

## From Methanol Masers to Hot Molecular Cores

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**Abstract.** We have found that methanol masers provide a signpost to the very earliest stages of the massive star formation process, before the onset of the UCHII region phase. They are invariably associated with embedded sources whose bolometric luminosities suggest they will soon become OB stars. Outflows frequently occur, and hot molecular cores are also associated with them. The absence of nearby UCHII regions implies that some cores must be internally heated. We also find cold sub-mm cores that do not have any other signposts of star formation. We suggest these may represent the earliest stages in the massive star formation process, soon after cloud collapse has begun.

This paper outlines a series of studies over the past five years on the evolutionary sequence and processes occurring during massive star formation. While this manifests itself through a variety of phenomena, and is clearly a key part of the Galactic ecology, it remains poorly understood due to the many competing processes at work, and their short timescales; eg see our papers on NGC 6334 (Burton et al. 2000) and Carina (Brooks et al. 2000, Rathborne et al. 2002).

A survey of 535 IRAS colour-selected sources as UCHII regions with the Parkes radio telescope found 201 to have methanol maser emission at 6.7 GHz (Walsh et al. 1997). Imaging the maser sites with the Australia Telescope, however, showed that most were not associated with radio continuum emission, and that most radio continuum sources did not have associated methanol maser emission (Walsh et al. 1998). The implication was that methanol maser emission appears before the onset of the UCHII region phase of massive star formation, and disappears shortly thereafter afterwards. We subsequently started an investigation of the nature of the 'isolated' methanol masers.

Imaging some of the maser sites in the near-IR, with CASPIR on the ANU 2.3-m telescope, showed they are frequently associated with embedded sources. Often this was the reddest source found in the field at  $3.5\mu\text{m}$ . For several maser sites, however, no associated near-IR sources were seen (Walsh et al.

1999). Mid-IR imaging, with the MANIAC camera on the ESO 2.2-m, invariably found embedded sources at 10 and  $20\mu\text{m}$ . Estimates of their luminosity showed they are all bright enough to produce the ionizing flux needed to create HII regions. We suggested the maser sites associated with only a mid-IR source are signposting an early stage of massive star formation, prior to UCHII region formation (Walsh et al. 2001).

Imaging at 450 and  $850\mu\text{m}$ , with SCUBA on the JCMT, of methanol maser sites virtually always found a deeply embedded sub-mm source. Determination of their SEDs showed they have bolometric luminosities in excess of  $10^3 L_{\odot}$  (Walsh et al. 2002b). Intriguingly, several sub-mm sources were also found that do not appear to be associated with any other signpost of star formation. They may mark the earliest stage of the collapse of a core?

Spectral line imaging, using UNSWIRF on the AAT, often shows radio HII regions at near-IR wavelengths; Br $\gamma$  bubbles with H $_2$ -emitting PDR envelopes. In addition, H $_2$  emission is also seen associated with methanol masers, apparently excited in shocks from outflows (Lee et al. 2001). In G323.74-0.26 three prospective  $\sim$ B0 stars are seen at different evolutionary stages, from embedded mid-IR source, to near-IR source, to HII region. An outflow originates from one of the pre-UCHII sources, shocking the gas (Walsh et al. 2002a).

A spectral survey from 86–92 GHz with the 22-m Mopra telescope of IRAS 17470–2853 (Kim et al. 2002) revealed the rich organic chemical signature of a ‘hot molecular core’ (HMC). A survey is now underway with the Mopra millimetre telescope for methyl cyanide (CH $_3$ CN) emission associated with isolated methanol masers. It is clearly seen in several sources and indicates the presence of HMCs (Balasubramanyam et al. 2002); warm ( $\sim$  100 K), dense gas accompanying the deeply embedded sources seen at IR and sub-mm wavelengths. It is clear that HMCs do not always need the presence of a nearby UCHII region to heat them. We believe we are seeing pieces of the evolutionary sequence towards massive star formation (see Lee et al. 2001).

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