DATA FILTERING IN STATISTICAL STUDIES OF FLARES RECORDED IN SKY FIELDS OF STELLAR AGGREGATES - DEMONSTRATED WITH THE EXAMPLE OF THE PLEIADES

G. SZÉCSÉNYI-NAGY
Eötvös University of Budapest
Department of Astronomy
H - 1083 Kun B. tér 2.
Hungary

ABSTRACT. Photometric data on flares of cluster flare stars published by different observers were - as a rule - collected during decades by different instruments and amidst various conditions. The uncritical use of these data in global statistical studies is usually unfair since such a collection is an indefinite mixture of high and low quality results. In order to make these investigations more reliable even the best and most complete photometric catalogues have to be filtered.

The first step of the procedure described in the paper is rejecting all flare events having too small amplitudes - seeing that they are underrepresented in the catalogue as opposed to medium and large amplitude flares. Then the photographic coverage of the aggregate has to be checked and all events observed in partially covered regions have to be excluded. Next any non-randomness in the time distribution of flares of each active object is to be unveiled and flares of the doubtful stars have to be omitted. Finally some objects are to be rejected for their individual characteristics.

The usefulness of the method is demonstrated with the example of the Pleiades, one of the richest open clusters known. More than 3000 hours of effective observing time has been devoted to flare photometry in fields centered upon Eta Tauri and the outcome of the programme the CPFS - the most complete catalogue of flare stars of the region - contains data of 519 flare stars and their 1532 flare events. Earlier versions of this catalogue or subsets of its data have been used to estimate the probable number of flare stars in the Pleiades region. Results of these attempts range from 600 to 2700 partly owing to the unreliability and incompatibility of the data sets. The method presented here is able to give much more reliable estimates but of course in the limited largest common field (LCF) only. As a result of the filtering the LCF contains 77% of the objects and 67% of the flares listed in the CPFS. Time sequence analysis of the 1026 flare events observed on 402 flare stars and statistical modelling of the phenomena suggested in an earlier paper fit each other almost perfectly.

The conclusion of the study is that the most likely number of flare stars in the reach of the telescopes used in this programme is between 520 and 600 in the LCF of the Eta Tauri fields. Their average flare frequency is about 1/2400h and the CPFS lists 70% of these objects. In order to be able to compare the Pleiades field flare stars and those of other

L. V. Mirzoyan et al. (eds.), Flare Stars in Star Clusters, Associations and the Solar Vicinity, 71–76.

https://doi.org/10.1017/S0074180900187479 Published online by Cambridge University Press

aggregates the method of filtering will be carried out throughout the analysis of the most extended data sets available.

1. PHOTOMETRY OF CLUSTER FLARE STARS

1.1. The Instruments

Since stellar aggregates containing a large number of known flare stars are in the 0.1-1.0 kpc distance range their flare-active members are very seldom brighter than m(U)=15. For that reason and the very low frequency of large amplitude flares wide field photographic cameras (mainly Schmidt telescopes) are used in flare patrol observations. In order to secure the most complete time-coverage the method of multiple exposures is employed as a rule. More details of the photographic flare photometry were discussed by Szécsényi-Nagy (1985).

1.2. Evaluation of the Plate Material and Publication of the Results

Photometric plates are visually checked and brightness changes noticed on them are estimated or measured by iris- or microphotometers. Observers usually report the position and minimum brightness of the active stars found and the amplitudes of their flares.

For a reliable statistical investigation of flare stars and flares the unambigous identification of these objects is essential. As data on flare stars and their flares in a field of about 30-35 square degrees containing the open cluster M45 were compiled and published with detailed maps of the region (The Catalogue of Pleiades Flare Stars, the CPFS, Haro et al. 1982) and since this is the home ground of many Northern hemisphere observers, it was obvious to choose the Pleiades to demonstrate the use of the method.

The CPFS lists photometric data of 1532 outbursts with amplitudes ranging from 0.3 to 9.0 magnitudes.

1.3. Reliability of the Published Flare Amplitudes

The number distribution of flare ups versus amplitude was computed with a resolution of 0.1 magnitude - the greatest one allowed by the published results (Fig.1.). The plot demonstrates plainly that observers tend to report - of course inadvertently - much more integer and half-integer (e.g. 1, 1.5, 2, 2.5, etc.) amplitude outbursts than their expected number might be. This serious selection effect is even more obvious if one compares the content of the integer (or half-integer) bins and that of their immediate neighbours. There are always local minima at these latter amplitudes.

Another characteristic feature of the amplitude distribution is that the frequency of outbursts decreases with increasing amplitudes. It is self-evident and well known from flare statistics of nearby flare stars or that of the sun that low amplitude flares are much more numerous than the high amplitude ones. It is clear from the plot of Fig.1. that the flare sample listed in the CPFS must be incomplete in the lowest amplitude bins. At least one third of the outbursts is missing in the 0.5 ± 0.2 mag range.

https://doi.org/10.1017/S0074180900187479 Published online by Cambridge University Press

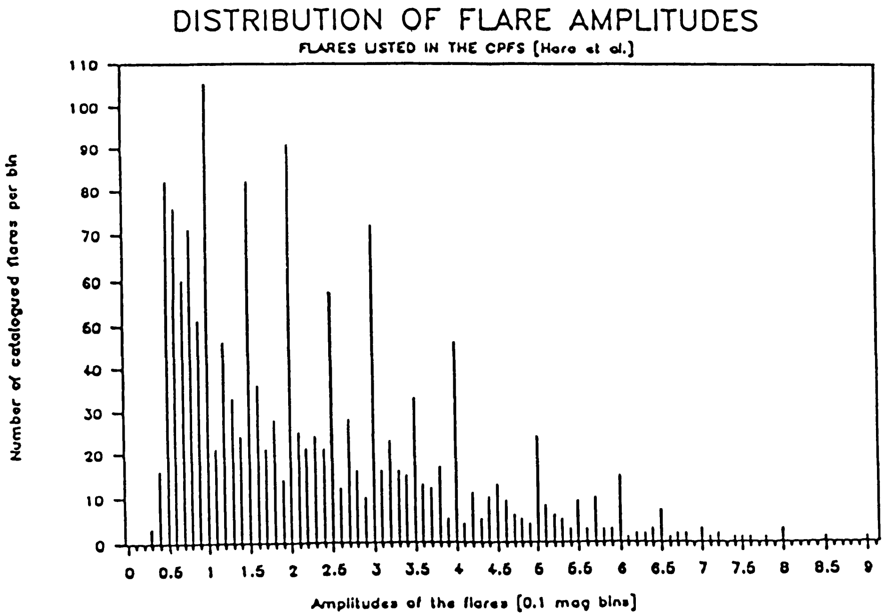

Figure 1. Low amplitude flares of stars of the Eta Tauri fields are considerably underrepresented in the CPFS because most of the observers are unable to detect these outbursts or quite simply ignore them.

The number of 0.8 mag outbursts is significantly higher than that of 0.7 magnitude ones but there is only a slight difference between the multitude of 0.6 and 0.5 mag flares. This fact and a comparison between the ratios of the length of 0.6/0.5 and that of 1.6/1.5 magnitude bars have to convince everybody of the incompleteness of the flare surveys at these low amplitudes. Although the 0.7 mag bin is surely much more complete than the half magnitude one for maximum safety all 237 flares of the 0.0-0.7 mag amplitude range were rejected. This move reduced the total number of accepted outbursts to 1295.

2. THE LARGEST COMMON FIELDS OF THE AGGREGATES

2.1. Uneven Photometric Coverage of the Fields

Photographic flare patrol observations have been carried out in at least eight observatories using nine or more different instruments. Unfortunately not only the optical system the aperture and the focal length of the cameras are different but their fields of view too (Szécsényi-Nagy 1983). In order to illustrate this problem it is enough to compare the larger Schmidt telescope of the Byurakan AO and the smaller one of the Asiago AO. While plates taken with the former cover an area of 14.14 square degrees those taken with the latter show more than 2.5 times larger field (approximately 37 square degrees). What is more the shape

https://doi.org/10.1017/S0074180900187479 Published online by Cambridge University Press

of the field of view of the instruments in question is often circular but in some instances it is square or octagonal. Consequently if stars of an aggregate are spread over a larger area than that of the smallest field camera used in the program photometric observations carried out by different instruments secure data of stars of incomparable fields.

In such cases it is necessary to determine the largest common field (LCF) of the telescopes and to restrict statistical flare analysis to stars of this area.

2.2. The Largest Common Field of the Pleiades

In order to determine the LCF of the Pleiades region photographic fields of Schmidt and Maksutov cameras of the following observatories were cross-checked: Abastumani, Asiago (2), Byurakan (2), Konkoly (Piszkéstető), Rojen, Sonneberg and Tonantzintla. At least 99% of the outbursts listed in the CPFS were recorded by these instruments (Haro et al. 1982) which were described in detail elsewhere (Szécsényi-Nagy 1986). The shape of the LCF of the above-mentioned telescopes was determined as the overlapping section of a 3.75x3.75 deg^2 square and a circle concentric with that with a radius of 2.375 deg. The center of the field is defined by the actual coordinates of Eta Tauri and two sides of it are parallel with the celestial equator. 71 flare stars listed in the CPFS lie outside the LCF of the Pleiades. These objects (which produced 121 observed outbursts) were wholly listed by Szécsényi-Nagy (1986). As a result of this spatial filtering the total number of accepted flare events dropped to 1174 and that of the accepted flare stars to 414.

3. TIME-DISTRIBUTION ANOMALIES OF FLARES OF THE MOST ACTIVE STARS

3.1. The Assumed Random Distribution of Stellar Flares

Flare occurrence studies of stars of the solar vicinity have concluded that outbursts of these objects are randomly distributed in time and consequently can be modelled by Poisson-distributions (Oskanyan and Terebizh 1971). For the definite physical similarity between cluster and solar vicinity flare stars the flare contribution of stars of aggregates has been analysed as the outcome of a group of random generators. Estimates of the flare star content of the Pleiades region based on these assumptions have ranged from 600 to 2700 (Szécsényi-Nagy 1986a and refs. cited therein).

3.2. Deviations From Random Distribution

For three flare stars of the solar neighbourhood Pazzani and Rodonó (1981) demonstrated that their flares were not randomly distributed in time but showed a tendency towards grouping. Some other flare stars seemed to change their mean flare frequency from year to year. Rodonó (1975) published markedly different values for the star II Tauri (1972:0.25h^{-1} and 1973:1.56h^{-1}) which very probably shows cyclic activity changes on the long run too (Szécsényi-Nagy 1986b and 1990). When the star is very active it produces 2-4 times more photographically detectable high amplitude

https://doi.org/10.1017/S0074180900187479 Published online by Cambridge University Press

flares than when it is quiet or least active. This particular object contributed 8% of all of the flares of the Eta Tauri fields consequently its variable activity should not be ignored.

3.3. Changing Activity of Stars of the Eta Tauri Fields

II Tau (also HII 2411 or CPFS 377) with its 120 flares listed in the CPFS seems to be the most powerful source of outbursts in the Eta Tauri fields. Despite its substantial contribution to the CPFS and for its above-mentioned cyclic activity variations (and its Hyades membership) it is better to reject all of its flares in a statistical study of the Pleiades region. In order to achieve the most reliable results flare distribution of all flare stars of the CPFS which produced at least 10 outbursts were checked. The method introduced and described by the author (Szécsényi-Nagy 1986 and 1989) led to the conclusion that besides II Tau 11 other flare stars of the CPFS (Nos 91, 143, 150, 194, 211, 256, 298, 354, 453, 454 and 477) must be omitted. This last move reduced the number of the stars involved to 402 and that of the flares to 1026. The effect of the filtering upon the relative contribution of flare stars of different activity to the total is illustrated by Fig.2. It demonstrates that changes due to filtering are really significant in the higher frequency bins and that implication of those objects which contributed 7 or more outbursts into the statistics may conclude to divergent solutions. To avoid this difficult problem models attributing lower statistical weights to these stars should be used in preference to any other.

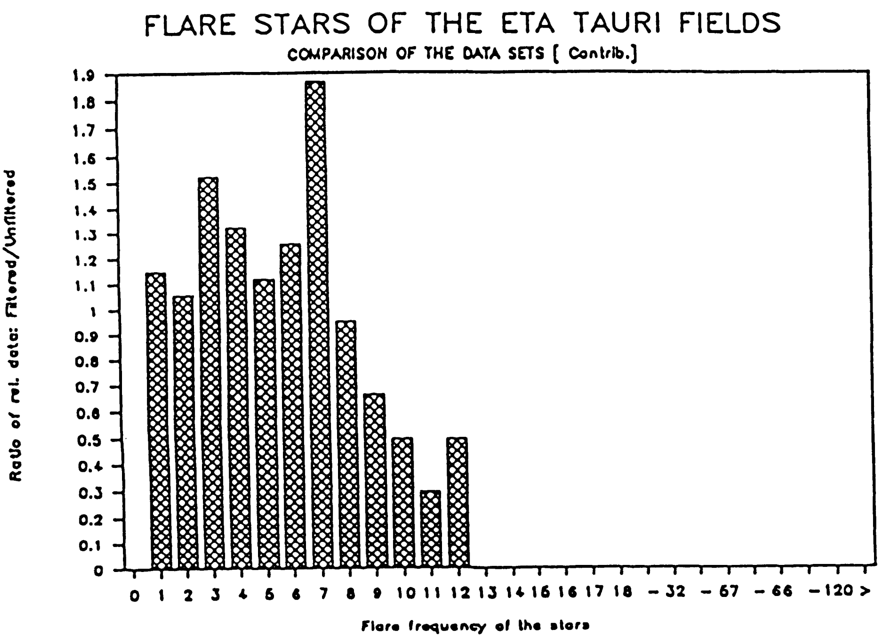

Figure 2. Filtering significantly diminished the relative flare contribution of the higher frequency (9...12) bins to the total of the M45 field.

https://doi.org/10.1017/S0074180900187479 Published online by Cambridge University Press

4. THE MOST LIKELY NUMBER OF FLARE STARS IN STELLAR AGGREGATES

4.1. Restrictions on Statistical Estimations of Flare Star Populations

Statistical studies of flare stars and their flares in fields of aggregates have been aimed at the estimation of the amount of these objects. Unfortunately most of the papers dealing with this topic ignore some very important limiting conditions. First of all simple statistical methods are unable to distinguish between cluster member and field flare stars. Consequently each result refers to both kind of objects. Secondly the estimates refer to the given region of the sky and to those latent objects only which are able to produce outbursts with high enough amplitudes to be detectable by the photometric techniques employed. Flare stars of the foreground may therefore significantly differ from those of the background of the aggregate.

4.2. New Values for the LCF of the Eta Tauri Fields (Conclusions)

It is well known that members of the Pleiades cluster are spread over a field of 50 square degrees or more. The present work was aimed at the analysis of the LCF defined in paragraph 2.2. which covers only 1/4 of the Pleiades region. Previous studies in this field which were based on a new global statistical procedure (Szécsényi-Nagy 1986) concluded that the most likely number of flare stars which are able to produce 0.5 mag. amplitude or brighter outbursts is about 650 and that their average flare frequency is 1/3000h. As data of the CPFS have recently been filtered the new set of accepted values has been re-examined.

The model which gives the best fit is composed of 560 flare stars with a mean frequency of 1 flare per 2400 hours. This result means that in the LCF of the Pleiades about 70% of the flare stars (members of the cluster and non-members too) which are able to produce outbursts of 0.8 magnitude or brighter have been catalogued.

5. REFERENCES

Haro, G., Chavira, E., González, G.:1982, Bol. Inst. Ton., 3, 1, 3.

Oskanyan, V.S. and Terebizh, V.Yu.:1971, Astrofizika 7, 83.

Pazzani, V. and Rodonó, M.:1981, Astrophys. Space Sci. 77, 347.

Rodonó, M.:1975, in V.E. Sherwood and L. Plaut (eds.)'Variable Stars and Stellar Evolution', IAU Symp. 67, 15.

Szécsényi-Nagy, G.:1983, Publ. Astr. Inst. Czech. Acad. Sci. 56, 219.

Szécsényi-Nagy, G.:1985, in L. Stegena (ed.)'Annales Univ. Sci. Budapest, Sectio Geoph. etc.' I-II. 308.

Szécsényi-Nagy, G.:1986, in L.V. Mirzoyan (ed.)'Flare Stars and Related Objects', BAO Symp. 1984, 101.

Szécsényi-Nagy, G.:1986a, in B.A. Balázs and G. Szécsényi-Nagy (eds.) 'Star Clusters and Associations', PES Symp. 6, 101.

Szécsényi-Nagy, G.:1986b, in L. Szabados (ed.)'Eruptive Phenomena in Stars', SPE Symp. Budapest 1985, 425.

Szécsényi-Nagy, G.:1989, in B.M. Haisch and M. Rodonó (eds.)'Solar and Stellar Flares', IAU Coll. 104, 143.

Szécsényi-Nagy, G.:1990, in M. Vázquez (ed.)'New Windows to the Universe', IAU XI ERAM (in press).