

# Tidal disruption events seen in the XMM-Newton slew survey

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**Abstract.** XMM-Newton performs a survey of the sky in the 0.2-12 keV X-ray band while slewing between observation targets. The sensitivity in the soft X-ray band is comparable with that of the ROSAT all-sky survey, allowing bright transients to be identified in near real-time by a comparison of the flux in both surveys. Several of the soft X-ray flares are coincident with galaxy nuclei and five of these have been interpreted as candidate tidal disruption events (TDE). The first three discovered had a soft X-ray spectrum, consistent with the classical model of TDE, where radiation is released during the accretion phase by thermal processes. The remaining two have an additional hard, power-law component, which in only one case was accompanied by radio emission. Overall the flares decay with the classical index of  $t^{-5/3}$  but vary greatly in the early phase.

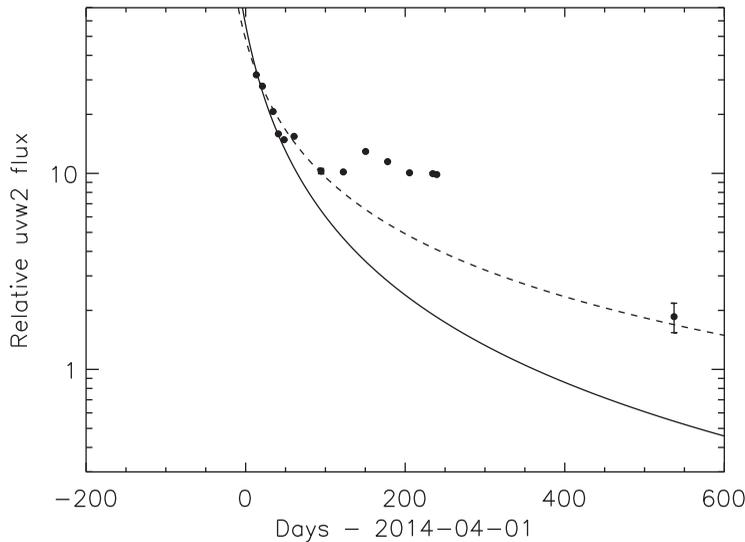
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## 1. Introduction

A tidal disruption event (TDE) occurs when a stellar object is gravitationally destroyed and subsequently accreted by a super-massive black hole (SMBH). It represents the onset of a brief phase of accretion activity in an otherwise dormant galactic nucleus and is characterised by a sudden dramatic rise in luminosity, and a decline to quiescence on a timescale of months to years.

Early work predicted that stellar debris would return into a tightly bound orbit about the SMBH and form an optically thick accretion structure close to the SMBH (e.g. Rees 1988). This would emit thermal radiation of temperature  $kT_{eff} \approx 40M_6^{-1/4}$  eV (Ulmer 1999) whose high energy tail would be visible in the soft X-ray band. Pioneering observations by ROSAT identified several X-ray flares in non-active galaxies (Komossa & Bade 1999; see Komossa 2015 for a recent review) characterised by a very soft X-ray spectrum. Explanations such as variable AGN, blazars, ULX, supernova or supernova remnants were excluded by the amplitude of the variability (factor  $> 1000$  for NGC 5905 and RXJ 1242-1119; Komossa *et al.* 2004) and high luminosities of up to several  $\times 10^{44}$  ergs/s. As their light curves have fallen consistently with the predicted rate,  $t^{-5/3}$  (Rees 1988, Guillochon & Ramirez-Ruiz 2013), TDEs are the most likely explanation for these events.



**Figure 1.** The Swift-uvw2 filter (1928Å) light curve of XMMSL1 J0740-85 fit with indices of  $-5/3$  (solid line) and  $-1.2$  (dashed).

## 2. XMM-Newton slew survey

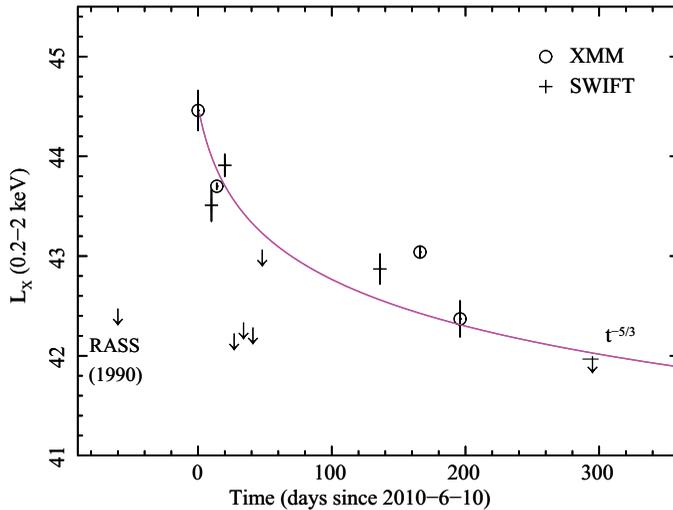
The XMM-Newton slew survey collates the data taken by the EPIC-pn camera while the satellite moves between targets. It has a sensitivity in the 0.2–2 keV energy band which is well matched with the ROSAT all-sky survey. Comparisons between these two surveys have led to the detection of several transient sources, including five candidate TDEs (Tab. 1). NGC 3599 and SDSS J1323+48 were found in archival data (Esquej *et al.* 2008) while SDSS J1201+30 (Saxton *et al.* 2012), 2MASX J0619-65 (Saxton *et al.* 2014) and XMMSL1 J0740-85 (Saxton *et al.* 2017) were found at the peak of their emission and had their decays monitored with Swift and XMM-Newton. XMMSL1 J063045.9-603110, a bright slew transient from 2011, has been proposed as a TDE in a dwarf galaxy (Mainetti *et al.* 2016). However, a contemporary optical spectrum localised the flare to the local group (B. Cenko, p.comm.) and so this remains unconfirmed.

The initial estimate of the tidal disruption rate from the XMM-Newton slew data was given as  $2.3 \times 10^{-4} \text{ gal}^{-1} \text{ yr}^{-1}$  (Esquej *et al.* 2008) based on two TDE. Scaling this calculation for the five which have now been found in data taken up until the end of 2014, gives a somewhat lower value of  $1.4 \times 10^{-4} \text{ gal}^{-1} \text{ yr}^{-1}$ .

### 2.1. Temporal characteristics

The XMM-Newton slew survey TDEs have faded in X-rays over periods of 6 months and more with an index compatible with  $t^{-5/3}$  in line with the ROSAT TDE and the original expectations. In XMMSL1 J0740-85 the UV flux fell with a flatter index of  $\sim 1.2$  (Fig. 1). This could be due to more flux entering the UV band as the flare cools. In detail though, the UV curve is seen to recover after about 100 days; a behaviour seen in other TDE (e.g. LeLoudas *et al.* 2016.). In analogy with the "supernova hump" in GRB this may imply a secondary emission mechanism; possibly circularisation and infall (LeLoudas *et al.* 2016; Krolik *et al.* 2016) or expelled unbound debris shocking against the ambient medium (Khokhlov & Melia 1996).

There is a lot of variability in the X-ray light curves. About 20 days after discovery, SDSS J1201+30 dropped in X-ray flux by a factor 50 within 1 week (Fig. 2). A similar



**Figure 2.** The 0.2–10 keV light curve of SDSS J1201+30 fit.

drop after  $\sim 30$  days was seen in XMMSL1 0740-85. The spectrum actually softens during the drop in 0740-85 excluding variations in neutral absorption and leaving ionised absorption or a change in the intrinsic emission as possible causes. Liu, Li & Komossa (2014) interpret the dip as evidence for a close binary black hole system, where the fall back of material onto the primary black hole is interrupted by the presence of the secondary.

Simulations have shown that the development of a TDE light curve is dependent on when the streams of tidal debris intersect each other (Hyashiki *et al.* 2013; Guillochon & Ramirez-Ruiz 2015; Shiokawa *et al.* 2015). Early interactions appear to be rare and in the majority of cases circularisation occurs late and at a large distance from the SMBH, leading to a *delayed* TDE with a longer rise to peak and a plateau that lasts months or even years. NGC 3599 with a plateau of  $\geq 18$  months may have been a *delayed* TDE (Saxton *et al.* 2015). Optically-selected TDEs have either no X-ray emission or flat X-ray light curves with  $L_X$  of a few  $\times 10^{41-42}$  ergs/s (e.g. ASSASN 14li, Holohein *et al.* 2016; ASSASN 15lh, Margutti *et al.* 2016). We are investigating a TDE recently found in the slew survey with similar behaviour. It could be that these TDEs are all delayed in some way, however there is a similarity between the luminosity and X-ray light curves of these events and those of extremely luminous young supernova remnants such as SN 2006jd (Stritzinger *et al.* 2012) and SN 2010jl (Chandra *et al.* 2012). The featureless TDE spectra, nevertheless, argue against the X-ray emission being produced by ISM shocks.

## 2.2. Spectral characteristics

Material falling back to the inner orbits around a  $10^{6-7} M_\odot$  black hole will heat up and emit radiation with an equivalent temperature of a few tens of eV. While this broadly matches the emission seen in the soft X-ray spectrum in no case have we been able to join the X-ray and UV emission with a single thermal multi-colour disk model.

In two of the slew sources, XMMSL1 J0740-85 and 2MASX J0619-65, a hard component is visible, stretching out to at least 10 keV. A similar component was seen in NGC 4845 (Nikolajuk & Walter 2013) and ASASSN-15oi (Holoien *et al.* 2016b). Weak radio emission was seen in NGC 4845 and XMMSL1 J0740-85 (Alexander *et al.* 2016) consistent with an outflow or a weak relativistic jet. This implies that a source of high-energy comptonising

**Table 1.** Candidate TDE found in the XMM-Newton slew survey.

Name	z	Log(L <sub>bol</sub> )	Flare? <sup>1</sup>		
			Soft-X	Hard-X	Radio
NGC 3599	0.002	42	Y	N	?
SDSS 1323+48	0.07	44	Y	N	?
SDSS 1201+30	0.146	45	Y	N	N
2MASX 0619-65	0.07	44	Y	Y	N
XMMSL1 0740-85	0.019	44	Y	N	Y

Notes:

<sup>1</sup>Was there a flare at this wavelength?

electrons, analogous to the comptonising corona of a steady-state AGN, can be produced during disruptions.

### 2.3. Host galaxy

A disproportionate fraction of optically-selected TDE are found in post-starburst galaxies (Arcavi *et al.* 2014), a feature that is shared by XMMSL1 J0740-85. Arcavi *et al.* (2014) suggested that starbursts triggered by galaxy mergers could produce binary black holes that dynamically enhance the TDE rate. Alternatively, starbursts could create central stellar overdensities where enhanced encounter (two body relaxation) rates lead to more TDE flares (Stone & Metzger 2016).

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