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Another non-segregated Blue Straggler population in a globular cluster: the case of NGC 2419

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Abstract. We have used a combination of *ACS-HST* high-resolution and wide-field *SUBARU* data in order to study the Blue Straggler Star (BSS) population over the entire extension of the remote Galactic globular cluster NGC 2419. The radial distribution of the selected BSS is the same as that of the other cluster stars. In this sense the BSS radial distribution is like that of ω Centauri and unlike that of all Galactic globular clusters studied to date, which have highly centrally segregated distributions and in most cases a pronounced upturn in the external regions. As in the case of ω Centauri, this evidence indicates that NGC 2419 is not yet relaxed even in the central regions. This observational fact is in agreement with estimated half-mass relaxation time, which is of the order of the cluster age.

Key words. Globular clusters: individual (NGC 2419); stars: evolution – general – blue stragglers

1. Introduction

In the Color-Magnitude Diagram (CMD), BSS define a sparsely populated sequence more luminous and bluer than the Turn-Off point (TO) of a normal hydrogen-burning main-sequence (MS). Hence they appear as stars more massive (see also Shara et al. 1997) and younger than the bulk of the cluster population. They are thought to form from the evolution of binary systems, either via mass-transfer/coalescence phenomena in primordial binaries [MT-BSS], or by stellar mergers induced by collisions [COL-BSS]. Since collisional stellar systems like Globular Clusters (GCs) dynamically evolve over a time-scale significantly shorter than their age, BSS are expected to have sunk into the cluster core, as have the majority of the most massive objects (like binaries and other binary by-products) harbored in the system. In many GCs the projected radial distribution of BSS has been found to be bimodal: highly peaked in the center, with a clear-cut dip at intermediate radii, and with an upturn in their external regions. Such a behavior has been confirmed in at least 7 GCs: (all references in Dalessandro et al. 2008) and M53

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(Beccari et al. 2008). Dynamical simulations (Mapelli et al. 2006) suggest that the observed central peak is mainly due to COL-BSS formed in the core and/or MT-BSS sunk into the center because of dynamical friction, while the external rising branch is made of MT-BSS evolving in isolation in the cluster outskirts. In these bimodal clusters the BSS always appear to be significantly more segregated in the central regions than the reference cluster stars. The only exception to these general observational features is ω Centauri (ω Cen). The large population of BSS discovered by Ferraro et al. (2006) in this giant stellar system has the same radial distribution of the normal cluster stars. This is clear evidence that ω Cen is not fully relaxed, even in the central regions, and therefore, the dynamical evolution of the cluster has not significantly altered the radial distribution of these stars.

Here we direct our attention to another massive cluster which shares a number of properties with ω Cen: NGC 2419. This remote object ($d \sim 81$ kpc, Harris et al. 1997) is one of the most luminous clusters in the Galaxy ($M_V = -9.4$ mag, see Bellazzini 2007, hereafter B07) similar to ω Cen and M54 (NGC 6715) that are probably remnants of stripped cores of dwarf spheroidals (see e.g. Layden & Sarajedini 2000; Bekki & Freeman 2003).

With its high luminosity and half-light radius ($r_h \simeq 25$ pc, B07), NGC 2419 lies (together with ω Cen and M54) in the (r_h, M_V) plane well above the locus defined by all the other Galactic GCs. Indeed, it is the most significant outlier, thus suggesting that it also might be the stripped core of a former dwarf galaxy (van den Bergh & Mackey 2004). Further, Newberg et al. (2003) suggested that NGC 2419 could be somehow connected with the Sagittarius (Sgr) dwarf spheroidal, since it seems to be located in a region with an overdensity of type-A stars which is in the same plane as the tidal tails of Sgr.

However, the high-quality CMDs of NGC 2419 recently published by Ripepi et al. (2007, see also B07) do not show any evidence of multiple stellar populations, in contrast to ω Cen (see for example Lee et al. 1999; Pancino et al. 2000) and possibly M54 (Layden & Sarajedini 2000; Monaco et al. 2005).

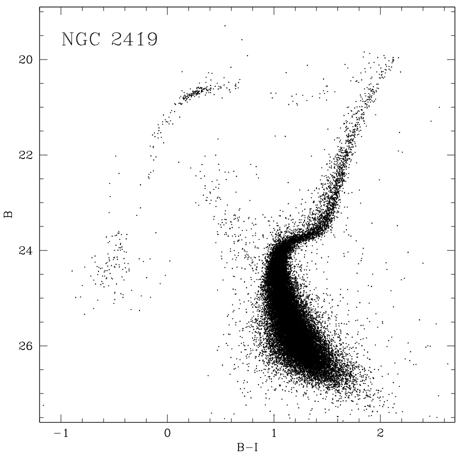

Fig. 1. (B, $B-I$) CMD of the *HST sample* for $r > 40''$ from the center, reaching down $B \sim 27$.

2. Observation and data analysis

We have used a combination of 2 complementary data sets:

1. High resolution set – This is composed of a series of public images obtained with the Wide Field Channel of the Advanced Camera for Surveys (ACS) on board the Hubble Space Telecope (HST): two F435W ($\sim B$ filter) images with $t_{\rm exp} = 800$ sec each, two F555W ($\sim V$ filter) images with $t_{\rm exp} = 720$ sec, and two F814W ($\sim I$ filter) images with $t_{\rm exp} = 676$ sec (Prop GO9666, P.I. Gilliland). These are the highest resolution ($\sim 0.05''$ pixel^{-1}) observations available to date for NGC 2419. As in previous works (see, e.g., Dalessandro et al. 2008), average ACS images were obtained in each filter, and they were corrected for geometric distortion and effective flux (Sirianni et al. 2005). The data reduction has been performed using the ROMAFOT package (Buonanno et al. 1983).

2. Wide field set – We have used a set of public V and I images obtained with the SUBARU Prime Focus Camera (Suprime-

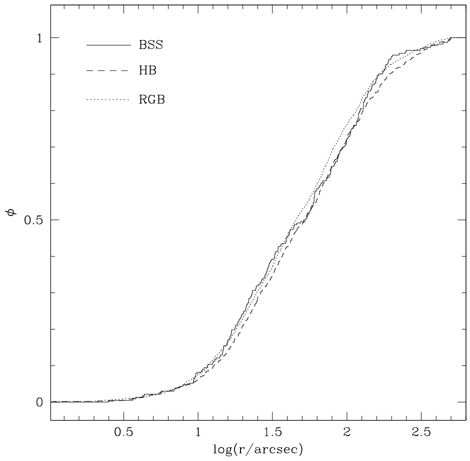

Fig. 2. Cumulative radial distribution of BSS, HB and RGB stars as a function of the projected distance from the cluster center.

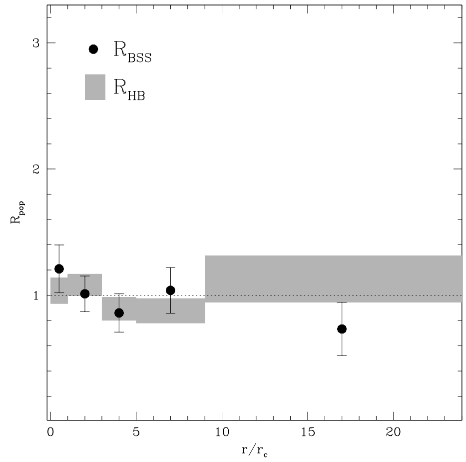

Fig. 3. Double normalized ratios as a function of the radial coordinates normalized to the core radius.

Cam) of the 8.2 m SUBARU telescope at the Hawaii National Astronomical Observatory of Japan. A combination of long-exposures ($t_{\rm exp}$ = 180 sec) and median exposure ($t_{\rm exp}$ = 30 sec) images has been retrieved from the Subaru Archive Web site (SMOKA). We have applied standard pre-reduction procedures using IRAF tools. The reduction was performed independently for each image using the PSF fitting software DoPhot (Schechter et al. 1993).

3. The population of BSS

To select the BSS population we have chosen to use the (B, $B-I$) CMD, in which the BSS sequence is better defined. To avoid spurious effects due to sub-giant branch star blends and Galaxy field star contamination, only stars brighter than $B \simeq 23.6$ (corresponding to ~ 1 mag above the TO) and with $B - I < 0.75$ have been selected. The position of the bulk of these stars in the ACS (V, $V-I$) CMD has then been used to define the BSS selection box for the *SUBARU sample*. The selected BSS population is among the largest ever observed in any stellar system, with more than 230 BSS in the brightest portion of the sequence.

Reference populations representative of the "normal" cluster stars are needed to properly study the BSS radial distribution. We considered both the HB and the RGB. Since the HST and the SUBARU samples have the V and I filters in common, we performed a homogeneous selection of these populations in the (V, $V-I$) plane.

A first qualitative comparison between the cumulative radial distribution of BSS and that of the reference populations (see Fig. 2) has been performed using the Kolmogorov-Smirnov test. This gives 70% and 50% probabilities that the BSS population is extracted from the same population as the HB and RGB stars, respectively. Hence, there is preliminary evidence that the radial distribution of BSS is indistinguishable from that of the "normal" cluster population, in contrast to what found in most of the typical GCs.

For a more detailed analysis, we have used the same technique described in previous works (see, e.g., Ferraro et al. 2006). The sampled area within $r = 500''$ (estimated tidal radius) has been divided in 5 concentric annuli. In each of these we have counted the number of BSS, HB and RGB stars and estimated the luminosity sampled. Then for each annulus we have computed the double normalized ratio defined in Ferraro et al. (1993). Surprisingly, we find that also the double normalized ratio of BSS is constant and fully consistent with the reference population, confirming again that no segregation signatures are visible for the BSS population of NGC2419, which shares the same radial distribution as the reference populations of the cluster.

4. Discussion

We can compare this observational evidence with theoretical time-scales expected on the basis of the cluster structural parameters. The central relaxation time (t_{r_c}, see Djorgovski 1993, for further details) as well as the characteristic relaxation time-scale for stars as massive as BSS ($M_{\rm BSS} \sim 1.2 M_\odot$, Ferraro et al. 2006; Davies et al. 2004) would suggest that some evidences of mass segregation should be visible at least in the core, at odds with the observed flat distribution of BSS. This result is similar to that found for ω Cen by Ferraro et al. (2006) where the relaxation time in the core was found to be ~ half the cluster age. In the case of ω Cen a number of possible explanations were examined, for instance, the possibility that ω Cen is the relic of a partially disrupted galaxy, which was much more massive in the past. A similar argument can be advocated for NGC 2419, which has also been suspected to be the relic of a small dwarf galaxy interacting with the Milky Way (van den Bergh & Mackey 2004). From the observational side, the BSS radial distribution shown in Fig. 2 and Fig. 3 suggests that in NGC 2419 (as in ω Cen) stellar collisions have played a minor (if any) role in modifying the radial distribution of massive objects and probably also in generating exotic binary systems. If dynamical evolution plays a central role in NGC 2419, the observed flat BSS distribution can be explained only by invoking an *ad hoc* formation/destruction rate balancing the BSS population in the core and in the outer region of the cluster. It is more likely that this flat distribution arises because the BSS we are observing result from the evolution of primordial binaries whose radial distribution has not been altered by the dynamical evolution of the cluster. Thus, as in the case of ω Cen, the BSS population observed in NGC 2419 could be a pure population of primordial binaries BSS (PB-BSS), and it can be used to evaluate the incidence of such a population in stellar systems.

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