

The Life Cycle of Star Clusters



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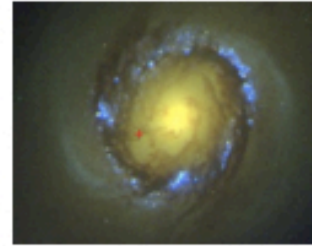
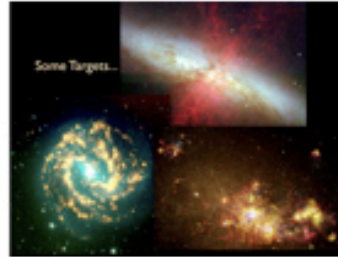
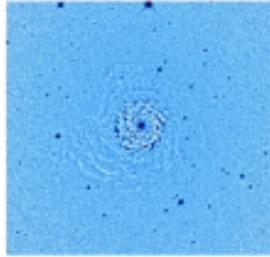
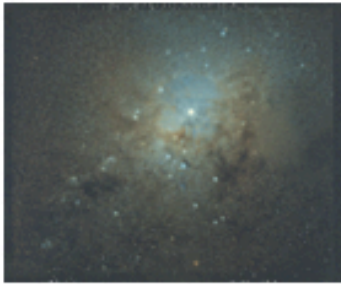
Historical Perspective: What we have learned from the Antennae

1. young globular clusters are still forming today (Whitmore & Schweizer 1995)
2. cluster luminosity & mass functions are power laws with indices ~ -2 (Whitmore & Schweizer 1995; Whitmore et al. 1999; Zhang & Fall 1999; Fall, Chandar & Whitmore 2009)
3. At least 20% (and possibly all) stars form in clusters (Fall, Chandar, & Whitmore 2005)
4. “Infant Mortality” (Fall 2004; Whitmore 2004; Fall, Chandar, & Whitmore 2005)



Are these results unique to the Antennae galaxies?

Historically, young massive clusters have been found in essentially all types of star-forming galaxies, e.g., mergers, starburst dwarfs, peculiar, barred, ring, spirals, irregulars, ...



NGC 1275

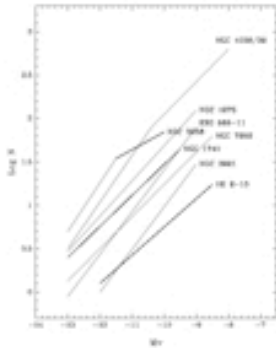
NGC 7252

NGC 4214, M82, M83

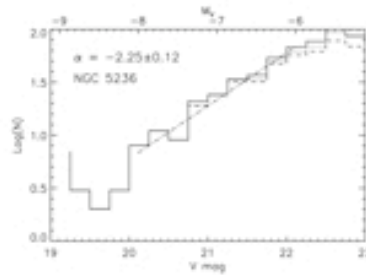
NGC 4314

M51

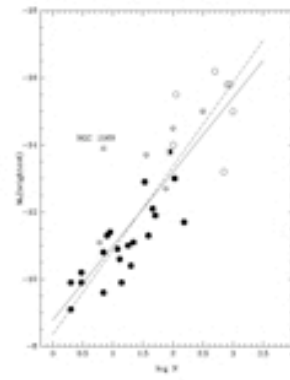
Various analysis over the past decade have suggested that the cluster systems are quite similar both physically (e.g., sizes) and demographically (e.g., mass and age distributions)



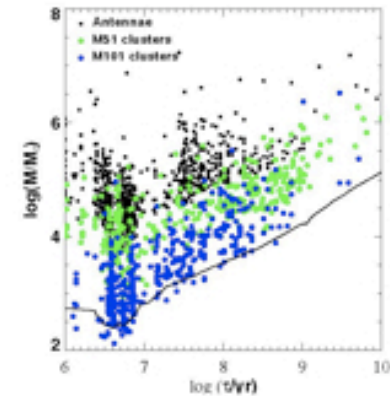
similar LF



found in spirals



similar correlations



similar mass vs. age

Lots of (indirect) evidence that clusters in other galaxies are similar to those in the Antennae. A good test: compare LMC vs. Antennae clusters directly

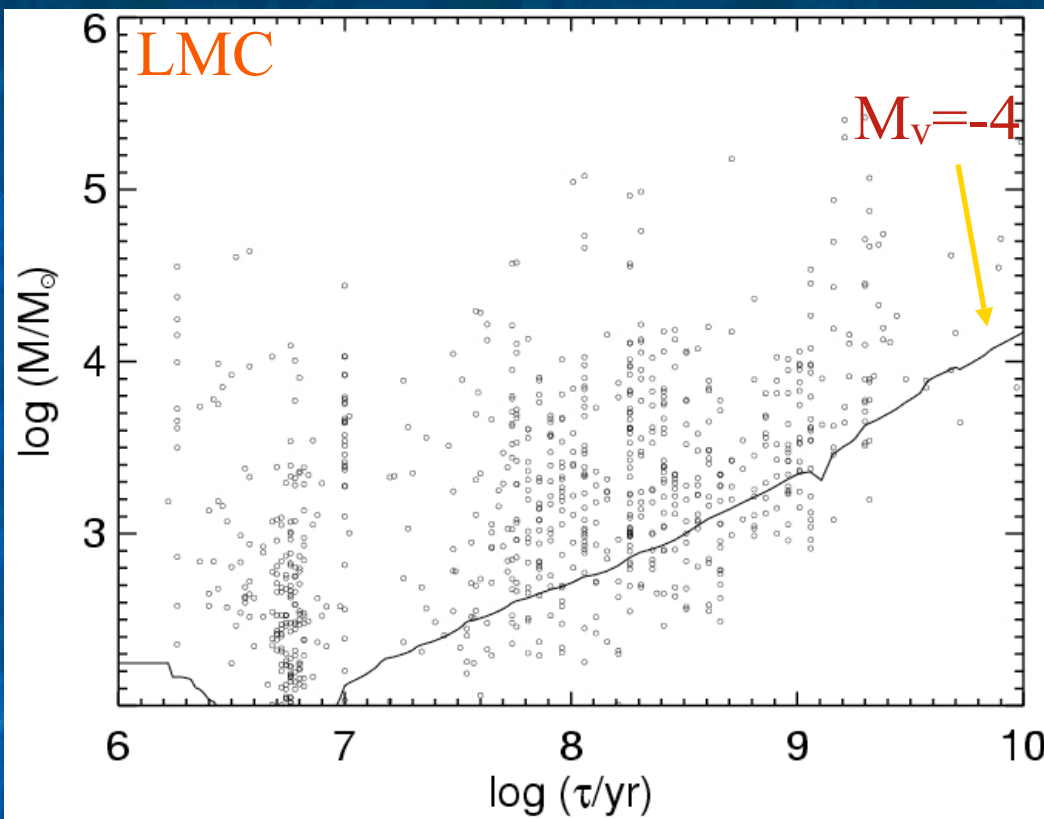
Antennae vs. LMC



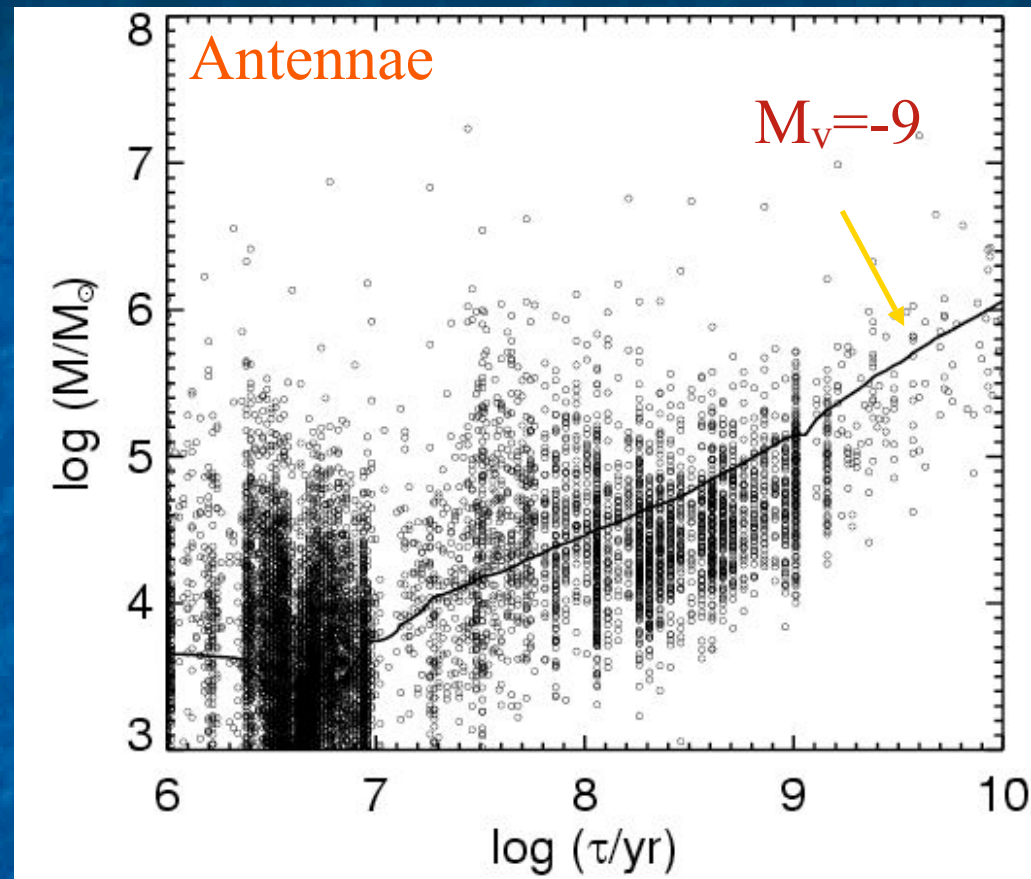
Antennae: *HST* UBVIH α imaging of several thousand clusters

LMC: ground-based UBVR imaging of ~ 850 clusters from Hunter et al. 2003

Joint Distribution of Cluster Masses & Ages



Chandar, Fall & Whitmore, submitted

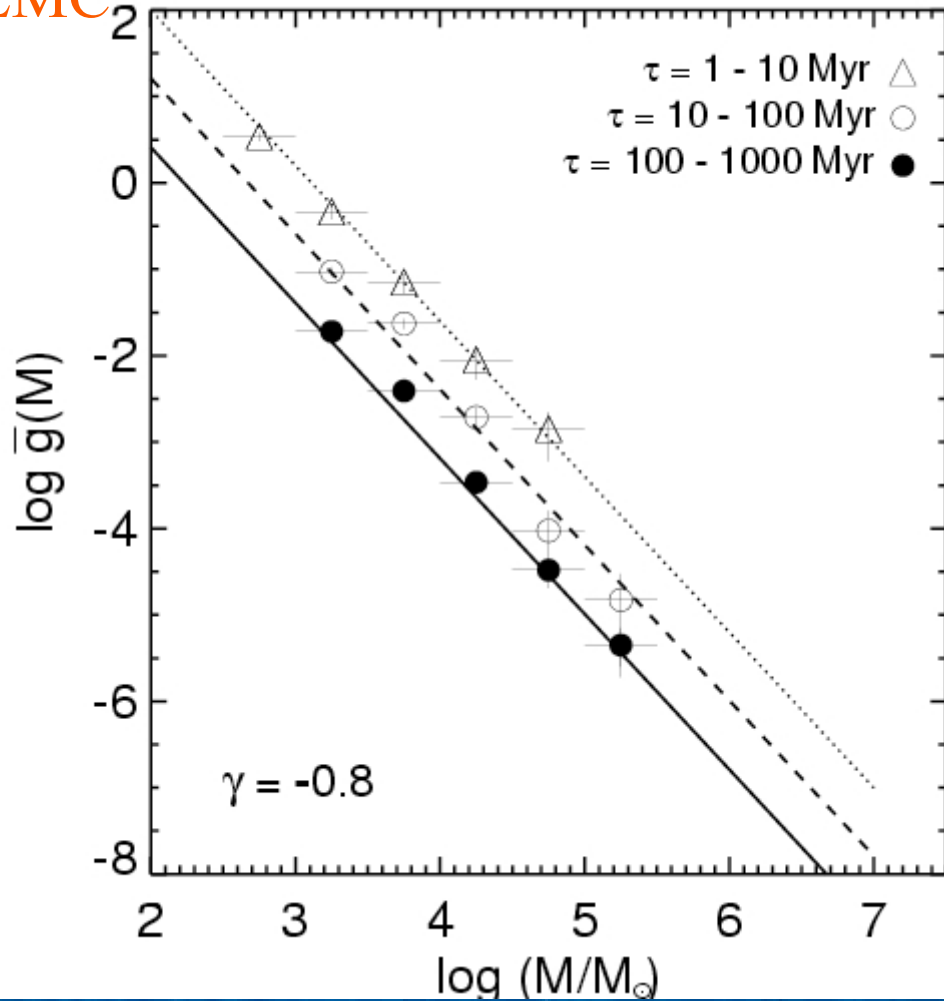


Fall, Chandar & Whitmore, submitted

“Universal” Model: The ages & masses of young cluster systems can be described *approximately* as: $g(M, \tau) \approx \psi(M) \chi(\tau) \sim M^{\beta} \tau^{\gamma}$ with $\beta \approx -2$ & $\gamma \approx -1$

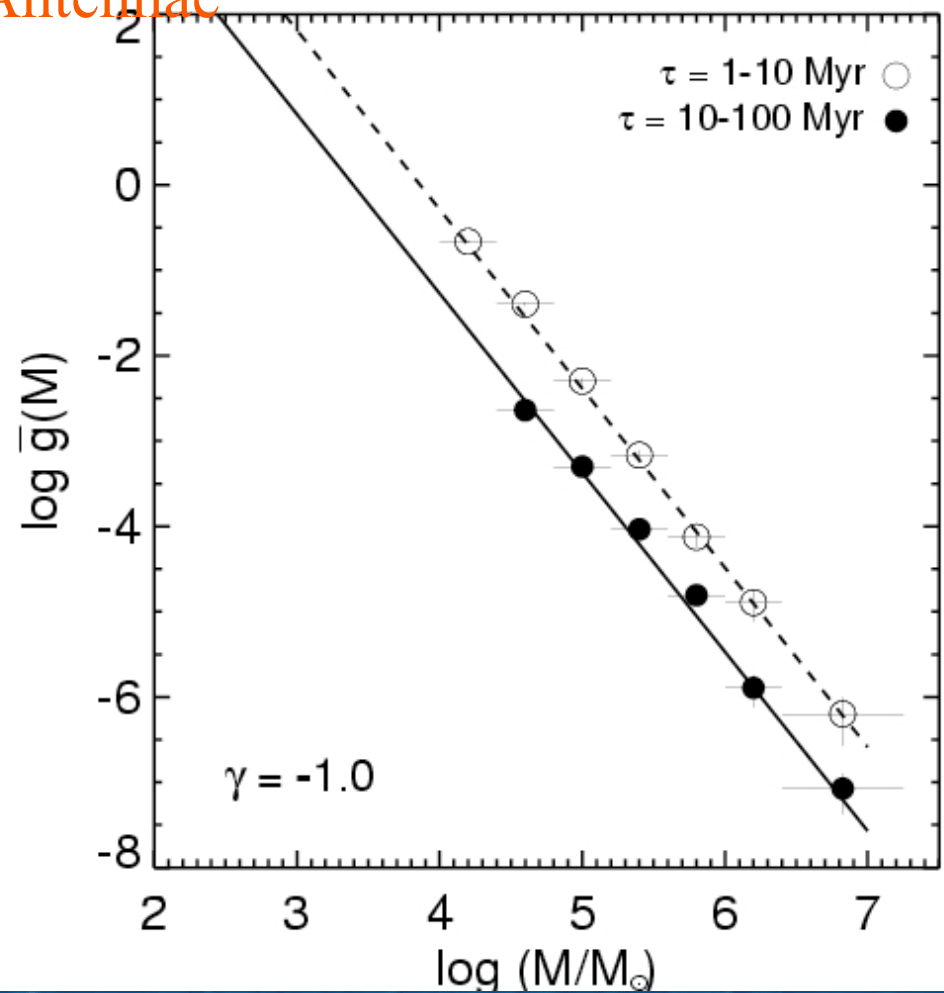
Cluster Mass Function

LMC



$$M^{-1.8} \tau^{-0.8}$$

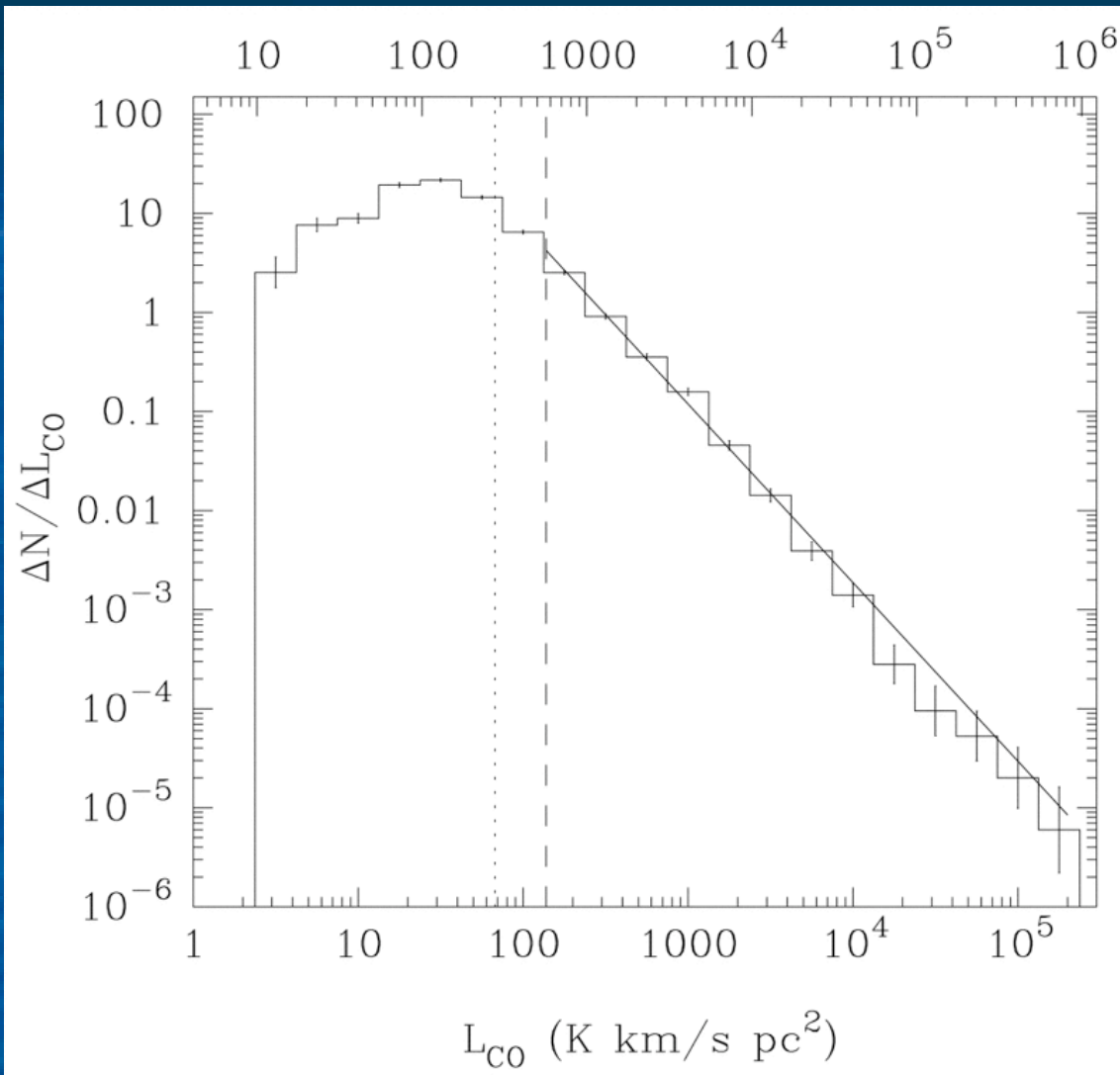
Antennae



$$M^{-2.0} \tau^{-1.0}$$

The *shape* of $g(M)$ doesn't change over time, but the *normalization* does

Molecular Cloud Mass Function



Milky Way (Heyer et al. 2001)

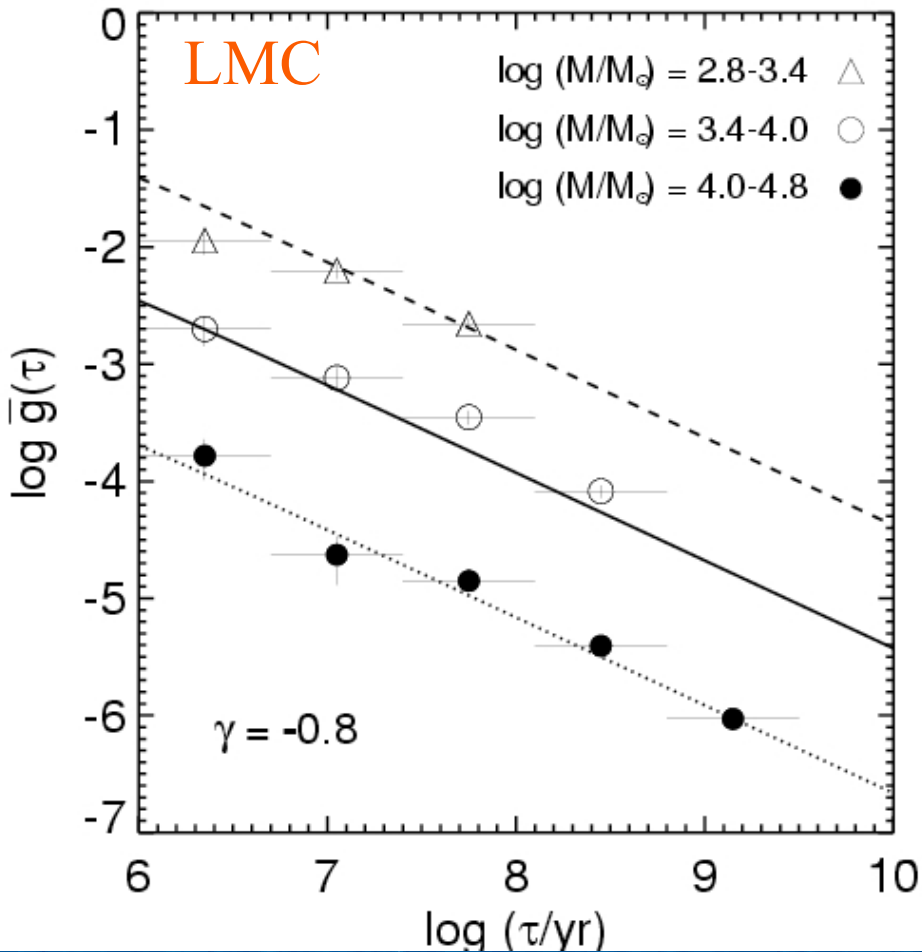
$$dN/dM \approx M^{-1.8}$$

LMC: (Fukui et al. 2001)

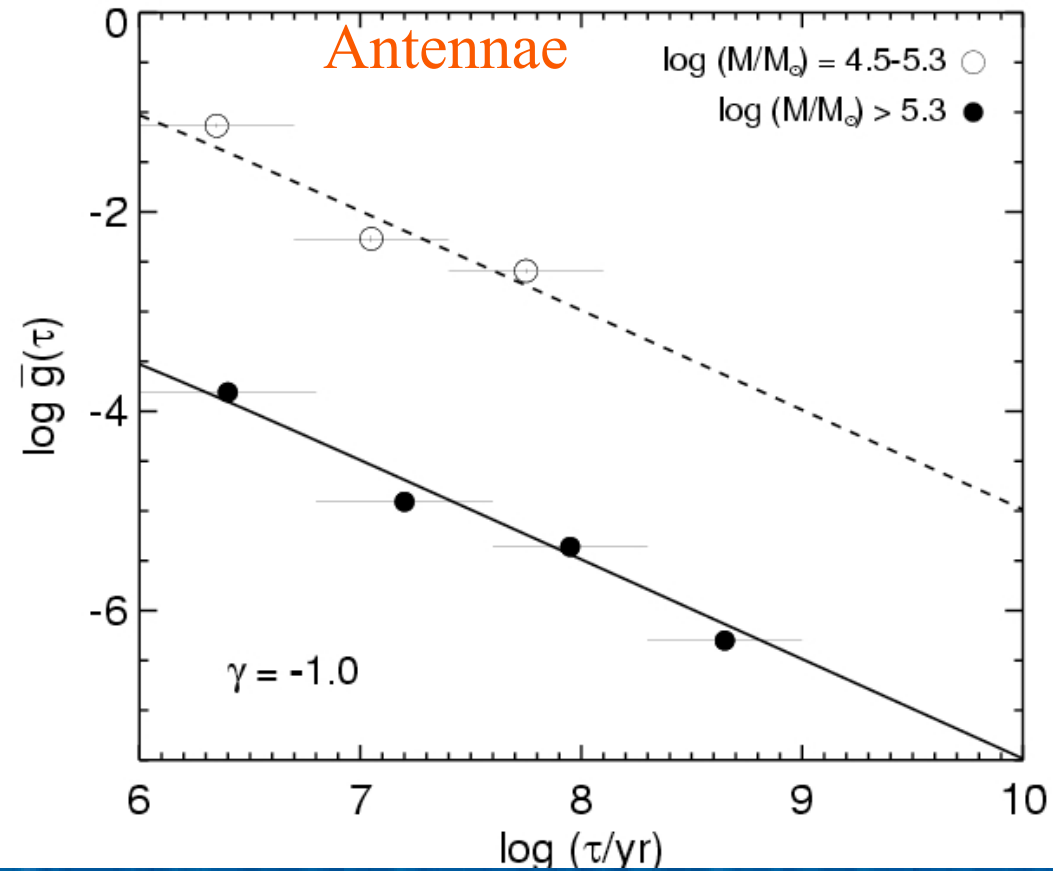
$$dN/dM \approx M^{-1.9}$$

The mass function of young clusters is v. similar to that of molecular clouds in the Local Group => suggests that the *average star formation efficiency is approximately independent of the masses of proto-clusters*

Cluster Age Distribution



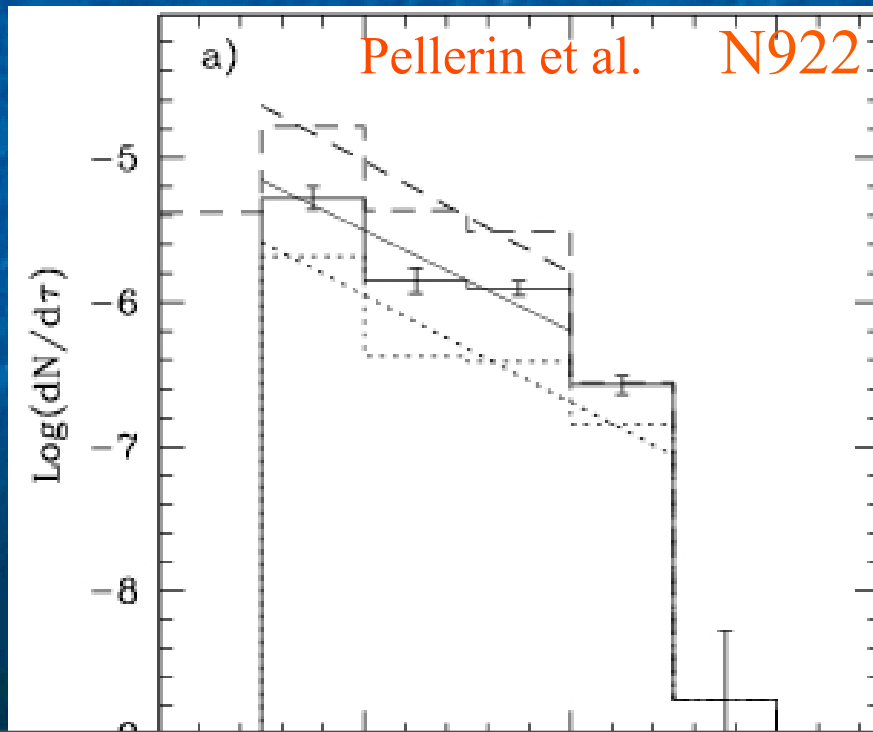
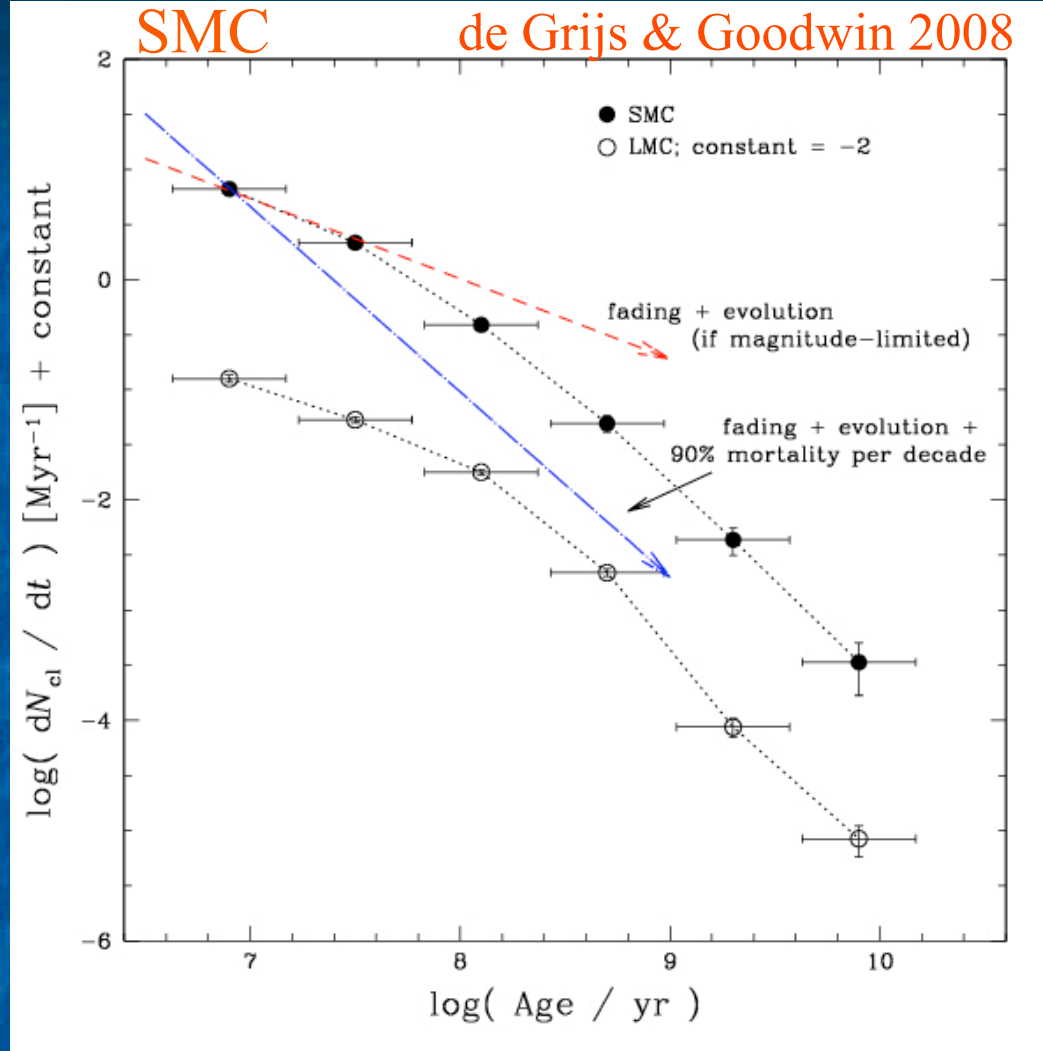
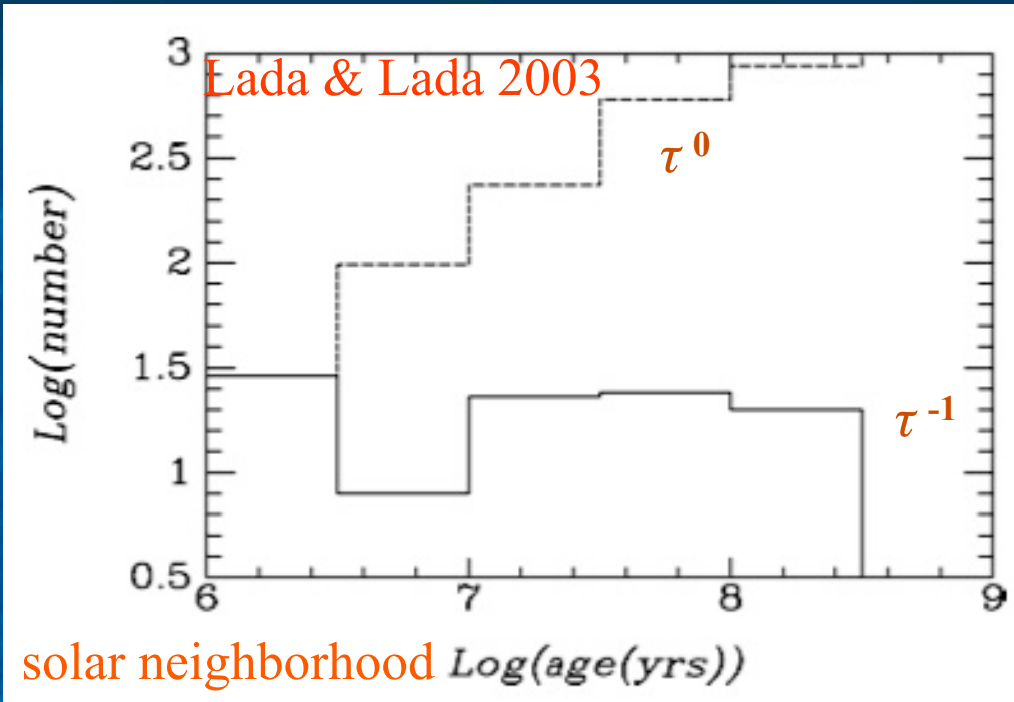
$$M^{-1.8} \tau^{-0.8}$$



$$M^{-2.0} \tau^{-1.0}$$

The shape of $g(\tau)$ does not change for different masses, but the normalization does (consistent with power law mass distribution).

A “Universal” Shape for the Cluster Age Distribution?



A similar declining form has been found for clusters in other galaxies

Interpretation: Mass Removal Processes for Young Clusters

The observed, declining shape of the age distribution likely results from a *combination* of different processes:

1. removal of internal ISM due to stellar feedback can unbind cluster stars (“infant mortality”) $\tau < 10^7$ yr
2. continued stellar mass ejection $\tau < 10^8$ yr
3. stellar escape due to tidal disturbances by passing molecular clouds $\tau > 10^8$ yr

(Relaxation-driven stellar evaporation will further erode cluster system on longer time scales; see Dean McLaughlin’s talk)

Conclusions: A Simple Picture for the Life Cycle of Star Clusters

-- MF of young clusters is v. similar to that of molecular clouds, & the average SFE is ~the same in low mass and in high mass clusters

-- many and possibly most stars form in clusters.

$g(M, \tau) \approx \psi(M) \chi(\tau) \sim M^{-2} \tau^{-1}$ for roughly $\tau < \text{few} \times 10^8$ yr indicates that clusters are fragile and disrupt rapidly, in a manner which is ~independent of their mass (i.e., little evidence for mass-dependent disruption in young Antennae, LMC, SMC cluster systems)

-- stars from the disrupted clusters form the field population

Hypothesis: this simple model is applicable to (young) clusters of different masses in many different galaxies.