New Astronomy 14 (2009) 528–538

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

Absolute parameters of the Algol binary Z Vul

C. Lazaro [a,b], M.J. Arevalo [a,b,*], J.M. Almenara [b]

[a] Departamento de Astrofísica, Universidad de La Laguna, E-38205 La Laguna, Tenerife, Spain
[b] Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain

ARTICLE INFO

Article history:
Received 19 December 2008
Accepted 19 January 2009
Available online 6 February 2009
Communicated by E.P.J. van den Heuvel

PACS:
97.80.-d
97.80.Hn
97.20.Ec
97.20.Ge
97.10.q
97.10.Nf
97.10.Pg
97.10.Kc
97.80-d
95.85.Gn

Keywords:
Binaries: general
Binaries: Algol systems
Stars: fundamental parameters
Stars: rotation
Stars: Individual: Z Vul
Photometry: infrared-spectroscopy

ABSTRACT

Spectra in the wavelength range 4230–9150 Å and the first light curves of Z Vul in the infrared J, H and K bands are presented. Our infrared JHK light curves and radial velocities, together with published radial velocity and UBV data are analyzed in order to determine a new set of stellar parameters. This allows us to determine new absolute parameters of the stellar components, the interstellar reddening and the distance to the system. We discuss the rotation of the primary star, finding that must be rotating faster than synchronous. From the visual–infrared photometry we find no evidence of IR excess in the system.

1. Introduction

Z Vul (SAO 87113, HD 181987, BD+25 3803) is an eclipsing binary of Algol type. Its composite spectrum shows that it is made up of an apparently *normal* primary component of spectral type B3-5V plus a secondary giant component of type A2-3III.

The mass of the primary component of Z Vul, $M_1 \simeq 5.4 M_\odot$, makes this binary an interesting system for the study of fundamental empirical relations such as the mass–radius and mass–luminosity of stars in the intermediate mass range, and the evolution of these stars in a close binary configuration. The semidetached systems such as Z Vul are presently considered evolved binaries, which have suffered significant mass exchange between the stellar components. The comparison with evolutive models points to the exchange of mass taken place in *case A*, before the exhaustion of hydrogen in the centre of the originally more massive star (now the secondary).

A valuable comparison between the observed properties of the stars and the theoretical models of structure and evolution must be based on the use of reliable stellar parameters, which can only be derived from the analysis of eclipsing binaries with well sampled and accurate light curves. In this work we present new light curves which fulfil these requirements, with the additional advantage that they have been obtained in the infrared bands, where the contribution of the secondary star to the total light of the system is larger than in the usual UBV bands, and particularly favourable if compared with the contribution in the U and B bands.

Different spectroscopic classifications of the hotter component of Z Vul have been published: B3 (Plaskett, 1920), B4 (Petrie, 1950), B5V (Roman, 1956). Popper (1957a) determined the intrinsic colours of the components of Z Vul from UBV photometry,

* Corresponding author. Address: Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain. Tel.: +34 922 318138; fax: +34 922 3118123.
E-mail addresses: clh@ll.iac.es (C. Lazaro), mam@ll.iac.es (M.J. Arevalo), jmav@iac.es (J.M. Almenara).

1384-1076/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.newast.2009.01.010

deriving (B–V) = −0.20 for the primary and (B–V) = +0.06 the secondary. His photometric UBV light curves solutions, together with the results of spectroscopic observations point out that the spectral types of the binary components are a more or less normal B3-4V type star and an A giant, type A2-3III, overluminous by about 1.5 mag. compared with a main-sequence star of the same mass. Popper (1957b) determined the radial velocity curves of both stellar components, finding: $K_1 = 92 \pm 2$ Km/s and $K_2 = 219 \pm 4$ Km/s, yielding a mass ratio for the system $q = 0.42 \pm 0.02$, and the mass functions $M_1 sin^3 i = 5.39 M_\odot$ and $M_2 sin^3 i = 2.27 M_\odot$.

Levato (1975), using photographic spectra, determined a spectral type B5 for the primary star, and a rotational velocity *Vsin(i)* = 195 Km/s. Newer determinations of the rotational velocity by Olson (1984) gave: $Vsin(i)_1 = 94 \pm 7$ Km/s, $Vsin(i)_2 = 72 \pm 13$ Km/s (measured in 1970), or $Vsin(i)_1 = 116 \pm 16$ (in 1982). These highly discrepant values for the rotational velocity of the primary star will be discussed later, in relation to the eclipse distortion shown by its radial velocity curve and the photometric light curves solutions.

Pfeiffer and Koch (1977) included Z Vul in their compilation of linear polarization measurements in close binaries, giving a mean value $\overline{P}(\%) = 0.9 \pm 0.1$, attributed to scattering from circumstellar matter dispersed as a consequence of mass transfer in the system.

Z Vul was included in the observation of Algol-type binaries in the far-ultraviolet (FUV) range. As in other Algol-type interacting binaries, the FUV spectral range of Z Vul shows absorption and emission lines of NV, CIV or SiIV, indicating the existence of a high temperature circumstellar plasma within the systems (Peters and Polidan, 1998). As in other close systems, there is no room to maintain a proper accretion disk, and the gas stream from the secondary star must impact directly on the photosphere of the hot component, presumably this energetic collision being the origin of the hot gas and some transient accretion structures around the primary star. The undetection of H_α emission supports the lack of an accretion disk.

Woodsworth and Hughes (1977) included Z Vul in their radio survey at 10.6 GHz, but the system was not detected. Z Vul has been identified as an IRAS source, IRAS 19196+2529, (Friedemann et al., 1996), detected in the 60 μ band but only with upper limits in 12, 25 and 100 μ, and then it seems not to present any clear long-IR excess. As far as we know, no infrared light curves have been published up to date.

Photometric UBV complete light curves have been published by Popper (1957a) and Broglia (1964), and have been analyzed using different methods. Popper (1957b), using the Russell and Merril method, found $r_1 = r_2 = 0.31 \pm 0.01$ and $i = 88^\circ \pm 1$, for the relative radii and orbital inclination. From his radial velocity curves, he derived stellar masses $M_1 = 5.4 \pm 0.4 M_\odot$ and $M_2 = 2.3 \pm 0.2 M_\odot$. A reanalysis of Broglia's (1964) and Popper's (1957a) UBV light curves was carried out by Cester et al. (1977), adopting a primary mass $M_1 = 5.4 M_\odot$ and a mass ratio *q* = 0.43. They obtained an inclination angle $i = 88^\circ \pm 1$ (depending on the photometric band), and for the effective temperatures and radii of the components they obtained the values: $R_1 = 4.5 R_\odot$, $R_2 = 4.6 R_\odot$, $T_{eff,1} \simeq 20,000 \pm 200$ K, $T_{eff,2} \simeq 9400–10,660$ K (higher from the U band). Their results pointed to a primary star overluminous for its mass, a result that seems to originate in the high effective temperature of the primary component derived from their fits.

More recently, Ghoreyshi et al. (2008), have reanalyzed Broglia's (1964) UBV curves. In this analysis, they maintained the temperature of the primary star fixed at 19,840 K, and it seems they have assumed synchronous rotation for both components. The masses derived from their analysis, $M_1 = 6.209 M_\odot, M2 = 2.67 M_\odot$ are larger than the values derived by Popper (1957b) from the radial velocity curves, and seems to be overestimated.

The analysis of the light curves that we present differs on several points from previous ones. Firstly, we use our own code (*BinaRoche*), based on different model atmosphere fluxes, geometry and minimization algorithms. Also we present and analyze the first infrared J, H, K light curves of Z Vul. As we search the best simultaneous fit in different photometric bands, our analysis allows us to determine the effective temperatures of both stellar components, the interstellar colour excess $E(B-V)$ and the distance of the system. Finally, as some spectroscopic studies have derived for the primary star a rotational velocity well in excess of its expected synchronous value, and given the clear distortion shown by the radial velocity curve collected by Popper (1957b) and our own spectra during the primary eclipse, we have searched for solutions with an asynchronous primary star, finding clear evidence of a faster than synchronous rotation of the hotter component. The analysis of our spectroscopic observations allows us to discuss the spectral classification of Z Vul components, and to increase the number of points of the published radial velocity curves of the system.

2. The photometric and spectroscopic observations

The infrared observations presented in this work were collected in June 1997 (12th to 25th). All the observations were carried out with the 1.5 m CST telescope at the Observatorio del Teide (Canary Islands, Spain). The instrumentation used consisted of a cooled broad band filters CVF photometer with an InSb detector. The aperture size was 15 or 20 *arsec*. The signal to noise ratio of the individual observations was always higher than 500. The collected number of data points in the light curves reach 645 in the J band, 671 in H and 673 in K.

BS7250 was used as a comparison star. This star has never been used before, but it is close to Z Vul and its spectral type is not very different to that of Z Vul. Standard stars of the Observatory were observed each night in order to check that the comparison star's brightness stayed the same. Within the errors of determination, the magnitudes of BS7250 always remained constant during the observation period, and its calibrated magnitudes were: J = 5.55 ± 0.01, H = 5.52 ± 0.01 and K = 5.50 ± 0.01. The BS7250 colour indices, (J–K) = 0.05 and (H–K) = 0.02, correspond to those of an unreddened A4 III star, close to the spectral type given in the DM Catalogue.

From the time of the minima in our JHK light curves we derive new ephemeris for the primary minimum. Adopting the orbital period from Nelson (2004) the ephemeris are:

$$HJD = 2450621.5889 + 2^d.4549328E$$

The differential magnitudes have been transformed to the standard Johnson system applying the telescope transformation equations. In Fig. 1 we show the colours (U-B), (B-V), (V-J), (V-H) and (V-K), where the UBV data is taken from Popper (1957a) and Broglia (1964), as explained in the next sections. In a close inspection of the (U-B) and (B-V) colours, a narrow depression (in the sense of bluer) can be appreciated in phases around 0.90–0.95. These perturbations in the UBV colours suggest the presence of interstellar matter between the stars, in agreement with the spectroscopic evidence in the ultraviolet range.

Some spectra of Z Vul and template stars of different spectral types were collected during March and June 2008. In Table 1 the HJD, spectral range and orbital phase of the observations are given. The template stars were chosen from the FK5 catalog and observed with the same instrumental configuration than Z Vul. The observations were performed with the IDS spectrograph on the INT (2.5 m) telescope at the Roque de los Muchachos Observatory with a spectral dispersion of about 0.5 Å/pixel.