MASSIVE MOLECULAR OUTFLOWS TOWARD 6.7 GHz METHANOL MASERS
By Eye and Machine Learning

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2. MAPPINGS of the Cambridge Gigaparsec 2.0 survey

BACKGROUND: Outflows and 6.7 GHz Masers

Our current understanding of the evolutionary sequence of massive stars is shown on the right. Our study involves the Hot Core (HC) phase, age ~106–107 yr, prior to the UC HII region.

- High detection rates of masers observed toward massive YSOs3,4 (probable mechanism for removal of angular momentum) from accretion3 suggests formation via direct accretion like low mass stars.
- Many uncertainties remain which motivate studying outflows:
  - the association between outflows and their embedded driving sources in complex clump environments3
  - the correlation between outflows’ morphology, physical parameters and central source conditions4
  - the applicability of low-mass outflow theories to high mass scenarios2.
- Advantage: outflows are large scale structures that much more visible than smaller YSOs or earliest observable signatures of star formation3.
- 6.7 GHz methanol masers also detected5–7 – uniquely associated with massive YSOs as important sign posts for YSOs in the UC phase1,11.
- An association has been seen in the occurrence of methanol masers and outflows6–8. Investigating such association contributes toward understanding details of HC phase, and on a bigger scale, the evolutionary time scale.

PHYSICAL PARAMETERS

- Target distances mainly obtained from Green3 and Roman-Duval5. Unknown distances computed from the Galactic Rotation curve using 12CO peak velocity.
- Physical parameters calculated following the approach of Beuther4, with corrections for use of 13CO instead of 12CO.
- Parameter averages - Table 1 (56 spectra, including sources with distance ambiguities and those with no mass estimates).
- Histograms showing comparisons with other authors4,5,7,12 shown in Fig. 3 – all ambiguities and offset sources excluded.
- Results:
  - mass distribution similar between 100-300M⊙, but disjointed for < 50M⊙ and > 500M⊙
  - dynamical time scales have similar distribution with unique sharp turn-over at 4x107 yr.
- Possible explanation:our data have a selection bias: every flow is associated with a 6.7 GHz maser. Both distributions suggest our population needs to be surveyed in the UV to determine the roles of others.

Propose following line of HC phase as opposed to Codelha12:

- No strong correlation between Lout and Lcore exist but we flagged targets according to their Lout range (Fig. 6) and saw: brighter maser and outflow luminosities show association with brighter cores.
- Significant positive relation exists between Lout and Mcore.

Above results agree with suggestion that the mass and luminosity of a massive YSO has an effect on the luminosity of the outflow it generates, as well as the maser it pumps.

 Appears as if pumping source of maser = driving source of outflow = supports the theory that massive stars form via accretion with a single site powering its outflow.

REFERENCES


OBservations and Outflow detections

- Observed 12CO and C18O p-p' maps toward a sample12,13 of 70 6.7 GHz methanol masers between 20° < l < 33.8° with JCMT-HARP.
- Detected 13CO clumps (curve b, panels (b-g)): 47 were closely associated with the masers.
- Analyzed associated spectra for Doppler broadened line wings.

 Criteria: (1) Upper C18O spectrum to 12CO peak. (2) Subtract this Gaussian from 12CO to get residual. Wings = points where (residual > 0) and (C18O T_A > 3σ on noise).
- With wings’ velocity ranges + create blue and red velocity integrated maps.
- Plotted blue and red maps as contours on the peak integrated 12CO background (Fig 2).

PARAMETER RELATIONS

- Calculated a mean accretion rate from our mean outflow mass flux5:
  \[ \dot{M}_{out} = \frac{2}{3} \frac{F_{out}}{O} \]
  which is sufficient to overcome radiation pressure in direct accretion20.
- A statistical significant relation exists between outflow and core masses (derived from C18O) over three orders of magnitude with \( \dot{M}_{out} \propto M_{core}^{4} \) (Fig. 5).
- Also a significant relation between \( F_{out} \) and \( M_{core} \) with \( \dot{M}_{out} \propto M_{core}^{3} \) (Fig. 4).
- Luminosity divisions from Shepherd20 on a \( M_{core} \) vs t relation that higher mass (and more massive) YSOs entrain higher mass outflows (Fig. 5, blue & red lines).

MACHINE LEARNING

- This discussed study emphasized the need for automated outflow detection methods.
- Explore the use of machine learning algorithms – Support Vector Machines (SVMs).
- Training data → create feature vector per pixel. Property values are “coordinates” in N-dimensional feature-space.
- SVM trained.
- Optimize adjustable parameters C (margin width) and g (boundary tightness).
- Effect of increasing γ.