Astron. Astrophys. 336, L5–L8 (1998)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

Observations of methanol masers in NGC7538: probable detection of a circumstellar disc

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Received 24 April 1998 / Accepted 28 May 1998

Abstract. We present VLBI observations of 6.7 and 12.2 GHz methanol masers in the star forming region NGC7538. Our results show the existence of two groups of masers. The first group exhibits a linear velocity gradient and forms a line in our VLBI map which is consistent with a rotating disc of masers seen edge-on around a massive star. The second group of masers are blueshifted with respect to the first group and lie in a conical region south of the inferred disc. We argue that these masers probably arise in an outflow emerging approximately perpendicularly to the disc. We find that the maser positions at 6.7 and 12.2 GHz are coincident and those of the second group correspond approximately to the absolute positions of NH_3, H_2CO and OH masers associated with the radio-continuum and infrared source NGC7538-IRS1.

Key words: HII regions – masers – stars: formation – circumstellar matter – techniques: interferometric

1. Introduction

Massive stars are formed in the dense cores of molecular clouds where the stars are hidden at optical wavelengths by the circumstellar dust.They actively participate in the heating of molecular clouds and in the enrichment of the interstellar medium in heavy elements. They also play an important role in the formation of new molecular cloud complexes responsible for the birth of new solar systems (Cameron 1992).

Observations of interstellar masers are potentially a powerful way of studying star formation regions in detail. However despite the important results from studies of OH and water masers, the dynamical picture has remained confused. In contrast, recent studies of the 6.7 GHz and 12.2 GHz methanol masers (Norris et al. 1993, 1998) have revealed masers distributed in lines showing linear velocity gradients which may be indicative of rotation in some cases. Furthermore recent surveys of the southern hemisphere 6.7 GHz methanol masers (Ellingsen 1996; Walsh 1997) reveal an association between CH_3OH maser emission and early phases of massive star formation.

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In this letter we present VLBI observations of 6.7 GHz and 12.2 GHz methanol masers toward the star forming region NGC7538.

2. Observation and data analysis

The $5_1 \rightarrow 6_0 A^+$ transition at 6668.518 MHz and the $2_0 \rightarrow 3_{-1}$E transition at 12178.595 MHz are the two strongest class II methanol maser emissions and appear to be very good tracers of massive star formation (Norris et al. 1988, 1993, 1998; Menten et al. 1991, 1992). We conducted VLBI observations at 6.7 GHz in May 1997 and at 12.2 GHz in July 1997 of NGC7538 ($(\alpha,\delta)_{1950} = 23^h 11^m 36^s.6, +61^o 11' 49''.9$, Menten 1991) using the EVN and VLBA respectively. Only the EVN is equipped to observe the 6.7 GHz masers and only the VLBA can observe at 12.2 GHz. The VLBA offers a maximum spatial resolution of 1 mas for the longest baseline while the minimum fringe spacing is 7 mas for the EVN. We obtained useful 6.7 GHz data from three of the four EVN antennas which were equipped at the time of our observations i.e Effelsberg (100m), Onsala (25m) and Medicina (32m). Observing scans of 40 minutes duration preceded by observations of continuum calibrator sources were repeated every 2 hours for EVN observations and every 1.5 hours for VLBA observations. The maser features generally span 10 km s^{-1} (Caswell et al. 1995) and so we used 0.5 MHz filters (covering 22 km s^{-1}) for EVN observations and 1 MHz filters (covering 25 km s^{-1}) for VLBA observations. Observations at both frequencies were recorded in a VLBA mode and correlated on the NRAO correlator using 512 spectral channels for the EVN data and 256 spectral channels for the VLBA data. The velocity resolutions were sufficient (0.04 km s^{-1} at 6.7 GHz and 0.1 km s^{-1} at 12.2 GHz) to distinguish the maser features, which are typically separated by 1 km s^{-1} and have FWHM of 0.2 km s^{-1} (Caswell et al. 1995).

All the data were calibrated and reduced using the Astronomical Image Processing System (AIPS). We used the spectral line calibration procedure described by Reid (1995) to calibrate the phase and the amplitude of the data. We used as a phase reference a feature which contained a strong signal and had close to zero closure phase implying it was a single, spatially isolated maser component. Once the data were calibrated, the source was imaged using the fringe-rate mapping technique (Walker 1981). We also mapped and CLEANed each spectral feature corresponding to a maser spot in the fringe-rate maps and checked the offset position from the position of the reference feature. We found that the position offsets obtained by those two mapping techniques corresponded within a positional error of 3 mas. These differences are probably dominated by errors in the fringe-rate mapping.

The absolute positions were measured using our 12 GHz data. They were obtained by applying only the phase calibration as determined toward the continuum calibrator and then amplitude calibrating and imaging our reference spectral feature. We assumed that the main spectral features ($-56.2\,\mathrm{km\,s^{-1}}$) at 6.7 GHz and 12.2 GHz were coincident in space and then found the absolute position of each maser feature from its offset to these reference features. We expect that the dominant contribution to errors in absolute position is that of the unmodelled atmosphere; we can set an upper limit to this from the continuum calibrator fringe rates implying an absolute position error of 10 mas.

3. Results and discussion

In Fig. 1, we show the cross-power spectra of the 6.7 GHz maser emissions on our shortest baseline i.e Effelsberg-Onsala. The shape of the spectrum is similar to that of the single dish spectrum observed by Menten (1991). Similarly, our observations at 12.2 GHz show the same result as Koo et al. (1988). However the flux densities of the cross-power spectra on our shortest baseline (corresponding to the fringe spacings of 18 and 17 mas at 6.7 and 12.2 GHz respectively) are about 2 to 4 times weaker than the flux densities of the total power spectra for 6.7 and 12.2 GHz maser emissions respectively. Similarly, Ellingsen (1996) in NGC6334F and Menten et al. (1992) in W3(OH) found that the flux densities of the cross-power spectra of the 6.7 GHz methanol masers are much weaker than those of the total power spectra. These results imply that the maser emission regions contain diffuse structures larger than our minimum fringe spacings.

We find that the methanol masers in this object (Fig. 2) fall into two distinct groups. The first group (masers labelled a to f) which produces the main amplitude peak at the velocity $-56.2\,\mathrm{km\,s^{-1}}$ forms a line. They also show a clear velocity gradient (Fig. 2). The second group (g, h, i, j, k) lie within a conical region of half opening angle approximately equal to 25^o whose projected axis is roughly perpendicular to the line of masers in group I. This group of masers are all blueshifted with respect to the first group.

If we assume that the brightest spectral feature at $-56.2\,\mathrm{km\,s^{-1}}$, has the same absolute position at 6.7 GHz and 12.2 GHz, we find that the 6.7 and 12.2 GHz maser positions are coincident within a positional accuracy of 6 mas for the central features (a-f) and 20 mas for the feature labeled j (Table 1) and that for (a-f) the two maser lines exhibit the same velocity-major axis offset diagram. However several maser sources detected at 6.7 GHz do not arise at 12.2 GHz (features g, h, i, k).

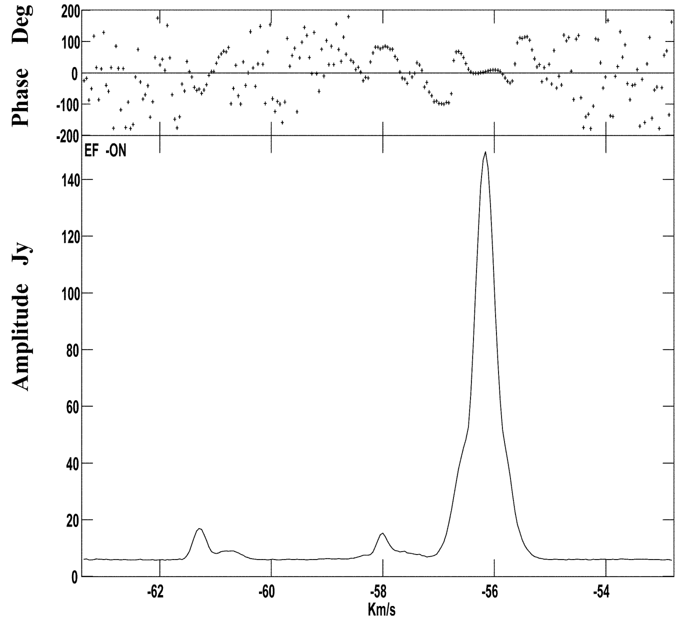

Fig. 1. Cross-power spectrum for the Effelsberg-Onsala baseline of the 6.7 GHz maser emission from NGC7538, averaged over the whole experiment

The set of points (a-f) show without doubt a linear structure in the VLBI map and a linear velocity gradient both at 6.7 and 12.2 GHz (Fig. 2). This structure is consistent with rotation in a nearly edge-on disc in which masers arise at some preferential radius r, presumably corresponding to the place where physical conditions are most suitable for maser action. Masers are likely in such edge-on systems because of the large path lengths of masing material along the line of sight. If we model this structure as a Keplerian disc seen edge-on rotating around a central mass M (Norris et al. 1998), the velocity gradient $\frac{dv}{dx} = \sqrt{GM/r^3}$ is equal to 1.5×10^{-2} km s^{-1} AU^{-1} corresponding to a value of $\frac{M}{r^3}$ of 2.5×10^{-7} M$_\odot$ AU^{-3} which lies in the range found by Norris et al. (1998). Unfortunately we do not know the maser distribution in the disc and what fraction of the disc is observed. It is probable that we see maser action only in regions directly in front of the star, where for a rotating disc the velocity coherence along the line of sight is greatest. However given that massive stars are a few tens of solar masses, from the observed ratio $\frac{M}{r^3}$ in NGC7538 we can estimate the radius of the disc at which the masers occur. We obtain r equal to a few hundred AU which is consistent with theoretical models of protoplanetary discs (Lin & Pringle 1990).

In Fig. 3, we plot all the known masers detected toward NGC7538 (Palmer 1984, Johnston et al. 1989, Campbell 1984). The maser groups (k, j) are almost coincident within the positional errors with the NH_3 and H_2CO maser positions (Johnston et al. 1989) which are believed to arise from outflows (Campbell 1984; Scoville et al. 1986). The group of masers (a-f) lies between the two 15 GHz continuum peaks (IRS1-N, IRS1-S) associated with the IRAS source NGC7538-IRS1 (Campbell 1984). This map is consistent with our interpretation that masers a-f form part of a circumstellar disc associated with the radio-

Table 1. Flux densities of CH_3OH masers in NGC7538. The labels refer to spectral features corresponding to the same velocity at both 6.7 and 12.2 GHz. Labels i, j, k refer to brightest maser feature of the different clusters of masers noted i, j, k in Fig. 2. RA is the right ascension offset and Dec is the declination offset

Label	LSR Velocity ($km\,s^{-1}$)	12.2 GHz			6.7 GHz		
		S(Jy)	RA(mas)	Dec(mas)	S(Jy)	RA(mas)	Dec(mas)
a	−55.50	6	12.23	−8.9	15.2	16.52	−11
b	−55.70	17	10.08	−4.0	64.6	10.60	−4.9
c	−56.00	27.5	4.92	−3.3	130.4	3.87	−1.4
d	−56.20	44.5	0.0	0.0	162	0.0	0.0
e	−56.46	32	−4.06	1.1	118.6	−5.35	0.9
f	−56.82	8.5	−8.22	1.0	46.2	−10.51	7.5
g	−57.47	0	–	–	11.8	118.45	−150.6
h	−58.05	0	–	–	21	159.20	−498.1
i	−60.85	0	–	–	7.8	−237.90	−262.5
j	−61.34	4	−76.14	−213.6	26.2	−67.68	−203.9
k	−60.68	0	–	–	8	−32	−196.8

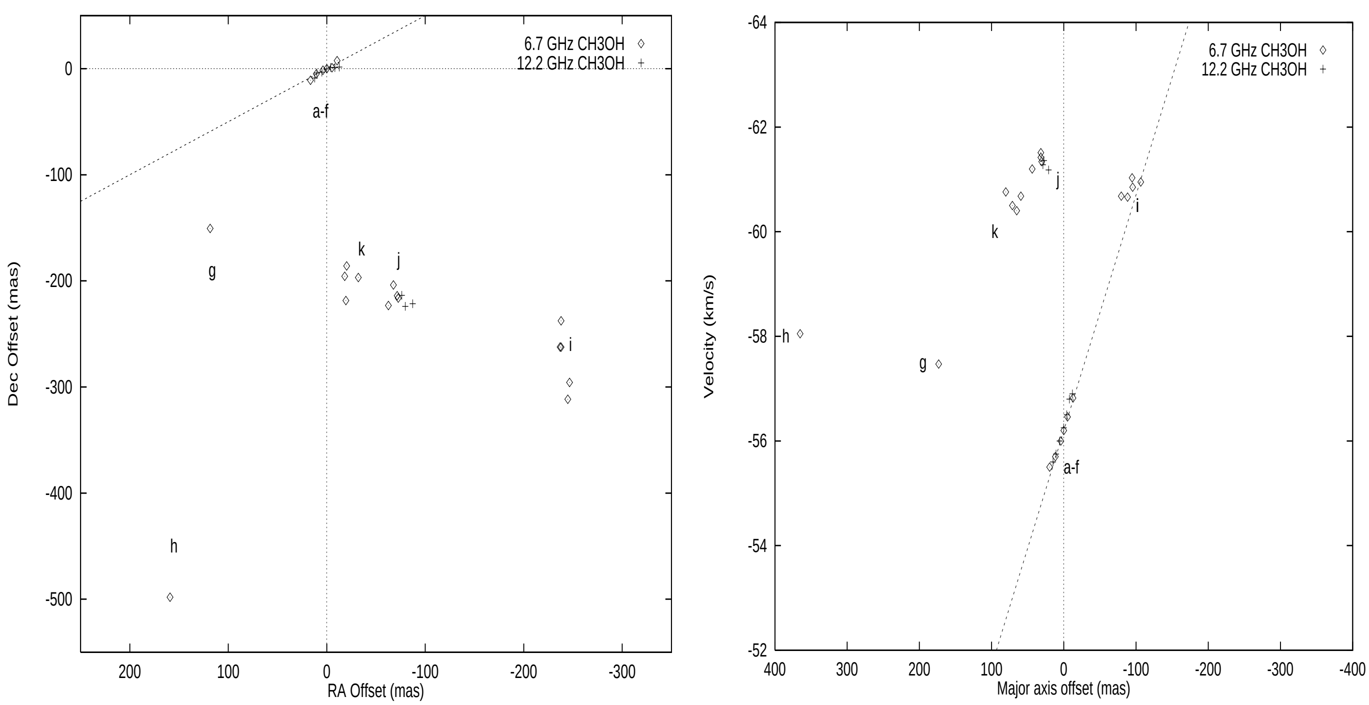

Fig. 2. Left: 6.7 and 12.2 GHz maser position offsets from the reference feature position. At the presumed distance of NGC7538 of 2.7 kpc, 100 mas corresponds to ∼250 AU. Right: Velocity-major axis offset diagram of NGC7538 where the major axis position is the position of the maser projected onto the dotted line passing through a-f in Fig. 2 left

continuum source NGC7538-IRS1. In addition it is natural to interpret the second blueshifted group of masers in the conical region south of the disc as part of an outflow. This result agrees with the 7″ resolution mapping in CO of a disc and approximately orthogonal high velocity outflow components with the same position angles as our VLBI features (Scoville et al. 1986).

Acknowledgements. We thank the observatories of the US and European VLBI Networks.

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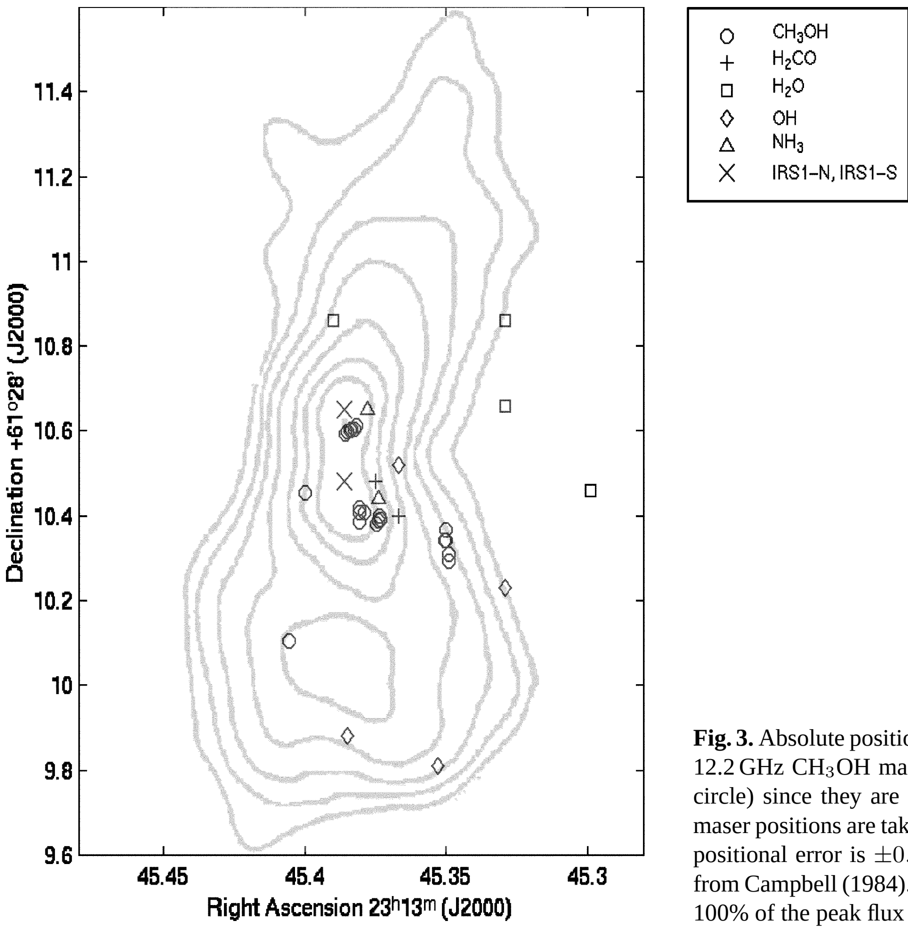

Fig. 3. Absolute positions of different masers in NGC7538. The 6.7 and 12.2 GHz CH_3OH masers are represented by the same symbol (open circle) since they are coincident when both occur. OH, NH_3, H_2CO maser positions are taken from Johnston et al. (1989) and their absolute positional error is ± 0.1 arcsec. The 15 GHz continuum map is taken from Campbell (1984). The contour levels are 2.5,5,10,20,40,60,80 and 100% of the peak flux

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