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POLARIMETRIC AND PHOTOMETRIC OBSERVATIONS OF LONG PERIOD VARIABLES

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Observations of 35 long period variables have been done mainly at the Byurakan Astrophysical Observatory during last years. A polarimetric monitoring of 34 stars has been carried out with simultaneous photometric measurements for some of them. Photometric data in the *UBVR* bands have been obtained for the star Y Ori, which is the faintest one. The results show that the degree of light polarization is correlated with the period and brightness of these stars. This indicates that the degree of light polarization is connected with the mass-loss as well. Finally the photoelectric observations of the stars Y Ori, T Cep, R Gem and R Boo show a short-term increase of their brightness in the decreasing branch of their light curves. The measured $(U-B)$ or $(B-V)$ colors of detected rapid variations are bluer than the colours of the star measured before these events. It is supposed that the change of polarization with time, relatively blue colors of miras near their minimum brightness and colours of detected rapid variations may be explained by the influence of a invisible blue companion, as in the case of the star R Aqr.

1. *Introduction.* The Asymptotic Giant Branch (AGB) is a critical stage of the stellar evolution. As it is well known, a major class of the oxygen-rich stars of the AGB is constituted by the long period variables (or Mira Ceti type stars) and located at the top of the AGB. They are late type red giants characterized by the presence of hydrogen emission lines and TiO absorption bands showing complex intensity changes along the period and by large rates of mass loss. The General Catalogue of Variable Stars (GCVS) contains about 5800 long period variables [1].

The investigation of the red giants and supergiants in the Byurakan Observatory began with the discovery of the changes in the stellar light polarization of the red supergiant μ Cep by Grigoryan [2]. Since 1995 a systematic photoelectric and polarimetric monitoring has been carried out for the selected Mira Ceti variables within the framework of French - Armenian astronomical cooperation (PICS).

The early polarimetric observations [2,3] of red variable stars were limited to the objects situated near the galactic equator and the wavelength dependence of the polarization was not studied. The intrinsic polarization was mixed with the interstellar polarization and little could be said about its properties. In 1966 large degrees of polarization increasing steeply towards the ultraviolet were found for several high galactic latitude miras and semi - regular variables. Variations of the polarization with time were detected for some of these stars [4]. Later this result has been confirmed by Vardanian [5,6]. For the stars o Ceti and R Hya the largest degree of polarization

is usually observed on halfway between the minimum and maximum brightness [7].

If the light polarization is produced by Rayleigh scattering on gas molecules or other particles in the stellar atmosphere, as first suggested by Shakhovskoj [3], then the characteristics of the intrinsic polarization, especially the variability, should be closely connected with the physical processes taking place in the outer layers of the atmosphere. In particular the results of Shakhovskoj [3] for the double stars and of Vitrichenko and Efimov [8] for the single stars suggest that the variations of the degree of polarization with time can be connected with mass loss. Since the mass loss phenomenon is observed in many stars on the AGB, polarimetric observations can help to understand the mechanisms taking place in this stage of evolution of the long period variables.

Important information about the miras can be obtained from their colorimetric observations and the study of the fine structure of their light curves. In this respect the observations of 67 long period variables by Mendoza [9] are especially useful. The stars have been observed in the spectral range 0.36-10.2 mm. Some of them show an ultraviolet excess near the minimum of brightness.

On the basis of classification of about 400 light curves of miras observed during 76 years Boughaleb et al [10] have shown interesting relationships between the characteristics of the light curves and the physical properties of the stars. Some miras show changes of their period from one cycle to another, as is well known, this is a direct evidence of the existence of thermal pulsations [11].

The detection of rapid variations - with time scale smaller than 30 days - is of particular importance. Historically the first detection of such variations has been done by Hetzler [12,13] in the red band of spectrum. On the basis of photographic observations done during 30 years in the near infrared Maffei and Tosti [14] also detected rapid variations of brightness and suggested that such variations are typical for some long period variables.

In this paper the results of polarimetric and photoelectric observations obtained for 35 long period variables in the Byurakan Observatory are presented.

2. *Observations.* Most of the photoelectric and polarimetric observations has been carried out in the Byurakan observatory with the use of a photopolarimeter attached to the 50 cm telescope. During the polarimetric observations of 1988, the 2.6 m telescope has also been used with the same apparatus. The monitoring of the program stars has been performed in the *UBVR* bands of the spectrum, and sometimes without filter.

The photopolarimeter works in the regime of amplification of the direct current and can serve as a photoelectric photometer when the polaroid is removed. A photomultiplier FEU 79 was used with a maximum of sensitivity in the spectral range 4000-4400A. A comparison star and background star have been measured for every program star. The accuracy of the photoelectric observations in the *UBVR* bands is about $0^m.02$ - $0^m.07$. The uncertainties of the polarimetric measurements are of the order of 0.2 - 0.4%. The position of polarization angle is determined with an accuracy of 2 - 5

degrees. A detailed description of the method and apparatus has been given earlier [15].

The photoelectric monitoring of Y Ori in the *UBVR* bands has been carried out with the 60 cm telescope of the Maydanak station of the Tashkent Astronomical Institute (Uzbekistan) in autumn 1989. More details about these observations have already been described by Melikian & Jakubov [16].

3. *Polarimetric observations.* The data of polarimetric observations for 34 stars are presented in Table 1, which gives in the successive columns the name of the star as found in the General Catalogue of Variable Stars (GCVS), the minimum P_{min} and maximum P_{max} values of the detected light polarization in U band, the telescope on which

Table 1

THE RESULTS OF POLARIMETRIC MEASUREMENTS

№	Star (GCVS)	$P_{min}(U)$	$P_{max}(U)$	Telescope	n
1	R Aql	<0.3	2.2	50cm	8
2	RT Aql	<0.3	<0.3	50cm	2
3	TU Aql	<0.3	2.1	50cm	2
4	v499 Aql	<0.3	<0.3	50cm	2
5	R Aqr	0.9	5.7	50cm	5
6	R Aur	<0.3	<0.3	50cm	2
7	UV Aur	<0.3	1.7	2.6m	3
8	R Boo	<0.3	<0.3	50cm	6
9	U Cam	<0.3	<0.3	50cm	3
10	S CrB	<0.5	<0.5	50cm	3
11	R Cas	<0.3	0.9	50cm+2.6m	3
12	V Cas	<0.3	<0.3	50cm	2
13	T Cep	<0.3	<0.3	50cm	6
14	R Cet	<0.3	<0.3	2.6m	2
15	U Cyg	<0.3	1.4	50cm	2
16	V Cyg	<0.2	<0.2	50cm	1
17	RT Cyg	<0.3	5.0	50cm	12
18	R Dra	<0.3	<0.3	50cm	4
19	R Gem	<0.3	<0.3	50cm	10
20	T Her	<0.3	<0.3	50cm	2
21	U Her	<0.3	1.7	50cm	3
22	RU Her	<0.3	<0.3	50cm	2
23	SX Her	<0.3	2.1	50cm	2
24	RX Lac	<0.3	<0.3	2.6m	2
25	W Lyr	<0.3	<0.3	50cm	2
26	X Oph	<0.3	<0.3	50cm	9
27	S Ori	<0.3	<0.3	50cm	6
28	R Peg	<0.3	<0.3	50cm	3
29	TU Peg	<0.3	2.1	50cm	2
30	R Ser	<0.3	<0.3	50cm	2
31	TU Tau	<0.3	2.0	2.6m	3
32	S UMi	<0.3	<0.3	50cm	4
33	R Vir	<0.3	<0.3	50cm	2
34	RS Vir	<0.3	<0.3	50cm	2

the observations have been done and the number of polarimetric measurements (n).

In all eleven cases of detection it may be established that the polarization is of stellar origin. As it was well discussed by Pfeiffer and Koch [17] there are four tests for checking the intrinsic character of the observed polarization: (*i*) the time dependence of the polarization, (*ii*) the determination of the interstellar light polarization by the measurements of field stars surrounding the program star, (*iii*) the polarization spectra and (*iv*) the rotation of the electric vector. In fact, those tests have been done on our polarimetric observations and have shown that the detected polarizations are indeed of stellar origin.

The first result of our polarimetric observations is the confirmation of the variable character of the degree of light polarization of the long period variables. The second result is the confirmation of the connection of the polarization with the brightness. The change of the polarization with time for some Mira Ceti type stars with short period (V CVn, $P = 198$ days) and longer periods (o Ceti, R Hya) has been observed and discussed by Serkowski [7]. It was shown in particular that the largest degree of polarization of V CVn is found at the minimum of brightness, while for the stars o Ceti and R Hya the largest degree of light polarization is found on midway of the increasing branch of the light curve. The investigation of the intrinsic polarization of red variable stars performed by Vardanian [6] shows that the largest degree of light polarization is observed near the minimum of their brightness. Using the present polarimetric observations and the results obtained earlier at the Byurakan Observatory by Vardanian [18], it has been shown that the largest degree of light polarization is expected to occur mainly on halfway between the minimum and the maximum [19]. This statistical result obtained for about 50 long period variables in fact is the same as that obtained by Serkowski for the stars o Ceti and R Hya [7]. For illustration, the dependence of the degree of light polarization for the star R Aql is presented in Fig.1.

It has been pointed out above that all miras for which the light polarization is detected show changes of light polarization in time. A significant degree of light

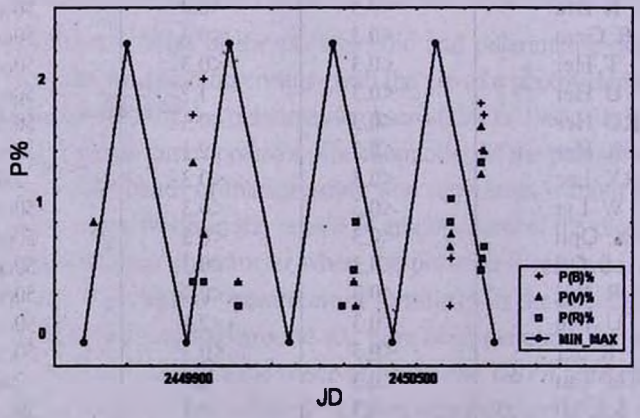

Fig.1. Dependence of light polarization degree on the brightness for the star R Aql. The solid line shows the brightness variation of R Aql during the observetional period.

polarization in the *U* band of spectrum was detected for the stars RT Cyg and R Aqr during our polarimetric observations [20,21]. As one can see from the data presented in Table 1, the difference between the detected minimum and maximum values of light polarizations of these stars is about 5%. Among the miras, R Aqr is one of the best studied. The optical and radio observations of the star indicate the existence of a jet [22,23]. Polarimetric observations of this star show a strong change of the degree of light polarization, especially in the *U* band [24,25]. This change of the light polarization is probably connected with the existence of the jet.

Probably, the strong change of the light polarization in the *U* band of the spectrum of RT Cyg is connected with similar feature, but the confirmation of its existence requires detailed spectroscopic and radio observations. It is interesting to point out that no strong changes in brightness of RT Cyg have been detected during the observational period.

4. *Rapid brightness variations.* Up to now most of the studies of the light curves of Mira Ceti type long-period variables are related to their long - term variations along their periods. Rapid brightness variations were first observed by Hetzler [12,13] in the red band of the spectrum of these stars. Later the existence of some sporadic analogous cases have been detected by other astronomers [26,27]. Using the near infrared photographic material for 182 long period variables obtained during 30 years (1961-1991), Maffei and Tosti [14] discovered 28 rapid variations in 18 stars. It is necessary to point out that not only rapid increases but also rapid decreases of the brightness have been detected by them. Short-term rapid variations with duration less than 10 days for the Mira Ceti type stars R Oct and RY Hyi have been detected by de Laverny et al [28]. More than 50 cases of rapid brightness variations have been detected from the Hipparcos observations with the amplitudes from $0^m.23$ -$1^m.11$ and with the duration from 2 hours up to almost 6 days [29].

During the construction of the light curve of Y Ori [30] the existence of short-time brightness variations in the increasing and in the decreasing branches of light curve have been suspected. Later a photoelectric *UBVR* monitoring of this star allowed Melikian and Jakubov [16] to detect an increase of brightness on the decreasing branch of the light curve in the *U* band only (see Fig.2). No variations of brightness were detected in the *BVR* bands of the spectrum.

The recent observations of long period variables in the Byurakan Observatory have been partly devoted to the study of such rapid variations. The preliminary results of these observations has been already published [20,21]. During the observations of long period variables listed in Table 1, three rapid brightness variations have been detected on the stars T Cep, R Gem and R Boo with a duration less than 20 days. In all cases (including Y Ori) the rapid variations have been detected in the decreasing branch of light curves about two months after the maximum of their brightness. In the Fig.3a-c the light curves of the pointed rapid variations are presented. In Table 2 the observed data of detected variations are given. In the columns of Table 2 the following data are presented successively:

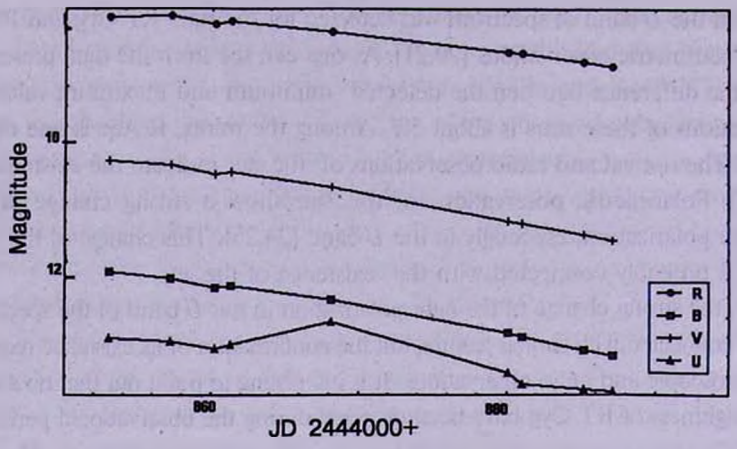

Fig.2. A rapid brightness variation detected in 50 days after the maximum on the star Y Ori in the *U* band only.

star's name, date of detection, observed amplitudes and color indices.

As one can see from the data of Table 2, the detected color indices *U-B* and *B-V* of the rapid variations are much bluer than the color indices of the stars just before these events. But on the other hand, it has been shown for these stars [6,9,16,18,20,21,30] that, approaching to the minimum of their brightness, the values of the color indices are relatively bluer than near the maximum. Already in 1945 Shajn [31] has pointed out that an ultraviolet excess exists at the minimum of brightness of the long period variables.

Table 2

THE DATA OF DETECTED RAPID VARIATIONS

Star	Date	Amplitude				Colors		
		U	B	V	R	U-B	B-V	V-R
Y Ori	12.12.1989	0.7	0.00	0.00	0.00			
T Cep	21.05.1996	-	0.60	0.39	-	-	1.45	-
R Gem	15.01.1997	-	0.49	0.21	-	-	1.15	-
R Boo	11.05.1997	-	0.43	0.13	0.00	-	0.65	0.97

The existence of the rapid variations with relatively blue colors and ultraviolet excess near the minimum brightness may have the same origin. One of the possible explanations on our point of view can be the existence of a secondary blue component whose influence is perceptible when the photosphere of red giant begins to be transparent to its radiation. In this case a good example can be the star R Aqr, for which the existence of a white dwarf (or jet) is suspected as a secondary component [22-25]. The existence of an invisible secondary component near the miras may explain the variation of light polarization as well. Thus, from this point of view, one of the directions of the future investigations of long period variables will be the search of their possible close companions.

5. *Conclusions.* The results of the photoelectric and polarimetric observations of some Mira Ceti type long period variables performed in Byurakan As-

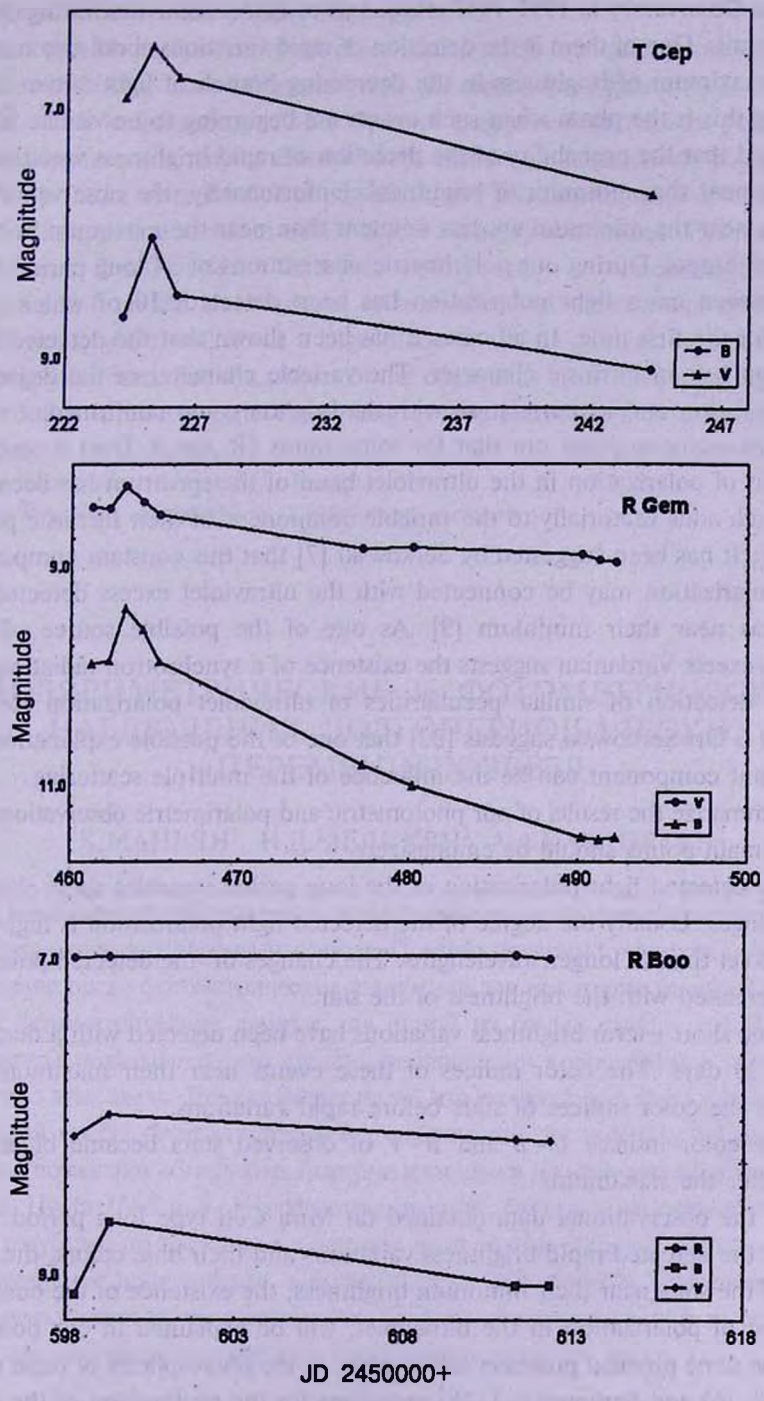

Fig.3. The rapid brightness variations detected on the stars T Cep, R Gem and R Boo. It is worth pointing out that in the case of rapid variation on the star R Boo no change was observed in the R band of spectrum.

trophysical Observatory in 1995-1997 allowed us to detect some interesting observational details. One of them is the detection of rapid variations about two months after the maximum of brightness in the decreasing branch of light curve. In all probability this is the phase when such events are beginning to be visible. It can be supposed that the probability of the detection of rapid brightness variations is increasing near the minimum of brightness. Unfortunately, the observations of these stars near the minimum are less frequent than near the maximum because of their brightness. During our polarimetric observations of 34 long period variables in eleven cases light polarization has been detected, 10 of which were detected for the first time. In all cases it has been shown that the detected light polarization has an intrinsic character. The variable character of the degree of light polarization and its correlation with the brightness are confirmed.

It is necessary to point out that for some miras (R Aqr,R Dor) a constant component of polarization in the ultraviolet band of the spectrum has been detected which adds vectorially to the variable component of their intrinsic polarization [7]. It has been suggested by Serkowski [7] that this constant component of light polarization may be connected with the ultraviolet excess detected for some miras near their minimum [9]. As one of the possible source of this ultraviolet excess Vardanian suggests the existence of a synchrotron radiation [6]. After the detection of similar peculiarities of ultraviolet polarization for the supergiant α Ori Serkowski suggests [32] that one of the possible explanations of this constant component can be the influence of the multiple scattering.

To summarize the results of our photometric and polarimetric observations the following main points should be emphasized:

1. The detected light polarization of the long period variables show changes in large ranges..Usually the degree of the detected light polarization is higher in the ultraviolet than at longer wavelengths. The changes of the detected polarization is correlated with the brightness of the star.

2. Some short - term brightness variations have been detected with a duration less than 20 days. The color indices of these events near their maximum are bluer than the color indices of stars before rapid variations.

3. The color indices $U-B$ and $B-V$ of observed stars became bluer 2-3 months after the maximum.

Thus, the observational data obtained on Mira Ceti type long period variables, like the detected rapid brightness variations and their blue colors, the blue colours of the stars near their minimum brightness, the existence of the constant component of polarization in the ultraviolet, will be explained in our point of view by the same physical processes taking place in the photospheres of these stars. Vardanian's [6] and Serkowski's [32] suggestions for the explanation of the constant component of polarization in the ultraviolet may have the same origin. Having analyzed the existence of the rapid brightness variations of the miras detected by Hipparcos de Laverny et al [29] suggested that the detected events may

be related to molecular opacity changes.

As a possible explanation of the observational results one can suppose the existence of an invisible blue close companion near the observed red giants. As in the case of R Aqr, and at least for some of Mira Ceti type long period variables the pointed above observed phenomena may be caused by the influence of a secondary companion.

In the future more detailed photoelectric and polarimetric observations for some selected long period variables with a higher accuracy are needed. The observations should cover 2 or 3 cycles of their periods. Especially, very interesting results may be obtained from the simultaneous colorimetric, polarimetric and spectroscopic observations, which will cover a large phase of their brightness variation, including their minimum. For the studies of the changes in the shape of the light curves of the miras a photoelectric monitoring of long continuance is needed as well.

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ПОЛЯРИМЕТРИЧЕСКИЕ И ФОТОМЕТРИЧЕСКИЕ НАБЛЮДЕНИЯ ДОЛГОПЕРИОДИЧЕСКИХ ПЕРЕМЕННЫХ ЗВЕЗД

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В Бюраканской обсерватории за последние годы выполнены наблюдения 35 долгопериодических переменных звезд. Помимо поляриметрических наблюдений проведены также фотометрические измерения для некоторых из них. Получены *UBVR* фотометрические данные для одной из самых слабых звезд - Y Ori. Результаты показывают, что степень поляризации коррелирует с периодом и яркостью этих звезд. Это указывает на то, что поляризация света связана также с потерей массы. Фотоэлектрические наблюдения звезд Y Ori, T Cep, R Gem и R Boo позволяют обнаружить быстрые изменения на нисходящей ветви кривых блеска. Цвета $U-B$ и $B-V$ зарегистрированных быстрых изменений являются более голубыми по сравнению с цветами звезд до этих событий. Предполагается, что изменение поляризации, а также относительно голубой цвет звезд вблизи минимума и цвета зарегистрированных быстрых изменений могут быть объяснены влиянием невидимого спутника, как в случае звезды R Aqr.

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