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On the occurrence of tidal tails in the Carina dSph

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Abstract. Wide field B,V photometry of the outer regions of the Carina dwarf spheroidal galaxy is presented. Six fields were observed to a distance from the centre up to 4.5 degrees. We detected a sizable sample of faint blue objects, with V≥ 23 and B-V≤ 0.4. These objects populate the same region of the color magnitude diagram of the Carina old Main Sequence stars. However, it is not clear whether they are tracing a tidal stream connecting Carina to the Galaxy. We also present some plausible working hypothesis concerning the nature of the objects.

Key words. Local Group – Stellar populations – Tidal tails

1. Introduction

The Local Group (LG) is a small sample of galaxies, dominated by two giant spirals, the Galaxy and M31. They are surrounded by ≈ 40 dwarf galaxies of different morphological types. These dwarf galaxies present quite different star formation histories (SFH), gas content, and chemical enrichments (Mateo 1998; Smecker-Hane et al. 1994; Gallart et al. 2004). Dwarf galaxies in the LG are a unique laboratory to study the formation and evolution of galaxies, since their stellar content can be investigated at star-by-star level. This means that the evolution of single galaxies, as well as the interactions with bigger ones, can be studied on a quantitative basis. Amongst dwarf galaxies, the class of dwarf spheroidals (dSphs) is important, because they are stellar systems with low-mass ($M \lessapprox 10^7 M_\odot$), low-surface brightness ($m \gtrapprox 23$ mag arcsec^{-2}), and low-internal velocity dispersion ($\sigma_v \leq 10 km/s$). Moreover, neither dust nor cool gas has been detected in LG dSphs yet. Their dynamical properties appear to be dominated by dark matter (DM), and indeed the M/L ratio estimated for these systems ranges from 5 (Fornax) to ≈ 300 (Draco,

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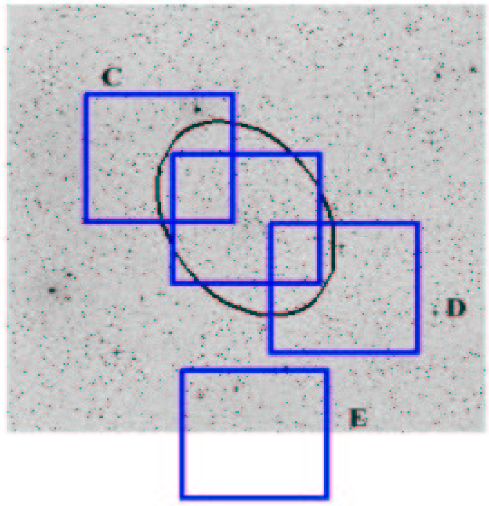

Fig. 1. $2^\circ \times 2^\circ$ DSS images with overplotted the position of central, C, D, and E fields. The ellipse shows the tidal radius of Carina. North is up, east is left.

Kleyna et al. 2001). For these reasons dSphs are key systems to test predictions based on Λ Cold Dark Matter (ΛCDM) models. In this scenario dSph galaxies are the first structures formed in the Universe, and from which bigger galaxies originate via merging and/or accretion processes. Moreover, (ΛCDM) models predict that stellar systems with masses and internal velocity dispersion similar to those of dSphs should have been able to form stars only in ancient epochs. This means that they should not have been able to retain enough gas to experience any star formation event in the last few Gyr. Such prediction supports the lack of gas and dust in dSphs, but it is in striking constrast with the complex star formation history of many LG dSph, in which a young population ($\leq 1Gy$) has been detected. Current estimates concerning the M/L ratio rely on the assumption that dSphs are relaxed systems, and high values of the M/L follow from the virial theorem. However, the firm detection of extra-tidal stars would be a very interesting empirical evidence at odds with this assumption. If these systems are tidally interacting with the Galactic potential well, the M/L ratio may be significantly overestimated, and in turn the DM content. It is worth mentioning that recent theoretical predictions (Hayashi et al. 2003; Moore et al. 1999), based on detailed N-body simulations, suggest that the tidal radius of dSphs may be larger by a factor ranging from 3 to 20 when compared with current estimates. In this context, Carina is a very interesting dSph, since it is the protoype of complex SFHs, with a well-defined evidence of a recent episode ($\leq 1Gy$, Monelli et al. 2003a). The existence of extra-tidal stars has been discussed in the literature (Kuhn et al. 1996; Majewski et al. 2000; Walcher et al. 2003), but no firm detection is available yet. We present deep wide field B.V photometry of six selected areas in the outskirts of the Carina dSph, and discuss the possible detection of extra-tidal stars.

2. Data set and reduction

Carina is characterized by low central density and large tidal radius ($\approx 30'$, Irwin & Hatzidimitriou 1995). For these reasons wide field cameras are mandatory to sample a significant fraction of the stellar content of this galaxy. Our data were collected with the Blanco 4m CTIO telescope, equipped with the MosaicII camera. The field of view is $36' \times 36'$, with a pixel scale of 0.27"/pix.

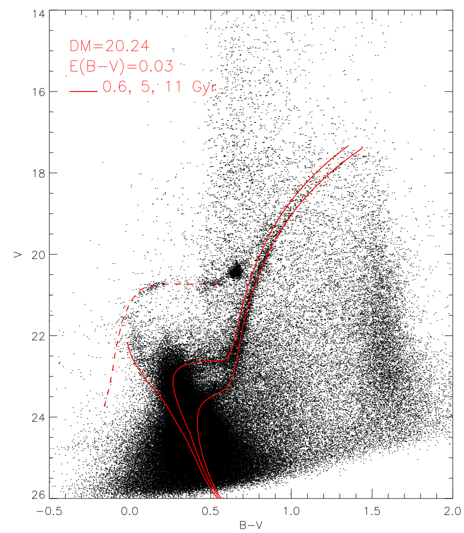

Fig. 2. CMD of the central field. Solid lines show theoretical isochrone at fixed chemical composition (Z=0.0004) and ages ranging from 0.6 to 11 Gyr. The dashed line shows the Zero-Age-Horizontal-Branch for the same chemical composition.

To identify extra-tidal stars in Carina we selected four regions mapping both the major and the minor axis up to 2° from the centre. Two more fields were chosen at intermediate directions and distances of 1 to 4.5° from the centre. For more details see Table 1 and Fig. 1.

field name	RA (h)	DEC (deg)	exp time B V
C	06:44:30	-50:44:00	9600 7200
D	06:39:30	-51:18:00	8800 6000
E	06:41:38	-50:58:00	5000 3000

Standard IRAF routines were applied for bias subtraction and flat field correction. The photometric reductions were performed with DAOPHOTII/ALLFRAME (Stetson 1995) reduction package. Fig. 2 and Fig. 3 show the CMD obtained from fields C and D. Individual panels show data collected with a single chip of the CCD camera (note that chip 3 was blind during the observations). These two fields are located approximately 25′ from the Carina centre and cross the tidal radius of Carina. The number of stars clearly decresases when moving from the centre to the outskirts, but there is a blue spur of faint objects ($B-V \leq 0.4, V \gtrsim 23$) that is present in all the panels. These objects have the same colours and magnitudes of the old Main Sequence (MS) of Carina, and are located at distances from the centre of the order of $\approx 40'$, i.e. well beyond the Carina tidal radius (Irwin & Hatzidimitriou 1995). Note that the stars plotted in this CMD have been detected in all the images. Fig. 2 shows the cumulative CMD of field E, located at one degree from the Carina centre. It is noteworthy that the same blue spur still appears.

Preliminary reduction of other three external regions support the detection of the blue spur sequence until 4.5° from the Carina centre. Moreover, the blue spur seems to be less populated at larger distances from the centre (see Table 1). However, integration time for the external fields are quite different, and therefore a quantitative analysis has not been performed yet.

3. Blue spur stars

Before we can assess the detection of such a strong component of extra-tidal stars, we have to analyze any possible source that can contaminate our sample. There are two main possible culprits: galactic field stars and background galaxies.

4. Conclusions

- We computed a synthetic CMD (Degl'Innocenti, (priv. comm.)) of the Galactic component for all our fields. Figure 5 shows an example comparing the real data with the simulation. All the features of the Galactic field are well represented by the model, but it predicts only a few tens of thick disk white dwarfs in the region corresponding to the blue spur. This supports the evidence

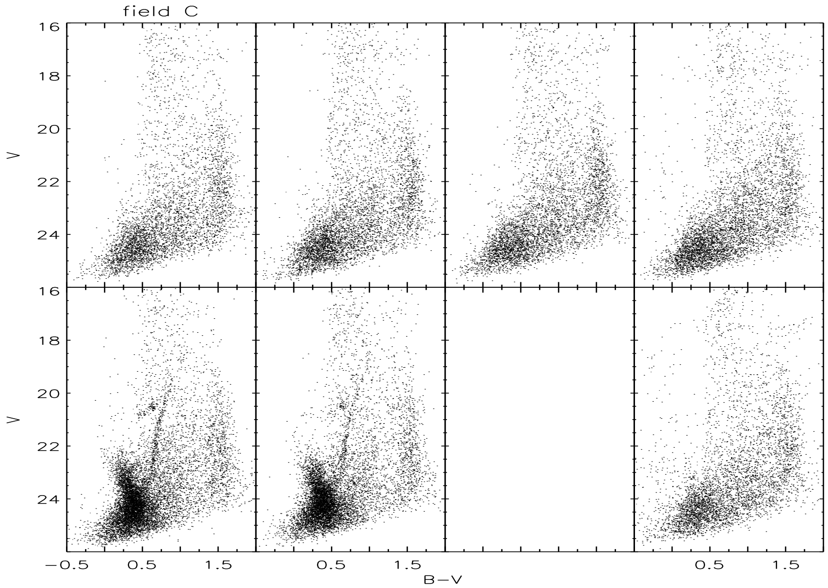

Fig. 3. CMD of field C. The eight panels clearly show the decreasing number of Carina stars, and the occurrence of a blue spur of faint objects with $B-V < 0.4$ and $V > 23$.

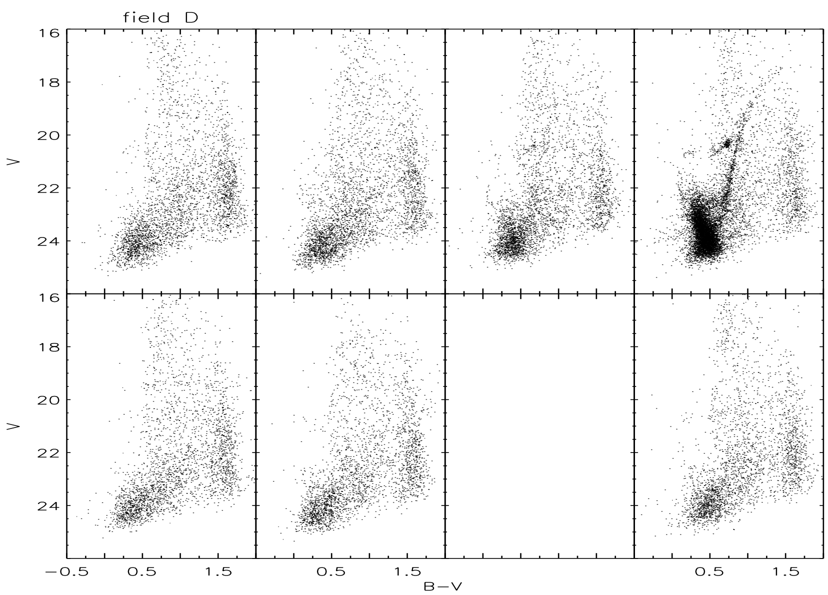

Fig. 4. Same as Fig. 3, but for field D.

that the blue spur is marginally populated by foreground stars.

• On the basis of current photometric data it is not possible separate backgroung galaxies from stars. To solve this problem we decided to use color-color planes based on near-ultraviolet and optical data. Interestigly enough, we found that the $U-V$ vs B–I colors allow a good separation between stars and

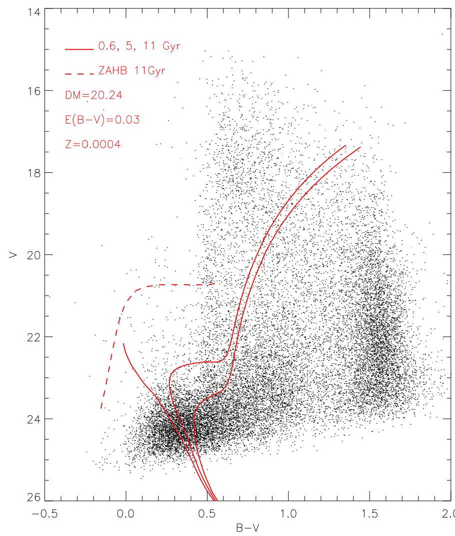

Fig. 5. Cumulative CMD of field E. This field is located 1° from the Carina centre in the southern direction.

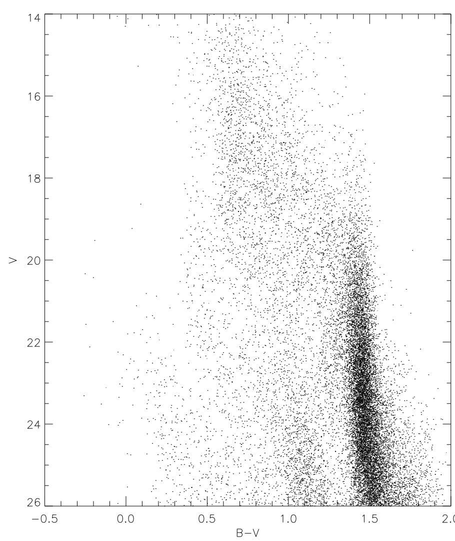

Fig. 6. Theoretical predictions based on Galactic models for the field E. Note that in the CMD region covered by blue spur stars are only present a few tens of disk white dwarfs.

galaxies. Figure 6 shows galactic evolutionary tracks for different morphological types and redshift smaller than 2 (Fioc & Rocca-Volmerange 1997), together with several stellar samples, namely field stars (Fontana et al. 2000), Reticulum (an old LMC globular cluster, Monelli et al. 2003b, middle), and NGC 3201 (Bedin et al. 2000, bottom). Data plotted in this figure show that the $U-V$ vs $B-I$ plane might allow us to split stars from background galaxies, since they are distributed in different regions.Note that the metal content marginally affects this approach, because the metallicity of the selected stellar samples ranges from solar (field stars) to [Fe/H]=-1.7 (Reticulum).

We have presented deep, wide-field B,V photometry of several regions in the outskirts of the Carina dSph galaxy. We detected a blue spur of faint objects that present the same colors and magnitudes of the old MS stars of Carina. These objects are present in all the observed fields, up to a distance of 4.5° from the centre. Comparisons with synthetic CMDs based on Galactic models strongly suggest that

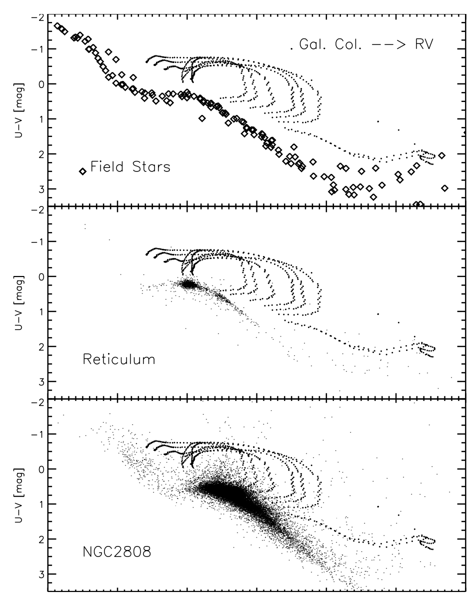

Fig. 7. Color-color $U-V$ vs $B-I$ plane, comparing three samples of stars of different metallicities with evolutionary tracks for galaxies. These tracks account for different morphological types for redshift smaller than 2. Deep and accurate photometry in four bands will allow us to split stars from galaxies, if any.

the contamination by Galactic field stars is marginal. However, on the basis of current data it is not possible to supply a quantitative estimate of the number of background galaxies in each field. We plan to address this open problem with new multiwavelength observations. This will allow us to put firm constraints on the detection of either extra-tidal stars or an extended halo in the Carina dSph.

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