Research in Astron. Astrophys. **2010** Vol. **10** No. **2**, 159 – 165
http://www.raa-journal.org *http://www.iop.org/journals/raa*

Research in Astronomy and Astrophysics

Photometric study of W UMa type binaries in the intermediate open cluster NGC 7789

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Received 2009 June 5; accepted 2009 October 23

Abstract The light curve solutions of two W UMa binary systems in the intermediate open cluster NGC 7789 are presented in this paper. These variables were observed using the 2 m telescope of the IUCAA-Girawali Observatory. The V passband photometric solutions of the two W UMa binaries were obtained using the latest version of the W–D program. The result shows that both systems are H-subtype W UMa binaries with high mass ratios.

Key words: binaries: eclipsing — binaries: close

1 INTRODUCTION

NGC 7789 is a rich intermediate aged open cluster located at $l = 115.49^\circ$ and $b = -5.36^\circ$. The first search for variable stars in NGC 7789 was conducted by Jahn et al. (1995), when 15 variable stars were discovered. Later, Kim & Park (1999) discovered 16 new variables, including 8 suspected variables along with three variables unraveled by Jahn et al. (1995). This cluster was again probed for new variables by Mochejska & Kaluzny (1999), who found 45 variable stars, including 35 variables which are eclipsing binaries, five pulsating variables and five miscellaneous variables. Out of 35 discovered eclipsing binaries, most of them show W UMa type variability with periods of less than a day, two of the variables belong to the RS CVn type systems and one variable is a cataclysmic binary. Additionally, one of the variables was found to be a δ Sct variable which is a blue straggler belonging to the cluster. Later, in 2000, photometric observations revealed the presence of 28 new variables in a field of about one degree centered on the cluster NGC 7789 (Zhang et al. 2003). Recent estimates of the age of the cluster were given as $\sim$1.6 Gyr (Gim et al. 1998) with a distance modulus of 12.3 (Jahn et al. 1995).

A photometric study of W UMa systems in the open clusters NGC 6791 and Be 33 was carried out and it was found that the mass ratios were close to unity and in one case greater than unity (Rukmini & Vivekananda Rao 2002; Rukmini et al. 2005). Similarly, photometric mass ratios were derived for four variables belonging to the open cluster Be 39 (Sriram et al. 2009). Since no photometric analysis has been carried out for the eclipsing binaries present in the open cluster NGC 7789, we have selected two eclipsing binary systems, V31 and V22, assigned by Mochejska & Kaluzny (1999). In this paper, photometric solutions of these two variables are presented.

2 OBSERVATIONS AND DATA REDUCTION

To obtain the photometric elements of the two W UMa type binary systems in NGC 7789, we have observed this cluster using the 2 m telescope of the IUCAA Girawali Observatory (IGO). The telescope is equipped with an IUCAA Faint Object Spectrograph and Camera (IFOSC) on the telescope's direct Cassegrain port. The IFOSC has a 2K $\times$ 2K thinned, back-illuminated CCD with 13.5 μm pixels. The field of view is about $\sim$10$\times$10 arcmin^2. The observations were carried out for 3 nights each during 2006 November 11–13 in V and I filters and 2008 November 22–24 in B and V filters. Observations were taken with the field centered at $\alpha = 23^{\rm h}56^{\rm m}44^{\rm s}$, $\delta = 56^\circ\ 45'\ 30''$. The exposure time was set to 600 s throughout the observations. The cluster was observed at various air-masses ranging from 1.1–2.0.

The IRAF software v12.1 was used to correct the raw images for bias and flat field in order to obtain clean images. We have found that I band images observed during the year 2006 were affected by fringes whose patterns varied from frame to frame and hence they were not used in the analysis. Differential photometry was carried out using suitable comparison stars very close to the variables in the same field (Figs. 1 and 2).

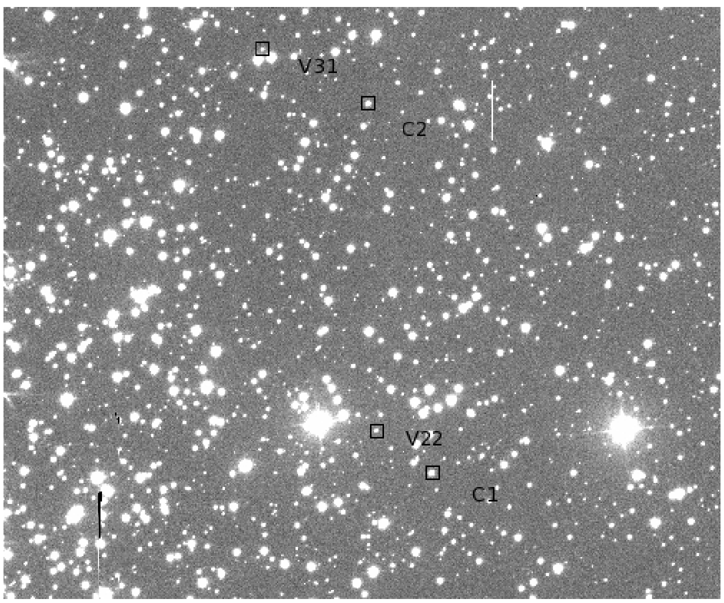


Fig. 1 NGC 7789 field along with positions of variables V31 and V22 and selected comparisons C1 and C2, highlighted by boxes.

Figures 1 and 2 show the positions of the variables and comparison stars. Here, V31 and V22 are the variables and C1 and C2 are the comparison and check stars respectively. We have performed aperture photometry using the PHOT package available in the IRAF software to obtain the instrumental magnitudes of the variable, comparison and check stars. It was found that the comparison and check stars, C1 and C2, were constant in brightness ($\Delta m = \mathrm{C2} - \mathrm{C1} \sim 0.021$) during the period of the observations. From the light curves (variable - comparison) obtained for the two variables, it was found that the amplitude of the light curves was similar to the published light curves of Mochejska & Kaluzny (1999). The variable and comparison stars' light curves are shown in Figure 3.

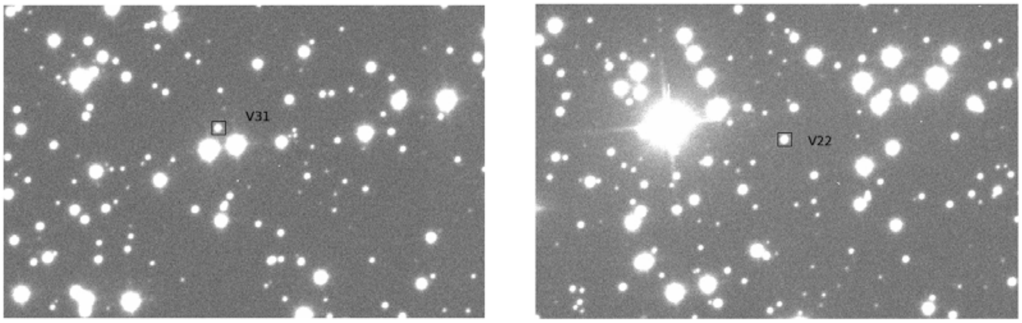


Fig. 2 Figures show the zoomed field of the respective variables. In the left panel, the box shows the variable V31 and in the right panel, the box shows the variable V22. North is up and East is left.

3 PHOTOMETRIC SOLUTIONS

The photometric solutions were obtained by using the latest Wilson-Devinney program with an option of non-linear limb darkening via a square root law along with many other features (Wilson & Devinney 1971; Van Hamme & Wilson 2003). Visual inspection of these variables revealed the W UMa type binary nature and hence mode 3 was used in the program. We have adopted the procedure of fixing the temperatures, 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 (Rukmini & Vivekananda Rao 2002; Rukmini et al. 2005; Sriram et al. 2009). To initially constrain the mass ratio parameter, the mean effective temperature of a cool star T_c, the dimensionless surface potentials Ω_h=Ω_c, and the monochromatic luminosity $L_h(B)$, along with orbital inclination i, are adopted as adjustable parameters. To determine the accurate value of the mass ratio, this parameter is also taken as an adjustable one along with the others, until a convergent solution is obtained. Figure 4 shows the weighted sum of the square of residuals ($\Sigma W(O-C)^2$) for different assumed mass ratios and the best value was found to be 0.906 $\pm$ 0.002 for V31 and 1.051$\pm$0.006 for V22. The results of the computed solutions are shown in Table 1. To obtain the theoretical light curves, we have used the LC program incorporating the final parameters resulting from the DC program. The observed and theoretical light curves for each variable are shown in Figure 5.

4 DISCUSSION AND RESULTS

The study of W UMa variable systems present in clusters is important in order to understand the underlying physics of the formation of the respective bodies and give some information on the parent cluster. Here, we have selected two eclipsing variables present in the intermediate open cluster NGC 7789 to derive the photometric solutions by using the W-D program. Each system is discussed below.

4.1 Variable V31

The sinusoidal variation of the light curve indicates a W UMa type binary system. The period of the system is around $\sim$0.3957$^{\mathrm{d}}$ and $B-V=0.90$ which corresponds to K2 spectral type (Mochejska & Kaluzny 1999). The best combination of q and i came out to be of the order $\sim$ 0.906 and $\sim$ 69 $^\circ$.

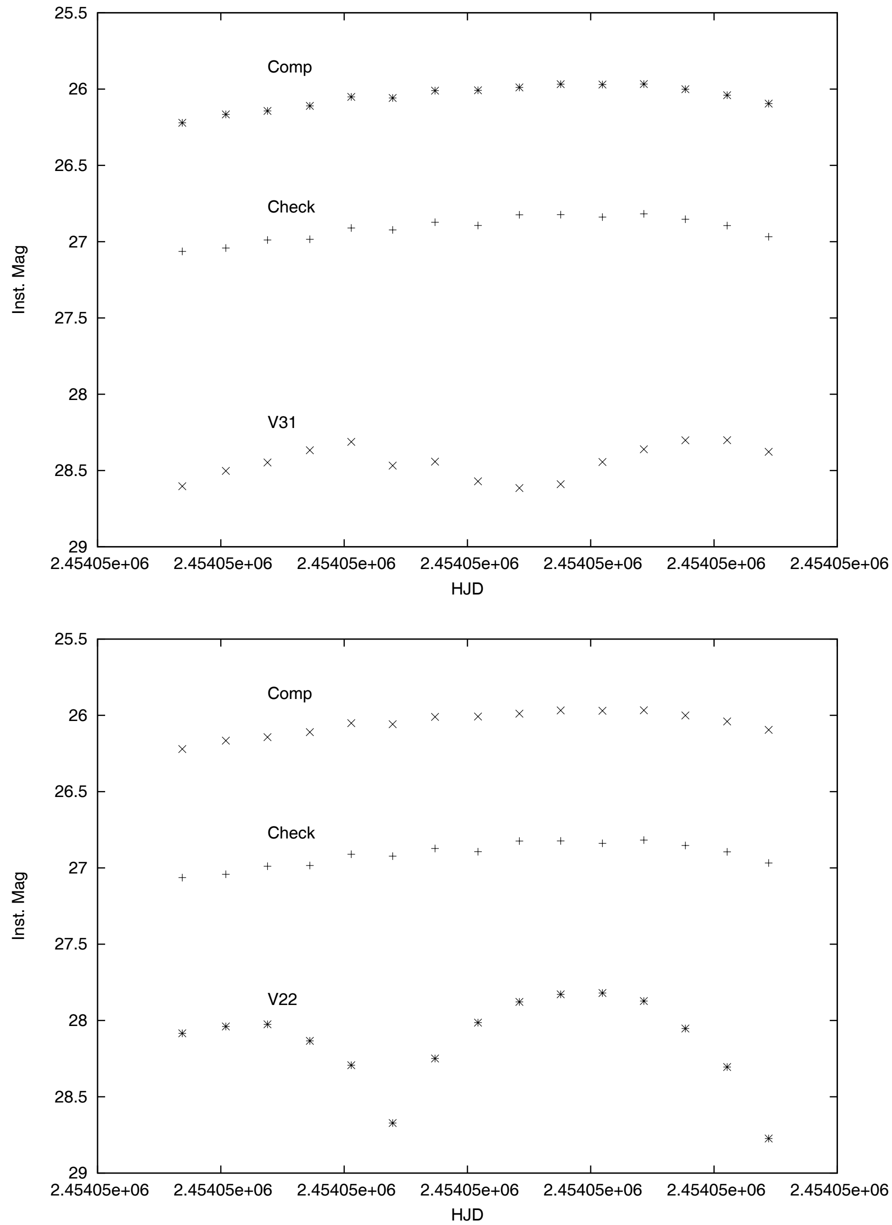


Fig. 3 Light curves of variables and comparisons.

4.2 Variable V22

The observed and theoretical light curves suggest that the variable is an H type W UMa binary system. The period of the system is around $\sim 0.3063^{\mathrm{d}}$ and the color ($B - V = 1.0$) value corresponds to K3 spectral type (Mochejska & Kaluzny 1999). The best combination of q and i is of the order $\sim$ 1.051 and $\sim 79^{\circ}$.

Table 1 Photometric Elements Obtained for Two Variables by Using the W-D Method

Element		V31	V22
$^{a}T_{e,h}$ K		4880	4600
$T_{e,c}$ K		4810±91	4440±77
q		0.906±0.002	1.051±0.006
i°		69.30±1.43	79.19±2.0
Ω		3.5489±0.0529	3.6866±0.0662
r_h	pole	0.3648±0.0037	0.3561±0.0077
	point	0.4056±0.0061	0.4098 ±0.0123
	side	0.3837±0.0032	0.3740± 0.0112
	back	0.4142±0.0033	0.4049±0.0143
r_c	pole	0.3473±0.0032	0.3366± 0.0132
	point	0.4239±0.0051	0.3688 ± 0.0154
	side	0.3643±0.0032	0.3297 ±0.0144
	back	0.3955±0.0050	0.3722 ± 0.0161
L_h		0.4565±0.0123	0.4548±0.0098
L_c		0.5435	0.5452
L_3		0.0	0.0
$^{a}x_h$		0.63	0.63
$^{a}x_c$		0.63	0.63
$^{a}g_h$		0.32	0.32
$^{a}g_c$		0.32	0.32
Σ		0.0016	0.0101
Spectral type		K2	K3
^{a}A$_h$		0.5	0.5
^{a}A$_c$		0.5	0.5

^{a} denotes the fixed parameters.

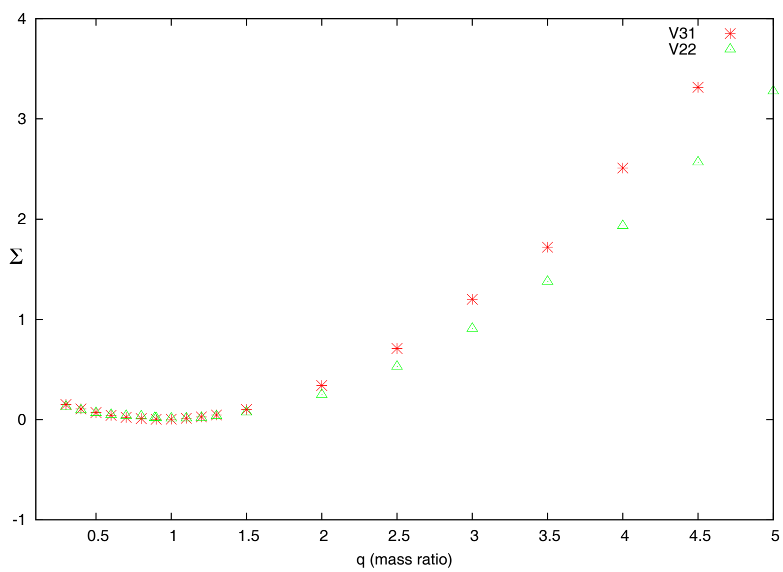
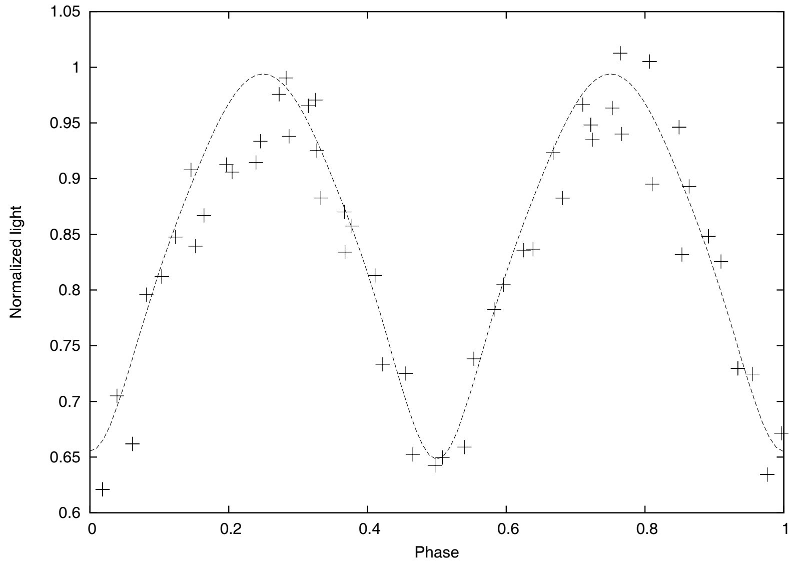


Fig. 4 q vs. sigma of the variables V31 and V22.



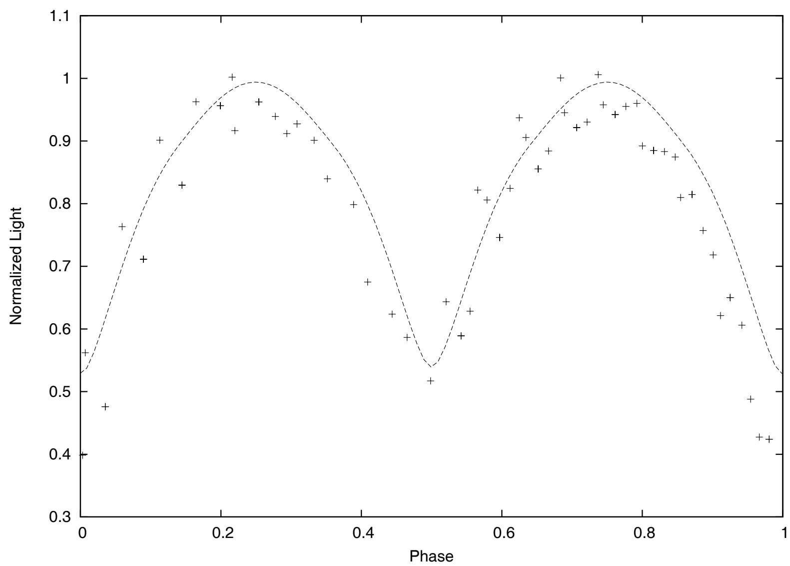


Fig. 5 Figure shows the best fit to the V passband light curve of the two variables (*upper* V31 and *bottom* V22) present in NGC 7789. The plus symbols represent the observed data and solid lines represent the theoretical fits.

The high photometric mass ratio obtained through fitting indicates that the variables are H-subtype W UMa systems. The database of light curve solutions of contact binary systems (Csizmadia & Klagyivik 2004) has seven H-subtype W UMa type systems in the period range of $0.3^{d} - 0.4^{d}$ and another four H-subtype systems whose periods are less than 0.28^{d}. The relationship between mass ratio and total mass of the contact binary system indicates that high mass ratio systems evolve towards low mass ratio systems due to the mass loss (Li et al. 2008). High mass ratio contact binary systems can be understood in the framework of the mass transfer process, implying that mass transfer is taking place from the primary (more massive) to the secondary component (less massive) decreasing the period of the respective system. The H-subtype classification suggests that the energy transfer rate is less efficient when compared to other contact binary systems (Csizmadia & Klagyivik 2004). It has been argued that the energy transfer is lower for a primary component with a higher evolutionary rate (Liu & Yang 2000). These results strongly indicate that in high mass ratio systems, the primary is at a late stage of evolution and relative energy and mass transfer is lower compared to low mass ratio binaries. The low mass transfer rate is due to the fact that it depends on the relative gravitational potential difference between the two binary components.

Qian (2001) has found a relationship between the period and mass ratio of W-subtype W UMa binary systems and suggested that for mass ratios $q > 0.4$, the period increases and for $q < 0.4$, period decreases. Since the sample is lower than this, Qian's result cannot be extended to other contact binaries and hence requires more observational and theoretical support. If thermal relaxation oscillation (TRO) is the underlying dynamical mechanism in these systems then the high mass ratio phase is one extreme of the TRO cycle (contact phase) evolving towards a semi-detached phase. Detailed modeling shows that, ultimately, the W UMa binaries will become a single star configuration system, and hence the high mass ratio system has to lose a significant portion of inherent mass and angular momentum in order to become a low mass ratio system, which must have relatively small periods. The photometric mass ratios of variables in Be 33, NGC 6791, Be 39 and NGC 7789 suggest that most of them are H-subtype, independent of the age of the cluster (Rukmini & Vivekananda Rao 2002; Rukmini et al. 2005; Sriram et al. 2009); however, this may be due to observational selection effects. To arrive at a definite conclusion, spectroscopic and photometric observations of W UMa systems in clusters are needed.

Acknowledgements We thank the anonymous referee for the useful comments. K. S. is supported by UGC through the Research Fellowship in Science for Meritorious Student scheme. We thank the Director of IUCAA for allotting the observing time on the 2.0 m telescope of IGO. The authors acknowledge Dr. Vijay Mohan for the useful suggestions.

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