MOTIONS IN THE SHELLS AND ATMOSPHERES OF V923 AQL AND EW LAC AND THEIR MANIFESTATION IN THE SPECTRUM

N. F. VOJKHANSKAYA

Special Astrophysical Observatory, Academy of Sciences, U.S.S.R.

The stars V923 Aql (HD 183656) and EW Lac (HD 217050) are marked in the General Catalog of Variable Stars (Kukarkin *et al.*, 1969) as unique, similar objects with shells. The two stars have quasiperiodic variations in brightness (Lynds, 1960; Walker, 1953). It is assumed here that the variation of brightness is caused by an inhomogeneous distribution of brightness over the surface of the star. A consideration of the literature data on the radial velocities V_r which we have carried out has shown that the variation of V_r is different (Figure 1).

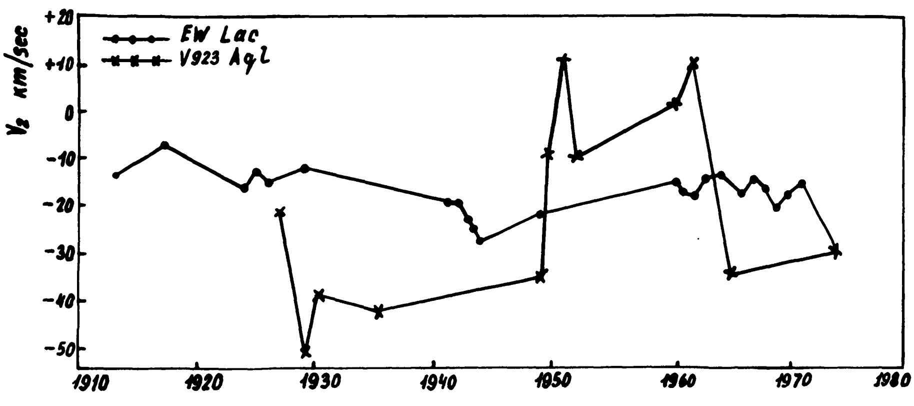

Fig. 1. Radial velocities of EW Lac and V 923 Aql.

For the spectrophotometric analysis, spectrograms with dispersion 29 Å mm^{-1} in the region λ 6700–3600 Å have been used. Twelve spectrograms for EW Lac and ten for V923 Aql were obtained. In addition, ten spectrograms of V923 Aql obtained at the Crimean Astrophysical Observatory in 1965 with a dispersion of 15 Å mm^{-1} in the region λ 4700–3700 Å were loaned to us by T. M. Rachkovskaya.

As a result of our analysis it has been determined that the shell spectrum of EW Lac varies markedly during the period of the order of 24 hours, which corresponds approximately to the photometric period. The lines arising in the atmosphere of the star do not vary. The behaviour of the He I lines is peculiar. In spite of the fact that He I lines most likely arise in the star's atmosphere, their intensities vary greatly, and the character of variation is similar to the intensity variation in the shell spectrum. Figure 2 shows the record of the portion of the spectrum containing the He I line λ 3926 Å in terms of relative intensities. Variation of the hydrogen lines with brightness phase is observed in the spectrum of V923 Aql. Line intensity

A. Slettebak (ed.), Be and Shell Stars, 327–331. *All Rights Reserved*

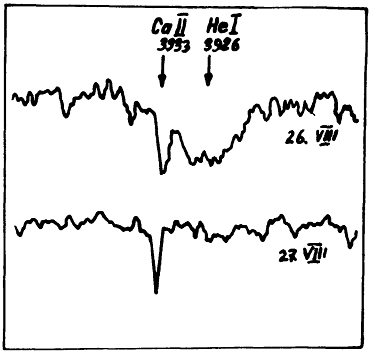

Fig. 2. Variations in He I λ 3926 Å in the spectrum of EW Lac.

variation of other elements, including He I, with light phase does not exceed measurement errors.

For radial velocity measurement we used a device in which setting on a line is performed by scanning the contour back and forth, thereby permitting splitting the observed contour into the shell line and that of the star. We have assumed here that the line core is formed in the shell and the outer parts of the contour in the star's atmosphere. The measured radial velocities are presented in Tables I and II.

TABLE I

Results of radial velocity measurements in the spectrum of V923 Aql

Phase	0		0.5		Error ($km\ s^{-1}$)
Line	1965	1974	1965	1974	
H (shell absorption)	−32	−33	−37	−21	±10
Hα (shell emission)	–	0	–	0	±10
H (star)	−59	−14	−85	−44	±20

TABLE II

Results of radial velocity measurements in the spectrum of EW Lac

Element	26 VIII, 1974	27 VIII, 1974	28 VIII, 1974
Fe I	+92±25	+124±5	
Fe II, Cr II, Ti II, Sc II, V II	+28±13	−20±8	
Mg II	−34.5	−20±8	
Ca II	−39.2	−20±8	
Si II	−21.9±0.3	−20±8	
H (shell, absorption)	−30±10	−20±8	
Hα (shell, emission)	−114.7	−48.9	−64.9
H (star)	−92±20	−80±19	
Ca I	−171	−224	
Na I	−45±5	−50±1	
O I	−59.4	–	
O II, C II, N II, N III	−8±8	+64±10	
He I	−21±10	−82±22	

https://doi.org/10.1017/S0074180900011499 Published online by Cambridge University Press

Velocities for EW Lac have been measured from lines of other elements (see Table II). If V_r is determined from a single line, the error is not given in Table II.

The difference between the hydrogen line contours in 1974 is greater than in 1965 (Figure 3). It can be seen from Table I that the velocities measured from shell lines during these years are the same, within the errors of measurement, while the

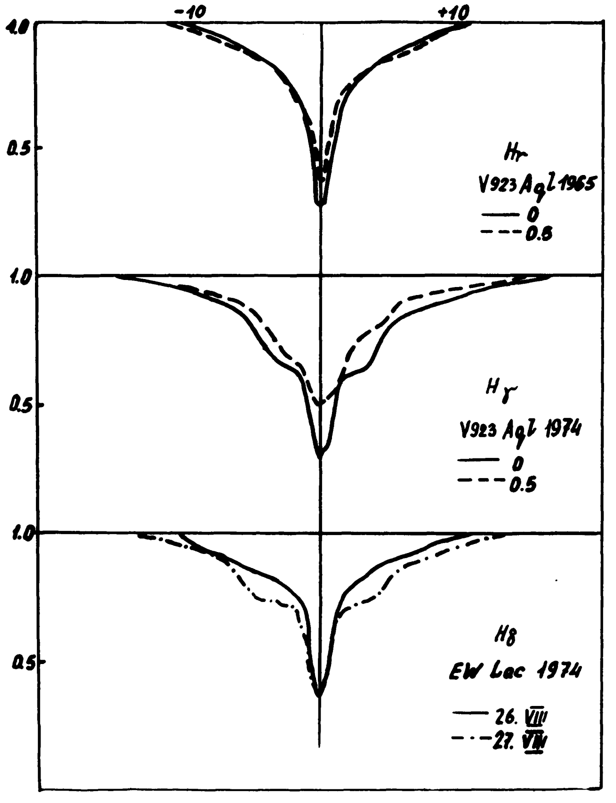

Fig. 3. Balmer line profiles in V 923 Aql and EW Lac.

velocities V_* measured from lines of the star are different. Comparison of the contours with the Table I data has shown that the larger the ratio of velocities V_* (in absolute value) in phases 0.5 and 0, the greater the difference between the contours in these phases. However the value of the velocity V_* is not the major factor determining the shape of the contour. A more important factor is, apparently, the dynamics of motions in the atmosphere and in the shell of the star. If can be seen in Figure 1 that after 1962 the velocity of expansion of the shell of V923 Aql had been rapidly increasing. After 1965 it ceased to increase. As a result of this, considerable inhomogeneities must have developed which would lead to broadening of the contours.

Hydrogen line contours in the spectrum of EW Lac vary in a different way. The radial velocity V_* defined from these lines turned out to be constant. In deeper layers

https://doi.org/10.1017/S0074180900011499 Published online by Cambridge University Press

of the star's atmosphere, where the lines of high excitation potential (C II, O II, N II, N III, He I) arise, the velocity V_* varies.

Taking EW Lac as an example we shall trace in detail the relation between the motion in the shell and the physical parameters determined from the spectrum. In Table III we present the dilution coefficients and the distances in units of the star's

TABLE III
Heights of spectrum formation of different elements and dilution coefficients for EW Lac

Element	26 VIII, 1974		27 VIII, 1974	
	r/R_*	W	r/R_*	W
Fe I	8.9	0.003	–	–
Fe II	6.6	0.006	–	–
Mg II	2.2	0.05	1.1	0.2
Si II	4.7	0.01	2.7	0.03
Ca II	4.2	0.01	4.5	0.01
O I	3.9	0.02	–	–
He I	0.8	0.4	0.7	0.5

radius at which spectra of the different elements arise. The velocity found from C II, O II, N II, N III lines is assumed to be the velocity of rotation of the star. It follows from Tables II and III that on August 26 the surface layers of the star which border the inner layers of the shell were expanding at a mean velocity of about -8 km s^{-1}, and on August 27 they were contracting at a velocity of $+64$ km s^{-1}. The deeper layers of the star's atmosphere, where He I lines arise were first expanding at -21 km s^{-1} and then at -82 km s^{-1}. Thus, radial velocity measurements have shown that the surface layers of the star do not remain stationary, but move at a variable velocity in both magnitude and the direction, which is certain to affect the state of the shell.

It can be seen from Tables II and III that on August 26 the outermost layers of the shell, where Fe I lines arise, were contracting at a velocity of $+92$ km s^{-1}, and on August 27 the velocity of contraction reached a value of $+124$ km s^{-1}. The deeper layers, in which the lines of singly ionized metals Fe II, Cr II, Ti II and Sc II are formed, were contracting at $+28$ km s^{-1} on August 26, while still deeper layers situated closer to the surface of the star, where H_{shell}, Mg II, Ca II, and Si II lines originate, were expanding at a mean velocity of -30 km s^{-1}. On August 27 all these elements had a velocity of about -20 km s^{-1}. The turbulent velocity defined from the curve of growth was 4 km s^{-1} on August 26, and on August 27 it had increased by a factor of 2. This fact can be accounted for if one refers to the analysis of the measured radial velocities. On August 26 the inner and outer layers of the shell were approaching each other. At some moment they collided, after which the magnitude and the direction of the velocity was determined by the motion of the more massive hydrogen envelope, and the radial velocities became equal. However, as a result of the collision of two fluxes turbulence developed and the turbulent velocity increased. This led to clearing of the shell: the optical depth in the Balmer lines was reduced by a factor of two. For example, in the Hδ line $\tau = 3.2 \times 10^2$ on August 26, and on August

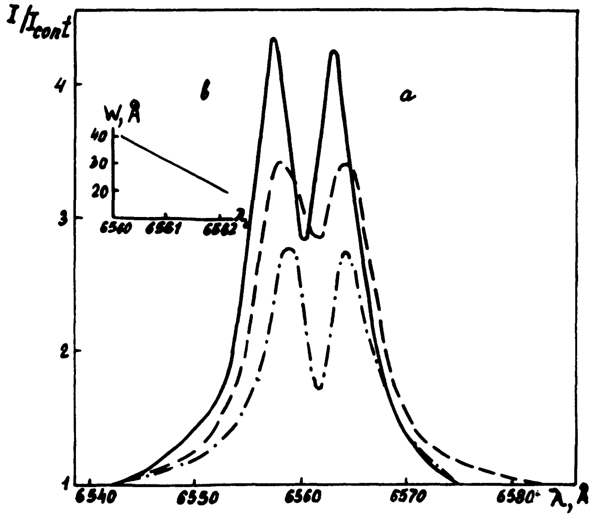

Fig. 4. Hα emission line profiles in EW Lac.

27 $\tau = 1.6 \times 10^2$. A still more obvious relation between the motion of matter in the shell and the intensity of the spectrum follows from Figure 4, where it can be seen that with increasing shortward shift of the Hα emission line, its intensity increases.

Balmer absorption lines formed at distances of 5–6 R_* have smaller velocities than those corresponding to the shift of the Hα emission lines. On the basis of the results presented in Table III it may be suggested that emission in Hα arises at a distance of $\gtrsim 10\ R_*$. If this is so, the velocity of the hydrogen atoms would then increase toward the outer border of the shell. It is difficult to say whether the observed acceleration will lead to a gradual spread and loss of the envelope. If the mass of the star is considered to be 12–13 $M_\odot$ and $R_* = 5\ R_\odot$ (Strand, 1969), the escape velocity at a distance 10 R_* would be about 300 km s^{-1}. The observed velocities are considerably smaller.

References

Kukarkin, B. V., Kholopov, P. N., Efremov, Yu. N., Kukarkina, N. P., Kurochkin, N. E., Medvedeva, G. I., Perova, N. B., Fedorovich, V. P., and Frolov, M. S.: 1969, *General Catalog of Variable Stars* (3d ed.) Moscow.

Lynds, C. R.: 1960, *Astrophys. J.* **131**, 390.

Strand, K. Aa.: 1969, *Stars and Stellar Systems* **3**, 273.

Walker, M. F.: 1953, *Astrophys. J.* **118**, 481.