Measuring ages and accretion

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Do we need to invoke episodic accretion?

CTTS accretion rates and ages can entirely explain stellar masses if:

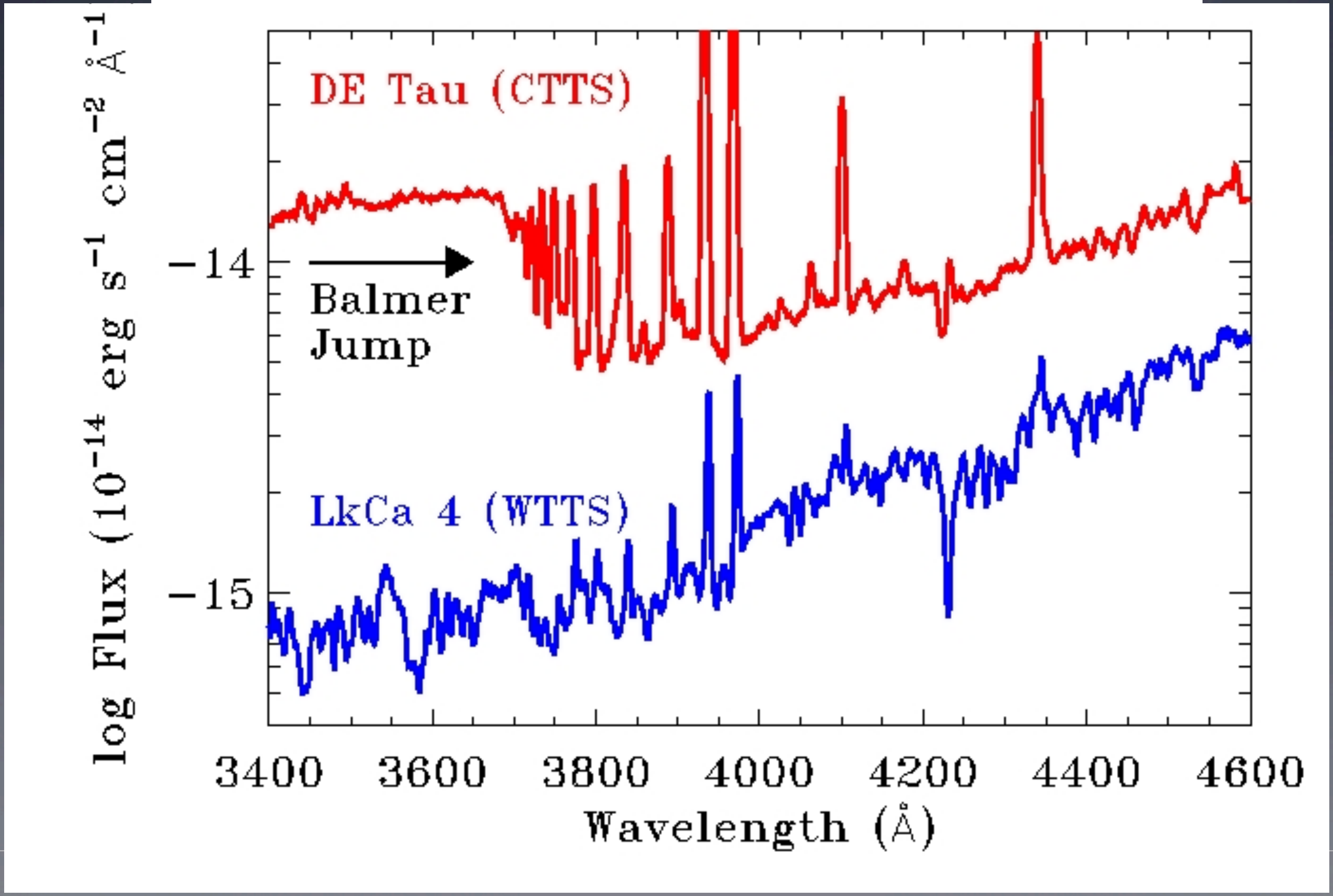
- accretion rates systemically low by a factor of 5
- ages are too young by a factor of 2
- we ignore that there's not enough mass left in disks

Accretion rate:	10^{-8} M_{sun}/yr	or	10^{-7} M_{sun}/yr
CTTS lifetime:	3 Myr	or	6 Myr
Total accretion:	0.03 M_{sun}	or	0.6 M_{sun}

does not consider an age-dependent accretion rate, ignore WTTs and BDs

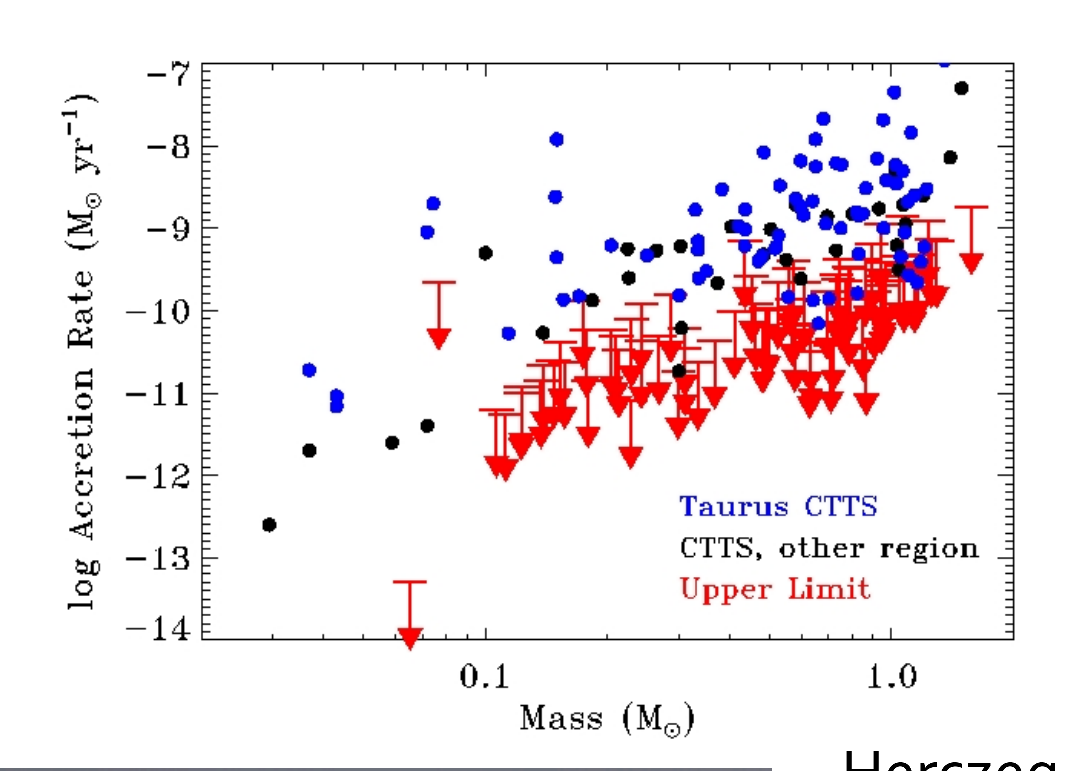
UV Excess Measures of Accretion

$$\dot{M} = (1 - \frac{R_*}{R_{in}})^{-1} \frac{L_{acc} R_*}{G M_*} \sim 1.25 \frac{L_{acc} R_*}{G M_*}$$



Accretion versus stellar mass

(e.g., Muzerolle et al. 2005; Mohanty et al. 2005; Natta et al. 2006; Fang et al. 2009; Sicilia-Aguilar et al. 2010, Manara et al. 2012; Alcala+2014)

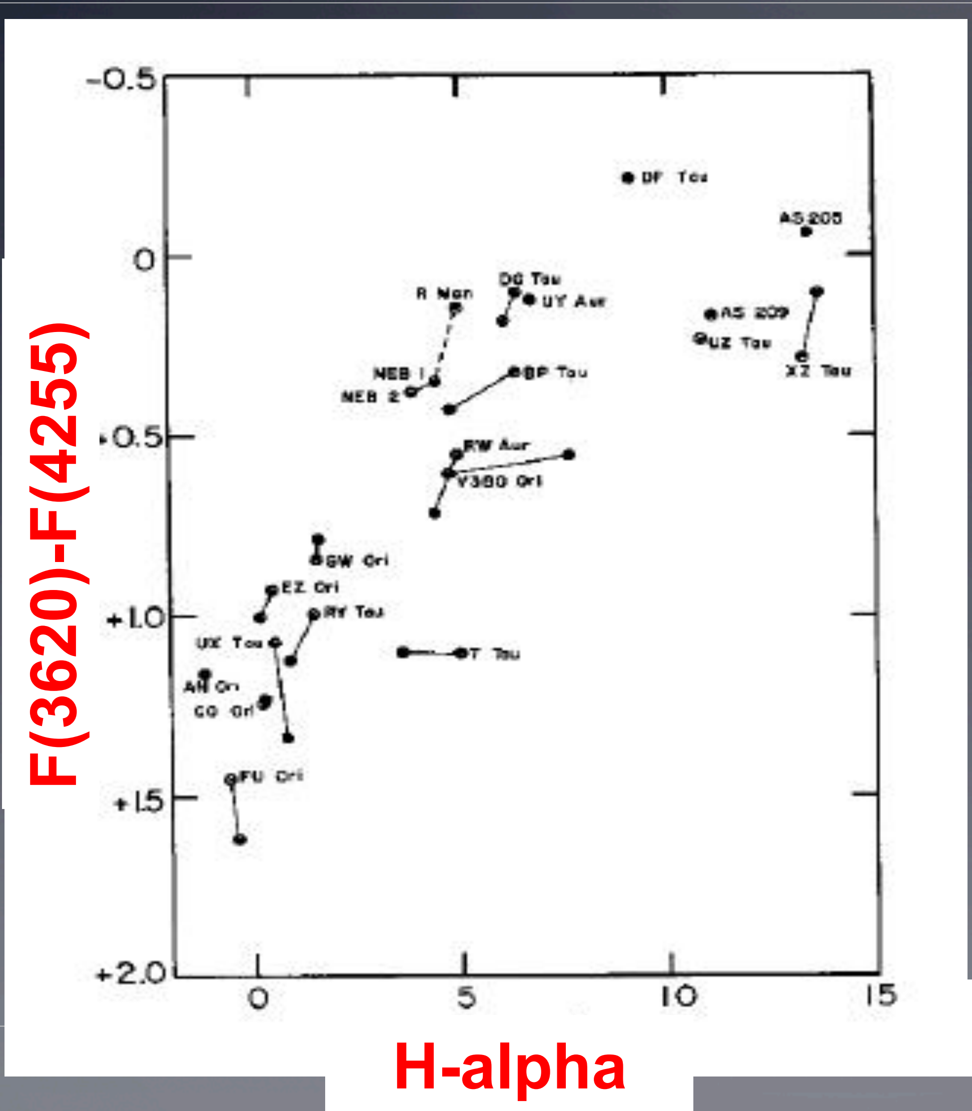


Herczeg in prep

$$\dot{M} \propto M^{\alpha}$$

- α = 1.5-3; depends on method, sample biases

Line luminosities as indirect accretion measurements



Kuhi (1966)

Line/continuum correlations (e.g. Kuhi 1966, Muzerolle +1998, Natta et al. 2000s, Fang et al. 2009, Alcala et al. 2014, etc.)

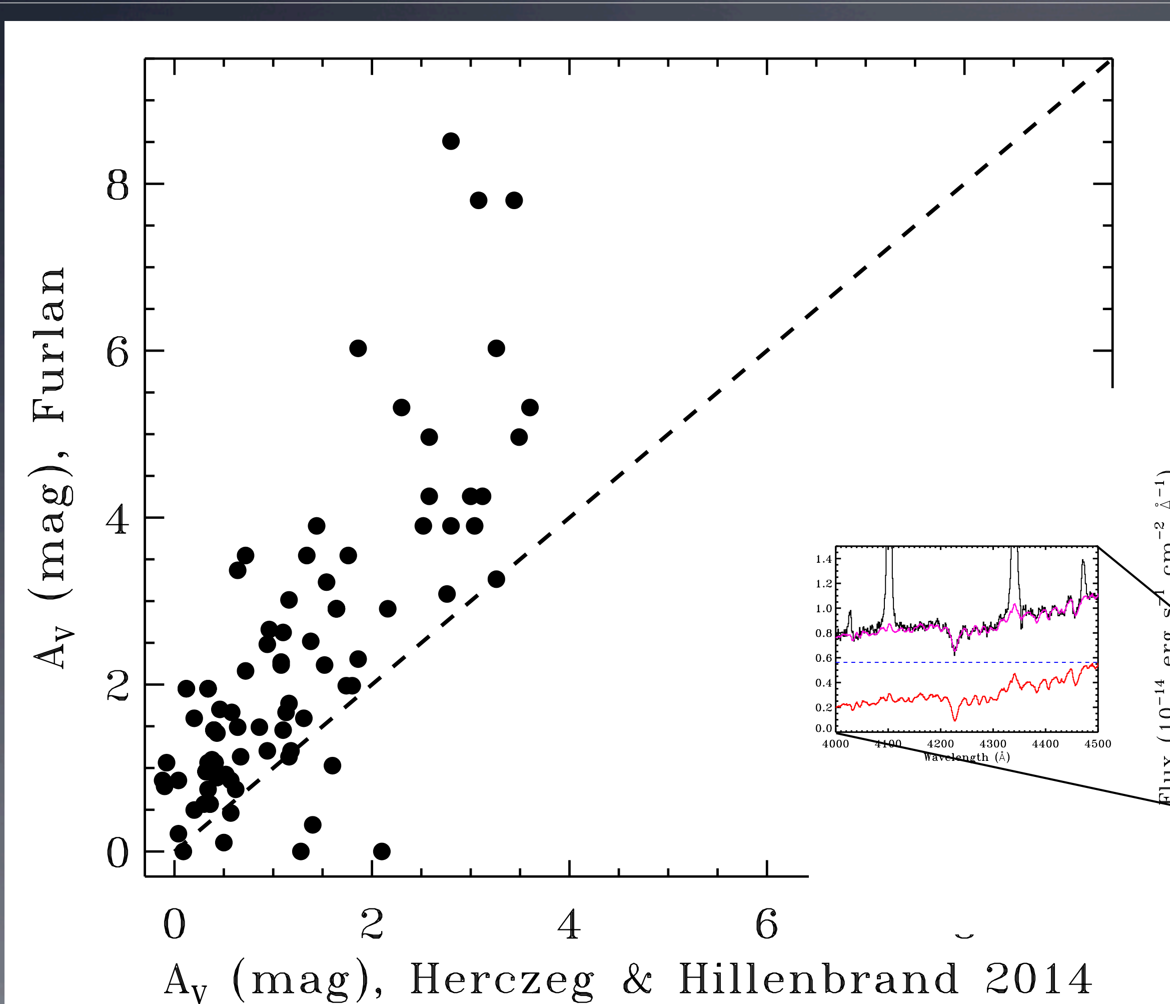
Correlations based on a small set of stars with U-band accretion rates

Uncertainties in accretion rates

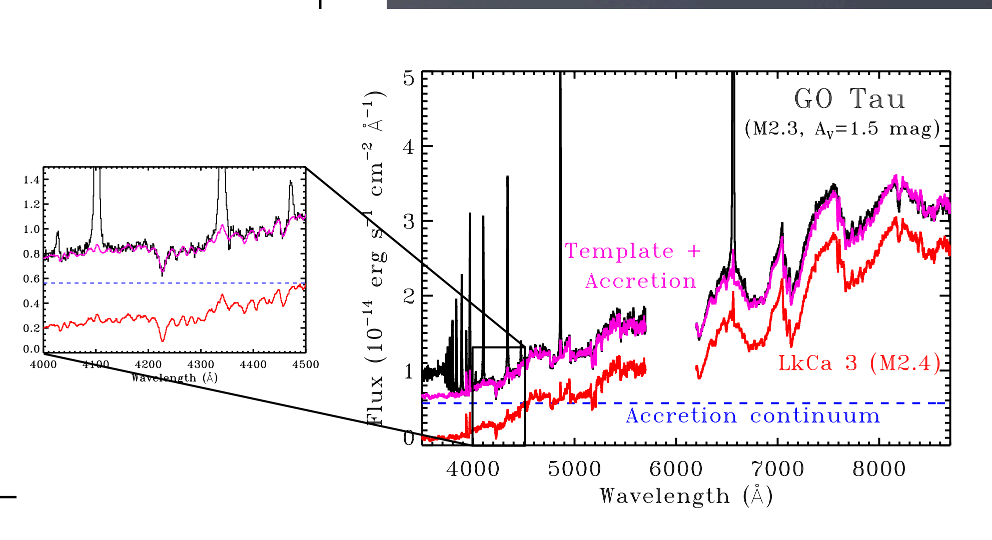
$$\dot{M} = (1 - \frac{R_*}{R_{in}})^{-1} \frac{L_{acc} R_*}{G M_*} \sim 1.25 \frac{L_{acc} R_*}{G M_*}$$

- Systematic uncertainties:
  - Bolometric correction in accretion luminosity
  - PMS tracks
  - Factor of 2 for radiative transfer (Hartigan et al. 1995)
  - Inner truncation radius (or random?)
  - Exclusion of emission lines (especially for BDs)
- Random uncertainties (but correlated with age!):
  - **Extinction, Distance (L_{acc}, R)**
- Methodological uncertainties
  - Scatter in emission line-accretion luminosity relationship (0.2-0.8 dex)
  - Uncertainties in origin of line emission

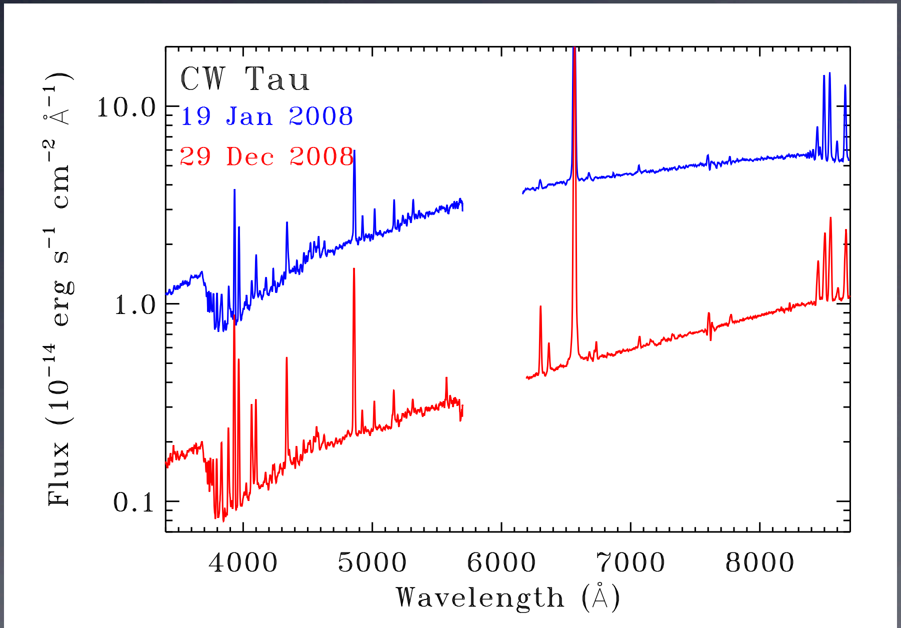
Problem: We don't know how to measure extinctions!

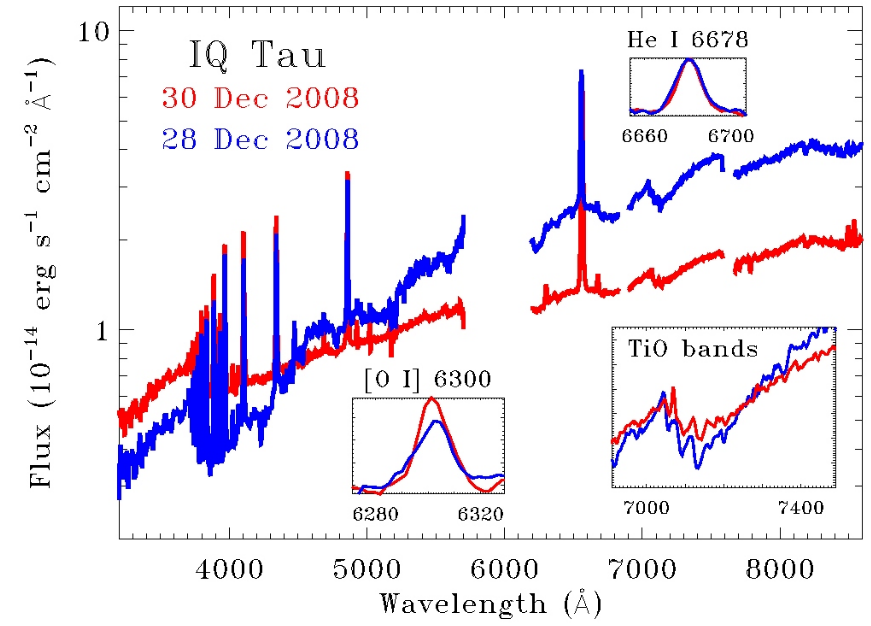


Near-IR extinctions would lead to 5x higher accretion rates



Variability in extinction
(Herczeg in prep; see also Luisa's talk)



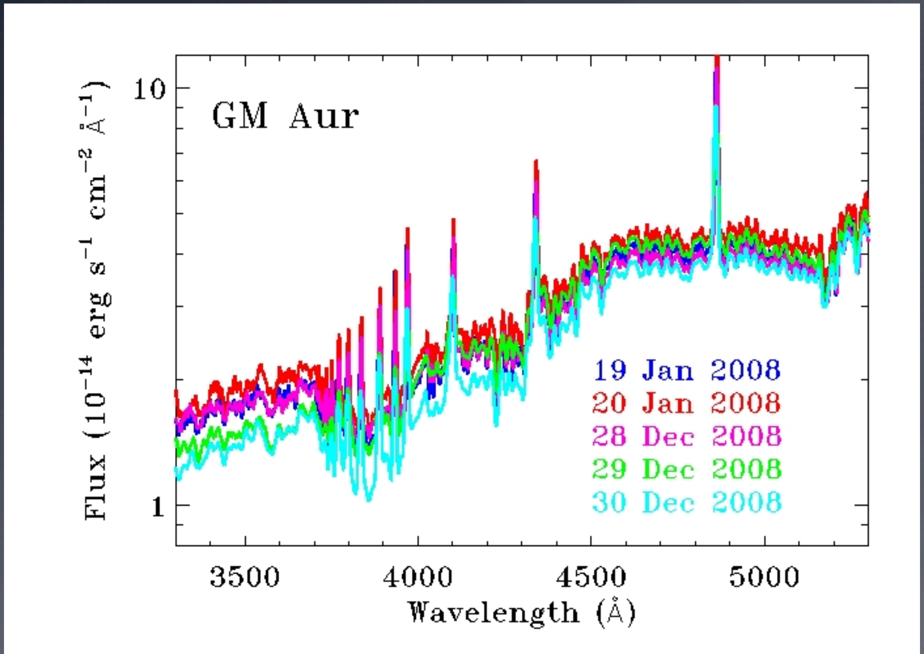


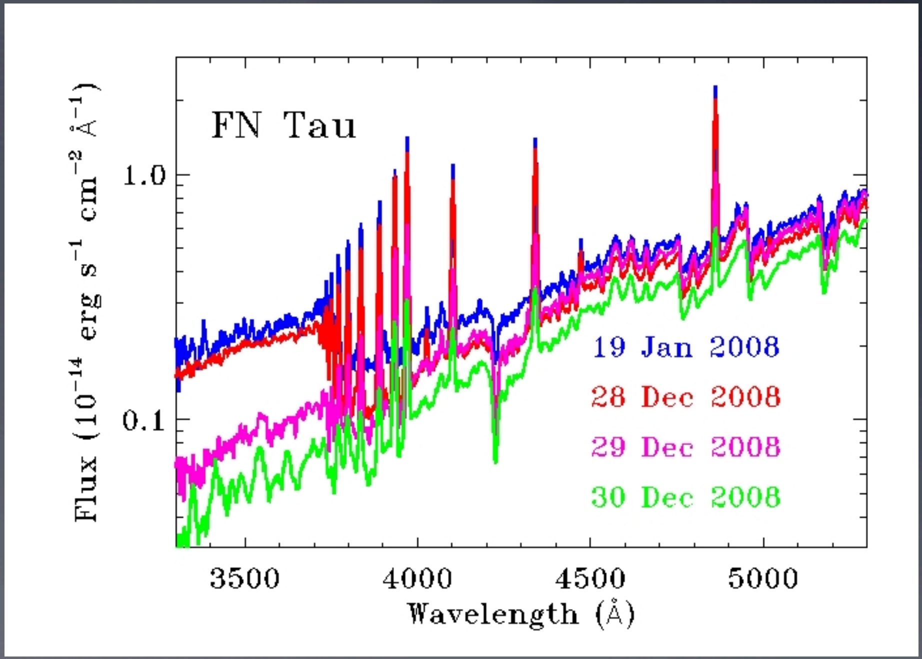
Gray extinction

Stellar luminosity change (not extinction)

Extinction, photosphere, and accretion variability in CTTSs, presumably also for younger objects

Variability in accretion
(Herczeg in prep, see also Luisa's talk)



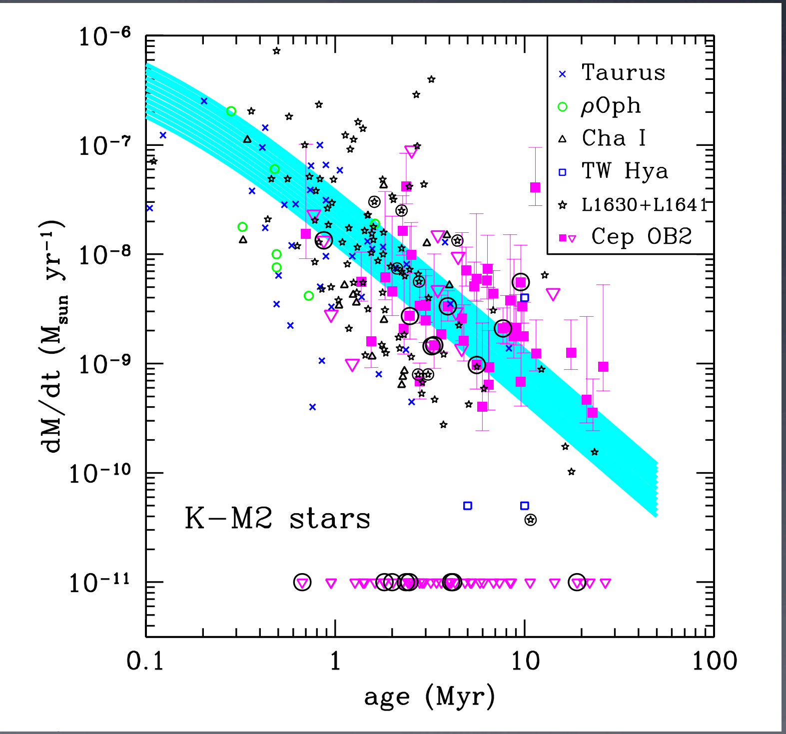


Costigan+2013: accretion rates vary by factor of 2,
Observed differences may be rotation and not real

Time evolution of accretion:

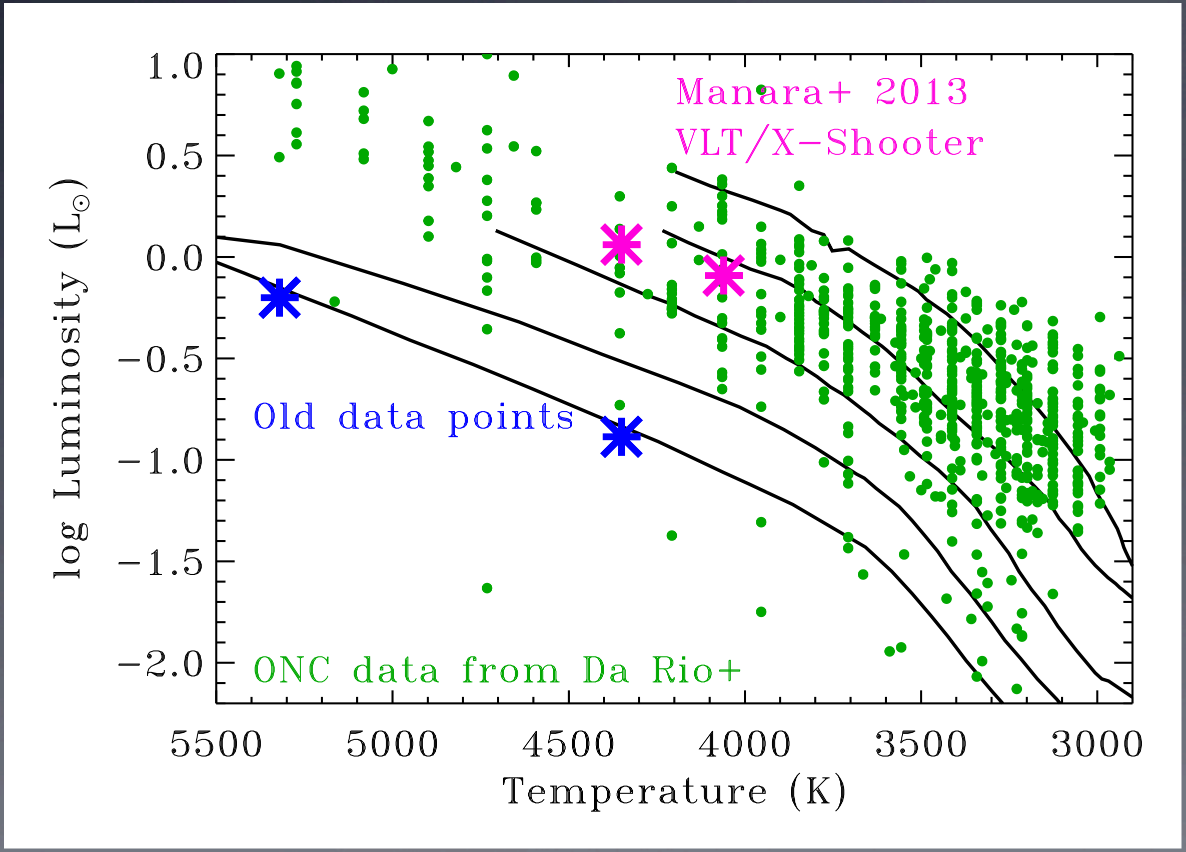
- Salyk et al. 2013: Pfund beta, reduces extinction problems for embedded objects
- Class I ccretion rates of 10^{-7}-10^{-8} M_{sun}/yr
- No clear differences between Class I and Class II accretion rates

Likely missing the high accretion rates during episodic outbursts



Sicilia Aguilar+2010, but possible mass dependence and correlated errors

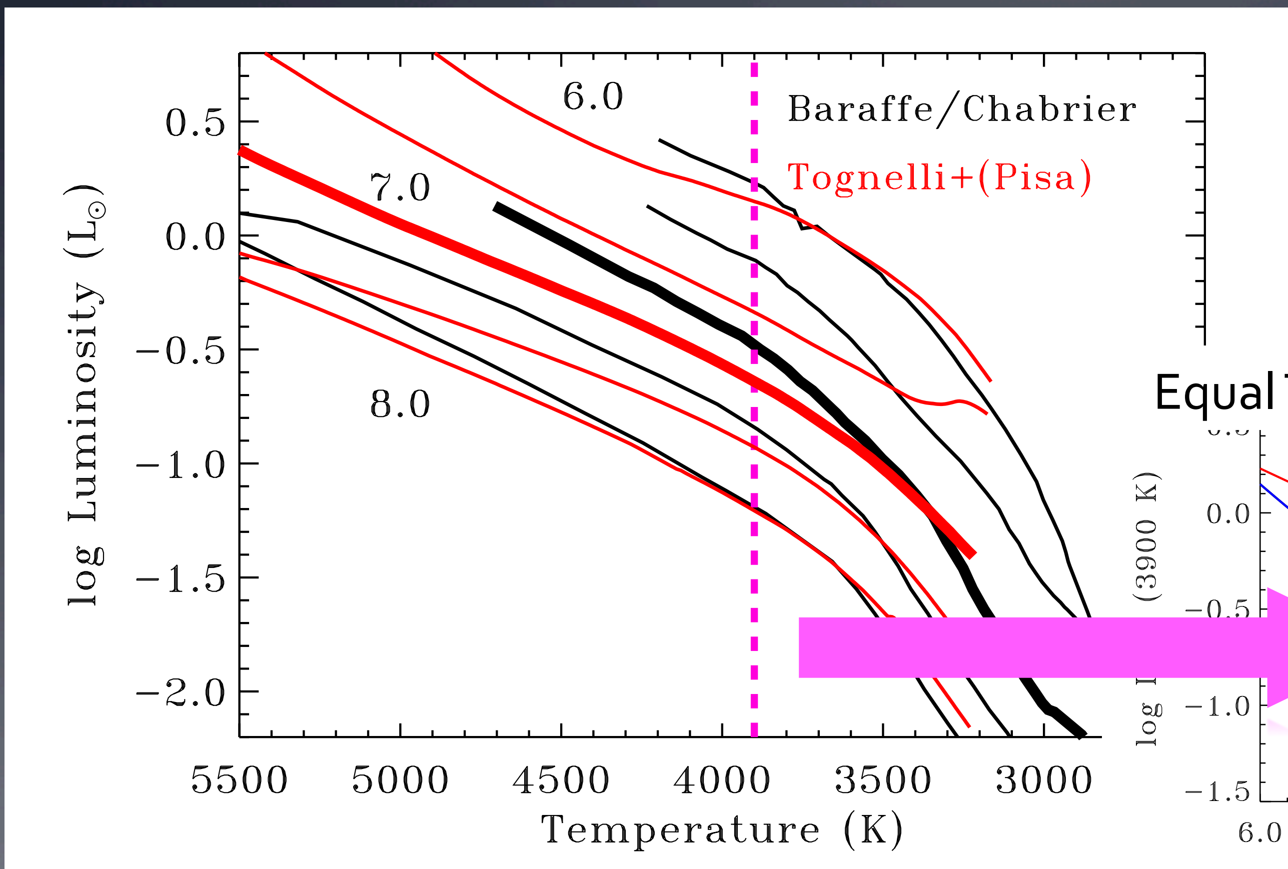
Age Measurements: HR diagram



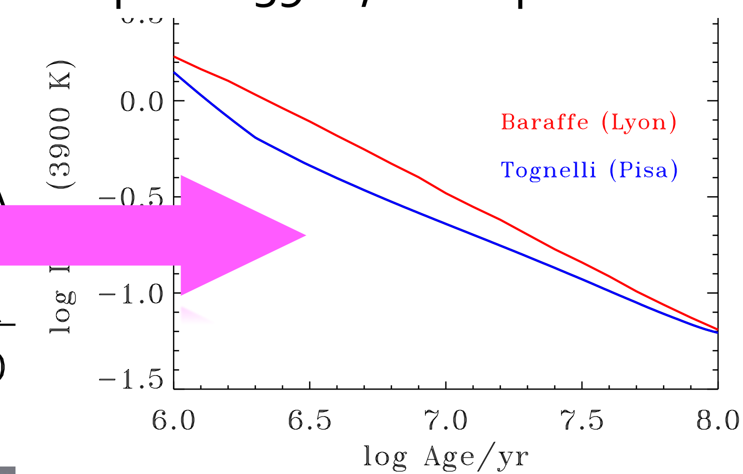
Every cluster has a lot of scatter: ages of individual stars are unreliable

Relative cluster ages reliable

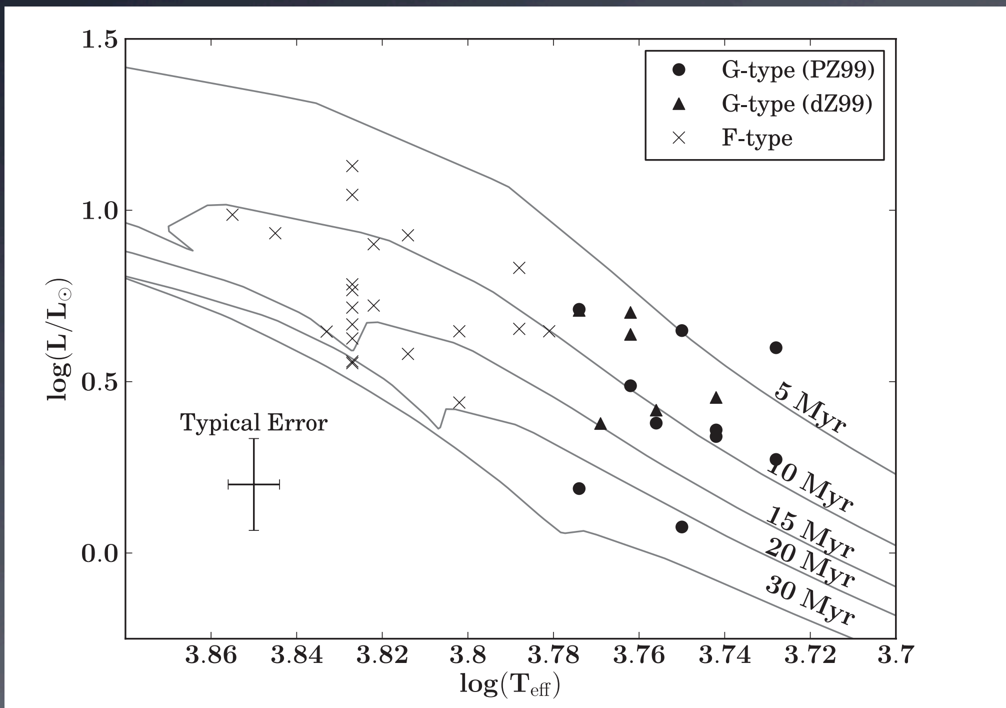
Age Measurements: HR diagram



Equal T=3900, not equal mass



Ages of intermediate mass stars
(Naylor 2009, Bell+2013; Pecaut & Mamajek 2012)



Upper Sco Age Estimates

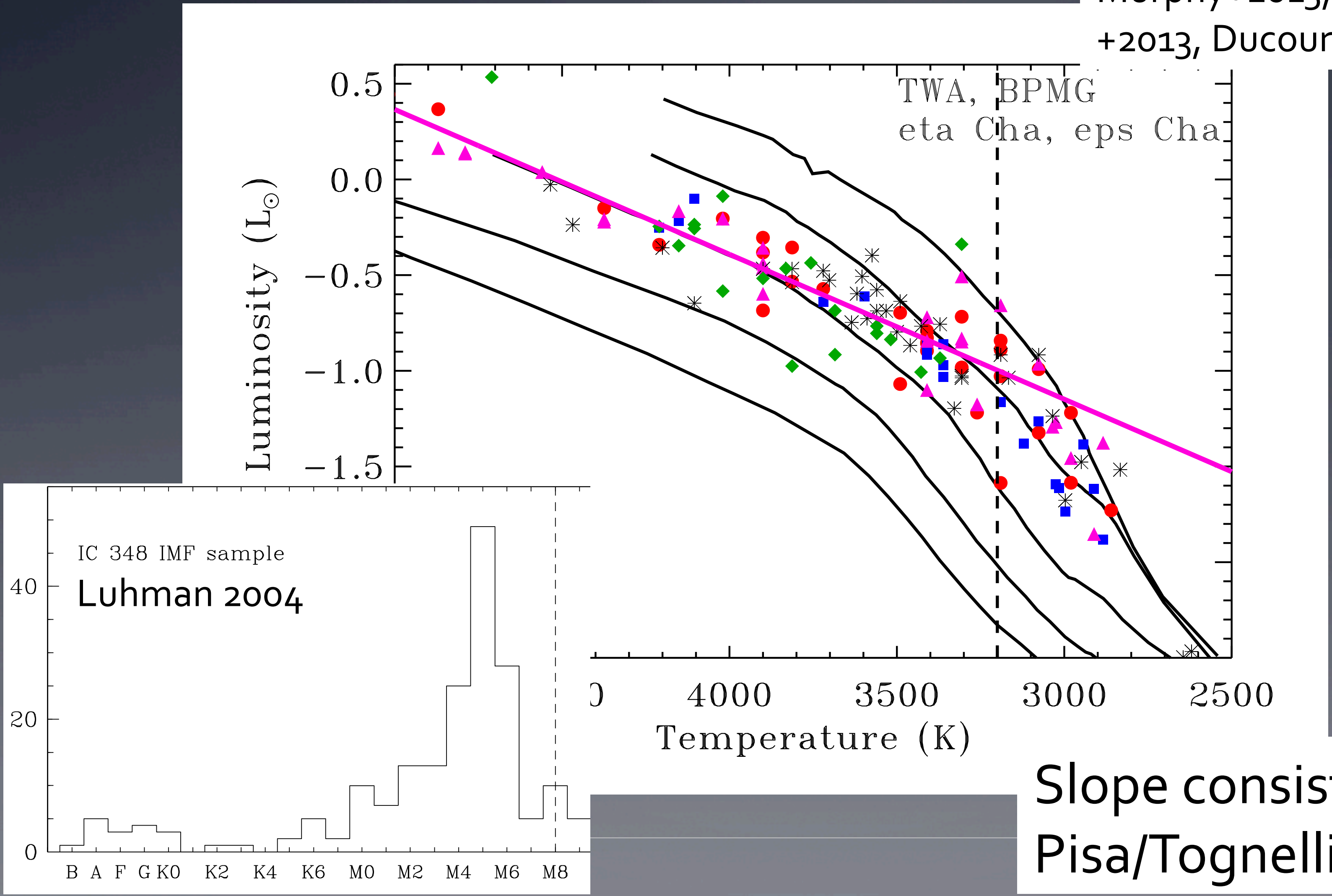
Sample	Age (Myr)
F-Type PMS	13 ± 1
Main-sequence Turnoff	10 ± 2
Antares	12 ± 2
A-Type Turn-on	10 ± 3
G-Type PMS	9 ± 2
Adopted Age	11
Statistical uncertainty	± 1
Systematic uncertainty	± 2

Hipparcos membership (De Zeeuw+1999); evolutionary tracks with rotation

M-dwarfs and previous intermediate-mass age: 5 Myr

Moving Group Isochrone: age depends on SpT/mass

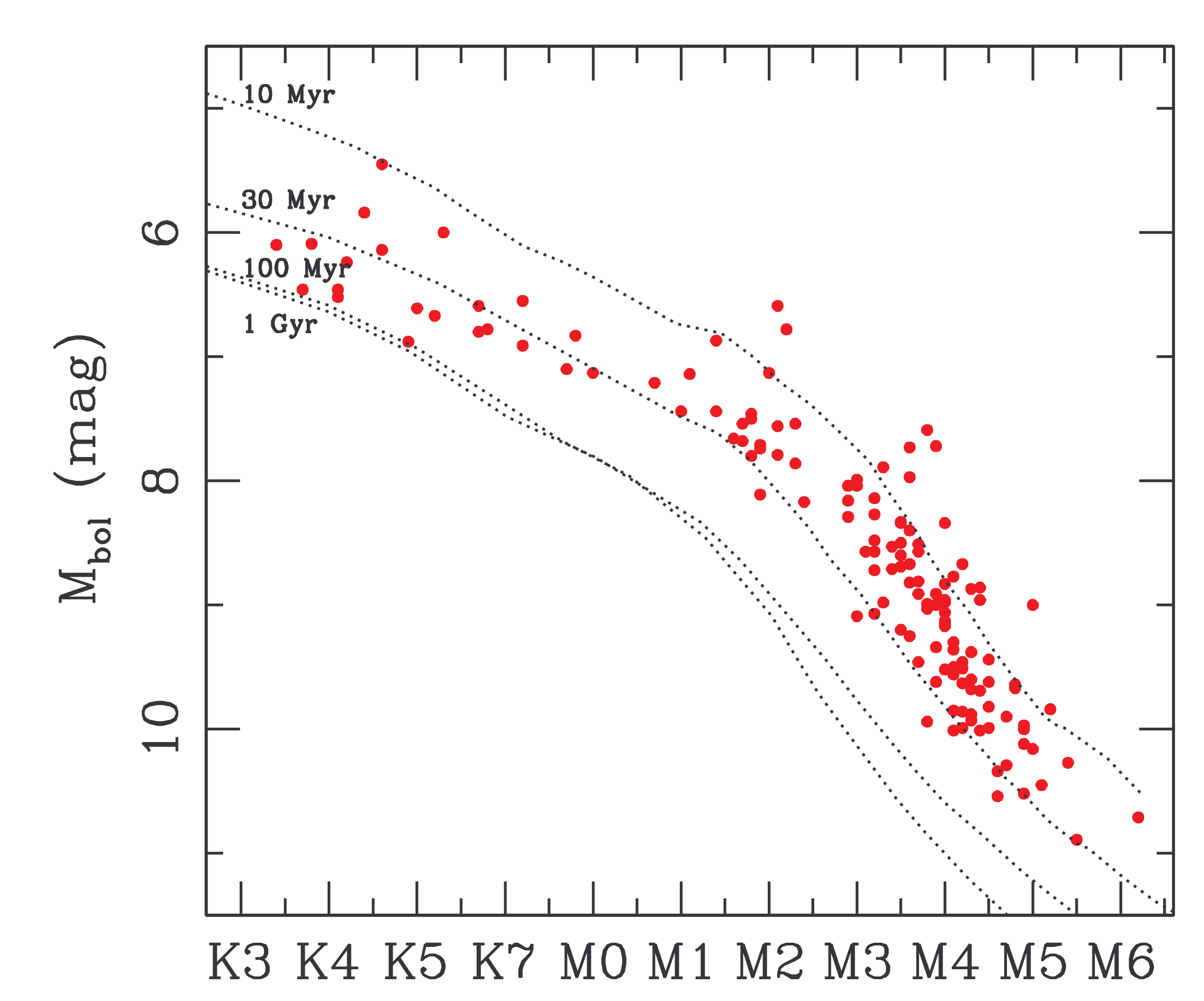
Membership: Malo+2013, Murphy+2013, Weinberger +2013, Ducourant+2014, etc.



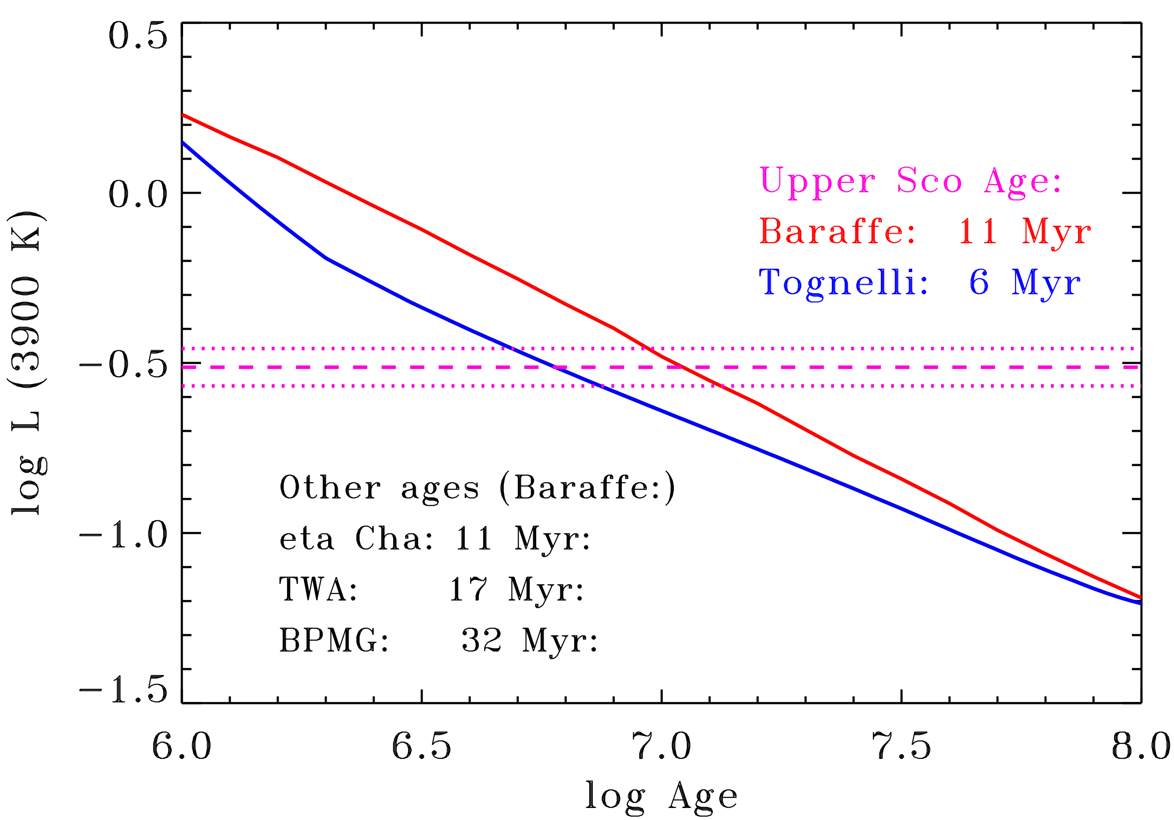
Slope consistent with Pisa/Tognelli+ tracks

Age depends on SpT

(Tuc-Hor, Kraus+2014)



Calibrating low-mass PMS ages



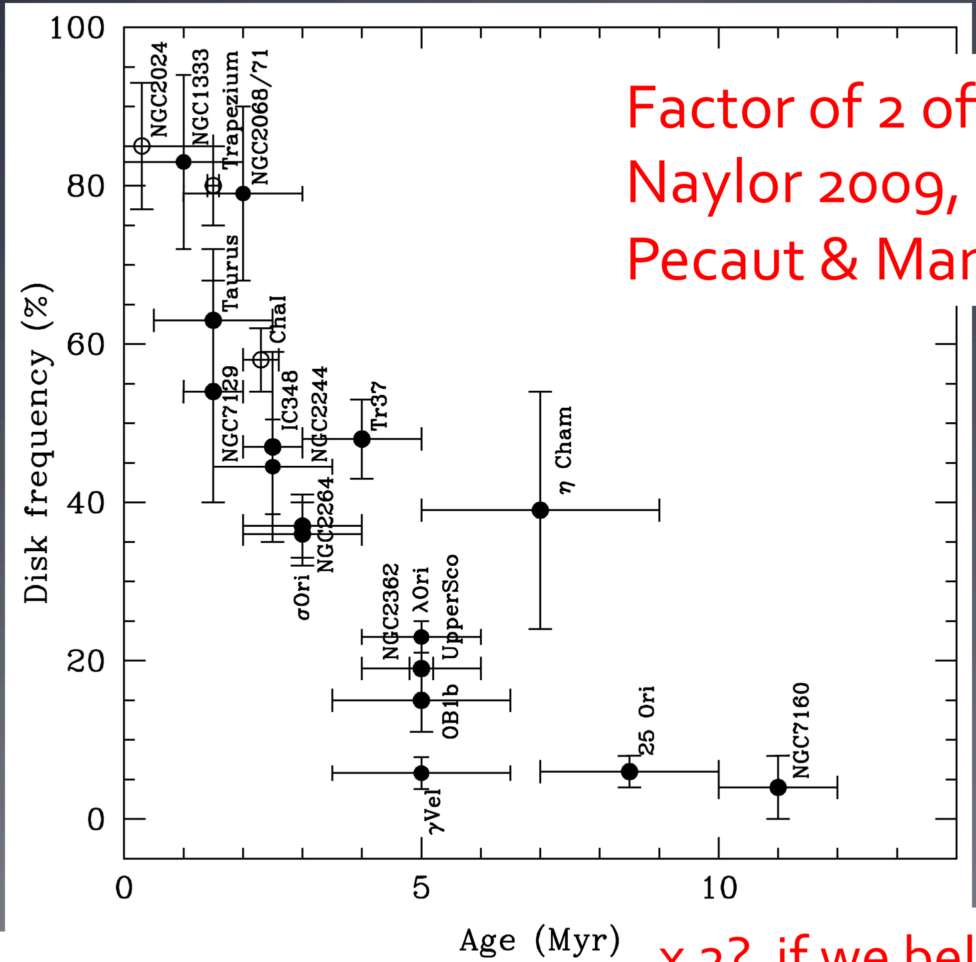
Age scaled to 3900 K

Mix Pisa/Tognelli slope with age from Barrafe+Chabrier Lyon isochrones

BPMG: older than Li age (Binks & Jeffries 2014)

Implications of older ages:

timescales for Class 0-Class II are longer!



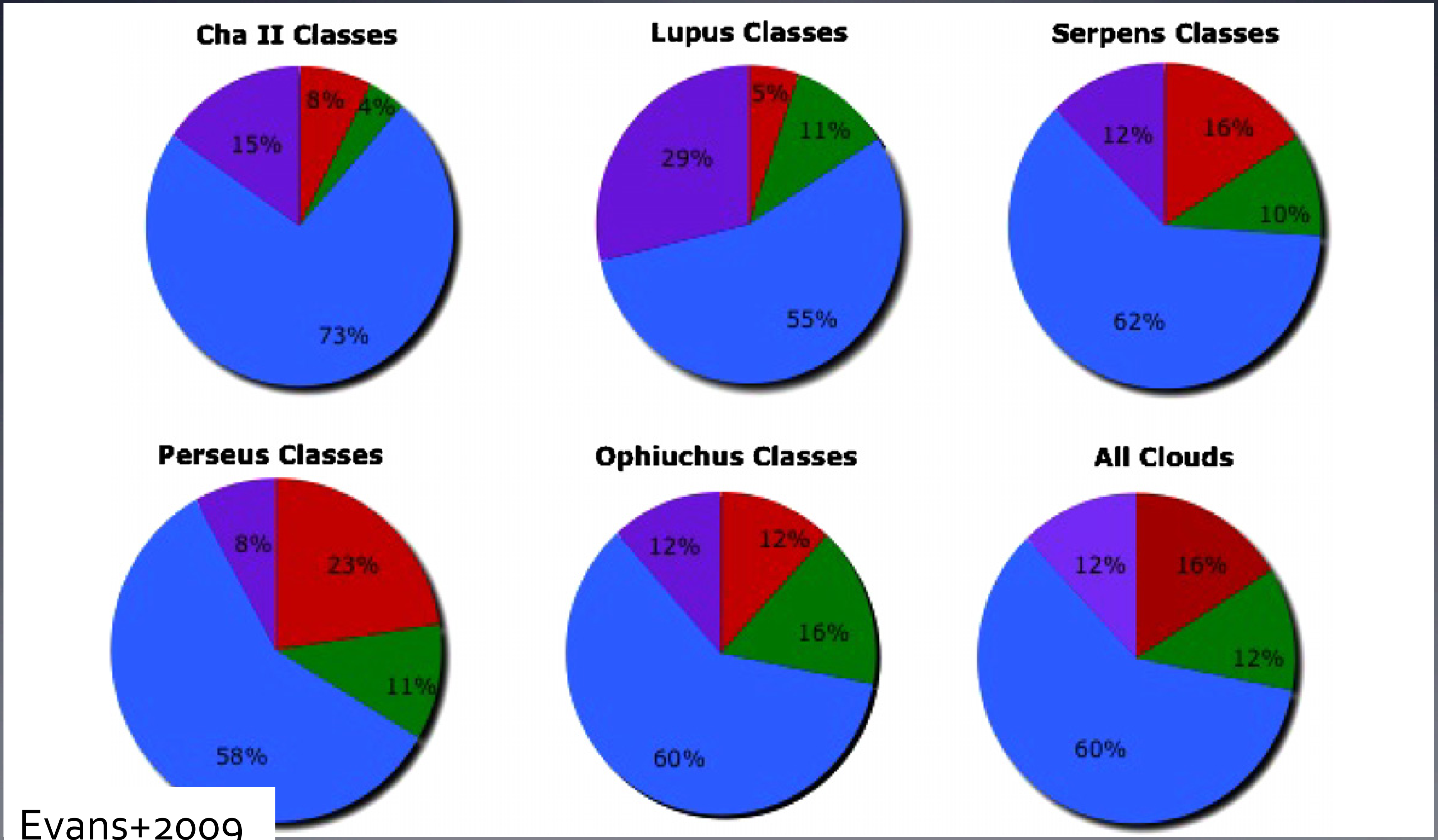
Factor of 2 offset in age? Naylor 2009, Bell+2013, and Pecaut & Mamajek 2012

Hernandez+2007

x 2? if we believe evolutionary tracks of 2-4 Msun stars

Envelope lifetimes:

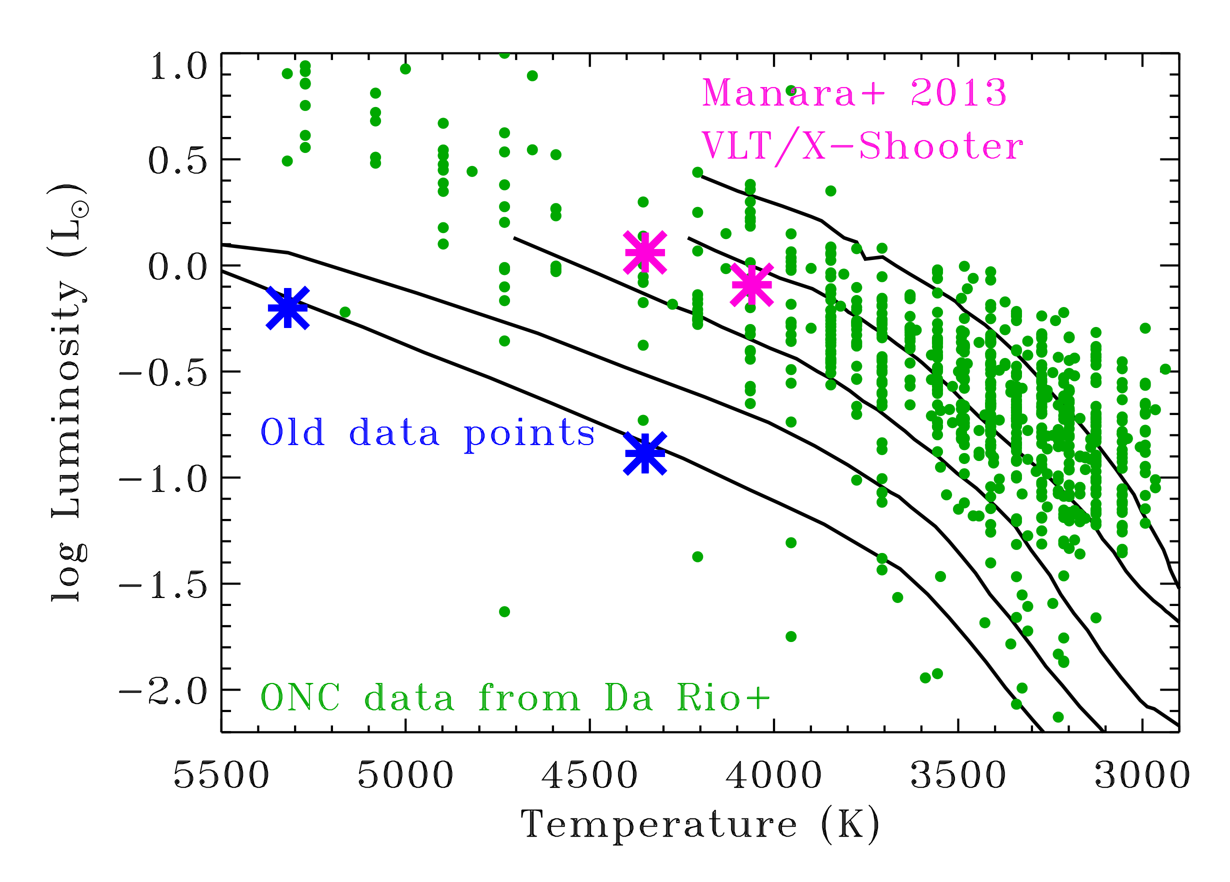
is there a mass dependence in statistics?



Evans+2009

Luminosity (age) spread

(Da Rio+2010/2012; Reggiani+2011)



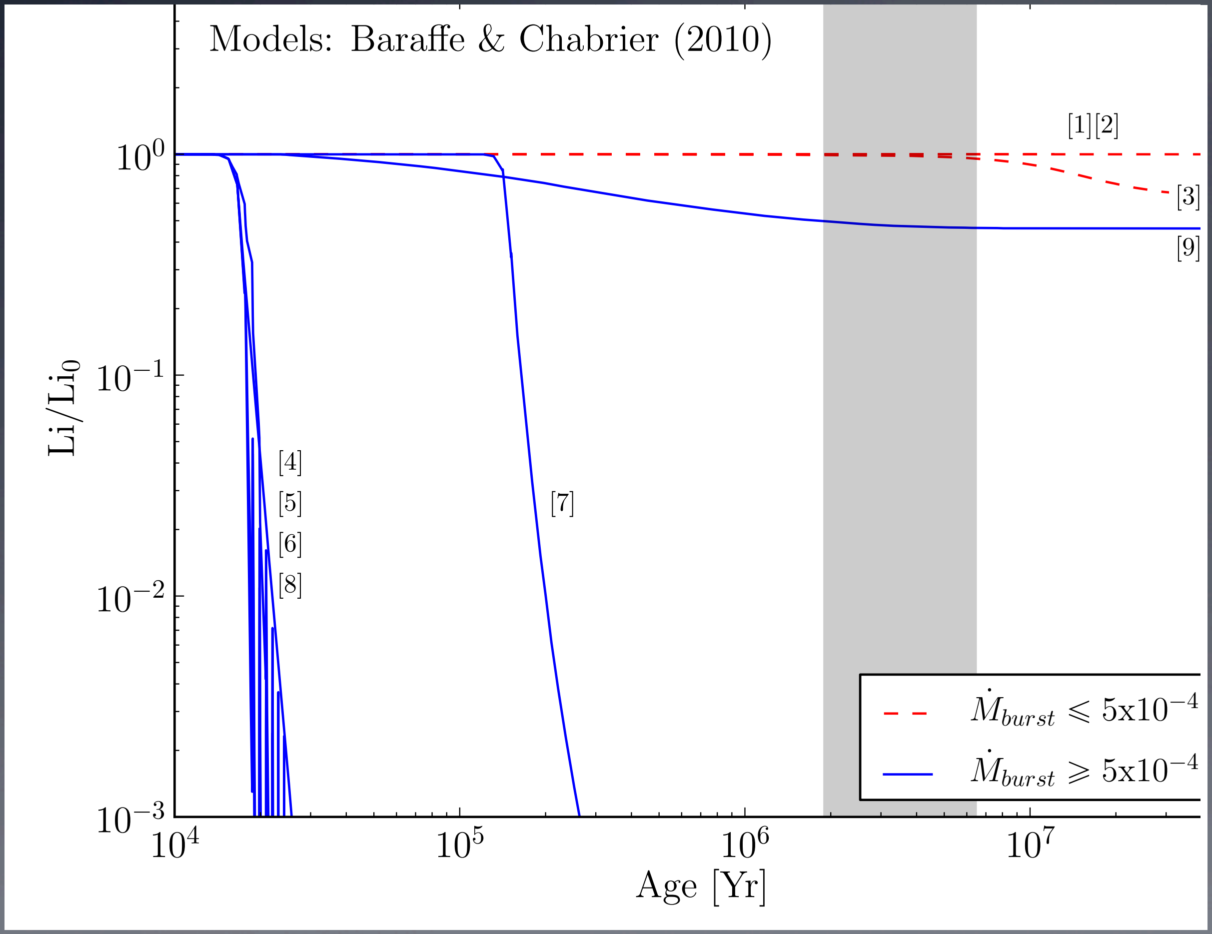
Standard deviation 0.4 dex in age

Better data: two discrepant points are no longer discrepant!

Observational errors significantly underestimated

See also Soderblom+ PPVI review and Herczeg & Hillenbrand (2014) for discussion on observational uncertainties, new SpT/Av

Episodic accretion: minimal lasting effects
(Sergison+2013)



Li depletion: cold accretion rates of 5 10^{-4} Msun/yr in <0.5% of objects

Skeptical conclusions?

- Accretion rates may be underestimated by a factor of 4
  - Factor of 2 systematic uncertainties
- PMS ages are likely underestimated by a factor of 1.5-2
  - Stage 0-2 lifetimes are longer!
  - Can find ad hoc low mass PMS tracks to reproduce IM ages
  - Are envelope lifetimes based on appropriate mass comparison?
- A parameter space may exist whereby stellar masses do not require episodic accretion
  - Observational constraints from tracks with episodic accretion?
  - Limits on major events: Sergison+2013