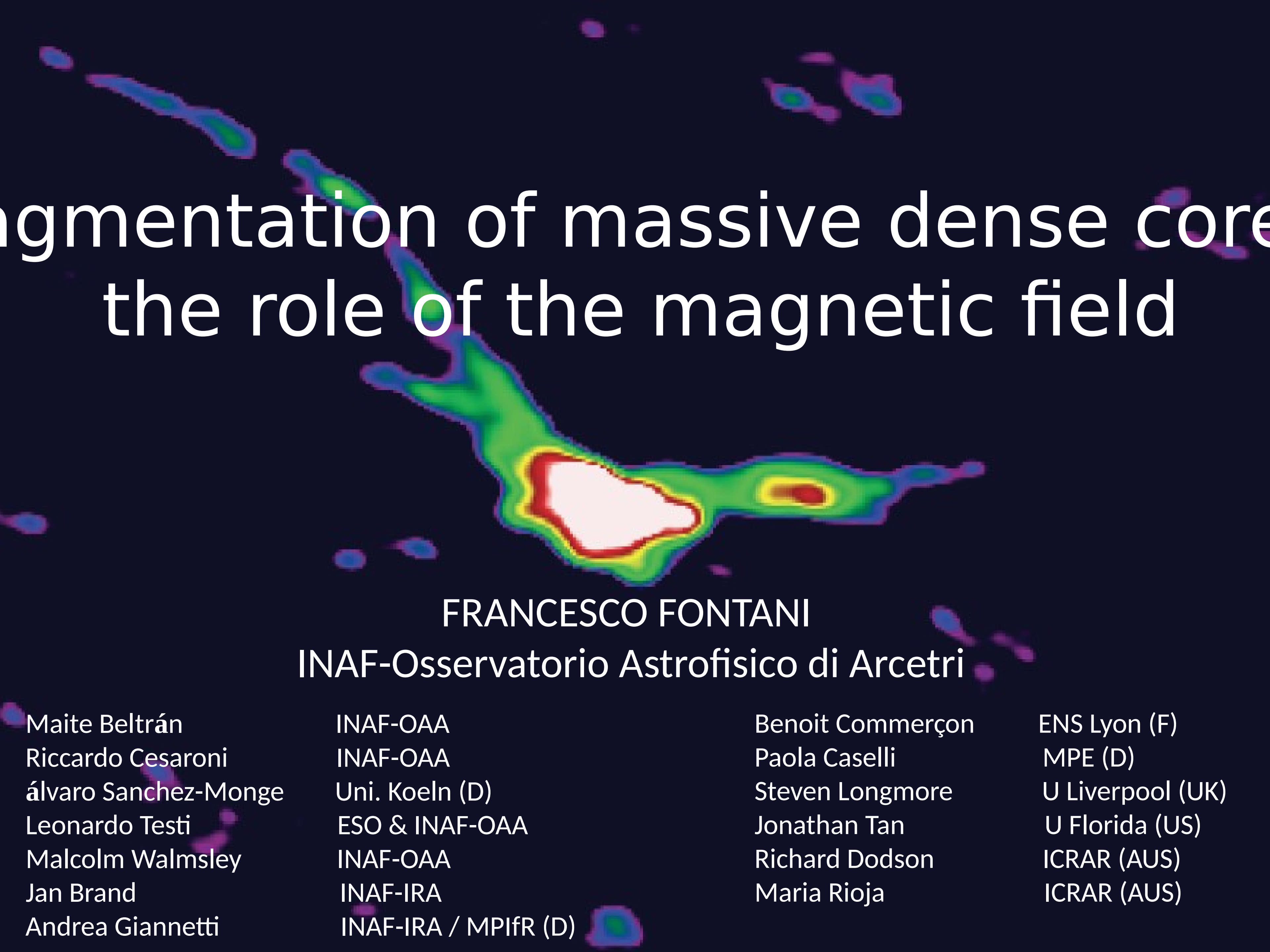

# gmentation of massive dense core
# the role of the magnetic field

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| Andrea Giannetti | INAF-IRA / MPIfR (D) |  |  |

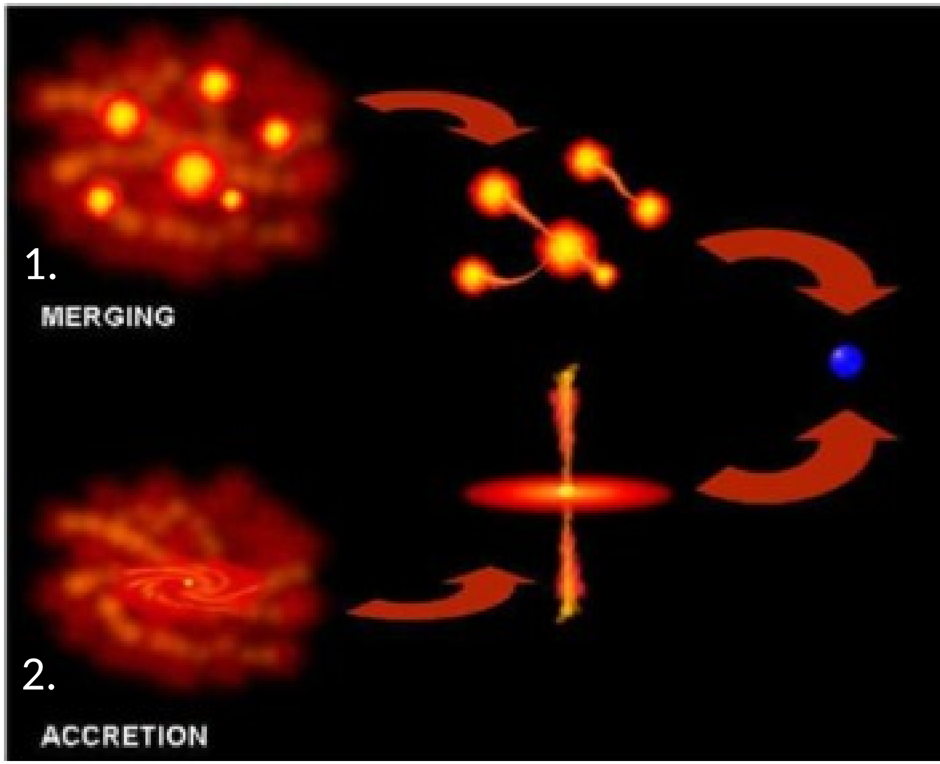
# *Why do we care about fragmentation?*

- **Multiple systems** and **clusters** are born from this process

- **Massive stars**, in theory, can form differently depending on the fragmentation of the parent core

1. COMPETITIVE-ACCRETION:
   Fragmentation favoured into many low-mass seeds which keep accreting from unbound gas
   (e.g. Bonnell et al. 1998, Bonnell & Bate 2005, Wang et al. 2010)

2. CORE-ACCRETION:
   Fragmentation inhibited, followed by non-spherical collapse
   (e.g. McLaughlin & Pudritz 1996, Yorke & Sonnhalter 2002, Tan & McKee 2003)



Courtesy of L. Carbonaro

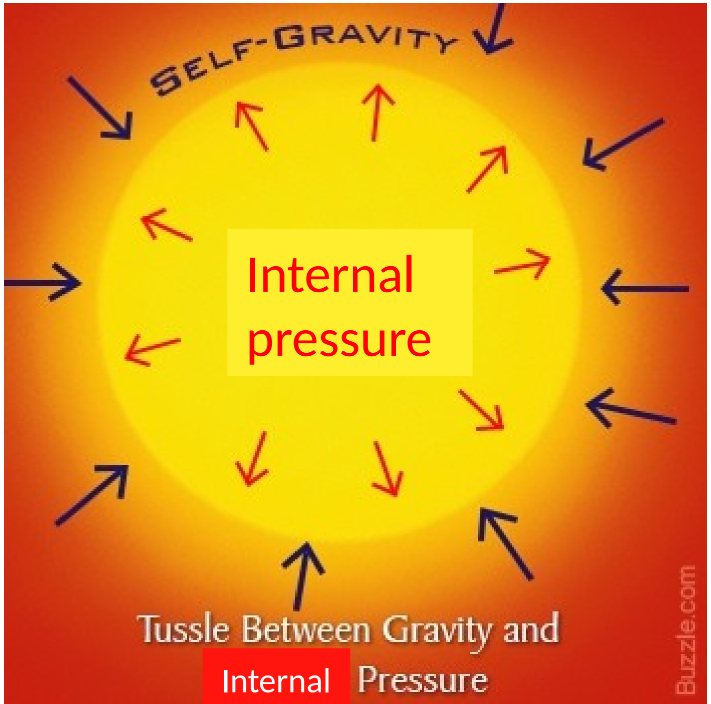
# Theory

Fragmentation influenced by:

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

Self-gravity vs Internal pressure

- ~~Thermal~~
- Turbulence
- Magnetic
- ~~Feedback~~



# *Theory*

**Fragmentation of a 100 $M_{□}$ core**

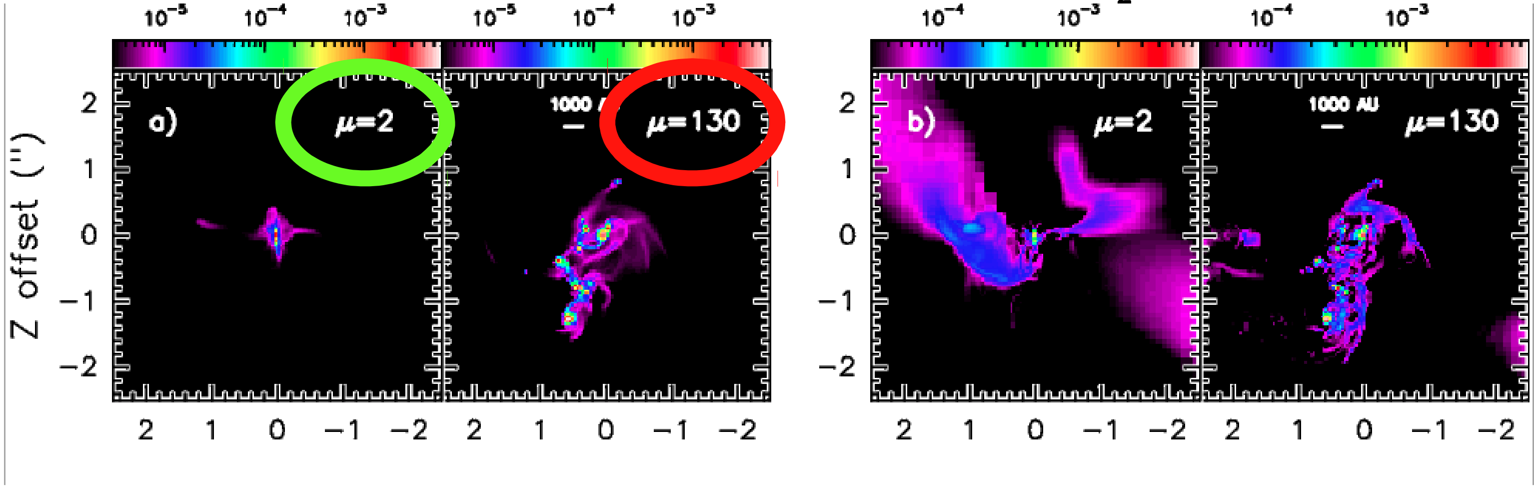
**RAMSES code**

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

**$\mu$ = 2 , dominant magnetic support**

**$\mu$ = 130, faint magnetic support**

**Model output (Hennebelle+11, Commerçon+12)**


**280 GHz cont.**

**$N_2H^+$ (3-2)**

Magnetic field dominates □ one (few) fragment(s)

Turbulence dominates □ many fragments

# *The sample*

Selection criteria:

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

**11 entries from MSX-dark cores (Beltrán et al. 2006)**

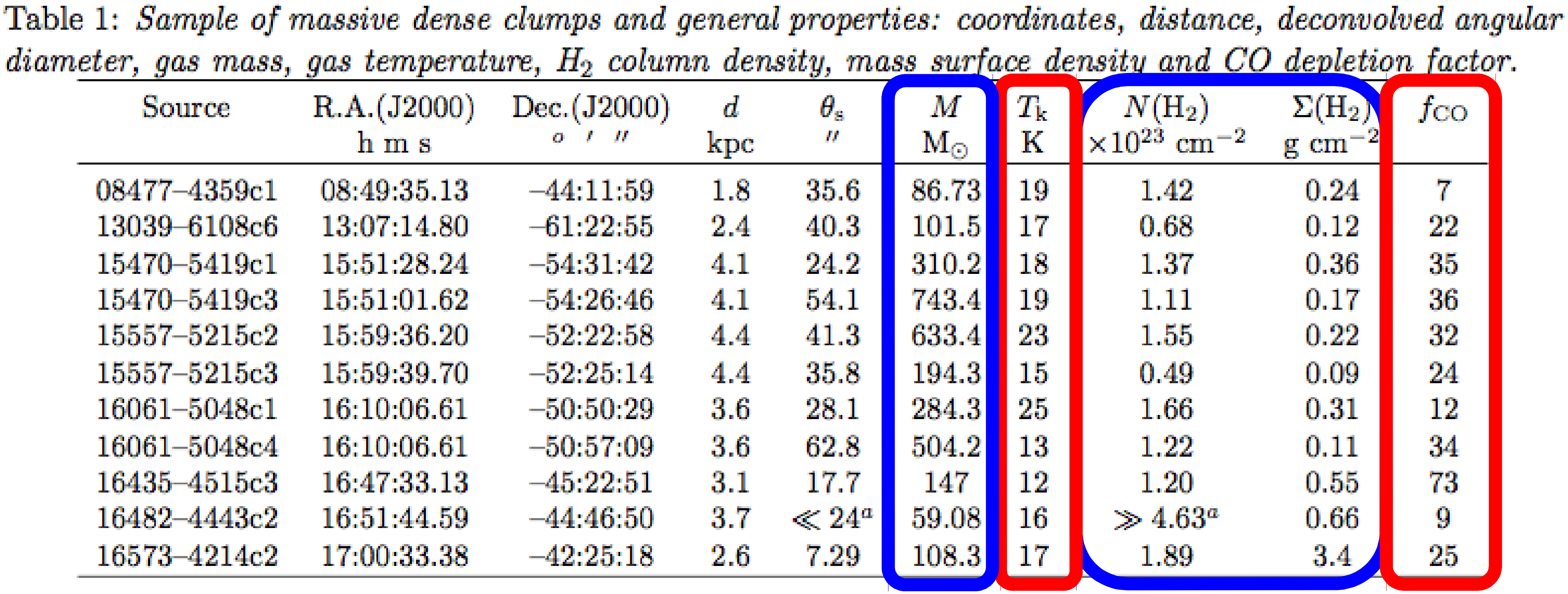


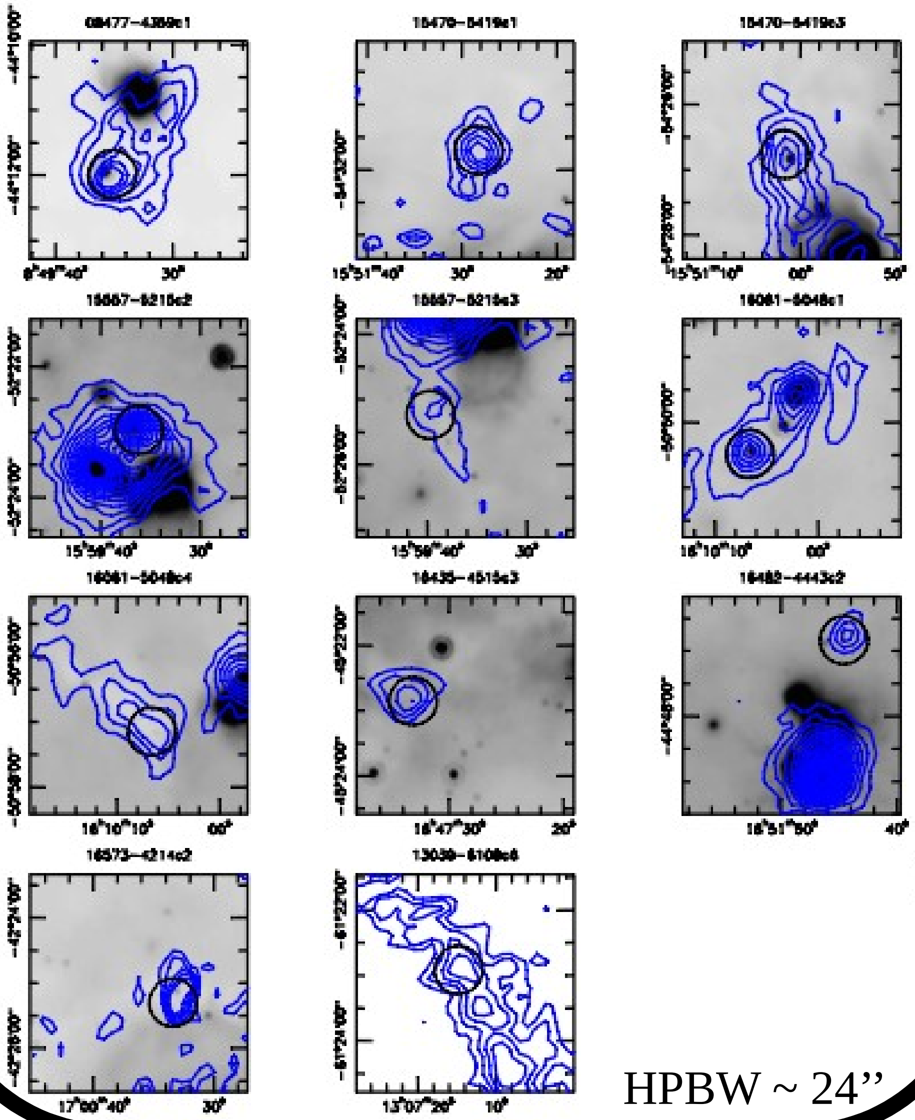
Table 1: *Sample of massive dense clumps and general properties: coordinates, distance, deconvolved angular diameter, gas mass, gas temperature, $H_2$ column density, mass surface density and CO depletion factor.*

| Source | R.A.(J2000) h m s | Dec.(J2000) $^\circ$ $'$ $''$ | $d$ kpc | $\theta_s$ $''$ | $M$ $M_\odot$ | $T_k$ 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

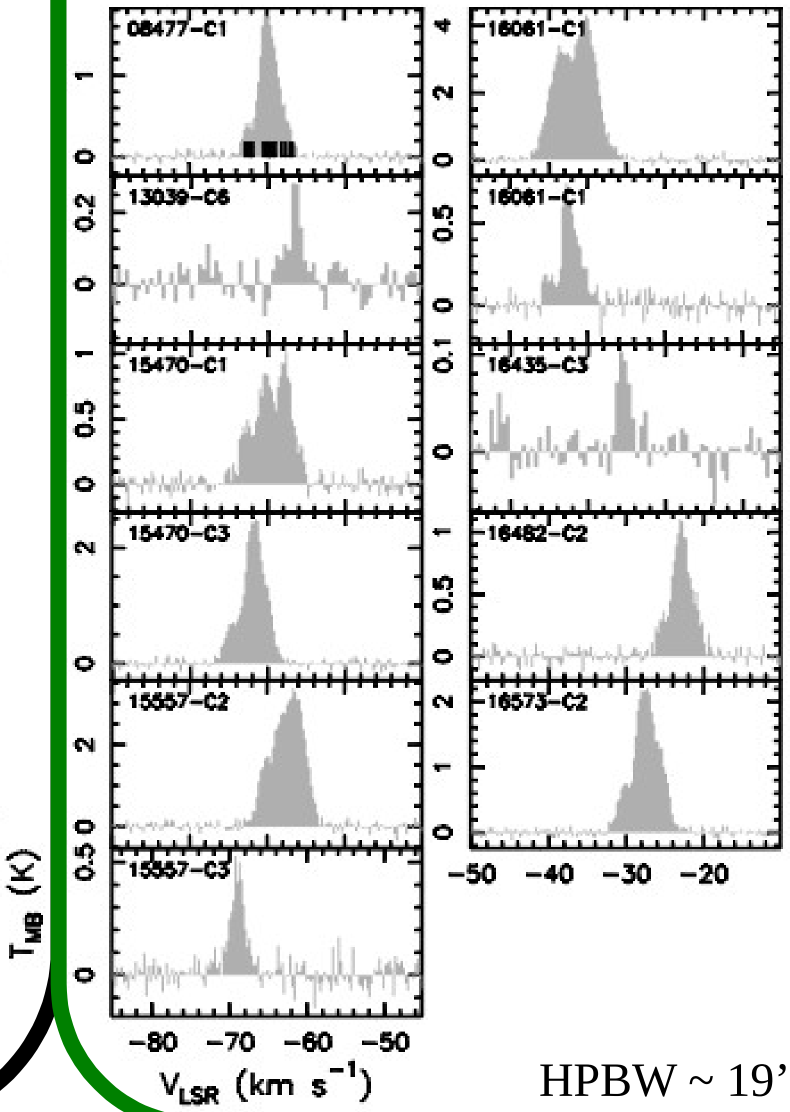
**SIMBA 1.2 mm** + **Spitzer 24 µm**
Beltrán+06, A&A, 423, 2342



HPBW ~ 24’’

## 4. Dense

APEX **$N_2H^+$(3-2)**, towards SIMBA peak
Fontani+12, MNRAS, 423, 2342



HPBW ~ 19’’

# *what we expected to see…*

**Fragmentation of a 100 $M_{\odot}$ core**

**RAMSES code**

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

**μ = 2 , dominant magnetic support**

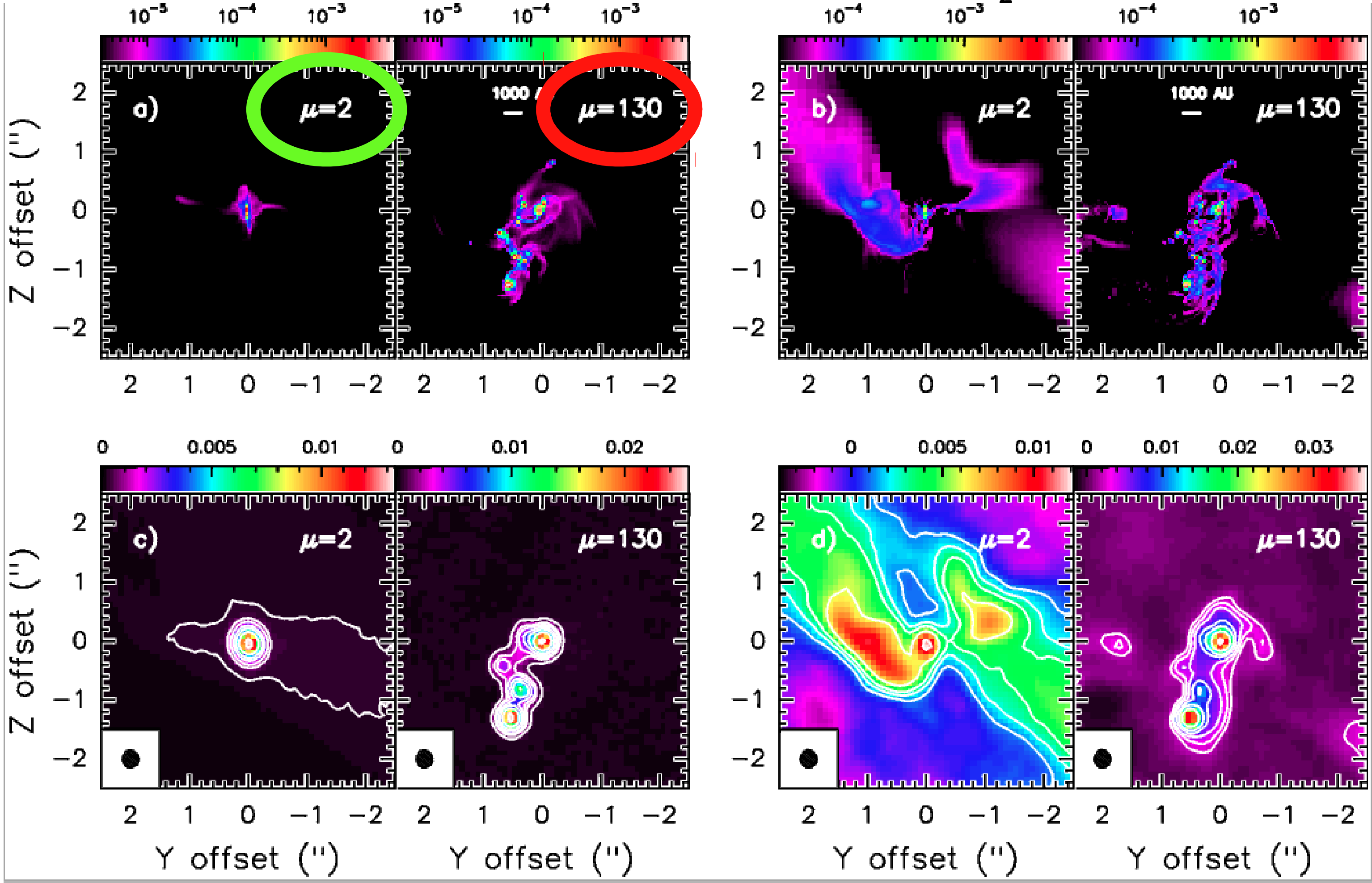
**μ = 130, faint magnetic support**

**Model output (Hennebelle+11, Commerçon+12)**

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

**280 GHz cont.**

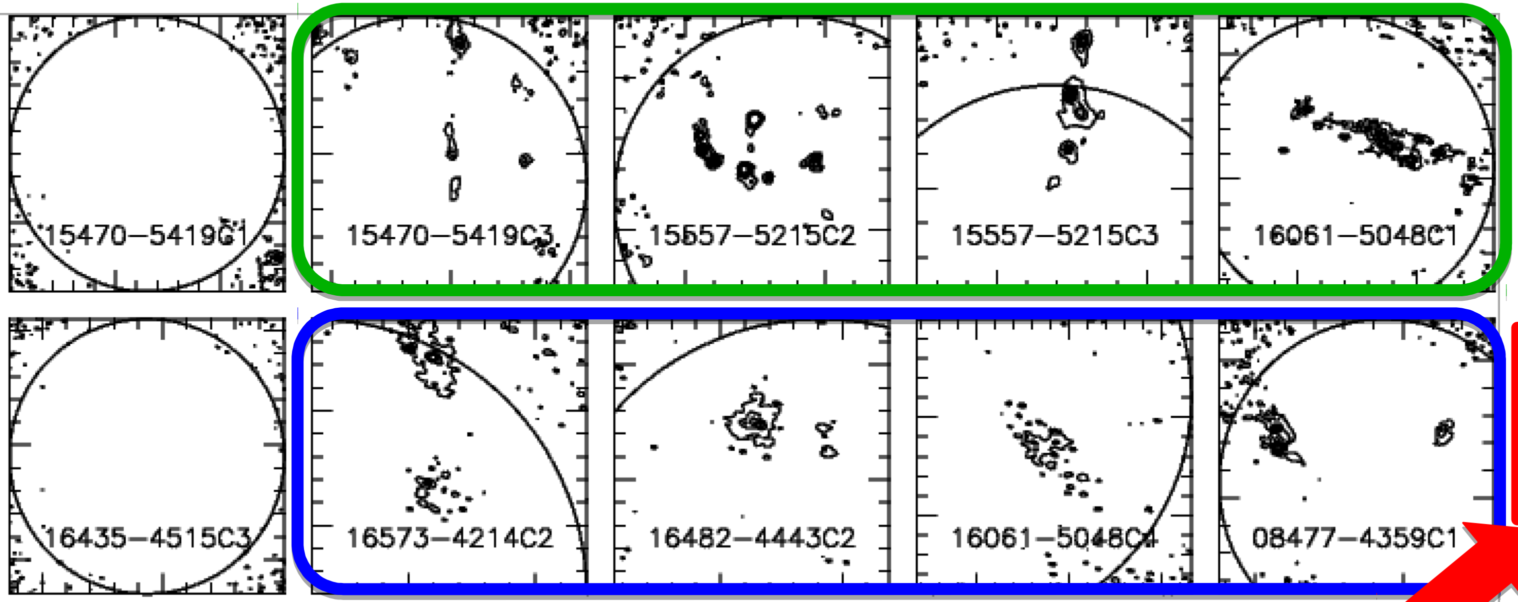
**$N_2H^+$ (3-2)**



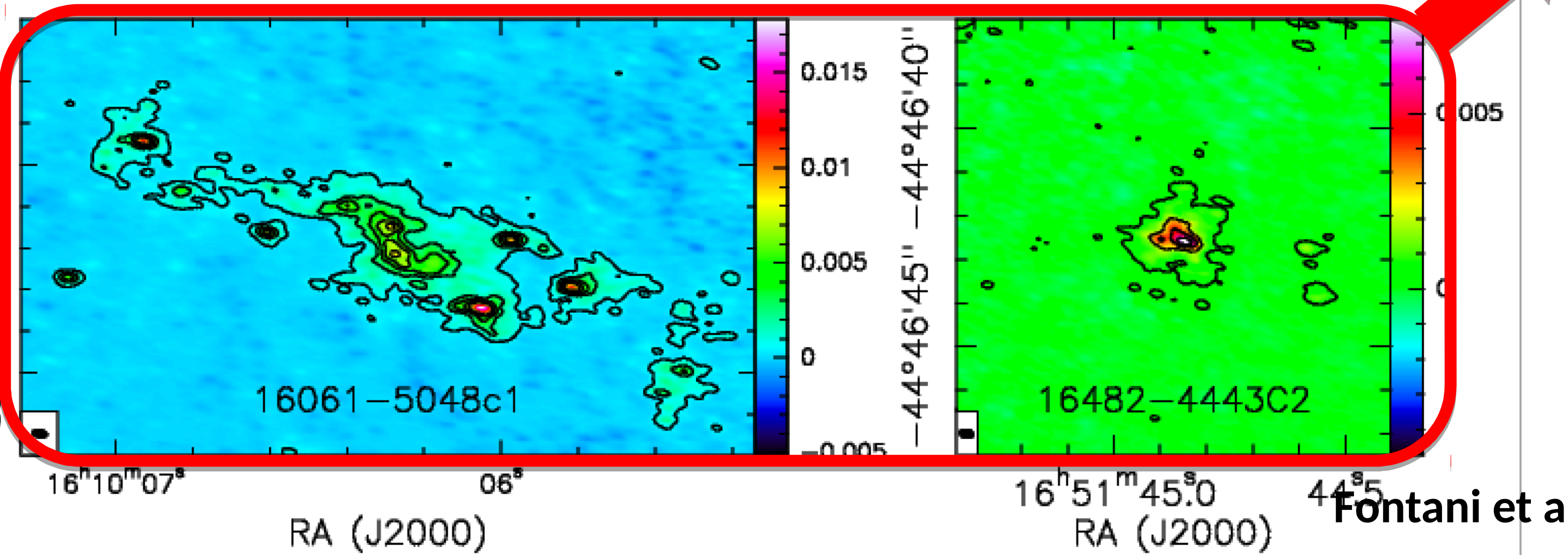
# ...and what we see: ALMA observations

## Continuum maps at 278 GHz

*Resolution*: θ~0.25''
*Sensitivity*: ~0.07 M$_{\odot}$



“extreme” cases:
- 12 fragments
- 4 fragments

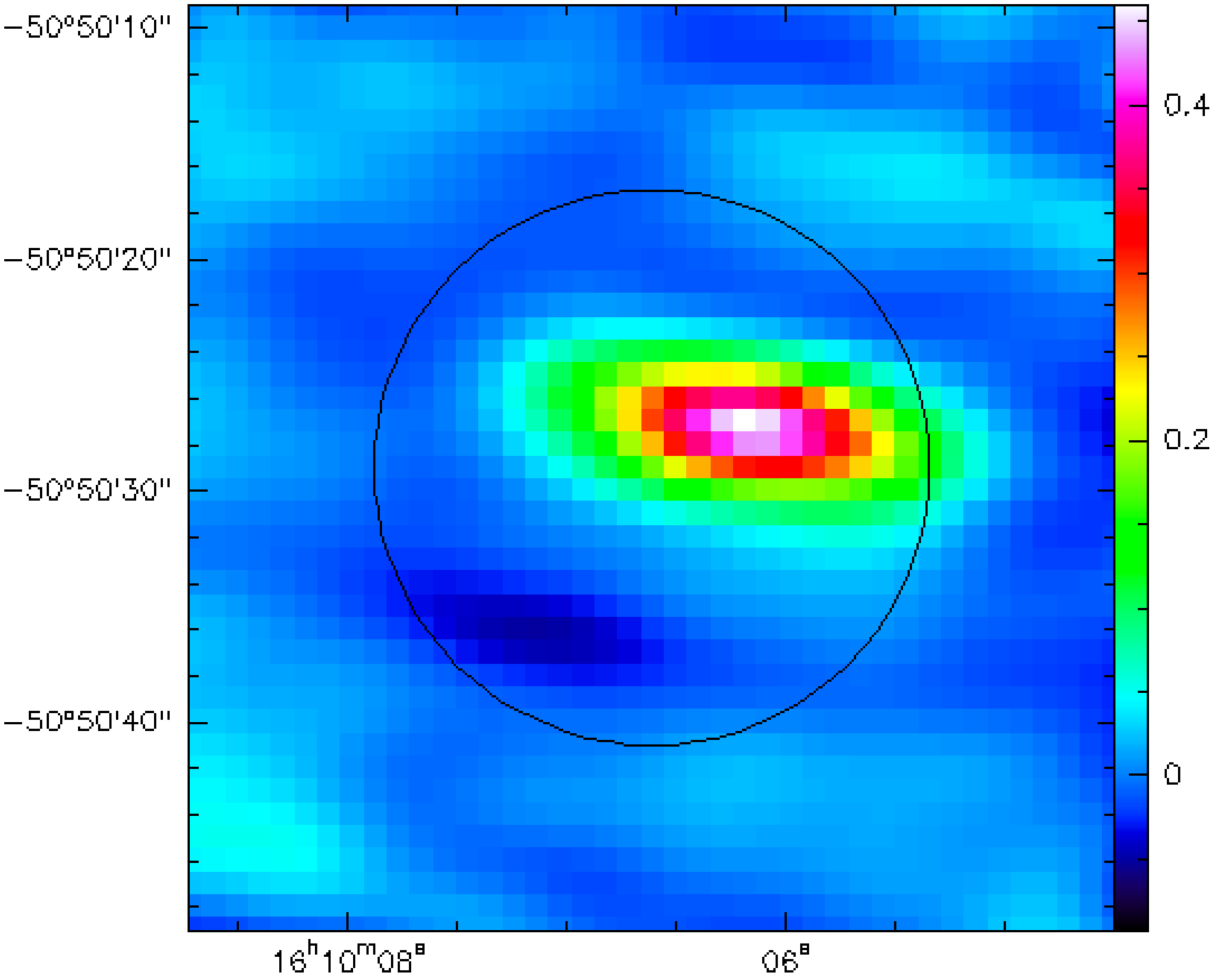


**Fontani et al. in preparation**

# …and what we see: ALMA-ACA

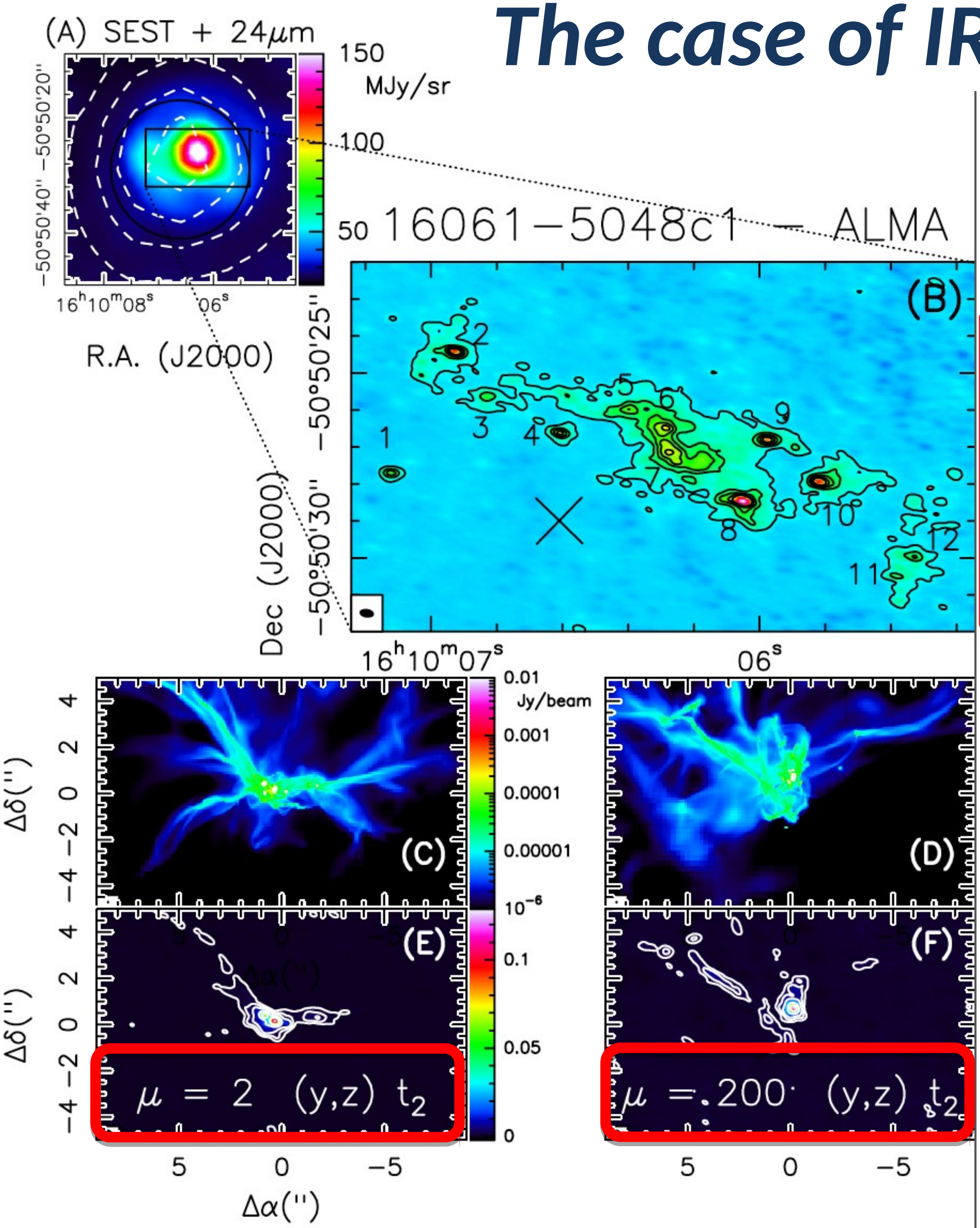
*Resolution*: θ~5.2''
*Sensitivity*: ~0.07 $M_\odot$

**IRAS 16061C1 at 278 GHz**



# *The case of IRAS 16061-5048C1*

**Fontani et al. 2016, A&A, 593, L14**



Despite many fragments, overall morphology more in line with strong magnetic support (μ=2)!!

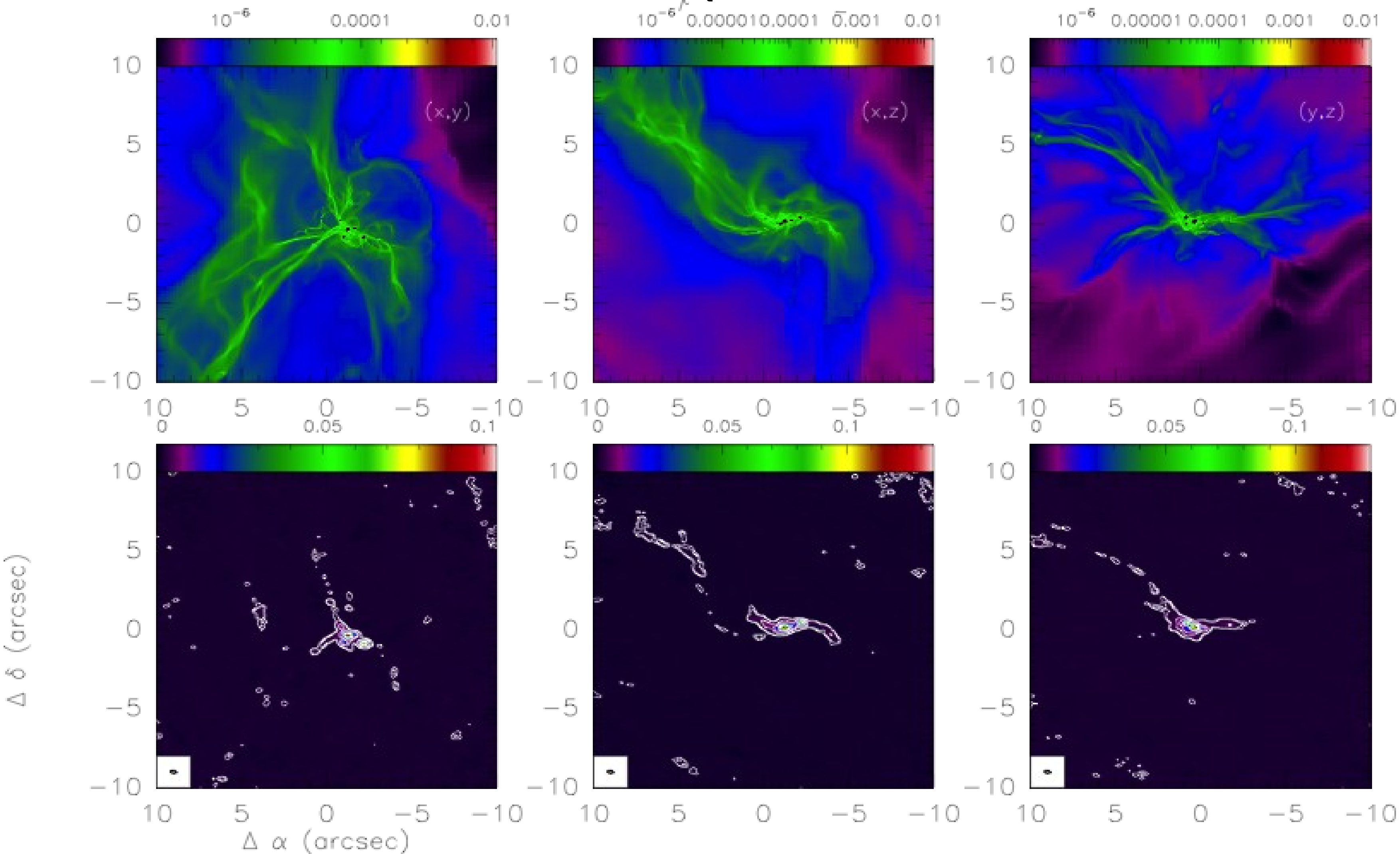
*Simulations run specifically for this clump:*

- M = 300 $M_{sun}$
- $T_k$ = 20 K
- Mach number = 6.44

# *The case of IRAS 16061-5048C1*

## Geometry: how this affect the (observed) fragmentation?

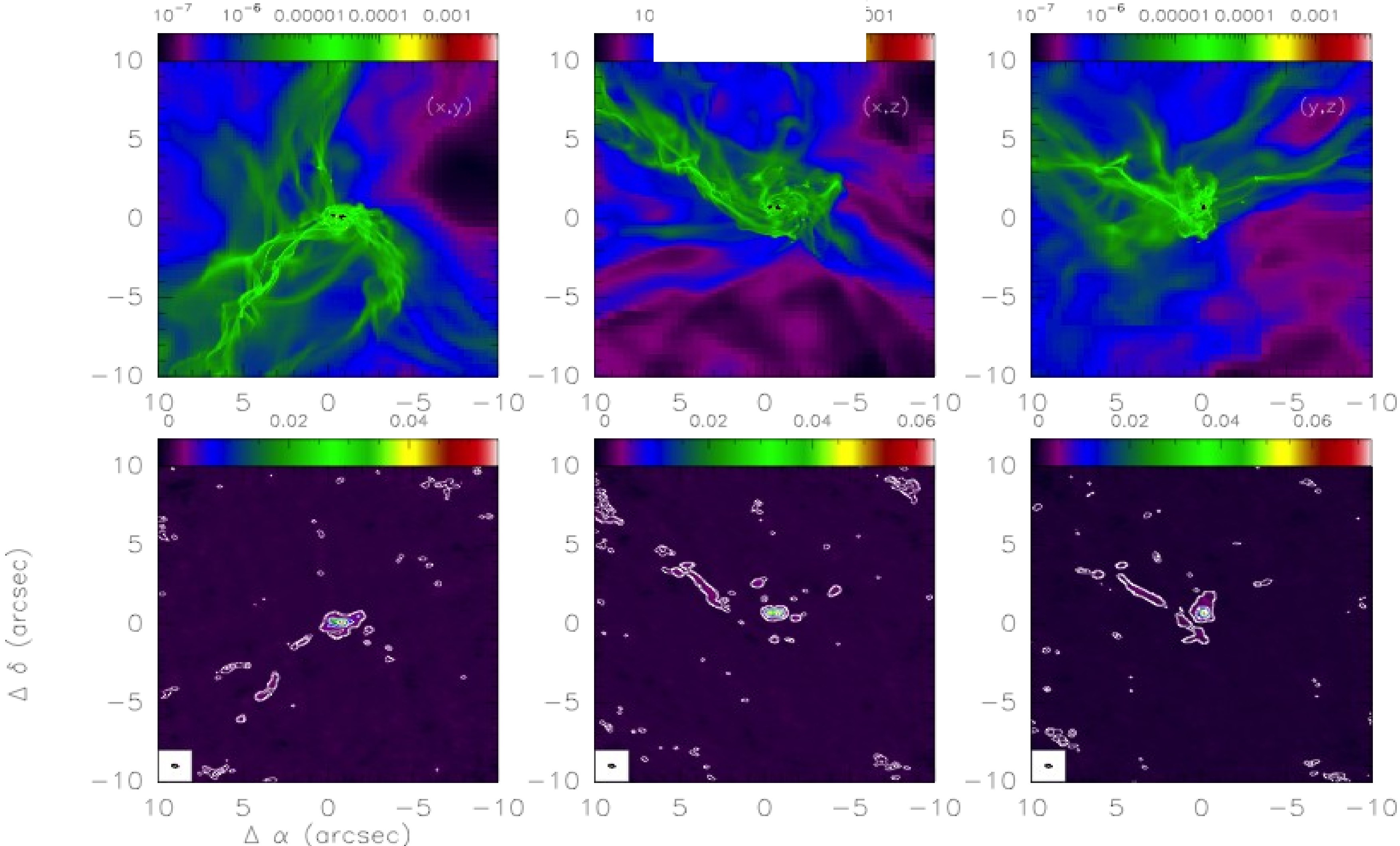
**μ = 2**



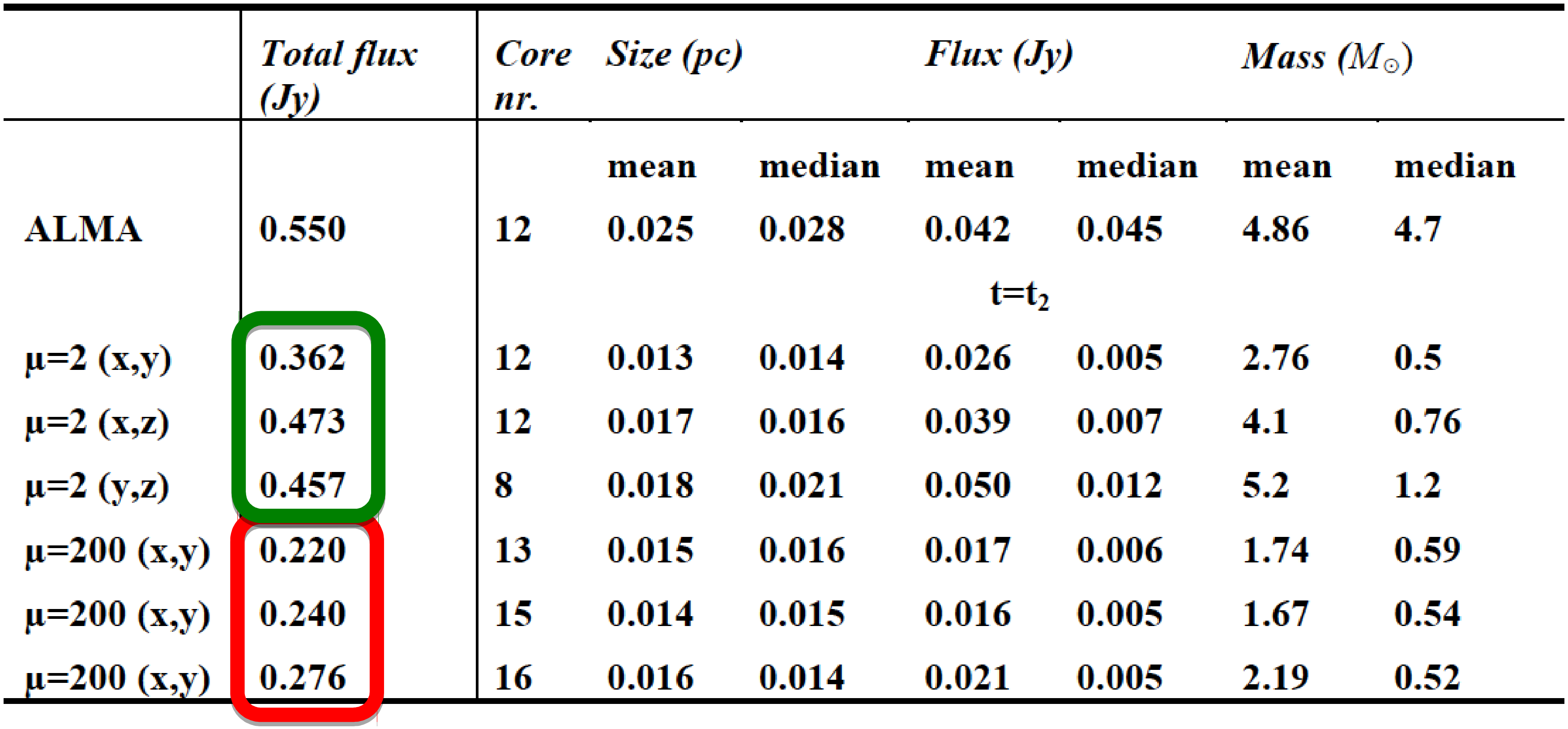
# The case of IRAS 16061-5048C1

**Geometry: how this affect the (observed) fragmentation?**

**μ = 200**

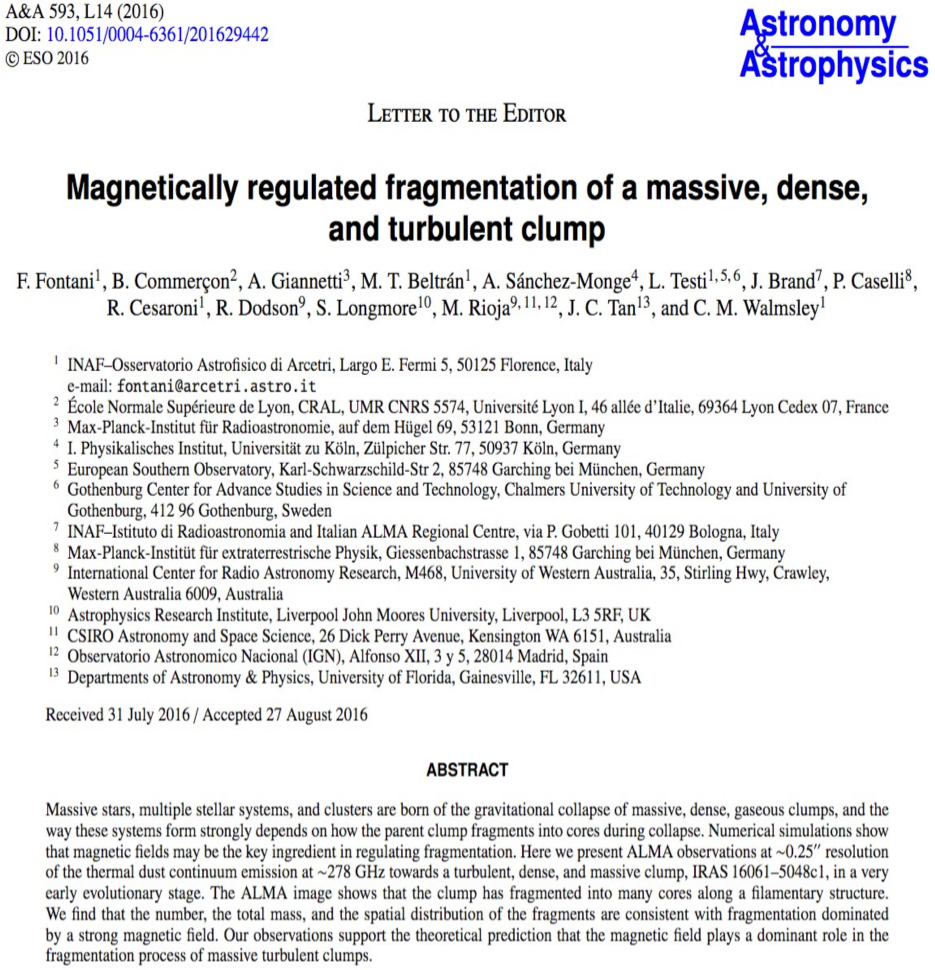


# The case of IRAS 16061-5048C1



| | *Total flux (Jy)* | *Core nr.* | *Size (pc)* | | *Flux (Jy)* | | *Mass ($M_\odot$)* | |
|---|---|---|---|---|---|---|---|---|
| | | | mean | median | mean | median | mean | median |
| **ALMA** | 0.550 | 12 | 0.025 | 0.028 | 0.042 | 0.045 | 4.86 | 4.7 |
| | | | | | $t=t_2$ | | | |
| μ=2 (x,y) | 0.362 | 12 | 0.013 | 0.014 | 0.026 | 0.005 | 2.76 | 0.5 |
| μ=2 (x,z) | 0.473 | 12 | 0.017 | 0.016 | 0.039 | 0.007 | 4.1 | 0.76 |
| μ=2 (y,z) | 0.457 | 8 | 0.018 | 0.021 | 0.050 | 0.012 | 5.2 | 1.2 |
| μ=200 (x,y) | 0.220 | 13 | 0.015 | 0.016 | 0.017 | 0.006 | 1.74 | 0.59 |
| μ=200 (x,y) | 0.240 | 15 | 0.014 | 0.015 | 0.016 | 0.005 | 1.67 | 0.54 |
| μ=200 (x,y) | 0.276 | 16 | 0.016 | 0.014 | 0.021 | 0.005 | 2.19 | 0.52 |

In the μ = 200 case, the fragments in the synthetic images NEVER reach the total flux observed
 Further indication in support of the strong magnetic case !



A&A 593, L14 (2016)
DOI: 10.1051/0004-6361/201629442
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LETTER TO THE EDITOR

## Magnetically regulated fragmentation of a massive, dense, and turbulent clump

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### ABSTRACT

Massive stars, multiple stellar systems, and clusters are born of the gravitational collapse of massive, dense, gaseous clumps, and the way these systems form strongly depends on how the parent clump fragments into cores during collapse. Numerical simulations show that magnetic fields may be the key ingredient in regulating fragmentation. Here we present ALMA observations at ~0.25″ resolution of the thermal dust continuum emission at ~278 GHz towards a turbulent, dense, and massive clump, IRAS 16061–5048c1, in a very early evolutionary stage. The ALMA image shows that the clump has fragmented into many cores along a filamentary structure. We find that the number, the total mass, and the spatial distribution of the fragments are consistent with fragmentation dominated by a strong magnetic field. Our observations support the theoretical prediction that the magnetic field plays a dominant role in the fragmentation process of massive turbulent clumps.

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ASTRONOMY

## Magnetism drives star birth

*Nature* **538**, 8 (06 October 2016) | doi:10.1038/538008b

**Subject terms:** Astronomy and astrophysics

Magnetic fields regulate how stars are born from massive clouds of interstellar gas.

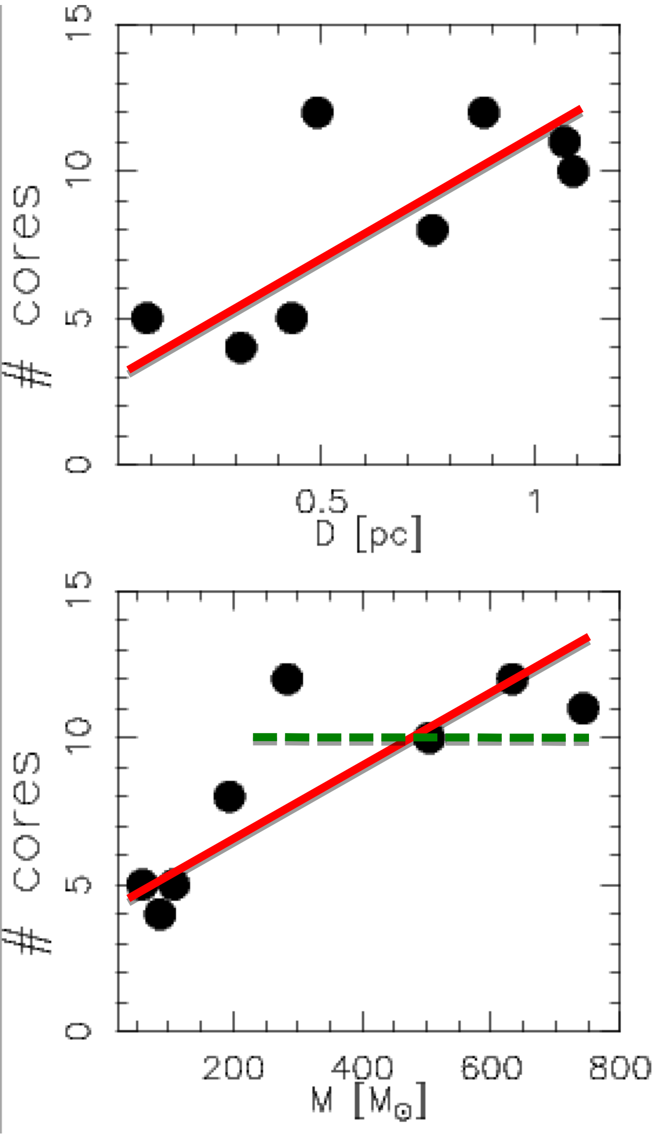
A team led by Francesco Fontani at the Arcetri Astrophysical Observatory in Florence, Italy, used high-resolution data from the Atacama Large Millimeter/submillimeter Array telescope in northern Chile to create detailed maps of a particular gas cloud. They found that the gas collapsed under the force of gravity and fragmented, forming a string of clumps that aligned themselves with the magnetic field. The clumps will eventually form the cores of future stars.

The study's findings confirm theoretical predictions that magnetic fields play a major part in where proto-stars form.

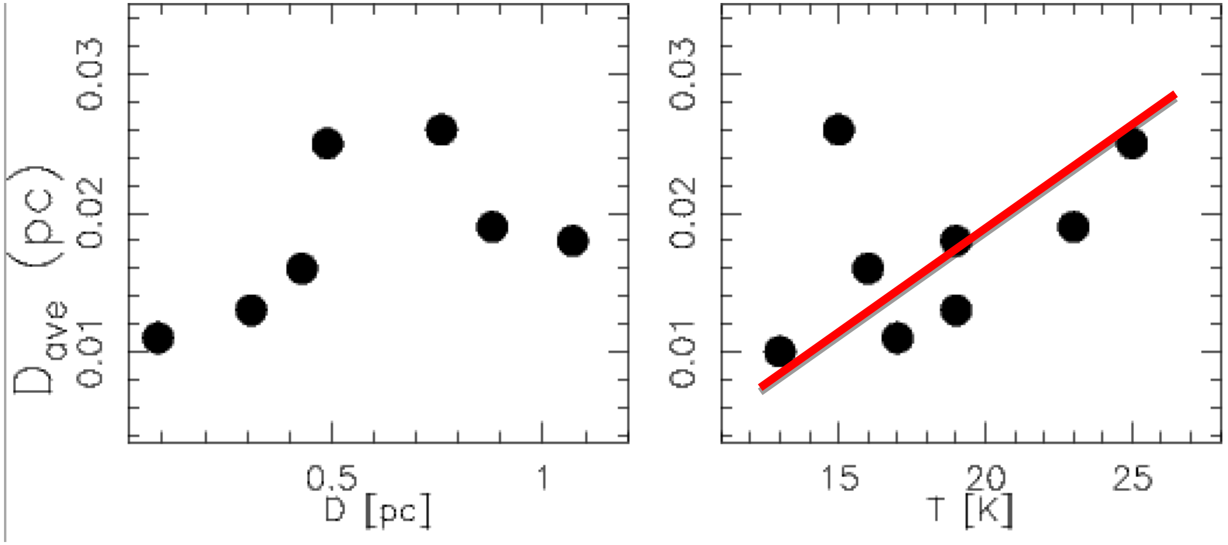
*Astron. Astrophys.* **593**, L14 (2016)

# *fragment population: some statistics*

# fragments vs core parameters



Average fragment Diameter vs core parameters



1- Larger and more massive cores tend to form more fragments

2- Larger and warmer cores tend to form larger fragments

**Fontani et al. in preparation**

# *Summary and conclusions*

1) Two populations of fragments:
   a) few fragments with a dominant one
   b) several (>10) fragments with similar masses

2) Larger and more massive cores form more fragments
   (# > 10 for M > $M_{\square}$)

3) The magnetic support can be dominant even for a
   highly fragmented clump
   □ appropriate initial conditions in models needed