H₂ and Methanol masers - outflow from the earliest stages of high-mass star formation?

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Abstract. We report the discovery of shocked H₂ emission at 2.12 µm associated with methanol masers, and discuss its implication for massive star formation.

1. Introduction

The relationship of two signposts of high-mass star formation, ultracompact (UC) regions and 6.7 GHz methanol maser emission, were investigated by Walsh et al. (1997, 1998) through low and high spatial resolution radio surveys. They showed that methanol maser emission does occur in massive star forming regions but away from UCHH regions. A hypothesis has emerged that methanol maser emission is the first prominent signature of massive star formation, being quickly destroyed as the UCHH region evolves. To test this hypothesis we looked for other indicators of star formation, such as embedded IR sources and outflows. We report the discovery of H₂ emission associated with methanol masers, a tracer of outflow activity.

2. Observations

The four IRAS sources from radio surveys of Walsh et al. were observed in H₂ 1–0 S(1) 2.12µm line emission using a NIR narrow–band tunable filter UNSWIRF² on the Anglo-Australian Telescope. Used at f/36, the UNSWIRF produced a

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²The University of New South Wales Infrared Fabry-Parot (Ryder et al. 1998)
circular image of 100" diameter at 0.8" pixelscale. One off-line setting (for continuum subtraction) and several on-line Fabry-Parot (FP) spacings, were taken for a few minutes first on a source and then on a sky position (for sky subtraction). A standard star was imaged at each of the FP settings for flux calibration, as was a diffuse dome lamp to obtain a flat field. The sky-subtracted and flat-fielded object frames were registered using field stars in the continuum frame. The continuum frame is scaled and subtracted from all other on-line frames to form a cube in increasing etalon spacing, from which the line flux and central velocities of the H₂ emission were determined through Lorentzian fitting.

3. Results

All the sources observed with the UNSWIRF show H₂ line emission associated with them (intensity maps in Fig. 1; Refer to Lee al. (2001) for velocity maps). IRAS 14567–5846 is associated with a large bright cometary UCHII region, but not with methanol maser emission. Fig. 1(a) shows weak H₂ emission appears to surround the UCHII region (in 2.2μm K-band continuum emission) in a shell. No significant velocity structure was seen in this source. A maser site G318.95–0.20, 2.5' SE of IRAS14567, is coincident with strong H₂ emission extending over 30'' (Fig. 1(b)). No radio continuum emission is found at this site (Ellingsen et al. 1996). Due to insufficient FP coverage, we only note that the velocity of the H₂ emission extends over at least 50 km s⁻¹.

Two methanol maser sites separated by 5'', found in IRAS 15278–5620 are associated with two embedded NIR sources (Fig. 1(c)). The UNSWIRF observation reveals fan-shaped H₂ emission NW of the maser sites, associated with K-band continuum nebulosity, and weak emission to the SE. The velocity maps (not shown here) show three components with the line centre velocities smoothly changing over about a 70 km s⁻¹ range: Two red-shifted components to the SE and ~ 30'' N, and one blue-shifted to the NW of the maser sites. In IRAS 16076–5134, a slightly elongated blob 10'' to the west of the maser site emits in H₂ line and K-band continuum emission (Fig. 1(d)). The H₂ line centre velocities range over 13 km s⁻¹, red-shifted relative to the maser emission velocity. Weaker H₂ emission is also detected to the SW of the maser site.

4. Discussion

In this section we briefly discuss the excitation mechanism of the H₂, and its role in the sequence of events that produces massive stars. For more detailed discussion, refer to Lee at al. (2001). The 1–0 S(1) to 2–1 S(1) line ratio of H₂ is often used to distinguish between the two excitation mechanisms, namely UV fluorescence and collision in shocks. With no 2–1 S(1) line intensity available, we rely on morphology and line velocities to infer the origin of the H₂ emission. UV fluorescence seems likely for IRAS14567, where the H₂ emission appears to surround the UCHII region forming a photo-dissociation region (PDR). In all other cases, non-detection of radio continuum emission i.e. the absence of UV photons, is suggestive of shock excitation of H₂ the most likely mechanism. In addition, the broad line width of H₂ line emission also favours shock-excitation.
Figure 1. Four sources observed in H$_2$ 1-0 S(1) line emission with the UNSWIRF are presented in contours. The underlying greyscale maps show 2.2μm K-band continuum emission. The ellipse in (a) indicates the IRAS error ellipse, and the plus signs mark the position of methanol maser sites.

For the origin of methanol maser emission, Walsh et al. proposed a pre-UC HII region hypothesis where the maser emission turns on during the protostellar phase before an UCHII region does. Our UNSWIRF observations show that all the the methanol maser emission is associated with (presumably shocked) H$_2$ emission that seems associated with the powering sources of outflows. Outflows occur only during an early stage of star formation, thus our results support the pre-UCHII origin of the methanol maser emission.

Compact and dense hot molecular cores (HMCs) are suggested not only to be sites of massive star formation, but may also represent an earlier stage in the star formation process than UCHII regions. If both HMCs and methanol maser emission were early signatures of high-mass star formation, how are they related? We propose that the formation of high-mass stars begins in HMCs where 1) heat from contraction releases methanol from grain surfaces into the
gas phase, 2) the gas is compressed, by outflows and/or in circumstellar disks, to create a sufficient column for masing. This stage is signposted by methanol maser emission and shocked H$_2$ line emission. 3) As the UCHII region develops and expands, it turns off methanol maser emission and forms a PDR envelope where H$_2$ is excited by UV fluorescence (summarised in Figure 2). A test for such a scenario is to look for cold molecular cores (earlier phase than HMCs in star formation sequence) associated with methanol maser emission. In addition, spectral energy distributions, thus spectral types, of the powering sources would enable us to discern between the pre-UCHII origin and non-ionizing star origin for methanol maser emission.

References