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The ultraviolet spectrum of the hydrogen-poor binary HD 30353*

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Abstract. The ultraviolet (IUE) high and low resolution spectra (from 1175 Å to 3200 Å) of the hydrogen-poor star HD 30353 are analyzed. The low resolution spectra show ultraviolet excess flux shortward of 1800 Å, when compared with the flux distribution of normal late-B–early-A supergiants. The low resolution spectra obtained at different epochs show no evidence of eclipses and no significant variations in the flux level.

The high resolution spectra show shortward-shifted stellar wind profiles of N V, C IV, Si IV, C II, Si II, Al II, Al III, Mg II and Fe II resonance lines. The terminal velocity from N V, C IV and Si IV lines is about $-650\ \mathrm{km\,s^{-1}}$. The Mg II resonance doublet shows P Cygni profiles and the emission strength may be variable. The average terminal velocity is $-415\ \mathrm{km\,s^{-1}}$. The subordinate lines of Mg II and the Fe II lines of UV multiplets 1, 2, 8, 9, 40, 41, 62, 63 and 68 also show shortward shifts (about $-200\ \mathrm{km\,s^{-1}}$). These lines show variations in strength and profiles and multiple narrow absorption components. The Fe III lines also show shortward shifts by about $-260\ \mathrm{km\,s^{-1}}$ and the lines of multiplet 34 present multiple absorption components.

Several strong lines of Ti II, V II, Cr II, Mn II and Fe II in the region 2850–3140 give orbital radial velocity shifts in agreement with the radial velocity data obtained from the optical spectrum.

The stellar wind profiles and the narrow multiple components suggest the presence of extended and multiple shells. The ultraviolet excess shortward of 1800 Å and the presence of N V and C IV lines suggest the presence of a source at temperature equal or greater than 30000 K. This source might be a late-O or early-B star, as suggested by the far UV flux distribution.

Key words: HD 30353 – hydrogen-poor binary – UV spectrum

1. Introduction

HD 30353 (KS Per), A5 Ie, is an extremely hydrogen-poor binary. The other binary systems similar to HD 30353 are Upsilon Sgr, LSS 1922 and LSS 4300.

Bidelman (1950) found the optical spectrum of HD 30353 to be very similar to that of Upsilon Sgr, but of slightly lower temperature. He estimated a spectral type A5 Ie with Hα in emission and no measurable Balmer discontinuity.

Wallerstein et al. (1967) derived the abundances of light elements in the atmosphere of HD 30353 and found $H/He=10^{-4}$, $C/N=10^{-3}$ and $O/N=2\,10^{-2}$. Helium and nitrogen are the most abundant elements; these abundances clearly suggest that HD 30353 has reached an advanced stage of evolution.

Stratification effects are evident in the excitation temperature which was found to vary from 5900 K for Fe I to 11000 K for Si II (Wallerstein et al., 1967). A similar result was found for Upsilon Sgr by Hack and Pasinetti (1963). This effect is due to the low opacity of the hydrogen-poor atmospheres.

HD 30353 is a single-lined spectroscopic binary. Heard (1962) found an orbital period of 360 d and mass function $f(m)=4.41\ M_{\odot}$. Recently Margoni et al. (1988) obtained new radial velocity measurements and, combining them with previous data, redetermined the orbital period and the mass function. They found $P=362.8$ d and $f(m)=3.6\ M_{\odot}$.

Although the mass function is relatively high, there is no trace of the spectrum of the companion in the optical region.

HD 30353 shows irregular light and color variations on a time scale of 30 days (Heard, 1962; Osawa et al., 1963; Nishimura et al., 1969). Morrison and Willingate (1987) found light and color variations on a time scale of 5 d in addition to the 30-day periodic light variations. All these photometric investigations found no evidence of eclipses.

The spectrum of HD 30353 has been analyzed by Nariai (1963, 1967), Wallerstein et al. (1967), Danziger et al. (1967) and Lee and Nariai (1969). Danziger et al. found an effective temperature of 10000 K and $\log g=2$, $M_V=-3.2$ and $E(B-V)=0.35$. Drilling and Schoenberner (1982), from a study of low-resolution far ultraviolet IUE spectra have found evidence for the presence of a hot (O–B) companion.

We have obtained several high and low resolution ultraviolet spectra of HD 30353 for studying the stellar wind features and the spectrum of the hot companion. In this paper we present an analysis of all the available ultraviolet spectra obtained by us or from the IUE data bank.

2. The observations

HD 30353 is much fainter and cooler than Upsilon Sgr; therefore exposures of several hours are necessary for obtaining

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* Based on observations by the International Ultraviolet Explorer (IUE) collected at the Villafranca Satellite Tracking Station and obtained from the IUE data bank. The data analysis has been performed at the ASTRONET pole of the Trieste Department of Astronomy and Trieste Observatory

Table 1. The observations

Image		R	Apert.	Year	Day	Exposure		Phase[a]
						m	s	
SWP	7249	L	L	1979	332.45	10	36	0.9558
	7358	L	L	1979	344.79	12	07	0.9898
	29134	L	L	1986	247.72	10	00	0.7702
	29135	L	L	1986	247.86	20	00	0.7706
	30138	L	L	1987	22.35	20	00	0.1550
	32200	H	L	1987	22.42	330	00	0.9337
LWR	6252	L	L	1979	332.45	2	16	0.9558
	6351	L	L	1979	344.78	2	17	0.9898
	10063	H	S	1981	62.94	225	00	0.2278
	11389	H	S	1986	233.21	300	00	0.6971
LWP	9023	H	L	1986	247.79	180	00	0.7704
	9987	L	L	1987	22.34	2	00	0.1550
	9988	H	L	1987	22.42	150	00	0.1552

[a] Phases are computed from the epoch of periastron passage JD 2435152 + 362.8 E (Margoni et al., 1988)

high resolution far ultraviolet spectra of this object with IUE. Hence we obtained just one high-resolution spectrum in the 1175–2070 Å region with an exposure of 330 min. Table 1 lists the images obtained by us in 1986–87 and those distributed from the IUE data bank relative to observations made in 1979 and 1981. The orbital phases given in Table 1 are computed from the epoch of periastron passage: JD 2435152 + 362.8 E (Margoni et al., 1988).

3. Analysis

All the spectra have a reasonably good signal-to-noise ratio, with the exception of the high resolution image SWP 32200 (exposure time 5 h 30 m) which is rather noisy toward shorter wavelengths.

The spectra have been reduced with the IUE programs of the Trieste ASTRONET Center (Allocchio et al., 1983).

3.1. UV flux distribution

Five low-resolution short-wave and three long-wave spectra of HD 30353 were obtained in 1979, 1986 and 1987 at different orbital phases (Table 1). No significant variations were observed in the 1175–3200 Å spectral region.

The SWP low resolution spectrum of HD 30353 obtained by us in 1987 is shown in Fig. 1. It is very similar to that of Upsilon Sgr. The strong absorption features of N V, C IV, Si IV are clearly present. They are not observable in the low resolution spectra of normal A-type supergiants. The N V resonance doublet is very weak or absent even in supergiants cooler than B1.

The flux distribution in the optical region indicates a temperature of 10 000 K (Danziger et al., 1967; Wallerstein et al., 1967; Nariai, 1967). The ultraviolet spectrum shortward of 1700 Å shows an excess ultraviolet flux which is attributed to the hot companion.

It is difficult to derive the $E(B-V)$ from the 2200 feature, because it coincides with the position where the flux of the companion decreases and that of the A-type star increases.

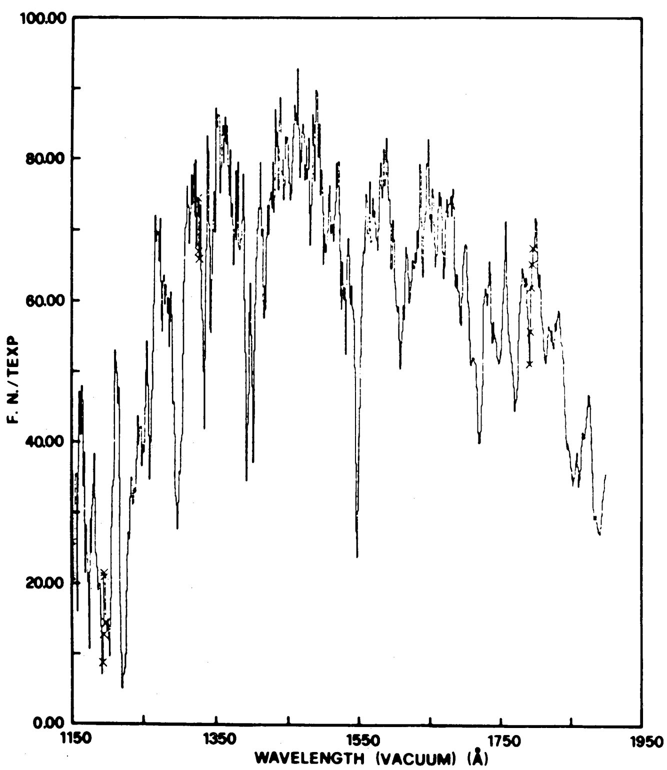

Fig. 1. The low-resolution far-UV spectrum of HD 30353

Danziger et al. (1967) estimate $E(B-V)=0.35$ from various arguments. We have plotted the $E(B-V)$ versus the distance modules of several stars in the same sky region ($\Delta\alpha = 8^m 4^s$, $\Delta\delta = 4° 45'$) (Fig. 2). V, $B-V$ and the spectral type are taken from the US Naval Observatory catalogue (Blanco et al., 1968); M_V and $(B-V)$ are derived from their spectral type (Allen, 1973). A clear correlation between distance and reddening is found. The

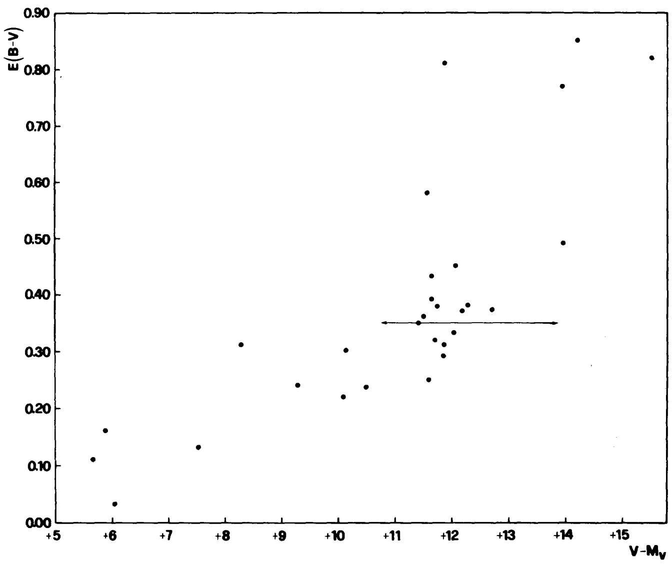

Fig. 2. The color excess $E(B-V)$ versus the distance modulus for stars in the same field as HD 30353. The horizontal arrow indicates the uncertainty in the distance modulus of HD 30353

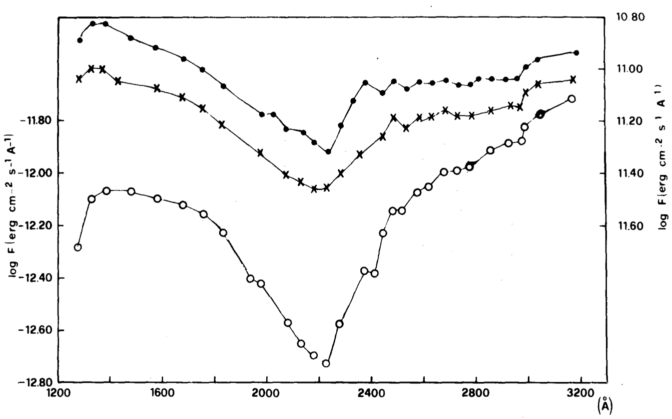

Fig. 3. The continuous spectrum of HD 30353. Open circles: the spectrum not corrected for reddening (left ordinate scale); crosses and dots: the spectrum corrected for $E(B-V)=0.33$ and 0.38 respectively (right ordinate scale)

absolute magnitude of HD 30353 is very uncertain. We have derived it from the width-luminosity relationship of the Mg II k line (Elgaroy, 1988). The width, measured at the base of the emission line, 4 Å, gives $M_V=-4$ (relation by Weiler and Oegerle, 1979), while the width measured at FWHM, 3 Å, gives $M_V=-6$ (relation from Vladilo et al., 1987). These relations are for late-type stars; however F-type stars fit it well. From this graph it follows that $0.30<E(B-V)<0.45$.

We have compared the observed flux corrected for $E(B-V)=0.33$ and 0.38 with several standard stars observed with IUE (Kalinowski, 1983; Heck et al., 1984). The far ultraviolet spectrum fits the spectra of standard stars of spectral types included between B0 and B1.5; the best agreement of the near ultraviolet spectrum is found with giant or supergiant stars of spectral type F0–F3.

Both for $E(B-V)=0.33$ and 0.38, the flux of HD 30353 at 1800 Å has about the same value as the flux between 2400 and 2600 Å (Fig. 3). From this datum we derive that the difference in visual magnitude between the hot companion and the F star is about 5 mag, which explains why we do not see any trace of the spectrum of the companion in the optical region.

3.2. Resonance lines

The interstellar lines detected in the ultraviolet spectrum of Upsilon Sgr (Parthasarathy et al., 1986) are also present in the spectrum of HD 30353 and have been used for deriving the wavelength scale in the high resolution spectra.

The resonance lines of C II, C IV, N V, Si II, Si IV, Al II, Al III, Mg II show shortward displaced absorption lines. These lines are optically thick and the flux at their core centers has zero intensity level (Fig. 4). These lines show broad asymmetric profiles, typical evidence of velocity gradients in the atmosphere; the Mg II doublet presents a P Cygni profile.

The edge velocities determined from these resonance lines are given in Tables 2 and 3. They are defined by the wavelength at which the shortward edge of the broad asymmetric absorption intersects the local continuum. The edge velocities of N V, C IV and Si IV are comparable and their average value is $-655\ \mathrm{km\,s^{-1}}$. These values are lower than the corresponding ones found for Upsilon Sgr (average value equal to $-778\ \mathrm{km\,s^{-1}}$) (see Table 2).

The broad profiles of N V and C IV are similar to those observed in O–early-B stars (Snow and Morton, 1976) and suggest a temperature equal to or higher than 30 000 K.

The presence of lines of N V and C IV, together with that of lines of C II, Si II and Al II, suggests the existence of a temperature

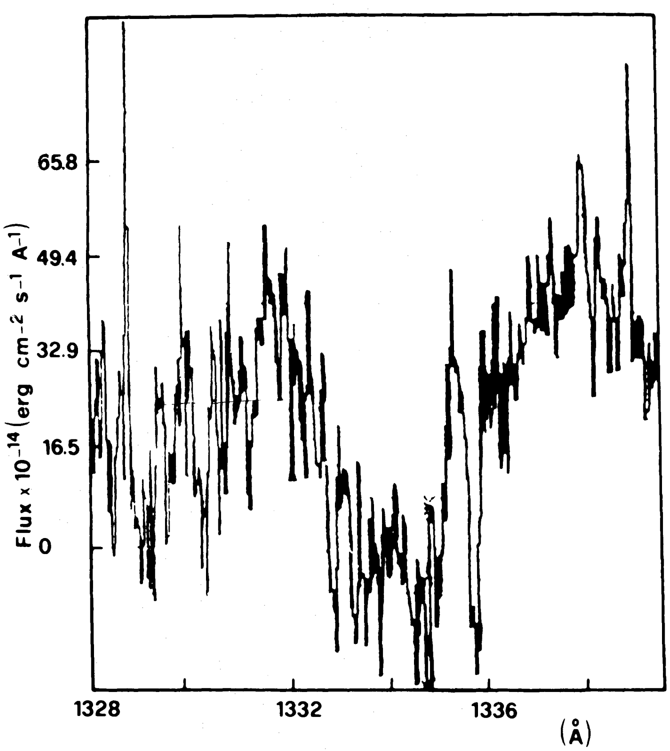

Fig. 4a. The C II resonance doublet

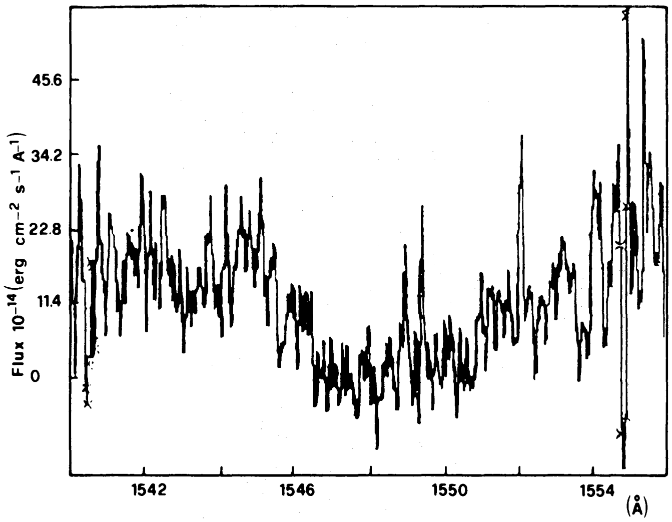

Fig. 4b. The C IV resonance doublet

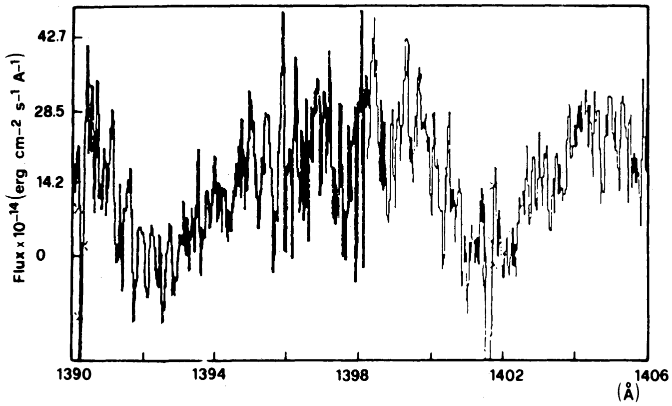

Fig. 4c. The Si IV resonance doublet

Table 2. Radial velocities of far UV resonance lines

Ion	Wavelength (Å)	RV at minimum intensity ($km\,s^{-1}$)	Edge velocity ($km\,s^{-1}$)	
			HD 30353	Upsilon Sgr
N V	1238.8		−678	
				−813
	1242.8		−676	
Si IV	1393.7	−330	−665	
				−800
	1402.7	−275	−645	
C IV	1548.2		−610	−720
C II	1334.5		−522	−637
Si II	1260.4	−219		
		−450		
	1264.7	−237		
		−427		
	1526.7	−237		
	1533.4	−241		
	1808.0	−183		
	1816.9	−203		
Al II	1670.8	−267		
Al III	1854.7	−197		
		−310		
	1862.8	−192		
		−336		

gradient in the wind, a result strictly similar to that found for Upsilon Sgr.

3.2.1. The Mg II resonance doublet and the subordinate doublet UV 3

We have four high-resolution spectra in the long-wave region, obtained at different phases in 1981, 1986 and 1987.

The Mg II resonance lines show P Cygni profiles with a strong broad absorption core, shortward shifted by about $-200\ km\,s^{-1}$ to $-300\ km\,s^{-1}$ with several components, and a strong sharp non-shifted absorption of interstellar origin (Fig. 5). Both the radial velocities of the cores and of the edges vary with time or with the phase (Table 3). We cannot say whether the emission strengths of the Mg II wings are variable, because the two LWR images have been obtained with the small aperture, which diaphragms a variable and unknown percentage of the stellar image, and the image LWP 9023 obtained with the large aperture is slightly saturated. However, we can estimate that the flux in the red emission wings of Mg II h and k lines is on the order of

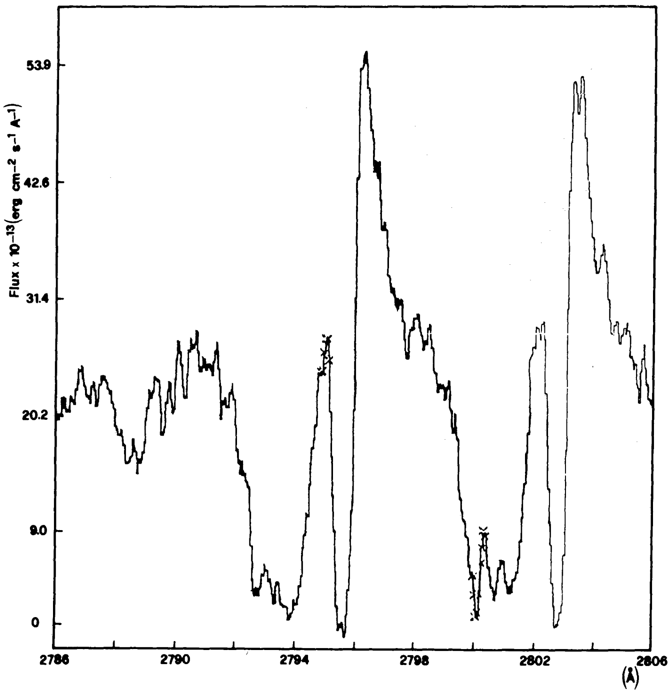

Fig. 5a. The Mg II resonance doublet and the Mg II multiplet 3, phase 0.15P

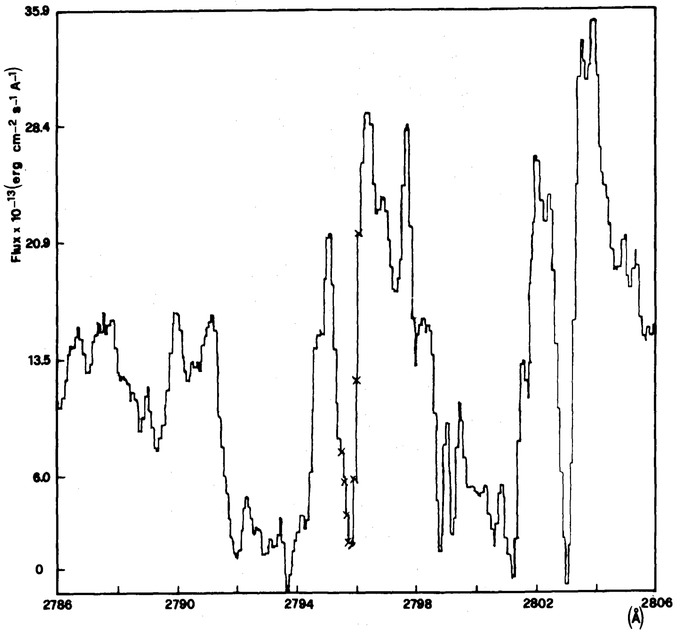

Fig. 5b. The same as Fig. 5a, phase 0.23P. This is the only image where the line 2797.98 Mg II (M 3) is clearly detectable

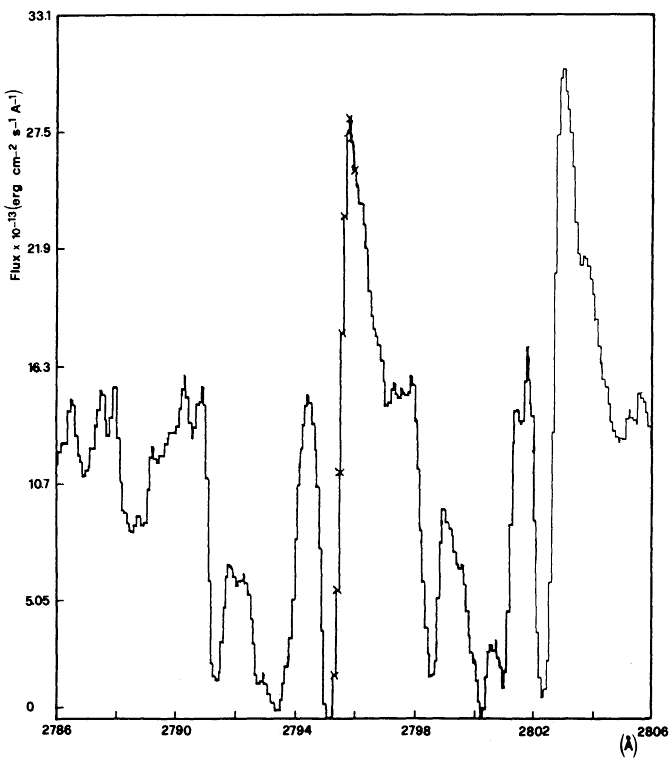

Fig. 5c. The same as Fig. 5a, phase 0.70P

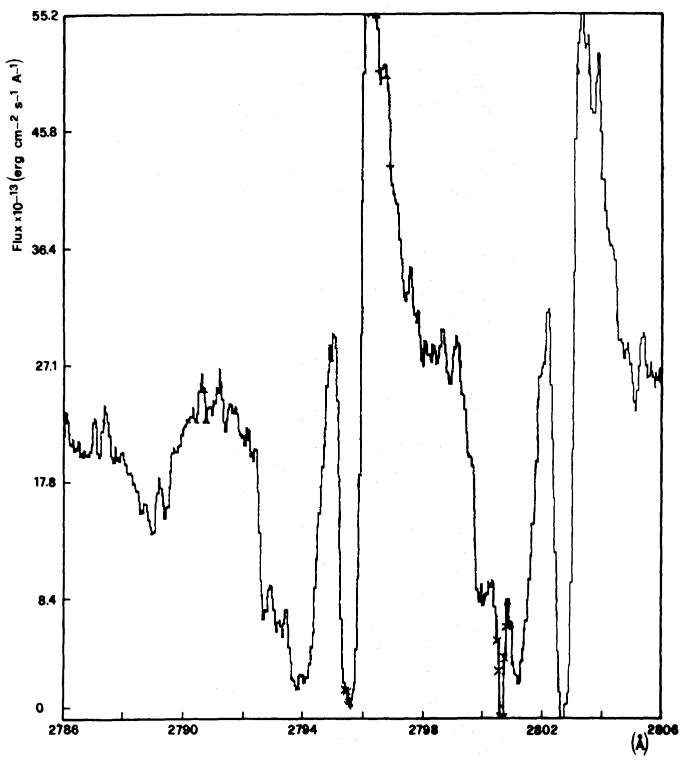

Fig. 5d. The same as Fig. 5a, phase 0.77P

10^{-11} erg cm^{-2} s^{-1}. In addition to the Mg II shortward shifted resonance lines, also the subordinate lines at 2790.77 Å and 2797.99 Å are found to be shortward shifted by a slightly less amount than the resonance lines. The 2790.77 Å line (Fig. 5) shows variations in strength and profile; it has several components and also shows a steep shortward edge and narrow absorption components similar to those seen in the resonance line profiles. The shifts of the 2790.77 Å line center are given in Table

Table 3. Radial velocities (km s^{-1}) of the Mg II lines and ratio R/V of the emission wing intensities

Line	Image	LWR 10063	LWR 11389	LWP 9023	LWP 9988
2795.5	V_m	−300	−271	−217	−238
	V_1	−225	−182	−161	−198
	V_2	−268	−247	−182	−247
	V_3	−311		−258	−311
	V_4	−408	−408	−300	−429
	V_{edge}	−485	−453	−350	−380
	R/V	1.7	1.9	1.95	1.9
2802.7	V_m	−320	−289	−214	−224
	V_1	−193	−150	−161	−182
	V_2	−262	−214	RM	−235
	V_3	−321		RM	−300
	V_4	−407	−407	−289	−428
	V_{edge}	−471	−465	−370	−385
	R/V	1.3	1.8	1.8	1.8
2790.8	V_1			−147	
	V_2	−152	−196	−190	−217
	V_3	−222	−233	−244	−260
	V_4				−292
2797.9	V_1	− 79			
	V_2	−149			

Table 4. Radial velocities of the Fe II lines (km s^{-1})

Line	M	SWP 32200 0.93P	Line	M	LWR 10063 0.23P	LWR 11389 0.70P	LWP 9023 0.77P	LWP 9988 0.15P
1266.69	9	−211	2388.63	2			−179	
1267.44	9	−198	2395.42	2			−221	
1608.45	8	−186	2404.43	2			−169	
1618.46	8	−235	2562.53	64			−195	
1621.68	8	−185	2591.54	64			−178	
1625.52	43	−185	2585.88	1		−197	−212	−212
1625.92	8	−185	2598.37	1	−228	−179	−187	
1629.15	8	−184	2599.39	1	−207	−196	−184	−190
1631.12	8	−147	2611.87	1	−180	−189	−180	−157
1633.91	43	−215	2613.82	1			−174	
1634.35	8	−202	2617.62	1	−186	−206	−168	−220
1636.33	8	−225	2620.41	1			−172	
1639.40	8	−183	2621.67	1			−168	
1641.76	68	−140	2625.66	1	−173	−176	−179	−207
1658.78	41	−155	2739.54	63	−191	−202	−191	−197
1659.49	40	−159	2743.20	62	−251	−196	−185	−218
1663.23	40	−184	2746.49	62	−208	−173	−173	−161
			2755.73	62		−194	−189	−178
	$\langle V\rangle$	−187			−203	−191	−183	−193
	s	26			26	11	14	24

(s = standard deviation)

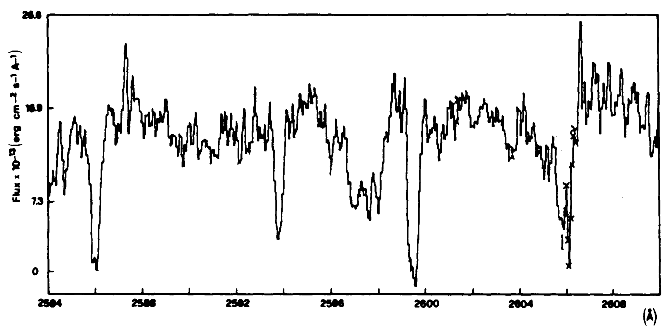

Fig. 6a. The spectral range 2584–2608 Å where the ground level lines at 2598.37 Å and 2599.35 Å are found, phase 0.15P

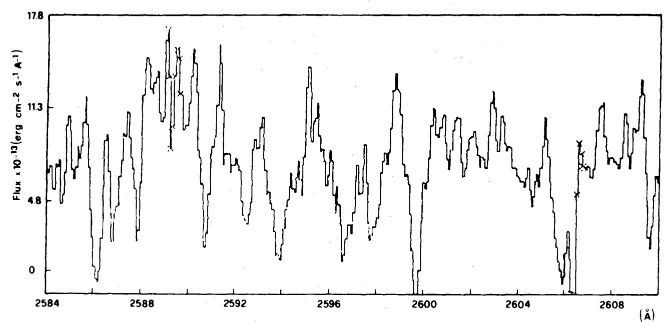

Fig. 6b. The same as Fig. 6a, phase 0.23P

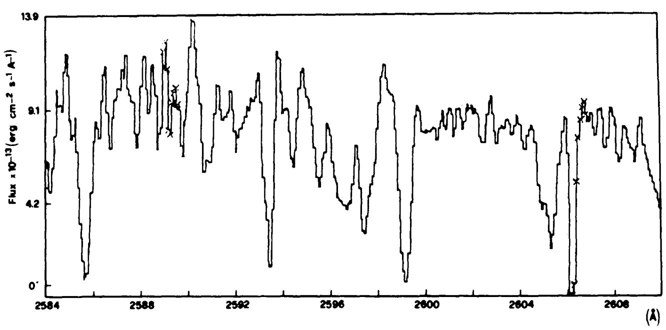

Fig. 6c. The same as Fig. 6a, phase 0.70P

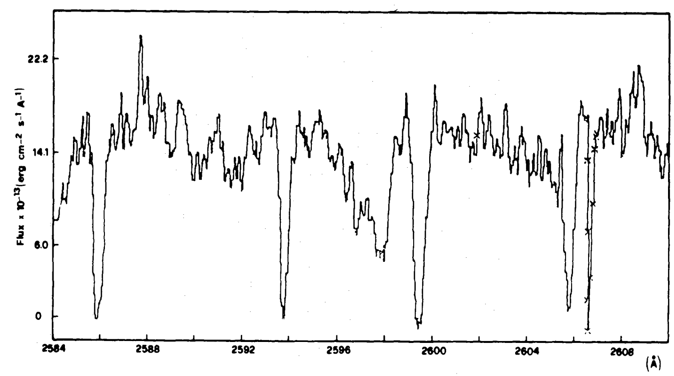

Fig. 6d. The same as Fig. 6a, phase 0.77P

3. The other line of the same multiplet, at 2797.98 Å falls in the red emission wing of the 2795.52 Mg II line and is not measurable. Only in the image LWR 10063 can an absorption line at 2797.12 Å cutting the emission wing of the Mg II 2795.523 be identified with the shortward shifted absorption of 2797.989. In the other images this line is not detectable. The P Cygni emission of the Mg II resonance lines suggest that HD 30353 is losing mass and also may have an extended chromosphere.

3.3. *The Fe II and Fe III lines*

All the strong Fe II lines of UV multiplets with low excitation potential lower than about 1 eV (multiplets 1, 2, 62, 63 and 64 in the near UV and multiplets 8, 9, 40, 41, 43 and 68 in the far UV) measurable in the high resolution spectra are shortward shifted. The profiles show multiple components and variability (Fig. 6). The list of these lines and their radial velocities are given in Table 4. The region 2300–2415 Å is noisy; however the Fe II ground level lines are detectable and violet shifted too. The average shortward shift of the Fe II lines is -190 ± 3 km s^{-1} in the near UV and -187 ± 6 km s^{-1} in the far UV, comparable to that found for the Mg II subordinate multiplet 3 of -215 km s^{-1}. Some of these lines show narrow absorption components (see Fig. 6); their strengths and profiles are variable.

For instance, the Fe II ground level lines at 2598.37 Å and 2599.35 Å in the image LWR 10063 exhibit a sharp violet shifted component at -228 and -207 km s^{-1}, looking very similar in shape to the interstellar lines and therefore suggesting that they are formed in an extended low density expanding medium. These same two lines in the image LWR 11389 are split into two narrow absorption components with mean shifts of -187 and -416 km s^{-1}. These profiles of the Mg II and Fe II lines indicate the presence of a cool wind, while the profiles of the N V, C IV and Si IV resonance doublets indicate the presence of a hot wind.

Several strong Fe III lines are present in the far UV spectrum. The majority of those measurable for radial velocity fall in the region 1830–2068 Å (see Table 5). They are all shortward-shifted, on the average, by -260 ± 8 km s^{-1}, a value equal to that found for the Mg II resonance lines. The three strongest lines of Fe III, belonging to multiplet UV 34 (Fig. 7), show six components with radial velocities ranging from about -490 to about -120 km s^{-1} (Table 5).

3.4. *The primary photospheric lines*

The majority of the lines measurable for radial velocity in the far UV and in the near UV at wavelengths shorter than about 2800 Å are shortward shifted, indicating that they are formed in an expanding envelope. In the region 2850–3140 Å, on the contrary, several strong lines from excited levels of Ti II, V II, Cr II, Mn II and Fe II are present, with radial velocity shifts in rather good agreement with those expected from the orbital radial velocity curve, derived from optical measurements (Margoni et al., 1988). Hence these lines must be formed in the photosphere of the cooler star. The average radial velocities derived from these lines are given in Table 6.

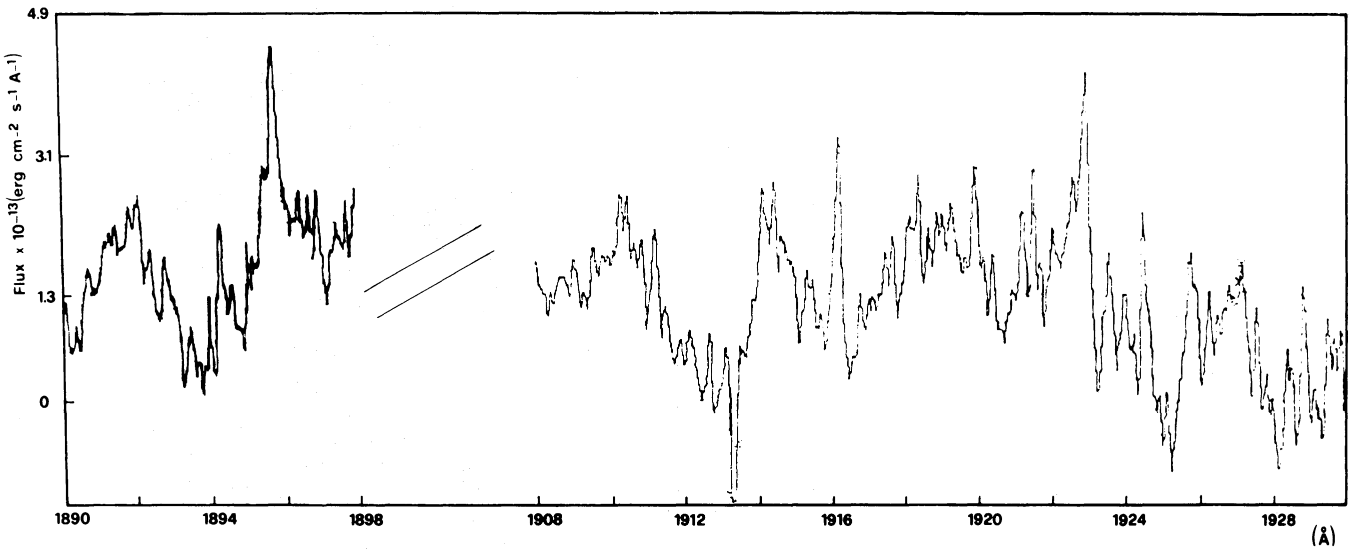

Fig. 7a. The three lines of multiplet 34 of Fe III showing multiple components

Table 5. Radial velocities of the Fe III lines (km s^{-1})

Multiplet 34	1895.46	1914.06	1926.30
V_m	−262	−243	−250
V_1	−499	−495	−483
V_2	−436	−432	−389
V_3	−349	−338	−328
V_4	−254	−244	−234
V_5	−207	−197	−203
V_6	−120	−118	−172

Line	M	
1837.59		−227
1866.30	52	−289
1877.99	63	−285
1943.48	51	−305
1951.01	68	−216
1954.22	61	−249
1976.13	54	−292
1978.42	54	−260
2061.55	48	−226
2068.24	48	−282
$\langle V \rangle$		−260
s		28

(s = standard deviation)

Table 6. Orbital radial velocities (km s^{-1})

Image	Phase	Spectral range 2850–3150 Å	Optical data (Margoni et al., 1988)
LWR 10063	0.23	+32±5	+18
LWR 11389	0.70	−42±1	−42
LWP 9023	0.77	−21±4	−32
LWP 9988	0.15	+55±4	+31

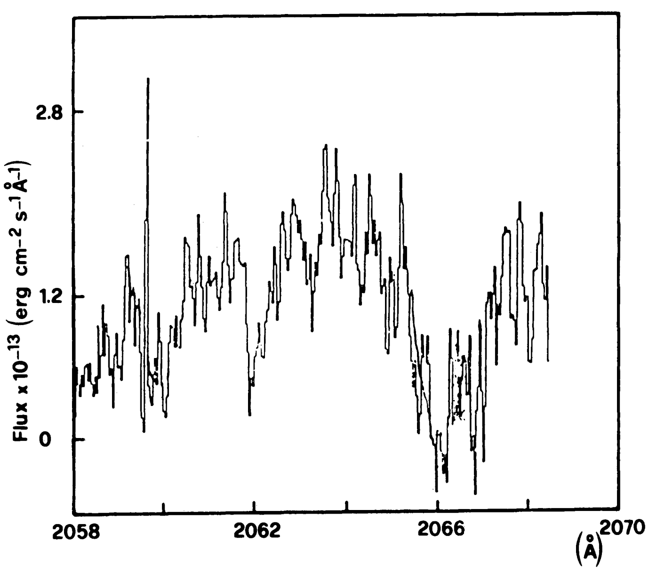

Fig. 7b. The two lines of Fe III, multiplet 48 at 2061.55 Å and 2068.24 Å

4. Conclusion

The stellar wind profiles of the resonance lines of N V, C IV and Si IV in the spectrum of HD 30353 are similar to those observed in Upsilon Sgr. However, HD 30353 shows shortward-shifted profiles also in the ground level lines of Fe II, in the subordinate multiplet 3 of Mg II, and in the excited lines of Fe III. Hence, besides the hot wind, a warm and a cool wind are present. This suggests that the shell around HD 30353 may be more extended than that of Upsilon Sgr.

We have insufficient observations for deciding whether the variations in strengths and profiles are irregular – as it is the case for Upsilon Sgr – or phase dependent.

The UV excess in the flux shortward of 1800 Å suggests that the companion is an early B-type star.

The break at λ 2200 Å suggests that at $\lambda<2200$ Å the contribution of the primary becomes negligible, and the contribution of the hot star becomes important.

The masses of the components of HD 30353 are uncertain. In the case of Upsilon Sgr the high-excitation broad absorption features observed in the far UV, showing no measurable orbital shifts suggest that the companion is more massive than the observable star (Parthasarathy et al., 1986). In the case of HD 30353 we cannot say anything because we have just one far UV image. Values of the order of 6 $M_{\odot}$ for the secondary and 2 $M_{\odot}$ for the hydrogen-poor star are suggested by Drilling and Schoenberner (1982) and by Margoni et al. (1988). Actually, if we exclude the hypothesis that the primary has a mass lower than 1 $M_{\odot}$, the secondary should have a mass of about 6 $M_{\odot}$ for $i=70°$.

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