OBSERVATIONAL EVIDENCES OF STELLAR WIND

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Abstract. Observations mainly from the IUE Spectra of HD 152236 (B1Ia) have been used to provide support to the various aspects of the theory of stellar wind (SW) and its interaction with the interstellar medium (ISM). Lines arising from excited levels connected radiatively to the ground level tend to be more frequent and/or strong compared to those arising from radiatively forbidden levels of similar excitation as expected from radiatively driven wind. The outward velocity from shifts of Si III lines from different excited levels increases steeply with decreasing excitation energy in agreement with theories. Absorption lines (P-Cygni like) of C II, Al II, Si II and Mg II shifted shortward by about 300 km s^{-1} suggest an expanding shell around the star. As this velocity is smaller than the terminal velocity (880 km s^{-1}) the circumstellar shell may have been formed as a result of interaction of SW with ISM.

1. INTRODUCTION

Mass loss from early type stars, especially the supergiants, has been observed. In one of the theories, the driving force behind the mass loss is the radiation pressure via line absorption, mainly the resonance lines (Lucy and Solomon 1970, Castor et al 1975). The theories also predict a steep increase of outward velocity (Hearn 1978, Castor 1978). Eventually the stellar wind (SW) is stopped by the interaction between the SW and interstellar medium (ISM) (Steigman et al 1975, Weaver et al 1977). Here we have looked for supporting evidences of these aspects of the theory using the IUE spectra of HD 152236, a B1 Ia star with E(B-V) = 0.63 and studied well in UV and other parts of the spectra (cf. Appenzeller and Wolf 1980, Wolf and Appenzeller and references therein).

2. IMPORTANCE OF RADIATION PRESSURE

A few lines of different ions from levels radiatively allowed as well as forbidden from ground level have been given in Table 1. The lines are chosen such that lines from allowed and forbidden levels have approximately same excitation and f-value. If absorption of radiation in lines are to be the driving force, we expect the lines on the left

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TABLE 1

Lines from radiatively allowed and forbidden levels of similar excitation energy

Ion	Lines from allowed levels				Lines from forbidden levels			
	λ_{Lab}	χ (eV)	f	λ_{obs}	λ_{Lab}	χ (eV)	f	λ_{obs}
C III	1531.83	32.1	0.48	1531.75	1620.56	32.2	0.35	1620.3
C IV	1230.28	39.68	~0.15	1230.5	1198.58	40.28	~0.05	absent
N IV	1309.55	50.15	-	1309.2	1273.72	50.32	-	1273.7
	-	-	-	-	1273.47	"	-	1273.2
	-	-	-	-	1272.74	"	-	absent
	-	-	-	-	1272.16	"	-	1271.7
Ne II	1688.36	26.91	~0.25	1687.5	1415.72	27.23	0.18	absent
	1681.68	"	~0.25	1681.3	1413.96	"	0.10	absent
	-	-	-	-	1405.37	"	0.11	1405.0

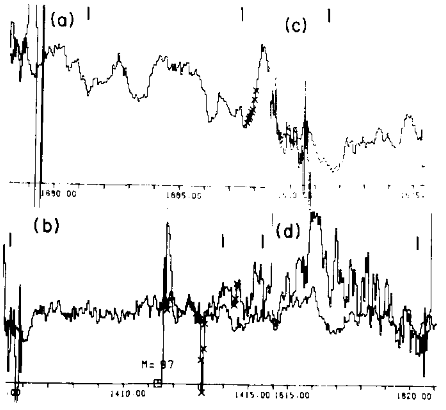

Fig. 1 Lines (marked at the top) from allowed (a,c) and forbidden (b,d) levels of NeII (a,b) and C III (c,d).

to be easily observable and/or stronger than the lines on the right. We have looked for these lines in the IUE spectra of HD 152236 and if present listed the wavelength under λ_{obs}. The table shows that the lines from allowed levels are observed more frequently than from forbidden levels. The Fig. 1 shows that the two Ne II lines from allowed level (Fig. 1a) are present but only one of the three lines from forbidden level may be present (Fig. 1b); the C III line from allowed level (Fig. 1c) is stronger than that from forbidden level (Fig. 1d). This gives additional credence to the hypothesis of radiatively driven wind.

3. STEEP INCREASE OF VELOCITY AT THE BASE OF THE WIND

Fig. 2 shows the outward velocity obtained from lines of Si III originating at levels with different excitation energies as a function of the excitation potential. More than one line has been observed from the same level. The velocity shown in the figure is the mean of velocities obtained from different lines and the error limits are the dispersion. The figure shows that outward velocity increases with decreasing excitation potential. As lines with smaller excitation potential arise at smaller optical depth and as the radial distance does not change much with optical depth, this implies a steep increase of outward velocity,.

One line of the doublets of O VI, N V, C IV and Si IV has f twice the other. Let Δv = (edge velocity of line with larger f) - (edge velocity of line with smaller f). We show in Fig. 3 the average value of Δv obtained from above lines (Snow and Morton 1976) as a function of spectral type. It shows that $\langle \Delta v \rangle$ is mostly negative, implying larger outward velocity for larger f line than smaller f. As lines with larger f arise at shallower depth than that with smaller f, this result also supports the steep outward increase of velocity.

4. INTERACTION OF STELLAR WIND WITH INTERSTELLAR MEDIUM

Fig. 4a shows the Si IV doublet in absorption with asymmetric profile having extended short wavelength edge. Fig. 4b shows the P-Cygni

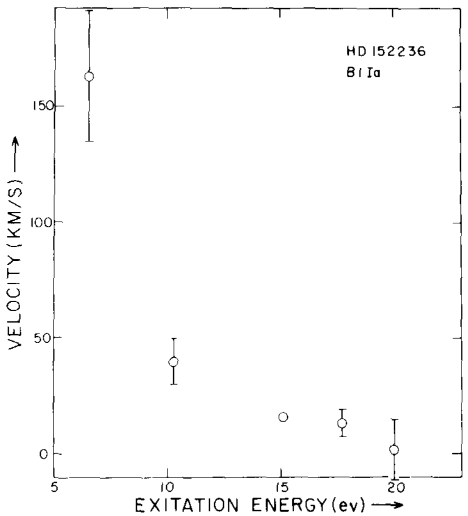

Fig. 2 Variation of outward velocity with excitation energy.

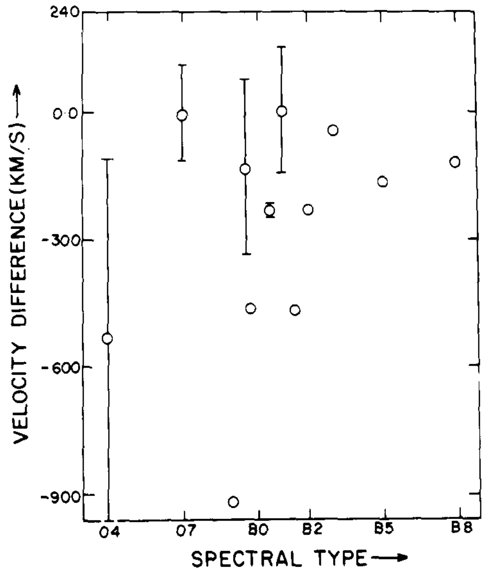

Fig. 3 Variation of Δv with sp.type.

profile of Al III doublet. The average value of the velocities corresponding to the short wavelength edges of these four lines is 880 km s^{-1} and the mean velocity for the absorption minima is 330 km s^{-1}. Fig. 5 shows the spectral regions covering Si II line at 1260 A (Fig. 5a), C II lines at 1334.5 Å and 1335.5Å(Fig. 5b), Al II line at 1670 Å (Fig. 5c) and Mg II doublets at 2795.5 Å and 2802.7 Å (Fig. 5d). Besides the interstellar absorption due to Si II (marked with long line) Fig. 5a shows an absorption shifted 1.3 Å shortward (marked with short line) from it. This may be blue shifted absorption of Si II line. Note that the line is like interstellar line and has no similarity with photospheric lines. Fig.5d shows that both the lines of Mg II have blue shifted (marked with small line) components. The shifted features have two

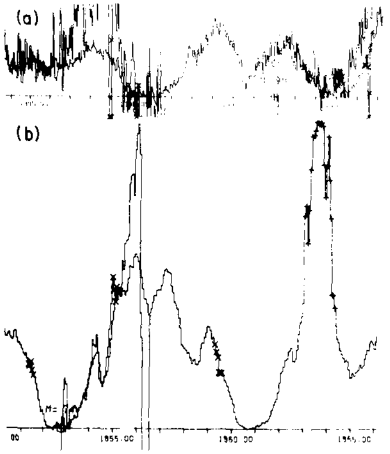

Fig.4 SiIV absorptions (a) & P-Cygni lines of Al III (b).

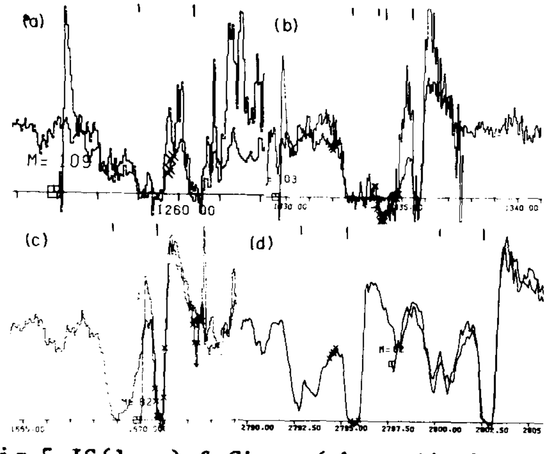

Fig.5 IS(long) & Cirst.(short line) abs. of Si II(a), CII(b), AlII(c) and Mg II (d).

components or central reversal due to large optical depth. Both the lines have emission components on the long wavelength side of the interstellar absorptions i.e. lines are P-Cygni type. Al II line (Fig.5c) is also P-Cygni type. The broad absorption shortward of interstellar absorption at 1335.5Å of C II (Fig.5b) may be blend of interstellar C II at 1334.5Å and shifted components of these lines. The lines are again P-Cygni type. The average value of the velocities corresponding to the shortward edges of these lines is 480 km s^{-1} and to the absorption minima is 300 km s^{-1}. These velocities are far smaller than the terminal velocity of 880 km s^{-1} mentioned earlier. These lines, therefore, originate in a shell formed by the interaction of the SW with ISM. As the lines are of P-Cygni type, the shell has to be within the field of view of 3" which gives, for a distance of 830 pc of HD 152236, a limit to the radial distance, r_s to the shell of 4×10^{16} cm. The column density of hydrogen is 3×10^{21} cm^{-2}, from equivalent widths of C II, Si II and Mg II lines assuming solar composition and these ions as the dominating ones. Thus we have $v_\infty = 880$ km s^{-1}, $r_s \leq 4 \times 10^{16}$ cm, $N_s = 3 \times 10^{21}$ cm^{-2} and $v_s = 300$ km s^{-1}; this following Weaver et al (1977) gives $t = 3$ yr, $n_o = 3 \times 10^3$ cm^{-3}, $\dot{M} = 2 \times 10^{-4} M_\odot$ yr^{-1} and $L_{K.E} = 5 \times 10^{37}$ ergs s^{-1} compared to $L_{Bol} = 4.4 \times 10^{39}$ ergs s^{-1} for HD152236 (Appenzeller and Wolf 1980).

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DISCUSSION

COSTERO: The Carbon II lines should not be expected to exist in the cromospheric part of a B1I star as the one you have shown us. Hence I believe you have put forward a very strong point in support of the existence of stellar wind and interstellar matter interaction. Is this star surrounded by an HII region or other evidence of dense clouds? How big is the reddening in the direction of the star?

TARAFDAR: Yes, if we take the theory of interaction of stellar wind with interstellar medium to be correct, we infer the existence of dense matter around the star. In fact, we get its density to be about 10^4 cm^{-3}. The colour excess of the star is 0.63 this is not inconsistent with its being inside a dense cloud.