

Blue Straggler Stars in Galactic Open Clusters and the effect of field star contamination

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ABSTRACT

Context. We investigate the distribution of Blue Straggler stars in the field of three open star clusters.

Aims. The main purpose is to highlight the crucial role played by general Galactic disk fore-/background field stars, which are often located in the same region of the Color Magnitude Diagram as Blue Straggler stars.

Methods. We analyze photometry taken from the literature of 3 open clusters of intermediate/old age rich in Blue Straggler stars, and which are projected in the direction of the Perseus arm, and study their spatial distribution and the Color Magnitude Diagram.

Results. As expected, we find that a large portion of the Blue Straggler population in these clusters are simply young field stars belonging to the spiral arm. This result has important consequences on the theories of the formation and statistics of Blue Straggler stars in different population environments: open clusters, globular clusters or dwarf galaxies.

Conclusions. As previously emphasized by many authors, a detailed membership analysis is mandatory before comparing the Blue Straggler population in star clusters against theoretical models. Moreover, these sequences of young field stars (blue plumes) are potentially powerful tracers of Galactic structure which require further consideration.

Key words. Milky Way: structure; Open clusters and associations: individuals: NGC 7789, Berkeley 66, Berkeley 70

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1. Introduction

In the last few years blue straggler stars (BSS) have received considerable attention. These bright stars appear above the turn off point (TO) in the color magnitude diagram (CMD) of stellar populations, along the extension of the main sequence (MS), and are almost ubiquitous. In fact BSS have been detected in globular clusters (Sandage 1953, Ferraro et al. 2003), Dwarf Galaxies in the Local Group (Momany et al. 2007), and Galactic open clusters (OCs) (Ahumada & Lapasset 2007, De Marchi et al. 2006, Xin et al. 2007). The formation mechanism of BSS in different environments is still lively debated, and we refer the reader to the quoted papers for all the details.

According to the recent analysis by Momany et al. (2007) Galactic open clusters, although being less populous than globular clusters and dwarf galaxies, seem to contain the largest percentage of BSS (see their Fig. 2). This appears to imply that the formation mechanism of BSS depends on the environment, being different in open and globular clusters and in dwarf spheroidal galaxies. However, open clusters are embedded in the Galactic disk, and are more affected by field star contamination than globulars. The amount of contamination depends on the cluster position, and can only be quantified by a detailed membership analysis, which unfortunately is available for only a handful of clusters (see Ahumada & Lapasset 2007 for more details).

A related problem in fact is that blue sequences in the CMD of dwarf galaxies (the so called *blue plumes*) bear much similarity with BSS sequences in open and globular clusters, but at the same time can be made of young stars, residuals of recent star formation episodes (Momany et al. 2007). A remarkable case is that of Canis Major (CMa, Bellazzini et al. 2004), a putative dwarf galaxy immersed in the third quadrant of the Galactic disk. The prominent *blue plume* visible in CMDs has been considered to be composed of 1-2 Gyr old stars and/or BSS (Bellazzini et al. 2006) belonging to CMa.

However, in a series of papers (Carraro et al. 2005, Moitinho et al. 2006, Pandey et al. 2006) similar sequences have been observed in CMDs across the entire third Galactic quadrant, and have been argued - based on a larger wavelength coverage - to be composed of young stars belonging to previously poorly known spiral features. These different views highlight the delicacy of interpreting CMDs and how the choice of photometric bands may be critical.

In this *Note* we investigate the BSS population in three OCs (NGC 7789, Berkeley 66 and Berkeley 70), located in the second Galactic quadrant, where the spiral structure is well known. We draw attention on the effect of field star contamination in cluster CMDs and to the need of detailed membership studies as the observational foundation for robust theoretical investigations of BSS formation mechanisms. Moreover, we show that the blue sequences like those found in the third Galactic Quadrant are also present in the second quadrant, and can be in most cases ascribed to spiral features.

2. The role of field star contamination

Our starting point is the new release of the BSS catalog by Ahumada & Lapasset (2007, hereinafter AL07). We opted to use this compilation amongst the various at disposal because it contains the most up-to-date list of BSS candidates in OCs. As the authors state, accurate membership studies, based either on radial velocity or proper motion, are unfortunately only available for a limited number of clusters, and therefore it is only possible to provide BSS candidates according to some

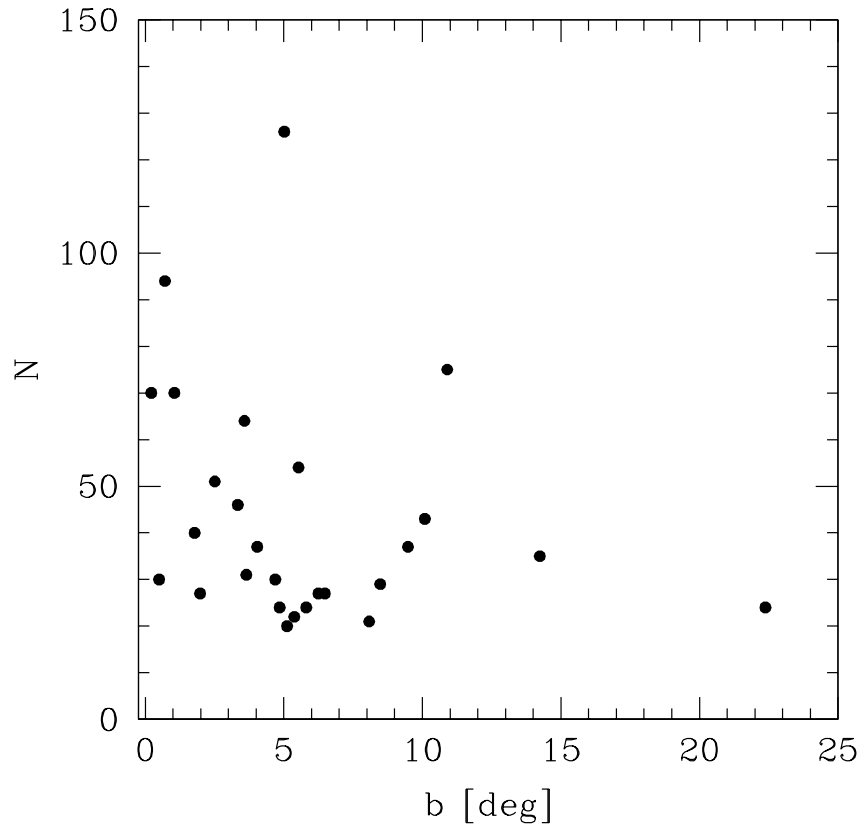


Fig. 1. Absolute number of BSS in the most BSS rich open clusters (AL07) vs their Galactic latitude.

less accurate criteria. The fact that BSS stars may occupy the same locus as field stars in the CMD is the main difficulty one has to deal with when providing robust BSS statistics.

To illustrate how crucial this contamination is, we consider the star clusters with the largest absolute populations of BSS listed in Table 6 of AL07. From the sample, we remove Ruprecht 46, which - interestingly for the purpose of this *Note* - has been demonstrated to be a chance alignment of field stars (Carraro & Patat 1995). Yet, this random enhancement of field stars leads the entries of *clusters* having the largest relative population of BSS (see Table 7 of AL07).

In Fig. 1, we plot the 28 entries of Table 6 of AL07 as a function of Galactic latitude. Clearly, there is a trend of having more BSS at lower Galactic latitudes, where field star contamination becomes more important.

Recently, Momany et al. (2007) have shown that field star contamination is the source of an artificially higher BSS fraction in the globular clusters NGC 6717 ($l = -11^\circ$) and NGC 6838 ($l = -5^\circ$) when compared to clusters of similar absolute magnitude but located at higher Galactic latitudes. The same seems to occur for Galactic open clusters. In the AL07 catalog - but also in all the other compilations (Xin et al. 2007, De Marchi et al. 2007) - M 67 and Berkeley 18 are two coeval and

Table 1. Fundamental parameters of the clusters under study, taken from WEBDA

<i>Name</i>	<i>l</i>	<i>b</i>	<i>Radius</i>	$(m - M)_V$	$E(V - I)$	<i>age</i>
	deg	deg	arcmin			Gyr
NGC 7789	115.53	-5.38	14.0	12.5	0.27	1.7
Berkeley 66	139.43	+0.22	2.0	17.5	1.55	5.0
Berkeley 70	166.89	+3.58	2.5	14.6	0.60	4.7

similar metallicity clusters, still Berkeley 18 at $(l,b) = (163.63,+5.02)$ has 4 times more BSS than M 67 at $(l,b)=(215.69,+31.89)$.

3. The spiral structure of the Milky Way

The majority of OB type stars are located in spiral arms and form sequences in the CMD blurred by differential reddening and distance spread due to the patchy and irregular shape of the arms. Still, these sequences are prominent.

In the last years we have provided evidence of such sequences in the fields of open clusters in the Third Galactic Quadrant (TGQ, Carraro et al. 2005; Moitinho et al. 2006), where no previously accepted indications of spiral arms were present. Similar results have been obtained by Pandey et al. (2006) for a sample of clusters in the 3GQ and Second Galactic Quadrant (SGQ).

We searched for the presence of spiral arm traces lines-of-sight of clusters listed in Table 6 of AL07 to understand whether BSS candidates could be mostly interpreted as young field stars. As an illustration, we consider here 3 cases: NGC 7789, Berkeley 66 and Berkeley 70, located at $(l,b) = (115.53, -5.38), (139.43,+0.22)$ and $(166.89,+3.58)$, respectively. These are three OCs with high relative populations of BSS (AL07, Table 7) and well separated in the SGQ. At odds with the case of the TGQ, these three clusters are located in the SGQ along directions where the presence of Perseus and of the Local arm are well established (Russeil et al. 2007). Moreover, according to the maps of Burton (1985), one can detect HI emission along these directions due to the prominent Local arm, which surrounds the Sun, and to the more distant, detached, Perseus arm.

3.1. NGC 7789

At $l=115^\circ$ (the Galactic longitude of NGC 7789), the maps of Burton (1985) clearly indicate that the Perseus arm is detached from the Local arm, and show HI emission down to at least $b = -6^\circ$. This implies that contamination from young stars in the Perseus arm can be important in the field of NGC 7789.

In the upper panels of Fig. 2 we show the CMD of NGC 7789 (left panel) and of the surrounding field (right panel). In the lower panel we plot the stellar spatial distribution, and illustrate with a circle 14 arcmin wide (the innermost one) the cluster region. An annulus far from the cluster and having the same area as the clusters is indicated with the two outermost circles. In particular, together with all the observed stars, we indicate with solid symbols (red squares when printed in color) the spatial distribution of the candidate BSS, as selected in each CMD. As for the selection, we adopted the same criteria as AL07 (see their Fig. 1): The solid isochrone and ZAMS (thick solid line) are drawn using the fundamental parameters of NGC 7789 (see Table 1) to show the region of the CMD where BSS candidates are to be searched for. We are aware that for this specific cluster a

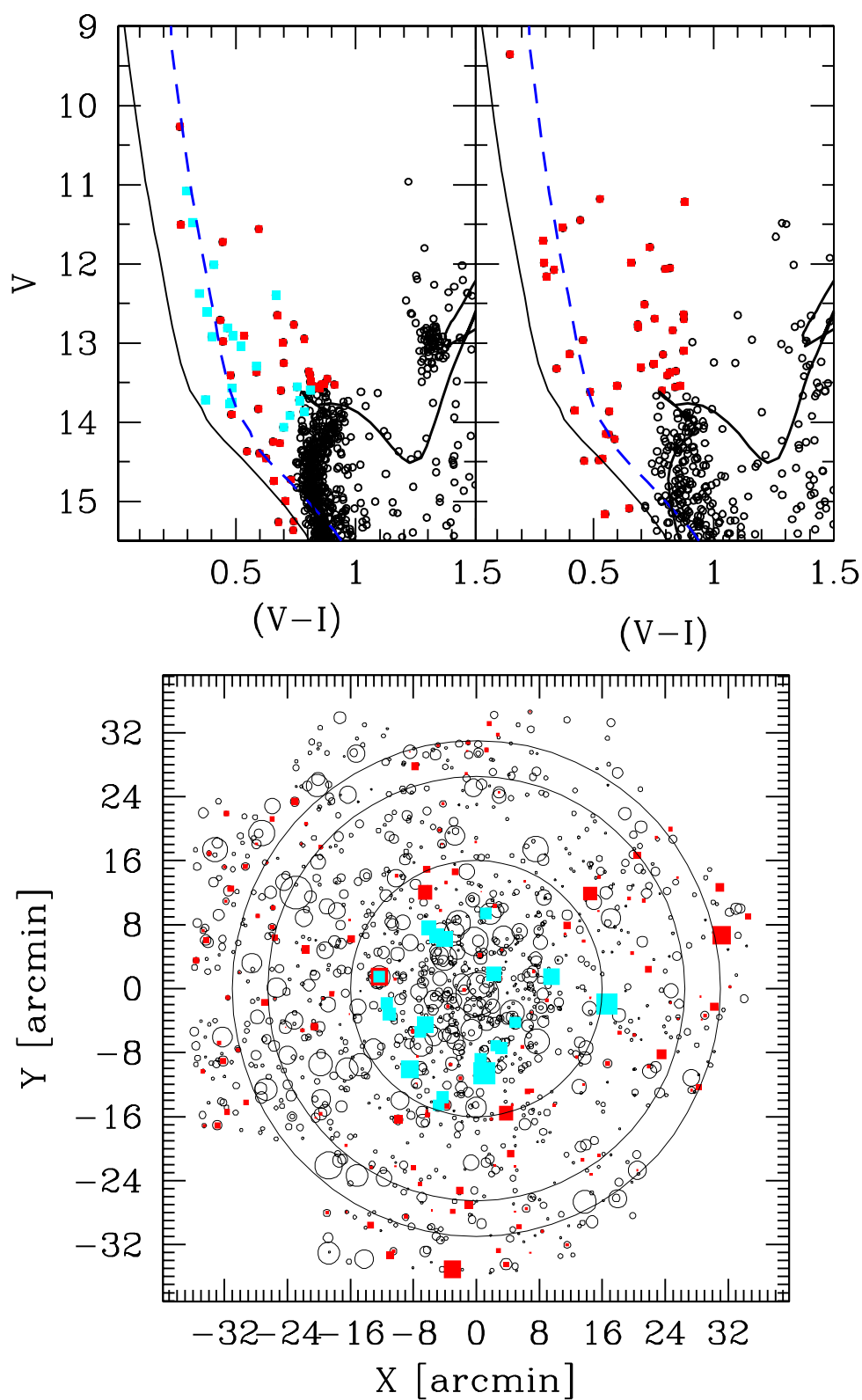


Fig. 2. Location in the CMD of NGC 7789 of BBS and field stars. In the upper left panel we show CMDs of NGC7789 from Gim et al. (1998) for all stars brighter than $V \sim 15.50$ and within the cluster radius (see Table 1). In the upper right panel, the CMD of an equal area field is shown for comparison. The cluster and field area are indicated in the lower panel, where the field of NGC 7789 covered by Gim et al. (1998) photometry is shown. In this panel the innermost circle indicates the cluster area, while the two outermost circles illustrate the field selection. This annulus have been chosen to have the same area and at the same time to be as far as possible distant from the cluster, to avoid contamination from NGC 7789 external halo stars. In all the panels filled squares (in red when color printed) refer to BSS stars, according to AL07 criteria (see text). Besides, different color filled squares (in cyan when color printed) are used for the BSS members of NGC 7789. In the CMDs, the two solid lines are an isochrone and a ZAMS drawn for the value of the fundamental parameters of NGC 7789 (see table 1). On the other hand, the dashed line (blue when printed in color) has been drawn for the theoretical distance modulus of the BSS members of the NGC 7789 cluster.

number of BSS (22) have been found to be cluster members, and we indicate them with magnitude-sized squares (cyan when printed in color) in Fig. 2. However, for the aim of this *Note*, what is actually relevant is the number of candidate BSS (*lacking a membership analysis in most cases, all stars in the appropriate region of the CMD are routinely considered to be BSS candidates*), and therefore we did not remove the members BSS from the candidate sample.

The first important fact to highlight is that candidate BSS are evenly distributed across the field. In the CMDs in NGC 7789 area (Fig 2, upper panels) we recognize a vertical sequence right above the TO, and an almost parallel, detached, bluer sequence. The BBS (see also Fig. 4 in AL07) do not follow closely none of these sequences, but are significantly spread in color.

While the sequence right above the TO is most probably due to a mix of binary stars and nearby field stars, the bluer sequence resembles the *blue plumes* found in dwarf galaxies (Momany et al 2007), or in the background of open clusters in the 3GQ (Carraro et al. 2005).

The bulk of these blue stars does not follow the solid ZAMS (compatible with stars at the same distance and reddening of NGC 7789), but lies red-ward. We suggest that this is a sequence of more distant and reddened young stars, similar to a *blue plume*. The dashed ZAMS (blue when printed in color) we over-imposed on it would in fact imply a distance of about 3 kpc, significantly larger than the distance of NGC 7789 (less than 2 kpc).

Along the *blue plume* we count about 34 stars. From AL07 we know that NGC 7789 harbors 22 BSS which are almost entirely concentrated within the cluster radius (see the bottom panel map). However, only a fraction of them (13) lie close to this blue sequence.

We conclude that a substantial fraction of the stars in the *blue plume* are young field stars located in the southern tail of the Perseus arm along the cluster line of sight, as evident also from the BSS candidates position in the field CMD (upper right panel). This result is supported by the HI radial velocity in the range of -65:-75 km/sec (Burton 1985), somewhat larger than NGC 7789 (-54.9±0.12 km/sec, Gim et al. 98).

Moreover, the NGC 7789 isochrone distance is in fact smaller than 2.0 kpc, while the distance to the HII regions associated to the arm (S163, S164, S166, and S170 for instance) at the same longitude of the cluster are larger (2.5--2.9 kpc, Russeil et al 2007), and compatible with the *blue plume*.

3.2. Berkeley 66

This is a distant open cluster, located well beyond the Perseus arm, but very close to the plane, and for that reason very reddened (Phelps & Janes 1996, Guarnieri & Carraro 1997, Villanova et al. 2005). It represents an interesting case since it lies along the line of sight where recently Xu et al. (2006) have estimated the distance to the Perseus arm to be about 2 kpc. In Fig. 3 we show the CMDs of Berkeley 66. The photometry is taken from Phelps & Janes (1996), who covered a $5'.1 \times 5'.1$ field around the cluster's nominal center and found that it has a radius smaller than 2 arcmin. This field of view is small and therefore we do not expect to find many stars associated to the Perseus arm, which lies much closer than the cluster.

In the left panel we consider only stars within the nominal cluster radius (2 arcmin, see Table 1), as defined by the circle in the lower panel map. We super-imposed an isochrone for the values of the basic parameters as in Table 1. A ZAMS for this reddening and distance modulus is also plotted

with the same symbols to guide the eye and indicate the region where BSS (filled symbols) are to be searched for, according to the AL07 criteria. The same representation is used in the field CMD (upper right panel), which contains all the stars outside the cluster area. This field -limited by the outermost circle in the map- has the same area of the cluster region. The spatial distribution of BSS candidates in the cluster and field is shown in the bottom panel, where the area covered by Phelps & Janes photometry is shown.

Within the cluster radius ($2'$) we count 63 BSS candidates (AL07 indicate 70, but possibly used a different radius). All stars 2.5 mag brighter than the TO are taken as BSS candidates. However, looking at the field CMD, the color and magnitude distribution of BSS candidates and the field stars are similar. In fact, we count in the field 68 BSS candidates. It is therefore likely that a significant number of BSS candidates are just field stars.

Although located behind the Perseus arm, no obvious traces of a tight young star sequence associated to the arm (*blue plume*) are found in the field of Berkeley 66. This is most probably due to the small field of view of the observations together with the highly irregular absorption and/or to the patchy structure of the arm.

3.3. Berkeley 70

This is another old star cluster reported to be very rich in BSS. AL07 list 64 BSS candidates, virtually all the stars above the TO. Although Berkeley 70 is relatively high above the Galactic plane ($b=+3.6^\circ$, Z approximately 250 pc), Burton (1985) has detected considerable HI emission toward its direction, which indicates that the Perseus arm is significantly thick, reaching up to $b = +8^\circ$ degrees. We take the photometry of Berkeley 70 from Ann et al. (2002), who performed a study of a $5'.8 \times 5'.8$ field centered on the cluster. The CMD is presented in Fig. 4 for the cluster (upper left panel) and field (upper right panel) region, together with the spatial distribution of all the stars and the candidate BSS (filled red circles when printed in color) in the lower panel map. Here the innermost circle corresponds to the cluster radius (~ 2.5 arcmin), whereas the region outside the cluster area and limited by the outermost circle identifies an equal area stellar field.

In the CMDs we over-imposed an isochrone and a ZAMS (solid lines) using the values from Table 1, and marked BSS candidates (following AL07) with filled symbols (red when printed in color). The upper part of the CMD is characterized by a number of blue stars close to the prolongation of the cluster's ZAMS, and another more scattered sequence right above the TO. The first of the two is a sequence of young stars at about the same distance of the cluster (~ 4.0 kpc), similar to the distance to the Perseus arm in this direction (Russeil et al. 2007), and therefore a fraction of these blue stars are likely to belong to the arm. Therefore, for the specific case of Berkeley 70, the Perseus arm young stars have roughly the same distance as the cluster, and for this reason we do not plot any additional ZAMS.

As an additional confirmation of their field stars nature, these stars are evenly distributed across the observed field and - according to the cluster radius (2.5 arcmin) - only a fraction of them lies within the cluster. The other, redder and more scattered sequence, is probably due to contamination of field stars near to the Sun, including stars in the Local arm. Besides, we note that other bright stars (brighter than the upper limit for BSS candidates according to AL07) lie close to this ZAMS, emphasizing their nature of young field stars associated with the arm.

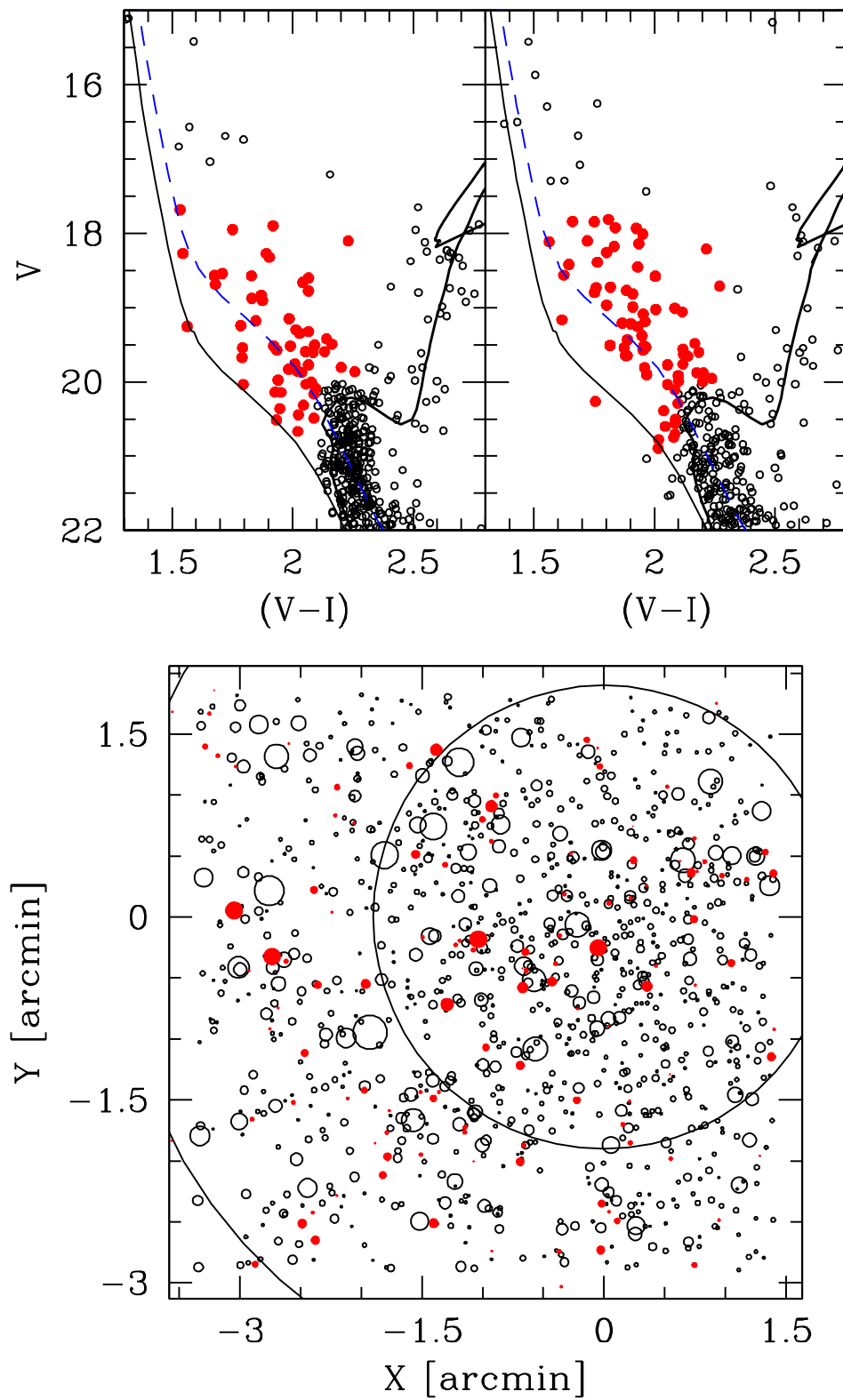


Fig. 3. Upper panels: CMD of Berkeley 66 for cluster (left) and field (right) regions, as defined in the lower panel, where the innermost circle is drawn adopting 2.0 arcmin for the cluster radius (see Table 1). The region outside the cluster area and limited by the outermost circle has the same area of the cluster region. Solid symbols (red when printed in color) indicate BSS candidates. The solid lines are a ZAMS and an isochrone for the most accepted values of the cluster fundamental parameters (as in Table 1), whereas the dashed line (blue when printed in color) indicates the expected location of young stars at the distance of the Perseus arm.

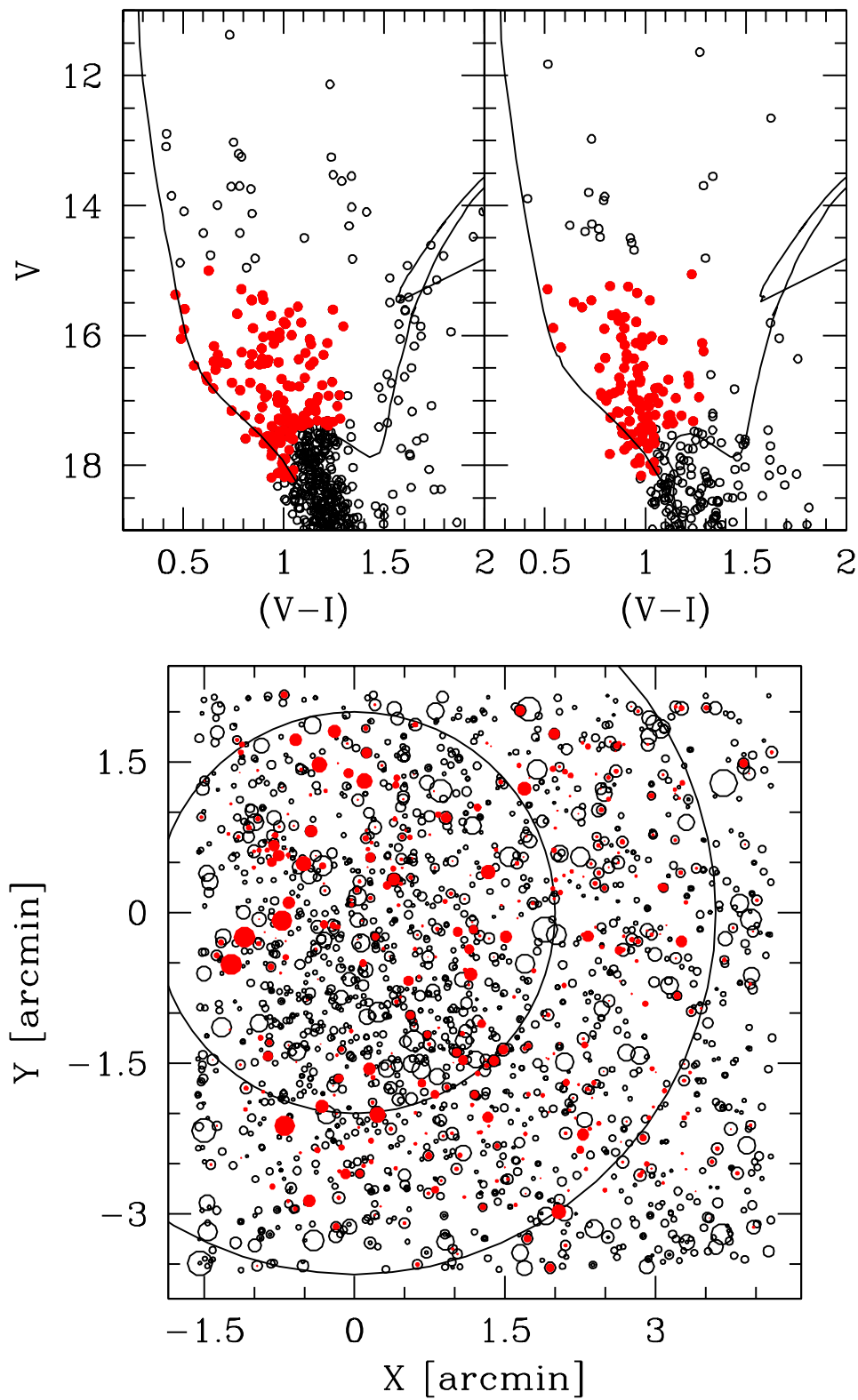


Fig. 4. Upper panels: CMD of Berkeley 70 for cluster (left) and field (right) regions, as defined in the lower panel, where the innermost circle is drawn adopting 2.5 arcmin for the cluster radius (see Table 1). The region outside the cluster area and limited by the outermost circle has the same area of the cluster region. Solid symbols (red when printed in color) indicate BSS candidates. The solid lines are a ZAMS and an isochrone for the most accepted values of the cluster fundamental parameters (as in Table 1).

Also in this case, the number and distribution of BSS candidates in the cluster and field CMDs are very similar.

We therefore conclude that the distribution of young blue stars in Berkeley 70 is that expected from the location of the cluster, right above and at the same distance of the Perseus arm.

4. Conclusions

The aim of this *Note* was twofold. On one side, we wanted to stress once again how derived statistics of BSS stars in Galactic OCs is crucially dependent on a proper accounting of field star contamination. Specifically, this paper addresses the effect of contamination introduced by the early type stellar component of spiral arms. Trends like the anti-correlation between absolute magnitude and BSS frequency (Piotto et al. 2004) must be reconsidered in the light of accurate radial velocity or proper motion-based memberships. Only this way the derived BSS population in OCs would be statistically meaningful. We are in the process of starting such observational effort for a number of selected open clusters.

On the other side, we have shown how the bulk of the stars populating the upper part of three representative open clusters (NGC 7789, Berkeley 66 and Berkeley 70) in the SGQ is mostly dominated by young stars located nearby the Sun - in the **Local** arm - and in the Perseus arm, which lies in front of (for Berkeley 66 and Berkeley 70), or beyond (for NGC 7789) these clusters. This was possible since we already know the existence, distance and location of the Perseus arm. This provides a confirmation that similar sequences found in the CMDs of stellar fields in other regions of the Galaxy can be used as spiral arm tracers (Carraro et al. 2005, Moitinho et al. 2007, Vázquez et al. 2007).

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