# A MINIMUM COLUMN DENSITY FOR O-B STAR FORMATION: AN OBSERVATIONAL TEST

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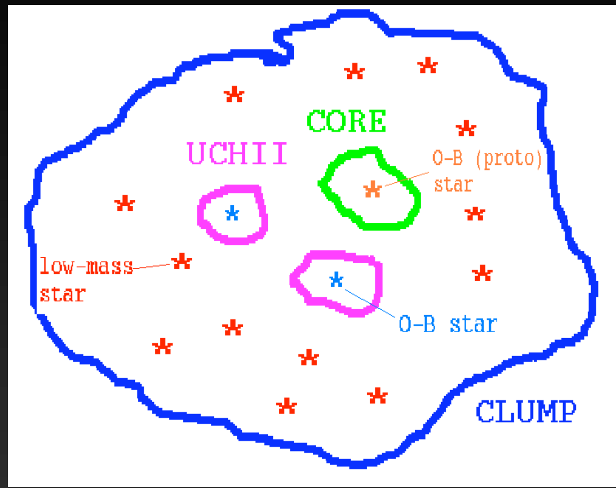
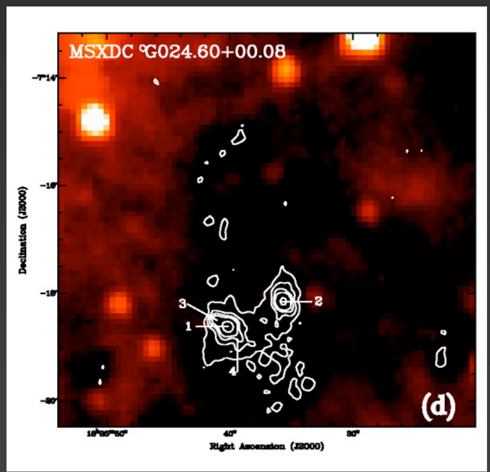
# IR-loud vs IR-dark high-mass molecular clumps

High-mass molecular clumps:
The **sites of cluster formation**

Size: 0.5 - 1 pc
Density: $10^4$ - $10^6$ $cm^{-3}$
Mass: $10^2$ - $10^4$ $M_{sun}$



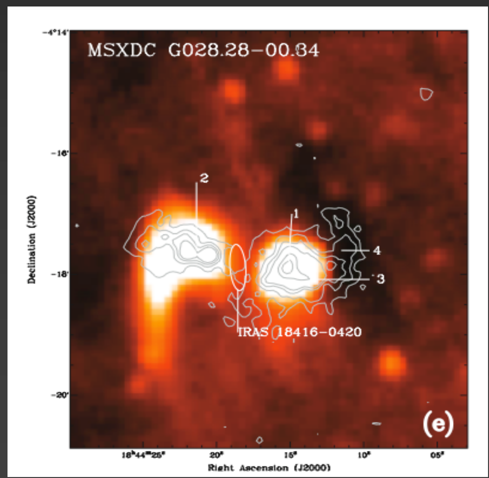

Infrared Dark Clumps




T = 10 - 20 K

time →

Infrared Loud Clumps




T = 30 - 50 K

*Rathborne et al. (2006):*

*Image: 8 μm MSX*
*Contours: 1.2 mm*

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constellation

# Aims and sample selection

## General goals

- Compare the star formation activity of IR-dark clumps with that present in IR-loud clumps: **evolutionary trends?**

- Check observationally **Krumholtz & McKee's** result:

$\Sigma \sim 0.7$ g cm$^{-2}$ is the **minimum surface density** required for high-mass star formation (*2008, Nature, 451, 1082*)

## The sample

19 IR-dark clumps
29 IR-loud clumps

**48 SOURCES**

**Selection Criteria (from 1.2 mm surveys)**

$\delta > -10°$

$M > 100\ M_{sun}$: massive

d < 4 kpc: angular diameters in the range 1'-2'

# IRAM 30-m observations

## Molecular tracers used

**Optically thick:**

$HCO^+$(1-0) @ 89.2 GHz

HCN(1-0) @ 88.6 GHz

Blue asymmetric line profile: infall

Broad line wings: outflow

**Optically thin:**

$C^{18}O$(2-1) @ 219.6 GHz

To define ambient velocity

López-Sepulcre et al. 2010, A&A 517, A66

4-8 August 2008

On-The-Fly mapping: 1’ x 1’ maps

López-Sepulcre et al. (submitted to A&A)

**Molecular jet tracers:**

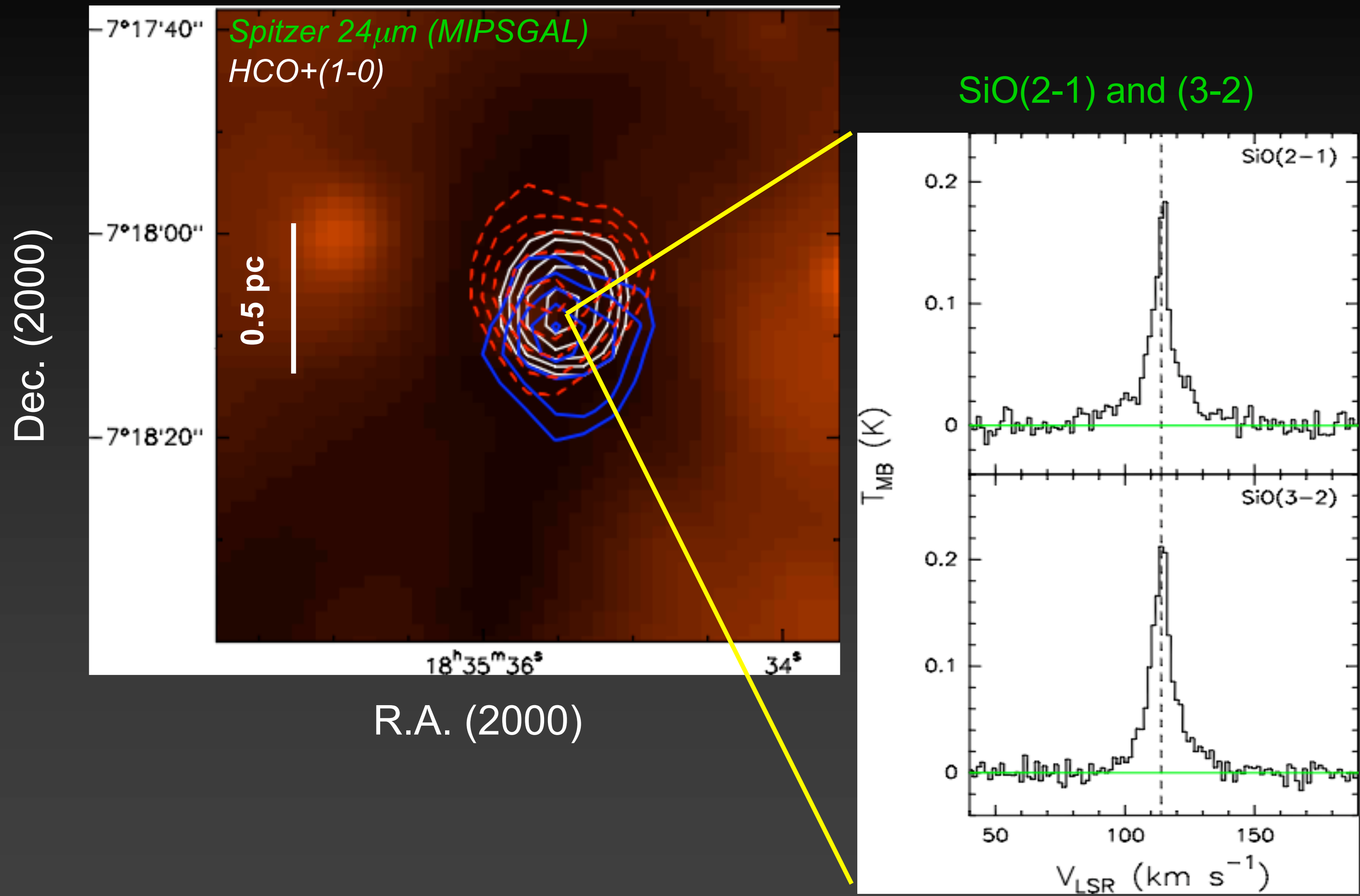
SiO(2-1) @ 86.8 GHz

SiO(3-2) @ 130.3 GHz

30 July - 2 August 2009

Single-pointing observations

# An Example: G24.60+0.1M2 (IR-dark)



# Outflow detection rate from $HCO^+$(1-0)

Total outflow detection rate: **75 %**

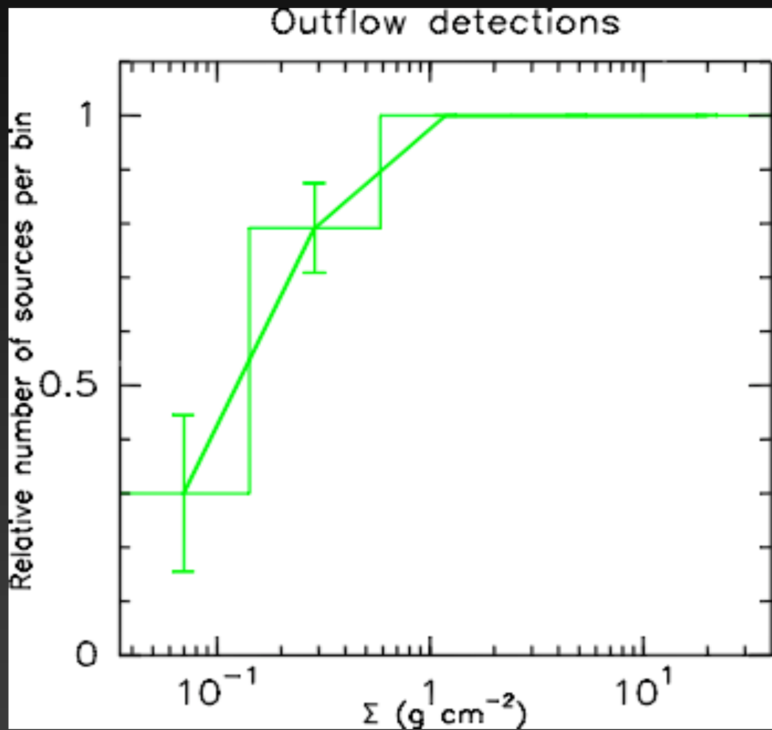
Empirical outflow detection threshold:

$\Sigma = 0.3$ g cm$^{-2}$

**OBSERVATIONS CONFIRM THEORY!**

Similar detection rates for both IR-dark and IR-loud sub-samples

Outflow detection rate vs sigma




**López-Sepulcre et al. (2010)**

# Outflow mass

$\Sigma > 0.3$ g cm$^{-2}$ : Mout > 10 Msun

⇓

Outflows driven by high-mass stars

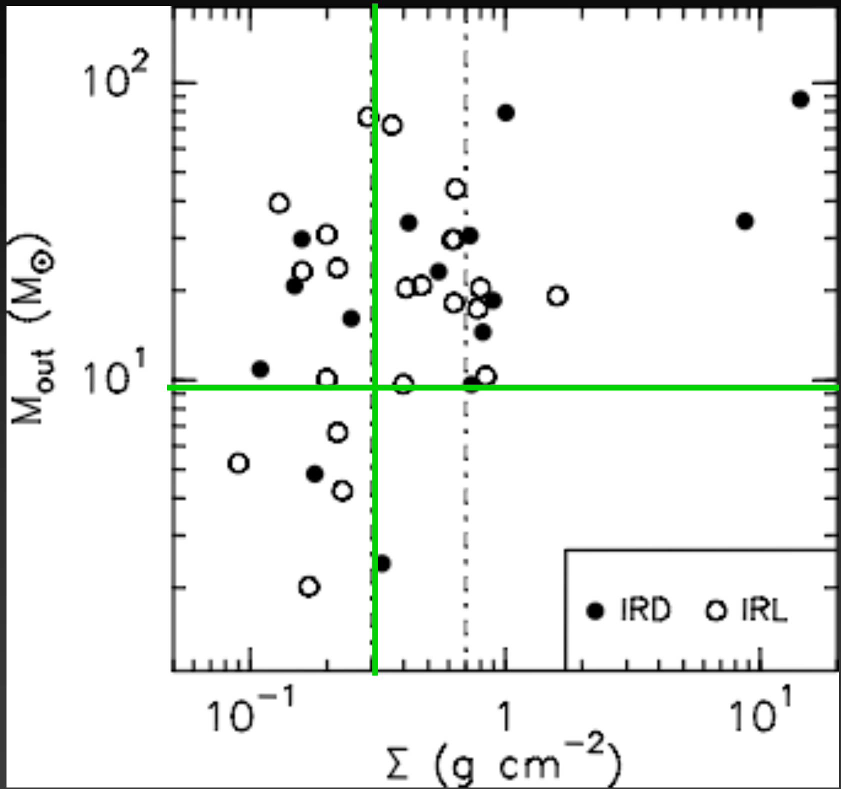
$\Sigma < 0.3$ g cm$^{-2}$

⇓

Outflows driven by both high and low-mass stars

Massive molecular outflows: more massive clumps drive more massive outflows:

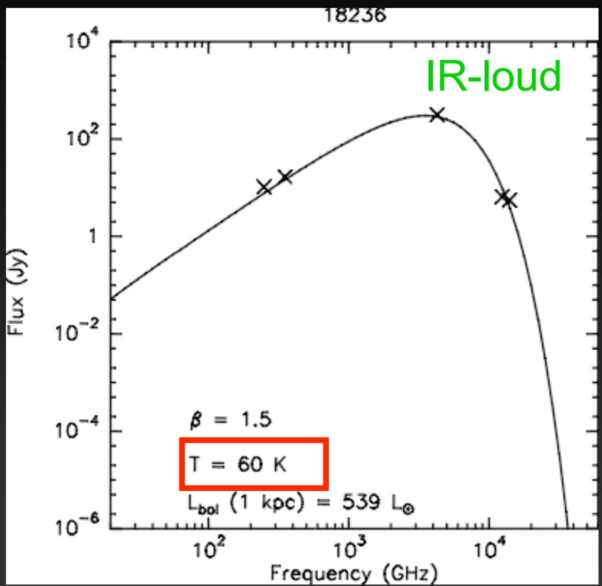
$$M_{\rm out} = 0.4 M^{0.7}$$

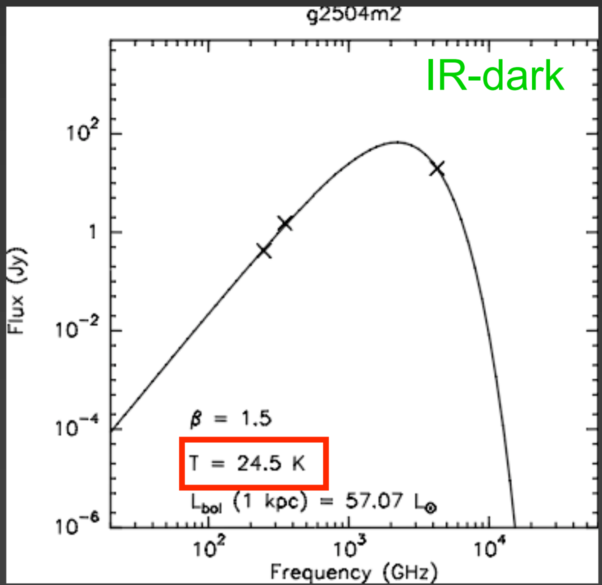



López-Sepulcre et al. (2010)

Need for high-angular resolution observations to disentangle outflow multiplicity

# Determination of bolometric luminosities




## Spectral Energy Distributions (SEDs)

MSX: 21.3 μm
Spitzer: 24 & 70 μm (MIPSGAL)
APEX: 850 μm (ATLASGAL)
Several surveys: 1.2mm
[IRAS: 60 & 100 μm]

## Modified Black Body Fit

$$F_\nu = \Omega_s B_\nu(T)(1 - e^{-\tau_\nu})$$

$$B_\nu(T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

$$\tau_\nu = \tau_0 \left(\frac{\nu}{\nu_0}\right)^\beta$$

$$\beta = 1.5$$

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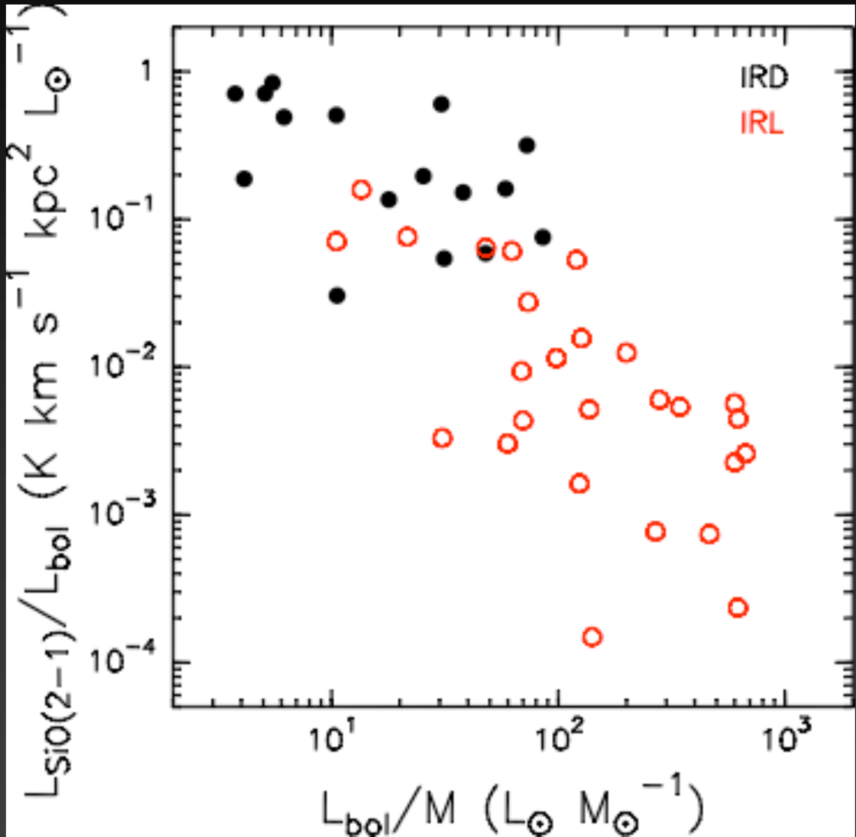
# SiO jet activity




**López-Sepulcre et al. (*in prep.*)**

Detection rate: 88%

SiO FWZP ≥ 10 km/s in all the detected sources

⇓

SiO jets

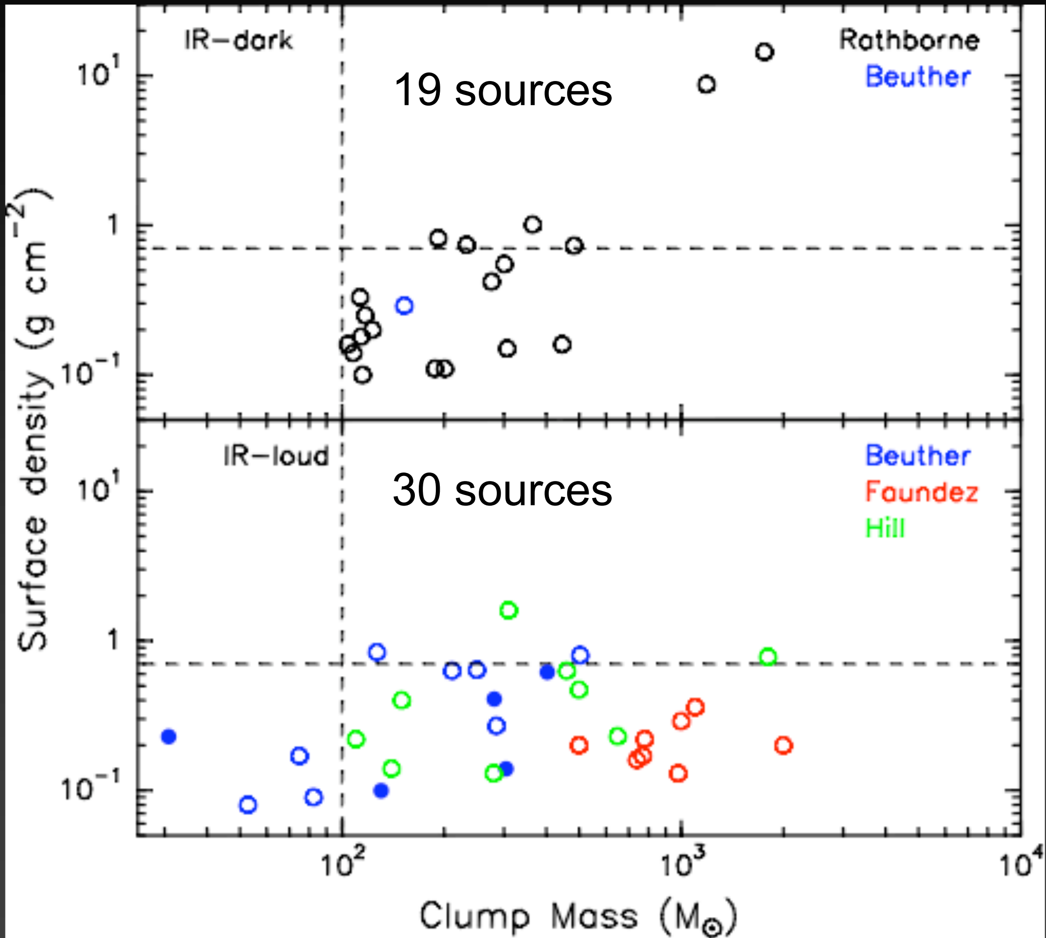
$L_{bol}/M$: measure of time or evolutionary phase

**JET ACTIVITY DECREASES WITH TIME**

# Summary

1. High outflow detection rate in both IR-dark and IR-loud sources; surface density outflow threshold found at 0.3 g $cm^{-2}$: observations confirm the theroretical prediction
2. Outflows more massive than 10 $M_{sun}$ for $\Sigma > 0.3$ g/$cm^2$: consistent with high-mass star formation at higher surface densities
3. Good correlation between outflow mass and clump mass: more massive clumps host more massive outflows
4. Evidence has been found that molecular jets are more active in the earliest evolutionary phases of cluster formation: decrease of jet activity with time

# The sample




NOTE: Σ is averaged accross the clump and therefore a lower limit

KEY:

○: original sample

●: "extra" sources

44 sources

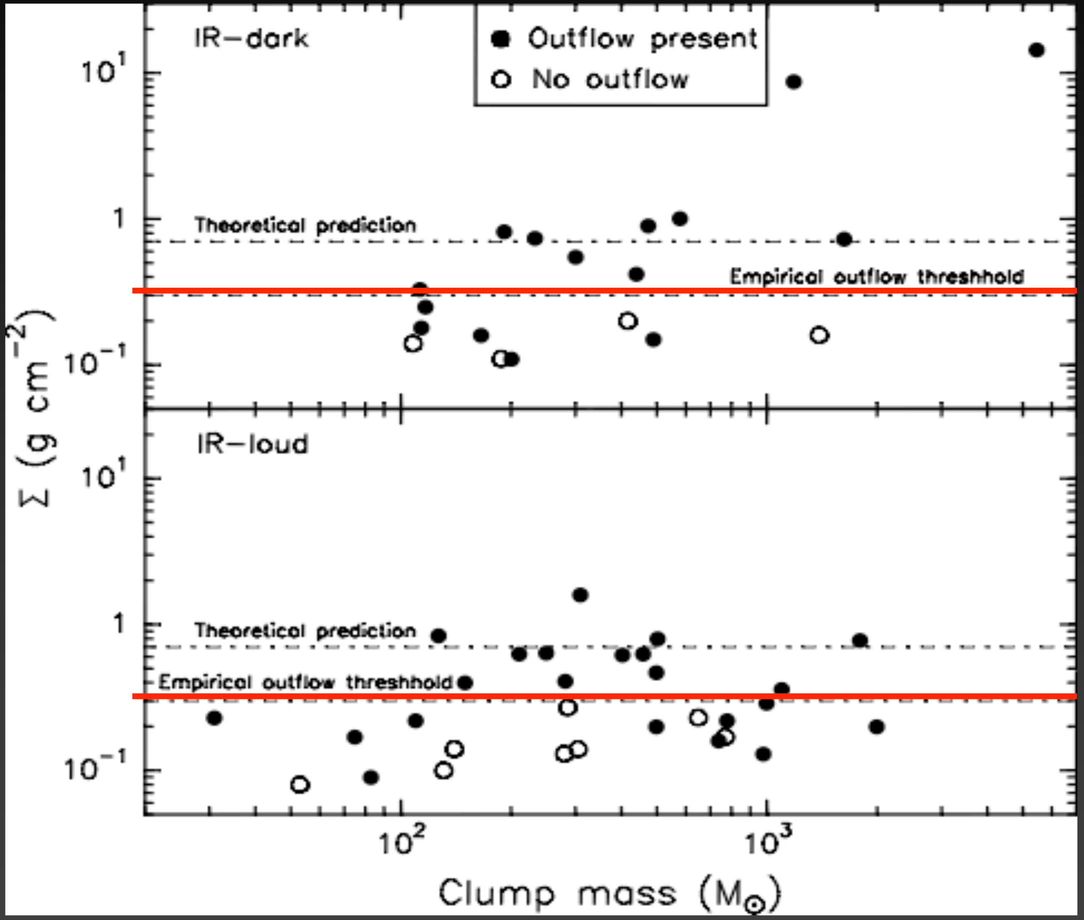
+

5 "extra" sources

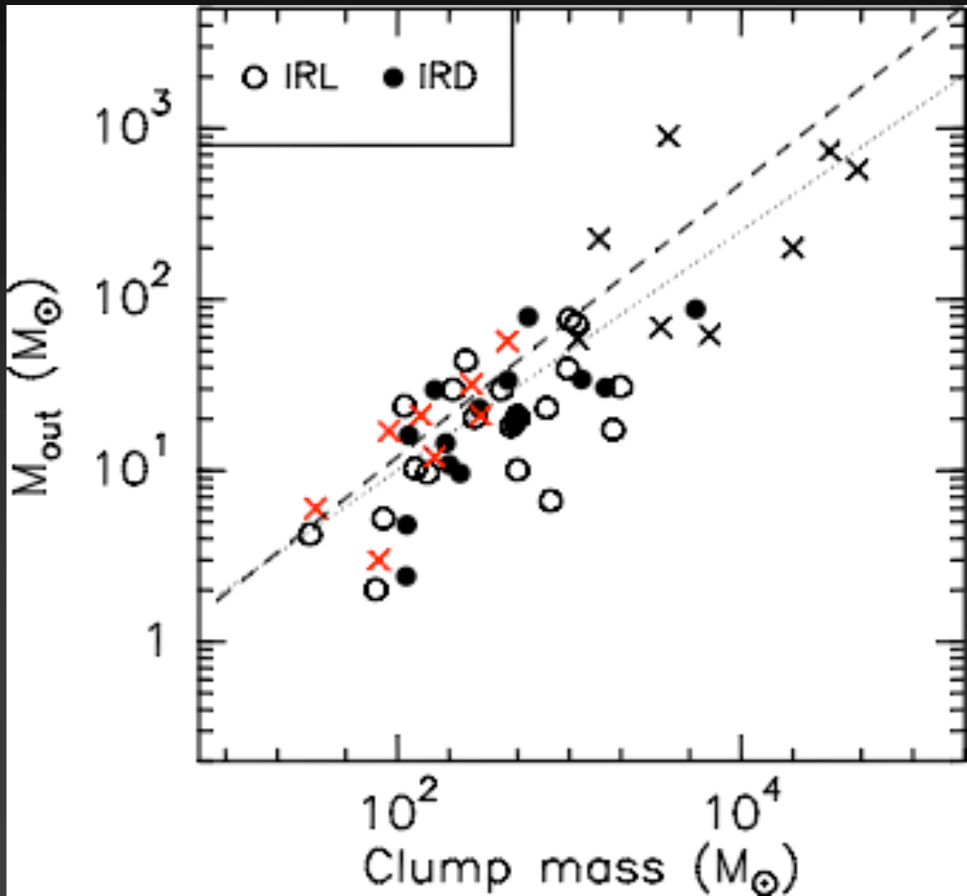
↓

48 sources

# Outflow detection rate



# Outflow mass



# SiO jet activity