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AM Herculis star EV UMa (RE 1307+535) in a high accretion state

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Abstract. We present results of the first simultaneous UBVRI-photopolarimetry of the AM Herculis system EV UMa (RE 1307+535), carried out in February 1999. EV UMa is known to have a large variation in circular polarization (–20% to +50%) in the R-band. It has an orbital period close to the theoretical lower limit for magnetic CVs. During our observations EV UMa was in a very high accretion state, (15.7 $\leq$ V $\leq$ 17.2), which was about two magnitudes brighter than during our earlier (1994) high state observations (17.8 $\leq$ V $\leq$ 18.8). Dramatic changes have occured in the circular polarization curves compared to earlier observations, in particular the positive circular polarization is now reduced almost by factor of ten. Circular polarization varied during our observations from –23% to +5% in the U-band, from –15% to +6% in the B-, V-, and I-bands, and from –12% to 7% in the R-band. An eclipse-like feature is seen in the optical light curves between the orbital phases $\Phi = 0.1$ and $\Phi = 0.3$. The presence of an eclipse and the reduction in the positive circular polarization during the same phase interval could be due to effects caused by the accretion stream. Our observations show that the accretion rate has increased and the accretion geometry has changed in EV UMa since our previous observations. We have calculated an improved ephemeris for EV UMa, based on the negative circular polarization maxima observed in 1994 and 1999. The new value for the white dwarf spin period is 0.05533887(2) days.

Key words: stars: magnetic fields – stars: novae, cataclysmic variables – accretion, accretion disks – stars: binaries: close – polarization

1. Introduction

Magnetic Cataclysmic Variables, mCVs, are binary systems, where a white dwarf (primary component) accretes matter from a K- or M-spectral type red dwarf (secondary component). AM Herculis stars are characterized by a strong circular polarization (up to $\sim 50\%$) and a magnetic field strength from 7 to 230 MG. Due to the strong magnetic field and the relatively small separation between the primary and the secondary, the rotation of the white dwarf is locked to the orbital period. The strong magnetic field prevents the formation of an accretion disk and material flowing from the red star is channeled towards the white dwarf along the magnetic field lines.

EV UMa (RE 1307+535) was detected by the ROSAT Wide Field Camera EUV survey and it was identified as an AM Herculis star by Osborne et al. (1994). The orbital period, 79.7 min, was the shortest among of all AM Herculis stars at that time. It is very near the theoretical lower limit for orbital period of Cataclysmic Variables, $P_{\rm min} \sim 80$ min, where the secondary star is close to the degeneration (Paczynski 1981; Paczynski & Sienkewicz 1981; Rappaport et al. 1982). During the low mass transfer the brightness of EV UMa may fall to V = 20.5 – 20.8, and R = 19.5 – 20.6 magnitudes (Osborne et al. 1994; Hakala et al. 1994). EV UMa has shown the largest broadband circular polarization variations (– 20% to + 50%) seen in any astrophysical object so far (Hakala et al. 1994). Osborne et al. (1994) calculated a lower limit for the distance of the EV UMa of $d \geq$ 705 pc giving an estimate $z \geq$ 630 pc, above the Galactic plane.

2. Observations

The photopolarimetric observations presented here were carried out between February 22 and 26, 1999, with the Turpol-photopolarimeter (Korhonen et al. 1984; Piirola 1988) at the 2.56 m Nordic Optical Telescope (NOT). It is possible to obtain with Turpol both circular and linear polarimetry, as well as photometry, simultaneously by using the multichannel polarimeter in the double image chopping mode. The polarimeter has four dichroic filters, splitting the light into the U-, B-, V-, R-, and I-bands. The superachromatic quarter-wave retarder is rotated in steps of 22.5°. For each step both polarized beams are integrated with a 25 Hz chopping frequency for a 10 s integration time. Including dead time corrections, the total time resolution for photometry is ~23 s. One complete polarization measurement, consisting of eight integrations, takes 3.05 minutes. Efficiency is ~70% for circular polarization and ~50% for linear polarimetry with the λ/4–retarder. Sky background polarization is directly eliminated by using a calcite plate as a

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⋆ Based on observations made with the Nordic Optical Telescope, operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

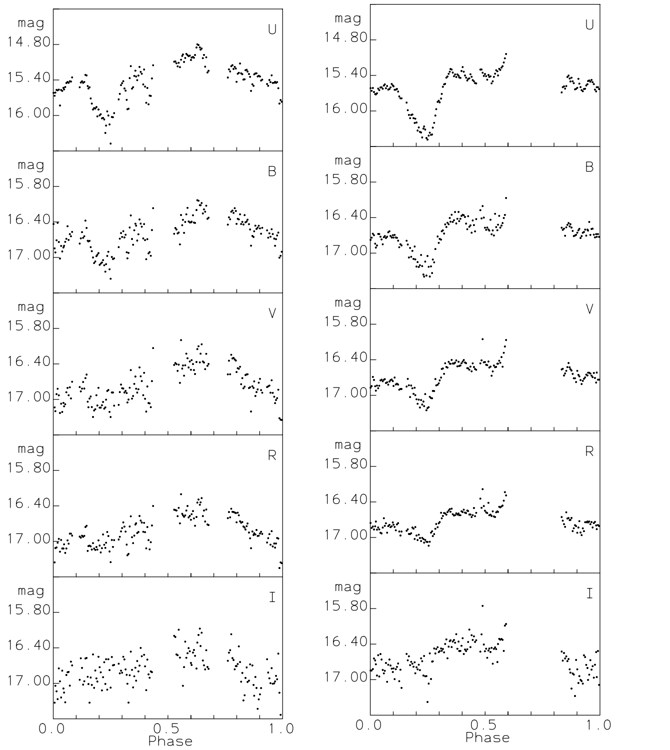

Fig. 1. UBVRI light curves of EV UMa during the nights 22/23 Feb (left) and 23/24 Feb (right), 1999. The orbital phases in Figs. 1. - 4. have been calculated by using the ephemeris of Osborne et al. (1994)

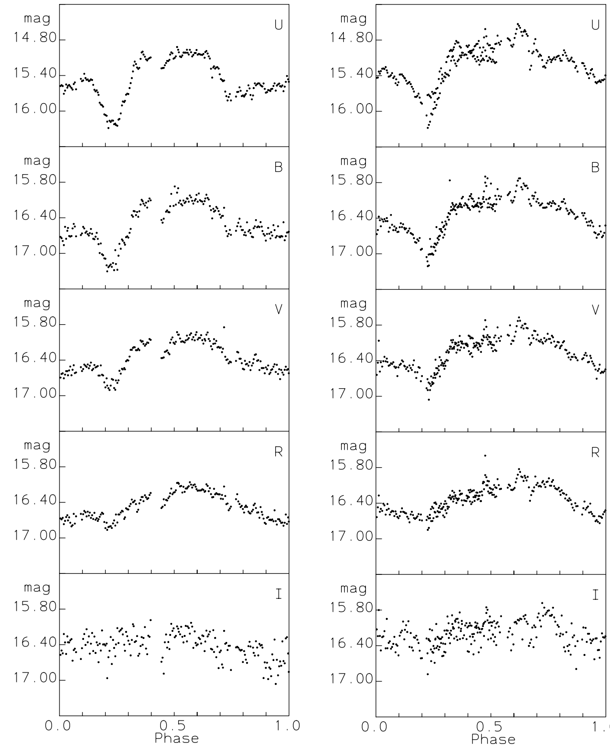

Fig. 2. UBVRI light curves of EV UMa during the nights 24/25 (left) and 25/26 (right) Feb, 1999.

beam splitter. The sky intensity was measured after every fourth complete polarization measurement, at every 13 minutes. Instrumental polarization was determined from observations of unpolarized standard stars, and the zero-point of position angle was measured from observations of large polarization standard stars.

CCD-observations were made on May 16, 1999, at the 60 cm Cassegrain telescope of the Royal Swedish Academy of Sciences at the Observatorio Astrofísico del Roque de los Muchachos, La Palma, with a SBIG ST-6 CCD-camera and a R-band filter. Standard CCD reductions (dark, bias, and flat-fielding) were applied. Differential photometry was performed with IRAF-routines. Typical errors for a 16 magnitude object were $\leq$ 0.05 magnitudes. A few white light CCD-frames were taken at the NOT in early June, 1999, to check whether the object was still in a high accretion state. The ephemeris of Osborne et al. (1994) (T) = HJD 244 8749.4421(5) + E$\times$0.05533838(26) has been used to calculate orbital phases.

2.1. Photometric UBVRI-observations

EV UMa was observed with the Turpol-photopolarimeter during 4 nights (from 22/23 Feb to 25/26 Feb). Datapoints (folded over the orbital phase) are shown in Figs. 1. and 2. Each dot presents a single photometric measurement. The light curves show that EV UMa was in a very high accretion state. In the V-band the brightness varied between 15.7 and 17.2 magnitudes, compared to V-band brightness V = 20.8 during low states (Osborne et al. 1994). An eclipse is seen clearly in the U-, B-, and V-bands. The eclipse is deepest, about one magnitude, in the U-band, whereas in the R- and I-bands the eclipse is noticeably smaller. Slight asymmetry is seen in the shape of the eclipse, the ingress being shallower than the egress, particularly on Feb 23/24 and 25/26. The maxima in the light curves are between orbital phases $\Phi = 0.6$ and $\Phi = 0.7$. Originally the ephemeris of Osborne et al. (1994) was determined so that the phase $\Phi = 0$ corresponds to the center of the intensity pulse in their white light and red light data.

The light curves obtained on 16 May, 1999, at the 60 cm Cassegrain telescope of the Royal Swedish Academy of Sciences, are shown in the Fig. 3. The difference between the brightness of two field stars and EV UMa, and brightness difference between the field stars are presented in Fig. 3. The stars are marked in the ALFOSC field of NOT-telescope, shown in Fig. 5. The brightness variation of EV UMa in the R-band in May is from peak to peak $\sim$0.5 mag, which is close to the same value as in February.

2.2. Polarimetry

EV UMa (RE 1307+535) is known to have a large range of circular polarization variations, e.g. in the R-band from –20% to +50% (Hakala et al. 1994). It has changed its polarization behaviour since the 1994 observations. In February 1999, the measured circular polarization in EV UMa varied from –23% to +5% in the U-band, from –15% to +6% in the B-, and V-bands,

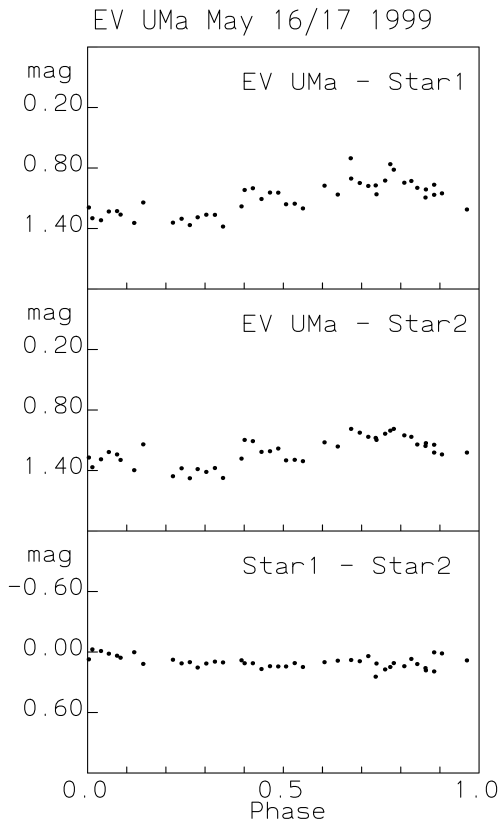

Fig. 3. The R-band light curves of EV UMa on 16/17 May 1999, obtained using the 60 cm Cassegrain telescope of the Royal Swedish Academy of Sciences, at La Palma. At the top is presented the difference between EV UMa and field Star 1, in the middle panel the difference between EV UMa and field Star 2, and in the bottom panel the difference between field stars Star 1 and Star 2.

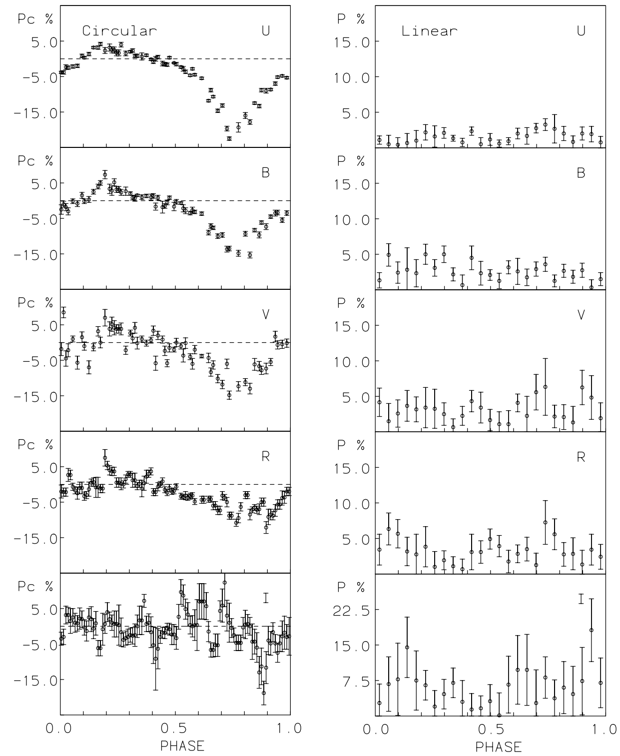

Fig. 4. Circular & linear polarization of EV UMa during the nights 22/23 Feb – 25/26 Feb, 1999.

and from –12% to 7% in the R-band (Fig. 4.). In the I-band the circular polarization is between 5% and –10%. In particular, the amplitude of the positive circular polarization has now reduced almost by a factor of ten compared to observations of Hakala et al. (1994), possibly due to dilution effects from the stream emission.

The eclipse (see chapter 2.1.) in the light curves is seen during the same phase interval as the positive circular polarization. This supports the conclusion that the reduction of the positive circular polarization in February 1999 is due to obscuration and dilution effects by the stream. The phases of the negative and positive maxima of circular polarization have shifted since observations of Hakala et al. (1994). The negative circular polarization maximum occurs now between the orbital phases $\Phi = 0.7$ and $\Phi = 0.8$, as earlier it was observed at the phase $\Phi = 0.5$. The positive circular polarization has now a maximum during the orbital phase $\Phi = 0.2$, whereas Hakala et al. (1994) observed the circular polarization maximum at the phase $\Phi = 0$ in February, 1994. The linear polarization data do not show any clear evidence of a linear polarization pulse.

The shift of both the positive and the negative circular polarization peaks by ~ 0.25 phase indicates that the ephemeris by Osborne et al. (1994) needs to be updated. By assuming that the cyclotron emission region near the negative magnetic pole is located at the same longitude as during the observations of Hakala et al. (1994) the negative circular polarization maxima observed on the three nights 1999 Feb 22/23, 24/25, and 25/26, give the new ephemeris:

$$\mathrm{T} = \mathrm{HJD}\ 2449388.6260(5) + \mathrm{E} \times 0.05533887(2).$$

The predicted timing error from the Osborne et al. (1994) ephemeris in 1999 is ± 16.8 min i.e., ± 0.2 phase. Therefore it is unlikely that any cycle count error has occured over the ~ 5 year span between the old (Hakala et al. 1994) and the new polarization observations.

3. Conclusions

Our observations provide the first simultaneous UBVRI-polarimetric data for EV UMa. They show that positive circular polarization peak value is reduced from +50% to +5%, while the negative circular polarization has more or less the same peak value than during observations of Hakala et al. (1994). The observed V-band magnitudes, between 15.7 and 17.2 increase the total ΔV (the lowest state: 20.8, Osborne et al. 1994) for EV UMa to 5.1 magnitudes. This new magnitude range, Δm=5.1 (V) for EV UMa is in better agreement with correlation found between Δm and $P_{\rm orb}$ in AM Herculis stars (see Warner 1999) i.e., the short orbital period mCV systems should have larger Δm than the long period mCV systems.

The deep eclipse with strong colour dependence in the light curves, and the reduction of the positive circular polarization

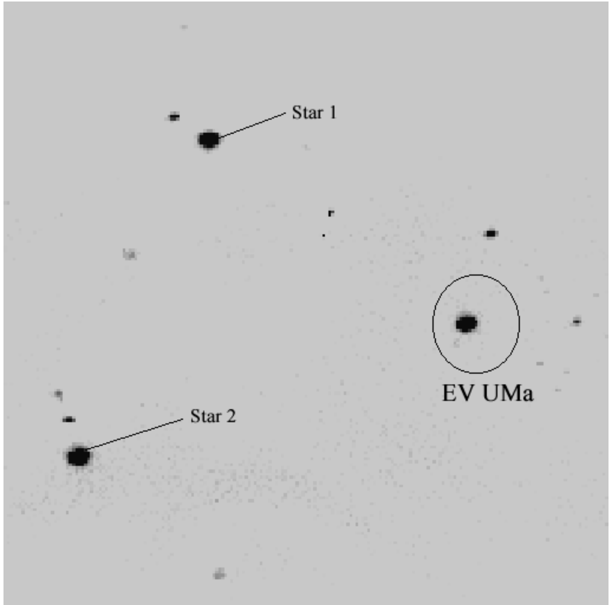

Fig. 5. The field of EV UMa in 6 June 1999 (NOT, 30 sec white light image). The brightness of EV UMa is still unusually high. Star 1 and Star 2, used for differential photometry, are shown.

in the same phase interval, give evidence of obscuration and dilution effects caused by the accretion stream. The high accretion rate from the secondary star may enhance the stream to the extent that it eclipses the accretion region of the positive circular polarization emission on the surface of the white dwarf almost completely. The circular polarization data could also be explained by a model where the enhanced accretion is captured almost entirely by the negative pole and the flow of material towards to the positive pole is thereby much reduced.

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