BOLETÍN DE LOS OBSERVATORIOS DE TONANTZINTLA Y TACUBAYA, VOL. 5, N°35, 1970.

ON SOME PROPERTIES OF FLARE STARS IN ORION

*G. A. Gurzadyan**

RESUMEN

Al analizar el material de observación de las estrellas ráfaga en la Asociación de Orión hemos llegado a las siguientes conclusiones: *a)* La actividad ráfaga de las estrellas en Orión aumenta a mayor distancia del centro. *b)* La energía relativa emitida en la explosión de una estrella ráfaga es mayor cuanto menor sea la luminosidad absoluta.

ABSTRACT

The analysis of the observational material of flare stars in the Orion association leads to the following conclusions: *a)* the flare activity of the stars in Orion increases with increasing distance from the center, *b)* the relative amount of energy discharged in the outburst of a star increases with decreasing absolute luminosity.

I. Introduction

At the present time a large amount of observational material on flare stars in the Orion association has been accumulated. The analysis of this material discloses several interesting properties within the system of flare stars and permits to arrive at some conclusions with respect to their evolution. In this article two main questions are examined: the distribution in Orion of flare and H_α emission stars and the power of the outburst as a function of the luminosity of the star.

II. The relative distribution of flare and $H\alpha$ emission stars in Orion

The lists of 254 flare stars in Orion discovered up to 1969 were given by Haro (1968), and Haro and Chavira (1969). The list of 267 H_α emission stars and peculiar objects in Orion was presented by Haro (1953). Based on these data, the maps of the apparent distribution of flare stars (Fig. 1) and H_α emission stars (Fig. 2) have been made. The Trapezium stars have been marked by a cross and are in the center of these maps.

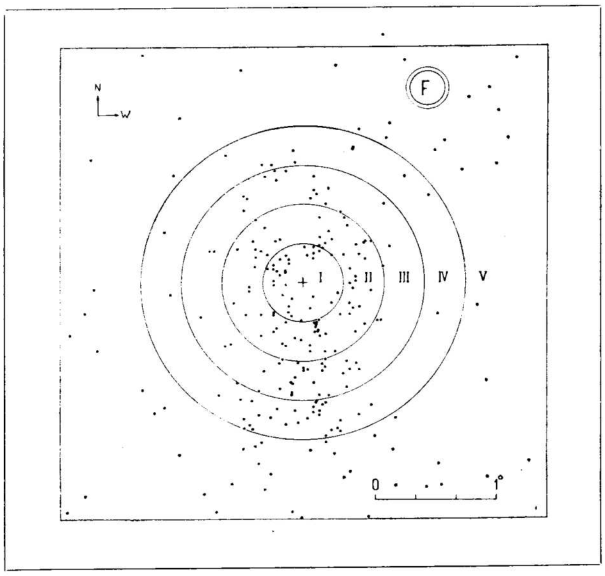

Fig. 1.—*Apparent distribution of flare stars in Orion.*

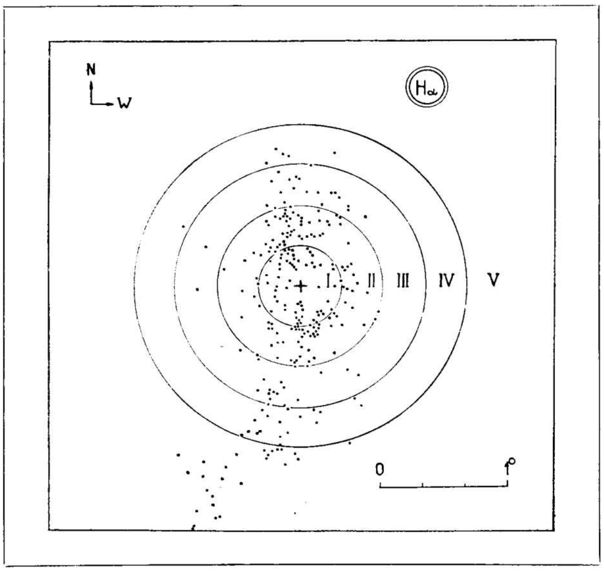

Fig. 2.—*Apparent distribution of the stars with H_α emission in Orion.*

* Burakan Astrophysical Observatory, Armenia, U. S. S. R.

In both of these maps the influence of the absorbing material on the apparent distribution of stars is clearly noticed, particularly in the asymmetry of the stellar distribution as well as in their increased total number in the directions of the areas of comparatively higher transparency. The absorbing material, however, has practically no influence on the character of the *relative* distribution of these stars even though it distorts their apparent distribution. Therefore the results of the analysis of their relative distribution and, in particular, the variation of their projected surface density with the distance from the center must have real physical significance.

Having this in mind, we have divided the whole Orion region (16 square degrees) into five concentric zones —from I to V— as shown in Figures 1 and 2. In Table 1 we give, in the first five columns: number of zone, size of each zone in angular units, their area in square degrees, and the number of flare and H_α emission stars in each zone. Using these data, the surface concentrations of flare and H_α emission stars are obtained (columns 6 and 7) as well as the relative density distribution, N_f and N_α, normalized to their surface densities in zone I (columns 8 and 9), where N_f and N_α represent the relative surface density of flare and H_α emission stars, respectively.

From the data presented in Table 1 it follows that the relative density N_α is higher than the relative density N_f. This means that the H_α emission star system has a considerably greater concentration toward the center of the association than the flare star system. Obviously, the N_f/N_α ratio may indicate the degree of concentration of flare stars relative to H_α stars; the values of this ratio are given in the last column of Table 1.

TABLE 1

Apparent distribution of flare and H_α emision stars in Orion

Zone	*Boundaries of zones from the centre (degr.)*	*Area of zone (sq. degr.)*	*Total Number* Flare	H_α	*Number of stars per sq degr.* Flare	H_α	*Relative Density* N_f	H_α	$\frac{N_f}{N_\alpha}$
I	0 - 0.33	0.34	31	61	91	180	1	1	1
II	0.33 - 0.67	1.07	71	116	66	108	0.72	0.60	1.2
III	0.67 - 1.00	1.72	49	38	28	22	0.31	0.12	2.5
IV	1.00 - 1.33	2.44	42	26	17	10	0.19	0.055	3.4
V	1.00 - 2.00	10.40	57	25	5.5	2.4	0.060	0.013	4.5

As it is seen, the N_f/N_α ratio certainly increases when passing from the inner zones to the outer ones, and is largest in zone V. This means that the farther from the center of the association, the larger the number of flare stars with respect to H_α stars. For instance, in zone V the relative number of flare stars is 4-5 times greater than the number of H_α stars. The variation of N_f/N_α with distance from the center of the association is shown in Figure 3.

Let us assume then that the star formation process originates, and generally continues, in the central parts of the association, and we may even assume that the number of "hotbeds" is more than one. The newborn and certainly unstable stars would move slowly away from the center of the association meanwhile undergoing changes in structure as well as in the rate of instability. Taking the flare and H_α emission stars in Orion as a single system, then the trends established above can be interpreted physically as follows: *the flare activity of stars in the Orion aggregate grows with increasing distance from its center.*

As, on the other hand, we are supposing that there is a relatively small possibility of star formation processes in the peripheries of the association, the increase in the ratio of flare stars to H_α emission objects in these regions, N_f/N_α, will be due to phenomena occuring in the stars already existing in the association i. e., of H_α emissions stars (T Tauri) reaching the state of flare stars. This can be a direct proof of the statement made by Haro (1962) to the effect that stars of the T Tauri type finally become "pure" flare stars. If we take into consideration the data given in Table 1, more than 80% of the initial number of H_α emission stars from the central part of the association would become flare stars when they reach its periphery.

Comparing the distance of the Orion association from the Sun ($\sim$ 500 parsecs) with a supposed rate of radial expansion of $\sim$ 15 km/sec., we find that it takes 10^6 years for a star to reach zone V from the center. However, in the meantime over ¾ of the initial number of T Tauri stars pass on to a flare star stage although some may keep features of the T Tauri type stars. It follows that the age of T Tauri type stars must be substantially smaller than 10^6 years, probably of the order of 2×10^5 years.

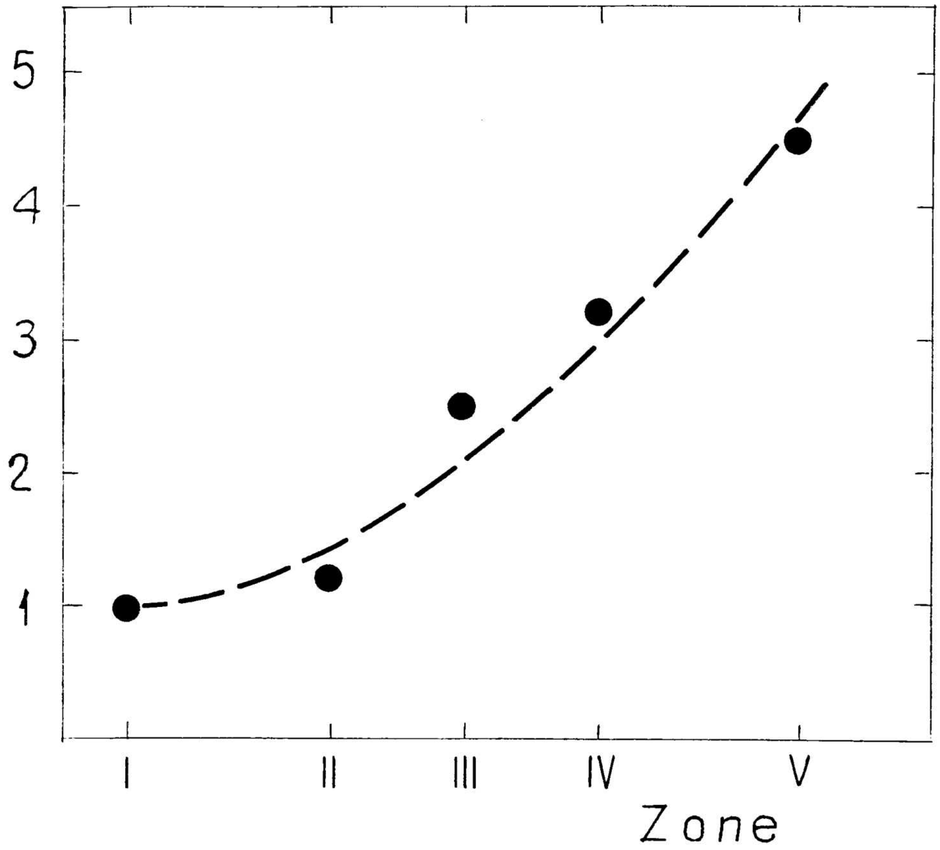

Fig. 3.—*The observed correlation between the relative number of flare stars with the distance from the centre of the Orion association.*

The example of the Pleiades cluster is an indirect but convincing proof in favor of the conclusion that evolution takes place from the T Tauri stage towards the flare star stage. Up to 1970 about 170 flare stars have been discovered in the Pleiades, but there are very few stars with strong H_α emission (Herbig 1950; Haro and Chavira 1965). An attempt by Herbig and Haro (See Haro 1968) to find T Tauri type objects in the Pleiades, among stars brighter than 16-17 visual magnitude, gave no positive results. On the other hand, the Pleiades cluster is considerably older than the Orion association (its age is estimated to be $\sim$ 2 to 4 $\times$ 10^7 years). Consequently, at present, the star formation process in the Pleiades is practically over; the last T Tauri stars probably originated about 2-3 $\times$ 10^7 years ago. The absence of typical T Tauri stars in the Pleiades may be explained either by suggesting that they never existed in this cluster or that they all became flare type stars. We do not have examples of very young clusters or associations without emission line stars; therefore, the former suggestion is not convincing. However, Haro's suggestion that in time T Tauri stars become typical or "pure" flare stars naturally explains their absence in the Pleiades. In such a case, the age of the cluster is likewise the age of the flare stars present in it.

With further reference to the established properties of the Orion flare stars, it should be pointed out that the increase of their flare activity linked to the increasing distance from the center of the association does not necessarily mean an increase of the general activity and strengthening of instability as the distance from the center increases. It can be exactly the contrary. As has been suggested by Haro and Chavira (1969) and by Gurzadyan (1970),T Tauri type stars present a permanent flare activity where the intervals between separate flares are practically nil or, using Haro's expression, the frequency of the flare-ups can be extremely high. In a given period of time the energy liberated during the "permanent" flare is much greater than that discharged by a star during incidental flares. But the relative number of H_α emission stars (stars with permanent flare activity) in the center of the Orion association is significantly greater than in its peripheries. Therefore, for the system of "flare stars + H_α stars", the nonthermal specific energy being discharged by one star will be much larger in the central part than in the peripheries.

Thus, the observed strengthening of the *relative* flare activity of Orion stars when moving from the center to the periphery of the association (Fig. 3) has an evolutionary explanation; it testifies to the weakening of the *general* activity of the stars (from the point of view of non-thermal energy) when receding, with aging, from the center of the association.

III. The dependence of the power of the outburst on the absolute luminosity of the star

If a flare star is, at the same time, a "normal" irregular variable, then for the same absolute amount of discharged outburst energy the amplitude of the sudden brightening will be larger when the star is at its minimum, and vice-versa. But the possibility is not excluded that the absolute amount of outgoing energy during the flare-up also varies, depending on the absolute luminosity of the star itself. This question can only be answered comparing with data on the power of the outburst, that is, on the mean amplitude of the flare-ups of the same star but at different stages of its irregular "normal" brightness.

Unfortunately, we do not yet have such data but we could try to answer this question based on the fact that *all* flare stars in a given association lie at the same distance from us; therefore, it can be considered that these stars (of different absolute magnitudes) as a whole are represented by a conventional flare star in different stages and with a variable absolute luminosity.

The practical application of this simple idea becomes difficult due to selection effects in our observed material, since for the faint flare stars lying beyond the limit of a given telescope the relatively small amplitude flare-ups are not registered, while in the case of bright stars both weak and strong outbursts are easily detected.

However observations in the ultraviolet might help overcome this selection effect. The limiting magnitude of the Tonantzintla Observatory 26-31″ Schmidt telescope lies at $U \sim 17^{m}5$ (Haro 1968); this means that a flare-up with an amplitude greater than $2^{m}5$ may be detected, without any selection, for *all* Orion flare stars brighter than $U = 20^{m}$. Considering that the amplitude of flares is larger than $2^{m}5$ while the stars themselves are brighter than 20^{m}, we can determine the real dependence of the mean power of the flare on the absolute luminosity of the star.

Selecting from the Tonantzintla Observatory lists (Haro 1968; Haro, and Chavira 1969) only those stars with listed magnitude and amplitude of the flare, we have found, in a quantitative form, the dependence of the mean amplitude of a flare $\overline{\Delta m_u}$ on its absolute luminosity; the dependence is given in Table 2.

TABLE 2

Dependence of the mean amplitude of the flare, $\overline{\Delta m_u}$, on the absolute luminosity for Orion flare stars

	15-16^m	*16-17^m*	*17-18^m*	*18-19^m*	*19-20^m*
Total number of flares ($\Delta m_u \geq 0^{m}5$)	11	16	27	43	8
Number of flares ($\Delta m_u \geq 2^{m}5$)	0	1	6	26	8
Mean amplitude $\overline{\Delta m_u}$	—	2.5	2.7	3.2	4.3

As can be seen in Table 2 the mean power of the flare $\overline{\Delta m_u}$ at first increases slowly, then faster, with decreasing absolute luminosity. In other words, the specific energy discharged in the form of a flare is larger in faint stars than in bright ones.

The flare stars in the Pleiades behave similarly, at least qualitatively, as can be seen from Table 3, in which 166 are included. The data of Tables 2 and 3 are presented graphically in Figure 4.

Thus, the data available at present on flare stars in Orion and the Pleiades permit us to conclude that the relative amount of energy discharged at a flare-up increases with the decrease of the absolute luminosity of the star. In other words, the flare stars show a tendency of getting rid of their inner energy faster with decreasing absolute luminosity. Simple calculations, based on the data of Tables 2 and 3, show that the *relative* energy discharged by flares of stars of $19\text{-}20^{m}$ is about two orders brighter than that of stars of $15\text{-}16^{m}$. But, in the case of stars of the $19\text{-}20^{m}$, the *absolute* energy of flares is only slightly larger than that of stars of the $15\text{-}16^{m}$.

TABLE 3

Dependence of the mean amplitude of the flare, $\overline{\Delta m_u}$, on the absolute luminosity for Pleiades flare stars

	$15\text{-}16^m$	$16\text{-}17^m$	$17\text{-}18^m$	$18\text{-}19^m$	$19\text{-}20^m$	$20\text{-}21^m$
Total number of flares in U ($\Delta m_u \geq 0^m5$)	24	31	15	26	25	6
Number of flares with ($\Delta m_u \geq 2^m5$)	2	4	7	18	21	6
Mean amplitude of flare $\overline{\Delta m_u}$	3.3	3.1	3.4	3.4	4.0	(5.4)

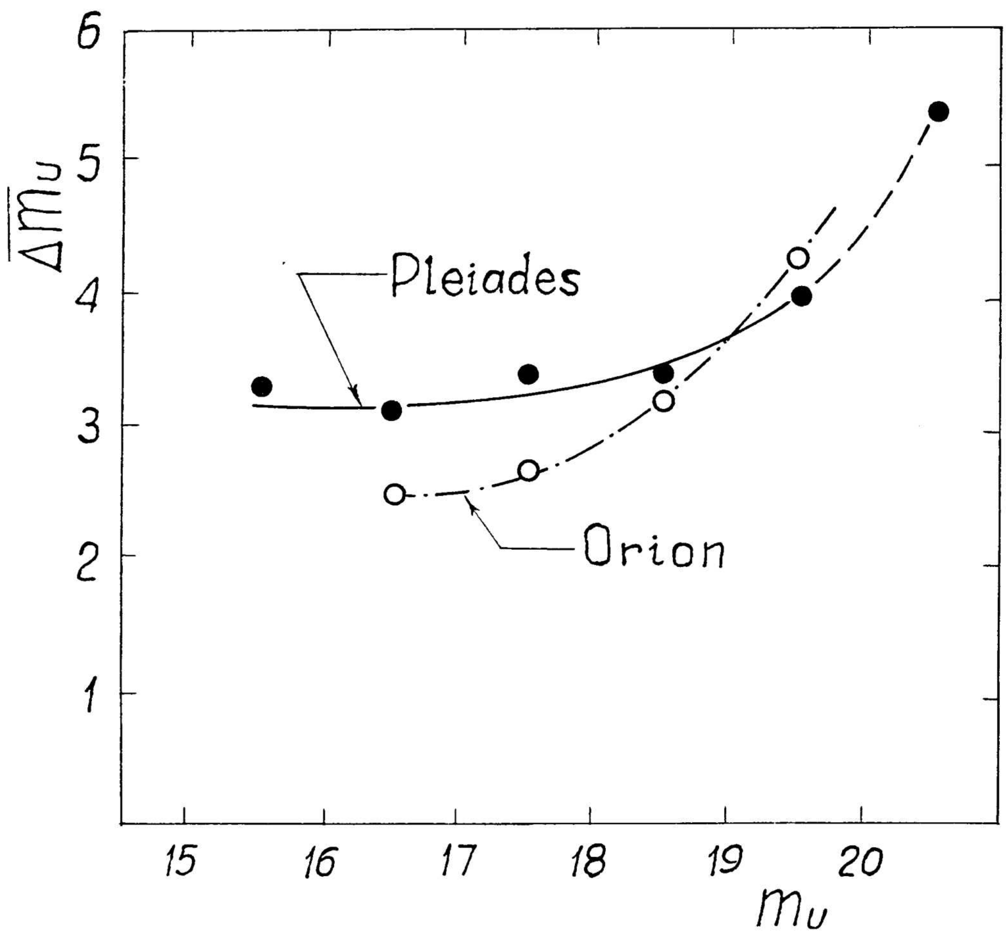

Fig. 4.—*The dependence of the power of flare stars,* Δm_u, *on the absolute luminosity of stars in Orion and the Pleiades.*

The above conclusion, which is rather unexpected, undoubtedly has a direct connection with the inner constitution of stars of late spectral types. In particular, the possibility is not excluded that there is some dependence between the above indicated property and the extension of the convective zone within the star. However, before going into further details, it is desirable to have additional data confirming this conclusion.

I am greatly indebted to Professor G. Haro for reading the manuscript and for valuable discussions.

REFERENCES

Gurzadyan, G. A. 1970, *Bol. Obs. Tonantzintla y Tacubaya*, **5**, 255.
Haro, G. 1953, *Ap. J.*, **117**, 73.
———. 1962, *Symposium on Stellar Evolution*, ed. J. Sahade (La Plata: Astr. Obs. Nat. University of La Plata), p. 45.
———. 1968, *Nebulae and Interstellar Matter*, ed. B. M. Middlehurst, and L. H. Aller (Chicago: University of Chicago Press), p. 141.
Haro, G., and Chavira, E. 1965, *Vistas in Astronomy*, **8**, ed. A. Beer and K. Aa. Strand (London: Pergamon Press), p. 89.
———. 1969, *Bol. Obs. Tonantzintla y Tacubaya*, **5**, 59.
Herbig, G. 1950, *Ap. J.*, **111**, 15.