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A large and homogeneous sample of SX Phe stars in the Fornax dwarf spheroidal galaxy

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Abstract. We report on the detection of sixty–one SX Phe stars in the Fornax dwarf spheroidal galaxy using the Wide–Field Imager at the 2.2m ESO–MPI telescope. In spite of their extreme faintness ($22.0 < B < 24.0$), the light curves of these short–period pulsators have been clearly detected. We compare the Period–Luminosity relations in the Fornax galaxy and in the Milky Way. The light curves of a candidate SX Phe star in the For 5 globular cluster is also presented (Magellan/Clay observations).

Key words. Stars: Population II – Stars: variables : δ Sct – Galaxies : Fornax – Stars: oscillations – Galaxies: distances

1. Introduction on the nomenclature of short–period pulsating stars

The nomenclature of the short–period (P <0.20 d) pulsating stars located below the Horizontal Branch in the classical instability strip is a bit confusing. In the Milky Way there is a physical distinction between δ Sct and SX Phe stars: the former are Pop. I stars, the latter are Pop. II stars. Among Pop. I stars, the amplitude can vary from a few 0.001 mag

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to several 0.1 mag. Even if high amplitude δ Sct (HADS) stars are likely radial pulsators, there are several examples of the excitation of nonradial modes (Poretti 2003). In a similar way, SX Phe stars show a mixture of modes, especially in globular clusters. Therefore, the separation between HADS and SX Phe stars is not an easy task in the Milky Way, if no details about the metallicity are known. The study of double–mode pulsators has introduced a new tool, since the ratio between the fundamental and the first overtone radial modes is sensitive to metallicity effects (Poretti et al. 2005).

In the past, it was quite common to use the term "Dwarf Cepheids" when these short–period variables were observed in globular clusters. This originates from the fact that they can be used as distance indicators since they follow a $P - L$ relation similar to the more evolved Classical Cepheids. However, the term has an unclear physical meaning in the astrophysical context, since the two groups of stars are quite different. It is more appropriate to use the SX Phe term to identify the short–period variables in the globular clusters, since they are most likely old, metal–poor stars. On the other hand, it sounds inappropriate for the variables in the galaxies, since they could have different ages and metallicities; hence, we should apply the same distinction as in the Milky Way, i.e., SX Phe and HADS stars. Such a distinction may seem a bit pedantic, so the old term "Dwarf Cepheids" still survives in the current literature.

The use of pulsating stars with period shorter than 0.20 d as distance indicators has made some progress in the last years, particularly in the case of globular clusters (e.g., Pych et al 2001, Mazur et al. 2003). On the other hand, due to their faintness, not many of these pulsating stars have been discovered so far in other galaxies: Mateo et al. (1998) and Poretti (1999) describe the first results obtained on the Carina dwarf spheroidal (dSph) galaxy. However, it appeared possible to exploit in a more complete way their potentialities by performing more intensive and deep surveys. Therefore, we were strongly motivated to start an observational project on the Fornax dSph galaxy with the twofold goal to reduce the gap between knowledge of SX Phe stars in the Milky Way and those in other galaxies and to test them as distance indicators.

2. Observations and data reduction

The feasibility of our project to detect SX Phe stars in external galaxies was demonstrated by the first observations of the northern part of the Fornax dSph galaxy in November 2001. The Wide–Field Imager (WFI) at the 2.2 m ESO–MPI telescope was kept fixed on the same position on three consecutive nights. Since the expected periods were very short, we took three consecutive images in *B*–light (700 sec each), followed by a single exposure in *V*–light (1000 sec). This strategy ensured the dense *B* timeseries necessary to perform a reliable frequency analysis and allowed us to obtain the mean brightness and amplitude values in a two–colour system. Photometric reductions were carried out with the packages DAOPHOT ALLSTAR-II (Stetson 1996) and ALLFRAME (Stetson 1994). The variable stars were identified using the Image Subtraction Technique as performed within the package ISIS 2.1 (Alard 2000). We have fully reduced four chips of the WFI mosaic, detecting 61 short–period stars and hundreds of RR Lyr variables. For the latter stars, see Clementini et al. (these proceedings) and Greco et al. (2005).

The Fornax galaxy is known to host "a mix of old and intermediate–age stars with different metal abundances" (Held 2005) and therefore we should distinguish between HADS and SX Phe stars. However, at this stage, we consider them all as SX Phe stars, i.e., stars belonging to the older population. This seems justified by the very short periods we found and by the average low metallicity of the Fornax galaxy. We also stress that such a sample is very large and, being comprised of similar stars at the same distance, quite unique for number and homogeneity.

3. The detection of SX Phe stars

The intranight light curves are accurate enough to exhibit the rapid variability of the SX Phe

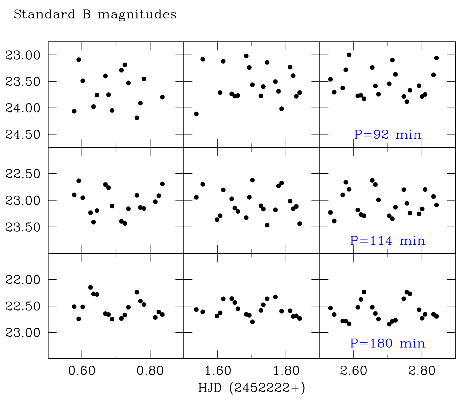

Fig. 1. The intranight light curves of three SX Phe stars in the Fornax galaxy. Variability is discernible on these curves even at the shortest periods (upper row). Note the faintness of the variables.

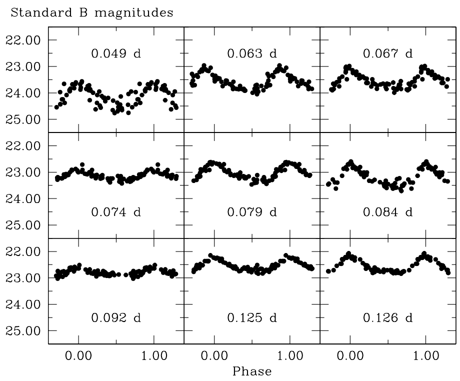

Fig. 2. Folded light curves of SX Phe stars in the Fornax galaxy. The B mean luminosity increases by 1.7 mag from the shortest to longest periods.

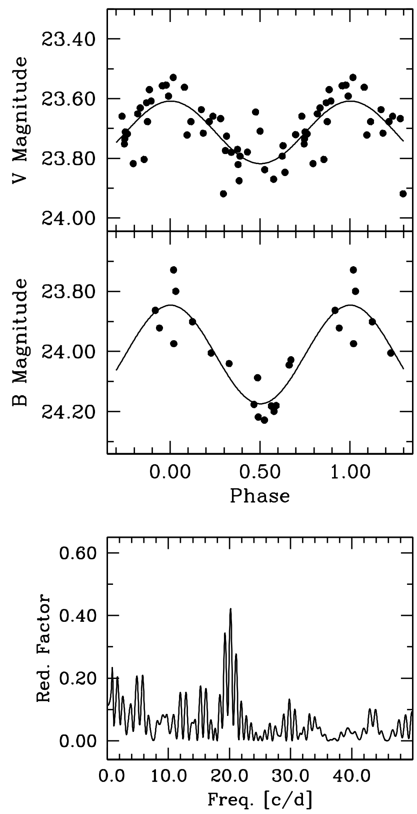

Fig. 3. Folded light curves and power spectrum of the candidate SX Phe star in the For 5 globular cluster (Magellan/Clay observations).

stars (Fig. 1), in spite of their extreme faintness ($22.0 < B < 24.0$). The timeseries just sketch the light curves for the shortest periods (upper row, P=92 min; each exposure covers 0.13 p). They define the light curve shape in a clearer way when the period lengthens (middle row, P=114 min; the exposure covers 0.10 p) and, finally, they show the regular light curve for the longest periods (lower row, P=180 min; 0.06 p). When performing the frequency analysis, the B data covering three consecutive nights ensured a high level of detection. Figure 2 shows the folded light curves in B–light (61 datapoints); the V data (17 points) have also been folded using the period values obtained from the more numerous B data. Figure 2 is a $P-L$ relation by itself: we can see how the mean B magnitude brightens from 24.0 to 22.0 with increasing period.

In a follow–up of the project, we obtained specific observations of the globular clusters in Fornax using the Magellan telescope and the Clay camera. Figure 3 shows the B and V light curves (the V filter has been used to obtain the denser timeseries here) and the power spec-

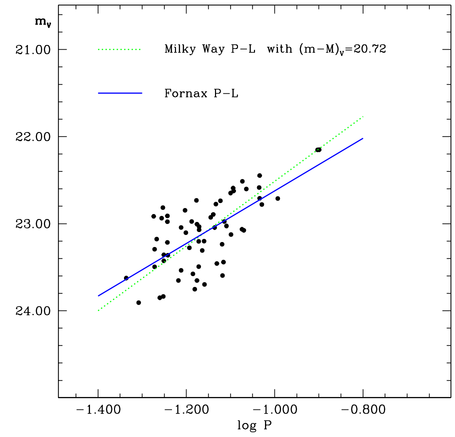

Fig. 4. The solid line (least–squares fit) is the $P-L$ relation as derived from Fornax SX Phe variables (filled circles); the dashed line is the $P-L$ relation as obtained from SX Phe and HADS stars in the Milky Way assuming $(m-M)_V$=20.72 for Fornax.

trum of the only candidate we found in For 5. The period is 0.0495 d (i.e., 71 min) and the full amplitude is 0.21 mag in V–light. We also note that two SX Phe stars were found in the outskirts of For 3 on the WFI images.

4. The $P-L$ relation and the distance modulus

We used the periods and the m_V apparent magnitudes to determine the slope of the Period–Luminosity ($P-L$) relation in Fornax (Fig. 4, solid line). The result, -3.02 ± 0.44, is smaller than that observed in the Milky Way (–3.725, McNamara 1997). We stress that the range covered by the Fornax stars in $\log P$ (from -1.35 to -0.90) is narrower than that covered by the Milky Way stars (from -1.40 to -0.55). The different distribution of periods probably reflects the differences in the stellar content: the Milky Way contains many more Pop. I HADS stars than Fornax and in turn these stars have longer periods than Pop. II SX Phe stars.

The $P-L$ relation given by McNamara (1997) can also be drawn in the $\log P - m_V$ plane by assuming a distance modulus of $(m-M)_V = 20.72$ for Fornax (dashed line), as derived from RR Lyr variables (Greco et al. 2005). As can be seen (Fig. 4), the two lines are nearly coincident in the period range of the Fornax variables. We can also make the reverse exercise to calculate the distance modulus of Fornax assuming the McNamara $P-L$ relation. In such a case we get $(m-M)_V = 20.71 \pm 0.04$, a value in excellent agreement with the previous ones (e.g., Buonanno et al. 1999, Saviane et al. 2000, Greco et al. 2005).

5. Conclusions

The large sample of SX Phe variables in the Fornax galaxy shows a well–defined $P-L$ relation, which is in good agreement with the one found in the Milky Way. The results briefly presented here seem to confirm that these short–period stars can be used as stellar candles in the Local Group and that they can provide an independent method to measure distances.

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