

AN AUTOMATIC SEARCH FOR FLARE STARS IN SOUTHERN STELLAR AGGREGATES OF DIFFERENT AGES*

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ABSTRACT. Statistically relevant samples of flare stars in stellar aggregates can be used to specify the stellar mass-age-activity-relation when the ages of the aggregates are known from independent investigations. Associations and clusters of the southern sky are currently surveyed with the GPO astrograph of the European Southern Observatory. The plates are digitized with the PDS 2020 GM^{plus} microdensitometer and the data are reduced automatically at the Astronomical Institute of Muenster University. The programme package "FLARE" is described. First results from the Orion association are presented.

1. Introduction

Stellar activity as observed in flare stars (UV Cet stars) and related objects (T Tau, H α emission, FU Ori stars) appears to play an important role during the early stages of stellar evolution (Ambartsumian 1969). The underlying physical processes and their decline with advancing age are, however, still not sufficiently well understood. Thus, it is of interest to study not only individual objects in detail but to improve the statistics of active stars and their degree of activity. The project described here aims at enlarging the number of known flare stars (currently 1414 verified plus 188 suspected UV Cet-type variables), and, in particular, to derive a mass-age-activity-relation from the frequency of flares and flare stars of different masses in stellar aggregates of various ages.

In addition to the general need for more data, the clear dichotomy of the data available in the northern and southern hemispheres requires additional surveys particularly in the south. The status of observations prior to the present study is shown in Tables 1 and 2 and in Fig. 1.

2. The Muenster Flare Star Project

The Muenster Flare Star Project started in 1985. The large demand on southern Schmidt telescope time for other surveys and atlases prompted us to work with the GPO astrograph of the European Southern Observatory, hoping that the smaller flare amplitudes in a blue band which does not extend into the ultraviolet would be compensated by the faster growth

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TABLE 1. Flare data in northern stellar aggregates.

aggregate	no. of flare stars	total observing time (h)	references
Pleiades	539	3250	1,2,3
Orion M42/M43	499	1590	4,5,6,7
Taurus Dark Clouds	102	870	8
NGC 7000 – IC5068-70	75	1185	9
Praesepe	54	660	10,11,12
Monoceros – NGC 2264	42	100	13
Cassiopeia – W3, IC 1848	25	62	14,15,16,17
γ Cyg – IC 1318	17	300	9
Coma Open cluster	14	338	18
Cepheus – NGC 7023	14	50	19,20
total	1381	8404	

(1) Haro *et al.* 1982; (2) Chavushian 1979; (3) Tsvetkov *et al.* 1989; (4) Haro 1953; (5) Natsvlishvili 1989; (6) Konstantinova-Antova and Tsvetkov 1988; (7) Present work, see Table 4; (8) Hojaev 1986; (9) Tsvetkov and Tsvetkova 1989; (10) Jankovics 1975; (11) Haro *et al.* 1976; (12) Mirzoyan and Ohanian 1986; (13) Parsamian *et al.* 1985; (14) Pulakos 1976a; (15) Pulakos 1976b; (16) Pulakos 1977a; (17) Pulakos 1977b; (18) Erastova 1981; (19) Mirzoyan *et al.* 1968; (20) Parsamian 1982.

TABLE 2. Flare star surveys in southern fields.*

field	no. of flare stars	total observing time (h)	references
Sco-Oph	10	118.5	1,2
Coalsack	3**	27	3,4,5
R CrA	2	9	6,7
<i>o</i> Vel	1	5.5	8
total	16	160	

* without Orion association (M42/M43), which is included in Table 1.

** plus 140 suspected fast irregular variables with small amplitudes found by Andrews (1972) in the first automatic search for flare stars and irregular variables.

(1) Haro and Chavira 1974; (2) Sun and Tong 1988; (3) Andrews 1972; (4) Sanduleak 1968; (5) Sanduleak 1969; (6) Hardy and Mendoza 1968; (7) Duerbeck and Tsvetkov 1989; (8) MacConnell and Mermilliod 1984.

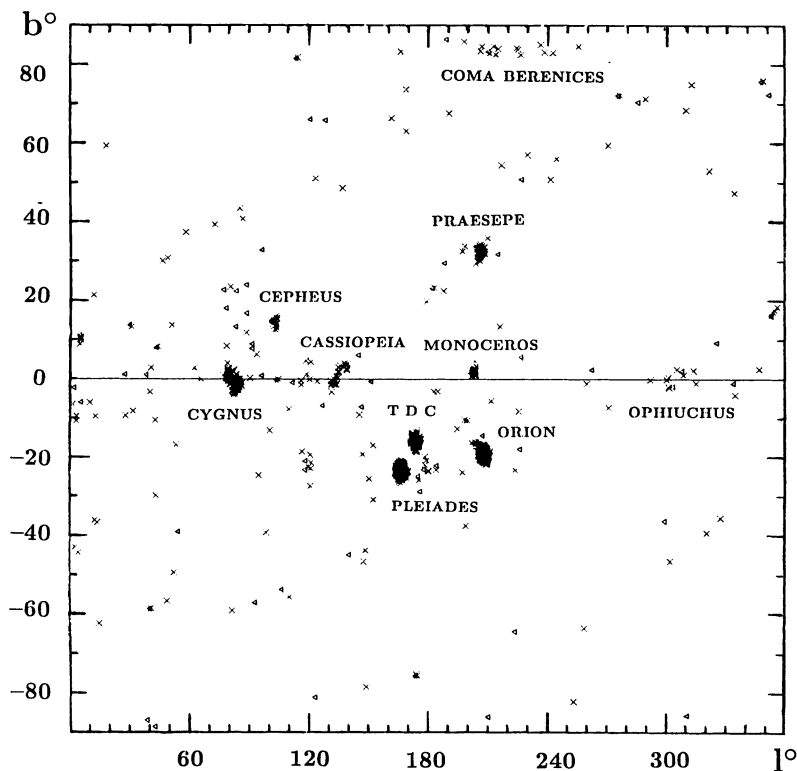


Fig. 1. Distribution of UV Ceti type stars in the Galaxy.

of the astrograph images. The field of the Orion association (M42/M43) which is not only well accessible from both hemispheres, but also one of the richest known regions of UV Cet and T Tauri stars, was chosen for tests of the detection power of the GPO and our reduction algorithms. The tests proved to be successful (Tsvetkov *et al.* 1986, Aniol *et al.* 1989).

3. Observations

The GPO astrograph has the following properties: 0.4 m aperture, focal ratio f:10, field size 4.2 square degrees, of those 2.3 square degrees practically coma-free. The complete fields are analyzed. With 10 min exposure time photographic magnitude 17.6 is reached on unsensitized Kodak IIa-O plates. Observations were carried out in the multiple exposure mode, usually with 5 to 7 observations per chain and ten minutes exposure time per image. To facilitate identifications of weak objects, deep plates were taken in the blue and red pass bands. So far, observations have been carried out during six observing periods in the southern summer and five observing periods in the winter; more observing time has been

granted. The fields and the total monitoring times are listed in Table 3. The number of chains recorded per plate is of the order 10 000. The total number of stellar images on the plates collected so far is of the order 20 million. Thus, automated data analysis becomes a necessity, while offering the further advantages of objectivity, higher ability for measuring fainter flares and flare stars, and detectability of longer period light variations through plate to plate comparison of chains.

TABLE 3. Data for southern stellar aggregates.

aggregate	R A (1950)	Dec (1950)	l	b	age (years)	dist. (pc)	no. of plates	no. of exp.	obs. time
Orion M42/M43	5 ^h 33 ^m	− 5°25′	209°2	−19°4	5×10^5	460	52	326	57 ^h 40 ^m
o Vel	5 40	−52 51	269.1	− 5.7	3×10^7	153	52	309	51 33
Θ Car	10 42	−64 20	289.5	− 4.4	3×10^7	155	51	302	50 20
Cha T1	11 05	−77 20	297.0	−15.3	$\approx 10^6$	140	49	303	52 10
Coalsack	11 49	−62 35	303.1	1.2	$\approx 10^6$	174	21	126	21 50
B228 Lup	12 49	−37 38	340.4	16.5	$\approx 10^6$	150	38	227	37 50
Sco-Oph	16 25	−24 10	353.9	17.1	$\approx 10^6$	150	37	226	37 40
B 59 Oph	17 12	−27 43	358.5	7.1	$\approx 10^6$	250	41	231	36 16
R CrA	19 01	−72 54	000.2	−18.0	10^7	129	53	228	53 00

4. Measurement and Automatic Data Reduction

Two flow diagrams of the program package FLARE, one for data preparation and one for data reduction, summarize the steps leading from photographic images to candidate lists of flare stars and other variables. The flow diagrams are shown in Figs. 2a and b.

Digitization. In order to obtain the data in machine processible form, the plates are scanned with the PDS 2020 GM^{plus} microdensitometer of the Muenster Astronomical Institute. With 20 μ m aperture and the same step size the relative positional accuracies are 0″.07 to 0″.14, depending on stellar brightness. Relative magnitudes within a given chain differ by no more than 0^m.08 to 0^m.12, depending on brightness. The total scan time per plate is 4^h, supervised time (plate adjustment, initialization) is less than 0.3^h. Up to 19 plates are stored on a single 8 mm video tape.

Segmentation. For storage, the digitized plate data are ‘segmented’, *i.e.*, all images are stored in ‘picture frames’ of 15 pixel \times 15 pixel each. This mode assures a minimum of storage space (1/3 that of a complete plate) and fast accessibility of all relevant information.

Image processing. This step includes the following procedures: Image reconstruction = object detection, determination of mean background density (averaged over several scan lines), local plate noise, positions in x and y , object radii, second order moments, and machine magnitudes for all objects.

Catalogue of image data. Through calibration with external catalogues, positions in α , δ , and photographic magnitudes are determined. The input catalogue for astrometric data is

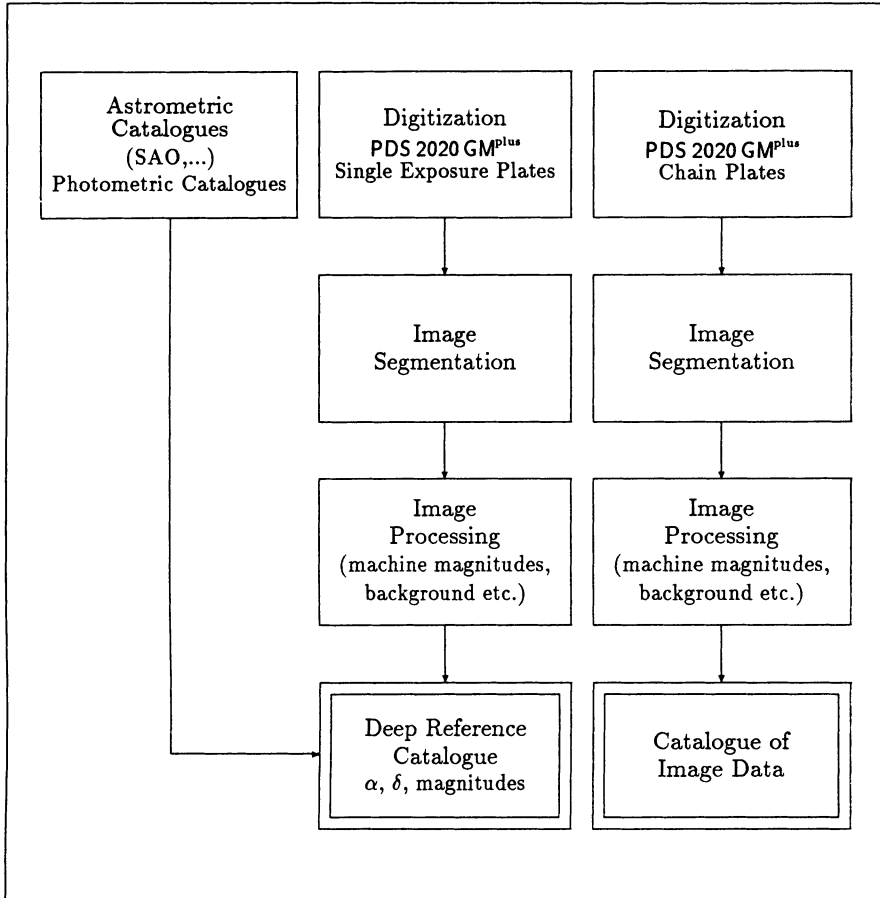


Fig. 2a. Preparation.

the SAO Catalogue, photometric data are taken from various sources. Catalogue positions are determined with an accuracy of $0''.5$. External magnitude calibrations are strongly affected by the lack of suitable standards. Their accuracy is at present $0^m.3$ to $0^m.4$.

Deep reference catalogue. The catalogue contains the machine and calibrated positions and magnitudes of all objects found on the deep plates. It is used in the subsequent reduction process.

Chain recognition by matching. All image data files are matched with the deep reference catalogue using the eastern images of the brightest chains for x,y -coordinate transformation. Positional accuracies after matching are $0''.3$. Also determined are the number of images per chain and the distances between chain images. The celestial coordinates from the deep plates are then assigned to all chains, including incomplete ones. The resulting lists of

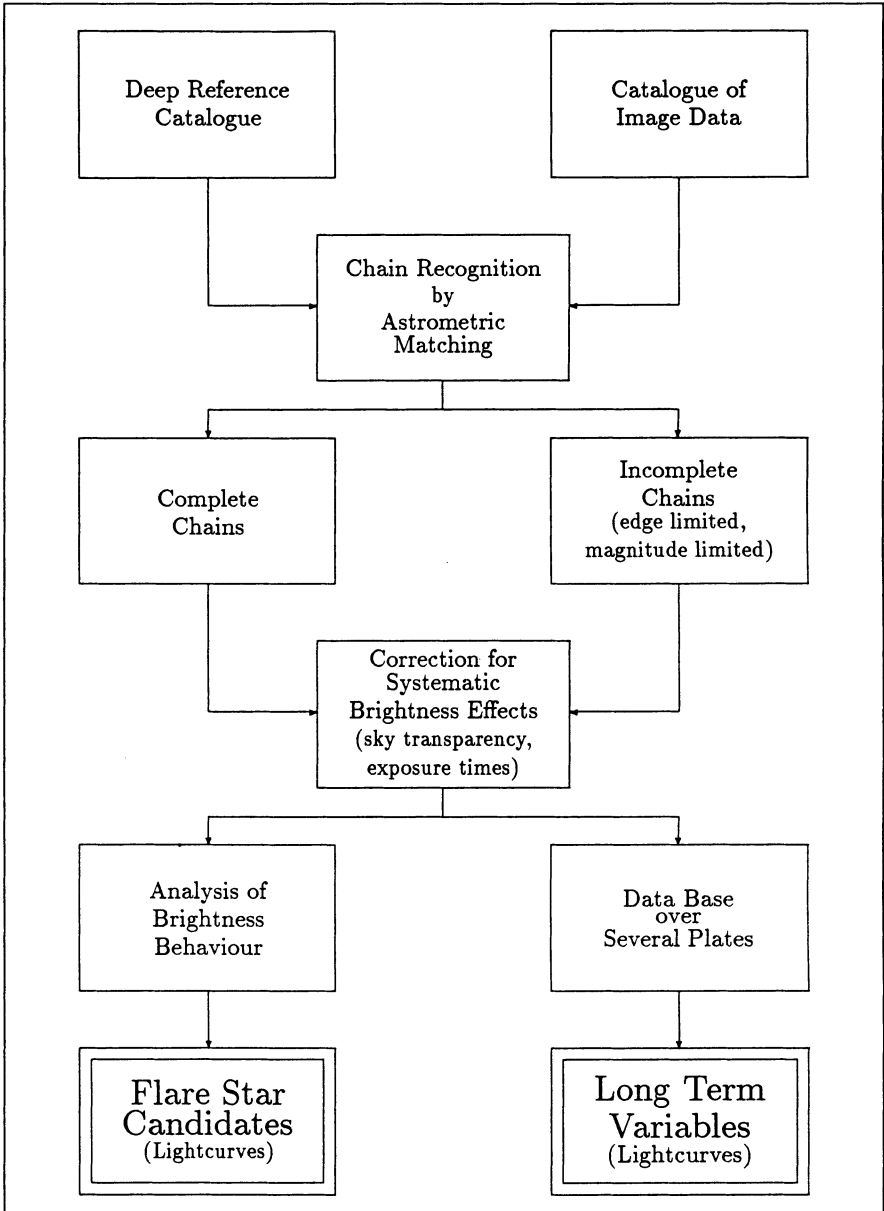


Fig. 2b. Main reduction.

complete and incomplete chains are used for further processing.

Correction for systematic brightness effects. Statistical analyses of image brightnesses (machine magnitudes) are used to correct for differences in exposure time and sky transparency within the chains.

Analysis of brightness behaviour. From the corrected magnitudes 'light curves' for all chains of a given plate are determined. In order to avoid magnitude effects, mean light curves for different magnitude intervals (generally 6 intervals over the total magnitude range) are obtained.

Flare star candidates. By comparison of all individual chains on a plate with the mean light curve of the proper magnitude range, the stars whose chains include at least one image brighter than a preset limit are classified as flare star candidates. Because relatively high accuracy internal plate magnitudes are used, the limit can be set as low as $0^m.3$ (approximately 3σ). In true flares, generally more than one image deviates from the mean. High resolution tracings and two-dimensional images of the chains of all candidates are checked visually, and final assignments as flares take into account the shapes of the observed outbursts.

Data base for all plates. All corrected chains found on all plates for a given star are collected in a data base.

Long term variables. This list contains all stars with light variations larger than the preset limit in any of the available chains, including those which have no identified flare event. For the determination of long term light variations the individual plate magnitudes are reduced to a common internal system. The accuracy is sufficiently high to detect variations within $0^m.5$. The majority of long term light curves found so far suggests irregular variables with time scales of days.

5. Results from the test region and conclusions

20 plates of the test region Orion M42/M43 were analyzed by the program FLARE. The results were compared with those obtained through visual inspection by one of us (M.K.T.) who has many years of experience in visual flare detection. The preset lower variation limit was 5σ following Oskanian and Terebizh (1971). The results are summarized in Table 4, which also includes one new flare star found by visual inspection of a section not included in the above test. Samples of the detected flare events are shown in Fig. 3. From the candidates of the automatic reduction program, 12 flare events could be verified, the others were included in the list of long term variables. Visual inspection of the plates without preselection yielded 8 flares. Besides the fact that automatic search increased the number of objects by 50%, it is interesting to note the characteristics of the additional flares: all are of low amplitude and some of them occurred on bright stars. They were verified by subsequent checks of the original plates. The results support our expectation that unbiased machine selection of flare candidates is particularly useful for objects which escape the strongly biased human eye. 10 of the observed stars are new flare stars. Six of them were previously known as variables (Kholopov 1985; Kholopov *et al.* 1985, 1987, 1989). This

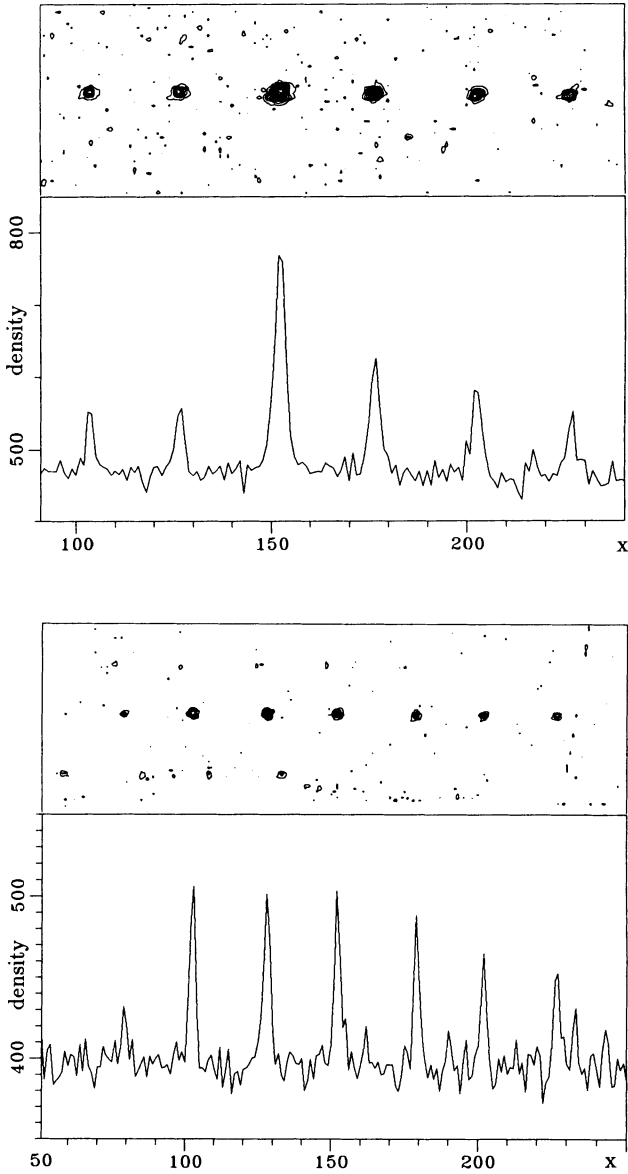


Fig. 3. Flare events in chains of LS6 and LS7 shown as high resolution two-dimensional contour plots and density tracings.

TABLE 4. New flare events and flare stars in the Orion M42/M43 association.

LS no.	ABC no.	GCVS CSV	R A (1950)	Dec (1950)	date (1985)	UT (max)	min. pg	max. pg	Δm (mag)	notes
1		AR	5 ^h 33 ^m 28 ^s .4	-5°06'59"3	10 Jan	2 ^h 43 ^m	15 ^m 16	14 ^m 53	0 ^m 63	1
2		V368	5 35 07.9	-5 13 45.1	11 Jan	1 26	15 . 84	15 . 20	0 . 65	
3	97	V714	5 30 45.9	-5 02 30.2	11 Jan	1 39	16 . 74	16 . 14	0 . 70	2
4*	416		5 32 22.7	-6 16 22.5	11 Jan	2 23	21 . 0 :	16 . 5	4 . 5 :	
5	344	6315	5 36 13.5	-5 50 39.7	13 Jan	4 02	16 . 92	16 . 32	0 . 59	3
6	145		5 34 02.4	-4 42 50.5	14 Jan	2 03	16 . 75	15 . 60	1 . 35	4
7	172		5 34 29.8	-5 00 45.8	15 Jan	1 42	16 . 89	16 . 07	0 . 82	3
8		AL	5 32 07.8	-5 46 39.9	17 Jan	2 38	16 . 11	15 . 28	0 . 83	
9			5 35 34.1	-4 54 56.9	21 Jan	1 53	16 . 84	15 . 79	1 . 15	
10	52		5 29 01.5	-5 39 43.3	26 Jan	2 45	16 . 46	15 . 34	1 . 12	5
11	450		5 36 11.1	-5 43 20.1	26 Jan	2 56	16 . 83	16 . 23	0 . 60	
12	453		5 36 23.9	-5 26 54.2	26 Jan	3 18	19 . 0 :	16 . 32	1 . 7 :	
13	239	KO	5 35 00.4	-4 33 05.8	26 Jan	3 29	15 . 84	14 . 24	1 . 65	1,3

* Found in a section outside the automatically reduced field.

(1) slow flare; (2) discovered as flare star T15 by Haro (1953); (3) H α emission star according to Parsamian and Chavira (1982); (4) discovered on patrol plate with exposures of 20 min per image; (5) discovered as flare star T260 by Haro and Chavira (1969).

2% increase in the total number of known flare stars in Orion corresponds to a discovery rate of 0.5 per monitoring hour as compared to 0.3 for the same region from all previous surveys—not taking into account different field sizes and centers, and the pitfalls of small number statistics.

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