A Search for Extragalactic Methanol Masers

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Abstract

A sensitive search for 6.7-GHz methanol maser emission has been made towards 10 galaxies that have yielded detectable microwave molecular–line transitions. These include several which show OH megamaser or superluminous H$_2$O maser emission. Within the Galaxy, CH$_3$OH and OH masers often occur in the same star formation regions and, in most cases, the CH$_3$OH masers have a greater peak flux density than their OH counterparts. Thus we might expect CH$_3$OH masers to be associated with extragalactic OH maser sources. We failed to detect any emission or absorption above our 60-mJy detection limit. We conclude that if the physical conditions exist to produce CH$_3$OH megamaser emission, they are incompatible with the conditions which produce OH megamaser emission.

Introduction

OH maser emission in galaxies other than our own was first detected 20 years ago (Whiteoak & Gardner 1973). Since then, extragalactic maser emission has been detected from three other molecules, H$_2$O, H$_2$CO and CH (Churchwell et al. 1977; Baan, Güsten & Haschick 1986; Baan et al. 1990; Whiteoak, Gardner & Höglund 1980). In most cases the extragalactic masers seem to be far stronger versions of Galactic masers. However, the OH molecule has also been found to exhibit a different class of maser emission. Megamaser galaxies, first discovered by Baan, Wood & Haschick (1982), are galaxies in which a substantial fraction of the molecular gas surrounding the nucleus is stimulated to emit maser radiation, so that the galaxy as a whole appears as a maser some million times more luminous than a normal Galactic maser. Where they occur, H$_2$CO emission appears to be associated with OH megamasers, and CH with superluminous H$_2$O masers.

In recent years, strong maser emission in our Galaxy has been discovered in the 12.2-GHz 2$_0$–3$_{-1}$ E and 6.7-GHz 5$_1$–6$_0$ A$^+$ transitions of CH$_3$OH (Batria et al. 1987; Menten 1991). So far, maser emission has only been detected towards star-formation regions, although
absorption has been detected towards both these regions and cold clouds (Walmsley et al. 1988; Peng & Whiteoak 1991). CH$_3$OH masers appear to be closely associated with OH and H$_2$O masers (Norris et al. 1993; Menten et al. 1993) and, in at least one case, the CH$_3$OH and OH masers are coincident within 2 arcsec, or 4000 AU. Since the same conditions appear to produce both OH and CH$_3$OH masers, we might expect OH megamaser emission to be accompanied by detectable CH$_3$OH maser or megamaser emission.

A preliminary search for the 12.2–GHz CH$_3$OH transition was made by Norris et al. (1987) towards a few known OH megamaser galaxies, but no systematic sensitive search has been published so far. Here we present the results of an exploratory search, made at the stronger 6.7–GHz transition.

**Observations**

The observations were made between 1992 February 25 and March 9 using the dual–channel cooled HEMT 6.7/12.2–GHz receiver at the Parkes 64–m telescope which, at 6.7 GHz, has a beamwidth of 3.3 arcmin. The equivalent system temperature for the observations was $\sim 60$ K. An autocorrelator provided two 512–channel spectra in orthogonal linear polarizations, each spread over 64 MHz. Thus the observations covered a velocity extent of $\sim 2800$ km s$^{-1}$ and had a velocity resolution (after Hanning smoothing) of 7.8 km s$^{-1}$. The spectra were obtained by taking two 10–min spectra on–source and two reference spectra, one offset by +15 min and the other by -15 min of right ascension. These were then used to produce two quotient spectra each with different references, yielding a total on–source time of 20 min. The resulting spectra for the two polarizations were then averaged and Hanning smoothed. The resulting rms noise level of a 10–min observation was typically 0.04 Jy. To achieve the desired sensitivity, multiple observations were made of each source. The total integration time for most sources was 20–40 min, but sometimes exceeded 1 hr; the resulting $3\sigma$ detection level was typically no greater than 0.06 Jy.
Flux density calibration was carried out using observations of the sources PKS 0407-658, Hydra A and PKS 1934-638, which were assumed to have flux densities of 2.19, 4.09 and 9.84 Jy respectively.

Ten galaxies were surveyed for the $5_{1-6_0}$ A$^+$ CH$_3$OH transition; six are known OH maser or megamaser sources (Whiteoak & Gardner 1973; Norris et al. 1989; Kazes et al. 1990) and two are known superluminous H$_2$O masers (Whiteoak & Gardner 1986). Thus the sample is strongly biased towards galaxies which show ultraluminous maser emission in other transitions.

**Results**

Our results are shown in Table 1. None of the ten galaxies observed contains a detectable 6.7-GHz CH$_3$OH maser.

The detection threshold of 60 mJy is significantly lower than that necessary to detect the OH and H$_2$O masers which exist in these sources. Given that the Galactic CH$_3$OH masers are typically much stronger than Galactic OH masers, this detection limit places a severe constraint on any CH$_3$OH maser emission, and demonstrates that the OH megamaser emission and superluminous H$_2$O maser emission are not accompanied by corresponding CH$_3$OH megamaser emission.

**Discussion**

In our Galaxy, 6.7-GHz CH$_3$OH masers are found solely in star formation regions, and are closely associated with OH and H$_2$O masers. Existing surveys (J. L. Caswell et al. in preparation) indicate that nearly all known OH masers are accompanied by 6.7-GHz CH$_3$OH activity, and vice-versa. 6.7-GHz CH$_3$OH masers have been detected towards two HII regions in the Large Magellanic Cloud (Sinclair et al. 1992; S. P. Ellingsen et al.
in preparation). The intrinsic peak flux density of these sources is of a similar strength to most Galactic masers. Since the same conditions appear to produce both OH and CH$_3$OH masers within the galaxy, we might expect the OH maser and megamaser emission in other galaxies to be accompanied by detectable CH$_3$OH maser emission, possibly even CH$_3$OH megamaser emission. Furthermore, in Galactic sources, the 6.7-GHz CH$_3$OH maser emission is typically much stronger than the corresponding OH emission, and so we might even expect extragalactic CH$_3$OH maser emission to be much stronger than that of the OH emission. The ratio of the peak flux densities of 6.7-GHz CH$_3$OH and OH masers spans several orders of magnitude, but is typically of the order of ten. With one exception, the sensitivity of this search would have been sufficient to detect any 6.7-GHz CH$_3$OH with peak flux density comparable to the OH or H$_2$O sources observed in these galaxies (see table 1). If we assume that in our sample there are no 6.7-GHz CH$_3$OH sources with peak flux greater than 3 times the quoted RMS noise level, then we have four sources with CH$_3$OH : OH flux ratios less than 0.3. Among Galactic masers, approximately 23% have CH$_3$OH : OH flux ratios less than 0.3, thus if we assume the same CH$_3$OH : OH flux ratio distribution for extragalactic sources then the probability that any four will all have flux ratios less than 0.3, is 0.28%. Hence it appears extremely unlikely that the extragalactic CH$_3$OH : OH flux ratio distribution is the same as that observed for Galactic masers.

The differences between Galactic and extragalactic masers sources might be attributed to one of the following causes.

(i) CH$_3$OH megamasers do not exist, because the physical conditions required to produce them do not exist.

(ii) Extragalactic CH$_3$OH masers or megamasers do exist, but require different physical conditions from those which produce ultraluminous OH and H$_2$O maser emission.

(iii) The pumping mechanism or efficiency of CH$_3$OH masers is such that peak flux density of extragalactic CH$_3$OH masers is below the detection limit of these
Megamaser emission requires a number of basic ingredients, such as a sufficient column density of molecules along the line of sight, a means of pumping the masers, and perhaps a background continuum source to provide the input to the maser. Galactic masers appear to require precise physical conditions such as a particular optical depth to the pump radiation. However, megamasers are relatively insensitive to the precise conditions, because the maser activity in these sources is distributed throughout a large region, and a wide range of physical conditions are available if the basic ingredients are present.

Thus our first hypothesis, that CH$_3$OH megamasers do not exist because the physical conditions required to produce them do not exist, implies that some physical condition is required for methanol maser emission, but that this condition is found only in very special circumstances, and will not be widespread through the disc of a galaxy. An example might be if Galactic CH$_3$OH masers occur only in concentrations of high density within protoplanetary discs, as suggested by Norris et al. (1993). It is possible that the mechanisms which produce increased CH$_3$OH density in Galactic star formation regions (Herbst 1991) cannot operate on a sufficiently large scale, or the radiation field in these regions causes depletion by disassociation of the CH$_3$OH molecules.

Our second hypothesis, that CH$_3$OH megamasers do exist, but require different physical conditions from those of OH megamasers, would be appropriate if, for example, the CH$_3$OH masers were radiatively pumped but the OH megamasers collisionally pumped. However, detailed differences, such as optical–depth effects, would not be sufficient to prevent megamaser emission.

The final hypothesis, that the extragalactic methanol masers are below the detection limit of our observations, implies that either the peak flux density of CH$_3$OH masers cannot greatly exceed that of the strongest Galactic CH$_3$OH masers, or the conditions which produce ultraluminous Galactic type OH and H$_2$O masers are not suitable for producing ultraluminous CH$_3$OH masers. We cannot attribute the non–detection of extragalactic
masers to a deficiency of CH$_3$OH, as it has been detected towards several galaxies at millimetre wavelengths (Henkel et al. 1987). One of the galaxies which we also observed (NGC 253), was found to have methanol abundances similar to those found in our Galaxy. NGC 253 is also the closest of the observed galaxies, but to detect any masers in our observations, an intrinsic peak flux density at least an order of magnitude greater than the strongest of the Galactic CH$_3$OH masers would have been required.

All of these cases place a severe constraint on models of CH$_3$OH maser emission. To determine whether extragalactic CH$_3$OH masers are common requires a more sensitive and more comprehensive survey.

**Conclusion**

We conclude that the absence of CH$_3$OH maser or megamasers implies that either the physical conditions required to produce ultraluminous CH$_3$OH maser emission are incompatible with those required to produce OH or H$_2$O emission, or that the ingredients necessary to produce masing in CH$_3$OH are not present on a large enough scale to produce megamaser emission.

**References**

Baan W. A., Güsten R., Haschick A. D., 1986, ApJ, 305, 830
Baan W. A., Henkel C., Schilke P., Mauersberger R., Güsten, 1990, ApJ, 353, 132
Baan W. A., Wood P. A. A., Haschick A. D., 1982, ApJ, 260, L49
Batrla W., Matthews H. E., Menten L. M., Walmsley C. M., 1987, Nat, 326, 49
Bottinelli L., Gougeuenheim L., Le Squeren L., Martin J. M., Paturel G., 1987, IAU Circ. 4379
Churchwell E., Witzel A., Huchlmeier W., Pauliny-Toth I., Roland J., Sieber W., 1977, A&A, 54, 969
Claussen M. J., Heiligman G. M., Lo K. Y., 1984, Nat, 310, 298
dos Santos P. M., Lépine J. R. D., 1979, Nat, 278, 34
Henkel C., Jacq T., Mauersberger R., Menten K. M., Steppe H., 1987, A&A, 188, L1
Herbst E., 1991, in Haschick A. D., Ho P. T. P. eds., Observatory Meeting, Vol. 1, Astronomical Society of the Pacific, San Francisco, p. 313
Kazès I., Proust D., Mirabel L. F., Combes F., Balkowski C., Martin J. M., 1990, A&A, 237, L1
Lépine J. R. D., dos Santos P. M., 1977, Nat, 270, 501
Menten K. M., 1991, ApJ, 380, L75
Menten K. M., Reid M. J., Pratap P., Moran J. M., Wilson T. L., 1993, ApJ, in press
Norris R. P., Caswell J. L., Gardner F. F., Wellington K. J., 1987, ApJ, 321, L159
Norris R. P., Gardner F. F., Whiteoak J. B., Allen D. A., Roche P. F., 1989, MNRAS, 237, 673
Norris R. P., Whiteoak J. B., Caswell J. L., Wieringa M. H., Gough R. G., 1993, ApJ, 412, 222
Peng R., Whiteoak J. B., 1991, Proc. Astr. Soc. Aust., 9, 287
Sinclair M. W., Carrad G. J., Caswell J. L., Norris R. P., Whiteoak J. B., 1992, MNRAS, 256, 33p
Staveley-Smith L., Norris R. P., Chapman J. M., Allen D. A., Whiteoak J. B., Roy A. L., 1992, MNRAS, 258, 725
Walmsley C. M., Batrla W., Matthews H. E., Menten K. M., 1988, A&A, 197, 271
Whiteoak J. B., Gardner F. F., 1973, Astrophys. Lett., 15, 211
Whiteoak J. B., Gardner F. F., 1986, MNRAS, 222, 513
Whiteoak J. B., Gardner F. F., Höglund B., 1980, MNRAS, 190, 17p
Table 1. The selected sample of galaxies. References: a, Whiteoak & Gardener (1986); b, Staveley-Smith et al. (1992); c, Baan, Wood & Haschick (1982); d, Bottinelli et al. (1987); e, Whiteoak & Gardner (1973); f, Norris et al. (1989); g, Lépine & dos Santos (1977); h, Dos Santos & Lépine (1979); i, Claussen, Heiligman & Lo (1984)

| Source       | Position (B1950) | Velocity range (km s$^{-1}$) | Density (Jy) | OH Peak (Jy) | H$_2$O Peak (Jy) | Ref. |
|--------------|------------------|-----------------------------|--------------|--------------|-----------------|-----|
|              | Right Ascension  | Declination                |              |              |                 |     |
|              | h m s            | ° ′ ″                       |              |              |                 |     |
| NGC 253      | 00 45 06         | -25 34 00                   | -900→1400    | 0.01         | 0.120           | 5    |
|              |                  |                             |              |              |                 | b,e,g|
| NGC 1068     | 02 40 07         | -00 13 30                   | 300→2500     | 0.03         | –               | 0.7  |
|              |                  |                             |              |              |                 | i    |
| NGC 1487     | 04 04 05         | -42 30 42                   | -300→1900    | 0.008        | –               | –    |
| NGC 1566     | 04 18 53         | -55 03 24                   | 400→2600     | 0.01         | < 0.040         | –    |
|              |                  |                             |              |              |                 | f    |
| 10039-3338   | 10 03 55         | -33 38 43                   | 9000→11200   | 0.02         | 0.315           | –    |
|              |                  |                             |              |              |                 | b    |
| 11506-3851   | 11 50 40         | -38 51 10                   | 2000→4200    | 0.01         | 0.105           | –    |
|              |                  |                             |              |              |                 | b    |
| NGC 4418     | 12 24 23         | -00 36 14                   | 1100→3400    | 0.02         | 0.004           | –    |
|              |                  |                             |              |              |                 | d    |
| NGC 4945     | 13 02 32         | -49 12 02                   | -600→1700    | 0.02         | -0.800          | 9→16 |
|              |                  |                             |              |              |                 | a,b,e,h|
| Circinus     | 14 09 18         | -65 06 19                   | -600→1700    | 0.02         | –               | 3→12 |
|              |                  |                             |              |              |                 | a    |
| Arp 220      | 15 32 47         | 23 40 10                    | 4300→6500    | 0.01         | 0.280           | –    |
|              |                  |                             |              |              |                 | c    |