Flare Stars

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(Read by H. MAUDER)

Introduction

Historically the first flares of brightness in some red dwarf flare stars were observed as early as in the first quarter of our century (1). However, those stars engaged the attention much later, after the discovery and study by W. LUYTEN (2) and A. JOY and M. HUMASON (3) of the flares of the prototype of this class of variable stars, i. e. UV Ceti, at the close of the forties.

A considerable number of flare stars has been discovered over a comparatively short period in the circumsolar volume and in stellar aggregates — associations and clusters. At present the number of discovered flare stars is well over 600. In the Pleiades cluster and the Orion association alone over 500 flare stars have been found out (4—6) and about 40 in the vicinity of the Sun (7). As a result of the growing interest in flare stars international campaigns were sponsored in recent years to make regular photographic observations of flare stars in some stellar associations and clusters and photoelectric observations of particular flare stars around the Sun in order to study them at great length.

The campaign, the active participants of which are the observatories of Armagh, Asiago, Boyden, Byurakan, Cerro Tololo, the Crimea, Catania, Tokyo, Tonanzintla and others, have substantially amplified our notions of flare stars.

It turned out that the flare phenomenon is unusual, more akin to the process of explosions than it was to be expected from the first observations. Photoelectric observations with high resolving power in time have, for instance, shown (8) that it takes the star but several seconds to go through the period of brightness increase while the decrease of brightness may continue over a long period. We naturally refer here to typical flares alone.

At the same time the phenomenon of the flare is remarkable from the physical point of view and turned out, a short while later, into an important indicator of the evolutionary stage of the star.

The present paper sets forth the latest data on flare stars in the light of their meaning for the problem of stellar evolution. Naturally it cannot claim catholicity of the subject. Only an attempt is made to consider several data on flare stars from the standpoint of those ideas on the evolution of stars that are advanced at the Byurakan Astrophysical Observatory of the Armenian Academy of Sciences (see, for instance, (9)). Great attention is paid to observational data relating to flare stars in associations and clusters.

That kindred relations exist between flare stars and stars of the T Tauri type is looked upon as an established fact nowadays. Sound proof in support of such relations has been produced by one of the authors of the present paper (10, 11) as well as by G. HARO (12, 13).

It was proved in Byurakan as early as in 1953 (10, 11) that the unusual peculiarities of radiation of the T Tauri and UV Ceti type stars, and foremost of all the presence or appearance from time to time in their spectra of excessive shortwave radiation — continuous emission, are signs typical of the earliest stages in the development of low luminosity stars.

Soon the discovery by HARO and his associates (12) of flare stars in stellar aggregates (associations and clusters) corroborated this point of view spanning a bridge between the stars of the T Tauri and UV Ceti types. Then the most typical flares were uncovered in certain stars of the T Tauri type. It became evident, in the light of those discoveries, that all the above stars form a wide class of comparatively young, related non-stable objects.

G. HARO (12, 13) was the first to appreciate the tremendous significance of the study of flare stars in order to form a picture of the earliest stages of evolution of dwarf stars. Relying on observational data concerning flare stars in stellar clusters and associations, he came to the major conclusion that the earlier stage in the evolution of dwarf stars, i. e. the stage of

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T Tauri (or RW Aurigae) is followed, roughly speaking, by a stage when one of the most important characteristics of the star is the ability to produce from time to time flares of considerable power.

An appreciable contribution to the discovery and study of flare stars has been rendered by L. ROSINO and his associates (14, 15) who confirmed many of HARO's results. This line was further developed in investigations conducted at the Byurakan Observatory (4, 16, 17).

The distinctive advantage of all those investigations lies in the fact that they are based on the generalization and theoretical analysis of observational data on flare stars and have no recourse to hypotheses that predetermine the direction in the evolution of the stars.

Spatial distribution of flare stars

The distribution of flare stars in the Galaxy, at least in its region available for the observations of stars of low luminosity, is quite unhomogeneous. The investigations of HARO, ROSINO and their associates (12—15, 18, 19) have established the fact that like stars of the RW Aurigae type, the flare stars tend to form groups located in stellar associations and in comparatively young clusters. In the general stellar field, at least among the dwarfs of G, K and earlier M types, the flare stars are quite few in number. There are some indications, although of no decisive value, to the effect that classical flare stars of the UV Ceti type around the Sun form likewise a physical system (1, 12, 20). Some definite evidence favouring this view has been obtained in a recent paper of M. A. ARAKELIAN (21) based on the statistical analysis of data on the spatial density of UV Ceti type stars, the kinematic characteristics of dwarf stars with emission lines in the spectra and the luminosity function in a close vicinity of the Sun.

The abundance of flare stars in stellar aggregates

When the number of flare stars, discovered in some aggregates (Pleiades, Orion), attained several dozens, it was natural that the question of their total number in those systems should come to the fore. A solution of this problem seemed feasible by comparing the number of those stars of the system, at which one single flare was observed, with the number of stars at which recurrent flares were observed. Of course, in this case certain assumptions are made on the random distribution of the flares of the given star in time (for instance, the Poisson distribution of the flare moments).

Estimating by statistical means the total number of flare stars in the Pleiades cluster, that appeared to be unexpectedly great (of the order 300), one of the authors of the paper (16) arrived at the conclusion that in this comparatively young system (the age is of the order of 2.10^7 (22)) all or nearly all the stars fainter than visual magnitude 13.3 are flare stars. This first and naturally quite rough statistical estimation of the total number of flare stars in the Pleiades was based on data of 60 flare stars known by 1968. The subsequent investigations (4, 17), based on richer observational data substantiated and somewhat specified this conclusion. For the lower limit of the total number of flare stars in the Pleiades an estimation of the order of 700 was obtained. Evidence favouring the big yet slow changes in the activity of some flare stars in the Pleiades (4) is conducive to the conclusion that the total number of flare stars is considerably larger than the estimations made.

Owing to the intense regular observations of the Pleiades region made largely in Asiago, Byurakan and Tonanzintla, the number of known flare stars in this region of the sky has exceeded so far 207 (4) that comes as a splendid proof to the conclusion on the abundance of flare stars in this system.

Flare stars in profusion are also observed in the Orion association. The total number of flare stars in this system is estimated to be of the order of 1000 (17).

These results, testifying to the fact that the number of flare stars is comparable with the total number of stars of low luminosities in those systems, show unequivocally that the stage of the flare star is a natural stage in the life of stars, and all dwarf stars or, in any case, most of them go through that stage.

Relation between the stages of RW Aurigae and the flare star

The existence of non-stable stars, possessing simultaneously the properties of the T Tauri type star and those of the flare star, attests that those stages in the evolution of dwarf stars sometimes mutually overlap in time. HARO (23) pictures their gradual transition in the form of the following evolutionary sequence:

1. T Tauri typical stars in which the flares superimpose with irregular changes (examples: DF Tau, DK Tau, YZ Ori, BW Ori).
2. Dwarfs of the later type in which spectral characteristics of the T Tauri type star still occur, although quite reduced, and the flares remain to be the most remarkable changes (examples: V 389 Ori, V 390 Ori).
3. „Pure" flare stars, in which properties of the T Tauri type stars have virtually disappeared, at least during the prolonged periods of a more or less constant minimum (examples: EY Tau, FF Tau, FH Tau, V 386 Ori, V 498 Ori), and for the most part flare stars in the associations.

To determine the evolutionary relation between the stages of RW Aurigae and the stage of the flare star, one of the authors (24) estimated the total number of the RW Aurigae type variable stars in the Orion association, which have experienced flares, basing his estimations on the statistics of the definite sample of this class of stars in this system. It was shown that only one-fourth of all the RW Aurigae type stars in the Orion system experience flares with an amplitude exceeding 0^m5. In view of the fact that the RW Aurigae stage is much younger than the stage of the flare star the conclusion was made to the effect that the flare activity starts only shortly before the end of the RW activity. However, a review of this concept might be necessitated in the light of the possible recurrence of the flare activity of the RW Aurigae type stars (4).

Spectra of flare stars

The spectra of all the flare stars in the intervals between the flares belong to the later K and M classes. The earliest spectral class of flare stars in stellar systems correlates with their age. In the quite young systems of Orion and NGC 2264 the earliest class is K0, in the comparatively older system of the Pleiades it is K 3 and attains as much as M0-M6 in the rather old systems of Hyades, Praesepe and Coma as well as among flare stars in the vicinity of the Sun (25, 26).

In general, the spectra of flare stars outside the flares differ from the spectra of normal dwarf stars by the presence of emission lines which in different intensities. In a comparatively low flare activity only the lines Ca II are observed in the emission, whereas in higher activity the Balmer lines of the hydrogen series are observed as well.

However, the spectra undergo radical changes during the flare. In flare time the spectral characteristics of flare stars almost completely coincide with the specific features observed in T Tauri type stars: apart from a bright intense line spectrum a strong continuous emission is present especially in the ultraviolet.

Thus the ability of the star to produce flare correlates with the presence in its spectrum of emission lines, in time of brightness minimum, testifying to their chromosphere activity. It was also made clear that the intensity of emission lines reduces as the corresponding system advances in age (Orion-Pleiades-Hyades) (26).

H-R diagram of flare stars

On the Hertzsprung-Russell diagram the flare stars fall in a region that coincides in some measure with that taken up by T Tauri stars.

On the diagram (V, B-V), compiled for the Orion association the flare stars are met with approximately from the 13.5 visual magnitude (18). All the bright flare stars are located above the main sequence when deflections from the latter do not exceed 1^m in the blue region of colours and attain 4^m in the red region. Flare stars fainter than 16^m are uniformly distributed on either side of the main sequence and occupy an area of up to several magnitudes on either side (18).

The basic difference between the diagrams of flare stars in the Pleiades and in Orion lies in the fact that in the former deflections from the main sequence are considerably less, while the brighter flare stars of the cluster are absolutely fainter and have a later type spectrum than in the Orion. This difference is more pronounced in case of the clusters Hyades, Praesepe and Coma (18).

The presence of an appreciable number of stars *below* the main sequence forms a characteristic and very important feature of the diagram (V, V-B) of flare stars, particularly of the Orion association. In this sense it reminds us of the diagram drawn up by P. P. PARENAGO (27) for stars of the cluster of the Orion nebula in the region of low luminosities.

Although considerable errors in determining the magnitudes and colours of faint stars might have had their possible influence on the diagram, nevertheless HARO believes (18) that both in the Orion and in the NGC 2264 faint flare stars exist that are certainly located much below the main sequence.

The existence of stars located on the Hertzsprung-Russell diagram in the region below the main sequence is confirmed by spectroscopic observations of the Pleiades and Hyades stars, made by G. HERBIG (28) as well as by multicolour photographic observations of flare stars in the Orion, made by A. ANDREWS (29). It was made clear, for instance, that in this system out of 19 flare stars, possessing large ultraviolet and blue excesses, 14 lie below the main sequence (29) on the diagram (V, B-V). This question needs further elaboration in view of its significance for stellar evolution.

Amplitudes of flares

The investigations of certain flare stars close to us (UV Ceti and others) have made it possible to determine the approximate law of the distribution of the amplitudes of flares. It turned out that the flare frequency increases as the amplitude decreases. However, this growth takes place in such a slow way that the mathematical expectation of the total energy, radiated by all the flares in photographic rays, appears to be finite and considerably less than the normal radiation of the star over the same period (30, 31).

The largest flares have been observed in photographic rays in some stars in the Pleiades. Of the photographic amplitudes observed in the Pleiades the largest equals about 7^m (32). In some cases amplitudes equal to 7^m and in one case of the Orion the amplitude exceeding 8^m (33) have been observed in U rays. In fact, photographic observations of flares in associations and clusters are of low resolving power in time. Thus in Tonanzintla, where observations of U-rays are centred as a whole, 15 minute exposures are practised. Meanwhile, the duration of the maximum itself must be much less. Therefore the observed values of the amplitudes are likely to be increased by 2—3^m. In other words, the true maximum amplitudes of flares in U-rays possibly attain 10^m.

The photographic observations of flares available cover only flares with amplitudes $\gtrsim 0^m.5$. Meanwhile, as noted above, flares of great amplitude (power) are by far rarer in particular stars than the flares of small amplitudes (31, 34). On the other hand, the observations of flares are relatively complete only for bright stars. In the case of flare stars fainter than the limiting magnitude of the telescope in the minimum we are deprived of considerably larger amplitudes as well.

Therefore the observed distribution of amplitudes of flares in stellar aggregates is quite distorted. In particular, a sharp increase of the mean amplitude in the transition to the faint stars, discovered for the Pleiades (17), is, no doubt, appreciably due to the selection of observations. Apart from this, a substantial role could apparently be attributed to the luminosity function of flare stars in the system, since the mathematical expectation of flares of definite amplitude in the totality of stars of a given luminosity depends on their total number.

Despite the paucity of observational material, the data available suggest a direct correlation between the amplitude and the duration of flares (minimum-maximum-minimum): with the increase of the amplitude of the flare its average duration augments (35, 36).

It should be added that in most cases the amplitude of the flare grows towards the ultraviolet.

Frequencies of flares

The statistics of flares, observed in the brightest stars of the UV Ceti type, shows (31) that the sequence of flares in every star is adequately expressed by Poisson's law. In this case the average frequency of flares is, in general, different in various flare stars.

For instance, according to statistical study (31), based on data of photoelectric observations of the UV Ceti and YZ Canis Minor is, the average frequencies of flares with amplitudes $\geqslant 0^m\!.15$ in those stars are equal respectively to 0.7134 hours^{-1} and 0.2274 hours^{-1} The average frequencies of flares in flare stars of stellar aggregates also differ markedly. Thus all the flares observed with an amplitude $\geqslant 0^m\!.5$ in the Pleiades are expressed adequately by the superposition of the Poisson distributions with two different frequencies differing by more than one order of magnitude (4, 17). However, an analysis of observational data evidences the changes in the frequencies of flares in flare stars in course of time. In addition to prolonged changes of the frequencies, pointing to the chance of some possible recurrence in the flare activity (4), the average frequency of flares certainly undergoes changes associated with the evolution of the stars. According to (17), the frequency of flares of the stars increases on the eve of the cessation of their flare activity. HARO considers (18, 25) that the frequency of the flares is, on the average, greater in older systems; but in the given system this picture prevails in older stars located nearer to the main sequence.

Energies of flares

In accordance with KUNKEL's estimation (30), the activity of flare stars in the vicinity of the Sun (UV Ceti type stars) has an upper limit: the averaged in time energy liberated during the flares does not go beyond one per cent of the energy radiated by the photosphere of the star. If this conclusion, corroborated in the investigation of V. S. OSKANIAN and V. YU. TEREBIZH (31), is valid, one should assume that the flares of flare stars, despite their high intensity, are insignificant in the energy balance of the star because of their short-lived duration and low frequency.

Calculations indicate that continuous and irregular variations in the brightness of the T Tauri stars are considerably more efficient, as far as the energy is concerned. The energies, accounting for the variations in the brightness of the T Tauri stars, are already comparable with the energy of the total radiation of the stars under consideration.

It should be noted that in both cases the matter concerns those energies that have manifested themselves in the form of optical radiation.. In the meantime, we already know from solar flares that a considerable part of the energy is spent on the formation of particles of high energies (protons of cosmic rays) emitted in the surrounding space. If we are to adopt the interpretation of flares as explosions, going on above the photospheric layers, it should be concluded, as is to be seen further, that at least in some cases the optical energy of flares forms but a small part of the total energy of the corresponding explosion. The total energy released during the flares can apparently exceed the energy contained in optical flares, at least by one or two orders.

Proper colours of flares

The colours of the excessive radiation, appearing during flares, can be derived from the observed colours of the total radiation of the flare star in the maximum and minimum of brightness (37). Observations show (38) that most of the flare stars in the minimum have the normal colours of B-V, corresponding to their absorption spectra.

The proper colours of the flares, B-V and U-B, determined for a number of flare stars in the vicinity of the Sun and also for the member of the Pleiades H II 1306 (34, 37), differ but slightly from each other and are quite at variance with the colours of the black-body radiation. This fact can apparently be regarded as a proof of the general non-thermal nature of the excessive radiation, accounting for the flare, depending but loosely on the physical parameters of the star, and especially on its effective temperature.

It should be pointed out that the proper colours of flares change considerably as the flare intensifies or dies away, remaining nearly all the time on the two-colour diagram (U-B, B—V) above the curve representing the colours of the black-body radiation for various temperatures (34).

Physical nature of flares

The problem of the nature of flares is of particular interest in matters of stellar evolution. It is closely related to the problem of the sources of the energy of flares.

According to the hypothesis, advanced and substantiated by one of the authors of the paper in Byurakan (10, 11), the continuous emission, usually present in spectra of the T Tauri type stars and appearing in the spectra of flare stars only during the flare, is of non-thermal nature. We ascribe this fact to the comparatively young age of the above stars and explain it in terms of the ejection into the outer layers of the star certain portions of pre-stellar matter and the release of energy they have brought into those layers. The process of flare, that can often occur high above the photospheric layers, results from the decay of this pre-stellar matter, and elementary processes must take place similar to those that are generally observed in nuclear decay.

The first part of this hypothesis (we shall designate it subsequently as the Byurakan hypothesis) is supported by later investigations. Thus, for instance, in the works of M. A. ARAKELIAN (39) and one of the authors of the paper (37, 40), certain evidence, based on the analysis of observational data concerning the flares, was obtained in favour of the non-thermal and non-synchrotron nature of continuous emission, appearing during the flares. This concept is apparently supported by the fact that optical flares of the UV Ceti type stars, at least the intense ones, are accompanied by radio flares, also of non-thermal nature (41).

We can further consider that the numerous attempts to explain the continuous emission by the known mechanisms of radiation failed to achieve success (40, 42). Scrutinizing and rejecting most of the existing interpretations of flares, R. E. GERSHBERG (42), arrives at the conclusion that the totality of *optical* observations is in line with the nebular hypothesis.

The nebular hypothesis, elaborated by GERSHBERG (43, 44) and also by KUNKEL (34), assumes that the radiation of flare stars during the flares is the superposition of the radiation of the star and the hot, ionized, and rapidly emitting gas mass ejected by the star. However, the nebular hypothesis also encounters serious difficulties (37) when it comes to an interpretation of the proper colours of flares, i. e. continuous emission. To overcome those difficulties KUNKEL (34) has considered another component of radiation, presenting the total radiation of the star during the flare as a combined radiation of the cold star, hot gas envelope and heated hot spot on the surface of the star. The rapid rate of flares is so far an insurmountable obstacle for the nebular model. The latest observations of S. CRISTALDI and M. RODONO (8), made with high resolving power in time, show that flares occur whose duration (minimum-maximum-minimum) is less than 15 sec.

As to the second part of the Byurakan hypothesis (10, 11) it should be noted that in all the interpretations of the continuous emission by known mechanisms of radiation, the question of the origin of energy remains open. As a matter of fact, they always presume the presence or appearance of unknown sources of energy in the star, heavily concentrated and localized not far from its surface. This is virtually the initial assumption of the Byurakan hypothesis (see, for instance, (40)).

It should be added that estimations of the energies accounting for the flare and for the irregular variations of the T Tauri type stars, presumably testify to the fact that the activity, produced by the nonstability of the young star, dies away with age. Possibly a complete extinction of the flare activity sets in at the time when the supplies of energy are consumed, which being concentrated within the star, are taken from its internal regions to the surface layers by carriers that remain unknown so far (portions of pre-stellar matter, according to the Byurakan hypothesis (10, 11).

„Fast" and „slow" flares

As noted above, the duration of the flare (minimum-maximum-minimum) depends, on the whole, on the amplitude. However, if the time of the inflammation of the flare is to be taken as its duration, then following HARO (19, 23), two essentially differing types of flares can be distinguished: „fast" and „slow" which are respectively shorter and longer than 30 minutes. Because of the low resolving power in time of photographic observations the limiting time of 30 minutes is determined by the conditions of observations of HARO and his associates (19, 23) using 15 minute exposures in the U-rays.

It is highly important that in such a division into „fast" and „slow" flares the duration of the flare is independent of the amplitude: „fast" flares with great amplitudes and „slow" ones with small amplitudes have been observed. For instance, in the flare star FSO 7 (the flare star of the Orion No. 7) a flare was recorded with an amplitude equal to $7^{m}.7$ in the ultraviolet for which the maximum was attained in 23 minutes in all (33).

Most flares are „fast". „Slow" flares have so far been observed only in seven flare stars of the Orion:

No.	V	B-V	References
66	$15^{m}.0$	$1^{m}.35$	(23, 29)
92	15.86	1.31	(23, 29)
149	16.61	1.14	(23, 29)
153	15.56	1.32	(23, 29)
177	16.7	1.5—1.8	(33)
229	17.6 U	—	(5)
239	19.5 U	—	(5)

In accordance with HARO's observations (19, 23), the „fast" and „slow" flares differ sharply in the nature of changes observed in the spectra of the corresponding flare stars. The „fast" flares are characterized by sharp changes in the radiation of the star in U- and B-rays and strong emission lines, while in V-rays, particularly in the red region, the changes are either small or are completely lacking. In the case of „slow" flares an intensification of the continuum in the red region of the spectrum is noticed, with a low intensity of the emission lines, notably H_{α}.

An interpretation of the difference of „slow" and „fast" flares and the phenomenon of fuors

The differences noted in the „slow" and „fast" flares, can be interpreted with the help of the Byurakan hypothesis (10, 11) concerning the nature of flares, if we assume that the phenomenon producing the flare takes place in various layers of the star. When the excitation energy is released high above the photospheric layers, in the chromosphere or the corona, a sudden and very rapid increase of the non-thermal short-wave (ultraviolet and blue) continuous emission occurs, that causes the flare of brightness of the star and at the same time the appearance of an intense emission line spectrum. When the energy is released in deeper, underphotospheric layers, an increase of thermal radiation must be observed, on the whole in the visible region of the spectrum, and a relatively small intensity of emission lines. The duration of the flare from the minimum to the maximum should in the latter case be correspondingly much longer than in the former case.

When such an interpretation of the difference of „fast" and „slow" flares is offered, one should expect that the „slow" flare stars can at times experience „fast" flares, too. In this connection it should be noted that out of seven „slow" flare stars in the Orion, for three (FSO 66, 149, 153) „fast" flares have already been observed, while the star FSO 177 shows irregular variations of brightness outside of flares (33).

Most stars which experience „slow" flares (four of the five with known colours), on the Hertzsprung-Russell diagram fall in the region above the main sequence, i. e. possess apparently more extensive photospheres than normal stars. It can be assumed that it is precisely for this reason that the probability of energy release under the photosphere — the probability of „slow" flares — is greater with them than with stars located below the main sequence.

It should be added that until recently „slow" flares have been observed only in the Orion association. This has served good reason for HARO to conclude (23) that such flares do not occur at all in the Pleiades stars. However, of late E. S. PARSAMIAN (45) has discovered a truly „slow" flare in the star FSP 103 (the flare star of the Pleiades). This fact can be taken as evidence in support of the above interpretation of the differences in „fast" and „slow" flares.

The fact that the energy of the „slow" flare of the star FSO 177 has proved at least several dozens of times larger than the maximum energy of „fast" flares in stars of the same magnitude in the Orion is likely to be taken as the most sound corroboration of the interpretation suggested by Byurakan concerning the phenomena of flares. If we assume the transition of nearly all of the explosion energy into the optical region during the „slow" flare of the FSO 177, we come inevitably to the conclusion that in fast flares only a one per cent energy is emitted into the optical part of the spectrum.

It should be pointed out in this connection that in the light of this interpretation simple explanation is offered to the basic phenomena alike, associated with the fuors (46). We designate in this way the phenomenon of brightness raising that has occured in variable stars of the FU Orionis (47) and LkH_α 190 = V 1057 Cygni (48, 49). If we assume that sources of non-thermal energy had been continuously present over the photospheres of these stars and that only an insignificant amount of this non-thermal energy turned into an optical radiation before brightness raising, then a „thermalization" of the whole energy, emitted by the sources, will occur following brightness raising during which extensive envelopes were formed in those stars that could absorb both the electromagnetic and the corpuscular radiations of the sources. Therefore the role of the envelope should be reduced to a mere transformation of nearly all of the emission of non-thermal sources into an optical radiation. This may bring about a hundred-fold increase of the optical luminosity of the star. Thus, the vital point in our assumption on fuors is to be sought in the fact that *during this phenomenon the total power of the energy sources in stars remains unchanged.* But in the pre-fuor stage only a small part of the energy stream is emitted in the observed optical rays, while in the post-fuor stage-nearly all of the energy.

Luminosities and masses of flare stars

Observations of flare stars in clusters and associations indicate the great variety in their luminosities. According to HARO (18) in the Orion association the visual absolute magnitude of flare stars varies in the interval of values from $+4^m$ to $+13^m$, i. e. their luminosities can differ by four orders. The brightest flare stars in the Pleiades have an absolute magnitude of $\sim +6^m$ (16).

Thus, the flare stars in associations and clusters have in most cases luminosities that surpass considerably the luminosities of flare stars in the vicinity of the Sun.

This and the spectral classes of the UV Ceti type stars presumably attest that the latter are rather old objects: in this grouping the flare activity in stars of higher luminosity has long been extinct.

The masses were determined but for a small number of the closest flare stars of the UV Ceti type. They are on the average of the order of 0.1 of the solar mass. For most flare stars the masses can be estimated roughly by means of the ratio mass-luminosity, the application of which is not well grounded in this case. In view of the fact, however, that the luminosities of flare stars in stellar aggregates exceed to a great extent the luminosities of the UV Ceti type stars, it can be maintained that their masses must be larger, on the average, by half an order; the great dispersion of luminosities indicates the great variety of masses in those stars.

Unusual distribution of flare stars in the Pleiades

A study of the distribution of flare stars in the corresponding systems is of significance to the problem of stellar evolution. Such a study, carried out for the system of the Pleiades by M. A. MNATSAKANIAN and one of the authors of the paper (50) has revealed that flare stars are nearly completely lacking in the central region of the system. The radius of this cavity is equal to 1.4 parsec. The partial density of flare stars reaches maximum at a distance of 1.5 ps from the centre of the system; then it diminishes more rapidly than $\sim r^{-2}$. These results have been obtained on the assumption that all the known flare stars in this region belong to the Pleiades system. An account of the probable existence of the field stars among them will lead to an increase of the cavity.

This result regarding the existence of a cavity in the distribution of flare stars in the central region of the Pleiades can hardly be interpreted as a consequence of the influence of the absorbing matter or the photographic effect of bright stars concentrated in this region, when such effect could hinder the detection of flare stars. It cannot be „false" either, i. e. the result of a random nature of the process of discovering flare stars.

The lack of flare stars around the centre of the Pleiades cluster can be explained by the assumption that stars, originating in the central part of the cluster, have removed from the centre of the system in course of their aging.

Conclusion

There is no more doubt that the flare stars form one of the initial stages in the evolution of dwarf stars. In this connection a detailed and profund study of flare stars is of paramount importance for the problem of stellar evolution.

The conclusion of HARO (18) can be quoted as an instance to the effect that there is a considerable number of young stars, located on the Hertzsprung-Russell diagram much *below* the main sequence. If this result is confirmed eventually it may prove fatal to the condensation hypothesis of star formation as the latter is unable to explain this fact. The present-day current theory of stellar evolution of stars by gravitational condensation until the main sequence is reached, worked out by CH. HAYASHI and his associates (see, for instance, (51)), can explain only the origin of those stars that lie *above* the main sequence on the diagram and come down gradually.

However, it is early as yet to draw final conclusions, and it is for subsequent observations to decide the issue.

Certain deductions can be made from the foregoing on the observational problems that are to be resolved in the domain of flare stars. It should be noted, foremost of all, that the joint efforts in photoelectric and photographic observations of flare stars proved to be quite fruitful and deserve further elaboration and better organization.

We may be allowed to enumerate a number of problems that seem to be of major importance to us.

Problems relating mainly to the statistics of flare stars:

1. The organization of regular campaigns of photoelectric observations consecutively dealing with various flare stars. Such observations will provide rich data for *the statistics of flares of particular stars* and will allow to compare the nature of activities of the various stars. Such campaigns for each given star could be useful when it is launched not earlier than in several years.

2. A further concentration of efforts on the photographic study of flare stars in the Orion and the Pleiades and in two or three poorer associations and clusters with a view to detecting the basic population of flare stars in them and also to making the *statistics of flares in those aggregates.*

3. Regular photoelectric observations in the U- or B-rays of bright stars of the Pleiades, concentrated on the limit (as to brightness), dividing the flare and non-flare stars, aimed at discovering flares with small amplitudes and, in general, with the object of studying the transition from flare to non-flare stars.

4. A more precise solution to the problem of recurrence of flare activity.

Problems bearing on the physics of particular flares:

1. Photoelectric observations of flares from ground observatories with the greatest resolving power in time and extraatmospheric observations with an exposure of the order of 0.1 sec. Such observations will enable us to form a clearer picture of the direct mechanism of energy release. Extra-atmospheric observations in the far ultraviolet and X-rays.

2. Three-colour photoelectric observations of flares with great amplitude. Meanwhile there is no need to keep necessarily to the colours of U, B and V. For instance, much could be derived from observations of U, B, R as far as the study of brightness diminution and the possible secondary processes associated with it are concerned (reflection from the photosphere of the star of the processed radiation).

3. Spectral observations of particular flares. Such observations are specially desirable during the campaigns of the respective stars.

With regard to the flare stars in their quiet state, we should like to underline the great desirability of spectral and multi-colour photoelectric observations of the known flare stars during the minimum brightness in the Orion and the Pleiades.

We should like to note in conclusion that it is highly desirable for a study of the nature of flares to focus attention also on phenomena in the T Tauri type stars and fuors, closely associated with physical processes analogous to those that take place in „fast" and „slow" flares.

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Discussion to the paper of AMBARTSUMIAN and MIRZOYAN

WALKER: The explanation of the existence of the faint RW Aur stars below the main sequence in the Orion nebula and in NGC 2264 is the following: These objects represent extreme cases of gravitationally contracting stars with infalling material in which the late type absorption spectrum is veiled by an overlying blue continuum. Spectroscopic observations show that in those stars that lie below the main sequence, this continuum is extremely strong, completely obliterating the photospheric absorption spectrum, and converting the colour of the star to appear to be very much bluer than it really is. This same effect, in lesser degree, explains the general scatter of the faint gravitationally contracting stars closer to the main sequence than predicted by theory. It appears likely that this blue continuum originates in some way by interaction of infalling material with the atmosphere of the star.

AIZENMAN: Recent work on stars of about 0.1 $M_\odot$ shows that two equilibrium models are possible for a given chemical composition. Now one of the two possible models lies below the main sequence and is probably unstable. Since these stars seem to be in the same region as the flare stars, and since the flare stars seem to lie both above and below the main sequence, I wonder if this might mean that some correlation might exist. One further point. The star that lies below the main sequence is not the star that would result from normal pre-main-sequence contraction. Some other mechanism would have to intervene in order to create such a star.

ROSINO: I should like to add that 3 slow flares have been hitherto discovered in the Plejades survey at Asiago. This probably means that the difference between Orionis and Plejades clusters from the point of view of the presence of „fast“ and „slow“ flares is perhaps not so strong as firstly believed.