Protostar Mass Due to Infall and Dispersal

Phil Myers
Harvard-Smithsonian Center for Astrophysics

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Toy model of protostar formation from smooth cold neutral flows in swimming pools with monsters

Introduction

Origin of stars is well studied…

birthplaces
star-forming gas
groupings
(e.g. Evans et al 09)

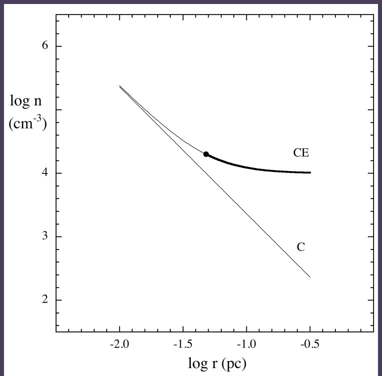
Origins of *stellar mass*…?

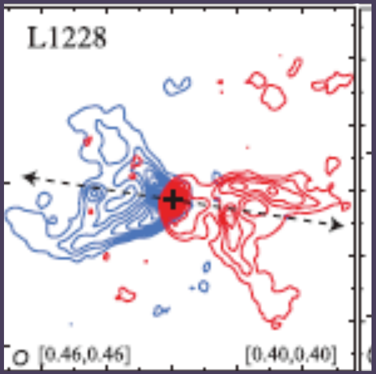
Model

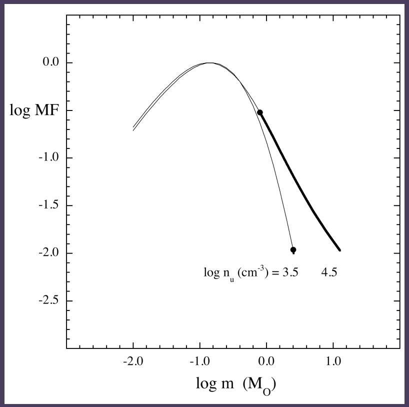
cores without boundaries
dispersal v. accretion sets $M_\star$

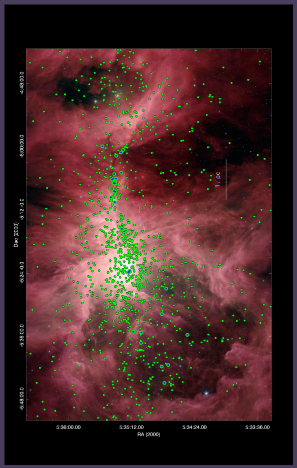
Results

low $M_\star$ from within core
high $M_\star$ from beyond core
varying dispersal times set IMF
only clusters make high $M_\star$

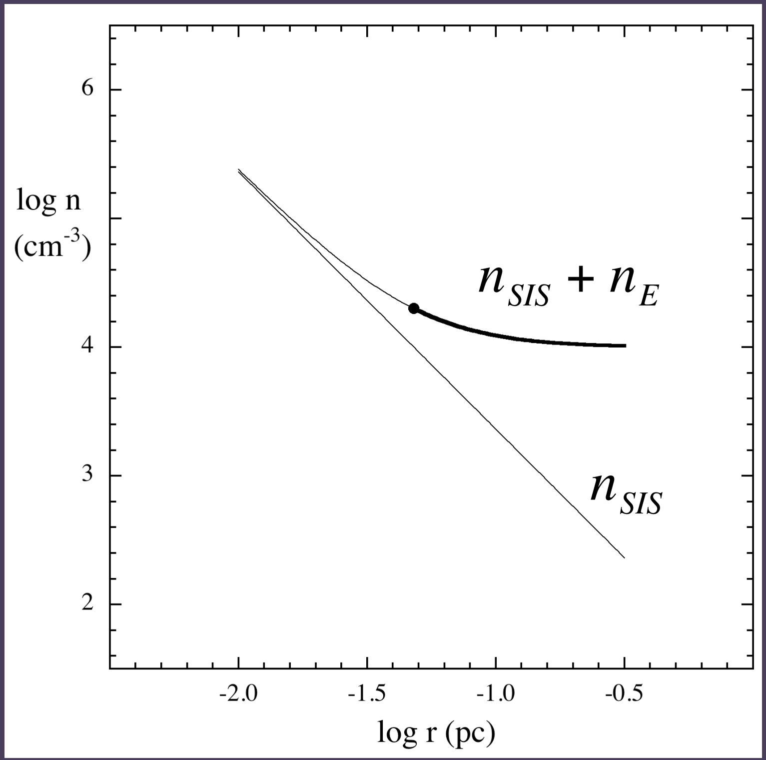








Cores without boundaries



Observations show "cores"with steep n superposed on "clumps" with shallow n (Kirk et al 06). No "boundary" as in BE model.

Simple core-environment model
$n=n_{SIS}+n_E$ starting to collapse

"Core" defined where steep meets shallow

"Isolated" cores low n_E sparse
"Clustered" cores high n_E crowded

Different environments U, L, F

Available mass increases with t_f

Mass (<r) available for spherical accretion in terms of core mass and free fall time (r):

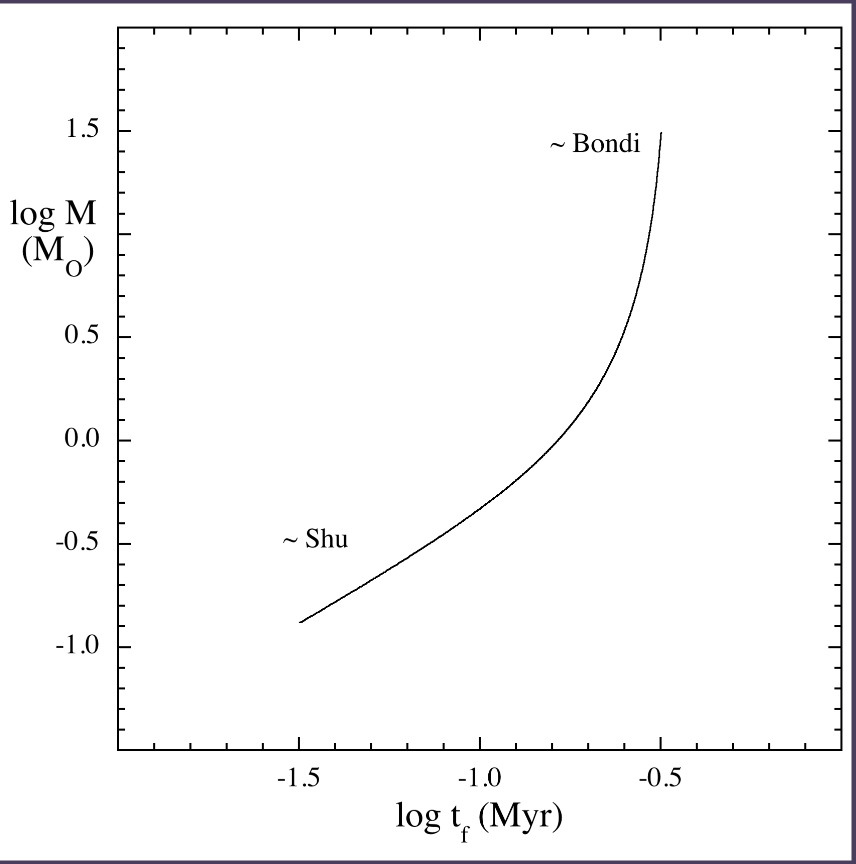
$M_{gas} = M_{core}\theta(1-\theta^2)^{-3/2}$

$\theta = t_f(r)/t_E < 1$, $M_{core} \approx M_J/4$

For fixed t_E, $M_{gas} = M_{gas}(t_f)$

Early: dM/dt = constant (~ Shu 77)

Late: $dM/dt \sim M^{5/3}$ (~ Bondi 52)



T = 10 K $n_E = 10^4$ cm^{-3} Myers 09

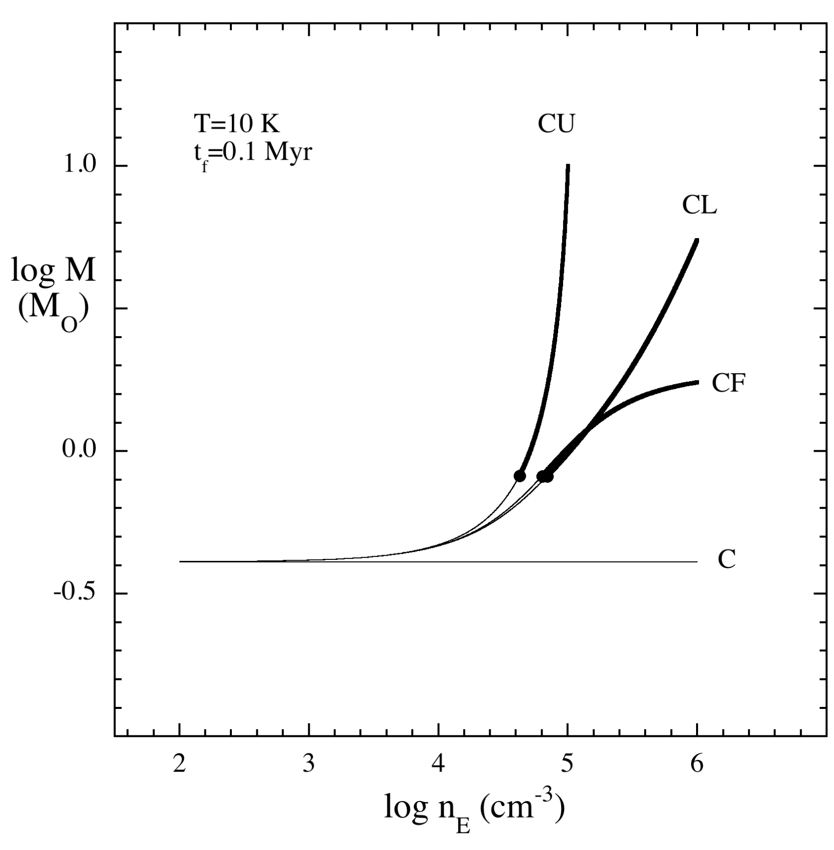
Available mass increases with n_E

In a free-fall time, "critical" density n_{E0}
sets equal mass available from core and environment

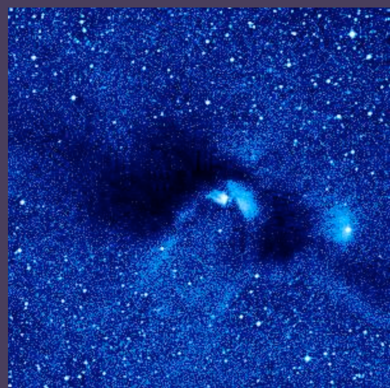
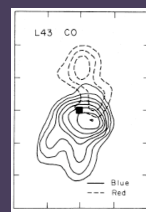
Isolated ★ formation
$n_E < n_{E0}$ widely spaced cores
most mass due to core
M increases weakly with n_E

Clustered ★ formation
$n_E > n_{E0}$ crowded cores
most mass due to environment
M increases strongly with n_E

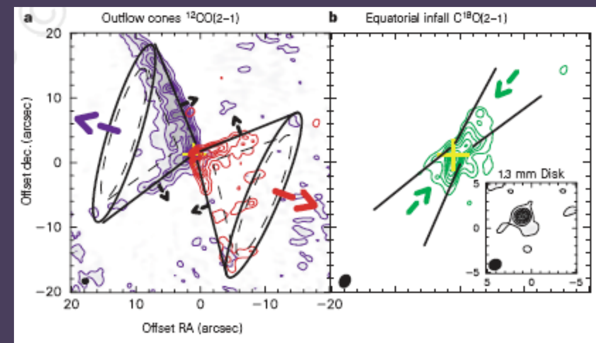
Increasing environment D
M increases from F to L to U



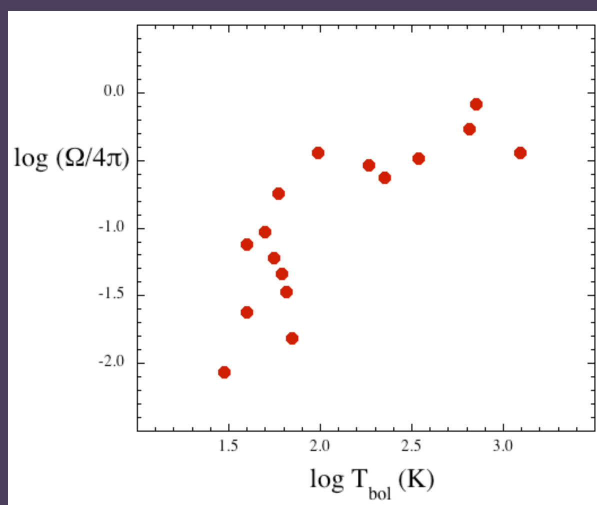
Cores disperse quickly

L43 Myers et al 88



B5 Velusamy & Langer 98



Arce & Sargent 06

Statistics of outflows, stars in cores:
cores with stars disperse in << 1 Myr

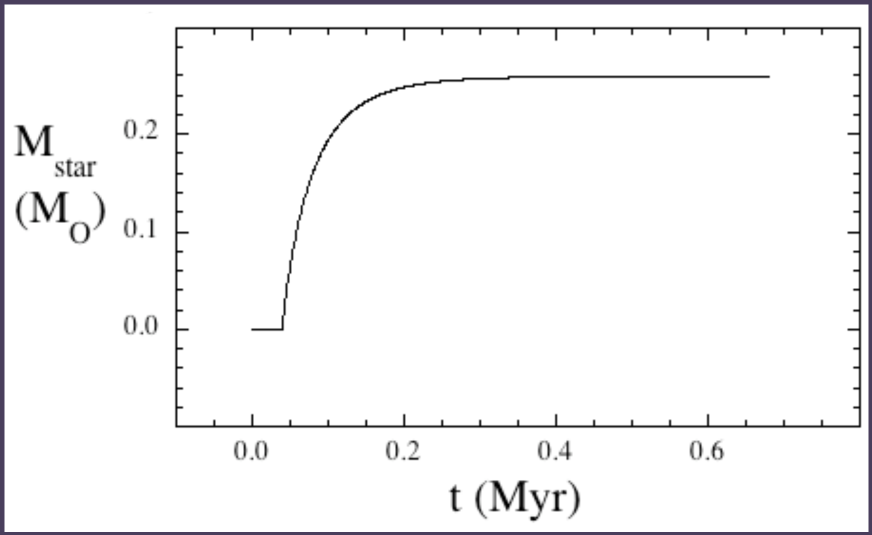
associated cores	all Class 0 protostars 0.03 of T Tauri stars (Jørgensen et al 08)
dispersal agents	outflows heating, unbinding turbulence, ionization competition, migration
dispersal time scale	t_d

Dispersal and accretion set $M_\star$

Protostar mass from dispersing, accreting gas, mass shells $dM(r,t)=dM(a,0)\exp(-t/t_d)$

Solution follows Hunter 62, no P, **B**, **J**, gas disperses but protostar (and disk) keep mass.

T=10 K
$n_u=10^3$ cm^{-3}
t_d=0.07 Myr



Myers 08

$M_{star}(t) \rightarrow$ final value $M_\star$

$M_\star \approx M_{gas}(t_d=t_f)$ justifies

"sudden stopping" →

$M_\star \approx M_{core}\theta(1-\theta^2)^{-3/2}$

Protostar mass function

If cold spherical accretion stops at t_f

$M_\star = M_{core}\theta(1-\theta^2)^{-3/2}$ $\theta = t_f/t_E < 1$

If θ same for all cores, $M_\star/M_{core}$ = constant

MFs have same shape (as in ALL 07)

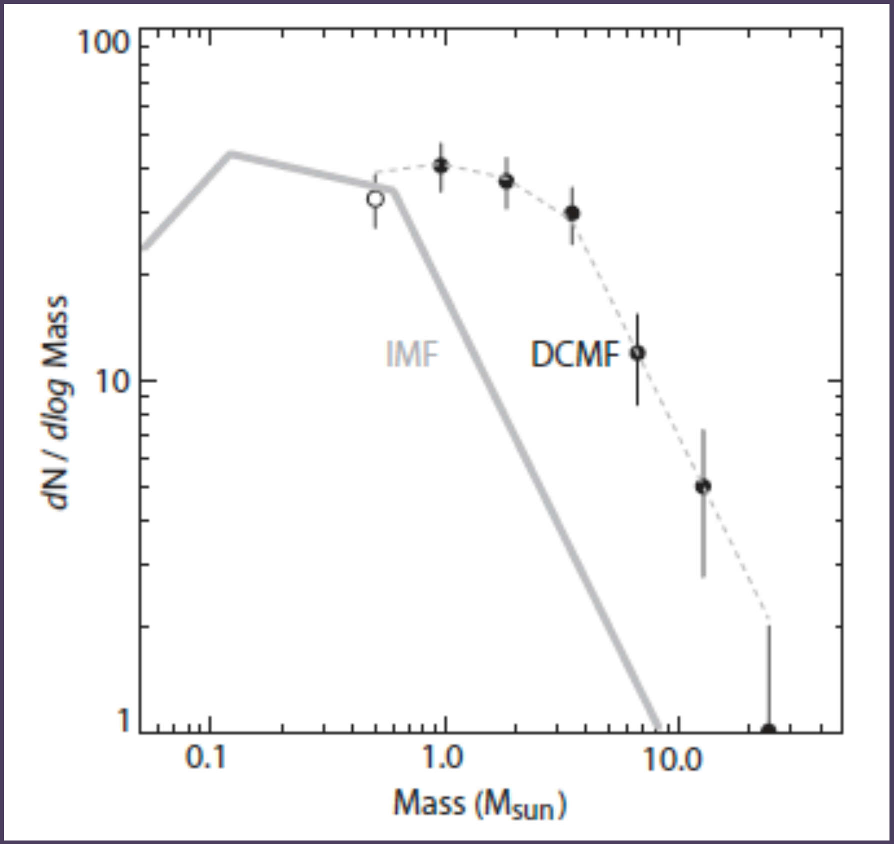
$\star MF \sim CMF$

But why should θ be constant?

If distributed θ , $M_\star/M_{core} \neq$ constant

Simplest distribution: equally likely stopping (Basu & Jones 04)

$p(\theta) \sim \exp(-\theta/<\theta>)$



Alves, Lada & Lada 07

Clusters make more massive stars

MFs for low and high n_E

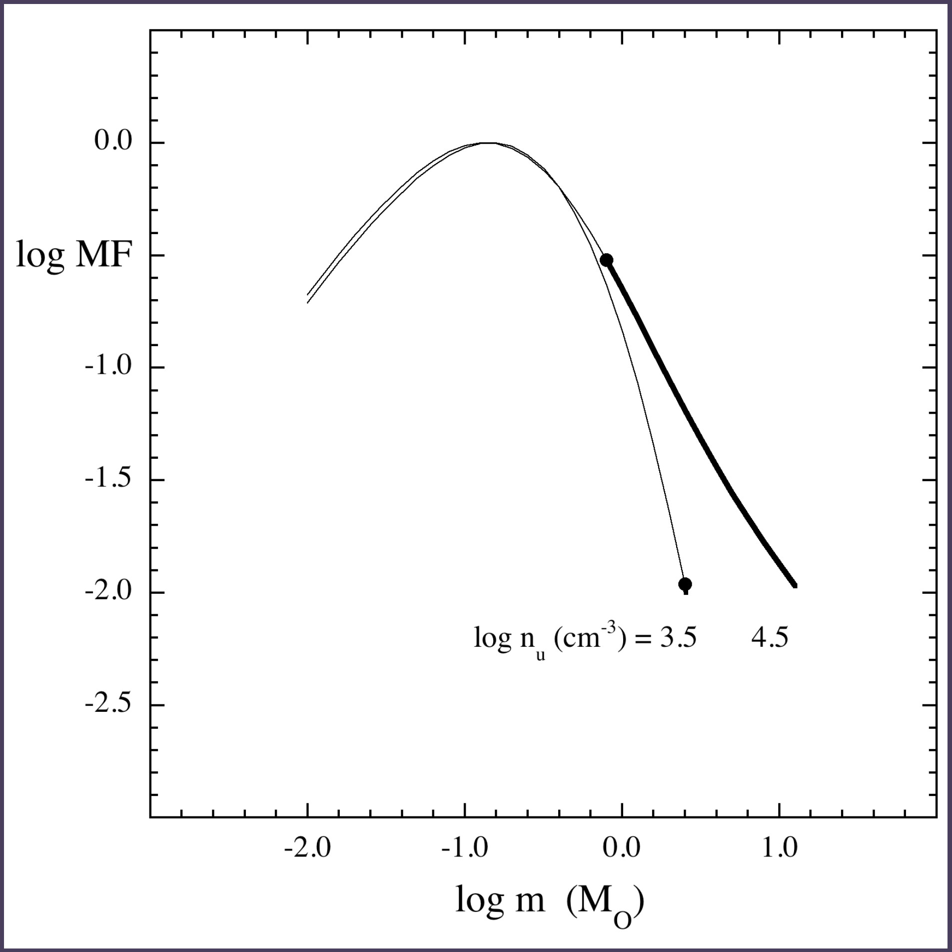
low n_E isolated ★s Taurus
high n_E clustered ★s Orion

T=10 K $\langle t_{stop} \rangle$ = 0.04 Myr

Same low-mass peak
due to accretion from within core
$m_m \sim \sigma^3 t_f$, independent of n_E

More massive stars
due to more accretion from beyond core for high n_E, only in clusters

Prediction: only low-mass stars
should form in filaments of low n_E



Myers 09

Caveats

Models are very idealized

Core-environment model ignores B, turbulence
Accretion model neglects thermal pressure, **B**, **J**
Dense gas dispersal ≈ sudden stopping of accretion

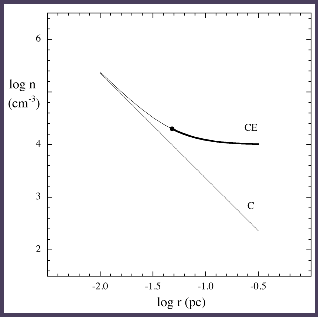
Probability of stopping accretion needs study

probably not confined to a unique time
decreasing with time, not necessarily exponential

Match to IMF is not "universal"

high-mass tail only for dense environments
same MF shape requires $\langle t_d \rangle \sim T^{-3/2}$, $n_E \sim T^3$

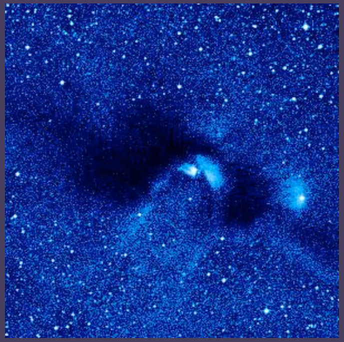
Summary



Core-environment systems have no accretion boundaries

Accretion and dispersal set protostar mass

Distributed stopping can match IMF

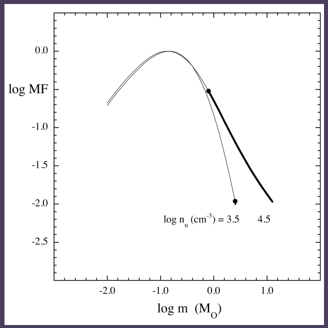


Predictions

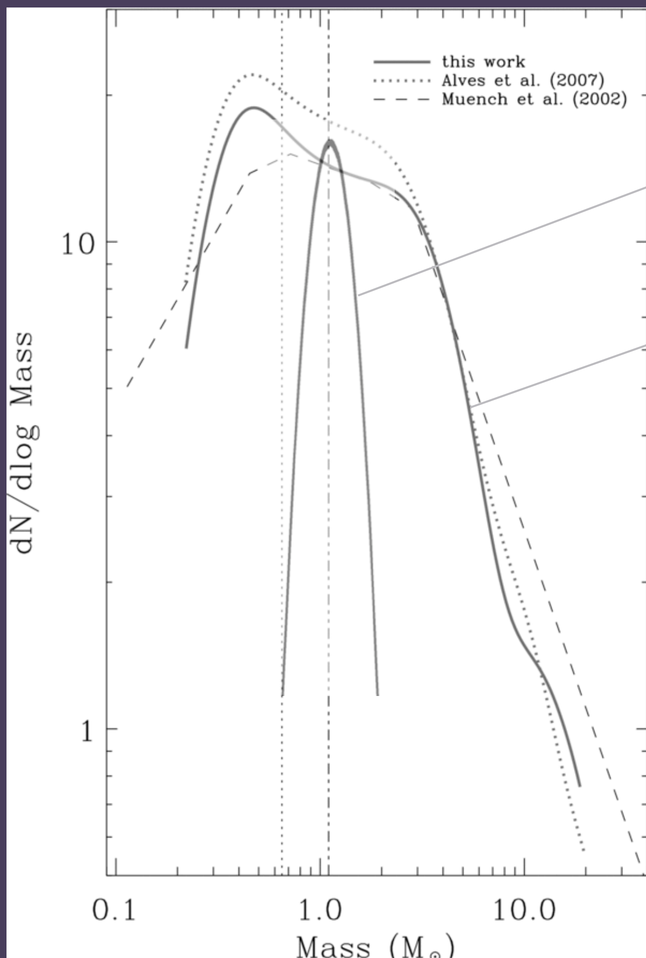
Low mass stars form in both isolated and clustered regions

High mass stars form only in clustered regions

Isolated cores in filaments form only low-mass stars



Why is model CMF narrower than observed?



They may not be so different.
Model CMF:
each core makes 1 star.

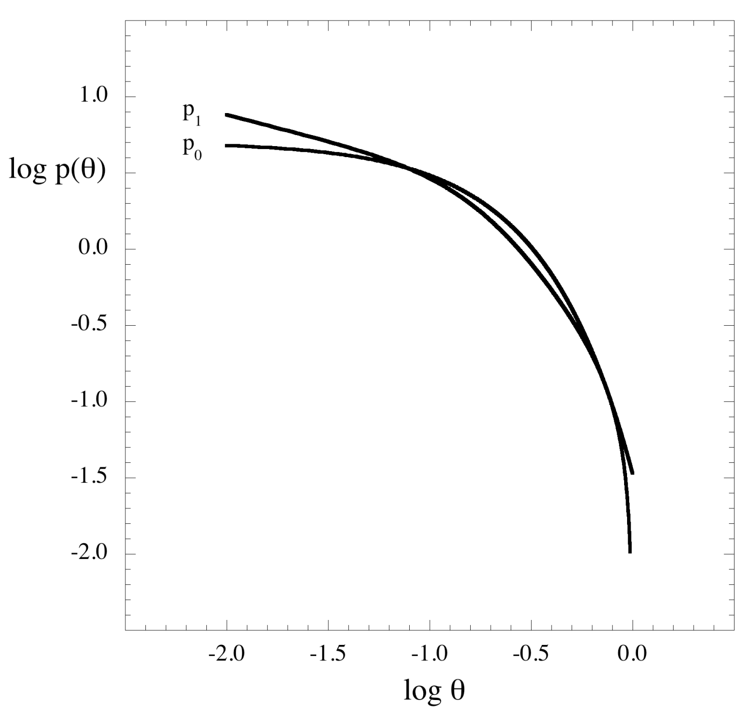
Observed CMF:
most massive cores make >1 star,
least massive cores make 0 stars.

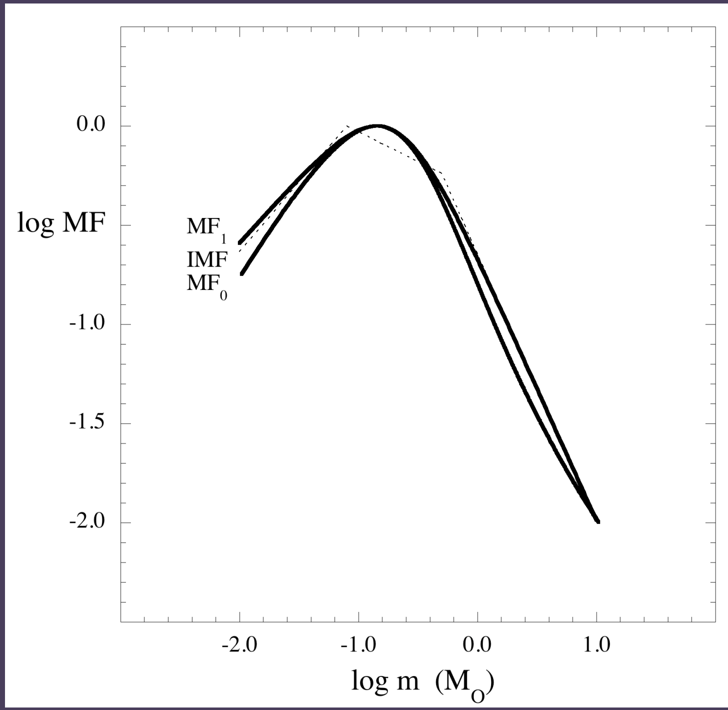
Correction narrows observed CMF,
closer to model CMF.

Temperatures of model CMF:
half-max at 7 K and 15 K,
similar to T(NH_3) in Perseus, 9-15 K
(Rosolowsky et al 07).

Observed CMF Pipe Nebula Rathborne et al 09

Identical cores, declining p(θ) can match IMF





$p_0(\theta)$ from "equally likely stopping"–gives MF_0; modified $p_1(\theta)$ gives better fit MF_1

$M_\star$ increases with dispersal time

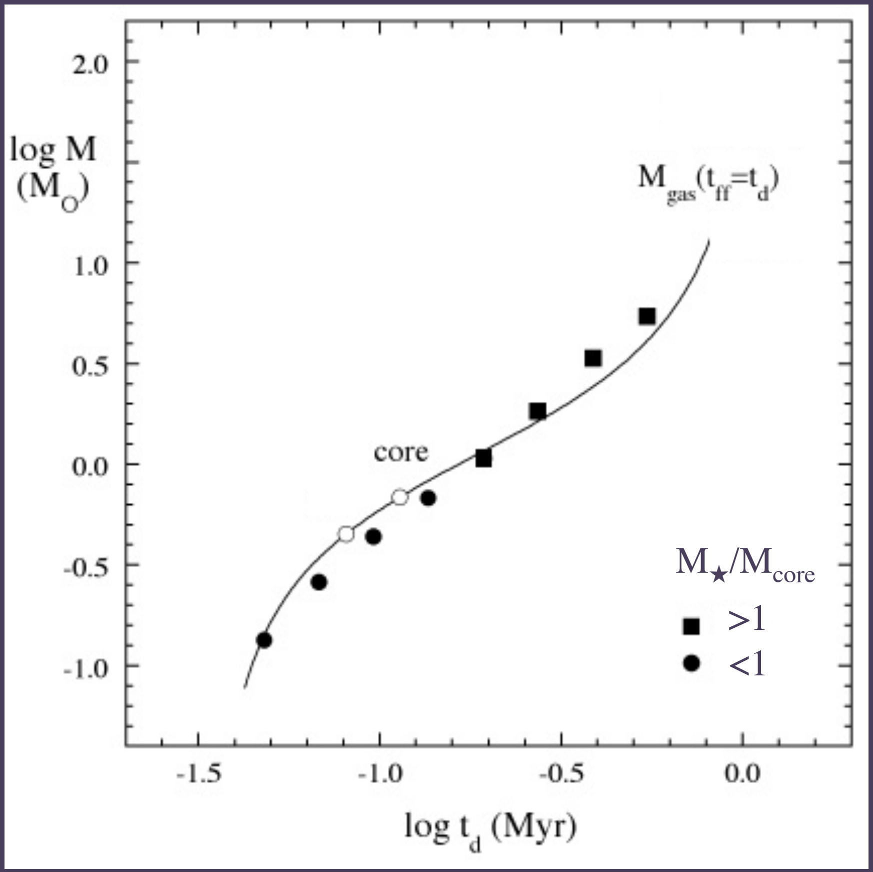
$M_\star$ (t_d) from accretion v. dispersal

isothermal sphere in uniform medium
$T=10$ K, $n_u=10^3$ cm^{-3}

$M_\star$ increases with t_d

$M_\star$ can arise within core,
or within and beyond core

$M_\star \approx$ initial gas mass in radius $t_{ff}=t_d$
dispersal time scale ≈ stopping time



Myers 08

MFs for distributed stopping times

Simplest distribution: equally likely stopping (Basu & Jones 04)

$p(\theta) \sim \exp(-\theta/\langle\theta\rangle)$ $\theta = t_{stop}/t_E$

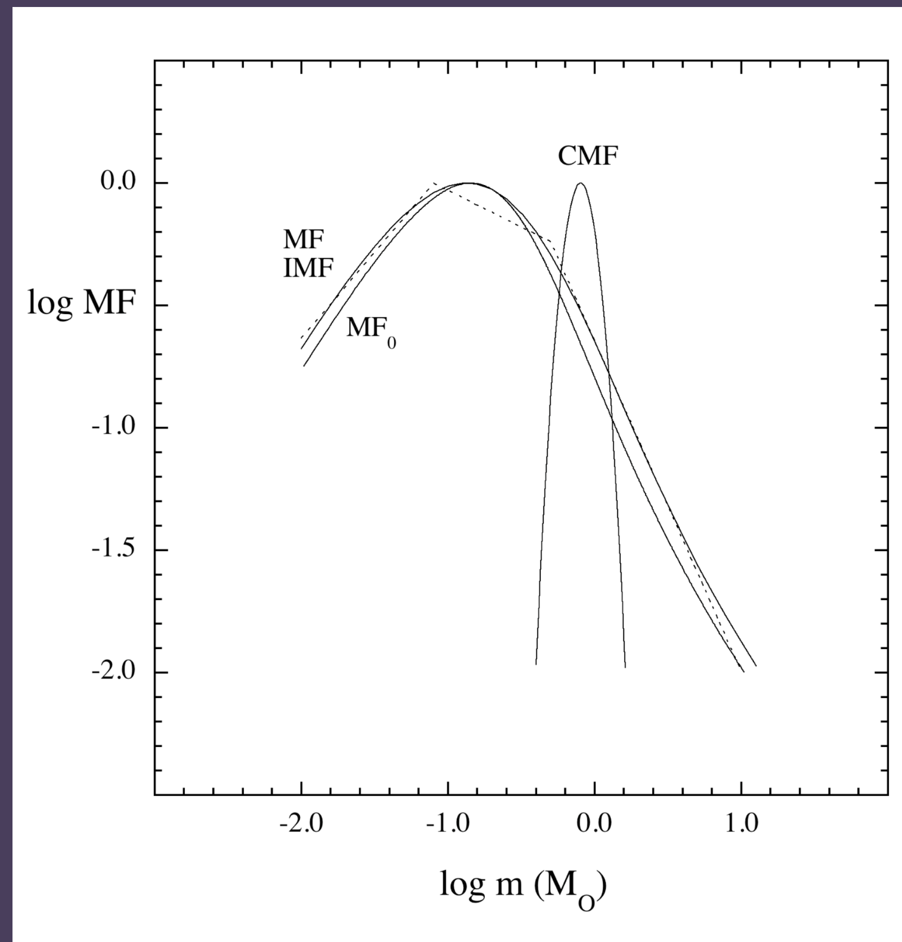
$T = 10$ K $n_E = 3\ 10^4$ cm^{-3} $\langle t_{stop} \rangle = 0.04$ Myr

Identical cores MF_0

very close to IMF, but too narrow, high mass tail not exactly a power law

Distributed cores MF

Log-normal CMF, $\sigma_{CMF} = 0.5$ matches IMF (also match with other $p(\theta)$s, CMFs)



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