How do stars get their masses?

and

A short look ahead

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CfA

Dense Core LXV • Newport, RI • October 23, 2009

Introduction

Origin of stars is well studied…

- birthplaces
- star-forming gas
- groupings

Origins of *stellar mass*…?

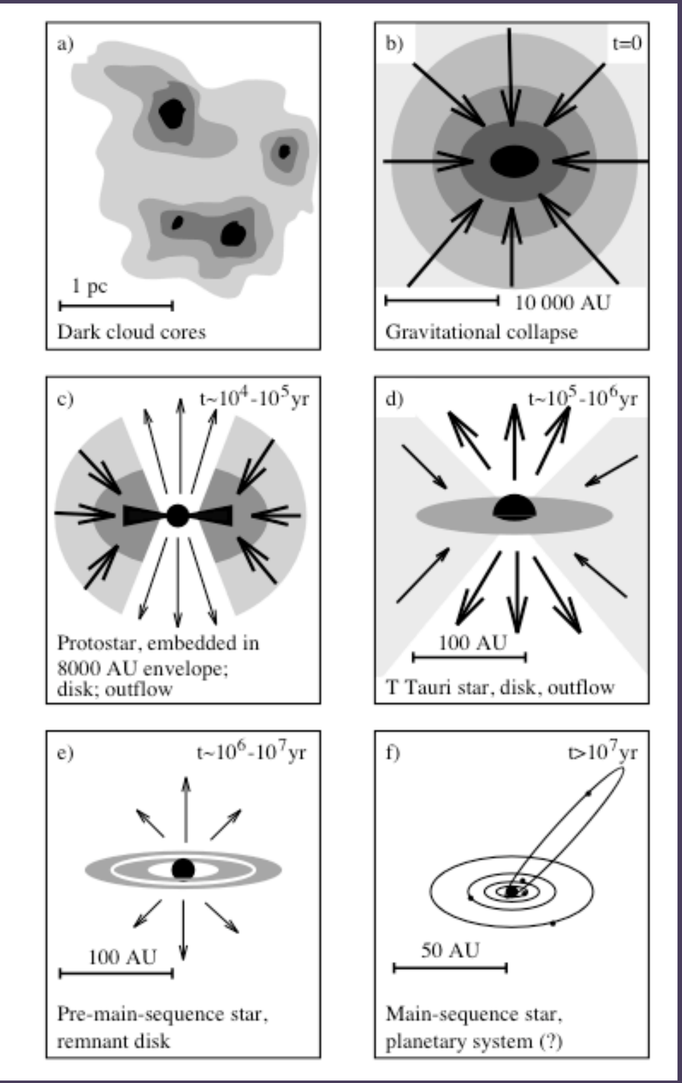
- few available models

New model

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

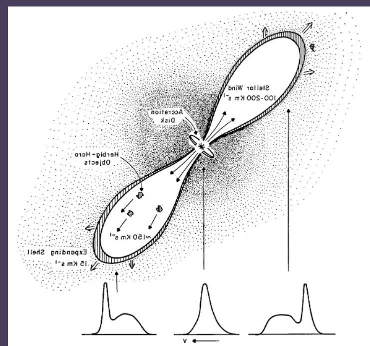
Results

- low $M_\star$ from core
- high $M_\star$ from core + environment
- varying dispersal times set IMF
- only clusters make high $M_\star$

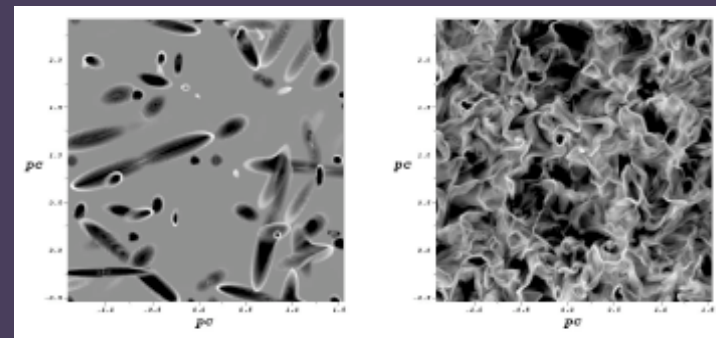


Hogerheijde 1998

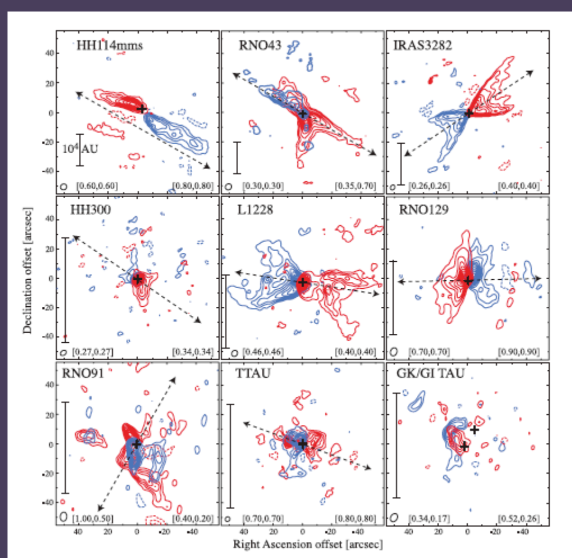
Dense gas dispersal



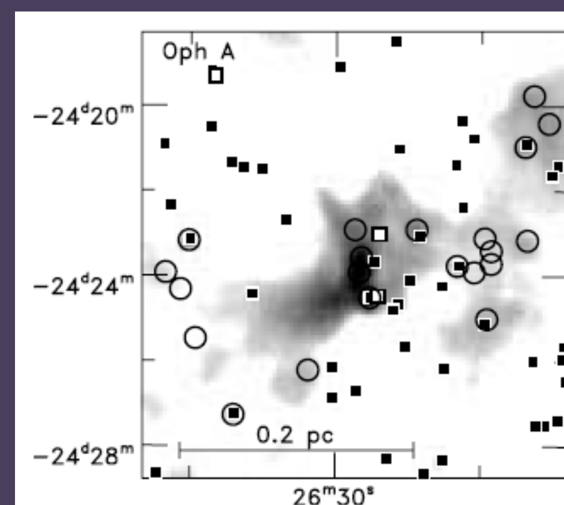
L1551 outflow - Snell, Loren & Plambeck 80



Cluster outflows generate turbulence
Li & Nakamura 06, Carroll et al 09

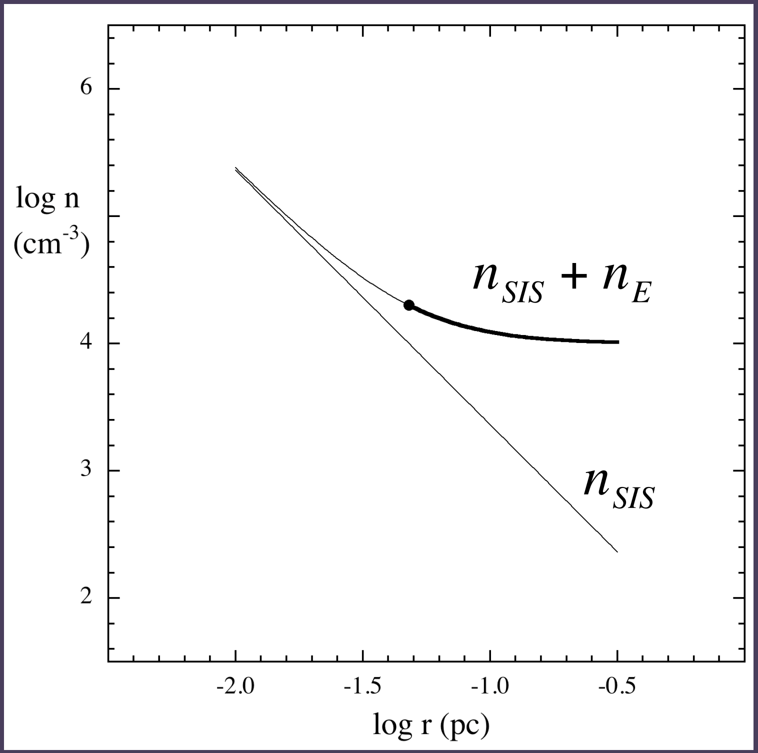


YSOs of increasing age Arce & Sargent 06



Protostars lose their cores after << 1 Myr
Jørgensen et al 08

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.

Single-star 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

Myers 09

Available mass increases with t_f

Mass available for spherical infall in terms of core mass and free fall time:

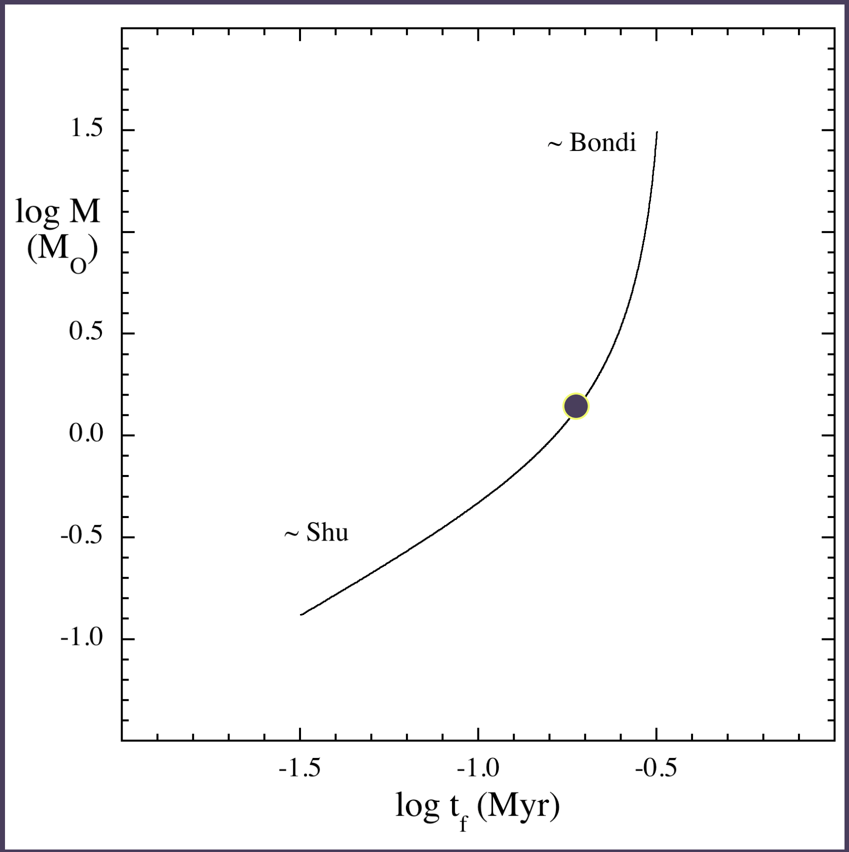
$M = M_{core} \theta (1-\theta^2)^{-3/2}$

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

M / M_{core} can exceed 1

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

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



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

Accretion model

Realistic accretion: stops gradually with time scale t_d

Model: accretion stops suddenly at time t_d

Realistic accretion: pressurized, intermittent, complex geometry…

Model: $M_\star = \varepsilon M(t_f = t_d)$ ε="accretion efficiency"

$M(t_f)$ cold spherical infall in time t_f

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

Distribution of infall times

Cold spherical infall stops at t_f

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

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

MFs have same shape (as in ALL 07)

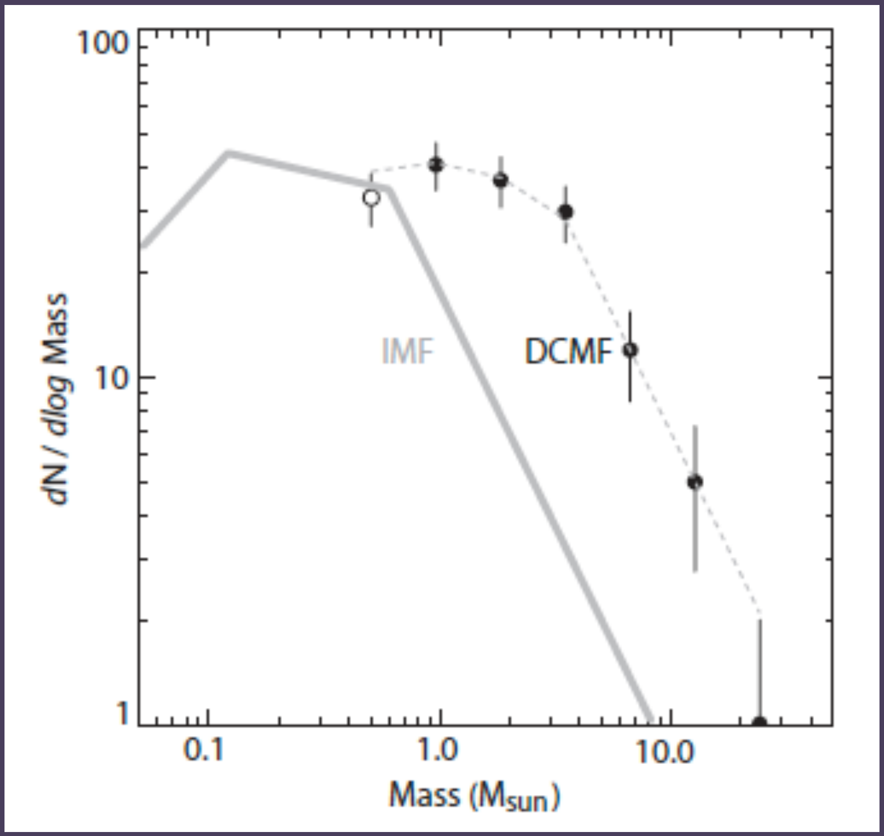
★MF ~ CMF

Why should θ be constant? If θ is distributed,

★MF is broader than CMF

Simplest distribution: ”waiting time” distribution (Basu & Jones 04)

$p(\theta) \sim \exp(-\theta/\langle\theta\rangle)$



Alves, Lada & Lada 07

Clusters make more massive stars

MFs for identical cores,
low and high n_E

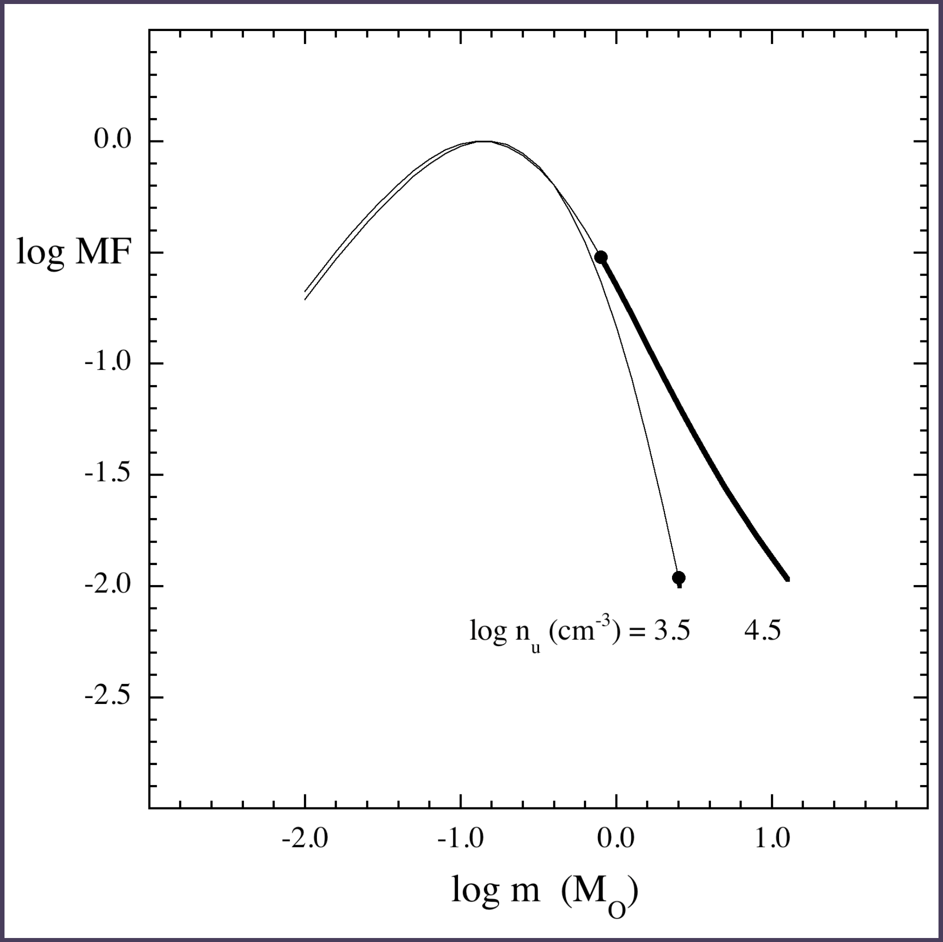
low n_E	isolated ★ s	Taurus
high n_E	clustered ★ s	Orion

T=10 K $\langle t_f \rangle$ = 0.04 Myr ε=1

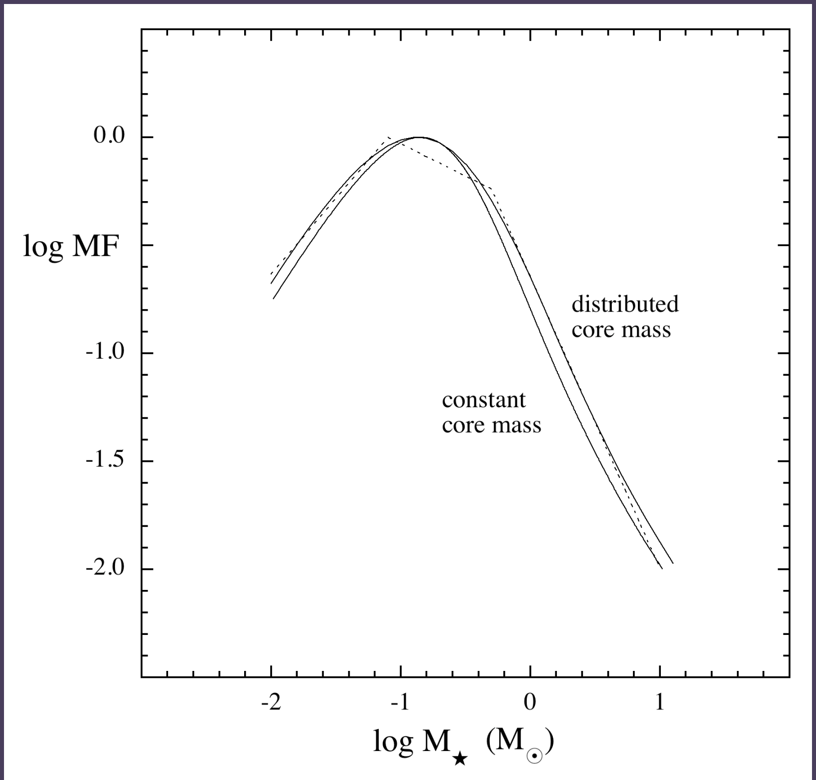
Same low-mass peak
due to accretion from within core
$m_m \sim \sigma^3 t_f$, independent of n_E

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



Combined distributions



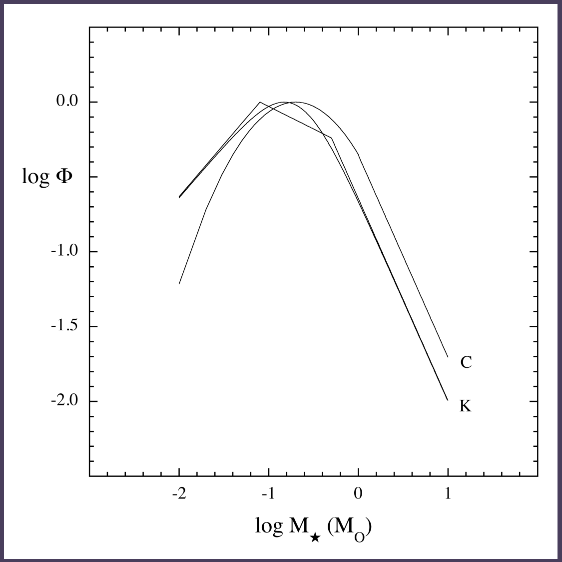
Combined MF matches IMF

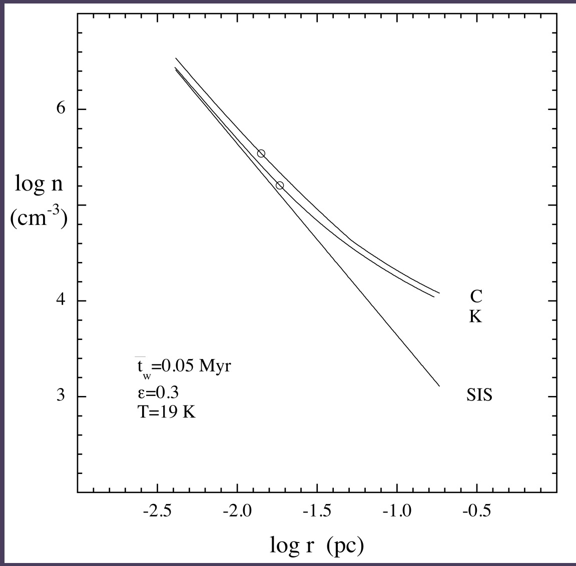
Same T, <t_f>, ε, n_{E0} as before.
Combine with log-normal MF of "single-star" cores, vary width for best match to IMF

Best match requires single-star CMF narrower than IMF,
narrower than observed CMF

Why do observed CMFs match IMF? (Swift & Williams 08, Hatchell & Fuller 08)

Initial conditions for IMF





Alternate approach:

Use IMF and waiting-time distribution to derive n(r) typical of IMF-clusters

Steep inside, shallow outside– like "TNT"model (Fuller, Ladd, Caselli).

This "clustered" profile resembles "isolated" profile, but is warmer and denser.

Implications

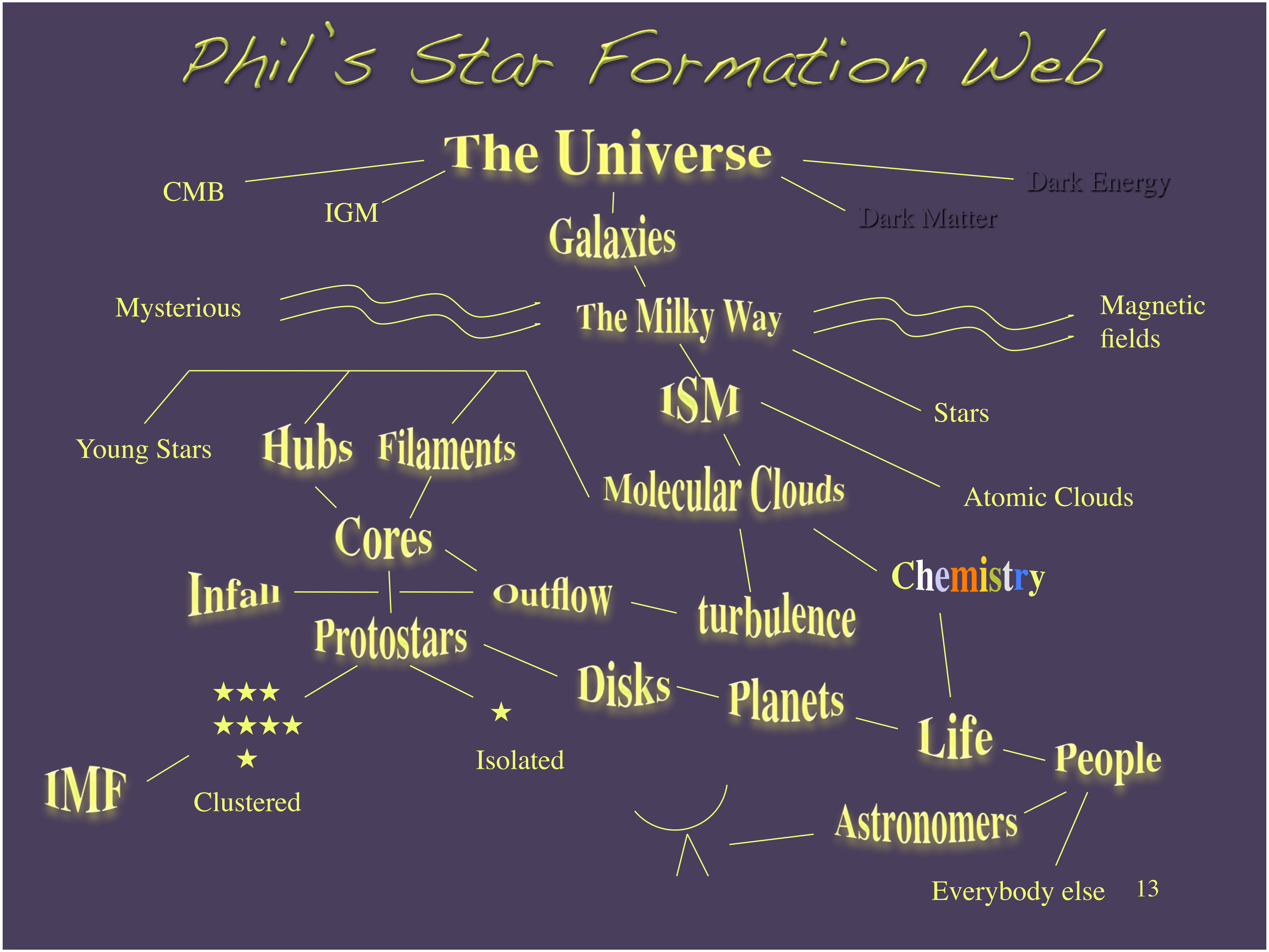
If all of this were true…

Cores	n(r) steep inside (thermal), shallow outside (magnetic, turbulent)
	form protostars, but core and protostar mass only weakly related
Protostars	mass can be less than or greater than core mass
	low and high mass form in the same protocluster
MFs	IMF a weighted record of the most common star formation conditions
	Width of single-star CMF < (width of observed CMF, width of IMF)

A short look ahead

Processes	What makes protoclusters? How does their dense gas structure evolve? How does their protostar accretion start? stop? What does their MF depend on? What are we missing?
Where to look	high column density high protostar fraction more distant "nearest" regions
Scales	cluster 1 pc core 0.1 pc disk 10^{-4} pc (20 AU)
Tools	Spitzer, Herschel, SOFIA, SCUBA-2, GBT, LMT, SMA, CARMA, PdBI, ALMA… adaptive mesh codes 3D MHD, gravity, realistic ICs …and smart, motivated people!

The bigger picture…


Phil's Star Formation Web
The Universe
CMB
IGM
Dark Energy
Dark Matter
Galaxies
Mysterious
The Milky Way
Magnetic
fields
ISM
Stars
Young Stars
Hubs
Filaments
Molecular Clouds
Atomic Clouds
Cores
Chemistry
Infall
Outflow
turbulence
Protostars
Disks
Planets
Life
People
★★★
★★★★
★
★
Isolated
Clustered
IMF
Astronomers
Everybody else
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Thank you!!!