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ANALYSIS OF SPECTRAL AND PHOTOMETRIC OBSERVATIONS OF THE CH CYG SYMBIOTIC STAR IN 2018

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The paper presents the results of a comparative analysis of the star's light curve with the spectrophotometric parameters of the $H\alpha$, $H\beta$, NaI doublets lines of the D1, D2 and HeI 5876 measured on the basis of highly resolved echelle spectra of the symbiotic star CH Cyg obtained in the 2018th ShAO telescope in 2018 using a modern light receiver. The results of the analysis showed that the equivalent width and intensity of the $H\alpha$, $H\beta$ and HeI 5876 emission lines increase with decreasing star brightness. Even at maximum brightness, the HeI 5876 line disappears. Changes in the values of equivalent widths and intensities of the components of the $H\beta$ line and the light curve V show the same character with the opposite phase. High-velocity wide absorption components with a speed of up to 800 km/s were found in the $H\beta$ and HeI 5876 lines.

The NaI doublet absorption line profiles show a two-component structure, and the change in depth ($1 - I/I_0$) of the red components of the D1 and D2 lines indicates exactly the same feature as the brightness change V.

Keywords: Symbiotic star – CH Cyg – echelle spectra – V magnitude – line profile – equivalent width.

1. INTRODUCTION

CH Cyg is very complex and mysterious variable comprehensively studied in a very large spectral scale. CH Cyg is symbiotic star was revealed in 80th years of 19th century. Photometric observation history for more than 130 years period is available for this star [12]. This is the brightest the closest one among symbiotics.

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The distance to this symbiotic star is about 244 pc according to data of Hipparcos [15].

Its visual magnitude is $V = 6.0^m$ in maximum and 10.5^m in minimum, it is bright in infrared ray and magnitude in $2\mu\text{m}$ is $K = -1^m$. First useful spectra of CH Cyg have been achieved by Joy in 1924 and 1927 [9]. According to 100 days period of well disseminated 5 spectra the spectral type of the star has been determined M6 and radial velocity has been determined -52.5 km/s . There is no information available about emission lines. In 1952 Gaposhkin classified [5] the CH Cyg as M6-M7 spectral class varying in 90-100 days period in 1^m amplitude by analyzing the Harvard patrol observation materials. It was even accepted as a standard star because these alterations were non noticeable in the spectrum. This classification was accepted true until 1963. For the first time Deutsch revealed a strong alteration in the spectrum of the star on September 1963 [4]. In the spectrum of the star hot blue continuum and emission lines of H I, He I, [Fe II] Ca II were observed along with absorption lines of neutral metal, which is the sign of a cold star. It repeated in 1965 again. Since that time the star attracted attentions and was accepted as a symbiotic star.

Periodic photometric, infrared, spectral and radio observations have been conducted thanks to convenient location of the star in the north hemisphere at $+50^\circ$.

Observations show that repetitive active processes occur in the star in various periods. Composition of the star has not been fully identified yet: binary and triple star system models have been proposed [6].

Nowadays, CH Cyg is one of the most researched and the least understood objects [3]. It is accepted that the activity of CH Cyg this star is generated from the energy released as a result of accretion of the red giant's wind by the hot component. The amount of accreting substance is dependent on pulsation of the giant and also on orbital movement of the star, of course if the orbit is elliptic. Several possible commonly accepted models have been proposed to explain the CH Cyg symbiotic system.

Magnetic rotator model [12], according to this model the CH Cyg is a binary star system comprising of a pulsating red giant and white dwarf with a powerful magnetic field moving in 5700 days period in an elliptic orbit. Hinkle [6] identified 756^d period of periodic of radial velocity in the spectrum of CH Cyg. They explained it with existence of the third G-dwarf in the inner orbit with a short period ($P = 756^d$) within the long period ($P = 5300^d$) of binary system. Later, after several observations and precisions, Hinkle refused from the triple stars model and proposed binary symbiotic system for the CH Cyg [7].

By proposing a long period 5650^d in [10] 1998-2001 Mikailov, based on spectra achieved in 1995-2004 Ijima et al. identified that 756^d period in radial velocity exists in optical region too for the spectrum lines of the red giant.

Table 1. Log of Spectral observations of CH Cyg in 2018

Spectrum number in the catalogue	Observation	UT date (day.month.year)	JD2458000+	Exp(s)	number of spectra
KF2271-72.fit	03.05.2018	21:27:03	242.39378	1500	2
KF2288-89.fit	05.05.2018	19:58:46	244.33248	1800	2
KF2431-32-33.fit	24.05.2018	21:26:14	263.39322	1500	3
KF2454.fit	04.06.2018	21:07:22	274.38012	1500	1
KF2483.fit	16.06.2018	21:51:45	286.41094	1200	1
KF2497-98-99.fit	19.06.2018	17:56:55	289.24786	1200	3
KF2508-09-10.fit	21.06.2018	18:42:22	291.27942	1500	3
KF2524-25-26.fit	22.06.2018	17:59:38	292.24975	1500	3
KF2533-39.fit	23.06.2018	19:43:00	293.32153	1500	7
KF2569-70.fit	25.06.2018	19:45:17	295.32311	1500	2
KF2580-81.fit	25.06.2018	21:24:36	295.39208	1500	2
KF2622-26.fit	26.06.2018	21:40:00	296.40278	1500	3
KF2666-67-84-85-92.fit	28.06.2018	23:36:59	298.48402	1500	5
KF2695-98.fit	29.06.2018	18:27:48	299.26931	1500	4
KF2709-11.fit	29.06.2018	20:02:43	299.33522	1500	3
KF2722-25.fit	30.06.2018	18:32:42	300.27271	1500	4
KF2753-56.fit	01.07.2018	18:28:46	301.26998	1500	4
KF2794-95.fit	02.07.2018	17:39:50	302.235995	1500	2
KF2812-13.fit	02.07.2018	19:57:49	302.331817	1500	2
KF2856-57.fit	05.07.2018	19:40:18	305.319653	1500	2
KF2916-17-26.fit	18.07.2018	19:32:48	318.314444	1500	3
KF2940-41.fit	19.07.2018	17:25:09	319.225799	1500	2
KF2942-43.fit	19.07.2018	18:16:07	319.261192	1500	2
KF2975-76.fit	24.07.2018	17:24:16	324.225185	1500	2
KF3011-12-13.fit	26.07.2018	17:55:05	326.246586	1500	3
KF3063-64.fit	29.07.2018	19:06:04	329.29588	1500	2
KF3071-72.fit	30.07.2018	17:28:16	330.227963	1500	2
KF3096-97.fit	02.08.2018	17:25:43	333.226192	1500	2
KF3149.fit	08.08.2018	19:54:23	339.329433	1500	1
KF3166-67.fit	16.08.2018	16:56:25	347.205845	1500	2
KF3273-76.fit	26.08.2018	19:58:53	357.332558	1500	4
KF3319-22.fit	29.08.2018	21:53:59	360.412488	1500	4
KF3325-28.fit	30.08.2018	0:00:23	359.500266	1500	4
KF3357-58.fit	30.08.2018	21:07:24	361.380139	1500	2
KF3361-62.fit	30.08.2018	22:41:33	361.445521	1500	2
KF3373-74.fit	11.12.2018	15:08:20	464.130787	2000	2
KF3382-83.fit	12.12.2018	15:41:12	465.153611	1800	2

These results confirmed that CH Cyg symbiotic system consists of 3 stars.

We CH Cyg symbiotic star introduce the comparison of the spectral parameters of $H\alpha$, $H\beta$, HeI 5876 and NaI doublet lines V light curve of the star based on spectra achieved on Shamakhy Observatory in 2018.

2. OBSERVATIONS AND DATA REDUCTION

All echelle spectra discussed in this paper have been managed in 2 meters telescope of Shamakhy Astrophysical Observatory in 2018 between May÷December, during 31 nights. The telescope is fitted with ShAFES - Shamakhy Fibre Echelle Spectrograph and CCD camera cooled by liquid nitrogen (Mikailov Kh. et al. 2020).

Spectral identification $R=\lambda/\Delta\lambda=28000$, spectral diapason 3900-7700 Å, chip 4096×4096 pixel, pixel size $15\times 15\mu m$. All spectra have been achieved in SLW regime of CCD, gain=1.27 e-/ADU, Read Out Noise (RON) =3.74.

All calibration screens have been achieved for each night: Sky, ThAr, Flat and Darks.

The interval of the observation period was 223 days and in this period nearly 100 echelle spectrum have been achieved. All spectra have been achieved within 119 days in sequence, just 2 spectr have been achieved after about ~ 100 days.

Spectra of the stars γ Lyr and 51 Dracon have been achieved in the same conditions for processing of the telluric lines in the spectra of CH Cyg symbiotic star and spectra of HD148783 (G Her, M6III) have been achieved in some nights for processing of the cold star M spectra. Wavelength calibration achieved with Sky and a ThAr hollow cathode comparison. The spectra were reduced using the software package new version of DECH (www.gazinur.com/DECH-software.htm) following the standard procedures. Extraction of all spectra have been managed by using IRAF mask.

Observation history is given in the table 1. Catalogue list of the spectra and date of achievement, universal time, exposition time and number of spectra achieved within a night have been given in the table.

3. PHOTOMETRICS OF CH CYG

17 nights of photometric observations of CH Cyg have been carried out in ZEISS-600 telescope of Shamakhy Astrophysics Observatory in 2018 July September. The telescope was fitted with 4096×4096 pixel (1 pix = 9 mic) size CCD type of light receiver and photometer with effective fields of view are of 17 arcmin (Abdullayev et al. 2012).

Light curve in V filter for the period of spectral observations of CH Cyg symbiotic star was composed based on our observations and AAVSO7 (www.aavso.org/lcg) database (Fig. 1). In the figure 1 empty circles match with the dates of observations. As it is seen from the figure, the star as active during observations and with in several days it got weakened by 1.5^m and reduced from 6.5^m to 8^m . It got its previous brightness after about 1 month. Fortunately, our spectral observations coincided with that period and covered that dramatic phase of the star.

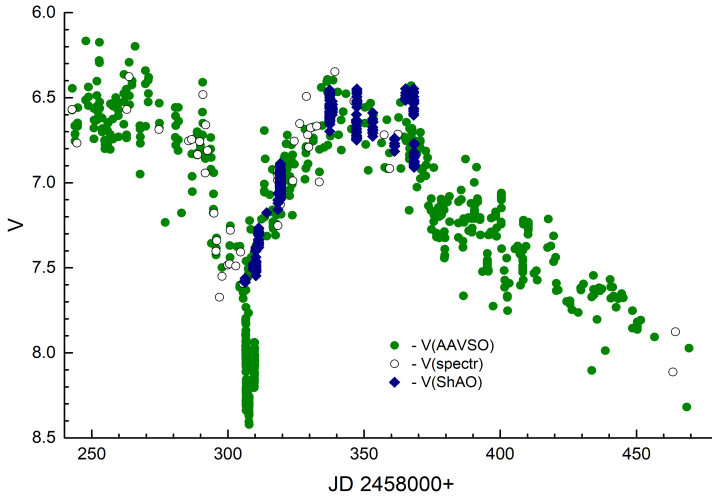


Fig. 1. Light curve of the CH Cyg symbiotic star in V filter. ●- AAVSO, ▲- ShAO data, ○- dates of spectral observations.

4. RESULTS OF MEASUREMENTS

In this paper we only worked with $H\alpha$ and $H\beta$ lines of Balmer series of the Hydrogen atom, HeI 5876 line of Helium atom, doublet lines of NaI D1 and D2 lines of Natrium atom. In the next studies it is planned to researches with the other spectral lines. $H\alpha$ and $H\beta$ lines are very bright and intense as radiation lines, hence it is possible to identify the structure of their profiles with high definition.

5. $H\alpha$ AND $H\beta$ HYDROGEN LINES

Profiles of $H\alpha$ and $H\beta$ lines are given in the Fig. 2. As it is seen from the figure, $H\alpha$ and $H\beta$ lines gave profiles with intensive alteration, centric absorption

and with binary V (Violet) and R (Red) components during period of observations.

In all the spectra red component was more intensive than blue component, e.g.: $8V/R < 1$. It indicates that all time through observations continuous flow of substance occurred. In some profiles the central absorption reduces, even lower than continuum. Large absorption components with high speed have been observed in the violet side of $H\beta$ line. Speed in the violet side of absorption components varies between $-660 \div -900$ km/s. Spectral parameters (ray speed, intensity,

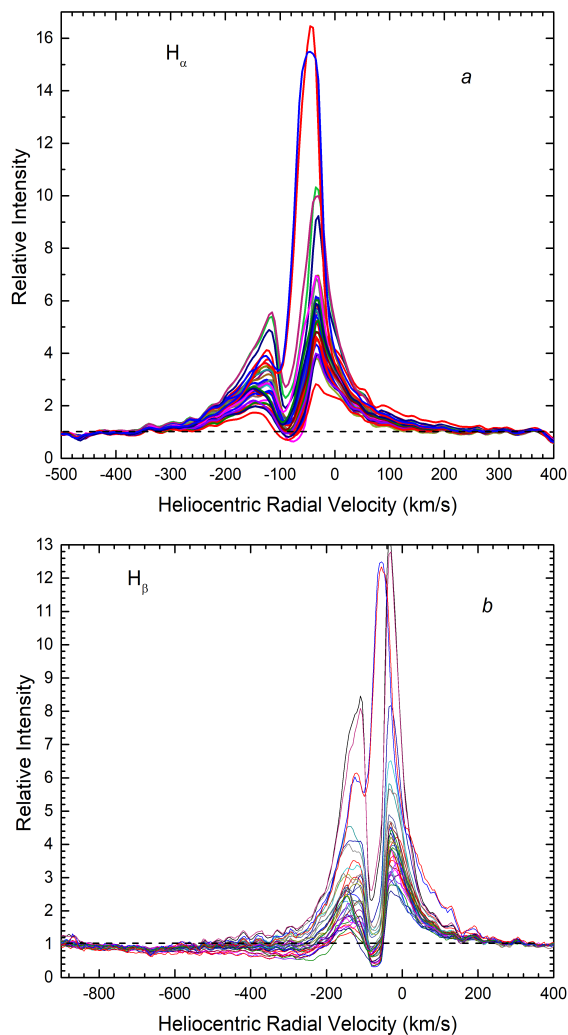


Fig. 2. Profiles of Hydrogen lines. a – $H\alpha$ line, b – $H\beta$ line. Continuum is indicated with dash line.

equivalent widths) of $H\alpha$ and $H\beta$ have been given in the table 2 and 3. Ray speed of R component of $H\alpha$ line was almost in close value in all the dates: $RV = -31 \div -33$ km/s. Only in the last two dates - 11th and 12th of December it slides towards 9 to the violet side in about in 10 km/s and was $RV = -43, \div -45$ km/s. Ray speed of V component was changed in $-116 \div -130$ km/s, and central absorption was changed in $-75 \div -103$ km/s. Alterations in ray speed is perhaps connected with alterations of intensity of V and R components. Ray speed of the second component of the V component is measured $-145 \div -150$ km/s. As it is seen from the table 2, intensity and equivalent width of components of $H\alpha$ line changes in about -5 times during the period of observations. Intensity of R component gets values in $2.8 \div 16.4$ interval, and intensity of V component is gets values in $1.73 \div 5.56$ interval.

While measuring the equivalent width of $H\alpha$ and $H\beta$ components the deepest point of the central absorption was taken as a border. That's why values of equivalent width of components should be considered as conditional. Equivalent width in $H\alpha$ lines got values in the $4.81 \div 29.2$ Å interval. The minimum value was recorded in 26-08-2018 and in that date HeI line disappeared.

$H\beta$ line's R component's ray speed alters more than $H\alpha$ during observation period: $RV = -7.4 \div -33$ km/s, and it got $RV = -52 \div -54$ km/s by sliding towards to the violet side on 11th and 12th of December by ~ 30 km/s. Most probably alteration in the speed is due to sharp change in intensity of R component. Ray speed of the $H\beta$ line R component was $-104 \div -153$ km/s, and ray speed of the central adsorption was close to $H\alpha$: $-70 \div -100$ km/s. Alteration of ray speed perhaps is due to changes in intensity of R and V components.

As it is seen from table 3, intensity and equivalent changes rapidly at the same observation period. Intensity of R component gets value of $2.2 \div 12.84$ and intensity of V component gets value of $1.63 \div 8.47$. Increasement of intensity of V component was 1.7 times more in $H\beta$ line than in $H\alpha$ line. Equivalent width of $H\beta$ line got value in $3.05 \div 23.94$ Å. Minimum and maximum proportion of values of equivalent widths of $H\alpha$ and $H\beta$ line were 6 and 8 respectively.

6. HEI 5876 AND NAI DOUBLET LINES

HeI λ 5876 and NaI doublet lines are the most visible lines after Balmer series lines of Hydrogen in the CH Cyg symbiotic star spectrum. HeI λ 5876 is generated in the adjacent cover around the hot star in the star wind. NaI doublet lines are indicators of star surrounding cover and neutral material zone. Study of these lines will allow to characterize the afore mentioned environments. HeI 5876 and NaI doublet lines profiles are given in the Fig.3. As it is clear from the figure, HeI 5876 and NaI doublet lines changed rapidly during observation season. In parallel

Table 2. Results of measurements of parameters of H α line.

JD 2458000+	RVkm/s				$\dot{I}_{\text{int}}$		EW(Å)		
	R	MU	V1	V2	R	V	R	V	R+V
242.3938	-30.90	-75.40	-124.00		5.70	3.90	9.20	6.25	15.45
244.3325	-30.60	-78.50	-124.00		5.85	4.20	10.45	6.39	16.85
263.3932	-32.40	-77.50	-127.00		5.34	3.68	6.88	6.15	13.03
274.3800	-31.79	-77.64	-125.90		3.98	2.30	6.40	3.52	10.07
286.4109	-31.98	-83.26	-128.28		4.92	2.95	6.86	4.48	11.35
289.2479	-31.90	-89.90	-129.40		9.26	4.85	13.27	7.63	20.09
291.2791	-32.24	-81.74	-127.46		5.58	2.95	7.47	4.39	11.86
292.2497	-32.34	-83.85	-123.64		5.67	3.34	7.80	4.95	12.76
293.2864	-32.44	-81.74	-127.46		6.05	3.60	7.80	4.91	12.72
295.3231	-32.92	-84.46	-125.10		5.40	3.50	6.77	5.27	12.04
295.3921	-32.65	-84.89	-125.44		5.24	2.96	6.90	4.45	11.34
296.4028	-34.00	-86.65	-123.02		5.59	3.37	7.28	5.33	12.61
298.4840	-31.85	-84.08	-122.77		6.95	3.19	9.02	5.21	14.23
299.2693	-32.69	-87.82	-117.61		10.25	5.42	14.48	8.75	23.24
299.3352	-32.97	-88.78	-116.39		9.96	5.56	15.45	9.08	24.51
300.2727	-33.53	-84.72	-124.78		6.08	2.76	7.25	4.29	11.54
301.2700	-33.12	-86.26	-123.80		6.10	2.81	7.51	4.50	12.02
295.3231	-32.92	-84.46	-125.10		5.40	3.50	6.77	5.27	12.04
295.3921	-32.65	-84.89	-125.44		5.24	2.96	6.90	4.45	11.34
296.4028	-34.00	-86.65	-123.02		5.59	3.37	7.28	5.33	12.61
298.4840	-31.85	-84.08	-122.77		6.95	3.19	9.02	5.21	14.23
299.2693	-32.69	-87.82	-117.61		10.25	5.42	14.48	8.75	23.24
299.3352	-32.97	-88.78	-116.39		9.96	5.56	15.45	9.08	24.51
300.2727	-33.53	-84.72	-124.78		6.08	2.76	7.25	4.29	11.54
301.2700	-33.12	-86.26	-123.80		6.10	2.81	7.51	4.50	12.02
302.2371	-33.40	-81.15	-126.10	-147.99	3.78	2.51	4.16	3.99	8.14
302.3335	-33.83	-82.55	-125.54	-146.35	4.31	2.99	5.00	5.19	10.19
305.3197	-32.60	-80.17	-123.00	-149.13	4.47	2.48	5.28	3.70	8.98
318.3163	-33.33	-87.39	-117.75	-145.76	6.87	2.96	8.52	4.71	13.24
319.2258	-34.53	-85.78	-119.61	-148.84	5.13	2.49	6.17	3.80	9.97
319.2258	-33.78	-85.52	-119.87	-147.90	5.37	2.55	6.61	4.02	10.63
324.2252	-33.81	-84.19	-129.36	-146.43	4.61	1.98	6.12	2.44	8.57
326.2485	-31.67	-88.20	-126.89	-144.20	4.54	2.08	5.82	2.38	8.20
329.2959	-32.59	-90.09	-123.75	-144.31	6.13	2.53	8.18	3.34	11.52
330.2104	-32.66	-93.40	-124.78		6.90	2.84	9.82	4.25	14.08
333.2262	-31.33	-85.96	-129.75	-143.42	5.24	2.11	7.09	2.39	9.48
339.3314	-31.56	-84.86		-143.90	3.97	1.96	4.81	2.33	7.14
347.2058	-32.88	-88.61		-147.81	4.00	2.19	5.08	2.65	7.74
357.3326	-32.73	-87.33		-145.05	2.80	1.73	3.32	1.49	4.81
360.4125	-32.51	-90.11	-127.50	-152.23	4.77	2.66	6.78	3.81	10.59
360.5003	-32.23	-90.61	-126.46	-149.75	5.45	2.71	7.55	4.03	11.58
361.3819	-32.96	-96.03		-147.32	6.02	2.71	8.80	3.99	12.79
361.4455	-32.84	-95.02		-148.05	5.92	2.65	8.48	3.74	12.22
464.1308	-43.36	-104.30	-127.07		16.43	3.59	21.83	5.09	26.93
465.1536	-45.21	-103.18	-127.80		15.45	3.90	23.76	5.44	29.20

Table 3. Results of measurements of parameters of $H\beta$ line.

JD 2458000+	RVkm/s			$\dot{I}_{int}$		EW(Å)		
	R	MU	V	R	V	R	V	R+V
242.3938	-19.55	-71.32	-123.74	3.62	3.00	4.09	2.34	6.43
244.3325	-15.12	-70.91	-123.75	4.19	3.51	5.35	2.93	8.28
263.3932	-32.54	-70.36	-132.60	2.92	2.51	2.66	2.26	4.92
274.3800	-21.58	-71.30	-104.22	2.23	1.63	3.71	0.81	4.52
286.4109	-22.64	-71.71	-113.63	2.77	1.83	2.67	0.98	3.65
289.2479	-29.78	-71.73	-110.65	4.38	3.01	4.13	2.84	6.97
291.2791	-27.89	-72.12	-111.22	3.07	1.82	3.18	0.81	3.99
292.2497	-18.78	-71.59	-113.89	3.06	2.02	3.41	1.18	4.59
293.2864	-21.01	-71.96	-114.92	3.40	2.29	3.57	1.31	4.88
295.3231	-30.46	-72.30	-123.61	3.89	2.81	3.69	2.49	6.18
295.3921	-26.69	-73.39	-125.94	3.84	2.31	3.90	1.41	5.31
296.4028	-31.90	-73.19	-134.80	5.85	4.54	6.40	5.94	12.37
298.4840	-29.78	-74.94	-126.41	8.15	4.08	8.90	5.36	14.26
299.2693	-32.84	-79.45	-109.03	13.19	8.47	12.83	11.12	23.95
299.3352	-31.71	-80.40	-109.87	12.84	8.02	12.78	10.71	23.49
300.2727	-31.31	-75.68	-116.67	6.47	3.36	6.50	4.60	11.09
301.2700	-30.00	-74.96	-111.40	4.88	2.77	4.70	3.19	7.90
302.2371	-25.92	-71.83	-137.74	4.07	3.10	4.39	4.00	8.40
302.3335	-26.53	-72.16	-134.38	4.66	3.99	5.23	6.05	11.28
305.3197	-25.47	-73.36	-132.24	5.67	3.13	6.25	3.89	10.15
318.3163	-30.82	-79.48	-137.88	4.50	2.63	4.57	2.61	7.20
319.2258	-33.68	-78.61	-150.18	3.36	2.20	3.22	1.55	4.78
319.3172	-30.03	-74.87	-149.10	3.19	2.08	2.83	1.20	4.10
324.2252	-23.40	-79.68	-138.03	3.51	1.36	3.90	0.30	4.12
326.2485	-29.26	-80.11	-145.35	3.78	1.57	4.08	0.61	4.69
329.2959	-30.56	-79.54	-114.00	2.55	1.87	4.28	0.86	5.14
330.2104	-28.89	-83.12	-136.33	3.79	1.77	3.62	0.88	4.50
333.2262	-27.21	-79.64	-144.54	4.41	1.48	4.53	0.36	4.89
339.3314	-29.84	-77.49	-153.23	2.58	1.47	2.54	0.51	3.05
347.2058	-12.74	-80.77	-141.11	3.43	2.23	4.03	1.23	5.26
357.3326	-7.38	-81.64	-145.22	3.11	1.86	3.69	1.05	4.74
360.4125	-30.12	-84.25	-147.68	4.65	2.79	5.11	2.02	7.13
360.5003	-29.71	-84.49	-145.58	4.20	2.46	4.52	1.58	6.10
361.3819	-23.09	-85.64	-147.57	3.95	2.69	4.35	1.94	6.29
361.4455	-22.48	-85.92	-147.91	3.81	2.45	4.23	1.52	5.75
464.1308	-54.62	-102.14	-121.35	12.45	6.02	17.54	7.04	24.58
465.1536	-52.36	-100.12	-120.83	12.26	6.13	18.13	6.48	24.61

with strengthening of HeI 5876 line (increasing of the intensity), strong emission lines appear in the red wing of the NaI doublet lines and it converts to P Cyg type of profile. Both of the doublet lines of NaI demonstrate binary structure compris-

ing of deep adsorption especially in the bright period of the star. HeI 5876 line almost disappears in maximum brightness and even large adsorption is observed. In the table 4 the results of spectrophotometric measurements of HeI 5876 and NaI doublet lines have been introduced. Ray speeds of each component of the NaI doublet lines demonstrates very close values. Ray speeds of the R components of D1 and D2 lines are varying in $-73 \div -85$ km/s interval and ray speed of the V component is varying in $-97 \div -103$ km/s interval. R-red component demonstrates the same radial speed with neutral hydrogen zone, i.e., the central absorption of Hydrogen lines (Fig.4). It is assumed that the R obsorption components of lines NaI D1 and D2 arise in the neutral absorption region.

Deepness of R and V components of NaI D1 line change in $0.59 \div 0.81$ and $0.40 \div 0.86$ interval respectively.

7. ANALYSIS OF PARAMETERS OF $H\alpha$ AND H LINES BY USING THE LIGHT CURVE

V light curve comparison of equivalent width and components' intensity of $H\alpha$ and $H\beta$ lines in the spectrum of CH Cyg symbiotic star have been introduced in the Fig.5 and 6 respectively. In the figures the right axes are in the increasing order towards to down. Comparison of equivalent widths of $H\alpha$ and $H\beta$ lines with light curve shows that, the typical feature for symbiotic stars - increase in equivalent width with decrease in brightness - is observed here. This principle failed in $H\alpha$ line in the dramatic phase (short term change in brightness) of the star.

As it is seen from the picture, character of changes in component's intensity and equivalent width of $H\beta$ line during the observation period fully coincide with changes of brightness in V filter. It makes opposite correlation, it means, equivalent width and intensity of the line increases as the brightness decreases.

8. ANALYSIS OF NAI DOUBLET AND HEI 5876 LINES BY USING THE LIGHT CURVE V

In the Fig.7 it is given the comparison of intensity of R components of NaI doublet lines with V light curve. As it is seen from the picture, changes of intensity of red components of D1 and D2 adsorption lines are the same for both lines and it demonstrates identical character with changes in light curve in V filter. Decrease in the deepness of the line is observed by decrease in brightness.

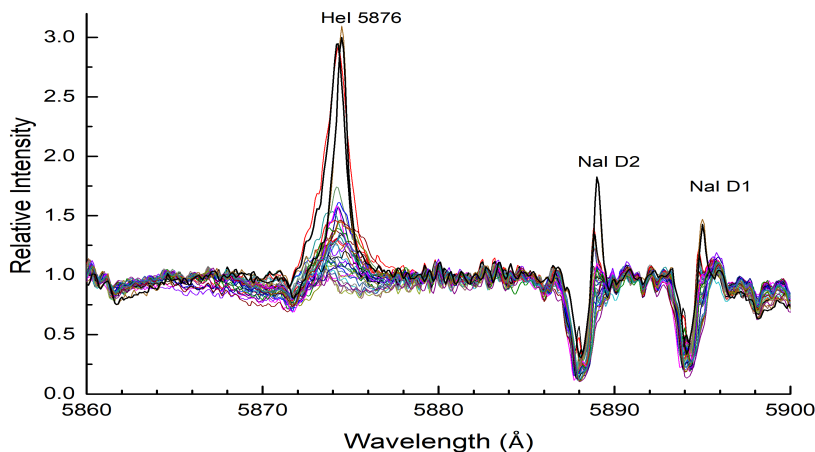


Fig. 3. Profiles of HeI λ 5876 and NaI D1, D2 lines.

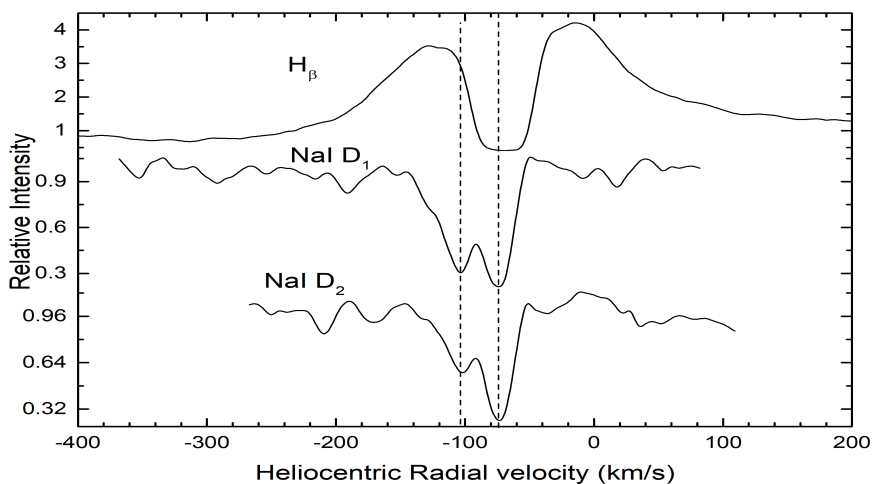


Fig. 4. Profiles of $H\beta$ and NaI D1 and D2 lines.

9. ANALYSIS OF HEI 5876 LINE WITH V LIGHT CURVE.

V light curve comparison of HeI 5876 line intensity and equivalent width has been introduced in the Fig. 8. As it is seen from the figure, convenience is observed in the character of changes of graphs if we do not consider the dramatic phase of the star. Values of equivalent width and intensity increases with decrease in the value of brightness. Usually, line's intensity and equivalent width decreases down

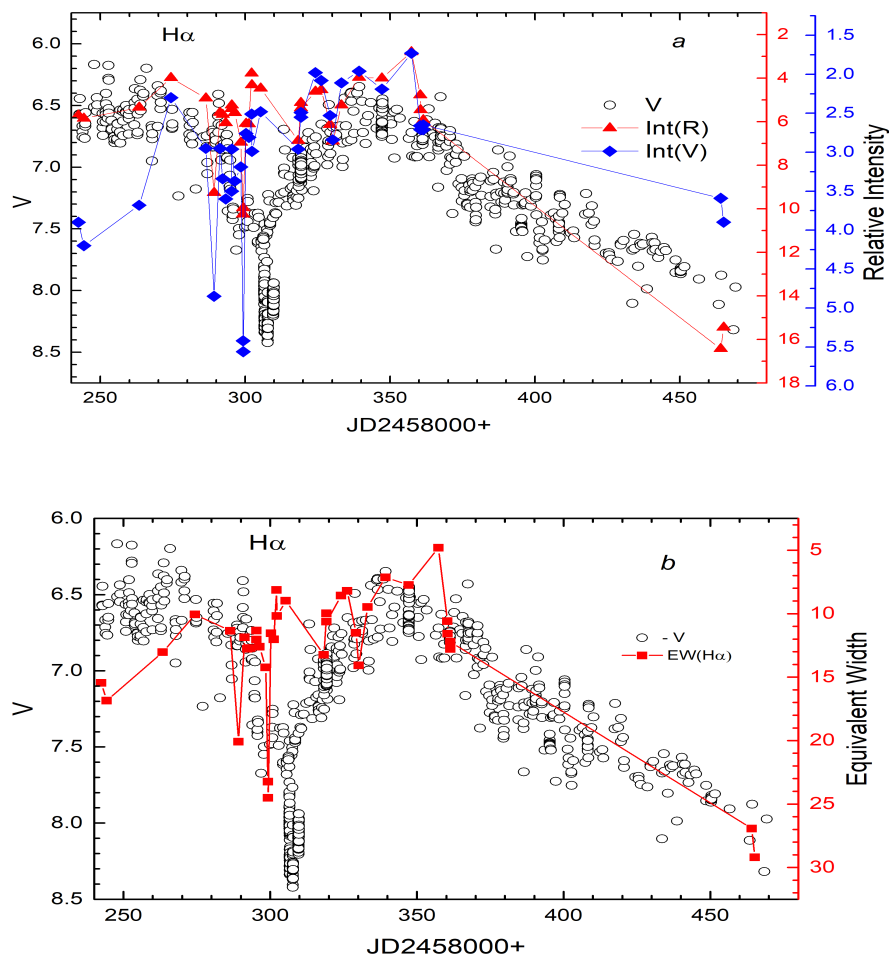


Fig. 5. Time changes of V light curve of CH Cyg symbiotic star and spectrophotometric parameters of H α line. a – changes in intensities, b – changes in equivalent width, $\circ$ – V filter light curve, $\blacktriangle$ – intensity of R component, $\blacklozenge$ – intensity of V component, $\blacksquare$ – equivalent width.

to seamless spectrum level as the brightness increases. Even it was observed that HeI 5876 line disappeared for 3 days in the maximum of brightness.

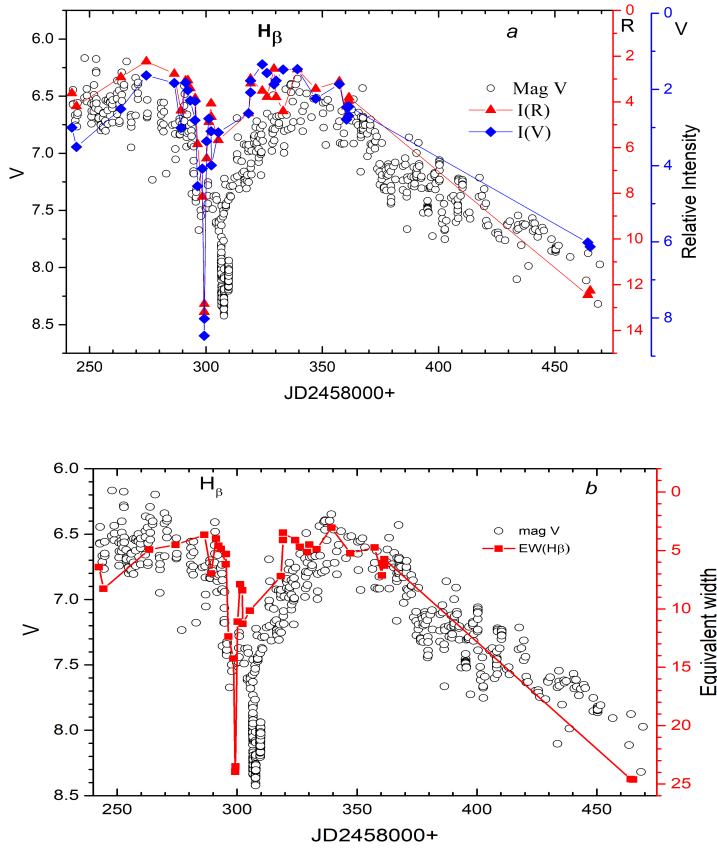


Fig. 6. Time changes of V light curve of CH Cyg symbiotic star and spectrophotometric parameters of H β line. a – changes in intensities, b – changes in equivalent width, $\circ$ – V filter light curve, $\blacktriangle$ - intensity of R component, $\blacklozenge$ - intensity of V component, $\blacksquare$ - equivalent width.

10. ANALYSIS OF CHANGES IN CH CYG SYMBIOTIC STAR

In some of our spectra V component of the H α and H β lines and HeI 5876 line was found with complex structure and multiple components. As we already know, the emission lines are formed in the cloud around the hot star and enlargement of the surrounding cloud can lead to formation of several components. Existence of adsorbing substance around the star in the visual direction causes formation of the central adsorption in the profile of the emission lines. In most cases central adsorption gets a very close speed to the mass center speed (-60 km/s). But if we don't consider the spectra achieved in the last two dates of our observation, the central adsorption slides towards the blue side of the spectrum

Table 4. Results of measurements of NaI doublet and HeI 5876 lines.

JD	2458000+	NaI D1					NaI D2					HeI 5876			
		RV		Int		EW	RV		Int		EW	Int			
		R	V	R	V	R+V	R	V	R	V	R+V				
		242.3938	-73.2	-102.3	0.76	0.40	0.59	-74.6	-103.7	0.79	0.64	0.83	-48.8	1.33	0.59
		244.3325	-73.8	-101.8	0.74	0.41	0.59	-75.4	-103.9	0.78	0.69	0.84	-62.5	1.46	1.26
		263.3932	-73.1	-102.4	0.78	0.67	0.99	-75.4	-103.7	0.81	0.84	1.29	-111.6	1.15	0.26
		274.3800	-76.9	-102.9	0.81	0.80	0.92	-79.3	-105.3	0.82	0.89	1.12			
		286.4109	-74.7	-102.9	0.79	0.61	0.88	-77.1	-104.2	0.81	0.80	1.13	-71.4	1.11	0.14
		289.2479	-74.5	-99.3	0.78	0.57	0.81	-76.6	-103.2	0.80	0.79	1.03	-59.9	1.56	0.62
		291.2791	-75.3	-100.8	0.79	0.61	0.81	-77.5	-103.8	0.80	0.79	1.04	-38.1	1.10	0.18
		292.2497	-74.3	-102.1	0.80	0.64	0.95	-90.4	-103.9	0.81	0.81	1.30	-65.6	1.29	0.87
		293.2864	-75.1	-102.3	0.77	0.66	0.98	-78.4	-104.6	0.78	0.86	1.28	-65.4	1.37	0.75
		295.3231	-75.8	-102.8	0.74	0.70	0.84	-78.7	-104.8	0.76	0.85	1.07	-84.0	1.07	0.07
		295.3921	-77.0	-102.5	0.73	0.70	0.83	-80.6	-104.7	0.74	0.85	1.09	-88.5	1.12	0.11
		296.4028	-79.0	-102.2	0.67	0.71	0.73	-84.3	-104.0	0.72	0.84	0.92	-84.0	1.53	1.00
		298.4840	-73.4	-101.0	0.65	0.71	0.70	-82.4	-103.4	0.68	0.81	0.85		1.32	0.60
		299.2693	-77.8	-101.8	0.59	0.67	0.65	-82.0	-104.3	0.65	0.82	0.82		2.90	3.39
		299.3352	-77.1	-101.3	0.59	0.68	0.65	-82.0	-103.7	0.64	0.80	0.81	-64.6	2.95	2.74
		300.2727	-81.3	-102.4	0.64	0.68	0.68	-84.2	-105.2	0.67	0.79	0.85	-100.2	1.10	0.06
		301.2700	-79.0	-101.6	0.65	0.72	0.72	-83.7	-104.7	0.71	0.84	0.93		1.04	0.02
		302.2371	-82.4	-99.7	0.69	0.75	0.82	-87.4	-104.5	0.74	0.81	0.97		1.07	0.01
		302.3335	-81.5	-101.6	0.66	0.75	0.76	-86.0	-105.4	0.71	0.79	0.92	-97.6	1.22	0.24
		305.3197	-83.8	-98.5	0.67	0.77	0.72	-86.9	-101.8	0.73	0.82	0.89			
		318.3163	-77.7	-100.5	0.74	0.75	0.87	-82.0	-102.8	0.79	0.86	1.07	-68.2	1.74	1.29
		319.2258	-80.3	-100.9	0.78	0.78	0.91	-84.8	-102.5	0.81	0.88	1.12	-81.7	1.25	0.37
		319.2258	-80.6	-101.1	0.77	0.79	0.92	-85.0	-103.4	0.82	0.88	1.15	-82.9	1.15	0.16
		324.2252	-79.6	-101.1	0.77	0.79	0.89	-86.4	-102.8	0.81	0.87	1.12	-61.5	1.20	0.33
		326.2485	-79.7	-101.0	0.74	0.70	0.80	-80.9	-103.3	0.76	0.84	1.02	-71.3	1.30	0.63
		329.2959	-78.2	-102.1	0.72	0.68	0.79	-82.4	-101.7	0.78	0.83	1.08	-64.4	1.60	0.97
		330.2104	-76.0	-100.9	0.70	0.63	0.76	-78.6	-102.9	0.77	0.82	1.06	-70.6	1.57	0.72
		333.2262	-78.0	-99.8	0.74	0.68	0.83	-81.1	-103.1	0.80	0.82	1.04	-72.3	1.39	0.80
		339.3314	-77.9	-98.4	0.79	0.75	0.98	-84.5	-100.7	0.85	0.89	1.21	-56.2	1.10	0.11
		347.2058	-82.5	-98.4	0.78	0.80	1.05	-83.4	-99.8	0.82	0.88	1.28	-59.8	1.26	0.51
		357.3326		-97.2		0.86	1.14		-101.5		0.90	1.37			
		360.4125		-99.8		0.82	1.05		-102.7		0.88	1.21	-44.9	1.46	1.05
		360.5003		-99.4		0.82	1.06		-101.8		0.89	1.26	-55.1	1.45	0.93
		361.3819	-81.9	-99.9	0.72	0.78	0.99	-84.5	-101.4	0.78	0.87	1.10	-62.7	1.35	0.61
		361.4455	-83.5	-99.4	0.73	0.79	1.00	-86.4	-102.0	0.80	0.88	1.14	-70.8	1.32	0.56
		464.1308		-101.1		0.68	0.50		-105.3		0.76	0.63	-65.5	3.07	2.07
		465.1536		-100.4		0.66	0.51		-104.5		0.69	0.60	-66.0	2.95	2.16

in about 20 -25 km/s and demonstrates the speed of ~ -70 km/s, -85 km/s. This is because the speed of the wind of the adsorbing particles in the neutral hydrogen region is greater than the speed of wind of released particles in the ionized

region. Absorption particles arrive in sooner than released particles. Deepness of the adsorbing component shows the density of the star wind (Burmeister M., and Leedjarv L., 2007). Also, if we consider that, $H\alpha$ and $H\beta$ lines form in the disc around the star, formation of binary component profile can be explained by this factor. Rapid destruction of binary component profile and especially decreasing the intensity of V component are explained by destruction of the disc (Burmeister, M. and Leedjarv, L., 2007). V/R proportion's being always less than 1 in our observations shows that continuous substance flow exists from the hot star.

Short term rapid changes in the star can be explained with the fact that, being in proximity for some years gives its effect when the hot star of the symbiotic system gets closer to the giant star, i. e., when the star moves through the periastron (Because the period is very long in CH Cyg star - 15 years). In this period intensity and amount of flow of substance from the giant star increases. As a result of that, stability of the disc around the hot star spoils and jet of substances are observed from the hot star and this is followed by rapid changes in $H\alpha$ and $H\beta$ lines (Wallerstein et al. 2010).

Emission lines with high ionization potential, including HeI 5876 are formed in the region near the hot star. Rapid changes in the HeI 5876, getting disappeared of the line and formation can be related to changes of ultraviolet rays emitting from the hot star. Photometric rapid changes prove that firmly.

The fact of ray speeds of NaI D1 and D2 doublet lines red components and central adsorption of $H\alpha$ and $H\beta$ getting the same value confirms that they have been formed in the same environment and in the neutral region around the star.

Increase in the deepness of red component of D1 and D2 lines of NaI with increase of brightness of the star can be estimated a result of enrichment of the neutral region with Na atoms and vice versa. The other approach is also possible. Decrease in the brightness of the star after the active phase of the symbiotic star CH Cyg can be explained with screening too. Strong release of substance in the active period results in getting the gas-dust cloud denser around the star. As a result of that, the star becomes screened and brightness decreases. Formation of a strong emission in the red wing of the NaI doublet lines and at the same time reinforcement of the emission lines $\lambda 6548 \text{ \AA}$ and $\lambda 6584 \text{ \AA}$ of [NII] which is the main indicator of the gas-dust cloud once again proves that. The same time increase in the equivalent width and intensity of $H\alpha$, $H\beta$ and HeI 5876 lines in several times while rapid collapse decreasing of brightness can be explained with changes in the density of the surrounding cover.

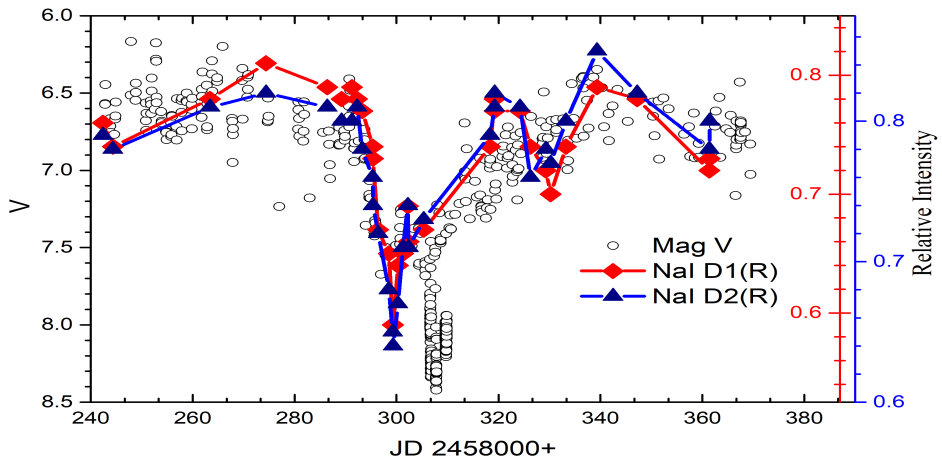


Fig. 7. Timely changes of V light curve of CHCyg symbiotic star and deepness of red components of NaI doublet lines of D1 and D2. $\circ$ – V filter light curve, $\blacklozenge$ and $\blacktriangle$ – deepness of D1 and D2 lines respectively.

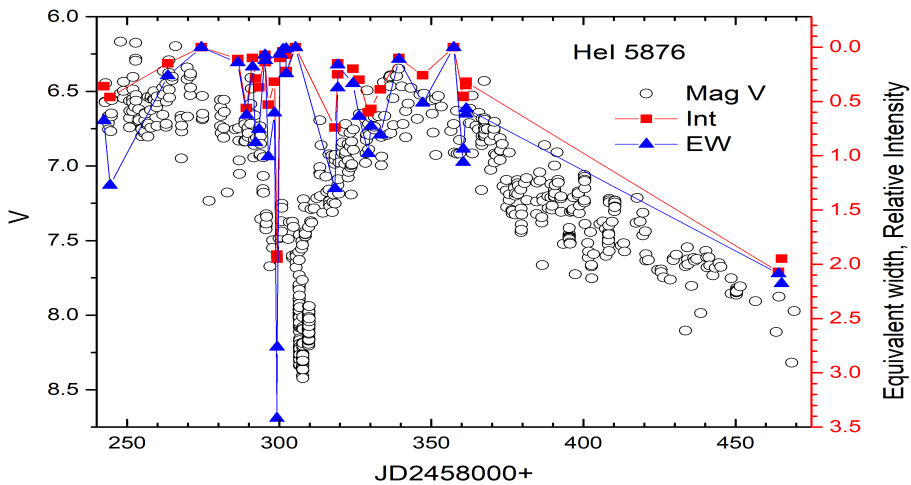


Fig. 8. Time based change of intensity and equivalent width of HeI 5876 and V filter light curve of CH Cyg symbiotic star. $\circ$ – brightness in the V filter, $\blacksquare$ – intensity, $\blacktriangle$ – equivalent width.

11. THE MAIN RESULTS

Following results have been summarized from the analysis of the CCD echelle spectra of CH Cyg symbiotic system achieved in 2018 for the first time.

1. Spectrophotometric parameters of $H\beta$ emission line such as equivalent width, intensity of the red and violet components provide alteration with the same character and opposite phase changes with light curve in V filter.

2. Profiles of both D1 and D2 doublet lines of NaI represents binary component structure and changes in the intensity of both lines' red component match with the character of changes in V light curve.

3. Rapid alteration of HeI λ 5876 Å line and full disappearing of emission have been observed.

4. Absorption jets with the speed of -800km/s have been observed in the violet wing of $H\beta$ and HeI λ 5876 lines.

REFERENCES

1. Abdullayev, B.I., Alekberov, I.A., Gulmaliyev, N.I., et al., 2012, Azerbaijani Astronomical Journal, №4, p.39-47.
2. Burmeister, M.; Leedjäv, L., 2009, Astronomy and Astrophysics, v. 504, Issue 1, 2009, pp.171-180.
3. Contini, M., Angeloni, R., Rafanelli, P., 2009, Astronomische Nachrichten, Vol.330, Issue 8, p.816.
4. Deutsch, A.J., 1964, Ann. Rep. Mt. Wilson and Palomar Obs.1963-1964, p.11-15.
5. Gaposchkin, S., 1952, The Observatory, vol.118, p.155-163.
6. Hinkle, K. H., Fekel, F.C., Johnson, D.S., Scharlach W.W.G., 1993, AJ, 105,107.
7. Hinkle K.H., Fekel F.C., Joyce R., 2009, ApJ, 2009, 692, 1360.
8. Iijima, T., Naito, H. and Narusawa, S., 2018, Astronomy & Astrophysics, v.622, A45, p.2-15.
9. Joy, Alfred H., 1942, ApJ, 96, 344.
10. Mikailov, Kh. M.; Khalilov, V. M., 2005, Kinematika i Fizika Nebesnykh Tel, vol. 21, no. 6, p. 452-460.
11. Mikailov, Kh. M.; Musaev, F. A.; Alekberov, I. A.; Rustamov, B. N.; Khalilov, O. V., 2020, Kinematics and Physics of Celestial Bodies, 2020, vol. 36, issue 1, pp. 22-36.

12. Mikolajewski, M., Mikolajewska, J., Khudiakova, T. N., 1990, *Astronomy and Astrophysics*, vol. 235, no. 1-2, p. 219-23.
13. Mikołajewski, M., Mikołajewska, J., Tomov, T., Kulesza, B., Szczerba, R., 1990, *AcA*, 40, 129.
14. Skopal, A, Vanko, M., Pribulla, T., et al., 1996, *Mon. Not. Roy. Astron. Soc.* 282, 327.
15. Van Leeuwen, F., 2007, *Astrophysics and Space Science Library*, Volume 350.
16. Wallerstein, George; Munari, U.; Siviero, A.; Dallaporta, S.; Dalmeri, I., 2010, *Publications of the Astronomical Society of the Pacific*, V. 122, Issue 887, pp. 12-16. www.gazinur.com/DECH-software.htm <https://www.aavso.org/lcg>

CALCULATION OF THE PROFILE OF THE CORONAL LINE $\lambda 171$ Fe IX IN THE EMISSION SPECTRUM OF SLOW MAGNETO-SONIC WAVES PROPAGATING IN THE SOLAR CORONA. 1. THE CASE OF CONSTANT DENSITY.

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The line profiles $\lambda 171$ Å Fe IX in the emission spectrum of slow magneto-sonic waves propagating in coronal loops are calculated for an optically thin layer and constant density cases. The line profiles were calculated at the following parameter values: the amplitude of the velocity at the wave $v_0 = 10$ km/s, the coronal loop width 2000 km and 5000 km, the wavelength $\Lambda = 20,000$ km and 50,000 km, the Doppler width $\Delta\lambda_d = 0.01$ Å and also at the values of sight angle and various phases of the wave. It is shown that the energy flux density and the values of the Doppler width strongly depend on the angle z and the phase of the wave.

Keywords: Line profiles–solar corona–coronal spectral lines–magneto sonic waves

1. INTRODUCTION

The research of MHD waves in coronal structures has excellent importance in coronal seismology. These waves can play a significant role in the corona's heating; besides, investigating these waves make it possible to study the solar corona's physical structure. Slow magneto-sonic waves are considered one of the candidates of heating the solar corona: these waves are generated in the photosphere as a p-mode, penetrate the corona without being reflected, are damped by the heat conduction mechanism, and consequently, can heat the corona.

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MHD waves in the corona were studied mainly from a theoretical point of view until the 90s of the last century. In the early 2000s, intensive extra-atmospheric observations of these waves in the corona spectrum's UV region was begun. Information about these problems could be found in the review articles [1–6]. In the present paper, the $\lambda 171$ Fe IX line profile in the spectrum of slow magneto-sonic waves propagating into coronal loops is calculated. Observations of these waves are often carried out in the indicated line [6].

Let us give the observed values of the physical parameters of slow magneto-sonic waves: the propagation velocity - 25-200 km/s, the amplitude of the intensity oscillations -0,7-14,6%, the oscillation period - 145-550 s [6], the energy density flux: $313 - 610^6$ [7, 8] $\text{erg } \text{sm}^{-2} \text{ s}^{-1}$

It should be noted that in the chromosphere and corona, Doppler shift's velocities are almost an order of magnitude less than the values of non-thermal velocities found by the Doppler widths [9].

2. DERIVATION OF THE EXPRESSION FOR THE SPECTRAL LINE PROFILE

Our task - calculating the emission line profile emanating from the coronal loop along the line of sight - LZ, making an angle θ with the loop axis. As far as we know from the literature, the spectral emission line profiles in the spectrum of slow magneto-sonic waves propagating in coronal structures were not calculated.

Let us assume that the coronal loop is optically thin and that the density does not change on the wave (in the following paper, we plan to consider the case with a changing density).

The emission profile of every elementary volume along the angle of sight is Doppler, with the Doppler width $\Delta\lambda_d$, which we accept constant along the line of sight.

Fig. 1 shows the diagram of propagation of slow magneto-sonic wave inside the coronal loop with diameter H on the direction of the X-axis of the XY coordinate system, the origin of which is located in the zero phases of the considered wave; the X and Y axes are located along and perpendicular to the loop axis, respectively. All signs were described in the text under Fig. 1. The amount of emission emanating from elementary volume $dl \cdot 1 \text{sm}^2$ located at distance l from the surface of the coronal loop, transmitting to the wavelength $\delta\lambda$ from the center of the line, is:

$$di = (\Delta\lambda) = i_0 \exp \left[- \left(\frac{\Delta\lambda - \frac{\nu l}{c} \lambda}{\Delta\lambda_d} \right)^2 \right] dl \quad (1)$$

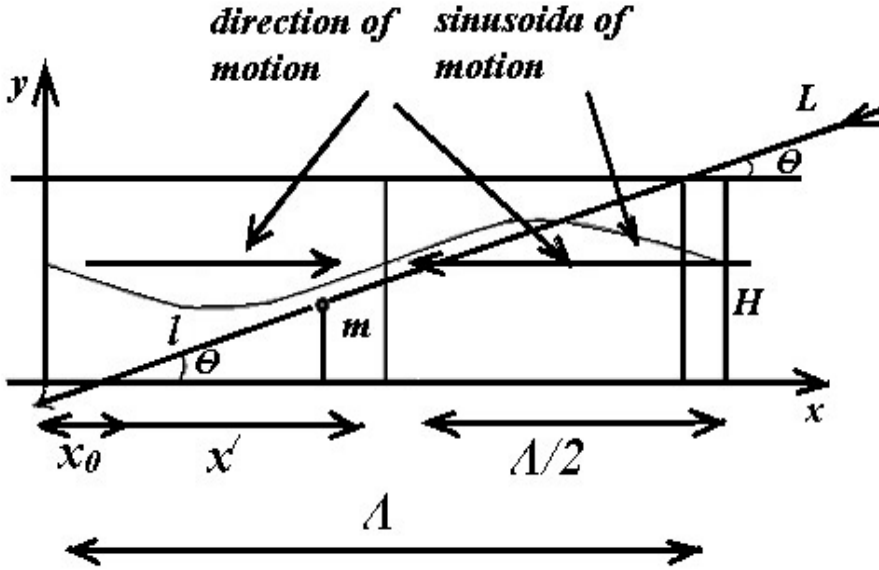


Fig. 1. Scheme of propagation of a slow magneto-sonic wave in a coronal loop; here H - the loop diameter, Λ - the sonic wavelength, L_s - the line of sight, θ - the angle between the line of sight and the direction of the loop axis, x_0 - the distance from the point of the zero phase of the wave (this point is also the origin of the coordinate system) to the intersection of the line of sight with the X -axis of the coordinate system; characterizes the phase x' - the distance along the X -axis from the point of intersection of the line of sight with the X -axis to the current considered elementary volume m , l - the distance along the line of sight from the point of intersection of the line of sight with the X -axis to the to the considered current elementary volume m

Here: i_0 - central intensity of emission profile of selected elementary volume, accepted to be constant along the whole length of the line of sight, L_s $\nu(l)$ - the rate of particles on the wave at distance l , s - speed of light. Then, the emission intensity from the entire length L of the line of sight at a distance $\delta\lambda$ from the center of the emission line will be:

$$I(\Delta\lambda) = i_0 \int_0^L \exp \left[- \left(\frac{\Delta\lambda - \left(\frac{\nu l}{c} \lambda \right)}{\Delta\lambda_d} \right)^2 \right] dl \quad (2)$$

Now we need to find $\nu(l)$. Particles motion at sonic wave is occurred along wave propagation by sine law (as can be seen from Fig. 1: $x = x_0 + x'$):

$$v(x) = \nu_0 \sin\left(\frac{2\pi x}{\Lambda}\right)$$

For the lines of sight passing through the same x_0 (this magnitude approximately characterizes the wave phase), conveniently use the expression, replacing $x = x_0 + x'$, and in this case, the variable will be x'

$$\nu(x') = \nu_0 \sin\left(\frac{2\pi(x_0 + x')}{\Lambda}\right) \quad (3)$$

Here: ν_0 - the velocities amplitude of particles' oscillations on the wave - wavelength of propagating slow magneto-sonic wave. It is obvious that the projection of the particle velocities amplitude on the line of sight will be:

$$\text{Further } \nu_{0L} = \nu_0 \cos \theta \quad (4)$$

$$\text{Then } x' = l \cos \theta \quad (5)$$

$$\nu = (l) = \nu_0 \cos \theta \sin\left[\frac{2\pi(x_0 + l \cos \theta)}{\Lambda}\right] \quad (6)$$

Putting (6) in (2), we obtain the final expression for calculating the spectral line's profile.

$$I(\Delta\lambda) = i_0 \int_0^L \exp\left[-\left(\frac{\Delta\lambda - \nu_0 \cos \vartheta \sin\left[\frac{2\pi(x_0 + l \cos \theta)}{\Lambda}\right] \frac{\lambda}{c}}{\Delta\lambda_d}\right)^2\right] dl \quad (7)$$

As can be seen from Fig. , The line of sight passes through oppositely directed motions on the wave, and therefore, to calculate the line profile, this expression is divided into two integrals for both motion sections as follows:

$$I(\Delta\lambda) = i_0 \int_0^{l_1} \exp\left[-\left(\frac{\Delta\lambda - \nu_0 \cos \vartheta \sin\left[\frac{2\pi(x_0 + l \cos \vartheta)}{\Lambda}\right] \frac{\lambda}{c}}{\Delta\lambda_d}\right)^2\right] dl + \quad (8)$$

$$i_0 \int_{l_2}^{l_1} \exp\left[-\left(\frac{\Delta\lambda + \nu_0 \cos \theta \sin\left[\frac{2\pi(x_0 + l \cos \theta)}{\Lambda}\right] \frac{\lambda}{c}}{\Delta\lambda_d}\right)^2\right] dl$$

$$l_1 = \left(\frac{\Lambda}{2} - x_0\right) \sec \theta$$

$$l_2 = \left[H - \left(\frac{\Lambda}{2} - x_0 \right) \operatorname{tg} \theta \right] \operatorname{cosec} \theta$$

using expression:

$$\nu_d = \frac{\int_0^L \nu(l) dl}{L}$$

We obtain magnitude of the Doppler shift:

$$\nu_{sh} = \frac{\nu_0 \Lambda}{2\pi L} \left[-\cos \left(\frac{2\pi x_0}{\Lambda} + \frac{2\pi L \cos \vartheta}{\Lambda} \right) + \cos \frac{2\pi x_0}{\Lambda} \right] \quad (9)$$

The calculation was conducted for the profile of $\lambda 171$ FeIX line; in the spectrum of slow magneto-sonic waves, this line is often used by observers. Calculation was conducted for the following parameter values: $\nu_0=10$ km/s, $\Lambda=20\,000$ km and $50,000$ km [10, 11], $H = 2000$ km and 5000 km, $L=H/\cos\nu$. $\Delta\nu_d = 0.01$, this corresponds to the temperature value $T = 10^6$ and at the values of the angle of inclination of the line of sight to the direction of wave motion $\theta = 10^\circ, 20^\circ, 30^\circ, 40^\circ, 50^\circ, 60^\circ, 70^\circ$ and 80° . Calculation of the considered spectral line profile allows us to reveal how different parameter values impact the considered wave's energy flux value and the values of non-thermal and Doppler shifts. The calculation results are given in the graphs. Fig. 2 shows examples of calculated profiles.

3. RESULTS

Velocities of Doppler shifts and non-thermal motions.

Figure 6 shows the values of velocities of the Doppler shifts ν_d and non-thermal velocities v_{nt} from the angle of inclination θ for different wavelengths Λ and loop diameter H . Fig. 7 shows the values of ν_d and v_{nt} for various values of the physical parameters indicated in the figure. Fig. 9 shows the dependence of non-thermal velocities on the angle of sight at the physical parameters' values indicated in the figure.

The values of the Doppler shifts ν_d , obtained by the authors from observations, are inconsistent: $\nu_d=3$ km/s, $\nu_{nt}=23$ km/s [9], $\nu_d=1.8-3.7$ [13], $\nu_d=0.2-1.2$ [14], $\nu_d=0.3-0.7$ [15], $\nu_d=1.3-1.6$ [16], $\nu_d=0.3-2.5$ km/s [20], $\nu_d= 3$ km/s [23]. In standing waves, the velocities of Doppler shifts are significantly higher: $\nu_d=18$ km/s [17], $\nu_d=200$ km/s [21], 191 km/s [22].

In [9], some authors' data are given, in which it is shown that the values of non-thermal velocities are almost an order of magnitude higher than the velocities of Doppler shifts. It is difficult to explain the data given in [9], taking into

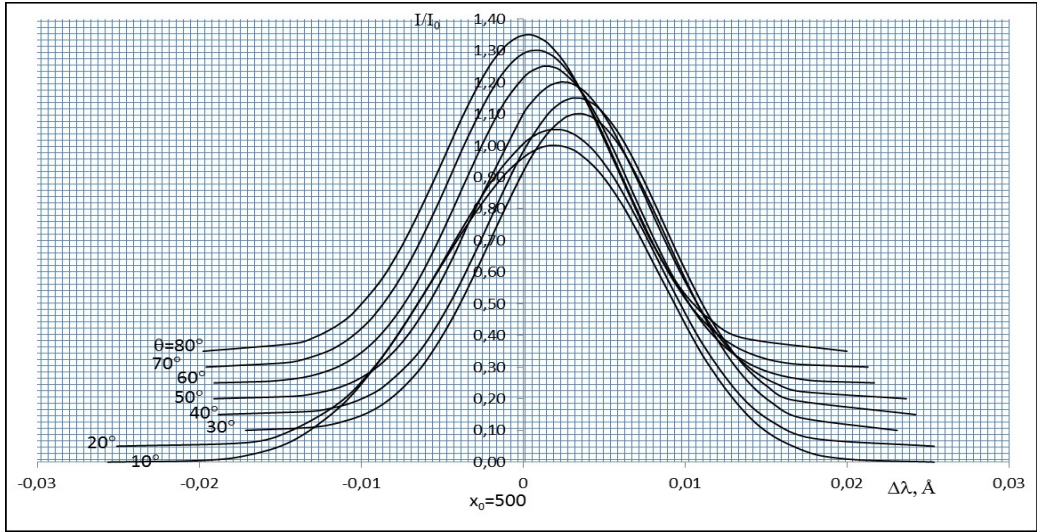


Fig. 2. Calculated profiles of the λ 171 FeX line at different values of the angle of inclination of the line of sight ν for a wavelength $\Lambda = 20,000$ km. Profiles are calculated in units of center intensity. Profiles are displaced along the intensity axis.

account the results of our calculations. It should be noted that regarding the observed values of non-thermal velocities, there are few cases of determining ν_{nt} in the emission spectrum of slow magneto-sonic waves. Let us give examples of some of them.

The authors [28, 29], based on many coronal active region line observations, found the value of non-thermal velocities of 17 km/s and 10 km/s. Authors [30, 31] found on the 171 Å line 7.5 km/s and 3 km/s, respectively. According to observations [32], in the Fe XIV 5303 line in the spectrum of slow waves, the velocity of Doppler shifts and non-thermal velocities are 0.3 km s⁻¹ and 10-20 km s⁻¹, respectively. As can be seen, these values are in limits, obtained by us. The authors [24] observed the Doppler shift in coronal loops up to 300 km/s.

The authors consider that these are motions on slow magneto-sonic waves. However, the authors observed at the limb of the sun, in this case, the observations were carried out perpendicularly to the tube of the loop, and since slow sonic-wave propagates along the tube and motions on it occurring along the propagation, then the authors observed perpendicularly to the motions on the wave, and consequently, the observed motions cannot be motions on the slow magneto-sonic wave. Probably, the observed motions are motions on the bending wave. The authors [25] obtained $v_d = 84$ km/s; the observed wave is considered to be slow magneto-sonic wave. However, according to the authors' observations, there is a phase shift by 90° between density change n_1 and velocity of motions on the

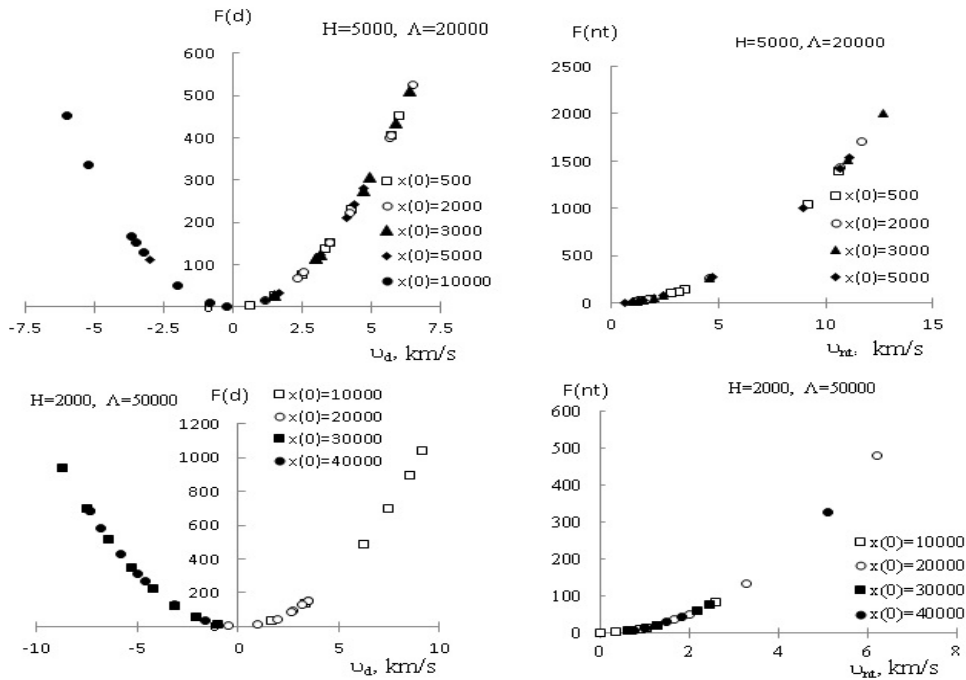


Fig. 3. Dependence of Energy flux density on Doppler shifts velocity (left) and non-thermal velocities obtained from Doppler width (right). Energy flux values in units $erg \cdot sm^{-2} \dots^{-1}$

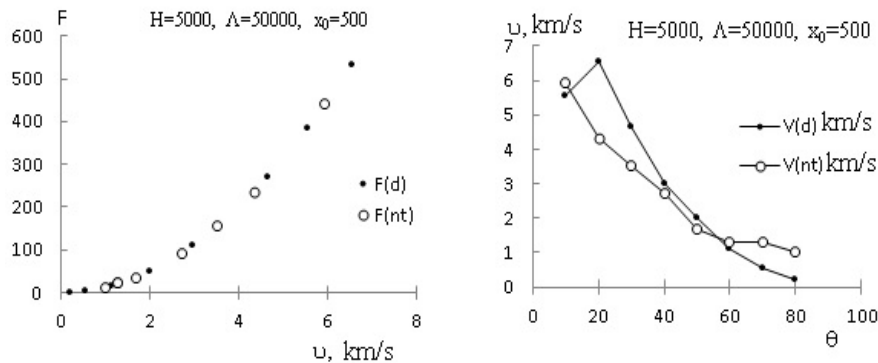


Fig. 4. Dependence of the energy flux density on Doppler shifts velocity (left) in $erg \cdot sm^{-2} s^{-1}$ and non-thermal velocities obtained from Doppler width (right) at specific values of the parameters.

wave v_1 ; since density change means the intensity change, we can assert that the observed wave was standing slow magneto-sonic wave.

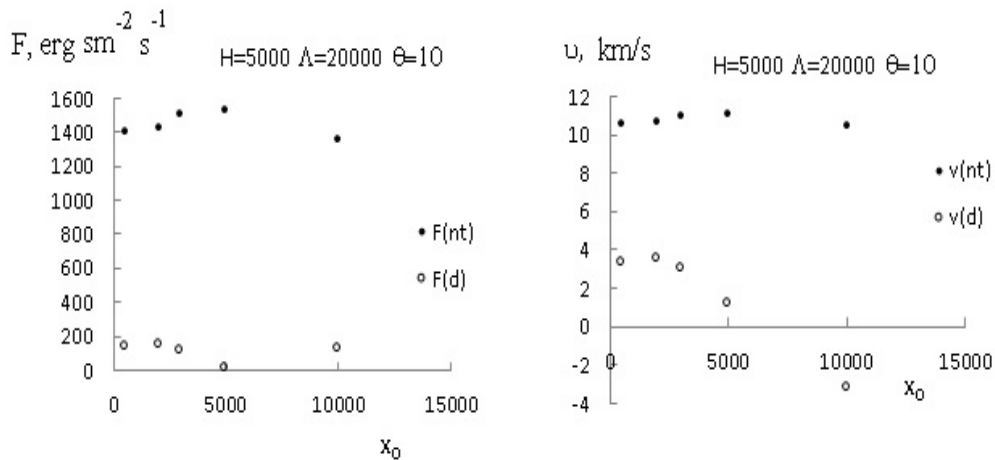


Fig. 5. Dependence of the energy flux density (left) and the phase velocities at $\theta = 10$.

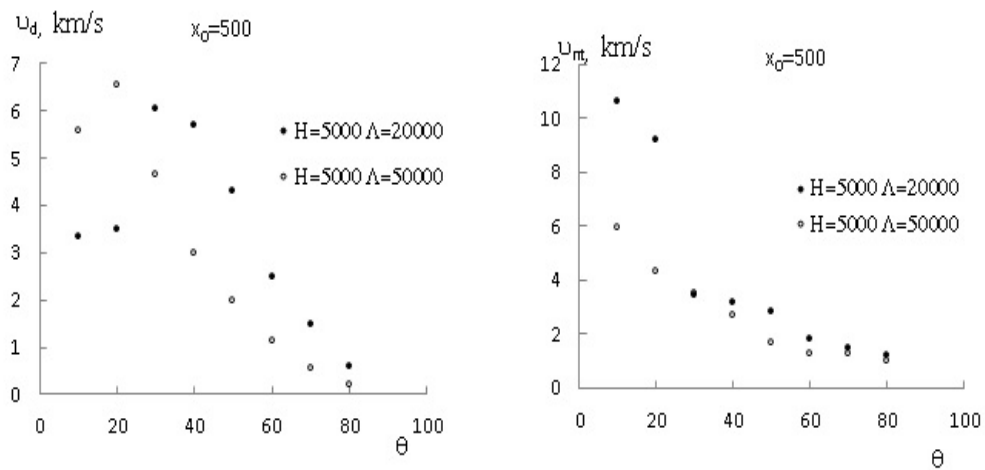


Fig. 6. Values of the Doppler shifts velocities v_d and non-thermal velocities from the inclination angle θ at various wavelengths Λ and loop diameter H

Fig. 8 shows the dependence curves of the values of non-thermal velocities and the velocities of Doppler shifts depending on the angle of the line of sight, wave phase, wavelength, and the coronal loop's width. As can be seen from graphs, velocities' values are changed from 12 km/s at small values of angle of sight to almost zero at large values of the angle of sight. The values of Doppler shifts at

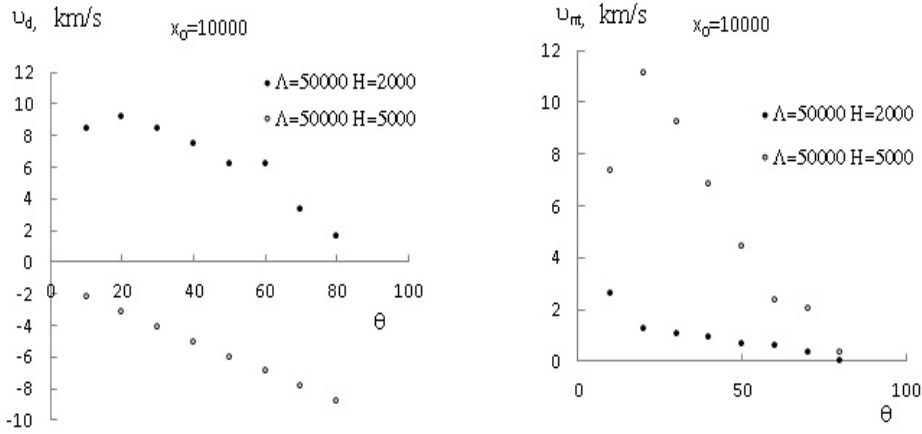


Fig. 7. Dependence of velocities on the angle of sight at indicated values of the parameters

large values of the angle of sight are close to the observed values, while at small values of angle of sight, our calculated values are mainly much higher than the observed ones. Apparently, it can be explained by the fact that the amplitude of the velocities on these waves is less than 10 km/s. As can be seen from Fig. 8, the velocities values depend on the loop width and wavelength.

Energy flux density. Fig.4 shows the dependence of the energy flux density on Doppler shifts velocity (left) in $sm^{-2}s^{-1}$ and non-thermal velocities obtained from the Doppler width (right) at specific values of the parameters. As shown in the figure, energy flux density increases with velocities increasing, which naturally, whereas with increasing of angle of sight θ to 100° , the flux density value decreases.

Fig. 5 shows the dependence of the energy flux density (left) and the phase velocities at $\theta = 10^\circ$.

Fig. 3 shows the calculated values of the energy fluxes density depending on the Doppler shifts velocities and non-thermal velocities obtained from the Doppler widths of the calculated profiles at various values loop width $H = 2000$ km and 5000 km and wavelength $\Lambda = 20,000$ km and $50,000$ km. The flux densities are calculated by the expression:

$$F = \frac{1}{2} \rho \nu^2 \nu_{ph}$$

Here: ρ - density, the root-mean-square velocity of motions on the wave, ν_{ph} - phase velocity of the wave.

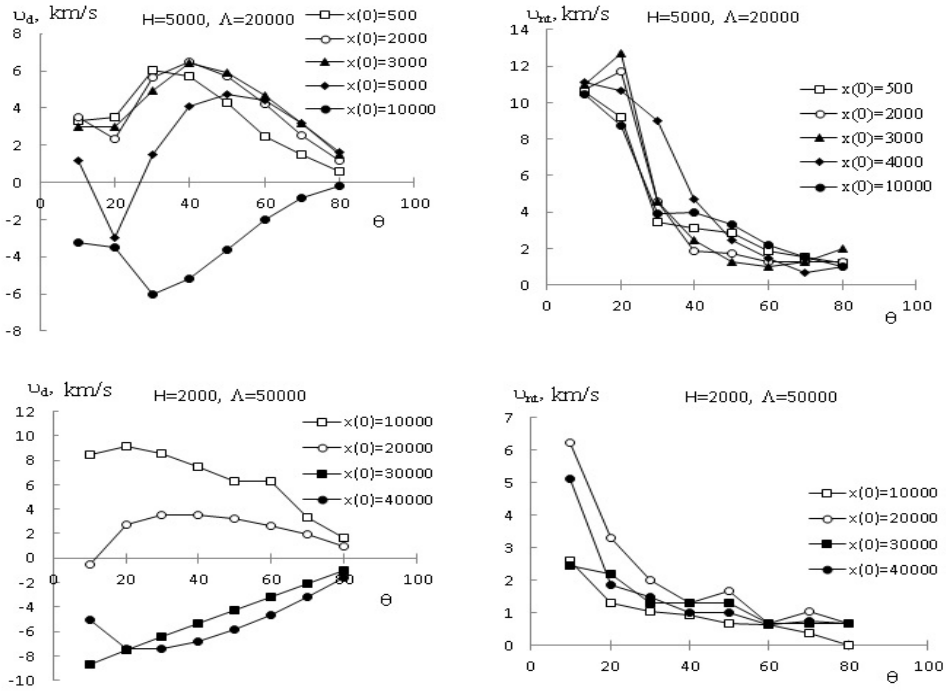


Fig. 8. Dependence of velocities on the angle of sight at various values of the phase

As can be seen from the figures, at values $H = 5000$ and $\Lambda = 20000$, the maximum value of F (nt) ($2 \cdot 10^3 \text{ erg sm}^{-2} \text{ s}^{-1}$) is almost five times greater than the maximum value of F (d) ($5.5 \cdot 10^5 \text{ erg sm}^{-2} \text{ s}^{-1}$).

Moreover, at the values of $H = 2000$ km and $\Lambda = 50000$ km, on the contrary, the maximum value of F (d) ($1 \cdot 10^3 \text{ erg sm}^{-2} \text{ s}^{-1}$) is almost two times greater than the maximum value of F (nt) ($5 \cdot 10^2 \text{ erg sm}^{-2} \text{ s}^{-1}$). This result shows that the flux values depend on the loop's width and the propagated slow sonic wavelength. The calculation of flux value for various values of the wave phase was performed. Fig. 3 shows how strongly the values of energy fluxes depend on the wave phase. The flux values at small values of the angle of sight vary from $2 \cdot 10^3 \text{ erg} \cdot \text{sm} - 2 \cdot \text{s}^{-1}$ but at high values of the angle of sight almost to zero. It should be noted that the values at small angles of sight are close to observed ones [1–6]. The minimum value of Doppler shifts velocities and non-thermal velocities are ~ 1 km/s and less; at this value, energy flux velocities are $\sim 10 - \text{erg sm}^{-2} \text{ s}^{-1}$. It means that depending on the angle of sight ϑ and the wave phase, the observed energy flux values will differ by almost two orders of magnitude or more. However, an equal amount of energy flowing in the magnetic tube. This remarkable result can explain

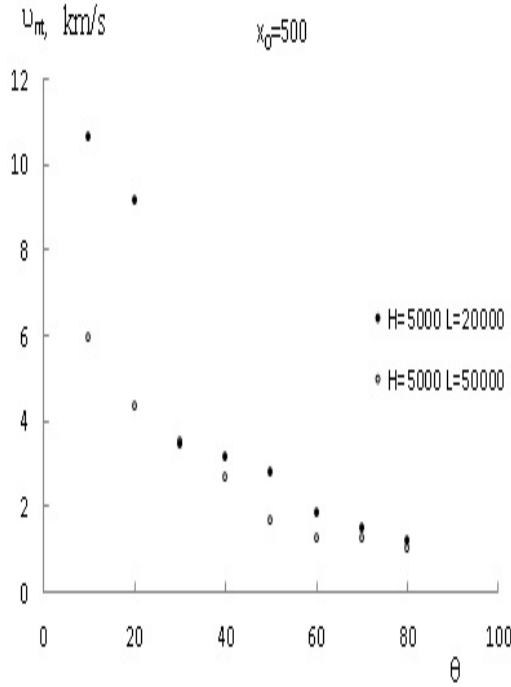


Fig. 9. Dependence of non-thermal velocities on the angle of sight at specified values of the parameters

the very different values of the energy flux of slow magneto-sonic waves obtained by various authors from observations [27].

The magnitude of the energy flux true value, calculated by the expression:

$$F = \frac{1}{4} \rho \nu_a^2 \nu_{ph}$$

Calculated by the given value of the amplitude of velocities $\nu_a = 10$ km/s on the wave is $\text{erg } \text{sm}^{-2} \text{s}^{-1}$. An interesting result is that the calculated (observed) energy flux values can be significantly less or significantly more than the true value: from almost zero at small values of θ .

Asymmetry

Authors choose the area of certain wavelength interval on the profile at equal distances from the center of the line when studying the asymmetry in the emission lines of the mz wave. Line asymmetry is estimated by expression $(R-B)/(R+B)$; here, R, B - the area's magnitude on red and blue sides from the center of the

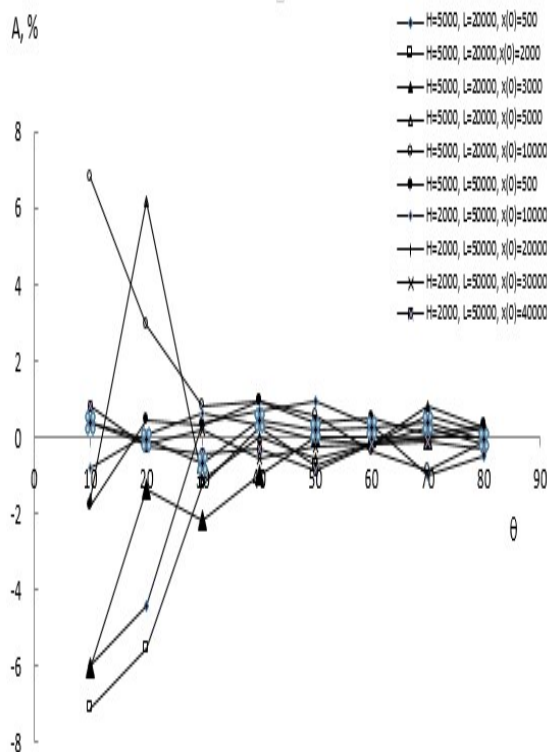


Fig. 10. Dependence of asymmetry on the angle of sight

line, respectively. It is conducted to reveal the presence of a possible flux of mass creating asymmetry [12].

We determined RB asymmetry over the entire wing of both blue (B) and red (R) since, in our case, the asymmetry is created by motions on the wave.

Almost in all works on determining the cause of the asymmetry of spectral lines, the authors conclude that the observed asymmetry is mainly blue, formed by plasma flow from below with velocities of 50–150 km/s [12, 18, 19]. In [19], the flux of mass from below is identified with spicules of type 2. In [26], the asymmetry is explained by the mass flux's quasiperiodic motion from below, which is superimposed on the mz wave.

The asymmetry values determined by us for all phases and wavelengths are shown in Fig. 10. As can be seen from the figure, at small values of the angle of the line of sight ($\vartheta > 300$), blue asymmetry is visible. At values of angle of sight $\vartheta > 30^\circ$ asymmetry is almost invisible. We can say that motions on the wave do not create asymmetry in the spectral line profile. It confirms the result obtained

from many author's observations that the flux of mass from below creates asymmetry, the emission profile of which is superimposed on the slow magneto-sonic wave's emission profile.

REFERENCES

1. De Moortel, I. and Nakariakov, V. M., 2012, "Magnetohydrodynamic waves and coronal seismology: an overview of recent results", *Philos. Trans. R. Soc. London, Ser. A*, 370, 3193–3216.
2. M.J. Aschwanden, *Physics of the Solar Corona—An Introduction*. (Praxis, Chichester, 2004). 1st Edition 2005 paperback
3. Nakariakov, V. M. & Verwichte, E. 2005 *Coronal Waves and Oscillations*. *Living Reviews in Solar Physics*, 2, 3.
4. De Moortel, I. 2005 An overview of coronal seismology. *Royal Society of London . Philosophical Transactions Series A*, 363, 2743–2760
5. De Moortel, I. 2006 Propagating magnetohydrodynamics waves in coronal loops. *Royal Society of London Philosophical Transactions Series A*, 364, 461
6. De Moortel, I. 2009 Longitudinal Waves in Coronal Loops. *Space Science Rev.*, 149, 65–81.
7. McEwan M. P. and De Moortel I. 2006.: Longitudinal intensity oscillations observed with TRACE: evidence of fine –scale structure. *A&A*, v. 448, p. 763-773.
8. Devlen E, Zengin Çamurdan D. , Yardımcı and Pekünlü E.R.: A new model for heating of the Solar North Polar Coronal Hole. *MNRAS*, v.467, pp133-144
9. Porter L.J., Klimchuk J.A. and Sturrock P. A. 1994.: The role of MHD waves in heating of the Solar Corona. *ApJ*, v. 435, pp 482- 501.
10. De Moortel, A.W. Hood, J. Ireland and R. W. Walsh, 2002, Longitudinal intensity oscillations in coronal loops observed with trace. II. Discussion of Measured Parameters *Solar Physics* 209: 89–108.
11. S. Krishna Prasad, D. Banerjee, T. Van Doorselaere, and J. Singh: «Omnipresent long-period intensity oscillations in open coronal structures». *A&A* 546, A50 (2012)
12. Verwichte E., Marsh M., Foullon C., Van Doorselaere T., De Moortel I., Hood A.W. and Nakariakov A.M.: Periodic spectral line asymmetries in solar coronal structures from slow magnetoacoustic waves. *ApJ*, 2010, v. 724, p. L194- 198
13. B. John T. Mariska, Harry P. Warren, David R. Williams, and Tetsuya Watanabe, Observations Of Doppler Shift Oscillations With The Euv Imaging Spectrometer On Hinode *The Astrophysical Journal*, 681: L41–L44, 2008.

14. N. Kitagawa, T. Yokoyama, S. Imada, and H. Hara: Mode Identification Of Mhd Waves In An Active Region Observed With Hinode/Eis. *Astrophysical Journal*, 721:744–749, 2010
15. J. Threlfall, I. DeMoortel, S. W. McIntosh, and C. Bethge: First comparison of wave observations from CoMP and AIA/SDO. *A&A* 556, A124 (2013).
16. T.J. Wang, L. Ofman J.M. Davila, and J. T. Mariska Hinode/EIS observations of propagating low-frequency slow magnetoacoustic waves in fan-like coronal loops *A&A* 503, L25–L28 (2009)
17. T. J. Wang, S. K. Solanki, D. E. Innes, W. Curdt, and E. Marsch: Slow-mode standing waves observed by SUMER in hot coronal loops. *A&A* 402, L17–L20 (2003)
18. Bart De Pontieu, Scott W. McIntosh, Viggo H. Hansteen, and Carolus J. Schrijver: Observing The Roots Of Solar Coronal Heating—In The Chromosphere. *Astrophysical Journal*, 701:L1–L6, 2009
19. Scott W. McIntosh and Bart De Pontieu: High-Speed Transition Region And Coronal Upflows In The Quiet Sun. *The Astrophysical Journal*, 707:524–538, 2009.
20. John T. Mariska and K. Muglach: Doppler-shift, intensity, and density oscillations observed with the extreme Ultraviolet imaging spectrometer on hinod. *ApJ*, v. 713, p.573–583, 2010.
21. Curdt W., Wang T.J., Innes D.E., Solanki S.K., Damasch I. E., Kliem B. and Ofman L: Dopler oscillations in hot coronal loops. *ESA_SP-506*,)), 2002.
22. Wang T.J., Solanki S.K., Curdt W., Innes D.E. and Dammasch L.E.,: Oscilating Hot loops observed by sumer. 2002 *ESASP.508.465W*
23. E.C. Bruner, Jr.: Dynamics Of The Solar Transition Zone. *The Astrophysical Journal*, 226:1140–1146, 1978
24. O. Kjeldseth-Moe and P. Brekke: Time variability of active region loops observed-with. The coronal diagnostic spectrometer (cds) on soho. *Solar Physics* 182: 73–95, 1998
25. L. Ofman and Tongjiang Wang : Hot Coronal Loop Oscillations Observed By Sumer: Slow Magnetosonic Wave Damping By Thermal Conduction. *Astrophysical Journal*, 580:L85–L88, 2002
26. Bart De Pontieu, and Scott W. McIntosh: Quasi-Periodic Propagating Signals In The Solar Corona: The Signature Of Magneto-acoustic Waves Or High-Velocity Upflows. *The Astrophysical Journal*, 722:1013–1029, 2010.
27. Mamedov S. G. et al: About heating of the Solar Corona. *AAJ*, № 14, p.62, 2014.

- 28.** David H.Brooks^{1,3} and Harry P.Warren:Measurments of non-thermal line widhts in solar active regions. The Astrophysical Journal, 820:63, 2016.
- 29.** E. O'Shea¹, D. Banerjee², and J. G. Doyle¹: A statistical study of wave propagation in coronal holes, A&A 463, 713–725 (2007).
- 30.** L.Ofman V.M.Nakariakov and C.E.Deforest:slow magnetosonic waves in coronal plumes.The astrophysical journal,
- 31.** I. De Moortel¹, J. Ireland², and R.W.Walsh¹: Observation of oscillations in coronal loops. Astron. Astrophys. 355, L23–L26 (2000)
- 32.** T.Sakurati,K.Ichimoto¹,K.P.Raju² and J.Singh²:Spectroscopic observation of coronalwaves.Solar Physics 209: 265–286, 2002

ASTEROID HAZARD AND INSTRUMENTAL CAPABILITIES OF THE SHAMAKHY ASTROPHYSICAL OBSERVATORY

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The 'ability of' Shamakhy Astrophysical Observatory's 'telescopes' to detect 'near Earth' asteroids and comets in the sky-monitoring mode is considered. It is shown Maksutov's mirror-lens telescope AST-452 fits for this aim the best of all.

Keywords: asteroids hazard– sky monitoring–telescope

1. INTRODUCTION

The main belt of asteroids is located between the orbits of Jupiter and Mars, but some asteroids move on very elongated elliptic orbits and can reach the terrestrial planets. Astronomers have long realized a hazard to humanity in the Earth's collision with asteroids. The catastrophe scale depends on the size, velocity, and composition of the matter of the celestial body [1, 2].

The smaller the size of the bodies crossing the Earth's orbit, the larger there are, and the greater their collision probability with the Earth. According to current estimates, the number of near-Earth asteroids (NEAs) with diameters less than 0.5 km is approximately 100,000, of which 22,261 objects are known at the beginning of March 2020 [3]. The problem is that the orbits of the NEAs are constantly changing due to close conjunctions with the terrestrial planets, which significantly complicates long-term predictions of these bodies' potential hazard. Besides, there are significant gaps in our knowledge of NEA's physical properties (size, mass, composition of matter).

The potential hazard posed by near-Earth asteroids is crucial to our civilization's future; in this regard, the UN established International Asteroid Day (30

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June annually) to draw the public, scientists, and government's attention to this problem. The first link in the protection system against probable collisions with asteroids - the patrol of the celestial sphere to detect asteroids approaching the Earth and determine their orbits. Let us consider in this respect the capabilities of the telescopes of the Shamakhy Astrophysical Observatory, operating in the sky-monitoring mode (sky scanners).

2. THE EFFECTIVENESS OF THE PATROL-TELESCOPE

According to [4], the effectiveness of the telescope operating in the sky-monitoring mode should be directly proportional to the path S that the scanner covers in the celestial sphere during operation Q and inversely proportional to the limited illumination n [$\text{photon} \times \text{sm}^{-2} \times \text{s}^{-1}$], which is capable of registering a light detector on a telescope of these sizes. Thus, $\text{Eff} \propto S/n$.

Let us choose the norming constant in the form $N/2\pi$, where N [$\text{photon} \times \text{ster}^{-1} \times \text{sm}^{-2} \times \text{s}^{-1}$] - illumination from the sky in a unit solid angle, 2π - solid angle of the hemisphere. Then, as follows from work [4],

$$\text{Eff} \propto (N/n) \times (1/2\pi) \times (Ld_{px}V_sQ/F) ,$$

Or in the stellar magnitude scale

$$-m_{\text{Eff}} = 2.5 \lg \text{Eff} = m - M + 2.5 \lg (Ld_{px}V_s/F) + \text{Const} \quad (1)$$

Here m - the stellar magnitude of the object or star in the bandwidth of the telescope optical system; M - the stellar magnitude of the sky background in a unit solid angle in the same wavelength interval; L - the size of the side of the CCD-matrix (number of pixels); d_{px} - the linear size of the element of the CCD-matrix; V_s - the velocity of the diurnal motion of the stars; F - the effective focus of the telescope; Const - normalization constant. Earlier in work [4], two modes of operation of the patrol-telescope were considered. In continuous mode, the telescope is stationary, but sky-monitoring in the camera's field of view occurs due to the diurnal rotation of the celestial sphere. Telescope exposes a selected sky region, participating in the diurnal rotation of the celestial sphere at quasi-continuous sky-monitoring mode (S.N Blazhko's method [5]). Then the telescope's field of view is shifted under one of the coordinates on the slight angle, and the neighboring sky region is exposed. The penetrating power of the telescope in this method is turn out to be more significant since short-term exposures give dot-matrix images of both stars and fast-moving objects. As shown in [4], under the condition of quasi-continuous sky-monitoring mode, formula (1) is transformed as follows:

$$-m_{\text{Eff}} = \text{Const} - 1.25 \lg(k_1^2 i) + 1.25 \lg(D^2/F) + 2.5 \lg[L^{3/2}(d_{px}V_s)^{1/2}] \quad (2)$$

Where $k_1 d_{px}$ - linear size of the star image or object on the matrix, i - the number of exposures of given sky region, D - aperture, and other designations are the same as in formula (1). It is convenient to compare the effectiveness of operation of the telescope under sky-monitoring mode with some "ideal scanner," equipped with the same receiving equipment and directed to the same region of the celestial sphere.

Let us determine the optical characteristics of this "ideal scanner" as follows. Since $D^2/F = A^2F$, we choose the relative aperture $A = 1$. Further, let us choose such effective focus that the size of the dot image in the focal plane to be equal to the matrix element (i.e. $k_1 = 1$).

From the ratio

$$k_1 = \alpha'' F / 206265 d_{px}$$

Have $F = 257.83$ sm, if $d_{px} = 0.0025$ sm and angular size of the star's image $\alpha \approx 2''$ (approximately the average annual image quality in conditions of the astro-climate of the Shamakhy Astrophysical Observatory). It is possible to determine the operating effectiveness of the current patrol-telescope (pt) concerning the "ideal scanner" by using the formula (2):

$$Eff_{pt}/Eff_{is} = 10^{0.4\Delta m_{eff}}$$

where

$$\Delta m_{eff} = 1.25 \lg A_{pt}^2 F_{pt} / 257.83 k^2 pt.$$

Table 1 shows the corresponding calculations for the stellar telescopes of the Shamakhy Astrophysical Observatory. It should be noted that telescopes with a "classical Cassegrain" optical scheme are unsuitable for sky-monitoring. The working effectiveness at the primary focus of the 2-meter Zeiss reflector is 12% relative to the "ideal scanner." The effectiveness is approximately 6 times higher for the telescope AST-452, which is inferior to a 2-meter reflector in penetrating capability but has a large field of view. Therefore, the mirror-lens telescope AST-452 of the Maksutov system is reasonably fit for monitoring the celestial sphere to detect NEO. This telescope has the following characteristics. The aperture - 35 cm, the effective focal length - 85.9 cm, the visual field aperture - 3° , the linear visual field - 6×6 cm, which accords to the linear size of the CCD-matrix with the number of elements 6000×6000 pixels if the average size of one pixel - 0.001×0.001 cm. Accordingly, the smaller the matrix size compared to the linear size of the telescope field of view, the lower the effectiveness of the patrol-telescope. Since the AST-452 telescope has an internal focus, the CCD-photometer must be located inside the telescope tube, which can adversely affect the image quality and reduce positional measurement accuracy. Therefore, we considered the short-focus astrograph RASA 279/620 capabilities as a possible replacement for

Table 1. The efficiency of stellar telescopes while scanning the sky continuously.

Telescope	Aperture	Focal	Effectiveness
	(sm)	length (sm)	(%)
AST-452	35	85,9	70.6
Zeiss-600	60	700	5,2
AST-8	70	1100	3,1
Zeiss-2000	200	2900 a)	2,1
Zeiss-2000	200	900 b)	11,9
Astrograph RASA 279/620	27.9	62	91.8

a) Cassegrain focus

b) Primary focus

the telescope AST-452. This astrograph has an external focus and high effectiveness as a patrol-telescope (see table 1). According to the developer's data [6], the optimal aperture of the field of view of the telescope is approximately 4.33 cm, or in an angular measure $\sim 4^\circ$. In order to ensure the calculated effectiveness of sky-monitoring by astrograph RASA 279/620, the size of the CCD-matrix must correspond to the linear size of the telescope's field of view, i.e., approximately 3×3 cm.

3. THE PENETRATING POWER OF THE PATROL-TELESCOPE.

The limiting stellar magnitude that telescope can record, calculated by using Baum's formula [7, 8]:

$$m = 3.75 + 0.5M - 2.15 \lg K - 2.5 \lg d / F - 1.25 \lg(1 + K_1) + 1.25 \lg D^2 (1 - K_2) q t \quad (3)$$

Where K determines how many times the desired signal exceeds the noise level; d - the linear size of a star image or object in the focal plane of the telescope; K_1 - the ratio of the instrumental background level to the signal from the sky background; K_2 - light loss in the atmosphere and telescope; q - the quantum output of the light detector; t - the exposure time; M, D, and F determine the same magnitudes as in the formulas above. We used conservative parameter values: $K = K_1 = 5$; $K_2 = 0.4$; $q = 0.9$, in order not to overestimate the capabilities of telescopes, when calculating by formula (3). The diameter of the scattering circle d depends on the image quality and corresponds to 2 arc seconds. The stellar magnitude from the sky background, within the unit solid angle, is accepted $M = -4.6^m$ on the bandwidth V of the Johnson-Morgan system [8]. It should be noted that the

exposure time of every star image or object depends on its angular dimensions and displacement velocity over the matrix (see formulas (10) and (11) in [4]). Considering this circumstance, the anticipated limiting stellar magnitude for the telescope AST-452 at the continuous sky-monitoring mode approximately 13.7^m , and at the quasi-continuous sky-monitoring mode, approximately 17.3^m . We obtained practically the same values of the anticipated threshold magnitudes for the astrograph RASA 279/620, at continuous and quasi-continuous sky-monitoring mode: $m = 13.5^m$ and $m = 17.2^m$, respectively. The penetrating power of this telescope turns out to be less than AST-452 due to the smaller aperture, but these differences are more theoretical than practical.

4. ESTIMATION OF THE MINIMUM SIZE OF BODIES THAT CAN BE DETECTED UNDER SKY MONITORING

The diameters of bodies corresponding to the obtained values of the limiting stellar magnitudes can be estimated by the formula:

$$m = Const - 2,5 \lg pV \pi R^2 f(\gamma) (r_s r_E)^{-2} \quad (4)$$

where pV – the visual geometrical albedo of body, $2R$ – its diameter in km, $f(\gamma)$ – phase function, γ – phase angle, r_s and r_E – heliocentric and geocentric distances of the object in a.u. $Const = 15.5^m$ is calculated from the "Ephemerides of Minor Planets for 1993" for asteroid 8 Flora at $r_s = 2.464$ a.u., $r_E = 1.545$ a.u., $2R = 144$ km, $\gamma = 12.8^\circ$ and $pV = 0.23$. Table 2. shows diameters of the bodies calculated by the formula (4) under the condition $pV = 0.05 - 0.3$ and $r_s = 1$ a.u.

According to the data in this table, a patrol-telescope based on AST-452 (or RASA 279/620) can register objects about ten kilometers in diameter at a geocentric distance $r_E \sim 1$ a.u. and about several meters in diameter at a distance from the Earth of the order of the first hundred thousand kilometers.

5. CONCLUSION

Let us formulate the main conclusions. AST-452 mirror-lens telescope has the best properties among the stellar telescopes of the Shamakhy Astrophysical Observatory for monitoring the celestial sphere in order to search and detect fast-moving near-Earth objects. It can register objects with a stellar magnitude of $\leq 17^m$, which corresponds to bodies of the order of ten kilometers in diameter at heliocentric distances of ≈ 1 a.u. or bodies several meters in diameter, at a distance of the order of the first hundred thousand kilometers. Astrograph RASA

Table 2. Smallest body sizes with albedo $0.05 < pV < 0.3$ near-Earth ($r_s = 1$ a.e.). Detected by the telescope AST-452 (or RASA 279/620).

Geocentric Distance (a.u.)	Body diameter (km)	Correction for the phase angle a)
while scanning the sky continuously		
english+ru+ru+		
$r_E = 1.0$	11.5 – 4.7 12.7 – 5.2	'1.8
$r_E = r_{Earth-Moon}$	0.03 – 0.012 0.033 – 0.013	'2.5
$r_E = 0.5 r_{Earth-Moon}$	0.14 - 0.006 0.016 -0.007	'3.5
while sky scanning quasi-continuously		
english+english+ru+ru+		
$r_E = 1.0$	2.20 – 0.89 2.31 – 0.94	'1.8
$r_E = r_{Earth-Moon}$	0.006 – 0.002 0.006 – 0.002	'2.5
$r_E = 0.5 r_{Earth-Moon}$	0.003 – 0.001 0.003 -0.001	'3.5

b) The lunar phase law passed. [10]

279/620 does not differ from AST-452 by properties in the sky-monitoring mode. For the full realization of the capabilities of these telescopes as sky monitors, the size of the CCD-matrix must correspond to the linear size of the telescope's field of view. Small matrixes significantly reduce the efficiency of the patrol-telescope. It should be noted that calculations were fulfilled for ideal astro-climatic conditions, correspond to the natural level of the night sky background. Unfortunately, the sky above the observatory turns out to be overexposed due to numerous hotels, restaurants, and campgrounds surrounding the observatory [9]. This circumstance noticeably affects the penetrating power of telescopes, negatively affects the accuracy of photometric measurements, and creates a real risk of damage to expensive measuring equipment.

REFERENCES

1. Bronshten V.A. Tunguska meteorite: the history of research. - M.: Selyanov A.D., 2000. — 312 .
2. Chelyabinsk superbolide / edited by N.N.Gorkavy, A.E.Dudorov. - Chelyabinsk: Publishing House of the Chelyabinsk State University, 2016. — 223.
3. Center for Near Earth Object Studies at JPL and NASA (<https://cneos.jpl.nasa.gov/>)
4. Shestopalov, D.I., Shustarev, P.N., 2000. Asteroid hazard and sky watch with groundbased telescopes. Circular of ShAO, No 97, 25 – 28.
5. Putilin I. I. Minor planets. – M.: GITTL1953. – 412.
6. Celestron Telescope Astrograph RASA 279/620 on CGX GoTo mount (https://www.teleskop-express.de/shop/product_info.php/language/en/info/p9172_Celestron-Teleskop-Astrograph-RASA-279-620-auf-Montierung-CGX-GoTo.html)
7. Methods of Astronomy / Edited by. V.A. Hiltner. - Moscow: Mir, 1967. – 325.
8. Mikhelson N.N. Optical telescopes: theory and design. - Moscow: "Nauka", 1976. –510 .
9. Shestopalov D.I., Shustarev P.N., Khalilov V.M., Mikailov Kh.M., Mamedov A.M., Shukurov M.E., Gyulmaliev N.I., 2006. Study of the background illumination of the night sky above Shamakhi Astrophysical Observatory. Azerb. Astron. J., No. 1 - 2, 53 - 56.
10. Allen K.L. Astrophysical quantities. - M .: "Mir", 1977.– 446

SPECTRAL CLASSIFICATION OF THE SEYFERT GALAXIES.

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On the base of large inclination to the plane of the rotation of the Seyfert galaxies was made for the θ variations spectral in the article. The course of coefficients and redness lines with a change in the spectral class of Seyfert galaxies was analyzed.

Keywords: Seyfert galaxies–spectral types of Seyfert galaxies.

1. INTRODUCTION

Since the time of discovery of the first quasars in the 60s of the XX century, astronomers had tried to restore some order on dozens of objects known as active galactic nuclei (AGN), which also include Seyfert galaxies. These are supermassive black holes at the centers of galaxies, intensively accreting matter (unlike relatively “silent” black holes such as Sagittarius A at the center of our galaxy). This problem is a complex task. The breakthrough took place in the 1980s when some of the peculiarities of AGN researchers were tried to explain by the differences in the orientation of the galactic plane (and consequently by the circumnuclear torus’s orientation to the line of sight, for example [1]). A similar model was named the unification model of AGN. In the unification model, two main zones of AGN are postulated, emitting broad emission lines (type I) and only narrow lines (type II), which are the same types of objects, but, at the same time, AGN of type I have broad emission lines and more high level of continuum emission. In contrast, type II AGN, has no broad lines and has only very narrow emission lines and a weaker continuum. The idea of the unification model lies in the fact that the central black hole is surrounded by darker torus consisting of gas and dust, at the same time, the torus is visible to the observer (like the galactic disc) either as a flame ($\theta \sim 90^\circ$) or from the edge ($\theta \sim 0^\circ, 180^\circ$). It is clear that

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intermediate values of θ are possible here (where θ - the angle between the plane of rotation of the galaxy and the line of sight). Consequently, if broad emission lines are formed in the region close to the central black hole, and narrow forbidden lines are emitted at a more remote distance outside the torus (in a region with a low density of interstellar matter), then the broad lines might be hidden depending on the angle, under which AGN are visible. The best evidence of this scenario is the spectropolarimetric observations of some AGN types II in which, in polarized light, broad emission lines are visible, which can happen if the region of emission of the broad line is hidden. Despite some successes of this unification scheme, some problems cannot be explained solely by eclipses, by clouds of interstellar gas-dust matter related with various torus orientations regarding the observer. Many AGN of type II does not have a hidden region of broad emission lines, even with profound observations in polarized light. Besides, X-ray spectra of many AGN type II do not indicate high column densities of the absorbing gas, as would be expected if these AGN were surrounded by absorbing torus. Because of these and other problems, for example, in work [2], another physical model to explain the differences between the observed types of AGN was proposed. Particularly, it was proposed that the difference in types of AGN is related to different accretion rates of interstellar matter onto the core. The authors found significant variance between the accretion rates of AGN of type I ($L/L_{\text{Edd}} > 0.01$) and AGN of type II ($L / L_{\text{Edd}} < 0.01$), where L - the internal bolometric luminosity of the core, L_{Edd} - the Eddington luminosity, which implies that the accretion rate, and not only geometric orientation, should play a significant role in the characteristics of emission lines observed in spectra of AGN.

Recently, increasingly observational works have appeared, in which cases of changes in the spectral type of dozens AGN in a relatively short time are described, i.e., dramatic changes occur in the profiles of emission lines of classification type of some AGN, in which changes from one spectral type to another are observed within a short time interval (from days to several years). It presents a particular problem for the unification model since it should be modified so that these relatively frequent changes in the spectral type of AGN would find a natural explanation in it, or a new model should be created to interpret various types of AGN. Firstly, for this, it is necessary to understand the physics of changing the types of AGN.

Currently, Seyfert galaxies researchers put forward various assumptions related to the nuclei of Seyfert galaxies. For example, in work [3], the authors consider that the spectral type changes are characteristic for all Seyfert galaxies. It merely needs to observe these galaxies for a long time. Besides, in the unification model, the cases require an explanation when broad emission lines disappear or weaken for a relatively short time (months - several years, works [4-7]).

Data analysis. Let us find out as far as the observed data on Seyfert galaxies corresponds to the models mentioned above and whether they are the goal of this work. If we analyze the behavior of the dependence of the photometric index (ug) on the spectral type (see Fig. 1), then the obtained picture fits well into our ideas about the evolution of galaxies (we took the data from the review [8] for several observation sites most affluent in Seyfert galaxies, in the $ugriz$ photometric system, with consideration of redness). It can be seen from the figure with the variation of spectral type from Sy1 to Sy2, the value of ($u-g$) increases, possibly related to the relative decrease of the number of stars of early spectral types with the evolution of galaxies. Unfortunately, direct proof of this assumption in our case is impossible (see Fig. 2) since the data on the ages of the corresponding galaxies taken by us from [8] are calculated (age at redshift), i.e., based on some assumptions. Based on the small number of points in Fig. 2 and their significant

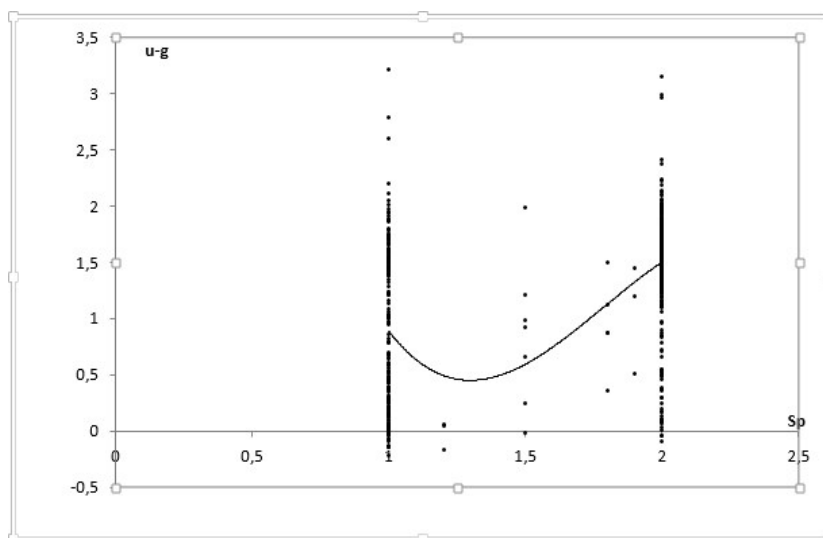


Fig. 1. Dependence of the color-index ($u-g$) values on the spectral type for Seyfert galaxies from overview [8] for some observation sites. Number of galaxies – 559. The fine line on the figure - the third-degree polynomial trend.

scattering, it is difficult to draw any conclusions about the variation of dependence. Consequently, at this stage, it is early to draw any conclusions about the evolutionary course of Seyfert galaxies of various spectral types, although the fact that some of them change their spectral type from time to time gives us some hope. However, it is first necessary to ensure that the inclination to the plane of rotation of Seyfert galaxies affects their spectral type in accordance with the unification model.

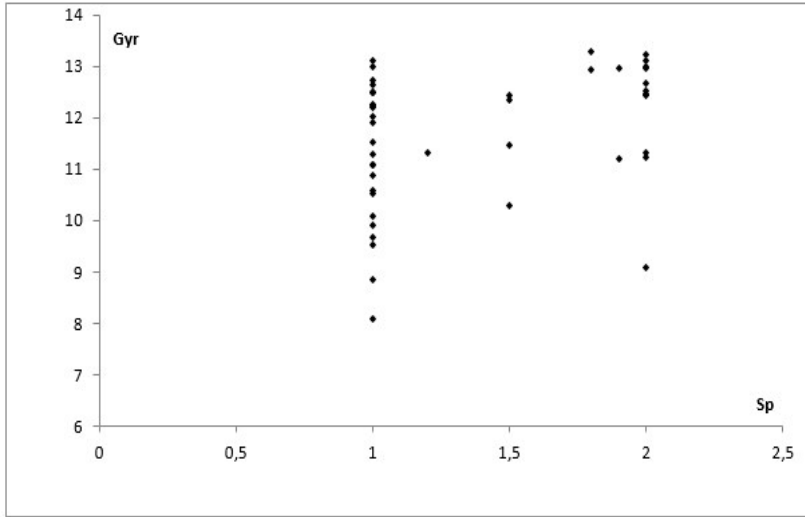


Fig. 2. Dependence of the age of the Seyfert galaxies from [8] on the spectral type.
The number of galaxies - 45.

For this purpose, based on data from the catalog [9], we built up histograms (see Fig. 3-6) of the distribution of the number of Seyfert galaxies, depending on the inclination of their rotation plane to the line of sight (θ°) for galaxies of spectral types Sy1, Sy2, Sy1.5, and Sy1.9, respectively. The data on the values of angle of inclination was taken from the site [9].

The data in [9] for Seyfert galaxies of spectral types Sy1.2 and Sy1.8 are too few for statistical analysis. As can be seen from Fig.3-6, if the corresponding distributions for Seyfert galaxies of types Sy1 and Sy2 are close to standard (continuous curves in the figures), the picture is different for types Sy1.5 and Sy1.9. Here the distribution maxima shift to the values $\theta \sim \theta^\circ, 180^\circ$, i.e., in this case, we observe the galaxy from the edge. The relatively small number of Seyfert galaxies of spectral types Sy1.2, Sy1.5, Sy1.8, and Sy1.9 can be explained by the flocculent structure of interstellar matter, hence the short duration of eclipses and the presence of Seyfert galaxies in an eclipse state in general, and accordingly changes of their spectral class. Incidentally, the second model with a change of the accretion rate does not contradict this.

Consider a two-index diagram (U-B) on (B-V) for Seyfert galaxies, constructed separately for various spectral types. Usually, it is constructed for stars to determine interstellar redness. The points on it, corresponding to stars with different redness of the same spectral type, fall on one straight line (redness line). We constructed a similar diagram for Seyfert galaxies; then, we draw inclined lines through the point arrays separately for each spectral type using the least-squares

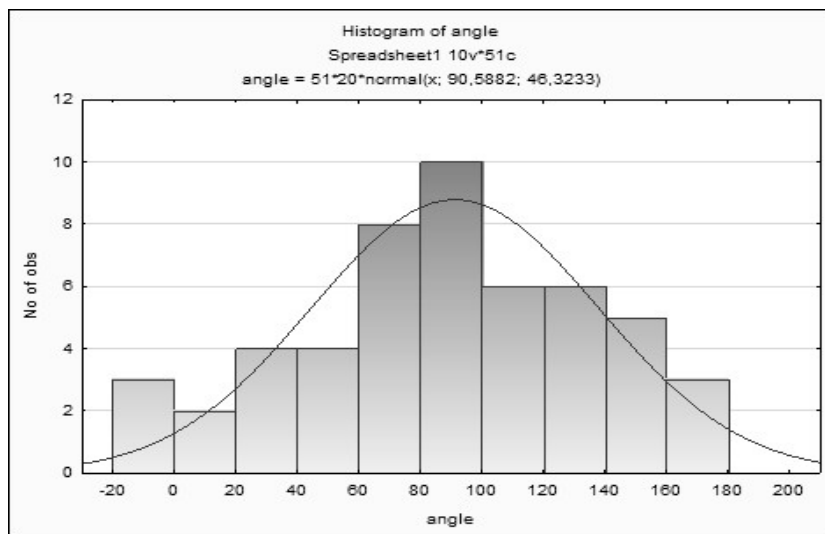


Fig. 3. Distribution of the number (ordinate axis) of Seyfert galaxies of type Sy1 depending on the angle of inclination of their plane of rotation to the line of sight (abscissa axis, in degrees). The number of data for galaxies of type Sy1 - 13975.

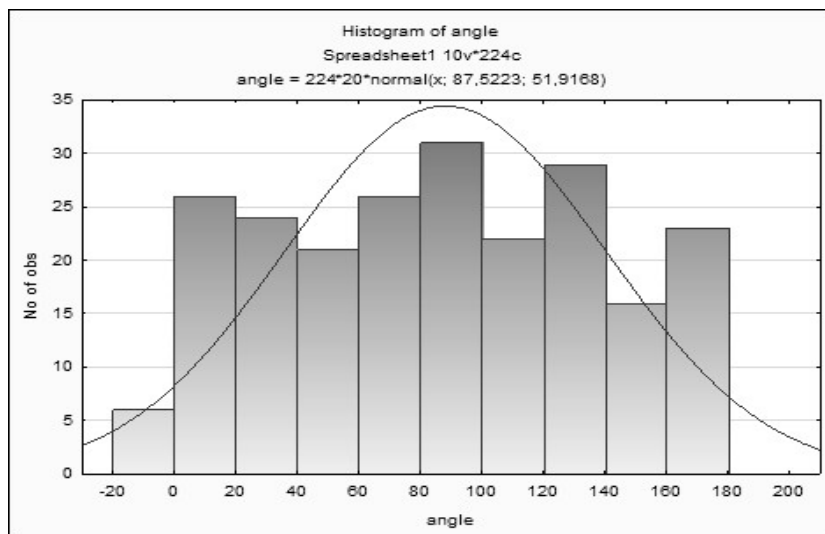


Fig. 4. Distribution of the number (ordinate axis) of Seyfert galaxies of type Sy1.5, depending on the angle of inclination of their plane of rotation to the line of sight (abscissa axis, in degrees). The number of data for galaxies of type Sy1.5 -361.

method. Then we have constructed a plot of the magnitude of the inclination coefficient α from the spectral type (Fig.7). As shown in Fig. 7, the value A increases by the jump from type Sy1 to type Sy1.2 and then monotonically de-

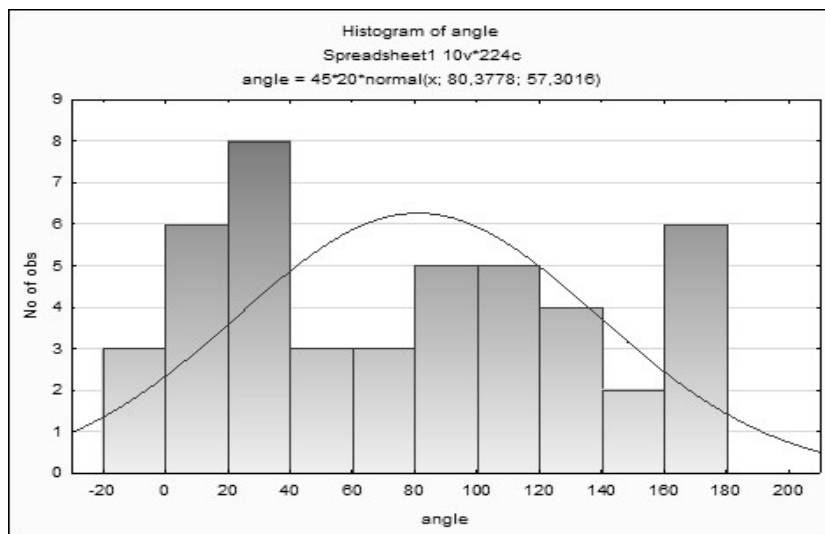


Fig. 5. Distribution of the number (ordinate axis) of Seyfert galaxies of type Sy1.9, depending on the angle of inclination of their plane of rotation to the line of sight (abscissa axis, in degrees). The number of data for galaxies of type Sy1.9 – 189.

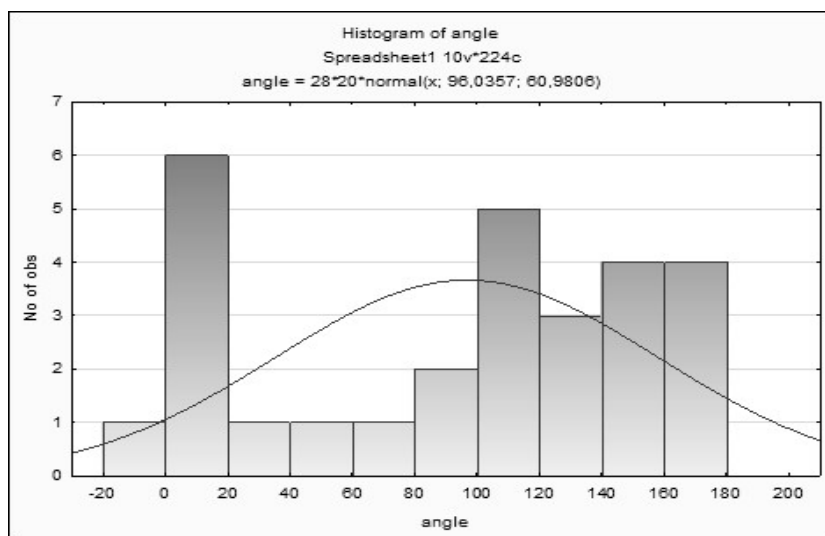


Fig. 6. Distribution of the number (ordinate axis) of Seyfert galaxies of type Sy2, depending on the angle of inclination of their plane of rotation to the line of sight (abscissa axis, in degrees). The number of data for galaxies of type Sy2 - 6024.

creases to type Sy2. It is probably due to gas-dust matter density in the disk of corresponding galaxies (see Fig. 1 of the present paper).

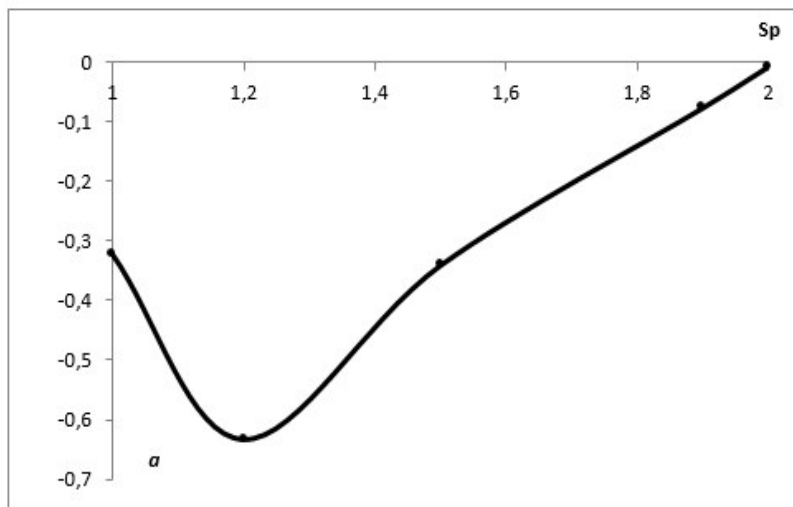


Fig. 7. Change of the inclination of the redness line from the spectral type of Seyfert galaxies.

2. CONCLUSION.

Thus, the following conclusions can be drawn from this work:

1. Observed data confirm the correlation between the angle of inclination of the plane of rotation of Seyfert galaxies and the line of sight and spectral type. It is probably due to eclipses of emission from the core, clouds of gas-dust interstellar matter of the disk, and the matter of the circumnuclear torus.
2. The density of gas - dust matter varies depending on the spectral type of Seyfert galaxies.

REFERENCES

1. Krolik J.Y., Begelman M.C., Molecular tori in Seyfert galaxies: feeding the monster and hiding it, 1988, Ap.J., 329, p.702-711.
2. Mankuzhiyil, N., Ansoldi, S., et al., The environment and distribution of emitting electrons as a functions of source activity in Mrk421., 2011, Ap.J., 733, p.14-20.
3. Oknyansky VL., Gaskell C.M. et al., The curtain remains open NGC2617 continues in a high state, 2017, MNRAS, 467, p.1496-1504.
4. Sekigucyi, K., Menzies J., W., Spectral variations in the broad line region NGC6814, 1968, A.J., 79, p.66-70.

5. Shapovalova A.,J., Poroshenko V.,T., Profile variability of the $H\alpha$ and $H\beta$ broad emission lines in NGC5548. 1984, MNRAS, p. 33P-39P.
6. Penston, V.,M.,Perez, E., An evolutionary link between Seyfert I and II galaxies,1990, MNRAS, 245, p.66-70.
7. Andrillat, Y., Spectral variations of the nucleus of the NGC3516, A&A, 2004, 422, p. 865-865.
8. <http://ned.ipac.caltech.edu>
9. <http://cdsweb.u-strasbg.fr>

TESTING THE HYPOTHESIS OF AN UNKNOWN PLANET USING THE MOID ANALYSIS

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MOID values for 1156 long-periodic comets with aphelion distances greater than 250 AU and slightly hyperbolic orbits relative to the assumed planet X are calculated. It was found that in 51 of them, these values do not exceed the radii of the spheres of influence of the planets. This is approximately 25 percent more than the background value and cannot be considered random. The obtained result can be considered as an additional argument in favor of the hypothesis under discussion.

Keywords: comets–planets–MOID.

1. INTRODUCTION

This work is a logical continuation of the paper that shows the existence of families of long-period and periodic comets of giant planets. Recall that in the cited works, an array of MOID (minimal orbital intersection distance) values was analyzed and their redundancy relative to giant planets was proved. In particular, [5] shows that the number of long-period comets with small MOID values is 1.4-1.7 times higher than the background values.

In this paper the question will be studied for the assumed Planet X with parameters:

$$a = 339 \text{ AU}(\pm 34), e = 0.16(\pm 0.02), \omega = 57^\circ(\pm 15^\circ), \Omega = 272.7^\circ(\pm 3^\circ), i = 86^\circ(\pm 2^\circ). \quad (1)$$

The hypothesis of the existence of such a planet belongs to one of the authors. The most complete review of the hypothesis and its main arguments is given in [4].

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2. DATA USED AND RESEARCH METHODOLOGY

To analyze the MOID values of known comets relative to the putative planet, the algorithms given in [3] are used.

In this task, the values of the radius of the sphere of action, which are determined by the formula [2] are used as the limit distances for analyzing MOID values for the planet X:

$$h = a_p \sqrt[5]{\left(\frac{M_p}{M_S}\right)^2} \quad (2)$$

Where, a – planet's semi-major axis, M_p – mass of planet, M_S – mass of Sun.

The subjects of this study are 1156 slightly hyperbolic and long-period comets with aphelion distances greater than 250 AU. The compiled list covers comets up to 2020. The last comet in it is C/2009 Y1. Their data is grabbed from JPL HORIZONS.

As an example for testing, we give the MOID values of two comets (elliptical and hyperbolic) with respect to (1):

$$\text{C/2012 L1; } r = 0.48 \text{ and C/1980 E1; } r = 1.14$$

3. CALCULATION RESULTS

The Guliyev hypothesis assumes that the mass of an unknown planet does not exceed 10 earth masses. This means that the analysis should select comets with MOID values up to 6 AU.

As a result of calculations, 51 comets with this characteristic were found in the considered list. Their list is given in table 1. Comets are characterized by relatively large perihelion distances (aver. 2.200 AU). Among them, objects with straight orbits dominate (31 vs. 20). 10 of them have slightly hyperbolic eccentricities.

The table also shows the values of the latitudes of the perihelion (B') of comets relative to the motion of the planet plane. 16 of the 51 values of this parameter are within 30 degrees of the plane. Consequently, the small MOID values of the selected comets are not always associated with this factor.

Table 1 shows the calculated values of the inclinations (I') of the selected comets relative to the plane of motion of planet X. There is a slight dominance of the values of this parameter near 0° and 180° . In particular, the regions $I' < 17^\circ$ and $I' > 163^\circ$ correspond to 8 and 5 values. Although their number exceeds the random norm, however, this does not mean that the assumed excess of MOID values is associated with this factor.

Table 1. Data on 51 long-period comets and calculated MOID values

comet	q (AU)	e	i	Ω	ω	MOID	B'	I'
C/1911 O1	0.489	0.997	33.81	294.21	153	0.28	0.5	55.4
C/2010 A4	2.738	0.99	96.73	346.69	271.69	0.36	-7.18	75.6
C/2019 J2	1.727	0.997	105.14	25.47	98.7	0.42	5.63	113.9
C/2012 L1	2.262	0.997	87.22	271.77	140.29	0.48	0.69	1
C/2008 E3	5.531	0.998	105.08	105.67	218.08	0.49	-4.21	162.3
C/2012 V2	1.455	0.997	67.18	262.17	217.32	0.73	3.57	21.1
C/2011 C1	0.883	0.997	16.83	192.44	84.47	0.82	-3.6	83.3
C/1997 A1	3.157	1.002	145.07	135.77	40.01	0.96	10.23	117.7
C/1850 Q1	0.566	1	40.06	208.11	243.2	1	-7.97	70.4
C/1980 E1	3.364	1.057	1.66	114.56	135.09	1.14	22.11	87.7
C/2005 N1	1.125	0.998	51.18	3.24	80.04	1.15	-6.04	88.8
C/2012 H1	1.296	1	27.74	125.98	137.99	1.2	5.29	109
C/1914 M1	3.747	1.003	71.04	271.51	14	1.21	-3.4	15.1
C/2010 B1	2.941	0.999	101.98	277.21	211.52	1.24	-3.48	16.7
C/2010 D2	3.917	1	59.17	314.89	129.12	1.54	10.69	48.8
C/2016 M1	2.212	1	91	92.19	209.77	1.77	-1.79	177.1
C/2004 U1	2.659	0.999	130.62	112.55	20.13	1.85	8.12	138.7
C/1925 F2	1.633	0.995	26.98	7.04	259.28	1.91	4.27	89
C/2013 E2	1.414	0.997	21.85	182.49	95.84	2.03	-5.1	86.2
C/2002 O4	0.776	1.001	73.13	321.04	105.94	2.16	5.02	50.1
C/1954 O2	3.87	1.001	100.39	265.34	144.67	2.24	2.9	15.6
C/2006 K1	1.752	0.992	144.26	243.81	143.46	2.26	4.23	62.6
C/1885 N1	2.507	1	80.62	93.9	178.52	2.29	-1.82	166.6
C/2014 G1	5.467	0.992	165.64	337.94	77.02	2.38	11.02	88
C/1955 G1	4.496	1.003	123.93	321.33	73.75	2.49	10.78	60
C/2016 A5	2.947	0.998	40.32	136.22	321.61	2.51	10.61	114.2
C/2003 T4	0.85	1	86.76	93.9	181.65	2.61	-2.36	172.6
C/1748 K1	0.625	1	67.08	36.64	245.67	2.66	4.51	120
C/1998 K3	3.547	1	160.21	307.96	47.84	2.8	10.51	77.9
C/1846 B1	1.481	0.992	47.43	113.27	337.99	2.93	4.92	129.7
C/1988 F1	1.174	0.998	62.81	288.77	326.51	3.06	-2.06	28.5
C/1988 J1	1.174	0.998	62.81	288.76	326.52	3.08	-2.05	28.5
C/1898 V1	2.285	1	22.5	97.24	4.64	3.31	9.88	108.6
C/1890 O1	0.764	1	63.35	15.83	85.66	3.44	5.44	100.8
C/2007 J1	5.368	1.002	89.84	65.52	93.7	3.67	5.59	153.5
C/1871 L1	1.083	1	101.98	213.7	96.32	3.7	4.62	59.8
C/1822 N1	1.145	0.996	127.34	95.24	181.11	3.73	-2.88	146.3
C/1920 X1	1.148	0.994	22.03	108.83	340.89	3.96	-1.18	107.2

Table 2. continuation table 1

C/2004 G1	1.202	1	114.49	228.38	110.49	3.98	5.66	50.8
C/1932 M1	1.647	1.001	78.39	246.09	69.79	4.03	2.33	26.6
C/1975 X1	0.864	1.001	93.96	281.49	215.47	4.61	3.42	12.5
C/1897 U1	1.357	1	69.61	33.49	65.91	4.9	-7.03	118
C/2006 S3	5.131	1.003	166.03	38.37	140.13	5.18	14.75	102
C/1980 L1	2.584	1	73.15	279.52	334.96	5.24	-1.61	15.1
C/1785 A1	1.143	1	70.24	267.21	205.63	5.26	2.71	16.5
C/1877 G1	0.95	0.999	121.15	318.33	63.12	5.27	2.26	56.5
C/1958 R1	1.628	1	61.26	323.78	100.74	5.34	-4.93	55.2
C/2010 J3	2.249	1	14.63	101.07	180.37	5.37	-9.67	100.6
C/1954 M2	0.746	1	88.54	75.57	254.73	5.59	-0.84	163
C/2014 M1	5.545	1	160.16	234.77	337.63	5.63	15.12	78
C/1975 T1	1.604	0.997	91.61	278.68	246.24	5.77	-2.17	8.8

In addition, table 1 shows the calculated inclinations (I') of the selected comets relative to the motion of planet X plane. There is a slight dominance of the values of this parameter near 0° and 180° . In particular, the regions $I' < 17^\circ$ and $I' > 163^\circ$ correspond to 8 and 5 values. Although their number exceeds the random norm, however, this does not mean that the assumed excess of MOID values is associated with this factor.

The possibility of determining the randomness measure of such comets was discussed in [6]. For a uniform or random distribution of MOID values, the number of MOIDs within an interval of 6 AU should be:

$$N = 2 \times 1156 \times 6/339 = 40.9$$

If the interval is limited to 5.77 AU (the extreme value in table 1), there should be 39 of them. This means that there is a significant advantage of the real value of MOIDs over the expected one (by about 25 percent).

4. CONCLUSION

Analysis of the MOID values of 1156 long-period comets relative to the assumed planet with orbital parameters (1) and identification of 51 comets among them allows us to draw a conclusion about the reality of the existence of such a planet. The obtained data can be considered as another argument in favor of the discussed hypothesis.

REFERENCES

1. Abalakin, E.P., Grebenikov 1976, Duboshin 1976 book Abalakin, V., E.P., A. Grebenikov, E. 1976, *Spravochnoe rukovodstvo po nebesnoj mehanike i astrodinamike*, Nauka.
2. Danby, J. 1992, 'Fundamentals of celestial mechanics', Richmond: Willman-Bell pp. 352–353.
3. Fouchard, Rickman, Froeschl, Valsecchi 2017, Fouchard 2017, distribution Fouchard, M., Rickman, H., Froeschl, C., Valsecchi, G. 2017, 'Distribution of long-period comets: comparison between simulations and observations', *Astronomy & Astrophysics* 604, A24.
4. Guliyev, A., Guliyev, R. 2019, 'System of long-period comets as indicator of the large planetary body on the periphery of the solar system', *Acta Astronomica* 69(2), 177–203.
5. Guliyev, A., Guliyev, R. 2020, 'On the existence of long-period comet families of the giant planets', *Astronomy Letters* 46(10), 702–704.
6. Guliyev, A., Guliyev, R., Gasimov, A. 2021, 'On the question of families of periodic comets of giant planets (mold analysis)', *Astronomical Circular*.

PHOTOSPHERIC VARIABILITY OF THE LATE B-SUPERGIANT HD199478

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The results of spectral studies of photospheric lines of the late B-supergiant HD 199478 (B8Iae) in the visual range are presented. It was first-ever shown that the radial velocities of photospheric lines, as well as the emission component of the $H\alpha$ line, to demonstrate synchronous variations. The equivalent widths variations of the photospheric lines and the emission component of the $H\alpha$ line tend to be anticorrelation. The parameters of the spectral lines vary quasi-periodically which are characterized by extrema (maxima and minima). The time scales between the nearby extrema are about 25 days, and the full cycle of the quasi-period is about 45 ± 10 days. It was first-ever revealed that the photospheric lines show blue shifts relative to the mass center of the system during the HVA (High Velocity Absorption) event. The distribution of the velocity gradient along the line shows the existence mainly radial, and to a lesser level, non-radial pulsations. The D NaI line profiles often exhibit signs of accretion of matter onto the star. It was shown that the observed photometric variability of the star can also be explained by radial pulsations.

Keywords: late B – supergiants – stars, spectral variability – stars, absorption spectrum – stars, stellar wind – stars, individual – HD 199478.

1. INTRODUCTION

In order to study the possible relationship between the stellar winds and the photospheres of BA supergiants (SGs), a systematic study of the variations in the spectral parameters and profiles (line profile variation – lpv) of the absorption lines and lines that are indicators of stellar wind is necessary. The variability in photospheres and stellar winds of a group of BA supergiants was studied in detail by Kaufer et al. [9–11]. Certain shifts in the profiles of photospheric lines were found in the dynamic spectrum. The authors showed that the time scale of these

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deviations is inconsistent with the periods of rotation of the stars.

One of the unusual features in the spectra of late B supergiants is the sudden appearance and disappearance of deep, blue-shifted high-velocity absorption component forming in the blue wing of the $H\alpha$ line (Kaufer et al. [9,10]). The essence of this event is that suddenly a strong outflow of matter forms at the base of the stellar wind, which subsequently spreads throughout the wind. A sudden variation in the wind structure is also possible when the substance from a completely ionized state goes into a recombination state for some unknown reason. Since the shell rotates along the line of sight, all the resulting modulations (density, temperature) in the wind structure can be observed (Kaufer et al., [10]). Despite the certain progress made in these studies, it is not yet completely clear how such variations in the structure of the wind may be related with the variability at the level of the stellar photosphere.

HD199478 (HR 8020, B8Iae, $V \approx 5.69$ mag) is the central star of the reflection nebula IC 5076. The star differs from the other B SGs in that it has an inverse distribution of radial velocities in the Balmer progression – higher members of the series have less displacements than lower members [2] – and, similar to Be stars, a double-peak $H\alpha$ emission [13,22]. According to Markova et al. [15], photospheric lines showed systematic shifts relative to the velocity of the center of the star with a characteristic time of about 20 days. In addition, these authors found a significant variation in the $H\alpha$ emission and, according to 2000 data, a wide absorption was observed during 60 days, indicating to accretion and outflow of the substance. The HVA event in HD199478, simultaneously observed in the $H\alpha$ and $H\beta$ lines, was also found in [6]. Only in one season of observations, that of 2011, [6] detected high-velocity absorption with a maximum displacement of -510 kms^{-1} and a duration of at least about 13 days. These authors showed that the characteristic time of variability of the hydrogen emission lines is $22 \pm 2 \text{ kms}^{-1}$, which is in good agreement with the data of Markova et al. [15].

The photometric behaviour of the star HD199478 is characterized by a prolonged irregular/multiperiodic variability with an amplitude of 0.15 mag in the B and V bands, over a period from 20 to 50 days [20]. The reason for such variations is not yet entirely clear.

The aim of this work, based on long-term spectral material, is to study the variability of different absorption spectral lines in the spectrum of HD 199478 and its relation, if any, with the stellar wind.

2. OBSERVATIONS

Spectral observations of the star HD 199478 were made on the 2 m telescope of the Shamakhy Astrophysical Observatory of Azerbaijan National Academy of

Sciences in 2011, 2013, 2014 and 2015. Observations were performed using an Echelle spectrometer built on the base of the Universal Astronomic Grid Spectrograph (UAGS) [17] and a CCD camera with 530×580 pixels. The optimal range of the spectrum covers the area $\lambda 4700\text{--}6700 \text{ \AA}$. The spectral resolution is $R = 14000$. For an average exposure time of 900 sec, the signal to noise ratio S/N reached 200–300 near the $H\alpha$ line. In the $H\beta$ region, the S/N ratio is approximately half of this value. A description of the observing facilities, observational conditions and data processing may be found in more detail in Mikailov et al. [17] and Ismailov et al. [5, 7].

The data were processed using the DECH20T software developed at the SAO RAS [4]. Two spectra of the program star, as well as of the standards, were observed in sequence one after the other each night to be averaged. Intensity measurement uncertainties were dependent on the S/N level, being 0.5–0.7% in the $H\alpha$ line region and reaching up to 1% in the $H\beta$ line region. After processing the spectrograms, the spectral orders containing the lines to measure were cleared of the Earth's atmospheric lines.

The basic information on the obtained spectral material is summarized in Table 1. The Table provides the dates of observations, the number of spectrograms per season (year), the average S/N value for the observing run, and the average signal accumulation time.

Table 1. Brief information about the spectral material.

Observation dates	JD 2450000+	Days in the run	N	S/N	t_{exp} (sec)
2011 July 2–October 6	5745.40 - 5841.26	96	17	180	1100
2013 July 22–November 25	6496.28 - 6622.19	126	14	195	900
2014 June 19–September 15	6828.18 - 6916.18	90	23	200	900
2015 May 27–July 9	7173.16 - 7213.27	40	10	220	900

The results of studying the $H\alpha$ and $H\beta$ hydrogen lines for individual years based on this spectral material are presented in [6]. In this paper, we present the results of studies of the absorption photosphere lines.

In order to investigate the possible connection between the stellar wind and variations in the photosphere, it is extremely important to study wind lines ($H\alpha$), photosphere - wind transition lines (i.e., the strongest absorption lines of CII, SiII, and HeI) and to make a detailed analysis of purely photospheric lines as well. For this purpose, we measured the strongest absorption lines, such as CII λ 6578, 6583 $\text{\AA}$, SiII λ 6347, 6371 $\text{\AA}$, HeI λ 5876, 4922 $\text{\AA}$, D1, D2 NaI. The set of lines also includes more than 40 absorption lines related to various elements such as HeI, SiII, FeII, FeI, SII, AlIII, NaII, YII, etc.

Unlike hydrogen lines, absorption lines do not contain emission components and the profiles of these lines are almost Gaussian curves. To evaluate the intensity, the equivalent widths (EWs) of the absorption lines were measured using the method of integration.

We conventionally grouped the lines according to their EW values: the weakest lines are included in the first group with $EW \leq 0.25 \text{ \AA}$. The second group includes lines with $EW \geq 0.25 \text{ \AA}$. To estimate the measurement errors in EW, we used the spectra of standard stars, which were obtained under the same conditions. Metal lines with equivalent widths in the range from 0.01 to 1.50 $\text{\AA}$ were selected from the spectrum of the standards. According to the spectrograms obtained for 14 nights of observations, the root-mean-square deviation of the equivalent widths varies from 10% to 2.5%, respectively. These measurements indicated that the mean uncertainty in measuring EWs of absorption lines of the star varied between 3.5–4.0%.

To measure radial velocities (RVs), we have used the cross-correlation method in which a selected section of the profile is smoothed by a cubic spline and the profile is subsequently superimposed on its mirror image produced by the program after smoothing. To get the profiles matched as good as possible, the method of shifting them relative to each other was used and the quality of the superposition obtained was controlled by the correlation coefficient. Since the wings of absorption lines were not overlapped so well as the central parts of the lines, the preference in combining mirror profiles was given to the center of the line and its lower part along the line peak. In addition, this approach allowed us to eliminate possible errors that might occur in determining the continuum level. This kind of measurements yields terms error for different lines varying between $\pm 1.5\text{--}2 \text{ km/s}^{-1}$. The reference measurements of radial velocities performed for different standard stars showed a high degree of coincidence of their measured RV values with the catalog data within $\pm 3 \text{ km/s}^{-1}$. We have not detected any systematic differences in our RV measurements for standard stars within the measurement uncertainties [5].

3. MAIN RESULTS

3.1. General Variability of the Photospheric Lines

The Table 2 presents the mean parameters for each year of observations - radial velocities RV and equivalent widths EW for all measured absorption lines. For each parameter, the standard deviation is given from the mean value σ_{rms} , which is an indicator of the magnitude of the parameter variation. As can be seen from Table 1, the radial velocities of different photospheric lines show an

interval of variations from -25 to -8 km s^{-1} . If we take into account the mass center velocity of the system, which is equal to -15 km/s^{-1} [12], then the range of RV variations in the absorption lines relative to the mass center of the system will be from -10 up to $+7 \text{ km/s}^{-1}$, respectively.

Our data showed that, this value most likely refers to the mean cluster velocity for IC 5076. Indeed, as can be seen from Table 2, the radial velocities of the weakest photospheric lines have values of $-24 \pm 2 \text{ km/s}^{-1}$ on average. We could take this value for the speed of motion of the mass center of the system, but we do not know if there is a stellar wind at this level of the photosphere, where the weakest lines are formed. In any case, this will not change the main results of this work.

We have investigated weak photospheric lines that form in the lower photosphere, being hence less influenced by wind. In addition we have considered strong photospheric lines that form in the photosphere, but can be more strongly influenced by the stellar wind, as well as the emission component of the $H\alpha$ line, which is completely forms in the upper parts of the wind. As was shown in Markova & Valchev (2000) and Ismailov&Ismayilova (2019), the $H\alpha$ line mostly is observed in double peak emission, with a variable relation of the V/R components.

One of the longest series of observations was made in 2014, in which 23 nights of observations were performed within 90 days (Table 1). In this section, we will consider the variability of the parameters of individual photospheric lines obtained in 2014. To detect a possible relationship in the variations in photospheric lines and lines that form in the stellar wind, we will also compare the results obtained for variations in photospheric lines with the data of the $H\alpha$ line.

Figure 1 shows diagrams of variations in time for the parameters RV and EW revealed in strong absorption lines with $EW \geq 0.25 \text{ \AA}$ according to the data through a season 2014. The bottom two panels show the parameters of the emission component of the $H\alpha$ line (Fig. 6 [6]). The two lower panels from left to right show the variations in the same parameters of the absorption lines, which can also be partially under influence of the stellar wind. As can be seen from Fig. 1, the radial velocities of strong absorption lines are vary smoothly and synchronously with the $H\alpha$ line emission. The minimum in the RV curve for the $H\alpha$ line is reached on JD 2456843, and the maximum on JD 24566869, the interval between them is approximately 26 days. The minimum on the RV curve along the indicated absorption lines occurs on JD 24566860, and the maximum is around JD 24566877, that is, in about 27 days.

Figure 1 demonstrates that the variation in the EW parameter for the $H\alpha$ emission is synchronous with its radial velocity, and the dates of their maximum and minimum coincide. The absorption lines show different patterns of EW variations relative to the $H\alpha$ line. For example, in the region of the maximum EW

Table 2. Seasonally averaged parameters of some photospheric spectral lines of the star HD 199478

Elements	λ (Å)	2011				2013			
		RV (km/s^{-1})	σ (km/s^{-1})	EW (Å)	σ (Å)	RV (km/s^{-1})	σ (km/s^{-1})	EW (Å)	σ (Å)
NaI	5889.95	-15.9	2.3	0.90	0.34	-14.6	2.2	0.87	0.012
Na I	5895.92	-15.8	2.1	1.19	0.18	-12.4	2.0	0.73	0.025
Na II	5688.21	-14.5	1.9	0.15	0.010	-16.1	4.6	0.15	0.010
C II	6578.05	-20.3	1.4	0.31	0.06	-17.9	4.3	0.24	0.017
C II	6582.88	-21.0	1.5	0.32	0.03	-16.8	4.2	0.22	0.019
HeI	4921.93	-18.5	2.7	0.45	0.042	-14.8	3.1	0.40	0.019
HeI	5015.68	-25.8	2.1	0.22	0.011	-14.8	1.6	0.23	0.039
HeI	5047.71	-21.1	2.8	0.15	0.007	-15.2	2.7	0.15	0.010
HeI	5875.62	-17.2	2.7	0.98	0.105	-12.4	1.4	0.74	0.013
Fe II	5018.44	-19.8	1.8	0.05	0.002	-17.9	1.8	0.02	0.017
Fe II	5276.001	-21.9	1.8	0.05	0.001	-20.9	2.0	0.03	0.001
Fe II	5316.23	-19.3	0.7	0.13	0.009	-18.3	0.8	0.14	0.010
Fe II	5482.31	-20.4	2.8	0.02	0.003	-19.2	2.7	0.05	0.002
Fe II	5487.62	-19.9	2.7	0.02	0.004	-19.6	2.5	0.02	0.003
Si II	5041.02	-23.5	1.3	0.21	0.025	-19.8	1.1	0.22	0.023
Si II	5055.98	-25.9	3.9	0.23	0.019	-22.4	2.4	0.25	0.010
Si II	6347.11	-23.1	2.4	0.85	0.071	-22.8	2.5	0.66	0.021
Si II	6371.37	-23.3	2.5	0.79	0.063	-23.1	2.7	0.53	0.017
S II	5212.62	-22.0	1.7	0.07	0.003	-20.2	1.5	0.05	0.002
S II	5320.73	-21.5	2.0	0.05	0.005	-19.6	2.2	0.06	0.002
S II	5453.86	-21.3	2.7	0.22	0.02	-20.0	2.9	0.20	0.038
S II	5009.57	-21.1	1.6	0.22	0.009	-20.0	1.2	0.22	0.016
S II	5032.43	-25.0	1.0	0.14	0.008	-20.7	0.4	0.15	0.012
S II	5432.8	-24.9	1.5	0.15	0.007	-22.3	1.4	0.15	0.007
S II	5639.97	-19.4	0.8	0.19	0.013	-20.1	1.5	0.18	0.008
S II	5647.03	-23.5	1.0	0.13	0.009	-19.2	1.1	0.13	0.008
S II	5212.62	-24.5	1.6	0.07	0.005	-20.7	1.7	0.05	0.005
S II	5320.73	-23.8	1.8	0.06	0.005	-21.8	1.5	0.07	0.003
S II	5345.72	-24.2	1.7	0.08	0.001	-20.8	1.8	0.08	0.002
S II	5428.67	-25.0	1.3	0.07	0.004	-22.5	1.3	0.06	0.004
S II	5606.15	-24.3	1.2	0.08	0.004	-20.9	1.3	0.09	0.004
S II	5659.99	-24.3	1.7	0.05	0.005	-16.8	2.9	0.06	0.005
S II	5664.78	-23.3	1.1	0.05	0.004	-19.1	2.6	0.07	0.005
Al III	5696.61	-21.3	1.7	0.14	0.021	-9.8	2.6	0.15	0.011
Y II	5473.38	-16.0	1.3	0.08	0.002	-18.9	2.3	0.09	0.024
Y II	5509.9	-24.1	4.0	0.13	0.012	-21.7	2.9	0.14	0.015
Fe I	5168.9	-23.8	3.3	0.23	0.012	-19.2	2.5	0.23	0.011
Fe I	5127.36	-23.4	3.6	0.09	0.011	-22.0	2.8	0.08	0.037
Fe III	5156.12	-23.2	3.6	0.06	0.007	-19.9	2.2	0.06	0.005
DIB	5780.63	-23.7	2.1	0.43	0.013	-16.0	2.8	0.42	0.013
DIB	5796.96	-15.8	3.0	0.12	0.010	-8.1	4.9	0.14	0.011
Cr I	5206.04	-19.2	1.6	0.01	0.018	-18.4	1.3	0.01	0.002
Cr II	5279.95	-19.6	1.7	0.02	0.002	-23.2	1.6	0.02	0.001

	2014					2015			
Na I	5889.95	-15.6	1.4	0.84	0.033	-13.3	7.3	0.82	0.01
NaI	5895.92	-14.5	1.6	0.72	0.034	-12.0	6.3	0.70	0.02
Na II	5688.21	-14.8	1.5	0.17	0.023	-18.1	5.5	0.14	0.010
C II	6578.05	-19.9	3.4	0.25	0.017	-21.7	4.1	0.23	0.01
C II	6582.88	-19.8	3.9	0.22	0.015	-21.9	5.2	0.21	0.01
HeI	4921.93	-19.9	2.9	0.47	0.031	-19.0	8.9	0.43	0.009
HeI	5015.68	-23.5	1.3	0.26	0.012	-23.7	2.4	0.25	0.007
HeI	5047.71	-21.5	2.6	0.18	0.018	-21.7	1.0	0.16	0.005
HeI	5875.62	-11.1	4.6	0.72	0.022	-11.5	6.5	0.78	0.021
Fe II	5018.44	-22.0	1.6	0.04	0.004	-19.6	15.1	0.06	0.002
Fe II	5276.001	-22.3	1.6	0.06	0.002	-24.7	1.2	0.04	0.002
Fe II	5316.23	-20.3	1.3	0.15	0.002	-21.9	0.6	0.14	0.010
Fe II	5482.31	-21.8	1.8	0.05	0.010	-22.9	1.8	0.04	7.326
Fe II	5487.62	-21.8	1.7	0.02	0.003	-22.5	2.2	0.03	0.003
Si II	5041.02	-25.5	1.7	0.24	0.017	-23.7	2.2	0.23	0.024
Si II	5055.98	-25.2	2.1	0.27	0.014	-23.6	1.9	0.25	0.014
Si II	6347.11	-20.5	3.6	0.68	0.018	-21.3	3.6	0.69	0.007
Si II	6371.37	-20.4	3.7	0.55	0.010	-22.5	3.3	0.51	0.027
S II	5212.62	-22.2	1.4	0.05	0.003	-25.2	3.1	0.06	0.004
S II	5320.73	-21.8	2.0	0.05	0.004	-20.1	2.0	0.04	0.002
S II	5453.86	-21.5	2.1	0.21	0.021	-24.1	1.4	0.21	0.021
S II	5009.57	-22.5	1.8	0.24	0.030	-25.8	3.6	0.21	0.020
S II	5032.43	-24.1	1.1	0.15	0.015	-26.5	4.1	0.16	0.015
S II	5432.8	-24.3	1.2	0.18	0.018	-24.5	1.5	0.19	0.017
S II	5639.97	-20.1	1.9	0.19	0.015	-21.2	0.9	0.21	0.024
S II	5647.03	-22.8	2.1	0.14	0.013	-22.9	0.8	0.15	0.012
S II	5212.62	-24.7	1.0	0.05	0.004	-25.5	1.6	0.06	0.005
S II	5320.73	-24.3	1.3	0.06	0.004	-24.8	1.3	0.07	0.001
S II	5345.72	-24.3	1.4	0.08	0.002	-25.0	1.1	0.08	0.002
S II	5428.67	-24.9	1.3	0.07	0.003	-24.0	1.4	0.08	0.003
S II	5606.15	-24.0	1.3	0.09	0.004	-23.0	1.0	0.08	0.002
S II	5659.99	-23.0	2.9	0.05	0.005	-20.0	2.5	0.06	0.003
S II	5664.78	-21.9	2.7	0.06	0.007	-	-	-	-
Al III	5696.61	-21.3	1.4	0.15	0.027	-18.9	5.0	0.18	0.018
YII	5473.38	-24.7	2.9	0.11	0.014	-21.5	2.5	0.12	0.002
YII	5509.9	-24.7	2.9	0.15	0.014	-22.1	2.2	0.08	0.019
FeI	5168.9	-26.5	3.4	0.24	0.018	-23.8	2.0	0.24	0.007
FeI	5127.36	-24.8	2.6	0.07	0.009	-23.4	2.1	0.10	0.011
Fe III	5156.12	-24.8	2.0	0.05	0.007	-23.4	1.7	0.07	0.005
DIB	5780.63	-23.2	1.9	0.43	0.014	-15.3	5.3	0.41	0.007
DIB	5796.96	-15.5	2.1	0.14	0.008	-7.9	7.8	0.12	0.019
Cr I	5206.04	-24.5	1.5	0.01	0.002	-21.9	1.5	0.02	0.007
CrII	5279.95	-24.0	2.1	0.02	0.002	-24.1	1.7	0.03	0.002

Table 3. Time variation parameters of 2011 data.

Atom	λ (Å)	Max, JD 2455000	RV, ($km\,s^{-1}$)	Min, JD 2455000	RV ($km\,s^{-1}$)	Max, JD 2455000	EW, (Å)	Min, JD 2455000	EW (Å)	Δt (RV) days	Δt (EW) days
HeI	4921	768	-15	808	-23	768	0.5	788	0.47	40	20
HeI	5015	762	-23	808	-29	749	0.2	788	0.23	46	39
HeI	5047	764	-17	809	-26	747	0.14	771	0.16	45	24
HeI	5876	762	-12	808	-20	747	0.88	757	1.06	46	10
Fe II	5018	745	-17	762	-23	749	0.05	789	0.056	17	40
Fe II	5276	745	-18	771	-24	762	0.02	776	0.018	26	14
Fe II	5316	745	-18	768	-20	745	0.12	769	0.15	23	24
Fe II	5482	745	-16	788	-25	745	0.015	789	0.023	43	44
Fe II	5487	745	-16	768	-24	756	0.019	808	0.03	23	52
Si II	5041	747	-22	788	-32	745	0.04	762	0.05	41	17
Si II	5056	749	-26	769	-25	745	0.038	771	0.052	20	26
S II	5010	750	-18	768	-22	757	0.21	789	0.18	18	32
S II	5032	747	-23	776	-26	747	0.13	776	0.15	29	29
S II	5640	750	-18	776	-20	749	0.2	768	0.18	26	19
S II	5647	747	-22	762	-25	756	0.14	768	0.12	15	12
S II	5433	745	-22	769	-26	749	0.14	768	0.16	24	19
S II	5454	745	-18	769	-23	747	0.19	769	0.16	24	22
S II	5606	747	-23	762	-26	745	0.099	769	0.085	15	24
S II	5660	745	-18	762	-25	747	0.044	769	0.057	17	22
S II	5665	745	-20	762	-24	757	0.056	789	0.049	17	32
S II	5213	745	-20	771	-26	764	0.049	808	0.059	26	44
S II	5321	747	-22	771	-27	745	0.058	764	0.069	24	19
S II	5346	745	-21	789	-26	745	0.08	756	0.075	44	11
S II	5429	745	-22	771	-27	745	0.079	762	0.069	26	17
Na II	5688	745	-13	762	-19	747	0.16	768	0.13	17	21
Al III	5697	745	-16	764	-23	745	0.16	769	0.09	19	24
Y II	5473	745	-14	756	-18	750	0.057	776	0.069	11	26
Fe II	5169	745	-17	769	-27	749	0.2	776	0.24	24	27
Fe II	5127	747	-14	769	-26	757	0.07	788	0.12	22	31
Fe III	5156	745	-15	771	-26	757	0.047	788	0.07	26	31
Mean										26	26
σ rms										10	10

values of the $H\alpha$ line, a minimum is observed for the lines HeI $\lambda 4921$ Å, CII $\lambda 6578$, 6583 Å, and Si II $\lambda 6347$, 6371 Å, i.e. there is an anticorrelation tendency. The D1, D2 NaI and HeI $\lambda 5876$ Å lines exhibit a slight increase in the region where the EW maximum of the $H\alpha$ line is observed, suggesting a direct correlation. This indicates that the D NaI and HeI $\lambda 5876$ Å lines are influenced by the upper part of the stellar wind. The cyclical nature of EW variations in the strongest absorption lines indicates that the stellar wind may exert an influence on these lines.

Table 4. Time variation parameters of 2014 data.

Atom	λ (Å)	Min, JD 2455000	RV, (km s^{-1})	Max, JD 2455000	RV (km s^{-1})	Min, JD 2455000	RV, (km s^{-1})	Δt_2 days	Δt_2 days	T, days
HeI	4921	830	-23	863	-15	879	-23	33	16	49
He I	5015	830	-24	877	-28	916	-24	47	39	86
HeI	5047	828	-24	862	-17	879	-25	34	17	51
HeI	5876	828	-15	862	-17	880	-20	34	18	52
Fe II	5018	836	-20	862	-24	888	-19	26	26	52
Fe II	5276	836	-21	864	-25	888	-20	28	24	52
Fe II	5316	835	-18	855	-22	880	-18	20	25	45
Fe II	5482	856	-19	875	-24	888	-20	19	13	32
Fe II	5487	842	-21	862	-25	888	-19	20	26	46
Si II	5041	843	-25	876	-27	888	-22	33	12	55
Si II	5056	843	-22	864	-28	888	-23	21	24	45
SII	5010	828	-26	856	-18	882	-25	28	26	54
SII	5032	830	-25	856	-23	876	-26	26	20	46
SII	5640	828	-17	851	-24	875	-17	23	24	47
SII	5647	828	-16	855	-24	875	-23	27	20	47
SII	5433	835	-25	850	-22	875	-26	15	25	40
SII	5454	835	-25	862	-23	876	-26	27	14	41
SII	5606	842	-24	850	-23	864	-26	14	15	29
SII	5660	828	-15	869	-25	888	-24	41	19	60
SII	5665	864	-24	830	-16	888	-23	34	58	92
SII	5213	830	-25	843	-23	862	-25	13	19	32
SII	5321	835	-25	850	-22	876	-26	15	26	41
SII	5346	835	-25	850	-21	882	-26	15	32	47
SII	5429	830	-25	850	-22	879	-27	20	29	49
SII	5688	835	-18	880	-12	864	-19	45	16	61
Na II	5697	836	-20	863	-23	888	-19	27	25	52
AlIII	5473	862	-27	888	-18	864	-23	26	24	50
YII	5169	835	-32	855	-22	875	-28	20	20	40
Fe II	5127	842	-27	855	-21	888	-26	13	20	33
Fe III	5156	842	-27	856	-22	916	-29	13	33	46
Mean								25	24	49
σ_{rms}								9	9	13
EW		Min 2455000	EW (Å)	Max 2455000	EW (Å)	Min 2455000	EW (Å)	Δt_1 days	Δt_2 days	T, days
HeI	4921	842	0.42	863	0.51	875	0.46	21	12	33
HeI	5015									
HeI	5047	842	0.16	869	0.22	908	0.16	27	39	66
HeI	5876	856	0.68	880	0.76	916	0.72	24	36	60
HeI	5018	828	0.026	850	0.019	877	0.032	22	27	49
Fe II	5276	856	0.058	875	0.055	888	0.058	19	13	32
Fe II	5316	842	0.018	855	0.02	875	0.018	13	20	33
Fe II	5482	842	0.13	862	0.15	879	0.12	20	17	37
Fe II	5487	828	0.023	856	0.018	877	0.026	28	21	49
Si II	5041	842	0.23	863	0.26	876	0.23	21	13	34

Si II	5056	842	0.25	864	0.29	877	0.25	22	13	35
SII	5010	842	0.22	862	0.28	882	0.19	20	20	40
SII	5032	851	0.13	830	0.18	875	0.13	21	45	66
SII	5640	850	0.16	856	0.2	869	0.18	14	13	29
SII	5647	843	0.13	888	0.16	869	0.12	25	13	48
SII	5433	830	0.17	843	0.21	863	0.15	13	20	33
SII	5454	828	0.2	855	0.24	879	0.17	27	24	51
SII	5606	836	0.094	828	0.14	877	0.085	26	32	58
SII	5660	851	0.044	830	0.06	888	0.048	21	58	79
SII	5665	855	0.054	830	0.07	888	0.049	25	58	83
SII	5213	850	0.048	882	0.059	875	0.049	15	13	28
SII	5321	850	0.058	869	0.069	880	0.059	19	11	30
SII	5346	830	0.079	842	0.083	862	0.075	12	20	32
SII	5429	830	0.07	850	0.079	877	0.068	20	27	47
Na II	5688	828	0.18	851	0.22	875	0.14	23	24	47
AlIII	5697	828	0.2	851	0.15	862	0.16	23	11	34
YII	5473	855	0.057	888	0.08	875	0.06	33	13	46
Fe II	5169	828	0.27	851	0.2	877	0.24	23	26	49
Fe II	5127	830	0.088	850	0.06	888	0.085	20	38	58
Fe III	5156	843	0.047	856	0.035	879	0.038	13	23	36
Mean								21	24	46
σ_{rms}								5	13	15

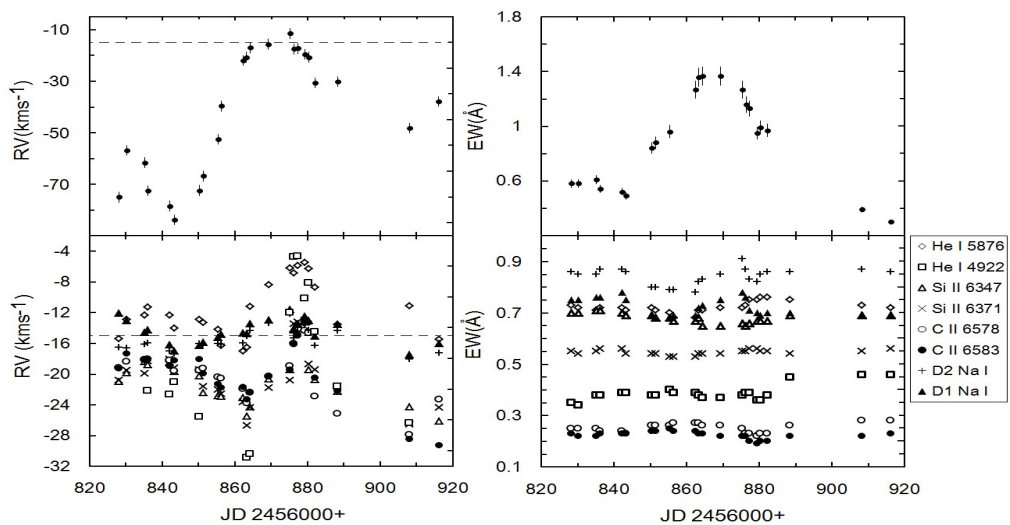


Fig. 1. Time variation of RV and EW parameters for absorption with $EW \geq 0.25 \text{ \AA}$ in 2014. The dashed horizontal lines in the left panels indicate the mass center velocity of the star.

Figure 2 shows the time variation diagrams for RV (left panels) and EW (right panels) parameters for the absorption lines FeII, SiII, and SII. As can be seen from

Table 5. Results of TVS analysis of some spectral lines.

N of lines	Lines (Å)	Vb (km s^{-1})	v_1 (km s^{-1})	Vc (km s^{-1})	v_2 (km s^{-1})	Vr (km s^{-1})	$v_2 - v_1$ (km s^{-1})	Vr-Vb (km s^{-1})	a_1	a_2	FWHM (Å)
2011											
1	C II 6578	-109	-67	-57	-26	5	41	113	0.031	0.03	2.032
2	C II 6583	-102	-72	-61	-21	10	51	112	0.024	0.029	2.016
3	Si II 6347	-98	-53	-30	-7	50	45	148	0.037	0.039	1.925
4	Si II 6371	-89	-45	-34	-11	53	34	143	0.031	0.028	1.865
5	HeI 5876	-93	-46	-31	-5	71	41	163	0.047	0.036	2.285
6	D2 Na I	-70	-24	-13	6	33	30	103	0.233	0.207	0.9
7	D1 NaI	-66	-32	-9	9	25	41	91	0.213	0.198	0.893
8	S II 5010	-	-39	-17	3	196	42	-	0.023	0.02	-
9	HeI 5016	-97	-61	-14	10	58	72	156	0.025	0.044	2.201
10	Fe II 5018	-107	-47	-12	12	95	59	202	0.029	0.025	1.593
11	Fe II 5027	-98	-56	-31	5	66	61	164	0.010	0.014	1.374
12	S II 5429	-82	-36	-13	11	69	46	151	0.016	0.016	1.465
13	S II 5433	-117	-60	-25	-2	32	57	149	0.013	0.011	1.664
14	S II 5454	-64	-42	-19	15	71	57	136	0.018	0.019	1.413
15	Y II 5474	-93	-37	-8	27	119	64	212	0.029	0.03	1.37
16	S II 5032	-97	-67	-35	11	16	78	112	0.01	0.008	1.557
17	S III 5041	-117	-60	-25	-2	32	57	149	0.013	0.011	1.538
18	He I 5048	-89	-44	-22	11	45	55	133	0.017	0.018	1.522
19	S III 5056	-56	-45	-13	8	41	54	97	0.01	0.014	1.881
	Mean	-91	-49	-25	3	57	52	141	0.044	0.042	1.639
	σ_{rms}	18	13	15	13	44	12	33	0.064	0.057	0.390
2013											
1	C II 6578	-81	-39	3	24	55	63	136	0.027	0.02	1.833
2	C II 6583	-124	-51	-18	1	22	52	145	0.028	0.021	2.275
3	Si II 6347	-114	-45	-11	24	81	69	195	0.087	0.076	1.943
4	Si II 6371	-116	-49	-16	17	84	66	199	0.067	0.061	2.118
5	HeI 5876	-130	-59	-12	23	82	83	213	0.066	0.068	2.314
6	D2 NaI	-75	-40	-17	-5	30	35	104	0.242	0.23	1.139
7	D1 NaI	-78	-32	-20	3	37	35	115	0.21	0.21	1.356
8	S II 5010	-	-	-	-	-	-	-	-	-	-
9	HeI 5016	-197	-63	-39	22	58	85	255	0.025	0.044	2.837
10	Fe II 5018	-107	-59	-23	14	134	72	240	0.024	0.033	1.812
11	Fe II 5027	-33	-41	-14	15	61	35	94	0.011	0.013	1.783
12	S II 5429	-143	-74	-30	11	-4	58	138	0.019	0.015	1.671
13	S II 5433	-152	-72	-37	-14	-3	57	149	0.028	0.027	1.661
14	S II 5454	-170	-81	-28	19	-4	67	166	0.034	0.033	1.612
15	Y II 5474	-148	-85	-32	22	2	96	150	0.014	0.014	1.368
16	S II 5032	-74	-57	-24	19	54	47	129	0.02	0.011	1.765
17	S III 5041	-75	-52	-6	52	17	103	92	0.015	0.014	1.931
18	He I 5048	-74	-40	-6	28	85	68	159	0.012	0.011	1.337
19	S III 5056	-66	-48	-12	34	68	45	134	0.018	0.022	1.698
	Mean	-109	-55	-19	17	48	63	156	0.053	0.051	1.816
	σ_{rms}	43	15	11	15	38	20	47	0.067	0.065	0.400

2014											
1	C II 6578	-74	-42	-21	10	52	52	126	0.025	0.024	1.849
2	C II 6583	-74	-42	-11	20	51	62	125	0.023	0.025	2.066
3	Si II 6347	-119	-49	-15	20	78	69	197	0.064	0.07	1.89
4	Si II 6371	-112	-45	-12	22	66	67	179	0.049	0.06	1.852
5	He I 5876	-102	-55	-20	5	74	82	176	0.077	0.084	2.297
6	D2 NaI	-77	-41	-18	4	107	34	184	0.423	0.354	1.579
7	D1 NaI	-71	-37	-14	19	77	34	148	0.393	0.332	1.566
8	S II 5010	-	-53	-22	24	100	88	-	0.018	0.022	2.227
9	HeI 5016	-109	-61	-25	-1	47	60	156	0.027	0.033	1.804
10	Fe II 5018	-118	-71	-35	1	60	71	179	0.029	0.026	1.794
11	Fe II 5027	-50	-39	-27	20	43	59	94	0.01	0.011	1.767
12	S II 5429	-91	-56	-22	1	25	58	115	0.014	0.012	1.669
13	S II 5433	-100	-54	-31	3	49	23	103	0.02	0.021	1.867
14	S II 5454	-109	-65	-31	2	35	66	144	0.038	0.04	1.611
15	Y II 5474	-100	-46	-25	4	18	32	118	0.016	0.016	1.953
16	S II 5032	-105	-59	-37	-13	11	46	116	0.013	0.017	1.75
17	S III 5041	-122	-76	-43	-19	27	46	148	0.017	0.015	1.533
18	He I 5048	-135	-90	-36	-17	1	56	135	0.018	0.015	1.707
19	S III 5056	-142	-86	-24	-15	36	56	178	0.027	0.023	1.874
	Mean	-101	-56	-25	5	50	56	146	0.068	0.063	1.824
	σ_{rms}	24	15	9	14	29	17	31	0.121	0.101	0.208
2015											
1	C II 6578	-150	-78	-26	6	48	104	198	0.018	0.022	2.053
2	C II 6583	-58	-77	-35	8	96	82	154	0.021	0.016	2.265
3	Si II 6347	-166	-74	-31	15	52	69	218	0.032	0.042	1.941
4	Si II 6371	-112	-68	-35	-2	42	66	155	0.033	0.027	1.878
5	HeI 5876	-126	-67	-20	15	74	82	200	0.059	0.059	2.532
6	D2 Na I	-99	-41	-29	-18	28	23	127	0.223	0.226	1.131
7	D1 NaI	-92	-47	-35	-12	33	34	126	0.23	0.21	0.898
8	S II 5010	-	-	-	-	-	-	-	-	-	-
9	HeI 5016	-176	-66	-48	19	67	85	243	0.047	0.052	2.201
10	Fe II 5018	-98	-61	-25	11	107	72	205	0.044	0.043	1.593
11	Fe II 5027	-82	-70	-28	24	72	94	154	0.014	0.022	1.374
12	S II 5429	-163	-79	-35	19	11	58	174	0.015	0.012	1.683
13	S II 5433	-159	-71	-26	22	26	69	185	0.022	0.022	1.674
14	S II 5454	-168	-85	-36	14	22	56	190	0.02	0.025	1.625
15	Y II 5474	-96	-82	-27	33	14	37	110	0.011	0.01	1.382
16	S II 5032	-86	-51	-27	8	54	59	140	0.026	0.029	1.557
17	S III 5041	-97	-62	-27	7	52	69	149	0.037	0.033	1.538
18	He I 5048	-72	-59	-15	19	64	78	136	0.028	0.032	1.522
19	S III 5056	-75	-52	-7	36	92	88	167	0.047	0.04	1.881
	Mean	-115	-66	-28	13	53	68	168	0.052	0.051	1.707
	σ_{rms}	38	13	9	14	28	21	36	0.065	0.062	0.404

the top left panel of Fig. 2, the radial velocities of the FeII lines mainly show a course of variations that is reverse with the radial velocities of the H α emission, except when the maximum of the FeII $\lambda 5316$ Å line is reached simultaneously with the H α line.

The SiII lines, as the FeII lines, clearly exhibit the wavelike variation in the RV and EW parameters, the amplitude of which is much larger than the values of the measurement uncertainties. Both SiII $\lambda 5041$ Å and $\lambda 5056$ Å lines have a course of variations that is reverse with the H α line, being in the same phase with the SiII $\lambda 6347$ Å and $\lambda 6371$ Å lines (Fig. 1).

The right panels in Fig. 2 show the time variations of the EW values of the Fe II, SiII, and SII lines. Weak absorption lines Fe II and SII show insignificant variations in EW (Fig. 3). EW variations of the SII $\lambda 5606$ Å, $\lambda 5665$ Å and FeII $\lambda 5482$ Å lines show minima at the moment when EW of the H α line reaches maximum.

As can be seen from the middle panel in Fig.2 for the SiII $\lambda 5041$ and $\lambda 5056$ Å lines, the RV parameters (left panel) and EW parameters (right panel) show reverse cyclic variations with phase - when the RV values are maximal (JD 2456243), the EW parameter reaches minimum. The time interval between two extrema is 40-45 days. On the whole, these results show that the star's variability is of quasicyclic character.

In Table 3 and Table 4, is given the information on the characteristic times of variations in the RV and EW parameters according to the data of the longest seasons - 2011 and 2014. These tables list the lines with clear cyclical variations. The 2011 observations allowed us to cover only two extrema, for example, one minimum and one maximum. The last columns present the differences between the dates of extrema δt for the RV and EW parameters. The last line of the table shows the mean value of the time interval between two extremum points. As can be seen from Table 3, for both RV and EW variations, the mean value between the two extrema is 26 ± 10 days. This timescale can be considered as half of the cycle of variations.

The 2014 season made it possible to detect three extremum dates on the cycles (min-max-min, or vice versa, max-min-max), according to the variation in the parameters of various absorption lines (see Fig. 1 and 1). Similarly to Table3, Table 4 also shows the dates of the extrema of the selected lines, as well as the differences between two adjacent extrema Δt_1 and Δt_2 , and the total times T between the first and last extrema. The first part of Table 4 presents the RV data, and the bottom second part of Table 4 contains the EW parameter data. As can be seen from Table 4, the timescales between the radial velocity extrema are 25 ± 9 days and 24 ± 9 days, making up 49 days for a full cycle, and the timescales for equivalent widths are 21 ± 5 days and 24 ± 13 days, making up 46 ± 15 days

for a full cycle. The results of Tables 3 and Table 4 show that a timescale of 20-25 days may be taken for a half-cycle and a span of about 40-50 days for a full cycle. Unfortunately, we do not have data that would be covering two complete cycles. Figure 2 also demonstrates cyclical variations in the EW and RV parameters of

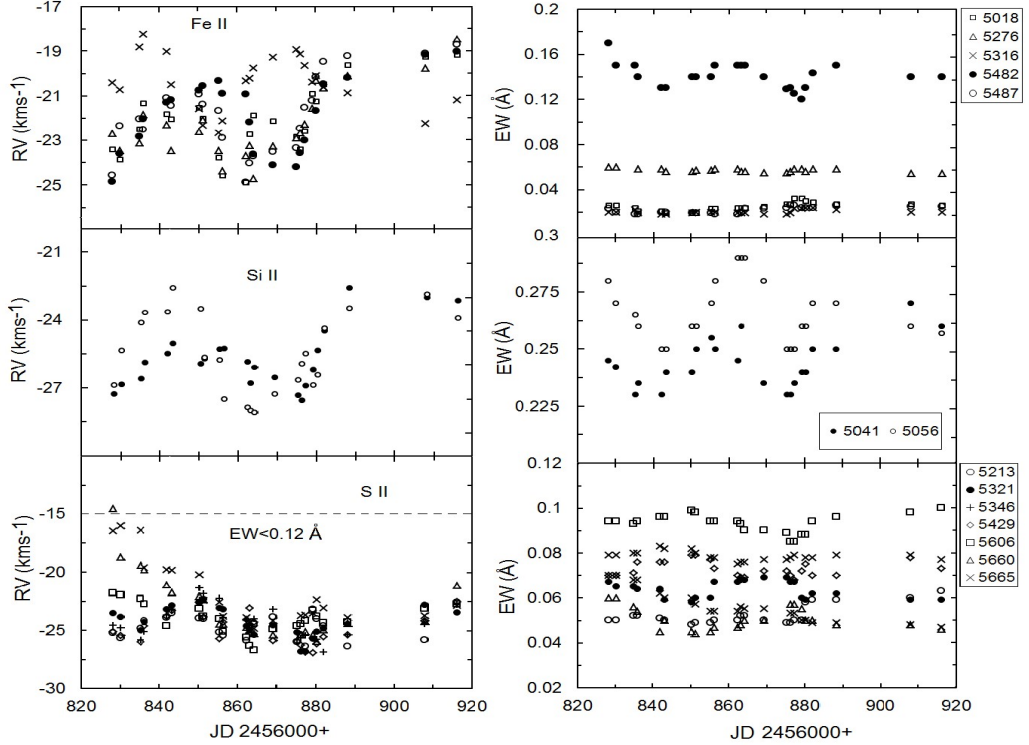


Fig. 2. Variations in time of the RV (left side) and EW (right side) parameters of absorption lines Fe II (top panels), S II (middle panels) and Si II lines (bottom panels) for the 2014 data. The dashed horizontal line in the left panel indicate the mass center velocity of the star.

the absorption lines. The characteristic time between the first and second extrema (i.e., from the minimum to the maximum, or vice versa, from the maximum to the minimum) is about 20-25 days. This characteristic time confirms the results of previous works (see, for example, Markova et al. 2008, Ismailov & Ismayilova 2019), where a 20-22 day timescale for H α line variations was detected.

3.2. The Detection of Line-Profile Variations

It is interesting to study the line-profile variations (LPV) along the profile of the photospheric spectral lines. For this purpose we used a statistical method

that was applied by Prinja et al. (1996) and was named the temporal variance spectrum (TVS) (Fullerton et al., 1996). This method was applied to analyze the radial velocity and intensity variability along the spectral line profiles (see, for example, Kaufer et al., 1997, Markova & Valchev, 2008). The method consists of calculating the root mean square (rms) of a series of spectrograms at a given wavelength of the spectral line profile as a function of wavelength σ_λ .

Figure 3 shows the average profiles of individual strong absorption lines observed in different parts of the spectrum for the 2014 season, as well as the profile of the TVS spectrum σ_λ obtained from the data of 23 spectrograms. As can be seen, the average profiles of the D NaI lines have relatively asymmetric red wings. The other absorption lines show a symmetrical structure. Here, in the TVS plots, the vertical dashed and solid lines schematically mark the boundaries within which the indicated parameters were calculated from each profile at a given wavelength. From the mean line profile the full line width at the half level of the residual intensity FWHM was measured. From the TVS profile, the border radial velocities V_b (blue) and V_r (red) were calculated at the level of the variability threshold with a significance level $p = 1\%$ relative to the continuum, their difference is $\Delta V = V_r - V_b$. For each TVS spectrum, the velocities v_1 and v_2 corresponding to each peak, the velocity of the central dip V_c between the profile peaks and the velocity difference $\Delta v = v_2 - v_1$ were measured, as well as the a_1 and a_2 , values corresponding to the σ_λ parameters for individual peaks. Table 3.1 shows a list of the groups with strong and weak photospheric lines, for which all the indicated parameters were obtained for all individual observation seasons.

To control the instrumental displacements, from the longest series of observations carried out over 23 nights in 2014, we plotted the average profile of the $\lambda 6520 - 6560 \text{ \AA}$ spectral region, containing weak H₂O lines of the Earth's atmosphere, the intensity of which is between 3-12% of the average continuum (left top panel in Fig.3). Since these lines are stable in wavelength, the TVS structures of the atmospheric lines show single peaks, in which σ_λ variations are only due to variations in the line intensities.

As we can see from Fig. 3, all TVS profiles of the absorption lines have two peaks with a central dip. Two peaks observation in the TVS spectra of the spectral lines indicate that in the main variability interval ΔV occurs on the line wings, and to a lesser degree in other parts of the profile. The velocities corresponding to the peaks v_1 and v_2 in the TVS spectra show the most probable values of the RV gradient (variations) along the spectral line. If we assume the pulsating nature of the observed LPV, then the appearance of two strongest peaks and weaker sections in the TVS line profile indicates the simultaneous existence of radial and non-radial pulsations. Non-radial pulsations are the main contributors to the center of the line TVS profile. Radial modes only contribute to the line

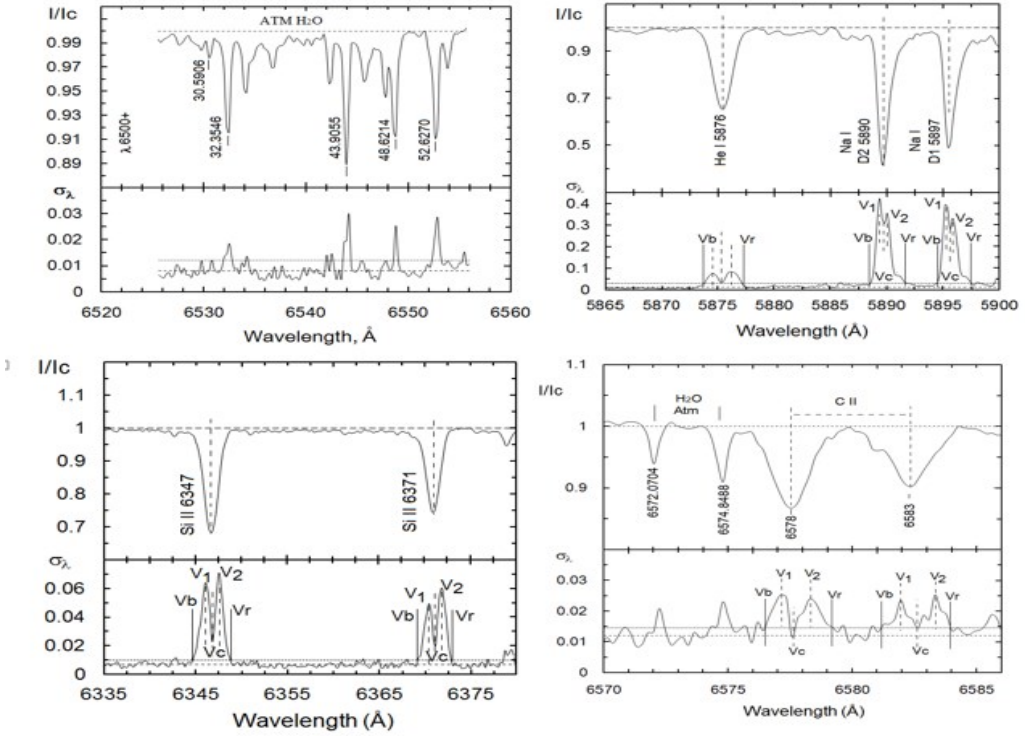


Fig. 3. Profiles of individual ranges of the star's spectrum, averaged over 23 nights of observations using the 2014 data, with the corresponding TVS spectra of these ranges. The top left diagram is plotted only for telluric lines. In each TVS spectrum, the horizontal bold dashed lines indicate the mean continuum level and the dotted lines correspond to the level of the variability threshold equal to $p = 1\%$. On the TVS profile of each line, the wavelength boundaries used to calculate the parameters presented in Table 6 are indicated.

wings, where the gradient in the line profile is strongest (see, for example, [11]).

Figures 4 and 5 based on the 2014 data, demonstrate also average profiles of two different parts of the star's spectrum, which contain a group of weak photospheric lines. As can be seen, the TVS structure of weak lines is almost the same as that of strong lines. In Table 5, where is presented all TVS analysis parameters, the lines with $EW \geq 0.25 \text{ \AA}$ are marked in bold. The rest of the lines in the list have $EW \leq 0.25 \text{ \AA}$, i.e.

belong to the first group of lines that are formed in a deeper part of the photosphere. It can be seen from Table 5 that the highest value of $\Delta v = v_2 - v_1$ is observed for the He I $\lambda 5876 \text{ \AA}$ lines, and the smallest for the D Na I lines. For the rest lines, including the weak lines of the photosphere, the value of Δv is within $60 \text{ km/s}^{-1} \pm 20 \text{ km/s}^{-1}$. This indicates that the most active variations

are generated in the higher-temperature regions of the photosphere, where helium lines are formed.

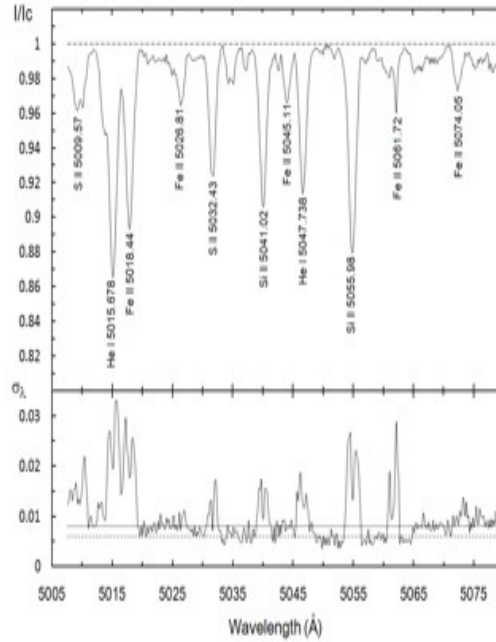


Fig. 4. The average profiles of the spectral region $\lambda 5005\text{--}5080 \text{ \AA}$ of the supergiant HD199478, obtained from the 2014 data, containing weak photospheric lines (top panel). Bottom is the TVS structure of this range. In each TVS spectrum, the horizontal bold dashed lines indicate the mean continuum level and the dotted lines belong to the level of the variability threshold equal to $p = 1\%$.

Figure 6 shows the distribution of the mean radial velocities RV , as well as the velocities v_1 , v_2 , V_c (Table 6), obtained in 2011 and 2014 for different lines. The horizontal straight dashed line shows the velocity level of the mass center of the star V_0 (-15 km/s^{-1} , [12]). The abscissa shows the numbers according to the list of spectral lines, which are presented in Table 6. Here the lines numbered 1-7 are the strongest lines, which are shown in bold type in Table 6. Numbers 8-19 are weak absorption lines with $EW \leq 0.25 \text{ \AA}$. Figure 6 shows that the V_c velocities are always systematically lower than the V_0 , which indicates a presence of the permanent matter outflow. Also, V_c does not always coincide with RV for different photospheric lines, although, for example, in 2011, the variations in these velocities are synchronous. The observed drift of the velocity V_c for different lines indicates radial wind propagation in different layers of the atmosphere.

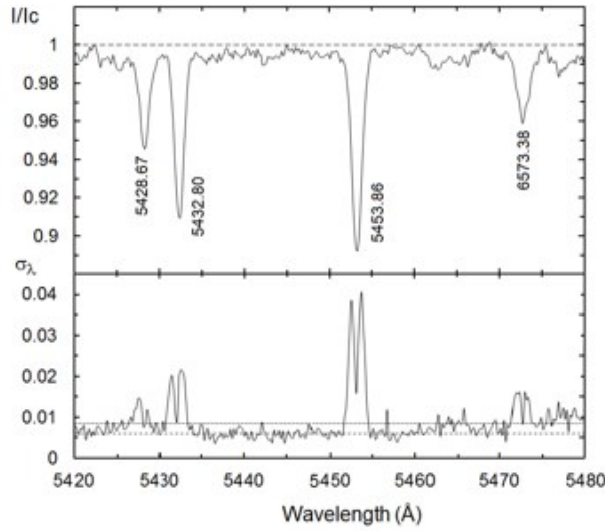


Fig. 5. The same as in Fig.4, for the $\lambda 5420\text{-}5480$ Å spectrum region, obtained in 2014 containing weak photospheric lines (upper panel).

As can be seen from Fig.6, the velocities v_1 , and v_2 corresponding to the peaks in the TVS structures for different lines are located symmetrically relative to the V_c velocity. The V_c velocity mainly shows the variation in the mean wind motion in a local area where considered spectral lines are formed.

3.3. Variability of Absorption Lines When Observing HVA

As shown by [6], high velocity deep absorption was detected in the spectrum of HD 199478 in 2011 on the blue wing of the $H\alpha$ line (HVA). The spectral material obtained allows us to study the variations in photospheric lines in the moment of the observation of this event. Figure 7 shows the time variation diagrams of the radial velocities and equivalent widths of the strongest photospheric lines obtained during 17 nights of observations in 2011. Each line of the panels on the left displays RV variations, on the right - EW variations of individual lines. The top first line on the panels shows the time variations in the parameters of the emission line $H\alpha$. This is shown for comparison with the same variations in absorption lines obtained at the same time (Ismailov&Ismayilova, 2019). As can be seen, RVs of the lines CII, HeI, SiII, as well as those of the D NaI line with a delay of maximum (by 12 days), show a smooth variation with an amplitude of $4\text{-}8 \text{ km/s}^{-1}$. If we take the velocity of the star mass center -15 km/s^{-1} , then the maximum in the RV variation for most absorption lines will be reached on JD 2455760 ± 3 , at positive values of the radial velocities.

As shown in [6], the HVA event in the star HD 199478 was observed in the time interval JD 2455764-2455776 (about 13 days), the boundaries of which are indicated by two vertical straight lines in Fig. 7. When comparing the data of the $H\alpha$ line with the data of the strongest absorption lines, we can state that the HVA event appeared right at the moment when RV values of strong absorption lines were maximal and positive, and continued to be observed as long as the RV values were decreasing to the minimum (on JD 2455776). In other words, during the appearance of the blue shift on the wing of the $H\alpha$ line, a blue shift of many absorption lines is observed, and this state continues until the disappearance of the HVA event. As shown in [6], the HVA event in the star HD 199478 was ob-

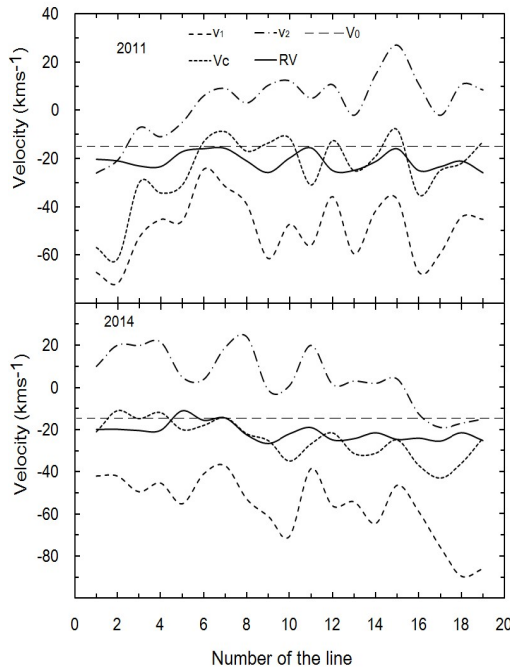


Fig. 6. Distribution of the mean radial velocities RV (solid curve), as well as velocities v_1 (large dotted line), v_2 (dotted line with a dot), V_c (small dotted line) (Table 4A) for different spectral lines according to the data of 2014 (top panel) and 2011 (bottom panel). The abscissas indicate the line number in the list of Table 3.1. The horizontal dashed straight line shows the velocity level of the stellar mass center V_0 . The top panel refers to the 2011 data, the bottom one, to the 2014 data. The designations of the parameters are the same in all panels.

served in the time interval JD 2455764-2455776 (about 13 days), the boundaries of which are indicated by two vertical straight lines in Fig.4. As can be seen from Fig.7, the RVs of the D NaI lines reach a maximum after the completion of the

HVA event, when the RVs of the remaining lines have already reached their minima. This means that after the completion of the HVA event and the disappearance of the blue shifts in other absorption lines, the D NaI lines exhibit the maximum positive RV value, that is, the accretion process is observed. Figure 8, also shows diagrams of time variations in spectral parameters for some weak photospheric lines. It can be seen from the left panels of Fig. 8 that the radial velocities for most of the lines exhibit a smooth shift to the blue part of the spectrum, which invariably continues its course during presence of the HVA event. At the end of the HVA event, the RV values of the weak lines reach their minima. The RVs of strong photospheric and H α lines reach their maxima at the onset of the HVA event (Fig. 7), i.e. at the maximal contracted state of the star. During the HVA, both weak and strong absorption lines show blue shifts, i.e. expansion of the star.

The equivalent widths of weak photospheric lines vary in different ways. For example, the EWs of the FeII $\lambda 5316$ and $\lambda 5487$ Å lines exhibit an increase, while the SiII $\lambda 5041$ and $\lambda 5056$ Å lines show a decrease, and weaker SII lines do not show significant variations during the HVA event at all. This shows that there are relatively stationary regions of the photosphere where weak absorption lines are formed (Fig. 8).

Now let us consider the variations in the profiles of absorption lines, according to the data of 2011. The average profiles of individual absorption lines, as well as the results of the obtained TVS spectra σ_λ for 17 nights of observations, are presented in Fig. 9. All designations here are the same as in Fig. 3. The double peak structure in the TVS spectrum suggests real variations of radial velocities along the spectral lines, in accordance with the velocity range ΔV . The velocities corresponding to the v_1 and v_2 peaks in the TVS spectrum show the most probable values of the RV variations along the spectral line. As can be seen from Fig. 6, RV variations on the center at the line are insignificant, and the largest variations occur on the wings of the lines at velocities v_1 and v_2 . Judging by the obtained TVS structures, RV variations observed in the velocity range ΔV , suggest that the radial mode gives contribution to the peaks, while the non-radial mode - to the other parts of the profile.

As can be seen from Table 5, the total range ΔV for the CII, SiII, He I lines was about 200 km/s^{-1} in 2011, and for the D NaI lines, about 125 km/s^{-1} . The FWHM of the average profile from the CII, Si II, and HeI lines was $80\text{-}90 \text{ km/s}^{-1}$, and much less for the D NaI lines, namely, $50\text{-}60 \text{ km/s}^{-1}$. This pattern persists for all other seasons (Table 5).

As can be seen in Fig. 9, the average profile of each line of the D Na I doublet consists of one strong and another weak red component. TVS profiles of the spectra of these lines also consist of two components, with the velocities of the first, strong components, corresponding to -19 and -14 km/s^{-1} , which coincide

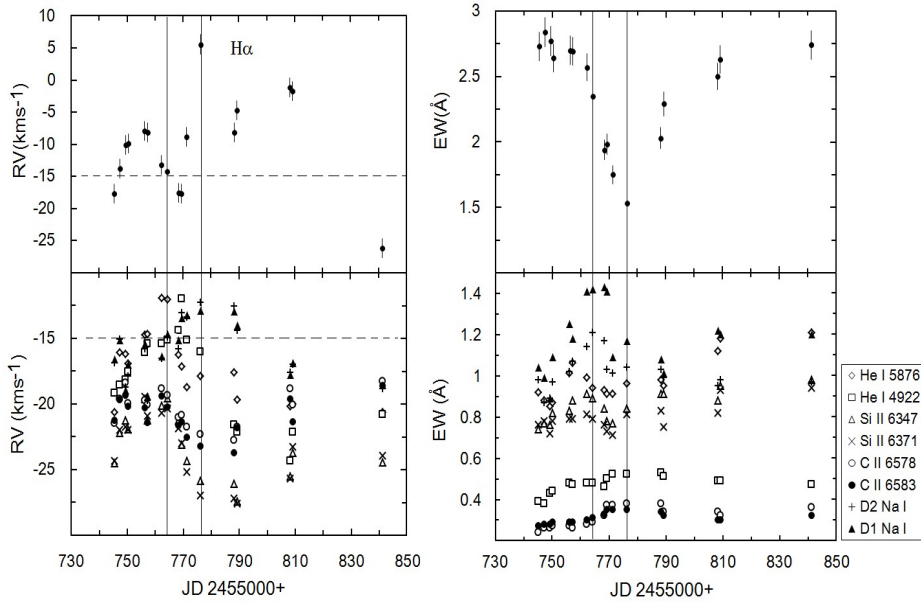


Fig. 7. Time variability in the RV and EW parameters for the emission $H\alpha$ line (top panels) and for the various strongest photospheric lines (bottom panels), according to 2011 data. Two vertical straight lines indicate the boundaries of the time interval when HVA was observed. The horizontal dashed lines on the left panels indicate the star's mass center velocity.

well with the mass center velocity of the system. And the velocities of the second peaks correspond to 47 and 31 km/s^{-1} , respectively, for the D1 and D2 NaI lines. This indicates that the D NaI doublet lines are formed in the upper part of the stellar wind, and the radial velocities of these lines in 2011 varied insignificantly. The weak red component, rather, is formed in the flow of the upper part of the envelope, showing the fall of matter onto the star at a velocity of about 40 km/s^{-1} .

For weak absorption lines for the seasons 2011, 2013 and 2015 we got similar TVS profiles with 2014 data (Table 5).

4. DISCUSSION AND CONCLUSIONS

Our results for the first time ever, have shown that the scale of temporal variations in photospheric lines is in good coincidence with the quasi-cyclic variability of the emission component of the line $H\alpha$. As shown in the work of Markova et al. (2008), the variability of the $H\alpha$ line cannot be represented as strict periodic. The instability of the periodicity according to the data of different years complicates

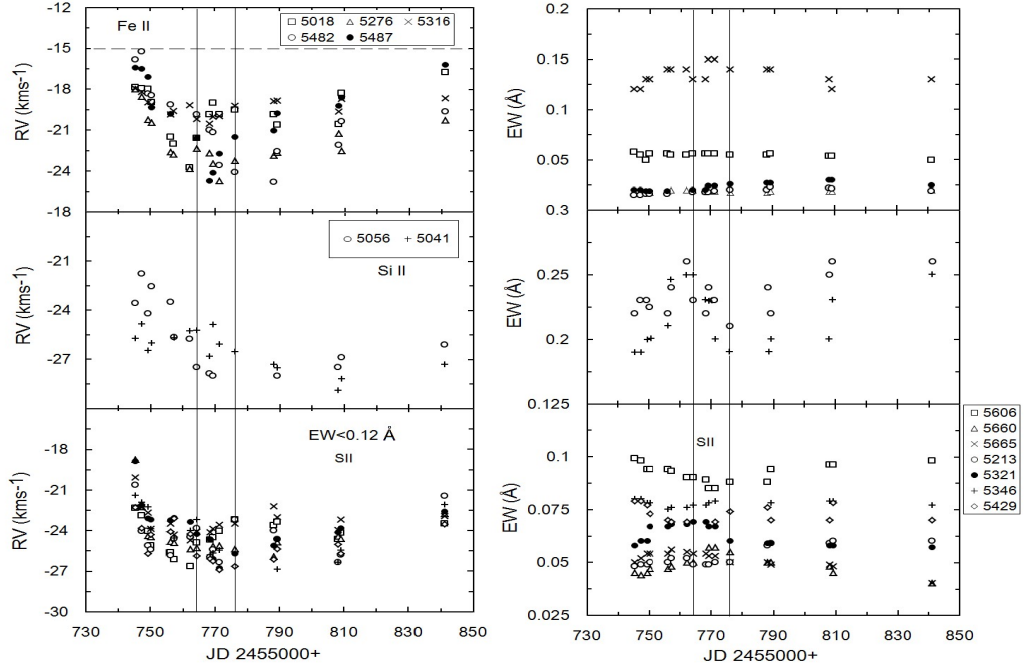


Fig. 8. The same as in Fig.2 for the data of season 2011. Two vertical straight lines indicate the boundaries of the time interval when the HVA was observed. The horizontal dashed line on the left panel indicates the star's mass center velocity.

the obtaining of accurate information about the pulsation modes and astroseismic information, which is required to study the photospheric variability in BA supergiants. Rather, photospheric variability occurs in quasi-cycles, individual fragments of which can be observed. Our data have shown for the first time that the parameters of photospheric lines from minimum to maximum (half cycle), or vice versa, vary over a timescale of about 25 days. In this star we detected the same characteristic time for hydrogen lines [6]. The scale of temporal variations of 40-50 days is typical for the full cycle of variations in hydrogen lines (see Table 2 from [6]). Our data revealed that these time scales are in good agree with absorption lines too.

We have shown that the root mean square deviations σ_{rms} of the RV and EW parameters observed over the season for strong photospheric lines is much larger than for weak photospheric lines (Table 2). Therefore, the observed quasicyclic variability is more clearly pronounced in the stronger photospheric lines. For weak lines, which are formed mainly in the lower photosphere, cyclic variations are observed in a weak form or are not observed at all within the measurement uncertainty. This result is typical for all observation seasons. This indicates that

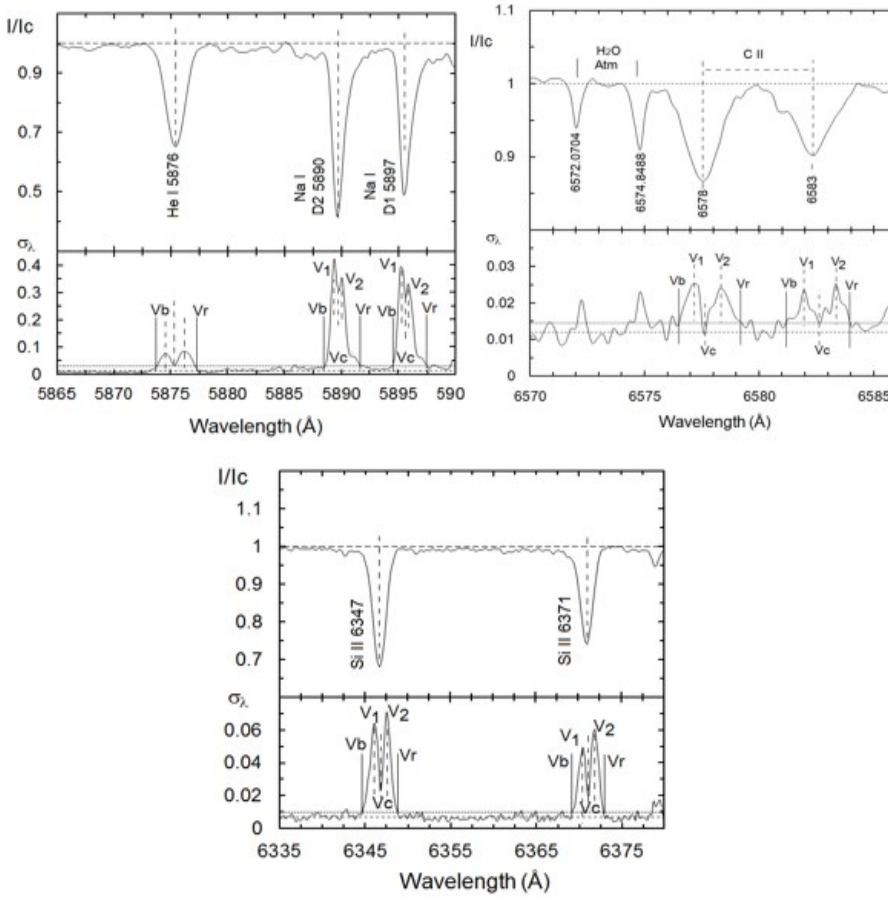


Fig. 9. The same as in Fig. 3 according to 2011 data.

the strongest photospheric lines, which are formed throughout the depth of the photosphere, are more influenced by the stellar wind in the upper photosphere. We have shown that, during the HVA event, the radial velocities of all photospheric lines exhibited an outflow from the star and the equivalent widths of individual photospheric lines were increasing, while in the outer part of the wind, where the H α emission is formed, EWs were decreasing. This indicates that a possible HVA event started in base of stellar wind and propagated subsequently into the wind. This observational fact is an argument in favor of the assumption on the existence of radial pulsation in such stars.

An analysis of the TVS structures of individual groups of photospheric lines has shown that the radial velocity variability is observed in both strong and most weak photospheric lines. Different absorption lines exhibit different radial velocity variation interval Δv . It has been shown that the highest value of Δv is

observed for the HeI $\lambda 5876$ Å lines ($80\text{--}120 \text{ km/s}^{-1}$), and the smallest for the D NaI lines ($20\text{--}35 \text{ km/s}^{-1}$) (Table 4). For the rest of lines, including weak lines of the photosphere, the value of Δv is in the range of $30\text{--}60 \text{ km/s}^{-1}$. This indicates that the most active variations are generated in the higher-temperature regions of the photosphere. As can be seen from Table 3.1, the seasonally averaged value of the velocity interval Δv along all lines is about 60 km/s^{-1} .

The data in Table 5 show that the mean values of the V_c parameter obtained both in 2014, when the star was not affected by the HVA event, and in 2011, when HVA was observed, are close to the observed radial velocities. The observed difference in the velocity V_c for individual lines is obviously related to the local physical conditions (temperature, wind speed, etc.) under which these lines are formed. It can be seen from Table 5 that the average value of the velocity V_c for individual seasons slightly differ from the average radial velocities (see Figure 6). The FWHM values for the absorption lines are larger than the projection of the rotational velocity of the star (Table 5). As was noted in Markova & Puls (2008), this may be partly due to the existence of macroturbulent velocity in the stellar atmosphere. These authors estimated the projection of the rotation velocity $v \sin i = 41 \pm 4 \text{ km/s}^{-1}$, the microturbulent velocity $\sim 8 \text{ km/s}^{-1}$, and the macroturbulent velocity about $40 \pm 3 \text{ km/s}^{-1}$. By using the expression

$$V(FWHM)[\text{km/s}^{-1}] = \sqrt{((v \sin i)^2 + \xi^2)} \quad (1)$$

an expected value of the macroturbulent velocity can be found [8]. Here V (FWHM) is the velocity value corresponding to the FWHM, $v \sin i$ is the projection of the rotation velocity to the line of sight, Ξ is the total velocity component due to the macro- and micro-turbulent velocities. It can be seen from Table 5 that the dominant FWHM value for strong absorption lines is about 2 Å, for weak photospheric lines it is about 1.6 Å, which correspond to velocities of 100 and 96 km/s^{-1} , respectively. Then, from this expression for ξ , a value of $\sim 91 \pm 9 \text{ km/s}^{-1}$ can be obtained, which is much larger than the value given in [16]. Therefore, we assume that one of the reasons for the additional expansion of absorption lines is the radial movement of individual clumps in the stellar wind. The existence of a clump-like wind structure in a spherically symmetric atmosphere of supergiants has been noted in different works (see, for example, [1, 8]). An additional argument in favor of this assumption is that in some seasons selected absorption lines showed high stability, while other spectral lines showed certain variability. This suggests that there are zones of local formations, with different physical conditions in the atmosphere of the star. The existence of radial motion of matter also follows from the structure of the $H\alpha$ emission component, which often shows two peaks with a variable V/R ratio [6, 8]. Such wavelike variations,

accompanied by the cyclic movement of matter, indicate that the structure of the stellar atmosphere is not spherically symmetric and does not have any stationary wind (see, for example, Morel et al. [16, 17].

Knowing the assumed value of the quasi-period P_ν in days, the amplitude of variations in the radial velocities of absorption lines A_ν in km/s^{-1} , the radius of the star R_* in solar radius, it is possible to estimate the amplitude of the light variation of the star due to the variation in the radius during pulsation [11]. This does not take into account variations in color-indexes. Using the averaged parameters taken from Table 3 for these parameters, we have used the values of 48 ± 10 days, $5 \pm 3 km/s^{-1}$ and $68 R_\odot$ [15], respectively. By using the expression

$$\Delta m_{rad} = 5 \log \left(1 + 0.02 \frac{P_{\nu[d]A_\nu[km/s^{-1}]}}{R_*[R_\odot]} \right) \quad (2)$$

for the amplitude of the brightness variation, we can get $\Delta m_{rad} 0.14^{+0.08}_{-0.05} mag$

As can be seen, this value of the light variation is in good agreement with the amplitude of the light variation of 0.15 mag [20], which was obtained from a large number of photometric observations. Hence it follows that the quasiperiodic pulsation of the star seems to be accompanied by a variation in the radius, the magnitude of which can be measured from the radial velocities of the photospheric lines.

The question of the main reason for the activity in the star's atmosphere remains open. Given the above, to explain the observed spectral variations, we tend to accept the concept of the appearance of inhomogeneity on the surface of the star. For the explanation of the observed results, apparently, the magnetic field can play a key role. Measurements of the longitudinal magnetic field BA type SGs show that the maximum value of the magnetic field strength for β Ori is 130 G, and for the remaining BASGs it is several gauss (see, for example, [23]). However, the inhomogeneity on the surface of the star can be caused by spots, where the local magnetic field is much higher.

So, based on the results of this work, the following conclusions can be drawn:

1. After having studied the spectrum of the supergiant HD 199478, we have established for the first time that variations in the radial velocities of photospheric lines and lines that are indicators of stellar wind (emission in the $H\alpha$ line) occur synchronously. An inverse correlation has been revealed in the behavior of the equivalent widths of strong photospheric lines and the emission component of the $H\alpha$ line. Weak absorption lines formed in the lower photosphere do not always indicate to a synchronous motion in the lower and upper photosphere.
2. The time scale of variations in radial velocities and equivalent widths of photospheric lines are in good agreement with the time of variations in the $H\alpha$ line. The

variation of the parameters of spectral lines occurs in quasiperiodic cycles, which are characterized by maxima and minima. The timescale of variation from one extrema to another is about 25 ± 4 days. The timescale of the full quasi-period is 45 ± 10 days. The amplitude of variations in radial velocities and equivalent widths for strong absorption lines is much larger than for weak absorption lines.

3. It was shown for the first time that during the HVA event, both strong and weak photospheric lines show a blue shift relative to the center of mass of the system. The same shift is observed in the emission component of the $H\alpha$ line. This suggests that a mass-loss event highly likely started at the base of the stellar wind with subsequent propagation into the wind.

4. The TVS structure of photospheric lines show that the variation in radial velocities most often manifests on the wings of photospheric lines, which is expressed by the appearance of two peaks on the TVS profiles. The distribution of the velocity gradient along the line show the existence of radial and non-radial pulsations. Localization of the velocity gradient on the wings of photospheric lines can be a consequence of rotational modulation due to the inhomogeneous surface of the photosphere.

5. The D NaI lines most likely form in the upper part of the wind, indicating from time to time to signs of the matter accretion to the star's surface.

6. The performed analysis has shown that the reason for the large expansion of photospheric lines may be a clumpy structure of the stellar wind.

7. The photometric variability of the star can be explained by the cyclical variation of the stellar radius, which confirms the existence of radial pulsations in the stellar atmosphere.

5. ACKNOWLEDGEMENTS

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REFERENCES

1. Chesneau O., Kaufer A., Stahl O. et al., 2014, A&A 566, A125
2. Denizman L., Hack M., 1988, A&AS 75, 79
3. Fullerton A.W., Gies D.R., Bolton C.T., 1996, ApJS 103, 475
4. Galazutdinov G.A. Preprint SAO RAS, 1992, № 92
5. Ismailov N.Z., Bahaddinova G.R., Kalilov O.V., Mikailov Kh.M., 2013, Astrophysical Bulletin, 68, № 2, 196

6. Ismailov N.Z., Ismayilova Sh.K. 2019, MNRAS, 485, 3558
7. Ismailov N. Z., Pogodin M. A., Bashirova U. Z., Bahaddinova G. R. 2020, Astron.Reports, 64, 231
8. Israelian G., Chentsov E., Musaev F., 1997, MNRAS, 290, 521
9. Kaufer A., Stahl O., Wolf B., et al. 1996a, A&A, 305, 887
10. Kaufer A., Stahl O., Wolf B., et al. 1996b, A&A, 314, 599
11. Kaufer A., Stahl O., Wolf B., et al. 1997, A&A, 320, 273
12. Kharchenko N. V., Scholz R. D., Piskunov A. E. et al. 2007, AN 328, 889
13. Markova N., Valchev T., 2000, A&A, 363, 995
14. Markova N., Prinja R. K., Markov H., et al. 2008, A&A 487, 211
15. Markova N., Puls J., 2008, A&A 478, 823
16. Markova, N., Puls, J., Repolust, T., et al. 2004, A&A, 413, 693
17. Markova, N., Puls, J., Scuderi, S., et al. 2005, A&A, 440, 1133
18. MikailovKh. M., Khalilov V. M., Alekberov I.A., Tsirk. ShAO, 2005,109, 21
19. Morel T., Marchenko S. V., Pati A. K. et al. 2004, MNRAS, 351, 552
20. Percy J., Palaniappan R., Seneviratne R. et al. 2008, PASP, 120, 311
21. Prinja R.K., Fullerton A.W., Crowther P.A., 1996, A&A 311, 264
22. Rosendhal J.D., 1973, ApJ 186, 909
23. Shultz M.,Wade G. A., Grunhut J., et al.MiMeS Collaboration, 2012, ApJ, 750, 2

MOLECULAR HYDROGEN IN THE SPECTRA OF URANUS AND NEPTUNE

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In August and September 2017, on the 2-meter telescope of ShAO by using a fiber-optic echelle spectrograph (ShaFES) with different spectral resolutions: $R = 28000$ and $R = 56000$, the spectra of Uranus and Neptune were obtained. In the spectra of these planets, absorption lines of molecular hydrogen H_2 in the bands (4-0) $\lambda 6435.03 \text{ \AA}$ and $6367.76 \text{ \AA}$ were studied, and line $S_4(2)$ was found. The upper limits of the absorption line intensity in the spectra of Uranus and Neptune were determined. Pressure values ($P = 2,1 \div 2,4$ atm for Uranus, and $P = 2 \div 2,3$ atm for Neptune) by half-breadth of the lines $\lambda 6367.76 \text{ \AA}$ and $\lambda 6435.03 \text{ \AA}$, in the (4-0) band of molecular hydrogen, in the spectra of Uranus and Neptune were estimated. Additionally, the rotational temperature ($90^\circ \pm 12K$ for Uranus, $101^\circ \pm 10 K$ for Neptune) was determined by the ratio of the intensities of these lines at the depth at which these lines are formed. Dynamical processes occurred on Uranus can be damping processes. The nature of the circulation in the atmosphere of Neptune is regulated "from below," from the planetary interior. Such non-stationary processes cause changes in the density of aerosol particles and their distribution on height in its atmosphere, temperature, and movement rate in the clouds.

Keywords: Uranus–Neptune–molecular hydrogen– quadrupole lines– rotational temperature–helium.

1. INTRODUCTION

The study of the chemical composition of the atmospheres of planets is necessary to understand their evolution better and is considered an essential task of modern planetology. In the atmospheres of big planets, the absorption bands of various compounds were studied by primitive methods of imaging spectroscopy, and in the thirties of the twentieth century, they were studied by the method

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of photographic spectroscopy with low and average dispersion. In parallel, some scientific predictions and theoretical calculations on the spectra of molecules that are part of the atmospheres of big planets appeared. The small average density and character of the atmospheres of the giant planets allows many researchers to hold to the opinion about the considerable content of hydrogen and helium in their atmospheres. The dipole moment for molecular hydrogen is zero, has no vibrational spectrum, and rotational transitions are also forbidden. Molecules consisting of identical atoms can have a nonzero quadrupole moment (the center of the electron cloud does not coincide with the center of the positive charge), i.e., the interaction between molecules is not described within the Hooke's law and turns into an anharmonic oscillator, for forbidden transitions are also allowed. It can happen with high molecular hydrogen content or when indicating the external electric field, or by mutual collisions of molecules. Consequently, instead of "vibrational lines," rotational-vibrational bands are formed near them, consisting of separate lines corresponding to different rotational transitions at the same vibrational level.

In 1938, G. Herzberg [1] predicted that the quadrupole bands of molecular hydrogen H_2 should be found in the spectra of giant planets. He firstly showed [2] that the faint, unidentified absorption line found by Kuiper [3] in the low-dispersion spectra of Uranus and Neptune is certainly the S (0) (3-0) line of the second overtone-induced H_2 band.

Later, Kiess C.C., Corliss C.H. and Kiess H.K. [4] managed to detect three lines of rotational-vibrational overtone (3-0) about 8200 Å, and Spinrad H., Trafton L.M. [5] detected two more lines of the H_2 (4-0) overtone, about 6400 Å in the spectrum of Jupiter. The lines of both bands of molecular hydrogen were detected in the spectra of all giant planets: the H_2 (4-0) overtone was distinguished by a low value of their intensity, and this allows us to assert that the H_2 (4-0) lines are not saturated even in the spectra of H_2 from deep layers atmosphere. Information about deeper layers in the atmospheres of giant planets was obtained with the help of spacecraft [8].

In work [7], it is noted that the data obtained during the eclipse of Neptune by spacecraft "Voyager-2" were used to study the thermal structure and composition of the troposphere and stratosphere of the planet.

Accurate data for the H_2 quadrupole lines, located in the visible and near regions of the IR spectrum, can ensure necessary conditions for a detailed analysis of the atmosphere of the giant planets. These lines are sensitive to hydrogen abundance, ortho-para ratio, vertical structure, cloud distribution, and the pressure-temperature profile of the planet's observed atmosphere.

The H_2 content is used in ratio to the abundance of other molecules (elements) to compare the solar abundance coefficients [8]. The abundance of H_2 is

an important parameter when constructing a model of the atmosphere of giant planets. Conduct spectrophotometric studies of the atmospheres of giant planets in the region of absorption lines of molecular hydrogen and calculating some parameters of the atmosphere is an essential task for elucidating the evolution of the atmospheres of these planets.

2. OBSERVATIONS AND RESULTS OF SPECTROGRAMS PROCESSING OF URANUS AND NEPTUNE.

In August and September 2017, the spectra of Uranus and Neptune were obtained on a 2-meter telescope of ShAO by using a fiber-optic echelle spectrograph (ShaFES) with different spectral resolutions: $R=28000$ and $R=56000$. An American-made CCD camera with a $4K \times 4K$ element matrix with an element size of $15 \times 15 \mu m$ was used as a light detector. About it and other spectrometers installed on the 2-meter telescope are written in more detail in the works of Kh.M. Mikhailov et al. [9,10]. The level of the continuous spectrum was drawn along the vertices of the peaks in each discharge when processing the obtained observational material (for more details on the details of this method, see [9,10],).

Drawing a continuous spectrum in this form makes it easier to compare the results of different observations. Besides, to control the accuracy of the continuum, solar lines with an intensity close to the investigated line in the planet's spectrum are selected each time. Then the accuracy of the measurements of equivalent widths and half width will be the same with measurements of the investigated lines of molecular hydrogen. The average errors in determining the equivalent widths of the solar lines [11] in our measurements vary from 4% to 10%. This accuracy also remains for the investigated lines of atmospheres of the planets.

Conducting the continuum - a crucial stage of the operation on which depends the further result of the spectral study.

As a rule, the line of the continuum is smooth and convex. If there are doubts about the correctness of the continuum in a given order, the energy distribution in neighboring orders of the spectrum can be compared. The intensities of neighboring orders in the echelle spectra are similar. The wide wings of the $H\alpha$ line do not allow us to see the level of the continuous spectrum, and if we conduct a false continuum in this order, we will obtain erroneous values of the equivalent widths. Next, we choose the curves of the continuum of neighboring orders. Then we shift up this curve to the maximum value. This curve can serve as a clue - where the continuum pass. As a result, we obtain the restored continuum.

Observation of Uranus on the 2-meter telescope with a spectral resolution $R = 56000$ allowed us to reveal another term related to the weak quadrupole transition of molecular hydrogen - H_2 (4-0) S (2). The message on detecting an absorption

Fig. 1. shows the absorption lines of molecular hydrogen H_2 located in the visible region of the spectrum of Uranus $\lambda 6367.76 \text{ \AA}$ and $\lambda 6435.03 \text{ \AA}$ in the H_2 (4-0) band.

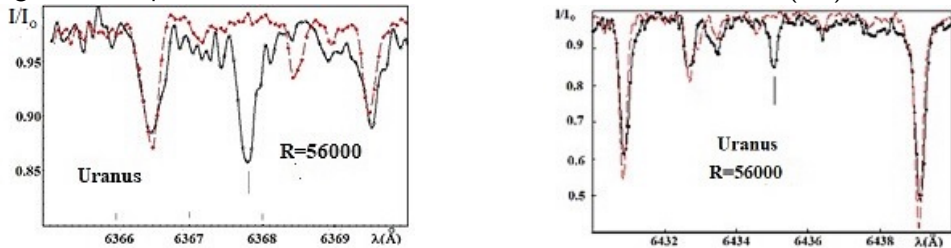
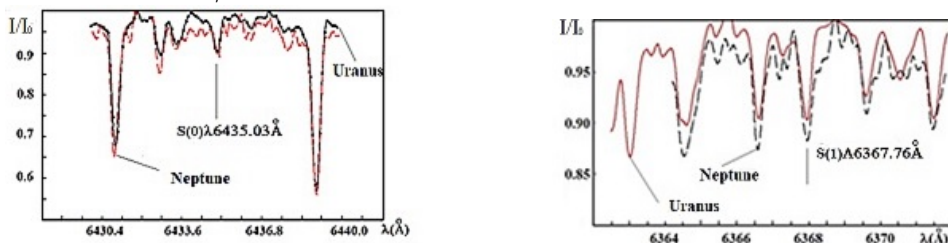


Fig. 2. The absorption lines of molecular hydrogen H_2 in the band (4-0) $\lambda 6435.03 \text{ \AA}$ and $6376.76 \text{ \AA}$ in the spectrum of Neptune: $R=28000$. At high spectral resolution, the lines on $\lambda 6367.76 \text{ \AA}$ and $\lambda 6435.03 \text{ \AA}$ are well visible.



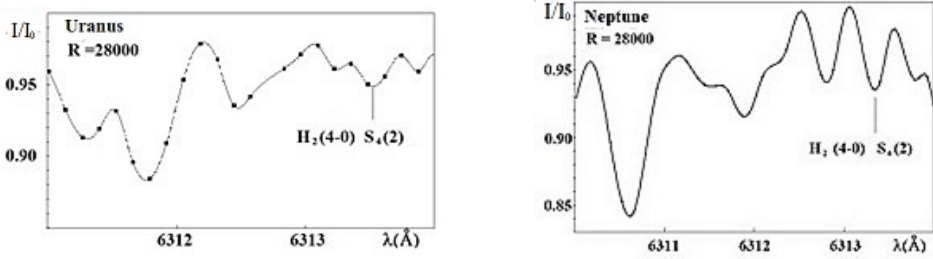
line on a wavelength of $6313.4 \text{ \AA}$ was first published by Enkrenes et al. [12] and later in work [13]. It should be noted that in work [12], the upper absorption limit in the H_2 (4-0) S (2) line was previously estimated, namely $< 2 \text{ m \AA}$.

The H_2 (4-0) S (2) line in the spectrum of Saturn was also detected during our observations. While processing the observational material of the H_2 (4-0) S (2) line profile in the Saturn spectrum, its intensity was determined, according to our measurements turned out to be $< 3 \text{ m \AA}$. According to Smith's estimates [13], the intensity of the H_2 (4-0) S (2) line in the spectrum of Jupiter - $\sim 1 \text{ m \AA}$, which corresponds to our estimates, $\sim 1.5 \text{ m \AA}$ in work [12]. According to [12], the intensity of H_2 (4-0) S(2) in the spectrum of Uranus - $< 1 \text{ m \AA}$ (Fig. 2 and 2). According to our observations, the intensity of the H_2 (4-0) S(2) line in the spectrum of Uranus is $< 4 \text{ m \AA}$, and in the spectrum of Neptune within $5 \div 8 \text{ m \AA}$. (Fig. 3).

Fig.3. Profile of the H_2 (4-0) S(2) line in the spectra of Uranus (left) and Neptune (right), obtained with spectral resolution $R = 56000$ and $R = 28000$, respectively.

There is also a weak telluric line at S(1) $\lambda 6367.76 \text{ \AA}$ in the spectral region, where the absorption line $6368.46 \text{ \AA}$ is located. The corresponding lines of the solar spectrum were considered as a comparison when determining the equivalent

Fig. 3. Profile of the H_2 (4-0) S(2) line in the spectra of Uranus (left) and Neptune (right), obtained with spectral resolution $R = 56000$ and $R = 28000$, respectively.



width and correcting the Doppler displacements. The quadrupole lines of molecular hydrogen in the visible region in the spectra of Uranus and Neptune are weak, unsaturated, and different rotational levels of molecular hydrogen are unequally populated. It should be noted that the reason for the excitation of rotational levels is the collisions during heat motions typical in the atmospheres of planets. In addition, estimates of the temperature of the planet's atmosphere, independent from heat emission measurements, can be determined on the intensity of rotational lines in molecular absorption bands on the reflected spectra of the planet. In case the frequency of transitions at collisions (without emission) exceeds the frequency of spontaneous transitions, the population of rotational levels is determined by the Boltzmann formula [12, 14]. It should be noted that by knowing the ratio of the populations of the two rotational levels, determined on the equivalent widths of these lines, it is possible to determine the rotational temperature of that layer of the atmosphere where the main absorption in these lines is created.

$$170 = T \ln[5.49 W_{S(0)} / W_{S(1)}], \quad (1)$$

Where $W_{S(0)}$ and $W_{S(1)}$ equivalent line widths S(0) and S(1) .

The rotational temperature for the atmospheres of Uranus and Neptune was calculated by the intensity ratios S(0) 6435.03 Å and S(1) 6367.76 Å (Table 1). By the half-breadth of the $\lambda 6367.76$ Å and $\lambda 6435.03$ Å lines in the spectra of Uranus and Neptune, in the (4-0) band of molecular hydrogen with consideration of the instrumental half-breadth, the pressure values were estimated at the depth, at which these lines are formed, by using the formula given in work

$$P = \frac{\Delta\nu}{\alpha} \left(\frac{T}{300} \right)^{1/2} \quad (2)$$

In formula (2) α - line half-breadth at normal pressure $P = 1$ atm and temperature $T = 76^\circ K$ (for Uranus [16]), $T = 72^\circ$ (for Neptune [16]) $\Delta\nu$ line half-breadth (sm^{-1}) in spectrum.

Table 1. Half-breadths and equivalent widths of molecular hydrogen lines S(0), S(1), the calculated values of pressure and rotational temperature at the formation levels in the atmospheres of Uranus and Neptune.

Parameters	Uranus		Neptune	
	S(0)	S(1)	S(0)	S(1)
$\Delta\lambda(\text{\AA})$	0.3	0.25	0.25	0.29
$P_0(\text{atm})$	2.4		2.0	
$P_1(\text{atm})$		2.1		2.3
$W(\text{m}\text{\AA})$	39.8	33.3	40.4	41.3
$T(\text{K})$	90.4		101	
Measurment error	11%		10%	

Belton et al. [17] show that the H_2 quadrupole lines related to vibrational-rotational transitions in the 4-0 band give a temperature of $118^\circ \pm 40^\circ$ K. According to observations of spacecraft "Voyager-2," measurements of heat flows coming from the planet showed that in the sub-cloud atmosphere, already at the level $P = 2.3$ bar, the temperature reaches 100° K. Higher, at a pressure level of 0.6 bar, the temperature at the equator and the light and dark poles is the same and equals 64° K, and in the middle latitudes is 2° K lower. The minimum temperature (53°K) was observed at a pressure level of 0.1 bar (higher than the visible cloud surface). For several nights, in order to study the profiles of the lines S(0) $6435.03 \text{ \AA}$ and S(1) $6367.76 \text{ \AA}$ in the spectrum of Neptune, the observations of this planet were carried out by the authors [18]. The authors of work [18] have registered $\sim 20\%$ change in equivalent widths in the indicated lines over the past 15 years. Authors note that the change of the equivalent widths within the measurement errors is related to change in the amount of tropospheric aerosol in the atmosphere of Neptune, where temporary brightening of methane clouds occurs (increasing of brightness in the centers of moderate and strong absorption bands). The limits of change in the temperature of the atmospheres of Uranus and Neptune, indicated in work [13], consistent with our measurements for the rotational temperature $T_r = 90^\circ - 114^\circ$ K and the pressure $P = 2.1 \div 2.3$ atm.

3. DISCUSSION

If Uranus and Neptune emitted only the heat that they receive from the Sun, then their temperature (equilibrium) would be at the level of 57° and 47° K, respectively. However, when actual measurements of heat flows were carried out, it

turned out that these two planets have the same effective temperature: $56^{\circ} - 58^{\circ}\text{K}$. It can only mean one thing: Uranus almost has no energy sources of its own, while Neptune has, and quite powerful ones, approximately 2.7 times more than what the planet receives from the Sun. The temperature of heat emission from Neptune reaches 59.3°K , even higher than that of Uranus (59.1°K). In work [6], the mole fraction of helium in the upper troposphere of Uranus, equal to 0.152 ± 0.033 (by volume), was determined on radio-eclipse and infrared spectroscopy data conducted by "Voyager-2". The corresponding mass fraction is $Y = 0.262 \pm 0.048$ (Table 2), close to the protostellar mass fraction of helium, equal to 0.28 ± 0.01 . This value is consistent with recent solar helium abundance estimates, making it possible to suggest that helium differentiation did not occur on Uranus. Comparisons with the values obtained earlier for Jupiter and Saturn show that helium migration to the core began long ago on Saturn and may have recently begun on Jupiter. Data [7] covers the altitude interval for the atmosphere of Neptune up to 250 km. In the upper layer of Neptune, associated with the atmosphere and accessible for measurements, contains hydrogen and helium, and the average helium content is higher than on Uranus. Comparison with infrared observations shows that the gas in the tropopause, observed near the 100-mbar level, is 77-85% hydrogen by density, and the rest is mainly helium. Estimates of the molecular

Table 2. The relative fraction of hydrogen and helium in the atmospheres of the giant planets and the protosun according to data of work [8].

Gas	Element	Protosun *	Jupiter	Saturn	Uranus	Neptune
H_2	H	0.835	0,8645	0.88	~ 0.83	~ 0.82
He	He	0.162	0.136	0.119	~ 0.15	~ 0.15
He	New data on the mass fraction of helium in the atmospheres of planets			0.11 [16]	~ 0.26 [6]	~ 0.25 [7]

hydrogen content in the atmospheres of Uranus and Neptune were carried out on different models of the atmosphere. If the formation of quadrupole lines of molecular hydrogen is only clear absorption, $U_{H_2} = 1460 \text{ km}\cdot\text{atm}$ (U_{H_2} is the molecular hydrogen content), or only scattering occurs, different authors estimate this value decreases to $560 \text{ km}\cdot\text{atm}$. According to data [8], helium differentiation (nuclear migration) has not been observed in these planets yet, and it is considered that the initial relative numbers within Uranus and Neptune are closer to the Sun. This factor is the same for Uranus, and Neptune does not explain the same extra emission of heat energy 6% of the first (Uranus) and 170% of the other (Neptune). Although, both of them are close in many of their characteristics.

It is clear that the cores of these planets vary significantly by size, even if they are identical by chemical composition. According to observations at the ShAO of Uranus and Neptune, it is found that in the center of the strong absorption band of methane $\lambda 6190 \text{ \AA}$, Neptune is brighter than Uranus [19]. It is shown that this effect is clearly performed and increases at the centers of other strong absorption bands of methane (Fig. 4). One more important observed result can be added

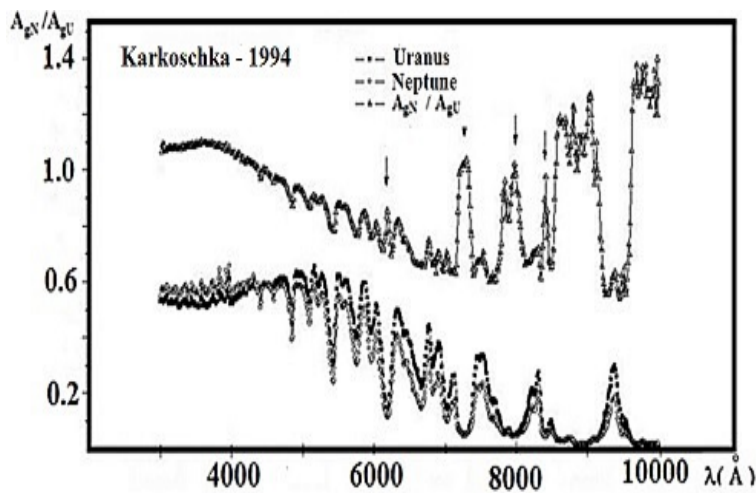


Fig. 4. According to the observed data, the ratio of monochromatic intensities of absorption bands in the spectra of Neptune and Uranus is [20]. The arrows show the central parts of the methane absorption bands.

to this. It was established that the monochromatic absorption in the spectrum of Uranus in the central region of the CH_4 methane band at $\lambda 6190 \text{ \AA}$ is greater than in the spectrum of Neptune, even though the intensity of other absorption bands increases during transiting from Uranus to Neptune. In weak and moderate absorption bands, Neptune is darker than Uranus. In the central parts of strong absorption bands, Neptune becomes brighter. Sometimes brightening (increase in brightness) disappears in moderate absorption bands and is observed only in relatively strong absorption bands of methane [21]. It is more probable that the core of Neptune is more enriched by isotopes of heavy elements than Uranus.

4. CONCLUSIONS

1. Based on the results of observations of Uranus and Neptune, it was found that changes in the intensity (equivalent breadth) of the $S(0) 6435.03 \text{ \AA}$ and $S(1)$

6367.76 Å lines do not exceed the measurement errors. The pressure values determined by the half-breadths of the indicated lines vary in the range from $2 \div 2.4$ atm.

2. The temperatures of Uranus and Neptune vary within $90 \div 118^0$ K, at the depth at which the H_2 (4-0) lines are formed, which is almost comparable for Jupiter and Saturn, which have internal sources of energy.

3. If Uranus has some internal energy sources, they do not exceed 6% of the heat received from the Sun. Then the emerging dynamic processes on Uranus can be damped processes.

In the atmosphere of Neptune, the nature of the circulation is regulated "from below," from the interior of the planet. Such nonstationary processes cause changes in aerosol particles density and their distribution on height in its atmosphere, temperature, rate of movement in the clouds. Furthermore, this leads to changes in the parameters for the atmosphere of Neptune, which we obtain from spectral and photometric observed materials.

REFERENCES

1. Herzberg G. On the possibility of detecting molecular hydrogen and nitrogen in planetary and stellar atmospheres by their rotation-vibration spectra. Ap.J. 1938. V. 87. P. 428-437.
2. Herzberg G. Spectroscopic evidence of molecular hydrogen in the atmospheres of Uranus and Neptune. Ap.J. 1952. V. 115. N. 3, P. 337-340.
3. Kuiper G.P. New absorptions in the Uranus atmosphere. Ap. J. 1949. V. 109. P. 540-541.
4. Kiess C.C., Corliss C.H. and Kiess H.K. High-dispersion spectra of Jupiter. Ap.J. 1960. V.132. P.221-231.
5. Spinrad H., Trafton L.M. High-dispersion spectra of outer planets: I. Jupiter in the visual and red. Icarus. 1963. V.2. 1. P. 19-28.
6. Hanel R., Lindal G., Marten A. The helium abundance of Uranus from Voyager measurements, Journal OF Geophysical Research, 1987. V. 92, No. A13, P. 15,003-15,010.
7. Lindal G.F., Lyons J. R., Sweetnam D. N., Eshleman V. R., Hinson D. P., Tyler G. L., The atmosphere of Neptune: Results of radio occultation measurements with the Voyager 2 spacecraft, Geophysical Research Letters, 1990. V. 17, N. 10, P. 1733-173.
8. Pater I. de and Lisssauer J.J. Planetary Sciences, Hardcover Hardcover– 2010.

9. Mikailov Kh.M., Khalilov V.M., Alekperov I.A. Echelle spectrometer of the Cassegrain focus of the 2-m telescope of the Shao National Academy of Sciences of Azerbaijan. Circular ShAO. 2005. No. 109. S.21-29.
10. Mikayilov Kh.M., Musayev F.A., Alakbarov I.A., Rustamov B.N., Khalilov O. V. SHaFES: Shamakhy Fibre Echelle Spectrograph. 2017, AJA . 2017. V.12. N.1. P.4-27.
11. Moore, Minnaert, M.G.J., Houtgast, 1966, The Solar spectrum 2935 Å to 8770 Å National Bureau of Standards Monograph 61, Second Revision of Rowlands Preliminary Table of Solar Spectrum wavelengths , P.350.
12. Encrenaz T. and Owen T., New observations of the hydrogen quadrupole lines on Saturn and Uranus, Astron. and Astrophys., 1973. V.28. P.119-124.
13. Smith W.H., Conner C.P., Simon J., Schempp W.V. and Macy W. The H₂ (4-0) S(0, 1 and 2) quadrupole features in Jupiter). Icarus, 1989. V.81, P.429-440.
14. Giver L.P. and Spinrad H., 1986. Molecular hydrogen features in the spectra of Saturn and Uranus, Icarus V.5, pp.586-589.
15. Moroz V.I., Fiziks of planets, Publisher «Nauka» , 1967. p.495.
16. Space from the Solar System deep into the Universe, 2nd Edition. M. FIZMATLIT, 2018, 544 p
17. Smith W.H. and Schempp W.V , Baines K.H., 1989, Limits on the diurnal variation of H₂ quadrupole features in Neptune, Ap.J., V. 343, PP.450-455.
18. Belton M.J.S. and McElroy M.B., Price M.J. Atmosphere of Uranus, 1970
19. Atai A.A. , 1980, Spectrophotometry of Uranus and Neptune in the λ 4300 - 7000 Å region, Astron. bulletin., T.14.№3, C.154-161.
20. Karkoschka E. 1994. Spectrophotometry of the Jovian planets and Titan at 300- to 1000 nm wavelength: The methane spectrum. Icarus, V.111, № 1, P.174-192.
21. Atai A.A., The planets of the Solar System «Lap Lambert Academic Publishing», 2018., 275C.

NECROLOGUE

Musayev Faig Adil was born on August 19, 1959, in the Guba region of the Republic of Azerbaijan. He graduated from the Azerbaijan State University (Baku State University) physics department in 1981 and began his career at the Institute of Space Research as a young specialist. In 1982, he was hired as a researcher at the ANAS (Azerbaijan National Academy of Sciences) Shamakhy Astrophysical Observatory. In 1992, Faig Musayev successfully defended his dissertation at



the Special Astrophysical Observatory of the Russian Academy of Sciences and received the degree of Ph.D. on physical and mathematical sciences.

In 1995, he resigned from the Shamakhy Astrophysical Observatory at his own request.

Since that year, he was continued his scientific activity at the Special Astrophysical Observatory of the Russian Academy of Sciences, one of the most famous astrophysical centers in the world. He worked there for many years and gained extensive experience in assembling specific electronic light receivers for telescopes. He has established himself as a highly qualified experimenter-spectroscopist in the assembly of optical devices. In recent years, the devices he had collected for telescopes in the observatories of Russia, Poland, and Bulgaria successfully have been tested and proved. Various authors had obtained interesting results based on high-quality observation materials obtained in the devices developed by him. Faig Musayev had special services in expanding relations between the Shamakhy Astrophysical Observatory and the Special Astrophysics Observatory of the Russian Academy of Sciences and in modernizing the instrument park of the Shamakhy Astrophysical Observatory. In addition, Faig Musayev personally assembled and put into operation the first 30,000-resolution Kude echelle spectrometer used on the 2-meter telescope of the Shamakhy Astrophysical Observatory. His contribution to the development of details of the high-resolution fiber echelle spectrograph, designed and currently used by the staff of the Shamakhy Astrophysical Observatory, is undeniable. During his tenure, he has published more than 150 scientific articles in the world's leading journals.

On June 1, 2021, Musayev Faig Adil passed away unexpectedly. In this regard, the staff of the Shamakhy Astrophysical Observatory of ANAS expresses

its condolences to the family members of the leading researcher of the Special Astrophysics Observatory of the Russian Academy of Sciences, Ph.D. on physical and mathematical sciences, our compatriot Musayev Faig Adil and expresses deep condolences.

The memory of Faig Musayev will always live in the hearts of those who love him. Rest in peace!

NECROLOGUE

Heavy loss to Azerbaijan Astrophysics.

Former senior researcher of the Shamakhy Astrophysical Observatory named after Nasraddin Tusi of the Azerbaijan National Academy of Sciences, associate professor, Ph.D. Izzet Ramzi oglu Salmanov has died. Izzet Salmanov was born



on May 20, 1940 in Vendam village of Gabala region. After graduating from Zagatala District Secondary School №1, he entered the Azerbaijan State University, graduated in 1964 with a degree in physics and astronomy. After graduating from the university, he began working at the Shamakhy Astrophysics Observatory. From 1968-1971 he studied at graduate school. In 1976, he defended his dissertation on "Spectrophotometric study of T-Taurus stars" and received the degree of Candidate of Physical and Mathematical Sciences. Later he worked as a scientific secretary of the observatory, head of the laboratory. In recent years, he worked as a senior researcher. The scientific researches carried out by I.Salmanov are mainly devoted to the study of T Taurus and Ae/Be Herbig type stars in the early evolutionary stage. For the first time, he made simultaneous spectral and photometric observations of SU Aur, V380 Ori, RY Tau, FU Ori stars in the 2 m telescope of the Shao. In this case, a spectroscope was used in the focus of Cassegrain, and a photometric cassette device was used in one of the 30-cm search tubes of the telescope. His articles in this field have been published in about 30 scientific journals, and there are references to these works by foreign scientists. He showed that as the brightness of the RW Aur increases, the intensity of the gas coating lines in its spectrum increases.

For the first time in the spectrum of that star, it was found that the emission and falling of radiation lines at velocity -80 to $+80$ -km/s for a month. Based on the analysis of these studies, he showed that such changes are due to active processes occurring in the stellar atmosphere. Based on the analysis of these studies, he showed that such changes are due to active processes occurring in the stellar atmosphere.

I.Salmanov has been an employee of the Sheki Regional Scientific Center since 1991, where he worked until recent years. In addition to his scientific work, he also taught at school and college. As a result, he received the title of associate

professor. In addition, he enthusiastically translated several valuable university textbooks from Russian into Azerbaijani. Although he could not publish these translations, those manuscripts remain and can be edited and published in the future.

Professor I. Salmanov again devoted the last years of his work to astrophysics. He studied the statistics of supernovas in galaxies and collected much information about them. He has constructed an initial version of the distribution curve of the supernova number in different types of galaxies. At the same time, I. Salmanov, along with other colleagues, is the author of several scientific articles in the field of active nuclear galaxies. He has participated in several international symposiums in Germany, the Czech Republic, and Poland.

The Shamakhy Astrophysical Observatory recognized him as a knowledgeable, humble, hardworking, intelligent man and a wonderful family man. Rest in peace!

NECROLOGUE

Azerbaijan's astronomical science has a heavy loss "Jafar Museyib oglu Kuli-Zade, a well-known scientist who made an undeniable contribution to the development of astrophysics in Azerbaijan, has passed away. We offer our deepest condolences to the relative's friends, share their grief, and wish them patience. Jafar



Museyib oglu Kuli-Zade was born on August 27, 1936, in the village of Khatinli, Tovuz region of Azerbaijan. After graduating from high school, he entered the present Baku State University, and then sent to Leningrad State University. He graduated from Leningrad State University in 1961. In order to broaden his education, he entered the graduate school of Astrophysics at the same university and, in 1966, defended his dissertation.

Kuli-Zade, who was very patriotic, returned to his homeland in 1966 and began working as a researcher at the Shamakhy Astrophysical Observatory of ANAS. Since 1969 he has been working as an associate professor at the Department of Molecular Physics of Baku State University. He has been working at the Department of Astrophysics since 1975, first as an associate professor, since 1991 as a professor, from 1997 to 2019 as the head of the Department of Astrophysics, from 2019 to the last days as a consultant-professor of the Department of Astrophysics. In 1992-94, he was invited to Turkey and lectured at Istanbul University.

Dedicating his life to the development of science and education, the immortal professor worked tirelessly until the last days of his life to enlighten the children of the Azerbaijani people. He not only taught various branches of astronomy and astrophysics, but he also wrote textbooks for future generations - "Classical Astronomy," "Atomic Spectroscopy," "Solar Physics," and "Fraunhofer Spectrum of the Sun."

Along with his achievements in education, Professor Kuli-Zade tirelessly contributed to research in science and gave many scientific research methods. He is the author of 230 scientific articles.

In 1991 he was awarded a diploma from the Cosmonautics Federation of the former USSR.

He has been a member of the European Astronomical Society since 2001. In 2009 he was awarded the title of "Honored Teacher" by the decree of the President of the Republic.

He has trained two doctors of sciences (consultants), three candidates of sciences, and more than 20 masters.

J.M. Kuli-Zade was a genius scientist - an intellectual, a beautiful man, a caring friend, and head of the family. The staff of Baku State University and the Shamakhy Astrophysical Observatory named after N. Tusi once again express their deep condolences to their relatives and friends, wish them patience.

NECROLOGUE

Azerbaijan's astronomical science has a heavy loss.

Dmitry Ivanovich Shestopalov, the leading researcher of the "Planets and small celestial bodies" department of the Shamakhy Astrophysical Observatory named after N.Tusi of ANAS, died on April 7, 2021. Unfortunately, during the pandemic, the COVID-19 virus did not pass unnoticed by our astronomer colleague D.I. Shestopalov made us feel pain by taking from us a hard-working man



who wasted his time in his scientific work.

Dmitry Ivanovich Shestopalov was born on April 22, 1952, in the city of Baku. He graduated from the Physics Department of Kharkiv State University, the Republic of Ukraine, in 1975 with a degree in Astronomy. He continued his postgraduate studies in astronomy at the same university. In 1980, he successfully defended his dissertation on "Polarimetric and colorimetric maps of the lunar surface" at the Sternberg State Astronomical Institute of Moscow State University, where he received a Ph.D. in physics and mathematics.

DI Shestopalov started his career as a junior researcher at the Shamakhy Astrophysical Observatory in 1978. Since 1980, he has been engaged in the "Study of the physical properties of asteroids" in the ShAO. During this time, most of the more than 170 scientific papers devoted to studying the physical properties of asteroids have been published in prestigious journals around the world. He was one of the main organizers and observers of spectral observations of asteroids in ShAO telescopes. In collaboration with the staff of St. Petersburg University, a program of research of radiation spectra reflected from meteorites close to asteroids due to their chemical composition was organized, and in-depth analysis was carried out. He was responsible for observing the asteroid Vesta, Mars, and Halley's International Cooperative Program from the ShAO. He was elected a Chairman of the Organizing Committee of the International Conference on Physics of Asteroids, organized in ShAO.

From 1983 he worked as a senior researcher, from 1992 as an associate professor, and from 1994 as a leading researcher in the department of "Planets and celestial bodies."

From 1980 to 1992, he was a member of the International Working Groups on Asteroids, Comets and Spectrophotometry, and Photometric Standards and Catalogs. In addition, he co-authored two monographs on the long-term study of asteroids in the ShAO and the book "Energy Distribution in the Spectra of 425 Bright Stars", which is central to the history of the ShAO.

It should be noted in particular that D.I. Shestopalov's scientific activity was carried out in Russia, Ukraine, the USA, France, Canada, Japan, and other countries. He had close scientific relations with his colleagues from other countries and carried out joint work. He was a regular participant of many international conferences, author of articles and theses published in more than 120 international journals and scientific conference proceedings.

D.I. Shestopalov has been a member of several working groups and, since 2001, a member of the European Astronomical Society and the American Geophysical Society.

He was closely involved in the scientific and public life of the observatory. Rest in peace.