RX J0501.7–0359: a new ROSAT discovered eclipsing polar in the period gap

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Abstract. RX J0501.7–0359 is a new $V \sim 17$ mag eclipsing polar discovered during the ROSAT all-sky survey (RASS). Extensive follow-up observations at X-ray (pointed ROSAT PSPC and HRI observations) and optical (time-resolved photometry and spectroscopy) wavelengths were obtained which allowed us to determine a very precise orbital period and to provide constraints for the masses of the binary components and the orbital inclination. With an orbital period of $P \sim 171$ min the system is placed at the upper end of the period gap. From the radial velocity amplitude of the secondary and the duration of the primary eclipse we obtain a mass ratio $q = M_2/M_1 = 0.83 \pm 0.15$ and an inclination $i = 75^\circ \pm 3^\circ$ for the system. This yields a white dwarf mass $M_1 = 0.43^{+0.10}_{-0.07} M_\odot$. Cyclotron humps might be present in some of our optical spectra leading to a tentative magnetic field strength of $B \sim 25$ MG.

1. Introduction

The ROSAT All-Sky Survey (RASS) revealed a great wealth of new objects with soft X-ray spectra. Our optical identification of a sample of these sources has led to a significant increase in the number of known polars (Beuermann 1998, Thomas et al. 1998). Detailed X-ray and optical follow-up studies allow us to determine their orbital periods, magnetic field strengths, accretion geometry, etc. This leads to a largely increased data base of known polars which is important for studying the general properties of these systems as well as their evolution. Apart from this it is important to study individual objects in great detail as many of the new systems have remarkable characteristics such as extremely short periods and high magnetic field strengths (see Burwitz et al. 1997, 1998).

2. Observations and discussion

RX J0501.7-0359 (= 1RXS J050146.2–035927) was detected as a soft (hardness ratio $HR1 = (−0.96±0.03)$, bright ($0.22±0.03$ cts/s), and variable X-ray source in the RASS (Voges et al. 1996). As its optical counterpart, we have identified an eclipsing $V \sim 17$ mag polar located at RA = 05h01m46s1, DEC = −03°59′32″.
Figure 1. Optical and X-ray light curves of RX J0501.7–0359 folded over its 171 min orbital period using the ephemeris given in Eq. 1. From top to bottom: V band optical light curve (Jan. 11–12, 1996), ROSAT all-sky survey light curve (Aug. 24–26, 1990), two short pointed ROSAT PSPC light curves (2.4 ksec, Feb 24, 1992 and 1.8 ksec, Feb. 15–22, 1993), and two pointed ROSAT HRI light curves (16.5 ksec, Sep. 8–16, 1995 and 28.8 ksec Feb. 26 – Mar. 19, 1996).
Here, we present the analysis of our large amount of follow-up observations of this new object: optical V-band CCD photometry with the Dutch 0.9-m telescope and time-resolved spectroscopy with EFOSC2 at the ESO/MPI 2.2-m telescope on La Silla, Chile, infrared J, H, and K photometry with MAGIC at the 3.5-m telescope on Calar Alto, Spain, and X-ray data with ROSAT using both the PSPC and the HRI.

The optical light curves show a strong modulation which could be caused either by cyclotron beaming or by variations of the effective emitting area of the accretion stream as seen from different angles during the orbit. The light curve also features a deep total eclipse of the accreting white dwarf and the stream by the secondary star and a pre-eclipse dip, possibly due to the accretion stream crossing our line-of-sight towards the accretion region (cf. Fig. 1, top panel).

From our optical, IR, and spectrophotometry, we have derived 16 mid-eclipse timings between August 1993 and January 1996. These were used to determine the orbital period of RX J0501.7–0359 very precisely and lead to the following ephemeris:

$$T_{\text{mid--eclipse}}(\text{HJD}) = 2449748.83782(20) + 0.11896906(7) \times E. \quad (1)$$
From the optical spectra we have determined radial velocities of the narrow and broad components of the Balmer (Hα, Hβ) and the HeII 4686Å emission lines. The average radial velocity curve yields an amplitude $K_2' = (73.6 \pm 25)$ km/s for the narrow component (cf. Fig. 2). Maximum redshifts of the broad and narrow components occur at orbital phases 0.02 and 0.12, respectively.

Assuming a Roche-lobe filling secondary star, Kepler's laws define a relation between the orbital period $P$ of a CV and the mass $M_2$ and radius $R_2$ of the secondary (Eq. 1 in Beuermann et al. 1998). As RX J0501.7-0359 is probably a system which has been born in the period gap, its secondary cannot be much evolved. Therefore, the theoretical mass-radius relation for ZAMS stars with solar metallicity (Baraffe et al. 1998 with fit parameters from Beuermann and Weichhold 1998, Eq. 5) provides a valid second relation between $M_2$ and $R_2$. 
The valid range for the orbital inclination $i$ and the mass ratio $Q = M_1/M_2$ is restricted to the shaded area. For the mass-function, the radial velocity amplitude of the narrow emission line component has been corrected for the offset between the center-of-light and the center-of-mass of the illuminated secondary (see Beuermann & Thomas 1990).

Combining both equations gives the mass-period relation

$$M_2/M_\odot = 0.0686 \left( P_{\text{orb}}/\text{hours} \right)^{1.59}$$

(2)

from which we obtain $M_2 = 0.36 M_\odot$ and $R_2 = 0.33 R_\odot$ for the mass and radius of the secondary in RX J0501.7-0359, respectively. The corresponding mass-function is shown in Fig. 4.

The duration of the eclipse, $\Delta T_{\text{ecl}} = (13.1 \pm 1.2) \min = (0.077 \pm 0.007) P_{\text{orb}}$, provides a second constraint for the inclination $i$ and the mass ratio $Q = M_1/M_2$ in this system (see Fig. 4). Combining both constraints the valid values for $i$ and $Q$ are restricted to the very narrow ranges $i = (75 \pm 3)^\circ$ and $Q = 1.20^{+0.18}_{-0.27}$ (shaded area in Fig. 4). Finally, using $M_2$ and $Q$ we get $M_1 = 0.43^{+0.10}_{-0.07} M_\odot$ for the mass of the white dwarf.

Besides atomic emission lines, our optical spectra of RX J0513.7-0359 generally show a smooth continuum (top and middle panel in Fig. 3). Only during
one observing run some hump structure might be present during the orbital phases 0.8–0.95 (bottom panel in Fig. 3). We have tentatively identified these features as the 5th and 6th cyclotron harmonics corresponding to a magnetic field strength of $B \sim 25$ MG in the accretion region. Given the weakness of the possible cyclotron signatures, the field strength of RX J0501.7-0359, however, has still to be regarded as uncertain.

The X-ray data show a very strong modulation with a bright phase lasting for about half of the orbital cycle (phases 0.35–0.75, cf. Fig. 1). This on-off modulation is most likely caused by the accretion pole disappearing behind the limb of the white dwarf. Two component (blackbody + thermal bremsstrahlung with $kT_{\text{tb}} = 20$ keV fixed) model fits to the ROSAT PSPC X-ray spectra which cover mainly the bright phase yield a blackbody temperature $kT_{\text{bb}} = 38^{+5}_{-10}$ eV with an absorption column density of $N_H = (0.78^{+0.14}_{-0.27}) \times 10^{21}$ atoms/cm$^2$ which is slightly above the galactic value of $N_{H,\text{gal}} = 0.60 \times 10^{21}$ (3σ errors are given).

The accretion geometry of RX J0501.7–0359 appears to be intriguing as the X-ray bright phase occurs around the superior conjunction of the white dwarf. This implies that the visible accreting pole must be located on the white dwarf hemisphere pointing away from the secondary star.

A more detailed analysis and discussion of our X-ray, optical, and IR data of this interesting new eclipsing polar in the period gap will be presented elsewhere (Burwitz et al., in prep.).

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