The Role of Episodic Accretion in Low-Mass Star Formation

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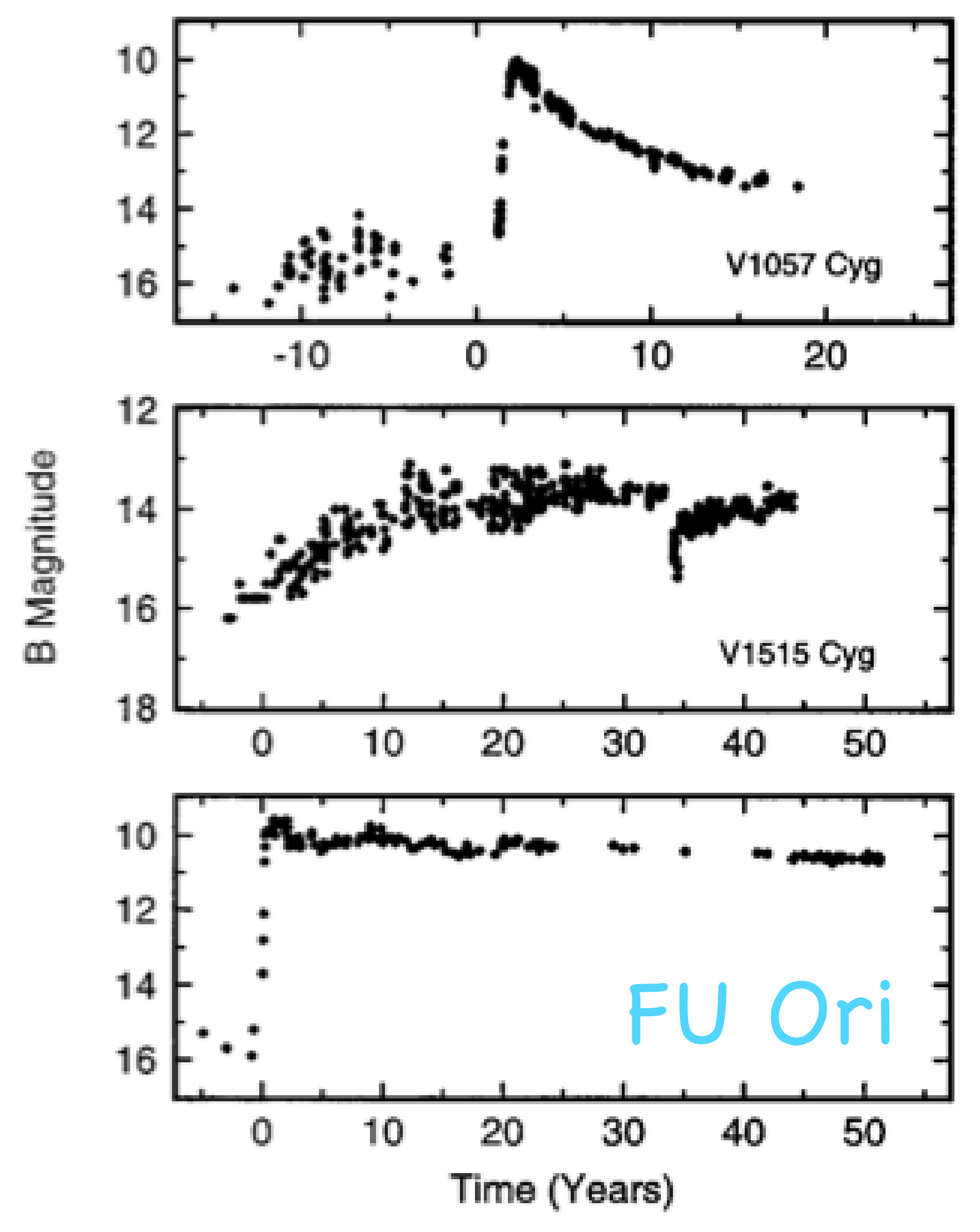
Very Low Mass Stars and Brown Dwarfs
October 14, 2011

Offner & McKee, 2011
Hosokawa, Offner & Krumholz, 2011

Definition

- ≥ 4 orders of magnitude in B magnitude (100 x L*)
- Absorption lines in optical spectra
- IR Excess (Class I/II protostars)
- Reflection Nebulae
- Δt = 10s years

Kenyon & Hartmann 96

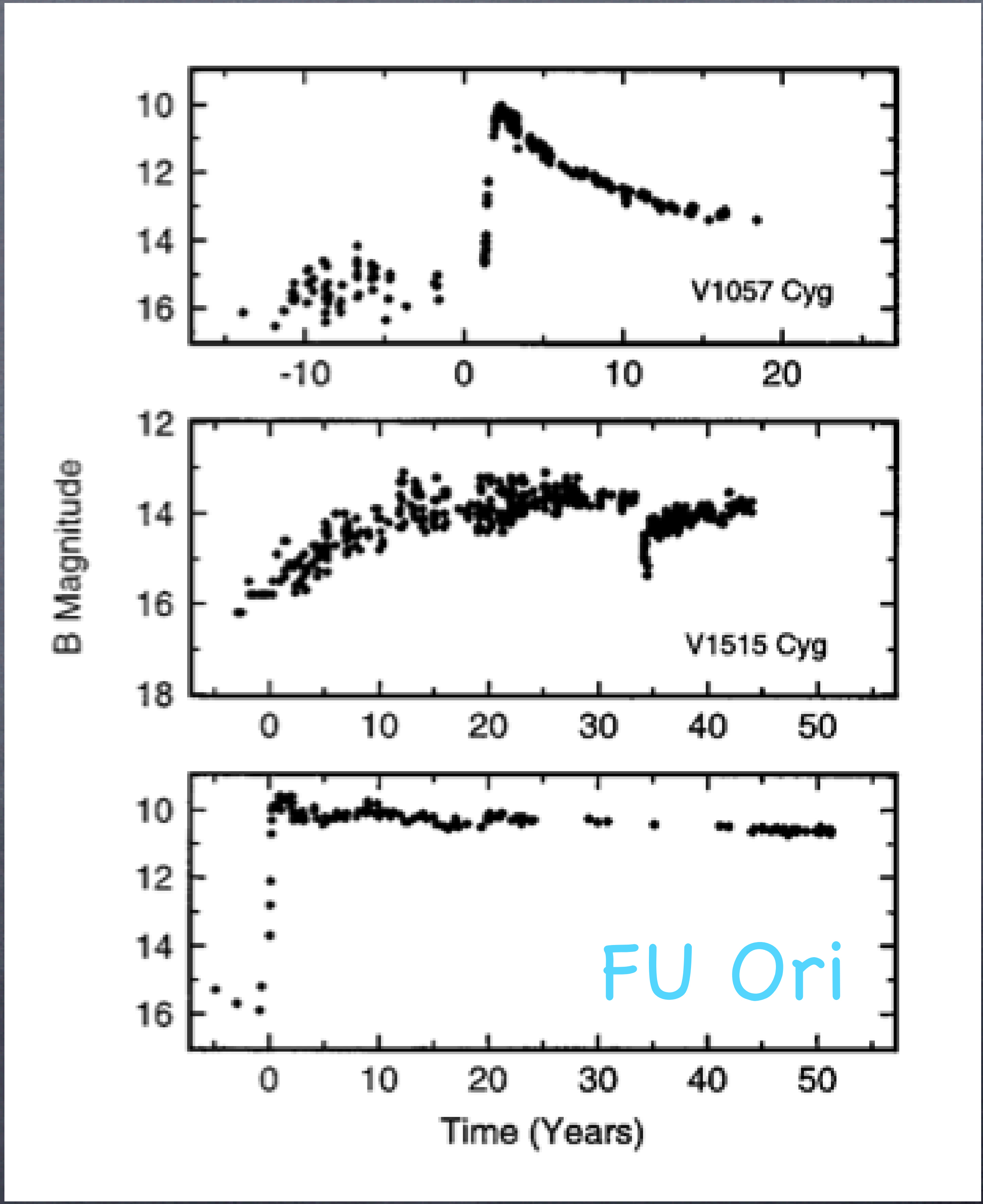


Definition

- ΔL = 20-220 Lsun

$$L_{\rm acc} = f_{\rm acc}\left(\frac{Gm\dot{m}}{r_*}\right)$$

Kenyon & Hartmann 96



Burst Origin

Offner et al. 2009, 2010

- Thermal Instability
  (Bell & Lin 94)
- Binary Interactions
  (Reipurth & Clarke 01,
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  (Vorobyov & Basu 2005+,
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100 AU

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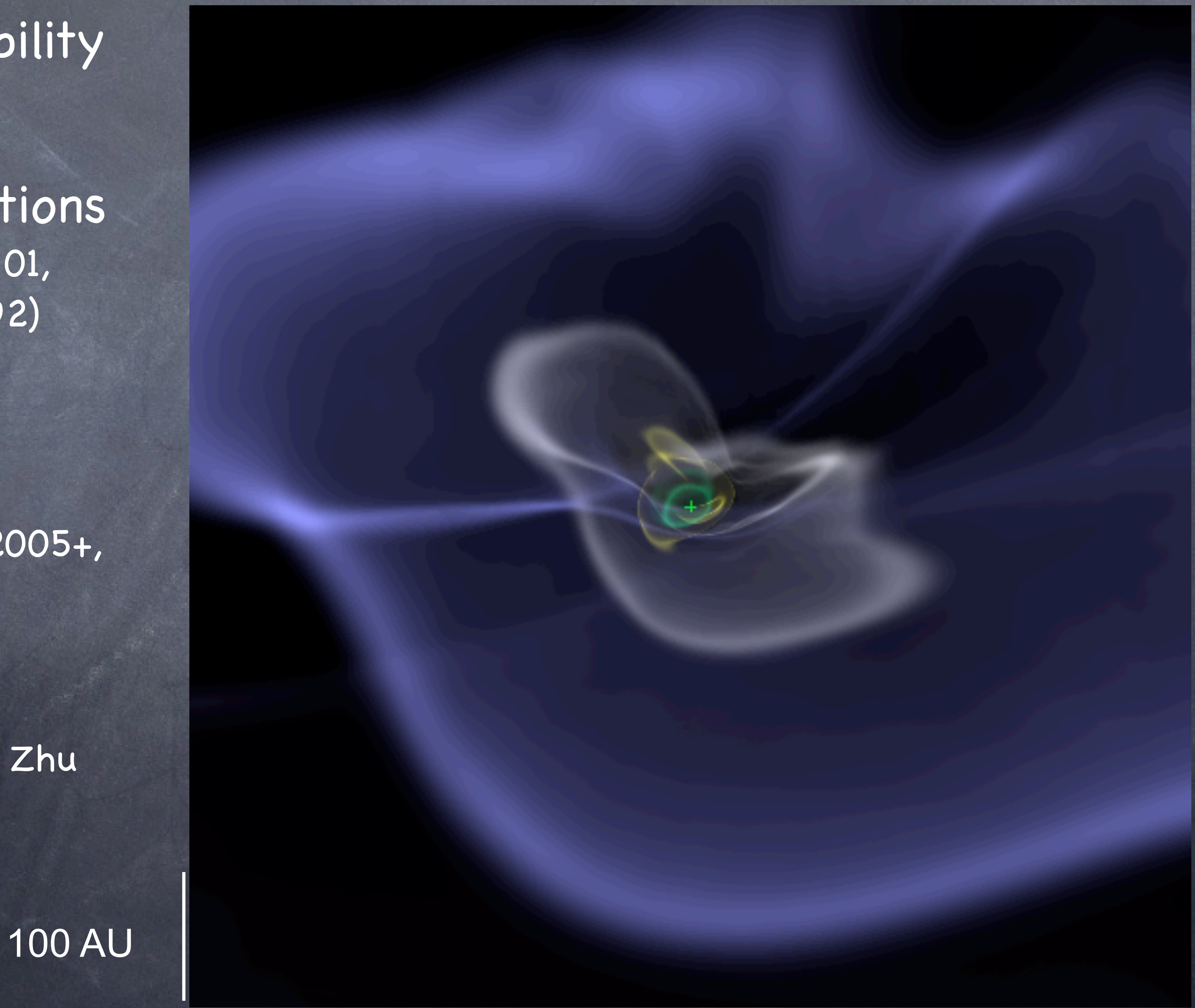

Offner et al. 2009, 2010

Estimations: Fraction of Mass Accreted

- N_p = # of bursting sources = 20 (observed in last 70 years)
- $\dot{N}_*$ = Star Formation Rate = 0.016 */yr
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1/4 of Mass

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$$\frac{\Delta t_{\rm high}}{< t_f >} = \frac{1200 \ {\rm yr}}{10^5 - 10^6 \ {\rm yr}} \simeq 0.01 - 0.001$$

Can Episodic Accretion Solve Open Problems in Star formation ??

(Embarrassing) Problem # 1: Luminosity Problem (I)

- Protostars are dimmer than star formation models predict (Kenyon et al. 1990)
- $\langle L \rangle_{obs} \cong 2$ Lsun for Class 0, I (Enoch et al. 2009)
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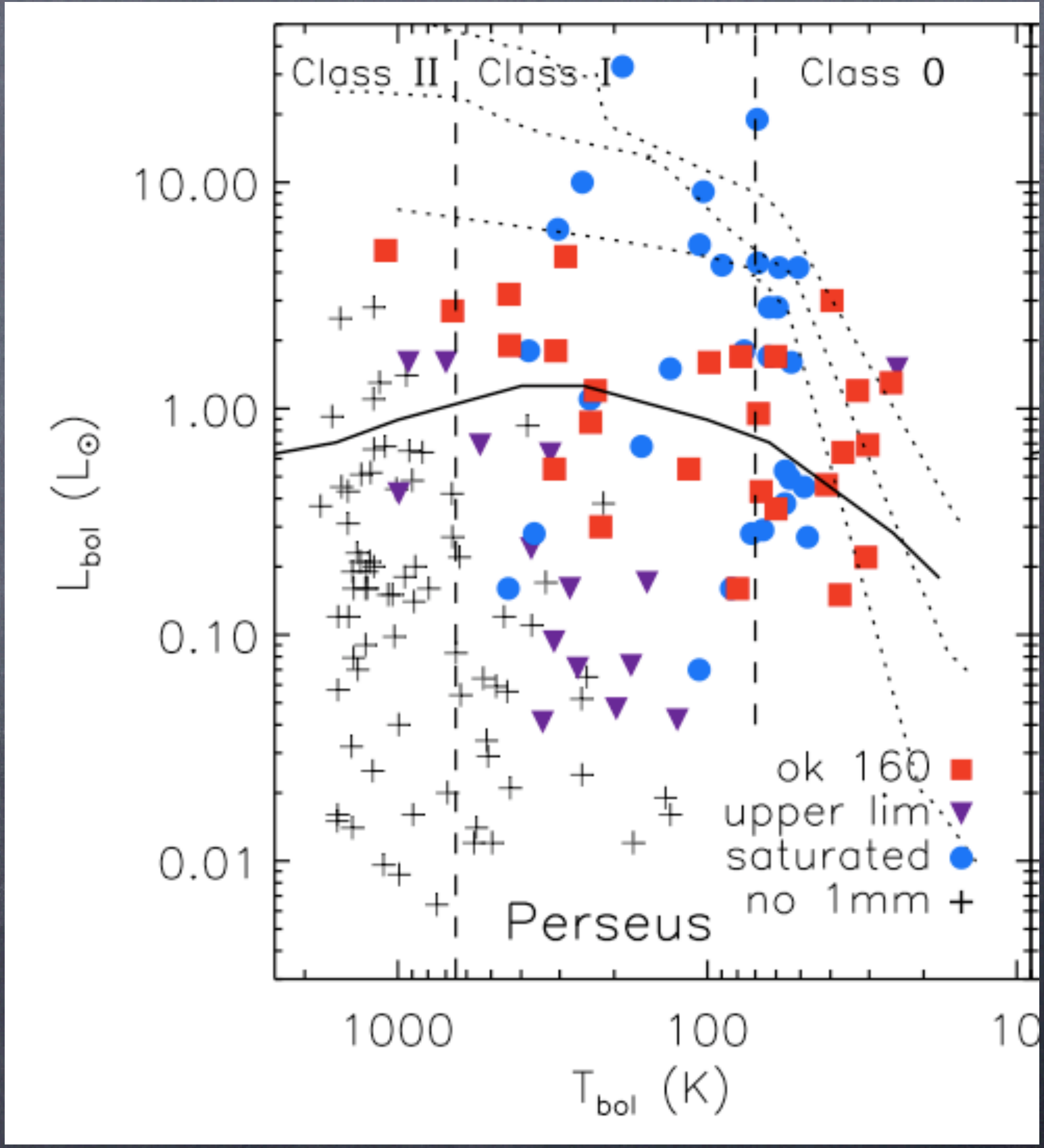
→ $<L>_{obs} \cong 5.3$ Lsun with extinction correction (Evans et al. 2009)

(Embarrassing) Problem # 1: Luminosity Problem (II)

Enoch et al. 2009

- Luminosities range over 3 orders of magnitude
- There are a large number of low-luminosity protostars



Protostellar Mass Function (PMF)

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- …but the initial mass function of stars (final protostellar masses) is well constrained.

Star Formation

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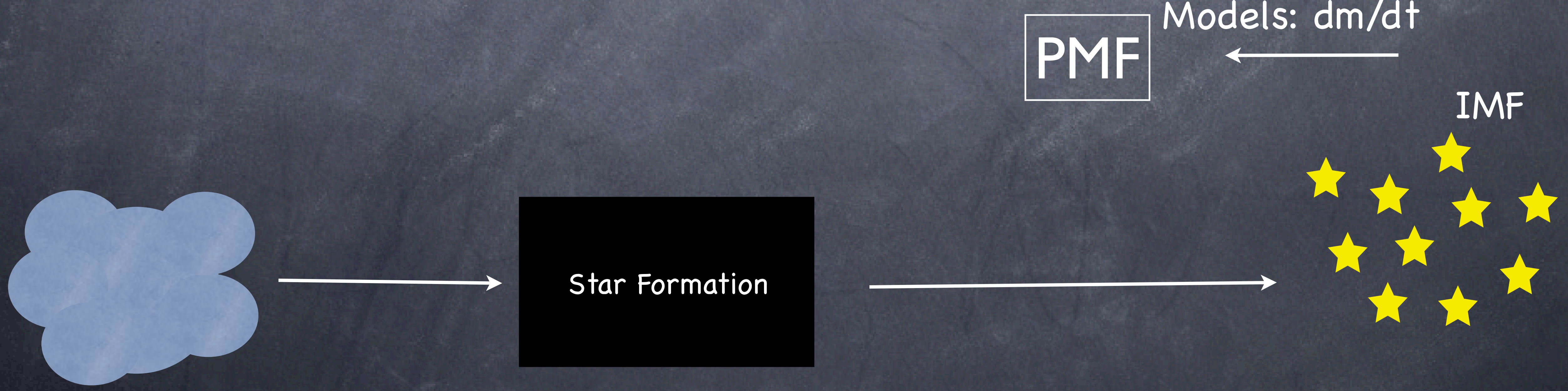

PMF

Models: dm/dt

IMF

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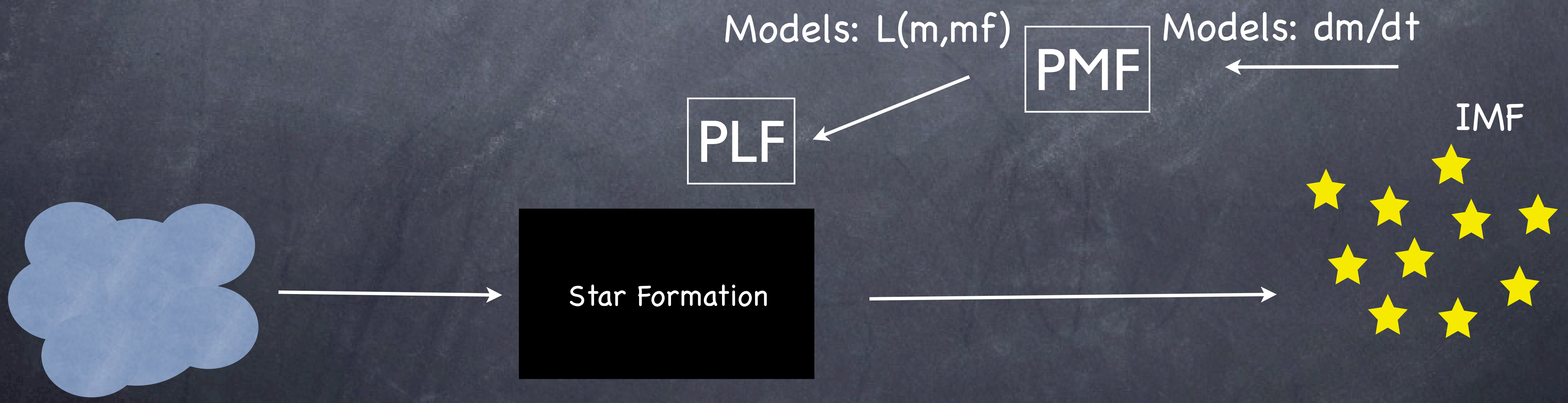

Models: L(m,mf)

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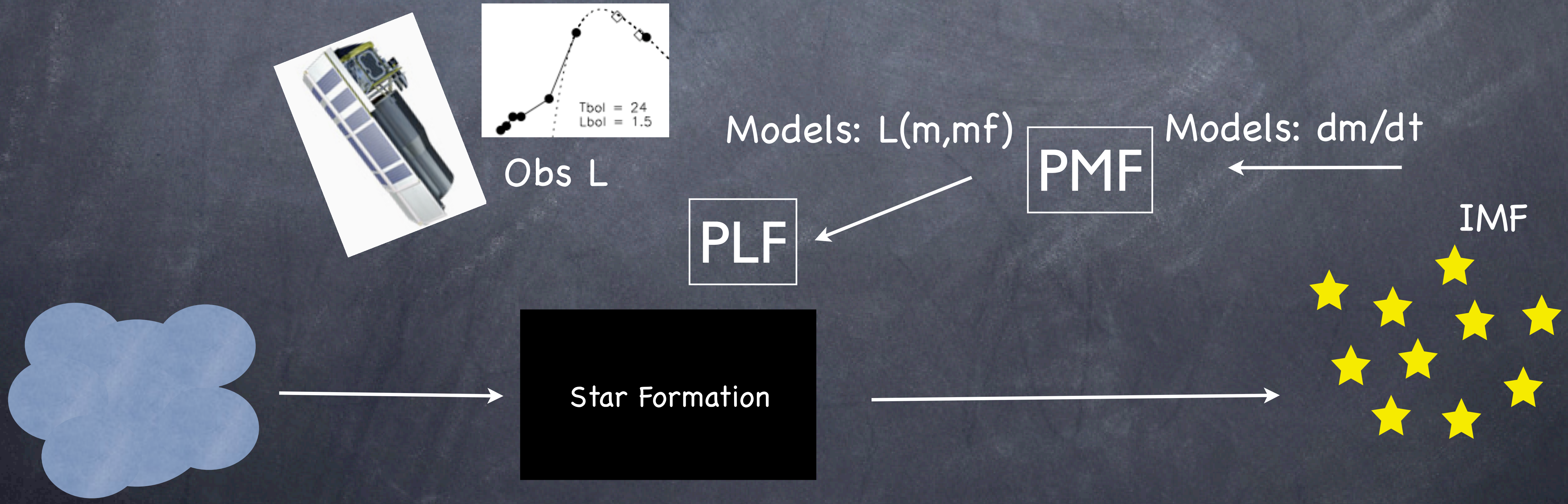

Obs L

Models: L(m,mf)

PMF

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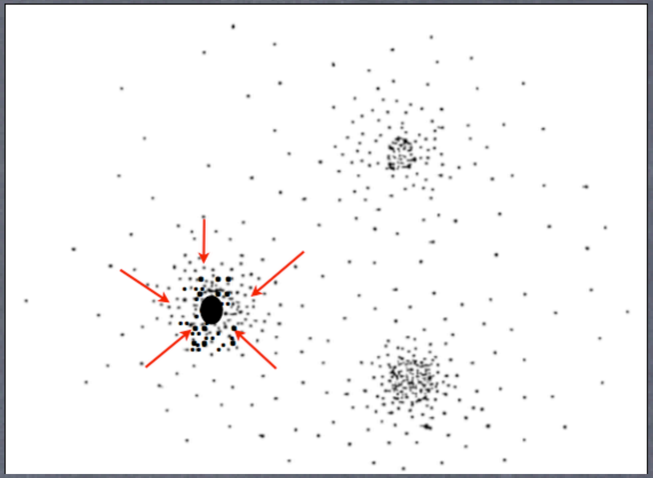
Star Formation

Ingredients

- IMF with upper mass cutoff, m_u: ψ_C (Chabrier 2005)
- Accretion rate as a function of the instantaneous mass, m, and final mass, m_f : $dm/dt\ (m, m_f)$
- Formation time as a function of stellar mass: $t_f\ (m_f)$
- Fraction of mass accreted in bursts, f_{epi}
- Fraction of accretion energy radiated away, f_{acc}

McKee & Offner (2010,2011)

Star Formation Models



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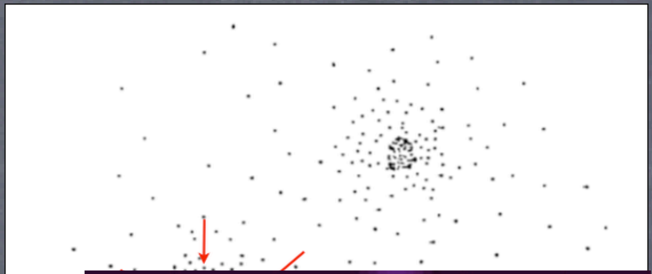
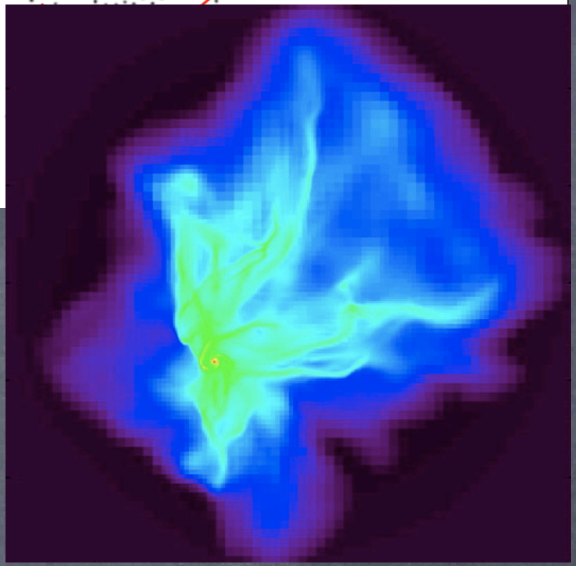
$\dot{m} = \dot{m}_{\rm S} \simeq c_s^3/G$

$t_f = m_f/\dot{m}_S$

Star Formation Models





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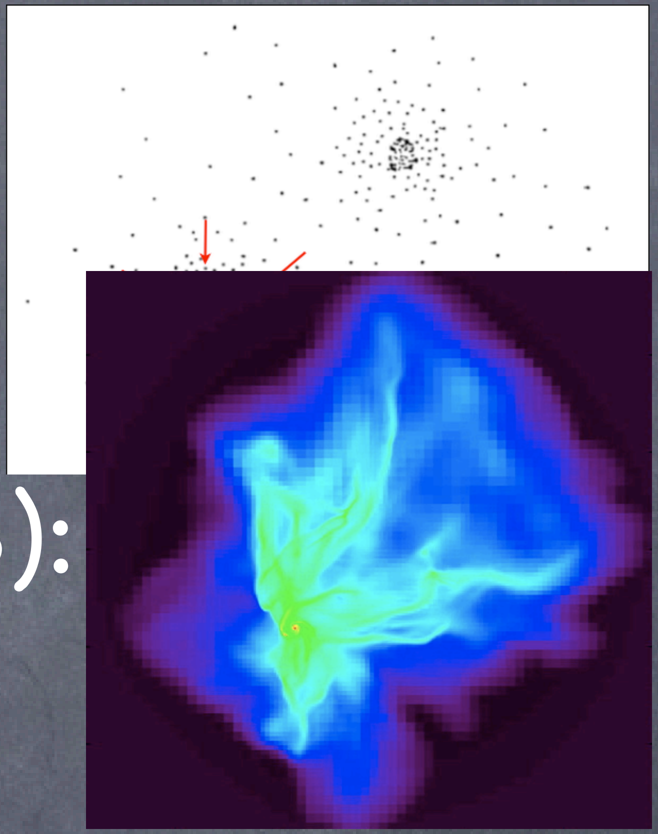
Star Formation Models



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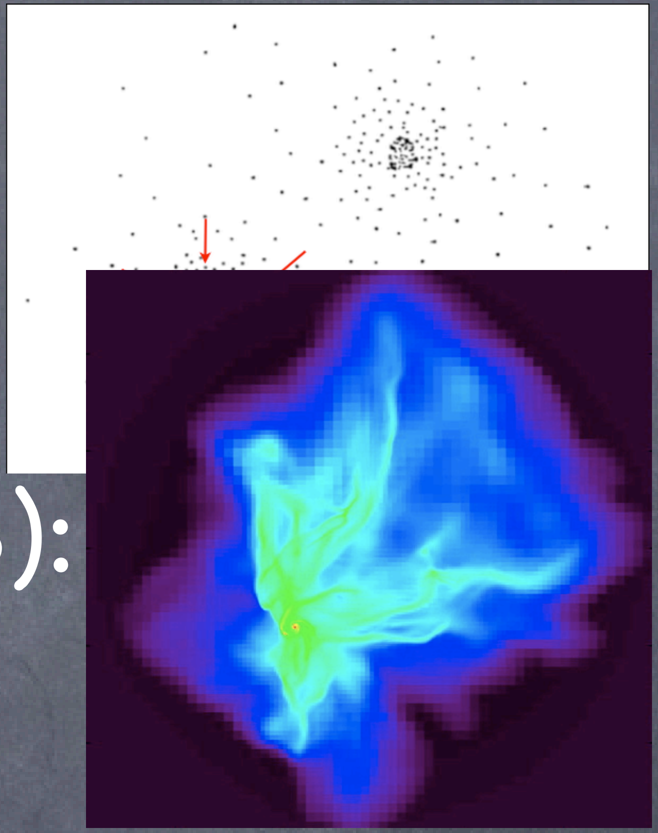
$$\dot{m} = \dot{m}_{\rm TC}(m/m_f)^{1/2} m_f^{3/2} \qquad t_f = t_f(1) m_f^{1/2}$$

Two-Component TC (2CTC, McKee & Tan 2003):

$$\dot{m} = (\dot{m}_{\rm S}^2 + \dot{m}_{\rm TC}^2 (m/m_f)^{1/2} m_f^{3/2})^{1/2} \quad t_f = \frac{2m_f}{\dot{m}_{\rm S}\left[1 + \sqrt{1 + (\dot{m}_{\rm TC}/\dot{m}_{\rm S})^2 m_f^{3/2}}\right]}$$

Star Formation Models



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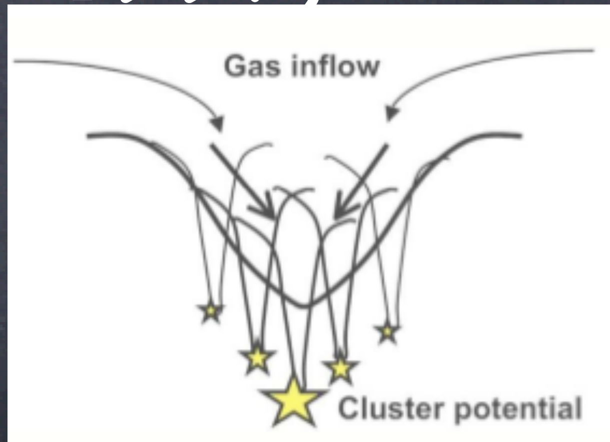
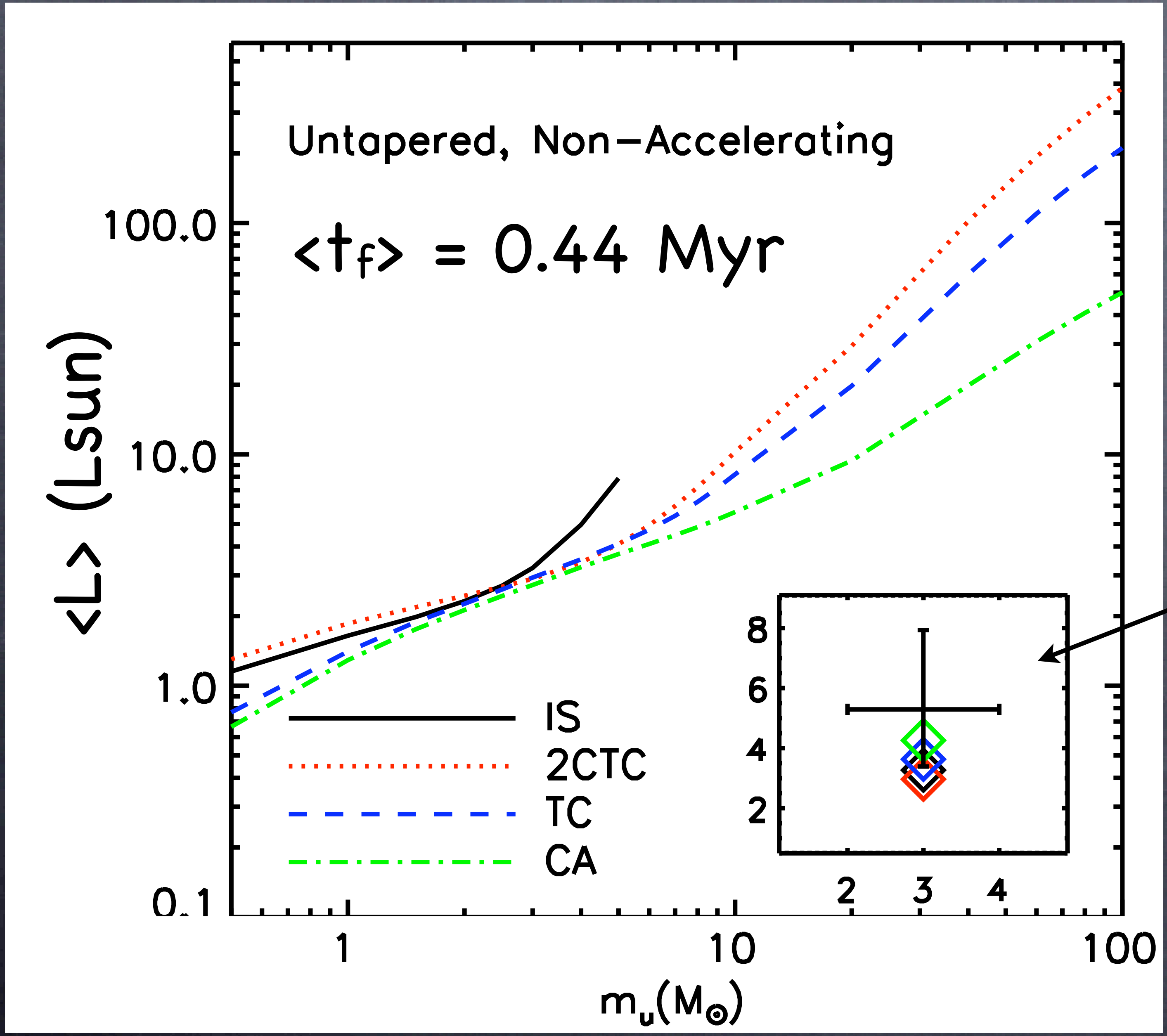
Competitive Accretion (CA, Bonnell et al. 1997):

$$\dot{m} = \dot{m}_{\mathrm{CA}}(m/m_f)^{2/3} m_f \qquad t_f = t_{ff} \propto \sqrt{\rho}$$



Mean Protostellar Luminosity

Mean Luminosity: $$< L >_p = \int_{m_l}^{m_u} d\ln m_f \int_0^{m_f} d\ln m \, L(m, m_f)\psi_{p2}$$



m_u = highest mass star forming in the cluster

Evans et al. 09

Offner & McKee 2011

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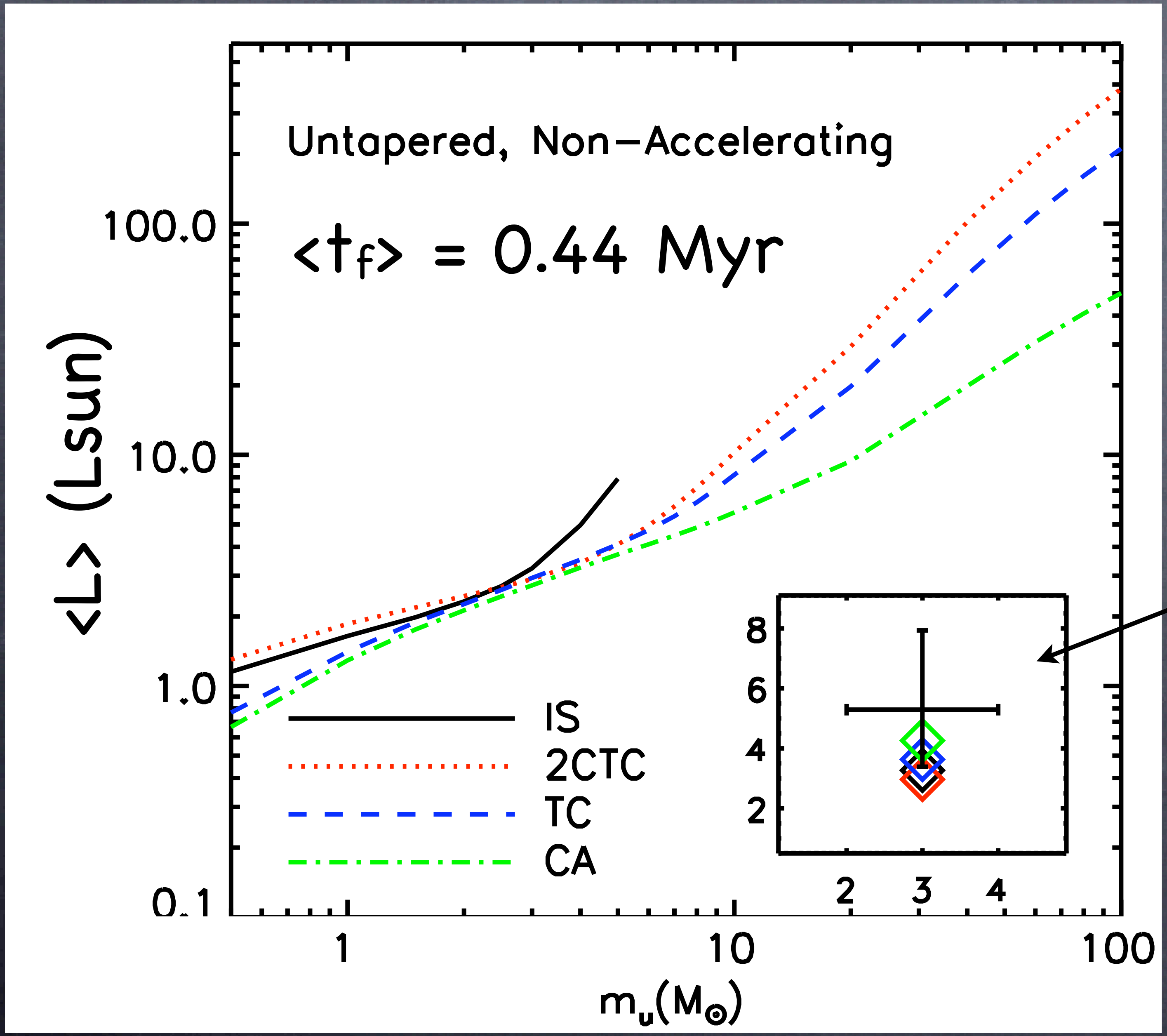


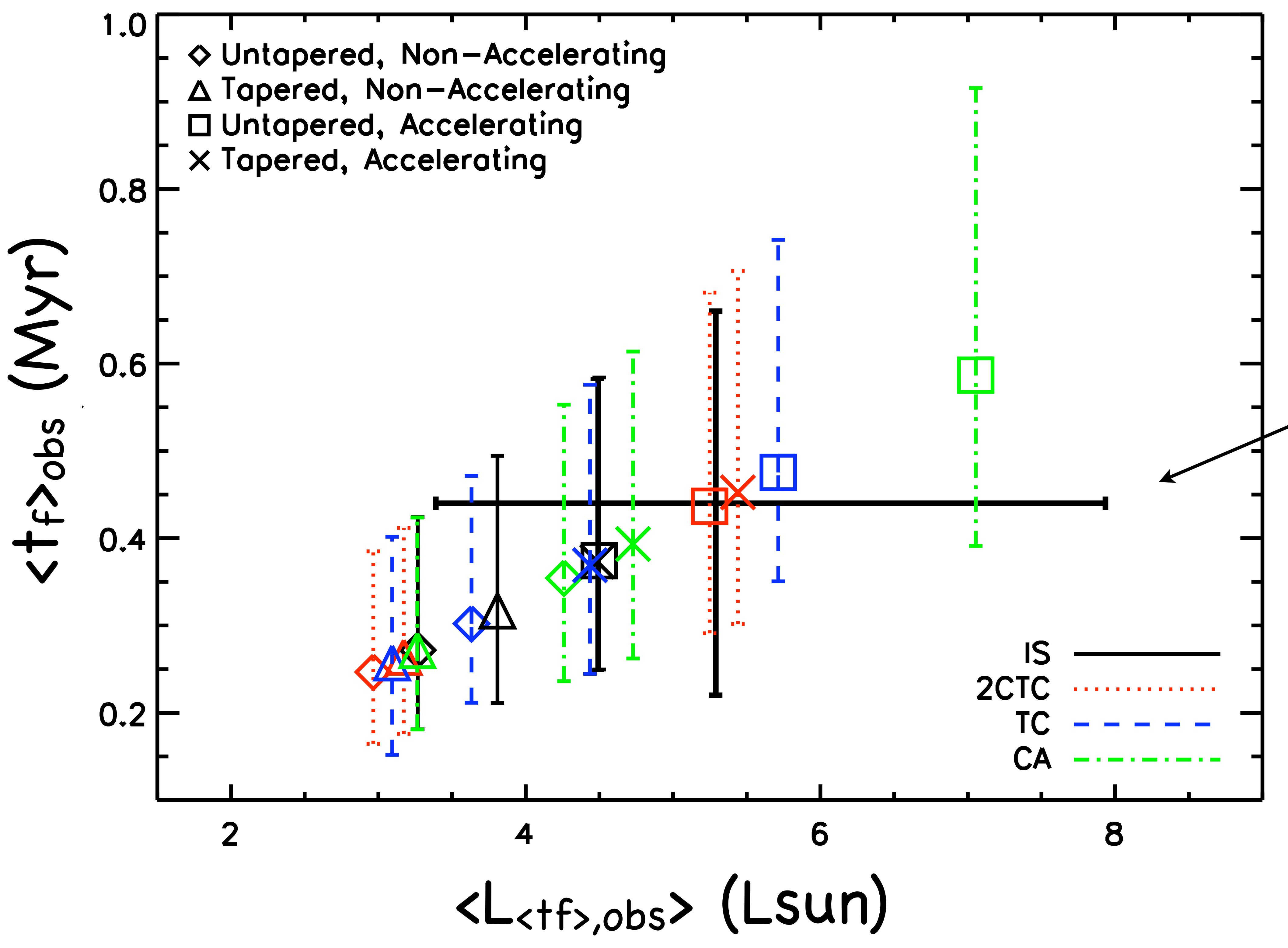
Evans et al. 09

m_u = highest mass star forming in the cluster

Models are too low!

Offner & McKee 2011

$\langle t_f \rangle$ vs $\langle L \rangle$



Disk lifetime = 2±1 Myr

Evans et al. 09

Offner & McKee 2011

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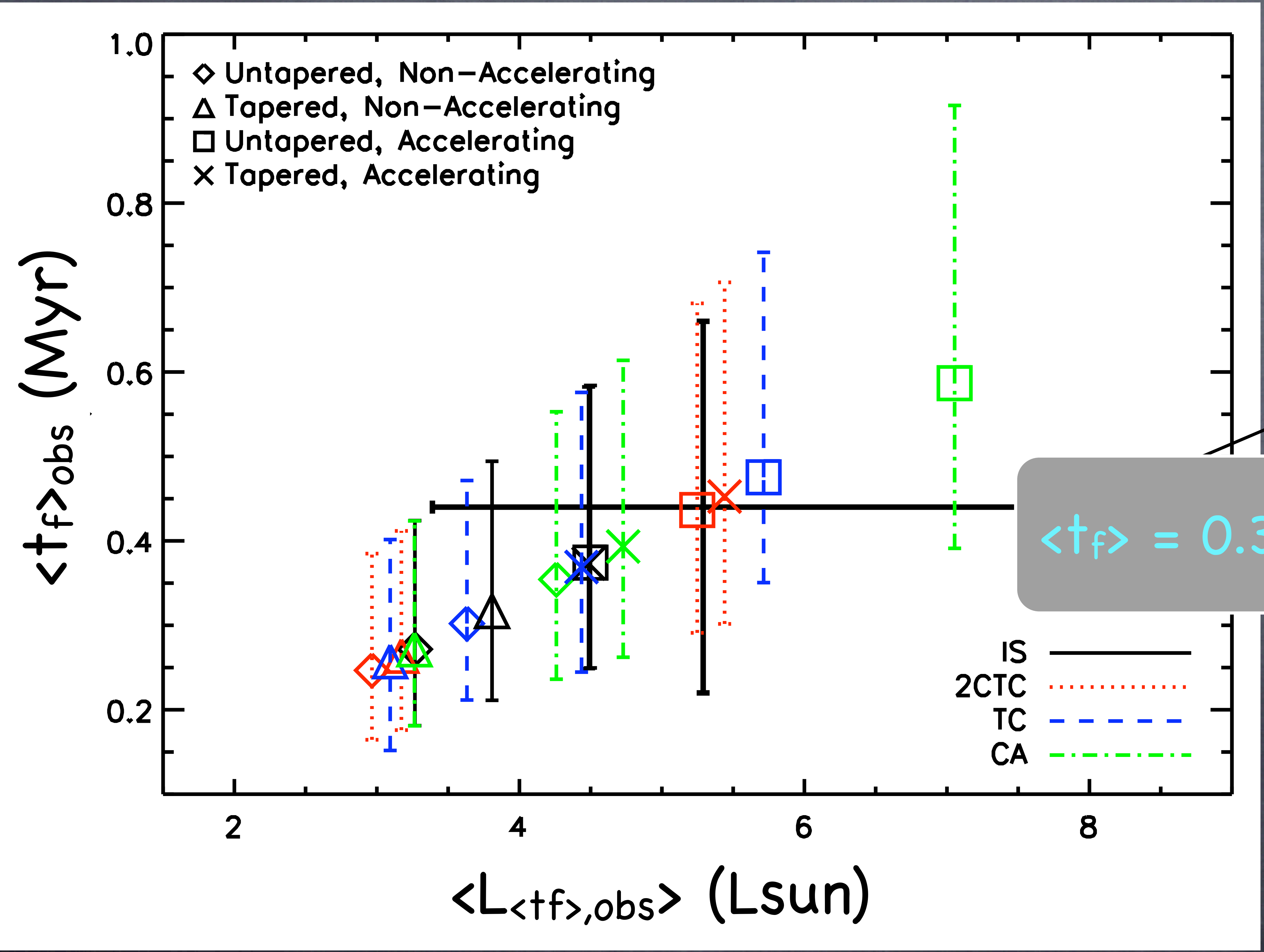

Disk lifetime
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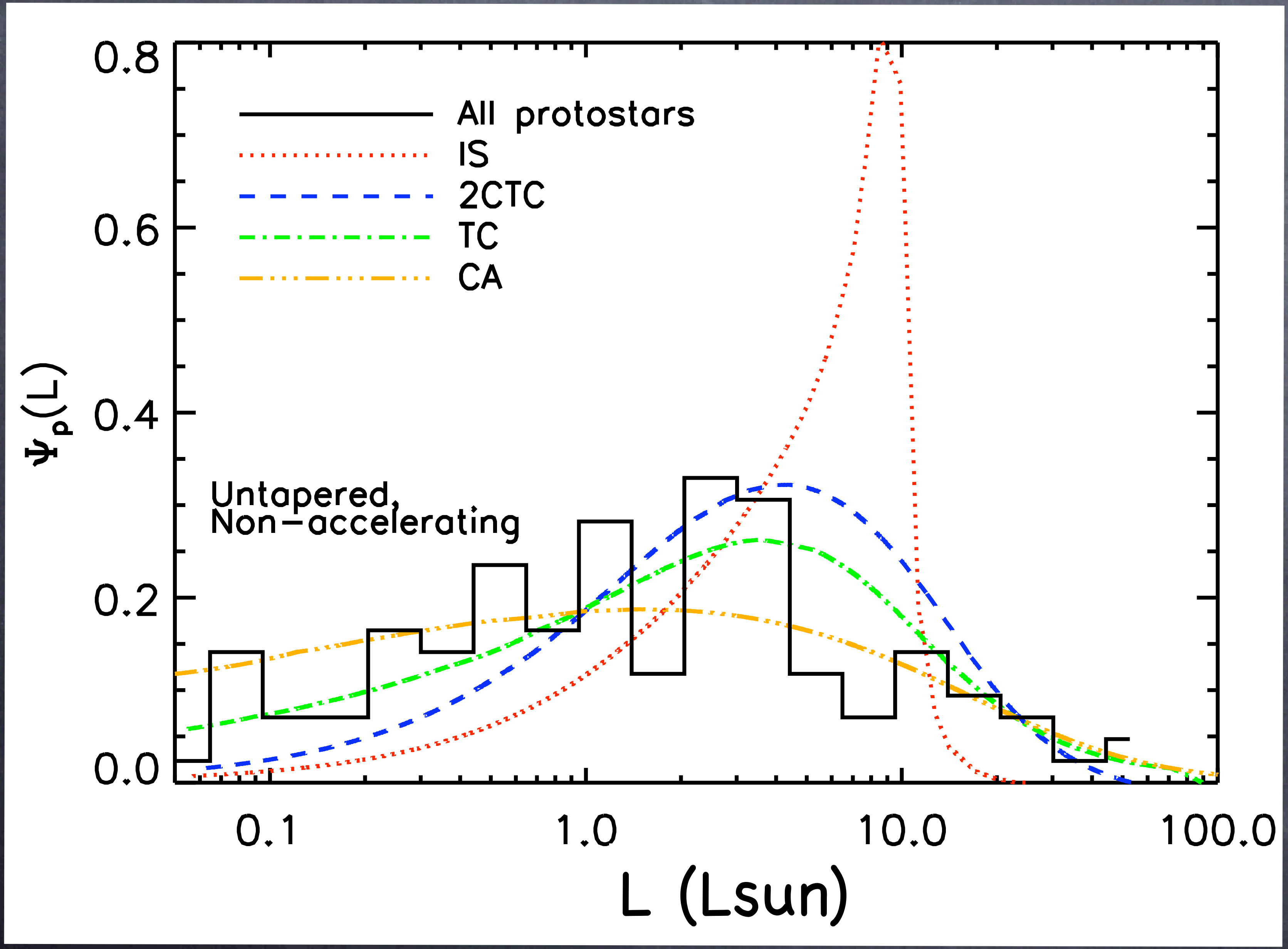
Evans et al. 09

$\langle t_f \rangle = 0.3 \pm 0.1$ Myr

Offner & McKee
2011

PLF Shapes

$$\Psi_p(L) = \int_{m_{f,l}}^{m_u} d\ln m_f \, \frac{\psi_{p2}[m(L,m_f),m_f]}{\left|\frac{\partial \ln L}{\partial \ln m}\right|}$$



- Models tend to peak towards higher luminosity with scaling using <L>
- Broad shapes of CA, TC show best agreement

Offner & McKee 2011

Verdict on Episodic Accretion

- Assuming some radiative inefficiency, f_{acc}=0.75, and some episodic accretion, f_{epi}=0.25, there is **no** luminosity problem (I)
- If f_{epi}=0.25, models suggest $\langle t_f \rangle$ = 0.3±0.1 Myr
- Episodic accretion is not needed to broaden the distribution -- if mdot depends on m, m_f there is **no** luminosity problem (II)
- Models with constant star formation time (CA, TC) agree better than models with constant accretion rates (IS)

Can Episodic Accretion Solve Open Problems in Star formation ??

Problem # 2:
Stellar Ages

How old are young stars?

For example:

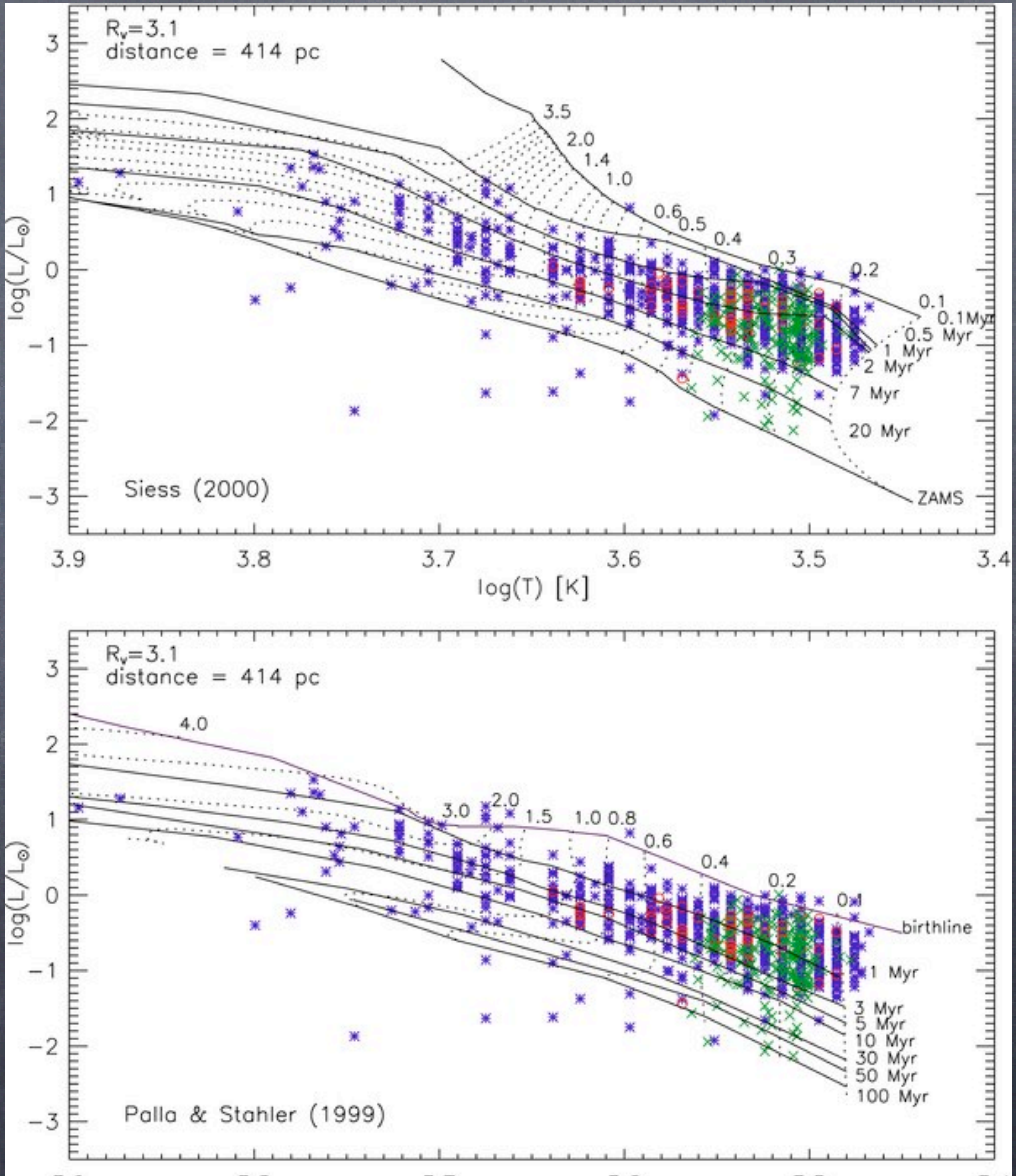
D’Antona & Mazzitelli (1994)

Baraffe et al. (1998)

Siess et al. (2000)

Palla & Stahler (1999, 2000)

Hartmann (2001, 2003)



ONC

(Da Rio et al. 2009)

Initial Models

Accretion Histories

Episodic

Constant

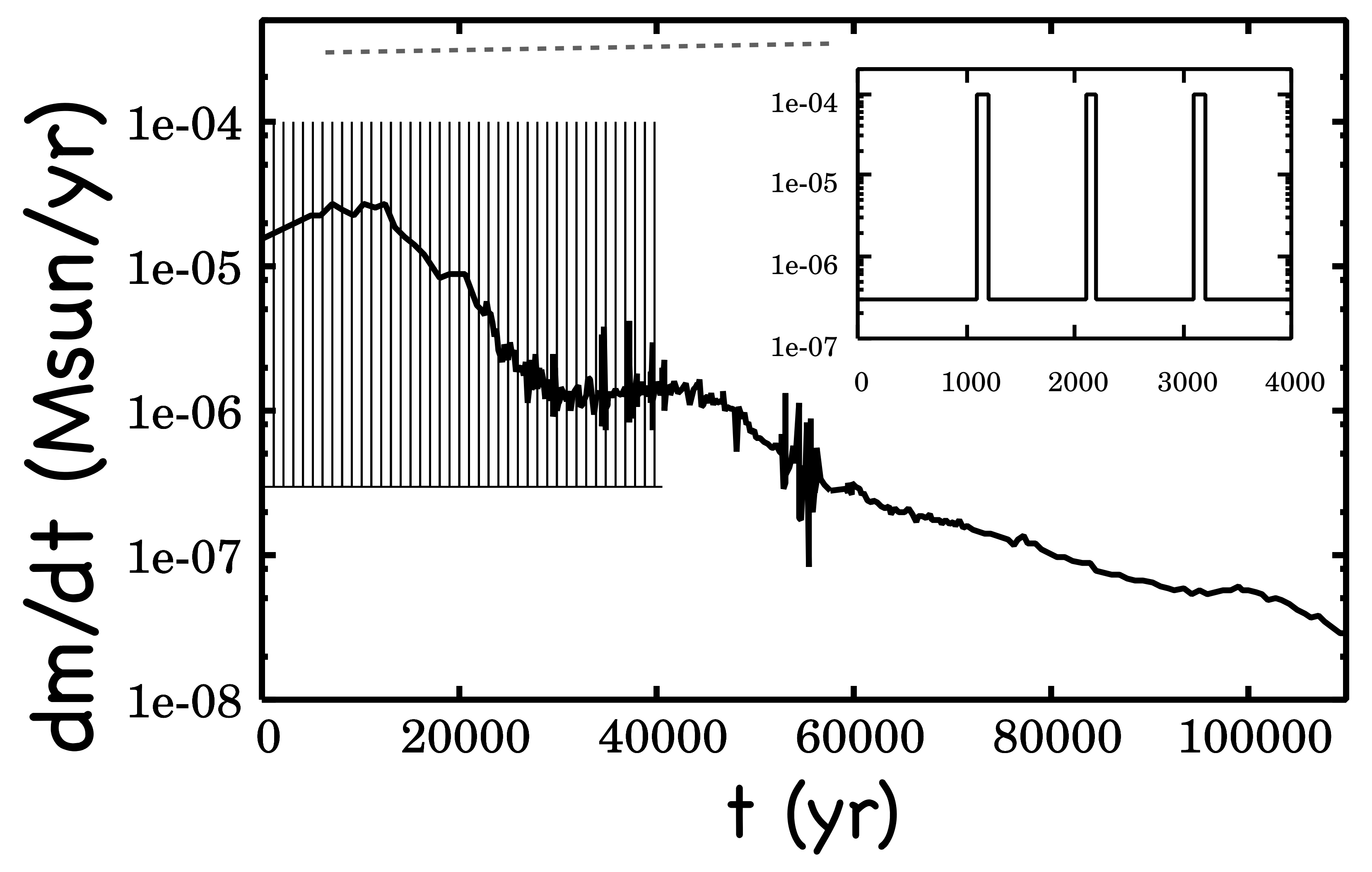
Declining (Offner 09)

Masses:

0.05-0.9 Msun

Boundary Condition

Hot or Cold



Hosokawa, Offner & Krumholz 2011

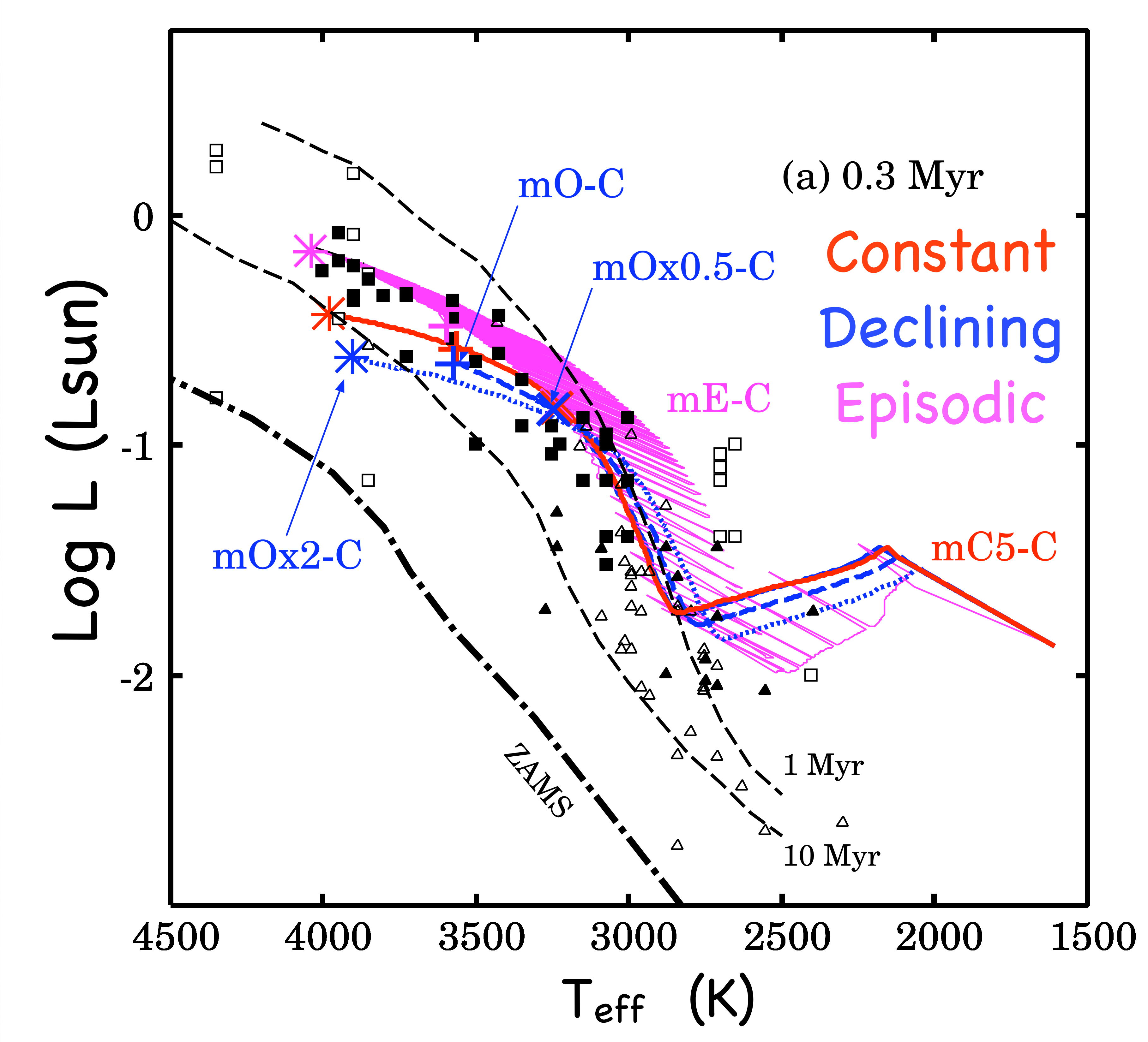
Model Definition

Hot ($\alpha>=0.2$)	vs.	Cold ($\alpha<0.2$)
"Spherical" Accretion directly hits and covers most of stellar surface (may arrive in a disk)		"Thin Disk" Accretion covers small fraction of the stellar surface
"Thermally Efficient" Some heat carried into stellar interior		"Thermally Inefficient" Material settles softly and stellar photosphere radiates freely (most energy lost)
Shock jump boundary conditions		Photospheric boundary conditions

Accretion History

HOK2011

Cold,
same initial
conditions,
different
accretion
histories



× 0.23 Msun
+ 0.45 Msun
✳ 0.90 Msun

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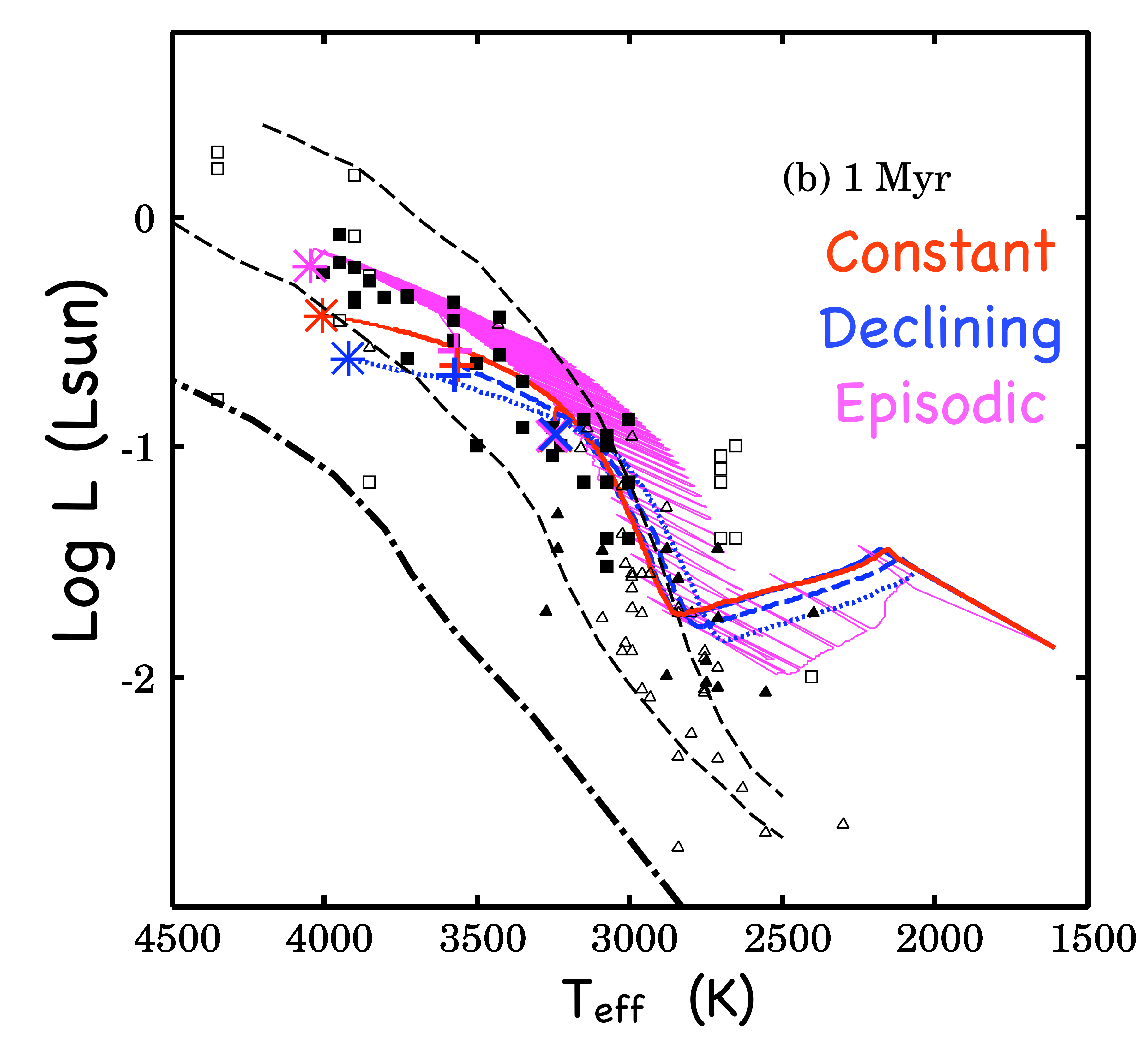

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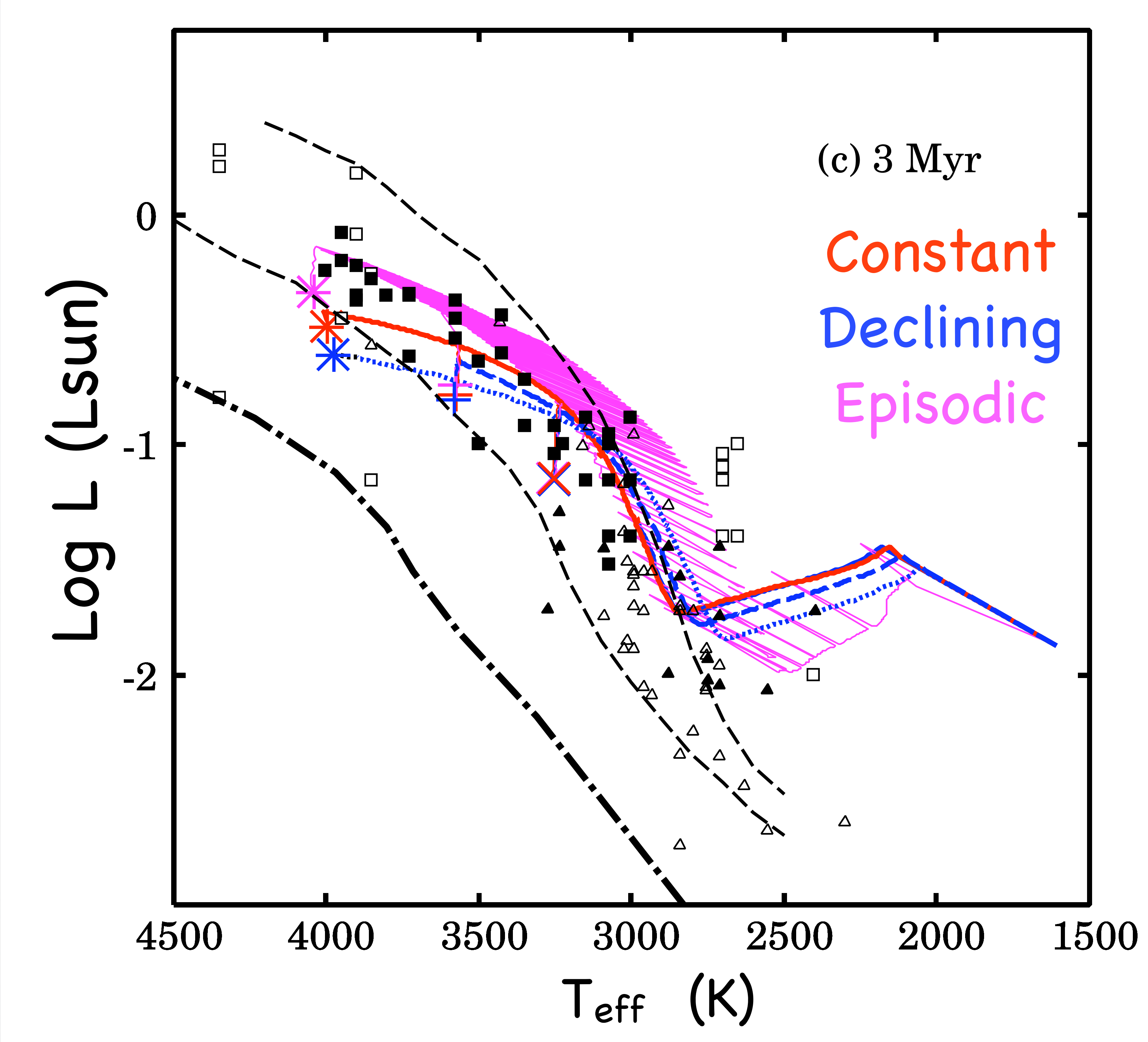

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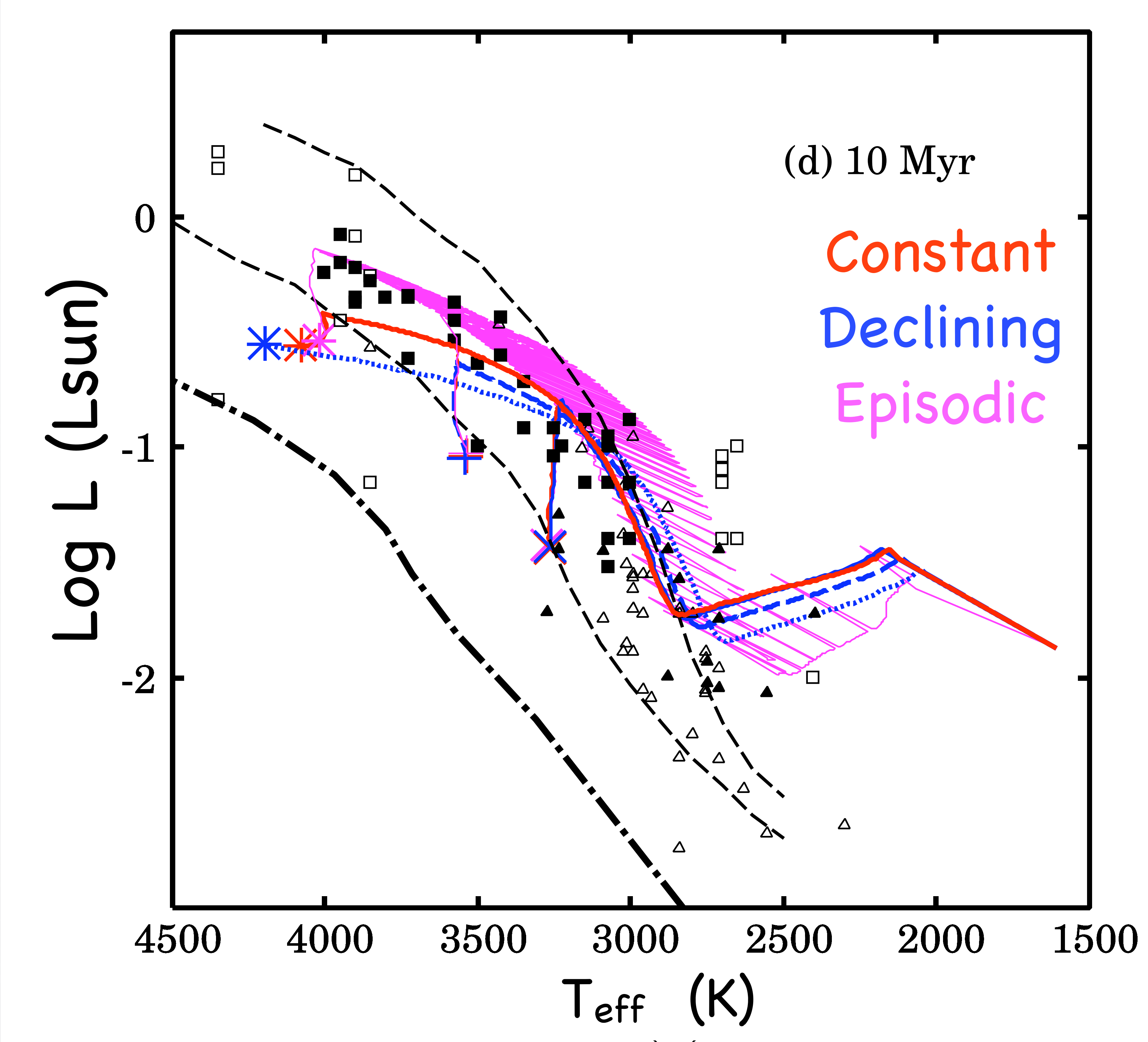
Accretion History

HOK2011

Cold, same initial conditions, different accretion histories

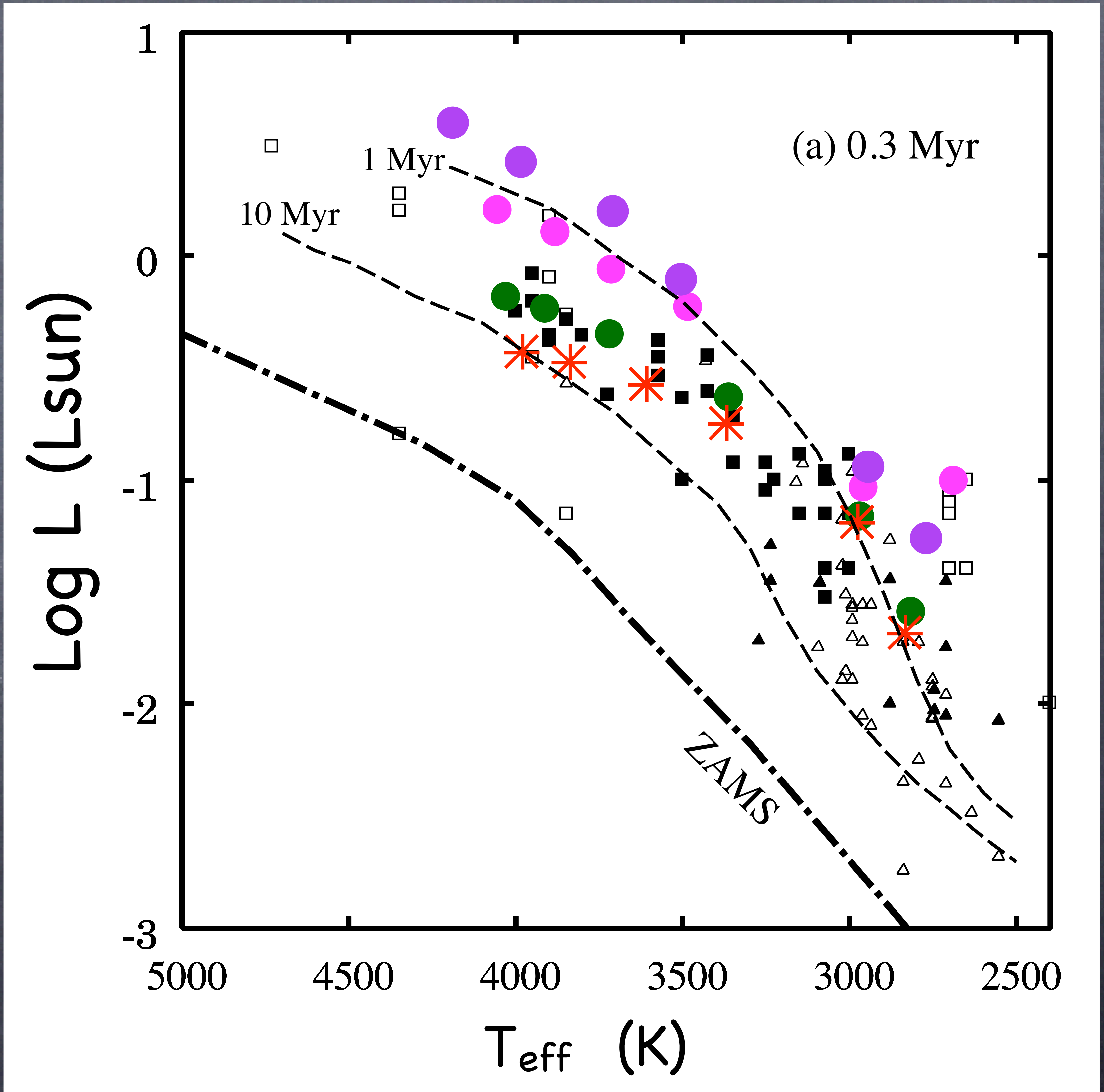
0.23 and 0.45 Msun show no / little dependence on accretion



Model Assumption

HOK2011

Same accretion history, different model



Hot (R=3.7)

Hot/Cold (M=0.03)

Cold (R=3.7)

Cold (R=1.5)

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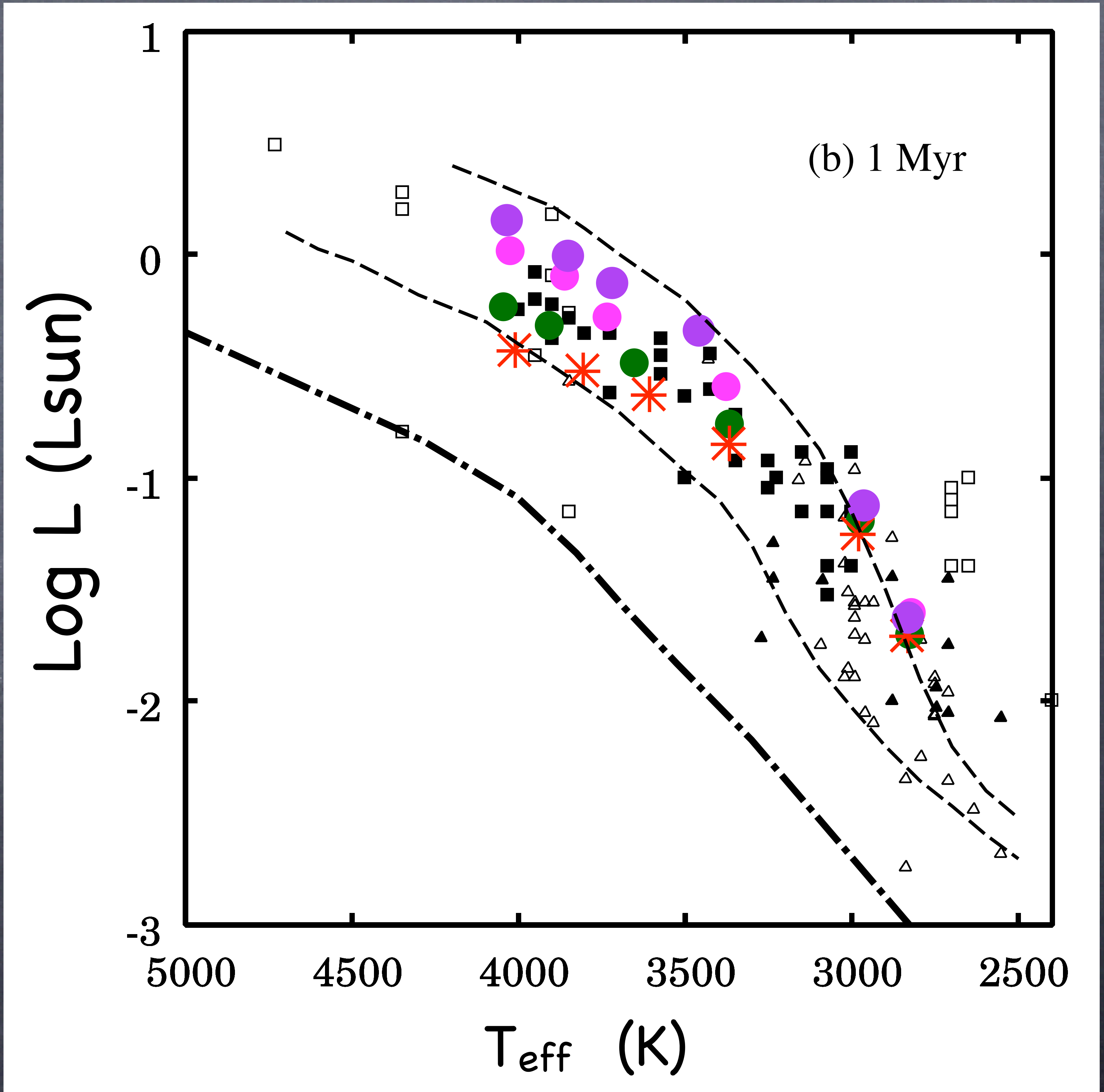

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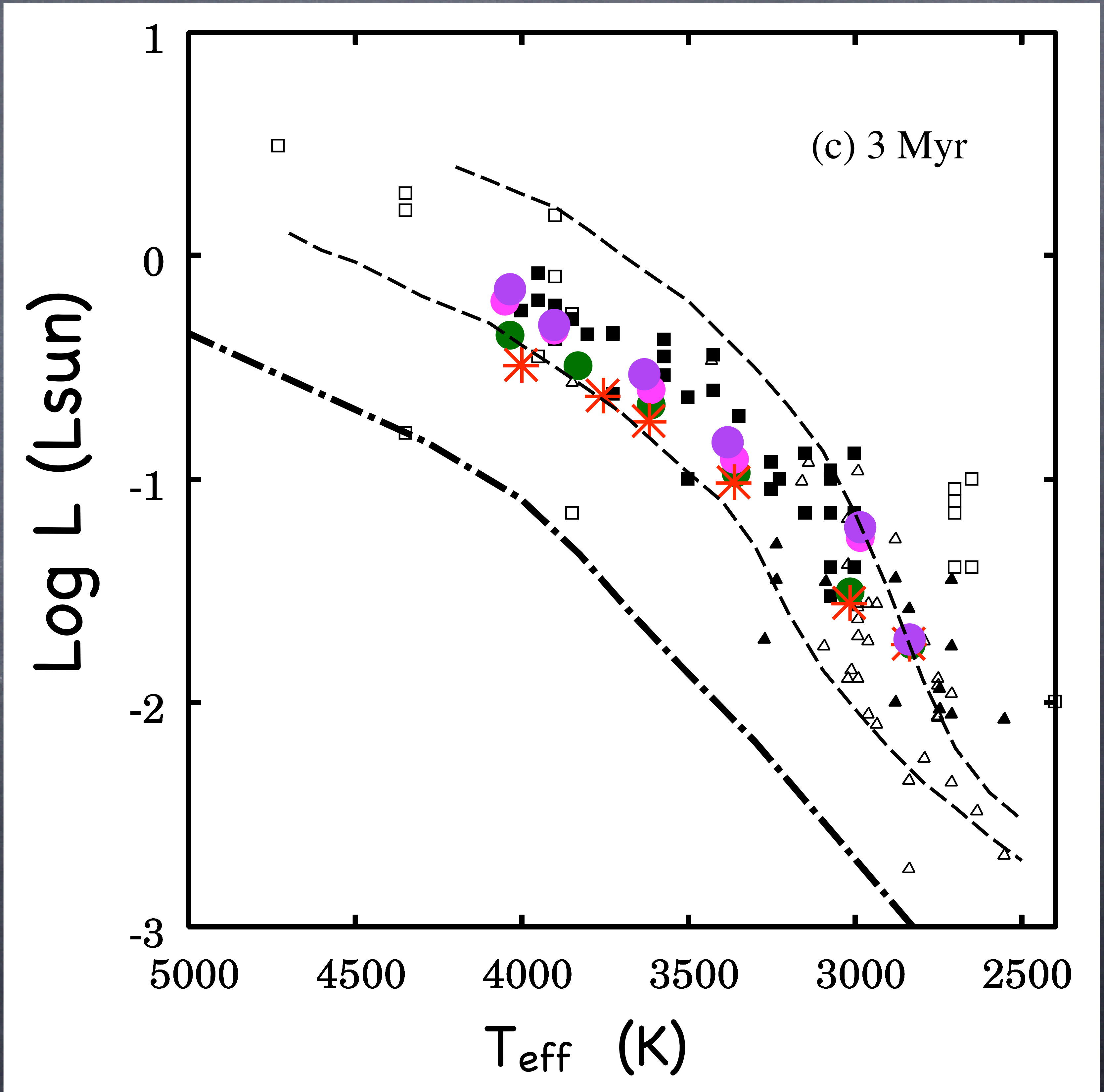

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Model Assumption

HOK2011

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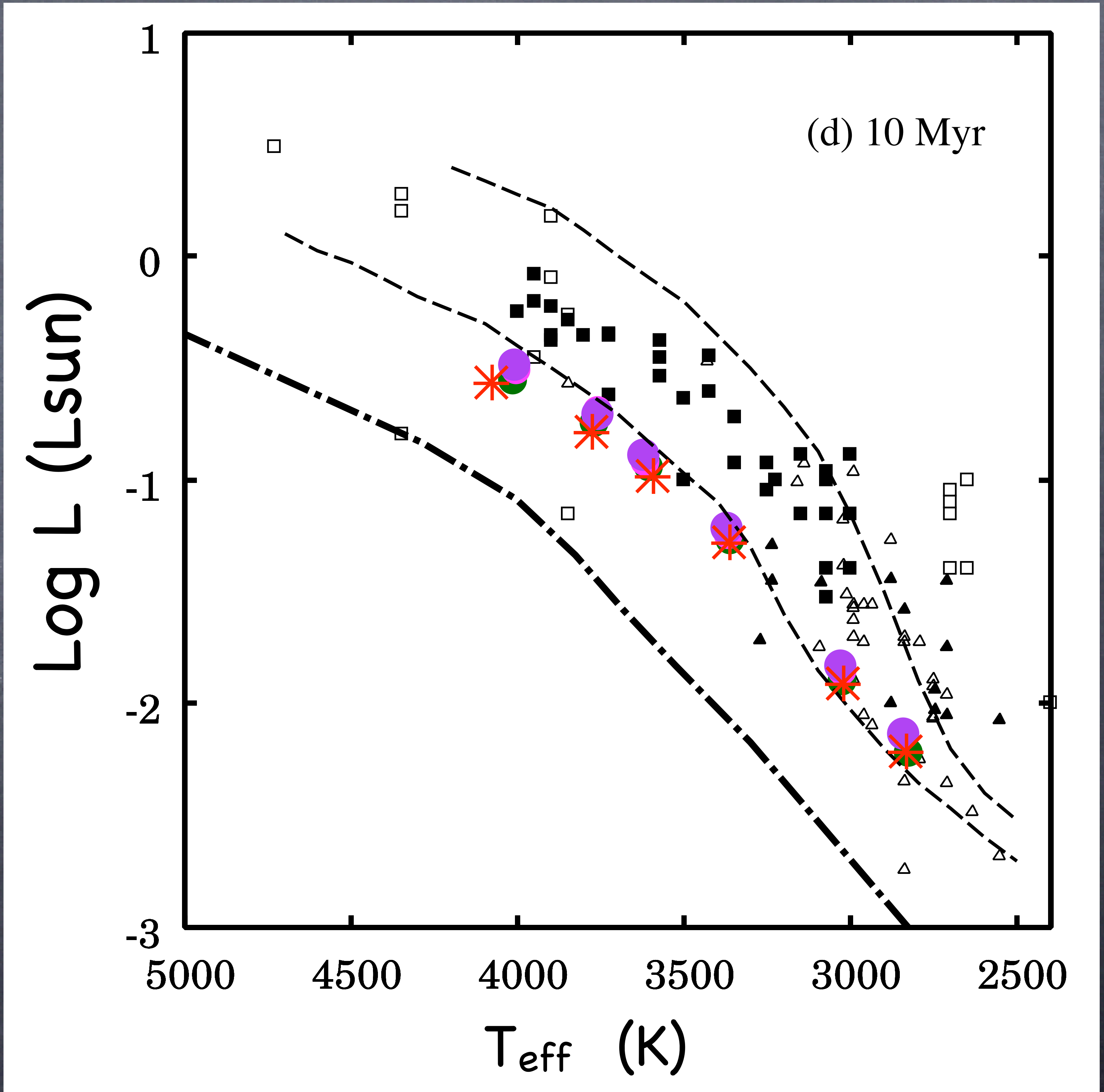
Need age spreads or hot and cold accretion with different initial conditions

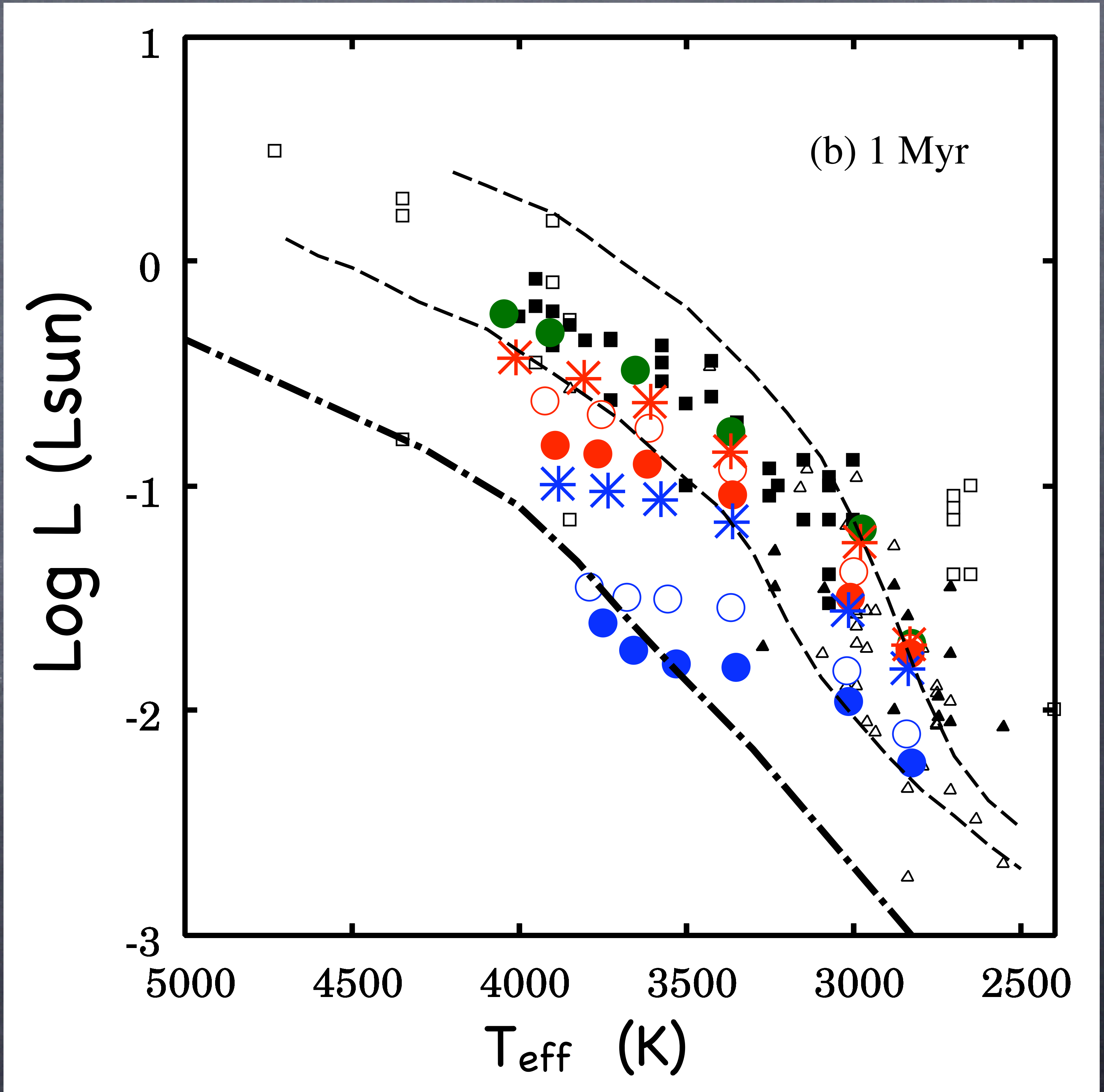


Initial Conditions

HOK2011

Same accretion history, Cold, different initial radii

- ● Cold (R=3.7)
- ✳ Cold (R=1.5)
- ○ Cold (R=1.0)
- ● Cold (R=0.65)
- ✳ Cold (R=0.3)
- ○ Cold (R=0.25)
- ● Cold (R=0.2)



Verdict on Episodic Accretion

- Initial conditions and model assumptions influence evolution more than accretion
- Accretion history mainly affects higher mass stars (>0.9 Msun) otherwise differences disappear in ~2 Myr
- Stellar age spreads are likely real (unless initial conditions know about final mass)

Conclusions

- Episodic accretion likely accounts for **25%** of the stellar mass, but ....
- **Not required** to explain distribution of protostellar luminosities
- It is **not useful** for explaining stellar age spreads