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

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1. **PRE-STEellar PHASE:**

2. **PROTO-STEellar PHASE**

3. **PRE-MAIN SEQUENCE PHASE**

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*Shu, Adams & Lizano 1987*
**Astrophysical context and motivation**

Two relevant timescales in the standard theory:

\[ t_{\text{acc}} = \frac{M_*}{(dM/dt)} \]

\[ t_{\text{K-H}} = \frac{GM_*^2}{R_*L_*} \]

- \( M_* < 8M_\odot \): \( t_{\text{acc}} < t_{\text{K-H}} \) \quad \text{pre-main sequence: YES}
- \( M_* > 8M_\odot \): \( t_{\text{acc}} > t_{\text{K-H}} \) \quad \text{pre-main sequence: NO}
- accretion on MS !
**Basic Problem of the Standard Model:**

The radiation pressure of the "embryo star" stops accretion when $M_* > 8 M_{\text{sun}}$ cannot form.

**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

*Fragmentation of the parent clump crucial.*
Fragmentation influenced by:

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

Gravity vs Magnetic support

Intrinsic turbulence

Protostellar feedback
Astrophysical context and motivation

Predictions of theoretical models:
(Hennebelle et al. 2011; Commerçon et al. 2012)

\[ \mu = \frac{(M/\Phi)}{(M/\Phi)_{\text{crit}}} \]

- \( \mu = 2 \), dominant magnetic support
- \( \mu = 130 \), faint magnetic support

Core separation \( \sim 1000 \) 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)

$\mu = 2$, dominant magnetic support  \hspace{1cm}  \mu = 130$, faint magnetic support

$\Rightarrow$ 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

\[ T < 20 \text{ K} \]
\[ n(H_2) > 10^5 \text{ cm}^{-3} \]

High CO (and CS) DEPLETION FACTOR

\[ f_D = \frac{X(\text{CO})_{T}}{X(\text{CO})_{O}} > 1 \]

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

<table>
<thead>
<tr>
<th>Source</th>
<th>R.A.(J2000)</th>
<th>Dec.(J2000)</th>
<th>d</th>
<th>$\theta_s$</th>
<th>$M$</th>
<th>$T_k$</th>
<th>$N(H_2)$</th>
<th>$\Sigma(H_2)$</th>
<th>$f_{CO}$</th>
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</thead>
<tbody>
<tr>
<td>08477–4359c1</td>
<td>08:49:35.13</td>
<td>-44:11:59</td>
<td>1.8</td>
<td>35.6</td>
<td>86.73</td>
<td>19</td>
<td>1.42</td>
<td>0.24</td>
<td>7</td>
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<tr>
<td>13039–6108c6</td>
<td>13:07:14.80</td>
<td>-61:22:55</td>
<td>2.4</td>
<td>40.3</td>
<td>101.5</td>
<td>17</td>
<td>0.68</td>
<td>0.12</td>
<td>22</td>
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<tr>
<td>15470–5419c1</td>
<td>15:51:28.24</td>
<td>-54:31:42</td>
<td>4.1</td>
<td>24.2</td>
<td>310.2</td>
<td>18</td>
<td>1.37</td>
<td>0.36</td>
<td>35</td>
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<tr>
<td>15470–5419c3</td>
<td>15:51:01.62</td>
<td>-54:26:46</td>
<td>4.1</td>
<td>54.1</td>
<td>743.4</td>
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<td>1.11</td>
<td>0.17</td>
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<td>15557–5215c2</td>
<td>15:59:36.20</td>
<td>-52:22:58</td>
<td>4.4</td>
<td>41.3</td>
<td>633.4</td>
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<tr>
<td>15557–5215c3</td>
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<td>-52:25:14</td>
<td>4.4</td>
<td>35.8</td>
<td>194.3</td>
<td>15</td>
<td>0.49</td>
<td>0.09</td>
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<tr>
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<td>16:10:06.61</td>
<td>-50:50:29</td>
<td>3.6</td>
<td>28.1</td>
<td>284.3</td>
<td>25</td>
<td>1.66</td>
<td>0.31</td>
<td>12</td>
</tr>
<tr>
<td>16061–5048c4</td>
<td>16:10:06.61</td>
<td>-50:57:09</td>
<td>3.6</td>
<td>62.8</td>
<td>504.2</td>
<td>13</td>
<td>1.22</td>
<td>0.11</td>
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<tr>
<td>16435–4515c3</td>
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<td>-45:22:51</td>
<td>3.1</td>
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<tr>
<td>16482–4443c2</td>
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<td>-44:46:50</td>
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<td>$\ll 24^a$</td>
<td>59.08</td>
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<td>108.3</td>
<td>17</td>
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</tbody>
</table>

3. Not blended

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

<table>
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<th>HPBW ~ 24”</th>
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4. Dense

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

<table>
<thead>
<tr>
<th>HPBW ~ 19”</th>
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</thead>
</table>
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- $N_2H^+ (3-2), n_{crit} \sim 3 \times 10^6 \text{ cm}^{-3}$

**Instrument configuration:** C32-5, $\theta\sim0.27''$ @ 280 GHz

**Integration time:** 20 minutes o. s. (3$\sigma\sim0.27$ mJy, i.e. 0.07 $M_\odot$)
$\mu = \frac{(M/\Phi)/(M/\Phi)}{\text{crit}}$

$\mu = 2$, dominant magnetic support

$\mu = 130$, faint magnetic support

What we expect to see…
Project postponed to cycle-2......