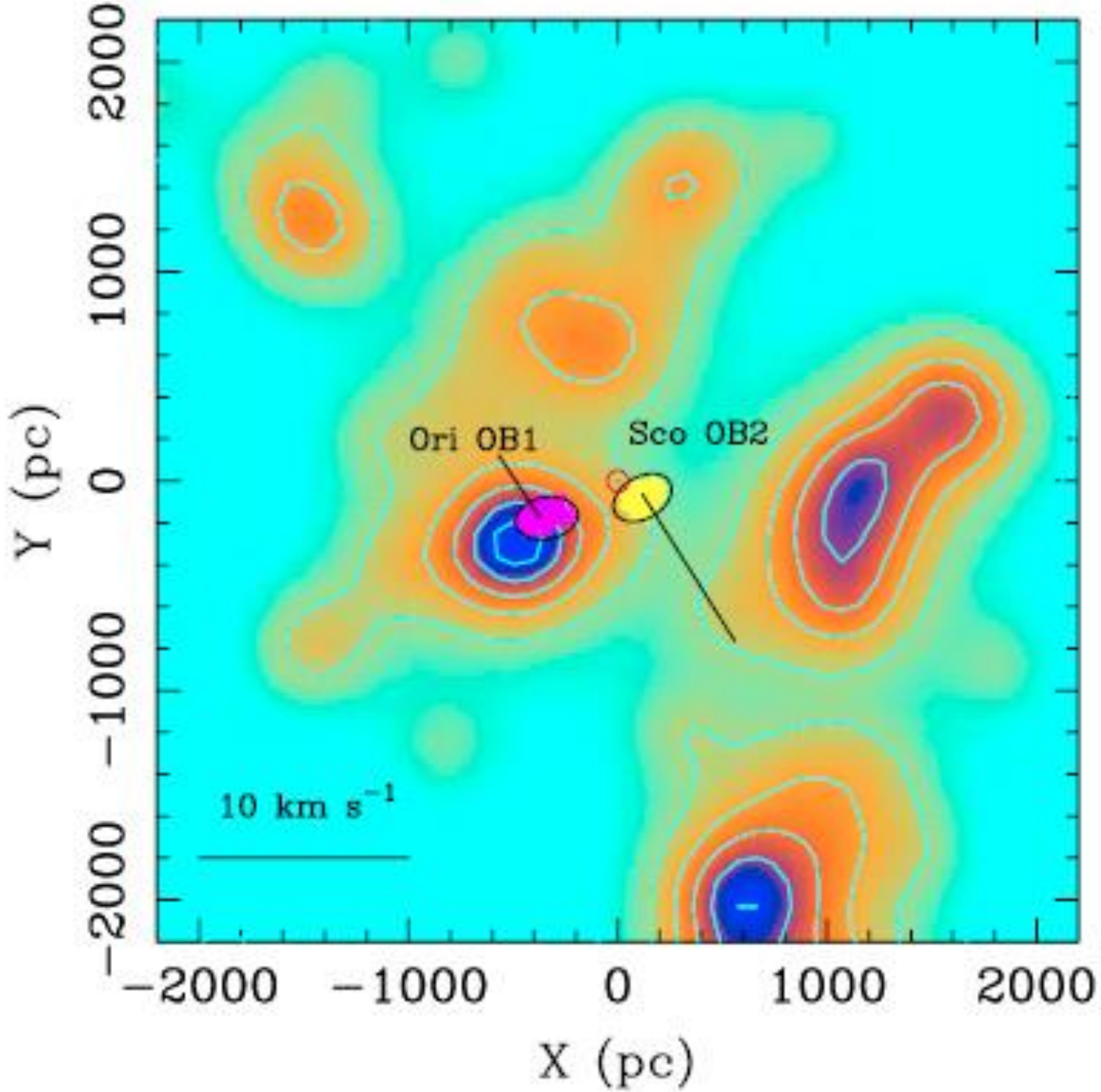
M11, NGC 6705: Total Mass
About 10000 M(sun), 200 Myr

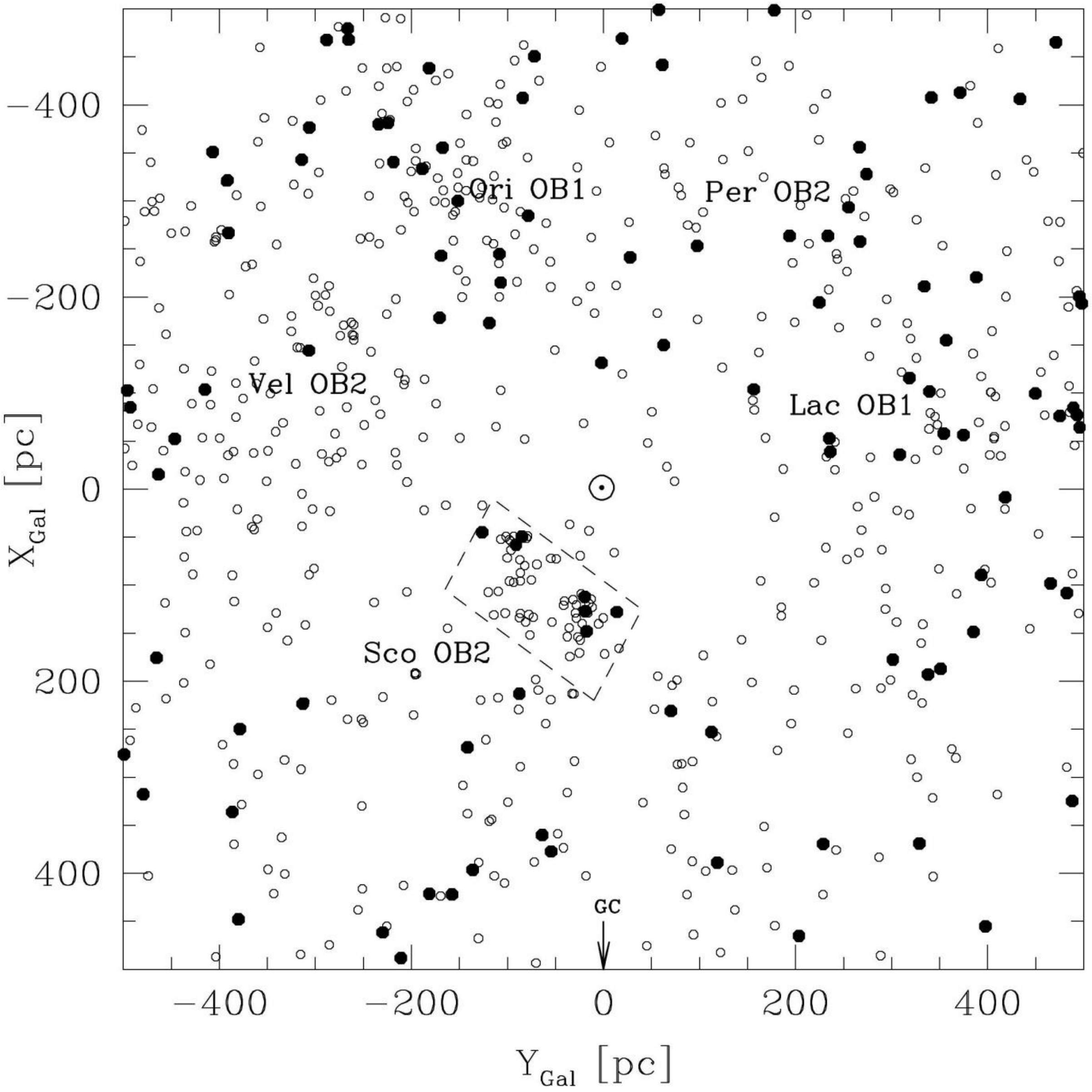
Orion Nebula, Distance about
450 pc, Total Mass about
5000 M(sun), Diameter about 3 pc

Cluster formation

- Observations versus Models
- Important parameters
  1. Time scale
  2. Total mass
  3. Initial Mass Function
  4. Velocity distribution
  5. Binary fraction
  6. Diameter
  7. Density distribution



Distribution of young open clusters and star forming regions from Alfaro et al., 2009, Ap&SS, 324, 141



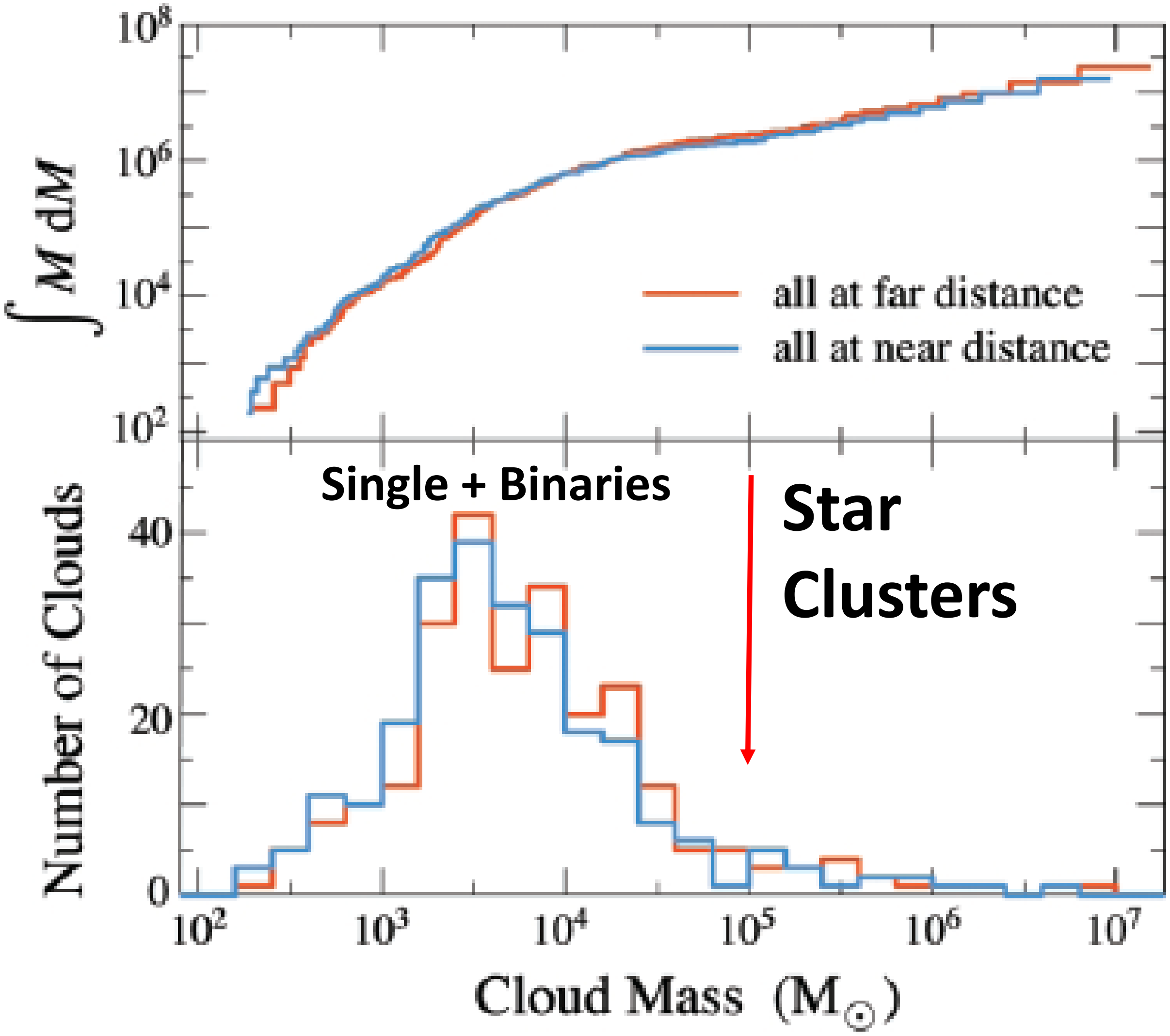
Stars hotter than B0 and B0 to B2

Distribution of star forming regions from Preibisch & Mamajek, 2008, Handbook of Star Forming Regions, Volume II

Giant Molecular Clouds

- Star Clusters can only form within „Giant Molecular Clouds“ (GMC) with a high enough initial mass
- The stellar formation rate in the solar neighborhood is very low
- But still there have to exist several GMCs to form Star Clusters
- Is the formation process the same for all observed Galaxy types?

Giant Molecular Clouds



Stark & Lee, 2006, ApJ, 641, L116

Single + Binaries

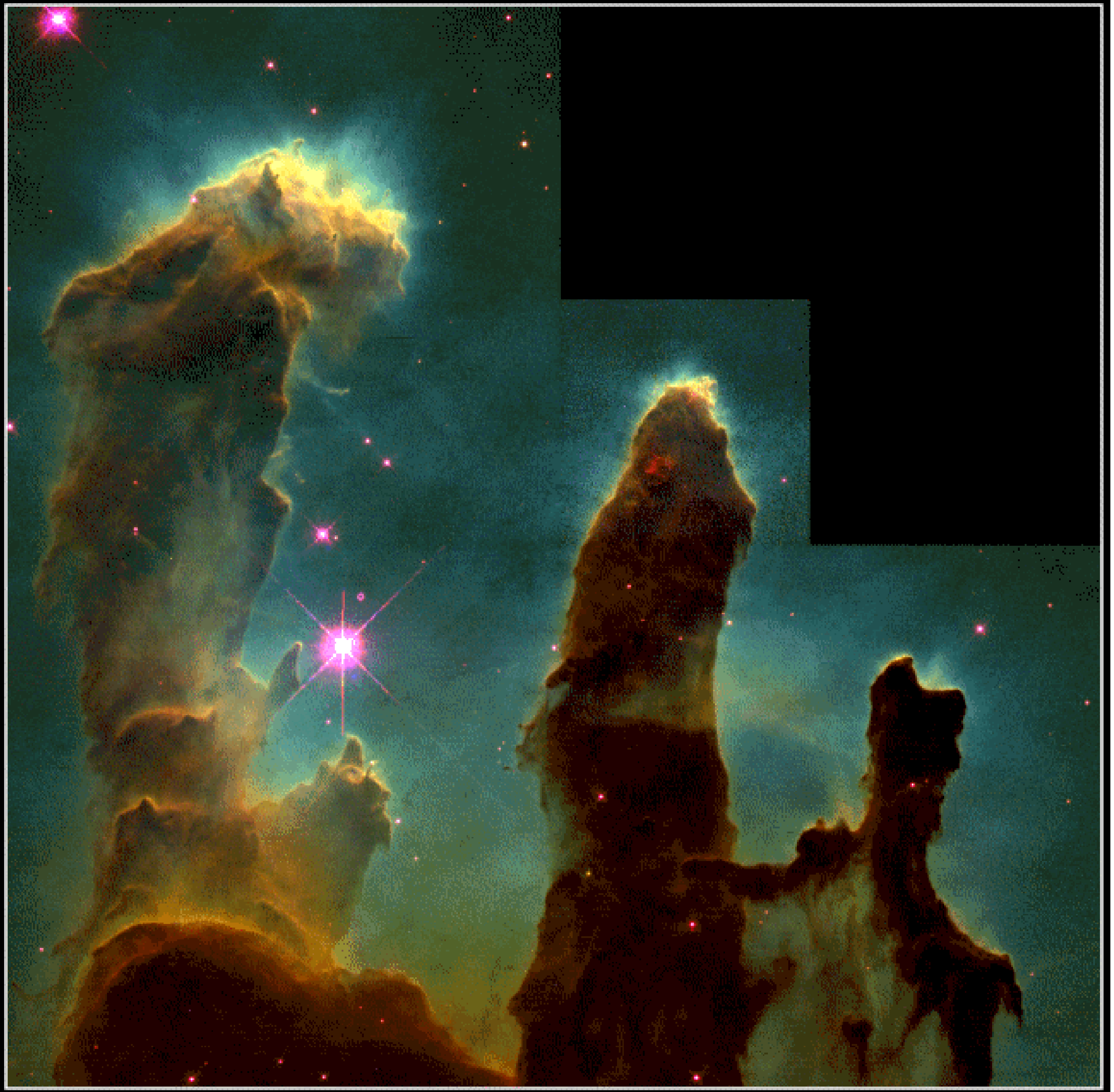
Star Clusters

Recent investigation of the ^{13}CO Gas within 2000 pc around the Sun

The number of young OCLs can be very well explained

Formation rate of 0.45 OCLs per kpc^{-2} Myr^{-1} in the galactic disk within 2 kpc around the Sun

Battinelli & Capuzzo-Dolcetta, 1991, MNRAS, 248, 76



Gaseous Pillars • M16 HST • WFPC2

PRC95-44a • ST ScI OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

NGC 6611 (M16)

d = 1750 pc
t = 8 Myr

Star formation „live“

Initial Mass Function

- The „Initial Mass Function“ (IMF) describes the mass distribution for a population of stars when they are formed together
- Relevant astrophysics:
  1. Size, total mass and metallicity of the initial GMC
  2. Fragmentation of the GMC
  3. Conservation of the angular momentum
  4. Local and global magnetic fields
  5. Accretion in the Pre-Main Sequence phase
- The only observational parameter for the test of stellar formation and evolution models
- We observe a luminosity function which has to be transformed to the IMF

Initial Mass Function

- Several most important questions are still not solved
  1. Is the IMF homogeneous within the Milky Way?
  2. Is the IMF constant throughout time?
  3. What is the influence of the local and global magnetic field on the IMF?
  4. What is the influence of the local and global metallicity on the IMF?

Initial Mass Function

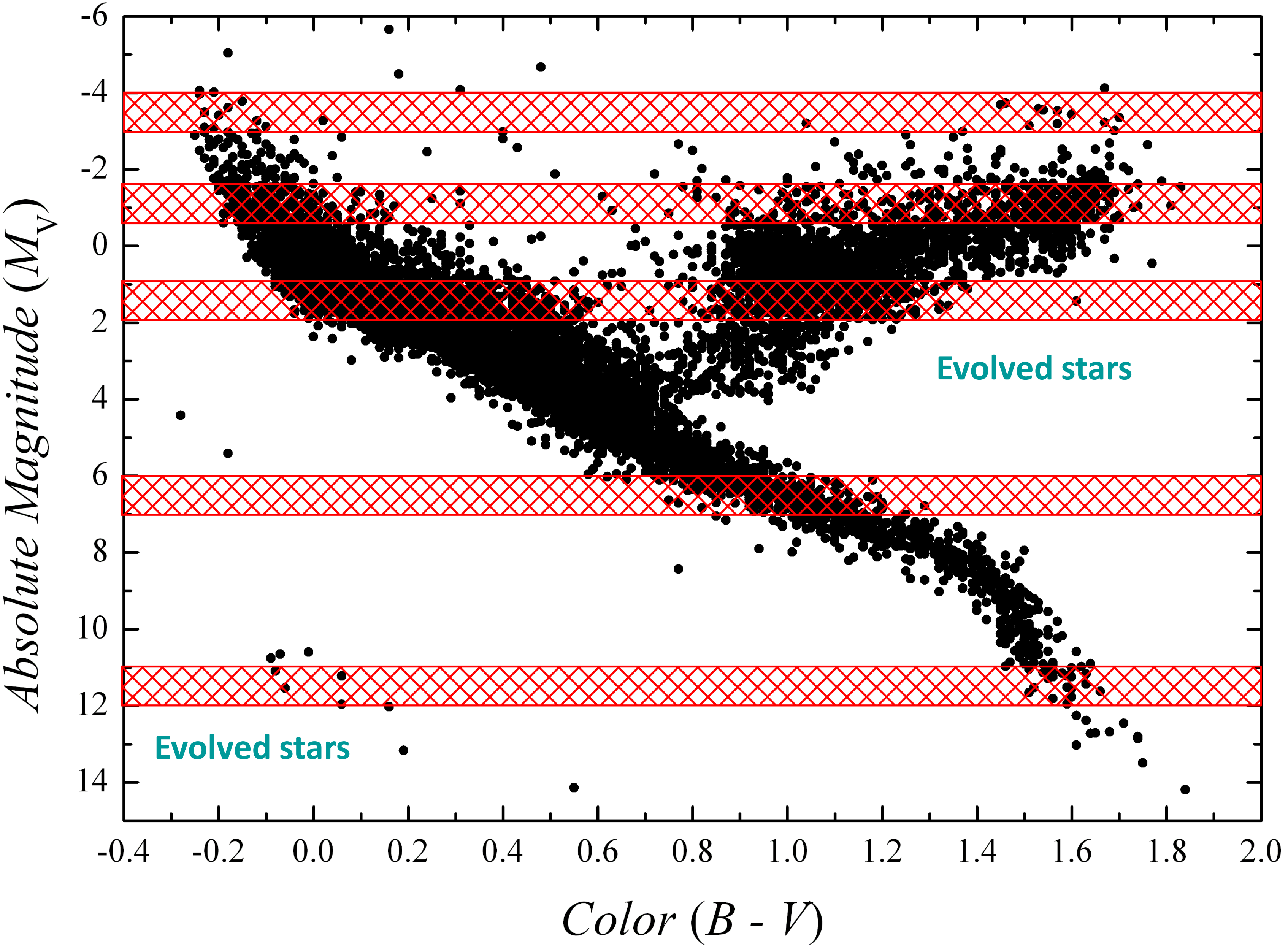
The IMF $\theta(m)$, often called „Present-Day Mass Function“ (PDMF), is defined as:

$$dN = \theta(m)\ dm$$

dN is the number of all stars per cubic parsec on the *main sequence* with a mass between M and (M + dm).

But we observe not the masses of stars but their magnitudes (relative and absolute) or luminosities.

So we have to define the luminosity function and transform it into the IMF.



In each row (M_V + dM) there is a mixture of main sequence and evolved objects. For the IMF, we need the main sequence only.

Luminosity function

The luminosity function $\Psi(M_V)$, is defined as:

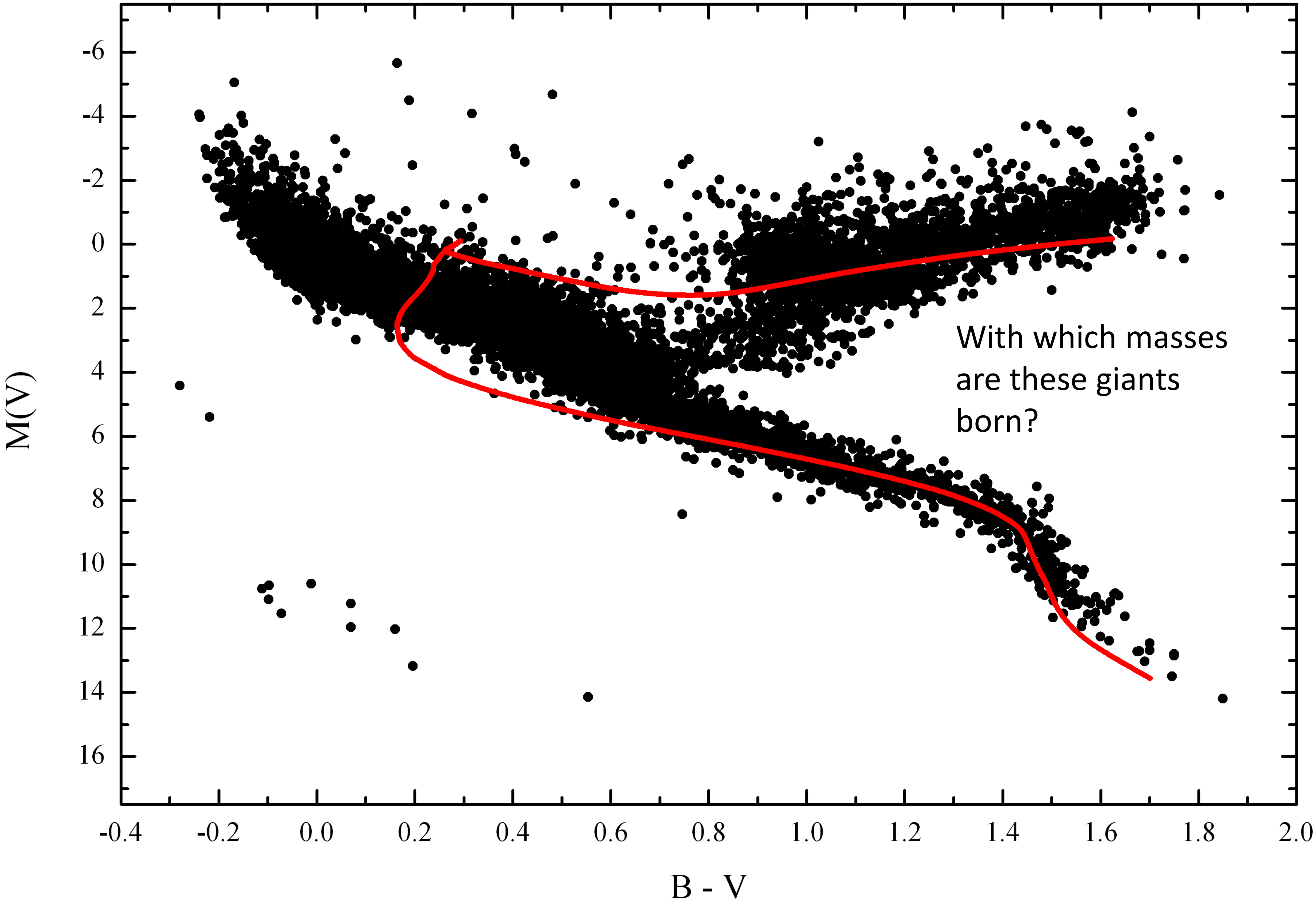
$$dN = -\Psi(M_V)\, dM_V$$

dN is is the number of all stars per cubic parsec on the *main sequence* with an absolute magnitude between M_V and $(M_V + dM_V)$. The transformation to the IMF is given as:

$$\theta(m) = -\Psi(M_V)[dm(M_V)/dM_V]^{-1}$$

The second term is the derivation of the Mass-Luminosity function $m(M_V)$. It is depending on the age (t), metallicity (Z) and rotation (v_{rot})

$$m(M_V) = m(M_V, Z, t, v_{rot})$$



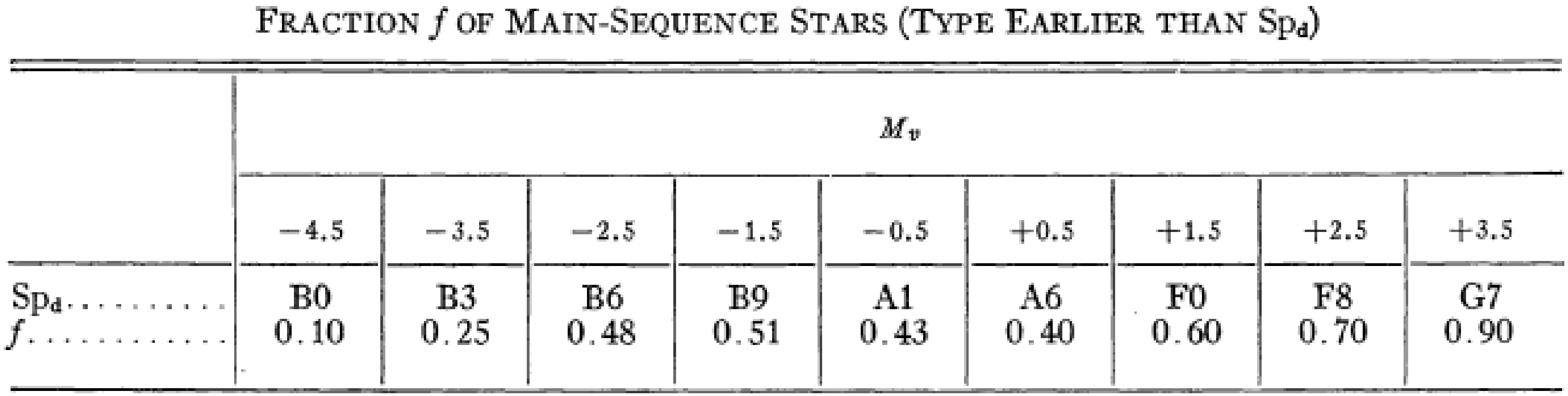
With which masses are these giants born?

Correction of the observations

We have to correct the complete observations for the evolved objects. There are three possibilities:

1. Take a statistical sample with a well known luminosity function (clusters)
2. Take a statistical sample with well known photometric magnitudes and distances
3. Take isochrones = theoretical star evolution = models based on observations = circular argument

All these methods are not self consistent and always introduce an unknown error to the analysis



FRACTION f OF MAIN-SEQUENCE STARS (TYPE EARLIER THAN Sp_d)

	M_v								
	−4.5	−3.5	−2.5	−1.5	−0.5	+0.5	+1.5	+2.5	+3.5
Sp_d..........	B0	B3	B6	B9	A1	A6	F0	F8	G7
f............	0.10	0.25	0.48	0.51	0.43	0.40	0.60	0.70	0.90

Salpeter, 1955, ApJ, 121, 161

Results of classical spectral classification, only 10% of stars with M_V = -4.5 mag are on the main sequence!

These values are depending on the chosen sample for the spectral classification and which classification scheme is applied.

The errors are rather large.

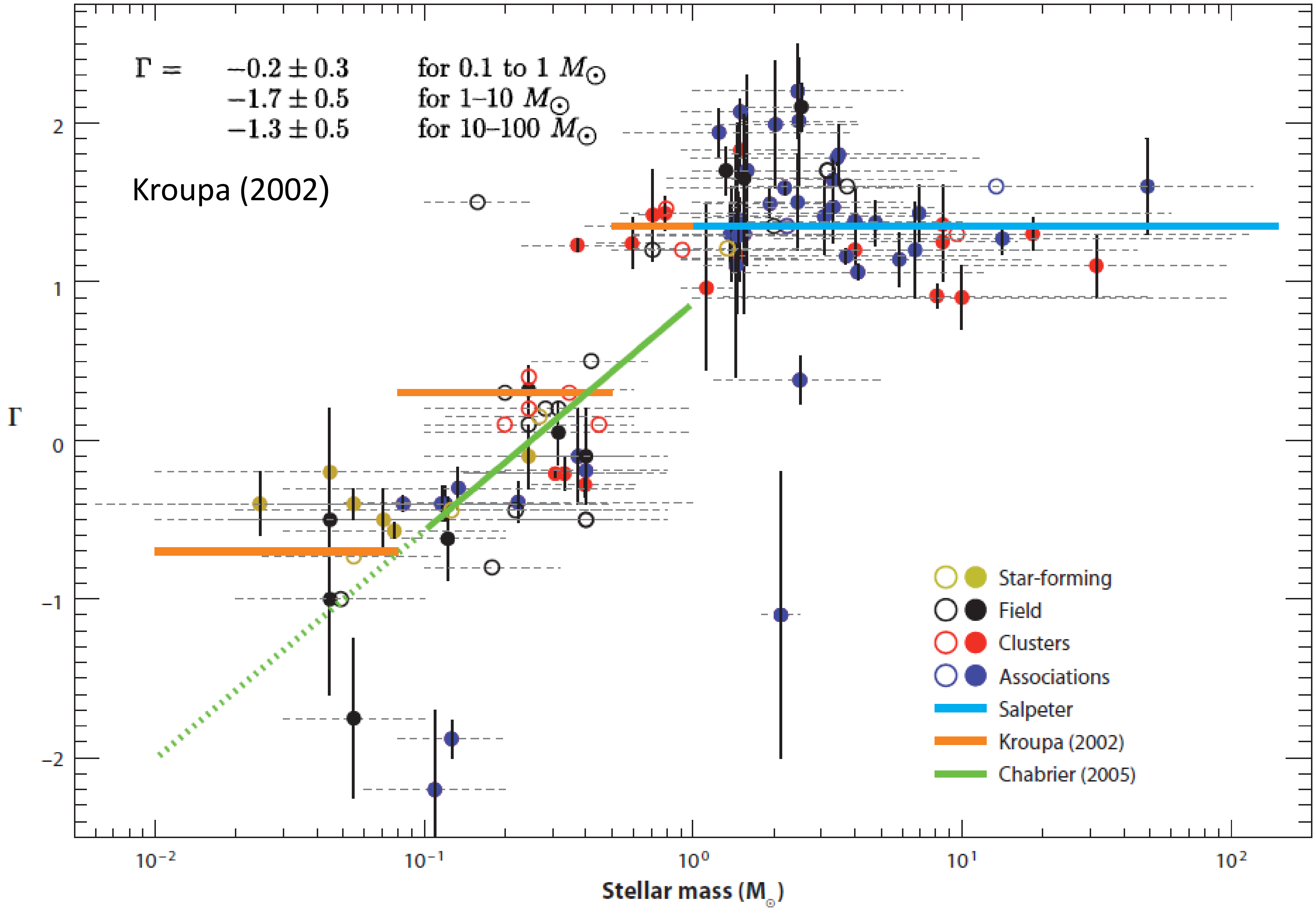
All observations have to be normalized to one “standard system” which means essentially to one “time scale”.

The observations show, that this heuristic law describes them very well

$$\theta(m) \approx m^{-\Gamma} \qquad \text{Salpeter law (1955)}$$

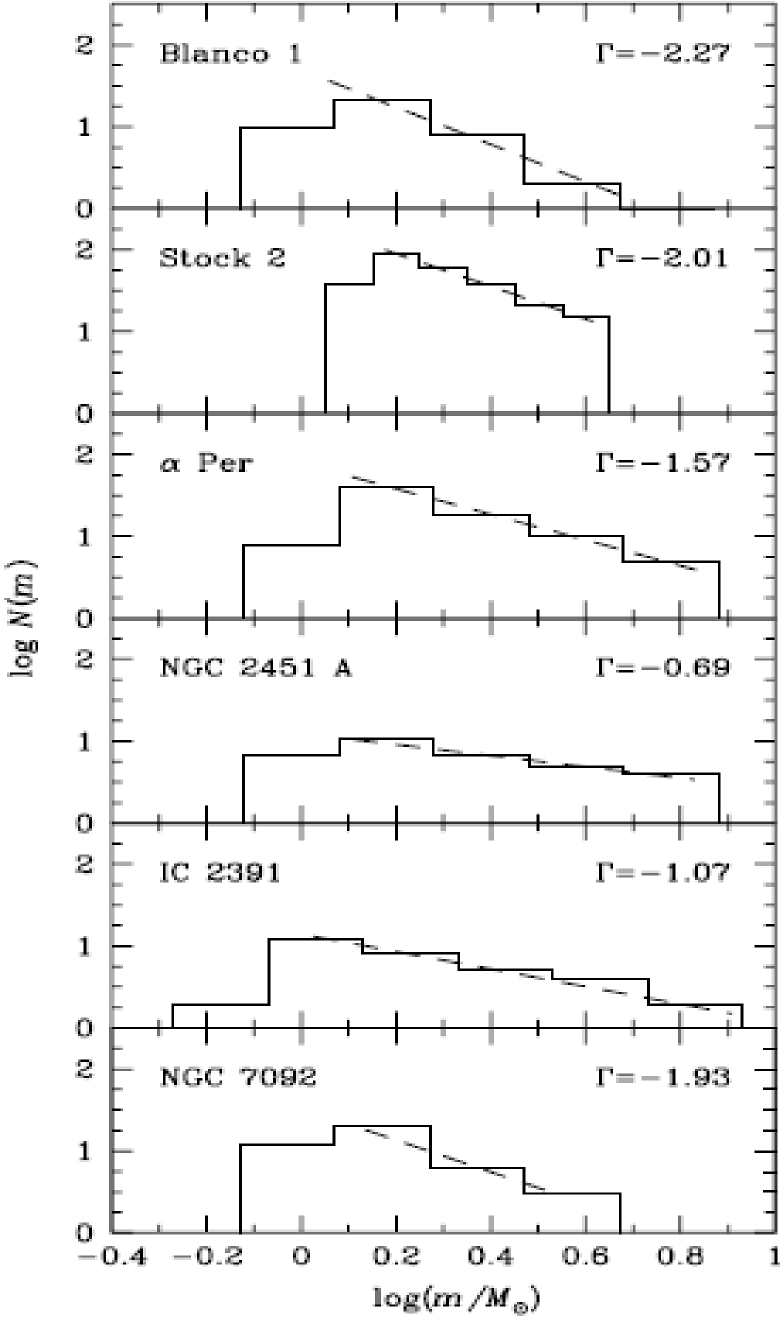
Star cluster are one of the most important observational test for the IMF because they, normally, have well defined ages, distances and metallicities. However, the errors are still quiet large.

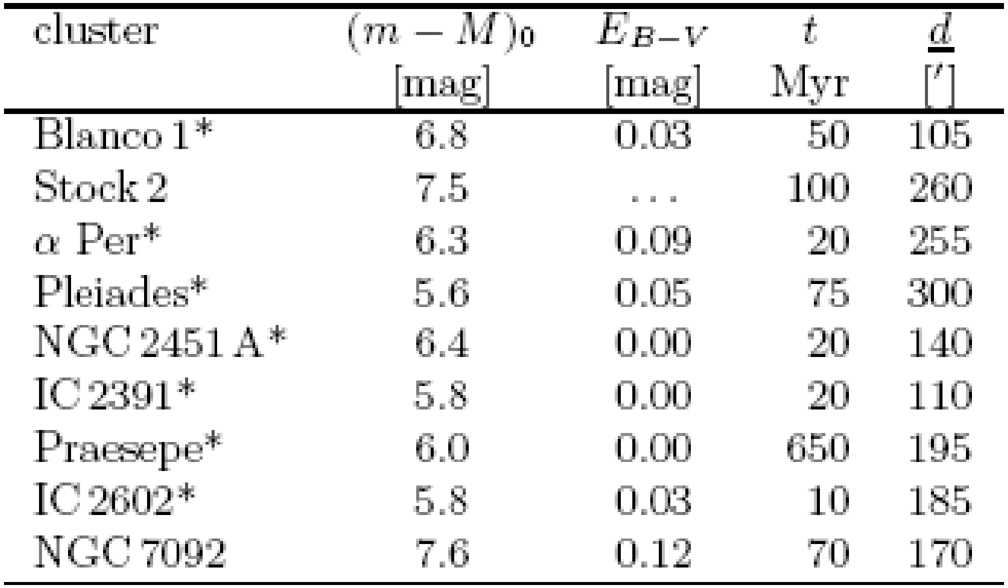
But there is still no homogeneous IMF determination for open clusters taking into account the available data.



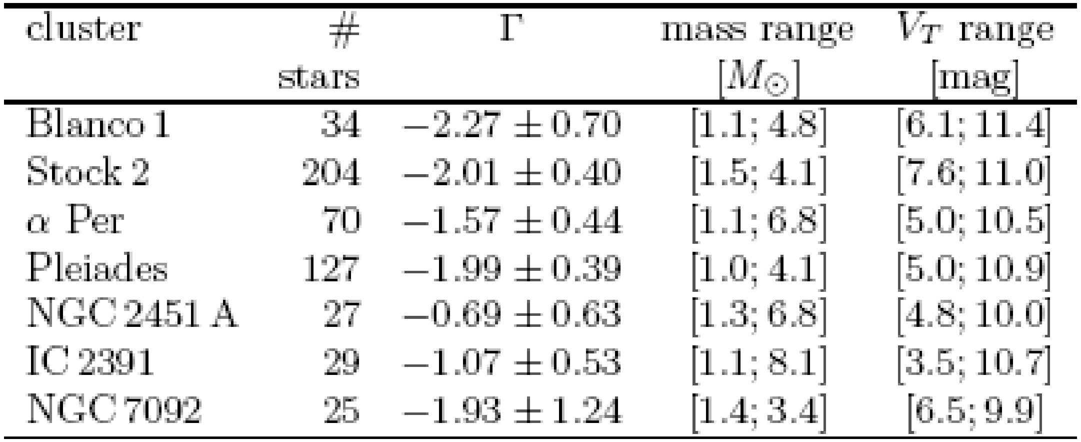
Bastian et al, 2010, Annual Review of Astronomy and Astrophysics, 48, 339

TYCHO2 data





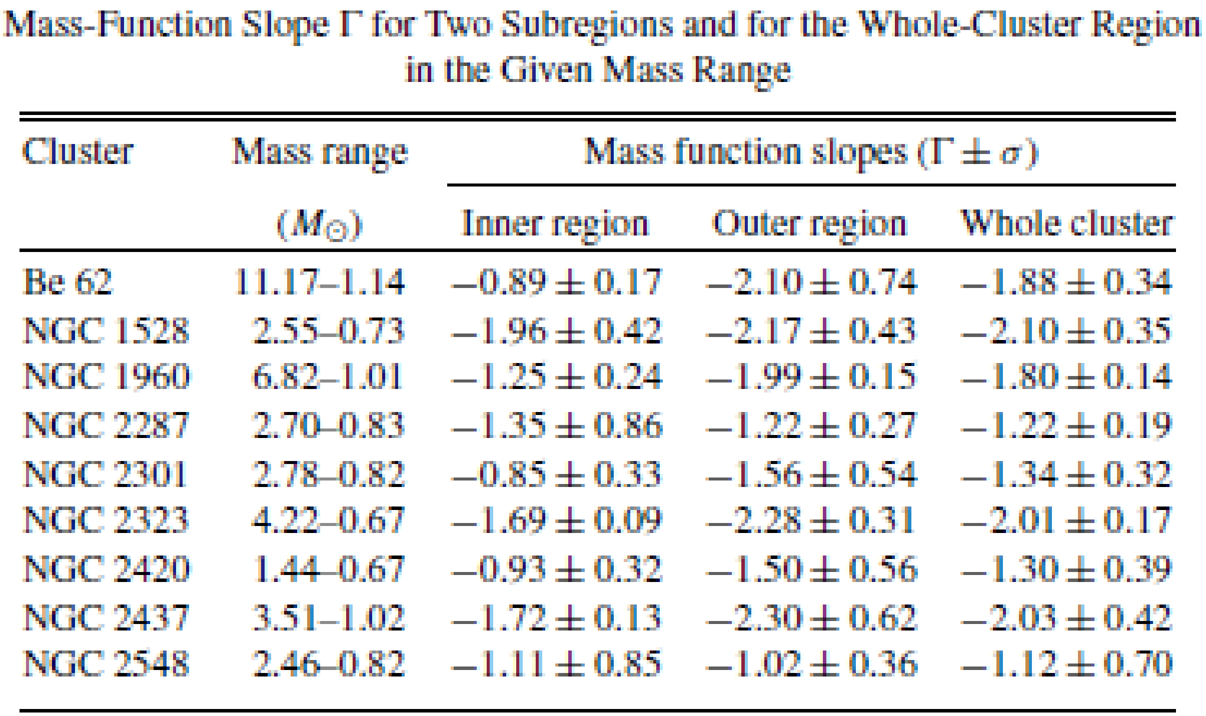
cluster	$(m-M)_0$ [mag]	E_{B-V} [mag]	t Myr	$\underline{d}$ [′]
Blanco 1*	6.8	0.03	50	105
Stock 2	7.5	. . .	100	260
α Per*	6.3	0.09	20	255
Pleiades*	5.6	0.05	75	300
NGC 2451 A*	6.4	0.00	20	140
IC 2391*	5.8	0.00	20	110
Praesepe*	6.0	0.00	650	195
IC 2602*	5.8	0.03	10	185
NGC 7092	7.6	0.12	70	170



cluster	# stars	Γ	mass range [$M_\odot$]	V_T range [mag]
Blanco 1	34	-2.27 ± 0.70	[1.1; 4.8]	[6.1; 11.4]
Stock 2	204	-2.01 ± 0.40	[1.5; 4.1]	[7.6; 11.0]
α Per	70	-1.57 ± 0.44	[1.1; 6.8]	[5.0; 10.5]
Pleiades	127	-1.99 ± 0.39	[1.0; 4.1]	[5.0; 10.9]
NGC 2451 A	27	-0.69 ± 0.63	[1.3; 6.8]	[4.8; 10.0]
IC 2391	29	-1.07 ± 0.53	[1.1; 8.1]	[3.5; 10.7]
NGC 7092	25	-1.93 ± 1.24	[1.4; 3.4]	[6.5; 9.9]

Sanner & Geffert, 2001, A&A, 370, 87

Saurabh et al., 2008, AJ, 135, 1934



Mass-Function Slope Γ for Two Subregions and for the Whole-Cluster Region in the Given Mass Range

Cluster	Mass range	Mass function slopes ($\Gamma \pm \sigma$)		
	($M_\odot$)	Inner region	Outer region	Whole cluster
Be 62	11.17–1.14	-0.89 ± 0.17	-2.10 ± 0.74	-1.88 ± 0.34
NGC 1528	2.55–0.73	-1.96 ± 0.42	-2.17 ± 0.43	-2.10 ± 0.35
NGC 1960	6.82–1.01	-1.25 ± 0.24	-1.99 ± 0.15	-1.80 ± 0.14
NGC 2287	2.70–0.83	-1.35 ± 0.86	-1.22 ± 0.27	-1.22 ± 0.19
NGC 2301	2.78–0.82	-0.85 ± 0.33	-1.56 ± 0.54	-1.34 ± 0.32
NGC 2323	4.22–0.67	-1.69 ± 0.09	-2.28 ± 0.31	-2.01 ± 0.17
NGC 2420	1.44–0.67	-0.93 ± 0.32	-1.50 ± 0.56	-1.30 ± 0.39
NGC 2437	3.51–1.02	-1.72 ± 0.13	-2.30 ± 0.62	-2.03 ± 0.42
NGC 2548	2.46–0.82	-1.11 ± 0.85	-1.02 ± 0.36	-1.12 ± 0.70

Typical values and errors