

Part 6

First Results from New Facilities



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First Results from ATCA at Millimetre Wavelengths

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Abstract. The newly upgraded Australia Telescope Compact Array (ATCA) at millimetre wavelengths is the first millimetre interferometer to be built in the Southern Hemisphere. The full array will be operational in 2004-2005 and will provide arcsec angular resolution at 3 mm and 12 mm. This will be a unique instrument to study at high angular resolution the interstellar chemistry and more generally the star formation process, especially in the bulk of the galactic plane and in the Magellanic Clouds. The upgraded ATCA will also be an excellent tool to detect dust emission from nearby protoplanetary disks. In this paper I will present the first results from the upgraded ATCA at 3 mm and 12 mm. The result review will cover the topics of massive star formation and hot molecular cores dust emission from star-forming regions and detection of protoplanetary disks.

1. Introduction

The Australia Telescope Compact Array (ATCA) - the radio interferometer of the Australia Telescope National Facility - has recently been upgraded to become the first millimetre interferometer in the Southern Hemisphere. ATCA, a telescope that traditionally operates at radio frequencies (i.e. wavelengths of a few cm to a few tens of cm), will henceforth allow observations at wavelengths of 12 mm and 3 mm.

To date three of the six antennas have been equipped with the 3-mm receiver and the full array is now operational at 12 mm. Once fully upgraded, the ATCA millimetre interferometer (ATCA-mm) will perform in the frequency ranges 16-26 GHz and 85-110 GHz (the 12 and 3 mm bands, respectively). ATCA-mm will be particularly suitable for studying processes in which molecular line emission at 12 mm (e.g. ammonia and water vapour masers) and 3 mm (e.g. methanol and silicon monoxide) are predominant. It will also be suitable to observe continuum emission (e.g. free-free emission and dust grain thermal emission).

These new instruments in the Southern Hemisphere have already attracted interest from various astronomy groups overseas (e.g. US, France, Sweden) and in Australia. To date, the main astrophysical topics studied with ATCA-mm are Star Formation Process in the Milky Way and in the Large Magellanic Cloud, Search for Protoplanetary Disks, Stellar Astrophysics (AGB stars, SNR) and Astrobiology/Exobiology. A review of the main results in Star Formation during

2002-2003 is given below while a more general presentation of the upgraded ATCA can be found in Wong & Melatos (2002).

2. Pre-planetary disks around young stars

Many young stars exhibit emission from circumstellar dust grains located in disks with properties similar to the early Solar system. Much activity is currently devoted to characterizing the physical properties of these disks to extract information on planet formation. Observations at millimetre wavelengths are especially important because the disk material beyond a few stellar radii is at temperatures from a few hundreds to a few tens of degrees Kelvin, and the physical and chemical conditions can be probed in detail in this part of the spectrum.

In 2002 using ATCA-mm, Wilner et al. (2003) observed TW Hya, the closest known classical T Tauri star, and HD 100546, a nearby Herbig Be star whose infrared spectrum shows crystalline silicates, indicative of comet-like dust. Two compact array configurations of three antennas were used, resulting in a resolution of about 2 arcsec. Detections were made toward both objects (Fig. 1) and have been reported in Wilner et al. (2003).

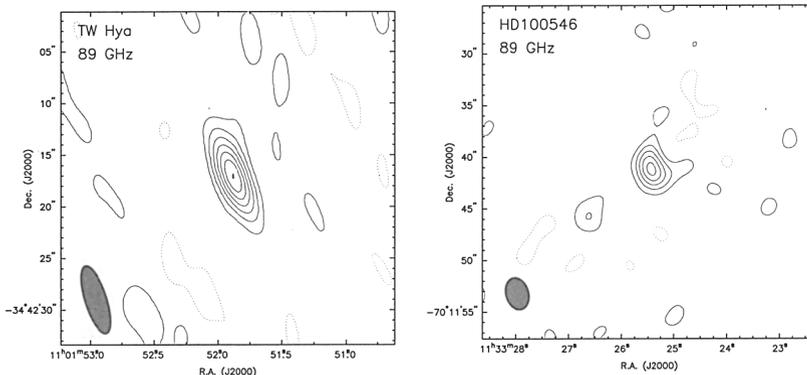


Figure 1. 89-GHz continuum emission detected from TW Hya and HD 100546. Gaussian fits to the visibilities gives a flux of 41 mJy for TW Hya and 36 mJy for HD 100546. TW Hya is unresolved while HD 100546 shows a hint of extended emission to the south-east. For TW Hya this flux measurement agrees well with expectations from previously reported measurements at higher and lower radio frequencies (Wilner et al. 2003).

3. Massive star formation in the Galactic Plane

3.1. Methanol masers as signposts of massive YSOs

Interstellar masers are potentially excellent tools to identify massive YSOs because they are powerful and arise from very compact regions whose absolute positions can be measured with an accuracy of a few mas using VLBI techniques. 6.7 and 12.2 GHz methanol masers have for instance proved to be remarkable probes in hunting down young massive stars (Minier, Conway & Booth 2001). They are associated with sub-mm cores, colour selected IRAS sources, mid-IR sources and radio continuum sources (see Ellingsen's review, this volume), i.e. signposts of massive star formation. So far, 570 methanol maser sources have been discovered via targeted surveys and unbiased surveys of the galactic plane. More interestingly, Walsh et al. (1998) have found that methanol masers are in fact generally *not* associated with radio sources i.e. ultra-compact HII regions (UC HII regions), but rather tend to be separated from them. Preliminary work with Mopra demonstrates that methanol masers are possibly associated with hot molecular cores (HMCs). The most common molecules found in the hot, dense environment of a young massive star are for example CH₃OH, NH₃, HCN, CH₃CN, HC₃N and the molecular cation HCO⁺. Minier et al. investigated in 2002-2003, with ATCA at 3 mm, the hot molecular core candidate associated with the methanol maser source G318.95-0.20. They used three different baseline configurations (EW214, EW352, 750A) to detect and image CH₃OH, HCN, HC₃N, HCO⁺ and H¹³CO⁺. The CH₃OH gas is confined in an unresolved core with a diameter less than 0.04 pc. The HCO⁺ emission arises from an extended region and a central core (Fig. 2). The extended emission, rapidly resolved with increasing baselines, probably arises in a bipolar outflow. Based on these observations, the mass of the molecular core is about 15-120 M_⊙, confirming the presence of a massive core associated with the methanol masers.

3.2. Probing gas conditions with methanol masers

Methanol masers require very specific densities and temperatures to switch on. Their observation at high resolution would reveal the nature of the physical conditions in the inner part of the protostellar envelope.

Methanol masers also exist at higher frequencies in the 3-mm range. They were predicted by Sobolev et al. (1997) and were observed at 85.5, 86.6, 86.9, 107.0 and 108.8 GHz (e.g. Cragg et al. 2001; Minier & Booth 2002). In the southern hemisphere G345.01+1.79, a massive star-forming region, exhibits strong methanol emission at 6.7, 12.2, 85.5, 86.6, 86.9, 107.0, 108.8 and 156.6 GHz. The millimetre emission lines have been interpreted as maser features based on their narrow line-widths, their velocity coincidence with the 6.7 and 12.2-GHz maser features and their LSR velocities distinct from that of the quasi-thermal emission seen at 108.8 GHz (Cragg et al. 2001). Ellingsen et al. (2003) have recently combined the multi-frequency maser observations with the Sobolev-Deguchi maser model and proposed to constrain density, dust and gas temperatures of the masing medium.

Minier et al. observed 85.5 and 86.9-GHz methanol masers in G345.01+1.79 with ATCA-mm in October 2002. Three antennas were used in the 750A configuration. 85.5 and 86.9-GHz masers were easily detected at the same velocity

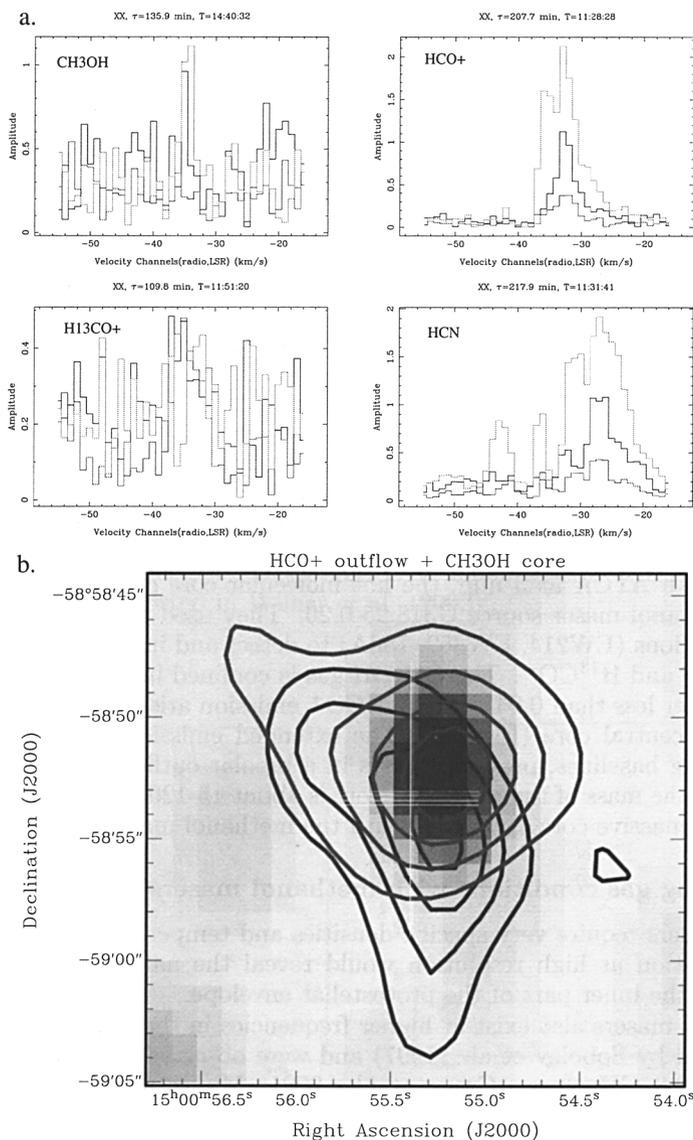


Figure 2. G318.95-0.20. a. Molecular line spectra taken on three ATCA baselines. HCO⁺ and HCN emission is resolved with increasing baselines, while CH₃OH intensity remains constant. b. Images of the thermal methanol emission (colour scale) and HCO⁺ emission (blue and red contours). The white crosses represent the methanol masers that coincide with a massive (15-120 M_⊙) molecular core. The methanol core is unresolved while the HCO⁺ emission is divided in blue- and red-shifted components.

as the 6.7 and 12.2-GHz masers (Fig. 3). Surprisingly, the 3-mm masers coincide in velocity and position with the cm masers, and hence coincide in space in G345.01+1.79. This is only possible for a narrow range of physical conditions according to the maser model (Fig. 3). Figure 3 suggests that the environment of the masing medium in G345.01+1.79 contains warm dust (250 K), cool gas (40 K) and a large methanol column-density.

3.3. Class I methanol masers, NH_3 in Orion and H_2O masers

ATCA will also be a powerful instrument to explore the southern sky using 25 GHz methanol maser (e.g. observations by Voronkov et al.), 22 GHz water masers and ammonia emission near 24 GHz. First detections of these lines are presented in Fig. 4.

3.4. Deuterated ammonia in NGC6334

Abundances of deuterated molecules can be enhanced by factors of 100 or more by isotropic fractionation. This is especially likely in cold molecular clouds, due to energy barriers for some of the key ion-molecule reactions involved in the formation and destruction of deuterated molecules (Watson 1974).

Deuterated ammonia was detected at 85.9 GHz in the NGC6334 region by Wong, Minier & Forster at the location of the brightest ammonia emitter in the sky, the source known as I(N). NGC6334:I(N) is known as a massive protostar candidate (Sandell 2000) with no radio continuum emission and with strong mm continuum emission. This is confirmed by the continuum maps at 12 mm and 3 mm. No emission is detected at 12 mm while a strong 3-mm continuum emission is seen at the location of I(N) (Fig. 4). At high angular resolution, NGC6334:I(N) is a cold core without ionised gas detectable and possibly harbours a high-mass protostar.

4. Massive star formation in the LMC

ATCA at 3 and 12 mm is also a unique instrument to study molecular gas emission in the LMC. Observations of molecular gas by Wong et al. in N113 (see Wong's paper, this volume) as well as a search for new water masers (Beasley et al.) have been undertaken in 2002-2003.

5. Conclusions

In 2002-2003, 43 projects have been carried out with the upgraded ATCA at millimetre wavelengths. 27 projects were directly related to star formation. The 12-mm system is fully operational while the 3-mm upgrade is expected to be complete in 2004-2005. The ATCA-mm is ongoing continuous upgrade and the observers are invited to visit the ATCA-mm web page for information on the current status of the mm receivers (www.atnf.csiro.au/observers/docs/3mm/).

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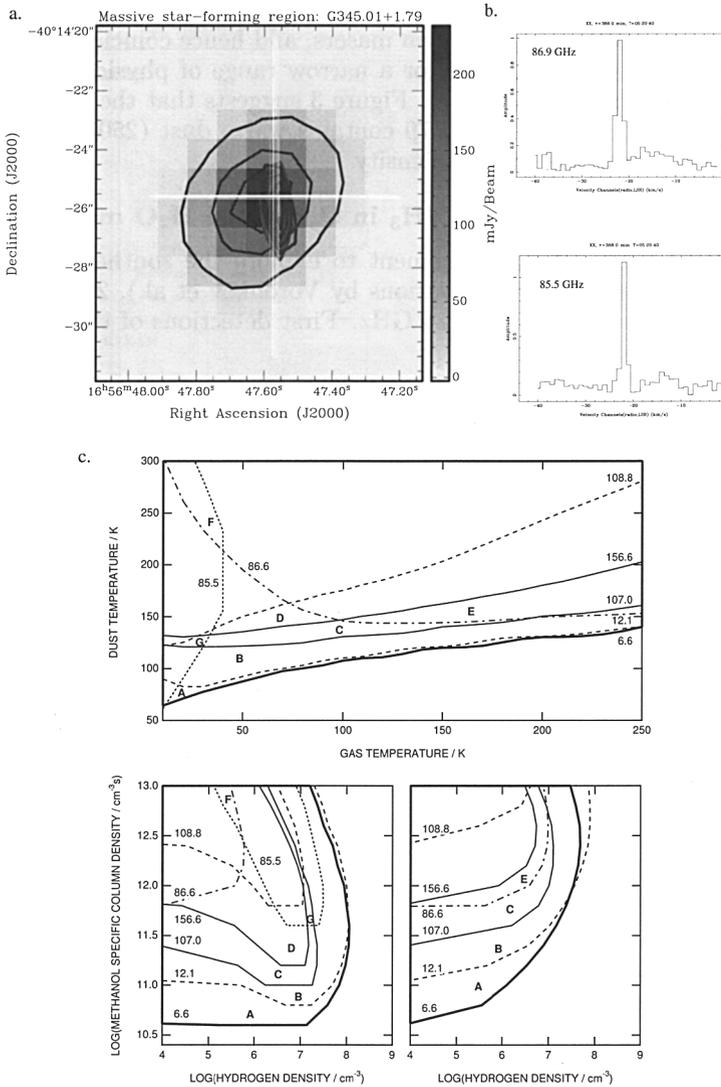


Figure 3. Methanol masers in G345.01+1.79. a. Positions of the 6.7 and 12.2-GHz masers (white crosses) and of the 85.5 and 86.9-GHz methanol masers (blue and red contours) overlaid on the radio continuum emission (colour scale and grey contours). b. ATCA 3-mm maser spectra. c. Modelling of the maser suitable conditions (Ellingsen et al. 2003). The contour diagrams show where methanol masers become active as function of density and temperature. Contours are labelled with the maser frequency in GHz and represent a brightness temperature threshold of 10^6 K. For instance, all masers are quenched for hydrogen densities greater than 10^8 cm^{-3} . G345.01+1.79 corresponds to point F in the diagram for which all transitions could be detected.

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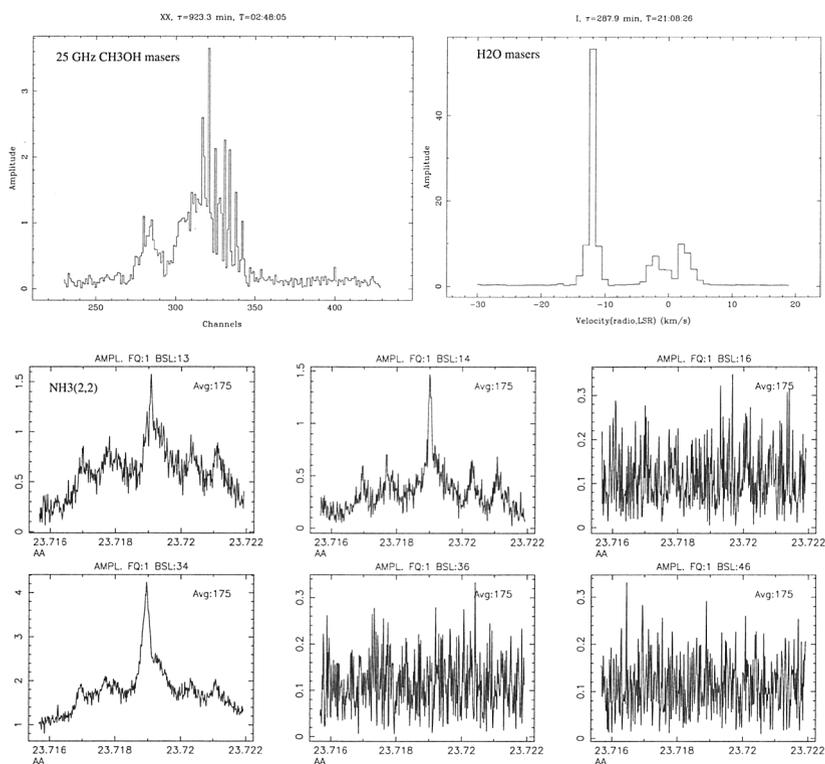


Figure 4. 25 GHz methanol masers in Orion KL (observations by Voronkov et al. in 2003), water masers in G345 and NH₃(2,2) emission in Orion KL (first light in April 2003)

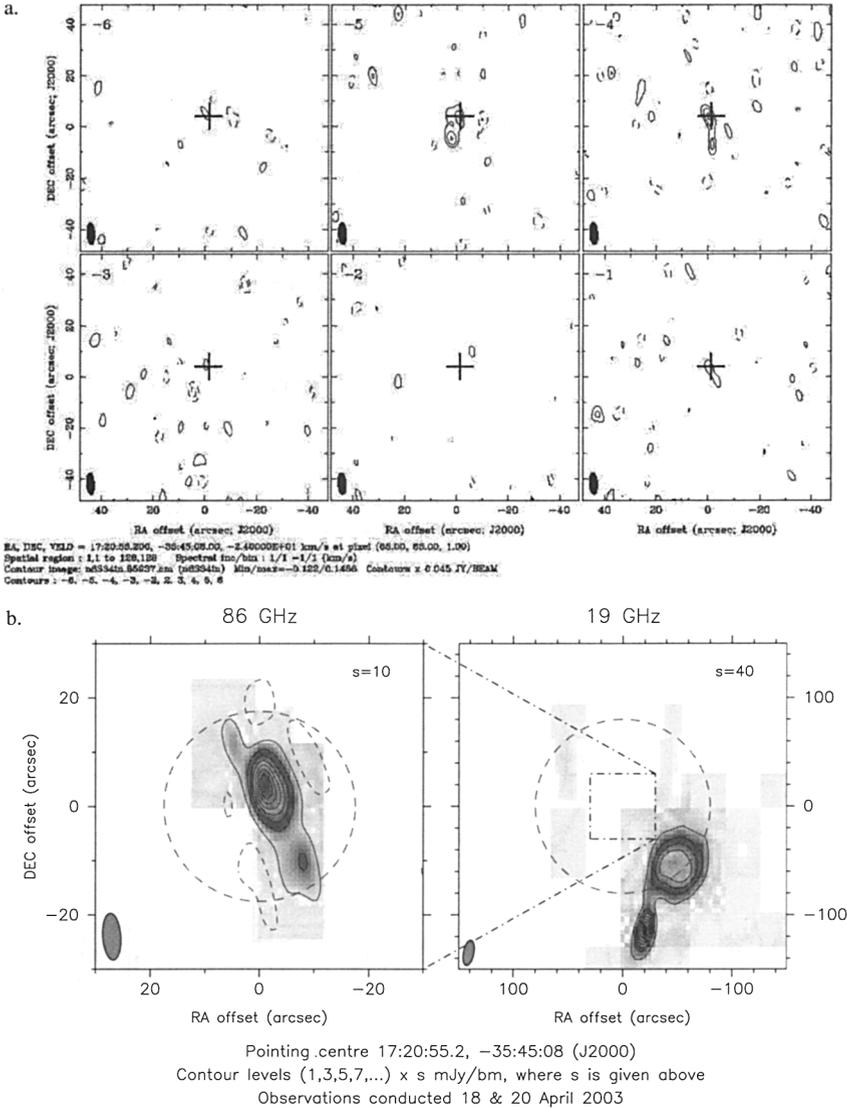


Figure 5. NGC6334. a. Deuterated ammonia channel maps taken with ATCA at 85.9 GHz in NGC6334:I(N). The velocity is given in each channel map. b. Continuum maps at 19 and 86 GHz. Observations were made by Wong, Minier & Forster in 2003.