Initial conditions and the IMF; a personal view

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Michigan Star and Planet Formation

Jeans lengths and masses

$c_s^2 < GM/r \propto \rho\, r^2$

$\Rightarrow$ collapse if $r > r_J \propto c_s\, \rho^{-1/2}$

or $M > M_J$

Jeans masses/lengths are ***MINIMA***

(gravity is a long range force)

$\Rightarrow$ GRAVITATIONAL FOCUSING is UNAVOIDABLE
because molecular clouds have MANY M_J

("competitive accretion"; filaments; clusters)

Initial/boundary conditions are <u>important</u>

cannot fully evaluate the plausibility of various theories without understanding how clouds are formed

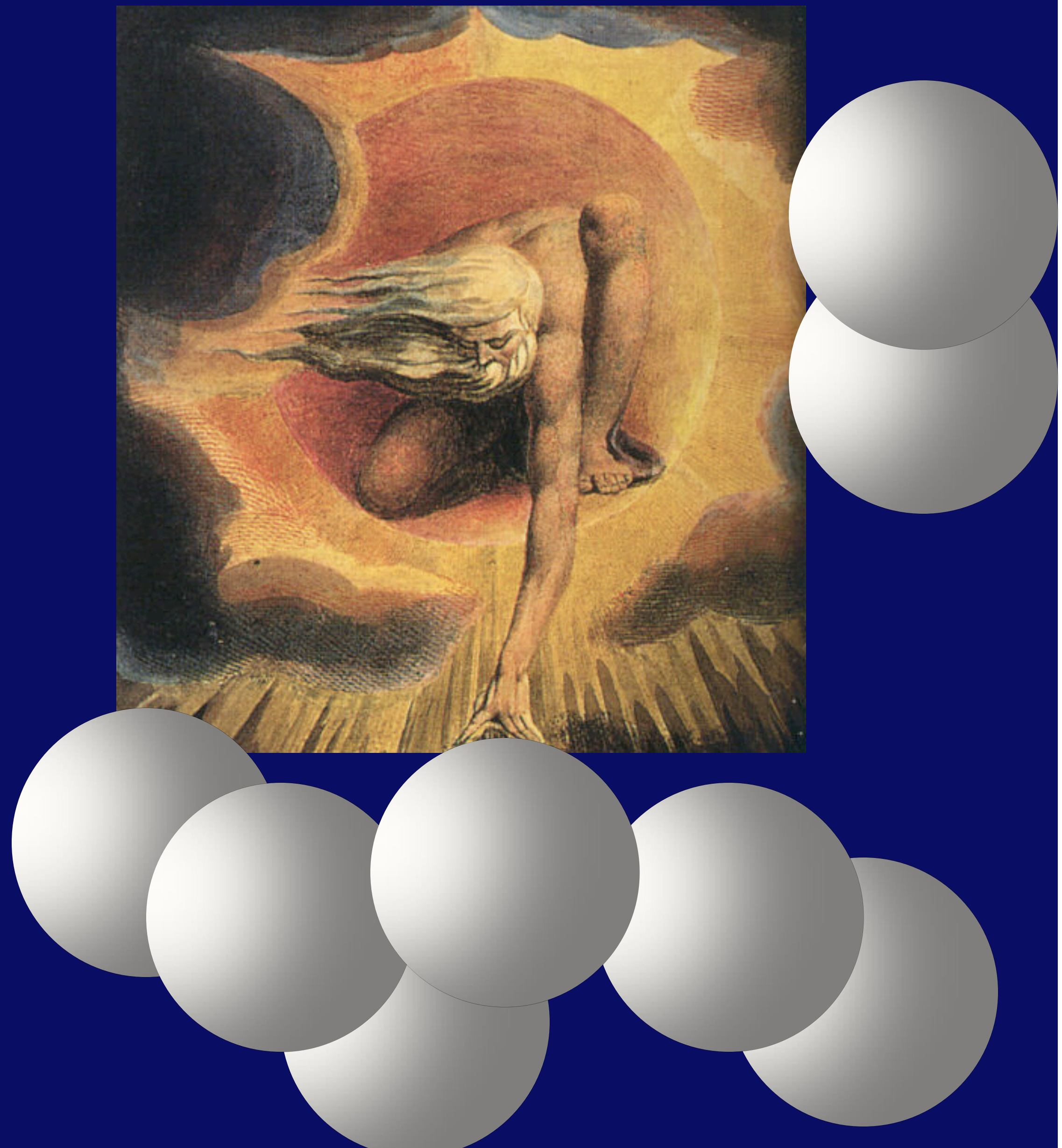
"You can't get there from here"

(initial/boundary conditions)

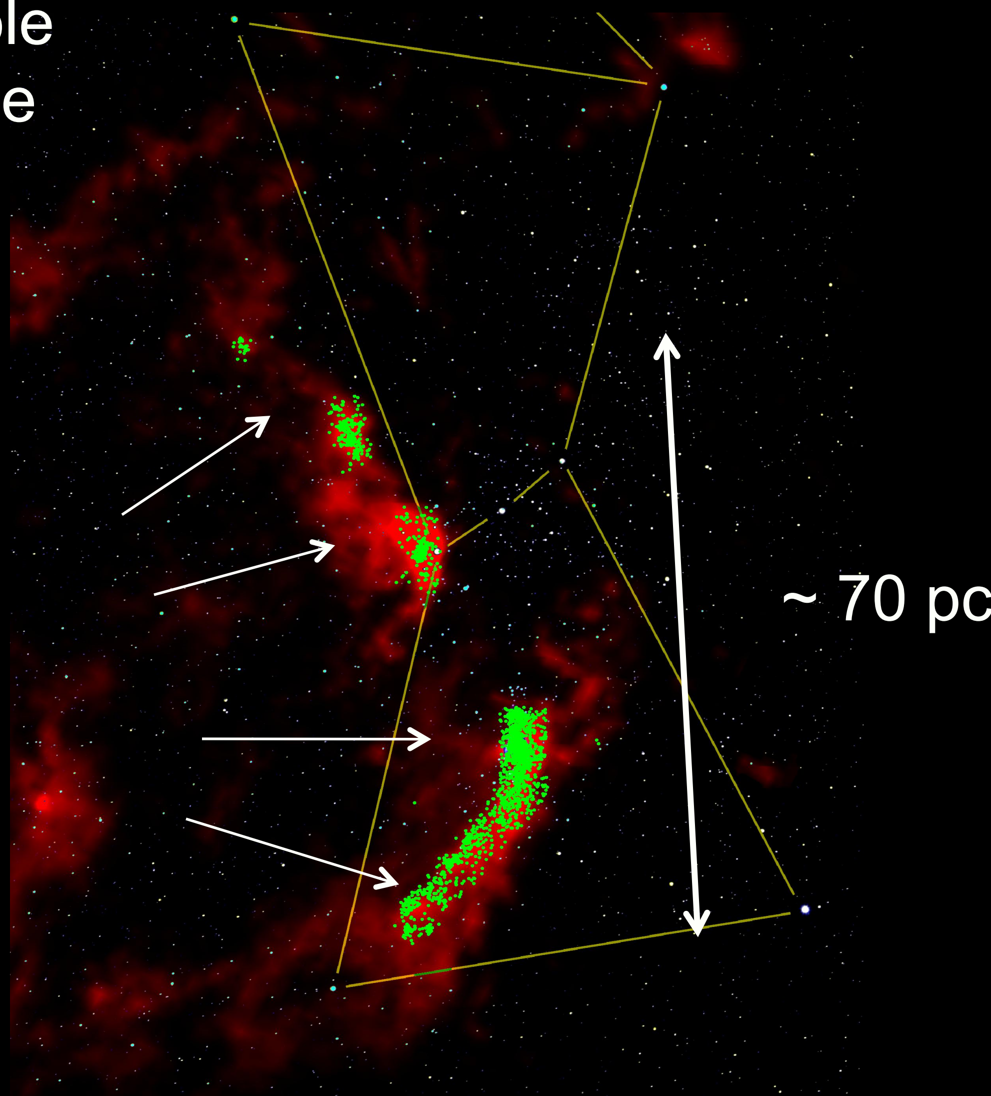
How is a cloud of MANY M_J assembled before it collapses?

One option:

"Just wait there while I bring the rest of the 10^5 thermal Jeans masses over... keep on moving so you don't collapse!

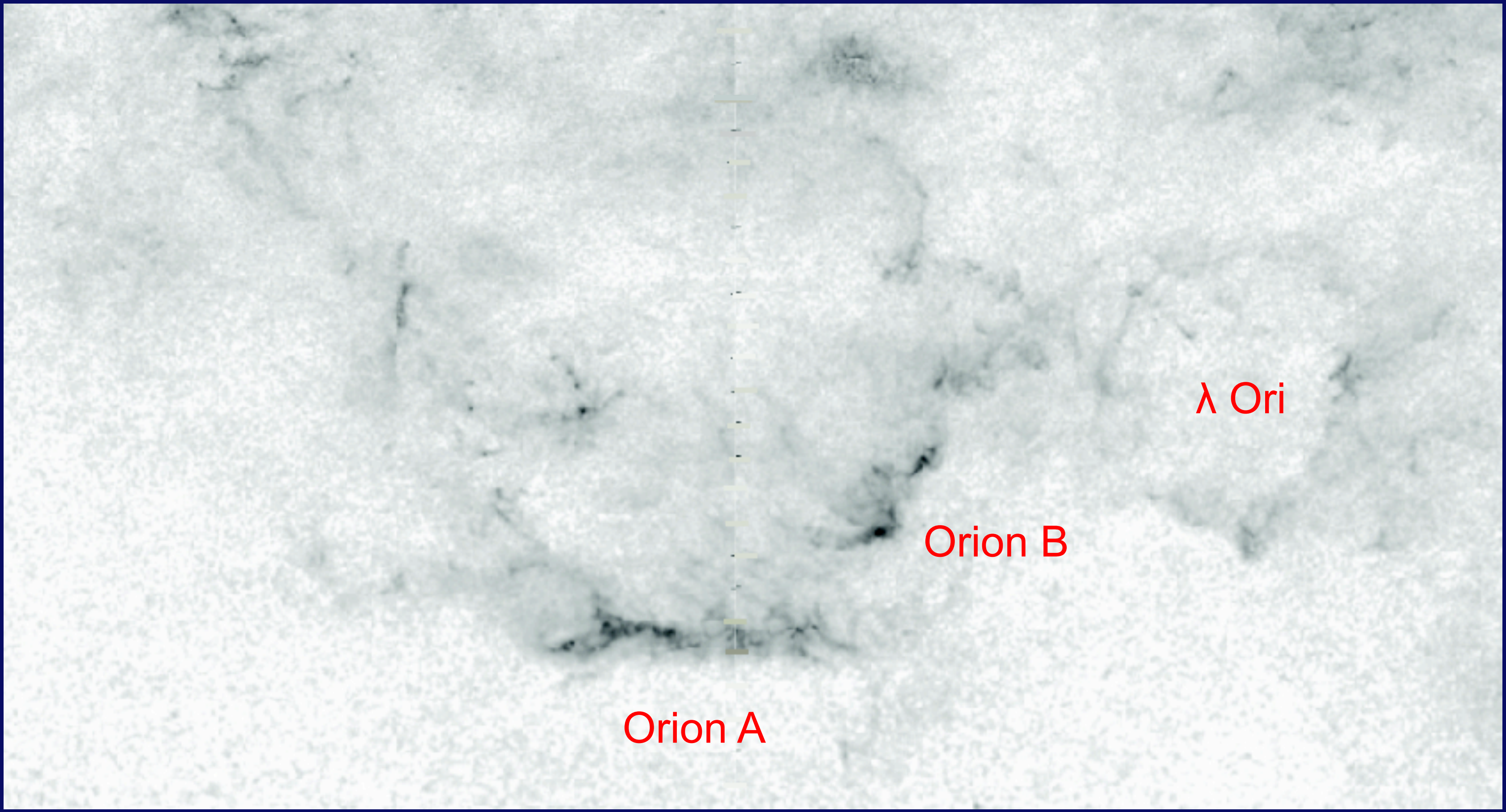


A more reasonable option: large scale flows



crossing time ~ 10-20 Myr; ages ~ 1-2 Myr (in clouds)

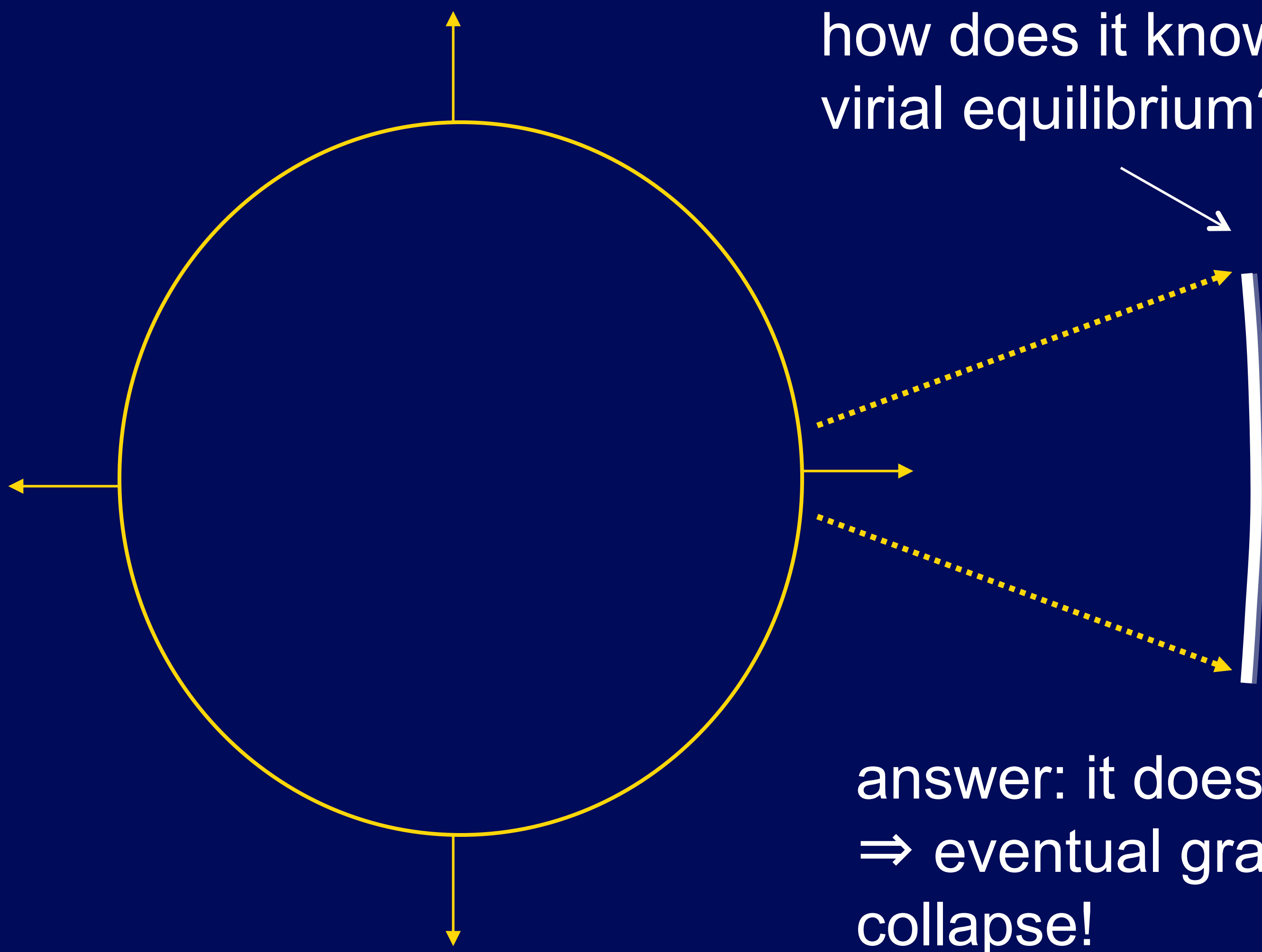
⇒ clouds are swept up in ⊥ direction



Froebrich & Rowles 2010, A_V map

Finite sheet evolution with gravity

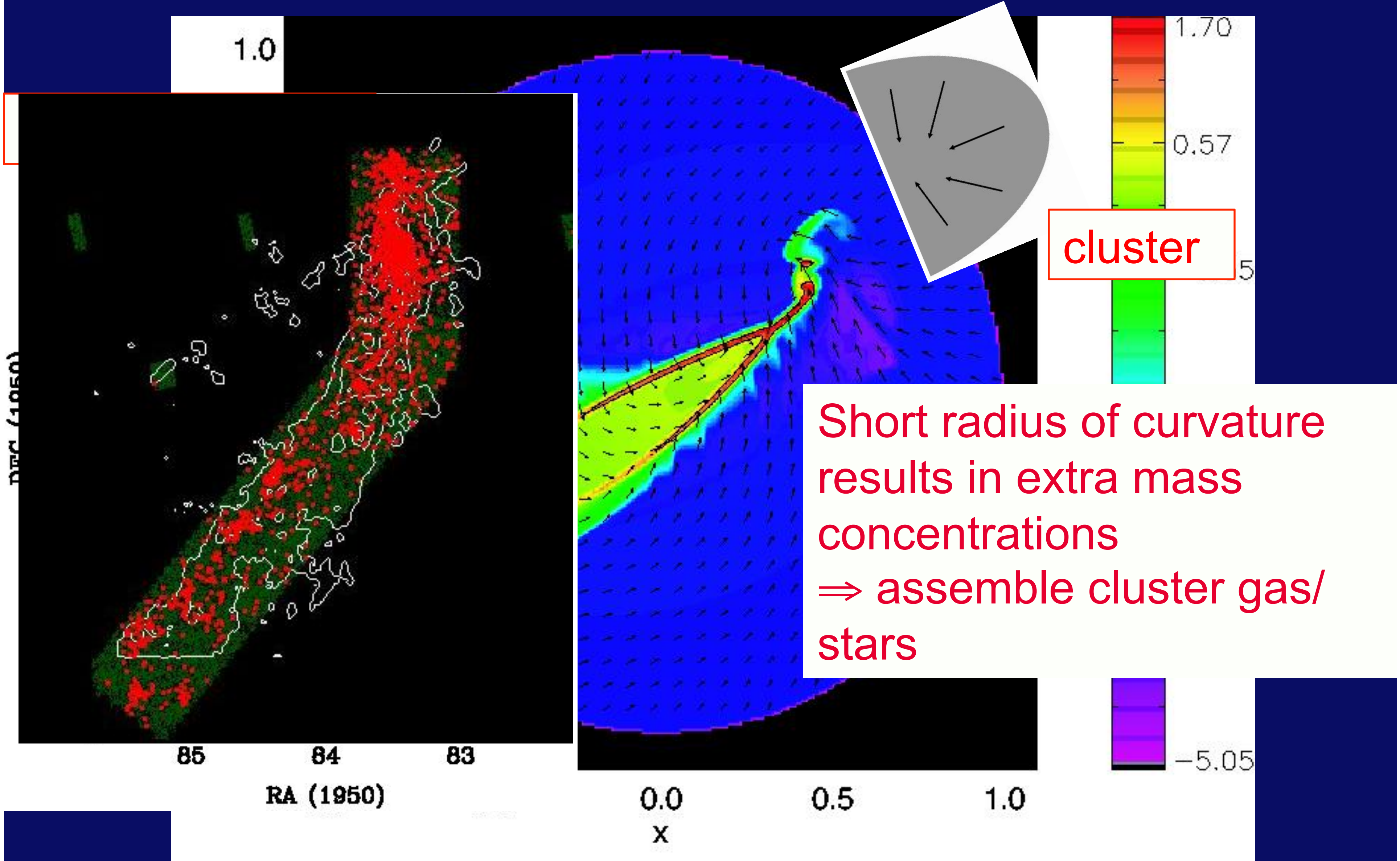
Burkert & Hartmann 04; piece of bubble wall ≈ sheet



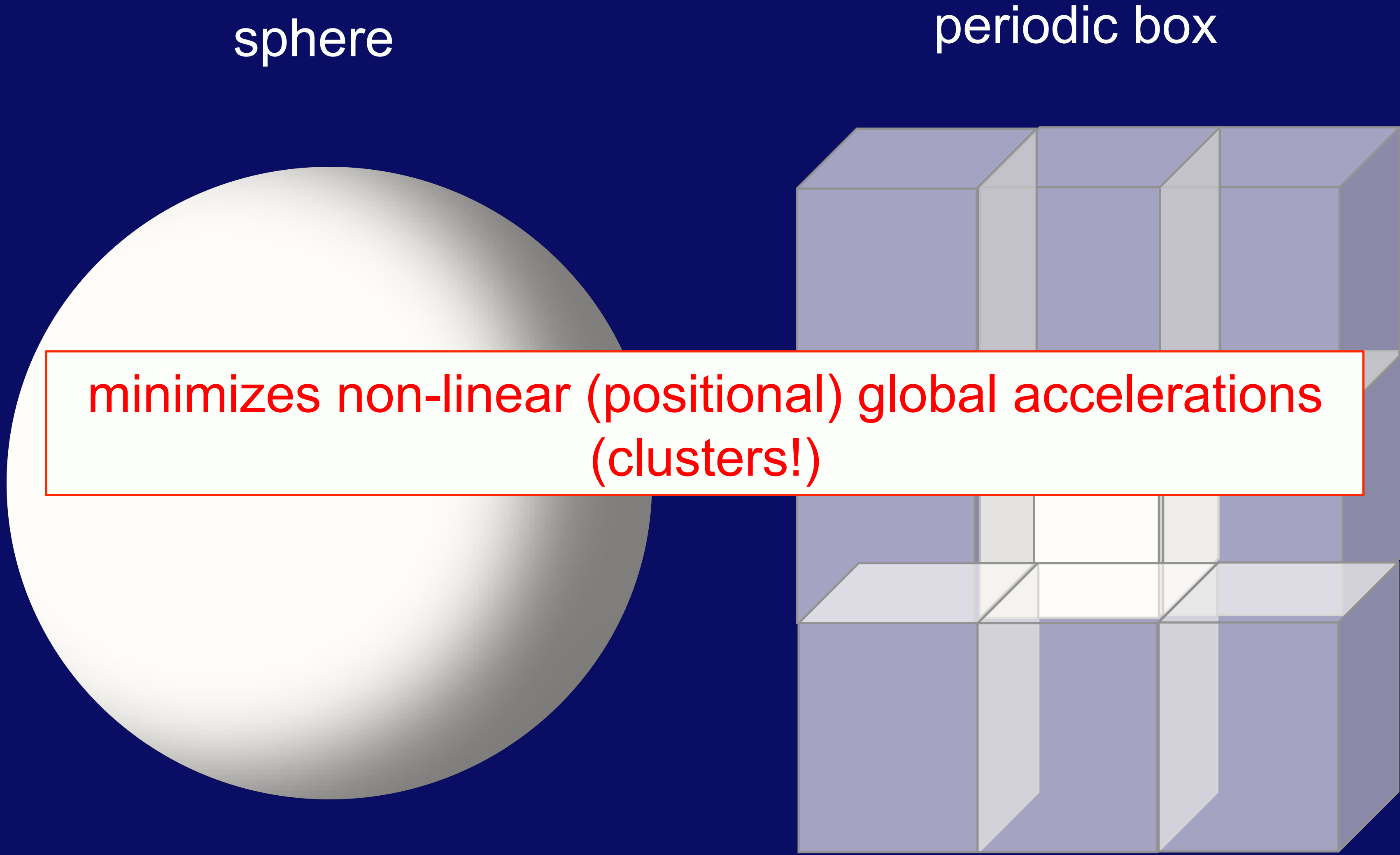
how does it know to be in virial equilibrium?

answer: it doesn't
⇒ eventual gravitational collapse!

Orion A (Hartmann & Burkert 2007): "global collapse" does ***NOT*** mean "collapse everywhere at free-fall"

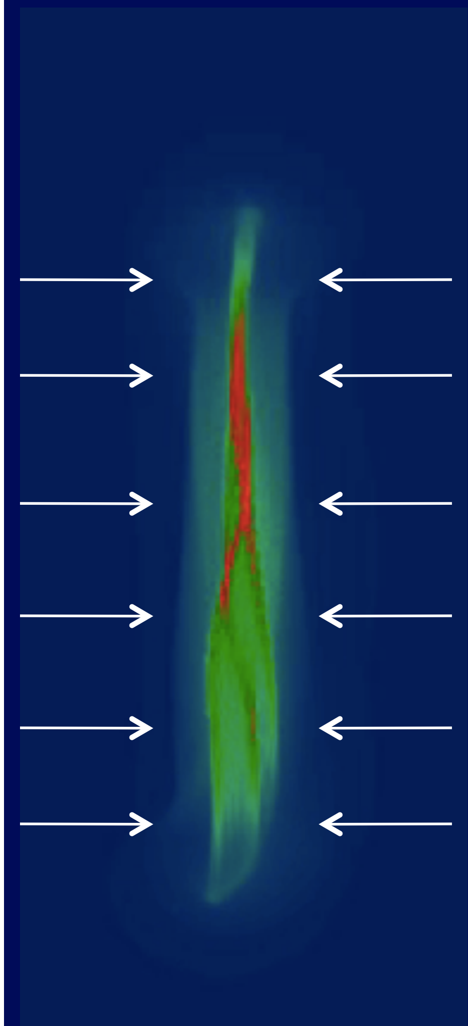


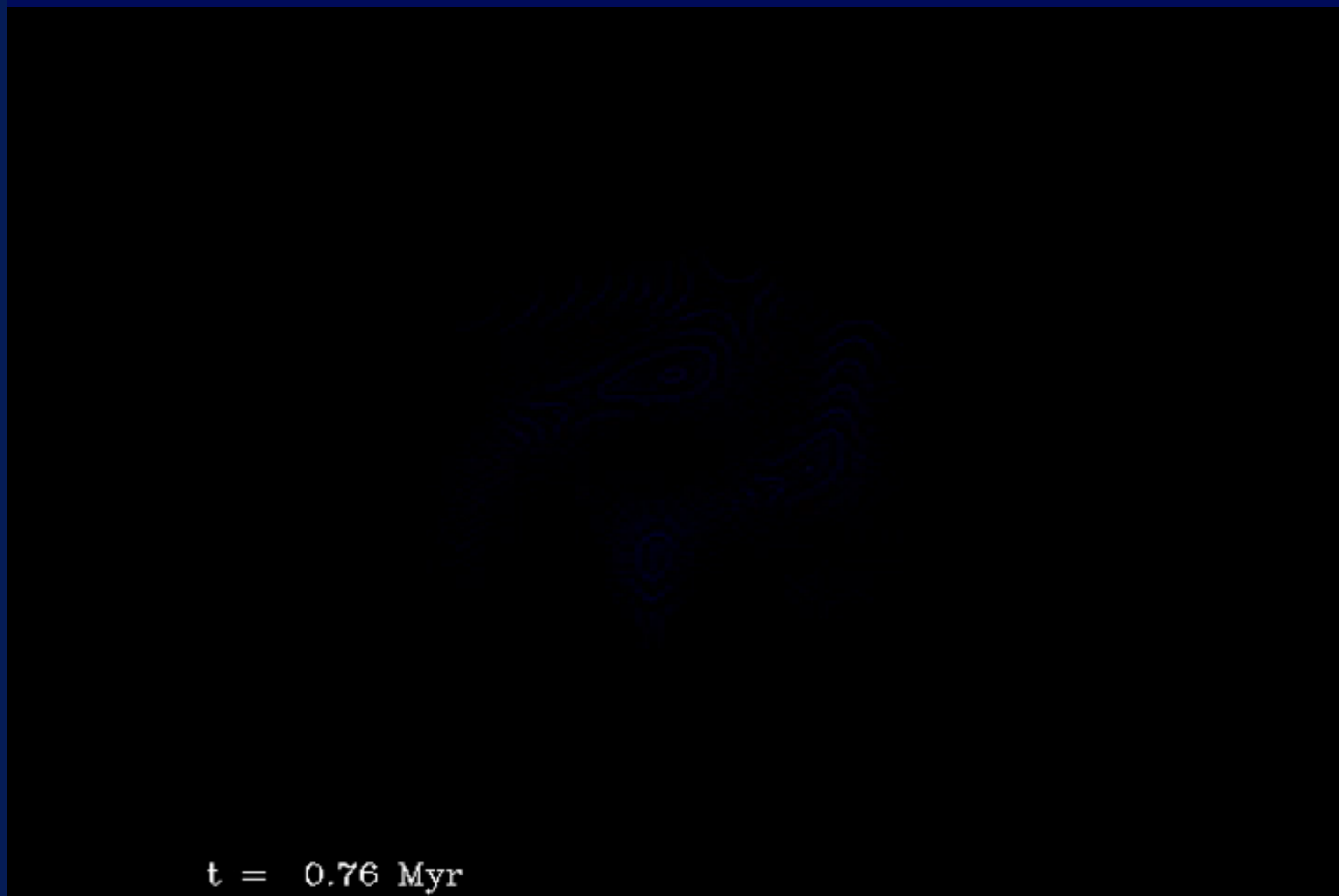
Popular cloud models



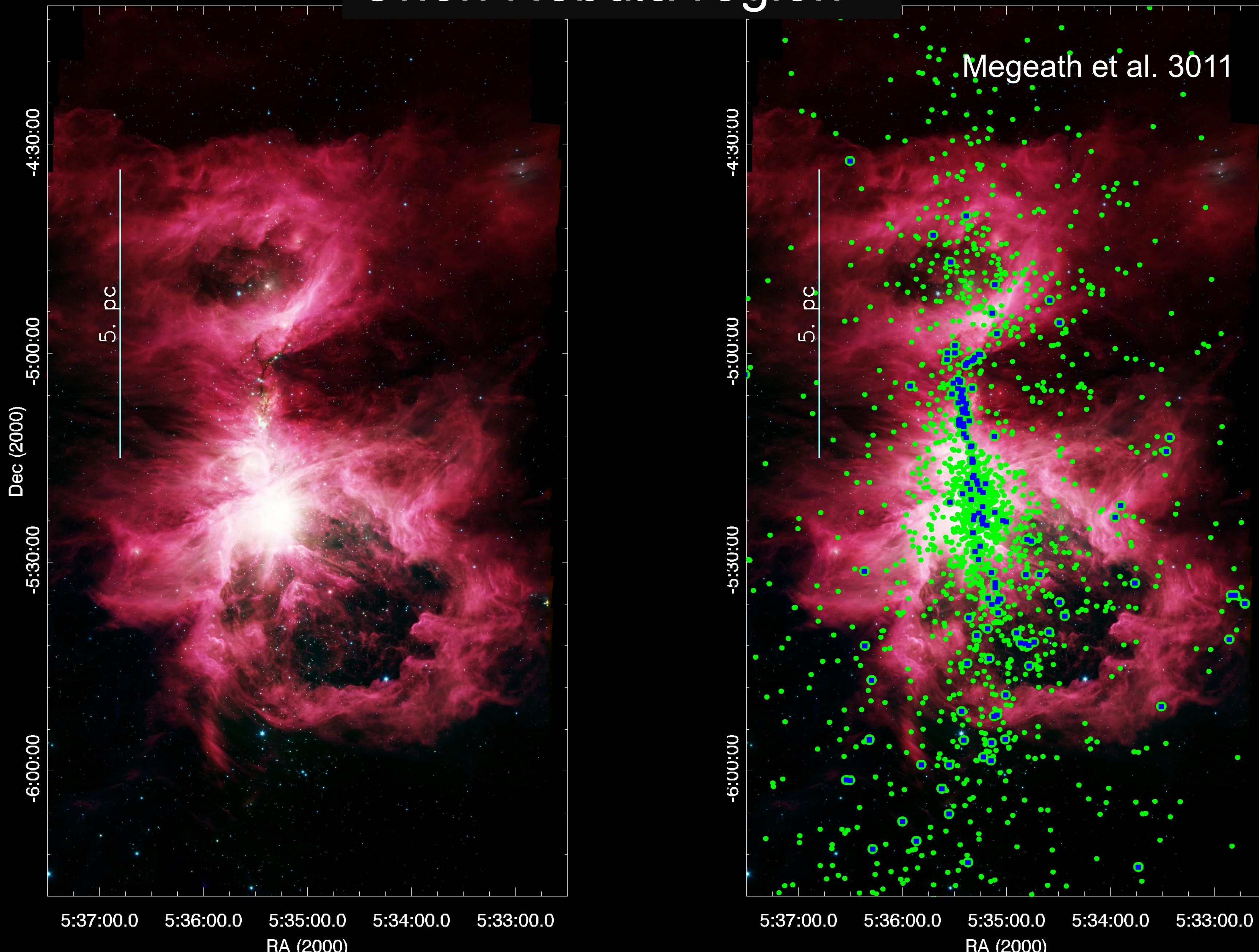
minimizes non-linear (positional) global accelerations
(clusters!)

F. Heitsch et al. 2007; sheet made by inflows with cooling, gravity; turbulence *first,* gravity *second*





Orion Nebula region

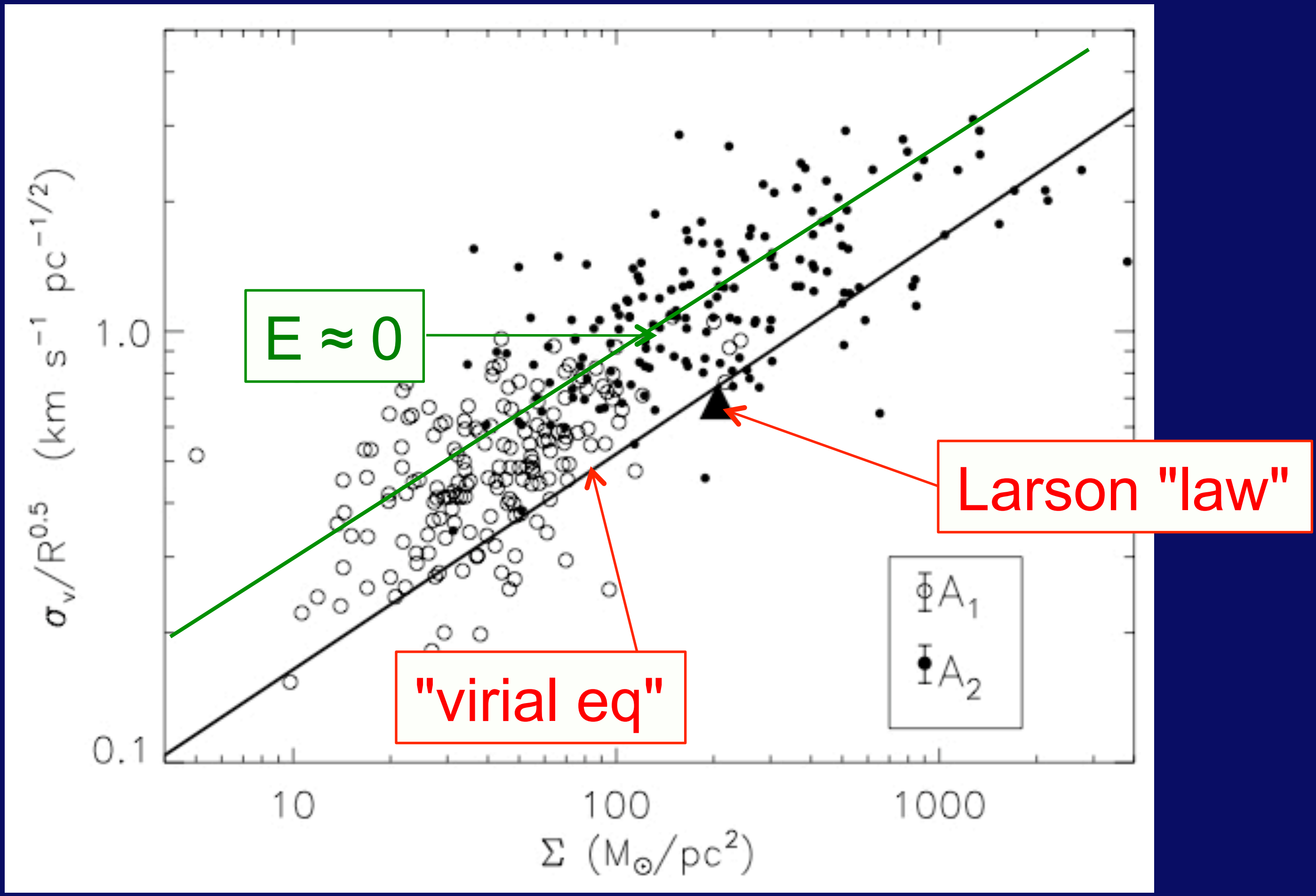


Turbulent substructure (Heitsch, Ballesteros-Paredes, Hartmann):

- (magneto) hydrodynamic turbulence – make the initial density fluctuations or "seeds”;

- large-scale gravitational acceleration – which accounts for much of the velocity dispersion in dense molecular clouds (makes filaments, clusters)

Ballesteros-Paredes et al. 2010: ~~"chaotic"~~ complex gravitational collapse/acceleration ⇒ "virial" cloud masses



Heyer et al. 2009

“Virial” cloud masses

$$G M / R \sim v^2$$

Where does the turbulence come from to JUST balance gravity?

If however motions are DRIVEN by gravity:

$$(2)\ G M / R \sim v^2$$

And there is no mystery.

How can one avoid non-linear spatial acceleration by gravity in a complex geometry with many Jeans masses?

Turbulent core models:

What is the mechanism which generates the turbulence ***in dense regions*** to balance gravity? How can it balance gravity if it is anisotropic?

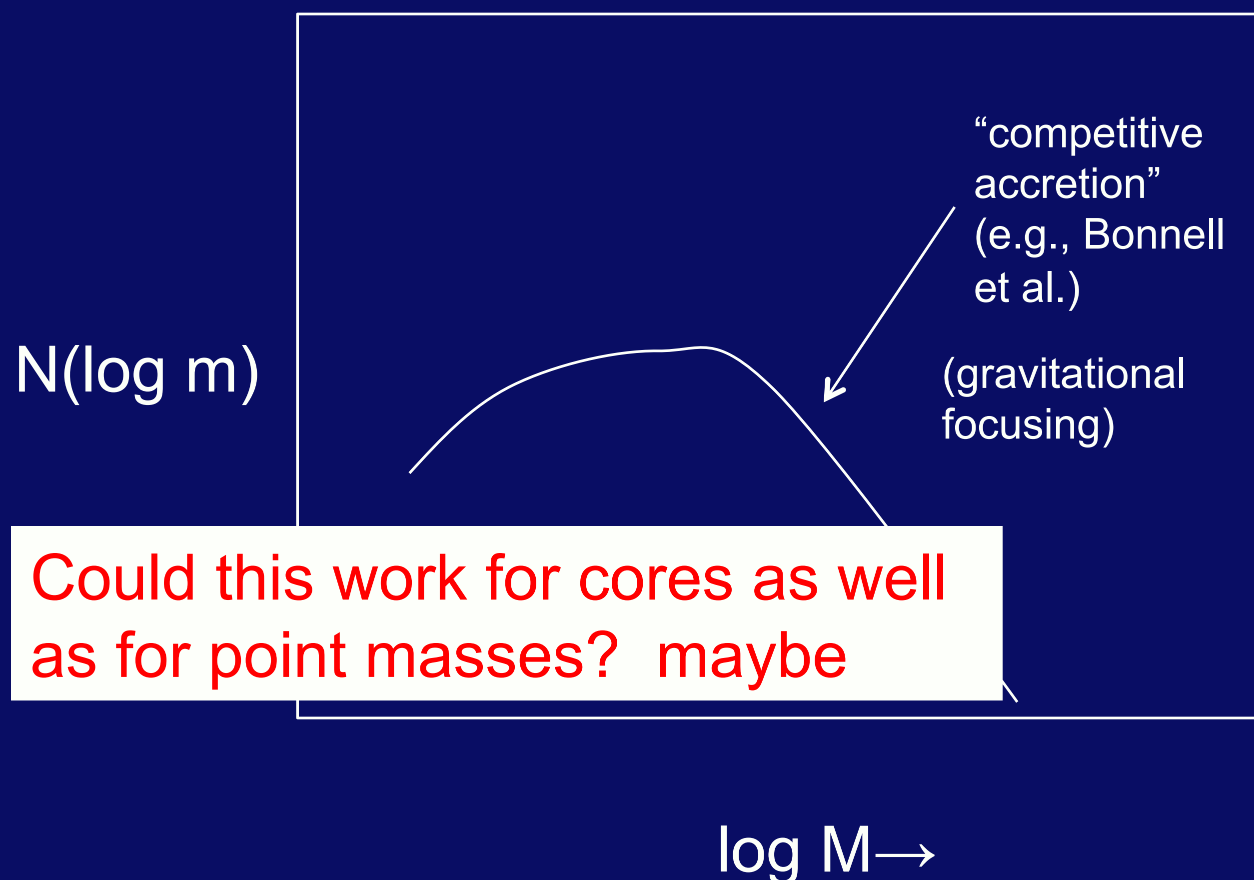
Why doesn’t it dissipate rapidly?

Collapse (gravitational focusing) models:

Would have problems if star-forming regions are long-lived

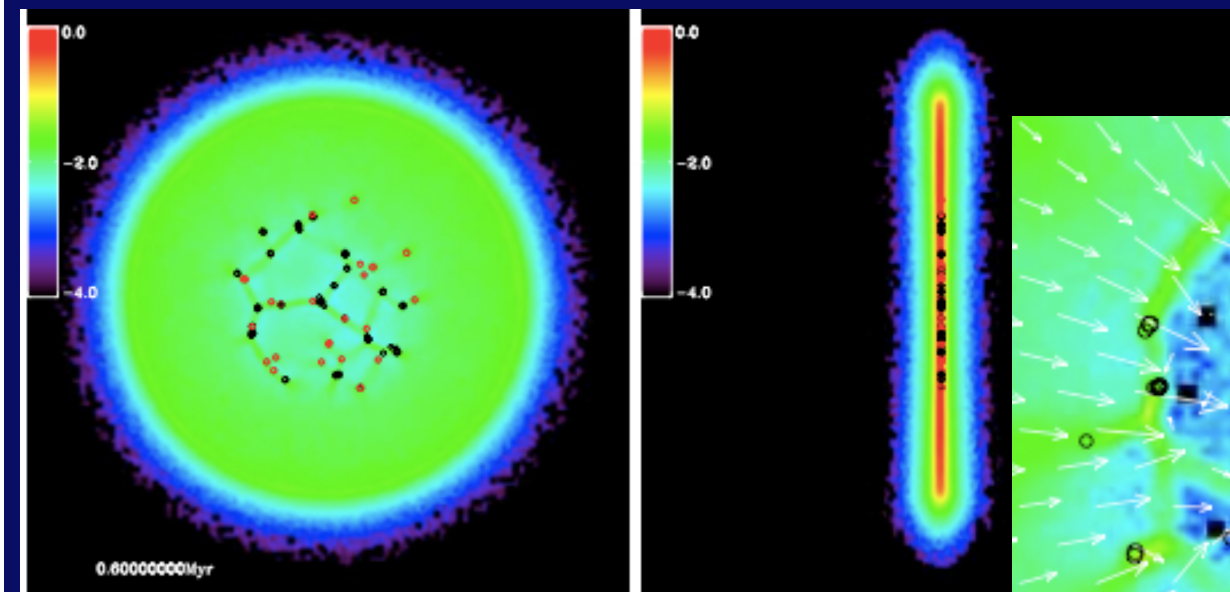
But they aren’t.

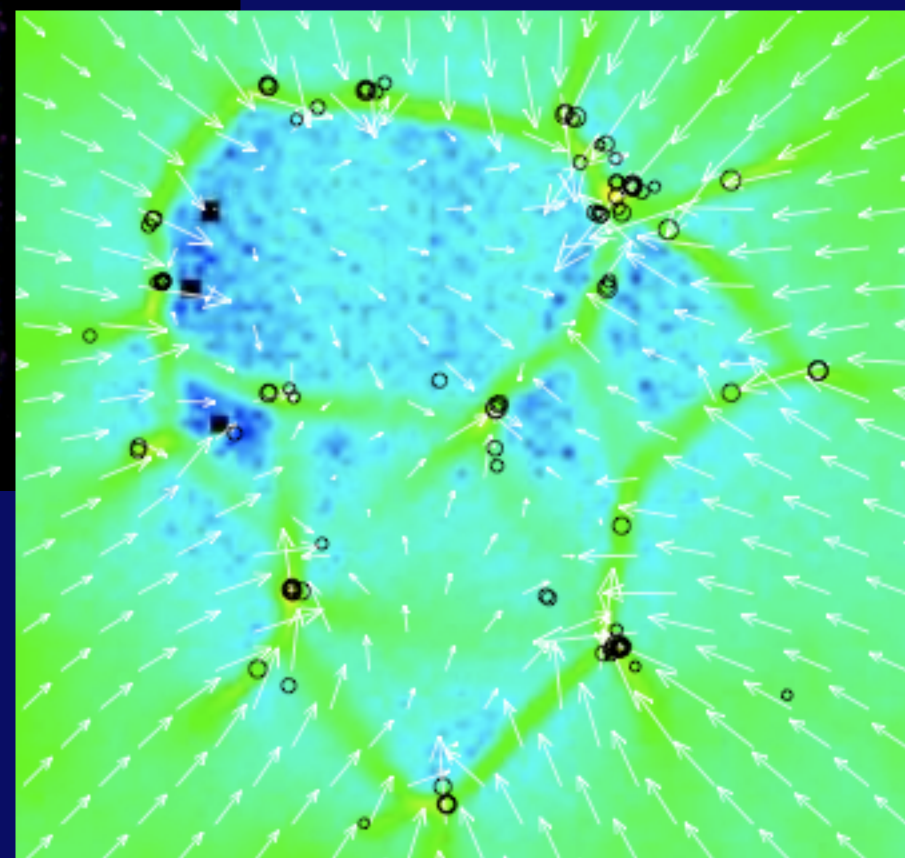
Gravitational focusing and the stellar IMF



Could this work for cores as well as for point masses? maybe

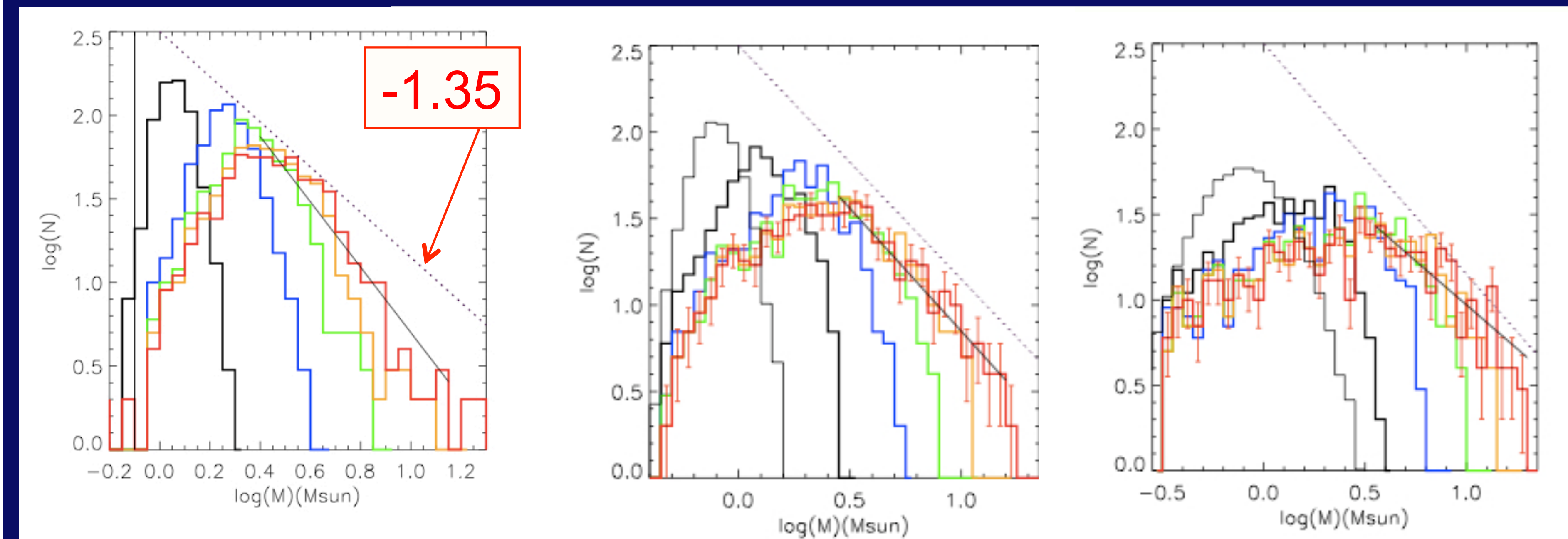
Accretion of randomly-placed sink particles in a sheet





Hsu, Hartmann, Heitsch, Gomez 2010

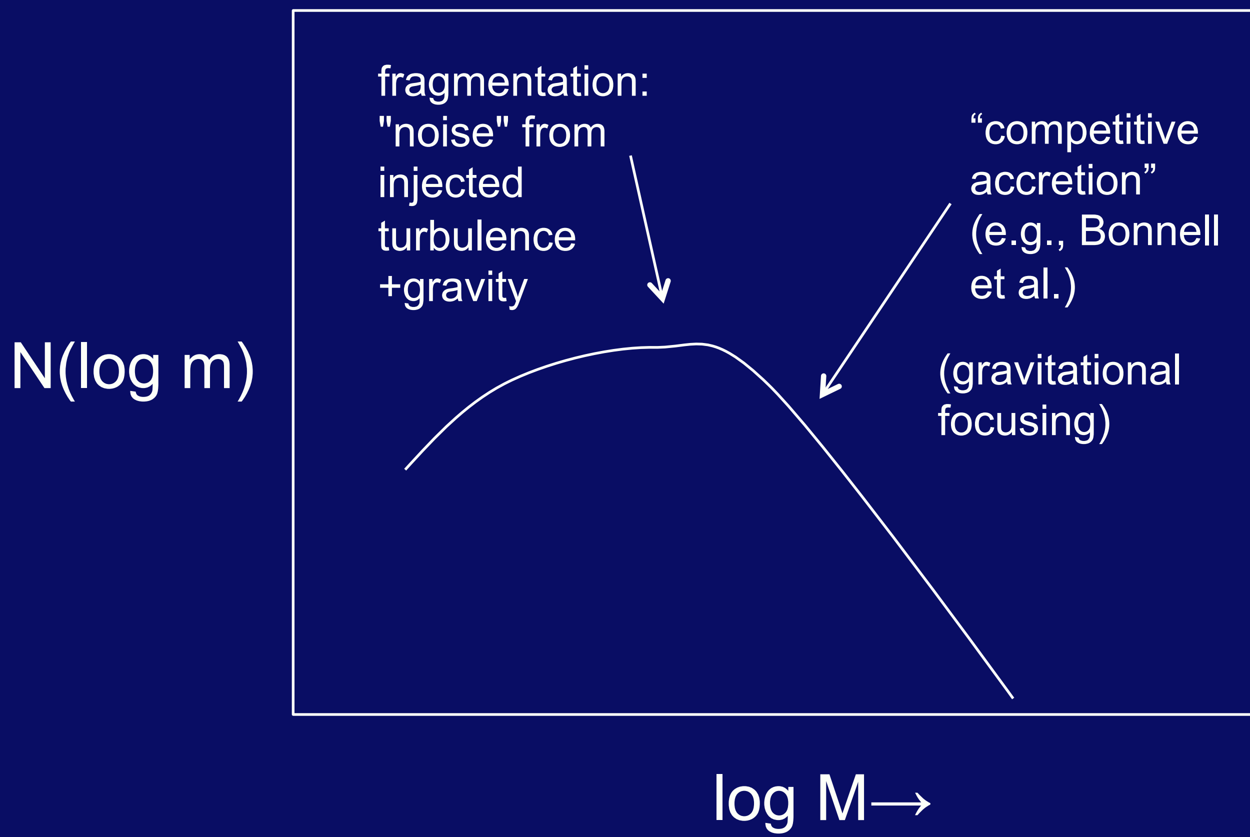
starting from a single-valued or narrow Gaussian mass distribution, high-mass IMF evolves toward Salpeter



$\Gamma \Rightarrow -1$ as limiting slope

- Don't need initial cluster;
- upper mass depends upon accretion to completion

(correlation between slope and upper mass cutoff?



- $M_J \propto T^2 P^{-1/2}$; Need ***MUCH*** higher pressures than ISM to make very low mass stars/bds ⇒ gravity!

What stops accretion?

NOT low-mass outflows – too collimated, infall too focused

I think there are two parts to this question:

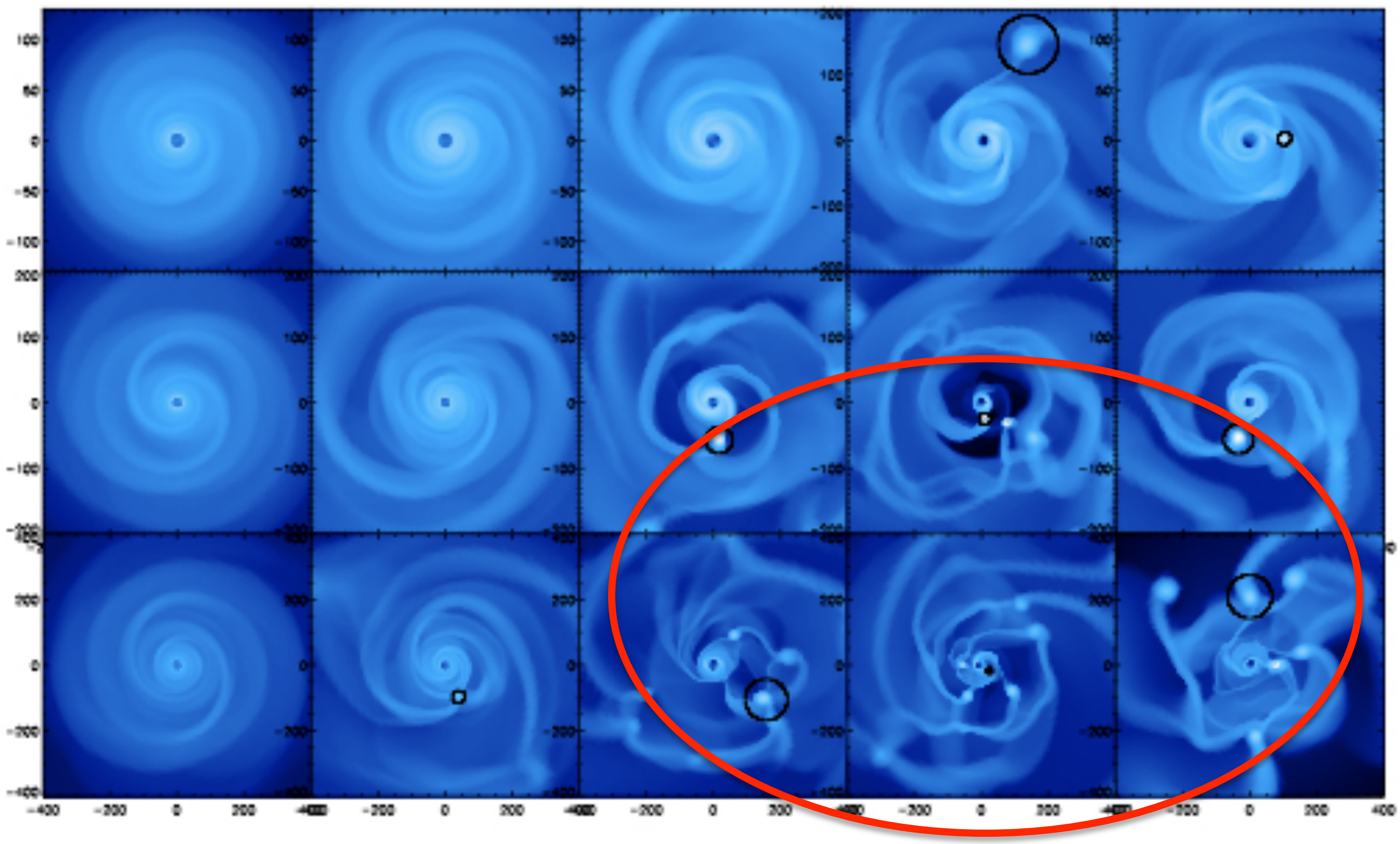
• *Local;* angular momentum ⇒ fragmentation

• *Global;* runaway gravitational acceleration results in star formation in only a small fraction of the cloud which is very dense;

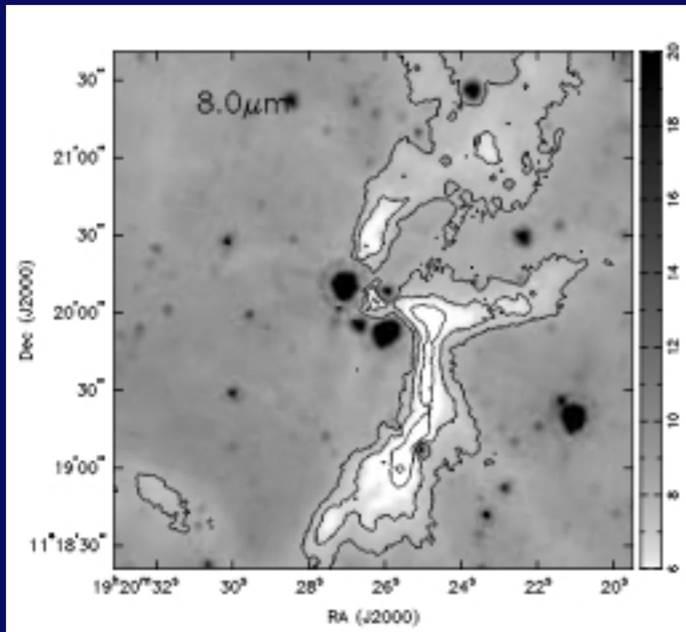
then low-density regions blown away by massive stars (either internal or external!)

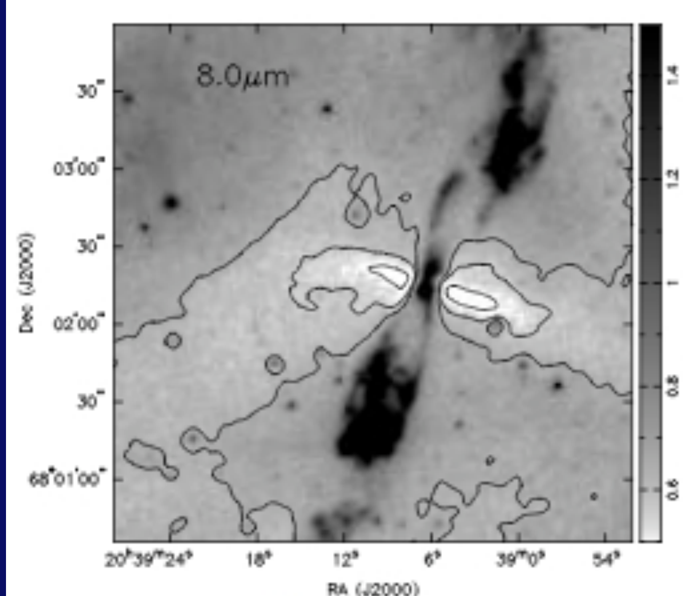
increasing dM/dt (infall) →

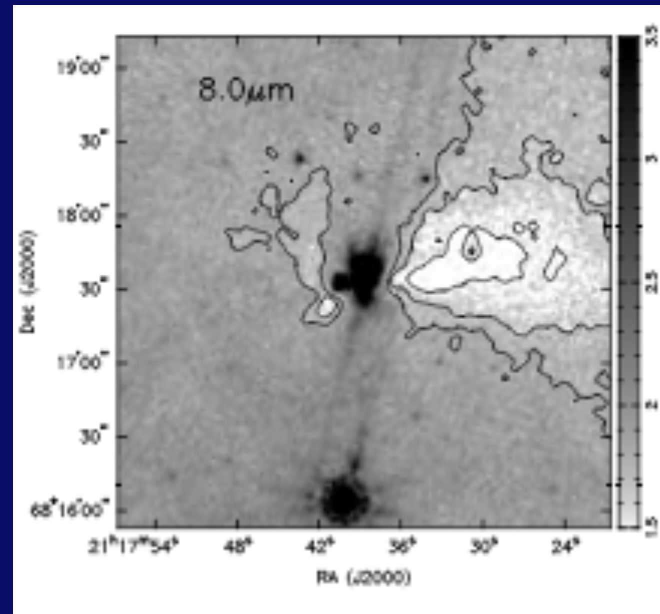
← increasing infall radius



Zhu et al. 2010, in preparation

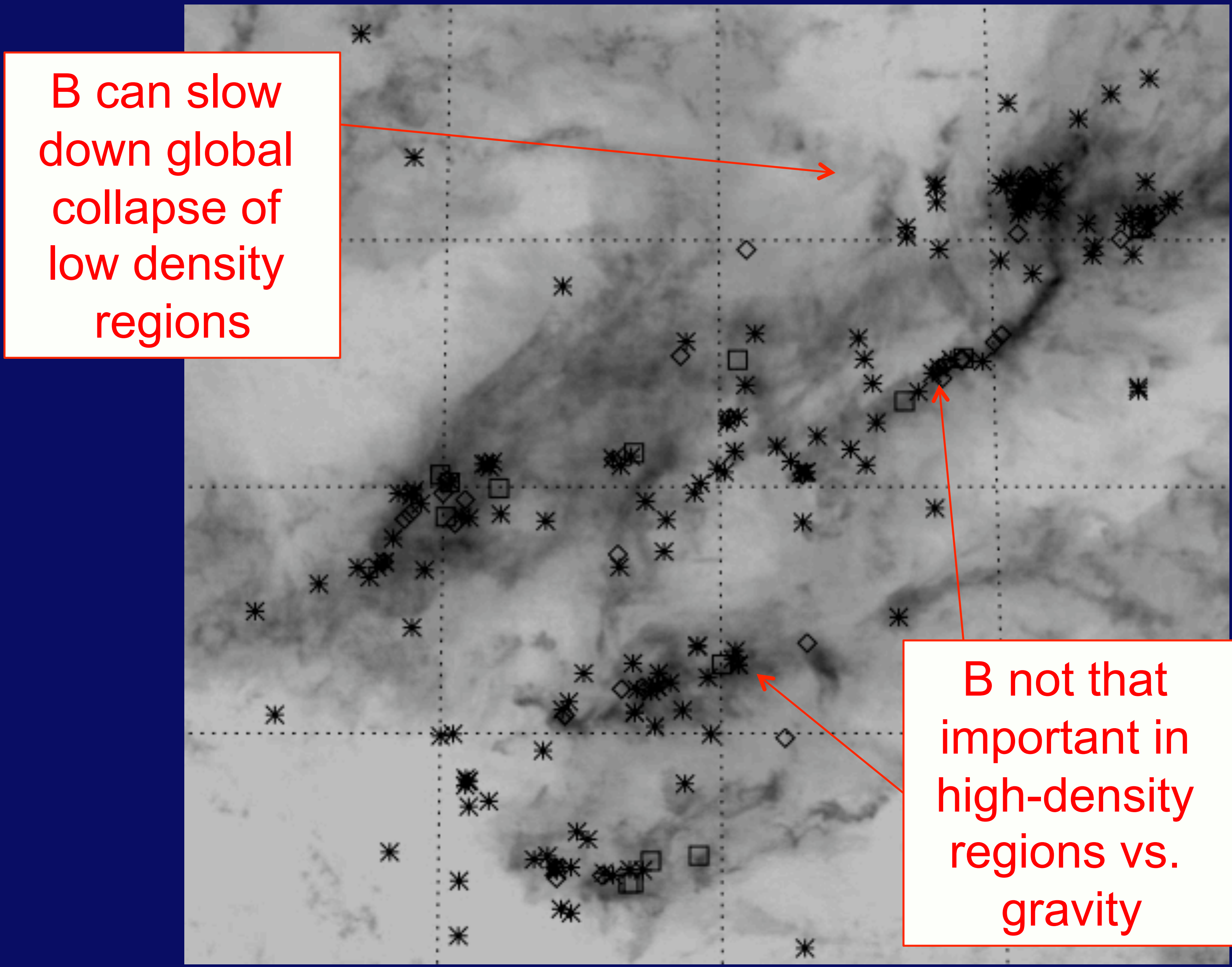




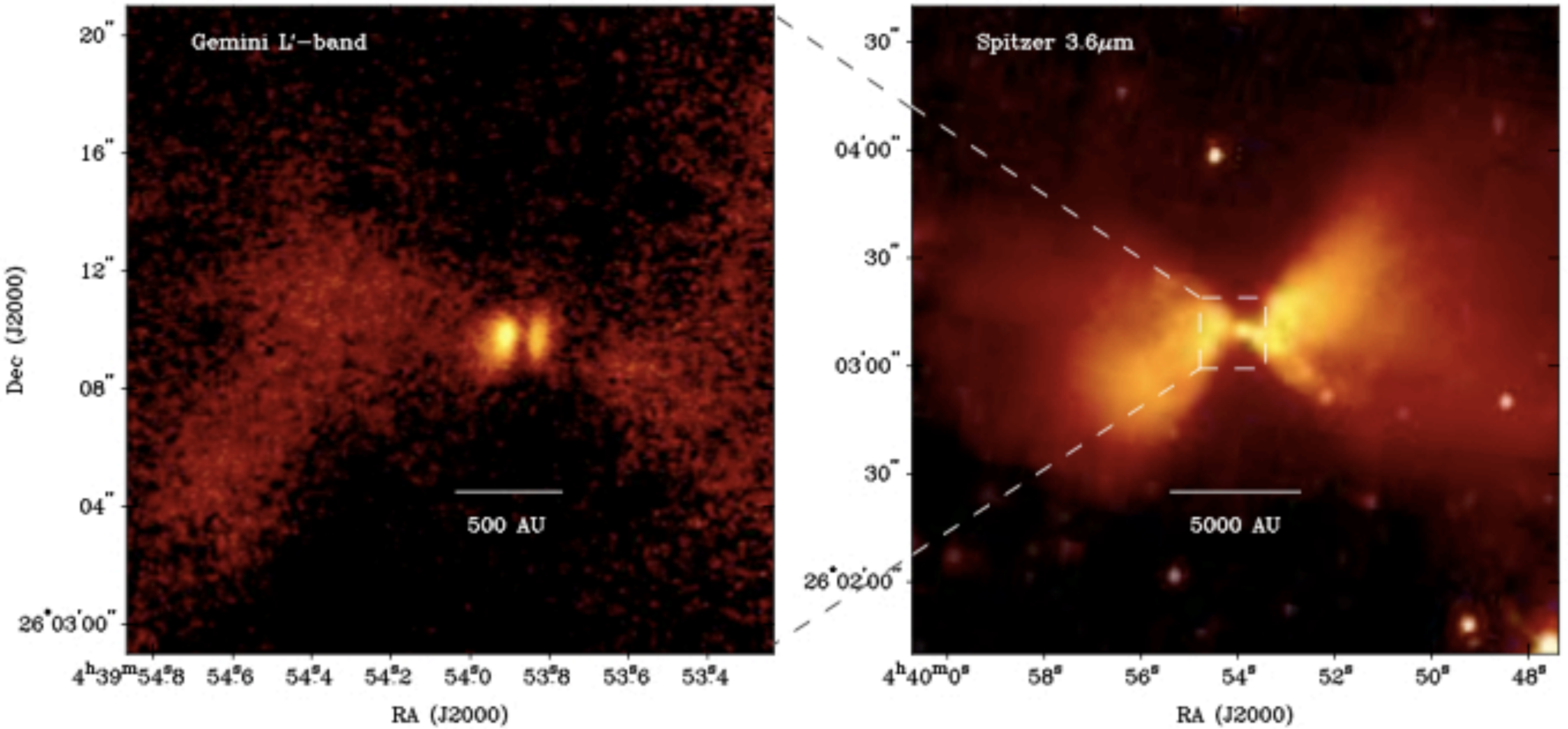


Many examples of complex, filamentary protostellar infall; non-axisymmetry ⇒ aids fragmentation into binary or multiple systems

Tobin et al. 2010, 8μm extinction maps from Spitzer



Goldsmith et al. 2009



Magnetic fields ***DO NOT PREVENT*** formation of large disks even at early stages

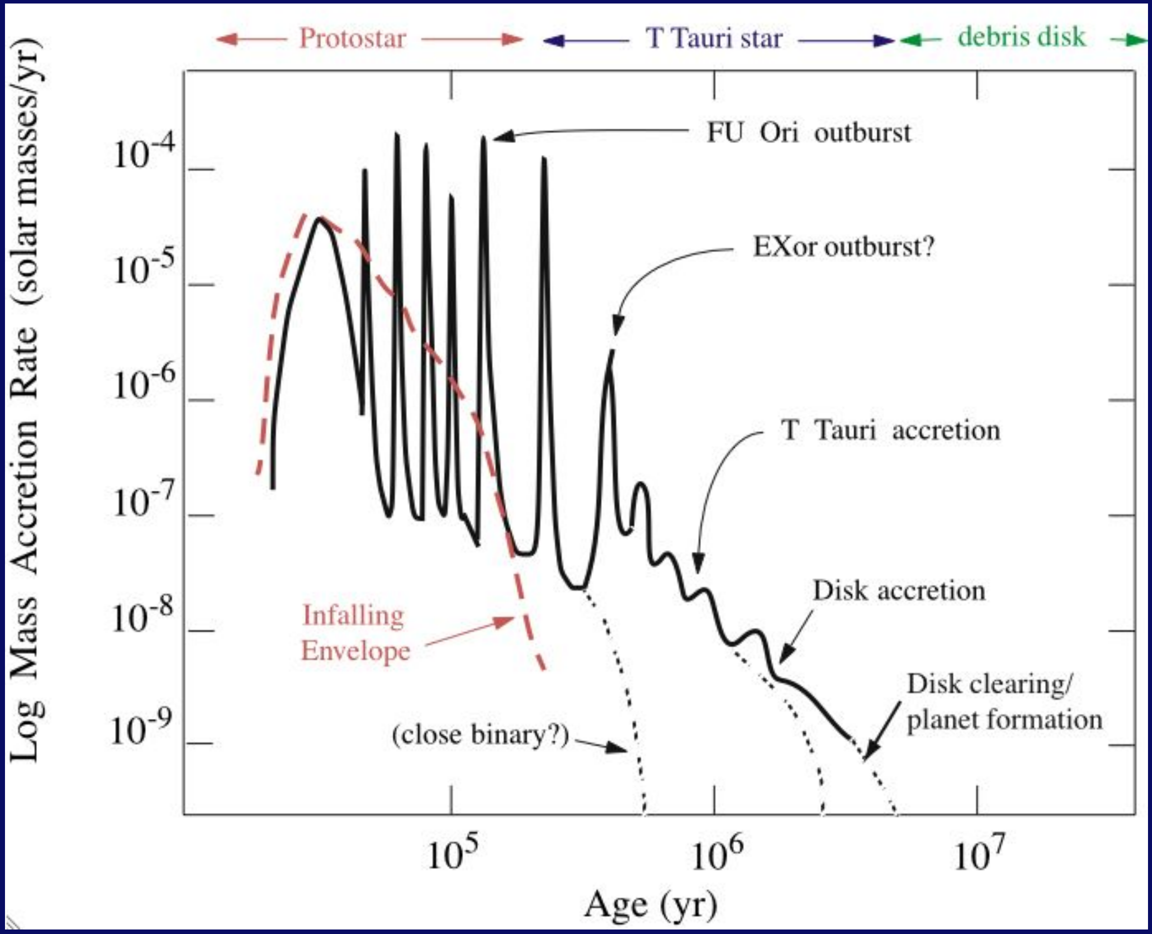
Tobin et al. 2010

Protostellar accretion and PMS stellar ages

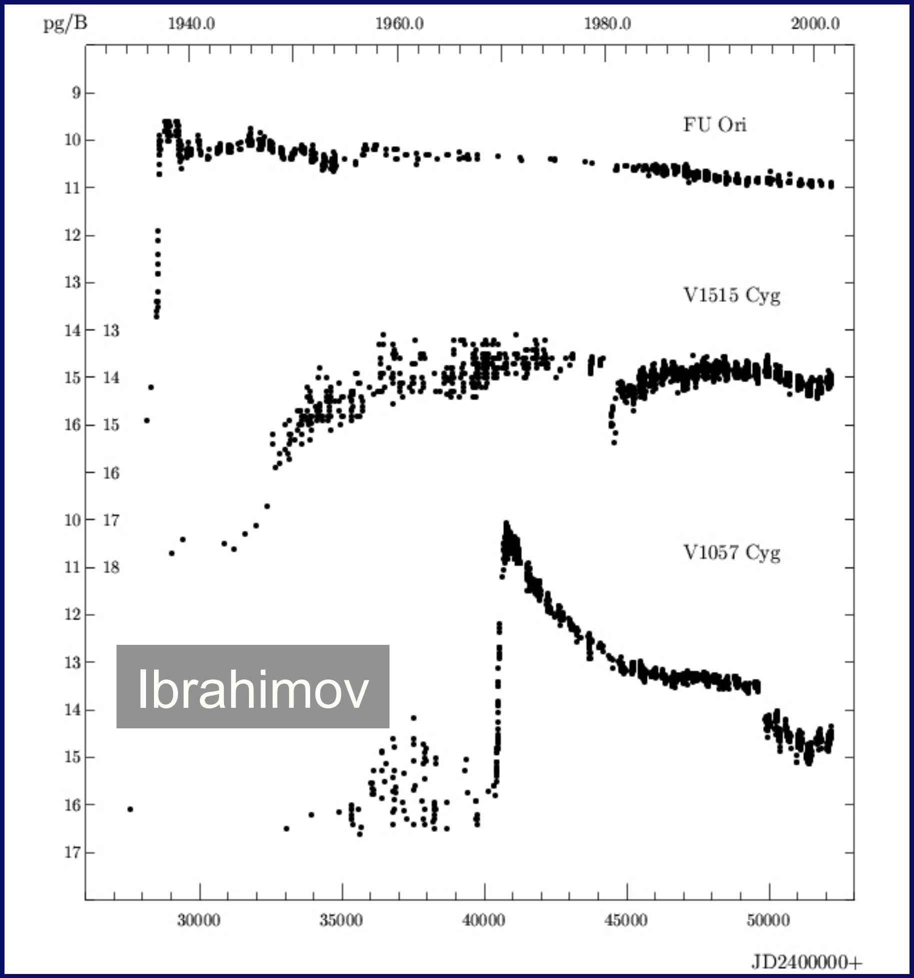
- stars MUST accrete much/most of their mass through disks

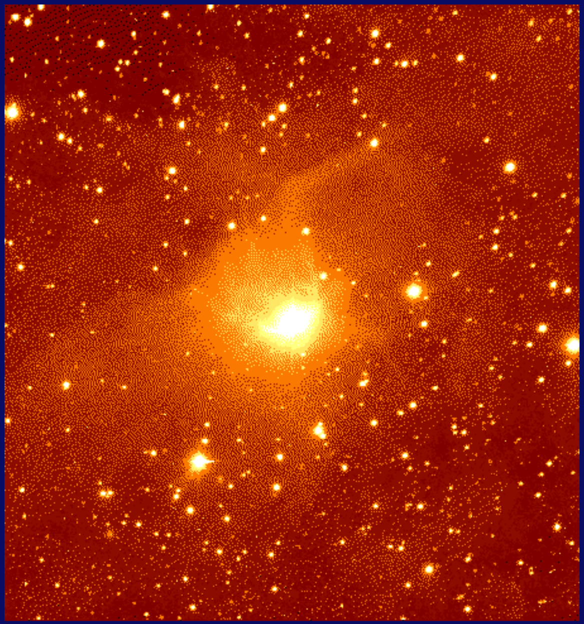
- *Episodic* bursts of accretion implied by the low luminosities of most protostars

- what does this mean for ages?

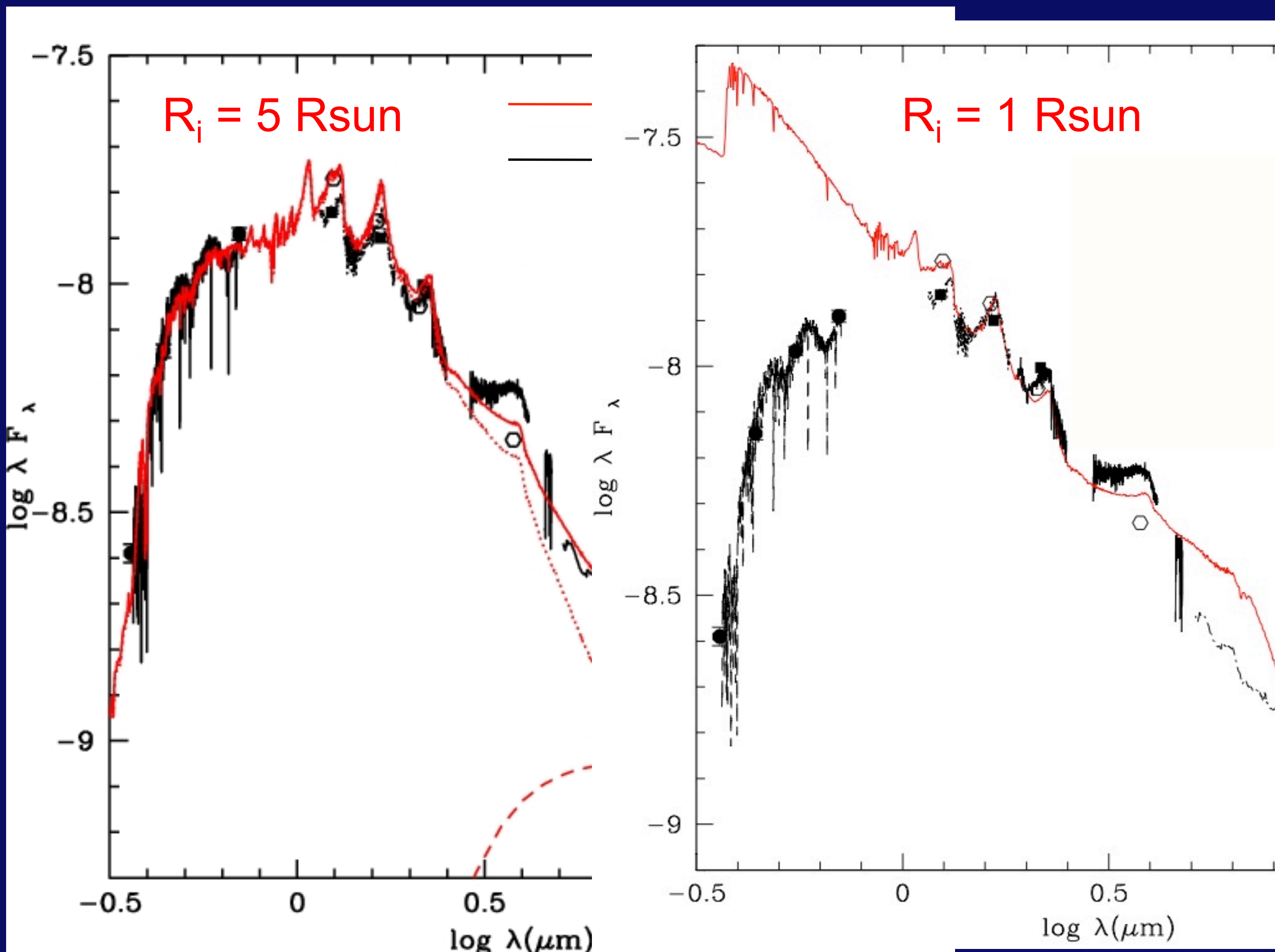


FU Ori objects: 10^{-4} Msun/yr accretion outbursts



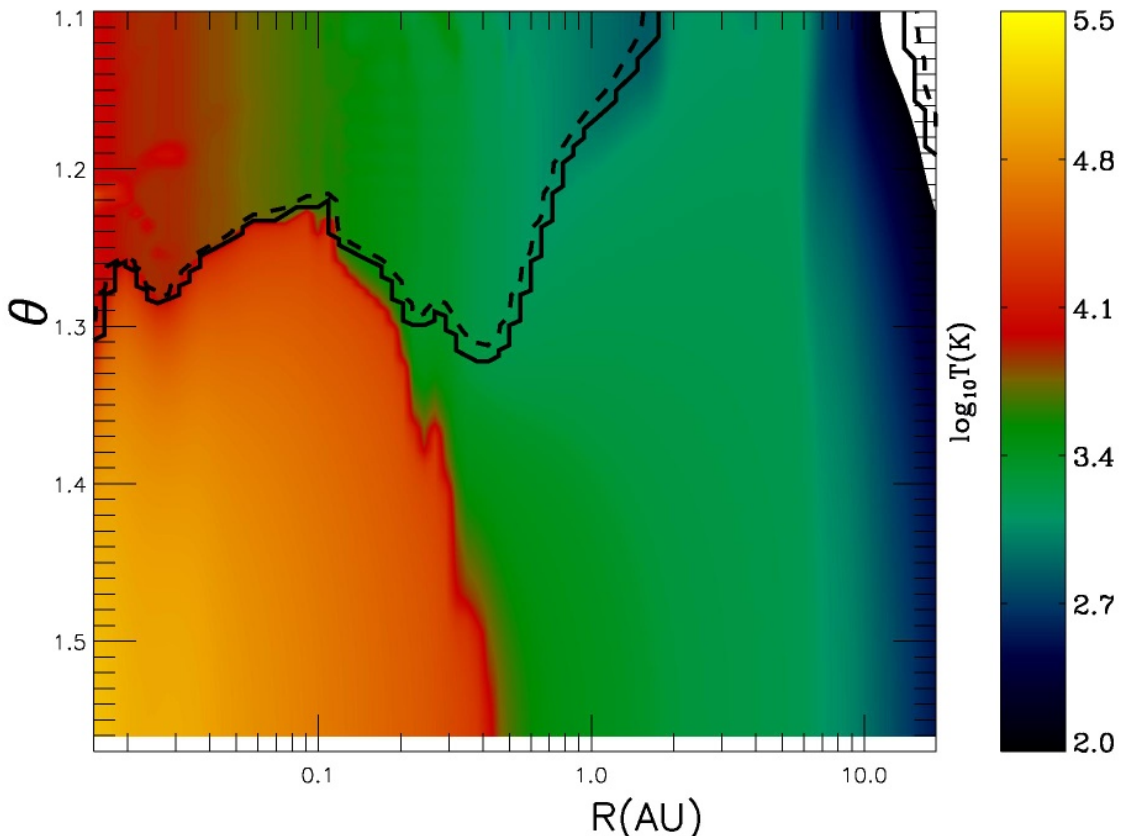


FU Ori: 10^{-4} $M_\odot$/yr accretion outburst



Zhaohuan Zhu et al. 2007, 2008

FU Ori disks are internally HOT!



Zhu et al. 2009

Inner disk temperatures are 1- 2 x 10^5 K!

Disk is geometrically thick (H/R ~ 0.3) – covers a significant fraction of the star!

Thick hot disk explains:
- no boundary layer
- large inner disk radius

⇒ expansion of star!

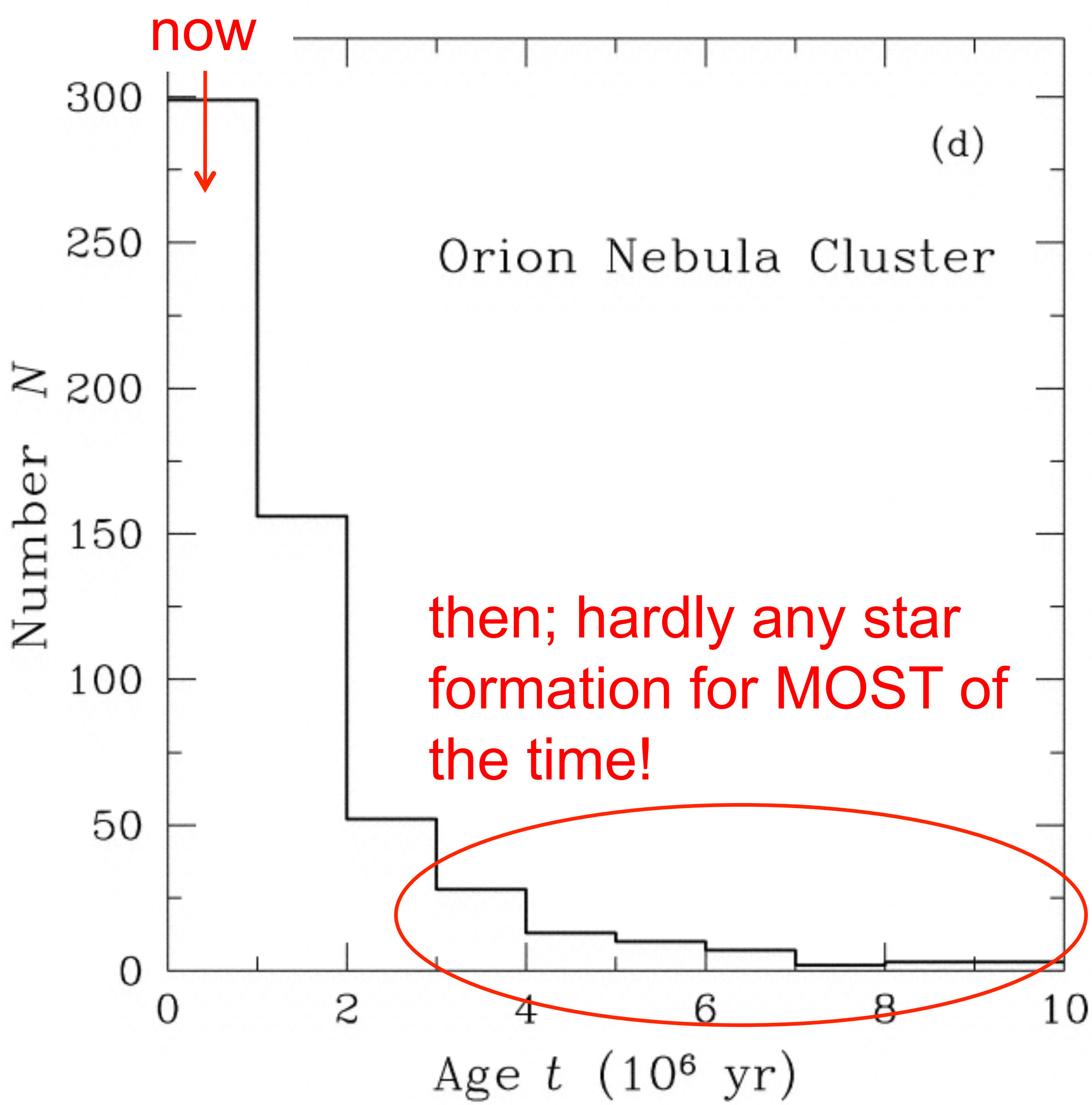
Add thermal energy ⇒ closer to usual birthlines;
INITIAL CONDITIONS might matter! (binaries esp.)

What are we trying to explain?

properties of "oldest" stars…

but do they belong??

membership is not straightforward!

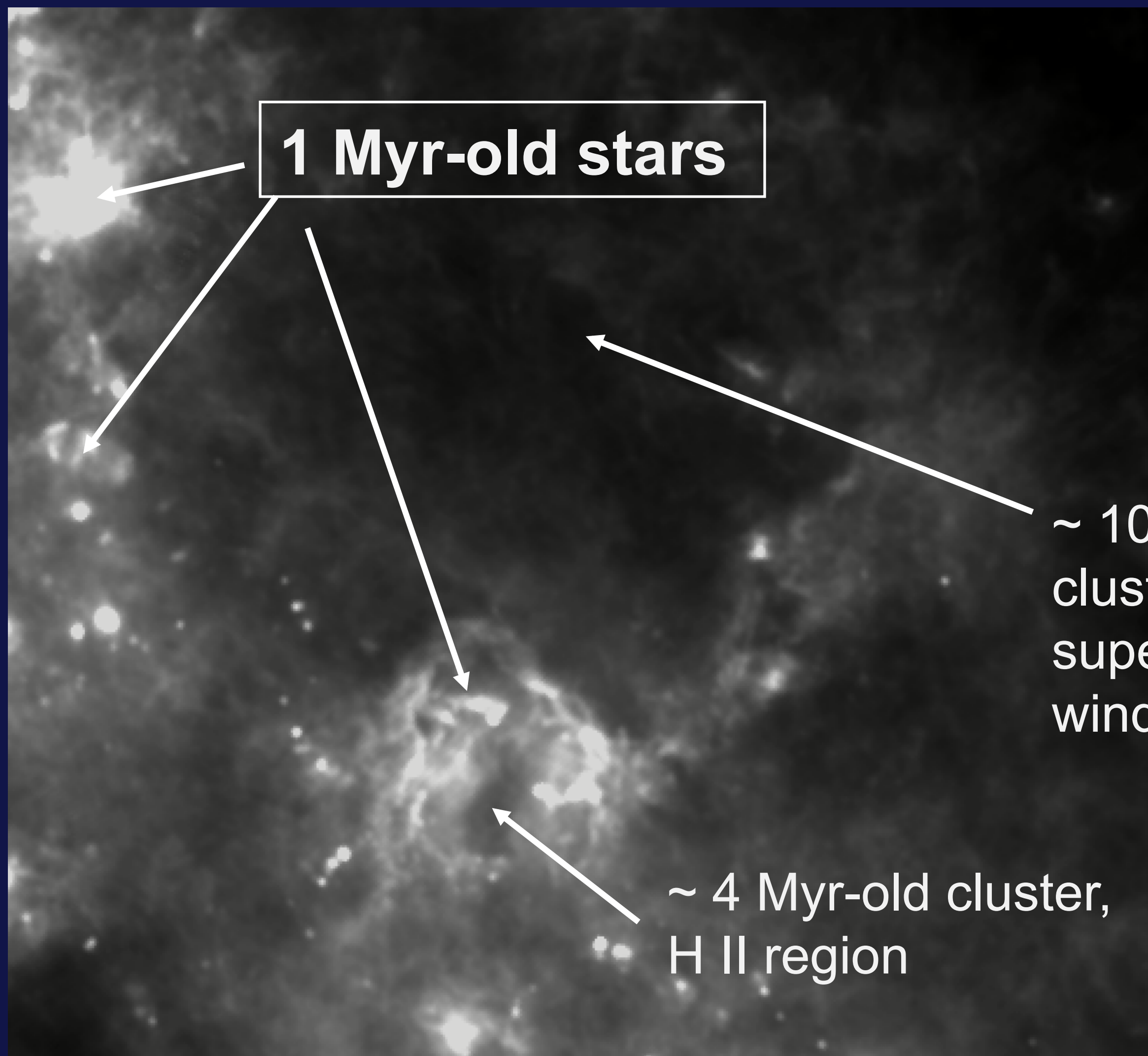


Palla & Stahler 2000

Star-forming “events” are spatially correlated!

Cep OB2

50 pc



100 μm IRAS dust emission

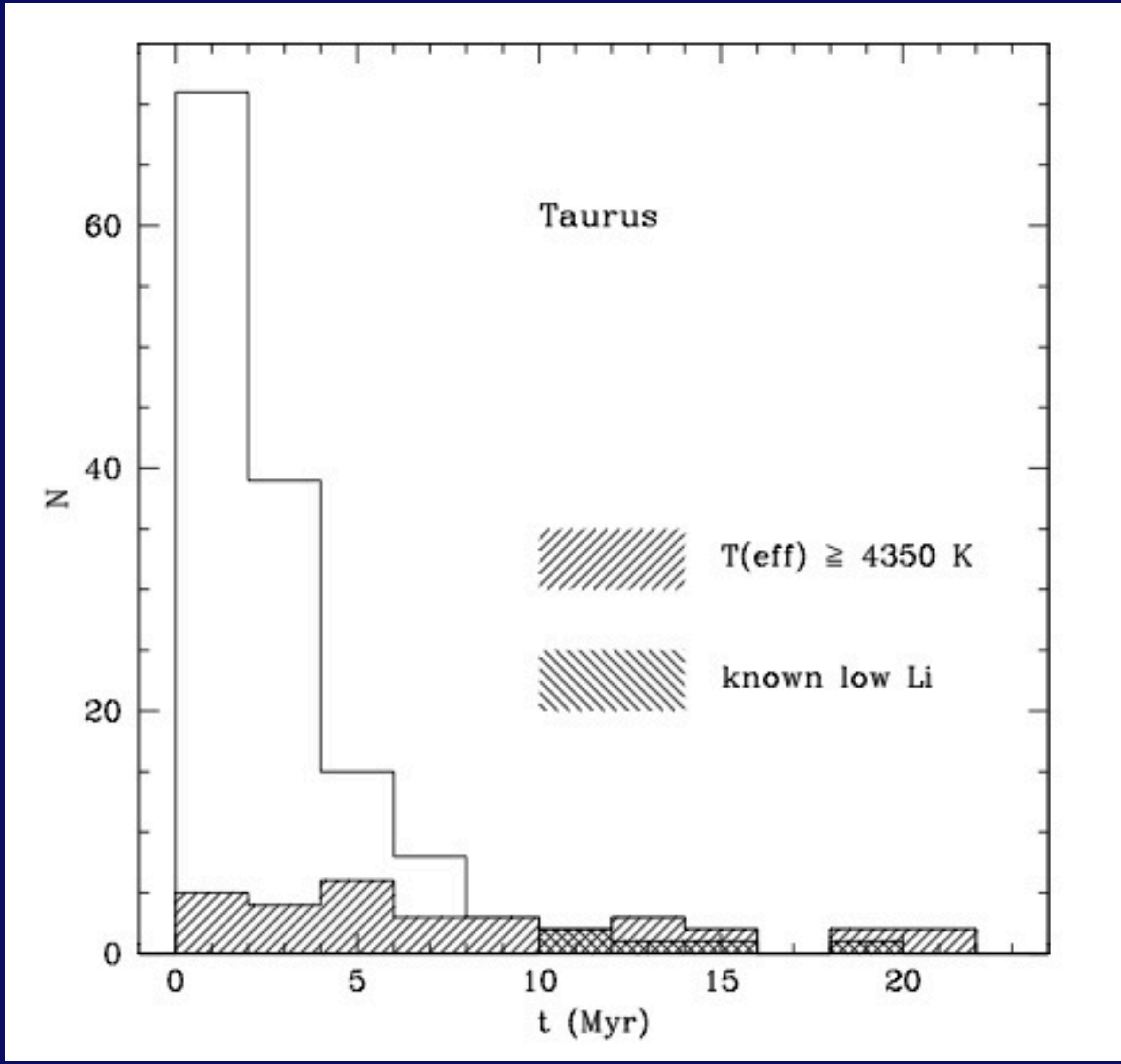
- Gravitational "focusing", operating on turbulent initial structure: makes filaments, clusters, high-mass IMF, and helps make lowest-mass fragments

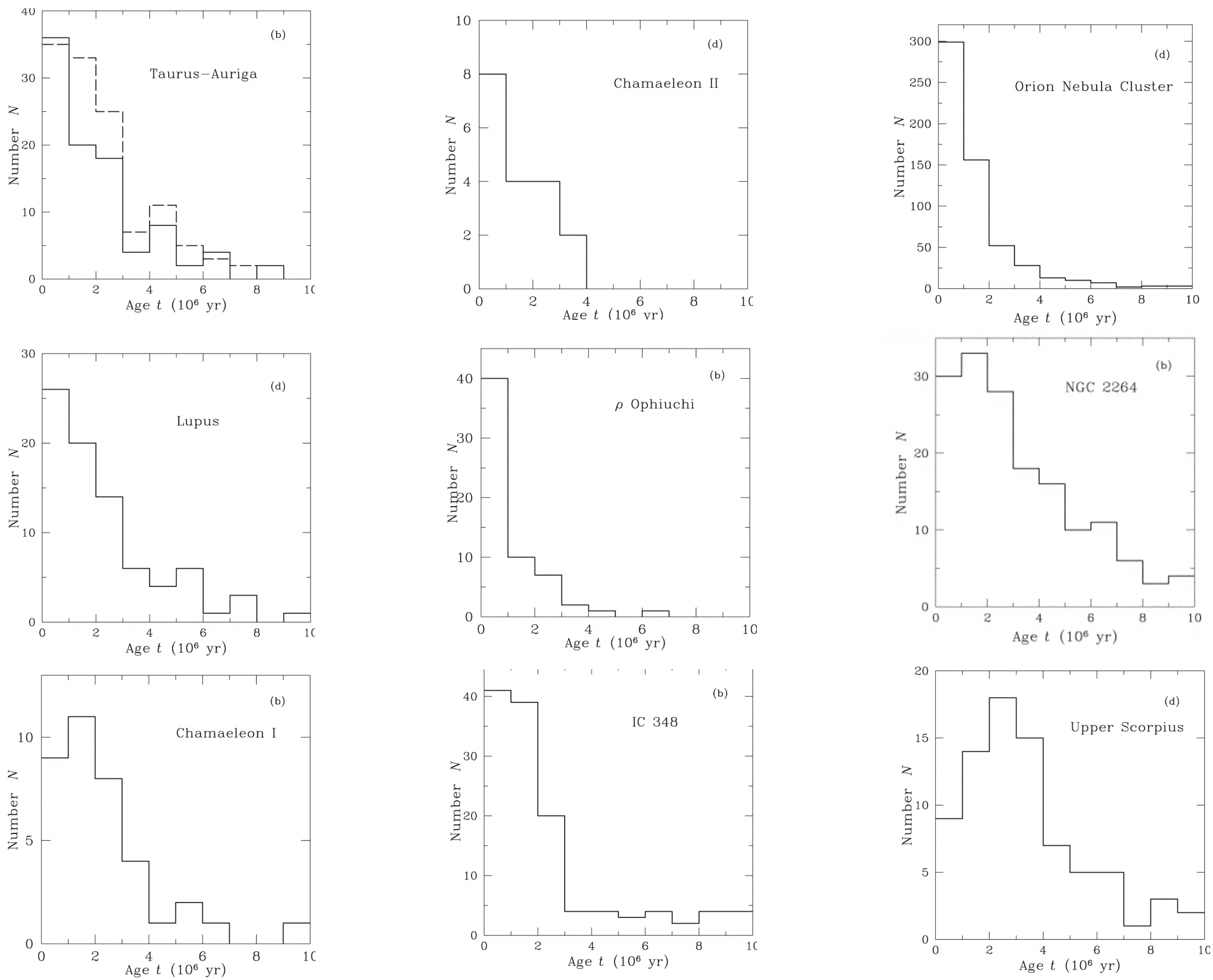
- Molecular clouds have regions of global gravitational collapse

- Accretion halted by fragmentation/stellar energy input

- episodic accretion vs. age spreads, magnetic activity, mixing… initial conditions

Beware of isochrone problems (mass dependence)





(b)
Taurus–Auriga
Number N
Age t (10^6 yr)
(d)
Chamaeleon II
Number N
Age t (10^6 yr)
(d)
Orion Nebula Cluster
Number N
Age t (10^6 yr)
(d)
Lupus
Number N
Age t (10^6 yr)
(b)
ρ Ophiuchi
Number N
Age t (10^6 yr)
(b)
NGC 2264
Number N
Age t (10^6 yr)
(b)
Chamaeleon I
Number N
Age t (10^6 yr)
(b)
IC 348
Number N
Age t (10^6 yr)
(d)
Upper Scorpius
Number N
Age t (10^6 yr)

Age "spreads" IN molecular clouds...

Vast amounts of unnecessary confusion can be avoided by keeping in mind the following:

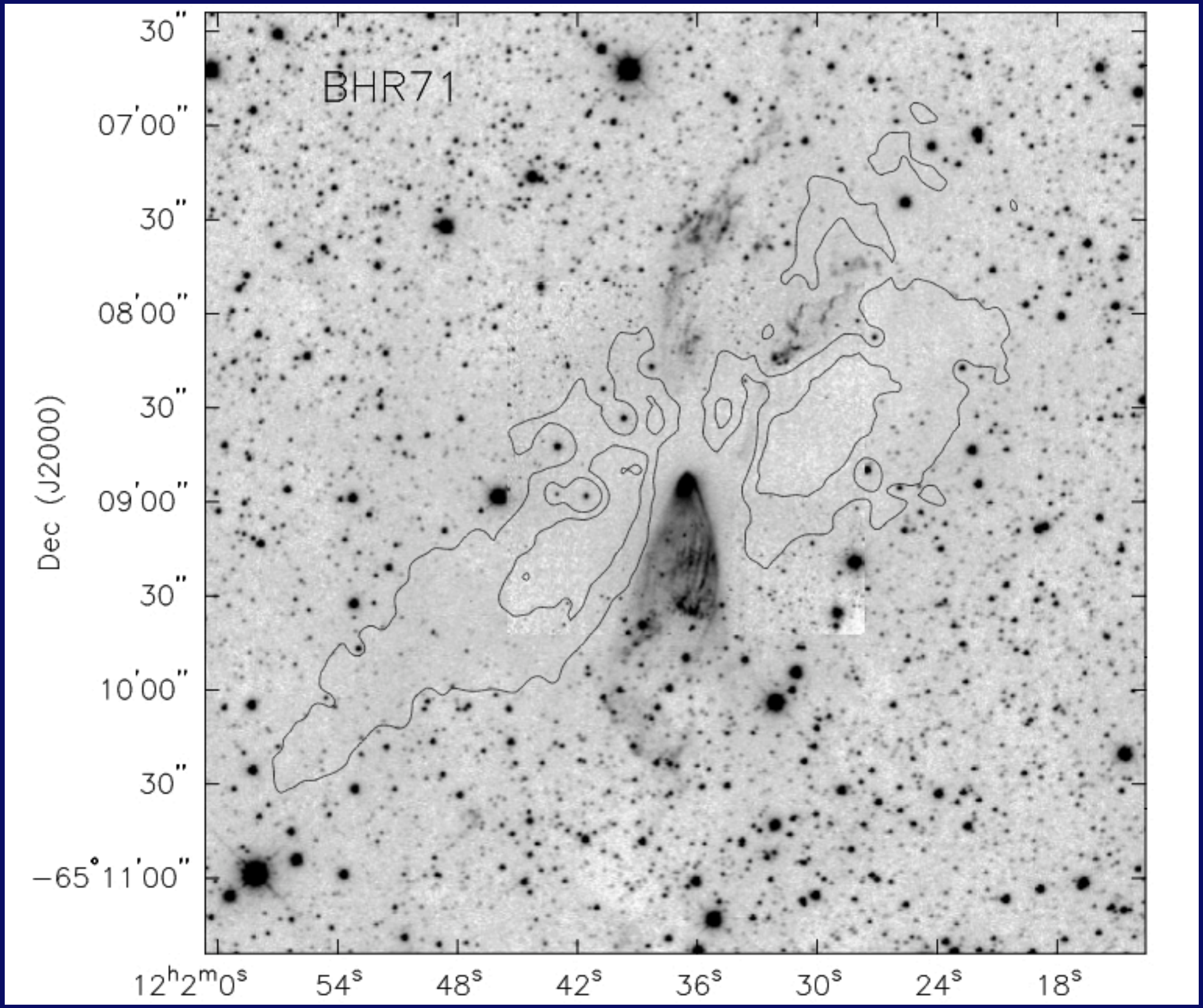
- The bulk of the population is *always* young

- The "old" stars are *always* a SMALL fraction of the total population

- There is no “cosmic vacuum cleaner” which eliminates contamination from foreground stars

- star formation *is spatially correlated*

Magnetic field dominated?
rotation (outflow) axis ≠⊥ to infall



gravitational focusing: clusters form preferentially at ends of filaments