$$dN/dm \propto m^{-\alpha} \quad \text{Salpeter value } \alpha = 2.35$$

$$\xi(\log m) = \frac{A}{\sqrt{2\pi}\sigma} \exp\{-\frac{(\log m - \log m_c)^2}{2\,\sigma^2}\} = \frac{dn}{d\log m}$$

# The sub-stellar IMF


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LAOG


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constellation

A European Commission Sixth Framework Programme
Marie Curie Research Training Network

$$\xi(M) = \frac{dN}{d\log M} = A\exp\left(\frac{-(\log M - \log M_c)^2}{2\sigma^2}\right)$$

$$\Psi(M) = \frac{dN}{dM} \propto M^{-\alpha} \text{ stars pc}^{-3}\, M_\odot^{-1}$$

# Thanks to…

constellation

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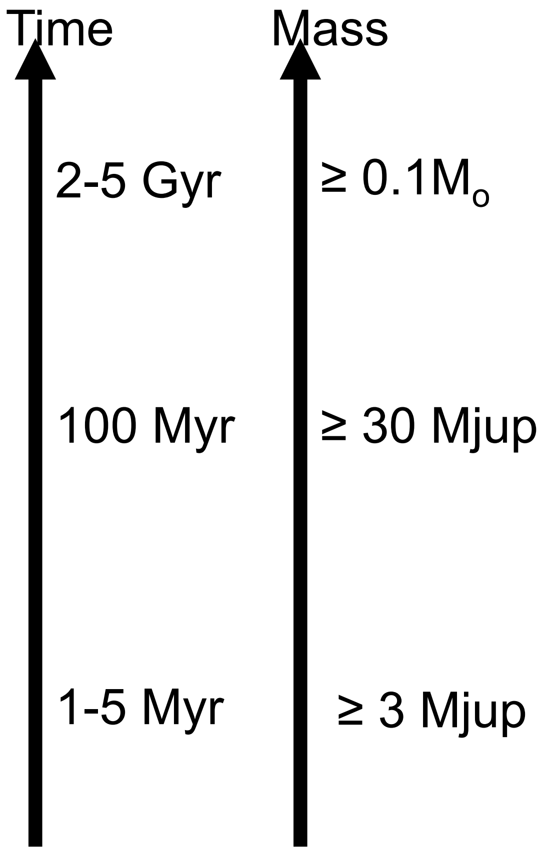
# Outline

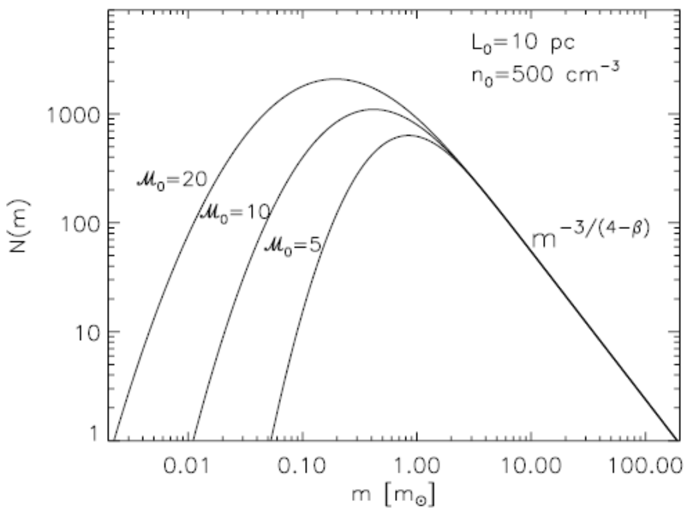
0. Observational and theoretical uncertainties in the derivation of the MF

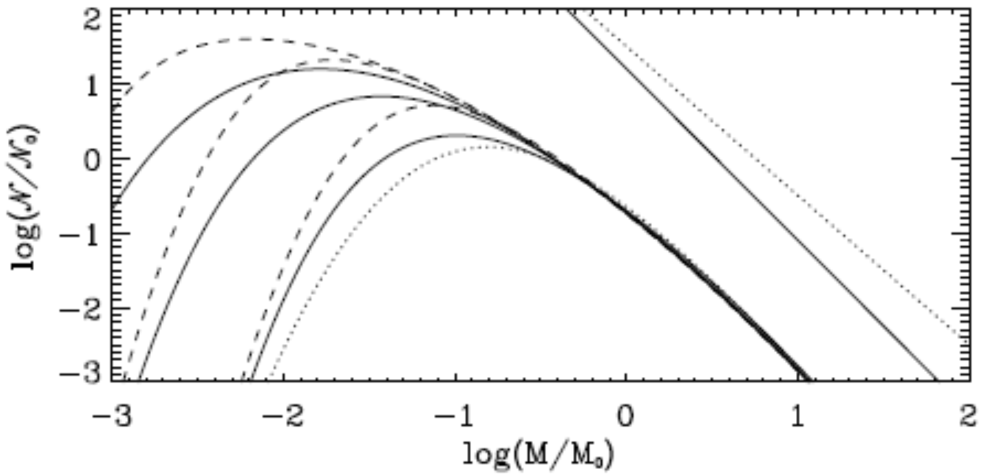
1. Galactic disc : *Low-mass stellar MF* estimates
2. Young open clusters : *Substellar MF* estimates
3. Star forming regions : *The lower end of the MF*



# The sub-stellar IMF

• How useful is it ? (dependence on local conditions, e.g. Padoan & Nordlund 2002, Hennebelle & Chabrier 2008)




- Can we measured it ?
- Yes, in principle, we can (Luminosity → Mass)
- But is is not easy…
- How reliable is it ?
- What are the uncertainties ?

# Observational uncertainties on the luminosity function (LF)

- **Contamination** of photometric surveys by field stars (dwarfs, giants) and/or extragalactic objects (galaxies, quasars)
- **Uncompleteness** of magnitude- and/or volume-limited surveys,  in particular when the extinction is spatially variable
- **Biases** (Malmquist, mass segregation) and **low number statistics** (Poisson, binning)
- **Multiplicity**, crowding, missed objects (e.g. near bright stars)

# Theoretical uncertainties on the mass function (MF)

- **Mass-luminosity relationship**: LF→MF (model-dependent, age-dependent)
- **Disk accretion** may affect the early evolution of young stars (cf. Baraffe et al. 2009)
- **Magnetic activity** impacts on the luminosity (hence, mass estimate) of low mass stars (cf. Jackson et al. 2009, Mohanty et al. 2009)

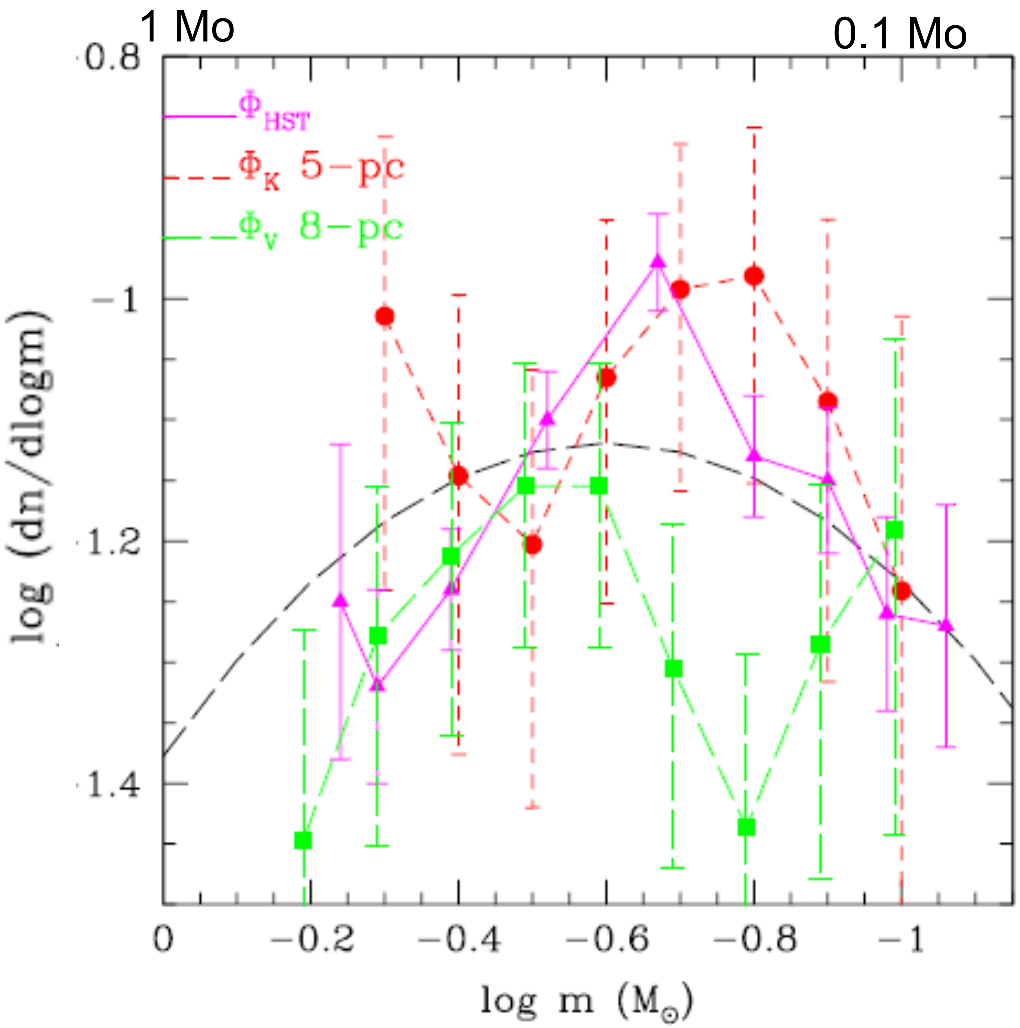
# Different sources of uncertainties for different environments

- **Field (2-5 Gyr):**
  age, mass, [Fe/H], Malmquist bias
- **Young open clusters (30-600 Myr):**
  contamination by field stars, dynamical evolution, mass segregation
- **Star forming regions (1-5 Myr):**
  variable extinction, accretion, mass-luminosity relationship
- **All:** multiplicity, magnetic activity

# I. The low-mass stellar MF ($M \geq 0.1\ M_o$)

Galactic disk (~2-5 Gyr)

# Galactic disk low mass MF




Chabrier 2005

**System MF** (unresolved binaries)

*Red dots:* 27 M dwarfs closer than 5 pc (Henry & MCarthy 1990)

*Pink triangles:* 1400 M dwarfs HST (Zheng et al. 2001)

$$\xi(M) = \frac{dN}{d\log M} = A\exp\left(\frac{-(\log M - \log M_c)^2}{2\sigma^2}\right)$$

$M_c$ = 0.25 Mo
σ = 0.55

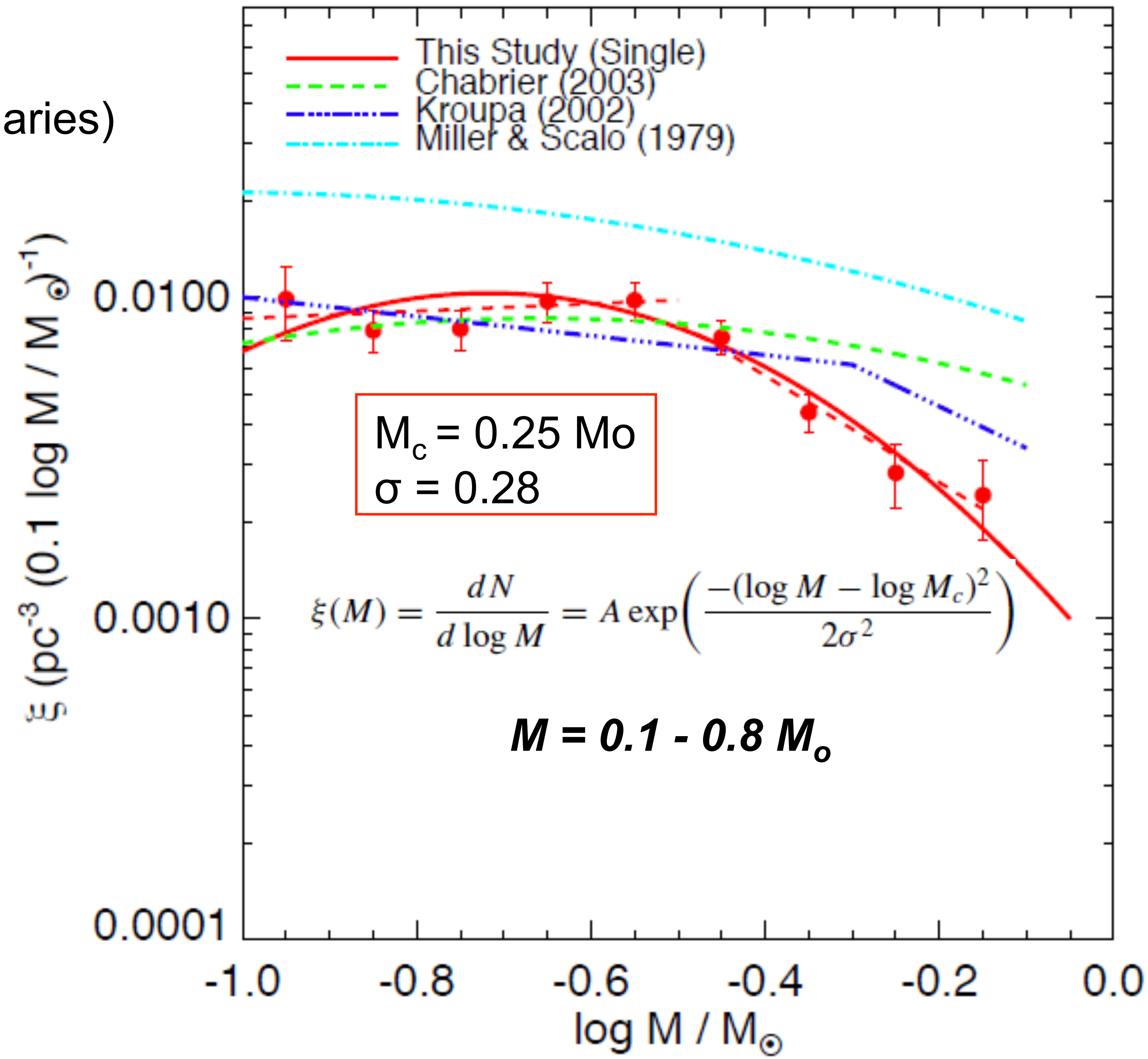
**Small sample size**
**Completeness limit ~ 0.1 Mo**

# Galactic disk low mass MF

**System MF** (unresolved binaries)

Bochanski et al. (2010)

SDSS/2MASS/GSC:
**~15,000,000 stars**
(0.1-0.8 Mo)



# Field substellar MF ?

- Several hundred L and T dwarfs known to date
- But: no “clean” sample with individually known distance + age => Mass
- Can’t estimate the field substellar MF directly (i.e., by counting BDs in mass bins)
- Instead, need a statistical model to predict the expected number of L and T dwarfs

(Monte Carlo simulations, e.g. Burgasser 2004)

  – galactic population (IMF) + galactic birth rate + Mass-Lum relationship + multiplicity rate
    => compare with (bias corrected) photometric surveys

# Field substellar MF ?

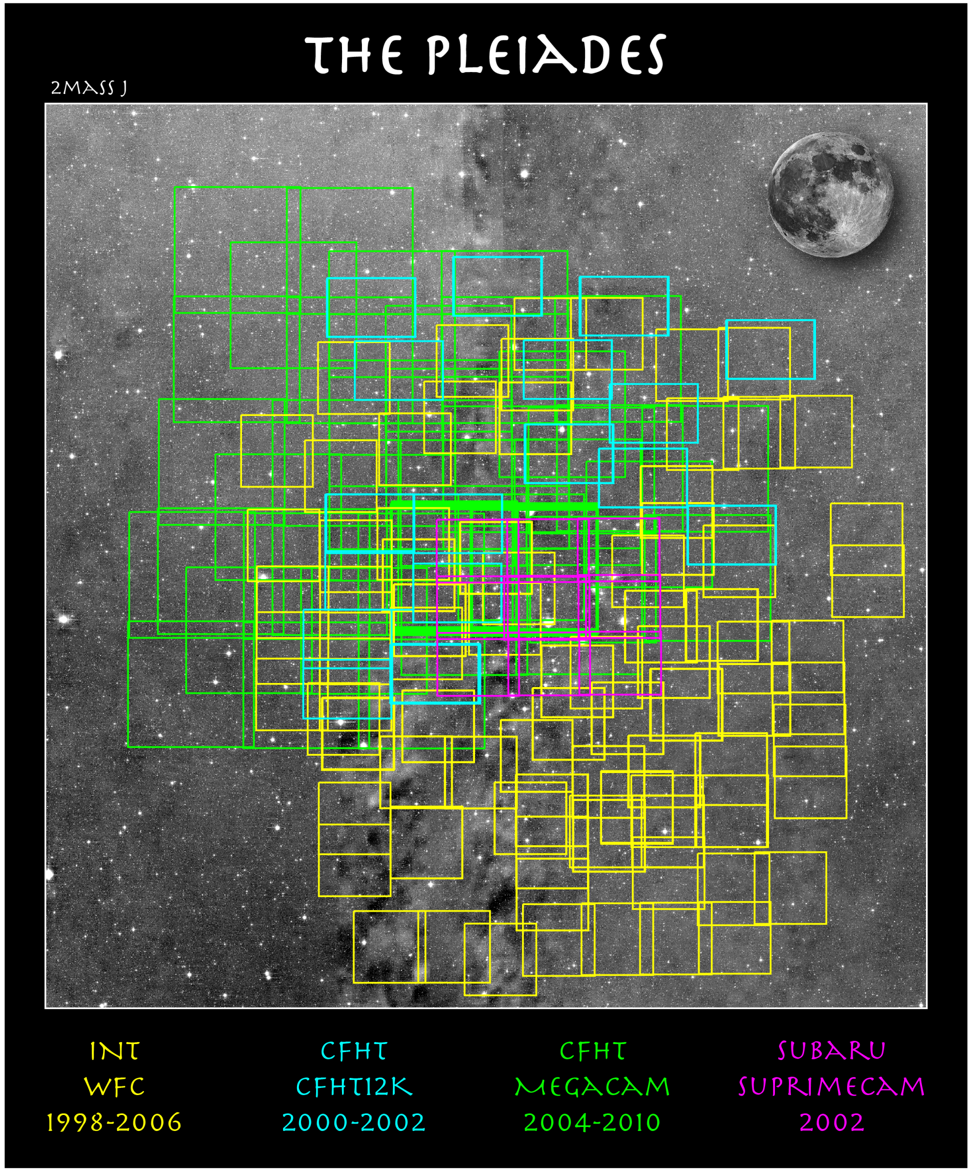
## Power-law index of the substellar field MF estimated from MC simulations

| Authors | Survey | Sample | α $dN/dm \propto m^{-\alpha}$ | Mass range |
|---|---|---|---|---|
| Pinfield et al. (2008) | UKIDSS LAS (mag-lim) | 17 late T dwarfs (>T4) | **-1.0 to 0.0** | ~0.04Mo |
| Allen et al. (2005) | 2MASS (vol-lum) | ~200 MLT dwarfs | **+0.3 +/- 0.6** | 0.04-0.10 Mo |
| Metchev et al. (2008) | SDSS/2Mass (mag-lim) | 15 T dwarfs (T0-T8) | **~ 0.0** | ≤0.075 Mo |
| Chabrier (2005) | Compilation | LMT dwarfs | **≤ 1.0 (or lognorm)** | ≤0.075 Mo |
| Cruz et al. (2007) | 2MASS (vol-lum) | 45 L dwarfs | **≤ 1.5** | ≤0.075 Mo |

# II. The substellar MF

Young open clusters (30-600 Myr)

# Pleiades : a benchmark cluster

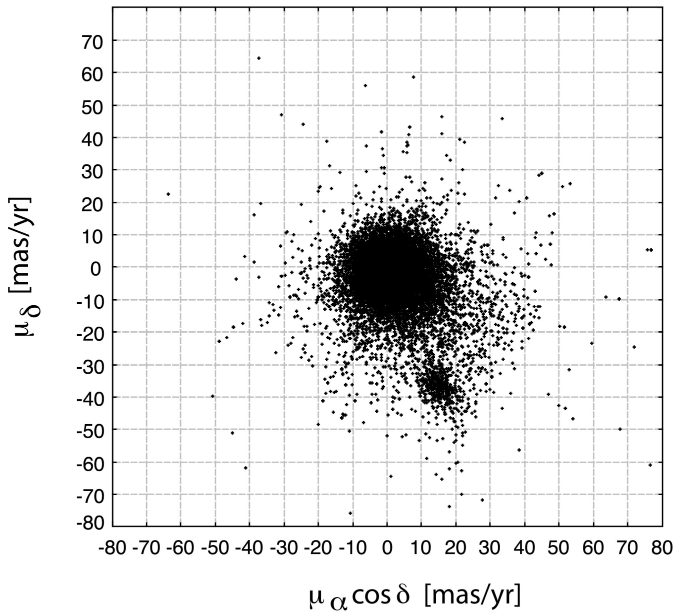



**Distance = 120-130 pc**

**Lithium age = 125 +/- 8 Myr**
(Stauffer et al. 1998)

**Star / BD boundary @ I ~ 17.8 mag**
(Bouvier et al. 1998)

Proper motion diagram from wide-field surveys (Bouy, Moraux, Bertin et al. in prep)



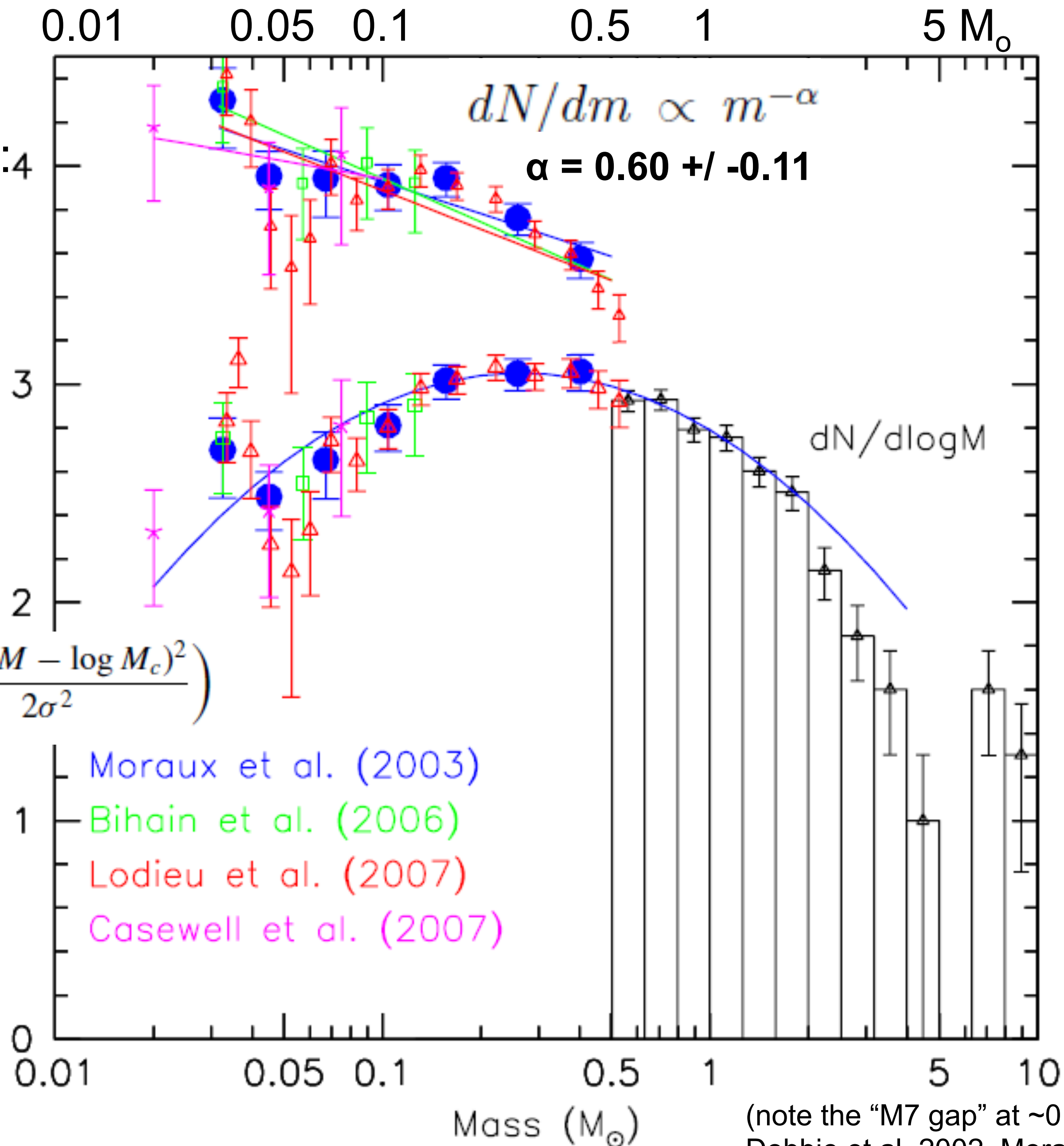
# Pleiades MF: optical - IR surveys

**System MF**
(unresolved binaries):
**~70 substellar members**

Lognormal fit :

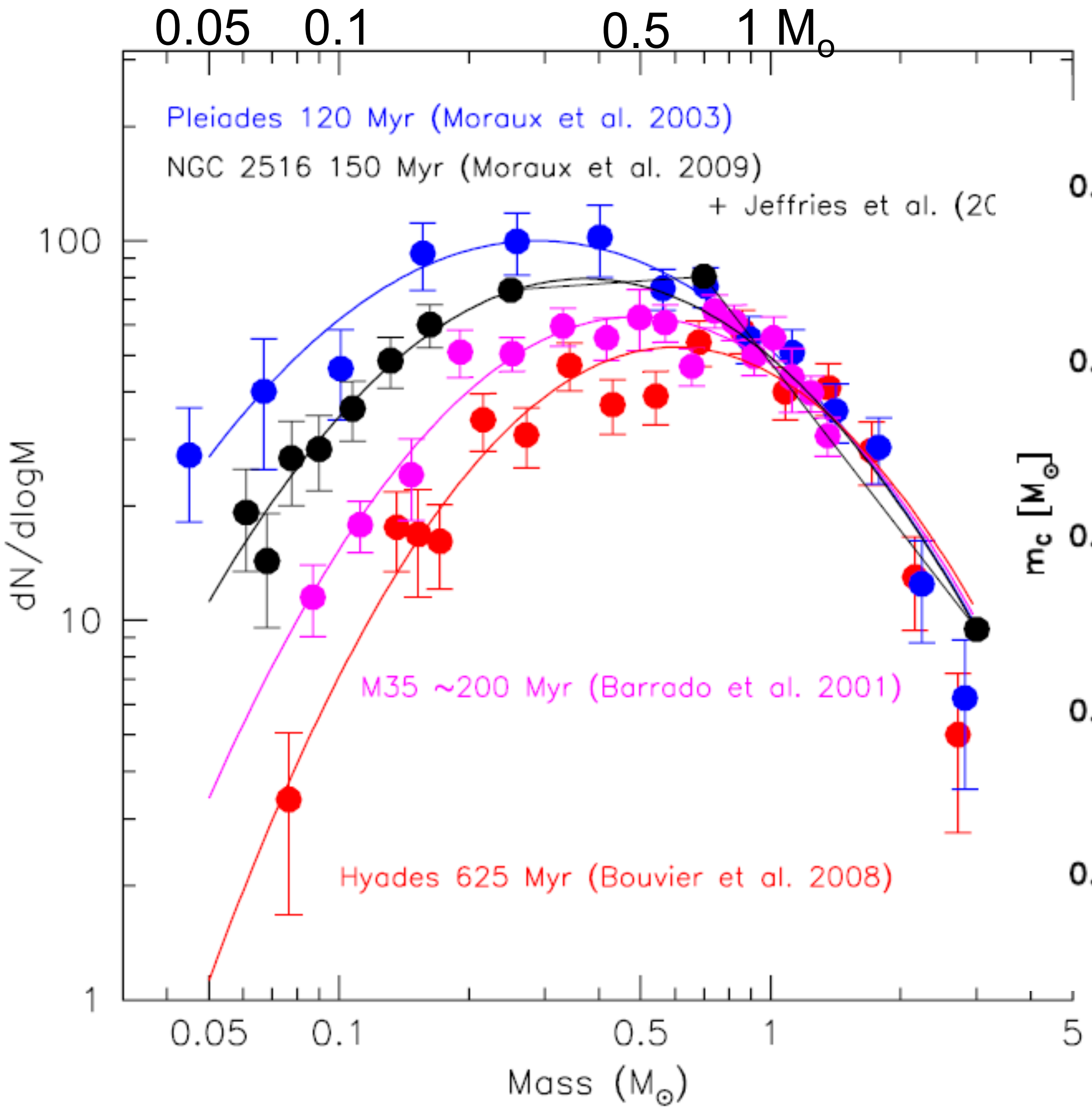
**$M_c$ = 0.25 Mo**
**$\sigma$ = 0.52**

$$\xi(M) = \frac{dN}{d\log M} = A\exp\left(\frac{-(\log M - \log M_c)^2}{2\sigma^2}\right)$$



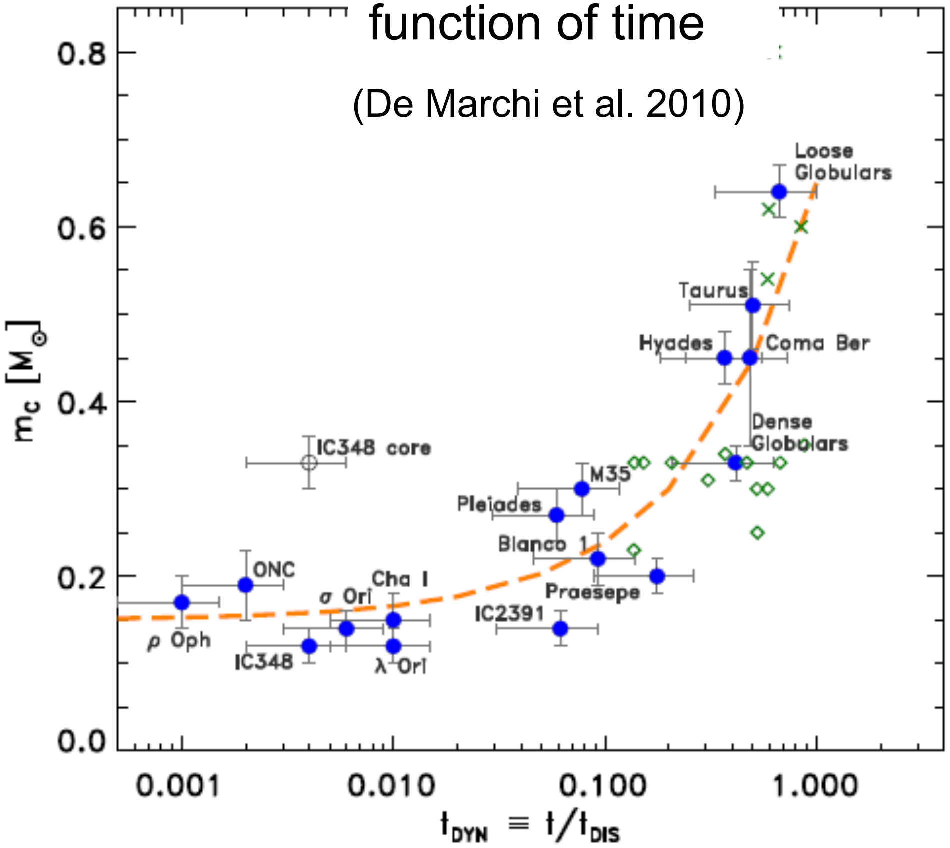

(note the “M7 gap” at ~0.05Mo; cf. Dobbie et al. 2002, Moraux et al. 2007)

# The dynamical evaporation of very low mass objects

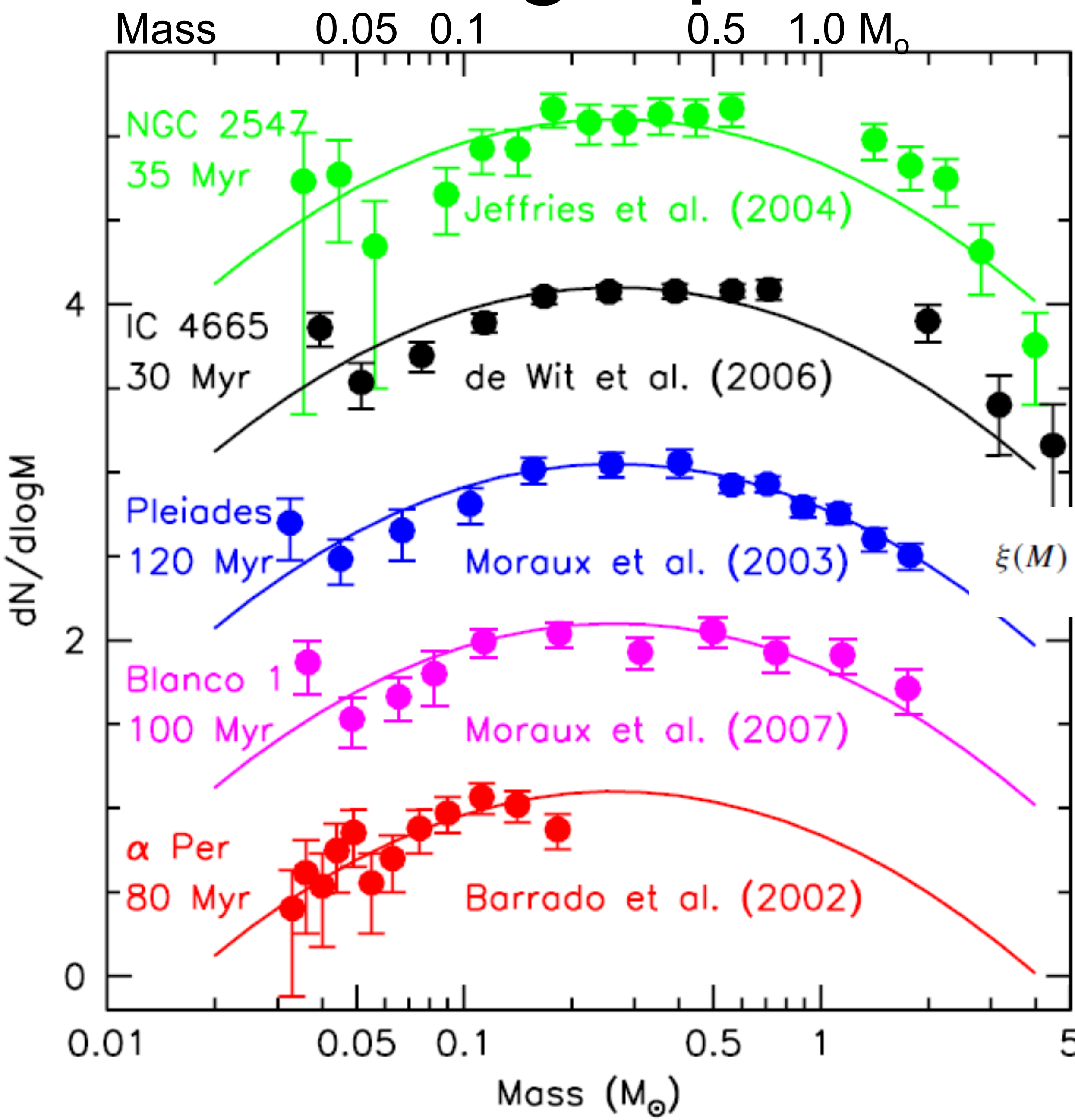



Peak mass as a function of time

(De Marchi et al. 2010)



# Young Open Clusters' MF




**System MF**
(unresolved binaries)

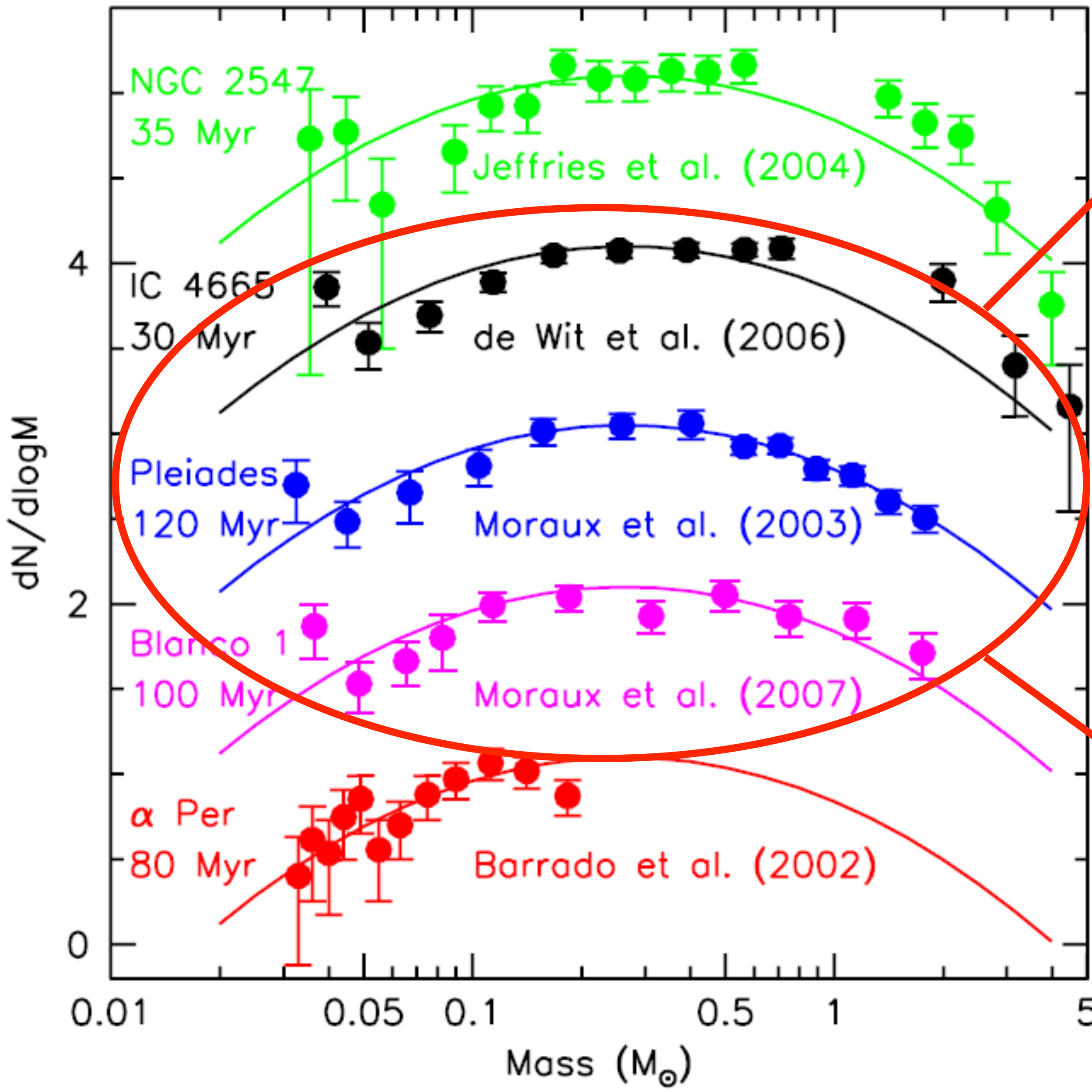
All observed YOC MFs consistent within errors with Pleiades lognormal fit in the mass range ~0.030-1.0 Mo

$$\xi(M) = \frac{dN}{d\log M} = A\exp\left(\frac{-(\log M - \log M_c)^2}{2\sigma^2}\right)$$

**$M_c$ = 0.25 Mo**
**σ = 0.52**

Little evidence for cluster-to-cluster variations

# Combining the YOC MFs




**System MF**
(unresolved binaries)

Same group

Same instrument

Same analysis

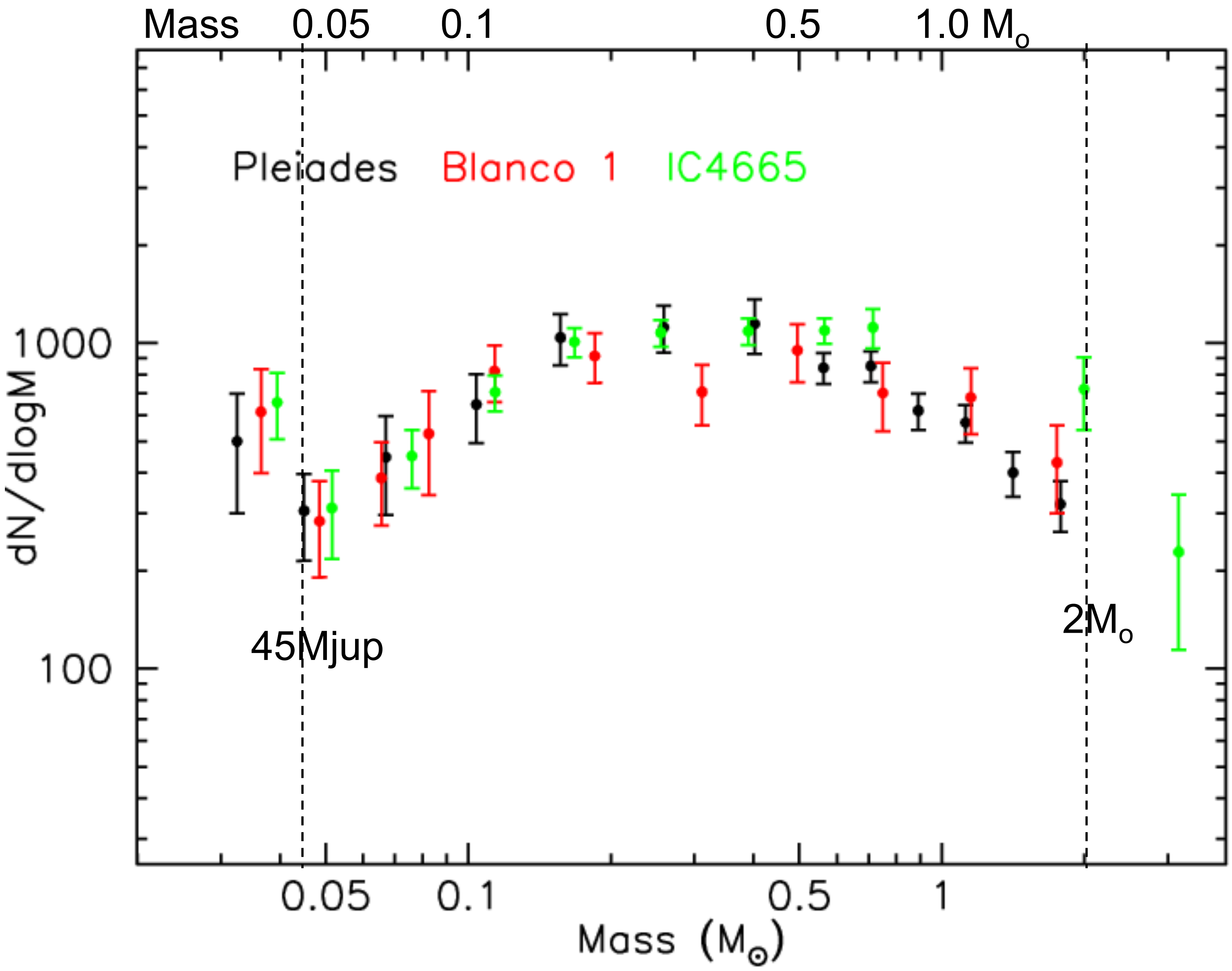
Same corrections (e.g. mass segregation)

Same models for M-L relationship

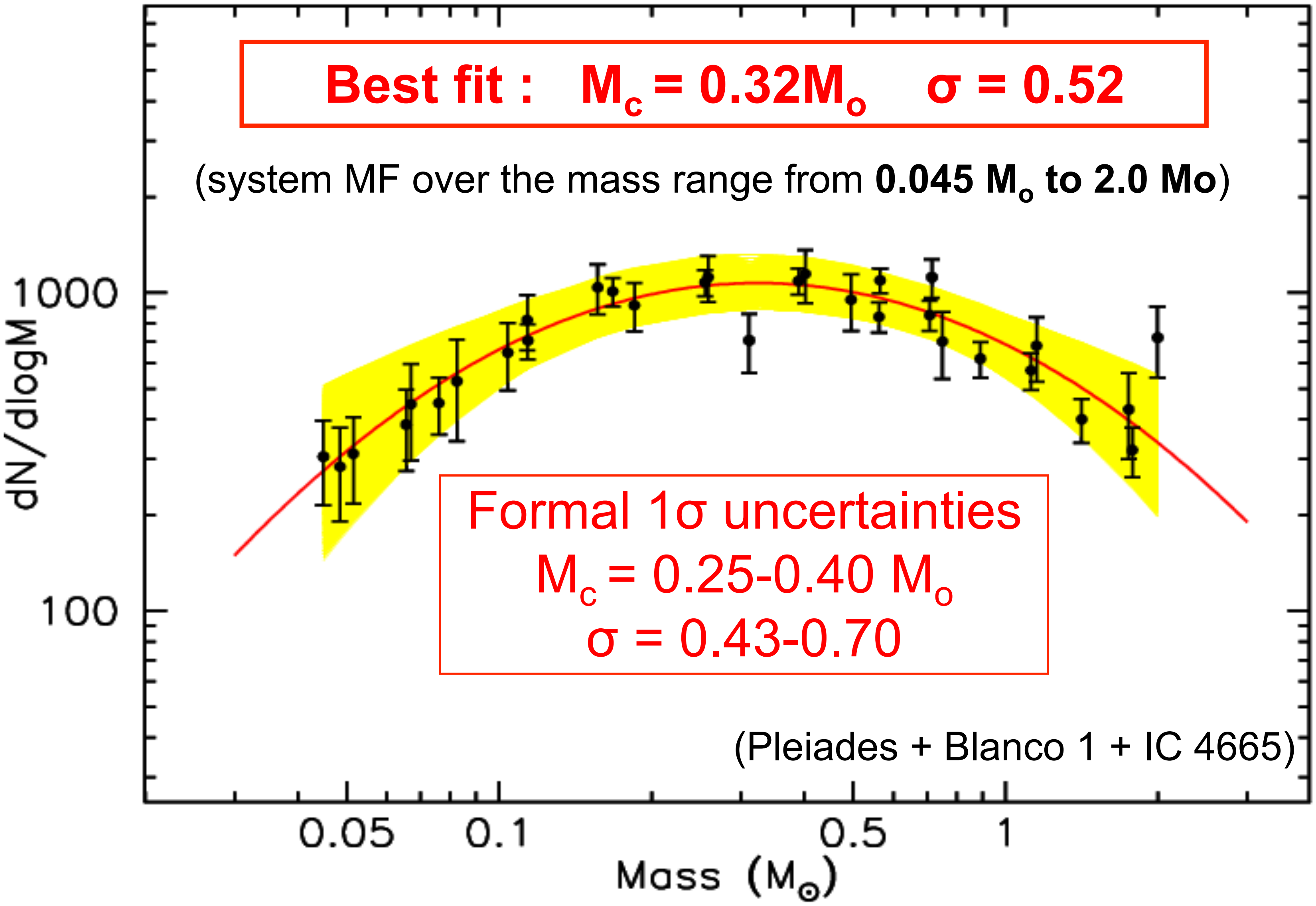
(Same referee ?)

Allows the derivation of an internally-consistent MF for young open clusters

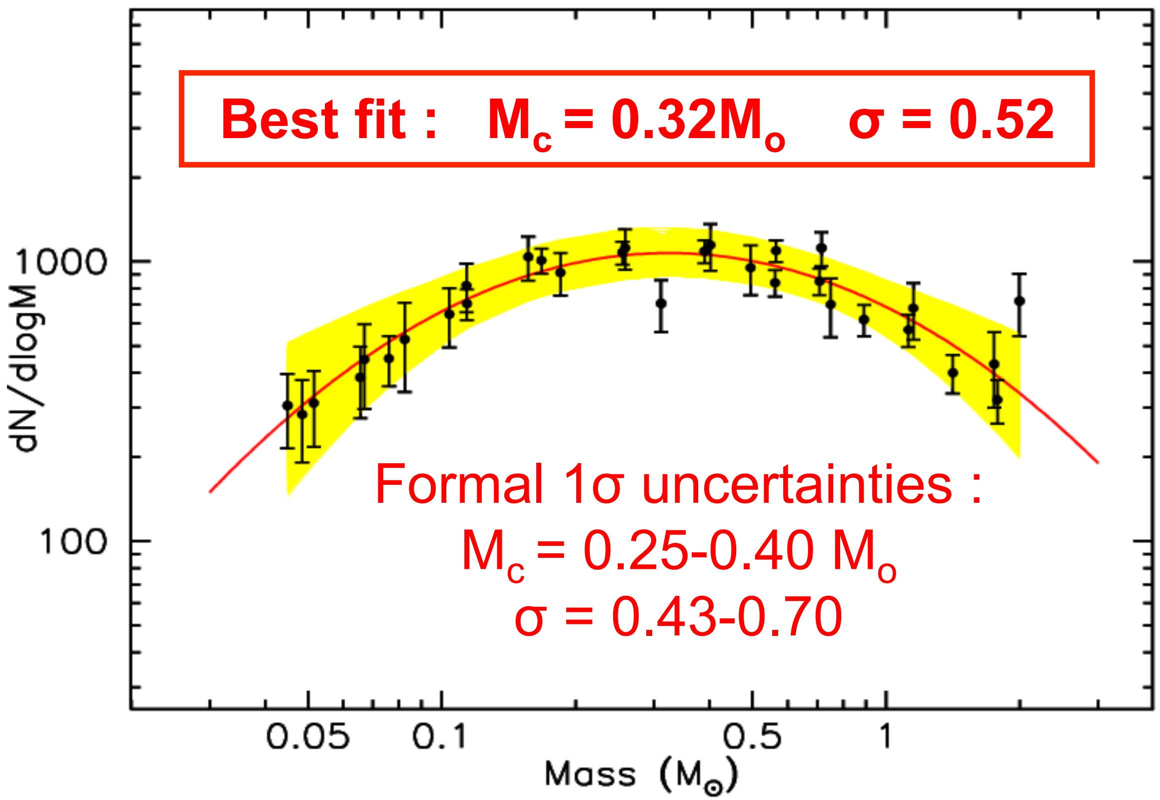
# The « generic » open cluster MF



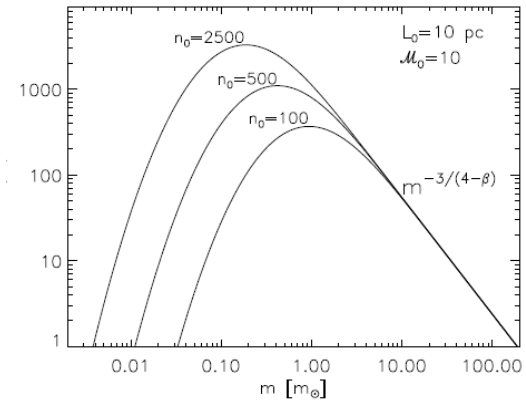
# A log-normal fit to the OCMF



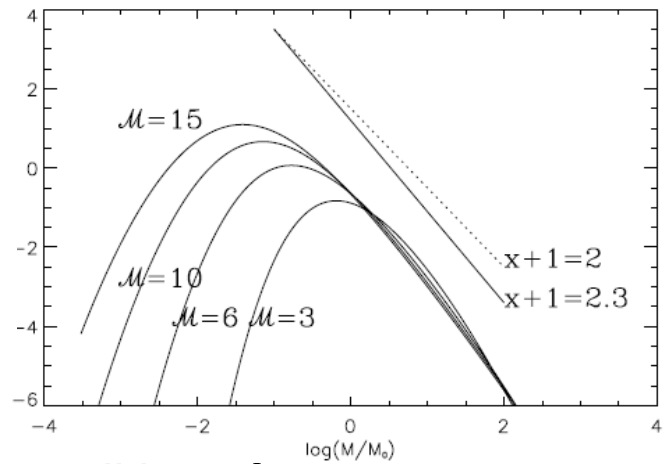
# Comparison to model predictions




Padoan & Nordlund 2002




Hennebelle & Chabrier 2008

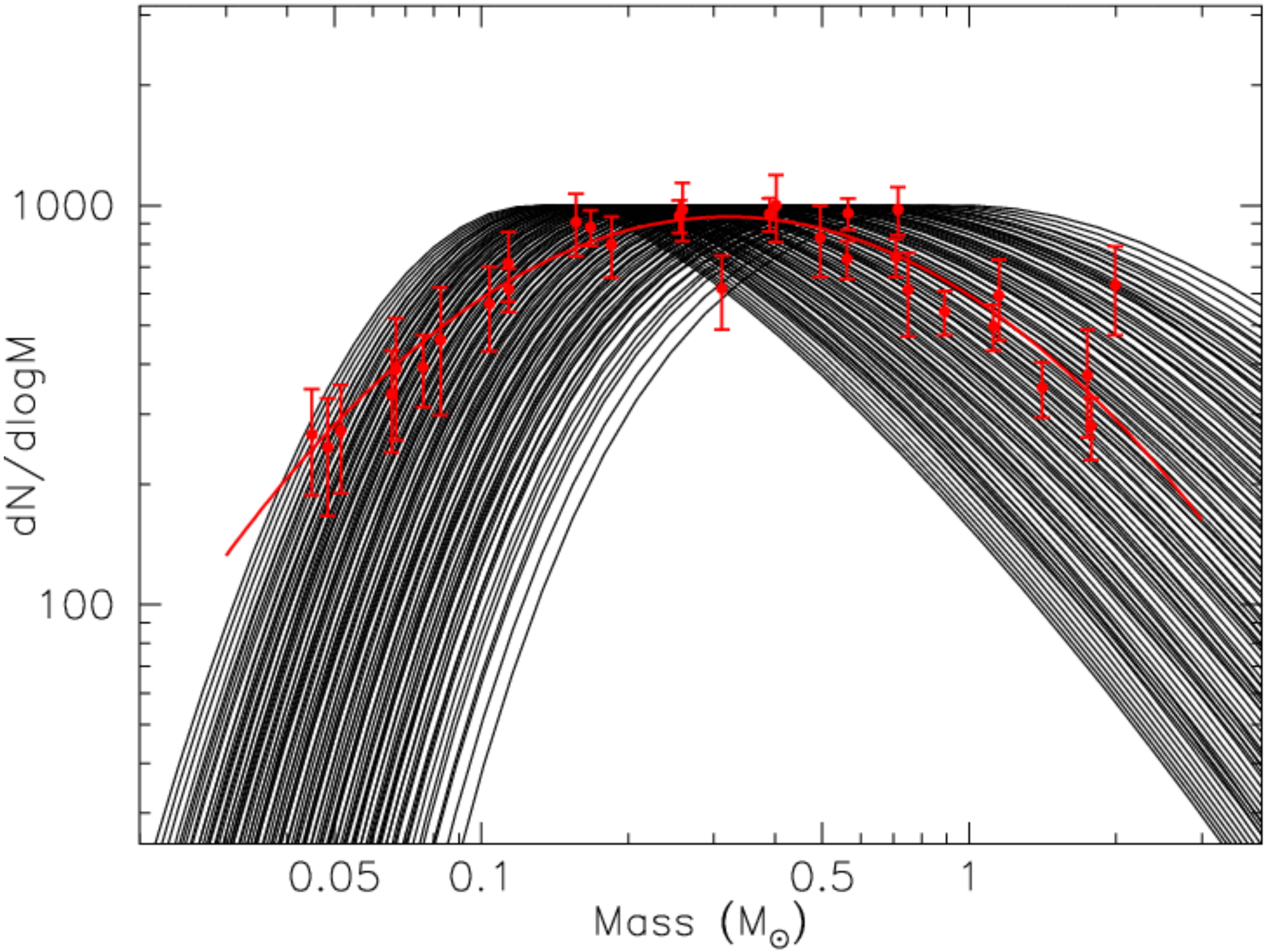



Were the 3 clusters formed under the same initial conditions ?

Or is the MF not very sensitive to local initial conditions ?

# CMF *vs.* IMF

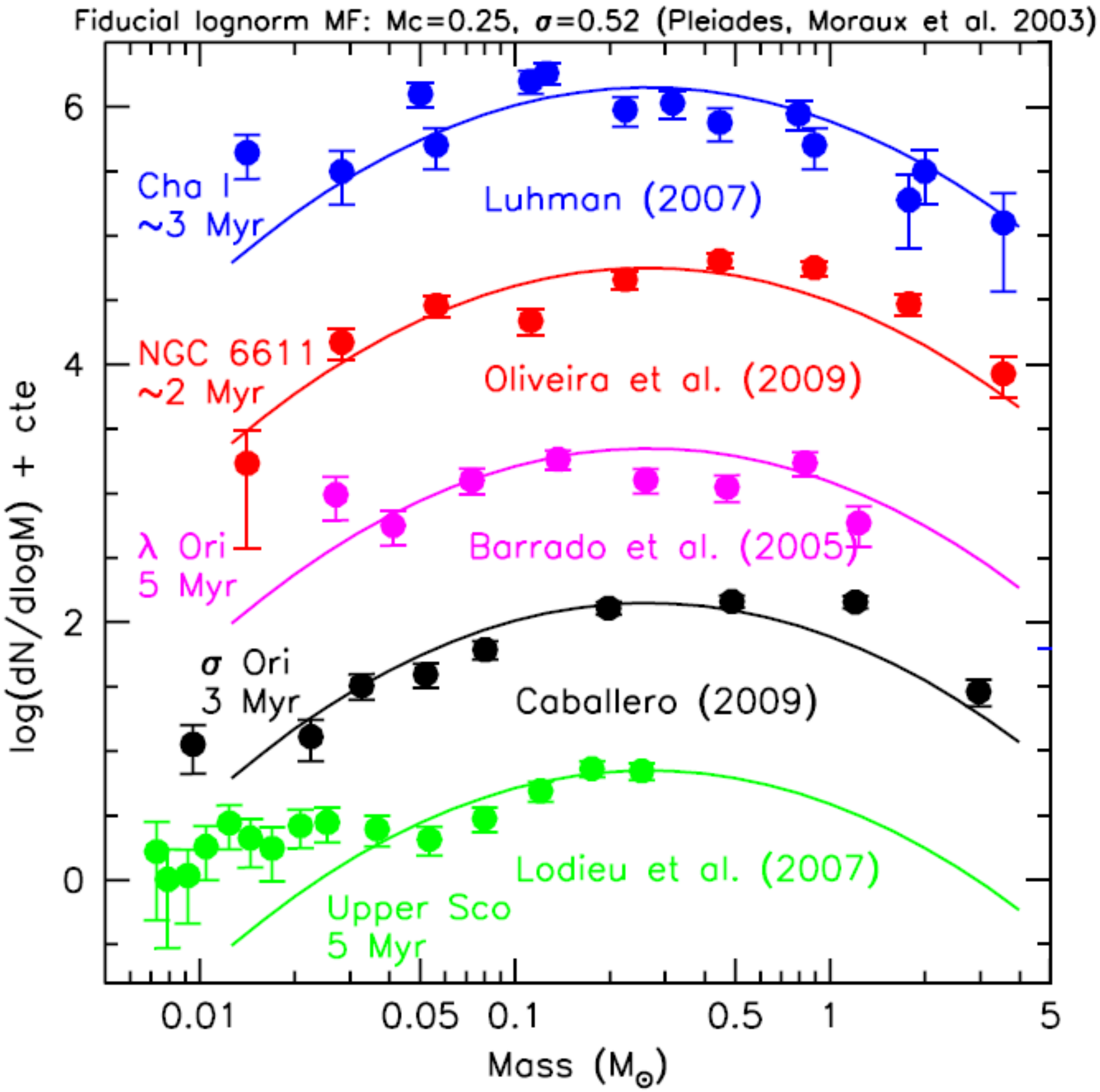
CMF grid model : L=2-4 pc;  logρ = 3.8-4.8 $cm^{-3}$    (Hennebelle & Chabrier 2009)



# III. Towards the planetary mass domain

Star forming regions (1-5 Myr)

# SFRs lower MF




**System MF**
(unresolved binaries)

Significant differences are observed at the lower end of the MF at young ages.

Some SFRs are consistent with the extrapolation of the Pleiades lognorm MF (e.g. NGC 6611), others not (e.g. Upper Sco).

*Issues:*

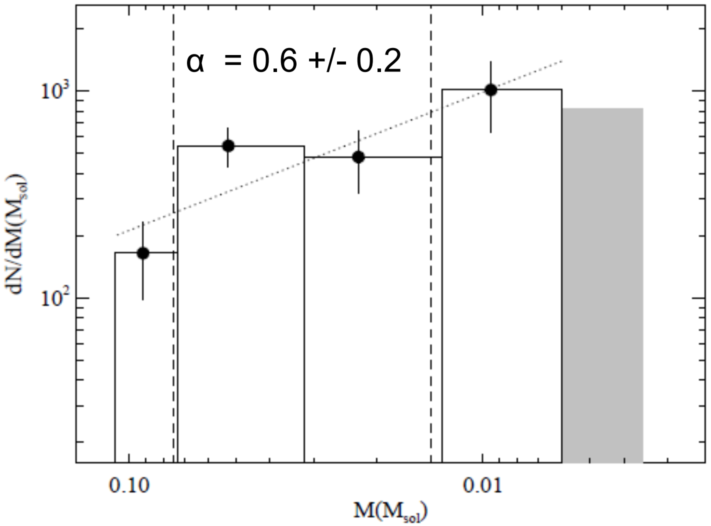
Residual contamination ? Incompleteness? Mass segregation ?

Uncertain luminosity-mass relationship below the DBML at these ages ?

# T dwarfs in SFRs

- T dwarfs are presumably below the Deuterium burning limit (~13 Mjup) at an age of 3 Myr *(models would predict ≤5 Mjup)*

Sigma Ori




Caballero et al. (2007)
Bihain et al. (2009)
Lodieu et al. (2009)

**<u>IC348 (~3 Myr):</u>**
IC348_CH4_2 : estimated Sp.T ~ T6 (Burgess et al. 2009)

**<u>Sigma Ori (~3 Myr):</u>**
S Ori 70: a T6 dwarf (Zapatero Osorio et al. 2002)
S Ori 72 and S Ori 73 : L/T and T dwarf candidates (Bihain et al. 2009)

# Summary

- *Galactic population:* the **stellar field MF** is +/- well constrained down to ~0.1 $M_o$; poorly known in the substellar domain due to age/mass uncertainties
- *Young open clusters:* the **substellar MF** is well-defined down to 30 Jupiter masses; the system MF can be described by **a lognormal mass distribution with Mc~0.3$M_o$ and σ~0.5 over the mass range 0.03-1.0 $M_o$**
- *Star forming regions:* give access to the **lower end of the IMF** down to the planetary-mass domain; masses still uncertain but very young T dwarfs indeed seem to exist : the lowest mass isolated objects ?

# The (local) IMF ?

adapted from Bastian, Covey, Meyer 2010