A MINIMUM COLUMN DENSITY FOR OB STAR FORMATION: AN OBSERVATIONAL TEST

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INTRODUCTION: HIGH-MASS STAR FORMATION

High-mass Star Formation: Scenarios

Theoretical problem

Stars with $M \geq 8M_{sun}$ reach the ZAMS while still accreting → radiation pressure should halt the accretion process

⇓

Stars with $M > 8M_{sun}$ cannot form (?!)

High-mass Star Formation: Scenarios

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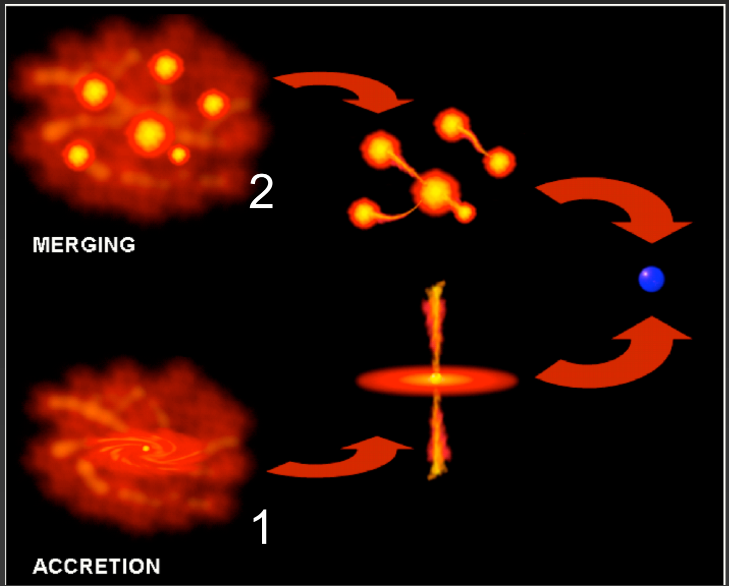
Scenarios



1. Accretion through disks and/or with larger accretion rates than those for low-mass stars

Well-defined disk/outflow system

2. Competitive accretion/merging of low-mass stars

Disks/outflows deeply altered

MARIE CURIE ACTIONS constellation

High-mass Star Formation: Scenarios

Theoretical problem

Stars with $M \geq 8M_{sun}$ reach the ZAMS while still accreting → radiation pressure should halt the accretion process

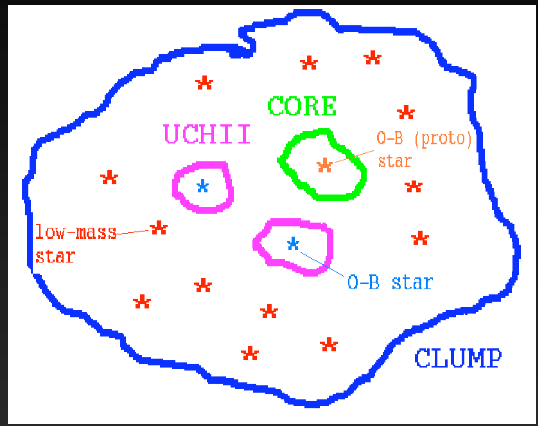
Observational difficulties

Rare; located at high distances (~ 5 kpc)
Rapid evolution towards ZAMS
Formation in clustered mode: confusion

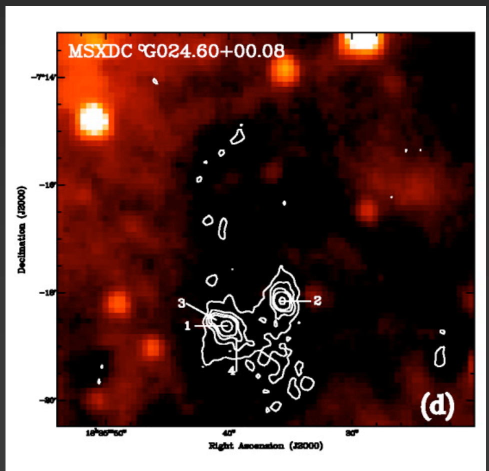
High-mass molecular clumps

The **sites of cluster formation**:

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



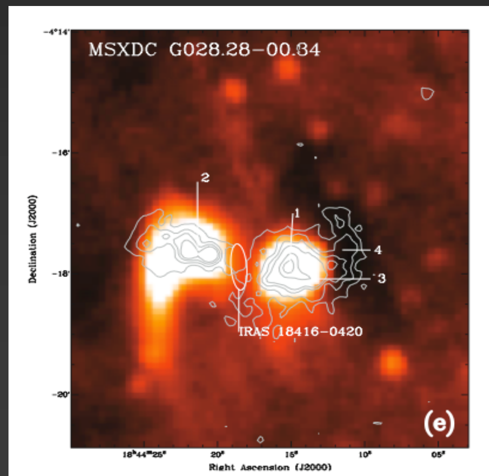
Infrared Dark Clumps



T = 10 - 20 K

time →

Infrared Loud Clumps



T = 30 - 50 K

Rathborne et al. (2006):

Image: 8 μm MSX
Contours: 1.2 mm

OUR MOLECULAR LINE SURVEY

Aims and sample selection

General aims of the project

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

-To check Krumholz & McKee's (*2008 Nature, 451, 1082*) result:

$\Sigma \sim 0.7$ g cm^{-2} is the **minimum surface density** required for high-mass star formation

The sample

Two sub-samples:

1. IR-dark clumps, from the 1.2-mm survey by Rathborne et al (2006)
2. IR-loud, from the surveys by Beuther et al. (2002), Faúndez et al. (2004) and Hill et al. (2005)

Selection Criteria

$\delta > -10°$

$M > 100\ M_{sun}$

$d < 4$ kpc

48 SOURCES

IRAM 30-m observations

Two observation runs:

Summer 2008

Summer 2009

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 (in press)

4-8 August 2008

On-The-Fly mapping: 1’ x 1’ maps

Molecular jet tracers:

SiO(2-1) @ 86.8 GHz

SiO(3-2) @ 130.3 GHz

López-Sepulcre et al. (in prep.)

30 July - 2 August 2009

Single-pointing observations

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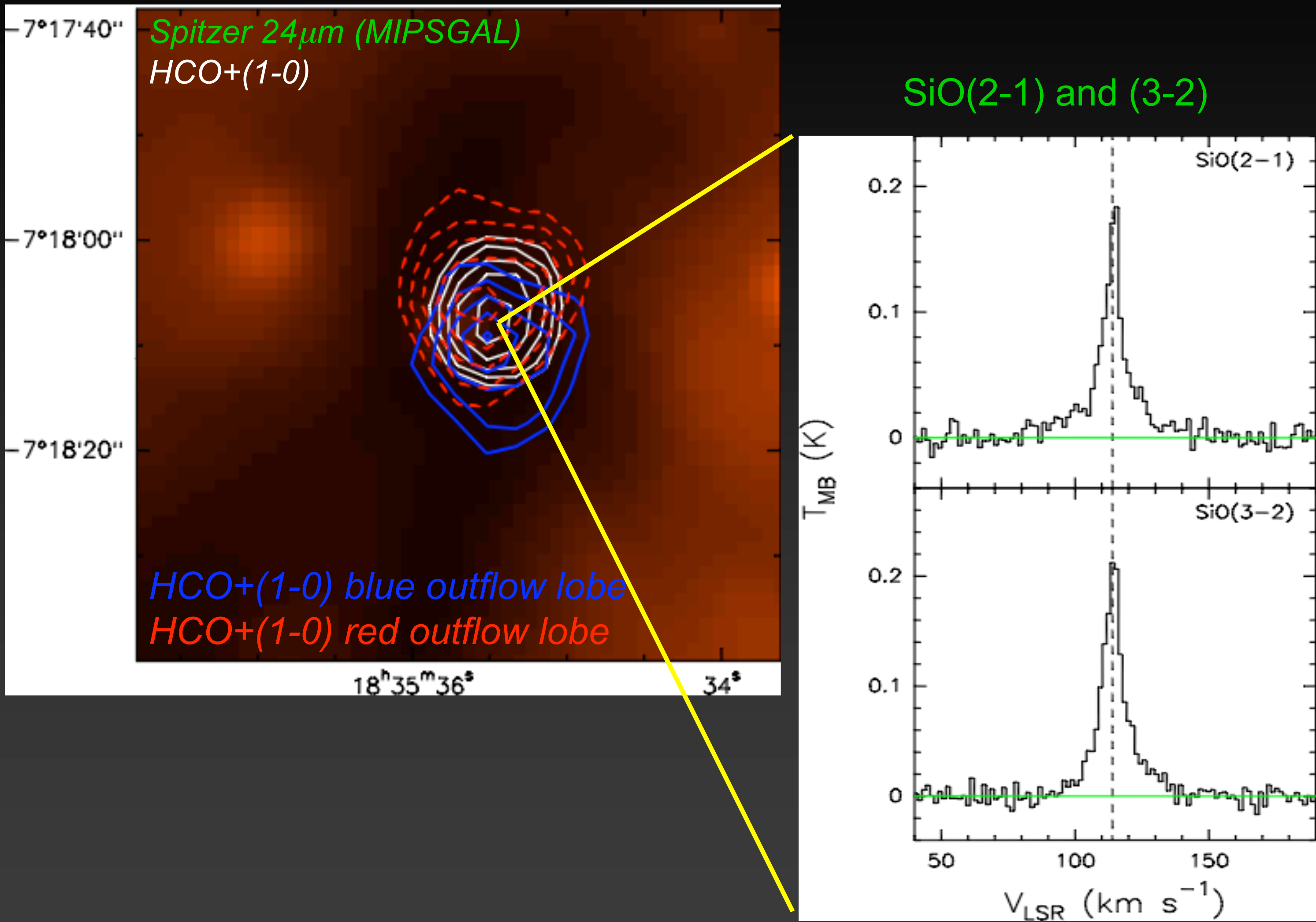
constellation

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



Outflow detection rate

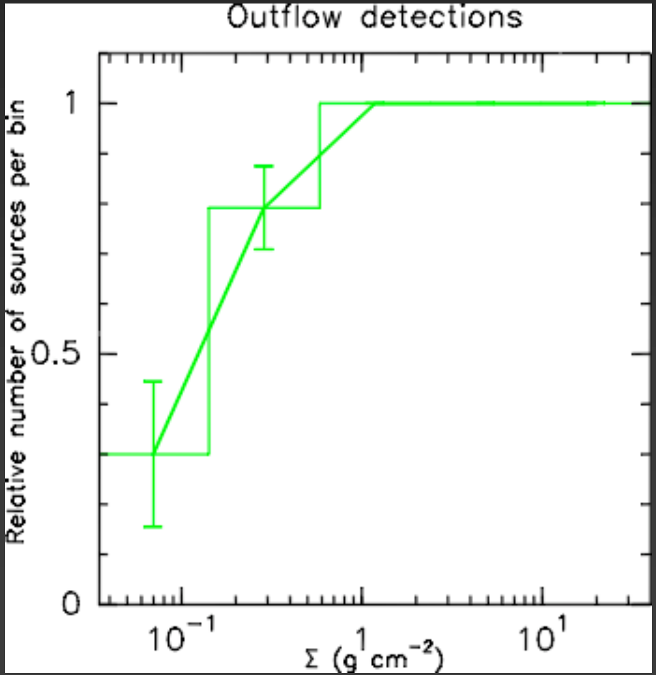
Total outflow detection rate:

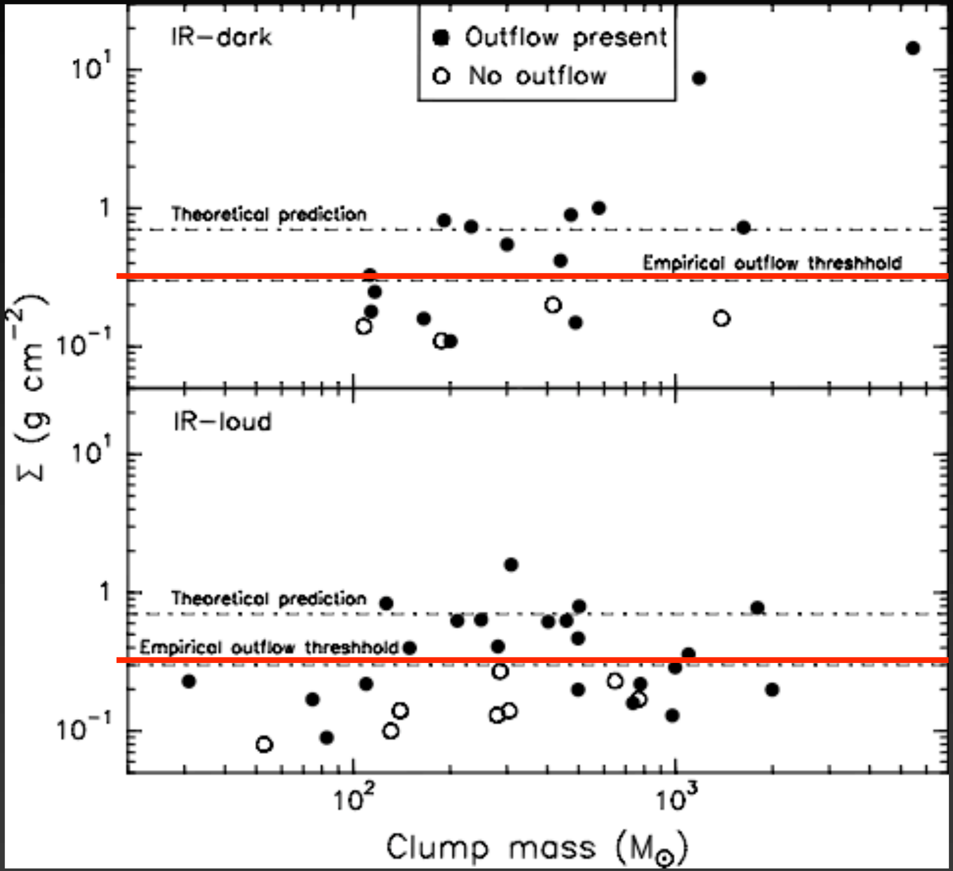
75 %

Empirical outflow detection threshold:

Σ = 0.3 g cm^{-2}

Outflow detection rate vs sigma





López-Sepulcre et al. 2010 A&A (*in press*)

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Outflow mass

KEY

Filled circles: IR-dark

Open circles: IR-loud

X : López-Sepulcre et al. (2009)

X : Beuther et al. (2002)

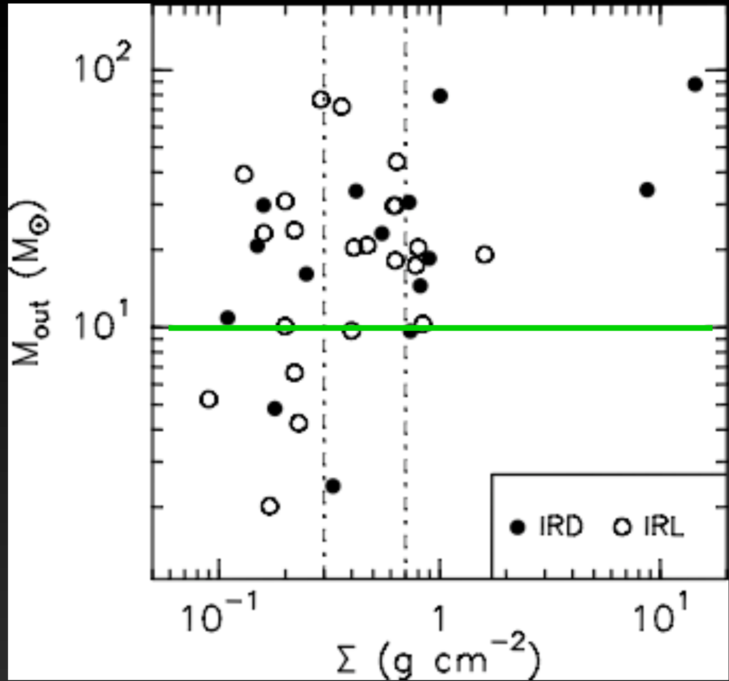
--- : Best fit to Beuther et al. (2002) points

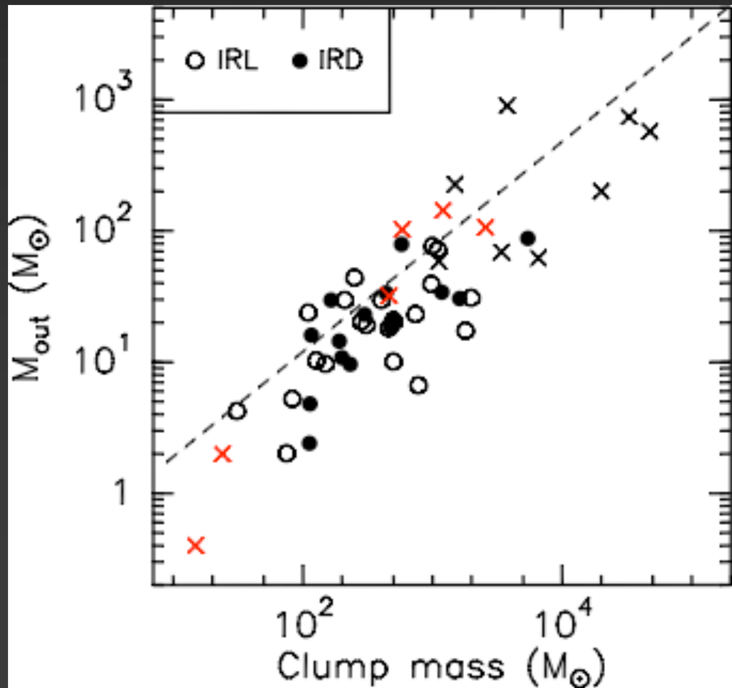
Massive molecular outflows: more massive clumps drive more massive outflows

Higher M_{out} for Σ > 0.3 g cm^{-2}

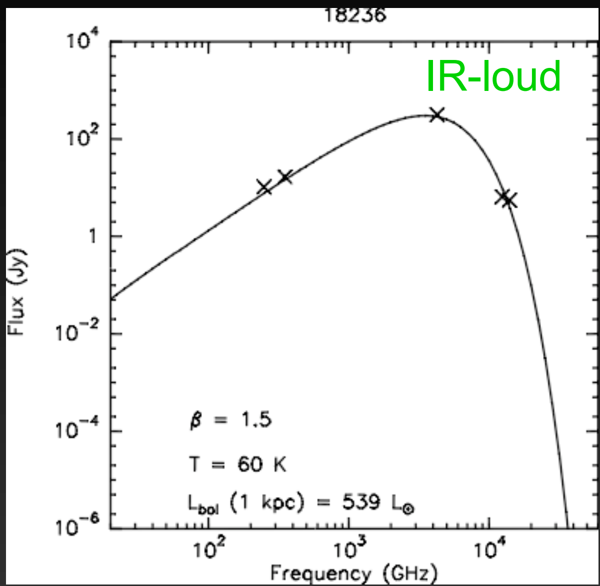
Need for high-angular resolution observations to disentangle outflow multiplicity

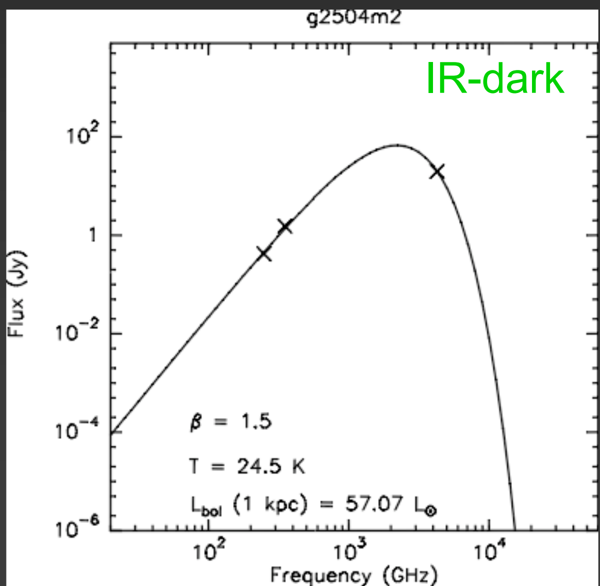
López-Sepulcre et al. 2010 A&A (*in press*)





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]

Grey Body Fit

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

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

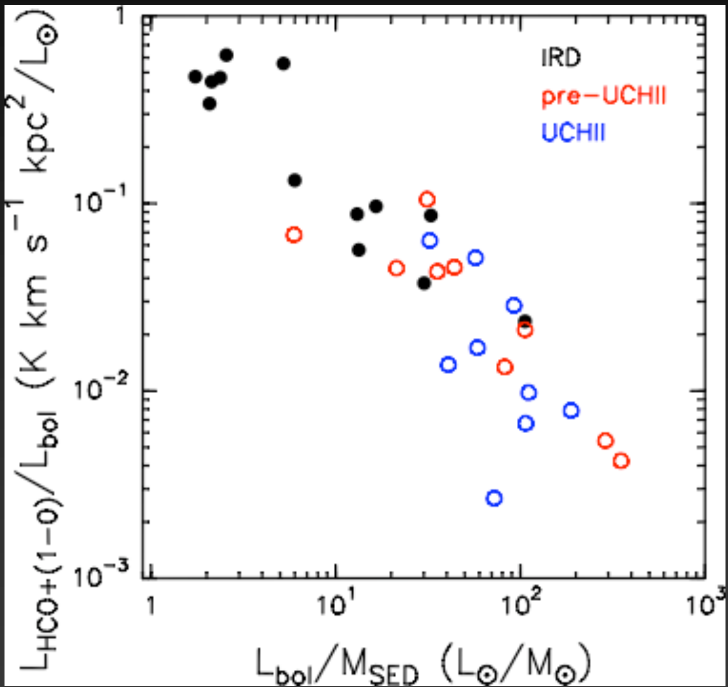
$$\tau_\nu = \tau_0 \left(\frac{\nu}{\nu_0}\right)^\beta$$

$$\beta = 1.5$$

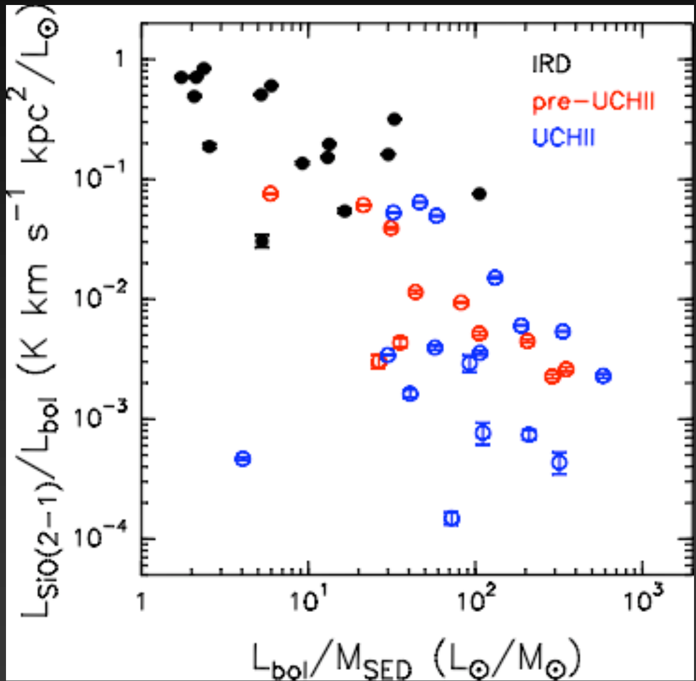
López-Sepulcre et al. 2010 (*in prep.*)

Evolution of jet and outflow activity

HCO⁺(1-0) outflow



SiO(2-1) jet



Molecular jet + outflow phase is more active in younger objects

López-Sepulcre et al. 2010 (*in prep.*)

Summary

1. A sample of high-mass star forming regions (IR-dark and IR-loud molecular clumps) with different surface densities has been mapped in HCO^+(1-0), HCN(1-0) and $C^{18}O$(2-1) transitions
2. High outflow detection rate in both IR-dark and IR-loud sources; surface density outflow threshold found at 0.3 g cm^{-2}
3. Good correlation between outflow mass and clump mass
4. Evidence has been found that molecular outflows and jets are more active in the earliest evolutionary phases of cluster formation