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Photometric variability of the 1H1936+541 star in 2008–2014

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We report the results of observations of the Be/X-ray binary system 1H1936+541. All of the data were obtained on the base of Lisnyky observational station (Astronomical Observatory of the Taras Shevchenko National University of Kyiv) and Southern Station of the Sternberg Astronomical Institute (Lomonosov Moscow State University), giving us three different CCDs in U, B, V, R, and I filters, from 2008 till 2014. During this time, photometrical variability occurred in all bands, however the most significant changes were present in U and I bands. Variabilities in these bands anti-correlate with each other and are in a good agreement with the model of decretion disks around Be stars. Thus, photometric variability claims for changes in the decretion disc structure. Further photometric and spectral observations can help us develop a physical model of this system.

Key words: stars: emission-line, Be, observations

INTRODUCTION

1H1936+541 belongs to the Be/X-ray binaries — a subgroup of high-mass X-ray binaries (HMXB). As an X-ray source it was described first in "The HEAO A-1 X-ray source catalog" [8] in 1984. Later, in 1988 it was supposed that the star DM+53°2262 is an optical component for the mentioned X-ray source [6] because this star was listed as an emission-line star with medium intensity, an H_α line in 1950 [2], and then in 1970 in "a catalogue of early-type stars the spectra of which have shown emission lines" [7], and it is located within the positional error box of the X-ray experiment HEAO A-1.

After detecting 1H1936+541 by HEAO A-1 it has never been detected by any other X-ray mission [5]. Furthermore, we have not found any data on optical variability of its optical component — the DM+53°2262 star. So, we conclude that the photometric investigation of this object is necessary, and therefore we carry it out.

OBSERVATIONS AND DATA PROCESSING

All the data were obtained at the base of the Lisnyky observational station (Astronomical Observatory of the Taras Shevchenko National University of Kyiv) and Southern Station of the Sternberg Astronomical Institute (Lomonosov Moscow State University) using of three different CCDs in U, B, V, R, and I filters from 2008 until 2014. At the Lisnyky observational station we used SBIG ST-8 CCD (510 × 340 pixels, which corresponds to the angular size of the field matrix $19'18'' \times 12'52''$) and PL47-10 FLI CCD (1056 × 1027 pixels, which corresponds to the angular field size matrix $19'25'' \times 18'53''$). At the Southern Station of the Sternberg Astronomical Institute we used Ap-47P CCD (528 × 512 pixels, which corresponds to the angular size of the field matrix $7'34'' \times 7'20''$).

The photometric image processing was carried out using standard methods of differential photometry. The dark frames of the same CCD were subtracted from the images, then the resulting image was divided into a flat field of the telescope (from which the dark frames were also subtracted). To find the instrumental magnitude of the star the intensity of sky background was subtracted from the image total intensity [3]:

$$m_{\rm inst} = -2.5\,\lg\left(I_{\rm sum} - I_{\rm sky}\right),$$

It is possible to transfer instrumental magnitudes into standard ones using a comparison of magnitudes of our object and those of the standard star:

$$m^*_{\rm inst} = m^{st}_{\rm syst} + \Delta m_{\rm inst},$$

where $\Delta m_{\rm inst}$ is the difference between the instrumental magnitude of the object and the standard star. As a standard star we chose HD 184658, which according to the SIMBAD database is not a variable star. Magnitudes of the HD 184658 as a standard were taken from the AAVSO Special Notice #213[1] and are listed in Table 1.

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To monitor and confirm variability of the object using differential photometry we used a few more control stars. Control stars were chosen so that they were present in all CCDs including the Ap-47P CCD, the field of view of which is the smallest one (Fig. 5).

Table 1: Standard magnitudes for HD 184658 from AAVSO Special Notice, except U-magnitude which is taken from [4] due to its absence there.

Name	U^*	B	V	R	I
HD184658	9.56	9.697	9.684	9.645	9.629

RESULTS

Following the image processing, we determined magnitudes of the investigated object 1H1936+541 in the standard photometrical system, and plotted lightcurves in all bands. In Fig. 1 all of these curves are presented. In U and B filters one can see increase of brightness of the object from the beginning of observations until December 2010. After that during a period of two years the small density of observational data does not give us a possibility to do unequivocal conclusions about the system state, however the decrease of brightness during this time interval is evident. Since July 2013 one can see another increase of the brightness in the U and B bands. In the R and I bands the situation is opposite: the brightness of the object firstly decreases up to December 2010, then it increases to its original values up until July 2013, after which it again begins to decrease. In V band the magnitude does not change significantly. The amplitude of the magnitude changes in different filters varies: in the U filter Δm is approximately 0.21; in the B filter it is ~ 0.23, in the R filter it is ~ 0.12, and in the I filter it is ~ 0.28. The uncertainty of stellar magnitude estimation for most of the data does not exceed $\pm 0.02^m$.

One of the important characteristics in photometric studies is the measure of colour — the difference between magnitudes obtained in different filters. The main ones are the colour indices $(U-B)$ and $(B-V)$. The $(U-B)$ index is a good indicator of the temperature of the O and B stars. These colour indices are shown in Fig. 2, 3. Additionally, according to the lightcurves (Fig. 1), the largest photometric changes of the object occur in the U and I bands. Therefore, we also present the $(U-I)$ colour index in Fig. 2.

Throughout the entire series of observations, the colour indices did not change much, except for one case near the Julian date JD = 2455400, which corresponds to a period in December 2010 – January 2011. The significance of these changes were confirmed by Sign Test (see Table 2). In Fig. 4, where different symbols stand for data obtained with different CCDs:

a) all the points near JD = 2455400 were obtained with the same instrument;

b) aside from "drop-down" points, all other data from this camera are in a good agreement with the whole light curve, so the "drop-down" points are not camera artifacts.

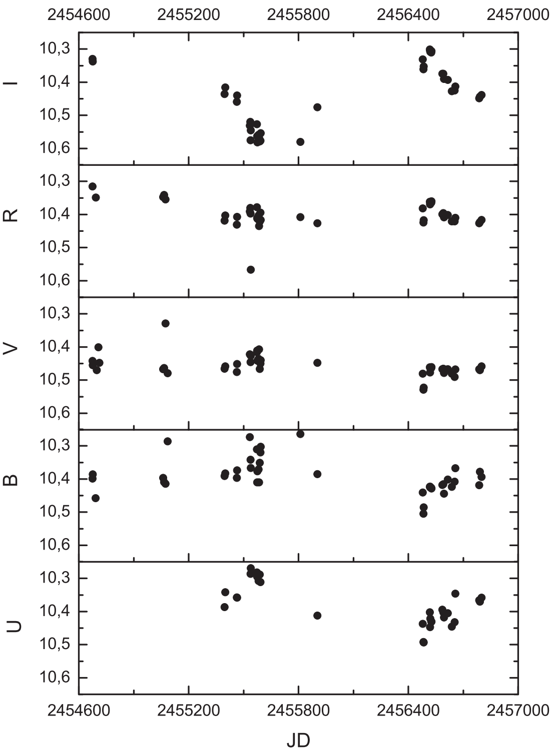

Fig. 1: Lightcurves of the 1H1936+541 in all bands.

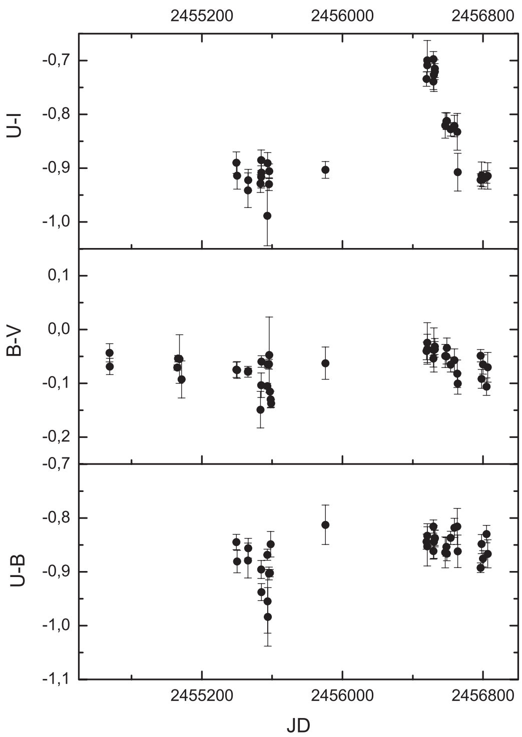

Fig. 2: Colour indices of the 1H1936+541.

Thus, we can conclude that changes in colour index shown in this plot really occurred in the system.

Comparison of $(U-B)$, $(B-V)$ plots and lightcurves in U and I bands yields the following results. The colour changes coincide in time with changes in magnitudes. Namely, the magnitude in the U-filter decreases, i. e. the brightness increases, and vice versa, for the I-filter (Fig. 3). Also, the correlation coefficient for the I filter and $(B-V)$ colour index is -0.63316 ± 0.00006, and 0.517 ± 0.004 for the U filter and $(B-V)$ colour index.

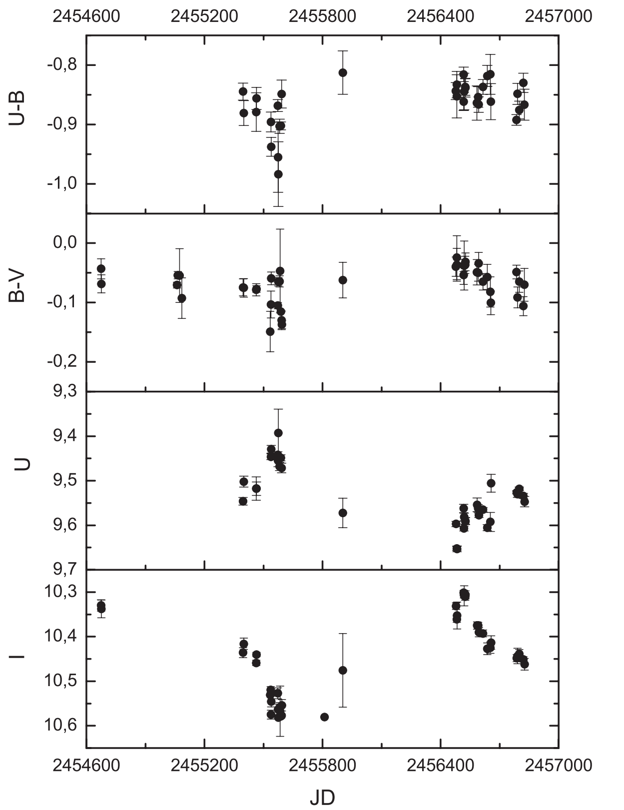

Fig. 3: Lightcurves of the 1H1936+541 in U and I bands, and $(B-V$ and $(U-B)$ colour indices.

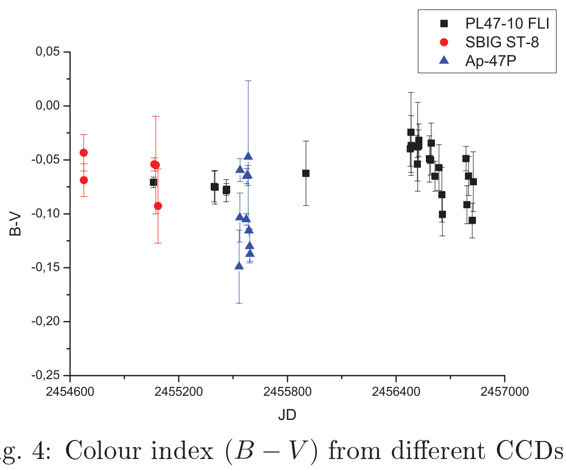

Fig. 4: Colour index $(B-V)$ from different CCDs.

To confirm that the observed changes are not just fluctuations in a frame of similar distribution, the Sign test were applied. This test function tests the hypothesis that two sample populations X and Y have the same mean of distribution against the hypothesis that they differ. For this purpose we have divided our data into two equal parts and compared them. The results of this test shows that these two samples of data have different means of distribution (in Table 2, the maximum number of signed differences between corresponding pairs of x_i and y_i, and its one-tailed significance).

Within the frame of the decretion disk model [1] this observed fact can be interpreted as the destruction of the disk, or a significant reduction in its size. The decretion disk is a powerful source of infrared radiation; hence its distruction should lead to decrease in the intensity of infrared radiation. On the other hand, in terms of geometry, a wide decretion disk can cover a significant portion of the surface of the star, thus preventing the spread of its own radiation, the main part of which is concentrated in the ultraviolet region. The disappearance of the decretion disk removes all obstacles, and the flux of radiation from the star increases.

Table 2: Results of the Sign Test.

Filter	Num. of points	Max. Num. of diff.	Signif.
U	40	17	0.001
I	33	13	0.013
U-B	33	13	0.025
B-V	41	17	0.004
U-I	33	14	0.006

Return of the system to the initial values of the colour indicates the re-formation of the disk, or its substantial growth. The lower brightness in the U filter and the greater one in I filter, comparable with the values from early observations, may indicate a more powerful drive than that which existed in 2008. Changing in magnitude in aforementioned bands and minor fluctuations in colour may indicate changes in the current system, which do not lead to catastrophic changes in the structure of the disk. However, in the near future the disk has to be disbanded again.

CONCLUSIONS

We conducted a series of observations of the object 1H1936+541 and got lightcurves in U, B, V, R, and I bands and colour indices for it. Our results indicate a violent physical processes in the system probably associated with the deformation and the re-formation of the decretion disk around the main component of Be/X-ray binary 1H1936+541. These results can be a small claim for the version of the Be/X-ray binary even without X-ray activity

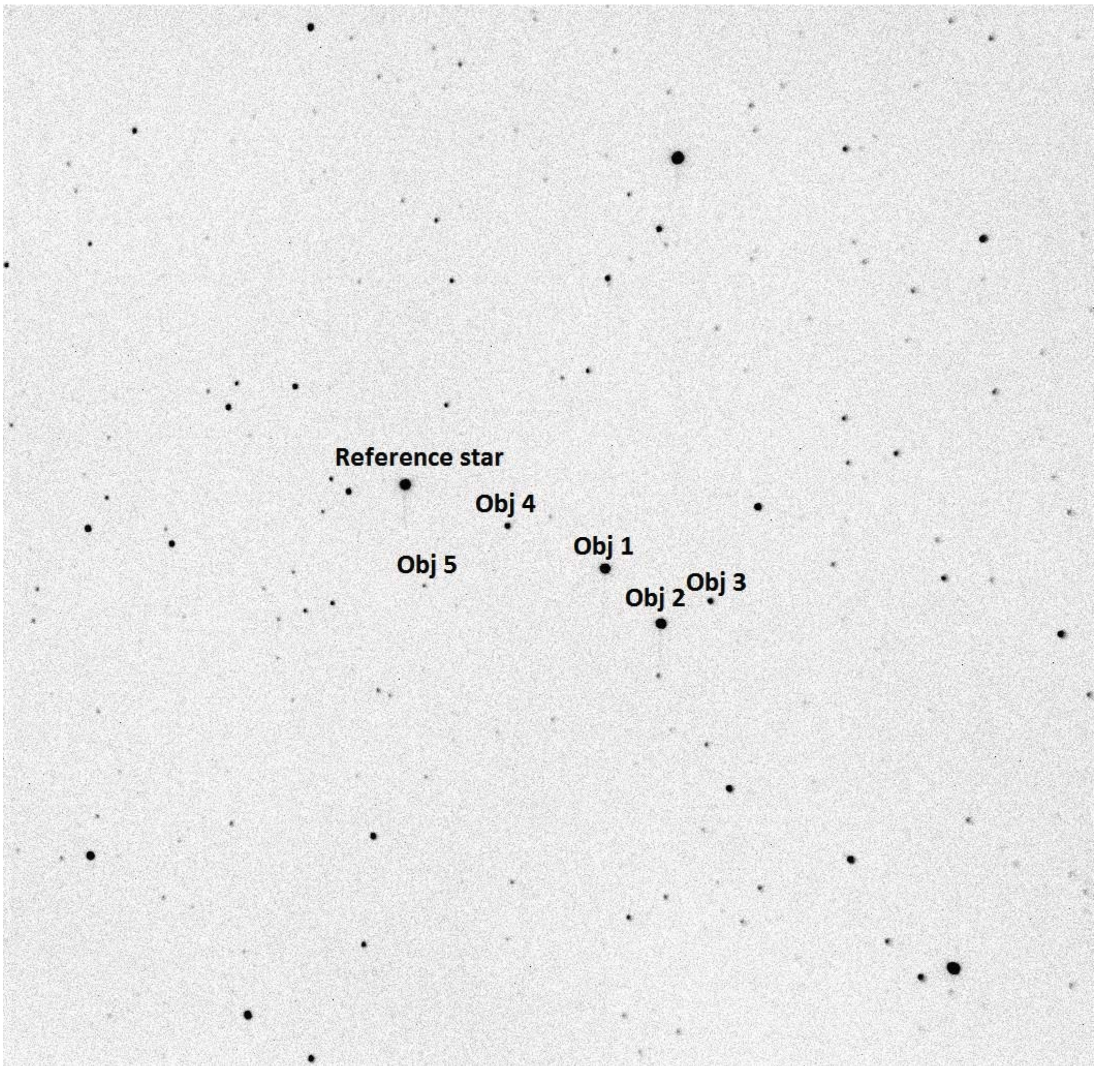

Fig. 5: The sky chart with the standard star HD 184658 (Reference star), our object 1H1936+541 (Obj1) and the comparison stars (Obj2, Obj3, Obj4, Obj5).

throughout past thirty years. We expect the next disbandment of the decretion disk in the nearest future. Hence, a detailed study of the processes associated with the conversion of the disk, and further observations, are necessary.

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