ε Aurigae 2009-2011 eclipse observations

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(Conference talk. Submitted on 14.03.2012; Accepted on 26.03.2012)

Abstract. An overview of our ongoing photometric and spectroscopic monitoring of the ε Aurigae eclipse in 2009-2011 is presented. The obtained until now observational data is described and discussed. The changes in the spectrum, which can be attributed to the eclipsing disk, are illustrated with the variations in the profiles and the equivalent widths of selected spectral features. The mean radial velocities measured in our spectra are compared with a recent spectroscopic orbital solution. The duration of eclipses is also discussed briefly.

Key words: stars: binaries: eclipsing – stars: individual: ε Aurigae

Briefly about the long story of ε Aurigae

Since about two centuries one of the brightest, longest period (27.1 years) eclipsing binary stars ε Aurigae remains an unsolved puzzle. Despite the long term observational and theoretical efforts some of the most important issues related to the nature of this binary system are still unanswered. The eclipses observed before the last one revealed that a bright F0 Ia star is dimmed by a huge, dark disk for about two years. The most promising models proposed to explain the observed properties of ε Aur consider a high-mass system or a low-mass system and respectively completely different evolutionary status of the components. According to the first model, the primary component is a young massive ($\sim 15\,M_\odot$) F0 supergiant and the secondary component is embedded in a proto-stellar/planetary disk. While according to the second one, the F0 supergiant is an evolved post-AGB low-mass ($\sim 1\,M_\odot$) star. In this case, a more massive component is hidden in a disk formed as a result of mass transfer during the evolution from the main sequence of the F0 supergiant. The nature of the invisible component in the disk center is a problem for both models. It is unclear, if this is a single object or a close binary system. A review of the properties and our understanding of ε Aur before the beginning of its last eclipse can be found in Guinan & DeWarf (2002).

A new opportunity to clarify the ε Aur mystery was the last eclipse of the system in 2009-2011. Observations of this eclipse were carried out in a very wide range from the far-ultraviolet to the far-infrared region. A massive amount of high quality data including photometry, spectroscopy, polarimetry, interferometry was collected. Some new, very interesting results were published and others will certainly be published in the near future. The occulting disk in ε Aur was directly detected by Kloppenborg et al. (2010) by the use of interferometric observations. The wide range spectral energy distribution (SED) of ε Aur published by Hoard et al. (2010) gives some support to the low-mass model and a B5 V star in the disk center. Observational evidences for disk structure (Leadbeater & Stencel 2010) and differential heating of the disk (Stencel et al. 2011) were reported as well.

In 2009 we started a long-term photometric and spectroscopic monitoring of ε Aur in the optics. This talk is aimed to summarize our observations and to present some preliminary results.

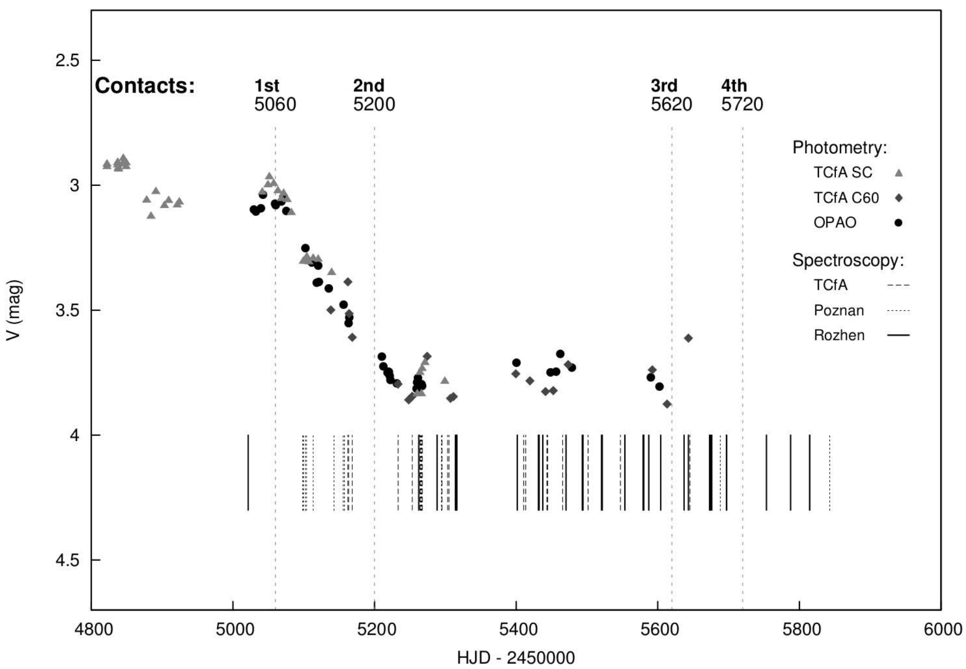

Fig. 1. V light curve (see the text) of the ε Aur eclipse based on our data obtained in 2009-2011. The moments of the four contacts (Stencel et al. 2011) are indicated with long vertical dashed lines. The different types of short vertical lines mark the times of our spectral observations.

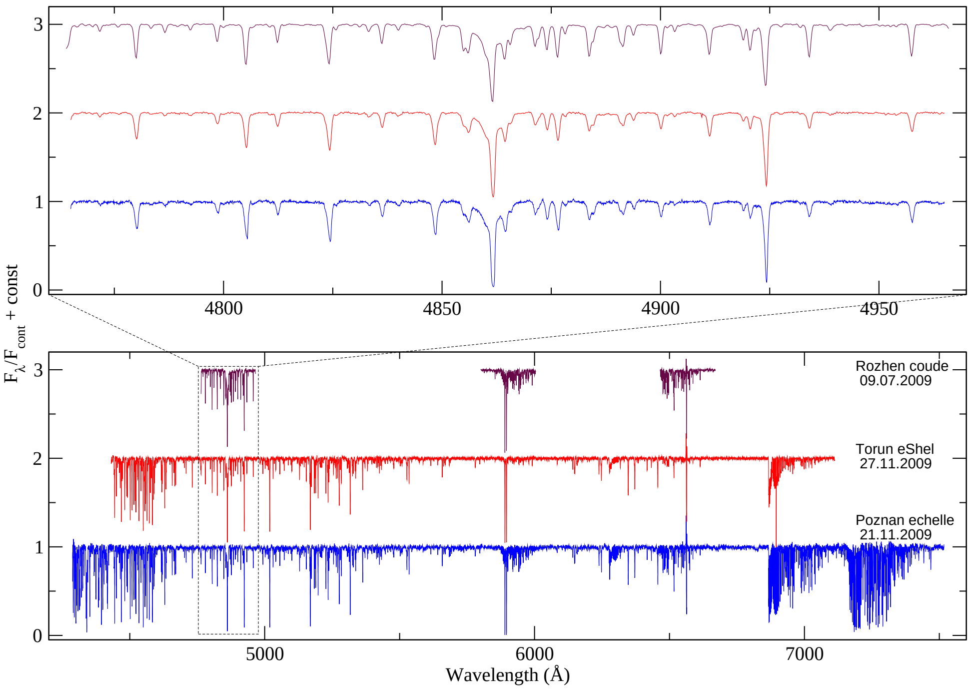

Fig. 2. Sample spectra of ε Aur to compare the three spectrographs used in our campaign.

1 Summary of the campaign

1.1 Photometric observations

Multicolor photometry of ε Aur was performed using three different photometric systems in two observatories - Piwnice observatory of the Torun Centre for Astronomy (TCfA) and Olsztyn Planetarium and Astronomical Observatory (OPAO). In Piwnice we used a SBIG STL-1001E CCD camera with $UBVR_{\mathrm{C}}I_{\mathrm{C}}$ filters attached to a 60-cm Cassegrain telescope (C60). The field of view covered was $\sim 11' \times 11'$. Additionaly, so called 'small camera' (SC), an achromatic telephoto MC APO Telezenitar-M 135/2.8 objective combined with SBIG ST-8XE CCD camera and BVR filters with transmission curves similar to the Johnson photometric system were used. In this case the field of view was $6° \times 4°$. The photometric system used in OPAO includes a 25/250-cm Schmidt-Cassegrain telescope and SBIG ST-8XME CCD camera with Johnson $UBVRI$ filters (field of view $\sim 16' \times 12'$). The accuracy of our measurements was as follows: $\pm0^{\mathrm{m}}\!.022, \pm0^{\mathrm{m}}\!.023, \pm0^{\mathrm{m}}\!.021, \pm0^{\mathrm{m}}\!.020$ and $\pm\, 0^{\mathrm{m}}\!.017$ in $UBVR_{\mathrm{C}}I_{\mathrm{C}}$ respectively for C60; $\pm0^{\mathrm{m}}\!.007, \pm0^{\mathrm{m}}\!.011$ and $\pm\, 0^{\mathrm{m}}\!.019$ in BVR respectively for SC; $\pm0^{\mathrm{m}}\!.017, \pm0^{\mathrm{m}}\!.010, \pm0^{\mathrm{m}}\!.010, \pm0^{\mathrm{m}}\!.010$ and $\pm0^{\mathrm{m}}\!.006$ in $UBVRI$ respectively for OPAO.

The final processing of the data and the transformation to the standard system are still in progress and because of this in Fig. 1 only the light curve in V is shown as an example. For the purposes of this figure BD $+43\,1168$ (C60, OPAO) and λ Aur (SC) were used as comparison stars.

1.2 Spectroscopic observations

The spectral data during the 2009-2011 eclipse of ε Aur was collected with three different spectrographs. Spectra with $R \sim 11\,000$ in the range 4430-7110 Å were secured with the fibre fed echelle *eShel* spectrograph attached to the 60/90-cm Schmidt-Cassegrain telescope at the Torun observatory. At the Borowiec station of the Poznan University Observatory ε Aur was observed spectroscopically with PST (Poznan Spectroscopic Telescope; Baranowski et al. 2009) equipped with 0.5-m mirror and fibre fed echelle spectrograph. The spectra cover a range from 4290 Å to 7515 Å with $R \sim 35\,000$. We used the coudé spectrograph of the 2-m RCC telescope at the Rozhen NAO to obtain spectra with resolving power 15 000 and 30 000. These spectra cover 200 Å or 100 Å ranges respectively around Hα, NaI $D_{1,2}$ and Hβ lines.

All spectra were reduced and calibrated using standard IRAF procedures, including bias, dark, flat-field corrections and spectra extraction with background subtraction. A journal of our spectral observations is given in Table 1. The spectra of ε Aur obtained with the different spectrographs are compared in Fig. 2.

Additionally, a spectrum of ε Aur from the ELODIE archive (Moultaka et al. 2004), obtained out of eclipse on November 2, 2003, was used as a reference.

2 A first look on the collected data

It is obvious from Fig. 1 that our photometric monitoring was not successful enough and that the observations did not cover the 2009-2011 eclipse of ε Aur very well. Because of weather and instrumental reasons the eclipse was totally missed after the third contact. Our own photometric data are very scarce and do not allow us to determine the eclipse parameters. Therefore, in this work we use the parameters defined on the basis of the vast amount of photometric observations collected in the framework of the *International Epsilon Aurigae Campaign* (http://www.hposoft.com/cam-paign09.html) and published by Stencel et al. (2011): $1^{\rm st}$ contact = JD 2 455 060; $2^{\rm nd}$ contact = JD 2 455 200; $3^{\rm rd}$ contact = JD 2 455 620; $4^{\rm th}$ contact = JD 2 455 720; mid-eclipse $\sim$ JD 2 455 390$\pm$10 days.

Our spectral monitoring of ε Aur was more successful. As can be seen in Fig. 1 and Table 1 the photometric eclipse is completely covered with spectral observations. However, it is apparent in Figures 3 and 4 that our observations were started shortly after the beginning of the spectral eclipse, and our last (for now) spectrum obtained on October 7, 2011 shows that the spectral eclipse was not yet finished. Some limitation in our spectral data comes from the small spectral regions that can be observed with the coudé spectrograph of the Rozhen NAO. Therefore, NaI $D_{1,2}$ and Hα are the only spectral lines for which the variations in their profiles, equivalent widths and radial velocities can be traced in detail.

2.1 Spectral lines variation during the eclipse

The only relatively strong emissions in the spectrum of ε Aur are the blue and the red peaks in the Hα profile. It is well known that these emission components show variations during and out of the eclipse (Cha et al. 1994; Chadima et al. 2011; and references therein). These changes are particularly remarkable during the eclipse when the red and the blue emission components disappear (are below the local continuum level) and appear again at different moments and both are totally absent around the mid-eclipse. Our spectral monitoring of ε Aur (Fig. 3) shows that the red emission component disappeared in early March 2010 (after second contact) and appeared again at the end of November 2010 (between mid-eclipse and third contact), i.e. after about 260 days. The blue emission disappeared sometime between late April and late July 2010 (between second contact and mid-eclipse) until the star was behind the sun. It appeared again at the end of March 2011 (between mid-eclipse and third contact). Assuming that the blue component disappeared in the middle between late April and late July 2010, the whole time interval during which it was not seen in the spectrum is about 280 days. One or both emission components were absent in the ε Aur spectrum for about 380 days. To explain the disappearance of the Hα emission Chadima et al. (2011) suggested that it is strongly absorbed by material in the occulting disk during eclipse. They estimated that the center of the companion's occulting disk transits the F supergiant disk in about 123 days. Partial or total absence of the Hα emission components for about 380 days suggests a much more extended region in which they originate in accordance with the assumption of Chadima et al. (2011).

The evolution of NaI 5889 Å and Hα lines, typical for the eclipses of ε Aur, is shown in Fig. 3. During the eclipse additional absorption components from the disk appear in many of the F supergiant photospheric lines. These components most probably originate in rarefied layers above the disk because, the disk itself is cold and opaque. During the ingress and the first half of the totality the additional absorptions are red-shifted because of the rotation of the leading portion of the disk which covers the primary at this time. During the second half of the totality and the egress the additional absorptions originate in the receding portion of the disk and are therefore blue-shifted.

Like in previous eclipses (see Lambert & Sawyer 1986) the variations of the disk absorptions are not symmetrical. As seen in Fig. 3 the blue-shift reaches larger values and the blue-shifted additional absorptions are more intensive. Around the mid-eclipse the Hα absorption is strongest and its wings reach $\sim$150-200 kms^{-1}. The red disk absorption shows maximal shift about mid-eclipse while the blue component is most shifted closer to the third contact. The Na I lines are most intensive around the third contact when the disk component with maximal blue-shift dominates the profiles (Fig. 3).

The variations of the equivalent widths of the Na I absorptions are demonstrated in Fig. 4. Because it is not easy to separate the photosphere and disk

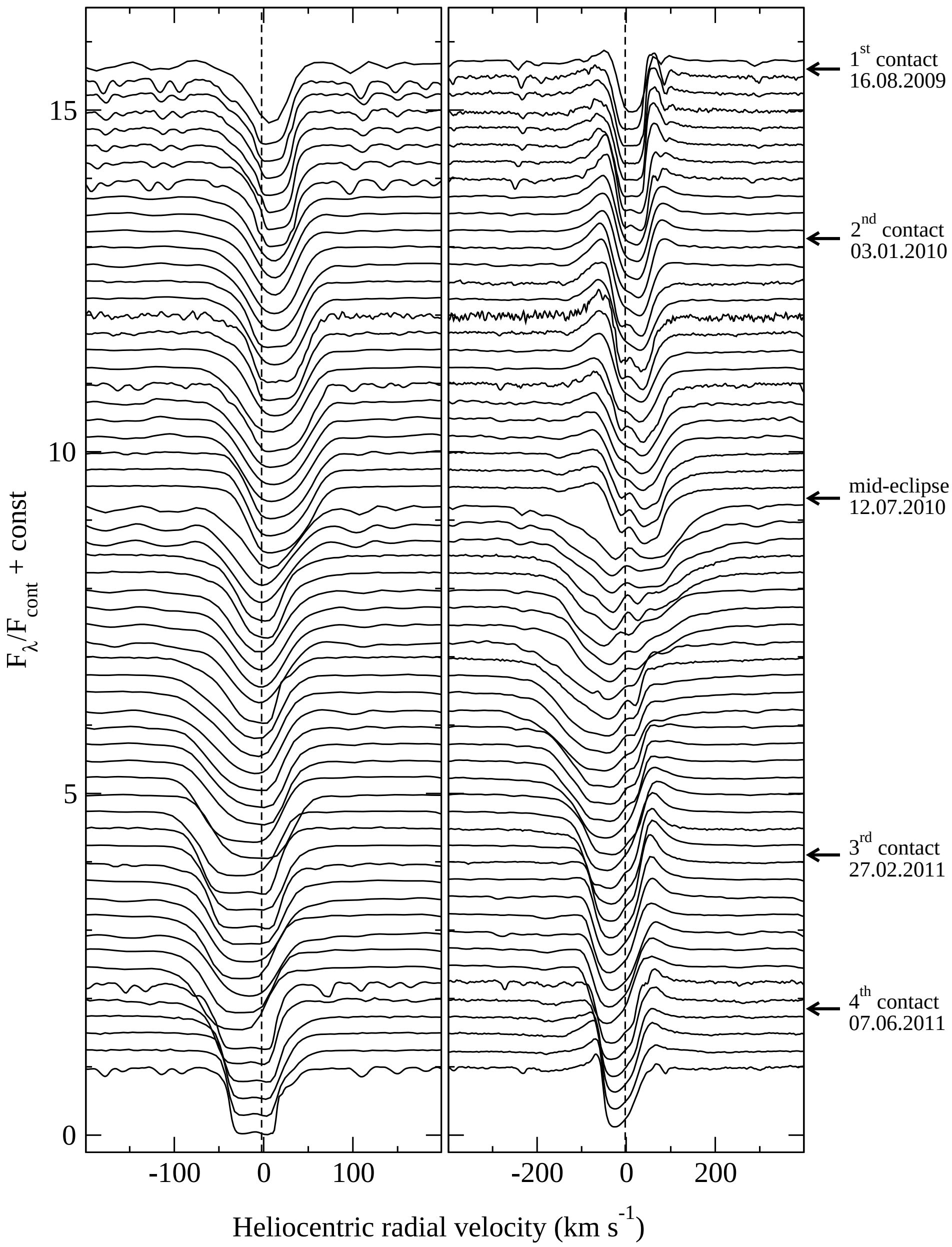

Fig. 3. Evolution of the profiles of NaI 5889 Å and Hα lines in the spectrum of ε Aur. The vertical dashed lines indicate the system γ-velocity (Stefanik et al. 2010). The moments of the eclipse are marked with arrows on the right side of the figure.

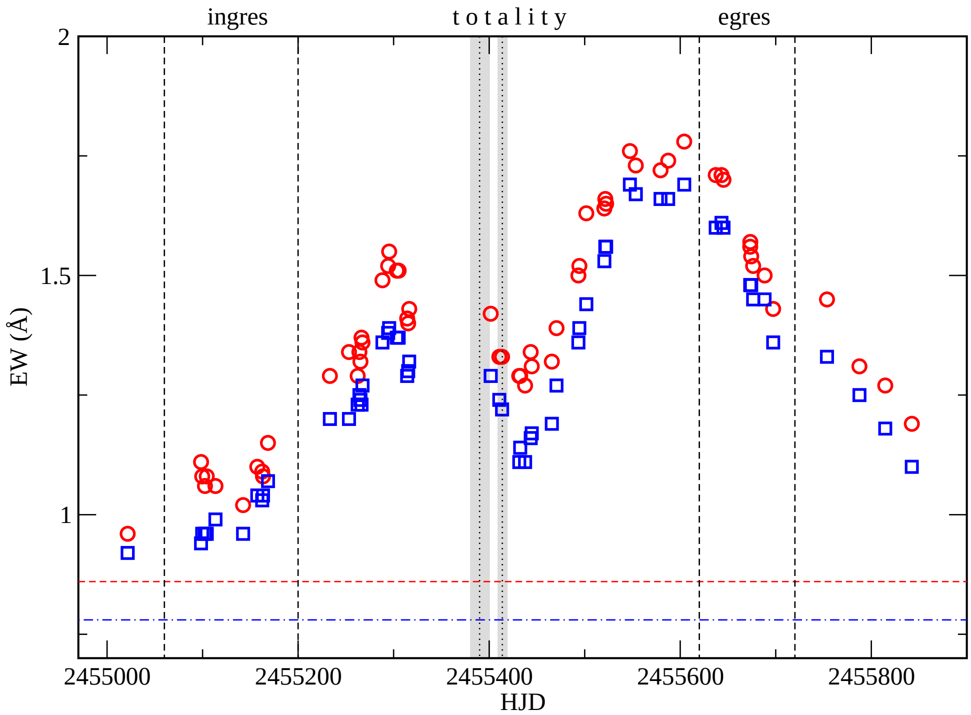

Fig. 4. Variation of the equivalent width of the Na I absorption lines. The four eclipse contacts are indicated with vertical dashed lines. The vertical dotted lines with gray error bars mark the mid-eclipse estimated by Stencel et al (2011)(*left*) and Stefanik et al. (2010)(*right*). With the horizontal dashed (5889 Å) and dot-dashed (5895 Å) lines the values of the EWs of the Na I features measured in the ELODIE out of eclipse ε Aur spectrum are shown.

absorption components, the total equivalent width for the entire profile is shown. To estimate the accuracy of our equivalent widths measurements, three diffuse interstellar bands at 5780 Å, 5797 Å and 6614 Å were used. We measured the equivalent widths of these features with an accuracy of about 7-8%. Since the diffuse interstellar bands are much weaker, we can assume that the accuracy of the measured equivalent widths of the spectral lines is of the order of 5% or better.

Two maxima and one minimum of the Na I equivalent widths during the eclipse are clearly pronounced (Fig. 4). The first peak is between the second contact and mid-eclipse, the stronger second maximum occurs slightly before the third contact. The moments of these peaks coincide with the time when the red and blue disk absorption components are most intensive. A minimum in the equivalent widths is observed shortly after the mid-eclipse and the reason is that at this time the red absorption component gradually disappears and the blue one is still not strong (see Fig. 3). The equivalent widths of Na I

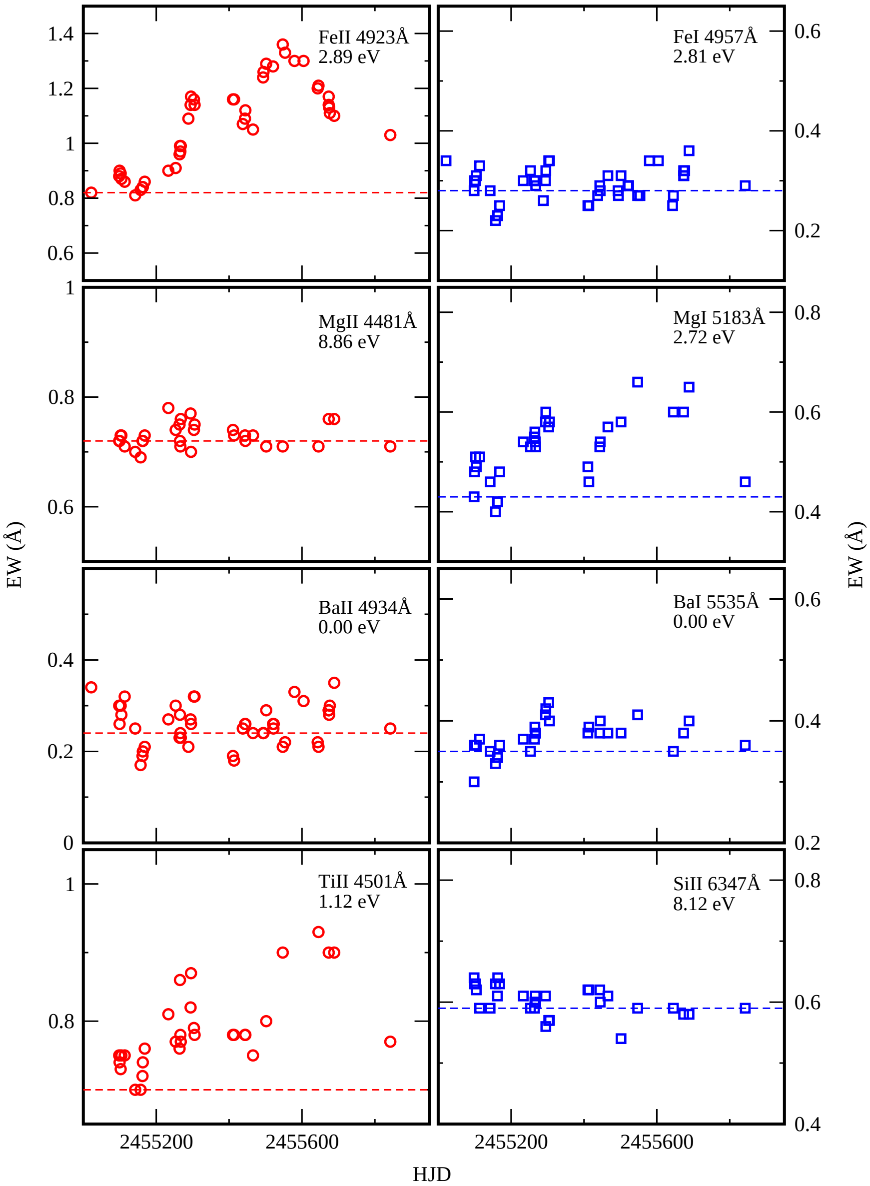

Fig. 5. Variation of the equivalent width of several lines with different excitation potentials in the spectrum of ε Aur. As in Fig.4 the horizontal dashed lines indicate the out of eclipse values.

absorptions remain above the values measured in the ε Aur out of eclipse spectrum during all the time of our observations. It is obvious from Fig. 4

that the spectroscopic eclipse as well as our monitoring started awhile before the first contact of the photometric eclipse. On the other hand, it can be seen that the fourth contact occurs well before the end of the spectroscopic eclipse which is still continuing during the time of this conference.

Such behavior of the equivalent widths of Na I absorptions is very similar to the changes in the equivalent widths of the K I 7664 Å and 7699 Å as well as Fe II 4523 Å and Ti II 4501 Å lines observed during the previous eclipse (see for instance Lambert & Sawyer 1986). A difference in the moments of the first maximum and the minimum in comparison to the observations of Lambert & Sawyer (1986) is evident. During the 1982-1984 eclipse the first maximum appears around or shortly after the second contact. While the minimum occurs around (K I) or before (Fe II and Ti II) the mid-eclipse (see Figures 5 and 9 in Lambert & Sawyer 1986). Despite the difficulties in the timing of the ε Aur eclipses, arising from the fact that the obscuring body is dark disk and the relatively scarce Lambert & Sawyer (1986) data, it seems that the differences between the moments of the first maximum and the minimum with respect to the time of the second contact and the mid-eclipse in two consecutive eclipses are very large to be random. Moreover, Lambert & Sawyer (1986) suggested that the variations in the equivalent widths of the spectral lines, caused by the disk absorption components, can be evidence for an off-center placement of the invisible object(s) in the disk as well as for differential heating of the disk.

In Fig. 5 the changes in the equivalent widths of several other spectral lines with different intensity and excitation potentials are shown. The variations in the equivalent widths of relatively strong, low extinction potential lines like Ti II 4501 Å, Fe II 4923 Å, Mg I 5183 Å and probably Ba I 5535 Å are evidently related to the development of the eclipse. They demonstrate the same behavior as Na I remaining all the time above the values measured in the out of eclipse ε Aur spectrum. Quite different are the changes in the equivalent widths of the relatively weaker, low excitation lines of Ba II 4934 Å and Fe I 4957Å. The significant variations around the out of eclipse values are connected with dramatic profile changes at certain moments (see Fig. 6) and their connection with the eclipse development is not so obvious. Similar is the behavior of the high excitation lines of Mg II 4481Å and Si II 6347 Å but their variations around the out of eclipse values are smaller and there are not dramatic variations in their profiles.

It should be noted that Sadakane et al. (2010) studied the changes in the equivalent widths of the ε Aur absorption lines in spectra obtained before the eclipse in 2008-2009. They found very large variations for absorptions arising from low excited levels and small variations for high excitation lines. They emphasize that their observations often show distorted or even double-bottomed shapes and suggested that these complex profile variations most probably reflect large-scale motions in the outer layers of ε Aur. Such intrinsic variability of the ε Aur spectral lines warns to be very careful when interpreting the changes observed during the eclipse. It seems that the best indicator of the changes in the optical spectrum caused by the eclipse remain the lines of K I which are not present out of it (Lambert & Sawyer 1986; Leadbeater & Stencel 2010).

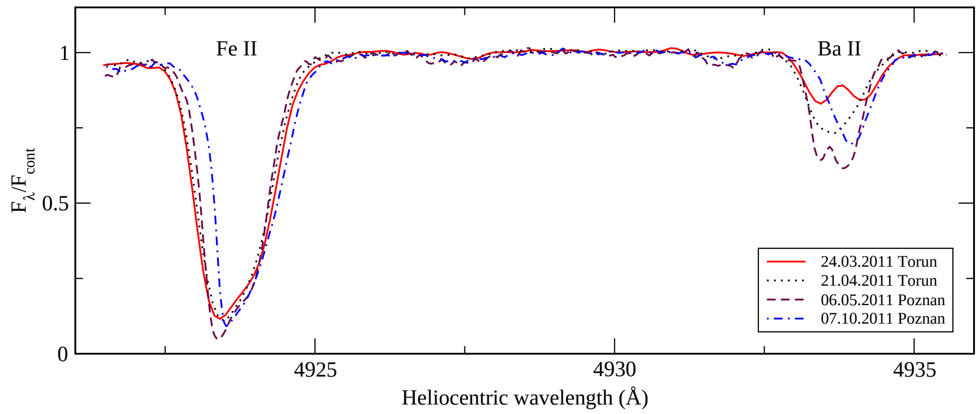

Fig. 6. Sample spectra, which demonstrate drastic changes in the Ba II 4934 Å line profile. For comparison the Fe II 4923 Å line is shown.

2.2 Mean radial velocities

Analyzing a large set of optical ε Aur spectra, obtained outside and during the eclipse, Chadima et al. (2011) reported about periodic, phase shifted variations in the radial velocities and the central intensities of Si II and Fe II lines. Preliminary radial velocity measurements of the same lines in our spectra show similar variations. However, our set of observations is relatively limited and collected only during the eclipse. On the other hand, remarkable profile changes make difficult the measurements of the radial velocities of individual lines. Careful measurements of the radial velocities of individual lines will be made later, taking into account a more accurate interpretation of their variations in combination with an attempt to disentangle the components of the profiles.

To obtain the mean velocities in our Torun and Poznan spectra we first measured the average radial velocity in the ELODIE spectrum of ε Aur. Using about 70 not blended, symmetric absorption lines we estimated a value of $8.32 \pm 0.28\,\mathrm{km\,s^{-1}}$. Then, each of our spectra was cross-correlated with the ELODIE spectrum in the spectral region 4500-6500 Å, excluding NaI $D_{1,2}$ and Hα lines.

The mean radial velocities measured in our spectra are compared in Fig. 7 with the radial velocity curve of the F supergiant and the system γ-velocity of the Stefanik et al. (2010) combined fit. The moments of the eclipse from Stencel et al. (2011) and the time of the mid-eclipse (JD 2 455 413.8±4.8 days) predicted by Stefanik et al. (2010) on the base of combined spectroscopic and photometric orbital solution are also shown in the figure. As it could be expected, the average radial velocity reflects the strong influence of the red-shifted disk absorption component of the lines during the first half of the eclipse and the dominance of the blue-shifted disk absorption during its second half. Our velocities show more or less equal amplitudes of about $\pm 10\,\mathrm{km\,s^{-1}}$ in

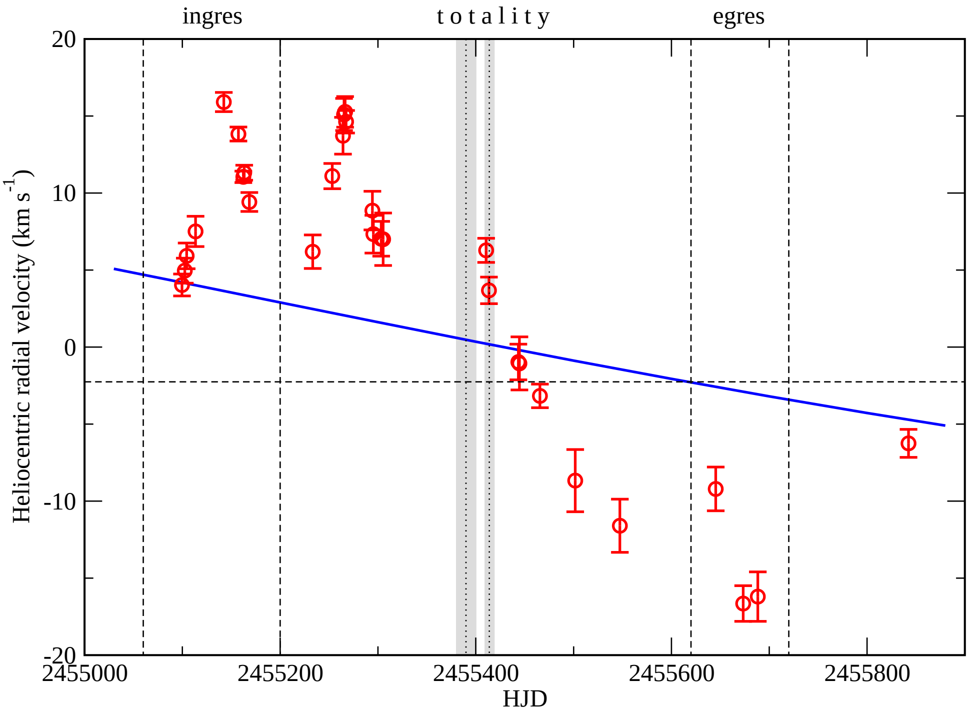

Fig. 7. The average radial velocities measured in our Torun and Poznan spectra of ε Aur. The eclipse moments are marked as in Fig.4. The inclined continuous line shows the F0 supergiant orbital velocity and the horizontal dashed line indicates the system γ-velocity (Stefanik et al. 2010).

contrast to the unequal (about $20\,\mathrm{km\,s^{-1}}$ and about $-40\,\mathrm{km\,s^{-1}}$) amplitudes at ingress and egress noted by Lambert & Sawyer (1986) for the two previous eclipses.

3 ε Aur & EE Cep

The light curves of the observed so far ε Aur eclipses are very similar to each other, but there are some obvious differences. It is known, for example (Schmidtke 1985), that eclipse duration, totality phase, ingress and egress, vary from eclipse to eclipse. One of the most likely explanations of this observational fact is that the disk changes in size or orientation (Carroll et al. 1991). A comparison of the light curves of the last two eclipses (see for instance Hopkins 1985, 2011) shows significant differences in the brightness variations during the totality phase. The noticeable increase in the brightness around the middle of the 1982-1984 eclipse, interpreted as evidence for the existence of a hole in the disk center (Wilson 1971; van Hamme & Wilson 1986, Carroll et al. 1991), is not observed during the last eclipse.

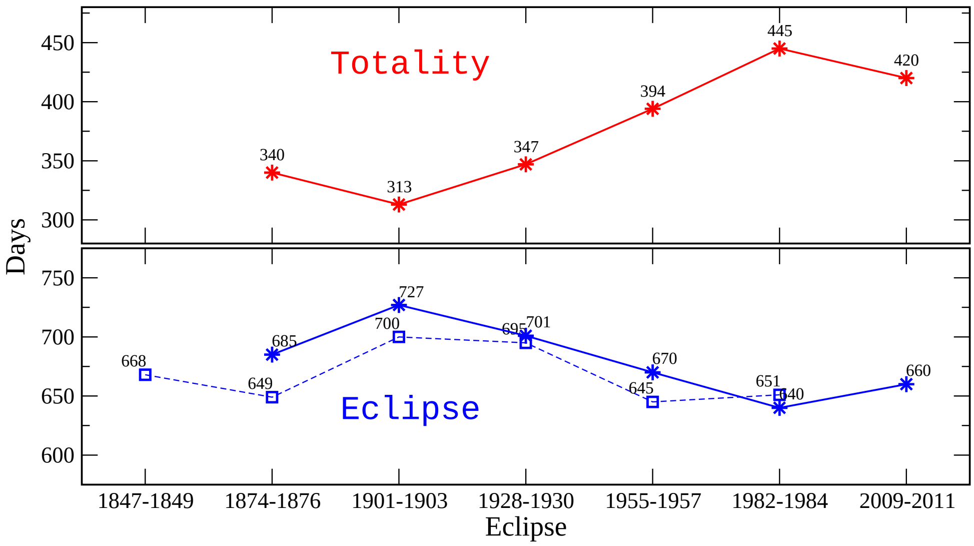

Fig. 8. Changes in the duration of the ε Aur entire eclipse and the totality phase. The data from Hopkins (2008) and Stencel at al. (2011) are shown with asterisks. The open squares represent the data from Stefanik et al. (2010).

In Fig.8 the variations in the duration of the entire eclipse and the totality phase for all recorded ε Aur eclipses are shown. The used data are from Hopkins (2008), Stencel at al. (2011) as well as the re-estimated duration of the previous eclipses from Stefanik et al. (2010). The data for the eclipse duration taken from different sources is in good agreement and demonstrates the same trend of changes. Obviously, the changes in the duration of the entire eclipse are opposite to those in the duration of the totality phase. The differences in the values of these changes between the 1982-1984 and 1901-1903 eclipses are of the order of 100 days. It is difficult to explain the large variations of the eclipse and totality phase duration times with changes in the disk size. Moreover, from Fig.8 we can speculate that these changes could be cyclic with a period of $\sim$ 160 years. Hence, it can be suggested that the changes are most likely caused by a periodic change in the orientation of the disk. A possible reason for the periodic changes in the orientation of the disk could be its precession. A precessing disk was proposed by Mikołajewski et al. (2005) to explain the different shape and depth of the eclipses of EE Cep, a star very similar to ε Aur (Mikołajewski & Graczyk 1999). The precession can change both the inclination of the disk to the line of sight and the tilt of its projection to the transit direction. This easily explains, for example, the absence of the remarkable brightness increase around the last mid-eclipse.

This or next eclipse?

Enormous amount of observational data have been accumulated worldwide during the last eclipse of ε Aur. The preliminary results published so far do not provide crucial observational evidence in favor of low-mass or high-mass system model and respectively the evolutionary status of the star. Let's hope that a detailed analysis of the recently obtained data will solve the longterm mystery of ε Aur and it will be not necessary to wait for the next eclipse.

Acknowledgements

Bulgarian co-authors acknowledge the partial support by Bulgarian NSF grants DO 02-85 and DO 02-362. This work is partially based on spectral data retrieved from the ELODIE archive at Observatoire de Haute-Provence (OHP).

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Table 1: Journal of the spectral observations of ε Aur.

Date	HJD 245...	UT (mid-exp)	Exp. (sec)	Spec. region	R $\lambda/\Delta\lambda$	Observat.
09-07-2009	5021.566	01:42:35	100	Hα	15 000	Rozhen
09-07-2009	5021.577	01:57:42	100	Hβ	15 000	Rozhen
09-07-2009	5021.572	01:51:30	60	NaI $D_{1,2}$	15 000	Rozhen
23-09-2009	5098.443	22:41:08	600	4290-7515 Å	35 000	Poznan
25-09-2009	5099.574	01:52:18	900	4290-7515 Å	35 000	Poznan
27-09-2009	5102.460	23:09:33	1200	4290-7515 Å	35 000	Poznan
29-09-2009	5104.416	22:07:15	2400	4290-7515 Å	35 000	Poznan
09-10-2009	5113.524	00:38:02	900	4290-7515 Å	35 000	Poznan
06-11-2009	5142.422	22:08:49	1800	4290-7515 Å	35 000	Poznan
20-11-2009	5155.645	03:29:31	900	4290-7515 Å	35 000	Poznan
21-11-2009	5157.284	18:49:42	1800	4290-7515 Å	35 000	Poznan
26-11-2009	5162.393	21:29:05	1200	4430-7110 Å	11 000	Torun
27-11-2009	5163.348	20:24:13	1200	4430-7110 Å	11 000	Torun
02-12-2009	5168.499	00:19:33	1800	4430-7110 Å	11 000	Torun
05-02-2010	5233.297	19:23:45	3600	4430-7110 Å	11 000	Torun
25-02-2010	5253.302	19:42:55	3600	4430-7110 Å	11 000	Torun
06-03-2010	5262.373	20:56:58	600	Hα	30 000	Rozhen
06-03-2010	5262.456	22:56:47	1050	KI 7699 Å	30 000	Rozhen
06-03-2010	5262.427	22:14:25	600	NaI $D_{1,2}$	30 000	Rozhen
08-03-2010	5264.228	17:39:19	1200	4430-7110 Å	11 000	Torun
10-03-2010	5266.396	21:38:00	2700	4290-7515 Å	35 000	Poznan
11-03-2010	5267.404	23:05:20	4800	4430-7110 Å	11 000	Torun
01-04-2010	5288.335	20:07:06	120	Hα	15 000	Rozhen
01-04-2010	5288.360	20:43:16	300	Hβ	15 000	Rozhen
01-04-2010	5288.350	20:28:24	180	NaI $D_{1,2}$	15 000	Rozhen
07-04-2010	5294.348	20:33:06	1800	4290-7515 Å	35 000	Poznan
08-04-2010	5295.328	20:16:26	2400	4430-7110 Å	11 000	Torun
16-04-2010	5303.323	20:31:50	4800	4430-7110 Å	11 000	Torun
18-04-2010	5305.290	19:33:29	3600	4430-7110 Å	11 000	Torun
27-04-2010	5314.262	18:23:05	300	Hα	30 000	Rozhen
27-04-2010	5314.249	18:05:02	300	NaI $D_{1,2}$	30 000	Rozhen
28-04-2010	5315.256	18:14:08	240	Hα	30 000	Rozhen
28-04-2010	5315.248	18:02:24	270	NaI $D_{1,2}$	30 000	Rozhen

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Date	HJD 245...	UT (mid-exp)	Exp. (sec)	Spec. region	R $\lambda/\Delta\lambda$	Observat.
29-04-2010	5316.306	19:26:07	540	Hα	30 000	Rozhen
29-04-2010	5316.291	19:05:15	735	NaI $D_{1,2}$	30 000	Rozhen
24-07-2010	5401.543	01:08:07	60	Hα	15 000	Rozhen
24-07-2010	5401.551	01:08:07	300	NaI $D_{1,2}$	15 000	Rozhen
02-08-2010	5410.551	01:49:17	3600	4430-7110 Å	11 000	Torun
05-08-2010	5413.535	01:24:48	3600	4430-7110 Å	11 000	Torun
23-08-2010	5431.530	00:46:06	540	Hα	30 000	Rozhen
23-08-2010	5431.519	00:30:36	360	NaI $D_{1,2}$	30 000	Rozhen
24-08-2010	5432.532	00:48:31	480	Hα	30 000	Rozhen
24-08-2010	5432.521	00:32:26	480	NaI $D_{1,2}$	30 000	Rozhen
29-08-2010	5437.537	00:50:01	180	Hα	15 000	Rozhen
29-08-2010	5437.544	01:07:20	240	Hβ	15 000	Rozhen
29-08-2010	5437.549	01:15:22	300	Hγ	15 000	Rozhen
29-08-2010	5437.570	01:44:21	180	NaI $D_{1,2}$	15 000	Rozhen
03-09-2010	5443.499	00:29:52	3600	4430-7110 Å	11 000	Torun
05-09-2010	5444.550	01:43:25	3600	4430-7110 Å	11 000	Torun
26-09-2010	5465.596	03:11:53	6600	4430-7110 Å	11 000	Torun
01-10-2010	5470.537	00:50:49	300	Hα	30 000	Rozhen
01-10-2010	5470.526	00:35:09	300	NaI $D_{1,2}$	30 000	Rozhen
23-10-2010	5493.390	21:18:27	150	Hα	15 000	Rozhen
23-10-2010	5493.405	21:39:09	150	Hβ	15 000	Rozhen
23-10-2010	5493.412	21:50:50	260	Hγ	15 000	Rozhen
23-10-2010	5493.425	22:07:48	150	NaI $D_{1,2}$	15 000	Rozhen
24-10-2010	5494.437	22:24:41	60	Hα	15 000	Rozhen
24-10-2010	5494.424	22:05:43	60	Hβ	15 000	Rozhen
24-10-2010	5494.421	22:01:52	60	Hγ	15 000	Rozhen
24-10-2010	5494.434	22:20:25	60	NaI $D_{1,2}$	15 000	Rozhen
01-11-2010	5501.673	04:34:49	3600	4430-7110 Å	11 000	Torun
20-11-2010	5520.555	01:14:59	300	Hα	15 000	Rozhen
20-11-2010	5520.613	02:37:45	300	Hβ	15 000	Rozhen
20-11-2010	5520.606	02:27:24	300	NaI $D_{1,2}$	15 000	Rozhen
21-11-2010	5521.568	01:33:34	300	Hα	15 000	Rozhen
21-11-2010	5522.407	21:41:18	300	Hα	15 000	Rozhen
21-11-2010	5521.585	01:57:50	300	Hβ	15 000	Rozhen
21-11-2010	5522.426	22:08:38	300	Hβ	15 000	Rozhen

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Date	HJD 245…	UT (mid-exp)	Exp. (sec)	Spec. region	R $\lambda/\Delta\lambda$	Observat.
21-11-2010	5522.435	22:22:09	300	Hγ	15 000	Rozhen
21-11-2010	5521.557	01:17:10	300	NaI $D_{1,2}$	15 000	Rozhen
21-11-2010	5522.415	21:52:24	300	NaI $D_{1,2}$	15 000	Rozhen
16-12-2010	5547.338	20:44:57	5400	4430-7110 Å	11 000	Torun
23-12-2010	5553.536	00:43:46	60	Hα	15 000	Rozhen
23-12-2010	5553.549	01:02:54	600	Hβ	15 000	Rozhen
23-12-2010	5553.559	01:16:54	900	Hγ	15 000	Rozhen
23-12-2010	5553.543	00:54:44	300	NaI $D_{1,2}$	15 000	Rozhen
17-01-2011	5579.370	20:46:58	100	Hα	15 000	Rozhen
17-01-2011	5579.387	21:12:06	180	Hβ	15 000	Rozhen
17-01-2011	5579.377	20:58:37	119	NaI $D_{1,2}$	15 000	Rozhen
18-01-2011	5580.327	19:45:48	180	Hα	15 000	Rozhen
25-01-2011	5587.453	22:47:34	753	Hα	30 000	Rozhen
25-01-2011	5587.438	22:25:25	752	NaI $D_{1,2}$	30 000	Rozhen
11-02-2011	5604.197	16:40:21	60	Hα	15 000	Rozhen
11-02-2011	5604.206	16:53:51	60	Hβ	15 000	Rozhen
11-02-2011	5604.211	17:00:58	120	Hγ	15 000	Rozhen
11-02-2011	5604.201	16:45:34	60	NaI $D_{1,2}$	15 000	Rozhen
16-03-2011	5637.257	18:10:30	240	Hα	30 000	Rozhen
16-03-2011	5637.240	17:45:48	240	NaI $D_{1,2}$	30 000	Rozhen
22-03-2011	5643.234	17:39:45	180	Hα	15 000	Rozhen
22-03-2011	5643.260	18:18:03	240	Hβ	15 000	Rozhen
22-03-2011	5643.245	17:56:52	240	NaI $D_{1,2}$	15 000	Rozhen
24-03-2011	5645.349	20:55:08	3600	4430-7110 Å	11 000	Torun
21-04-2011	5673.235	17:43:36	50	Hα	15 000	Rozhen
21-04-2011	5673.248	18:02:59	50	Hβ	15 000	Rozhen
21-04-2011	5673.256	18:14:51	60	Hγ	15 000	Rozhen
21-04-2011	5673.268	18:32:21	60	NaI $D_{1,2}$	15 000	Rozhen
21-04-2011	5673.356	21:43:25	7200	4430-7110 Å	11 000	Torun
22-04-2011	5674.234	17:43:03	30	Hα	15 000	Rozhen
22-04-2011	5674.245	17:58:29	60	Hβ	15 000	Rozhen
22-04-2011	5674.249	18:04:38	140	Hγ	15 000	Rozhen
22-04-2011	5674.270	18:34:35	60	NaI $D_{1,2}$	15 000	Rozhen
24-04-2011	5676.244	17:57:50	60	Hα	15 000	Rozhen
24-04-2011	5676.259	18:18:53	120	Hβ	15 000	Rozhen

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Date	HJD 245...	UT (mid-exp)	Exp. (sec)	Spec. region	R $\lambda/\Delta\lambda$	Observat.
24-04-2011	5676.263	18:24:48	200	Hγ	15 000	Rozhen
24-04-2011	5676.279	18:47:59	120	NaI $D_{1,2}$	15 000	Rozhen
06-05-2011	5688.322	20:00:27	1200	4290-7515 Å	35 000	Poznan
15-05-2011	5697.267	18:32:04	300	Hα	30 000	Rozhen
15-05-2011	5697.251	18:08:25	180	NaI $D_{1,2}$	30 000	Rozhen
11-07-2011	5753.566	01:42:22	300	Hα	30 000	Rozhen
11-07-2011	5753.559	01:31:08	240	NaI $D_{1,2}$	30 000	Rozhen
14-08-2011	5787.577	01:54:00	186	Hα	30 000	Rozhen
14-08-2011	5787.585	02:05:27	152	NaI $D_{1,2}$	30 000	Rozhen
10-09-2011	5814.563	01:30:26	248	Hα	30 000	Rozhen
10-09-2011	5814.572	01:43:35	219	NaI $D_{1,2}$	30 000	Rozhen
07-10-2011	5842.377	21:07:11	4550	4290-7515 Å	35 000	Poznan