The Dynamical Evolution of Young Embedded Cluster and Infant Mortality


UK Astrophysical
Fluids Facility
Matthew Bate
EXETER

Introduction

- The term of "infant mortality" is firstly proposed by Lada & Lada, 2003. However, the beginning of this question can be tracked back to Wilking & Lada (1983) on the study of star formation efficiency (SFE).
- About 90-95% of embedded clusters must emerge from molecular cloud as unbound cluster.
- The observations toward star formation regions give the maximum SFE ~30%.

TABLE 2 Star-formation efficiencies for nearby embedded clusters

Cluster name	Core mass ($M_\odot$)	Stellar mass ($M_\odot$)	SFE	References
Serpens	300	27	0.08	Olmi & Testi 2002
Rho Oph	550	53	0.09	Wilking & Lada 1983
NGC 1333	950	79	0.08	Warin et al. 1996
Mon R2	1000	341	0.25	Wolf et al. 1990
NGC 2024	430	182	0.33	E.A. Lada et al. 1991a,b
NGC 2068	266	113	0.30	E.A. Lada et al. 1991a,b
NGC 2071	456	62	0.12	E.A. Lada et al. 1991a,b

The Star formation Efficiency

Wilking & Lada, 1983, ApJ, 274, 698-716

$$M_i V_i^2 = \frac{GM_i}{R_i}$$

$$V_i = \sqrt{\frac{GM_i}{R_i}}$$

$$V_{esp} = \sqrt{\frac{2GM_\star}{R_i}}$$

$$\frac{M_\star}{M_i} > 0.5$$

$$\frac{M_\star}{M_\star + M_{gas}} > 0.5$$

M_i: the total mass

$M_\star$: the stellar mass

R_i: the cloud radius

- If we remove all gas suddenly and leave stars. The escape velocity is given by Viral Theorem can be written as V_{esp}.
- To keep this system bounded, it is required that $V_i < V_{esp}$. This gives an important result on stellar mass and total mass.

What is the time scale of cluster disruption?

N-body Simulation

Goodwin & Bastian, 2006, MNRAS, 373,752-758

$$\rho(r) = \frac{3M_{\rm p}}{4\pi R_{\rm P}^3} \frac{1}{[1 + (r/R_{\rm P})^2]^{5/2}}$$

$$Q = T/|\Omega|$$

$$\epsilon = 2Q$$

$$\mu(r) = \mu(0)\left(1 + \frac{r^2}{a^2}\right)^{-\gamma/2}$$

$$r_{\rm c} \sim a(2^{2/\gamma} - 1)^{1/2}$$

- N-body simulation with post-gas expulsion.
- Density function of stars.
- Instead of mass produced in star formation eSFE, ε, is defined in term of energy. T: kinetic energy, Ω: potential energy.
- No external tidal field and mass loss during stellar evolution.
- No IMF, all stars are equal-mass particles.
- The core radius is also defined (Elson, Fall & Freeman, 1987).
- Note: the typical size (corona) of an open cluster is ~6 pc.

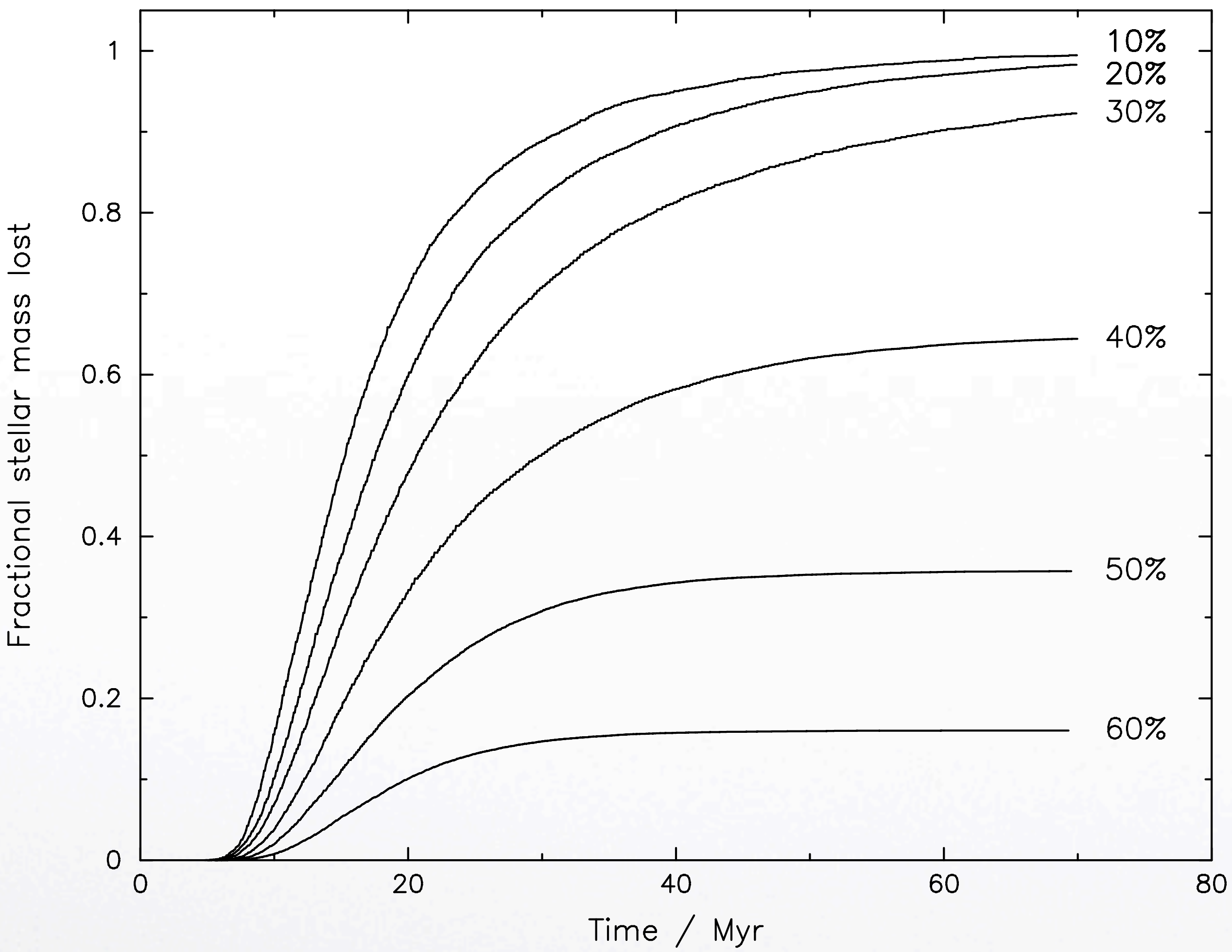

Figure 1. The fraction of stars which are pushed over 20 pc of the centre of mass of the cluster with time for clusters with eSFEs between 10 and 60 per cent. Clusters with eSFEs <30 per cent are unbound and rapidly disperse into the field, but clusters with slightly higher eSFEs are able to retain a bound core of stars.

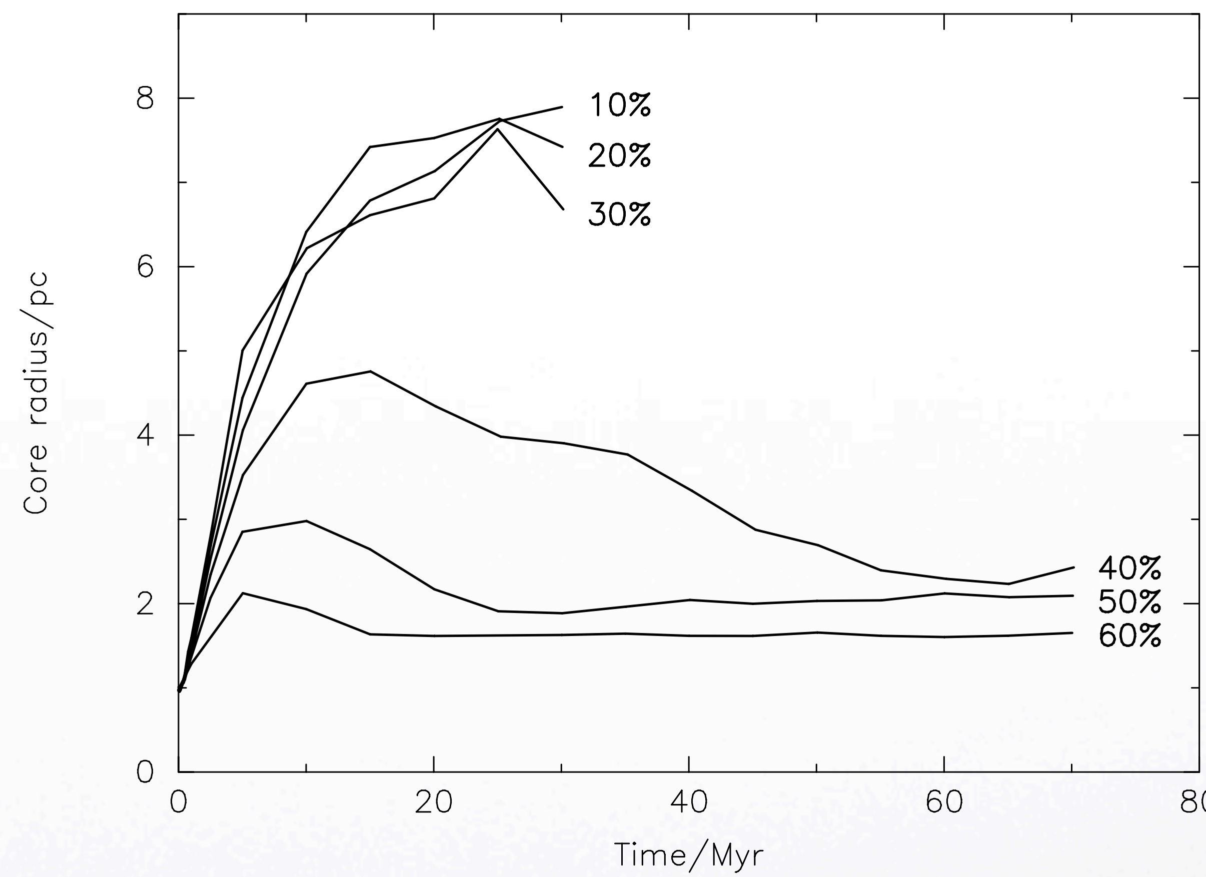

Figure 2. The evolution of the core radius as measured from the a and γ parameters of the best-fitting EFF profile (see text) with time for clusters with eSFEs between 10 and 60 per cent. Note that measuring the core radii of low-eSFE clusters at late times becomes very difficult due to the low numbers of stars still within a nominal 20 pc radius cluster, therefore we do not plot low-eSFE clusters beyond 30 Myr as the values of the core radius become meaningless.

- Cluster with eSFE < 30% becomes unbounded after few tens Myr as it is incapable to reach a equilibrium.
- For cluster with larger sSFE, it remain a bounded core but may lost a significant fraction of mass.
- The core radius increase as the cluster expand. The bump of high eSFE curve is due to the star at outskirts. By 60 Myr, most of the excess light have gone, as these stars become physically detached from the cluster.
- The dynamical mass (measured from velocity dispersion) is not a good measure of true mass during the expansion phase (Fig. 4).
- Comparing with the simulation result and observed data, the lower limit of infant mortality rate ~50% can be set for younr clusters (Fig. 5).

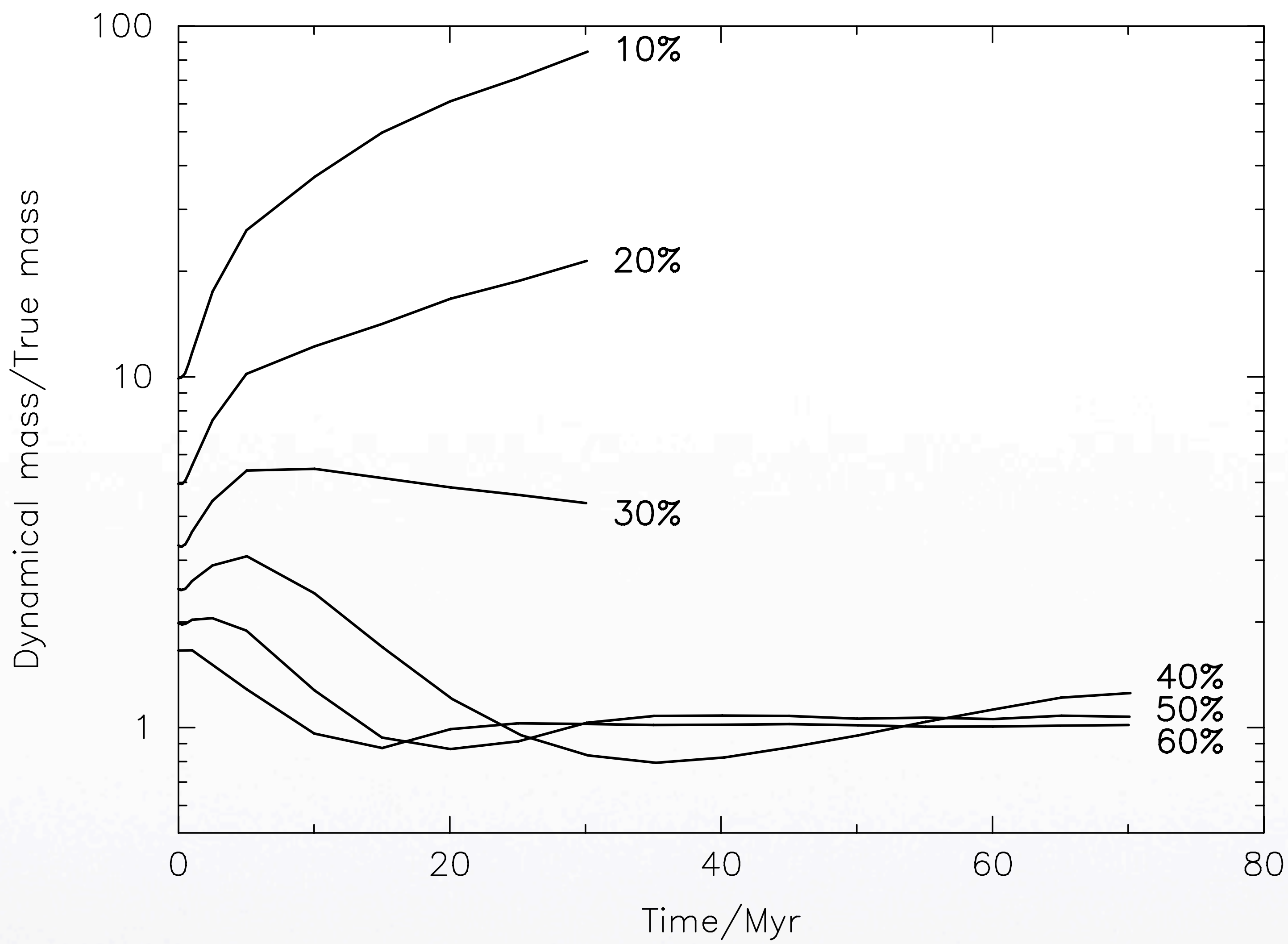

Figure 4. The ratio of dynamical mass to 'true' mass (the mass within 20 pc of the cluster centre) against time after gas expulsion for eSFEs between 10 and 60 per cent. Note that the dynamical masses of disrupting (eSFEs of 10–30 per cent) clusters become rather meaningless after ∼20 Myr due to the low number of stars within 20 pc of the nominal cluster centre.

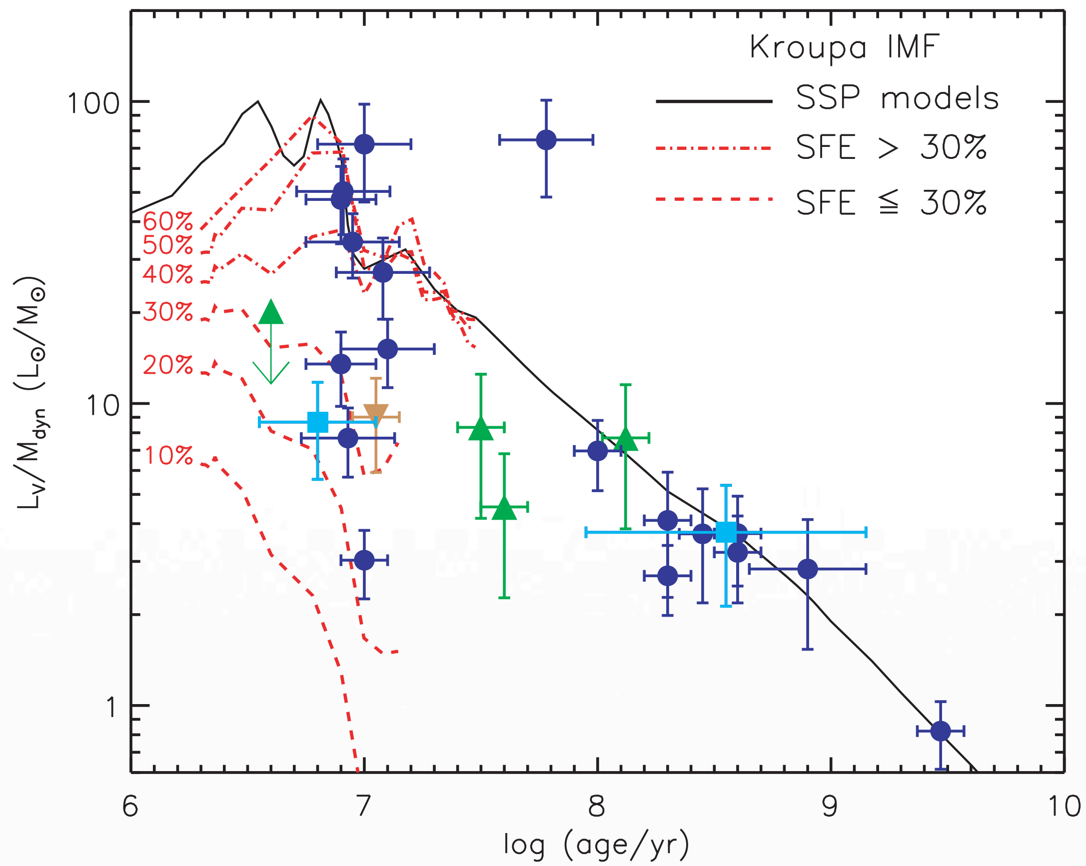

Figure 5. The light-to-mass ratio of young clusters. This figure is colour in the online article on Synergy. The circles (blue) are taken from Bastian et al. (2006) and references therein, the triangles with errors (green) are LMC clusters (McLaughlin & van der Marel 2005), the upside down triangle (brown) is for NGC 6946−1447 corrected for internal extinction (Larsen, Brodie & Hunter 2006), and the squares (cyan) are from Östlin, Cumming & Bergvall (2006). The triangle without errors is the tentative upper limit for cluster R136 in 30 Dor (Bosch et al. 2001; Hunter et al. 1995). The solid (black) line is the prediction of SSPs with a Kroupa (2002) stellar IMF and solar metallicity from the SSPs of Maraston (2005). The dashed and dash–dotted lines (red) are the SSP model tracks folded with the effects of rapid gas removal following non-100 per cent SFEs (i.e. Fig 4). Dashed lines represent the SFEs where the clusters will become completely unbound. We have assumed that the residual gas has been removed instantly at an age of 2 Myr.

How the cluster mass effect the cluster mortality?

N-body Simulation, no need!

Gieles & Bastian, 2008, A&A, 482, 165-171

- Observation indicated ~70% of clusters in M51 do not survive past 20 Myr, roughly independent of cluster mass.
- Observational data shows that the time disruption time scale of extragalactic cluster can be ~ Gyr.
- Major questions:
  - is the cluster disruption independent of cluster mass and environment?
  - What is the relative fraction mass in bound and long lived (>10 Myr) cluster.

$$\phi(M) = \frac{dN}{dM} = A\,M^{-\alpha},$$

$$\begin{aligned} N &= \int_{M_{min}}^{M_{up}} A\,M^{-\alpha}\,dM \\ &\simeq \frac{M_{max}^{\alpha-1}}{M_{min}^{\alpha-1}}, \alpha > 1 \\ &\simeq \frac{M_{max}}{M_{min}}, \alpha = 2, \end{aligned}$$

$$M_{max} \propto N^{1/(\alpha-1)}.$$

$$N_{bin} \propto \frac{dN}{d\ln(t)} = t\,\frac{dN}{dt}$$

$$M_{max} \propto N_{bin}^{1/(\alpha-1)} \propto t^{1/(\alpha-1)}.$$

$$\mathrm{CFR} \propto t^{\eta}$$

$$M_{max} \propto t^{(1+\eta)/(\alpha-1)}.$$

$$N_{bin} \propto \frac{dN}{d\log(t)} \propto t^{1+\log(1-f_{MID})}.$$

$$M_{max} \propto t^{(1+\log(1-f_{MID}))/(\alpha-1)},$$

In a plot of $\log(M_{max})$ vs. log(age) we thus expect a slope

$$\begin{aligned} \text{slope} &= \frac{1+\log(1-f_{MID})}{\alpha-1} && (11) \\ &= +1 \qquad \text{for } f_{MID}=0,\ \alpha=2, && (12) \\ &= 0 \qquad \text{for } f_{MID}=0.9 \text{ and all } \alpha. && (13) \end{aligned}$$

- f_{MID}=0.9: 90% of clusters are destroyed in each age dex.

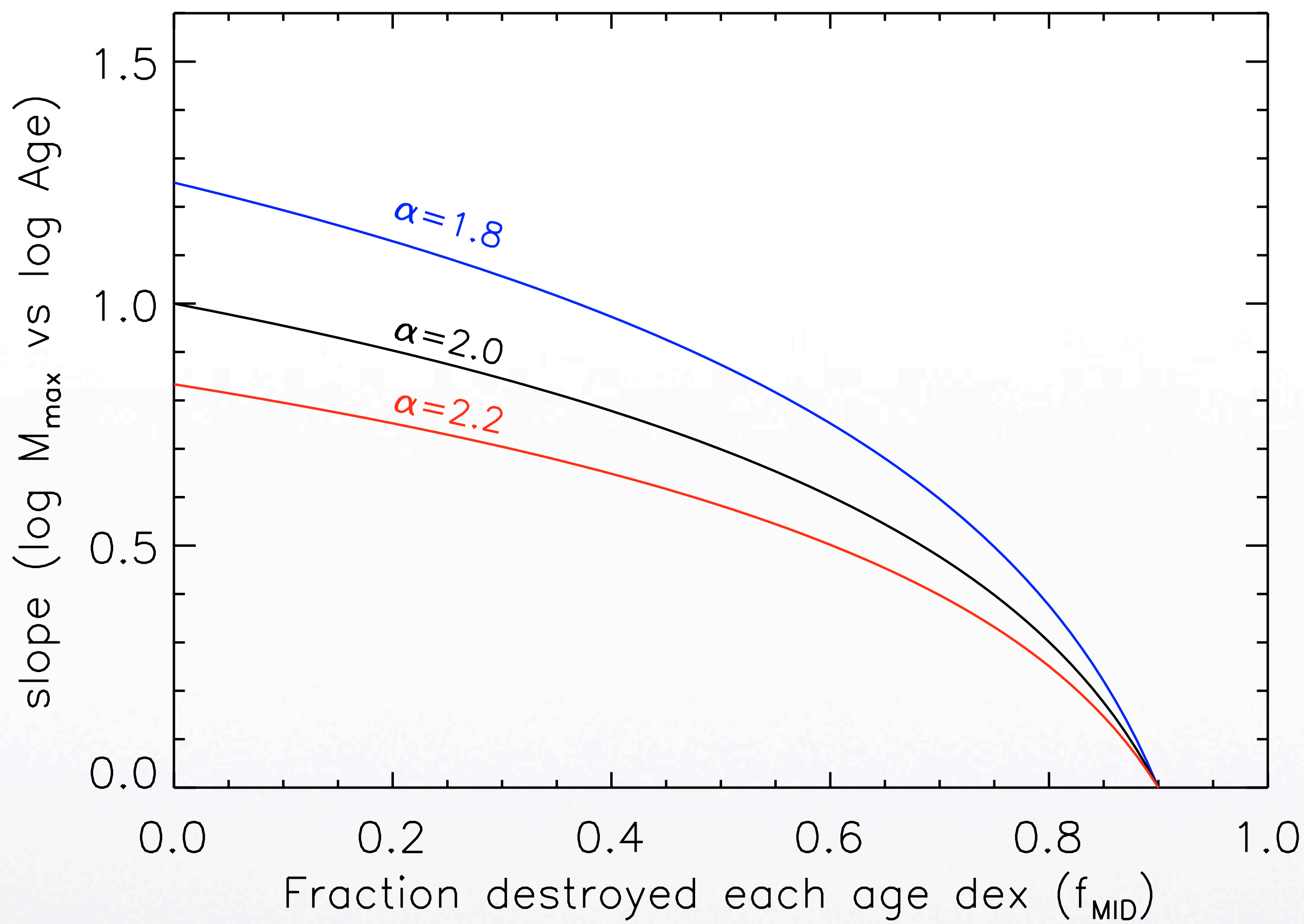

Fig. 1. Predicted slopes for $\log(M_{\max})$ vs. log(age) for different MID fractions ($f_{\rm MID}$) and three different indices of the CIMF (α) (Eq. (11)).

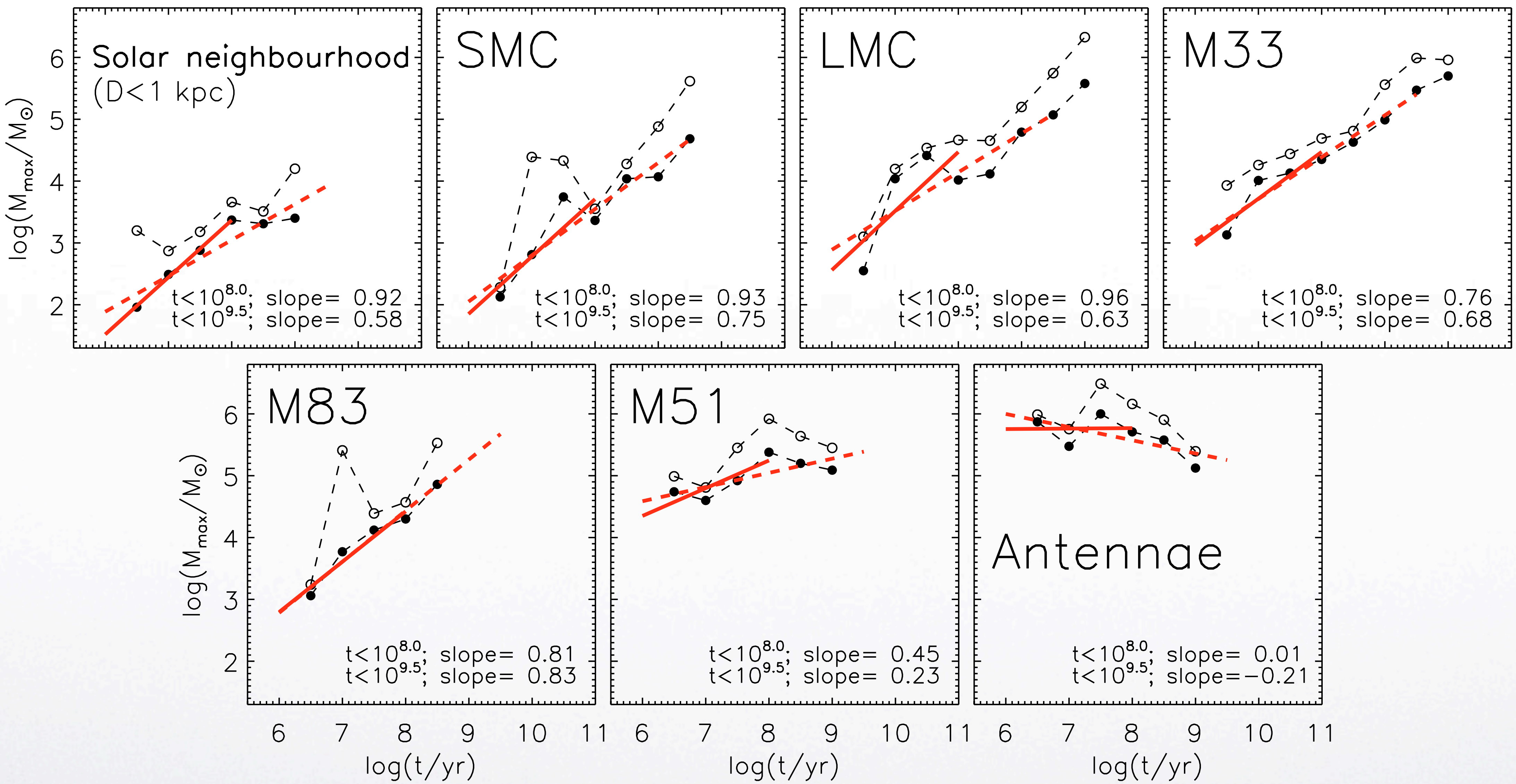

Fig. 2. Evolution of $M_{\max}$ with equal size log(age) bins for the seven galaxies in our sample (open circles). The third most massive clusters ($M_{\max,3rd}$) in each bin are shown as filled circles. Fits to log($M_{\max,3rd}$) vs. log(age) on two different age ranges are shown as dashed and full lines.