MASS LOSS OF B1Ia-O SUPERGIANTS AND EVOLUTIONARY CONSEQUENCES

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I. Observations

The superluminous B supergiants are loosing mass and their progenitors are supposed to be O stars between O3 and O6 and hence it is justified to talk about B1Ia-O supergiants in this Symposium. Extensive high dispersion spectroscopic observations of four luminous B1 supergiants of the southern hemisphere have been carried out during 1972 and 1975 at ESO, La Silla. Some characteristic data of the program stars are summarized in Table 1.

Table 1: Some characteristic data of the B1 supergiants

Object	Spectral type	M_V	M_{bol}	T_{eff}
HD169454	B1Ia-O	-8.5	-11.0	24200
HD152236	B1Ia-O	-8.7	-11.3	24200
R116	B1Ia-O	-8.2	-10.7	24200
BD-14°5037	B1.5Ia-O	-7.0:	- 9.5	23150

R116 is the brightest B supergiant of the LMC and hence its absolute visual magnitude is well known which is of special importance for the determination of the mass loss rates.
The most conspicuous spectroscopic features of our programme stars are P Cygni type profiles of several lines, especially of H_α (Sterken and Wolf, 1978a). These P Cygni profiles are variable with time.
Fig. 1 shows the line profile variations of the H_α and HeI λ5876 lines of HD152236 on two spectrograms taken at a time difference of 30 days in 1973 (note that the interstellar sodium lines are almost identical on both spectrograms which shows that variations due to instrumental effects are negligible).
The program stars are also radial velocity variables (Sterken and Wolf 1978b). The range of the variations which may occur on time scales of days is up to 30 km/sec and is higher than the velocity of sound which is about 20 km/sec in the atmospheres of these stars.

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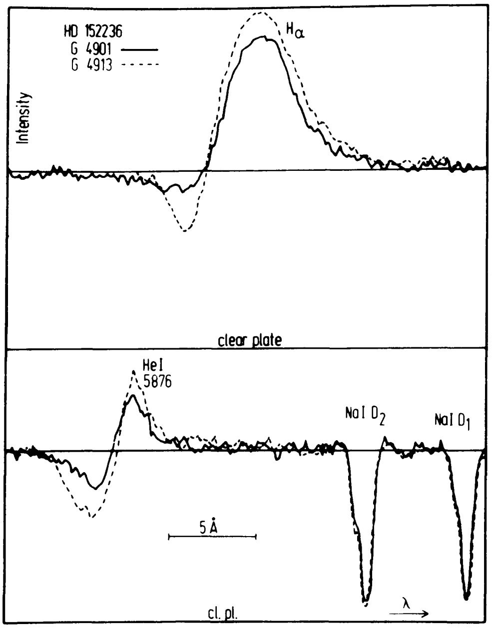

Fig. 1: Line profile variations of the H_α and HeI λ5876 lines of HD152236 on two spectrograms taken at a time difference of 30 days in 1973.

II. Mass Loss and Mass Loss Variations

From the H_α P Cygni profiles mass loss rates were determined according to the method suggested by Hearn (1975). In this method a uniform spherical symmetric expanding shell is assumed. The excitation and ionization balance in the shell is determined by radiation from the star. The calculated shell radius is about five times the stellar radius, the electron density in the shell is $n_e \approx 5 \times 10^9 cm^{-3}$ and the mean mass loss rates are of the order of $1.5 \times 10^{-6} M_\odot y^{-1}$ (see Table 2).

Table 2: Shell radius R_{sh}, mean electron densities n_e, and mean mass loss rates $\dot{M}$ of the program stars

	HD152236	HD169454	BD-14°5037	R116
R_{sh} / R_*	4.9	5.7	5.0	10.4:
n_e [cm^{-3}]	5.5 10^9	5.0 10^9	6.2 10^9	1.4 10^9:
$\dot{M}$ [$M_\odot y^{-1}$]	1.5 10^{-6}	1.7 10^{-6}	3.4 10^{-7}:	1.8 10^{-6}

The observed H_α intensity and profile variations are interpreted in terms of time dependent density variations in the shell, implying variable mass loss rates. The mass loss variations are as high as a factor of two and may occur on a time scale of days. Therefore one has to conclude that a steady state driving mechanism can not provide a complete description of the stellar wind mechanism in extreme B supergiants. Allowance has to be made for a time dependent process.

III. Evolutionary Consequences

The mass loss rate determinations are obviously of interest in connection with the current evolution theories of very massiv stars. In Fig. 2 the evolutionary tracks (cf. de Loore et al. 1978) of mass loosing stars with initial masses of 60 and 100 $M_\odot$ and with mass loss rates of about 3×10^{-6} and 8×10^{-6} $M_\odot y^{-1}$ are shown together with the most luminous galactic stars (taken from Hutchings, 1976). The asterisks denote the position of the B1 supergiants studied here. Time marks (t_1, t_2, t_3) characterizing the evolutionary speed during the shell burning phase are quoted. The assumed mass loss rates for which the evolutionary tracks were calculated are comparable to the rates found by us (and are comparable to the rates found in stars of previous evolutionary phases by several authors (cf.e.g. the review article by Lamers and Morton, 1976). The obvious lack of extreme supergiants later than B2 and brighter than $M_{bol} \approx -9$ has been discussed recently by de Loore et al.(1977). According to the theoretical evolution calculations including mass losses of the above mentioned quantities, this zone of the HRD between t_2 and t_3 should be populated with comparable density as the area to the left between t_1 and t_2.

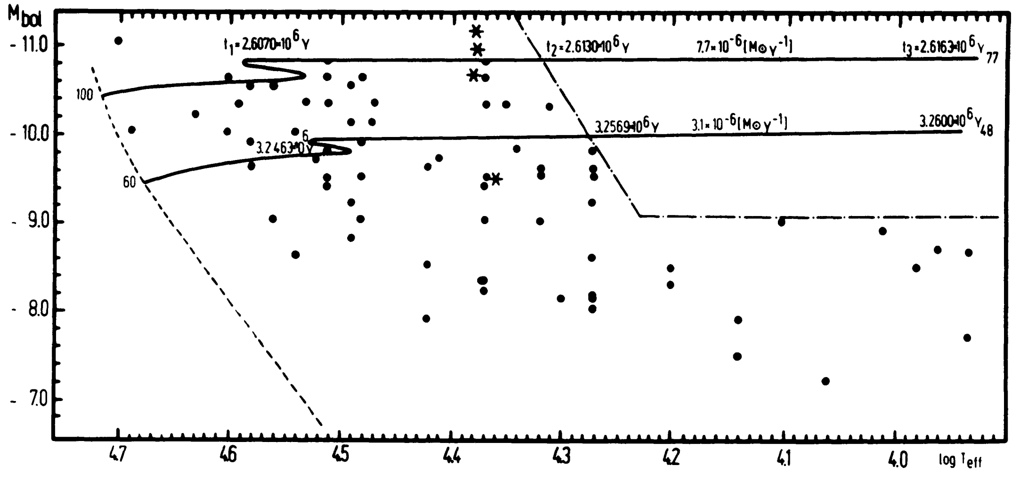

Figure 2: Theoretical HR diagram with the most luminous galactic stars. The asterisks denote the position of the B1 supergiants studied here. The evolutionary tracks (de Loore et al. 1978) of mass loosing stars with initial masses of 60 and 100 $M_\odot$ are included. For more details see in the text.

A possible explanation may be that all stars on the parts of the evolutionary tracks beyond $t_2 \approx 3\ 10^6$ are variables. Objects occasionally found in just this zone of the HRD are the Hubble-Sandage-variables. These very luminous variables of spectral type A to F (Hubble and Sandage, 1953) with absolute photographic magnitudes around -10 (Rosino and Bianchini, 1973) show considerable excess in the UV with U-B values of -0.8 to -0.9 (Sharov, 1975). Therefore their absolute bolometric magnitudes are probably even larger than -10. One may speculate therefore that the Hubble-Sandage-variables represent the later rather violent evolutionary phases of the very massive stars, observed as extreme B supergiants a few 10^3 years earlier.

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References:

Hearn, A.G.: 1975, Astron.Astrophys. 40, 277
Hubble, E., Sandage, A.: 1953, Astrophys.J. 118, 353
Hutchings, J.B.: 1976, Astrophys.J. 203, 438
Lamers, H.J.G.L.M., Morton, D.C.: 1976, Astrophys.J.Suppl. 32, 715
de Loore, C., De Grève, J.P., Lamers, H.J.G.L.M.: 1977, Astron.Astrophys. 61, 251
de Loore, C., De Grève, J.P., Vanbeveren, D.: 1978, Astron.Astrophys. 67, 373
Rosino, L., Bianchini, A.: 1973, Astron.Astrophys. 22, 453
Sharov, A.S.: 1975, IAU Coll. "Variable Stars a. Stellar Evolution" (Eds. Sherwood, Plaut, pg. 275)
Sterken, C., Wolf, B.: 1978a, Astron.Astrophys. (in press)
Sterken, C., Wolf, B.: 1978b, Astron.Astrophys.Suppl. (in press)

DISCUSSION FOLLOWING WOLF AND STERKEN

Lamb: The F- and G-type supergiants lie in the Hertzsprung gap. The evolutionary timescale for crossing this region is only a few times 10^4 yrs. Thus, the interesting question concerns the absence of red supergiants at high luminosity rather than the absence of F- and G-type supergiants. A comparison of evolutionary timescales suggests that there should be at least 100 times more early-type supergiants (O, B, and A) than F- and G-type supergiants.

Chiosi: I would like to remark about the comment sometimes made that the observed lack of very massive red supergiants can be explained in terms of the neutrino cooling in phases beyond the core He burning. Red supergiants are in the core He burning phase and according to the current wisdom the fraction of lifetime spent in this area ranges from a significant value to almost the totality. In particular the most massive objects are thought to have the whole core He burning as red supergiants no matter what criteria are adopted for intermediate semiconvective/fully convective instability. In such a case the τ_B/τ_R ratio does not vary (increase) in the presence of the neutrino cooling as the central He burning is almost insensitive to it -- see Chiosi (1978, IAU Symp. No. 80, in press).