Accretion in Clusters

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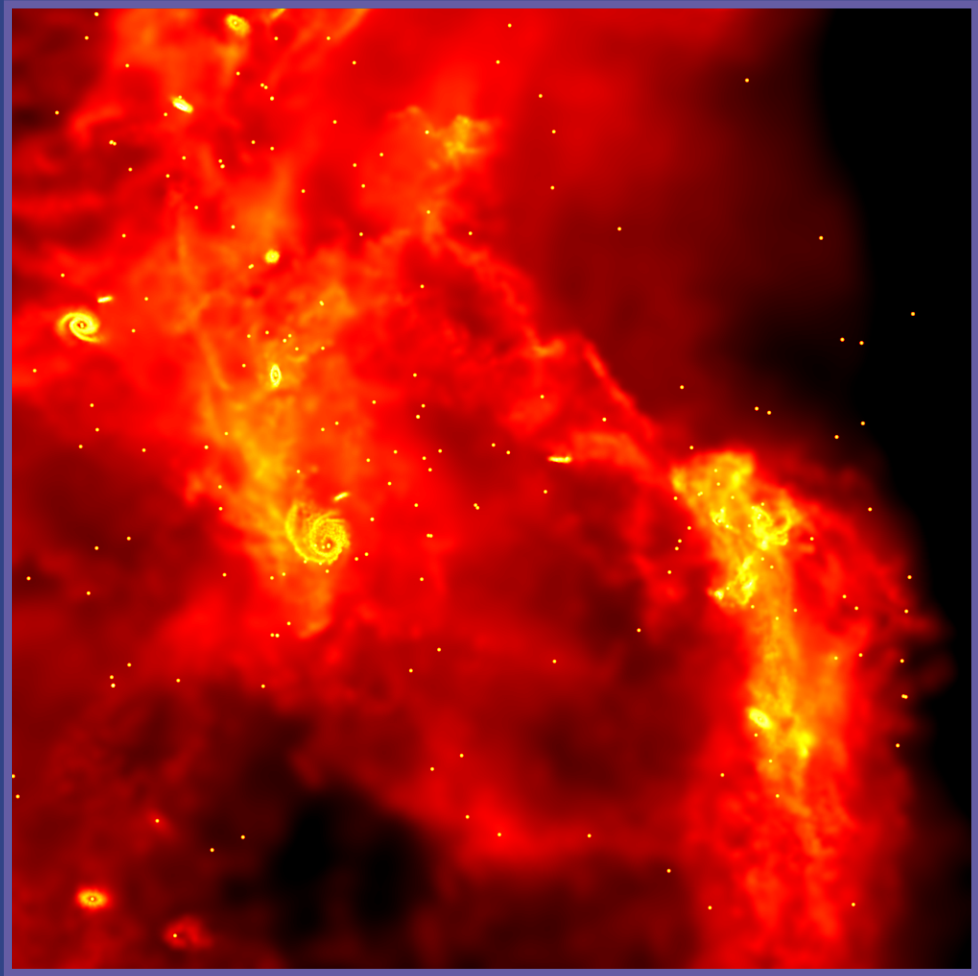
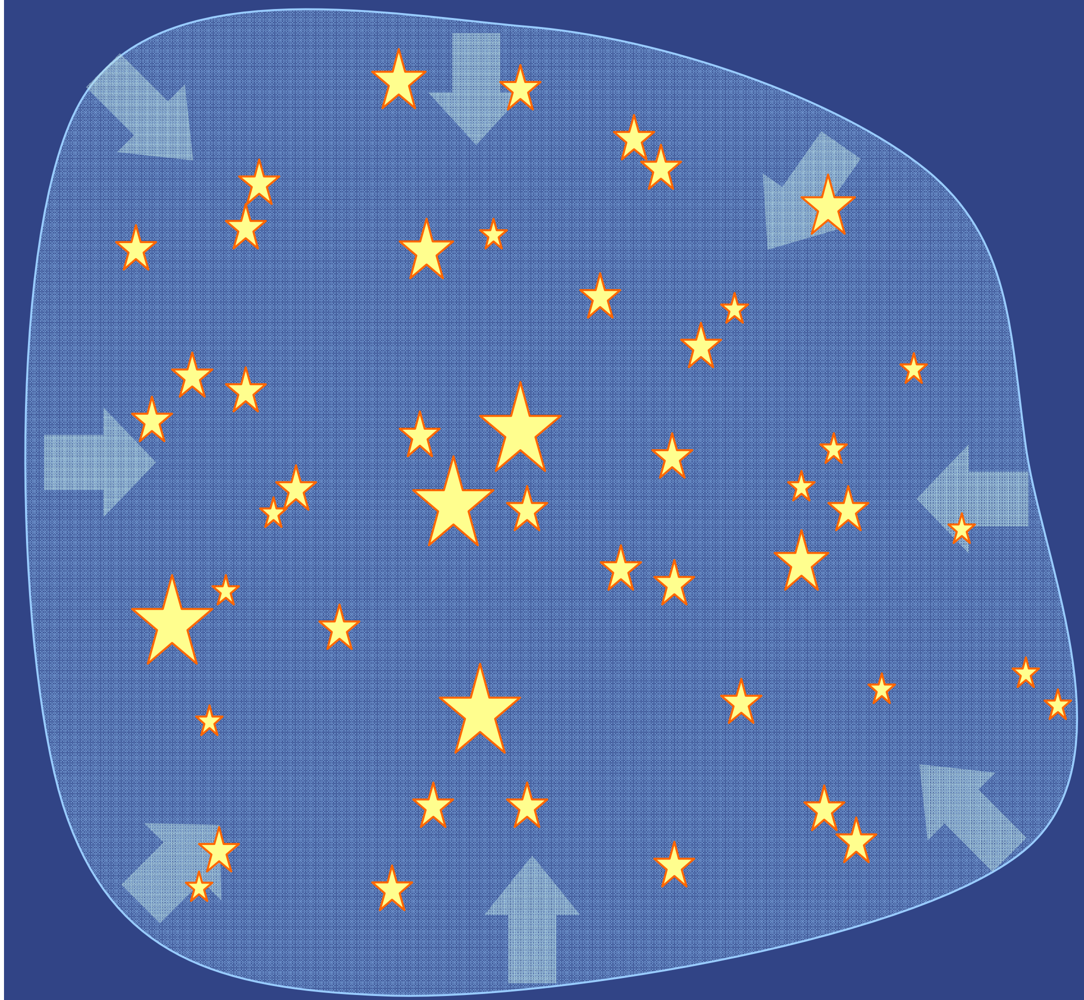


On what scale is accretion most important?

What determines the IMF?

IMF from competitive accretion

Collapsing proto-cluster core



- Bound region forms and starts to collapse.
- Fragmentation of molecular cloud sets the **seeds** for the formation of young system.
- Subsequent accretion from the cloud shapes the masses of the stars.
- Dynamic process.
- IMF **grows (but always has the same shape)!**

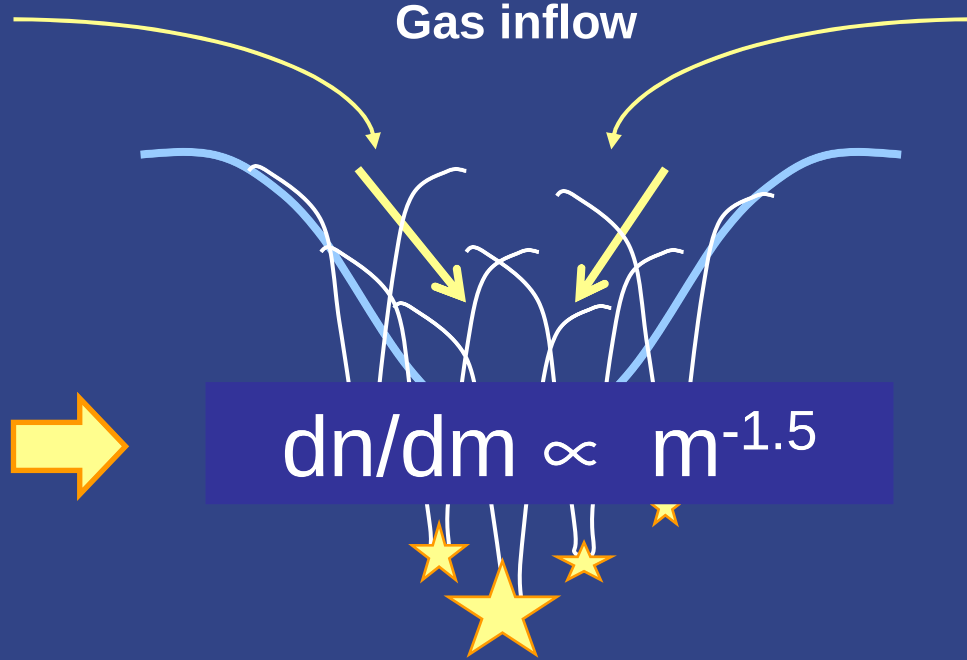
Accretion and the IMF…

Bonnell et al 2001a,b

Accretion rate: $\dot{M}_* = \pi \rho V_{\rm rel} R_{\rm acc}^2$

• Initially, fragmentation occurs as gas falls into the protocluster core potential. Low relative velocity between gas and protostellar embryos:

$$R_{\rm tidal} \approx 0.5 \left(\frac{M_*}{M_{\rm enc}} \right)^{1/3} R,$$



$dn/dm \propto m^{-1.5}$

• Once the protostars dynamically interact, their motions are determined by encounters. Accretion is now defined by the Bondi-Hoyle radius:

$$R_{\rm BH} = 2GM_*/(V_{\rm rel}^2 + c_{\rm s}^2)$$

$dn/dm \propto m^{-2.5}$

Accretion and the IMF…

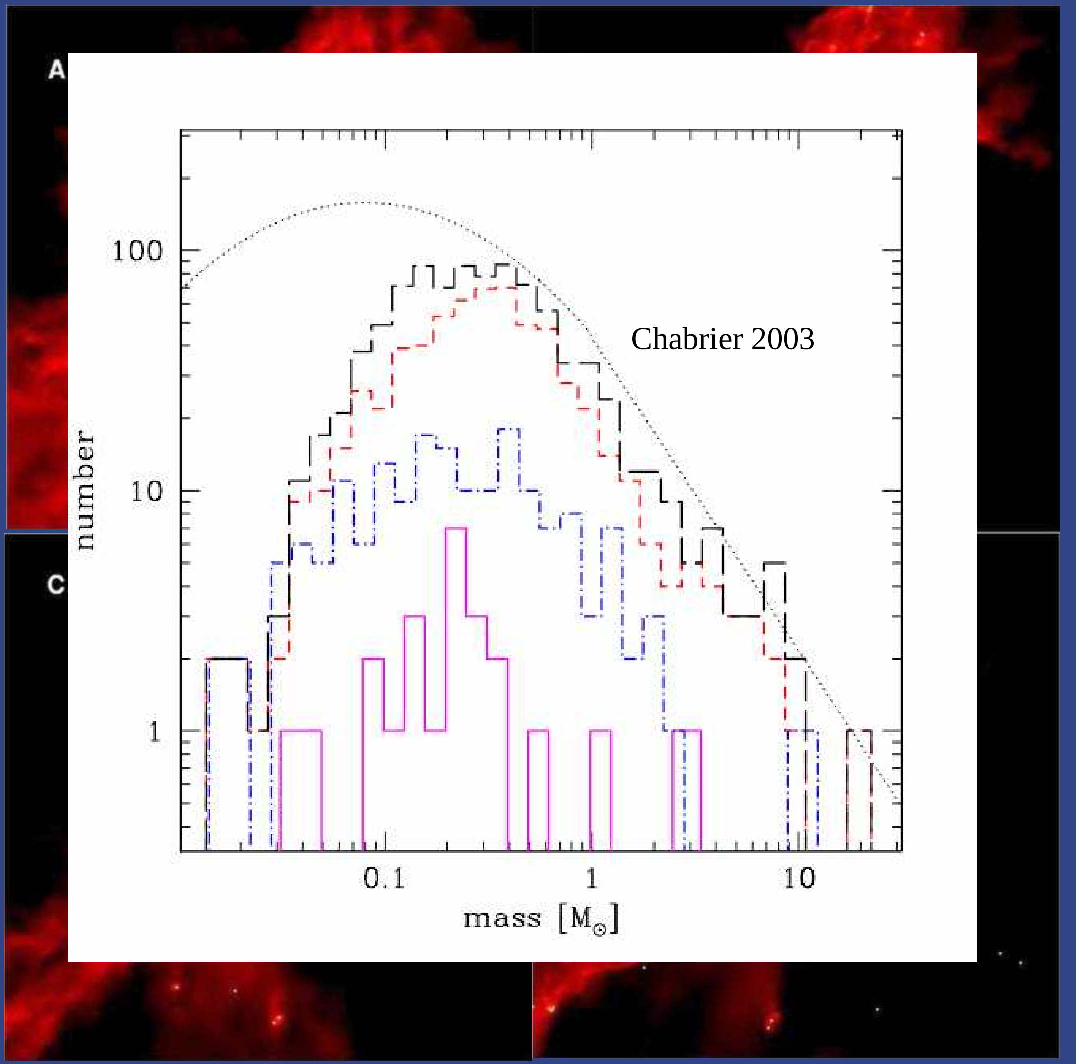
- Once the first protostellar encounters:

Combination of tidal and BH accretion

Protostellar mass function grows with time, but is always consistent with the IMF.

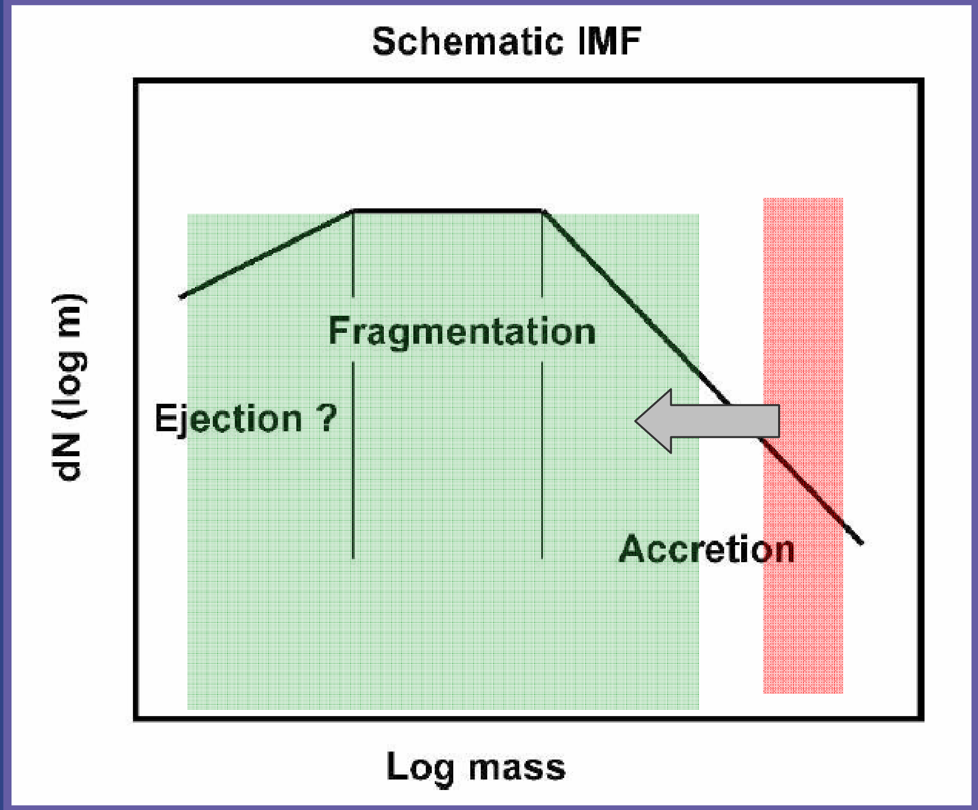
Creates a naturally mass segregated cluster.

Bonnell, Vine & Bate 2004



Accretion and the IMF…

- 3 processes control the full IMF in the cluster accretion process:
    - Fragmentation
    - Accretion
    - Ejection



- All parts of the IMF depend on each other.

Conditions for competitive accretion…

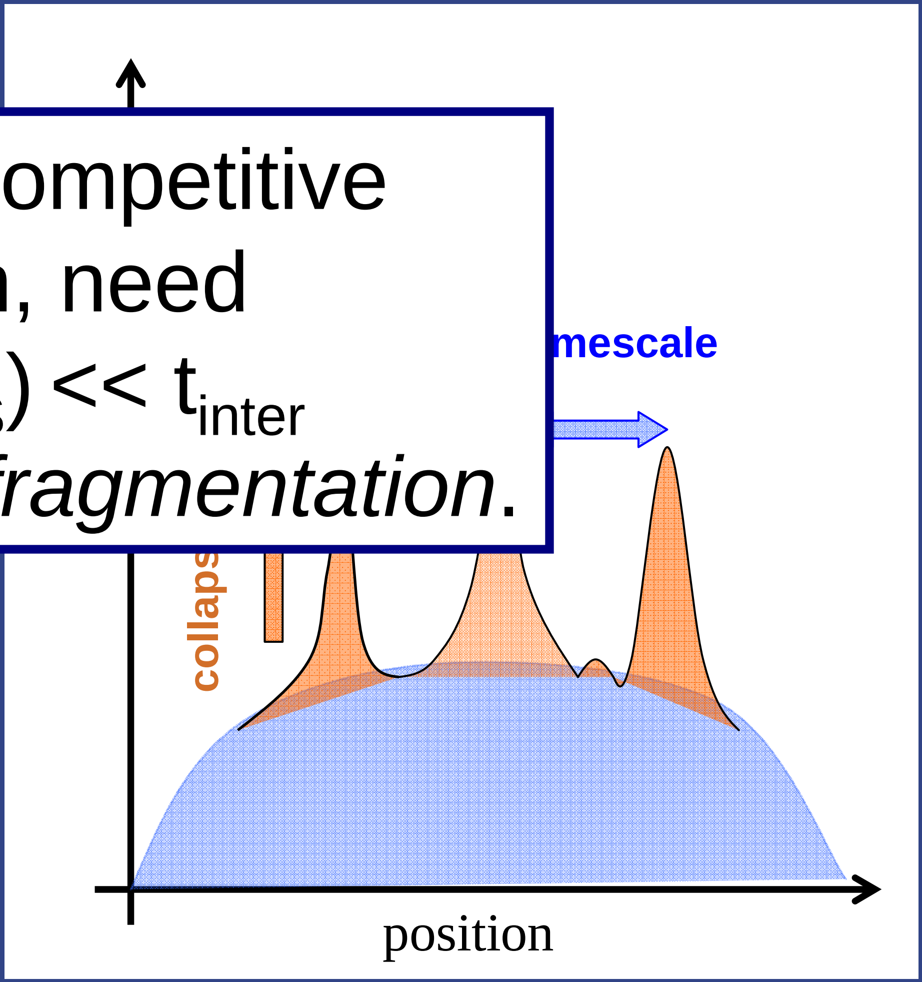
• Competitive accretion requires a region in which the collapse ti interactio similar.

• If the clu cloud den equal, then:

$$t_{inter} \sim t_{coll} \sim t_{ff}$$

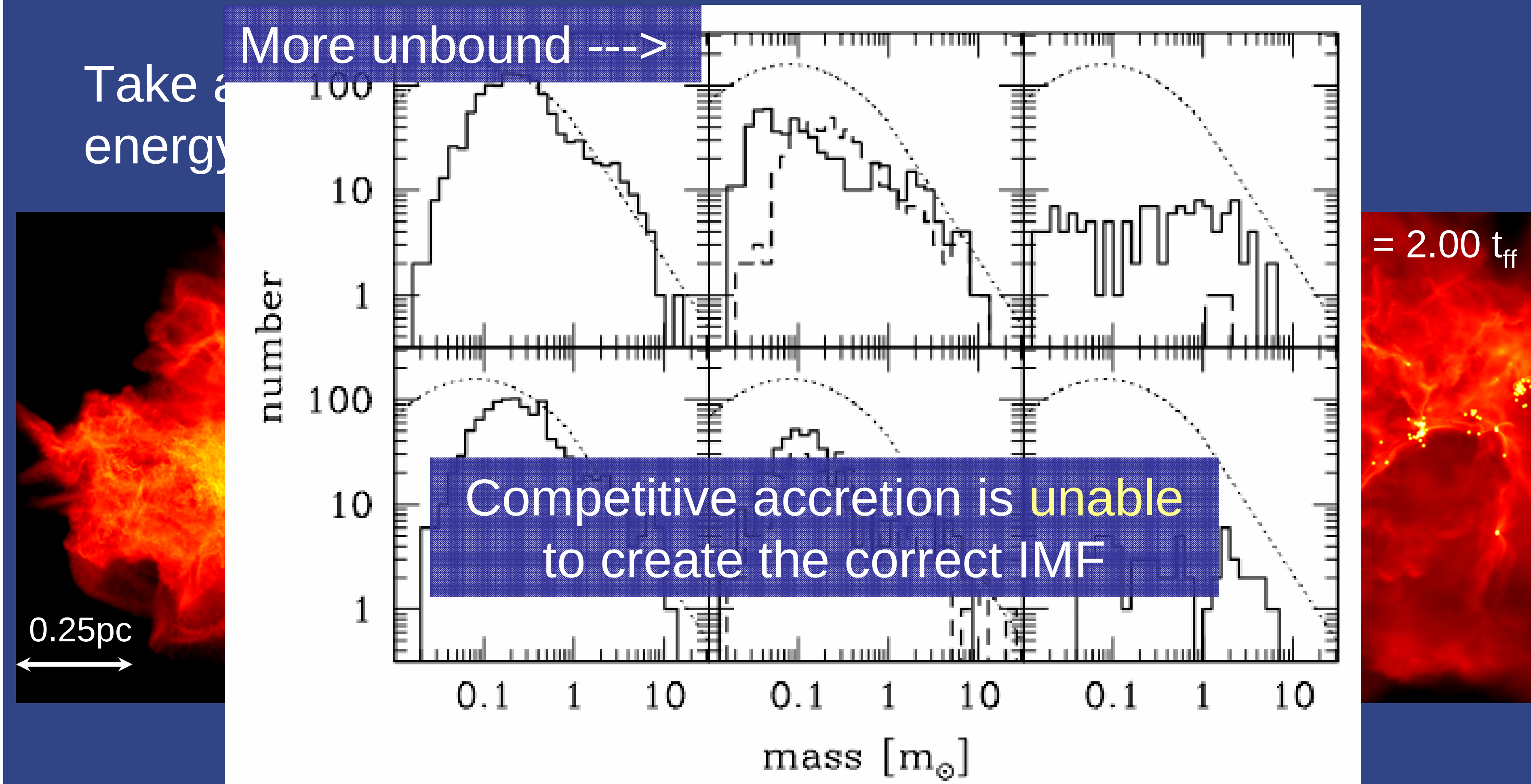
• Any region with multiple Jeans masses automatically satisfies this requirement.

To prevent competitive accretion, need
t_{coll} (or t_{PMS}) << t_{inter}
*at the **onset** of fragmentation*.



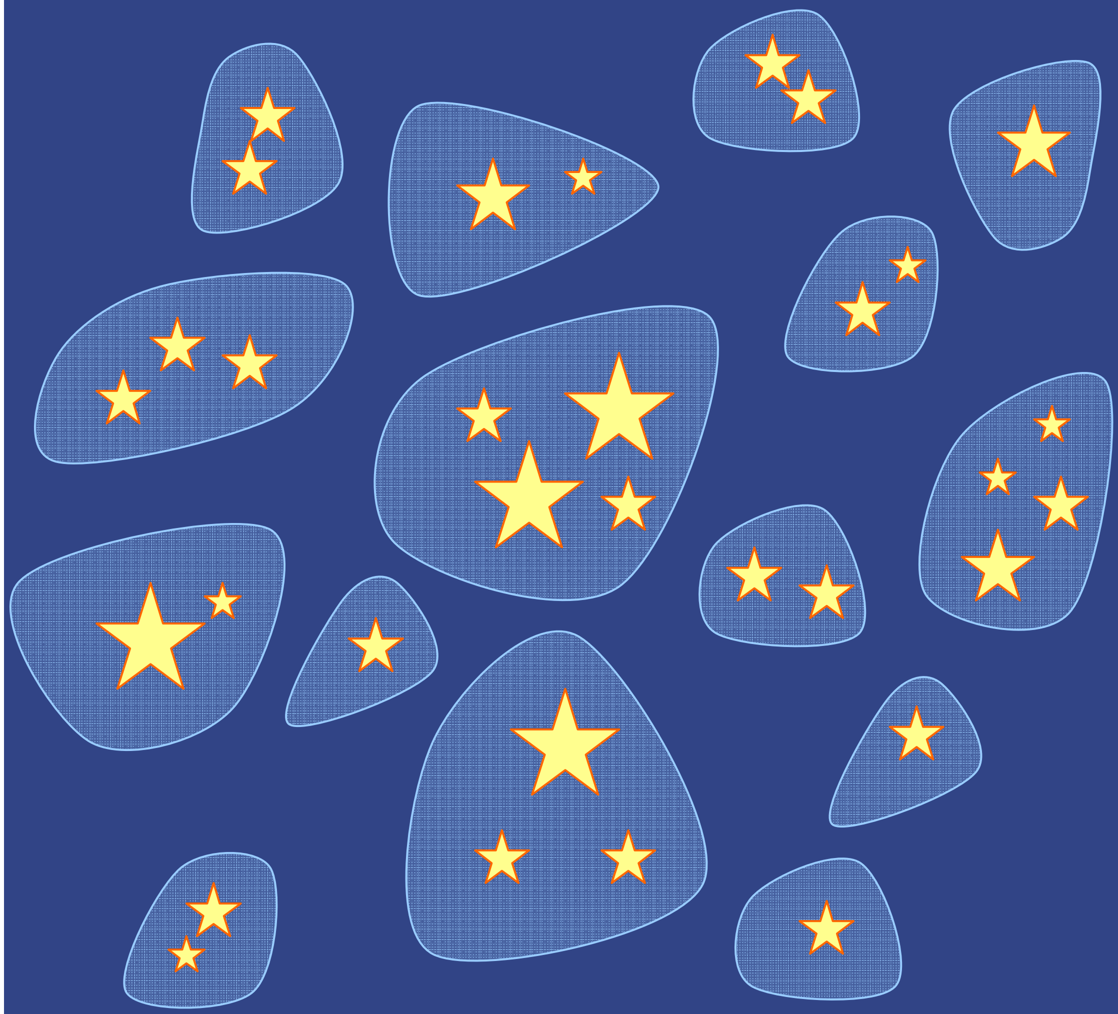
What happens when regions don’t interact?

Take a... energy...



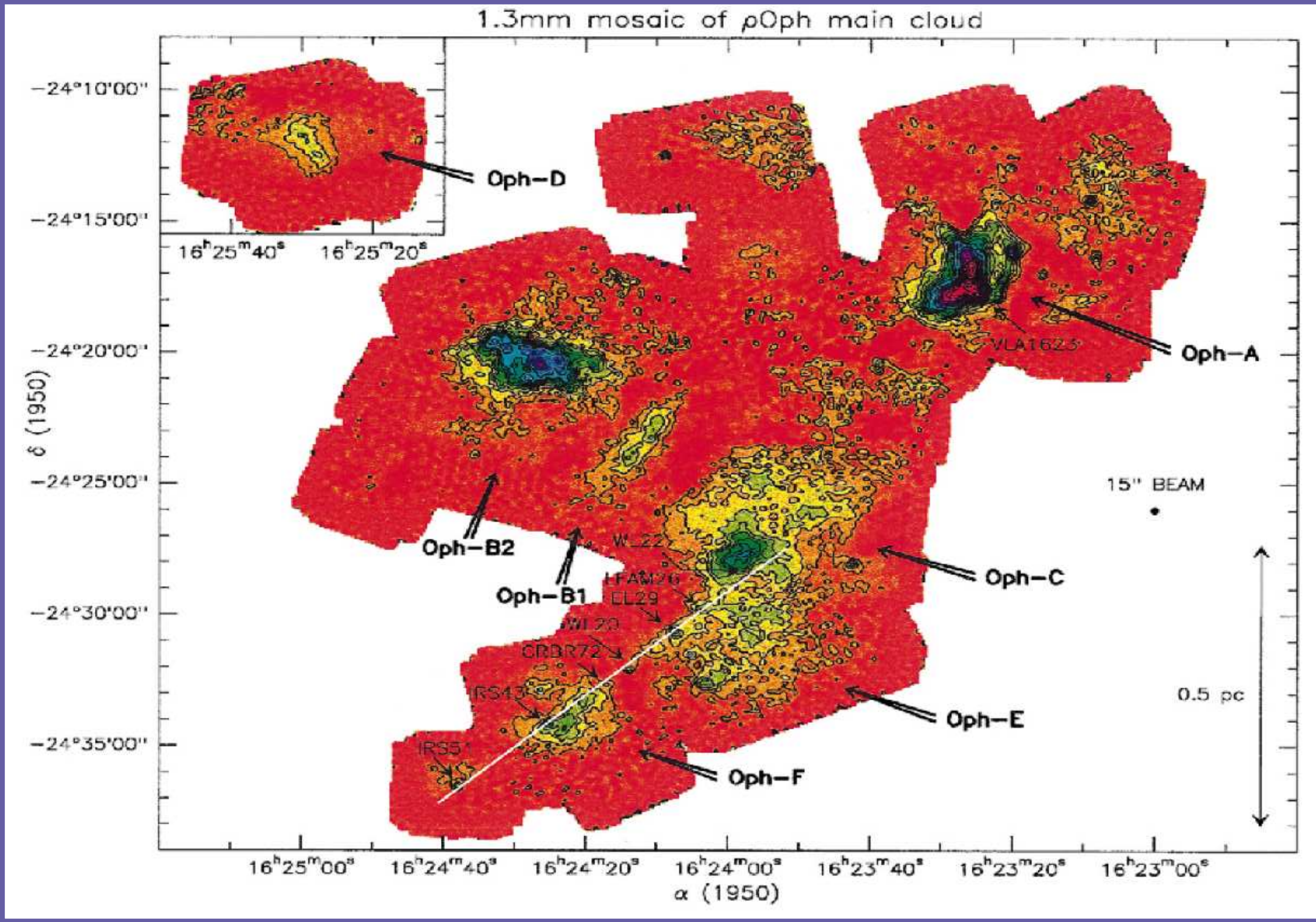
Clark et al (2007)

IMF from fragmentation



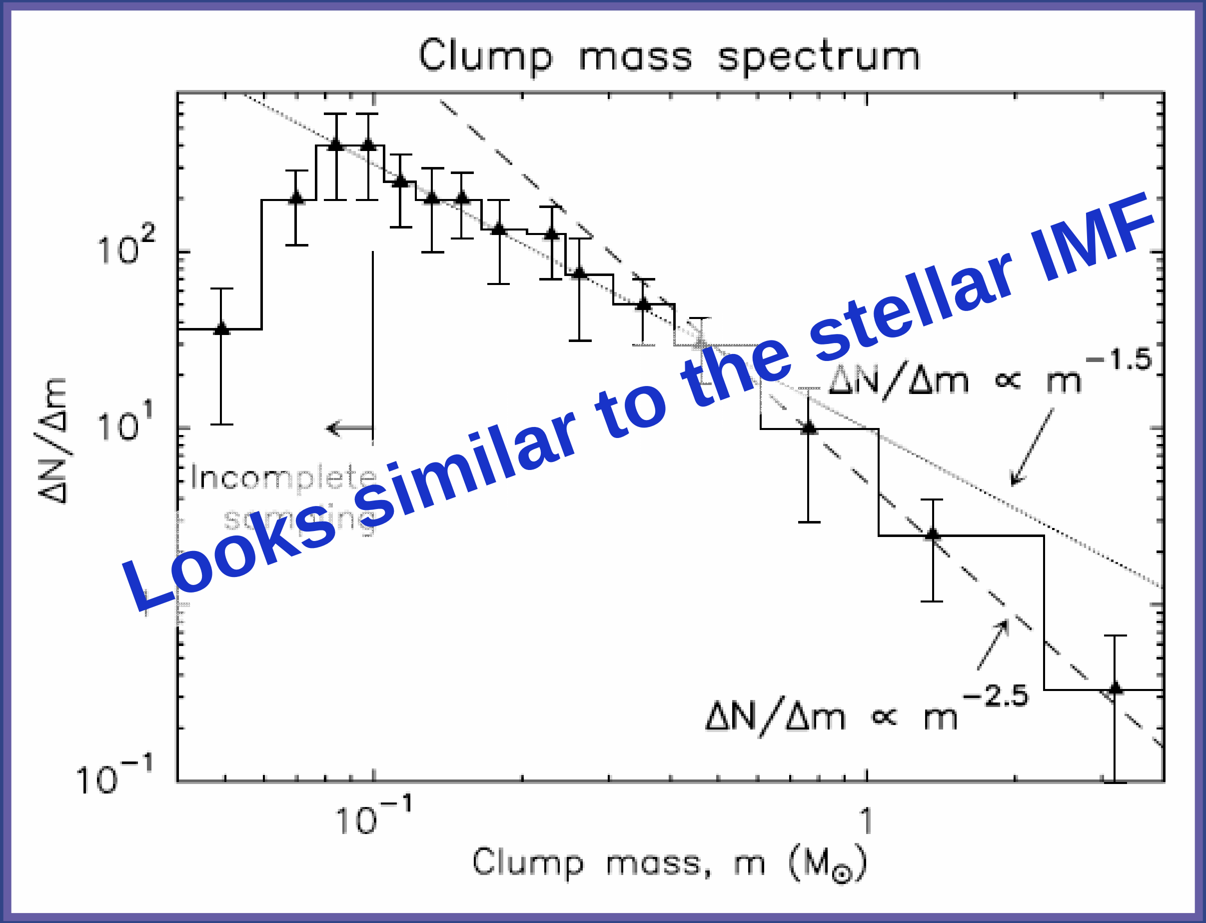
- Fragmentation of molecular cloud sets the mass for star formation **locally**.
- Subsequent accretion from the cloud is unnecessary/unimportant
.
- Static process.
- IMF is **primordial**.

The IMF from fragmentation



Motte, André & Neri 1998, A&A 336, 150

The IMF from fragmentation



Motte, André & Neri 1998, A&A 336, 150

Similar results:

Testi & Sargent (1998)

Johnstone et al (2000, 2001, 2006)

Nutter & Ward-Thompson (2006)

Lada et al 2006

Observational predictions

Accretion IMF…

• Cloud sh… global col… bound).

• Some d… mass seg… visible.

• Interacti… comparable to the PMS timescale.

• Massive, pre-protostellar cores should be fairly rare.

Fragmentation IMF…

• Cloud appears not to be …y.

…raction …nger than …e.

…und

• No clear reason why mass segregation should exist in the PMS phase.

ALMA will provide the line-widths at the necessary scales (all!) to help distinguish between these two contrasting pictures.

Competitive accretion within the fragmentation model?

What if the clump MF is the origin of the system IMF?

- Highly likely that each bound 'clump' will form more than one star (Andre et al 2000; Goodwin et al 2004a,b; Goodwin & Kroupa 2005).
- Observations show that multiplicity of embedded protostellar objects is higher than in the field star population (Duchene et al 2004; Correia et al 2006)
- More massive clumps may be unstable to fragmentation during collapse (Andre et 2000).
- Competitive accretion?

Core fragmentation test

1000 au

QuickTime™ and a
GIF decompressor
are needed to see this picture.

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Accretion rates

- From self-similar collapse ($1/r^2$ profile, Shu, Adams & Lizano 1987): $dm_*/dt \sim 0.98c^3/G$
- However many authors have shown that the accretion is higher than this: e.g. Foster & Chevalier 1993; Basu (1997); Ogino et al (1999); Whitworth & Ward-Thompson (2001), Motoyama & Yohsida (2003); Banerjee & Pudritz (2007).
- Typically caused by deviation from the ($1/r^2$) profile for the inner region: so called Larson-Penston solution (Larson 1969; Penston 1969), but then rate declines exponentially.
- More mass in the inner region than self-similar model.
- Consistent with the observations: e.g. Bontemps et al (1996); Myers el al (1998); Brown & Chandler (1999).

Accretion rates

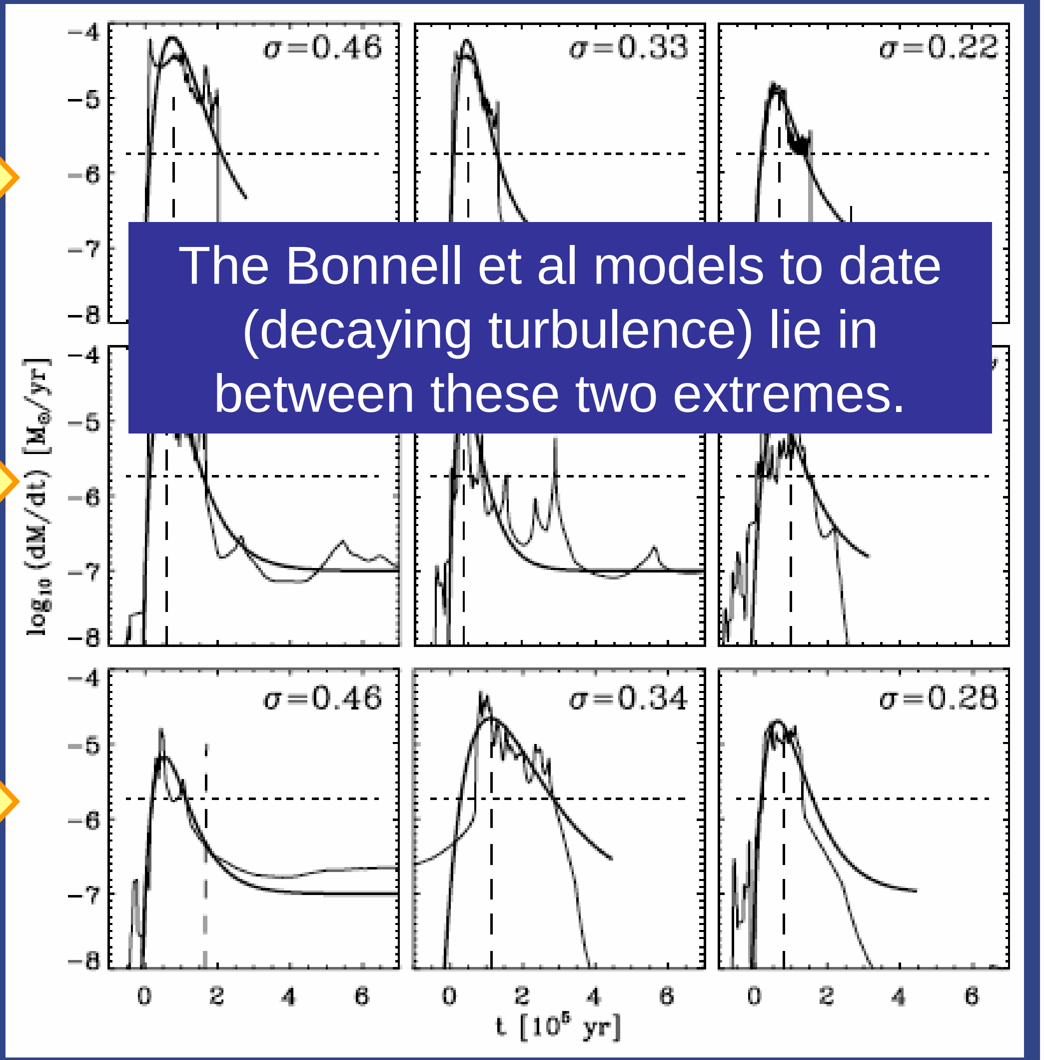
Schmeja & Klessen (2004), looked at simulations by Klessen:

$$\log \dot{M}(t) = \log \dot{M}_0 \, \frac{e}{\tau} \, t \, e^{-t/\tau}$$

1) Gaussian density fluctuations, no kinetic support. Highly clustered environment.

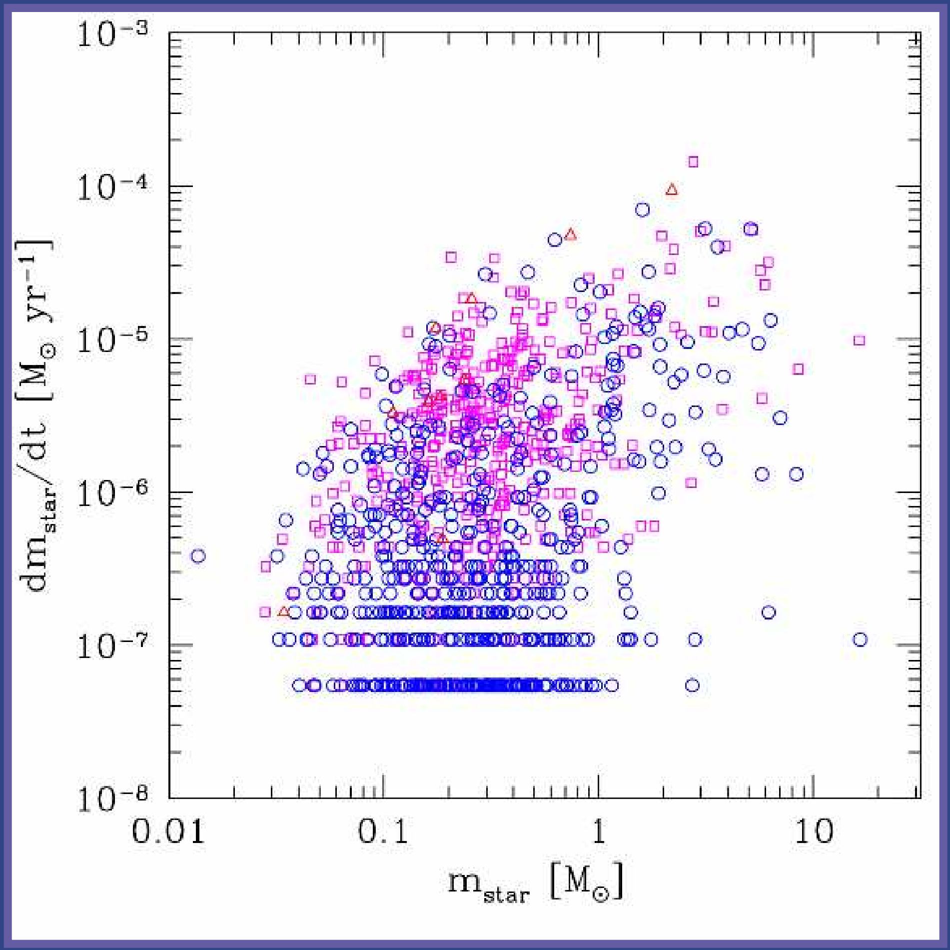
2) Large scale driving. Support on large scales. Highly clustered environment.

3) Small scale driving: support on small scales. Comparatively isolated star formation.



The Bonnell et al models to date (decaying turbulence) lie in between these two extremes.

Accretion rates



- In competitive accretion, the accretion rates are **not constant.**
- But result is complicated, since some objects are in the tidal lobe accretion phase, while others are in BH phase.
- Also sensitive to:
  - local density (BH)
  - volume averaged densities (tidal)

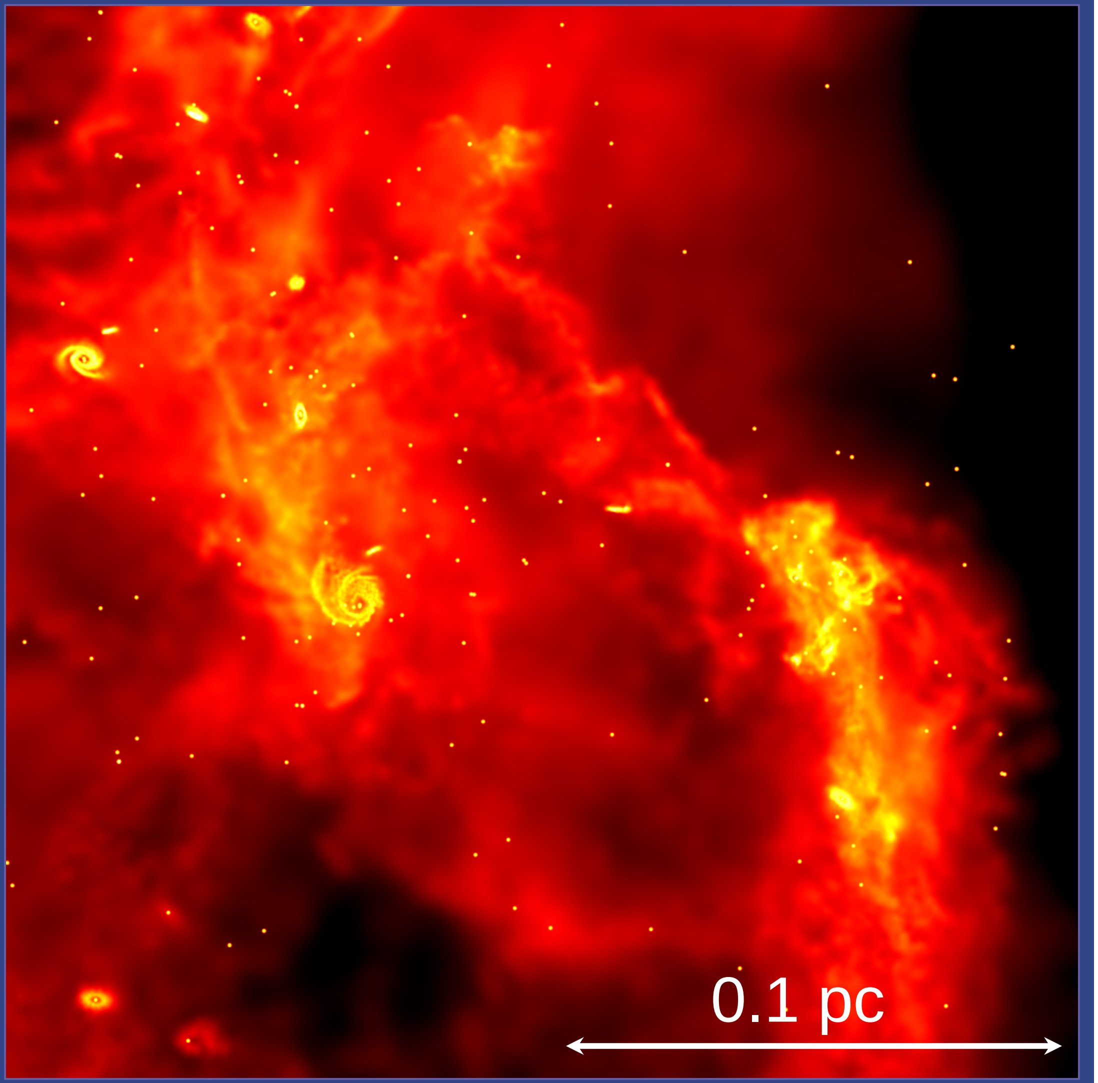
Discs in dense clusters

• Originally assumed that a densely clustered environment would destroy discs (Bonnell et al 2003)…

…Not true!

• Higher resolution simulations show that discs can survive even these extreme conditions.

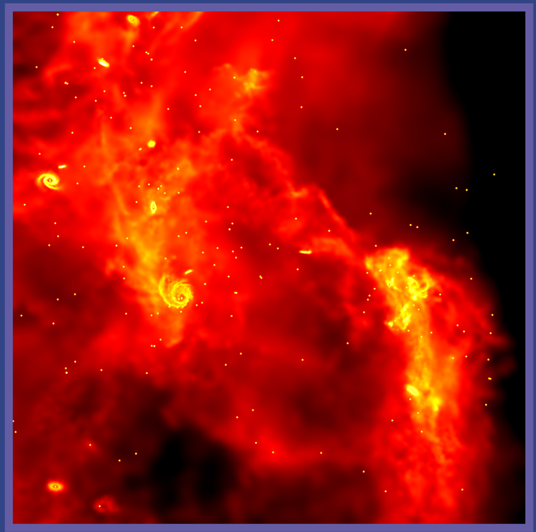
• Good news, since most stars are formed in massive clusters (Lada & Lada 2003).

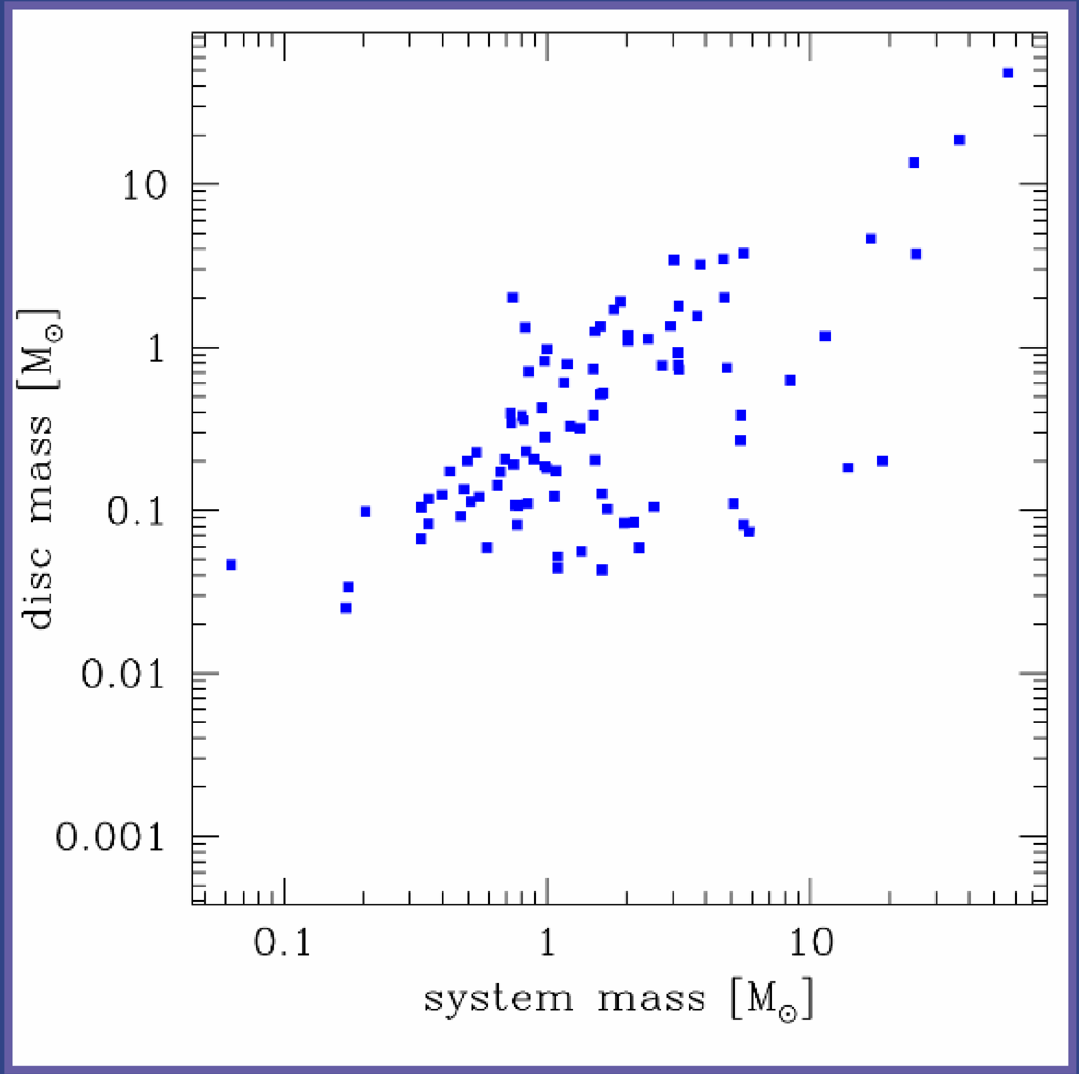


Discs in dense clusters

- Relationship between disc mass and protostellar system mass:

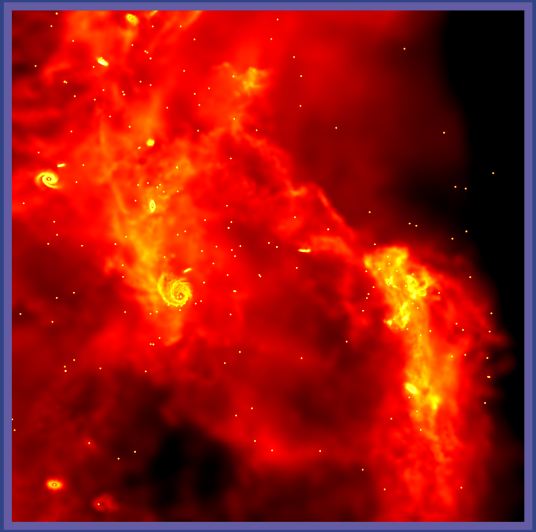
$$m_{disc} \propto m_{sys}^{1.5-2}$$

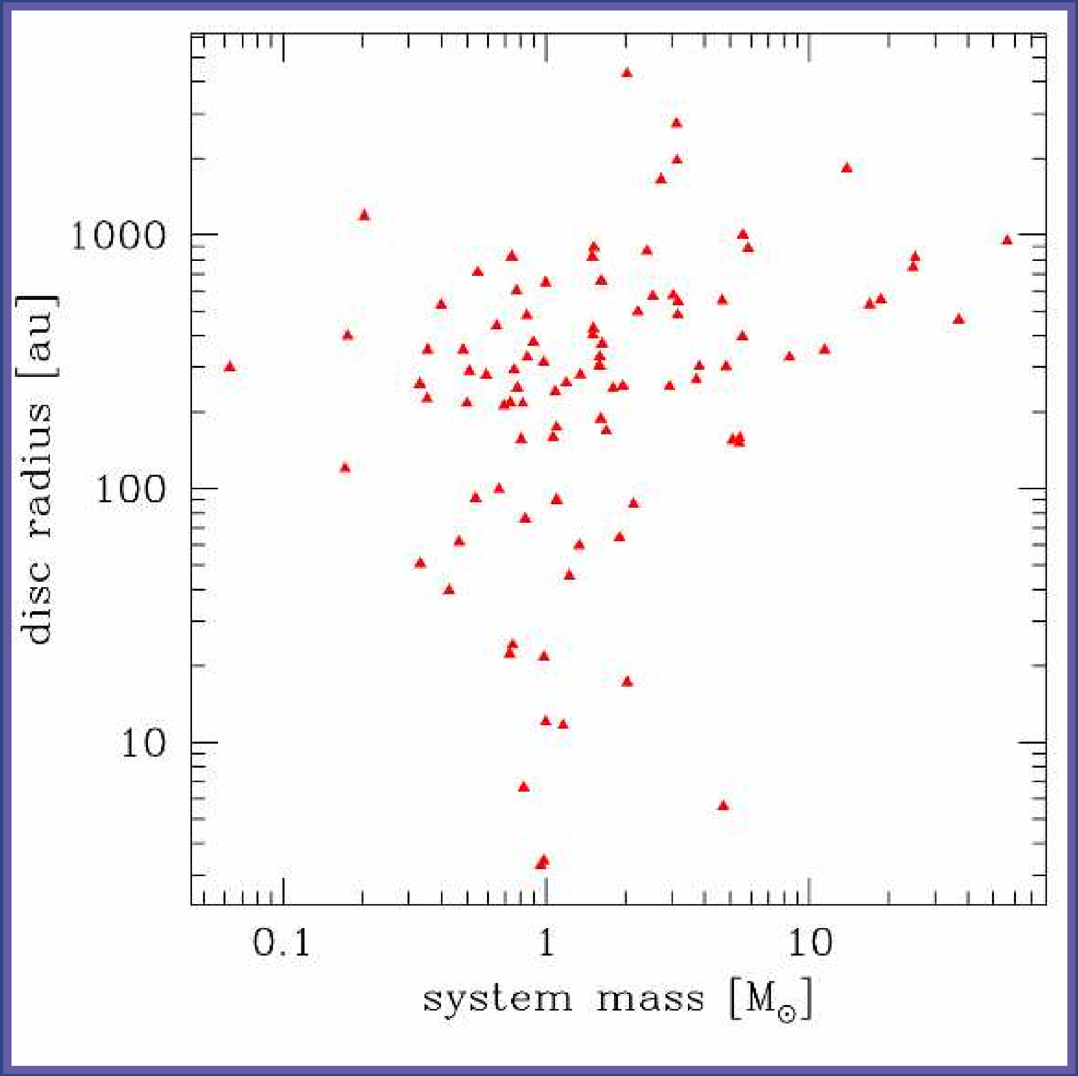




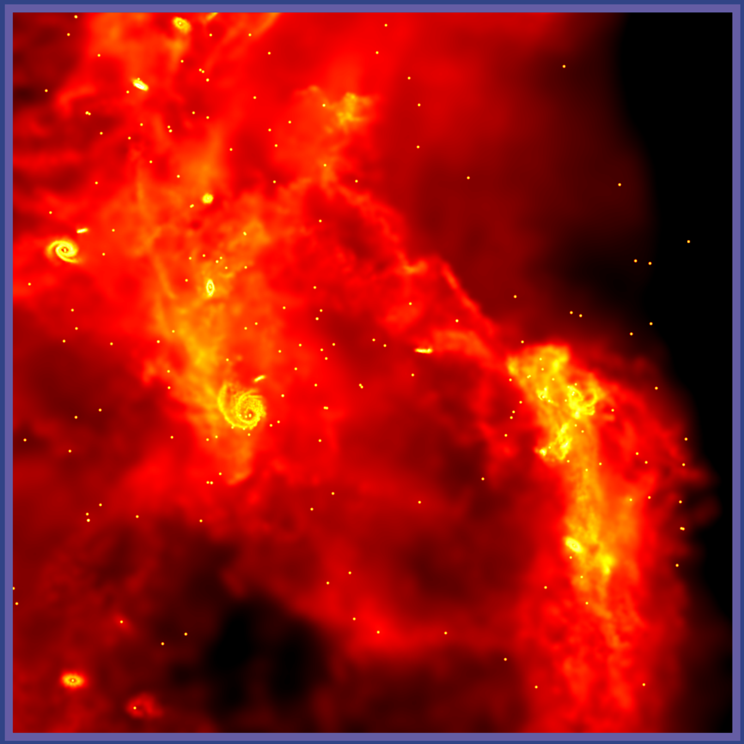
Discs in dense clusters

- However the relationship between the disc radius and the system mass is **not so clear!**





Discs in dense clusters



• Turbulence causes neighbouring regions to have different local angular momentum:

Discs seen with a variety of projections.

• Protostars/systems can loose their discs via interactions, but can rapidly accrete new ones, provided they are still in a dense enough environment.

• New discs are not necessarily aligned to the rotational plane of the protostars/systems.

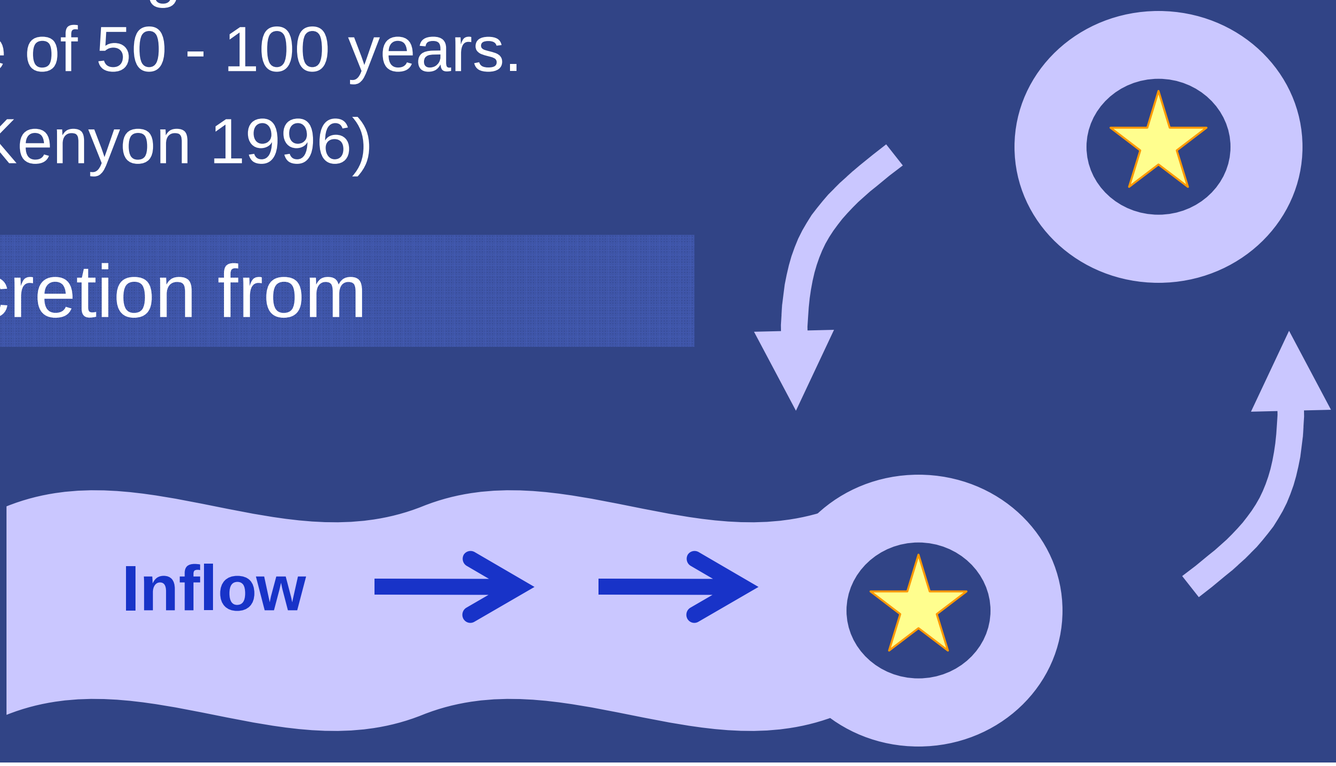
FU Orionis objects?

Properties…

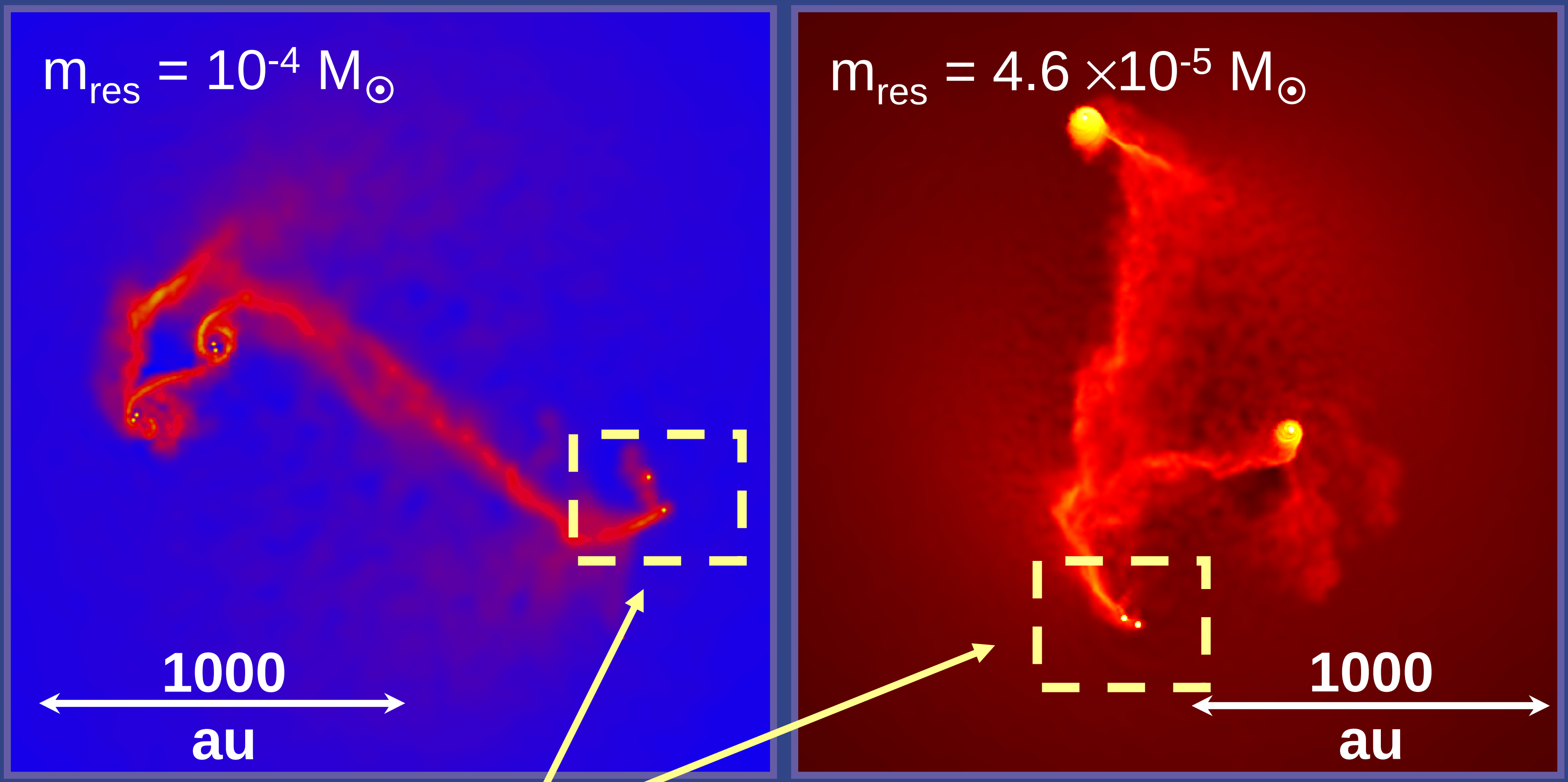
- Occurs in young embedded systems
- High accretion rates ~ $10^{-4} M_{\odot}\ yr^{-1}$
- Decay from this high accretion occurs on a timescale of 50 - 100 years.

(Hartmann & Kenyon 1996)

…binary accretion from filament?



FU Orionis objects?



We ran two simulations: found at least two such examples!

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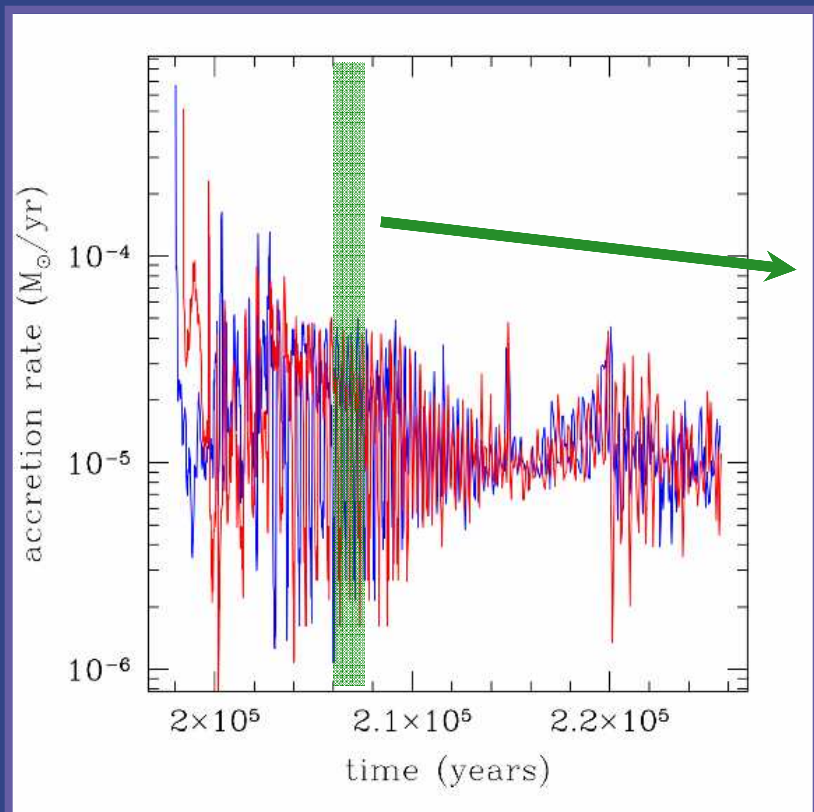
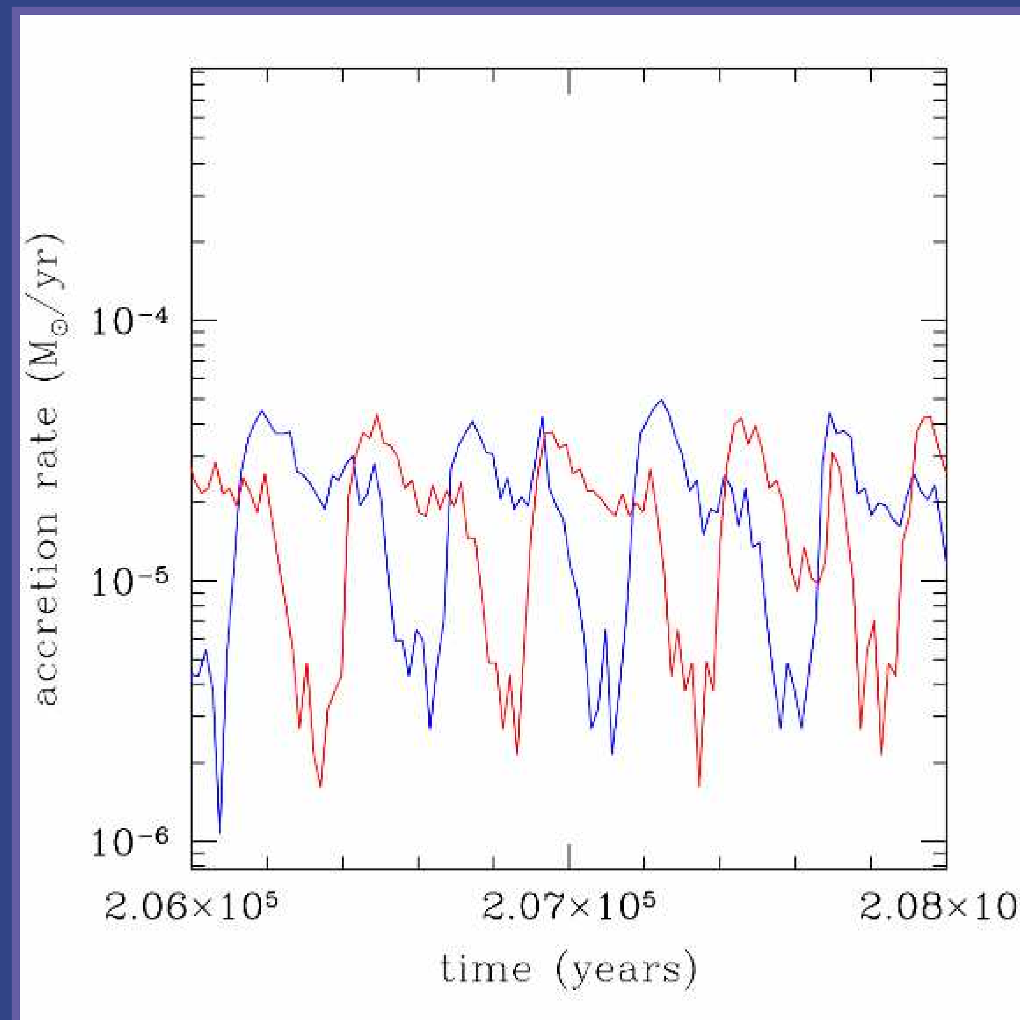
FU Orionis objects?

… binary accretion from filament?

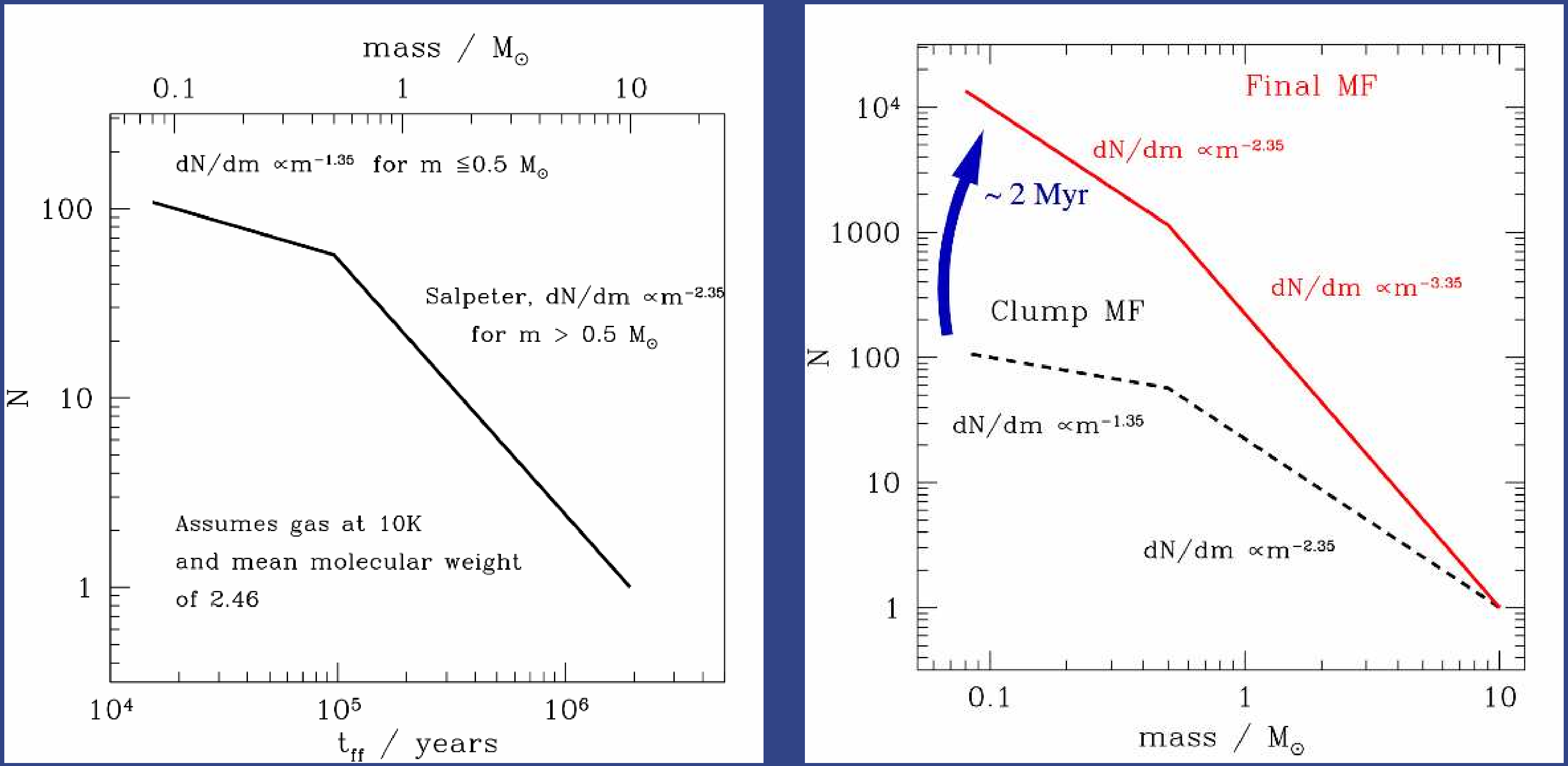




Conclusions…

- With better maps of the velocity structure in star forming regions, ALMA will help distinguish between global accretion and local accretion -> IMF formation.
- What fraction of the CMFs constitute bound pre-protostellar cores?
- Should also be able to test whether the disc properties predicted by competitive accretion are realistic!
- Does competitive accretion dominate on small scales
- How much structure is there at the 100 AU scale in protostellar cores?

A timescale problem?



Clark, Klessen & Bonnell 2007

Stability of sub-mm clumps

• The stability of clumps seen in the sub-mm observations is **very sensitive to the assumed dust temperature.**

$$N_{H2} \propto 1/T_{dust} \text{ --> } M_{clump} \propto T_{dust}^{-1}$$

Jeans mass: $m_J \propto [T_{gas}]^{3/2} [\rho]^{-1/2}$ and again $\rho \propto T_{dust}^{-1}$

So the inferred jeans mass in the clump depends on assumed dust temperature:

$$m_J \propto T^{3/2} (T^{-1})^{-1/2} \propto T^2$$

Observed stability is then the number of Jeans masses:

$$\mathbf{N_J = M_{clump}/m_j \propto T^{-1} \times T^{-2} \propto T^{-3}}$$

ALMA --> LINE-WIDTHS!

Thermal properties of the gas

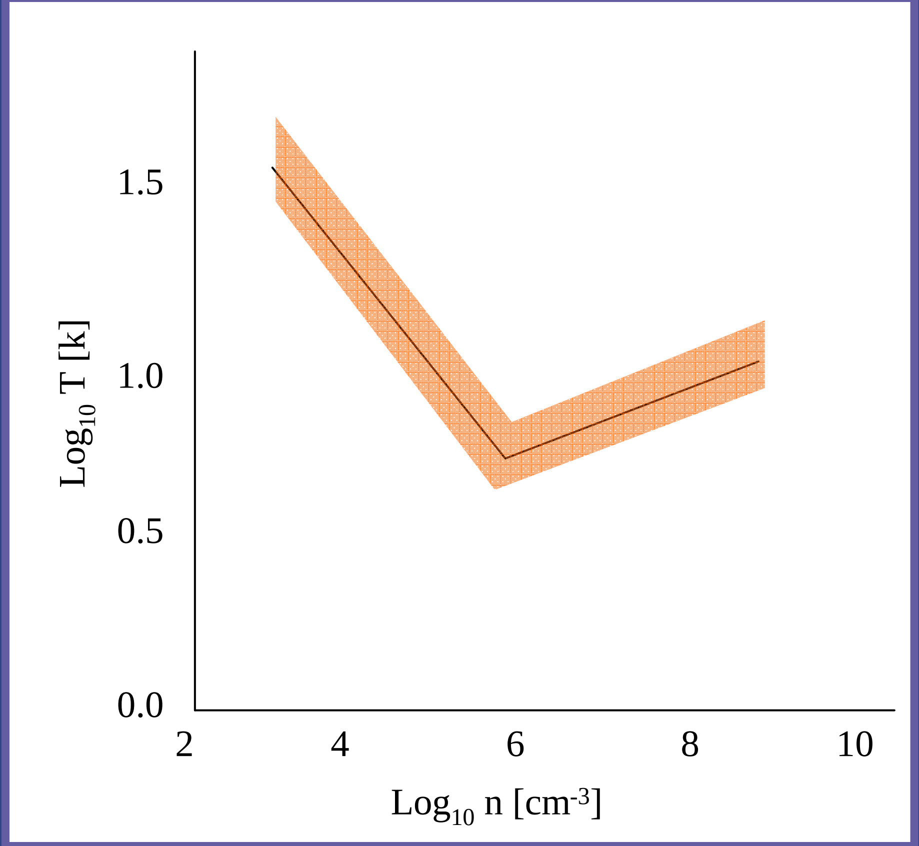
Larson (1985, 2005) suggested that the typical stellar mass may by set by a heating and cooling processes in the molecular gas. Suggested a characteristic Jeans mass, controlled by a special density and temperature:

$T = 4.4\ (\rho\ /10^{-18})^{-0.27}\ K$,

$(\rho < 10^{-18}\ gcm^{-3})$

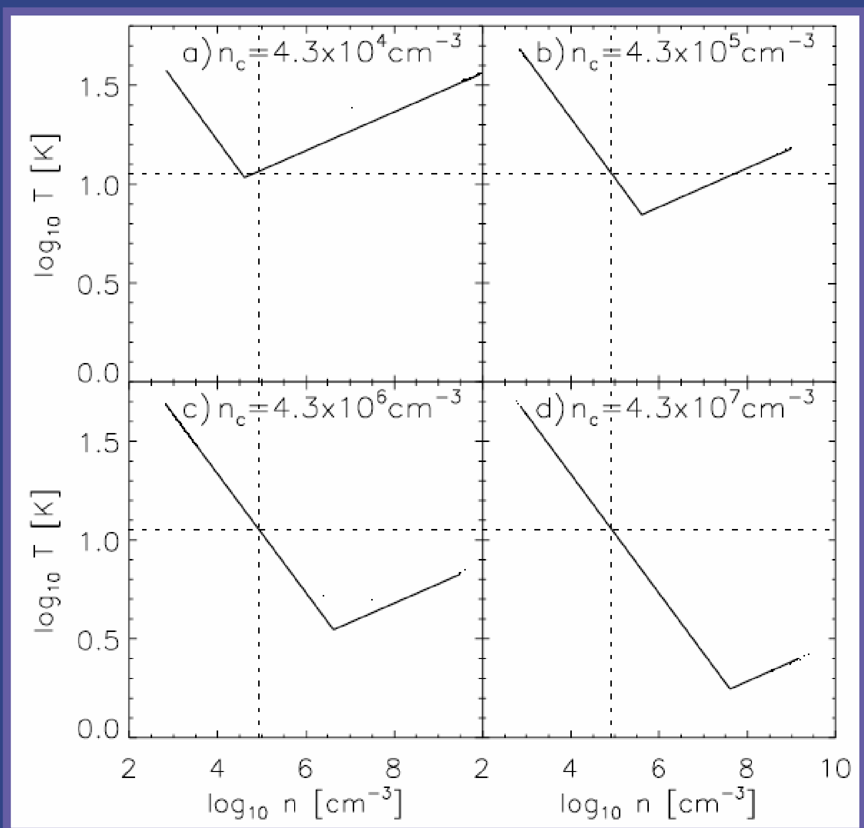
$T = 4.4\ (\rho\ /10^{-18})^{+0.07}\ K$,

$(\rho > 10^{-18}\ gcm^{-3})$



Thermal propertie[...] gas

Jappsen et al (2005) investigated this idea in detail with simulations of driven turbulence.



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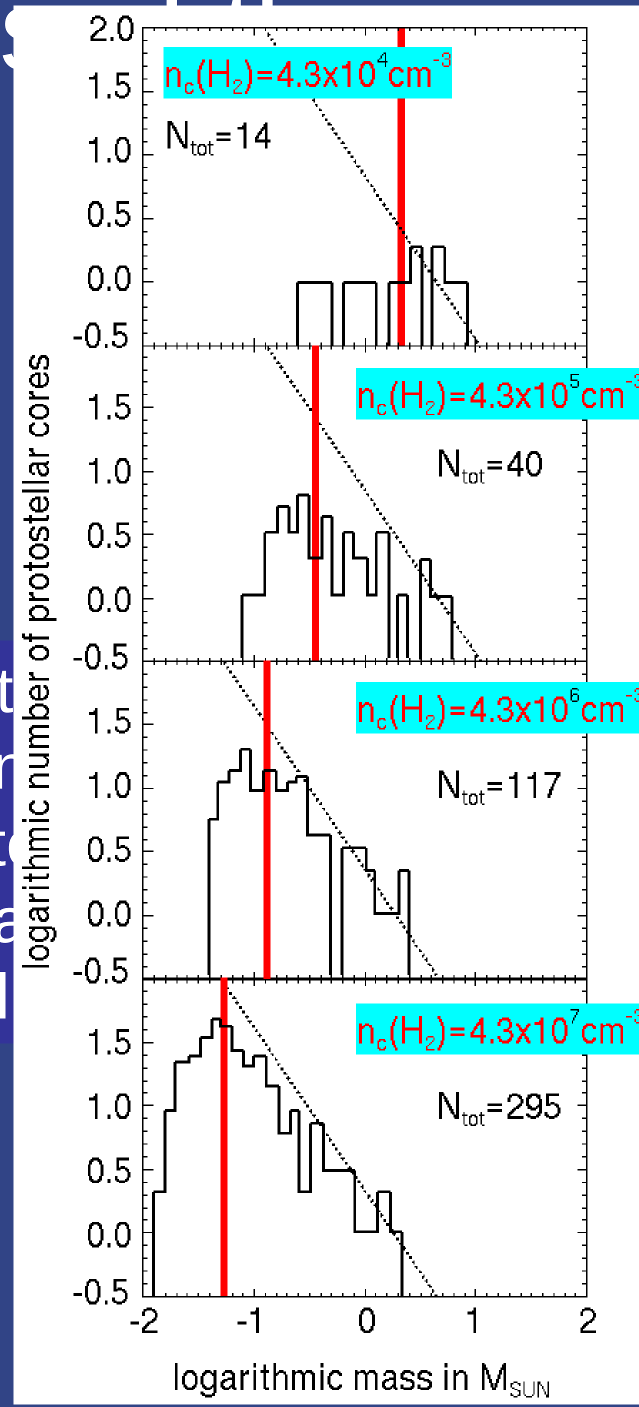
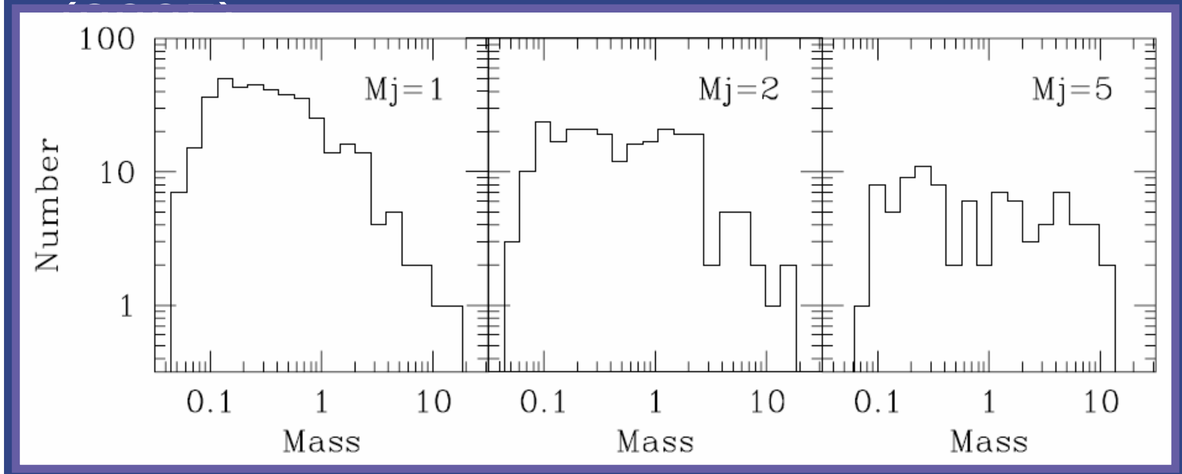


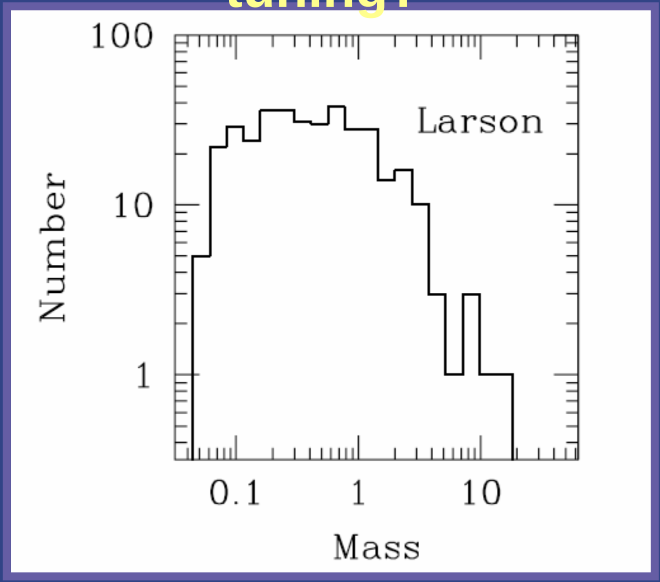
Good news for accreting the IMF

Bonnell, Clarke & Bate



Found that changing the initial Jeans mass in the set-up, alters the position of the 'knee' in the IMF.

Does competitive accretion really need such fine tuning?



Not if Larson is correct:

Using an equation of state similar to that proposed by Larson (2005), the cloud is able to generate a more typical IMF, even from a cloud with much lower initial densities and higher initial temperatures.

Core fragmentation test

Initial conditions:

$3M_\odot$; $m_J = 1\ M_\odot$; $\rho = 2 \times 10^{-19}$ g cm^{-3}

$\alpha \sim 0.48$; $\beta \sim 0.02$

Uniform sphere at

EOS: $p \propto \rho^\gamma$

$\rho < 10^{-15}$ $\gamma = 1.0$

$10^{-15} < \rho < 10^{-13}$ $\gamma = 1.1$

$10^{-13} < \rho < 10^{-11}$ $\gamma = 1.4$

$10^{-11} < \rho$ $\gamma = 1.0$

2×10^6 SPH particles: $m_{res} = 4.6 \times 10^{-5} M_\odot$