

Letter to the Editor

Discovery of the bright eclipsing polar RXJ 2107.9–0518

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Abstract. We report the discovery of a new eclipsing AM Herculis variable (polar) as optical counterpart of the X-ray bright, soft, high-galactic latitude X-ray source RXJ2107.9–0518 detected during the ROSAT All Sky Survey (henceforth designated to as RX21). With $V \simeq 15^m.3$ in its high accretion state RX21 is the brightest among 5 known eclipsing systems. The eclipse lasts 9.75 minutes and was detected at optical and X-ray wavelengths. The optical eclipse lightcurve is structured due to subsequently vanishing and reappearing lightsources (the white dwarf and the accretion stream). The morphology of the X-ray lightcurve is suggestive of only one active pole. The orbital period is 125 min, close to the lower edge of the CV period gap, implying either an unusual binary evolution or a massive white dwarf. A low-resolution spectrum obtained in a state of reduced accretion displays cyclotron lines as well as spectral features of the secondary star. The implied field strength in the accretion region is $B \sim 37$ MG, the distance to RX21 is $d \sim 250$ pc.

Key words: cataclysmic variables — AM Herculis binaries — stars: individual (RXJ2107.9–0518) — Binaries: eclipsing — X-rays

1. Introduction

In the pre-ROSAT era 17 confirmed polars were known. Although some of them were known as variable stars in the past (e.g. AM Her, VV Pup) most were originally detected as X-ray sources (Ariel, Uhuru, EINSTEIN, EXOSAT) and only later identified optically. One of the outstanding properties of this class is its period distribution with 6 out of 17 systems clustering in a 2 min interval around 114 min. Based on this peculiar distribution far-reaching conclusions concerning the binary evolution, the angular momentum loss mechanism, the masses of the sec-

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*Based on observations collected with the ESO/MPI 2.2 m telescope in MPI time and the ESO/Dutch 90 cm telescope

ondary stars and of the white-dwarf primaries could be drawn (e.g. Ritter & Kolb 1992).

Since all polars are soft X-ray emitters the number of known sources was expected to increase considerably after completion of the ROSAT All Sky Survey (RASS) (Beuermann et al. 1987). This larger sample would give a sound basis for statistical studies as well as for tests of evolutionary scenarios. We, therefore, initiated an optical identification programme of bright, soft, high-galactic latitude RASS sources (count rate ≥ 0.5 PSPC cts/s, $HR1 < 0.0$, $|b| > 20^\circ$). Taking our results and those from the WFC-team (Watson 1993) together to date 15 new polars could be identified, 12 of them with measured orbital periods. Surprisingly, none of the new systems falls in the famous period spike at 114 min (Beuermann & Thomas 1993). Here we report the first eclipsing new cataclysmic variable discovered with ROSAT.

2. Observations and results

2.1. The RASS X-ray observations

RX21 was regarded as a secure AM Her candidate based on its X-ray properties as observed in the RASS. The net observation time was ~ 500 s spread over 1.67 days (Oct. 31/Nov. 1 1990) and 26 individual scans with exposure times ranging from 2.4 s to 25.1 s. A total of 372 photons were collected with an average hardness ratio $HR1 = -0.91 \pm 0.09$. The source displayed a 100% flux modulation with peak PSPC count rate corrected for vignetting and effective area of 3.9 cts/s. The on-/off-behaviour of the X-ray source suggested a possible periodicity of about 124 min, which is in the typical range found among the polars. Although not strongly constrained, the soft part of the X-ray spectrum was compatible with a blackbody of $kT_{bb} \sim 40$ eV. The ROSAT position of RX21 is (J2000) $\alpha = 21^h07^m57^s.9$, $\delta = -05^\circ17'42''$ with a 1σ error circle radius of $5''$. The star next to the ROSAT position on the UKST IIIaJ plate of the field lies $5'.1$ away and has a B -magnitude of $15^m.3$. It was our prime candidate for optical follow-up studies. A finding chart (CCD-image obtained at the ESO/Dutch 90 cm telescope) is reproduced in Fig. 1.

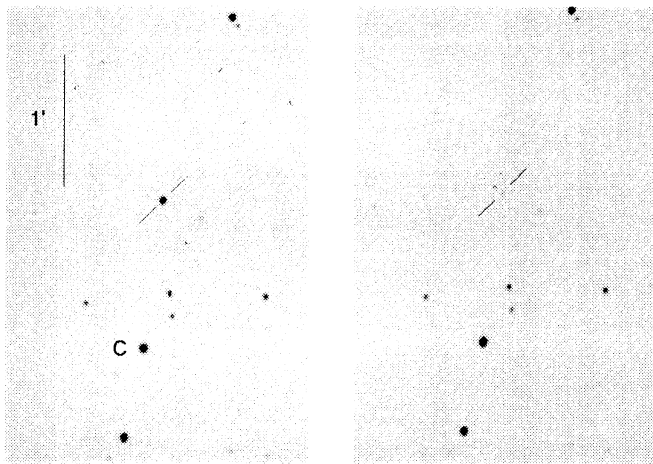


Fig. 1. CCD images of the region around the X-ray source RXJ2107.9-0518 (RX21) obtained with ESO/Dutch 90 cm telescope in white light. North is top and east is to the left. The size of the field is approximately 2.4×3.5 arcmin². The correct scale is given in the left image. The images were chosen to show maximum and minimum brightness of the source. In the eclipse RX21 becomes as faint as its 20mag neighbour. The star marked 'C' was used as comparison for differential photometry (Figs. 3 and 4)

2.2. A low-resolution spectrum

A low-resolution spectrum (FWHM ~ 30 Å) of RX21 covering the whole optical wavelength range, $\lambda\lambda 3500 - 9000$ Å, was obtained on August 19, 1992, under good photometric conditions. We used the ESO/MPI 2.2 m telescope at La Silla, Chile, with the ESO Faint Object Spectrograph and Camera (EFOSC2) equipped with a Thomson CCD with pixel size $19 \mu\text{m}$ as detector. RX21 was exposed for 20 min corresponding to 0.16 phase units of the binary orbit (period derived below). The observation starts at HJD 244 8853.64186 which corresponds to eclipse phase $\phi = 0.86$. Hence, the spectrum was centered on the bright phase and covered half of the eclipse (which was not known at the time of observation). The original spectrum is shown in Fig. 2a (upper panel). With $V \sim 17^{\text{m}}.7$ the source was considerably fainter than expected from the scan of the UKST plate. It displayed all the hallmarks of a polar in a low state of accretion: weak emission of $\text{H}\alpha$, TiO bands and the NaI $\lambda\lambda 8183, 94$ absorption lines from the M-dwarf secondary and, after subtraction of a suitably scaled spectrum of a single M dwarf, the blue spectrum of a largely inactive white dwarf (Figs. 2a and b). The magnetic nature of the white dwarf becomes obvious from the detection of pronounced cyclotron line emission as well as the (tentative) identification of photospheric Zeeman absorption lines which are probably of photospheric origin (indicated by triangles in Fig. 2b).

Using Baileys method (1981) and appropriate scaling of G3-33 (= Gl83.1), a single M dwarf of spectral type dM4.5 in the Boeshaar (1976) system, we estimate the distance to RX21 to be $d = 245 \pm 25$ pc. The error given includes only the uncertainty of the scaling and does not account for uncertainties in the true spectral type of the secondary star and for possible errors of our spectrophotometric calibration.

The continuum flux of the spectrum shown in Fig. 2b is deeply modulated by cyclotron line emission. Hence, accretion had not entirely ceased at the time of our observation. We identified the intensity maxima at 7800 Å, 6300 Å, 5200 Å and 4600 Å with the

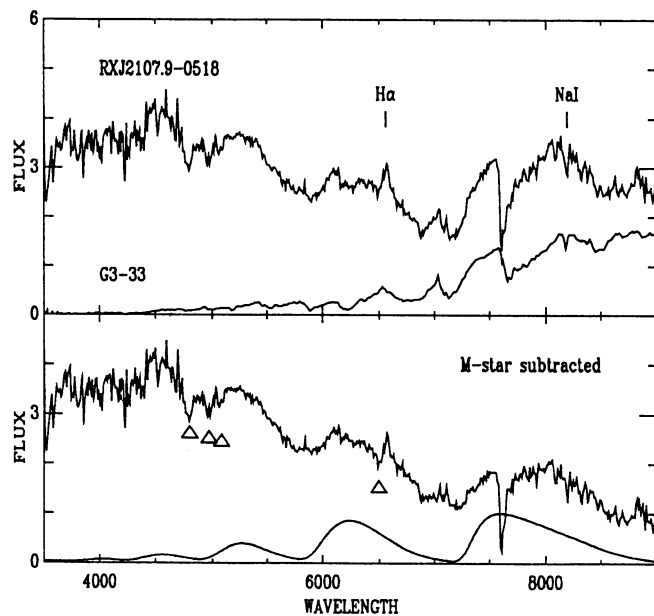


Fig. 2. (a) (upper panel) Low-resolution spectrum of RX21 obtained on August 19, 1992, and suitably scaled spectrum of the single M-dwarf G3-33 (Gl83.1). Flux units are $10^{-16} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1}$. $\text{H}\alpha$ emission lines and NaI absorption lines from the secondary star are labeled. (b) (lower panel) Same as above after subtraction of the M-dwarf spectrum. Triangles indicate our likely identification of Zeeman absorption troughs. The lowest curve is a cyclotron model for homogeneous plasma conditions which explains the low-frequent intensity modulations

4th – 7th cyclotron harmonics. A cyclotron model for an assumed 10 keV plasma with polar angle 80° and magnetic field strength $B = 37$ MG, which reproduces the observed positions of cyclotron lines well, is also shown in Fig. 2b. Fits with harmonic numbers 3 – 6 or 5 – 8 were significantly less successful and can be ruled out.

2.3. Optical photometry

RX21 was observed photometrically with the ESO/Dutch 90 cm telescope equipped with a CCD camera during four nights between September 30 and October 4, 1992. Only the first two nights were reasonably photometric (transparency variations $\lesssim 5\%$). The observations in the remaining nights were affected by cirrus and clouds. RX21 was observed for a total of 10^h. Individual integration times were 30 s, the time overhead for CCD-readout and storage of data was about the same, and the time resolution finally achieved was about 1 min. The observations were performed in white light. Our spectral bandpass was, therefore, limited by the atmospheric cutoff and the response of the UV-coated GEC-CCD to $\sim 3000 - 10000$ Å. Because of the poor photometric quality of the observational nights, the CCD-counts of RX21 were reduced to the counts of a comparison star 67'3 south and 8'4 east of RX21 (see Fig. 1).

When these photometric observations were performed RX21 had returned to its high accretion state. Maximum brightness (0.46 relative counts in Figs. 3 and 4) correspond to $V \sim 15^{\text{m}}.3$. The brightness of the system dropped abruptly for approximate-

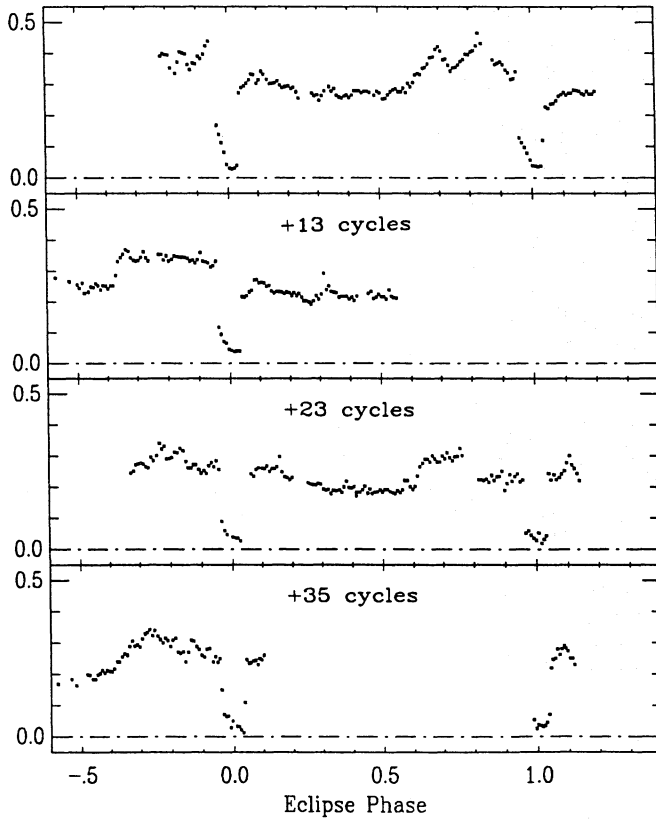


Fig. 3. Individual light curves of RX21 in original time sequence obtained early October 1992 with the ESO/Dutch 90 cm telescope in white light. Time has been transformed to phase according to the ephemeris of Eq. 1

Table 1. Eclipse timings T_0 (center)

Cycle	HJD 2440000+	Error	O - C
Optical data			
0	8896.54345	60	-29
1	8896.63057	25	-7
13	8897.67224	25	-17
23	8898.54079	25	17
24	8898.62742	25	-1
35	8899.58242	25	-4
36	8899.66942	25	14
196	8913.56081	35	26
X-ray data			
-8064	8196.42357	70	1

ly 10 min during eclipse. In early October we could monitor 7 eclipses, spanning a range of 37 cycles upon which a preliminary ephemeris could be built. Subsequently, a short sequence of exposures centered on the expected eclipse time could be gathered at the ESO/MPI 2.2 m telescope with EFOSC2 on October 18, 1992. The exposures on Oct. 18 were taken through a standard V-filter with integration times of 30 sec. The improved ephemeris including this new eclipse time was of sufficient accuracy to extend back to the ROSAT All Sky Survey without period alias. Three RASS survey scans were found to fall into the eclipse and

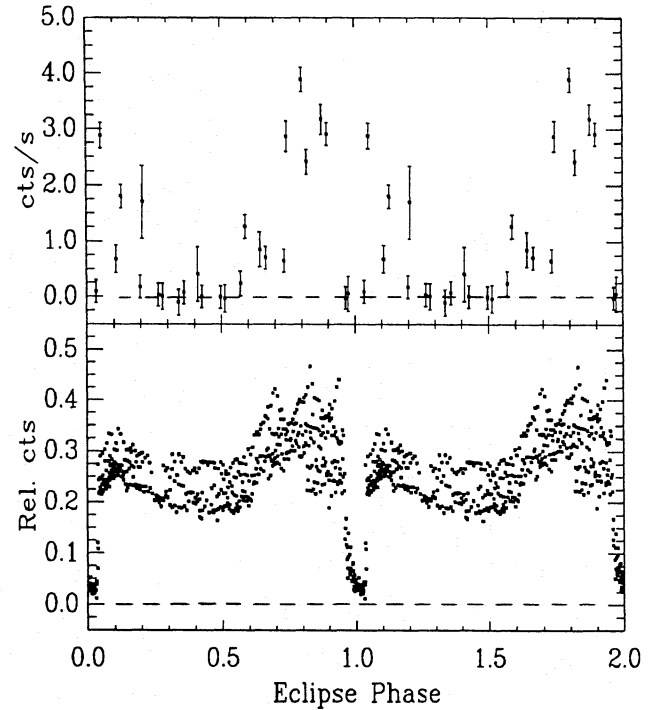


Fig. 4. (a) (upper panel) RASS scan light curve of RX21 folded over the ephemeris of Eq. 1. All data are shown twice for clarity. (b) (lower panel) White-light and V-filter photometry of RX21 performed in October 1992. Again the data are folded over the eclipse ephemeris and plotted twice

were used to establish our final optical/X-ray ephemeris of eclipse center as unweighted linear fit to the eclipse times compiled in Table 1:

$$T_{\text{ecl}} = \text{HJD } 244\,8896.54374(18) + E \times 0.086820459(24). \quad (1)$$

Numbers in parentheses give the uncertainties in the last digits. The final period of 125.021 min is in close agreement with our tentative period derived from the RASS data alone. All optical data obtained early October are shown in original time sequence in Fig. 3 and all optical/X-ray data folded over the ephemeris of Eq. 1 are shown in Fig. 4. The light curves display the signature of a one-pole accreting, eclipsing AM Herculis binary and look very similar to those of UZ For (Beuermann et al. 1988, Osborne et al. 1988). The X-ray/optical bright phase lasts for $\sim 55 - 65\%$ of the orbital period. This quantity is not well defined presently because of pronounced X-ray flaring and because of the smooth decline of the optically bright phase. The better defined onset of the bright phase displays a phase jitter of 3 - 4%. As a consequence of these uncertainties and fluctuations and especially due to the lack of polarimetric data we cannot constrain the probable latitude of the accretion spot. The longitude of the spot may be inferred from the phase lag of the eclipse center with respect to the center of the bright phase to be $25^\circ - 40^\circ$.

We note that the overall system brightness faded by $\sim 1^{\text{m}}5$ during our monitoring observations at the beginning of October. Together with the X-ray flaring, the variable shape of the optical light curve (Fig. 3), the observed low-state in August 1992, and the phase jitter of the onset of the bright phase this is a further hint to the high variability of RX21 on short and long timescales.

2.4. Eclipse and stellar parameters

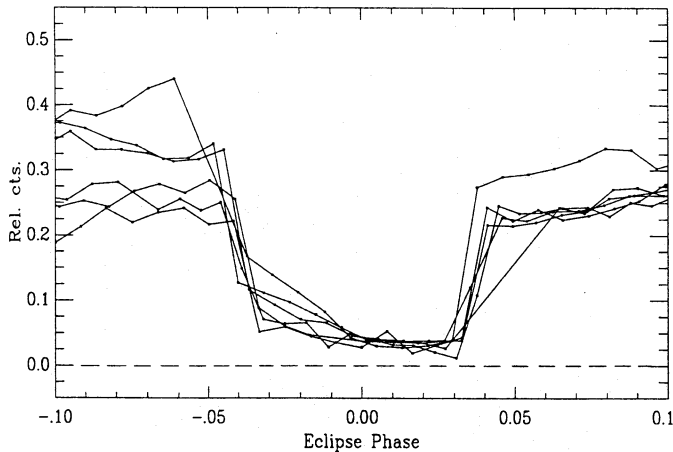


Fig. 5. Detailed representation of the optical eclipse of RX21.

The depth of the optical eclipse, if measured relative to the immediate pre-eclipse brightness, varies between 3^m3 and 3^m7 in our white-light observations, it reaches $\Delta V \simeq 4^m5$ in the mid-October observation. The X-ray eclipse is total. The varying depths of the white-light eclipses is explained by the varying brightness of individual bright phases whereas the deeper eclipse in the V-filter is a consequence of the red color of the secondary star. No further information about the secondary than that obtained from the spectrum shown in Fig. 2 is presently available. We, therefore, assume for further analysis that the secondary fills its Roche-volume and obeys the empirical mass-radius relation for ZAMS stars derived by Caillault & Patterson (1990). Using the approximation for the spherical equivalent of the Roche-radius given by Eggleton (1983) the mass of the secondary can be calculated as a function of mass ratio $q = M_2/M_{wd}$ and period P . Its value is weakly dependent on q , a good approximation is $M_2 = 0.147 M_\odot$. Caillault & Patterson mentioned a 12% rms dispersion in radius which yields a corresponding dispersion in mass of $\Delta M_2 = 0.021 M_\odot$ (at a period of 7501 sec). The width of the eclipse (half width $\Delta\phi_{1/2}$ measured in phase units) in combination with Roche geometry can be used to constrain the mass ratio q , the white dwarf mass M_{wd} and the orbital inclination i . This method was outlined by Chanan et al. (1976, see their equations 1 – 5). We used a similar approach and computed iteratively the corresponding (i, q) -relations for fixed eclipse width. The observed width of the optical eclipse is 580 ± 15 s ($\Delta\phi_{1/2} = 13.9^\circ \pm 0.4^\circ$), the X-ray eclipse lasts longer than 538 s. This is the most extended eclipse observed among the polars (in absolute time units as well as in phase). The smallest allowed value of q (for $i = 90^\circ$) consistent with the assumptions mentioned and the observed eclipse width is $q = 0.177$, from which $M_1 < 0.95 M_\odot$ follows ($\Delta t_{cl} = 565$ sec, $M_2 = 0.168 M_\odot$ assumed). If we assume a standard mass for the white dwarf of $0.6 M_\odot$ ($q = 0.245$) and the nominal eclipse length, the inclination is $i = 84.7^\circ \pm 1.0^\circ$. In principle the white dwarf radius (and hence mass) can be constrained from the ingress or egress duration but our time resolution is not sufficient to resolve these events. Using a formula derived by Bailey (1990) the ingress/egress times can be estimated to ~ 40 sec.

In Fig. 5 we show all our eclipse data in more detail with individual trains of data points connected by lines. From this repre-

sentation it becomes clear that the eclipse has internal structure. After the initial steep decline of brightness at $\phi = 0.961$ which corresponds to the eclipse of the white dwarf together with the hot accretion spot (expected ingress time < 1 min and not resolved here) a second source of light with varying brightness is eclipsed. The eclipse becomes total around $\phi \sim 0.0$, i.e., 290 sec after its start. The extent of this region in the orbital plane is of the order of some $10 R_{wd}$. The one and only structure of this elongation is the accretion stream, most probably the part connecting the stagnation region in the orbital plane with the accretion region on the white dwarf surface. A similar eclipse pattern was observed in WW Hor (Beuermann et al. 1990). It is worthwhile to note that the brightness of the accretion stream is well correlated with the overall system brightness. The egress of the accretion stream from eclipse terminates around phase $\phi = 0.1$.

3. Conclusions

We have shown RXJ2107.9–0518 to be an eclipsing AM Herculis binary with a period of $P = 125$ m close to the lower edge or even inside the CV period gap. The occurrence of a system at such period requires either a massive white dwarf or the system to be born in the gap or the system born not far above the upper edge of the gap (Hameury et al. 1991). Our mass estimate, although not very restrictive, is in favour of one of the two latter possibilities. More detailed conclusions regarding the stellar components, the location and extent of different sources of light in the system as well as the orbital inclination can be drawn if detailed spectral data and X-ray/optical photometric data with high time resolution are available. RX21 is an ideal target for detailed studies using different observational techniques because it is by far the brightest system among the rare species of eclipsing polars.

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