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Photometric studies of close binary systems

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Abstract. Two eclipsing binary stars of the Algol type, RZ Cassiopeiae and R Canis Majoris, are observed in the near IR photometric bands J and K and the light curves are analysed using the Wilson - Devinney light curve synthesis program. Existing light curves of these systems in the optical bands are also analysed with the same program. In the case of RZ Cas, the J & K band light curves gave higher values of bolometric albedo of the secondary star, compared to what is expected theoretically. Also the near IR light curves yielded lower values of derived values of the temperature of the secondary star T_2. These two factors are considered as the indication of the presence of a dark spot on the back side of the secondary star and the values of the spot parameter are derived using the model.

For R CMa, T_2 was found to increase towards the near IR wavelengths, from the optical bands. This is interpreted as due to the presence of localized gas in the system. Also T_2 derived from the H_α light curves is found to be higher than that derived from the neighbouring bands. This is explained as due to the difference in the photospheric absorption of H_α in the photospheres of the primary and the secondary. The moments of primary minima follow the periodic O-C curve observed for R CMa, giving more faith in the presence of a third body in the system, which was proposed before. But the nature of the third body, if present, is still uncovered.

Key words: Stars: eclipsing - infrared: light curves - stars: activity - stars: individual (RZ Cas, R CMa)

1. Introduction

Algol Binaries form a subgroup of nearly 400, in the large family of close binary systems. A typical Algol comprises of a main sequence primary star of late B to early F in spectral type and a secondary star, which is a sub giant of spectral type G to K, in contact with its Roche Lobe. The sub gaint secondary is the less massive among the two which is the famous' Algol Paradox' which was solved in '60s. The present understanding about the formation of Algols tells that, to begin with, the present secondary was the more massive one, it evolved faster and in the process of expansion towards the giant branch subsequent to the exhaustion of the core

Hydrogen fuel, it filled its Roche Lobe. The present primary, sitting well within its Roche Lobe accreted a significant portion of the matter overfilling the companions Lobe and in that process, it became the more massive one than the present secondary. It is still continuing in the main sequence stage.

Since the shape of the secondary stars is highly distorted from spherical geometry, they are expected to spin synchronously with the orbital rotation, which makes their rotation faster than single stars of same spectral type. The additional presence of convective envelope makes the Algol secondaries suitable candidates for the presence of chromospheric activity. Observations of Algols in the Radio and X-ray wavelengths have shown strong indications of the presence of magnetic activity in the system at levels similar to what is seen in RS CVn systems which show high levels of magnetic activity, in the optical photometric bands and at Radio wavelengths. But in the optical light curves of Algols, we may not find the signatures of spots associated with the secondary stars since the secondary stars are much fainter than the primaries and consequently, the secondary eclipses are very shallow. To resolve the surface features of the secondary star, we must observe the light curves at a wavelength, where the secondary eclipses are deep enough to resolve the surface features of the secondary star. In Algol type systems, the secondary eclipse depth increases from optical to near IR wavelengths, due to increasing relative contributions of the scondary star towards the total system light. Previous observation of β Per in the J band have shown activities similar to spots (Richards 1990).

In this work, light curves of two well known Algols, RZ Cas and R CMa are studied in the near IR bands, J & K. RZ Cas is a partially eclipsing system, with a primary eclipse, which shows occasional appearance of a flat minimum. R CMa is an interesting binary system with the lowest known total mass and hosting the secondary with the lowest known mass among Algols.

2. Observation and data analysis

The observations are done with the 1.2m telescope of the Mt. Abu Observatory, Rajastan, India and a near IR photometer using an LN2 cooled InSb detector. The light curves are analyzed using the Wilson-Devinney model (Wilson 1993) adopting a semi-detached configuration. 839 and 947 individual observations are obtained for RZ Cas in the J & K band respectively. The IR light curves are analyzed along with the light curves in the UBV bands observed by Chambliss (1976). A temperature of 8720 K is adopted for the primary star for its spectral type A2 V.

For R CMa, the light curves are obtained with 837 points in the J band and 972 in the K band with good coverage of phases. 11 other published light curves in the optical photometric bands - U, U_n, B, B_n, V, V_n, $H_{\beta w}$ & $H_{\beta n}$ of Guinan (1977), V light curve of Sato (1971) and $_{\alpha\omega}$ & $H_{\alpha n}$ light curves of Edalati, Khalesse & Riazi (1989) - were also analyzed with the same model. Analysis was done adopting the primary to be an F1 V star with a temperature of 7310 K.

The parameters derived from the analysis of J and K bands for RZ Cas and R CMa are given in Table 1. From the observed system magnitudes outside the eclipse and using the values of relative light contribution from the individual components evaluated at the same phases, magnitudes and colors of the components are calculated and the spectral types of the secondary stars are derived for both the systems. Table 2 shows the absolute elements derived. The evolutionary status of RZ Cas and R CMa are studied comparing the derived values of the absolute elements with the model of Schaller et al. (1992) and Lang (1992). Fig. 1 & 2 show the light curves of RZ Cas and R CMa with the model fits. The light curves shown are binned in the phase intervals of 0.1.

New ephemeris' are derived for RZ Cas and R CMa from our observed moments of primary minima. The enhanced depths of secondary eclipses in the near IR has enabled us to determine the moments of secondary minima with nearly the same accuracy as that of the primary minima. The secondary minima occurred at phase 0.5 and the eclipse durations are same for the secondary and the primary eclipses implying circular orbits.

Table 1. Elements obtained from the analysis of J and K band data of RZ Cas and R CMa. f: Parameter not changed during the analysis

Parameter	RZ Cas				R CMa	
	J Band	K Band	J & K Combined J Band	J & K Combined K Band	J	K
T^f_1 (K)	8720	8720	8720		7310	7310
$T_2 K$	4349(30)	4415(44)	4359(28)		4580(25)	5158(47)
q^f	0.331	0.331	0.331		0.158	0.158
i	82°.10(9)	81°.54(11)	82°.01(8)		79.37(0.09)	79.47(10)
Ω_1	4.413(47)	4.401(53)	4.408(45)		3.566(36)	3.612(53)
Ω_2	2.5339	2.5339	2.5339		2.123	2.123
r_1 *pole*	0.244(3)	0.245(3)	0.245(2)		0.293(3)	0.289(4)
r_1 *point*	0.249(3)	0.250(4)	0.250(2)		0.300(3)	0.296(5)
r_1 *side*	0.247(3)	0.248(3)	0.247(2)		0.297(3)	0.293(5)
r_1 *back*	0.249(3)	0.249(3)	0.249(2)		0.299(3)	0.295(5)
r_2 *pole*	0.2684	0.2684	0.2684		0.2173	0.2173
r_2 *point*	0.3886	0.3886	0.3886		0.3202	0.3202
r_2 *side*	0.2796	0.2796	0.2796		0.2260	0.2260
r_2 *back*	0.3123	0.3123	0.3123		0.2579	0.2579
x^f_1	0.250	0.150	0.250	0.150	0.315	0.198
x^f_2	0.470	0.320	0.470	0.320	0.450	0.270
x^f_1 *bol*	0.573	0.573	0.573		0.464	0.464
x^f_2 *bol*	0.528	0.528	0.528		0.537	0.537
g^f_1	1.00	1.00	1.00		1.00	1.00
g^f_2	0.32	0.32	0.32		0.32	0.32
A^f_1	1.000	1.000	1.000		1.00	1.00
A_2	0.56(5)	0.49(6)	0.53(4)		0.50	0.84(16)
$L_1/(L_1 + L_2)$	0.768(6)	0.661(8)	0.767(4)	0.664(4)	0.823(4)	0.723(8)
$L_2/(L_1 + L_2)$	0.232(12)	0.339(20)	0.233(8)	0.334(10)	0.177(7)	0.277(17)
l^f_3	0.000	0.000	0.000	0.000	0.000	0.000
Phase Shift	0.0000(1)	0.9999(2)	0.0000(1)		0.0007(3)	-0.0005(3)
<u>Spot</u>						
<u>Parameters :</u>						
Latitude^f	80.00	80.00	80.00			
Longitude^f	175.41	182.64	174.72			
Ang. Rad.^{f}	20.43	20.48	20.53			
Temp. f.^{f}	0.739	0.783	0.743			

Table 2. Absolute Dimensions of RZ Cas and R CMa

Parameter	RZ Cas		R CMa	
	Primary	Secondary	Primary	Secondary
Mass ($M_\odot$)	2 .21 ± 0.26	0.73 ± 0.07	1.07 ± 0.19	0.17 ± 0.03
Mean radius ($R_\odot$)	1.69 ± 0.06	1.95 ± 0.06	1.50 ± 0.03	1.15 ± 0.03
Mean Temperature (K)	8720 ± 100	4257 ± 26	7310 ± 100	4355 ± 240
($L / L_\odot$)	14.90 ± 1.06	1.12 ± 0.01	5.78 ± 0.38	0.43 ± 0.095
Mean log(g)	4.33 ± 0.02	3.72 ± 0.01	4.11 ± 0.03	3.54 ± 0.01
M_{bol}	+1.81 ± 0.05	+4.66 ± 0.3	+2.88 ± 0.03	+5.71 ± 0.4

3. Results ard conclusions

a. RZ Cas

The temperature of the secondary star (T_2=4250 K), derived from the J and K band light curves, was found to be less than what was derived from the UBV bands by ~ 300 K. The bolometric Albedo of the secondary surface (A_2), which paramterizes the reflection effect of the surface of the secondary star, derived from the J & K bands, is greater than 0.7 whereas the value expected from theory for a star with a convective atmosphere is 0.5. This can point to the probable inadequacy of the bolometric treatment of reflection effect in binary systems.Other two possible reasons for this high A_2 are the presence of a cool dark spot on the back surface of the secondary star or a gas stream from the lobe-filling secondary through the inner Lagrangian point directed towards the pole of the primary star. The model fitting was done with a cool dark spot on the back surface of the secondary star. The J band light curve gave a better fit with a cool dark spot with an angular radius of 20° and a temperature factor of 0.74. The residuals are less for the J band light curve for the model with the spot. But in K band the convergence of the spot parameters was not satisfactory. The value of A_2 also came down to 0.5 with the introduction of a spot on the secondary. The T_2 in these bands also increased by another 150° with the spots, reducing the discrepancy in the derived values of temperatures between the optical and the Near IR bands (this will obviously happen once we introduce a dark spot on the back surface of the secondary star). At present the spot on the secondary is proposed as a strong possibility which has to be verified through further and more accurate observations.

From the derived colors, we classify the secondary star as K1-K4 IV. The primary's mass, luminosity and radius are normal for a main sequence star of its observed spectral type, though slightly underluminous for a ZAMS star of its mass.

The secondary eclipse shows asymmetry both in J & K bands, especially near the end of the eclipse, where it shows a depression and large scatter. This is more in the J band than in the K band. This phenomenon is seen in some other Algols and in some short period RS CVn systems. This is probably due to the presence of a gas stream.

One of the interesting features observed in RZ Cas in previous optical light curves was the occasional appearance of a flat primary minimum. But the color of the system at the primary minima was always indicative of a partial eclipse only. None of our observed primary eclipses

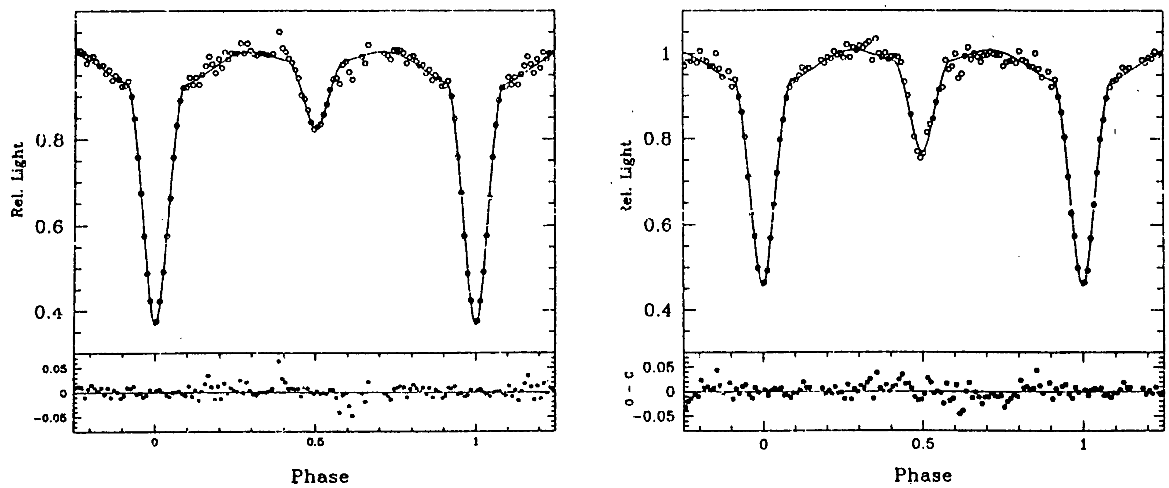

Figure 1. J&K band light curve of RZ Cas. The circles show the normal points formed from the observed light curve and the continous line shows the model with sopt

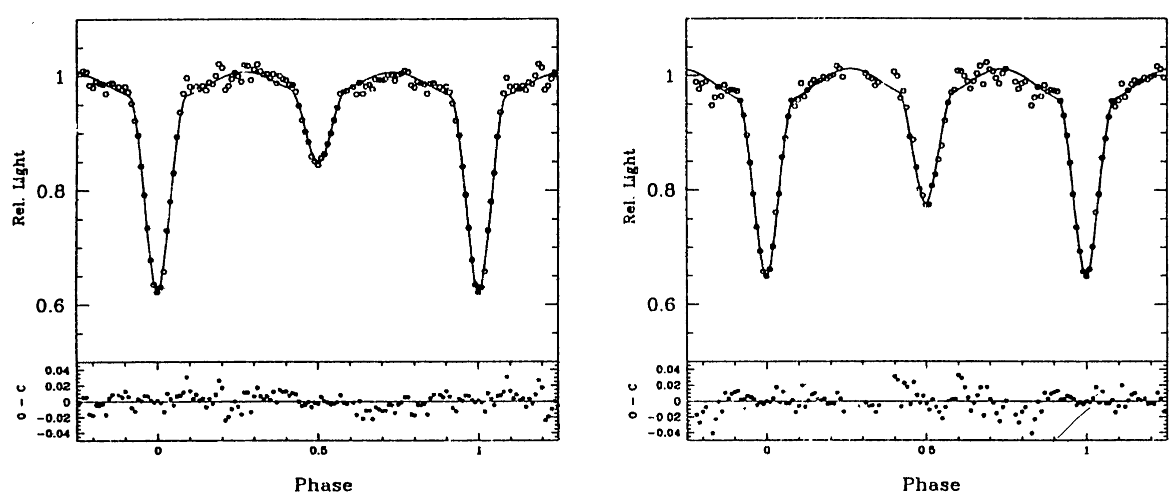

Figure 2. J&K band light curves of R CMa with the fitted model

showed a flat minimum. The observed infrared colors of the system at the primary minima also confirm the presence of a partial eclipse. The frequent occurrence of the flat primary minimum can be due to circumstellar matter in motion.

b. R CMa

A systematic variation of the T_2 from ~ 4100 K in the U and B_n band to ~ 5100 K in the K band is observed. The secondary eclipse is much deeper in the K band than what is expected from the system parameters derived from the V band light curve and this results in a higher temperature of the derived value of the secondary star. This is likely to be caused by the absorption due to localized gas in the system which is proposed as a further study to detect through near IR phase resolved spectroscopy. It is also found that the T_2 derived from the H_α light curves is more than what derived from the light curves in the nearby wavelengths, with the $H_{\alpha n}$ light curve giving a slightly higher T_2 than the $H_{\alpha w}$ light curve. This is interpreted as due to the strong photospheric absorption in H_α on the primary photosphere and much weaker absorption on the secondary. Light curves derived in these bands should not be used to derive the parameters of the system unless the effects of filter bandwidth and the line absorption are taken care of in the analysis.

From the derived colors, the secondary star is classified as K3-4 IV. But it has to be noted that the values of the secondary temperature, derived from different light curves show a larger uncertainty, that that is seen from the colors.

The primary lies close to ZAMS in the HR diagram whereas the secondary is overluminous for its temperature. Both the components are overluminous , hotter and larger for main sequence star of their masses. The departure of the secondary can be understood as due to its evolution out of the main sequence. The overluminosity of the primary is interpreted as due to its increased He content resulting from the He enriched material gained from the secondary star. The evolutionary process which has lead to the formation of R CMa as an Algol in its present state is a bit puzzling and it needs detailed model calculations of the binary star evolution since the system which is at present with a total mass of 1.2 $M_\odot$ would have thrown away nearly 0.9 $M_\odot$ if it has to evolve into its present form.

Previous studies have found a nearly sinusoidal O-C curve for the moments of primary minima of R CMa. It was interpreted as due to the light time effect arising from the presence of a third body in the system (Radhakrishnan, Sarma & Abhyankar 1984). Our observed values of primary minima also follow the predicted values of O-C for a periodic variation. But the present J&K light curves cannot be fitted for the presence of a third body due to the depth of the secondary minima, which is getting enhanced towards these wavelengths. The effect of a non-eclipsing third body will be to suppress the depths of both the eclipses in a light curve. So the nature of the third body, if present, is uncertain at the present stage.

In the case of R CMa also the A_2 showed variations from the theoretically expected value of 0.5 K band light curve gave value of 0.84 where as J band gave 0.5 as expected. In all other bands except, in U, the broad band light curve gave a higher value for A_2 compared to the narrow band. This result can give clues about the often found variations of A_2, derived from Algol light curves.

The variation of the secondary temperature at different wavelengths is a major problem in Algols which needs careful attention. There can be different reasons like the phase dependent absorption by gas stream or disk. Doing near IR spectroscopy in the JHK regions and looking at the variations in the continuum at different phases can help in detecting and quantifying the presence of circumstellar matter. Also it is worth monitoring the light curves in the Near IR wavelengths to look for the presence of stellar activity on Algol secondaries.

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