Maser Disks or Maser Outflows?

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Summary

Linearly distributed masers, especially methanol masers, have generally been thought to exist in and be tracing edge-on circumstellar disks. A recent survey searched for outflows in H_2 emission perpendicular to these maser/disk distributions (De Buizer 2003). Instead of finding H_2 emission perpendicular to the maser distributions, the majority of sources had H_2 emission distributed closer to parallel. This creates a serious problem for the hypothesis that the masers are generally circumstellar disk tracers, and hinted at the possibility that the masers may instead be related to outflows. H_2 emission can be stimulated by other means than outflow-related shock, therefore follow-up observations in SiO emission were performed be De Buizer et al. (2007). **The general conclusion from these observations were that the SiO outflows are inconsistent with the idea that linearly distributed masers are generally tracing circumstellar disk orientations, and that observations are more compatible with the masers being outflow-related (see examples below: G331.132-0.244 and G320.23-0.28).**

Further recent observations in the mid-infrared (5-25 μm) of massive young stellar sources have also yielded a surprising result: many show evidence of mid-infrared continuum emission from outflows and jets. These observations correlate well with other larger-scale outflow indicators and their geometries, such as what is seen in shock-excited H_2 and CO emission. In many cases these mid-infrared observations identify the local maser emission as outflow or jet related. Thanks to the increase of facility-class mid-infrared imagers on large aperture telescopes (8-10m), we are achieving high resolutions in the mid-infrared (~0.25-0.60") that allow us to see the detailed morphologies of the mid-infrared outflows around these young stellar sources. **The mid-infrared emission seen from these sources is not from circumstellar disks or envelopes, but instead may be interpreted as arising from the directly heated dust on the walls of the outflow cavity or from material caught up in the outflow (see examples below: G35.20-0.74 and NGC7538 IRS 1).** An outflow cavity can be created by a molecular outflow or jet punching a hole in the dense clump of obscuring material surrounding a young stellar source.

G35.20-0.74

The cm radio continuum emission at this site was resolved by Heaton & Little (1988) into a north-south bipolar radio jet coming from a UC HII region (Figure 1b). The mid-infrared observations of De Buizer (2006) of this region reveal a spectacularly extended source that starts at the central UC HII region and extends northward in the direction of the northern radio outflow knots (Figure 1a). There is no infrared emission from the southern jet location. The mid-infrared images look very reminiscent of a monopolar outflow jets like those seen in near-infrared H_2 emission for low-mass young stellar objects. Because the filter bandpasses do not encompass any outflow diagnostic lines (like H_2), **it is concluded that this source is dominated at wavelengths >3 μm by reradiated thermal dust emission from the jet cavity. It also appears that a majority of the masers exist on the walls at the base of this cavity and therefore may all be stimulated to emit by the outflow** (Figure 1c).

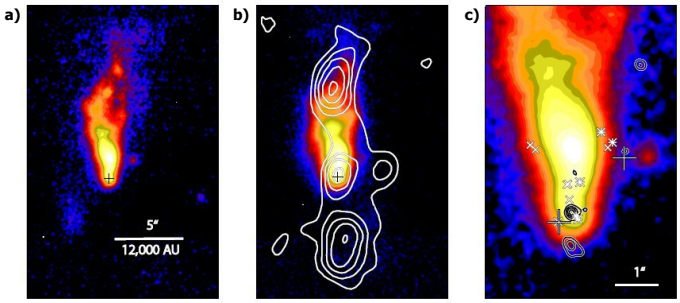

Figure 1. *(a)* The jet from G35.20-0.74 at 11.7 μm with T-ReCS on Gemini South. (b) The mid-infrared jet overlaid with the low-resolution radio continuum observations of Heaton & Little (1988). The central radio blob is a UC HII region. *(c)* The radio continuum emission from the UC HII region (thin black; Gibb et al. 2003) The water (crosses), OH (asterisks), and methanol (large plus signs) masers are in a V-shape and trace the walls of the jet as seen in mid-infrared emission.

G331.132-0.244

This source contains nine methanol maser spots oriented E-W with a velocity gradient along the spot distribution (Phillips et al. 1998). There is only one knot of H2 emission on the field (De Buizer 2003), that is elongated in its morphology and situated close to the linear maser distribution axis (Figure 3). The SiO map of De Buizer et al. (2007) shows that the SiO emission is centered on the maser location and distributed at an angle very close to that of the methanol masers (Figure 3). Once again, **the similarity in angles for the masers, and all outflow tracers is not what is expected for the disk scenario, and therefore may hint at a relationship between the masers and the outflow for this source.**

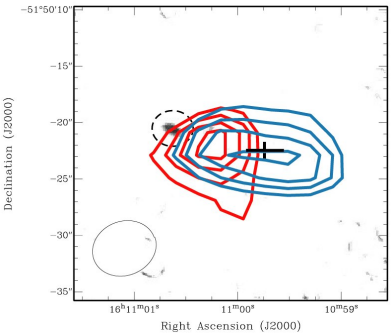

Figure 3. *The 2.122 μm H_2 emission that is being shock excited by a possible outflow in G331.132-0.244 is shown as greyscale and encircled in a dashed ellipse. The red and blue contours display the red and blue shifted outflow emission in SiO. The maser location is shown as a cross, the elongated axis of the cross defining the position angle of the linearly distributed methanol masers at this location.*

NGC 7538 IRS 1

This source has gained a lot of attention because one group of methanol masers associated with the source has linearly distributed methanol masers with a clear velocity gradient that can be well-modeled by an edge-on circumstellar disk rotating in a Keplerian fashion (Pestalozzi et al. 2004). However, Hoffman et al. (2003) found the formaldehyde masers at this location were also distributed in a linear fashion and also have a velocity gradient. However the formaldehyde maser position angle (PA) is nearly perpendicular to the methanol masers.

Mid-infrared observations revealed a larger-scale elongation in dust emission at the exact P.A. of the CO outflow. De Buizer & Minier (2005) claim that this MIR emission is outflow related. Since the CO and H_2 outflow as well as the MIR outflow emission are at a similar PA to the methanol masers, it is conjectured that these masers exist on the outflow cavity wall and not in a disk. The mid-infrared emission was also found to be elongated on a small scale at the exact PA and similar extent as the formaldehyde masers. De Buizer & Minier (2005) suggest this may be the thermal emission from the rotating R~150 AU circumstellar disk (Figure 2).

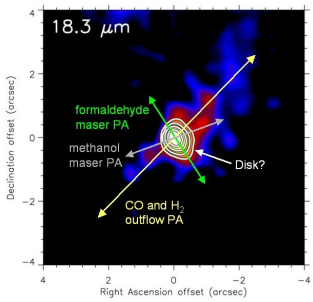

Figure 2. *The deconvolved 18.3 μm image of NGC7538 IRS 1. The contours around the bright elongated central region may be thermal emission from a circumstellar disk around this source.*

G320.23-0.28

There are ten methanol maser spots in the linear distribution associated with G320.23-0.28, spread out over 0.5″ and at an angle of ~86°. In the observations of De Buizer (2003), the H_2 emission is shown to be situated exactly parallel to the position angle of the methanol maser distribution. Furthermore, the observations of De Buizer et al. (2007) have revealed SiO emission distributed at the same angle as the H_2 emission and the methanol maser position angle (Figure 4a). In Figure 4b, a 3-color Spitzer image is shown with the 4.5 μm channel (and outflow tracer) in green. The 4.5 μm outflow emission is distributed at the same position angle as all the other outflow indicators in this field, adding further evidence to the outflow nature of the H_2 emission. **The similarity in angles for the masers, and all outflow tracers again create problems for the disk scenario for the masers.**

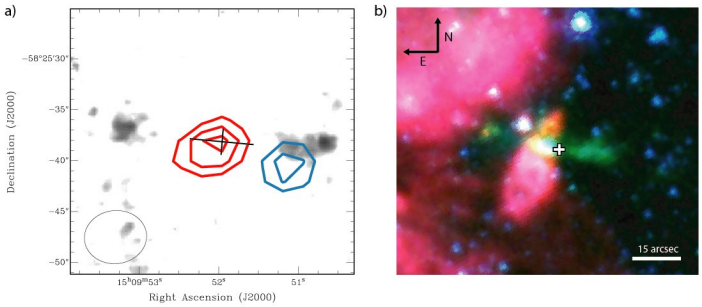

Figure 4. *(a) The 2.122 μm H_2 emission that is being shock excited by a possible outflow in G320.23-0.28 is shown as greyscale. The red and blue contours display the red and blue shifted outflow emission in SiO. The maser location is shown as a cross, the elongated axis of the cross defining the position angle of the linearly distributed methanol masers at this location. (b) A 3-color Spitzer IRAC image of the region centered on the maser location (white cross). Red is 8.0 μm, green is 4.5 μm, and blue is 3.6 μm. The 4.5 μm filter encompasses many outflow lines and shows enhanced emission above the other filters in the outflow at this location.*

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