Comparison of photometric and spectroscopic parameters of eclipsing contact binary stars

Patricia Skelton

Department of Mathematical Sciences, PO Box 392, UNISA, 0003, South Africa

E-mail: skeltpl@unisa.ac.za

Abstract. To model an eclipsing contact (EC) binary star requires the temperature of at least one of the components, usually T_1, and the mass ratio q. Other parameters are determined by minimizing residuals between the model and phase-magnitude data. Rucinski *et al.* (2005) have pointed out that model solutions of EC stars obtained from photometric data are unreliable because the photometrically determined mass ratios are different to those determined from spectroscopic data. The temperatures determined from colour indices are also found to differ from those determined spectroscopically. Clearly, in order to produce reliable models of these stars requires a combination of photometric and spectroscopic data. Using the SpCCD spectrograph on the 1.9m telescope at the South African Astronomical Observatory in Sutherland, spectroscopic data were obtained for selected EC stars. The results of the observations and a comparison of the photometrically and spectroscopically determined temperatures and mass ratios are presented.

1. Introduction

Eclipsing contact binary stars, or EC stars, have orbital periods of less than 1 day [1]. The component stars of an EC system range in spectral type from mid-A to late-K and each is assumed to be a main sequence star. Binnendijk [2] divided EC stars into two subclasses which he called A-type and W-type. In the A-type systems, the larger component has a higher temperature than its companion, whereas in the W-type systems the smaller component has a higher temperature than its companion. Observationally it has been found that the A-type systems tend to have low mass ratios $q < 0.3$ and spectral type from A to F [3]. The W-type systems tend to have mass ratios $q > 0.3$ and spectral types of G or K.

Modelling to determine the parameters of as many EC stars as possible may help to answer the many questions we have about the formation and evolution of EC stars. To determine the absolute parameters of an EC star requires a combination of photometric and spectroscopic data. Due to the large number of automated sky surveys, there is no shortage of photometric data of EC stars [4]. One example is the All Sky Automated Survey (ASAS). Since the project began, over $50,000$ variable stars have been detected and of those, over $5,000$ have been classified as EC stars. A large portion of the variable stars discovered by the ASAS have not been classified previously as variable stars. For the newly discovered EC stars, absolute parameters have yet to be determined for these stars due to the lack of spectroscopic data.

It is in general agreement that physical parameters of EC stars obtained from the use of photometric data only are often unreliable. Terrell & Wilson [5] have shown that this is especially true of photometric mass ratios determined for partial eclipsing systems. For total eclipsing systems, the situation is different because the durations of the eclipses constrain the ratio of the radii of the component stars and hence the mass ratio q [6]. This implies that for a total eclipsing system, the photometric mass ratio should be very close, if not equal to, the spectroscopically determined mass ratio.

In a series of papers, Rucinski and collaborators have published the results of radial velocity studies of close binary stars (see *Radial Velocity Studies of Close Binary Stars*, Papers I − XV). The authors have pointed out that for most of the stars in their programme, the photometrically determined mass ratios are not equal to the spectroscopically determined mass ratios [7]. XY Leo is an example of just how difficult it is to determine a reliable mass ratio for a partial eclipsing system using photometric data only. Rucinski and Lu [8] determined a spectroscopic mass ratio $q_{\rm sp} = 0.348(29)$ which is substantially smaller compared to the photometric mass ratio $q_{\rm ph} = 0.726$ as determined by Niarchos *et al.* [9]. For most total eclipsing systems, Rucinski and Lu have found that the spectroscopic mass ratio is in good agreement with the photometric mass ratio. UZ Leo is an example of a total eclipsing system whose photometric mass ratio differs from the spectroscopic mass ratio. Vinko, Hegedues & Hendry [10] determined two possible photometric mass ratios, $q_{\rm ph} = 0.2329$ and $q_{\rm ph} = 0.2266$, for UZ Leo. These two values differ substantially from the spectroscopic mass ratio, $q_{\rm sp} = 0.303(24)$, determined by Rucinski and Lu. These results demonstrate the importance of determining the spectroscopic mass ratios for EC stars.

For modelling and for EC subclass classification, it is important to know the spectral type. For systems that do not have spectroscopic data, estimates of the temperatures are obtained from photometric colour indices. Due to uncertainties regarding reddening corrections and the effect of interstellar extinction, infrared colour indices like $J - K$ and $H - K$ provide more reliable estimates of temperatures compared to $B - V$ colour indices [4]. In the series of papers by Rucinski and collaborators, cases are presented where the spectral type determined from different photometric colour indices do not match and these also differ from the spectral type obtained from spectroscopic data.

Spectroscopic data for two total eclipsing EC stars ASAS 120036−391536 and ASAS 093818−675524 were obtained. The results of the spectroscopic data analysis for the two stars are presented.

2. Observations

Observations were carried out using the SpCCD spectrograph on the 1.9m telescope at the South African Astronomical Observatory (SAAO) Sutherland. Both stars were observed during two runs in 2013 (February and May). Grating 4 with 1200 lines mm^{-1} and resolution of 1 Å was used. The grating has a useful range of 800 Å and a blaze wavelength of 4600 Å. The grating was centred close to the blaze angle in order to have a spectral range coverage of around 4200 − 5000 Å. This wavelength coverage includes the two Balmer lines, Hγ and Hδ, as well as a plethora of iron and other ‘metal’ lines in the range 4300 − 4500Å. The intrinsic shape of the iron and ‘metal’ lines is symmetric and narrow [11], and due to the large number of these lines, they have proven to be useful in measuring radial velocities via cross-correlation.

Observations of both ASAS 093818−675524 and ASAS 120036−391536 were targeted at and around the quadratures with a few spectra obtained at phases 0 and 0.5. The latter observations assist with determining the relative system velocity which is required in order to determine the spectroscopic mass ratio. For both stars, the spectra obtained close to phase 0.5 correspond to the total eclipse portions of their light curves (see Figure 1). Since the light from one component is visible during this phase, these spectra were used to determine the spectral type of the eclipsing component. A total of 46 spectra were obtained for ASAS 093818−675524 and 34 spectra for ASAS 120036−391536. Spectra for two radial velocity standard stars, HD 126053 and HD 154417, were obtained in order to be used for the radial velocity measurements of ASAS

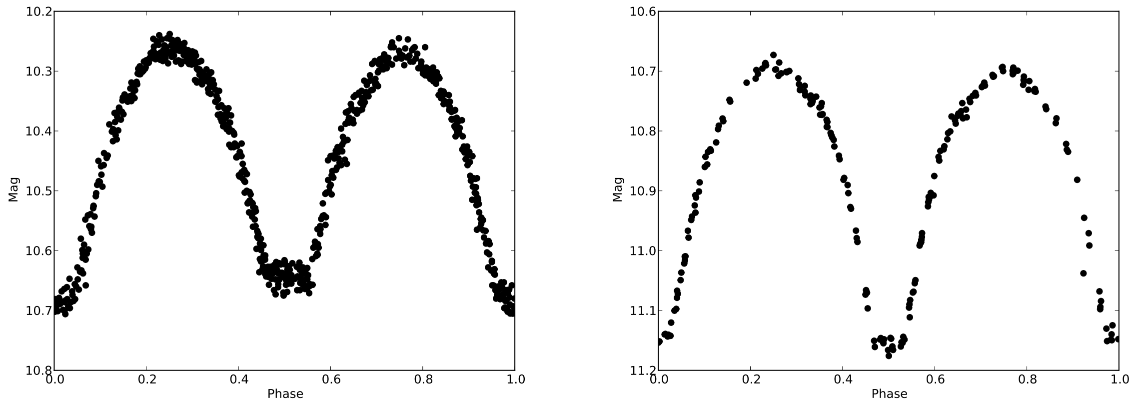


Figure 1. Phase-Magnitude diagrams for ASAS 093818−675524, left, and ASAS 120036−391536, right. Both stars display total eclipses at phase 0.5.

093818−675524 and ASAS 120036−391536.

Standard CCD reductions were performed using the relevant routines in IRAF. Spectra were extracted using the APALL task and wavelength calibrated using CuAr arc lamp exposures. Radial velocities were measured by cross-correlation with the spectra of the radial velocity standard stars, using the FXCOR task in IRAF. The radial velocity standard star HD 154417 (F9V, $V_r = -16.70$ km s^{-1}) was used for ASAS 093818−675524 and HD 126053 (G1.5V, $V_r = -19.40$ km s^{-1}) for ASAS 120036−391536.

PHOEBE, an eclipsing binary modelling software package [12] based on the Wilson-Devinney code [13], was used to determine the relative system velocity and spectroscopic mass ratio for both EC stars. To determine the spectral types of ASAS 093818−675524 and ASAS 120036−391536, the phase 0.5 spectra of both stars were cross-correlated with the spectra of main-sequence stars of spectral types from mid-A to late-K using FXCOR. The heights of the cross-correlation peaks were used to identify which spectral types best matched the phase 0.5 spectra.

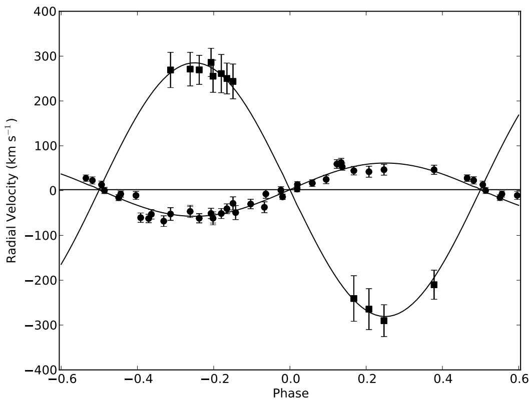
3. Results

3.1. Radial Velocities

Photometric mass ratios for both stars were determined by using the iterative procedure described by Wadhwa and Zealey [14]. The software package PHOEBE was used to model the stars and the Differential Corrections (DC) routine of the programme was used to refine the parameters. Photometric mass ratios $q_{\rm ph} = 0.170$ and $q_{\rm ph} = 0.256$ were determined for ASAS 093818−675524 and ASAS 120036−391536 respectively.

The radial velocity curves for both stars are shown in Figure 2. Filled circles correspond to the radial velocities of the primary component and the filled squares correspond to the radial velocities of the secondary component. The DC routine in PHOEBE returned a spectroscopic mass ratio $q_{\rm sp} = 0.210$ for ASAS 093818−675524 and $q_{\rm sp} = 0.315$ for ASAS 120036−391536. For both stars, the spectroscopic mass ratio does not equal the photometric mass ratio. Although both systems are total eclipsing systems, the fact that $q_{\rm ph} \neq q_{\rm sp}$ highlights the importance of using spectroscopic data to determine the mass ratios of EC stars.

During the calculation of the phase values for ASAS 093818−675524, it became clear that the given ASAS period was incorrect as the maximum radial velocities did not correspond to phases 0.25 and 0.75. The period was adjusted to correct for this but during the analysis in



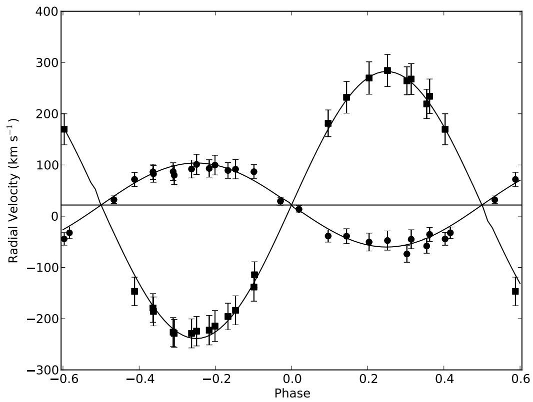


Figure 2. Radial velocity curves for ASAS 093818−675524, left, and ASAS 120036−391536, right.

PHOEBE, a phase shift of 0.5 had to be introduced so that the synthetic radial velocity curve matched the observed radial velocity curve. The ASAS data for ASAS 093818−675524 suggests that the period of the system is changing and so a period analysis will need to be performed in order to refine the period and determine a period change rate.

3.2. Spectral Types

Table 1 lists the V magnitude, $B-V$ colour indices, 2MASS colour indices and corresponding spectral types for both ASAS 093818−675524 and ASAS 120036−391536. The $B-V$ colour indices were taken from the SIMBAD astronomical database and the 2MASS colour indices were taken from the ASAS site. The spectral types corresponding to the $B-V$ colour indices were taken from Fitzgerald [15] and those corresponding to the 2MASS colour indices were taken from Straižys and Lazauskaitė [16].

Table 1. V magnitude, $B-V$ and 2MASS colour indices and corresponding spectral types for ASAS 093818−675524 and ASAS 120036−391536.

ASAS ID	V	$B-V$	$J-H$	$H-K$	Sp. Type ($B-V$)	Sp. Type ($J-H$)	Sp. Type ($H-K$)
093818−675524	10.26	0.73	0.30	0.08	G7V	G5V	G5V
120036−391536	10.45	0.80	0.41	0.07	K0V	K0/1V	G0V

Running the phase 0.5 spectra for both stars against the template spectra resulted in a spectral type classification of F7V for ASAS 093818−675524 and G6V for ASAS 120036−391536. Figure 3 shows the spectrum of ASAS 093818−675524 along with the spectrum of an F7V star. Figure 4 shows the spectrum of ASAS 120036−391536 along with the spectrum of a G6V star. The spectroscopically determined spectral types of both stars differs from the spectral types determined from the photometric colour indices.

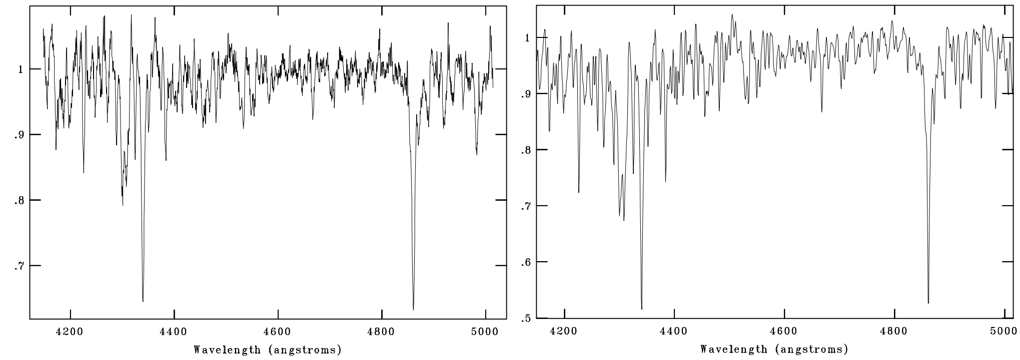


Figure 3. Spectrum of ASAS 093818−675524, left, and the best matching spectrum, F7V, on the right.

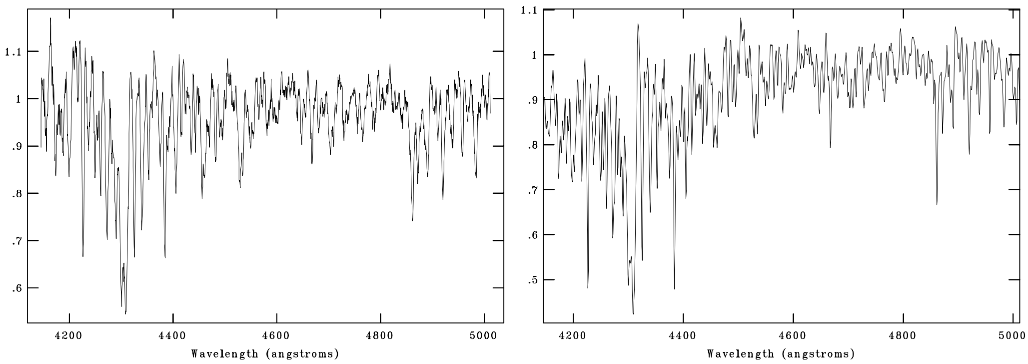


Figure 4. Spectrum of ASAS 120036−391536, left, and the best matching spectrum, G6V, on the right.

4. Discussion

Spectroscopic mass ratios and spectral types for two total eclipsing EC stars, ASAS 093818−675524 and ASAS 120036−391536, have been determined from analysis of spectroscopic data. Table 2 lists the results of the analysis. For both stars, the spectroscopically determined mass ratios are different to the photometrically determined mass ratios. The spectral types for both are also found to differ to the spectral types associated with the $B - V$ and 2MASS colour indices of the stars. The results illustrate the importance of using spectroscopic data to determine mass ratios and spectral types.

The spectroscopic mass ratios and spectral types have been used to determine the subclass type for both stars. For ASAS 093818 − 675524, the mass ratio and spectral type are consistent with the A-type subclass. For ASAS 120036 − 391536, the mass ratio and spectral type are consistent with the W-type subclass.

Acknowledgments

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Table 2. Mass ratios and spectral types determined for ASAS 093818−675524 and ASAS 120036−391536.

ASAS ID	q	Sp. Type
093818−675524	0.210	F7V
120036−391536	0.315	G6V

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