THE ECLIPSE OF EPSILON AURIGAE
VISIBLE SPECTROSCOPY AND ULTRAVIOLET ACTIVITY

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We report the preliminary results of the study of several high-resolution spectrograms ($\lambda 3500$ - $\lambda 7000$ Å), obtained at the Haute Provence Observatory (OHP) in France, at different epochs before, during and after the eclipse. We also compare some of these spectrograms with corresponding IUE high-resolution observations, in order to study the effects of the intrinsic UV activity, towards the longer wavelengths.

1. The Visible Spectrum

As during the previous eclipses, we have observed the appearance of sharp absorption components on the red side of the strong low-excitation lines and of the Balmer lines during the ingress phase, and on the violet side during the egress phase (Ferluga and Hack, 1985: Paper I). This additional spectrum, which we call "shell spectrum", appears only during the eclipses and is very well observable during the partial phases of the eclipse. During totality it is observable as a strong deepening of the absorption cores of the strongest lines, especially the Balmer lines. The shell spectrum is explained by a gaseous envelope surrounding the eclipsing body and rotating in the same sense as the orbital motion. Since the shell spectrum appears before the beginning and disappears after the end of the photometric eclipse, the gaseous envelope must be more extended than the occulting body (a dusty disk, as suggested by the IR observations by Backman et al. 1984). The shell has about the same excitation temperature of the photosphere of the F0Ia primary, but a much lower density. This is indicated by the fact that the quantum number of the last resolved Balmer line is $n = 31$ in the photospheric spectrum and $n \gtrsim 50$ in the shell spectrum; moreover, the high excitation lines and all the faint lines do not present the shell component. (Fig.1)

The shell responsible for the additional spectrum has an absolute value of the rotational velocity lower before totality than after it (e.g., 277 days before mid eclipse the shell RV is +15 km/s and, 269 days after it, it is -35 km/s; 227 days before it, it is +17 km/s, and 221 days after it, it is -37 km/s). that is, the part of the shell which follows in the orbital motion rotates faster than the preceeding one. Moreover, both parts of the shell show a rotational velocity which increases from the outer part to the inner one, reaches a maximum and then decreases again (Fig. 2). The general behaviour and the values of the RV are the same as observed by Struve et al. (1958) during the 1955-57 eclipse.

At the epoch of the brightening on Jan. 1984 near the end of totality (Ôki et al., 1984) the shell has the maximum negative RV and also maximum intensity. Weak low-excitation lines which generally do not show the shell components show it in the spectrum (GB 8177) taken at the OHP on Jan 24, 1984 (*) . This fact could indicate that in correspondence of a diminution of the density of the dusty disk we observe the absorption of the F0 Ia

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(*) Note. The same behaviour is shown in the UV by the spectrum LWP 2673, obtained with the IUE at high resolution on Jan 20, 1984.

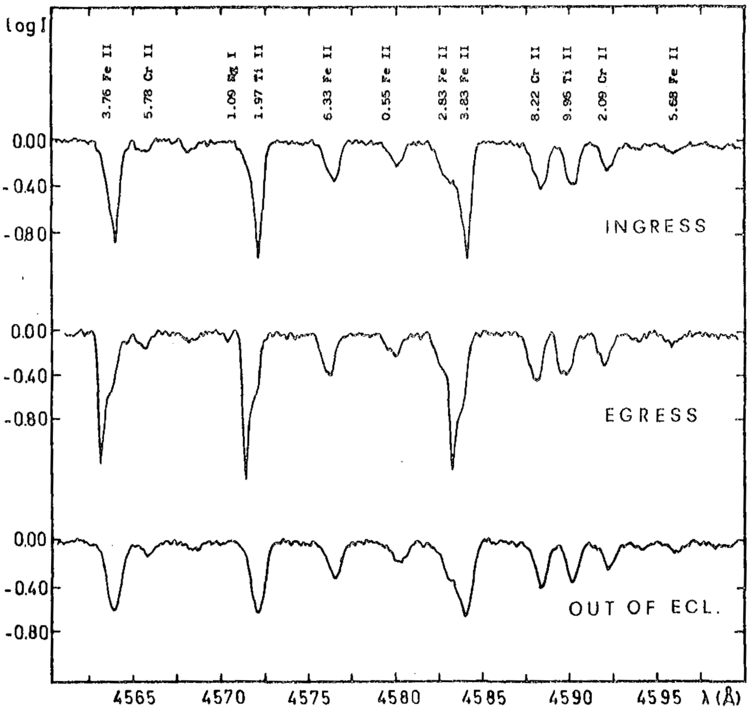

Fig. 1 - The shell spectrum. An additional component is superimposed over the stronger low-excitation lines. This component is red-shifted on ingress (Nov 19, 1982) and violet-shifted on egress (March 29, 1984). The spectrum taken out of eclipse (Jan 4, 1981) is reported for comparison.

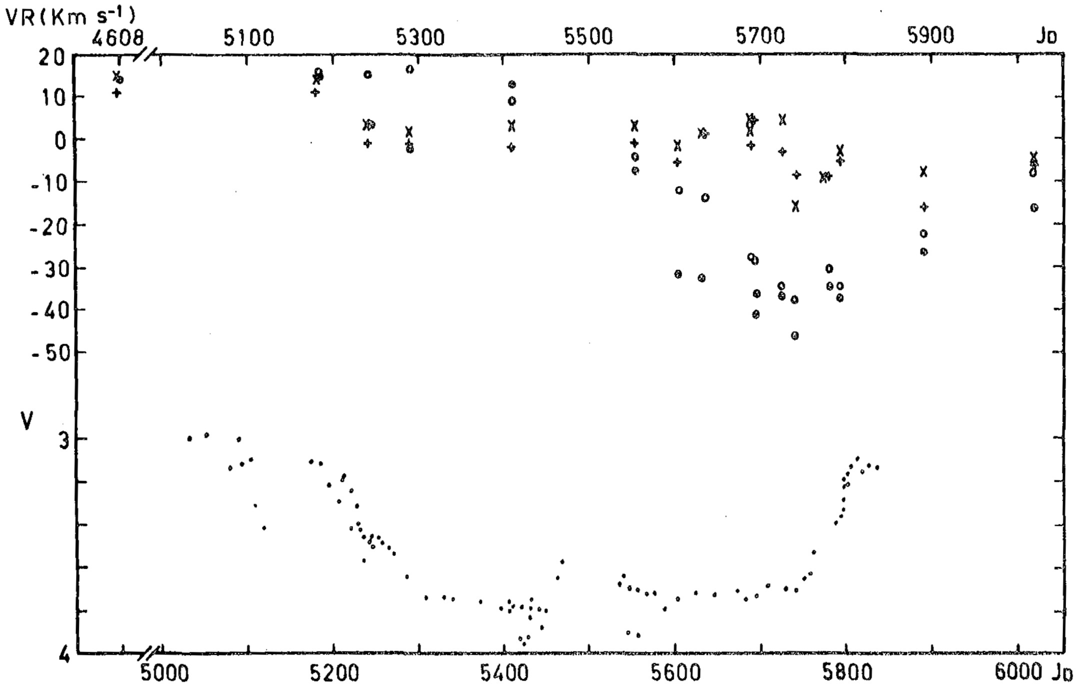

Fig. 2 - The radial velocity curve during the eclipse (together with the V light-curve reported at the bottom for comparison [ε Aur Newsl.11, 32]).The shell components of $H\alpha$, $H\beta$, $H\gamma$, (⊚), and of other lines (o), have radial velocities wich are positive on ingress and negative on egress. At the same time the stellar line Mg II λ 4481 (+), and the other lines with dominant stellar component (x), show a remarkably slower variation, due to the orbital motion.

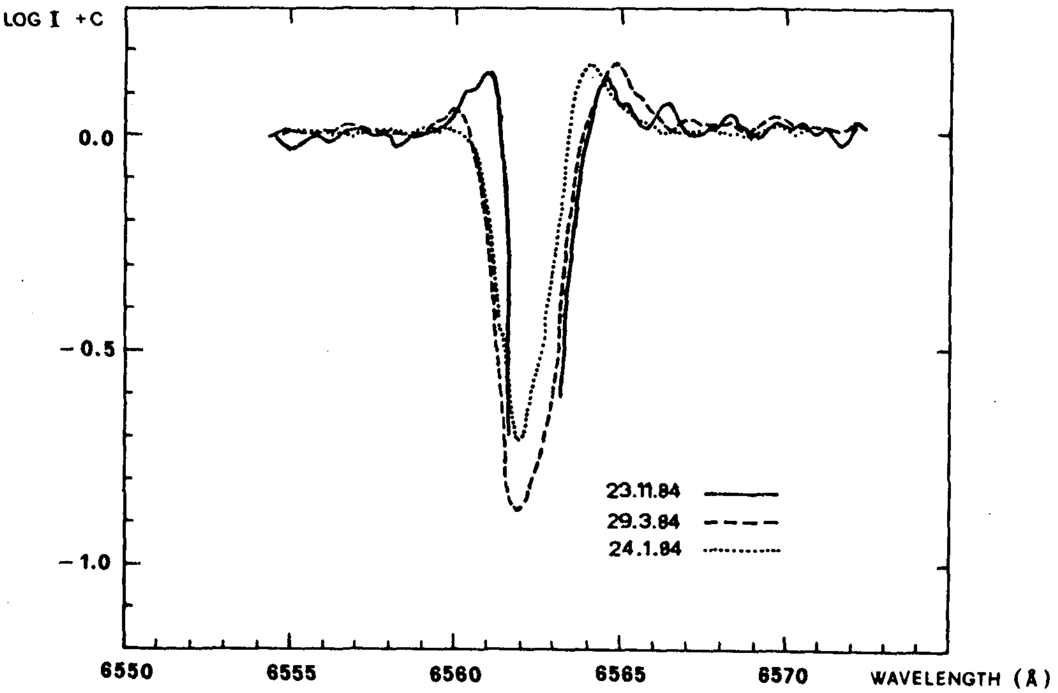

Fig. 3 – The behaviour of H_α at egress. A post-eclipse profile (solid line) is compared with the profiles at egress (dashed) and at early egress (dotted) . Profiles on totality are shown in paper I, while the profiles on ingress are given by Boehm,Ferluga,1984(IBVS 2326)

light from a part of the shell close to the orbital plane where the density and the rotational velocity are probably higher than above and below the plane.

The strongest lines in the photospheric spectrum, H and K of Ca II, during the partial phases of the eclipse appear to be predominantly due to the F0 Ia spectrum, while the contrary is true for the Balmer lines. Moreover, they have a complex structure also out of eclipse . In fact, the spectrum taken in Jan 1981 shows that the H and K lines have a violet-shifted component at about −30 km/s, probably of CS origin, which was observed also by Struve in 1950 (Struve 1951) and by Adams in 1940. The presence of a CS shell is confirmed by the UV emissions O I λ1302 and Mg II λ2800 which are not affected by the eclipse.

The general behaviour of H_α (Fig. 3) is very similar to that described by Wright and Kushwaha (1957) during the previous eclipse. The RV of the various absorption components, the half-width and intensity of absorptions and emissions are given in paper I.

During the UV phases of activity observed with IUE the lines of low excitation are weaker, while the lines of higher excitation are not weaker or are just slightly weakened. The weak lines which are all F0 Ia photospheric lines (i.e. without shell components) remain unchanged. This suggests (see the next section) that the UV activity of the companion increases the state of excitation of the shell. The same effect can be produced by the activity of a hot spot on the surface of the primary, hypothesized by Parthasarathy and Lambert in 1983 as an alternative explanation of the UV excess observed at λ shorter than about 1600 Å.

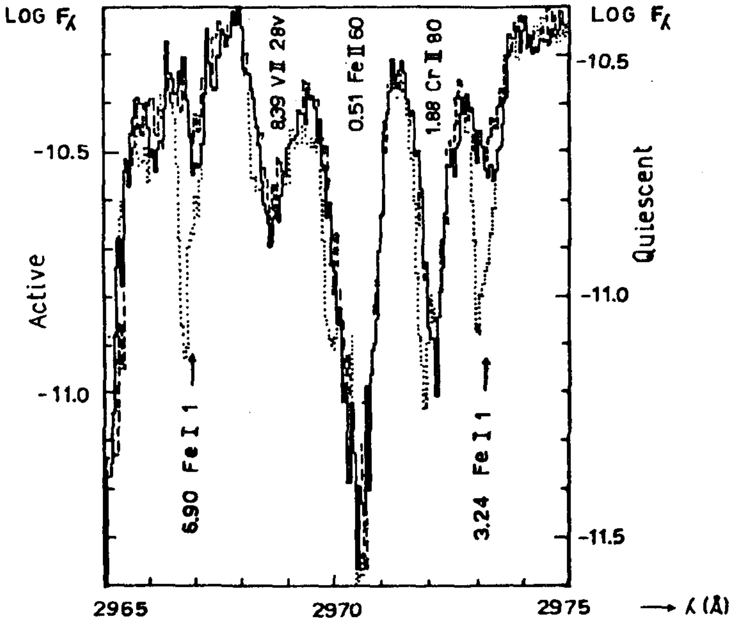

Fig. 4 - Line variations during UV activity. With respect to the quiescent phase on Sep 6, 1984 (······), the profiles of Fe I UV 1 resonance lines are "filled" during activity on March 12, 1982 (———), and they are still more filled during the activity peak on March 26, 1982 (----). Note that the "filling" acts on the doppler-shifted part of the lines.

2. The "active spectrum"

As happens for the depth of the eclipse, also the determination of the shell spectrum, in principle, is affected by the problem of separating the effects of the eclipse from those related with the intrinsic far-UV activity. The influence of this activity, over the spectral lines of the system, can be studied in correspondence of the two active periods which have been observed in the UV since now: the first occurred before the eclipse, on March 1982, while the second occurred during totality, on March 1983. Since for the active period in totality it is difficult, if not impossible, to separate the effects of the eclipse and of the activity, here we shall discuss the pre-eclipse activity period in some detail.

The activity phase in 1982 was the strongest and reached its observed maximum, Δ m = 1.75 mag at 1500 Å, on March 26 (Boehm, Ferluga, Hack, 1984); two weeks before, on March 12, the activity was weaker, Δ m = 1.25 mag at 1500 Å. It is then particularly interesting to compare these two IUE high-resolution spectra, LWR 12777 and LWR 12866, taken in 1982 on March 12 and March 26 respectively (spectral range λλ 2600 ÷ 3100 Å); unfortunately, we do not have optical spectrograms at that epoch. Since both spectra are "active", there are no large variations in the line profiles (paper I); but a detailed inspection reveals that some groups of lines appear to change their relative intensities slightly.

In particular, we may notice that, in correspondence of a higher degree of activity, the stronger mid-UV lines of Fe I, such as λλ 2966.9 - 2973.1 Å resonances or the multiplet V9, seem to be partially "filled". The same thing happens to several low-excitation lines of Ti II, and in particular to the strong low-excitation lines of V II belonging to the multiplets UV 3-10-11-12 (EP $\lesssim$ 0.4 eV) and V 26-27-34-42. Also the absorption wings of the Fe II λ 2599 Å resonance line, and particularly the large absorption wings of the Mg II λ 2800 Å resonance doublet, appear to be flattened by the effect of activity. The filling occurs generally on the *red side* of the lines, and on both wings of the Fe II and Mg II resonances; the effect is about 0.2 - 0.3 magnitudes, between March 12 and March 26, 1982. At the same time, the continuum is raised by about 0.1 mag, in the "window" around 3080 - 3087 Å.

Such effects are greatly enlarged, if we compare these *active* pre-eclipse spectra, with a *quiescent* post-eclipse spectrum: in our case let us consider LWP 4158, obtained with IUE at high resolution on September 6, 1984. After overcoming some calibration problems (the last spectrum was taken with a different IUE camera), there still remains a difference of about 0.5 mag, between the mid-UV continuum enhanced by activity (1982), and the quiescent one (1984); then, while the continuum is raised, the behaviour of the line-components of the mid-UV spectrum, with respect to activity, can be classified as follows.

(*i*) *Normal.* The majority of the lines apparently follow the variation of the continuum, increasing their central flux by ∿ 0.5 mag in activity, with no remarkable variation in the profile.

(*ii*) *Filled.* This is the case (Fig. 4) of the already-mentioned lines of Fe I, Ti II, V II, and wings of Fe II - Mg II resonance lines, which are filled in pre-eclipse activity by ∿ 1 mag. (*)

(*iii*) *Unchanged.* Activity does not affect remarkably the central flux of some high-excitation lines, such as Fe II multiplets UV 62 and higher (EP $\gtrsim$ 1 eV), or Cr II multiplets UV 5 and higher (EP $\gtrsim$ 1.5 eV); so these lines appear to be deepened, with respect to the enhanced continuum. This effect should be dominant in the far UV, producing the deepening of lines observed at low resolution. Moreover, these lines do not show any remarkable doppler shift depending on activity (or on eclipse phase).

(*iv*) *Circumstellar.* Also the circumstellar emission components of strong resonance lines, such as Fe II λ 2599 Å and Mg II λ 2800 Å, remain unchanged by activity, as well as O I λ 1302 Å (observed in the low-resolution mode).

These observed effects can be easily explained by the presence of an additional spectrum, produced by the source of far-UV variability, and superimposed over the spectrum of the system. This *active spectrum* should be very similar to that of the primary, in order to leave it practically identical; the only difference should be a slightly *higher temperature* (together with the absence of absorption wings in Fe II and Mg II resonance lines).

As a consequence, one would have (*ii*) fainter low-excitation lines, producing the observed filling (and the wings of Fe II and Mg II resonances would be filled as well); moreover, one would also have stronger high-excitation lines, adding no appreciable flux (*iii*) to the underlying stellar spectrum.

(*) Note. The behaviour of an even larger number of low-excitation lines, known to possess a violet-shifted shell component in the post-eclipse spectrum of Sept 1984, is apparently similar. The same behaviour is shown, symmetrically, in the pre-eclipse spectra of March 1982. Just because the shell absorption is weaker at ingress, on comparing a pre-eclipse spectrum with a post-eclipse one, these lines appear to be "filled" on the violet side before the eclipse: this effect has nothing to do with activity, and it should be distinguished from case (ii).

Intermediate situations would generate case (*i*), while circumstellar emission components (*iv*) would clearly remain unaffected. Finally, we note that in case (*ii*) the residual line is not red-shifted in pre-eclipse activity, since the "filling" acts on the *doppler-shifted* part of the line (Fig. 4); also in case (*iii*) there is no shift during activity. This should mean that the hot source is either on the primary, or at the center of the companion, but in any case not rotating with the shell.

3. Conclusions

From the results of the present and previous eclipses of Epsilon Aur it is evident that the spectroscopic and photometric observations are completely explained by the presence of the following bodies:

a) the F0 Ia primary, whose spectrum is always observable;

b) a cool body ($T \sim 500$ K) which is responsible for the photometric eclipse of the primary (Bakman et al., 1984). This dusty disk or ring must be made of particles much larger than those present in the IS dust, because no additional reddening is observed at 2200 Å during the eclipse;

c) a gaseous envelope more extended than the dusty disk, which is responsible for the additional spectrum appearing during the eclipse;

d) an extended envelope surrounding the whole system, where the emissions of OI λ1302 and MgII λ2800 are formed;

e) a faint hot body which is not eclipsed and whose radiation dominates at $\lambda \lesssim 1500$ Å. In fact the depth of the eclipse tends to become zero at $\lambda \lesssim 1500$ Å, thus indicating that the excess in the UV is real and not due simply to scattered light from longer wavelengths in the spectrum of the primary, or in other-words, it is not simply an instrumental effect. This hot body may be a star (as suggested by Hack and Selvelli, 1979) or a binary system (as suggested by Lissauer and Backman, 1985), whose radiation, escaping from the poles, excites and ionizes the gaseous envelope, producing the shell spectrum; or it may be a hot spot on that part of the surface of the primary which is not occulted by the dusty disk (as suggested by Parthasarathy and Lambert, 1983). The hot body (star, binary system or hot spot) is variable in light.

Acknowledgments

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