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REMARKABLE ABSORPTION STRENGTH VARIABILITY OF THE ε AURIGAE Hα LINE OUTSIDE ECLIPSE

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In April and May 2005 the Hα line of ε Aur was observed in an exceptional 'weak absorption phase'. In the period October 2005 to November 2006 the normal line profile was registered again, with a variable absorption and a weak red-shifted emission component. The time variations of the line profile and a comparison with former observations outside eclipse are presented.

ε Aur is a binary system, consisting of a yellow supergiant (F0Ia) and an enormous dusty gas disk, that eclipses every 27 years the primary component for approximately two years. From the eclipsing light curve it is concluded that within the dust disk one or two (B?) stars exist, which have so far never been observed directly (Stencel, 1985). The first contact of the next eclipse is expected in August 2009. Castelli (1978) lists the characteristic parameters of the primary component (F0Ia). The Hα line of ε Aur is reported in the literature to be variable, but the line always shows a strong photospheric absorption and mostly weak emission components on the edges of the absorption.

The observations cover the period from 1 April, 2005 to 15 November 15, 2006 (out of eclipse, phase ≈ 0.9). The used amateur equipment consists of a Maksutov Newton telescope (127 mm of aperture, f 1/8) and a slitless reflecting grating spectrograph (grating 25 mm $\times$ 25 mm, 1200 lines/mm, collimator $f = 135$ mm, camera objective $f = 135$ mm). The CCD camera (Audine, KAF 401E) is water-cooled. The chip temperature was, depending on the ambient temperature, between -10 and -30 °C. The dispersion is 41 Å/mm or 0.38 Å/pixel within the range of the Hα line. The resolution was measured from the FWHM of terrestrial lines to 0.8 Å ($R = 8,000$). The quality of the adjustment and the mechanical stability of the system limit the exposure times for a single exposure between 30 and 60 sec. For each sum spectrum, between 10 and 80 single photographs were taken. The data were reduced using ESO MIDAS and the OPA scripts of G. Gebhardt (www.spektros.de). The single photographs are corrected by the median of 10 darks and the background of the sky before extraction of the spectra and their registering. No flatfield correction is performed. The final S/N of the continuum is between 120 and 400 (Table 1). The slitless spectra were wavelength calibrated by using 3 to 6 photospheric absorption lines from the following list: Fe II: 6416.90 Å, 6430.84 Å, 6456.38 Å, 6516.05 Å, Si II: 6347.10 Å, 6371.36 Å as reference lines. The quality of EW measurements is demonstrated by comparison of the EW-integration results of this lines with the data given by Castelli (1978) and the integrations of a reference spectrum of ε Aur (20031101) given in ELODIE (Table 2).

Table 1: List of spectra and equivalent widths of components of ε Aur Hα line

Hα line measurements of ε Aur				Equivalent width [Å]		
Date	JD	Exposure time [min]	S/N	Blue wing	Central absorption	Red wing
April 1, 2005	2,453,462.42	5	140	−0.13	0.01	−0.15
April 11, 2005	2,453,472.40	10	170	−0.18	0.06	−0.17
April 21, 2005	2,453,482.40	10	150	−0.07	0.06	−0.15
May 10, 2005	2,453,501.40	10	120	−0.14	0.06	−0.24
May 11, 2005	2,453,502.40	10	270	−0.06	0.08	−0.15
October 30, 2005	2,453,674.48	30	300	0.00	0.66	0.00
December 10, 2005	2,453,715.50	18	280	0.00	1.07	−0.05
January 23, 2006	2,453,759.31	27	300	0.00	0.99	0.00
January 24, 2006	2,453,760.32	25	400	0.00	1.04	0.00
January 30, 2006	2,453,766.36	30	350	0.00	1.02	0.00
February 1, 2006	2,453,768.32	30	320	0.00	1.02	−0.04
March 12, 2006	2,453,807.33	42	270	0.00	0.78	−0.07
March 13, 2006	2,453,808.42	25	390	0.00	0.82	−0.04
April 7, 2006	2,453,833.42	15	160	−0.06	0.69	−0.04
April 19, 2006	2,453,844.34	15	160	0.00	0.60	−0.10
May 2, 2006	2,453,858.40	50	370	0.00	0.55	−0.12
September 10, 2006	2,453,988.48	30	200	0.00	0.70	0.00
September 21, 2006	2,454,000.53	27	190	0.00	0.66	0.00
October 7, 2006	2,454,016.42	60	360	0.00	0.54	−0.01
November 15, 2006	2,454,055.46	52	210	−0.02	0.49	−0.06

In Fig. 1 the observed spectra and the reference spectrum are plotted. Between 1 April (JD 2453462) and 11 May, 2005 (JD 2453502), the Hα line shows a nearly symmetrical shell spectrum with small variations of the V/R ratio of the emission components and an exceptionally small absorption component in the line core. On 30 October, 2005 (JD 2453674) the Hα line was detected in pure absorption. Until the end of the 2006 observing season, the line was observed in normal absorption, with an occasional variable red shifted emission component. Two types of line profiles can be distinguished: The 'weak absorption phase' from the beginning of the observations (1 April to 11 May, 2005), and the 'normal absorption phase' later. The emission components of the 'weak absorption phase' are symmetrically shifted towards the blue and red, respectively, by about 80 km/s relative to the absorption minimum. In the 'normal absorption phase' the red wing maximum is red-shifted by about 100 to 160 km/s. The equivalent widths of the blue wing, the red wing and the absorption core in the spectra were calculated (F/Fc $>$ 1 emission, F/Fc $<$ 1 absorption, Table 1). Fig. 2 shows these EW's as time series. The variability of the absorption component is the most dominant effect.

Because of the unusual eclipsing behaviour, which is caused by a dusty cloud every 27.08 years, the star has been observed intensively. The investigations focus on those approximately 2 years of the eclipsing events. Castelli (1977, 1978) also published two measurements out of eclipse (1971). The variable Hα lines consisted of a central absorption (F/Fc 0.45 and 0.55) and two weak emission components which are shifted relative to the core of the absorption by -72 km/s and $+61$ km/s, respectively. Radial outward flows are attributed to instabilities in the star producing the blue-shifted emission component. Gas from behind the star causes the red-shifted emission component. The last eclipse of 1982 to 1984 is summarized by Stencel (1985). The Hα line profiles of 1984 (Ferluga & Heck in Stencel, 1985) resemble the normal absorption phase, whereby partly also more intensive

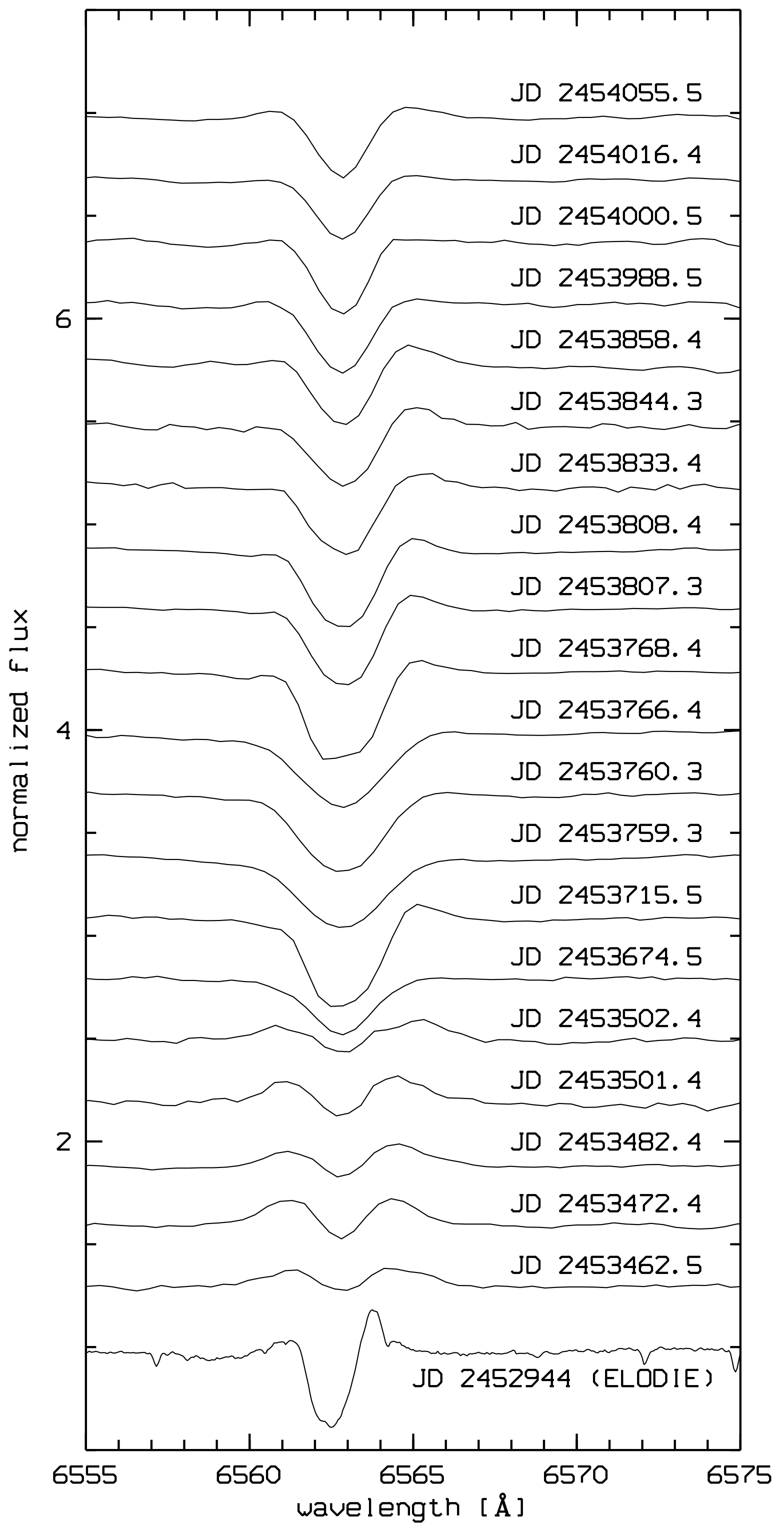

Figure 1. Hα line profiles of ε Aur (measurements April 2005–November 2006 and a reference spectrum ELODIE of November 2003

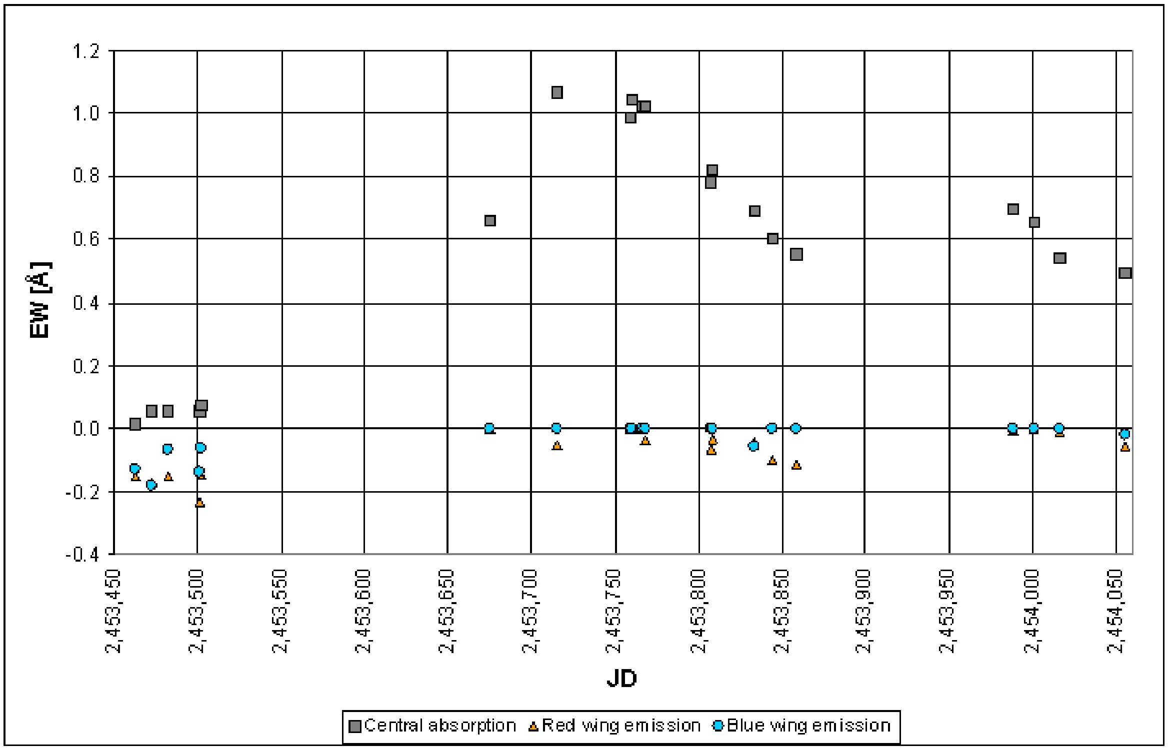

Figure 2. Equivalent widths of ε Aur Hα line components outside eclipse April 2005–November 2006

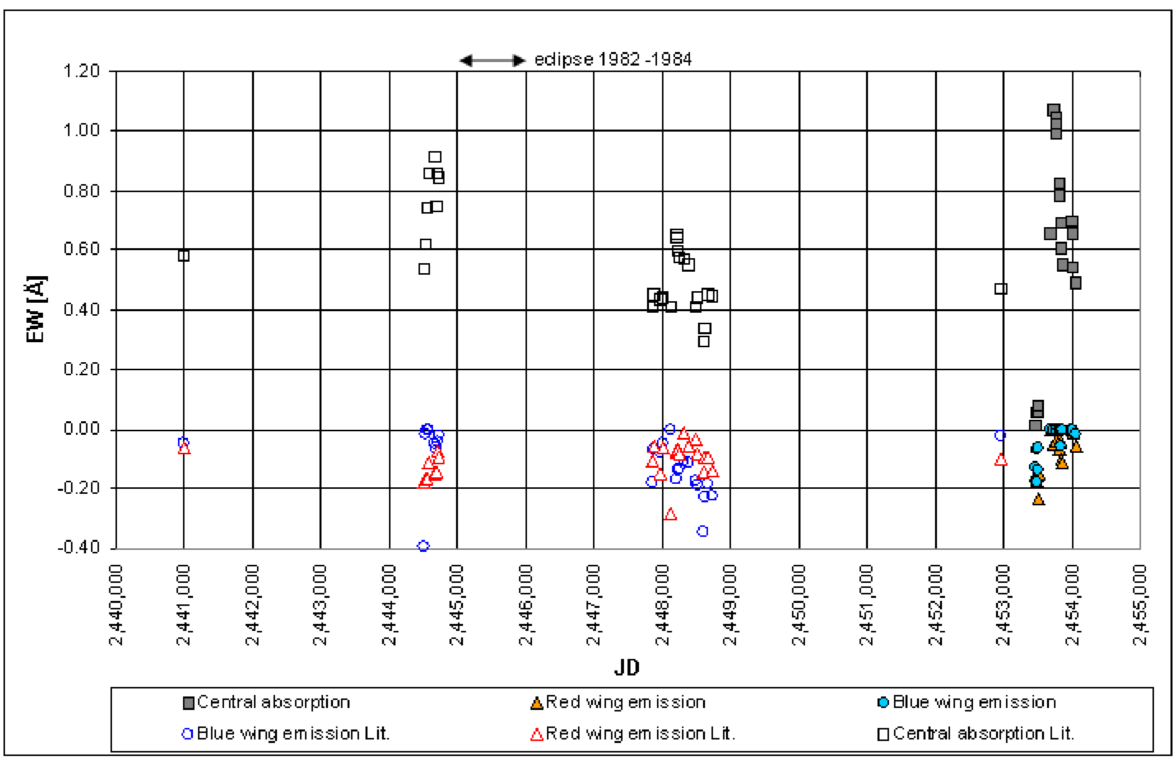

Figure 3. Equivalent widths of ε Aur Hα line components outside eclipse, including data of Castelli (1978), Ferro (1985), Cha et al. (1995) and ELODIE (20031101)

Table 2: Comparison of EW differences of measured spectra and reference spectra of ε Aur

		Reference spectra [Å]		Measurements [Å]			Differences [Å]	
Line	Ion	Castelli	ELODIE	Average	Std. dev.	No. of meas.	Castelli	ELODIE
6347	SiII	0.694	0.627	0.596	0.027	5	−0.098	−0.031
6371	SiII	0.531	0.538	0.529	0.024	7	−0.002	−0.009
6416	FeII	0.245	0.191	0.190	0.030	14	−0.055	−0.001
6432	FeII	0.178	0.158	0.170	0.027	17	−0.008	0.012
6456	FeII	0.539	0.533	0.513	0.034	17	−0.026	−0.020
6613	?	–	0.120	0.120	0.012	13	–	0.000

blue wings were registered. However, one year earlier the spectra showed the absorption with stable red wings and variable blue wings (Boehm & Ferluga, 1983). 15 spectra, measured between September 1980 and May 1981 by Ferro (1985), just one year before the eclipse of 1982 to 1984, showed a 'normal absorption phase' similar to Fig. 1 with stable red wing and variable blue wing. Hα line profiles measured by Cha et al. (1994) in November 1989 until April 1992 also resemble the profiles of the normal absorption phase in Fig. 1. The radial velocities of the absorption centers vary between +0.4 and −39.1 km/s, the emission components vary parallel to it around −60 and +60 km/s, respectively. The equivalent widths of the absorption move between 296 and 650 mÅ, the emission components between 0 and 343 mÅ (blue wing) and 0 and 295 mÅ (red wing). Additional measurements of Cha et al. (1995) in the year 1993 show absorption with a clear blue emission wing (EW approx. 200 to 300 mÅ), but only a weak red wing. The absorption line has an EW of approx. 550 mÅ in this period. The authors discuss their observations using a model, which explains the emissions with a rotating inhomogenous gas ring around the primary F0Ia component. UV-spectroscopy with the HST taken on 16 February, 1996 are described by Sheffer & Lambert (1999). The split resonance lines are attributed to a gas disk rotating in the orbit around the invisible secondary component. The rotation speed of the disk was determined from the distance of the emission maxima to 103 km/s. The origin of the emissions from a gas disk around the secondary component is not confirmed, however.

Published spectra could be digitized (Castelli: spectrum February 1971; Ferro: spectra 1980-1981)). The calculated component equivalent widths of the published spectra, of the ELODIE reference spectrum (2003) and the results of Cha et al. (1994, Table 2) are shown in Fig. 3 together with the equivalent widths of Table 1. The time series demonstrate the exceptionally small central absorption in spring 2005. The star shows a remarkable variability in absorption strength of the core of the Hα line outside eclipse, also in former observations.

It remains to conclude:

- Hα line in predominant emission and vanishing core absorption - like in spring 2005 is an exceptional phenomenon of ε Aur.
- The absorption components EW of the Hα line show a remarkable variability outside eclipse.

The line profile variations in the optical spectrum outside of the eclipsing phase, e.g. the presented observation of an exceptionally weak absorption phase in Hα, are still not satisfactorily explained. The interpretation of the Hα line in eclipse has to take the out-of-eclipse variations into account. Further observations, also far from eclipse, are needed.

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