The double blue straggler sequence in NGC 2173: a field contamination artefact?

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ABSTRACT

Li et al. (2018a) (hereafter L18) detected two apparently distinct populations of blue straggler stars (BSSs) in the young globular cluster NGC 2173, a similar feature as observed in numerous Galactic globular clusters (GCs). However, because of the large distance to NGC 2173, which is located in the Large Magellanic Cloud, precise proper motion measurements for these BSSs are unattainable. In addition, there are no observations of any nearby reference field observed with the same instrumental setup (Hubble Space Telescope equipped with UVIS/WFC3 and using the F336W and F814W filters), which renders estimating the level of field contamination for these BSSs difficult. Recently, Dalessandro et al. (2018) (D18) compared the observed color–magnitude diagrams (CMDs) of both the cluster and a nearby reference field (although observed with the ACS/WFC instrument). They conclude that the bifurcated pattern of BSSs in NGC 2173 observed by L18 is a field contamination artefact.

In this note, we explore the central concentration properties of the removed ‘field stars’ identified by D18. Our purpose is to examine if these ‘field stars’ are spatially homogeneously distributed. Employing a Monte Carlo-based approach, we have carefully studied the probability that any such central concentration may be caused by small number statistics. We find that, in most cases of, the ‘field stars’ removed by D18 exhibit a clear central concentration, which cannot be explained on the basis of small number statistics alone. Therefore, we suggest that D18 may well have overestimated the field contamination level, implying that the bifurcated BSS pattern in NGC 2173 cannot, in fact, be explained by field contamination.

METHOD

For distant clusters without precise measurements of their stellar proper motions, the best method to estimate field contamination by comparing with photometric measurements of a nearby reference field. However, L18 highlighted the unavailability of an appropriate nearby reference field observation, which makes precisely estimating the level of field contamination impossible. As an alternative approach, one can examine the central concentration of the stars of interest, combine with Mento Carlo-based simulations aimed at quantifying whether the observed population of stars may be composed of cluster members. This latter method has been used by many previous studies (e.g., Li et al. 2018b).

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By comparison of the photometric measurements of L18 and D18 for the cluster’s BSS region, we determined which ‘field stars’ were identified by D18 (see their Fig. 5). In the left-hand panel of Fig. 1 we show the NGC 2173 CMD, highlighting the D18 ‘field stars’. In the right-hand panel, we show their spatial distribution.

We next calculated the number density profile of these ‘field stars’. If they are genuine field stars, a central peak in their number density profile would not be expected. Because of their small number (14), we calculated their number densities in only three radial intervals: (1) from 0 to the cluster’s core radius, \( r_c = 2.7 \) pc (L18), (2) from \( r_c \) to the half-mass radius, \( r_h = 9.7 \) pc (L18), and (3) beyond \( r_h \). Both \( r_c \) and \( r_h \) are indicated in the top right-hand panel of Fig. 1. Fig. 1 (bottom) shows the number density profile of the D18 ‘field stars’. A clear central concentration is observed.

Because the number of removed stars is small, it is possible that their spatial concentration is caused by small number statistics. To quantify this possibility, we employed a Monte Carlo method similar to that used by Li et al. (2018b): we randomly generated 14 artificial stars that were spatially homogeneously distributed. We then calculated the ratio of their numbers inside and outside \( r_h \). We repeated this procedure 10,000 times and recorded how often the artificial stars achieved a higher number ratios than the observations. None of our simulations reproduced the
observed concentration, implying a probability that the observed peak of the ‘field stars’ could have been caused by small number statistics of less than 0.01%.

In their Fig. 6, D18 show nine additional tests of ‘decontaminated’ CMDs, obtained by changing the color–magnitude cells’ dimensions and the grid limits, which they used for removing stars from the CMD. We also examined the corresponding spatial distributions of the removed ‘field stars’ for these nine cases: see Fig. 2. Most of these examples again show central concentrations. In fact, the core of NGC 2173 only occupies an area of 1.6% of the full image. If the stars removed by D18 were field stars, in most cases we should not find any star within the core region. However, the number ratio of stars in the core region with respect to that outside of this region ranges from 10.7% to 35.7% (1 to 5 stars).

Using the same method, we plot the number density profiles and calculate the concentrations’ significance levels of the removed ‘field stars’ corresponding to Fig. 6 of D18: see Fig. 3. We find that only in one case, corresponding to the top left-hand panel of D18’s Fig. 6, the significance of the concentration is 88%. In all other cases, these removed ‘field stars’ exhibit clear concentrations with significance levels (σ) greater than 90% (indicated at the top of each panel in Fig. 3). Again, these results unequivocally suggest that D18 may have overestimated the field contamination in all nine cases.

DISCUSSION AND CONCLUSIONS

D18 suggested that more than 40% of the BSS candidates in the NGC 2173 CMD, may actually be field stars. As we have shown in this note, the ‘field stars’ removed by D18 are more likely spatially associated with the cluster, indeed at high levels of significance. The field contamination levels determined by D18 have most likely been overestimated. We suggest that this disagreement with our previous publication might have been caused by the nature of the reference field used by D18. The observations of the cluster region and the reference field employed by D18 are rather different: the former was observed with the UVIS/WFC3 instrument, while the latter was observed using the ACS/WFC. Moreover, the cluster and field regions used by D18 have been observed through different passbands and with different exposure times. Therefore, these authors were forced to cross-calibrate the instrumental magnitudes difference between two different filter systems. However, their results reveal non-zero calibration uncertainties when one directly compares their photometry. For instance, in Fig. 4 of D18, the slope of the main-sequence (MS) of their reference field is clearly different from that of the cluster, which clearly demonstrates the prevailing calibration uncertainty. In addition, as shown in Fig. 4 of L18, the stellar completeness for stars within $r_c$ is lower than that in the outer regions; the former is only $\sim 90\%$ of the latter. This is not considered by D18.

In most cases, BSSs are expected to have a bimodal radial distribution (e.g., Ferraro et al. 2012), in particular in dynamically young clusters like NGC 2173. It is possible that the average stellar number density in the outer region would be even higher than at intermediate radii. If so, using a BSS sample drawn from the outer region as reference to the field, would inevitably overestimate the genuine level of field contamination in the inner cluster region$^1$.

D18 concluded that “NGC 2173 turns out to be a young cluster with a single and poorly populated BSS sequence, which can likely be the result of binary evolution” and “[a]s a consequence, the case of NGC 2173 is not relevant for the understanding and the discussion on the origin of the double BSS sequences observed so far in a few old globular clusters (Ferraro et al. 2009; Dalessandro et al. 2013; Simunovic et al. 2014).” However, as we have shown here, these conclusions are likely incorrect owing to their overestimation of the level of field contamination. L18 estimated the significance of the bifurcated BSS pattern in NGC 2173 at 99.95% (see their Fig. 5). This high significance indicates that both the blue and red sequences are not ‘poorly populated’. Finally, if the bifurcated pattern discussed by L18 is a field contamination artefact, it is difficult to explain why field stars with different ages and metallicities would populate two clearly distinct sequences. So far, the most viable explanation of these two BSS sequences is that they originated in the star cluster environment, although it is still a mystery how one could produce such bifurcated BSS sequences in a (dynamically) young cluster.

$^1$ Although D18 state that their adopted reference field is located well beyond the cluster’s tidal radius, both L11 and McLaughlin & van der Marel (2005) derived a significantly larger tidal radius.
Figure 2. Spatial distributions of the 'field stars' removed by D18 (their Fig. 6). The red and blue circles indicate the core and half-mass radii, respectively.

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Figure 3. As Fig. 2, but the nine test cases corresponding to Fig. 6 of D18.

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