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POLARIMETRIC ANALYSIS OF A SLOW FLARE OF AD LEO

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A flare event of AD Leo has been observed at Belgrade Astronomical Observatory on March 21-st, 1974 during a series of patrol observations of flare stars. The observation was done with the 65-cm refractor and a D. C. polarimeter (Kubičela et al., 1976). On the basis of the obtained data a polarimetric and a photometric analysis is possible.

The detection of eventual linear polarization of star radiation during a flare is certainly of great importance in interpreting the phenomenon. As few of the earlier attempts of such polarimetric observations (Oskanjan, 1964, Zappalà, 1969, Grigoryan and Ericyan, 1970, Kubičela and Arsenijević, 1970, Grigoryan and Ericyan, 1971, Efimov and Shakhovskoj, 1972) and some general estimations of these (Efimov, 1970, Gershberg, 1970) were not conclusive, a new polarimetric flare analysis is being attempted here. The polarimetric analysis is performed bearing in mind the subtlety of such observations and a rather moderate size of the instrument utilized. Consequently, one can expect results of not very high statistical importance and a proper attention has to be paid probably only to the observed relative polarimetric changes.

Photometry of the phenomenon

The observation of AD Leo lasted from $22^h\ 42^m$ UT March 21-st, 1974 till $0^h\ 17^m$ UT March 22-nd. The light curve in V spectral region obtained by continuous recording is shown by heavy line in Figure 1. Time is given in minutes begining at the moment of the first intensity maximum ($22^h\ 59^m.5$ UT). The photometric record is interrupted because of frequent polarimetric sky control. Eleven intervals of integration of polarimetric signal, lasting for 3 to 6 minutes, marked with I through XI are given above the light curve. The intensity scale is given in undisturbed star intensity units.

Besides the primary maximum, which itself might be double, the light curve clearly exhibits a secondary maximum 49 or 50 minutes after the first one. The primary intensity increase, lasting for 1.5 minutes, amounts to 0.24 and the secondary to 0.11 magnitudes. The duration of the whole event, after the primary maximum, has been estimated to 62.5 minutes. The integral intensity of the flare event was $P = 13.28$ minutes and the air mass at the moment of the first maximum $X = 1.214$.

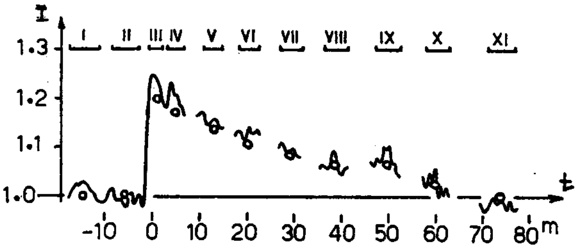

Fig. 1. Light curve of AD Leo on March 21-st, 1974. Zero of the time scale is at $22^h59^m.5$. I through XI are the intervals of integration of polarimetric signal.

The light curve derived from D. C. levels of the averaged polarimetric records (from Y—X recorder) is shown with circlets in Figure 1. The corresponding intensity values are given also in the first column of Table I. In spite of a slight difference with respect to the former curve (in the intervals from IV through VII) these data have been used in the polarimetric analysis.

Polarimetric analysis

The observing conditions during the night 21/22 of March have been estimated as very good. In spite of being quite high, the sky polarization was not changing except at the very end of observation. In any case, it was controled 9 times during the observation, correspondingly interpolated and taken into account in the reduction.

The obtained values of polarization parameters are given in Table I. The amount of polarization, p, is given in percents of the observed intensity averaged within the corresponding interval of a polarimetric measurement. Position angle

Table I

Mean Light Curve and Polarimetric Data

N° of measurement	I	p %	Δ θ 0	θ 0	Group	p_q %
1	1.000	0.41	23	145	Q	0.41
2	1.000	0.73	158	100	Q	0.73
3	1.200	1.40	42	163	P	1.68
4	1.170	0.69	45	166	P	0.81
5	1.135	0.88	34	156	P	1.00
6	1.105	0.24	28	149	P	0.27
7	1.083	0.65	51	172	P	0.70
8	1.063	0.64	20	141	P	0.68
9	1.065	0.57	136	77	S	0.61
10	1.025	0.51	145	86	S	0.52
11	1.000	0.57	13	134	Q	0.57

of the polarization plane in the column $\Delta\,\theta$ is given in the instrumental system (also used throughout the present analysis) and in the column θ it is given in the equatorial system (from *N* towards *E*). In the column „group“ the polarimetric measurements are arranged into three groups according to the three phases of the light curve: *Q* — out of the flare, *P* — during the primary, and *S* — during the secondary flare. In the last column, p_q, the degree of polarization has been expressed in percents of the interpolated intensity of undisturbed star, $p_q = Ip$.

The polarimetric data p_q from Table I are shown in Figure 2 as additive vectors in p, $2\,\Delta\,\theta$ — polar coordinate system. When right-angle components of a polarization vector, $\Delta\,x$ and $\Delta\,y$, were considered, the x and y — axes were assumed placed in the directions $2\,\Delta\,\theta = 0$ and $2\,\Delta\,\theta = 90°$ respectively. All the vectors in Figure 2 have their common origin at 0 and the corresponding vertices at points 1 to 11 according to their numbers in Table I. The vectors themselves are not drawn in full.

One immediately notices that the vectors can easily be divided into three groups: vectors 1, 2 and 11, vectors 3 through 8, and vectors 9 and 10 (polygonal contours in Figure 2). These groups correspond to the three characteristic photometric phases of the light curve, *Q*, *P* and *S* from Table I.

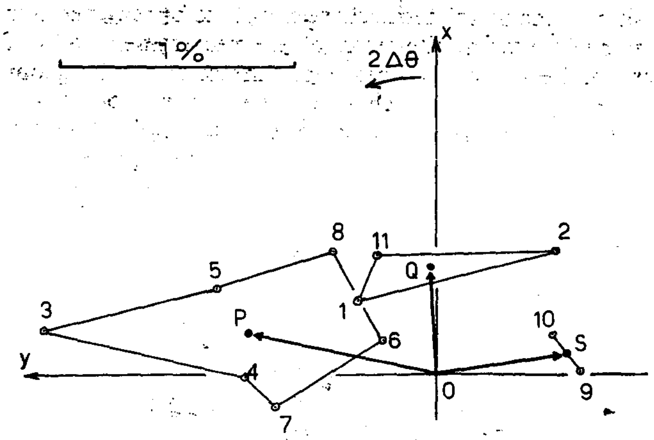

Fig. 2. Polarimetric data, p_q, from Table I as additive vectors in the p_q, $2\Delta\theta$ — polar coordinate system. 1% polarization unit is given in the upper-left corner.

Averaging the polarization vectors in each of the three groups, one obtains mean vectors $\vec{Q}$, $\vec{P}$, and $\vec{S}$, (Figure 2), and might readily conclude that the polarization parameters have been different during the three phases of the flare event. They amounted to:

	p	$\Delta\,\theta$	θ
	%	°	°
Q:	0.46	1.7	123
P:	0.81	38.5	160
S:	0.55	140.0	41 .

2*

Reliability of that conclusion will depend on wether the errors of the observation could be evaluated and on their values. As in the analysed case there are only 11 independent measurements, the corresponding r.m.s. errors will have their relative errors of about 21% (Bol'shakov, 1965, p. 90).

Calculated r.m.s. errors found from the 11 vectors, taking x and y as arguments, are:

$$s_x = \pm 0.23\ \% \text{ and}$$
$$s_y = \pm 0.69\ \%.$$

These should be the same because of their invariability with respect to the change of the coordinate system (Serkowski, 1962). As this is not the case, one should assume some systematic errors or a real polarimetric change, especially along the y-axis ($|s_y| > |s_x|$). The latter assumption, supported by the polarimetric groups being synchronous with the photometric phases of the flare event, seems to be more probable.

Once assumed, the polarimetric changes have to be removed from the observed data in order to be able to find the errors of the measerement itself. The corresponding reduction has been done by translating the mean of the groups Q, P and S into one point, e.g. point Q, not changing the relative positions of point within a group. The result is shown in Figure 3 and the applied corrections are given in Table II.

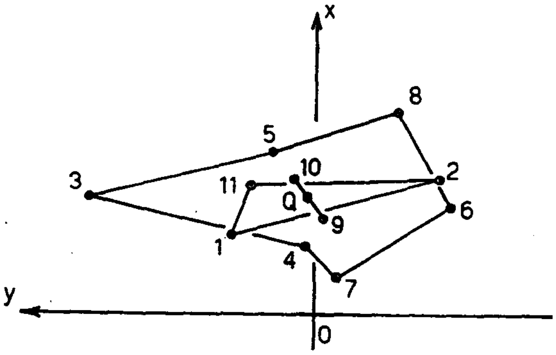

Fig. 3. The polarimetric data groups from Figure 2 reduced to the group Q.

Table II

Reduction to the Group Q

N° of measurement	Δ x %	Δ y %
1, 2 and 11	0.00	0.00
from 3 to 8	+0.27	−0.77
9 and 10	+0.36	+0.58

A new calculation of the r.m.s. errors of the right-angle components of the polarization vectors gives:

$$\sigma_x = \pm 0.18\% \text{ and}$$
$$\sigma_y = \pm 0.41\% .$$

Now, the errors are more alike ($s_y : s_x = 3.00$ but $\sigma_y : \sigma_x = 2.28$) but not yet equal. Being in no position to find some independent arguments for interpretation and estimation of further systematic effects, one might take the smaller number (0.18 %) as upper limit of the error of measurement. However, keeping a safety interval, one would prefer a mean value of the two r.m.s. errors. Such a mean, according to Bol'shakov (1965, p. 103) is given by:

$$\sigma_p = \frac{1}{p} (p_x^2 \sigma_x^2 + p_y^2 \sigma_y^2)^{1/2}$$

where p_x, p_y and p are the right-angle components and the intensity of the polarization vector of an arbitrary point. Taking $p_x = p_y = 1$ and $p = (2)^{1/2}$, one finds:

$$\sigma_p = \pm 0.32\%.$$

At the same time the ellipse of equal probabilities (Smirnov and Dunin—Borkovskij, 1965, paragraph 5.2.4) has been reduced to a circle of equal probabilities. Then, taking into account the number of measurements within the groups *Q*, *P* and *S*, the r.m.s. errors of the mean vectors are:

$$\sigma_Q = \pm 0.18\% ,$$
$$\sigma_P = \pm 0.13\% \text{ and}$$
$$\sigma_S = \pm 0.23\% .$$

In order to apply the 3 σ — criterion to the evaluated polarization changes, the vectors $\overrightarrow{OQ}$, $\overrightarrow{OP}$ and $\overrightarrow{OS}$ from Figure 2 have been redrawn in Figure 4, the 3 σ — circles of equal probabilities have been constructed around points *Q*, *P* and *S*, and the vectors of the polarization changes found as follows:

	p	$2\Delta\theta$	$\Delta\theta$	θ
	%	0	0	0
QP:	0.81	110	55	176
PS:	1.34	266	133	74
SQ:	0.68	58	29	150.

It can be seen that two of the noticed changes, $\overrightarrow{QP}$ and $\overrightarrow{PS}$ are bigger (the later for about two times) than the corresponding errors. The third change, $\overrightarrow{QS}$, is equal to $3\sigma_S$ and somewhat bigger than $3\sigma_Q$.

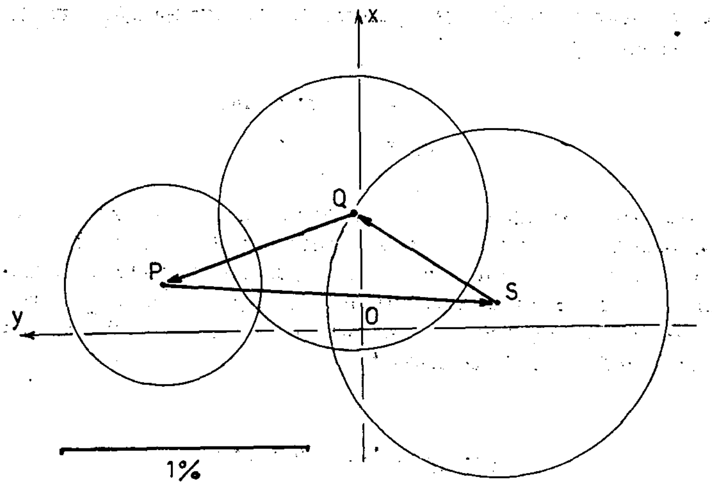

Fig. 4. Relative polarization changes between groups P, Q and S with the 3 σ-circles.

Having always in mind what has bean stated on the low statistical importance of this result (evaluated from 11 measurements only) one has to be very careful in its further interpretation.

However, in the first approximation a physical conclusion is possible. Namely, it is possible to assume that the observed polarization changes $\overrightarrow{QP}$ and $\overrightarrow{PS}$ can be attributed to the additional intensity of radiation observed during the primary and the secondary flares. Then, the degree of polarization of additional radiation is:

$$p_M = \text{observed polarization change} \,/\, (I_M - 1)$$

where I_M is the intensity I from Table I averaged within the duration of each of the flares. So, one obtains:

$$p_M \text{ (primary flare)} = 6\% \text{ and}$$
$$p_M \text{ (secondary flare)} = 30\%,$$

where the latter amount is less certain because of small $I_M - 1$ for the secondary flare. Assuming the same physical mechanism of polarization and the same geometrical situation, the two p_M-amounts should be the same. So, one can perhaps tentatively conclude that the efficiency of the polarization mechanism acting during a flare is of the order of 10 percents.

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