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The Fornax Project

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Abstract.
The Fornax Project aims at mapping the classical instability strip of the Fornax dwarf spheroidal galaxy, from the faint Dwarf Cepheids ($V \sim 24-25$ mag) to the bright Anomalous Cepheids ($V \sim 19$ mag). To achieve this goal, deep B, V time-series photometry of the galaxy has been obtained with the Wide Field Imagers (WFIs) of the ESO 2.2 m and CTIO 4 m telescopes, and the Clay camera at the Magellan 6.5 m telescope. Preliminary results are presented on the Oosterhoff classification of the RR Lyrae stars identified in a northern portion of Fornax field and in three of its globular clusters.

Key words. Galaxies: individual: Fornax dSph – Globular Clusters: individual: Fornax 3, Fornax 4, Fornax 5, Fornax 2 – Stars: variables: other – Stars: oscillations

1. Introduction

The Fornax Project is an international collaborational set up to make a comprehensive and deep study of the short period variable stars in the field and in the globular clusters (GCs) of the Fornax dwarf spheroidal (dSph) galaxy. The Fornax dSph is relatevely close to the Milky Way (d= 140 kpc) and hosts a system of five globular clusters (Baade & Hubble 1939;

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Hodge 1961, 1965, 1969). Previous studies of variability in Fornax include the Bersier & Wood (2002) survey of the 0.5 deg^2 central region of the galaxy, and the Mackey & Gilmore (2003, hereafter MG03) detection of candidate variables in Fornax 1, 2, 3 and 5, based on HST archive data. Both these studies were lacking in several respects, since they were either too shallow, or spanned a too short time baseline to reliably determine the pulsation characteristics and to detect faint variables such as the Dwarf Cepheids (DCs). Our survey supersedes these previous works in spatial coverage, time resolution, depth and photometric accuracy. Data collection and variable star identification strategies of the Fornax Project are optimized to cover the Fornax classical instability strip from $V \sim 24-25$ mag to $V \sim 19$ mag. This magnitude range includes RR Lyrae stars, DCs, Anomalous Cepheids (ACs) and Population II Cepheids (P2Cs), for which we are obtaining well sampled, deep and accurate light curves allowing independent estimates of periods and pulsation properties. Our study provides a deeper knowledge of the properties of the DCs in an extragalactic system (see Poretti et al., these proceedings), and allows us to map the star formation episodes that have occured in Fornax using the various types of variables as tracers of the different stellar populations. Important clues on how our Galaxy has formed will also be derived from the comparison of the pulsation properties of the Fornax variables with those of their Milky Way counterparts.

2. Observations and data reductions

Our dataset consists of deep ($V \simeq$ 24-26 mag), high accuracy, well-sampled B, V time-series data covering about 1 deg^2 of the Fornax dSph, obtained with the WFIs of the 2.2 m ESO-MPI and the 4 m Blanco CTIO telescopes, and of high spatial resolution photometry of Fornax clusters taken with the 6.5 m Magellan/Clay telescope. Observations were optimized to allow a good sampling of the DCs light curves (typical periods $P \leqq 0.2$ d) and to detect brighter variables with periods $P \lesssim 2$ d (e.g. ACs). Point-spread-function (PSF) photometry of the data was performed with the packages DAOPHOT-ALLSTAR II (Stetson 1996) and ALLFRAME (Stetson 1994). Variable stars were identified with the Image-Subtraction Method as performed within the package ISIS2.1 (Alard 2000, for the 2.2 m ESO WFI data) and the SuperMACHO pipeline (Rest et al. 2005, for the 4 m CTIO WFI data). Both packages are optimized to detect variable stars in crowded fields, and are much more effective than traditional techniques identifying low-amplitude, faint variables such as the DCs. Data analysis is in progress, and here we present preliminary results on the variable stars found in the four lower chips of the 2.2 m ESO WFI mosaic covering a $33' \times 34'$ portion of Fornax centered at $\alpha_{2000} = 02^h39^m59^s$, $\delta_{2000} = -34°10'00''$ (hereafter Fornax Field_1, see Section 3), and in four of the galaxy's GCs (Section 4).

3. Field variable stars in Fornax

The lower 4 CCDs of Fornax Field_1 cover an area of about 0.16 deg^2, and are found to contain 706 candidate variable stars. We have already confirmed and classified 355 of them. Study of the remaining objects is in progress. This number gives a lower limit for the variable star density in Fornax twice as large as that derived by Bersier & Wood (2002), corresponding to more than 2000 variable stars in total. The classified variables include: 247 RR Lyrae stars (among which are about 50 double-mode pulsators), 11 ACs, 67 DCs, and 30 binary systems. The DCs sample in Fornax is so far the largest one in an extragalactic stellar system. Figure 1 shows the color-magnitude diagrams of the four lower CCDs of Fornax Field_1 with the variable stars marked by filled symbols. We have fully analyzed the variable stars in one of these four CCDs (namely Chip 6) and found for the RR Lyrae stars average periods of 0.595 d (r.m.s.= 0.039) for the *ab*-type, and 0.361 d (r.m.s.= 0.040) for the *c*-type variables, respectively. Thus, similarly to other Local Group dSphs, the field RR Lyrae stars in Fornax appear to have properties intermediate between the two Oosterhoff types (Oosterhoff 1939) observed for the Milky Way cluster vari-

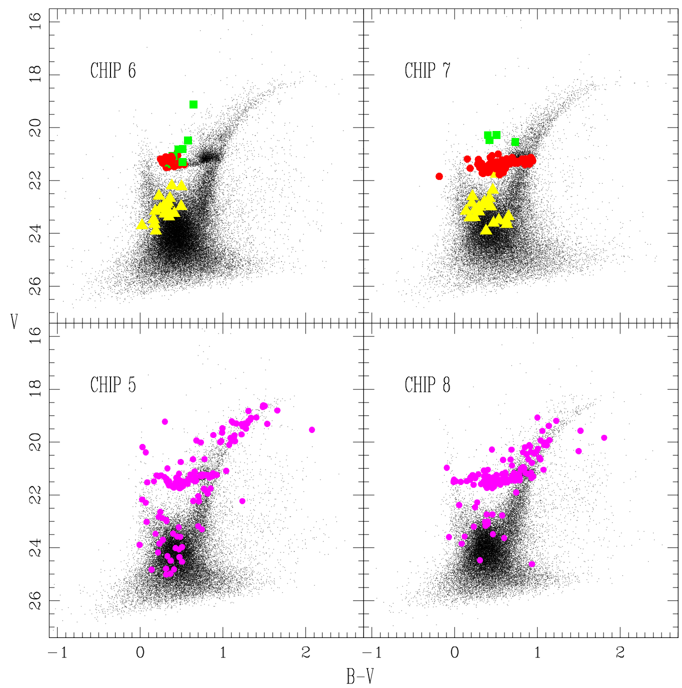

Fig. 1. Color-magnitude diagrams of lower 4 CCDs of Fornax Field_1. Different symbols in the two upper panels of the figure are: RR Lyrae stars (filled circles), ACs (filled squares), and DCs (triangles). Filled circles in the two lower panels are candidate variables not yet classified. According to the location on the horizontal branch many of them are likely RR Lyrae stars.

ables. The average V magnitude of the field RR Lyrae stars in Chip 6 is: $\langle V(RR)_{\rm field} \rangle$ = 21.281 ± 0.100 mag and leads to a distance modulus of: $\mu_{\rm Fornax}$=20.72±0.10 mag, in very good agreement with estimates by Buonanno et al. (1999), Saviane et al. (2000), MG03.

4. Variable stars in the Fornax GCs

We have observed four of the Fornax GCs and identified variable stars in all of them. Figure 2 shows the color-magnitude diagrams of the four clusters with the variable stars marked by filled symbols. They are mainly RR Lyrae stars, but we also identified a few DCs and ACs/P2Cs. Results on the cluster variables are summarized in Table 1. Only for Fornax 3, 4 and 5 does our sampling of the RR Lyrae light curves enable a reliable definition of the periods, allowing a comparison with the Milky Way GCs in the Oosterhoff log$\langle$ $P_{ab}\rangle-$ [Fe/H] plane. According to mean period of the *ab*-type RR Lyrae stars Fornax 3 and 5 fall respectively at the edges of the Oosterhoff II and I regions defined by the Galactic GCs, while Fornax 4 falls inside the "Oosterhoff gap". However, this cluster appears to have a bimodal period distribution with peaks around 0.55 and 0.65 d, as if the two Oosterhoff types were both present inside the cluster.

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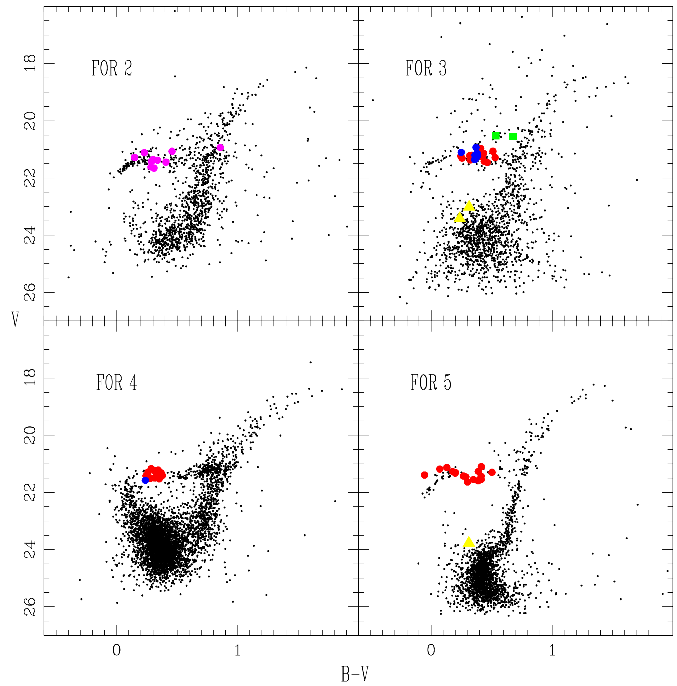

Fig. 2. Color-magnitude diagrams of Fornax clusters 2, 3, 4 and 5. Different symbols are: RR Lyrae stars (filled circles), ACs/P2Cs (filled squares), and DCs (triangles).

Table 1. Properties of the variables in Fornax GCs.

Type	For 2	For 3	For 4	For 5
RR Lyr	10	28	18	17
DCs	–	2	–	1
ACs/P2Cs	–	2	–	–
$\langle P_{ab} \rangle$	–	0.606	0.592	0.576
$\langle P_c \rangle$	–	0.358	0.359	0.353
[Fe/H][a]	−1.79	−1.96	−2.01	−2.20

[a]Metal abundances are from Buonanno et al. (1998,1999)

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