# ATLASGAL: methanol masers at 3 mm

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Methanol ($CH_3OH$) masers are common phenomena in star formation regions and powerful tools to study the physical conditions of the gas. The main goals of this study are (1) to search for new methanol masers at 3 mm, (2) to statistically study the relationship between class I masers and shock tracers, (3) to study properties between methanol masers and their host clumps, also as a function of their evolutionary stage and, (4) to better constrain the physical conditions through multiple co-spatial maser line pairs.

## Observations

- Targets: 408 ATLASGAL clumps
- Telescope: IRAM-30 m (83.8 – 115.7 GHz)
  Observing dates: 2010.05 – 2012.10
  Beam size: 29 arcsec @ 84 GHz
  1 σ rms: 0.2 Jy @ ~0.7 km/s

## Maser Detection

- Class I $CH_3OH$ masers(*):
  54 (**50 new**) masers at 84 GHz
  100 (**29 new**) masers at 95 GHz
  4 (**4 new**) masers at 104.3 GHz; the known number has increased from 5 to **9**
- Class II $CH_3OH$ masers(†):
  11 (**8 new**) masers at 107 GHz; the known number has increased from 25 to **33**
  **No** sources show maser emission at 85.5, 86.6, 86.9, 104.1 and 108 GHz

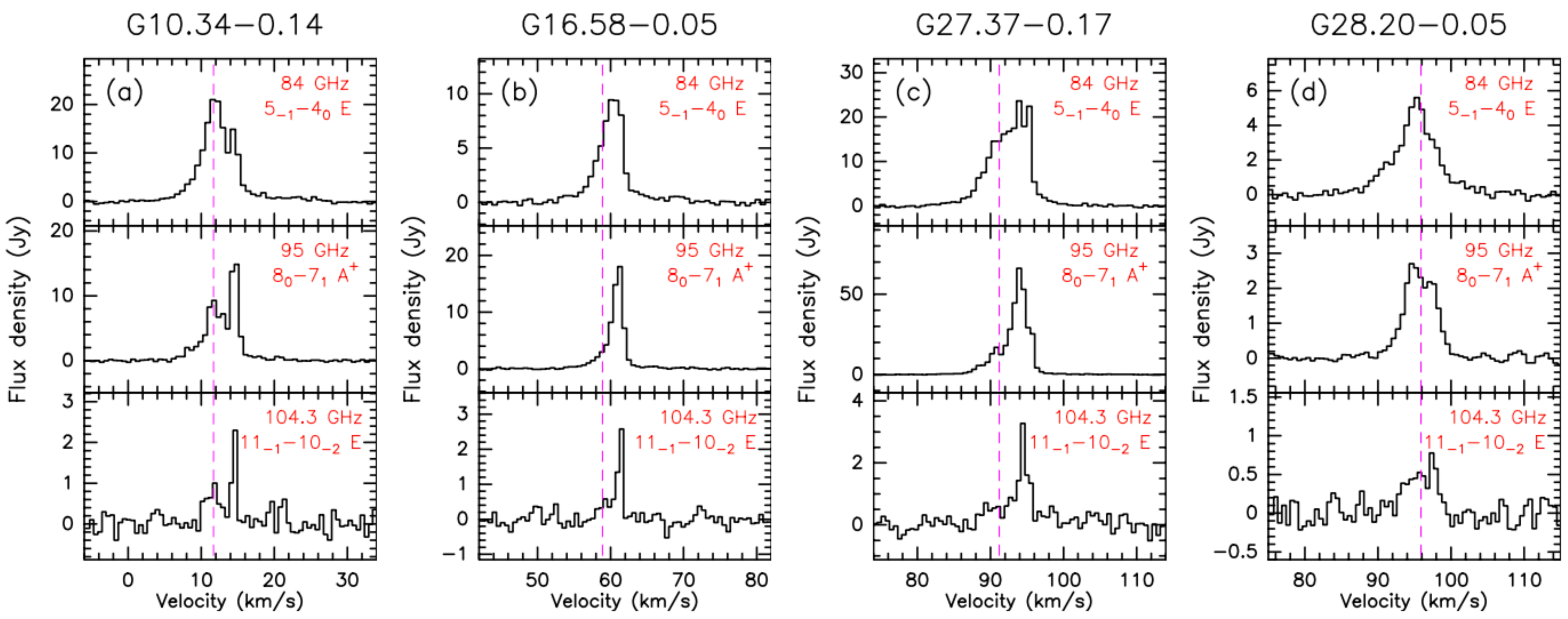



**Fig. 1**: Spectra of the 84, 95, 104.3 GHz lines for 4 sources showing 104.3 GHz methanol maser features.

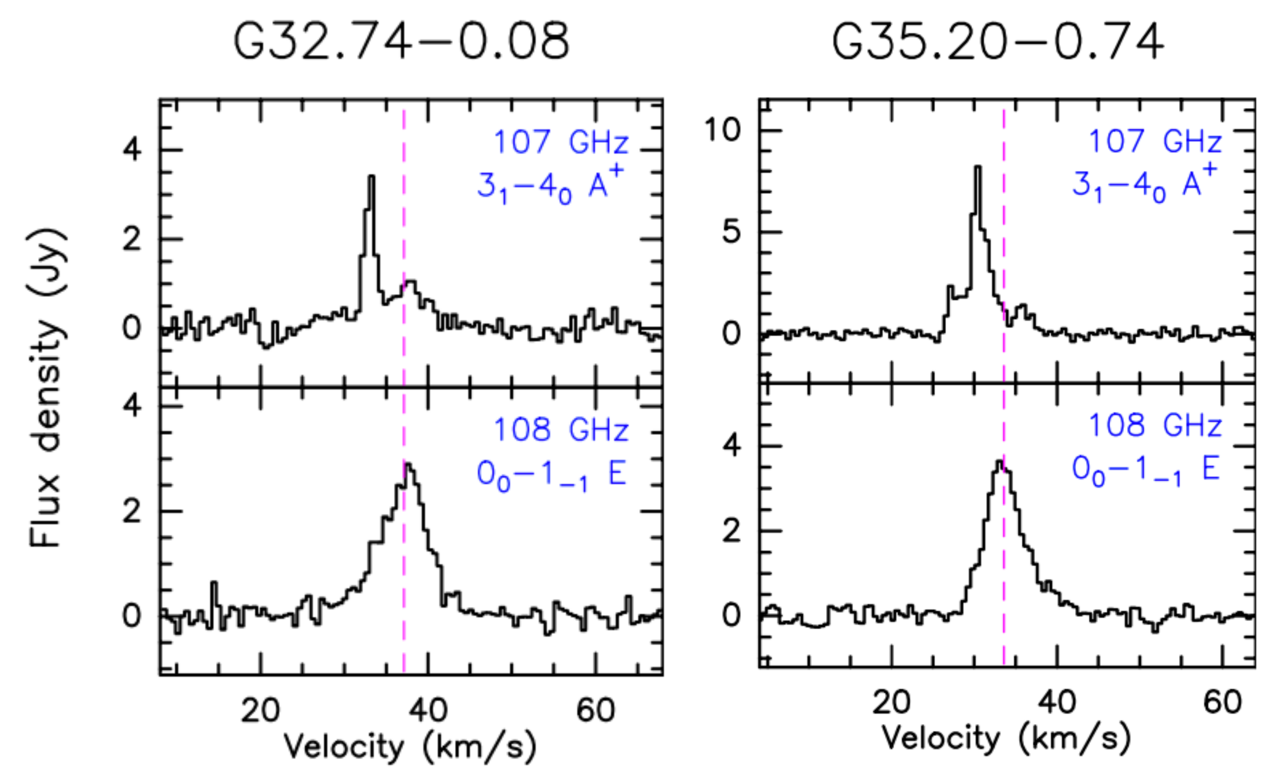
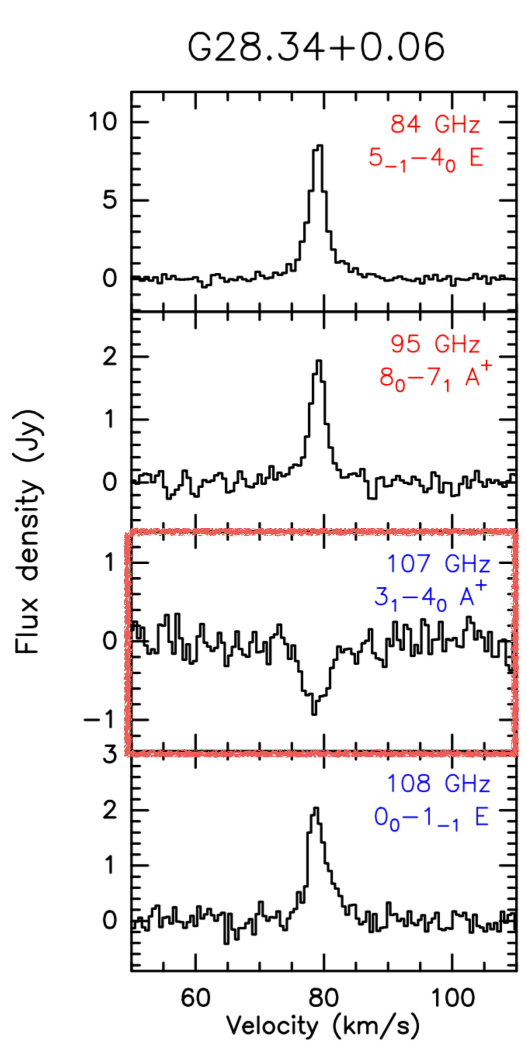



**Fig. 2**: Examples of sources showing newly detected 107 GHz methanol masers.

## Anti-inversion of the 107 GHz line



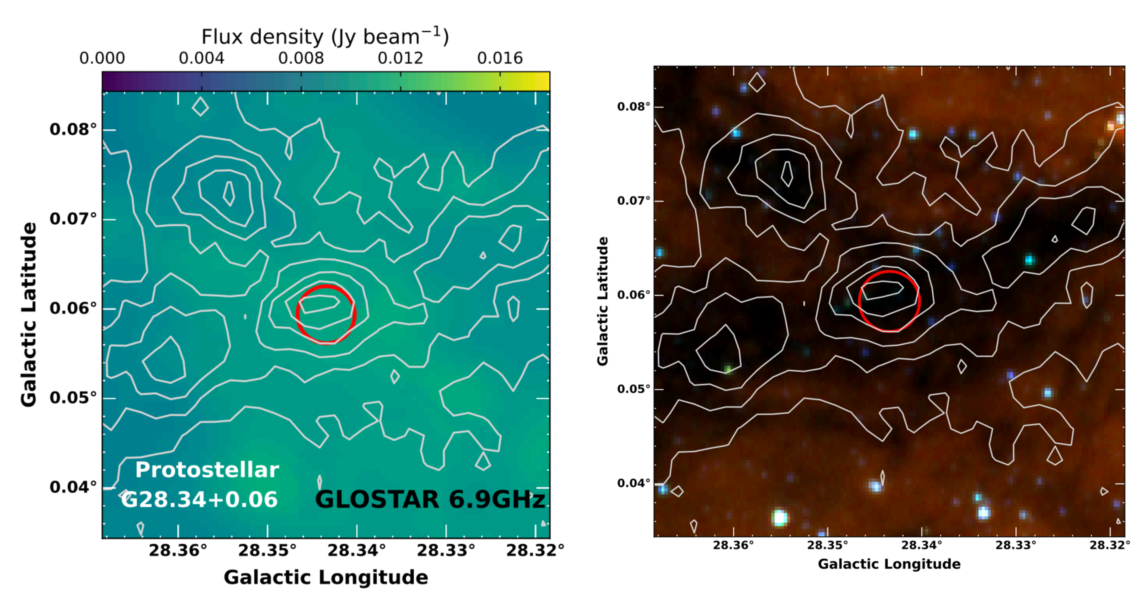




**Fig. 3**: (Left) Example of spectrum showing 107 GHz absorption features. The ATLASGAL 870 μm emission contours superpose on 6.9 GHz GLOSTAR VLA+Effelsberg continuum background (middle) and IRAC three-color (4.5/5.8/8.0 μm) map (right). The red circle shows the targeted position and beam size toward G28.34+0.06.

- **19** sources show 107 GHz $CH_3OH$ absorption features
- Analysis on background dust and free-free emission → 107 GHz $CH_3OH$ absorption toward CMB, $T_{ex} < T_{CMB}$

## The evolutionary stage of $CH_3OH$ masers

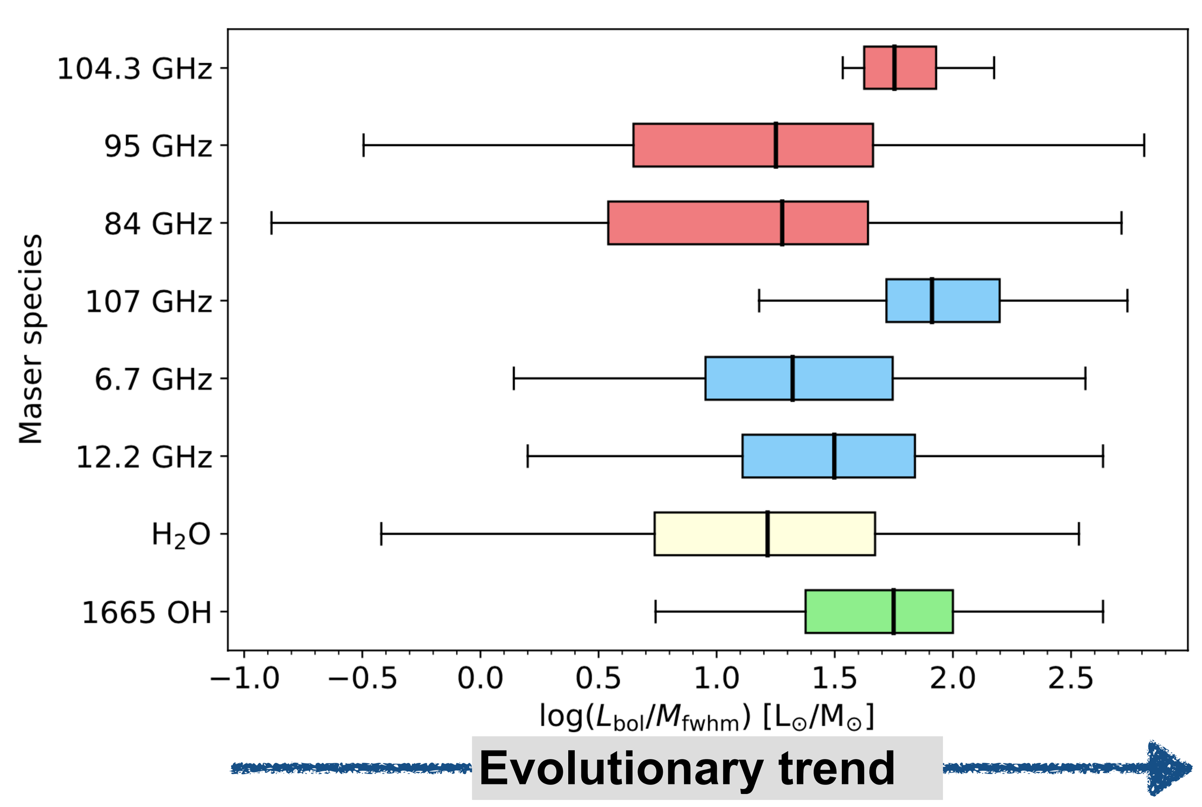



**Fig. 4**: Box plot shows the distributions of bolometric luminosity-to-mass ratios for clumps associated with different masers. Except for 3-mm $CH_3OH$ masers, the plotting data are taken from Ladeyschikov et al. (2022).

## The properties of class I $CH_3OH$ masers are regulated by SiO traced shocks

- More and stronger class I masers were detected towards sources showing SiO line wings than sources without SiO wings.
- The total integrated intensity of class I masers is positively correlated with SiO integrated intensity and FWZP of SiO (2–1) emission.

## Physical properties on a clump scale

- Isotropic luminosity or integrated intensity of class I masers vs. properties of associated ATLASGAL clumps:
  positive correlation: $L_{bol}$, $M_{clump}$, $N(H_2)$
  no statistically correlation: $L/M$, $T_{dust}$, $n(H_2)$
- Clumps with 104.3 GHz masers generally show brighter $L_{bol}$, warmer $T_{dust}$, larger $L/M$ ratios, and denser environments.

## Using multiple class I masers to constrain physical conditions

- myRadex (a RADEX analog)
- Maser feature at 15 km/s in G10.34-0.14 →
  $T_{kin}$ = 57±3 K
  $n$(para-$H_2$) = 7.9(±2.5)×$10^5$ $cm^{-3}$

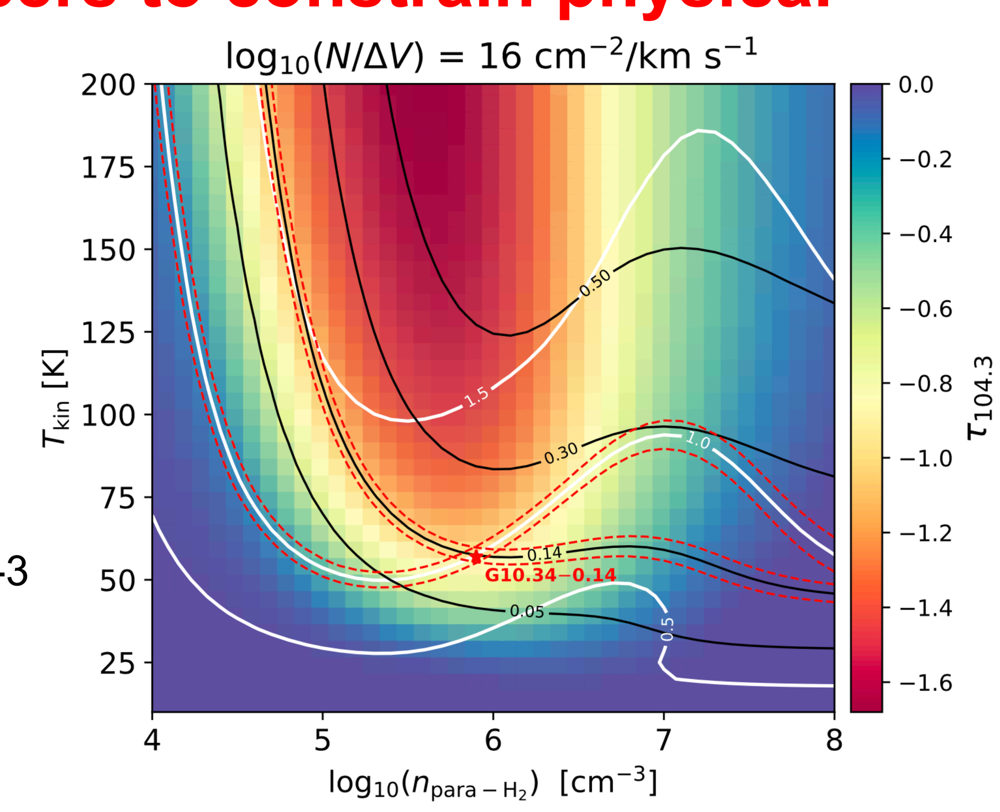



**Fig. 5**: Statistical equilibrium calculations result. The colored background shows negative optical depths of 104.3 GHz CH3OH line. The black and white contours represent the peak intensity ratios of Tr,104.3/Tr,84 and Tr,95/Tr,84, respectively.

* W. Yang, et al. submitted to A&A; † W. Yang, et al. in prep.
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