Three newly discovered globular clusters in NGC 6822

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ABSTRACT

We present three newly discovered globular clusters (GCs) in the Local Group dwarf irregular NGC 6822. Two are luminous and compact, while the third is a very low luminosity diffuse cluster. We report the integrated optical photometry of the clusters, drawing on archival CFHT/Megacam data. The spatial positions of the new GCs are consistent with the linear alignment of the already-known clusters. The most luminous of the new GCs is also highly elliptical, which we speculate may be due to the low tidal field in its environment.

Key words: galaxies: star clusters – galaxies: individual (NGC 6822)

1 INTRODUCTION

In ΛCDM cosmology, large galaxies are assembled as the result of the accretion and merger of smaller galaxies. If the globular cluster (GC) systems of large galaxies are also formed, at least in part, from the accretion of GCs from the smaller systems, then the GCs themselves can act as beacons of this process. Indeed, the seminal study of the Galactic GCs by Searle & Zinn (1978) was crucial for understanding the history of our own Milky Way (MW). Being compact and luminous, GCs are excellent probes when field star populations cannot be resolved. In our previous work \cite{Huxor2011, Mackey2010}, we have shown that the GC population of the outer halo of M31 arises largely from the accretion of dwarf galaxies. In many cases, one can identify the remnants of dwarf galaxies in the process of delivering their clusters into M31, where they are becoming part of its retinue of GCs. A similar process is also taking place in the MW, where the Sagittarius dwarf is most likely contributing its GCs to the MW halo \cite{Bellazzini2003, Law2010}. Recent work by Keller, Mackey, & Da Costa \cite{Keller2012} also supports the view that many GCs found in the outer halo of the MW have been accreted alongside their (now disrupted) dwarf galaxy hosts. They conclude that the MW halo has experienced the accretion of some three Magellanic-like or equally up to 30 Sculptor-like dwarf galaxies, or some intermediate mix of both types. Knowledge of the characteristics of the types of GCs found in a range of dwarf galaxies will assist in determining which scenario may have occurred.

To use GCs as probes, it is essential to understand the properties of the GC systems of dwarf galaxies, the relationship of these properties to their host galaxies, and whether we can still identify these after they have been accreted into a more massive galaxy. Dwarf irregulars are particularly interesting in this regard as they are usually found in the field. Their relative isolation makes them ideal laboratories for studying the pristine properties GC systems. This contrasts with dwarf spheroidal and elliptical galaxies which are usually found close to more massive galaxies, and thus they (and their GCs) will likely have been influenced by them. Motivated by our previous work in which wide-area searches yielded the discovery of many new clusters in M31 \cite{Huxor2008, Martin2006, Huxor2003, Cockcroft2011}, and the M31 satellite galaxies NGC 185 and NGC 147 \cite{Veljanoski2012}, we decided to investigate the outer regions of the dwarf irregular NGC 6822 which benefits from extensive archival CFHT/MegaCam imaging, and in which Hwang et al. \cite{Hwang2011} have recently discovered four new extended star clusters.

NGC 6822 is a member of the Local Group, and is not associated with either the MW or M31. We use an adopted distance of 472 kpc determined as the average of published values for which the error of the distance modulus is < 0.2 mags \cite{Gorski2011}. It has an absolute magnitude $M_V$ of $-15.2$ \cite{Mateo1998}.\* Email:avon@ari.uni-heidelberg.de
and an $R_{25}$ of 465 arcsec (RC3.9 value, reported by NEF) equal to $\sim 1$ kpc at our adopted distance. NGC 6822 possesses a number of interesting features including a ring of gas and stars which is almost perpendicular to the main body of the galaxy (de Blok & Walter 2000). The galaxy has also been found to have an extended stellar spheroid (Battinelli, Demers, & Kunkel 2006) (see Figure 1). The central regions of NGC 6822 contain many young massive clusters (Chandar, Bianchi, & Ford 2000); however, until very recently, it was believed that there was only one truly old globular cluster in the system (Grebel 2002), known as Hubble VII – one of his original list of “nebulae” in NGC 6822 (Hubble 1925). Cohen & Blakeslee (1998) undertook a spectroscopic study of this object, reporting an age of 11 Gyr and $[\text{Fe/H}] = -1.95$ dex. Another of Hubble’s candidates, Hubble VIII, has also been subjected to detailed study and appears to be a massive intermediate-age cluster. Using HST/WFPC2 observations, Wyder, Hodge, & Zucker (2000) derived an age of 1.5 Gyr however a spectroscopic study by Strader, Brodie, & Huchra (2003) found it to be somewhat older at 3–4 Gyr. Both Chandar, Bianchi, & Ford (2000) and Cohen & Blakeslee (1998) derive spectroscopic $[\text{Fe/H}]$ estimates for Hubble VIII, finding a value of about $-2.0$ dex.

In addition, NGC 6822 possesses four extended star clusters (SC1–SC4, shown in Figure 1) that have been found beyond the main body of the galaxy (Hwang et al. 2011). These were discovered in a wide-field CFHT/Megacam survey of NGC 6822 that covered a region of $3^\circ \times 3^\circ$. The clusters have half-light radii of 7.5–14 pc, and colour-magnitude diagrams that are consistent with a wide range of ages (2–10 Gyr) and metallicities ($Z = 0.0001 – 0.004$). These clusters are very similar to the extended clusters found in M31 (Huxor et al. 2005) and M33 (Stonkutė et al. 2008) with a couple of the clusters (SC1 and SC4) being very distant from NGC 6822 itself. Hwang et al. (2011) also noted that the extended clusters project on a line that is consistent with the major axis of the old stellar halo.

Drawing partly on the data from the Hubble clusters, Strader, Brodie, & Huchra (2003) suggest a view of NGC 6822 in which there has been a relatively constant star formation rate over time, with occasional stochastic outbursts that result in the formation of star clusters. A similar scenario has also been outlined by Colucci & Bernstein (2011).

2 THE SEARCH FOR NGC 6822 CLUSTERS

An initial study of the archives found that NGC 6822 had considerable and contiguous coverage in CFHT/Megacam imaging (see Figure 2). This is a wide-field camera at the Canada-France-Hawaii Telescope (CFHT) with a $1^\circ \times 1^\circ$ field of view and a pixel scale of 0\".187. We naturally use the same imaging as that of Hwang et al. (2011), but also include additional fields that extended the coverage and fill the gaps between the CCDs in their survey. In total, we searched 15 CFHT/Megacam fields from the programs 2003BK03, 2004AC02, 2004AQ08, and 2005AK08, with observations taken over the period August 2003–August 2006. Science exposures ranged from 660 – 1200 seconds in the g-band, 360 – 1000 seconds in the r-band, and 150 – 460 seconds in the i-band.

The images were visually inspected since star clusters at NGC 6822’s distance are easily resolved in CFHT/Megacam imaging, and indeed this is the optimal way to identify any additional examples of the extended clusters. We are only concerned with the outer regions of NGC 6822, and do not study the main body of the galaxy where many young clusters have already been documented (Krienke & Hodge 2004).

We also examined archival Subaru/Suprime-Cam imaging of NGC 6822. This instrument has a $\sim 0.5^\circ \times 0.5^\circ$ field of view and a pixel scale of 0\".20, and the imaging was mainly concentrated on the inner regions of the galaxy. We utilised only those images for which the exposure was greater than 200 seconds. Those available in the archive were obtained in B,V,R or I-band filters, and were taken for proposals 001422, 000005, 002419, 003147, 099005, 094151, and 05226. Although these pointings did not extend much beyond the main body of NGC 6822, many of the images were deeper than those from CFHT/Megacam and they proved useful to confirm, or otherwise, candidate clusters found in the CFHT/Megacam imaging.

3 THE NEW CLUSTERS

The search for new GCs found a total of three new clusters, in addition to rediscovering all those of Hwang et al. (2011). Two are luminous compact classical clusters, and one is very faint and appears extended in form. We continue the naming convention used by Hwang et al. (2011), and denote them as

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1 http://ned.ipac.caltech.edu/
2 The majority of these are HII regions. Hubble VI is a young cluster and the nature of Hubble IX is still unclear.
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Figure 2. Locations of the CFHT/Megacam fields studied. The centre of NGC 6822 is represented by the small solid square, and the ellipse is the same as that in Figure 1.

Figure 3. The two new compact GCs, SC6 (left) and SC7 (right) from CFHT/Megacam i-band imaging. Each image is 20 by 20 arcsec. North is up and East is to the left. The circle overlaid on SC7 has a radius of 30 pixels (c.f. Figure 5).

Figure 4. The new extended GC, SC5, from r-band CFHT/Megacam (left) and Cousins-I-band Subaru/Suprime-Cam (right) imaging, stretched to highlight the faint cluster. Each image is 30 by 30 arcsec. North is up and East is to the left.

Table 1. Locations of the new clusters, and their projected distances \( (R_{proj}) \) from the centre of NGC 6822 (RA = 19\(^{h}\) 44\(^{m}\) 57.7\(^{s}\), Dec = –14\(^{\circ}\) 48\(^{\prime}\) 12\(^{\prime\prime}\)).

| ID | RA(J2000) | Dec(J2000) | \( R_{proj} \) (kpc) |
|----|-----------|------------|-----------------|
| SC5 | 19\(^{h}\) 43\(^{m}\) 42.30\(^{s}\) | –14\(^{\circ}\) 41\(^{\prime}\) 59.7\(^{\prime\prime}\) | 2.6 |
| SC6 | 19\(^{h}\) 45\(^{m}\) 37.02\(^{s}\) | –14\(^{\circ}\) 41\(^{\prime}\) 10.8\(^{\prime\prime}\) | 1.6 |
| SC7 | 19\(^{h}\) 46\(^{m}\) 00.85\(^{s}\) | –14\(^{\circ}\) 32\(^{\prime}\) 35.4\(^{\prime\prime}\) | 3.0 |

SC5, SC6 and SC7 (in order of right ascension). The coordinates of these objects and their projected distance from the centre of NGC 6822 are listed in Table 1. The two luminous clusters (SC6 and SC7) are clear examples of GCs (see Figure 3). The new faint cluster (SC5) is, in contrast, much more diffuse. Although barely detected in a single exposure from the CFHT archive, SC5 can be seen more clearly in a stacked image available through the CFHT archive (Figure 4 left panel), and also in a deep archival Subaru/Suprime-Cam image (Figure 4 right panel). SC5 resolves into stars while SC6 and SC7 only do so in their peripheries.

3.1 Integrated Photometry

Integrated photometry was undertaken for the two most luminous new clusters, using the archival imaging data available. The results are reported in CFHT/Megacam filter magnitudes (which are similar but not identical to standard Sloan filters) in Table 2.

In our photometry we used large apertures that enclose the full extent of the cluster for the total magnitudes. As there is no evidence that GCs have strong colour gradients, we employed smaller apertures to obtain more reliable colours. Photometric calibration of the CFHT data was undertaken using the magnitudes derived for the one pointing taken in photometric conditions, and cross-calibrating the other data using stars common to both.

Photometry for the brightest cluster, SC7, proved problematic. In the archival CFHT/MegaCam data, the cluster is saturated in the g- and r-bands and photometry can only be undertaken in the i-band. However, shorter exposures of cluster SC7 were also in the CFHT archive, taken for the purposes of photometric calibration. In these exposures, SC7 unfortunately lands on the edge of a CCD making measurements of the full cluster impossible. Hence, we use the central region of the shorter exposures to obtain the colours using an aperture radius of 1.5\(^{\prime\prime}\). We then estimate the total magnitudes by using an aperture of radius 6\(^{\prime\prime}\) on the long i-band image and applying the colour measurements to obtain total g- and r-band magnitudes. For cluster SC6, no such problem arose: the apertures employed for the deriving the color and total magnitude had radii of 2\(^{\prime\prime}\) and 4.7\(^{\prime\prime}\) respectively.

The very faint cluster SC5 was also difficult to photometer. This object is visible in a long CFHT/Megacam r-band stack (11000 seconds) but the g and i-band data, even when stacked, are too shallow to detect the cluster. The r-band stack was photometered with an aperture radius of 10\(^{\prime\prime}\). SC5 was also found in archival Subaru data, confirming its status as a cluster.
Photometry in the CFHT/Megacam filter set was also converted to Johnson-Cousins V and I for SC6 and SC7. This was achieved by using the colour transform equations given on the SDSS web-pages. This was not possible for SC5 as we require photometry in more than the one filter for the transform equations.

Extinction is known to be a major issue with NGC 6822 due to its low Galactic latitude. Battinelli, Demers, & Kunkel (2006) use the stellar population of NGC 6822 to estimate the foreground reddening across the area discussed in this paper, and find it is not only significant, but also patchy. Specifically, E(B-V) ranges from 0.19 to 0.30 (their Figure 2). We correct for this using the extinction maps – interpolated to the position of the new clusters – and relative extinction for the Sloan band-passes from Schlegel, Finkbeiner, & Davis (1998). The g, r and i-magnitudes of the new clusters – and relative extinction for the Sloan filter for the transform equations.

Ellipticity and PA as derived from IRAF/ELLIPSE on left panel of Fig.3). The ellipticity has a value of ~0.25 over a large range of radii. The FWHM of the image is 4.7 pixels (dashed vertical line).

### 3.2 Ellipticity of SC7

Visual inspection reveals that cluster SC7 is significantly elongated. We used IRAF/ELLIPSE to derive the ellipticity and position angle (PA) of the major axis of SC7 using a fixed centre and the results are shown in Figure 5. The PA beyond ~12 pixels is 50° and the ellipticity has a value of ~0.25 over the main body of the cluster. This high ellipticity is unusual for a GC and makes SC7 a clear outlier in a plot of $M_{V0}$ versus ellipticity (Figure 6).

### 4 DISCUSSION AND SUMMARY

The new clusters reported here substantially increase the number of classical GCs found in NGC 6822. If all the new massive clusters (excluding SC5, which is too faint to be

Table 2. Photometric properties of the new clusters. Extinction corrections use values estimated from the extinction map of Schlegel, Finkbeiner, & Davis (1998). The g, r and i-magnitudes are in the CFHT/Megacam filter system. Photometric errors on the colours (derived for a inner aperture for SC6 and SC7 – see text) are estimated at ±0.03 magnitudes. The major source of error for the total magnitudes is the uncertainty of the memberships of cluster stars within the aperture, which are estimated at ±0.03 magnitudes.

| ID  | $g_0$ | $r_0$ | $i_0$ | $V_0$  | $(V-I)_0$ | $M_{V0}$ | E(B-V)  |
|-----|-------|-------|-------|--------|-----------|----------|---------|
| SC5 | –     | 19.43 | –     | –      | –         | –        | 0.199   |
| SC6 | 15.55 | 15.01 | 14.79 | 15.28  | 0.84      | –8.09    | 0.190   |
| SC7 | 15.02 | 14.43 | 14.10 | 14.77  | 1.05      | –8.60    | 0.207   |

Figure 5. Ellipticity and PA as derived from IRAF/ELLIPSE for SC7. The PA is ~50° over radii of ~10–30 pixels (c.f. circle found in comparable studies of local dwarfs) prove to be genuinely “old” GCs, then the four clusters in Hwang et al. (2011) and the two in this work would increase the specific frequency of NGC 6822 to $S_N \sim 7$, comparable to the newly-enlarged GC systems of NGC 147 and NGC 185 (Veljanoski et al., in prep.). This value is also consistent with values found for dwarf irregulars in the Virgo and Fornax galaxy clusters (Seth et al. 2004).

The cluster SC7 is of relatively high luminosity and SC6 is almost as luminous, with $M_{V0} \sim -8$ mags. The GC systems of M31 and the Milky Way have median values of $M_V$ are ~7.9 and -7.3 respectively (Huxor et al. 2011), so both SC6 and SC7 are brighter than the turnover of the globular cluster luminosity function for these galaxies. Previously, in Mackey et al. (2007) and Huxor et al. (2011), we found that M31 possesses a number of luminous GCs in its outer stellar halo, for which no counterparts exist in the Milky Way (exception the very unusual cluster NGC 2419). If, as seems likely, the accretion history of M31 was different from that of the MW, we may have a natural source of M31’s luminous halo GCs in the accretion of systems such as NGC 6822. However such events would have had to happen at an early epoch since there is no evidence for young populations - which dominate in galaxies like NGC 6822 - in the M31 halo today.

The origin of high ellipticities in GCs, such as that of SC7, has been the subject of some debate. Kontizas et al. (1990) find that the ellipticity for young SMC star clusters is greater than for the clusters in the somewhat more massive LMC, and similar results lead Georgiev et al. (2008) to argue that the tidal field of the host galaxy is likely to
One last notable aspect of the newly discovered GCs is that they lie in the linear arrangement noted by Hwang et al. (2011). As we have surveyed the full area in Figure 2 this distribution cannot be a result of incomplete areal coverage. Such a disk alignment would not be unusual – the cluster population of the LMC exhibits disk-kinematics Schommer et al. 1992, Grocholski et al. 2009 – but it would raise new questions about the formation of NGC 6822. If the GC system is found to exhibit disk-like kinematics, it might be hard to reconcile with a scenario where the galaxy formed via the merger of two similar mass gas-rich dwarfs Bekki 2008. We have spectroscopic data for SC6 and SC7, and are currently obtaining data for other clusters in NGC 6822 to study the kinematics of the cluster system and address this question.

To summarise, we have presented the discovery of three new star clusters in the outskirts of NGC 6822 based on searches conducted with archival datasets. Two of these objects are massive compact GCs, very distinct from the extended clusters found by Hwang et al. (2011). The third is a very low-luminosity diffuse cluster. We have measured integrated photometry for these objects, but additional characterisation (e.g. structural parameters, stellar populations) will require deep high resolution data. SC6 and SC7 are so compact that $R_h$ is comparable to the FWHM in the data presented here. One of the clusters, SC7, is highly elliptical which we speculate could be due to the low tidal field it has experienced in the outer regions of a dwarf galaxy.

We note in closing that it is remarkable that SC6 and SC7 were not discovered earlier. These are high luminosity GCs in a Local Group galaxy that has been studied very extensively. This underscores yet again how the outer regions of galaxies have the ability to surprise and provide important clues about their histories.

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