MOLECULAR OUTFLOWS TOWARD METHANOL MASERS:
Detection methods and calculation of their properties

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THE ROLE OF METHANOL MASERS AND MOLECULAR FLOWS IN HIGH MASS STAR FORMATION

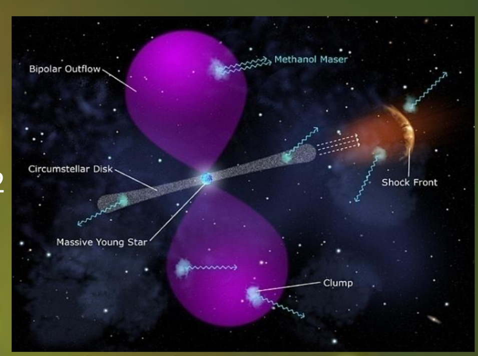

Photo credit: Yvonne Kei-Nam tang (Cornell University).

- Interstellar methanol (CH_3OH) exhibits maser emission toward star-forming regions → cm and mm wave transitions[1].
- **Two classes**:
  - ***Class I*** – Trace distant parts of molecular outflows from YSO's[1,2]
  - ***Class II*** – In the vicinity of massive YSO's, uniquely associated with high mass star formation regions[1,2].
  - Strong emission at 6.67 and 12.1 GHz with spots ~5x10^{13} cm[3,4].
- Class II methanol masers are ideal tracers of star formation sites in Galactic structure because the Galaxy is transparent at 6.67 GHz.
- Class II methanol masers (6.7 GHz) occupy probably a brief phase in the development of a massive YSO (~10^4 years[5]) - the stage immediately before that of the UC HII region[6,7].
- Methanol masers are associated with a high mass star's evolutionary phase when outflows occur[8,9].
- Accretion of massive stars cannot easily be observed due to current resolution limitations, but its presence can be inferred from larger scale infall / outflow, the latter serving as an escape mechanism for the angular momentum that builds up during accretion[10,11].
- Transitions of CO and its isotopes provide useful molecular lines to study outflows and their dynamics.

SOURCE SELECTION AND OBSERVATIONS

- Dataset: sample of 80 6.7 GHz methanol maser coordinates drawn from the MMB survey combined with Pestalozzi et al. (2005) General Catalogue.
- ^{13}CO (3-2) and C^{18}O (3-2) molecular line maps were observed in multiple sub-band mode with the HARP (4x4-element Heterodyne Array Receiver Programme) instrument on the 15m JCMT telescope, Hawaii.
- Beam size 14" at 345 GHz.
- Reductions were done with the *Starlink* software to produce despiked, baseline-removed, channel-binned, *p-p-v* cubes (Figure 1).
- The observed data cubes were matched with ^{12}CO out cuts from the JCMT HARP ^{12}CO Galactic Plane Survey.
- The C^{18}O and ^{13}CO lines provided optically thin core tracers, while the ^{12}CO served as an optically thick surface / outflow tracer.

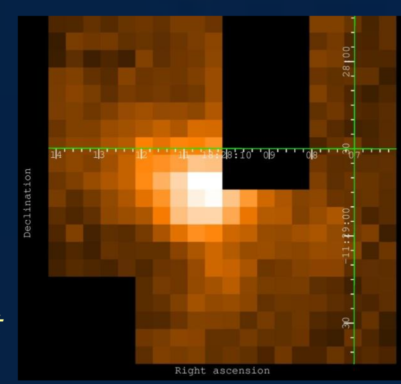

Figure 1: ^{13}CO p-p-v cube aimed at Maser G20.081-0.13.

AIM

The aim of this phase of the project is (i) to optimize an automated search method for CO outflows associated with methanol masers, and then (ii) to calculate physical parameters of the detected outflows in order to reveal the properties of the massive YSO's associated with these methanol masers.

DETECTION METHODS

- Supersonic CO emission in YSO's showed outflowing material lying in two lobes of gas, respectively blue- and red-shifted with the YSO inbetween[12].
- Various outflow detection methods:
  - ~ line wing detection in 1D spectra[8,13]
  - ~ visual inspection of 2D *p-v* diagrams[14,15] or
  - ~ visual detection of outflows in 3D visualization of *p-p-v* cubes (e.g. Arce et al. 2010).
- This presentation focuses on **two 1D line wing detection methods**.

1. HATCHELL[13]

- Simplified initial assumption: turbulent ^{12}CO line width to be ~(peak velocity ± 3km/s).
- Outflow criterion: All Temp > 3σ (of noise level) for velocity outside (C^{18}O line centre ± 3 km/s).
- Figure 2. shows criterion ranges and wings detected for G20.08-0.13.

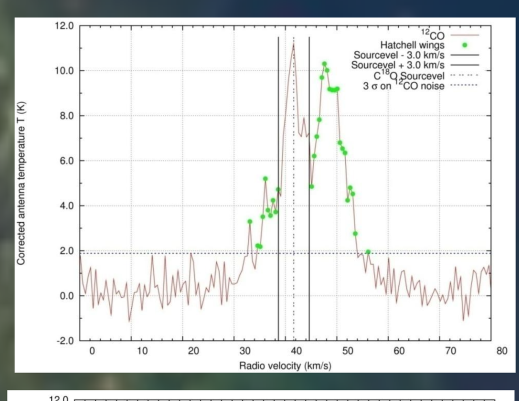

Figure 2: Wing detection with method 1.

2. VAN DER WALT[16] & CODELLA[8]

- Scale C^{18}O peak to max temperature of ^{12}CO.[8]
- Gaussian fit to the C^{18}O line by removing profile points from outsides (wings) until peak is fitted (FWHM=5.09).[16]
- All ^{12}CO points outside Gaussian with T>3σ selected as wings.
- Figure 3.

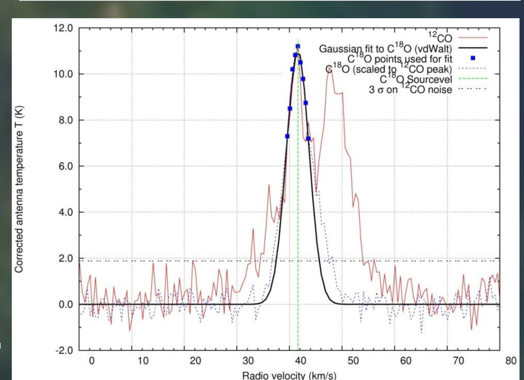

Figure 3: Wing detection with method 2.

THE OUTFLOW ASSOCIATED WITH METHANOL MASER 20.081-0.13

- A typical example is the outflow associated with methanol maser G20.08-0.13 detected at 3.4 kpc[17].
- Figure 4: Visual inspection of the *Gaia* 3D isosurface representation of the ^{12}CO cube → high velocity feature clearly shown – utilized this method as initial visual identification.

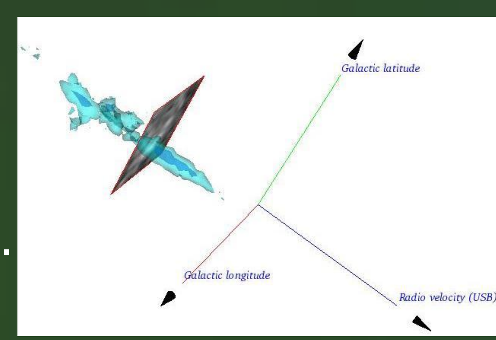

Figure 4: Gaia 3D isosurface image of p-p-v cube.

- Fig. 5: Comparison between two 1D line wing detection methods
  - → blue wing ranges equal
  - → red wings' minima differs by 1 km/s (Method 2 is closer to the peak velocity).
- Figure 6 & 7: Outflows indicated by 2D intensity contours, levels from 30% - 90% of peak wing integrated intensity in steps of 10%[18].

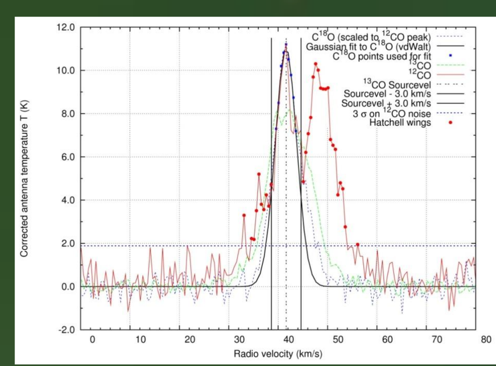

Figure 5: Comparison between line wing detection Methods1 & 2.

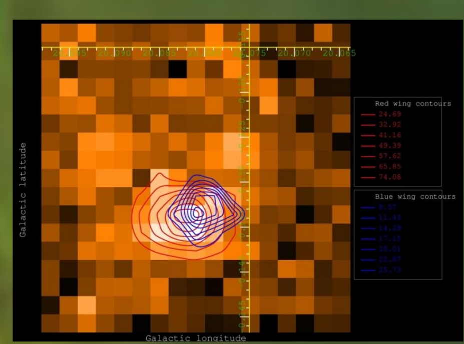

Figure 6: Red and blue lobes according to Method 1.

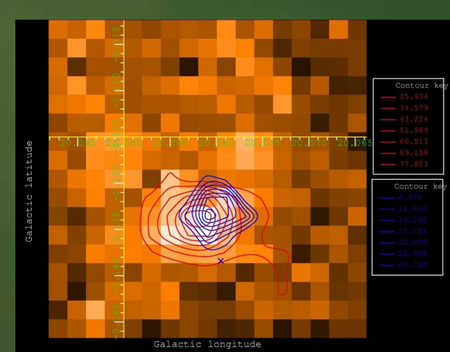

Figure 7: Red and blue lobes according to Method 2.

OUTFLOW PARAMETERS

- Using the approach from Beuther et al.[18], the outflow parameters of G20.08-0.13 were calculated, with the *linear sizes* of the two outflow lobes, the *mean values of integrated wing emission*, the *average radius* of the two flows and their respective *maximum velocity separation* as input parameters.
- The H_2 column density were calculated using Hatchell[13]'s approach. $N_{H_2} = 2.5 \times 10^{19} \left(\frac{\int T^*_{MB}\, dv}{K\, km\, s^{-1}} \right) cm^{-2}$
- Although this is only preliminary results, all parameters were of the same order as those calculated by Beuther[18].

PARAMETER	VALUE
Column Density N (cm^{-2})	N_b = 4.9 x 10^{20} N_r = 18 x 10^{20}
Total mass M_{out} (M_o)	114
Momentum p (M_o km s^{-1})	1220
Energy E (erg)	1.35 x 10^{46}
Characteristical time scale t (yr)	3.29 x 10^4
Mass entrainment rate of molecular outflow M_{out}/t (M_o / yr)	3.46 x 10^{-3}
Mechanical force F_m (M_o km s^{-1} /yr)	3.71 x 10^{-2}
Mechanical luminosity L_m (L_o)	3.37

FUTURE SCOPE

- This poster only presented a preliminary study of outflow detection techniques on a single source.
- Data of at least 200 more methanol masers is available in ^{13}CO and C^{18}O, with corresponding images from the JCMT HARP ^{12}CO Galactic Plane survey.
- For such an amount of data, outflow detections should be automated. The next step is to identify and automate the best outflow search technique.
- As a general search for outflows is not restricted to methanol masers: once this searching method is developed and tested on the methanol maser catalog, it can be utilized in a wider search for outflows across the evolutionary stages of high mass star formation.
- Resulting calculated outflow parameters can cast some light on the dynamics present during the formation process of massive stars.

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