Probing the earliest stages of massive star formation in cluster-forming clumps

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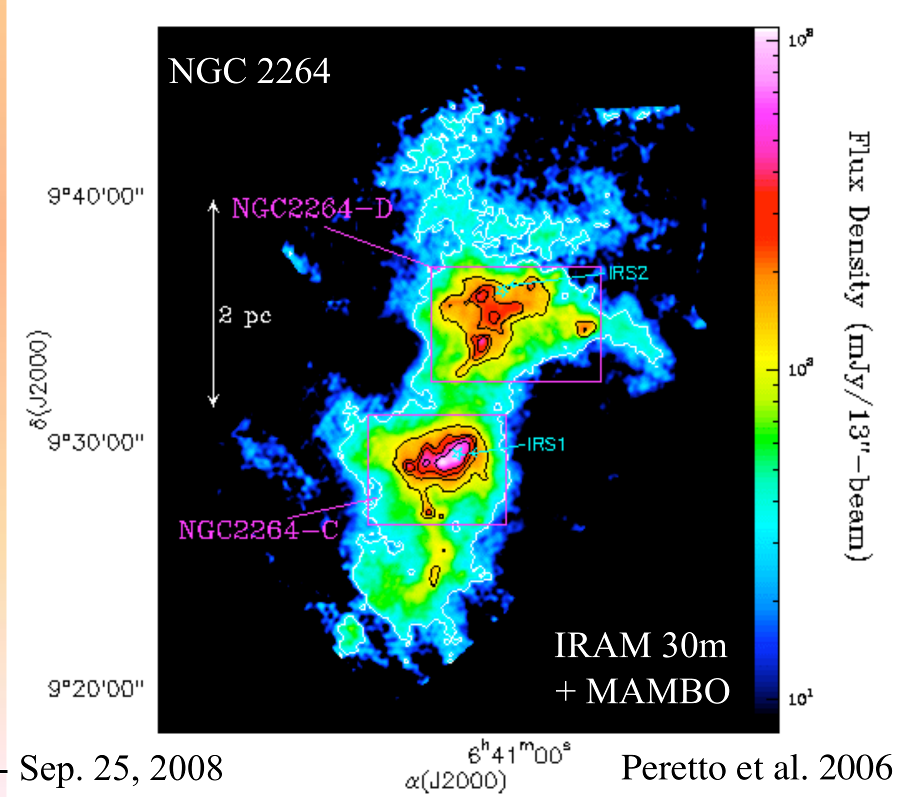
Outline:

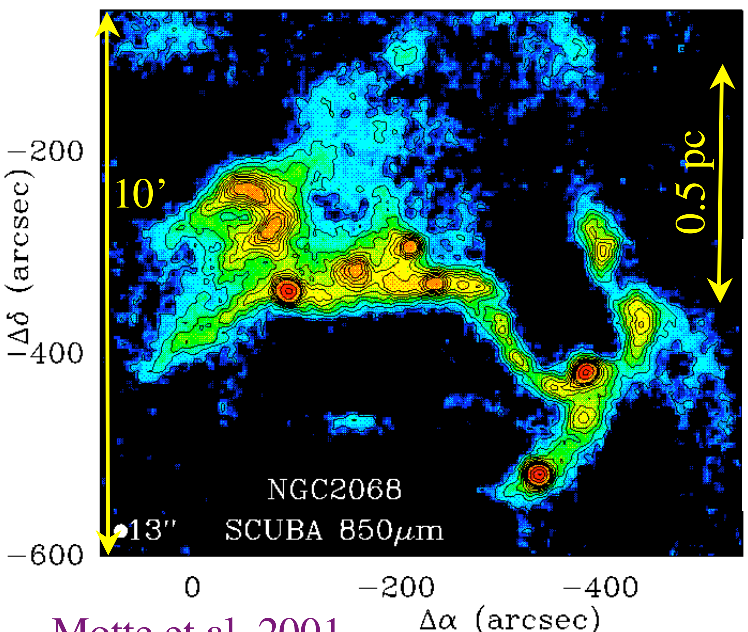
- Introduction: protocluster condensations
- Subvirial core-core motions
- Evidence of large-scale collapse in NGC 2264C
- Implications



Peretto et al. 2006

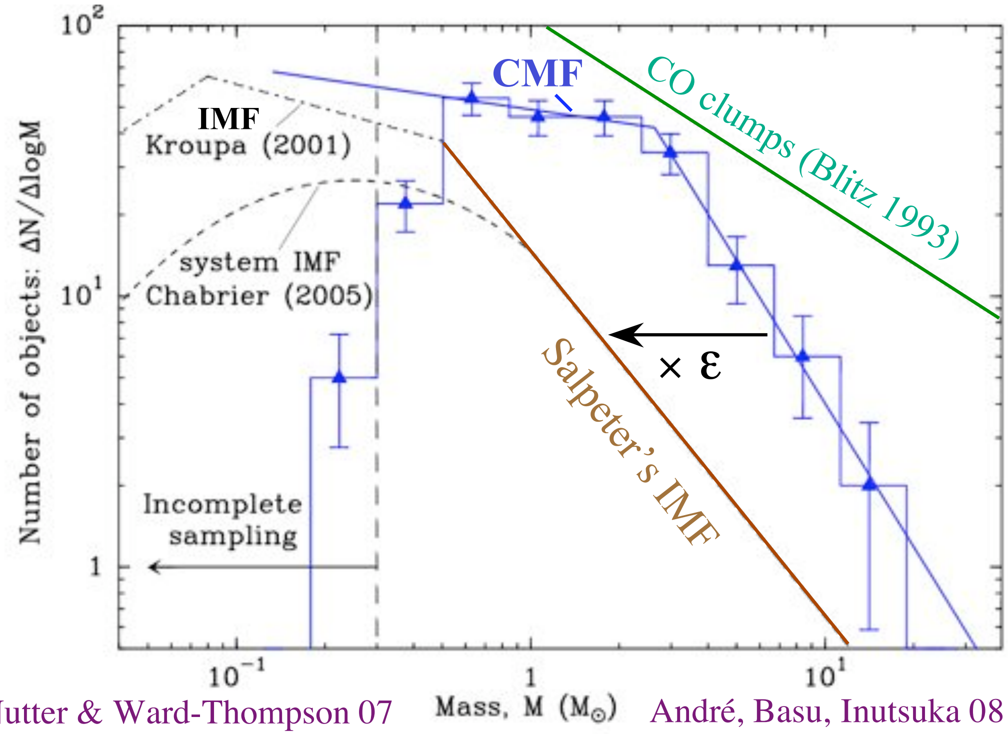
The prestellar core mass function (CMF) in protoclusters resembles the IMF

NGC2068 (Orion B) at 850 μm



Motte et al. 2001

Prestellar Core Mass Function (CMF) in Orion



Nutter & Ward-Thompson 07   André, Basu, Inutsuka 08

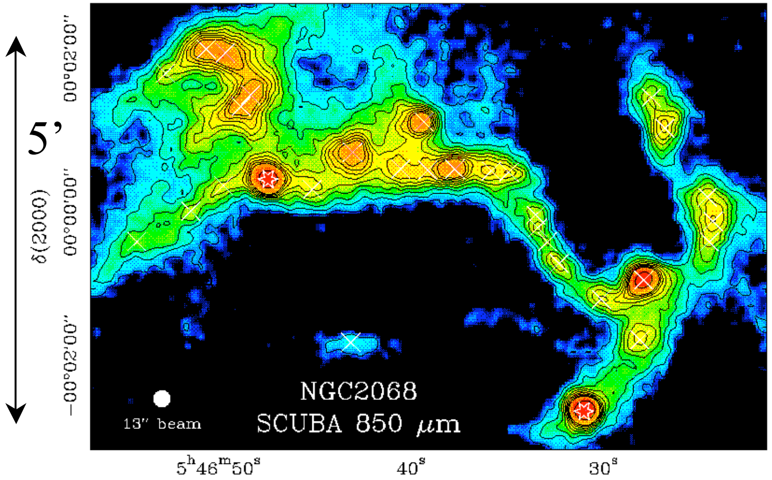
➜ The IMF is at least partly determined by pre-collapse cloud fragmentation between $M_* \sim 0.1$ and $\sim 5\ M_\odot$

See also: Motte, André, Neri 1998; Testi & Sargent 1998; Johnstone et al. 2000, 2001; Beuther & Schilke 2004; Stanke et al. 2006; Enoch et al. 2006; Reid & Wilson 2006

➜ One-to-one correspondence between core mass and stellar mass $M_* = \varepsilon\, M_{core}$ with $\varepsilon \sim 0.2$-0.5 (?) (cf. turbulent fragmentation scenario Padoan & Nordlund 2002, Hennebelle & Chabrier 2008)

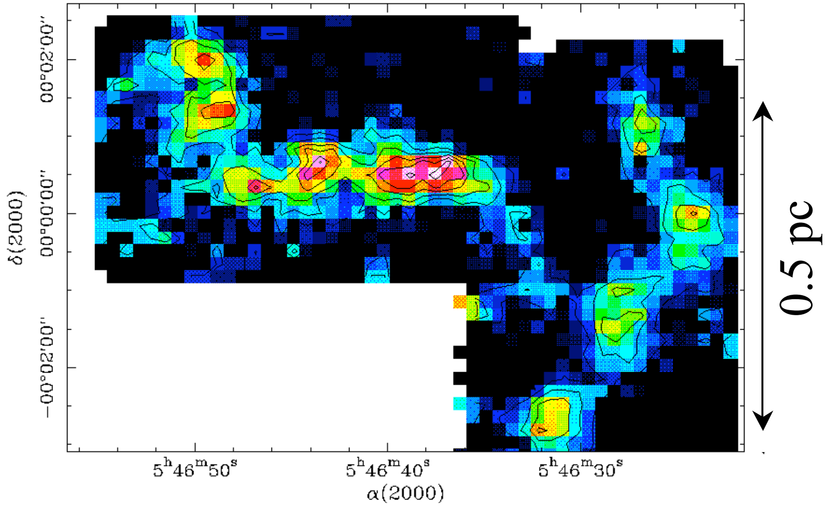
Relative motions of prestellar condensations in protoclusters

NGC2068 - 850 μm continuum (JCMT)



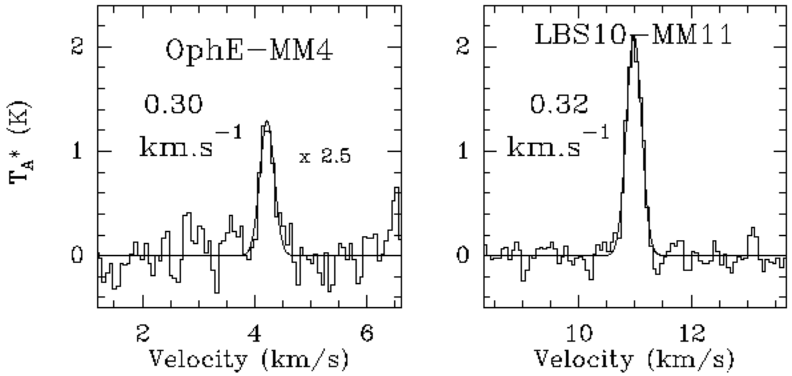
Motte et al. 2001

NGC2068 in N_2H^+(1-0) (IRAM 30m)



Narrow N_2H^+(101-012) lines ($\Delta V < 0.5$ km/s)

➜ Self-gravitating condensations ($M_{smm} \sim M_{vir}$)



André, Belloche, Motte, Peretto 2007, A&A

Subvirial core-core velocity dispersion:

$\sigma_{3D} \sim 0.65$ km/s $< \sigma_{VIR} \sim 2.1$ km/s

for both NGC 2068 and ρ Oph (25+41 objects)

➜ **Collision time ~ Crossing time**:

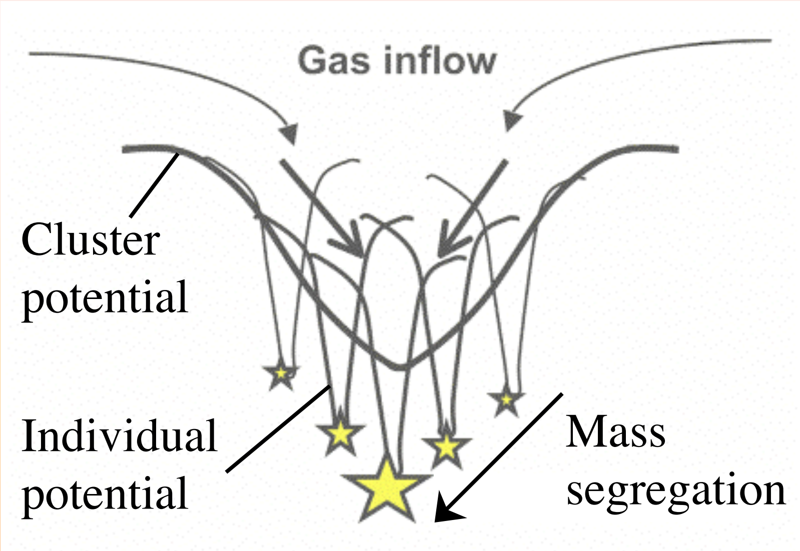
$D/\sigma_{3D} \sim 1\text{-}2 \times 10^6$ yr

>> condensation lifetime ~ $1\text{-}5 \times 10^5$ yr

➜ Not enough time for dynamical interactions

➜ Global contraction of protoclusters ?

Comparison with the competitive accretion picture



(e.g. Bonnell et al. 2001, Bate & Bonnell 2005)

$\dot{M}_{acc} \sim \pi \, \rho_{back} v_{rel} R_{acc}^{2}$ (cf. Bonnell et al. 2001)

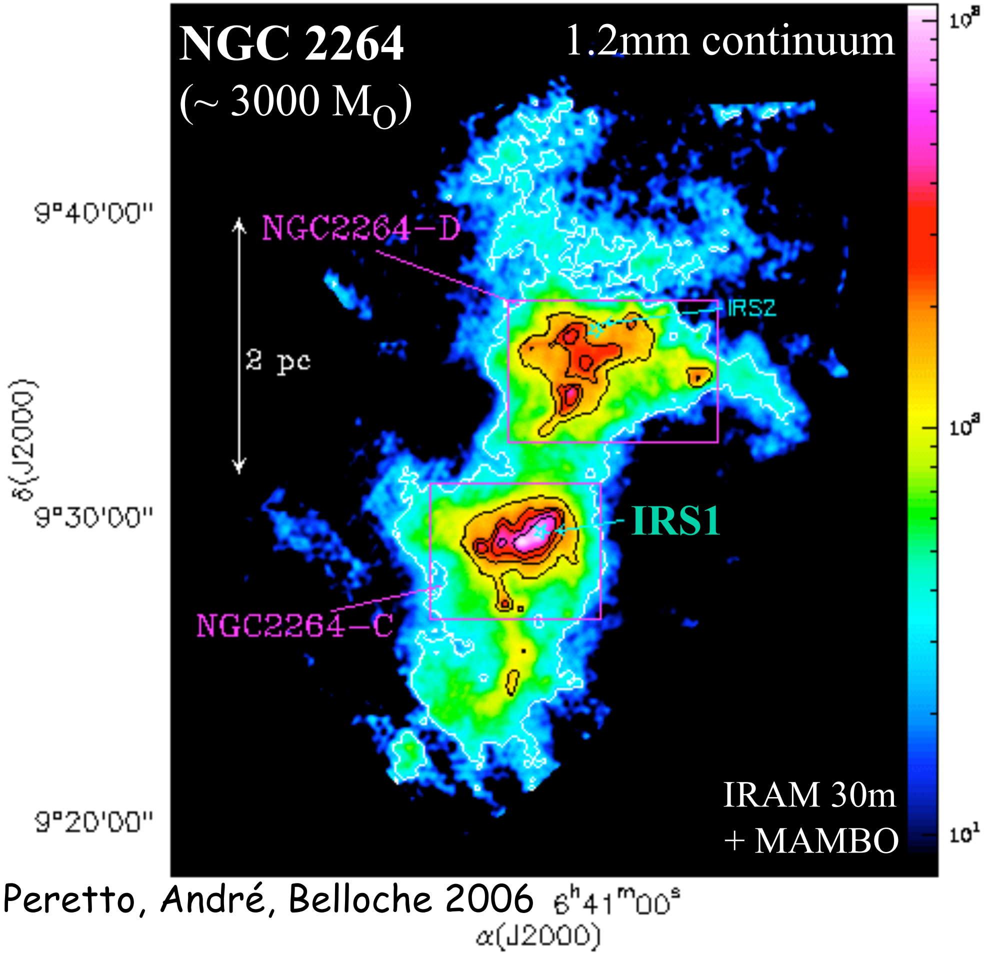
$\rightarrow \dot{M}_{acc} \lesssim 10^{-6} \, M_{o}/yr < a_{eff}^{3}/G$ **in ρ Oph cluster**

(André et al. 2007)

$n_{back} \sim 10^{5}$ cm^{-3}
$v_{rel} \sim 0.3$ km/s
$R_{acc} \sim 3000$ AU

- **Unlikely to be dominant at protostellar stage (Class 0/I): $\dot{M}_{acc}$ too low compared to $\dot{M}_{inf}$ from collapse** (see also Krumholz et al. 2005)
- **May possibly govern the growth of starless condensations produced by gravoturbulent fragmentation toward an IMF-like mass spectrum**

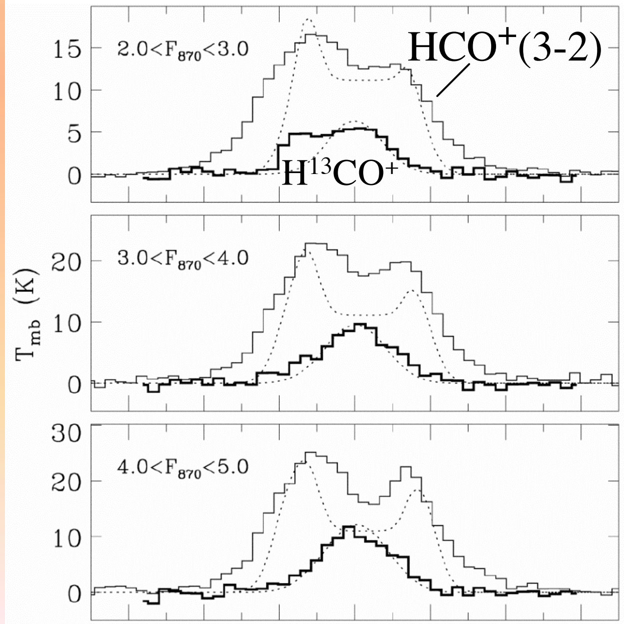
Global contraction and central interactions in protoclusters: The example of NGC2264-C in Mon OB1 (d~800 pc)



Peretto, André, Belloche 2006

- Cluster-forming region (cf. Lada & Lada 2003)
- Has already formed massive stars (e.g. IRS1: B2 ZAMS)

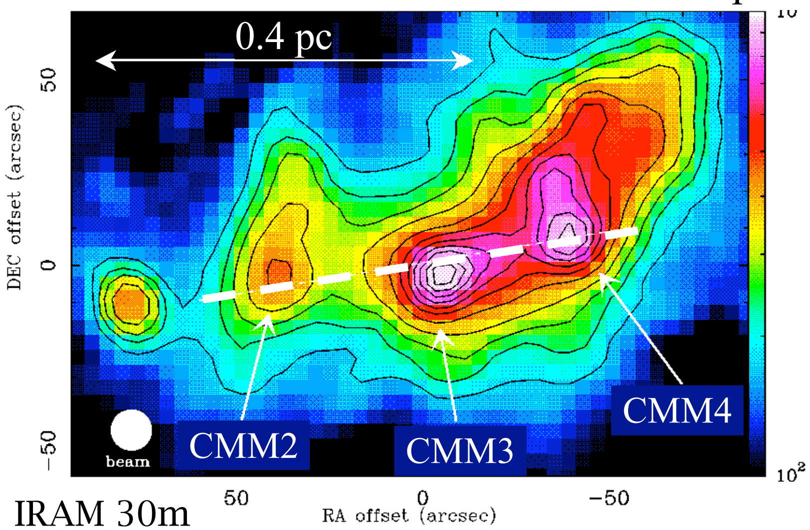
Large-scale infall in C & D (Williams & Garland 2002)



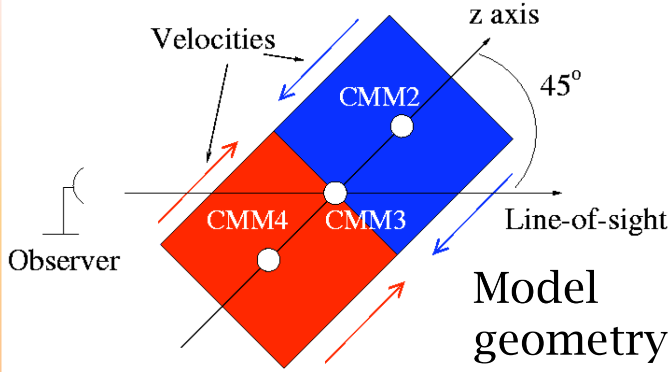
Evidence of large-scale collapse and central dynamical interactions in the NGC2264-C protocluster

(Peretto, André, Belloche 2006, A&A, 445, 979)

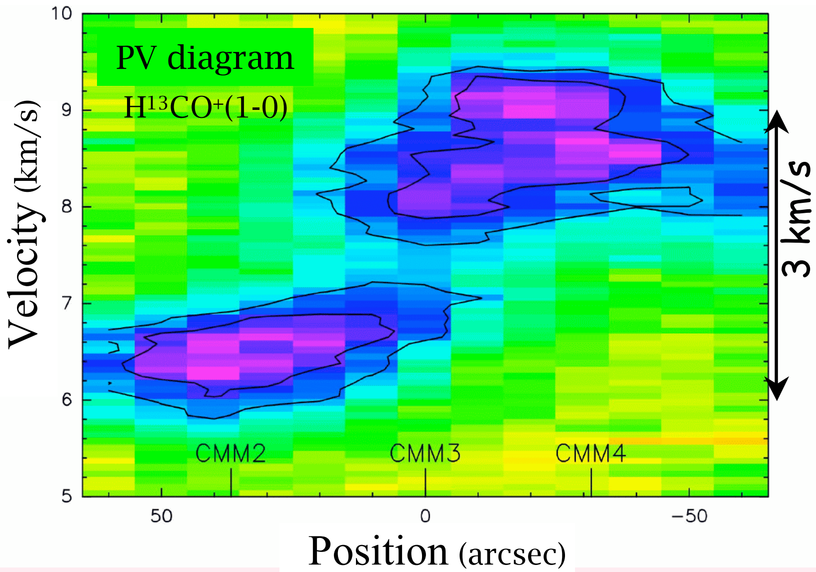
NGC2264C: 1.2mm continuum map



A ~ 1600 M_o cluster-forming clump with several Class 0 objects and widespread infall motions



Sharp central discontinuity in velocity



$M = 15 + 40 + 35 = 90\ M_o$

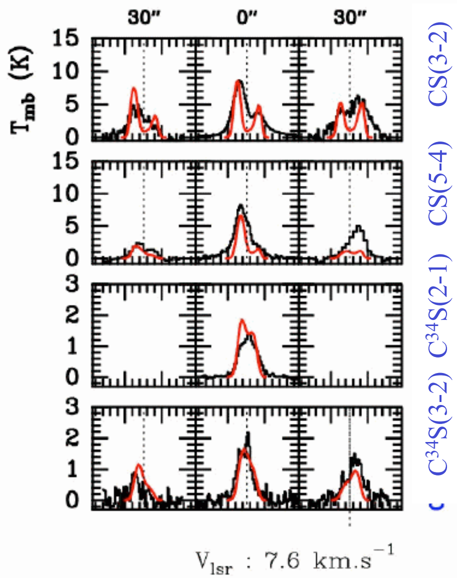
$V_{inf} = 1.5$ km/s

↓

Potential formation of massive core by merging of 3 Class 0 objects ?

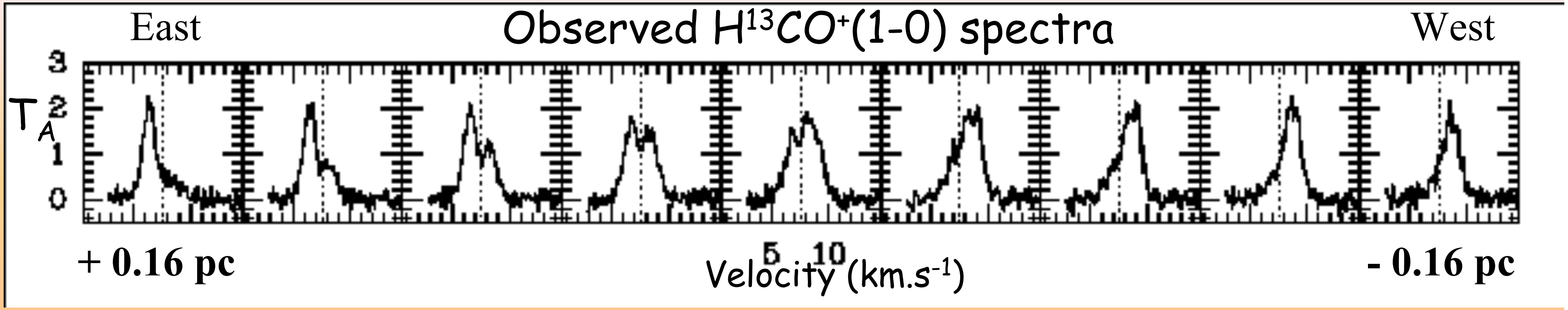
(cf. Bonnell et al. 1998)

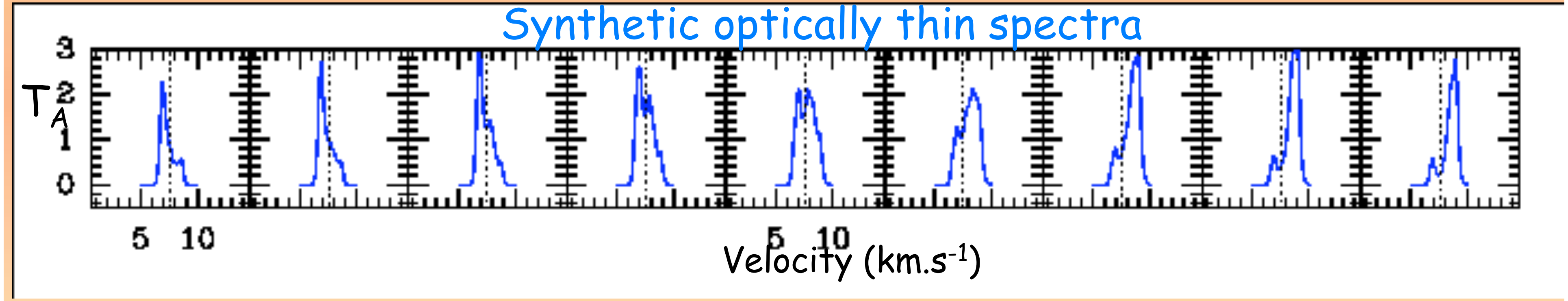
CS line profiles with radiative transfer



Model of large-scale axial collapse

Observed vs. synthetic spectra along the long axis of NGC2264-C



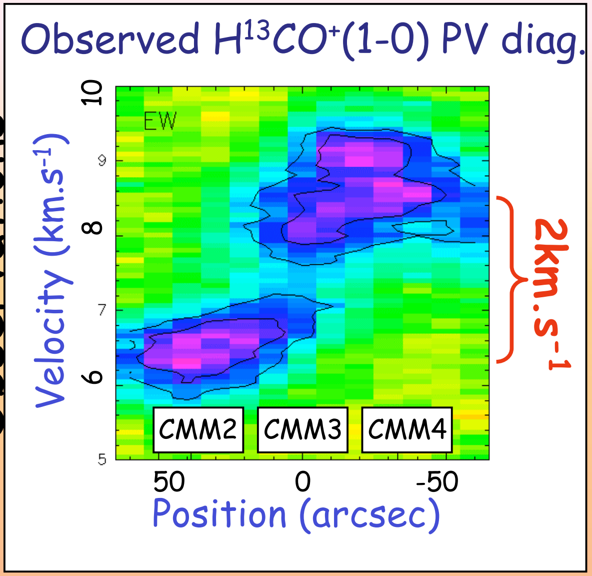


→ Estimated total infall inflow rate toward C-MM3:

$\dot{M}_{inf} \sim 3 \times 10^{-3}\ M_\odot/yr$ **(Peretto et al. 2006)**

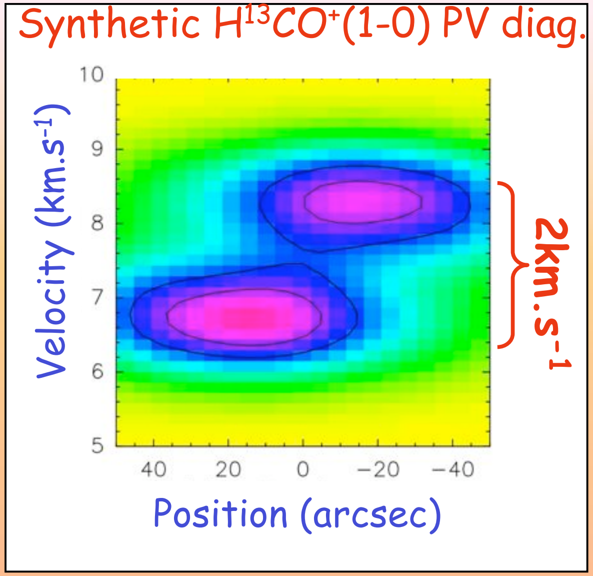
Collapse rather than rotation

Observations

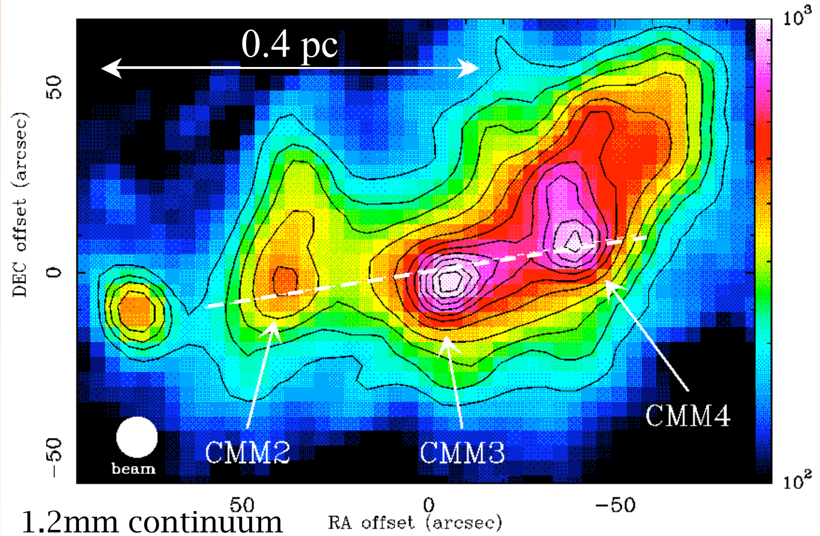


Collapse

Radiative Transfer



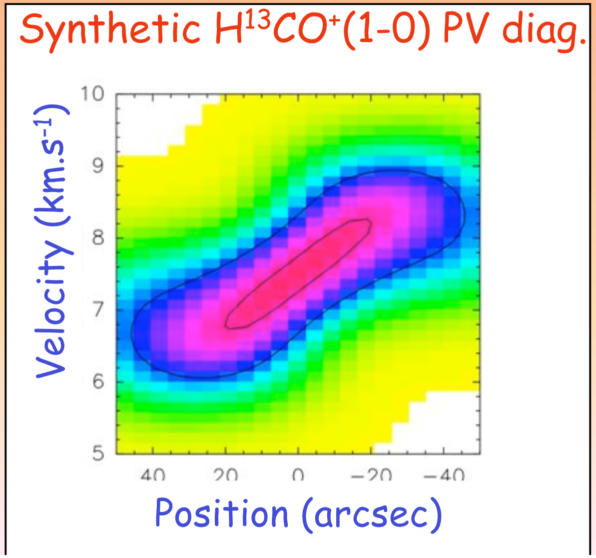
A rotating edge-on toroid ?



1.2mm continuum

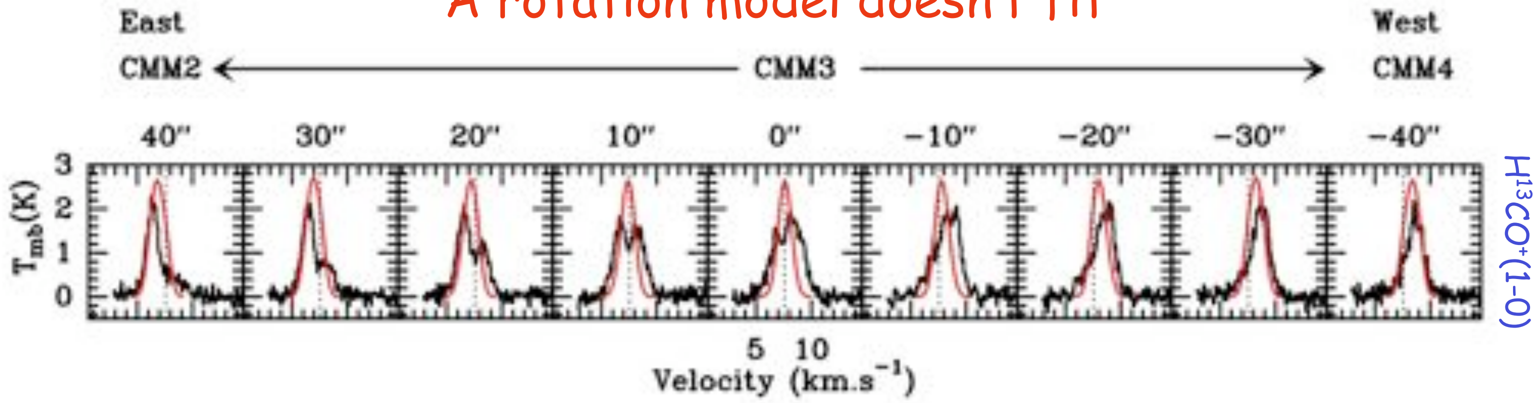
Rotation

Radiative Transfer

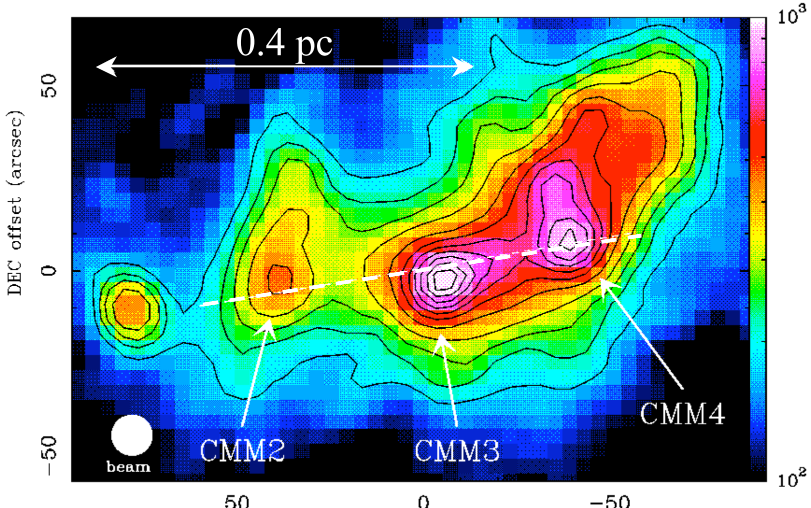


Collapse rather than rotation

A rotation model doesn't fit



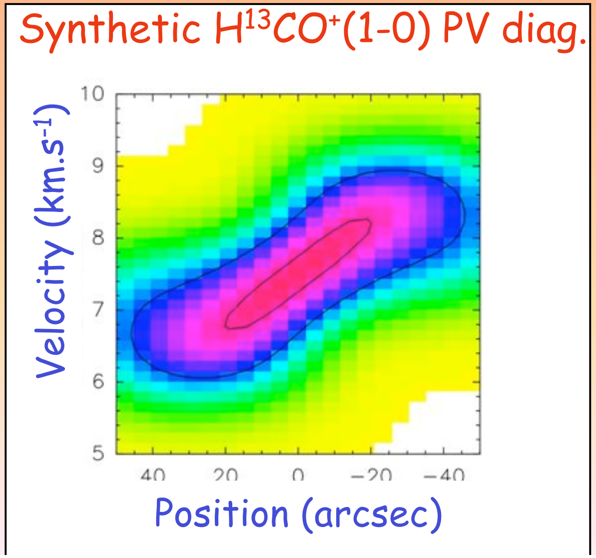
A rotating edge-on toroid ?



1.2mm continuum

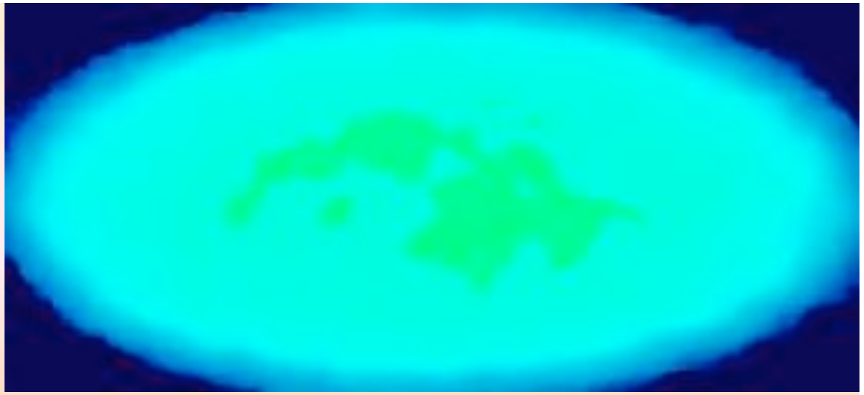
Radiative Transfer

Rotation



Comparison with SPH collapse simulations of a Jeans-unstable ellipsoidal clump

Peretto, Hennebelle, André 2007, A&A, 464, 983



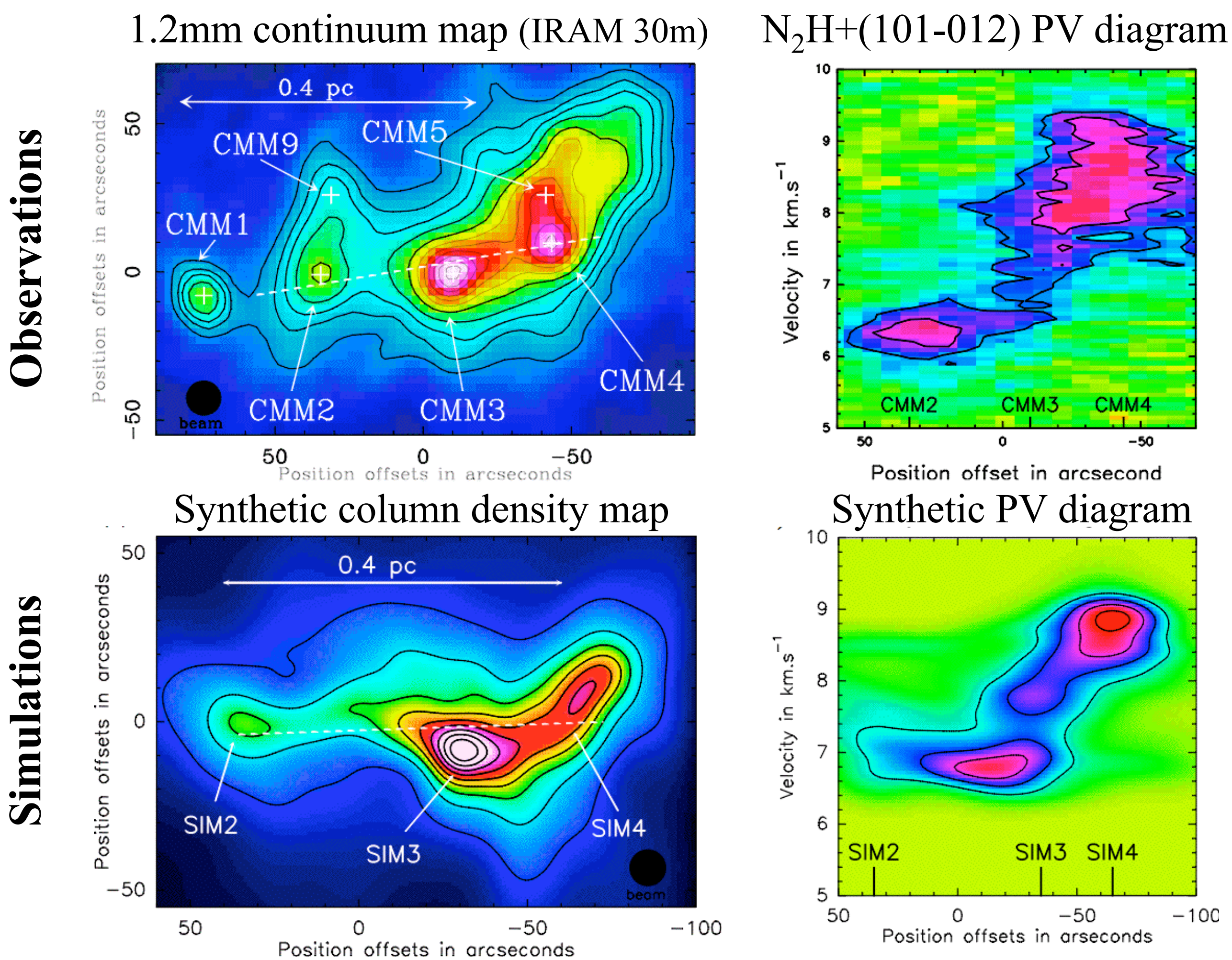
Potential formation of massive ($M > 50\ M_o$) core by merging of > 3 Class 0 objects

Total inflow rate:

$\dot{M}_{inf}\sim 3\times10^{-3}\ M_O/yr$

With ALMA:

Similar studies possible in more distant, more massive protoclusters



Conclusions

- **Problem with turbulent core model (McKee & Tan 2003):**

➢ Direct evidence that some young protoclusters are far from virial equilibrium and in a state of large-scale, global contraction.

- **Problems with competitive accretion model (Bonnell et al. 04):**

➢ The core-core velocity dispersion observed in young, nearby protoclusters is small and not consistent with strong dynamical interactions in general, except at the very center of protoclusters.

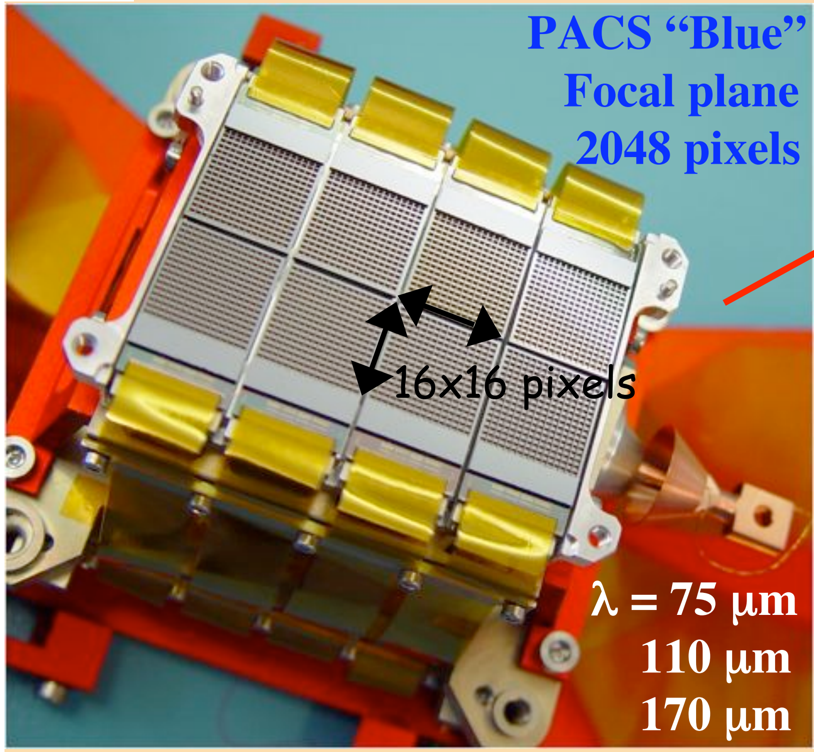
➢ Competitive accretion is too slow to be the dominant mechanism once individual protostellar collapse sets in.

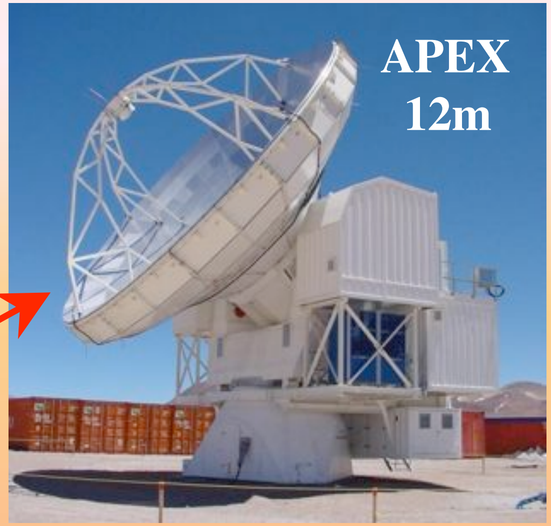
➜ **A mixed scenario may be the solution:**

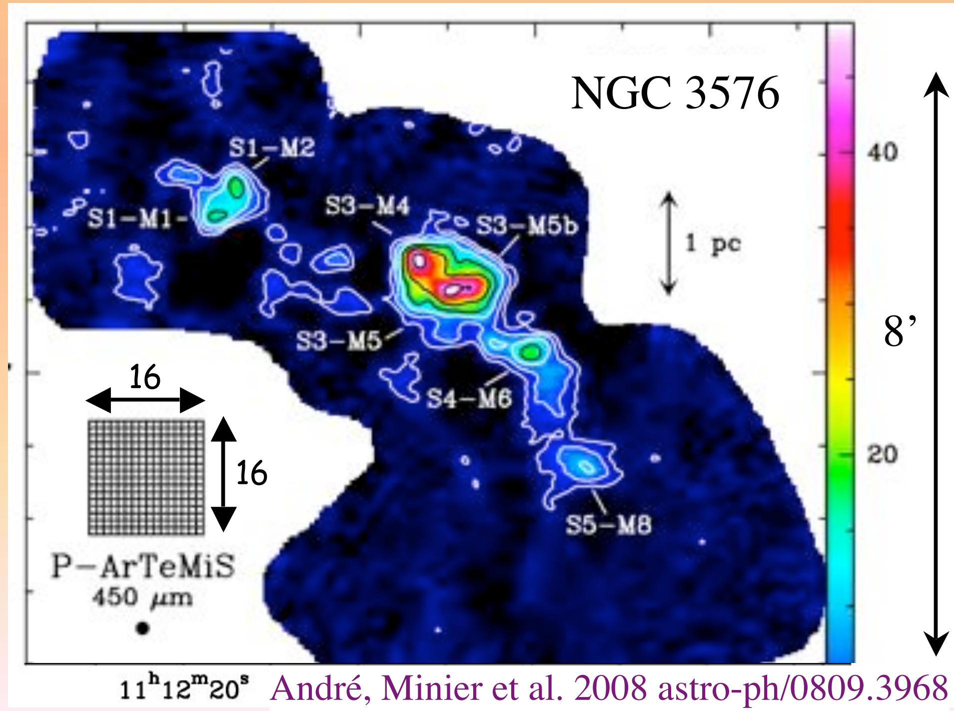
Formation of a massive, ultra-dense core through the merger of Class 0 objects in the center of a collapsing clump

ArTéMiS : A large-format submm bolometer camera for APEX

Irfu cea saclay





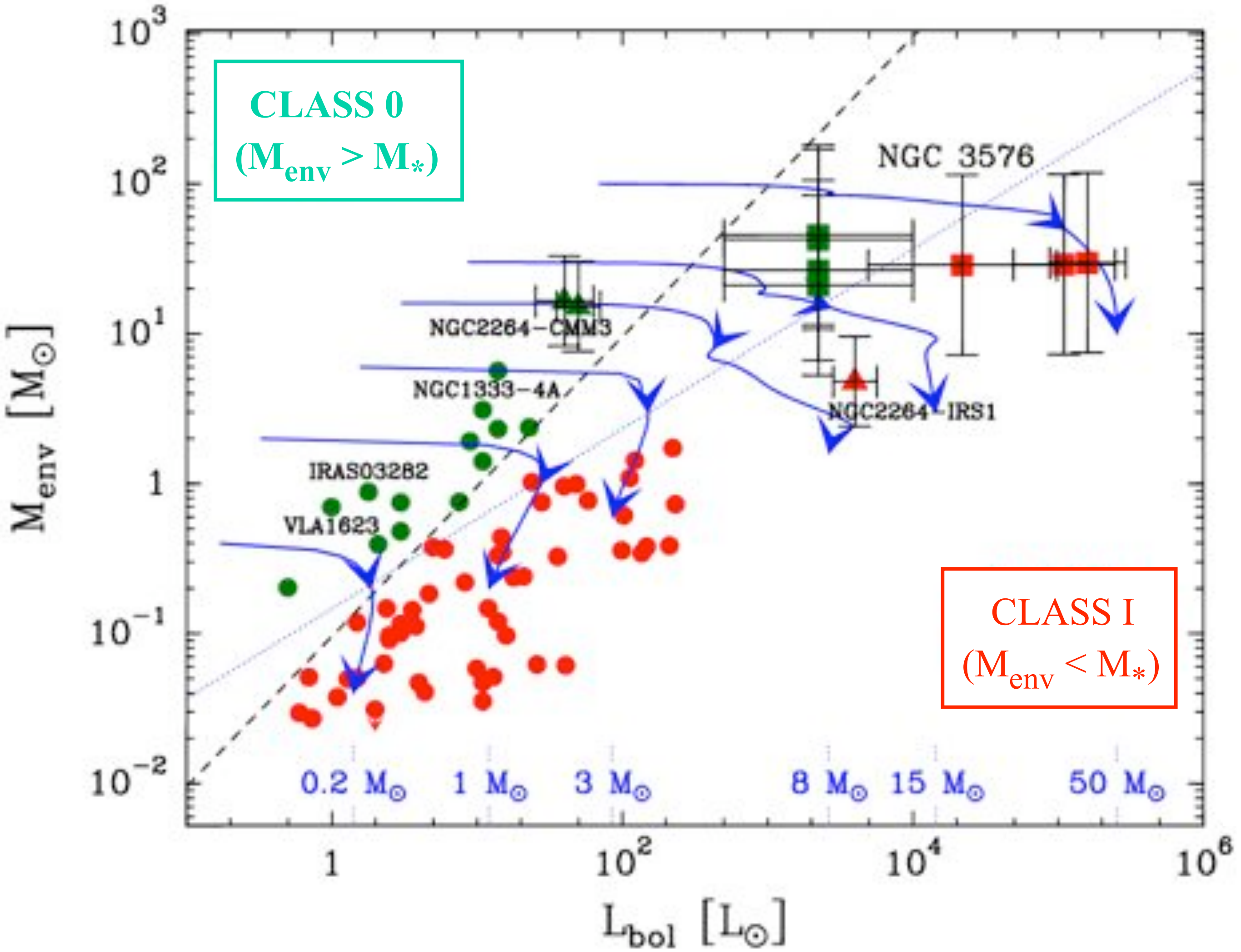


André, Minier et al. 2008 astro-ph/0809.3968

ArTéMiS : ~ 64 x 32 pixels @ 450 µm
~ 64 x 32 pixels @ 350 µm
~ 32 x 32 pixels @ 200 µm

Prototype : P-ArTéMiS (16x16) λ = 450 µm

Placing massive protostars in the M_{env} - L_{bol} evolutionary diagram



Evolutionary tracks:

$L_{bol} = GM_*\dot{M}_{acc}/R_*$
$+ L_*$ (birthline)

$\dot{M}_{acc} = M_{env}/\tau$
$= (M_{frag}/\tau)\, e^{-t/\tau}$
with $\tau = 10^5$ yr

cf. Saraceno et al. 1996, Bontemps et al. 1996, André et al. 2000 (PPIV), André et al. 2008