

First spectra of the W UMa system V524 Monocerotis[★]

T. H. Dall and L. Schmidtbreick

European Southern Observatory, Casilla 19001, Santiago 19, Chile
e-mail: tdall@eso.org

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Abstract. We present the first high-resolution spectra of the W UMa contact binary V524 Mon. The spectra of the two components are very similar, resembling a G5 and a K0. We find the radial velocities and rotational velocities consistent with corotation. We estimate the radii and the masses and derive a mass ratio $M_2/M_1 = 2.1$. We confirm that V524 Mon is a W-type contact system, likely enclosed in a common convective envelope, as found by Samec & Loflin (2003). We do not find evidence for the expected level of emission in the chromospheric Ca II H and K lines, neither H α , indicating that the magnetic activity is much weaker than expected or that other processes are hampering chromospheric emission.

Key words. stars: binaries: symbiotic – stars: binaries: spectroscopic – stars: chromospheres – stars: activity

1. Introduction

The W UMa variables are eclipsing contact binaries with components of spectral types F–K, with periods in the range 0.2 to 1.5 days, although the distribution is strongly peaked between 0.25–0.6 days (Rucinski 1994, 1998). As the components of these systems are rapid rotators, they normally show strong chromospheric and coronal emission (Rucinski et al. 1985) obeying a period-activity relation, where the activity increases towards shorter periods. However, for the very fast rotators a saturation of the magnetic activity is reached. In the X-ray emitting corona, this is the result of a decreased coronal filling factor, caused by the partial covering of the two components by an envelope of matter flowing from the secondary to the primary and back, partly covering the surfaces and suppressing long-lived magnetic structures (Stępień et al. 2001). In the chromosphere, the flow of matter should not seriously dampen the magnetic activity. Here the main problem is measuring the emission features, because of the extreme rotational broadening and the underlying continuum. For this reason the UV range where there is little continuum is best suited for chromospheric studies, although for the late spectral types the Ca II H and K lines should be accessible as well.

Recently, Samec & Loflin (2003) presented precise UBVR light curves of the overlooked W UMa system V524 Monocerotis (GSC 00153-01410, $B = 14.40$). From their own data and the literature, they found an orbital period $P = 0.283616$ d, hence a short period system which is expected to be very active. They presented a quadratic ephemeris, with a decreasing period, which, according to Samec & Loflin, could indicate that V524 Mon is losing angular momentum,

presumably due to magnetic braking. While in a previous analysis, Hoffmann (1981) suggested the lightcurve to be of A-type, Samec & Loflin find W-type lightcurves which indicate “the presence of heavy, saturated magnetic activity”. Their model had a mass ratio $M_2/M_1 = 1.84$, fill-out 4.5% and a hot spot on the primary.

In this paper we present the first high-resolution spectra of V524 Mon. The spectra confirm the model of Samec & Loflin based on derived rotational and radial velocities, and the inferred spectral types. However, the spectra also show less than expected chromospheric emission.

2. Observations

We have obtained three high-resolution ($R \sim 48\,000$) spectra of V524 Mon, using FEROS at the ESO/MPI-2.20 m telescope at La Silla, Chile. The spectra all have exposure times of 1800 s and were acquired during on-the-fiber guiding tests on faint targets. The mid-exposure times are HJD 2 453 018.69848, 2 453 018.72169 and 2 453 018.74310, corresponding to phases 0.12, 0.20 and 0.28 respectively, using the quadratic ephemeris of Samec & Loflin. The linear ephemeris give indistinguishable phases.

Standard data reduction was performed with MIDAS including bias and flatfield correction, order extraction and wavelength calibration. The spectra have a FWHM resolution of 0.15 Å and cover the range 3800–9000 Å. FEROS is not the optimum choice for such faint targets, so the S/N is ~ 40 around H α , declining to 10–15 near the Ca II resonance lines. No velocity or spectrophotometric standards were observed during the night.

[★] Based on observations made with FEROS at the ESO/MPI 2.2 m telescope at ESO, La Silla, Chile.

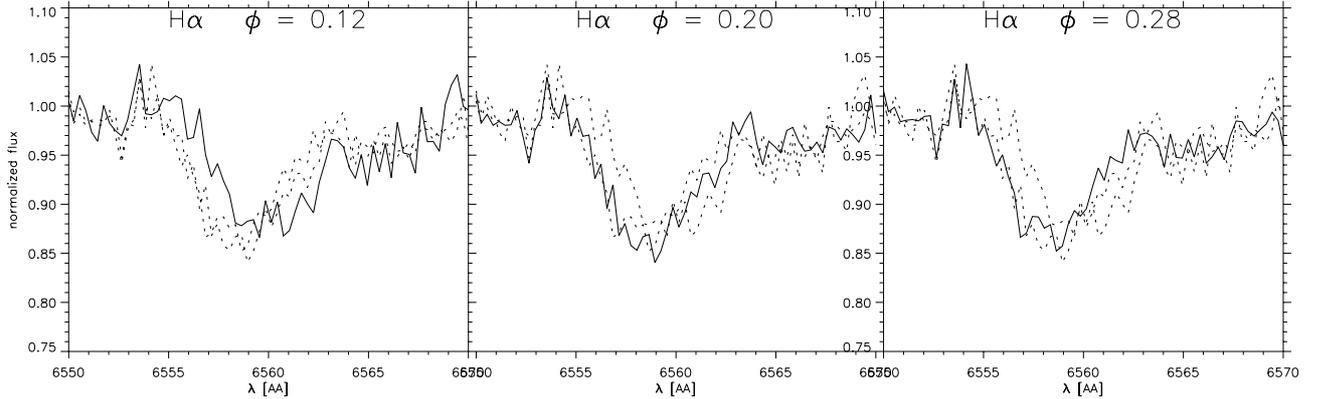


Fig. 1. The $H\alpha$ line region in each spectrum, rebinned to suppress the noise. At each phase, the two other spectra are over-plotted for reference.

3. Analysis and discussion

Evident in all three spectra are absorption features of the two stellar components from the Balmer lines, Ca II H+K, Ca I ($\lambda 4227 \text{ \AA}$), Fe I ($\lambda 4383 \text{ \AA}$) Mg I Eb and Na I D, all rotationally broadened. Also present are narrow Na D interstellar absorption lines.

3.1. Binary parameters

As expected for a WUMa-system, there is a very high degree of similarity between the spectra of the two components, which indicates that the stars are indeed enclosed in a common convective envelope. The strong rotational broadening of the stellar lines makes a spectral classification of the two components quite difficult. Nevertheless, all recognisable lines which are typical of late-G to early-K are present in both stars. They also have approximately the same relative strengths, except for the Balmer lines which are clearly stronger for component 1 than for component 2 (labelling follows Samec & Loflin 2003). On the basis of our spectra we assign a formal spectral type of G5 for the hotter component (1) and K0 for the companion (2). Because of the broadening and the low S/N we estimate a few subclasses of uncertainty in the spectral classification. The interpretation would be as follows: the hotter component (1) is brighter and shows stronger Balmer lines. The cooler component (2) shows intrinsically stronger Ca I and Fe I but weaker Balmer lines. Since it is fainter, the Fe and Ca lines appear to be of equal strength, while the Balmer lines appear very weak. This is in full agreement with the model of Samec & Loflin, where the larger but fainter star (2) has the cooler surface.

In Fig. 1, for all three spectra a region centred on $H\alpha$ is plotted, showing clearly the change of line position and shape with orbital phase. From the lines of Fe I ($\lambda 4383.544 \text{ \AA}$) and Ca I ($\lambda 4226.728 \text{ \AA}$), as well as from $H\alpha$, we estimate the radial velocities as a function of phase. The values are given in Table 1 and plotted in Fig. 2, together with a simple sinusoidal fit, i.e. assuming a circular orbit.

We find a best fit for a system radial velocity of 60 km s^{-1} and amplitudes of 250 km s^{-1} and 120 km s^{-1} for the two components. Note that the component with the strong Balmer lines has the higher amplitude and is hence the less massive star.

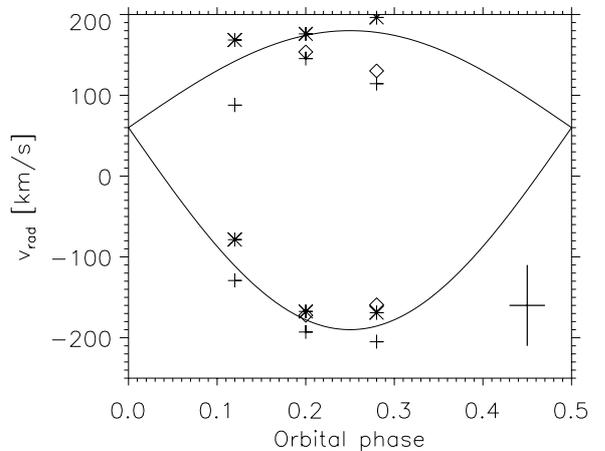


Fig. 2. Measured radial velocities and simple sinusoidal fits to the data. The cross in the lower right corner indicate typical error bars. *: Fe; +: $H\alpha$; \diamond : Ca.

Table 1. Radial velocity as function of phase measured in different absorption lines.

| Component ... @ phase | v_{rad} [km s^{-1}] | | |
|--------------------------|---|-----------|-------------|
| | Ca I (4227) | $H\alpha$ | Fe I (4383) |
| 1 @ 0.12 | | -129.2 | -78.6 |
| 1 @ 0.20 | -172.2 | -192.9 | -167.5 |
| 1 @ 0.28 | -159.1 | -205.0 | -169.0 |
| 2 @ 0.12 | | 87.8 | 168.4 |
| 2 @ 0.20 | 153.7 | 145.4 | 176.0 |
| 2 @ 0.28 | 130.2 | 114.4 | 196.3 |

From this we derive a mass ratio $M_2/M_1 = 2.1 \pm 0.4$, consistent with the findings of Samec & Loflin, who from their model fit find a mass ratio of 1.84. Note that our velocity errors are rather high due to the extreme broadening of the lines, and that the fit is done over only three points along the orbit, although covering the times of maximum radial velocity separation. Hence, we expect the listed radial velocities to be accurate only to within $\pm 40 \text{ km s}^{-1}$.

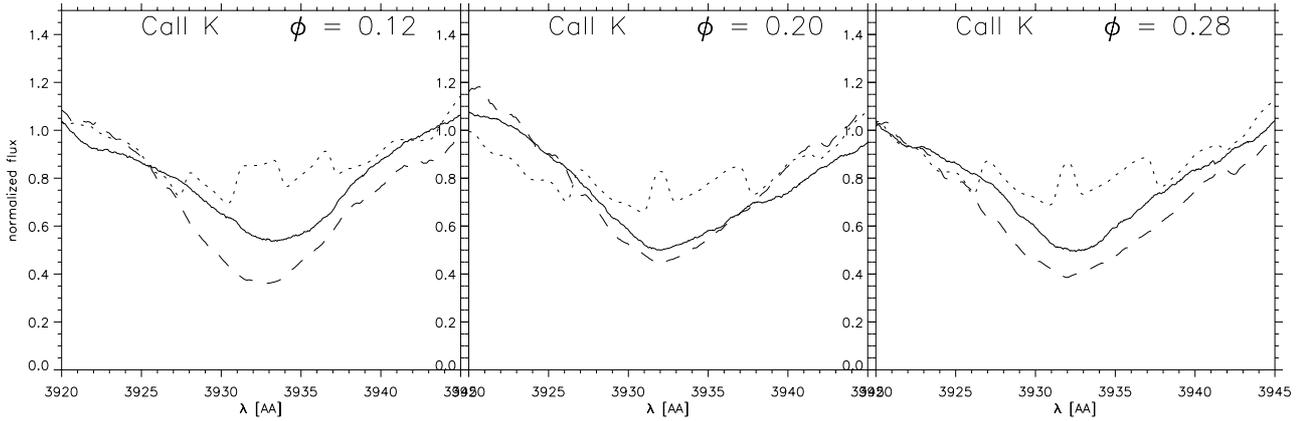


Fig. 3. The Ca II K line at the three phases (solid line) smoothed to suppress the noise. The dashed line is constructed from a solar spectrum and the dotted line from a spectrum of a well-known active star – see text for discussion.

Table 2. The derived parameters for V524 Mon. See text for error estimates.

| | Component 1 | Component 2 |
|---|-------------|-------------|
| Sp. type | G5 | K0 |
| Mass (M_{\odot}) | 0.5 | 1.1 |
| Radius (R_{\odot}) | 1.25 | 1.35 |
| RV ampl. [km s^{-1}] | 250 | 120 |
| v_{rot} [km s^{-1}] | 220 | 240 |

Using our derived radial velocities together with the period $P = 0.2836$ d and the inclination $i = 79.1$ derived by Samec & Loflin, we compute the masses of the two components as $M_1 = 0.5(3) M_{\odot}$ and $M_2 = 1.1(6) M_{\odot}$. Both masses are inconsistent with the corresponding stellar type as can be expected for components of a system with a common convective envelope. However, the mass ratio together with the spectral types of the components, i.e. the fact that the star of later type has the higher mass, does indicate that component 2 is an already evolved star which reached contact during its evolution off the main sequence, and has lost some part of its mass to the common envelope (see e.g. Iben & Livio 1993).

From the line-broadening, we estimate the rotational velocities to be 220 km s^{-1} and 240 km s^{-1} for components 1 and 2 respectively. This gives a radius difference of only $\sim 10\%$ assuming the stars are co-rotating. For the individual radii we then get $R_1 = 8.7(4) \times 10^5 \text{ km} = 1.25 R_{\odot}$ and $R_2 = 9.4(4) \times 10^5 \text{ km} = 1.35 R_{\odot}$, using an inclination of 79.1 .

In Table 2 we summarise the derived parameters for V524 Mon.

3.2. Magnetic activity

The efficiency of the dynamo and hence the activity level is usually described in terms of the Rossby number, $R_0 = P\tau_c^{-1}$, where P is the rotation period and τ_c is the convective turnover time. It has been established empirically (Noyes et al. 1984, and subsequent studies) that the activity of single stars scales with R_0^{-1} . At very low Rossby number (very fast rotation) a

saturation sets in: the activity stays roughly constant as the rotation period decreases. This is thought to be linked to the complete filling of the stellar surface by active regions.

The late-type (W-type) W UMa systems all have very high activity levels, as has been confirmed by several studies (e.g., Cruddace & Dupree 1984; Rucinski et al. 1985; Stępień et al. 2001). However, because of the extreme rotational broadening, the usual optical chromospheric activity indicators, the Ca II emission cores, are very difficult to observe.

In Fig. 3 we show our three spectra of V524 Mon centered on the Ca II K line. The dashed line shown on the figure was constructed from a spectrum of the Sun in the following way: Two versions of the same solar spectrum were added, one of them shifted in wavelength according to the orbital phase. The result was smoothed to wash out the fainter lines, mimicking the effects of rotation, and then plotted on top of the similarly smoothed V524 Mon spectrum. The upper dotted curve was constructed in the same way but with a spectrum of HD 82558 (LQ Hya, K0Ve), an active star of the BY Dra type which shows strong Ca II emission lines. Both spectra were obtained by Dall (2004; unpublished) using the same setup as for V524 Mon. Since the spectral types are similar, and since the S/N is too low to allow a reliable fit, this approach is a valid way to look for excess emission in the rotationally broadened line profiles. Neither the Sun nor HD 82558 provides a satisfactory fit to the spectra of V524 Mon. We have chosen to match as closely as possible the far wings of the lines in a conservative way, i.e. chosen the lowest possible “safe” positioning of the HD 82558 template and the highest possible one for the solar template in order to minimize the fitting bias. Even so, the spectrum of V524 Mon does not show the level of emission fill-in seen in the HD 82558 template, but rather resembles the line shape of the solar case.

We will now justify the choice of HD 82558 as a reference for the expected Ca II emission. It is generally accepted that all active binaries obey the flux-flux scaling relations established from the study of single stars (see e.g. Schrijver & Zwaan 2000; Messina et al. 2001). Moreover, Rucinski (1985) notes that the late-type W UMa systems have activity levels expected by extrapolating from moderately rotating G-K stars to large values of R_0^{-1} (i.e., fast rotation). Hence, we can estimate the

expected emission from the scaling relation between the transition line and chromospheric line fluxes presented by Montes et al. (1996) for active binaries. Using a typical CIV line flux listed by Vilhu & Walter (1987) for W UMa systems, we find for the Ca II K line $F_S(\text{Ca II K}) \sim 10^7 \text{ erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$, i.e. roughly equal to the flux from the most active systems of the BY Dra type, hence the comparison with HD 82558 is justified.

It is clear from Fig. 1 that the H α line appears in absorption, which is another indication of the lack of strong activity. We have not attempted to estimate whether some fill-in is present in H α . Because of the strong temperature dependence of the Balmer lines, any such estimates would be highly uncertain given the uncertainties of spectral type and temperature.

It is clear from Fig. 3 that any emission present in the core of the Ca II K line is much weaker than expected. In the following we will discuss the possible causes for the lack of strong Ca II emission in the spectra of V524 Mon.

All studies of single stars indicate that the activity is well correlated spatially, from the corona to the photosphere (Messina et al. 2001), meaning that the flux-flux relationships are valid. Up to the present, there have been no indications that this was not the case for binaries as well. Furthermore, according to the study by Montes et al. (1996), binaries tend to be overactive relative to single stars, although still following a R_0^{-1} relation. Saturation is thought to have occurred for all W UMa systems due to the extreme rotation.

Recently Stępień et al. (2001) argued that the asymmetric distribution of coronal X-ray activity on W UMa stars (Brickhouse & Dupree 1998; Gondoin 2004) is due to the attenuation of long-lived magnetic regions by mass flows. In this picture, the mass flow covers the whole surface of the secondary and a broad equatorial band on the primary, drawing magnetic loops back into the photosphere before they become large enough to reach the corona, effectively reducing the coronal filling factor. Since we have only sampled a fraction of the orbit of V524 Mon, one explanation of the missing emission might be that the chromospheric activity has a highly uneven spatial distribution, resembling the situation for the corona, which would mean that the flux-flux relationships are not valid. However, several studies seem to indicate that the chromospheric activity is rather uniform over the common convective envelope and that the flux in a given emission line is constant over the orbit (e.g., Rucinski et al. 1985; Vilhu & Walter 1987). Moreover, the inferred asymmetry of the corona may be biased by heavy X-ray flaring activity, hence the amount of asymmetry in the corona is not a settled issue.

If the two stars are not yet in contact, then the chromospheric emission pattern may very well be asymmetric as observed by Dummmler et al. (2003). However, the excellent fit to the W-type lightcurves of V524 Mon, and the indication of corotation argues strongly against this possibility.

Another possibility is that the definition of the Rossby number, and indeed the concept of the usual differential-rotation fed dynamo may be quite meaningless in the close, rapidly rotating environment of a contact system, calling for a revision of the current picture of dynamo action in very rapidly rotating stars, and possibly also incorporating the unique effects of a close binary. It seems, though, that there exist activity cycles

in W UMa systems (see Yang & Liu 2003, for a recent discussion). These have periods comparable to the solar case, hence should we by chance have observed V524 Mon during a “quiet” state, then there is a good chance that quick follow-up observations will find it still in this state.

Finally, the problem may lie with the Ca II lines themselves. These have a fairly low formation temperature compared to most other (UV) chromospheric emission lines, and hence if the interface between the photosphere and the chromosphere is quite different to the solar case, there may exist physical conditions that inhibit the formation of these lines. However, the emission cores of the Mg II h and k lines, which are formed at approximately the same temperatures, are generally observed in W UMa stars.

4. Conclusion

Comparing our findings with the model presented by Samec & Loflin (2003), we find good overall agreement. We determine formal spectral types of G5 for the hotter, less massive component and K0 for the larger component. Thus we confirm their interpretation of V524 Mon being a W UMa contact binary of W-type and refute Hoffmann’s classification, also confirming that photometric light-curve fitting and modelling (Bradstreet 1992; Wilson 1994) does produce excellent and reliable results.

However, all such short-period late-type systems have very high activity levels, as has been confirmed by several studies, but our study does not bring forth clear evidence of strong chromospheric activity. On the contrary, there seems to be an emission-deficiency in the cores of Ca II H and K with respect to the expected activity level.

We suggest that the discrepancy could be due to an incomplete understanding of the influence of very high rotation rates on the structure of the convection zone and the differential rotation, and hence on the dynamo mechanism. We also believe that a better understanding of the influence of close binarity on the generation and morphology of magnetic fields is necessary. Alternatively, we suggest that the conditions in the chromosphere of the star may suppress the Ca II H+K emission, although we note that the similar Mg II h+k lines follows the established flux-flux relations in other W UMa stars.

It seems that it is at present not possible, or at least very difficult, to use the Ca II emission as an indicator of chromospheric activity in contact systems, whether or not this is due to intrinsic effects.

More observations are needed to clarify the activity status of this supposedly very active system.

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