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Stellar populations in the Carina dSph galaxy

M. Monelli[1,2], M. Nonino[3], G. Bono[1], A.R. Walker[4], R. Buonanno[1,5], F. Caputo[1], C.E. Corsi[1], M. Dall'Ora[6], P. François[7], S. Moehler[8], A. Munteanu[9], L. Pulone[1], V. Ripepi,[6], H. Smith[10], P.B. Stetson[11], F. Thévenin[12]

[1] INAF, sezione di Roma, Via Frascati 33, 00040 Monteporzio Catone, Roma, Italy
e-mail: monelli@iac.es
[2] Instituto de Astrofísica de Canarias, C/ Via Lactea, 38205 La Laguna, Tenerife, Spain
[3] INAF, Sezione di Trieste, Via Tiepolo 11, 34131 Trieste, Italy
[4] Cerro Tololo Inter-American Observatory, NOAO, Casilla 603, La Serena, Chile
[5] Universitá di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy;
[6] INAF, Sezione di Capodimonte, Via Moiariello 16, 80131 Napoli, Italy
[7] GEPI, Observatoire de Paris-Meudon, 92125 Meudon Cedex, France
[8] European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching bei Mnchen, Germany
[9] Universitat Pompeu Fabra, Dr. Aiguader 80, 08003 Barcelona, Spain
[10] Dept. of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
[11] Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, NRC, 5071 West Saanich Road, Victoria, BC V9E 2E7, Canada
[12] Observatoire de la Côte d'Azur, BP 4229, 06304 Nice Cedex 4, France;

Abstract. The small and elusive Carina dSph still presents many open questions concerning its stellar populations and dynamical evolution. It presents a unique star formation history, with well separated episodes over a time of ~10 Gyr. However, the complex star formation history does not seem to have caused a strong chemical evolution of its stellar content. Moreover, the occurrence of extra-tidal stars has not been firmly established. These might be the signature of ongoing tidal interaction with the Galaxy, or belong to a diffuse halo as suggested by recent N-body simulations. We undertook a photometric and spectroscopic investigation over a substantial fraction of the Carina body, to fully characterize its stellar content.

Key words. Galaxies: dwarf – Galaxies: Local Group – Galaxies: individual (Carina) – Techniques: photometric – Techniques: spectroscopic

1. Introduction

The Carina dSph galaxy is a stellar system relevant to understanding the general properties of the Local Group galaxies. It presents a complex star formation history (Smecker-Hane et al. 1994; Monelli et al. 2003), with distinct episodes spaced out by long quiescent phases. As a consequence of this mix of

Send offprint requests to: M. Monelli

populations a sizable sample of variable stars, both in the H- and He- central burning phase, have already been detected (Munteanu et al., this volume). Moreover, photometric investigations support the evidence that the spread in the chemical composition is quite small (Monelli et al. 2003), but spectroscopic results based on bright Red Giants (RG) support a larger intrinsic spread (Koch et al. 2004).

The occurrence of extra-tidal stars and tidal streams connecting Carina with the Galaxy has been investigated using different stellar tracers (Kuhn at al. 1996; Majewski et al. 2000a,b), but no firm conclusions have been reached yet (Morrison et al. 2001). Recent N-body simulations (Hayashi et al. 2003; Kazantzidis et al. 2004) support the existence of diffuse halos surroundings nearby dSphs. According to these simulations, the tidal radii of dSphs with low central density might be underestimated up to a factor of 20.

We present the results of a photometric and spectroscopic campaign aimed at studying the Carina dSph galaxy. We discuss here the occurrence of extra-tidal stars and present preliminary results concerning the radial velocity distribution.

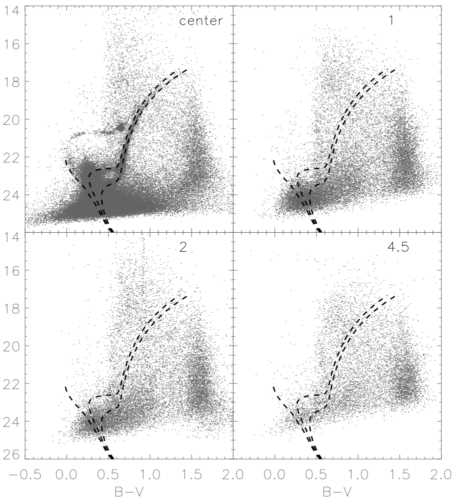

Fig. 1. Top Left - CMD (V,$B-V$) of the Carina central region (36×36 arcmin) which includes $\approx 90,000$ objects. The comparison with stellar isochrones (DM=20.24, E(B-V)=0.03) suggests that the three main star formation episodes occurred at t ≈11, 5, and 1 Gyr ago. **Others** - The same isochrones have been overplotted on the CMDs of three external regions located at 1.0, 2.0 and 4.5 degrees from the center. Note that the spur of faint blue objects located at 23≤V≤24.5, B-V≤0.4 is located in the same CMD region of the Carina old MS stars. The different CMDs include on average $\approx 20,000$ objects.

2. Photometric data

We observed the central region and eight fields along the major and minor axes, with distances ranging from 0.5 to 4.5 degrees from the Carina center. These regions have been observed in B and V bands with the MOSAICII camera (f.o.v. 36′×36′) available at the 4m CTIO Blanco telescope. Multi-epoch data have been collected between December 1999 and January 2005. The photometric analysis was performed using DAOPHOT/ALLFRAME. Fig. 1 shows the Carina V,B-V color-magnitude diagram (CMD) of the central (top left panel) and of selected outer regions. The CMDs of the external fields disclose a sizable sample of faint blue objects (23≤V≤24.5, B-V≤0.4). The comparison between observations and isochrones, for fixed chemical composition (DM=20.24, Z=0.0004), indicates that these objects are located in the same CMD region as the old TO stars we have already detected in the Carina center.

To understand the nature of these objects we investigated the occurrence of contamination by background galaxies (Bono et al. 2005). To estimate the number of galaxies in our CMDs we devised a new photometric diagnostic, based on the (U-V,B-I) color-color plane. We collected U,I-band data with the MOSAICII camera for the central region and for a field located 1 degree south of the Carina center. We selected ≈6000 objects in the region where background galaxies are expected (Bono et al. 2005). Fig. 2 shows the Carina V,B-V CMD before (left) and after (right) subtracting background galaxies. This diagnostic appears to work quite well, and indeed down to $V \sim 23.5$ ≈70% of blue objects appear to be real stars. Moreover, the TO region seems better defined, and the color spread of the Main

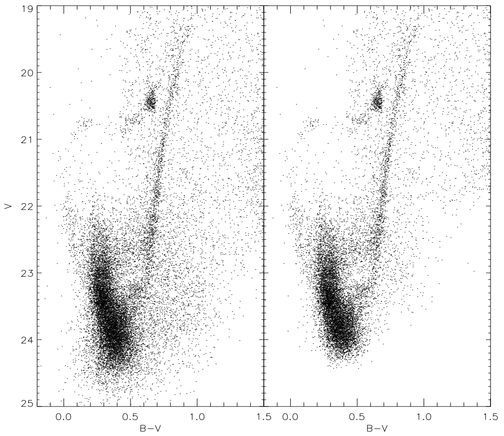

Fig. 2. The left and the right panel show the CMD of the Carina central regions before and after removing the galaxy contamination. Approximately ≈ 6000 galaxy candidates have been selected from the color-color plane and subtracted. The left panel shows the objects (≈40000) which have been detected in all the four bands. The TO region of the old stellar component appears better defined in the right panel and the spread in color of MS stars is smaller.

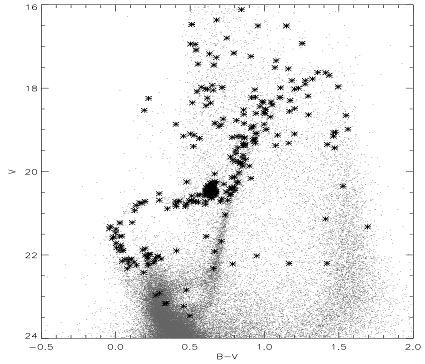

Fig. 3. Position on the CMD of the stars we selected for spectroscopy. The targets have been selected to study the kinematical and chemical properties of the three populations in Carina.

Sequence (MS) is smaller. Unfortunately, the limiting magnitude of U and I-band data are too shallow to firmly establish the nature of the objects around the TO luminosity of old MS stars ($V \sim 24.5$, $U \sim 25$). This problem is even more severe for the field located at 1 degree from the Carina center (bad weather conditions), and a meaningful comparison between the two fields is not possible with the present data. However, the circumstantial evidence that the blue objects we detected are located in a region of the color-color plane typical of MS stars indicates that they might be truly Carina stars.

3. Spectroscopic data

Despite the complicated star formation history, the photometric data support the evidence of a small spread in the metal content (Monelli et al. 2003): *i)* the small luminosity spread of the Horizontal Branch; *ii)* the small color spread of the Red Clump; *iii)* the thickness of the RGB. However, the subtle effect of the age-metallicity degeneracy cannot be excluded until the chemical composition is known. To quantitatively constrain this effect, and to study the kinematical properties of stars from different populations, we collected low-resolution spectra with FORS2@VLT (f.o.v. $6.8' \times 6.8'$). We observed two regions close to the Carina centre, and three fields located across the core radius, at $\sim 10'$ from the centre. We adopted the 1400_V grism (λ_{cent}=520.0nm, $\Delta\lambda$=130nm), and spectra were collected for 330 stars. The targets are plotted in Fig. 3. We selected objects from different populations, ranging from the tip of the RGB down to the MS stars of the young and intermediate-age population. The wavelength calibration has been done using daily He, Ne, HgCd arcs, and, in order to improve the calibration, wavelengths values for the transitions used were taken from http://physics.nist.gov/. Moreover, a few high S/N ratio spectra have been collected with FORS2 and the 1028z grism (λ_{cent}=860.0nm, $\Delta\lambda$=175nm). Fig. 4 shows two examples of spectra collected with FORS2. The high S/N ratio of the spectra will allow us to determine precise radial velocities, and homogenous estimates of the chemical compostion (Thévenin et al. 1992). Preliminary results are shown in Fig. 5, where the comparison between the ra-

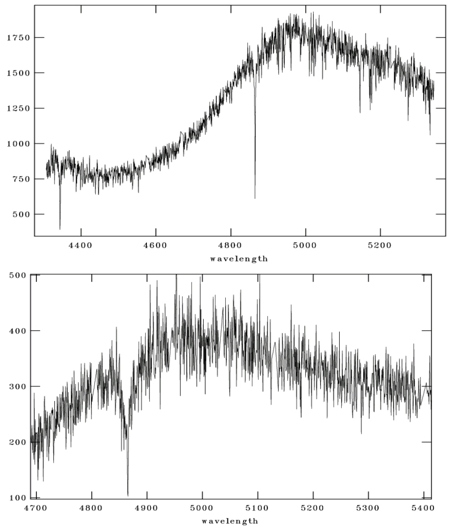

Fig. 4. Two examples of spectra collected with FORS2, adopting the 1028z grism and an integration time of 4800s. *Top* - RGB star (B=20.91, B-V=0.63): the H_β (486.1nm), the H_γ(434.2nm),and Mg triplet (≈517nm) features are clearly visible. *Bottom* - Spectrum of a MS star (V=22.3, B-V=0.35. This star is much fainter, but nonetheless the S/N ratio allows the detection of the H_β and the Mg triplet)

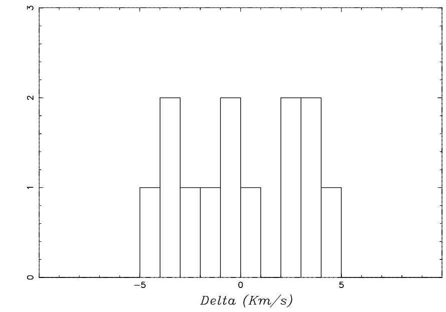

Fig. 5. Comparison of the radial velocity for a sample of 13 star in common with Mateo et al. (1993).

dial velocity estimates for a sample of stars in common with Mateo et al. (1993) is shown.

4. Conclusions

We have presented preliminary results of a long-term photometric and spectroscopic project aimed at investigating the stellar content of the Carina dSph (Monelli et al. 2005, in prep.). Accurate estimates of a basic parameter such as the tidal radius still hinge on the robust multiband identification of the Carina faint stellar components. In particular, it appears crucial to establish whether both old and intermediate-age, extra-tidal stars are present in Carina, and in turn whether they are distributed in an extended spherical halo or along tidal stream(s). These occurrences will supply robust empirical constraints on the physical assumptions currently adopted in numerical simulations of galaxy formation and evolution. Moreover, the spectra we collected will be an important step to understand the dynamical and chemical evolution of this system.

No doubt a comprehensive photometric and spectroscopic investigation of the Carina stellar structure will be an important step forward in our knowledge of these elusive stellar systems and how they interact with the Galaxy.

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