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HST photometry of the binary globular cluster Sersic 13N-S in NGC 5128*

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ABSTRACT

Using Hubble Space Telescope archival images we resolved individual stars in two young globular clusters centered in the giant HII region Sersic 13, on the dust band of NGC 5128. We resolved 5 sources in the southern cluster and 4 sources in the northern one. The high U luminosity of these stars ($-9.3 < M_{F336W} < -7.8$) added to the previously detected WR features in the integrated spectra of the clusters suggest we are identifying the most massive stars of the clusters, with O or WR spectral types, whose masses can even reach 120 $M_{\odot}$. We have estimated their ages in $t \leq 6 \times 10^{6}$ yr for comparison with two different set of isochrones, which is consistent with an scenario where the clusters form a binary pair that would merge in a short timescale.

Key words. galaxies: individual: NGC 5128 – galaxies: star clusters

1. Introduction

Since the term super star cluster (SSC) was suggested by van den Bergh (1971) in reference to bright infrared knots in M 82, it has been used to refer to young massive star clusters embedded in giant HII regions of merging and starbursting galaxies. According to Whitmore (2001) these objects show masses between 10^{5} and 10^{7} $M_{\odot}$ and very high densities ($\rho \sim 10^{5}$ $M_{\odot}\,\mathrm{pc}^{-3}$) which, added to their young ages ($t \sim 1$–10 Myr), have made several authors postulate that SSCs are recently-formed globular clusters (Schweizer 1984; Whitmore & Schweizer 1995; Maíz-Apellániz 2001).

Because the Milky Way is not currently in an active intense star formation phase, this kind of object is not common in the Galaxy and the candidates are found preferably in the galactic center (Morris & Serabyn 1996, and references there in), so they have been observed mostly in IR wavelengths. Therefore, almost all the known SSCs are extragalactic objects and their study is limited by the distance.

R136 in 30 Doradus in the LMC is the best studied SSC (see, for example, Selman et al. 1999; Bosch et al. 1999). Its proximity makes it the only one where the star content can be studied directly, which is particularly important to learn about the star formation history and the IMF of the cluster. Massey & Hunter (1998) obtained HST spectra of the 65 bluest stars in R136, and found that the majority of these stars are type 03, being the hottest, most luminous and most massive stars known ($M \sim 50$–120 $M_{\odot}$).

If SSCs are formed by such massive stars, we expect to be able to define their individual stars photometrically in nearby objects, out to a distance of a few Mpc, using high resolution instruments like the HST cameras, at least for the most luminous components in each cluster. This is not simple, especially because such objects are embedded in high extinction HII regions.

In this paper, we present the results of photometry performed on HST/WFPC2 images of Sersic 13, a giant HII region in the dust band of NGC 5128 (Centaurus A). The ionizing central source in Sersic 13 was shown by Minniti et al. (2004) to be formed by a close pair of bright and blue star clusters. Our goals are to resolve individual stars in each cluster, and to estimate their ages. The study is also oriented to explore the possibility that these clusters – as an interacting pair – could merge in the future, evolving to a very massive star cluster.

The plan of the paper is the following: in Sect. 2 we describe the data and the reduction process. The results, presented in Sect. 3, are discussed in Sect. 4, where we also describe the process to obtain an age estimation for the clusters. Section 5 summarizes the results of this work.

2. Multicolor photometry

We searched the Hubble Space Telescope online archive for Wide Field Planetary Camera 2 (WFPC2) images of NGC 5128, approximately centered on Sersic 13. Images in three bands, *F336W*, *F555W* and *F814W*, were obtained,

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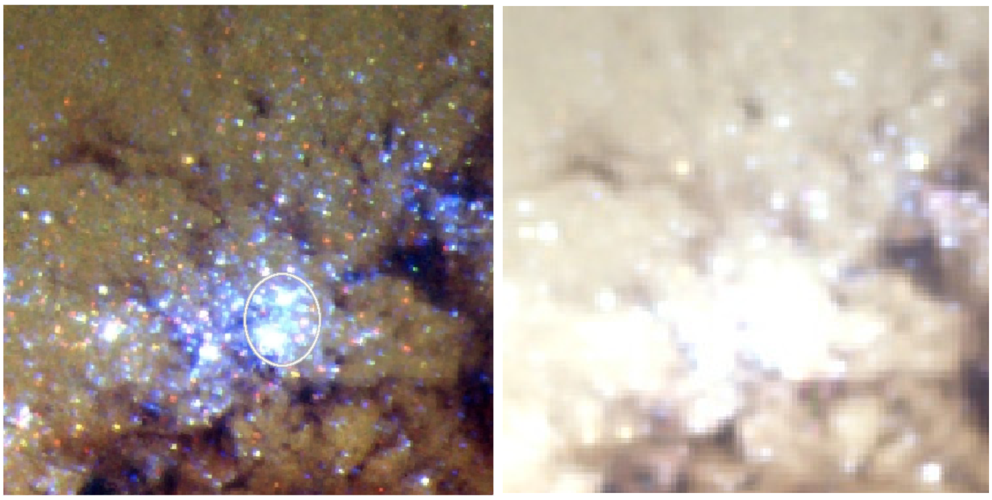

Fig. 1. The WFPC2/HST color image (*left*) for Sersic 13 area compared with a FORS2/VLT image (*right*) for the same region. In the HST image it is possible, even visually, to define individual point sources. The field is ∼1′ × 1′ and north is up and east to the left. The binary clusters are the two bright sources, just south of the center, indicated by the circle in the HST image.

with exposure times of 1800, 60 and 60 s, respectively (Proposal IDs: 6578, 6789, 6789). These filters are the nearest equivalents to Johnson-Cousins *U*, *V* and *I* bands according to WFPC2 Instrument Handbook[1]. The target region is ∼1′ × 1′, or projected 1.1 × 1.1 kpc^2, which corresponds to ∼30% of the WFPC2 field of view.

We combined at least two images in each band in order to minimize the effect of cosmic rays. After that, a standard reduction process was done using the available tasks in the APPHOT package of IRAF. Aperture photometry was performed over a merged U and I source list.

A color image composed of the UVI images using the COLOR package in IRAF is shown in Fig. 1 next to a VLT image of the same region, taken under 1″ seeing, for comparison. Aside from Sersic 13-N and Sersic 13-S, there appear other fainter clusters in the region, as well as a complex dark cloud structure.

The photometry detects a total of 1796 sources in the selected 1′ × 1′ HST field. From the coordinates in this list we could separate the sources contained in a circular area around the estimated center for each cluster. The diameter is taken to be the separation of the clusters. With this procedure, and on the basis of their magnitudes and sizes, it is possible to resolve 5 sources in the southern cluster, Sersic 13-S, and 4 sources in the northern one, Sersic 13-N. In addition a multiple detection, corresponding to a very luminous object with a *FWHM* larger than the point sources, is obtained for the central region in the cluster nuclei, which gives more accurate coordinates for the cluster centers at: RA(2000) = 13:25:26.51, Dec(2000) = −43:00:09.6 and RA(2000) = 13:25:26.54, Dec(2000) = −43:00:11.9. These give a projected separation of 2.34 arcsec, or 43.5 pc. The positions of the objects and the centers of the clusters are shown in Fig. 5.

The results of the photometry are presented in Table 1. The data were corrected using for the total reddening in the field of Sersic 13: $E(B-V) = 0.23$ according to Rosa & D'Odorico (1986), and using Rieke & Lebofsky (1985) interstellar extinction tables. We assume a distance to NGC 5128 of 3.84 Mpc (Rejkuba 2004), in order to estimate the absolute magnitudes of the sources. Figure 2 shows the color−magnitude diagrams for the sources defined in the clusters (yellow for the Sersic 13-N and red for Sersic 13-S) plotted together with all the sources in the field (blue symbols).

Table 1. Photometry for the stars resolved and the cores of the clusters, assuming $E(B-V) = 0.23$ and $d = 3.84$ Mpc. The *x* and *y* coordinates corresponds to the position in the chip and the first component in each cluster, S_0 and N_0 respectively, is the nucleus.

ID	x	y	M_{F814W}	M_{F555W}	M_{F336W}
S_0	156.464	141.761	−11.40	−11.36	−12.52
S_1	152.662	135.563	−7.35	−7.76	−9.34
S_2	149.287	144.951	−7.81	−7.49	−8.77
S_3	156.938	149.177	−8.24	−7.70	−9.26
S_4	152.218	153.100	−6.65	−6.90	−8.31
S_5	164.261	141.302	−7.34	−6.43	−7.91
N_0	179.242	144.106	−10.69	−11.09	−12.54
N_1	185.427	134.498	−7.47	−7.75	−9.33
N_2	172.494	140.542	−5.13	−5.99	−7.87
N_3	168.281	140.623	−6.13	−6.73	−8.30
N_4	177.742	131.582	−6.83	−7.50	−9.35

In the CMDs the stars in Sersic 13-N and Sersic 13-S look more luminous than the other sources in the field and in the *F814W* vs. (*F555W*−*F814W*) they also look bluer. Their *U* absolute magnitudes are $-9.3 < M_{F336W} < -7.8$, which corresponds to the brighter 20% of the sources. In the *V* band they appear bright too ($-7.7 < M_{F555W} < -5.9$, 35% brighter), but in the *I* band their luminosity is comparable to the general behavior of the sources in the area ($-8.2 < M_{F814W} < -5.1$,

[1] Biretta et al. (2001), WFPC2 Instrument Handbook, Version 6.0 (Baltimore: STScI).

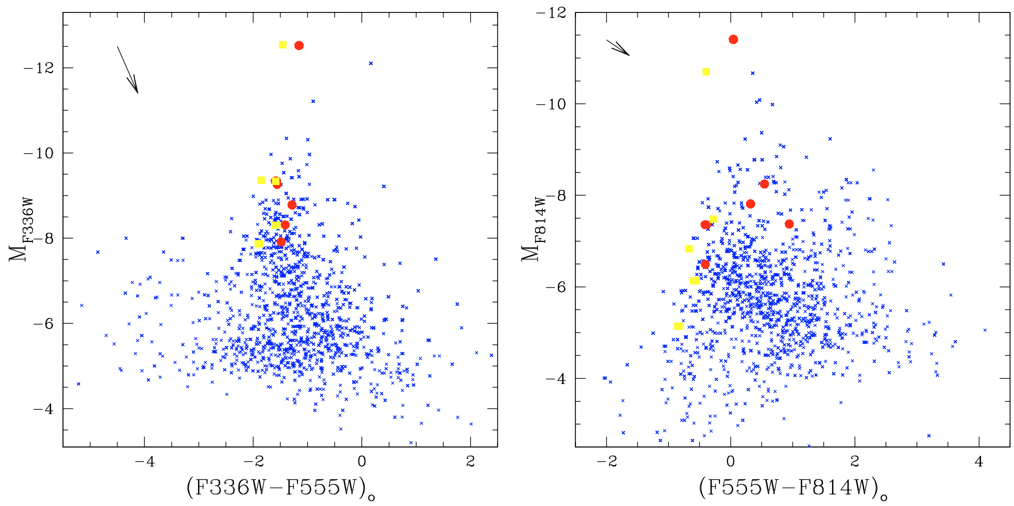

Fig. 2. CMDs for all the sources defined in the field emphasizing the stars in the clusters and including the extinction vector for the region, red circles for Sersic 13-S and yellow squares for Sersic 13-N. The two brightest points in each diagram correspond to the cluster nuclei.

70% brighter). Their *V* band luminosity is just comparable with the most luminous Galactic WR stars, which have magnitudes between $-8 < M_V < -2$ (van der Hucht 2001), with just the brighter 13% in the range of the resolved stars in the Sersic 13 region. In this whole field there is a clear excess of bright blue stars, many of which could be WR stars, according to the characteristic wide emission features seen in the cluster spectra.

We checked the completeness of our photometry for each band by adding a distribution of false stars consistent with the magnitude distribution of the real objects. The percentage of recovered stars indicates that there is no significant incompleteness brighter than $M_{F814W} = -5.6$, $M_{F555W} = -5.2$ and $M_{F336W} = -8.7$.

3. The binary cluster Sersic 13N-S

The dust band in NGC 5128 is believed was formed as the product of a recent merger between the original elliptical galaxy with an other smaller galaxy, and its high gas content made it the principal star formation region in this galaxy (Israel 1998). In consequence, numerous star clusters are expected be found in that dust lane (Peng et al. 2002). Nevertheless, the study of these objects is strongly limited by the high extinction in the area, and by their small angular sizes.

In the case of Sersic 13-N and Sersic 13-S we are able to identify a compact central nucleus generated by the integrated contribution of all the stars. In the FORS2/VLT images (Minniti et al. 2004) the clusters look very similar with $FWHM \sim 3.1$ pix. for a pixel scale of 0.2″/pix, which corresponds to ~11.5 pc, but in our *F555W* band image the situation is different. The nuclei have $FWHM \sim 2.1$ and 1.9 pixels for a pixel scale of 0.1″/pix that is equivalent to 3.9 and 3.5 pc, and ellipticities of 0.09 and 0.23, for Sersic 13-S and Sersic 13-N respectively. This shows that the clusters are very concentrated with a PSF close to the stellar PSF of 2.97 pc $< FWHM_\star <$ 3.35 pc, and lower than the typical PSF of the other cluster in the region ($FWHM > 4.28$ pc).

At large enough distances away from the cluster nuclei, the individual brightest stars can be resolved. They are located in the external region of the clusters, some of them in the zone between the clusters, and they show a $FWHM \sim 3.35$ pc. However, we cannot exclude, with the available resolution, that one or more of the objects measured here are blends or binaries, which are very numerous even in R136, for which much higher resolution images are available. In R136 some of the individual sources of Melnick (1985) were later recognized to be multiple by Massey & Hunter (1998), so we must consider the caveat that some of the point sources detected here might be multiple rather than individual stars.

The high *U*-band luminosity of the stars compared to the surrounding field, even though they are located in a complex dusty region, is an indicator of their youth and, as we will discuss below, allow us to make an estimation of their age. Additionally, in an environment where part of the light is diffuse, these high mass stars, significantly more luminous than their neighbors, dominate the light of the clusters and appear to be the only discrete sources that can be defined.

We also explore the possibility that the high luminosity of the stars is an effect of blending: because of the high concentration in the area, multiple sources could be adding their brightness inside the chosen aperture. Nevertheless this it is not necessarily the case because at the earliest times in massive enough star clusters, the emission is dominated by light coming from the most massive stars, O or B spectral types. Particularly, an HST spectroscopic classification by Massey & Hunter (1998) showed that the core region in the nearby SSC R136 is populated by O3 supergiants stars and several H-rich WN stars whose masses extend above 120 $M_\odot$, and with magnitudes comparable to our results. Unfortunately, the distance to NGC 5128 does not allow us to obtain individual star spectra, but the presence of this type of star can explain the WR-type emission observed in the integrated spectra of the clusters (Minniti et al. 2004).

The IMF behavior in the SSCs is critical to understanding their evolution. In the case of R136 it was first believed that

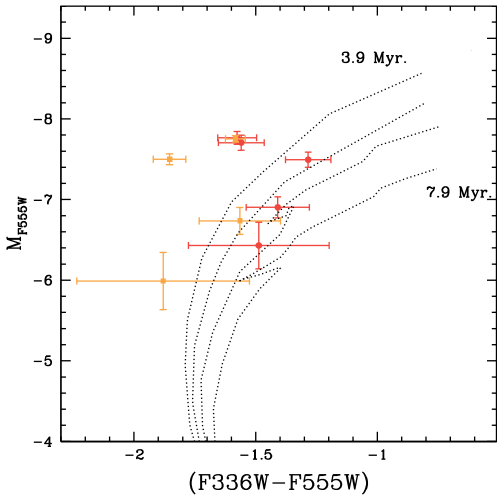

Fig. 3. CMD of the defined stars in each cluster plotted over Padova evolutionary tracks corresponding to 3.9, 5.0, 6.3 and 7.9 Myr. Yellow squares for Sersic 13-N and red circles for Sersic 13-S.

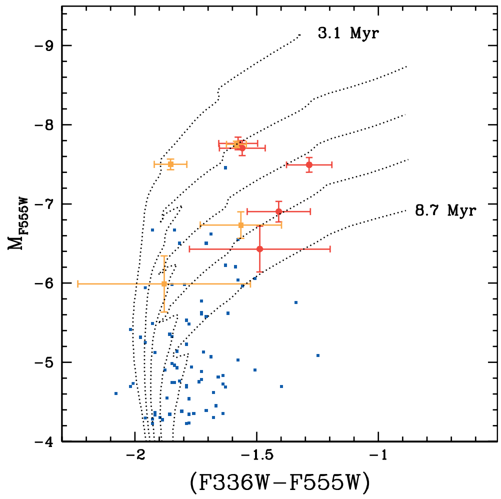

Fig. 4. CMD of the defined stars in each cluster plotted over Geneva evolutionary tracks corresponding to 3.1, 4.4, 5.6, 6.9 and 8.7 Myr. with the same colors distribution used in the previous plots. Blue squares corresponds to the 65 O3 stars defined by Massey & Hunter (1998) in R136.

low mass stars were absent (Cassinelli et al. 1982), but the better resolution of HST studies of the cluster later showed that it is consistent with a standard Salpeter IMF above 2 $M_\odot$, flattening at lower masses (Sirianni et al. 2000). Hunter et al. (1996) derived an R136 IMF from the intermediate mass stars that predicts at least ~6 stars with $M = 50{-}120\ M_\odot$, which was later confirmed by the Massey & Hunter (1998) spectroscopic classification of the 65 most luminous stars in the cluster as O3 spectral type. Considering that Sersic 13-N and Sersic 13-S are as bright as or brighter than R136 (Minniti et al. 2004) this number must be a lower value than the expected for the clusters, so we are probably not defining all the stars in this bin of masses because some of them are missing in the concentrated central core.

The derived visual magnitudes for the nuclei are −11.3 and −11.1 for Sersic 13-S an Sersic 13-N respectively. So, if the clusters cores are just formed for WR stars with an absolute magnitude of −7 (corresponding to the brightest WR stars observed in R136 core) we need at least ~50 WR stars in each cluster core to explain the observed luminosity.

Because of the small age dispersion between globular clusters components we can estimate the age of Sersic 13-N and Sersic 13-S from the age of their stars. We then performed a comparison with population synthesis models using a set of Padova isochrones (Girardi et al. 2002) with special bolometric corrections and magnitudes for the WFPC2 filters. In this diagram, shown in Fig. 3, we can observe a broad dispersion between the points because of the different masses of the stars and the uncertain reddening. Nevertheless, the sources are located in a well defined area with ages younger than 6.3 Myr, and on average they follow the track corresponding to 3.9 Myr. If we plot the same data over a set of Geneva isochrones (Lejeune & Schaerer 2001) we can obtain a similar estimation, but in this case the objects look a little older, following a tendency nearest to the 5.6 Myr isochrone (Fig. 4).

In order to compare the behavior of the objects defined in each cluster with components of the SSC R136 we plotted both data in Fig. 4. Here R136 data, obtained from Table 2 in Massey & Hunter (1998), are corrected for reddening choosing $E(B-V) = 0.34$ (Fitzpatrick & Savage 1984) and we are assuming a distance of 51 kpc to the LMC to calculate the absolute magnitudes. From this diagram we can observe that the magnitudes obtained for the objects defined in our clusters are comparable just to the most luminous components of R136, which is not a surprise considering that our study is strongly limited by distance, but unfortunately again introduces the blend problem. On the other hand, it is also interesting to observe that the R136 stars do not have smaller scatter than our objects, indeed some scatter seems to be intrinsic at these high magnitudes.

If we analyze the components of each cluster individually, a slight difference in their average behavior is observed. In the Padova isochrone diagram the Sersic 13-S components look older, with a mean value close to 5 Myr, while Sersic 13-N components seem to follow a younger tendency, showing that they started their formation processes at different time, separated by ~1−2 Myr. But this may be an observational effect. In Fig. 2 we have plotted the extinction vector for the data. It is evident in the two diagrams that Sersic 13-S components look redder than Sersic 13-N sources, but the shift is in the same direction as the extinction vector. This effect is more evident in the *F814W* vs. (*F555W* − *F814W*) diagram. This suggests the possibility that the clusters are under different extinction conditions, probably because they are not both at the same distance from us, and the light coming from one of them passes through a bigger amount of gas and is more significantly scattered. If this is the case, Sersic 13-S would be more distant than Sersic 13-N. In the case of a higher extinction for Sersic 13-S, the redder points would match but the bluer ones would be too blue compared to the isochrones. The hypothesis of Sersic 13-S being farther away depends on the presence of localized extinction in this region.

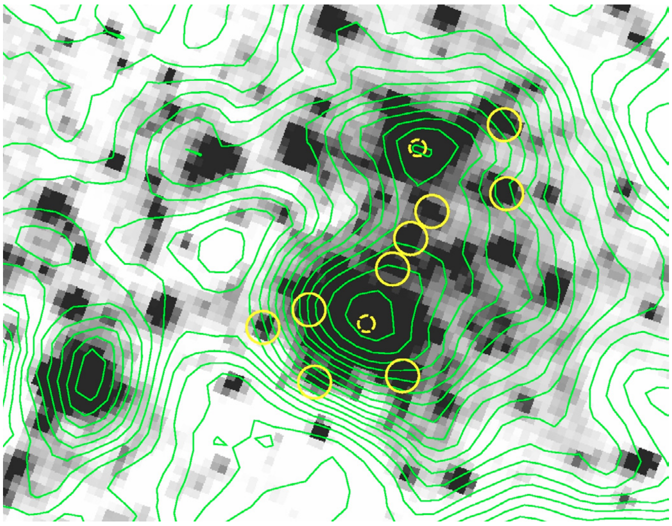

Fig. 5. Light contours of the expanded *F555W* band image of the clusters region suggesting the presence of a star bridge. Yellow circles show the positions of the stars defined in the region.

Clearly extinction is not uniform, but if we assume that extinction is uniform and equal for both clusters, Fig. 3 suggests that the clusters may have different ages. With this assumption, Sersic 13-S seems to have ongoing star formation with stars as old as 5 Myr (some blue hypergiants) and really young O3/WN(h) stars with ages below 2 Myr following a younger isochrone, as it also seems to be the case for the Sersic 13-N objects. This has been found as well for R136 (Massey & Hunter 1998; Hunter et al. 1997).

The age we have estimated for the clusters is in agreement with the scenario in which they would merge in the future proposed by Minniti et al. (2004). Simulations show that the timescale predicted for the merge is a few orbital periods (Sugimoto & Makino 1989), which in this case corresponds to 8 Myr. The 3.9 Myr age inferred from the Padova isochrones is too young for the beginning of the merger and it is not possible to observe specific star transfer signs, which could be evident from a star bridge between the clusters like the one that it is apparently observed between the clusters NGC 1971 and NGC 1969 in the LMC (Dieball & Grebel 2000).

Figure 5 shows an expanded image of the clusters in the *F555W* band, with the light contours of the objects. The presence of the star bridge is suggested, but the resolution is not good enough to be conclusive. We note that if the clusters are older, 5 Myr instead of 3.9 Myr, as the Geneva isochrones suggest, it would be more likely to see merging features.

A third cluster candidate, 2.5 mag fainter than Sersic 13-N, is seen separated from Sersic 13-S by ~1.5 times the distance between Sersic 13-S and Sersic 13-N. This object was barely detectable in the VLT B image (Minniti et al. 2004). Spectroscopic observations are required to establish whether this object might be physically related to the Sersic 13 clusters. Aside from the bridge suggested before, there is a feature resembling a tail below Sersic 13-S, and a possible bridge connecting Sersic 13-S with the third cluster mentioned above.

Then, with the dynamical considerations described in Minniti et al. (2004), and the measure of the age made here, a future merger between Sersic 13-N and Sersic 13-S to form a massive globular cluster, have a real chance to happen, even though the binary nature of this cluster depends on the assumed distance to the center of the galaxy.

For the most massive globular cluster in our Galaxy, ωCen, a similar possibility has been put forth by Ferraro et al. (2004). Using high resolution images taken with VLT and HST, they discovered an anomalous sub-giant branch (SGB) in the CMD of ωCen. The new SGB defined an older star population in the cluster, indicating an extra-cluster origin for the metal-rich dominant population, first suggested by Ferraro et al. (2002). This extra-cluster enrichment could be the product of the merger of clusters like Sersic 13-N and Sersic 13-S in NGC 5128.

4. Conclusions

We have resolved a set of nine stars on the clusters Sersic 13-N and Sersic 13-S, located in the largest HII region of the dust band of NGC 5128. The photometric data of these stars placed them in the category of very massive stars, with masses well over 50 solar masses.

We estimated an age of $t \leq 3.9 \times 10^6$ years for the clusters by comparison with Padova isochrones and $t \leq 5.6 \times 10^6$ years using Geneva isochrones. The accuracy of this procedure is uncertain, especially for high mass stars, but with the current data we are not able to obtain a better estimation. The ages agree, however, with the results from integrated spectroscopy. A deeper HST photometry or the use of adaptive optics could improve the resolution, but certainly is not able to obtain information on low and intermediate mass stars, which could help us to trace the formation history of the clusters. Additionally, further IR studies may allows to account for the reddening influence, and to obtain more information on the individual massive components of the clusters.

An age of $t \leq 6 \times 10^6$ years is compatible with the scenario where the clusters are gravitationally bound, and that they will merge in the future. This is interesting in light of the recent study of Ferraro et al. (2004) that suggests that the very massive Galactic cluster ωCen is the product of a merger between two smaller star clusters.

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