I. BACKGROUND

This is the fifth RAO report. It summarizes the volunteered activities of some, but not all, of the astronomy, astrophysics and space science personnel at the University of Calgary through the period Sept. 1986-1989 not included in the previous report (Milone & Clark: BAAS 19, 502, 1987) or earlier. In 1989, the space science group became part of a federal Centre of Excellence. Also in 1989, the Department of Physics and Astronomy became the Department of Physics and Astronomy. Infrastructure support for the RAO comes from the Department, University, and from the Canadian Natural Sciences and Engineering Research Council.

II. PERSONNEL CHANGES

The RAO continues to be administered by T.A. Clark and E.F. Milone, Co-Directors, who are responsible to the Head of the Physics and Astronomy Department. During this period, C.J. Bland retained that position. The RAO continued to grow during this period thanks to his support.

S. Kwok was promoted to Professor in 1988. In 1989-90, he was awarded a Visiting Fellowship by the National Institute of Standards and Technology and spent the academic year at the Joint Institute for Laboratory Astrophysics at the University of Colorado. NSERC Fellow D.A. Leahy became Assistant Professor in 1987, and A.R. Taylor was named NSERC Research Fellow in 1987. J.E. Penfold of Mt. Royal College was named Adjunct Associate Professor in 1988. In the academic year 1989-1990, R.H. Nelson of New Caledonia College and Prince George, BC spent his sabbatical leave in the department. Postdoctoral associates joining the during this period were C.R. Stagg (optical astronomy) from the Univ. of Manchester, and C.-Y. Zhang (infrared astronomy) from the Univ. of Groningen. The following post-doctoral associates left to accept positions elsewhere: S.J. Schiller (South Dakota State University), L. Varga (Defense Research Establishment, Val Cartier, Quebec), and K. Volk (NASA-Ames). O. Aaquist, J. Chan, G. Groisman, H. Kenny, C. Marshall, and J. Murtha received MSc degrees. Other graduate students during this period included: S. Dougherty, G. Gussie, F. Langill, J. Van Leeuwen and B. Wallace. NSERC undergraduate scholars were J.R. McVean and P. Radau. Federal SEED and/or provincial STEP undergraduate grant holders were: J. Antonio, G. Bryan, S.C. Grifiths, K. Robinson, C. Rousseau, J. Van Leeuwen, S. Warrington, G. Wells, and G. Young. These students carried out RAO observing and computational projects.

III. FACILITIES AND EQUIPMENT

The Infrared Telescope assumed operational status in 1988 but systems continue to be improved. Its design, construction, and ancillary equipment have been described to the IAU (Milone and Clark 1988) and in an invited paper to the conference on automated telescopes held in Tucson in May, 1989 (Clark and Milone 1989). Most recently, papers on both the equipment and data acquisition were presented at the CASCA Montreal meeting (Clark et al. 1989 and Milone et al. 1989). The phase was completed with a formal ceremony in May 1987 at which Dr. G.V. Coyne, Director of the Vatican Observatory, dedicated the Infrared Telescope (IRT), and Dr. H.J. Smith, Director of the McDonald Observatory, brought the greeting of the International astronomical community. D. Parent was a student at the University of Calgary presided; also present were Mr. A.R. Cross, the RAO’s benefactor, Mrs. Cross, prominent Calgarian and Mr. Cross’ sister, Mrs. Mary Dover, the Chairman of the Board of Governors of the University of Calgary, Mrs. Wagner, and the RAO’s co-directors. The first users’ meeting took place in May, and the second in October, 1989. The telescope is now in regular use. The current absolute pointing accuracy is ±3 arc minutes over most of the sky and is improving with the pointing model, a high-order polynomial. The telescope control software caches the residuals as they are observed and continually improves the coefficients. Star tracking is maintained with screen centroiding. The tracker image is provided by a TV camera at the Cassegrain focus of a Celestron guide telescope. Locked into this mode, tracking can be maintained to ±3 arc seconds. Improvements continue on the guidance systems, the IRRADS automatic extinction compensation system, dome structure and detectors. Experiments are currently underway to assess the feasibility of tracking on the chopped image, which can be sampled through a dichroic or thinly coated gold tertiary mirror. Telescope nodding permits the star tracker box to move to the desired position, typically ~0.7 arc minute in a few seconds. The quality of the stellar images achieved with the current metal mirror of the IRT is typically 10 arc seconds and is dependent on ambient dome conditions. The control and data acquisition computers are Zenith 286 microcomputers. Taylor implemented an automatic centroiding algorithm which causes the telescope to move so as to maximize the infrared signal. The telescope is therefore able to carry out photometric programmes on relatively bright stars.

The infrared instrumentation for the IRT consists of two Infrared Labs dewars for InSb JHKL photometry and 1.98 μm CFP photometry with a S1:Ge detector, and a Fourier Transform Spectrometer. The backplane of the IRT permits three instruments to be mounted at one time.
The next major development stage will involve the replacement of the present 1.5-m metal primary mirror with a 1.83-m honeycomb mirror which will have two secondaries figured to give f/14 and f/35 effective focal ratios. The new-generation mirror was purchased from R. Angel’s group at the Optical Sciences Center at the University of Arizona with the help of a grant from the university’s Special Projects Fund. It is currently undergoing final figuring in Arizona under a cost-sharing agreement between the University of Calgary and the Astrophysical Research Consortium. The University of Calgary share of this cost was met by a generous donation from A. R. Cross, the RAO’s benefactor, and by provincial matching. Following completion, the mirror will be used at Apache Point for approximately two years, after which it will be shipped to the University of Calgary.

In 1989, vacuum equipment was installed at the IRT to permit faster turn around of the dews, and a second installed to pump on the inner dewar flasks to achieve temperatures below the Lambda point for programmes requiring greater sensitivity at JHK.

Light curve productivity continues to be high with the 0.6-m telescope thanks to the Rapid Alternate Detection System (RADS), an automated chopping, gated pulse-counting, system. Improved readout and computer facilities (2386 microcomputers) are making this system even more efficient. Data from the optical telescope have contributed to two MSc and two PhD theses and to more than a score of faculty, graduate and undergraduate research projects over the past decade. For analyzing data, university mainframes include a Honeywell Multics and a CDC Cyber 205 Supercomputer. The front-end of the Cyber 205 is a Cyber 860 with NOS/VE operating system, which can also be used for computing. A Sun 4/260 computer with supporting facilities serves image-processing workstations; it was obtained under an NSERC Equipment grant to Kwok, and supports an IRAS Data Analysis Facility. Major activities of the facility include recalibration and extraction of 170,000 spectra from the Low Resolution Spectrometer on the IRAS satellite.

IV. RESEARCH
A. BINARY AND VARIABLE STARS

A principal program of the RAO is the study of double-lined spectroscopic and eclipsing binary stars in the open clusters of the galaxy to improve our understanding of both binary stars and clusters (Milone and Schiller 1988; Schiller and Milone 1987; Schiller and Milone 1988). A benefit of this work has been an independent determination of the distance of the Hyades from the components of HD 27310. Following work on DS And in NCG 752, a second short-period variable and contact system candidate has been under investigation in that cluster: H235 photometry has been obtained at RAO and at Table Mountain, CA, and radial velocities at DAO. For the UY Lyrae in NCG 6791, radial velocity analysis is continuing and light curves are complete. Light and radial velocity analyses of the systems OX Cas, QX Cas, SZ Cam (with A.J. Wesselink), V440 Cyg (with A. Underhill, UBC) and EM Cep are in progress. G. Hill, W. Fisher and F. Younger and other DAO personnel have helped our programs significantly either by providing RV reduction and analysis software or helping to obtain reticon/CCD spectra.

Binary star analysis has provided evidence that the process prior to the analyses of asymmetric light curves of O’Connell effect systems do indeed produce correct system elements when the system is freed of light curve distortions by either simulated spots or sine-rectification (Milone, Wilson, and Brinkman 1987). The shallow contact system YV Bootis has been observed and modeled by Milone, Groisman, Fry, and D. Bradstreet (Eastern College, Pa.) and has been shown to be a W-type system with a small O’Connell Effect; the model was compared to modeling of previously published light curves, revealing closely similar parameters; however, significant differences from previous modeling attempts using the Russell-Merrill and frequency domain methods suggest that caution should be exercised in using those methods without radial velocity information. Milone and Stagg have remodeled the light and radial velocity curves of AE Phe using an enhanced version of the Wilson-Devinney program (see §5). Simultaneous IR and optical observations of selected bright eclipsing binary systems, such as 441 Boo, are continuing at DAO. DAO radial velocity data of the nearly equal mass component contact system VZ Psc (Brinkman and Milone 1989) and combined light curve and radial velocity analyses of the system are underway by Milone, Nelson, and undergraduate P. Amerl. The radial velocity study of V728 Her has been under study by Nelson, Penfold, and Milone, with help from graduate students J. Van Leeuwen and A. Kyrgoussios. Van Leeuwen has completed a radial velocity study of IR Cas and light curve analysis is in progress by Milone and Van Leeuwen. Other field binaries still being monitored at RAO and for which radial velocity observations at DAO are continuing include AO Cam, CG Cyg (with Robb, U. Victoria), RT Lac, and RW Com. The last three are O’Connell Effect systems constituting important case studies of perturbed light curve binaries for detached, semi-detached, and contact systems, respectively. CCD and photoelectric observations of the Southern hemisphere O’Connell Effect system VY Cru are under study by Milone and van Houten. Early type W UMa systems are the target of a study by Linnell (Michigan State U.) and Milone.

Milone, Fry, Nelson, and undergraduates J. Van Leeuwen, C. Rousseau, J. Bourassa, P. Radau, M. Urednicek, and J. McVean have obtained complete, good precision and nearly simultaneous JHK and UBVRI light curves for five short-period & Scuti variables (GG And, DY Her, EH Lib, DY Peg) and BVR photometry and find Wesselink radii. Milone, Fry, Penfold, Van Leeuwen, and K.M. Yoss (U. Illinois) have carried out the radial velocity observations on DAO’s telescopes equipped with reticons and velocity scanner. W.J.F. Wilson and Milone are carrying out the analyses. In a test of relative precision and accuracy of CCD and photoelectric photometry, simultaneous

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Observations of DY Her were obtained by Milone and Schiller on two telescopes about 100 km apart at the McDonald Obs. in 1988.

Near IR and x-ray emission of $B_\text{w}$/x-ray binaries are being studied with ground-based IR telescopes and the ROSAT x-ray satellite, respectively, by Waters and Taylor to investigate $B_\text{w}$ star envelopes.

Tenna satellite observations of the massive x-ray binary GX301-2 are being studied by M. Matsuoaka (RIKEN, Tokyo) and Leahy. This source exhibits an unexplained phenomenon which provides evidence for an accretion shock front near the neutron star (Leahy et al. 1988c). The 6.4 kev fluorescent line emission is being studied as a probe of the distribution and physical state of the matter in this system (Leahy et al. 1988a,b), and spectral changes with phase are revealing details of the emission region.

Taylor has used the VLA and European VLBI Network (EVN) to obtain high resolution images of novae QU Vul and RS Oph, during radio outburst. The observations trace the dynamical evolution of the material ejected by the nova and reveal bipolar geometry and in the case of RS Oph, the presence of nonthermal radio emission.

The Symbiotic variable HM Sge was observed at 21-cm at the VLA by Leahy and Taylor. A search for a hydrogen emission line in progress which would signify a neutral hydrogen shell, in accord with a recent model for symbiotic systems. Exosat observations of CH Cyg from 1985 have been analyzed; soft x-rays were discovered, indicating the presence of a million degree boundary layer between the white dwarf in the system and an accretion disk (Leahy and Taylor 1987). Taylor and B. E. Saquist (U. Toronto) have completed a VLA survey of symbiotics and have noted a number of correlations among radio, IR and optical properties. Long-term radio monitoring of AG Peg, Z And, and CH Cyg are continuing. Fry, Leahy, and Milone are also continuing optical and IR studies of bright symbiotic stars such as CH Cygni as well as mid-IR and optical flux from IRAS-bright close binary systems.

B. STARS AND CLUSTERS

Multimwavelength observations of evolved stars are being pursued vigorously.

Taylor, Clark, and graduate student S. Dougherty have made infrared observations of $B_\text{w}$ stars which have strong emission in IRAS four-colour photometry. The observations are being made in conjunction with VLA and IUE campaigns to constrain models of the circumstellar envelope geometry. Taylor's VLA observations of $B_\text{w}$ stars showing strong 4-color IRAS emission have provided the first radio emission detection from a conventional $B_\text{w}$ star. Bjorkman (U. Colorado), Waters (U. Amsterdam), Persi (IAS, Italy), and Taylor have targeted IUE near-IR, and radio data to constrain geometric models of the circumstellar envelope.


Dust continuum emission has been detected in three asymptotic giant branch stars at 650, 800, and 1100 μm. Observations were carried out at the JCMT by Marshall, Leahy and Kwok. These results contribute greatly toward the determination of the emissivity index in the previously unobserved 100 μm to 1 mm region of the electromagnetic spectrum.

MERLIN (Nuffield Radio Astronomy Labs, UK) has been used by R. Davies (Jodrell Bank), M.F. Bode (Lancashire Polytecth., UK) and Taylor to obtain 0.1" resolution thermal emission maps at 6cm of regions near luminous early type stars. Images of the Wolf-Rayet star W147 show it to be a double radio source.

A study by Leahy of the theoretical framework for the solution of the EM structure of rapidly rotating magnetospheres is continuing; a numerical study of the derived equations is in progress. A comparison of observed x-ray pulsar pulse profiles to study neutron star parameters is also being done by Leahy.

The distance and state of evolution of open clusters of the galaxy are being studied through member stars which are double-lined spectroscopic and eclipsing binary components. Schiller (SDSU) and Milone are pursuing a binaries-in-clusters program which makes use of optical data from DAO, Table Mountain, Ca., McDonald Obs, Tx, and Behlen Obs, Ne, and of radial velocity data from DAO (see SA).

A program of ground-based identification of IRAS sources is being continued by Kwok and Hrivnak at CFHT, UKIRT, and IRTF. This has led to the discovery of 15 proto-planetary nebulae. Follow-up ground-based observations are being carried out at DAO, KPNO, OH, and JCMT. Highlights of the results include: 1) the discovery of an unidentified emission feature at 21μm in five proto-planetary nebulae; 2) inverse P Cygni profiles in ten Brackett lines in IRAS 07134+1005; 3) identification of C2 and C3 molecules in several highly carbon-rich proto-planetary nebulae; and 4) CO emission from many proto-planetary nebulae. The discovery of such transition objects has been shown to be extremely valuable in filling the missing link between the asymptotic giant branch and planetary nebulae evolution.

C. INTERSTELLAR MATTER

Six compact planetary nebulae have been surveyed for absorption due to circumstellar atomic hydrogen at 21cm by Taylor using the Westerbork Radio Synthesis Telescope; five were positive detections. Subsequent VLA observations of IC418 revealed a large halo of...
discovered in the far IR solar spectrum on 1982 and 1985 balloon flights. Observations of the Sun in the 20μm window from Mauna Kea have been carried out as part of a search for the n=8-7 transitions of these species of atoms (Clark, Naylor, and Schultz 1987); the search thus far has been unsuccessful.

Clark intends to monitor the solar five-minute oscillations also. It is expected that the far IR solar continuum should show such variations in view of the strong CO periodicity, and the fact that radiation from these two spectral wave lengths originate in the same atmospheric layers.

Approval has been obtained from the Space Division of the Canadian NRC to recommence solar balloon flights, and the telescope system and interferometers are being rebuilt in preparation for those flights. An innovative solution to the problem of channel fringes in FT spectra has been found for the Fourier Transform Spectrometer.

Stagg and M. Bailey (U. Manchester) have shown that terrestrial cratering rate can be accounted for by a large number of very faint comets, but that the size distribution of terrestrial craters is inconsistent with this hypothesis. On the other hand, the number and size distribution of of Earth-crossing asteroids are consistent with the crater distribution data, and can account for most if not all Earth craters. Stagg and Bailey have also calculated the probability of capture (to observed short period orbits) for comets entering the solar system for the first time, as a function of perihelion distance; on the basis of the observed numbers of short period comets, they argue against the Oort comet cloud being strongly condensed. It is therefore unlikely to yield intense comet "showers". Both conclusions argue against comets being a significant source of terrestrial cratering.

E. SOLAR PLANETARY RELATIONS

A Centre of Excellence Network for Space Research has been established at the University of Calgary by the Canadian government. Directed by Cogger, the Centre also involves Clark, Murphee, Sreenivasan, Taylor, and Venkatesan among local scientists. Venkatesan and colleagues have established observatories of ground-based magnetometers and riometers at the South Pole, Sondrestrom (Denmark) and at Iqaluit (Frobisher Bay, NWT). Data from these stations relate to the solar wind interaction with, and the transfer of energy to, the magnetosphere. The group continues to carry out image processing of auroral images from the Viking satellite, and to study optical emission and solar cosmic ray correlations.

F. THEORETICAL ASTROPHYSICS (Incomplete)

A new theory on the origin of carbon stars was developed by Chan and Kwok. Radiative transfer models were made to interpret the infrared spectra of visual and infrared carbon stars.
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An integrated model of asymptotic giant branch evolution including mass loss and dredge up of heavy elements was developed by Bryan, Volk, and Kwok. The model was successful in the prediction of the luminosity function of M and C stars and provides new constraints on the mass loss formula on the asymptotic giant branch.

A theoretical evolutionary model for proto-planetary nebulae was developed by Volk and Kwok. The model predicts observational properties of planetary nebulae and allows the discovery of such objects from ground-based telescopes.

G. SOFTWARE DEVELOPMENTS

Software developed for data acquisition at the RAO's telescopes is described in §III.

A simple computational method for stellar models with convective cores suitable for instructional purposes was developed (Leahy 1988). Using Monte Carlo simulations, an improved method for determining period and amplitude of sinusoidal signals in x-ray data was devised (Leahy 1987c).

The Wilson-Devinney synthetic light curve code has been optimized for the Cyber 205 Supercomputer by Milone and Schiller and a Kurucz atmosphere code was recently installed by C.R. Stagg (Milone and Stagg 1989a,b; Stagg and Milone 1989a,b; Milone et al., 1989). The code has also been parallelized to run on a 64-processor Myrias computer. Groisman developed graphics packages on the University of Calgary Honeywell Multics mainframe and on PCs to more graphically illustrate output from the Wilson Devinney LC subroutine.

A radiative transfer code to compute continuum spectra and images for circumstellar disk has been developed by Taylor and Dougherty and is currently implemented on the Myrias computer.

H. EXTINCTION AND STANDARDIZATION

The implementation of recommendations made to the infrared community by the joint IAU commission (8 and 25) meeting held in Baltimore, 1988 (Milone 1989b, 1989d) should make it possible to minimize the effects of atmospheric water vapor content on infrared observations. One of these recommendations is for the manufacture and distribution of narrower filters which are better centered on the atmospheric windows; another is the modeling of the atmosphere as observations are made, to improve the extinction corrections. The first will require new filter sets for broad band photometry, and the second, a dedicated microcomputer linked to the DAC, which must be operated in a multi-tasking role.

V. OTHER ACTIVITIES

Clark was a member of the Canadian National Research Council Associate Committee on Space Research and its Joint Subcommittee on Space Astronomy, and attended the Reston meeting on NASA Small Attached Payloads Committee on behalf of this subcommittee. Clark completed a number of multiple-choice test banks for using in non-science-major astronomy course examinations.

Kwok completed terms on the Canadian NRC Associate Committee for Astronomy, the Canadian Astronomical Society's subcommittee on theoretical astronomy, and the GAS optical and infrared subcommittee, in 1988, and on NRAO's VLBA refereeing committee in 1989; he became a member of the NRC National Facility Board, NRC's joint subcommittee on Space Astronomy, and the Canada Space Agency, in 1989. He also serves on NRC's Joint Subcommittee on Space Astronomy, the council of the Canadian Institute for Theoretical Astrophysics, and on the advisory committee of the Canada Astronomy Data Centre. Kwok was a member of the SOC for IAU Symposium 131, the 4th Trieste Workshop on Pulsation and Mass Loss in Stars, and for IAU Colloquium 103, all in 1987; and for the Workshop on Angular Momentum and Mass Loss for Hot Stars, in 1989. He presented ten invited review papers in the interval 1987-1989.

Milone continued on the Organizing Committee of Commission 25 (Photometry and Polarimetry) and organized and chaired two sessions of the joint commission (9 and 25) meeting on Infrared Extinction and Standardization, at the Baltimore IAU meeting. The proceedings of that meeting have been published by Springer Verlag (Milone 1989b). He was awarded a Killam Resident Fellowship in Fall 1988 for work on two books related to astronomical teaching: Challenges of Astronomy: Hands On Experiments for the Sky and Laboratory, a translation and revision of Astronomische Musterversuchung by W. Schlosser and Th. Schmidt-Kaler of Ruhr Univ., FRG; and Exploring Ancient Skies, a textbook and comprehensive bibliography on ancient astronomy by D. H. Kelley (Archaeology) and Milone. Both are to be published by Springer-Verlag. He authored/presented six invited papers in the interval 1987-1989.

Taylor served on the Observing Priorities Committee of DRAO, in the Working Group for Canadian participation in ESO's QUASAT mission, on the Scientific Objectives Committee, core science team and imaging team of the Soviet Radiosatellite VLBI mission. He is also serves on the Radio Astronomy subcommittee of NRC's Associate Committee on Astronomy and on NRC's Committee on the Future of the Algonquin Radio Telescope.

CITA's 1988 "Kingston Meeting" was held at the University of Calgary's Kananaskis Centre, on the theme "Cosmological Constraints from Stellar Evolution." Kwok and Leahy were the LOC.

Clark, Fry, and Milone continued to lecture to local area high schools and other organizations and to provide astronomy and astrophysics career counseling on science careers days.
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