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# A Search for Flare Stars With the GPO Astrograph

*R. ANIOL, H. W. DUERBECK, W. C. SEITTER, Astronomisches Institut der Universität Münster, F. R. Germany*
*M. K. TSVETKOV, Department of Astronomy, Academy of Sciences, Sofia, Bulgaria*

## 1. Flare Stars in Young Stellar Aggregates

The first systematic investigation of flare stars by the Mexican astronomer Guillermo Haro marks the beginning of long-term, multi-site studies of these objects in young stellar aggregates. His first series of observations with the Schmidt telescope of the Tonantzintla Observatory already showed the close relation between stars in the T Tauri stage and cool dwarf stars with enhanced UV activity (= flare stars), both types of objects being still in their early stages of evolution.

After 30 years of subsequent investigations, some of the conclusions by Haro are substantiated on the basis of extensive observational material, while the new results also gave a clearer picture of the nature of flare stars. Some of the main achievements and results to be substantiated by further studies are:

- More than 1,000 flare stars in the aggregates of Orion, the Pleiades, NGC 7000 (North America nebula), Praesepe, Coma, and others were discovered.
- The physical correspondents of flare stars in aggregates are the UV Ceti stars in the solar neighbourhood.
- By observing multiple flares in given stars, the lower limit of the number of flare stars in various aggregates could be estimated: Orion – 1,500; Pleiades – 1,000, NGC 7000 – 400, Praesepe – 300, Coma – 100 stars.
- It was found that, for a given aggregate, the spectral type of the brightest flare star and the maximum flare amplitude both correlate with the age of the aggregate.
- In stellar evolution, the T Tauri stage is followed by the flare star stage.
- There are two major types of flares, fast and slow ones. It is concluded that all flares have the same physical origin, since there are also rare flares of intermediate speed.

The close correspondence between flare stars in aggregates and in the solar vicinity, as well as some analogy between the flares in these stars and the solar flares suggest theoretical models for the underlying physical process(es). However, a general picture which includes all aspects of the problem of correlating the properties of flare stars, UV Ceti stars and older main sequence stars, has not yet been developed.

## 2. The GPO Astrograph

The GPO astrograph was one of the first telescopes on La Silla. At its previous location Zeekoegat in South Africa (1961–1966) and during its first years on La Silla, it was mainly used to obtain objective prism spectra of stars in the direction towards the Magellanic Clouds. One of the rare spectra of Sk – 69° 202, the star that later became SN 1987A, was taken with this instrument.

A new chapter for the GPO was opened with increasing interest in direct plates. Most of them are used for *astrometric* purposes: for asteroid observations, proper motion studies, and for the input catalogue of the HIPPARCOS astrometric satellite mission. Recent highlights of the southern sky, Halley's Comet and the Supernova 1987A, tempted more observers to "try" the GPO. We will report on one of our two *photometric* surveys, the search for flare stars with the GPO. Figure 1 displays the observational activity of the last two decades.

## 3. The Suitability of the GPO for a Flare Star Search

Until now, patrol observations of flare star fields were predominantly carried out with Schmidt telescopes in the northern hemisphere. The Schmidt telescopes in the southern hemisphere were to a large extent occupied by atlas

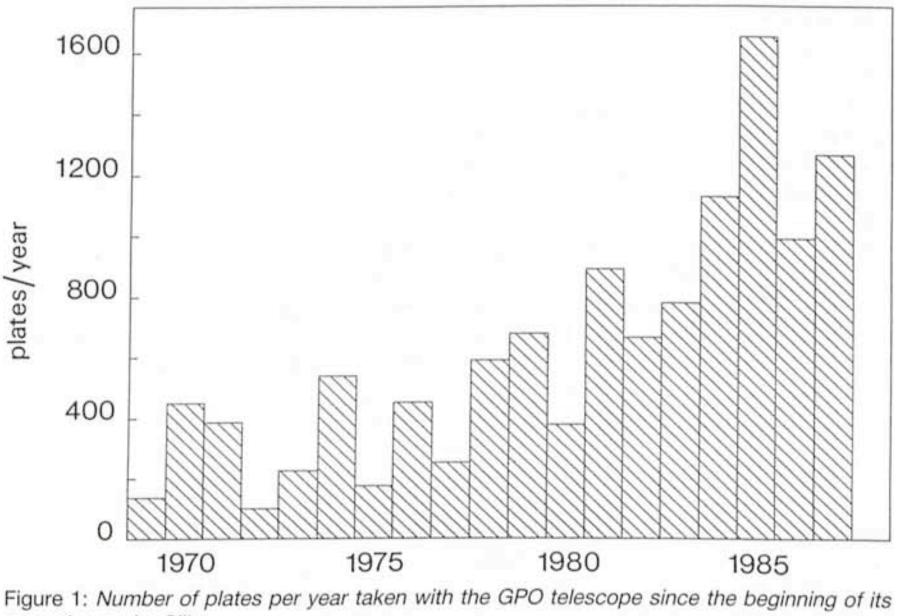


Figure 1: *Number of plates per year taken with the GPO telescope since the beginning of its operation on La Silla.*

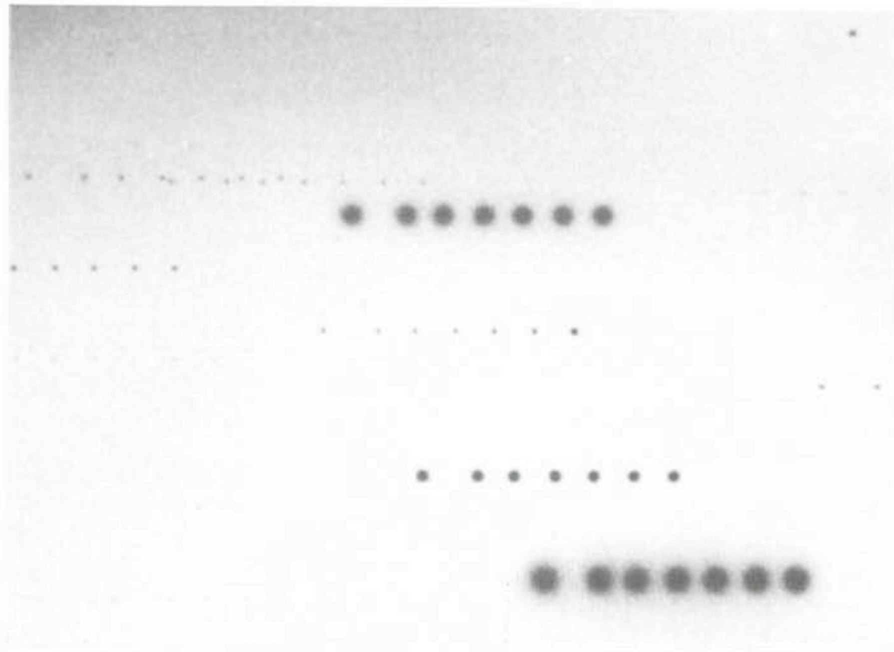

Figure 2: *Section of a multiple exposure plate of the Orion nebula region, showing the rise of a slow flare of KO Ori (emulsion IIa–O, exposure time 6×10 minutes).*

work. It thus seemed worthwhile to try the GPO telescope for a survey of southern fields.

While an astrograph has weak transmission for ultraviolet light, where most of the radiation of the flare is emitted, it has a more suitable image growth which makes small magnitude differences better measurable. In order to calibrate the *detection power* of the GPO, we chose the well studied region of the Orion nebula (M42/M43), the centre of the richest field of UV Ceti and T Tauri stars.

The visual inspection of the test plates (by M.K.T.) showed that the UV deficiency is indeed compensated by the enhanced image growth and that at least as many flare events per unit area and unit time are discovered on GPO plates as on Schmidt plates (Tsvetkov et al., Comm. Konkoly Obs. No. 86, Budapest 1986, p. 429.)

New fields of the survey are the young clusters ο Vel (IC 2391), Θ Car (IC 2603), and the dark cloud regions Cha T1, Sco-Oph, ϱ Oph, and Sco-Sgr.

## 4. Methods of Reduction

Generally, five to seven exposures of ten minutes duration each, separated by 30″, are made per plate. An example is shown in Figure 2, which portraits one of the rare *slow* flares, here of the star KO Ori.

For the beginning of the flare star project, we intended to reduce the multiple-exposure plates fully automatically. All plates are scanned with the PDS 2020GM plus microdensitometer at the Astronomical Institute Münster. The programme package developed by one of us (R.A.) includes:

1. plate preprocessing
2. chain recognition
3. search for flare event candidates
4. history of variability.

In part one, the data are brought into the form needed for the subsequent processes. Image segmentation and restauration is performed with a programme written by H. Horstmann for a galaxy survey on ESO/SRC atlas plates. The microdensitometer coordinates are transformed into celestial coordinates, using an astrometric programme written by H.J. Tucholke. The first step is the transformation of the coordinates for a single long exposure *master plate.* This is necessary because the deep plate registers stars which may be visible on the multiple exposure plate only during a stellar brightening. The accuracy is better than 1″, when stars from the SAO catalogue are used. Next, coordinate transformations are made between the master plate and the multiple exposure plates. The coordinates are assigned to the eastern image of each *chain of exposures.*

Finally, the *machine magnitudes* of the images are calculated using a standard characteristic curve.

The data are now ready for the second part of the programme, whose purpose it is to determine the mean distances between the images in the chains and their standard errors. Chains with a smaller number of images (weak stars drowned in a variable sky background) or chains with more images than exposures (caused by the almagamation of two chains with equal coordinates in declination) are not analysed at this stage. The resulting mean distances between images are determined within 0.5″ to 1.0″.

It is now possible to look for *all* chains. The amalgamated chains can generally be separated without difficulty on account of their larger number of members. Shorter chains and even single images can be found using the coordinate list of objects found on the master plate. Before storage, the chains are marked with identifiers, which give the total number of images. Incomplete chains or single images are stored separately, because they have a higher probability of resulting from a flare star.

The third part of the programme is devoted to the search for flare events. A *standard light curve* (variation of magnitude across a representative chain) must be known in order to determine the presence of a flare by comparison with a given chain. Because of the scatter in the magnitudes of individual chains, a *mean* light curve must be used. In order to avoid systematic effects, mean light curves are obtained separately for given magnitude intervals.

A chain showing at least one significant deviation from the mean lightcurve marks a flare candidate, though, as a rule, a true flare produces several devia-

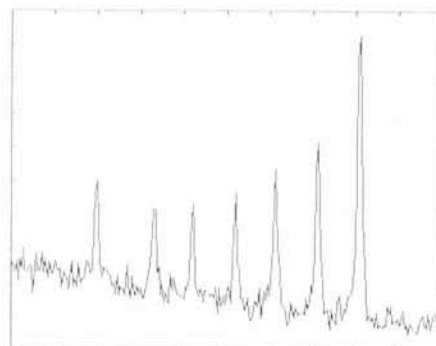

Figure 3: *Intensity tracing of the slow flare of KO Ori.*

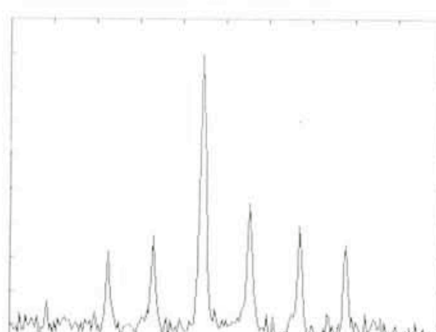

Figure 4: *Intensity tracing of a fast flare observed in a newly discovered flare star in Orion.*

tions. The method is very sensitive. By visual inspection, only flares of amplitudes larger than $0\overset{m}{.}6$ are found. Here it seems possible to decrease the limit to about $0\overset{m}{.}3$. The method also yields useful results for plates taken under non-photometric conditions; such plates, however, are rarely obtained at La Silla.

The flare candidates are stored in a "flare-file". This file contains also information about celestial coordinates, magnitudes of the images and density of the sky background. The last value is especially important for checking the reliability of a reported flare event, because a strong variable background, even when properly subtracted, can produce systematic exposure effects. Another problem appears for almagamated chains in regions of *high* star density. It occasionally happens that stars from the two chains merge into single images of higher brightness. This can occur at any position in the chain.

At last, the discovered flare events can be inspected in the form of tracings or digitized images of the chain. The images reveal only flare events with sufficiently large amplitudes, while the tracings clearly show also the fainter flares and the variations of the sky background. Two examples of flare stars are given in Figures 3 and 4.

The final part of the programme, which is under development, offers the user the possibility to combine results from *different* plates, in order to study the complete available history of all stars in the field. For flare stars, this means better confirmation, especially in cases of low amplitude flares of higher frequency, and thus higher sensitivity of the photographic flare search. Also, typical time scales for more frequent flares can be determined. Finally, other types of variables with longer periods can be detected.

# Dust in Early-Type Galaxies

*M. P. VÉRON-CETTY and P. VÉRON, Observatoire de Haute-Provence, France*

## Introduction

A brief historical review of the discovery and exploration of elliptical galaxies has been published by de Vaucouleurs (1987). We have made use of it to write this introduction.

The most widely used classification system for galaxies is that proposed by Hubble in 1926. The sequence of classification, as originally presented, consisted of a series of elliptical nebulae ranging from globular (E0) to lenticular (E7) forms, and two parallel series of unwiding spirals, normal (S) and barred (SB). The figure following the symbol E is equal to the ellipticity (a−b)/a with the decimal point omitted, a and b being respectively the major and minor axis of the galaxy.

Elliptical galaxies have been described by Hubble as highly concentrated objects with luminosity falling rapidly away from bright, semistellar nuclei to undefined boundaries; small patches of obscuring material are occasionally silhouetted against the luminous background, but otherwise these nebulae present no structural details.

No elliptical galaxies are known that are flatter than E7; galaxies which are flatter invariably show an outer region of low surface brightness which resembles a thin fundamental plane.

The transition from E7 to Sa appeared very abrupt. With accumulating data, and especially with the increasing number of good photographs taken with the 100-inch Mount Wilson reflector, numerous systems have been recognized as soon as 1936 by Hubble which are later (flatter) than E7, but which show no spiral structure. These galaxies fill the gap between E7 and Sa and are called S0 or SB0 (Sandage, 1975).

The S0 class has been described for the first time in 1961 by Sandage. S0 galaxies appear to form a transition between the E galaxies and the true spirals; the transition from E to S0 is smooth and continuous. The division between E and S0 is made on the basis of the presence or absence of an outer amorphous envelope or thin fundamental plane surrounding the nuclear regions. Some S0 galaxies exhibit a structureless envelope similar to that of the normal S0's, but a sharp, narrow absorption lane is found within the lens; the lane is in an arc concentric with the nucleus. These galaxies are called $S0_3$.

A more quantitative way to separate E from S0 has emerged from the study of the light distribution in galaxies. De Vaucouleurs (1959) has pointed out that elliptical galaxies have a single-component surface brightness distribution which follows closely the de Vaucouleurs relation:

$$\log I(r) \propto r^{1/4}$$

(r is the distance from the centre of the galaxy) while the surface brightness distribution for spirals and S0 galaxies show two main components: an inner spheroidal component which follows the de Vaucouleurs law, and an outer exponential component (disk) with:

$$I(r) = I(o) \times e^{-\alpha r}$$

This result has been confirmed since by a number of more recent works (see for instance: Freeman, 1970; Kormendy, 1977 a, b and c).

However, the classification of most galaxies has been made by visual inspection of photographic plates rather than by measurement of the brightness distribution leading to some misclassification especially when the galaxy contains dust.

Dust was clearly visible on a photograph of NGC 1316 taken in 1943 by Paraskevopoulos; but it was mistaken as plate defects by Shapley who could not believe that an elliptical galaxy could contain dust (Hodge, 1975). Probably because of the presence of this dust, NGC 1316 was called Sa pec by Sandage and Tammann (1981); however, Schweizer (1980) has shown that it is a typical Morgan D-type galaxy with an elliptical-like spheroid embedded in an extensive envelope.

In the course of a survey of bright southern galaxies, a pair of abnormal objects have been observed by de Vaucouleurs (1953) which shared most of the characteristic peculiarities of the bright radio galaxy NGC 5128 (Centaurus A), i.e. radio emissivity and dust; these galaxies are NGC 1316 (Fornax A) and NGC 1947, to which de Vaucouleurs added a northern galaxy, NGC 2537; however, at the time, radio positions were not accurately measured; the errors were of the order of 1°, and only NGC 1316 has been confirmed as a radio source; moreover, NGC 2537 is an Sc galaxy and of no interest here. NGC 1947 is indeed an early-type galaxy ($S0_3$ pec), but not a radio source (Möllenhoff, 1982).

Shobbrook (1963) has discovered a dust lane in the elliptical galaxy NGC 4696 and used it as an argument for the identification of this galaxy with