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SPECTROPHOTOMETRIC STUDIES OF NONSTABLE STARS III. THE SPECTRUM OF FG SAGITTAE IN 1968—1973*

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The results of a spectrophotometric study of FG Sagittae based on the observations made in 1968—1973 and covering the region 3100—6100A are presented. In this period the spectrum of FG Sagittae changed continuously and according to the BCD-classification transformed from A3Ib type to F7Ia (Table 2). Its variation was especially sharp between June and September 1970.

Introduction. Among the known non stable stars, FG Sge represents an exceptional case. It is the only object which has shown a regular increase of brightness for more than seventy years, the luminosity being now about fifty times larger than at the beginning of the century. In the spectrum of this peculiar variable, spectral lines having the P Cygni profile have been observed by G. H. Herbig and A. A. Boyarchuk [1] suggesting the existence of an expanding envelope around this star. According to the same authors the gaseous envelope surrounding the star has been ejected about 3000 years ago. These facts bring them to the important conclusion that FG Sge is the nucleus of a planetary nebula just beginning the ejection of a second envelope.

The spectrum of FG Sge has been described by K. G. Henize [2], G. Richter [3]. Ch. Bertaud [4], G. H. Herbig and A. A. Boyarchuk [1]. The spectrum displayed a "never seen" type of variation, passing regularly through all the spectral classes between B4I by Henize [2] and the present G spectrum by V. P. Arhipova [5] and J. Smolinski, J. L. Climenhaga and T. Kipper [6].

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

A large number of photoelectric observations of FG Sge have been done by various authors and particularly by W. Wenzel and W. Fürtig [7—9], and V. P. Arhipova [5, 10]. These data show, in particular, that the brightness of the star is no longer increasing in observed part of the spectrum; the decrease started for the U, B and V magnitudes respectively around 1960, 1968 and 1975.

Finally, another unique and very important feature in the evolution of this star has been recently discovered by G. E. Langer, R. Kraft and K. Anderson [11]; a strong increase of abundances for elements corresponding to the „s-process" that occured between 1965 and 1971*. The star also displays more common features, such as erratic fluctuations with a time scale of days etc. (see, for example, [13]).

Tentative explanations of the FG Sge phenomenon are based on two main pictures of this object;

1) an optically thick shell expanding around a presently invisible very hot central star [1] or

2) a very brief evolutionary stage of a real star [11, 14, 15].

Many calculations have been done; they are based on the values of fundamental parameters such as interstellar reddening, distance, absolute magnitude, effective temperature, gravity etc. and these values are uncertain because the only way to get them is to force FG Sge into the spectral classifications of normal objects. Whether this is justified or not depends on the consistency of the spectral types given by different criteria and this is why we undertook a spectrophotometric study of FG Sge.

Observation. The observations have been done at the Haute-Provence Observatory between November 1968 and September 1973, using the Chalonge spectrograph [16] attached at the Cassegrain focus of the 193-*cm* reflector. The 14th magnitude companion of FG Sge has always been kept out of the slit of the spectograph and the influence of the surrounding nebula is negligible. The mean resolution of the spectra is 10 A and the measurements cover the spectral range 3100—6100 A. The dispersion of the Chalonge spectrograph is 470 A/*mm* at 6000 A, 220 A/*mm* at 4340 A and 83 A/*mm* at 3200 A.

Table 1 gives the data concerning various spectrograms used in the present work. The comparison star has always been HD 73 except for the first spectrum where it was 69 Cyg.

* According to J. S. Tenn and E. M. Barsman [12] strong absorption lines of s-process continued to grow stronger from 1972 to 1973 and remained about the same from 1973 to 1974.

Table 1

THE SPECTRAL OBSERVATIONS FG Sge .

No.	Spectrum No.	Data	Exposure (*min*)	Emulsion (Kodak)
1	6911—10	19.11.68	70	103aD
2	6911—28	21.11.68	70	"
3	6913—8	26.11.68	70	"
4	6964—28	26.10.69	135	"
5	6964—25	28.10.69	60	"
6	B378—31	10.06.70	135	IaO
7	B379—6	28.06.70	150	"
8	6980—10	3.09.74	90	103aD
9	6984—6	6.09.70	80	"
10	6984—28	7.09.70	90	"
11	6988—10	11.09.70	90	IaO
12	7020—26	27.09.71	90	"
13	7022—10	28.09.71	90	103aD
14	7022—24	29.09.71	120	"
15	7022—28	30.09.71	90	"
16	B480—10	26.09.72	150	"
17	B481—26	6.10.72	120	IaO
18	B522—32	29.09.73	80	103aD

From the beginning of the observations until about 1971, the continuum was reasonably well defined between the main absorption lines; the obtained spectral energy distributions deviated somewhat from that of a blackbody as in ordinary stars and we did not meet any special difficulty in deriving color temperature and Balmer discontinuities.

Table 2 gives the values of some of the parameters derived from the energy distribution in the continuum [17],

Φ_b : spectrophotometric gradient for the 4500—4000 A spectral range (column 2);

D : Balmer discontinuty (column 3);

λ_1 : mean position of this discontinuity (column 4);

n : number of determinations (column 5).

Fig. 1 shows the variations of D and Φ_b as a function of time, Fig. 2 the "travel" of FG Sge across the λ_1D-diagram on which the curves of equal MK spectral type and luminosity class are shown [19]. Fig. 3 and 4 give the tracing corresponding to eight spectra.

Table 2

PARAMETERS OF THE SPECTRUM OF FG Sge

Data	Φ_b	D	$\lambda_1 - 3700$	n	BCD	Spectral type: Arhipova [10]	Spectral type: Langer et al. [11]	Φ_{ub}	E (Φ_b)	E (B — V) = 0.64E (Φ_b)
Oct. 1966 (14—18)*	1.79	0.480	06:		A3—4 Ia:					
Nov. 1968 (19—26)	1.95	0.534	12	3	A3 Ib			1.17	0.78	0.50
Oct. 1969 (26—28)	2.29	0.523	13	2	F2 Ia	F5—6 (G band) F0 (K line)	F1	1.89	0.40	0.26
June 1970 (10)	2.27	0.494	15	1	F3 Ia		F2	1.95	0.31	0.20
June 1970 (28)	2.85	0.424	06	1	F5 Ia		F2	2.12	0.73	0.47
Sept. 1970 (3—11)	3.21	0.362	01	4	F6 Ia	F6—8	F2	2.20	1.01	0.65
Sept. 1971 (27—30)	3.07	0.325	08	4	F7 Ia	G0 (G band)	F4	2.35	0.72	0.46
Sept. Oct. 1972	4.28	0.10:		2			F5—6			
Sept. 1973 (28)	4.93	0.10:		1						

* Measurements by T. P. Roark [18].

The BCD spectral type [20] deduced from the positions of FG Sge on Fig. 2 are listed in Table 1 (column 6). For comparison, [the spectral types from other authors are also given (column 7 and 8). On Fig. 2 the curves of equal MK spectral type are also curves of approximately equal intrinsic color temperature (i. e. for "unreddened" stars), and the corresponding value of the intrinsic gradient Φ_{ob} is indicated on each of them. Thus for each position of FG Sge in the diagram the Φ_{ob} can be obtained by interpolation, and its values are listed (column 9). The excess in blue gradient $E)\Phi_b) = \Phi_b - \Phi_{ob}$ is also given (column 10) and transformed (column 11), for comparison with other determinations, in $E(B-V)$ by the empirical formula $E(B-V) = 0.64\, E(\Phi_b)$. It must be kept in mind that this $E(B-V)$ reflects mainly the reddening of the continuum and is not directly comparable to the observed photometric $E(B-V)$ when strong lines are present in the spectrum.

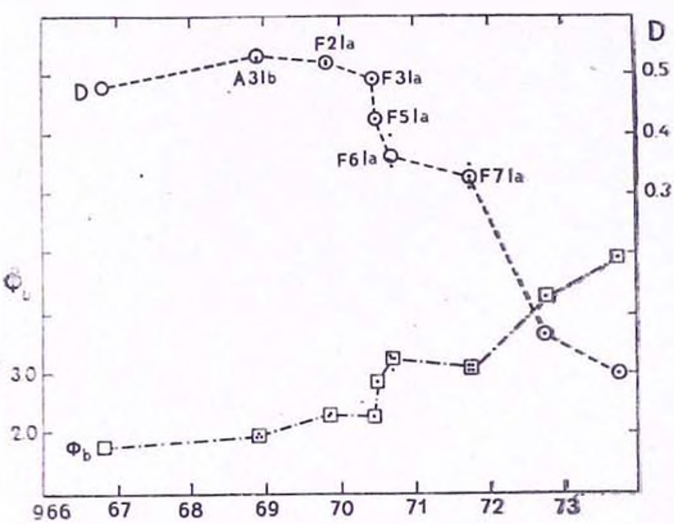

Fig. 1. D and Φ_b as a function of time. The corresponding BCD spectral types are indicated. The 1966 values are from Roark, 1968. Small black dots: individual measurements.

After 1971 the precise location of the continuum on the microphotometric trancings became more difficult because of the presence of many absorption lines. The hydrogen lines became very weak, the correspondingly small Balmer jump was not well defined and no significant value could be obtained for λ_1. Moreover, the energy distribution in the continuum differs from that of the blackbody even when small spectral intervals are considered, and Φ_b is a mean value for 4500—4000 A.

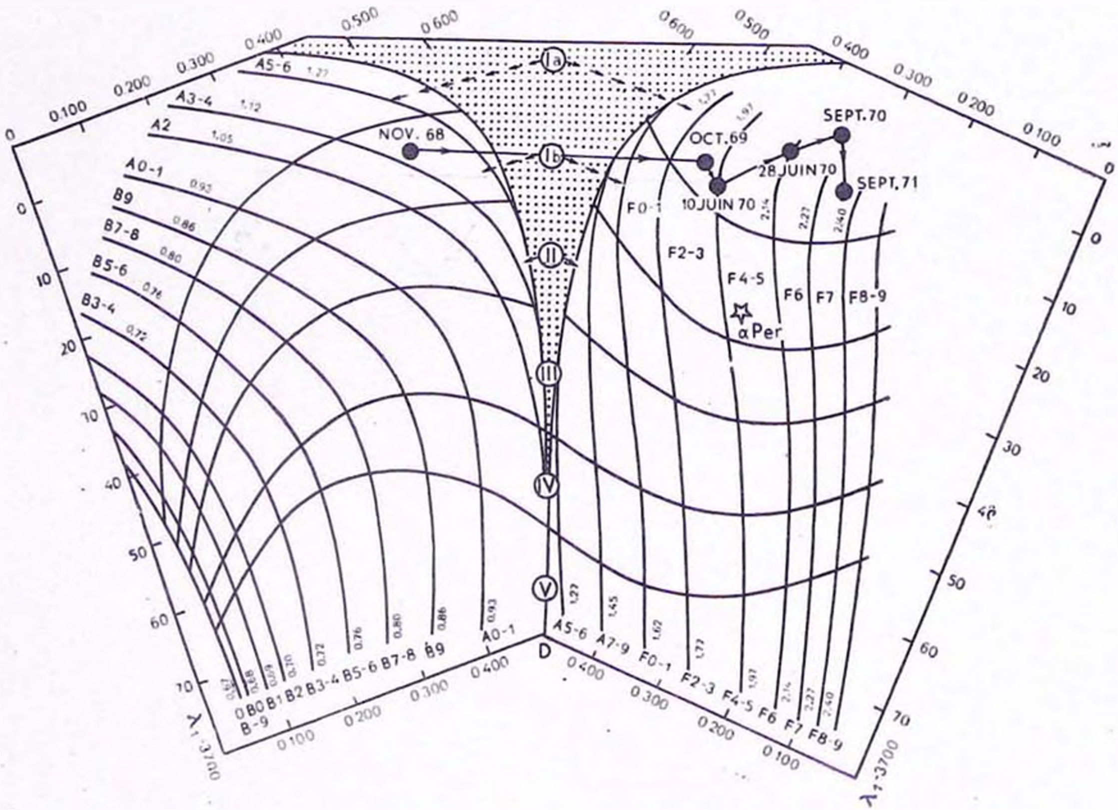

Fig. 2. Successive position of FG Sge in the λ_1D-diagram from November 1968 to September 1971. For comparison, the position of α Per is indicated. Note the very rapid change of the star between June and September 1970.

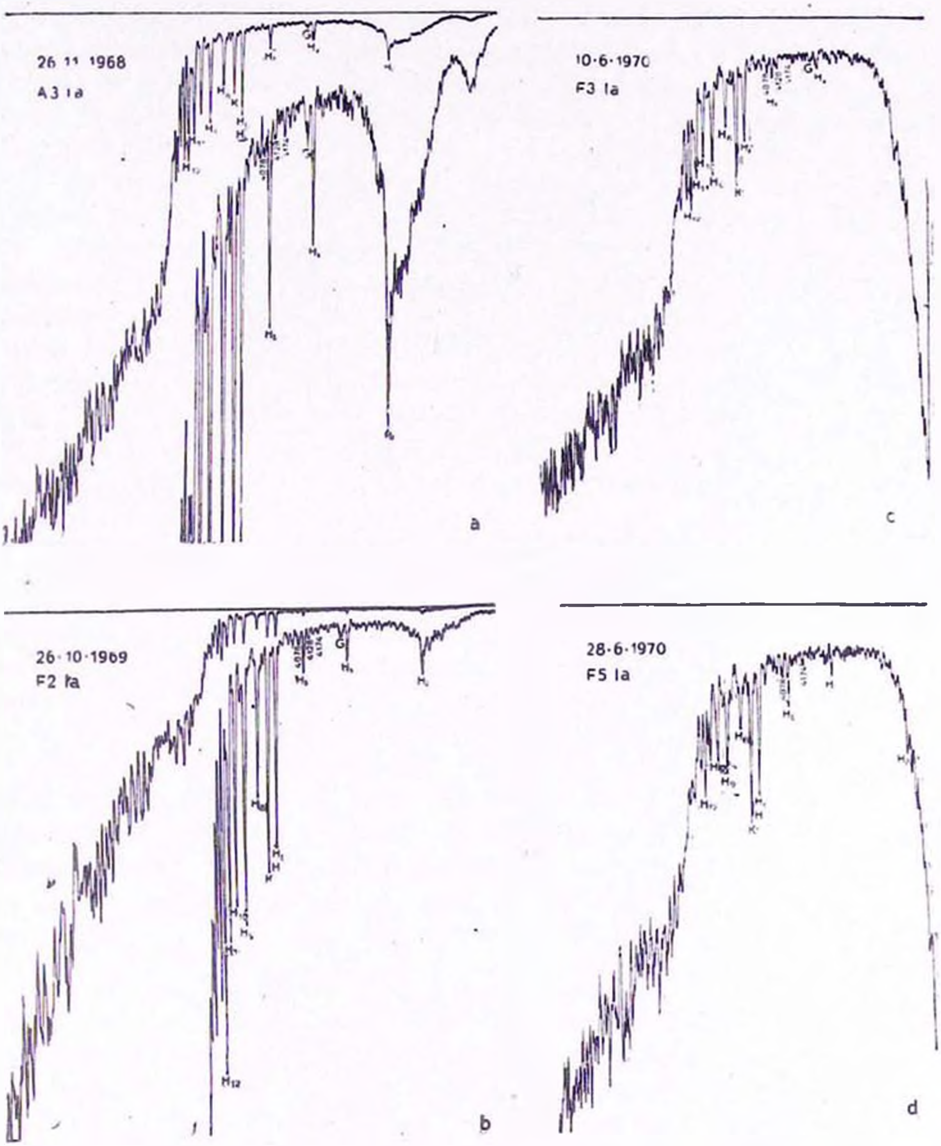

Fig. 3. Microphotometer tracings of FG Sge spectra corresponding to the dates indicated on each of them. The two curves on figures a, b are tracings of the same spectrum with different sensitivities of the the microphotometer.

Note the strong increase of the high luminosity indicators λλ 4078, 4128, 4174 between June and September 1970 (see text).

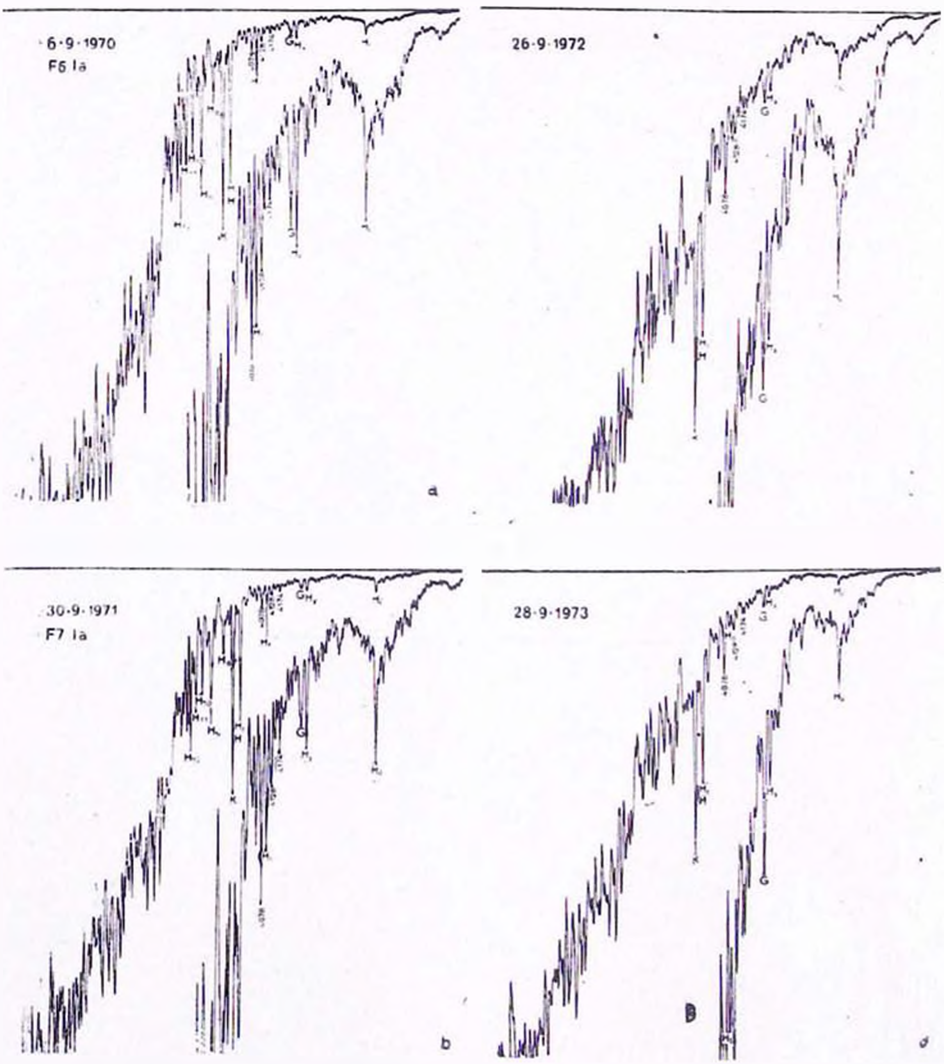

Fig. 4. Microphotometer tracings of FG Sge spectra. The marks are the same as for Fig. 3.

Results.

a) *Spectral classification.* Assumptions on effective temperature and gravity are necessary to build models of FG Sge and these quantities are generally derived from a „spectral type". But since the beginning of the spectroscopic observations, FG Sge has never completely mimicked the spectrum of a normal star. For instance, the spectral type derived from the G band is always later than that given by the K line. Table 1 shows that in 1969, according to V. P. Arhipova [10], the G band type was F5—F6 and the K type F0. This phenomenon is clearly visible on all our spectra between 1969 and 1972. Langer et al. [11] used other criteria to obtain spectral types, and the types finally adopted to derive the abundances in FG Sge are listed in Table 2.

All these spectral types differ significantly and no clear indication is given on the luminosity class. As the BCD-classification is based on quantitative parameters depending mostly on the physical conditions of hydrogen in the photosphere, it may give spectral types relatively reliable to derive effective temperatures and gravities. Table 2 (column 5) gives the BCD-types, deduced from the position of FG Sge on Fig. 2. They are later than those adopted by Langer et al. [11], later also than the K line type, but earlier than the G band one. The luminosity class Ib in 1968 became Ia in 1969, and Fig. 2 shows that FG Sge is very far in luminosity class from the supergiant α Per to which it is often compared.

b) *Interstellar reddening.* Table 2 shows that, between 1968 and 1971, the excess in blue gradient has been changing with time by an amount apparently too large to be attributed either to observing uncertainties (to test the measurement's self-consistency, Fig. 1 gives the individual values for D and Φ_b; the uncertainty on one measure of λ_1 is approximately 4A) or to the influence of line blanketing. This means that the interstellar interpretation of FG Sge's color excess prior to 1965 is questionable; part of this excess could be intransic (i. e., due to the stellar constitution), the true interstellar absorption being different (smaller or even perhaps larger) from what has been assumed to derive important parameters such as distance, absolute magnitude, intrinsic colors etc.

c) *Did something happen between June and September 1970?* Fig. 1 and 2 show that, apart from the general trend towards later spectral types, FG Sge has undergone a very rapid change in spectral type, luminosity class and color between June and September 1970. Although the two measurements of June have a smaller weight, the occurence of a change seems to be real. It was accompanied by a change in the general aspect of the spectrum in which the hydrogen lines decreased while the G band and K line became more prominent at the same time, high luminosity indicators such as the blends $\lambda\lambda$ 4078, 4128 and 4174 A strongly increased (see Figures 3c, 3d and 4a), in agreement with the large variation of λ_1 which shifted FG Sge in the λ_1D diagram (see Fig. 2), from a point near the limit between Ia and Ib, to regions very far towards higher luminosities.

Whether this change has been unique since the beginning of the spectroscopic observations is not known. Photometric observations made by W. Wenzel and W. Fürtig [8, 9], V. P. Arhipova [5, 10] and others [13, 21] show that the star is variable on a time scale of days, but simultaneous spectroscopic, spectrophotometric and photometric observations are lacking.

However it is interesting to note that the 1970 spectral evolution of FG Sge could be related to the changes in surface abundances observed by Langer et al. [11]: I. J. Christy-Sackmann and K. H. Despain [14] calculated the enrichment rate per year for the „s-process" elements Zr, La, Ce, and found that it reached a very pronounced maximum between 1969 and 1970. This suggests that the maximum enrichment rate of FG Sge could be closely connected to the rapid spectral changes observed by us in June and September 1970.

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СПЕКТРОФОТОМЕТРИЧЕСКОЕ ИЗУЧЕНИЕ НЕСТАЦИОНАРНЫХ ЗВЕЗД
III. СПЕКТР FG СТРЕЛЫ В 1968—73 ГГ.

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Представлены результаты спектрофотометрического изучения FG Стрелы, основанного на наблюдениях, выполненных в 1968—73 гг. и покрывающих область 3100—6100 A. В этот период спектр FG Стрелы изменялся непрерывно и по BCD-классификации преобразовался от спектрального типа A31b до F71a (табл. 2). Его изменение было особенно резким между июнем и сентябрем 1970 г.

REFERANCE

1. *G. H. Herbig, A. A. Boyarchuk*, Ap. J., 153, 397, 1968.
2. *K. Henize*, P. A. S. P., 73, 159, 1961.
3. *G. Richter*, Astr. Nachr., 285, 274, 1960.
4. *Ch. Bertaud*, J. des Obs., 44, 81, 1961.
5. *V. P. Arhipova*, Perem. Zvezdy, 20, 143, 1975.
6. *J. Smolinski, J. L. Climenhaga, T. Kipper*, P. A. S. P., 88, 67, 1976.
7. *W. Wenzel, W. Fürtig*, Die Sterne, 43, 19, 1967.
8. *W. Wenzel, W. Fürtig*, Mitteil. Verand. Sterne, 5, 165, 1971.
9. *W. Wenzel, W. Fürtig*, Mitteil. Verand. Sterne, 6, 18, 1972.
10. *V. P. Arhipova*, Perem. Zvezdy, 18, 183, 1971.
11. *G. E. Langer, R. Kraft, K. Anderson*, Ap. J., 189, 509, 1974.
12. *J. S. Tenn, E. M. Barsman*, Bull. A. A. S., 7, 432, 1975.
13. *J. Papousek*, Contr. Astr. Inst. Univ. Brno, 2, No. 18, 1972.
14. *I. J. Christy-Sackmann, K. H. Despain*, Ap. J., 189, 523, 1974.
15. *R. K. Ulrich*, Ap. J., 192, 507, 1974.
16. *A. Baillet, D. Chalonge, L. Divan*, Nouv. Rev. Optique, 4, 151, 1973.
17. *D. Chalonge, L. Divan*, Ann. Astrophys., 15, 201, 1952.
18. *T. P. Roark*, P. A. S. P., 80, 712, 1968.
19. *D. Chalonge, L. Divan*, Astron. Astrophys., 23, 69, 1973.
20. *D. Chalonge*, Rich. Astron., 5, 345, 1958.
21. *J. D. Fernie*, Ap. J., 200, 392, 1975.