FLARE STARS IN STELLAR ASSOCIATIONS AND CLUSTERS AND THEIR PLACE IN STAR EVOLUTION

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RESUMEN. Se consideran las estrellas ráfaga en asociaciones, cúmulos y en el campo de la Galaxia y se muestra que algunos parámetros que caracterizan la actividad de fulguración están relacionados con la edad de los agregados estelares. La actividad de fulguración es una etapa evolutiva inevitable a través de la cual muy probablemente pasan tanto las estrellas enanas de los agregados estelares como las de campo en la Galaxia.

ABSTRACT. Flare stars in associations, clusters and in galactic field are considered; it is shown that some parameters which caracterize flare activity are connected with the age of star aggregates. Flare activity is unavoidable evolutionary stage through which probably are passing dwarf stars in star aggregates as well as in galactic field.

INTRODUCTION

The study of early phases of stars in aggregates-stellar associations and clusters of various ages permit to retrace not only the evolution of stars of various masses but also to retrace the evolution of aggregates themselves.

Until recently the mass, the luminosity and the temperature have been considered as the basic parameters which characterize the physical state of stars. But now it is becoming clear that the flare activity is an important characteristics of relatively young stars of small masses ($M < 2\ M_{\odot}$), i.e. of the majority of stars. The flare activity is casual process and parameters which characterize such process need a careful definition. The problem of investigation of evolution of stars became more complicated. But at the same time the hopes that large variety of data will permit to interpret in a right way the existing facts is increasing.

Observations of T Tauri stars, flare stars and related objects in stellar aggregates carried out during the last decades, showed that in these cases we really deal with extremely young and interesting objects. Their study will permit to solve the problem of, those accesible to us, earliest stages of stellar evolution. At the same time it became clear, that no existing theory on stellar evolution fully satisfies the observations, which almost every year discover new facts. It is sufficient to name for example the discovery of fuors-stars which experience brightness increases similar to those of FU Orionis itself, or the presence of some flare stars below main sequence (Haro 1964).

I. VARIOUS FLARE OBJECTS

The idea on flare stars appeared after the discovery of flares in one of nearest star UV Ceti, by Carpenter in 1948 (Luyten 1949), though first flares have been observed much earlier by Hertzsprung in 1924 and by van Maanen (1940, 1945).

At present we deal with the following four types of objects which, from the point of view of physical process remind more or less the named star;

1. Flare stars of solar vicinity.
2. Flare stars in stellar aggregates.

3. The Sun and other dwarf stars which experience weak flares.
4. Flaring X-ray sources.

Before discussing the question as to what extent these objects are similar to each other and differ from each other, whether we deal with a common class of homogeneous events, we should pay attention to the fact that there exist stellar objects which flare but in a quite different way.

Those are Novae, Supernovae, stars of U Geminorum type, etc. of the noted objects of four types is by the following: many properties of their flares, in particular, the repeatibility, duration, are similar to each other but differ appreciably from that of Novae, Supernovae, stars of U Gem type, etc.

For a more correct determination of the type of a star in the outlined categories of dwarf flare stars it is worthwhile to formulate those properties which more or less characterize the types of stars. Observations of flare stars in solar neighbourhood and in stellar aggregates permitted to note those main properties, which are characteristic for the objects of the noted four types:

Those are:

1. Short duration of flare (minutes, rarely hours; according to photoelectric records flares of very small amplitude last less than a minute).
2. The absence of periodicity of flares and casualness of their distribution in time.
3. The appearance or increase of continuum spectra, especially in its short wave region during flare.

Observational data relating to flare stars in solar neighbourhood, in stellar aggregates and also to flare X-ray sources (bursters) and to the Sun showed that the nature of flare activity of objects of the first two types is the same. Let us consider these objects in more detail. But before turning to a detailed consideration of flare stars in stellar aggregates and in solar neighbourhood let us briefly dwell on solar flares and flare X-ray sources.

The energy emitted in chromospheric optical flares on the Sun are by 2-4 orders less than energy emitted during optical flares of stars of UV Cet type.

The Sun is around 10^3 times older than flare stars of the same spectral types in stellar associations. Even if to accept that the nature of flare activity of the Sun and stars of UV Cet type is the same, quantitative differences in the character of flares could appear during the evolution of the Sun.

The observational data on flare X-ray sources (bursters) indicate some similarity of them with flare stars of UV Cet type. But in the case of accepted distances the energy of flares of X-ray sources is by several orders more powerful than energy of X-ray component of UV Cet stars (Heise *et al.* 1975). The difference between these objects is qualitative. The fact that no flare X-ray sources are identified with flare stars, known from optical observations, confirms this.

Since we, more or less, know the ages of open star clusters, the study of flare stars in open clusters should be the basic way for understanding the relations between parameters which characterize flare activity and phase of evolution of the star. This should give the possibility to reveal changes of flare activity depending on age of the star.

The observational data relating to flares in aggregates, accumulated in many years, permitted to approach the solution of some problems connected with the role of flare activity in the evolution of stars.

II. FLARE STARS IN STELLAR ASSOCIATIONS, CLUSTERS AND GALACTIC FIELD

The flare activity of stars in stellar aggregates was first detected during searches of stars with Hα in emission and of fast variables in the Orion association (Haro and Morgan 1965). By that time the light curves of flares of stars of UV Cet type were known appreciably well.

First detected flares of the Orion stars already showed that photometric characteristics of their brightness during flare are very similar to that of flares of dMe type stars in the solar vicinity. In 1954 Ambartsumian's (1954) and Haro's (1954) papers appeared almost simultaneous in print. In the first paper, proceeding from the presence of continuous emission, and in the second one, proceeding from the photometric characteristics of flares, it was supposed that the flare activity of the Orion stars and in the solar vicinity is due to the same phenomenon. However, for the final decision the confirmations by spectral and colorimetric observations of both type of flare stars were necessary.

The most part of information on the nature of flare stars of UV Cet type in the solar vicinity have been obtained at the MacDonald and at the Crimean Observatories. Observations showed that the spectra of stars in the ultraviolet is being overflowed by continuous emission which extends far in the ultraviolet. As far as in the visual and red regions of the spectra, the changes are less prominent. (Kunkel 1967, Gershberg 1970).

Spectral and simultaneous photoelectric observations made by Bopp and Moffett (1973, 1976) showed that fast rise, up to the maximum, is determined by continuous emission, the duration of the emission being of the order of 1-3 minutes.

Proper emission of flares of UV Cet type have the following color indexes: $\overline{U-B} = -1^{m}.2$, $\overline{B-V} = -0^{m}.1$ (Gershberg 1970).

First spectral observations of flare stars in the Orion were made in the red part of spectra by Haro (1964) with the 4° objetive prism at the Tonantzintla Observatory. Observations showed that the Hα emission line is appearing or is becoming more intense during the flare, meanwhile continuum in the red part of the spectra remains almost unchanged. First spectral observations of flare stars in the Pleiades star clusters have been carried out in the Byurakan Observatory (Parsamian 1972) with the 40" Schmidt telescope in conjunction with 1°.5 objective prism, which permitted to study the behaviour of the continuous spectrum in the region from 3600 Å to 6000 Å. The distribution of energy in the longwave part of the spectrum of the flare of M4 type star (obtained by substracting the spectrum of a star in normal state from the observed one) was similar to that of stars of late *A* subtypes, the shortwave part of the spectrum was similar to that of early *B* type stars. Thus during flare the emission in the visible part has increased, the shortwave part has changed due to appearance of strong continuous emission with a maximal intensity in the interval λλ3600-3200 Å. Spectral observations fully confirm the hypotheses on the identity of the nature of flare stars in the solar vicinity and in aggregates.

To answer the question as to whether there exists a quantitative difference between proper colours of radiation during flaring of the UV Cet type stars and flare stars in stellar aggregates, multicolour observations in stellar associations and clusters were needed. Measurements of the colour of radiation in UBV (Kunkel, Moffett), of stars of almost exclusively of solar neighbourhood have been made yet before seventies.

First casual three colour observation in UBV of the flare of the star HII 1306 in the Pleiades was made by Johnson and Mitchell (1958). This observation showed, first, that flare stars exist not only in stellar associations but also in middle age clusters and, second, that the colour of the flare does not differ from that of stars in the solar neighbourhood.

First systematic simultaneous photographic observation in U and B of flare stars of the Pleiades started in 1970 at the Byurakan Observatory (Parsamian and Chavushian 1972, 1975), and were followed by three colour observations in UBV (Mizzoyan *et al.* 1981). The results of all these observations led to one conclusion: the flares of stars in stellar aggregates do not differ by their spectral and colorimetric characteristics (within the limits of the spread of those parameters from those of stars in the solar vicinity.

Thus, the flares of stars both in stellar aggregates and in the galactic field have common physical nature which means that the evolution processes characteristic for flare stars in stellar aggregates are characteristic for the galactic field stars as well.

III. FLARE STARS AS ONE OF THE SUBSEQUENT STAGES OF EVOLUTION OF T TAURI TYPE STARS

On of the important conclusions made by Haro (1964) from the study of flare stars in the Orion stellar association was the conclusion that flare activity is a subsequent stage of evolution of T Tauri type stars. A little later, in 1970, Ambartsumian showed that about a quarter of RW Aurigae type stars undergo flares and also that observations evidence that flare activity starts only after the development of RW-stage or may be a little before its end. New observational data permit to think that the percentage of stars of RW Aur's which undergo flare activity is appreciably more than a quarter.

In turning to a middle age cluster like, for example, the Pleiades, flare stars almost completely loose the characteristics of the RW Aur type stars.

IV. TOTAL NUMBER OF FLARE STARS IN STELLAR CLUSTERS

One of the main problems in studying flare stars in a system is the estimation of the full number of flare stars, the knowledge of which permits to answer another, not less important question: whether all dwarf stars in aggregates are flare stars?

To estimate this number by discovering all or a almost all flare stars in the aggregate the observations during several tens of years are needed. But Ambartsumian (1969) solved the inverse problem, and using known, from observations, numbers n_1, n_2 of flare stars which have been observed once or twice, respectively, showed how to determine the number n_0 of flare stars which have not yet been observed and then to determine the total number of all flare stars in a given system:

$$n_0 \leq \frac{n_1^2}{2n_2}$$

According to this the total number of all flare stars in the Pleiades cluster is about 1000, while the number of all stars in the Pleiades (estimated from the probable mass of the cluster) has always been less than this figure. On the basis of this an important conclusion was made: the flare activity is a natural phase in evolution of dwarf stars and that this phase should be passed by all or almost all stars of this type (Ambartsumian 1969).

Ambartsumian and his collaborators (1971), using statistical data assumed that the majority of the flare stars have certain cycles of flare activity with a duration of periods of about ten years or even more, and that during more than half of the time, activity of stars is by several times less than mean activity. This probably explains the fact that in the epoch of our observations only about half of the stars with stellar magnitudes in the interval $14. \leq m_{pg} \leq 16.0$ have flared. These stars were suggested to be members of the Pleiades by their proper motions according to Hertzsprung *et al.* (1947). The percentage of flared stars is about 80% if we use Jones (1973) definition of the cluster membership.

V. THE DETERMINATION OF AGES OF STELLAR ASSOCIATIONS AND OPEN CLUSTERS

The study of stellar clusters has been made in the past by the study of their bright members. But the detection of a large number of flare stars in stellar associations and clusters and also the fact, that the flare activity is a natural stage of evolution of dwarf stars, indicated the possibility to study the evolution of stellar aggregates and their ages by the study of flare stars.

The method of determination of the age of the cluster by the absolute luminosity M_V of the turning point on the Hertzsprung-Russell diagram in the case of very young clusters meets with a difficulty that arises from the appreciably large dispersion of the luminosities M_V for a given spectral type and for a given age. As the result of this, the turning point is sometimes being determined with great uncertainty. Therefore it is natural to look for other criteria for the determination of ages. It is at the same time desirable that the parameters used for this purpose be very sensitive to age in young clusters. Since each young cluster contains a totality of flare stars, the statistical properties of which strongly depend on the age, it is natural to look among parameters, describing this totality for the criterium of age. Haro (1964) was the first who mentioned that the earlier the spectral type of the brightest star the younger the cluster.

After Haro's (1964) work it became obvious that the earliest spectral type of a flare star or its absolute stellar magnitude (at minimum brightness) of one of the brightest flare stars (Parsamian 1976), that is the coordinates of that point on the main sequence which separates flare stars from non flare stars, may be considered as such a parameter. Unfortunately the determination of this point is somewhat undefinite task depending a little from the method and duration of observations. Therefore, it is desirable to accept as a criterium such parameters for the determination of which a large number of observational data have been used.

The determination, from observations, of the absolute magnitude of the brightest flare star in each of the studied stellar aggregates gives the basis for arranging aggregates in order of increasing M_f (absolute stellar magnitude of the brightest flare star). The comparison of this array with the aggregates age (T), determined with the, considered as a classical, method of deflection in the upper part of main sequence, permits to suggest that M_f is a monotonously increasing function of age, $M_f = \phi(T)$. Of course on the basis of data from three or four stellar aggregates and because of some uncertainty in the determination of M_f, it is difficult to decide how strong this monotony is. Moreover, it is hard to reject the possibility that the value of M_f may be affected both by the age and by some other parameters of the cluster such as, for example, chemical content, total mass, etc. Nevertheless, the obtained data evidence such a strong dependence of M_f with age that it seems reasonable to accept conditionally, as a starting point, that M_f is a monotonous function of age, independent of other parameters.

Thus for the determination of the degree of evolution of a stellar aggregate there are at present two parameters: the absolute magnitude of the brightest star of the cluster, M_V, and the absolute magnitude of the brightest flare star at minimum brightness, M_f, the dispersion of M_V being larger that the statistically determined dispersion of M_f. Both of these two values are functions of the age T and should be connected with each other. In the first approximation the connection between M_V and M_f may be presented as

$$M_V = -12.2 + 2.1 M_f$$

After choosing the parameter or parameters sensitive to age, the question of the absolute calibration of the parameters remains, i.e. the determination of its (or their) dependence with age.

The richness of stellar aggregates in flare stars may without any doubt, permit to determine more definitely the ages of the aggregates by the study of flare stars. But to turn into the determination of the age in years, the method of absolute calibration should be developed. Unfortunately such an absolute calibration, very rough of course, may be made only with the use of ages of clusters determined by the turning point of the upper part of the main sequence on the Hertzsprung-Russell diagram. But as we will see later, we can, on the basis of the mentioned Haro's rule or flare energy, say very definitely which one of two stellar aggregates is older.

Let us consider now in more detail the dependence of the cluster ages from the flare energies.

The study of flare stars in stellar associations and clusters showed that there exists a dependence between upper limits of flare amplitudes and luminosities of stars of different clusters (Parsamian 1976, 1977). This dependence obtained for difference clusters (Orion, Pleiades, Praesepe) with known ages, permitted to obtain the dependence between an angular coefficient of the straight line, which characterizes the distribution of the maximal amplitudes of flares of cluster stars, and the age:

$$K = 1.31 - 0.06 \log T \tag{1}$$

Thus knowing from observations only the values of flare amplitudes it is possible to determine the age of the cluster. In such a way, the age of the cluster NGC 7000 turned to be of the order of 2.10^6 years.

If, on the other hand, the distance of the cluster is known, its age could be determined by using the relation

$$\log T = 0.7 M_f + 3.9 \quad , \tag{2}$$

where M_f is the absolute magnitude of the brightest flare star of the cluster in the ultraviolet.

The ages of stellar aggregates in which flare stars have been observed could be also estimated by using the mean absolute magnitude of flares of the whole cluster as a parameter. If, as it follows from what it was said, for each value of brightness there exists a maximal amplitude of flare, then it means that the mean energy of flares of clusters of different ages should depend on the cluster age. The younger is the cluster the larger should be the mean energy of flares of the whole cluster. Using the data from three stellar aggregates with known ages, the following dependence between the mean energy of flares of the whole stellar aggregate and its age is obtained by using the mean absolute magnitude of pure flares of the first 20 brightest flare ups, $\overline{M}_o$,

$$\log T = 0.6 \overline{M}_o + 4.0 \tag{3}$$

VI. THE DETERMINATION OF AGE OF FLARE STARS OF GALACTIC BACKGROUND

The data on flare stars in stellar aggregates permit not only to determine the age of aggregates themselves but also, which is more important, to suggest a method of determination of ages of flare stars by some natural extrapolation. The importance of the problem is understandable if we consider that the origin of flare stars of the solar neighbourhood and of the general galactic field is not known until now.

The comparison of the energies emitted during flares in different clusters showed that the change of flare energy takes place mainly with the change of age. The increase of the aggregate age leads to the decrease of the maximal energy emitted during flare. This fact permitted to determine the existence of a dependence between the absolute magnitude of the maximal flare ups and the ages of the flare stars of different luminosities, namely,

$$\log T = C_1 - C_2 M_{o(max)}$$

If the obtained dependences between the brightness of maximal flare, ups the absolute magnitude of the star and the age are universal, then they open the possibility to determine the age of any flare star of known absolute luminosity on the basis of these dependences if so many flares have been observed that the maximal absolute luminosity of its flare is possible to estimate with more or less accuracy.

Knowing $M_{o(max)}$ from observations it is possible to determine the age of the star. Thus the ages of the most observed flare stars of the solar neighbourhood should not exceed the following values: BY Dra: 7.10^8 years; AD Leo and EV Lac: 3.10^8 years; YZ CMi: 1.10^9 years, and UV Cet: 9.10^8 years. At this point we may note that the obtained data on flare stars of late dM_e types showed that they could very conditionally be called young stars.

VII. THE FUNCTION OF THE FREQUENCY DISTRIBUTION OF FLARES IN A STELLAR AGGREGATE

The next question which is also connected with the evolution of stellar clusters is the determination of the distribution function of the frequency of flares stars of a cluster. Observations of flare stars in stellar aggregates showed that flare stars have different frequencies of flares which depends of the cluster age, the luminosity of a flare star, etc.

We have presented above the method of determination of a full number of flare stars in a cluster by using, in a first rough approximation, the idea on the mean frequency of flares for the whole cluster.

But for the description of an aggregate of flare stars both the total number of flare stars N and the function of their distribution $f(\nu)$ by mean frequencies ν should be known. To solve this problem it is necessary to monitor the cluster for a long time to estimate for each flare star the value of the mean frequency of its flares. This procedure could not be carried in practice since the observations of stellar aggregates during the last 20 years permitted to discover more than two flares of just a negligible part of flare stars while the basic part of flare stars remain undetected yet. For this reason Ambartsumian (1978) put forward the problem of the statistical determination of the *total number* of flare stars and of their distribution by the mean frequencies of flares without determination of the mean frequencies for each star. The problem was solved by using the chronology of detecting "the first flares" and chronology of confirmations, i.e. distribution by time of "second flares". For the determination of the unknown mean frequency of flares the conversion of the Laplace integral transformation should be made and the distribution function of the mean frequency of flares with an accuracy of a constant coefficient should be determined; finally

$$f(\nu) = Ce^{-\nu s} \nu^{-4/3} ,$$

and the relation for the total number of flare stars for different frequency intervals are obtained:

$$dN = NC\, e^{-\nu s} \nu^{-4/3}$$

Ambartsumian (1978) used this results namely for the Pleiades in the case of which the parameter S = 385 hours.

Similar calculations have been made for the Orion association (Parsamian 1980). The distribution function of flare frequency for the Orion association was the same as for the Pleiades cluster, just the parameter $S \approx 1400$ hours.

The age of the Pleiades cluster is by two orders more than that of the Orion association, therefore it is natural to expect the change of some "age" parameters which characterize the flare activity of stars. The comparison of the total number of flare stars with the mean frequencies of flares larger than some ν_0 in the Orion association and the Pleiades cluster showed that in the Orion association there are practically no stars with the mean interval between flares $\leq 400^h$, and in the Pleiades there are about 20 such stars, i.e. the Pleiades are richer in frequently flaring stars which, as investigations showed, are weak stars with absolute magnitudes in the ultraviolet $\geq 13^m$ (see Table 1).

Meanwhile starting already from the mean interval between flares of about 1800^h, the number of flare stars in the Orion association is larger than in the Pleiades cluster. Thus perhaps at the initial phase after the formation of the association the frequency of flares of all

TABLE 1

Pleiades		Orion association	
P*	N	P*	N
77	0.04	231	0.06
96	0.18	278	0.25
128	0.7	347	0.84
192	3.1	463	3.50
385	17	694	13.9
1280	94	1389	32
		4630	468

* P is the interval between two consequent flares. N is the total number of flare stars. The data are given for the Pleiades and the Orion association correspondingly.

flare stars has been of the same order. The same refers to the distribution of flares by their energies as well. But the flares of brighter stars happen more frequently though the observed frequency may even be smaller since flares of small energies are not observable. The frequency of flares of bright stars decreases with time faster and, in the case of weaker stars, higher frequency of flares is observed.

CONCLUSIONS

We considered some parameters which characterize flare activity of stars and showed that they all are connected with the age of aggregates which contain flare stars.

Thus flare activity is a natural evolution stage of development of dwarf stars, the stage which both the dwarf stars in clusters and stars in general galactic field pass through.

REFERENCES

Ambartsumian, V.A. 1954, *Comm. Byurakan Obs.* 13, 3.
Ambartsumian, V.A. 1969, *Stars, Nebulae, Galaxies* (Erevan), p. 283.
Ambartsumian, V.A., Mirzoyan, L.V., Parsamian, E.S., Chavushian, O.S., Erastova, L.K. 1971, *Astrofisika* 7, 319.
Ambartsumian, V.A. 1978, *Astrofisika* 14, 367.
Bopp, B.W. and Moffett, T.S. 1973, *Ap. J.* 185, 239.
Bopp, B.W. and Moffett, T.S. 1976, *Ap. J. Suppl.* 31, 61.
Gershberg, R.E. 1970, *Flare of Red Dwarf Stars* (Moscow).
Haro, G. 1954, *Bol. Obs. Tonantzintla* 11, 11.
Haro, G. 1964, *IAU Symposium № 20, The Galaxy and the Magellanic Clouds*, ed. F.I. Kerr and A.W. Rodgers, p. 30.
Haro, G. 1968, *Stars and Stellar Systems*, eds. B.M. Middlehurst, L.H. Aller, Chicago, 7, 141.
Haro, G. and Morgan, W.W. 1953, *Ap. J.* 118, 16.
Heise, J., Brinkman, A.C., Schijver, J., Mewe, R., Gronenchild, E., Boggende, A. and den Grindlay, J. 1975, *Ap. J.* 202, L73.
Henoux, J.C., Nakadawa, Y. 1977, *Astron. Astrophys.* 57, 105.
Hertzsprung, E., Sanders, C. and Kooreman, C.J. 1947, *Ann. Leiden Obs.* 19A, 5.
Johnson, H.L., Mitchell, R.I. 1958, *Ap. J.* 128, 31.
Jones, B.F. 1973, *Astron. Astrophys. Suppl.* 9, 313.
Kunkel, W.E. 1967, *Optical Study of Stellar Flares* (Austin).
Luyten, W.J. 1949, *Ap. J.* 109, 532.
Mirzoyan, L.V., Chavushian, O.C., Melikian, N.D., Natsvlishvili, R. Sh., Ohanian, G.B., Hambarian, V.V., Garibjanian, A.T. 1981, *Astrofisika* 17, 197.
Parsamian, E.S. 1972, *Comm. Byurakan Obs.* 44, 14.
Parsamian, E.S. 1976, *Astrofisika* 12, 235.
Parsamian, E.S. 1977, *Star Cluster Symposium* (Budapest), p. 119.
Parsamian, E.S. 1980, *Astrofisika* 16, 677.
Parsamian, E.S., Chavushian, O.S. 1972, *Comm. Byurakan Obs.* 44, 17.
Parsamian, E.S., Chavushian, O.S. 1975, *Comm. Byurakan Obs.* 46, 18.

van Maanen, A. 1940, *Ap. J.* 91, 503.
van Maanen, A. 1945, *P.A.S.P.* 57, 216.

DISCUSSION

Peimbert: Has there been any photometric work, in the Soviet Union, to try to find out if there are flare stars below the main sequence?

Parsamian: Such work on flare stars in Pleiades was made in Byurakan Observatory.

Storchi Bergmann: How do you detect the flare stars?

Parsamian: It is well known of multiple imagines which first used G. Haro.

Peimbert: Which is the relation between the absolute energy of the most energetic flare, for a given spectral type, and the spectral type

Parsamian: The brightest the flare star more energetic the flares with maximal amplitudes.

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