The old Star Cluster (SC) systems surrounding any sofar investigated galaxy represent a powerful tool for the understanding of the cosmological evolution of their host galaxies. Phases of enhanced cluster formation can be identified by reliably age dating the clusters. These are symptoms of violent star formation, results of intense starbursts as commonly seen in merging nearby galaxies and high-z forming galaxies. However, the young SC systems of nearby merging galaxies and the old SC systems of nearby passive galaxies (most likely resulting from high-z starburst events of these galaxies) appear to be significantly different in terms of their mass functions. Whether this difference originates in differences in the formation physics/environment or is only due to dynamical evolution of the cluster systems is currently a hot issue. A main diagnostic for the survival probability of a newly formed cluster is most likely its compactness, since less compact, fluffy clusters are more vulnerable to destructive interactions with the galactic environment of the cluster. For these reasons, we developed 1) a tool to significantly improve photometry of nearby SCs (which appear resolved on high-resolution images, provided e.g. by HST), by accurately measuring and taking the cluster size into account, and 2) a tool to effectively determine ages and masses (plus metallicities and extinctions) of SCs from multi-wavelength photometry, ranging from the UV to the NIR. We will present these tools and applications to SC systems in different nearby SC-forming galaxies, comprising a wide range of environments for the newly born clusters. These applications, though preliminary, will help to disentangle the effects leading to the observed differences in SC systems.

1 Why young nearby star clusters?

Strongly bound, hence long-lived star clusters present a fossil record of the violent star formation history of their host galaxies. (Almost) all galaxies known contain old star clusters, globular clusters, with ages around a Hubble time. The formation conditions of this cluster population give vital clues to the conditions during the formation of the host galaxy itself. However, due to the high redshift of galaxy formation (and accompanying globular cluster formation) and the
related limited spatial resolution (see Fig. 1, left & middle panel) this process cannot be studied directly. Globular clusters are characterised by a tidally truncated light profile (King 1962), they are relaxed, round systems (see Fig. 1, right panel), and the GC system as a whole shows a Gaussian-shaped luminosity/mass function.

On the other hand, young clusters with a large range of dynamical, structural and photometric properties are currently produced in all starburst environments (for a few examples see Fig. 2 Fig. 3 from Maiz-Apellaniz 2001). While some (if not most) of them are expected to dissolve in the near future (see Whitmore 2004 and Bastian et al. 2005 for “infant mortality” of young clusters), some have the potential to survive for a Hubble time to produce a secondary population, similar to the old globular clusters, but with enhanced metallicity. The average newly-born star cluster does not show signs of tidal truncation (but will probably develop this during the future interaction with the galactic gravitational potential), are not (yet) completely relaxed, and the cluster system as a whole seems to follow a power-law luminosity/mass function (although this is questioned recently, e.g. de Grijs et al. 2003a, Goudfrooij et al. 2004, de Grijs et al 2005b).

Therefore, both types of objects seem to be very distinct, though similar formation mechanisms are expected. The relation between both classes could be clarified by investigating intermediate-age cluster systems. Unfortunately, the number of such systems is still small, pos-
sibly due to selection effects. Two well-studied cases are NGC 1316 (Goudfrooij et al. 2004) and the fossil starburst region M82-B (de Grijs et al. 2003a). In both cases the presence of a turnover (of roughly Gaussian shape) in the luminosity/mass functions of the clusters related to the intermediate-age starburst/merger event is clearly seen (de Grijs et al. 2003a, Fig. 1 [reproduced here in Fig. 3]; Goudfrooij et al. 2004, Fig. 3). However, due to the small number of such systems, the need to understand the nearby young star cluster formation, evolution and destruction is still urgent.

2 Improved photometry for (young) star clusters

Despite the advances in cluster spectroscopy, the use of integrated, multi-band photometry is still (and probably will be) the most commonly used tool to study extragalactic star cluster systems. While CMD analysis and spectroscopy is always limited to few individual (especially nearby) clusters, integrated photometry gives, with few exposures, the properties of the whole cluster sample in the field-of-view.

Though widely used, aperture photometry (and size determination) of clusters has its caveats which are not yet well studied. For HST observations the most important are the undersampled PSFs, and the possibility to resolve star clusters in nearby (∼ 20-25 Mpc) galaxies. By definition, aperture photometry using finite apertures does underestimate the total source flux. While this is well studied for point sources and can be corrected for using aperture corrections (ACs) (Holtzman 1995), these corrections become increasingly inaccurate with increasing (apparent) source size.

Therefore, we performed a large-scale study on the size determination and photometric accuracies for HST observations of resolved clusters. We created artificial clusters using the BAO-LAB package by S. Larsen (to be obtained from http://www.astro.ku.dk/~soeren/ and described in Larsen 1999) as the package to create artificial clusters most realistic, in conjunction with PSFs and diffusion kernels produced by TINY TIM (Krist & Hook 1997).

We performed tests with various observational (different HST cameras, chips, filters, sub-pixel shifts), computational (size fitting radius, aperture annuli) and cluster settings (size, light profile, brightness, sky background). For each setting we have determined the relations between input FWHM of the cluster and the FWHM of a fitted Gaussian (=“measured size”) and parametrised the relations in form of 5th order polynomials. We have chosen to fit a Gaussian for

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Figure 3: Parameter distributions of clusters in the fossil starburst region M82-B. The vertical lines indicate selection limit. Left panel: Absolute V-band magnitudes, normalised to a common cluster age of 1 Gyr. Right panel: Cluster masses. From de Grijs et al. (2003a)
Figure 4: Differences between measured (Gaussian) FWHM and input light profile FWHM (models indicated in legends). Left panel: King (1962) models with different concentration indices $r_{\text{tidal}}/r_{\text{core}}$. Right panel: Elson et al. (1987) models with different power-law slopes.

Figure 5: Left panel: Theoretical ACs to infinite radius as function of intrinsic cluster size = cluster FWHM (in WF3 pixel) for 3 different aperture annuli. Right panel: Comparing the accuracy of AC determination for our method and the widely used $\Delta$mag method.

reasons of general applicability and computational fit stability. Some results for various input cluster light profiles are shown in Fig. 4.

In addition to the cluster sizes we also determined ACs for a number of typical aperture radii, correcting the source magnitude determined in the finite aperture to infinite aperture.

While fitting the whole cluster image would be the best way to do, the still most commonly used size measure to date utilises the magnitude difference in two concentric apertures with different radii centred on the cluster. Usually radii of 0.5 and 3 pixels are used. Apart from severe centring problems caused by the use of a 0.5 pixel aperture radius this method uses only part of the light profile information, hence a lower accuracy as compared to our method could be expected, and is proven in Fig. 5 right panel.

The full set of results (including a “cookbook” on how to improve cluster photometry) will be presented in Anders et al. (2005).
Determining (young) star cluster properties

Having a set of cluster magnitudes in a number of passbands at hand enables one to retrieve the physical parameters of this cluster, namely age, metallicity, extinction within the host galaxy, and mass. This can be done by comparing the observed Spectral Energy Distributions (SEDs; the data set containing all magnitudes of a given cluster) with model predictions, e.g. with GALEV models (Schulz et al. 2002, Anders & Fritze – v. Alvensleben 2003, Bicker et al. 2004), GALAXEV = B&C models (Bruzual & Charlot 2003), StarBurst99 (Leitherer et al. 1999) or PEGASE (Fioc & Rocca-Volmerange 1997). Many people use these models and developed their own programs to perform the comparison between models and observations, usually in a least-square sense. However, these programs are only briefly explained, mainly in the context of a larger observational paper. So-far only few large-scale quality assessments or studies pointing at caveats and strengths of parameter determination by SED analysis was carried out (from the observational point-of-view e.g. de Grijs et al. 2003b,c; from a more theoretical point-of-view e.g. de Grijs et al. 2005a).

With our AnalySED code for SED analysis of clusters we can obtain the clusters parameters age, metallicity, internal extinction and mass, and for each parameter the related 1σ uncertainties. While building this code, we carefully evaluated various aspects and caveats of it (in fact, the general results are valid for all least-square SED comparison programs). We studied the impact of the choice of filters, the observational uncertainties, a priori assumptions during the analysis and various cluster parameters (hence, differently shaped SEDs). For this we have constructed cluster SEDs with known parameters, added noise to the cluster magnitudes, and then retrieved the cluster parameters using the AnalySED tool, comparing the results with the input values. In Fig. 6 left panels, we show the impact of the filter choice on the parameter determination accuracy, as an example. As can been seen for the youngest age (8 Myr) the U band (and to a lesser extent the B band) are most important for accurate parameter determinations, while for the oldest age (10 Gyr) the B band (and to a lesser extent the V band) are most important. For filter combinations strongly biased towards either UV-blue or (even more pronounced) red-NIR passbands the results show strong deviations from the input values, misleading the interpretations of the observations. This confirms the need to carefully choose the filters for observations, spanning a wavelength range as long as possible. In Fig. 6 right panel, we display SEDs of solar metallicity for 5 different ages, from 8 Myr to 10 Gyr to illustrate the changes of these SEDs with time, and therefore the potential to age-date clusters based on their SEDs.

The full study is presented in Anders et al. (2004b).

Application: NGC 1569

We have applied the AnalySED tool to a data set for clusters in the nearby dwarf starburst galaxy NGC 1569. We identified a number of 165 clusters in this galaxy, enlarging the sample of known clusters by roughly a factor of 3. We find the majority of the clusters to be of low mass, rather comparable to Galactic open clusters than Galactic globular clusters. Hence, the vast majority of the clusters are expected to dissolve in the near future. However, 6 star clusters are more massive than the median mass of the Galactic globular clusters of $10^{5.2} M_\odot \sim 1.6 \times 10^5 M_\odot$. These clusters have the potential to become globular cluster-like objects in a Hubble time, though they will lose mass due to dynamical and stellar evolution.

The age distribution confirms the recent burst of star formation inferred already from CMD analysis and the presence of large HII regions.

The complete analysis is presented in Anders et al. (2004a).
Figure 6: Left panels: Comparison of input cluster parameters with retrieved values for 5 different cluster ages and a number of filter combinations (indicated in the legend): Age (upper left panel), extinction (upper right), mass (lower left) and metallicity (lower right). Symbols indicate the median retrieved values, vertical lines the associated 1σ uncertainties, horizontal lines the input values. Right panel: Comparison of SEDs of different ages.

PA and UFvA like to thank the conference organisers for the pleasant and fruitful conference, as well as for financial support.

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