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SPECTRAL MONITORING OF LONG PERIODIC ECLIPSING SYSTEM EPSILON AURIGAE DURING 2008–2010

The results of spectral observations of eclipsing binary system Epsilon Aurigae are presented. Observations were carried out using the coude echelle spectrograph on 2-m telescope Zeiss-2000 at the Terskol Peak Observatory with spectral resolution $R = 45000$.

Epsilon Aurigae is long periodic eclipsing binary system that consists of F0 supergiant star as first companion and huge gas dust disk as second companion. The uniqueness of this system is that eclipses of star by a gas-dust disk occur with 27.1 years period and continues two years.

Presented spectral observations Epsilon Aurigae were carried out in period May 2008 – May 2009 outside eclipse, December 2009 at the beginning of eclipse and March 2010 within eclipse. Based on the results of observations, an analysis of the variability for H_α line was made and some other spectral lines at the pre-eclipse and eclipse stages. Long-term variations of H_α line profiles were detected.

Key words: Epsilon Aurigae, eps Aur, long-periodical eclipsing system, gas-dust disk, H_α line.

Introduction. Epsilon Aurigae (eps Aur, SAO39955, HIP23416, HD31964; $\alpha=05^h01^m58.13^s$, $\delta=+43^\circ49'23.9''$ (J2000)) is a long periodic eclipsing binary system at the distance 625 pc from the Sun. Primary component of system is F0 supergiant with mass $M_{\text{Star}} \approx 15 M_{\text{Sun}}$ and diameter $D_{\text{Star}} \approx 150 D_{\text{Sun}}$. The star is eclipsed by a dark gas-dust disk with a period 27.1 years (9886 days) [1], [2]. Eclipse duration is 2 years. Eps Aur is the eclipsing binary system with longest known orbital period.

Second component is gas-dust disc with mass $M_{\text{Disc}} \approx 14 M_{\text{Sun}}$. Diameter $D_{\text{Disc}} \approx 20 \text{ AU}$ ($500 D_{\text{Sun}}$) and temperature $T = 500^\circ \text{ K}$. Inside of disc according to indirect observational data there are two unknown objects, possibly a binary system of two small stars.

Contact moments of last eclipse are presented below [3]:

1 th contact:	RJD 55070	2009 August 16
2 ^d contact:	RJD 55250	2010 February 22
Eclipse middle:	RJD 55400	2010 July 22
3 rd contact:	RJD 55620	2011 February 27
4 th contact:	RJD 55800	2011 August 26

where $\text{RJD} = \text{JD} - 2,400,000$ and the uncertainty in timings is at least one to two weeks.

Observations. Presented periodical spectral observations of the long periodic eclipsing binary eps Aur were carried out by authors over a period from March 2007 to December 2011. First results for observations out of eclipse in 2007 are presented in [4]. In this paper spectral data obtaining for five nights during period May 2008 – March 2010 are reported (Tab.1).

Spectral observations were done at the Terskol Observatory with help 2-m telescope Zeiss-2000 and coude echelle spectrometer. The wavelength range is 3700 to 9000 Å. The spectral resolution is $R = 45000$. Standard spectra processing was done in program DECH95 and DECH20T.

List of Epsilon Aurigae spectra

Table 1

Date	Spectra number per night	Exposure time, sec	Average S/N in H_α line field
2008.05.24	4	300	200
2008.12.15	3	1200	230
2009.05.01	5	300	380
2009.12.22	4	500	220
2010.03.20	13	500	200

Data analysis and results. First of all we research evolution of H_α line profiles. We have analyzed the long-time variations (outside eclipse, beginning of eclipse and within eclipse) and short-time variations (during some hours per night).

Also we have review the behavior of the following absorption lines, some of them exhibited long-term variability in paper [5]: Fe I (3922.9 Å), Ti II (4028.0 Å), Ti II (4443.85 Å), Ti II (4468.48 Å), H_β (4861.5 Å), Na D I (5889.953 Å), Na D II (5895.923 Å), O I (7772 Å).

Long-time variability of spectral lines.

Figure 1 shows H_α line profiles for five nights noted above: outside eclipse (24.05.2008, 15.12.2008, 01.05.2009), beginning of eclipse (22.12.2009) and within eclipse (20.03.2010). Each profile is result of averaging for some spectra obtaining during corresponding night.

H_α line was detected in absorption. The prominent nonsymmetrical details – blue and red emission wings – are presented in each profile. Also it is necessary to note in last data (2010.03.20) red wing in H_α profile disappeared. Behavior of H_α line profile within eclipse also are described in [1]. Authors showed an emission component (Figure 2) appeared in the core of the H_α line close to the rest wavelength from MJD 55150 onward as the absorption increased in this region. Data analysis by authors [1] indicated this became more clearly defined as the surrounding flux level dropped further and moved across the region from red to blue. The shape of the emission component is revealed as the absorption region broadened and swept across it through mid-eclipse. It is clear that the constant emission component is only revealed as the surrounding flux level drops [1].

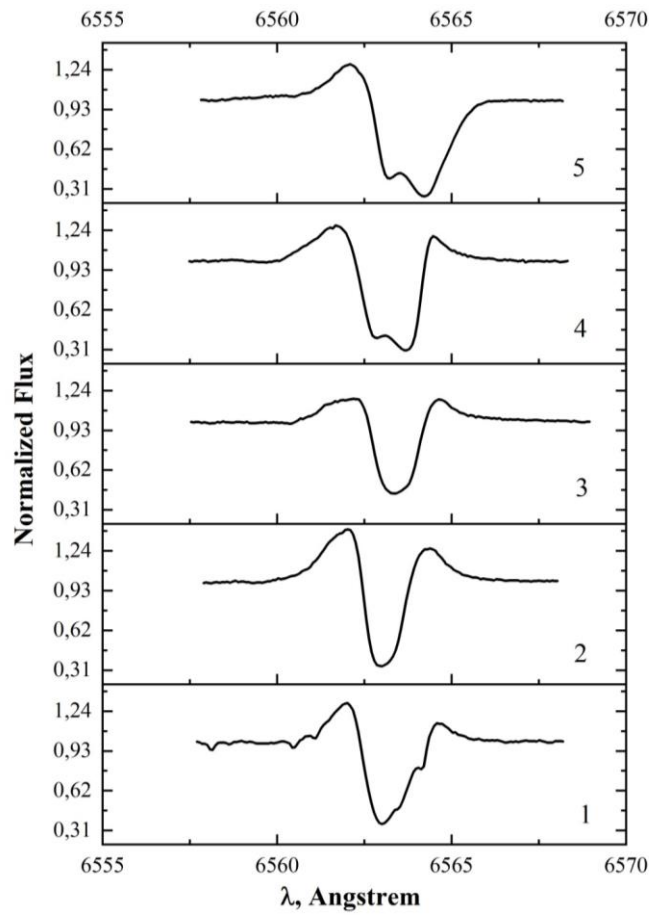


Fig. 1. Evolution of H α line profiles of eps Aur for period May 2008 – March 2010. Numbering of spectra: 1) 24.05.2008, 2) 15.12.2008, 3) 01.05.2009, 4) 22.12.2009 and 5) 20.03.2010

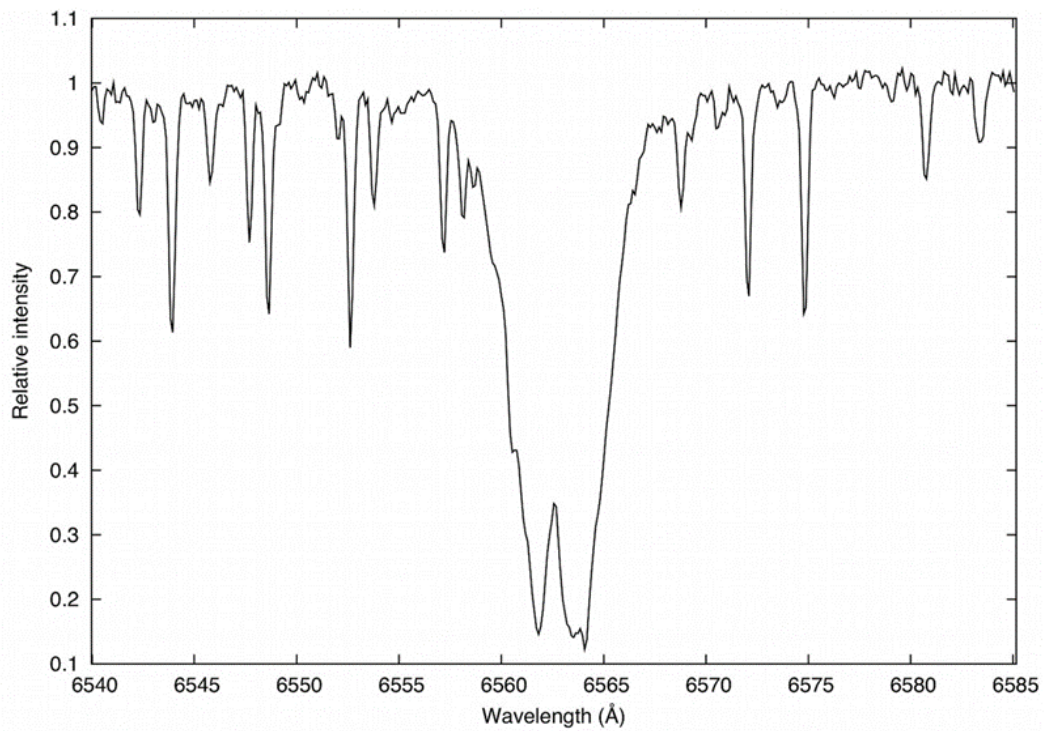


Fig. 2. Spectrum of eps Aur showing emission component at bottom of H α absorption line. Observations of 12.939/7/2010, R. Leadbeater, TN 0.25 m, Lhires3 2400 g/mm, 0.107 Å/pixel [1]

On base of spectral observations taken during the 1982–1984 eclipse authors in [6] presented variations of H α line profile in different phases of eclipse. Figure 3 indicates that the hydrogen gas is rotating with a disklike structure around the center of the secondary component and the rotational velocity increases at the inner region of the disk [6].

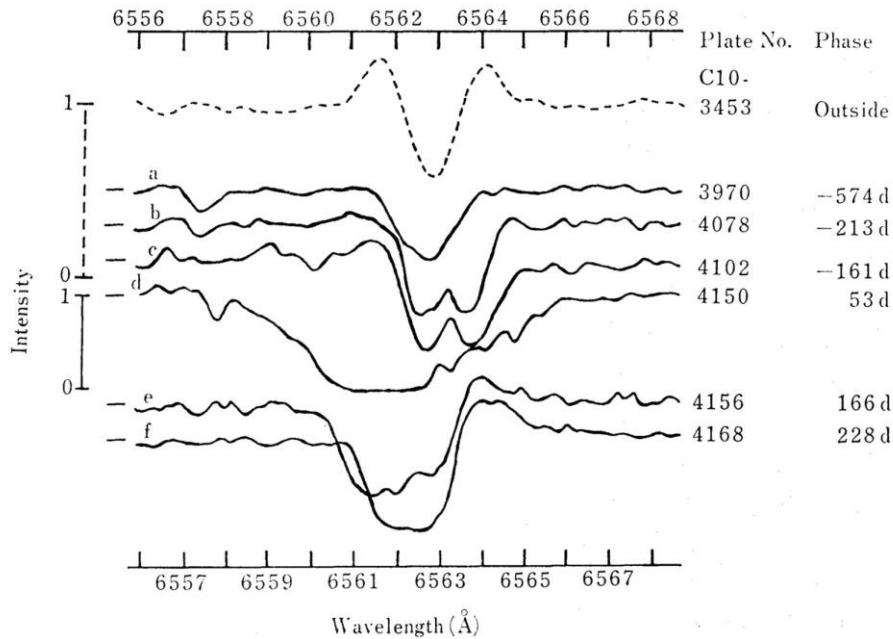


Fig. 3. Variation in the H α absorption due to the secondary gas with eclipse phase [6]

The value variations of equivalent widths (EW) of the blue wing, the red wing and the absorption core for H α line profiles were calculated ($F/F_c > 1$ – emission, $F/F_c < 1$ – absorption) and given in Table 2. EW were calculated by direct numerical integration of area under line profile.

In paper [1] during the eclipse phase and outside it too, there were many small variations in EW. The authors suggest that the occulting object and F star hydrogen disk may be clumpy. The F star may have also an intrinsic pulsating activity [7] that produces such variations. EW of H α line in [1] has irregular variations like small steps during its increasing and decreasing phases. It has been interpreted as an indication of structures (possibly ring-like) within the disc [8].

Table 2

Long-time EW variations of H α line components of eps Aur

Date	EW of blue wing, Å	EW of central absorption, Å	EW of red wing, Å
2008.05.24	- 0.263205	0.778247	- 0.104892
2008.12.15	- 0.474382	0.638114	- 0.271455
2009.05.01	- 0.222835	0.641791	- 0.178547
2009.12.22	- 0.326701	1.017150	- 0.149343
2010.03.20	- 0.381070	1.413320	0.0

EW of some absorption lines H α , H β , K I, Na I – D1/D2 blend and O I multiplet near 7772 Å demonstrated long-time variability during 1983–1984 eclipse [5]. So, we measured EW of lines Fe I (3922.9 Å), Ti II (4028.0 Å), Ti II (4443.85 Å), Ti II (4468.48 Å), H β (4861.5 Å), Na D I (5889.953 Å), Na D II (5895.923 Å), O I (7772 Å) and presented results in Tab.3. There are registered unsystematically slight variations of EW values and their partially correlations.

Table 3

Long-time EW valuations of some spectral lines of eps Aur

Spectral Line/Data	2008.05.24	2008.12.15	2009.05.01	2009.12.22	2010.03.20
Fe I (3922.9 °Å)	0.107491	0.211569	0.007585	0.321521	0.265277
Ti II (4028.0 °Å)	0.242421	0.351733	0.080849	0.434650	0.396700
Ti II (4443.85 °Å)	0.787041	0.785434	0.327080	0.989206	0.920322
Ti II (4468.48 °Å)	0.609311	0.657184	0.173548	0.793768	0.744834
H β (4861.5 °Å)	1.131782	1.581563	0.568435	1.742588	1.946235
NaDI (5889.953°Å)	0.899209	0.764251	0.436443	1.070421	1.248458
NaDII(5895.923°Å)	0.781408	0.684393	0.477766	1.031314	1.175775
OI (7772°Å)	0.941498	0.904108	0.541140	0.899957	0.988148

Short-time variability of spectral lines.

We registered several eps Aur spectra per night to search the fast variations of H α line and some other spectral lines. Figure 4 illustrates small variations of H α line profiles during each of five nights. The results of EW measurements for H α line components for the same period are presented in Tab.4. Figure 5 demonstrate variations of EW for H α line components during five nights.

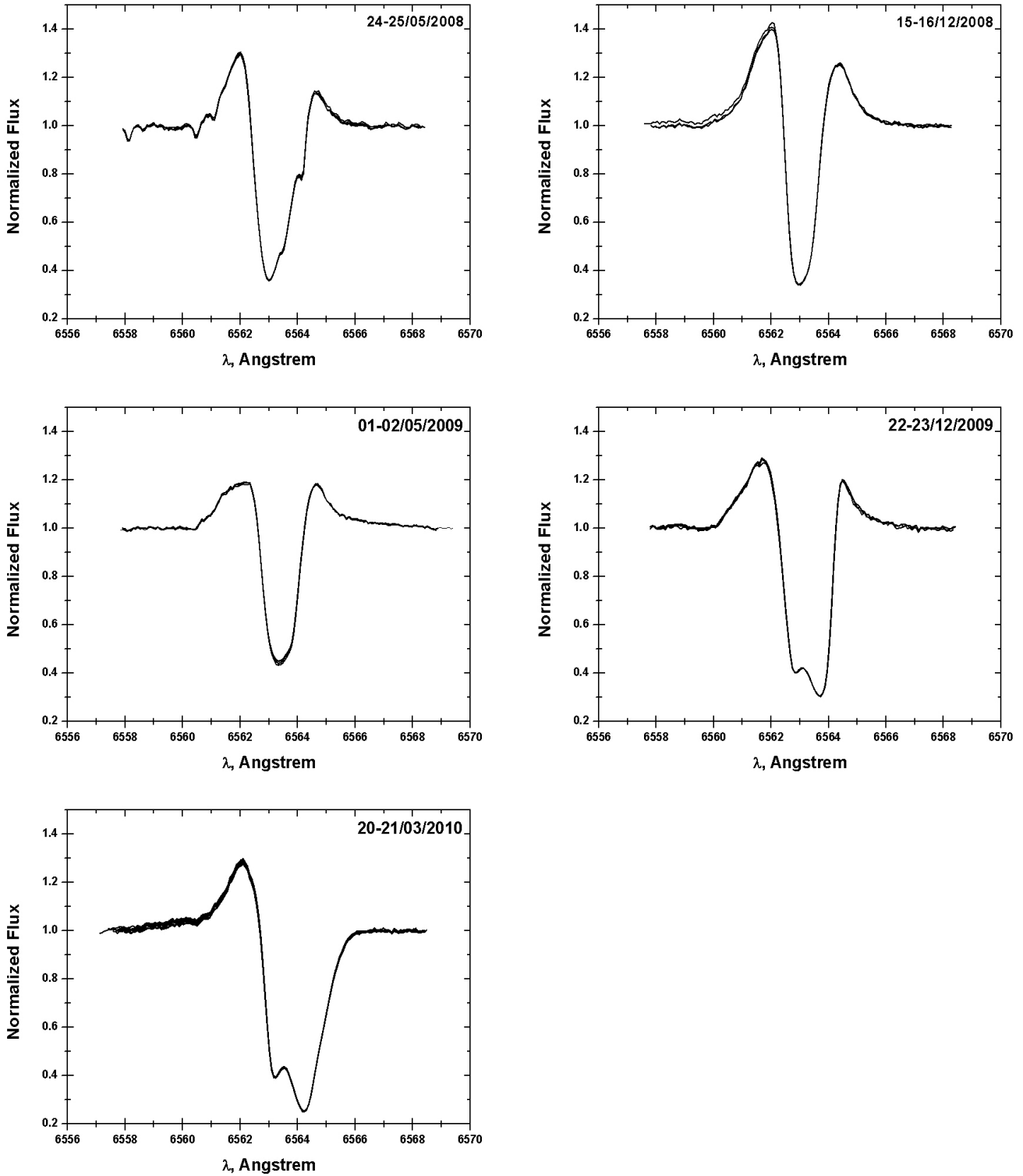


Fig. 4. H α line profile short-time variations during five nights: outside eclipse (24.05.2008, 15.12.2008, 01.05.2009), beginning of eclipse (22.12.2009) and within eclipse (20.03.2010)

Table 4

Short-time EW variations of eps Aur H α line components

Date	No.	JD	EW of blue wing	EW of central absorption	EW of red wing
2008.05.24	1	2454611.27607	- 0.251728	0.792680	- 0.094692
	2	2454611.28052	- 0.268184	0.776360	- 0.112277
	3	2454611.28543	- 0.246527	0.794002	- 0.090590
	4	2454611.28977	- 0.258773	0.782532	- 0.097164
2008.12.15	1	2454816.35190	- 0.523668	0.630709	- 0.263132
	2	2454816.36458	- 0.461052	0.640903	- 0.252545
	3	2454816.37947	- 0.476873	0.638099	- 0.267691
2009.05.01	1	2454953.38263	- 0.256438	0.628126	- 0.211192
	2	2454953.38680	- 0.255006	0.638090	- 0.209928
	3	2454953.39305	- 0.241881	0.623562	- 0.211234
	4	2454953.39721	- 0.254896	0.614383	- 0.221902
	5	2454953.40138	- 0.258588	0.624821	- 0.216590
2009.12.22	1	2455188.23655	- 0.327208	1.010449	- 0.150145
	2	2455188.24428	- 0.351816	1.006754	- 0.168621
	3	2455188.25239	- 0.338547	1.009995	- 0.157944
	4	2455188.25844	- 0.352167	1.007191	- 0.160541
2010.03.20	3	2455276.24684	- 0.363982	1.414620	0.0
	4	2455276.25378	- 0.435401	1.401485	0.0
	5	2455276.26073	- 0.434937	1.399685	0.0
	6	2455276.26698	- 0.428216	1.398648	0.0
	7	2455276.27392	- 0.433850	1.405607	0.0
	8	2455276.28017	- 0.447961	1.401470	0.0
	9	2455276.28712	- 0.393925	1.417273	0.0
	10	2455276.29406	- 0.418274	1.406891	0.0
	11	2455276.30031	- 0.351988	1.416444	0.0
	12	2455276.30726	- 0.407158	1.412571	0.0
	13	2455276.31351	- 0.399029	1.415640	0.0
	14	2455276.32045	- 0.395229	1.416950	0.0
	15	2455276.32670	- 0.393526	1.407133	0.0

Conclusions. The following results have been obtained in this paper. Absorption and emission components of the H α line profiles show remarkable variability in process of entrance to eclipse of eps Aur system (long-time variations) and practically don't show variability in periods of some hours (short-time variations are minimal or absent). EW values of H α line components show the same variations.

EW value variations of other spectral lines are weak and slightly correlate with each other over long periods of time, and such variations do not appear on short-time intervals for several hours.

Long-Time Variations of spectral lines: Profiles and EW of absorption and emission components of H α line demonstrate notable variability from 2007 to 2010 out of eclipse, during pre-eclipse and within eclipse. H α line profile shows prominent variations of core profile deformations in absorption at the beginning and near to mid-eclipse. There are blue and red emission wings were not symmetrical in this periods. For other presented lines there are found unsystematically slight variations of EW values and their partially correlations between some lines.

According to our spectral data an emission component in the core of H α line appears nearly to second contact moment. This coincides with the observational results of other authors [1; 6; 9]. In paper [9] authors speculate that the increase in the strength of the H α absorption observed near mid-eclipse arises from hydrogen gas in the central region of the disk. This gas produces an additional H α absorption in the spectrum of the F0 star near mid eclipse as its light shines through the central opening of the disk [9].

Short-Time Variations of spectral lines: Out of eclipse, at the beginning of eclipse and within eclipse prominent short-time variations in profiles and EW of H α component were not found for period some hours. Max EW variations of H α components reached up to 5–8%. For other noted lines no variability, reaching 5% limit, were detected.

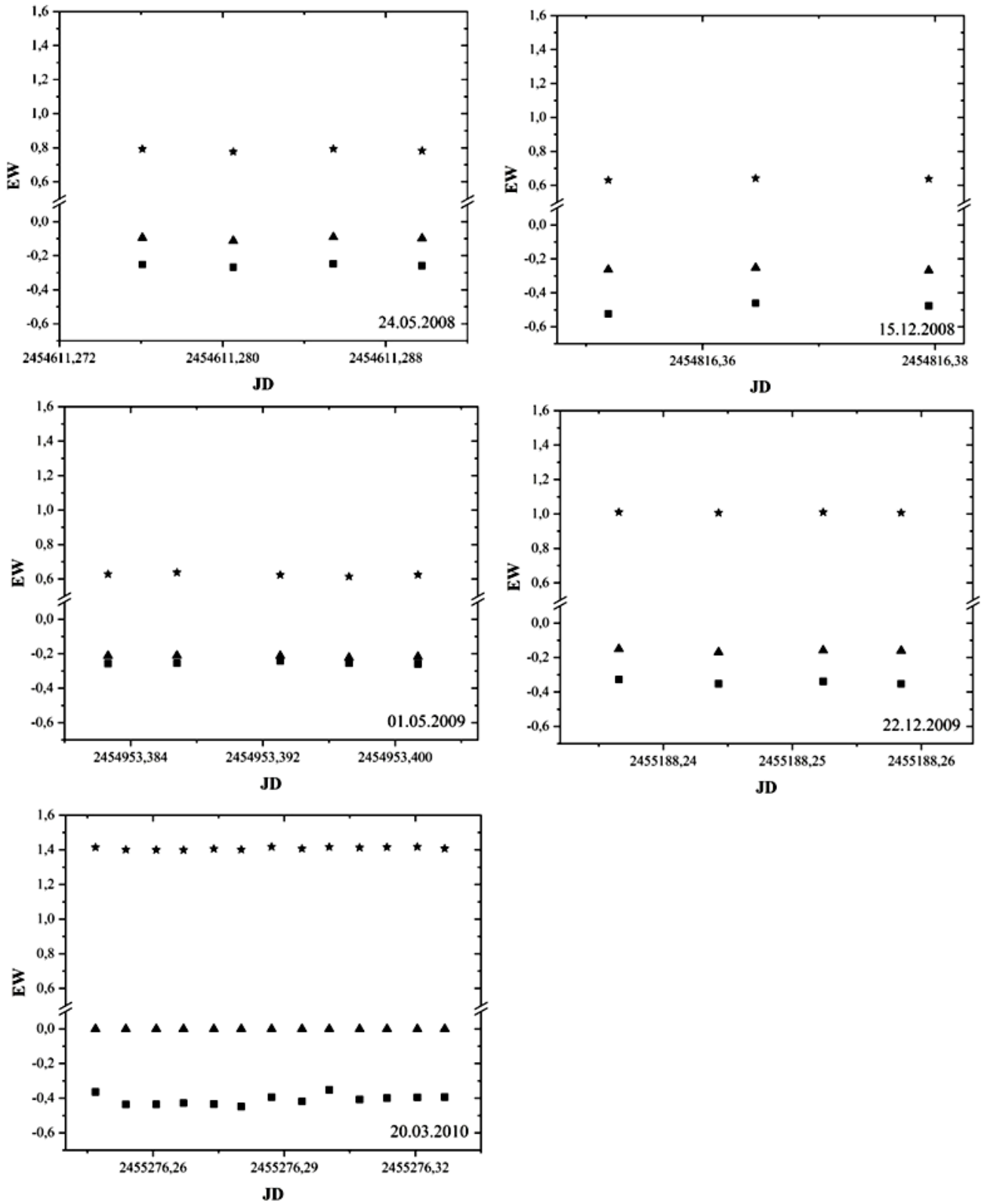


Fig. 5. Variations of EW for H α line components during five nights: outside eclipse (24.05.2008, 15.12.2008, 01.05.2009), beginning of eclipse (22.12.2009) and within eclipse (20.03.2010). Symbols: * – central core in absorption, ■ – blue wing, ▲ – red wing

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СПЕКТРАЛЬНИЙ МОНІТОРИНГ ДОВГОПЕРІОДИЧНОЇ СИСТЕМИ EPSILON AURIGAE ЗА ПЕРІОД 2008–2010 рр.

Наведено результати спектральних спостережень затемненої подвійної системи Epsilon Aurigae. Спостереження проводили з використанням куде-ешелле спектрографа на 2-метровому телескопі Zeiss-2000 обсерваторії піка Терскол зі спектральною роздільною здатністю $R = 45\,000$.

Epsilon Aurigae є довгоперіодичною затемненою подвійною системою, яка складається з першого компонента – надгіганта спектрального класу F0 та другого компонента – величезного газопилового диска. Унікальність об'єкта полягає в тому, що затемнення зорі газопиловим диском відбуваються з періодом 27,1 років і тривають два роки.

Представлені спектральні спостереження Epsilon Aurigae проведено в період з травня 2008 по травень 2009 р. на стадії перед затемненням, у грудні 2009 р. на початку затемнення і в березні 2010 р. уже на стадії затемнення. За результатами спостережень виконано аналіз змінності профілю лінії H_{α} та деяких інших спектральних ліній перед затемненням і під час затемнення. Виявлено довготривалі варіації профілів лінії H_{α} .

Ключові слова: Epsilon Aurigae, eps Aur, довгоперіодична затемнена система, газопиловий диск, лінія H_{α} .