COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 6054

Konkoly Observatory
Budapest
19 April 2013

HU ISSN 0374 – 0676

PHOTOMETRIC ANALYSIS OF VARIABLE STARS IN NGC 299

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NGC 299 (RA $00^{h}53^{m}24.74^{s}$, DEC $-72°11'47.6''$, J2000) is a young and relatively small star cluster in the Small Magellanic Cloud (SMC). It is classified as a Type I cluster on the SWB scale (Searle, Wilkinson, & Bagnuolo 1980). Matteucci et al. (2002) analyzed a color-magnitude diagram (CMD) from B and V observations and, based on the brightness of the upper main-sequence termination point, estimated the cluster's age to be 15-20 Myr. They commented on the three brightest stars in the field and suggested these might be He-burning giants. We further discuss the nature of these stars later in this paper. Rafelski & Zaritsky (2005), using data from the Magellanic Clouds Photometric Survey (MCPS; Zaritsky et al. 2002), calculated integrated colors for a sample of SMC clusters. From a comparison of these colors with simple stellar-population models, they derived an extinction-corrected age of 28-100 Myr for NGC 299. Fitting an isochrone model to a MCPS CMD, Glatt, Grebel, & Koch (2010) found a cluster age of ∼25 Myr. Piatti et al. (2008) fitted a CMD on the Washington photometric system with an isochrone model to obtain an age of 25^{+6}_{-5} Myr. They also examined the stellar density profile (stars per unit area, unweighted by luminosity) and determined the cluster's full width at half maximum ($r_{\rm FWHM}$) and outer radius ($r_{\rm cls}$) that we adopt below. Hill & Zaritsky (2006) showed the brightness profile of NGC 299 is well modeled by a King model.

A significant percentage of hot stars in the SMC are photometrically variable. This behavior is most pronounced for Be stars. Diago et al. (2008) analyzed MACHO observations for a large sample of spectroscopically selected stars and found that 4.9% (9 out of 183) of B stars and 25.3% (32 out of 126) of Be stars were low-amplitude, short-period pulsating variables. Similarly, in a study of OGLE-II data for NGC 330 (a SMC cluster notable for its large population of Be stars), Schmidtke, Chobanian, & Cowley (2008) found that pulsations were present in >20% of their entire sample. The percentage was even greater for known Be stars. Although no comprehensive spectroscopic study of NGC 299 has been undertaken, Martayan et al. (2007), in a survey of SMC B and Be stars, investigated four stars that might be cluster members. The three brightest of these (i.e., #11617, #11998, and #14323 on the numbering system discussed below) were found to be evolved B-type stars, while the faintest one (#11979) was classified as type B3 IVe.

We present here an analysis of 8 seasons of OGLE-III photometry (Udalski 2003; Udalski et al. 2008) for NGC 299, which lies in field SMC102.1. An I-band finding chart is shown in Fig. 1. The two inner circles mark radii corresponding to $r_{\rm FWHM}$ (=12.6″) and $r_{\rm cls}$ (=29.4″), respectively. All stars within the outer circle ($r_{\rm lim}$=45″) were examined. The central portion of the cluster is dominated by light from a very bright star that lies ∼1″ from the center. Hence, the central region is not well resolved, and the OGLE-III star closest to the center position is at r=5″.

A CMD from V and I data in the OGLE-III photometry maps is shown in Fig. 2. A box is drawn around hot stars on or near the upper main sequence. Stars in this region of the diagram are likely to show short-period, low-amplitude pulsations (e.g. see Balona 2010; Kołaczkowski et al. 2006; Moffat 2013). The faint limit of the box is set at I=18.2, which corresponds to the expected brightness of a B5 V star at the distance of and with an extinction appropriate for the SMC. Within the box there are 27 stars, of which 6 have $r > r_{\rm cls}$. These outliers are unlikely to be cluster members. When scaled by area on the sky, we estimate that ∼1 (out of 12) of the hot stars with $r < r_{\rm FWHM}$ is not a cluster member. Similarly, about 4 stars (out of 9) with $r_{\rm FWHM} < r < r_{\rm cls}$ are not members. Based on the young age for NGC 299, none of the red giants lying to the right side of the box can be a cluster member.

A plot of σ_I vs. I from OGLE-III data is shown in Fig. 3. Many stars fainter than $I \sim 18.5$ have larger than expected photometric dispersion for their mean brightness. However, almost all faint stars with usually high σ_I lie close to the cluster's center ($r < r_{\rm FWHM}$), while very few are found outside $r_{\rm cls}$. Hence, we conclude that it is the lack of consistent spatial resolution of stars near the cluster's core, rather than photometric variability, that leads to most of the scatter for faint stars in the diagram.

All stars within the box shown in Fig. 2 were selected for further study. There were ∼710 I-band observations per star. The time-series data were analyzed for periodic signals using the Period04 analysis package (Lenz & Breger 2005). The search covered frequencies in the range 0-20 day^{-1}, which is appropriate for the identification of orbital systems as well as pulsating B/Be stars. For one star with a decidedly non-sinusoidal light curve (very narrow eclipses), the phase-dispersion minimization technique of Stellingwerf (1978) was used to determine the best photometric period.

As noted by Diago et al. (2008), the period analysis of a synoptic data set often shows significant 1-day aliasing. Many stars in the present sample show this effect, having fictitious periods comparable to the duration of OGLE-III observing or at high-frequency aliases near f=1, 2, 3, ... day^{-1}. The analysis can be further complicated by inadequate spatial resolution. Only three hot stars in the direction of NGC 299 show a meaningful photometric signal. Two stars are eclipsing binaries, while a third star shows large, intrinsic variations that are not periodic. There is no evidence for variability in the four hot stars with known spectral types. The results are summarized in Table 1 and shown in Fig. 4. We note that no short-period pulsating variables are present in NGC 299. This may be related to age, as other SMC clusters with a large population of pulsating variables (i.e., NGC 330) are thought to be slightly older.

Comments on individual sources.

SMC102.1 #11727: Based on its brightness (the third brightest of all stars enclosed by the box in Fig. 2) and its proximity to the cluster's center (well within $r_{\rm FWHM}$), this star is likely to be a cluster member. The photometric variability is typical of a Be star, although no spectrum is available. The large amplitude (ΔI=0.35 mag) and long duration (>3 yr) of the outburst are consistent with that of a Be star with a Type-1 (hump-like) light curve (Mennickent et al. 2002). We searched for low-amplitude pulsations in the

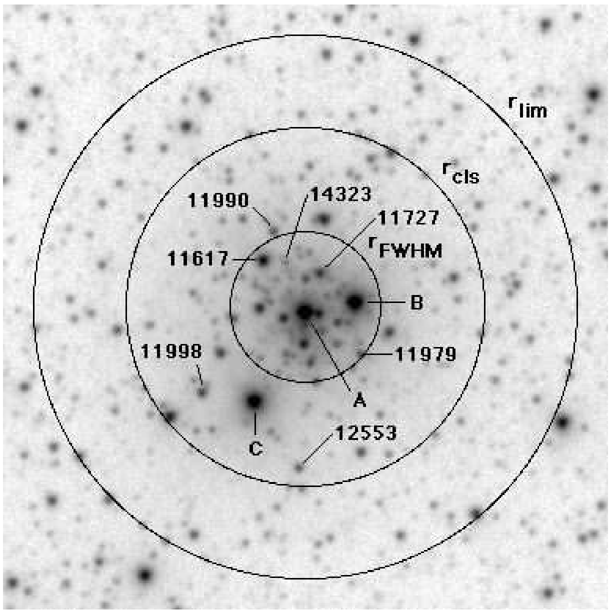

Figure 1. An I-band finding chart for NGC 299. The field of view is $100'' \times 100''$, with north up and east to the left. Stars with numerical identifications refer to their sequence number in OGLE-III field SMC102.1, while the stars labeled A, B, and C are too bright to be in the OGLE data base.

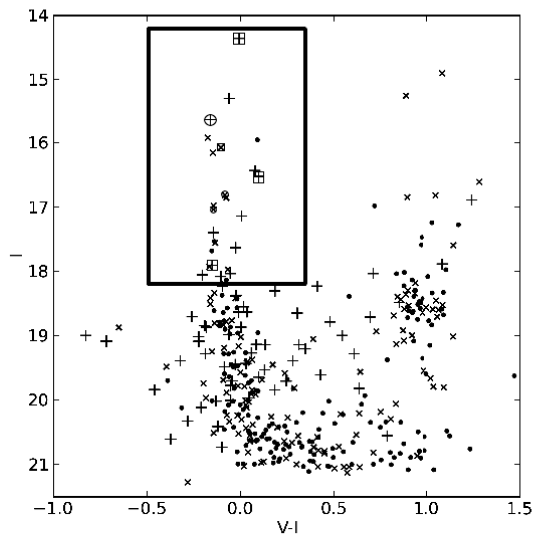

Figure 2. I vs. $V-I$ CMD from OGLE-III data for NGC 299. The box outlines that portion of the diagram in which hot, pulsating variables are likely to be found. Different symbols indicate relative distances from the cluster's center: plusses (+) for $r<r_{\rm FWHM}$, crosses ($\times$) for $r_{\rm FWHM}<r<r_{\rm cls}$, and filled circles ($\bullet$) for $r_{\rm cls}<r<r_{\rm lim}$. Open circles ($\bigcirc$) are drawn around variable stars, while open squares ($\square$) mark those stars with known spectral types (either B or Be).

Table 1. Variable Stars in the Field of NGC 299

OGLE-III ID	RA (J2000)	DEC (J2000)	I (mag)	$V-I$ (mag)	T_0 (JD 2453000+)	GCVS Type	P (days)	r ($''$)
SMC102.1 #11727	0:53:24.14	−72:11:42.3	15.638	−0.160	...	BE?	...	6.0
SMC102.1 #11990	0:53:25.77	−72:11:35.3	16.812	−0.084	1.022	EB	1.59362	13.2
SMC102.1 #12553	0:53:24.98	−72:12:14.4	17.032	−0.144	1.25	EA	14.74086	26.9

OGLE-III ID refers to the sequence number in field SMC102.1. I and $V-I$ are the mean magnitude and color in the OGLE-III photometry map. T_0 represents the time of phase zero, GCVS Type is the variability type, P denotes the period, and r is the distance from the cluster's center.

first 4 seasons of OGLE-III data (when the light curve was nearly flat), but found none. An additional search was made of the entire data set, after subtracting second-order polynomial fits from individual seasons of data. Again, no low-amplitude pulsations were found.

SMC102.1 #11990: This star lies just outside $r_{\rm FWHM}$ and is likely to be a cluster member. An orbital period of 1.59 days was found in this β Lyrae-type eclipsing binary system. The primary eclipse has a depth of ΔI=0.12 mag, with the depth of secondary eclipse being 0.09 mag.

SMC102.1 #12553: The cluster membership of this star is questionable, as it lies close to $r_{\rm cls}$. An orbital period of 14.74 days was found in this Algol-type eclipsing binary system. The light curve shows two very narrow eclipses, neither of which is fully resolved in OGLE-III data. We tentatively identify the broader eclipse (with a duration of ∼0.04P) as the primary and the narrower eclipse (∼0.02P) as the secondary. Further observations are needed to confirm these assignments. The depths and durations of the eclipses are consistent with two nearly identical mid-B main-sequence stars in a 14-day orbit and viewed at an inclination close to 90°. Secondary eclipse falls at phase 0.533, implying an eccentric orbit.

The brightest stars in the direction of NGC 299 (labeled A, B, and C in Fig. 1) have been observed by the Two Micron All Sky Survey (2MASS; Cutri et al. 2003). The K_s magnitudes and $J-K_s$ colors for these stars are consistent with those of red supergiants in the SMC (Boyer et al. 2011). All three stars are likely to be cluster members. Stars A and B are well within $r_{\rm FWHM}$, while star C lies just outside of it. No OGLE-III photometry is available for these stars. Therefore, we could not examine their long-term variability.

Acknowledgments: The OGLE project has received funding from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement no. 246678 to AU.

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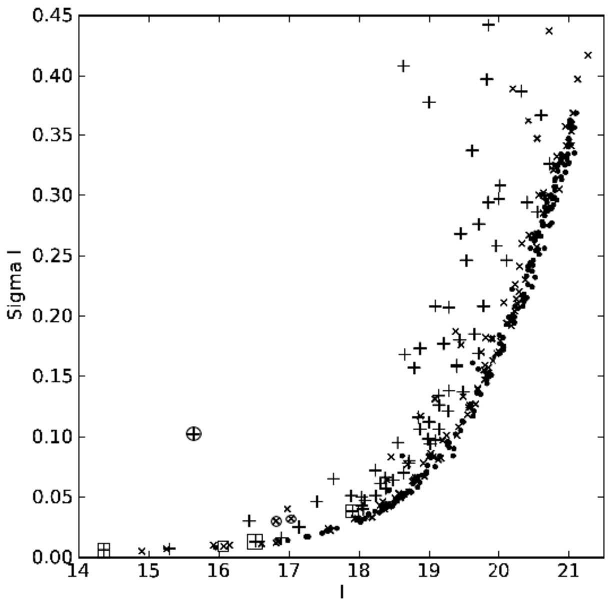

Figure 3. σ_I vs. I from OGLE-III data for NGC 299. Different symbols indicate relative distances from the cluster's center: plusses (+) for $r<r_{\rm FWHM}$, crosses (×) for $r_{\rm FWHM}<r<r_{\rm cls}$, and filled circles (●) for $r_{\rm cls}<r<r_{\rm lim}$. Open circles (◯) are drawn around variable stars, while open squares (□) mark those stars with known spectral types (either B or Be).

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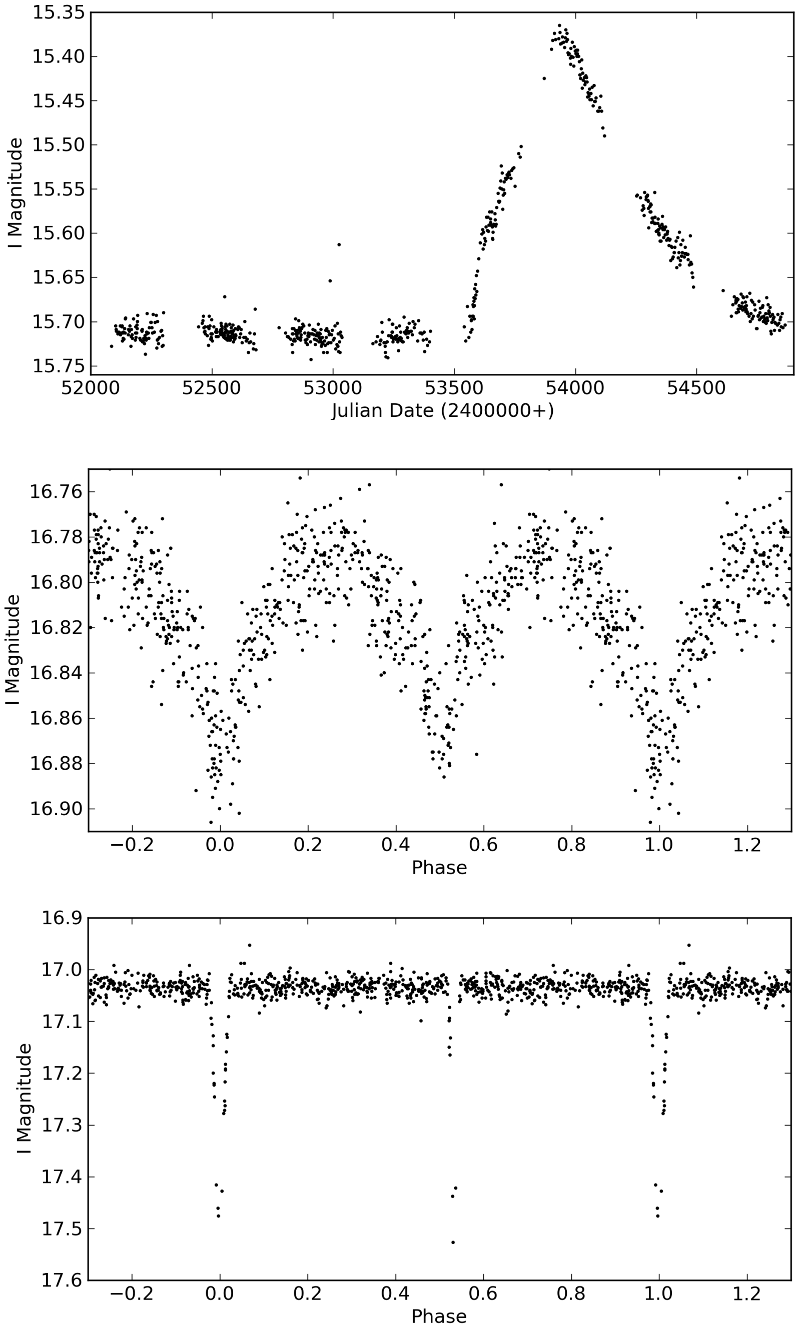

Figure 4. OGLE-III *I*-band light curves for variable stars in the field of NGC 299: SMC102.1 #11727 (top), SMC102.1 #11990 (middle), and SMC102.1 #12553 (bottom). See the text and Table 1 for additional information and comments on individual sources.