Proceedings of the VII Bulgarian-Serbian Astronomical Conference (VII BSAC)
Chepelare, Bulgaria, June 1-4, 2010,
Editors: M. K. Tsvetkov, M. S. Dimitrijević, K. Tsvetkova, O. Kounchev, Ž. Mijajlović
Publ. Astron. Soc. "Rudjer Bošković" No 11, 2012, 127-139

ASTROINFORMATICS FOR THE FLARE STARS IN STELLAR CLUSTERS AND ASSOCIATIONS

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Abstract. Applying the subjects of Astroinformatics to the data concerning the photographic observations of the flare stars in stellar clusters and associations we aim to enable extracting unrevealed knowledge for this type of variable stars, as well as to re-use the accumulated observing material (photographic plates) already in digital form, supplying digital curation. The database for the detected photographically flare stars (UV Ceti type variability with designations in the General Catalogue of Variable Stars - UV and UVn) in stellar clusters and associations as the Pleiades, Orion M42/M43, Taurus Dark Clouds, Cygnus NGC 7000, Praesepe, NGC 2264, Cygnus IC 1318, Coma Open Cluster, Alpha Perseus Cluster, Scorpius-Ophiuchus, and others, is present. The metadata records for the flare stars and their registered flare-events is described, as well as the access, data mining, possibilities for information searches, and flare stars plate visualization. The automated flare stars search, started on the basis of scanned flare stars monitoring plates of the Rozhen Observatory obtained with the 50/70/172 cm Schmidt telescope in the period 1979 - 1995, is expected to increase the number of discovered flares compared to the visual inspection by a blink-comparator done before in the observatory.

1. INTRODUCTION

Very briefly Astroinformatics can be described as data-oriented astronomy including data organization and data description, information retrieval and data mining methods, information visualization and knowledge extraction. Astroinformatics has as one of its subjects Semantic Astronomy for precise representation of the astronomical object nature in order to provide useful data queries, mining, access, dissemination and as a result - knowledge extraction. Ruling by this principle as a definition of Flare Stars in Stellar Clusters and Associations we comprise all variable stars showing flare activity - a randomly quick increase of the brightness across the spectrum (with greater increase in the ultraviolet) and a decline from maximum to minimum by several tenths up to

several magnitudes in U band for some minutes up to some hours (Fig. 1). One of the brightest stars observed photographically in the stellar clusters and associations and shown flare-event is V 1396 Cyg with maximum brightness 11.65 (pg). The amplitude of brightness increase can reach up to 9.0 (U) magnitude - examples of registered flare-events with a big amplitude can be found in the stars V1710 Cyg with Δm= 7.0 (pg), V669 Tau with Δm= 8.0 (U), V1125 Ori with Δm= 8.3 (U), SV Ori with Δm= 8.4 (U), V356 Tau with Δm= 8.5 (pg), V341 Tau with Δm= 9.0 (U), V 515 Per with Δm= 9.0 (U)**.** The flare stars being K-M spectral type dwarf stars belong to the population of young stellar clusters and associations. They are designated with "UV" type stars (from the prototype star UV Cet), and "UVn" (because the connection with nebulae) in the General Catalogue of Variable Stars (GCVS, Kholopov et al. 1985-1988). Flare-events can happen once every few days or less frequently. The flare activity is a common characteristic in the early evolution of all red dwarf stars. The evolution scenario follows the scheme:

T Tau Type stars → Flare Stars → Main Sequence Stars.

The UV Ceti type stars from the solar neighbourhood are the older red dwarf stars with smaller masses, which have survived their original aggregate, and now being already disintegrated belong to the general galactic field population.

Another flare-like activities were discovered in many types of stars across the HR diagram: some Wolf-Rayet stars, stars of B and A spectral types, RS Cvn system, some members of Algol and W UMa systems, FK Com stars, brown dwarfs, and even evolved systems, containing white dwarfs. All these phenomena (despite of the fact that many of them need confirmation) are very interesting for understanding of the flare activity nature. Thus the reason for the flare-like events occurring in the chromospherically active stars sometimes is a companion star in a binary system caused tangled magnetic field, another reason is an axial rotation of a star with spots.

The review of all observed characteristics - energy, amplitudes, time-scales, frequencies, shows differences, probably due to the different origin. That is why collecting flare star data we have restricted the observed phenomena - so called flares, classical flares, flashes, microflaring, to the UV Ceti type variability as is classified in the GCVS (http://www.sai.msu.su/gcvs/gcvs/iii/vartype.txt). The number of variable stars designated clearly as UV and UVn in the version from March 2011 of the GCVS (Samus et al., 2011) is 1559 with including UV Ceti type stars from the solar neighbourhood. The discovery of flare stars in stellar clusters and associations continue to happen now but with other types of observations – e.g. Chandra X-ray Observatory since its beginning of operation in 1999 has discovered a lot of X-ray flares from young stars (see in particular the results of Chandra Orion Ultradeep Project). The CCD observations having smaller field of monitoring in comparison with the earlier wide-field photographic observations also contribute to the increasing number of the flare stars. For

example, on October 29, 2010 in the Pleiades cluster in a 19 mag (V) star, unknown up to the moment as variable star, a flare with amplitude 4.7 (V) was registered (Masi, 2010).

Applying the subjects of Astroinformatics to the data concerning only the photographic observations of the flare stars in stellar clusters and associations we aim not only to re-use the accumulated monitoring photographic plates already in digital form, supplying digital curation, but also to enable extracting unrevealed knowledge for this type of variable stars.

2. FLARE STARS SEARCHES IN STELLAR CLUSTERS AND ASSOCIATIONS

In order to investigate this phenomenon and to reveal its nature, flare star searches in stellar clusters and associations begun in the Pleiades and the Orion region in 1947 and later on done in the frames of the international cooperative programme of several astronomical observatories - Tonantzintla, Byurakan, Asiago, Abastumani, Konkoly, Rozhen, etc. by photographic multiple exposure plate observations up to the last ones in the Pleiades and Cygnus in 1986, and in the Orion region in 1989. A lot of observing material was collected in the form of multiple exposure plates obtained by the multi-exposure method (stellar chains) applied with wide-field telescopes (Schmidt or Maksutov type). According to this method after a single exposure with duration usually of 5 up to 10 minutes, the telescope is moved along the Right Ascension coordinate and a new exposure is made with the same duration. The number of stellar images in one such chain is optimal up to 6. At a star showing brightness variations within the time period less than 10 minutes, its images in the respective stellar chain would be not equal. Monitoring the stars in this way one can discover not only brightness variability, comparing the plates obtained in the same region but in different periods, but also to detect brightness variability with time resolution less than 10 minutes.

In Fig. 1 the two-dimensional contour plot and density tracing of the flare star V 1214 Ori with the registered flare-event on January 14, 1985 in quiet state of the brightness 16.75 (pg), and reached maximum of the brightness 15.60 (pg), is shown. This flare star has shown two flare-events known as AB145 and the shown in Fig. 1 - LS6.

We collected the data from the flare star photographic monitoring observations in the stellar clusters and associations done in the period of the 60s up to the middle of 90s of last century. The observations are done as in the frames of the international cooperative programme, as well as from incidental observations. The stellar clusters and associations, where the number of observing hours is more than 100, are given separately. The flare stars proved to be from the solar neighbourhood and observed photoelectrically are not included. Not taken in view are the applied different observing techniques for flare star observations in stellar clusters and associations such as the fibre-fed multi-object spectrograph FLAIR on the UK Schmidt telescope in Australia (Guenther, 1995), and CCD based

photometer attached to the 70 cm Abastumani Observatory meniscus telescope (Kurtanidze, 1995) for time-resolved spectroscopy and multicolour photometry.

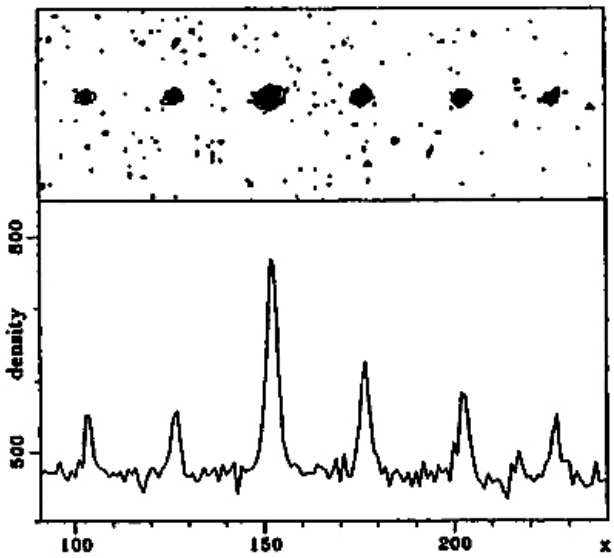

Figure 1. Two-dimensional contour plot and density tracing for a flare-event of V 1214 Ori.

Table 1: Flare stars photographic monitoring observations in stellar clusters and associations.

Stellar cluster or association	**Number of flare stars**	**Number of registered flares**	**Observing time (hours)**
Orion M42/M43	564	827	1591
The Pleiades	547	1635	3250
Taurus Dark Clouds	102	122	870
Cygnus NGC 7000	83	120	1168
Praesepe	59	146	680
NGC 2264	42	43	105
Cygnus IC 1318	17	18	300
Coma Open Cluster	14	21	338
Alpha Persei Cluster	7	7	128
Scorpius-Ophiuchus	14	15	321
Others	70	70	800
Total	**1519**	**3024**	**9551**

The distribution of the number of discovered flare stars (with total number 1519) and their registered flare-events (with total number 3024) in the respective stellar cluster or association (Fig. 2), as well as the distribution of the used observing time of 9551 hours versus the name of respective stellar cluster or association (Fig. 3) are given.

An automated flare search method was applied for some southern stellar aggregates with different age (Aniol et al., 1990, Winterberg et al. 1995). This method removed partially the selection effect due to the used 10-minute duration of the single exposure, which is a low time resolution. Thus it may preclude detection of energetic, but low amplitude flare-events on bright stars. So the flare star surveys with used flare star monitoring photographic method of multi-exposure images each of 10-minute duration usually discover the most chromospherically active stars. The less active stars could be missed. If the star is very faint it will be impossible to observe small flares. On the other hand this method increased the number of discovered flares (mainly slow flare events, flares on bright stars and on In-type variables) by 50 % compared to visual inspection by a blink-comparator.

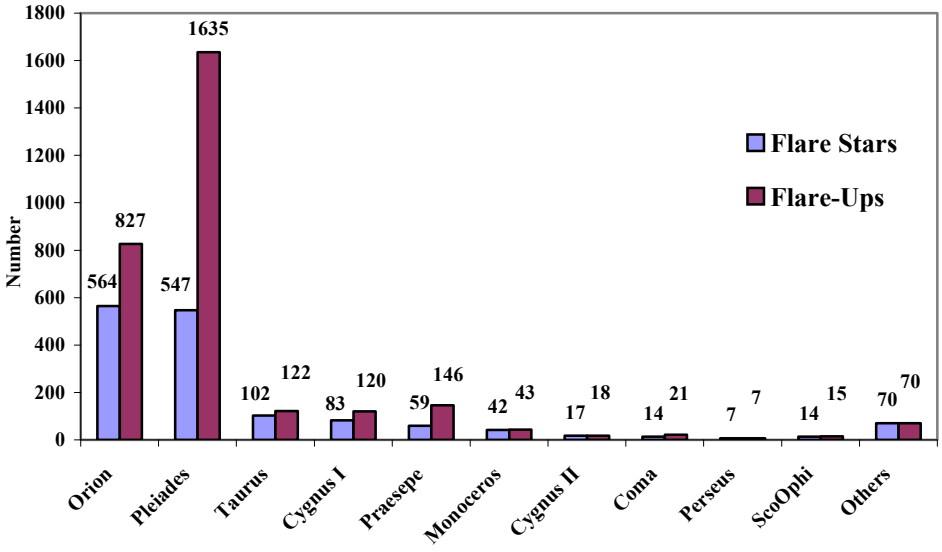

Figure 2. Flare stars and flare-ups in stellar clusters and associations.

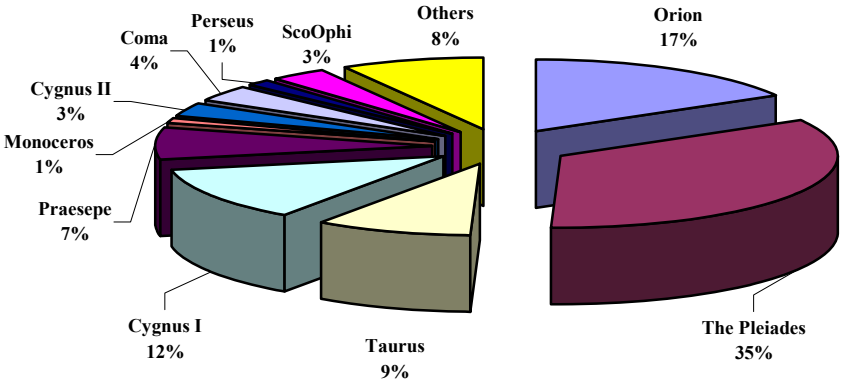

Figure 3. Used observing time for flare stars investigations in stellar clusters and associations.

3. EXISTING CATALOGUES OF FLARE STARS IN STELLAR CLUSTERS AND ASSOCIATIONS

We compiled catalogues or made computer-readable versions of already existing catalogues:

- Machine-readable version of the Tonantzintla Pleiades Flare Stars (Haro+, 1982, VizieR Catalogue - II/131 since 1987);
- Catalogues of the Cygnus flare stars (Tsvetkov and Tsvetkova, 1990);
- Catalogue of flare stars in the Praesepe cluster (Tsvetkova et al., 1991).

The original catalogues were checked by the help of a special programme package FLAREBASE (Tsvetkov et al., 1994). The aim was not only the preparation of master catalogues but also to make a critical evaluation and to ensure the homogeneity of the data, which are needed for basic statistical investigations, such as the construction of the number distribution of flare stars by stellar magnitude in quiescence or by outburst amplitude, time, and energy parameters in order to calculate the total flare event energy, etc.

4. FLARE STARS DATABASE

From the work on the flare stars catalogues in order to provide direct access to the original flare star data the Flare Stars Database (FSDB) was established (Tsvetkova et al., 1995; Tsvetkova et al., 1996). The FSDB is a database not only for UV Ceti type stars but also for their registered flare-events, which are missing in the other existing astronomical catalogues and data sets like GCVS, the Set of Identifications, Measurements and Bibliography for Astronomical Data

(SIMBAD), and the Database on UV Ceti Type Flare Stars and Related Objects (Gershberg et al., 1993, 1999).

The comparison with the mentioned catalogues and databases revealed that:

- in the GCVS, as well as in SIMBAD, the given information on stellar magnitude at minimum and maximum is not sufficient for assigning the flare event parameters. Very often, the lack of flare star identification charts is a reason for some misidentifications and errors in the GCVS (Tsvetkova and Tsvetkov, 1989),
- Gershberg's et al. (1993) database contains the data of only 230 UV Ceti type stars and some related objects. The complementary Catalogue and Bibliography of the UV Cet-Type Flare Stars and Related Objects in the Solar Vicinity of Gershberg et al. (1999) with 463 objects doubled the number of the stars and presented their astrometric, spectral, photometric data, as well as information on the infrared, radio and X-ray properties, and general stellar parameters.

Each flare-event is identified uniquely by the name of the variable star according to the GCVS (5 bytes); the name of the constellation (3 bytes); the date of the flare event - year, month, day (6 bytes); the consecutive number of events, occurring on the same date (1 byte). For example, the second flare-event happened and registered on the same date December 6, 1972 on the star V 426 TAU will have the identifier V_426TAU7212062.

After analysing the existing flare star data and having in mind the needed parameters describing the flare event we have adopted for the FSDB the following structure, shown in Table 2 with the flare stars metadata set.

The most serious obstacle for the FSDB is the lack for some stars in the literature of some necessary flare-event parameters as beginning and duration. Another lack is the flare star identification charts because of the faintness of some flare stars in minimum. That is why most of the astrometric works, as a rule, do not include flare stars yet (exceptions are the Pleiades flare stars and the works of Stauffer et al. 1991, and Prosser et al. 1991), but they go deeper and deeper reaching faint magnitudes.

5. DIGITAL PLATE ARCHIVES FROMMONITORING FLARE STARS PLATES

With collecting the observing material on whose basis these flare stars searches were made, and with preparing digital plate archives we aim search, preservation and re-usage of the world wide-field photographic monitoring flare stars plates. The digital plate archives can assemble and explore massive data sets and in this way to reveal a new knowledge existing in the data, but still not recognized in any individual data set. The next step towards the systematic astronomical research is the plate digitisation. The plate digitization makes possible automatic search for brightness increase, yielding in discovery of more flare stars in comparison with the usual plate checking. The organization of the plate scans in an image database

and the development of a software system for object plate identifications and for searching in an image database with many data storage variants is the last step.

Table 2: Structure and Content of the FSDB.

MAIN DATA

↓ ↓ ↓ ↓

Flare-event identifier
Equatorial coordinates (R. A., DEC) of flare star for equinox J2000.0
Equatorial coordinates (R. A., DEC) of flare star for equinox J1950.0
Galactic coordinates in the l(II), b(II) system
Julian date of the flare-event
First registered flare-event
Telescope used
Stellar magnitude at minimum in U or Pg/ BPOSS bands
Stellar magnitudes at maximum in U- and Pg bands
Amplitudes in U and Pg bands
Criterion - $\Delta m > 5\sigma$
V magnitude, B-V and U-B indices at minimum
Spectral class
Aggregate membership

↓ ↓ ↓ ↓

CROSS-IDENTIFICATION
IDENTIFICATION CHARTS
REFERENCES
NOTES

The preparation of the digital plate archives of photographic monitoring flare stars plates began with the plates obtained in the Pleiades cluster as a good and accessible sample. The total number of the known Pleiades flare stars according to the Flare Stars Database (Tsvetkova et al., 1995) is 547, including some stars with doubtful membership to the flare stars class variables according to Tsvetkova and Tsvetkov (1989). The statistical evaluation of the total number of all flare stars in the Pleiades (registered and not registered up to now) is about 1000. Precise coordinates of the known Pleiades flare stars were determined as a necessary step to the further work of automated search for flare stars and investigations of long-term brightness variations. Searching the WFPDB for the Pleiades plates more than 3100 plates obtained in the period 1885 – 1998 were found in the observatories in Asiago (Italy), Sonneberg (Germany), Harvard (USA), Kyiv (Ukraine), Moscow (Russia), Rozhen (Bulgaria), Konkoly (Hungary), Byurakan (Armenia), Potsdam (Germany), Edinburgh (UK), Bamberg (Germany). The archive of the digitised plates in the Pleiades stellar cluster contained already about 1500 plates. One of these plates is present in Fig. 4 giving the low-resolution digitized image (with the kept marks of the observer) of the Rozhen

Schmidt telescope plate with the WFPDB identifier ROZ050_002278 taken on September 30, 1984 in the Pleiades cluster with the detected flare R24 in V 853 Tau. This large data set gives the opportunity to obtain almost continuous photometric data set for the red dwarf stars in the cluster and to search for probable cycles in the flaring activity as is found for some flare stars.

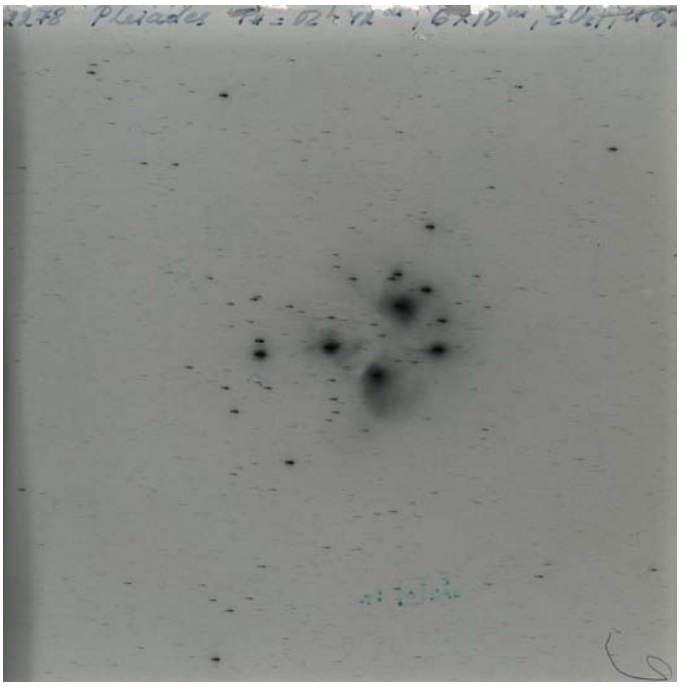

Figure 4. Plate with the WFPDB identifier ROZ050_002278 in the Pleiades cluster.

Another example is the Konkoly Flare Star Digital Archive containing representative plates obtained with the Schmidt telescope of Konkoly Observatory as one of the observatories taking part in the observation campaign for search and investigations of the flare stars in different stellar clusters and associations. Besides the primary aim to serve for investigations of the flare stars another result of this archive is the realization of an interlinking the electronic Information Bulletin on Variable Stars (IBVS) with the Wide-Field Plate Database (WFPDB). The plates are scanned with resolution up to 1200 dpi for plate visualization and to preserve the observer marks. The image is saved as TIFF (7322x7322 pixels) and as JPEG file (compressed to 2000x2000 pixels). After the cleaning the observer marks the plate is scanned with high resolution (2400 dpi) and saved as FITS file.

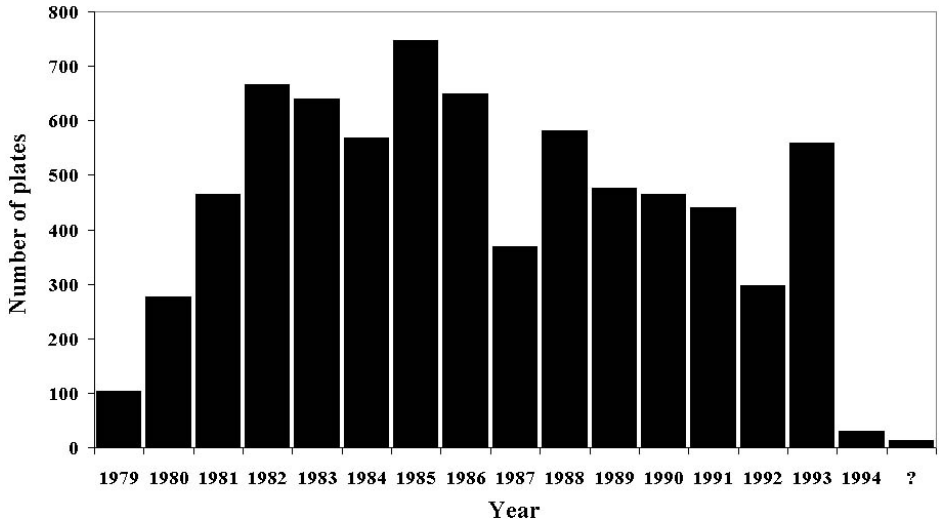

Figure 5. Time distribution of the Rozhen Schmidt telescope plates.

Now having at disposal an observing material (more than 1500 plates) from the monitoring flare star observations in Rozhen Observatory, done with the 50/70/172 cm Schmidt telescope in the period 1979 – 1995, we have started preparation of the Rozhen Flare Stars Digital Plate Archive in order to apply an automated flare stars search method on the basis of scanned flare stars monitoring plates of the Rozhen Observatory. Information for the plate archive of Rozhen Schmidt telescope (concerning the plate digitization as method of observation, plate size, etc.) can be found in Tsvetkova et al. (2010). Some useful characteristics of the plate material obtained with the Rozhen Schmidt telescope as time distribution of all plates, as well as observing programmes distribution, are presented in Figs. 5-6, respectively.

There are at disposal for plate scanning three EPSON flatbed scanners: EXPRESSION 1640XL and PERFECTION V700 PHOTO (in Sofia Sky Archive Data Center) and EXPRESSION 10000XL (in Rozhen Observatory). The plates are scanned in the whole density range 0 – 255 and Gamma = 1.00 twice according to a system for quick plate visualization (Preview plate images) with low resolution (1200 dpi), aiming easier web accessibility and storage of the information from the observer marks on the plate with Adobe Photoshop programme and plate storage in TIFF file format and compressed 1000x1000 pxl JPEG file format, and second time – after cleaning the plate with 2400 dpi resolution for further work (high-resolution scans) with the scanning programme SCANFITS in FITS file format. The volumes of the output files are given in Table 3.

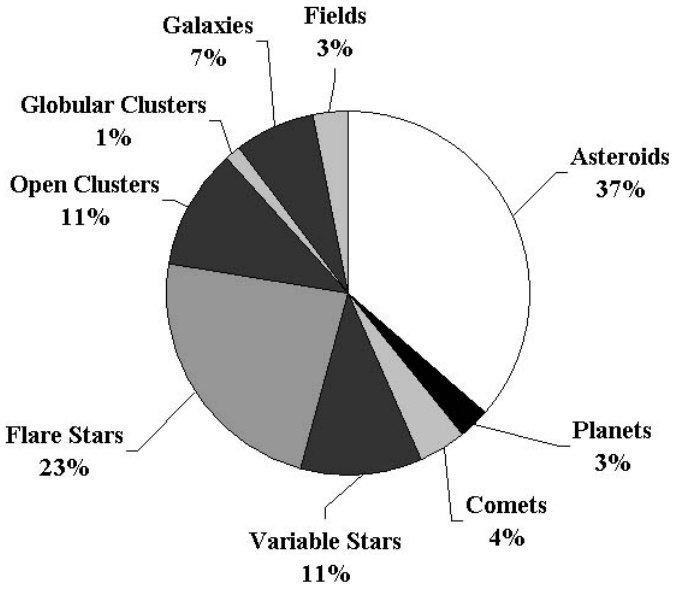

Figure 6. Used observing programmes for plate observations with the Rozhen Schmidt telescope.

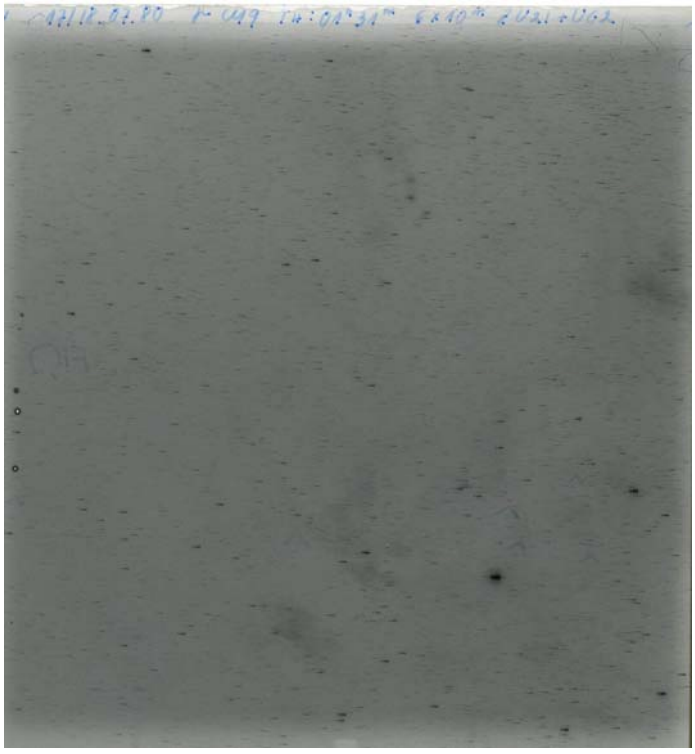

Figure 7. Plate with the WFPDB identifier ROZ050_000194 in the Gamma Cyg region.

Table 3: Output files volume of the Rozhen flare stars plate scanning.

File Format	Volume (MB)
JPEG	2.4
TIFF	107.0
FITS	286.0

The Rozhen Schmidt telescope plate with WFPDB identifier ROZ050_000194 was taken in the Gamma Cyg region on July 17, 1980. On the plate the flare R5 in the star V1757 Cyg with amplitude bigger than 4.8 (U) was registered.

It could be expected that the undertaken automated flare stars search will increase the number of discovered flare stars and flare-events compared to the visual inspection by a blink-comparator done before in the observatory.

Acknowledgements

This work is supported by the Bulgarian National Science Fund (with the grants BG NSF DO-02-273 and BG NSF DO-02-275).

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