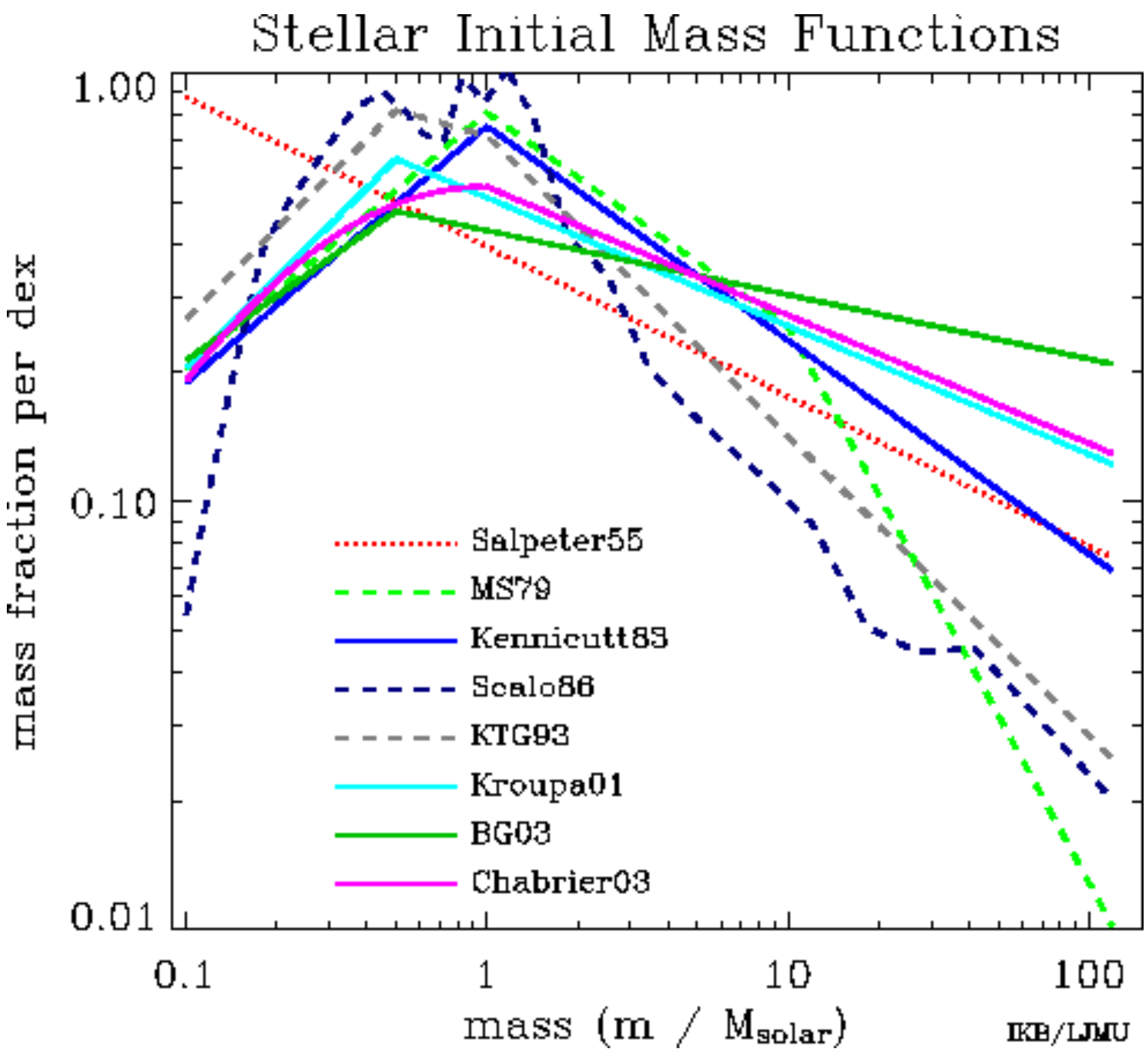
A non-universal IMF in Galactic stellar clusters

Sami Dib

NBIA & STARPLAN

The Galactic field IMF



The Most "popular" IMF functional forms

The multi-exponent power law (Kroupa 2002, Kroupa 2013):

$$\xi(m) = k \begin{cases} \left(\frac{m}{m_H}\right)^{-\alpha_0}, & m_{low} \leqslant m \leqslant m_H, \\ \left(\frac{m}{m_H}\right)^{-\alpha_1}, & m_H \leqslant m \leqslant m_0, \\ \left(\frac{m_0}{m_H}\right)^{-\alpha_1}\left(\frac{m}{m_0}\right)^{-\alpha_2}, & m_0 \leqslant m \leqslant m_1, \\ \left(\frac{m_0}{m_H}\right)^{-\alpha_1}\left(\frac{m_1}{m_0}\right)^{-\alpha_2}\left(\frac{m}{m_1}\right)^{-\alpha_3}, & m_1 \leqslant m \leqslant m_{max}, \end{cases} \quad (1)$$

with exponents

$$\begin{aligned} \alpha_0 &= +0.30, & 0.01 \leqslant m/M_\odot \leqslant 0.08, \\ \alpha_1 &= +1.30, & 0.08 \leqslant m/M_\odot \leqslant 0.50, \\ \alpha_2 &= +2.30, & 0.50 \leqslant m/M_\odot \leqslant 1.00, \\ \alpha_3 &= +2.35, & 1.00 \leqslant m/M_\odot, \end{aligned} \quad (2)$$

The lognormal distribution (Chabrier 2003, 2005):

$$\xi(\log m) = 0.076 \times \exp\left\{-\frac{(\log m - \log 0.25)^2}{2 \times 0.55^2}\right\}, \quad m \leq 1\ M_\odot$$

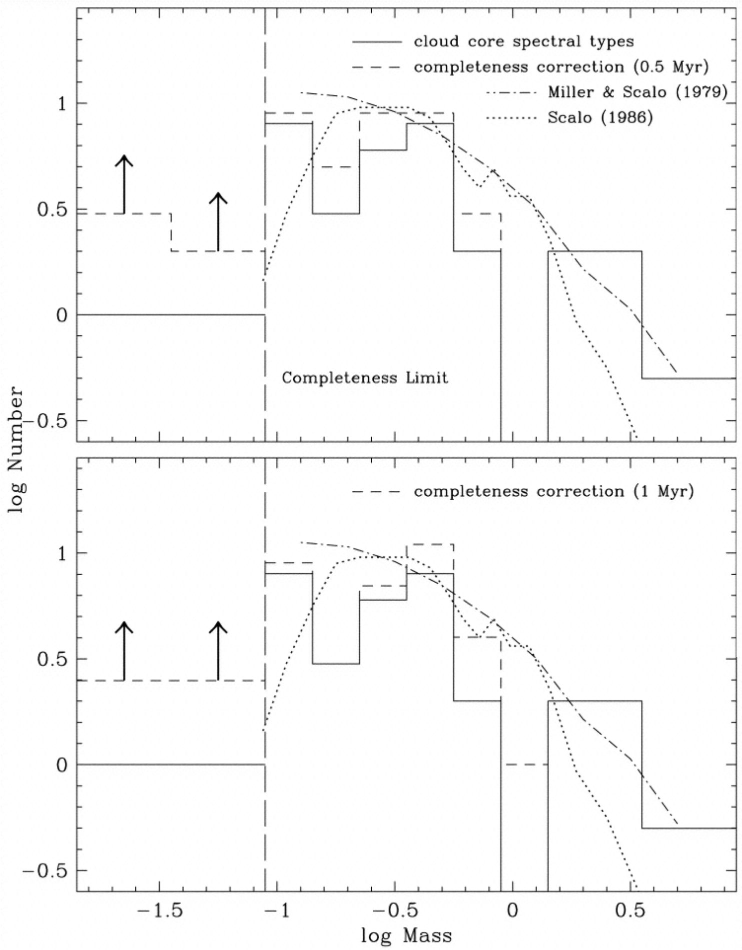
$$= 0.041\, m^{-1.35 \pm 0.3} \quad , m \geq 1\ M_\odot$$

The STPL (single power law tapered) IMF (de Marchi & Parecse 2002; Parravano et al. 2010):

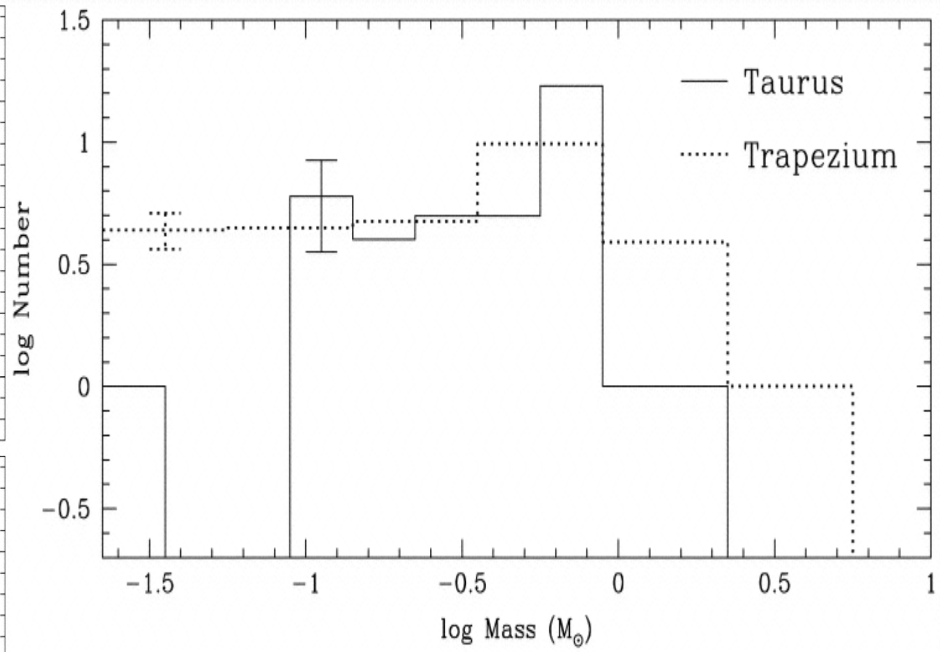
$$\xi(\log M) = kM^{-\Gamma}\left\{1 - \exp\left[-\left(\frac{M}{M_{ch}}\right)^{\gamma+\Gamma}\right]\right\} = kM^{-1.35}\left\{1 - \exp\left[-\left(\frac{M}{0.42}\right)\right]^{0.57+1.35}\right\}$$

$$0.1 \leq M / M_{sol} \leq 120$$

The IMF of young (< 2 Myrs) embedded/semi embedded Stellar Clusters



rho-Ophiucus

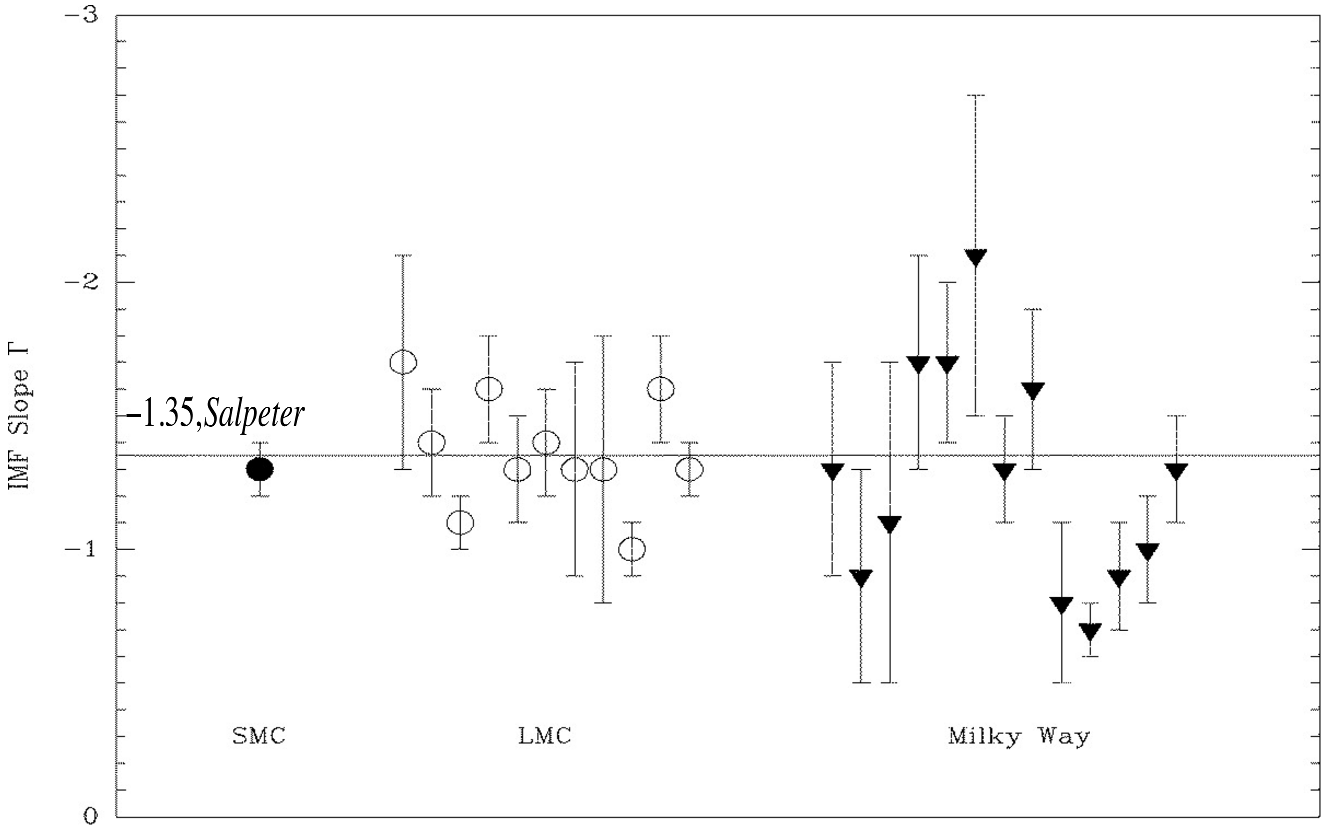


Taurus

Luhman & Rieke 1999; Luhman 2000, ++

The IMF of Open Stellar Clusters

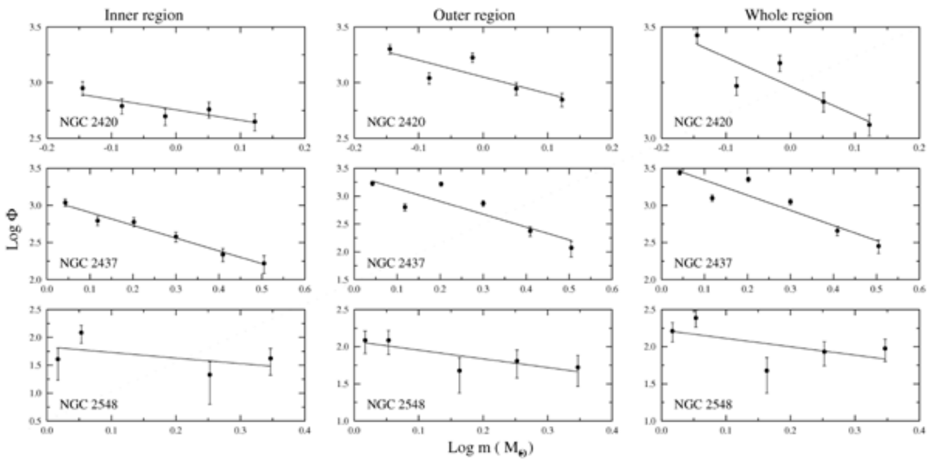
comparing the slope at the intermediate-to-high mass end

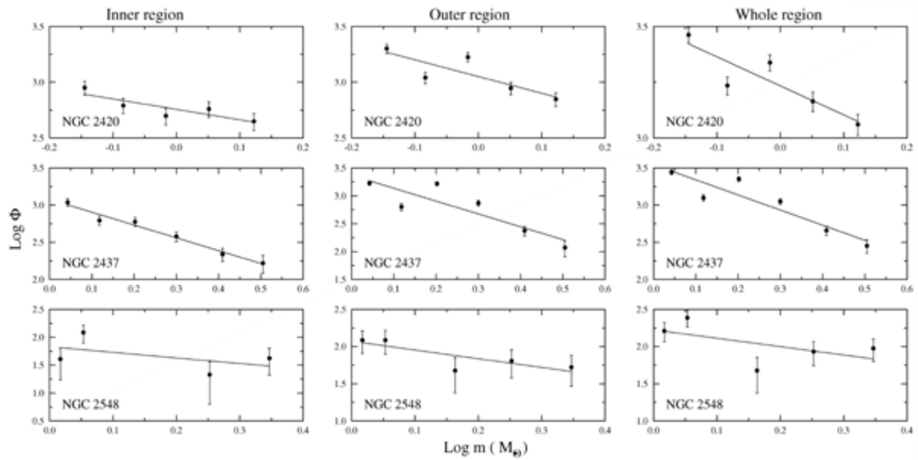


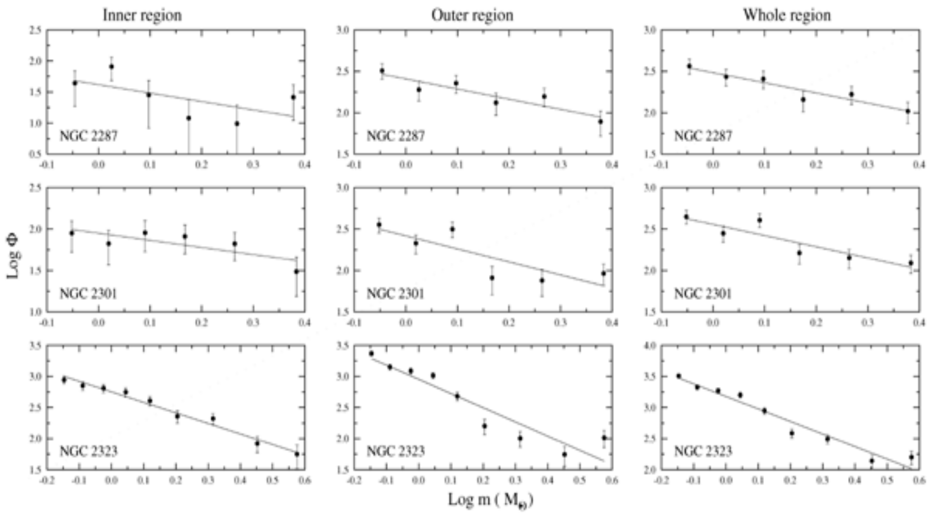
Massey et al. 1995a,b
Massey 2003

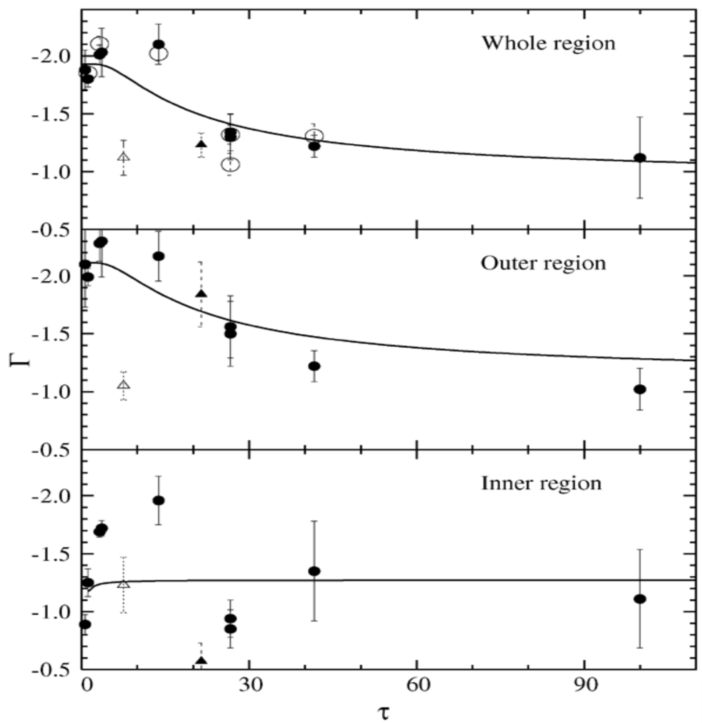
The IMF of Open Stellar Clusters

comparison of the slope at the intermediate-to-high mass end



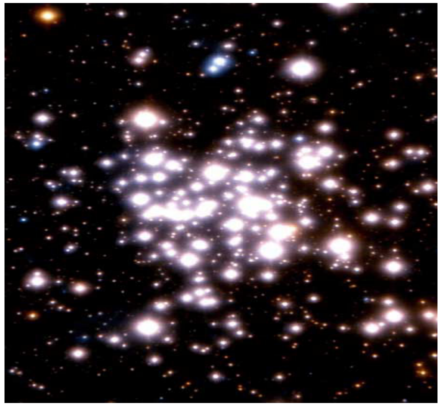


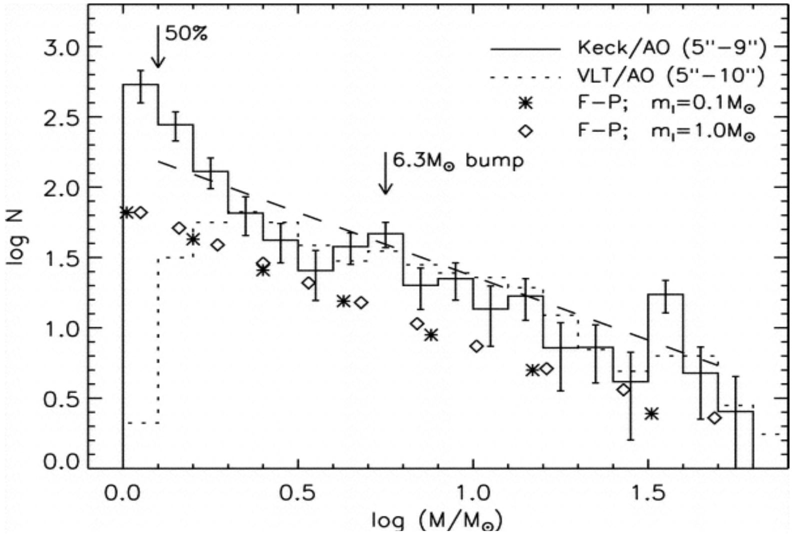




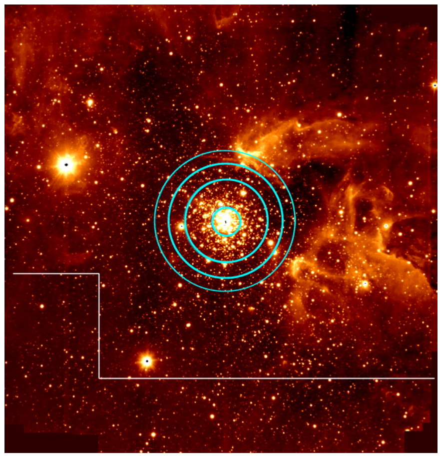
Sharma et al. 2008

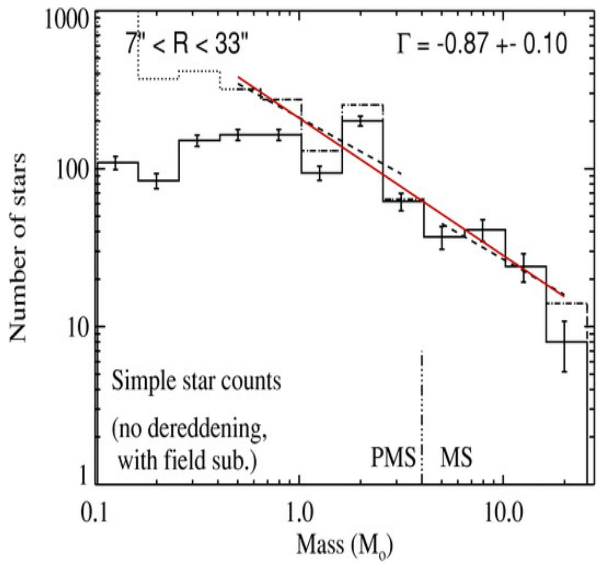
The IMF of Starburst Clusters: Arches, NGC 3603, ..





Figer 1999; Stolte et al. 2005, Kim et al. 2006 Espinoza et al. 2010, Habibi et al. 2014

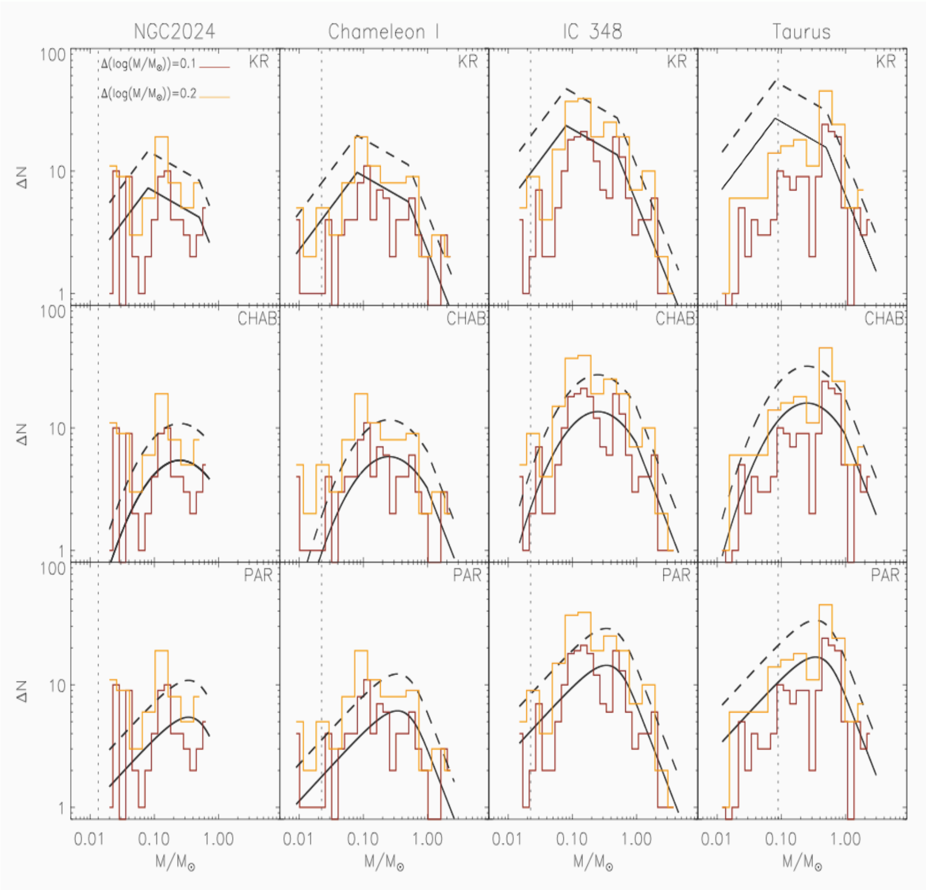


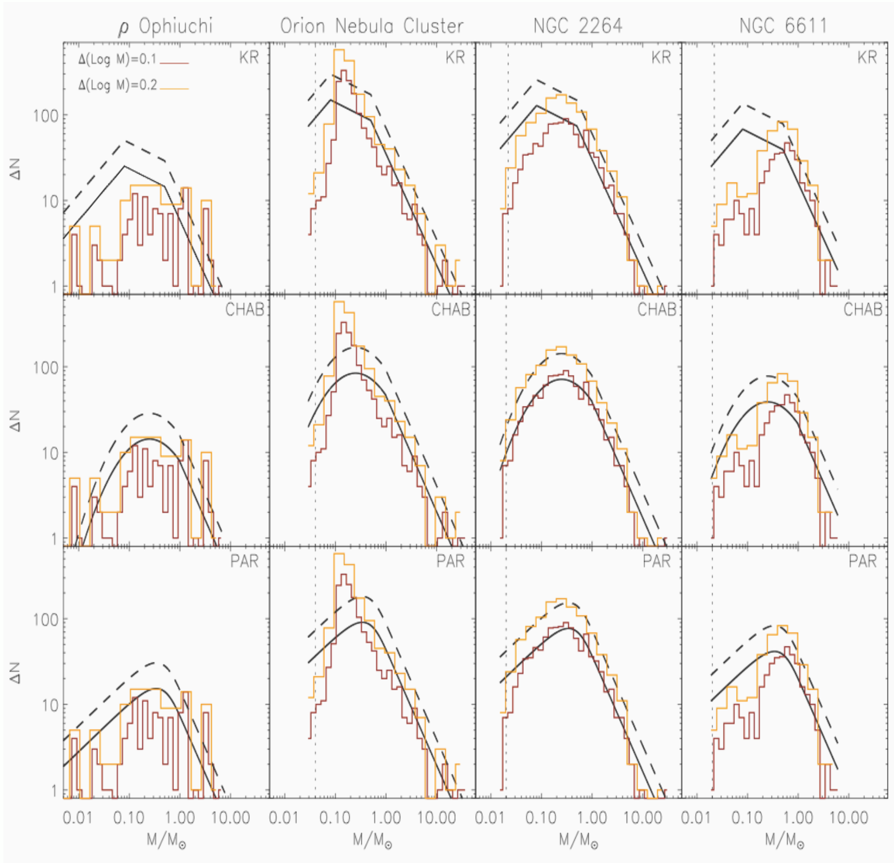


Stolte et al. 2006

Characterizing The IMF of stellar clusters

I-overplotting the binned MF with the field IMF

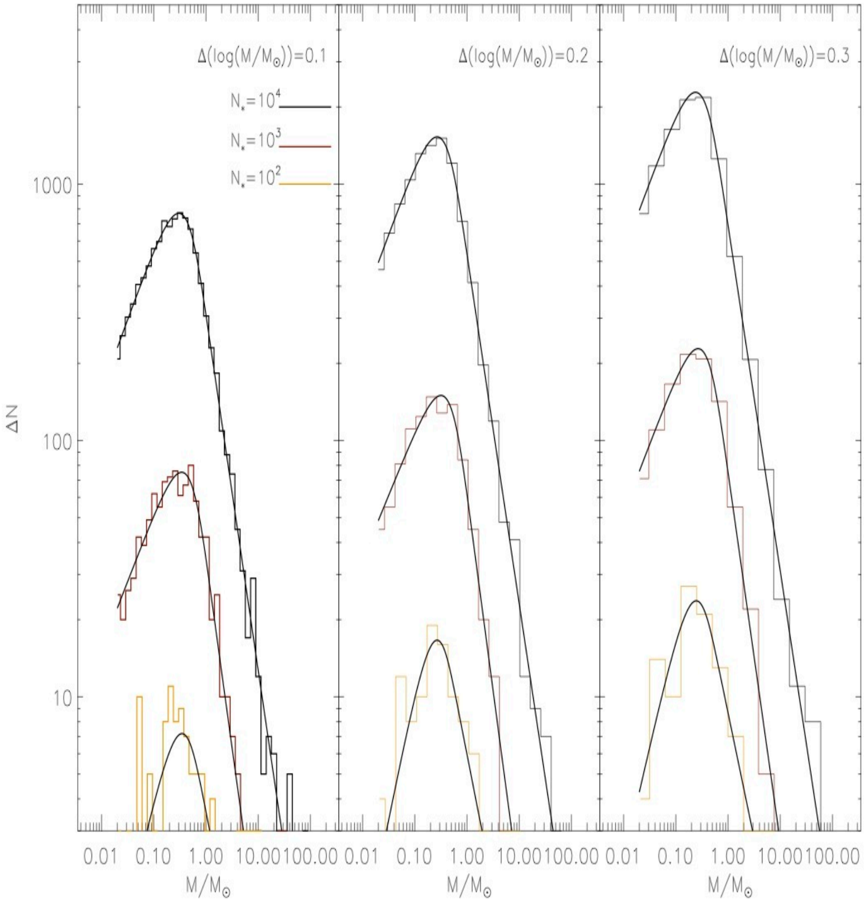


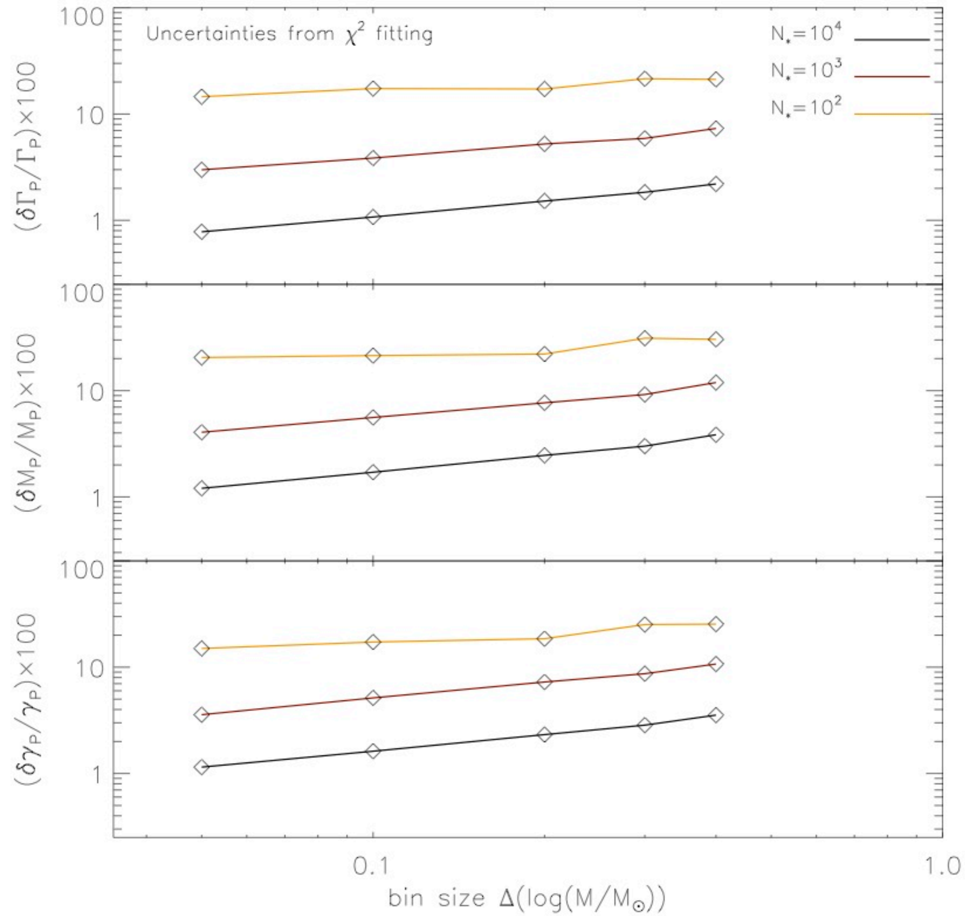


Dib 2014

Characterizing The IMF of stellar clusters

II-Fitting the binned MF using a χ^2 minimization





Dib 2014

See also Maiz Appelaniz & Ubeda 2005

Characterizing The IMF of stellar clusters

III- Bayesian statistics: Bayes Theorem

$$P\left(M_i \middle| D\right) = \frac{P\left(M_i\right) P\left(D \middle| M_i\right)}{P\left(D\right)}$$

Avoids:

- The effects of the bin size
- Making subjective choices about break points

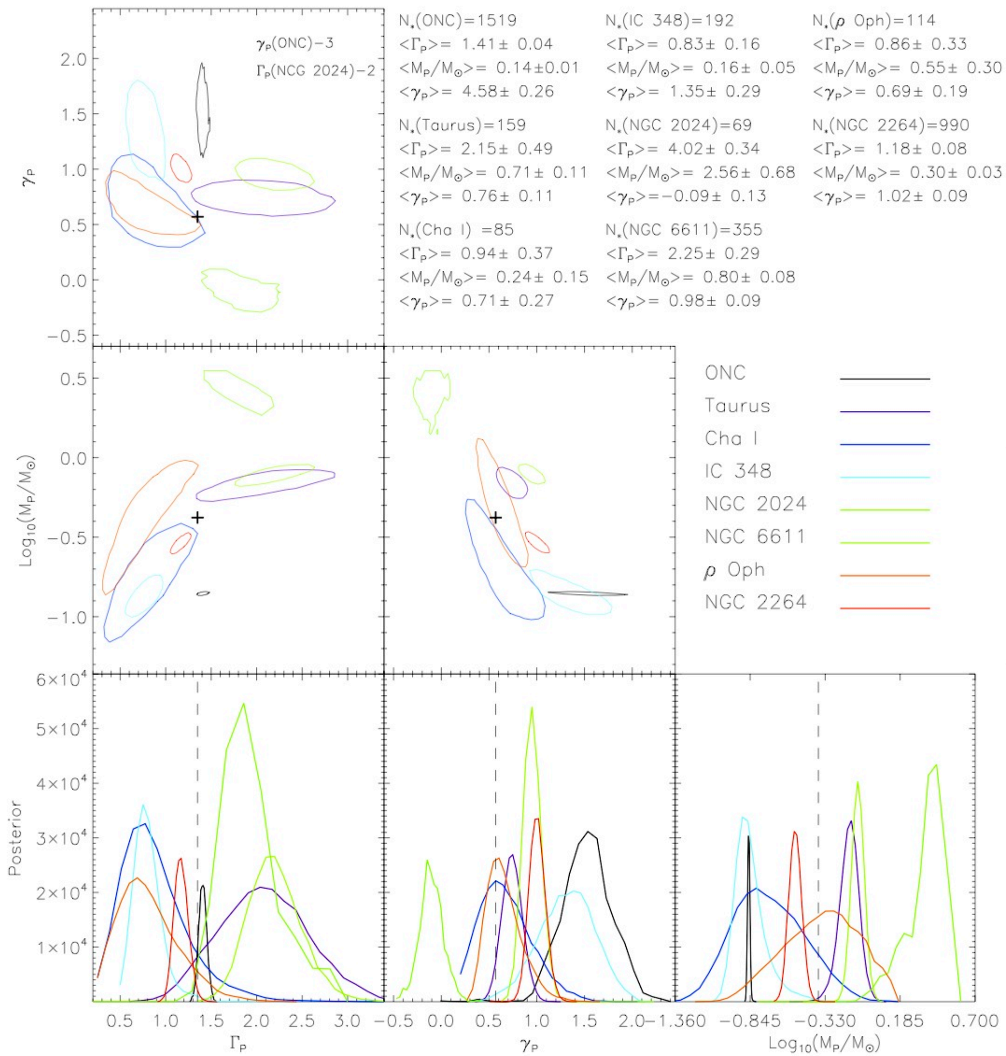
Allows for:

- Including the effects of individual uncertainties on masses
- Effects of completness
- Use of prior information

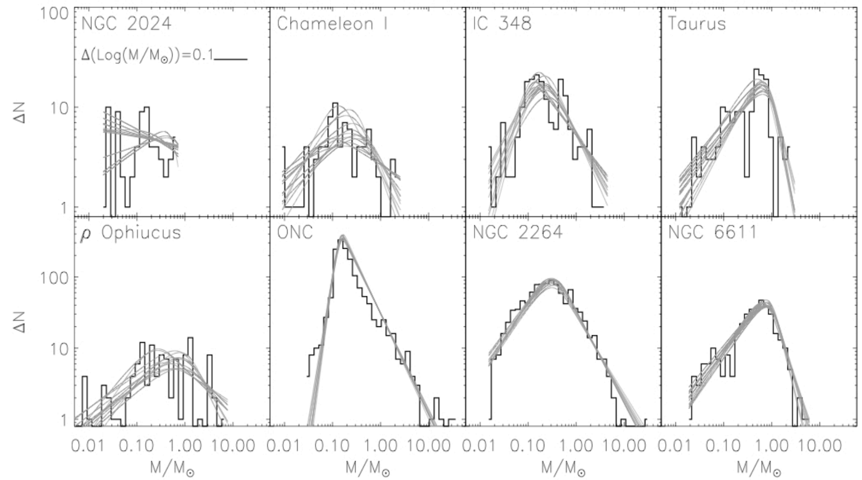
Application to young Galactic Stellar Clusters

Case of tapered power-low likelihood function

$$\xi(\log M) = kM^{-\Gamma}\left\{1-\exp\left[-\left(\frac{M}{M_{ch}}\right)^{\gamma+\Gamma}\right]\right\}$$



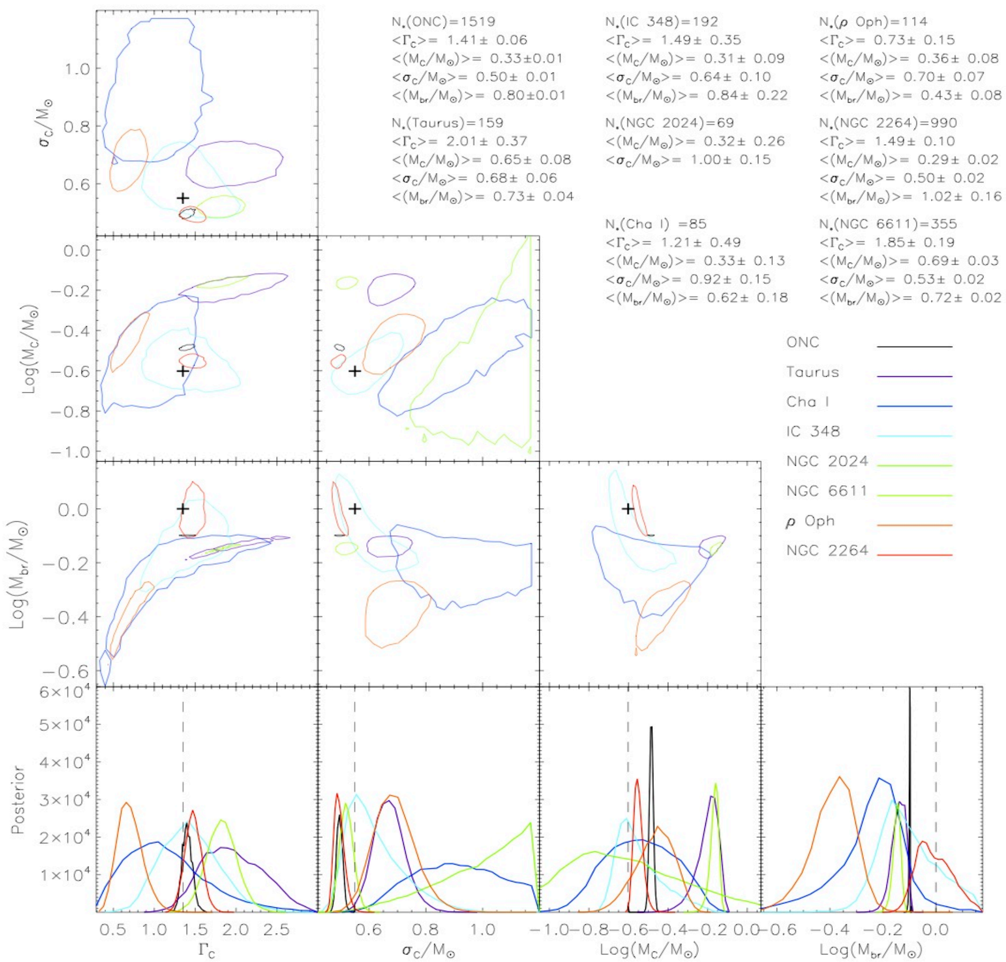
No overlap in the parameters at the 1σ confidence limit



Dib 2014

Application to young Galactic Stellar Clusters

Case of “Chabrier”-like likelihood function

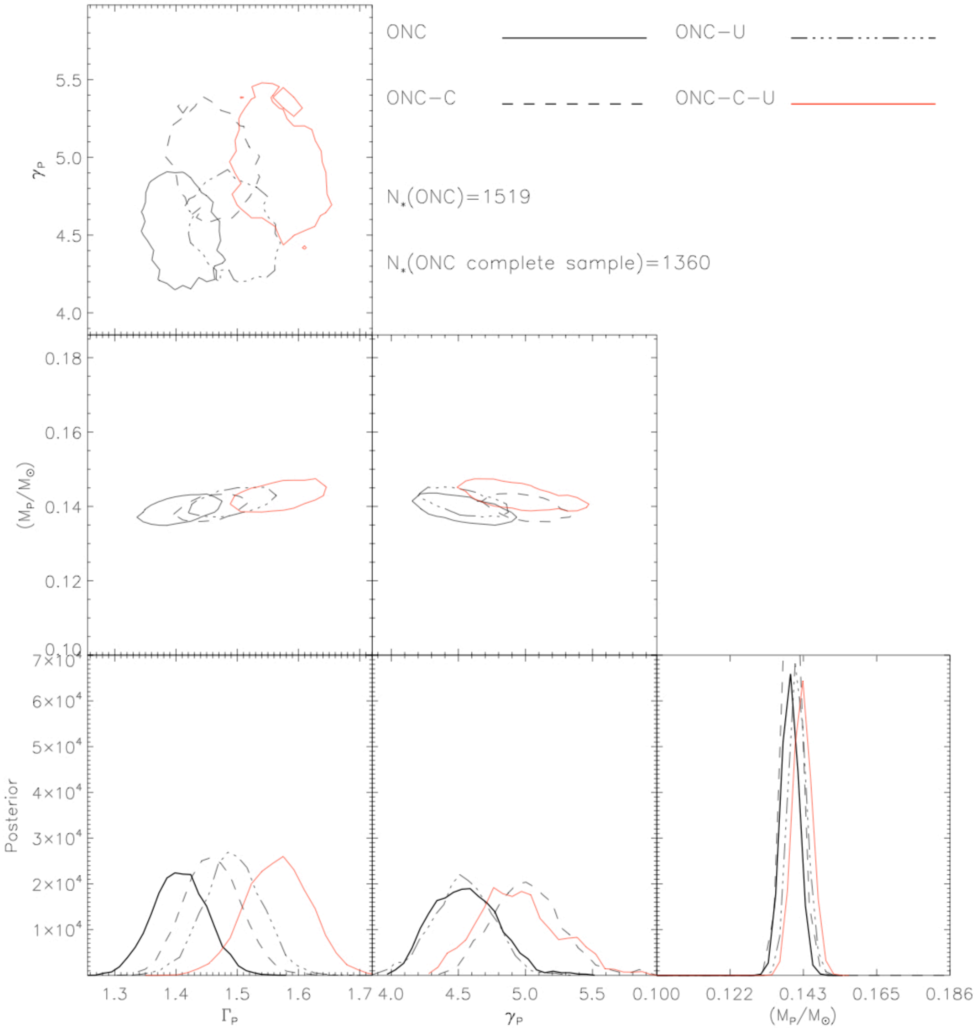


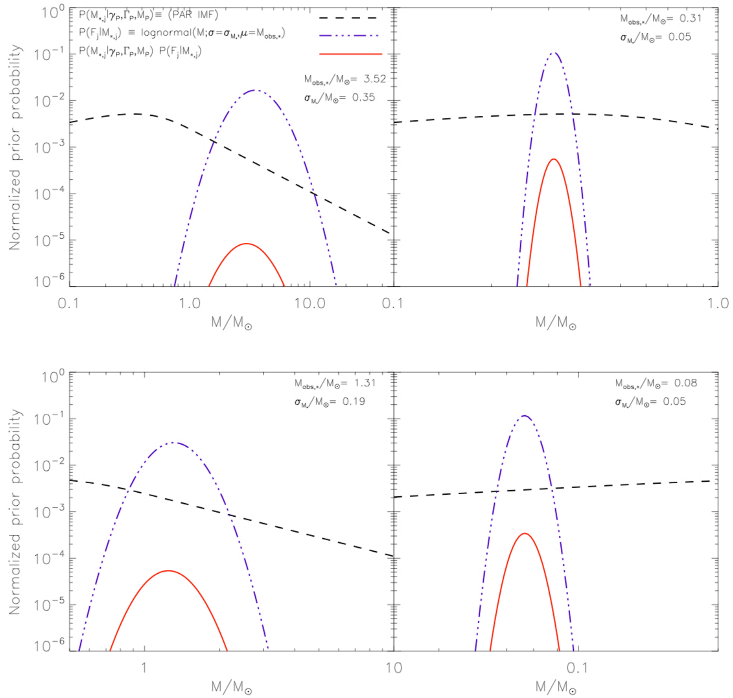
No overlap in the parameters at the 1σ confidence limit

Dib 2014

Application to young Galactic Stellar Clusters

Effect of completeness & mass uncertainties

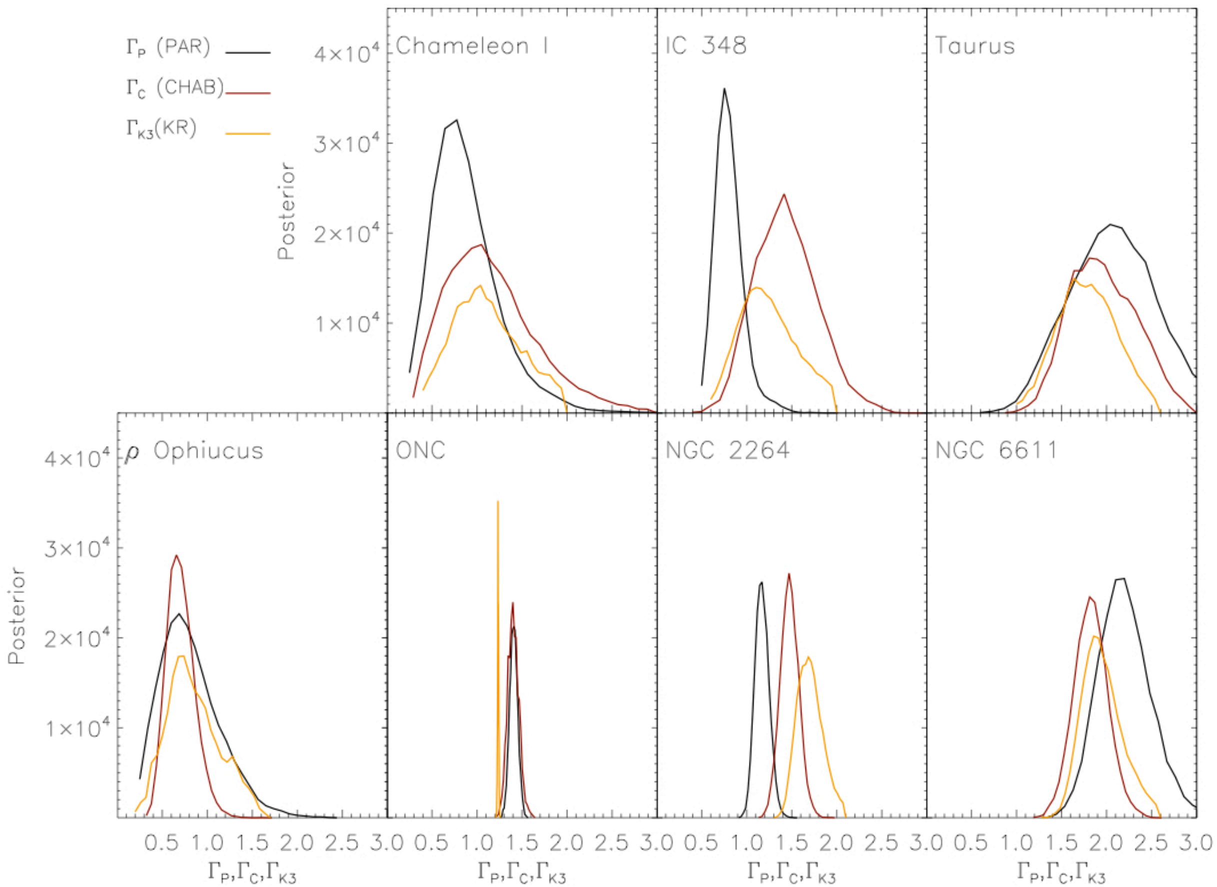




Dib 2014

Application to young Galactic Stellar Clusters

Compare the different likelihood functions



Dib 2014

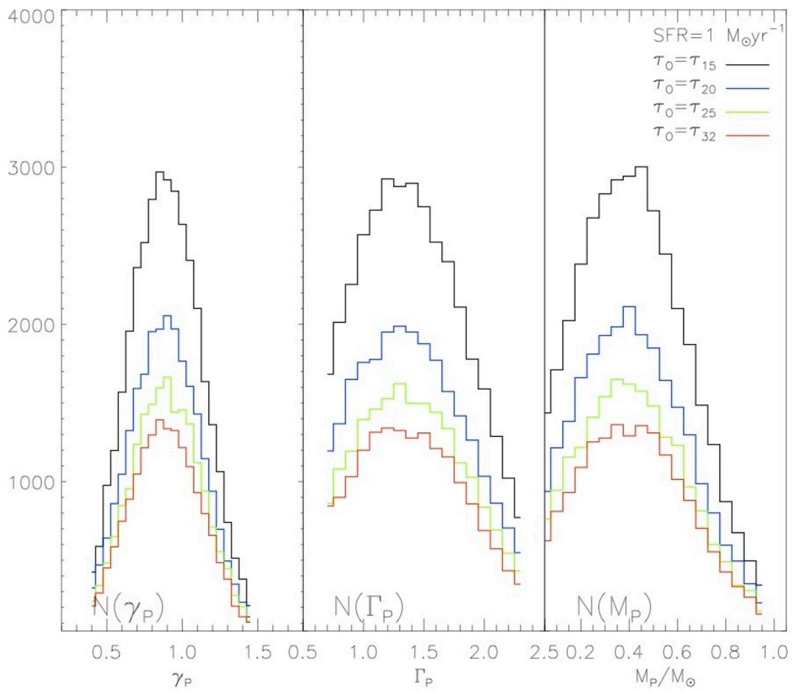
Take-home point

IMF of Galactic clusters not universal !

- Dynamical effects
- Binarity corrections

needed

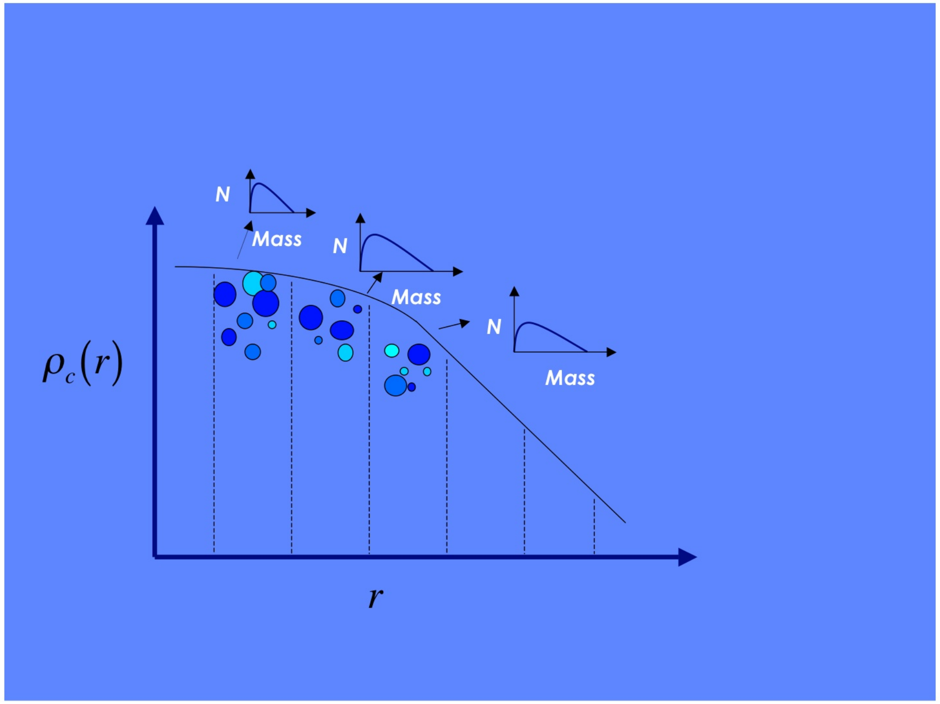
- Larger samples, uncertainty measurements on indivudual masses
- Derive masses using several stellar evolutionary models



what is the parent distribution of the IMF parameters ?

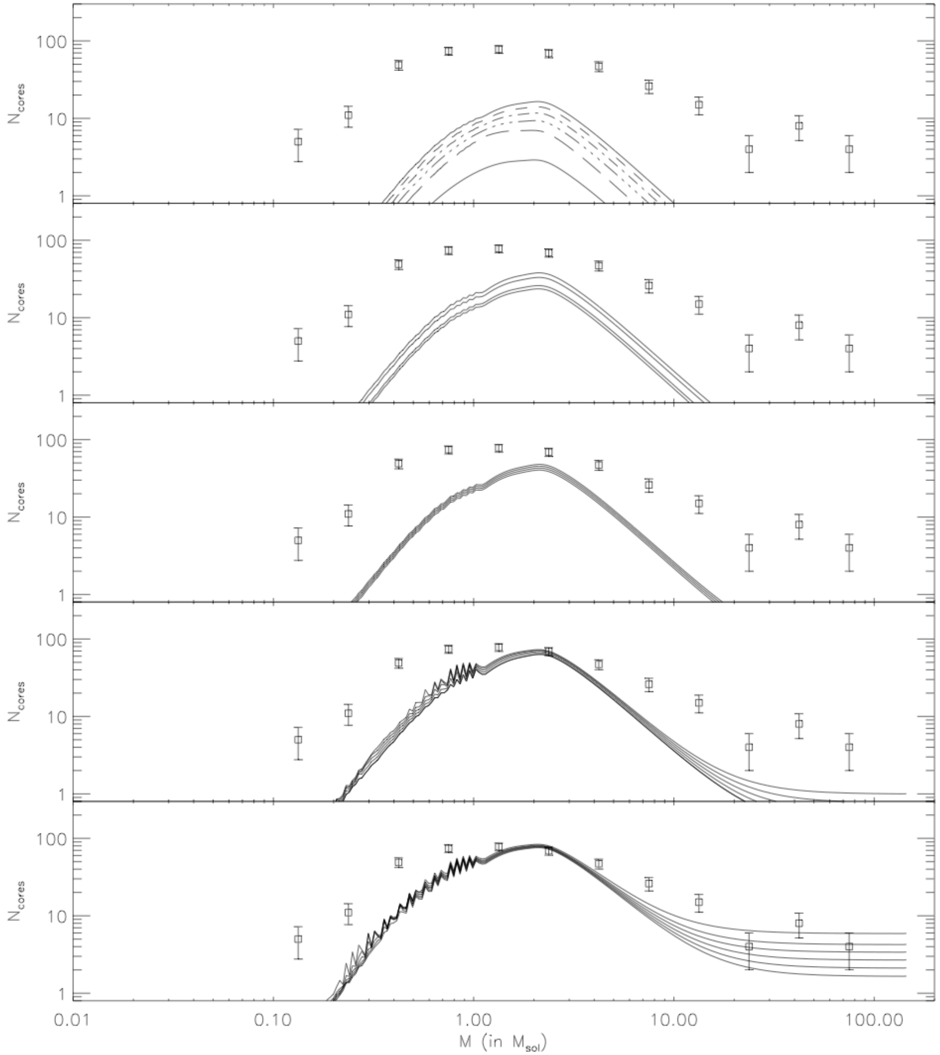
In the presence of accretion on cores
Variations of the SFE and IMF

$$\frac{dN(r,M,t)_{acc}}{dt} = \left(-\frac{\partial N}{\partial M}\dot{M} - \frac{\partial \dot{M}}{\partial M} N \right)(r,M,t)$$



Dib et al. 2010

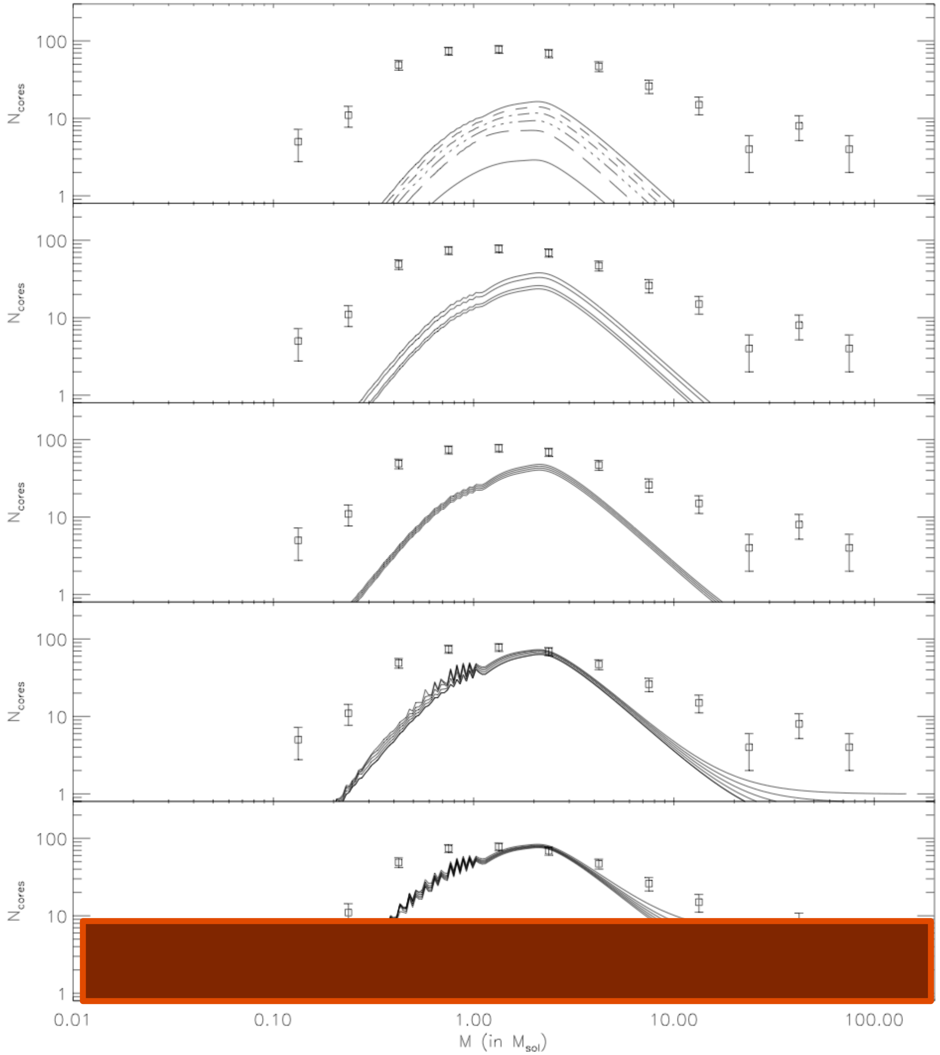
$$\frac{dN(r,M,t)_{acc}}{dt} = \left(-\frac{\partial N}{\partial M}\dot{M} - \frac{\partial \dot{M}}{\partial M} N \right)(r,M,t)$$



Data points: Orion A+B cloud Johnstone & Bally 2006?

Dib et al. 2010

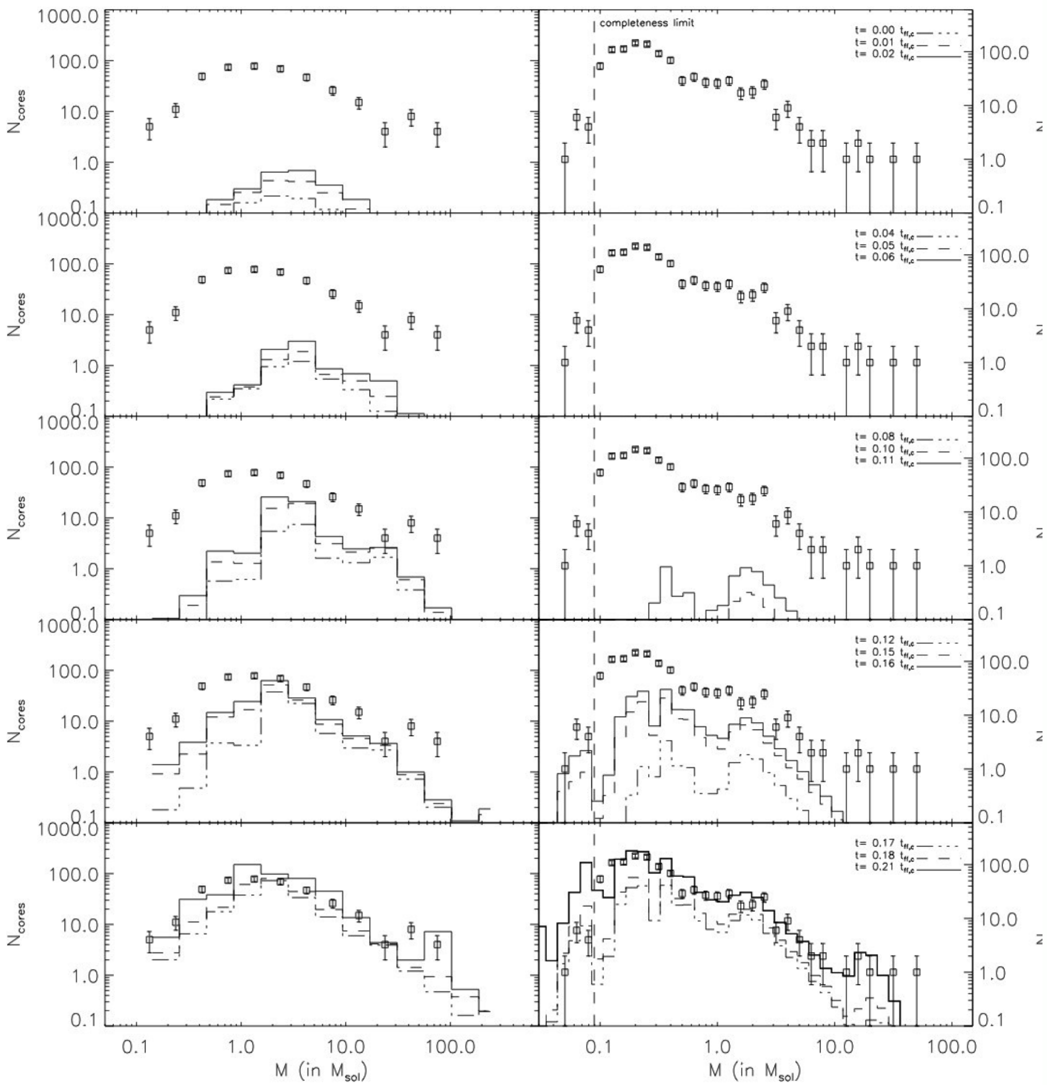
$$\frac{dN(r,M,t)_{acc}}{dt} = \left(-\frac{\partial N}{\partial M}\dot{M} - \frac{\partial \dot{M}}{\partial M} N \right)(r,M,t)$$



In low-mass clusters: no tail at high stellar masses

Dib et al. 2010

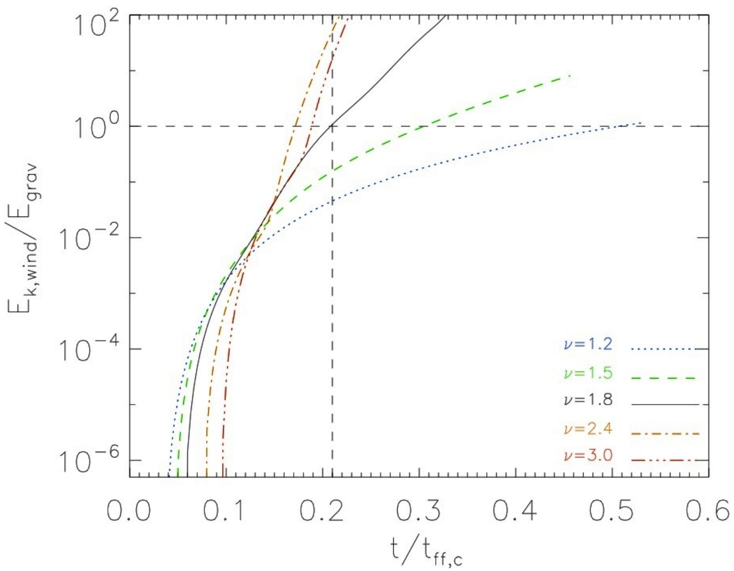
Application to the Orion Cloud and the ONC

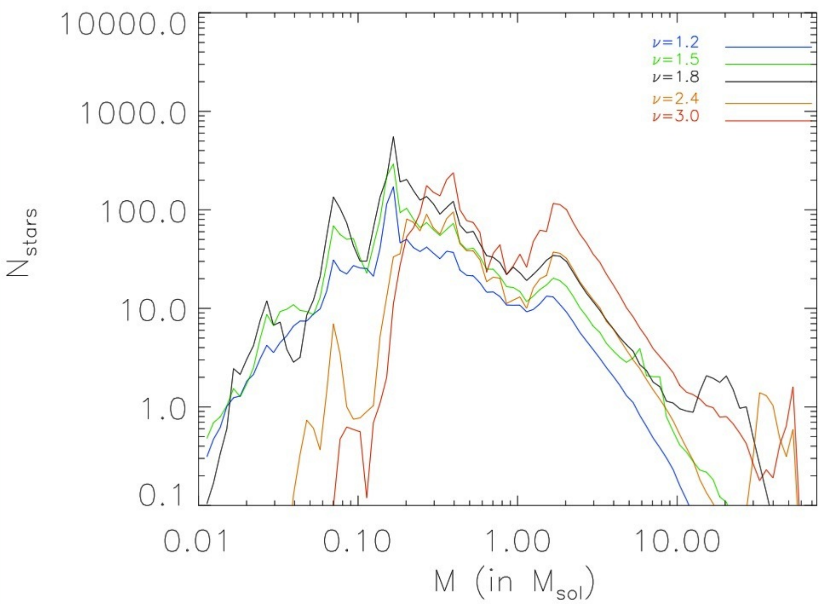


Dib et al. (2010)

Variations with the cores properties

Effect of varying the lifetimes of the cores+stopping effect of feedback

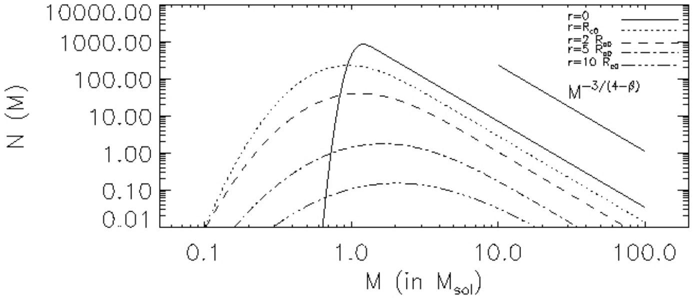




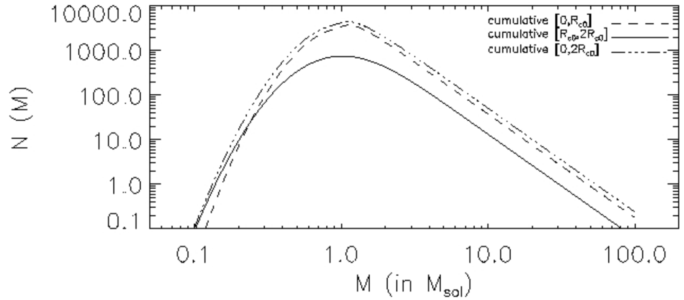
Dib et al. 2010

Effects of core coalescence

Initial conditions (Padoan & Nordlund 2002) → **calculate instanteneous cross section of collision between contracting objects of Masses M_i and M_j and integrate over the mass spectrum.**



$$\sigma(M_i, M_j, r, t) = \pi\left(R_i(t) + R_j(t)\right)^2\left[1 + \frac{2G\left(M_i + M_j\right)}{2v^2(R_i(t) + R_j(t))}\right]$$



$$\frac{dN(r,M,t)_{coal}}{dt} = \frac{1}{2}\eta(r)\int_{M_{\min}}^{M-M_{\min}} N(r,m,t)N(r,M-m,t)\sigma(m,M-m,r,t)v(r)dm$$

$$-\eta(r)N(r,M,t)\int_{M_{\min}}^{M_{\max}} N(r,m,t)\sigma(m,M-m,r,t)v(r)dm$$

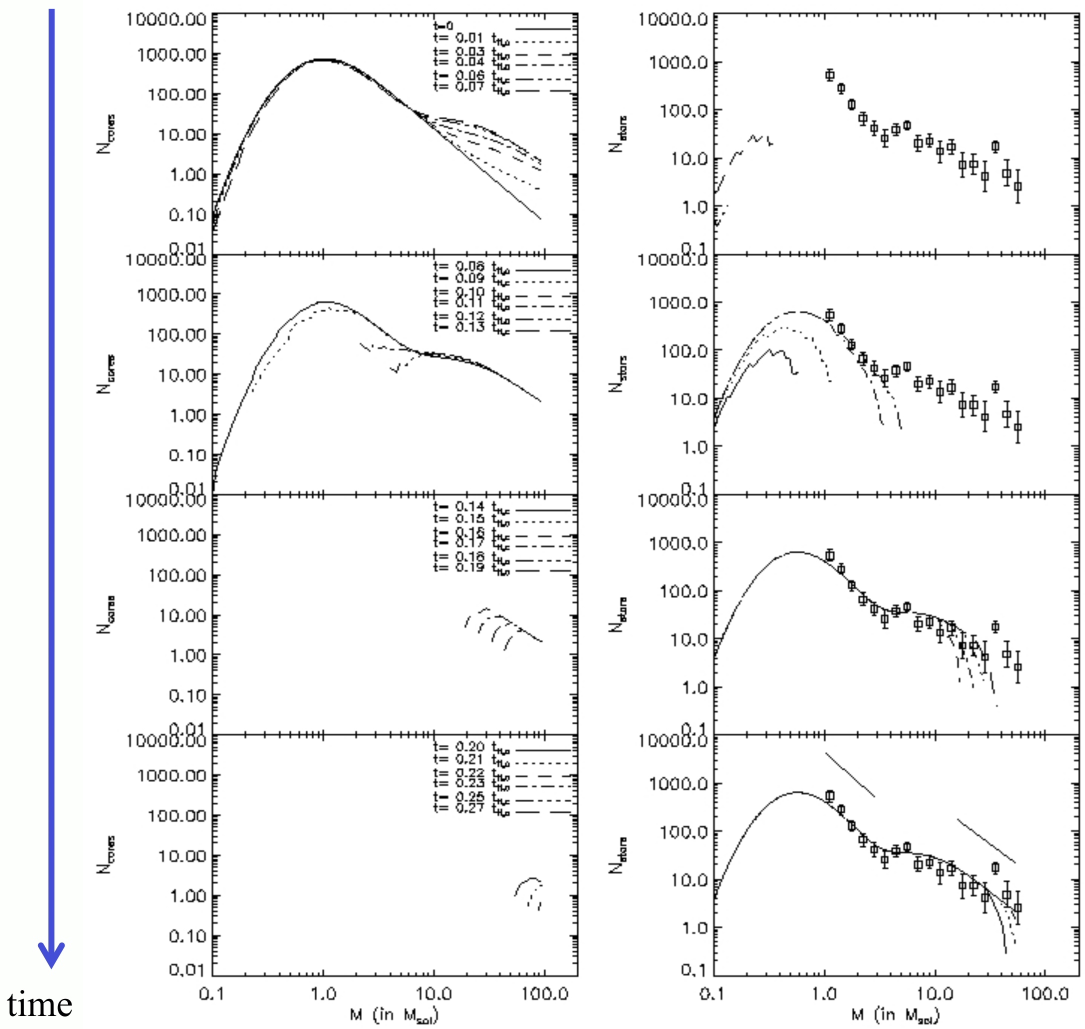
α=0.4

β=1.8

Slope= -3/(4-β)-1=-2.33

Dib et al. 2007

Core coalescence: application to Starburst Clusters

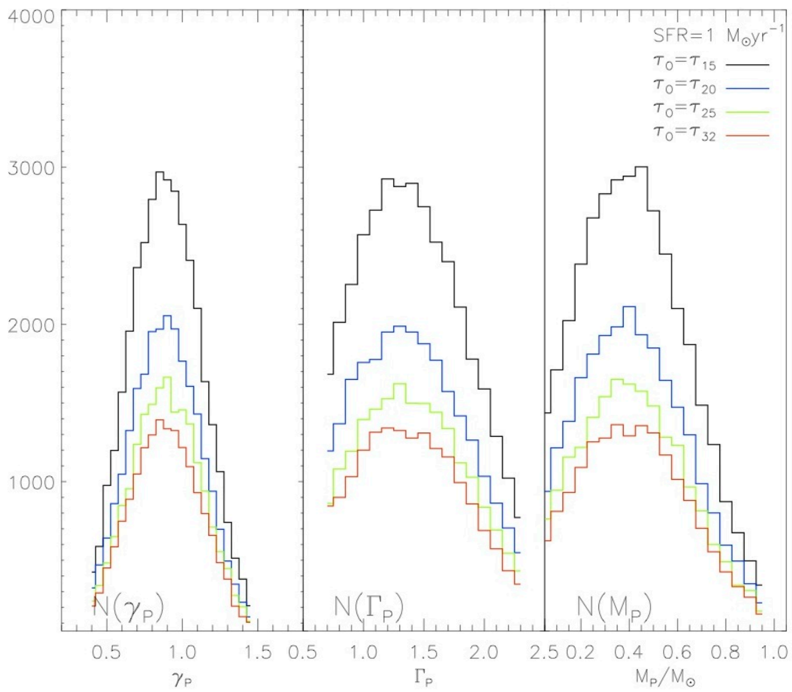


Dib et al. 2007

Take-home point 2

Star formation processes that can generate "non-standard" prmordial IMFs in clusters exist

What is their frequency ?



what is the parent distribution of the IMF parameters ?