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The Globular cluster system of M31

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Abstract. I present here some results of the extensive revision work of M31 confirmed and candidate globular clusters. The Revised Bologna Catalog, RBC, www.bo.astro.it/M31 is currently the largest and most complete database available online. Two spectroscopic surveys are in progress to confirm RBC cluster candidates as well as newly identified candidates at large distances from the center of M31. I have also studied a subsample of bright and young (age ≤ 2 Gyr) clusters in M31 that doesn't appear to have any counterpart in the Milky Way.

Key words. Galaxies: individual: M 31 – Galaxies: star clusters – Catalogs

1. Introduction

The study of globular clusters (GC) systems is a fundamental astrophysical tool to investigate the formation and the evolution of distant galaxies. GCs are ubiquitous and abundant in virtually any type of galaxy; they are intrinsically bright and can be identified even at large distances; their integrated colors and spectra are relatively easy to interpret, since they typically host a Simple Stellar Population (Renzini & Fusi Pecci 1988); their kinematics are powerful probes for the gravitational potential of their parent galaxy (see Brodie & Strader (2006), and references therein).

The GC system of the Andromeda galaxy (M31) is of particular interest, since it provides (a) the nearest system in a spiral galaxy to compare directly with the GC system of the Milky Way (MW), and (b) a general testbed for the study of distant GC systems, since the physical quantities that are derived from integrated measures can be directly compared with those obtained by the analysis of the Color-Magnitude Diagram of the member stars, that can be resolved with the Hubble Space Telescope (HST) (see, e.g. Fusi Pecci et al. (1996); Brown et al. (2004); Rich et al. (2005)). The GC system of M31 is much more populous than that of the MW, with more than 300 confirmed clusters, to compare with the ≃ 150 of our galaxy. In particular, Barmby & Huchra (2001) estimated the total number of M31 GCs as 475± 25, more than a factor 3 larger than in the MW. It is clear that even this very basic fact must reflect a fundamental difference in the evolutionary paths of these galaxies: this provides a very good example of what we hope to learn by studying the GC system of M31.

2. The Revised Bologna Catalog

The M31 GC system has been subject of extensive study since the dawn of extragalactic

⋆ This research is in collaboration with M. Bellazzini, A. Buzzoni, L. Federici and F. Fusi Pecci astronomy (Hubble 1932) up to the present day (see, for instance, Battistini et al. (1987), Barmby et al. (2000) and reference therein). However most of the known candidates GCs of M31 have been identified by (typically visual) inspection of wide field photographic plates and a systematic search and/or analysis with CCD cameras is still lacking. Comprehensive lists of M31 GCs should be necessarily assembled from different databases: the homogeneity among the various sources may be poor or difficult to assess. On the other hand, a catalogue of M31 clusters as complete and homogeneous as possible is clearly overdue, and it is a fundamental requirement for any meaningful comparison with other systems.

In this framework, I have collected and reanalyzed all the photometric data available in the literature on M31 GCs and candidate GCs, taking CCD photometry as a reference, when possible, and reporting all the optical (*UBVRI*) photometry to a common system. Next, I added to the database the near infrared photometry for 693 confirmed and candidate M31 GCs, extracted from the 2MASS (Skrutskie et al. 2006) database. The 2MASS J, H, K magnitudes of these objects have been transformed to the same homogeneous photometric system of existing near infrared photometry of M 31 globulars.

The final Revised Bologna Catalogue (RBC) (available in electronic form: www.bo.astro.it/M31) contains ∼ 1200 entries, and is the most comprehensive list presently available, including all the already confirmed clusters (by means of spectroscopy and/or high resolution imaging, see Galleti et al. 2006a), all the known but yet-to-confirm candidates as well as all the proposed candidates whose non-M31-GC nature has been ascertained observationally (Galleti et al. 2004). Keeping record of the latter class of objects is very useful not only to avoid duplicating observations, but also to characterize the observable properties of the typical contaminants, in order to assess selection criteria that may maximize the return of observational campaigns. Most spurious cluster candidates are actually found to be (a) background galaxies or (b) foreground Galactic stars (less frequent alternatives are HII regions and asterisms).

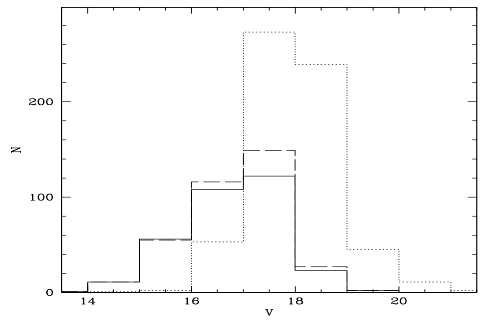

Fig. 1. The V luminosity function for confirmed M 31 clusters, *before* (solid histogram) and *after* (dashed histogram) this survey. The candidates M 31 clusters is also superposed (dotted histogram). Note the huge number of yet-to-confirm candidates at $V > 17.0$

3. A spectroscopic survey of globular clusters in M 31

I have started a long term project to obtain a complete census of the GCs in M31, in particular (1) to classify the already known candidates clusters, considering that ∼ 60% of the RBC is constituted by candidates, and (2) to find unknown GCs at very large distances ($R > 40$ kpc) from the center of the M31 galaxy, a nearly unexplored realm.

3.1. Classification and radial velocity for 76 candidate clusters

In the RBC there are hundreds of known GC candidates whose nature is still to be ascertained. Most of these candidates pertain to the faintest part of the GC luminosity function which, at present, is far from complete (Fig. 1).

I have performed a large spectroscopic survey of known candidates, to assess their nature and study their kinematic and physical properties. A bona-fide M31 GC should have a radial velocity compatible with the systemic velocity of the parent galaxy ($V_r = -300 \pm 450$ km/s), while a typical background galaxy have recession velocities of several thousands km/s, has

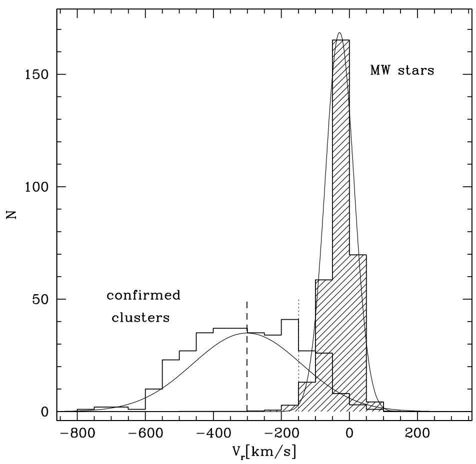

Fig. 2. Velocity distribution of confirmed M31 clusters (empty histogram). The adopted systemic velocity of M31 is marked by a dashed segment; the dotted segment marks the radial velocity threshold beyond which the contamination by foreground stars may become a serious issue. A Gauss curve with mean $\mu = -301.0$ km s^{-1} and standard deviation $\sigma = 160.0$ km s^{-1} is also superposed. The hatched histogram is the distribution of Galactic stars as predicted by the Besançon model (Robin et al. 2003). A Gauss curve with mean $\mu = -29.0$ km s^{-1} and standard deviation $\sigma = 42.6$ km s^{-1} is also superposed.

$V_r > 5000$ km/s. On the other hand, Galactic foreground stars have a radial velocity distribution that significantly overlaps the M31 range $-150 < V_r < +100$ km s^{-1} (Robin et al. (2003), see Fig. 2). In these cases we must recur to image analysis to distinguish between point sources (contaminating stars) and extended sources (GCs). I have implemented a method to distinguish these objects on low-resolution imaging using morphological parameter provided by with Sextractor (Bertin & Arnouts (1996), see for detail Galleti et al. (2006a)).

I have obtained low-resolution spectroscopy of 76 candidates M31 GCs never followed up before and 57 already confirmed. Observations were obtained using AF2-WYFFOS@WHT, DoLoRes@TNG and BFOSC@Loiano. As a result of the analysis I have provided 42 newly confirmed GCs of M31. Moreover, the various set of radial velocities for M 31 GCs available in the literature has been reported to the same scale, multiple measures have been averaged, and a final merged catalog has been produced (Galleti et al. 2006a). In terms of the luminosity function the survey provides a strong contribution in the $17.0 < V < 18.0$ range, where it adds 30 new clusters to the previously known 120 (see Fig. 1).

Moreover, I have measured the Lick indices (Trager et al. 1998) for a subset of the newly and previously confirmed clusters for which I have obtained good quality spectra. I have combined the new and existing indices available in the literature to establish a new homogenous metallicity scale for M31 GCs. This scale is based on the Lick index Mg2 and the [MgFe] composite index, that have been calibrated against Galactic GCs available in literature. The newly established metallicity scale is superior to previous ones in term of both internal and external consistency for M31 GCs (Galleti et al. 2007b).

3.2. Remote candidate clusters

The clusters located at large projected distances from the center of the galaxy are very interesting objects because they constrain the mass profile at large radii, where kinematical information is missing even from the HI surveys. I have also performed a search for candidate GCs located at large (projected) distance from the center of M31.

Until two years ago the outermost M31 cluster known was G1, located at $R_p \simeq 35$ kpc. This situation was quite disappointing, since in the Milky Way there are seven clusters lying at $R_{GC} > 40$ kpc, while M31 - which, as said, has a much richer GC system - seemed to have none.

In this framework, $\sim$ 30 new candidates have been selected from the 2MSS Extended Source Catalogue (XSC) in a $\sim 9^o \times 9^o$ area centered on M31 and located more than 3^o away from the center of the galaxy. The candidates were selected by similarity of their structural parameters (apparent diameters, magnitude, el-

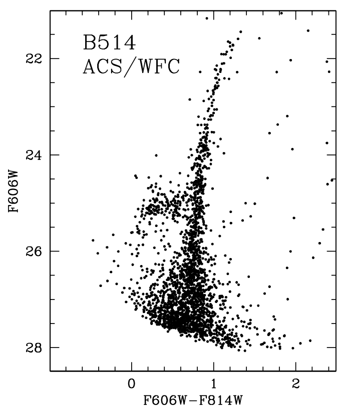

Fig. 3. HST/ACS Color Magnitude Diagram of the remote M31 globular cluster B514.

lipticity, as provided by the XSC) with confirmed M31 GCs and by careful inspection of their DSS-2 images.

In a first pilot project I obtained low-resolution spectra (and estimated the radial velocity) of the two brightest objects with the Cassini telescope at the Loiano Observatory. One of them revealed to be a background galaxy, the other is a genuine M31 globular (B514), located at $R_p \simeq 55$ kpc from the center of M31 (Galleti et al. 2005). The observed spectra indicated old age and low metallicity for B514. Subsequent follow up with HST ACS/WFC allowed us to obtain a deep Color Magnitude Diagram, confirming B514 as a genuine old and metal-poor, bright GC ($M_V \simeq -9.1$), with a blue Horizontal Branch (Fig. 3, Galleti et al. (2006b)). Subsequently, I have observed and identified four other remote clusters at $R_p > 40$ kpc (Galleti et al. 2007a).

4. Young globular clusters in the disk of M31

The presence in M31 of stellar systems similar to MW globulars in luminosity and shape but with integrated colors significantly bluer than the bluest MW counterparts is well know and documented. I have studied the properties of a sample of 67 blue clusters in M31, extracted from the RBC, and selected according to their color ($(B-V)_o \leq 0.45$) and/or the strength of their $H\beta$ spectral index ($H\beta \geq 3.5$Å).

The selected sample of Blue Luminous Compact Clusters (BLCCs) is the largest so far identified, and represents a significant fraction ($\gtrsim 15\%$) of the entire GC population of M31.

BLCCs are located mainly in the outskirts of the M31 disk, are strongly correlated with disk substructure and share the kinematical properties of the thin, rapidly rotating disk component.

Comparison with integrated properties of cluster of known age as well as with theoretical population synthesis models indicates that these objects are young (age ≤2Gyr, Fusi Pecci et al. (2005)). Follow-up studies of this interesting class of clusters are ongoing, from the ground and from the space.

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