The Carina project: 
color magnitude diagram and radial distribution

M. Castellani\textsuperscript{1}, G. Bono\textsuperscript{1}, R. Buonanno\textsuperscript{1}, F. Caputo\textsuperscript{1}, V. Castellani\textsuperscript{1}, C.E. Corsi\textsuperscript{1}, M. Dall'Ora\textsuperscript{1,2}, M. Marconi\textsuperscript{3}, M. Monelli\textsuperscript{1,2}, M. Nonino\textsuperscript{4}, L. Pulone\textsuperscript{1}, V. Ripepi\textsuperscript{3}, H.A. Smith\textsuperscript{5}, A.R. Walker\textsuperscript{6}.

\textsuperscript{1} INAF, Osservatorio Astron. Roma, via Frascati 33, 00040 Monteporzio Catone, Rome, Italy. e-mail: marco@gruppolocale.net
\textsuperscript{2} Università di Tor Vergata, Rome, Italy
\textsuperscript{3} INAF, Osservatorio Astron. Capodimonte, Napoli, Italy
\textsuperscript{4} INAF, Osservatorio Astron. Trieste, Italy
\textsuperscript{5} Harvard-Smithsonian Center for Astrophysics, USA
\textsuperscript{6} National Opt. Astr. Obs., Tucson, USA

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. CM diagram – Dwarf galaxy – Photometry

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 sug-
gested by [Hurley-Keller et al. (1998)] that this galaxy underwent significant bursts of star formation at 3, 7 and 15 Gyr 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 ≃ 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 ≤ 1.0 arcsec both in the B and V band. This allowed us to obtain accurate photometry (S/N ≃ 50) down to V ≃ 23 and B ≃ 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 probability 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 high 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
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 $\approx 1$ 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 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.

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.

the peak of this population is $\approx 2$ 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
This figure "cmd.png" is available in "png" format from:

http://arxiv.org/ps/astro-ph/0301388v1