Methanol Masers: Tracers of discs?

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The EVN has been used to image the 6.7-GHz methanol maser emission from two regions of massive star formation. Both sources show emission with a linear morphology similar to other methanol maser sources which have previously been interpreted as delineating edge-on circumstellar discs around young massive stars.

1. Introduction

Methanol masers are found in regions of massive star formation typically identified by the presence of luminous *IRAS* PSC sources, UCHII regions or OH masers. As they are very luminous (typically 10 times stronger than any associated OH masers) they make excellent probes of the environment around massive stars. Radio (and millimeter) wavelength continuum & molecular lines and IR observations are the only way to study young massive stars as dust obscures the central object at optical wavelengths. ATCA observations of the 8.6-GHz continuum associated with many 6.7-GHz methanol sources have shown that roughly one third to one half have detectable UCHII regions and those that do are mostly unresolved or barely resolved in the 1 arcsec synthesised beam (Phillips et al 1998b, Walsh et al 1998). This suggests that methanol is associated with very young massive stars and small, probably suppressed, UCHII regions.

High resolution observations of the 6.7-GHz methanol transition using the ATCA (Norris et al 1993, Phillips et al 1998b) have shown than many sources (17 out of 38) have a linear morphology, most with a velocity gradient along the line. This has been interpreted (Norris et al 1993, Norris et al 1998, Phillips et al 1998b) as the maser components delineating a edge-on circumstellar disc around a young massive star. Observations by Minier et al (2000a) using the European VLBI network have also found many linear sources which they also attribute to edge-on circumstellar discs.

An edge-on disc model is thought to be a more natural model over other possibilities such as jets or collimated outflow and shock fronts. We would expect collimated jets to have much higher velocities (e.g. Rodriguez et al 1989, Rodriguez et al 1990) while low velocity outflows tend to be extended. OH masers are thought to form in a layer of cool dense gas between the shock and ionization front around a compact HII region (Elitzur 1992) which could give a linear morphology, however this does not explain the velocity gradients which are seen.

It would be desirable to make observations of the methanol sources using other wavelengths/techniques to independently detect evidence of a disc. IR observations have so far failed to elucidate any evidence either for or against the disc model (Phillips 1998a, Walsh et al 1999). This may be because the sources are embedded in a cocoon of warm dust which obscures a more compact disc. VLBI proper motion studies have also started in the Northern and Southern hemisphere (Phillips 1998a, Minier 2000b) however it is too early for any conclusive results. An alternative approach is to use millimeter instruments to image (potential) outflow perpendicular to the disc and high density tracers in the disc itself. To date, most methanol observations have been made in the Southern hemisphere and are not observable to Northern millimeter interferometers. The EVN has relatively recently installed 6.7-GHz receivers on 5 antennas opening up the Northern sky to methanol imaging (while the 12.2-GHz methanol transition is observable using the

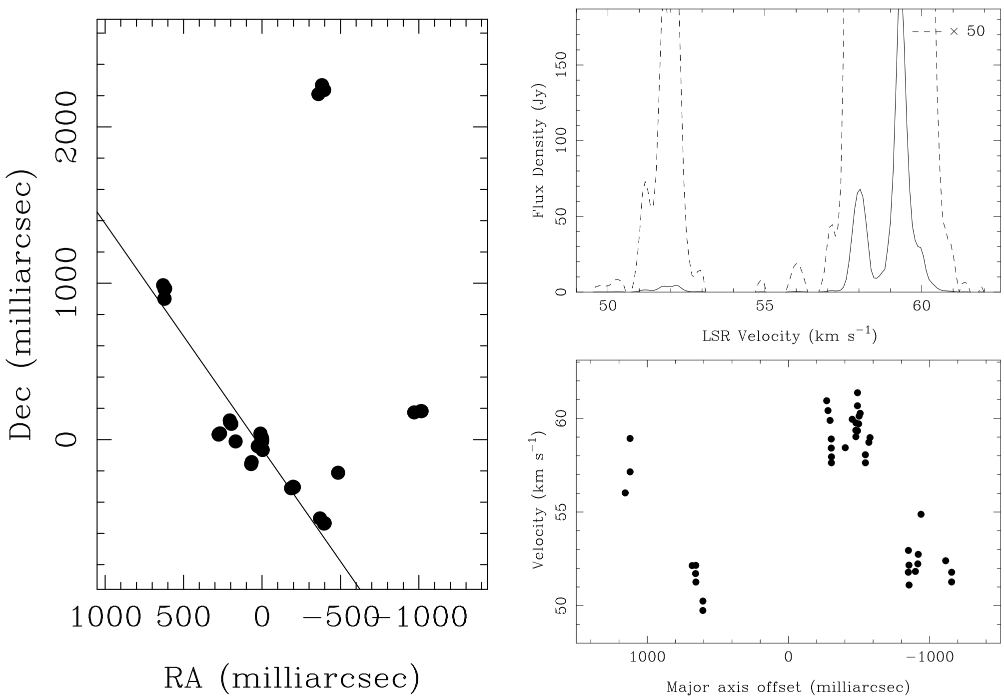

FIGURE 1. G 49.49−0.39 (W51): Position of maser components, Spectrum and Position/Velocity diagram of the 6.7-GHz EVN data.

VLBA, there are actually only a handful of observable 12.2-GHz masers in the North). As well as providing access to different sources, the EVN opens the possibility of observing methanol sources using one of the many millimeter interferometers in the Northern hemisphere.

2. Observations and Results

Three sources were selected from Menten (1991) which have not previously been observe with the EVN (e.g. Minier 2000b). All sources have been previously observed using the ATCA to obtain arcsecond accurate positions.

The EVN is equipped with 5 receivers which can observed the 6.7-GHz methanol transition with SEFDs ranging from 50 to 1500 Jy and baseline lengths from 630 to 1430 km. Observations consisted of switching between the three sources (and calibrators) over the 18 hour experiment. Each source typically was observed for 22 minutes at a time with a 2 minute observation of a delay calibrator before and after the source. A bright bandpass calibrator/fringe finder was observed periodically during the observation. The data were calibrated and fringe fit in AIPS and Difmap was used to self calibrate a single bright spectral component and the complex gains applied to the whole data set. Amplitude calibration was performed using a-priori antenna system temperature measurements (and self calibration); the autocorrelations were *not* used. Final imaging was performed in AIPS and positions for the spectral components derived by fitting a 2 dimensional Gaussian in the image plane. The results for the first two sources are presented here in Figs. 1 & 2.

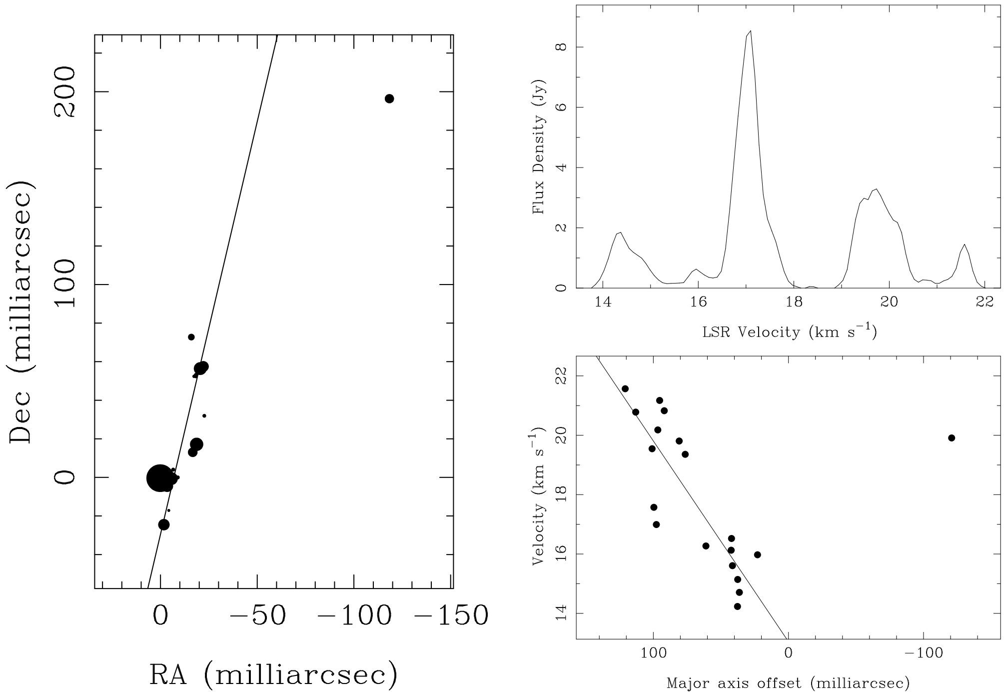

FIGURE 2. G 59.78+0.06: Position of maser components, Spectrum and Position/Velocity diagram of the 6.7-GHz EVN data.

2.1. *G 49.49−0.39 (W51)*

The W51 region contains many dense molecular cores. The methanol maser emission presented in Fig. 1 is associated with the compact molecular core W51e2. Observations by Zhang et al (1997, 1998) of NH_3, CH_3CN and other molecules suggest that the region is undergoing collapse. This source also contains OH and H_2O masers (Forster & Caswell 1989). The methanol distribution is quite complex, but the emission in the South-East forms a line of 1.5 arcsec (11000 AU assuming a distance of 7.7 kpc (Caswell et al 1995). This large size is not necessarily surprising as this is one of the most luminous of all methanol sources.

2.2. *G 59.78+0.06 (V 645Cyg)*

The methanol source G 59.78+0.06 is often (incorrectly) identified with the unrelated region V 645Cyg. The source is associated with OH and H_2O masers (Lada et al 1981, Braz & Sivagnanam 1987) and is near a CO bright spot (Lada et al 1981). The current EVN results are shown in Fig. 2. The source is quite compact (overall only 200 milliarcsec) and has a linear morphology, although the component in the North-West does not lie on the line formed by the rest of the components. The emission from the South-East shows a velocity gradient along the line, but this is not seen on a component by component basis. The isolated component in the North-West does not follow this velocity distribution. Interestingly, the spectrum shows a classical three peaked Keplerian profile.

3. Discussion

Both G 49.49−0.39 and G 59.78+0.06 show linear structure similar to methanol sources previously seen. However the two sources have quite different properties. G 59.78+0.06 is quite small; the SE component (with linear velocity gradient) is 0.2 arcsec in extent. The near/far kinematic distance to the source is 1.3/7.3 kpc, giving a size of 130 or 1460 AU. If Keplerian motion is assumed a central mass of 0.8/4.2 $M_{\odot}$ is found. The (single dish) peak flux density is quite weak (40 Jy (Caswell et al 1995)) yet the source has a quite rich spectrum; thus the source is thought more likely to be at the far distance. This still makes the implied mass of the source quite small. It should be noted though, that the calculation of the source mass has an R^3 dependence. Is the total size of the disc is under estimated the derived mass will be a lot smaller. For instance, if the velocity gradient of the SE emission is used but the total extent of the source is used in the calculation, (doubling the size) the near/far derived masses become 6.4/34 $M_{\odot}$.

G 49.49−0.39 is a much larger source, and while it does have a linear component no velocity gradient is present. Interestingly if the NW cluster of components in the line is ignored the size (7000 AU) of the source is closer to those seen by Phillips et al 1998b and it shows red and blue shifted sides. The derived Keplerian mass is 81 $M_{\odot}$. While ignoring one component is a little arbitrary, ATCA observations of this source show that there is a lot of methanol emission in this region spread over a region of ∼2 arcminutes. This is a complex region of star formation so the alignment of unrelated object is possible.

4. Conclusions

The two sources observed with the EVN have morphologies consistent with the edge-on disc model although they hardly (on their own) strongly supporting the disc model. However other methanol sources show a wide range of morphologies from very linear sources to those with a quite complex structure and no over all structure. It should be noted that other models (shock fronts for instance) do not naturally explain the morphology of these sources at all.

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