Why Do Core Mass Functions Resemble the IMF?

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Introduction

Conventional Wisdom

Cores form stars	Beichman et al 1986, Jørgensen et al 2007
Core mass functions resemble IMF	Motte et al 1998, Alves et al 2007
Core structure resembles BE sphere	Ward-Thompson et al 1999, Alves et al 2001

Inconvenient Truth

Unlike BE model, observed cores have no known "mass boundary"

Old Question

Why doesn't a collapsing core gain mass from its environment?

Suggested answers - Jeans mass, outflows, magnetic forces, turbulence --cf. Larson 1985, Nakano et al 1995, Matzner & McKee 2000, Nakamura & Li 2005

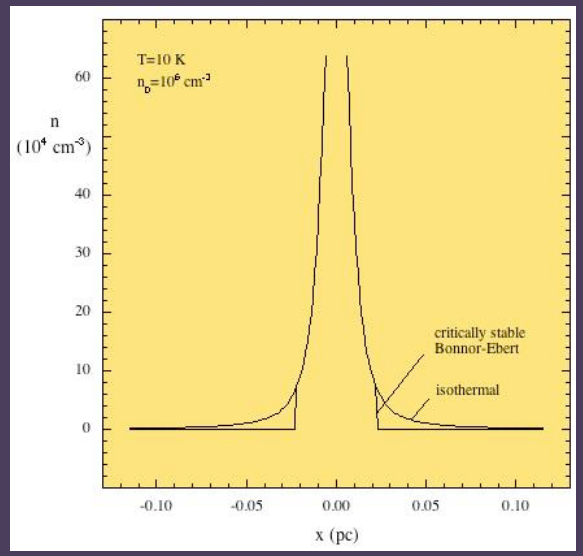
Today's Answer It can: infall and dispersal "compete" for the gas within a Jeans mass

Outline of Talk

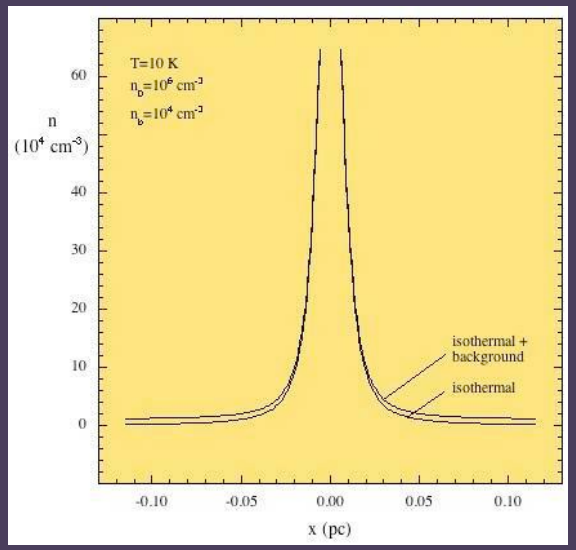
• "More realistic" core-cloud model	thermal structure, background, neighbors
• Evidence for gas dispersal	cores harbor protostars but not T Tauri stars
• Infall & dispersal calculation	solution gives $M_{star}(t)$ given t_d, $M(<r)$
• Predictions	M_{star}/M_J between $0.3(t_d/t_u)$ and 1 high contrast, fast dispersal -> observed SFEs, $M_{star} \propto M_{core}$
• Conclusion	models of initial cloud and dispersal/ infall match stellar properties better than just assuming $M_{star}=M_{BE}$ or $M_{star}=M_J$
• Caution...	work in progress

Core Properties and Models

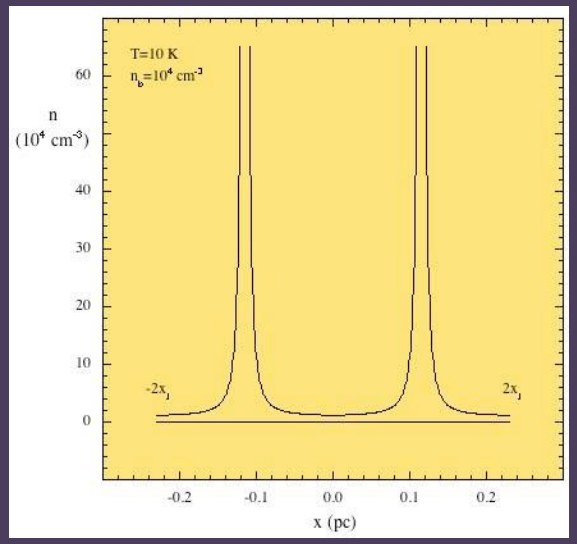
To understand stellar masses, we need more realistic models of the initial core and cloud. Observations by COMPLETE team, by Enoch et al 2006, 2007, and many other observers show...



observed cores are extended, more like IS than BE model



but core "background" density is not zero as in IS model



core background extends only until the next core, as in Jeans fragmentation

Core Dispersal

How long does a core last after it forms a star?

YSO class	fraction of cores harboring YSO	
0	1.0	
I	0.51	
F	0.15	
II	0.05	
III	0	Jørgensen et al 07

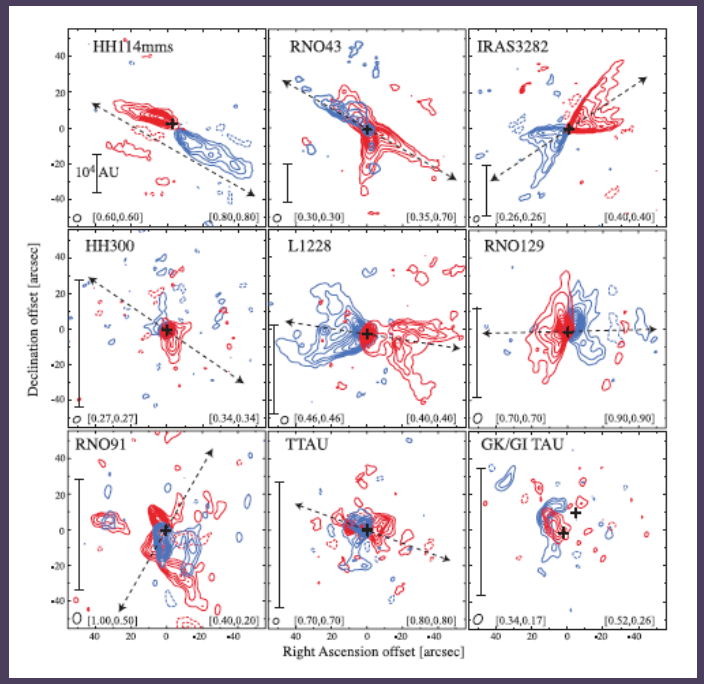
Estimates of Class 0/I lifetime, Myr

Oph	0.2±0.1	Wilking et al 89
Tau	0.15±0.05	Kenyon & Hartmann 95
Per	0.26	Hatchell et al 06
IC348	0.2	Muench et al 07
c2d	0.46	Evans et al 07

Inference A core becomes undetectable in a fraction of a Myr after star formation

Simple model $n(t)=n(0)\exp(-t/t_d)$, t_d=0.1-0.3 Myr

Dispersal mechanisms include outflows, ionization, heating from embedded star *and* from nearby stars (especially in clusters)



Arce & Sargent 06

IS+U Model

Observations motivate "IS+U" model, a "thermal physics" model of initial conditions for star formation (Larson 03) B and turbulence now negligible.

$$\rho(r) = (\rho_0 - \rho_u)\exp[-\psi_{IS}(r)] + \rho_u$$

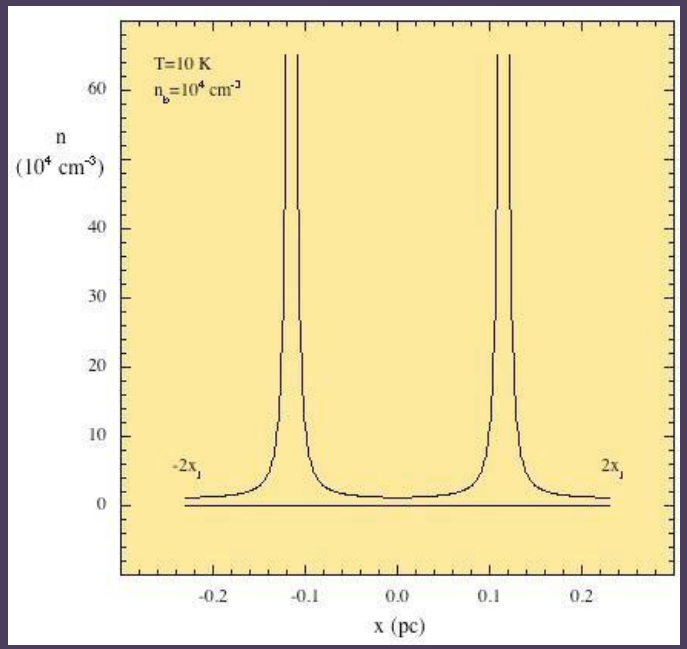
ρ_0 = peak density,
ρ_u = density of uniform background
$\psi_{IS} = \ln(\rho_0/\rho)$ for isothermal sphere
$r < r_{max}$=Jeans radius of background gas
T = constant

A Molecular Cloud "Unit"

inner structure	isothermal sphere
outer structure	uniform medium
mass	one Jeans mass
dynamical status	starting to collapse

Caveat 1: more realistic: turbulent background gas has greater T than core gas

Caveat 2: more realistic: prolate core in cylindrical background



Two neighboring IS+U units

Infall and Dispersal of a Spherically Symmetric Cloud

Initial cloud collapses and "disperses" according to

$$\ddot{r}(r,t) = -\frac{GM(<r,0)\exp(-t/t_d)}{r^2}$$

Dispersal e-folding time scale t_d is independent of r (highly simplified).

Solution follows Hunter (1962), no thermal pressure, gas disperses but star does not.

Solution example initially uniform Jeans sphere*:*

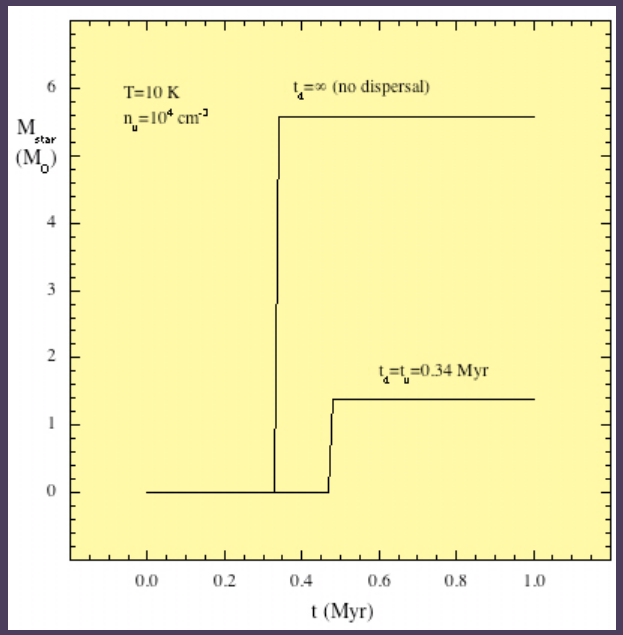
No dispersal--uniform collapse, $M_* = M_J$, $t_* = t_u$

With dispersal--cloud collapses uniformly,
but with ever-decreasing mass, $M_* < M_J$, $t_* > t_u$

Expressions for M_* and t_* depend on t_d/t_u :

$$M_* = M_J\left(1 - 1/\theta\right)^2$$

$$t_* = -t_u\theta\ln\left(1 - 1/\theta\right), \quad \theta \equiv 2t_d/t_u \geq 1$$



Infall and Dispersal of IS+U Cloud

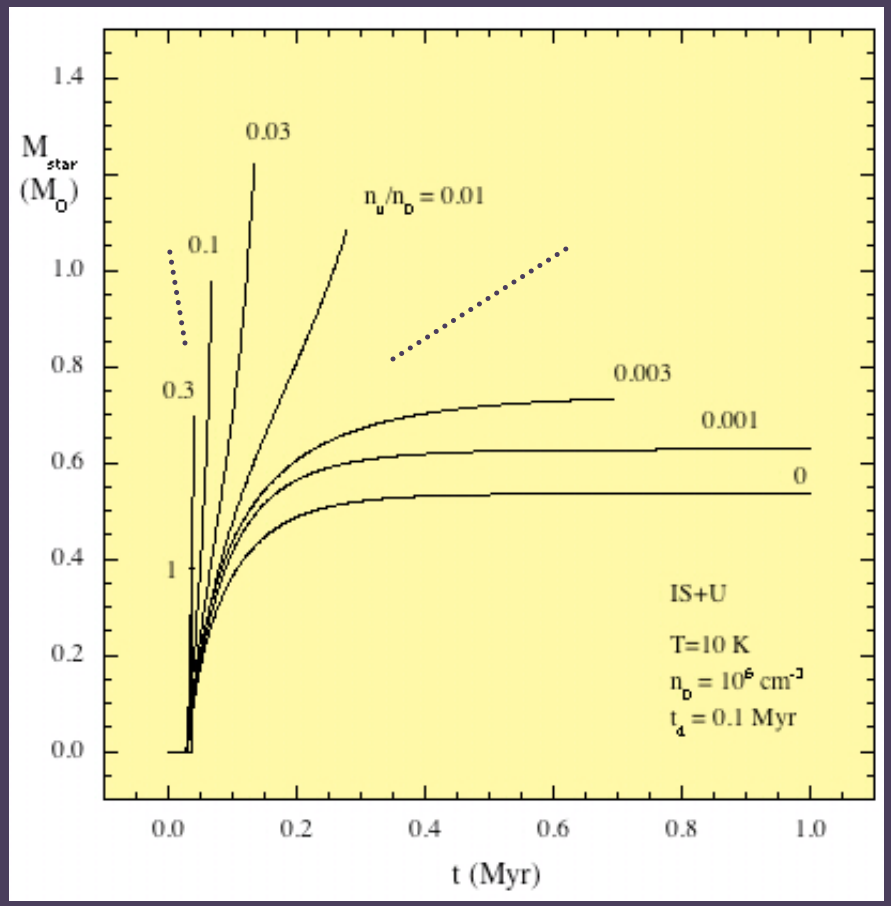
Calculation as for uniform Jeans sphere, but with IS+U initial density.
Cf. Foster & Chevalier 1993, Banerjee, Pudritz & Holmes 2004

Parameters n_0 = peak density = 10^6 cm^{-3} t_d = dispersal time scale = 0.1 Myr
T = gas temperature = 10 K (all masses scale as $T^{3/2}$)
n_u = uniform background density, 0, 10^3, 3 10^3, ...10^6 cm^{-3}

Range of n_u 3 groups of **density contrast** n_0/n_u, **relative dispersal rate** t_u/t_d

n_u (cm^{-3})	n_0/n_u peak density / bkgd density	t_u/t_d dispersal rate / bkgd infall rate
0 10^3 3 10^3	high (>300)	fast (>6)
10^4 3 10^4 10^5	medium (10-100)	medium (1-3)
3 10^5 10^6	low (1-3)	slow (0.3-0.6)

$M_{star}(t)$



M_{star} between $\pi\sigma^3 t_d/G$ and M_J, M_{star} scales as σ^3

infall modes

high contrast, fast dispersal

- most background gas disperses before it can fall in
- low M_{star} from core, set by $\pi\sigma^3 t_d/G \approx (0.3 t_d/t_u) M_J$

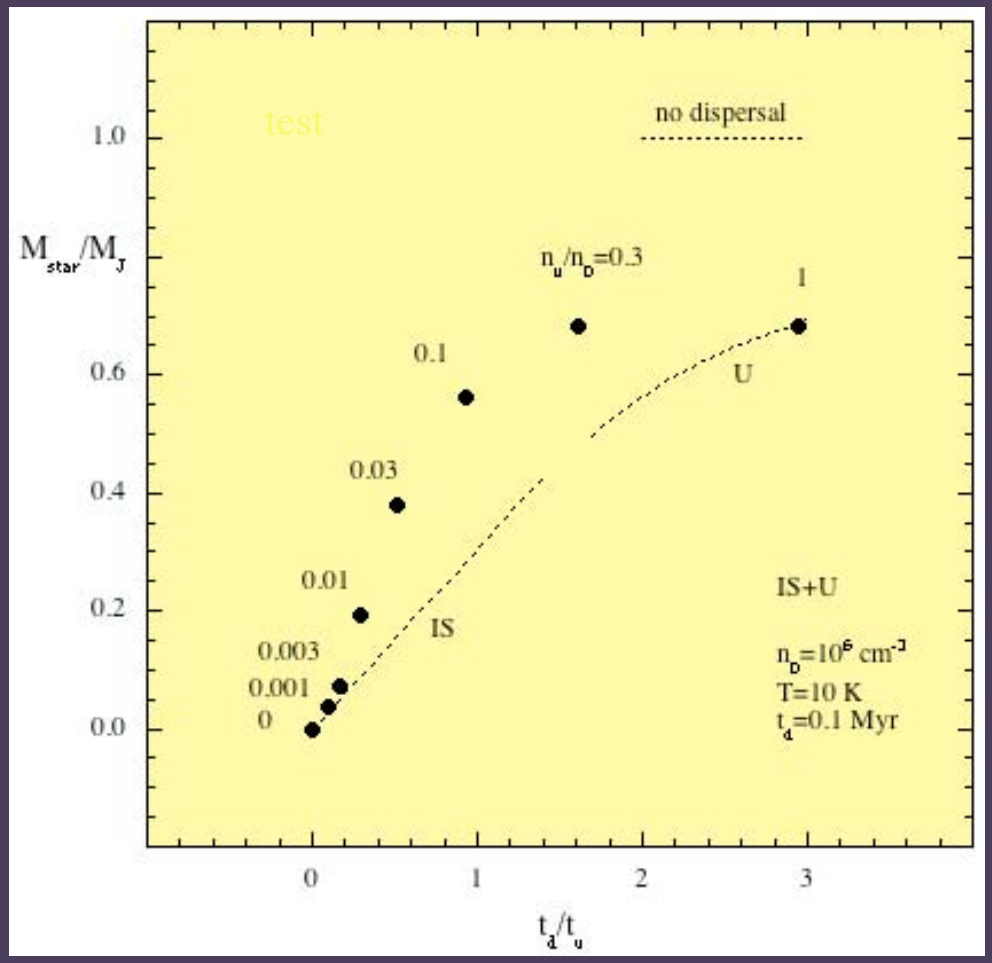
medium contrast and dispersal

- some background gas falls in
- high M_{star}, from core+bkgd

low contrast, slow dispersal

- most background gas falls in
- low M_{star} from bkgd, set by M_J

Star Formation Efficiency (SFE)



Assume cloud = sum of identical IS+U units --> SFE = M_{star}/M_J indep of T

No dispersal SFE = 1

With dispersal SFE < 1

…IS only core
…U only background
● IS+U core + background

SFE(IS+U) exceeds SFE (IS) and SFE(U)

Star formation is more efficient when both core and background gas contribute

Observed SFEs

Global SFEs $A_V>2$, $<M_{star}>=0.5\ M_O$ SFE < 0.1

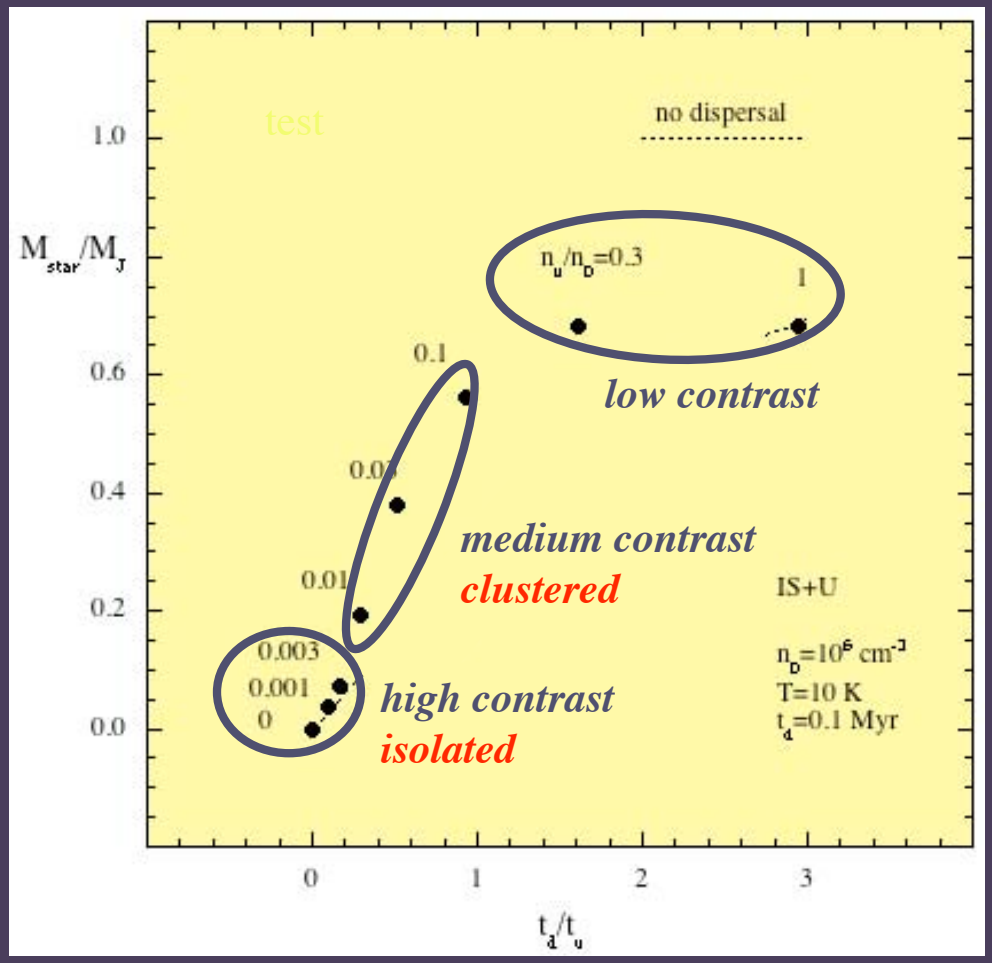
0.019	Cha II	
0.025	Per	
0.031	Lup	
0.040	Oph	
0.042	Ser	(Evans et al 07-c2d)

but SFE > 0.1 in "clustered" regions of the same clouds, and in bigger clusters:

0.14	Per-NGC 1333	
0.16	Per-IC348	
0.10	Oph-L1688	(Jørgensen et al 07- c2d)
0.25	Mon R2	
0.33	NGC 2024	
0.30	NGC 2068	(Lada & Lada 03)

Caveat - observed SFEs are comparable to model SFEs only in relative sense

Matching Model to Observed SFEs

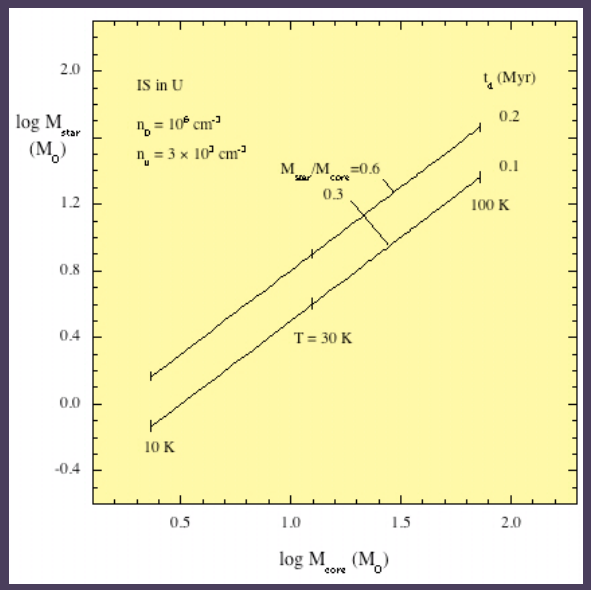


Isolated SFEs < 0.1 match high-contrast cores ($n_u \leq 3\ 10^3$ cm^{-3})

Clustered SFEs >0.1 match medium-contrast cores ($n_u = 10^{4\text{-}5}$ cm^{-3})

The greatest SFEs > 0.6 exceed what is known in well-studied regions, and come from "unrealistic" IS+U models of very low contrast.

M_{star} and M_{core} Correlate



basis for correlation

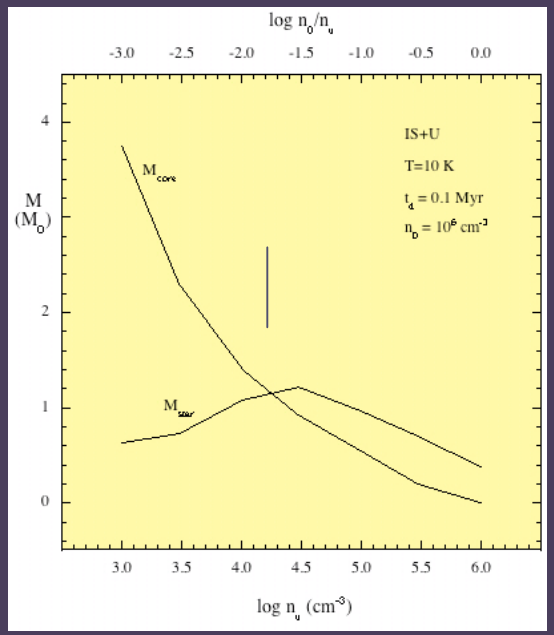
M_{core} = mass above background = $f(n_0, n_u)\ T^{3/2}$

$M_{star} = g(n_0, n_u, t_d)\ T^{3/2}$

so a *small* variation of n_0, n_u, t_d

and a *larger* variation of T give

$M_{star} \propto M_{core}$



parameter choices to match M_{star}/M_{core}, M_{star}

for t_d=0.1 Myr, $n_0=10^6$ cm^{-3}, $n_u=3\ 10^3$ cm^{-3},

M_{star}/M_{core} = 0.3 as in Alves, Lombardi & Lada 07,

M_{star} =0.4 -22 M_O for T=7-100 K

but M_{star}/M_{core} < 1 only for high contrast cores (favored by selection)

Conclusion

- Cores have "backgrounds" but don't have mass boundaries
- Isothermal sphere on a uniform background ("IS+U") is more realistic than the BE sphere or the Jeans mass
- Cores and their environs disappear in < 1 Myr
- Infall and dispersal of IS+U predicts M_{star} between $\pi\sigma^3 t_d/G$ (high contrast, low SFE) and M_J (low contarst, high SFE)
- SFE ~ M_{star}/M_J matches observed values for high contrast ($n_0 >> n_u$) and fast dispersal ($t_d << t_u$)
- M_{star} increases from ~0.4 to ~20 M_O as T increases from ~7 to 100 K