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

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

The sub-stellar IMF

LAOG

Laboratoire d'AstrOphysique de Grenoble

J. Bouvier

LAOG

constellation

A European Commission Sixth Framework Programme

Marie Curie Research Training Network

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

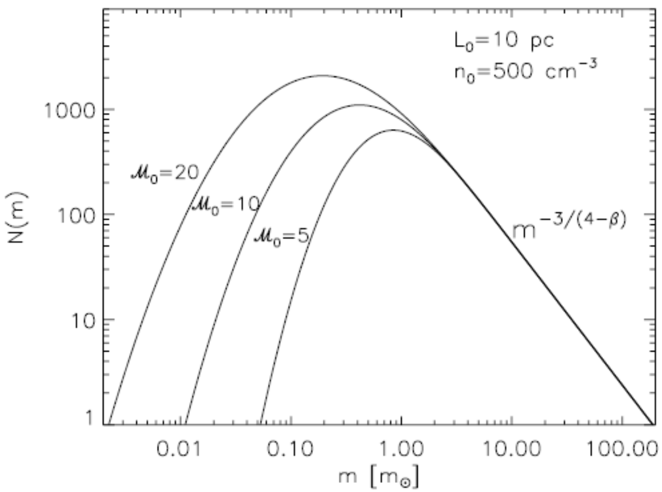
$$\Psi(M) = \frac{dN}{dM} \propto M^{-\alpha} \text{ stars pc}^{-3}\, M_\odot^{-1}$$

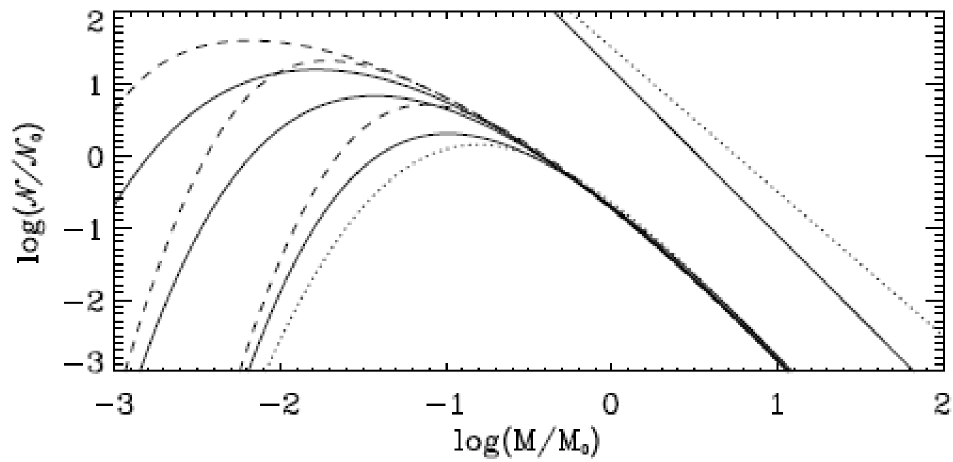
Brownies… of the 3rd kind

…the type you may find in Amsterdam (S., priv.comm.)

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, we can ! (Luminosity → Mass)
- But, 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)

Uncertainties

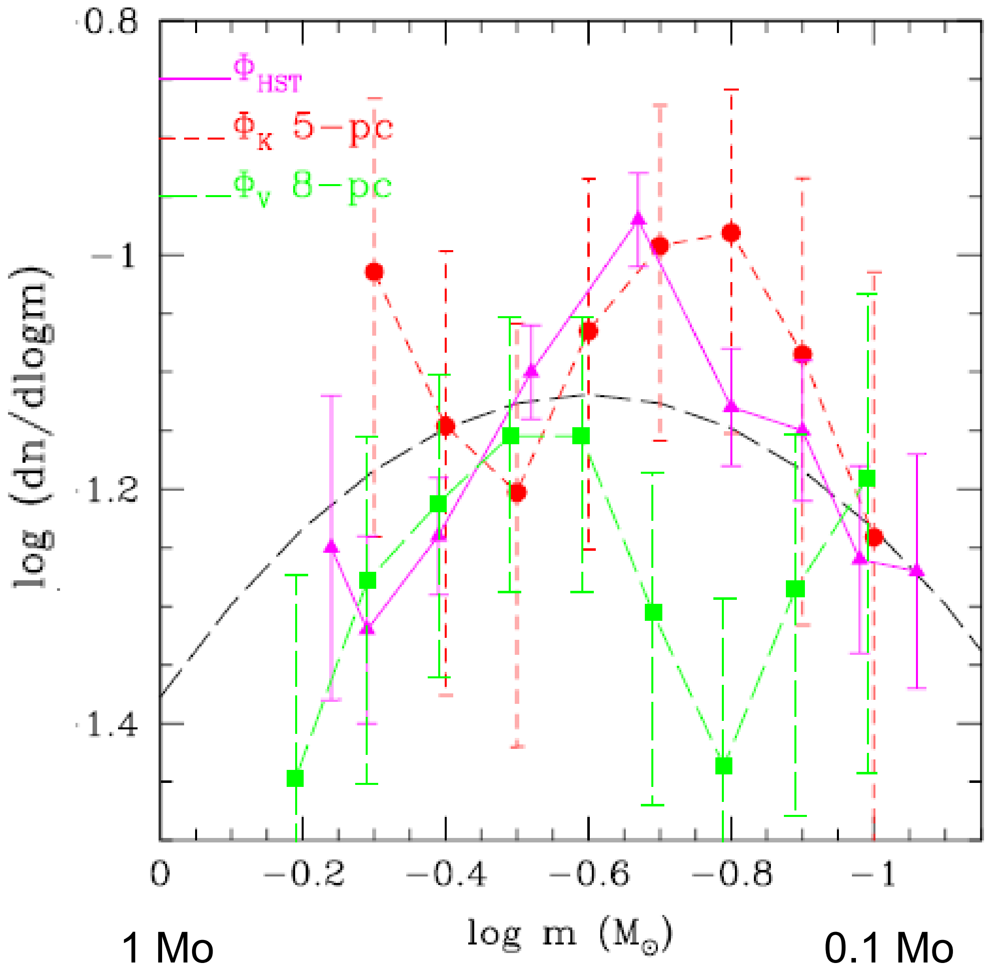
- Field (2-5 Gyr) issues: age, mass, [Fe/H], sample completeness
- Young open clusters (30-600 Myr) issues: contamination, dynamical evolution, mass segregation
- Star forming regions (1-5 Myr) issues: variable extinction, accretion, mass-luminosity relationship
- All: multiplicity, magnetic activity

I. The low-mass stellar MF

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

Large statistical uncertainties

Completeness limit ~ 0.1 Mo

Galactic disk low mass MF

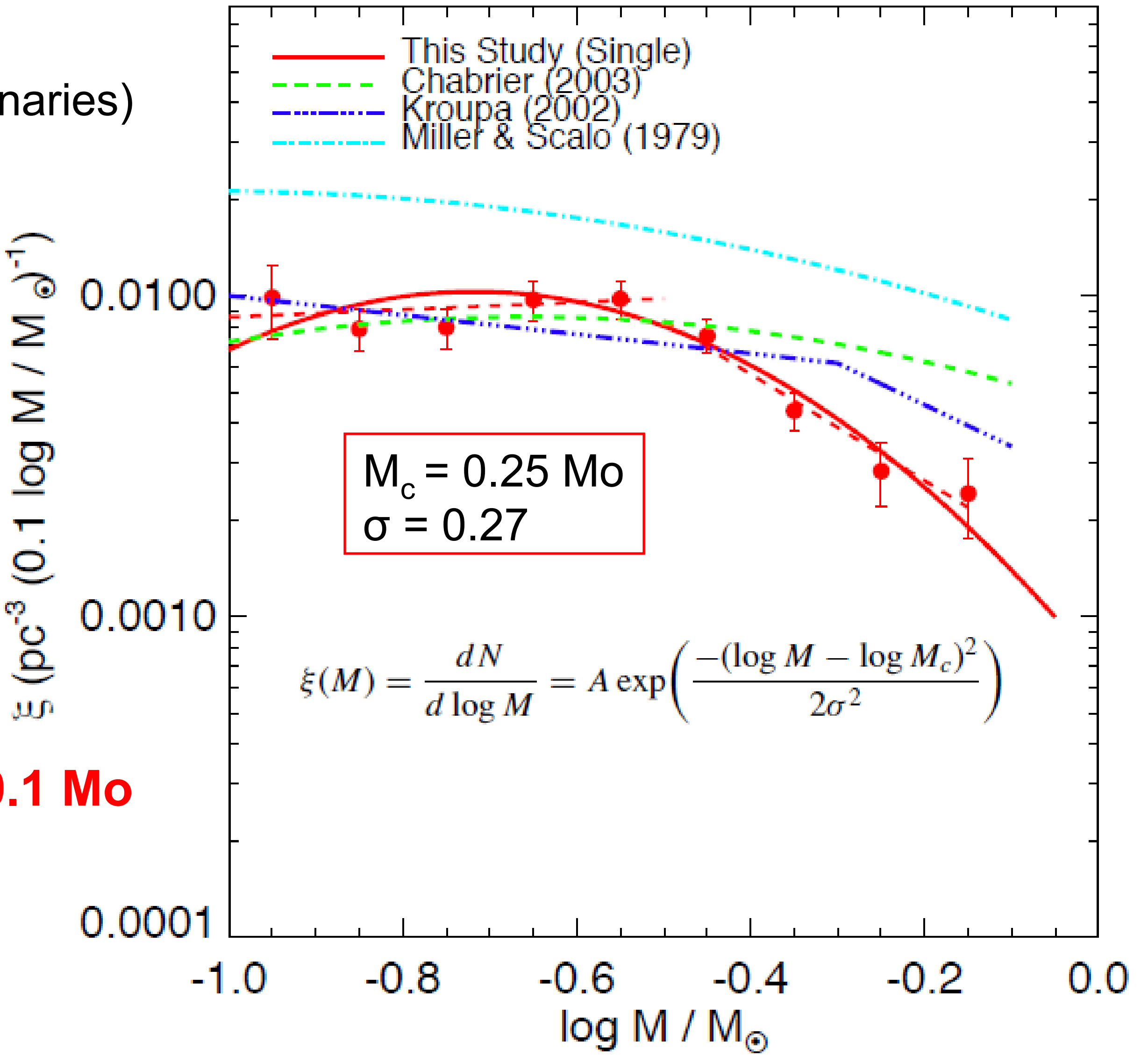
System MF (unresolved binaries)

SDSS/2MASS/GSC:
~15,000,000 stars
(0.1-0.7 Mo)

Covey et al. 2008
Bochanski et al. 2009

Not a power-law !

Completeness limit ~ 0.1 Mo



Field substellar MF

- More than 700 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

Field substellar MF ?

- Large uncertainties still on field L-T dwarf MF
- Consistent with lognorm extrapolation of the stellar MF to the BD regime ? and/or power-law with $\alpha \sim -1.0$ to $+1.0$?
- Numerical simulations have a number of parameters : galactic birth rate, 3D galactic model, scaling of different surveys, LT-dwarf absolute magnitudes and colors, binarity, etc…
- **Field MF is now reasonably well-known down to ~0.1-0.2 Mo, but still uncertain below**

II. The substellar MF

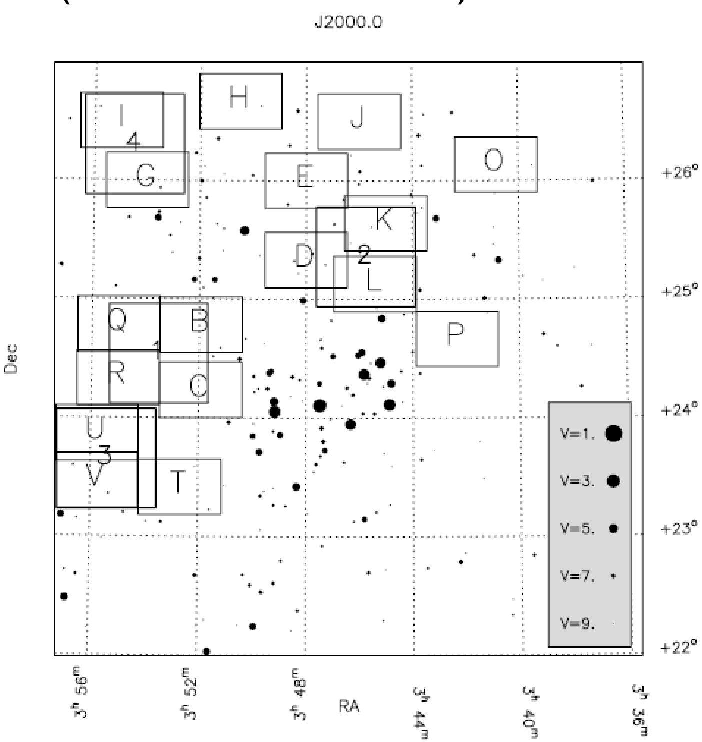
Young open clusters (30-600 Myr)

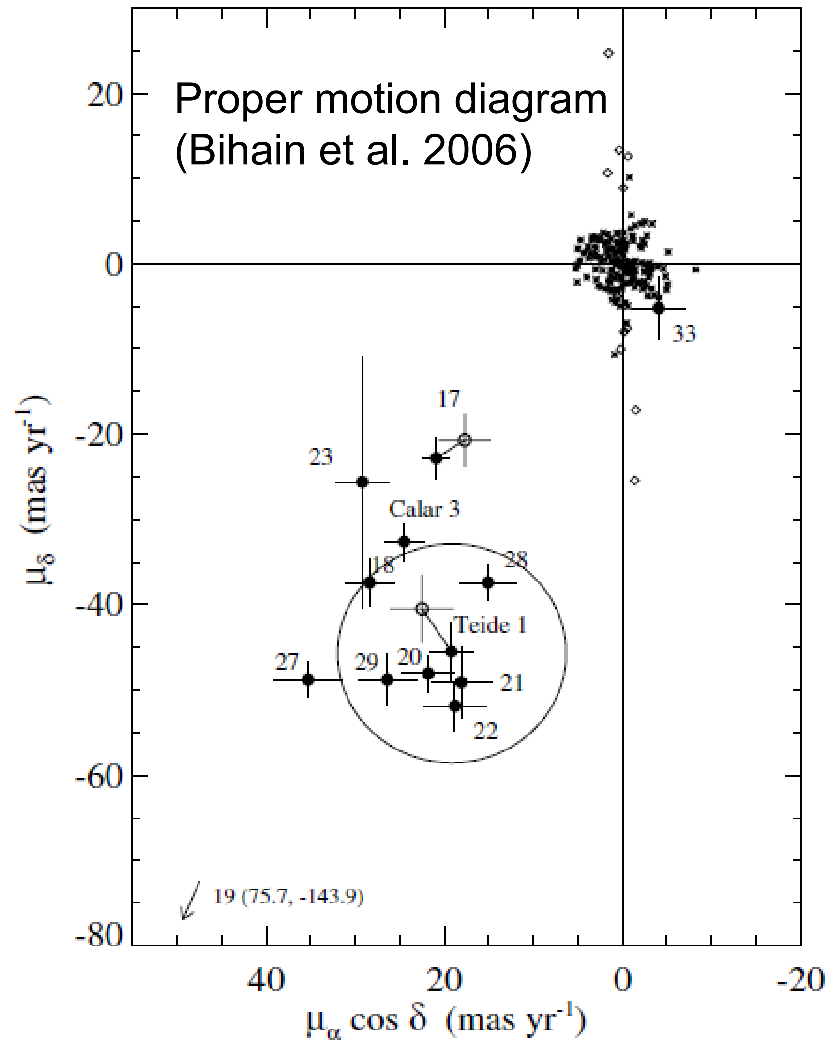
Pleiades : a benchmark cluster

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

Distance = 120-130 pc

Wide-field surveys
(Casewell et al. 2007)

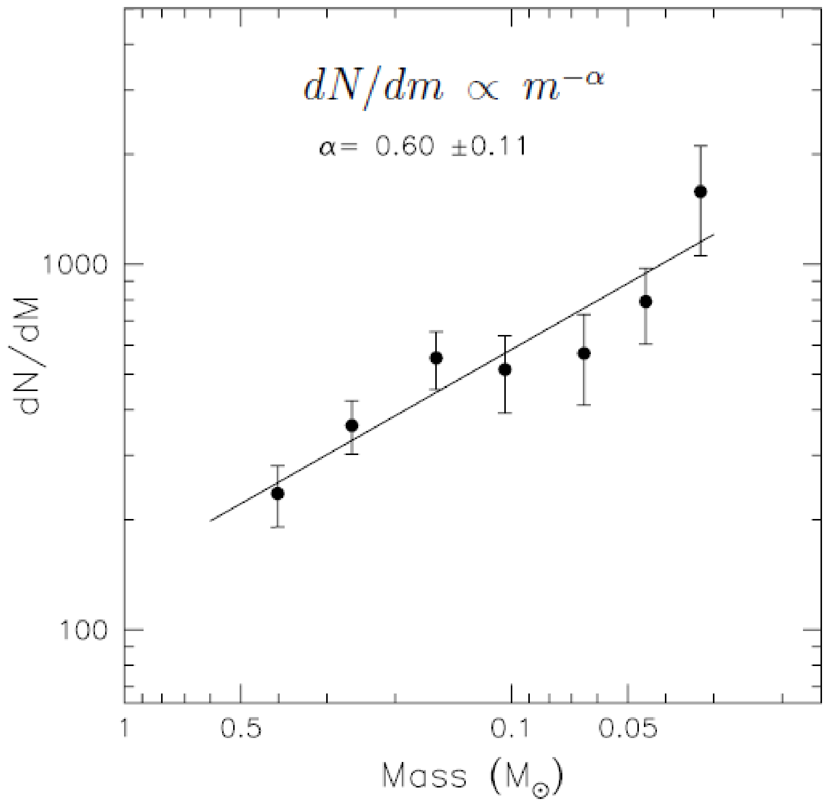




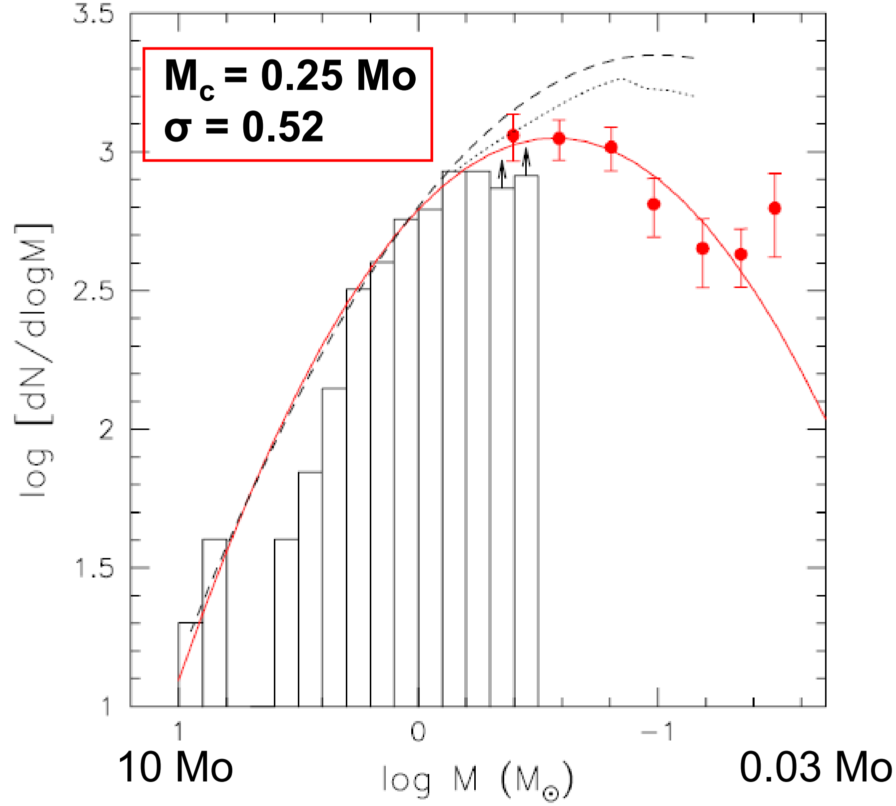
Pleiades MF

Optical surveys: completeness limit ~30 Mjup

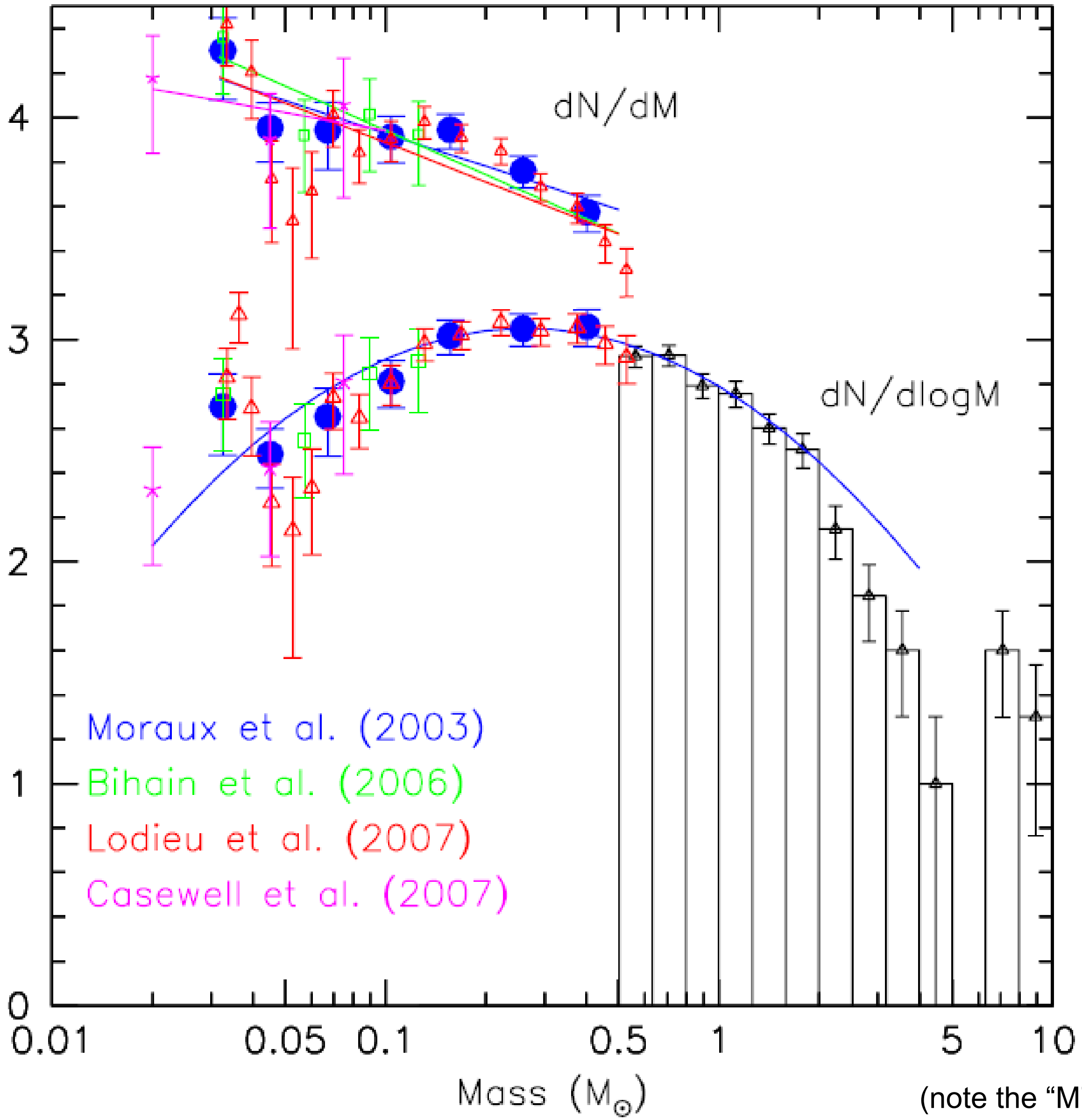
System MF (unresolved binaries): 40 substellar members



Moraux et al. 2003

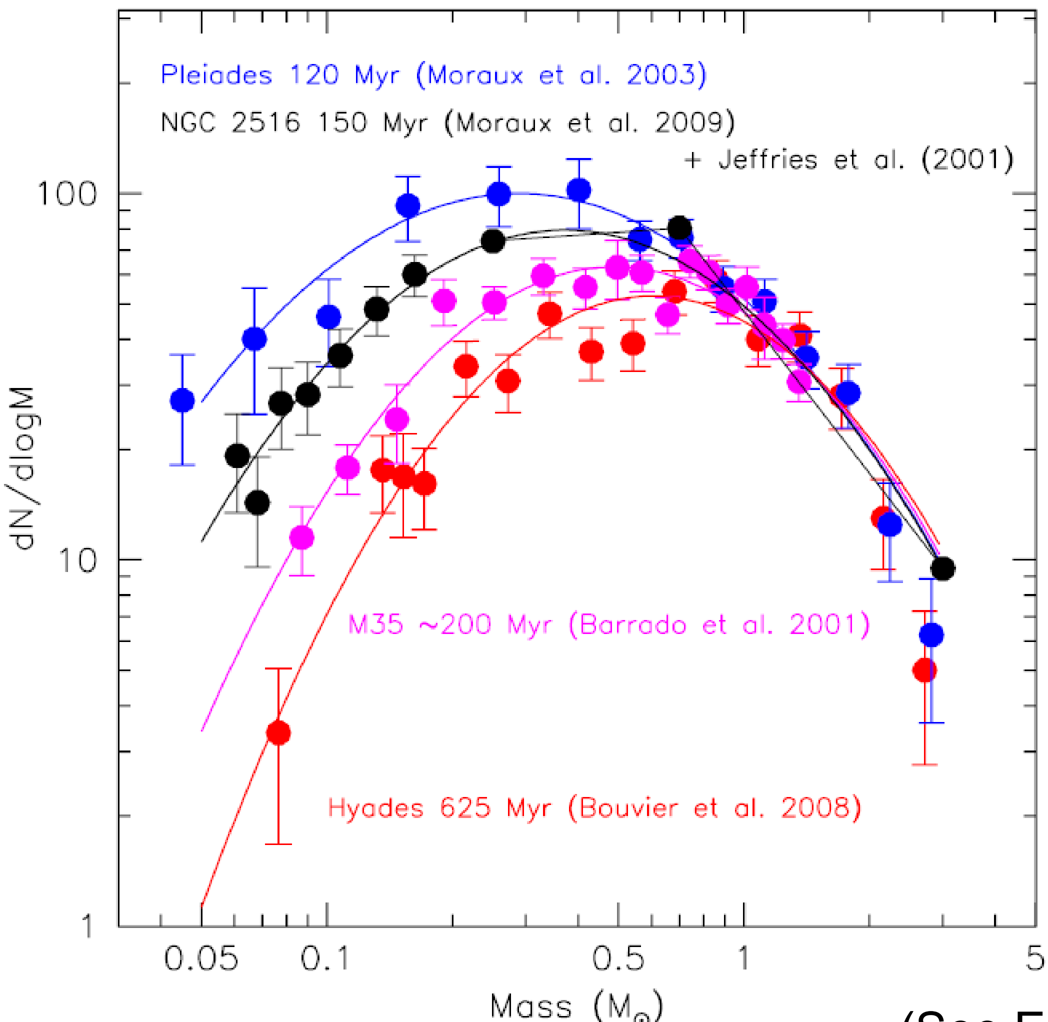


Pleiades MF: recent opt/IR surveys

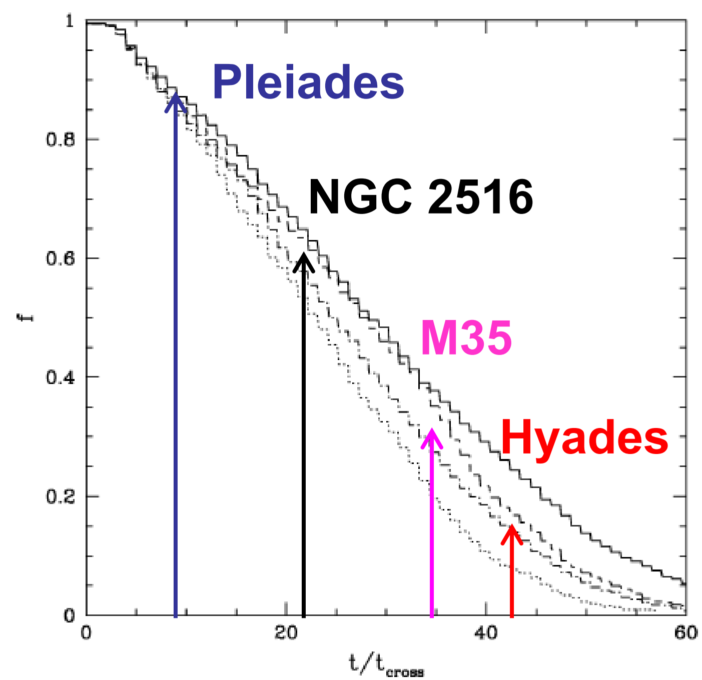


(note the "M7 gap" at ~0.05Mo; cf. Dobbie et al. 2002, Moraux et al. 2007)

The dynamical evaporation of very low mass objects



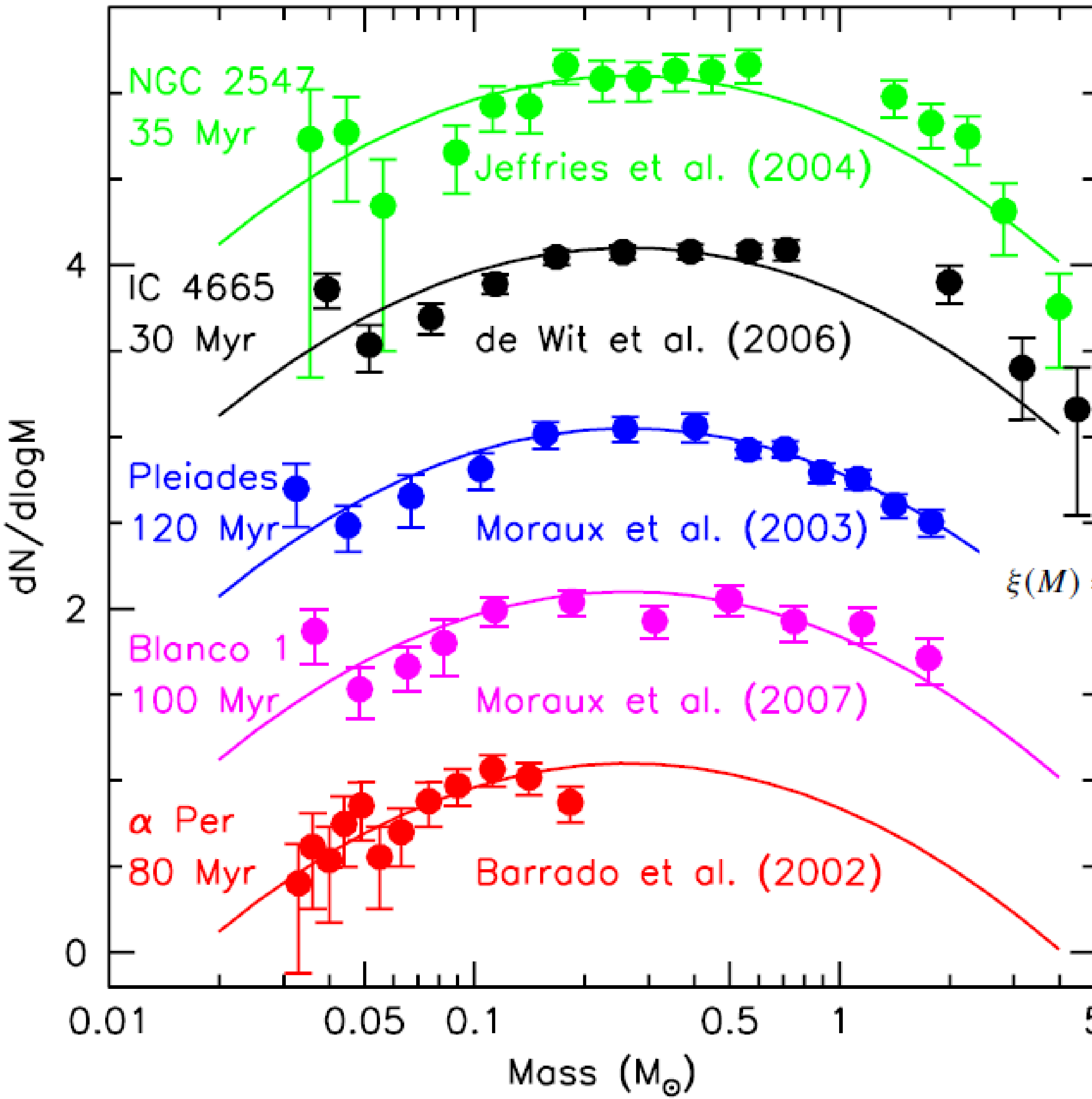
Fraction of BD as a function of time



Adams et al. 2002

(See E. Moraux's poster at this conference)

YOCs 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

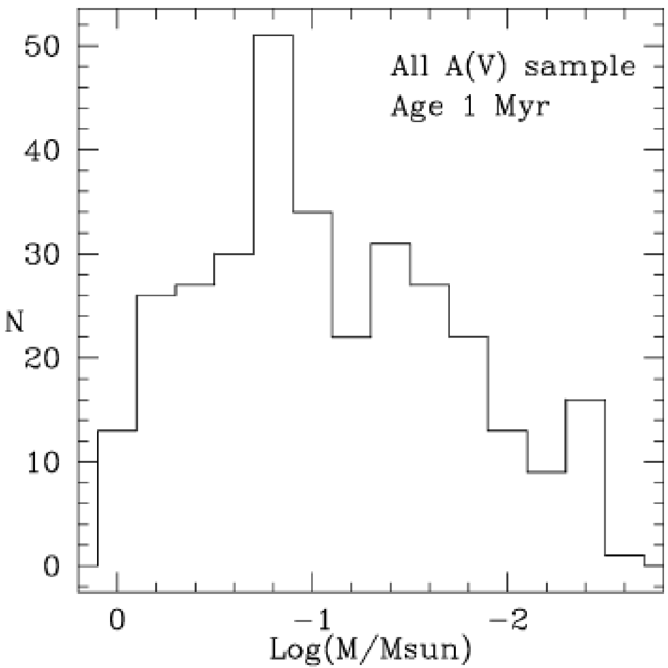
Little evidence for cluster-to-cluster variations

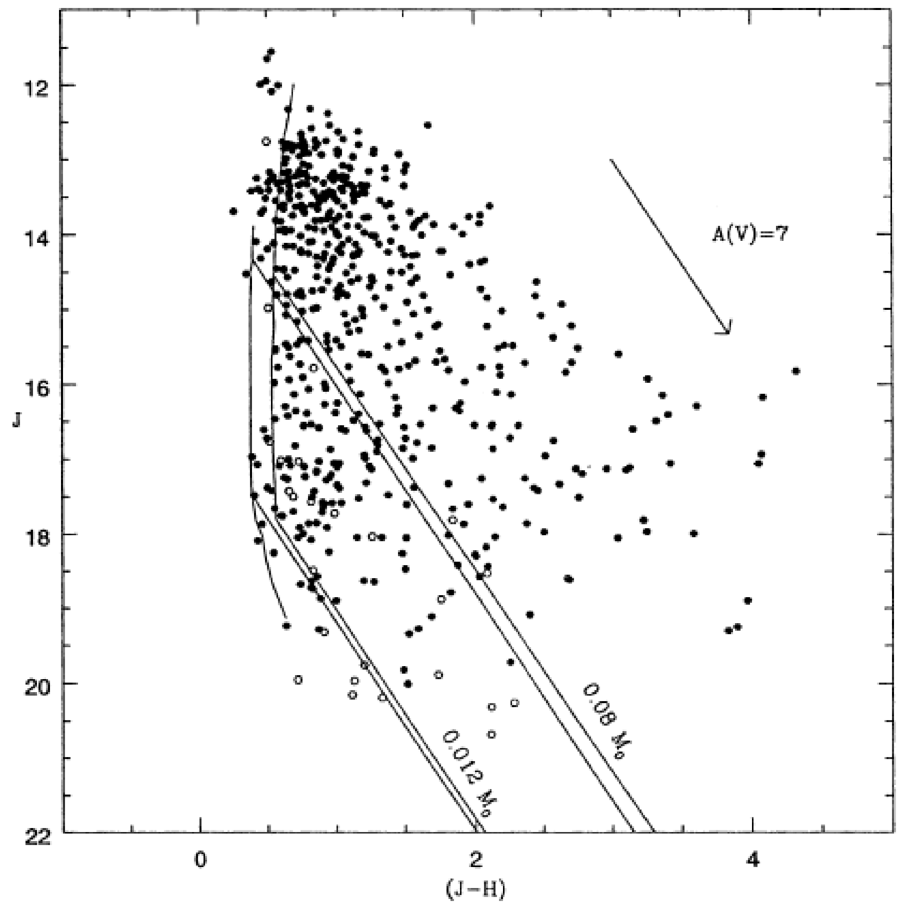
III. Towards the planetary mass domain

Star forming regions (1-5 Myr)

The Orion Nebula Cluster

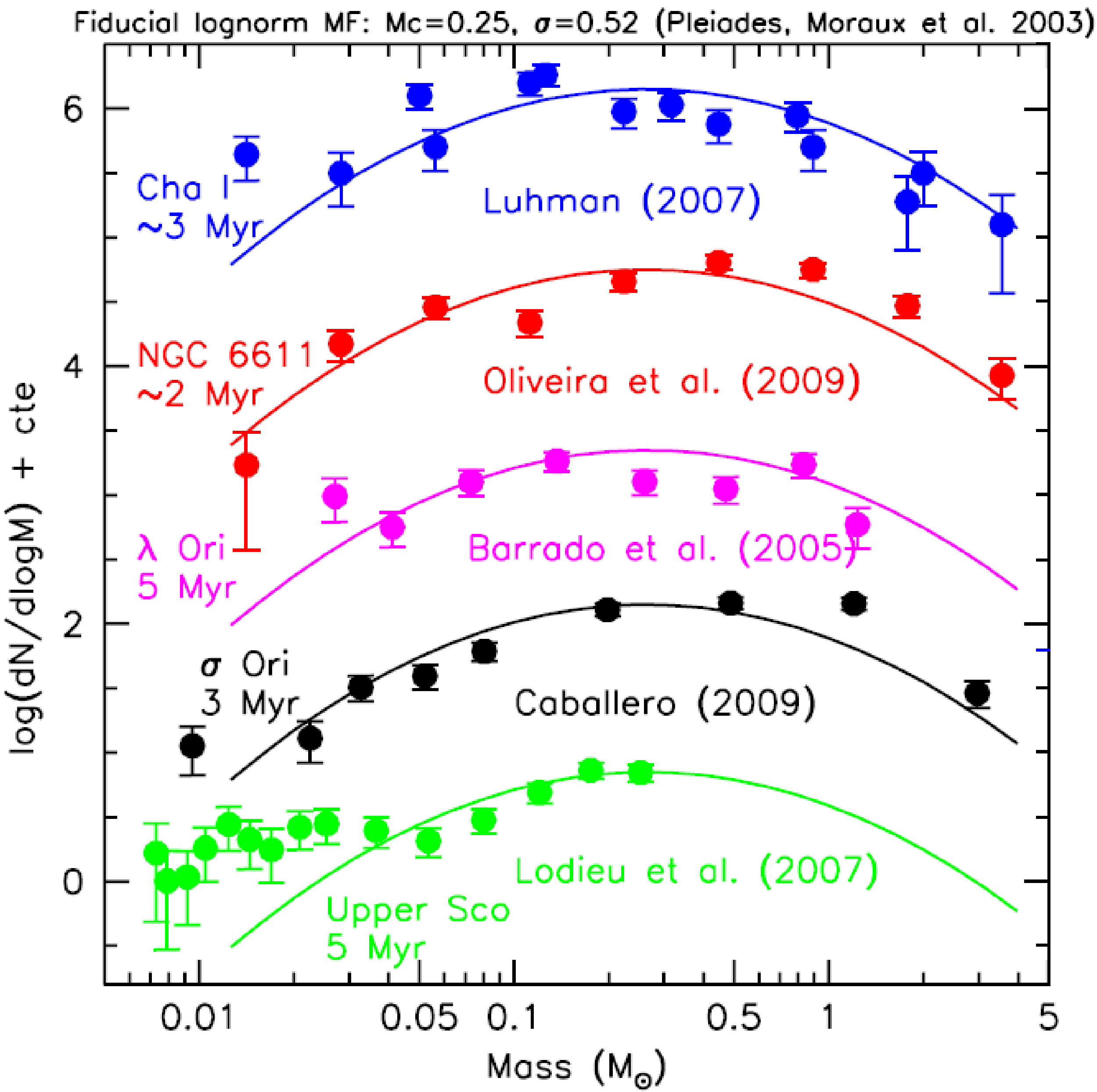
- Lucas & Roche (2000)
- Search for isolated planetary mass objects (IPMOs)





IPMOS [3-15 Mjup] ~ 1 to 14% of the ONC population (Lucas et al. 2006)

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:

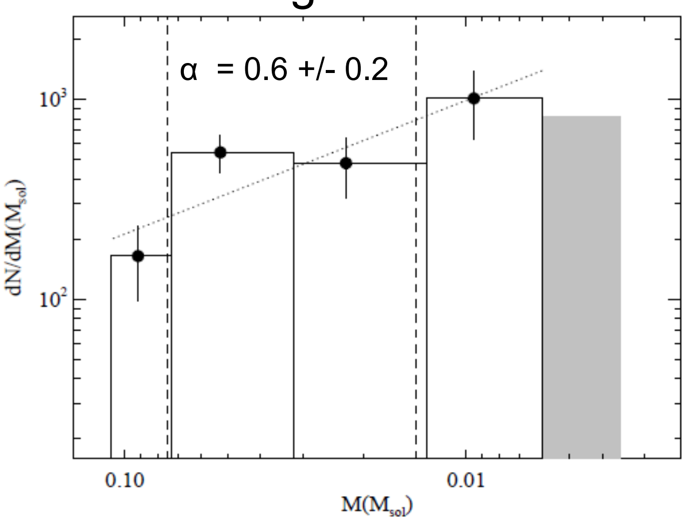
Residual contamination ? Incompleteness? Mass segregation ?

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)

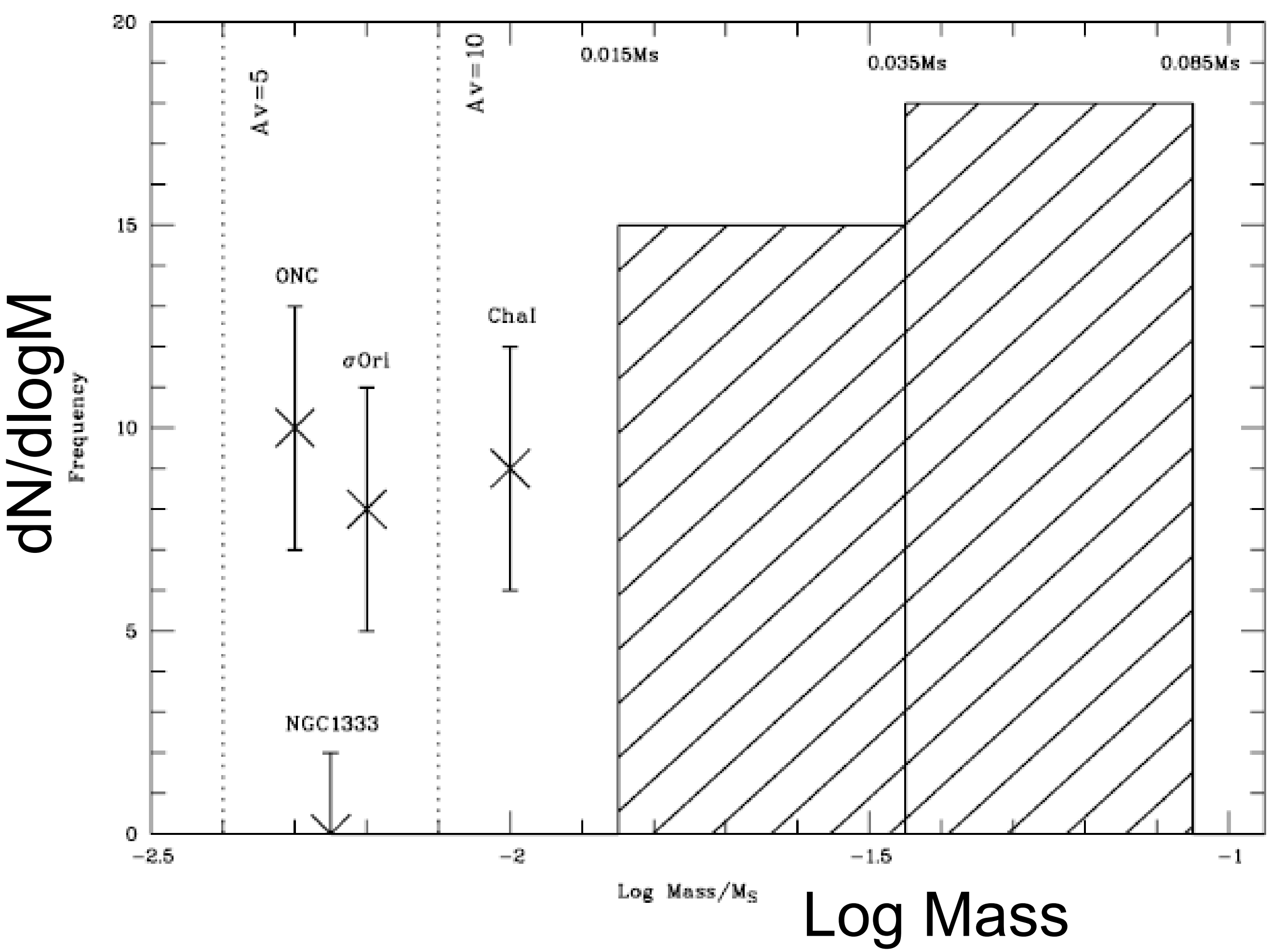
<u>IC348 (~3 Myr):</u>
IC348_CH4_2 : estimated Sp.T ~ T6 (Burgess et al. 2009)

<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)

NGC 1333 : the end of the IMF ?

No objects below the DBML (~13 Mjup) in NGC 1333 ?

Scholz et al. 2009



Summary

- *Galactic population:* the **stellar field MF** is well constrained down to 0.1 Mo; poorly known in the substellar domain due to age/mass uncertainties
- *Young open clusters:* the **substellar MF** is reliable down to 30 Jupiter masses; the system MF is well-described by a **lognormal mass distribution with <M> ~ 0.25 Mo and σ ~ 0.5** over the mass range 0.03-1.0 Mo
- *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: lightest known isolated objects !