PHOTOMETRIC AND SPECTROSCOPIC PECULIARITIES OF THE UNIQUE HERBIG BE STAR HD 52721 – AN ECLIPSING CLOSE BINARY SYSTEM

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Accurate reduction of former observational data as well as results of the new photometric study of the Herbig Be star HD 52721 carried out in 2010 – 2013 at the Kislovodsk Mountain station of the Pulkovo Observatory showed that the period P = 1.610 days is the true orbital period of the eclipsing binary system containing two B-type components with similar parameters. This fact was completely confirmed by results of the spectroscopic investigation of this object carried out in 2009 – 2010 at two observatories (Crimean AO and OAN SPM observatory in Mexico). Azimuthal circumstellar inhomogeneities rotating rigidly with the system's components have been revealed in the internal and also in the external envelopes of the system. Possible origin of these features is discussed.

Keywords: Eclipsing binary systems – Herbig Ae/Be stars — Circumstellar envelope

1. PHOTOMETRIC INVESTIGATION

HD 52721 (GU CMa, MWC164, B2Vne,$V = 6^m.61, B - V = 0^m.04$) is a young PMS object (Herbig Be star) [1]. It is connected with the association of reflection nebulosities CMaR1. It demonstrates a reach emission spectrum and a

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far-IR excess as a result of emission of the relict cold dust in remote envelope [2]. HD 52721 is an unique Herbig Be star: its light variability is typical for eclipsing binary systems [3].

The long-standing (1987 – 1998) photometric UBVR-monitoring was carried out in the Maidanak Observatory (Uzbekistan) in the framework of the "ROTOR" program. The results of the period search of the data were published in [4]. Two periods with equal probability were found: $P_1 = 1.610158^d and P_2 = 0.8508^d$. It has been found that: a) the phase light curve for $P = 1.61^d$ demonstrates no meaningful difference in the profiles of two photometric minima, and b) no color effects are present at different phases of the both phase light curves.

Authors of [2] included the results of the Maidanak's photometry in their full scale paper and proposed two hypotheses explaining this cyclic light variability:

1. HD 52721 is an eclipsing binary system including two B-type components with the same radii and effective temperature. The eclipse is observed twice during one orbital period $P = 1.610^d$.

2. The secondary component is low-mass K-type star with the brightness much less than that of the primary B-type star, and the true orbital period is 0.805d. In this case we do not observe a minimum when the secondary is eclipsed by the primary. To examine the both hypotheses ws carried out the revision of the Maidanak's photometric data. We determined the orbital period more precisely: $P = 1.6101524^d \pm 0.0000021^d$ (instead earlier 1.610158d) for the longer period and took into account the long-term light variations between observing seasons. This allowed us to improve the phase light curve. It is presented in Fig.1 (left).

One can see that: a) the both minima in the phase curve for $P = 1.610^d$ are noticeably different in depth and, b) the colors are more red at phases of the light minima.

The similar phase light curve was constructed using the photometric data of HD 52721 taken from the ASAS data base is given for comparison (Fig.1, right top). Near 500 V-measurements of the objects were obtained in 2003 – 2009. The different depths of two minima is confirmed by these data. Additionally, some local features are clearly observed at different phases.

So, our results confirmed that HD 52721 is an eclipsing binary system with two similar B-type components and the true orbital period $P_{orb} = 1.610^d$.

We performed our own photometric observations of HD 52721 at Kislovodsk Mountain Station of Pulkovo Observatory in 2010 – 2013 to investigate various local features in the light curve observed at different phases of the orbital period. The 0.15-m Maksutov telescope was used that was equipped by the CCD-photometer containing a matrix KAF-1600 (1530×1020 pxl, field 21'×14').The spectral sensitivity of the photometer corresponds to the standard band R but much more broad.

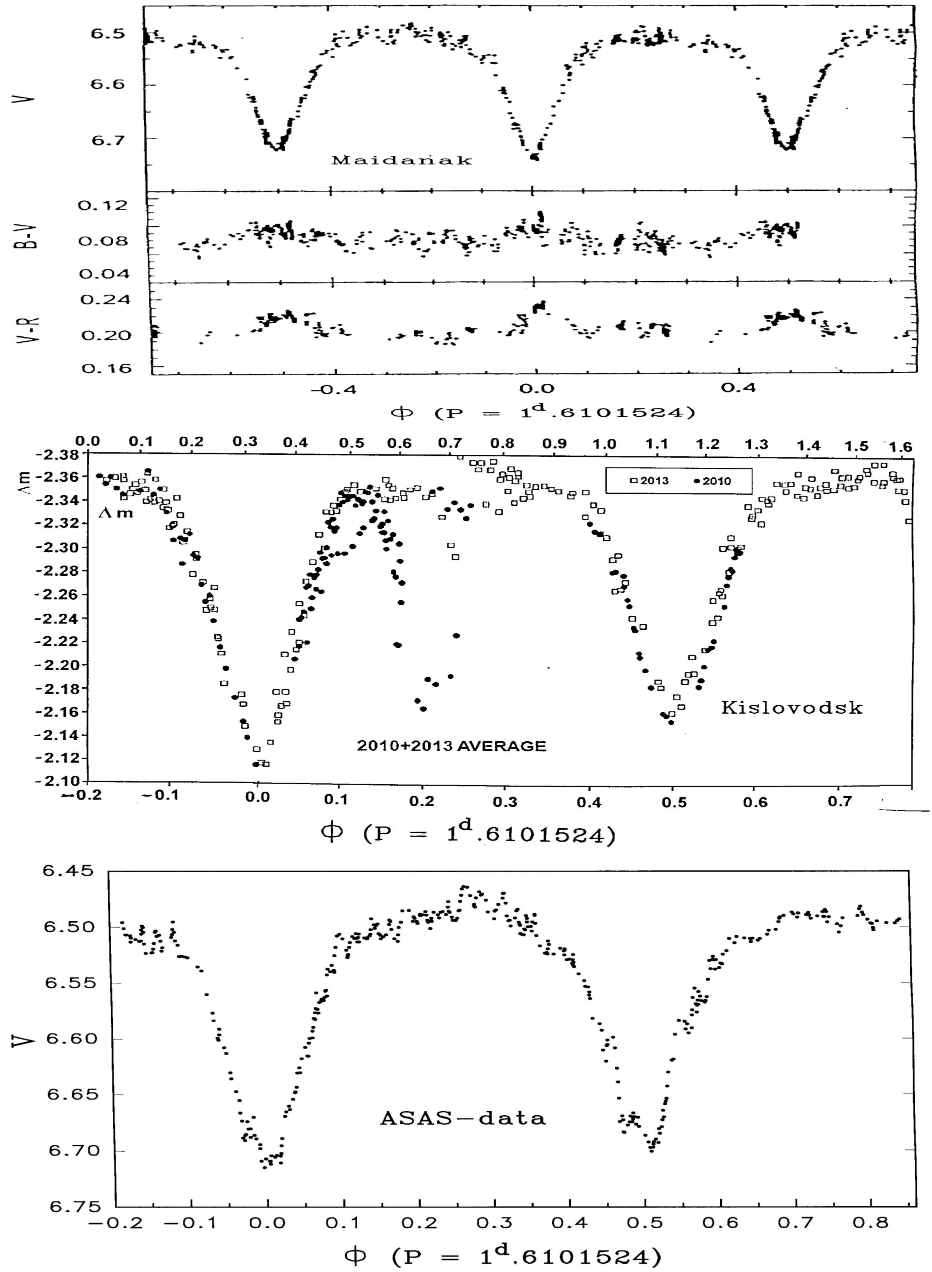


Fig. 1. HR diagram for CTTS (a) and WTTS (b) - from [1]. The solid lines mark the evolutionary tracks calculated with Y = 0.277 and Z=0.02 - for stars with different masses from 0.2 to 2.7 $M_{\odot}$. The dashed lines indicate isochrones for ages of 10^6, 10^7, and 10^8 yr. The author adopts a grid of evolutionary tracks from [2] computed for PMS stars. Objects above the red line have no radiative core.

Observations were carried out during 10 nights in March, 2010 and during 25 nights in January, 2013. The full number individual measurements was near 4000, then all the data were averaged over 10 values. The object HD 52774 having the same color indexes as HD 52721 was chosen as a comparison star. A special packet Apex II for reduction of photometric images developed in the Pulkovo Observatory was also used [5]. The phase light curve constructed for the period P = 1.6101524 relative to the comparison star is shown in Fig.1 (right bottom). One can see that: a) depths of the both photometric minima are actually different, b) deep additional minimum at phase Φ near 0.20 was observed in 2010 during 4 nights, which were arranged not consecutively (on 17, 20, 23 and 28 Masch), whereas his signs were absent on 12, 18, 19, 24, 25 and 27 March, c) a local feature in the phase light curve was observed near the phase Φ = 0.25-0.30 in 2013 similar to that which was seen in the phase curve constructed for the ASAS data in 2003-2009 (Fig.1, right). In more detail see [6].

2. SPECTROSCOPIC INVESTIGATION

Observations were performed at two observatories in 2009 – 2010. One of them was the Crimean AO (2.6-m Shajn telescope, coude spectrograph ASP-14, R=25000). 54 spectra in regions of Balmer lines and HeI 5876, 6678 lines have been obtained during 14 nights in 2009-2010. The second observatory was OAN SPM (Ensenada, Mexico) with the 2.1-m telescope + echelle spectrograph (R=17000). 40 spectra in the region $\lambda\lambda$ 3800-6800Åhave been obtained during 5 nigjts in Feb. 2010.

Atmospheric lines.

Fig.2 (left) illustrates velocity variations of several atmospheric lines with the phase Φ of the orbital period. The phase Φ = 0 corresponds to the moment of maximum eclipse of the more bright primary by the secondary. The velocity scales in the plots are given in respect to the mass centre (+25.4 km/s). These dependences are typical for a binary system with similar but not the same parameters of its components. The observed profiles are combinations of two profiles forming in the atmosphere of each component. One can see in figure, that $V_r < 0$ at phases Φ from 0 to 0.5 when the primary moves toward the observer, and $V_r > 0$ at phases Φ from 0.5 to 1.0, when the primary moves away from the observer. This means that the contribution of the primary to the observed atmospheric profiles is larger than that of the secondary. The profiles of atmospheric lines demonstrate a puzzling phase dependences. We can see in literature different estimations of Vsin i from 200 to 450 km/s. It is expected for the binary system with two B-type components. The orbital velocity of the system's components can be estimated from the mass function as approximately $V_{orb} \sim 250 km/s$.

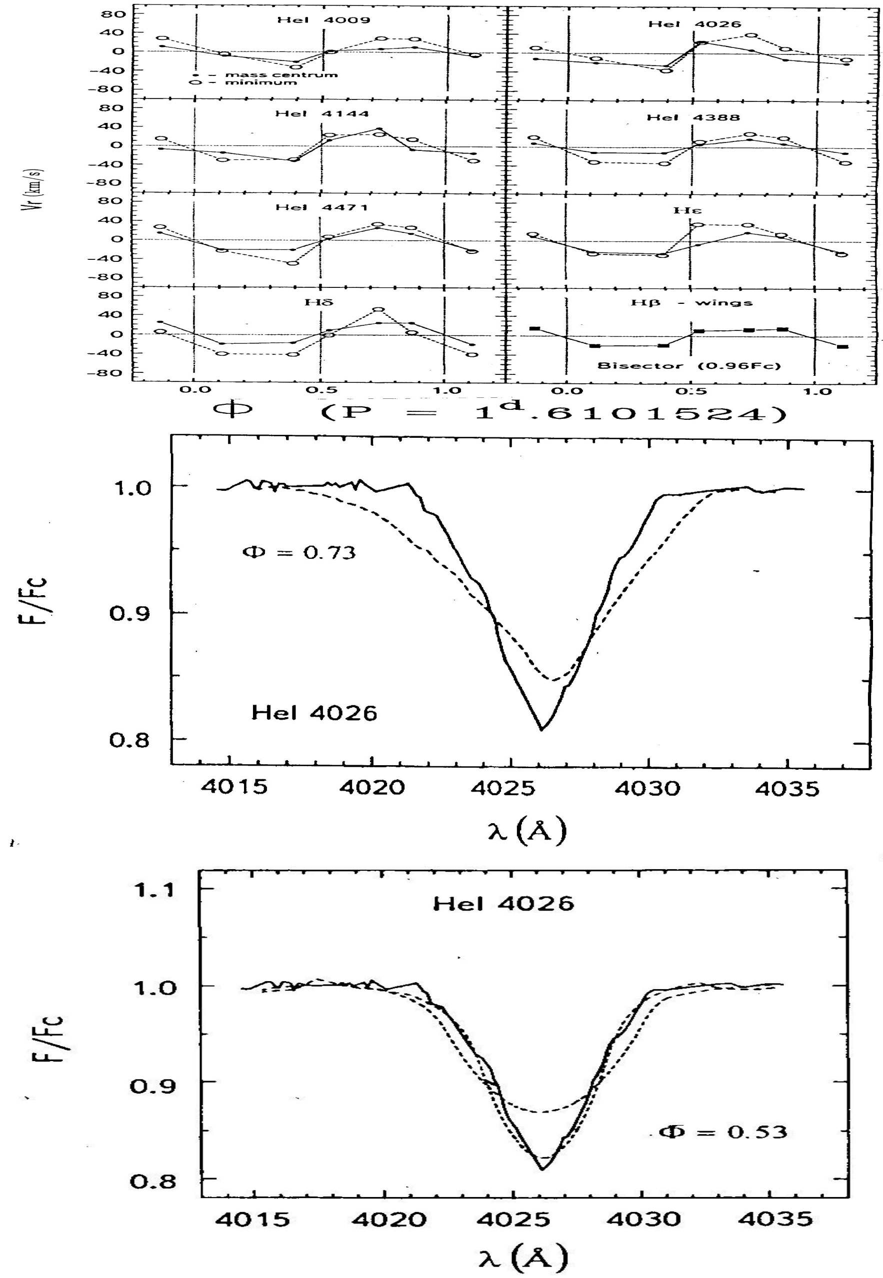


Fig. 2. HR diagram for CTTS (a) and WTTS (b) - from [1]. The solid lines mark the evolutionary tracks calculated with Y = 0.277 and Z=0.02 - for stars with different masses from 0.2 to 2.7 $M_{\odot}$. The dashed lines indicate isochrones for ages of 10^6, 10^7, and 10^8 yr. The author adopts a grid of evolutionary tracks from [2] computed for PMS stars. Objects above the red line have no radiative core.

At the phase of minimum $\Phi = 0.53$ (Fig.2, right top) the profile of the typical atmospheric line HeI 4026 can be fitted by a single model profile: $T_{eff} = 25000K, logg = 4.0, V_{sin}i = 200$ km/s. This means that two components of this compound profile are forming in atmospheres of two stars of similar spectral type. Fig.2 (right bottom) illustrate the profile of the same line HeI 4026 observed in the maximum of brightness ($\Phi = 0.73$). The profile is expected to be broadened due to the orbital motion of the system's components (it is seen) and bifurcated. But the lasr is not seen.

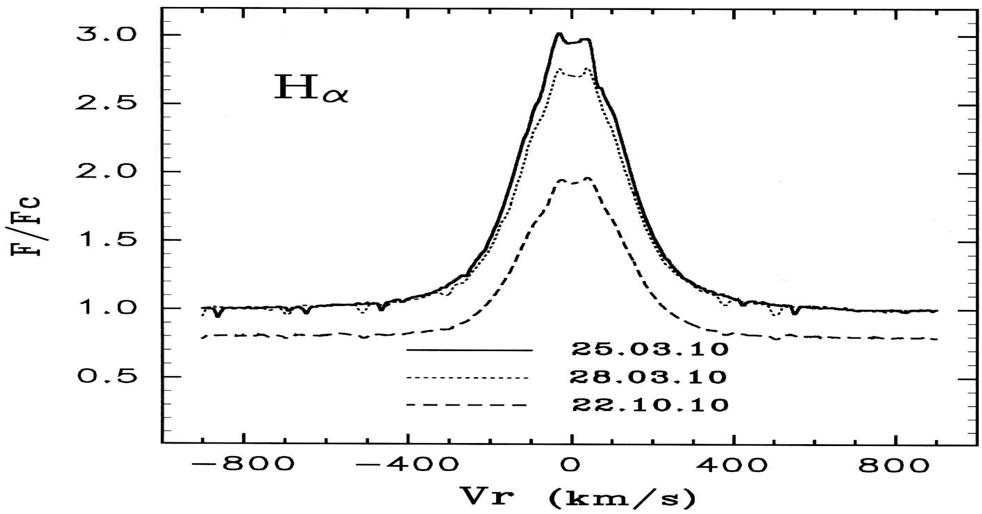
The question is: why? This effect can be easy explained.

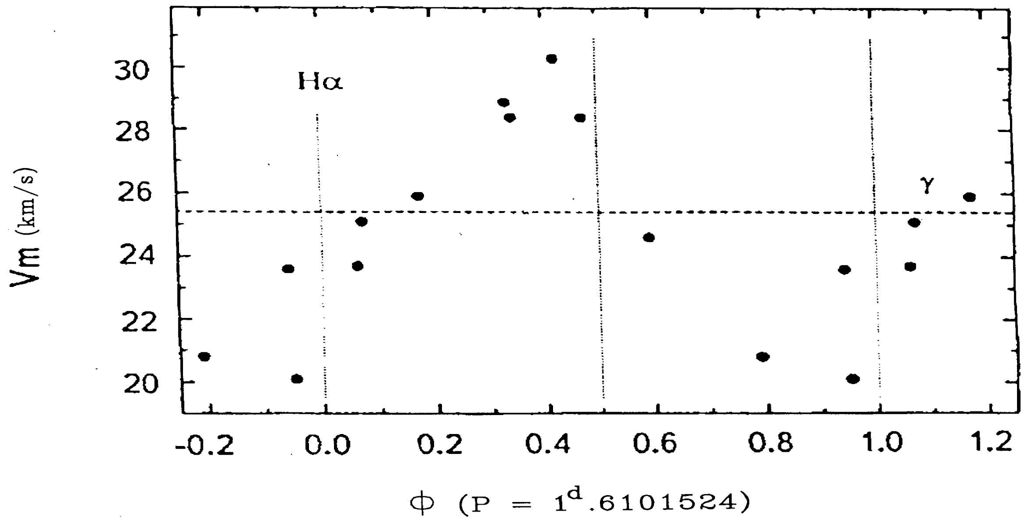
According to the SIMBAD data base, one more star is situated close to HD 52721 ($\Delta\rho = 0.6"$, δm $\sim 0.9^m$). The field star is placed at $\sim$ 600 a.u. from the binary system and is evidently not connected with the system gravitationally. But its brightness is comparable with that of each of both system's components. The object is placed too close to HD 52721 in projection onto the sky, and has to be non-resolved during photometry as well as spectral observations. Therefore, it has to affect the results of observations.

If the spectral type of the third star is similar to that of components of the system, it does not distort the profiles of atmospheric lines in the minimum of brightness, because velocities all of them are the same. At phases of photometric maximum, the profiles of the system's components have to mave apart toward blue and red, but the profile of the third star has to be non-shifted. As a result, the compound profile has to look as broadened but not bifurcated.

Circumstellar (CS) lines.

Typical profiles of the Hα line observed in different dates are shown in Fig.3 (left). Pase dependence of the mass centre Vm of the emission Hα profile is presented in Fig.3 (right). One can see, that Vm $>$ Vγ (mass centre of the system +25.4 km/s) if the secondary moves away from the observer, and Vm $<$ Vγ if the secondary moves toward the observer. The circumstellar Hβ line looks like a double-peaked emission overlapping the atmospheric broad absorption component (Fig.4, left). The CS line component is redshifted if the secondart moves away from the observer ($\Phi < 0.5$) and is blueshifted when the secondary moves toward the observer ($\Phi > 0.5$). The profiles of HeI 6678 line are of the same type as that of Hβ, and demonstrate similar phase dependence. Fig.4 (right) illustrates the phase dependence of the indicator of asymmetry of the 4observed absorption profiles "a", overlapped by blue/red-shifted CS emission component. This indicator is entered as the ratio of equivalent widths (EW) of the blue (v) and red (r) parts of the absorption profile separated by the radial velocity of the mass centre of the system Vγ. If a > 1, the emission component is redshifted and if a < 1, it is blueshifted.

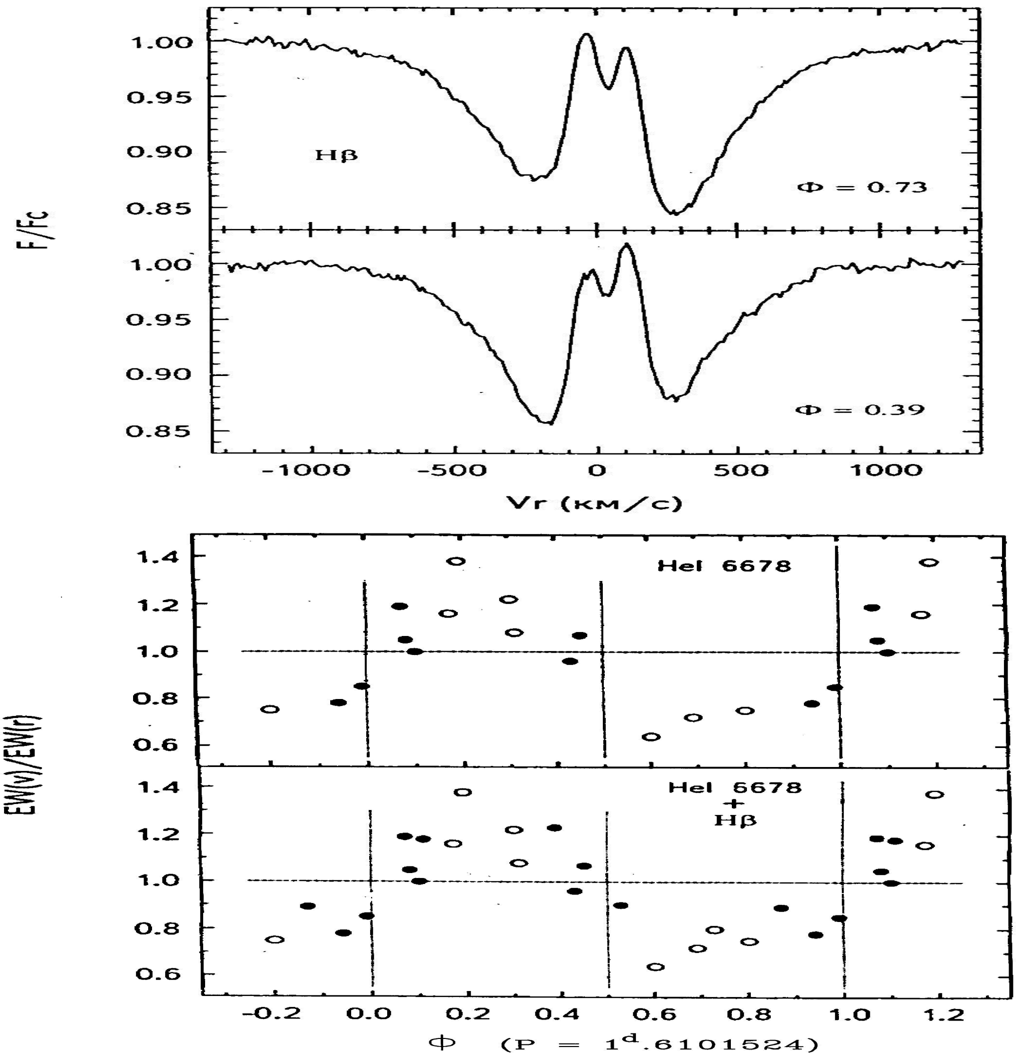




Results of our spectroscopy showed that a disklike CS envelope around HD 52721, and this inhomogeneity rotates rigidly with the components of the system. In more detail see [7].

3. CONCLUSIONS

• Revision of old photometric data and our own photometric and spectroscopic study of the Herbig Be star HD52721 confirm that the object is a binary system containing two B-type stars with similar parameters and the orbital period P = 1.6101524 days.



• Inner envelope of the system is azimuthally inhomogeneous gaseous disk concentrated toward the secondary. The azimuthal inhomogeneity rotates around the system with the period equal to the orbital period of the system. Possible interpretation of such gas distribution in the envelope: a) stream-like flow of the gas away from the secondary through the external Lagrange point, or b) a result of interaction of stellar winds of both the components, if the wind from the primary is more strong [8].

• The additional photometric minimum observed in 2010 at phase $\Phi \sim 0.2$ can be connected with a stream-like flow moving from the external circumbinary envelope toward the system. Possible existence of such structural features was predicted by model hydrodynamical (SPH) calculations (see, for example, [9]).

Such stream can intersect the line of sight once during the orbital period and lead to an appearance of additional local photometric minima.

• Existence of a high temperature zone on stellar surfaces of both the components on sides facing one against another, can explain reddening colors of the object at phases of mimima as well as an appearance of a local brightening at phases of its photometric maxima.

• It has been shown that the presence of an once more star close to the system HD 52721 can explain a number of observational peculiarities of the object which remained incomprehensible before.

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REFERENCES

1. Finkenzeller,U. , Mundt, R. .1984, Astron.Astrophys.Suppl.Ser., 55, 109

2. Tjin A Djie,H.R.E., et al. 2001, Mon.Not.Soc.Roy.Astron.Soc., 325, 1441

3. Claria, J.J. 1974, Astron.J.. 79,1022

4. Ezhkova, O.V. 1999, Inform.Bull.Var.Stars, №4693

5. Kuprianov, V.V., et al. 2008, Adv.Space Res. 41, 1029

6. Pavlovskiy, S.E., et al. 2015, Astron.Lett., 41, 209

7. Beskrovnaya, N.G., et al. 2013, Astrophysics, 56, 42

8. Usov, V.V. 1991, Mon.Not.Soc.Roy.Astron.Soc., 252, 49

9. Sotnikova, N.Ya., Grinin, V.P. 2007, Astron.Lett., 33, 667