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The Carina Project: color magnitude diagram and radial distribution

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Abstract. We present B, V photometric data of the Carina Dwarf Spheroidal Galaxy (dSph), collected with the Wide Field Imager (WFI) available at the 2.2m MPI/ESO telescope. We briefly discuss the main features of the color magnitude diagram (CMD) and in particular the mix of stellar populations present in this galaxy. A preliminary analysis of the spatial distribution of these populations over a substantial fraction of the body of the galaxy is also presented.

Key words. Galaxies: dwarf – Galaxies: individual (Carina) – Local Group – Stars: evolution

1. Introduction

DSphs are key stellar systems in several long-standing astrophysical problems (Dekel & Silk 1986), tightly connected with the evolutionary history of Local Group (LG) galaxies (Grebel 2001). Empirical evidence suggest that the bulk of LG dSphs have experienced a much more complex star formation (SF) history than Galactic globular clusters (Hodge 1989). Therefore, the stellar population content of dwarf galaxies is a target of great relevance. However, the limited area covered by astronomical detectors hampered for a long time an exhaustive investigation of these extended celestial objects and only recently the use of wide field detectors allows extensive sampling of their stellar populations.

To take advantage of such an opportunity we planned to use the WFI available at 2.2m MPI/ESO telescope to investigate stellar populations in Carina. In the dSph realm, the Carina galaxy is one of the most prominent example of multiple stellar populations, since its CMD shows a complex star-formation history. It has been suggested by Hurley-Keller et al. (1998) that

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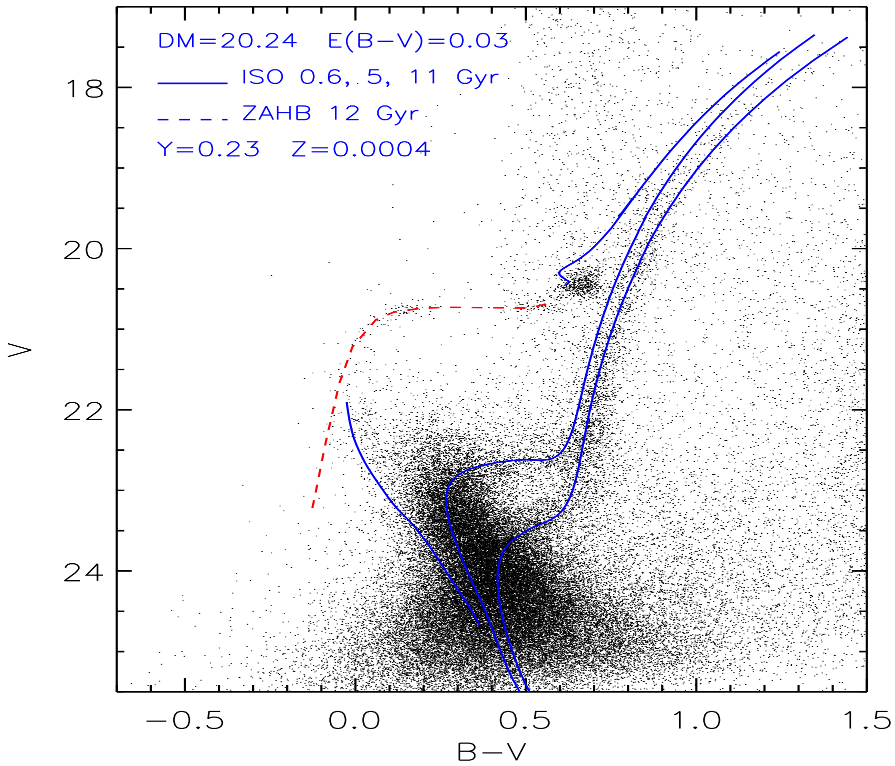

Fig. 1. The CMD of Carina. Selected isochrones and a Zero Age Horizontal Branch (for the labeled assumption on distance modulus, reddening, and chemical composition) are superimposed on the CMD of the galaxy.

this galaxy underwent significant bursts of star formation at 3, 7 and 15 Gyrs ago.

The *Carina Project* was driven by these stimulating peculiarities and aims at fully exploiting modern technological capabilities of wide field imagers to improve current knowledge of the stellar content of LG dSphs. In the following we present preliminary results concerning the CMD and the radial distribution of the Carina stellar populations.

More detailed information concerning *variable stars* and *evolutionary properties* can be found in the papers by Dall'Ora et al. and by Monelli et al. in these proceedings.

2. Observations and data reduction

Multiband B and V time series data of the Carina dSph were collected over three consecutive nights. To allow the sampling of the light curve of radial variables such as RR Lyrae and Anomalous Cepheids, we secured 54 consecutive B and V exposures of $\simeq$ 500 sec. each. The observed field covered an area of 34' x 33', pointed at the center of the galaxy. We have had an average seeing $\leq$ 1.0 arcsec both in the B and V band. This allowed us to obtain accurate photometry (S/N$\simeq$50) down to V$\simeq$23 and B$\simeq$23.5

NOAO mscred tasks (in the *IRAF* data analysis environment) were used for bias subtraction, dark count correction and flat fielding. With the exception of a few low-quality images, we stacked the eight individual CCD chips, using the entire set of B and V images (we used the *DAOPHOT* procedure *daomatch*, *daomaster* and *montage*). Photometry over the median image was carried out by using DAOPHOT package. A total of 68000 stars were identified and measured with the PSF fitting algorithm *allstar*.

3. The color magnitude diagram

Fig. 1 shows the CMD of the galaxy, obtained following the procedure outlined above. Main features of the diagram are: (i) broad main sequence, (ii) multiple, well-populated sub-giant branches, (iii) sizeable samples of blue and red horizontal branches stars, (iv) a well defined plume of blue, bright stars (V$\simeq$22).

To provide quantitative estimates of both mean metallicity and distance modulus of Carina, we superimposed selected stellar tracks and isochrones, from the "Pisa Evolutionary Group" (Castellani et al. 2003, in preparation) on our CMD. Best fit is obtained for values of metallicity Z$\simeq$0.0004 and for distance modulus (m-M)$\simeq$20.24. As a whole, the age of the old stellar component in Carina safely ranges from 10 to 12 Gyrs, while the bulk of "young" stars present turn-off ages of the order of $\simeq$5 Gyrs.

Moreover, our CMD brings forward the occurrence of younger Main Sequence (MS) stars with an age of the order of 1 Gyrs. Such an occurrence is interesting because data available in the literature so far suggested that the most recent burst of SF took place $\simeq$ 2-3 Gyr ago.

4. Radial distribution

On the basis of preliminary empirical evidence Mighell (1997) suggested that the old and the "not-too-old" populations in Carina present different radial distributions. To investigate this issue, we selected stars in suitable boxes representative of both populations (see Fig.2). When compared to similar analyses available in the literature, our approach presents the substantial advantage of quite large stellar samples, both for "old" ($\simeq$1000) and "young" ($\simeq$5000) populations.

Fig. 3 (left panel) shows that there is a detectable offset, of about two arcmin, in the peak density between the "old" population and the Carina center. On the other end, we found that (Fig.3, right panel) the isodensity contours of the "young" population appear much more regular when compared to the "old" one, resembling quite well the density distribution of the entire galaxy.

To estimate on a quantitative basis the difference between the two populations we performed several Kolmogorov-Smirnov (KS) tests. We found that the two "old" subsamples (Horizontal Branch, HB, and Sub Giant Branch, SGB) present the same radial distribution, since the KS probabil-

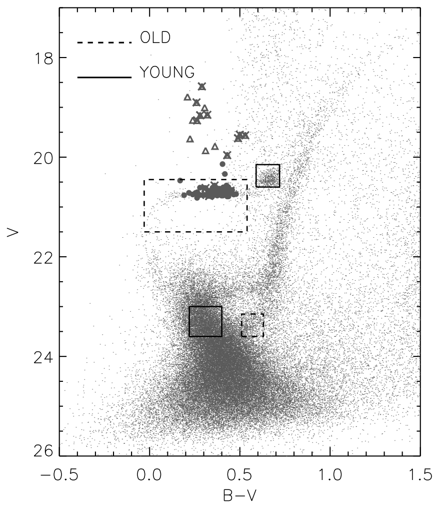

Fig. 2. Dashed and solid boxes show the CMD regions selected as representative of the "old" (HB and SGB) and the "young" (Red Clump, not-too-old MS) population respectively.

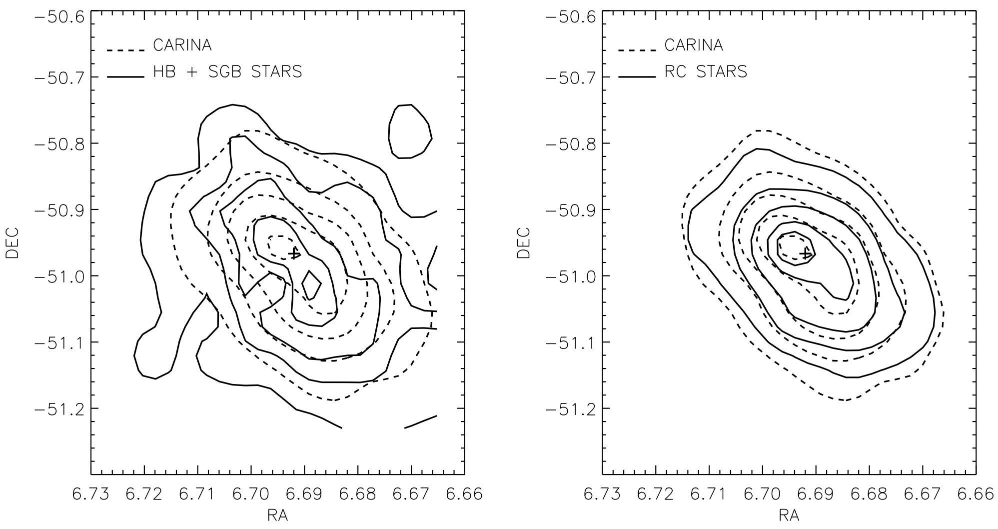

Fig. 3. Left panel: Isodensity map of the Carina stellar content (dashed) and of the "old" stellar population (solid) Right panel: Isodensity map of the Carina stellar content (dashed) and of the "young" stellar population (solid). In both panels, a cross marks the center of the galaxy.

ity is equal to $\simeq$ 90%. The same outcome applies to the two "young" samples, namely Red Clump stars and not-too-old MS, and indeed the probability given by the KS test is as hight as $\simeq$ 94%. On the other hand, the KS test applied to the "old" and the "young" samples, supplies a vanishing probability that the two distribution are the same.

We also investigated the spatial distributions of the two populations along the major and minor axis. We found that the distribution of the "old" component is broader than the distribution of the "young" component. *These evidence further support the suggestion of a difference in the spatial distribution between the "old" and the "young" stellar populations.*

5. Conclusions

We performed photometry of Carina DSph using the 2.2 WFI at ESO. Our investigation shows several interesting features both for the CMD and for the radial distribution of the stars. Moreover, current photometry suggests that last star formation episode took place $\simeq$ 1 Gyr ago, at variance with previous findings in literature. We also found that *stellar populations of different age present different radial distribution:* the spatial distribution of the old population along the major and minor axes is more asymmetric when compared with the intermediate age population. Moreover, the peak of this population is $\simeq$ 2 arcmin off-center.

References

Dekel, A. & Silk, J. 1986, ApJ, 303, 39

Grebel, E. 2001, Astrophysics and Space Science Supplement, 277, 231

Hodge, P. 1989 Ann. Rev. Astron. Astrophys. 27, 139

Hurley-Keller, D., Mateo, M., Nemec, J., 1998, AJ, 115, 1840

Mighell, K.J. 1997, AJ, 114, 1458