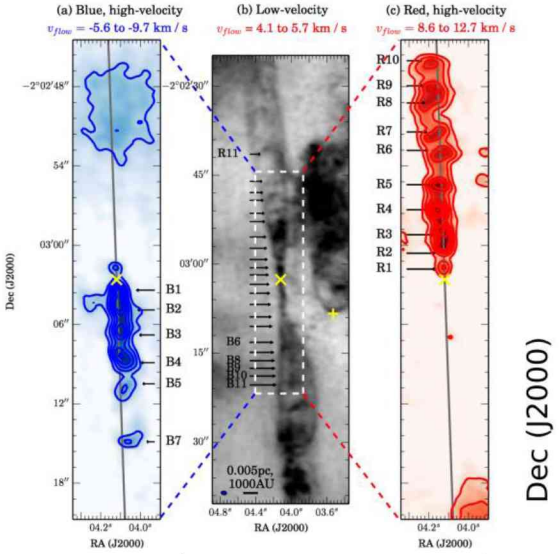
# Characterising the Impact of Jets and Outflows in the High Mass Regime with NOEMA

**Nichol Cunningham, IRAM**

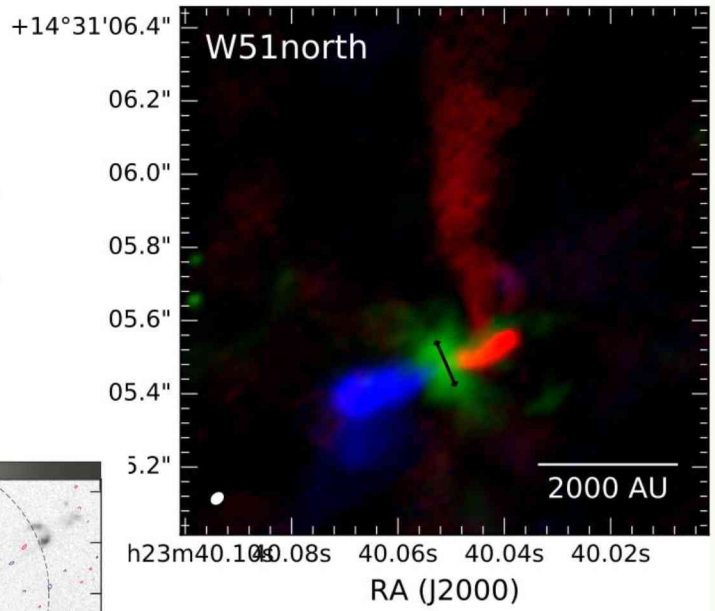
**S. Lumsden (Leeds), L. Maud (ESO), T. Moore (Liverpool), S. Purser (DIAS)**

**York September 18th 2019**

# Jets and Outflows

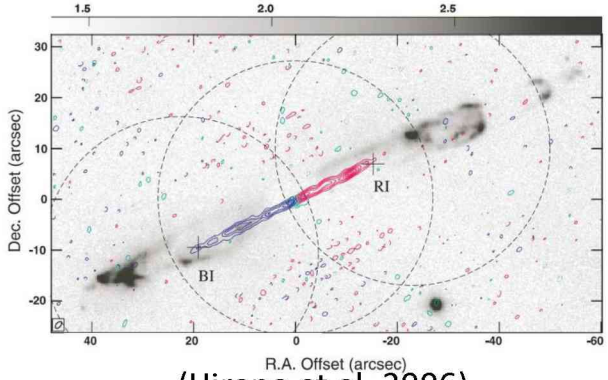



(Plunkett et al. 2015)

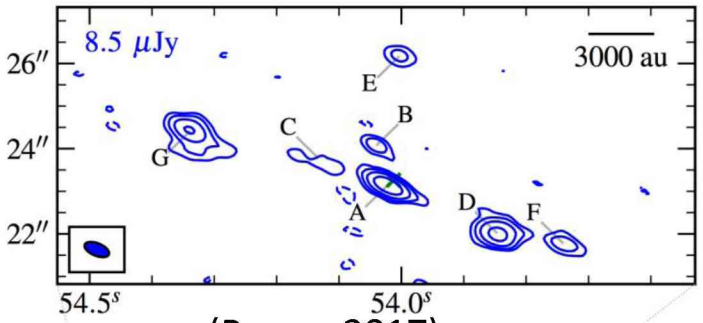



(Goddi et al. 2018)

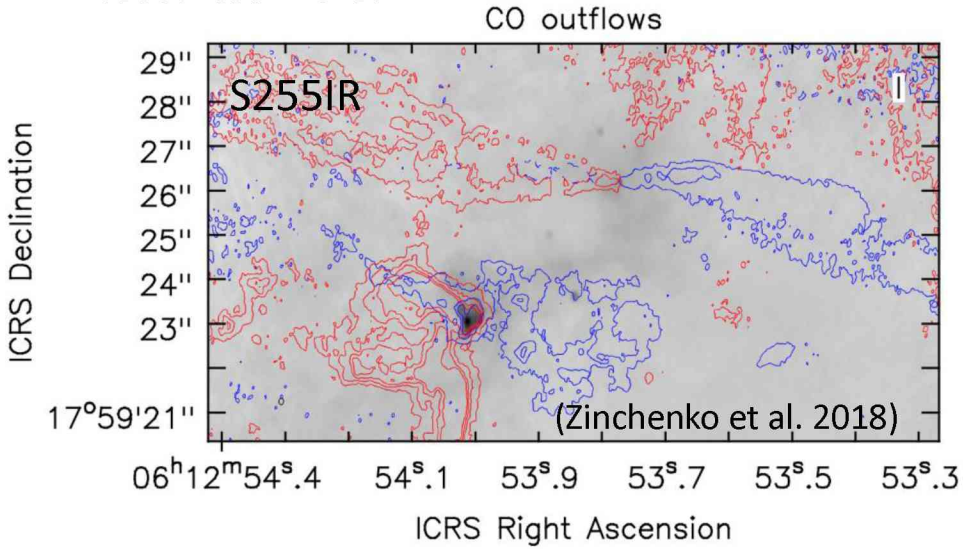
- Outflows are observed across all mass/luminosity ranges.
- A common link between outflow and accretion.
- Outflows are observationally more accessible to probe than small scale disks.
- Are outflows in the low and high mass regime driven by the same mechanisms?




(Hirano et al. 2006)

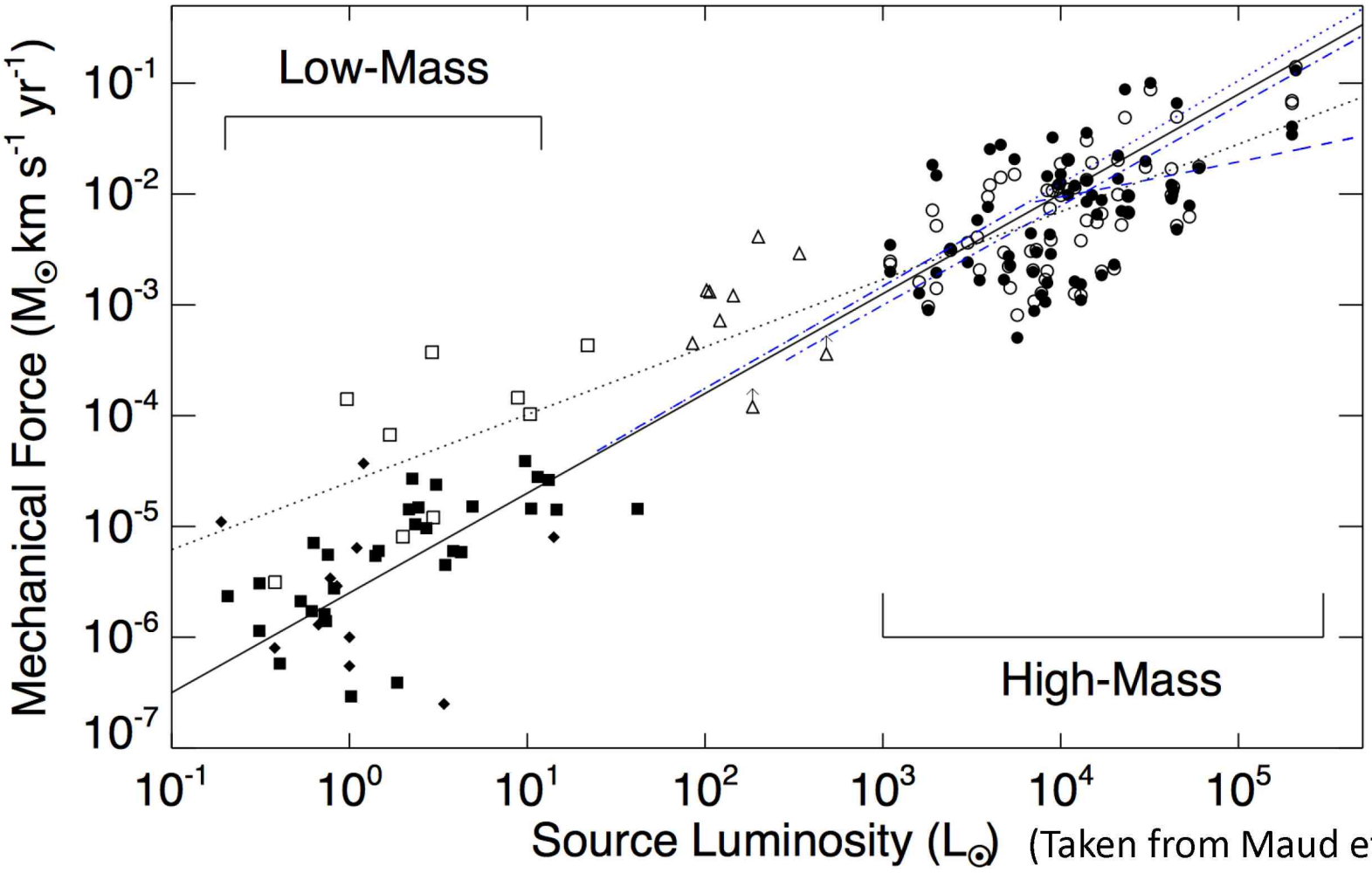



(Purser 2017)




(Zinchenko et al. 2018)

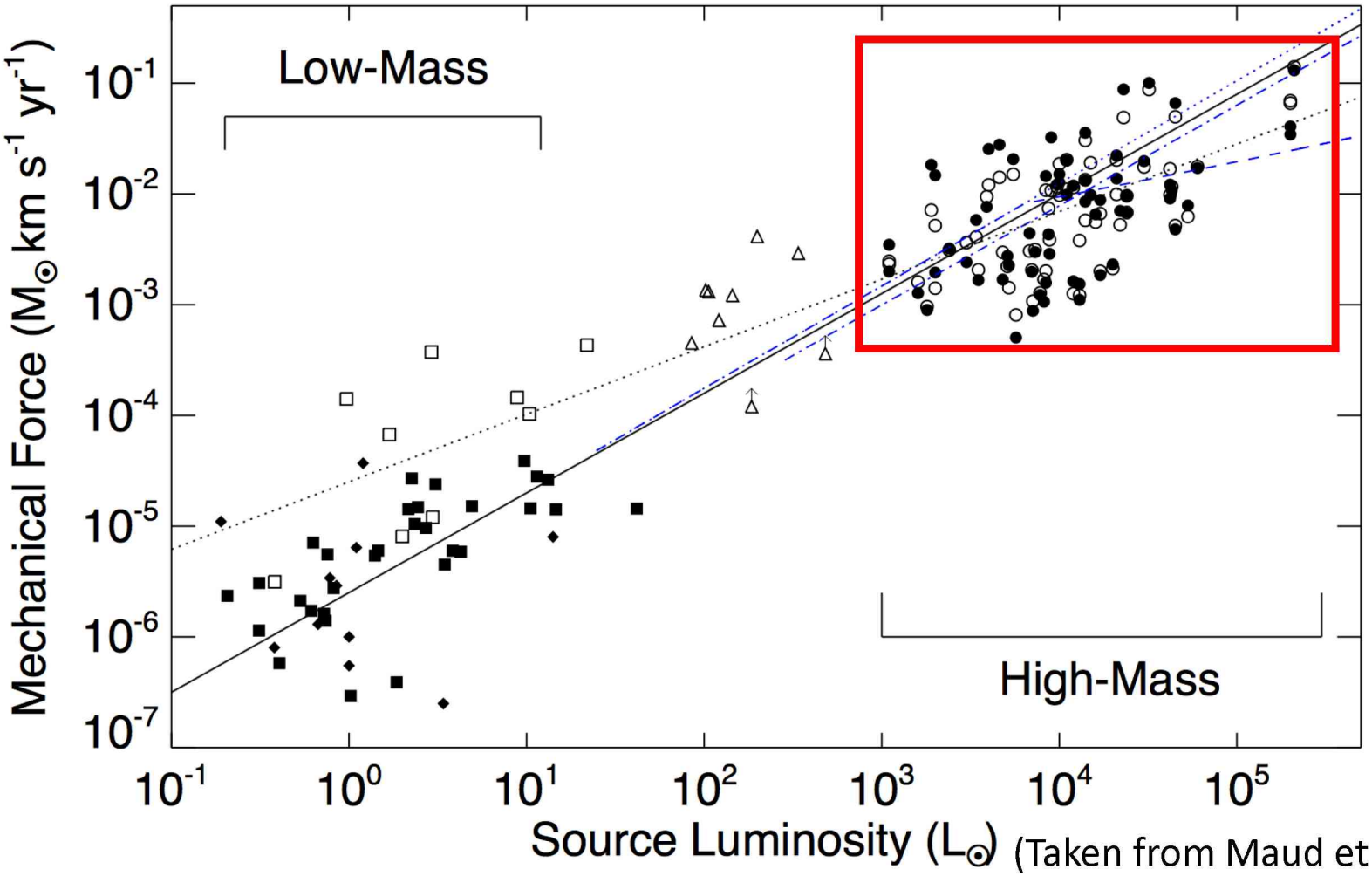
# Outflow Properties with Luminosity




(Taken from Maud et al. 2015b)

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

# Outflow Properties with Luminosity

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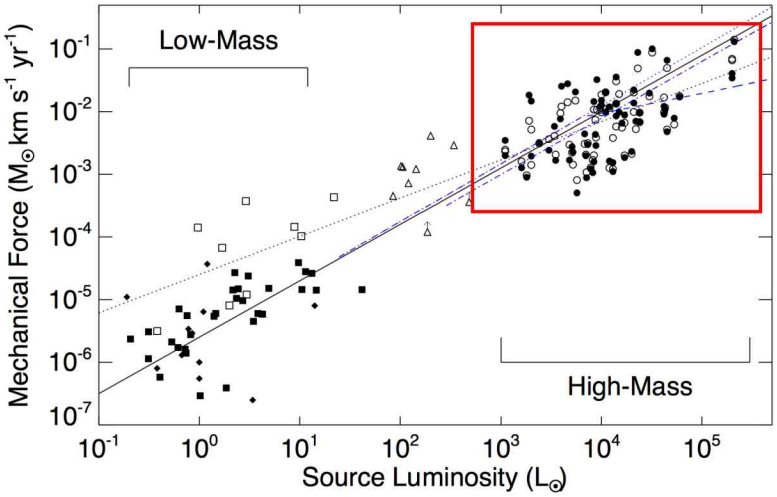
# The Initial Sample

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

- 100 RMS sources observed in 12CO (3-2) (Maud et al. 2015b)
- 66% have an outflow detected in CO.



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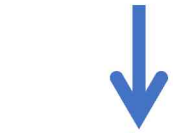

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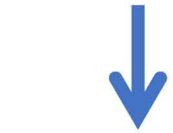

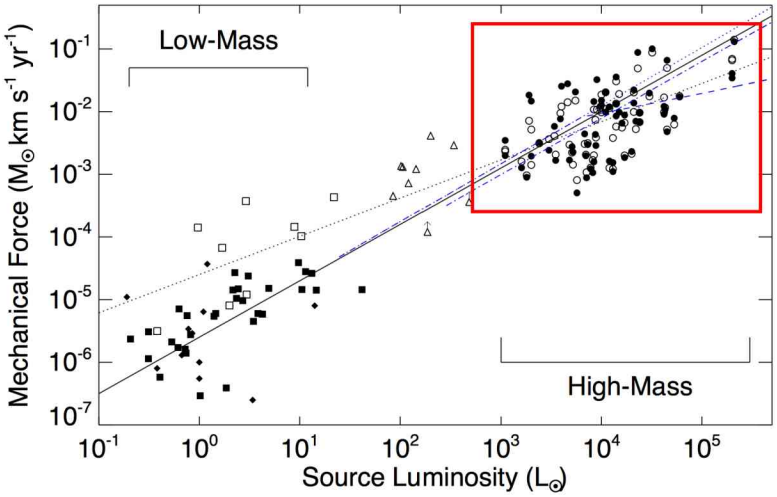


- 31 sources observed with the JCMT (~14" resolution) (Cunningham et al. 2018) for SiO (8-7), HCO+(4-3) and H13CO+(4-3) (~350-GHz).
- SiO "active" outflow tracer. HCO+/H13CO+ infall tracers
- In the low mass regime SiO is more prominent in the Class 0 sources.
- SiO was found towards younger regions and associated with faster more powerful outflows.

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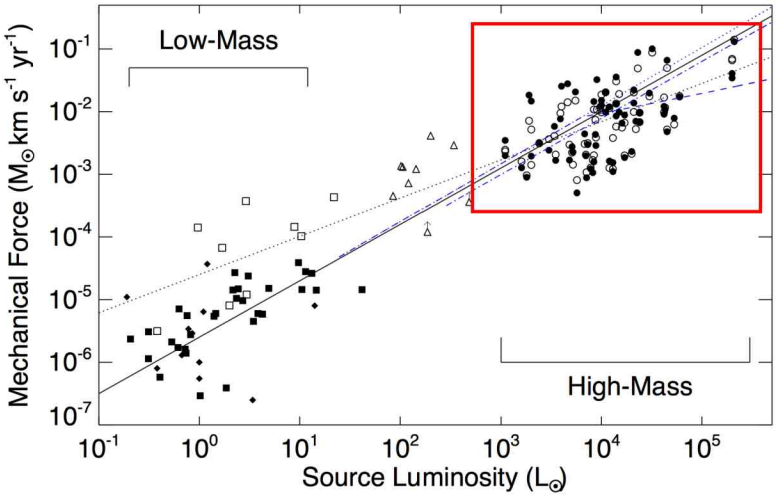


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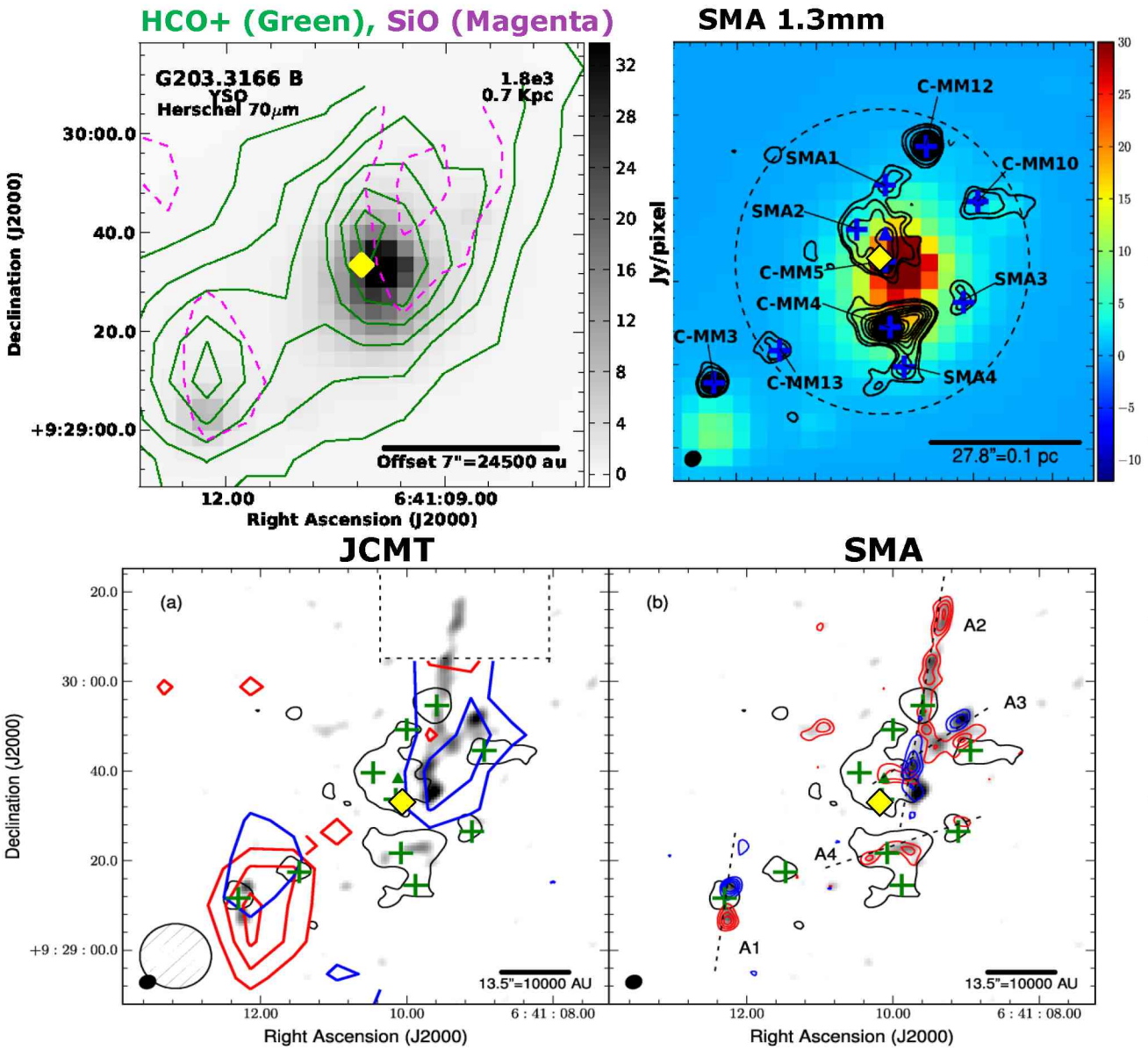
- Additional follow-up observations at 1.3mm (230-GHz) with the SMA (3" resolution)
- G203.3166/NGC 2264-C (Cunningham et al. 2016)
- SiO (5-4), CO (2-1) – SiO found towards young, intermediate mass stars in the cluster

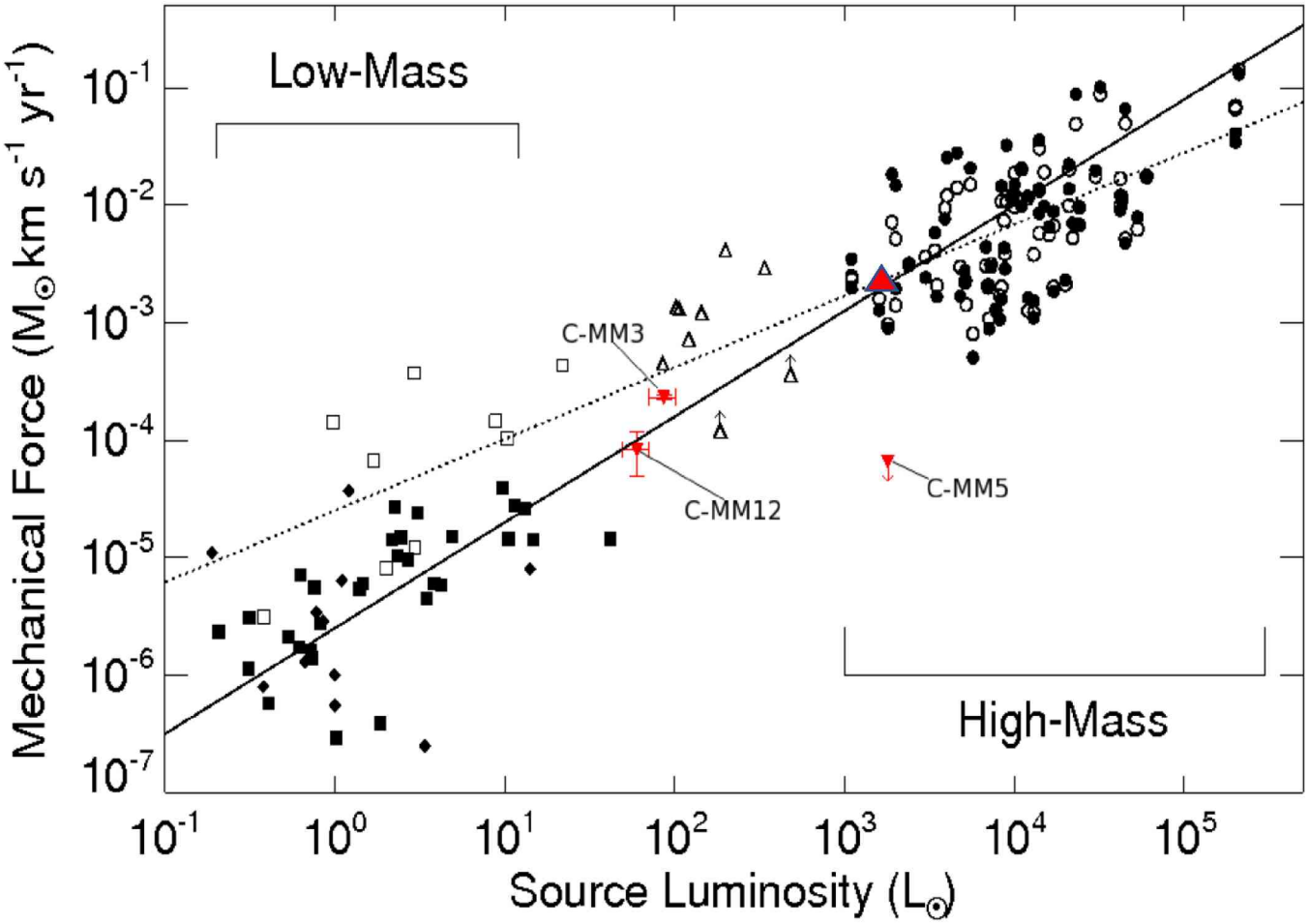
# What is Driving the Outflow(s) – NGC 2264-C




- At low resolution, it is difficult to associate the outflow with the driving core.
- At high resolution, two well defined bipolar outflows are identified.
- Which are driven by the young, compact, intermediate mass sources.
- The IR-bright RMS source does not appear to be driving an outflow.

(Cunningham et al. 2016, 2018)

# What is Driving the Outflows




Adapted from Maud et al. (2015)

Bontemps 1996 low mass Class 0 – open squares, Class I – closed squares
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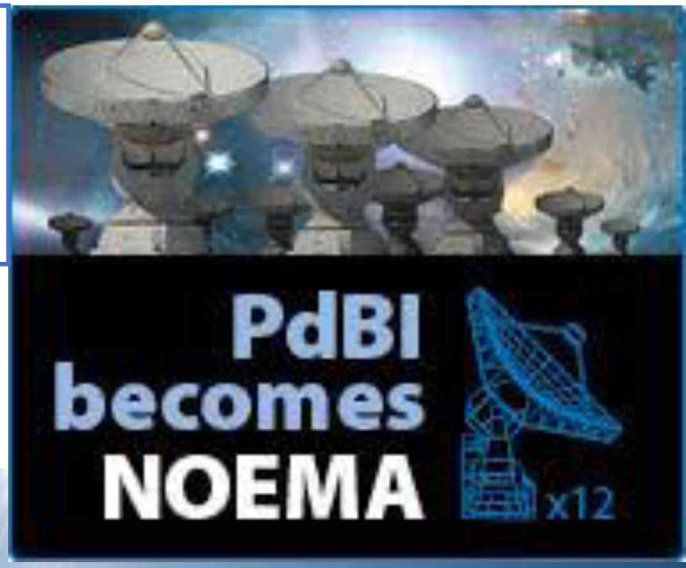
# NOEMA – IRAM (Plateau de Bure)

## (NOrthern Extended Millimeter Array)

Antenna: 10 → 11(Next year) → 12
Bandwidth: PolyFiX upgrade 32GHz –up to 62.5kHz resolution
Frequency coverage: 70.4-119, 127-182, 196-276 GHz
Resolution: 0.5”- 4”

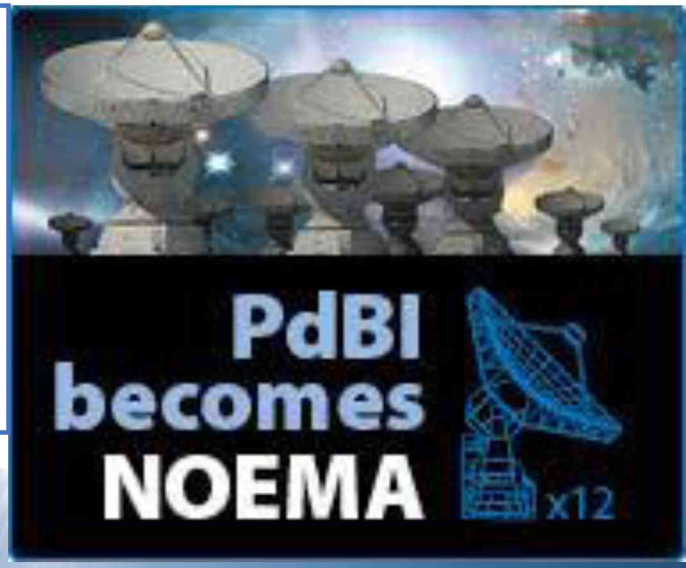



# NOEMA – IRAM (Plateau de Bure)

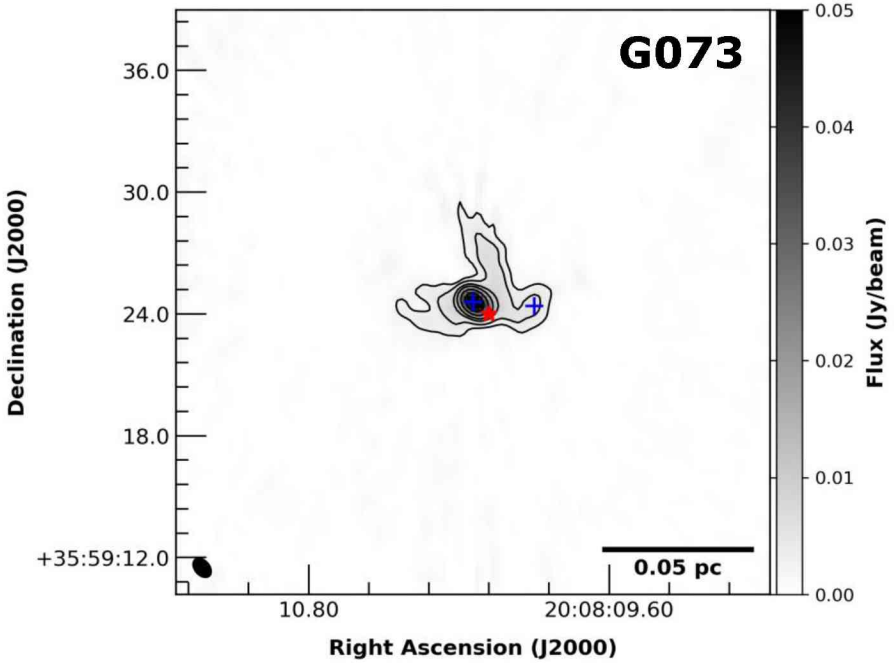
## (NOrthern Extended Millimeter Array)

Aim: Characterise core and outflow properties in a homogeneous manner.
Observations: 3 RMS sources, mosaics at 1.3mm covering SiO, 12CO- (~1")
Followed with 30m maps for short spacing (~9").

Sources: Similar distance 1.4kpc, previously observed CO outflows, similar luminosity and mass properties, but different outflow properties.
G073.0633- IRAS 20062+3550 / Mol116
G078.1224- IRAS 20126+4104
G079.1272- IRAS 20216+4107

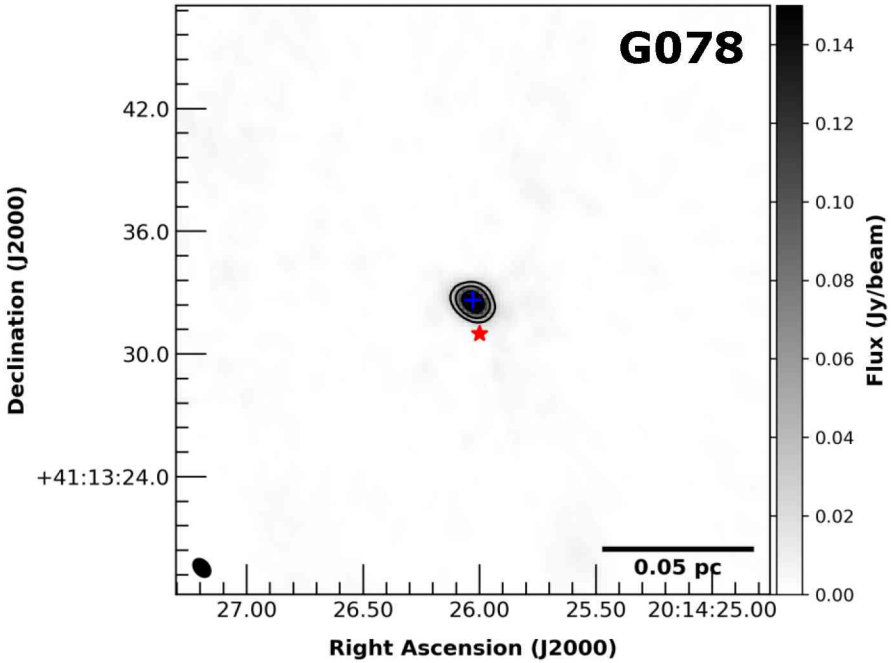


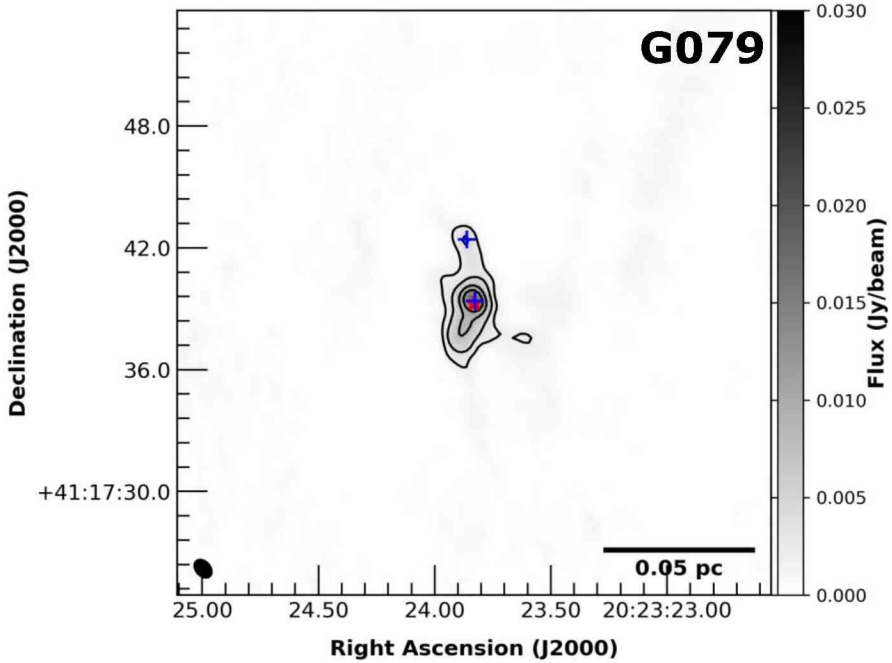

# NOEMA 1.3mm continuum



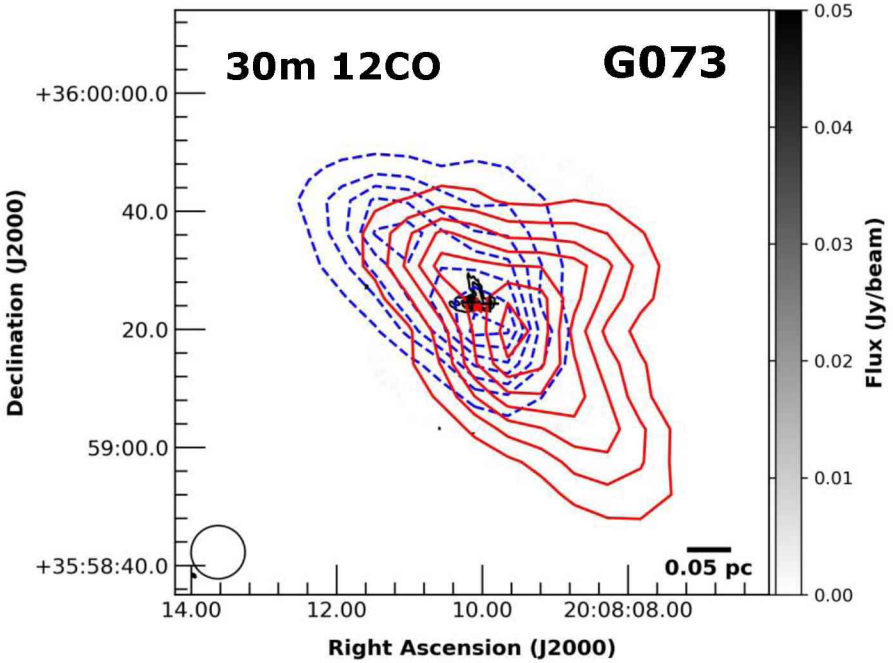

- Mass:
- G078 15 Msun
- G073 4 Msun
- G079 2 Msun
- 0.1 Msun limit

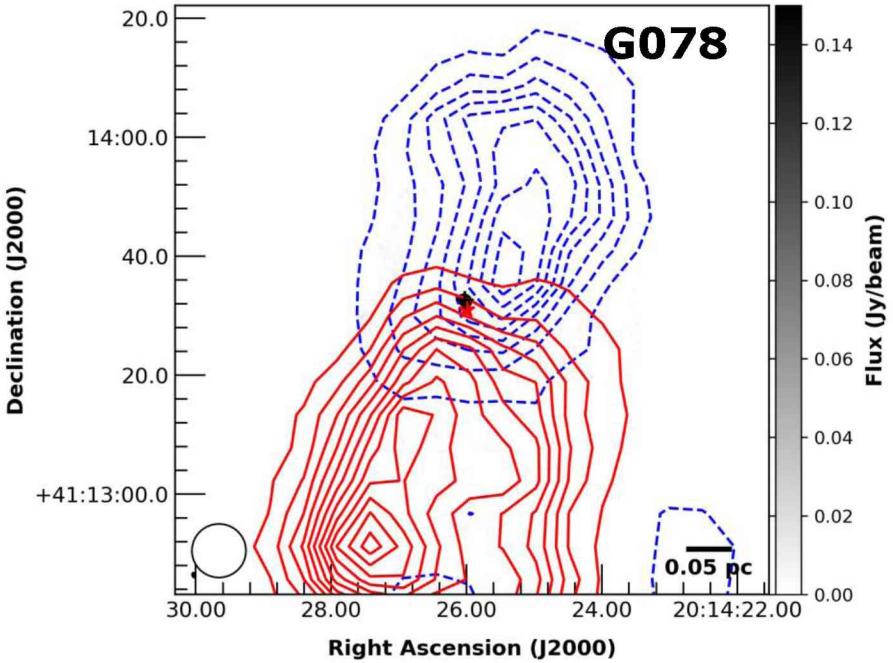
- One dominant core in each source. Associated with the RMS, IR-Bright sources.



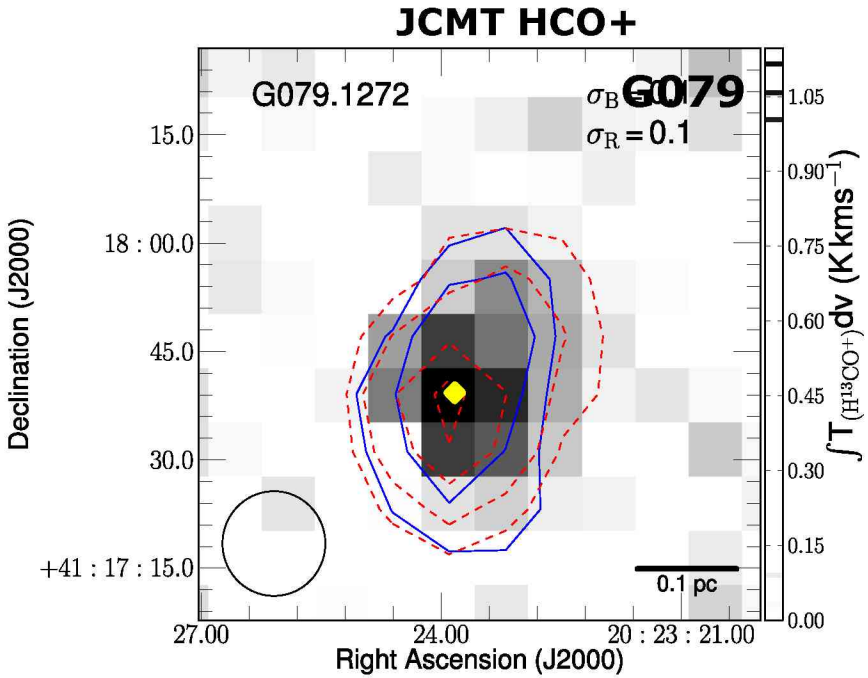



# 30m 12CO Blue-/Red-shifted maps

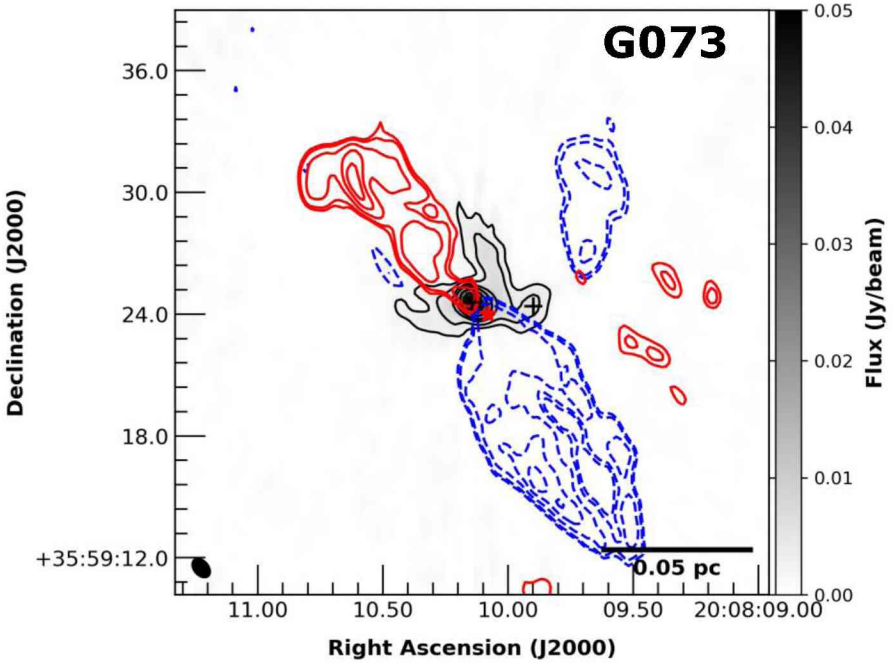


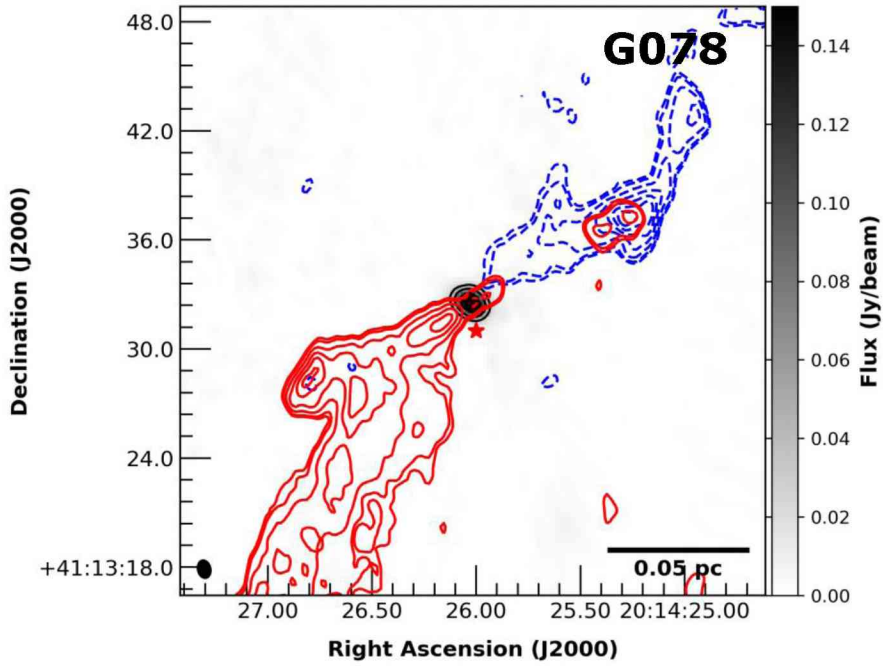

- 30m maps of 12CO for G073, G078 (G079 waiting to be re-scheduled)
- 2'x2' maps, ~0.8x0.8pc
- For G073, G078 red-/blue-shifted lobes offset on the sky.
- Appear to be one outflow associated with the RMS source.

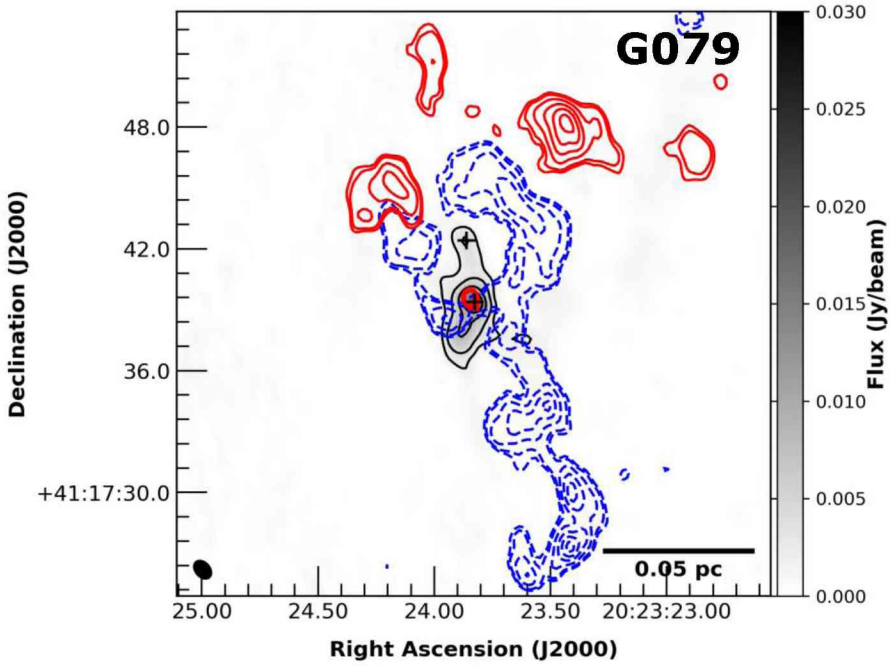


# NOEMA 12CO Moment maps

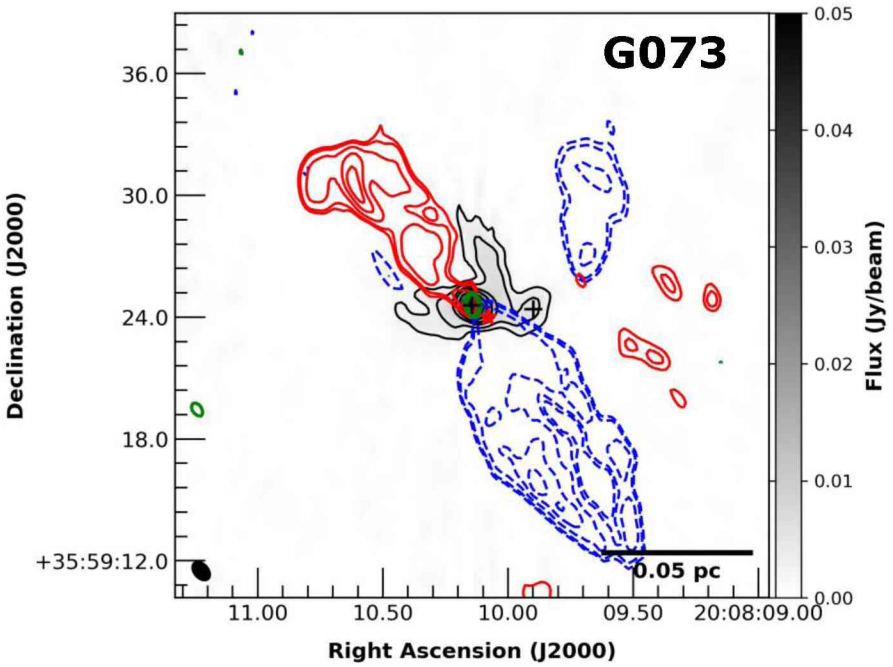



- Higher resolution ~1" 12CO NOEMA maps
- For G073, G078 bipolar outflow, centered on compact core, RMS source.
- G073 up to 30km/s
- G078 up to 50km/s
- Differences in the morphology of the outflows, and outflow properties.



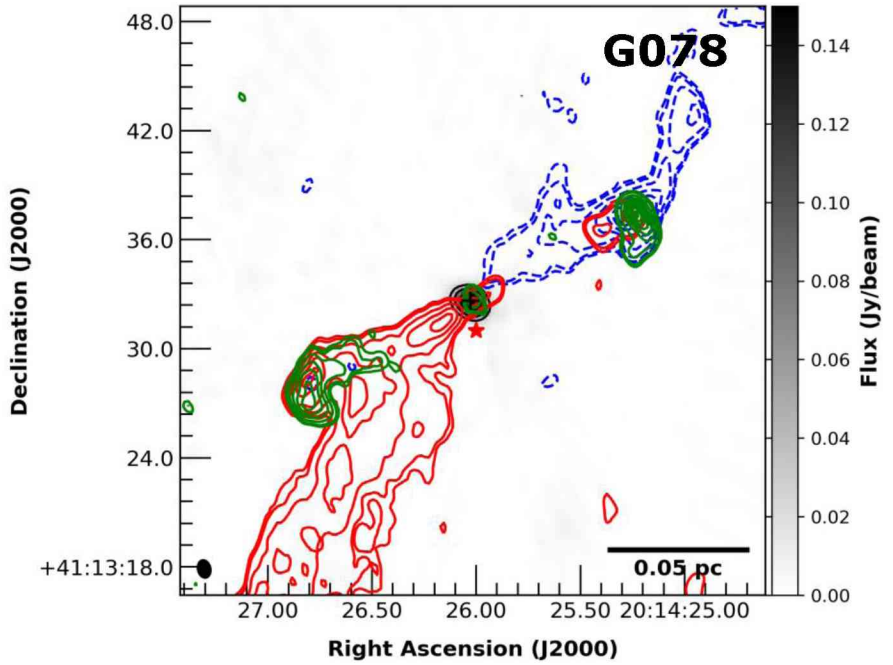



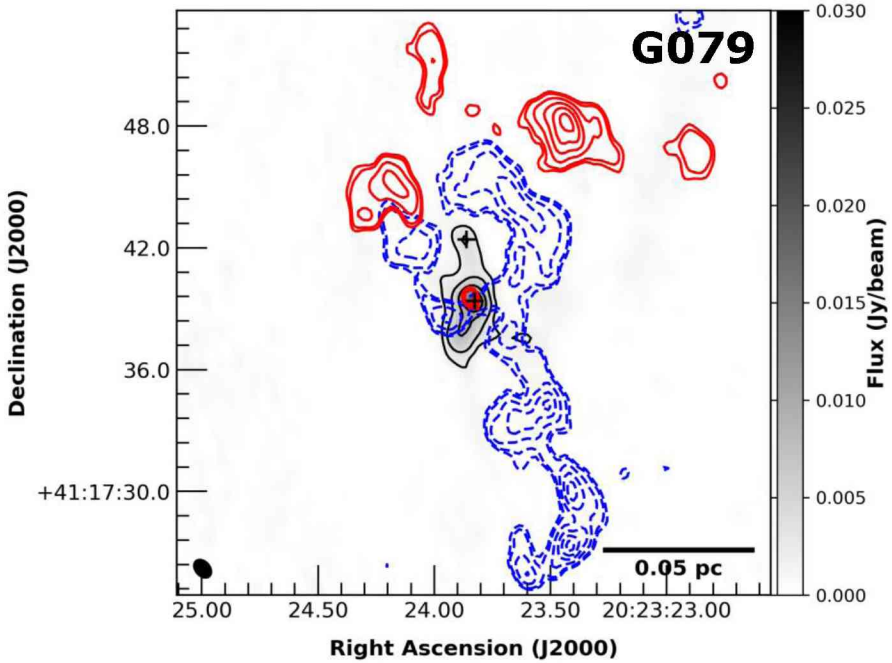
# NOEMA 12CO+SiO Moment maps



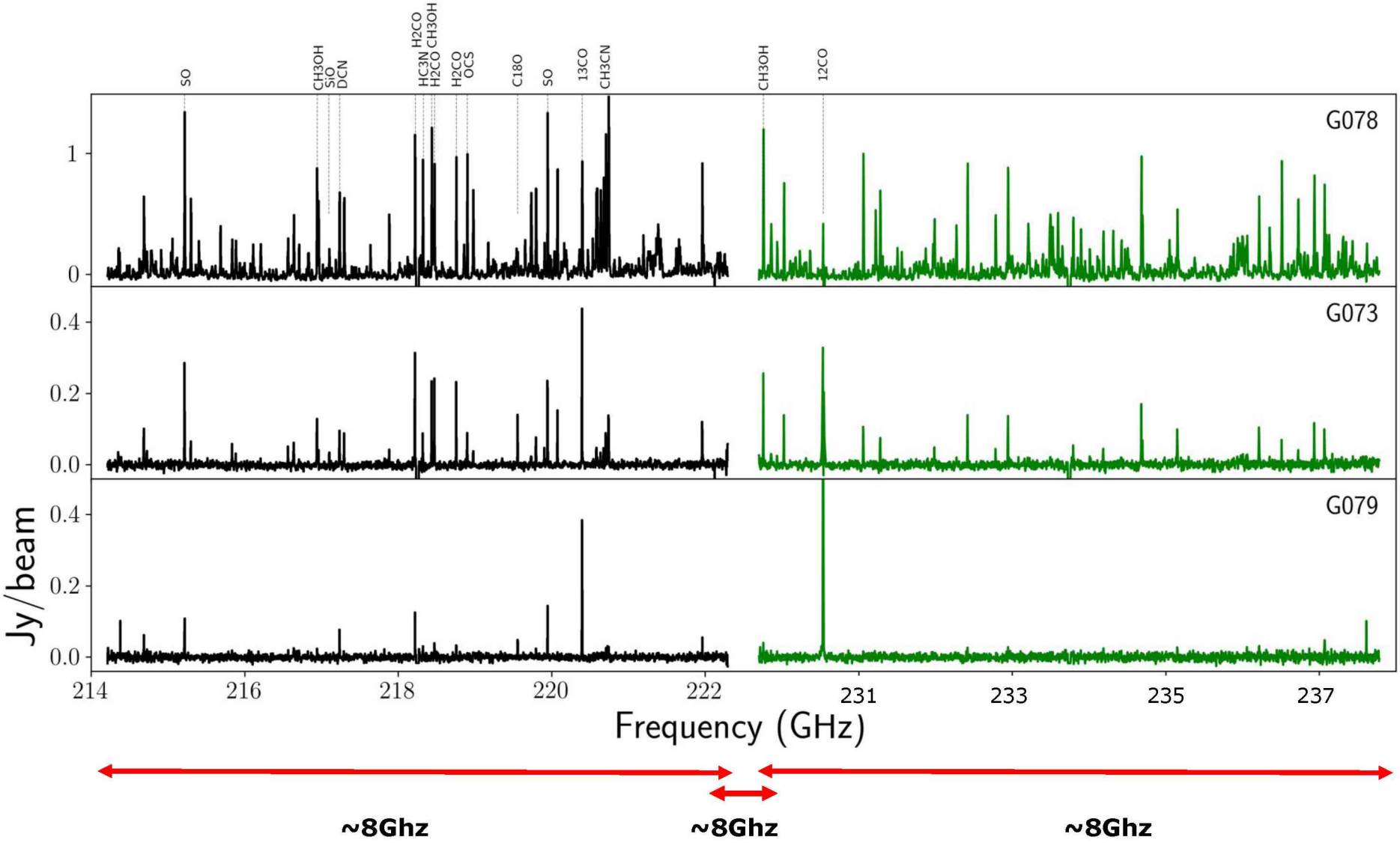

- SiO Integrated intensity NOEMA maps **(Green contours).**
- SiO observed towards G073, G078. Non-detection towards G079.

- Differences in the morphology of the SiO outflows, and outflow properties.
- More powerful outflow may exist for relatively small timescales.



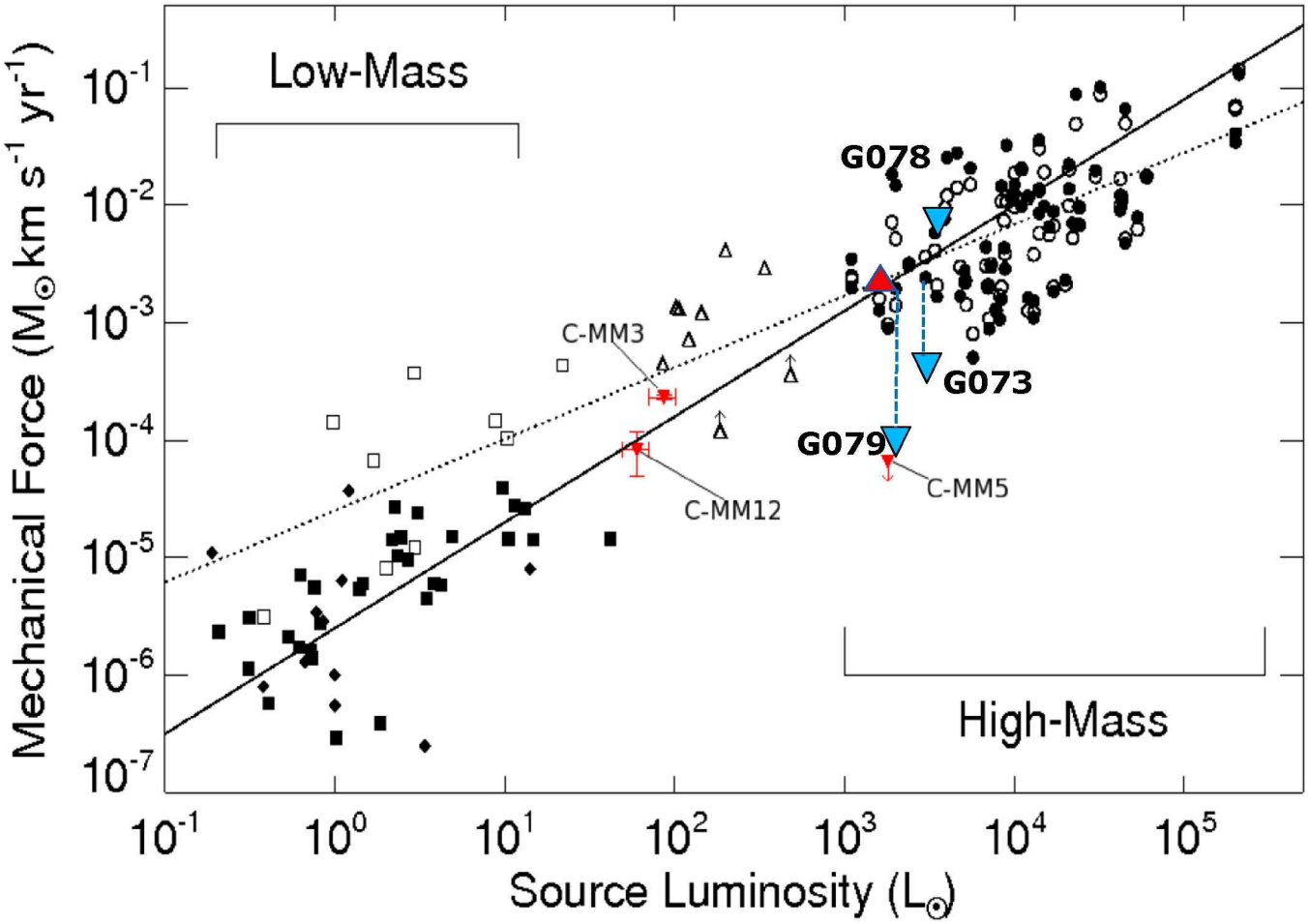



# PolyFiX Spectra




~8Ghz ~8Ghz ~8Ghz

# What is Driving the Outflows

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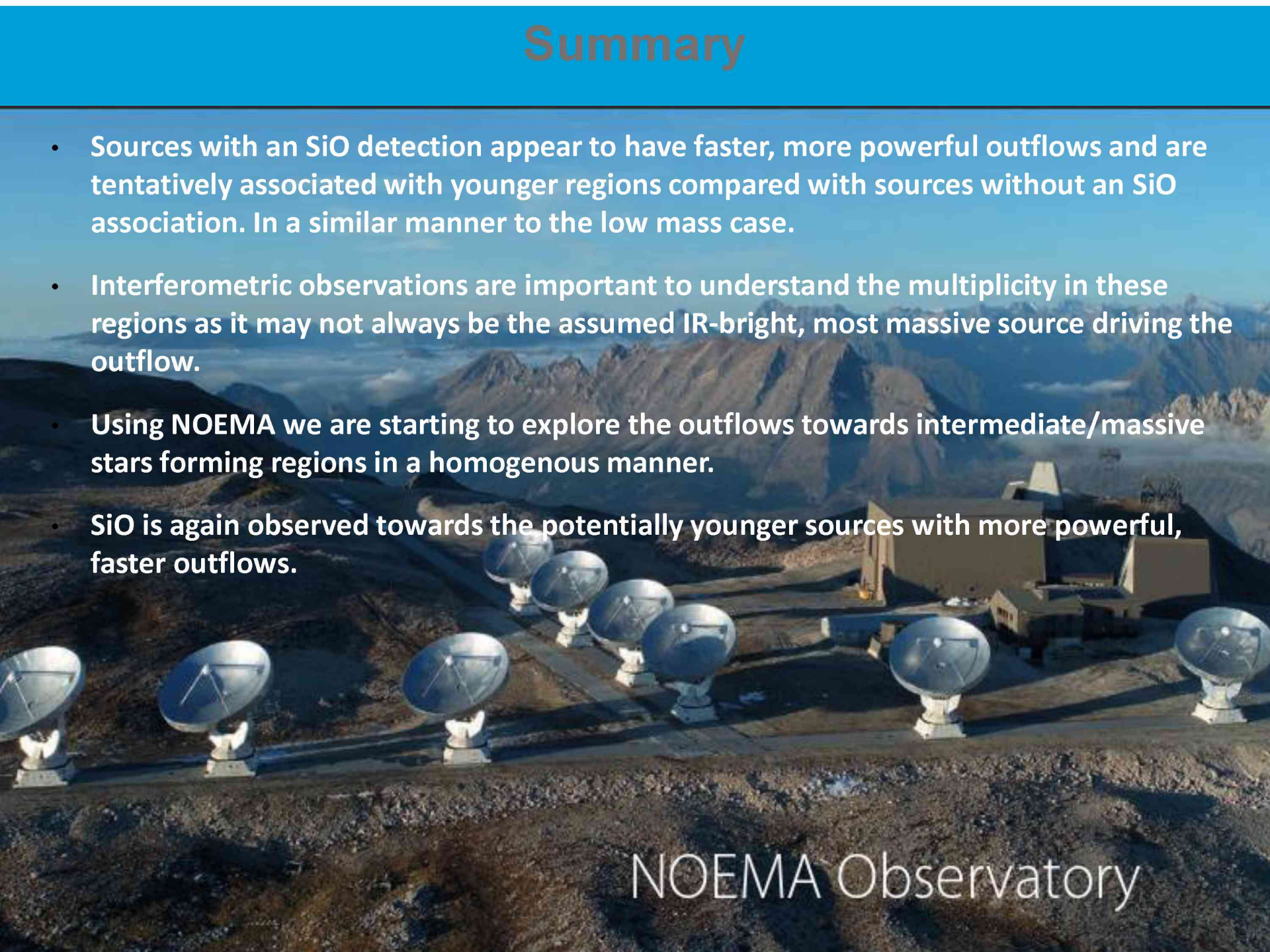
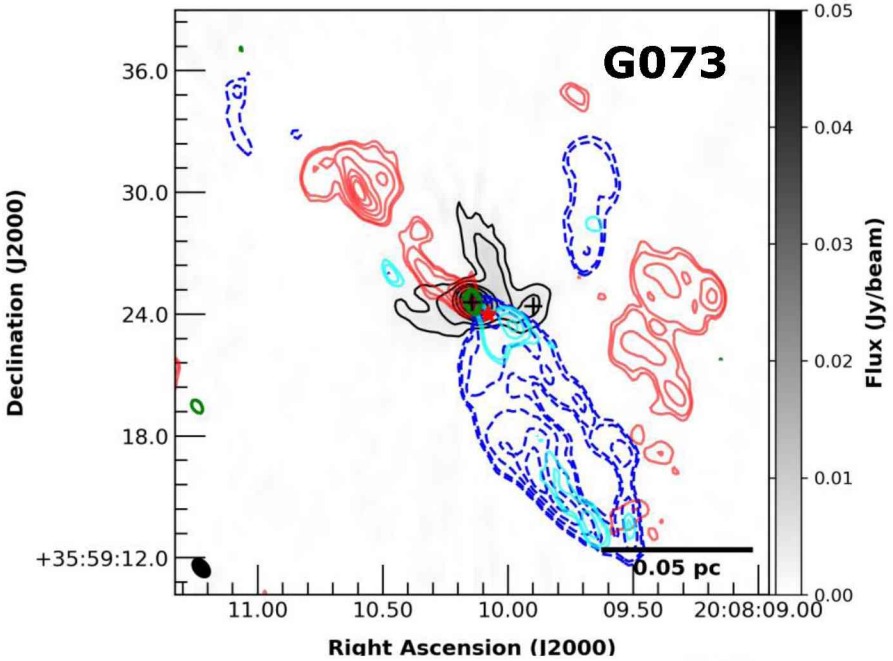
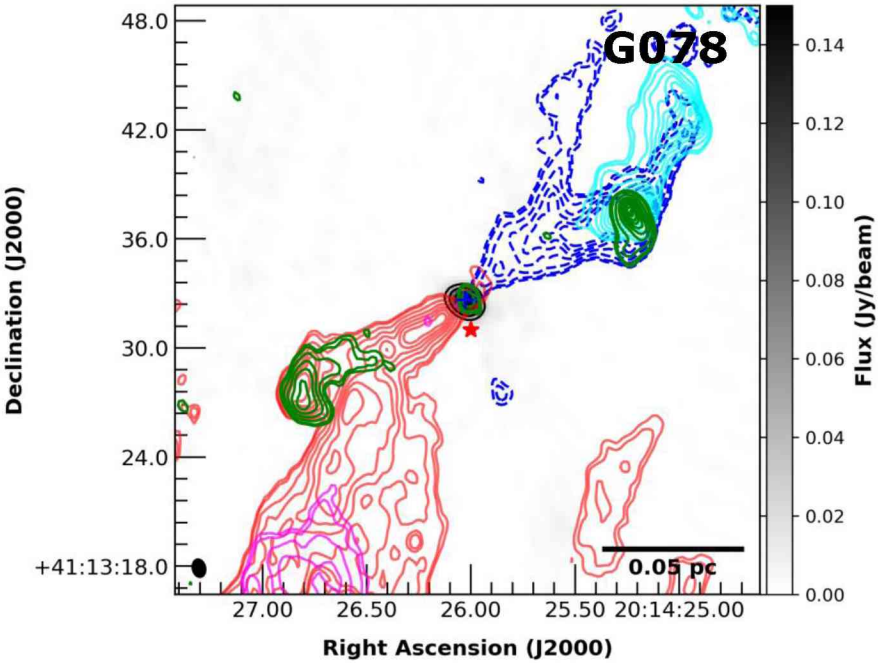
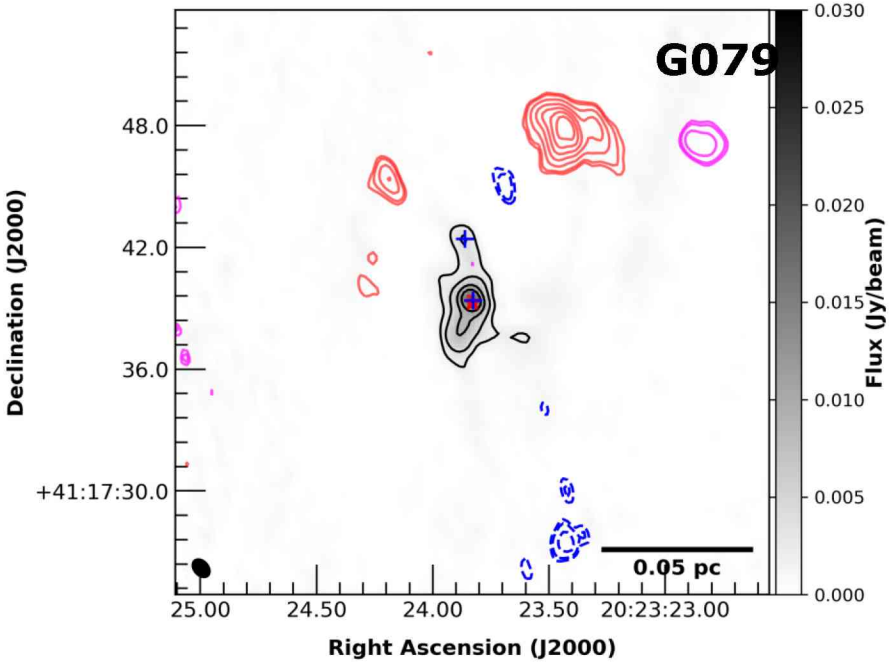
# Summary

- Sources with an SiO detection appear to have faster, more powerful outflows and are tentatively associated with younger regions compared with sources without an SiO association. In a similar manner to the low mass case.
- Interferometric observations are important to understand the multiplicity in these regions as it may not always be the assumed IR-bright, most massive source driving the outflow.
- Using NOEMA we are starting to explore the outflows towards intermediate/massive stars forming regions in a homogenous manner.
- SiO is again observed towards the potentially younger sources with more powerful, faster outflows.

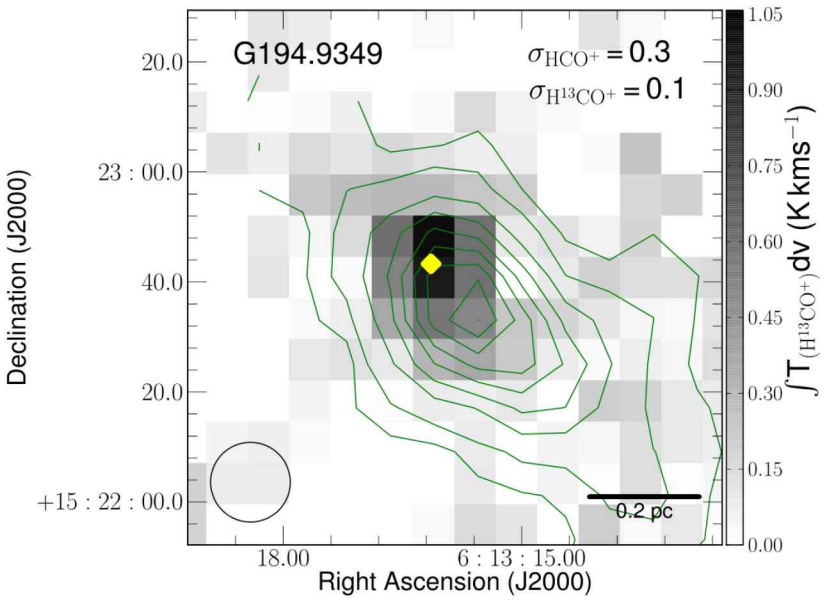


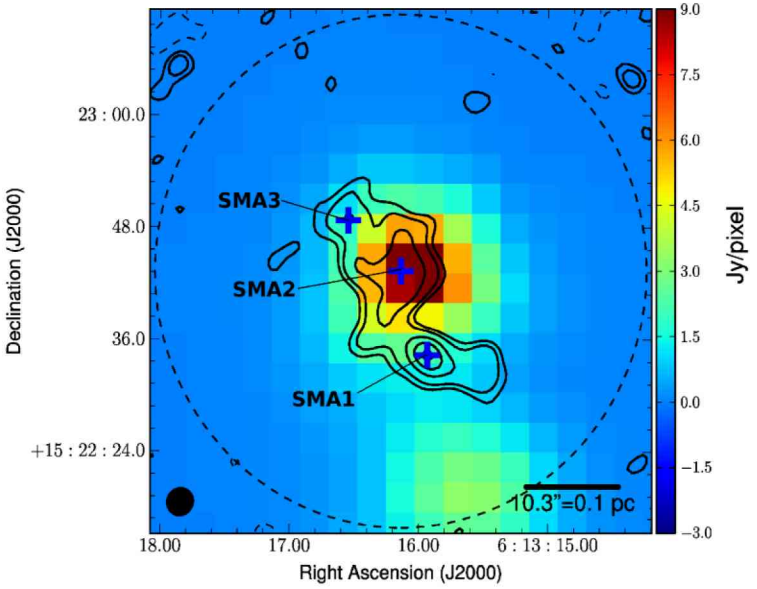

G073
Declination (J2000)
Right Ascension (J2000)
Flux (Jy/beam)
0.05 pc
36.0
30.0
24.0
18.0
+35:59:12.0
11.00
10.50
10.00
09.50
20:08:09.00
0.05
0.04
0.03
0.02
0.01
0.00

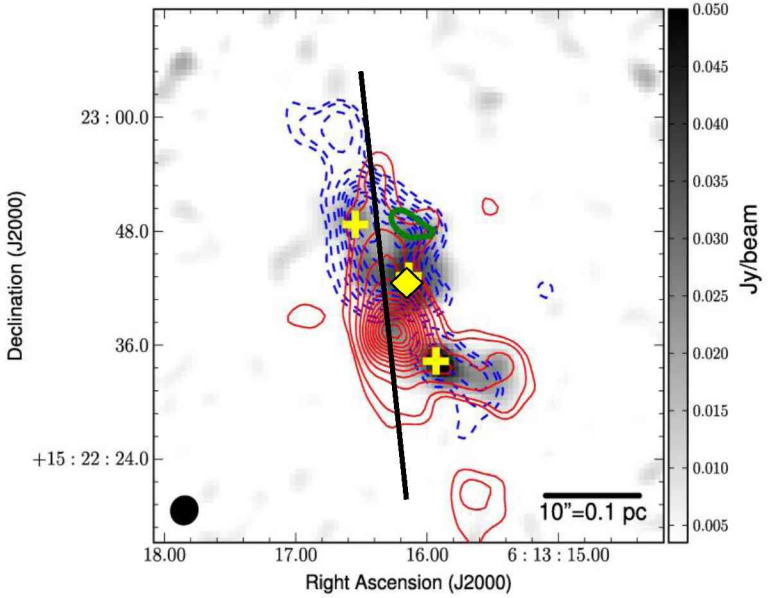

G078
Declination (J2000)
Right Ascension (J2000)
Flux (Jy/beam)
0.05 pc
48.0
42.0
36.0
30.0
24.0
+41:13:18.0
27.00
26.50
26.00
25.50
20:14:25.00
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00


G079
Declination (J2000)
Right Ascension (J2000)
Flux (Jy/beam)
0.05 pc
48.0
42.0
36.0
+41:17:30.0
25.00
24.50
24.00
23.50
20:23:23.00
0.030
0.025
0.020
0.015
0.010
0.005
0.000

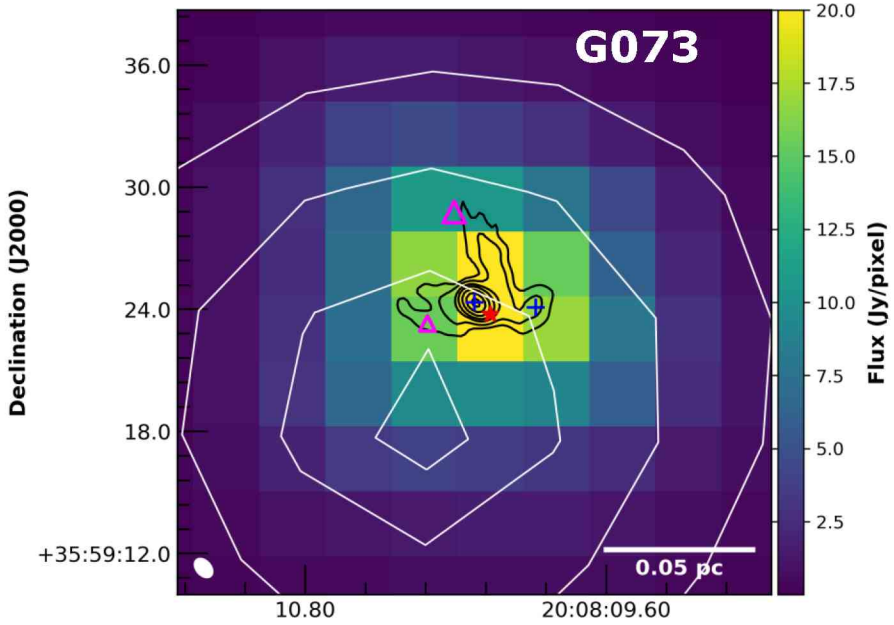
# What is Driving the Outflow(s) – G194.9349

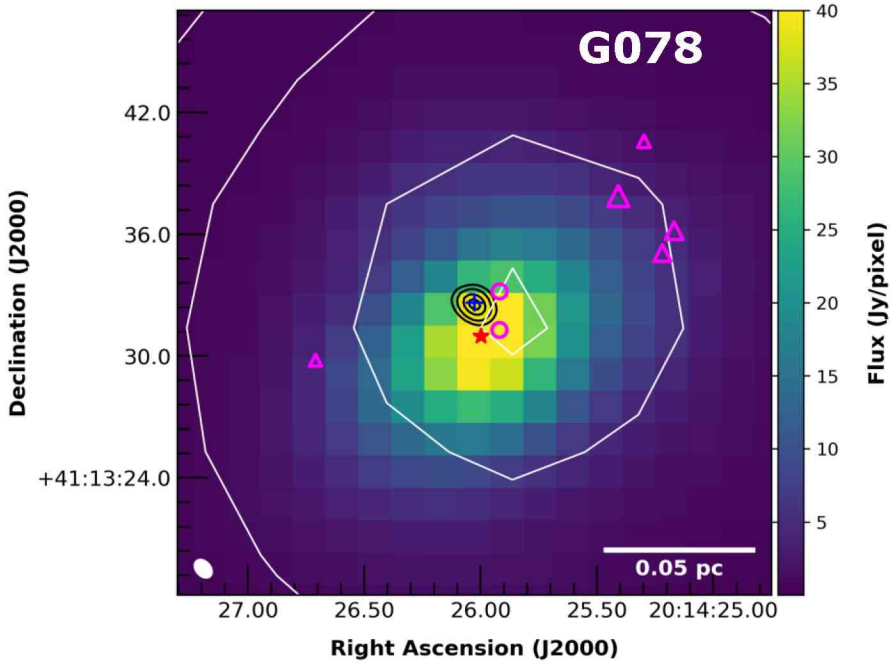


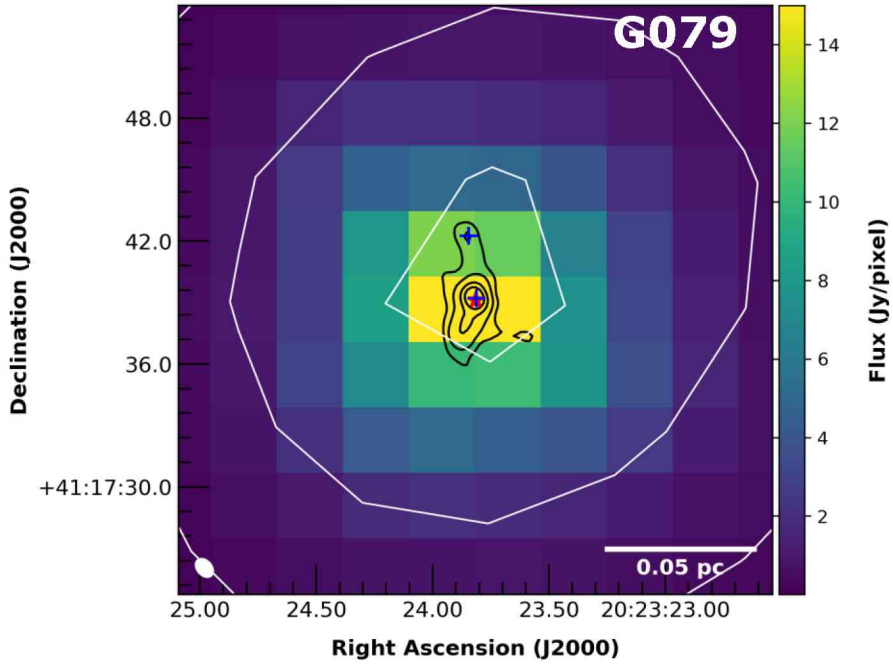




- No SiO observed in the single dish data
- At high resolution, one obvious bipolar outflow appears to be driven by the RMS source.
- Both outflow and source found to be older.


G073
36.0
30.0
24.0
18.0
+35:59:12.0
10.80
20:08:09.60
Declination (J2000)
0.05 pc
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
Flux (Jy/pixel)


G078
42.0
36.0
30.0
+41:13:24.0
27.00
26.50
26.00
25.50
20:14:25.00
Declination (J2000)
Right Ascension (J2000)
0.05 pc
40
35
30
25
20
15
10
5
Flux (Jy/pixel)


G079
48.0
42.0
36.0
+41:17:30.0
25.00
24.50
24.00
23.50
20:23:23.00
Declination (J2000)
Right Ascension (J2000)
0.05 pc
14
12
10
8
6
4
2
Flux (Jy/pixel)