The protostellar luminosity problem: "historical perspective"

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A subject made possible by IRAS...

THE ASTRONOMICAL JOURNAL VOLUME 99, NUMBER 3 MARCH 1990

AN *IRAS* SURVEY OF THE TAURUS–AURIGA MOLECULAR CLOUD[a),b)]

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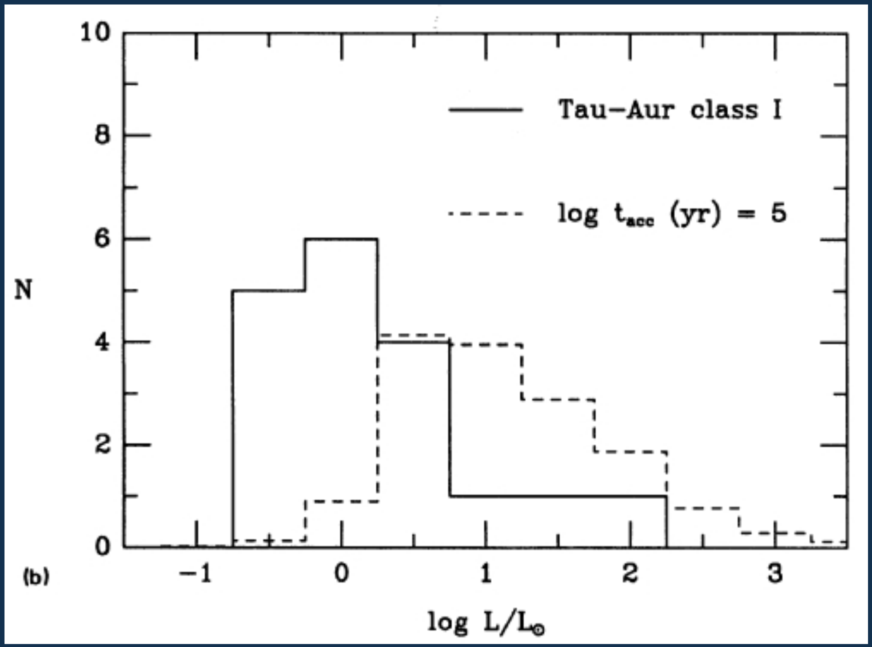
"…embedded objects are not more luminous than CTTS…
L(bol)s imply dM/dt ~ 10^{-7} $M_\odot$/yr …"

"The apparent disagreement between accretion rates inferred from τ(embedded) and luminosities can be reconciled if a star accretes most of its mass in a time << τ(emb) or the ages of TTS have been underestimated *(and thus τ(emb) is longer)*

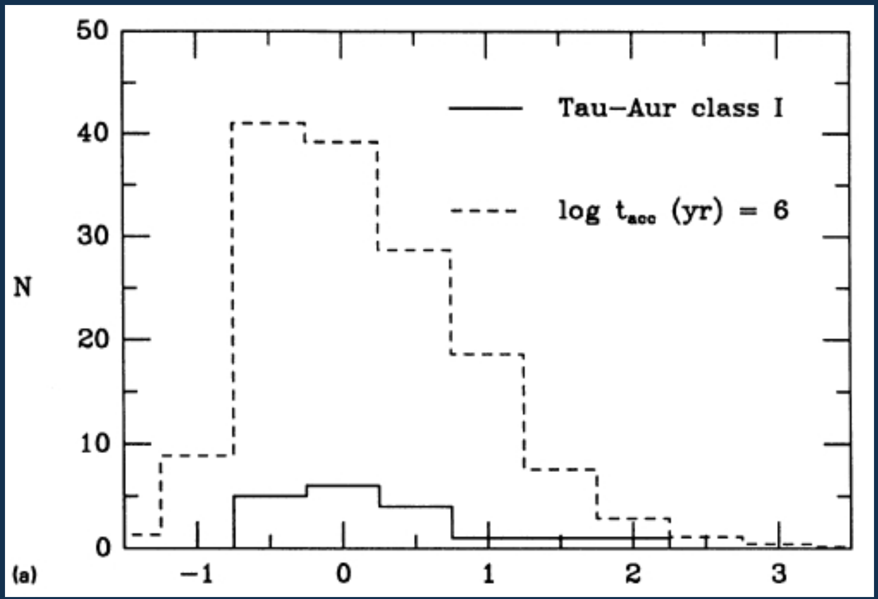
If either hypothesis is correct, dM/dt (embedded)… are not simply related to the infall rates… probably because infall occurs first to circumstellar disks."



Constant accretion:
dM/dt $\propto$ M(final) (all masses take the same time to form)

t(acc) = 10^5 yr;

right N(proto), L too high



t(acc) = 10^6 yr;

right L, N(proto) too large

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NEW PRE-MAIN-SEQUENCE STARS IN THE TAURUS–AURIGA MOLECULAR CLOUD[1]

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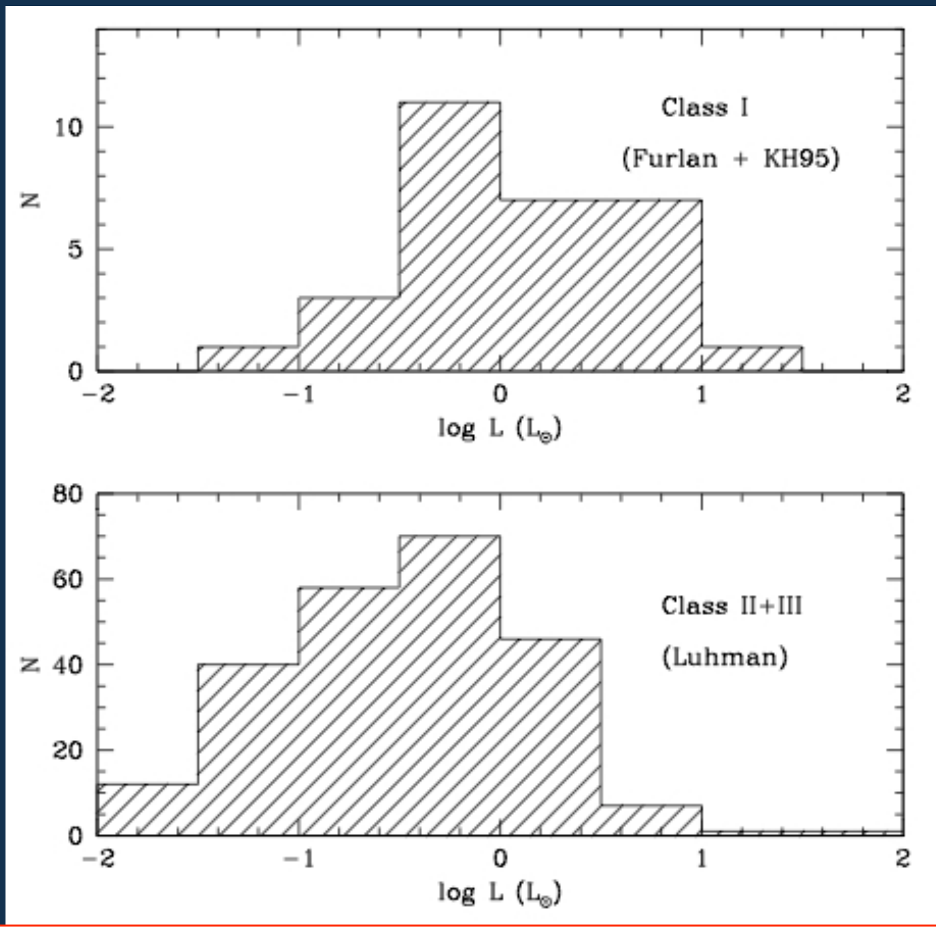
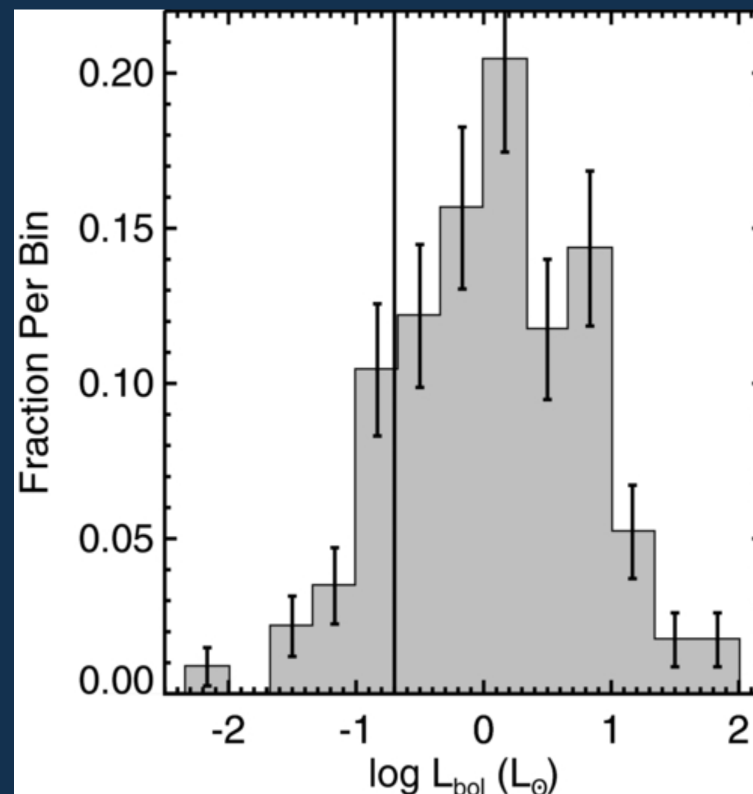
PRE–MAIN-SEQUENCE EVOLUTION IN THE TAURUS-AURIGA MOLECULAR CLOUD[1]

SCOTT J. KENYON[2] AND LEE HARTMANN





Spitzer: much better statisics, ~same result

Dunham+ 2013

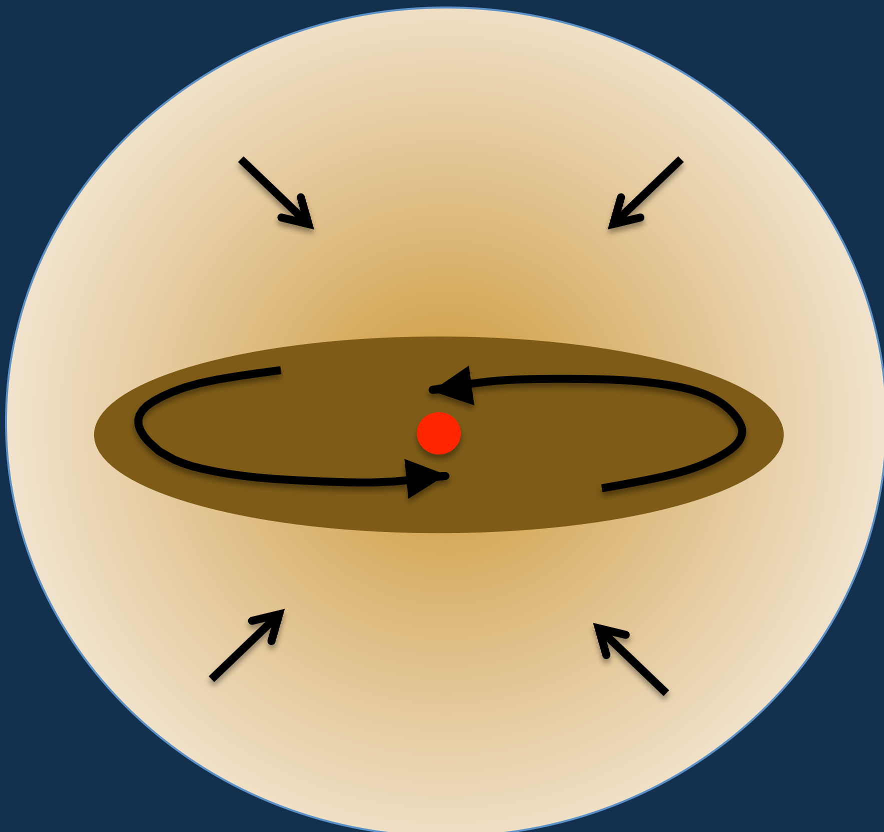
Total system luminosity can be written as

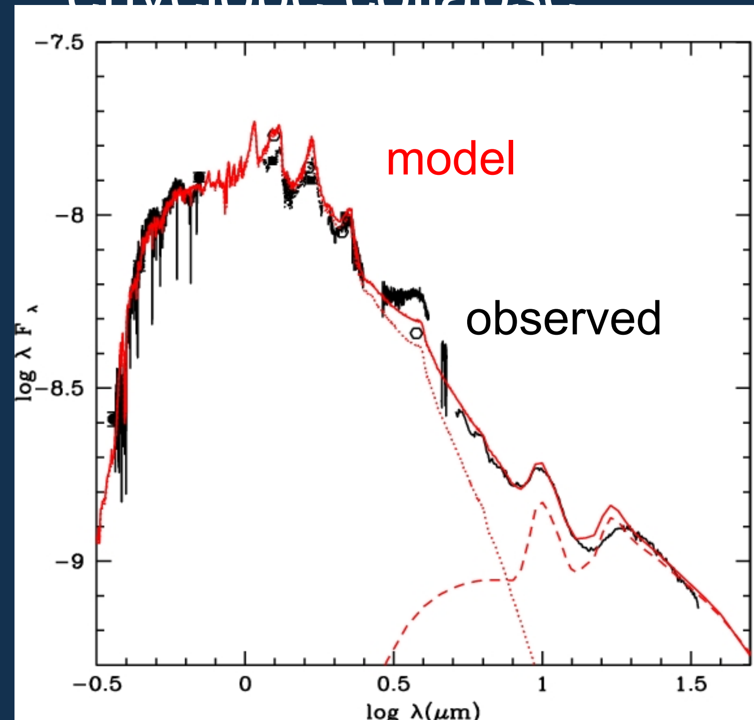
$$L = L_* + L(acc) = \frac{3}{7}\frac{GM_*^2}{R_*\,t_{KH}} + \frac{GM_*\dot{M}}{(2)R_*}$$

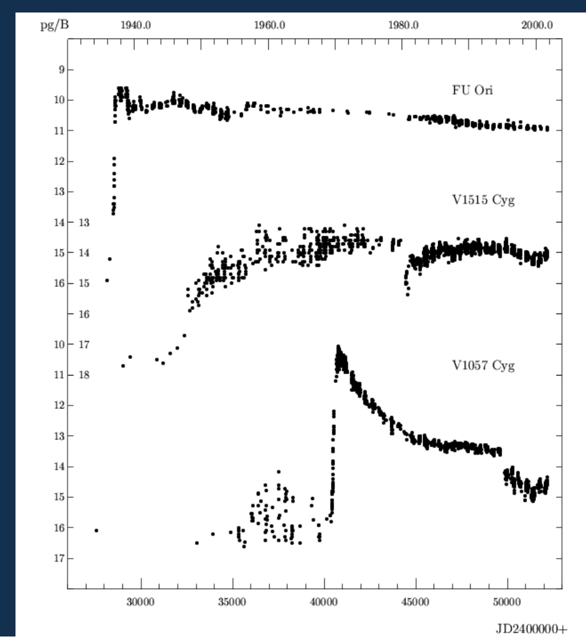
$$\sim L_*\left[1 + \frac{7}{6}\frac{t_{KH}}{t(acc)}\right]\,, \quad t(acc) \equiv \frac{M_*}{\dot{M}}$$

$t_{KH} > t(acc) \Rightarrow$ protostars should be more luminous than T Tauri stars (of the same mass)

suggestion (KHSS90, K94, KH95): pileup in disks followed by outbursts envelope collapse







no reason why the infall time must equal the accretion time through the disk - why not assume non-steady accretion?

However:

Offner & McKee 2011: analyze the protostellar luminosity function with many scenarios.

⇒ argue don't need outbursts to explain luminosity

complicated problem – explore with toy models, assuming disk dM/dt = infall dM/dt (no bursts)

$$L(acc) = \frac{G}{(2)} \frac{M_*}{R_*} \dot{M}$$

Protostellar luminosity function: affected by...

- $R_*(M_*)$
- missing energy (winds)?
- dM(infall)/dt
- disk accretion
- IMF
- SFR(t)?

Here I focus only on:

- mass infall rates

$$L(acc) = \frac{G}{(2)} \frac{M_*}{R_*} \dot{M}$$

My "fit" for 0.1 $M_\odot \lesssim M \lesssim 0.9\ M_\odot$

$\Rightarrow M/R \propto M^{0.74}$

$\Rightarrow$ for a given accretion rate dM/dt, accretion luminosity is LARGEST for the LARGEST MASS protostars

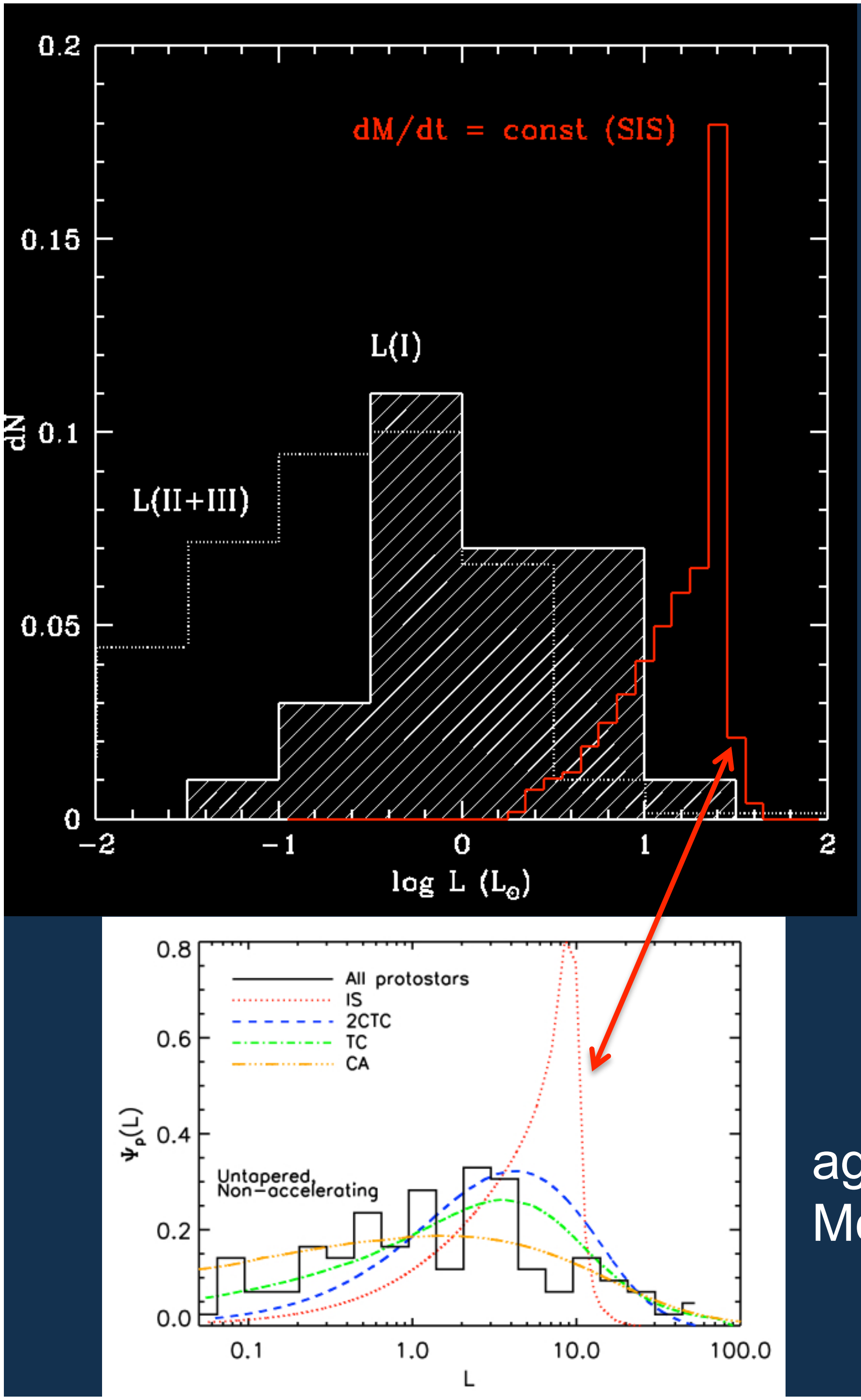
First historical model: the Singular Isothermal Sphere

$$\dot{M} \sim c_s^3/G \sim 2 \times 10^{-6}\, T_{10}\, M_\odot yr^{-1}$$

$$M = 0.3 M_\odot\,,\, R = 1.3 R_\odot\,,\, L(acc) = 7.3(\times 2) L_\odot$$ X

$$t(acc) = \frac{M}{\dot{M}} = 0.15\, Myr\, \frac{M}{0.3 M_\odot} T_{10}^{-1}$$?

Even worse: *shape* of LF



Why?

⇒ accreting at a rate INDEPENDENT of the (final) mass means *most* protostars are *"massive"*

⇒ higher L(acc)

agrees with Offner & McKee 2011

Second historical model: the (critical) Bonnor-Ebert Sphere

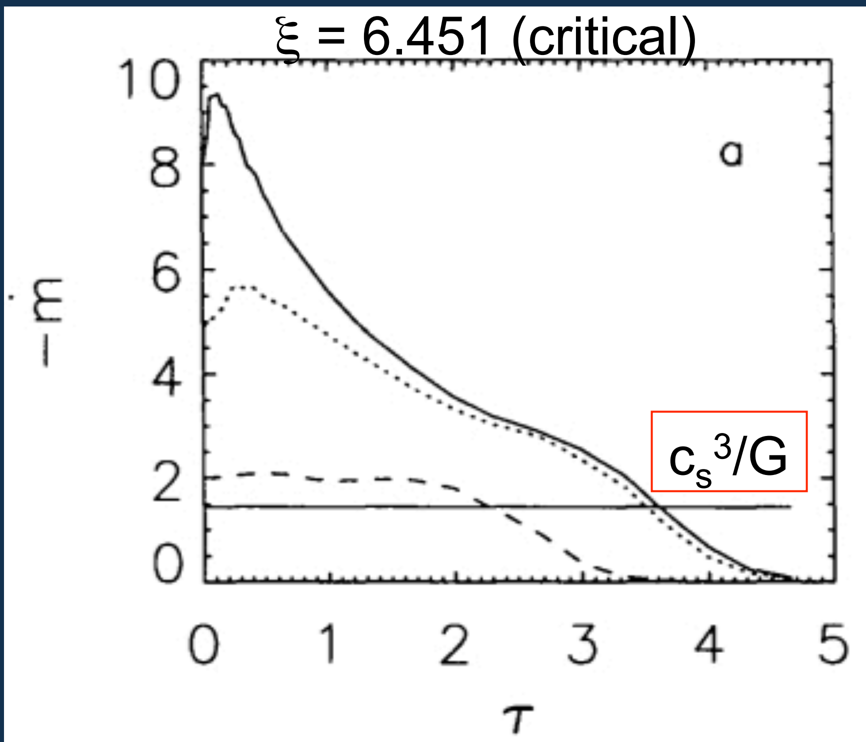
$$M_{BE} \sim \frac{c_s^3}{G}(0.5G < \rho >)^{-1/2}$$

$$\sim \dot{M}(SIS) \times t_{ff}$$

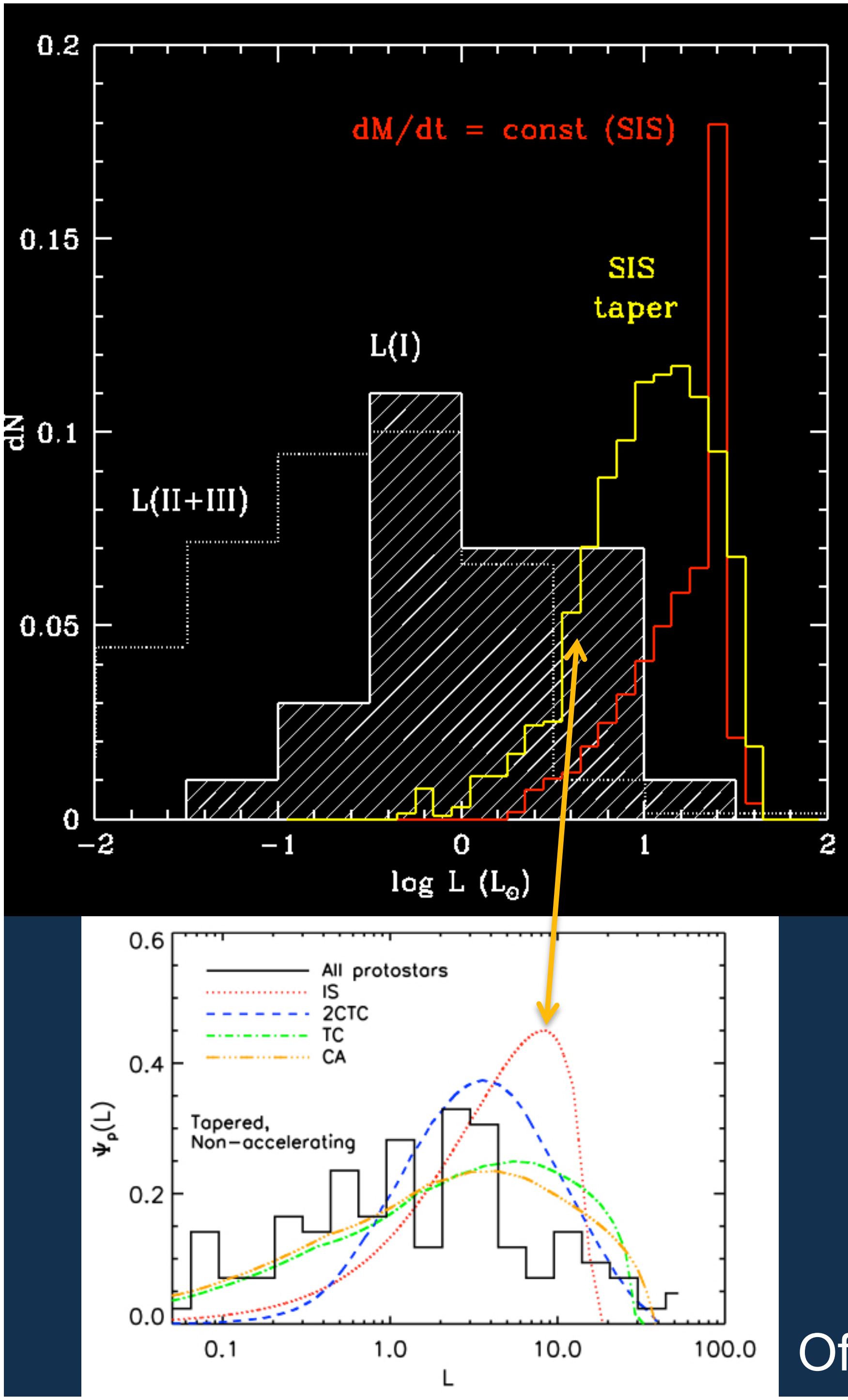
$$t_{ff} \sim M_{BE}/\dot{M}(SIS)$$

⇒ time taken to form is ∝ mass, like SIS:

⇒ "tapered" accretion, but *faster* than SIS



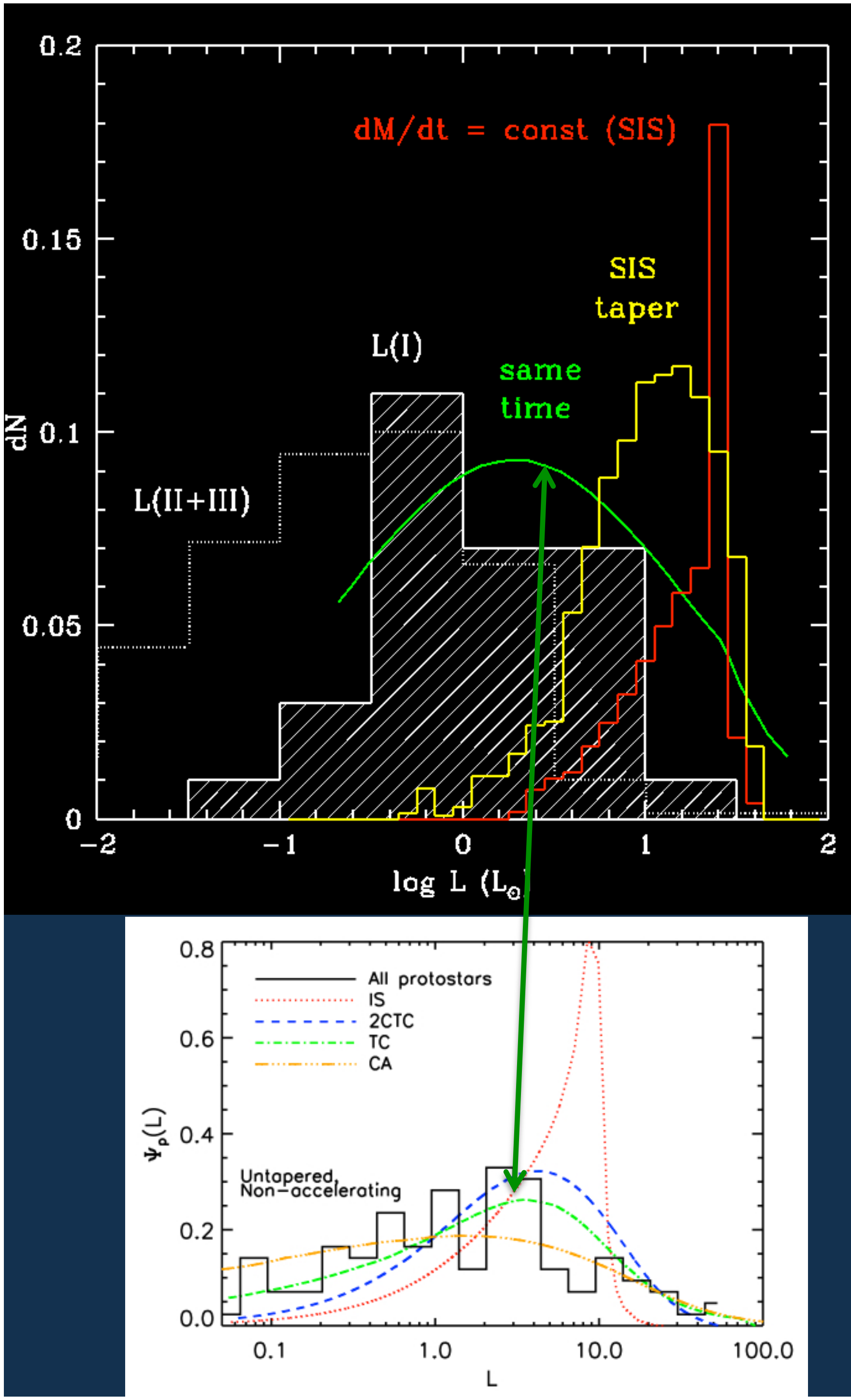
Foster & Chevalier 93



SIS taper (critical BE sphere collapse) a bit better, but not much

(dM/dt HIGHER than in the pure SIS case)

Offner & McKee 2011

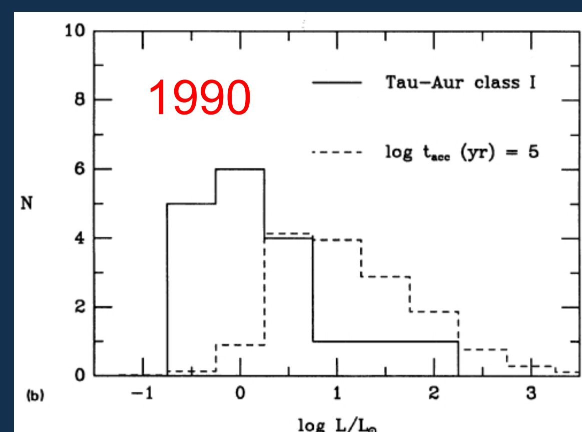


The solution??

assume all stars form in the same time, independent of final mass

[dM/dt ∝ M(final)]

⇒ even though massive (proto)stars have higher L(acc), less frequent



BUT...

The (critical) Bonnor-Ebert Sphere: ~ one Jeans Mass:

$$M_{BE} \sim \frac{c_s^3}{G}(0.5G < \rho >)^{-1/2} \sim \dot{M}(SIS) \times t_{ff}$$

OM11 need long lifetimes ⇒ dM/dt *less than SIS/BE*

- *especially slow for* 0.1 $M_\odot$; need low densities for long free-fall times - but this is *opposite* to the Jeans mass criterion for fragmentation $M_J \propto \rho^{-1/2}$

(i.e., the reason why t_{ff} ~ t(form) ∝ M(final) is the Jeans mass criterion)

*** problem for theories in which the core MF ⇒IMF ***

OM11: form all masses in equal time (TC/CA), t(form) ~ 0.6-0.8 Myr:

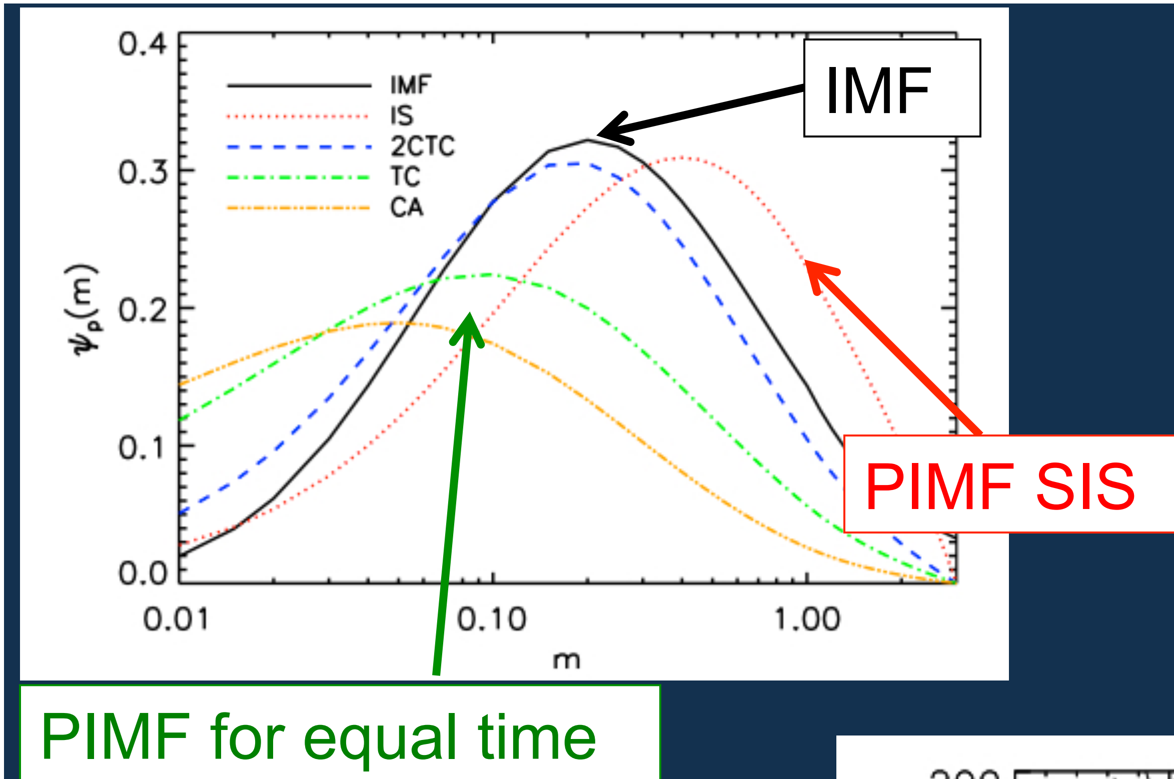
BUT: for typical mass ~ $0.1 M_{\odot}$ $\Rightarrow$ $dM/dt \sim 1.5 \times 10^{-7} M_{\odot}/yr$ (!)

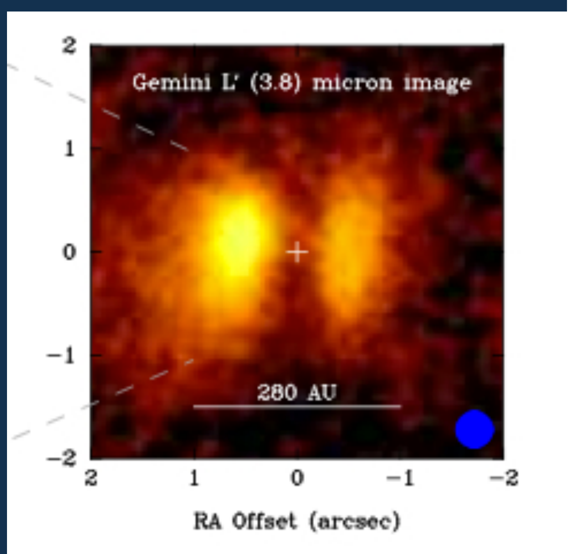
~ 0.1 SIS, ~ 0.05 BE(crit)!? how does one do this?

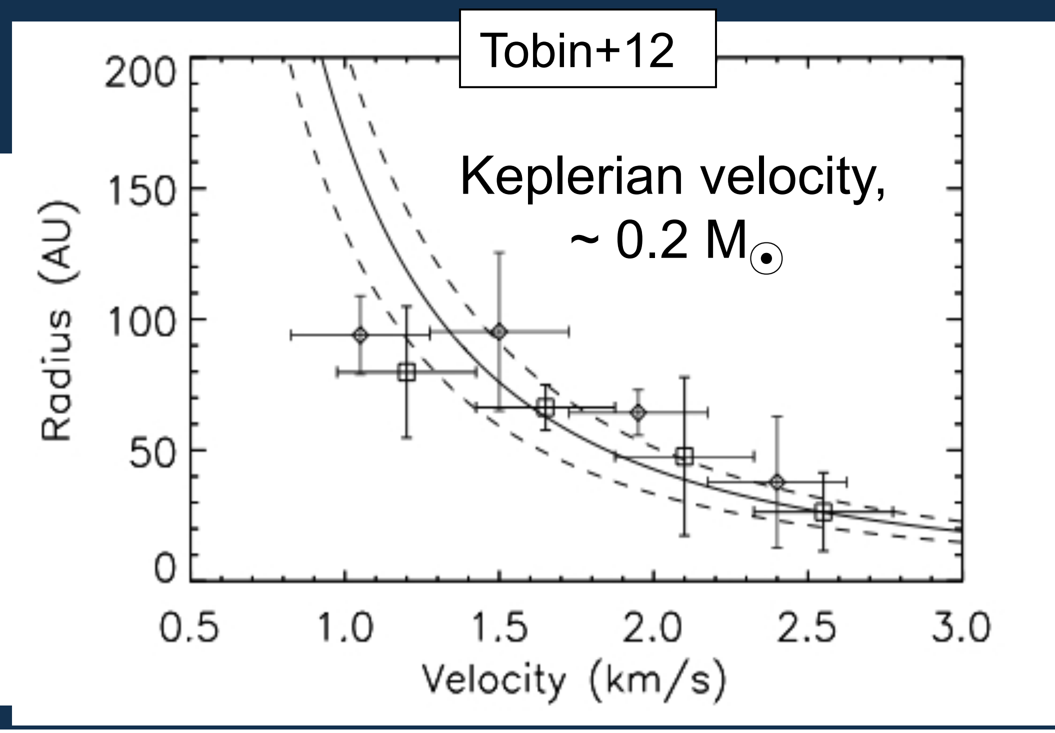
OM “solve” the PLF with... low accretion rates! *(e.g., KHSS)*

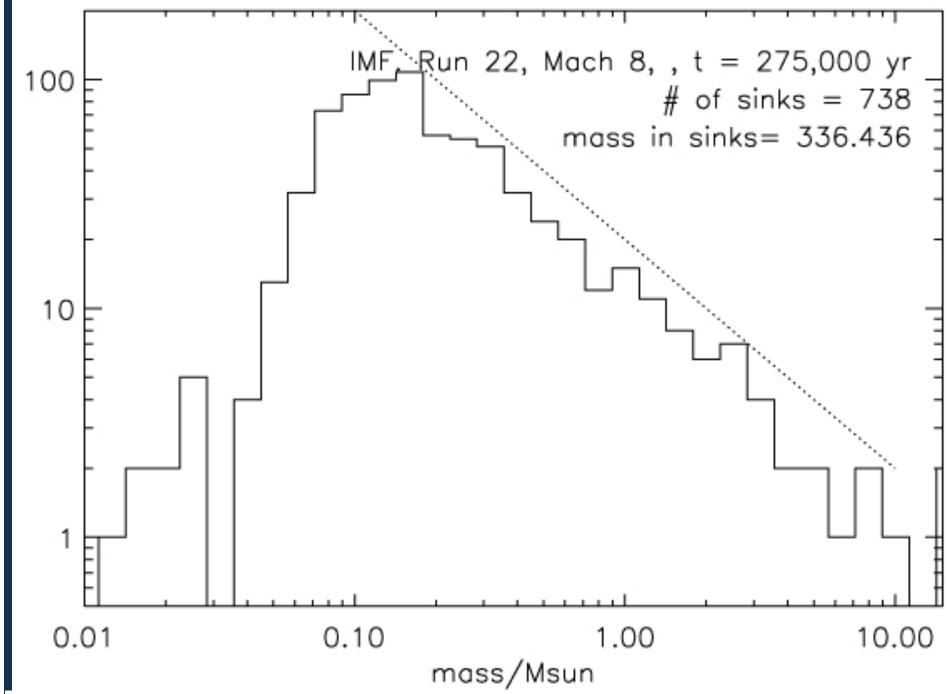
To distinguish between two extremes – typical masses of protostars

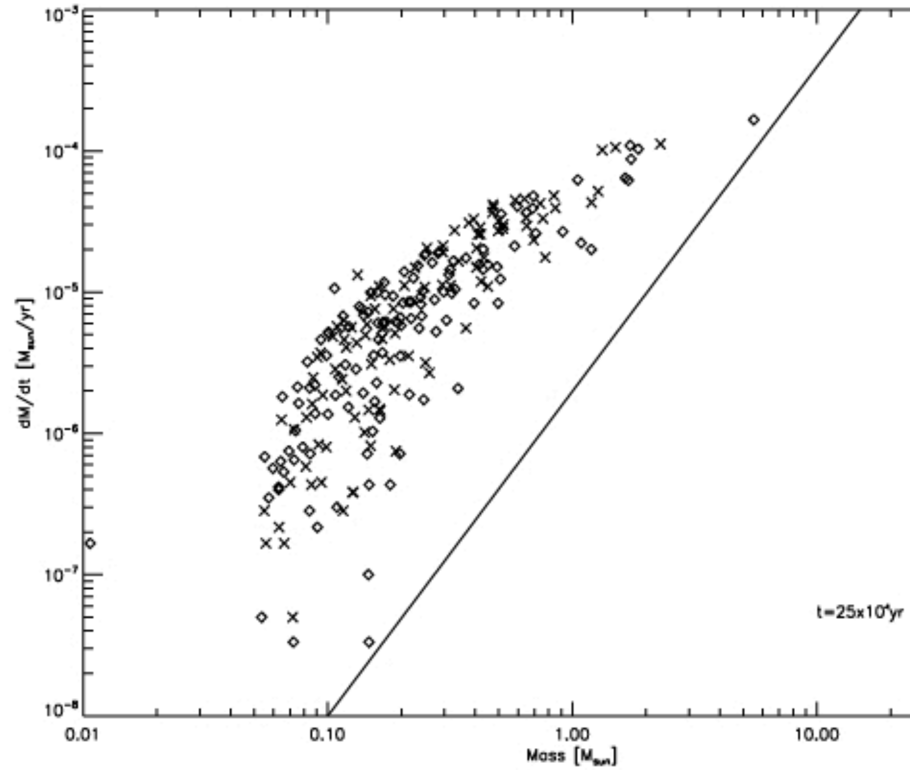
ALMA: measure from infall and/or disk rotation?

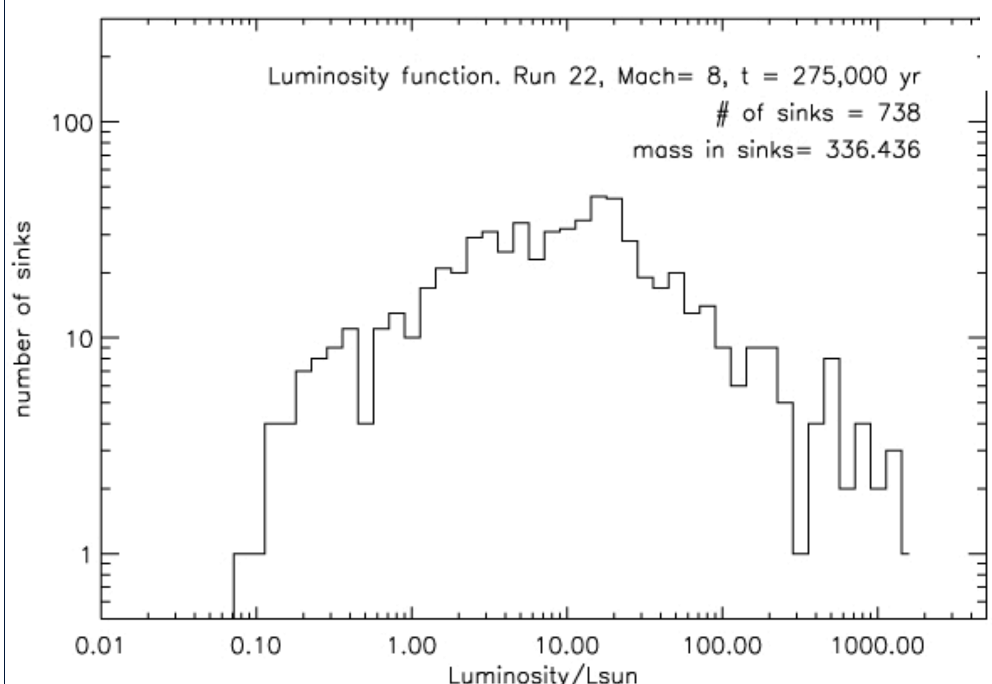












work in progress: sink formation in non-driven, isothermal cloud collapse:

get Γ=-1, $\langle dM/dt \rangle \propto M^2$ despite huge time variations:

$dM/dt \propto \rho M^2 v^{-3}$; M^2 is an attractor (Ballesteros-Paredes+ 2014) so what's the solution?

- time-dependent disk accretion?

frequency of large (FU Ori) outbursts doesn't seem to be sufficient. Smaller, more frequent outbursts?

+ some observations where dM/dt(in) < dM/dt(acc)

... higher final masses need lower dM/dt. I think these are more likely to have outbursts ⇒ higher angular momentum ⇒ longer disk accretion timescales

- Winds take away most of the energy? more than half? Implies dM/dt estimates from L(acc) too low by a LOT?

Need to "tidy up" Spitzer observational estimates