MIRA (in California).

5.1 The Sun

Thomas and B. Lites (HAO, Boulder) carried out observations of dynamical phenomena in sunspots using the Vacuum Tower Telescope, Advanced Stokes Polarimeter, and Universal Birefringent Filter at NSO (Sacramento Peak) in October 1993. They obtained several good data sets which are now being reduced and analyzed to give time series of Doppler velocity and vector magnetic fields in a sunspot and the surrounding active region. These time series will be used to study sunspot seismology and the Evershed flow.

5.2 Bolide AIDA

Meisel continued a research collaboration with V. Getman (Tadjik Astronomical Institute) and J. Mathews (Penn State University, Communications and Space Research Laboratory) on Bolide AIDA. This object appeared over Puerto Rico in April 1989 and information was obtained with seven different instruments. The final data analysis indicates this object was quite unusual, perhaps even unique. A paper describing this object is in preparation for presentation at the Division of Planetary Sciences of the American Astronomical Society, Fall Meeting in Washington DC as well as publication the Icarus, the Planetary Science Journal (Meisel, Getman, Mathews, *et al.*, 1994).

5.3 Hubble's Variable Nebula

Work continues at the Mees Observatory on Hubble's Variable Nebula. Because of poor observing weather, only a limited number of images could be obtained. Preliminary reduction of these images indicate that SII emission seems to be concentrated around R Mon, while H-alpha is more wide-spread.

5.4 The Comet Levy-Shoemaker Jupiter Impacts

Optical color video observations were made by Meisel at the Mees Observatory during the B impact event and prior to the F impact event. The remaining Mees time during the impact period was given to Zoran Ninkov and Roger Easton of RIT for taking optical CCD images in narrowband filters including the 8900 methane band. All images obtained are being analyzed. Additional CCD images were obtained by undergraduate and graduate students in the Department using the campus 14″ telescope (the Wilmot Observatory).

The near infrared group (Forrest and Pipher) collaborated with Howell and Woodward (Wyoming), Orton (JPL), Nicholson (Cornell), and Gehrz (Minnesota) to obtain IR images of the Comet Levy-Shoemaker Jupiter impacts, and of the aftermath disturbances of Jupiter, in an observing run at WIRO from 13-24 July, 1994. Fast photometry of impacts available at that site (B, U, V), as well as 2% spectral resolution images at a variety of wavelengths (generally from 4 to 2.9 μm, 2.2 to 1.9 μm, and 1.8 to 1.6 μm) were obtained. Nothing significant was seen at the time of the impacts, although there were observable spots later for the U and V sites, but not for the B site. Other impacts were not available at WIRO: the various disturbances from other impacts were monitored throught the run. The only obvious spectral feature was a large brightness in the Q spot's first rotation around Jupiter at a wavelength near 3.4 μm. Emission at this wavelength is a signature of hydrocarbon emission. In addition to the 2% spectral monitoring, images in the 4.7 μm narrow band were obtained, where thermal emission from deep within the Jovian atmosphere can be seen. The structure in these images was most amazing. Thermal emission was not detected from any of the impact sites, but there was a suggestive thermal ring around one of the major spots. This type of ring is seen around the Great Red spot. This work is still in progress.

5.5 Observations of Star Formation Regions and Nebulae

Howard, Pipher and Forrest (1994) report on near infrared imaging of the MonR2 high mass star formation region at H, K, L″ broad-band wavelengths, as well as in emission lines at Brα and γ, and in dust emission features at 3.29 and 3.4 μm. These data allowed determination of the extinction at a 1″ spatial scale in the region, and led to the development of a torus model for the dense molecular gas surrounding the HII region. The 3.29 and 3.4 μm dust feature emission coincides with the 2.2 μm scattering ring.

The ISI team has now obtained a large number of images of prominent young-stellar-object (YSO) ouflow regions in broadband continuum light and spectral lines including [Fe II] 1.64 μm, H_2 v = 1-0 S(1) 2.12 μm and H Brγ 2.17 μm. Among the regions imaged are the "classic" molecular shock regions Orion-KL, NGC 7538, Cepheus A, L1551 and DR21, along with lesser-known objects such as L1157. A typical result is that in the GGD 37 region (Cepheus A West), in which the shock appears as a lobe composed of many arcs and filaments, in each case composed of a molecular hydrogen component nestled about a [Fe II] component which lies closer to the outflow source. The image thus shows an unambiguous and detailed separation between the cloud shock (shown in molecular hydrogen) and wind shock (shown in [Fe II]), for the first time. The H_2 and [FeII] emission in CepA outline separate velocity lobes pointing to the source of excitation of CepA, an object not detected in the near IR. These data are being analysed at present (Forrest *et al.* in preparation). Several areas in the Orion OMC-1 region are also being studied in these same diagnostic lines: in particular, the 'finger'-like protruberances described by Burton and Allen (1994) are being investigated. Piché *et al.* (1993) describe the state of H_2 gas in L1448, one of the youngest bipolar molecular outflows known, through imaging in the H_2 2.122 μm line as well as the 1-0 S(0) line at 2.223 μm. A surprising range of line flux ratios was found, encompassing dissociative and non-dissociative shocks. A similar study of L1157 has begun.

Howard, Pipher, Forrest (1993) report on preliminary J, H, K, Brγ, Brα and 3.29 μm dust emission imaging of K3-50, a compact HII region complex. A paper will be written on K3-50 incorporating further observations at higher spatial and spectral resolution. Also in progress is a paper on the star formation region S255 which has also been studied in a similar manner. Howard is investigating high mass star formation regions as part of his PhD thesis research.

Piché, Howard and Pipher (1994a) have imaged in H_2 (2.122 μm) the energetic young stellar object NGC 2264G and associated Herbig Haro object (HH124) with the Rochester array camera at Mt. Lemmon Infrared Observatory. The outflow driving source (IRAS 06382+1017) is deeply embedded near the symmetry center of the outflow, and is associated with an infrared reflection nebula. Brγ emission probably associated with the IRAS source accretion disk was detected, and H_2 emission associated with the outflow is found in a direction diferent from the reflection nebula direction. The H_2 spatial distribution is morphologically reminiscent of bow shock wings.

Hodge *et al.* (1993) has obtained observations of several planetary nebulae in a hydrogen recombination line, H_2 line emission, and in certain unidentified lines at 2.199 and 2.287 μm (Geballe, Burton & Isaacman, 1991), in order to investigate whether the responsible species' emission coincides with the ionized region, or the PDR. By this technique, in combination with other observations, the authors plan to deduce the excitation state of the responsible species.

Observation of young OB clusters such as IC1805, Berkeley 86 and NGC3296 have been obtained at BURI using large format CCDs. These data are being analyzed by Ninkov and the RIT group to determine the population of stars below the mass of B stars in such clusters.

5.6 The Galactic Center

Libonate, Pipher, Forrest, and Ashby (1994) present low and high resolution H and K band spectra of compact 2.2 μm Galactic Center sources thought to be possible young mass-losing stars, as well as comparison spectra of the LBV P Cygni and a WR star, HD 192163. The Brackett line widths and flux ratios indicate that many of these are strong stellar wind sources. Nine of the wind sources appear to contribute a significant fraction of the total luminosity of the Galactic center. Libonate (PhD thesis, 1994) further discusses Galactic center data obtained with the Rochester IR cameras. He examines the evidence for a cusp in the stellar density, required by massive black hole models of the Galactic center luminosity, and finds no evidence for a cusp: he sets an upper limit on the putative black hole mass a factor of ten less than generally postulated. Libonate further develops wind models to described the observed helium and hydrogen emission line spectra of Galactic center wind sources. Although the WR stage is longer-lived than the LBV stage, Libonate only finds one WR star, as compared with 9 LBV stars in the Galactic center cluster. He uses this observation to time the beginning of the presumed starburst at the Galactic center.

5.7 Extragalactic Objects

The Rochester/NRL/NASM/Wyoming collaboration has concentrated on observations of emission lines from both active and starburst galaxies. The ISI team (Satyapal *et al.* 1993, 1994) report on high spatial resolution ($1''$) and moderate spectral resolution ($\lambda/\Delta\lambda$ = 800) Paβ and Brγ Fabry-Perot imaging observations of the central kiloparsec of M82. These observations, in conjunction with new near-infrared broad-band imaging observations, are used to examine the extinction toward the starburst region, the state of the ionized gas and the nature of the stellar population. Enhancements in the extinction-sensitive Paβ /Brγ flux ratio are found to trace out the molecular lobes seen in CO, supporting the assumption that we are observing a dense torus surrounding the central stellar clusters and HII regions. Using a non-uniform foreground screen model for the Paβ /Brγ flux ratio, the derived visual extinction toward the starburst region is found to vary from 2 to 12 magnitudes, significantly smaller than is adopted in most other studies of the stellar population in the starburst region of M82. The extinction-corrected absolute K magnitude in a $30''$ aperture centered on the nucleus is found to be -22.0 mag. This is substantially fainter than values previously adopted, amounting to as much as a reduction of a factor of about 3 in the intrinsic K luminosity. This may affect the inferred IMF for the starburst region of M82. The recombination line images were used to estimate separately the contribution to the near-infrared continuum bandpasses from free-free and free-bound processes and the emission from dust. These sources of emission do not contribute appreciably to the total near-infrared continuum and thus it can confidently be assumed that this emission is dominated by starlight. In addition, they present narrow-band imaging observations of the 3.29 μm unidentified dust feature. The emission is seen to be well-correlated with the Brγ emission. The ratio of the total far-infrared luminosity to the de-reddened 3.29 μm feature luminosity is found to be 1340 $\pm$ 260 for M82, significantly smaller than the ratio obtained using the uncorrected 3.29 μm feature flux (1690 $\pm$ 200).

Greenhouse *et al.* (1993) present images of M82 in the [FeII] 1.64 μm line: surprisingly, the image of the starburst core is quite diffuse, and shows little correspondence with either Brγ or Pβ images, or with supernova remnants detected at radio wavelengths.

Observations of other galaxy nuclei, at broad-band wavelengths, in emission lines, and in the 3.29 μm feature emission, are presently being reduced. Turner (1994; PhD thesis, in preparation) is analyzing galaxy-galaxy mergers.

Watson and Guptill have continued their program of molecular observations of polar ring galaxies, and have detected and partially mapped eight of a sample of ten of these objects in the CO J = 2-1 line, using the Caltech Submillimeter Observatory. (Initial results are presented by Watson *et al.*, 1994.) In each case the molecular component of the polar ring is substantial, comprising $1-20\times10^8$ solar masses, and in some cases the molecular component outweighs the neutral atomic component. All of the galaxies detected show low to moderate star formation efficiency indices (0.1-10 $L_\odot$ /$M_\odot$), much lower than that of other galaxy-interaction remnants such as starburst galaxies (typically 200 $L_\odot$ /$M_\odot$). They will be extending the program during the next year by obtaining high-resolution, interferometric CO maps of their brightest sources, to facilitate detailed dynamical modelling of the rings and derivation of the underlying distribution of mass in host galaxy and halo.

5.8 Observations of Binary Stars

Ninkov and Deeg, in collaboration with Laurance Doyle (NASA Ames) and Jean Schneider (Meudon Observatory) have made observations of eclipsing binary stars to study the feasibility of detecting transits of extrasolar planets. A full campaign is planned for the spring of 1995 using observatories in Europe, the Continental USA, Hawaii and Korea.

6 Instrumentation

6.1 Near Infrared Camera

The Rochester Near Infrared camera utilizes an SBRC 256 $\times$ 256 InSb array, the best one produced on the SIRTF project (see below), run at an optimized temperature of 26K. A cold filter wheel houses J, H, K, L'', M', 3.3 μm filters, and two CVFs chosen from CVFs covering the H, K, L/M bands. A DSP-based array controller, in the backplane of a 486 microcomputer was developed at Rochester, as were various other system components (A/D boards, special bias cards, preamps, I/O board). Clocked drivers (level shifters), and other bias cards were designed and built to Rochester specifications. A Sun IPC computer communicates with the 486 computer via ethernet, and Sun programs (*e.g.* Vu-Fits) are used to view the data. Rochester programmer-analyst McFadden wrote a GUI for observing use: the observing program is in C-Forth. Warm J/H and K - band FPs are interspersed in the optical path of the Rochester spectrometer for higher spectral resolution.

The FP computer communicates with the Camera computer to assure appropriate camera conditions for a given FP observation.

Plans to build an echellette IR spectrometer are underway. Woodward (WIRO) will collaborate with Rochester. Libonate has completed an optical design.

6.2 Far-infrared Spectroscopic Camera

An imaging far-infrared Fabry-Perot spectroscopic camera, based upon the 6×6 Ge:Ga BIB detector arrays, has been constructed at Rochester by Raines, Guptill and Watson. Its characteristics include four focal-plane pixels per Airy disk at 160 microns; adjustable velocity resolution down to a minimum of 60 km/s; good instrument throughput and background-limited sensitivity. This instrument has been selected to fly on the NASA Kuiper Airborne Observatory next year to carry out a program of imaging observations of far-infrared molecular lines in shicks associated with YSO outflows.

7 Detectors

7.1 Near IR Detector Array Test and Evaluation

Rochester, under the auspices of SIRTF grants, and several space oriented NASA grants, has been involved in an extensive test and evaluation program for infrared detector arrays. Our primary efforts have been expended on the InSb arrays/multiplexers baselined for the SIRTF Infrared Array Camera. Currently, 256×256 InSb arrays, of low-doped material, bonded to the CRC 463 multiplexer are being studied. Quantum efficiencies in excess of 90%, dark currents < 1 e^-/s, and multiply sampled noise of 12 e^- have been obtained in one array, operating at 26K. We are planning to test an array bonded to the CRC 744 multiplexer (10K operation) as soon as one is delivered, and are beginning to retrofit our system for test and evaluation of 1024×1024 Aladdin InSb arrays.

HgCdTe arrays, with ~ 5 μm cut-off wavelength, produced by Rockwell International, Science Center are being tested by our group. To date, new process BPH and MBE HgCdTe seem most promising. Generation-recombination limited dark current at 55K has been achieved with the BPH material.

7.2 Ge:Ga BIB detector arrays and imaging spectrometer

Watson and his group, with J.E. Huffman (Rockwell) and T.N. Krabach (JPL), continue to develop germanium blocked-impurity-band (BIB) detector arrays, a radiation-hard planar detector technology developed for use in the 50-200 micron channels of SIRTF. Currently 6×6 and 4×16 arrays are produced, and achieve peak quantum efficiency up to 20% and dark current below 100 e/s, suiting the requirements of the SIRTF instruments. Work this year has focused on improvement in the photoresponse time constant of the detectors, which have hitherto been rather slow at low backgrounds, and upon modelling of the long-wavelength response and optimization of the structure and doping. The latter details can be found in articles generated this year (Watson 1994; Watson *et al.* 1994).

7.3 Visible-light Arrays

Testing of large format CCD and CID arrays continues in Ninkov's laboratory at RIT and results have been reported in Ninkov (1994), Ninkov, Tang and Carbone (1994), Ninkov, Tang and Easton (1994) and Deeg and Ninkov (1995) under the support of NSF and NASA instrumentation grants. The development of low noise CID and Active Pixel Sensor CID devices will lead to a radiation hard sensor for space applications.

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