

First SIMBA observations towards CH₃OH masers

Masers from blind surveys mark the earliest stages of massive star formation

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Abstract. We report SIMBA 1.2 mm dust continuum observations of the environments of eight methanol maser sources, all discovered during spatially fully-sampled, untargeted surveys of the galactic plane. We summarise our search for possible associations of the masers with IR sources (IRAS and MSX) and find that it is not always possible to make definite associations. A preliminary characterisation of the IR sources found in the maser neighbourhood is given according to their position in the [60–25]–[25–12] colour-colour diagram.

Key words. masers – stars: formation – infrared: stars – circumstellar matter – HII regions – stars: evolution

1. Introduction

Massive star formation has attracted increasing interest in recent years, with the mounting evidence that methanol masers provide excellent tracers and probes of the high-mass star formation process (e.g. Hunter et al. 1998; Minier et al. 2001). Such evidence has led to several surveys aimed at identifying new high-mass stars, often targeting IRAS colour-selected UCHII regions (Caswell et al. 1995; Schutte et al. 1993; Szymczak et al. 2000). Although making significant contributions to the discovery of new massive star forming regions (MSFRs), such surveys have yielded only a $\sim 15\%$ detection rate of methanol masers.

An alternative approach for discovering MSFRs has been provided by *blind* surveys of 6.7 GHz methanol masers. In particular, the surveys of Ellingsen et al. (1996) and Pestalozzi et al. (2002, in prep.) have sampled in a consistent manner large regions of the Galactic plane from the southern and northern hemispheres respectively. Since the majority of methanol masers revealed in these surveys does not have a clear association (within the positional accuracy) with IRAS sources, the question has arisen: could they be tracing early stages of the high-mass star formation process, in which the still highly-embedded, nascent star is radiating much of its flux in the millimetre and submillimetre regions (as suggested by Walsh et al. 1999)?

With the aim of answering this question, in addition to ascertaining the SEDs for regions for which there is existing IR data (IRAS and MSX), we report here on 1.2 mm bolometer observations of the regions surrounding eight

6.7 GHz methanol masers detected in blind surveys. This constitutes the first part of our follow-up investigations for understanding the methanol maser phenomenon, and the evolutionary route to forming massive stars.

2. Observations

Observations were made using the SIMBA 1.2 mm bolometer array on the SEST on 19 October 2001. SIMBA is a 37-channel hexagonal array in which the HPBW of a single element is about $24''$ and the separation between elements on the sky is $44''$. The bandwidth in each channel is about 50 GHz. Spectral line emission present in the band may contribute to the total continuum flux values reported in this paper, though not more than 30% as in the case of molecular rich clouds (e.g. IRC+10216, L.-Å. Nyman, priv. comm.). These observations were made in fast-mapping mode. Areas typically of $600'' \times 384''$ were imaged in order to detect nearby IRAS sources in the field, using a scan speed of $80'' \text{ s}^{-1}$. Typical total observation times were around one hour per source, during which 5 to 6 maps were produced. Zenith opacities lay in the range 0.217–0.270 throughout the observing run. The resulting data were reduced with the MOPSI mapping software package developed by R. Zylka, using a “deconvolution” algorithm¹ to remove the contribution of the electronics arising from the fast-mapping observing mode, the “converting” algorithm (Salter 1983) to convert the coordinates from rectangular to equatorial, and partly the NOD2 and GILDAS libraries. The calibration of our data was performed using 1.2 mm Uranus data for

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¹ Developed within the SIMBA collaboration.

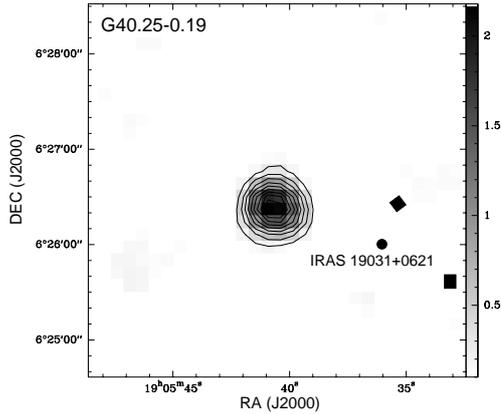


Fig. 1. SIMBA maps of the 1.2 mm dust continuum towards the methanol masers listed in Table 1. Circles indicate the IRAS source, diamonds the MSX source, squares the methanol maser position. Contours and grey scale indicate the 1.2 mm intensity in Jy. Here we show the region around G40.25-0.19.

19 October. The multiplication factor between counts and Jy was $166.5 \text{ mJy count}^{-1} \text{ beam}^{-1}$ (Table 1).

3. Results and discussion

Figures 1 and 2 show the images obtained at 1.2 mm for the sources listed in Table 1. The same table gives the peak and integrated fluxes of the detections of the 1.2 mm dust continuum. For the position accuracy of the 1.2 mm emission we adopt the FWHM of one channel of the array ($24''$). For the IR sources we refer to the literature ($1-2'$ for IRAS, $5''$ for MSX). The positions of the southern methanol masers are accurate to better than $1''$ (Ellingsen, priv. comm.). The position of G41.34-0.14 has been determined to an accuracy of 5 mas^2 , while for G40.25-0.19 the uncertainty is larger (about $1'$). We refer to Ivezić & Elitzur (2000) for the discussion about the IRAS sources found close to some methanol masers. In their reanalysis of the colour properties of the galactic IRAS sources they find a consistent separation of the Point Source Catalogue (PSC) into four classes that, according to the authors, are due to different spatial distribution of the dust around those sources. Confirmation comes from radiative transfer calculations for a point source surrounded by a dust envelope. By varying p in the power law density profile r^{-p} the authors produce solutions characterised by the optical depth τ_ν . Making use of that study we are able to infer density profile and optical depth of some of our sources.

3.1. G40.25-0.19

G40.25-0.19 has been detected both by the Onsala blind survey and by the colour-selected survey of Szymczak et al. (2000). Our SIMBA map of G40.25-0.19 shows only one site of emission which has no associated IR emission. The methanol maser emission is well-separated from the

1.2 mm emission peak. Poor positional accuracy of the methanol maser does not allow us to draw conclusions about associations. Further continuum and molecular line observations are required in order to characterise the nature of this region.

3.2. G41.34-0.14

G41.34-0.14 (component a in Fig. 2) was detected by Pestalozzi et al. (2002, in prep.) during the Onsala 6.7 GHz blind survey. It has two main spectral features, the strongest is approximately 20 Jy. The associated IRAS source has been systematically discarded by colour-selected surveys, since it does not match any criteria for UCHII regions. It seems to have a flat density profile ($p = 0$) and an optical depth of $\tau_\nu \sim 0.1$. In the same field we have discovered two other 1.2 mm sources, of which b has both an IRAS and MSX counterpart, whilst c does not have any IR counterpart.

3.3. 327.12+0.51

This strong (80 Jy, three spectral features) methanol maser was first detected by MacLeod & Gaylard (1992). It has OH and H₂O associated masers (Batchelor et al. 1980; Caswell et al. 1983), making it a classical high mass star formation region. IRAS 15437-5343 shows colours of an UCHII region and appears deeply embedded (high optical depth $\tau_\nu \sim 100$). Its density profile is fairly flat ($0 \leq p \leq 0.5$). 8.6 GHz and 6.67 GHz continuum emission (12 and $<12 \text{ mJy}$ respectively) have been observed by Walsh et al. (1998) at more than $1'$ offset from the IRAS source. Phillips (1998) detected a 0.5 mJy 8.6 GHz continuum peak at $1'$ from the methanol maser. VLBI observations of the methanol maser (Phillips 1998) show a linear distribution of the maser components with a linear velocity gradient. Assuming a Keplerian disc, the mass for the central object is estimated to be $14.7 M_\odot$.

3.4. 327.59-0.09 & 327.62-0.11

There are two weak (3 Jy), single featured methanol masers in the SIMBA field, a, b as 327.59-0.09 and 327.62-0.11 respectively (Ellingsen et al. 1996). Both show clearly associated 1.2 mm and MSX counterparts. IRAS 15490-5353 could be related to component b. No other counterpart is visible. As for 333.13-0.56, we suggest that the methanol masers trace very deeply embedded objects.

A third 1.2 mm peak of emission is visible in the field (component c), having an MSX and probably an IRAS counterpart, but no methanol maser.

3.5. 329.34+0.15

This single featured 15 Jy methanol maser has been discovered by Ellingsen et al. (1996) and is clearly associated with IRAS 15567-5236, an UCHII region.

² Observed with the Jodrell-Bank–Cambridge baseline.

Table 1. Source list with J2000 coordinates, radial velocities of the methanol maser emission, 1.2 mm peak, integrated flux and rms. References: 1) Pestalozzi et al. (2002, in prep.); 2) MacLeod & Gaylard (1992); 3) Ellingsen et al. (1996); 4) Walsh et al. (1998); 5) Phillips (1998); 6) Szymczak et al. (2000).

Source	RA(2000)	Dec(2000)	v_{LSR} [km s ⁻¹]	Peak [Jy]	Int. flux [Jy/beam]	rms
G40.25−0.19 ^{1,6}	19 05 32.6	+06 25 38	+70.0	2.55	2.64	0.164
G41.34−0.14 ¹	19 07 21.870	+07 25 17.34	+14.0	0.30	0.38	0.036
327.12+0.51 ^{2,3,4,5}	15 47 32.729	−53 52 38.90	−87.1	1.54	2.06	0.070
327.59−0.09 ³	15 52 36.824	−54 03 18.97	−86.3	0.34	0.44	0.050
327.62−0.11 ³	15 52 50.241	−54 03 00.71	−97.5	0.43	0.72	0.050
329.34+0.15 ^{3,4}	16 00 33.154	−52 44 40.00	−106.5	4.37	6.67	0.132
332.35−0.44 ³	16 17 31.560	−51 08 21.55	−53.1	0.67	0.76	0.052
333.13−0.56 ³	16 21 35.742	−50 40 51.29	−56.8	3.06	4.83	0.200

Schutte et al. (1993) did not detect any methanol maser above their 5 Jy limit. Walsh et al. (1998) detect both a 8.6 and a 6.67 GHz continuum peak (<20 and 270 mJy/beam respectively). The colours of IRAS 15567-5236 suggest that we are observing a young object with very low optical depth ($\tau_\nu < 0.1$). The density profile is fairly flat, $p = 0.5$.

3.6. 332.35-0.44

This weak (4 Jy, one spectral feature) methanol maser was discovered by Ellingsen et al. (1996). It seems to lie on the edge of a 5 GHz peak of emission (Haynes et al. 1978). Both IR sources appearing in the SIMBA field fall on top of the 1.2 mm peak of emission, within the positional accuracies. The colours of the IRAS source are not representative for an UCHII region. The IRAS source seems to have a flat density profile ($p = 0$) and low optical depth, $\tau_\nu \sim 0.1$.

3.7. 333.13-0.56

This 6.7 GHz maser source was detected by Ellingsen et al. (1996). It shows three distinct spectral features, the strongest being about 17 Jy. It does not have any IRAS counterpart within the positional accuracies. An MSX source lies at an angular distance of $>1.5'$ from both the methanol maser position and the peak in the 1.2 mm emission. The methanol maser and the strong 1.2 mm emission are spatially coincident within the positional accuracies. This indicates that the methanol maser is tracing a very deeply embedded object.

4. Conclusions

We can divide the observed source list into two separate groups: 333.13-0.56, 327.62-0.11, 327.59-0.09, G41.34-0.14 in the first group; 332.35-0.44, 327.12+0.51, 329.34+0.15 in the second. G40.25-0.19 is left out of the discussion because of the poor positional accuracy of the methanol maser. The first group collects all sources with either no IRAS counterpart or a weak one. These sources could have been detected only by blind surveying. The 1.2 mm

dust continuum confirms the existence of dust where a methanol maser is detected. We consider them as the group of young, still embedded sources. The sources of the second group have clear IRAS and MSX counterparts. The colours of the IRAS sources fulfil the selection criteria by Wood & Churchwell (1989) or Szymczak et al. (2000), so we can consider them as (young) UCHII regions. The lack of cm continuum emission towards most of the sources can be explained in two ways: we can see it as a further argument to strengthen our hypothesis that these sources are in early stages of the stellar evolution; it could also be argued that those central stars are not massive enough to produce Lyman α photons. We prefer the former idea, as methanol masers are known to trace young massive stars.

Despite the clear separation into two classes of the sources, it remains difficult to find correlations between the 1.2 mm flux density and the methanol flux density. Furthermore it is puzzling to notice that 327.59-0.09 and 327.62-0.11 do have a 1.2 mm and an MSX counterpart but no clear IRAS counterpart. These topics will be investigated further, by observing in the submillimetre range (850–450 μm).

The observations lead us to the following conclusions:

- Blind surveys of methanol masers facilitate the detection of young, still deeply embedded high-mass star formation regions.
- IRAS sources associated with methanol masers show a flat density profile ($0 \leq p \leq 0.5$), which means that they can be classified as objects in an early stage of massive star formation.

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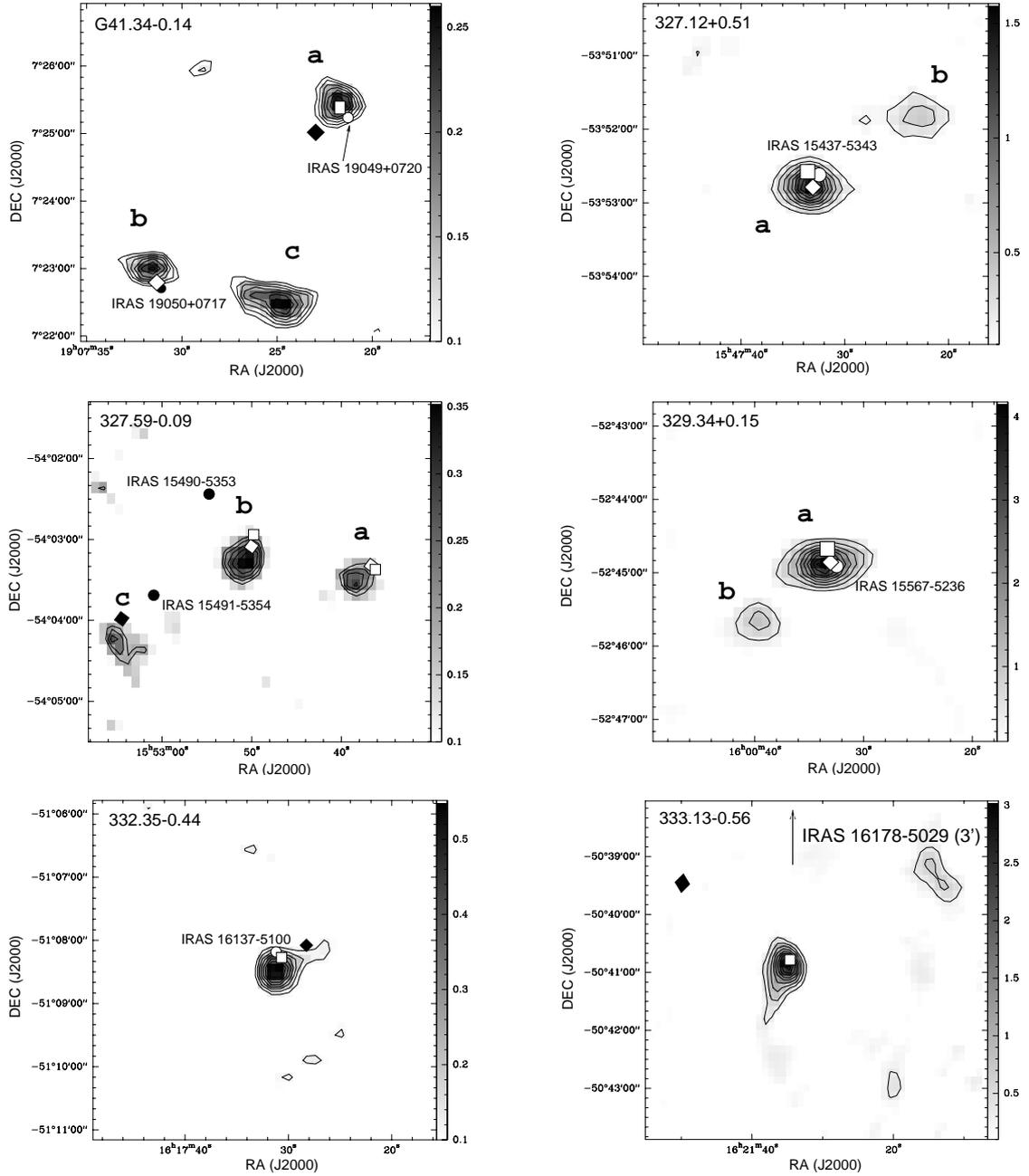


Fig. 2. SIMBA maps of the observed methanol maser sources listed in Table 1, continued. For details see Fig. 1.

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