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IDENTIFYING LINES IN THE IUE SPECTRUM OF THE WOLF-RAYET STAR HD193077

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RESUMEN. Presentamos el espectro de HD193077 en el rango espectral $\lambda\lambda$1200-2000 Å obtenido con el IUE. Se proponen identificaciones para las líneas de emisión y se discuten varios aspectos del espectro de líneas en absorción angostas.

ABSTRACT. The IUE spectrum of HD193077 (WN6 + O + ?) is rich in lines. Here we present probable identifications for all emission lines which are evident in the 1240 - 1800 A wavelength range, and we discuss several aspects of an intriguing narrow absorption line spectrum.

Key words : LINE-IDENTIFICATION -- STARS-WOLF-RAYET

INTRODUCTION

The Wolf-Rayet (WR) star HD193077 has been the subject of controversy during the past 6 years. Although it was originally classified WN5 + O by Smith (1968), Massey (1980) did not find periodic radial velocity variations, and suggested that the absorption lines might originate in the photosphere of the WR. This would be the first case of a WNE star with visible photospheric absorption lines. The implied large H abundance on its surface would also be peculiar. Combining data from various authors, as well as new observations, Lamontagne et al. (1983) reported radial velocity variations in the absorption spectrum which might be consistent with a long period (1763 days) while short timescale variations in the emission line spectrum (2.3 days) also appeared. Thus, these authors suggested that HD193077 consists of a triple system: WR + collapsed companion + distant O-star companion, although the possibility of a line-of-sight coincidence for the O-star could not be ruled out. Recently, however, Moffat et al. (1986) have shown that this latter possibility is not feasible, and thus, either HD193077 is a system containing an O-star, or the absorption lines originate in the WN star.

One of the intriguing peculiarities of this system is the width of the optical H and He absorption lines. Massey (1980) concluded that these lines are rotationally broadened, and noted that the rotational velocity implied (vsin i $\sim$500 km s^{-1}) is among the largest reported for O-stars. As we shall show below, this may prove to be very important for an accurate interpretation of the IUE high dispersion spectrum which we present.

In this paper we present the ultraviolet spectrum of this system as obtained by the IUE in the $\lambda\lambda$1200-2000 A wavelength range.

OBSERVATIONS

The observations were made with the IUE (Boggess et al. 1978a, 1978b), in both high and low dispersions. All images were obtained with the Short Wavelength Prime (SWP) camera through the large aperture, and during the high radiation US2 shifts.

[1]Guest observer International Ultraviolet Explorer Satellite

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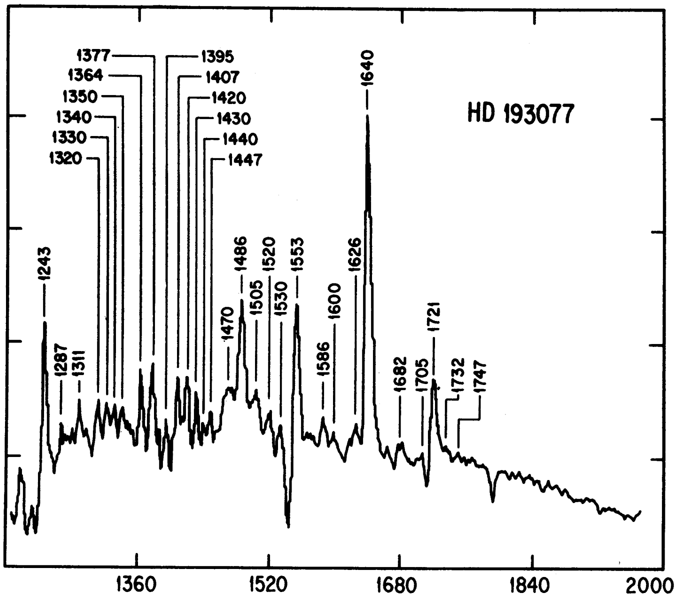

Fig. 1. Low dispersion spectrum of HD193077 obtained by coadding 8 individual IUE images. Wavelength positions for all resolvable maxima are indicated.

The journal of high dispersion observations of HD193077 is presented in Table 1, where we list the SWP numbers, and the Julian date of the observation. The low dispersion observations have already been listed in Koenigsberger and Auer (1985).

The standard reduction procedures were applied at the GSFC Regional Data Analysis Facility. The individual images were then coadded in order to construct one mean high dispersion spectrum and one mean low dispersion spectrum. These average spectra are ideal for the identification of weak and stable (with time) features. As noted by Koenigsberger and Auer (1985), the low dispersion spectra do not reveal variability over the 7 days of observation.

The average low dispersion spectrum and portions of the average high dispersion spectrum are shown in Figures 1 and 2, respectively. No correction for interstellar reddening was applied.

TABLE 1. Journal of high dispersion IUE observations

SWP	15574	15582	15596	15613	15625	15641
JD(-2444000.)	936.7	937.7	938.7	940.6	941.6	942.6

HD193077 is a "narrow"-line WN6, which allows many of the numerous lines in the crowded region shortward of ∿1500 A to be resolved. The position of the maxima on the low dispersion spectrum are indicated for all these lines in Figure 1. Clearly, each one of these emissions is a blend of several lines. However, due to the large velocity gradient in the WR wind, most lines are still blended on the high dispersion spectrum, as is the case for optical observations. This is evident from Figure 2, where selected portions of the average high dispersion spectrum are presented.

The problems inherent to line identification of WR spectra are well known: line blending, placing the continuum, co-existence of various degrees of ionization, wavelength shifts, etc. Since the spectrum of HD193077 is no exception, we limit the identification of lines to those indicated in Figure 1. For each line we have searched for likely identifications

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TABLE 2. PROBABLE CONTRIBUTING SPECIES TO THE EMISSION LINES

λ (A)	λ_{max} (A)	30-40 eV	40-60 eV	60-80 eV	80 eV
1243	1242.5	...	...	NIV M18.92 (3)	NV M1 (2)
1272	1272.5	...	...	NIV M18.75 (5)	FeVI 1271-73 (4)
	1277.5	...	...		FeVI 1276-79 (4)
1287	1287.5	...	...	NIV M18.87 (1)	
				FeV 1286-88 (3)	FeVI 1285-88 (5)
1311	1311.0	SiIII M10 (1)	CIII M11.44	NIV M18.55 (1)	...
				FeV 1306-13 (9)	
1320	1323.5	...	...	NIV M18.81	...
				FeV 1317-25 (10)	
1330	1329.0	SiIII M53 (1)	CIII M11.59	FeV 1326-32 (6)	FeVI 1326-31 (4)
			FeIV 1328-29 (2)		
1340	1337.5	...	FeIV 1336.0	OIV 1338.6	
				FeV 1336-40 (4)	FeVI 1336-38 (3)
1350	1350	...	NIII 1347 (2)	OIV 1343.5	
				FeV 1345-55 (7)	FeVI 1348-53 (4)
1364*	1363.5	SiIII M38 (3)	SiIV M19	FeV 1359-67 (15)	FeVI 1361 (1)
		SiIII M46 (2)			
		SiIII M68 (2)			
1377	1377.5	SiIII M67 (6)	...	FeV 1372-82 (15)	OV 1371.3
	1385.5	...	FeIV 1381.5	...	...
1395	1394.0	SiIII M37 (3)	SiIV M1 (1)	FeV 1390-96 (8)	...
			FeIV 1394-96 (2)		
1407	1408.1	...	SiIV M1 (1)	OIV 1405,07	...
			FeIV 1407-10 (3)	FeV 1404-12 (14)	
1420	1419-21	SiIII M9 (1)	FeIV 1420-24 (7)	FeV 1415-24 (15)	OV 1417-19 (4)
		SiIII M62 (1)			
1430	1431.5	SiIII M66 (1)	CIII M11.52 (3)	FeV 1427-34 (10)	...
		SiIII M62 (1)	CIII M11.75 (4)		
			CIII M12.05 (2)		
			FeIV 1427-34 (10)		
1440*	1439.5	SiIII M3.05 (1)	FeIV 1439-40 (2)	NIV M18.96 (1)	...
		SiIII M66 (4)		FeV 1438-41 (3)	
1447	1447.5	SiIII M3.05 (1)	FeIV 1446-50 (5)	NIV M18.85 (1)	...
				FeV 1445-50 (8)	
1470	1465.0	...	FeIV 1464-66 (3)	FeV 1460-69 (12)	...
	1469.5	...	NIII 1470-71 (3)	FeV 1469-72 (4)	...
			FeIV 1470-72 (3)		
1486	1484-85	...	FeIV 1483-89 (4)	NIV M0.01 (1)	...
			CIII M12.04 (3)	FeV 1477-79 (15)	
			OIII 1477		
1505	1495.0	FeIII M85	FeIV 1490-97 (6)	FeV 1490-97 (4)	...
	1501.0	SiIII M36 (5)	...	...	NV M63 a
1520*	1515.0	SiIII M94 (1)	FeIV 1505-24 (12)	FeV 1505-20 (8)	
1530*	1531.0	...	FeIV 1525-32 (8)	...	...
	1535.0	...	SiIV M24	...	...
			CIII M11.65		
			FeIV 1532-37 (10)		
1553	1551.0	...	...	CIV M1 (2)	NV M46 (2)
1586	1583.0	SiIII M59 (1)	OIII 1585		
			FeIV 1580-91 (15)	FeV 1580-91 (10)	
1600	1600.0	...	FeIV 1597-02 (10)	...	...
1626*	1624.0	SiIII M45 (3)	CIII M11.72	FeV 1520-26 (3)	NV M50, 52
			FeIV 1620-26 (14)		NV M53
1640	1640.0	...	HeII M12 (3)	OIV 1639 (2)	OV 1643
			SiIV M28		
			FeIV 1636-46 (13)		
1682*	1679.0	SiIII M58	SiIV 1672	...	...
			OIII 1679		
			FeIV 1675-83 (8)		
1705	1704.0	...	NIII 1694-1700 (3)	NIV M18.91 (3)	NV M45 (2)
			FeIV 1695-1707 (18)		
1721	1719.0	...	SiIV M10 (1)	NIV M7	...
			FeIV 1715-25 (15)		
1732	1732.0	...	NIII 1730	...	...
			SiIV M10 (1)		
			FeIV 1726-36 (11)		
1747	1747.0	...	NIII M19 (4)	...	...
			FeIV 1745-52 (4)		

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among the elements He, C, N, O, Si, and Fe, in the line lists of Kelly and Palumbo (1973), Reader et al. (1980), Ekberg (1975a, 1975b) and Ekberg and Edlen (1978).

In Table 2 we list the wavelength designations from Figure 1, the estimated position of maxima from the high dispersion spectrum, and the possible identifications, in order of increasing ionization potential. We have chosen to list the lines in terms of multiplet numbers when available (preceded by "M" in the table) or wavelength. Also, the number of lines involved is listed in parenthesis.

Given the subclass WN6, we expect N IV (IP = 78 eV) to be the dominant ionization stage of Nitrogen, and thus the species listed in the column of 60-80 eV should, in general, be major contributors. Clearly, however, each line contains additional contributions from, at least, the other elements listed. A more complete discussion of emission line identifications in the IUE high dispersion spectra of other WR stars is given by Willis et al. (1986), and we refer the reader to this Atlas for a more detailed description. However, we do wish to note the probably strong contribution of Fe V to numerous emission lines. The importance of Fe (and thus other iron peak elements) has been suspected on the basis of spectral variations in WN + O binaries (Koenigsberger 1983; Koenigsberger and Auer 1985; Eaton et al. 1985a).

ABSORPTION LINES

A careful inspection of the high dispersion spectrum discloses numerous absorption features, which we classify as follows:

1. Possible photospheric features: These will be presented elsewhere.

2. Normal, unshifted interstellar features: All expected interstellar absorptions are present and will not be discussed here.

3. Interstellar-like absorptions shifted by -42 km s^{-1} with respect to the normal interstellar components: These are associated with the resonance lines of C IV, Si IV and Al III and are marked "b" in Figure 2. Similar absorptions have been observed in other WR stars in the Cygnus region and it is suspected that the double structure is caused by a common cause for all Cygnus OB1/S109 objects (van den Hucht, 1986, private communication).

4. Absorptions shifted by -1250 km s^{-1}: These are associated with the C IV and Si IV resonance lines and with N IV 1718 A and are marked "c" in Figure 2. Because they are in the throughs of P Cygni absorptions, their widths are difficult to assess although we estimate a total width of ∿200 km s^{-1}. In addition, many are near the overlap between echelle orders, so their intensities must be regarded with caution.

The presence of these so-called narrow components is not too surprising. They are similar to the "narrow" absorptions generally observed in the UV spectra of OB stars (Morton, 1976; Underhill 1975) the properties of which have recently been analyzed by Prinja and Howarth (1986). One interpretation is that they arise in a plateau in the velocity law of the stellar wind. This plateau may result from the onset of instabilities in a radiation pressure driven wind (see models by Lucy 1982, 1983). An interesting alternative proposed by Mullan (1984) is that the narrow components arise in corotating interaction regions (CIRs). Given the large rotation velocity implied by the optical absorption lines, this interpretation is attractive, and would imply that the narrow components might be associated with the O-star, instead of the WR.

5. Very narrow and generally weak absorptions for which we have been unable to assign reasonable identifications: These features are the most intriguing Most are very weak (almost at noise level) and very narrow (near the resolution limit) and thus they must be regarded with extreme caution. In addition, some may be attributable to fixed pattern noise. However, the absorptions at, for example, 1360.9, 1419.1, and 1482.1 A certainly appear to be real.

Given the narrow absorptions at -1250 km s^{-1} described above, the question arises whether these weak features are similarly shifted absorptions arising from transitions between excited states. The detection of such features would be of importance since the conditions of the gas in which they arise could be derived. We have searched for very narrow, shortward-

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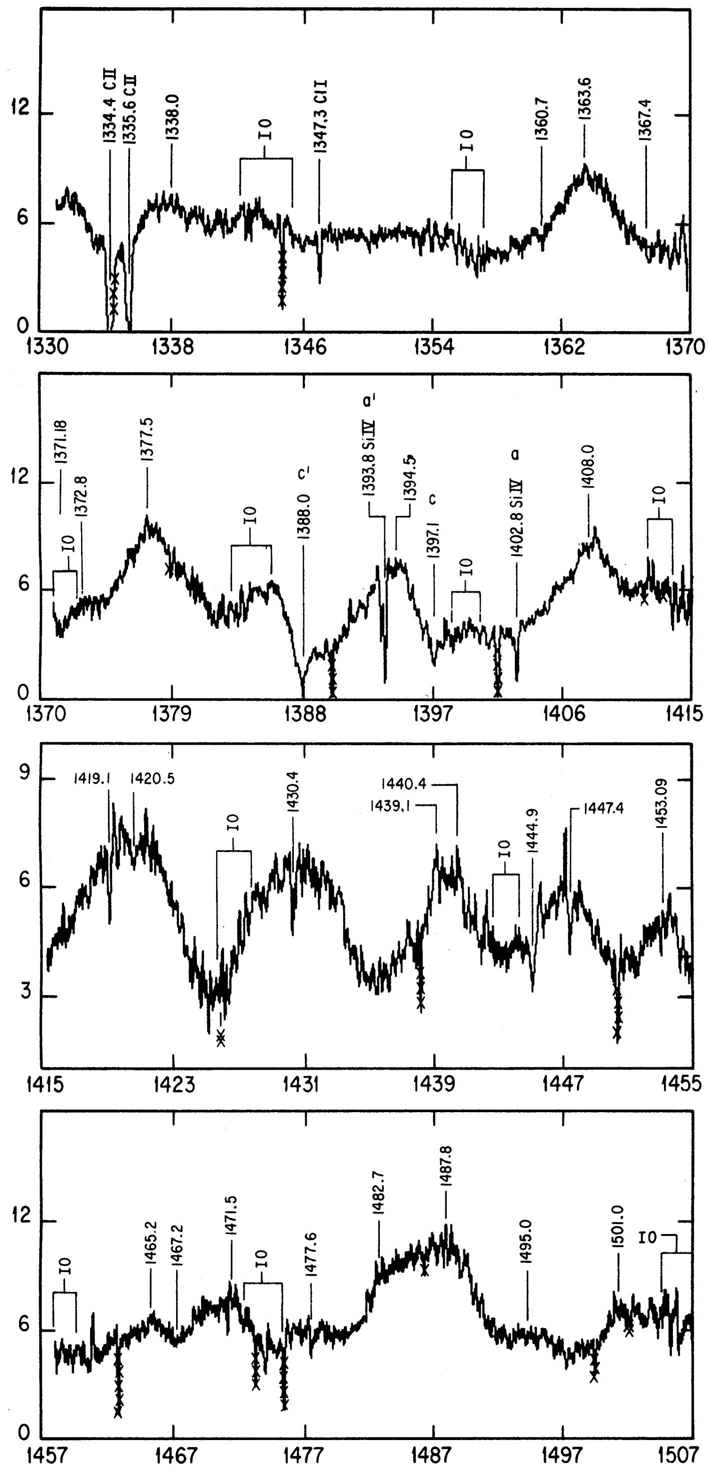

Fig. 2a. Selected regions of the IUE high dispersion coadded spectrum of HD 193077. Fiducial marks are indicated by "x", and "IO" indicates the position of echelle interorder overlap regions. A five-point smoothing function has been applied to the data in this figure. Wavelength positions of selected features are given.

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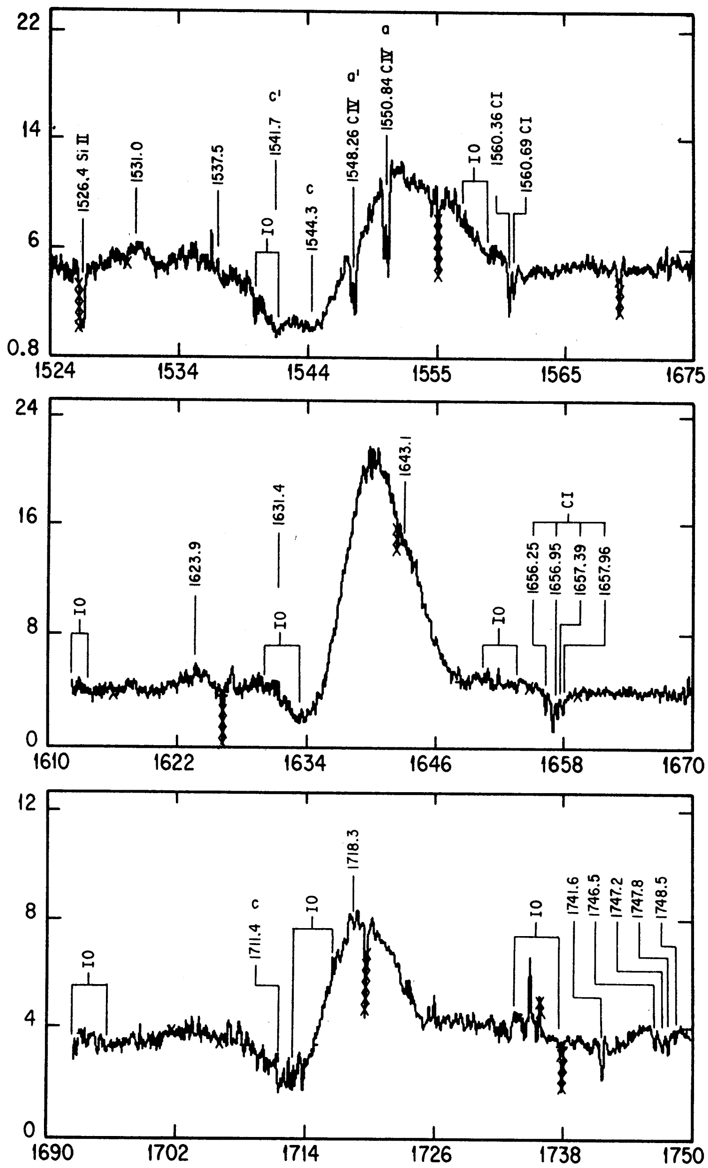

Fig. 2b. Selected regions of the IUE high dispersion coadded spectrum of HD 193077. Fiducial marks are indicated by "x", and "IO" indicates the position of echelle interorder overlap regions. A five-point smoothing function has been applied to the data in this figure. Wavelength positions of selected features are given.

shifted absorptions associated with all the tabulated lines of N IV and the strongest lines of Fe V and Fe VI, and find features at speeds ranging from -1100 km s^{-1} to -1300 km s^{-1}. The only exception is the line at 1482.1, which, if due to N IV 1486 is at -890 km s^{-1}. We emphasize that this is all highly speculative at the moment. However, assuming that filamentary shocks do indeed permeate radiation-pressure driven winds, combined column densities of numerous shocks might be sufficient to produce observable features arising from transitions between excited states.

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DISCUSSION

We have presented preliminary results of the analysis of the high dispersion spectrum of HD193077. At this point we are unable to contribute to the discussion regarding the binary or triple nature of this system. However, we hope that a detailed analysis of variability in the high dispersion spectrum (to be forthcoming!) may yield relevant information.

The presence of narrow absorptions corresponding to different velocity systems requires further analysis. The spectra of other early-type stars in the vicinity of HD193077 should be inspected in order to determine whether the -42 km s^{-1} components arise in a common shell, or are restricted to material associated with the WR. Also, a careful analysis of the -1250 km s^{-1} component should be carried out on the individual images in search of variability.

It is important to note that Prinja and Howarth's analysis of narrow absorption lines in OB stars suggests a correlation between fast rotators and the presence of narrow absorptions in their UV spectra. In HD193077 there is evidence for both fast rotation and narrow absorptions. In addition, fast rotation can be linked to magnetic fields, which in turn can produce enhanced mass-loss via Alfven waves (see Cassinelli, 1981, for models applied to WR stars), or can lead to CIR's (Mullan 1984). However, before any conclusions can be drawn regarding the origin of the narrow components, the question of the binary or triple nature of HD193077 must be settled.

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