National Research Council of Canada
Herzberg Institute of Astrophysics
Dominion Radio Astrophysical Observatory
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This report covers the period from 1 April 1995 through 31 March 1996.

1. PERSONNEL

The professional continuing staff of the Observatory comprises T.L. Landecker (Director), C.R. Purton (Deputy Director), L.A. Higgs, G.J. Hovey, J.D. Lacey, K.F. Tapping, A.G. Willis and W. Wyslouzil. D.R. Karpa has been filling Hovey's position while the latter is on study leave at the University of British Columbia. R.S. Roger retired from the Observatory staff in January 1996, but is continuing as a Guest Worker to represent Canadian radio-astronomy interests in radio-spectrum management. A.D. Gray is a Research Associate. S.M. Dougherty (Research Associate, U. Calgary) came to DRAO in September 1995, to work on the Galactic Plane Survey. G.H. Moriarty-Schieven (Research Associate) left the Observatory in September 1995. J.A. Galt continues as a Guest Worker.

P.E. Dewdney, based at DRAO, is the Coordinator of Future Radio Telescope Initiatives for the Herzberg Institute of Astrophysics. The activities of this program are reported elsewhere.

T.A. Burgess, B.R. Carlson and D.D. Wellborn continue to work on the Space VLBI correlator project (supported by the Canadian Space Agency), along with W.T. Petrachenko (Natural Resources Canada, Ottawa) who has been seconded to the project.

K.F. Tapping completed his Ph.D. at U. Utrecht in June 1995. D.A. Lyder (Ph.D candidate, U. Victoria) is completing his thesis research at the Observatory.

J.F. Vaneldik (U. Alberta) spent the summer of 1995 at DRAO, and A.R. Taylor (U. Calgary) and H.J. Wendker (Hamburg University) have made lengthy visits.

2. INVOLVEMENT IN THE SCIENTIFIC COMMUNITY

L.A. Higgs serves on the Board of Directors of CASCA as Past-President (1994-96), is a member of its Radio Astronomy Committee and chaired (1993-96) a CASCA committee which allocated travel grants to scientists from the Former Soviet Union. He is also a member of the Canadian Time Allocation Group for the James Clerk Maxwell Telescope. C.R. Purton is also a member of the Board of Directors of CASCA. R.S. Roger is the Canadian radio astronomy representative on the Radio-Communication Study Group 7 of the International Telecommunications Union with responsibility for spectrum management for radio astronomy in Canada. K.F. Tapping is the Chairman for Canada of Commission J (Radio Astronomy) of the International Radio Science Union (URSI), and is acting as Secretary of the Canadian National Committee of URSI.

P.E. Dewdney is on the Science Councils of both the RadioAstron and the VSOP Space VLBI projects. and is a member of the Working Group on Global VLBI of URSI Commission J. He is also a member of the Canadian Science Team for the ODIN satellite-borne sub-millimetre telescope, a joint project of Sweden, Canada and France. L.A. Higgs is a member of the Large Telescope Working Group which was established by URSI Commission J, and of a Working Group on Astronomy from the Moon established by IAU Commission 44. K.F. Tapping is participating in the Working Group on Proxy Measures of Solar Activity. A.G. Willis serves on the Scientific and Technical Advisory Group for AIPS++.

Three staff members are Adjunct Professors at Canadian universities: T.L. Landecker and A.G. Willis at the University of Alberta, and P.E. Dewdney at the University of Calgary. T.L. Landecker is a member of the Board of Governors of Okanagan University College. L.A. Higgs is a member of the B.C. Science Council (Okanagan).

3. TELESCOPES

DRAO is operated by the Herzberg Institute of Astrophysics (HIA) as a National Facility for Canadian radio astronomy. Two radio telescopes, the Synthesis Telescope and the 26-m Telescope, are available to outside 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 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.

4. THE SYNTHESIS TELESCOPE

The DRAO Synthesis Telescope has both continuum (1420 MHz and 408 MHz) and spectral line (H I) capability. Its combination of antenna size (9 m) and baseline (600 m) gives it a wide field of view (2° and 8° at 1420 and 408 MHz) and good angular resolution (1.0 and 3.5 arcmin at 1420 and 408 MHz) and makes it well suited for studies of the interstellar medium in our Galaxy and in nearby external galaxies. In particular it is a unique instrument for the study of the interstellar H I with arcminute resolution while retaining good sensitivity to extended structure. Channel widths from 0.1 to 3 km/s are available from 256-channel spectrometers to suit Galactic and extragalactic observations; the seven antennas provide complete baseline coverage from 13 to 600 m. Information on broad structures, corresponding to baselines shorter than 13 m, is derived from observations with the DRAO 26-m Telescope (H I line) or from other single-antenna observations.

The completion of the 256-channel spectral correlators and the development of a 1420-MHz polarization capability

are the most recent accomplishments in a long series of improvements to the Synthesis Telescope. In addition, solar imaging is now possible.

Gray, with the assistance of summer student K. Douglas (U.B.C.) made holographic maps of the Synthesis Telescope antennas during 1995. This work has led to a better knowledge of the state of reflectors, and has indicated that one antenna has a significant defocus error, which will be corrected.

The bulk of the observing time on the telescope is now devoted to the Galactic Plane Survey (see below); applications for other observations are also accepted but only a few can be scheduled. Proposals for Synthesis Telescope observations should be addressed to C.R. Purton (e-mail crp\@drao.nrc.ca); proposal deadlines are October 15 and April 15. A data reduction *cookbook* is available.

5. THE 26-M TELESCOPE

The DRAO 26-m Telescope is equipped with receivers covering 1350 to 1750 MHz and 6.6 GHz. All receivers have two polarizations, connected to a digital spectrometer. The main areas of application of the L-band receiver are H I and OH spectroscopy. Recombination line observations are also possible. The 6.6-GHz receiver has been built for the maser line of methanol. At 6.6 GHz the beamwidth is $7.5'$ and the aperture efficiency of the antenna is $\sim$16%. The 26-m Telescope is also routinely used to obtain H I data that complement Synthesis Telescope data by providing low-spatial-frequency information. Proposals for use of the telescope should be addressed to the Director of the Observatory (e-mail director\@drao.nrc.ca).

6. COMPUTER SYSTEM

The computer system is built around three IBM RS/6000/550 computers together with two 320H workstations and an SGI Indigo 2, all connected by a local area network with the *VMS* computers which currently operate the Observatory's telescopes. A migration of the telescope-control computers and data-acquisition software to a *UNIX* environment is now underway. Virtually all data reduction programs now run under *UNIX*.

Visualization software is available for working with spectral-line data cubes. *X-windows* software for the production of videos has been developed; this medium is well-suited for the display of H I data cubes by animation through velocity channels. Special techniques have been developed for the animated display of merged data sets that combine H I, CO, infrared, and radio continuum.

An export package of DRAO software is available; it is principally useful for processing data from the DRAO telescopes, but includes general-purpose plotting and data manipulation programs. The combination of single-antenna data with Synthesis Telescope images is possible with this software. The package includes about 90 different programs, but excludes (for practical reasons) programs related to data acquisition from the DRAO telescopes. It is supported, within the limits of available personnel, on IBM RS6000 (under *AIX*), SUN (under *SunOS*) and SGI (under *IRIX*) computers. Some programs require an IDL licence. Direct enquiries to L.A. Higgs (e-mail lah\@drao.nrc.ca)

7. AIPS++

HIA is a partner in the AIPS++ project, the development led by the National Radio Astronomy Observatory of a new image processing system for radio astronomy. A.G. Willis is contributing to the development of software.

8. IMAGE PROCESSING

The Synthesis Telescope employs small antennas, which confer a wide field of view and permit observations of extended structures. However, the small antennas have relatively high sidelobe responses, especially at 408 MHz where the antenna diameter is only 12 λ. Imaging in the vicinity of strong sources, such as Cas A and Cyg A, is difficult because of emission received in the sidelobes, and dynamic range problems arise in such areas. Because of differences between individual antennas, standard image-processing techniques cannot remove these problems. Willis and Higgs have developed a simple procedure to overcome such effects by calculating the response of the telescope to a model of the source (derived from observations of high angular resolution) and fitting model visibilities to observed visibilities for each interferometer pair.

Willis has tested methods to correct effects arising from different antenna diameters, and continues to investigate algorithms to improve the quality of images produced by the Synthesis Telescope. Recent areas of research include the problem of subtracting a pure continuum image from ''line'' observations that include both line and continuum emission, the subtraction of solar continuum interference from visibilities, and investigating how large-scale irregularities in the shape of dish surfaces translate into image imperfections.

9. INSTRUMENTATION

The requirements of the Galactic Plane Survey have stimulated a number of improvements in the instrumentation of the Synthesis Telescope and the 26-m Telescope during 1995-96. These have been carried out mainly by the engineering and computing team of Hovey, Karpa, Willis and Wyslouzil. A noise-injection system which enables continuous monitoring of gain and system temperature variations has been implemented on the Synthesis Telescope. Corrections for correlator non-linearity and ''non-quadraturity'' between real and imaginary visibilities are now applied, and improved models of the fields containing calibration sources have been developed. All of these improvements have contributed to greater consistency in the calibration of the data and the resulting dynamic range of the instrument.

During the period of this report, a new 256-channel autocorrelation spectrometer, similar to the spectral correlators for the Synthesis Telescope, is being brought into operation on the 26-m Telescope. The H I receiver has been modified to maximize dynamic range and linearity, new calibration arrangements have been installed, and the antenna aperture efficiency remeasured. The software and operating arrangements for the telescope and the new spectrometer are being

modified to be compatible with the scheduling and data-handling arrangements used for the Synthesis Telescope.

10. THE GALACTIC PLANE SURVEY

Taylor (U. Calgary) is leading a consortium of 33 scientists from Canada and other countries who are carrying out a program of panoramic imaging of the northern Galactic plane in the radio continuum, infrared and H I and CO emission, using the DRAO Synthesis Telescope and other instruments. Observations at DRAO began in March 1995, with the intent of completely mapping, in a five-year period, a strip 8.5° wide in Galactic latitude along the plane from $l = 75°$ to $l = 147°$. This will require the observation of some 190 individual fields (each 2° in diameter at 1420 MHz). Images of these fields will be assembled into larger mosaic images, which will eventually cover the entire survey region. After a proprietary period, the survey data will be made available to the worldwide astronomy community through the Canadian Astronomical Data Centre, operated by HIA in Victoria. Scientific analysis of the Galactic Plane Survey data in Canadian universities is being supported by a grant from the Natural Sciences and Engineering Research Council.

As of the end of March 1996, 19% of the Synthesis Telescope observations have been completed in 20% of the allocated observing period. During this same period, 12 fields outside the region of the Galactic Plane Survey have been observed for other users of DRAO.

The DRAO observations will be complemented by data in other wavebands made available by members of the consortium. These data include high-resolution IRAS data, CO images from a new FCRAO survey, 151 MHz continuum images from Cambridge University, and 232 MHz and 327 MHz continuum images from the Miyun Synthesis Telescope (Beijing Astronomical Observatory). The total of these data will form the basis for a wide variety of studies of the ''ecosystem'' of the Milky Way. Enquiries about the survey should be addressed to Taylor (e-mail russ\@bear.ras.ucalgary.ca) or Dewdney (e-mail ped\@drao.nrc.ca).

11. SPACE VLBI

Canadian collaboration in Japanese and Russian Space VLBI missions (VSOP and RadioAstron) is continuing, funded by the Canadian Space Agency (CSA). Since the Japanese space radio telescope is to be launched in February 1997, the emphasis is now on the VSOP program. Dewdney is the Canadian Principal Investigator. Operational plans are being made to process Space VLBI data using the correlator which is now approaching completion at DRAO. Progress on an end-to-end VLBI system has been steady over the last year. Test observations using a network of five Ground Radio Telescopes (GRT's), equipped with CSA's S2 recorders (developed by the Institute of Space and Terrestrial Science (ISTS)), are expected to be complete before the end of 1996. Other S2-equipped GRT's will also participate. Deployment of recorders at three NASA Tracking Stations later in the year will complete the deployment of all the VLBI equipment for VSOP from Canada.

The total time on the spacecraft has been divided roughly into three parts - 50% for General Observing Time (GOT), 25% for a survey of high brightness temperature (high-Tb) sources and maser sources (the VSOP Survey), and 25% for engineering time. The GOT is by open application; the Survey is by invitation of the VSOP mission. The priorities for Canadian participation are the VSOP Survey, a deep survey of high-Tb sources using Arecibo (with other GRT's), and Southern Hemisphere imaging (for GOT). The distribution of S2 recording systems is well suited for each of these types of observations, since there will be only S2 systems at Arecibo, South Africa (Hartebeesthoek) and at several observatories in Australia. Image processing, planning of observations, and quality control of data is being done in the Department of Physics and Astronomy at the University of Calgary. Further information can be found on the DRAO Web page (http://www.drao.nrc.ca) under the VLBI heading. Enquiries should be directed to P.E. Dewdney (e-mail ped\@drao.nrc.ca).

12. RESEARCH WITH THE 26-METRE TELESCOPE

The 26-m Telescope will be used to provide information on large H I structures in the area covered by the Galactic Plane Survey. The information will be incorporated into Synthesis Telescope images (with suitable filtering) to ensure that all angular scales are truly represented in the Survey H I images. Tapping is leading this program, assisted by Galt. A detailed investigation of the sidelobe characteristics of the antenna will be carried out, after which a wide area of the Galactic plane will be sampled at an interval of about 0.3 beamwidths. The H I spectral data will then be corrected for sidelobe contributions before being incorporated into the Galactic Plane Survey images.

The 26-m Telescope has been inactive for much of 1996 while engineering modifications in preparation for the Galactic Plane Survey observations have been carried out. Before that, it has been used for a wide variety of OH and H I investigations, and most recently for methanol maser observations. Galt, with Feldman and Polanen (HIA), have searched a number of star-forming regions for methanol maser emission in the 6.6-GHz line. Eight new sources were discovered and known sources have been monitored to search for intensity and polarization changes. In the course of Lyder's thesis research, he and Galt have discovered a new methanol maser source in Perseus.

13. POLARIZATION OF GALACTIC EMISSION

Analysis by Gray of the polarization data obtained in the Pilot Project for the Galactic Plane Survey (work done in collaboration with Landecker, Dewdney, and Normandeau and Taylor (U. Calgary)) has produced some interesting results concerning the anti-correlation of detected polarized signal from the Faraday-rotated Galactic background and large H II regions. This work suggests that polarization may be used as a probe of extended low-density envelopes around H II regions. An unusual polarized feature coincident with the W5 H II region suggests the presence of a bubble in the

interstellar medium, but no source has yet been identified as the origin of the bubble. Papers on both of these features are currently in preparation.

14. STAR-FORMATION REGIONS

Lyder has continued his thesis research, entitled ''Star Formation in Camelopardelis: Cam OB1,'' under the supervision of Purton and Gower (U. Victoria). A comparison of CO ($J=1-0$) emission with optically identified stars has established the distance to this star-forming region to be about 975 pc. Two distinct different stellar groups have been identified, one of older and more massive stars, and one of younger, less massive stars. They may be the result of a sequence of star formation related to dynamical interaction of two CO complexes.

15. PHOTODISSOCIATION REGIONS

Blouin (U.B.C. M.Sc. student) and McCutcheon (U.B.C.) with Dewdney, Roger, Purton and colleagues in the Netherlands have mapped the continuum and H I-line emission associated with the nebula Sharpless 185 which comprises two comet-shaped clouds, IC 59 and IC 63, illuminated by the star γ-Cas. These Synthesis Telescope observations are compared with far-infrared, optical and CO maps of the region to determine the photochemical evolution of the gas components with respect to ionization, dissociation and thermal balance. The observations in H I and far IR have also yielded a new example of a dissociating star unrelated to the γ-Cas complex. Blouin's M.Sc. thesis (U.B.C., 1995) describes much of this work in detail.

16. H II REGIONS

The nearby (750 pc) H II region IC 1396, which contains a number of dense cometary globules, was observed as part of the Galactic Plane Survey. Moriarty-Schieven, with Xie (U. Maryland) and Patel (CfA), have found that some of the globules have caps of ionized gas (observed by their radio continuum emission) on the side facing the ionizing star, and H I ''tails'' extending as much as 8 pc. The tails are probably material ablated from the globules by photoionization or dissociation and blown away from the globule by the wind from the central star.

17. WOLF-RAYET STARS AND THEIR ENVIRONS

Dougherty has been involved in the study of non-thermal radio emission from Wolf-Rayet systems in collaboration with Williams (Royal Obs., Edinburgh), van der Hucht (SRON, Utrecht), Bode (JMU Liverpool) and Davis (NRAL, Jodrell Bank). Using the MERLIN array, the star WR 146 is resolved into two components separated by 116 milliarcseconds. The weaker southern source is identified as thermal emission arising from the stellar wind of the WR star and the stronger northern source as non-thermal emission. They suggest the non-thermal component is due to the interaction of the WR wind with that of a O9.5–B0 companion that has been identified from optical spectra of the system. They are pursuing further radiometric observations at high frequency to confirm the nature of this source.

A similar two component structure is seen in the star WR 147, with the two components separated by 0.7 arcseconds. Using the UKIRT telescope, a source that is coincident with the non-thermal component of the system, identified as a B0 main-sequence star, has recently been detected. The hypothesis is that this is also a colliding-wind system. Of the four Wolf-Rayet stars that exhibit non-thermal emission, three are now identified with colliding-wind systems.

Arnal (Instituto Argentino de Radioastronomia) and Roger have analyzed Synthesis Telescope observations of the surroundings of the Wolf-Rayet star WR 3 (HD 9974). They find evidence of an ovoidal minimum in the H I distribution that may have been created by the joint action of the progenitor to HD 9974 and the WR star itself. A geometrical model fitted to these observations may explain some of the features seen in other interstellar bubbles related to WR stars.

18. RADIO SOURCES NEAR THE GALACTIC CENTRE

Gray has made VLA observations in collaboration with Goss (NRAO-VLA) to further study the unusual Galactic Centre filamentary object known as ''The Snake'' (G359.1 $-$00.2), following up on unusually high rotation measures (5500 rad/m^2) found in previous ATCA observations at 4.8 GHz. The new data are at 8.5 GHz, to help constrain intrinsic magnetic-field orientation and provide more detail in regions adversely affected by depolarizing effects at the lower frequency. These data are still being analysed, but already confirm the high rotation measure and promise to aid significantly in the interpretation of the origins of the high rotation measure as well as of the object itself.

Gray has also made new VLA observations of a new potential SNR near the Galactic Centre. G357.1$-$00.2 was identified as having an atypical ''S''-shaped morphology in low-resolution 843-MHz images, and the high-resolution VLA data at 1.4 and 4.8 GHz show that the detailed structure is very unusual, with tangled and highly polarized filaments defining the shape of the object seen at lower resolution. The interpretation of this object as an SNR is by no means certain, and further investigation may be necessary to probe this object and its association, if any, with a nearby pulsar and the adjacent peculiar source G357.7$-$0.3 (''The Tornado'').

19. SUPERNOVA REMNANTS

Roger and Leahy (U. Calgary) have been investigating the interaction of the bright supernova remnant IC443 with the surrounding ISM through Synthesis Telescope observations of the continuum radio emission at 408 MHz and 1420 MHz. At 1420 MHz the strongest fractional polarization is confined to the less bright areas of emission, indicating a high degree of depolarization in volumes of high emissivity. The radio emission lends scant support for the existence of a second older remnant to the south-east of IC443, suggested by the X-ray observations with ROSAT.

Leahy (U. Calgary) and Roger are studying the variations of the spectral index within emitting features of the Cygnus Loop SNR, using Synthesis Telescope observations at 408 and 1420 MHz together with published Effelsberg observations at 2695 MHz. Pronounced spectral curvature is evident,

particularly in emission from the bright north-east rim. Studies of the polarization characteristics at 1420 MHz are being prepared for publication.

Pineault (U. Laval), Landecker, Swerdlyk (U. Guelph) and Reich (MPIfR, Bonn) have made new observations of the supernova remnant CTA 1 with the DRAO Synthesis Telescope, with higher sensitivity than earlier observations. A low-level extension to the north-west, suspected from the earlier observations, is confirmed. The extension is probably the result of breakout of the blast wave into a low-density region of the interstellar medium. The spectral index in the breakout region is higher than in the bright shell. This is supported by flux-density measurements at low frequencies, including a flux density at 22 MHz obtained from DRAO archives. The spectral-index pattern is similar to that seen in other breakout remnants. The spectral-index variation is interpreted as the result of a lower Mach number for the shock in the breakout region.

Landecker and Higgs, in collaboration with Zhang and Zheng (Beijing Astron. Obs) have obtained a flux density at 232 MHz for the supernova remnant G76.9+1.0. Combining this flux density with existing data at other frequencies indicates that the SNR has a spectral index of about 0.6 above 1 GHz with a possible break at about 1 GHz to a flatter spectral index below that frequency.

Zhang and Zheng (BAO), together with Landecker and Higgs, have made a new map of the very bright supernova remnant G78.2+2.1 at 232 MHz using the Miyun Radio Synthesis Telescope. By combining this data with images at 408, 1420, 2695, and 4850 MHz, they have been able to demonstrate that there are significant variations of spectral index across the remnant; comparison of all pairs of data produce a similar result. Regions of higher spectral index (steeper spectra) appear around the periphery of the remnant and in its central area. There is no clear correlation of spectral index with intensity across the SNR. Contamination from background or foreground emission may contribute to the spectral-index variation, but it is likely that physical conditions differ from place to place within the SNR, with local effects on particle acceleration which then appear in the radio spectrum.

20. INTERMEDIATE VELOCITY CLOUDS

Shaw, Bates, Kemp, Keenan (Queens U., Belfast), Davies (NRAL) and Roger have studied the H I in an intermediate-velocity cloud (IVC) in the foreground of the globular cluster M13 using the 76-m Lovell Telescope and the DRAO Synthesis Telescope. The IVC is found to have a two-component structure with dense cloudlets embedded in an extended diffuse component. The components are probably in pressure equilibrium. Comparisons of the high-resolution H I column densities with optical absorption lines of sodium at the same velocity yields an abundance ratio N(Na I)/N(H I) of $\sim 2 \times 10^{-8}$ for the cloudlets.

21. EXTRAGALACTIC ASTRONOMY

Together with Mack and Klein (U. Bonn) and O'Dea of the STScI, Willis is continuing to investigate the properties of large radio galaxies. This work involves the intercomparison of high-resolution, low-frequency images obtained with the Westerbork Synthesis Radio Telescope with corresponding images obtained at higher radio frequencies with the Bonn 100-m telescope.

Carignan (U. Montreal) and Purton have observed H I emission from the dwarf irregular galaxy DDO 154. Observations with the DRAO Synthesis Telescope and the 26-m Telescope have measured emission from extended structure missed with the VLA in D-configuration. By combining VLA and DRAO data, the rotation curve of the galaxy can be extended beyond the turnover point, establishing the mass of the system. A value of $\sim 3 \times 10^9$ M$\odot$ is found, of which more than 90% must be dark matter.

22. THE 2800-MHZ SOLAR FLUX MONITORING PROGRAM

The National Research Council has been making regular, precise determinations of the total solar flux at 10.7 cm since 1946. The choice of 10.7 cm as the observing wavelength, close to the peak of the spectrum of the slowly-varying (S-) component, together with the continuity, quality and consistency of the data, have resulted in the use of this measurement worldwide as a primary index of solar activity. Since 1990 this program has been located at DRAO. The measurement, known as the Penticton 2800-MHz flux or as the 10.7-cm flux, is used in its own right and as a proxy for other quantities which are more difficult to measure. The 10.7-cm flux has played a pivotal role in at least 250 papers published in the last five years.

Two independent, automated flux monitors are operated, with automatic data distribution by facsimile and e-mail. During 1995-96, work has been directed towards increasing the level of automation in the routine acquisition and distribution of data, and in more fully integrating the daily operational support of the solar monitors into arrangements for data management for the other DRAO telescopes. In order to make daily and past data as widely available as possible, and to reduce the total cost of data distribution, the information is now available on the World Wide Web, through the DRAO home page. Enquiries about the Solar Program should be directed to solar\@drao.nrc.ca.

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