

ATLASGAL: methanol masers at 3 mm

W. Yang¹, Y. Gong¹, K. M. Menten¹, F. Wyrowski¹,
J. S. Urquhart², C. Henkel^{1,3,4}, T. Csengeri⁵, S. P. Ellingsen⁶,
A. R. Bemis⁷ and J. Jang¹

¹Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
email: wjyang@mpifr-bonn.mpg.de

²Centre for Astrophysics and Planetary Science, University of Kent, Canterbury CT2 7NH, UK

³Astronomy Department, Faculty of Science, King Abdulaziz University, PO Box 80203,
Jeddah, 21589, Saudi Arabia

⁴Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi 830011, PR China

⁵Laboratoire d'astrophysique de Bordeaux, Univ. Bordeaux, CNRS, B18N, allée Geoffroy
Saint-Hilaire, 33615 Pessac, France

⁶School of Natural Sciences, University of Tasmania, Private Bag 37, Hobart, Tasmania 7001,
Australia

⁷Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA Leiden, The Netherlands

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 (CH₃OH) 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 CH₃OH masers are divided into two categories ([Batra et al. 1987](#); [Menten 1991](#)). Class I CH₃OH masers are thought to be tracers of shocked regions and are produced by collisional pumping (e.g., [Leurini et al. 2016](#)). Class II CH₃OH 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 μ m 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.

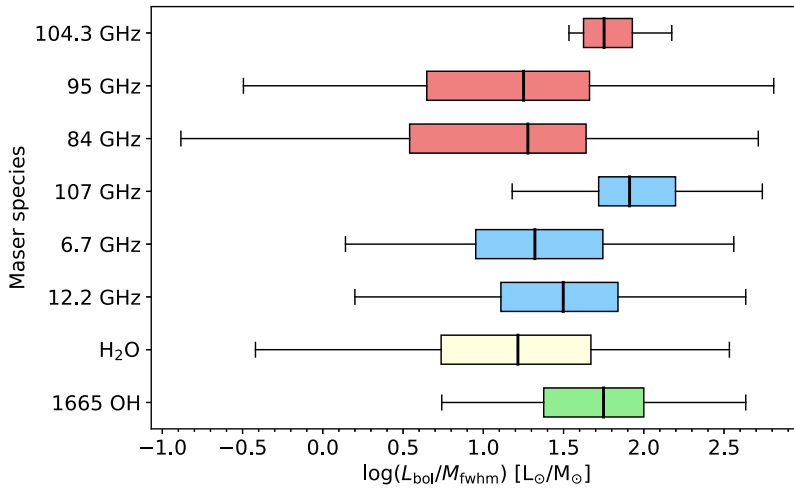


Figure 1. The box plot shows the distributions of bolometric luminosity-to-mass ratios for clumps associated with different masers. Except for 3-mm CH₃OH masers, the plotting data for H₂O, OH, and class II methanol masers at 6.7 and 12.2 GHz are taken from Fig. 7(A) in Ladeyschikov *et al.* (2022).

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 CH₃OH 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 CH₃OH 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 CH₃OH masers show positive correlations with the following properties of associated ATLASGAL clumps (Urquhart *et al.* 2022): bolometric luminosity, clump mass and peak H₂ column density. There is no statistically significant correlation between the luminosity of class I CH₃OH and the luminosity-to-mass ratio, dust temperature, or mean H₂ volume density.

- Through studying the evolutionary stages of different masers during star formation (see Fig. 1), we found that CH₃OH masers at 104.3 (107) GHz appear to trace a short and evolved stage compared to the other class I (II) CH₃OH masers.

- Our statistical equilibrium calculations show that physical conditions can be better constrained in regions with multiple class I CH₃OH masers (more details in Yang *et al.* 2023).

Supplementary material

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

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