Long-Term Photometric Study of the Flare Star EV Lac: 1983 - 2001

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Abstract

We present the results of a long-term spot photometry of the flare star EV Lac during 1983-2001. The homogeneous data sample is obtained with the computer controlled photometer and the 60 cm telescope of the Rozhen National Astronomical Observatory (Bulgaria). The photometric (rotational) period of Pettersen (1980a) is confirmed and slightly refined, $P = 4.^{d}3734$. The light curves in V have been modeled, using the code of Eker (1994). Two spots prevail in the light curves: a large high latitude spot (65º – 90º) and a smaller spot at low latitudes (–27º – 50º). The phases are consistent in 1983 – 1996. However, comparison with the data of Pettersen (1980) from 1974 shows phase discrepancy. After 1996, phases are steadily decreasing, suggesting a spot migration in longitude. The mean V brightness of EV Lac and the amplitude of the rotational modulation (light curves amplitude) do not support any suggestion for a long term cyclic behaviour of the stellar photospheric activity.

1. Introduction

EV Lac (Gliese 873, Sp type dM4.5e) is a well known flare star, one of the best observed in recent years. It is generally regarded as a single star (Pettersen, 1980b). EV Lac is also a low amplitude photometric variable, due to rotational modulation of the light by photospheric spots. The rotational period, 4.573 d, was reported by Pettersen (1980a), and which is the period of rotation. Later, the photometric period has been refined by Pettersen et al (1983), and by Pettersen et al (1992). Their last value of the period, determined from a 10–y data sample, is 4.376 d. Leto et al (1997) obtained for the period 4.45 d for 1970. The differences in the published values of the period may be due partly to observing uncertainties, however, also real changes, resulting from spot migration are possible. EV Lac has been often included in observational campaigns for flare monitoring (e.g. Cristaldi and Rodono, 1970; Mavridis et al, 1982; Panov et al, 1982; Pettersen et al, 1983; Gershberg et al, 1991; Alekseev et al, 1994; Abdul-Aziz et al, 1995; Berdyugin et al, 1995; Leto et al, 1997; Zhilyaev et al, 2007). Attempts have been made to study possible variations of the flare activity level and its possible connection to active stellar longitudes (spots). Pettersen et al (1983) found no spot/flare relationship, but they argue that their negative result could be expected, if a large photospheric spot is seen all the time due to a suitable observing angle. Mavridis and Avgoloupis (1986) claim to have found mean quiet-state luminosity variations with an amplitude of 0.3 mag and a period of about 5 years. The same periodicity they found in the mean annual values of the flare activity. Leto et al (1997) obtained a phase modulation of the normalized flare occurrence in the year 1970 and also confirmed the variation of the flare activity level with about 3 y period during 1970-1977. Alekseev and Gershberg (1998) studied the flare activity of EV Lac during 1986 – 1995 and found clear evidence of a 7.3 y cycle in the flare activity variation. In this report, we studied the long term photometric behaviour of EV Lac, using our homogeneous data set of spot photometry from 1983 – 2001 and other published data.

2. Observations

Spot photometry of EV Lac was obtained during 1983 – 2001, using the 60 cm telescope of the Rozhen Nat. Astronomical Observatory (Bulgaria), and the UBV, computer controlled, photon counting photometer. In 1983 – 1990, only V observations were obtained. For 1991 – 2001, observations were carried out in B and V. Magnitude differences were obtained with respect to the comparison star HD 215576 (V= 9.184, B–V = 1.183). The star C1 from Pettersen (1983) served as a check. No variability of the comparison star greater than 0.01 mag could be found and the measurements are consistent within the errors. Care was taken to account for dead-time, extinction and the instrumental system corrections. A single data point is the average of four 10s integrations and a mean of 3 – 5 individual data was obtained.

3. Modeling of the light curves

Light curves modeling has been done, in order to look for the distribution of the spots on the photosphere, and to look for possible spot migration. We used the technique, described by Eker (1994), and a computer code written by D. Dimitrov. Only light curves in V were modeled. V_{max} was obtained as the maximal brightness value from the whole sample. For the temperature difference between the photosphere and the spot ΔT we used the considerations of Pettersen (1980a), and the amplitude of his $\Delta(V - R)$ measurements. The angle $i = 60^o$ has been set arbitrary, because $v \sin i$ is too small ($v\sin i = 4.5\ km \cdot s^{-1}$, according to Johns-Krull and Valenti, 1996), in order to allow for an exact determination of angle i.

4. Discussion of results

From the whole data set, we derived the ephemeris:

$$\text{JD (minimum light)} = 2445906.369 + 4.^{d}3734 \times E.$$

Table 1. Parameters for the light curves modeling of EV Lac

Parameter		**EV Lac**
T_{phot}	[K]	3300
ΔT	[K]	500
i	[°]	60
V_{max}	[mag]	10.16
u		0.81
HJD_0	[days]	2445906.369
P	[days]	4.3734

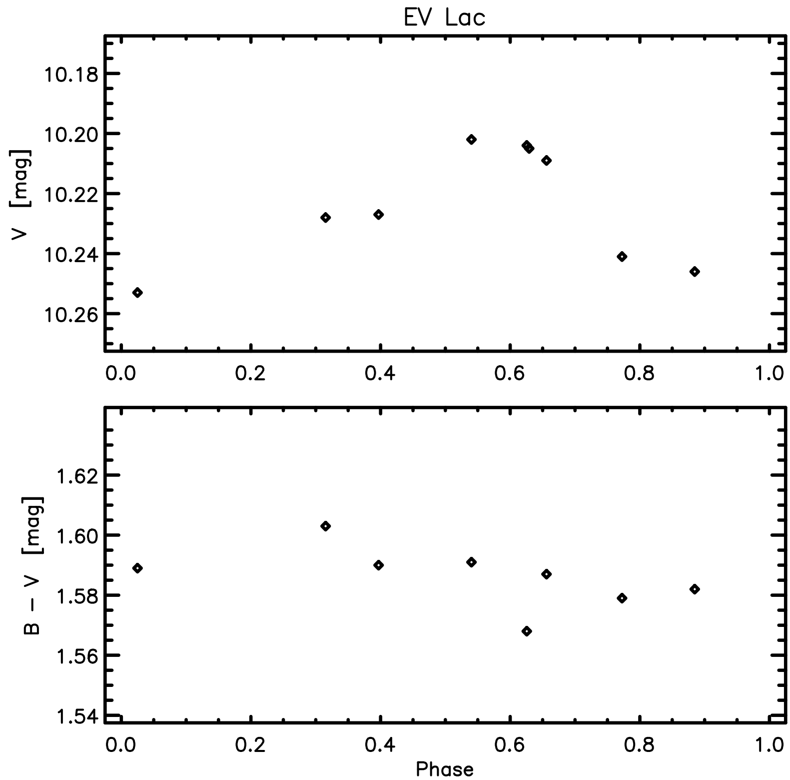

Fig 1. *Light curve in V and B–V for EV Lac in 1995*

Since minimum light should correspond to the maximum spot visibility, we used these values for the light curves modeling (Table 1). In Fig 1, the V light curve is shown (upper panel) together with the B–V variation (lower panel). There is a clear correspondence of minimum light and reddest color, which should be expected from the spot hypothesis. The only other published spot photometry data that we could find is from Pettersen (1980a). Comparison with the Pettersen's data from 1974 shows a phase discrepancy. Phases of minima and maxima of light from our data are shown in Fig 2. From Fig 2, we can see that phases drift to smaller

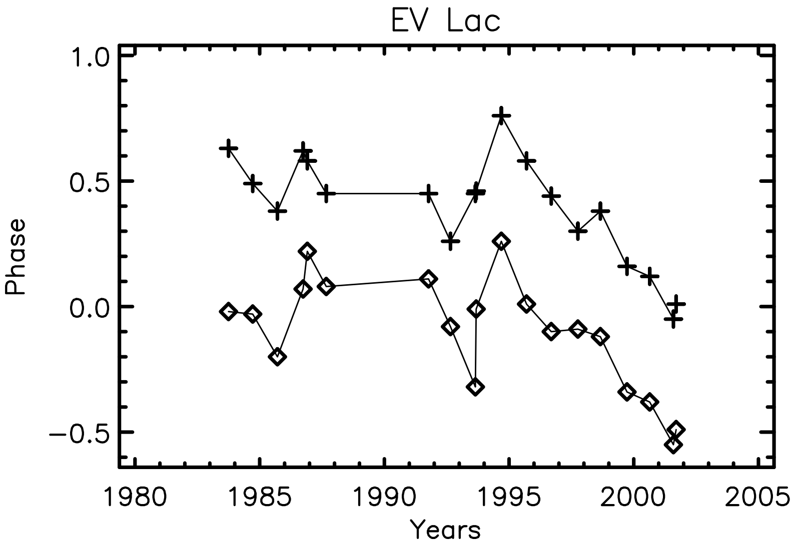

Fig 2. *Time dependence of phases of maximum light (crosses) and minimum light (rhombs)*

values after 1996. This is an indication of spot migration and spot restructuring on EV Lac. Therefore, the ephemeris shown above is exact only for the time 1983 – 1995. The spot migration hypothesis is also supported by the results of the modeling, presented in Table 2. The columns of Table 2 are self-explanatory: columns 2-7 contain the longitude, latitude and size of the detected two spots, columns 8 -11 contain the phases and the magnitudes in minimum and maximum light, respectively. Columns 12 and 13 contain the mean magnitude and the amplitude of the V light curve. From Table 2, there are two spots apparent in the light: a large (size: 20º - 25º) high latitude spot and a smaller (size: 5º – 15º) spot in the lower latitude region. In Table 2, after 1998, the parameters for the second spot disappear. This does not necessarily mean that the second spot disappeared but rather our data is not well distributed over the photometric cycle to allow for spot 2 detection. In 1996 – 2001, there is a systematic drift of the photometric phases (Fig 2) towards decreasing phases, and which is seen also in the shift in longitude of spot 1 (Table 2). Probably, this is due to a spot migration parallel to the equator of the star, in a

Table 2. *Results from the light curves modeling*

Year	l1	b1	r1	l2	b2	r2	φ_{min}	V_{min}	φ_{max}	V_{max}	V_{mean}	ΔV
1983.75	48.5	83.9	25.2	330.0	–27.0	12.5	0.98	10.251	0.63	10.208	10.230	0.043
1984.72	356.5	72.0	24.6	271.0	–15.0	13.0	0.97	10.282	0.49	10.180	10.232	0.102
1985.71	317.3	87.2	24.7	280.3	–11.2	8.7	0.80	10.246	0.38	10.215	10.227	0.031
1986.74	18.0	64.0	22.0	122.0	15.7	14.8	0.07	10.280	0.62	10.169	10.233	0.111
1986.91	6.0	65.0	20.0	108.0	15.0	15.1	0.22	10.270	0.58	10.168	10.224	0.102
1987.67	303.1	74.8	20.2	46.0	43.9	15.9	0.08	10.282	0.45	10.182	10.231	0.099
1991.77	40.0	80.7	24.0	231.0	24.0	8.4	0.11	10.248	0.45	10.212	10.227	0.036
1992.65	332	85.1	25.2	173.5	50.0	8.0	0.92	10.241	0.26	10.224	10.233	0.018
1993.65	46.0	87.0	24.5	242.0	–10.0	9.8	0.68	10.234	0.45	10.218	10.227	0.016
1993.68	348.0	89.0	29.0	358.0	5.0	5.0	0.99	10.259	0.46	10.244	10.250	0.015
1994.69	96.0	84.5	26.8	0.0	0.0	0.0	0.26	10.255	0.76	10.217	10.235	0.038
1995.70	43.0	82.0	25.0	306.0	25.0	8.0	0.01	10.254	0.58	10.203	10.232	0.050
1996.69	338.5	85.9	24.7	310.0	22.0	5.1	0.90	10.244	0.44	10.211	10.226	0.033
1997.76	327.5	82.0	24.0	197.0	20.0	10.0	0.91	10.243	0.30	10.205	10.230	0.039
1998.66	318.5	88.3	25.6	0.0	0.0	0.0	0.88	10.233	0.38	10.222	10.228	0.011
1999.73	236.5	85.6	26.5	0.0	0.0	0.0	0.66	10.248	0.16	10.219	10.233	0.030
2000.64	223.5	79.8	26.2	0.0	0.0	0.0	0.62	10.268	0.12	10.201	10.232	0.067
2001.59	162.5	84.0	29.5	0.0	0.0	0.0	0.45	10.277	0.95	10.228	10.251	0.049
2001.70	182.5	86.4	31.5	0.0	0.0	0.0	0.51	10.282	0.01	10.249	10.265	0.033

sense of decreasing longitudes. In Fig 3 we plotted the long term light variations of EV Lac, folded with the above ephemeris. We added observations by Pettersen (1980a) for 1974, Pettersen et al (1992), for 1979, 1981, 1983, 1986, 1987, 1988, 1989, and by Leto et al (1997), for 1970-1972. Variations of the amplitude of the light curve are clearly seen, with the largest amplitude in 1986 ($\Delta V = 0.102$ mag). There are slight systematic differences between the different photometric systems used, apparently due to rest-errors in the standard transformation of magnitudes. From Fig 3, no long term periodicity is seen in the data. We carried out a periodicity search with the code PERIOD 04 (Lenz and Breger, 2005) using all mean-brightness values, displayed in Fig 3. No significant period could be found. Therefore, the question of a long term activity cycle of the mean brightness of EV Lac remains open. Since the previous studies concern the time 1970 – 1981, our conclusion about absence of a cycle does not necessarily mean a contradiction to previous results. It should also be mentioned that Alekseev and Gershberg (1998) did not find any periodicity in the spottedness of EV Lac from a 25 y data record.

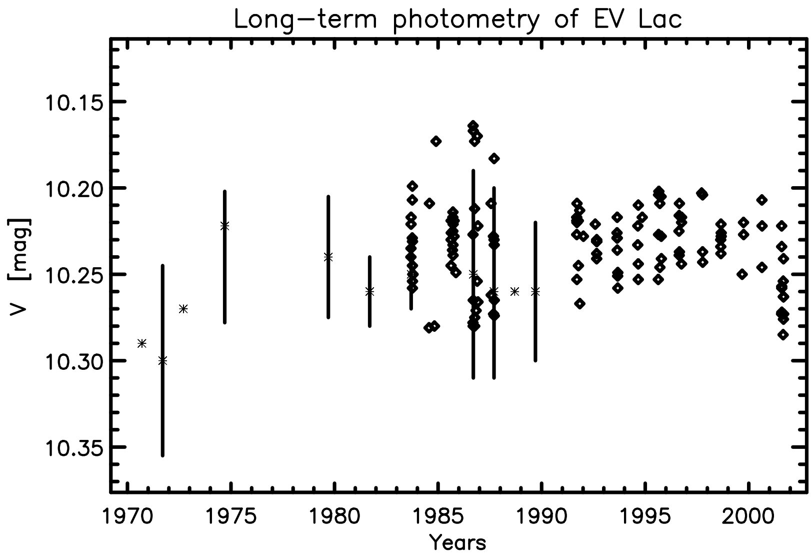

Fig 3. *Long term light variations for EV Lac in V. Bars denote amplitudes of light curves, stars are mean brightness, and the rhombs are data from this study. The spread of rhombs in mag denotes the amplitude of the respective light curve*

5. Conclusions

EV Lac is a very active flare star in the whole spectrum from radio to X- ray (Osten et al 2005). Its activity is undoubtedly related to magnetic fields and their restructuring. According to the standard theory, EV Lac should be almost a fully convective star and generation of magnetic fields by dynamo action could be expected. Johns-Krull and Valenti (1996) reported a strong, $B = 3.8$ kG magnetic field and a 50% coverage of the surface. Longitudinal magnetic field ranging from 18 to -40 G was reported by Phan-Bao et al (2006). They have also detected magnetic field variations on a timescale of 50 min, and which are not due to flaring events. In the previous section, we have seen variations of the light curve amplitude on a timescale of months, probably resulting from the spot restructuring. The spot migration in longitude could be a hint to a slowly changing magnetic field geometry.

Our negative result for a long term cycle of photospheric activity, based on the spot photometry data, should be tested with further observations.

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