# YOUNG MASSIVE CLUSTERS IN NON-INTERACTING GALAXIES

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Abstract Young star clusters with masses well in excess of  $10^5 M_{\odot}$  have been observed not only in merger galaxies and large-scale starbursts, but also in fairly normal, undisturbed spiral and irregular galaxies. Here we present virial mass estimates for a sample of 7 such clusters and show that the derived mass-to-light ratios are consistent with "normal" Kroupa-type stellar mass distributions.

Keywords: galaxies: star clusters — galaxies: spiral — galaxies:irregular.

## **1.** Introduction

Young star clusters with masses in the range  $10^4 M_{\odot} - 10^6 M_{\odot}$  ("young massive clusters"; YMCs) are frequently observed in a wide variety of external galaxies (see review in Larsen 2004). Determining the mass-to-light ratios of YMCs is a matter of considerable interest, because this may lead to constraints on the stellar mass function (MF). The MF, in turn, is of interest not only for the general question whether or not there is a universal MF, but also for the long-term survival of YMCs. Here we discuss new results for a sample of 7 YMCs, for which we have attempted to constrain the MF using dynamical mass-to-light ratios.

## 2. Data

Three of our target clusters are located in spiral galaxies (one in NGC 6946 and two in NGC 5236) and were selected from the sample of Larsen & Richtler (1999). The other four are in dwarf irregulars (2 in each of NGC 4214 and NGC 4449) and were selected from Billett et al. (2002) and Gelatt et al. (2001). Archive HST/WFPC2 imaging is available for all our targets, and the clusters are all free of crowding and appear superimposed on a reasonably smooth background. The host galaxies have estimated distances in the range 2–6 Mpc, making the clusters appear well resolved on HST images although a correction for instrumental resolution is still necessary when measuring the sizes. Based

ID	$R_{ m hlr} \ [ m pc]$	$v_x$ [km/s]	Log(age) [yr]	$M_{ m vir} \ [10^5 \ M_{\odot}]$	$ ho_0 [M_\odot{ m pc}^{-3}]$
N4214-10	4.33±0.14	5.1±1.0	8.3±0.1	2.6±1.0	$(2.5 \pm 1.0) \times 10^3$
N4214-13	$3.01 {\pm} 0.26$	$14.8 {\pm} 1.0$	$8.3 {\pm} 0.1$	$14.8 {\pm} 2.4$	$(1.9 \pm 0.6) \times 10^5$
N4449-27	$3.72 {\pm} 0.32$	$5.0{\pm}1.0$	$8.9 {\pm} 0.3$	$2.1 \pm 0.9$	$(1.9 \pm 0.8) \times 10^3$
N4449-47	$5.24 {\pm} 0.76$	$6.2 \pm 1.0$	$8.5 {\pm} 0.1$	$4.6 \pm 1.6$	$(6.8 \pm 2.4) \times 10^3$
N5236-502	$7.6 \pm 1.1$	$5.5 \pm 1.0$	$8.0 {\pm} 0.1$	$5.2 {\pm} 0.8$	$(2.8 \pm 1.0) \times 10^3$
N5236-805	$2.8 {\pm} 0.4$	$8.1 \pm 1.0$	$7.1 \pm 0.2$	$4.2 \pm 0.7$	$(1.6 \pm 1.1) \times 10^4$
N6946-1447	$10.2{\pm}1.6$	$8.8{\pm}1.0$	$7.05{\pm}0.1$	17.6±5	$(2.3 \pm 0.8) \times 10^4$

*Table 1.* Data for the YMCs.  $R_{hlr}$  is the half-light radius,  $M_{vir}$  is the virial mass,  $v_x$  is the line-of-sight velocity dispersion and  $\rho_0$  is the estimated central density.

on photometry, ages were estimated to be in the range 11 Myr – 800 Myr and all clusters have photometric mass estimates greater than  $10^5 M_{\odot}$ . The expected velocity dispersions are of the order 5–10 km/s.

The two clusters in NGC 5236 were observed with the UVES echelle spectrograph on the ESO Very Large Telescope, while the remaining clusters were observed with HIRES and NIRSPEC on the Keck I telescope. The spectral resolution was between  $\lambda/\Delta\lambda = 25000$  and  $\lambda/\Delta\lambda = 60000$  and the S/N typically about 20-30 or better per resolution element. Velocity dispersions were measured using the cross-correlation technique of Tonry & Davis (1979). In brief, the cluster spectra were first cross-correlated with the spectrum of a suitable (red supergiant) template star. The template star spectrum was then cross-correlated with the spectrum of another template star. The velocity dispersion of the cluster spectrum was then essentially given as the quadrature difference between the gaussian dispersions of the peaks of the two crosscorrelation functions. The cluster sizes were derived from the HST/WFPC2 images by convolving EFF models (Elson, Fall & Freeman 1987) with the WFPC2 point-spread function and solving for the best fit to the observed images (Larsen 1999). Cluster ages and reddenings were estimated by comparing multi-colour photometry with Bruzual & Charlot (2003) simple stellar population (SSP) models. For further details concerning the data reduction and analysis we refer to Larsen et al. (2005; for NGC 4214, NGC 4449 and NGC 6946) and Larsen & Richtler (2005; for NGC 5236).

## 3. Virial mass-to-light ratios and the MF

Our results for the 7 YMCs are summarised in Table 1. As expected from the photometry, all clusters have virial masses in excess of  $10^5 M_{\odot}$ , and two have masses  $> 10^6 M_{\odot}$ . Interestingly, there is little if any correlation between cluster mass and half-light radius. Central densities, estimated from the EFF



Figure 1. Comparison of observed mass-to-light ratios with SSP models

fits, are listed in the last column and range from  $\sim 1000 M_{\odot} \,\mathrm{pc}^{-3}$  to greater than  $10^5 M_{\odot} \,\mathrm{pc}^{-3}$ .

In Fig. 1 we compare the observed mass-to-light ratios with predictions by SSP models for various MFs. The solid line shows the  $M_V$  magnitude per solar mass for solar metallicity and a Salpeter (1955) MF with a lower mass limit of  $0.1M_{\odot}$  from Bruzual & Charlot (2003). The other curves show our calculations for Salpeter MFs with lower mass limits of  $0.01M_{\odot}$ ,  $0.1M_{\odot}$ and  $1.0M_{\odot}$  (long-dashed, dotted-dashed and triple dotted-dashed lines) and a Kroupa (2002) MF (short-dashed line), obtained by populating solar-metallicity isochrones from Girardi (2000) according to the various MFs. It is not strictly correct to put all YMCs on the same plot, since the clusters in NGC 4214 and NGC 4449 may have metallicities of only 1/4-1/3 solar (Larsen et al. 2005). However, the V-band M/L ratios are predicted to change by less than 0.2 mag for models of 1/5 solar metallicity (shifting the curves in Fig. 1 upwards).

The comparison in Fig. 1 suggests that our data are mostly consistent with a Kroupa-type MF or a Salpeter MF extending down to  $0.1 M_{\odot}$ . At the present level of accuracy, we cannot distinguish between these possibilities. It should also be noted that there is a degeneracy between the MF slope and the lower mass limit. However, there is no suggestion that any of the YMCs studied here have significantly top-heavy MFs. It should be kept in mind that the virial mass estimates are subject to a number of uncertainties which are not easily quantified. In order to assess the role of macroturbulence in the template stars

we used several stars in the cross-correlation analysis and found no strong dependence on the choice of template star. However, it is difficult to find local red supergiants which are as luminous as those expected to be present in the youngest clusters, and if the macroturbulence varies significantly with luminosity then this may lead to systematic errors. Mass segregation (primordial or dynamical) can also lead to erroneous results if the virial theorem is applied blindly. Recent calculations by A. Lançon (this meeting) suggest that mass segregation will typically lead to the cluster masses being underestimated, i.e. the data points would shift downwards in Fig. 1 and the case for top-heavy MFs would then seem even weaker.

### 4. Summary

Using a combination of ground-based high-dispersion spectroscopy and HST imaging, we have derived virial mass-to-light ratios for a sample of 7 YMCs with masses in the range  $10^5 M_{\odot}$ – $10^6 M_{\odot}$  in nearby spiral and irregular galaxies. By comparing the mass-to-light ratios with predictions by SSP models, we conclude that our data are consistent with "normal" (e.g. Kroupa 2002-type) stellar mass functions, suggesting that the clusters may eventually evolve into objects which will be very similar to the globular clusters commonly observed around galaxies.

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