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Environmental effects on the globular cluster blue straggler population: a statistical approach

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Abstract.
Blue stragglers stars (BSS) constitute nowadays an ubiquitous population of objects whose origin involves both dynamical and stellar evolution. In this work we analyze the properties of a catalogue of BSS extracted from an homogeneous sample of 56 Galactic globular clusters observed with WFPC2/HST and described in Piotto et al. (2002). The goal of this study is to reveal possible environmental dependencies of the number of BSS with other Globular Cluster parameters. Therefore we explore possible monovariate relations between the frequency of BSS (divided in different subsamples according to their location with respect to the parent cluster core radius and half mass radius) and the main parameters of their host GC. We also make use of the Principal Component Analysis to extract the main parent cluster parameters which characterize the BSS family. We find that any subpopulation of BSS strongly depends on the luminosity of the cluster, on the extension of the cluster horizontal branch and on the central velocity dispersion: more luminous clusters, clusters with a smaller central density, and a smaller central velocity dispersion have a higher BSS frequency. Moreover, we find that clusters having higher masses, higher central densities, and smaller core relaxation timescales possess on average more luminous BSS. Finally we point out a possible different behavior of BSS in clusters having different luminosities: while more massive clusters seem to host BSS mainly dependent on the collisional parameter, smaller ones are mostly influenced by the cluster luminosity and the dynamical time–scales.

Key words. stars:blue stragglers-luminosity function–Hertzsprung-Russell (HR) and C-M diagrams– globular clusters:general

1. Introduction

Blue straggler stars (BSS) are located blueward and at brighter magnitudes than the turnoff (TO) in the color-magnitude diagram (CMD). The simple presence of such stars in a CMD poses serious challenges to the stellar evolution theory, since cluster stars with masses higher than the TO mass should have already been evolved off the main sequence (MS) toward the red giant branch (RGB). After their discovery by Sandage (1953), BSS have been detected in all stellar associations, from open (Ahumada & Lapasset 1995, 2007; de Marchi et al. 2006) to globular clusters

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(GC, see Piotto et al. 2004, for a recent compilation of an homogeneous sample of BSS in GC), to dwarf galaxies (Momany et al. 2007). In order to explain their existence both dynamical processes happening during the cluster lifetime and the stellar evolution have to be taken into account. Two different mechanisms have been proposed so far to account for BSS existence: one describes BSS as the by–product of primordial binaries that simply evolve transferring their masses up to a complete coalescence (McCrea 1964; Carney et al. 2001), and we will call these BSS *primordial*. The other one predicts that BSS are formed from the merger (collision) of two main sequence stars during the dynamical evolution of the cluster (Bailyn 1995), therefore we will call these BSS *collisional*.

It has already been found by Piotto et al. (2004) that the relative number of BSS in the central regions of the cluster shows an anticorrelation with the absolute luminosity (and hence mass) of the host cluster. A similar trend between the BSS frequency and the total cluster luminosity has been confirmed also in open clusters (de Marchi et al. 2006). Finally a distinction in the BSS luminosity function was found when dividing clusters according to their integrated luminosity: more luminous GC have brighter BSS .

In this work, based on a sample of 56 GCs, we will look for any possible correlation between the number of BSS inside and outside the core and the half–mass radius and the GC main parameters.

2. The database

The catalogue of BSS adopted for this study is basically the catalogue used by Piotto et al. (2004), which has been extracted from the HST snapshot catalogue described in Piotto et al. (2002). With respect to the BSS sample used by Piotto et al. (2004), we applied an additional selection on the faintest BSS with the purpose to avoid including normal TO and lower sub giant branch stars with large photometric errors. We could reliably select BSS in a sample of 56 GCs. We refer the interest reader to the original paper (Moretti et al. 2007) for a careful description of the selection mechanism. The paper also lists the origin of each cluster parameter that we have been using for the analysis.

Once selected our BSS catalogue, we divided it in subsamples of BSS inside and outside the core radius (I_cBSs and O_cBSs, respectively), and inside and outside the half–mass radius ($I_{hm}BSs$ and $O_{hm}BSs$, respectively). Only the $I_{hm}BSs$ and $O_{hm}BSs$ were defined for the whole sample of 56 GCs, while the I_cBSs and O_cBSs subsamples were defined only for 43 GCs, i.e. all clusters but the PCC ones. We calculated the total and the relative number of BSS . The BSS counts were corrected for completeness. The relative numbers of BSS is defined as the absolute number of BSS , divided by the total luminosity of the host cluster (in units of $10^4 L_\odot$) sampled by our WFPC2/HST images.

We will show the main results we obtain for the existing correlations between the absolute and relative numbers of BSS with the main cluster parameters in the case of core-BSS. The other samples correlations can be found in Moretti et al. (2007).

3. Core population of BSS

In the analysis of the core population of BSS we do not take into account the PCC clusters, since for these objects the definition of core radius is not reliable (Trager et al. 1993, 1995). Therefore, we show monovariate relations for a subsample of 43 clusters, i.e. the whole sample of non-PCC clusters.

The dependence on the total cluster luminosity is shown in Fig. 1, upper panel. In order to quantify the significance of our linear fits we performed a robust fit and calculated the dispersion using a bootstrap technique. In the insets of the figures illustrating the monovariate correlations, we give the best fitting straight line slope α together with its 1-σ error. Dashed and continuous lines fit the I_cBSs and O_cBSs, respectively. The Figure shows that the normalized number of I_cBSs is on average higher than the normalized number of O_cBSs, as expected from mass segregation, being BSS more massive than normal clus-

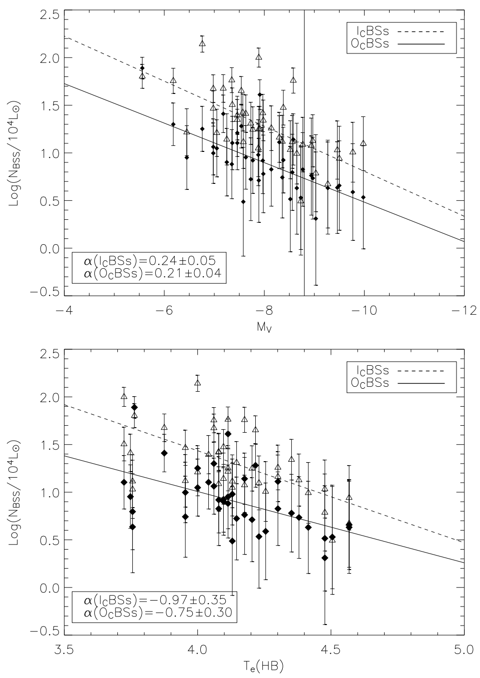

Fig. 1. *Upper panel:* total number of BSS as a function of the host cluster integrated absolute magnitude. Diamonds refer to the number of O_cBSs, triangles to the number of I_cBSs. The number of BSS normalized to the sampled luminosity in unit of 10^4 solar luminosities in the F555W HST band. *Lower panel*: normalized number of BSS as a function of the host cluster maximum HB temperature.

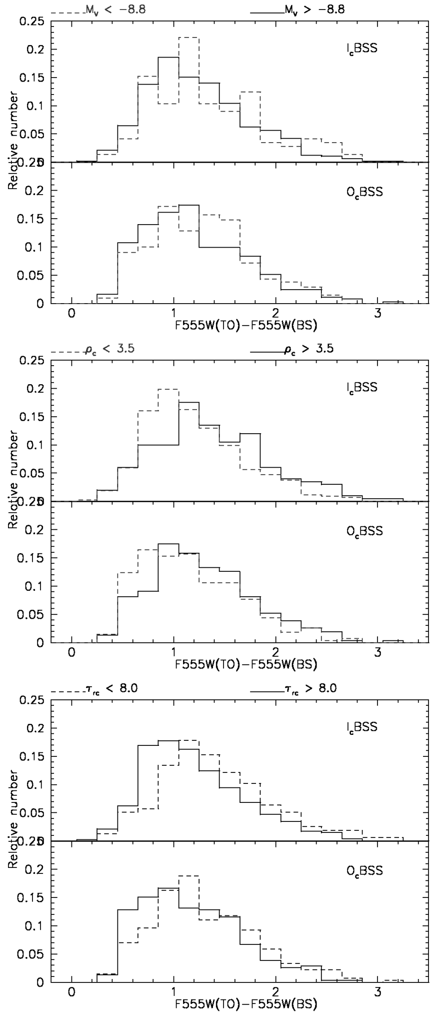

Fig. 2. Luminosity functions of I_cBSs (upper panel) and O_cBSs (lower panel) for different subsamples of globular clusters: from top to bottom clusters are divided according to M_V, ρ_c, τ_{rc}.

ter members, and further demonstrates that the normalized number of BSS per unit luminosity nicely anti–correlates with the cluster luminosity. This anti–correlation is similar for both the I_cBSs and the O_cBSs. This implies that the frequency of BSS, independently from where it is measured, holds the same dependence on the cluster total light (mass).

Lower panel of Fig.1 shows that there is a correlation between the maximum temperature of the HB and the relative number of BSS with hotter HB clusters (i.e. clusters with more extended HBs) hosting less BSS per unit luminosity, both inside and outside the core.

We also considered the possible effects of M_V, ρ_c, τ_{rc} on the BSS luminosity function. As in Piotto et al. (2004), for each BSS we calculated the luminosity relative to the parent cluster TO luminosity, extracted from De Angeli et al. (2005). We then divided the catalogue of GCs into two samples according

Table 1. Correlation matrices for different subsamples. $N_{\rm BSS}$ is the normalized number of BSS .

	$r < r_c$	$r > r_c$	$r < r_{hm}$	$r > r_{hm}$
	$N_{\rm BSS}$	$N_{\rm BSS}$	$N_{\rm BSS}$	$N_{\rm BSS}$
$N_{\rm BSS}$	1.000	1.000	1.000	1.000
M_V	0.741	0.705	0.752	0.519
Γ_{coll}	-0.321	-0.331	-0.401	-0.126
τ_{rc}	-0.364	-0.296	-0.086	-0.112
τ_{rhm}	-0.568	-0.630	-0.505	-0.524
ρ_c	-0.355	-0.361	-0.403	-0.172
$[Fe/H]$	0.351	0.546	0.310	0.403
Age	-0.011	0.076	0.061	0.059
$T_{eff}(HB)$	-0.569	-0.536	-0.614	-0.384
σ_v	-0.475	-0.442	-0.519	-0.269

to 1) their luminosity ($M_V > -8.8$ and $M_V \leq -8.8$); 2) their central density ($\rho_c > 3.5$ and $\rho_c \leq 3.5$); 3) their core relaxation time–scale ($\tau_{rc} > 8.0$ and $\tau_{rc} \leq 8.0$). In our first analysis, we excluded the PCC clusters. The LFs of each cluster have been added together to construct the total LF for each subsample. The final luminosity functions have been normalized to the total number of BSS in each subsample.

Figure 2 shows the three sets of normalized luminosity functions we obtain subdividing our subsample of non-PCC clusters (43 objects) according to (from top to bottom in the figure) their M_V, ρ_c, τ_{rc}. In each panel, the lower sub–panels refer to the O_cBSs, the upper sub–panels to the I_cBSs. The continuous line corresponds to BSS in clusters with $M_V > -8.8$, $\rho > 3.5$ and $\tau_{rc} > 8.0$, while the dashed line corresponds to BSS in clusters with $M_V \leq -8.8$, $\rho \leq 3.5$ and $\tau_{rc} \leq 8.0$. Figure 2 shows that the BSS peak tends to be brighter in more luminous (massive) clusters, in clusters with higher central densities and in clusters with smaller τ_{rc}. This holds for both subsamples of inner and outer core BSS .

4. PCA analysis

Since GCs constitute a complex family of objects, which depend on many parameters, often mutually related (Djorgovski & Meylan 1994, and references therein), we decided to use the PCA analysis to test which ones influence more the BSS populations. Before performing the statistical analysis, data were normalized to have null mean and unit variance.

Tab.1 shows that the main contributors to the total variance are the cluster luminosity, the maximum temperature along the HB, the velocity dispersion and the half mass relaxation time–scale, though the weight of these dependencies is slightly different for the different subsamples. I_cBSs which dependencies are listed in column 1 seem to be more influenced by the core and half mass relaxation timescales (with respect to the whole BSS population) and less by the maximum temperature along the HB and the velocity dispersion.

5. Conclusions

In this work, we analyzed the properties of the BSS population in the photometrically homogeneous sample of CMDs provided by Piotto et al. (2002).

We then investigated the possible correlations of the absolute and relative numbers of BSS with the main cluster parameters, and obtained the following results:

- The population of BSS inside the core radius show a statistically significant anti-correlation with the cluster total luminosity, i.e. more luminous clusters have a smaller fraction of BSS . There is also a marginal anti-correlation between the fraction of BSS and the half mass relaxation time. The metallicity does not play any role, while there is a noticeable correlation between the fraction of BSS and the extension of the cluster HB: hotter HB clusters possess less BSS per unit luminosity. Finally clusters with higher central velocity dispersions host less BSS per unit luminosity.
- From the analysis of the luminosity functions of different subsamples we find that BSS have a more luminous LF peak in more massive clusters, in clusters with higher central densities and in clusters with smaller core relaxation timescales.

The multivariate analysis confirms the main correlations identified in the monovariate analysis. In particular, it shows that most of the variance of the sample is accounted by the dependence of the BSS frequency on the total luminosity, the maximum temperature along the HB, the velocity dispersion, and on the half mass relaxation time–scale. There is also a dependence on the central density and, noticeably, a marginal dependence on the collisional parameter.

According to the prediction of Davies et al. (2004), less luminous clusters are expected to produce more BSS via mass transfer, while in more luminous ones collisions should play a more important role.

Our results on the BSS luminosity function indicate that clusters having different luminosities host different populations of BSS .

Other interesting results concerning BSS populations in bright and faint clusters have been finally derived using the PCA analysis.

The results seem to suggest that in bright clusters the number of $I_c BSs$ strongly depends on the collisional parameter and on the central density, as expected if these BSS were produced mainly by collisions. This is in agreement with the results by Mapelli et al. (2006).

On the other hand, in faint clusters, $I_c BSs$ are dominated by the effects of clusters luminosity and dynamical time–scales, in agreement with the Davies et al. (2004) model.

An interpretation of the complex observational scenario disclosed by our analysis of the dependence of BSS on the parent cluster parameters is beyond the purposes of the present paper. However, we hope that the various relations above discussed can help interpreting the origin of BSS in globular clusters.

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