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The blue plume population in dwarf spheroidal galaxies: genuine blue stragglers or young stellar population?

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Abstract. In the context of dwarf spheroidal galaxies it is hard to firmly disentangle a genuine Blue Stragglers (BSS) population from a normal young main (MS) sequence. This difficulty is persistent. For a sample of 9 non-star forming Local Group dwarf galaxies we compute the "BSS frequency" ($F^{\rm BSS}_{\rm HB}$) and compare it with that found in the Milky Way globular/open clusters and halo. The comparison shows that $F^{\rm BSS}_{\rm HB}$ in dwarf galaxies, at any given M_V, is always higher than that in globular clusters of similar luminosities. Moreover, the estimated $F^{\rm BSS}_{\rm HB}$ for the lowest luminosity dwarf galaxies is in excellent agreement with that observed in the Milky Way halo and open clusters. We conclude that the low density, almost collision-less environment, of our dwarf galaxy sample point to their very low dynamical evolution and consequent negligible production of collisional BSS.

Key words. Galaxies: dwarf – globular clusters: general – blue stragglers – stars: evolution

1. Introduction

First identified by Sandage (1953), Blue Stragglers are usually defined as a hotter and bluer extension of normal main sequence stars) The origin of BSS is sought as either *primordial binaries* coeval with the globular/open cluster formation epoch, or to a continuous production (in successive epochs) of *collisional binaries* due to dynamical collisions/encounters experienced by single/binary stars throughout the life of the cluster.

Piotto et al. (2004) presented a homogeneous compilation of ∼ 3000 BSS (based on HST observations of 56 globular cluster), and derived a significant and rather puzzling anti-correlation between the BSS specific frequency and the cluster total absolute luminosity (mass). That is to say that more massive clusters are surprisingly BSS deficient, as if their higher collision rate had no correlation with the production of collisional BSS. Another puzzling observable is that the BSS frequency in Milky Way field (Preston & Sneden 2000) is at least an order of magnitude larger than that of globular clusters.

In the context of dwarf galaxies one *cannot* exclude that blue plume stars may include genuinely young main sequence (MS) stars, i.e. a residual star forming activity (e.g. Held

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2005, and references therein). A useful indicator of the presence of a recent star formation in a galaxy is the detection of a vertical extension in correspondence of the red HB region. Stars forming this sequence are usually called vertical clump stars (VC, Gallart et al. 2005). These are helium-burning stars of few hundred Myr to ~ 1 Gyr old population whose progenitors are to be searched in the blue plume. Nevertheless, we note that Ferraro et al. (1999) identify a similar sequence in the M80 globular cluster and ascribe it to the evolved-BSS population. We therefore cautionly conclude that the detetction of VC star in a dwarf galaxy is not a clear-cut evidence of the presence of a young MS population.

To shed light on the BSS-MS ambiguity in dwarf galaxies, we measure the BSS frequency in 9 non-star forming dwarf galaxies and compare it with that derived in other stellar systems. Dwarf spheroidals/irregulars in which there is *current* or recent (≤ 500 Myr) star formation are not considered. Dwarf spheroidals/irregulars showing evidence of recent ≤ 500 Myr star formation (e.g. Fornax dwarf, Saviane et al. 2000), or young MS stars reaching the horizontal branch [e.g. Sagittarius irregular, Momany et al. (2005)] level have been excluded. The Canis Major dwarf galaxy (Martin et al. 2004 and Bellazzini et al. 2004) was not included [see arguments in Momany et al. (2004) and (2006)]. The Carina dwarf (Monelli et al. 2003), is one of those showing evidence of star formation in recent epochs (~ 1 Gyr), and we include in our sample so as to compare with other dwarf galaxies of similar luminosities.

2. The dwarf galaxy sample

The BSS frequency was derived for Sagittarius, Sculptor, Leo II, Sextans, Ursa Minor, Draco, Carina, Ursa Major and Boötes. The Sagiitarius data are based on *BVI* 1° × 1° WFI@2.2m data, from which we excluded the inner 14′ × 14′ region around M54. These were reduced and calibrated following the standard recipes in Momany et al. (2001) and (2002). For the remaining dwarf galaxies we estimate the BSS frequency from either public photometric catalogs (Sextans by Lee et al. 2003) or photometry kindly provided by the authors (Ursa Minor by Carrera et al. 2002, Draco by Aparicio et al. 2001, Sculptor by Rizzi et al. 2003, Ursa Major by Willman et al. 2005, Boötes by Belokurov et al. 2006 and Carina by Monelli et al. 2003).

All the photometric catalogs extend to and beyond the galaxy half light radius; i.e. we cover a significant fraction of the galaxies and therefore the estimated BSS frequency should not be affected by specific spatial gradients, if present. The only exception is that relative to Sagittarius. With a core radius of ~ 3.7°, the estimated BSS frequency of our 1° square degree field refers to less than 3.5% areal coverage of Sagittarius, or a conservative ~ 6% of the stellar populations. Therefore the Sagittarius BSS frequency should be considered with caution. In order to account for the foreground/background contamination, star counts were also performed on simulated diagrams (using the Trilegal code Girardi et al. 2005) and these were subtracted from the BSS and HB star counts for the dwarf galaxy sample. We calculate the specific frequency of BSS (normalizing the number of BSS to the HB) as: $F^{\rm BSS}_{\rm HB} = \log(N_{\rm BSS}/N_{\rm HB})$.

3. BSS frequency in dwarf galaxies and globular clusters

Figure 1 displays the $F^{\rm BSS}_{\rm HB}$ *vs* M_V diagram for our dwarf galaxy sample together with the data-points of Piotto et al. (2004) and De Marchi et al. (2006) for globular and open clusters, respectively. Of the original open cluster sample we only plot clusters for which ≥ 2 BSS stars were found. To the globular cluster sample we add the BSS frequency of ωCen as derived by Ferraro et al. (2006), and that of NGC1841 (Saviane et al. 2003) the LMC most metal-poor and most distant LMC globular cluster. Figure 1 clearly shows that, regardless of their specific peculiarities, ωCen and NGC1841 are consistent with the general globular clusters $F^{\rm BSS}_{\rm HB}-M_V$ anti-correlation, adding only universality to it.

As for the dwarf galaxy sample, it results immediately that the *lowest luminosity*

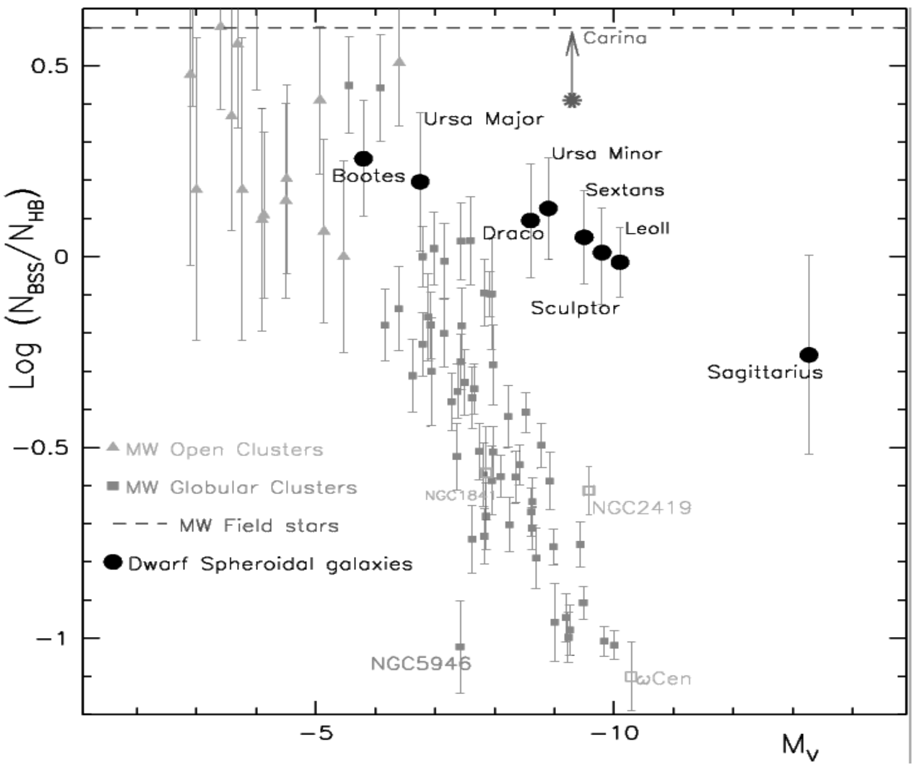

Fig. 1. The $F_{\rm BSS}$ vs M_V diagram for globular clusters (Piotto et al. 2004) open clusters (De Marchi et al. 2006) and dwarf spheroidal galaxies. The horizontal line shows the mean BSS frequency for Milky Way field stars (Preston & Sneden 2000).

dwarfs (Boötes and Ursa Major) would possess a higher $F_{\rm HB}^{\rm BSS}$ than globular clusters with similar M_V. Most interestingly, their $F_{\rm HB}^{\rm BSS}$ is in fact fully compatible with that observed in open clusters. This compatibility between dwarf galaxies and open clusters may suggest that there exists a "saturation" in the BSS frequency (at 0.3 – 0.4) for the lowest luminosity systems. Thus, the relatively high $F_{\rm HB}^{\rm BSS}$ of Boötes and Ursa Major adds more evidence in favor of a dwarf galaxy classification of the 2 systems. Indeed, although their luminosities is several times fainter than Draco or Ursa Minor, the physical size of the two galaxies ($r_{1/2} \simeq$ 220 and 250 pc respectively) exceeds that of more massive galaxies like Ursa Minor ($r_{1/2} \simeq$ 150 pc).

Another interesting feature is the significant difference between the BSS frequency of Carina with that derived for dwarf galaxies with similar luminosity, i.e. Draco, Ursa Minor, Sextans, Sculptor and Leo II. Although it is only a lower limit, the "BSS" frequency for Carina is of great help in suggesting a threshold near which a galaxy BSS frequency might hide some level of recent star formation. The aforementioned 5 galaxies however have a lower BSS frequency, a hint that these galaxies possess a normal BSS population rather than a young MS.

Lastly, leaving aside the extreme dynamical history of Sagittarius and allowing for the uncertainties (due to the heavy Galactic contamination and the relatively small sampled populations) it turns out that its blue plume-HB frequency is (i) lower than that in a star-forming galaxy like Carina, and most interestingly; (ii) in good agreement with the expected BSS frequency (note a hint of a $F_{\rm HB}^{\rm BSS}$ – M_V anti-correlation for the 7 remaining galaxies in our sample). Added to the clear absence of MS stars overlapping or exceeding the Sagittarius HB luminosity level, we suggest that the Sagittarius blue plume is a "normal" BSS sequence. As a matter of fact, *Sagittarius is probably the nearest system with the largest BSS population: over 2600 BSS stars in the inner* $1^\circ \times 1^\circ$ *field.*

4. A $F_{\rm HB}^{\rm BSS} - M_V$ anti-correlation for dwarf galaxies ?

We here explore the statistical significance of a possible $F_{\rm HB}^{\rm BSS} - \rm M_V$ correlation. The linear-correlation coefficient (Bevington 1969) for the 8 galaxies (excluding Carina) data-points is 0.984. The corresponding probability that any random sample of uncorrelated experimental data-points would yield a correlation coefficient of 0.984 is $< 10^{-6}$. Given the greater uncertainties associated with the Sagittarius BSS frequency, one may be interested in the correlation coefficient excluding the Sagittarius data-point. In this case, the resulting correlation coefficient remains however quite high (0.972) and the probability that the 7 remaining data-points would randomly correlate is as low as 10^{-4}. Thus, the statistical significance of the $F_{\rm HB}^{\rm BSS} - M_V$ anti-correlation in non star-forming dwarf galaxies is quite high. We follow the methods outlined in Feigelson & Babu (1992) and fit least-squares linear regressions. In particular, the intercept and slope regression coefficients were estimated through 5 linear models (see the code of Feigelson & Babu for details) the average of which gives (a, b)=$(0.699 \pm 0.081, 0.070 \pm 0.010)$ and (a, b)=$(0.631 \pm 0.120, 0.062 \pm 0.014)$ including and excluding the Sagittarius data-point, respectively. The reported errors were estimated through Bootstrap and Jacknife simulations so as to provide more realistic a and b errors.

However, to firmly establish this $F_{\rm HB}^{\rm BSS} - M_V$ anti-correlation one needs to increase the dwarf galaxies sample, in particular at the two luminosity extremes. Unfortunately there are not many non star-forming dwarf galaxies with $-13.3 \leq M_V \leq -10.1$, and few exceptions may come from deeper imaging of galaxies like And I and And II. On the other hand, more Local Group dwarf galaxies are being discovered in the low luminosity regime $(-8.0 \leq M_V \leq -5.0)$, and it is necessary to include these in any analysis similar to ours.

5. Conclusions

For a sample of 8 non star-forming dwarf galaxies, we have tested the hypothesis that the blue plume populations are made of a genuine BSS population (as that observed in open and globular clusters) and estimated their frequency with respect to HB stars. Should this assumption be incorrect (and the blue plume population is made of young MS stars) then one would not expect an anti-correlation between the galaxies total luminosity (mass) and the blue plume frequency, but rather a correlation between the two. Instead, and within the limits of this and similar analysis, we detect a statistically significant anti-correlation between $F_{\rm HB}^{\rm BSS}$ and M_V. Thus, should a dwarf galaxy "obey" the $F_{\rm HB}^{\rm BSS} - M_V$ anti-correlation displayed by our sample then its blue plume population is probably made of blue stragglers.

We also estimated stellar specific collision parameter ($\log \Gamma_\star$: the number of collisions per star per year). The mean collisional parameter of the 9 studied galaxies is $\simeq -19$. The lowest value is that for Sagittarius with $\log \Gamma_\star \simeq -20.2$, and this is due to its very extended galaxy core. Compared with the mean value of -14.8 for the globular clusters sample [see lower right panel of Fig. 3 in Momany et al. (2007)] the estimated number of collisions per star per year in a dwarf spheroidal is 10^{-5} times lower.

To summarize, from Fig. 1 one finds that $F_{\rm HB}^{\rm BSS}$ in dwarf galaxies is (i) always higher than that in globular clusters, (ii) very close, for the lowest luminosity dwarfs, to that observed in the MW field and open clusters, (iii) the Carina specific $F_{\rm HB}^{\rm BSS}$ frequency probably sets a threshold for star-forming galaxies, and most interestingly, (iv) shows a hint of a $F_{\rm HB}^{\rm BSS} - M_V$ anti-correlation. This almost precludes the occurrence of collisional binaries in dwarf galaxies, and one may conclude that genuine BSS sequences in dwarf galaxies are mainly made of primordial binaries.

Lastly, it is interesting to note how the BSS frequency in the low-luminosity dwarfs and open clusters ($\log(N_{\rm BSS}/N_{\rm HB}) \sim 0.3-0.4$) is very close to that derived for the Galactic halo ($\log(N_{\rm BSS}/N_{\rm HB}) \sim 0.6$) by Preston & Sneden. The latter value however has been derived relying on a composite sample of only 62 blue metal-poor stars that are (i) distributed at different line of sights; (ii) at different distances; and most importantly, (iii) for which no observational BSS-HB star-by-star correspondence can be established. Thus, allowing for all these uncertainties in the field BSS frequency, it is safe to conclude that the observed open clusters-dwarf galaxies BSS frequency sets a realistic, and observational upper limit to the primordial BSS frequency in stellar systems.

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