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PHOTOMETRIC AND SPECTRAL STUDY OF THE STAR AS 442

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The results of long-term spectral and photometric observations of the AeBe Herbig-type star AS 442 were analyzed. Based on more than 1300 measurements taken in UBVR filters at the Maidanak Observatory in Uzbekistan in 1982-1996, the light curve and color dependence curves of the star were constructed, and the periodicity of these changes in different seasons was checked by applying statistical Fourier analysis. It was shown that no stable periodicity was detected in the changes in brightness and colors. The star is bright in most cases, but large-amplitude eclipses were detected in three seasons.

Spectral observations of the star were carried out at the 2 m telescope of the Shamakhi Astrophysical Observatory during 2020-2024. It was shown that the spectrum of the star exhibits serious changes. Various structural changes detected in the Hβ line can be explained by the ejection and accretion of matter in the circumstellar disk. Such profiles exhibit a stable structure over the observation season.

Keywords: *young stars, circumstellar disks, photometry, spectroscopy, object – AS 442.*

INTRODUCTION

The star AS 442 (SpB8-A0, V~11 mag) was first discovered by [14] as an object with a medium-intensity Hα emission line. In [15], the spectral class of the star was B9 or A0, and a weak emission component in the Hβ line was found using low-resolution spectra. [2] first showed that the equivalent width (Ew) of the Hα emission line in the star's spectrum was -23 Å, and that it had an infrared (IR) emission excess, and it was included in the AeBe Herbig star catalog.

The first data on the physical parameters of the star were given in [12, 13]. It was shown that the Hα emission line and the D NaI doublet lines in the star's spectrum show strong variations. The authors determined the star's spectrum to be B8, its mass to be 3.5 $M_\odot$, the equivalent width of the Hα line to be EW= -32.7Å, and the width at 10% of the line intensity to be HαW10 = 646 km/s, and determined that the Hα line profile is IIIB according to the classification [1]. The Hα line has two emission peaks, one of which is less than half the intensity of the other. In addition, the HeI 5876, D NaI, [OI] 6300 and 6363 Å lines were detected in the star's spectrum. In [11], the star's temperature was determined to be 11000 K, the distance to the star to be 826 pc, the age to be 1.5 Myr, and the interstellar reddening coefficient Av=3.85 [9].

UBVR photometric observations of the star were mainly performed at the Maydanak Observatory in Uzbekistan, and the obtained materials were collected in the Strasbourg CDS archive [3, 5]. Based on this material, the photometric variations of the star were studied [10]. It was shown that the brightness of the star shows small amplitude variations around the value close to the maximum, but in some years the brightness decreases sharply. Such variations are characteristic of UXOR-type stars. The search for periodic variations in this work did not yield any results.

In recent years, several studies have determined the physical parameters of the star AS 442 [4]. In [17], it was shown that it forms a visual binary system with a B component at a distance of 4.75” from the bright star A in the center.

In this work, the results of a long-term photometric and spectral study of the star are presented for the first time.

MATERIAL AND METHODS

Broadband UBVR photometric observations of the star were carried out at the Maydanak Observatory in Uzbekistan using the ROTOR program. The results are collected in the Strasbourg CDS archive Herbst et al. (1994), Grankin et al. (2007). The photometric archive of young stars is located at http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/461/183. Observations of the AeBe Herbig-type star AS 442 were carried out regularly for 14 consecutive years during JD2445879-2450791 (1984-1997). In different years, 60-150 measurements were taken per year. During this period, stellar magnitudes of the star AS 442 in the U and R bands were determined by more than 1300 BV and slightly less than this. Typical measurement errors for the star AS 442 are ±0.01 mag in the BVR filters and 0.05 mag in the U filter.

In Figure 1, the light curves obtained over the entire observation period of the star are shown in different colors. As can be seen, the change in the brightness of the star is on average 0.7 mag in the U filter, 0.4 mag in the B filter, and 0.3-0.4 mag in the V and R filters.

Overall, the brightness of the star during different seasons exhibits chaotic variations around approximately the same average value. Only during 3 different seasons does the star JD 2447677-2448588 (1989-1991) show deep minima of the UX Ori type. Each of these minima clearly shows short-term variations during the day (Figure 2).

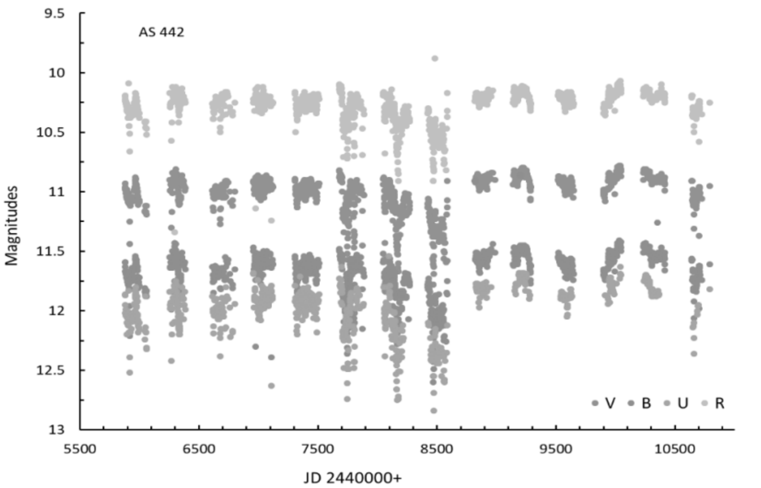

Fig. 1. 14-year light curves in the UBVR bands of the star AS 442. Different colors indicate stellar sizes in different filters

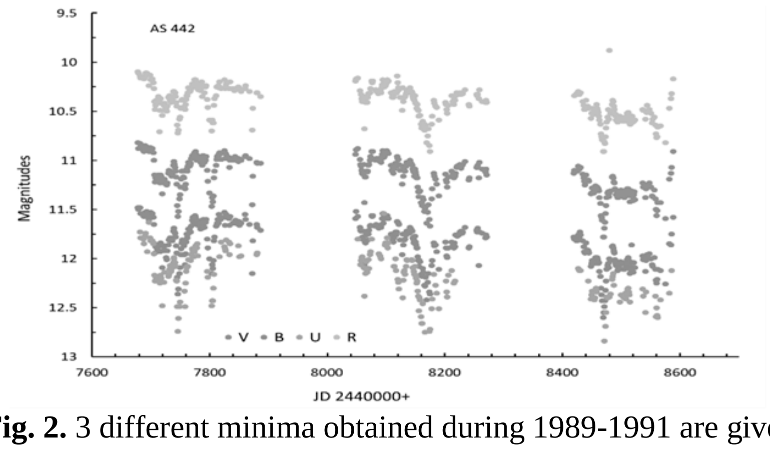

Fig. 2. 3 different minima obtained during 1989-1991 are given

Figure 2 shows that in each of these 3 seasons the star's brightness periodically showed deep minima. The time intervals between the minima occur at approximately the same date in all filters, and the time interval between two adjacent minima varies from 27 to 96 days. The amplitudes of the brightness decrease are as follows: ΔU~1 mag, ΔB~0.8 mag, ΔV~0.70 mag, and ΔR~0.4 mag. Since the brightness change in all filters is of the same nature, we will focus on the V light curve from now on.

Figure 3 shows the general light curve and the time-dependent color curves in the V filter. As can be seen, the average color values remain constant in different seasons: <U-B>=0.3 mag, <B-V>=0.55 mag, <V-R>=0.74 mag. Note that the color indices change as in the case when there are no deviating minima, even during the period of sharp brightness decrease. Figure 4 shows the dependence of the star's color indices on the brightness V. As can be seen, the B-V and V-R colors show a linear variation with brightness, albeit slightly, throughout all seasons.

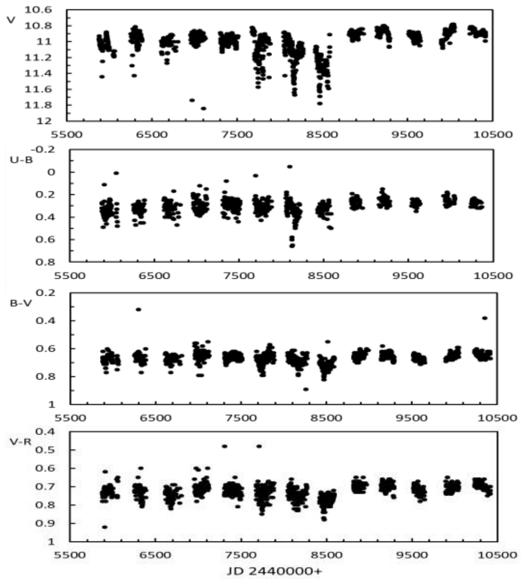

Fig. 3. Top-down–V light curve, U-B, B-V, and V-R color indices change over time

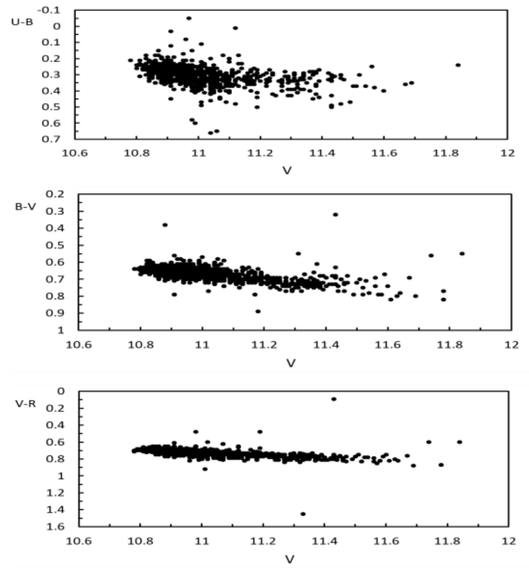

Fig. 4. The dependence of the color indices of the star AS 442 on the brightness

Although a linear change is also observed in the U-B color, the deviation from linearity is relatively large compared to other colors.

As can be seen from Figure 4, as the brightness of the star decreases, all color indices decrease proportionally. This feature proves that the decrease in brightness in the corresponding bands is mainly due to shielding. A certain deviation from linearity in the U-B color indicates that other physical phenomena are involved in the color change in addition to shielding.

In order to detect a periodic component in the brightness of the star AS 442, we divided the results that make up the general light curve into separate arrays. The main purpose of doing this is that it would be more expedient to search for all the points obtained over a period of 14 years in different arrays rather than in a common array. In this case, the distortion of the stochastic components present in the brightness variation would be minimized. In Table 1, the first column shows the serial number of the array, the second column shows the time interval during which that array was obtained, and the third column shows the number of points obtained in each array. In the table, seasons in which three consecutive deep eclipses occurred are shown in bold.

To search for periodicity in the brightness variation, we used the Period 04 program [7], which was developed based on the method of [8] and [16]. The program is based on the determination of the most probable periods in the power spectrum by applying Fourier analysis.

Figure 5 shows examples of power spectra obtained for different arrays. The study showed that several periods are repeatedly detected in individual arrays. Of these, periods of 50±3 days (in 4 arrays), 76±2 days (in 4 arrays), and 80±2 days (in 2 arrays) were obtained. However, none of these periods are detected in all other arrays. Therefore, we conclude that these observational results do not allow us to separate the periodically varying part of the brightness from the stochastic component that causes chaotic variation.

Table 1.

Distribution of observation results by arrays

№	**JD 2440000+**	**N**
1	5879.523 - 6061.115	76
2	6255.196 - 6383.209	68
3	6613.389 - 6802.127	54
4	6957.335 - 7124.144	96
5	7307.331 - 7507.074	149
6	7677.447 - 7887.073	137
7	8048.43 - 8271.116	138
8	8419.426 - 8588.207	104
9	8819.373 - 8986.133	86
10	9140.46 - 9289.133	92
11	9517.446 - 9647.151	82
12	9897.444 - 10046.147	83
13	10234.394 - 10415.101	76
14	10641.417 - 10791.122	46

As can be seen from Figure 5, in most cases the most probable periods for different arrays fall within the range of 50-80 days. However, such periods, which appear in some arrays, are not observed in most other arrays.

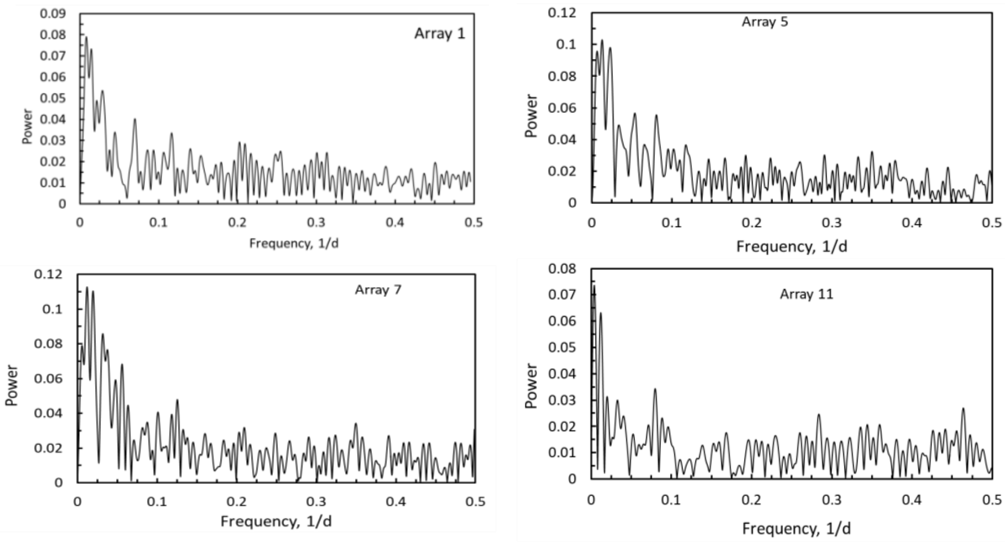

Fig. 5. Examples of power spectra across different arrays

Spectral observations of the star AS 442 were performed on the Universal Astro Grid Spectraograph (UAGS) spectrograph set at the Cassegrain focus of the 2 m telescope of the SHAR. An Andor CCD camera (ikonL-936-BEX2-DD) with a number of elements of 2048x2048 and a size of one element of 1px=13.5 μm was used as a light receiver. A Canon FF (f=200 mm, f/2) high-power lens was used to adapt the CCD camera to the spectrograph. The focal lengths of the collimator and the camera in the spectrograph were Fcoll = 1100 mm, Fcam = 200 mm, and the incidence and scattering angles were 27.5° and 20.5°, respectively. Since the resolution in the focal plane of the camera is determined by the size of two pixels, the monochromatic width of the spectrograph slit in the case of binning 1x1 is S' = 2 px = 0.027 mm. The Cassegrain focus of a 2 m telescope is F = 29500 mm, and the scale in the focal plane is μ = 6.99″/mm. Then we take 0.99” for the width of the entrance slit. Accordingly, for 2x2 binning we take the same parameter as 1.99”. In such a complex, the spectra of weak variable stars, galaxies and nebulae can be obtained [6].

A diffraction grating with 651 lines/mm was used in the spectrograph. In the first arrangement, the linear inverse dispersion in the case of binning 1x1 is 144 Å/mm (D = 1.9 Å/mm), and the spectral range is λ 3600-8000 Å. In other words, the average spectral resolution in the Hα (λ 6563 Å) region is R = 3400. A more detailed description of the spectrograph is given in [6].

For the grading of the images obtained on the spectrograph, auxiliary frames – flat, bias, dark and ThAr lamp spectra were also recorded during each observation. The obtained materials were processed using the DECH package program (Galazutdinov G., http://www gazinur.com/DECH-software.html). The processing process was carried out by a standard method. Based on measurements made on standard stars, the errors in various lines for radial velocities are ±3-5 km/s, and for hydrogen lines in A0-A6 class stars for equivalent widths ± 0.5-0.6 Å. Table 2 gives the observation log of the star AS 442. The columns, from left to right, list the observation date, Julian date, exposure time, UT (Universal Time), binning, and signal-to-noise parameters next to the Hα line in the spectrum.

Table 2.

Spectral observation table of the star AS 442

Tarix	JD 2450000+	Eksp.vaxtı(san)	UT	Binning	S/N
16.07.2020	9047.446	300	22:43	3x3	80
19.07.2020	9050.455	700	22:55	2x2	95
24.07.2020	9055.479	700	20:05	2x2	87
19.08.2020	9080.339	700	20:08	2x2	85
05.08.2021	9432.341	700	20:12	2x2	84
06.08.2021	9433.276	700	18:28	2x2	89
10.09.2021	9468.331	700	19:58	2x2	77
13.09.2021	9471.298	700	19:05	2x2	68
21.06.2022	9752.406	1200	21:49	1x1	127
30.06.2022	9761.345	1200	20:17	1x1	113
01.07.2022	9762.383	1200	21:12	1x1	128
25.08.2022	9817.276	2400	18:38	1x1	133
26.08.2022	9818.255	2000	18:08	1x1	120
27.08.2022	9819.253	1800	18:05	1x1	121
28.08.2022	9820.24	1800	17:46	1x1	114
29.08.2022	9821.238	1800	17:45	1x1	116
30.08.2022	9822.242	1800	17:49	1x1	115
31.08.2022	9823.251	1800	18:02	1x1	110
16.09.2022	9839.3104	1800	19:27	1x1	120
02.10.2022	9855.225	2400	17:25	1x1	118
04.10.2022	9857.244	2400	17:52	1x1	120
08.09.2024	10562.214	1500	17:29	1x1	115

Figure 6 shows an example of the overall appearance of the spectra of the star obtained on 21.06.2022 and 30.06.2022, and a fragment of the spectrum in the range λ 3700-4500 Å on a larger scale. As can be seen, in the spectrum, along with the lines of the strong Balmer series, D Na I, He I, Ca I, K CaII, Fe II 4924, etc. lines are observed. The change in the absorption spectrum on the two dates given on the same scale is clearly visible: the absorption lines on 21.06.2022 are more intense.

RESULTS AND DISCUSSION

Figure 7 shows graphs of the change in the equivalent widths (open circles) and semi-widths (black circles) of the hydrogen lines during the observation period. The Hα line is emission, and the Hβ, Hγ and Hδ lines are absorption lines. As can be seen from Figure 6, the average value of the equivalent widths of the Hα line increases during 2020-2022, and decreases in 2024. The equivalent width and semi-width of the Hα line change in opposite directions. At the same time, as the Hα emission line strengthens, the equivalent widths of other hydrogen lines decrease. As the emission spectrum strengthens, the emission components arising in the absorption lines also appear, so a decrease in the equivalent widths is observed.

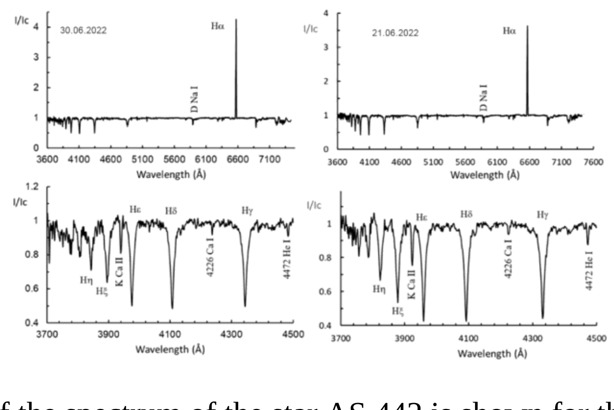

Fig. 6. An overview of the spectrum of the star AS 442 is shown for the dates 21.06.2022 and 30.06.2022. The panels below show a larger-scale representation of the spectrum on those dates in the range λ3700-4500 Å.

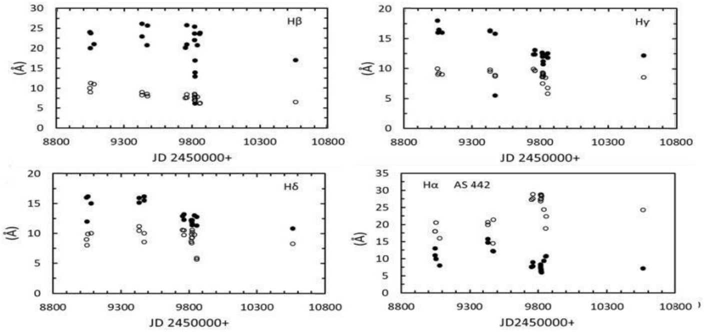

Fig. 7. Variation of the equivalent widths (open circles) and semi-widths (black circles) of the Hα-Hδ lines with time. The Hα line is a strong emission line, the remaining lines are absorption lines.

Figure 8 shows the profiles of the Hβ line and the Fe II 4924 line located on its right wing, taken at different times. As can be seen, one or two emission peaks are observed in the Hβ line at different times. This variation remains constant throughout the season.

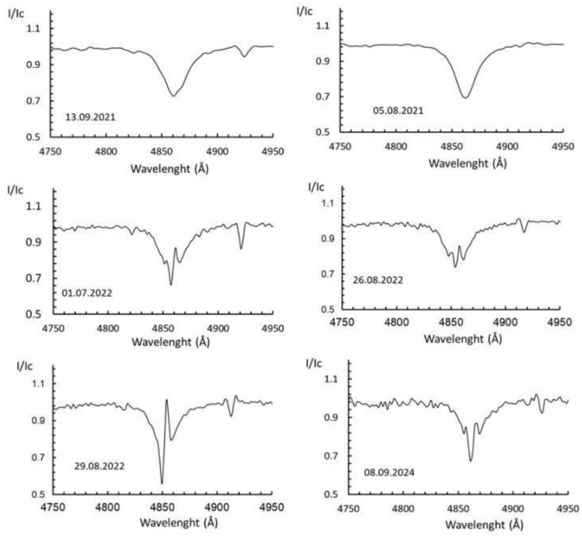

Fig. 8. Change in the profile of the Hβ line. The profile of the Fe II 4924 line is also clearly visible on the right wing of the Hβ line

CONCLUSION

In this work, a photometric and spectral study of the Herbig AeBe type star AS 442 with a complex circumstellar structure was performed. The photometric results were performed with 1300 measurements on each filter taken in UBVR filters in 1982-1996. Statistical Fourier analysis was applied based on the measurement results taken in different seasons and it was shown that no periodic variation observed in all arrays is detected. The obtained photometric variations occur as a result of the shielding of the star's radiation by optically thick gas-dust fragments present in the circumstellar disk.

Spectral studies of the star were performed on the basis of spectra obtained with a resolution of R=3400 on a 2 m telescope at the SHAR during 22 nights in 2020-2024. It was shown that although the absorption and emission spectrum of the star remains stable within different observation seasons, it shows serious changes over the years. It has been shown for the first time that the radiation component observed in the Hβ line is the ejection and return of matter in the circumstellar disk towards the observer. This confirms that active dynamical processes are occurring in the stellar disk.

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AS 442 ULDUZUNUN FOTOMETRİK VƏ SPEKTRAL TƏDQİQİ

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İşdə AeBe Herbiq tipli AS 442 ulduzunun uzunmüddətli spektral və fotometrik müşahidələrinin nəticələri təhlil edilmişdir. 1982-1996-cı illərdə Özbəkistanın Maydanak rəsədxanasında UBVR süzgəclərində alınmış 1300-dən çox ölçmə əsasında ulduzun işıq əyrisi və rəng göstəricilərinin parlaqlıqdan asılılıq əyriləri qurulmuş, statistik Furye analizin tətbiqi ilə müxtəlif sezonlarda bu dəyişmələrin periodik olub-olmaması yoxlanmışdır. Göstərilmişdir ki, parlaqlıq və rənglərin dəyişməsində sabit qalan hər hansı periodiklik aşkar edilmir. Ulduz əksər hallarda parlaq halda olur, lakin üç sezonda böyük amplitudlu tutulmalar aşkar olunmuşdur.

Ulduzun spektral müşahidələri 2020-2024-cü illər ərzində Şamaxı Astrofizika Rəsədxanasının 2 m teleskopunda yerinə yetirilmişdir. Göstərilmişdir ki, ulduzun spektri ciddi dəyişmələr nümayiş etdirir.

Hβ xəttində aşkar olunmuş müxtəlif strukturlu dəyişmələr ulduzətrafı diskdə maddənin atılması və akkresiyası ilə izah edilə bilər. Bu cür profillər müşahidə sezonu daxilində sabit struktur nümayiş etdirir.

Açar sözlər: *cavan ulduzlar, ulduzətrafı disklər, fotometriya, spektroskopiya, obyekt – AS 442.*

ФОТОМЕТРИЧЕСКОЕ И СПЕКТРАЛЬНОЕ ИССЛЕДОВАНИЕ ЗВЕЗДЫ AS 442

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Проанализированы результаты многолетних спектральных и фотометрических наблюдений звезды типа AeBe Хербига AS 442. На основе более 1300 измерений, проведенных в фильтрах UBVR в Майданакской обсерватории в Узбекистане в 1982-1996 годах, построены кривая блеска и кривые зависимости цвета звезды, а также проверена периодичность этих изменений в разные сезоны с применением статистического анализа Фурье. Показано, что устойчивой периодичности в изменениях блеска и цвета не обнаружено. Звезда яркая в большинстве случаев, но в трех сезонах были обнаружены затмения большой амплитуды.

Спектральные наблюдения звезды проводились на 2-метровом телескопе Шамахинской астрофизической обсерватории в течение 2020-2024 годов. Показано, что спектр звезды демонстрирует серьезные изменения. Различные структурные изменения, обнаруженные в линии Hβ, можно объяснить выбросом и аккрецией вещества в околозвездном диске. Такие профили демонстрируют стабильную структуру в течение сезона наблюдений.

Ключевые слова: *молодые звезды, околозвездные диски, фотометрия, спектроскопия, объект – AS 442.*