Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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ATLASGAL: methanol masers at 3 mm

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Abstract. We analyzed the 3 mm wavelength spectral line survey of 408 clumps from the APEX telescope large area survey of the Galaxy, focusing on the methanol maser transitions. The main goals of this study are (1) to search for new methanol masers, (2) to statistically study the relationship between class I masers and shock tracers, (3) to study the properties between methanol masers and their host clumps, also as a function of their evolutionary stages and, (4) to better constrain the physical conditions using multiple co-spatial line pairs.

Keywords. Masers, star: formation, ISM: molecules, radio lines: ISM

1. Introduction

Methanol (CH_3OH) masers are common phenomena in star-formation regions, providing numerous maser transitions with inverted populations highlighting conditions with enhanced activity (e.g., Menten 1991). These CH_3OH masers are divided into two categories (Batrla *et al.* 1987; Menten 1991). Class I CH_3OH masers are thought to be tracers of shocked regions and are produced by collisional pumping (e.g., Leurini *et al.* 2016). Class II CH_3OH masers are found in close proximity to infrared sources, OH masers and ultracompact HII regions, and are believed to be radiative pumped (e.g., Cragg *et al.* 2005).

The APEX telescope large area survey of the Galaxy (ATLASGAL) is an unbiased 870 μm sub-millimetre continuum survey of the inner Galaxy (Schuller *et al.* 2009), providing a large inventory of dense molecular clumps. A number of 408 ATLASGAL sources were selected to cover a large range of evolutionary stages, and were observed using the IRAM-30 m with a frequency coverage of 83.8 – 115.7 GHz (Csengeri *et al.* 2016). This well characterized sample allows us to search for new methanol masers and perform a statistical analysis of the properties of detected masers and their associated star-forming clumps at different evolutionary stages.

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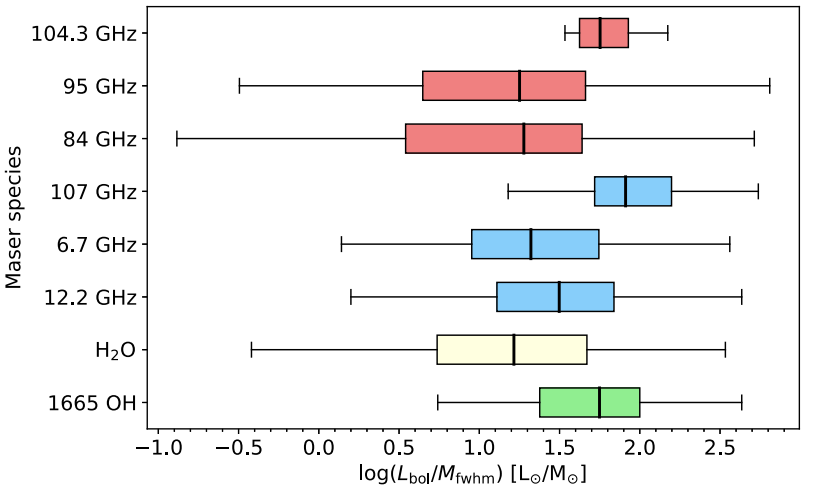

Figure 1. The box plot shows the distributions of bolometric luminosity-to-mass ratios for clumps associated with different masers. Except for 3-mm CH_3OH masers, the plotting data for H_2O, OH, and class II methanol masers at 6.7 and 12.2 GHz are taken from Fig. 7(A) in Ladeyschikov *et al.* (2022).

2. Detection

• A total of 54, 100 and 4 sources were detected to show class I maser emission at 84 ($J_k = 5_{-1} - 4_0\ E$), 95 ($8_0 - 7_1\ A^+$) and 104.3 GHz ($11_{-1} - 10_{-2}\ E$), respectively. Among them, fifty 84 GHz masers, twenty nine 95 GHz masers, and four 104.3 GHz masers are new discoveries. Our work increases the rare class I maser at 104.3 GHz from five to nine (Yang *et al.* 2023).

• Eleven sources were detected to harbor class II methanol maser emission at 107 GHz ($3_1 - 4_0\ A^+$), and the known number of detections has increased from 25 to 33. No sources show maser emission at 85.5, 86.6, 86.9, 104.1 and 108 GHz (Yang *et al.* in prep).

• We also detected 19 sources with CH_3OH absorption features at 107 GHz, which could be anti-inversion, since analyses show that their continuum background is dominated by the Cosmic Microwave Background.

3. Results

• We found that (1) more and stronger class I CH_3OH masers were detected towards sources showing SiO line wings than towards sources without SiO wings; (2) the total integrated intensity of class I masers is positively correlated with SiO integrated intensity and FWZP of SiO (2–1) emission. These facts strongly suggest that the properties of class I masers are regulated by shock properties also traced by SiO.

• The properties of class I CH_3OH masers show positive correlations with the following properties of associated ATLASGAL clumps (Urquhart *et al.* 2022): bolometric luminosity, clump mass and peak H_2 column density. There is no statistically significant correlation between the luminosity of class I CH_3OH and the luminosity-to-mass ratio, dust temperature, or mean H_2 volume density.

• Through studying the evolutionary stages of different masers during star formation (see Fig. 1), we found that CH_3OH masers at 104.3 (107) GHz appear to trace a short and evolved stage compared to the other class I (II) CH_3OH masers.

• Our statistical equilibrium calculations show that physical conditions can be better constrained in regions with multiple class I CH_3OH masers (more details in Yang *et al.* 2023).

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Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1743921323002569

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