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A survey of variable stars in the globular cluster NGC 362

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Abstract
We present the first results of our survey in NGC 362 globular cluster. We found numerous variable stars in the field: 38 RR Lyr stars, 5 eclipsing binaries and 13 other pulsating stars. Five RR Lyrae stars can be member of the halo/SMC population.
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1 Introduction

Although globular clusters are primary testbeds of modern astrophysics due to large number of stars with the same age and composition, there are still a number of unstudied clusters, mostly in the southern hemisphere. We have been carrying out a CCD photometric survey project of southern globular clusters since mid-2003. Here we present the first (and still preliminary) results for NGC 362, which is one of the brightest unstudied southern clusters, located in front of the outer edge of the Small Magellanic Cloud.

2 Observations and data analysis

Our V-filtered photometric observations were carried out between July 2003 and October 2004 on 17 nights at Siding Spring Observatory, Australia. We used the 1m ANU telescope equipped with the Wide Field Imager; three chips of the WFI gave $\sim 40' \times 26'$ field of view. In addition to the photometry, we measured radial velocities for the brightest RR Lyrae stars from medium-resolution spectra, taken with the 2.3m ANU telescope. All data were processed with standard IRAF routines, including bias and flat-field corrections. Instrumental magnitudes were obtained via a semi-automatic pipeline using daophot tasks for PSF photometry. Another method of data reduction was applying image substraction using ISIS 2.1 package (Alard, 2000).

After a careful selection of ensemble comparison stars, variables were identified with visual inspection of the resulting light curves. Periods were determined with a combination of Fourier analysis, phase dispersion minimization (Stellingwerf, 1978) and string-length minimization (Lafler & Kinman, 1965).

3 Variable stars

Our results regarding variable stars can be summarized as follows.

- From the ensemble photometry of over 10,000 stars, we found 38 RR Lyr variables in the cluster, of which 31 are new discoveries.
- We found 8 long period (>1 d) RR Lyr-like variables, which are either candidate above-horizontal-branch stars (AHB stars, Diethelm (1990)) or short-period Type II Cepheids.
- We also discovered several short-period eclipsing binaries, most likely in the galactic foreground of the cluster.
- A number of stars on the red giant branch showed evidence for variability on a time-scale of 10-50 days, suggesting the presence of RGB pulsations predicted by Kiss & Bedding (2003).
- We have tried to find faint RR Lyr stars in the halo of the SMC, but the results so far are not fully conclusive.

3.1 Regular RR Lyr stars

We identified 33 RRab/RRc variable stars with very similar mean apparent brightnesses, so that they are all members of the cluster. The measured radial velocities for 5 RR Lyr stars supported this conclusion for having the same ∼200 km/s mean velocity as the cluster itself (Fischer, 1993). The two light curves below show the light curve shape changes with the increasing period. Current data include some of the non-photometric nights, which is why there is increased scatter in the light curves.

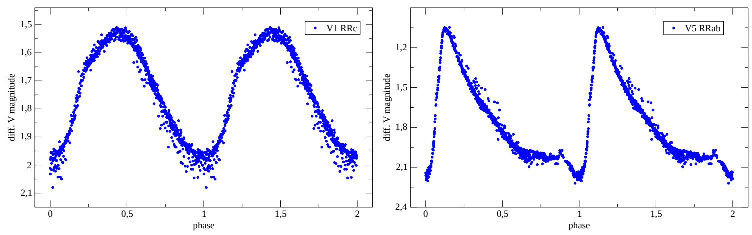

Figure 1: *Light curves of regular RR Lyr stars. Left: V1, P=0.342d. Right: V5, P=0.528d.*

3.2 Blazhko RR Lyr stars

A large fraction of RR Lyr stars show periodic amplitude and/or phase modulations, the so-called Blazhko-effect, which is still one of the greatest mysteries in classical pulsating stars, e.g. Chadid et al. (2004). In our sample, two variables, V6 and V18, have the strongest light curve modulations, while further five stars (V9, V12, V13, V19 and V31) exhibited only subtle changes during the 15 months of observations. The phase diagrams of V6 and V18 can be seen in Fig. 2.

3.3 Other short-period variable stars

We found, of course, a large number of variable stars belonging to other classes. Interestingly, we also identified a few RR Lyr stars that are several magnitudes fainter than those in the cluster. We suspect these to belong to the outer halo of the Small Magellanic Cloud; a more secure membership investigation is in progress. It is worth mentioning that some of the field variable stars (V4, V7, V21, V26, V29) have particularly RR Lyr-like light curve shape but with periods

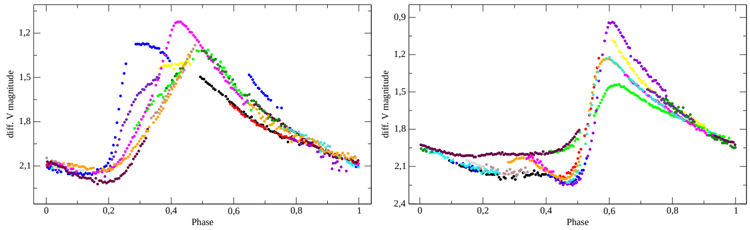

Figure 2: *RR Lyr stars with Blazhko-effect. Left: Phase diagram of V6. Right: Phase diagram of V18.*

greater than 1 day; one of them (V7) has almost 4 days period. Depending on their position in the colour-magnitude diagram, these stars can be either above-horizontal-branch (AHB) variables (Diethelm, 1990) or Type II Cepheid. V21 showed a peculiar bump on the descending branch of the light curve. Its origin is not clear yet.

4 Other results

In order to determine the metallicities and from those parameters the absolute magnitudes of some of the RR Lyr stars we applied the equations Nr. 3 of Jurcsik & Kovács (1996), $[Fe/H] = -5.038 - 5.394P + 1.345\phi_{31}$ and Nr. 5 of Kovács & Jurcsik (1996), $M_V = 0.19[Fe/H] + 1.04$, respectively. The results of the calculations can be seen in Tab. 1.

The colour-magnitude diagrams shown in Fig. 3 are produced with rejecting the stars which positions fall off from a given radii fixed on the center of NGC 362, $\alpha_{2000.0} = 1^h3^m14^s.3$, $\delta_{2000.0} = -70^o50'54''$ (Dorman et al., 1997). The applied radii are $3'$, $5'$, $10'$ and $30'$, respectively. The CMDs show increasing field contamination, a noticeable feature is a somewhat dimmer secondary RGB of the Small Magellanic Cloud (SMC) which is in the line of sight of NGC 362. The presence of stars from the SMC contaminates the CMDs which involve greater number of stars (N) so we used the second diagram (N=4060) in order to determine the properties of NGC 362.

To determine the distance modulus, age, metallicity and reddening of the cluster we fitted the VI Padova isochrones (Girardi et al., 2000). To fit the isochrones we have attempted to match the slope of the RGB to fit metallicity, fit the RGB tip for distance, the SGB for age and the position of the base of

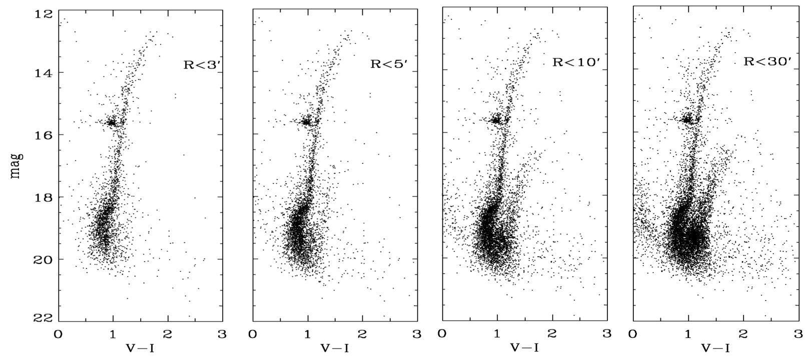

Figure 3: *CMDs of the central regions with different radii.*

the RGB for reddening. As the best fit we found the 8.9 Gyr isochrone with metallicity $Z = 0.001$ and it gives an apparent distance modulus of $\mu = 15.2{\pm}0.4$ and $E(V-I) = 0.19$. The next best fit is also shown in the left side panel of Fig. 4 which gives the same metallicity, distance and reddening but an age of 10 Gyr. The right side panel of Fig. 4 shows a surface density profile of the cluster. This diagram clearly shows a very high density of stars in the centre of the cluster. This plot however, does not show any evidence for the existence of tidal tails caused by the cluster's motion around the galaxy.

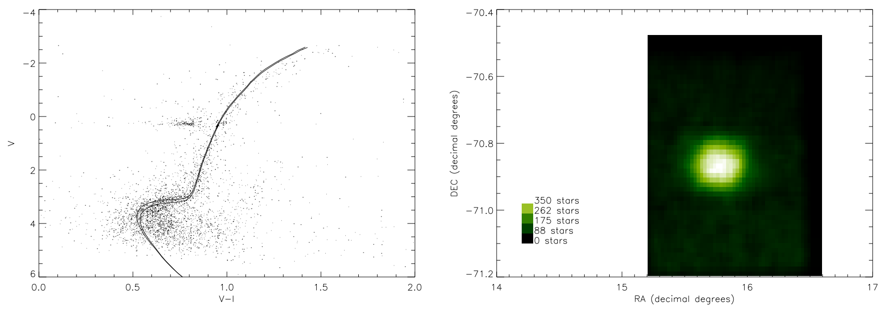

Figure 4: *Left: Isochrone fitting. Right: Surface densities of NGC 362*

Table 1: *Metallicities of the RR Lyrae Stars.* † *Blazhko effect present.* * *Outliers?*

Star	Period	ϕ_{31}	$[Fe/H]$	M_V	Distance(pc)
V1	0.3425	4.1616	−1.28	0.79	8354
V3	0.4901	4.6615	−1.44	0.77	7820
V5	0.5286	4.9274	−1.26	0.80	7946
V8	0.3333	3.8357	−1.67	0.72	7890
V9	0.5851	5.3094	−1.05	0.84	9238
V11	0.5146	5.1881	−0.83	0.88	10601
V12†	0.4202	4.4477	−1.32	0.78	9312
V16	0.5098	4.6814	−1.49	0.75	6526
V31*	0.4708	4.6953	−1.26	0.79	29308
V32*	0.5757	4.1546	−2.55	0.55	24271
V34	0.6271	5.6164	−0.86	0.87	8078
Average	0.4907	4.6981	−1.37	0.78	8418

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