

National Research Council of Canada
Herzberg Institute of Astrophysics
Dominion Radio Astrophysical Observatory
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This report covers the period from 1999 April 01 through 2000 March 31, while publications are for calendar year 1999.

1. PERSONNEL

The professional staff of the Observatory comprises T.L. Landecker (Director), P.E. Dewdney (Deputy Director), T.A. Burgess, B.R. Carlson, A.D. Gray, L.A. Higgs, G.J. Hovey, C.R. Kerton, L.B.G. Knee, B.D. Parchomchuk, K.F. Tapping, B.G. Veidt, and A.G. Willis.

Dewdney is the Manager for the Square Kilometre Array for the Herzberg Institute of Astrophysics. Carlson and Veidt carry out engineering research in this area. The activities of this program are reported under the Office of the Director General.

Knee and Kerton are NRC Research Associates, while C. Brunt is a Research Associate with U. Calgary. All three are working on the Canadian Galactic Plane Survey (CGPS) at DRAO. R. Kothes and B. Uyaniker are NSERC Visiting Fellows, also working on the CGPS. Uyaniker started in 1999 October, moving from MPIfR in Bonn. Kerton, formerly of U. Toronto, came in 1999 November on completing his Ph.D. He replaced B.J. Wallace, who moved in 1999 July to a position with the Smithsonian Astrophysical Observatory in Hawaii.

S.M. Dougherty manages the Space-VLBI Correlator (supported by the Canadian Space Agency). Also working on the project are D. Del Rizzo, A. Fink, and W.T. Petrachenko, the latter seconded to HIA from Natural Resources Canada (Ottawa).

S. Pineault (U. Laval) began a sabbatical year at DRAO in 1999 August. He was joined in 2000 January by his Ph.D. student, F. Cazzolato, who is working with him for the remainder of the sabbatical. J.I. Harnett (U. Technology, Sydney, Australia) spent a sabbatical period at DRAO during 2000 February and March.

J.A. Galt, J.D. Lacey, C.R. Purton, and R.S. Roger are continuing as Guest Workers. A. Yar joined DRAO as a Guest Worker in 2000 March.

A.C. Guerra (formerly Thorsley) is a graduate student in Electrical Engineering at U. Alberta, and is carrying out her M.Sc. research at DRAO.

2. INVOLVEMENT IN THE COMMUNITY

Landecker is an Adjunct Professor at the University of Alberta, and is also a member of the Okanagan High-Technology Council and the South Okanagan Advanced Projects Committee. These latter organizations promote the growth and the health of knowledge-based economic activity in the Okanagan region of B.C.

Dewdney is an Adjunct Professor at the University of Calgary, and serves on the Canadian Astronomical Society

(CASCA) Radio Astronomy Committee, the Joint Space Subcommittee on Astronomy, the International Square Kilometre Array Steering Committee, the VSOP International Steering Committee, and the Global Very Long Baseline Interferometry Working Group.

Tapping serves on the CASCA Radio Astronomy Committee, and, on behalf of CASCA and NRC, represents Canadian astronomers in frequency protection. He is a member of the Canadian Delegation to the International Telecommunications Union participating in Working Group 7(d). Tapping is also Chairman of the Okanagan Basin Institute, a non-profit organization contributing to strategic planning in the region.

Dougherty is a member of the CASCA Radio Astronomy Committee, and also serves on the VSOP International Steering Committee. Knee serves as an external referee for the Canadian Time Allocation Group (CTAG) for the James Clerk Maxwell Telescope (JCMT). Willis serves on the AIPS++ Scientific and Technical Advisory Committee.

3. TELESCOPES

The Herzberg Institute of Astrophysics (HIA) operates DRAO as a National Facility for Canadian radio astronomy. Two radio telescopes, the Synthesis Telescope and the 26-m Telescope, are available to external users. The Solar Flux Monitoring Program provides data to a worldwide community of users as a scientific service.

A newsletter concerning new developments of DRAO projects, telescopes, and software is published at six-month intervals; it is available on request. Information about DRAO, including the newsletter, is available on the World-Wide Web at <http://www.drao.nrc.ca>.

3.1 The Synthesis Telescope

The DRAO Synthesis Telescope (ST) is a unique instrument for the study of the interstellar medium. It operates simultaneously at two frequencies, recording three data products: spectral information in the 1420 MHz neutral hydrogen (H I) band, full polarization information in continuum bands flanking the spectrometer band, and total intensity in a 408 MHz continuum band. The H I spectrometer features 256 channels over a bandwidth selectable from 0.125 to 4.0 MHz (channel widths from 0.1 to 3 km s⁻¹), and can cover velocities from -1000 to +3000 km s⁻¹, making it well suited to studies of the interstellar medium in our Galaxy and in nearby external galaxies.

The ST employs seven antennas of 9 m diameter distributed along an east-west baseline. Using 12 configurations of the antennas, it fills the aperture plane from 13 to 604 m, yielding sensitivity to structures from 45' to 1' across a field of 2° at 1420 MHz. (At 408 MHz it is sensitive to structures from 150' to 3.5' over a 6° field.) Information on structures

corresponding to baselines shorter than 13 m is routinely added to ST data, being derived from H I-line observations with the DRAO 26-m Telescope, or from other single-antenna observations.

For the past 5 years approximately 85% of available observing time on the Synthesis Telescope has been devoted to the acquisition of data for the Canadian Galactic Plane Survey (CGPS), a project aimed at gaining a better understanding of the interstellar medium in our Galaxy. The CGPS is discussed in more detail below. The remaining observing time on the Synthesis Telescope has been set aside for competitive, peer-reviewed time-allocations to external users. A total of 33 external observations were made during the 5 year period of the survey, in addition to 4 sessions of solar observing near summer solstice (1995, 1996, 1998, 1999).

Observing efficiency has increased substantially since the beginning of the CGPS. In 1995 about 44 fields were observed, but at present observing is progressing at a rate of about 51 fields per year, a 16% increase, and close to the theoretical maximum possible with current scheduling practices. This has been made possible by a decline in down-time due to equipment failures.

Proposals for external observations with the Synthesis Telescope should be addressed to Gray (Andrew.Gray@nrc.ca); proposal deadlines are October 15 and April 15. A data reduction "cookbook" is available.

3.2 The 26-m Telescope

The DRAO 26m Radio Telescope is equipped with receivers for making observations between 1350 and 1750 MHz (L-band), and at 6.6 GHz. All receivers are equipped for observing two polarizations. A digital spectrometer is used, which is also capable of making simultaneous observations in two polarizations. The main areas of application of the L-Band receiver are H I and OH spectroscopy, although some observations of recombination lines have been made. Much of the observing time on the 26-m Telescope uses this receiver to collect low-spatial-frequency information to complement H I observations made with the Synthesis Telescope. The 6.6 GHz receiver can be used for observations of cosmic methanol; however, the antenna efficiency at this frequency is low (about 16%) and the half-power beamwidth is $7.5'$, about 8 times the RMS pointing accuracy.

During 1999, Higgs accurately measured the antenna pattern at 1420 MHz of the 26-m Telescope within 30° of the main beam, using the Sun as an emission source. These measurements have been combined with electro-magnetic calculations of the antenna pattern and an analysis of ground-radiation curves to give a good estimate of the overall pattern of the antenna. The derived pattern has been used to correct for stray radiation the 25 000 H I spectral observations in the Galactic plane made in 1997. These spectra are being used to derive short-spacing data for CGPS H I observations with the Synthesis Telescope. A paper titled "Low Resolution DRAO Survey of H I Emission from the Galactic Plane" is being prepared by Higgs, in collaboration with Tapping.

A detailed analysis of the accuracy of the H I spectra observed with the 26-m Telescope has been completed, using

observations made during the above survey, observations made following the survey with a modified receiver, and spectra from the Leiden/Dwingeloo Survey. This has indicated that in any channel in which the brightness temperature exceeds 10 K, the absolute accuracy is 1.6 K or 6%, whichever is less. This and earlier studies also indicate that a small fraction (2%) of the Leiden/Dwingeloo Survey spectra have calibration errors of more than 10%.

For further information on the telescope, contact Tapping (Ken.Tapping@nrc.ca). To apply for observing time, contact Gray (Andrew.Gray@nrc.ca).

4. COMPUTER/SOFTWARE SYSTEMS

The current computing power at the Observatory consists of a 32-node (450-MHz dual-processor) Beowulf cluster, a 300-MHz single-processor Sun UltraSPARC, a 200-MHz single-processor UltraSPARC clone, two 200-MHz dual-processor UltraSPARC clones, seven IBM RS/6000 servers (two model 320Hs, two model 520s, two model 550s, and one 58H), an SGI Indigo 2, and numerous X-terminals and PCs. All the computers at the Observatory are connected by a local area network.

Hoffmann, Willis, Gray, Tapping, and Landecker have modified Synthesis Telescope observing system software to better integrate mechanisms for producing the non-sidereal antenna and fringe-stopper tracking rates required for observations of solar system objects. Current projects that will benefit from this upgrade include the on-going research program investigating Solar radio emissions, as well as a new project aimed at using the Moon as a calibration reference at 408 MHz.

Higgs has continued to support the DRAO "export package" of application software, adding new programs as they are needed. This software package is supported for IBM RS/6000 machines running AIX, Sun machines running Solaris or Sun O/S, SGI machines running IRIX, and PCs running Linux. In the past year, software for determining the best-fitting spectral-index distribution over a region observed in four or more frequencies has been developed, as well as a program for convolving images, in which the spatial resolution is a function of image position, to a new resolution. In addition, algorithms for the automatic identification of H I self-absorption features have been devised. Higgs has also developed an archive FITS format for visibility data recorded by the Synthesis Telescope which can be read in the AIPS environment, and an extensive suite of telescope control and data analysis software to enable the use of the Sun in determining the 26-m Telescope antenna pattern within 30 degrees of the main beam.

5. AIPS++

AIPS++ is a new image-processing system for radio astronomy, being developed by the U.S. National Radio Astronomy Observatory. The Herzberg Institute of Astrophysics is a partner in the project, and Willis continues to serve on the AIPS++ Scientific and Technical Advisory Committee. In the past year, DRAO has provided considerable input to the package, as it is the first institution to install the package on a distributed processing system (Beowulf). This has

revealed numerous flaws in the package, which have been rectified, making AIPS++ more robust.

6. JCMT CORRELATOR

DRAO is playing a leading role in the development of the Auto-Correlation Spectrometer Imaging System (ACSIS) that is being built for the James Clerk Maxwell Telescope (JCMT), in an international collaboration with groups at the UK Astronomy Technology Centre at the Royal Observatory, Edinburgh (ROE), and the Joint Astronomy Centre (JAC) in Hawaii.

The ACSIS system is a correlation spectrometer that will connect to a receiver array via the Nasmyth focus to provide rapid spectral-line imaging capability. ACSIS will support up to 32 beams—a vast advance over the present single-beam systems—and will be able to sample 20 spectra per second. This will permit fast, multi-beam scanning of large areas of sky. An innovative data processing unit will provide the observer with gridded, calibrated 3-D data cubes in-hand when the observation is over.

When ACSIS is installed (projected for fourth quarter 2001), it will be able to produce 1024-point spectra over an 800-MHz bandwidth (providing a velocity resolution of 1 km s^{-1} at 345 GHz), every 50 ms from 32 beams on the sky (the instantaneous bandwidth per sampler is 2 Gbit s^{-1}). Numerous other observing modes will also be available, including a narrow-band mode, providing 8192 channels (a velocity resolution of 0.03 km s^{-1} at 345 GHz).

An important aspect of ACSIS is its ability to process data at 10 MB s^{-1} and display results in real time. Processing operations supported include normalization and linearization of auto-correlation functions, chop/nod demodulation, sky subtraction, data decimation in time or frequency, averaging, co-adding spectra, baseline fitting, flat-fielding, and spatial gridding. Real-time display of data provides an astronomical and engineering interface to the system, which will allow the observer to make real-time observing decisions that depend upon previous results. Observing modes will include: raster, jiggle, stare, and 5-point.

The project is close to half way to completion. The detailed design was finished on schedule in 1999 June and prototypes now exist for all the sections except the IF, which should be available in a few months. B. Force (JAC) is developing the microwave components of the IF system. Various filters have been tested and Force is now working on the down-converter module, which translates the signals from the front-end receivers to baseband. K. Yeung (HIA/JCMT Group) has completed the design of the IF control hardware and software. S. Gray (U. Victoria student) has written software for the IF system. A 16-element 350-GHz receiver (HARP) is being developed for ACSIS by MRAO in Cambridge, UK, and the HIA/JCMT Group, in Victoria; Yeung is now working on the HARP project. At present this is the only heterodyne receiver array under development for the JCMT.

R. Casorso (HIA) has designed and built a prototype 2 Gbit s^{-1} A/D converter, and it has passed initial tests. Burgess has completed development of the prototype correlator and has begun testing it with the A/D converter.

The greatest challenge at present is the data processing. The prototype system consists of 8 dual-processor PCs, each running Linux. It must synchronize closely with the telescope observing system, particularly with the movement of the antenna and the sub-reflector. Willis and J. Lightfoot (ROE) are working on this system. Lightfoot has developed what is essentially a programmable calculator for the reduction and calibration of ACSIS data, and Willis is integrating this calculator into the rest of the ACSIS system. A.-C. Lachapelle (U. Sherbrooke student) has worked with Willis to complete development of a prototype real-time display system. Once this and the other systems are ready, a final design review will be held before large-scale production of components takes place. This design review is expected in the last quarter of 2000.

Pictures of recent prototypes and more information on ACSIS may be found on the DRAO web site <http://www.drao.nrc.ca>.

7. CANADIAN GALACTIC PLANE SURVEY

The Canadian Galactic Plane Survey (CGPS) Consortium, led by A.R. Taylor (U. Calgary), now comprises 57 scientists at 24 institutions in Canada and 5 other countries. The project is aimed at gaining a better understanding of the interstellar medium (ISM) and the processes that take place within it, on scales ranging from the influence of single stars to Galaxy-wide phenomena like spiral density waves. Data being acquired or reprocessed for the survey include radio continuum images at metre and decimetre wavelengths, H I and CO spectral lines, and mid- and far-infrared images, all with arcminute resolution over a 9° wide strip between Galactic longitudes $l=74^\circ$ and $l=147^\circ$. More details on the survey may be found at <http://www.ras.ualgary.ca/CGPS>.

DRAO's contribution to the survey comprises 408-MHz and 1420-MHz radio-continuum and H I spectral-line data. Much of the observing time on the Synthesis Telescope has been devoted to this project since 1995 March. The 5-year observing project is now complete, with 192 fields observed for the survey. Processing of the data is continuing at DRAO, and is currently about 60% done, with completion expected by the end of 2001. The data reduction effort at DRAO and subsequent scientific analysis at Canadian universities is being supported by a grant from the Natural Sciences and Engineering Research Council (NSERC). The data reduction is being carried out by the team of Brunt, Kerton, Knee, Kothes, Parchomchuk, and Uyaniker at DRAO, and Gibson (U. Calgary). Knee co-ordinates the DRAO work.

The processed data are initially available to Consortium members only, but—after a proprietary period—are being released to the worldwide astronomy community through the Canadian Astronomy Data Centre (CADC), operated by HIA in Victoria. The first such data, at the high longitude end of the survey, are already available at CADC (<http://cadcwww.hia.nrc.ca/>).

7.1 Phase 2 of the CGPS

Planning for a Phase 2 CGPS project is under way, with considerable debate within the Consortium regarding how

best to utilize any additional telescope time to further the science being extracted from the existing CGPS database (some of which is discussed below under “Research Activities”), and to open new avenues for research. Observing for the Phase 2 project is likely to begin in 2000, but the future of the project is still dependent on the availability of external funding.

An important consideration in the planning process is the advent of the surveys with comparable goals being undertaken elsewhere. The Southern Galactic Plane Survey (SGPS) has begun using the Australia Telescope (AT) to image the region between longitudes $l=255^\circ$ and $l=357^\circ$. A group of Canadian, U.S., and Australian scientists has proposed linking the CGPS and the SGPS to yield a database covering about 90% of the Galactic disc by using the Very Large Array (VLA) to observe those longitudes inaccessible to both the Canadian and Australian telescopes. The first allocation of VLA time has now been awarded for this work, to image the region from $l=65^\circ$ to $l=18^\circ$. This group includes A.R. Taylor (principal investigator) and S. Gibson (U. Calgary), Landecker, Brunt, and Kerton (HIA), J. Irwin (Queens U.), P. Martin (U. Toronto), J. Dickey and N. McClure-Griffiths (U. Minnesota), B. Gaensler (MIT), M. Heyer (U. Massachusetts), J. Jackson (Boston U.), J. Lockman (NRAO), and A. Green (U. Sydney). Together, the CGPS, the SGPS, and the VLA survey (the VGPS) will provide a continuous, panoramic vista of the neutral hydrogen in the 1st, 2nd, and 4th quadrants of our Galaxy at an unprecedented arcminute-scale resolution.

A logical first step for CGPS Phase 2 observations will therefore be an extension to $l=65^\circ$ to complete coverage of the Cygnus-X region and to join up with the VGPS. Extension to $l=180^\circ$ is also being considered to complete coverage of the Perseus Arm. At the time of writing, discussion within the consortium continues on the merits of extensions in latitude. A series of pilot fields at high latitudes (up to $b=30^\circ$) was observed with the Synthesis Telescope in early 2000 to provide data for this debate.

Enquiries about CGPS or the Phase 2 project should be addressed to Taylor (russ@ras.ucalgary.ca) or Landecker (Tom.Landecker@nrc.ca).

8. SPACE VLBI

The Japanese-led VSOP mission is now entering its fourth year of operation, and many science results from observations with the HALCA satellite are now appearing. A symposium was held in 2000 January at ISAS, Tokyo, to celebrate this science endeavour. The 80 delegates in attendance were treated to talks on AGN, jet structure, intra-day variables, supernovae, interstellar scattering, masers, X-ray binaries, and the connection with observations/science from other wavelength regions, particularly X-ray and gamma ray energies. Dougherty presented a paper on HALCA observations of the unusual X-ray binary system LSI +61°303, a research collaboration with A.R. Taylor and W. Scott (U. Calgary), and M. Peracaula and J. Paredes (U. Barcelona). Canada is also making a major contribution to the VSOP Survey and the VLBA Pre-launch Survey of radio bright AGN's. About 200 Survey sources have been observed, and about half have

been reduced at the processing center at U. Calgary. The VLBA pre-launch survey has been fully analyzed and the results submitted for publication.

The science achievements of the VSOP mission have not been without their difficulties. After recovering from an on-board system failure in 1999 January, HALCA performed flawlessly until 1999 October, when one of four reaction wheels failed and HALCA started to tumble. Normal attitude was regained on 2000 February 5, and scheduled observations commenced on March 8, but the loss of a reaction wheel has restricted pointing capability. Initial observations after recovery are being made in the anti-Sun direction. Experiments to ascertain the ability to point the spacecraft in other directions are being conducted.

With the HALCA observing program halted for the bulk of the autumn season, the Canadian S2 correlator has been able to complete correlation of all experiments that were part of the aggressive schedule employed to maximise the scientific return of the mission in the aftermath of the on-board system failure last year. To date, a total of 204 observations have been handled: 184 of these have been successfully correlated and released, and only 16 have been abandoned. The remainder are in various stages of correlation.

The great success of VSOP has initiated a new era in VLBI radio astronomy. By operating at higher frequencies, with higher sensitivity and higher orbits, the next generation of Space-VLBI (SVLBI) missions presently being planned by the international community will enable scientists to explore a number of exciting areas of astrophysics requiring high resolution observations. At the present time there are three future SVLBI missions in some stage of planning or development: the Japanese VSOP-II mission, ESA ISS-SVLBI mission, and the NASA/JPL ARISE mission. These missions all aim to achieve much higher sensitivity than VSOP by increasing the bandwidth of the recorded signal (at least 1 Gbit s^{-1}), and increasing the antenna area (15-25m diameter). In addition, they aim to have larger apogee heights than VSOP, and operate at frequencies as high as 86 GHz, giving resolutions up to 40 times that of VSOP.

It is hoped that Canada will be able to play a role in these exciting new missions through the new S3 high-bandwidth record/playback systems being designed at the Space Geodynamics Laboratory, and/or possibly through the correlator design group at DRAO, or even through space-craft components.

In addition to SVLBI correlation, the Canadian S2 correlator supports frequency-switched geodesy experiments. The Geodetic Survey Division (GSD) of Natural Resources Canada (NRCan) is presently testing the S2 geodesy system using the Canadian Transportable VLBI antenna (presently sited at DRAO), the Algonquin Radio Observatory in Ontario, and another antenna in Yellowknife, NWT.

9. FREQUENCY PROTECTION

Tapping represents NRC in national and international forums to protect the frequency bands in the radio spectrum allocated by international agreement to radio astronomy. In order to increase the expertise level in spectrum management

in the millimetre and sub-millimetre bands, P. Feldman (HIA) has now joined the frequency protection effort.

Over the last five years, changing circumstances have made spectrum protection a critical issue for radio astronomers. New radio services, some using constellations of hundreds of satellites, and new technologies using high-altitude transmitter platforms, partially or totally negate the classical methods of protecting radio observatories from interference, namely geographic location and local topography. Pressure from the operators of the new radio services has led to an international decision to conduct a study in which radio astronomy must establish and justify the protection needed for effective observations to be possible in each individual allocated band.

Efforts are focussed on defining the protection envelope in terms of all available dimensions, including mean and peak levels of interference and an upper limit to the amount of observing time at any observatory that can be lost due to interference.

The Iridium satellite communication system (now defunct) provided an important experience in dealing with the issue of satellite interference to radio astronomical observations, politically, managerially, and practically. Galt constructed and operated an automated system for monitoring the Iridium signals in their allocated band, and levels of interference in the 1610.3–1613.8 MHz radio astronomy band. Although Iridium is no longer functioning as a communication system, Iridium signals are still being detected using this equipment. With the current low level of traffic, however, no significant problems with interference to observations have been encountered. Galt has also developed a more general-purpose interference monitor that can be applied to future interference problems when they occur.

The other issue important to radio astronomers has been the announced intention of the International Telecommunications Union to change the spectrum allocations in the band 71–275 GHz, and, later, 275–900 GHz. Canadian astronomers have contributed to a spectrum plan that has been accepted in a number of countries. However, some of those who wanted the allocations changed are now suggesting that the whole issue be dropped for the time being.

Enquiries regarding spectrum management should be directed to Tapping (email: Ken.Tapping@nrc.ca).

10. RESEARCH ACTIVITIES

10.1 Wolf-Rayet Stars

Cazzolato and Pineault have completed their analysis of the ISM surrounding the Wolf-Rayet star WR 143. As originally suspected, this star appears to be surrounded by a thick shell of neutral hydrogen. The kinematic distance derived for this structure does not however agree with the distance estimate for the star. This is interpreted as indicating that, since the star is in front of the Cyg OB1/OB3 super-bubble, the H I shell (and the star) is located in material expanding away from the super-bubble towards the observer.

Pineault has also joined M. Arnal, C. Cappa, and S. Cichowolski (UNLP, Argentina) in a study of the environment of the Wolf-Rayet star WR 130. A preliminary analysis

has shown the presence of a thick shell of ionized gas and heated dust surrounded by a shell of neutral hydrogen. Interestingly, the star itself is not near the geometrical center of this shell structure but rather embedded in it. Further analysis is currently underway to obtain the physical parameters of the various components and propose a consistent overall picture.

Dougherty has continued work on non-thermal radio emission from Wolf-Rayet systems in collaboration with P. Williams (IfA, Edinburgh). They have identified the companion to WR 146 as a high luminosity O8 star, using a high resolution blue spectrum obtained from the William Herschel Telescope. This identification is corroborated by the high mass loss rate inferred from VLA 22 GHz observations that detected winds from both the WR star and the O-star companion. In addition, they have shown that 80% of non-thermal emitting WR stars are binary systems. This strongly supports the hypothesis that non-thermal emission from WR stars (and possibly massive stars in general) results from binary interaction.

Dougherty has also obtained high temporal resolution observations of the 78-day WC6+O8.5 binary WR 11 throughout the orbit, using the Australia Telescope. Made in collaboration with J. Chapman (ATNF), A. Moffat (U. Montreal), and C. Leitherer (STScI), these observations will test whether relativistic electrons escape from deep within the stellar wind envelope of the WR star to large radii along the contact discontinuity between the two stellar winds. Dougherty spent a month visiting the ATNF to reduce these data in 1999 September.

10.2 Space-VLBI observations of LSI +61° 303

Dougherty, with A.R. Taylor and W. Scott (U. Calgary), and M. Peracaula and J. Paredes (U. Barcelona), have used a global array of ground radio telescopes and the Japanese orbiting radio telescope HALCA to obtain multi-epoch, high resolution images of a radio outburst from the unusual X-ray binary LSI +61° 303. These images represent the best ever obtained for this unusual source. They reveal an apparently stationary pattern of symmetric emission extending about 2 mas on either side of a central source. The extended emission is reminiscent of the precessing radio jets seen in SS 433. The central source is observed to expand at a rate of 0.2 mas d^{-1} . At the distance of the source, this corresponds to 700 km s^{-1} .

Dougherty has also been actively involved in a number of other projects that utilize the unique signal processing capabilities of the S2 correlator at DRAO.

10.3 Dust in the Galaxy

Kerton completed his Ph.D. thesis with U. Toronto. The work, entitled “Multiwavelength Studies of Dust Associated With Galactic H II Regions,” made extensive use of CGPS data, and describes in detail the creation of a mid-infrared data set that is now part of the CGPS multi-wavelength data base. This data set is based on a reprocessing of IRAS 12 and 25 μm data to higher resolution.

10.4 Isolated H II Region KR 140

Kerton, collaborating with P.G. Martin (U. Toronto/CITA) and D.R. Ballantyne (U. Toronto, now Cambridge), has completed the analysis of the isolated H II region KR 140. The CGPS data set was used to examine the region in the context of the surrounding interstellar environment. The region appears to be isolated from the nearby vigorous star formation activity in W3/W4/W5. D. Johnstone (U. Toronto) has recently joined this group which is now utilizing SCUBA data from the JCMT to explore the small-scale star-forming regions surrounding the H II region.

10.5 H I Self-absorption

Higgs, Dewdney, and Brunt are collaborating with S. Gibson and A.R. Taylor (U. Calgary), W. McCutcheon (UBC), and H. Wendker (Hamburg) on a systematic search for H I self-absorption features in the CGPS. Brunt has been gathering ^{12}CO and ^{13}CO data and generating simulated H I data sets to test automated detection algorithms. The first paper resulting from this project, by Higgs, Dewdney, Gibson, and Taylor, has been accepted by *The Astrophysical Journal*, and presents data on a small representative sample of the many H I self-absorption features seen throughout the area covered by the CGPS, in particular in the Perseus Arm but also in the Local Arm.

Knee and Brunt are using CGPS data to search for and study the phenomenon of large-angular-scale self-absorbing H I clouds near the Galactic Plane. The first structure to be identified and characterized is a large arc or band of absorption at the large radial velocity (with respect to the LSR) of -80 km s^{-1} , located in the direction of the Perseus Arm. The absorbing cloud is likely to be a phenomenon of the local ISM, which implies that this cold atomic cloud ($T \sim 30\text{ K}$) has a remarkably large peculiar velocity with respect to standard Galactic rotation models. There are hints in the CGPS data that large scale H I self-absorption features are widespread in the Galaxy.

10.6 Star Formation in NGC 1333

Knee and G. Sandell (NRAO) have mapped the NGC 1333 star formation region in the 850 and 450 μm dust continuum using the JCMT. They find more than 30 discrete sources, of which nearly all strong sources are Class 0 protostars, as are many of the fainter ones. The cloud structure is dominated by dust ridges and shells caused by powerful outflows, and there is some evidence for outflow-triggered star formation. The mass spectrum of the discrete sources is rather flat: this may be due to a small sample size or to lack of resolution of multiple sources, but could also suggest that the mass function in an active cluster-forming core differs from that of the standard IMF.

10.7 Stellar Wind Phenomena in the CGPS

Knee, B. Wallace (CfA), and M. Normandeau (U.C. Berkeley) are continuing their study of stellar wind related phenomena in the CGPS. The target of their study is a group of high-velocity H I filaments which appear to radiate from the

Wolf-Rayet star WR 5 and the adjacent O-star HD 17603. The H I filaments have an LSR velocity of -60 km s^{-1} with evidence of acceleration along their length. There is a possible morphological association of these filaments with CO emission and a possible large scale H I shell at -14 km s^{-1} .

Pineault, N. St-Louis (U. Montreal), Normandeau and their Argentinian colleagues M. Arnal, C. Cappa and S. Cichowolski (UNLP) met at DRAO to continue their work on the search for stellar wind bubbles around massive stars. They concentrated their efforts on about a dozen known O (some of them Of) stars. They have detected specific features associated with individual objects (e.g. neutral hydrogen or infrared shells), but it has become clear that questions of a more general scope need to be addressed, among them the development of better statistical tools (within the context of the CGPS database) to make an unambiguous assessment of the statistical significance of suggested associations, and a better understanding of the factors determining the relative strength of continuum (ionized gas, heated dust) and neutral features.

S. Mashchenko (U. Montreal), Pineault, and St-Louis are proceeding with a project to use Mashchenko's algorithms to search for the signature of bubbles, shells or cavities around a large sample of candidate objects (as opposed to pointed studies) in the CGPS database.

10.8 Polarization of Galactic Emission

Gray has continued to work with Landecker, Dewdney, Willis, Taylor (U. Calgary), and M. Normandeau (U.C. Berkeley) on studies of Faraday rotation of the polarized Galactic synchrotron radiation by magneto-ionic media in the interstellar medium (ISM). This has resulted in a publication in *The Astrophysical Journal* (Gray *et al.* 1999) on the magnetic field and diffuse gas structure in the vicinity of the W3/W4/W5/HB 3 complex which discusses the extended low-density envelopes of the H II regions W 3 and W 4 detected via this method.

Within the CGPS consortium, polarization studies are being pursued by the team of Brown and Taylor (U. Calgary), Dewdney, Gray, Landecker, and Uyaniker (HIA), and Peracaula (U. Barcelona). Brown is using Faraday rotation measurements of compact sources in the CGPS region as a tool to probe the Galactic magnetic field. Peracaula has prepared rotation-measure images to investigate the magneto-ionic component of the ISM.

Uyaniker began processing CGPS polarization images in 1999 October, and is investigating new techniques for the reduction and analysis of the polarization data, including the combination of single-antenna polarization data from Effelsberg with Synthesis Telescope polarization data.

Uyaniker has also recently completed a paper on the turbulent interstellar magnetic fields in collaboration with R. Beck and E. Berkhuijsen (MPIfR), and is working on the polarization data from the Effelsberg Medium Latitude Survey, comparing it with ROSAT all-sky survey to determine on the nature of the disk-halo connection towards the Cygnus Superbubble. This work is in collaboration with E. Fürst (MPIfR) and B. Aschenbach (MPIfEP), and will soon be published.

10.9 Supernova Remnant Studies

In the wide-field images of the Canadian Galactic Plane Survey it is not uncommon for H II regions and supernova remnants (SNRs) to occur in clusters on the sky. Two efforts are underway to determine whether this apparent clustering is significant, or is merely the result of chance superpositions.

R. Christie (Okanagan University College) and Landecker are investigating a group of objects near $l=127^\circ$. Evidence from H I features, morphologically associated with the individual objects, is that the two SNRs and three H II regions in this group are all at the same distance.

Kothes and Landecker, together with D. Routledge and T. Foster (U. Alberta) are investigating a group of two SNRs and at least five H II regions near $l=94^\circ$. In this cluster, there is a striking pairing, in which each SNR lies adjacent to an H II region of nearly the same angular size. Foster and Routledge have investigated one of these pairs, the SNR G94.0+1.0 and the H II region NRAO 655 (as part of Foster's M.Sc. thesis). This study identified H I features associated with NRAO 655. In a companion investigation, Foster detected recombination-line emission from NRAO 655 using the 26-m Telescope. The group is now extending recombination-line observations to other objects in the cluster in an attempt to establish kinematic distances.

Kothes has discovered several SNR candidates in the CGPS data, close to the Cygnus-X region. Two of those are very weak sources expanding in stellar wind bubbles. Radial velocities suggest that one of these bubbles is located in the Cygnus arm at a distance of about 10 kpc with a radius of about 150 pc.

Kothes is also collaborating with W. Reich (MPIfR) in a study of the SNR G11.2-0.3. A pulsar within an x-ray emitting nebula was recently discovered in the geometrical center of G11.2-0.3 using ASCA observations. Kothes and Reich used the 100-m Effelsberg telescope to detect a flat-spectrum synchrotron source at the same position, making the remnant a member of the small group of composite SNRs (which show a flat spectrum core within a steep spectrum shell).

Uyaniker, Landecker, Kothes, and Gray have embarked on a study of the SNR HB21, including polarization and H I data from the CGPS. Preliminary results show strong depolarization coincident with and perhaps extending beyond the brightest total intensity emission, possibly an indicator of shock pre-cursors. Uyaniker is also collaborating with W. Reich (MPIfR) in studying the depolarization of W63, with multi-frequency polarimetry measurements using the Effelsberg 100-m telescope.

Pineault and G. Joncas (U. Laval) have completed their analysis of Synthesis Telescope observations of the new SNR G106.30+2.76. The continuum and H I-line observations are consistent with a dynamical model in which the SNR is in the very late stages of its isothermal evolution, where the pressure inside the SNR is approaching that of the ambient interstellar medium.

10.10 Interstellar Turbulence

Brunt, in collaboration with M. Heyer (FCRAO), E. Vazquez-Semadeni (UNAM), and B. Pichardo (UNAM), is

studying interstellar turbulence in both molecular (FCRAO Outer Galaxy Survey) and atomic (CGPS) gas. Estimation of turbulent energy spectra in the ISM is carried out via the use of principal-component analysis (PCA). To investigate the accuracy of this method, magneto-hydrodynamical simulations of the ISM are 'observed' and subjected to the same analysis as real data. This study will be combined with the results of the H I Power Spectrum project being undertaken by S. Gibson (U. Calgary), D. Green (MRAO), M. Normandeau (U.C. Berkeley), Purton (HIA), and X.-Z. Zhang (BAO), with a view to making a link between the dynamical and structural states of atomic gas and the sources of energy input in the Galaxy.

10.11 CO in the Far Outer Galaxy

Brunt has been working on the development of a data-processing scheme to remove correlated noise (due to reference-shared measurements) in the FCRAO Outer Galaxy Survey. This scheme has been very successful, and has allowed him to obtain a very good sample of molecular clouds in the Outer Spiral Arm. The arm is kinematically distinct feature beyond the Perseus Spiral Arm in the second quadrant of the Galaxy. If the molecular material that comprises the arm is at its kinematic distance, then it is estimated that around $3 \times 10^5 M_\odot$ of molecular mass lies in the longitude range $l=115-140^\circ$, centered on latitude $b \approx +2^\circ$. This material is at a Galactocentric radius of around 17 kpc and appears to be participating in the warp of the Galaxy, lying at around 300 pc above the local Galactic mid-plane.

This segment of the Outer Arm is almost certainly an extension of the spiral arm found in the first Galactic quadrant. Previous searches for CO emission in this region have missed most of this arm due to low sensitivity, restricted latitude coverage, or low spatial resolution. Pointed studies towards IRAS sources in this region (Brand & Wouterloot 1994; A&AS, 103, 503), have shown that several of the clouds in this arm are actively forming stars, and are associated with H II regions.

10.12 H I Line-widths in Galaxies and the Tully-Fisher Relation

Brunt has developed a new Fourier-space H I line-width measurement scheme for external galaxies. S. Schneider (U. Massachusetts) is working with Brunt to investigate how this measurement scheme compares to the standard H I line-width measurements. Initial tests are promising; this will ultimately be applied to the Tully-Fisher relation, with a view to improving the accuracy of the calibration.

10.13 X-Ray Absorption and H I Column Measurements

Brunt, along with J. Bregman (U. Michigan), are using the Synthesis Telescope to obtain neutral hydrogen measurements towards two galaxy clusters for which x-ray absorption measurements have been made. These will provide a way to study the physical properties of H I gas in addition to the existing self-absorption and continuum absorption techniques.

10.14 Solar Research

Solar research at DRAO is carried out by Tapping, with various collaborators, including I. Burke (McDonald Detweiler), H. Cameron (Acadia U.), K. Harvey (NSO-Kitt Peak), R. Mathias (U. British Columbia), D.L. Surkan (White Clinic), and K. Zwaan (Utrecht; now deceased). Research is focussed on measuring and mapping the slowly varying component of solar radio emission, modelling it, and using the results to study the structure and evolution of solar magnetic structures. As part of the study of the S-component, full-disc maps have been made of solar emission at 21 cm wavelength using the Synthesis Telescope for every year since 1992 (except 1997), as part of a program of studying sources of the slowly-varying component and any cycle-related effects (with Burke, Cameron, Harvey, Zwaan). In a previous study at 2.8 cm wavelength, the brightest sources occur in active regions which are growing rapidly, are magnetically complex, and which are producing small flares (all evidence of dynamism). The picture at 21 cm wavelength is different. The sources are brightest when their host regions have achieved their maximum size. The S-component at 21 cm wavelength can be accounted for in terms of free-free thermal emission from plasma concentrations trapped in magnetic loops overlying active regions. At 2.8 cm wavelength other emission mechanisms must be invoked. This raises interesting questions as to the mix of mechanisms that might be producing the 10.7 cm flux.

Other research is into the relationship between solar magnetic activity, as indicated by the 10.7 cm flux and other indices), and various terrestrial processes, including some biological phenomena (with Mathias and Surkan). In addition to well-established climatic connections, there seems to be a relationship between the level of solar activity and the frequency of antigenic shifts in certain viruses. This underlines the value of continuing research into the relationship between solar activity and energy output with environmental conditions.

11. GRADUATE STUDENTS

A. Guerra (formerly Thorsley) is finishing up work on extending the holography efforts pioneered by summer and co-op students working with Gray. A major limitation of previous efforts was that celestial sources are too weak to adequately probe the outer portions of the patterns of the Synthesis Telescope antennas in a reasonable time, so Thorsley has designed and built a transmitter to operate from local hill-tops, devised observing strategies to make the necessary observations at low elevation in the near-field of the array, and implemented iterative methods for reconstructing the far-field pattern from incomplete near-field measurements. This work is expected to be completed in spring of 2000.

L. Belostotski has completed his M.Sc. thesis research at the Observatory, designing a phase-locked local-oscillator distribution and focal-distance measurement system for the Large Adaptive Reflector project. He was awarded the degree by U. Alberta in 1999 October, and moved to an engineering position in industry.

Parchomchuk of the DRAO staff successfully completed her M.Sc. in computer science with the Open University (UK), being awarded the degree in 1999 December.

12. THE 2800-MHZ SOLAR FLUX MONITORING PROGRAM

The Solar Flux Monitoring Program is now in its 55th year. Since its beginning in 1946, the program has provided measurements of the 10.7 cm flux as an index of solar activity to a world-wide community of users. This index, the integrated emission at 10.7 cm wavelength from all sources present on the solar disc, is one of the main measures of solar activity. It finds a wide range of applications, including solar physics, solar-terrestrial relationships, space weather, atmospheric predictions for satellites in low Earth orbit, and communications. As a proxy for solar ultraviolet emissions and irradiance, the 10.7 cm flux is now being used in agriculture, fisheries and climatic studies. It is incorporated into two indices used to describe the upper atmosphere: the International Reference Ionosphere (IRI) and the Mass-Spectrometer-Incoherent-Scatter (MSIS) index.

The program uses two independent, automatic flux monitors, both sited at DRAO. One acts as a backup for the other. Data distribution is also automated, with flux values being transmitted by fax and e-mail. Other users obtain the data from the DRAO web site <http://www.drao.nrc.ca>. Enquiries regarding the program or data should be directed to Tapping (Ken.Tapping@nrc.ca).

13. PUBLICATIONS

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13.3 Books

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