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Photometric binaries in 50 globular clusters

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Abstract. The HST/ACS Survey of Galactic globular clusters (GGCs) is a HST Treasury project aimed at obtaining high precision photometry in a large sample of globular clusters. The homogeneous photometric catalogs that has been obtained from these data by Anderson et al. (2008) represents a golden mine for a lot of astrophysical studies.
In this paper we used the catalog to analyze the properties of MS-MS binary systems from a sample of fifty GGCs. We measured the fraction of binaries (divided in different groups), studied their radial distribution and constrained the mass ratio distribution. We investigated possible relations between the fraction of binaries and the main parameters of their host GGCs.
We found a significant anti-correlation between the binary fraction in a cluster and its absolute luminosity (mass).

Key words. stellar dynamics – methods: observational – techniques: photometric – binaries: general – stars: Population II – globular clusters: general

1. Introduction

Knowledge of the binary frequency in Globular Clusters (GCs) is of fundamental importance for a lot of astrophysical studies.

Binaries play an important role in the dynamical evolution of a clusters. Interactions with hard binaries pump kinetic energy into the cluster core, slowing the core collapse and, eventually, causing the core to re-expand, if the number of binaries is large enough. In general, binaries are a fundamental ingredient in any dynamical evolution model of a GC.

Exotic stellar objects, like Blue Stragglers, cataclysmic variables, millisecond pulsars and low mass X ray binaries are believed to represent evolutionary stages of close binary system. The determination of the fraction of binaries plays a fundamental step towards the understanding of the evolution of these peculiar objects. Furthermore, binary stars introduce systematic errors in the determination of the main sequence (MS) fiducial line and move it toward red colors with respect to its correct position.

Finally, a correct determination of the mass and luminosity functions requires a correct measure of the fraction of binaries.

Up to now, three main techniques have been used to measure the fraction of binaries in GGCs (Hut et al. 1992).

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The first one identifies binaries by measuring their radial velocity variation (eg. Latham 1996). This method relies with the detection of each individual binary system but, due to the limits in sensibility of spectroscopy, these studies are possible only for the brightest GGCs stars.

The second technique is based on the search for photometric variables (eg. Mateo 1996). As well as the previous one, it is able to infer specific properties of each binary system (like the measure of orbital period, mass ratio, orbital inclination). Unfortunately, it is biased towards binaries with short periods and large orbital inclination. Moreover these techniques have a low discovery efficiency and are very expensive in terms of telescope time because it is necessary to repeat measures in time.

A thirty approach, that is based on the analysis of the number of stars located on the red side of the main sequence (MS) ridge line (MSRL) may represent a more efficient method to measure the fraction of binaries in a cluster for several reasons:

- availability of a large number (thousands) of stars makes it a statistically robust method;
- it is cheep in terms of observational time: two filters are enough for detecting binaries and repeated measurements are not needed.
- it is sensitive to binaries with any orbital period and inclination

This approach have been used by other groups (see Sollima et al. 2007 and references therein) to study the population of binaries in GGCs. The relative small number of clusters that have been analyzed, is consequence of the intrinsic difficulties of the method:

- high photometric quality is required;
- in some cases, the differential reddening spreads the MS and makes it more difficult to isolate the binary sequence;
- an accurate analysis of photometric errors as well as a correct estimate of field contamination are necessary to disentangle real binaries from bad photometry and field stars.

In this paper, we analyze the catalogs obtained by Anderson et al. (2008) from HST ACS/WFC data. We exploited both the homogeneity of this dataset, and the high photometric accuracy of the measures to derive the fraction of binaries in the central regions of fifty GGCs.

2. Outliers in the Color-Magnitude Diagram

Binaries that are able to survive in the dense environment of a globular cluster are so close that even the Hubble Space Telescope (HST) is not able to separate their single components. For this reason, light coming from each star will combine, and the binary system will appear as a single point-like source.

In this paper we will take advantage from this instrumental limit to search for binaries by analyzing their peculiar position in the Color-Magnitude diagram (CMD).

In the most general case, if we consider two stars in a binary system and indicate with m_1, m_2, F_1 and F_2 their respective magnitudes and fluxes, a simple algebraic count demonstrate that the binary will appear as a single object with a magnitude:

$$m_{bin} = m_1 - 2.5\ log(1 + \frac{F_1}{F_2})$$

In the case of a binary formed by two MS stars (MS-MS), fluxes are related to stellar masses (M_1, M_2), and its luminosity depends on the mass ratio $q = M_2/M_1$ (in the following we will assume $M_2 < M_1$, $q < 1$). The binaries formed by an equal mass pair form a sequence parallel to MS, and $\sim$ 0.75 magnitudes brighter. When the masses of the two components are different, the binary will appear redder and brighter than the MS and it will be located in a CMD region on the red side of the MSRL.

An obvious consequence of this analysis is that our capability in detecting binaries depends meanly by the photometric quality of the data. Binaries with large mass ratios have a large distance from MSRL and are relatively easy to be detected. On the contrary, a small mass ratio pushes binaries near the MSRL and makes it hard to separate them from single MS stars. Moreover, the poorer photometry of faint stars limits the luminosity (mass) range where they can be detected and studied.

3. Method

The limited photometric precision makes it impossible to measure the overall population of binaries even in a small region of clusters. For this reason, in this paper, we do not pretend to measure the global fraction of binaries in a cluster, but will limit our study to particular subsamples of them. Each group is formed by objects that share all the same properties in terms of luminosity and mass ratio.

We isolated three samples of high mass ratio binaries (defined as the binary systems with, $q > 0.5$, 0.6 and 0.7) and separately studied the properties of each group. In addition we derived also the global fraction of binaries.

We performed our study in the magnitude range $3.75 < \Delta(I_{F814W}) < 0.75$ below the main sequence turn off. The extremes of this interval will be indicated with I_{bright} and I_{faint}.

3.1. High-q binary fraction

In order to measure the fraction of high q binaries, we divided the CMD in two regions (see Fig.1):

A region (A) that includes all the MS single stars and the binaries with a primary star with $I_{bright} > I > I_{faint}$. It is formed by three subregions. The first one (A_1) includes all the MS single stars and MS-MS binaries with small mass ratios; it is limited by dashed lines in Fig.1 and corresponds to the CMD portion with a color distance from the MS ridge line smaller than three times the MS dispersion; the second (A_2) includes all the binary candidates with high mass ratios. In Fig.1 it corresponds to the CMD portion on the red side of the A_1 region and is delimited by:

- the track formed by a binary system with a primary star with $I = I_{bright}$ and a mass ratio ranging from 0 to 1 on the top;

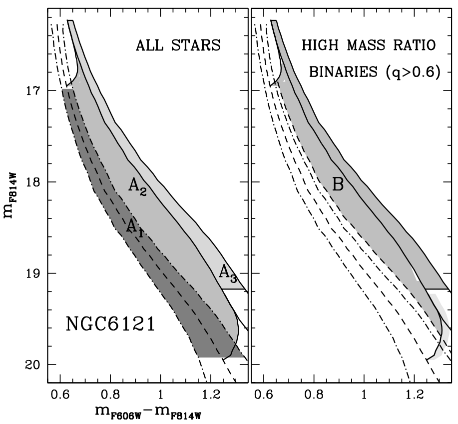

Fig. 1. Grey areas are the regions of the NGC 6121 CMD adopted to select all the (single and binary) cluster stars (right) and the candidate binaries with q>0.6 (left) in a range of 3 I_{F814W} magnitudes.

- the corresponding track for a binary system with a primary star of mass I_{faint} on the bottom;
- the ridge line for an equal mass binary system on the red side.

The third region (A_3) contains all the binaries with $q \sim 1$ that are shifted by photometric errors to the right of an equal mass binaries fiducial line. It is adjacent to the region A_2 and it is limited by the ridge line for an equal mass binary system shifted in color by three times the main sequence photometric dispersion on the left side.

The second region B is defined as the portion of the region (A) on the red side of the track formed by a binary star with $q = q_{tr}$ and it includes all the binaries formed by a primary star with $I_{bright} > I > I_{faint}$ and a mass ratios greater than a threshold value (q_{tr}). In this work we separately studied the samples of binaries with mass ratios larger than q_{tr}=0.5, 0.6 and 0.7. Unfortunately, regions A and B are populated by field stars, while chance superposition of two unrelated stars (apparent binaries) may reproduce the behaviour of a genuine binary system.

To estimate the quantity of background/foreground objects that casually overlap the cluster CMD we used the galactic models of Girardi et al. (2008) (with the exception of seven clusters, where we could isolate field stars through proper motions). The fraction of apparent binaries has been quantified by performing artificial star tests.

We further applied a the technique described in Milone et al. 2008 to correct the spread in color caused by differential reddening and/or spatially dependent zero point photometric errors.

In order to measure the fraction of high mass ratio q binaries, we started by deriving the observed numbers of stars in regions A (N^A_{OBS}) and B (N^B_{OBS}). Then we evaluated the corresponding values of artificial stars (N^A_{ART} and N^B_{ART}) and field stars (N^A_{FIELD} and N^B_{FIELD}) The correct numbers of real, field and artificial stars are calculated as $N = \sum 1/c_i$, where c_i is the completeness.

High mass binary fraction is calculated as

$$f_{bin} = \frac{N^B_{OBS} - N^B_{FIELD}}{N^A_{OBS} - N^A_{FIELD}} - \frac{N^B_{ART}}{N^A_{ART}}$$

3.2. The global binary fraction

In the case of MS-MS binaries with small mass ratios, the distance from the MSRL is comparable to the size of photometric errors in color. Therefore these objects appear mixed to single stars, and a more sophisticate statistical analysis is required to derive their contribution to the global fraction of binaries.

In order to estimate the global fraction of binary systems we adopted a statistical method which is based on the comparison of the observed data with more then 10,000 simulated CMDs enriched by different fractions of binaries with a given $f(q)$. Details of this technique are outside the purpose of this work and will be explained in a forthcoming paper (Milone et al. 2008). We want emphasize here that the adopted statistical approach is very sensitive to small inaccuracies and the results that we present are to be considered just as approximate estimates of the real fraction of binaries

4. Results

We investigated if the fraction of binaries depends on the radial distance from the cluster center. To this aim we divided the ACS field into four concentric annuli, each containing roughly the same number of stars, and measured the fraction of binaries in each of them.

In (at least) the ~ 60 % of the 37 GGCs with good photometry in the innermost regions, binaries are more centrally concentrated than single MS stars. In the other objects, their distribution is consistent with a flat distribution, probably, as a consequence of the small radial coverage of our field of view.

In the following, we present preliminary results that involve binaries selected from different cluster regions:

– inside the core radius (I_{CORE} sample);
– between the core and the half-mass radius (HM sample);
– outside the half-mass radius (O_{HM} sample).

Even if data used in this paper are homogeneous as they came from the same observing facility (ACS/HST) and have been reduced adopting the same techniques, their photometric quality (and completeness) may vary from one cluster to the other, mainly, as a consequence of the different stellar densities.

For this reason, it was possible to include in the I_{CORE} sample only 35 out 50 GGCs. In addition, the limited ACS field of view reduced the number of GGCs with HM and O_{HM} samples to 46 and 29 respectively.

We explored possible relations between the fraction of binaries and the main parameters of their host GGCs absolute visual magnitude, metallicity, collisional parameter, core and half mass relaxation time, central density and concentration (from Harris et al. 1996, 2003).

We found an highly significant anticorrelation between the binary fraction and the total cluster luminosity with clusters with fainter absolute luminosity have higher binary fractions. This anti-correlation is shown in Fig.2 for the I_{CORE} sample and in Figs.3 and for the HM (bottom panel) and O_{HM} (upper panel) samples. A similar anticorrelation has been found

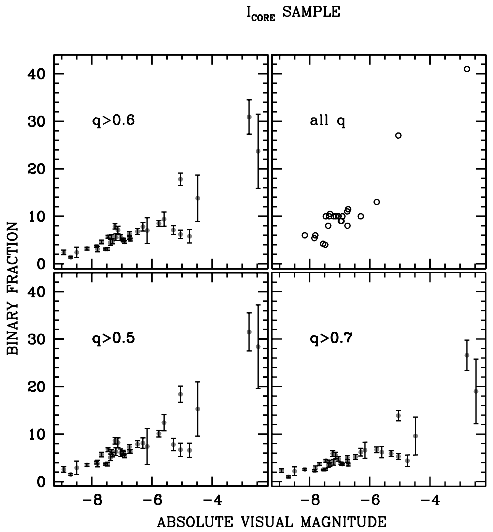

Fig. 2. Fraction of binaries with $q > 0.5$, 0.6 and 0.7 and global fraction of binaries in the core as a function of the host GGCs luminosity.

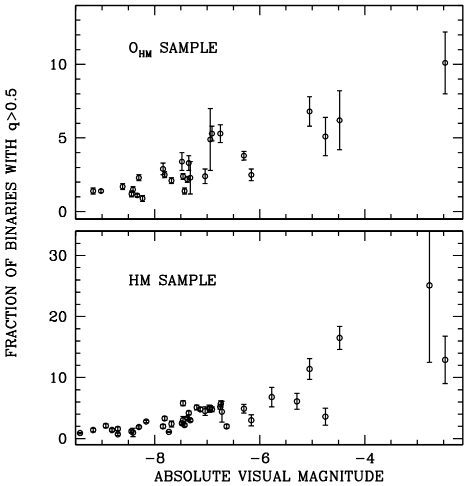

Fig. 3. Fraction of binaries with $q > 0.5$ for the O_{HM} (top) and HM samples (bottom)

by Piotto et al (2004) and Moretti et al. (2008) between the frequency of blue stragglers and the luminosity of the cluster. It is very tempting to connect BSS and binaries populations in GGCs: the BSS frequency can be in fact

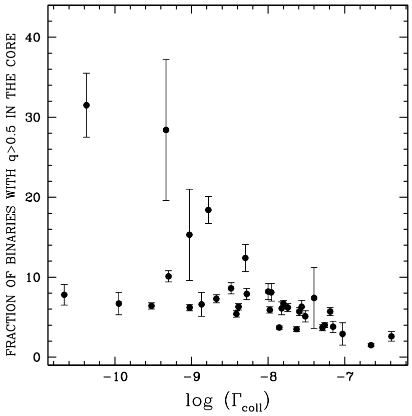

Fig. 4. Fraction of binaries with $q > 0.5$ in the core as a function of the collisional parameter (Davies et al. 2004)

related to the evolution of the binary fraction due to encounters as described by Davies et al. (2004). We found only a marginal correlation between the binary fraction and the cluster collisional parameter

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