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Optical-near infrared photometry of the Galactic globular cluster NGC 6441

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Abstract. We present optical- near infrared photometry of the peculiar Galactic globular cluster NGC 6441. By using the K-band Period-Luminosity-Metallicity ($PLZK$) of its RR Lyrae stars, we supply a new estimate of its distance. With this distance, we discuss the comparison in the K-$(J-K)$ plane between observations and "canonical" evolutionary models.

Key words. (Galaxy:) globular clusters: individual (NGC 6441) -- stars: horizontal-branch – stars: variables: other – techniques: photometric

1. Introduction

The Galactic Globular Cluster (GGC) NGC 6441 presents several interesting features: a high metal abundance ($[Fe/H] = -0.53$) and an extended Blue Horizontal Branch (EHB) — at odds with the general trend observed in the Galaxy and with the expectations of the canonical evolutionary models — and a tilted Red HB.

Observationally, accurate photometric studies on NGC 6441 are hampered by strong differential reddening, serious field contamination, and high central concentration.

It is worth noting that the differential reddening, alone, does not seem to explain the Horizontal Branch morphology (Raimondo et al. 2002), nor has any meaningful spread in the metallicity been found (Gratton et al. 2007). Therefore, to explain both the EHB and the tilted Red HB, two different populations have been proposed (Busso et al. 2007; Caloi & D'Antona 2007), one with a "canonical" helium content of $Y \sim 0.26$, and one with helium enrichment up to

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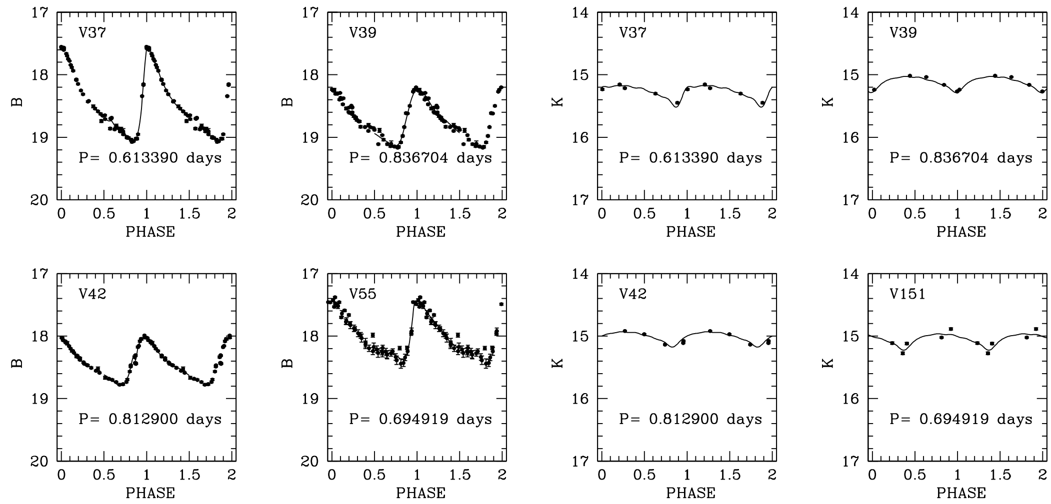

Fig. 1. In the left panels we show the *B*-band light curves of some selected RR Lyrae variables in NGC 6441. *K*-band light curves of the same variables are shown in the right panels. The new variable with the exceptionally long period of $\sim$ 1.07 days has labeled as V151.

$Y \sim 0.4$. Moreover, to fully account for the observed distribution of the stars along the HB, a spread in the helium content between these two values is required.

Even though NGC 6441 is a metal-rich cluster, it hosts a sizable sample of RR Lyrae stars (67, Corwin et al. 2006) and the mean period of its fundamental RR Lyrae is <Pab>$\sim$ 0.759 days, even longer than those typical of the metal-poor GGCs. In order to explain this peculiar feature, shared with the GGC NGC 6388, the need for a new Oosterhoff class has been suggested (Catelan 2006).

RR Lyrae stars are excellent distance indicators, and their absolute *V*-band magnitude is usually calibrated as a linear function of the metallicity. Unfortunately, accurate estimates of mean *V*-band magnitudes of RR Lyrae in NGC 6441 are hampered by the aforementioned strong differential reddening. Moreover, evolutionary effects can effectively increase their luminosity (as suggested by the long pulsation periods).

To overcome the problem concerning the evolutionary status of these objects, as well as to reduce the impact of the differential reddening, we will use the *K*-band Period-Luminosity-Metallicity relation (e.g. Bono et al. 2003; Sollima, Cacciari & Valenti 2006). Theoretical and empirical evidence indicates that this approach is marginally affected by evolutionary effects and reddening uncertainties, and has only a mild dependence on the stellar mass. Finally, optical - near infrared colors are very sensitive to the effective temperature, allowing a meaningful comparison with the theoretical models. Here we present our optical (*B, V, I*) and near infrared (J, K_s) catalogs of NGC 6441, together with a new estimate of its distance based on the *PLZK* relation.

2. The dataset

Optical photometry is based on data available in the public archives or donated by colleagues, collected with several telescopes (CTIO 0.9 m, ESO/Danish 1.54 m, ESO/MPI 2.2 m, and FORS@VLT), for a maximum of 82 epochs in the *V* band, spanning more than three years and covering a field of $34' \times 30'$, well beyond the cluster tidal radius (8′, Harris 1996). It is worth noting that some of these data have already been published (Layden et al. 1999;

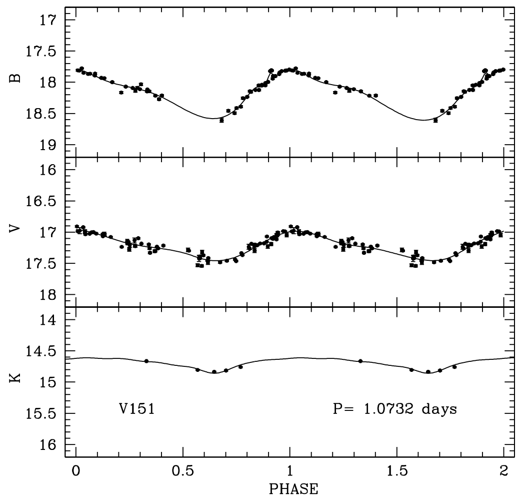

Fig. 2. From top to bottom panel: B, V, K light curves of the new candidate RR Lyrae variable V151. See text for details

Pritzl et al. 2001). A single photometric catalog containing more than 691,000 objects was obtained following the ALLFRAME (Stetson 1994) standard approach. Near-infrared data were collected with SOFI@NTT in the 2002, with 6 and 5 epochs in the J and K_s bands, respectively. The field was of $5' \times 5'$, centered on the cluster, while the external fields observed for the background subtraction were included in the general catalog as well. A separate ALLFRAME run was performed on the NIR data, producing a NIR catalog containing more than 25,000 stars. A final photometric catalog, containing merged optical and NIR data, was therefore generated.

3. Variable stars and distance

At the present time 40 variable stars have been analyzed, 23 of which being previously known RR Lyrae variables.

Optical pulsational parameters (amplitudes and mean magnitudes) of the detected RR Lyrae stars were obtained by fitting spline curves to the observed points, while K-band light curves were fitted with the templates by Jones, Carney & Fulbright (1996). Since the NIR light curves are almost sinusoidal and of low amplitude, the splines give mean magnitudes that are in excellent agreement with those calculated with the templates, within few hundredths of magnitude. In Fig. 1 we show some B (left panel) and K (right panel) light curves. Updated periods for the detected variables were computed with PERIOD04 (Lenz & Breger 2005), on the basis of the optical photometry.

We have also detected a new candidate RR Lyrae star, with an exceptionally long pulsation period of $\sim$ 1.07 days (shown in Fig. 2, provisionally named V151). If confirmed, this star would therefore be the RR Lyrae with the longest period known so far. Interestingly, the RR Lyrae K-band template by Jones, Carney & Fulbright (1996) perfectly fits the observed points.

The left panel of Fig. 3 shows mean K-band magnitudes of the detected variables as a function of the period (empirical PLK relation). It can be clearly seen that in this plane RR Lyrae stars can be easily distinguished from bright variables and/or blends.

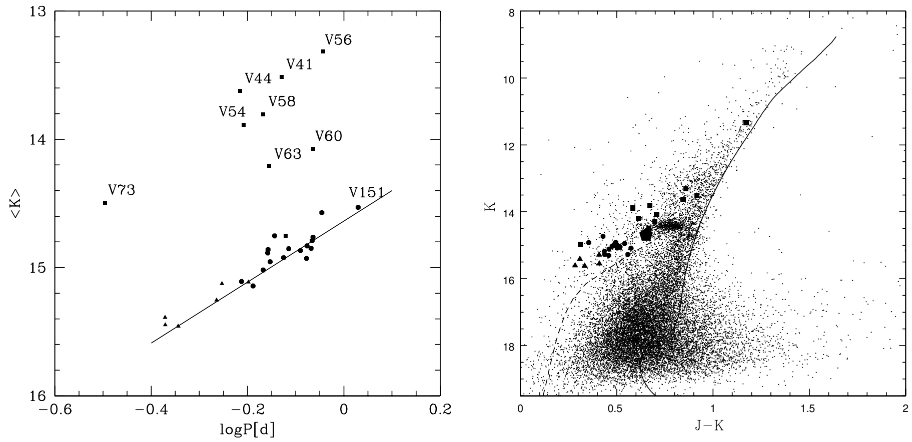

Fig. 3. *Left Panel*: observed *PLZK* relations for the candidate RR Lyrae stars analyzed so far. Confirmed fundamental (RRab, filled circles) and fundamentalized first-overtone (RRc, filled triangles) pulsators are easily split from blends and/or bright variables (filled squares). The new long period candidate RR Lyrae is labeled as V151. The straight line represents the Sollima, Cacciari & Valenti (2006) calibration, shifted in magnitude to match the observed distribution. *Right Panel*: K vs. $J-K$ CMD showing the comparison between observations and theory. Variable stars are shown with filled symbols, and the filled pentagon marks the candidate RR Lyrae V151. See text for details.

Interestingly, the aforementioned new candidate RR Lyrae star seems to follow the *PLK* relation quite well. The observed slope is $\alpha = -2.26\pm0.15$, in good agreement with the values available in the literature. The simple mean of the derived true distances, by adopting an extinction of $E(B-V) = 0.47$ mag (Harris 1996), is $(m-M)_0 = 15.67 \pm 0.07$ mag (see Table 1). This distance modulus will be adopted for the following discussion.

4. Discussion and final remarks

In the right panel of Fig. 3 we show in the K vs. $J-K$ plane the comparison between data and a cluster isochrone (solid line) at fixed age and chemical composition. The adopted isochrone is of 12 Gyrs, $Z = 8 \times 10^{-3}$, and $Y = 0.256$, taken from the BaSTI library (Pietrinferni et al. 2004), and shifted according to the the above distance and to a reddening of $E(B-V) = 0.47$. In the same figure we also show a Zero Age Horizontal Branch (ZAHB) sequence (dashed line), with the same characteristics as the isochrone. Filled points mark the positions of the analyzed variable stars. The agreement between data and observations is not satisfactory, since the observed HB is clearly brighter than the ZAHB, even taking into account post-ZAHB evolutionary effects. Also the isochrone appears to be systematically redder than the observed Red Giant Branch (RGB). These findings may suggest a shorter distance and/or a smaller reddening. Moreover, a larger true distance of $(m-M)_0 = 15.9$ mag, as derived from the distance of $(m-M)_{F555W} = 17.4$ derived by Busso et al. (2007), definitely does not properly fit the RGB, nor the observed distribution of the RR Lyrae stars. Interestingly, the Bono et al. (2001) calibration of the *PLZK* gives a shorter true distance of $(m-M)_0 = 15.51$ mag, which provides a much more satisfactory agreement between theory and observations (see Dall'Ora et al. 2007). Unfortunately, the slope of the Bono et al. (2001) *PLZK* calibration is $\alpha = -2.07$, in only marginal agreement with the slope observed in NGC 6441.

We conclude by noting that the *PLZK*-based distance estimates are only marginally affected by the differential reddening, since a spread of $E(B-V) = 0.12$ mag (Busso et al.

Table 1. Distance moduli of NGC 6441, obtained with different *PLZK* calibrations available in the literature.

Reference	Slope	$(m - M)_0$ (mag)
Bono et al. (2003)	−2.10	15.58
Cassisi et al. (2004)	−2.34	15.74
Catelan, Pritzl & Smith (2004)	−2.35	15.63
Sollima, Cacciari & Valenti (2006)	−2.38	15.73

2007) reflects in a spread of only 0.04 mag in the *K*-band. Moreover, we note that a higher helium content would have non negligible effects on the *PLZK*, with a brighter zero point and a steeper slope (M. Catelan, *priv. comm.*). This, in turn, would imply a longer distance to NGC 6441 and a larger discrepancy between theory and observations.

A forthcoming study, coupling the NIR and the optical data we already secured, will allow us to complete the analysis of the variables in our catalog, to produce a detailed reddening map based on the RR Lyrae pulsational properties (e.g. Piersimoni, Bono & Ripepi 2002), and to evaluate the contamination of the field stars by means of color-color planes.

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