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The Methanol Multibeam Survey

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Abstract. A new 7-beam methanol multibeam receiver is being used to survey the Galaxy for newly forming massive stars, that are pinpointed by strong methanol maser emission at 6.668 GHz. The receiver, jointly constructed by Jodrell Bank Observatory (JBO) and the Australia Telescope National Facility (ATNF), was successfully commissioned at Parkes in January 2006. The Parkes-Jodrell survey of the Milky Way for methanol masers is two orders of magnitude faster than previous systematic surveys using 30-m class dishes, and is the first systematic survey of the entire Galactic plane. The first 53 days of observations with the Parkes telescope have yielded 518 methanol sources, of which 218 are new discoveries. We present the survey methodology as well as preliminary results and analysis.

Keywords. stars: formation, Masers, Surveys, (galaxies:) Magellanic Clouds

1. Introduction

The 6668-MHz methanol maser has an intrinsic relationship with high-mass star-formation, having to date been observed exclusively in association with known high-mass star-formation tracers (Minier *et al.* 2003). The theory of massive (>8 $M_{\odot}$) star-formation is not clearly defined, as the accretion processes of low-mass star-formation encounter conflicts between radiation pressure, thermal pressure and the accretion flow when scaled to high masses (Keto 2003, Yorke 2004). Within the context of massive star-formation, gaseous A^+ type methanol is stimulated to produce a strong maser from the $5_1 \rightarrow 6_0$ transition at 6668.5192 MHz, first observed by Menten (1991). The 6.668-GHz methanol maser is therefore a useful tool to trace the Galactic distribution of massive star formation (and indeed the structure of the Galaxy itself).

The Methanol Multibeam (MMB) Survey is a Galactic plane survey for both 6.668-GHz methanol and 6.035-GHz excited OH, observing $0° < l < 360°$, b $\pm 2°$. The survey will take about 200 days split between the Parkes telescope in the southern hemisphere and the Lovell telescope in the northern. All detections will have high-resolution follow-up observations using the Australian Telescope Compact Array (ATCA) and the Multi-Element Radio Linked Interferometer Network (MERLIN). In addition to the Galactic plane survey, the MMB project will incorporate a survey of the Small and Large Magellanic Clouds and a pulsar survey "piggyback".

2. MMB Survey

2.1. *Multibeam Receiver*

The MMB survey is being conducted with a new 7-beam receiver jointly constructed by Jodrell Bank Observatory and the ATNF. This receiver comprises an hexagonal layout of 7 identical feeds capable of dual circular polarization over a large bandwidth. The low noise amplifiers are indium-phosphide High Electron Mobility Transistors (HEMTS), and along with 7 polarizers and 14 frequency downconverters, were constructed at JBO. The ATNF designed and constructed the feeds for the Parkes dish, along with the waveguide interface, provision of a 500-Hz switched noise diode calibration system, and the dewar assembly. The ATNF team also conducted all the receiver integration and rebuilds. The receiver was successfully commissioned at Parkes on the 21st of January 2006 and took first light on the 22nd January (Figure 1).

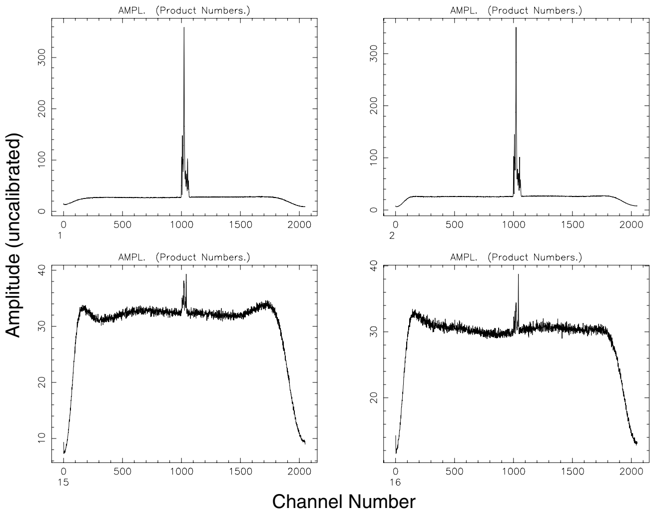

Figure 1. First light of the MMB survey, maser source G309.21+0.48. Top spectra are 6.668-GHz methanol in both right and left polarizations, bottom are 6.035-GHz OH in both polarizations.

2.2. *Survey Characteristics*

For the Parkes observations the correlator is configured for a bandwidth of 4 MHz, which corresponds to 180 $\mathrm{km s^{-1}}$ at 6.668 GHz, but 150 $\mathrm{km s^{-1}}$ is taken as fully usable. The centre velocities and range for observations have been determined from the Galactic CO emission of Dame, Hartmann & Thaddeus (2001); to fully cover the required velocities there is one setting for $20° < | l |$, two for $6° < | l | < 20°$, three for $2° < | l | < 6°$ and finally 4 for $| l | < 2°$. Doppler tracking is incorporated via the first 2 local oscillators. The correlator has 2048 frequency channels for each IF and each polarization, and the resultant 28*2048 spectra are dumped every 5 seconds. The 2048 channels across 4 MHz gives a velocity resolution of 0.0879 $\mathrm{km s^{-1}}$ at 6.668 GHz (0.0971 $\mathrm{km s^{-1}}$ at 6.035 GHz). This is well within the established velocity width of methanol masers (0.2 - 0.3 $\mathrm{km s^{-1}}$). The system temperature is typically <20 K. The FWHM beam for methanol is 3.2 arcmin and for the excited OH it is 3.4 arcmin. The beams are spaced at 6.46 arcmins, so the total multibeam footprint is 15 arcmins wide. The beam pattern (Figure 2), is oriented at an optimal 19.1° to the scan direction (the plane of the Galaxy) which maintains equal beam spacings (Condon, Broderick & Seielstad 1989).

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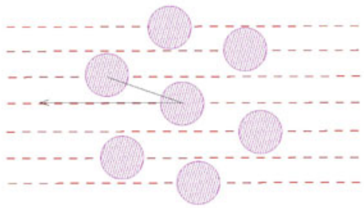

Figure 2. Multibeam Footprint, oriented at 19.1° to the Galactic plane.

Scans are conducted across 2° in longitude at a rate of 0.1° per min. The beams are then displaced by 1.23 arcmin in latitude before scanning back. There is then a larger displacement of 15 arcmins to the next scan pair, thus fully sampling a block of Galaxy of 2° in longitude by 4° in latitude requires 32 scans. One scan takes 20 mins, therefore a 2° by 4° block is completed in ∼10 hours of observing time. Only one pass is needed as there is minimal RFI at 6.668 and 6.035 GHz at the Parkes site. The beam sensitivity varies by at worst ±3.5% across a 2° by 4° block.

For the purposes of calibrating the noise diode equivalent flux density values seen by each beam, and to measure pointing offsets, the continuum source 1934-638 is observed daily, using a SPOT schedule which scans each beam across the source in RA and Dec. Calibration stability is further checked by observing on most days a known maser source in MX mode (in which a source is tracked, and the pointing centre cycled through each of the beams). Commonly used sources are 232.621+0.996 for methanol, and 300.069+1.147 for both methanol and excited OH.

2.3. *Data Reduction*

The raw correlator data is processed through the package LIVEDATA, developed by Mark Calabretta, to facilitate processing of multibeam spectral line data (http://aips2.nrao.edu /docs/cookbook/cbvol3/node5.html). This removes a bandpass estimate and calibrates the flux density using a table of values derived from the SPOT observation data. LIVEDATA processing is done in realtime, automatically streaming the raw data from the correlator. The resultant Single Dish FITS files are then gridded using a top-hat smoothing kernel with a radius of 4.4 arcmin and a cutoff of 2.2 arcmin, to form Galactic longitude-latitude-velocity cubes with GRIDZILLA (also developed by Mark Calabretta). These data cubes are first examined by eye using the Kvis visualization tool (which is part of the Karma library) and then we run an automated detection algorithm developed by Maxim Voronkov. This gives us a typical rms noise of 0.17 Jy, and hence a 3.5σ detection limit of 0.6 Jy.

3. Results

In the first 12 months since commissioning the new receiver, observations have been made at Parkes over 53 days, completing 106 degrees of longitude. This represents 64% of the Parkes part of the survey, 32% of the total survey. The observations have yielded 518 methanol maser detections, of which 218 represent new sources (Figure 3). Most of our new detections are below 4 Jy, typically around 1 Jy peak intensity, with linewidth FWHMs of less than 0.2 $\mathrm{km s^{-1}}$. The detections include several far-side outer Galaxy masers.

4. Statistics

In terms of survey statistics Figure 4 shows a plot (using data from the first 5 observing sessions) of the Galactic distance as calculated using the rotation curve of Brand & Blitz

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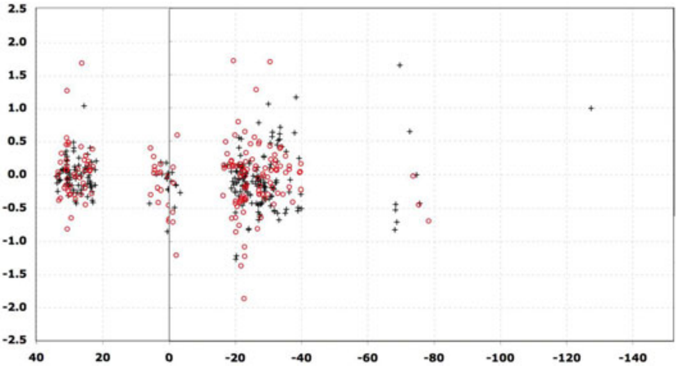

Figure 3. Longitude vs latitude plot for the Parkes survey region showing the MMB detections to date. Crosses represent previously known, circles new detections.

(1993) against number of sources, employing 1 kpc bins. This distribution is comparable to that found by Pestalozzi, Minier & Booth (2005) with the peak at the molecular ring distance. Figure 5 shows the flux density distribution, clearly highlighting the abundance of new detections at low flux densities. It is also possible to see that the peak in total detections at approximately 2 Jy, agrees with the observations of the Arecibo Galactic Plane Survey (Pandian, Goldsmith & Deshpande 2007), which has an rms noise level of $\sim$70 mJy per spectral channel.

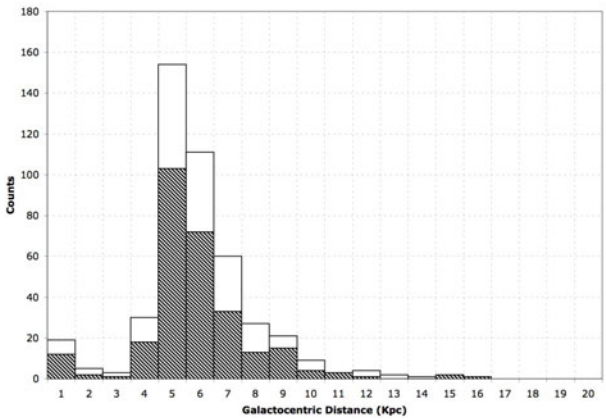

Figure 4. Galactocentric distance against number counts based on 1 kpc bins for the MMB survey. Shaded represents previously known detections from Pestalozzi, Minier & Booth (2005), white represents new detections from this survey.

5. High Resolution Follow-up

The Parkes detections can readily be positioned to an accuracy of the order of 30 arcsec, which is adequate for Galactic distribution studies, but it is not enough to determine the characteristics of massive star-formation, the association of the 6.668-GHz methanol maser with other species of masers, or the detailed structure of individual sources. The positions of the Parkes detections are then observed with MERLIN and the ATCA to refine the positions to the sub-arcsec accuracy achievable with these telescopes. So far, all 218 new detections have been observed and positioned using ATCA observations and 30 sources have been observed with MERLIN in the $20° < l < 30°$ region, positioning 25.

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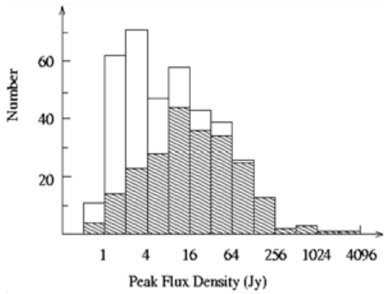

Figure 5. Peak flux density distribution for the known (shaded) and new (white) detections for the MMB survey.

6. Pulsar Survey "Piggyback"

In addition to the main MMB survey, we are also conducting "piggyback" observations on a Pulsar survey using our receiver. This is just at the methanol frequency, so as to allow us to use 4096 channels across an 8 MHz bandwidth, thus giving the same spectral resolution as the main survey, but across a wider velocity range. The pulsar survey covers a quite small area, primarily near the Galactic centre, but may extend out to $-45° < l < 60°$. The principal advantage of this "piggybacking" is to provide long integrations, which taking into account the higher background noise, will give an order of a magnitude improvement in sensitivity, and thus should provide a good indication of the completeness.

7. Conclusions

The Parkes observations of the MMB are over 60% complete and have yielded 518 detections, 218 of which are new and have been positioned to 0.1 arcsec with ATCA. The Parkes observations will be complete in 2008, at which point the receiver will move to Jodrell to complete the Galactic survey by 2010. The final MMB catalogue of 6.668-GHz methanol should thus be complete by 2011. With the complete catalogue the authors will also provide IR identifications and complementary survey associations (such as the CORNISH VLA continuum survey), distances to the detections, and an analysis of the Galactic distribution. The deep integration pulsar survey "piggyback" data will provide information on the completeness of the MMB survey. The MMB can be found online at http://www.jb.man.ac.uk/research/methanol/.

Acknowledgements

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