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SPECTROPHOTOMETRIC STUDIES OF NON STABLE STARS
I. A FLARE OF SS CYGNI*

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A spectrophotometric investigation of SS Cyg during a flare has been made. The observations have been carried out at the Cassegrain focus of the 193 *cm* telescope of the Haute-Provence Observatory (France) with the Chalonge spectrograph in October 1966. A description of the spectrophotometric method used is given. The energy distribution in the continuum compared with the black body radiation of a temperature 5200°K, the spectrophotometric gradients for the wavelength intervals λλ 3150—3700 and λλ 4000—6200, as well as the Balmer discontinuity have been determined in minimum and maximum brightness and on the increasing branch of the light curve. The results first obtained in the present work (the ultraviolet spectrophotometric gradient at minimum brightness and the unusually large and strongly shifted towards the long wavelengths Balmer jump during the rapid rise of the star brightness) are shortly discussed.

Introduction. The study of spectra of variable stars is of great interest to understand the nature of phenomena leading to the variations of their radiation. This is especially important for non stable stars showing irregular variations of brightness. As it has been shown by V. A. Ambartsumian [1] it is practically impossible to explain the irregular changes of brightness and spectrum of some non stable stars by known mechanisms of thermal radiation.

From this point of view the continuous emission observed in spectra of the T Tau stars and related objects is of particular importance. It has a comparatively high intensity usually in the ultraviolet region.

* Instead of the word „outburst" which is in general use we prefer the word „flare" because the first implies the idea of an explosion.

In order to study the changes of the energy distribution in the spectra, including the ultraviolet region, we began the observations of some non stable stars in 1966.

In this paper, after a brief description of the spectrophotometric method used in Paris, we give the results obtained for SS Cyg.

The spectrophotometric method. Spectra of the non stable star SS Cyg have been obtained at the Cassegrain focus of the 193 *cm* telescope of the Haute-Provence Observatory (France), with the Chalonge spectrograph.

The Chalonge spectrograph [2] has been especially designed for spectrophotometric work on continuum. The dispersion is moderate (about 220 Å/*mm* at H_γ) but the quartz and fluorite optics gives spectra of very good quality over a wide range of wavelengths (6200—3100 Å). The main characteristic of this spectrograph is that the widening is obtained by an oscillation of the plate-holder around a point situated on the ultraviolet part of the spectrum, between 2500 and 3200 Å. With this system, spectra are triangular, the red side being more widened than the ultraviolet one (Fig. 1). The interesting result of this type of widening is a strong concentration of the ultraviolet light relative to the red one making it possible to obtain on the same spectrum sufficient darkening as far as 3100 or 3200 Å in the ultraviolet without overexposing the long wavelengths, even for rather red objects. Without this concentration, two or three spectra instead of one would often be necessary to cover the whole range 6200—3100 Å, and the large uncertainty in the fitting together of these two or three spectra would completely spoil the accuracy of the results.

The concentration can be easily changed (from a factor $r = 3$ to higher values) by moving the centre of rotation along the spectrum and fitted to the colour of the observed stars. The concentration $r = 3$ gives a rough compensation for the loss in the ultraviolet light due to atmospheric extinction and is sufficient for relatively hot objects; but much higher concentrations ($r > 3$) are used for very red stars.

In the course of the observations, as well as during their reduction, much care is taken to obtain accurate energy distributions:

a) A monochromatic calibration curve is done for each of the wavelengths measured.

b) Comparison stars are chosen among the O and early B types, for which the continuum can be well defined even at moderate dispersions.

c) If no determination of the atmospheric extinction can be done during the night, the comparison star S_0 is chosen in the neighbourhood of the observed star S, and its spectrum taken with almost the same zenithal distance; the very small corrections for differential atmospheric extinction between S_0 and S are then computed with mean values for the extinction coefficients and amount of ozone.

d) A rapidly rotating sector situated just behind the slit of the spectrograph, makes it possible to reduce the light of the comparison star without any change in the energy distribution. In this way, the spectrum of a comparison star S_0, even three or four magnitudes brighter than the star S, can be taken with the same exposure time. In the present work on non stable star, this necessary condition for correct photometry was generally fulfilled, but in a few cases and in order to save time during the observations, the exposure time of S_0 has been reduced; as the Schwarzschild coefficient of the plate depends on the wavelength, the consequence of this reduction is an apparent change in the energy distribution. In order to eliminate this source of errors, the Schwarzschild coefficient was determined for every wavelength and the corresponding corrections calculated: they were very small.

e) As the standard star S_0 had been previously compared to a black body (in an unpublished work performed at the Institut d'Astrophysique of Paris and based on observations made at the high altitude observatory of Jungfraujoch in Switzerland), the final result of the present study is the energy distribution of the non stable star with a black body radiation of a given temperature: it renders all the calculations in colour temperature and Balmer jump much easier.

The observations of SS Cygni. The non stable star SS Cyg is a spectroscopic binary [3], both components of which (B and G types) are supposed to be eruptive variables. The large changes of brightness have a cycle of about 50 days [4]. The energy distribution between 4600 and 4000 Å at maximum brightness is usually similar to the distribution of a normal A2—A3 star [5, 6]. At minimum brightness an excess of blue radiation is observed compared to the normal cold star energy distribution [5—7]. Moreover small rapid changes of brightness are observed during minimum, probably of non thermal origin [7].

Unfortunately, the observations of the spectrum of SS Cyg during these rapid changes are extremely difficult. However, it can be supposed that the energy distribution changes in ultraviolet take place even during long periods. For studying the energy distribution in the spectrum of SS Cyg in different phases of its brightness variations we took some spectrograms of this star in October of 1966. After two nights of observations a rapid increase of its brightness began, connected with the beginning of a flare. Thus we succeeded to observe a whole period from minimum to maximum. The data corresponding to these observations of SS Cyg are given in Table 1.

Table 1

THE SPECTRAL OBSERVATIONS OF SS CYG

Date (1966)	J. D. (mid. exposure)	Exposure (min)	Plates
Oct. 19	2439 418.33	150	Eastman 103aD
Oct. 21	420.34	"	"
Oct. 22	421.29	"	"
Oct. 27	426.26	10	"
"		18	"
Oct. 28	427.27	25	"
"		30	"
Oct. 29	428.27	46	"
"		30	"

The most typical spectra and their microphotometric tracings are respectively presented in Figures 1 and 2. The transformation of the spectrum of SS Cyg during the observed flare (evolution of the continuum and the lines) is very conspicuous.

According to the observations of A.A.V.S.O. [8] we have observed the 507th recorded maximum of SS Cyg, which was a maximum of type A9 [9], that is a long maximum with the most rapid rise of brightness. The maximum is flatter and longer (sixteen days between 10.0 I. and 10.0 D.) than all of those observed in 1966 [8]. The light curve of SS Cyg for October 1966, including the observed maximum, is shown in Fig. 3 (from [8]); the observations of Table 1 are indicated by the arrows; the magnitudes deduced from our spectra, and given in Table 3 (column 3), are added (open circles).

Table 2

COMPARISON STAR FOR SS CYG

Name	m_v	λ_1	D	Type λ_1, D
HD 73	8.5	3757	0.108	B1.5 IV—V

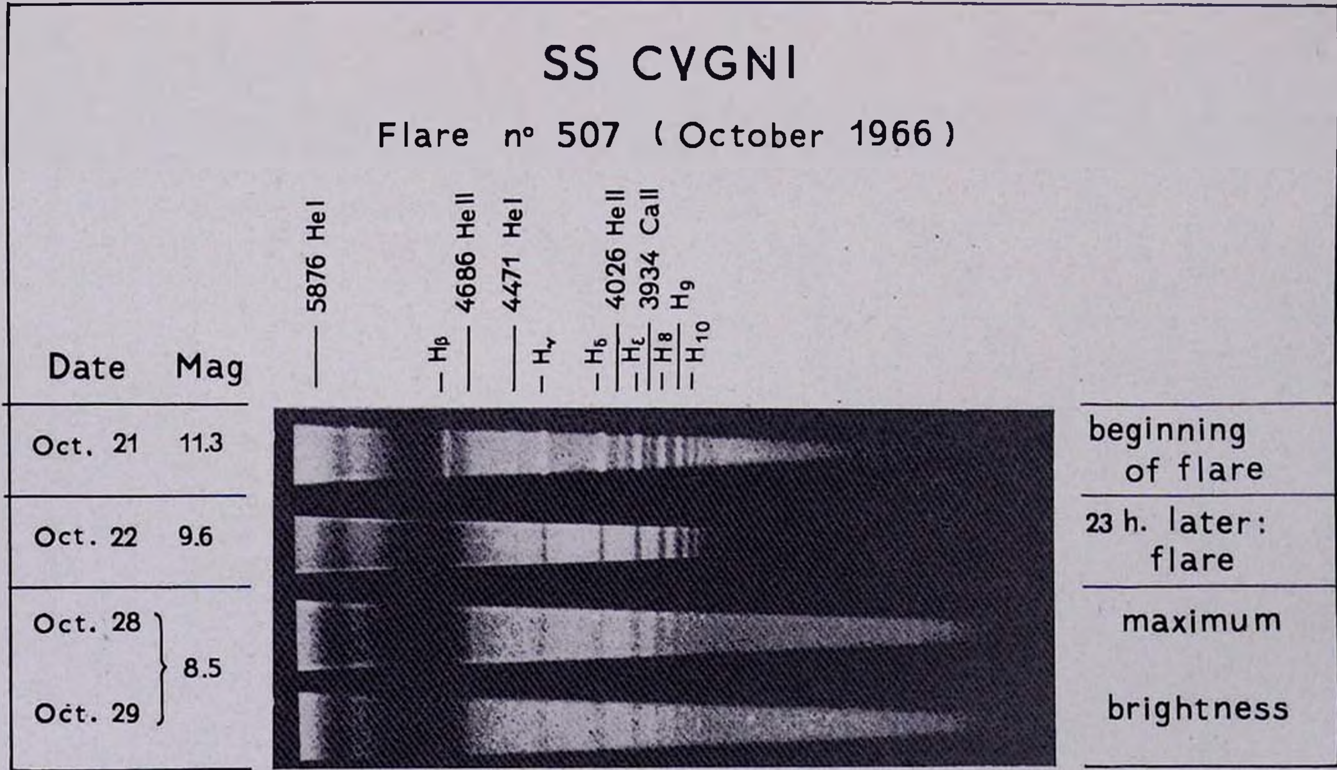

Fig. 1. The most typical spectra of SS Cygni during the flare n° 507.

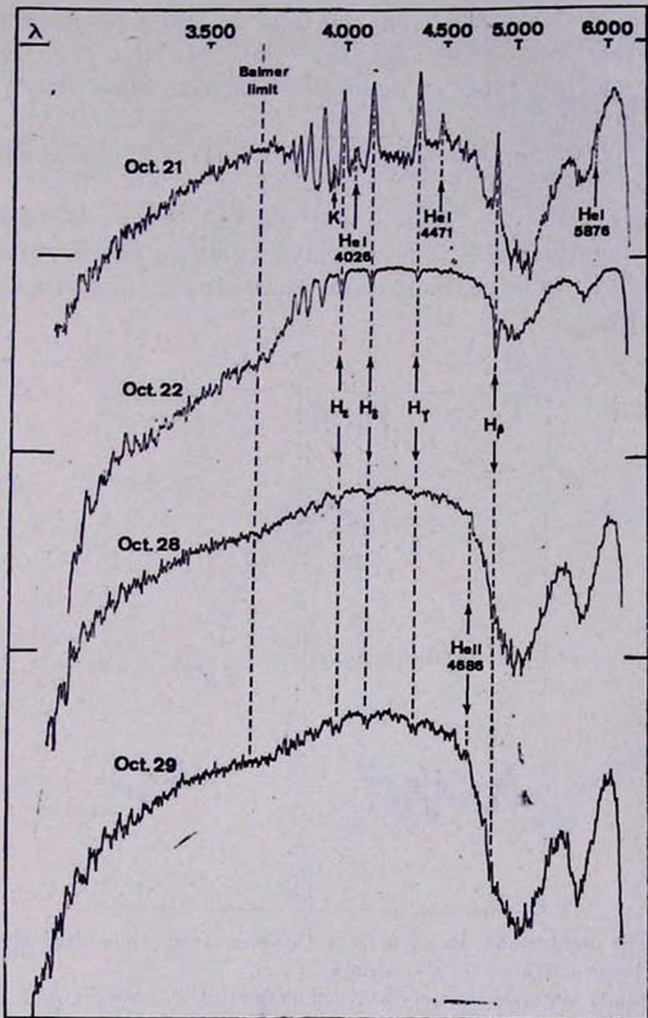

Fig. 2. Microphotometer tracings of the spectra of Fig. 1:

a) Oct. 21, a few hours only before the flare; the typical emission line spectrum always observed at minimum light is seen, as well as the continuous Balmer emission, first suspected by Hinderer [5].

b) Oct. 22, twenty three hours only after the former spectrum, during the very rapid rise of brightness (m=9.6). Deep and broad absorption lines are visible; the Balmer jump is in absorption and has the highest value ever observed for SS Cyg, D=0.30; the colour temperature is much higher than at minimum.

c) Oct. 28 and 29: the star is still at maximum; the only lines present are broad and shallow Balmer absorptions with a central emission, and the 4686 Å HeII line, in emission.

All the measurements of the continuum of SS Cyg have been made with the help of the comparison star HD 73. Table 2 gives its spectral type and visual magnitude. As the star has not been classified by Morgan, its spectral type is deduced from the values of λ_1 and D, as is indicated in [10].

HD 73 fulfills the conditions required for a good comparison star in the case of SS Cyg:

1) its spectral type is early and the continuum well defined;

2) the magnitude 8.5 is large enough and, with the rotating sector, can be increased up to 12 and made equal to that of SS Cyg even at minimum light;

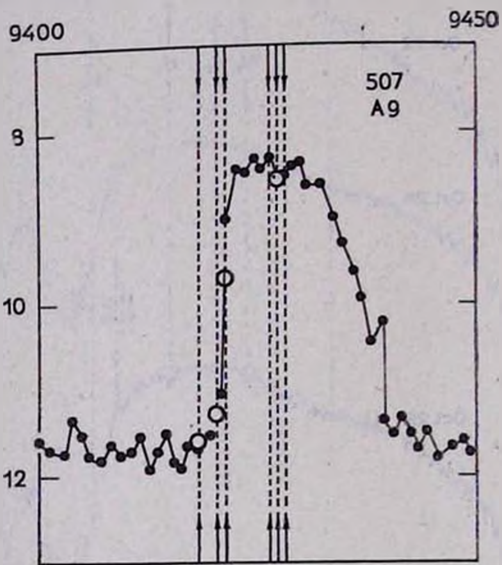

Fig. 3. The light curve of SS Cyg in October 1966 from [8], with the dates of our observations indicated by the arrows.

Open circles: our own measurements of magnitudes, from Table 3.

3) the difference in air mass between HD 73 and SS Cyg never exceeded 0.01 except in one case where it was 0.09 (on Oct. 27). The very small corrections for differential atmospheric extinction were calculated with the theoretical monochromatic absorption coefficients given by the Rayleigh law and the amounts of ozone measured at Mont-Louis (300 *km* from the Haute-Provence Observatory) by Vigroux, and kindly communicated by him before publication.

4) The provisional absolute calibration of HD 73 that has been done at the Institut d'Astrophysique de Paris by Chalonge and coll. gives the values of $\log I_{HD\,73} - \log B_{5200}$. Combining this with the pre-

sent measurements of $\log I_{SS\,Cyg} - \log I_{HD\,73}$, we obtain the energy distribution in the continuum of SS Cyg, compared with a black body radiation at 5200 °K.

The values of $\log I_{SS\,Cyg} - \log B_{5200}$ are plotted against of $1/\lambda$ in Figures 4 and 5. It appears that in the wavelength intervals 4600—4000Å and 3700—3150Å the energy distribution of SS Cyg is that of a black body. From the slopes of the straight lines in Figures 4 and 5 the

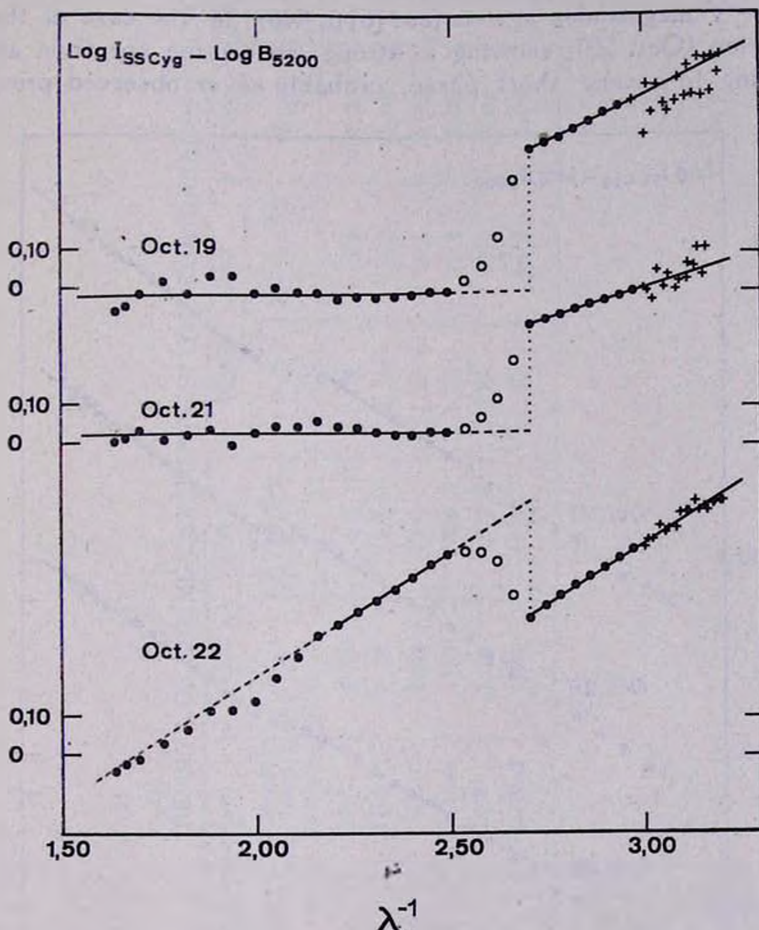

Fig. 4. The absolute energy distribution in the continuum of SS Cyg:

● —intensities corresponding the continuum and measured on a smooth curve avoiding the lines and granulation of the plate, as shown in [10] p. 204.

+—same, but these points had to be corrected for the ozone absorption; no smoothing being done, the scatter is somewhat greater.

o—intensities corresponding to a pseudo-continuum, joining the points of maximum intensity between the Balmer lines; they are outside the wavelength intervals in which the gradients are defined.

spectrophotometric gradients Φ_b and Φ_{uv} are derived, and the Balmer jump D is measured at $\lambda = 3700$ Å ($1/\lambda = 2.70$). Even in the larger interval 6200—4000 Å a mean spectrophotometric gradient Φ_{rb} can be defined. The results of these measurements together with the corresponding visual magnitudes of SS Cyg are given in Table 3:

Column 1 — the dates of the observations in J. D.

Column 2 — the magnitude of the star from [8] and corrected to reduce it to the V magnitudes system (see [6] p. 446) in the case of the third observation (Oct. 22), showing a strong absorption spectrum and corresponding to a very short phase, probably never observed previously,

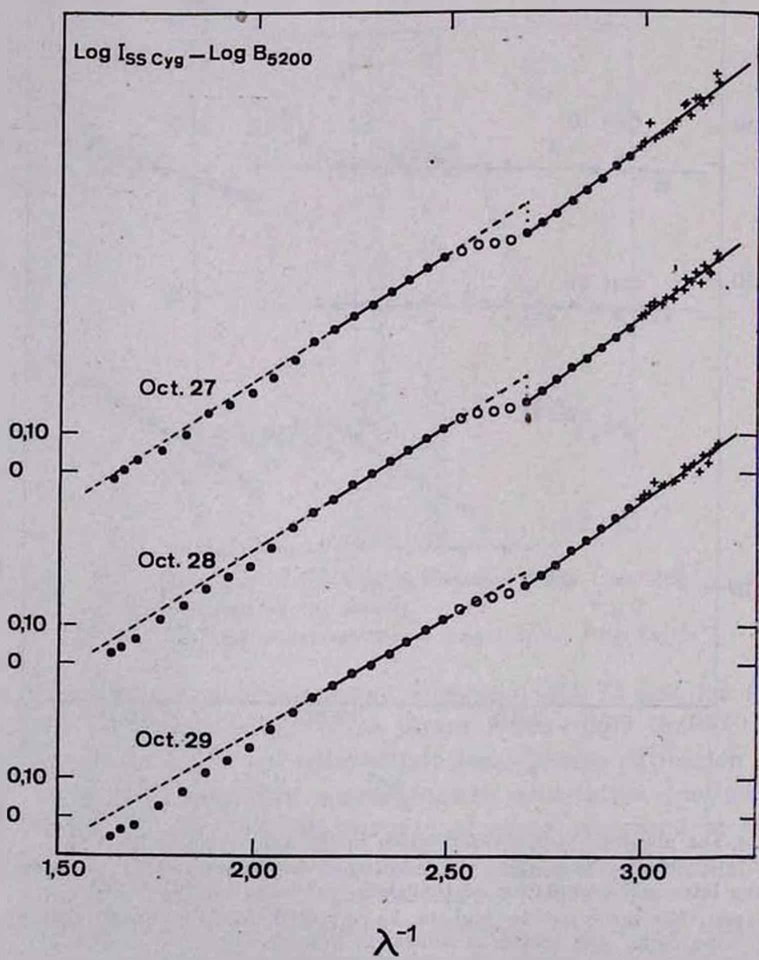

Fig. 5. The absolute energy distribution in the continuum of SS Cyg. The marks are the same as for Fig. 4.

Table 3

RESULTS OF THE MEASUREMENTS OF THE CONTINUUM OF SS CYG

J. D.	Visual magnitude		$6200 > \lambda > 4000$		$4600 > \lambda > 4000$		$3700 > \lambda > 3150$		D	n
	from [8]	from the present spectra	Φ_{rb}	$T_c \cdot 10^{-2}$°K	Φ_b	$T_c \cdot 10^{-3}$°K	Φ_{uv}	$T_c \cdot 10^{-3}$°K		
418.33	11.6	11.5	2.77	5.2	2,77	5.2	1.70	8.5	−0.38	1
420.34	11.3	11.2	2.76	5.2	2,76	5.2	1.98	7.3	−0.28	1
421.29	ill-defined	9.6	1.23	13.1	1.25	12.1	1.30	11.3	+0.30	1
426.26	8.5	ill-defined	1.20	13.6	1.23	12.4	1.00	15.4	+0.08	2
427.27	8.5	8.7	1.18	13.9	1.27	12.0	1.02	15.1	+0.06	2
428.27	8.5	ill-defined	1.23	13.1	1.37	10.9	1.04	14.6	+0.04	2

of the very rapid increase of brightness, the magnitude could not be deduced from [8]; it had to be determined by another method and is given in the next column.

Column 3 — the V magnitude, measured on our spectra: it is possible, knowing the intensities, the diaphragms used, the exposure time, the Schwarzschild coefficient... etc., to calculate V, and it has been verified [11] that under certain conditions (clear sky, correct guiding of the telescope...) the results are quite reliable. These conditions were nearly fulfilled on four of our six nights; the corresponding points are plotted in Fig. 3 (open circles) and the agreement with the curve given by Mrs Mayall [8] is very good. From all this we conclude that the magnitude 9.6 obtained for the strong absorption spectrum of J. D. 2439421.29 can be considered as reliable.

Columns 4 to 9 — Φ_{rb}, Φ_b, Φ_{uv} and the corresponding colour temperatures.

The probable errors are roughly equal to:

$\pm$ 0.03 for Φ_{rb},

$\pm$ 0.05 for Φ_b and Φ_{uv},

$\pm$ 0.01—0.02 for D.

Column 10 — the Balmer jump D.

Column 11 — the number of spectra of SS Cyg.

For the observations made on 27, 28 and 29 October (the last three in the Table 3) during the flat maximum (see Fig. 3) Table 3 gives the mean values of the measured quantities for each night. It must be noted that due to the flattness of the observed maximum the magnitudes of SS Cyg for these days do not differ by more than $0^m\!.1$.

Discussion. The colour temperature of SS Cyg is higher in the ultraviolet range than in the photographic range both at minimum and maximum brightness, but this difference is larger at minimum. The Balmer discontinuity is negative at minimum (—0.28 ÷ —0.38), becomes positive (+0.30) during the rise of brightness, then decreases to 0.08—0.04 at maximum.

In the present state of our knowledge, it is difficult to add something new to what has been said on the complicated SS Cyg system. The components actually known (a B star, a G one, a shell around the B star and perhaps an absorbing envelope around the whole system) give a great number of parameters that can be adjusted to explain the experimental results, and new observations are wanted. Yet a new result, very important for our knowledge of the shell, is the value of Φ_{uv} at minimum light; it may help to recognize if the ultraviolet radiation can be explained by the existence of the shell alone, or if entirely new phenomena occur.

In addition, the strong absorption spectrum appearing with the increase of brightness now is better known. Particularly it is established that the Balmer jump can reach still higher values (D = 0.30)

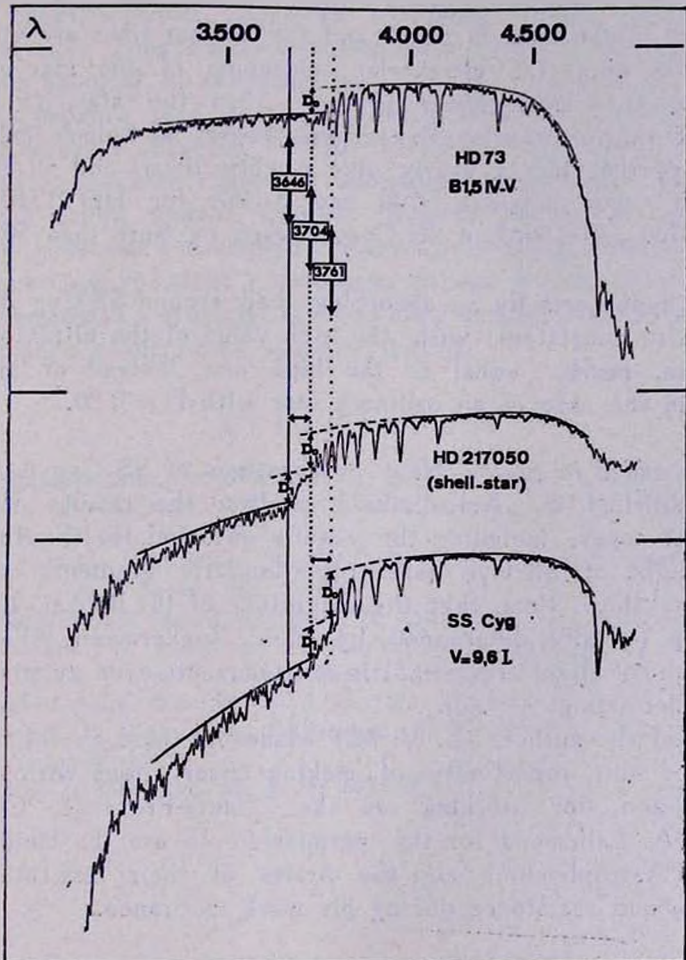

Fig. 6. The absorption spectrum of SS Cyg at V=9.6 I. compared with that of a normal B star (HD 73) and a B shell star (HD 217050).

than those observed by M.-C. Zuckermann ($D = 0.23$ [6]) and is strongly shifted. This large discontinuity is inconsistent with the B type spectrum of the ordinary photographic range ($\lambda > 3700$ Å) and the analogy between the spectrum of SS Cyg in this phase and the shell spectrum of HD 217050 appears in Fig. 6; this analogy makes most probable that in the case of SS Cyg as in the case of HD 217050, we see the spectrum of a B star with the plausibly small Balmer jump D_0, on which the absorption D_1 produced by a shell (see [12]) is superposed. Still there is a great difference between these two cases: HD 217050 is a normal B dwarf and the Balmer lines are visible until about 3700Å where the ultraviolet continuum of the star begins; the shell being at a much lower pressure than the star, its continuum begins at a shorter wavelength near the theoretical Balmer limit, 3646 Å. For SS Cyg the star is nearly like a white dwarf and all the phenomena that occur between 3700 and 3646Å for HD 217050, appear between 3760 and 3700Å in SS Cyg, shifted by more than 50Å towards the red.

This hypothesis by an absorbing shell around SS Cyg during this phase is also consistent with the high value of the ultraviolet colour temperature, nearly equal to the blue one, instead of being much lower as in the case of an ordinary star with $D = 0.30$.

Note added in proof. New observations of SS Cyg made in 1967 (to be published in „Astrofizika“) confirm the results discribed in the present paper, including the results obtained for the first time at minimum light of SS Cyg (spectrophotometric gradients and Balmer jump). They show, thus, that the magnitude of the Balmer discontinuity of SS Cyg (-0.56) determined by M.-C. Zuckermann [6] on decreasing branch of light ($m \cong 10.5$) is not correct: even at minimum it is much smaller (about -0.40).

One of the authors (L. V. M.) wishes to thank Professor Ch. Fehrenbach for the opportunity of making observations with the 193 *cm* telescope and for working in the Haute-Provence Observatory, Professor A. Lallemand for the permission to use the facilities of the Institut d'Astrophysique and the Staffs of their Institutions for the hospitality and assistance during his work in France.

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СПЕКТРОФОТОМЕТРИЧЕСКОЕ ИЗУЧЕНИЕ НЕСТАЦИОНАРНЫХ ЗВЕЗД
I. ОДНА ВСПЫШКА SS ЛЕБЕДЯ

Д. ШАЛОНЖ, Л. ДИВАН, Л. В. МИРЗОЯН

Выполнено спектрофотометрическое исследование SS Лебедя в период одной ее вспышки. Наблюдения были проведены в кассегреновском фокусе 193 *см* телескопа Обсерватории Верхнего Прованса (Франция) со спектрографом Шалонжа в октябре 1966 г. Дано описание использованного спектрофотометрического метода. Определены распределение энергии в непрерывном спектре относительно излучения абсолютно черного тела с температурой 5200 °К, спектрофотометрические градиенты в областях $\lambda\lambda$ 3150—3700 и $\lambda\lambda$ 4000—6200, а также величина бальмеровского скачка в минимуме и максимуме блеска и на восходящей ветви кривой блеска. Кратко обсуждены результаты, впервые полученные в настоящей работе (ультрафиолетовый спектрофотометрический градиент в минимуме блеска и аномально большой и сильно смещенный в сторону длинных волн бальмеровский скачок в период быстрого возрастания яркости звезды).

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