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The Milky Way Halo – Stars and Gas

The Origin of the Universal Globular Cluster Mass Function

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Initial GC mass distribution? **Clues about cluster formation ...**

Present-day mass distribution

Mass Spectrum dN/dm

Two-index power-law

Mass Function dN/dlogm

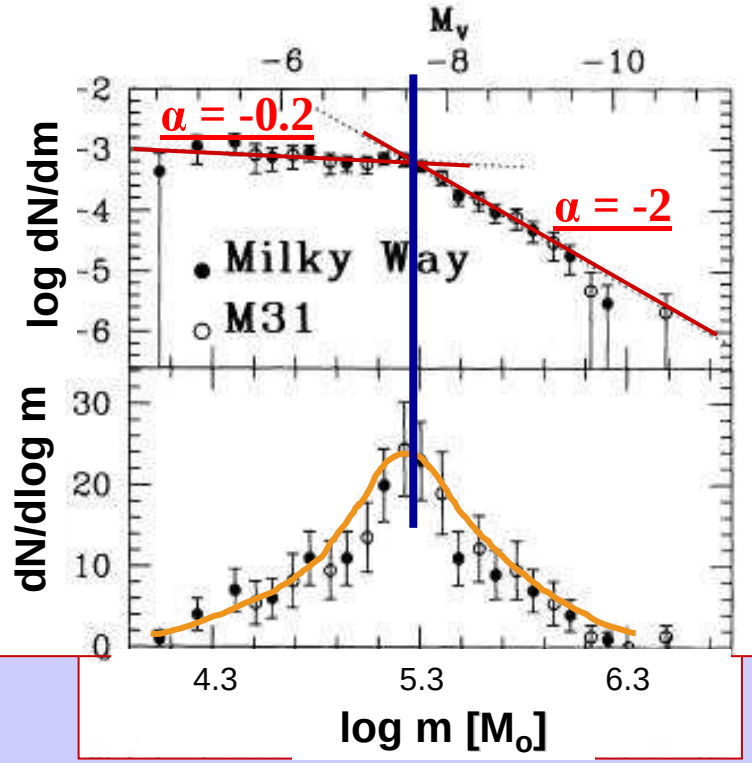
Bell-shaped (Gaussian)

13 Gyr of dynamical evolution in the tidal field of the host galaxy:

- cluster mass loss
- cluster destruction

Initial mass distribution ?

Fig.1 McLaughlin & Pudritz (1996)



The GCMF is almost **universal** (MW, M31, M87)

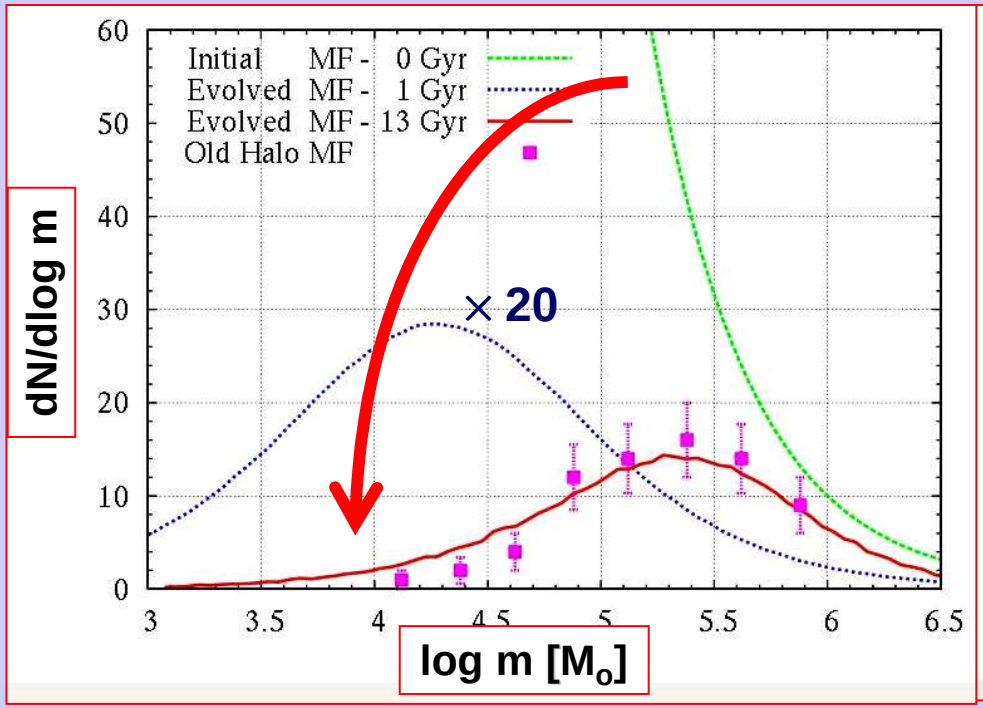
Initial Mass Distribution of Globular Clusters?

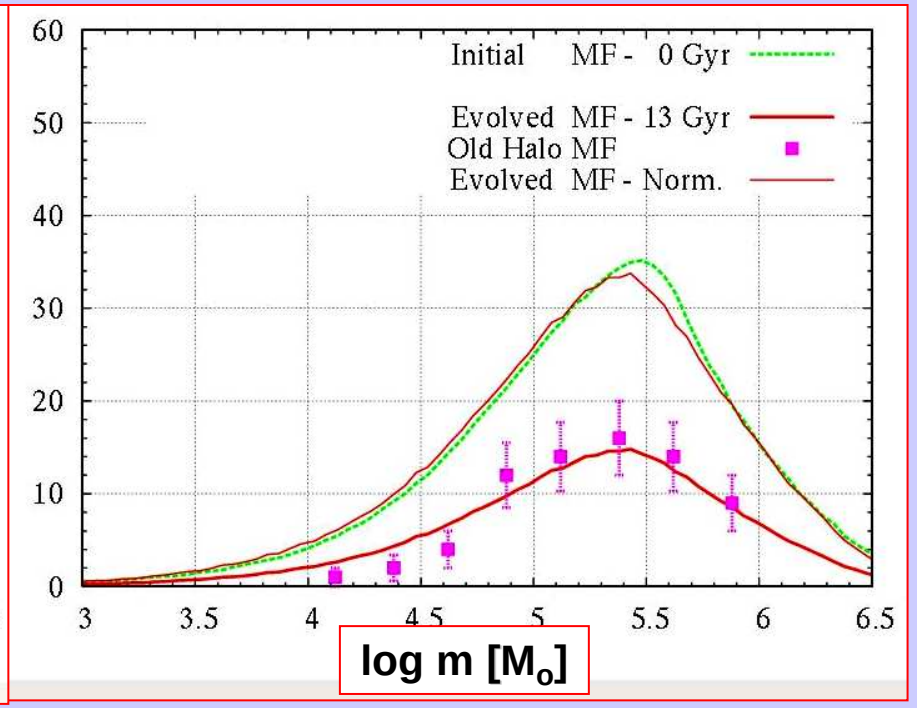
Hyp. 1: Power-Law
$dN/dm = k\ m^{-2}$

- Preferential removal of low-mass globular clusters (Fall & Zhang 2001, McLaughlin & Fall 2007)
- Gaussian: imprint of dynamical evolution over a Hubble-time

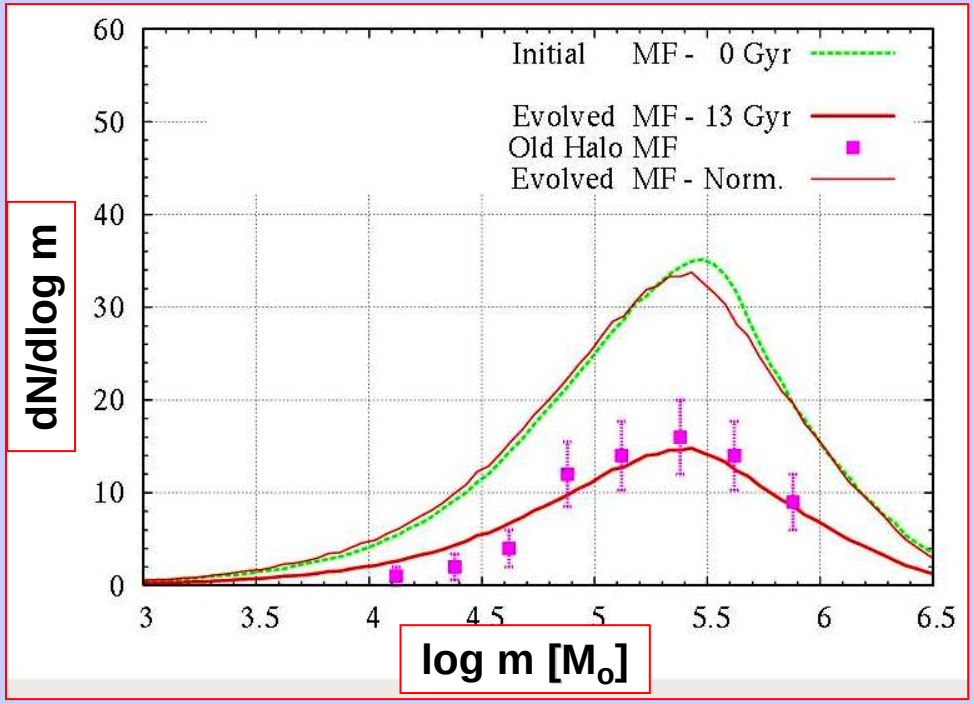
Hyp. 2: Gaussian dN/dlogm
$[logm]_{TO} \cong 5.3$ and $\sigma \cong 0.6$

- Present-day MF = equilibrium state (Vesperini 1998)
- Gaussian : preserved imprint of GC formation process





A Gaussian Initial Mass Distribution of Globular Clusters



In the frame of the Gaussian hypothesis:

- present-day GCMF = preserved imprint of GC formation process (equilibrium state)

- the GCMF universality arises from the cluster formation process

Questions:

- Origin of a Gaussian IMF for old globular clusters ?
- Why is it universal among galaxies ?
- Why is the GC IMF different from the cluster mass function inferred for mergers and starbursts ? ($dN/dm = k\ m^{-2}$)

Origin of the Shape of the Initial Cluster Mass Function ?

- Stellar cluster:
  conversion of a cloud of gas into stars

- Protostellar cluster
  = gas + stars = gas-embedded cluster

- SNII activity

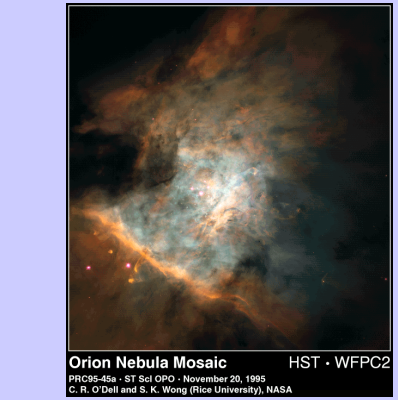
  → removes left-over star forming gas

  → terminates star formation

  → weakens protocluster gravitational potential

  → **escape of stars or**
  complete disruption of the protocluster

- → **gas removal controls the initial mass of a star cluster and may therefore influence the shape of the initial cluster mass function**



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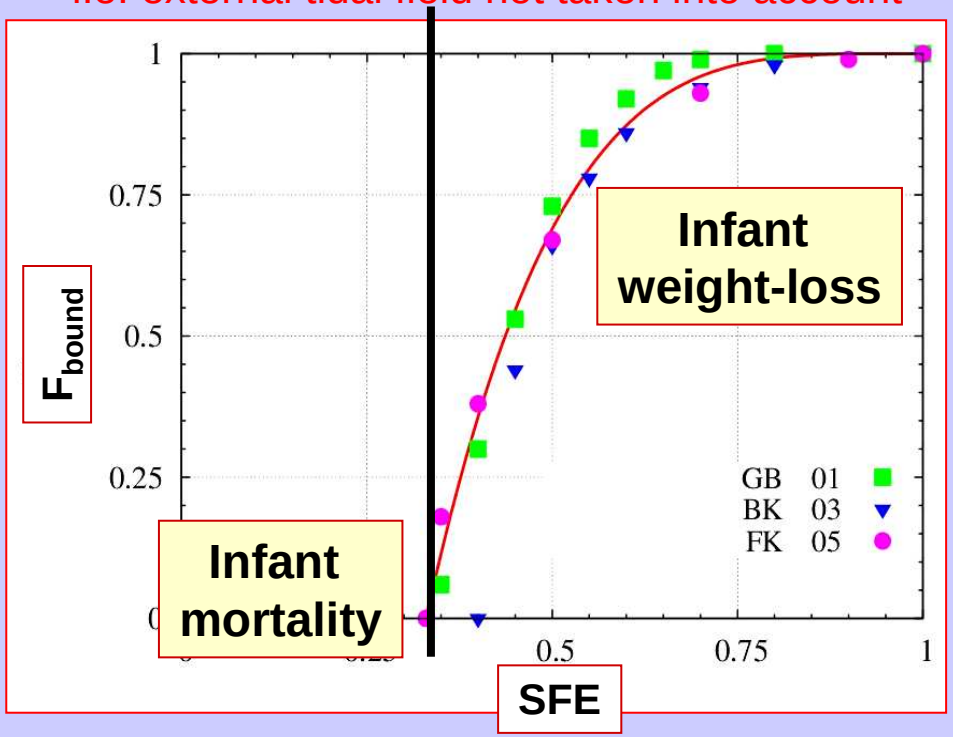
The ICMF and the GC gaseous progenitor MF

SFE
= fraction of gas ending up in stars

F_{bound}
= fraction of stars remaining bound to the cluster after gas removal

For an isolated cluster,
i.e. external tidal field not taken into account



$$m_{cluster}^{init} = F_{bound} \times SFE \times m_{cloud}$$

GB 01 = Geyer & Burkert 2001
BK 03 = Boily & Kroupa 2003
FK 05 = Fellhauer & Kroupa 2005

ICMF ≡ f(ranges of SFE and **F_{bound}**, cloud MF)

[1] Cloud mass distribution:

$$\frac{dN}{dm} \propto m^{\alpha}$$

≅ Giant Molecular Clouds and their cores in the Local Group

Mass range: [**4E5**, 1E7]M_o

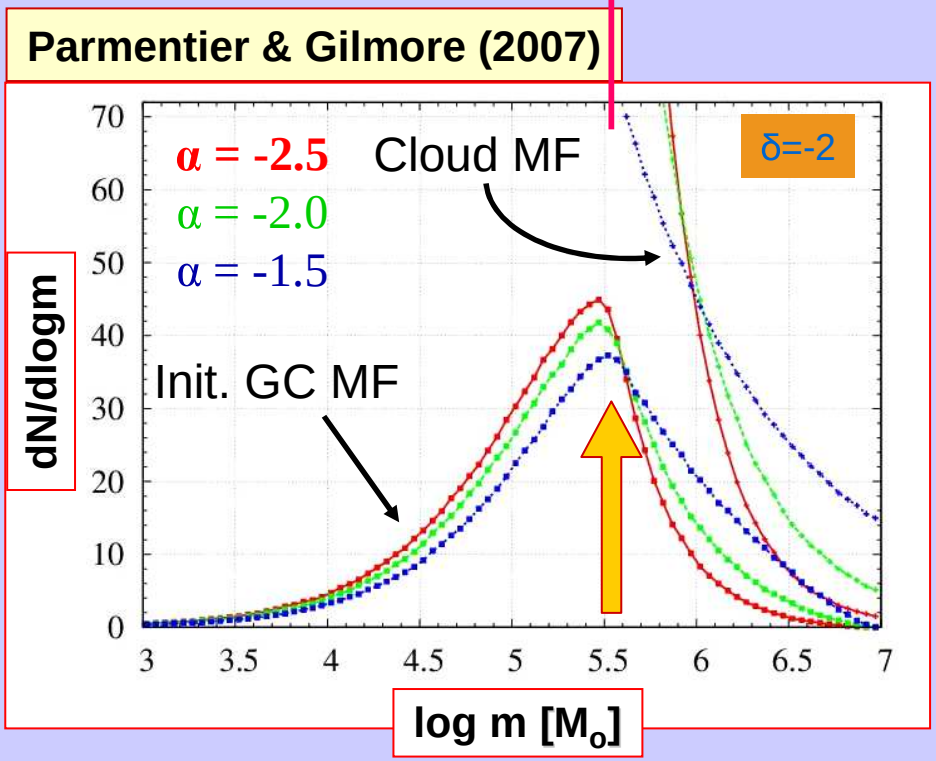
[2] SFE distribution:

$$P(SFE) = \frac{dN}{d\varepsilon} \propto \left(1 + \frac{\varepsilon}{\varepsilon_c}\right)^{\delta}$$

[3] Gas removal:

$$F_{bound} \; vs. \; SFE$$

Low-mass truncation

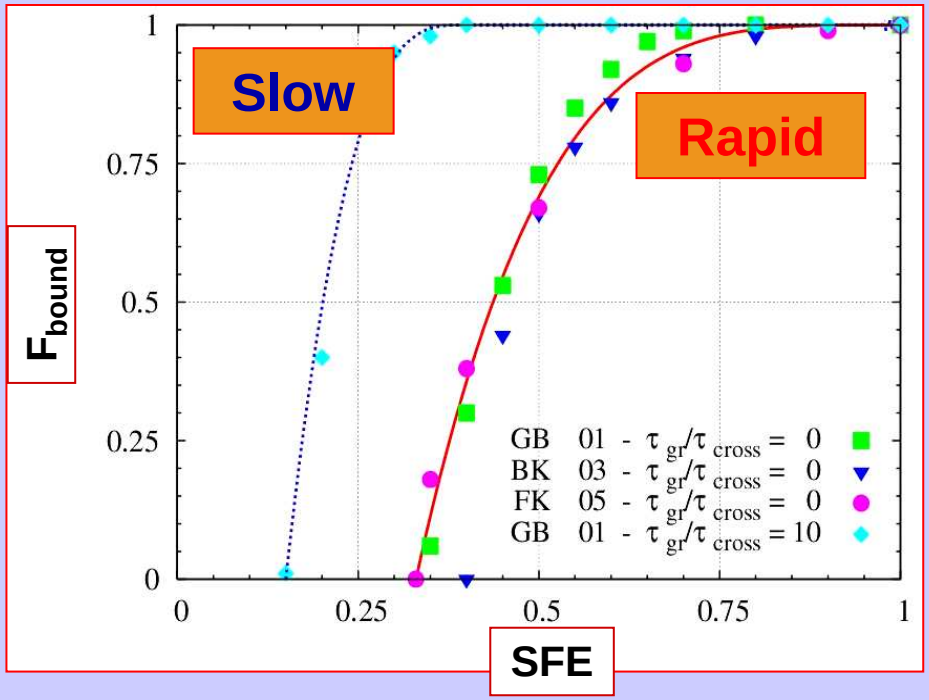


The truncated power-law of the protoglobular clouds has evolved into a bell-shaped ICMF

What does the ICMF turnover depend on ?

$$m_{GC}^{init} = F_{bound} \times SFE \times m_{cloud}$$

[3] [2] [1]



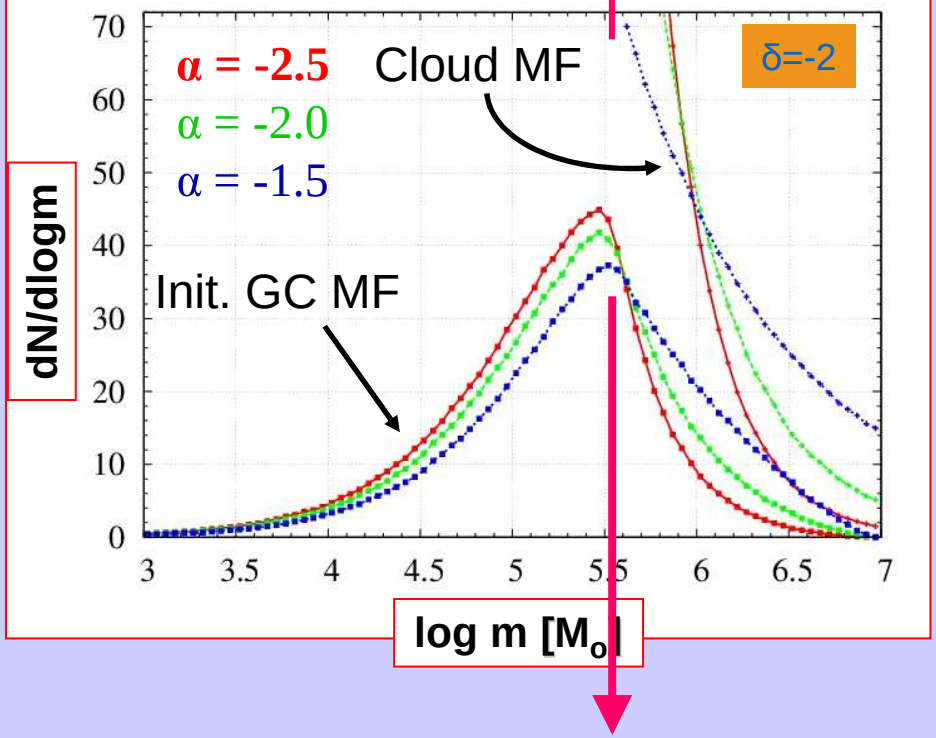
[1]
- Spectral index α of cloud mass spectrum,
- Upper limit of cloud mass range,
- Lower limit of cloud mass range,

[2]
- Slope δ of the P(SFE)
- Core ε_c of the P(SFE)

[3]
- Gas removal time-scale

Low-mass truncation

Parmentier & Gilmore (2007)



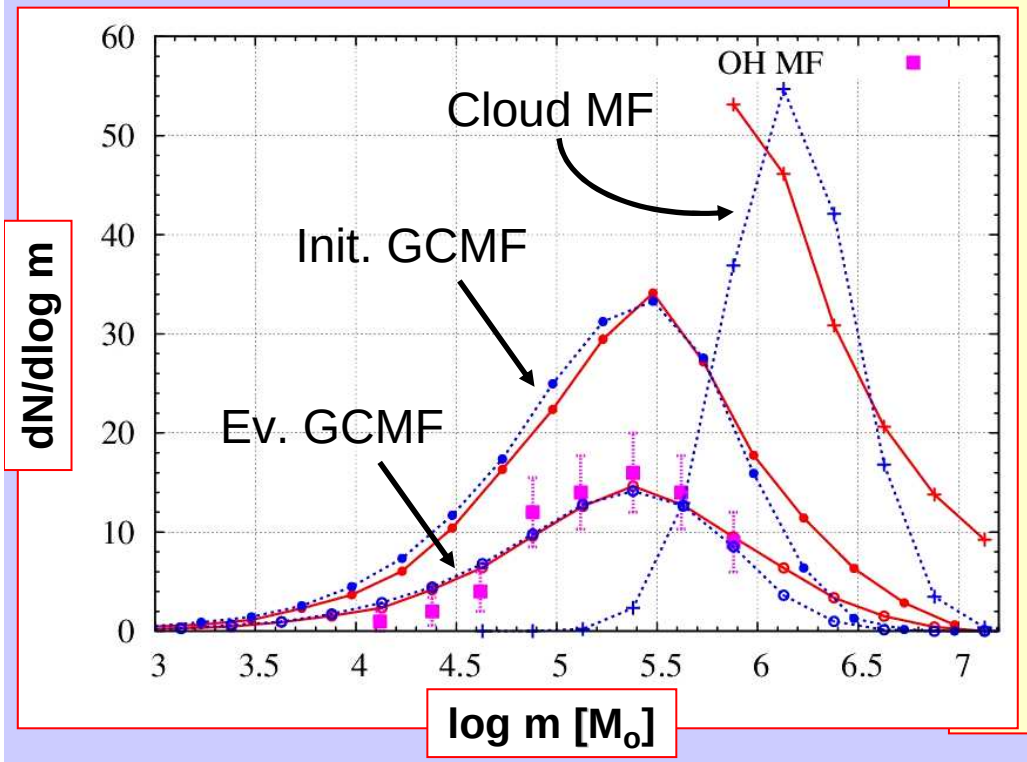
Peak of the initial cluster mass function is tracked by the lower mass limit of the gaseous precursors.

A narrow cloud mass range provides a good solution

§ $m_{low} = 6 \times 10^5\ M_o$
§ $m_{up} \geq 5 \times 10^6\ M_o$

A peak-shaped cloud mass function (e.g. narrow Gaussian) too …

→ **Shape of the protoglobular cloud MF is irrelevant**

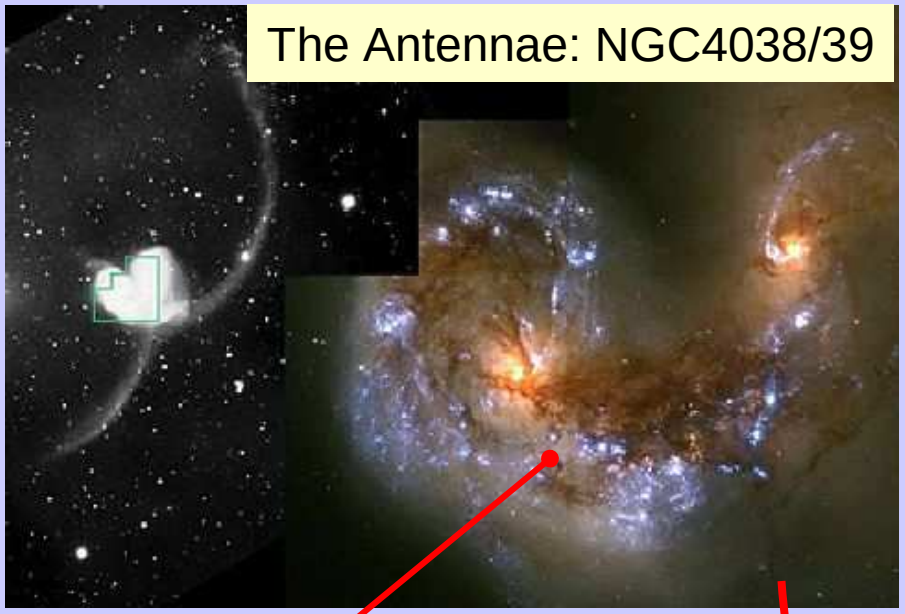


Universal GC MF ?

- Gas removal (regardless of its time-scale)
- Common protoglobular cloud mass-scale ($\cong 10^6 M_o$), which may be an imprint of the protogalactic era (Fall & Rees 1985; Bromm & Clarke 2002)

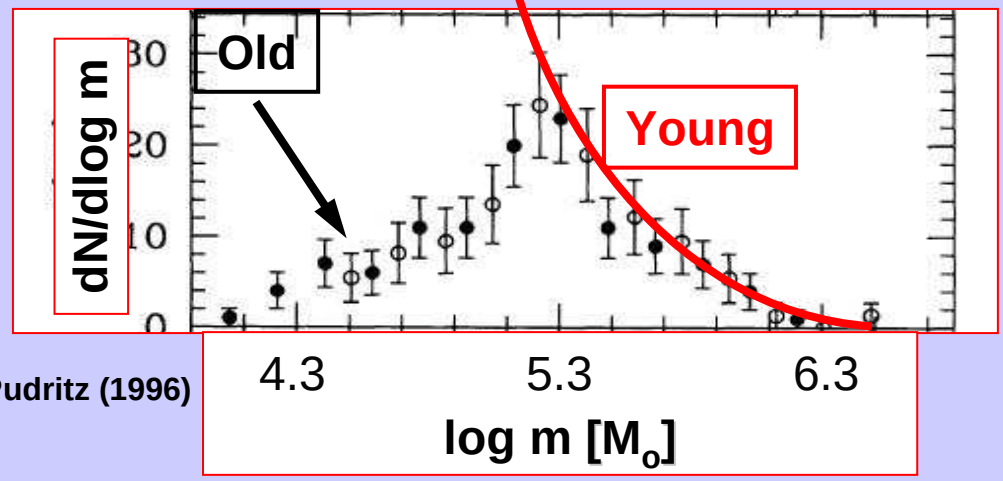
→ an initial/observed GCMF with the right turnover and the appropriate width

Old Globular Clusters vs. Young Star Clusters



The Hubble Space Telescope has detected **Young Massive Star Clusters** in violent star forming environments. As for their cluster mass function, a **power-law** is often reported.

$$\frac{dN}{dm} \propto m^{-2} \equiv \frac{dN}{d\log m} \propto m^{-1}$$



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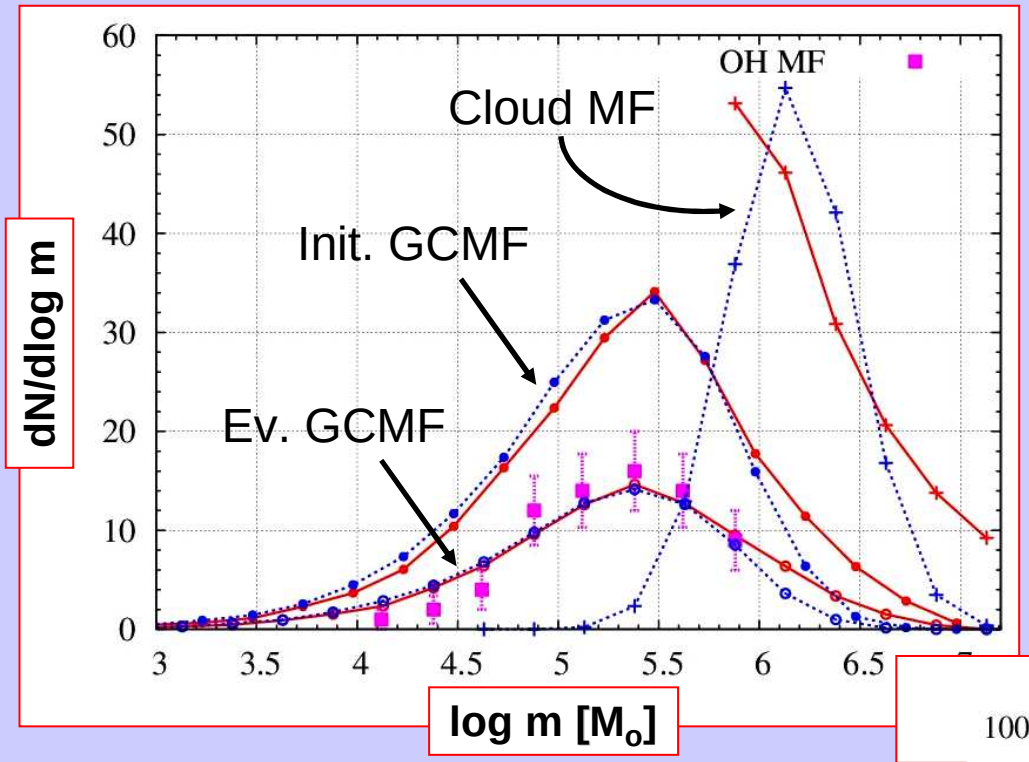
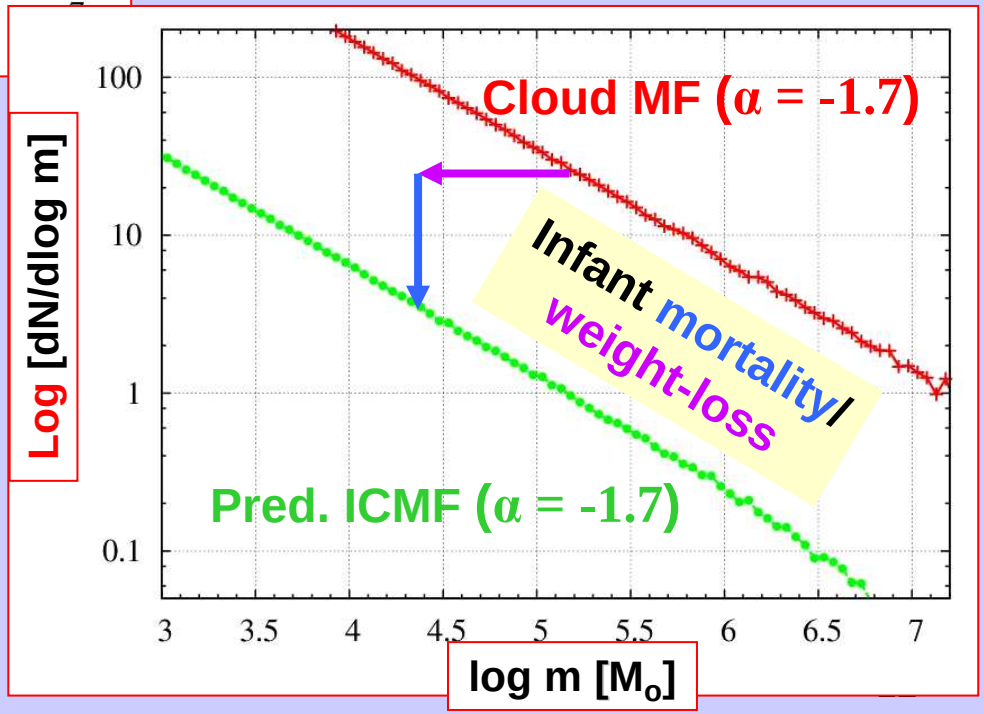


Old GCs:
characteristic protoglobular cloud mass of $10^6 M_o$

Young massive star clusters in starbursts:
a featureless power-law mass function for the gaseous progenitors is conducive to the same initial cluster mass function



From the cluster scale to the galactic scale ...

- Modelling of isolated protocluster gas removal dates back to:
  - Hills (1980), Lada et al. (1984)

- **The profound impact of gas removal upon properties of**

  - individual clusters
    their structure at age ≅ 10 Myr, Bastian et al. 2006,
  - systems of clusters
    origin of the Gaussian initial mass function of GCs,
    Parmentier & Gilmore 2007,
  - whole galaxies
    most stars form in gas-embedded clusters,
    Lada & Lada 2003, Kroupa 2005

Embedded protoglobular clusters may well be the fundamental building blocks of the whole Galactic stellar Halo

is fully realized now only !

References

The whole work presented here is detailed in Parmentier & Gilmore '07

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