А С Т Р О Ф И З И К А

ТОМ 18 МАЙ, 1982 ВЫПУСК 2

УДК 524.338.5—355—13

SPECTROPHOTOMETRIC STUDIES OF NON-STABLE STARS. IV. ON THE SPECTRUM OF V1057 CYGNI*

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Received 3 March 1982

The results of a spectrophotometric study of V1057 Cyg based on the observations made in 1971—1973 with the Chalonge spectrograph are presented. It is shown, that after the "brightening" of V1057 Cyg an absorbing shell was present around it which brought to increase of the magnitude of the Balmer jump and decrease of its wave-length (Fig. 3 and Table 3). The spectrophotometric parameters determined using 1971—1972 observations indicate the spectrum B6III—B8.5IV for the "inner star" and B8II—III—B9IV for the "whole star", according to the BCD-classification. For comparison the spectra of FU Ori obtained with the same spectrograph have been used. The presence of large number of absorption lines in the ultraviolet region of FU Ori spectrum excludes a possibility of the BCD-classification for it. This is the main difference between V1057 Cyg and FU Ori spectra in the ultraviolet region. Besides, the Balmer jump for FU Ori (Table 4) is considerably smaller than for V1057 Cyg (Table 3). The obtained results are considered as favouring the Ambartsumian's interpretation of the fuor phenomenon, according to which the "brightening" of the star is a consequence of the conversion of the energy of high-energy particles existing around it into an optical radiation within a shell ejected by the star during its "brightening".

1. *Introduction.* V1057 Cyg was the first fuor (the object showing the FU Ori type brightening [1]) which became known as having the T Tau type spectrum before its brightening. In 1957, more than 10 years before this brightening, during the compilation at the Lick Observatory of a list of H_{α}-emission objects in the spectrum of this star (known as LkH$_{\alpha}$ 190) the emission lines of HI, CaII and FeII have been found which are characteristic for the T Tau type spectrum [2].

The rapid evolution of V1057 Cyg which took place in 1969—70 has been discovered by Welin [3]. During about 250 days its brightness has increased by more than 5 mag. Thus, V1057 Cyg was the second object showing such unusual brightening after the brightening of the well known FU Ori in 1936 [4, 5].

* The observations have been performed at the Haute-Provence Observatory (CNRS), France.

During last years some new fuors and fuor-like objects have been found which proved the evolutionary significance of objects of such kind. From this point of view their physical properties and the suggested interpretations for the fuor phenomenon have been discussed by Herbig [6] and by one of the authors [7].

In this paper we describe some results of the spectral observations of V1057 Cyg made after its brightening.

2. *Observations*. The spectral observations of V1057 Cyg have been carried out at the Haute-Provence Observatory. The Chalonge spectrograph [8] attached at the Cassegrain focus of the 193-cm reflector has been used. The list of these observations of V1057 Cyg is given in Table 1.

Table 1

THE SPECTRAL OBSERVATIONS OF V1057 CYG

Sp. No.	Data	Exposure (min)	Emulsion (Kodak)
B451—8	Nov. 24, 1971	120	IaO
B452—10	Nov. 25, "	180	IaO
B452—6	Nov. 26, "	180	IaO
B480—25	Sept. 17, 1972	240	103aD
B481—6	Oct. 3, "	240	IaO
B482—25	Oct. 6, "	70	103aD
B520—28	Sept. 19, 1973	120	103aD

For comparison some spectra of FU Ori obtained with the same spectrograph have been used (Table 2). With the exception of one observation in 1972, all the observations of FU Ori were obtained before the brightening of V1057 Cyg. V1057 Cyg and FU Ori were compared with the standard star HD 73 ($D = 0.109$, $\Phi_b = 0.87$, $\Phi_{UV} = 0.72$) [9]. Only one spectrum of FU Ori, taken in 1966, was compared with another standard (HD 14633).

Table 2

THE SPECTRAL OBSERVATIONS OF FU ORI

Sp. No.	Data	Exposure (min)	Emulsion (Kodak)
6804—28	Oct. 31, 1966	30	103aD
6910—8	Nov. 19, 1968	120	IaO
6911—32	Nov. 21, "	180	103aD
6913—5	Nov. 26, "	120	103aD
B481—7	Oct. 1, 1972	60	IaO

In addition the following coude spectrograms (dispersion 20 A/mm) of V1057 Cyg and FU Ori have been obtained with the 152-cm telescope:

V1057 Cyg — Nov. 26, 1971 (Plate No. 866, Exposure — 224 min, Kodak IIaO backed),

FU Ori — Nov. 30, 1971 Plate No. 867, Exposure — 170 min, Kodak IIaO backed).

The low dispersion spectrograms (220 A/mm at H_γ) used cover the spectral region 3100—5000 A and the coude spectrograms — the region 3700—5000 A.

3. *The line spectrum.* The coude spectrogram of V1057 Cyg shows only absorption lines (Fig. 1) the most prominent of which are the Balmer lines and the H and K lines of CaII. The Balmer lines are seen up to approximately H16. These lines have nonsymmetric profiles presenting a narrow absorption component on their red side. The general appearance of the line spectrum of V1057 Cyg leads to classify it as about A3.

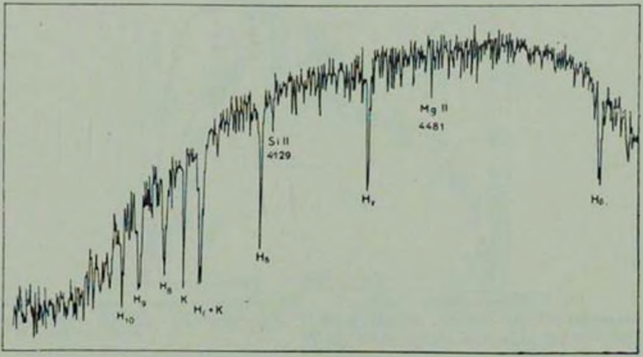

Fig. 1. Microphotometric tracing of the coude spectrogram of V1057 Cyg, obtained in Nov. 26, 1971 with the 152-cm reflector.

A comparison of this spectrum with the line spectrum of FU Ori shows that the Balmer lines of V1057 Cyg are considerably wider and more diffuse than in the case of FU Ori. At the same time one can suspect that the K-line of CaII in the spectrum of V1057 Cyg has a weak longward emission component which is not so conspicuous as it is in the spectrum of FU Ori.

There is an impression also that the Balmer lines and the H and K lines of CaII are shortward shifted. This shift is probably related to an expanding shell, as has already been mentioned by Gahm and Welin [10].

The line λ 4481 of Mg II is relatively strong, as well as the line λ 4129, which is probably the superposition of two Si II lines: λ 4128 and λ 4130. These last remarks are important since the mentioned lines of Mg II and SiII are generally faint in shell stars [11], but in the case of V1057 Cyg one can suspect the existence of an absorbing shell around it.

4. *The continuum. Probable existence of an absorbing shell.* The study of the continuum in the spectrum of V1057 Cyg using the low dispersion spectrograms gives some evidence in favour of the existence of an absorbing shell around this star.

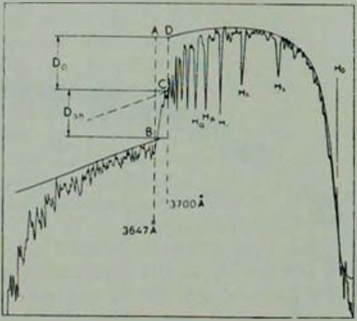

Fig. 2. Microphotometric tracing of a low dispersion spectrogram of the shell star HD 217050. (D is the Balmer jump D_0 of the inner star and AB — the Balmer jump of the whole star (inner star + shell).

To illustrate this we present in Fig. 2 the microphotometric tracing of a spectrogram of the known shell star HD 217050 taken with the Chalonge spectrograph. It is well seen on this tracing that after the last visible Balmer lines there is a sort of break at C with a change of slope. This point C may be considered as the beginning of the ultraviolet continuum (dotted line) that would be observed in the absence of the shell. So CD would represent the Balmer jump D_0 of the inner star (Fig. 2), AB being in both cases the Balmer jump of the whole star (inner star + shell). Other examples of this phenomenon have yet been given (see, for example, [12]).

The registrogram of one of our low dispersion spectra of V1057 Cyg (Fig. 3) shows that the situation is approximately the same in

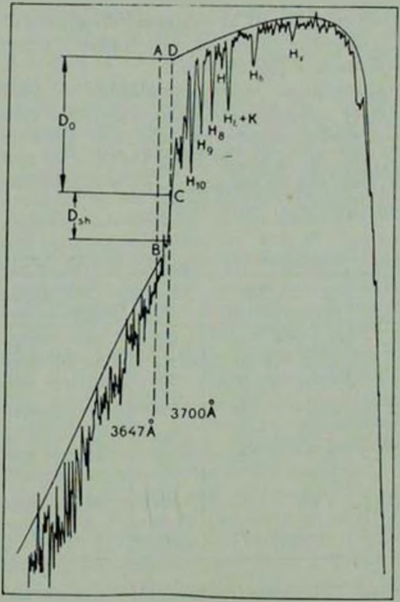

Fig. 3. Microphotometric tracing of one of the low dispersion spectrograms of V1057 Cyg obtained in Nov. 25, 1971. The appearance of the tracing is very similar to that of the known shell star HD 217050 (Fig. 2), which makes probable the existance of a shell around V1057 Cyg. With this assumption Balmer jumps of the inner star $D_0 = DC$ and of the shell D_{sh} are indicated. The observed Balmer jump of the whole star $D = AB = D_0 + D_{sh}$.

the case of this fuor: the observed Balmer jump AB of V1057 Cyg is too large compared with the depth of the Balmer lines. As we saw (Fig. 2), this appearance is characteristic of stars having an absorbing shell.

Thus, from the appearance of the spectrum of V1057 Cyg (Fig. 3) one can assume that in this case also there exists an absorbing shell around the star.

In this connection it is necessary to notice that the inner part of this shell represents now the new photosphere of V1057 Cyg and in fact it is responsible for the brightening of the star. Only the outer part of this shell is observed in the spectrum of V1057 Cyg as an absorbing shell. Therefore when we say further "inner star" we mean V1057 Gyg with its new photosphere.

With this assumption the spectrophotometric parameters of the "inner star" can be computed and Table 3 gives the values so obtained. The spectrophotometric parameters have also been computed for the "whole star" (Table 3), λ_1 and D being the position and the magnitude of the Balmer jump and Φ_b and Φ_{UV} — the spectrophotometric gradients in the blue and ultraviolet, respectively.

Table 3

SPECTROPHOTOMETRIC PARAMETERS OF V1057 CYG

Data	Inner star		Whole star			
	D_0	λ_1-3700	D	λ_1-3700	Φ_b	Φ_{UV}
Nov. 24, 1971	0.258	32	0.300	28	3.47	3.09
Nov. 25, „	0.240	35	0.300	28	3.58	2.99
Nov. 26, „	0.294	36	0.338	31	3.40	2.92
Mean 1971	0.264	34	0.313	29	3.48	3.00
Sept. 17, 1972	0.390	52	0.453	48	3.44	2.97
Oct. 3, „	0.423	54	0.448	52	3.07	3.60
Oct. 6, „	—	—	—	—	3.40	—
Mean 1972	0.407	53	0.451	50	3.30	3.29
Sept. 19, 1973	—	—	—	—	3.95	—

The spectral BCD classification [13] corresponding to the values D and λ_1 given in Table 3 is:

B6III for the inner star and
B8II-III for the whole star, in 1971

and

B8.5IV for the inner star and
B9IV for the whole star, in 1972.

The data of Table 3 show the cooling of V1057 Cyg which is better seen when one considers the Balmer jump D and less definitively the ultraviolet spectrophotometric gradient Φ_{UV} for the "whole star".

Because of the faintness of V1057 Cyg in the ultraviolet region of our single spectrogram obtained in 1973 (Sept. 19) the BCD-classification was impossible in this case. Nevertheless the spectrophotometric gradient Φ_b in this case probably indicates a further cooling of V1057 Cyg.

Thus, the BCD-classification of V1057 Cyg shows that its spectrum was of the B6—B8 type in 1971 and B8—B9 type in 1972. Therefore, the H and K lines of CaII and large number of faint metallic lines must be attributed to the shell.

From this discussion we may conclude that in November 1971, and probably in September-October, 1972, V1057 Cyg had an absorbing shell the Mg II and SiII lines belonging to the star and not to the shell.

It is necessary to mention here that the spectral classes of V1057 Cyg corresponding to the BCD-classification are considerably earlier than the classes determined from the absorption lines. For example, on the coude spectrograms obtained with the 3-m reflector of the Lick Observatory in March and April, 1971 the spectrum of V1057 Cyg was near A1 [14]. As it has been pointed out by Herbig and Harlan [14] the spectrum of V1057 Cyg is a peculiar one: the spectral classes determined in shortward region (3900—4300A) were systematically earlier, than those obtained in more longward region (6000—6600A). Moreover, Gahm and Welin [10] have mentioned that the spectral class of V1057 Cyg determined by the Balmer lines and the K line of Ca II is much earlier than that obtained by the metallic lines, that is the spectral class was different when different criteria were used.

The most important observational fact mentioned earlier by many observers (see, for example, [10]) and confirmed by the above-presented data is the fundamental change of the spectrum of V1057 Cyg during its brightening in 1969—1970, from T Tau type to the earlier types.

The existence of an external shell around V1057 Cyg producing the absorption lines and the additional Balmer jump is also very important from the point of view of the interpretation of the fuor phenomenon. It can be assumed that the appearance of this shell is a result of the ejection of the stellar matter during the brightening of V1057 Cyg.

5. *Comparison with FU Ori.* Some of the differences between the spectra of two fuors V1057 Cyg and FU Ori obtained from their coude spectrograms have been mentioned already. We give here a comparison of these spectra using the low dispersion spectrograms taken with the Chalonge spectrograph.

The spectrophotometric parameters of FU Ori obtained from the low dispersion spectrograms listed in Table 2 are given in Table 4. The parameter λ_1 can not be defined for FU Ori and no BCD-classification of its spectrum can be done because of the faintness of the Balmer jump and the presence of strong metallic lines. No absorbing shell in the Balmer continuum can be seen on the low dispersion spectrograms of FU Ori.

Table 4

THE SPECTROPHOTOMETRIC PARAMETERS OF FU ORI

Date	D	Φ_b	Φ_{UV}
Oct. 31, 1966	0.057	3.90	2.09
Nov. 19, 1968	0.019	4.59	2.87
Nov. 21, „	0.091	4.39	2.95
Nov. 26, „	0.059	4.24	—
Mean 1968	0.054	4.41	2.91
Oct. 1, 1972	0.072	4.17	2.41

The main difference between the spectrophotometric parameters of two fuors is in the magnitude of the observed Balmer jump D. For FU Ori during our observations (October, 1966 — October, 1972) D was always less than 0.1, whereas for V1057 Cyg, even if one takes only the Balmer jump D_0 of the inner star (without the shell) it is in all cases larger than 0.2.

At last, it can be noted that during all observations of FU Ori (Table 4), during six years, no essential changes of its spectrophotometric parameters are seen. At the same time the spectrophotometric parameters of V1057 Cyg even during two years have changed considerably and indicate a rapid cooling of its radiation (Table 3).

The comparison of the low dispersion spectrograms of two fuors: V1057 Cyg and FU Ori, presented in Fig. 4, shows considerable difference between them, especially in the shortward region, after the Balmer jump. The more detailed study of the differences between the spectra of these two fuors is in fact impossible with the low dispersion spectrograms.

Thus, in spite of the common physical nature of these two fuors there are some essential differences in their spectroscopic properties.

6. *Discussion*. The observational fact that the fuor V1057 Cyg was a T Tau type star before its brightening excluded the possibility to in-

terprete the fuor phenomenon (the unusual brightening of this star), as the result of the rapid collapse bringing to the origin of a very young star — an explanation which has been suggested by Herbig [5] for the brightening of FU Ori.

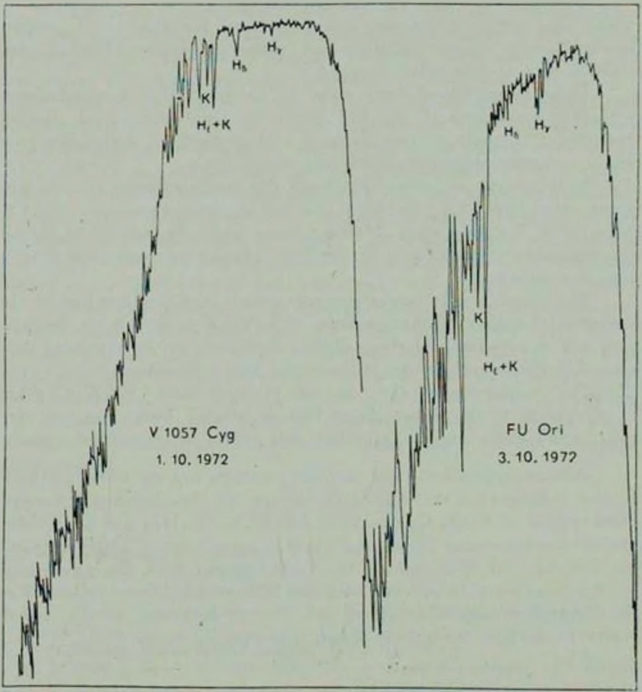

Fig. 4. A comparison between the microphotometric tracings of two fuors: V1057 Cyg and FU Ori, which shows the considerable differences between them especially in the ultraviolet region of the spectrum.

The discovery and study of new fuors and fuor-like objects confirmed the close evolutionary connection between them and the T Tau type stars [6, 7]. It became very probable that the fuor phenomenon occurs as a rule in the T Tau type stars and related objects. In agreement with this point of view the study of flare stars in stellar aggregates showed that there exist some similarities between the fuor phenomenon and "slow" flares (according to Haro's classification of stellar flares [15]) [1, 7].

On the other hand, the fundamental change of the spectrum of V1057 Cyg during brightening is an intrinsic one due to the corresponding change of star radiation and cannot be explained by the dissipation of a circumstellar cloud.

These observational facts seem to be in a satisfactory agreement with Ambartsumian's [1, 16] hypothesis on the liberation of discrete portions of the energy from the pieces of protostellar superdence matter in or under photospheres of very young stars.

In the frame of this hypothesis the pre-brightening T Tau type spectrum of V1057 Cyg and some common physical properties of FU Ori with the T Tau type stars [16] have been used by him [1] to discuss the evolutionary significance of the fuor phenomenon and to suggest a simple explanation of it.

The main results of the present paper: the confirmation of the fundamental change of the spectrum of V1057 Cyg during its brightening and the evidence of the probable existence of an absorbing shell around it can be considered in favour of this explanation.

The comparison of the spectra of two fuors: V1057 Cyg and FU Ori made in this paper shows that in spite of their common physical nature there are also essential differences between these spectra.

Acknowledgements. The authors wish to express their gratitude to Dr. J. Berger for the assistance during the low dispersion spectral observations of V1057 Cyg in 1971 and Dr. C. T. Hua and Dr. C. Bardin for the assistance during the coude observations of V1057 Cyg and FU Ori. One of the authors (L. V. M.) thanks Prof. Ch. Fehrenbach for the possibility to observe with the 193-cm and 152-cm reflectors of the Haute-Provence Observatory and Dr. J. Audouze for the opportunity to work at the Institut d'Astrophysique de Paris.

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СПЕКТРОФОТОМЕТРИЧЕСКОЕ ИЗУЧЕНИЕ НЕСТАЦИОНАРНЫХ ЗВЕЗД. IV. О СПЕКТРЕ V1057 ЛЕБЕДЯ

Д. ШАЛОНЖ, Л. ДИВАН, Л. В. МИРЗОЯН

Представлены результаты спектрофотометрического исследования V1057 Лебедя, основанного на наблюдениях, выполненных в 1971—73 гг. со спектрографом Шалонжа. Показано, что после возгорания V1057 Лебедя вокруг звезды наблюдалась абсорбционная оболочка, что привело к возрастанию бальмеровского скачка и уменьшению соответствующей ему длины волны (рис. 3 и табл. 3). Определенные по наблюдениям 1971—1972 гг. спектрофотометрические параметры (табл. 3) указывают на спектр B6III—B8.5IV для «внутренней» звезды и B8II-III—B9IV для «всей» звезды, по классификации в системе BCD. Для сравнения использованы спектры FU Ориона, полученные тем же спектрографом в 1966—72 гг. Наличие большого числа линий поглощения в ультрафиолетовой области спектра FU Ориона исключает возможность его BCD-классификации. В этом заключается основное различие между спектрами V1057 Лебедя и FU Ориона, в ультрафиолетовой области. Кроме того величина бальмеровского скачка у FU Ориона (табл. 4) значительно меньше, чем у V1057 Лебедя (табл. 3). Полученные результаты рассматриваются в пользу предложенной В. А. Амбарцумяном интерпретации явления фуора, которая предполагает, что «возгорание» звезды является следствием конверсии в оптическое излучение энергии высокоэнергетических частиц, существующих около нее в газовой оболочке, выброшенной звездой в период «возгорания».

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