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DETECTION OF 5-6 DAY OUTBURSTS IN FLARE ACTIVITY IN EV LACERTAE, INTERPRETED AS A ROTATIONAL EFFECT, AND A TENTATIVE REPORT OF TEMPORAL RELATIONSHIPS BETWEEN FLARE EVENTS

Early international collaborative monitoring of dMe flare stars arranged by the IAU Commission 27 Working Group concentrated on fortnightly runs on a few selected stars, namely, UV Cet, AD Leo, YZ CMi and EV Lac. In the Seventies, long series of observations were appearing, and usually were spread over very much wider time intervals, and important new and largely independent results using high time-resolution and/or simultaneous spectroscopic coverage were reported. In 1970, coverage of EV Lac was about 128 hours on 18 consecutive nights, and results show that the star was apparently 'flare-free' on 7 nights, with grouped outbursts of activity on other nights. The present paper deals with the unusually good series of observations of EV Lac between July and October 1975 at about 1-second resolution.

In 1975, a total of 208 hours coverage of EV Lac in the B or U band, spanning 79 days, was obtained after allowance for overlap, and a total of 50 separate flares, with a few being observed at more than one station, were successfully recorded at six observatories (Catania, Crimea, Herstmonceux, Oslo, Stephanian and Tokyo), yielding an average of 1 flare/4.16 hours. Examination of the time distribution of flares and coverage again shows, however, that flares occur in groups. As many as 42 out of the 50 flares are found in groups, each group lasting 5 or 6 consecutive nights, suggesting several distinct outbursts of stellar activity, not a long-term periodic phenomenon. Within each group the rate of flaring is double the above-quoted average, reflected in the fact that during only 108.4 hours of the total 208 hours was EV Lac flaring at all. The best example of these groups of flares is shown by the following diary of events. On 30 and 31 Aug and 1 Sept 1975, there were no flares in 9.5 hours total coverage, while 10 flares occurred over the following 6 nights, 2 - 7 Sept, during 28.4 hours coverage. Furthermore, the termination of this group is

Table I

Flares in 1975 and their Observed Characteristics (See Text)

No	1975	UT	HJD	ΔU	ΔB	P_U	P_B	Obs	Ref *	Group
1++	20 Jul	$00^h02^m.1$	$2613^d.50293$	-	$0^m.24$	-	0.36	Ste	e	-
2	27 Jul	01 44.8	2620.57468	$2^m.07$	0.83	12.15	2.32	Cat	a	-
3-6	3 Aug	-	-	<0.3	-	-	-	Tok	f**	5?
7	3 Aug	16 07.0	2628.17383	1.9	0.43	-	0.85	Tok	f	5?
8	3 Aug	16 33.8	2628.19242	5.9	3.35	-	34.0	Tok	f	5?
9	7 Aug	23 32	2632.44139	-	0.08	-	0.06	Cri	b	5?
10	10 Aug	21 39	2635.40473	-	0.18	-	0.64	Cri	b	1
11	10 Aug	21 55	2635.41584	-	0.44	-	0.46	Cri	b	1
12	11 Aug	21 49	2636.41173	-	0.10	-	0.14	Cri	b	1
13	11 Aug	23 14	2636.47076	-	0.07	-	0.38	Cri	b	1
14	12 Aug	23 20.2	2637.47506	-	0.07	-	0.02	Ste	e	1
15	14 Aug	22 29	2639.43961	-	0.50	-	3.91	Cri	b	1
16	14 Aug	22 59	2639.46044	-	1.63	-	5.50	Cri	b	1
17	15 Aug	00 00	2639.50280	-	0.73	-	0.64	Cri	b	1
18	15 Aug	01 14.4	2639.55447	2.47	1.26	17.30	4.60	Cat	a	1
19	15 Aug	21 51.0	2640.41322	-	0.19	-	0.73	Ste	e	1
20	29 Aug	21 58.1	2654.41876	-	0.15	-	0.06	Ste	e	-
21	2 Sep	23 55.7	2658.50060	-	0.31	-	0.06	Her	c	2
22	3 Sep	00 11.1	2658.51126	-	0.08	-	0.01	Ste	e	2
23	4 Sep	01 12.6	2659.55401	0.52	0.10	1.20	0.09	Cat	a	2
24	6 Sep	00 55.2	2661.54203	0.40	0.06	2.33	0.20	Cat	a	2
25	7 Sep	19 47.5	2663.32837	0.37	0.14	0.70	0.11	Cat	a	2
26	7 Sep	20 07.6	2663.34233	0.58	-	0.17	(0.02)+	Cat	a	2
27	8 Sep	00 07.5	2663.50893	0.40	-	0.03	(0.00)	Her	c	2
28	8 Sep	01 14.0	2663.55511	1.04	-	2.94	(0.42)	Her	c	2
29	8 Sep	02 00.3	2663.58723	0.48	-	0.68	(0.10)	Her	c	2
30	8 Sep	02 13.3	2663.59631	0.28	-	0.46	(0.09)	Her	c	2
31	12 Sep	22 10.2	2668.42755	0.50	-	0.19	(0.03)	Cat	a	-
32	12 Sep	23 46.6	2668.49450	2.15	0.93	14.15	2.45	Cat	a	-
33	13 Sep	00 14.3	2668.51373	0.67	-	4.03	(0.58)	Cat	a	-
34	13 Sep	00 44.5	2668.53470	1.43	1.03	30.55	3.78	Cat	a	-
35	14 Sep	01 14.3	2669.55540	0.99	0.34	2.76	0.45	Cat	a	-
36	28 Sep	23 26.3	2684.48050	0.76	0.28	1.47	0.50	Cat	a	3
37	28 Sep	23 53.2	2684.49918	0.42	-	1.40?	(0.20)	Cat	a	3
38	29 Sep	23 02.0	2685.46362	1.39	0.54	7.48	3.60	Cat	a	3
39	1 Oct	22 15.0	2687.43098	1.99	1.38	24.41	6.98	Cat	a/e	3
40	3 Oct	20 38.2	2689.36376	-	0.21	-	3.2	Ste	e	3
41	7 Oct	19 25.1	2693.31296	-	>0.64	-	1.25	Osl	d	4
42	7 Oct	22 46.2	2693.45260	-	0.11	-	0.15	Ste	e	4
43	7 Oct	23 12.6	2693.47093	-	0.09	-	0.03	Ste	e	4
44	8 Oct	19 22.8	2694.31133	-	0.10	-	0.28	Ste	e	4
45	8 Oct	19 59.9	2694.33713	-	0.10	-	0.06	Ste	e	4
46	8 Oct	21 35.4	2694.40341	0.85	0.25	2.45	0.16	Cat	a	4
47	9 Oct	02 39.1	2694.61432	0.43	-	0.70?	(0.10)	Cat	a	4
48	10 Oct	20 37	2696.36286	-	0.1	-	-	Osl	d	4
49	11 Oct	21 37.3	2697.40470	-	0.20	-	0.45	Ste	e	4
50	11 Oct	22 07.8	2697.42591	-	0.14	-	0.63	Ste	d/e	4

* Refs: a) Rodonò & Andrews (unpublished) private communication b) Bruevich et al.1980 c) Andrews 1982 d) Andersen 1976 e) Contadakis et al.1980 f) Kodaira et al.1976.

** Four small flares recorded between 14-16hrs UT. Details not available.

\+ Parentheses indicate empirical relationship, $P_U = (1/7)P_B$, invoked.

++ Double peak.

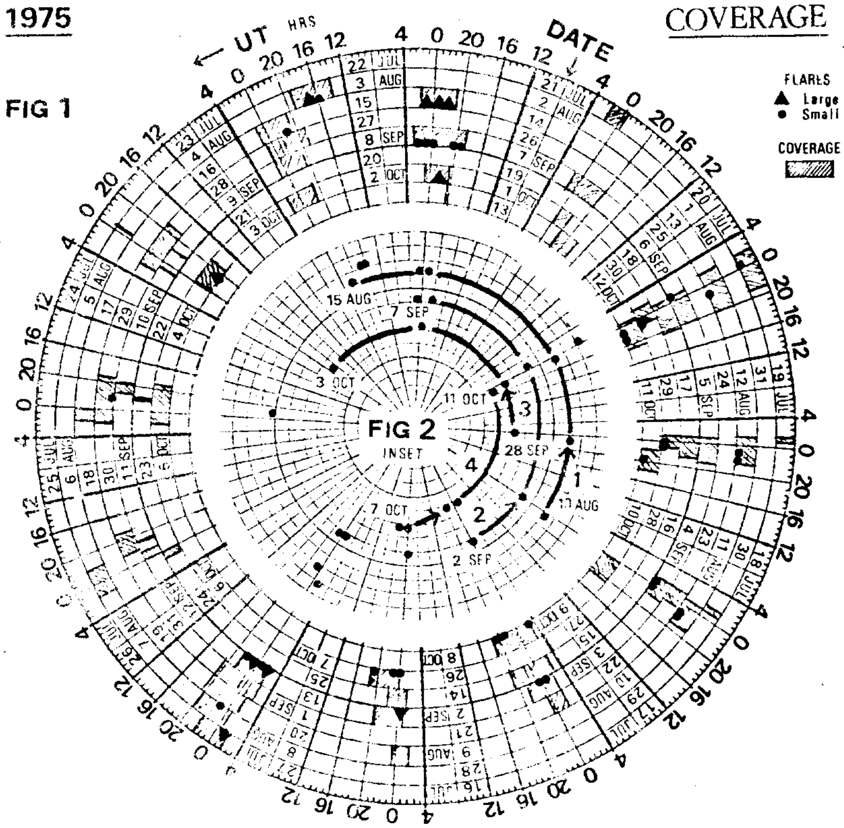
clearly defined by an absence of flaring during 11.5 hours coverage over the 4 succeeding nights, 8 - 11 Sept. At least three other such groups are tentatively identified in the 1975 data. No such strong grouping appears in the 1970 data, although there is a 'switching off' on 3 consecutive nights (5 - 7 Sept 1970) during 12.5 hours coverage, EV Lac having flared over 5 consecutive nights (29 Aug - 2 Sept 1970) with no flares on either 28 Aug during 7.5 hours or 3 Sept during 6 hours.

A list of all flares in 1975 is given in Table I, together with some of their observed characteristics. The Heliocentric Julian Date less 2440000^{d} ($\pm 0^{d}.00005$) of the time of flare maximum (HJD), the amplitude in U or B, the integrated intensity or equivalent duration in minutes (P), and

EV LAC 1975

FLARES AND COVERAGE

FIG 1



the flare group to which it has been assigned are tabulated. A summary of the coverage and flares is shown in Fig.1, arranged in a tentative 12-day cycle for reasons set out below. The inset (Fig.2) is a diminished version of Fig.1 with solid lines joining the hypothetical groups (Nos.1-4), with dates of commencement and termination. Symbols differentiate between large flares ($P_B > 2$ mins) and small events. When P_B is not available, it is estimated using an approximate empirical result that $P_B = (1/7)P_U$. In Table II, a summary of some relevant data for each of five groups is given,

Table II

Summary of 'Group' Data

Group	Dates 1975	Coverage hrs	Flare Nos (See Table 1)	Rate flares/hr	ΣP_B mins	Rel.Energy (*)
1	10-15 Aug	21.8	10 to 19	2.18	17.02	0.0130
2	2- 7 Sep	28.4	21 to 30	2.84	1.12	0.0007
3	28 Sep-3 Oct	18.5	36 to 40	3.08	15.75	0.0142
4	7-11 Oct	24.7	41 to 50	2.74	3.11	0.0021
(5)?	(3- 7 Aug)	(15.0)	(3 to 8)	(2.14)	(37.59)	(0.0418)

* Relative Energy/unit coverage = ΣP_B /(Coverage x 60)

the last group, No.5, consisting of flares only from the very active phase observed by Kodaira, Ichimura & Nishimura (1976) during a long observing run on a single night, and a single flare on 7 Aug. The mean rate of flaring (Table II, Col.5) is remarkably constant, but the total integrated intensities within each group vary considerably. A measure of the relative total energy per unit coverage (last Col.) also shows distinctive variations of an order of magnitude. Partly for this reason, it is suggested that the flares in 1975 occurred in several active areas, possibly at different longitudes. See Fig.3.

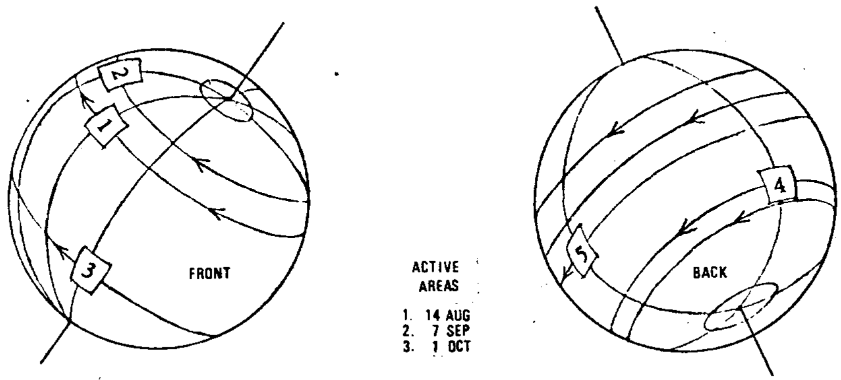


Figure 3

Interpreting 'groups' as 'active areas', a schematic representation of the visible hemisphere (front) on, say 7 Sept. 1975, would show an active area (Group 2) near the limb. After that date, it had passed around the receding limb due to stellar rotation, and could have apparently 'switched-on' initially when it first appeared 5 or 6 days previously around the other, approaching limb. This suggests a period of rotation of approximately 12 days. The separation in latitude in Fig.3 is purely arbitrary. An earlier active area (No.1) and later active areas (Nos.3-5) may be placed on the front or back hemisphere according to this hypothetical 12-day rotation period. Flares are assumed to be frequent within an active area, the lifetime of which lasts typically less than one rotation, and new active areas are assumed to be relatively rare globally. Unfortunately, due to the observing window of a few hours each night (about 3-6 hrs), aliasing with 24 hours in previous frequency analyses was unavoidable. We also note that the possible binary nature of EV Lac could modify the true period with interference from a non-synchronous orbital period. Outbursts of activity, however, seem prevalent in the 1975 data. Nevertheless, the associated, small rotational velocity (v sini = 1 km/sec) for a red dwarf with a photometric radius of $0.22R_\odot$ (Gershberg 1970) and a rotational period of 12 days, is doubtful. A submultiple or related period is possible with additional effects due to differential rotation.

An interesting statistical anomaly is noted for three large flares in 1975, which occurred at $01^h14^m.4$ UT on 15 Aug (Catania, No.18), at $01^h14^m.0$ on 8 Sept (Herstmonceux, No.28) and at $01^h14^m.3$ on 14 Sept (Catania, No.35). After heliocentric correction, these events show a mean 'drift' of only 3 secs/day. The author has carefully searched the original Catania data, amongst others, and one interpretation is that this anomaly is a rare chance coincidence of the time of the Herstmonceux flare and the termination time of the Catania observations which depended to some extent on whether a flare was in progress at or near 'close-down', shortly after 01^h UT. However, further examination of the time distribution of all 50 flares of 1975 has revealed other events which are related in time, suggesting, albeit tentatively, an internal stellar 'clock', governing the appearance of flares. Approximate but significant 'periods' between flares have been reported by a number of authors for several flare stars, with searches performed using frequency analysis but these are never confirmed. A 'mean interval' between large flares has also been frequently used to define a 'photometric rotation period', as well as defining an indicator of activity. It is perhaps pertinent to this question that the estimated rotational velocity of a dMe star from an extrapolation of the spectral-type/rotation relation is about 10 km/sec which is about equivalent to a 1-day period. Spectroscopic work suggests $v \sin i$ <25km/sec (Wilson 1961). In Table III, the mean value of the quantity, $\Delta T = 1 - (T_{B-A}/N)$, which expresses the departure from the nearest whole number of days (N), of the interval (T_{B-A}), between flares B and A, per day. This 'drift rate' is recognizable in six individual sets, one of which is the above 'anomaly' (See Table III, Col.2).

Table III

Mean ΔT(Flare B - Flare A) in mins/day for six different Drift Rates

Advance(+), Retard(-)

(and rms deviation in ΔT in secs/day)

ΔT =	+2.5271	+0.0540	-2.4118	-3.9361	-6.1142	-9.8685	mins/day
B-A =	24-17	28-18	22- 2	20-16	26-15	44-23	
	35-24	35-28	[32-22] *	44-20	31-18	45-33	
	30-18	——	[42-32]	21-18	44-31	——	
	37-12	$\pm 0^{s}.9$	42- 2	46-21	33-24	$\pm 5^{s}.3$	
	——		36-18	39-22	39-33		
rms	$\pm 4^{s}.8$		43-33	49-39	46-39		
			——	——	34-28		
(A,B are Flare Nos from Table 1)			$\pm 1^{s}.7$	$\pm 5^{s}.7$	38-34		
					37-29		
					41-31		
					44-18		
					——		
					$\pm 17^{s}.0$		

* Multiples of same 'interval' ($4^{d}.99162$)!

N.B. Times of flares are usually only given to nearest 0.1 min, and infrequently to nearest second, due to ambiguity in multi-peaks or very slow rise times.

Another is the sidereal drift (Col.4), commented on earlier by the present author (Andrews 1968) and by Herr (1970 & 1971). Out of the total 50 flares, 31 are thus accounted for in Table III. The rms deviation within each set is remarkably small, being of the order of the accuracy of the timing of flare events. Flare No.18 appears most frequently, which may indicate some significant patterning of the events around this event. A sidereal drift due to spurious flares occurring at the same hour angle of the telescope seems here to be ruled out, as several stations are involved. It is of particular interest that a relationship between the drift rates (ΔT) is evident for the 'retardation' sets, in that their ratios are almost constant (~1.6). See Table IV. The author has no suggestions as to the

Table IV

Ratio between Mean Drift Rates

ΔT	Ratio
+2.5271	
+0.0540	
-2.4118	>1.63
-3.9361	>1.55
-6.1142	>1.61
-9.8685	

reasons for these latter results unless they are connected with differential rotation between active areas at differing stellar latitudes. These results are sufficiently puzzling to stimulate further work on the time distribution of flares.

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