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FLARE STARS IN THE PLEIADES REGION. II

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SUMARIO

Aparte de presentar algunas nuevas estrellas Ráfaga en la región de las Pleyades, se hace un análisis de las 166 estrellas Ráfaga conocidas, de las cuales en 32 se ha encontrado que el fenómeno ráfaga repite dos o más veces. Suponiendo que la probabilidad de aparición de estrellas Ráfaga obedece a la ley de Poisson, se encuentra que el número total de posibles estrellas ráfaga en un campo de 16 grados cuadrados, con centro en Alcyone, es del orden de 600 en concordancia con los cálculos previos realizados por Ambartsumian y colaboradores. Por lo que se refiere a la incidencia de las explosiones en las estrellas Ráfaga estudiadas. se concluye que existe una definida tendencia en el sentido de que a mayor brillo de la estrella, más pequeña la amplitud máxima aparente observada y, por lo contrario, mientras más débil la estrella, mayor la máxima amplitud de variación. Al mismo tiempo, se dan algunas evidencias en el sentido de que la incidencia del fenómeno ráfaga está correlacionada tanto con la magnitud de la estrella como con sus características espectroscópicas en emisión.

Basándonos en los espectrogramas obtenidos por Kraft y Greenstein, y por McCarthy, se establece también una correlación entre el grado de actividad cromosférica, derivado de la intensidad de las líneas CaII y H observadas, y la posibilidad de detectar el fenómeno ráfaga en estas estrellas. Parece ser que utilizando la dispersión de 200 Å/mm y el poder resolutorio obtenido por Kraft y Greenstein, se puede determinar cuál es el grado "mínimo" de actividad cromosférica para que el fenómeno ráfaga ocurra. En el caso de las Pleyades, las estrellas con tipo espectral K3 indican el límite mínimo en donde se dá suficiente actividad cromosférica para que el fenómeno ráfaga pueda ser detectado mediante los métodos fotográficos empleados.

Las estrellas Ráfaga de las Pleyades y sus características espectroscópicas observadas refuerzan, y en muchos aspectos prueban, que nuestra primitiva hipótesis en que se conectaba —en un sentido evolutivo— a las estrellas T Tauri muy jóvenes y a las estrellas Ráfaga en diferentes agregados estelares y en la vecindad del Sol es válida.

I. *Introduction*

In an earlier article by Haro and Chavira (1969; "Paper I"), besides presenting the general information available at that time about the number, probable membership and kind of apparent distribution of the Pleiades field flare stars, several considerations were made concerning the spectral characteristics and the frequency of outbursts in these stars. Kraft and Greenstein's spectroscopic observations (1969) served to establish a correlation between a degree of chromospheric activity in a star and the possibility of detecting flare-ups within our photographic method. In other words, based on two different sets of observations (the known flare stars and the available slit spectrograms), we concluded that the dispersion used by Kraft and Greenstein — 200 Å/mm — and the spectral resolving power obtained by them seemed to mark a very important critical value for a given relative intensity of the CaII emission lines and, through this, a rather sharp measurement of the degree of chromospheric activity in a dwarf star which would permit to predict the lower limiting physical conditions of a late "main-sequence" object eventually recognizable as a "pure" flare star.

Owing to the fact that from the four K3*V* Pleiades stars contained in Kraft and Greenstein's list two (HII 740 and 2908) showing relatively strong CaII emission lines were observed at 90 Å/mm and of the other two, (HII 2199 and 2588) at 200 Å/mm, in only one a very weak or doubtful CaII in emission (HII 2588 = K3*V*e?) was noticed —and also because at that time none of these stars were suspected to be flare stars— we concluded very conservatively that the earliest possible flare star in the Pleiades aggregate could be of type ~K4*V*. With the new data on hand we shall try to clarify and refine some aspects of the problem.

Regarding the incidence of outbursts in the Pleiades stars, it also seems that we need to be more specific and give some additional arguments in order to prove that we cannot interpret the observed results directly in the sense that the brighter the star or the earlier its spectral type, the more frequent the incidence of flare-ups. As we said before (1969; "Paper I"), what most probably happens in this latter respect is that in the case of the Pleiades we are dealing mainly with a problem of observational selection.

II. *New Flare Stars in the Pleiades Region*

The multiple exposure ultraviolet photographic material obtained on the Pleiades region during the period October 7, 1969 — March 5, 1970 comprises 104 plates with 600 different exposures taken in 150 hours of observation. Due to irregular weather, the quality of the multiple series of stellar images is far from being homogenous and the average limiting *U* magnitudes in the whole set of plates is ~17.0. Our results are summarized in Table 1. As usual, column one gives the Tonantzintla serial numbers — the ones in italics indicate that the outburst repeats in the given stars, either in the "new" flare stars or in the stars listed before (Haro 1968; Haro and Chavira 1969; Parsamian and Chavira 1969; Ambartsumian *et al.* 1969).* From the list of flare stars discovered at the Burakan Observatory (Nos. 113 to 127) there are at least two, 118 and 121, that may correspond to the same flare stars numbered in our new list as 148 and 152, respectively, but we are not absolutely certain due to the lack of identification charts. The other columns in Table 1 are self explanatory. Figures 1 and 2 show some examples of the Pleiades flare stars contained in Table 1.

TABLE 1

New Flare Stars in the Pleiades Region

No.	*Star*	*R. A. (1900)*	*Dec. (1900)*	*Mag. in* U	ΔmU	*Spectral Type*	*Date of Flare*	*Ref**
102		3^h34^m8	$+24°50'$	~20.0	~4.0		1969 12/11	
147		3 37.1	23 45	18.4	2.4		1970 1/3	
148		3 37.2	24 20	18.5	3.5		1970 2/2	
149	HII 146	3 37.7	23 08	17.0	0.6	K7-M0*V*e	1969 11/9	1,2
150		3 38.1	24 45	18.3	3.0		1970 2/4	
79		3 39.3	24 55	18.2	4.3	(M)	1970 2/4	
151	HII 1103	3 40.7	23 06	17.3	0.5	K7*V*e	1969 11/9	1,2
152		3 41.1	24 09	19.0	3.5		1970 2/6	
153		3 41.3	23 56	~22.0	~8.0		1970 1/3	
154		3 42.2	22 44	18.8	3.5		1970 2/27	
155		3 42.3	23 40	19.5	5.5		1970 1/7	
156	vM 46	3 42.6	23 58	18.0	0.9		1969 10/9	3
157	HII 2144	3 43.1	23 26	17.6	1.2		1969 10/15	1
157	HII 2144	,,	,,	,,	1.0		1969 11/8	
92		3 43.8	24 27	19.0	2.5	(M)	1969 12/4	
158		3 44.8	22 01	~19.0	~4.0		1969 10/19	
159		3 46.1	24 12	17.7	1.2		1970 2/4	
99		3 49.0	22 31	17.8	1.5	(M:)	1969 12/10	
55	HII 2411	3 43.7	24 01	16.8	~0.4	dM4e	1969 10/9	1,4
55	,,	,,	,,	,,	1.8	,,	1969 11/13	
55	,,	,,	,,	,,	~0.4	,,	1969 12/10	
55	,,	,,	,,	,,	~0.5	,,	1969 12/10	
55	,,	,,	,,	,,	~0.5	,,	1969 12/13	
55	,,	,,	,,	,,	0.7	,,	1970 1/7	
55	,,	,,	,,	,,	~0.5	,,	1970 1/11	
55	HII 2411	3^h43^m7	$24°01'$	16.8	0.9	dM4e	1970 1/29	

* References: (1) Hertzsprung (1947); (2) Kraft and Greenstein (1969); (3) van Maanen (1945); (4) Herbig (1962).

III. *The Flare Phenomenon and the Appearance of Emission Lines in the Spectra of Pleiades Field Stars*

From the slit spectrograms obtained by Kraft and Greenstein (1969), and by McCarthy (1969), on the Pleiades field stars using different dispersions that go from 90 Å/mm to 380 Å/mm, we have found that they observed 63 different stars fainter than $V = 13.0$ having in common only 8 of these objects. From these 63 stars observed spectroscopically there are 47 that show either the CaII lines in emission or both the CaII and H emission lines (Kraft and Greenstein's list) and Hα emission lines (McCarthy's list).

Collecting all the available data on the Pleiades flare stars (Haro 1968; Haro and Chavira 1969; Parsamian and Chavira 1969; Ambartsumian *et al.* 1969; Haro and González 1970; and the

* Following the Tonantzintla serial numbering for the Pleiades flare stars, Ambartsumian and collaborators (1969) published a list of flare stars (from Nos. 113 to 146) found at the Burakan Observatory plus some other flare objects discovered at the Alma-Ata, Budapest and Asiago Observatories. Dr. Rosino very kindly provided us with identification charts for the Asiago flare stars contained in the Burakan Observatory list under serial numbers from 131 to 146. Rosino and Piggato's (1969) paper was received when this article had already been sent to press.

Figure 1

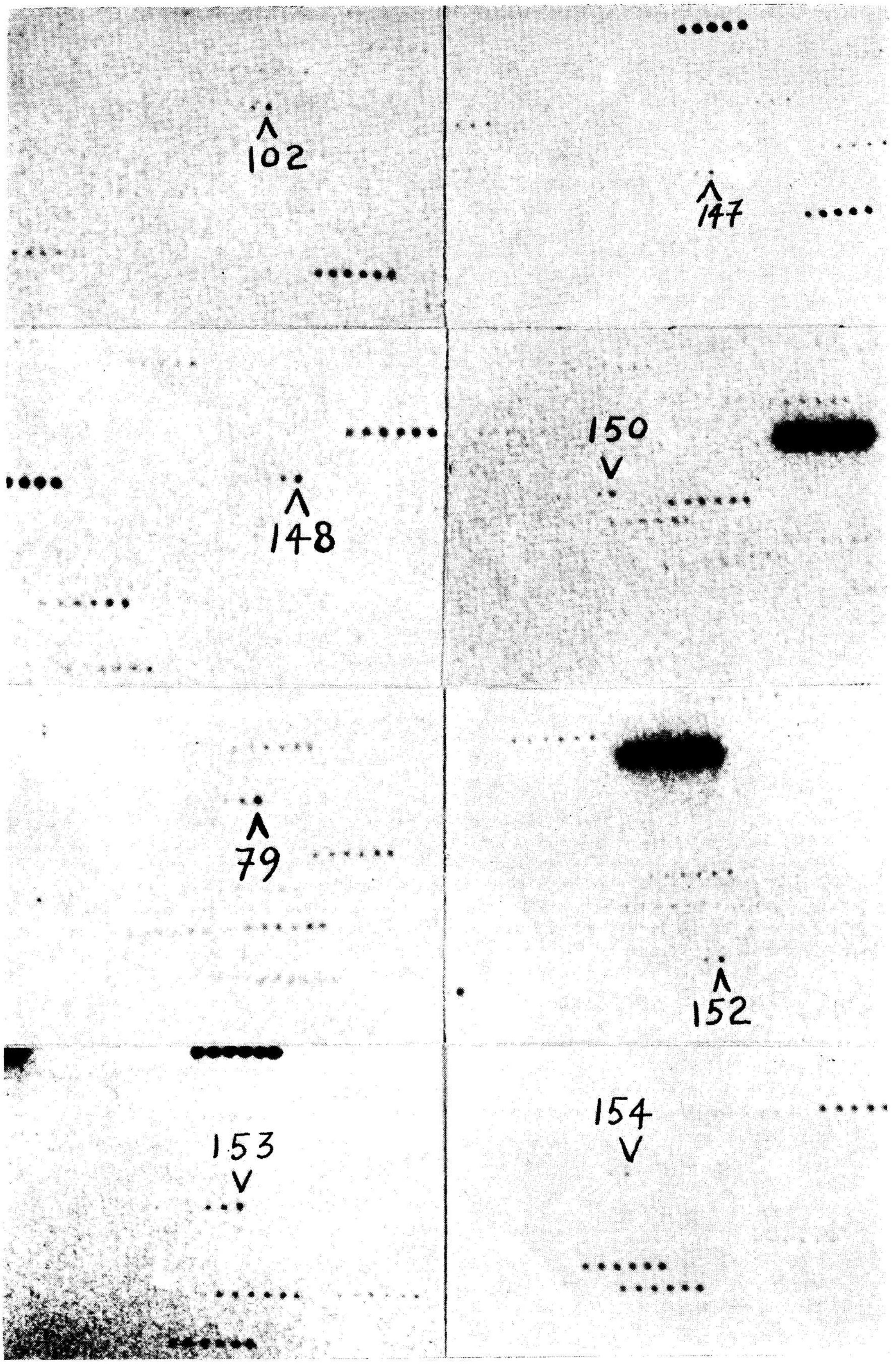
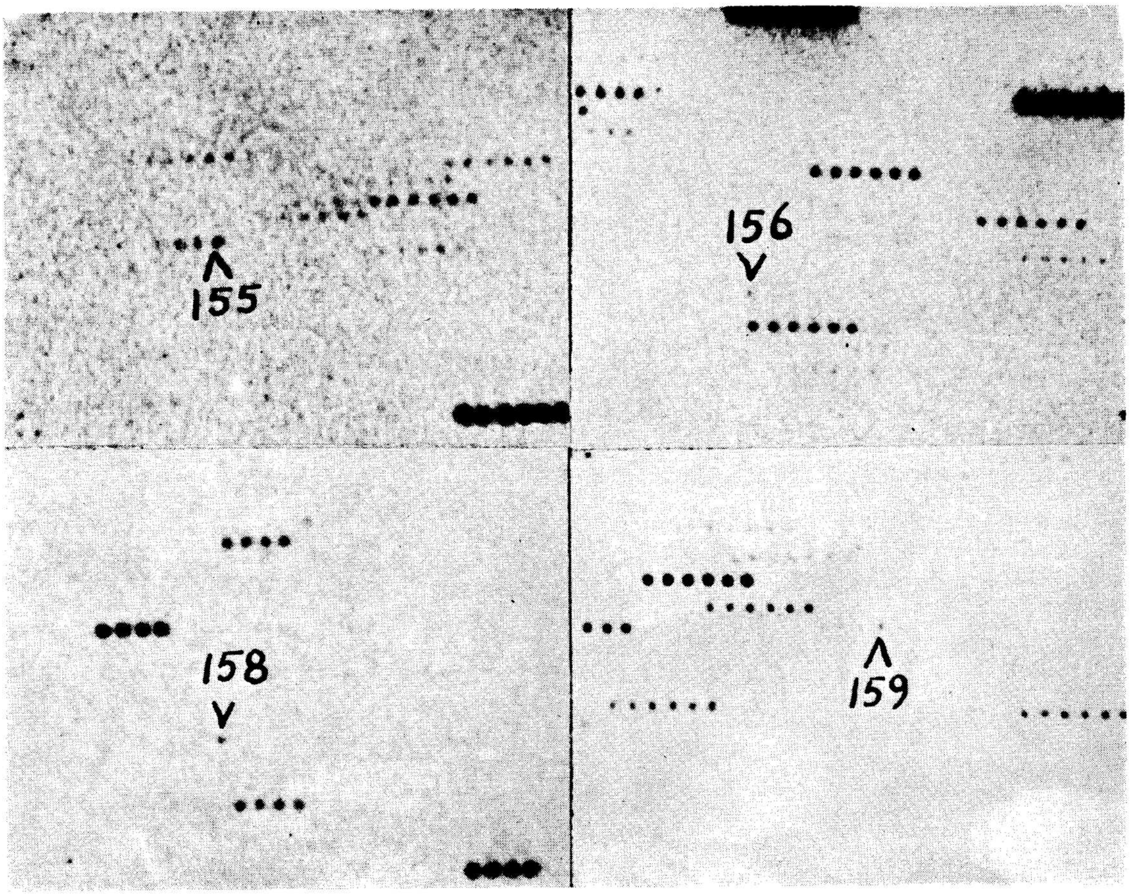


Figure 2



Figs. 1 and 2: *Multiple exposures showing flare-ups in some of the stars contained in Table 1 (marked with arrows and the corresponding Tonantzintla serial number). Each exposure was of 15 minutes with less than 1 second between exposures. The order of the exposure goes from right to left.*

objects listed in Table 1 of this paper) in Table 2 we present all the known flare stars classified spectroscopically by Kraft and Greenstein, and by McCarthy. In the first column of this Table we give the corresponding Tonantzintla serial numbers; the second column contains the Hertzsprung *et al.* (1947), the van Maanen (1945) and the LLP McCarthy numbers; columns 3 and 4, the V magnitudes by Johnson and Mitchell (1958) and by Iriarte (1967), respectively; column 5, the U magnitudes derived by us and based, when possible, on the magnitudes and colors given by the aforementioned authors; column 6, the spectral types by Kraft and Greenstein (1969); column 7, the spectral types by McCarthy (1969); column 8 contains some clarifying notes.

Upon analyzing the data contained in Table 2, several comments and considerations can be made:

a) Flare star HII 2411 has not been included because it is a well known member of the Hyades. With the exception of flare stars Nos. 105 and 18 (LLP 106 and 121) all the others have been recognized as proper motion "members" of the cluster.

b) From the 49 Pleiades field stars observed spectroscopically by Kraft and Greenstein, 39 show emission lines. From this number, in 25 stars only CaII in emission was detected and 8 of them (32%) are known flare stars. From the 14 stars in which Kraft and Greenstein noticed — apart from the CaII — Hβ and sometimes higher members of the Balmer series in emission, 11 (78.6%) are known flare objects.

c) From the 22 Pleiades field stars observed spectroscopically by McCarthy, 13 show Hα in emission (including HII 2411 and LLP 109) and, from these, 9 (69.25%) are known flare stars. As can be noticed from Table 2, flare stars HII 1653, 347, 793 and 191 were not listed by McCarthy as Hα emission objects but Kraft and Greenstein detected CaII emission lines in HII 191 and CaII plus H emission lines in HII 1653 and in HII 347.

TABLE 2

Pleiades Flare Stars with CaII and H Emission Lines Classifide by Kraft & Greenstein and McCarthy

Tonant. No.	*Hertzsprung, van Maanen and McCarthy Nos.*	V *J & M*	V *I*	*mag* U	*Sp. K & G*	*Sp. McCarthy*	*Notes**
166	HII 2908	13.02	13.41	15.48	K3*V*e	—	1,2,3
165	HII 2588	13.10	—	15.26	K3*V* (e?)	—	3,4
19	HII 1531	13.30	13.41	15.68	—	dK7e-dM0e	3,4,5
21	HII 1653	13.31	13.69	15.92	K4.5*V*e	dK7	2,3,5,6
8	HII 357	13.46	13.52	15.95	K6*V*e	dK4e	3,4,5,7,8,13
162	HII 676	13.56	—	16.12	K3.5*V*e	—	3,4
13	HII 686	13.62	—	15.7:	—	dK7e	2,8
109	HII 2927	13.92	—	16.22	K4*V*e	—	3,4,6
73	HII 335	13.94	13.78	16.11	K5*V*e	—	2,3,13
160	HII 347	14.01	—	16.58:	K7*V*e	dM1	2,6,8
107	HII 2208	14.13	—	16.74:	K6*V*e	—	2,6
88	HII 2193	14.16	—	16.48:	K6*V*e	—	2,6
46	HII 793	14.34	14.32	16.77	—	dM0,dM1	2,3,5
7	HII 191	14.38	14.39	16.97	K7-M0*Ve*	dK7	2,3,5
68	HII 134	14.44	14.39	16.94:	K7*V*e	—	2,6
149	HII 146	14.52	14.60	17.01:	K7-M0*V*e	—	2,6
70	HII 212	14.57	—	16.88:	K7*V*e	—	2
151	HII 1103	14.81	—	17.28:	K7*V*e	—	2,6
56	HII 2601	14.99	15.09	17.65:	M3*V*e	—	2,6
14	HII 906	15.24	—	17.66:	K7-M0*V*e	dM2e	2,8,9
113	HII 624	15.42	—	17.82:	M2*V*e	—	2,6,10
93	HII 2602	15.52	—	18.12:	M2.5*V*e	—	2,6
15	vM16 (LLP89)	16.09	—	18.21:	—	dM1e-dM2e	2,8
105	LLP 106	—	—	16.5pg	—	dM3e	8
87	LLP 109	—	—	16.1pg	—	dM2:	11
18	LLP 121	—	—	17.2pg	—	dM3e	8,12

* *Notes to Table 2:* 1) Palomar plate taken at 90 Å/mm; 2) Johnson and Mitchell's (1958) photographic magnitude; 3) *U* magnitude derived either from Johnson and Mitchell's (1958) or Iriarte's (1967) photoelectric magnitudes and colors; 4) Johnson and Mitchell's (1958) photoelectric *U* magnitude; 5) spectrum taken at 135 Å/mm by McCarthy (1969); 6) apart from the CaII emission Kraft and Greenstein noticed, at 200 Å/mm, emission in Hβ and sometimes in higher members of the Balmer series; 7) strong disagreements between the *U* magnitudes derived from Johnson and Mitchell's, and Iriarte's data; 8) spectrum taken by McCarthy at 270 Å/mm; 9) spectrum taken by Kraft and Greenstein at 380 Å/mm; 10) star HII 624 appears in Ambartsumian's *et al.* list (1969) as flare star No. 113; 11) spectrum taken by McCarthy at 360 Å/mm; 12) classified by Haro as M3-4e Hα; 13) *U* variable in Iriarte's list (1967).

d) In the list published by Kraft and Greenstein there are 4 stars classified as K3*V*. One of these, HII 2199, has no emission lines and because of its apparent visual magnitude (V = 14.38) can hardly be considered as a member of the cluster. The other 3 (HII 740, 2588 and 2908) show CaII in emission. Two of these last stars have been found to be flares (HII 2588 and 2908). It is perhaps important to emphasize that two of these K3*V*e stars (HII 740 and 2908) were observed in Palomar plates taken at 90 Å/mm and that one of the flare stars, HII 2588, K3*V* (e?), was taken at 200 Å/mm. It is strongly suggestive that, using this last dispersion and the corresponding spectral resolving power, this is the very limit in which the CaII line can be faintly detected in a Pleiades star member. This argument could be strengthen by the fact that two proper motion "members" of the Pleiades (HII 945 and 3069), classified as K2*V* by Kraft and Greenstein, do not show traces of emission using a dispersion of 200 Å/mm. Anyway, in this last respect there are some disturbing observations which arise doubts either about the proper motion membership criterion for these early K type Pleiades stars under consideration or in regard to the photoelectric magnitudes or the spectral classification system used by Kraft and Greenstein. For instance Wilson (1963), using a 38 Å/mm dispersion, found that star HII 2881, V = 11.5 has a K2 spectrum and stars HII 885 and 1100, with V = 12.0 and 12.2 respectively, are of K3 type. Although it is well known that the spectra, magnitudes and colors of the Pleiades stars do not correlate consistently —and this is again confirmed by the data contained in Table 2— the magnitude differences between the K2-K3 stars observed by Kraft and Greenstein and the K2-K3 stars observed by Wilson are extremely large.

e) All the stars earlier than K2 classified by Kraft and Greenstein can certainly be considered as non-members of the cluster —even though they have the Hertzsprung Pleiades "members" proper motion— because of their spectral type and apparent visual magnitudes. Probably the same can be said about star HII 2082 with spectral type M0*V* and photoelectric visual magnitude 13.98. Based on two discordant photoelectric observations, this particular star was presented by Johnson and Mitchell (1958) as a possible "flaring" object.

f) Some of the Hertzsprung "non-member" proper motion Pleiades stars not observed by Kraft and Greenstein or by McCarthy (with the exception of HII 2411, a Hyades star which is not listed in Table 2) have been recognized as flare stars. Table 3 complements, up to the date of writing this article, the previous list of Hertzsprung "non-members" given by Haro and Chavira (1969; "Paper I"). We strongly recommend the spectroscopic observation of these stars.

TABLE 3

Pleiades Flare Stars with Hertzsprung's "Nonmembers" Proper Motion

Hertzsprung Nos.	m_{pg}	*Flare Star No.*
HII 230	15.36	42
HII 500	16.2	44
HII 924	16.4	131
HII 1069	14.55	80
HII 1547	16.1	140
HII 2144	16.4	157
HII 2411	15.52	55
HII 2879	15.57	57

IV. *The Incidence of Outbursts in the Pleiades Field Stars*

Gathering all the available information mentioned in the second paragraph of section III, there are 166 known different flare stars in the Pleiades field and a good number of repeated flare-ups in at least 32 of them. Table 4 summarizes the results obtained in this regard at different Observatories. The first column gives the name of the Observatory; the second column, the number of the "new" flare stars originally discovered; the third column, the number of repeated outbursts detected in some of the 32 stars listed in the second column; the fourth column gives the references.

TABLE 4

Pleiades Flare Stars and Repeated Flare-ups Found at Different Observatories

Name of Observatory	*No. of "new" Flare Stars Found*	*Repeated Flare-ups Detected in 32 Flare Stars*	*Ref**
Lowell Obs.	1	———	1
Tonantzintla Obs.	122	104 (in 31 Stars)	2,3,4,5,6,7,8,9
Asiago Obs.	25	6 (in 3 Stars)	10,11,12
Burakan Obs.	15	2 (in 2 Stars)	11
Alma-Ata Obs.	1	———	11
Budapest Obs.	2	———	11

* *References:* (1) Johnson and Mitchell (1958); (2) Haro (1963); (3) Haro and Chavira (1966); (4) Haro (1968); (5) Haro and Chavira (1966); (6) Parsamian and Chavira (1969); (7) Haro and Parsamain (1969); (8) Haro and Chavira, the present article (1970); (9) Haro and González (1970); (10) Rosino (1966); (11) Ambartsumian *et al.* (1969); (12) Rosino and Pigatto (1969).

In Table 5 we are listing with more detail the 32 Pleiades field stars in which two or more flare-ups were observed and that, to our present knowledge, have been published. Column one gives the corresponding Tonantzintla serial number; column two, the Hertzsprung and van Maanen numbers when available; column three, the *U* magnitudes in descending order of brightness — when possible we have derived m*U* from Johnson and Mitchell's (1958) or Iriarte's (1967) photometric work; column four gives the approximate maximum Δm*U* observed; column five, the average of the different Δm*U* observed in the given stars; column six, the number of flare-ups detected in each star; column seven contains the spectral types given either by Kraft and Greenstein (1969) or by McCarthy (1969). The spectral types in parenthesis are rough approximations by Haro, and the spectra of HII 1306 and HII 2411 by Herbig (1962). For references regarding the outbursts observed, the ones given in Table 4 can be consulted.

TABLE 5

Pleiades Field Stars with Two or More Flare-ups Observed

Tonant. No.	*Star*	*m*U	*Maximum* Δ*m*U	——— Δ*m*U	*Flare-ups Observed*	*Spectral Type*
19	HII 1531	15.68	1.0	0.7	2	dK7e-dM0e
108	——	15.8	1.3	1.0	2	(M)
17	HII 1306	15.85	3.7	1.12	5	dK5 (e)
21	HII 1653	15.92	1.4	0.9	4	K4.5*V*e—dK7
8	HII 357	15.95	2.0	1.3	9	K6*V*e—dK4e
73	HII 335	16.11	3.5	2.15	2	K5*V*e—
88	HII 2193	16.5	3.0	2.5	2	K6*V*e—
107	HII 2208	16.7	1.8	0.75	2	K6*V*e—
55	HII 2411	16.8	3.7	0.87	56	dM4e
70	HII 212	16.9	3.4	2.15	2	K7*V*e—
149	HII 146	17.0	3.0	1.15	4	K7—M0*V*e
56	HII 2601	17.6	2.5	1.55	2	M3*V*e—
157	HII 2144	17.6	1.2	1.1	2	————
39	——	17.7	5.0	3.6	2	————
14	HII 906	17.7	3.0	1.75	6	K7-M0*V*e—dM2e
99	——	17.8	2.7	2.1	2	(M:)
16	HII 1286	18.0	2.3	1.9	2	(M)
93	HII 2602	18.1	3.1	2.9	2	M2.5*V*e—
10	——	18.2	1.5	1.3	2	(M)
15	vM16	18.2	5.0	4.3	3	dM1e-dM2e
79	——	18.2	4.3	3.65	2	(M)
62	——	18.5	3.2	2.16	3	————
40	——	19.0	4.5	4.25	3	————
90	——	19.0	5.1	5.0	2	(M)
92	——	19.0	3.3	2.9	2	(M)
96	——	19.4	5.9	4.2	2	(M)
101	——	19.5	8.0:	4.3:	6	(≶ M2)
5	——	19.6	3.3	3.1	2	————
2	——	20.0	6.5	6.2	2	(M)
27	——	20.0	4.5	4.2	2	(M)
102	——	20.0	4.5	3.9	3	————
20	——	21.2	8.0:	6.5:	2	————

The analysis of Table 5 immediately reveals several outstanding features:

i) All the 14 flare stars with two or more outbursts, from which slit spectrograms have been obtained using different dispersions (from 135 Å/mm to 420 Å/mm), show CaII in emission. From these 14 stars, in 11 (78.6%) H emission lines have been detected either by Kraft and Greenstein or by McCarthy, or Herbig. The remaining 3 stars without observed H emission lines are: HII 1306 taken by Herbig at 420 Å/mm, and HII 212-HII 335 observed by Kraft and Greenstein at 200 Å/mm, showing the *K2* emission with *EW* (Å) of 4.0 and 2.4 respectively.

ii) The flare stars with the larger incidence of outbursts are: *a)* HII 2411, a Hyades star with strong H and CaII emission lines (dM4e, 56 different flare-ups reported); *b)* HII 357, in which McCarthy found Hα in emission at 135-270 Å/mm, and Kraft and Greenstein observed the CaII emission at 200 Å/mm (K6*Ve* — dK4e, 9 different flare-ups); *c)* HII 906, observed by Kraft and Greenstein at 380 Å/mm and by McCarthy at 270 Å/mm, find-inding CaII and Hα emissions respectively (K7-M0V*e* — dM2e, 6 different outbursts); *d)* flare star No. 101, spectroscopically observed by Haro using the Tonantzintla Schmidt objective prism ($\lesssim$ M2, 6 different flare-ups); *e)* HII 1306, observed by Herbig at 420 Å/mm (dK5e, 5 different flares); *f)* HII 1653 observed by Kraft and Greenstein, who found CaII and H emission lines at 200 Å/mm, and by McCarthy at 135 Å/mm without detecting emission lines (K4.5*Ve* — dK7, 4 different flares); *g)* HII 146 observed by Kraft and Greenstein at 200 Å/mm,, finding CaII and H emission lines (K7-M0*Ve*, 4 different flares); *h)* vM16 observed by McCarthy at 270 Å/mm, finding Hα in emission (dM1e-dM2e, 3 different flares). There are also three other flare stars, Nos. 40, 62, and 102, which are as faint or fainter than m*U* = 18.5, that have shown 3 different flare-ups each and very probably are of M type.

iii) From the 32 Pleiades field stars with two or more flare-ups, only 7 show spectral types as late as K7. The others are K7-M0 or later. Because of the very red and infrared colors we are considering all the stars in Table 5, for which the spectral type is not determined, as M type stars.

iv) In Table 5 there is a strong, clear tendency in the sense that the fainter the flare stars considered, the larger the amplitude of the observed outbursts and —most probably— the real frequency of flare-ups is also larger than in the brighter stars. If this is so, we can establish a correlation between the Pleiades star magnitudes and spectra and the incidence of flares. Although three of the brightest flare stars in Table 5 (HII 357, HII 1306 and HII 1653) have shown 9, 5 and 4 different outbursts, respectively, and their spectral types are earlier than K7, we insist on our previous argument (Haro and Chavira 1969; "Paper I"): *1st)* that for a given spectral type there are stars which show more frequent flares than the others, and *2nd)* that in general and in the case of the Pleiades we are dealing mainly with a problem of observational selection. In the faint flare stars, as faint or fainter than ~m*U* 17.3, due to the limiting magnitude in our plates we can only detect —in the best of cases— outbursts of Δm*U* larger than 0.5 mag. (we have considered 0.4 — 0.5 as a "safe" amplitude flare in our photographic material). Therefore, a flare star of *U* magnitude ~18.0 needs to show flares of at least 1.2 magnitudes in our plates, and a ~19.0 magnitude star must show a minimum Δm*U* = 2.2 in order to safely be recorded as a flare-up, etc. All the small amplitude flare-ups that, to the best of our knowledge, are the most frequent ones will be unobservable and "lost" in stars fainter than ~17.3. The Hyades star HII 2411 can be an excellent example strongly supporting the above statements. In this particular star, m*U* = 16.8, which is always under control in our plate material, 56 different outbursts have been reported; the maximum Δm*U* observed being 3.7 and the average Δm*U* = 0.87. If this star should be at the distance of the Pleiades aggregate, only 3 of the 56 known outbursts would have been detected.

Of course, it can be argued that a Hyades flare star can have a larger outburst incidence than a Pleiades star but there are several probable members fainter than the 18.0 *U* mag., in which three or more very large amplitude bursts (> 3.0 *U* mag.) have been observed and we can be reasonably certain that the considerably more frequent outbursts of significant lower amplitude have not been noticed in our photographic material just because of observational bias (mainly, the limiting magnitude in the multiple exposure plates).

v) The Hyades star HII 2411 is not only outstanding due to the relatively very large number of flare-ups observed but also because only 2, out of 56 outbursts, have been reported by the Asiago observers. This could be mainly accounted for by the dominantly ultraviolet observations performed in our Observatory. In contrast, 2 of the 3 flare-ups observed in flare star No. 15 (van Maanen 16) and 2 of the 9 outbursts in flare star No. 8 (HII 357) were found in Asiago. At the Burakan Observatory only 2 repeated flare-ups were detected in flare stars Nos. 40 and 101.

It can be of statistical interest to point out that from the 122 flare stars originally discovered at the Tonantzintla Observatory, only in 5 of them repeated flare-ups have been found in other Observatories (flare stars Nos. 8, 15, 40, 55 and 101). On the other hand, from the 44 flare stars originally discovered in other observatories only in the one found by Johnson and Mitchell (1958) at Lowell (flare star No. 17, HII 1306) four additional outbursts were detected at Tonantzintla.

We need to clarify that in flare star No. 8 (HII 357), after finding the first flare-up with $\Delta mU = 2.0$ and analyzing Johnson and Mitchell's photometry we concluded that they observed a small flare of $\Delta mU = \sim 0.5$. In the above comments we have not considered the Burakan Observatory flare stars Nos. 118 and 121, that may correspond to the stars listed in Table 1 under Nos. 148 and 152. But even if we include these last two stars it is surprising that from 44 flare objects found by other observers, we have been able to detect repeated flare-ups in only 3 of them. In 31 of the 32 flare stars listed in Table 5 —the only exception being No. 15 (van Maanen 16)— we have been able to observe, at Tonantzintla, one or several repeated outbursts.

V. *Further Discussion and Summary*

In the Pleiades field, in an area of approximately 16 square degrees centered in Alcyone, 166 flare stars have been found (there are two doubtful cases) and in at least 32 of them two or more different outbursts were detected. Of course we cannot consider that all the flare stars found are members of the Pleiades aggregate and good evidence in this sense is given by the well known Hyades star HII 2411, to which we can probably add the Hertzsprung non-member proper motion flare stars listed in Table 3 and the M type flare stars which due to their approximate spectral type and apparent magnitudes can be excluded. In a conservative way we have tentatively assumed (Haro and Chavira 1969; "Paper I") that about 80% of the Pleiades field stars can be real members of the cluster.

Following Ambartsumian *et al.* (1969) and supposing that the probability of flare star appearance obeys Poisson's law we found that the total number of expected flare stars in the Pleiades field under consideration is of the order of 600, which is in perfect agreement with the results of Ambartsumian *et al.* In this simple computation we are taking into account 166 known flare stars, 32 with two or more flare-ups; from these latter, 21 have shown only two repetitions.

Regarding the incidence of outbursts in the known flare stars in the Pleiades field, we believe that there exists enough evidence to support the following conclusions: *a)* There is a marked tendency in the sense that the brighter the star, the smaller the maximum Δm observed and in the faint stars the maximum Δm's are, in general, considerably larger. This does not necessarily mean that the absolute amount of energy liberated in the second case is always greater than in the first; in this last regard we need to take into consideration the absolute brightness of the star during quiescence and the corresponding absolute burst increment. *b)* If we recognize that, in general, the number of small amplitude flare-ups in many of the well known flare stars is enormously greater than the large amplitude bursts in the same stars (Kunkel 1967), we can unavoidably conclude that from the data obtained on the Pleiades flare stars there must be —even if we cannot observe them because of the limiting magnitude in our plates— a larger incidence of flare-ups in at least the fainters stars ($mU \lesssim 18.0$) which have shown two or more large amplitude flare-ups. *c)* It is difficult to agree with the statement made by Ambartsumian *et al.* (1969) in the sense that the brighter the star, the larger the incidence of small flare-ups (smaller than ~ 0.5 mU) because even if it is true that with the rough photographic technique employed they cannot easily be detected, exactly the same can be said regarding the case of the faint flare stars; most surely in this latter case it would be worst. From the physical point of view, we also cannot understand how the Armenian astronomer's preliminary conclusion can be justified. If the probability of producing large and small outbursts in what we have called "pure" flare stars is correlated with the degree of chromospheric activity revealed by the presence of CaII and H emission lines, then generally the fainter stars in the Pleiades field —based on the given spectroscopical sample available— would be the ones in which the flare incidence is larger.

The data collected on the 166 Pleiades field flare stars give new support to our earlier suggestion (Haro 1968; Haro and Chavira 1969 "Paper I") when comparing the Orion flare stars with the Pleiades flares: while in the Orion association there exist typical and extreme T Tauri stars that at the same time show sporadically, and superimposed on their "normal" irregular light curves, conspicuous flare-ups —and furthermore there are "pure" flare stars of the "slow" and "fast" types— in the Pleiades only "fast", "pure" flare stars have been found. By "pure" flare stars we mean the very rapid variables in which the strong T Tauri spectroscopic properties, as defined by Herbig (1958), have decayed or substantially diminished. The term "slow" refers only to the cases in which the time of rising from "normal" minimum to maximum is, within our photographic limitations, $\gtrsim$ 30 minutes.

From the slit spectrograms taken by Kraft and Greenstein, and McCarthy, we can conclude that all the Pleiades flare stars —if properly observed at 200 Å/mm— will show emission lines and that there is a strong statistical correlation between the intensity of these lines (CaII and/or H) and the flare phenomenon appearance and incidence. Thus, for instance, in 25 Pleiades stars observed by Kraft and Greenstein, in which they only found CaII in emission, there are 8 known flare stars (32%); but in the 14 stars with CaII plus H emission lines observed by them at 200 Å/mm, 11 are flares (78.6%). It can be of some significance to point out that flare star HII 2588, in which only a very faint or doubtful CaII emission appears (K3*V*e?), was taken at 200 Å/mm; the other two K3*V*e stars, HII 740 and HII 2908 (the latter being a known flare star), were observed at 90 Å/mm with CaII in emission but without reported emission at Hβ or in any of the higher members of the Balmer series. The same is true for star HII 676, classified as K3.5*V*e, at 200 Å/mm. In contrast, from 4 K4*V*e-K4.5*V*e Pleiades stars observed by Kraft and Greenstein at 200 Å/mm, 2 show, besides CaII, the H lines in emission. By a significant coincidence we also found that from the 14 flare stars with two or more outbursts observed, from which slit spectrograms have been obtained using dispersions from 135 Å/mm to 420 Å/mm, in 78.6% of cases (11 stars), apart from the CaII some of the Balmer lines are in emission.

If we take into account that from 1963 to 1970 the Pleiades field stars have been observed, at different Observatories, only during less than 1000 hours looking for flare stars, it is more than easy to conclude that all the stars showing a weak CaII or CaII plus H in emission at approximately 200 Å/mm dispersion will undoubtedly be flare stars.

It seems that, within the Kraft and Greenstein spectral classification system, the 200 Å/mm dispersion and the spectral resolving power obtained by them constitute a very efficient and critical measurement of the "minimum" chromospheric activity that would be necessary in a star to give place to the flare phenomenon detectable through the kind of photographic method employed by us.

After re-examining all our available plate material we found that the earliest flare star in the Pleiades region is K3*V*e in the Kraft and Greenstein spectral classification system. We have thoroughly examined in all our plates the two K2*V* stars (HII 945 and 3069) contained in the Kraft and Greenstein list, and stars HII 2881 and HII 1100,885 classified by Wilson (1963) as K2 and K3 respectively, without finding any signs of flickering.

There is no doubt that the spectra, magnitudes and colors of the Pleiades stars do not correlate consistently. Besides considering that this can be due to differences in the interstellar absorption, we cannot neglect the possibility of contemplating this inconsistency as caused by distinct stages of an evolutionary process.

The Pleiades flare stars and their new spectroscopic features observed reinforce, and we believe that in many aspects they prove, our primitive hypothesis connecting —in an evolutionary sense— the very young T Tauri stars and the flare stars in different stellar aggregates and in the vicinity of the Sun.

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