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Photometric study of an eclipsing binary in Praesepe

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Abstract We present CCD photometric observations of an eclipsing binary in the direction of the open cluster Praesepe using the 2 m telescope at IUCAA Girawali Observatory, India. Though the system was classified as an eclipsing binary by Pepper et al., detailed investigations have been lacking. The photometric solutions using the Wilson-Devinney code suggest that it is a W-type W UMa system and, interestingly, the system parameters are similar to another contact binary system SW Lac.

Key words: binaries: eclipsing — binaries: close — open clusters: Praesepe

1 INTRODUCTION

Among eclipsing binaries, short period ($\leq$ 1 d) low temperature contact binaries are important astrophysical systems (Yakut & Eggleton 2005). They are often found in fields as well as in galactic and globular clusters with relatively high frequencies (Rucinski & Duerbeck 1997; Rucinski 1998, 2000). Contact binaries in clusters are of great importance as their evolution can be understood on the basis of host cluster age; however no concrete correlation is yet revealed. The theoretical understanding of their origin, evolution, thermal equilibrium and mass exchange remains poorly understood; however detailed modeling suggests that they coalesce in their final stage (Stepien 2006). On the other hand, for a few contact binaries the observational properties of the binary components are known accurately (e.g. 52 W-type and 60 A-type W UMa systems, see tables 1 and 2 of Gazeas & Stępień 2008).

Pepper et al. (2008) have obtained light curves for 66 638 stars in NGC 2632 (Praesepe) out of which 208 were variables and among them $\sim$100 were categorized as eclipsing binaries. Four eclipsing binaries among them have been classified into W UMa type systems (TX Cnc, EF Cnc, GW Cnc, EH Cnc) and the observational properties of the remaining eclipsing binaries whose periods fall in the range from 0.26 – 11.03 days have yet to be studied. One of the variables (KELT ID KP101231) was selected for photometric studies. The J, H and K magnitudes of the variable are 9.794, 9.391 and 9.272 respectively and R_k is 10.987. The period of the selected variable was found to be 0.2910 d with an amplitude of $\sim$0.5. Our work draws motivation from the fact that the observational properties of very few contact binary systems with such a short period are known and hence we present the detailed V passband photometric solutions for this variable using the Wilson-Devinney (W-D) code (2003 version).

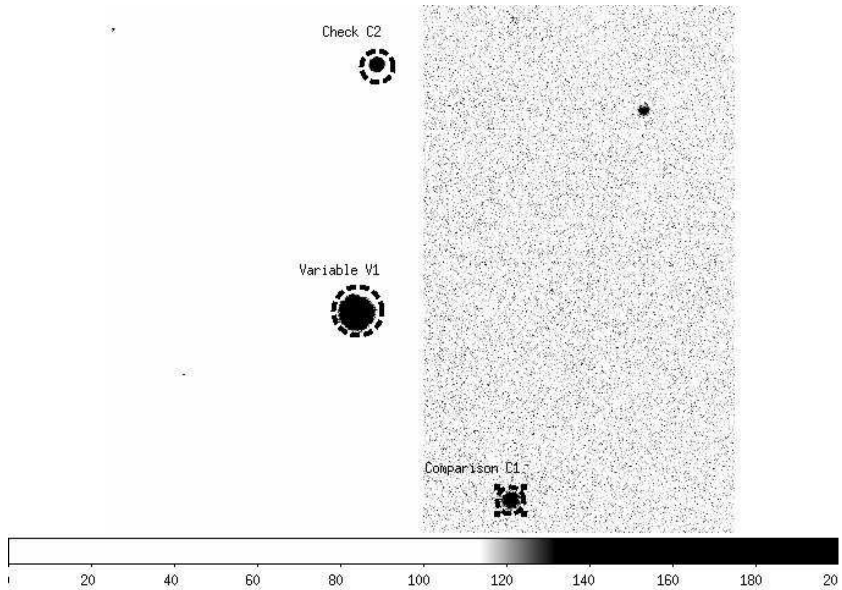

Fig. 1 ∼10×10 arcmin image of the field of NGC 2632. The variable, comparison and check stars are marked.

2 OBSERVATIONS AND DATA REDUCTION

The V band CCD photometric observations of the variable were carried out using the 2-m IGO telescope in India. The observations were performed during two nights on 2012 February 26 and 27. The IUCAA Faint Object Spectrograph Camera (IFOSC) was used, which is equipped with an EEV 2k×2k thinned, back-illuminated CCD with 13.5 μm pixels. The CCD used for imaging provides an effective field of view of ∼10×10 arcmin^2 on the sky corresponding to a plate scale of $0.3''$ per pixel. A total of 289 frames in the V band were obtained with an exposure time of 10–35 s for a good photometric accuracy and the field was centered at $\alpha_{\rm J2000} = 08^{\rm h}57^{\rm m}9.71^{\rm s}$, $\delta_{\rm J2000} = 18°56'44.12''$.

We have performed aperture photometry with the *apphot* package available in IRAF software. Figure 1 shows the positions of the variable (V1), comparison (C1) and check (C2) stars. It was found that the comparison and check stars were relatively constant in brightness. From the light curve (variable - comparison) obtained, it is found that the shape and depth are similar to the published light curve by Pepper et al. (2008). Figure 2 shows the light curve Δm (Comparison-Check) versus HJD, which is constant in brightness.

3 PHOTOMETRIC SOLUTIONS

The visual inspection of the variable resembled a W UMa type binary in nature and hence mode 3 was finally adopted after noticing that mode 2 was converging to mode 3. The photometric solutions were obtained by using the W-D program with an option of non-linear limb darkening via a square root law along with many other features (van Hamme & Wilson 2003). We also determined the period of the variable to be $P = 0.2910$ d using the Lomb-Scargle periodogram (Scargle 1982; Zechmeister & Kürster 2009), which is similar to the value obtained by Pepper et al. (2008). We have adopted the procedure of fixing the temperature, limb darkening coefficients, x_h and x_c, gravity-darkening coefficients g_h and g_c and albedos, A_h and A_c, for the components as described in our earlier papers

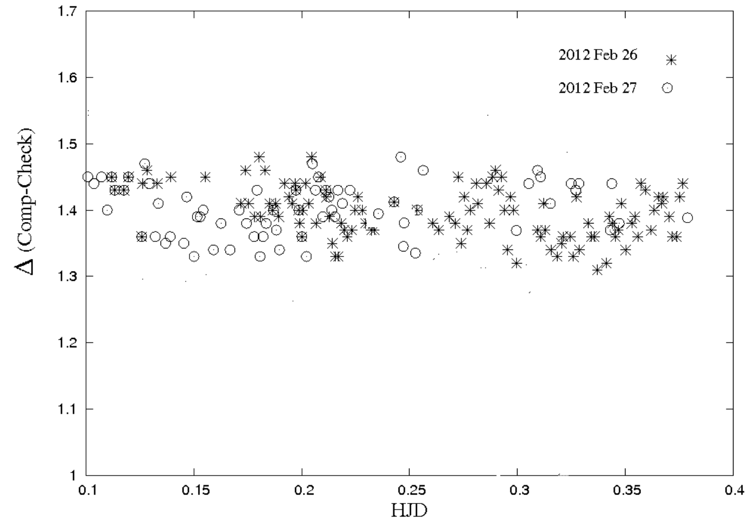

Fig. 2 The figure shows the magnitude difference between comparison and check stars versus HJD (2455984+ and 2455985+) for observations on two nights respectively.

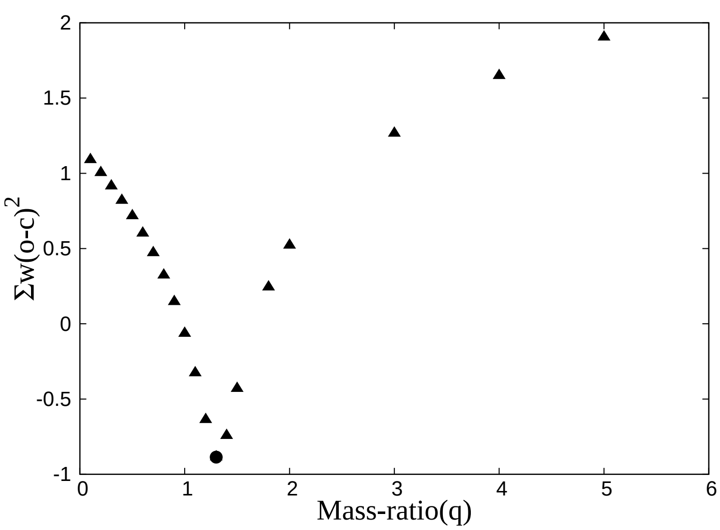

Fig. 3 The figure shows q versus $\Sigma W(O-C)^2$ for the variable V1.

(Rukmini & Vivekananda Rao 2002, Rukmini et al. 2005, Sriram et al. 2009; Sriram & Vivekananda Rao 2010; Shanti Priya et al. 2011 and Kiron et al. 2011a,b, Kiron et al. 2012). The mass ratio is an important parameter for a binary system and is a pivotal parameter to describe the evolution of a contact binary system. To constrain the mass ratio parameter, initially, mean effective temperature of the cool star T_c, the dimensionless surface potentials Ω_h=Ω_c, and the monochromatic luminosity L_h(V) along with the orbital inclination *i* were adopted as adjustable parameters. To determine an accurate value for mass ratio, this parameter was also taken as being adjustable along with the others, till a convergent solution was obtained.

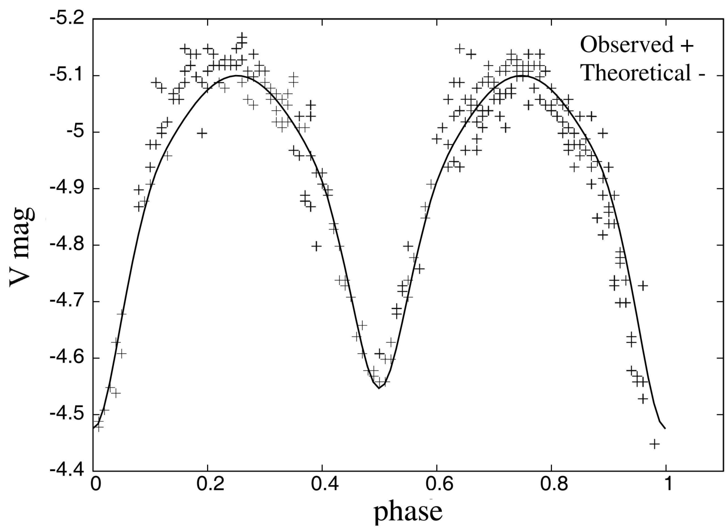

Fig. 4 The figure shows the best fit to the V passband light curve of the variable V1.

Table 1 The Photometric Elements Obtained for the Variable (V1) by Using the W-D Method

Element		V1
Period (d)		0.2910
$T_{e,h}$ (K)		5477
$T_{e,c}$ (K)		5309±6
q		1.29±0.01
i°		76.22±0.10
Ω		4.1580±0.0188
fill-out factor		0.1104
r_h	pole	0.3408±0.0024
	side	0.3579±0.0029
	back	0.3929±0.0046
r_c	pole	0.3835±0.0022
	side	0.4054±0.0028
	back	0.4382±0.0041
L_h		0.5668±0.2718
L_c		0.6142
x_h		0.60±0.05
x_c		0.60±0.05
$\Sigma W(O-C)^2$		0.01954
Spectral type		G6-K0
A_h		0.5
A_c		0.5

Figure 3 shows the weighted sum of square of residuals ($\Sigma W(O-C)^2$) for different values of the assumed mass ratio and the best value was found to be 1.29 ± 0.01 for the variable V1. The results of the computed solutions are shown in Table 1. To obtain the theoretical light curves, we used the light curve program incorporating the final parameters resulting from the DC program. The observed and theoretical light curves for the variable are shown in Figure 4.

4 DISCUSSION AND RESULT

The study of contact binary systems is important in order to understand the physics of their formation and evolution. The system also gives some information about its parent cluster if it happens to be a member. However the selected variable was not found to be a member of the cluster NGC 2632 (Pepper et al. 2008), but the present study is a preliminary investigation of a short period binary, and the number of such short period contact binary systems are relatively less studied. The period of the system is around ∼0.2910 d and the $J - H = 0.40$ value corresponds to G6–K0 spectral type (based on Allen's table; Allen 2000). The best fit solution revealed that the temperature difference between the components is ∼168 K, suggesting that they have a high degree of thermal contact. The best combination of q and i is 1.29 and ∼76.22° respectively. The fill-out factor is 0.1104, i.e. the two components of the binary system show a contact of ∼11% in their common envelope. The solutions indicate that V1 is a W-type W UMa type variable. Gazeas (2009) obtained a three dimensional correlation using the primary's mass, period and mass ratios which are stated below:

$$
\begin{aligned}
\log M_1 &= 0.725 \log P - 0.076 \log q + 0.365 \\
\log M_2 &= 0.725 \log P + 0.924 \log q + 0.365 \\
\log R_1 &= 0.930 \log P - 0.141 \log q + 0.434 \\
\log R_2 &= 0.930 \log P + 0.287 \log q + 0.434 \\
\log L_1 &= 2.531 \log P - 0.512 \log q + 1.102 \\
\log L_2 &= 2.531 \log P + 0.352 \log q + 1.102
\end{aligned}
$$

Substituting the mass ratio from the best fit solutions, we derived the following:

$$
\begin{aligned}
M_1 &= 0.9288\, M_\odot, \\
M_2 &= 1.1982\, M_\odot, \\
R_1 &= 0.5752\, R_\odot, \\
R_2 &= 0.5129\, R_\odot, \\
L_1 &= 0.4881\, L_\odot, \\
L_2 &= 0.6082\, L_\odot.
\end{aligned}
$$

The solutions of the variable (V1) were found to be similar to the properties of another contact binary system, SW Lac ($P = 0.32$ d, $T1 = 5800$ K, $T2 = 5515$ K, $q = 1.270$, $i = 80°$ and $f = 30\%$) (Gazeas et al. 2005). It can be observed that mass ratio, inclination and radius parameters closely match.

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