OPTICAL PHOTOMETRY OF FLARES AND FLARE STATISTICS

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1. INTRODUCTION

This review discusses optical observations of flares and the results gleaned from these. Excellent reviews of flare activity have been published in the past and one might mention in particular Kunkel (1975), Gershberg (1978) and Gurzadyan (1980). In general these have been more broadly based than the present review incorporating other aspects of flare stars e.g. BY Dra variability, spectroscopic observations, etc. Since these other aspects of flare star behaviour are being covered elsewhere in this volume we will confine ourselves exclusively to optical photometry of the flare phenomenon itself. We will also confine ourselves to the solar-neighbourhood flare stars (i.e. the UV Ceti stars) since other contributors will discuss the T-Tauri, RS CVn, BY Dra and other flaring objects.

2. DEFINITION OF A FLARE

The first problem we address is that of defining what we mean by a flare. Fig.1 illustrates what might be called the "classical" flare light curve. It has a fast rise to maximum light followed by a quasi-

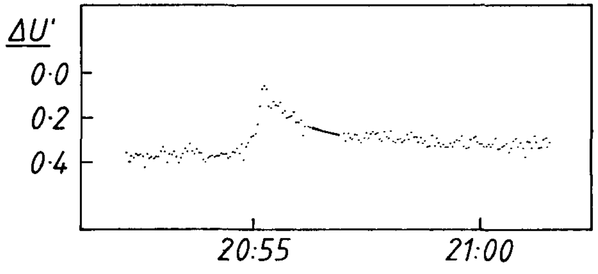

Figure 1. Flare on Gliese 867A observed by Byrne (1979).

P. B. Byrne and M. Rodonò (eds.), Activity in Red-Dwarf Stars, 157–174.

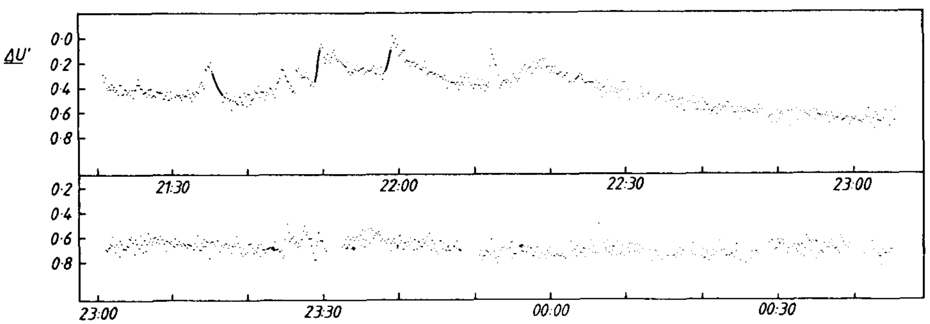

Figure 2. Flare activity on G1867B observed by Byrne (1979).

exponential decay. The timescale of the rise is generally in the region of 1-1000 seconds, while that of the decay ranges between 1-100 minutes. Such simple flares are not in fact common. The most frequent complication is that of a break or change in slope during decay. When this occurs the initial rate of decay is rapid and then slows considerably. Secondary peaks may occur, some rivalling the primary maximum.

In the most extreme cases a bout of flare activity may be accompanied by a general rise in the "quiescent" stellar background. Superimposed may be many individual flare outbursts. This may continue for several hours before the star settles back to a steady background level (See Fig.2). Fortunately it appears that for statistical purposes counting such outbursts as single "flare events" or as a collection of individual flares does not affect the eventual outcome (see below).

The break in the rate of decay referred to above appears to have a real physical significance. Bopp and Moffett(1973) carried out simultaneous photometry and spectroscopy of flares on UV Ceti and found

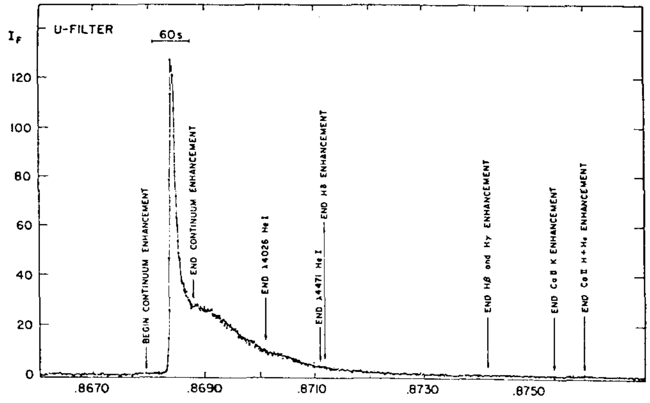

Figure 3. Spectroscopic features of a flare (Bopp & Moffett 1973).

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(see Fig.3) that the rapidly varying initial phase is associated with enhancement in both lines and continuum. After the break in slope the continuum enhancement ceased and the excess radiation was provided by emission lines of Ca H + K and the Balmer lines. These results were expanded and reinforced by Moffett and Bopp (1976) and more recently by Mochnacki and Zirin (1980) using a multichannel spectrophotometer.

As the time resolution of flare observations is increased faster changes in the light curves are apparently registered (e.g. see Moffett and Bopp 1976). Kodaira et al. (1976) have made simultaneous observations in five wavebands with a time resolution of 0.1 secs. They found however that features on a timescale less than about 5 seconds did not correlate in the different bands suggesting that this may be the physical limit of the time variations of major features of the light curve within at least those particular flares.

3. COLOURS OF FLARE LIGHT

It has been obvious for a considerable time that the broad-band colours of flare light are extremely blue. Kunkel (1970) derived mean colours based on UBV photometry of 21 flares of $(\overline{U-B}) = -1.12 \pm 0.15$ and $(\overline{B-V}) = -0.0 \pm 0.22$. Moffett (1974) compiled UBV data for 409 flares on 13 different flare stars and produced (U-B) colours for 153 of them and (B-V) for 77. The lesser number of (B-V) colours is due to the relatively smaller amplitude of flares in the V band. Mean colours from Moffett's data are $(\overline{U-B}) = -0.88 \pm 0.31$ and $(\overline{B-V}) = +0.34 \pm 0.44$, somewhat redder than Kunkel's means but agreeing within the formal errors. The dispersion about these mean values for individual stars and individual flares is considerable. For instance Flare No.1 observed by Flesch and Oliver (1974) had peak colours $(U-B) = +0.29$ and $(B-V) = +0.56$. Lacy et al. (1976) in analysing Moffett's data derived the following relationships between flare energies in the Johnson bands.

$$E_U = (1.20 \pm 0.08)E_B = (1.79 \pm 0.15)E_V.$$

In terms of flux per unit frequency interval this is quite a flat spectrum increasing somewhat towards the UV.

Several authors have attempted to trace the time-evolution of the colours of flare light. Kodaira et al. (1976) investigated two flares of very different amplitudes on EV Lac in five non-standard wavebands in the optical. They found that the spectrum was flat and did not appear to evolve with the progress of the flare. Furthermore although the flares were of very different amplitudes their colours were indistinguishable. Similar conclusions were reached by Cristaldi and Longhitano (1979) from 9 flares on 4 different flare stars observed in Johnson UBV. Walker (1981) observed a large flare also in UBV on Prox. Cen. (B-V) and (U-B) colours remained constant over a considerable duration of the flare and only late in the decay did the colours

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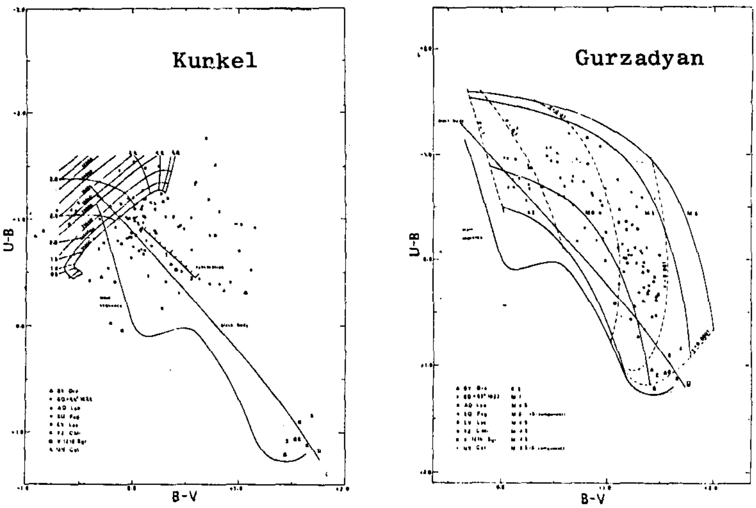

Figure 4. Observed and model flare colours (Cristaldi & Rodonò 1975).

begin to evolve towards the red.

These broadband colours have been used to test the validity of various flare models. Cristaldi and Rodonò (1975) have superimposed grids on the two-colour (U-B)-(B-V) diagram, based on the models by Gershberg (1967), Kunkel (1970) and Gurzadyan (1972). They conclude that the former two are ruled out by their data while Gurzadyan's inverse Compton model can be made to fit the data (see Fig.4). The data of Kodaira *et al*. likewise eliminate Kunkel's model. Indeed they conclude that Balmer line emission contributes but little to the total flare output. Gurzadyan (1979) has analysed this latter data and shown it to be consistent with his model. These conclusions contrast sharply with that reached by Mochnacki and Zirin (1980) who substantially agree with the model of Kunkel.

If the above discussion illustrates anything it illustrates the wide variety of types of flare observed. This variety is reflected both in the dispersion in the colours of flare light and in the relative importance of the fast and slow components of the light curve. Broadband photometry is probably a very crude tool for making physically meaningful interpretations from the data. This is especially so in the Johnson UBV system where the U-band, in which flares are most easily detected (Kunkel 1973), includes the higher members of the Balmer series, the Balmer continuum, Balmer jump and Ca H & K. Yet photometry has enormous practical advantages over spectroscopy. So attempts to circumvent this problem by using non-standard photometric systems such as those employed by Kodaira *et al*., Mochnacki and Zirin, and Byrne *et al*. (1982a) are to be pursued wherever possible.

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4. TIME DISTRIBUTION OF FLARES

Early work on the time distribution of flares suggested a variety of possible periods (Andrews 1966, Osawa et al. 1968, Chugainov 1969). When effects of aliasing with the observing interval and the daily cycle of observation are taken into account these periods are shown to be spurious. There are nevertheless compelling reasons for searching for such periodicities. This is particularly true of the BY Draconis variables. These stars are believed to possess large starspots (Vogt, this volume). By analogy with the Sun active regions would be associated with such spots and would in turn produce flares. Thus one might expect a higher probability of registering flares when the spot is facing towards the observer.

Oskanyan and Terebizh (1971), Kunkel (1973) and Lacy et al.(1976) all examined large flare data sets and could not distinguish the resulting time distribution from Poisson. This is true whether individual flare peaks or clusters of such peaks (called "flare events" by Moffett (1974)) are considered. All, however, remarked on the possible existence of "precursor flares" i.e. pairs of flares closely spaced in time but whose light curves do not overlap; furthermore the preceding flare is generally the smaller in amplitude by a factor of 3 or more (Fig.5).

Recently Pazzani and Rodonò (1981) have examined this question of "precursor" events. They based their analysis on extensive data on three flare stars observed at Catania, UV Ceti, EQ Peg and YZ CMi. For UV Ceti the times of 424 flare events were analysed. Significant departures from Poissonian behaviour were found for (a) the distribution of time intervals between successive events, (b) the number of events within a fixed time interval and (c) the number of events observed in each complete observing session. The probability that these effects arise by chance lie between 0.1% and 1%. So the physical reality of precursors would appear confirmed.

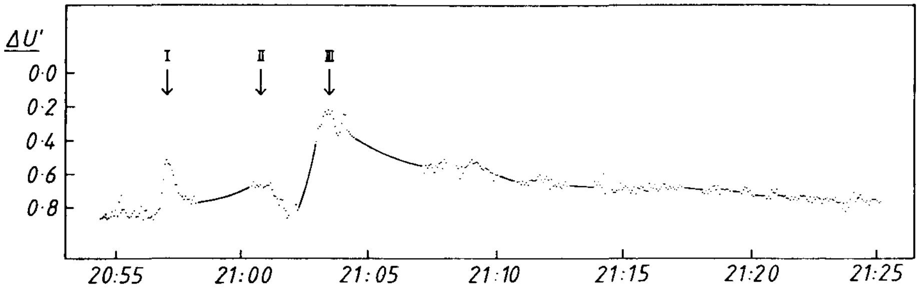

Figure 5. Example of a precursor flare (I) from Byrne (1979).

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Lacy et al. (1976) also tested the hypothesis that flare stars behave like relaxation oscillators i.e. that the time between successive flares is related to the energy of the preceding one. They reject the hypothesis on the basis of their data but point out that the result is not necessarily definitive since there may be many active regions on any given star giving rise to flares at any one observing interval. Furthermore, their data was collected over more than one observing season in which time individual active regions would alter or die away completely.

It is of interest to inquire whether on the BY Draconis variables in particular some kind of flare periodicity might reveal itself. Busko and Torres (1978) examined flare activity on a number of known BY Dra stars. They remarked on the unusually large scatter in (U-B) on the star AU Mic which, at the time of their observations, was the largest amplitude BY Dra variable known. A larger scatter in (U-B) than expected on the basis of photon statistics is a common phenomenon of active flare stars (see e.g. Byrne and McFarland 1980) and is generally ascribed to low level flare activity from events not individually distinguishable. The scatter in Busko and Torres (U-B) light curve for AU Mic shows a clear correlation with the mean V light curve in the sense that the (U-B) scatter (= low level flare activity) is greatest at V minimum i.e. greatest spot visibility (Fig.6). Furthermore exceptionally strong flares may occasionally correlate with maximum spot visibility, e.g. the large flare observed by Byrne et al. (1982b) on Gliese 182. So careful examination of the BY Draconis flare stars in particular seems warranted.

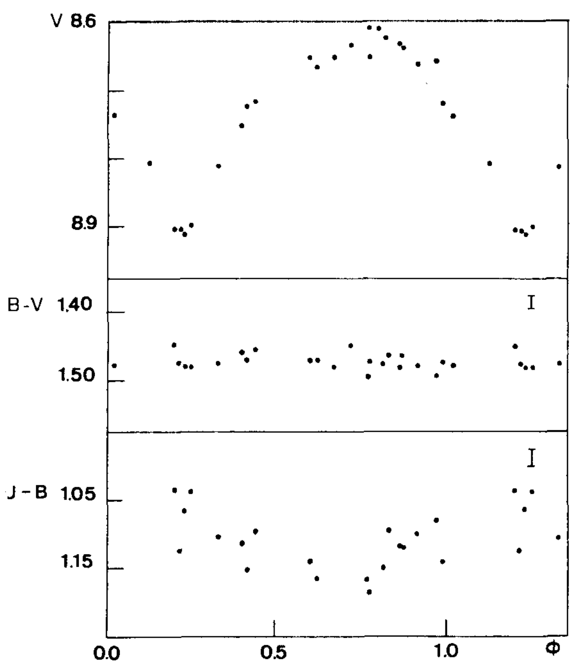

Figure 6. BY Dra-type variability in AU Mic (Busko & Torres 1978).

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5. THE TIME-AVERAGED ENERGY RELEASED IN FLARES

Two different methods of examining time-averaged activity are currently in use. Kunkel (1973, 1975) postulates a standard form of light curve similar to that in Fig.1. This has the advantage that it is entirely specified by its peak magnitude U(peak) and by the time constant of the quasi-exponential decay, T_q. The second method has been developed by Gershberg (1972) and Lacy et al. (1976). They evaluate the integral of the observed lightcurve and refer this to the pre-flare brightness of the star, which is assumed equal to its mean luminosity. Most subsequent work has adopted one of these two forms of analysis and so it is appropriate that we examine them here.

Kunkel (1973) demonstrated that irrespective of aperture there is considerable detection advantage in using the Johnson U-band and this is largely what subsequent observers have used. In analysing his own extensive data Kunkel showed that for a given star the time taken to reach a fraction (1/q) of the flare's peak brightness T_q is independent of U(peak). This introduces a considerable simplification since for any given star a flare's energy is proportional to U(peak) only. In fact the activity of the star can now be specified in terms of a characteristic magnitude U_o such that flares with U(peak) brighter than this will occur at a rate 1 hr^{-1}. He then showed that the rate of occurence of flares of U(peak) = U is given by $R(U) = \exp\left[a(U-U_o)\right]$ per hour. The constant a determines the relative frequency of large and small flares and Kunkel showed that it has a value indistinguishable from 1 for all of the stars he observed.

The rate equation can now be integrated between suitable limits to derive the time-averaged energy release in flares. These limits must be finite or the integral will be infinite. So Kunkel referred to his own spectroscopic model of stellar flares (Kunkel 1970) to derive an upper limit. His model indicates mean parameters for stellar flares derived on the assumption of Hydrogen recombination as the dominant source of optical radiation, which in turn imply that U(peak) reflects the area of the flare on the stellar surface. Since a flare cannot be bigger than the visible hemisphere of the star, he adopts the corresponding U(peak) as an upper bound to the rate integral. The lower limit is derived directly from observations of the mean quiescent U magnitude on each night of observation. The scatter in these data are attributed to flares which are individually unobservable and this allows an empirical estimate $U(peak)_{min}$ on the assumption that the constant a above stays close to 1 for the smallest flares.

Kunkel took this analysis one stage further. Using his spectroscopic model he calculated a bolometric correction to the energy of each flare which when corrected for distance could be normalized to the bolometric luminosity of the underlying star. For instance, Kunkel's own observations of UV Ceti yield an estimate of 0.4% of L_{bol} emitted as flare light. In this way Kunkel (1973) was able to suggest that all flare stars emitted less than $1\%L_{bol}$.

Kunkel's treatment has several serious deficiencies. Shakovskaya (1974) showed that the rate of decay in flares is related to their peak magnitude. Therefore in Kunkel's notation a standard value of T_q cannot be used. Furthermore multicolour observations of flares show a wide spread in flare colours which do not agree with Kunkel's model (see section 3) while recent IUE observations of flares (Butler et al. 1981; Bromage, Private Communication) confirm this. So even on a given star flare temperatures may vary widely.

Gershberg (1972) and Lacy et al. (1976) directly integrated the flux under the observed flare light curve and referred to the star's pre-flare brightness to calculate the energy. While there are difficulties with this approach, (Where does the flare begin and end? What if the pre-flare brightness is itself undergoing change (see Byrne 1979; Rodonò et al. 1979)) it does not depend on a chain of inter-relationships as does that of Kunkel. Use is made of cumulative frequency diagrams in determining total flare energy. An example is shown in Fig.7. Gershberg drew attention to the fact that there is a linear portion to these diagrams precisely in the range of flare energies where S/N is best. Above and below this range the slope changes. His proposal was that these changes of slope reflected respectively a saturation effect at the largest energies and the effects of detection threshold at the lower energy end. If the linear relation extended to unobserved flares then the time-averaged flare energy could now be determined as the integral under this line. E_{max} is indicated by the upper turnover and E_{min} as a physical limit of $\sim 10^{26}$ ergs similar to that suggested by Sturrock and Coppi (1966) for solar flares.

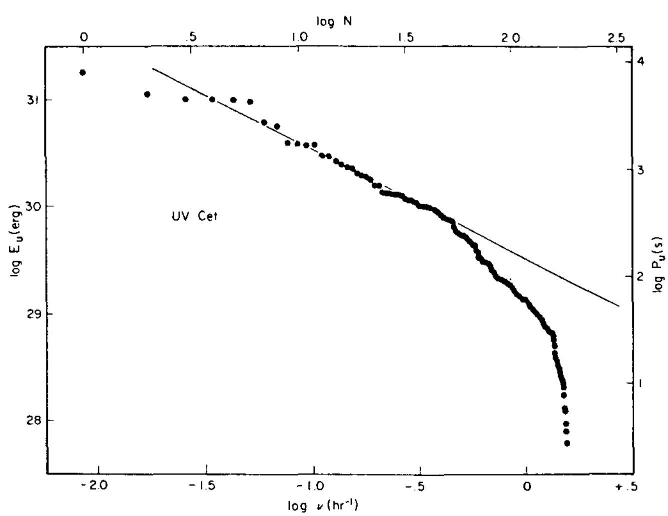

Figure 7. Cumulative frequency diagram from Lacy et al. (1976).

Both Kunkel and Lacy *et al*. conclude that the absolute energy in flares decreases with the luminosity of the star. Kunkel (1973) suggests that there exists an upper envelope to flare activity defined by

$$M_{U,0,max} = 10.8 + 0.408M_V$$

where $M_{U,0,max}$ is the value of U(peak) expressed as an absolute magnitude. This envelope corresponds to a star expending $\sim 1\% L_{bol}$ in flares.

Lacy *et al*. find similar relationships for both the mean energy $\bar{E}_U$ of flares and L'_U the time-averaged rate of release of flare energy: both measures are in the U-band. For instance in the latter case Lacy *et al*.'s relationship takes the form

$$\log L'_U = (0.60 \pm 0.05) \log q_U + (10.3 \pm 1.0)$$

wherein q_U is the quiescent luminosity of the star in the U-band. Several authors have, since then, examined stars not included in Lacy *et al*.'s original sample and found good agreement with their results (see e.g. Byrne and McFarland 1980). A similar dependence on stellar luminosity was found by Cristaldi and Rodonò (1975).

6. OTHER CORRELATIONS WITH LUMINOSITY

Although Kunkel (1973) found that the constant a in his rate equation was close to 1 for all his stars (i.e. that flares of every amplitude contributed equally to the time-averaged flare energy output of the star) Gershberg (1972) and Lacy *et al*. (1976) found that the relative contribution to total flare energy output of large and small flares varied with spectral type. This relative contribution can be gauged from the slope β of the cumulative frequency diagrams (c.f. Fig.6). Lacy *et al*. found a loose correlation between β and q_U, the quiescent U-band luminosity as follows.

$$\beta = (0.11 \pm 0.02) \log q_U - (3.9 \pm 0.5).$$

The relationship is in the sense that the more luminous stars emit a greater proportion of their time-averaged flare energy in large flares. Kunkel also noted this but attributed it to selection effects. Observations on bright stars, however, with good signal-to-noise have shown it to be real (see e.g. Byrne 1979 and Byrne and McFarland 1980).

Attention has previously been drawn to the effect of mixing data of different detection thresholds together in determining β even for a single star (Byrne and McFarland 1980). As pointed out in the previous section the detection threshold shows itself as a turn-down from the linear portion of the graph. Mixing data will result in several breaks in slope occurring which, if ignored, will lead to an apparent steepening of the cumulative frequency graph. Thus values of β should be determined

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separately for small sets of data taken under conditions of uniform detection threshold. We illustrate this effect in Fig.8 where different sections of the graph with the same slope (broken lines) are separated by the breaks already referred to. This latter slope is different from the overall slope determined by Lacy et al. (solid line).

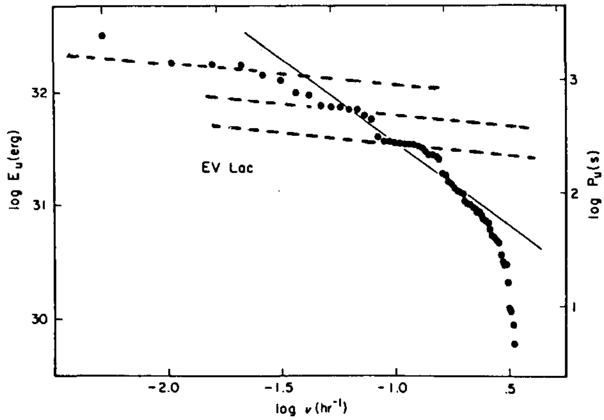

Figure 8. Cumulative frequency diagram from Lacy et al. (1976)(See text).

A relation between the durations of flares and the star's luminosity is well established, in the sense that more luminous stars give rise to flares which on average last longer. Kunkel (1973) quantified this using as parameters the time taken to reach half the peak brightness $T_{0.5}$ and the star's absolute V magnitude M_V. He suggests that

$$\overline{\log T_{0.5}} \sim -0.15M_V + (1.61 \pm 0.17).$$

Results by Busko and Torres (1978) on 4 flare stars are in agreement with this relation.

7. VARIATIONS IN ACTIVITY WITH TIME

Since the proposed mechanisms for flare star activity are like those for the Sun it has been natural to seek a periodic behaviour analogous to that of the solar, 11-year spot/activity cycle. The definitions of activity parameters defined in the previous sections may be used for this purpose. The most direct suggestion yet of such a cycle was presented by Kunkel (1975a) for the star Wolf 630 (Gliese 644A). On the assumption that the constant a in Kunkel's (1973) rate equation is 1 data on 120 U-band flares have been used to determine U_o, the peak magnitude at which the rate of flaring is 1 hr^{-1}. U_o reportedly varies in phase with the star's orbital period of 1.715 years (Fig.9). The effect is only marginally significant however and in view of our discussion in Section 5 should be treated with caution.

Busko and Torres (1978) observed AU Mic in 1974 and compared their cumulative frequency diagram for the star with that from Kunkel's (1973)

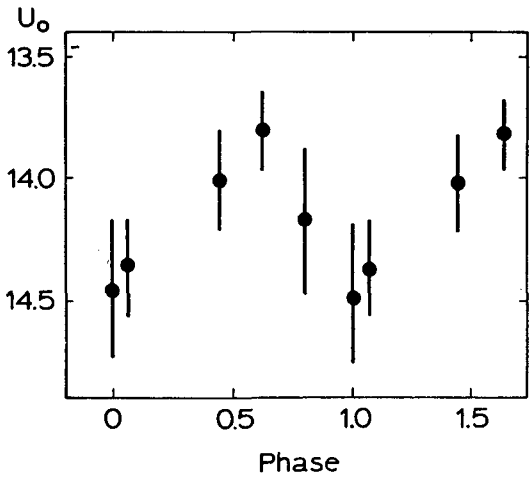

Figure 9. Variations in flare activity for Wolf 630 (Kunkel 1975a).

1970 data. A change in slope between the two is noted but the authors dismiss it as possibly of statistical origin. Byrne and McFarland (1980) compared two season's data on both components of the star Gliese 867 and concluded that no change was apparent in their activity levels.

There are stars within the general population which show flare activity but at a level very much lower than the "standard" UV Ceti stars. Kunkel (1973) drew attention to the low activity of the stars Gliese Nos.54.1, 229 and 752B. For these stars Kunkel measured $M_{U,0}$ = 18.3, 18.4 and an upper limit for Gl 752B of 21.2. Kunkel's own mean relationship for the most active stars would predict $M_{U,0}$ = 15.9, 14.6 and 18.4 respectively. Pettersen and Griffin (1980) have discussed photometric flares on Gliese 15A, 424 and 725A and showed that these too have much depressed flare activity with respect to the most active objects. Byrne (1981) has shown that Gliese 825 should be similarly classified. All of these stars are old disk population stars according to the criteria set up by Veeder (1974) except Gliese 229. It is therefore tempting to conclude that flare activity is a function of stellar age and so in the old disk population activity is reduced. Walker (1981), however, has compared the activity of Prox. Cen (Gliese 551) with the active flare stars and found it too markedly deficient in spite of its well established youth. Byrne et al. (1980) reached a similar conclusion based on chromospheric emission-line strengths measured with IUE.

Membership of a binary system is sometimes cited as a means of enhancing or prolonging the flare active phase in the life of a star. Rodonò (1978) has examined flare activity in 9 binary systems and has been unable to find any correlation with semi-major axis over a range of nine orders of magnitude in separation. Furthermore Gl 182 has been found to be a high-activity star from both IUE spectra and optical flare photometry (Byrne et al., 1982b) in spite of it being old disk population and a single star (Bopp and Fekel 1977). EQ Vir (Gliese 517; Ferraz-Mello 1972) and AU Mic (Gliese 803; Kunkel 1973) are other active single stars. So the link between flare activity and binary nature is not a simple one.

We are forced to conclude therefore that if flare activity varies with time the data presently available do not make it unambiguously clear.

8. PRE-FLARE DIPS/INCREASES

For some years pre-flare dips in intensity have been reported in the journals (Rodonò et al. 1979, Cristaldi et al. 1980 and references therein). Examples of two extreme cases are seen in Figs.11 (Giampapa et al. 1982) and 10 (Flesch and Oliver 1974). The former exemplifies a rare large U-band dip. That in Fig.10 is observed only at the red end of the spectrum and indeed corresponds in time to a pre-flare brightening in the U-band. Two dips are also seen in the post-flare decline in Fig.10 and at least one of them corresponds to U-band brightening.

Statistical studies of the occurrence of pre-flare dips and rises have been carried out by Shevchenko (1973), Bruevich et al. (1980) and Cristaldi et al. (1980). Shevchenko and Bruevich et al. have found that dips preferentially precede flares of small amplitude, while rises appear preferred in large amplitude flares. Bruevich et al. also conclude that dips occur more commonly at near IR wavelengths being observed in up to 70% of cases. Cristaldi et al. examined B-band data for 277 flares on 7 stars and observed that pre-flare rises are about 2-3 times more common than dips. They agree that dips occur preferentially on smaller

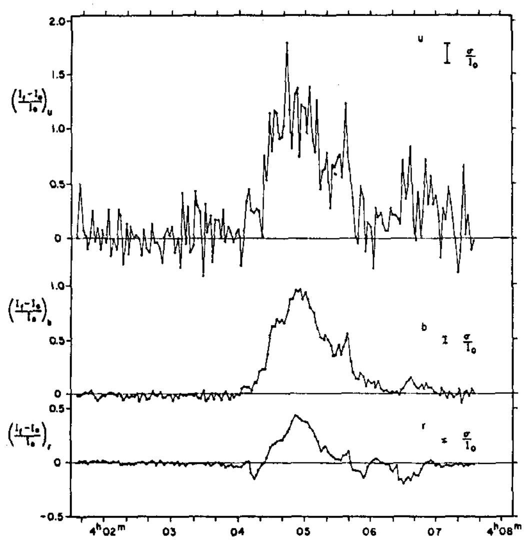

Figure 10. Three-colour data on dips (Flesch & Oliver 1974).

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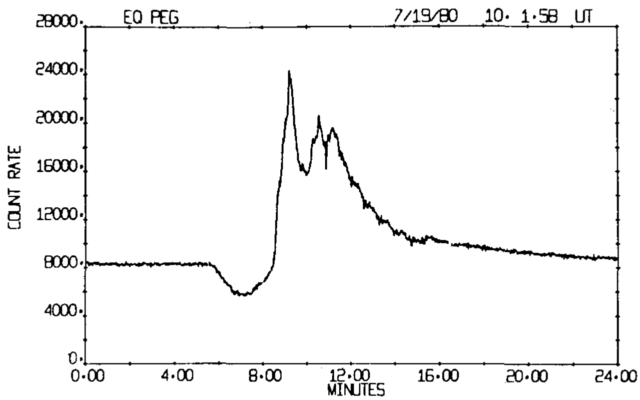

Figure 11. U-band dip from Giampapa et al. (1982).

flares. They also comment that pre-flare rises occur on flares with longer rise-times. This may of course be a result of longer rise times in large amplitude flares. From those flares for which multicolour observations are available it appears that dips are redder than the quiescent star's light (see also Flesch and Oliver), a result in agreement with Bruevich et al.'s findings.

Model predictions of preflare dips have been made by Gurzadyan (1968, 1980), Mullan (1975) and Grinin (1976). We do not discuss the inverse-Compton model of Gurzadyan since it predicts negative flares in the 1-2 μm spectral region which are the inverse of the optical curve and coincident with it in time. Mullan's model proposes that the "red" preflare dips are caused by episodes of Hα absorption. Bruevich et al's infra-red filter does not include Hα however and so Mullan's proposal cannot be invoked to explain their data. Grinin has put forward a model based on increased H^- continuum absorption resulting from impulsive heating of the chromosphere by a downflow of material, which when it reaches the photosphere causes the optical flare. This predicts the correct time and spectral sequence for the observed events and deserves further investigation.

The large U-band flare observed by Giampapa et al. (1982) on EV Lac seems to be of a very different kind to those discussed above. It is possible that an episode of increased Balmer absorption similar to that discussed by Mullan could affect the U-band sufficiently to cause this kind of flare.

9. POLARIZATION

Since the flare phenomenon is magnetically-related attempts were made quite early on in the history of flare star observing to register polarization both in the quiescent state and during flares. Oskanyan (1964) and Kubicela and Arsenijevic (1966) recorded detections of polarization of the order of several percent. Zappala (1969) later investigated ten stars to a much higher sensitivity without positive effect. Reports of polarization have persisted in the literature however (see e.g. Koch and Pfeiffer 1976). Recently a series of high precision measurements have been described (Pettersen and Hsu 1981; Clayton and Martin 1981) which place upper limits of a few tenths of a percent on any intrinsic polarization present in the flare stars. At present therefore we must regard the presence of polarization in flare stars as unproven at least in the quiescent state.

10. CONCLUSION

Although it is true that progress in understanding the physics of flare stars will probably come from the increasingly sophisticated observations outside the optical wavebands, optical photometry is the data which can be gathered with the greatest ease. As a result investigations requiring continuous monitoring over a long timebase will continue to rely heavily on optical photometry. This is probably true also of the need for ground-based data to compliment space-borne instruments (see e.g. papers presented at this meeting by Andrews et al. and Butler et al.). One would wish to encourage, however, a move away from UBV photometry towards somewhat narrower bands with more discriminating power. This is especially important in the U-band region of the spectrum.

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DISCUSSION

Evans: I will be glad to take notice of these criticisms of Lacy, Moffett and Evans. I had better go tell Lacy and Moffett and have a look at what you say. What I really wanted to remark upon, however, was that there are very few observations of correlations between flaring and spot variations. Pettersen and I are currently together some work by a student called Gary Kern in which two stars which showed spot variations were monitored for a considerable length of time for flares. A reasonable number of flares were found and so far as it goes a reasonably good correlation between flare incidence and the appearance of spots was found. There are some complications but that is the general conclusion. As to precursors with regard to which one always feels somewhat biblical, Lacy who was an expert statistician convinced us that there was not anything in it. However I must relate a story about this phenomenon which does not occur and how we actually used it. Bopp, in an earlier manifestation was working with Moffett doing simultaneous spectroscopy and photometry of flares. Moffett working photometrically, when he saw a precursor, would telephone Bopp on the other telescope and tell him to start a spectroscopic exposure. This is in fact how a good chunk of his (Bopp's) doctoral thesis was obtained i.e. using a phenomenon which does not exist. (laughter)

Byrne: So he owes his doctorate to the existence of precursors.

Kodaira: You said that there is no colour evolution of flares. How closely would you place limits on such colour evolution? I, myself, have made five channel simultaneous observations with good time resolution and I noticed that all the energy fluxes remained remarkably constant until very near the end of the flare. It has been said by many broad-band observers and also cited by theoreticians that flare colour evolves in some certain direction in the two-colour diagram in agreement with certain models.

Byrne: One must pay attention to the kind of errors involved in these colour determinations and they can be quite large as you know yourself. For instance, the amplitudes of flares decrease very rapidly as one goes to the red and so the signal-to-noise can also decrease. As a result (B-V) colours can be quite difficult to determine over any length of time. It is obvious that the colour of the flare light must eventually change and evolve towards that of the undisturbed star. The evidence that we have, for istance in Walker's observations, would suggest that within a tenth of magnitude the colours of the flare light over the maximum and for a considerable time after maximum remain constant.

Vaiana: That includes the spike portion?

Byrne: Yes, it does.

Haisch: I have two questions. Based on your knowledge of the frequency of occurrence of flares how often you expect the multiple spikes to be the superposition of flares going off in different parts of the stars. Secondly, do you believe in negative flares? I have seen a few references to these in the literature.

Byrne: On the second question first; if you refer to the written version of my review you fill find a discussion of negative preflare dips. They are almost undoubtedly real. They have been observed very widely.

Vaiana: And frequently?

Byrne: Yes, frequently, particularly in the redder photometric bands. With regard to the occurrence and reality of multiple peaks, this may depend on the star you are looking at. If you are looking at a late-type, very active star which flares frequently then the chances of superposition are very much greater. When however one observes an MO star, which would flare relatively infrequently and with greater energy, then multiple peaks would almost certainly be connected events. I would quote the example of Gliese 182 which I have already mentioned. We have observations of multiple peaks in this star although if flares on average only once every 20 hours.

Oskanian: Recently two papers were published in Astrofizika concerning BY Dra itself. These papers were based on 5 years data gathered at Konkoly Observatory, Budapest and at Byurakan Observatory. We have 20 flares in all. We could not find any correlation between the time of occurrence of flares and the phase of the slow light variations.

Byrne: How large was the amplitude of the BY Dra variability at that time?

Oskanian: About 0.1 or 0.2 magnitudes.

Byrne: I would suggest that it may be best to look at a BY Draconis variable which has the maximum possible amplitude and that this would imply a large concentration of spots and associated flaring active regions on one hemisphere.

Oskanian: At that moment this was the amplitude and it was impossible to ask the star to have a greater amplitude.

Bromage: In deference to those of us who work in wavebands where magnitudes are meaningless and we work in energy, can you say if there is a believable set of relationships which predict the frequency of flares of more than a certain energy in any given band on different stars?

Byrne: Yes, I believe so. The paper of Lacy, Moffet and Evans in particular and some of the follow up works using their methods do in fact allow you to make such predictions in energy terms.

Bromage: Taking into account different observers using different apertures?

Byrne: Yes, taking that into account. We have uniform data sets of our own which were taken under fairly uniform conditions and over a relatively short space of time so that the activity of the star does not vary. These agree with Lacy, Moffett and Evans' results quite well. So we would place a high degree of reliance on some of their relationships.