Discovery of the magnetic cataclysmic variable
XMM J152737.4–205305.9 with a deep eclipse-like feature

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ABSTRACT

We report the identification and subsequent examination of a polar-type cataclysmic variable named XMM J152737.4–205305.9 newly discovered with the X-ray Multi-Mirror Mission (XMM-Newton). This discovery was made by matching the XMM-Newton data archive with the cataclysmic variable candidate catalog provided by Gaia Data Release 3 (DR3). The use of X-ray photometry led to the identification of two distinct dips that exhibit a recurring pattern with a precise period of 112.4 (1) min in two XMM-Newton observations made one year apart. The data obtained from photometry provided by the Zwicky Transient Facility (ZTF) and the Asteroid Terrestrial-impact Last Alert System (ATLAS) survey consistently indicate the presence of mass-accretion states that differ by up to 2 mag. Following the optical data, the Spectrum Röntgen Gamma (SRG)/eROSITA All Sky Survey observed the system at two different X-ray levels, which may imply different accretion states. Following these observations, the low-resolution spectrum obtained using SALT spectroscopy exposes the prominent hydrogen Balmer and helium emission lines, strongly supporting the categorization of this system as a polar-type magnetic cataclysmic variable. The XMM-Newton observations conducted at various X-ray levels reveal a consistent pattern of a deep dip-like feature with a width of ≈9.1 min. This feature implies the presence of an eclipse in both observations. According to Gaia data, the object is located at a distance of 1156 ± 12 pc, and its X-ray luminosity lies within the $L_X = (3–6) \times 10^{31}$ erg s$^{-1}$ range.

Key words. binaries: close – stars: fundamental parameters – novae, cataclysmic variables – stars: individual: XMM J152737.4–205305.9 – X-rays: binaries

1. Introduction

Cataclysmic variables (CVs) refer to binary systems characterized by a white dwarf (WD) primary star that is actively accreting mass from a low-mass main sequence star as a secondary that is in a semi-detached form (Warner 1995). If the magnetic field of the white dwarf (WD) is low or absent, accretion onto the WD takes place through a surrounding accretion disc. If the WD possesses a magnetic field of moderate or strong intensity ($>10^7$ G), the formation of the disc will either be limited or completely inhibited. Instead, the mass will accrete through the magnetic field lines that fall onto the magnetic poles of the WD. The systems known as polars (or AM Her systems) exhibit the highest levels of magnetic field strength among the CVs. These systems, characterized by relatively short orbital periods (<2h), are commonly described as soft X-ray emitters (Ritter & Kolb 2003; Kuulkers et al. 2006; Mukai 2017). Strong magnetic field and close orbital interactions keep both stars in synchronous rotation (Cropper 1990). Due to the locked orbits and the absence of a surrounding disc, these objects host mass accretion in a comparatively more sterile environment than other subtypes of CVs. Hence, it can be inferred that these objects hold significant potential for effectively monitoring mass-accretion processes, advancing our understanding of the intricate interplay between plasma and magnetic field interactions.

The occurrence of mass accretion induces X-ray emission from the white dwarf due to the creation of shocks. Hence, it can be observed that these kinds of objects exhibit more prominence within the X-ray region as compared to other wavelength ranges. In particular, the Röntgensatellit (ROSAT) All Sky Survey has been able to increase the number of identified polars considerably (Beuermann et al. 1999).

Polars have a discernable X-ray spectrum that has a slightly flat plateau-like shape, particularly within the X-ray wavelength range of 0.05–10 keV (Kuulkers et al. 2006). The spectrum obtained from a multitemperature area is likely to be the result of a mixture of several emission processes and emission regions. One notable component among these is blackbody radiation in soft X-rays, which may be considered particularly distinctive in the polars. A projecting feature observed in the soft X-ray spectrum is one of the distinctive X-ray features of polars and arises from reprocessed radiation by the white dwarf (King & Lasota 1979; Lamb & Masters 1979). Interestingly, the polar survey conducted by Ramsay & Cropper (2004) with the X-ray Multi-Mirror Mission (XMM-Newton) and all serendipitous discoveries made with XMM-Newton since then (Vogel et al. 2008; Ramsay et al. 2009; Webb et al. 2018; Schwake et al. 2020) did not reveal any further evidence of soft X-ray emission from a large number of magnetic CVs. Also, the first eROSITA-discovered polar did not show pronounced soft X-ray emission (Schwope et al. 2022).

An essential characteristic of polars that is frequently employed for classification purposes is the presence of distinctive features in their optical spectrum. The most important
features that distinguish these objects from other CVs are the emission lines seen in the spectrum. The spectrum is primarily characterized by the H Balmer, with notable He I (4472 Å and 5876 Å) and He II (4686 Å) emission lines; these are determining factors in their categorization (Szkody et al. 2002; Breedt et al. 2014; Thorstensen et al. 2016). These lines often exhibit a single-peaked shape due to the lack of an accretion disk but show asymmetric profiles due to the presence of an accretion stream (Schwope et al. 1997).

As active mass-accretion systems, polars display random brightness changes, as interruptions or limitations in accretion flow might occur occasionally. The observed variations in brightness, which are thought to be associated with the activity of the secondary star (Livio & Pringle 1994; Kafka & Honeycutt 2005), can render the polars rather dim when there is little mass accretion, making their detection challenging given their location beyond the detectable range of existing observational instruments. Through the use of predominantly long-term sky-surveying initiatives, it became feasible to identify these bodies throughout their phase of increased mass accretion. Accordingly, many CVs have been discovered serendipitously with all-sky surveys or pointed observations of the relevant sky region. Here we report a CV discovery obtained in this manner. XMMJ152737.4−205305.9, or hereafter XMM152737, was discovered by correlating the CV candidate catalog released by Gaia Data Release 3 with the XMM-Newton archive. We describe the observations that led to our discovery in Sect. 2. In Sect. 3, we present our primary results and discuss some fundamental parameters of the object.

2. Observations

The Gaia Data Release 3 (DR3; Gaia Collaboration 2021) catalog contains classifications of 12.4 million variable sources, and of these, 7306 sources identified based on long-term photometric variations are presented as CV candidates (Rimoldini et al. 2023). In order to detect and identify new magnetic cataclysmic variables, we correlated the source coordinates in this catalog within the XMM-Newton data archive. The matching process is applied with a default search radius predefined by the XMM-Newton database of 18 arcmin for every object. As a result of this search, nearly 400 objects were found to be in at least one observational data set in the XMM-Newton archive. Subsequent thorough searches in databases and the literature revealed that the majority of these 400 objects, especially the bright ones, are known CVs. We saw remarkably sudden and prominent fluctuations in one of the systems whose light curve we investigated. Further examination revealed fast and short-term eclipse-like variations in the XMM-Newton X-ray light curve of XMM152737 that had never been investigated before. In order to classify and fully understand the nature of the object, and determine its distinguishing characteristics, we analyzed data from available public archives and performed descriptive low-resolution optical spectroscopy.

2.1. XMM-Newton observations

The X-ray observations of the object were performed with XMM-Newton on July 29, 2021, and August 14, 2022. The pointed observations were carried out under the Multi-Year Heritage program. These observations were planned to investigate the quasar QSO J1526−2050. The observation IDs are 0884991701 (Obs 1) and 0886210801 (Obs 2) and lasted 116 ks and 103 ks, respectively. Both observations were operated in full-frame mode with thin filters. All XMM-Newton instruments (EPIC-pn, EPIC-MOS, Optical Monitor, and RGS) were used together but due to the smaller fields of view of all other instruments, only EPIC-pn with its large field of view gave useful data (Strüder et al. 2001). The source coordinates are given in the XMM-Newton database as RA = 15:27:37.50 and Dec = −20:53:05.4 with 0.3 arcsec position errors. The object was discovered at the edge of the detector; an X-ray image of the object obtained during Obs 1 is shown in Fig. 1. The system is also noted in the XMM-Newton’s fourth serendipitous source catalog with a source ID of 4XMM J152737.4−205305 (Webb et al. 2020).

The data were reduced with Science Analysis System (SAS) software that was purposely produced for the reduction of XMM-Newton data (Gabriel 2017). The EPIC-pn data were processed with the epchain task to generate calibrated event lists. The time columns in the event list were corrected to the Solar System barycenter using the barycen task in the XMM-Newton archive. The barycen task was performed by using the barycentric coordinates of the primary star (Gaia DR3) and the barycentric coordinates of the secondary star (Gaia DR3). The background rate was estimated using the same method as in Obs 1.

In Obs 2, this flare activity was observed at random intervals throughout the entire observation. Likewise, in this observation, a clean event file was obtained with tabgtigen.

2.2. Gaia observations

In Gaia DR3 (Gaia Collaboration 2021), XMM152737 is quoted as ID 5290647986316685824 with the sky coordinates of Dec2000 = 231.906207 deg and RA2000 = −20.8852306 deg. The mean brightness of the object is 19.08 ± 0.02, 19.39 ± 0.06, and 18.43 ± 0.05 in the G, G_BP, and G_BP passbands.
ATLAS\textsuperscript{1} database using forced photometry. Figure 3 shows the long-term brightness behavior of XMM152737, which varied between 18 and 21.5 mag. Data points whose sky brightness is greater than the source brightness are omitted.

2.4. ZTF observations

XMM152737 was observed by the Zwicky Transient Facility (ZTF; Masci et al. 2019) between May 2018 and July 2022. \( g \) and \( i \) filters are used in these observations. The brightness of the object was variable over a wide range between 17.3 and 21.6 mag. XMM152737 was therefore identified as the ZTF transient ZTF19aauyhu and classified as a likely CV by the ALeRCE broker (Förster et al. 2021) but no follow-up work was initiated. The ZTF light curve is also shown in Fig. 3.

2.5. Pan-STARRS observations

XMM152737 was also observed by the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS; Chambers et al. 2016) and given a source ID of PSO J152737.450−205305.091. Its brightness was obtained as \( m_g = 20.25, m_i = 18.86 \pm 0.1, m_r = 18.50 \pm 0.12, m_c = 19.95 \pm 0.07, \) and \( m_m = 18.06 \pm 0.12 \) in different passbands.

2.6. GALEX observations

The Galaxy Evolution Explorer (GALEX; Martin et al. 2005) also observed XMM152737, listing an observation ID of 6383159947039868090. The ultraviolet brightness was measured as \( m_{\text{NUV}} = 21.99 \pm 0.46 \) in the near-ultraviolet region (1750–2800 \( \text{Å} \)) with 200 s exposure time.

2.7. eROSITA all-sky survey observations

The extended Roentgen Survey utilizing an Imaging Telescope Array (eROSITA) instrument (Predehl et al. 2021) on board the Spexrum-Roentgen-Gamma (SRG) spacecraft (Sunyaev et al. 2021) has four sky surveys and XMM152737 has been detected in each sky survey. We downloaded the data from DATool\textsuperscript{2}, which is part of the eROSITA Science Analysis Software System (eSASS) and the data version c947 was used for further analysis (Brunner et al. 2022). The sky positions of XMM152737 were measured in these scans as eRASS1 RA = 231.9073 (8) deg and Dec = −20.8856 (8) deg, eRASS2 RA = 231.906 (1) deg and Dec = −20.885 (1) deg, eRASS3 RA = 231.906 (1) deg and Dec = −20.885 (1) deg, and eRASS4 RA = 231.9079 (6) and Dec = 20.8845 (6), respectively. The uncertainties are given in the parenthesis with one sigma confidence for the last digits. The observation log of the relevant observations is displayed in Table 1.

2.8. SALT spectroscopic observations

An optical spectroscopic identification of the source was carried out with the 11 m Southern African Large Telescope (SALT) at Sutherland Observatory (Buckley et al. 2006). Two 900 s exposures were obtained with the Robert Stobie Spectrograph (RSS, Burgh et al. 2003) on April 26, 2023. The used grism PG0700 covers the wavelength range 3579–7462 \( \text{Å} \) with two gaps at 4867–4937 \( \text{Å} \) and 6195–6255 \( \text{Å} \) due to chip gaps on the sensor. The used grism together with the used slit width of 1:5

\textsuperscript{1} https://fallingstar-data.com
\textsuperscript{2} https://erosita.mpe.mpg.de/internal/DATool/
3. Analysis and results

3.1. XMM-Newton observations

3.1.1. X-ray photometry

X-ray light curves of XMM152737 are shown in the original time sequence in Fig. 4. The data were used in the interval 0.2–10 keV and time bins of 50 s. The most striking feature of the X-ray light curve of the object is the succession of pulses, or, in other words, consecutive hump-like structures. These humps individually exhibit a highly variable behavior. It is noticeable that each hump includes a deep and narrow dip-like minimum, and with wide minima between the humps. The wide minima can always clearly be recognized while the dip-like minimum is difficult to follow in individual humps because of the overall high degree of variability and relative faintness of the source.

We searched the X-ray light curves for possible strong periodic signals by computing Lomb & Scargle periodograms (Lomb 1976; Scargle 1982). The period analysis was performed using photons between 0.2 and 10 keV with 50 s time bins. We searched for significant peaks in the frequency interval from 0 d−1 up to the Nyquist frequency of the XMM-Newton data (480 d−1). In both data sets, we obtained only one single peak at the same period of \( f = 12.81 \text{ cycles d}^{-1} \) (0.078 days) and its harmonics. The power spectra are shown in Fig. 5.

The deep dip, which is particularly noticeable in the complex structure of the light curve, exhibits apparent boundaries and demonstrates a sharp decline. The obtained timings from these distinct edges were used to ascertain the precise center of the deep dip and enhance the period acquired from the periodogram. For this process, the ingress (\( T_i \)) and egress (\( T_e \)) times were determined along the light curves obtained in the 30 s time bin in the deep dip. The selection of phase zero was established at the midpoint (\( T_{\text{min}} \)) of these \( T_i \) and \( T_e \) times from both XMM-Newton observations. The regression was first performed for the 12 continuous photometric cycles obtained from Obs 1. The period obtained after regression of the first observation was measured as 0.07799 ± 0.00003 days. The initial regression has an inaccuracy of 2.9 s. If the regression error is obtained by Obs 1 interpolated to Obs 2 – that is, 380.77 days later –, the accumulated error can produce a cycle count error with 2.1 cycles. Although this suggests that both observations should be evaluated separately, we also consider it appropriate to include the regression including Obs 1 and Obs 2 together here, as this error may be caused

Table 1. Observation log of the eROSITA All Sky Surveys and pointed observations covering the location of XMM152737.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Count rates (s−1)</th>
<th>Time (MJD)</th>
<th>Total exposure (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>eRASS1</td>
<td>0.355 ± 0.061</td>
<td>59802.836</td>
<td>111</td>
</tr>
<tr>
<td>eRASS2</td>
<td>0.150 ± 0.036</td>
<td>59082.290</td>
<td>143</td>
</tr>
<tr>
<td>eRASS3</td>
<td>0.160 ± 0.042</td>
<td>59251.562</td>
<td>19</td>
</tr>
<tr>
<td>eRASS4</td>
<td>0.261 ± 0.050</td>
<td>59441.375</td>
<td>120</td>
</tr>
<tr>
<td>XMM-Newton (Obs 1)</td>
<td>0.0173 ± 0.0006</td>
<td>59426.071</td>
<td>110 ks</td>
</tr>
<tr>
<td>XMM-Newton (Obs 2)</td>
<td>0.0143 ± 0.0007</td>
<td>59806.842</td>
<td>106 ks</td>
</tr>
</tbody>
</table>

Notes. The given times (MJD) refer to the midpoints of the observations. The net count rates were obtained in the 0.2–10 keV energy range.
Table 2. Minimum times, cycles, and ΔT times of the XMM152737.

<table>
<thead>
<tr>
<th>Minimum times (BJD)</th>
<th>Cycles</th>
<th>ΔT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2459425.6822 (4)</td>
<td>0</td>
<td>7.28 × 10^-12</td>
</tr>
<tr>
<td>2459425.7597 (4)</td>
<td>1</td>
<td>4.88 × 10^-4</td>
</tr>
<tr>
<td>2459425.8382 (2)</td>
<td>2</td>
<td>-2.40 × 10^-5</td>
</tr>
<tr>
<td>2459425.9165 (4)</td>
<td>3</td>
<td>-2.86 × 10^-4</td>
</tr>
<tr>
<td>2459425.9948 (2)</td>
<td>4</td>
<td>-6.48 × 10^-4</td>
</tr>
<tr>
<td>2459426.0720 (2)</td>
<td>5</td>
<td>1.90 × 10^-4</td>
</tr>
<tr>
<td>2459426.1501 (4)</td>
<td>6</td>
<td>7.80 × 10^-5</td>
</tr>
<tr>
<td>2459426.2279 (4)</td>
<td>7</td>
<td>2.66 × 10^-4</td>
</tr>
<tr>
<td>2459426.3062 (4)</td>
<td>8</td>
<td>-4.60 × 10^-5</td>
</tr>
<tr>
<td>2459426.3844 (4)</td>
<td>9</td>
<td>-3.08 × 10^-4</td>
</tr>
<tr>
<td>2459426.4625 (4)</td>
<td>10</td>
<td>-4.20 × 10^-4</td>
</tr>
<tr>
<td>2459426.5400 (2)</td>
<td>11</td>
<td>6.79 × 10^-5</td>
</tr>
<tr>
<td>2459806.6529 (4)</td>
<td>4885</td>
<td>6.54 × 10^-4</td>
</tr>
<tr>
<td>2459806.7322 (4)</td>
<td>4886</td>
<td>-6.58 × 10^-4</td>
</tr>
<tr>
<td>2459806.9658 (4)</td>
<td>4889</td>
<td>-2.44 × 10^-4</td>
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<tr>
<td>2459807.0435 (4)</td>
<td>4890</td>
<td>-5.92 × 10^-6</td>
</tr>
<tr>
<td>2459807.1219 (4)</td>
<td>4891</td>
<td>-4.18 × 10^-4</td>
</tr>
<tr>
<td>2459807.2002 (4)</td>
<td>4892</td>
<td>-6.80 × 10^-4</td>
</tr>
<tr>
<td>2459807.2775 (4)</td>
<td>4893</td>
<td>8.07 × 10^-6</td>
</tr>
<tr>
<td>2459807.3561 (4)</td>
<td>4894</td>
<td>-6.04 × 10^-4</td>
</tr>
</tbody>
</table>

Notes. The cumulative error obtained from regression from the Obs 1 indicates that the second observation might result in a variance of 2 cycles in the cycle count. Thus, the cycles of the second observation are denoted by a colon.

by the low-signal-to-noise ratio data. These measurements are shown in Table 2. Given the uncertainty in the number of cycles for the second observation, the number of cycles is indicated with a colon symbol for Obs 2. Thus, a weighted linear regression between the times T_min and the cycle numbers was used to derive

\[ \text{BJD}(T_{\text{min}}) = 2459425.6822(8) + 0.07798799(5) \times E. \]  

where the numbers in parentheses give the uncertainties in the last digits. In addition to this regression, we find it appropriate to highlight the periods that may cause ±1 and ±2 cycle ambiguities in the final period. The periods that can be obtained as a result of ±1 cycle difference are 0.077972 days and 0.078002 days, while the periods that can be obtained as a result of ±2 cycle difference are 0.077955 days and 0.078020 days, respectively. Zero time refers to the center of the dip or eclipse. The residuals of this linear fit are shown in Fig. 6. In the following, all phases refer to the ephemeris given in Eq. (1). We used this ephemeris to produce phase-folded light curves. Figure 7 displays folded light curves obtained from the XMM-Newton observatory. The narrow dip and hump-like structures are similarly observed in both light curves. Both datasets indicate a single period based on our timing analysis. This behavior is consistent with the \( P_{\text{orb}} = P_{\text{spin}} \) behavior seen in polar-type magnetic CVs. The identified period is likely the orbital period.

We generated energy-resolved and phase-folded X-ray light curves in two energy bands: a soft band between 0.2−1 keV and a hard band between 1−10 keV. These are shown in Figs. 8 and 9. Within the errors, both dips have a similar width. The dip or eclipse has a length of 9.2 ± 1.2 min and 9.1 ± 1.4 min for Obs 1 and Obs 2, respectively. The errors in the eclipse lengths are derived from the standard deviation of these individual measurements. When considering errors, both observations indicate the net count rates are compatible with zero in the dips. The second wide minimum, on the other hand, always has positive counts. The mean count rates obtained from the 0.2−0.4 phase interval are 0.014 ± 0.002 count s^{-1} and 0.05 ± 0.01 count s^{-1} for Obs 1 and Obs 2, respectively.

The center of the vast minimum is located at phase 0.35 (see Fig. 7). The mean count values obtained from the 0.65−0.9 phase interval (bright phase) are 0.30 ± 0.01 counts s^{-1} for Obs 1 and 0.24 ± 0.01 counts s^{-1} for Obs 2. The difference is a factor 1.25 but morphologically, the two light curves are very similar.

We calculated the hardness ratio (HR) between the two bands to better understand the deep dip-like features and possible small variations, which are defined as HR = \((H−S)/(H+S)\) and hence vary between −1 and +1 (see Fig. 8). In Obs 1, between two dips, the HR varies slightly and spreads around 0.2 during the bright hump. Negative counts in the center positions of the dips prevent the calculation of meaningful HR values. At the same time, no significant hardening is detected in the ingress and egress of the dips, which could be related to mass transition or absorption.

In Obs 2, HR is a little more variable. However, as in the first observation, it scatters around 0.2, and similarly, there is no sign of hardening related to an element that can create absorption in the ingress and egress parts of the dip (see Fig. 9). Given
Fig. 7. Folded X-ray light curves of the XMM152737 obtained in the 0.2–10 keV energy range by XMM-Newton with time bins of 50 s. The insets focus on the deep dip interval. The bold red line shows the grouped phase bins with 0.01 phase units.

that both observations include negative counts, it is not practical to carry out a significant calculation in vast and deep minima. Therefore, the HR values in these intervals are outside the accepted range of variation. However, it is important to note that we do not detect evidence of a hardening or absorption condition, which, if detected, would suggest the presence of mass flow at the ingress and egress of the deep minimum.

3.1.2. X-ray spectroscopy

A spectral analysis was performed with the XSPEC package (version 12.12.0 Arnaud 1996; Dorman & Arnaud 2001). Only photons between 0.2 and 10 keV were included in the spectral analysis. We started the spectral analysis by considering only the bright phase in the light curve within the phase range of \( \phi = 0.65–0.90 \) (see Fig. 7). We assume that the bright phase will contain the physical status of the main radiation region on the source. Photons were grouped with a minimum of 20 counts per bin and we used \( \chi^2 \) statistics to optimize the fit.

As the count values of the object were higher in Obs 1, we started the spectral analysis with these data. Initially we used a single collisionally ionized APEC emission model (Smith et al. 2001) with solar abundances (Wilms et al. 2000) absorbed by some cold interstellar matter with hydrogen column density \( (N_H) \) so that our model reads TBABS * APEC in XSPEC. This basic model qualitatively describes the spectrum fairly well. The model gave the \( \chi^2 = 52 \) for 50 degree of freedom \( \chi^2 = 1.04 \). Interestingly, the temperature value is pegged at the maximum for the APEC model. We used the steppar command in XSPEC to see any possible statistical minima between 0.05 and 64 keV. The statistical minimum shows a decreasing trend, implying temperature is higher than 64 keV and it is not possible to detect

Fig. 8. Energy-resolved light curves and HR variation of the XMM152737 with the Obs ID of 0884991701 (Obs 1). These phase-folded light curves are produced from 100 s time-binned time series.

Fig. 9. Energy-resolved light curves and HR variation of XMM152737 with the Obs ID of 0886210801 (Obs 2). These phase-folded light curves are produced from 100 s time-binned time series.
the exact minimum point. The difficulty in detecting the spectrum temperature is thought to be connected to the fact that the photon contribution in the hard X-ray region (>5 keV) is higher than predicted. Particularly in terms of magnetic CVs, pegging at the maximum allowed temperature is typical. The real temperature should be much lower but the presence of extra hot photons (>5 keV) causes the spectrum to be measured too hot in the model temperature due to the reflection, one should be considered the main emission model with the reflect model or partial covering fraction absorption (PCFABS; for more information, see Mukai 2017; Schwope et al. 2020). Therefore, we replaced the absorption component with a partial covering fraction absorption (PCFABS) and reapplied the fit. This simple model gives a very good fit and XSPEC measures a lower temperature of \( kT_{\text{apec}} = 21 \) keV (see Fig. 10). The final fit is yielded with the \( \chi^2 = 52 \) for 49 degrees of freedom \( \chi^2 = 1.06 \).

We tried to model the spectrum for the bright phase using the same spectral model for Obs 2. We were not able to obtain meaningful temperature values in any of our trials with PCFABS. Similarly to the previous observation, the temperature value was trapped at the maximum value. In the parameter test conducted with the \textit{steppar} command, we find that the temperature enters the 90\% confidence value limit after 11 keV. However, we cannot see any dip point of the statistical minimum in the temperature range defined for APEC. We then tried to change our absorption method and changed PCFABS to the TBABS. The fit was repeated and finally we were able to calculate a temperature, albeit with large error margins. The result obtained with this model is \( \chi^2 = 40 \) for 38 degrees of freedom, and \( \chi^2 = 1.05 \). The best-fit parameters for the bright phase spectra are shown in Table 3.

One of the most interesting results from Obs 1 is the high hydrogen column density. The column density in bright phase spectrum is significantly higher than the Galactic column density. In the direction of the object, the galactic column density is \( N_{\text{H,gal}} = 8.32 \times 10^{20} \) cm\(^{-2}\) according to HI4PI Collaboration (2016). According to this result, the column density for Obs 1 appears to be a factor of 18 higher than the galactic column density. This is relatively high. However, we want to emphasize that even the lower error limit on this parameter of 0.45 (factor of ≈6) is considerably higher than the galactic column density. Instead, a difference of a factor of 0.3 is seen between the column density from Obs 1 and the column density derived from Obs 2. Our analysis suggests that the spectrum acquired during the high state and bright phase – particularly when the accretion region is at its maximum visibility – could be affected by certain absorption features. Given the current accretion condition of the object, it is plausible that it could be attributed to either a stellar wind or an accretion curtain, or perhaps an extended part of an accretion stream. The model combining absorption components (TBABS * PCFABS * APEC) was also evaluated for Obs 2. However, no significant results were obtained from measuring the parameters of the partial absorption component. The total column density calculated using TBABS is comparable to the model that does not include partial absorption.

The spectra seen in the two observations exhibit a notable absence of the blackbody extension in the soft X-ray regime. Many polars have a soft X-ray radiation component in the X-ray spectrum. The photosphere of the WD located under the shock can be exposed to radiation from above and heated by the shock region, resulting in the formation of a highly concentrated soft X-ray source (Mukai 2017). While the absence of the spectral extension associated with this emission does not necessarily indicate that the object is not a polar, this extension typically appears in polars. The detection of this emission was not evident in serendipitously discovered polars by XMM-Newton observations. The narrow coverage of the energy area of the instrument or suppression of the accretion region by an absorber is regarded to be the underlying cause of its nonexistence in the spectra we study here.

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**Table 3.** Spectral parameters from the bright phase interval (\( \phi = 0.65–0.90 \)):

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Obs 1 – Model: PCFABS * (APEC)</th>
<th>Obs 2 – Model: TBABS * (APEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{\text{H}} ) (10(^{22} ) cm(^{-2}))</td>
<td>1.41±1.35 ( \pm 0.79 )</td>
<td>0.03±0.03 ( \pm 0.02 )</td>
</tr>
<tr>
<td>CvrFract</td>
<td>0.45±0.12 ( \pm 0.13 )</td>
<td>46(^{-14}) ( \pm 11 )</td>
</tr>
<tr>
<td>( kT_{\text{apec}} ) (keV)</td>
<td>21(^{+19}) ( \pm 11 )</td>
<td>46(^{+14}) ( \pm 11 )</td>
</tr>
<tr>
<td>( \chi^2 ) (d.o.f.)</td>
<td>1.06 (52/49)</td>
<td>1.05(40/38)</td>
</tr>
</tbody>
</table>

| Unabsorbed fluxes (10\(^{-13} \) erg cm\(^{-2} \) s\(^{-1}\)) | | |
| \( F_{0.5–2.5} \) | 0.91±0.79 \( \pm 0.09 \) | 0.6\(^{+0.7}\) \( \pm 0.6 \) |
| \( F_{2.5–10} \) | 2.35±0.31 \( \pm 0.39 \) | 1.54\(^{+0.13}\) \( \pm 0.23 \) |
| \( F_{\text{bol}} \) | 5.8\(^{+1.5}\) \( \pm 1.5 \) | 6.3\(^{+0.85}\) \( \pm 0.50 \) |
| \( L_X \) (erg s\(^{-1}\)) (10\(^{31}\)) | 4.6 ± 1.2 | 5.0 ± 0.8 |

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**Fig. 10.** Mean bright-phase spectra of XMM152737 for Obs 1 and Obs 2. The bright phase spectra obtained between 0.65 and 0.90 photometric phases according to Eq. (1).
We calculated the unabsorbed fluxes in different bands using the best-fit models for both observations. The cflux command in XSPEC was used for this. For a more comprehensive total X-ray flux calculation in models, we created dummy responses using the XMM-Newton response matrices loaded into XSPEC and the unabsorbed bolometric flux was calculated in the range $10^{-6} - 10^{-1}$ keV with reference to the corresponding model parameters. The correction factors ($F_{bol}/F_{0.5-10}$) for the total X-ray flux in both luminosities are 1.77 and 2.94, respectively. The results of these calculations and their uncertainties are shown in Table 3.

Determination of the mass-accretion rate of the object involves the computation of the total X-ray flux derived from an ideal model fitted throughout the X-ray spectrum. This calculation assumes a correlation between the observed emission and the amount of energy produced during the accretion process ($L_{acc} \approx L_X$). Furthermore, it is essential to include the nonghnetal cyclotron emission ($F_{cyc}$) generated by the motion of matter within a magnetic field, in addition to X-rays ($F_{acc} \approx F_X + F_{cyc}$). However, the strength of this radiation strongly depends on the geometry and can vary significantly depending on the orbital inclination and the spatial arrangement of the accretion structures, which cannot be precisely identified with the available data. Hence, the contribution of this emission is omitted in the present computation.

The distance of the object is given as 1156 pc by the Gaia DR3 catalog. Using this distance, with a WD mass of 0.8 $M_\odot$, which is assumed to be the average value for CVs (Littlefair et al. 2008; Savoury et al. 2011; Pala et al. 2022), and a radius calculated for this mass using the formula provided by Nauenberg (1972), we calculate an X-ray luminosity for Obs 1 of $L_X = 4.6 \pm 1.2 \times 10^{31}$ erg s$^{-1}$. Thus, when the X-ray parameters obtained from the bright-phase spectrum and the distance of the object are taken into account, we calculate a mass-accretion rate in Obs 1 of $M = 5.0 \pm 1.0 \times 10^{-12} M_\odot$ yr$^{-1}$. When we perform similar calculations for the data obtained from Obs 2, the X-ray luminosity is $L_X = 5.0 \pm 0.8 \times 10^{31}$ erg s$^{-1}$ and the mass-accretion rate is $M = 5.3 \pm 0.7 \times 10^{-12} M_\odot$ yr$^{-1}$. From these calculations, it can be assumed that for a fixed distance of 1156 pc, the mass accretion between the two XMM-Newton observations, the accretion rate of XMM152737 varied between $(4-6) \times 10^{-12} M_\odot$ yr$^{-1}$. We only take into account the errors in fluxes in these calculations. Considering the distance error derived from Gaia DR3, with 817 pc and 1876 pc as upper and lower limits, it can be stated that $M$ lies within the range of $(3-13) \times 10^{-12} M_\odot$ yr$^{-1}$. Both observations indicate a similar accretion rate for XMM152737.

### 3.2. Long-term optical photometry

The long-term optical photometry of XMM152737 is shown in Fig. 3. While ATLAS observations are the longest in duration, they also encompass the temporal range of the observations provided by the ZTF survey. The observed data demonstrate comparable patterns over the intersecting time interval. Within the ATLAS survey, the brightness of the object exhibits a variation stretching from 17.9 to 21.4 mag in $c$ band (i.e., a difference of 3.5 mag). The ZTF, which operates with Sloan Digital Sky Survey (SDSS) filters, recorded brightness variations in the range of 18–20.6 mag in $g_z$ band. Furthermore, Fig. 3 illustrates the match in the first (Obs 1) XMM-Newton observation and the corresponding optical data.

We find no pattern in the X-ray behavior in the optical light curves when compared to the photometric period. There may be several reasons for this. The large optical variations in the

![Fig. 11. SALT spectrum of XMM152737.](image)

ATLAS and ZTF light curves may be due to orbital motion or various mass-accretion states. Inadequate light-curve sampling or period inaccuracy from the first observation may have caused a cycle alias in Obs 2 similar to that seen in the optical observations, leading to misplaced photometric data points. One or more of these may be the origin of this incompatibility.

Hence, we cannot comment on the phase-dependent orbital variability in the optical wavelength range. So far there has been no dedicated time-resolved optical photometry and the accuracy of our ephemeris is not sufficient to construct a phase-binned light curve from the sparsely sampled ZTF or ATLAS data.

### 3.3. SALT spectroscopy

Figure 11 shows the average combined flux-calibrated spectrum of the two SALT observations of XMM J152736. The gaps seen in the spectrum at 4867–4937 Å and 6195–6255 Å are from the chip gaps in the sensor. The spectrum shows very prominent Balmer emission lines, although Hβ (at 4861 Å) is partially cut off because of the occurrence (or overlap) of the chip gap. Apart from the Balmer lines, there are emission lines of He I at λ4472, 5876, and 6678 Å, as well as He II λ4686 Å.

Close inspection of the emission line profiles, especially the Balmer series, also shows possible indications of multiple components; however, these might also be due to noise in the data. Measurements of the most prominent emission lines were obtained using the Python package lmfit (Newville et al. 2016) on the average combined spectrum from the two SALT observations. However, before measuring the spectral lines, this average combined spectrum was first continuum normalized using the numpy Python package by dividing the spectrum by a fourth-degree polynomial that was fitted to the continuum. Figure 12 shows an example of the lmfit model fit to Hα, while Table 4 shows the radial velocity as well as the FWHM of the most prominent emission lines.

He I 16680 could not be accurately modeled using lmfit due to high noise levels in the spectrum. All of the lines show blueshifted radial velocities, indicating that high-resolution time-resolved spectroscopic observations could be a viable way to obtain additional parameters such as the orbital period of the system. The equivalent width (EW) was measured by fitting a Gaussian profile to the respective line. The uncertainty of the EW was derived by determining the uncertainty in the flux value.
which was derived from the uncertainties in the FWHM and the peak flux. These were found from the lmfit measurements of the line profile. A possible uncertainty in the continuum was neglected.

The continuum is rising toward the red wavelength range with maxima around 6600 Å and 5700 Å. This is reminiscent of a cyclotron continuum originating from a moderate magnetic field strength, perhaps similar to that seen in V834 Cen (Schwope & Beuermann 1990). Whether or not the two mentioned maxima represent individual cyclotron harmonics is difficult to decipher given the rather modest wavelength coverage of the spectra and the lack of time resolution, and therefore lack of phase coverage. However, both the presence of high-excitation emission lines and the shape of the continuum strengthen the polar interpretation of the system.

### 3.4. eROSITA All Sky Survey

The survey images obtained from eROSITA are shown in Fig. 13. XMM152737 was detected in all surveys. In eRASS1 (0.36 ± 0.06 count s\(^{-1}\)) and eRASS4 (0.26 ± 0.05 count s\(^{-1}\)), the object has higher counts than others, while in eRASS2 (0.15 ± 0.03 count s\(^{-1}\)) and eRASS3 (0.16 ± 0.04 count s\(^{-1}\)), low counts or lower energies were detected. As can be seen from Fig. 3, there is no overlap with the long-term photometric data. In addition, we would like to point out that eRASS4 and XMM152737-Obs 1, which are the closest points to each other, may be in a similar accretion state considering the photometric data points.

As in XMM-Newton, we obtained the HR values of the system for the all sky survey as HR1 = 0.33 ± 0.23 (eRASS1), HR2 = 0.18 ± 0.15 (eRASS2), HR3 = 0.34 ± 0.15 (eRASS3), and HR4 = 0.05 ± 0.19 (eRASS4), respectively. These values calculated from the energy ranges 0.2–1.0 keV and 1.0–10 keV. Given the errors, it can be inferred that the HR, which refers to the spectral shape, behaves similarly to the bright phase in XMM-Newton observations.

![Fig. 13. Images of the XMM152737 during the four eROSITA All Sky Surveys. The images shown were obtained in the 0.2–10 keV energy range. The white apertures are positioned according to the eRASS1–4 detections with 30 arcsec. The dashed white circles show the uncertainties of these detections within 3σ confidence.](image)

### 3.5. Status of the eclipse-like feature and accretion geometry

There are two possible explanations for the prominent dip-like structure observed in the X-ray light curve. Either it is caused by an eclipse of the white dwarf by the donor star or an obscuration of the accretion region on the white dwarf by the accretion stream (stream dip). When discussing its likely nature, we are restricted to X-ray data; time-resolved optical photometry would facilitate an interpretation but none is available. We first reiterate the main observational features of this dip-like structure before discussing the possible implications of both hypotheses.

The dip is a persistent and consistently well-defined structure, it does not show any energy dependency, and its width is the same in both observations. The ingress into and the egress from the dip are not resolved in our data. These properties clearly argue in favor of the eclipse interpretation. In objects that show both an eclipse and a stream-dip or just the dip, the phase and width of the dip are often remarkably variable, with the phase of the dip showing a jitter or a trend with the mass-accretion rate, its width, and its energy dependence (see e.g., Schwarz et al. 2009; Clayton & Osborne 1994, for HU Aqr and EK UMa, respectively). None of these factors apply to the feature in XMM152737, which is a strong argument for an eclipse but does not definitively exclude a dip.

If we assume that XMM152737 is eclipsing, the following constraints on its geometry can be derived. Assuming the secondary star has a mass of 0.14 \(M_\odot\), following Knigge et al. (2011), and the white dwarf has a mass of 0.8 \(M_\odot\), we infer a minimum inclination of \(i > 80.5^\circ\) from the length of the eclipse.

![Fig. 12. lmfit model fit to the spectral region around the Hα emission line. The fit consists of a straight line approximating the continuum and a Gaussian for the line itself. Shown is the two-component fit with a red line and the data in blue in the upper panel, while the bottom panel shows the residuals of the fit.](image)
The center of the bright phase is located at $\phi_{\text{obs}1} = 0.88 \pm 0.03$ and $\phi_{\text{obs}2} = 0.84 \pm 0.03$. These values were determined as midpoints between phases of half light during the rise and fall to the main hump. The phase difference between the center of the bright phase and the eclipse gives the longitude of the accretion region; that is, a 0.12 and 0.16 phase unit difference between the bright phase center and eclipse. The angle we find of $50 \pm 18^\circ$ is typical for polars (Cropper 1988).

The colatitude of the accretion region ($\beta$) is difficult or impossible to determine with some precision. The bright phase length, $\Delta \phi > 0.5$, places the observer and accretion zone in the same hemisphere compared to the orbital plane (the “northern” or upper hemisphere). The radial and longitudinal extent of the region and potential contributions from another location on the white dwarf limit our conclusions about $\beta$. Polarmetric observations are necessary for distinctive results (see examples in Bailey & Axon 1981; Brainerd & Lamb 1985; Piirola et al. 1987).

Regarding XMM-Newton, the eclipsing scenario is perhaps questionable in one component. If the inclination is high and the accretion region is on the upper hemisphere, the matter that feeds the accretion region is crossing the line of sight. Other polars then show a stream dip. A prominent example is HU Aqr (Schwoppe et al. 2001). The absence of such a dip might challenge the proposed accretion geometry described above. However, there are counterexamples. V808 Aur is almost an exact copy of HU Aqr, in particular regarding its accretion geometry, but does not show X-ray dips; it only shows optical dips in the very high state (Worpel & Schwoppe 2015; Schwoppe et al. 2015). Furthermore, our spectral analysis reveals a high absorbing column depth, which could imply absorption in an extended accretion curtain instead of a more focused stream.

We now briefly discuss the alternative scenario, the dip-like feature is a stream-dip. We then infer $i > \beta$, that is, likely in the range $45^\circ < i < 75^\circ$, where the maximum value of $i$ is given by the lack of an eclipse. If XMM152737 is not eclipsing, the true phase zero is not known and can only be determined through phase-resolved spectroscopy tracing features originating from the secondary star (some absorption lines or narrow emission lines from the irradiated front side). Otherwise, one can only assume that XMM152737 shows an average behavior. If it does, then the stream dip might be suspected to occur at phase 0.85. True phase zero would occur somewhere at the end of the X-ray-bright phase, and therefore the main accretion column would then be situated at a considerable distance from the secondary star ($\psi > 90^\circ$). Such an accretion geometry is rather unusual for polars, which is a further argument against the stream-dip hypothesis.

4. Discussion and conclusion

Here, we present results acquired by integrating a comprehensive X-ray analysis of XMM-Newton with data collected from several sky surveys and the subsequent SALT observation of XMM152737. With the obtained data, we identify this object to be a polar-type magnetic CV.

XMM152737 was the target of two distinct XMM-Newton observations conducted over a time interval of one year. The light curves are very similar, and the periods derived from the period analysis demonstrate congruence, yielding identical values. The system has a singular period that corresponds to the synchronous rotation characteristic observed in polars. In particular, the power spectrum of the optical or X-ray light curves of intermediate polars indicates additional frequencies. These frequencies occur due to the lack of synchronization between the orbital motion and the spin of the white dwarf. Periodograms often exhibit complex frequency distributions (Norton et al. 1996). The distinct presence of a single period and its harmonics in the power spectrum, along with its short orbital period – which is highly reminiscent of polars (Ritter & Kolb 2003) –, lead us to classify XMM152737 as a polar.

The X-ray light curves have a prominent hump-like structure that encompasses a distinct dip-like feature. The observed deep structure exhibits a consistent width, despite being derived from distinct levels of X-ray emission. This feature leads us to assume that it is an eclipse. The length of the deep eclipse-like feature is similar to the length of the eclipse-like features found for known eclipsing polars HU Aqr (Schwarz et al. 2009) and V808 Aur (Worpel & Schwoppe 2015). In Obs 1, the HR variation is likely the same, changes within 0.0–0.2 in the bright phase, and is compatible with these known objects.

The low-resolution spectrum acquired from the SALT observation has prominent emission lines corresponding to hydrogen and helium, which are the most conspicuous characteristics indicative of its polar nature. The prevalence of the He II line is a characteristic linked to magnetic cataclysmic variables (Szkyodi et al. 2002). The spectrum displays two weak humps reminiscent of the cyclotron humps observed in polars. The object is considered to be a white dwarf with a weak magnetic field.

The almost simultaneous observations conducted by ZTF and ATLAS suggest that XMM152737 exhibits wide brightness variation over a timescale of years. This behavior was also detected by the eROSITA All Sky Survey. This high variability is a phenomenon observed in magnetic CVs with variation in the amount of mass flow and is common in some known polars (AM Her, Wu & Kiss 2008) and intermediate polars (MU Cam, Staude et al. 2008). Nevertheless, it is important to highlight that the significant variation in brightness observed in XMM152737 might be attributed to the fact that the observations studied here were obtained during distinct orbital phases, which exhibit pronounced eclipses. On the other hand, even in these distinct scenarios, the photometric period, X-ray behavior, and optical spectrum features of the system primarily indicate its polar nature.

The two XMM-Newton observations studied here exhibit different levels of X-ray emission. The temperatures we obtain are within the ranges indicated, especially for polars (Kuulkers et al. 2006). The spectra observed for Obs 1 exhibit a dominant presence of hard X-ray photons, which we attribute to reflection. Mukai (2017) observed that the temperature in the X-ray spectrum, particularly in magnetic CVs where hard X-rays are prevalent, could potentially be attributed to the phenomenon of reflection. The potential challenge in X-ray fitting described in the X-ray spectrum of X-ray spectrum is effectively addressed by the implementation of a complex absorber, in particular for Obs 1 in our case. Nevertheless, this issue is not observed in Obs 2.

The X-ray spectra acquired from both observations exhibit an absence of the typical blackbody emission characteristic of polars. This feature was also not visible in the discovered polars by XMM-Newton (Ramsay & Cropper 2004) and first recorded polar discovered by the eROSITA All Sky Survey (Schwoppe et al. 2022). Another intriguing finding derived from the spectra of XMM152737 pertains to the high column densities derived from the bright phase, which are considerably higher than the Galactic column density. The significant column density can be attributed to either partial absorption by dense material or absorption by ionized material. The spectral fit in magnetic CVs
frequently suggests the existence of a partial obscuring absorber, where some photons are detected directly, while others can be seen through an intervening absorber. The 45% partial absorption seen in Obs 1 appears to be in line with this. This physical behavior indicates that the absorber is comparable in size to the X-ray-emission region and may be located close to the white dwarf or within the binary itself (Mukai 2017). In the deep dip were found to correspond to an eclipse, one would expect to observe the accretion stream 0.1–0.2 phases before the deep dip in the bright phase. While the light curves do not provide a clear indication of the absorption impact caused by the accretion stream, the presence of a high column density in the spectrum suggests a potential correlation with this accretion element. In particular, the high column density obtained in the bright phase is similar to those previously obtained from EXOSAT observations of EF Eri, a known polar (Watson et al. 1989). For EF Eri, these column densities were often obtained at the dip regions related to the stream. In the case of XMM152737, the source of this absorption is perhaps an extended accretion curtain covering the entire bright phase and covering the accretion column.

According to the results presented here, we strongly believe that XMM152737 is a polar-type CV. We are unable to find any further information on the object in other data archives in addition to the data provided here. The data employed in this study do not provide sufficient information to accurately describe the status of the eclipse-like feature. High-speed photometric measurements are necessary in order to gain a more comprehensive understanding of this behavior. The addition of new samples to CVs is of great importance as they are crucial for understanding how these systems evolve and occur as they are at the last step of stellar evolution. We hope that studies of these objects will also help us to understand the distribution of magnetic CVs and the presence of magnetism in the Milky Way. Advanced tools like eROSITA now have the resolving power to detect these typically faint sources.

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