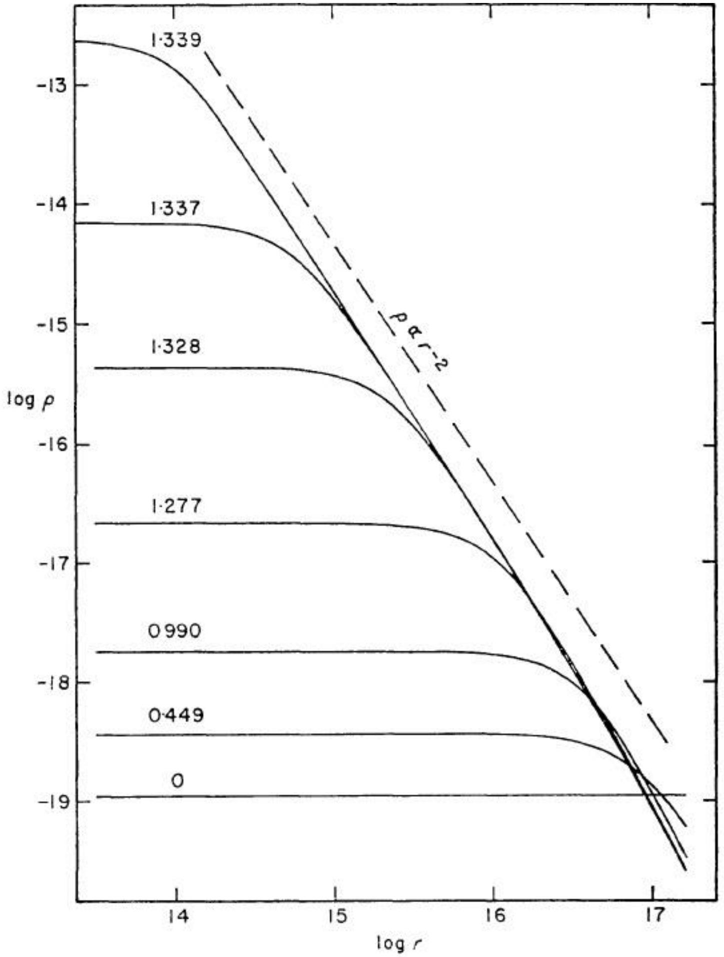
# Stellar Mass Accretion

SHANTANU BASU

Western UNIVERSITY · CANADA

# Prestellar Core Collapse




Direct collapse of a spherical isothermal cloud.

Q. $\rho = \rho(t)$ or $\rho(r,t)$ during collapse?

A. Collapse is highly nonhomologous!

Larson (1969)

Q. What happens when central region becomes opaque and nonisothermal?

Initial uniform density, $M > M_{Jeans}$

# Prestellar Core Collapse

Collapse of an isothermal spherical fragment whose mass exceeds the Jeans mass.

Larson (1969)



and the density distribution becomes peaked at the centre. The collapse of the central part of the cloud continues approximately as a free fall (even though pressure gradients are *not* negligible), and since the free-fall time depends inversely on the density, the collapse proceeds most rapidly at the centre where the density is highest; thus the density distribution becomes more and more sharply peaked at the centre as the collapse proceeds.

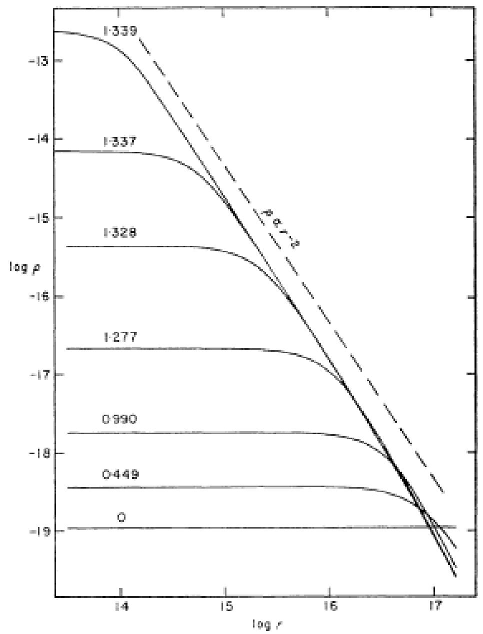



FIG. 1. *The variation with time of the density distribution in the collapsing cloud (CGS units). The curves are labelled with the times in units of* $10^{13}$ *s since the beginning of the collapse. Note that the density distribution closely approaches the form* $\rho \propto r^{-2}$.

Key result: $r^{-2}$ density profile

Shrinking central flat region size

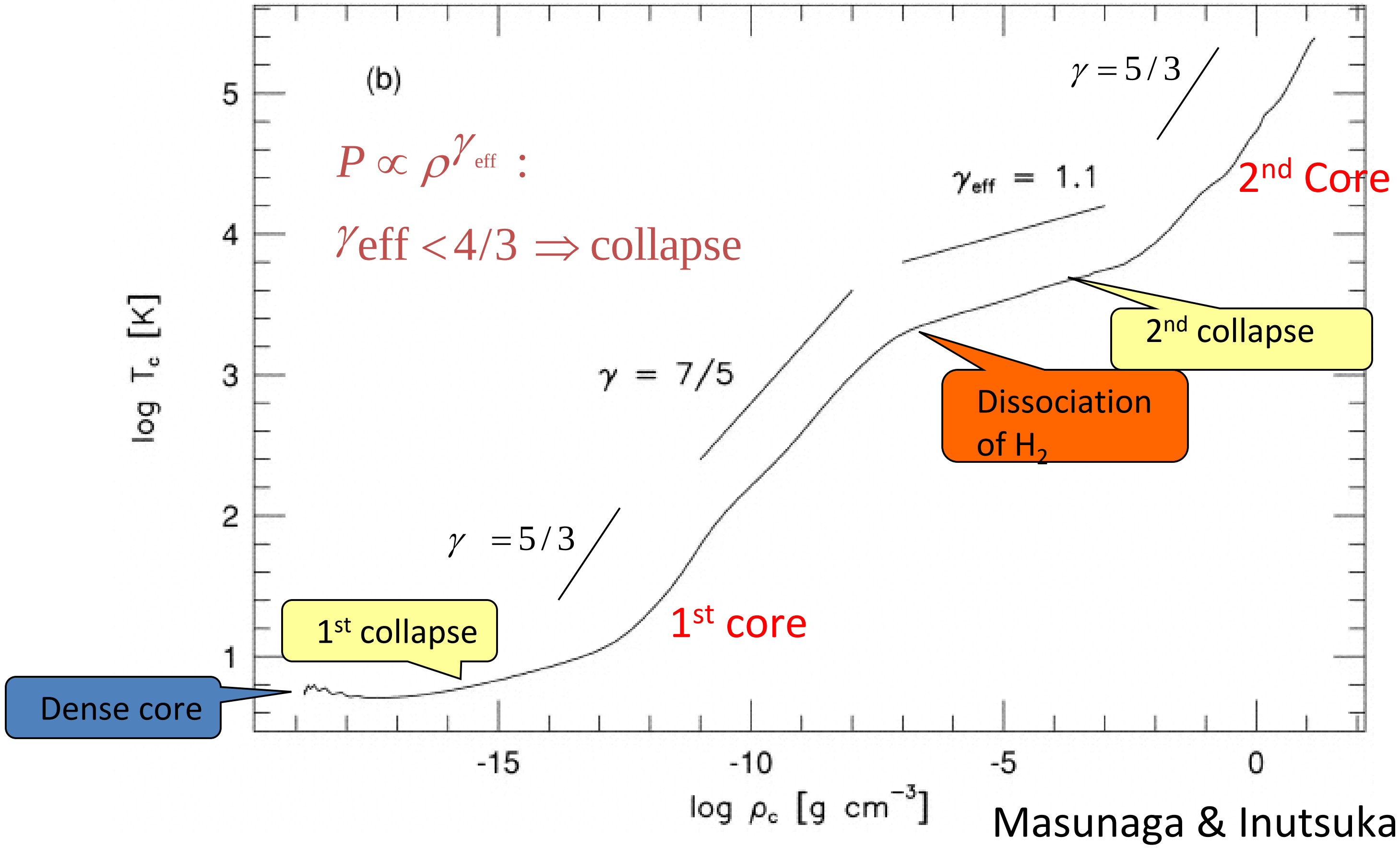
$$R \propto \lambda_J \propto \rho^{-1/2}$$

# Thermodynamics of Collapse

Dense cores isothermal due to atomic/molecular line cooling and (later) dust emission.

First core (size ~ few AU) when central density peak becomes opaque to dust emission.

Second core (size ~ $R_{sun}$, mass ~ 0.01 $M_{sun}$ initially) is the "protostar."




Masunaga & Inutsuka (2000)

# The Accretion Phase

Define $t = 0$ as the moment of protostar formation.

Asymptotic self-similar $r^{-2}$ density profiles reached in prestellar phase ($t < 0$) lead to predicted accretion rates onto protostar during $t > 0$:

For equilibrium singular isothermal sphere at $t = 0$:

$$\rho = \frac{c_s^2}{2\pi G r^2}, v_r(t=0) = 0 \quad \Rightarrow \quad \dot{M} = 0.975 \frac{c_s^3}{G}.$$

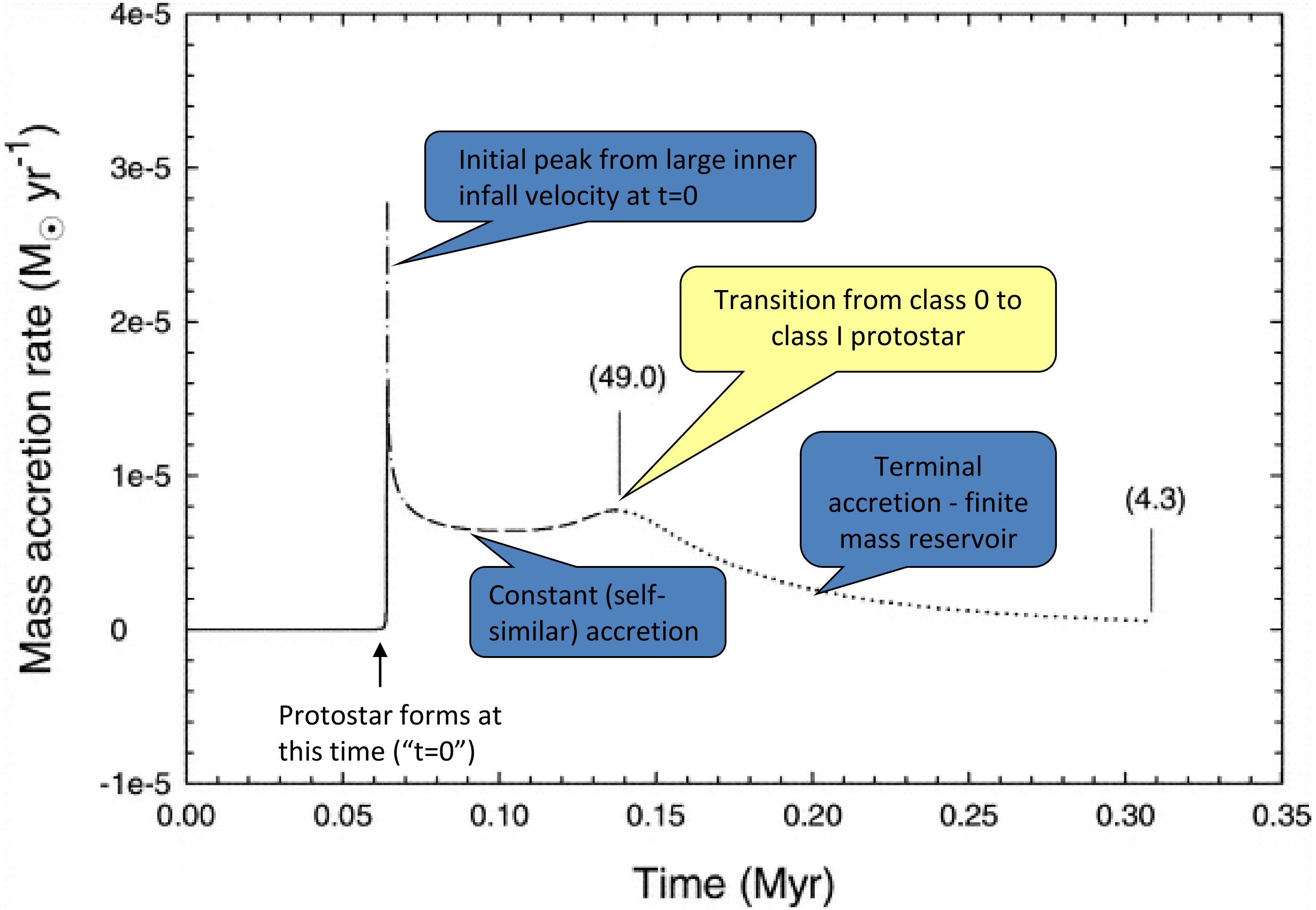
Rapid gravitational infall within a radius $r = c\,t$, the expansion wave radius.

Shu (1977)

Star formation is an accretion problem!

# Typical YSO accretion history

No rotation included.




Number in parentheses = percentage of total mass remaining outside the central sink (protostar).

Vorobyov & Basu (2005,2006)

# Disk formation *after* protostar formation

Central point mass dominates inner gravitational field.

$$a_c = \frac{j^2}{r^3} \text{ but } g = \frac{Gm_*}{r^2} \propto \frac{1}{r^2}$$

where $r$ is the comoving position of an infalling mass shell

For a Lagrangian mass shell, the centrifugal acceleration comes into balance with gravity at a centrifugal radius

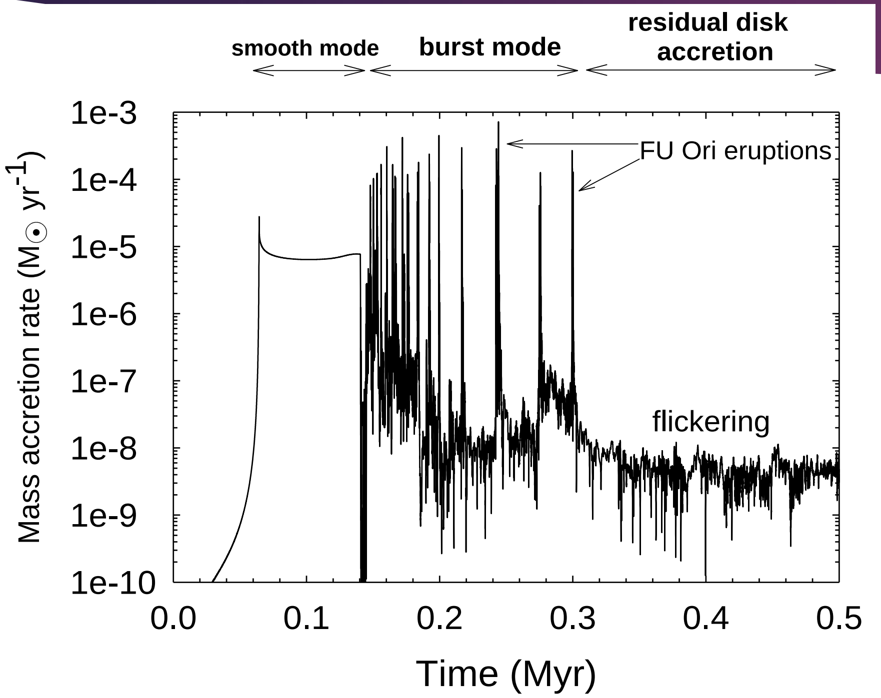
$$r_c = \frac{j^2}{Gm_*}$$

For a dense core that starts with

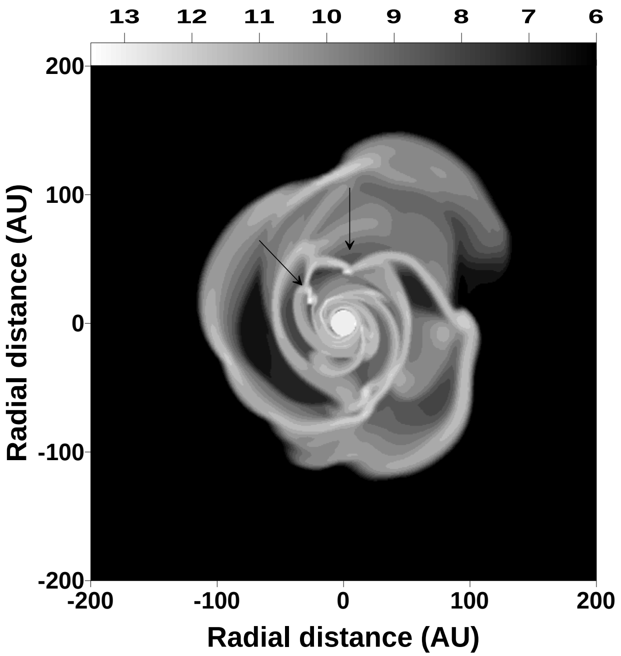
$$r = 0.1\,\text{pc}, \Omega = 10^{-14}\,\text{rad s}^{-1}, m = 2\,\text{M}_\text{sun}$$

$$\Rightarrow r_c \approx 250\text{ AU.}$$

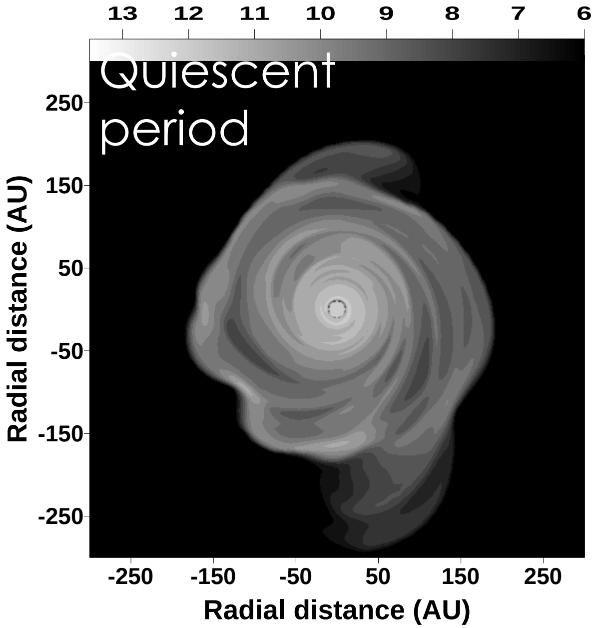
# High-res Disk Formation and Episodic Accretion




Just before a burst



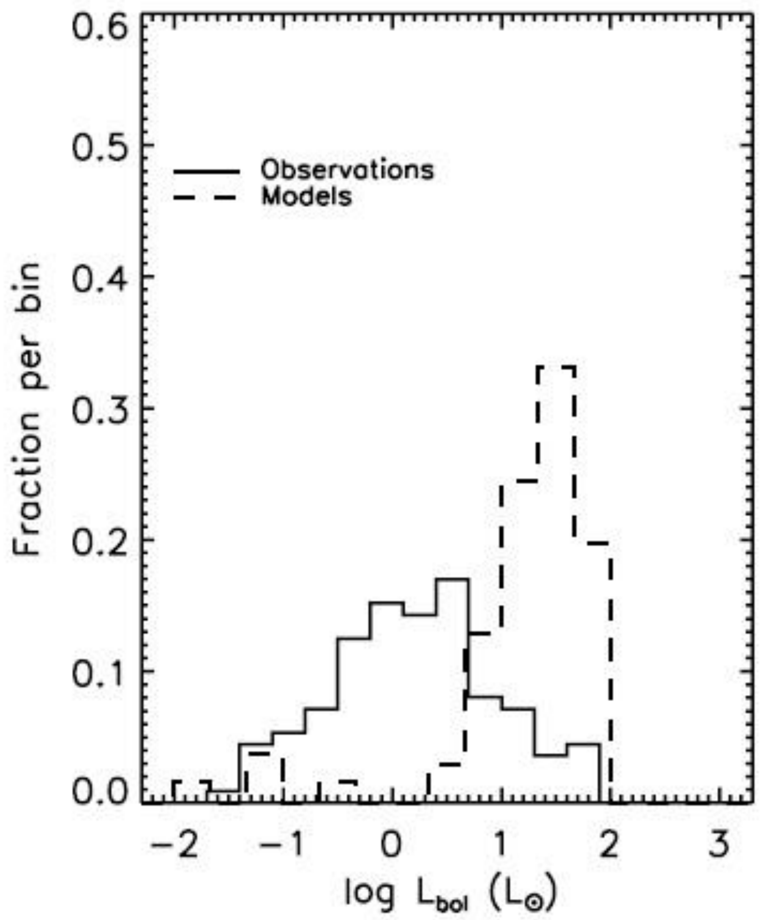

Nonlinear instability → clumps → efficient angular momentum transport




Bursts of accretion occur during the early accretion phase, as clumps are formed and driven inward. This is followed by a more quiescent phase that is still characterized by flickering accretion.

Vorobyov & Basu (2006, ApJ, 650, 956 )

# Luminosity distribution in embedded phase



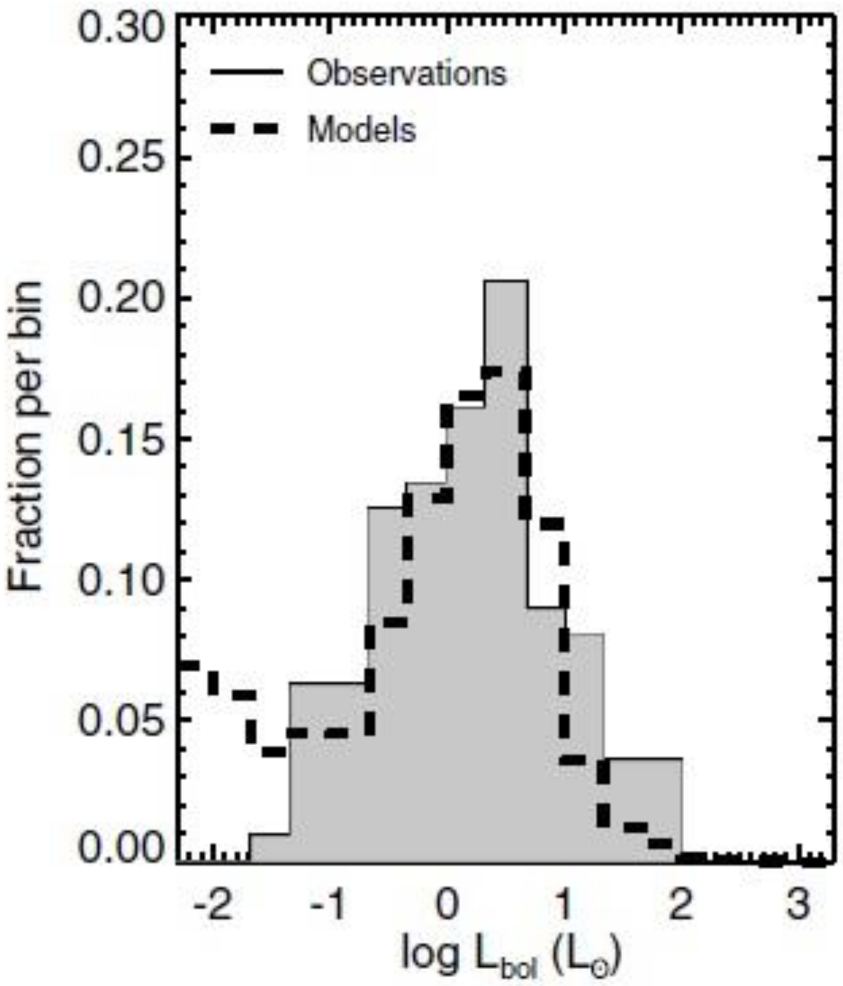

Dunham et al. (2010)

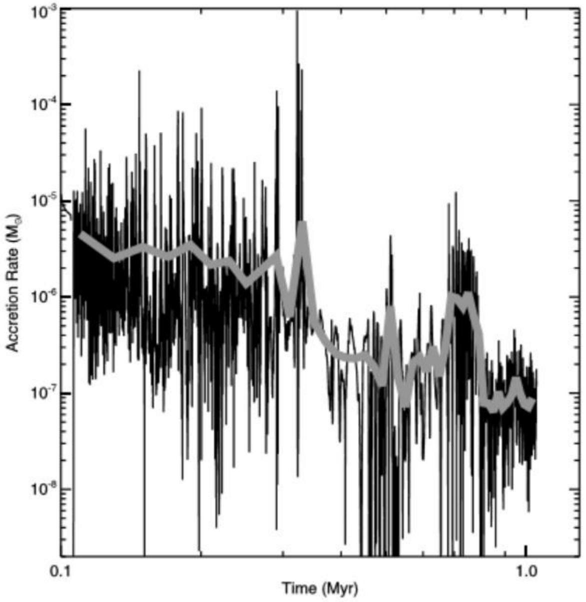
$$L \approx \frac{GM\dot{M}}{R} = \frac{Mc_s^3}{R} \approx 10L_{sun}$$

for $M = 0.5M_{sun}, R = 3R_{sun}, T = 10\text{K}.$

Dashed line is predicted luminosity distribution of embedded protostars using smooth accretion of inside-out collapse of a singular isothermal sphere.

# Luminosity distribution in embedded phase

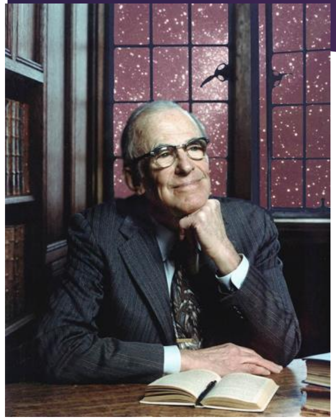


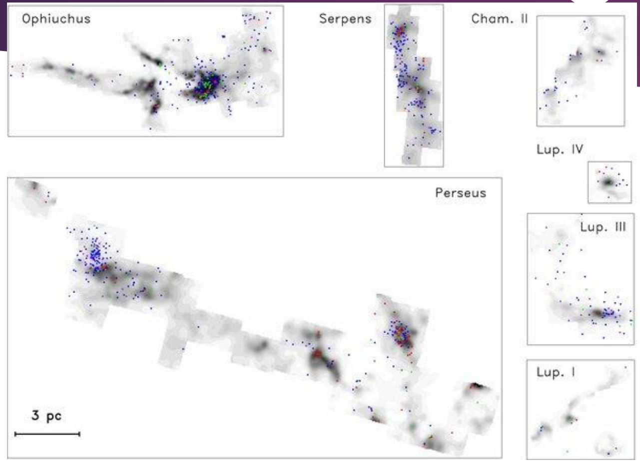

A combination of declining accretion rate and episodic bursts can resolve the luminosity problem.

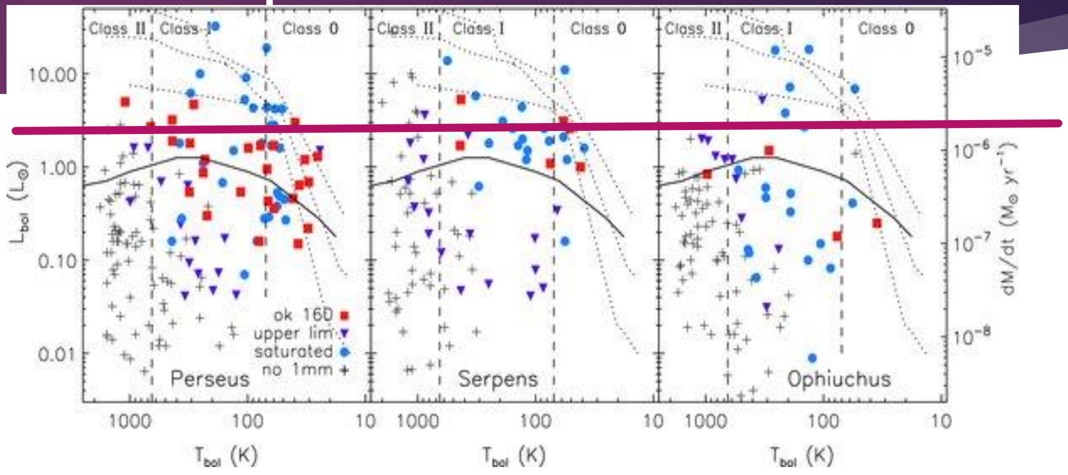
Dunham and Vorobyov (2012)

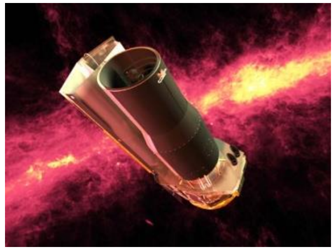
# Spitzer Telescope Survey → Episodic Accretion Paradigm Required



Lyman Spitzer Jr. (1914-1997)



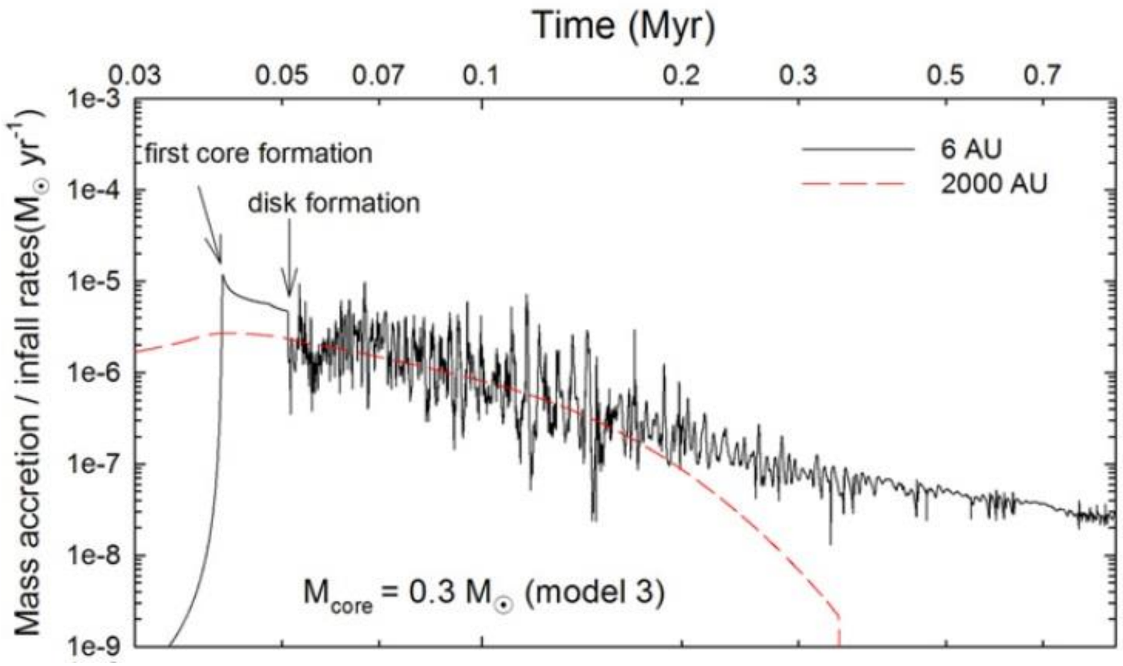
Spitzer Space Telescope, infrared wavelengths

Source counts lead to estimated lifetime of main mass accumulation phase (Class 0 and Class I) of ~ 0.5 Myr. For mean stellar mass ~ 0.5 $M_{sun}$, mean accretion rate is ~ $10^{-6}$ $M_{sun}$/yr (Blue horizontal line).

But most luminosities of sources fall far below this line, with a small fraction lying above the line → episodic accretion is required!

Enoch et al. (2009), Evans et al. (2009)

# Long term accretion history




Vorobyov & Basu (2015)

Multiple phases:

1. Smooth accretion rate ~ $c^3/G$
2. Burst mode of accretion after disk formation, with decline in mean value due to finite mass reservoir
3. Steady-state accretion after envelope accretion ends

# Summary of Stellar Mass Accretion

- Gravitational collapse is highly nonuniform, a "runaway collapse"
- Central density peak increases rapidly, leaving an $r^{-2}$ density profile behind it
- Once central density peak becomes opaque, it becomes a hydrostatic protostar that accretes matter from surrounding envelope
- Disk formation occurs after protostar formation and leads to a burst mode of accretion
- Later phase is a steady power-law declining accretion rate driven by disk internal torques
- High mass stars may require an additional phase of rapid accretion