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ASTRONOMY AND ASTROPHYSICS

The Ultraviolet Spectrum of the Eclipsing Binary Epsilon Aurigae*

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Summary. The results of the observations of the ultraviolet spectrum of Epsilon Aur obtained with IUE are given. The short-wave spectrum ($\lambda\lambda$ 1150–1800) has been obtained in the low resolution mode, while the long-wave spectrum ($\lambda\lambda$ 1900–3200) has been obtained in the high resolution mode. The main results are the following: the flux emitted at $\lambda < 1650$ is larger than that expected from the F 0 Ia primary and indicates the presence of a hot star of $T_e \simeq 15{,}000$ K and $R \simeq 2 R_\odot$. The line spectrum supports this value of T_e. A strong emission of O I at λ 1302 is indicative of the presence of an envelope of H II. The long-wave spectrum is characterized by the presence of strong absorption lines of once-ionized metallic atoms. The flux distribution is that expected for an atmospheric model with $T_e = 7500$ K, log $g = 1$, which explains the visible spectrum. The two resonance lines of Mg II present emission of the central part of the line, cut by a strong absorption core, which can be of interstellar and chromospheric origin. The width w of the emission components fit the relation M_v vs. log w derived for late type stars by Evans et al. (1975) and by Kondo et al. (1976) for $M_v = -7$.

Key words: Epsilon Aur – UV spectrum – hot companion

Introduction

Epsilon Aur is a single-line spectroscopic binary whose visible component is a supergiant F 0 Ia; it is eclipsed once every 27.1 yr by the invisible companion. The eclipse is total; the whole minimum lasts 714 d, and for 330 d the star remains at a minimum of constant brightness. The amplitude is 0.8 mag and is independent of wavelength. The eclipse is peculiar because: a) during totality we always see the spectrum of the primary F 0 Ia star; b) from the amplitude of the minimum we might expect the two stars to have about the same magnitude, while only one spectrum is visible at maximum light, even when doubling of lines is expected.

These inconsistencies can be removed by assuming that the invisible companion is surrounded by a disk or ring which is the eclipsing body. The fact that the minimum amplitude is independent of the wavelength was explained by assuming that the eclipsing body is a disk or ring of dust particles (Kopal, 1954, 1971; Huang, 1965, 1974; Wilson, 1971) or of ionized atoms which explain the opacity of the disk or ring as produced by electron scattering only (Hack, 1959, 1961).

This second hypothesis was suggested by the characteristics of the spectrum of the eclipsing body which is observable during the partial phase of the eclipse (Hack, 1959). It is not identical to that of the F 0 Ia star, as we should expect if it were due to stellar light simply scattered by dust particles, but the lines originated from non-metastable levels are much fainter than those in the stellar spectrum, indicating that they are formed in a rarefied medium. However, the non-metastable levels of Mg I, Ca I and Fe I are more populated than is expected from the diluted radiation of the primary star at the surface of the eclipsing body. Hence, if the primary is responsible for the excitation of the eclipsing body (as was suggested by Kuiper et al., 1937), it must be richer than expected in ultraviolet radiation. To explain the observations, Hack (1959, 1961) suggested that the ultraviolet radiation does not come from the primary but from an invisible companion which is assumed to be a hot star surrounded by a ring. It was found that the opacity of the ring could be explained by electron scattering and should be able to produce the observed depth of the eclipse and its independency of wavelength and that other wavelength-dependent causes of opacity were negligible. Possible values of the effective temperature and radius for the companion were computed from the observed characteristics of the spectrum of the eclipsing body (Hack, 1961). Values ranging from $T_e = 15{,}000$ K and $R = 60$ $R_\odot$ to $T_e = 100{,}000$ K and $R = 1$ $R_\odot$ were found. Other suggestions, made by Cameron (1971) and by Wilson (1971), were that the secondary could be a black hole; the source of high-temperature radiation required for explaining the spectroscopic features of the eclipsing ring could be provided by the accretion mechanism, heating the gas at perhaps $\sim 10^6$ K (Wilson, 1971). In order to check these various hypotheses, we have observed the ultraviolet spectrum of Epsilon Aur with IUE.

The Observations

Previous observations of the far ultraviolet spectrum of Epsilon Aur were attempted with Copernicus, but the star was too faint in that spectral region to obtain a significant number of counts. The region 2700–3200 Å was observed with BUSS (Balloon-Borne Ultraviolet Stellar Spectrograph) on September 17, 1976, and the results are consistent with those given by the visible region of the spectrum, which is that of a supergiant star with $T_e = 7800$ K and log $g = 1$ (Castelli, 1978). Observations made with experiment S2/68 on TD-1 do not permit us to derive the spectrum but only the mean flux at $\lambda\lambda$ 1565, 1965, 2365 and 2740

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* Based on observations by the International Ultraviolet Explorer (IUE) collected at the Villafranca Satellite Tracking Station of the European Space Agency

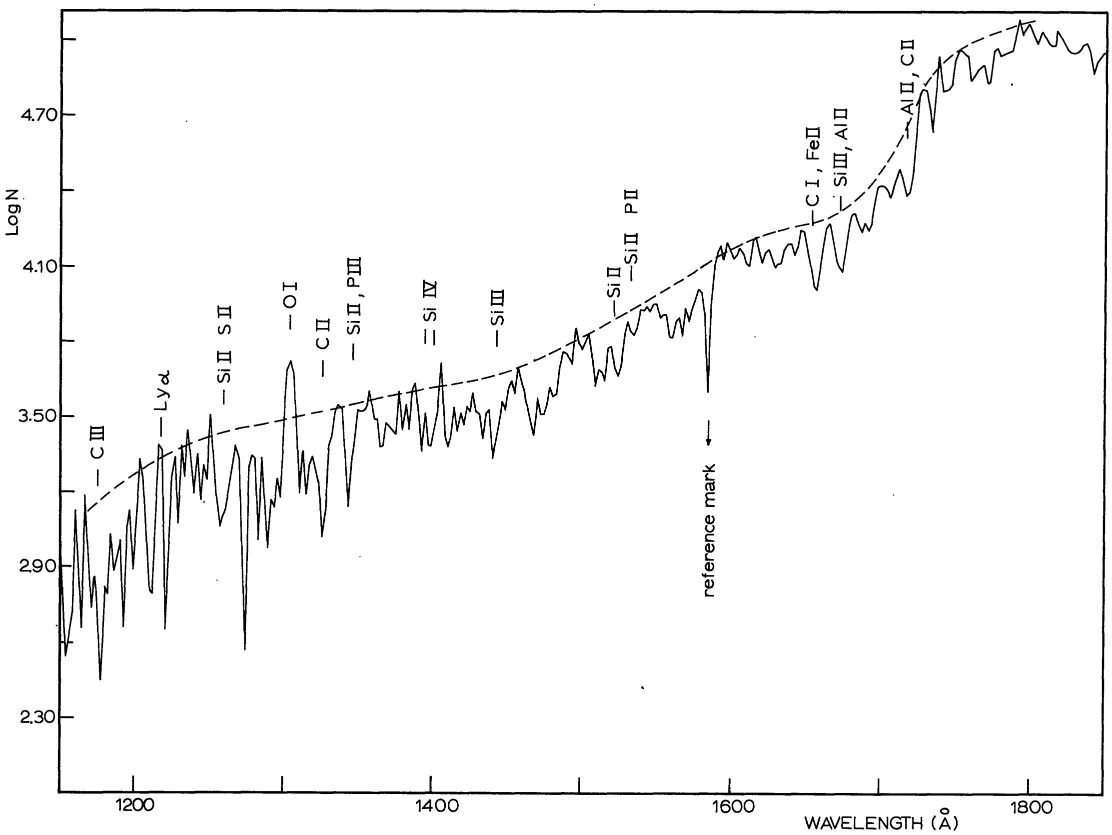

Fig. 1. The low resolution spectrum of Epsilon Aurigae. The ordinates are log N, where N are IUE counts, corrected for the camera background. The adopted continuum is indicated with the dashed line

Table 1. The Observations

Date	Exposure (min.)	Start time (U.T.)	Image N°	FWHM[a] (Å)	Slit	Camera	Notes
1978,							
Apr. 19	30	$4^h\ 12^m\ 0^s$	SWP 1384	5.5 to 7	3"	SW Prim.	overexposed at λ> 1750
Apr. 19	60	5 15 0	LWR 1339	0.2±0.1	3"	LW Red.	underexposed at λ> 2200 and overexposed at λ> 2900

[a]) Boggess et al., 1978

(Thompson, 1977). The data do not make it possible to decide if at the shortest wavelength available the flux differs appreciably from that expected from the F supergiant.

Epsilon Aur was observed with IUE (Table 1) on April 19, 1978. The short-wave spectrum indicates the presence of a hot continuum with several absorption lines and a strong emission identified with λ 1302 O I. The long-wave spectrum is that expected for an F-type supergiant.

The Continuous Spectrum

The continuum has been traced as a smooth line passing through the highest points of the whole spectrum (Fig. 1). On this continuum we have read the values N given in Table 2. N is the output of the IUE software, or net flux. This flux N can be transformed into absolute flux $\mathscr{F}(\lambda)$ in erg cm^{-2} s^{-1} A^{-1} by means of the relation $\mathscr{F}(\lambda)=N(\lambda)S(\lambda)^{-1}t^{-1}$ where $S(\lambda)$ is the sensitivity of the IUE camera determined by Bohlin, and t the exposure time in seconds. The values for $S(\lambda)$ are given for the low resolution mode. For the high resolution mode, no definite calibration is yet available; however, a reasonable estimate is that the data valid for the low resolution can be applied by dividing them by 150 for the short wave range, and by 60 for the long wave range (Selvelli, 1978).

To derive the energy distribution of the companion it would be important to use the values of the flux observed at the shortest wavelengths accessible to the SWP camera (λ 1150). However, the presence of a faint image at wavelengths shorter than the sensitivity limit at λ 1150 indicates the presence of light scattered from longer wavelengths. The amount of this scattered light is evaluated by measuring the net flux N remaining at the center of Ly α, which is equal to 500. By subtracting this value from the net flux we compute the absolute observed flux corrected for scattered light.

We want to compare the energy distribution of Epsilon Aur with that observed for Alpha Car (F0 Ia, $E_{B-V}=+0.01$) with

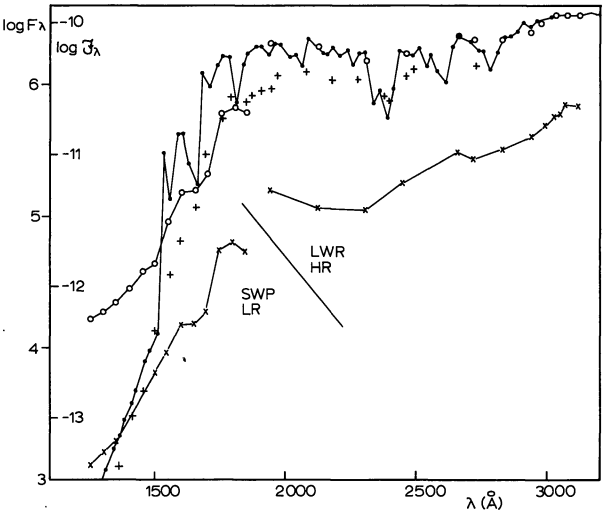

Fig. 2. The continuous flux at the earth $\mathscr{F}_\lambda$ (in erg cm^{-2} s^{-1} A^{-1}) observed for Epsilon Aur (*x*, non-corrected for interstellar extinction, and ⊙ corrected for interstellar extinction with $E_{B-V}=0.30$) and that observed for Alpha Car (S2/68 observations) divided by 30 (+) in order to make it comparable with that expected for Epsilon Aur which is 3.7 mag less bright than Alpha Car. F_λ is the flux (erg cm^{-2} s^{-1} A^{-1}) computed for an atmosphere with parameters $T_e=7500$ K and $\log g=1$ (•——•). SWP, LR: observations made in the low resolution mode with the short-wave primary camera; LWR, HR: observations made in the high resolution mode with the long-wave redundant camera

Table 2. Observed and predicted fluxes

λ	N(λ)	$S(\lambda)^{-1}$	𝔉(λ) observed	𝔉(λ) corr.scatt. light	𝔉(λ) corr.IS extinction	𝔉(λ) predicted	𝔉 corr. / 𝔉 pred.
SWP	t=1800^s						
1150	1202	2 E-13	1.33 E-13	7.80 E-14	1.15 E-12		
1175	1585	1.04 -13	9.2 -14	6.26 -14	9.09 -13		
1200	2148	5.9 -14	7.0 -14	5.40 -14	7.51 -13		
1250	2679	3.3 -14	4.9 -14	3.99 -14	5.40 -13		
1300	3162	3.2 -14	5.6 -14	4.73 -14	6.12 -13	1.15 E-14	53
1350	3631	3.4 -14	6.85 -14	5.91 -14	7.03 -13		
1400	4169	4.0 -14	9.26 -14	8.15 -14	9.13 -13	1.08 -13	8.5
1450	4786	4.8 -14	1.28 -13	1.14 -13	1.23 -12	1.57 -13	7.8
1500	7047	5.9 -14	2.31 -13	2.15 -13	2.23 -12	2.83 -13	7.9
1550	9036	6.4 -14	3.21 -13	2.80 -13	2.88 -12	1.10 -12	2.6
1600	15276	5.9 -14	5.01 -13	4.84 -13	4.97 -12	2.45 -12	2.0
1650	18030	5.1 -14	5.11 -13	4.96 -13	5.03 -12	3.70 -12	1.4
1700	27290	4.4 -14	6.67 -13	6.55 -13	6.70 -12	1.20 -11	0.6
1750	94624	3.75 -14	1.97 -12	1.96 -12	1.97 -11	1.95 -11	1.0
1800	120000	3.3 -14	2.2 -12	2.20 -12	2.13 -11	2.98 -11	0.7
1850	116000	3.0 -14	1.93 -12	1.93 -12	1.96 -11	2.78 -11	0.7
LWR	t=3600^s						
1988	8300	2.4 -12	5.52 -12		6.6 -11	4.00 -11	1.65
2122	9600	1.5 -12	3.96 -12		6.0 -11	4.06 -11	1.5
2309	15000	9.3 -13	3.87 -12		4.9 -11	4.20 -11	1.2
2450	40000	5.7 -13	6.36 -12		5.8 -11	4.45 -11	1.3
2654	113600	3.4 -13	1.08 -11		7.2 -11	5.06 -11	1.4
2720	111200	3.2 -13	9.60 -12		6.9 -11	4.70 -11	1.5
2832	134400	3.1 -13	1.14 -11		6.6 -11	5.03 -11	1.3
2938	146400	3.6 -13	1.44 -11		7.8 -11	6.62 -11	1.2
2973	145600	4.1 -13	1.68 -11		9.0 -11	7.02 -11	1.3
3017	145600	5.2 -13	2.10 -11		1.1 -10	8.08 -11	1.4
3051	132800	5.9 -13	2.18 -11		1.1 -10	8.03 -11	1.4
3068	129600	6.9 -13	2.48 -11		1.3 -10	8.21 -11	1.6
3123	82400	1.0 -12	2.34 -11		1.1 -10	8.34 -11	1.3
3167	82400	1.5 -12	3.42 -11		1.62 -10	9.01 -11	1.8
3205	76000	2.0 -12	4.26 -11		1.98 -10	9.12 -11	2.2

experiment S2/68 on TD-1 (Jamar et al., 1976). To do this it is necessary to correct the flux at the earth of Epsilon Aur for interstellar extinction. We have used the relation by Nandy et al. (1975) between the equivalent width of the interstellar absorption feature centered at λ 2200 vs. the color excess E_{B-V}. We have found $W=144$ A, with an error which can be estimated of ± 30 A like that given by Nandy et al., corresponding to $E_{B-V}=+0.30$; this value is in agreement with that derived by comparing the observed color $B-V=+0.54$ (Hoffleit, 1964) with the average color for F0 supergiants given by Allen (1973), $B-V=+0.25$. Table 2 gives $N(\lambda)$ in column 2; the observed flux in column 4; the observed flux, corrected for scattered light, in column 5; the flux corrected for scattered light and for interstellar extinction, using the relation given by Nandy et al. (1975), assuming $E_{B-V}=+0.30$, in column 6; the value of the flux predicted for Epsilon Aur, assuming that it has the same flux distribution observed for Alpha Car with experiment S2/68 ($\lambda \leq 2740$) (Jamar et al., 1976) and OAO-2 ($\lambda > 2740$) (Code and Meade, 1976), in column 7; the ratio between the flux observed (corrected for interstellar extinction) and the flux predicted, in column 8. This ratio ranges between ~50 at λ 1300 (a value whose error can be estimated to be ±30, because the predicted flux has been obtained by linear extrapolation of the logarithm of the flux measured for Alpha Car with experiment S2/68) to about 8 at λλ 1400–1500, and becomes about 1 at $\lambda \geq 1650$. The flux at $\lambda > 1865$ is obtained by the high resolution spectrum. The sensitivity $S(\lambda)$ for the LWR camera has been divided by 60.

It is evident from these data that a hot object contributing to the far UV spectrum of Epsilon Aur is present.

To obtain the absolute flux we should also take into account the light-loss due to the 3″ hole at the entrance of the spectrometer. The fraction lost varies with focus and also depends on the centering accuracy of the stellar image with respect to the 3″ hole. Under typical observing conditions the light-loss is estimated to be about 50%±20%. This correction, however, does not affect the energy distribution; moreover, the transmission of the hole is estimated to be grey within ±2%.

The flux distribution observed and corrected for interstellar extinction is given in Fig. 2, together with that observed for Alpha Car and compared with the surface flux computed by Kurucz et al. (1975) for $T_e=7500$, $\log g=1$, solar composition.

Because of the uncertainty with which $S(\lambda)$ is known, because we cannot measure the fraction of scattered light except at λ 1216 and because of the unknown loss of light at the entrance aperture, we cannot compute accurate values of the effective temperature and the radius of the companion to fit the observed values of the flux. Moreover the eclipsing body, ring or disk, surrounding the companion, can appreciably reduce its brightness. With all these causes of uncertainty in mind, we can estimate that the effective temperature and the radius of the companion are about 15,000 K and 10^{11} cm respectively, i.e. a hot dwarf of absolute bolometric magnitude about 5 mag fainter than that of the primary (which is classified as luminosity class Ia or $M_{\mathrm{bol}} \sim -7$). This estimate is confirmed by a comparison with the short-wave low-resolution spectrum of the hot halo star Feige 86, also observed with IUE on April 17, 1978, and which is classified B6, $V=10$ mag. The companion of Epsilon Aur (after correction for interstellar extinction) is about 0.75 mag brighter than F 86 in the range λλ 1200–1400; this permits us to estimate for it an apparent visual magnitude $V=9$, that is 6 mag fainter than the main component ($V=2.99$).

The estimate for T_e and R has been made as follows: if we assume that the predicted flux is well representative of the flux

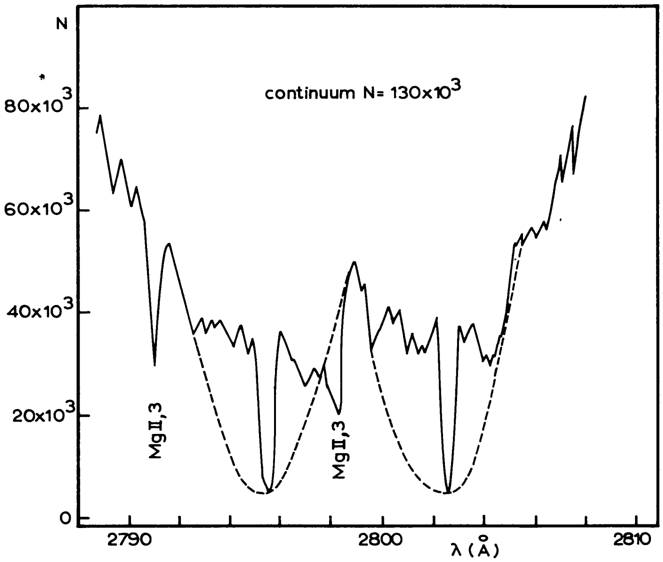

Fig. 3. The profiles of the Mg II resonance lines and the Mg II lines of multiplet 3. The ordinates are IUE counts, N, corrected for the background. The IUE counts N are transformed in flux in erg cm^{-2} s^{-1} A^{-1} through the relation $\mathscr{F}_\lambda = N S_\lambda^{-1} t^{-1}$.

Table 3. Determination of R_B

T_B(K)	R_A(cm)	T_A(K)	R_B(λ1300)	R_B(λ1450)	R_B(λ1575)
11000	10^{13}	7500	2.3 10^{11}	2.2 10^{11}	6.6 10^{11}
11000	10^{13}	8000	4.5 10^{12}	3.2 10^{12}	2.1 10^{12}
15000	10^{13}	7500	8.9 10^{10}	9.3 10^{10}	3.0 10^{11}
15000	10^{13}	8000	1.7 10^{12}	1.4 10^{12}	9.3 10^{11}
18000	10^{13}	7500	5.6 10^{10}	6.2 10^{10}	2.1 10^{11}
18000	10^{13}	8000	1.1 10^{12}	9.1 10^{11}	6.6 10^{11}
11000	4 10^{12}	7500	9.2 10^{10}	8.8 10^{10}	2.6 10^{11}
11000	4 10^{12}	8000	1.8 10^{12}	9.1 10^{11}	8.3 10^{11}
15000	4 10^{12}	7500	3.6 10^{10}	3.7 10^{10}	1.2 10^{11}
15000	4 10^{12}	8000	6.95 10^{11}	5.5 10^{11}	3.7 10^{11}
18000	4 10^{12}	7500	2.2 10^{10}	2.5 10^{10}	8.4 10^{10}
18000	4 10^{12}	8000	4.4 10^{11}	3.6 10^{11}	2.6 10^{11}

Solution giving the least scatter:

15000 4 10^{12} 7570 R_B = 1.1 10^{11}

ΔT_A = 150 ΔR_B = 1.6 10^{11}

$(M_A - M_B)_{bol}$ = −4.8

$(M_A - M_B)_{5575}$ = −6.2

V_B = +9.2

of the main component (Epsilon Aur A), we can write the following relations:

Let us call

$$r_\lambda = \frac{R_A^2 F_{\lambda A} + R_B^2 F_{\lambda B}}{R_A^2 F_{\lambda A}} = \frac{\mathscr{F}_{\lambda\,\mathrm{obs}}}{\mathscr{F}_{\lambda\,\mathrm{pred}}}$$

where $\mathscr{F}_{\mathrm{obs}}$ is the flux at the earth given in column 6 of Table 2 and $\mathscr{F}_{\mathrm{pred}}$ in column 7 of Table 2, $F_{\lambda A}$ and $F_{\lambda B}$ are the surface fluxes of the primary and the companion respectively.

$r_{1300} = 53 \pm 30$ is very uncertain because it depends on the extrapolation of the flux observed with S 2/68 for Alpha Car from λ 1420 down to λ 1300.

$r_{1450} = 8.1 \pm 0.2$ is the average value found for the range λλ 1400–1500.

$r_{1575} = 2.3 \pm 0.3$ is the mean value found at λ 1550 and λ 1600.

$r_{\lambda \geq 1650} = 1.2 \pm 0.2$ is the mean value found for the range λλ 1650–3125.

With these data we can derive the flux at the earth received from the companion, by the relations

$$r_\lambda - 1 = \frac{\mathscr{F}_{\lambda B}}{\mathscr{F}_{\lambda A}} = \frac{R_B^2 F_{\lambda B}}{R_A^2 F_{\lambda A}}. \quad (1)$$

It follows

$\mathscr{F}_{\mathrm{B}\,1300} = 6\ 10^{-13}$ erg cm^{-2} s^{-1} A^{-1}

$\mathscr{F}_{\mathrm{B}\,1450} = 1.1\ 10^{-12}$

$\mathscr{F}_{\mathrm{B}\,1575} = 2.3\ 10^{-12}$

$\mathscr{F}_{\mathrm{B}\,1650} \leqslant 3.7\ 10^{-12}$

We can therefore estimate that the maximum of the energy curve occurs within the interval λλ 1350–1600, and this indicates an energy distribution very similar to that of an unreddened B7–B9 star, as observed with experiment S2/68. The radius of the companion is computed using the relations (1). R_A is included between 4 10^{12} and 10^{13} cm, as indicated by the observations of the eclipse (Wilson, 1971). R_B has been computed using the three values of r at λ 1300, λ 1450 and λ 1575; for F_A we have used the surface flux computed by Kurucz et al. for log $g=1$, solar composition and values of T_e included between 7500 and 8000 K and for F_B the flux computed by the same authors for log $g=4.5$ (but it depends only slightly on the gravity) and T_e equal to 11,000 K, 15,000 K and 18,000 K. The results are given in Table 3. The best values of R_A and T_B, i.e. those which give the least scatter of T_A and R_B around their mean values are the following: $R_A = 4\ 10^{12}$, and $T_B = 15{,}000$ K. It follows: $R_B = 1.1\ 10^{11}$, $\Delta R_B = 1.5\ 10^{11}$, $T_A = 7570$ K, $\Delta T_A = 150$ K, a value very close to that found by Castelli in her fine analysis of Epsilon Aur (1978), $T_e = 7800$.

From these data it appears that the companion of Epsilon Aur is a hot dwarf of absolute visual magnitude about −1, therefore falling on the main sequence. Since the ring which is supposed to surround it and to be responsible for the eclipse of the primary, absorbs about 0.8 mag (this is the observed depth of the eclipse, independent of wavelength in the photographic and visible range), the companion is probably brighter by 0.8 mag. If the absorbing properties of the ring are independent of λ also in the ultraviolet, this means that the energy distribution is not affected, but the radius is larger by a factor $2^{1/2}$, i.e. within the order of the errors by which R_B can be determined, and smaller by one order of magnitude than that predicted for explaining the ionization of the absorption-line spectrum of the ring observed during the eclipse 1955–57.

The circumstances of the eclipse and the spectroscopic observations of the spectrum of the ring during the partial phases of the eclipse (Hack, 1959, Wilson, 1971) indicate that the ring has an outer radius of about 10^{14} cm, a thickness in the orbital plane of about 10^{13} cm, and an electron density of about 10^{11} cm^{-3}. If we assume for the height of the ring a value included between 10^{-2} and 10^{-1} of the outer radius, we find that the mass of the ring is 10^{-7} or 10^{-6} solar masses. Since the system is not close, the presence of the ring around the secondary cannot be explained by mass exchange between the two stars. It is possible that the companion is a past nova, and that the ring is formed with gas

Table 4.

λ	Ion	Multiplet	Remarks
1175	C III	4	strong
1190	C I	9.02, 11, 14	
	Si II	5	
	S III	1	
1200	N I	1	strong
	S III	1	
1212	Ly α		very strong
	Si III	2, 11	
1216 E?	Ly α		emission or noise
1221	Ly α ?		strong
	Cr III	7, 14	
1240-1250	N I	5	
	N V	1	
	C III	9	
	Si II	8, 13.05	
	S II	1	
1257(1255-65)	C I	9, 59	very strong
	C III	11.53	
	Si II	4	
	S II	1	
	Ca III		
	Cr III	5, 6, 20	
	Fe II	9	
1274	C I	7	strong
	Fe II	9	
1284	Ti III	2	
	Cr III	12	
	Mn III	9	
1290-1298	C I	51, 53, 54	
	Si III	4	
	Ca III		
	Ti III	1, 2	
	Mn III	9	
	Fe II	86, 87, 88	
1303 E	O I	2	very strong emission
1312-1316	C I	44, 45, 47, 48	noise?
	Si II	3	
	Si III	10	
	P II	2	
	Ca III		
1326	C I	4	very strong
	C II	1, 11	
	Ca III		
	Ti III	4	
1344	Si II	7	very strong
	Si III	39	
	P III	1	
1356	C I	40, 40.01, 41, 42, 43	
	O I	1	
	Si II	7	
1366-1375	B II	1	strong
	C I	39	
	Si III	38, 46	
	Fe II	103, 152	
1380	P III	7	noise?
	S I	7	
1385	S I	7	noise?
	Ca III		
1394	Si IV	1	very strong
	S I	7	
1395-1403	Si IV	1	very strong
	S I	7	
	Ca III		
1411	N I	10	
1417-1434	C I	65	noise?
	C III	11, 52	
	Si III	9	
	S I	5	
1441	Si III	3.05	very strong
1449-1456	C I	38	noise?
	Si III	3.05	
	Ca III		
	Ti III	5	
1469	C I	35, 35.01, 36	very strong
	Fe III		
1475	C III	12.04	very strong
	S I	3, 4	
	Fe II	192, 193	
1483	C I	3, 4	very strong
	S I	3, 4	
	Ca III		
1495	N I	4	strong
	Fe III	85	
1502	Si III	36	strong
	P III	6	
1510	C I	64.04	very strong
	Si II	11.01	
	Fe III		
1516	Fe III		very strong
1525	Si II		very strong
	Fe III		very strong
1536	Si II	2	very strong
	P II	1	
1542	P II	1	noise?
	Ca III		
1547	Fe III	84	noise?
1553	C IV	1	noise?
1560	C I	3	strong
	Ca III		
	Fe II	45, 46	
1568	Fe II	44, 45	
1573	Ca III		
	Fe II	45	
	Fe III		
1596	Fe III	119	noise?
1602	C I	63	noise?
	Fe III	118, 119	
1613	Sc III	1	strong
	Mn III	18	
	Fe II	43	
	Fe III	116	
1622	Mn III	18	strong
	Fe II	8, 43	
1633	Fe II	8, 43, 68	strong
1643	Fe II	8, 68	strong
1658	C I	2	very strong
	Fe II	40, 41	
1676	Si I	23	very strong
	Si III	58	
	P I	2	
	Al II	2	
	Fe II	40, 102	
1688-1693	Si I	21	strong
	P I	2, 6	
	Cr III	71	
	Fe II	40, 41, 85	
	Ni III	16, 25	
	Cu III	12	
1708	Cr III	71	strong
	Fe II	38, 84	
	Ni II	4	
	Ni III	16, 25	
1719	C II	14.02	very strong
	Al II	6	
	Fe II	38, 84	
	Ni III	16, 30	
1736	Mn II	13	strong
	Ni III	15	
1743	N I	9	very strong
	Mn II	13	
	Fe II	101	
	Fe III		
	Ni II	5	
	Ni III	15	
1759	C I	62	very strong
	Al II	5	
	Ca III		
	Fe II	101	
	Ni II	4	
1771	Si I	14	very strong
	Fe II	20, 29	
	Co III	21	
	Ni III	14	

Notes:

HI: Ly α	IS in absorption, central emission very doubtful.
He II	1640 certainly absent.
C I, C II, C III	Present.
C IV	Absent (IP of C III = 47.7 e V).
N I	Probably present.
N II, N III	No strong lines in this spectral region.
N V	The resonance lines might be present in a blend, but their presence is very doubtful (IP N IV = 77.1 e V).
O I	Present.
O II, O III	No strong lines in this region.
Al II	Present.
Si I	Possibly present.
Si II, Si III	Present.
Si IV	Present (IP Si III = 33.3 e V).
P I	No strong lines in this region.
P II, P III	Present.
S I	No strong lines in this region.
S II, S III	Present.
Ca III	Probably present.
Iron group once- and twice- ionized	Probably present.

expelled during an outburst. Absolute magnitude and spectral type of quiescent recurrent novae have similar values to those derived for Epsilon Aur B (Payne-Gaposchkin, 1957).

The Line-Spectrum

The far ultraviolet line spectrum is characterized by several absorption lines and one strong emission line at λ 1302 due to the resonance line 1302.174 O I and to the other two lines of the same multiplet, λ 1304.858 and λ 1306.023. The presence in emission of this line indicates the existence of an envelope where hydrogen is mostly ionized. In fact, when hydrogen is ionized, oxygen will also be ionized by the Lyman continuum photons, because H I and O I have almost identical ionization potentials. In this case we expect also a strong Ly β emission, which can explain the λ 1302 emission as follows: since the triplet λ 8446 O I ($3p^3P-3s^3S^0$) has been observed in emission in many emission-line stars, while the triplet λ 7772 ($3p^5P-3s^5S^0$) is in absorption, or, if in emission, much fainter than λ 8446, it has been suggested that Ly β (λ 1025.72, high E.P. = 12.04) can overpopulate the upper level of λ 1025.77 O I (high E.P. = 12.03 eV) and from that level $3d^3D^0$ a cascade down to $2p^{4\,3}P$ and then to $3s^3S^0$ explains the emission at λ 8446 (Hopfield, 1924; Bowen, 1947; Hiltner, 1947; Keenan and Hynek, 1950). Then a cascade down to $2p^{4\,3}P^0$ will explain the 1302 emission.

The presence of an envelope of ionized hydrogen is proved by the presence of emission wings at H α. Ly α, instead, is mainly in absorption, a fact which can be explained by interstellar absorption. A similar phenomenon was observed in the case of Beta Lyrae which has much more conspicuous emission at H α than Epsilon Aur; yet, in spite of this fact, it does not show any trace of emission at Ly α (Hack et al., 1975). However we cannot completely exclude the presence of a central emission in Epsilon Aur Ly α; in fact we observe an absorption at λ 1212 and another at λ 1221 cut by an „emission", but the noise in this region of the spectrum is too strong to be sure of this interpretation (see Fig. 1).

The identification of the main contributors to the absorption lines is given in Table 4 and confirms that the companion is not extremely hot. λ 1640 He II and λλ 1548–1550 C IV are absent, while λλ 1394–1402 Si IV are present. All the strongest lines of C I, C II, C III, N I, O I, Si II, Si III, Si IV, P II, P III, S II, S III and probably Ca III, and of once- and twice-ionized atoms of the iron group are present. The presence of the N V resonance lines is very doubtful.

The near ultraviolet spectrum obtained in the high resolution mode is characterized by strong absorption lines, mainly of once-ionized metallic atoms. The most interesting features are the Mg II resonance lines, which were already observed with BUSS in 1976, but were strongly underexposed. In the present spectrum they show a strong and sharp absorption core which is only slightly shifted shortward (−0.2 and −0.1 A for λ 2795 and λ 2802 respectively) relatively to the position expected from that of the other absorption lines. The two stellar lines produce a depression in the continuum extending over about 50 A. The stellar line profiles are distorted and flattened near the central part (Fig. 3). If the central part is interpolated assuming that it is a gaussian curve (dashed line), it appears evident that the central part of the lines is filled with emission. The strong absorption core can be a reversal feature formed in the chromosphere of the star or an interstellar feature, or a blend of the two. We have computed the distance d of Epsilon Aur by means of the relation

$$V=M_V+3E_{B-V}+5\log d-5$$

for $M_V=-7$ and $M_V=-8$. We have found $d=688$ and 1042 pc respectively. We have measured the equivalent widths of the Mg II absorption cores relatively to the central emission used as adjacent continuum. The results are $W_{2795}=0.52$ A, $W_{2802}=0.55$ A. By plotting these values of the equivalent widths on the relation Equivalent width vs. distance, derived by the data given by Lamers and Snijders (1975), we find $d=1000$ pc ± 400 pc. Hence it seems probable that the absorption cores are mainly of interstellar origin.

The profile of the Mg II resonance lines is similar to that observed for Alpha Car with Copernicus by Evans et al. (1975), but the width of the emission is 5.1 A, and that of Alpha Car is 1.9 A, suggesting that Epsilon Aur has a larger luminosity than Alpha Car. However Alpha Car does not fit the relation between absolute visual magnitude and width of the Mg II emission derived by Evans et al. (1975) and by Kondo et al. (1976) for solar type stars, while Epsilon Aur falls on the relation for $M_V=-7$. The flux in the emission is about $2.5\ 10^{-12}$ erg cm^{-2} s^{-1} A^{-1}, and after correction for interstellar extinction is $1.4\ 10^{-11}$. The analogous flux for Alpha Car is $3.1\ 10^{-10}$, i.e. 22 times that for Epsilon Aur, while the expected value due only to their difference in apparent magnitude is 30.

Conclusion

The ultraviolet spectrum of Epsilon Aur permits us to draw the following conclusions: the system is composed of an F0 Ia primary of absolute visual magnitude −7, and of a late B dwarf falling on the main sequence. However, in spite of this position on the HR diagram, it seems possible that the companion is an evolved star, may be a past nova that has ejected the material forming the ring, which is necessary to explain the characteristics of the eclipse. In fact the system is not close, $R_A+R_B \simeq 10^{-2}\ a$, where a is the distance between the two stars; therefore the ring cannot be formed with mass transferred from the primary to the secondary. Another possibility could be that the secondary is a Be star surrounded by a ring; however the mass of the ring is about 10^{-6} solar masses, i.e. much larger than that of the shells of Be stars, whose radii extend to a few stellar radii, and whose masses range between 10^{-10} and 10^{-8} solar masses.

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