WORKSHOP REPORT

Millimetre-wave Astronomy

Abstracts from a One-day Workshop held on 19 April 1995 at the Australia Telescope National Facility

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Summary: A Millimetre-wave Astronomy Workshop was held at the CSIRO Radiophysics Laboratory in Marsfield, Sydney, on 19 April 1995. The workshop, sponsored by the Australia Telescope National Facility (ATNF), was a meeting of mm-wave specialists as well as astronomers and students interested in the field, and attracted about 80 participants from 13 institutions. The program consisted of 23 oral contributions (5–45 min) followed by lively discussions. Abstracts of most of the contributions are presented here, arranged by groups dealing with subjects such as 'A Basic Introduction', 'Astronomy in the mm-range with Mopra' and 'Projects: Galactic and Extragalactic 3 mm-wave astronomy'.

Overview of Millimetre-wave Astronomy

W. Jack Welch

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The millimetre/sub-millimetre wavelength interval is the short-wavelength decade of the radio spectrum, and it offers unique opportunities for the study of astronomical objects that are essentially thermal sources. The sensitivity comes from the blackbody spectrum of these sources. In addition, a rich spectrum of interstellar molecular lines lies shortward of 4 mm, and emission of continuum radiation from dust is observable only at wavelengths below about 3 mm. The dense part of the interstellar medium, made up of molecular hydrogen, contains half the gaseous mass of the galaxy and is studied through its collisional excitation of trace molecules, such as CO and HCN, at mm wavelengths. On the largest scales, it is found in giant molecular clouds which are as massive as globular clusters, and on the smallest scales it turns into stars with disks and probably planets. In other galaxies, it produces normal stellar associations, starbursts, AGN, and probably black holes. The envelopes of the red giant stars return material to space enriched in heavy atoms. The dense gas in the stellar envelopes and the interstellar medium are pervaded by a complex chemistry which can be studied by the emission and absorption of molecular lines at mm wavelengths.

Millimetre History in Australia

John Whiteoak

Australia Telescope National Facility, CSIRO

The first serious 3 mm observations in Australia were actually made with an optical telescope: 115-GHz CO observations with the 4 m AAT in 1975–76. The project provided the first detection of CO in the Magellanic Clouds. CSIRO had planned a 30 m mm-wave telescope during the early 70s, but the project fizzled out when Canada decided not to join it. However, as a result of the continuing interest, a 4 m antenna was constructed at Epping in the mid 70s, and yielded an extensive CO survey of the southern Galactic plane, plus smaller surveys of other molecular-line transitions. The initial plans for the AT did not specifically include a stand-alone mm-wave facility. However, the antenna design allowed for future operation at mm wavelengths; the 22 m antenna near Coonabarabran is now being fitted out with a 3 mm SiS receiving system.

3 mm Spectral Line Observations

John Whiteoak

Australia Telescope National Facility, CSIRO

In July 1994 a 3 mm SiS receiving system was installed on the 22 m AT Mopra antenna, heralding a new era for Australian radio astronomy. Although the system was incomplete, tests over the following few

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months suggested that when complete, the facility will provide world-class continuum and molecular-line observations in the frequency range 85–116 GHz.

Capabilities of 3 mm Receiver at Mopra

Graham Moorey

Australia Telescope National Facility, CSIRO

As the first step towards equipping the Australia Telescope (AT) array with mm-wave receivers covering the 86–115 GHz band, a prototype receiver was built and installed on the 22 m antenna at Mopra.

This talk outlines the design criteria and construction of the receiver, taking into consideration the antenna structure and the possible use of existing electronics installed in the antenna.

A summary will be given of the initial installation and the resulting receiver and system characteristics. From these commissioning tests it has become clearer which engineering changes will be required before the mm-wave receiver system can be opened to the general astronomical community.

Observing at Mopra

Robina Otrupcek

Australia Telescope National Facility, CSIRO

The Mopra 22 m antenna is part of the Australia Telescope National Facility (ATNF) operated by CSIRO. It is intended for use both in conjunction with AT antennas (the six 22 m dishes of the Compact Array in Narrabri and the 64 m Parkes dish) and other antennas in Australia or elsewhere, very-long-baseline interferometry networks (VLBI), and as a stand-alone instrument. For general information see the Mopra World Wide Web homepage.

The antenna has been used for VLBI observations since November 1991. Since December 1993 it has also been used for single-dish observations in the 1·2–9·2 GHz frequency range. A high-frequency SiS receiver was installed in August 1994 with a possible frequency range of 86–115 GHz, although tuning difficulties kept observations during commissioning time (September to November 1994) in the range 86–90 GHz. The improved SiS receiver will be re-installed and tested in June 1995.

The Mopra control and operating systems are a hybrid of systems used at the Compact Array and the Parkes telescope. Whereas the Mopra antenna, receiver, engineering and monitoring systems are similar to those of the Compact Array, the observing software SPECTRA and the correlator control program MPCOR have been adapted from the single-dish system at Parkes. For operation at mm wavelengths, further programs are available, e.g. POINT to measure the pointing accuracy of the telescope, and SKY DIP to obtain the opacity of the atmosphere.

Using the system will be much the same as conducting line observations at Parkes. The SiS receiver will be tuned to the required line frequency; assistance will be available to set up the SPECTRA and MPCOR parameters, and there will be regular supervision by AT staff during the scheduled time.

There is currently no scanning facility available. Therefore, observations will be for a designated integration time on a single sky position which the antenna will track. Broad lines will require an off-source reference observation and a signal observation of similar duration; the quotient will be automatically stored by SPECTRA. Narrow-line observations can economise on integration time by shifting the centre frequency of the reference observation rather than moving off-source; the resultant quotient can be easily 'folded' in the reduction program.

There will be a dual-channel system so that one channel can be kept tuned to 86 GHz to check the pointing of the telescope on SiO masers which are associated with stars and therefore have accurate positions. The other channel can be tuned to 115 GHz for observations of CO. We expect a pointing accuracy better than 15″ and hope that it will be closer to 5″. The correlator bandwidth range will be 4–256 MHz, but the channel range for 256 MHz will be 256 channels, increasing to 8192 for 4 MHz. The antenna efficiency is expected to be 30–40% at 86 GHz.

A list of further observing parameters has been compiled by Lister Staveley-Smith and can be obtained via anonymous ftp or the World Wide Web.

The *MOPRA HANDBOOK—Operating Manual* is currently being written and will be available soon, together with the other AT User Guides.

CO in Galaxies

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Sensitive observations of the CO molecule in galaxies give us a lot of very interesting new information. The kinematic information in the spectra tells us about the motions in the inner parts of a galaxy, which until now have been only poorly known. The comparison of the intensity of different CO line transitions and isotopic species allows us to study the physical conditions in galaxies. The comparison of data obtained with identical angular resolution in the H I line and more recently in the 1 mm continuum gives us additional information on the dynamics of a galaxy.

The number of detections of CO in galaxies has now passed the 2000 mark. Most of these detections are for northern galaxies. Sensitive receiver systems allow us either to detect a weak distant galaxy or to map a large nearby one. One of the important functions of CO studies is their use in determining the H_2 mass. The comparison of different line transitions tells us something about the optical depth and temperature. The study of isotopic species tells us a lot about the chemistry in galaxies.

A survey of CO emission of northern edge-on galaxies with the IRAM 30 m telescope in Spain (http://iram.fr/www/iram/) was aimed at getting the dynamic data for M 82, NGC 891, NGC 3628, NGC 4565, NGC 4594, NGC 4631, NGC 5907, and NGC 7331. Also, the face-on galaxies NGC 3627, NGC 4414 and M 51 were studied. We were able to map many of these galaxies in the 1 mm continuum with the new 19 channel MPIfR multibeam bolometer, which gives us the distributions of cold dust. Comparable data in other spectral ranges (radio continuum, H I line, infrared, optical, X-ray, etc.) are also being collected with similar angular resolution to allow detailed comparisons. In addition, high-angular-resolution studies in CO of central regions of some of the galaxies have started with the Plateau de Bure interferometer to show details (such as bars) in the nuclear structure.

The large southern galaxies NGC 55, NGC 253, NGC 1808 and NGC 4945 were studied in CO with the 15 m SEST telescope. Preliminary maps of other southern galaxies NGC 613, NGC 1433, NGC 1566, NGC 1672 and NGC 2442 were also made. The H I data for some of these objects were obtained with the Australia Telescope Compact Array (ATCA). However, until now the CO data on southern objects has is in general been very sparse.

Opportunities to use Mopra at 115 GHz should correct this deficiency in southern CO data and usher in a new era of extragalactic research. In particular, with the addition of multibeam receivers, the complete mapping of large areas (like the Magellanic Clouds) will be possible in future.

The observations described in this contribution are part of a multi-national collaboration between J. Whiteoak (ATNF), M. Guelin (IRAM), R. Wielebinski (MPIfR), and others. Theoretical considerations are supported by F. Combes and J. Palous (Prague).

H I/CO in the Galaxy NGC 253

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The galaxy NGC 253 is a well-known nearby spiral galaxy showing numerous peculiar features (e.g. a nuclear ring, gas outflow, a bar, and a warp) which we study using tracers of the different gas phases. Its large starburst activity places NGC 253 among the most prominent extragalactic sources in the radio, IR and X-ray spectral regions. Whereas the X-rays trace the hottest gas component, Hα emission shows the distribution of the ionised gas at several thousand Kelvin. The warm component of the neutral gas is best studied through H I line emission, and CO is usually used as a tracer of the cold molecular gas phase. The neutral gas component of NGC 253 was studied in H I with the Australia Telescope Compact Array (ATCA), and in CO ($J = 1$–0) with the Swedish–ESO Submillimetre Telescope (SEST) at La Silla, Chile. Several other molecular lines have been observed in NGC 253, which is in fact the richest extragalactic molecular source both in terms of line strength and number of molecular species detected.

First results of the H I observations have been published by Koribalski, Whiteoak & Houghton (1995, PASA 12, 20). Whereas the H I emission traces the large-scale distribution and kinematics of the neutral atomic gas, the H I absorption against the central continuum emission allows a glimpse into the dynamics of the cool gas ($T \sim 100$ K) in the nuclear region.

Other Molecules in Galaxies

John Whiteoak

Australia Telescope National Facility, CSIRO

Although the 115 GHz CO line is the favourite molecular-line transition being studied in other galaxies, 3 mm transitions of other molecules can also be detected in several dusty galaxies, providing information about chemical composition and excitation conditions in these galaxies. The current number of transition detections is 27. Best southern objects include NGC 4945, NGC 5128, Circinus Galaxy and the Magellanic Clouds.

Redshifted Extragalactic CO

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A number of high-redshift, luminous galaxies have recently been found in the IRAS catalogue. A few of these have been detected and even mapped in CO. Further study of these objects offers the opportunity to view galaxy formation and possibly the structure of strong gravitational lenses.