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Dust, HII and molecules towards OH and H_2O masers

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Abstract. Radio synthesis observations made with the BIMA interferometer at 29, 86 and 216 GHz are presented for twelve galactic fields containing multiple interstellar OH and H_2O maser sites. A dusty molecular cloud was found at 20 of the 23 maser sites in the fields studied. The clouds have masses in the range 50 to 800 $M_\odot$ and diameters between 0.1 and 0.5 pc.

The data show that most masers are located near the centers of massive, dusty molecular cores. The cores appear to be centrally condensed and internally excited. These results suggest that most masers found in star-forming regions are associated with a massive young object at the center of a collapsing molecular cloud. The kinematics of the core gas, and association with ultra-compact HII regions, implies that the duration of the maser phase includes collapse, expansion and early formation of an HII region.

1. Introduction

It has long been assumed that OH and H_2O masers mark the locations of massive star forming regions in the galaxy, and that a deeply embedded OB star or star cluster is responsible for maser excitation at these sites. However, attempts to detect the ionized zone around such stars have resulted in fairly low detection rates (Tofani et al. 1995; Ellingson et al. 1996; Codella et al. 1997; Forster & Caswell 2000). This could mean that the masers are not always associated with massive ionizing stars. Perhaps they are powered by embedded intermediate or low–mass stars, or maybe they are fragments of the ISM excited by shocks, jets or ejected material from a remote source.

Another possibility is that the masers *are* associated with the formation of a massive star, but arise prior to the development of a detectable HII region. This could be during the protostellar stage before the star is hot enough to produce UV photons, or during a later accretion phase where there is sufficient infalling neutral material to keep the HII region small (Walmsley 1995). Whatever the excitation process is, it must be capable of supplying the sometimes prodigious energy output of the maser radiation, and it must last $\sim$10% of the lifetime of OB stars, or $\sim 10^5$ years.

The aim of the BIMA observations reported here is to learn more about the environment of OH and H_2O maser sites, and in particular about the nature of the source powering the maser emission itself.

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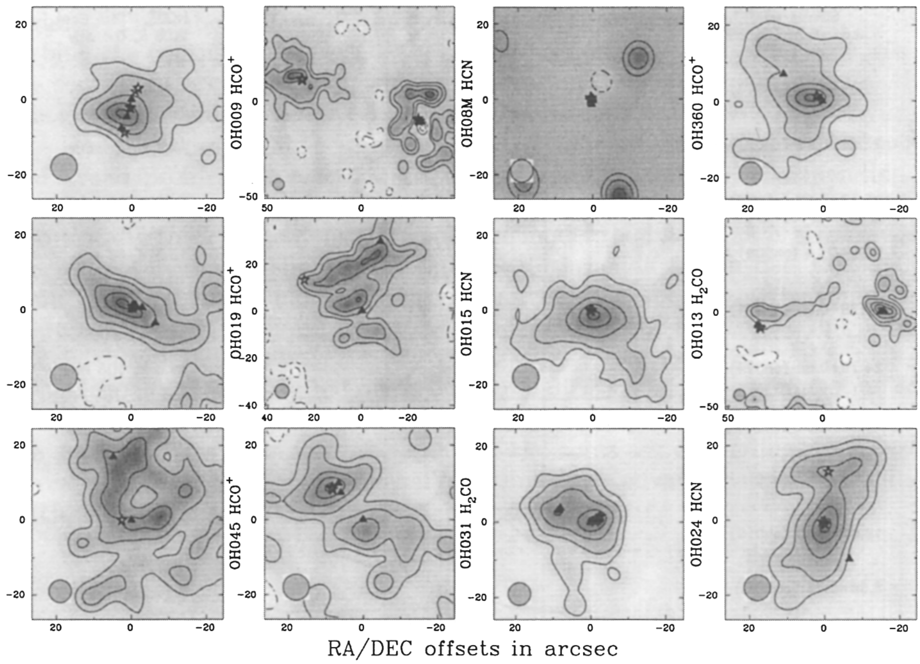

Figure 1. Molecular clouds at OH (open stars) and H_2O (filled triangles) maser sites. Integrated molecular line images are shown for each field. Field sizes vary; the 7″ beam is shown in the lower left corner.

2. Observations

Twelve fields were selected from among the 74 galactic fields containing both OH and H_2O masers studied by Forster & Caswell (1989). High–declination fields containing multiple maser sites with large separations were preferred. Seven of the twelve fields contain compact HII regions, and five do not.

The observations were made with the BIMA interferometer at 1cm, 3mm and 1mm wavelengths. Scaled arrays were used to provide a spatial resolution <7″ at all frequencies. Spectral lines of CH_3OH, HCN, HCO^+, ^{13}CS and H_2CO were observed at a velocity resolution of 1.3 km s^{-1}, and ~1 GHz of line-free continuum was obtained simultaneously.

3. Results

Molecular line images for the observed fields are shown in Figure 1. Line emission was detected in all fields except OH360. Of a total of 23 maser sites, 20 are located within a molecular clump or core. The molecular cores have diameters between 0.1 and 0.5 pc, with a mean of ~0.25 pc. At the critical density of the HCN line (2x10^6 cm^{-3}) a core 0.25 pc in diameter has a mass of ~800 $M_\odot$. The distribution of dust closely follows the molecular line distribution. Assuming the dust is at 50K and has a linear emissivity law, the 1mm total flux density

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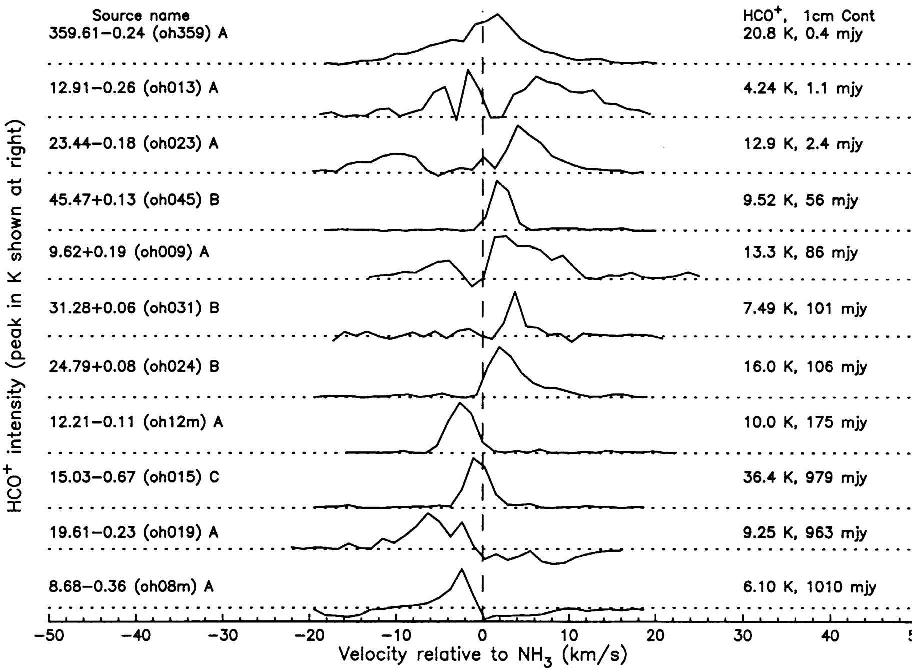

Figure 2. 3mm HCO^+ (J=1–0)spectra toward maser sites. The vertical line indicates the velocity of the ambient gas. The peak brightness temperature of the HCO^+ line and the peak flux density of the 1 cm continuum emission is show at the right of each spectrum.

can be used to estimate the dust mass (Woody et al. 1989). The derived dust masses range from 110 to 825 $M_{\odot}$ with a mean of 430 $M_{\odot}$.

Codella et al. (1997) observed OH024 in the 2–2 and 3–3 lines of NH_3 with the VLA. Like us, they also found molecular clumps at both maser sites in this field. Their ammonia clumps are denser (1.7x10^7 cm^{-3}) and warmer (90K) than our HCO^+ and H_2CO clumps. This suggests that the clumps are centrally condensed, becoming warmer and denser toward the center.

Figure 2 shows HCO^+ spectra at the peak of the clump emission in each field. The single-dish 23 GHz (J=1,1) NH_3 velocity is used as a reference to align each spectrum with the ambient velocity of the gas. The spectra are ordered according to the 1cm continuum flux, with the highest at the bottom. Since the 1cm flux measures the radiation of free–free emission from HII regions, this ordering might indicate an evolutionary sequence. The older sources with well-developed HII regions would appear at the bottom, and the younger ones at the top.

A surprising result is that the presumably youngest maser sites tend to have the broadest and most complex spectra. The peaks of their profiles are shifted toward the red, and they often show apparent self–absorption features. Spectra toward the bottom of the sequence are narrower, and their peaks are blue–shifted. The bottom two spectra are toward maser sites with strong UCHII regions. These both show distinct red-shifted absorption lines. If the gas absorbing the continuum is part of the molecular core, and if the HII region is at the center of the core, the red-shifted absorption is unambiguous evidence that this gas in infalling.

Does this mean that the presumably younger sources with red-shifted peaks and broad profiles are expanding? Simple spherical models of expanding or contracting molecular clumps predict asymmetric double-peaked line profiles for optically thick transitions. In a collapse model the blue peak is stronger and the self-absorption is slightly red-shifted (Hogerheijde & van der Tak, 2000), while in an expansion model the reverse is true. The spectra at the top of Fig. 2 are thus better fit by an expansion model, while the spectra at the bottom clearly show infalling gas.

Although the red-shifted peaks offer an indication that the younger molecular cores are expanding, more detailed modeling is needed to accurately interpret the spectra. This is important because if the cores are expanding, this argues strongly for the presence of a central YSO in a fairly advanced stage of evolution at these sites.

4. Summary

OH and H_2O masers are almost always found embedded within molecular cores. These cores are large (~0.25 pc), massive (~800 $M_\odot$) and dusty. The cores appear to be centrally condensed, with temperatures rising to at least 90K and densities $>10^7 cm^{-3}$ toward their centers.

The masers are generally located near the centers of the cores. This suggests that the masers are excited by a massive object which has formed or is forming there by gravitational collapse. What this object (or objects) is remains uncertain. Spectral lines from the core gas show evidence for both contraction and expansion. In order to interpret the observed spectra accurately however, 3-D radiative transfer models incorporating realistic physics are needed.

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