UNSTABLE PROCESSES IN ECLIPSING POLAR HU AQUARII

T.A. Somova[1], N.N. Somov[1], J.M. Bonnet-Bidaud[2],
V.P. Goranskij[3], E.A. Barsukova[1]
[1] Special Astrophysical Observatory of the Russian AS, Nizhnij Arkhyz 369167, Russia
[2] Service d'Astrophysique, CEN Saclay, CEA/DSM/DAPNIA/SAp,
F-91191 Gif sur Yvette Cedex, France
[3] Sternberg Astronomical Institute, Universitetskii prospect, 13,
Moscow, 119899 Russia

ABSTRACT. We present the results of optical time-resolved spectroscopy and photometry of the eclipsing polar HU Aquarii, which were obtained with the help of the scanner of the 6 m telescope in July, 1994 and the CCD photometr of the 1 m telescope in September, 2002. Study of the parameters of Balmer and HeII emission lines in the spectra of HU Aqr has revealed significant variations with the phase of orbital period on a time-scale of 5-10 min and from day to day. Spectral light curves (integrated flux in the range of wavelengths 4000-5000Å) have also shown significant variations. The bottom of the primary eclipses in the spectral light curves was 318 ± 12 s with variable ingress (328-388 s) and egress (85-333 s). The form of the spectral light curves is strongly variable on a time scale of 1-1.5 hours. In particular the radial velocity curves on July 14, 1994 demonstrated a deviation from a sinusoid near the orbital phase 0.5 which is considered to be the result of occultation of the magnetic part of the accretion stream by the white dwarf. Simultaneously the spectral light curve has shown several features:

– the dip at the phase 0 is associated with the eclipse of the white dwarf and accretion stream by the secondary;
– at the phase ≈ 0.85 the pre-eclipse dip due to the eclipse of the accretion spot by the accretion stream;
– the dip at the phase 0.5 which, as we suppose, is caused by the eclipse of the accretion spot by the white dwarf;
– at the phase 0.46 the pre-eclipse dip due to the eclipse of the accretion spot by the magnetic part of the stream.

The two pre-eclipse dips at the phases 0.85 and 0.46 point to the location of the accretion spot on the magnetic field line between two parts of the accretion stream which come out from the spot along the field line in approximately opposite directions. The direction of the field line and the character of perturbation of the emission lines at the phase 0.5 exclude the location of the accretion spot in the accretion column and is an indication of the hot spot on a magnetic field line where the horizontal or ballistic part of the stream is captured by the magnetic field as it was predicted by Liebert and Stockman, 1985. The duration of the dip at the phase 0.5 gives the upper limit for the distance from the center of the white dwarf to the accretion spot of $\approx 12R_{wd}$. The location of the accretion spot is far from the basis of the accretion column and should be considered as a second hot spot in the system. The hot spot is the principal source of the optical radiation of the system in the high state of accretion. The absence of the dips at the phases 0.5, 0.46 and 0.85 on other neighboring dates of our observations is the evidence of the instability of accretion geometry on the time-scale of 1 day.

Photometrical observations during two nights in September 2002 found HU Aqr in the intermediate state, closer to the low state of brightness of the system. The light curve in V filter showed only the primary eclipse without the dips at the phases of 0.5 and 0.85.

Key words: accretion – stars:individual: HU Aqr (RXJ2107-05) – stars:binaries: general – stars: cataclysmic variables

1. Introduction

Magnetic cataclysmic variables (MCVs) are close binary stars in which a Roche lobe–filling late–type secondary transfers matter to a strongly magnetized white dwarf primary. Polars or AM Her stars form the subclass of MCVs and include synchronous systems in which the spin period of the white dwarf is equal or close to the orbital period (Liebert and Stockman, 1985; Cropper, 1990; Warner, 1995). Accretion on the white dwarf is the principal process in the stars and study of instability of accretion geometry in eclipsing systems can give important information about location of the emission regions inside the systems. HU Aqr was discovered as the ROSAT source RE 2107-05 by the satellite's Wide Field Camera (Hakala et al., 1993)

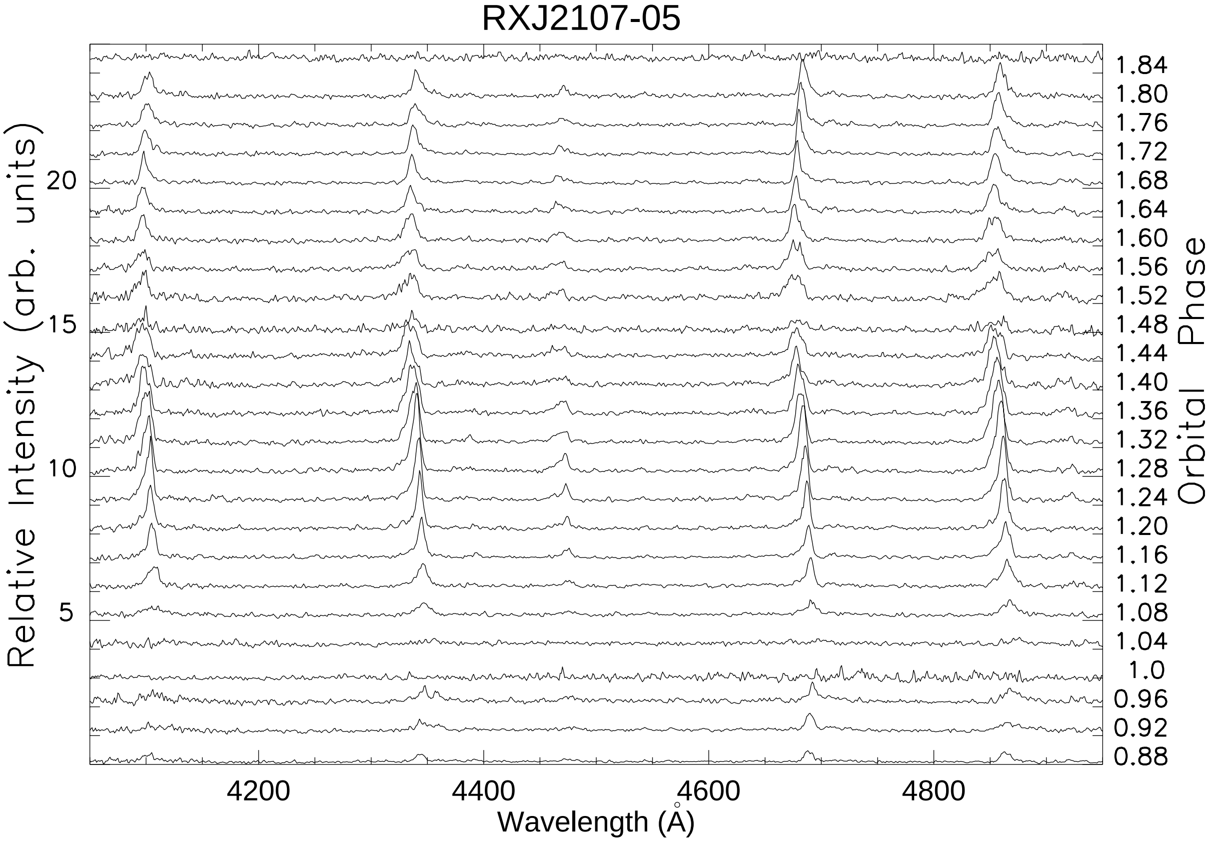

Figure 1: Variations of the relative intensity spectra which were obtained on 07/14/1994 with orbital phase

and independently by the X-ray telescope (RXJ 2107.9-0518; Schwope et al., 1993) as a highly modulated soft X-ray source with a period of 125.02 min. Multiple follow-up optical and X-ray observations have showed that the object is the brightest MCV ($V \approx 15.3$) (Shwope et al., 1993; Schwope et al., 2001 and references therein).

2. Observations

Spectral observations were carried out at the Special Astrophysical Observatory on July 11, 14, 15 and 16 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 ≈ 1000 Å within the range 3900–5100 ÅÅ with a dispersion of 1 Å/channel (spectral resolution $\approx 2\AA$) and a temporal 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. To analyze the behaviour of the parameters of emission lines (equivalent width, relative intensity, radial velocities of the peak and centroid) we have integrated from the original data the spectra with the temporal resolution 300 s. Spectral light curves or integrated flux within the wavelength range 4000–5000 ÅÅ were measured from the spectra with the temporal resolution 50 s.

3. Results

In Figure 1 we show time-resolved spectra which were obtained on July 14 1994. Time increases from bottom to top. The orbital phase is presented along the right vertical axes. The spectra are normalized to the continuous one. The variations of the profiles of the emission lines near the orbital phases 0.0, 0.5 and 0.85 are readily seen. Similar variations were absent in the spectra recorded on others dates and we find useful to compare the behaviour of brightness of the object on different dates. Spectral light curves (integrated flux within the range 4000–5000 ÅÅ) on July 11, 14, 15 and 16, 1994 are presented in Figure 2. The bottom of the primary eclipses in the spectral light curves was 318 ± 12 s with variable ingress (328-388 s) and egress (85-333 s). The form of the spectral light curves is

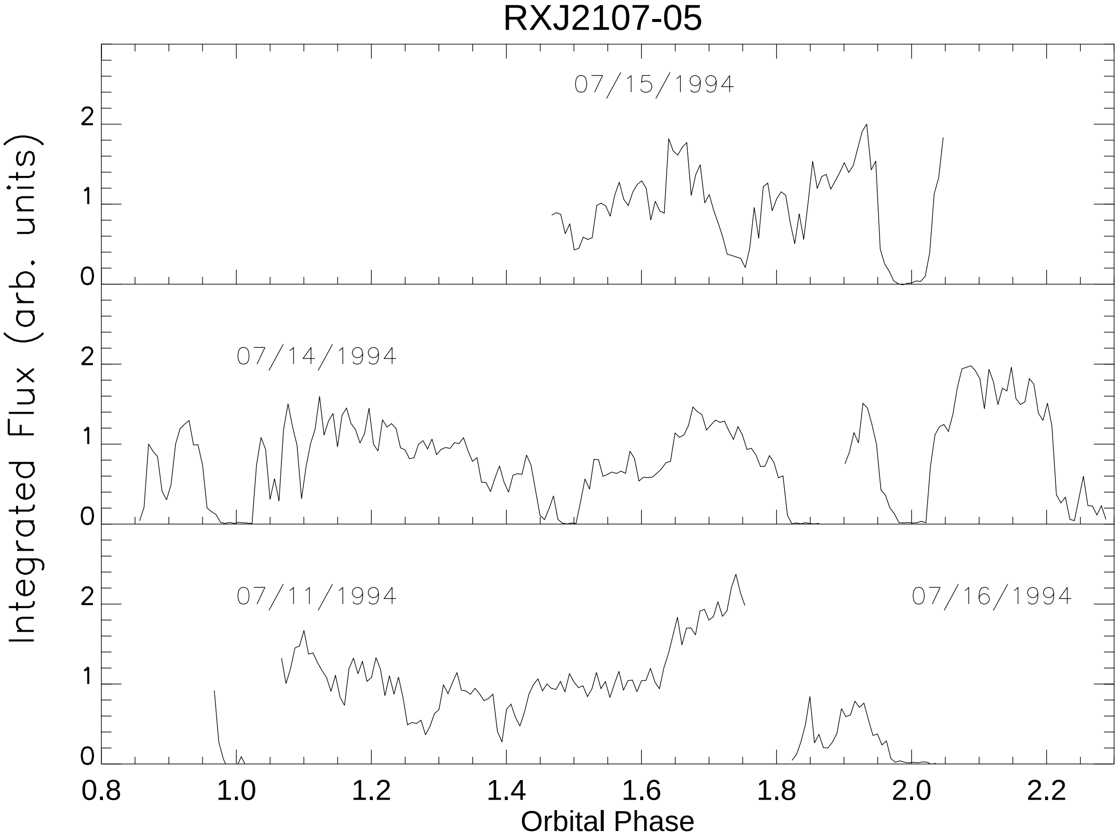

Figure 2: The spectral light curves which were obtained on July 11, 14 and 15 1994

strongly variable on the time scale of 1-1.5 hours.

The spectral light curve on July 14, 1994 (middle panel) manifests
(1) the dip at the phase 0.0 associated with the primary eclipse of the white dwarf and accretion stream by the secondary;
(2) the dip at the phase 0.85 or the primary pre-eclipse dip due to the eclipse of the accretion spot by the accretion stream;
(3) the dip at the phase 0.5 caused by the secondary eclipse of the accretion spot and accretion stream by the white dwarf;
(4) the dip at the phase 0.46 or the secondary pre-eclipse dip due to the eclipse of the accretion spot by the accretion stream;
If the dips (1,2) are known and were observed in the X-ray and optical light curves (Schwope et al., 2001) then the features (3,4) are new and unstable. The behaviour of the equivalent widths of the $H\beta$ emission line is shown in Figure 3. Radial velocity curves measured from the peaks of the $H\beta$ line are plotted in Figure 4. It is easy to see significant deviations from a sinusoid in the curves which reflect perturbations of the profile of the $H\beta$ line simultaneously with the features (3,4) in the spectral light curves. The detected spectral variations permit one to consider the feature (3) as a result of the eclipse of the accretion spot and stream by the white dwarf and the feature (4) as the eclipse of the accretion spot by the branch of the magnetic part of the accretion stream. In this case the interpretation of the features (3,4) is symmetrical to that of the features (1,2). The duration of the secondary eclipse gives the upper limit for the distance from the center

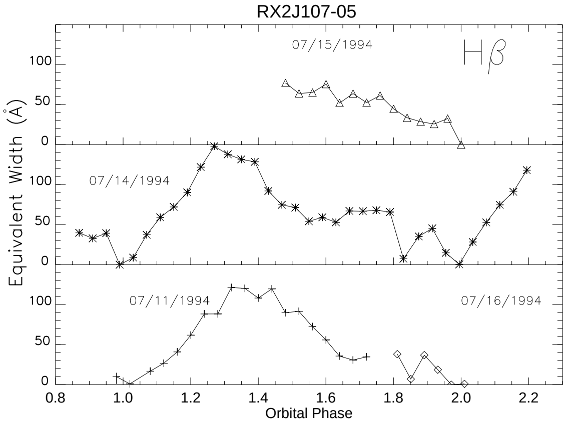

Figure 3: The variations of the equivalent widths of the $H\beta$emission line over the orbital period on July 11, 14, 15 and 16, 1994

of the white dwarf to the accretion spot of $\approx 12R_{wd}$.

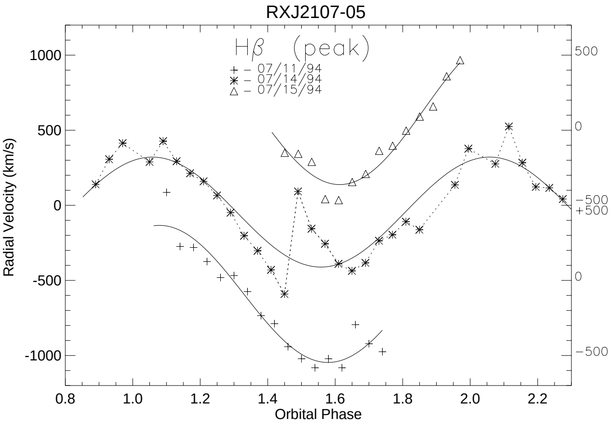

Figure 4: The radial velocity curves measured from the peaks of the $H\beta$ emission line for the observations on 11, 14 and 15 July 1994

Presence of two pre-eclipse dips points to the location of the accretion spot on the magnetic field line between two parts of accretion stream which come out from the spot along the field line in approximately opposite directions.

The direction of the field line, the phase of the secondary eclipse and the character of perturbation of the emission lines at the phase 0.5 exclude the location of the accretion spot in the accretion column and are indicative of the hot spot on the magnetic field line where the horizontal or ballistic part of the stream is captured by the magnetic field. Such a hot spot was predicted by Liebert and Stockman, 1985. The detected hot spot is far from the basis of the accretion column and should be considered as a second spot which is the principal source of the optical radiation of the system in the high state of accretion. Absence of similar events in other neighboring dates of our observations is the evidence of the instability of accretion geometry on the time-scale of 1 day.

Photometrical observations during two nights in September 2002 found HU Aqr in the intermediate state, closer to the low state of brightness of the system. The light curve in V filter showed only the primary eclipse without the dips at the phases of 0.5 and 0.85. is presented in Figure 5.

4. Conclusions

We have presented the results of optical time-resolved spectroscopy and photometry of the eclipsing polar HU Aquarii. We found that the parameters of Balmer and HeII emission lines in the spectra of HU Aqr revealed significant variations over the orbital period and on a time-scale of 1 day. We recorded on July 14, 1994 the variations of the spectral light curves simultaneously with the perturbations of the radial velocity curves which is evidence of at the secondary pre-eclipse dip at the phase 0.46 and the secondary eclipse of the accretion spot by the white dwarf at the phase 0.5. The phase and duration of the secondary eclipse and the character of perturbation of the emission lines at the phase 0.5 exclude the location of the accretion spot in the accretion column and indicate at the hot spot on the magnetic field line where the horizontal or ballistic part of the stream is captured by the magnetic field (Liebert and Stockman, 1985). Photometrical observations during two nights in September 2002 found HU Aqr in the intermediate state, closer to the low state of brightness of the system. The light curve in V filter showed only the primary eclipse without the dips at the phases of 0.5 and 0.85.

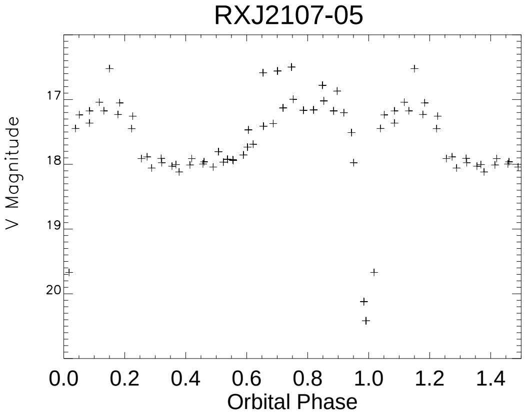

Figure 5: The light curve in V filter obtained in September 2002

References

Afanasiev V.L., Lipovetsky V.A., Mikhajlov V.P., Nazarov E.A., Shapovalova A.I.: 1991, *Astrofiz.Issled.(Izv. SAO)*, **31**, 128.

Cropper M.: 1990, *Space Sci. Rev.*, **54**, 195.

Drabek S.V., Kopylov I.M., Somov N.N., Somova T.A.: 1986, *Astrofiz.Issled.(Izv. SAO)*, **22**, 64.

Hakala P.J., Watson M.G., Vilhu O., Hassall B.J.M., Kellett B.J., Mason K.O., Piirola V.:1993, *MNRAS*, **263**, 61.

Liebert J., Stockman H.S.: 1985,*in: CVs and LMXBs, eds. D.Q. Lamb and J. Patterson*, 151.

Schwope A.D., Tomas H.C., Beuermann K.: 1993, *Astronomy and Astrophysics*, **271**, L25.

Schwope, A.D., Schwarz, R., Sirk, M., Howell, S.B.: 2001, *Astronomy and Astrophysics*, **375**, 419.

Somova T.A., Somov N.N., Markelov S.V., Nebelitsky V.B., Spiridonova O.I., Fomenko A.F.: 1982, *in: Instrumentation for Astronomy with Large Optical Telescopes, ed. C.M.Humphries, Reidel*, 283.

Warner B.: 1995, *Cataclysmic Variable Stars* (Cambridge: Cambridge Univ. Press).