The evolution of the stellar mass function of globular clusters

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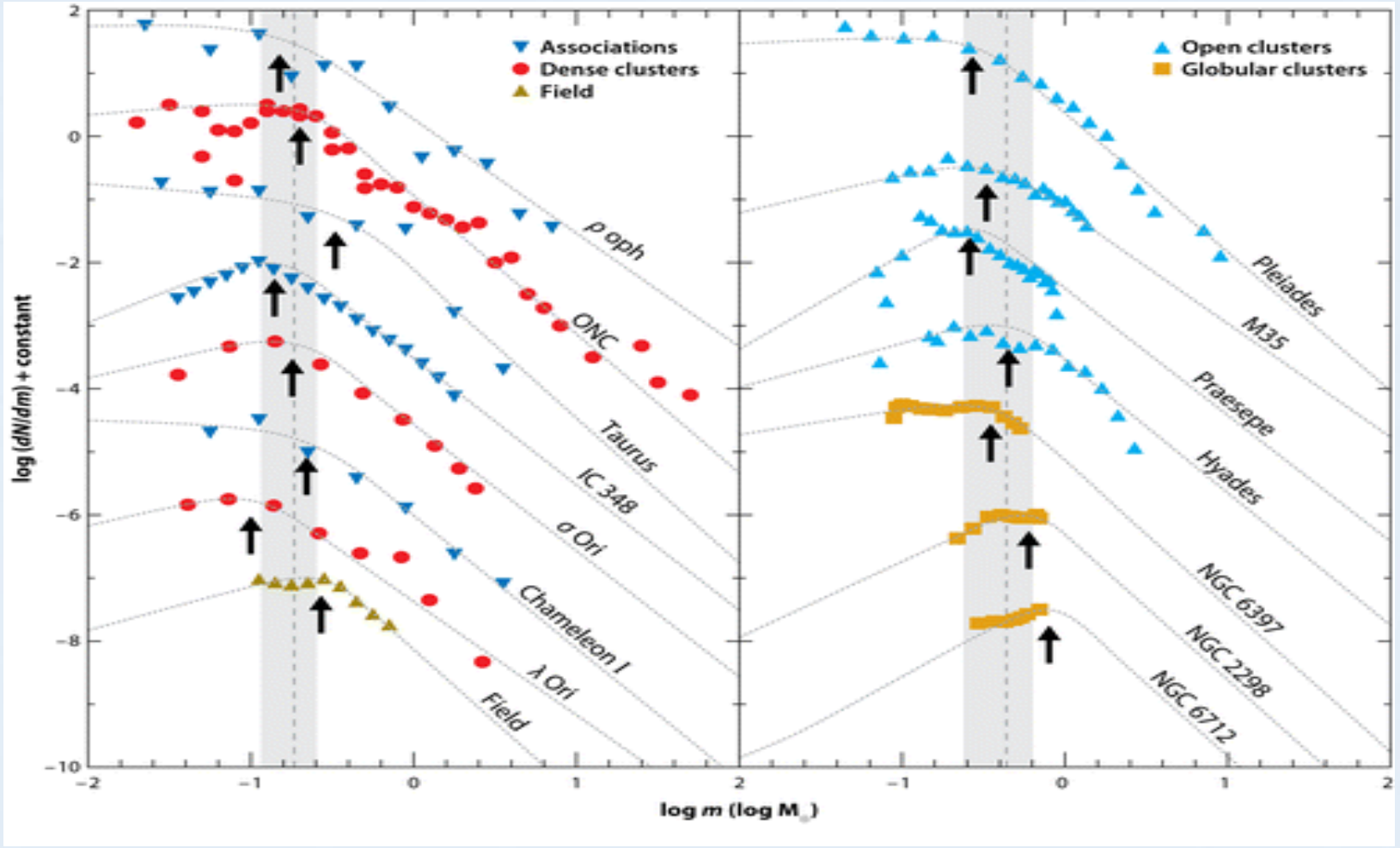
Padova 24-09-2013

Why do we care about the evolution of the mass function of star clusters?

1. **The present mass function of clusters provides information about the history of the cluster, including the IMF.**

2.. **The evolution of the mass function is important for understanding the photometry of unresolved clusters (interaction history of galaxies)**

Observed stellar mass functions

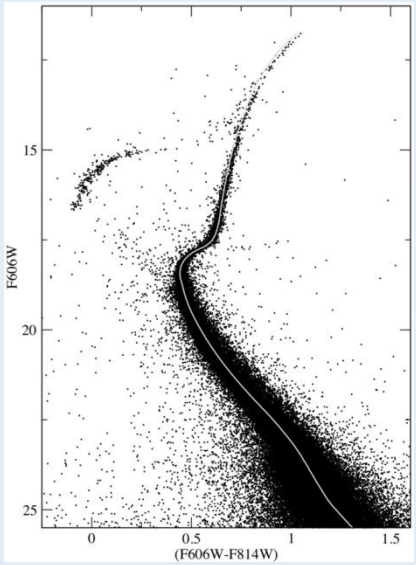


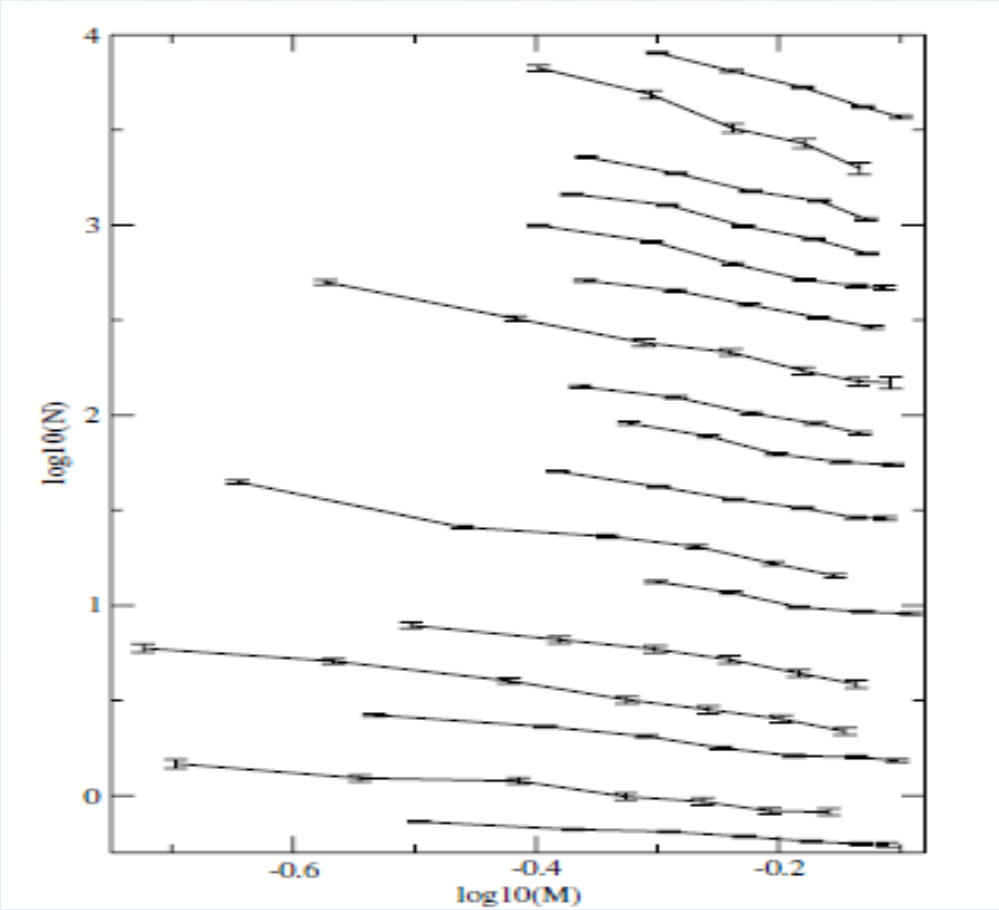
Bastian et al. 2010

Comparison with observations

Global mass functions of 17 MW GCs

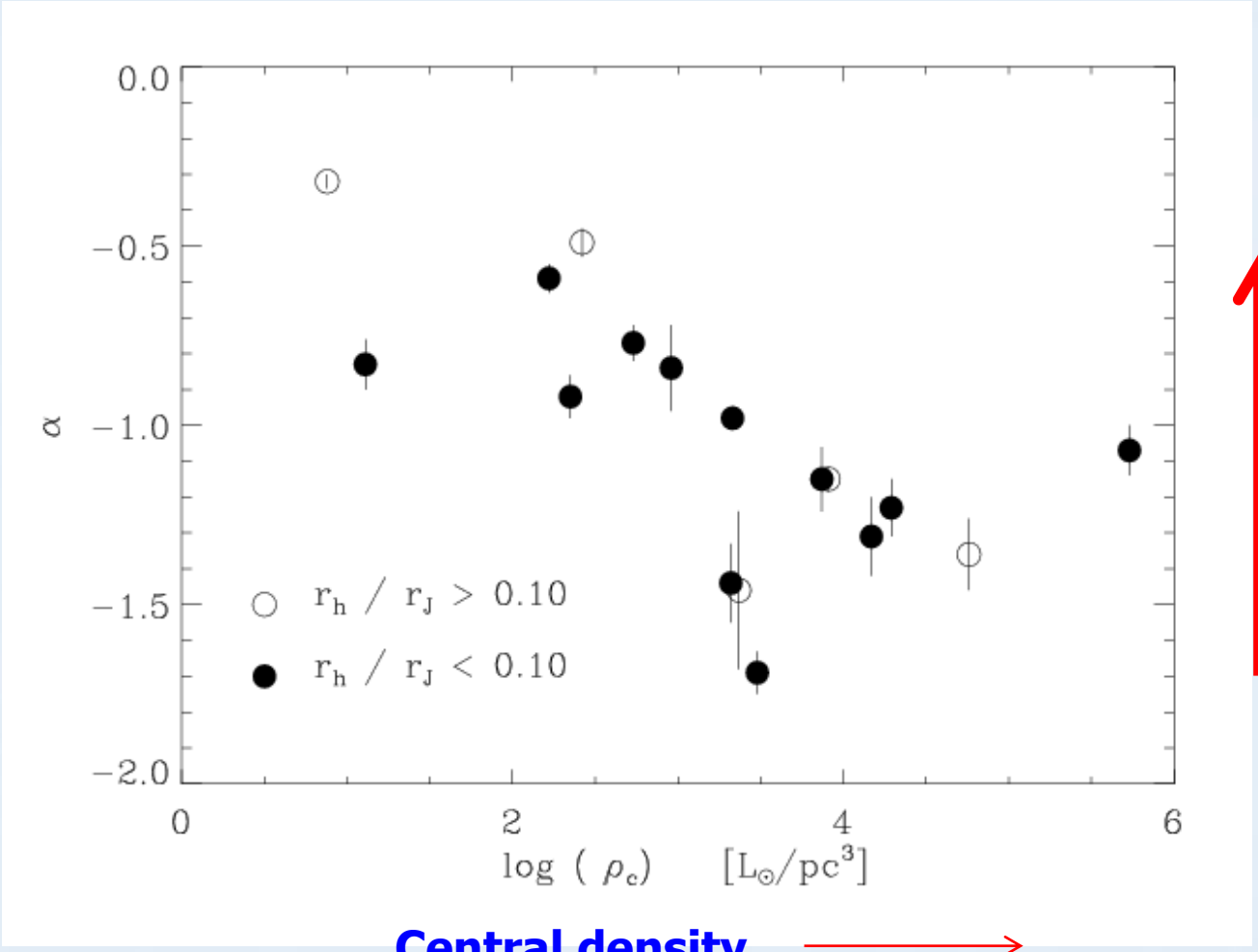
Based on a homogeneous analysis of HST-ACS observations





Paust et al. 2010

Relation between MF slope and central density



high

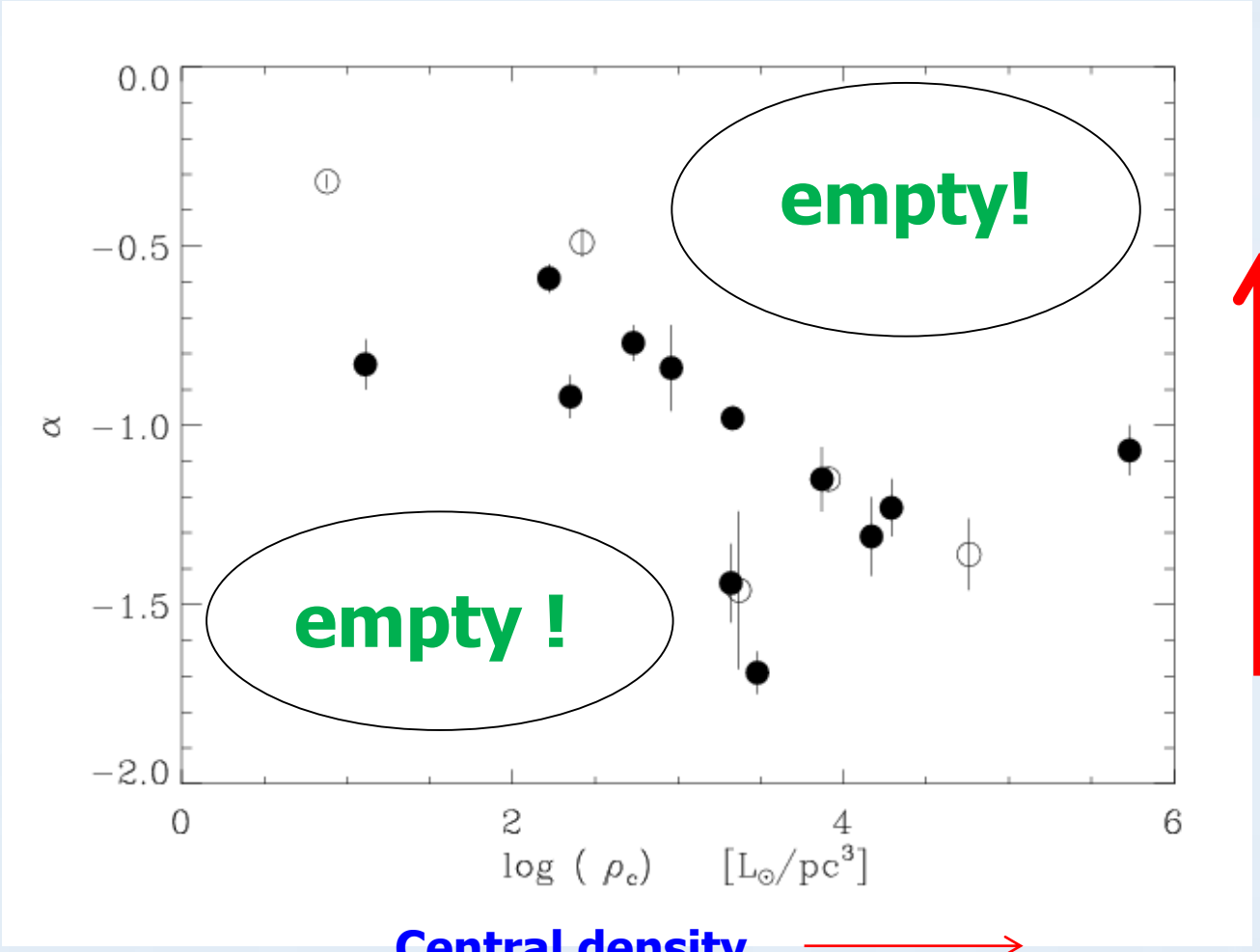
Low mass star depletion

low

Central density

Observations by Paust et al. 2010

Relation between MF slope and central density



high

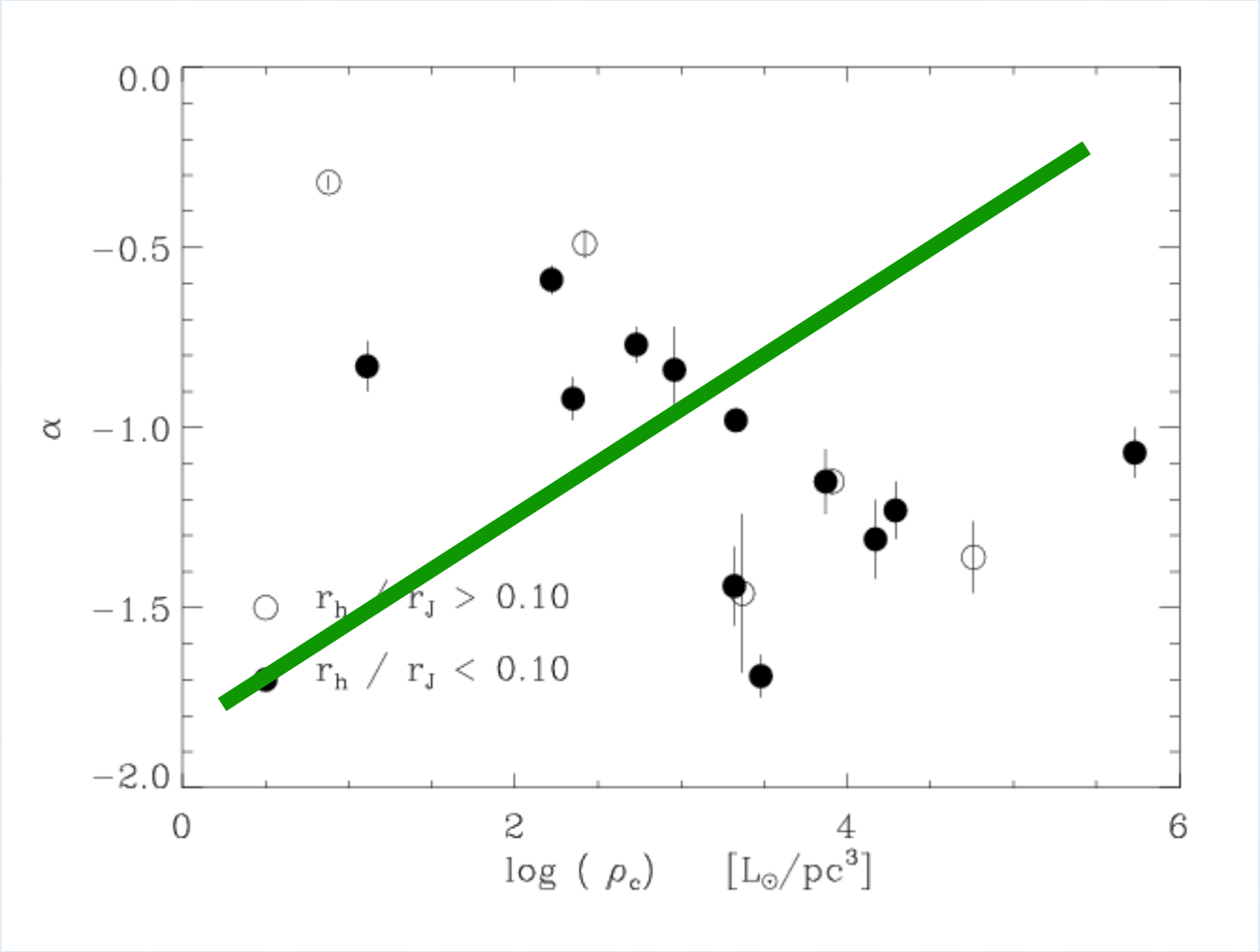
Low mass star depletion

low

Central density

Observations by Paust et al. 2010

Relation between MF slope and central density



The expected relation !!

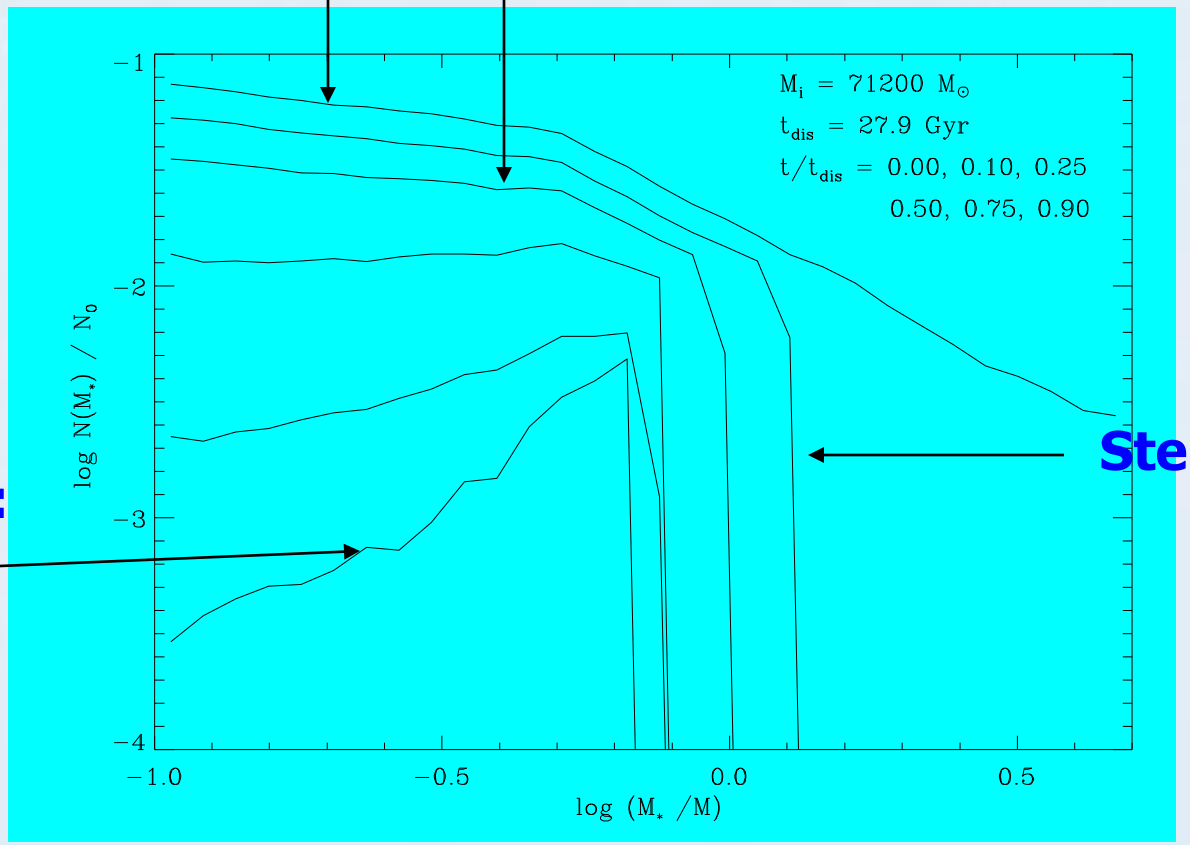
Observations by Paust et al. 2010

The evolution of the MF of star clusters: an analytic description

Lamers, Baumgardt, Gieles 2013 MNRAS 433, 1378

Initial MF

Early dissolution



Dissolution after mass segregation:

loss of low mass stars

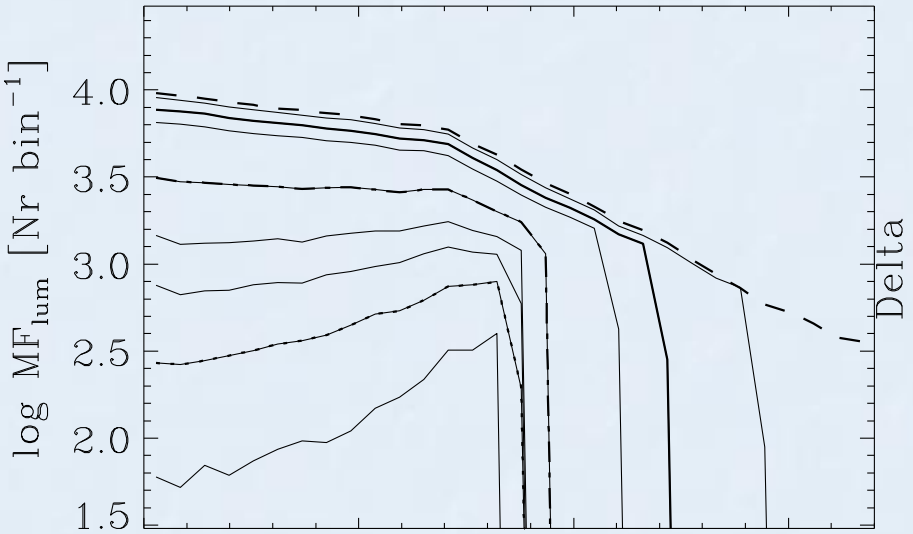
Stellar evolution

N-body simulations by Baumgardt & Makino 2003

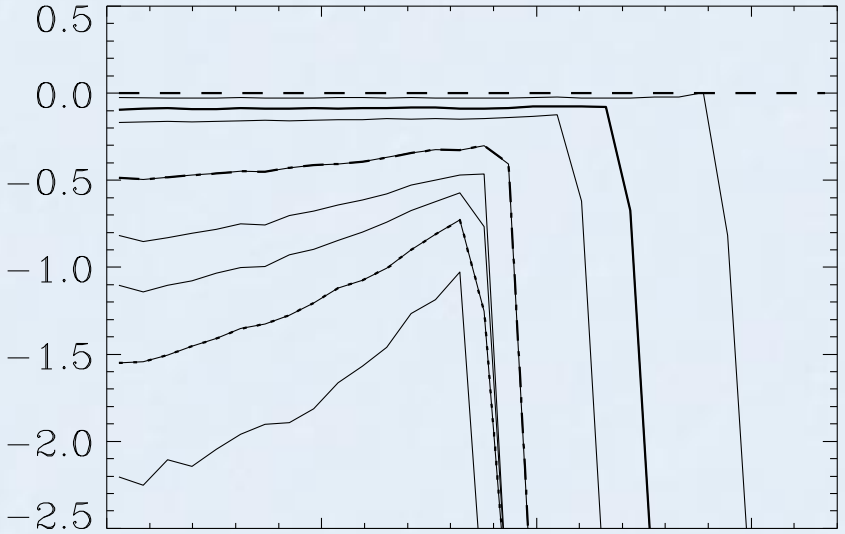
The Differential Mass Function : a practical way to describe the MF evolution

Delta (t, m) = log N(t,m) / N(0,m)

The mass function



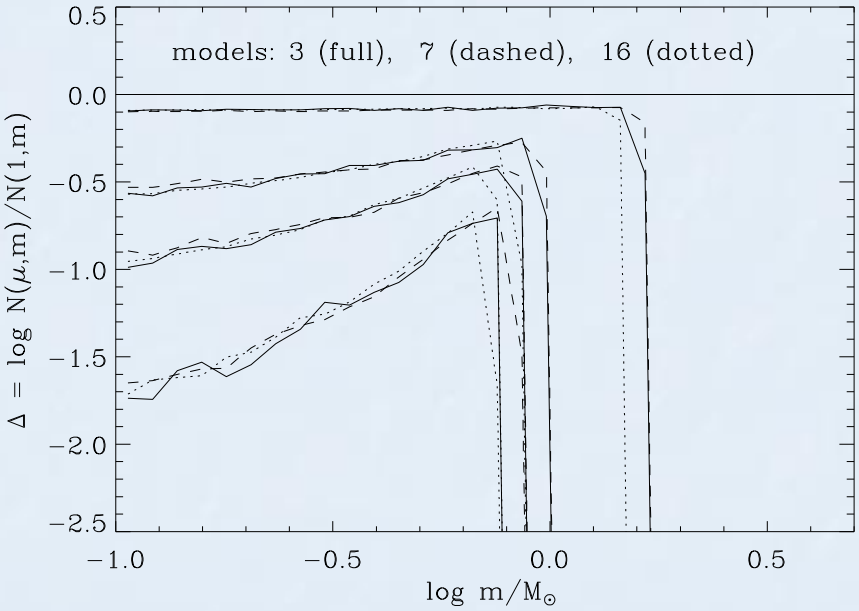
Differential mass function



The differential mass function is very similar for a large range of cluster models "if compared at different mass-fractions"

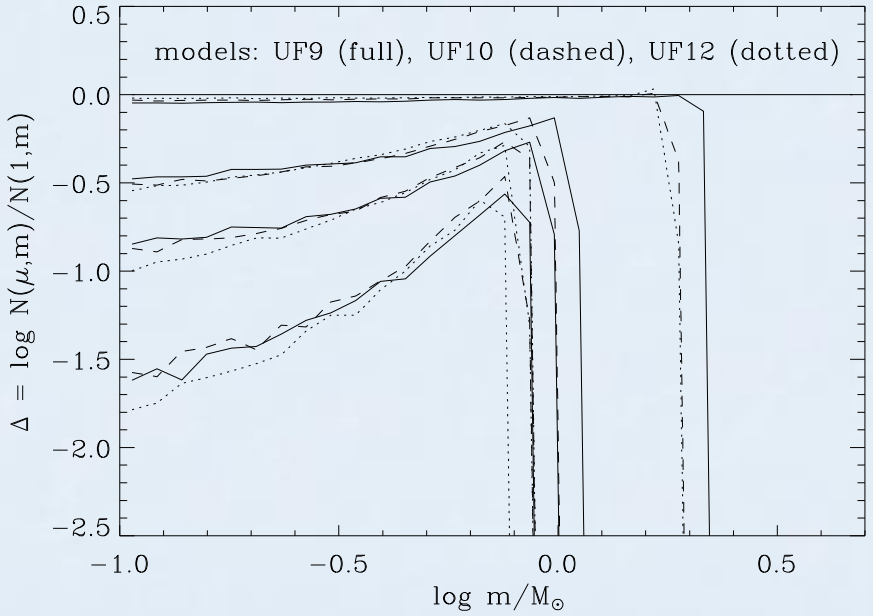
Models with different ages

t = 28, 20, 17 Gyr

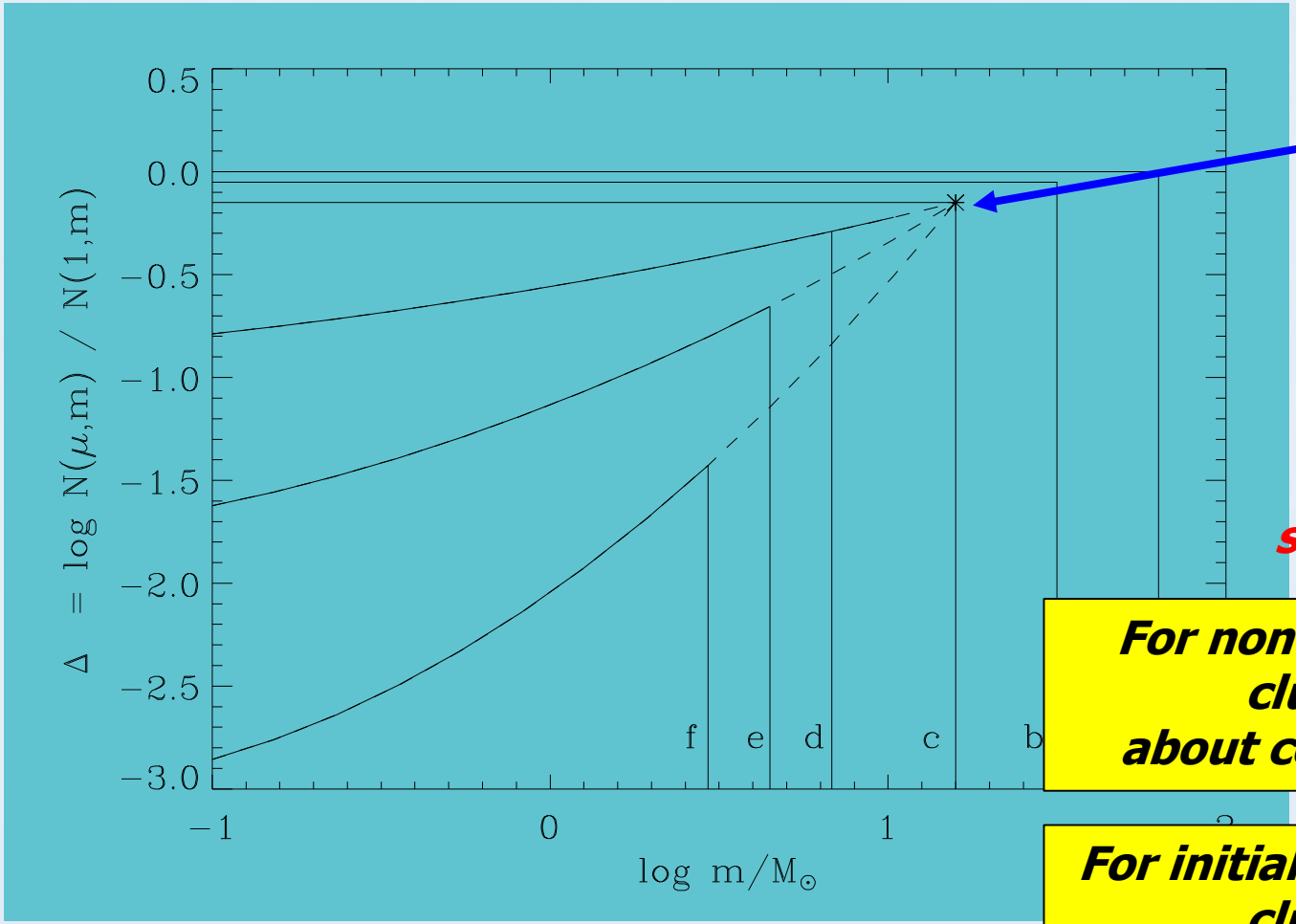


Models with different initial concentrations

r_h = 0.5, 1, 4 pc



A schematic description of the evolution of the mass function



depletion point

When does the cluster reach global mass segregation ??

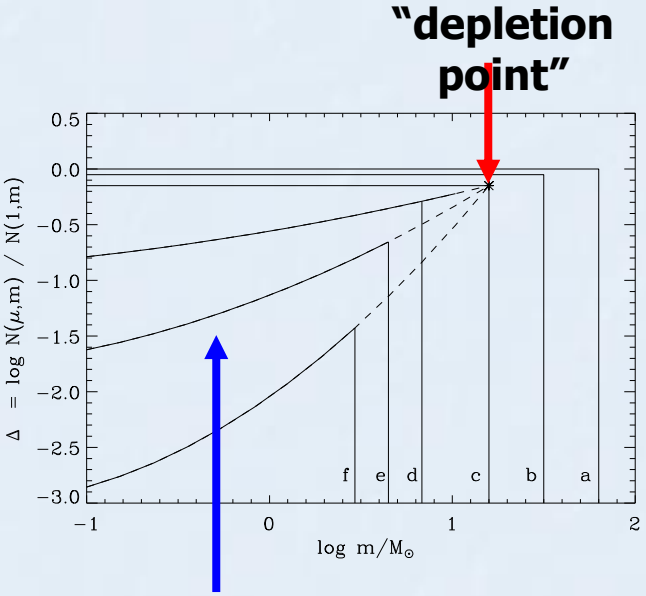
For non-segregated clusters: about core collapse

For initially segregated clusters: right away

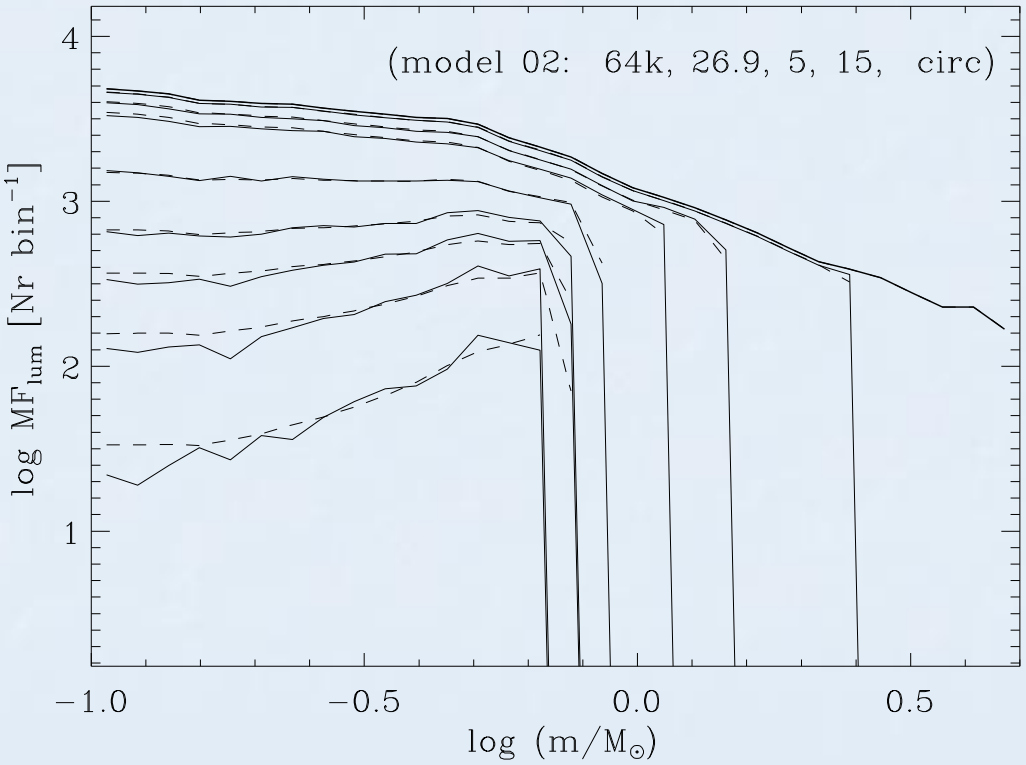
The predicted evolution of the MF

Full lines = N-body model

Dashed lines : prediction

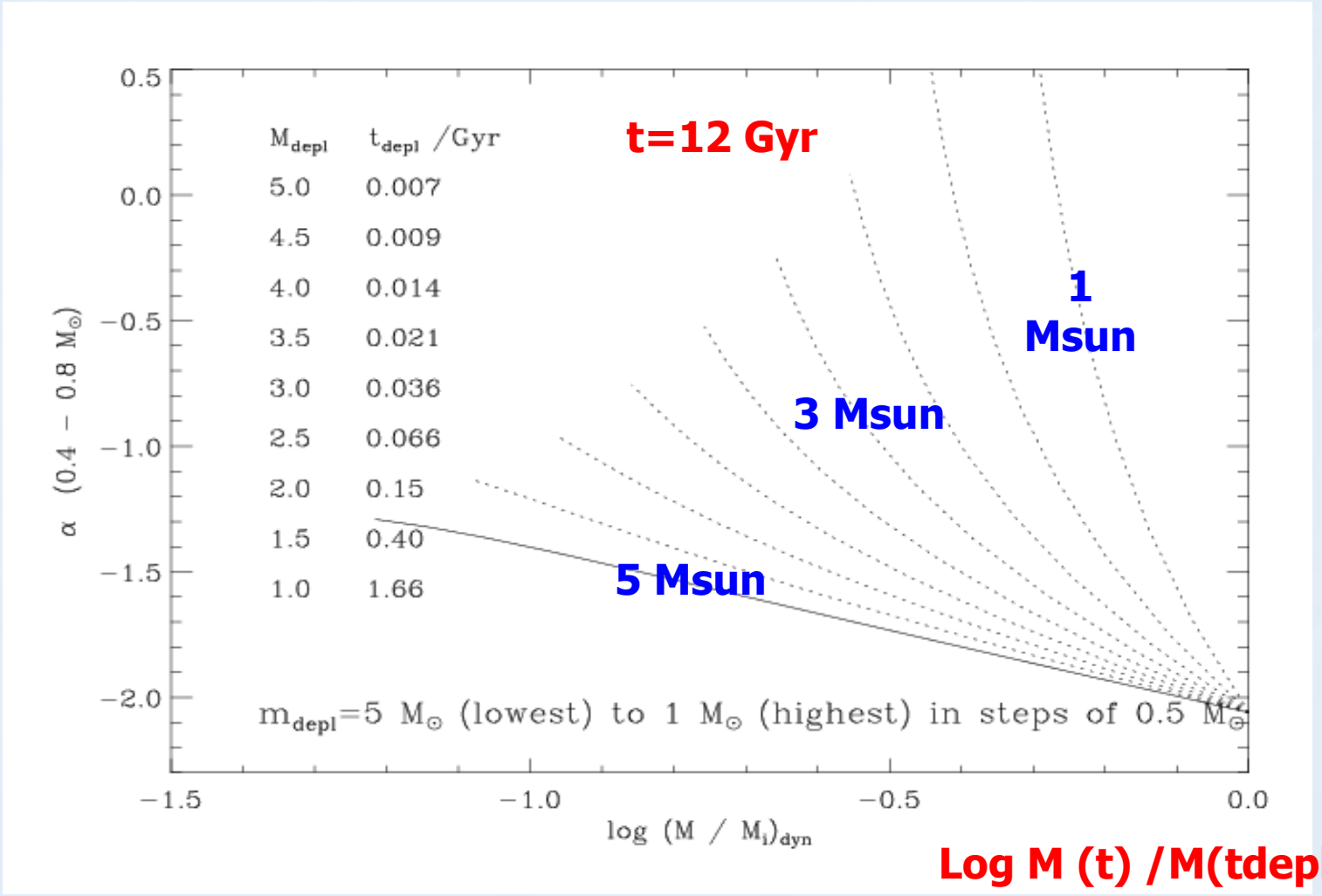


Shape of DMF



L et al. 2013 submitted

Predicted relation between MF slope, fraction of lost mass, time of mass segregation.



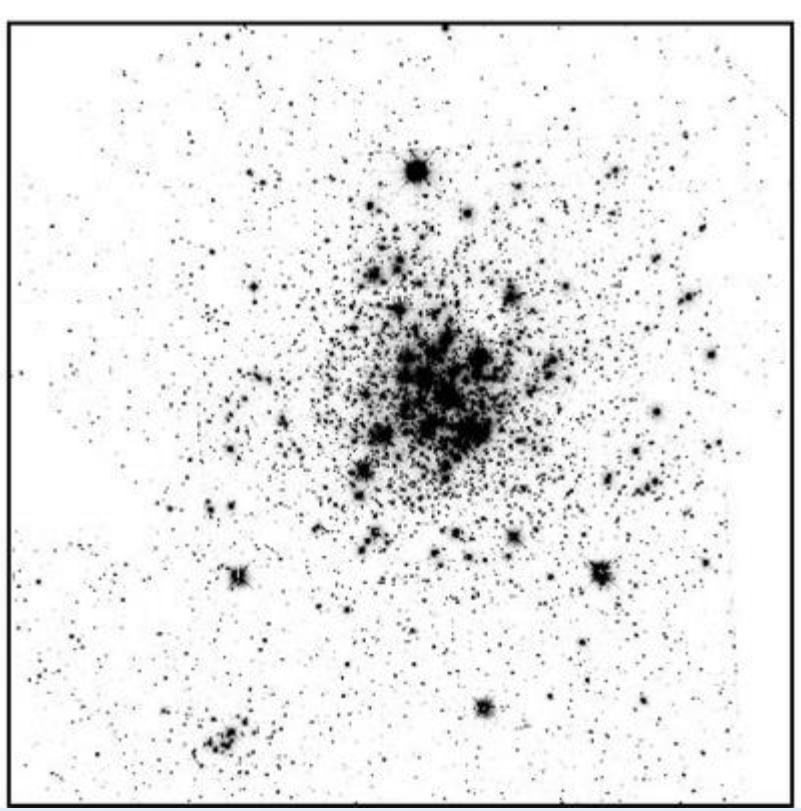
How the MF gets a flat slope (-1<α<-0.5)

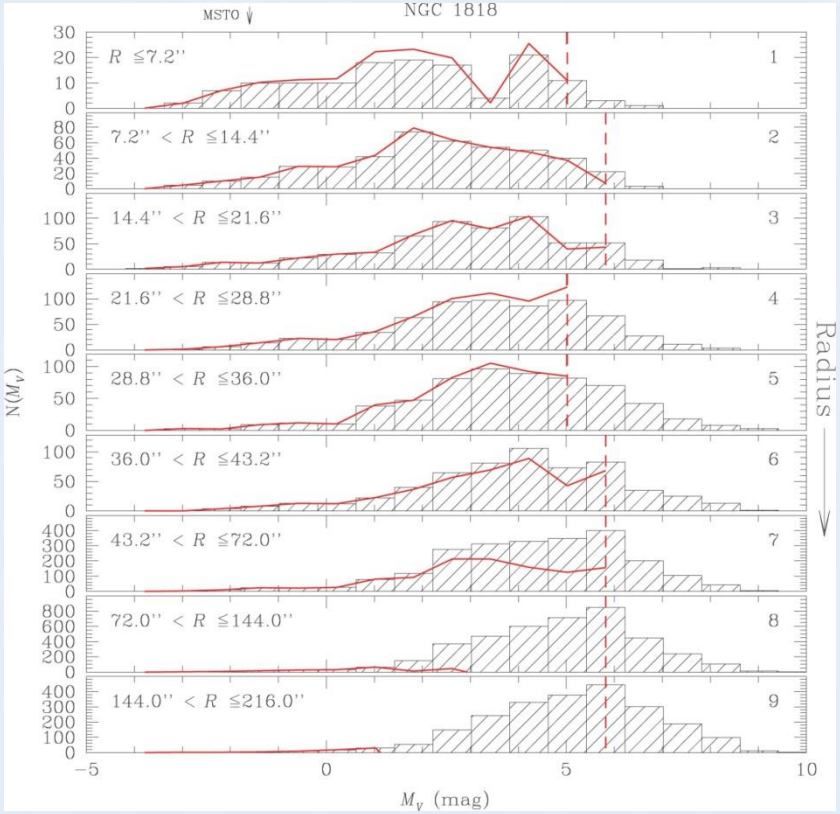
without initial mass segregation

m_{depl}	t_{cc}	$M(t)/M(t_{depl})$
1.1 Msun	**> 1 Gyr**	**~ 0.6**
2.5 Msun	**0.1 Gyr**	**~ 0.3**
4.0 Msun	**0.01 Gyr**	**~ <0.1**
10 Msun	**0.003 Gyr**	**< 0.01**

Initial mass segregation?

NGC 1818 in LMC
t=7 Myr M =3 1^4 Msun r_h = 2.7 pc

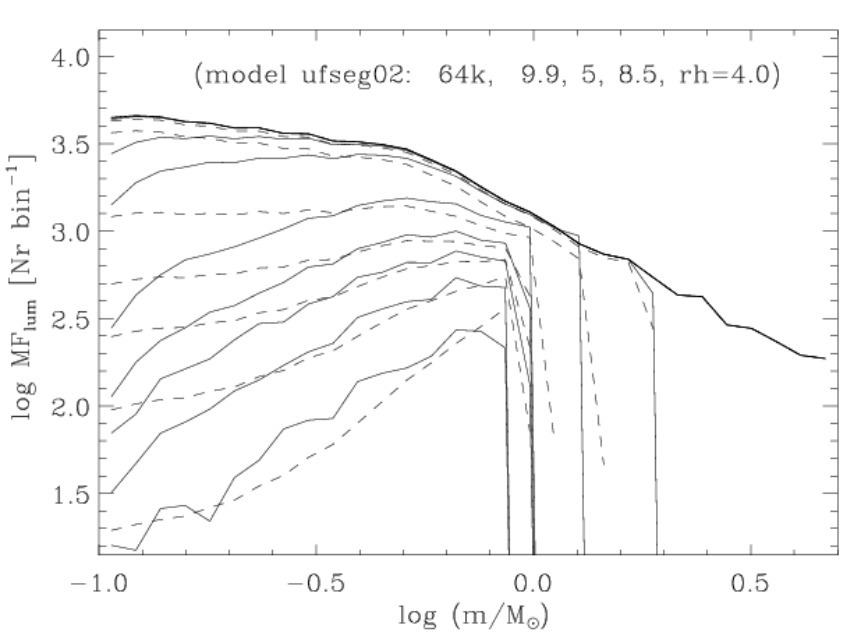




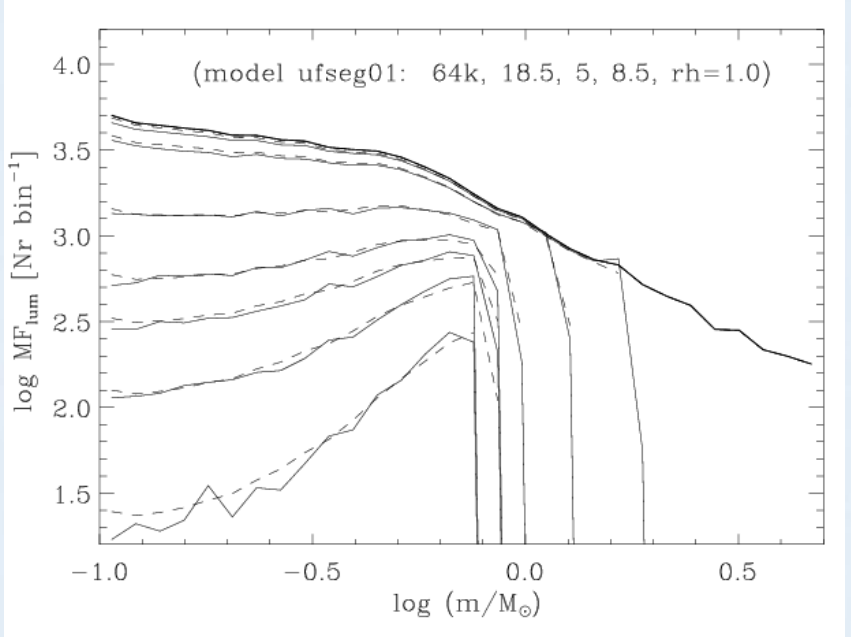
De Grijs et al. 2002

The effect of initial mass segregation

Two similar models
with the same severe initial mass segregation



Strong tidal field
strong mass loss before t_cc



Weak tidal field
strong mass loss after t_cc

Baumgardt et al. 2008

Strong depletion of low mass stars

without assuming that the cluster is almost completely dissolved: M/Mi > 0.20

1. **Without initial mass segregation**

   - after core collapse

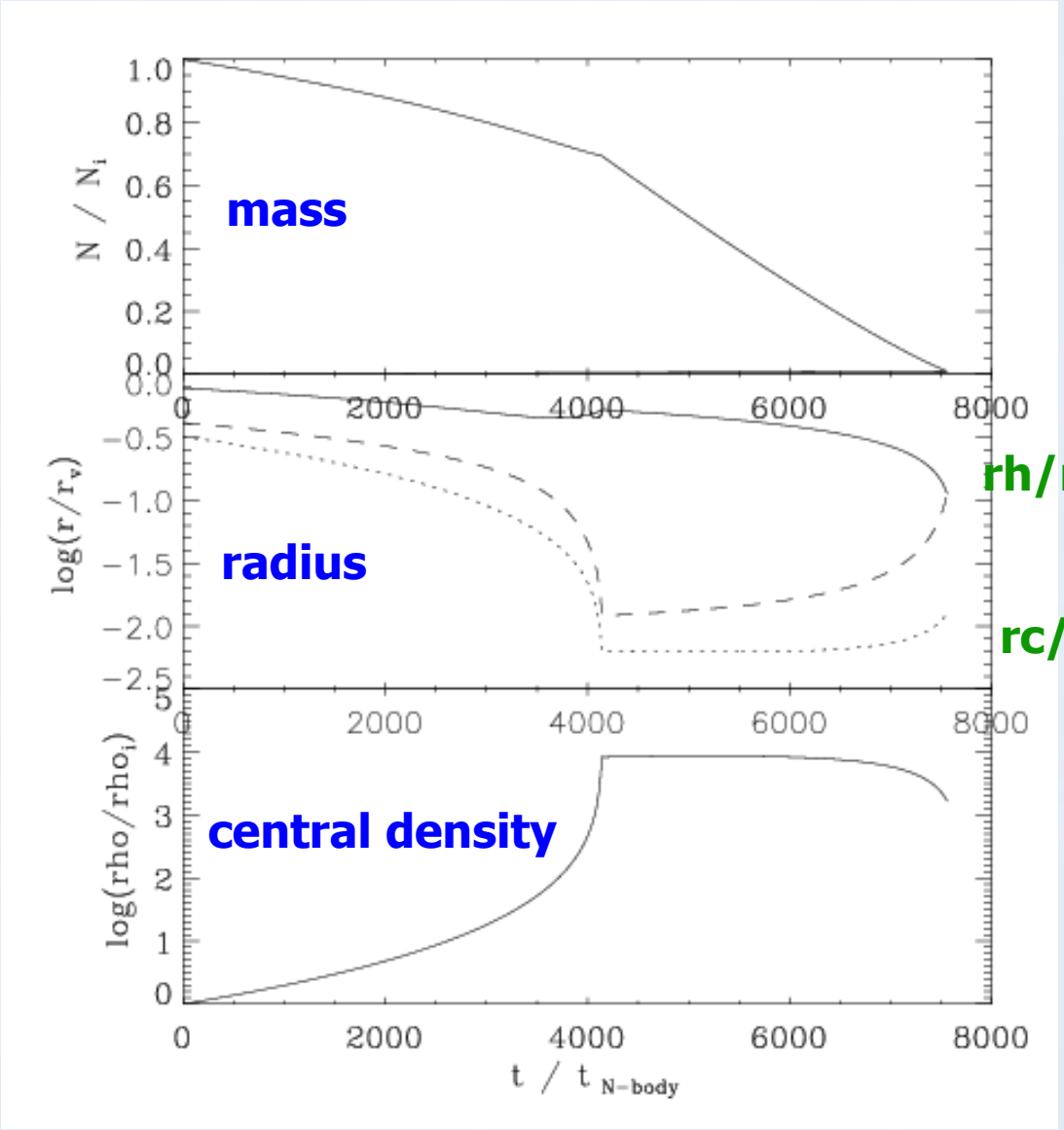
   - small m_depl -> late core collapse

2. **Severe initial mass segregation**

   - no core collapse yet or ecent core collapse

   - but dynamical mass loss

Mass-radius-density evolution: N=3. 10^4



R_h=0.10 R_v

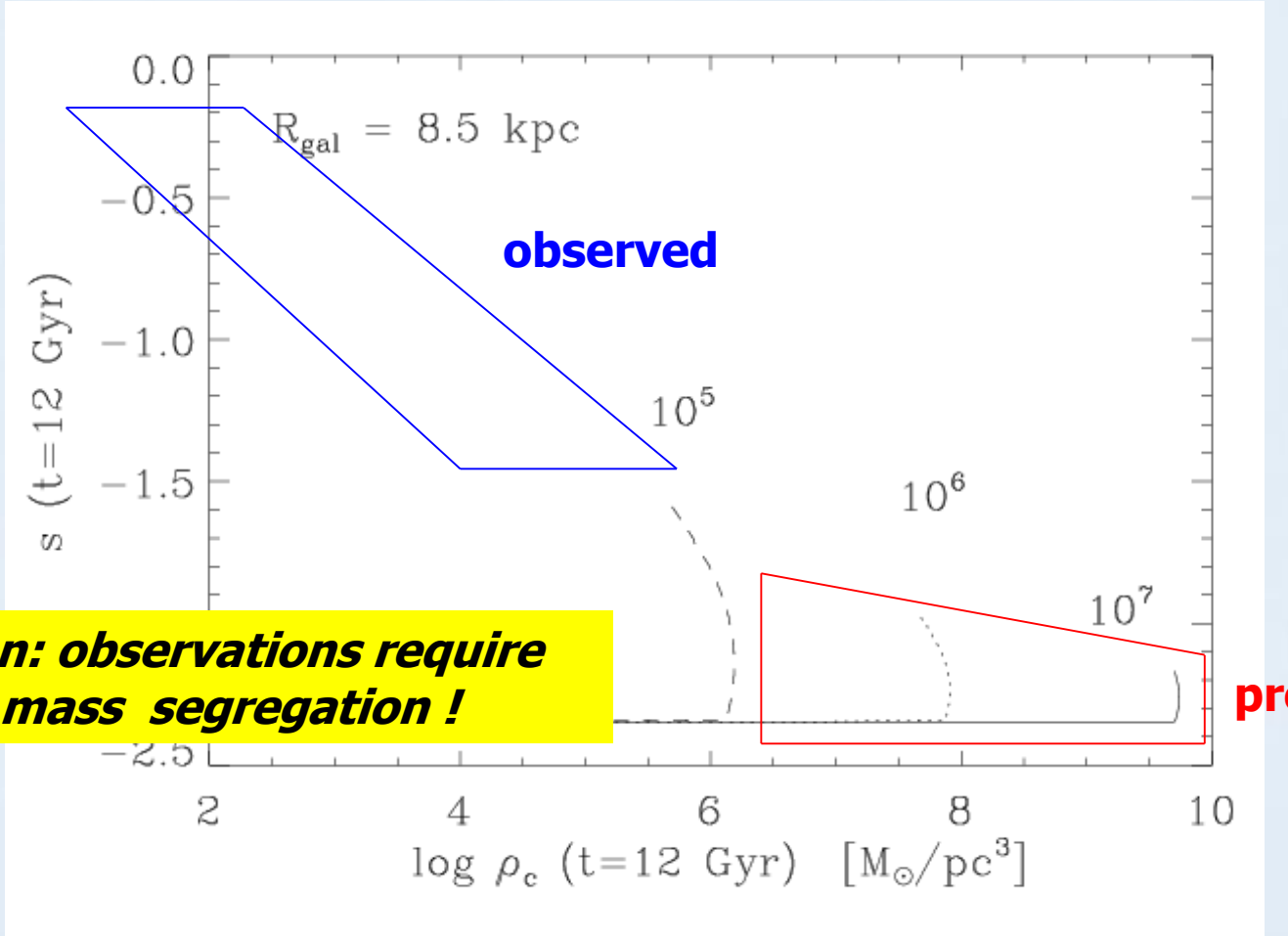
Time in N-body units:

=(GM/R^3)^0.5

EMACSS – programma: Lamers

The relation between central density and α at 12 Gyr

No initial mass segregation



Conclusion: observations require initial mass segregation !

Strong depletion of low mass stars

without assuming that the cluster is almost completely dissolved: M/Mi > 0.20

1. **Witout initial mass segregation:**

   - **after core collapse**

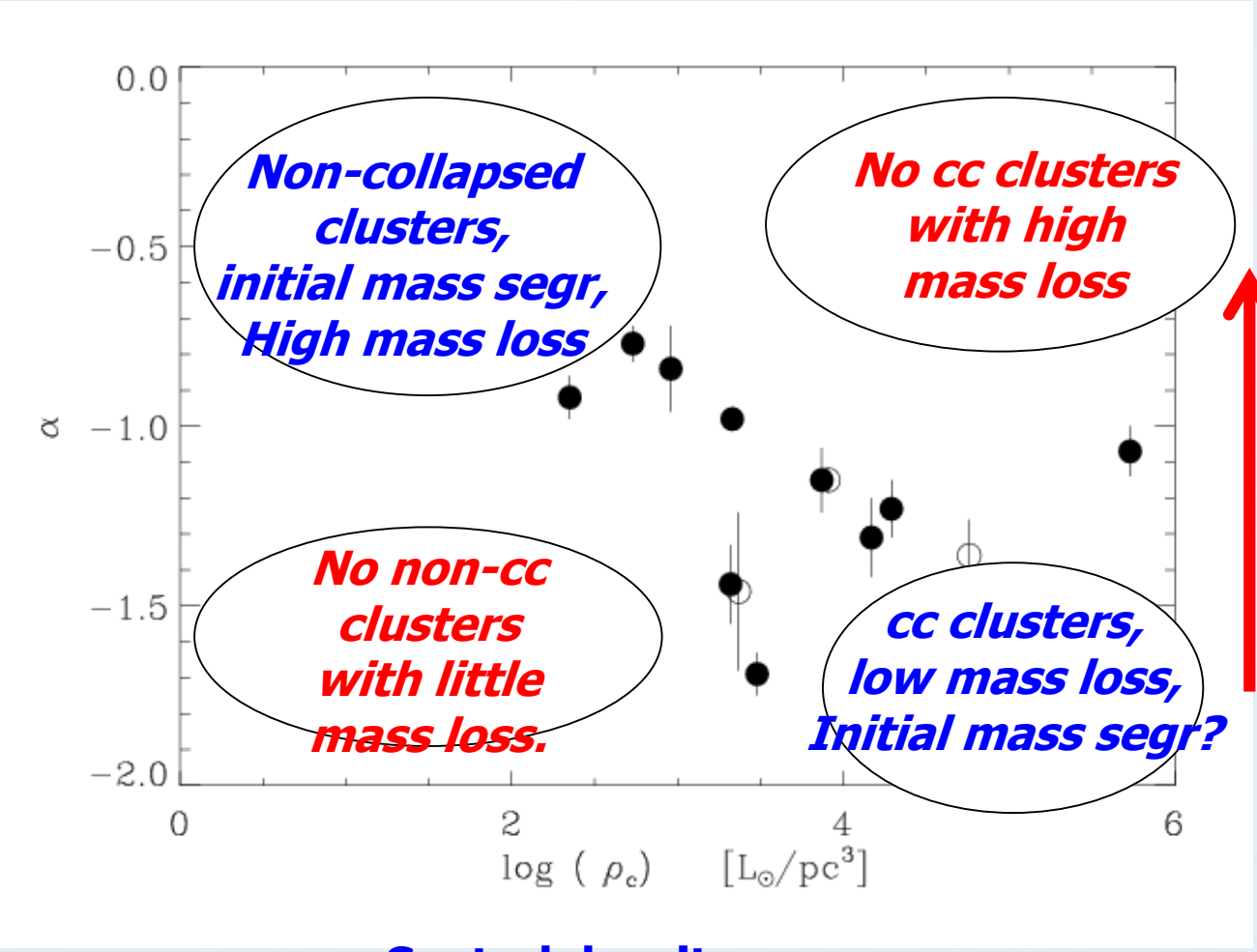
   - **large m_{depl} -> late core collapse : tcc > 1 Gyr**

2. **Severe initial mass segregation**

   - **no core collapse yet but high dynamical mass loss**

   - **or recent core collapse and high dynamical mass loss**

Relation between MF slope and central density



Low mass star depletion

Central density

Observations by Paust et al. 2010

Conclusions:

1. ***The observed mass fuction of GC clusters correlates with present central density***

2. ***This relation provides insight in the conditions during and after GC formation***

3. ***Core-collapsed clusters have lost only a small fraction of their mass after cc.***
   Initial mass segregation : unknown?
   (initial radius small compared to tidal radius)

4. ***Non-core-collapsed clusters must have lost a large fraction of their initial mass, and***
   they must have been initially mass segregated.
   (initial radius large compared to tidal radius

Caution: these conclusions are based on models without black holes and a large binary population

5. ***Quantitative work in progress.***

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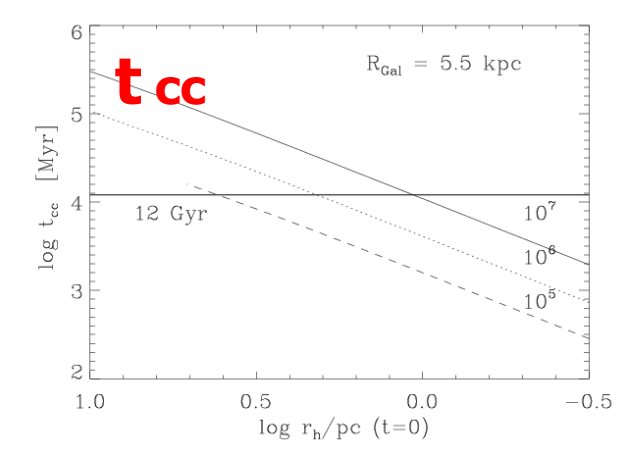
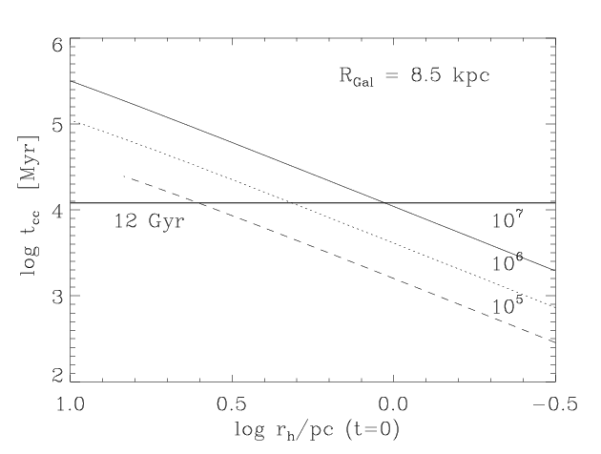
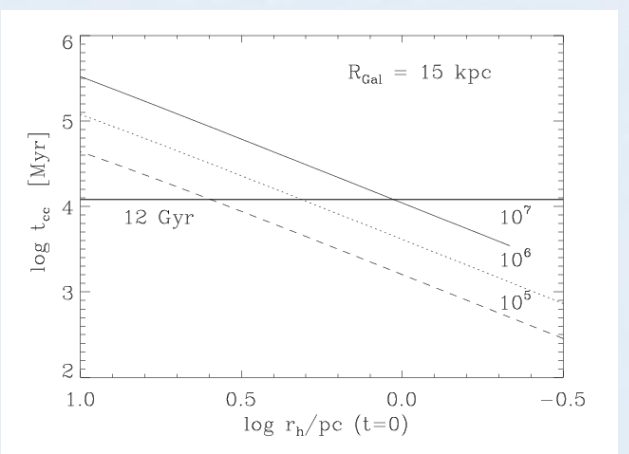
EMACSS models of the evolution of star clusters

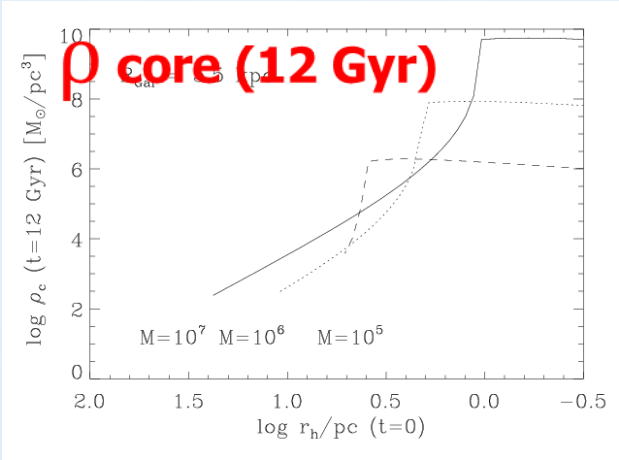
Gieles et al. 2013 MNRAS submitted

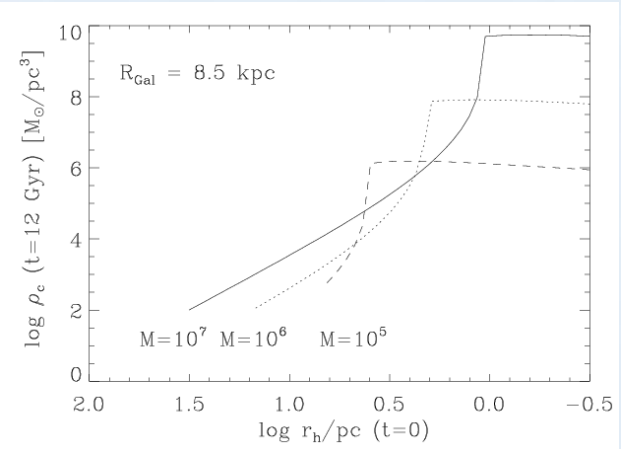
5.5 kpc ***8.5 kpc*** ***15 kpc***

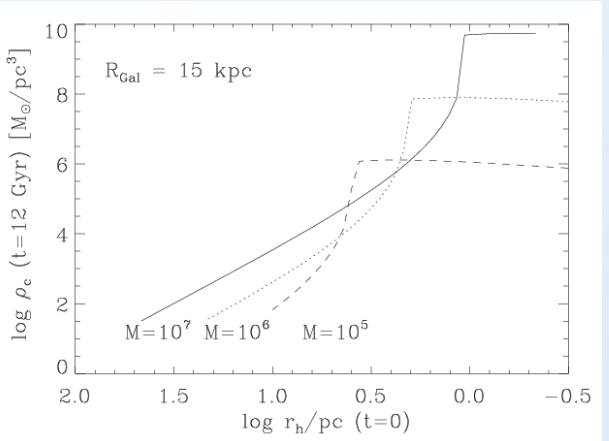












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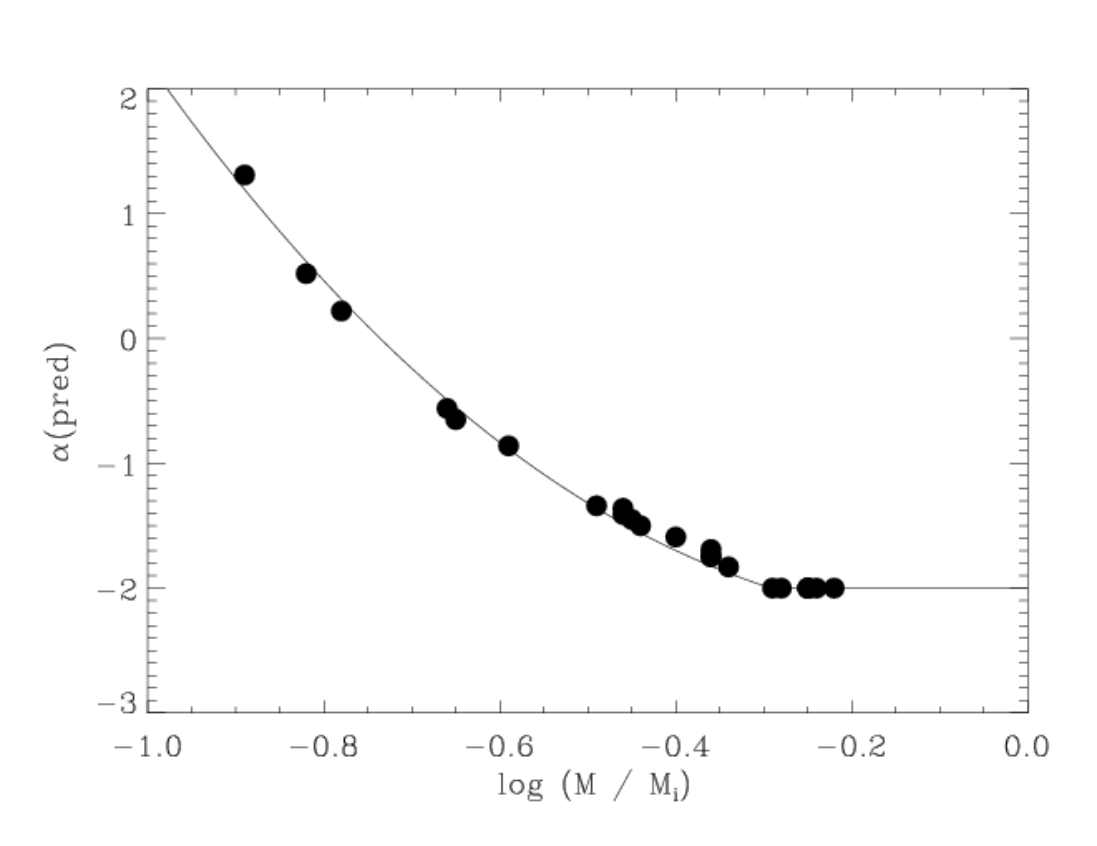
The predicted relation between the slope of the MF at 0.4 – 0.8 Msun is an indication of the fraction of mass that the cluster has lost.

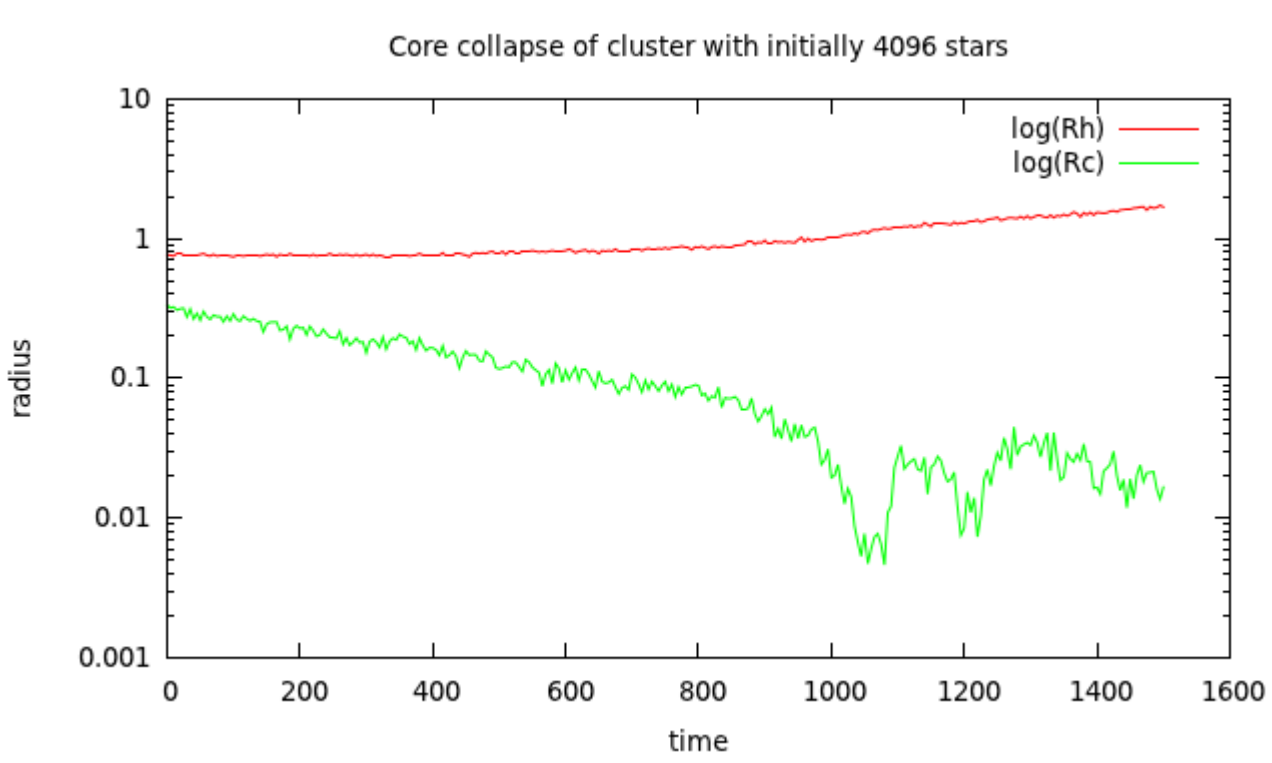


This figure is for clusters with an age of 12 Gyr, that stars with a Kroupa IMF

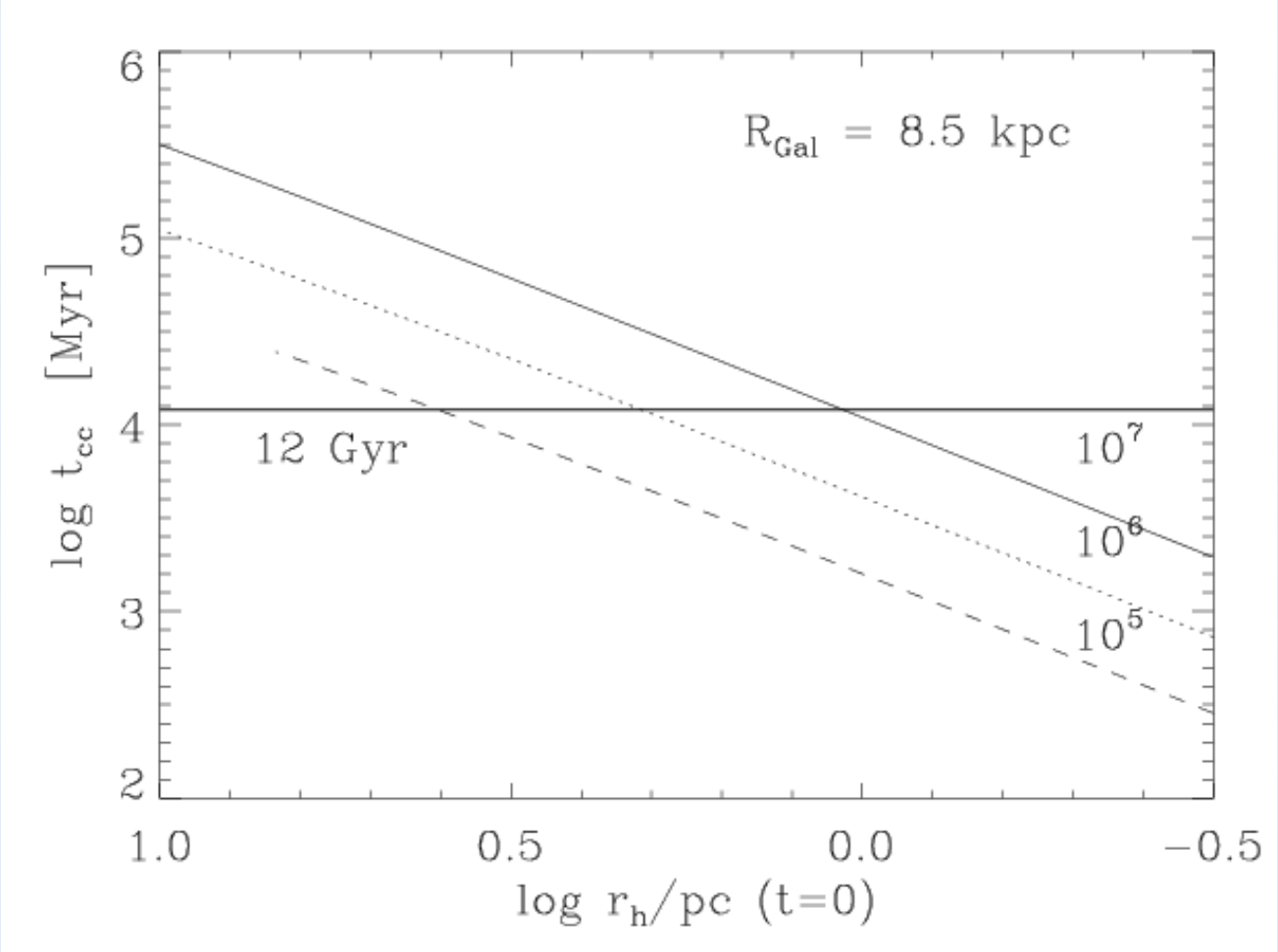
Core collapse:

Energy equipartition: v^2 ~1/m

massive stars lose energy and move to the center
low mass stars gain energy and move to outskirts

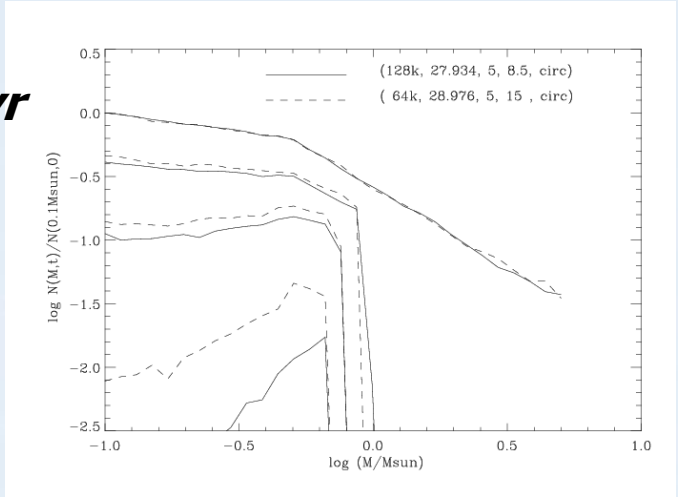


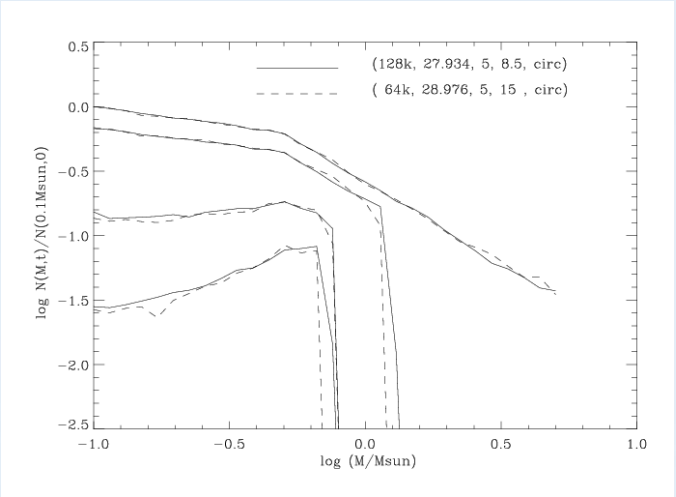
Core collapse time of GC of different initial half-mass radii



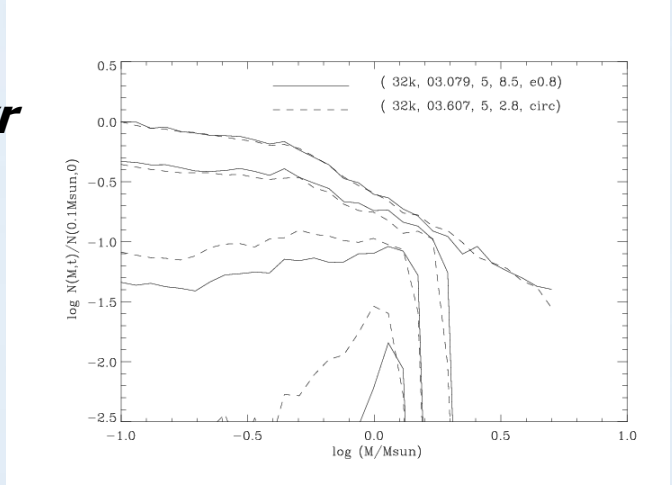
The evolution of the MF in pairs of models

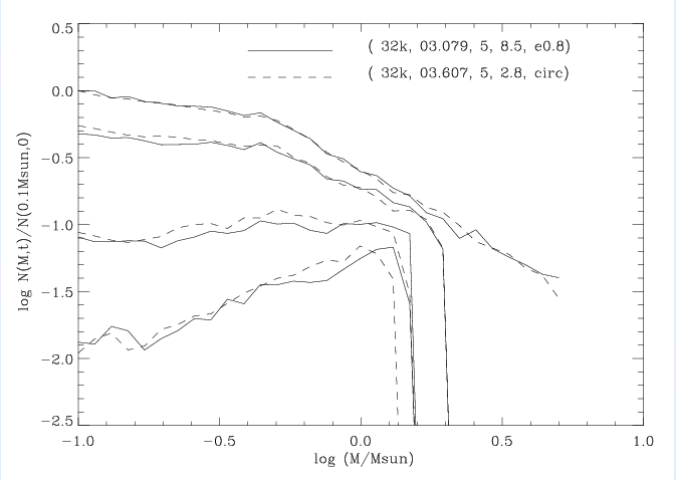
T=28 Gyr





T= 3 Gyr





t=0.0 , 0.5, 0.8, 0.9 T

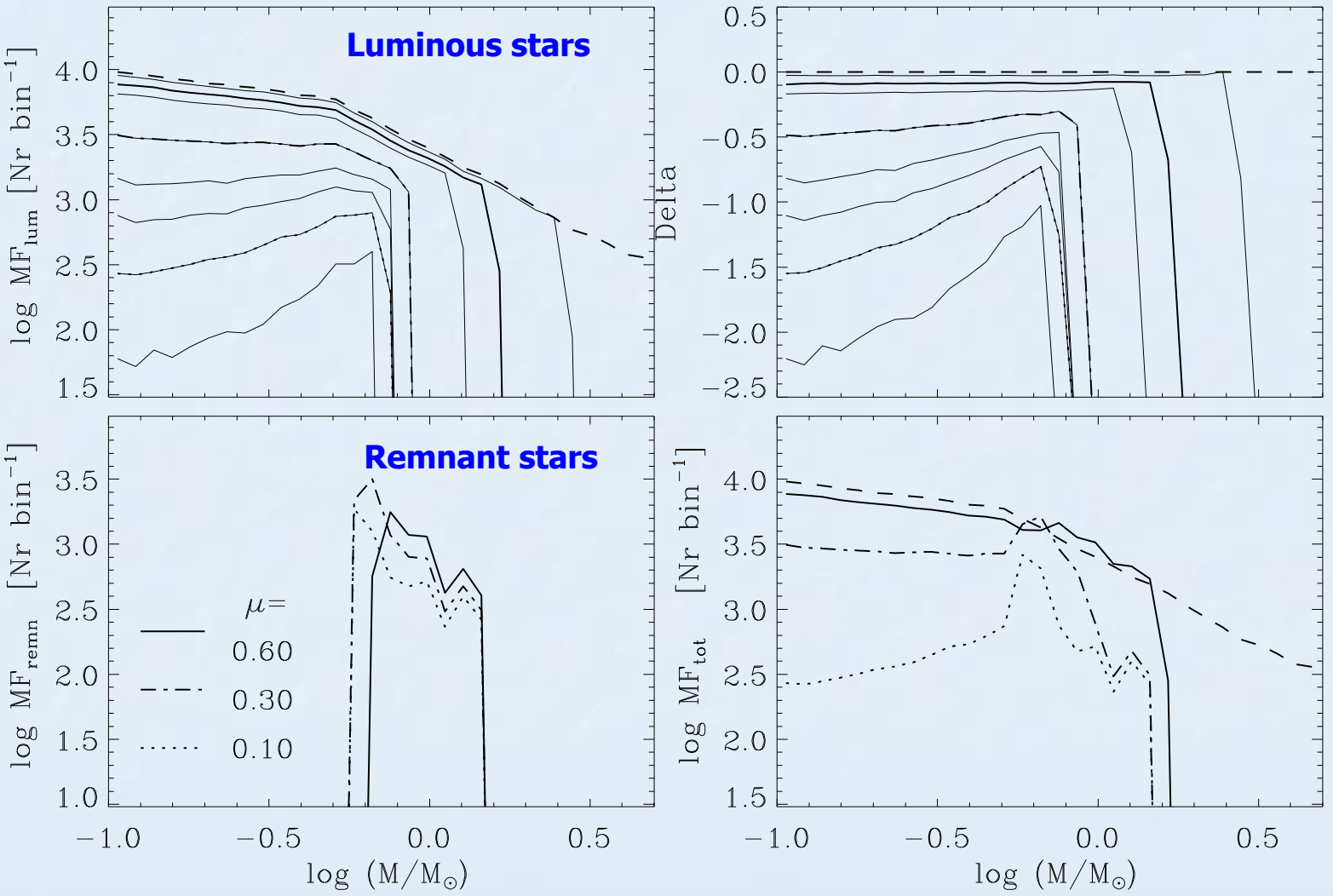
M=1.0, 0.5, 0.2, 0.1 Mi

Compared at the same times

Compared at the same mass fraction

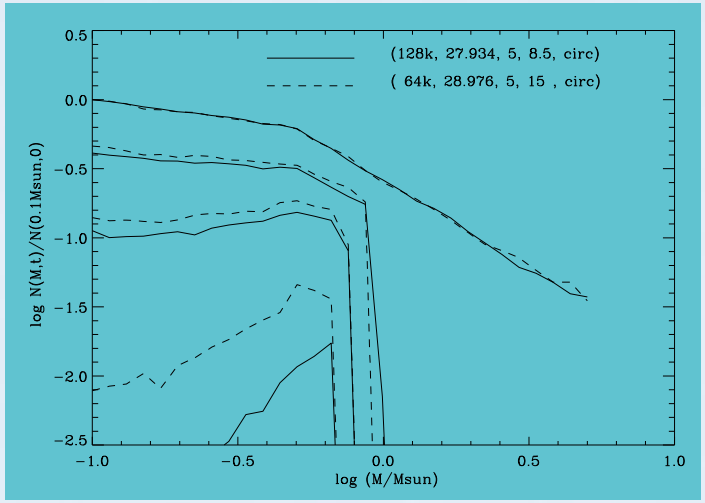
Models by Baumgardt and Makino 2003

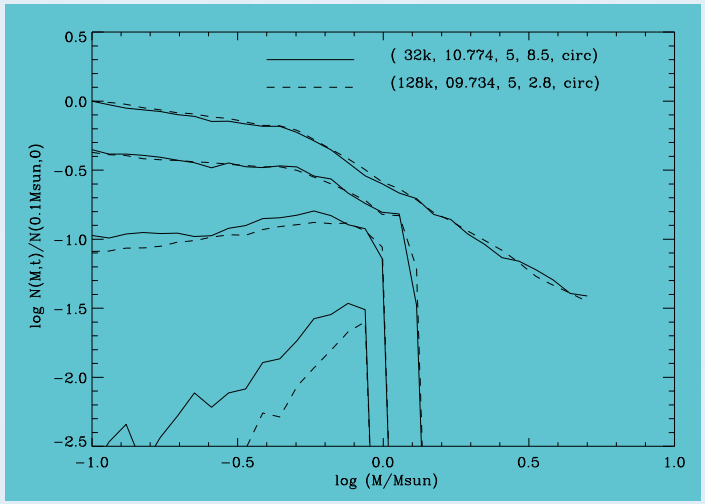
The role of remnants



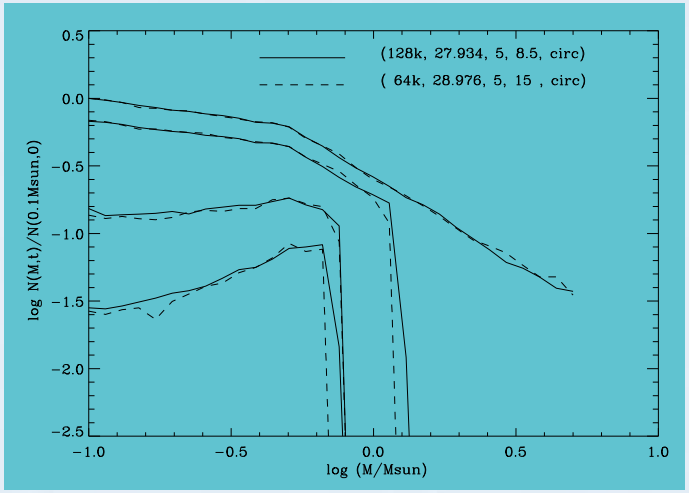
The evolution of the stellar mass function

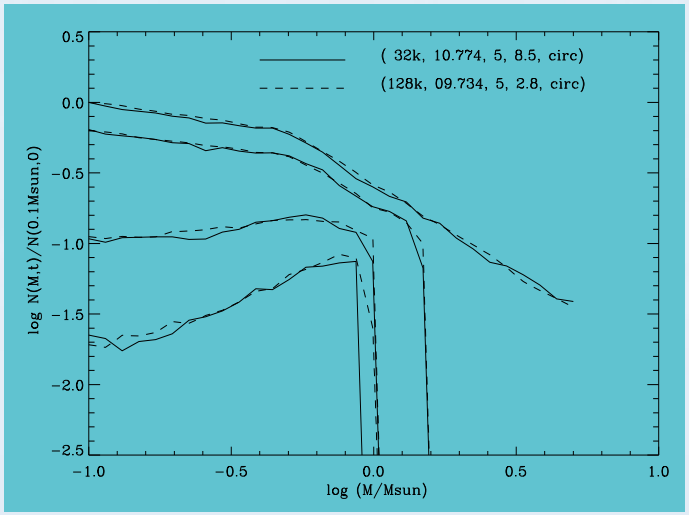
The MF of 2 models at the same times



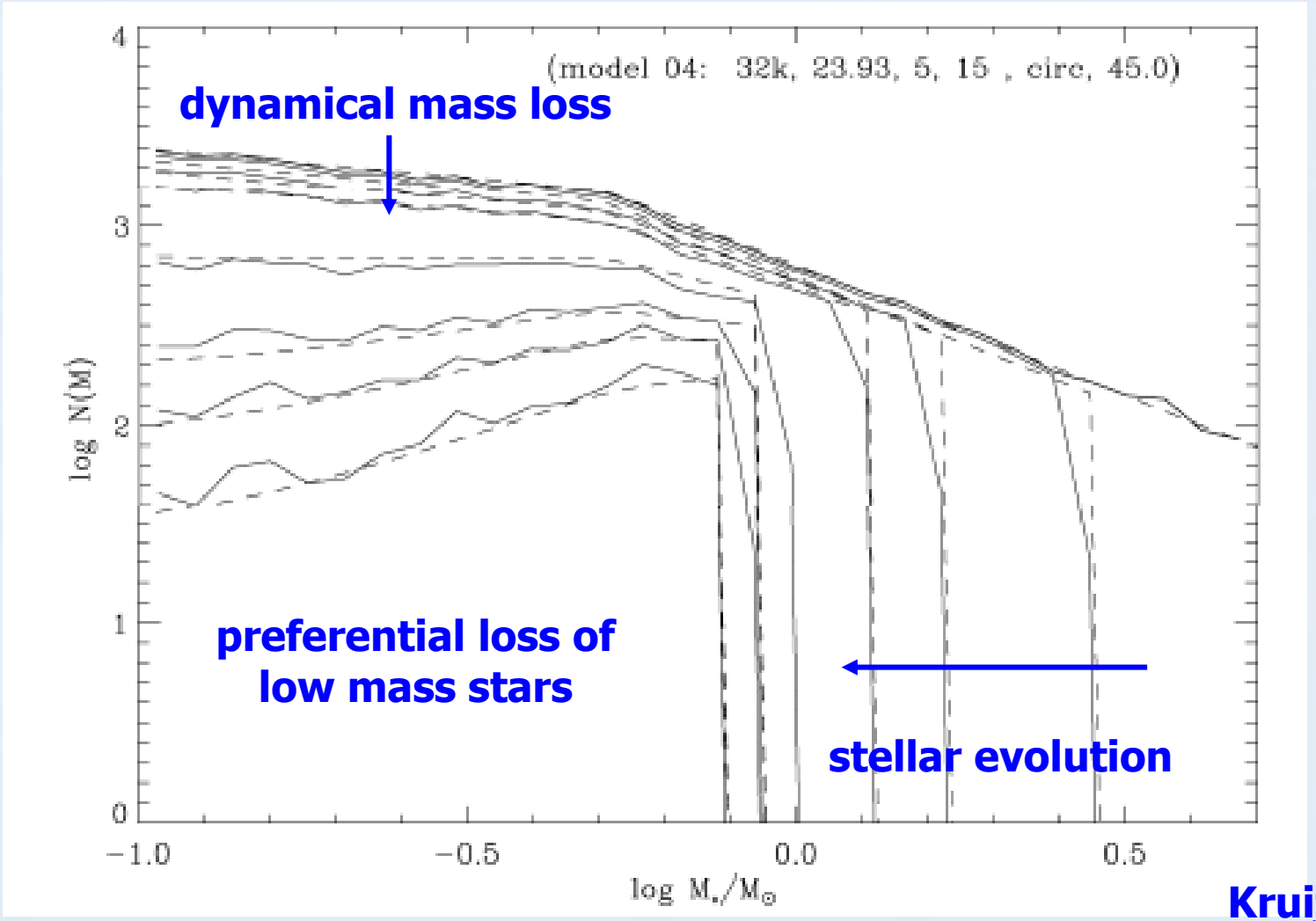


The MF of 2 models at the same mass





The changing stellar mass function



Kroupa IMF

0.10 – 15 Msun

$\mu = M(t)/M_i$

1.0 0.60

0.50 0.30 0.2

0.15 0.10

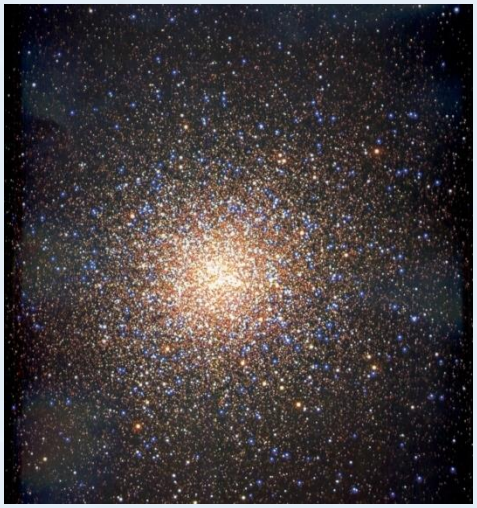
Kruijssen, 2009
Lamers et al 2010

Star clusters

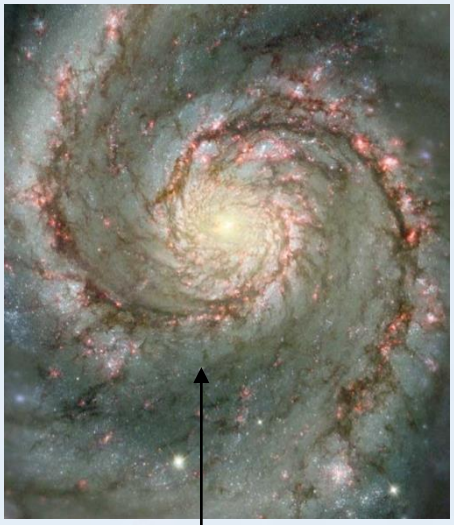
Cluster samples:

1000s of clusters

Young starcluster in the LMC



Old starcluster in the MW halo



Starcluster at 8.4 Mpc

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