Feedback-regulated star formation:

Dual constraints on the SFE and the age spread of stars in cluster

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SFE in clusters

Time dependent SFE in A molecular cloud/ clump

$$SFE(t) \approx \frac{M_{cluster}(t)}{M_{gas,initial} + M_{gas,acc}(t)}$$

Final value of the SFE

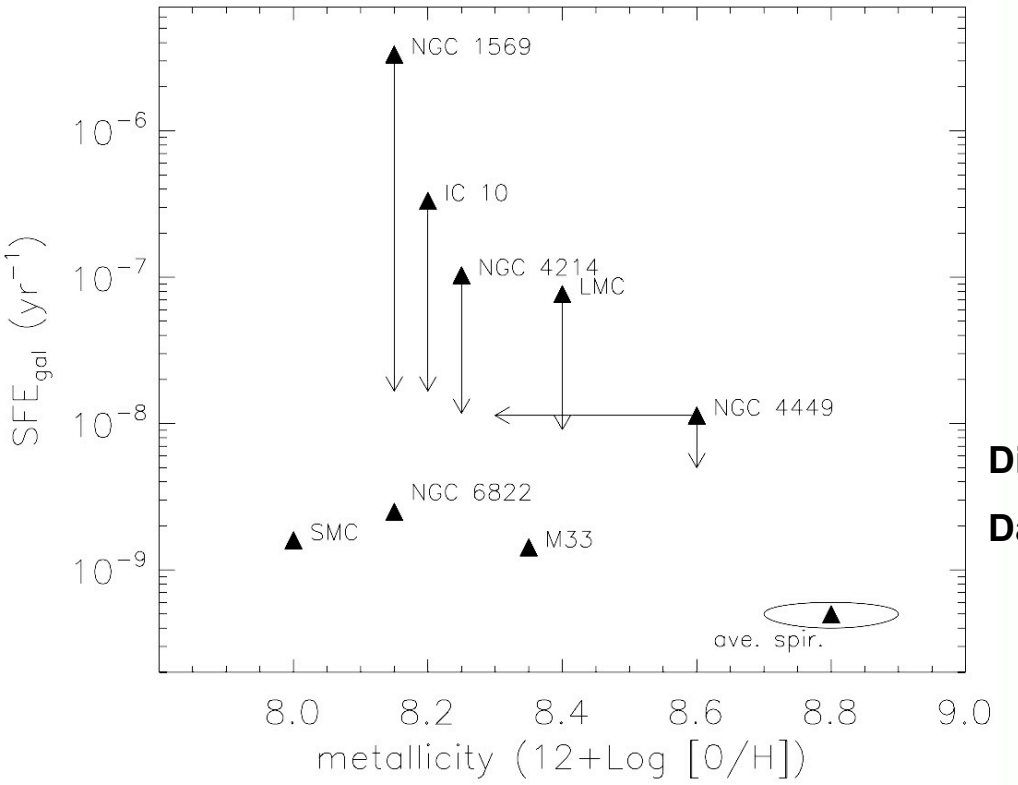
$$SFE_f = SFE(t_{\exp}) = \frac{M_{cluster}\left(t_{\exp}\right)}{M_{gas,initial} + M_{gas,acc}\left(t_{\exp}\right)}$$

In the observations

$$SFE_f \approx \left[\frac{M_{cluster}}{M_{gas,present} + M_{cluster}}\right] \approx [0.05 - 0.7]$$

No established dependences on mass, metallicity, environment. **e.g. Lada & Lada (2003)**

SFE in Galaxies



$$SFE_{gal} \approx \frac{SFR_{gal}}{M_{H_2}}$$

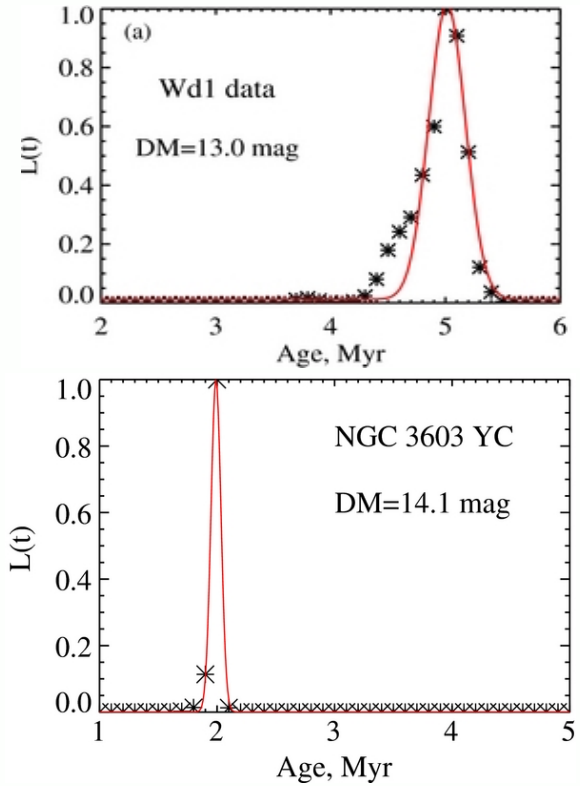
Dib et al. (2011)

Data compiled from:

- **average spirals (Murgia et al. 2002)**
- **M33 and NGC6822 (Gratier et al. 2010a,b)**
- **SMC (Leroy et al. 2006)**

Age spreads in young clusters: observational constraints

$$\Sigma_* \approx 10^4 M_{sol} pc^{-2}$$

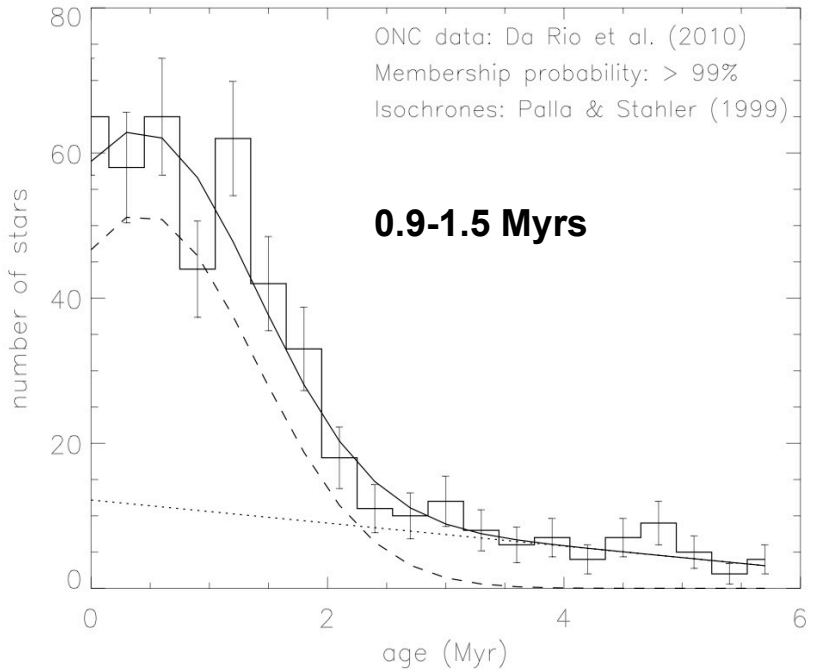


0.4 Myrs

0.1 Myrs

Kudryavtseva et al. 2012

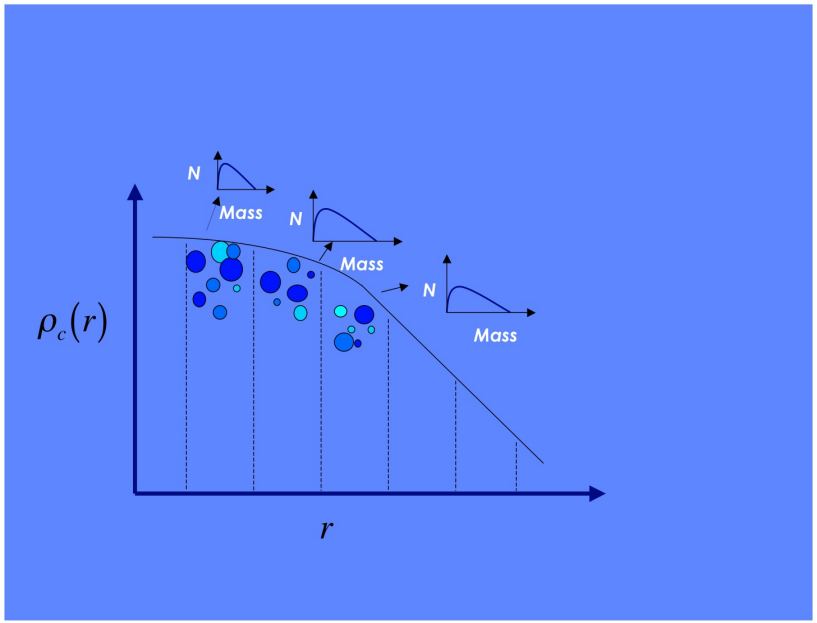
$$\Sigma_* \approx 10^2 M_{sol} pc^{-2}$$



0.9-1.5 Myrs

Dib et al. (2013)

Star cluster formation model



Dib et al. 2011, 2013

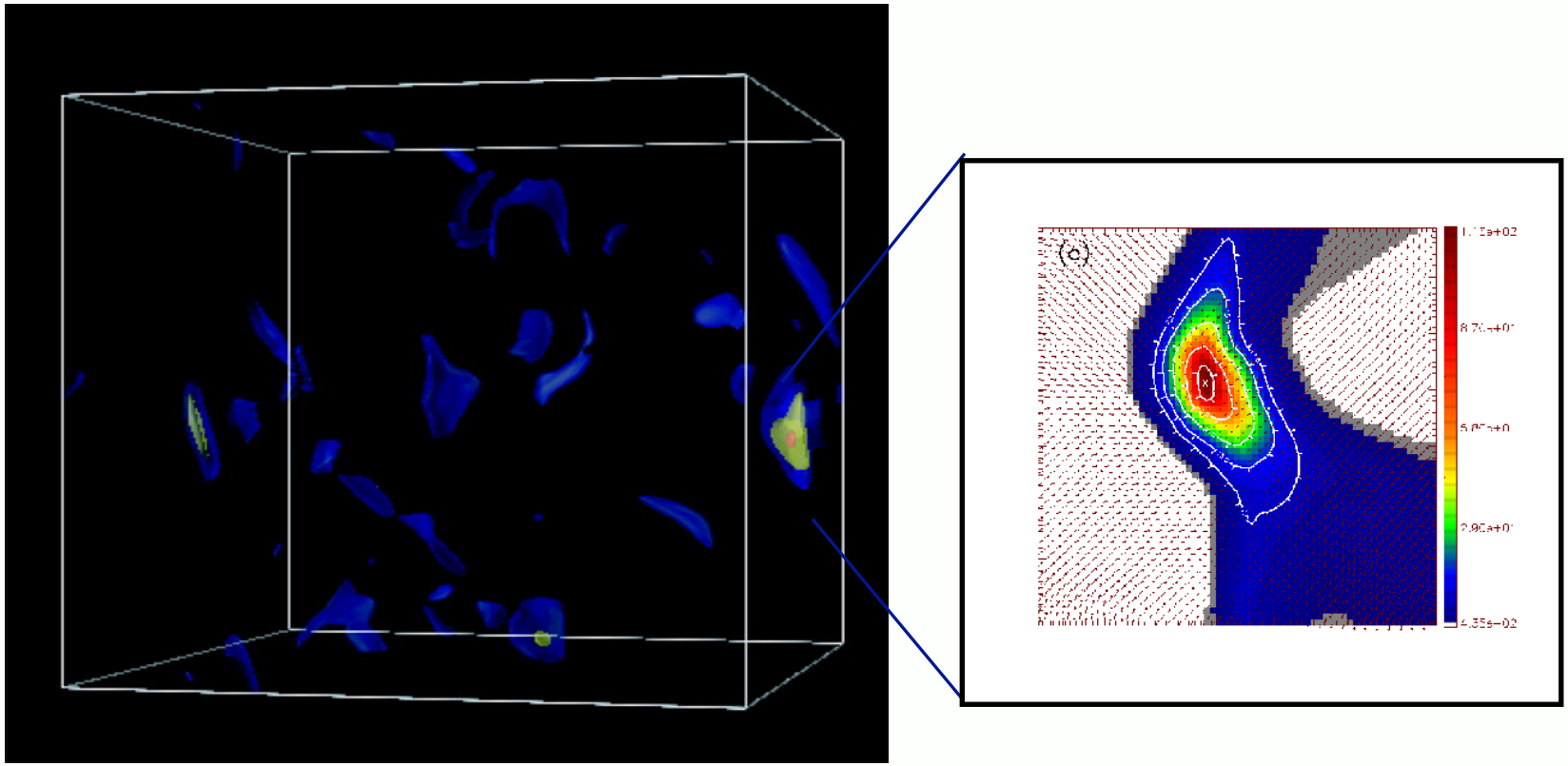
Basics of the model

- **turbulent fragmentation** of a protocluster clump of mass M
- Cores form with a fixed (or time evolving) CFE_{ff}
- cores have finite lifetimes [1-10] t_{ff}
- CMF → IMF (1core → 1 star)
- **Feedback** from massive stars
- Gas is expelled when $E_{wind,eff}/E_{grav}$ =1

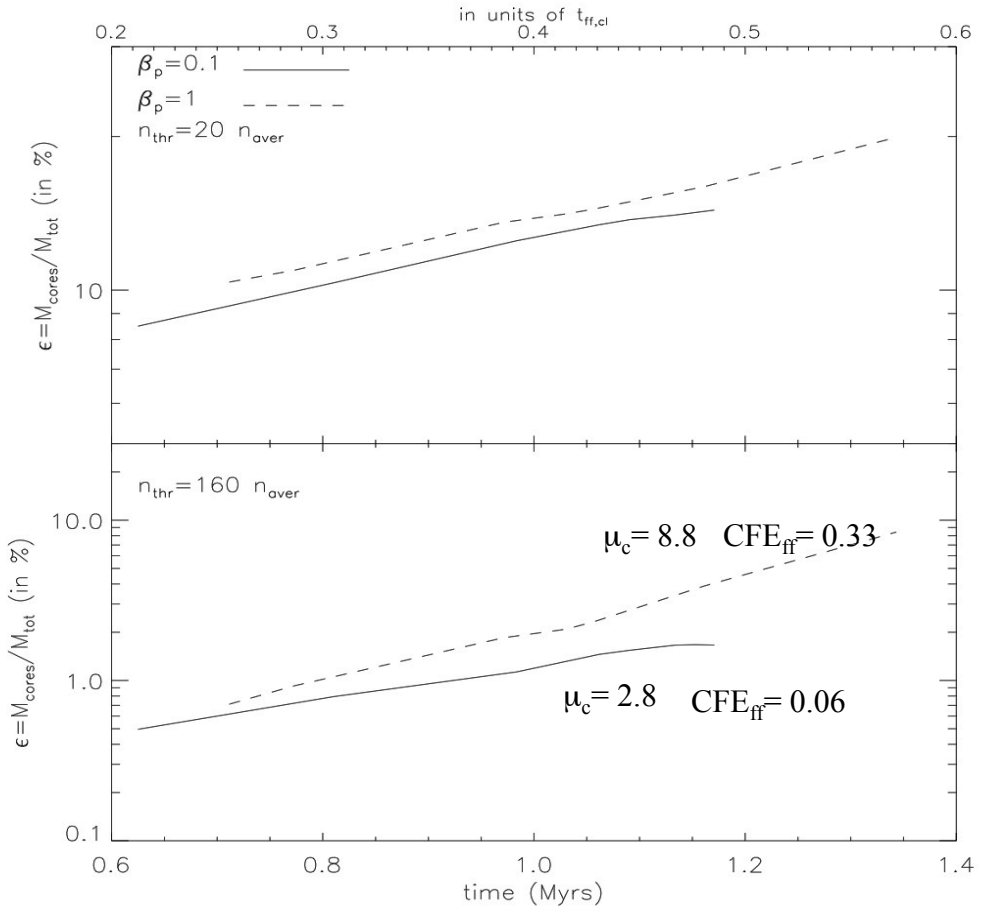
CFE_{ff}: insight from numerical simulations

Simulations of Turbulent, magnetized, and self-gravitating clouds

with the AMR code RAMSES (resolution of 4096^3), Dib et al. (2010)



CFE_{ff}: insight from numerical simulations



Dib et al. in 2010

Feedback model: stellar winds

Stellar mass loss rate $\left(\frac{dM}{dt}\right)_*$

Terminal wind velocity v_∞

Energy cumulated in winds

$$E_{wind} = \int_{t''=0}^{t''=t} \int_{m=5M_{sol}}^{m=80M_{sol}} \left(\frac{N(m)(dM/dt)_*(m)v_\infty^2}{2} dm \right) dt''$$

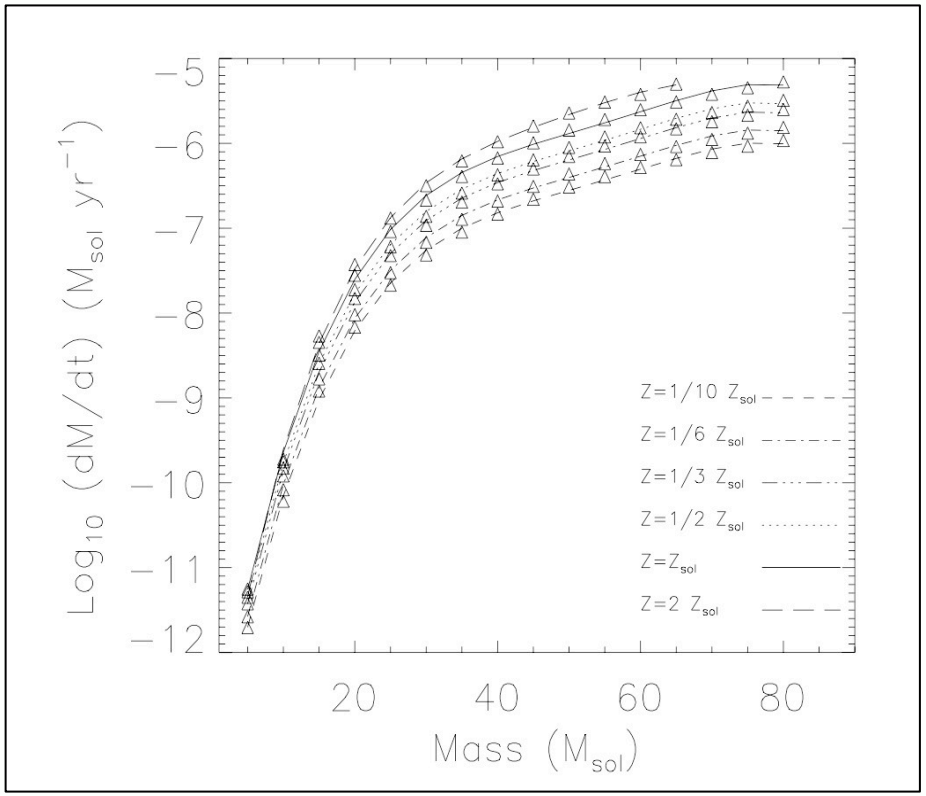
Fraction of wind energy that counters gravity $E_{k,wind} = \kappa E_{wind}$

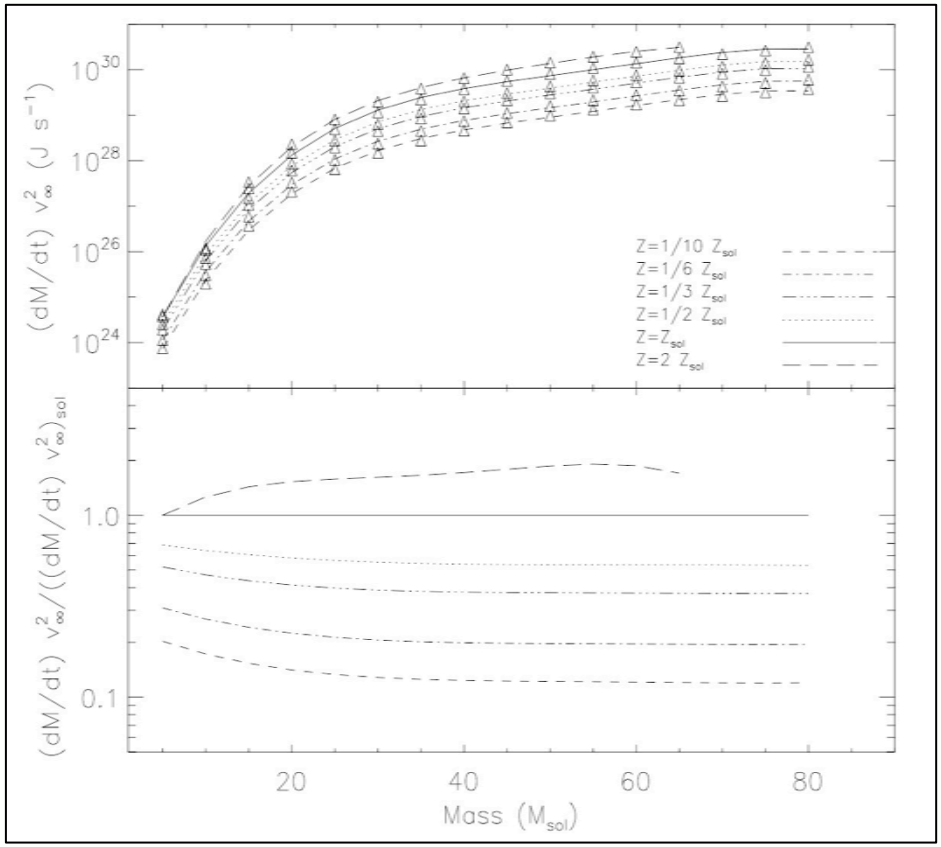
$k < 1$

Feedback model: stellar winds

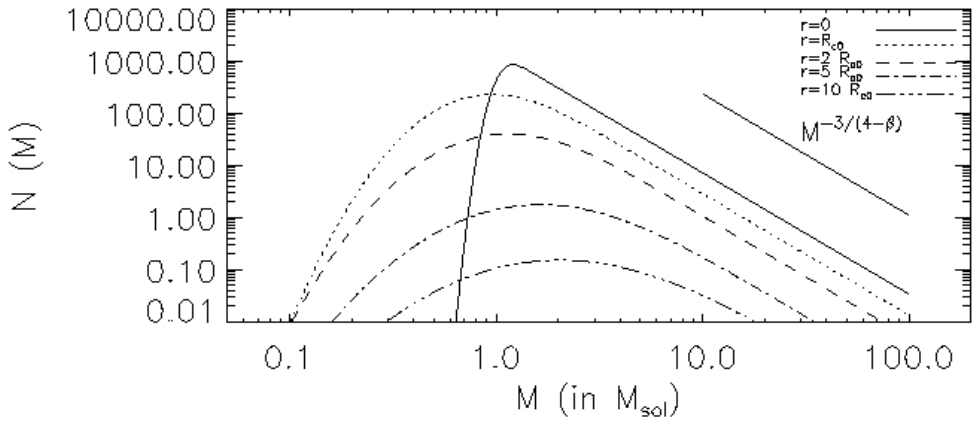
- **Main sequence models of OB stars (≥ 5 $M_\odot$) (using CESAM)** $\dot{M}$ $\dot{M} v_\infty^2$

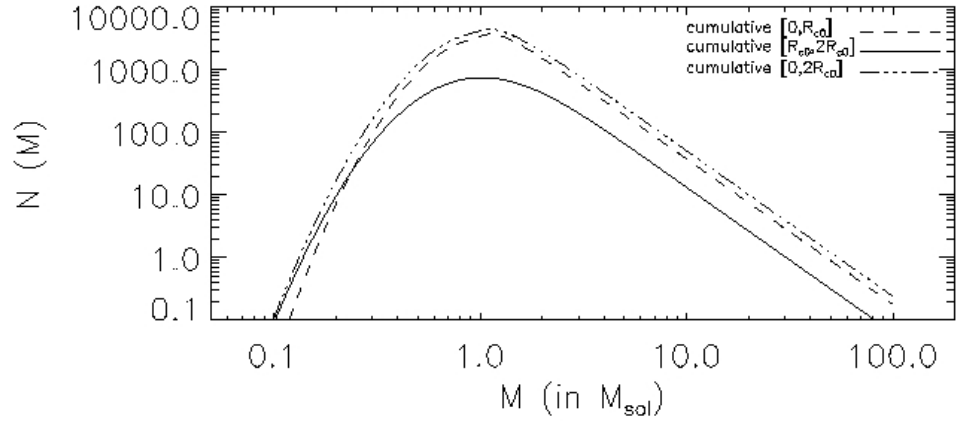
- **(T_{eff}, L_*, R_*) ➔ Stellar atmosphere model (Vink et al.) ➔**





Initial core mass function

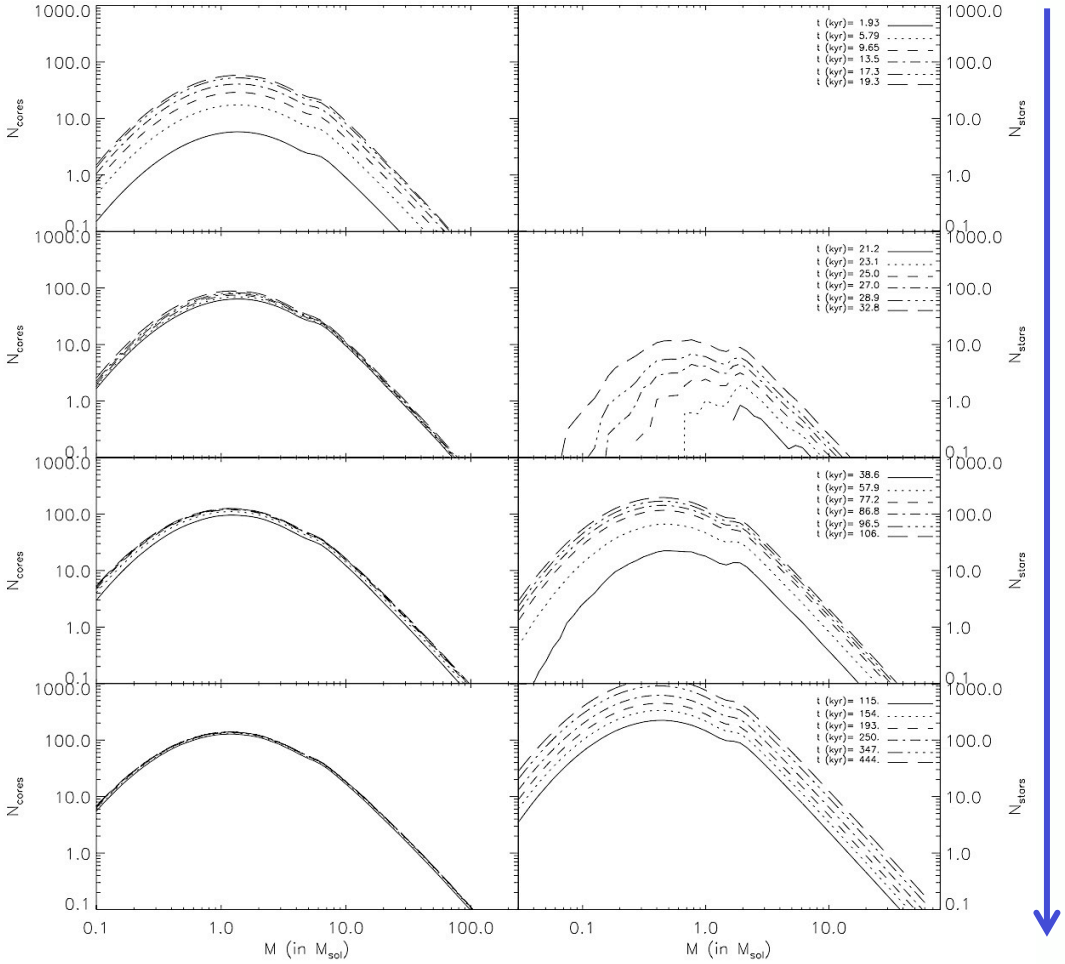




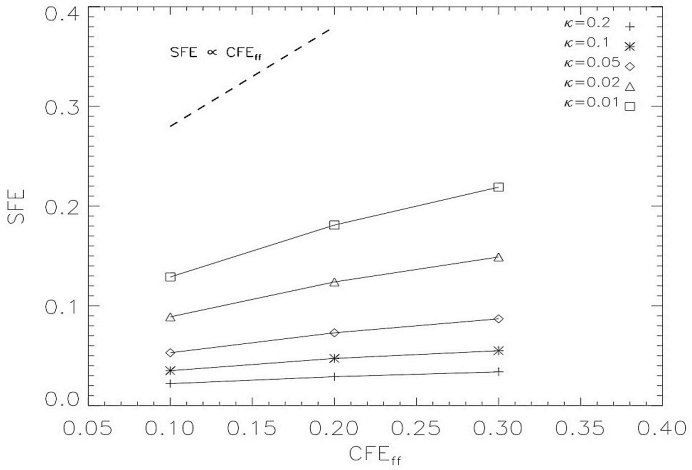
Turbulent fragmentation:

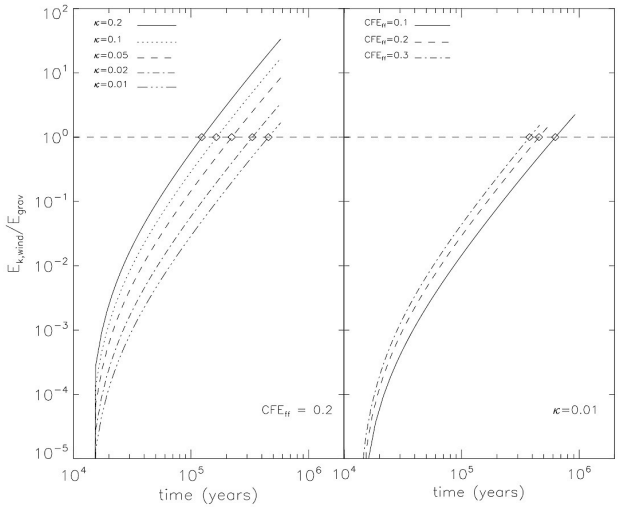
e.g., Padoan & Nordlund (2002)

Star cluster formation model

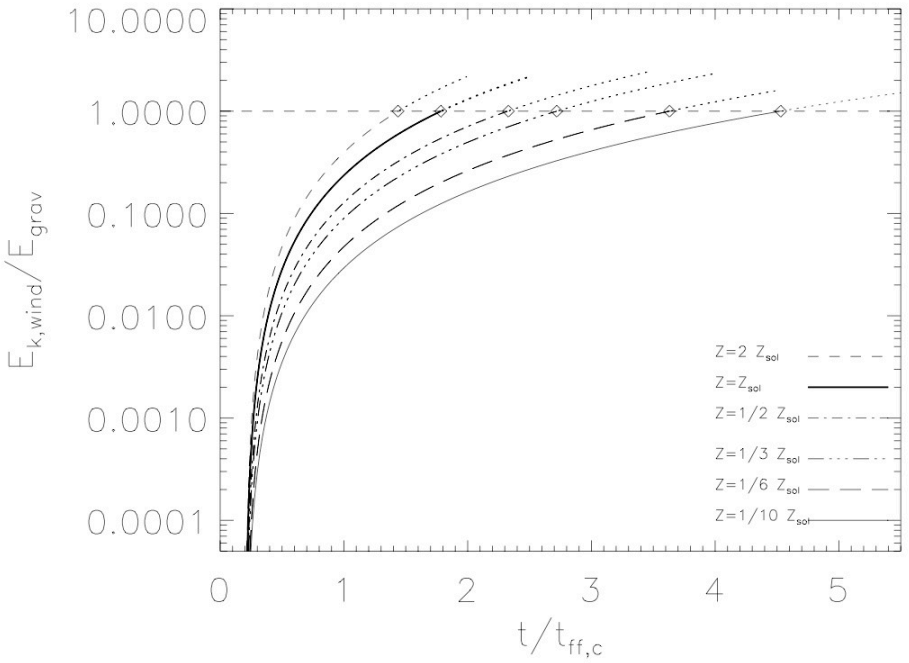


time





Dependence of the SFE on metallicity



Dib et al. (2011)

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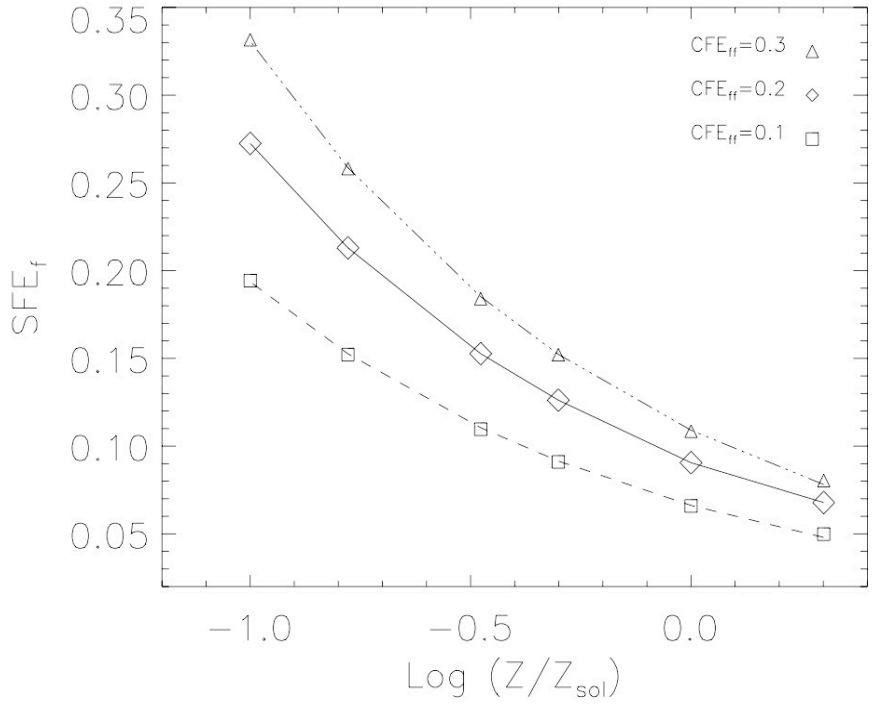
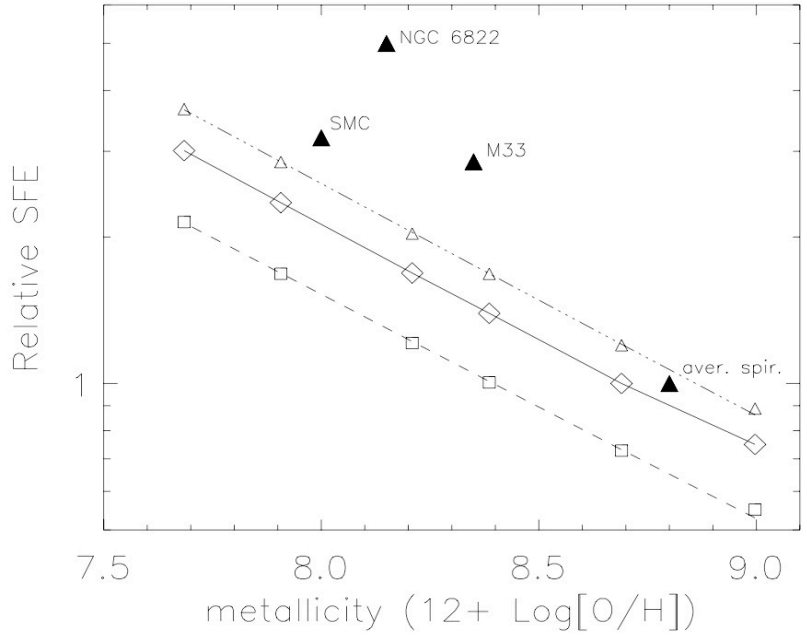




Dib et al. (2011)

Dependence of the CFH/SFH and cloud mass

- **clump masses [$5\text{x}10^4$-$5\text{x}10^5$]]**

▪ **Models with uniform star formation: constant CFE_{ff}**

$$CFE_{ff} = 0.1, 0.2, 0.3$$

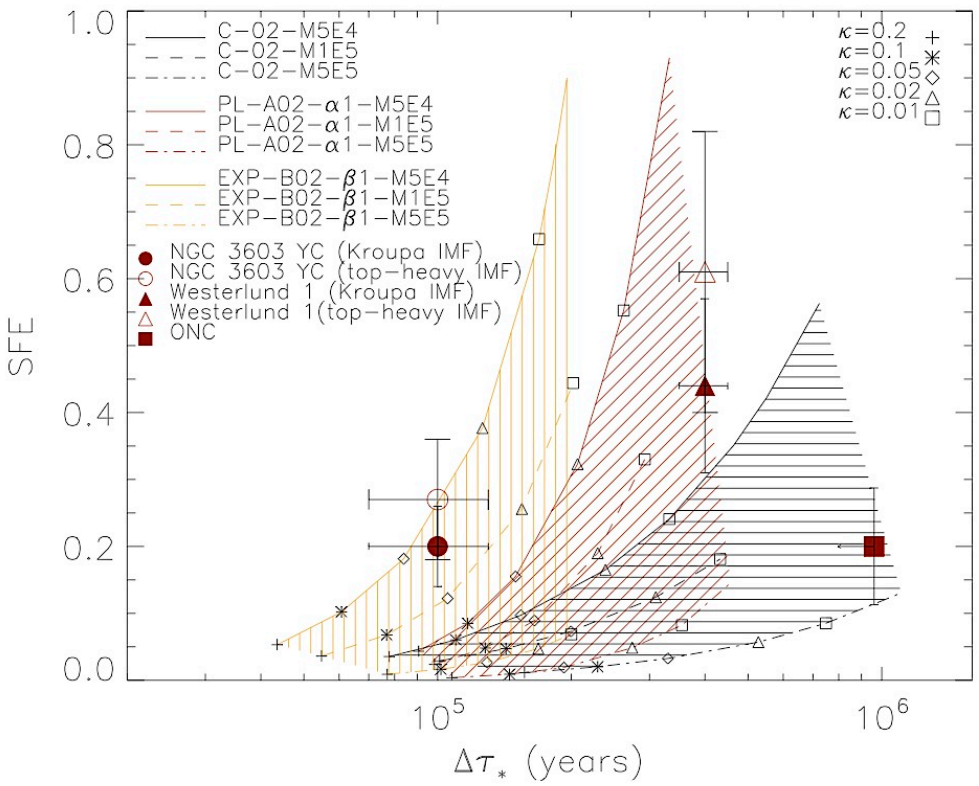
▪ **Models with accelerated star formation**

Power laws:

$$CFE(t) = A\left(\frac{t}{f_{ff}}\right)^{\alpha}$$

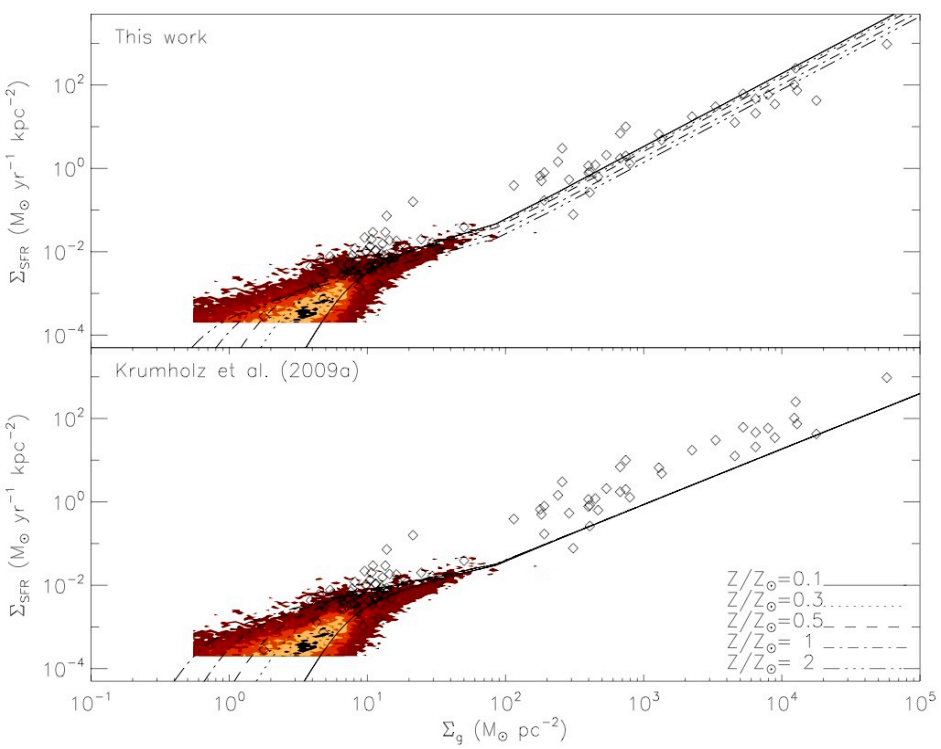
Exponential laws:

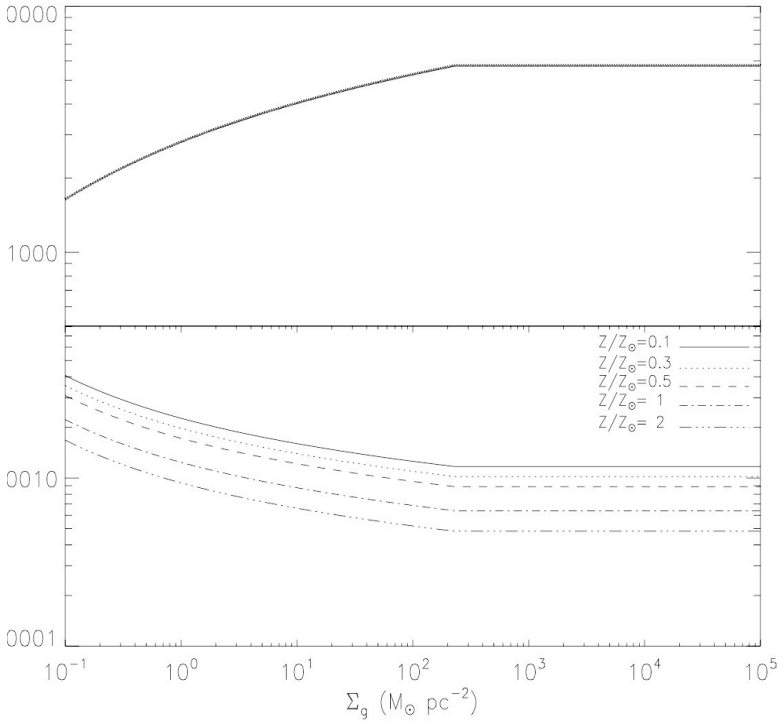
$$CFE(t) = B\exp\left(\frac{1}{\beta}\frac{t}{t_{ff,cl}}\right)$$



Dib et al. (2013)

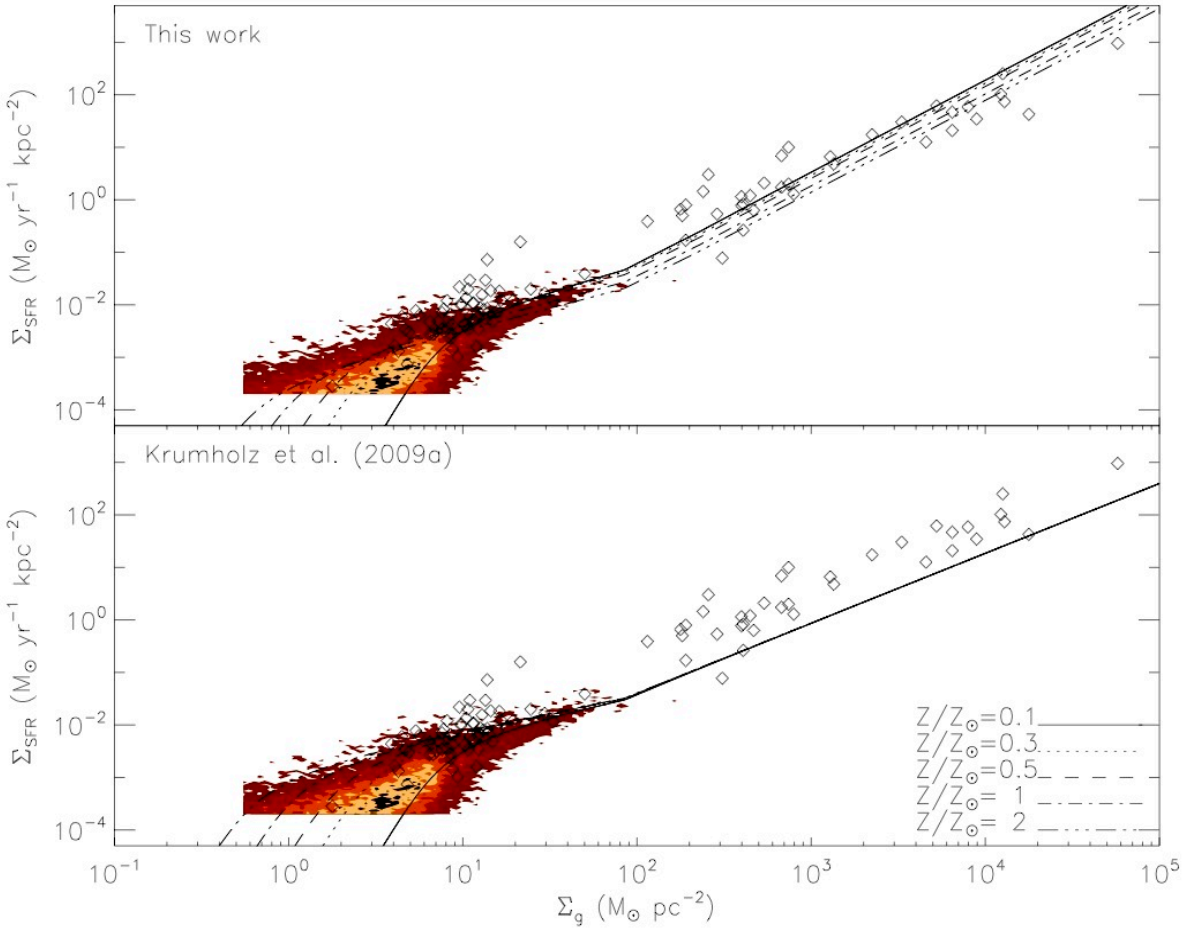
Implications for the SF scaling relations



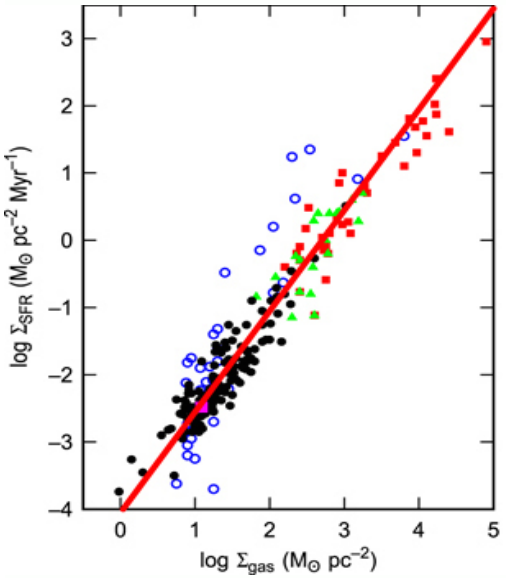


Dib et al. 2011,2013

Implications for the SF scaling relations



Dib 2011



Kennicutt & Evans 2012

Summary

- **Turbulence, magnetic fields, thermal physics, radiation & feedback regulate the rate of core/star formation in a molecular cloud/clump**

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- **Feedback sets the final SFE**
- **Feedback sets the age spreads**
- **SFE-age spread relation, with a mass and metallicity dependance**
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