XMM-Newton slew survey discovery of the nova XMMSL1 J070542.7-381442 (V598 Pup)

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ABSTRACT

Aims. In an attempt to catch new X-ray transients while they are still bright, the data taken by XMM-Newton as it slews between targets is being processed and cross-correlated with other X-ray observations as soon as the slew data appears in the XMM-Newton archive.

Methods. A bright source, XMMSL1 J070542.7-381442, was detected on 9 Oct 2007 at a position where no previous X-ray source had been seen. The XMM slew data and optical data acquired with the Magellan Clay 6.5 m telescope were used to classify the new object.

Results. No XMM slew X-ray counts are detected above 1 keV and the source is seen to be ∼750 times brighter than the ROSAT All-Sky Survey upper limit at that position. The normally mV∼16 star, USNO-A2.0 0450-03360039, which lies 3.5″ from the X-ray position, was seen in our Magellan data to be very much enhanced in brightness. Our optical spectrum showed emission lines which identified the source as a nova in the auroral phase. Hence this optical source is undoubtedly the progenitor of the X-ray source—a new nova (now also known as V598 Pup).

The X-ray spectrum indicates that the nova was in a super-soft state (with kTeff≈35 eV). We estimate the distance to the nova to be ∼3 kpc.

Conclusions. The XMM-Newton slew data present a powerful opportunity to find new X-ray transient objects while they are still bright. Here we present the first such source discovered by the analysis of near real-time slew data.

Key words. Novae – Stars: individual: V598 Pup – Surveys – X-rays: general

1. Introduction

While optically detected novae are fairly common, the discovery of Galactic novae by their X-ray emission is rare due to the large sky area which needs to be surveyed. In the whole of the ROSAT All-Sky Survey (RASS) for instance, ROSAT discovered only 3 new novae and detected a further 4 previously known ones (Orio et al. 1993). X-ray emission from several optical novae in M31 has been detected (Pietsch et al. 2007), and it is thought (e.g. Mukai et al. 2008) that many X-ray transient sources may be classical novae.

To date, the publicly available XMM-Newton slew data covers over 25% of the sky, while the soft band (0.2–2 keV) slew sensitivity limit (6×10^{-13} ergs cm^{-2} s^{-1}) is close to that of the RASS (the hard-band [2–12 keV] limit is 4×10^{-12} ergs cm^{-2} s^{-1}). For details of the slew data analysis, the construction and characteristics of the first slew survey catalogue, and the first science results see Saxton et al. (2008) and Read et al. (2006). The near real-time comparison of XMM-Newton slew data with ROSAT data is now giving, for the first time, the opportunity to find all manner of high-variability X-ray objects, e.g. tidal disruption candidates – black holes at the centres of galaxies, currently being fuelled by the tidal disruption of a star (Esquej et al. 2007), plus AGN, blazars, and also Galactic sources such as novae, flare stars, cataclysmic variables and eclipsing X-ray binaries. It is only with such a large-area survey as the XMM-Newton Slew Survey, that such rare events have a chance of being caught. In an effort to find transient X-ray sources while they remain active, we are now attempting to perform the slew data acquisition, reduction, analysis and source-searching as quickly as possible. Catalogue cross-correlations with RASS and ROSAT pointed data fluxes and upper limits are swiftly preformed to identify highly variable X-ray candidates. Slew datasets are made available in the XMM science archive (XSA) typically ∼10 days after the slew has been per-
formed. This systematic processing of the most recent data has been performed since October 2006.

One such rare event, XMMSL1 J070542.7-381442 was discovered in an XMM slew from 9 Oct 2007. In this letter we describe the XMM-Newton slew observations, the identification of the optical counterpart and a spectral confirmation of the source as a nova. The optical lightcurve of the source up to six months after outburst is also presented.

2. XMM-Newton slew observations

XMMSL1 J070542.7-381442 was discovered at an X-ray position of 07:05:42.7-38:14:42 (J2000; error radius: 8") in slew 9143400002, made in the EPIC-pn full-frame mode using the medium filter (Read et al. 2007a). Contours of the XMM-Newton slew data are shown superimposed on an optical DSS image in Fig.1. This sky position has not yet been observed during any other XMM-Newton slew.

The source passed through the centres of CCDs 3 & 12 of the EPIC-pn detector in 14 s, at a large off-axis angle (minimum 14°) such that an effective vignetting-corrected soft band (0.2−2 keV) exposure time of 3.9 s was achieved. A total of 210 source counts lie within a radius of 20", yielding a (EPIC-pn: 0.2−2 keV) count rate of 54.5 ct s⁻¹, after correcting for the encircled energy function. The high count rate indicates that the spectrum is affected by pile-up, though the effect here, far off-axis, is less than on-axis (the on-axis limit is 6 ct s⁻¹ for EPIC-pn full-frame mode). X-ray loading (Smith 2004), where events below the cut-off threshold sum together to produce artificial accepted events, is also present. These effects work to distort the spectrum and make quantitative spectral analysis difficult. One can minimize these effects by ignoring the central part of the Point Spread Function, and we therefore extracted a spectrum of the source from within an annulus of 5°−60° radius, centred on the source position. Just single events were selected, and these were spectrally grouped to give a minimum of 20 counts per bin. Slew data also has as yet unresolved problems associated with the motion of the source across the detector: approximations currently have to be made when calculating the associated effective area and detector response matrix files. To perform a qualitative spectral analysis, an effective area file, accounting for the removal of the piled-up core, was generated by averaging the individual core-removed effective area files at 9 different positions along the detector track made by the source. This takes into account to a good approximation the variations in the vignetting and the PSF. Individual BACKSCAL values have been set by hand, as have the EXPOSURE values, estimated by calculating the distance travelled by the source in detector coordinates and finding the time taken to do this given a 90 deg hr⁻¹ slew speed, then subtracting the appropriate fractions for chip gaps and bad pixels (calculating the exposure time from the source lightcurve, gives the same value to within a few tenths of a second). For the response matrix, we used the equivalent canned detector response matrix for the vignetting-weighted average source position, for single events and for Full Frame mode: epn_1f20w_y6_6.9.rmf. A background spectrum was extracted from a much larger region close to the source and at a similar off-axis angle.

Simple power-law, blackbody, thermal Bremsstrahlung and optically thin hot plasma models are unable to fit the spectrum adequately (all have a χ² < 12 for 6 degrees of freedom). Given that the source is identified as a nova (Section 3), a more physically realistic white dwarf atmosphere model, of the type used to model the nova V1974 Cyg (Balman et al. 1998), was used, yielding an acceptable fit (reduced χ² = 1.4), an effective temperature of 35 ± 1 eV and an N_H of 4.8 ± 2 × 10²⁰ cm⁻² (errors 90% for one interesting parameter). The spectrum and model fit are shown in Fig.2. The model normalization can be used to derive a distance to the source (assuming the emission to be sub-Eddington, and a typical emitting region of spherical radius 10⁸ cm) of 8 ± 2.3 kpc. A PIMMS² v3.9d conversion of the RASS 0.0076 ct s⁻¹ 2σ upper limit corresponds to an EPIC-pn limit ~750 times less than observed of 0.073 ct s⁻¹, assuming the same spectral model.

3. Optical observations

The field containing XMMSL1 J070542.7-381442 was observed on 16 Nov 2007 with the Magellan Clay 6.5m telescope at Las Campanas Observatory. A bright, saturated optical counterpart was found, with a position consistent with the m_v~16 point-like source USNO-A2.0 0450-03360039, at a distance of 3.5° from the slew position. On the basis of the positional coincidences, the USNO object was proposed as a possible progenitor to the nova (Read et al. 2007a, Torres et al. 2007). This claim was confirmed with the detection of the radio counterpart to the slew source, which has a high-precision position consistent with the USNO object (Rupen et al. 2007).

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1. http://xmm.esac.esa.int/external/xmm_user_support/documentation/w3pimms.html
2. http://heasarc.nasa.gov/Tools/w3pimms.html
Spectroscopic observations of the optical counterpart were obtained with the Low Dispersion Survey Spectrograph (LDSS-3), equipped with the 400 line mm$^{-1}$ VPH ALL grism and a mask with a 1′′ width long-slit cut near the centre of the field of view. The detector was the STA0500A 4k×4k unbinned CCD. This setup allowed us to cover the spectral range 3510–10620 Å with a dispersion of 2.0 Å pix$^{-1}$ and a resolution of ≈ 8 Å FWHM. Several exposures (2×1 s, 1×2 s, 1×5 s and 1×60 s) were obtained. These spectra were affected by second-order light contamination beyond ∼7000 Å. In order to obtain useful coverage in the red, we also acquired 1 s, 5 s and 60 s spectra with the OG590 order-blocking filter, giving useful 5800–10620 Å wavelength coverage. The frames were reduced using standard routines in IRAF. The spectra were then extracted and wavelength-calibrated with the help of HeNeAr calibration lamp spectra. The instrumental response was corrected using spectroscopic standard stars observed with and without the blocking filter. The shape of the continuum is reliable except at the blue and red ends.

A blue and a red spectrum are shown in Fig. 3. The spectra were obtained 163 days after the maximum optical brightness reported by Pojmanski et al. (2007) (see Section 4). The data show emission lines characteristic of a late post-outburst nova spectrum. The strongest lines in the blue spectrum are [O III] $\lambda$5007, 4959 followed by H$\alpha$ blended with [N II] $\lambda$6583, [O III] $\lambda$4363 (blended with H$\gamma$), [N II] $\lambda$5755 and H$\beta$. The strongest emission feature in the red spectrum is due to [O III] $\lambda$$\lambda$7319–7330 auroral transitions. The emission lines have an average FWHM of 2070 ± 50 km s$^{-1}$, as derived from isolated line profiles and correcting for the instrumental broadening. H$\beta$ is stronger than He II $\lambda$4686. This characteristic together with the presence of strong forbidden [O III], [N II] and [O III] auroral lines, and weak Ne lines suggest that this source was a Fe II nova (see e.g., Williams 1992). However, the data were acquired too long after maximum light to make an accurate classification possible. The nova was observed in the A0 auroral phase according to the Tololo classification (Williams et al. 1991; Williams et al. 1994) – any forbidden auroral transition at wavelengths $\lambda$$\lambda$3600–7600 has a flux larger than that of the strongest non-Balmer permitted lines, and [O III] $\lambda$4363 is the strongest auroral transition. The coronal [Fe x] $\lambda$6375 line (if present) is weaker than [Fe v] $\lambda$6375, excluding the possibility of a coronal stage.

4. Optical light curve

Analysis of archival robotic optical survey data from 3-minute CCD exposures (pixel size 14″.8), obtained with a 70 mm (200 mm focal length) f/2.8 telephoto lens in the course of the All Sky Automated Survey (Pojmanski 2002) show that the visual magnitude of this source rose from $m_V$$\sim$14 to $m_V$$\approx$4.1 between 2 Jun (23:27 UT) and 5 Jun (23:13 UT) 2007, and has declined since (see Fig. 4). The source was seen to be saturated...
in the June 5th observation, and it is thought that the source may have been 0.1–0.5 magnitudes brighter. The decline from outburst (±2.4 magnitudes in 12 days, then a further 2.8 magnitudes in 62 days) indicates that this is a nova of speed class 'very fast' (Warner 1995). The later decay rate (mid-August onwards) is 1.36±0.04 mag per 100 days (including errors to obtain a reduced \(\chi^2\) of \(\approx 1\) for the fit).

5. Discussion

XMM-SL J070542.7-381442, as a confirmed classical nova, has been given the name V598 Puppis (Samus 2007). With a peak \(m_V\leq4\), it is one of the brightest optical novae seen for many years. A \(m_V\leq4\) nova has been discovered in eruption every 8 years or so (Warner 1995), and the only nova discovered in recent decades of comparable peak optical magnitude are V382 Vel (\(m_V\leq3\)) and V1494 Aql (\(m_V\leq4\)), both discovered in 1999, and V1280 Sco (\(m_V\leq4\)), discovered in Feb 2007.

On the basis of the optical spectrum, this nova was observed in the \(A_0\) auroral phase, and was likely a very fast, Fe\(\pi\) nova (Section 3 and Williams et al. 1991; Williams et al. 1994), though an accurate classification is now, late after maximum brightness, not possible. The soft (\(kT_{\text{eff}}\approx35\) eV) X-ray spectrum indicates that the nova was in a super-soft state (Pietsch et al. 2007). Such a state is due to nuclear burning on the white dwarf (Ness et al. 2007). Measurement of its intensity, duration and temperature can constrain the distance to the nova and the mass of the white dwarf (e.g. Balman et al. 1998; Lanz et al. 2005). From the slew measurement of V598 Pup, we see that the delay from the outburst (2–5 Jun 2007) to the onset of the X-ray super-soft state is \(\approx127\) days. This is short when compared with the \(\approx200\) days seen in V1974 Cyg (Krautter et al. 1996), \(\sim6\) months of V382 Vel (Orio et al. 2002) and 6–8 months of V1494 Aql (Drake et al. 2003), but long when compared with the 29 days of RS Oph (Osborne et al. 2006).

From the Galactic latitude and the fact that the Galactic scale height of white dwarfs is \(<500\) pc (conservatively, Nelson et al. 2002), an upper limit to the distance of V598 Pup of \(\approx2.1\) kpc can be derived, consistent with the 4.3±2.3 kpc, estimated from the X-ray spectral fitting. Another way to estimate the distance is to use the relation between absolute magnitude at maximum brightness and the time, \(t_2\), that the light curve takes to decline 2 magnitudes below maximum brightness (see e.g. equation 5.2 in Warner 1995). Using \(t_2\approx9\pm1\) days, we estimate \(M_V\approx-8.4\pm0.4\). With \((\mu_V=0.27\pm0.15\) (90% error), as derived (Predehl & Schmitt 1995) from \(N_V=4.8\times10^{20}\) cm\(^{-2}\), \(M_V=8.4\pm0.4\) and peak \(m_V=4.1\), we derive a distance of 2.8\(_{-0.8}^{+0.4}\) kpc. An absolute magnitude of \(M_V=-8.4\) would imply a peak luminosity of order \(\sim7\) times the Eddington luminosity for a \(1 M_\odot\) white dwarf. This is quite typical for novae. The source had, at the time of the slew detection, an absorbed \((0.2–2\) keV) X-ray flux of \(1.54_{-0.23}^{+0.08}\times10^{-10}\) erg cm\(^{-2}\) s\(^{-1}\), corresponding to, assuming a distance of 3 kpc, a \((0.2–2\) keV) X-ray luminosity of \(1.6_{-0.2}^{+1.0}\times10^{38}\) erg s\(^{-1}\), and a bolometric luminosity of \(2.4_{-0.7}^{+1.7}\times10^{36}\) erg s\(^{-1}\) (errors calculated at the boundary of the 90% region for two interesting parameters; \(N_V\) & \(kT_{\text{eff}}\)). This is at the lower end of the super-soft luminosities discussed e.g. in Orio et al. (2002) and Ness et al. (2007).

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Fig. 4. V-band magnitudes from Pojmanski et al. (2007) of the optical counterpart to XMM-SL J070542.7-381442. The 2007 dates of the XMM-Newton slew and Magellan observations are marked.