Circumstellar Emission and Variability among Southern Supergiants

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Introduction

Circumstellar spectral lines, especially those which directly indicate the flow of stellar material, like P Cygni lines, have been observed since the beginning of our century. The peculiar character of P Cygni itself was conspicuous on Harvard objective prism plates already in 1890. Though until today the number of these obviously mass-loosing stars grew steadily, especially since the beginning of UV astronomy, we do not know very much about the physical mechanisms which are basically responsible for the loss of stellar material. Regarding the hot stars, models are favoured in which the photospheric radiation pressure, especially in the UV, or mechanisms in stellar coronae are supposed to be the driving motors of stellar winds (see e.g. J. P. Cassinelli et al., *Publications of the Astronomical Society of the Pacific,* **90,** 496, 1978), while for the cold end of the spectral sequence, acoustic phenomena, generated in the outer stellar convection zones, seem to accelerate the outflowing masses. The medium spectral types F and G appear to show the least tendency towards mass loss. Or is it possible that the lack of suitable theories in this temperature range is at least partially responsible for the lack of systematic observations? Whether these stars are indeed more resistant to mass loss is one of the questions of our programme.

An important aspect of our programme was photometric work in addition to spectroscopic observations, because the physical processes governing the flow of stellar matter are expected to have some effect on the total electromagnetic radiation of the star. Photometric variations may reveal the regular or irregular character of these processes. Unresolved stellar companions, a possible external cause of mass loss, can be detected by light changes of the eclipsing type.

Up to now we know some stars of supergiant type Ia which have P Cygni line profiles and also show intensity variations of undeterminate character (e.g. S Doradus and the group named after it). Simultaneous spectroscopic and photometric observations of further supergiants in this programme are important in answering the questions whether this group contains particularly good candidates for stellar mass loss and what basic mechanisms play a major role in this cosmic game.

Observational Programme

We, the author in collaboration with another member of the Astronomical Institute Münster, Klaus Rindermann, observed on La Silla from July 20 to August 4, 1980. For photoelectric UBV photometry we used the 61 cm Bochum telescope during the whole period, while the coudé spectrograph at the 1.5 m ESO telescope was assigned to us for 6 parallel nights. Unfortunately the weather conditions proved to be so bad that only 5 photometric nights and 2 spectroscopic half nights, i.e. 1 effective night, remained for evaluation. The photometric quality of these nights was average to good. The scarcity of the collected data forced us, however, to eliminate some of our programme tasks from the beginning. In spite of this restriction, the observational results proved to be so interesting, that not only several of our original questions got definitive answers, but some new surprising aspects arose which deserve more observational studies. As an example we show the Hα line profiles of two G0 type stars (HR 4511 and 7066), which indicate a rather complex and certainly unusual shell structure (Fig. 1).

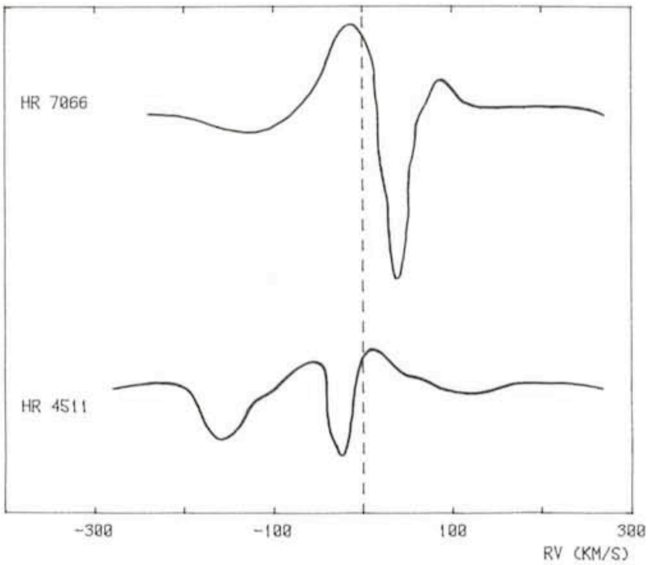

Fig. 1: *Density profiles (smoothed) of the Hα lines for two G0 type supergiant stars. The profiles are of complex P Cygni type. Given radial velocities refer to the system velocity (variable) of each star, indicated by the broken line.*

Initially our observational programme intended to answer the following questions:

1. Which and how many of the programme stars show P Cygni line profiles or at least some emission (in Hα)?
2. How large is the mass loss indicated by these lines?
3. Are there short-term (several days) spectral variations among the mass-losing stars?
4. Which and how many programme stars exhibit light and colour variations?
5. What character have these light and colour variations?
6. Are potential light variations correlated with mass loss indicators and/or spectral variations?

As programme stars we chose bright supergiants (luminosity class Ia) of spectral types B to G.

Observational Material

In order to compensate for the relatively low photometric quality of the nights, all photometric reductions of our programme stars refer to suitably chosen means of all

TABLE 1

Star (HR)	BSC: Type (LC Ia)	BSC: Var.	Spectral emission ($H\alpha$) Type	Spectral emission ($H\alpha$) RV_W (Abs.) (km/s)	Maximum deviation (V) (mag)	Maximum deviation (V) (s. d. (C))	Var.
4110	F0	V?	rev. P. Cyg	+130	0.021	2.25	V?
4147	B5				0.013	1.45	
4169	A0		P Cyg I	−168:	0.173	20.35	V
4198	B3	V?			0.029	3.42	V?
4228	A0				0.010	1.19	
4250	A0				0.008	0.91	
4337	G0		no emission				
4338	B9		rev. P Cyg	+115	0.002	0.22	
4352	F0		no emission		0.001	0.07	
4438	A0				0.056	6.05	V
4441	G0	V?			0.280	30.46	V
4442	A2				0.012	1.27	
4511	G0		P Cyg IV	−222:	0.038	4.17	V
4541	A2				0.019	2.10	V?
4644	B9				0.027	2.77	V?
4653	B2				0.017	1.87	
4876	A1	V?			0.016	2.77	V?
4887	B9				0.053	13.87	V
5379	A2		no emission		0.008	0.83	
6131	B2		P Cyg I	−198:	0.023	4.44	V
6142	B1				0.044	4.74	V
6155	B0		no emission		0.028	6.66	V
6262	B1e	V?	P Cyg I	−254:	0.021	4.16	V
6450	B4		weak emission		0.017	1.81	
6615	F2		no emission				
6812	B8p	V	P Cyg III	−98:			
6822	B0		no emission		0.014	2.89	V?
6825	A0				0.021	2.25	V?
7066	G0e	V	P Cyg IV	−225:	0.394	38.05	V

Columns 1, 2 and 3: Star number, spectral type and variability after D. Hoffleit, *Catalogue of Bright Stars* (BSC), New Haven, 1964. – Column 4: P Cygni type according to C.S. Beals, *Publ. Domin. Astrophys. Obs.*, Vol. IX, No. 1, 1950. – Column 5: Radial velocity of absorption component (wing) with respect to system velocity. – Columns 6 and 7: Maximum single deviation (absolute value) of V magnitudes from night-to-night mean differences of all comparison stars (see text), given in magnitudes (6) and in units of standard deviation of comparison stars (7). – Column 8: Variability according to our definition: V = deviation (column 7) larger than 4 standard deviations; V? = deviation between 2 and 4 standard deviations.

measurements of all comparison stars. These means are obtained from the various night-to-night differences in the V magnitudes of the comparison stars. This procedure has the additional advantage that comparison stars which are variable can easily be detected and eliminated. Most of the comparison stars are constant and, taken over the 5 good nights, show that deviations from the mean are not too large. Only two obviously variable stars (HR 6164 and 6261) have larger deviations. If we eliminate these, then the V mean difference between the first and the second night with 0.017 mag ± 0.005 (s. d.) appears to be the only significant trend. All other night-to-night differences deviate on the average by less than $0\overset{\mathrm{m}}{.}01$, so that this is the upper limit for all errors due to the reduction procedure in the nights from July 21 to 30.

A total of 26 programme stars was observed photometrically. For 15 of the programme stars we obtained coudé spectrograms on Kodak 098-04 emulsion with a dispersion of 12.4 Å/mm and a useful spectral interval between 5700 and 7300 Å.

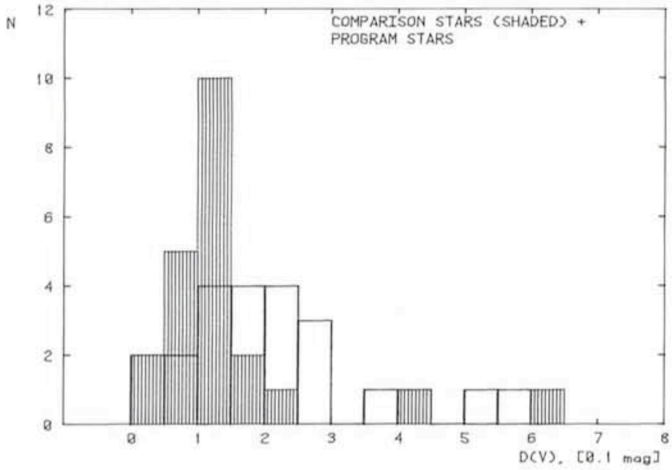

Fig. 2: *Frequency distribution of maximum single deviations (absolute value) of V magnitudes from night-to-night mean differences of all comparison stars. Two groups are plotted: all comparison stars (shaded) and all programme stars.*

Preliminary Results and Interpretation

Table 1 lists the preliminary results for all observed programme stars. From columns 6 and 7 we clearly see that a good number of stars have statistically significant deviations. To have a check, we computed the same maximum single deviations for all comparison stars and compared them with those of the programme stars (Fig. 2). Here we see that the comparison stars have a distinct, small scattering frequency distribution (except for the two stars found to be variable) with a mean value near 0.012 mag – for the *maximum* deviation, *nota bene!* – the programme stars, on the other hand, show a clear displacement to larger deviations, the three extremes lying far outside of our diagram. This indicates a general tendency towards variability, especially in view of the fact that a maximum of 5 observations per star is not sufficient for catching each possible variable.

From the listed data we see:

1. 9 out of 15 stars (60%) exhibit Hα emission, 6 of them with more or less typical P Cygni line profiles (3 B, 1 A and 2 G stars, the latter with complex profiles, as shown in Fig. 1), 2 more with reverse P Cygni profiles (B, F) and 1 star with weakly indicated emission (B), possibly another P Cygni candidate.
2. The radial velocities of the P Cygni absorption components (edge of short wavelength wing) relative to the system velocities show a slight dependence on spectral type: for early B stars we find values around –200 km/s, for A stars around –100 km/s. The two G stars with complex profiles have again velocities of about –200 km/s.
3. 10 out of 26 stars (38%) are clearly variable with deviations of more than 4 standard deviations from the respective mean of the comparison stars, at least 7 more (27%) can be classified as suspected variable stars (deviations between 2 and 4 standard deviations).
4. 7 stars (78%), possibly 8 (89%), out of 9 emission line stars are variables or suspected variables. The 4 photometrically observed stars without visible emission features include 2 apparently non-variable stars (types A and G), 1 suspected (B) and 1 variable star (B).
5. Among the variables are 7 newly found variables: HR 4169, 4438, 4511, 4887, 6131, 6142, 6155.
6. Among the 17 stars of spectral types later than B9 we find the most clearly non-variable as well as the variable stars with largest amplitudes (HR 4169, 4441 and 7066), while the 9 stars of types B0 to B5 are all variable with low amplitudes (Fig. 3).

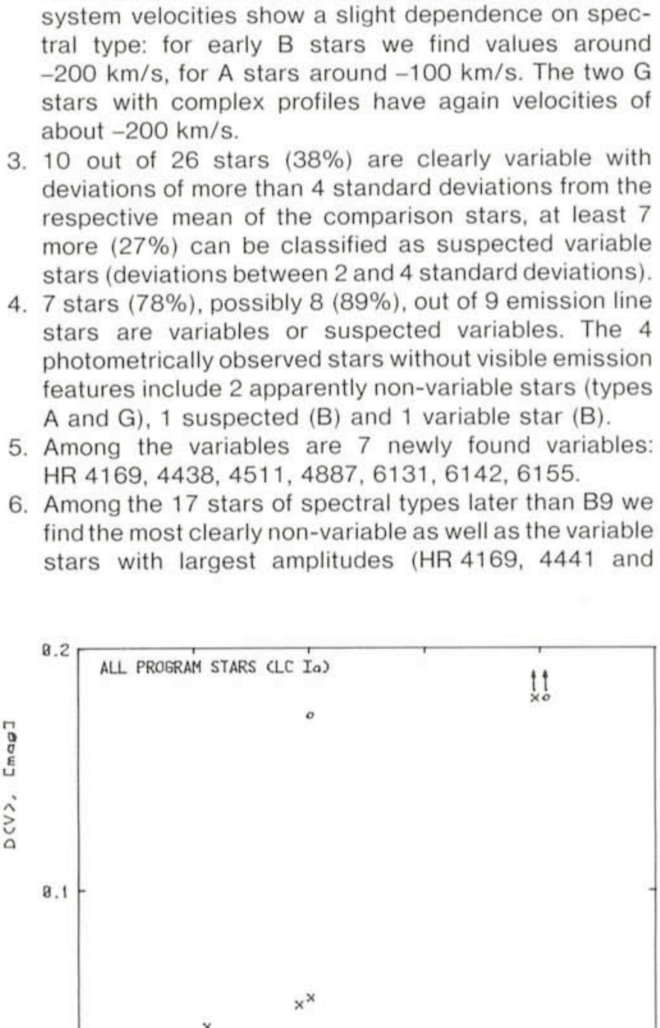

Fig. 3: *Maximum single deviation (absolute value) of V magnitudes from night-to-night mean differences of all comparison stars plotted against spectral type of each programme star. Small circles indicate stars showing Hα emission.*

Our results may be summarized in this way:

Variability and the existence of P Cygni or emission lines in stellar spectra seem to be a rather common feature among supergiant stars of early and medium spectral types. A good correlation exists between the presence of emission lines, mainly of P Cygni type, and the presence of variability. Vice versa, this does not hold as well: variable supergiants do not always show indications of spectral emissions, at least in our limited sample of spectra. It is quite conceivable that this absence can be explained by short-term weakening of the emission lines, especially if irregular, possibly eruptive mechanisms of stellar mass loss play a role. The detection of line variations of this type was one of our original programme points which had to be omitted due to bad weather. When this weakening occurs we would generally expect a lower tendency towards variability which is not in contradiction with our data. Among the 4 non-emission-line stars we find 3 non-variables which is, compared with the emission-line stars, a distinct but not significant increase in the number of quiescent objects.

Possible quiet phases during the supergiant stage, which may be restricted to limited regions of the HRD, certainly pertain to the nature of the driving mechanisms of the mass flow. The behaviour of the early B type stars with their weak but always visible activity is sufficiently different from the behaviour of the A to G types which show a separation into inactive and strongly active groups. This is observational evidence of different driving mechanisms in addition to more theoretical considerations employed so far. For B stars the "superficial" causes (coronae, photospheric radiation pressure) may indeed be solely responsible, whereas the later stars could be transition types to the cool stars with deeper-lying phenomena related to their outer convection zones. In this intermediary group not all members may be able to fulfil the necessary conditions for being variable.

As usual we must conclude that further observations are needed. One fact however is evident: the supergiant stars, this mildly spectacular phase of stellar evolution, play a more and more important role for mass loss among stars. Possibly, they begin to rival the supernovae, these most popular objects regarding mass loss!

Visiting Astronomers

(April 1 – October 1, 1981)

Observing time has now been allocated for period 27 (April 1 – October 1, 1981). As usual, the demand for telescope time was much greater than the time actually available.

The following list gives the names of the visiting astronomers, by telescope and in chronological order. The complete list, with dates, equipment and programme titles, is available from ESO-Garching.

3.6 m Telescope

April:	Surdej/Swings/Osmer, Schnur, Weigelt, Fitton, Fusi Pecci/Cacciari/Battistini/Buonanno/Corsi, Alcaino, Kohoutek.
May:	Kohoutek, Wehinger/Gehren/Wyckoff, Querci, F./Mauron/Perrin/Querci, M., Koornneef/Wester-