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

High Frequency Science Workshop, Green Bank 21st September 2015

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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

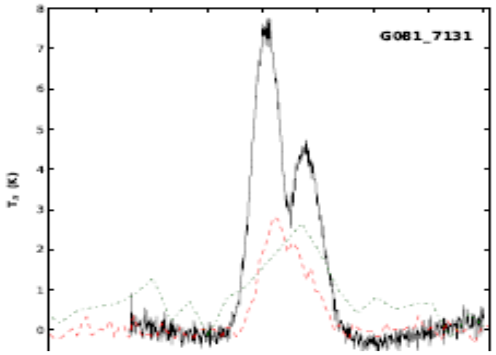
- Drawn from the RMS survey (Lumsden et al. 2013)

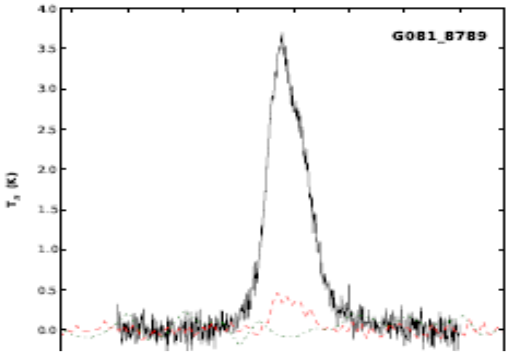
  http://www.ast.leeds.ac.uk/RMS/.

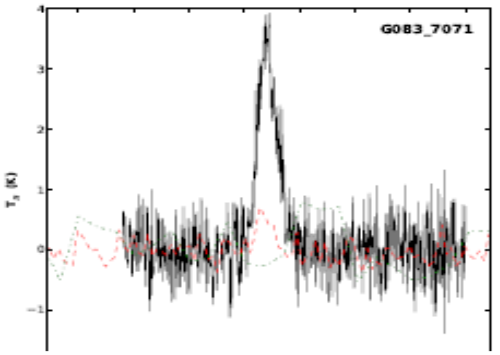
- 30 sources observed with the JCMT (~15" resolution) for SiO (8-7), HCO+(4-3) and H13CO+(4-3) (~350-GHz).
  - All had previously confirmed CO (3-2) outflows (Maud et al., 2015)
  - SiO "active" outflow tracer.
  - In the low mass regime SiO is more prominent in the Class 0 sources.
  - Observations 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.

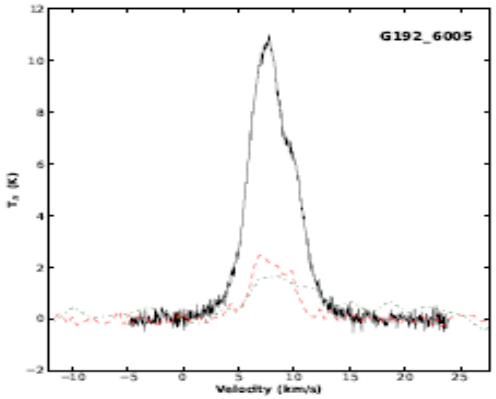
•1 potential infall candidate.

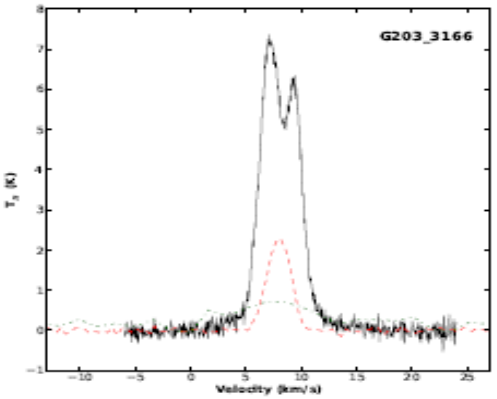
•Several additional HCO+ and SiO components Offset from the RMS source

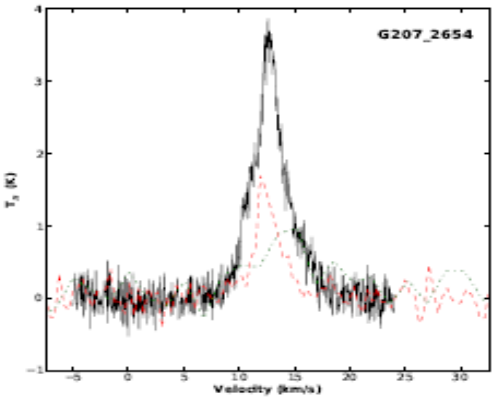
•What are the differences in the detected non-detected sources?

•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

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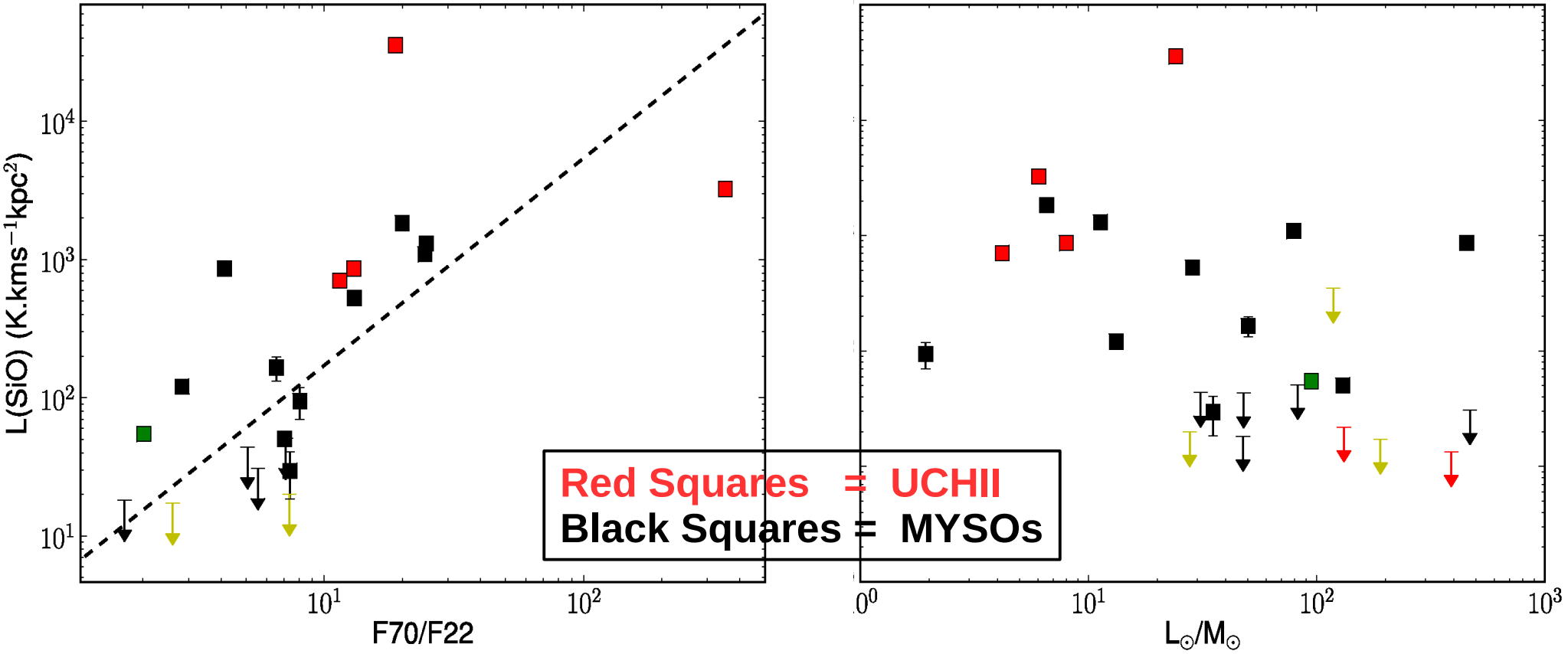
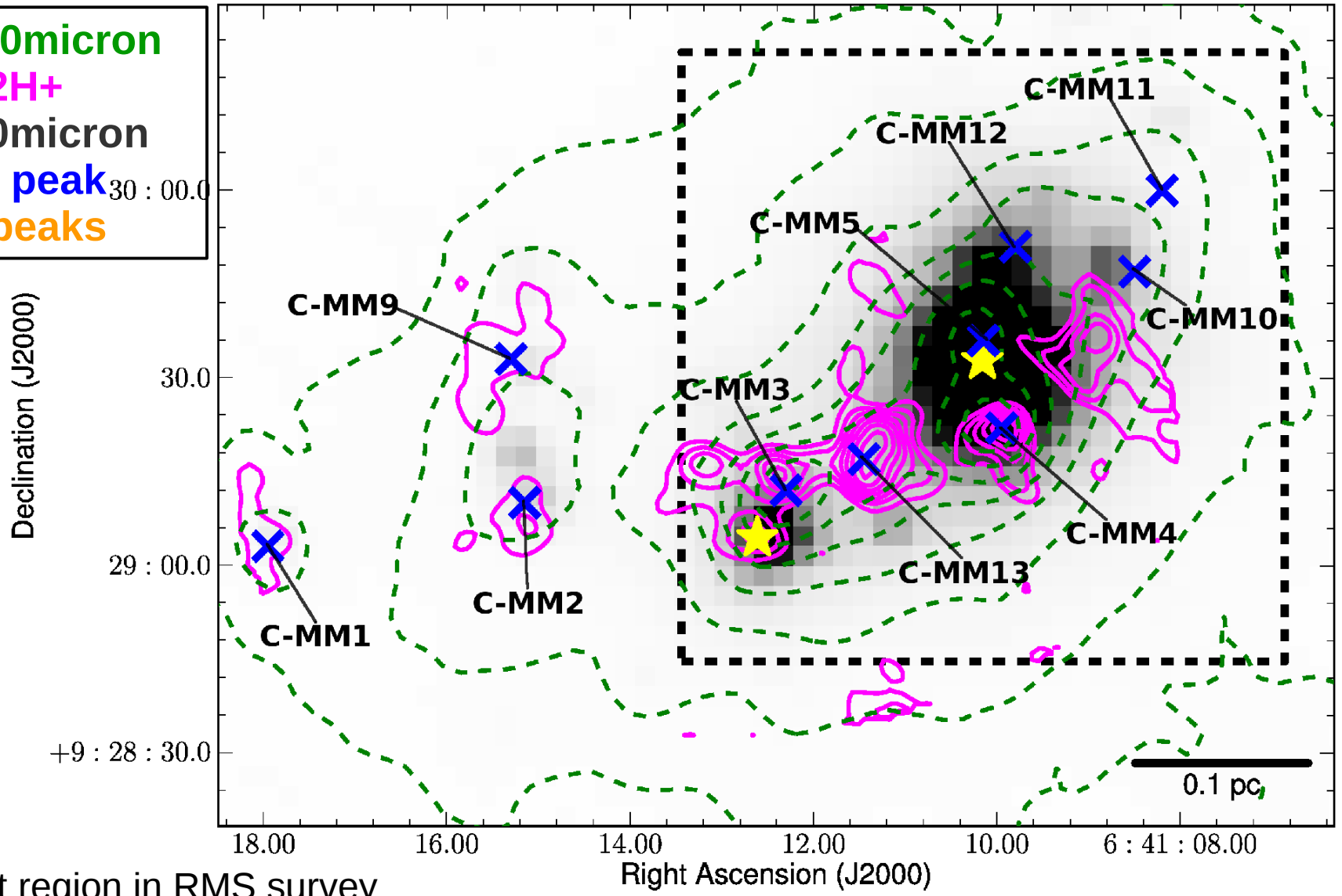


- **Prominence of SiO towards younger sources.**
- **The UCHII regions with SiO appear to be young.**

SMA-G203.3166 / NGC 2264-C
SiO (8-7) detected

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

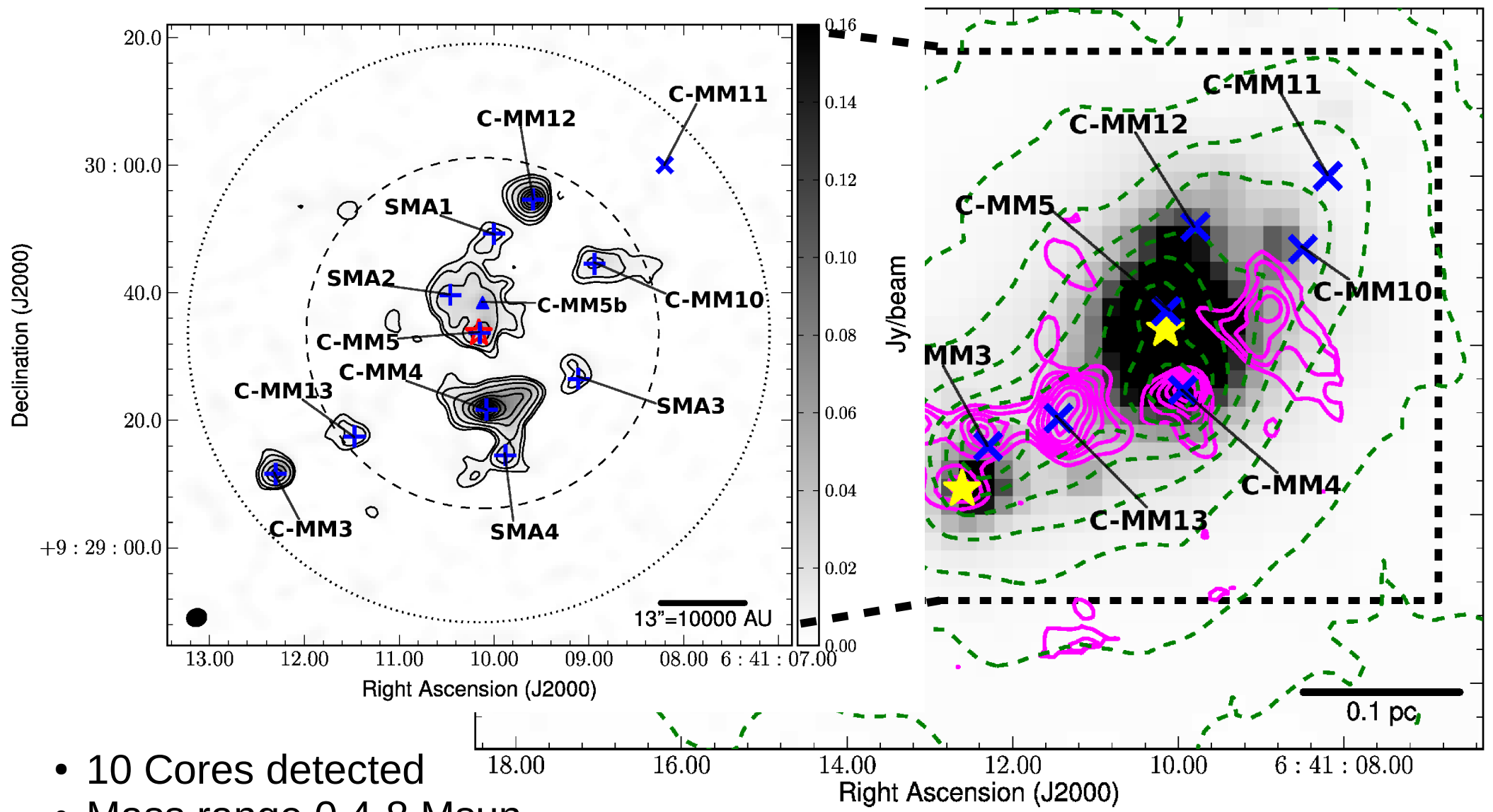


- 740pc – closest region in RMS survey
- RMS source 9.5Msun

(Di Francesco et al. 2008, Peretto et al.2006, HOBYS PI Motte)

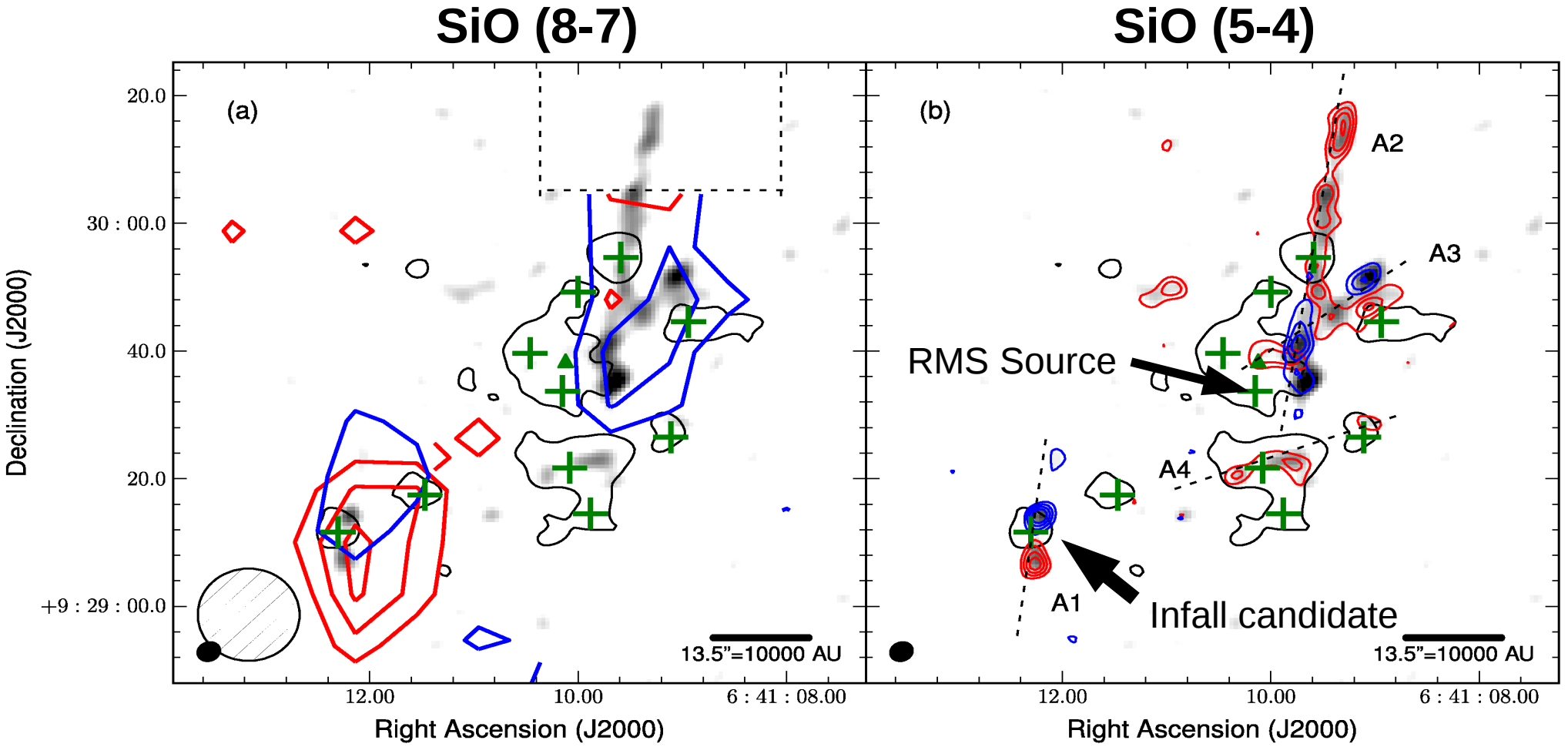
SMA-G203.3166 / NGC 2264-C

SMA 1.3mm Continuum



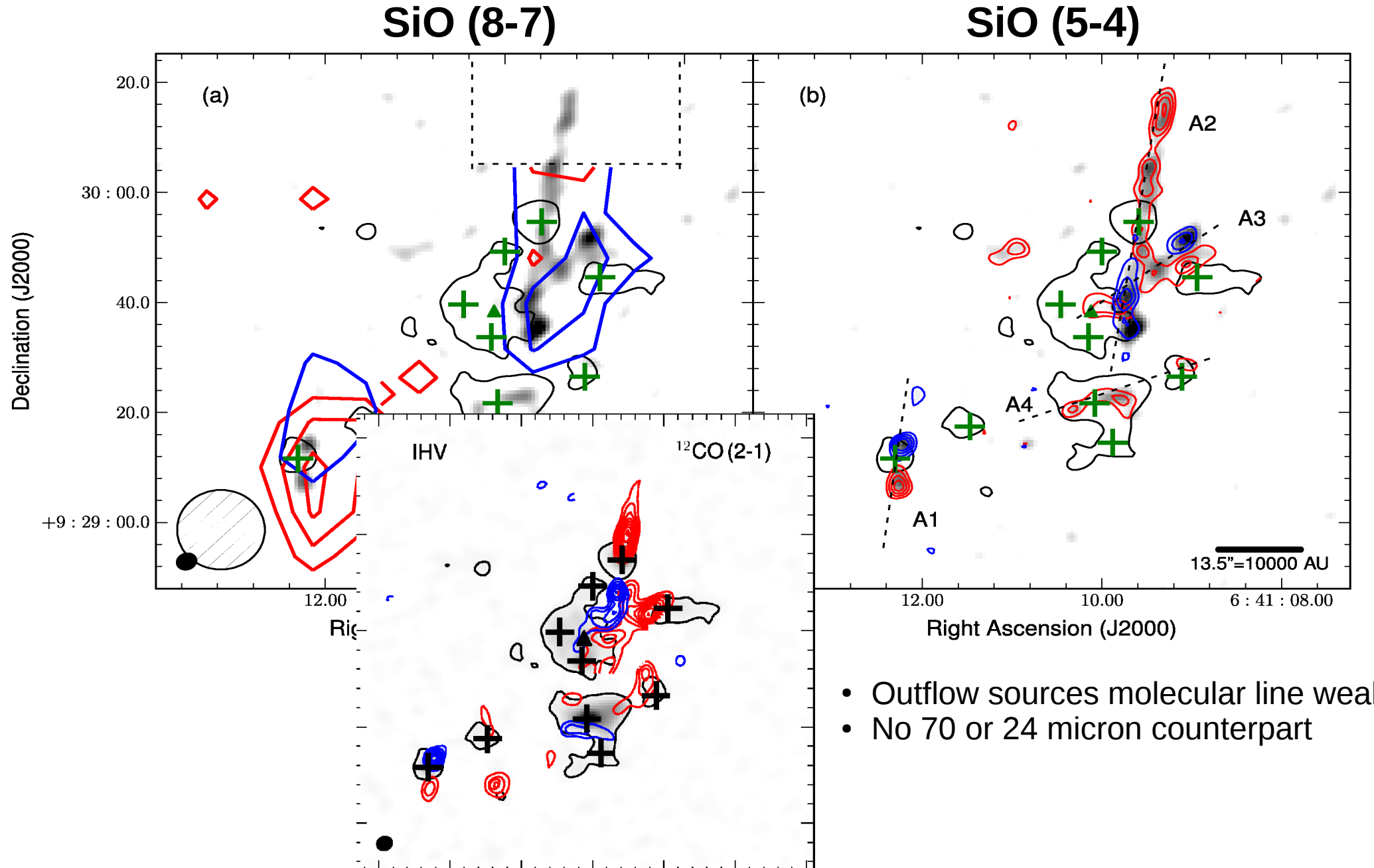
- 10 Cores detected
- Mass range 0.4-8 Msun
- Mass ~700Msun (Ward-Thompson et al.2000)

SMA-G203.3166 / NGC 2264-C



Red-shifted emission ~ 10 - 40 km/s
Blue shifted emission ~ -20 – 4km/s
Vlsr~7 km/s

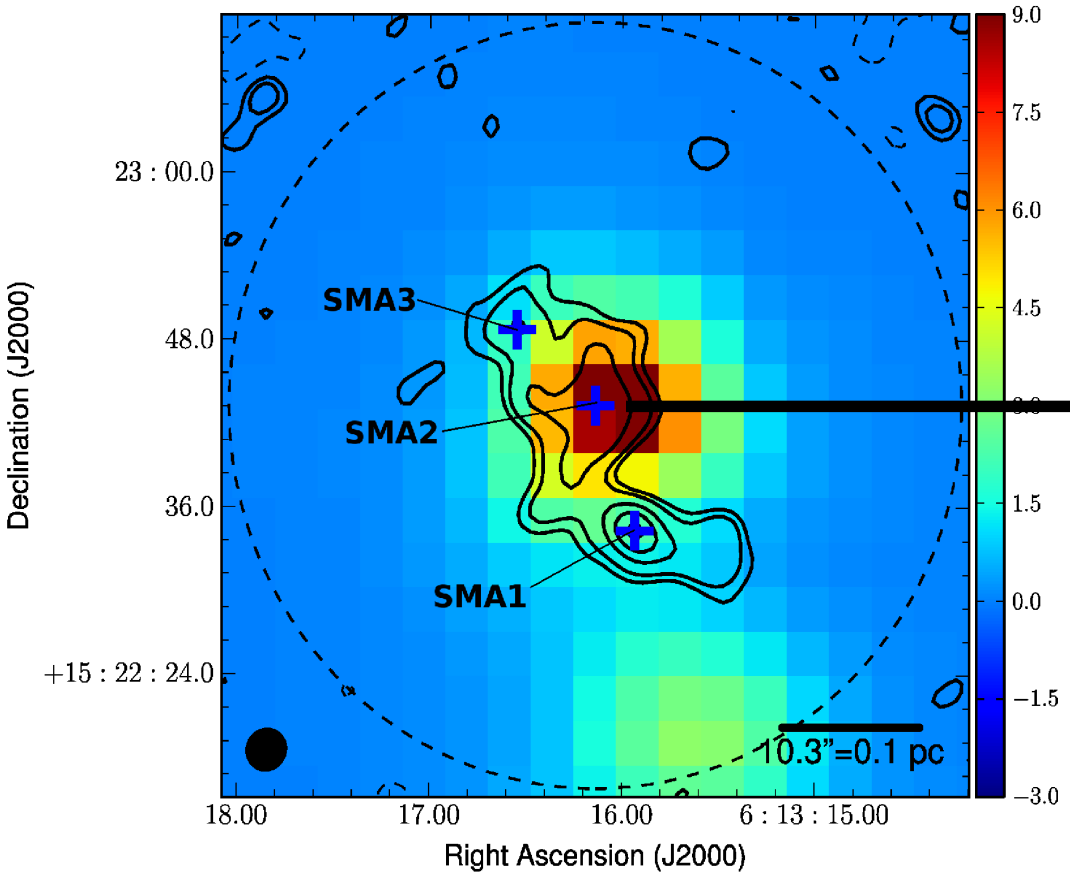
SMA- G203.3166 / NGC 2264-C



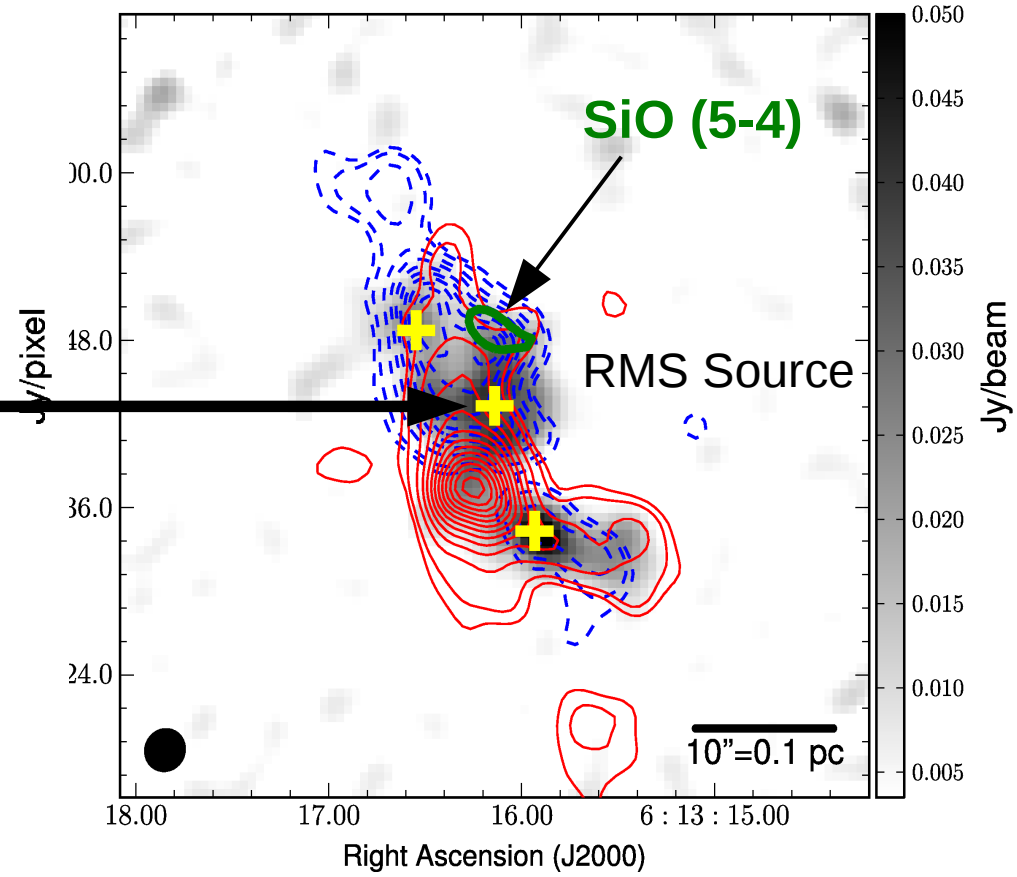
- Outflow sources molecular line weak
- No 70 or 24 micron counterpart

G194.9349
SiO (8-7) Non-Detection

Black contours = 1.3mm continuum
Colourscale = Herschel 70 micron



CO 2-1



- 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.

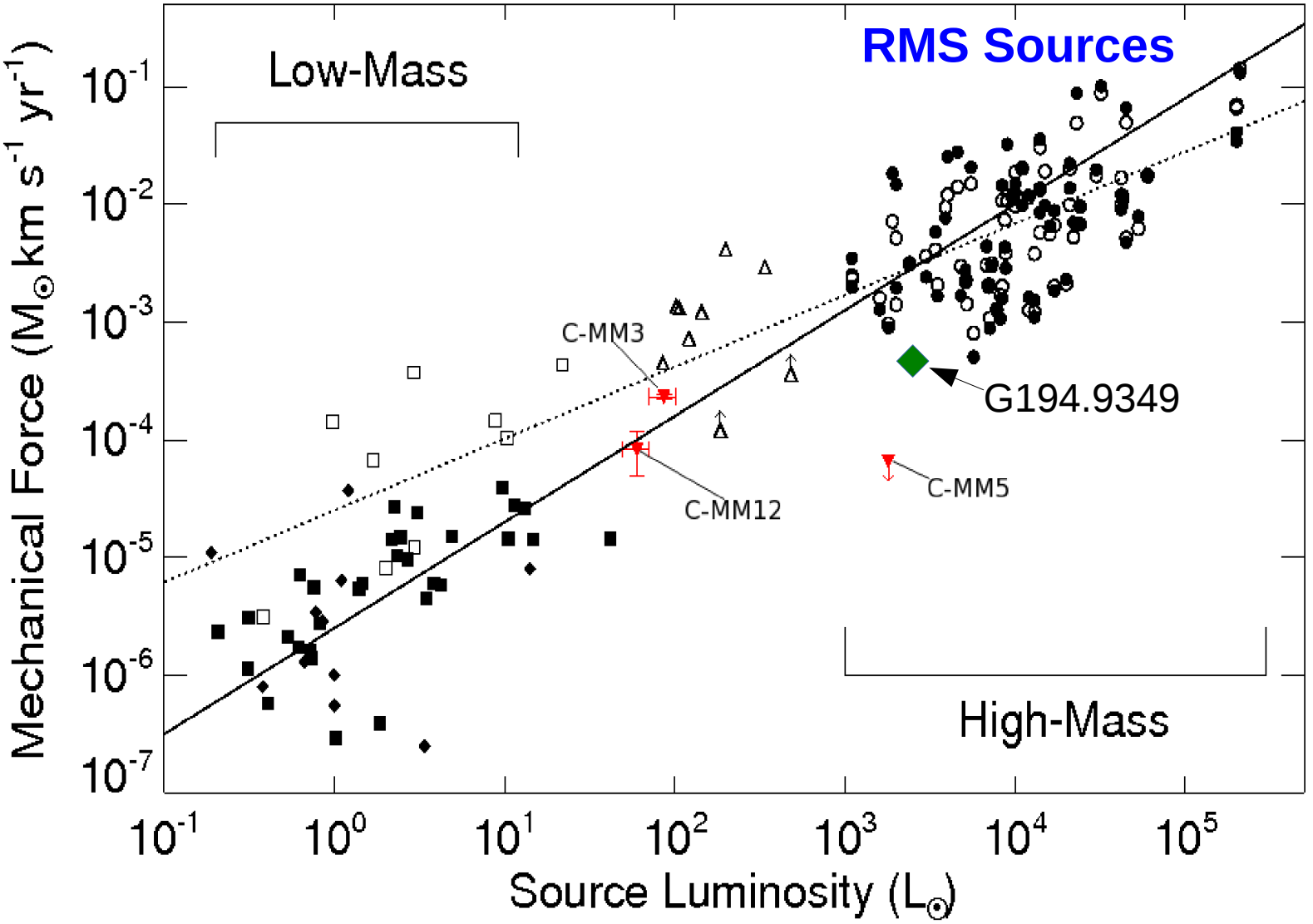
- Many of the regions in the JCMT survey (resolution ~15”) indicate an offset between the SiO emission and the RMS source
- Green bank would allow comparative spatial resolution to Herschel 70micron - allow for the youngest sources in regions to be identified.

- 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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