Discovery of an OH(1720 MHz) Maser in the LMC

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ABSTRACT

We report the first study of OH(1720 MHz) masers in the LMC in order to probe regions where supernova remnants interact with adjacent molecular clouds. Using the ATCA, we observed four sources in the LMC and detected a single OH(1720 MHz) maser with a flux density of 377 mJy toward 30 Doradus. No main line emission at 1665 or 1667 MHz was detected. The observed OH(1720 MHz) maser emission from 30 Dor shows characteristics similar to the well-known collisionally-pumped supernova remnant masers found in the Galaxy, though 30 Dor is known as a star forming region. It is possible that shocks driven by a nearby supernova remnant or by strong stellar winds from young stars are responsible for production of OH(1720 MHz) maser in 30 Dor. Future studies are required to distinguish between collisional and radiative pumping mechanisms for the 30 Dor OH (1720 MHz) maser.

1. Introduction

In the past decade, OH(1720 MHz) maser emission has been found to be a powerful tool to investigate how shocks from supernova remnants interact with molecular clouds in the Galaxy (e.g. Frail et al. 1994; Wardle & Yusef-Zadeh 2002). In these cases, the so-called supernova remnant (SNR) masers are thought to be collisionally excited by the passage of the supernova remnant shock through the surrounding molecular clouds. The physical
conditions for the population inversion and amplification in the 1720 MHz line alone requires densities $\sim 10^5 \text{ cm}^{-3}$, temperatures in the range 30–125 K, an OH column density in the range $10^{16}$–$10^{17} \text{ cm}^{-2}$ and an absence of a strong FIR continuum (Elitzur 1976; Lockett, Gauthier & Elitzur 1999). The latter constraint explains why this class of OH(1720 MHz) masers is rare in star forming regions where the UV radiation from hot, massive young stars is absorbed by dust grains and re-radiated in the FIR.

The OH molecule has two rotational ladders, $^2\Pi_{3/2}$ and $^2\Pi_{1/2}$; all levels are further split by lambda doubling and hyperfine splitting. Ground-state transitions include the two main lines of OH, at 1665 and 1667 MHz, and the two satellite lines, at 1612 and 1720 MHz. Radiative pumping can produce strong OH maser emission at 1665, 1667 and 1612 MHz, but can provide only weak emission (relative to 1665 and 1667 MHz lines) at 1720 MHz. However, collisional pumping in SNR masers produces strong maser emission in the OH(1720 MHz) line, with no emission from other ground state transitions.

A total of about 20 SNR masers have been found in the Galaxy (e.g., Green et al. 1997; Koralesky et al. 1998; Yusef-Zadeh et al. 1999). Motivated by the bright maser line emission from the Galactic center and W28, we searched for SNR masers in the 30 Dor region of the LMC. Here, we present the first discovery of OH(1720 MHz) line emission in the LMC. The observed flux density is 377 mJy; if this OH(1720 MHz) maser were at the distance of the Galactic center, it would be 12 Jy. This is within a factor of two of the observed flux density ($\approx 7.4$ Jy) of the strongest OH(1720 MHz) maser in Sgr A East, which is known as a SNR interacting with an adjacent molecular cloud near the Galactic center (Yusef-Zadeh et al. 1999).

These initial results reported here were first presented in the workshop “$10^{51}$ Ergs: The Evolution of Shell Supernova Remnants,” hosted by the University of Minnesota, 1997 March 23-26. Another analysis of this maser line emission from the LMC has recently been given by Brogan et al. (2004).

2. Observations & Results

In an initial observation in 1996, three fields (30 Dor, N44, and N49) were observed in a single 12 hour period with 6-kilometer array of the Australia Telescope Compact Array (ATCA) to search for OH(1720 MHz) emission. In this first observation, a single strong maser was identified near the core of 30 Dor. In order to confirm the detection of the 30 Dor maser in 1997 we used the ATCA to conduct a 13-hour follow-up observation of the initial three fields and an additional field (N132D) in the OH(1720 MHz) line. An additional 13
hours was spent on the four fields to look for OH emission in the main lines at 1665 and 1667 MHz. These regions were chosen because they have some of the largest concentration of SNRs and molecular clouds in the LMC. For all observations, 1934-638 was used as the primary calibrator and 0407-658 was used to calibrate the bandpass and complex gains. The important observational parameters are presented in Table 1.

All calibration and data reduction were carried out using the Multichannel Image Reconstruction, Image Analysis and Display (MIRIAD). The antenna gains and bandpasses were calibrated and then the continuum emission was subtracted in the visibility domain using UVLIN program of MIRIAD. For 30 Dor, the observations from 1996 and 1997 were processed separately in order to look for variability. In order to search for maser emission, the entire 4 MHz bandwidth was imaged using natural weighting across the entire 30′ primary beam of the ATCA; a cube with 1024 Hanning-smoothed spectral line channels (with a channel resolution of $\sim$0.68 km$s^{-1}$) was created. In the case of the 30 Dor field, the two days’ data were imaged separately in order to look for variation in the maser strength. In order to determine the maser line characteristics, the channels within $\pm$ 30 km$s^{-1}$ of the detected 30 Dor maser were imaged at the highest velocity resolution (i.e., not Hanning smoothed) of 0.34 km$s^{-1}$. All image cubes were deconvolved using the CLEAN algorithm of MIRIAD. Because the 30 Dor maser was not at the center of the observed field, the final deconvolved images were corrected for the attenuation of the primary beam.

Out of the four fields observed, the only emission detected was a single OH(1720 MHz) maser near the core of 30 Dor. The properties of the maser are given in Table 2. The position was determined by fitting a two-dimensional Gaussian (using IMFIT in MIRIAD) to the strongest channel of the data. The line width and center velocity were determined by fitting a Gaussian to the line profile with the PROFIT program of the Groningen Image Processing SYstem (GIPSY). The flux density of the maser was determined separately for the two observations in order to determine if any significant variation had occurred. A continuum image of the 30 Dor field from the Sydney University Molonglo Sky Survey (SUMSS, Bock, Large, & Sadler 1999) is presented in Fig. 1, with the position of the detected maser shown by the dark cross. A spectrum of the OH(1720 MHz) maser in 30 Dor is shown in Fig. 2. In the OH(1720MHz) line, the only maser detected was the strong one in 30 Dor. In the OH lines at 1665 and 1667 MHz, no masers were detected in any field; in particular no main line masers were detected at the position of the 30 Dor OH(1720 MHz) maser.

The strong OH(1720 MHz) maser detected in the initial observation was confirmed in the follow-up observation a year later. The intensity of the maser did not change significantly between the two observations; in the initial observation the maser was $337 \pm 34$ mJy beam$^{-1}$ and in the follow-up observation it was $370 \pm 28$ mJy beam$^{-1}$. We present 3-σ upper limits
for all three lines and all four fields in Table 2.

Our results are in general agreement with those reported by Brogan et al. (2004). In particular, Brogan et al. report two additional weak ($<28 \text{ mJy beam}^{-1}$) masers in the 30 Dor field. In our observations, the noise toward these masers was too large (12 mJy beam$^{-1}$) to have detected them. The noise of the 30 Dor observations was larger than that toward the other fields because the pointing center of the 30 Dor observations was not centered on the maser position (12$'$.8 distant in 1996 observations). Brogan et al. also reported the detection of two weak OH(1720 MHz) masers in N49 at the level of 25-35 mJy beam$^{-1}$. After careful analysis of our two OH(1720 MHz) observations toward N49, we do not detect the masers reported by Brogan et al. The 1996 and 1997 datasets have sensitivities (3-$\sigma$ detection thresholds) of 16 and 21 mJy beam$^{-1}$, respectively. It is possible that the maser lines in N49 have a line width smaller than our channel width (our channel width is 0.68 km s$^{-1}$, compared with 0.34 km s$^{-1}$ for Brogan et al.). It is also possible that the maser emission is variable. An additional epoch of sensitive observations are needed to confirm the potential variability.

3. Discussion

The coincidence between the OH(1720 MHz) maser emission and the prominent 30 Dor region raises the obvious question of whether the maser source is radiatively-pumped in the HII complex region (or the cluster of young stars R136) or collisionally excited by the passage of a shock running into a molecular cloud. The possible photo-excitation of the OH(1720 MHz) maser by the HII region in 30 Dor can be investigated by observing the main OH lines at 1665 and 1667 MHz. In a previous observation of 30 Dor with the Parkes telescope having 12$'$.5 resolution, thermal absorption is detected at a level of 90 and 140 mJy at the LSR velocities of 245 and 247 km s$^{-1}$, respectively with no evidence of emission (Gardner & Whiteoak, 1985). This is consistent with our results from our ATCA observations at 1665 and 1667 MHz, in which no emission was found (see Table 2). Additionally, no absorption was detected in our observation, suggesting that the thermal absorption observed at Parkes was resolved out by the ATCA (which have a minimum spacing of 214 m, corresponding to a limit to the largest observable structure of 1$'$.6). In total, the OH results from our ATCA observations and those from Parkes show two components: smooth thermal absorption in all the OH ground-state transitions at 1612, 1665, 1667, and 1720 MHz along with a spatially-compact, spectrally-narrow maser line at only detected at 1720 MHz. The OH properties are consistent with a model, in which diffuse cold molecular gas, which is observed in OH absorption, exists around the HII regions, and a shock driving into the molecular gas has
dissociated water in the gas, increasing the OH abundance and exciting the OH(1720 MHz) line.

SNR masers are thought to be collisionally excited by C-type shocks passing through a molecular cloud. These shocks are usually detected at the interface of SNRs and adjacent molecular clouds. It is possible that the OH(1720 MHz) maser in the LMC may be associated with the shock from an obscured supernova in the vicinity of the HII region. The nebula is characterized by filamentary optical structures filled with X-ray emitting gas. It has been speculated that supernova shocks may play a key role in the formation of the nebula and in the heating of the hot gas (Bamba et al. 2003). Indeed, a number of young SNRs including N157B, have been identified in the vicinity of 30 Dor (Chu et al. 1995; Lazendic, Dickel & Jones 2003). Furthermore, two high-mass X-ray binary candidates have been discovered in the core of the nebula, suggesting recent supernova explosions at or near the central star cluster R136 (Wang 1995). It is also possible that the maser could be pumped by collisions between strong stellar winds into a clumpy environment. Portegies Zwart, et al. (2002) have determined that the X-ray point-source emission observed from Chandra can be explained by a colliding wind binaries. Shocks from winds into the dense molecular environment could result in the observed OH(1720 MHz) emission. There is clear evidence of molecular gas in the 30 Dor region as indicated by the detection of CO emission using the SEST mm-wave telescope (Johansson et al. 2003) and of extended 2.1212 μm H$_2$ 1–0 S(1) ro-vibrational line emission using the 2.2 m ESO-MPIA telescope in La Silla with the FAST imaging NIR-spectrometer (Krabbe et al. 1991). However, firm identifications of SNRs and molecular clouds within the nebula have been difficult, primarily because of the overwhelming thermal radio continuum and optical background. It has been suggested that many SNRs may hide inside the nebula.

Most observations of star forming regions show ground-state OH (1665/67 MHz) masers which are thought to be pumped radiatively. The unaccompanied OH(1720 MHz) SNR masers are believed to be collisionally excited. This distinction is under refinement due to recent observations of the $^2\Pi_{1/2}, J=1/2$ excited state of OH at 4765 MHz which is detected in a number of star forming regions where OH(1720 MHz) maser line emission has also been detected (Palmer, Goss & Whiteoak 2004; Palmer, Goss & Divine 2003). Moreover, in a number of star forming regions excited OH(4765 MHz) masers are spatially coincident with OH(1720 MHz) ones. In W3(OH), measurement of these coincidences has been most precise so far: about one-third of the 4765 MHz maser spots coincide with 1720 MHz spots to an accuracy < 10 AU (Palmer, Goss & Whiteoak 2004). This spatial correlation suggests that both the excited OH (4765 MHz) maser emission and ground state OH(1720 MHz) masers can be pumped radiatively in environments of high densities and temperatures (Gray et al. 2001). It will be important to investigate whether OH (4765 MHz) emission is coincident with
the detected OH(1720 MHz) masers in 30 Dor. If the two maser emissions are correlated in 30 Dor, it would suggest a radiative pumping mechanism. However, the lack of main line OH emission at 1665/67 MHz is puzzling in this radiative pumping scheme. Thus, we believe that OH(1720 MHz) maser line emission is collisionally pumped, either by SNR or wind interactions with surrounding molecular clouds.

4. Summary

We report the detection of the first OH(1720 MHz) maser in the LMC. Out of four fields (30 Dor, N44, N49, and N132D) a single strong OH(1720 MHz) maser is detected near the center of 30 Doradus. The maser emission was confirmed by subsequent observations and no significant variation was detected in the 11 months between the two observations. No significant emission was detected in the OH 1665 and 1667 MHz lines toward the OH(1720 MHz) maser or in any of the observed fields. The lack of OH(1665 and 1667MHz) maser emission coincident with the OH(1720 MHz) maser strongly suggests that the 1720 MHz maser is collisionally-excited, rather than radiatively-pumped from the nearly 30 Dor HII regions.

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REFERENCES

Bamba, A., Masaru, U., Nakajima, H. & Koyama, K. 2003 ApJ 602, 257
Bock, D.C.-J, Large, M.I. & Sadler, E.M. 1999, AJ 117, 1578B
Brogan, C.L., Goss, W.M., Lazendic, J.S., & Green, A.J. 2004 AJ 128, 700
Chu, Y.-H., Dickel, J.R., Staveley-Smith, L., Osterberg, J., & Smith, R. C. 1995, AJ 109, 1729
Elitzur, M. 1976, ApJ 203, 124
Frail, D.A., Goss, M.W. & Slysh, V.I. 1994, ApJ 424, L111
Gardner, F.F. & Whiteoak, J.B. 1985, MNRAS 215, 103
Gray, M.D., Cohen, R.J., Richards, A.M.S., Yates, J.A. & Field, D. 2001, MNRAS 324, 643
Green A.J., Frail, D.A., Goss, W.M. & Otrupcek, R. 1997, AJ 114, 2058

Johansson, L.E.B., Greve, A., Booth, R.S., Boulanger, F., Garay, G., de Graauw, Th., Israel, F.P., Kunter, M.L., Lequeux, J. Murphy, D.C., Nyman, L.-Å. & Rubio, M. 1998, A&A 331, 857

Koralesky, B., Frail, D.A., Goss, W.M., Claussen, M.J. & Green, A.J. 1998, AJ, 116, 1323

Krabbe, A., Storey, J., Rotaciu, V., Drapatz, S. & Genzel, R. 1991, in The Magellanic Clouds: Proceedings of the 148th Symposium of the IAU, held in Sydney, Australia, July 9-13, 1990. Eds.Raymond Haynes & Douglas Milne. IAU Symp. 148, (Kluwer: Dordrecht), 205

Lazendic, J.S., Dickel, J.R., & Jones, P.A. 2003, ApJ 596, 287

Lockett, P., Gauthier, E. & Elitzur, M. 1999, ApJ 511, 235

Palmer, P., Goss, W.M. & Devine, K.E. 2003, ApJ, 599, 324

Palmer, P., Goss, W.M. & Whiteoak, J.B. 2004, MNRAS 347, 1164

Portegies Zwart, S.F., Pooley, D. & Lewin, W.H.G. 2002, ApJ 574, 762

Wang Q.D. 1995, ApJ 453, 783

Wardle, M. & Yusef-Zadeh, F. 2002, Science, 296, 2350

Yusef-Zadeh, F., Roberts, D.A., Goss, W.M., Frail, D.A. & Green, A. 1999, ApJ 527, 172

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Table 1. Observational Parameters

| Observing Parameter       | Value                                           |
|---------------------------|-------------------------------------------------|
| ATCA Array                | 6 km configuration                              |
| Velocity coverage         | −83 to +614 km s\(^{-1}\)                       |
| Velocity resolution       | 0.68 km s\(^{-1}\) (Hanning smoothed)           |
| Resolution                | 8″ × 7″                                         |
| Field of view             | 30′                                             |

**Initial**
- **Date**: July 19, 1996
- **Transitions**: OH(1720 MHz)
- **Fields**: 30 Dor, N44 & N49
- **Total observing time**: 2 × 8 hr

**Follow-up**
- **Date**: May 9, 1997
- **Transitions**: OH 1665, 1667, 1720 MHz
- **Fields**: 30 Dor, N44, N49, N132D
- **Total observing time**: 1.4 × 8 hr
Table 2. Maser Parameters

| Field          | Frequency (MHz) | Peak Flux Density (mJy beam⁻¹) | Observing Date   | Line Peak (mJy beam⁻¹) | Line FWHM (km s⁻¹) | V_LSR (km s⁻¹) | Position          | Extent (arcsec) | PA (°) |
|----------------|----------------|--------------------------------|------------------|------------------------|---------------------|----------------|-------------------|----------------|--------|
| **30 Dor Field** |                |                                |                  |                        |                     |                |                   |                |        |
| OH(1665 MHz)   | 18.9           | (3-σ upper limit)              | Initial - July 1996 | 377 ± 34               | 0.861 ± 0.087       | 242.693 ± 0.012 | RA(J2000) 05h 38m 45s 00    | 4″5 × 0″6      | 112°   |
| OH(1667 MHz)   | 21.1           | (3-σ upper limit)              |                  |                        |                     |                | Dec(J2000) -69° 05′ 07″5' 5   |                |        |
| OH(1720 MHz)   | 14.0 mJy beam⁻¹ (3-σ upper limit) |                  |                  |                        |                     |                |                   |                |        |
| **N44 Field**  |                |                                |                  |                        |                     |                |                   |                |        |
| OH(1665 MHz)   | 14.4           | (3-σ upper limit)              | Follow-up - May 1997 | 370 ± 28               | 0.796 ± 0.068       | 242.779 ± 0.026 | RA(J2000) 05h 38m 45s 00    |                |        |
| OH(1667 MHz)   | 17.4           | (3-σ upper limit)              |                  |                        |                     |                | Dec(J2000) -69° 05′ 07″5' 5   |                |        |
| OH(1720 MHz)   | 14.0           | (3-σ upper limit)              |                  |                        |                     |                |                   |                |        |
| **N49 Field**  |                |                                |                  |                        |                     |                |                   |                |        |
| OH(1665 MHz)   | 15.0           | (3-σ upper limit)              |                  |                        |                     |                |                   |                |        |
| OH(1667 MHz)   | 17.1           | (3-σ upper limit)              |                  |                        |                     |                |                   |                |        |
| OH(1720 MHz)   | 15.9           | (3-σ upper limit)              |                  |                        |                     |                |                   |                |        |
| **N132D Field** |            |                                |                  |                        |                     |                |                   |                |        |
| OH(1665 MHz)   | 14.7           | (3-σ upper limit)              |                  |                        |                     |                |                   |                |        |
| OH(1720 MHz)   | 21.0           | (3-σ upper limit)              |                  |                        |                     |                |                   |                |        |
Fig. 1.— Pseudocolor image of 30 Dor from Molonglo Observatory Synthesis Telescope (MOST) at 843 MHz from the SUMSS at a resolution of $11\textquoteright 3 \times 8\textquoteright 2$. The cross (+) marks the position of the detected OH(1720 MHz) maser. The spectra at this position from all three observed OH lines are displayed in Fig. 2.
Fig. 2.— Plots of OH emission (1665, 1667 & 1720 MHz) at the location of the detected OH (1720 MHz) maser in 30 Dor (+ in Fig. 1). The spectral and spatial parameters of the maser emission are given in Table 2.