Fragmentation of massive dense clumps: unveiling the initial conditions of massive star formation (ALMA cycle-1 accepted project)

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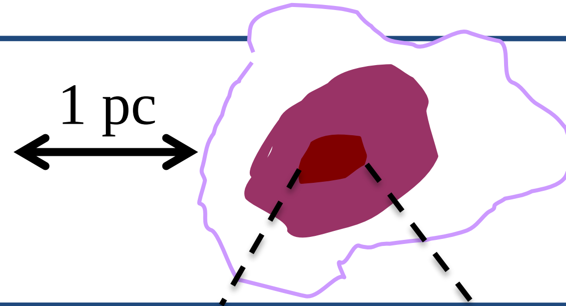
Astrophysical context and motivation

Star formation: standard theory

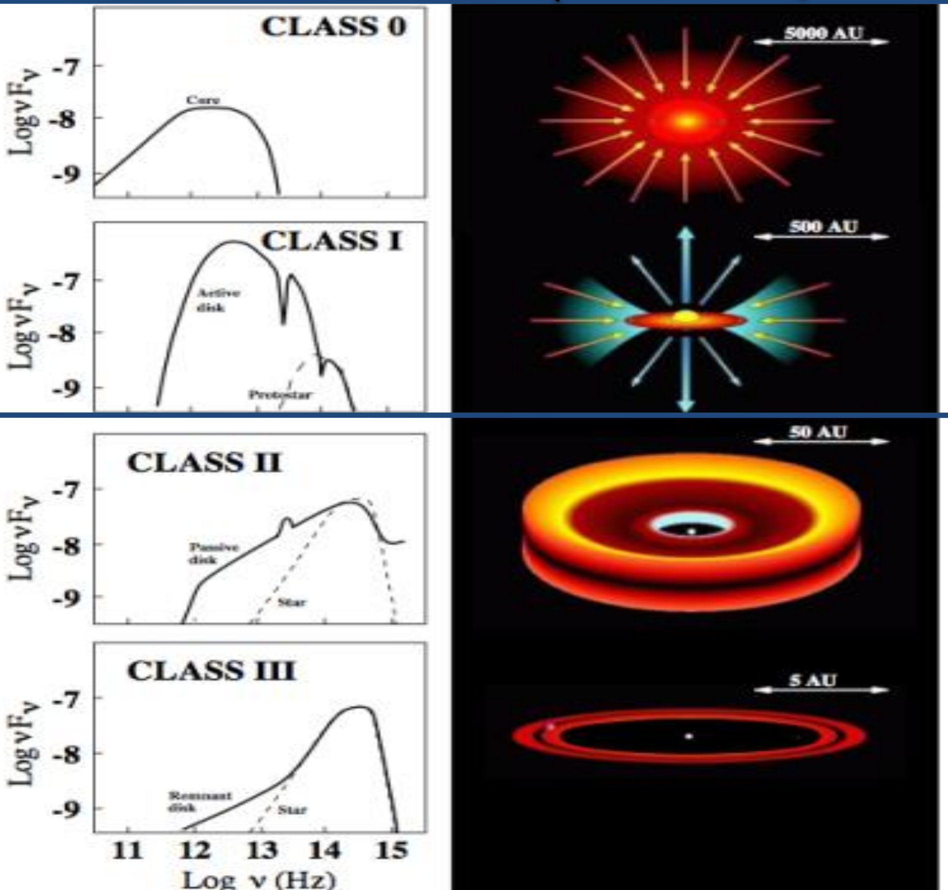
Shu, Adams & Lizano 1987



1. **PRE-STELLAR** PHASE:

2. **PROTO-STELLAR** PHASE

3. **PRE-MAIN SEQUENCE** PHASE

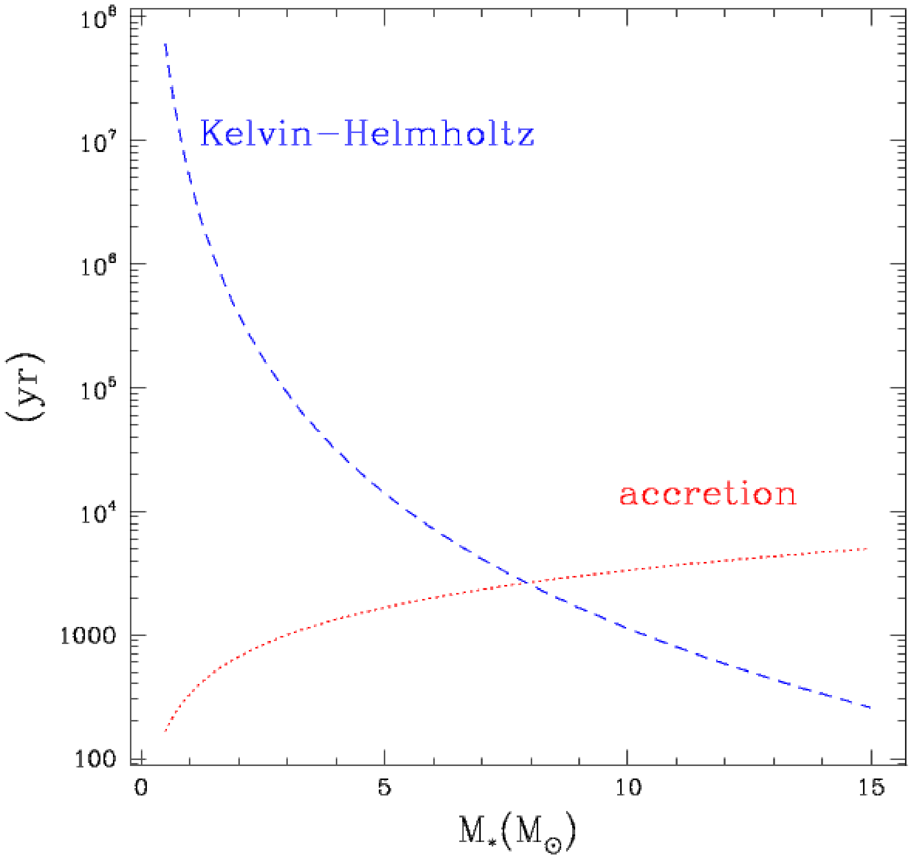


Astrophysical context and motivation

Two relevant timescales in the standard theory:

$$t_{acc} = M_*/(dM/dt)$$

$$t_{K\text{-}H} = GM_*^2/R_*L_*$$



$M_*<8M_\odot$: $t_{acc} < t_{K\text{-}H}$ → pre-main sequence: YES

$M_*>8M_\odot$: $t_{acc} > t_{K\text{-}H}$ → pre-main sequence: NO

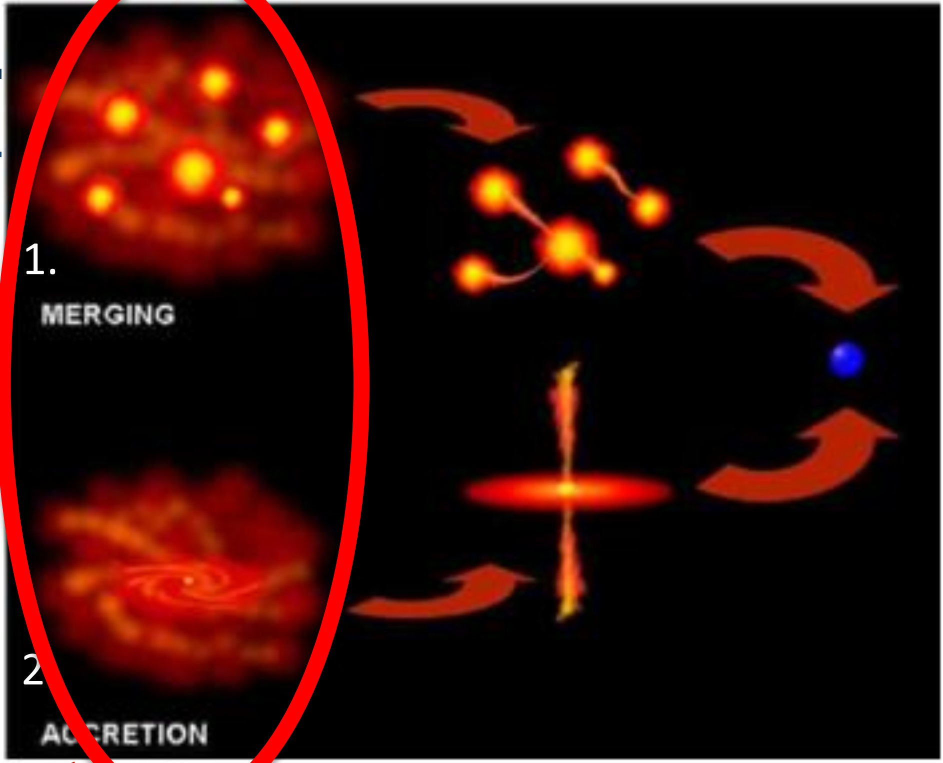
accretion on MS !

Astrophysical cont

BASIC PROBLEM of the STANDARD

The radiation pressure of the "emb

➡ $M_* > 8M_{sun}$ CANNOT



Courtesy of L. Carbonaro

SOLUTIONS:

1. COMPETITIVE-ACCRETION:
   Fragmentation of a massive clump into many low-mass seeds which keep accreting from unbound gas, and/or merge through collisions
   (e.g. Bonnell et al. 1998, 2001, Bonnell & Bate 2005, Wang et al. 2010)

2. CORE-ACCRETION:
   Fragmentation of a massive clump inhibited, and non-spherical collapse into a single high-mass star or close binary system
   (e.g. Wolfire & Cassinelli 1978, McLaughlin & Pudritz 1996, Yorke & Sonnhalter 2002, Tan & McKee 2003)

Fragmentation of the parent clump crucial

Astrophysical context and motivation

Fragmentation influenced by:

(e.g. Krumholz 2006; Hennebelle et al. 2011)

gravity vs

- Intrinsic turbulence
- Magnetic support
- Protostellar feedback

Astrophysical context and motivation

Predictions of theoretical models:

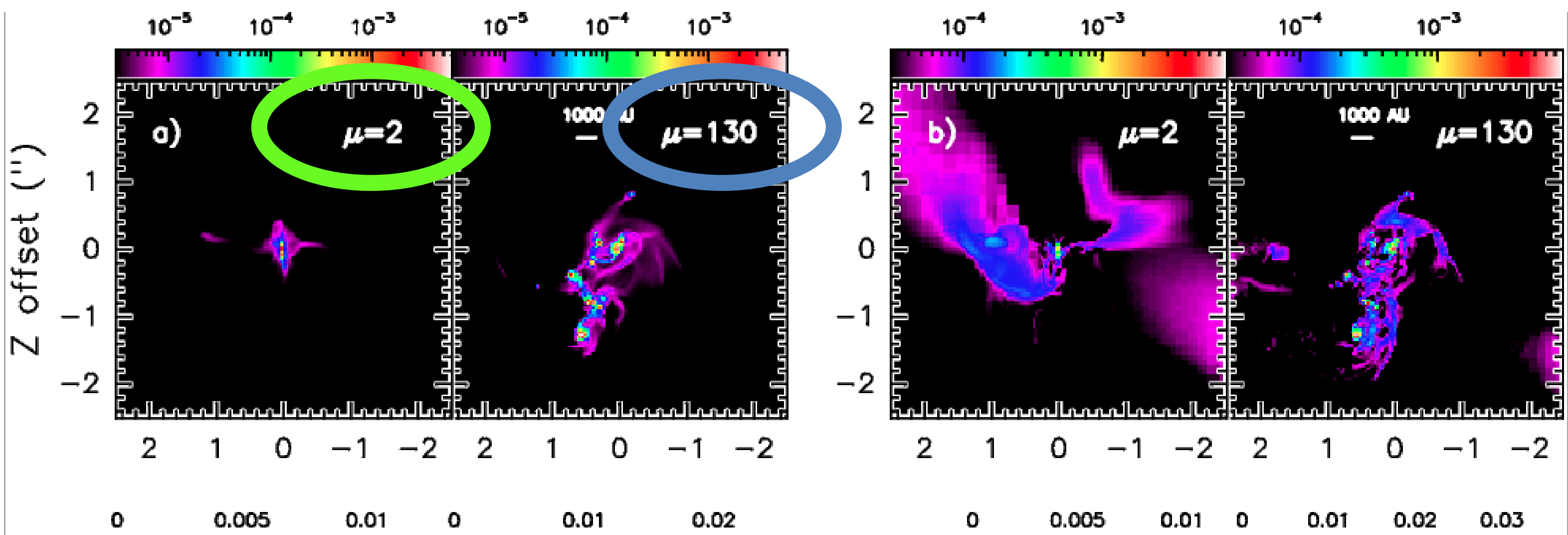
(Hennebelle et al. 2011; Commerçon et al. 2012)

$\mu = (M/\Phi)/(M/\Phi)_{crit}$

μ = 2 , dominant magnetic support

μ = 130, faint magnetic support

280 GHz cont. **N_2H^+ (3-2)**



Core separation ~ 1000 A.U. Masses: from 0.2 to 10 $M_\odot$

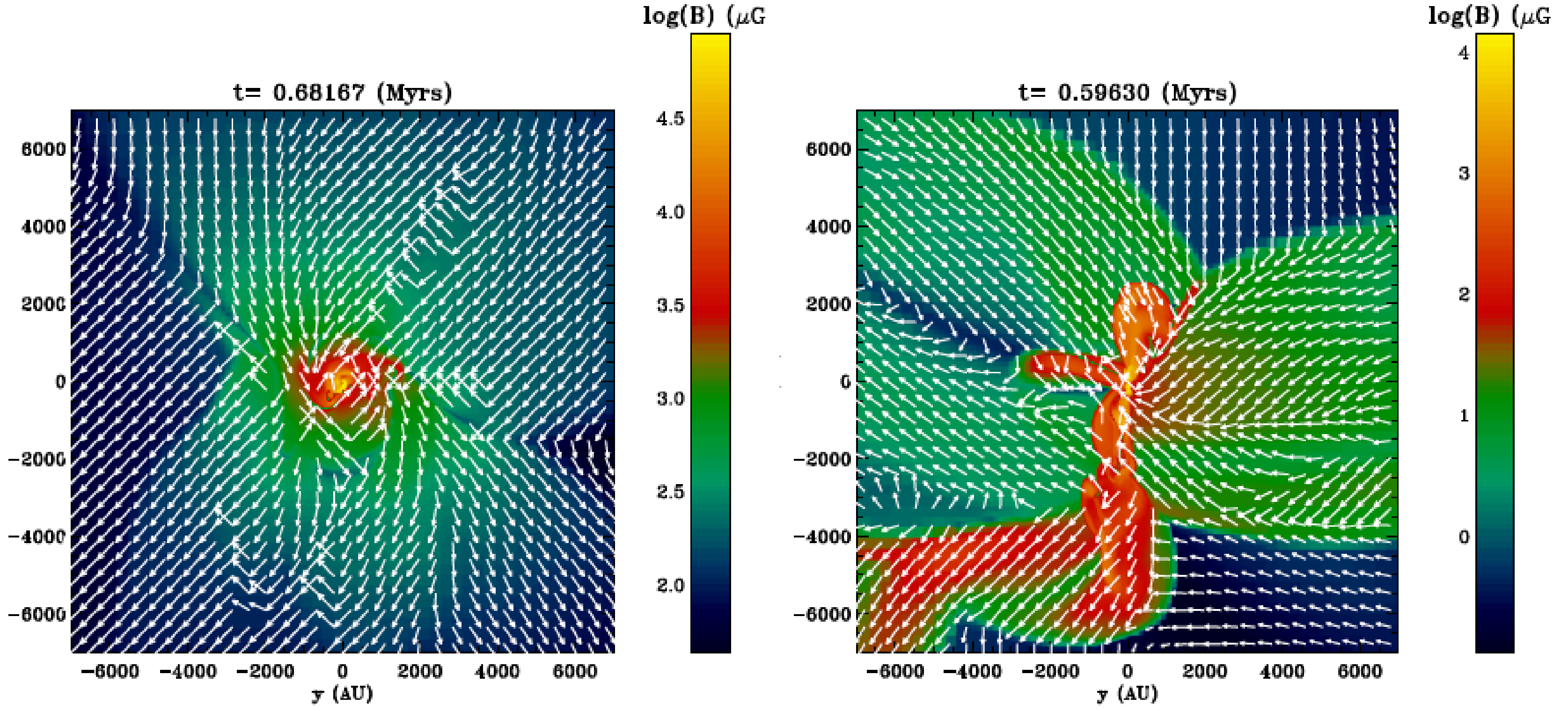
➔ The role of magnetic field can be tested deriving the population of fragments (or cores) in pristine massive clumps

Astrophysical context and motivation

Predictions of theoretical models: magnetic vectors

(Hennebelle et al. 2011; Commerçon et al. 2012)

μ = 2 , dominant magnetic support   μ = 130, faint magnetic support



➔ The role of magnetic field can be tested deriving the population of fragments (or cores) in pristine massive clumps

Testing theories with observations

Problems:

- Massive starless clumps are RARE
- Typical distances greater than 1 kpc: SMALL ANGULAR SIZE
- Surrounded by large amount of other gas: CONFUSION
- FREEZE-OUT of species commonly used to derive physics and kinematics

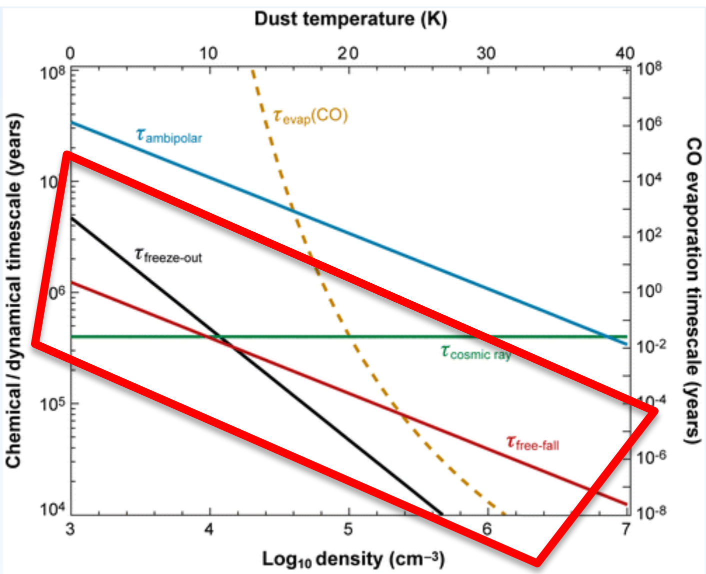
$T < 20$ K

$n(H_2) > 10^5\ cm^{-3}$

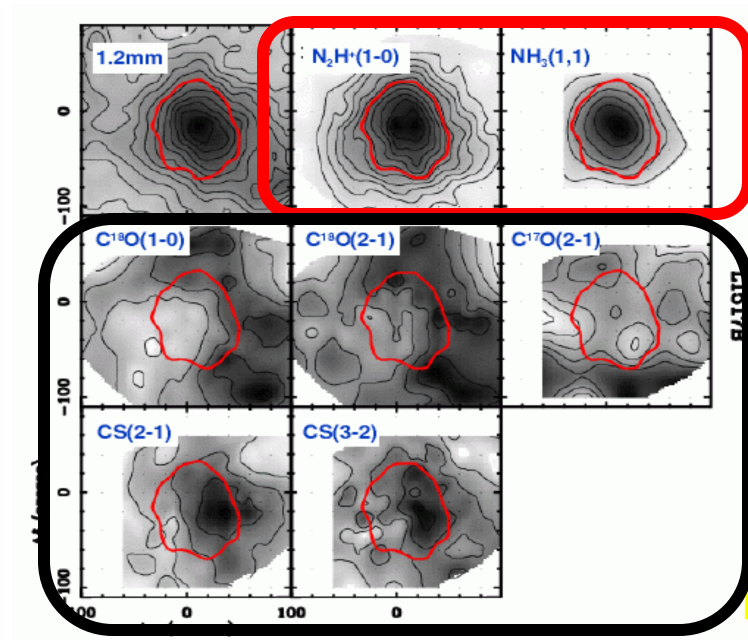
High CO (and CS) DEPLETION FACTOR

$f_D = X(CO)^T/X(CO)^O > 1$

(e.g. Caselli et al. 2002, Tafalla et al. 2004, Fontani et al. 2012)



Bergin EA, Tafalla M. 2007.
Annu. Rev. Astron. Astrophys. 45:339–96



The need for ALMA (cycle-1)

- Few studies with linear resolution 1500 – 2000 AU so far
- Current facilities (except ALMA) cannot reach the requested sensitivity (0.2 $M_\odot$ ~ Jeans mass) in reasonable integration times for many sources
- ALMA in cycle-1 offers: (1) the sensitivity and (2) the angular resolution appropriate for this project

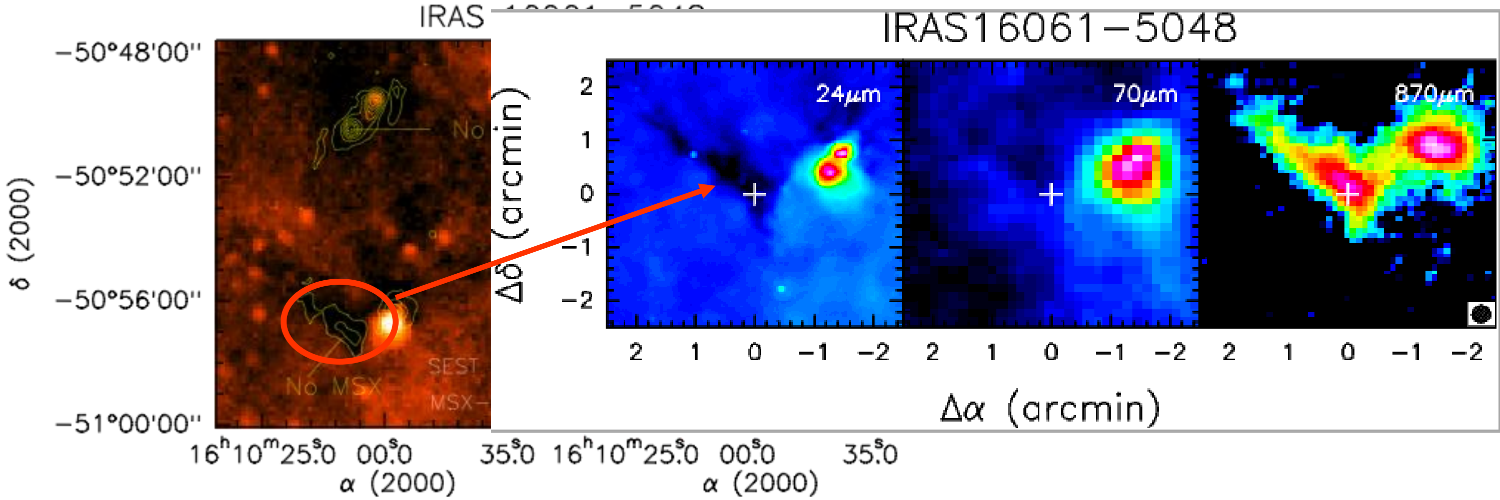
…but finding good targets is challenging!

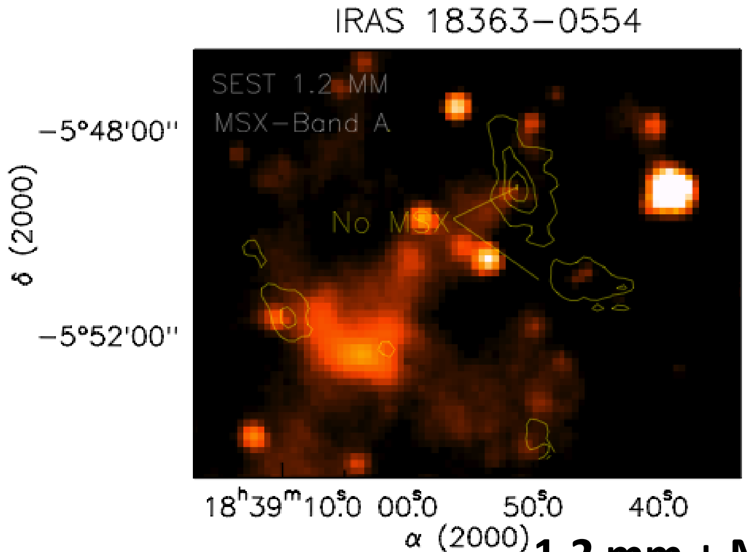
The sample

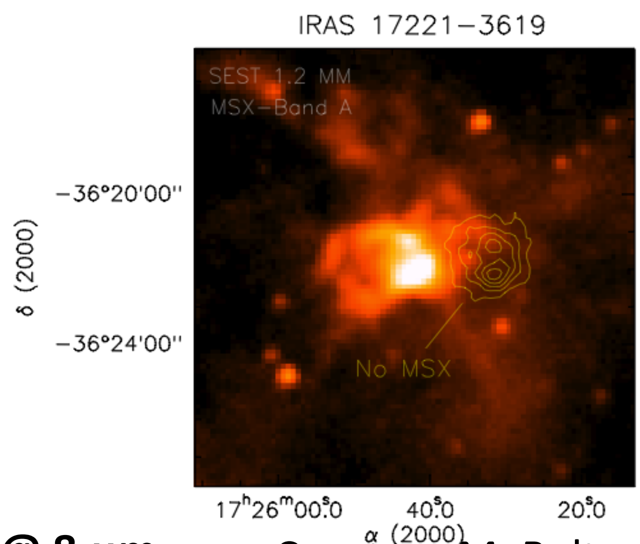
Initial sample: 95 millimeter continuum clumps, MSX-dark

(Fontani+2005; **Beltrán+2006**; Fontani+2012; Sánchez-Monge+2013; Giannetti+2014)

1.2 mm + MSX @ 8 μm







1.2 mm + MSX @ 8 μm

Courtesy M. Beltran

The sample

Selection criteria:

1. Potential sites of massive star formation
2. Cold and chemically young
3. Not blended
4. Dense

↓

1. Mass, $N(H_2)$, $\Sigma(H_2)$ > threshold values for massive star formation
2. CO depletion factor $f_D \geq 7$
3. Clumps isolated, or separated by more than the SIMBA HPBW from other clumps and signposts of star formation activity
4. Detection in the (non-depleted) high-density gas tracer N_2H^+

The sample

11 entries

1. Potential sites of massive star formation

2. Cold and chemically young

Table 1: *Sample of massive dense clumps and general properties: coordinates, distance, deconvolved angular diameter, gas mass, gas temperature, H_2 column density, mass surface density and CO depletion factor.*

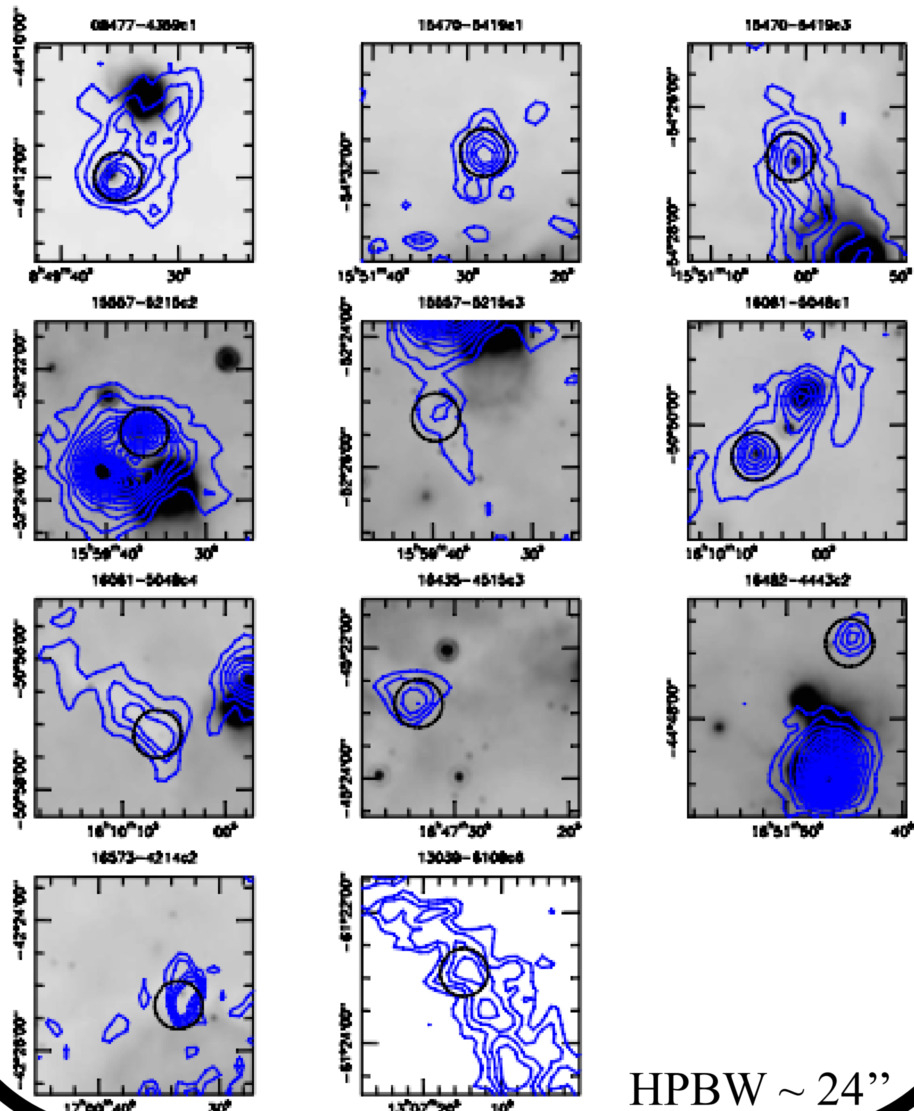
Source	R.A.(J2000) h m s	Dec.(J2000) ° ′ ″	d kpc	θ_s ″	M $M_\odot$	T_k K	$N(H_2)$ $\times 10^{23}$ cm^{-2}	$\Sigma(H_2)$ g cm^{-2}	f_{CO}
08477–4359c1	08:49:35.13	–44:11:59	1.8	35.6	86.73	19	1.42	0.24	7
13039–6108c6	13:07:14.80	–61:22:55	2.4	40.3	101.5	17	0.68	0.12	22
15470–5419c1	15:51:28.24	–54:31:42	4.1	24.2	310.2	18	1.37	0.36	35
15470–5419c3	15:51:01.62	–54:26:46	4.1	54.1	743.4	19	1.11	0.17	36
15557–5215c2	15:59:36.20	–52:22:58	4.4	41.3	633.4	23	1.55	0.22	32
15557–5215c3	15:59:39.70	–52:25:14	4.4	35.8	194.3	15	0.49	0.09	24
16061–5048c1	16:10:06.61	–50:50:29	3.6	28.1	284.3	25	1.66	0.31	12
16061–5048c4	16:10:06.61	–50:57:09	3.6	62.8	504.2	13	1.22	0.11	34
16435–4515c3	16:47:33.13	–45:22:51	3.1	17.7	147	12	1.20	0.55	73
16482–4443c2	16:51:44.59	–44:46:50	3.7	$\ll 24^a$	59.08	16	$\gg 4.63^a$	0.66	9
16573–4214c2	17:00:33.38	–42:25:18	2.6	7.29	108.3	17	1.89	3.4	25

Fontani+12, MNRAS, 423, 2342

3. Not blended

SIMBA 1.2 mm + **Spitzer 24 μm**

Beltràn+06, A&A, 423, 2342

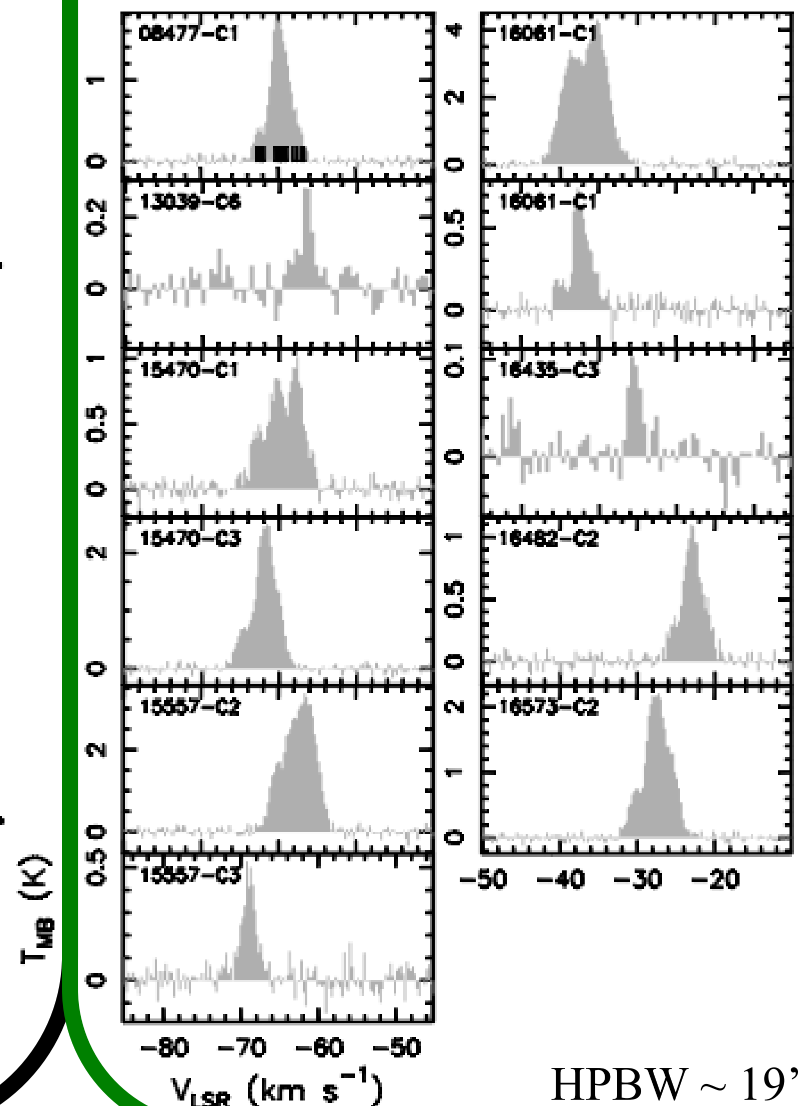


HPBW ~ 24”

4. Dense

APEX **N_2H^+(3-2)**, towards SIMBA peak

Fontani+12, MNRAS, 423, 2342



HPBW ~ 19”

Immediate objective

Goals: 1- CORE POPULATION (mass, number, geometric distribution)
2- KINEMATICS
at a linear resolution comparable to the typical fragment separation (~ 1000 A.U.)

Tracers: 1- Continuum @ 280 GHz;
2- N_2H^+ (3-2) , $n_{crit} \sim 3 \times 10^6$ cm^{-3}

Instrument configuration: C32-5, $\theta \sim 0.27''$ @ 280 GHz

Integration time: 20 minutes o. s. ($3\sigma \sim 0.27$ mJy, i.e. 0.07 $M_\odot$)

What we expect to see….

$\mu = (M/\Phi)/(M/\Phi)_{crit}$

μ = 2 , dominant magnetic support

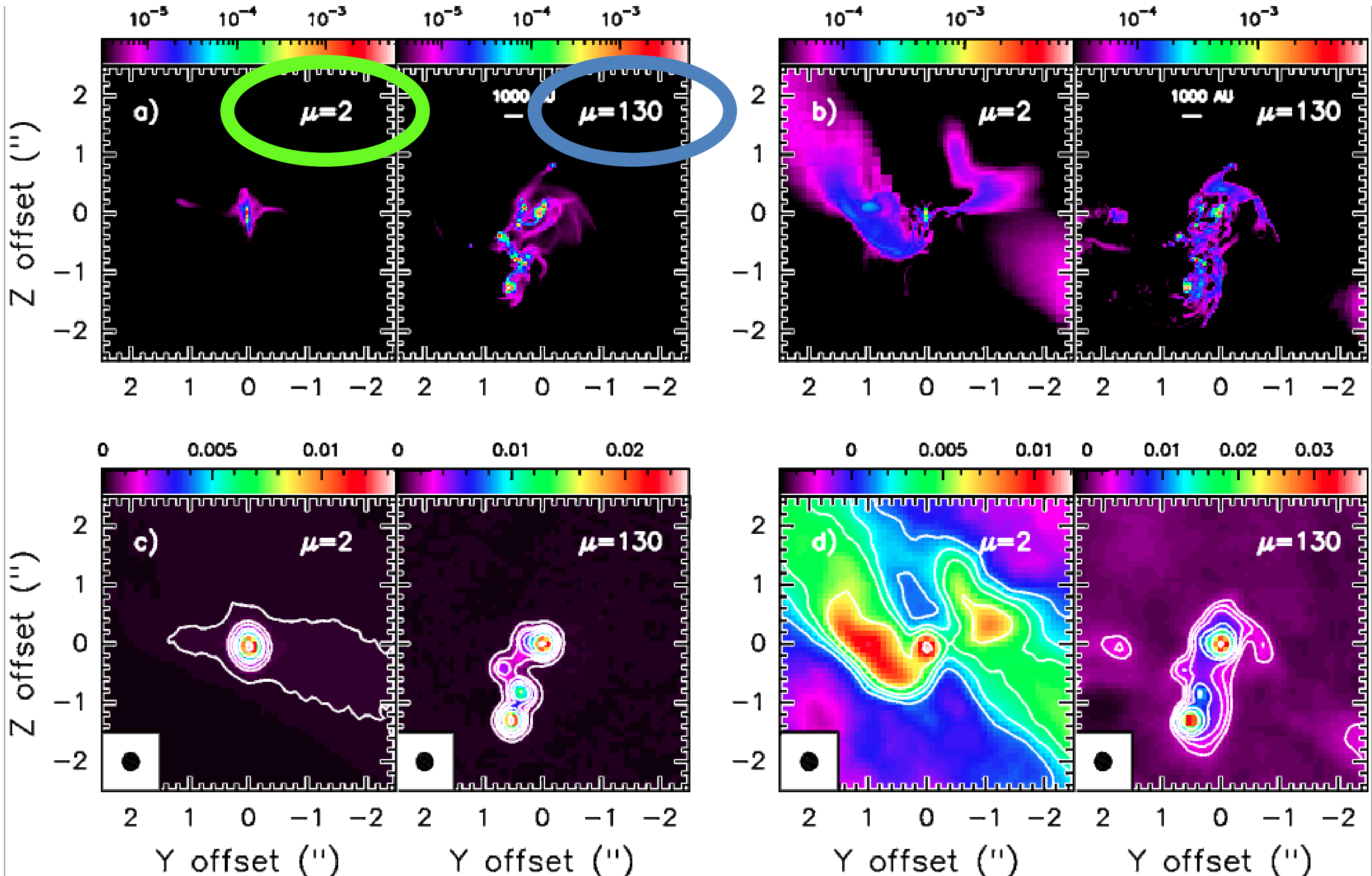
μ = 130, faint magnetic support

280 GHz cont.

N_2H^+ (3-2)

Model output (Hennebelle+11, Commerçon+12)

CASA Simulations (θ ~ 0.27", 20 mins, cycle-1)



Project postponed to cycle-2……