Photometric binaries in fifty 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 analyse 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 foundamental importance for a lot of astrophisical 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 reexpand, if the number of binaries is large enough. In general, binaries are a foundamental ingredient in any dynamical evolution model of a GC.

Exotic stellar objects, like Blue Stragglers, cataclismic 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 foundamental 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).
The first one identifies binaries by measuring their radial velocity variation (e.g., 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 (e.g., 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 third 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 cheap 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 has been used by other groups (see Sollima et al. 2007 and references within) 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 pointlike source.

In this paper we will take advantage from this instrumental limit to search for binaries by analyzing their peculiar position in the 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:

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

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 ~ 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 mainly 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 \( I_{\text{bright}} \) and \( I_{\text{faint}} \).

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 \( I_{\text{bright}} > I > I_{\text{faint}} \). It is formed by three subregions. The first one (A1) 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 (A2) includes all the binary candidates with high mass ratios. In Fig.1 it corresponds to the CMD portion on the red side of the A1 region and is delimited by:

- the track formed by a binary system with a primary star with \( I = I_{\text{bright}} \) and a mass ratio ranging from 0 to 1 on the top;
- the corresponding track for a binary system with a primary star of mass \( I_{\text{faint}} \) on the bottom;
- the ridge line for an equal mass binary system on the red side.

The third region (A3) 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 A2 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 \( I_{\text{bright}} > I > I_{\text{faint}} \) 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 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 $A$ ($N_{\text{OBS}}^A$) and
$B$ ($N_{\text{OBS}}^B$). Then we evaluated the cor-
responding values of artificial stars ($N_{\text{ART}}^A$ and
$N_{\text{ART}}^B$) and field stars ($N_{\text{FIELD}}^A$ and $N_{\text{FIELD}}^B$). The
correct numbers of real, field and artificial stars
are calculated as $N = \sum c_i$, where $c_i$ is the
completeness.

High mass binary fraction is calculated as

$$f_{\text{bin}} = \frac{N_{\text{ART}}^B - N_{\text{FIELD}}^B}{N_{\text{ART}}^B - N_{\text{FIELD}}^A}.$$

4. Results

We investigated if the fraction of binaries de-
pends 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 mea-
sured the fraction of binaries in each of them.

In (at least) the $\sim 60\%$ 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 dif-
ferent cluster regions:

- inside the core radius ($I_{\text{CORE}}$ 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 homoge-
neous as they came from the same observ-
ing 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 $I_{\text{CORE}}$ sample only 35 out 50 GGCs. In
addition, the limited ACS field of view reduced
the number of GGCs with $HM$ and $O_{HM}$ sam-
ple 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 con-
centration (from Harris et al. 1996, 2003).

We found an highly significant anticorre-
lation between the binary fraction and the total
cluster luminosity with clusters with fainter ab-
solute luminosity have higher binary fractions.

This anti-correlation is shown in Fig 2 for the
$I_{\text{CORE}}$ sample and in Figs 3 and 4 for the $HM$
(bottom panel) and $O_{HM}$ (upper panel) sam-
ple.

A similar anticorrelation has been found by
Piotto et al (2004) and Moretti et al. (2008)
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)

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 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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