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Long-term photometric flares patrol (1967-1977) on EV Lacertae: a clear evidence of a longitude concentrated flaring activity in 1970*,**

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Abstract. We report on a large sample of homogeneous photoelectric data obtained by monitoring the red dwarf flare star EV Lac. The data were collected in 10 years (1967-77) at Catania Astrophysical Observatory on Mt. Etna and consist of 212, 170, and 128 flares detected in the U, B and V band during total monitoring times of 903, 1013, and 864 hours, respectively.

The peak luminosity, the total energy emitted, the rise and decay times were measured for each flare. A statistical analysis of this data sample is presented.

A well defined phase modulation of the normalized flare occurrence rate in 1970 clearly suggests that, at that time, on EV Lac flaring activity was concentrated at a preferred longitude.

Key words: stars: EV Lac – stars: flare; activity; rotation

1. Introduction

EV Lac (BD +43^{o}4305; d=5 pc; Sp=dM4.5e) is a well known flare star, generally regarded as a single star (Pettersen 1980b). From astrometric data, Lippincott (1983) suggested the presence of a substellar mass companion with a period P$\sim$ 45 y and an orbital eccentricity of 0.5. However, because of the large separation between the two binary components, the EV Lac rotation rate, and consequently its activity level, should not be significantly affected by its binary nature.

EV Lac is also classified as a low-amplitude photometric variable of BY Draconis type. The light curve periodic modulation of BY Dra stars is usually interpreted as evidence of photospheric spotted regions (see, e.g., Rodonò 1986, Rodonò et al. 1986).

Mahmoud and Olah (1981) did not find any periodicity in the B-band light curve of EV Lac over the years 1973 to 1976. However, Pettersen (1980a) reported a photometric period of $4^d.373$, from data acquired in 1979. This period was later refined to $4^d.375$ by Pettersen et al. (1983) who analyzed data acquired between 1979 and 1981. The stability of the light-curve (ΔV $\sim$0.08 mag) over $\sim$2.5 y led these authors to conclude that the lifetime of the dominant starspot group was longer than 2.5 y.

Subsequently, Pettersen et al. (1992) obtained EV Lac light curves with ΔV $\leq$0.1 mag and an almost unchanged phase of light minimum in the years 1979-1989. However, some of these light curves were rather flat, but at a suppressed brightness level, being suggestive of a high degree of spottedness. From these 10 y data, Pettersen et al. (1992) derived a photometric period of $4^d.376$ and concluded that starspots on EV Lac were only occasionally evenly distributed, being generally located along preferred longitudes.

EV Lac was one of the flare stars selected in the sixties to search for flares and stellar cycles by the IAU Commission 27 Working Group chaired by P. F. Chugainov. Since then, EV Lac has been the primary object of several observational campaigns (e.g.: Cristaldi & Rodonò 1970, 1973, 1975; Mavridis et al. 1982; Pettersen et al. 1983; Gershberg et al. 1991; Alekseev et al. 1994; Abdul-Aziz et al. 1995, Berdyugin et al. 1995) aimed at investigating the statistical properties of optical flares and possible correlations between flare characteristics (such as energetics, time-scales, colours, etc.) and global stellar parameters (such as luminosity, rotation, atmospheric structure, etc.). Previous statistical investigations of M dwarf flares can be found in Lacy et al. (1976), Gershberg & Shakhovskaya (1983) and Shakhovskaya (1989).

Details of possible stellar flare models, flaring behaviour and the scenario of solar-stellar connection can be found in the proceedings of the IAU Coll. 104 on *Solar and Stellar Flares*

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[*] Based on observations collected at the "*M.G. Fracastoro*" mountain station of Catania Astrophysical Observatory, Italy

[**] Table 2 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

Table 1. Number of flares (N_{fl}), total coverage time (T), and mean flare occurrence rate (R).

		91-cm			61-cm			30-cm			Total		
		N_{fl}	T (h)	R (h^{-1})	N_{fl}	T (h)	R (h^{-1})	N_{fl}	T (h)	R (h^{-1})	N_{fl}	T (h)	R (h^{-1})
U	1967												
	1968				0	88.1	0				0	88.1	0
	1969												
	1970	68	98.3	0.69	14	86.0	0.16	0	2.5	0	78	178.4	0.44
	1971	5	26.7	0.19	27	91.6	0.29	1	5.4	0.18	33	123.7	0.27
	1972	11	21.9	0.50	11	111.5	0.10				22	133.3	0.16
	1973	8	28.4	0.28	18	102.3	0.18	2	27.5	0.07	28	157.3	0.18
	1974	3	8.1	0.37	13	46.1	0.28				16	54.2	0.29
	1975				18	106.1	0.17				18	106.1	0.17
	1976				5	32.1	0.16				5	32.1	0.16
	1977				12	29.6	0.40				12	29.6	0.40
	Total	95	183.4	0.52	118	693.4	0.17	3	35.4	0.08	212	902.8	0.23
B	1967												
	1968				0	88.1	0	0	3.8	0	0	89.3	0
	1969	0	1.3	0	26	158.1	0.16				26	160.9	0.16
	1970	0	0.7	0	15	88.0	0.17	3	21.9	0.14	18	110.6	0.16
	1971	4	7.4	0.54	27	101.0	0.27	5	34.7	0.14	34	142.7	0.24
	1972	2	2.4	0.83	11	110.1	0.10	0	2.7	0	12	114.5	0.10
	1973	8	28.4	0.28	18	102.3	0.18	2	27.5	0.07	28	157.3	0.18
	1974	3	18.2	0.16	14	46.1	0.30				17	64.3	0.26
	1975				18	111.6	0.17				18	111.6	0.17
	1976				5	32.1	0.16				5	32.1	0.16
	1977				12	29.6	0.40				12	29.6	0.40
	Total	17	58.4	0.29	146	867	0.17	10	90.6	0.11	170	1012.9	0.17
V	1967							3	27.0	0.11	3	27.0	0.11
	1968	0	65.0	0	0	88.1	0	0	7.3	0	0	140.6	0
	1969				0	4.1	0				0	4.1	0
	1970	0	1.7	0	13	86.0	0.15	1	11.2	0.09	14	99.0	0.14
	1971	3	3.0	1.00	27	94.3	0.29	4	17.6	0.23	32	115.0	0.28
	1972				11	110.1	0.10	0	4.6	0	11	116.0	0.09
	1973				18	102.3	0.18	2	40.2	0.05	20	142.5	0.14
	1974				13	46.1	0.28				13	46.1	0.28
	1975				18	111.6	0.17				18	111.6	0.17
	1976				5	32.1	0.16				5	32.1	0.16
	1977				12	29.6	0.40				12	29.6	0.40
	Total	3	69.7	0.04	117	704.3	0.17	10	107.9	0.09	128	863.6	0.15

(Haisch & Rodonò 1989), and IAU Coll. 151 on *Flares and Flashes* (Greiner et al. 1995), as well as in reviews by Pettersen (1991), Haisch et al. (1991), and Haisch & Schmitt (1996).

Several authors have investigated whether a correlation between stellar flares and active photospheric areas, as generally seen on the Sun, does exist. Solar flares, in fact, often develop within solar plage areas generally associated with underlying complex sunspot regions. Pettersen et al. (1983) and Roizman (1984) did not find any correlation between the EV Lac flare activity and the rotational modulation due to starspots. These authors, however, investigated only data covering one observation season. On the other hand, from data acquired in 208 h monitoring time in 1976, Andrews (1982) found that flares on EV Lac occurred in groups at 5-6 days interval. Mavridis & Avgoloupis (1986) showed that during the years 1971-1980 there was a 5-year activity cycle in EV Lac. These authors found both that the quiet-state luminosity and the flare activity level were modulated by the same 5 y period, but with a phase shift, in the sense that years of low flare activity were followed by years of high quiet-state luminosity. Doyle (1987) analyzed the data on flare monitoring acquired over the years 1973-1982 and found some correlation between flare frequency and rotation period in 1973-1976. This correlation was not evident in subsequent years.

In this paper we present flare data derived from ten years of EV Lac photometric monitoring carried out at Catania Observatory. The observations and the reduction method we adopted are presented in Sect. 2. The statistical relations among some parameters of the EV Lac flares are given and discussed in Sect. 3.1. The light curves are given in Sect. 3.2. In Sect. 3.3

the correlation between flare activity level versus the rotationally modulated light curve phase is investigated. The conclusions are summarized in Sect. 4.

2. Observations and reduction method

The data presented in this paper were collected from 1967 to 1977 by using four telescopes at the *Serra La Nave* (SLN) mountain station of Catania Observatory recently dedicated to *Mario G. Fracastoro*: a 91-cm Cassegrain reflector, a 61-cm quasi-Cassegrain reflector, and two 30-cm Cassegrain reflectors. All telescopes were equipped with similar photometers with uncooled EMI 6256 photomultipliers (S13 spectral response) and a combination of Schott filters to match the standard U B V Johnson system.

2.1. Flare monitoring data

The data acquired during the flare monitoring, originally recorded on strip-charts, were reduced according to the following procedure: we used a scanner to generate electronic images of the portions of the strip-charts where flares were recorded. Flare data were then extracted from these images and reduced by means of an IDL procedure (FLRED) we specifically developed for this purpose.

A total monitoring time of 1272 h was collected: 903, 1013, and 864 h of which were in U, B, and V bands, respectively. The sum of time coverage in the three bands exceeds the effective total coverage because the observations were generally done in more than one filter. A total of 254 flare events were detected, 212, 170, and 128 of which in the U, B, and V bands, respectively. Details on the time coverage, number of observed flares and occurence rate in each band and year are given in Table 1.

The following quantities were measured for each flare in each band: time of light maximum (UT$_{max}$), luminosity at maximum (L_{max}), integrated energy (E), rise-time to the highest peak (t_s), duration of the light decrease to quiescence (da), flare amplitude (Δm). The flare energies (E) were derived from the quiescent EV Lac luminosity (L) times the equivalent duration (P):

$$E = L \times P \tag{1}$$

where $L = 5.01 \times 10^{28}$, 3.49×10^{29}, 7.84×10^{29} erg s^{-1}, in U, B, and V, respectively, as derived from flux calibration by Gershberg & Chugainov (1969) by assuming a distance of 5 pc (Gliese 1969) and U=12.89, B=11.83, V=10.25 (Andrews & Chugainov 1969) for the quiescent magnitudes of EV Lac. The equivalent duration (P) is defined as

$$P = \sum_f \frac{I_f - I_o}{I_o} \Delta t \tag{2}$$

where I_o and I_f are the intensities of the star in its quiescent and flaring states, respectively.
Individual flare data are given in Table 2 that is only available in electronic form at the CDS.

Table 3. Log of the data used for rotational modulation analysis

Year	Telesc.	No.	Band	Comparison	Check(s)
1969	61-cm	247	B	BD+43 4304	BD+43 4303
1970	61-cm	29	UBV	BD+43 4299	BD+43 4303 BD+43 4304
1971	61-cm	43	UBV	BD+43 4299	BD+43 4303 BD+43 4304
1972	61-cm	21	UBV	BD+43 4299	BD+43 4303 BD+43 4304

2.2. Rotation modulation data

To derive the outside of flare seasonal light curves of EV Lac, differential measurements were sparsely done during the course of the flare monitoring. In 1967-68, BD+42 4527 was used as comparison star. However, this star was found to be a semiregular red variable (α Ori-type). Therefore, beginning in 1969, BD+43 4299, BD+43 4303 and BD+43 4304 were used as comparison stars, following Andrews & Chugainov (1969). Reliable and more extended data to build seasonal light curves of EV Lac were secured only from 1969 to 1972. A summary of these observations is given in Table 3.

3. Results

3.1. Statistical analysis

3.1.1. Flare energies and accumulated flare frequency distribution

The fractional distributions of the number of flares versus their total energy E are shown in the semi-log plots in Fig. 1 for U, B and V bands. At low energies, the number of detected flares decreases dramatically because of instrumental sensitivity limit. The range of energies covers four decades in U and B distributions, and less than three decades in the V distribution. The decrease of the number of flares at high energies allows us to estimate the maximum energy release through the flare mechanism operating on EV Lac. In fact, our coverage time is sufficiently extended for our sample to be considered complete consistently with known flare statistics (Shakhovskaya 1989). Actually, according to the latter study, in a total observation time comparable to our 1272 h coverage, we can expect the occurrence of only one flare with total energy release in excess of 10^{33} erg, as observed.

The rate of energy emitted as flares (L_f), according to Lacy et al. (1976), is given by:

$$L_f = 10^a \frac{b}{b+1} (E_{min}^{b+1} - E_{max}^{b+1}) \tag{3}$$

where E_{max} and E_{min} correspond to the largest and the least energetic flare which can be produced by the star, respectively, and a and b are parameters that can be derived from the analysis of the accumulated frequency distribution. The accumulated frequency distribution of U-band flares is shown in Fig. 2, where the total flare energy release (E) is plotted versus the mean occurrence rate (N/T) of flares with energy larger than E (in ergs)

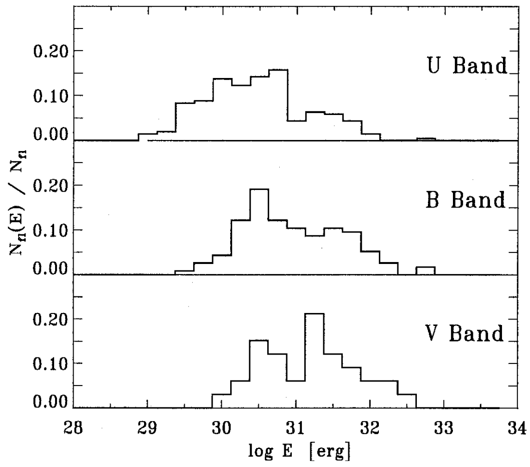

Fig. 1. Flare energy distributions

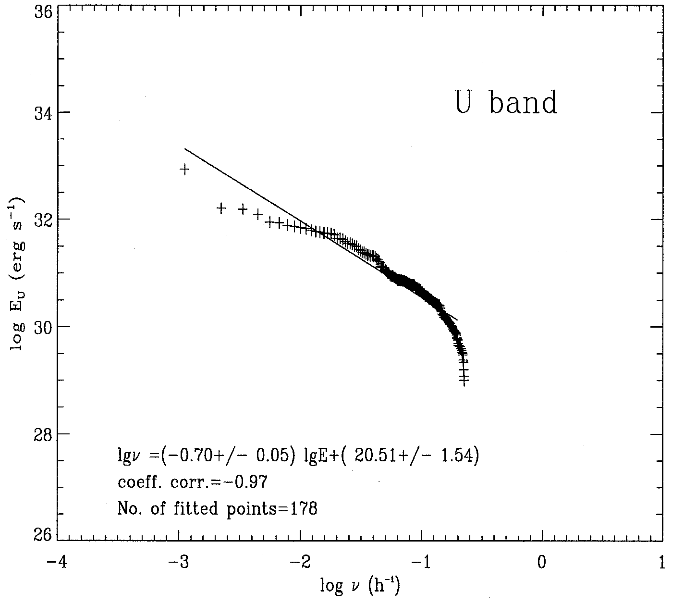

Fig. 2. The accumulated frequency distribution of U-band flares.

detected during the time T (in seconds). The dramatic decrease of the occurence rate at lower energies is due to instrumental detection limits (Gershberg 1972). Above the detection threshold the distribution is approximately linear and can be fitted by the relation:

$$\log \frac{N}{T} = a + b \log E_U \tag{4}$$

All flares observed in the U-band were included in the distribution: 95 of them were observed with the 91-cm telescope, 118 with the 61-cm telescope and 3 with the 30-cm telescope. Since the energy at which detection effects become apparent varies with the telescope used, we have excluded from the linear fitting those flares with energy lower than the onset of detection effects that was determined from observed 61-cm telescope observations (notice that the 3 flares observed with the 30-cm telescope are above this lower limit). The least-squares fit to the linear portion yields:

$$\log \left(\frac{N}{T}\right)_U = (20.5 \pm 1.5) - (0.70 \pm 0.05) \log E_U \tag{5}$$

where the estimated errors for the coefficients a and b were computed as $a/\sqrt{n}$ and $b/\sqrt{n}$, with n the number of data points used in the linear fit.

Taking E_{max} and E_{min} as the largest (10^{33} erg) and the smallest (10^{29} erg) flare energies observed in U-band, we derived:

$$L_f(U) = 1.46 \times 10^{27}\,\mathrm{erg\,s^{-1}} \tag{6}$$

The ratio between the total energy released by flares and the energy emitted in the U-band by the quiet star (that is a parameter independent of the calibration of the quiescent flux from the star), thus results:

$$L_f(U)/L_U = 0.0291 \tag{7}$$

a result only marginally different from that given by Lacy et al. (1976) ($L_f(U)/L_U = 0.032$). This confirms Lacy's at al. (1976) conclusion that the flare energy spectrum of EV Lac is not affected by time variablity as observed for other dMe sources. As derived by numerical experiments, L_f is almost independent from the choice of E_{min} but is determined by the largest flare events. In fact, even assuming E_{min} as low as 10^{24} erg (a *nanoflare* on the Sun), the average flare energy production of EV Lac in the U-band remains unchanged within the 2nd decimal digit, whilst a choice of E_{max} only one order of magnitude greater yields a two times larger flare energy output.

Cumulative frequency distributions of B- and V- band flares have also been computed. We found:

$$\log \left(\frac{N}{T}\right)_B = (19.2 \pm 1.8) - (0.66 \pm 0.06) \log E_B \tag{8}$$

$$\log \left(\frac{N}{T}\right)_V = (19.9 \pm 3.6) - (0.69 \pm 0.12) \log E_V \tag{9}$$

Therefore:

$$\begin{aligned} L_f(B) &= 1.08 \times 10^{27}\,\mathrm{erg\,s^{-1}} \\ L_f(V) &= 4.97 \times 10^{26}\, erg\, s^{-1} \end{aligned} \tag{10}$$

and

$$\begin{aligned} L_f(B)/L_B &= 3.1 \times 10^{-3} \\ L_f(V)/L_V &= 0.6 \times 10^{-3} \end{aligned} \tag{11}$$

The slope we found from the cumulative flare distributions ($b \sim 0.7$ for U, B, and V -band flares) is a typical spectral index for flare stars in the vicinity of the Sun (Shakhovskaya 1989). Gershberg (1989) showed that the spectral index b depends on the star age. Therefore, the flare characteristics, such the energy distribution, are linked to stellar rotation rates and, consequently, to magnetic activity levels.

Table 4. Mean flare activity level on yearly time-scale. The data considered are those acquired in the B-band with the 61-cm telescope. P is the probability that the observed flare frequency is different from the expected value only by chance.

Year	No. of flares	Cov. (h)	Mean flare occurence	Exp. no. of flares	χ^2	P
1968	0	88.1	0.00±0.00	14.7	14.73	0.0001
1969	26	158.1	0.16±0.03	26.4	0.01	0.9316
1970	15	88.0	0.17±0.04	14.7	0.01	0.9413
1971	27	101.0	0.27±0.05	16.9	6.05	0.0139
1972	11	110.1	0.10±0.03	18.4	2.98	0.0840
1973	18	102.3	0.18±0.04	17.1	0.05	0.8294
1974	14	46.1	0.30±0.08	7.7	5.13	0.0235
1975	18	111.6	0.16±0.04	18.7	0.02	0.8778
1976	5	32.1	0.16±0.07	5.4	0.03	0.8736
1977	11	29.6	0.37±0.11	5.0	7.39	0.0065
Average	145	867.0	0.17±0.01			

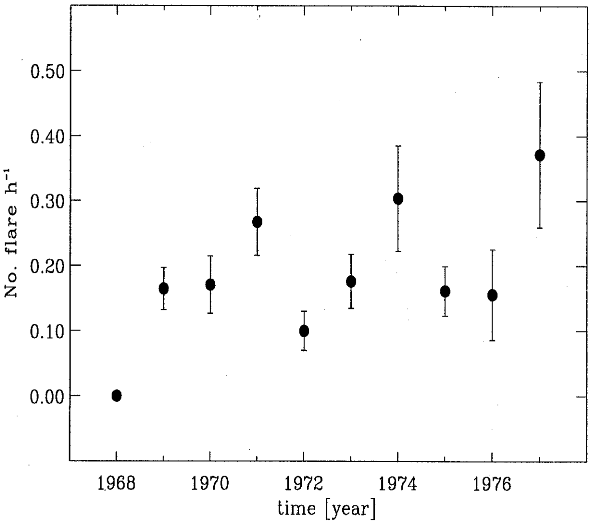

Fig. 3. The time behavior of the yearly mean flare frequency.

3.1.2. Flare occurence rate on time-scales of 1 y.

We have analyzed the time behavior of the flare occurence rate of EV Lac on time-scales of 1 y. The observed flare occurence rate is $n/T \pm \sqrt{n}/T$, where n is the number of flares observed during the coverage time T in each season. In Fig. 3 the time behavior of the flare frequency parameter is shown for the subset of data acquired in the B-band with the 61-cm telescope, which is the most conspicuous data set we acquired with the same instrument in a single filter. The choice to inspect the time variability of flare frequency, separately for each filter and telescope, is to avoid effects linked to inhomogenities in the data. A slight modulation in the flare occurence is apparent from ~1970 with a period close to 3 years. The observed time distribution can be tested against the null hypothesis, i.e. that no variation in flare frequency actually took place. We computed the expected number of flares for each season by multiplying the monitoring time by the average flare frequency that we found to be 0.17 $flare\,h^{-1}$ (see Table 4).

A χ^2 test comparing the observed and expected numbers leads to the conclusion that the probability that the level of activity in 1971, 1974 and 1977 by chance was higher than the mean level is of order of 1.4%, 2.3%, and 0.6%, respectively. On the other hand, the lack of flare detection in 1968, despite 88 h of coverage, has a high significance (0.01% probability that it was a chance result). Therefore, the apparent 3 years modulation in flare activity, that should have required a high level of flare occurence also in 1968, does not appear to indicate a permanent cycle.

3.1.3. Color-color energy correlations

The observations performed in more than one filter allow us to compare the flare energies in different colours. The analysis of 57 flares contemporarily observed in U and B -bands yields the following linear relation:

$$E_U = (1.19 \pm 0.17)\, E_B \qquad c.\,c. = 0.95 \qquad (12)$$

where $c.\,c.$ indicates the linear correlation coefficient, consistently with the relation found by Lacy et al. (1976) from the analysis of a more extended data sample, but concerning flares on eight stars. The analysis of 27 and 26 flares observed simultaneously in B and V -bands and in U and -V bands, respectively, leads to the following relations:

$$E_B = (1.23 \pm 0.23)\, E_V \qquad c.\,c. = 0.94 \qquad (13)$$

$$E_U = (0.91 \pm 0.18)\, E_V \qquad c.\,c. = 0.93 \qquad (14)$$

The costant in relation (14) is quite different from the analogous one (1.79 ± 0.15) given by Lacy et al. (1976), and is not consistent with the extrapolation of the U-V relation that can be derived from relations (12) and (13). We believe that we underestimate the constant in relation (14) because of fewer data points are available to us and because of the more limited range of energy covered by our data (two decades) in comparison with about six decades covered by the Lacy et al. (1976) data. On the other hand, by using relation (13) to convert to V -band energies the flare energies measured in B -band, the data acquired contemporary in U and B can be also used to determining the U-V relation, thus increasing the number of data points to 60. The relation found in this way is closer to that obtained by Lacy et al. (1976):

$$E_U = (1.49 \pm 0.18)\, E_V \qquad c.\,c. = 0.95 \qquad (15)$$

3.1.4. Flare time-scales

The distributions of the rise-times to the highest flare peak (t_s) and of the descent times from flare maximum to quiescence (da) are shown in Fig. 4 for U -band flares.

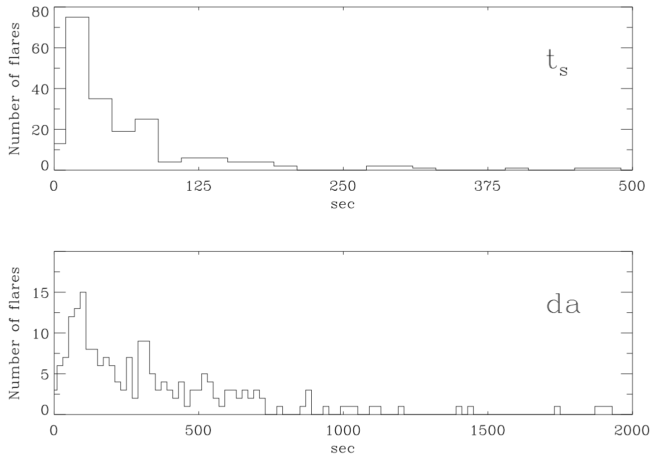

Fig. 4. Distribution of rise-times (t_s) to the highest peak (*top panel*) and descent times (da) from the flare maximum to quiescence (*bottom panel*), for the flares observed in U -band.

In early studies on stellar flares several authors (e.g. Haro & Chavira 1955, Pettersen et al. 1984) inferred that flare durations are correlated with spectral types, i.e. long duration flares more often occur on the more luminous stars. However, Gershberg and Shakhovskaya (1973) showed that the largest flares last longer than the smallest flares. Therefore, since large flares preferably occur on luminous stars while small flares dominate on faint stars because of contrast effects, a spurious correlation between flare duration and spectral type does result. We have also investigated the relationships between flare time-scales and flare energies. In Fig. 5 the flare time-scales (t_s and da) are plotted versus flare energies (E_U). Least square fits to the data give the following relationships:

$$\log t_s = (0.44 \pm 0.05) \log E_U - (11.8 \pm 1.5) \quad c.c. = 0.65 \quad (16)$$

$$\log da = (0.53 \pm 0.04) \log E_U - (13.9 \pm 1.2) \quad c.c. = 0.84 \quad (17)$$

which confirm the existence of a general correlation between the time charactistics of a flare and its energy. Within each energy value the time-scales of individual flares span 1-2 order of magnitudes with the rise-time showing the largest scatter. We note that, for a given energy value, slow or long-duration flares could escape detection while fast or short-duration flares are easily detectable because they should have intense peak luminosities. Therefore, the bottom part of the trends shown in Fig. 5 does not suffer from detection limit.

Flares of equal energy output but different time-scales presumably reflect different physical characteristics of the flaring region such as size, strength of the magnetic field where the magnetic reconnection takes place, electron density and flaring plasma temperature.

The slope of relation (16) is larger than in the analogous relation given by Pettersen (1989) but derived from the analysis of flares from a large sample of different type of stars - from the brightest dKe's to the faintest dMe stars.

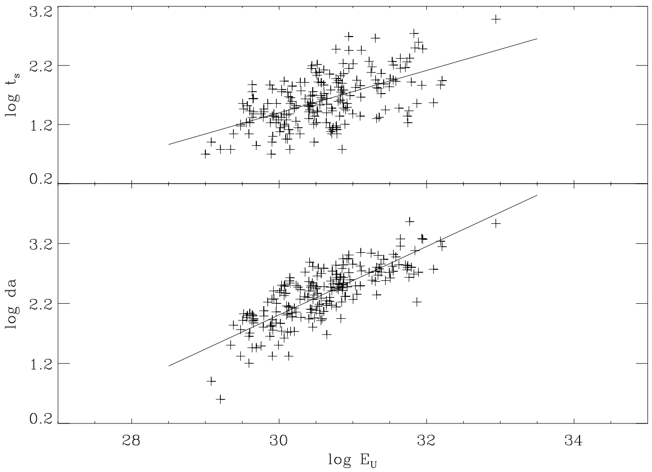

Fig. 5. Relationships between flare time-scales and flare energy.

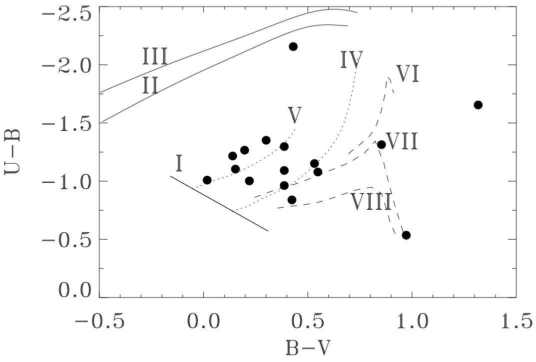

Fig. 6. The colours of flaring plasmas at light maximum in the two-colour diagram (cf. text).

3.1.5. Correlation between flare colour indices

The colours of the most intense UBV flares at light maximum, computed according to Cristaldi & Rodonò (1975), are given in the two colour diagram in Fig. 6. In the same figure the following models given by Gershberg et al. (1991) are shown: I) blackbody emissions from 8,000 to 20,000 K; II-III) hydrogen plasmas, optically thin in the Balmer continuum, with T_e=10,000 K and electron densities 10^{12} and 10^{14} cm^{-3}, respectively; IV-V) optically thick plasmas at T_e=10,000 K and T_e=15,000 K, respectively; VI-VII-VIII) dwarf star upper layers heated by proton beams with threshold proton energy of 1, 2 and 5 MeV, respectively.

The EV Lac flare colour indices are spread over a large area in the two colour diagram. However, a concentration close to the region of optically thick plasma emissions at 1-1.5$\times 10^4$ K is apparent, but flare events compatible with proton beam are also observed.

3.2. *Light curves*

Assuming that the light curves are due to rotationally modulated visibility of surface inhomogenities, we have performed

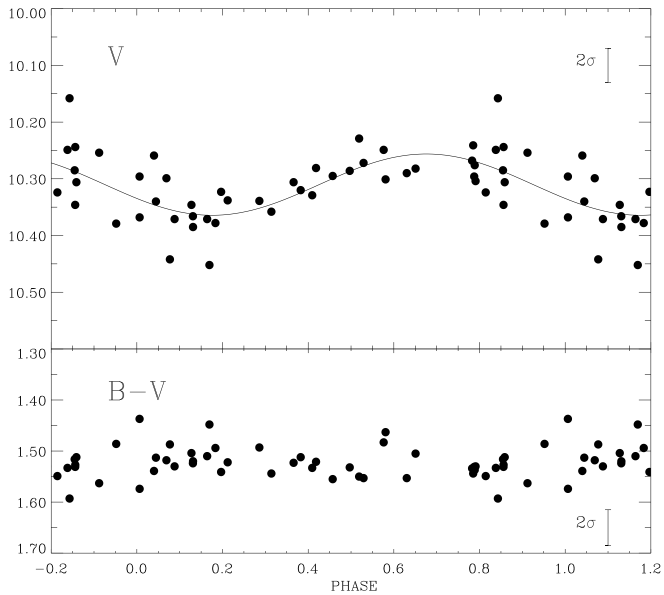

Fig. 7. EV Lac V and B-V light curves in 1971. Phases are computed using the ephemeris HJD0=2440793.5085, and P=4.45.

Table 5. Mean seasonal magnitudes of EV Lac

Year	V	B-V	U-B
1970	10.29±0.04	1.52±0.05	0.97±0.11
1971	10.30±0.03	1.53±0.06	0.92±0.09
1972	10.27±0.04	1.54±0.06	0.93±0.14

a Fourier analysis of seasonal data series from 1969 to 1972 by periodogram analysis for unequally spaced data (Scargle 1982, Horne & Baliunas 1986). The resulting periodograms reveal significant periodicity (with confidence level greater than 99%) only for the data acquired in the V-band in 1971 ($4^d.45 \pm 0^d.01$, with a confidence level of 99.6%). A similar period ($P=4^d.44 \pm 0^d.02$) results from the analysis of the B-band 1971 data, but with a confidence level of 96.9%. The U-band data acquired in the same year are more noisy than the B- and V- band data, therefore it was not possible to identify any significative periodicity. The 1971 V and B-V light curves are shown in Fig. 7, where phases were computed by adopting JD 2440793.5085 as initial epoch and $P=4^d.45$. The 1971 V light curve can be reproduced by a sinusoidal function with peak-to-peak amplitude of 0.11 mag and the light minimum at ϕ=0.18.

In 1969, 1970, and 1972 the EV Lac magnitude was constant within 0.04 mag. Mean seasonal values of the EV Lac V magnitude, B-V and U-B colours are listed in Table 5, where we have not included the 1969 data because they were obtained in the instrumental system.

3.3. Phase distribution of flare occurence

One of the objectives of the present work was to investigate possible spatial correlation between flares and photospheric spot regions. To perform such an investigation, the behaviour of the flare occurrence rate versus rotational phase was analyzed. For each data subset, we computed the mean flare occurence rate, i.e. the ratio between the number of flares and the flare coverage, in intervals of 0.1 phase length. The resulting behaviour of flare occurence versus the photometric phase are shown in Fig. 8 for the subsets 1968-1975. The data acquired in 1976-1977 have not been considered for the purpose of the present analysis because the total coverage obtained in these years (≤32 h) is too short to get reliable conclusions. To avoid effects due to inhomogeneties in the data (e.g. different detection limits of the different instruments, etc.) the flare occurrence rates have been separately computed for the data sets acquired with the same telescope and passband. In most cases only the data acquired in the U-band with the 61-cm telescope were used. This is not the case for the 1969 data, because in this case only B-band observations were available, and for the 1970 data, because about 98 h of U band monitoring with the 91-cm telescope (the best conditions to detect flares) were available. The total coverage (in hours), the total number of observed flares, the passband and the telescope aperture are given in the Fig. 8 for each curve. The phases have been computed by using JD 2440793.5085 as initial epoch and $P=4^d.45$ as done for the 1971 V-band light curve (cf. Fig. 7).

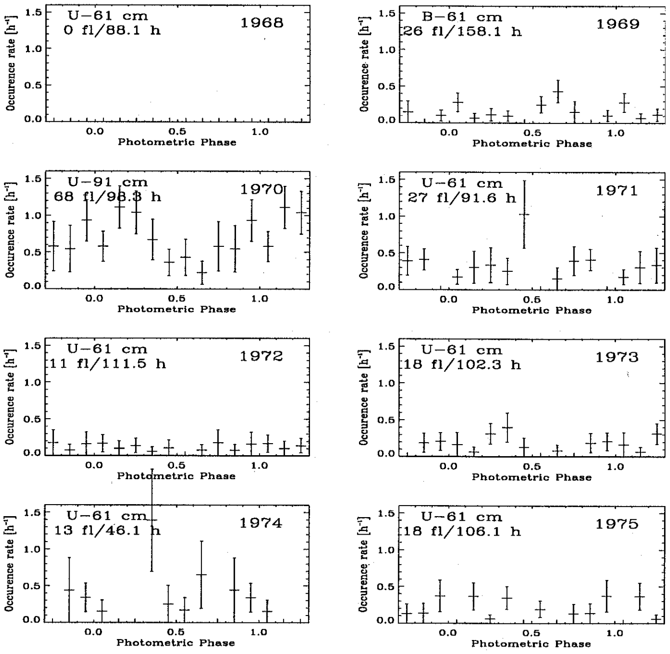

Fig. 8. Flare occurence rate versus photometric phase.

A well defined behaviour of the flare occurrence rate versus phase is apparent only in the 1970 data. However, we believe that the lack of rotational modulation of the flare occurrence at the other epochs is not a conclusive result because of the higher threshold for flare detection with the 61-cm telescope than with the 91-cm telescope.

To ascertain that the modulation of flare occurrence found in 1970 is not spuriously given by an anticorrelated modulation

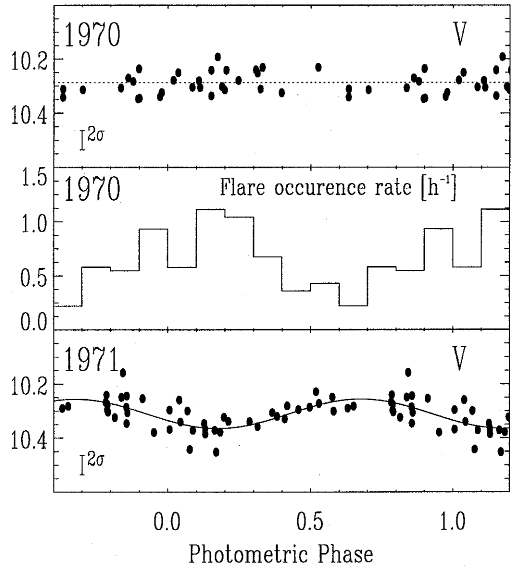

Fig. 9. *Top panel:* V-band light curve in 1970. *Middle panel:* Normalized flare distribution in 1970. *Bottom panel:* V-band light curve in 1971.

with the coverage time (fl_{occ} = N_{fl}/Cov), we have inspected the behaviour of coverage versus phase. The coverage appears slightly modulated in phase with the flare occurrence rate. Being at the denominator, the observed coverage behaviour cannot artificially enhance the flare occurence rate. For the sake of comparison, in Fig. 9 we have plotted the V-band light curves observed in 1970 and 1971 (top and bottom panels, respectively) and the flare occurrence behaviour in 1970 (middle panel). In 1970 the V-band light curve was flat, therefore the EV Lac photosphere was uniformely covered by spots or completely unspotted. On the contrary, in 1971 the V-band light curve had a minimum at phase ∼0.2, that implies a concentration of spots at that phase. The maximum of flare occurrence in 1970 lies in the phase interval 0.1-0.3. Therefore, the concentration of spots in 1971 was at almost the same stellar longitudes where flare activity was concentrated in the previous observational season.

To test the significance of this apparent correlation between the site of preferred flare occurrence in 1970 and the site most covered by spots in 1971, we have computed the linear correlation coefficient (r) between R_{fl} (the number of observed flares/hour, binned in 0.1 phase intervals) and V_m (the mean V value at the central phase of each bin). The result was r=0.77. The probability of determining such a correlation by chance from an uncorrelated population is <0.01 for N=10 data points, as in our case.

4. Conclusions

UBV photoelectric photometry aimed at studying flare activity on EV Lac has lead to the detection of a total of 254 flares in 1272 h of monitoring time.

We find that three percent of the energy emitted by EV Lac in the U -band is due to flare emission, while this energy fraction in the B and V bands goes down to 0.3% and 0.06%, respectively. A comparison with previous results in the literature shows no significant variation of the flare energy distributions with time.

The flare activity level computed on a yearly time-scale shows a slight variability with a period of ∼3 year beginning from 1970. This result is similar to Mavridis & Avgoloupis's (1986) result. Their data on flare occurrence, from 1971 to 1980, show the same time variability in the years 1971-1976 as our data. It should be noticed, however, that these authors suggest a period of flare activity close to 5 years.

Flare energies in U, B and V bandpasses were found to be strongly correlated; the slope of the E_U-E_B correlation is consistent with the slope derived by Lacy et al. (1976) from analysing flares on different flare stars.

The observed values of the flare rise time and decay time are slightly correlated to the flare energies. The correlation is better and steeper for the decay time than for the rise time. Flares of equal amount of energy output can be characterized by 1-2 order of magnitude different time-scales. A comparison of the empirical relation between the rise time and the energy in the U-band found by us and that one derived by Pettersen (1989) from a wide sample of flare stars, yields to the conclusion that the relation that holds for EV Lac is definitely steeper than the general one; i.e. EV Lac flares with a certain value of energy are characterized by a mean rise-time higher than the value predicted by the general law given by Pettersen (1989).

Seasonal light curves from 1969 to 1972 reveal that EV Lac exhibited rotational modulation only in 1971.

We have investigated the behaviour of the flare occurence rate versus the rotational phase. Our data allowed us to ascertain a well defined rotational modulation of the flare occurence rate in 1970. There is a strong spatial correlation between the site of high flare activity level in 1970 and the site in which spots were clustering in the successive observational season. We suggest that this scenario is reminiscent of the solar one: flares occur more frequently in region of emerging magnetic flux, i.e. where spots are growing up (Rust 1972, van Hoven et al. 1980, Priest et al. 1986). This result is in agreement with the conclusion by Doyle (1987) that now can be more strictly constrained by our data.

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