*Magnetic stars, 2004, 272-278*

# Step-like variations in the optical spectrum of the magnetic cataclysmic variable EU UMA (RE1149+28)

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**Abstract.** We present the results of optical time-resolved spectroscopy of the magnetic cataclysmic variable EU UMA (RE1149+28) obtained with the help of the scanner of the 6 m telescope on April 3 and 4, 1994. Analysis of the behaviour of the parameters of Balmer and HeII emission lines in the spectra of EU UMA has revealed

– dips in the behavior of equivalent widths of the lines repeatable with the orbital period. Considering the dips as a result of eclipse of the most part of the accretion stream by the secondary we have improved the value of the orbital period of $90.1441 \pm 0.0007$ min and estimated the inclination of the system as $\approx 70°$;

– the radial velocity variations over the orbital period and the oscillations of the velocities of the center of gravity and the peak of the lines with periods of 45 min and 37 min, respectively. We associate the 45 min oscillations with the radiation from the accretion curtain or the beginning of the magnetic part of the accretion stream and the 37 min variations with the radiation from the regions with strong resonance magnetic fields, which was observed as monochromatic pulsations in the spectra of intermediate polars (Somov et al. 1997, 1998a, 1998b, 2000, 2001). The presence of the 45 min oscillations is an argument in favor of synchronous rotation of the accretion curtain or diskless accretion in the system. The 37 min variations point to asynchronous rotation of the white dwarf over a spin period of $\approx 74$ min.

Spectral light curves (integrated flux in the range of wavelengths 4000–5000 Å) have shown significant changes of the mean fluxes ($\approx 4$ times) and of the composition of quasi-periodic oscillations in the range of periods 20–120 min on a time-scale of 1 day. In the high state of brightness on April 3, 1994 the spectral light curve showed a hump which corresponds to the hot spot in the treading region, where the ballistic stream is redirected to follow the magnetic field lines of the white dwarf.

In the low accretion state on April 4, 1994 the spectral light curve showed a step-like jump when the mean brightness of the object increased $\approx 2$ times. Such a behaviour of the system can be the result of the change of the magnetic part of the accretion trajectory due to asynchronism. We found a relationship between the jump of brightness and the jump of the phase and amplitude of the 37 min oscillations in the emission lines. On the basis of all the detected properties we conclude that the system manifests the properties of both a polar and an intermediate polar and is asynchronous magnetic rotator with a polar-like magnetic field and with the magnetic and rotation poles close to each other.

**Key words:** accretion – stars: binaries: close – stars: individual: EU UMA (RE1149+28) – stars: cataclysmic variables – stars: rotation – oscillations

# 1 Introduction

Magnetic cataclysmic variables (MCVs) are close binary stars in which a strongly magnetized white dwarf primary accretes matter from a Roche lobe–filling late–type secondary. The MCVs form two subclasses: polars known as AM Her stars are synchronous systems in which $P_{spin} = P_{orbit}$, where $P_{spin}$ is the spin period of the white dwarf and $P_{orbit}$ is the orbital period (Liebert and Stockman 1985; Cropper 1990; Warner 1995), and intermediate polars (IPs) known as DQ Her stars (Patterson 1994). The subclass of IPs includes the objects containing magnetic, rapidly and asynchronously rotating ($P_{spin} \ll P_{orbit}$) white dwarfs. The principal criterion of asynchronism of the IPs is the presence of a rapid periodicity in the light curve, usually at optical or X–ray wavelengths. In addition to this periodicity some intermediate polars manifest emission–line profile variations over the spin period which affect the whole profile (Patterson 1994). In addition the Monochromatic Quasi–Periodic Oscillations (MQPOs) with the spin period in the narrow wavelength passbands (1 Å) were detected in the profiles of emission lines in the optical spectra of the IPs with polar–like magnetic fields (Somov et al. 1997, 1998a,b, 2000, 2001). Spectral variations of the emission–line profiles over the spin period are the secondary criterion of asynchronism of the MCVs.

RE 1149+28 (EU UMa) was discovered as a probable new AM Her star in observations made with the ROSAT Wide-Field Camera (Mittaz et al. 1992). The light curve measured from the all-sky EUV survey data was highly variable and exhibited a 1-d periodicity with a probable binary period of either 90 or 103 min. Optical spectroscopy showed clear evidence of systematic variations of radial velocities of the emission lines at a period consistent with the 90 or 103-min photometric variations. RE1149 + 28 exhibited an unusually large EUV-to-optical flux ratio compared to previously known AM Her stars detected in the ROSAT survey (Mittaz et al. 1992).

Extreme Ultraviolet Explorer photometric observations showed light-curve variations on orbital to yearly timescales, as well as long-term mean flux level changes of a factor of 2. These observations of RE 1149 were consistent with a relatively low system inclination and provide a best-fit orbital period of $90.14 \pm 0.015$ minutes (Howell et al. 1995).

The optical spectroscopy of EU UMa (RE1149+28) carried out on February 13, 1993 at the 6 m Special Astrophysical Observatory telescope revealed an orbital period of the system of $90.0 \pm 0.2$ minutes from line radial-velocity measurements, however, the velocities measured from the peak of the HeII 4686Å line yielded a mean period of $73.5 \pm 1.9$ min. The $H\beta$ and He II 4686 Å lines exhibited P Cyg profiles at selected phases. The spectral-line parameters were found to vary significantly on time scales from 5 to 15 minutes (Somova et al. 2003).

We here continue to present the results of optical time-resolved spectroscopy of the magnetic cataclysmic variable EU UMA (RE1149+28).

# 2 Observations

Spectral observations were carried out at the Special Astrophysical Observatory on April 3 and 4, 1994, using the spectrograph SP–124 (Afanasiev et al. 1991) placed at the Nasmyth secondary focus of the 6 m Big Telescope Azimuthal (BTA). The spectrograph equipped with a 1200 lines/mm grating gave a reciprocal dispersion of 50 Å/mm. A multichannel photon-counting system or a television scanner with two lines of 1024 channels recorded two spectra simultaneously (Somova et al. 1982; Drabek et al. 1986). A 2–arcsecond slit was used. The spectra were obtained in a wavelength passband of $\approx$ 1000 Å within the range 3900–5100 ÅÅ with a dispersion of 1 Å/channel (spectral resolution $\approx$ 2 Å) and a time resolution of 32 ms. The spectra were recorded continuously, and a He–Ne–Ar lamp was observed before and after the exposures for the wavelength calibration. The behaviour of the parameters of emission lines (equivalent width, relative intensity, radial velocities of the peak and the center of gravity) was investigated from the spectra with a time resolution of

270 s. Spectral light curves or integrated flux within the wavelength range 4000–5000 ÅÅ were measured from the spectra with a time resolution of 27 s.

# 3 Results

In Figure 1 we show the mean relative intensity spectra which were obtained on April 3 and 4, 1994. The spectra contain, as it is typical for MCVs, the emission lines of hydrogen, HeII 4686 Å, HeI. The emission lines have narrow and broad components superimposed on each other. The mean spectra on April 3 and 4, 1994 are only slightly different from each other.

Spectral light curves on April 3 and 4, 1994 are presented in Figure 2. The spectral light curves have shown significant changes of the mean fluxes ($\approx 4$ times) and of the composition of quasi-periodic oscillations in the range of periods 20–120 min on a time-scale of 1 day. In the low accretion state on April 4, 1994 the spectral light curve showed a step-like jump at phase 0.86, when the mean brightness of the object increased $\approx 2$ times. The 37 min ocillations dominated in the periodogram of the spectral light curve.

In the high state of brightness on April 3, 1994 the spectral light curve showed a hump corresponding to the hot spot in the threading region of the accretion stream in the standard model of polars (Liebert & Stockman 1985).

Analysis of the behaviour of the parameters of Balmer and HeII emission lines in the spectra of EU UMA has revealed dips in the behavior of equivalent widths of the lines repeatable with the orbital period. The variations of equivalent widths of the $H\beta$, $H\gamma$ and HeII 4686 Å emission lines over the orbital period, which were recorded on April 3 and 4, 1994, are shown in Figure 3.

Considering the dips as a result of eclipse of the most part of the accretion stream by the secondary and using the results of spectral observations of EU Uma in 1993 (Somova et al. 2003), we have improved the value of the orbital period of $90.1441 \pm 0.0007$ min and have estimated the inclination of the system as $\approx 70$ degrees;

Analysis of radial velocity variations has detected, in addition to the changes over the orbital period, the oscillations of the velocities of the center of gravity and the peak of the lines with the period of 45 min and 37 min, respectively. The behaviour of radial velocities of the peak and the center gravity of the $H\beta$ emission line over the orbital period on April 3, 1994 with the 45 min variations of the center of gravity (left top panel) and the 37 min oscillations of the peak (right top panel) of the line are plotted in Figure 4.

The 45 min oscillations affect the whole profile of the lines and are caused by the radiation from the accretion curtain or the beginning of the magnetic part of accretion stream. At the same time the 37 min variations should be attributed to the narrow part of the lines and can be explained by the radiation from the strong resonance magnetic fields which was observed as monochromatic pulsations in the spectra of intermediate polars (Somov et al. 1997, 1998a, 1998b, 2000, 2001). The presence of the 45 min oscillations is an argument in favor of synchronous rotation of the accretion curtain with the orbital motion or diskless accretion in the system. However the 37 min variations point to asynchronous rotation of the white dwarf over the spin period of $\approx 74$ min. The 74 min period was observed in the radial velocity of the peak of HeII 4686Å in 1993 (Somova et al. 2003). The variations of O–C of radial velocities of the peak and the center of gravity of the $H\beta$ emission line over the orbital period on April 4, 1994 are presented in Figure 5. The relationship between the jump of brightness at orbital phase 0.86 and the jump of the amplitude and phase of the 37 min oscillations is seen in the right panel. As for the 45 min oscillations of the center of gravity (left panel), after the step-like jump the oscillations disappeared, and the 28 min noise oscillations are presented in Figure 5 (left panel). We consider the step-like jump of brightness and the jumps of the phase, amplitude and mean value of the 37 min variations as a result of the change of the magnetic part of the accretion trajectory caused by the asynchronism of the system. The magnetic part of the accretion stream showed up in our observations as follows. The beginning of the accretion curtain produced the 45 min variations and rotates synchronously with the orbital period. The regions in the strong magnetic fields are responsible for the 37 min oscillations. The intermediate magnetic part of the accretion stream manifested itself as periodical pulsation and was recorded in the periodogram of the spectral light curve on April 4, 1994, as the dominating feature at the 37 min period. The absence of the 74 min or 37 min pulsations in X-ray light curves indicates that the magnetic and rotation poles are located close to each other.

# 4 Conclusion

Basing on the detection of the 37 min oscillations of the peak of emission lines and the presence of the 37 min pulsations in the spectral light curve in the low accretion state, we conclude that the system is an asynchronous magnetic rotator with a polar-like magnetic field and its magnetic and rotation poles are situated close to each other.

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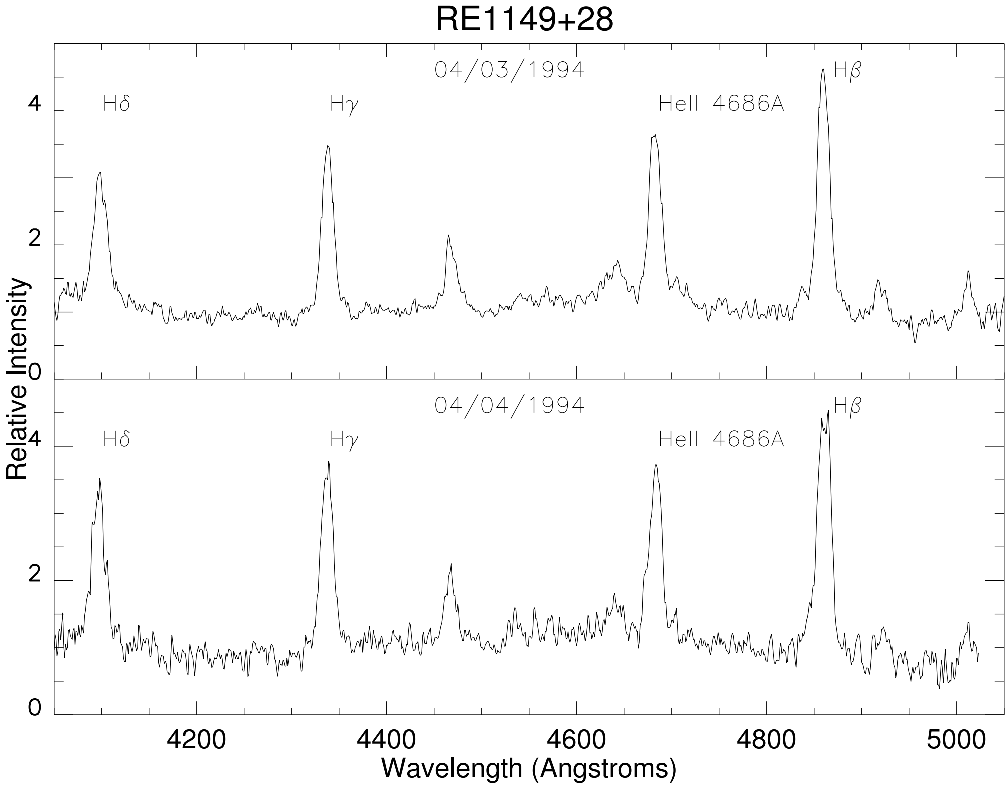


Figure 1: *The mean relative intensity spectra which were obtained on April 3 and 4, 1994.*

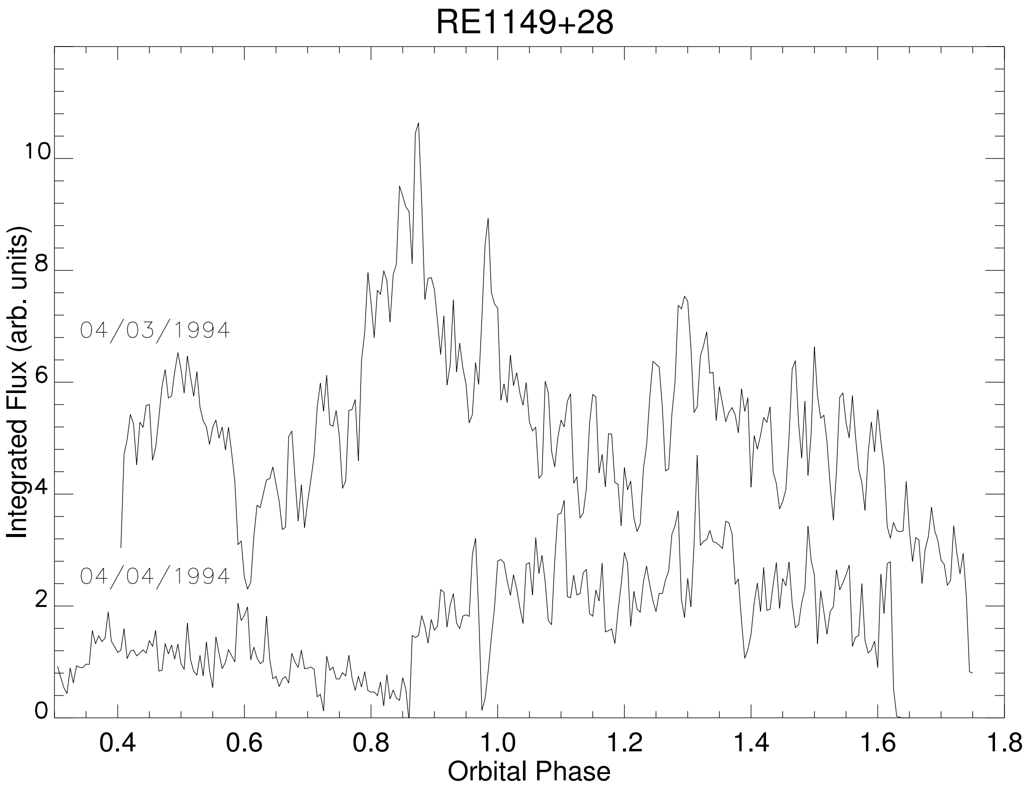


Figure 2: *The spectral light curves which were obtained on April 3 and 4, 1994.*

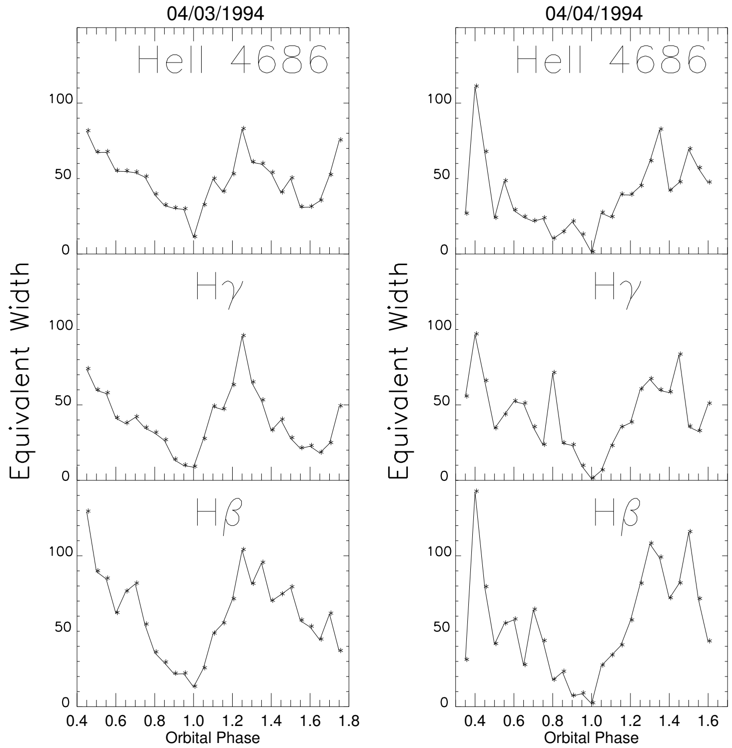


Figure 3: *The variations of equivalent widths of the Hβ, Hγ and HeII 4686Å emission lines over the orbital period which were recorded on April 3 and 4 1994.*

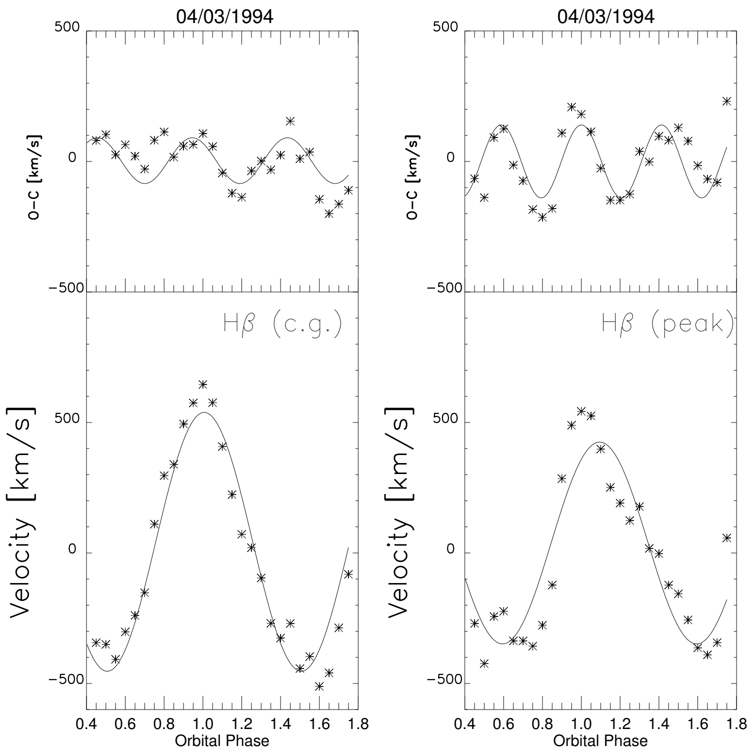


Figure 4: *The variations of radial velocities of the peak and the center of gravity of the Hβ emission line over the orbital period which were recorded on April 3, 1994.*

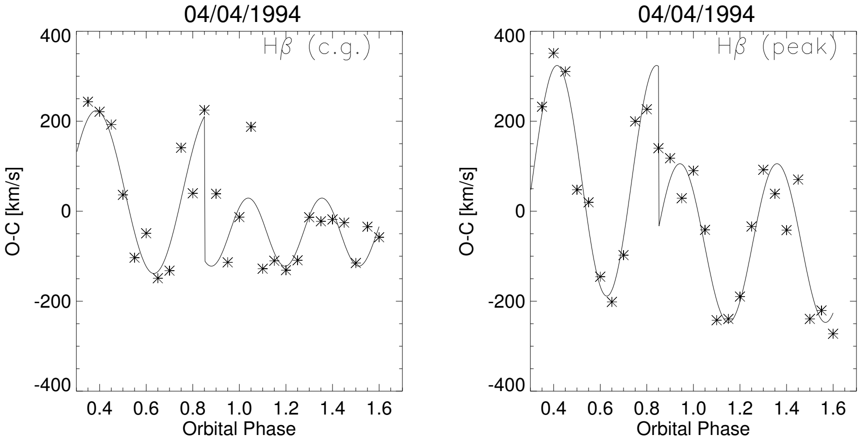


Figure 5: *The variations of O–C of radial velocities of the peak and the center of gravity of the Hβ emission line over the orbital period which were recorded on April 4, 1994.*