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A NEW ''SLOW'' FLARE STAR IN ORION

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RESUMEN

Se definen las características fotométricas y espectroscópicas de las estrellas Ráfaga "lentas" y "rápidas" y se presenta un nuevo caso de Ráfaga "lenta" en Orión, con un incremento en su radiación ultravioleta de $\geqslant$8.4 magnitudes, durante un lapso de 118 minutos. Las peculiares características físicas observadas en los dos tipos de estrellas Ráfaga, se interpretan como resultante de diferentes niveles de profundidad estelar en donde la explosión que da origen al cambio de brillo integrado, tiene lugar. Se concluye, asimismo, que las estrellas Ráfaga "lentas" sólo ocurren en agregados estelares muy jóvenes, en donde aún existen estrellas de tipo T-Tauri, aportando un nuevo dato observacional en el estudio de la evolución de los grupos estelares.

I. Introduction

In previous articles (Haro, 1964, 1968) we have emphasized — from the available spectroscopic and photometric data — that in the young Orion association there are two different outstanding types of flare stars: (a) the "fast" and (b) the "slow" ones.

In case (a) the magnitude rise from minimum to maximum is very rapid. In a matter of few minutes, or perhaps even seconds, the total light of a star is conspicuously enhanced. The photoelectric observations of the classical *UV* Ceti type stars in the solar vicinity or the observation by Johnson and Mitchell (1958) of the Pleiades flare star H_{II}1306, represent good extreme examples of the aforementioned. Our own photographic studies of flare stars in different associations and particularly in the Orion aggregate, although having very obvious limitations — mainly the time length of each exposure, 10^m to 15^m — permit us to conclude, by deriving the most probable and "conservative" rising part of the light curves, that a "fast" flare-up takes — from normal minimum to maximum — a time that is comprised between very few minutes up to a top possible extreme lapse of no more than 20 minutes (in the instance of the 10^m multiple exposure images) or 30 minutes if the unit of the exposure time is 15^m. In other words, a "fast" flare star will show its rising toward maximum in one or at most in two consecutive images in our large series of multiple exposure plates. This does not mean, of course, that the real rising time of the flare up would be necessarily equal to the length of the exposure time of one or two consecutive images. On the contrary, the maximum can be reached within very few minutes, either during one single exposure or in the interval between the last seconds or minutes of a given exposure and the first seconds or minutes of the succeeding one. We are sure that this is what really happens in the very large majority of the flare stars observed in Orion.

The "slow" flare stars, case (b), are the ones that show in our series of consecutive exposures 3 or more images of 10^m or 15^m each, growing towards maximum until it is reached. In this case, the *minimum* possible time of rising would be comprised within 20^m to 30^m or from 30^m to 45^m, depending on the exposure unit.

In order to be on the very safe and conservative side, let us — for convenience — define a "fast" flare star as the one that from normal minimum to maximum takes less than 30 minutes; a "slow" flare star is the one that takes more than 30 minutes in order to reach the maximum amplitude. Very few of the observed objects, and only in Orion, can be classified as "slow" flare stars.

Regarding the spectroscopic features, there are also outstanding differences among the "fast" a) and the "slow" b) flares:

a) During the outburst only the ultraviolet, blue and part of the yellow continuum are enhanced. The emission lines are extremely strong but the red continuum does not seem to be affected. In our Tonantzintla Schmidt camera objective prism plates the Hα emission line suddenly appears with great intensity or is strongly enhanced, but the nearby red continuum does not change appreciably; at the end of the flare, the Hα emission disappears in our low dispersion spectral plates.

b) In the two instances in which we have obtained simultaneous and consecutive observations — spectroscopic and direct exposures — of a "slow" flare star before, during and after the outburst (up to now only 5 "slow" flares are known in the Orion region), the spectral characteristics with our low dispersion in the red (6100 A to Hα) are the following: i) during the prolonged minima before the outburst no emission at Hα is observable; ii) during the rise to maximum the red continuum is significantly intensified and the Hα emission line is rather weak, and noticeably only after the maximum is reached; iii) after the minimum integrated light is

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again reached, the Hα emission line is faintly visible for one or two days although the red continuum goes back to its normal minimum intensity.

Good photographic reproductions of some of our spectral plates, which show the spectral red features of the "fast" and "slow" flare stars, are contained in Figures 1 and 7 of Haro and Terrazas' paper (1954) and in Fig. 1 of an article by Haro(1964).

II. The new "slow" flare star in Orion

According to the definition given before and accepting that a flare star can be classified as a "slow" one only when the time of rising from normal minimum to maximum is $>30^m$, we have found in our previous work only 4 examples of this type of variables and all of them in the Orion association. They are the Orion flare stars Nos. 66, 92, 149 and 153 (Haro, 1968). Three of these "slow" flares, Nos. 66, 149 and 153, have also shown the "fast" flare features. Probably, considerably more extensive observations would eventually permit to find this type of objects in NGC 2264 or in some other very young stellar aggregates. In the Pleiades field, notwithstanding the already large amount of collected material, not a single star has shown the "slow" flare characteristics.

The new multiple exposure plates obtained on the Orion region during the winter time 1965-1966, 1966-1967, 1967-1968 and in the first months of 1969 by E. Chavira, have enabled one of the authors (G.H.) to find a good number of new flare stars and to detect repeated flare-ups in the previously known. The corresponding general results will be published in a near future.

In the present paper we are dealing mainly with one "new" flare star of the "solw" type, which shows a large amplitude range of variation in the ultraviolet (103aD or 103aO Eastman Kodak plates behind an ultraviolet filter), and 3 more flare stars of the "fast" type in its immediate vicinity. The area in which these 4 flare stars are contained is 0.04. square degrees localized in an obscure section, 1.25 degrees southwest from the Trapezium. Everything seems to indicate that these 4 flare stars and the irregular variable SW Ori, localized in the same small area, belong to the complex Orion association.

TABLE 1

The Orion Available Photographic Material Inspected

Spectral Region	*Number of Plates*	*No. of Exposures*	*Total Obs. Time*	*Different Periods*
U	518	2210	583^h	1955-1969
B	318	786	174^h	1921-1962
V	149	212	29^h	1950-1962
R	183	353	140^h	1947-1967
I	94	420	108^h	1950-1961

TABLE 2

Orion Flare Stars Nos. 177, 178, 179 and 143

No	*Parenago No*	*R.A. (1900)*	*Dec. (1900)*	*U*	*B*	*V*	*I*	ΔmU	*Date of Flare*	*Ref**
177	1323	5^h29^m1	−6°40′3	19.7	18.2 – 18.5	16.7	15.0	8.4	1965 12/27	1,2,3
177	,,	,,	,,	,,	,,	,,	,,	3.6	1965 12/28	
177	,,	,,	,,	,,	,,	,,	,,	3.2	1967 2/13	
178		29.1	34.8	18.5	17.6	16.0	13.5	2.1	1965 1/30	
178		,,	,,	,,	,,	,,	,,	2.3	1968 1/3	
179		29.2	39.2	18.1	16.7 – 17.1	15.5	14.0	2.9	1968 1/2	
143	1502	5^h29^m6	−6°42′9	17.0	15.8	14.6	13.5	1.3	1965 1/9	3,4

* (1) Pickering (1904); (2) Hoffmeister (1923); (3) Parenago (1954); (4) Haro (1968).

All the available photographic material in our Tonantzintla Observatory plate file, summarized in Table 1, has been newly inspected. The principal results of this repeated examination are synthetized in Table 2, in which column one gives the Tonantzintla serial numbers for the flare stars

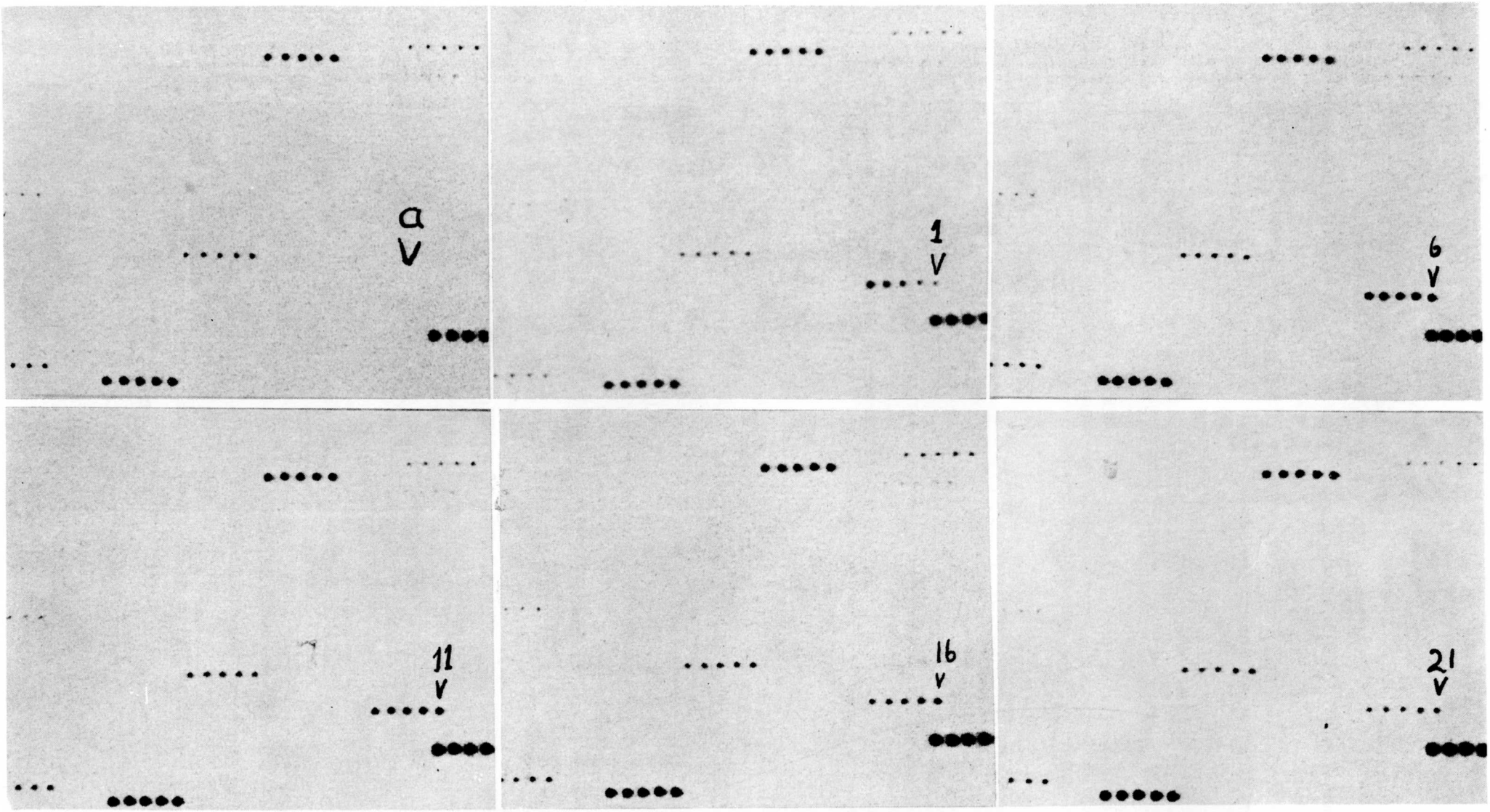

Fig. 1.—*In the upper left section of this figure, marked with an arrow and a letter* a *the reproduction of the last serie of exposures obtained during the night 25-26 Dec. 1965 of the non visible "slow" flare star Nº 177. Immediately to the right the first serie of 5 exposures made the following night (26-27 Dec.), the first exposure is marketd with an arrow under Nº 1. Following the other 4 consecutive series of exposures in which the first exposure in each serie is marked with numbers 6, 11, 16 and 21 respectively. The order of the exposures (15^m each) goes from right to left, with less than 1 second between exposures. See Table 3.*

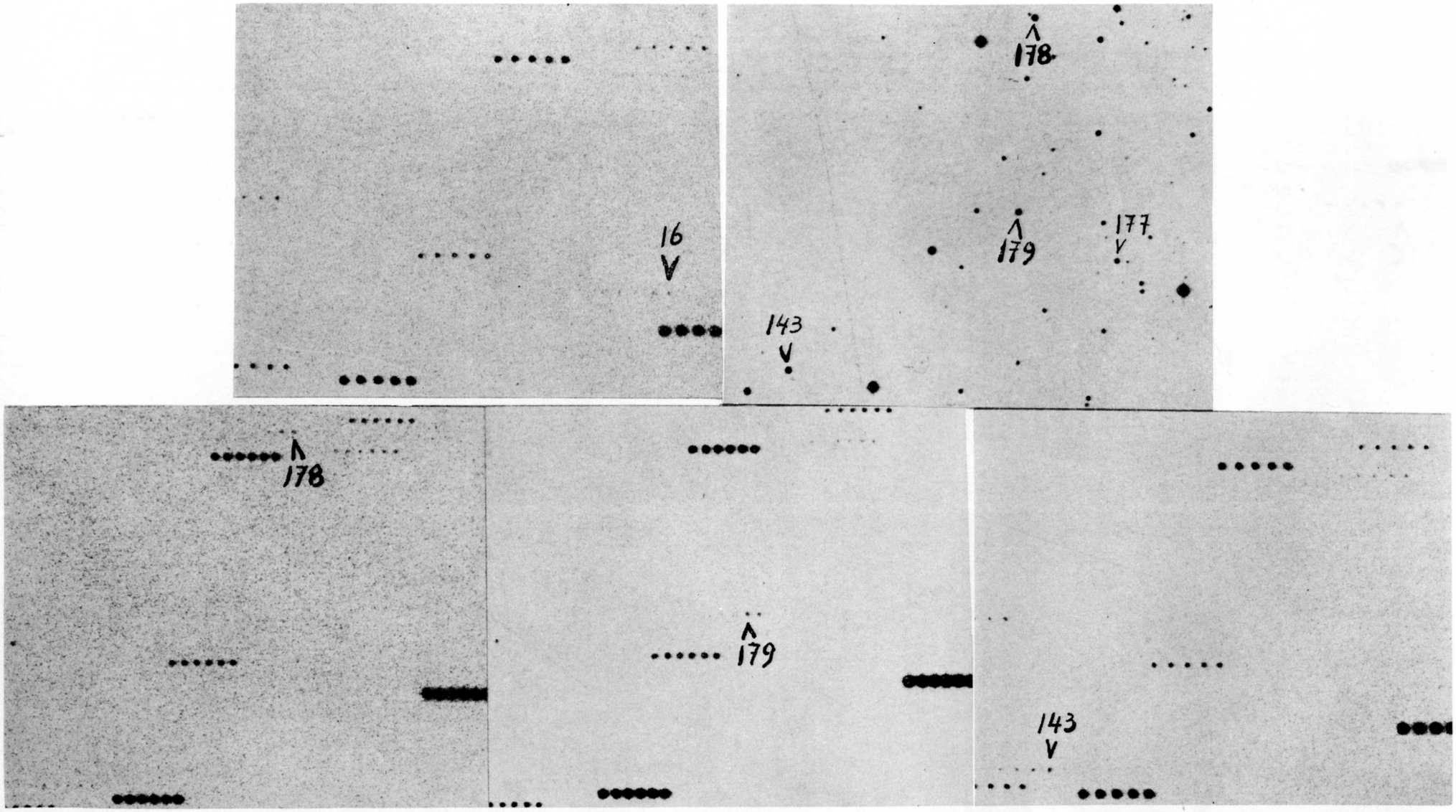

Fig. 2.—*In the upper left part of this figure, the flare star Nº 177 appears during exposures 16 to 20 obtained during the night 27-28 Dec. 1965 (See Table 3). To the right the identification chart (Infrared plate) of flare stars 143, 177, 178 and 179. In the lower section of the figure the series of immages in which the flare-ups of stars 178, 179 and 143 were detected. In all cases the multiple-exposures were 15 minutes each with less than 1 second between exposures. The order goes from right to left.*

(Haro, 1968); column two, the Parenago numbers (1954); columns three and four, the R.A. and Dec.; column five, the ultraviolet magnitudes in our system during normal minima; column six, the blue or photographic magnitudes and the range of the apparent smooth irregular variation — not flare-ups — derived from all our blue exposures; in column seven, the same for the visual magnitudes; in column eight, the roughly approximate infrared magnitudes (8500 A); in column nine, the ultraviolet amplitude of the flare-ups observed; in column ten, the date of the outburst; and, in the last column, the References.

Of the 4 objects listed in Table 2, the ones with Nos. 143, 178 and 179 — according to the criterion given before — can be considered as "fast" flare stars. No. 177, Parenago 1323, undoubtedly qualifies as a remarkable "slow" flare with an amplitude in the ultraviolet $\geqslant$ 8.4 magnitudes and with a rising time from minimum to maximum of nearly 118 minutes — or an increase of its total U brightness at a rate of $1.^{m}0/14$ minutes — if we assume that the constant average rate of increasing brightness which was actually observed (Fig. 1), from the U magnitudes 15.7 up to 11.3, can safely be extrapolated down to the minimum normal U magnitude 19.7.

The ultraviolet magnitude during normal minimum in this "slow" flare star was determined through the measurement of several blue Tonantzintla and Mount Palomar Schmidt plates, and adding to the photographic magnitudes a conservative value of U-B = +1.2. This seems to be justified because in two 40^{m} ultraviolet exposures (103aD Eastman Kodak plates behind a Scott UGI filter) obtained by one of the authors with the Mount Palomar 48" Schmidt camera — and reaching limiting magnitude ~19.5 — the flare star does not appear.

Table 3 contains the observational data derived from our ultraviolet exposure plates during three consecutive days in December 1965. The time of each exposure was 15 minutes and the average limiting U magnitude in the original plates is approximately 17.5. We are giving the U.T. mid point of each consecutive exposure and the corresponding integrated U magnitude observed.

As it can be noticed from Table 3, during the night 25-26 December 1965, the flare star No. 177 was not visible in our plates, and, therefore, its U magnitude was fainter than 17.5. Very probably it was at its "normal" minimum U magnitude ~19.7. On the following night the first ex-

TABLE 3

"Slow" Flare Observational Data in December 1965

Serial No of each Exp.	*U.T. Dec. 26 - 1965 and Observed U Mag.*		*U.T. Dec. 27 - 1965 and Observed U Mag.*		*U.T. Dec. 28 - 1965 and Observed U Mag.*		*U.T. Dec 29 - 1965 and Observed U Mag.*	
1	$1^{h}52^{m}30^{s}$	—>17.5	$2^{h}33^{m}30^{s}$	— 15.7	$2^{h}11^{m}30^{s}$	—>17.5	$3^{h}45^{m}30^{s}$	—>17.5
2	2 07 30	,,	48 30	14.6	26 30	,,	4 00 30	,,
3	22 30	,,	3 03 30	13.6	41 30	,,	15 30	,,
4	37 30	,,	18 30	12.7	56 30	,,	30 30	,,
5	52 30	,,	33 30	11.5	3 11 30	,,	45 30	,,
6	3 19 30	,,	55 30	11.7	34 30	,,	5 08 30	,,
7	34 30	,,	4 10 30	11.7	49 30	,,	23 30	,,
8	49 30	,,	25 30	11.8	4 04 30	,,	38 30	,,
9	4 04 30	,,	40 30	11.7	19 30	,,	53 30	,,
10	19 30	,,	55 30	11.9	34 30	>17.5	6 08 30	,,
11	42 30	,,	5 17 30	13.0	56 30	16.8	30 30	,,
12	57 30	,,	32 30	13.0	5 11 30	16.8	45 30	,,
13	5 12 30	,,	47 30	13.3	26 30	16.8	7 00 30	,,
14	27 30	,,	6 02 30	13.4	41 30	16.8	15 30	,,
15	42 30	,,	17 30	13.6	56 30	16.8	30 30	,,
16	6 04 30	,,	40 30	13.7	7 34 30	16.1	52 30	,,
17	19 30	,,	55 30	13.8	49 30	16.1	8 07 30	,,
18	34 30	,,	7 10 30	14.1	8 04 30	16.2	22 30	,,
19	49 30	,,	25 30	14.2	19 30	16.2	37 30	,,
20	7 04 30	,,	40 30	14.3	$8^{h}34^{m}30^{s}$	16.3	$8^{h}52^{m}30^{s}$	>17.5
21	27 30	,,	8 01 30	14.5				
22	42 30	,,	16 30	14.5				
23	57 30	,,	31 30	14.6				
24	8 12 30	,,	46 30	14.6				
25	$8^{h}27^{m}30^{s}$	>17.5	$9^{h}01^{m}30^{s}$	14.7				

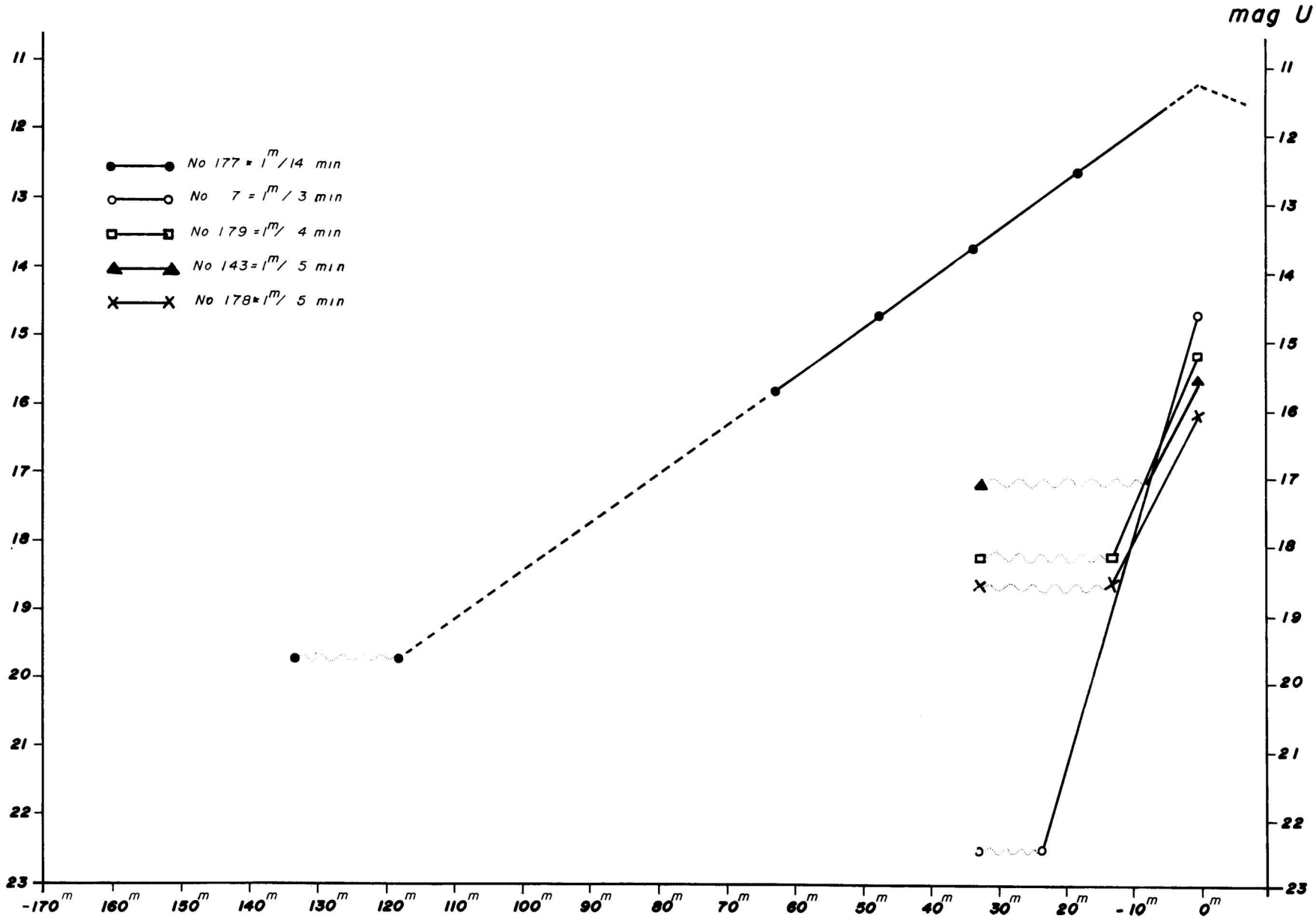

Fig. 3.—*The rising part of the light curves of the Orion flare stars numbers 7, 143, 177, 178 and 179.*

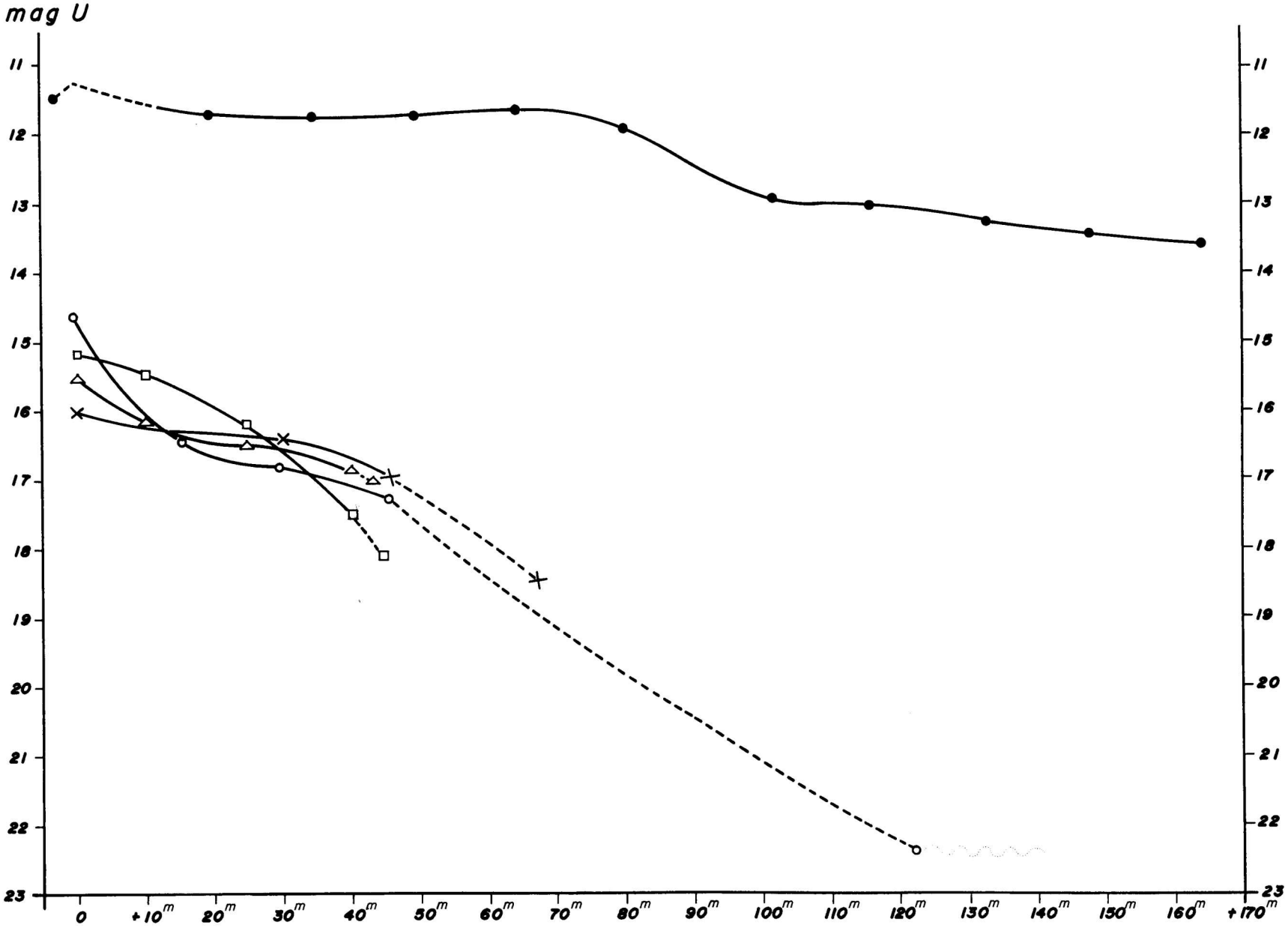

Fig. 4.—*The declining parts of the light curves of the Orion flare stars numbers 7, 143, 177, 178 and 179. See text.*

posure of the multiple series of images shows the star at magnitude $U = 15.7$ and then, at a constant rate of approximately $1^m/14$ minutes, reaches maximum and from it goes down at a considerably slower and variable decreasing rate until — in the last exposure of the same night — its magnitude is 14.7. During the succeding night, December 27-28, in the first 10 exposures the star is fainter than 17.5 and appears again in exposures 11 to 15, reaching a secondary flat maximum during exposures 16 to 20 and then disappears (see Fig. 2).

III. Light Curves of the Orion flare stars Nos. 7, 143, 177, 178 and 179

In Fig. 3 we have drawn the rising part of the light curve of the "slow" flare star No. 177 and, for comparison, the corresponding derived light curve sections of the "fast" flare stars Nos. 7, 143, 178 and 179. We have assumed, based on many other observations, that the rate of brightening per unit time is almost constant for the great majority of flare stars and thus we can extrapolate relatively safely the same rate of increase which is observed in the magnitude range of our plates down to the very limiting "normal" minimum magnitude of the flare stars, even if this does not appear in our multiple exposure photographic material.

Accordingly, we have obtained the following values as a maximum rate of brightening for the 5 flare stars involved:

No. 177 = 1 mag./14 minutes. (Time from minimum to maximum = 118 min.)
No. 7 = 1 mag./3 minutes. (Time from minimum to maximum = 23 min.)
No. 143 = 1 mag./5 minutes. (Time from minimum to maximum = 7.5 min.)
No. 178 = 1 mag./5 minutes. (Time from minimum to maximum = 12.5 min.)
No. 179 = 1 mag./4 minutes. (Time from minimum to maximum = 12 min.)

Although the flare star No. 7 (Haro, 1968) is far from the small area in which the other 4 flares are found, it is quite interesting because — apart of being a "fast" flare star — its outburst amplitude is of the order of 7.7 U magnitudes. The "normal" minimum of this star is U mag. $\sim$22.2; it does not appear in the blue Mount Palomar Schmidt plates (limiting B mag. $\sim$21.1) and its color index $U - B$ has been taken as $+1.2$.

Fig. 4 represents the declining light curves from maximum and back to minimum for all the flare stars, with the exception of No. 177. The decline of this last "slow" flare was observed during 5 hours after maximum until it reached $mU = 14.7$. A very rough extrapolation gives us a total time of decline — from maximum and back to minimum — of the order of 17 hours.

We are not really certain that this star went back to its normal minimum in 17 hour because during the succeeding night, although not visible in the first exposures (see Table 3), it appeared again in exposures 11 to 15 with an approximate constant U mag. = 16.8, reaching a secondary maximum at U.T. = $7^h\ 34^m$ of the same day.* Probably this flare star was fluctuating down to "normal" minimum, passing through secondary maximum amplitudes, during at least more than 36 hours.

Unfortunately, there were no simultaneous spectroscopic observations and therefore we cannot say with certainty anything about the spectral features of this "slow" flare star during the outburst. Anyway we can guess that the spectroscopic characteristics in the 2 previous "slow" flare stars, which were observed simultaneously in spectral and direct plates, can be almost the same in the new "slow" flare star.

In the many low dispersion red and infrared Tonantzintla spectral plates in which star No. 177 appears, it is difficult to determine the spectral type. We can only say that it is not later than M2 and probably is comprised between spectral range K7-M1.

IV. Summary and preliminary discussion

The new "slow" flare star No. 177 was known before as a variable star by Miss Livitt (Pickering, 1904), Hoffmeister (1923) and Parenago (1954), but none of these authors give information about the light curve. Probably they observed this variable during some of its rather flat maxima, without recognizing its nature of "slow" flare star. In all our photographic material (see Table 1), which perhaps is the more extensive one that has been examined for this particular star, it seems that with exception of the three flare-ups listed in Table 2, the object behaves most of the time as an irregular variable of very small amplitude.

* On the 28 of December 1965 and during the interval between U.T. 6^h40^m and 7^h27^m the observation was stopped due to bad weather. Probably in the above mentioned lapse the variable reached its real secondary maximum.

Because of its probable spectral type (K7-M1), its visual magnitude and colors, its localization in a rather obscured region in Orion, the type of variables in its immediate surrounding and its very nature of "slow" flare star, we conclude that it belongs to the Orion association and therefore is at the same distance.

As we have said before, the only 5 "slow" flare stars known up to now are found in the Orion association, a remarkably young aggregate. Most probably this is another conspicuous peculiarity that distinguishes the stage of evolution of a young T-association from a "middle-age" aggregate as is the Pleiades, or the older ones as are Praesepe, Coma, the Hyades and the flare stars in the solar neighborhood.

While in the Orion field, centered in the Trapezium and covering an area of 16 square degrees, we have found 176 flare stars (Haro, 1968) plus the 3 listed in this paper (Table 2) and out of this total number (179) 5 are outstanding "slow" flare stars which take more than 45 minutes to rise from minimum to maximum — that is, one "slow" outburst every 36 flare stars —, in the 16 square degrees area around Alcyone none of the 112 flare stars discovered show the "slow" characteristics even if we take as minimum rising time for a "slow" flare 20 to 30 minutes. It can be important to emphasize that the "slow" nature of a flare star does not depend on the amplitude of the outburst. Thus, for instance, among some other examples we have presented the case of the Orion flare star No. 7, which in about 23 minutes and at a rate of 1 mag./3 minutes reaches Δ mU = 7.7.

The very fact that the "slow" flare stars appear only in a stellar group in which the most outstanding and typical T Tauri objects are still one of the dominant peculiarities (Haro and Herbig, 1955) naturally led us to believe that we are dealing with a fundamental problem related to the evolution of general physical characteristics and internal structure of the late type stars.

One of the authors (Haro, 1964, 1968) has stressed, following Ambartsumian's ideas (1954, 1957), that the different photometric and spectroscopic features observed in the "fast" and "slow" flare stars can be due to the fact that the phenomenon which produces the outburst takes place at different layers or depths of a given star. According to Ambartsumian, if the energy that causes the changes in the star is liberated above the photospheric layers, mainly in the chromosphere, a sudden and very rapid increase of the nonthermal ultraviolet and blue continuum emission would occur, giving rise to a sharp light variation and simultaneously to an intense bright-line spectrum. When the energy is liberated in deeper zones, an increase in the thermal radiation as well as in the nonthermal continuous emission would be observed, with a lower relative intensity of the emission lines. The light variation, either from minimum to maximum or from maximum back to minimum would be considerably slower than in the first case.

From the results obtained until now — especially in Orion and in the Pleiades — it seems that the younger the stellar aggregate and therefore the younger the flare stars involved, the more propitious the internal physical conditions of a late type star in order to give place to a "slow" outburst.

It is tempting to further speculate even in a considerably slower flare process. Thus, for instance, the appearance in one Herbig-Haro object of the two new emission nebulous nuclei discovered by Herbig can be a sample of a long-term outburst at the source where the ionizing radiation originates (Haro and Chavira, 1966) — or the other very conspicuous case represented by FU Ori. But here, for the moment, we are entering into the realm of simple conjectures.

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