IUE AND GROUND-BASED OBSERVATIONS OF MASS-LOSS

IN THE MAGELLANIC CLOUDS

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ABSTRACT

Ground-based and IUE observations of hot stars in the Large and Small Magellanic Clouds have been carried out to investigate the mass-loss process in these objects and to search for differences with galactic hot stars. Preliminary results show that in a large proportion of the stars observed the mass-loss process is taking place. A mechanism for acceleration of the wind in OB stars is proposed.

INTRODUCTION

This study of hot stars in the Large and Small Magellanic Clouds was carried out in order to:

(a) investigate in detail the mass-loss process in hot stars;

(b) investigate possible differences in the mass-loss characteristics due to chemical composition differences;

(c) investigate whether there exist broad differences between the mass-loss process as it occurs in the three galaxies, namely the two Magellanic Clouds and our own.

This paper presents some general results of the study. In particular a mechanism that accounts naturally for the acceleration of winds in hot stars is proposed.

OBSERVATIONS

Photometric observations were carried out with the ESO 50 cm photometric telescope in La Sillar, in September 1979. The diaphragm used was 15 arc sec in diameter. The U, B, V and Hβ photometric results shown in Table 1 are the average of three or four nights of observations. Night-to-night deviations were at most one or two tenths of a magnitude in V. The photometric standards used were taken from the E-region standards for U, B, V and Hβ photometric list of Crawford and Mander [1]. The values shown in brackets are not our own data. Spectroscopic observations were carried out in September 1979 (indicated S) and January 1980 (J) with the ESO 1.52 m telescope and Boller & Chivens spectrograph. In September the dispersion used was 114 Å/mm. Recording was with a two-stage EMI intensifier tube and III a-J baked plates. In January the dispersion was 60 Å/mm. Recording was with a three-stage EMI intensifier tube and III a-J baked plates. The spectrum was widened in both cases.

While only two spectra per star could be obtained in September, at least three sets of spectra, each with three different exposure times, were obtained in January. This will allow us to establish if spectral variability occurs with a period of four months and also with a shorter period of about one week.

Observations were carried out with IUE in January (J) of those stars that had not already been studied by other investigators. These were obtained at the same time as the ground-based observations from La Silla. Use of the archived IUE observations will be made as this material becomes available.

An additional set of stars was observed at the end of March with IUE. The IUE observations were made in the low dispersion mode in all cases.

RESULTS

Although the analysis of the data is still in a preliminary phase, some general results can already be indicated.

A significant fraction of the stars observed show mass-loss, as indicated for example by broad Hα emission or by P Cygni type profiles in the UV lines. These stars have been identified with an asterisk in the column "mass-loss" of Table 1.

As an illustration of the results obtained, Figures 1, 2, 3 and 4 show the spectrum of the star HD 35343 (SK 94). This star is classified as Bep in the Sanduleak catalogue and shows a large number of emission and absorption lines.

The most prominent emission lines in the visible part of the spectrum are those of the Balmer series of Hydrogen of which Hα, Hβ and Hγ are shown in Figures 1, 2 and 3 respectively. The profiles of the three lines appear to be asymmetric. It is not clear if this is due to the contamination by absorption lines of other atoms in the blue side of each of the lines or if these are real P Cygni-like profiles. The halfwidth at zero intensity measured towards the red wing is 40 Å for Hα corresponding to an expansion velocity for the wind of V_{exp} = 2057 Km/s. The equivalent values for Hβ are 24 Å corresponding to 1580 Km/s and for Hβ the width is 12 Å corresponding to 830 Km/s. Other emission lines in the visible are those of SII 6521 and 6386, SiII 6371 and 5915, FeIII 6323, HeII 6310 (weak) 4686 (strong) and 4200 (strong), [OIII] 50006 and 4958, SiIII 4532 and 4567 and SIII 4478.

In the ultraviolet region the following lines are found in emission: NII 1758 and 1748, HeII 1640, CIV 1550 and 1549, SiIV 1394 and 1403 and NV 1239 and 1243. The wind velocity as measured from both the HeII and CIV profiles turns out to be 1550 Km/s which is significantly lower than that measured from Hα. This may be due to the depletion of hard-ionizing photons which restrict the presence of CIV to regions closer to the star.

DISCUSSION

It appears that in a broad sense the properties of the mass-loss process in the hot stars of the Magellanic Clouds and those of our own galaxy are very similar, although differences of detail, as already shown by Hutchins[2], can be seen and will be further investigated.

Of particular interest is the confirmation of weak correlation found for galactic OB stars (Panagia and Macchetto[3]) between the terminal velocity and the effective temperature (Figure 4). A similar correlation between terminal velocity and excitation class has been found by Willis[4] for WN stars. In both cases the higher the effective temperature the higher is the terminal velocity. In addition for all high temperature (or excitation) stars the momentum carried by the mass-loss ($MV\infty$) exceeds the momentum that the stellar radiation can release to the wind through single scattering, ϕ Lc (where ϕ is some effective efficiency factor, usually of the order of 0.1). Clearly a more efficient process is needed to account for the wind acceleration - this can be provided by multiple scattering of hard UV photons in the range - 200 to 500 Å (Panagia and Macchetto[3]). The process can be described qualitatively as follows. In the interval 200-500 Å the number of expected atomic and ionic lines is very large (a hundred or so) so that the average separation between subsequent lines is of the order of $c\Delta\lambda/\lambda \simeq 1000$ Km/s. Therefore, when a photon in this range is re-emitted in the backward direction (after being absorbed at a given position of the envelope) it can be absorbed at the opposite side of the envelope by a line transition which is shifted to the red by about $c\delta\lambda/\lambda \simeq 2v$ relative to the transition which had produced the first absorption. This process can be repeated several times (typically 5 to 20) until the photon eventually either excapes in the outward direction or hits the star and is thermalised. Therefore, the efficiency of this process is mainly determined by geometry and only marginally by both mass-loss rate and chemical abundances. With this mechanism the momentum given to the wind can amount to several times (5-20) L (200-500 Å/c, which is just what is needed to explain the acceleration of the wind in OB stars, and possibly in WR stars too (Panagia and Macchetto[3]).

In addition, since the acceleration due to multiple scattering is most efficient at some distance from the stellar surface (typically 2 to 4 stellar radii) the wind velocity is expected to present a gradual rise with radius and to approach the terminal value quite far from the star. This also agrees well with observations.

REFERENCES

1. Crawford, D. L. and Mander, J., 1966, Astron. J., 71, 114.
2. Hutchins, J. B., 1980, Astrophys. J., 235, 413.
3. Panagia, N., and Macchetto, F., in preparation.
4. Willis, A., 1980, Proc. Second European IUE Conf., 25-28 March 1980, Tübingen.

Table 1

Star	Spectral type	V	B − V	U − B	Hβ	Spectrum Visible	IUE	Mass-loss
Large Magellanic Cloud								
HD 32228	09.5 + W	10.789	−0.170	−0.906	2.679	S/J	J	*
38282	WN6	11.177	−0.144	−0.872	2.256	S		
HDE 268605	09.7 IB	11.355	−0.137	−0.964	2.644	S		
268743	06	11.643	−0.172	−0.906	2.331	S		
269090	BO I	11.682	−0.075	−0.929	2.558	S		
269333	B1	11.260	−0.158	−0.825	2.467	S/J		*
269357	06	12.123	−0.249	−1.024	2.269	S		
269445	OBf	11.459	0.242	−0.805	2.163	S/J		*
269546	B4	9.921	−0.064	−0.751	2.548		J	
269676	04-5	11.510	−0.193	−0.908	2.516	S/J		*
269698	04 If	11.877	−0.156	−0.932	2.579	S/J		*
269810	03IF	12.269	−0.232	−1.004	2.643	S/J		*
269828	08	11.181	0.007	−0.791	2.557	S/J		*
269858	OI	11.094	−0.067	−0.900	2.212	S		
269891	BO.7	11.449	0.149	−0.701	2.450	S		
269896	ON 9.7	11.363	−0.018	−0.866	2.475	S		
269936	BO.7	11.202	−0.041	−0.829	2.524	S		
270952	06 IAF	12.018	−0.192	−0.998	2.443	S/J		*
271213	B3 IA	12.261	−0.105	−0.708	2.737	S		
No photometry								
HD 34664	BEP	(11.83)	−	−	−	J	J	*
35343	PEC	(9.8)	−	−	−	J	J	*
HED 269748	WR	(12.8)	−	−	−	J	J	*
Small Magellanic Cloud								
HD 4862	OB	10.768	1.099	0.917	2.624			
5045	OB	11.077	−0.047	−0.872	2.487	S/J		*
5030	B6 I	11.229	0.080	−0.473	2.513	S/J		*
BBBB1, SK31	OB	11.146	−0.020	−0.740	2.549	S		
HD 5291	OB	10.858	0.062	0.618	2.511	S		
5980	OB + W N3	11.967	−0.231	−1.004	2.458	S/J		*
46531	OB	11.798	−0.164	−0.863	2.565	S/J		*

S = September 1979
J = January 1980

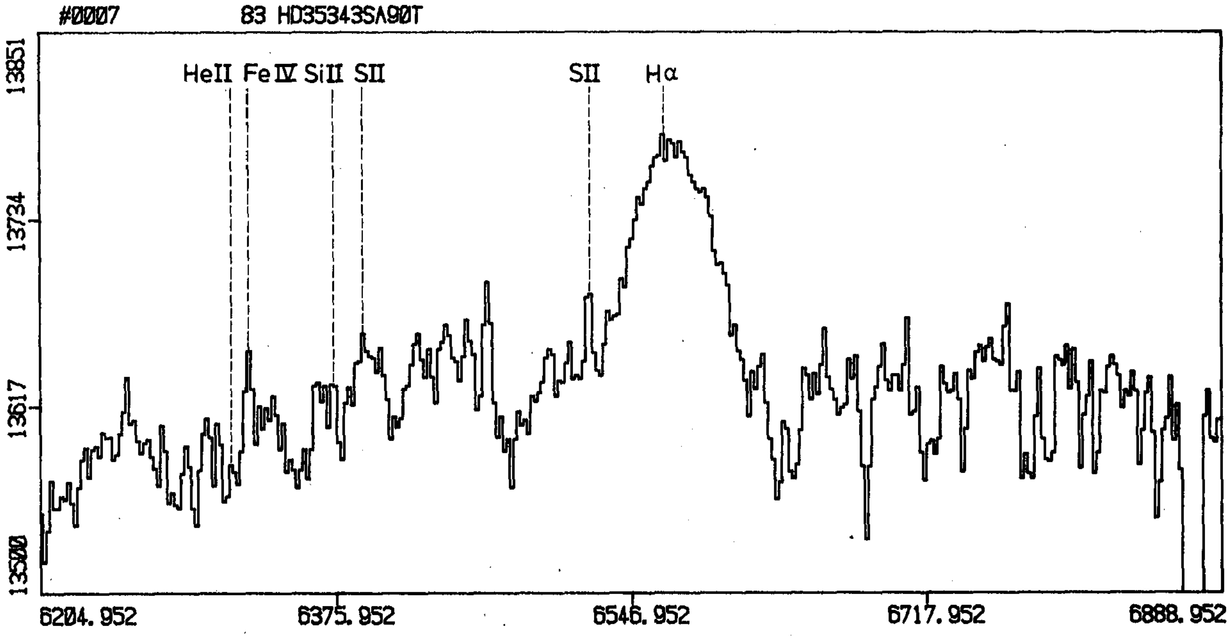


Figure 1

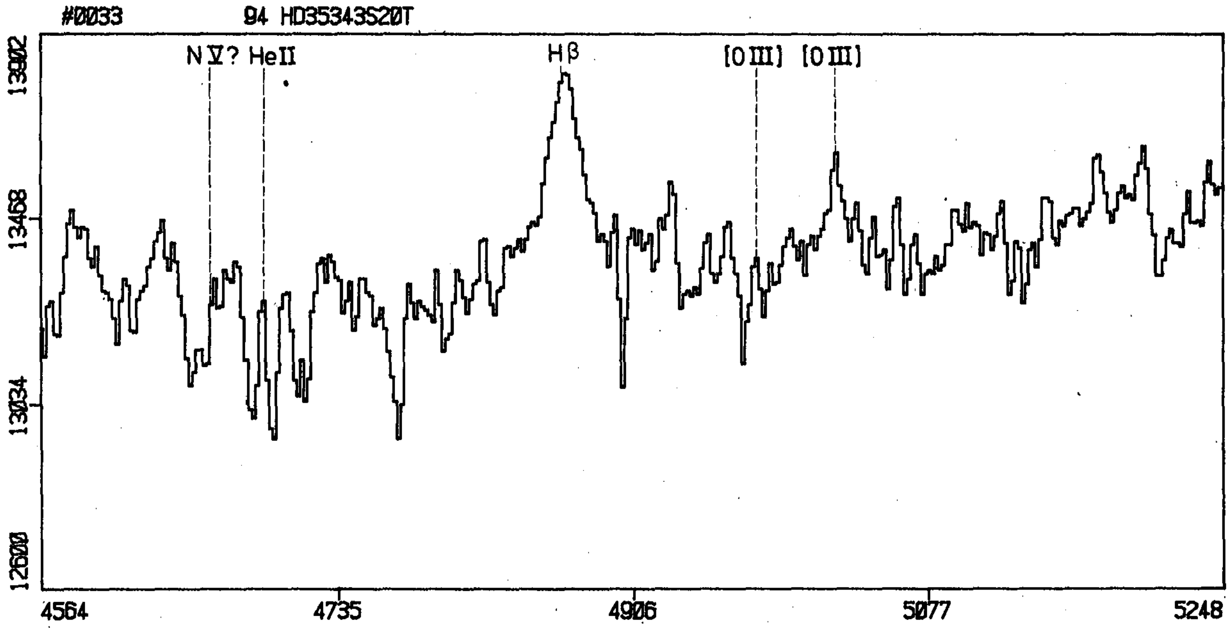
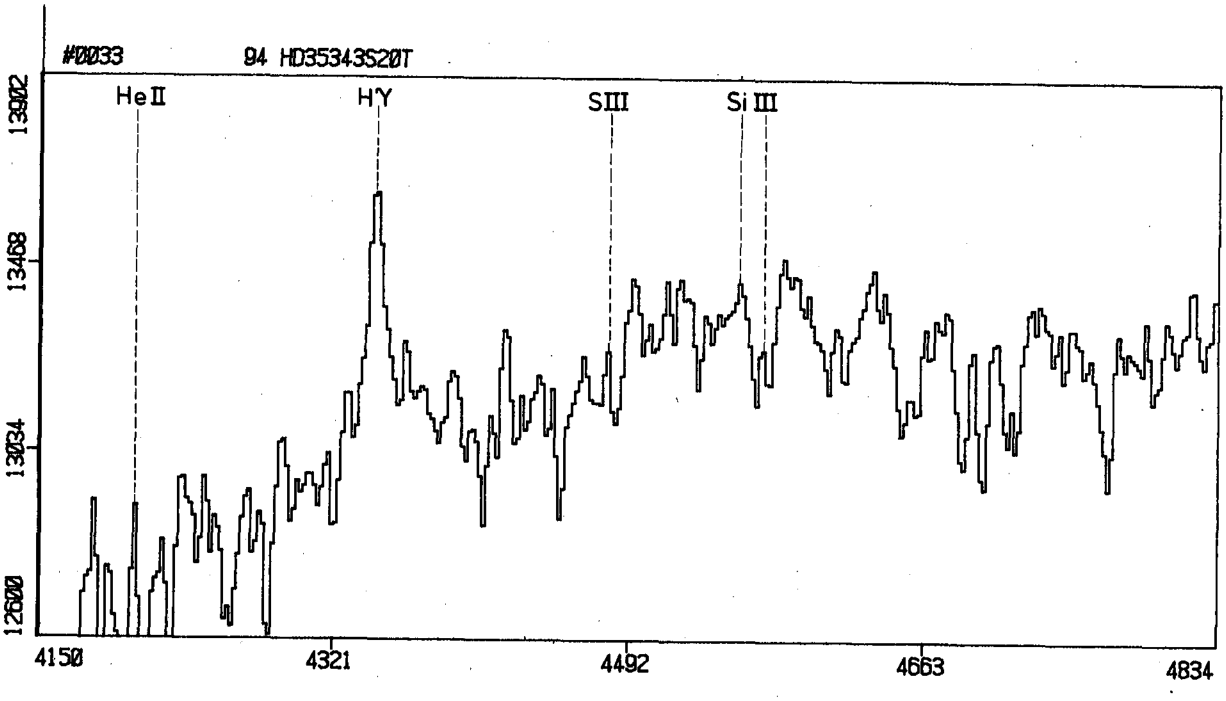
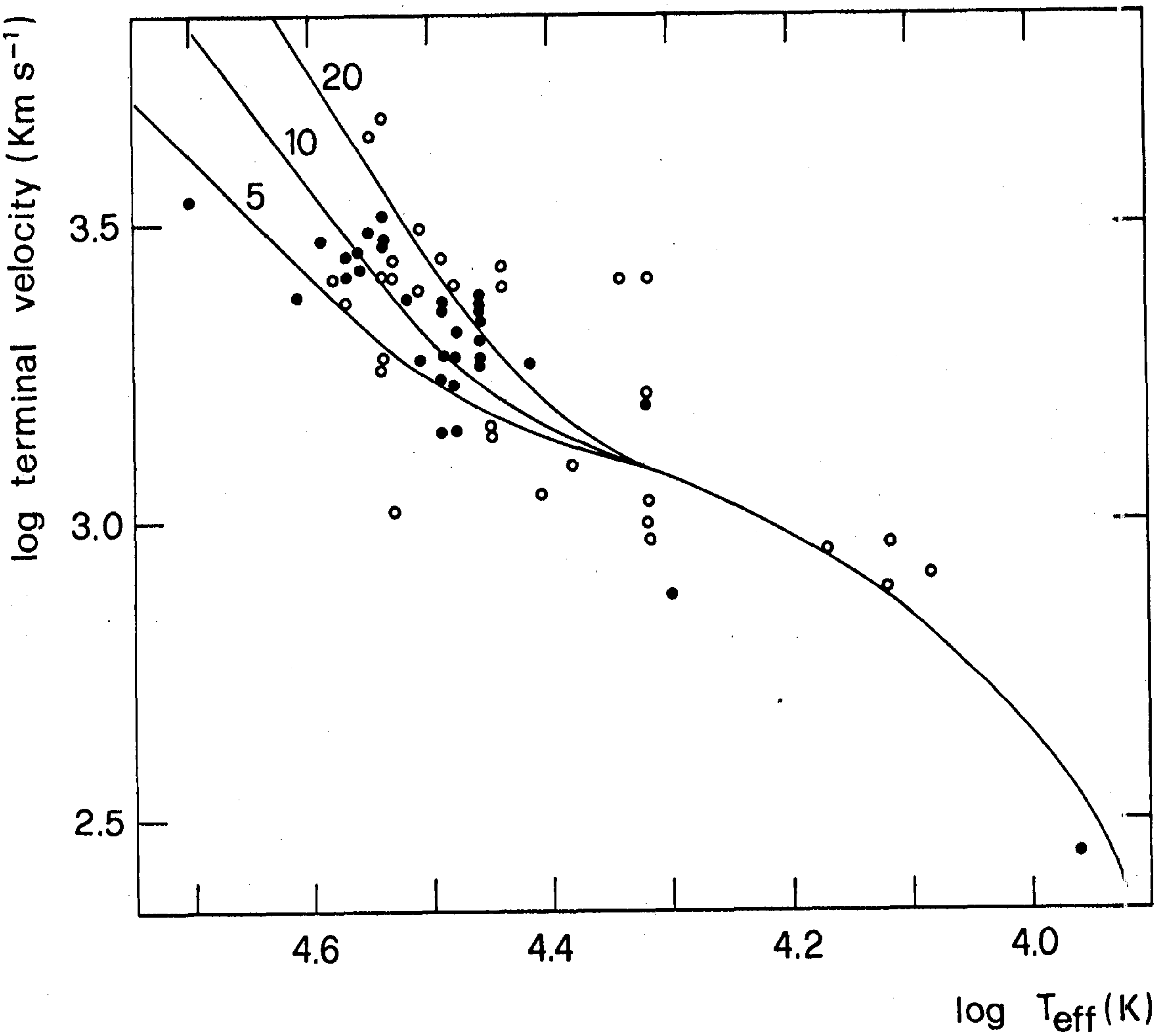


Figure 2



#0033
94 HD35343S20T
He II
H'Y
SIII
Si III
13902
13468
13034
12600
4150
4321
4492
4663
4834

Figure 3



log terminal velocity (Km s^{-1})
3.5
3.0
2.5
20
10
5
4.6
4.4
4.2
4.0
log T_{eff} (K)

Figure 4