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Photometric and polarimetric observations of U Ophiuchi

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Abstract. The results of the photoelectric and polarimetric observations of detached binary system U Oph made with 50 cm. AZT-14 telescope at Byurakan Observatory in U, B, V, R bands are presented. The intrinsic character of the polarization and its variable behaviour is confirmed. For the first time a strong change in polarization signal has been detected for 30 min. For at least 23 years the polarization mean value has increased. It is suggested that stellar wind mass loss could be responsible for polarization signal behaviour for long timescales whereas its short-term variations may be caused by eruptive mass outflows within the same process due to asynchronous rotation of the components.

Key words: stars: binaries polarization: eclipsing – polarization – stars: U Oph – stars: mass loss

1. Introduction

This article is dedicated to a photometric and polarimetric study of U Oph carried out within the framework of an extensive investigation of visual binary stars with variable components (hereafter VBVC) currently being conducted at Astronomical Observatory "Ramón María Aller" of the University of Santiago de Compostela.

The main purpose is to isolate certain groups of VBVC with primaries belonging to different types of variables (eclipsing, pulsating, eruptive, etc.) and investigate the possible correlation between variability type of the primary star and physical state and evolutionary status of its companion. As a second step the astrophysical and dynamical parameters of such systems will be investigated.

Obviously the comparison between results obtained with those for non-variable primaries is of interest too.

U Ophiuchi (HD 156247, WDS 17165+0113) is known as a bright (V = 5.88, B-V = 0.06; Hoffleit and Jaschek, 1982) eclipsing binary system with an orbital period of 1.6773522 days (Huffer and Kopal, 1951) with both components belonging to spectral class B5V (Abrami, 1958).

As a main component this star is included in the New Catalogue of Variable Visual Binary Stars published by Proust et al. (1981). Possibly, U Oph constitute a physical pair (ADS 10428) with its component of apparent magnitude 13.0 and spectral class G0 5 (Gahm et al., 1983) situated at angular distance 20".4.

The spectroscopic orbit has been determined by various authors, most recently by Holmgren et al. (1991 and refrences therein) as well as data of photometric properties and light curve. In particular, brightness difference between components is $\Delta B = 0.44 \pm 0.14$ coinciding rather well with previous value Δm = 0.35 given by Huffer and Kopal (1951).

The first polarimetric observations of U Oph had shown rather strong polarization signal as well as its variable character (Shakhovskoy, 1964; Coyne,1970a; Vardanian, 1985). The first of these authors pointed out the possibility of small variations in polarization based on 28 polarimetric measurements obtained for 12 nights.

Coyne (1970a) and Vardanian (1985) certainly confirmed that polarization degree varies in the range 1.09–2.28% and 1.2–3.4%, respectively.

From analysis of polarimetric observations Coyne (1970a) suggested either mass transfer or stellar wind mass loss as being responsible for the observed polarization signal.

Mass transfer in conventional sense (as in Algol, for example) by a gas stream from semi-detached secondary is not consistent with the known geometry of U Oph (Holmgren et al., 1991). Neither may mass loss be explained by the jets of material perpendicular to orbital plane of the binary as in β Lyrae (Harmanec et al., 1996) since the system is a clearly detached one.

In this paper results of both photometry and polarimetry of U Oph as well as a qualitative description of the possible mechanism responsible for its observed polarization signal are presented.

2. Observations and results

Both photometric and polarimetric observations in U, B, V and R bands were carried out within a period from August 8 to

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Table 1. The accuracy of photometric and polarimetric measurements.

	U	B	V	R
σm	0.02	0.01	0.01	0.02
σP %	0.07	0.06	0.06	0.08

September 6 of 1989 with 50cm. AZT-14 telescope at the Byurakan Observatory using attached photopolarimeter working in constant current reinforcement regime and FEU-79 photomultiplier.

The instrumental photometric system used is very close to Johnson's standard bands. Differential photometry has been carried out using for comparison standard star SAO 122244 of apparent magnitude 6.7 situated very next to U Oph.

Detailed description of the instruments as well as data reduction procedure is given by Eritsian and Nersesian (1984).

In total, 22 photoelectric and 25 polarimetric measurements were made in 17 nights. Each series of continuing measurements lasted about 1-1.5 hours including the standard star measurement.

Due to its brightness, the observations of U Oph have been carried out with rather high accuracy. In self-descriptive Table 1 data on errors in brightness (σm) and polarization ($\sigma P\%$) measurements for each photometric band are presented.

The accuracy of polarization angle measurement was 1-2 deg.

The results of observations are given in Table 2, where date of observation (JD), polarization (P%), polarization angle (θ) and brightness variation (Δm), relative to the comparison star (in each photometric band) are presented. Notice that at August 8 and 9 the measurements were made in B band only.

In Fig. 1 the plots of the brightness variation (1a) and polarization signal (1b) against JD are shown.

The data given in Table 2, indicate the correlation between wavelength and polarization signal seen better in Fig. 2 where corresponding plots (with error bars) for JD 244771.300 and JD 244775.200 are shown. For instance, at JD 2447771.300 the polarization signal values in U, B, V and R bands were 4.0%, 2.8%, 3.0% and 2.3%, respectively.

Apart of that, the polarization signal during our observations had changed in relatively wide range being especially strong in U band.

From Fig. 1b one can see, in partcular that at JD 2447767.200 the polarization signal has rapidly changed from 2.1% to 3.4% for less than 3 hours (JD 2447767.300). Yet more spectacular variation was registered in B band at August 8 (JD 2447747) when signal has increased by 1.4% for 30min. only. Notice that signal measurement error was 0.06% in B band.

One must note that such rapid variations of polarization signal are an important evidence of its intrinsic origin.

3. Discussion

Huffer and Kopal (1951) have shown that maximal depth of U Oph eclipse is δm = 0.745. It is known that for β Lyr maximum variation of polarization is related with its main and secondary minimum (Coyne, 1970a) and further observations have shown similar indications in the case of U Oph (Coyne, 1970b).

U Oph has been detected by us three times at its brightness minimum and four times at maximum. Based on these data in Table 3 for each colour band the mean value of the brightness variation (ΔU, ΔB, etc.) at these minima Δm (min) and maxima Δm (max) as well as respective mean values of polarization P(min) and P(max) are presented.

For example, full depths of eclipses observed at minimum in U, B, V and R bands are ΔU = 0.59, ΔB = 0.53, ΔV = 0.58 and ΔR = 0.58, respectively.

One must remember that brightness variation Δm is always that measured relative to standard star whereas Δm (min) given in Table 3 is, for example Δm mean value averaged for 3 minima. The same are definitions for the maximum.

One can see from these data that despite rather strong brightness variations both at minimum and maximum, the polarization mean value changes are insignificant (they coincide within measurement accuracy given in Table 1).

Hence we may suggest that during our observational run in all probability there was no correlation between polarization signal and phase of brightness variation.

Notice, however that differences between polarization signal registered at the brightness maximum often clearly overcome the measurements accuracy (see Fig. 1a and b).

Thus, our data confirm that variable polarization is an intrinsic property of U Oph as it was found by the above mentioned authors earlier. Indeed, 1) clear correlation between polarization degree and wavelength, 2) the absence of polarization signal from a standard star situated very next to U Oph, 3) rapid changes of polarization signal, show clear evidence of intrinsic character of the polarization.

In Fig. 1 the light curves of U Oph in different colors (1a) and corresponding values of polarization (1b) are shown. As one can see in Fig. 1b, for 2-3 hours and sometimes even 30 min. polarization shows a much larger change than its mean value near maximum or minimum (see Table 3). For instance, at August 8 the polarization in B band increased from 2.7% to 4.1% for 30 min. only, while brightness changed from 1.28 to 1.07 at same period. Data presented in Table 3 show that in B band brightness mean values in maximum and minimum have changed from 1.30 to 0.84, but corresponding polarization values remained almost constant (2.8% - 2.9%).

It means that even if it exists, the correlation between brightness and polarization is very weak. The largest variation was registered in U band (1.7 - 4.3%) being also significant in other photometric bands (see Table 2).

As was mentioned above, the first polarimetric measurements of U Oph have shown weak variations of the polarization signal (Shakhovskoy, 1964). Furthermore, Coyne (1970a) noted variations in range 1.09% - 2.28% and further Vardanian (1985) has found variations between 1.2% and 3.4%.

As polarimetric observations by Coyne were made in 1966-1968, those by Vardanian (1985) mainly in 1971 and Vardanian and Eritsian (1989) in 1985, we can follow the polarization

Table 2. The results of polarimetric and photometric observations of U Oph.

JD	P (%)				θ (degree)				Δm			
2447 +	U	B	V	R	U	B	V	R	U	B	V	R
747.020		3.4				101				1.30		
747.027		2.7				101				1.28		
747.035		3.5				106				1.17		
747.042		4.1				115				1.07		
748.020		3.1				106				1.14		
748.027		3.4				106				1.24		
748.035		3.7				110				1.19		
748.042		3.9				106				1.21		
749.400	3.6	3.3	3.5	3.0	101	106	101	101	1.30	0.85	0.55	0.21
764.100	4.3	3.4	3.8	3.6	86	78	74	82				
765.100	3.4	3.3	2.8	3.2	77	79	96	96				
766.100	2.7	2.6	2.5	2.6	86	82	72	91				
766.300	3.7	2.9	2.6	3.1	96	96	106	106	1.67	1.13	0.72	0.74
767.200	2.1	3.1	2.5	2.6	78	86	96	91	1.75	1.27	1.01	0.72
767.300	3.4	2.5	3.8	3.3	82	86	82	77	1.69	1.28	0.88	0.64
768.300	2.7	2.5	3.2	3.0	82	86	96	82	1.78	1.26	0.89	0.59
769.300	2.7	2.7	2.4	2.7	86	101	82	96	1.63	1.23	0.48	0.56
770.200	2.2	2.9	2.8	2.7	96	96	101	103	1.19	0.80	0.43	0.14
770.500	3.7	2.5	2.6	3.1	86	96	101	101	1.28	0.87	0.54	0.24
771.300	4.0	2.8	3.0	2.3	86	96	91	96	1.78	1.33	0.96	0.69
772.400	3.3	2.5	3.0	3.2	86	96	91	106	1.50	1.16	0.79	0.60
773.300	3.2	2.9	3.0	2.7	96	91	101	96	1.75	1.33	0.91	0.70
774.200	3.4	3.1	2.7	3.2	96	96	86	101	1.62	1.31	0.97	0.68
775.200	1.7	2.1	2.2	2.7	91	91	96	96	1.41	0.93	0.57	0.35
776.300	3.0	2.7	2.5	2.5	96	91	96	91	1.40	0.98	0.87	0.62

Table 3. Mean values of brightness variation and polarization at maximum and minimum.

	U	B	V	R
Δm (min)	1.26	0.84	0.51	0.20
P % (min)	3.2	2.9	3.0	2.9
Δm (max)	1.77	1.30	0.94	0.68
P % (max)	3.0	2.8	2.9	2.7

behaviour between 1966 and 1989 (present paper) shown in Fig. 3.

As with all observations, polarization differs insignificantly on wavelength, in Fig. 3 mean value of polarization ($\bar{\text{P}}$ %) averaged for all available data at a given epoch is shown.

The circle size in Fig. 3 is proportional to the number of polarimetric measurements (for instance, its size corresponds to 76 measurements we have made in 1989). One can see that polarization mean value has increased - its maximal value registered by us in 1989 is about 2% more than that obtained by Coyne in 1966 (Coyne, 1970a) though further observations are needed to verify this trend.

Notice that Coyne (1970a) suggested the existence of possible correlation between phase of eclipse and polarization, but from Vardanian's observations it is hard to make certain conclusions regarding this problem. According to data presented in Table 3, polarization signal does not correlate with brightness phase.

Thus, the existence of such a correlation, if any, is very weak and consequently needs special highly accurate observations including those with better time resolution.

We note especially the existence of weak brightness variations out of eclipses. Both brightness and rapid polarization changes possibly are caused by the same physical processes.

As was mentioned in Introduction neither mass transfer in the conventional sense nor material jets as in β Lyrae are consistent with U Oph known parameters and, in particular its geometry (Holmgren et al., 1991).

It is quite likely that stellar wind mass loss or even colliding winds could be responsible for observed polarization signal for long timescales. As regards its short-term variations they may be caused by eruptive outflow of significant gas amounts within the same process.

Since both components show slightly non-synchronous rotation the stellar winds are also likely to be considered as possible source of polarization signal short-term variations. Due to rotation asynchronism and taking into account that the system is clearly detached, the significant mass and/or particles outflows (eruptive and therefore, possibly short-lasting) take place at the components very detachment zone.

4. Conclusions

The results of this photometric and polarimetric studies enable us to confirm both the existence of intrinsic polarization and

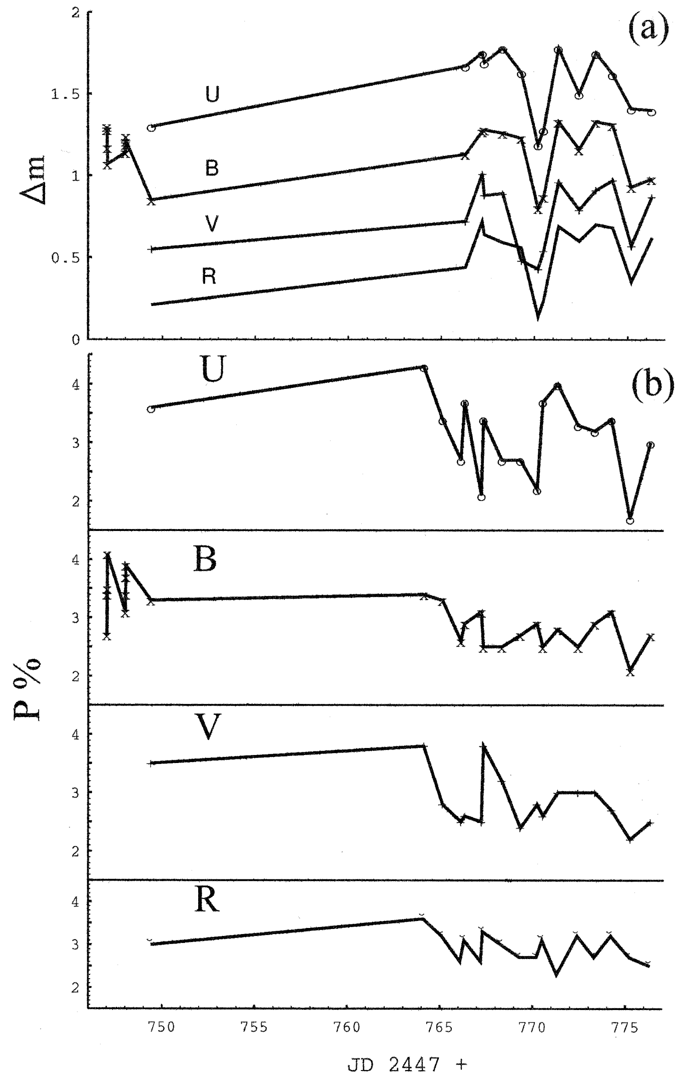

Fig. 1a and b. The light curves (**a**) and polarization variations (**b**) of U Oph.

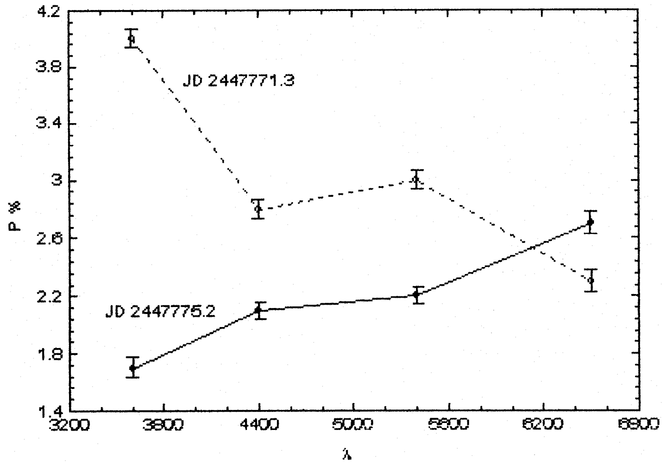

Fig. 2. The polarization signal - wavelength correlation.

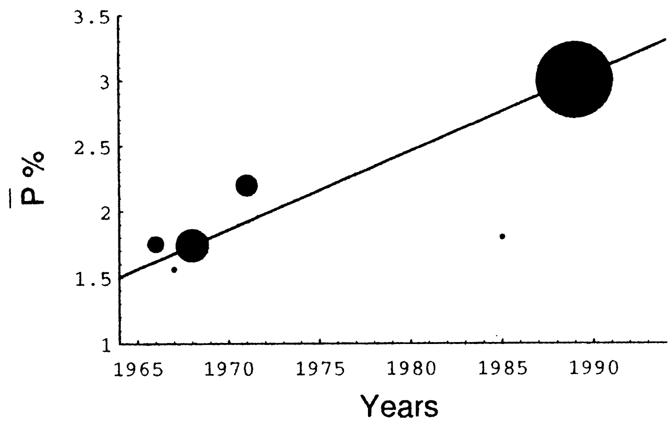

Fig. 3. The increment of U Oph polarization mean value.

its variability which coincides rather well with data obtained earlier by other authors.

It seems very important to note the registration of *rapid* (within few hours and even 30 min.) changes in polarization as well as increment of its mean value for at least 23 years - a fact not mentioned before by other authors.

To summarize main conclusions of the present study :

1. In all probability U Oph light polarization is not connected with the phase of brightness variation in spite of some possible indications (Coyne, 1970a).
2. For the first time we have detected rapid (for 30 min.) variations of U Oph polarization. Such rapid changes can hardly be explained either by rotation of components or by mass transfer from one to another.
3. The polarization signal from 1966 to 1989 has shown an increase by 2%.
4. Probably, the stellar winds mass loss is responsible for polarization signal behaviour for long timescales whereas its short-term variations may be caused by eruptive mass outflows within the same process due to asynchronous rotation of the components.

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