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FLARE STARS IN STAR CLUSTERS AND THE FAINT END OF THE STELLAR LUMINOSITY FUNCTION

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Abstract. Flare stars belong to the red dwarfs, the faintest stellar objects known. dK and dM stars contribute about half of the total stellar mass in the solar vicinity. Since they are unobservable in the r¿100 pc range they are a kind of dark matter candidates. Probably at least half of these stars are flare stars which can be detected (during high amplitude outbursts) at a significantly larger distance. This fact makes these faint objects and their investigation exceptionally important. The results of a two decades long photometric and astrometric programme are summarized below.

1. INTRODUCTION

The very first observation of a flare phenomenon on a star other than the Sun was made by E. Hertzsprung in 1924. He successfully photographed the sudden brightness increase of a star now called DH Carinae. He noticed and misinterpreted the phenomenon explaining it as the consequence of an impact of an asteroid into the star. During the next decades the frequency and the time-development of similar events observed by others and, as the strongest evidence, the reoccurences of the phenomenon in the case of the same stars, made this naive hypothesis to be rejected. However, the truth is that the real physical causes of this phenomenon, called the flare activity have not been found yet. This may explain why the study of flare stars is still a popular field for the astrophysicists of the last decade of the XXth century.

At rest these variables, called UV Ceti-type after their well known representative, are red dwarfs with extremely low energy output. Their spectra contain emission lines, and in most of the cases they can be classified as (dK)-dMe their decimal classes running from M0 to M6.5. Because their absolute visual magnitudes are between +10 and +18 with a few exception, only the ones in the immediate solar neighbourhood can be observed with photoelectric photometers and spectrographs mounted onto small or medium sized telescopes. But there are hardly more than fifty of that type (Kunkel 1965) and there is only a dozen, which flare up with a high enough frequency that it would be worthwhile to observe them photometrically in uninterrupted mode. Fortunately in the early fifties Haro and Morgan discovered that these peculiar stars seem to cluster in certain parts of the sky (Haro and Morgan 1953). Objects with similar properties to that of UV Ceti were identified in the Orion nebula and its close neighbourhood, though at first they were considered as a separate class of the variable stars, and therefore they were called flash- not flare stars. Since the so called Orion association - presumably to which the majority of these variables belong - is so far from the solar system that the individual photoelectric observation of its red dwarfs would be wasteful, photographic methods have been used for the observation of the whole field of this association and other stellar aggregates.

2. THE OBSERVATIONS

The photometric observations have been made most frequently in the UV or blue ("photographic") range of the electromagnetic spectrum with large field and fast astro-cameras, mainly of the Schmidt type. These telescopes are extremely effective in the ultraviolet since their optics is composed of a highly reflective mirror and a very thin correcting plate, made of a kind of UV-transparent glass. Since the intrinsic brightness variation of these stars during a flare up is definitely the most prominent in the UV- continuum and seconds or minutes later in some spectral lines, the strategy of taking long series of short photographic exposures of those regions of the sky which contain nearby - and preferably young - star clusters or associations proved to be very successful. Following the study of the Orion association researchers in Hungary and other countries investigated a lot of galactic clusters and groups of stars and discovered that flare stars can be recognized in many of them. There are two limitations of their detection. First, the galactic clusters almost without exception can be found in the Milky Way, where the interstellar absorption is the strongest. Second the flare stars are of extraordinarily low luminosity. Since 1952, the beginning of the photographic patrolling of star clusters and other suspicious stellar groups flare stars have been discovered and identified in the field of at least half a dozen nearby aggregations (Szecsenyi-Nagy 1990 and references therein). The most important discovery for us was the one showing flare stars in the field of Eta Tauri or of the Pleiades. This relatively young open cluster is not too far away from us (its distance being 126 pc or its distance modulus about 5.5 magnitude) and is very nicely placed on the fall-winter sky of the observers of the northern hemisphere. The cluster has known member stars spread over a sky field of at least 30-50 square degrees and is reasonably abundant in low mass red dwarf stars too. The results of our decades-long flare programme combined with those of the Abastumani, Asiago, Byurakan, Padova, Palomar, Rozhen, Sonneberg, Tautenburg and Tonantzintla teams have been published mostly in observatory bulletins as well as annals or conference proceedings. It is worthwhile therefore to summarize those ones, which may be of greater importance in other fields of astronomy and astrophysics.

3. PHOTOMETRIC PROPERTIES OF FLARE STARS DISCOVERED IN FIELDS OF STELLAR AGGREGATES

Based on our own results and data collected from the literature we were able to demonstrate the existence of a more or less definitive correlation between the ultraviolet flare amplitude (expressed in magnitudes) and the apparent ultraviolet brightness of the quiescent star. Since all of these stars were found in the vicinity of the Pleiades cluster, they were supposed to be cluster members and only some objects could be exceptions (definitely not more than 2-3 in the region) of it. The outcome of the study was that those stars which are fainter in minimum, are able to produce the flares of the greatest known amplitudes (up to 6-8 magnitudes) in the ultraviolet band (Szecsenyi- Nagy 1980). However the significant spread was annoying enough and urged me forward the introduction of a new parameter describing more conveniently the energetic properties of the flare phenomena. The Ultraviolet Flare Overproduction (or briefly UFO, just to give a scientific meaning to this then remarkably popular abbreviation) is given in USO (Ultraviolet Solar Output) units and shows a definite exponential correlation with the duration of the flares expressed in minutes. The greatest problem in that study and its extensions was, that only a limited number of Pleiades flares had been photometrically well calibrated and published in detail. For the photometric data collected by the Hungarian team an other, even more significant relation has been found. In this the ultraviolet output of the flare at the maximum point of its "light curve" has been expressed in USO units and has been compared to the total UFO of the same star during the same event. A linear correlation of the two parameters has been found with a coefficient of correlation exceeding 0.95 and this suggests that the ultraviolet over- production of the stellar flares in Pleiades field are in excellent correlation with the ultraviolet overproduction of the given flare‘s peak point. In order to characterize the energetic properties of Pleiades field flare stars more exactly an other program has been run. Altogether more than 500 flare ups and their photometric data were ordered into a flare database and reduced systematically. A new variable, the cumulative flare overproduction (both in the ultraviolet and in the photographic range) has been defined and computed and plotted against increasing amplitude limits. The result is a graph, looking like an almost straight echelon the slope of which provides the new parameter characterizing the energetic properties of the object in the ultraviolet or in the photographic bands. This method proved to be incredibly sensitive to the physical constitution of the objects. The echelon graph of one of the stars investigated showed a strange, doubly-sloped structure, which suggested the duplicity of the object being composed of two flare stars of different activity. Later it has been found, that the star is really a binary (Szecsenyi-Nagy 1988).

Having collected enough photometric data about flares of almost 600 flare stars of the field of the Pleiades cluster, it was clear, that some of the stars are much more active than others. From our own observations and from data published by the members of the other teams I was able to list 17 stars with at least 10 observed flare ups although hundreds of stars produced only one or two flares during the same time. Or not? This was not absolutely clear whether every star got the same amount of attention (or observing time). I had to correct the observations of the different groups to this effect which is the result of the differences between the photographic cameras of the observatories (caused mainly by the various photometric fields and speed of the telescopes). To overcome these diffi- culties the Largest Common Field (LCF) of the Eta Tauri fields has been defined and based on it the time-like parameter PMT (Pleiades Mean Time) has been introduced. The latter successfully randomized the data of the photometric observations and proved to be an excellent variable being suitable to substitute total or effective observing time (Szecsenyi-Nagy 1986, 1990b).

As a by-product of the use of the new time parameter PMT significant long-term variations of the flaring activity of the flare stars discovered in the Eta Tauri fields were found. These variations appear as a specific pattern in the time distribution of the observed flare ups (in fact on the flare up versus PMT graph). What we see is that short periods (some years) of enhanced flare activity are embedded in far longer ones (decades), during which the star seems to be very much alike its low-activity neighbours. It may be very important in statistical investigations, that activity variations of this kind which convert them into quiescent red dwarfs temporarily, very probably screen a lot of flare stars from the astronomers' view. Another result of the same study was the discovery of the cyclic activity of the star CPFS91 and the estimation of the length of its activity cycle which is in the 20 years range, not far from the magnetic cycle of our Sun (Szecsenyi-Nagy 1989). It has been found too that the flaring frequency of at least two out of three active flare stars - irrespective of their cluster membership probability, apparent brightness or average flare frequency - can vary by a factor of ten. Since the photometric fields centered upon Eta Tauri contain flare stars of very different ages (the Pleiades cluster members are in the 50-80 million years age bracket whilst the star which has produced the most of the observed flare events in the field belongs to the Hyades group and is about 600-800 million years old, moreover some of the stars can be foreground objects with ages similar to that of the galactic field or of that of the Sun - some billions of years). The most important statements of that study can be summarized as follows (Szecsenyi-Nagy 1990) :

(i) the ratio of randomly flaring objects amongst Pleiades members is the same (1/3) as amongst the whole sample while the changeable activity seems to be more general
(ii) activity cycles are characterized by short high activity and much (4 to 20 times) longer low activity or even inactive periods
(iii) flaring frequency in maxima can exceed the minimum frequency by a factor of 5-25
(iv) activity changes of this character were observed on stars of the same spectral type (dM3) but very different ages (50 million to approximately 5000 million years)

4. CLUSTER FLARE STARS AND THE LUMINOSITY FUNCTION

At the time of its discovery the Hertzsprung-Russell diagram (or the HRD) did not contain red dwarf stars at all. Stars less luminous than the Sun were extremely underrepresented in the sample of that time. This is of course absolutely normal, since faint and red objects could have hardly been recorded by the very low sensitivity photographic materials and slow optical systems used by the observers of those years. With the advent of giant telescopes and even more with the extended use of modern astronomical cameras, which were able to record huge fields of the sky simultaneously, the number of red dwarfs incredibly increased. As our recently published textbooks tell the story, most of the stars are main sequence stars and at least three quarters of these are red dwarfs (dK and dM spectral class objects). Based on these statistical values it becomes clear that the majority of the stars building up the Galaxy are red dwarfs. Unfortunately these objects are extremely faint and this fact severely limits the probability of their discovery. We were able to spot these objects only in the close vicinity of the Sun. The result is that 70 stars and 85 farther from the Sun the statistics is worsening step by step. In the kpc distance range the faintest dwarfs are practically unobservable and going deeper into the galactic disk or halo even the "brighter red dwarfs" will disappear. At the same time it is well known, that galaxies and amongst them our own too seem to be much slimmer than they would have to be in order to keep their companions. Where and in which forms this mass can exist? This is a very difficult problem, and no definitive answer has been given yet to it.

Why can flare stars help in answering? The idea is that flare stars, because of their strange behaviour and extremely large amplitude brightness variations, can be observed to much farther than the quiescent red dwarfs. Another advantage of these objects is that they are often concentrated into star clusters and associations (Szecsenyi-Nagy 1986a, 1986b) and this fact offers the possibility of locating them using photometric and other data concerning brighter stars of the same cluster or group. The most shocking result of the photographic flare patrols and the statistical investigations based on the data collected by these programs is that the most actively observed young clusters are extremely rich in flare stars. The Pleiades e.g. contains at least 3-5 times more of this species than the total number of its stars discovered before the start of international flare programs. It was shown in the early eighties that the field scrutinized by the photo- graphic cameras hid more than a thousand flare stars around Eta Tauri. In the next decades many of these objects were identified thanks to their flare activity and it was calculated too, that tens of thousands of hours of photographic observations are needed to discover the large majority of these faint stars (Szecsenyi-Nagy 1983). With the introduction of the new semiconductor based detectors (or simply CCD cameras) and other revolutionary observing techniques and methods into the flare star research programs as suggested by the author too (Szecsenyi- Nagy 1990c, 1994, 1995), we will learn much more in much shorter time than has been found during the past half century.

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