Photometric and Photopolarimetric Observations of a New Polar
USNO-A2.0 0825-18396733

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We present photometric and polarimetric observations of a new magnetic cataclysmic variable, presumably a polar, USNO-A2.0 0825-18396733. The photometric observations were carried out with the SAO RAS Zeiss-1000 telescope, and the polarimetry was performed with the 6-m BTA telescope. The refined orbital period \( P = 0.08481(2) \); the brightness of the system varied from 17.5 to 20.0 in the \( R_c \) filter. Polarimetric observations of the object in the \( V \) filter revealed strong variable circular polarization: \(-2\%\) to over \(-31\%\). This indicates that the variable USNO-A2.0 0825-18396733 is a polar.

1. INTRODUCTION

AM Her-type stars, or polars, are a subclass of cataclysmic variables. The system consists of a white dwarf (the main component) and a red dwarf star that fills its Roche lobe (the secondary component). Peculiar properties of polars are associated with a strong magnetic field of the white dwarf. It prevents the formation of an accretion disk and directs the material along the magnetic field lines to the magnetic poles of the white dwarf. The accretion column is one of the main sources of radiation in the optical and X-ray ranges. The optical radiation of polars is strongly polarized. Surveys on the polars are compiled by Voikhanskaya [1] and Cropper [2].

For the first time, strong polarization was found in AM Her, the first representative of this type of systems. Tapia [3] discovered linear and circular polarization in the \( V \) and \( I \)
bands. Linear polarization reached 6.8% at the maximum, and the circular ranged from 4% to −9.5%. As a result of these observations, it was concluded that the white dwarf has a strong magnetic field of about \(2 \times 10^8\) G. AM Her was later observed in its low brightness state [4–6], and the white dwarf magnetic field strength as determined by the locations of the Zeeman components of hydrogen lines proved to be 13 MG, which is much lower than that proposed by Tapia. The magnetic field strength estimate based on the degree of linear and circular polarizations is inefficient, since they largely depend on the geometry of a system. At the moment, the detection of polarization of optical radiation is the main criterion for discovery of polars.

The studied object USNO-A2.0 0825-18396733 (hereafter USNO 0825) was found while a region in the Aquila constellation was observed by a team of amateur astronomers [7] using the 30-cm Astrotel-Caucasus Observatory Ritchey–Chretien telescope and an Apogee Alta U9000 CCD detector. They have obtained 98 images with 300-second exposures, without a filter. The system ephemeris was determined thereon:

\[
\text{HJD} = 2455387.3976(\pm 0.001) + 0.0840(\pm 0.0004) E,
\]

where the zero phase corresponds to the time of minimum brightness. A short period and a significant amplitude of the brightness variability of the object are fairly typical of cataclysmic variables. Strong lines of H, He I, and the He II 4686 Å line are visible in the spectrum obtained by N. Borisov and V. Shimansky on the 6-m telescope in August 2010. The intensity ratio \(I_{\text{He II 4686}}/I_{\text{H}\beta} \sim 0.8\), which is typical of polars [8].

We have carried out photometric observations of USNO 0825 to clarify the period of variability, and the first polarimetric observations to determine the nature of the object. Section 1 describes the observations, Section 2 is devoted to the analysis of the observations, and the conclusions of the study are given at the end.

2. OBSERVATIONS

2.1. Photometry

Photometric observations were carried out on the SAO RAS 1-m Zeiss-1000 telescope with the use of the standard photometer and a CCD detector EEV 42-40 (2048×2048 pixels
sized 13.5 × 13.5 m) with nitrogen cooling. The observations were carried out in the $R_c$ filter in autumn 2010, exposure time was selected depending on weather conditions and object brightness. A reference star and two comparison stars were selected close to the object (Fig. 1). The reference star was linked to standard stars 1925 ($V = 12.39$, $V - R = 0.221$) and 2093 ($V = 12.54$, $V - R = 0.370$) from area S111 of the Landolt catalog [9]. The observations were reduced with the DAOPHOT package in the IDL. The magnitudes are presented in Table 2.

### 2.2. Polarimetry

Polarimetric observations in the $V$ filter were carried out on the SAO RAS BTA telescope using the SCORPIO-2 focal reducer [10] and an EEV 42-90 CCD (4600×2048). A Wollaston prism and a quarter-wave plate were used as a polarization analyzer. During the 1.5-hour-long observations on November 6, 2010, eighty images with 60-s exposures were obtained. A 2×2 binning and the restriction of the readout area of the chip to 711×711 pixels allowed us to reduce the readout time to 5 s. Given the time of rotation of the quarter-wave plate, the time between the exposures amounted to 70 s. The size of the images during that night $d = 2''$. An example of the frame is shown in Fig. 2, where the field of the object can be seen in the ordinary (top) and extraordinary (bottom) rays. When the quarter-wave plate is rotated, the rays are interchanged. At the time of the observations, the unit was not equipped with a suitable mask, hence a slit width of 10'' was used. Due to limited observing time, we failed to observe the entire orbital period. The information about the conducted observations is given in Table 4. Figure 3 demonstrates the variations in brightness and circular polarization of the comparison stars and the reference star. Table 2 presents the mean values and standard deviations of circular polarization.

Data reduction was conducted in the IDL environment; the technique, examples, and formulae can be found in [11].
3. OBSERVATION ANALYSIS

The obtained photometric time series have been processed with V. P. Goransky’s EF-
FECT code. Using the Lafler–Kinman method, the period of the system was refined:

$$\text{HJD} = 2455503.2584(\pm 0.001)$$

$$+0.08481(\pm 0.000002) \text{E},$$

where the zero phase corresponds to the minimum brightness time.

Figure 5a presents the light curve of the object in the $R_c$ band, folded with our period. The measurement errors varied from night to night but did not exceed $0.3^m$. They are not shown in the figure. To illustrate the accuracy of observations, Fig. 5b shows the comparison star brightness variations obtained on November 2, 2011. The brightness of the system reaches the maximum at phase $\varphi = 0.65$. The total brightness amplitude of the system amounts to $2.5^m$. Let us note two features of the orbital brightness variations: a deep eclipse and large brightness fluctuations of up to $\Delta m \sim 1^m$. The latter indicates large non-stationarity of the accretion process. Because of this, the type of eclipse (full or partial) cannot be determined.

The $V$-band light curve was a byproduct of our polarimetric observations (Fig. 4b). The brightness of the object was calculated by summation of the intensities of the ordinary and extraordinary rays in each frame. The brightness estimates were obtained at intervals of 70 s. Quasiperiodic variations of the system brightness are clearly visible. In our case they occur approximately every eight minutes with an amplitude of up to $\Delta m \sim 0.25^m$.

A comparison of our results with the results of [7] showed that the scatter of values on our light curve is twice as large. The light curve in [7] has an asymmetric shape, which is not observed for our light curve. This may be due to variations in the state of the system or inaccurate determination of the period. An error of $0.0004$ at such a short period may yield a daily phase shift by $\varphi = 0.083$.

The results of polarimetric observations were folded with our period. The circular polar-
ization curve in the $V$ filter is shown in Fig. 4a. Circular polarization of USNO 0825 reaches $-31\%$ at phase $\varphi = 0.9$, the minimum value is $-2\%$ at phase $\varphi = 0.38$. Unfortunately, we could not observe throughout the entire period. The degree of circular polarization can possibly be even higher or will decrease and will change its sign.
4. CONCLUSION

We have presented the results of photometric and polarimetric observations of USNO-A2.0 0825-18396733. Our polarimetric observations have revealed that the visible radiation of the system is highly polarized. This determines the system as a polar. Circular polarization in the $V$ filter reaches at least $P_V = -31\%$. The study has refined the orbital period of the system to $P = 0.408481(2)$ and showed that the brightness variability amplitude in the $R_c$ filter is about $2.55$. Quasiperiodic ($P \sim 8 \text{ min}$) brightness variations of up to $\Delta m \sim 0.25$ occur in the system. We have compared the object with the already studied V834 Cen [12] and RX J1313.32–3259 [13] systems, which are similar in the shape of the brightness and circular polarization curves. Both objects at the minimum brightness phases show weakening of circular polarization. The authors surmise that there occurs an eclipse of the cyclotron radiation region by an accretion structure. At the same time, RXJ1313.32–3259 shows the change of the sign of the circular polarization in the blue range and in the white light (see Figs. 9 and 10 in [13]), which indicates the appearance of the second accretion region on the visible hemisphere of the white dwarf. As the position angle of linear polarization shows, the main accretion region is located all the time on the visible hemisphere of the white dwarf. For a complete analysis of USNO 0825, additional polarimetric, spectral, and photometric observations are required.

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Figure 1. An image of the USNO 0825 region obtained on the Zeiss-1000 telescope. The numbers denote: (1) the object; (2) the reference star; (3, 4) comparison stars.

Figure 2. An image of the USNO 0825 region obtained in the polarimetric mode with SCORPIO-2. Light is divided into the ordinary (top) and extraordinary (bottom) rays. The numbers denote: (1) the object; (2) the reference star; (3, 4) comparison stars.

Table 1. Observing log of USNO-A2.0 0825-18396733 observations

| Date          | Duration of obs. | Exposure, s | Number of images | Seeing, arcsec |
|---------------|------------------|-------------|------------------|----------------|
| Oct 6, 2010   | 2.17 hours       | 1.08        | 200              | 29             |
| Photometry    |                  |             | 100, 120, 150    | 32             |
| Nov 1, 2010   | 2.17 hours       | 1.08        | 100              | 34             |
| Nov 2, 2010   | 1.75 hours       | 0.88        | 100              | 2              |
| Polarimetry   | 1.5 hours        | 0.74        | 60               | 80             |

Table 2. Magnitudes and rates of circular polarization of the reference stars

| Star | $R_v$, mag | $V$, mag   | $P_v$, %     |
|------|------------|------------|--------------|
| 2    | 15.35      | 16.702     | $-0.08 \pm 0.29$ |
| 3    | $16.05 \pm 0.04$ | $17.620 \pm 0.011$ | $-0.17 \pm 0.77$ |
| 4    | $16.37 \pm 0.05$ | $17.785 \pm 0.017$ | $-0.005 \pm 0.78$ |
Figure 3. Variations of circular polarization of the comparison stars and the reference star (a), and the brightness variations of the comparison stars relative to the mean value (b). Triangles denote the reference star, squares mark comparison star 3, diamonds—comparison star 4 (see Fig. 1).
Figure 4. Circular polarization curve (a) and light curve (b) of USNO 0825 in the V filter.
Figure 5. Light curve of USNO 0825 (a) and brightness variation of the comparison stars relative to the mean value (b) in the $R_c$ filter.