Molecular Outflows and Infall towards a Sample of Massive Star Forming Regions

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Massive Star Formation and Molecular Outflows

• Why are they important?

• Important in removing angular momentum and potentially set the final mass of the central star.

• Bipolar molecular outflows are found across all forming stellar size scales, including brown dwarfs (e.g. Whelan 2006).

• Observed correlation in their properties (e.g. Mass, momentum, force and energy) from low to high mass regime (e.g. Bertout and Cabrit 1992).

• Different tracers possibly an evolutionary indicator?
The Sample

• Drawn from the RMS survey (Lumsden et al. 2013)
  http://www.ast.leeds.ac.uk/RMS/.

• 30 sources observed with the JCMT (~15” resolution) for SiO (8-7), HCO+(4-3) and H13CO+(4-3) (~350-GHz).
  • All had previously confirmed CO (3-2) outflows (Maud et al., 2015)
  • SiO “active” outflow tracer.
  • In the low mass regime SiO is more prominent in the Class 0 sources.
  • Observations show SiO luminosity and abundances increasing with evolution (e.g. Klaassen et al. 2011)

• Additional follow-up observations at 1.3mm (230-GHz) with the SMA (3” resolution)
  • G203.3166/NGC 2264-C (Cunningham et al. Submitted MNRAS)
  • G194.9349-IRAS 06103+1523
  • SiO (5-4), CO (2-1)
  • Plus many more lines (~30 transitions in total e.g. SO, DCN, CH3CN, CH3OH)
JCMT Survey

- 55% have SiO (8-7) detection.
- 1 potential infall candidate.
- Several additional HCO+ and SiO components Offset from the RMS source
- What are the differences in the detected non-detected sources?
- Prominence of SiO towards younger regions, based on 70micron/22micron flux and Lbol/M ratios
- Follow-up high resolution observations of two regions, one without SiO and one with SiO
JCMT Survey

- ~55% have SiO (8-7) detection.
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- What are the differences in the detected non-detected sources?

Prominence of SiO towards younger sources.
- The UCHII regions with SiO appear to be young.
SMA-G203.3166 / NGC 2264-C
SiO (8-7) detected

Green  = 450micron
Magenta = N2H+
Greyscale = 70micron
X = 3mm cont peak
* = 24micron peaks

- 740pc – closest region in RMS survey
- RMS source 9.5Msun

(Di Francesco et al. 2008, Peretto et al.2006, HOBYS PI Motte)
- 10 Cores detected
- Mass range 0.4-8 M$_{\odot}$
- Mass ~700M$_{\odot}$ (Ward-Thompson et al.2000)
Red-shifted emission ~ 10 - 40 km/s
Blue shifted emission ~ -20 – 4km/s
Vlsr~7 km/s
- Outflow sources molecular line weak
- No 70 or 24 micron counterpart
**G194.9349 SiO (8-7) Non-Detection**

- 70 micron bright RMS source is driving the outflow
- No extended SiO component.
- Whole region molecular line weak compared with NGC2264-C
Future Work with the GBT

- Frequency range contains a multitude of molecular emission, SiO, HCO+, H13CO+, CS and many more.
- Probe the infall, outflows
- Chemical diversity in star forming regions.

- Many of the regions in the JCMT survey (resolution ~15") indicate an offset between the SiO emission and the RMS source
- Green bank would allow comparative spatial resolution to Herschel 70micron - allow for the youngest sources in regions to be identified.

- Need the high resolution to resolve a single core and outflow, but the single dish is needed for zero spacing and to identify the interesting objects initially to observe at higher resolution.
Summary

- Not all CO outflows have associated SiO counterpart.
- At high resolution the outflows associated with SiO are dominated by the mm brightest, molecular line weak, IR-dark sources (i.e. potentially the youngest).
- IR bright RMS source in NGC 2264-C has no obvious molecular outflow, yet it has associated CH3CN, HC3N emission and disc (e.g. Grellmann et al. 2011).
- **SiO associated with youth at both low and high resolution.**
  - Similar to the low mass regime.
Outflow Force vs Luminosity

Adapted from Maud et al. (2015)

Bontemps 1996 low mass Class 0 – open squares, Class I – closed squares
Duarte Cabral 2014 – intermediate Class 0 - open triangles
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Outflows

NGC2264-C

G203.3166
YSO
Herschel 70 μm

1.8e3
0.7 kpc

G203.3166 ALL

G207.2654