FLARE STARS IN STAR CLUSTERS, ASSOCIATIONS AND SOLAR VICINITY

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ABSTRACT. The observational data on flare stars observed in star clusters and associations as well as in the solar vicinity (the UV Ceti type stars) are discussed. The analysis of these data show that they constitute one common class of objects possessing flare activity and the differences between them are conditioned by the age differences. The stage of flare activity is an evolutionary stage, one of the earliest stages of evolution passed by all red dwarf stars. It comes before the end of their T Tau stage of evolution. The UV Ceti type flare stars in the solar vicinity seem to be the population of the general galactic field, which were formed in the systems, already desintegrated. Most probably the stellar flares are the result of the release of the the surplus energy having intra-stellar origin.

1. INTRODUCTION

The discovery of flare stars in associations and star clusters of different ages turned out to be significant for the problem of stellar evolution. Namely, this discovery allowed to establish that the flare star stage is an evolutionary stage for all red dwarf stars. At the same time it has been shown that this stage of flare activity is one of the early stages of evolution of dwarf stars. Thus, owing to the study of flare stars a possibility has appeared to receive a definite idea on the evolution of dwarf stars based on the observational approach (see, for example, [1-5]).

On the other hand, the study of flare stars, on the whole, is of great importance for the physics of stars, as the discovery of flare phenomenon in young stars was compeletely unexpected for the contemporary theories of stellar evolution and has not yet its generally assepted

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explanation. Therefore, because of the wide range of flare star luminosities observed in star clusters and associations of different ages indicating on large scale differences in conditions of formations of stellar flares their study can bring to a better understanding of the nature of this unusual phenomenon (see, for example, [4]).

Owing to these two circumstances the further investigations of flare stars became one of the actual problems of modern astrophysics.

In this paper we discuss some results of the flare star study in the light of the investigations carried out at the Byurakan Astrophysical Observatory.

2. EVOLUTIONARY STATUS OF FLARE STARS

An estimate of the total number of flare stars in the comparatively young (age $7x10^7$ years [6]) star cluster Pleiades, obtained by Ambartsumian [7] showed that all (or almost all) stars of low luminosities in this system are flare ones. This unexpected result based on an analysis of observational data had extraordinary importance. It brought to natural conclusion that all dwarf stars at a definite stage of their evolution possess an ability to show flares of radiation i.e. possess flare activity.

The fundamental conclusion showing that the flare activity characterizes an evolutionary stage of red dwarf stars has been confirmed by further investigations of flare stars in the Pleiades and other stellar systems of different ages (see, [4,8].

Owing to the fact, that young dwarf stars, in one of the early stages of evolution possess high flare activity, an unusual rich abundance of flare stars is observed in associations and in comparatively young star clusters. The following Table 1, which contains the estimates of the numbers of them - N in some nearest clusters and associations, is a good illustration of this.

The estimations of total numbers of flare stars presented in Table 1 have been received by the simple formulae [7] giving the number of unknown flare stars in system

$$n_o = \frac{n_1^2}{2n_2}$$

where n_1 and n_2 are numbers of flare stars observed in one and two flares respectively. (This formulae gives the lower limit of the number n_o [9]).

The data of Table 1 show rich abundance of flare stars in young and comparatively young stellar systems, which is a strong confirmation of the above mentioned evolutionary status of flare stars. They testify, that the stage of flare activity is indeed one of the early stages of evolution for red dwarf stars.

TABLE 1. The numbers of flare stars in some nearest star clusters and associations [10]

System	n	n_o	N
Pleiades	546	448	994
Orion I	482	989	1471
TDC*	102	430	532
Cygni(NGC 7000)	67	336	403
Praesepe	54	161	215
Monocerotis I (NGC 2264)	42	400	442
	1293	2764	4057

* TDC - Dark Clouds in Taurus

3. DURATION OF THE FLARE ACTIVITY STAGE

According to generally accepted idea the rates of evolution depend on the mass of a star, in the sense that the duration of any evolutionary stage decreases with the stellar mass (luminosity). In particular the duration of the flare activity stage should decreas with the increase of luminosities of flare stars. There are several observational manifestations of this phenomenon.

1. The luminosity of the brightest flare star in a given system depends on its age. The older the system the higher this luminosity (the earlier the spectral class of the brightest flare star). This regularity has been detected by Haro and Chavira [8].

2. The relative number of flare stars among all red dwarf stars in each system is increasing to the lower luminosities. This number for a definite luminosity seems to be decreasing with the increasing of the age of the system [11].

3. The older the system containing flare stars the lower their luminosities [12].

These regularities can also be considered as evidences in favour of the evolutionary status of flare stars.

The correlation between the mean luminosity of flare stars and the age of the corresponding system, based on the

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photographic observations of flare stars in the nearest star clusters and associations is presented in Fig.1.

This correlation allows to estimate the age of a system by the mean luminosity of flare stars in it, that is the mean luminosity of flare stars is a definite indicator of its age.

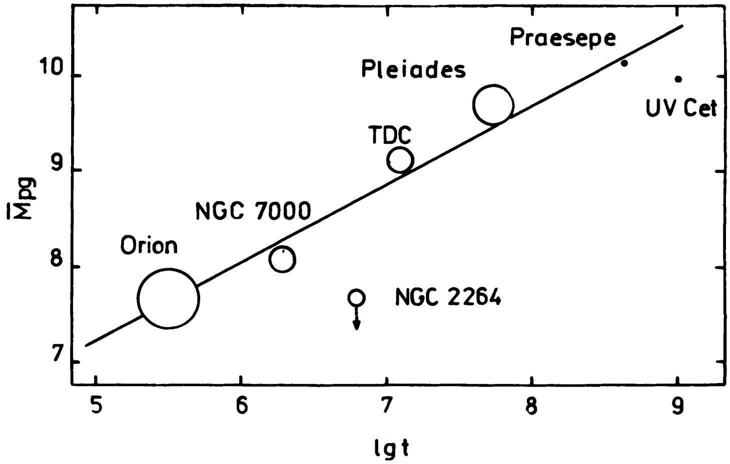

Figure 1. Correlation between the mean absolute photographic magnitude (M_{pg}) of flare stars and age of the system (t, in years) containing them. The circle areas are proportional to the numbers of stars used. After the paper [14].

Fig.1 indicates, that the age of flare stars can reach hundreds of millions and more years. Indeed, calculations made by Kunkel [13], for example, show that for stars having luminosity equal to $M=15^m$ the duration of flare activity stage approaches 10^{10} years that is the age of our Galaxy.

Thus, in spite of the fact that the evolutionary stage of flare activity is one of the early stages in the evolution of red dwarf stars a star of low enough luminosity can stay in this stage hundreds of millions and more years.

For our further discussion it should be noted that Fig.1 shows in particular that the UV Ceti type flare stars of the solar vinicity have very low luminosities, which correspond to their old age.

This is a very important conclusion. In the light of this conclusion the existence of a large number of flare stars possessing very low luminosity in the general star field of the Galaxy should be explained namely by the large duration of the flare activity stage for very low luminosity stars (mainly of M-type).

4. THE UV CETI TYPE STARS- THE POPULATION OF GENERAL GALACTIC STAR FIELD

Let us assume that the space distribution of the UV Ceti stars in the Galaxy is uniform. In this case the observational data on these stars in the vicinity of the Sun allow us to estimate the number of flare stars which can be discovered (during the definite time) by photographic observations made with the wide-angle telescopes in the regions of the sky free of star clusters and associations. A comparison of such estimations with the results of the flare star observations showed [15] that they are in agreement. It means that our assumption is right: the space distribution of the UV Ceti stars at least in the observed part of the Galaxy is practically uniform. Speaking more exactly they are distributed approximately in the same way as all faint stars. Taking into account that the UV Ceti stars are similar to the flare stars in star clusters and associations in their physical properties [14] one can conclude that they constitute a population of general galactic field [15]. Moreover, it is very probable to assume that the density of number of the UV Ceti type flare stars does not differ in other parts of our Galaxy. They were formed in associations and clusters but having very low luminosities the UV Ceti type stars survived their maternal systems which were desintegrated already.

The mean density of the number of flare stars in stellar aggregates exceeds their mean density in the general star field in some orders of magnitude. For example, the mean density of flare stars in the Pleiades cluster is larger than that in the general galactic field at least by two orders of magnitude. Calculations showed [16] that the relative number of the background flare stars among flare stars observed in the regions of star clusters and associations is less than 20% . As their mean flare frequencies are lower than the mean frequencies for the members of aggregates this relative number can not be larger than 10% of known flare stars.

Assuming that the UV Ceti stars present a population of the general galactic field and their space distribution is uniform in the sense that their percentage among all stars is the same everywhere and equal to that near the Sun one can estimate the total number of them in the Galaxy. It turns out to be equal to 4.2×10^{9}. According to the luminosity functions of the corresponding groups the total number of non-flaring red dwarf stars must be essentially larger. Assuming further that the ratio of flaring and non-flaring red dwarf stars is the same for the whole Galaxy then for the total number of non-flaring red dwarfs one can obtain 2.1×10^{10}.

Therefore, the total number of red dwarf stars in the

Galaxy will be $2.5x10^{10}$, that is about one forth of the total number of all stars in our stellar system. Taking into account that the masses of red dwarf stars in the most cases are not larger than $0.1\mathfrak{M}_\odot$ for the total mass of all red dwarf stars in the Galaxy we obtain a magnitude of the order of $10^9\mathfrak{M}_\odot$. This does not contradict to Oort's estimation [17].

The observational data on the UV Ceti stars of the solar vicinity are in agreement with the idea that they are coming out from the desintegrated systems - star clusters and associations. Apparently, this conclusion is correct also for non-flaring red dwarfs of the general galactic field. In favour of this conclusion one can consider in particular the calculations of the numbers of stars which could be formed in the OB- and T - associations, correspondingly, during the life of our Galaxy, made by Ambartsumian [18] as far back as in 1950. They testify that all stars of the flat and intermediate subsystems in the Galaxy could be formed in stellar associations.

5. FLARE STARS - POST T TAURI STARS

Due to the fact that the duration of each evolutionary stage depends on the mass (luminosity) of stars in associations we observe stars which are in different stagesof evolution. The existance of the stars being in different evolutionary stages in the same system allowed to determine the sequence of the early stages which were passed through by stars on the base of their observations in stellar associations only.

For example,in stellar associations the flare stars coexist with the T Tauri stars, which represent the typical (characteristic) population of the T-associations. At the same time they are numerous in the comparatively old star clusters like the Pleiades and Praesepe, where the T Tauri stars are absent.

This means, that the T Tauri stars are younger than flare stars and naturally are in the earlier stage of evolution. At the same time this observational fact indicates, that the duration of the T Tauri stage in average is shorter than that of the flare activity stage.

These important circumstances gave grounds to Haro [19] to conclude for the first time that the evolutionary stage of flare activity of red dwarf stars follows immediately the stage of the T Tauri stars. This conclusion became firmly established as a regularity of stellar evolution after Ambartsumian's [7] first estimation of the total number of flare stars in the Pleiades cluster and its qualitative confirmation by observations .

Indeed, as one can see from Table 1 the number of the known flare stars in the Pleiades region is at present 546.

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Out of them not more than 10% can be the general galactic field stars. Therefore,the number of known flare stars in this cluster already exceeds 500 i.e. larger than we had from the initial estimate of it.

The conclusion on the connection of the stage of flare activity with the T Tauri stage brings to two serious questions:

1.Whether all T Tauri stars transform into flare stars;

2.Whether it is the possible transition from the T Tauri stage to the stage of flare activity, if we consider the masses (luminosities) of the corresponding stars.

The first question have been discussed in Ambartsumian's paper [20]. It has been shown that in the Orion association about one forth of all T Tauri stars were at the same time flare stars (known or having ability to show photographic flares). This estimate of the relative number of the T Tauri stars having flare activity is an approximation. The new estimations show that it can reach 50% (see, for example, [21]).But it is more important that there is no doubt at present that not all T Tauri stars are flaring-up. However, the analisis has shown that the answer to the first question is apparently positive: it is difficult to assume that the red dwarf stars have two different ways of evolution. As to the second question, the transition between the T Tauri and UV Ceti stages seems to be quite possible from the point of view of the corresponding obsereved luminosities.

6. PHYSICAL PROPERTIES OF THE FLARE STARS

Thus, at present there are enough grounds to consider that the flare stars observed in star clusters and associations and the UV Ceti stars of the solar vicinity have common physical nature and the observed differences betweenthem are due to the defferences in their ages.

Indeed, the flare stars in star clusters and associations being formed comparatively recently, are connected with a more or less dense diffuse matter, they have higher luminosities and are more active than the UV Ceti stars of the solar vicinity. The latter, on the contrary, left already their maternal systems, where they were formed, the diffuse matter co-existing with them in their youth has dispersed long ego, now they have lower luminosities and are less active. According to the space distribution the UV Ceti stars constitute a population of the general galactic field.

Due to their low luminosities the UV Ceti type stars can be observed only in the nearest vicinity of the Sun. That is the reason that the physical study of stellar flares' phenomenon practically is completely based on the observations of the UV Ceti stars of the solar vicinity.

Almost all information on physical properties of stellar flare radiation at present was obtained from the UV Ceti flare observations. These observations include the wide region of spectrum, beginning from radio and finishing with far ultraviolet and X-ray wavelengths.

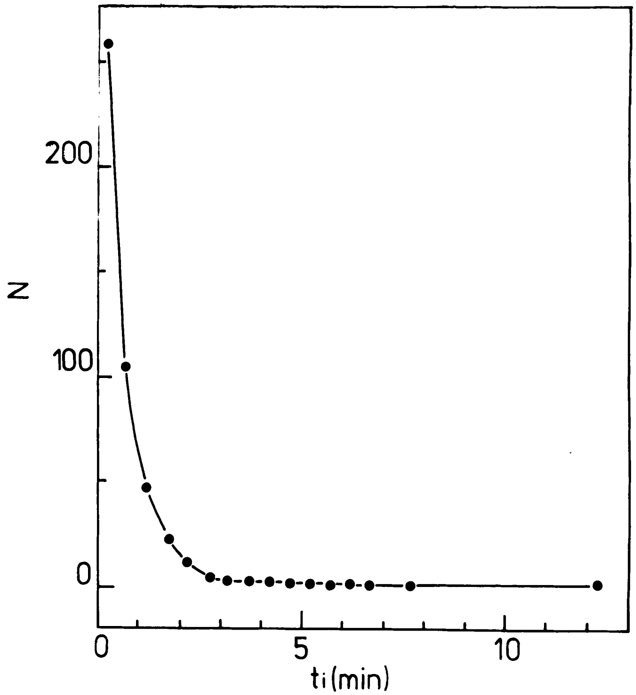

Figure 2. The distribution of the increasing times of flares – t_i for the UV Ceti stars according to Moffett's photoelectric observations [23]. N – number of flares. After the paper [24].

On the contrary, the photographic observations of stellar flares in star clusters and associations were very important for the evolutionary study of flare stars. At the same time they helped us for better understanding of the nature of flare phenomenon.

In this connection, it should be particularly mentioned that namely owing to photographic observations of stellar flares in systems Haro [22] has divided all flares into two classes, according to their increasing times: "fast" flares with this time shorter than 20–30 min, and "slow" flares for which it is longer.

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The flares of these two classes possess some, quite different pecularities. Though as it has been shown recently the distribution of flares by the increasing time (Fig.2) is a continuous one. i.e. quite different increasing times are observed Haro's classification is of great significance for understanding of the flare phenomenon.

The matter is that, the "fast" and "slow" nature of flares does not depend on the physical state of a flare star having a flare on the whole , but due to physical conditions in the active zone of a star, where the energy of flare is liberated. In favour of this conclusion one can consider the eloquent obsevational fact, that the most flare stars, observed in"slow" flares have shown also "fast" flares.

As an illustration of this observational fact on Fig.3 light curves of two complex flares are presented,which are combinations of two flares, happened on the same star one after another. The first of them is a combination of light curves of "fast" and "slow" flares.

Without considering the physical pecularities of stellar flares belonging to two mentioned classes we would like to note that their differences (velocity of light increasing, mean frequency, colour of flare emission, total energy of optical radiation) can be explained satisfactorily by Ambartsumian's hypothesis [26,27] on the flare activity.

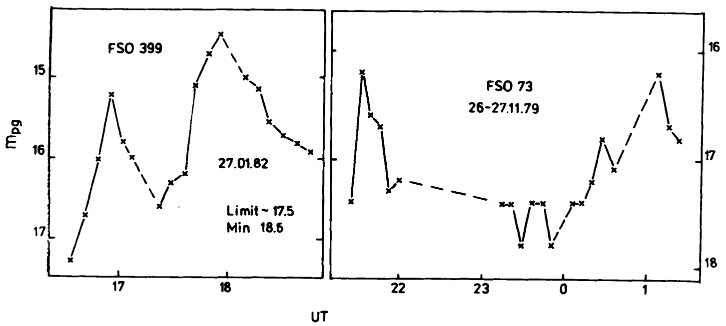

Figure 3. Photographic light curves of two complex flares observed on the Orion flare stars No.73 and No.399, which are combinations of light curves of "fast"-"slow" and "slow"-"slow" flares, respectively. After the paper [25].

According to this hypothesis (see, in detail, [4]) the differences between "fast" and "slow" flares are due to the differences existing in the star atmospheric layers, where a flare is held (above or below the photosphere).

It should be noted that the flare phenomenon has a physical similarity with the fuor phenomenon. Namely, the differences between radiations in prefuor and postfuor phases are like the differences between those of "fast" and "slow" flares [27].

In favour of the common physical nature of the flares and fluor-like variations, as well as the T Tauri type irregular changes, one can consider the observational fact that sometimes these phenomena happen on the same stars. This is known for T Tauri stars and fuors since 1970. But for flare stars it became known recently when Natsvlishvili [21] discovered fuor-like variations on the flare star FSO 435 in Orion.

It is important to add that there are some grounds to assume [27] (see, also [4,28]) that the energy responsible for both flare and fuor phenomena comes from internal layers of the star that is it has an intra-stellar nature.

7. CONCLUSION

The study of flare stars having different ages in star clusters, associations and in the general galactic field (the UV Ceti type stars) in last decades brought to the following results.

1. The stage of flare stars is an evolutionary stage, one of the early stages of evolution for all red dwarf stars. This stage is characterized by flare activity, which appears before the end of the earliest stage of evolution of these stars, the stage of the T Tauri stars.

2. The flare stars in systems and in the solar vicinity constitute one common class of objects, possessing flare activity and the differences between them are explained by the differences in their ages.

3. The UV Ceti stars of solar vicinity are the population of the general galactic field. They were formed in star clusters and associations, which had enough time to desintegrate. The relative number of field flare stars among the flare stars discovered in the regions of these systems is of the order of 10% .

4. It is very probable that the stellar flare phenomenon is the result of the leaving and liberation of the surplus energy having intra-stellar origin.

It should be added that in spite of the serious achievments in the study of flare stars there are many unsettled problems in this field. Many of them have special importance for the physics and evolution of stars.

Concluding the present paper, let us note some of these problems.

a). Are there flare stars of very low luminosities ($M_{pg} > 15^m$) like the faint stars of the UV Ceti type of the solar vicinity in star clusters and associations?

b). What kind of correlation does exist between the appearences of the stellar flare phenomenon in different spectral regions from radio to X-ray?

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c). What is the nature of stellar instability in the early stages of stellar evolution (T Tauri stars and related objects)?

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LANG: Fast (minutes) and slow (hours) flares are also detected at radio wavelengths from the same flare star, but we also detect low-level emission lasting for days. Is there evidence for this longer, slower variation in the optical region of the spectrum?

MIRZOYAN: Yes, this has been discussed by Ambartsumian. But maybe there is some confusion since the optical distinction between fast and slow flares as introduced by Haro has been made from the rise time parameter, not the total duration. Concerning the latter, I may note that some flares observed in the optical had durations longer than that of radio flares.

LANG: What is the relation between rise times and total duration?

MIRZOYAN: The rise times for individual flares do not depend on their total duration.

APPENZELLER: Do you have any information on the mass distribution (from the location of the objects in the HR-diagram) of the large number of flare stars which you have detected?

MIRZOYAN: The masses of flare stars are not known as we have no direct determination of them. We can only estimate masses by using the mass-luminosity relation for flare stars.