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Blue straggler stars in globular clusters: chemical and kinematical properties

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Abstract. Blue Straggler stars are present in all the properly observed globular clusters. They mimic a rejuvenated stellar population and their existence has been a puzzle for many years. We performed an extensive spectroscopic survey of the surface abundances and the rotational velocities of Blue Straggler stars in different globular clusters, by using the high-resolution spectrograph FLAMES@VLT in the UVES+GIRAFFE combined mode. In this contribution we show our main results obtained for M4, ω Centauri and M30.

Key words. blue stragglers; globular clusters; stars: abundances; stars: evolution; techniques: spectroscopic

1. Introduction

Blue Straggler stars (BSSs) are commonly defined as stars brighter and bluer (hotter) than the main sequence (MS) turnoff (TO). Firstly discovered in 1953 in the globular cluster (GC) M3 (Sandage 1953), they lie along an extension of the MS in the color-magnitude diagram (CMD). According to their position in the CMD and also from direct measurements (Shara et al. 1997), they are more massive than normal MS stars thus indicating that a process able to increase the initial mass of a single star must be at work. Two main scenarios have been proposed for their formation: BSSs could be the end-products of stellar mergers induced by collisions (COL-BSSs; Hills & Day 1976), or they may form by the mass-transfer activity between two companions in a binary system (MT-BSSs; McCrea 1964), possibly up to the complete coalescence of the two stars. Hence, BSSs represent the link between standard stellar evolution and cluster dynamics: they are able to give information about the dynamical history of the cluster (Ferraro et al. 2012), the role of the dynamics on stellar evolution, the amount of binary sistems and the role of binaries in the cluster evolution. Indeed, distinguishing COL-BSSs from MT-BSSs is crucial to use these stars as GC dynamical probes.

The spectroscopic analysis seems to be the most promising way to discriminate between the two formation channels: in fact, it allows to derive both chemical abundances and rotational velocities. From a chemical point of view, COL-BSSs are not expected to show any abundance anomaly, since hydrodynamic simulations suggest that very little mixing should occur between their inner cores and their outer envelopes (Lombardi et al. 1995). At odds, depleted surface abundances of C and O are expected for MT-BSSs, since the accreted material should come from the core region of

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a peeled parent star where nuclear processing has occurred (Sarna & de Greve 1996. Concerning the rotational velocities, the theoretical scenario is more complicated. MT-BSSs are expected to have high rotational velocities because of the angular momentum transfer with the mass (Sarna & de Greve 1996). Unfortunately, accurate simulations are lacking, mostly because of the difficulty in following the evolution of a hydrodynamic system (the mass transfer between binary components) for the lenght of time required for the system to merge. According to some authors (Benz & Hills 1987), also COL-BSSs should rotate fast. Nevertheless, braking mechanisms (like magnetic braking and disk locking) may intervene (both for MT- and COL-BSSs) with efficiencies and time-scales not well known yet (see Leonard & Livio 1995 and Sills et al. 2005), thus preventing a clear prediction of the expected rotational velocities.

In this context the advent of 8-10 meters class telescopes equipped with multiplexing capability spectrographs has given a new impulse to the study of the BSS properties.

By using the multi-object spectrograph FLAMES at ESO VLT in the UVES+GIRAFFE combined mode, an extensive survey has been performed in order to obtain abundance patterns and rotational velocities for representative samples of BSSs in a number of GCs. The first result has been obtained by Ferraro et al. (2006a, hereafter F06): by measuring the surface abundance patterns of 43 BSSs in 47 Tuc, a sub-population of 6 BSSs with a significant depletion of C and O with respect to the dominant population, has been discovered. This evidence has been interpreted as the presence of CNO burning products on the BSS surface and it is the first detection of a chemical signature pointing to the MT formation process for BSSs in a GC.

The observations in 47 Tuc have also shown that most of the BSSs are slow rotators (v sin(i) < 10 $\mathrm{km s^{-1}}$), with velocities compatible with those measured in TO stars (Lucatello & Gratton 2003). Only one BSS having a really large rotational velocity (v sin(i) $\sim$ 80 $\mathrm{km s^{-1}}$) has been observed. No correlation has been found between CO depletion and rapid rotation.

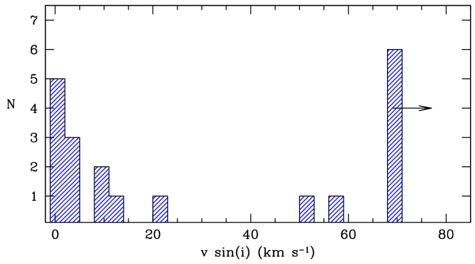

Fig. 1. Rotational velocity distribution for BSSs in M4. Upper limits are marked with an arrow.

2. M4

M4 is the closest Galactic GC (2.1 kpc, Harris 1996). We observed 20 BSSs and 53 TO stars along the entire extension of the cluster. We found (Lovisi et al. 2010) that the C and O abundances of the BSSs are totally in agreement with those of TO stars, so that no CO-depleted BSS is observed in our sample. The most intriguing result of this study concerns the BSS v sin(i) distribution which is shown in Fig. 1: most of the BSSs have low rotational velocities ($\lesssim$ 20 $\mathrm{km s^{-1}}$) in agreement with the TO stars, but 8 out 20 BSSs have v sin(i) > 50 $\mathrm{km s^{-1}}$. Only lower limits (marked with an arrow) have been computed for 6 of them, suggesting v sin(i) higher than 70 $\mathrm{km s^{-1}}$. This is the largest fraction (40%) of fast rotating BSSs ever found in any GC.

3. ω Centauri

ω Centauri is one of the most studied objects in the Milky Way since the 1960s. All the evidence collected so far - kinematics, spatial distribution and chemical composition - suggests that it is not a "genuine" GC but more likely the remnant of a dwarf galaxy that merged with the Milky Way in the past. The particular dynamical status of ω Centauri has been confirmed also by the radial distribution of its BSS population that is not centrally peaked (as observed in all the dinamically evolved GCs) but completely flat, suggesting that ω Centauri is

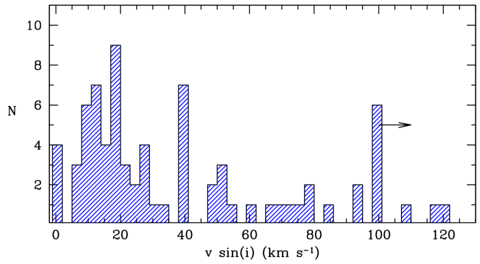

Fig. 2. Rotational velocity distribution for BSSs in ω Centauri. Upper limits are marked with an arrow.

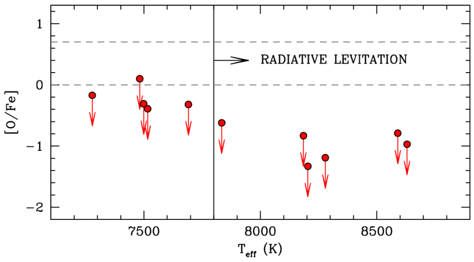

Fig. 3. O abundances as a function of the effective temperature for the BSSs in M30 compared with RGBs values from Carretta et al. (2009, grey dashed lines). The vertical line marks the limit for the occurrence of the radiative levitation.

not relaxed yet (Ferraro et al. 2006b, 2012). For this reason, the entire BSS population in ω Centauri has been suggested to be formed through MT in binary systems (Ferraro et al. 2006b).

78 BSSs have been observed along the entire extension of the cluster. Their v sin(i) distribution is shown in Fig. 2: most of the BSSs have values < 20 kms^{-1} but a large fraction (corresponding to the 30% of the sample) has v sin(i) > 50 kms^{-1}up to values larger than 100 kms^{-1}.

4. M30

M30 is one of the 21 Galactic GCs that are likely to have experienced the core collapse (Djorgovski & King 1986). Two well distinct and almost parallel sequences of BSSs have been observed in the CMD of M30 by Ferraro et al. (2009). The suggested scenario is the following: 1-2 Gyr ago M30 underwent the core collapse that has boosted both the rate of direct stellar collisions, and the MT processes in binary systems. As a result, two different BSS sequences are now observed, the blue one formed by COL-BSSs and the red one by MT-BSSs. We observed 12 BSSs, 4 in the blue sequence and 8 in the red one. The rotational velocity distribution shows that most of the BSSs rotate slowly with values ranging between 0 and 25 kms^{-1}. Only one fast rotating BSSs (having v sin(i) > 90 kms^{-1}) has been identified. Moreover, there are hints that the BSSs in the blue sequence rotate faster than those in the red one.

Whereas the low metallicity of the cluster prevent us from obtaining meaningful C abundances, we derived upper limits for the O abundances (see Fig. 3). Due to the radiative levitation effects (that alter the surface chemical abundances of BSSs hotter than ~7800-8000 K, see Lovisi et al. 2012), reliable upper limits for the O abundance have been obtained only for the 5 coldest BSSs (that are not affected by radiative levitation). The upper limits for 4 of them are incompatible with the O distribution of the giant stars in M30 (Carretta et al. 2009), pointing out the occurence of an O-depletion among these BSSs.

5. Conclusions

Chemical and kinematical properties of BSSs in three GCs have been studied. We found that BSSs in M4 do not show any evidence of CO-depletion. This might be due to the fact that all the BSSs in this cluster have a collisional origin. Nevertheless, the size of the sample is small and the lack of CO-depleted BSSs could be a statistical effect. Moreover, an intriguing scenario proposed by F06 suggests that the depletion is a transient phenomenon, since it could be erased by some mixing mechanism. We found evidence of O depletion in 4 out of the 5 coldest BSSs of M30 that do not suffer from radiative levitation effects. In particular, we note that the O-depleted BSSs in M30 all belong to the red sequence that is suggested to be have a MT origin.

Concerning the rotational velocities, the distribution of the BSSs in M30 is very similar to that found in 47 Tuc by F06: almost all the BSSs rotate slowly and only one BSS shows v sin(i) > 50 $\mathrm{km s^{-1}}$. On the contrary, a large fraction of fast rotating BSSs (v sin(i) >50 $\mathrm{km s^{-1}}$) has been identified in M4 and ω Centauri, corresponding to the 40% and 30% of the entire sample respectively. These are the largest fractions of fast rotating BSSs ever found in any GC.

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