Tidal disruption events from the first XMM-Newton Slew Survey

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Outline

- Detection of tidal disruption events in X-rays using XMM-Newton slew data
- Determination of properties close to the outburst
  - Do they agree with previous candidates?
- Evolution of the events - X-ray and optical follow-up
  - Do post-outburst optical spectra show any evidence of the disruption event?
  - Is the X-ray luminosity following the expected behaviour $t^{-5/3}$ law?
  - Is the observed variability an isolated or recurrent event?
- Properties of the candidates (e.g. M_{BH}, released energy, accreted mass)
- Tidal disruption rate

The XMM-Newton Slew Survey Source Catalogue

- Shallow survey of the sky taking advantage of the time spent manoeuvring the telescope – intermediate position between pencil-beam looks and dedicated all-sky surveys.

- Cross-correlation with the RASS – scientific validation of the slew catalogue.

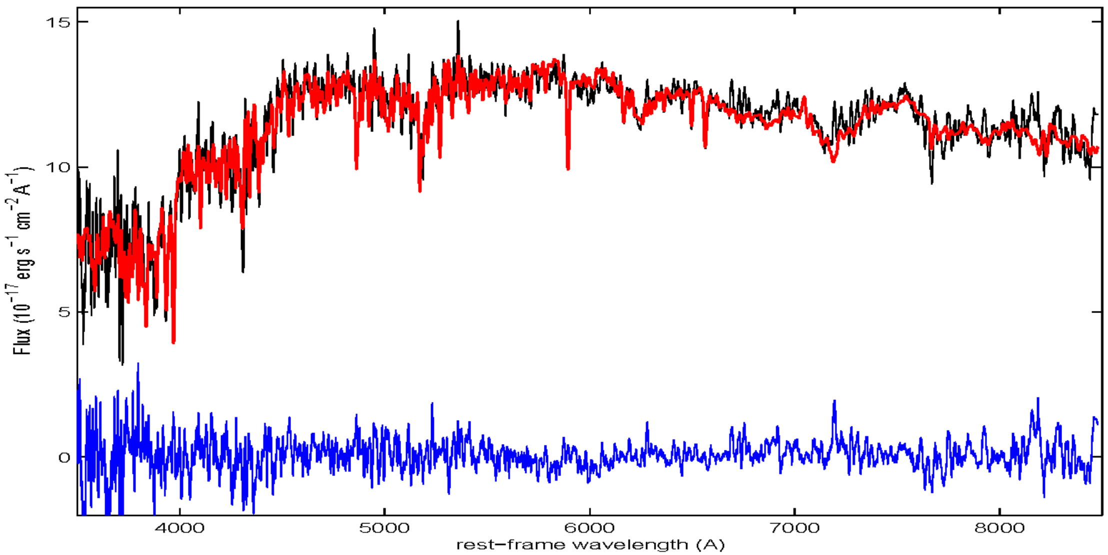
- 5 highly variable sources previously classified as non active galaxies:
  - variability factors from 20 to 90
  - soft X-ray spectra
  - Soft X-ray luminosities from 10^{42}–10^{44} erg s^{-1}

Candidate selection

- X-ray and optical follow up observations of all 5 of them.
- Three were discarded as TDE
  - strong optical emission lines
  - luminosity decline not compatible with TDE
  - we are investigating them in the context of AGN outbursts
- Two good candidates - this talk!
  - SDSS J1323 and NGC 3599 with variability factors of 83 and 88 (~150 using ROSAT pointing) respectively.

SDSS J1323: Optical data

Pre-outburst spectrum



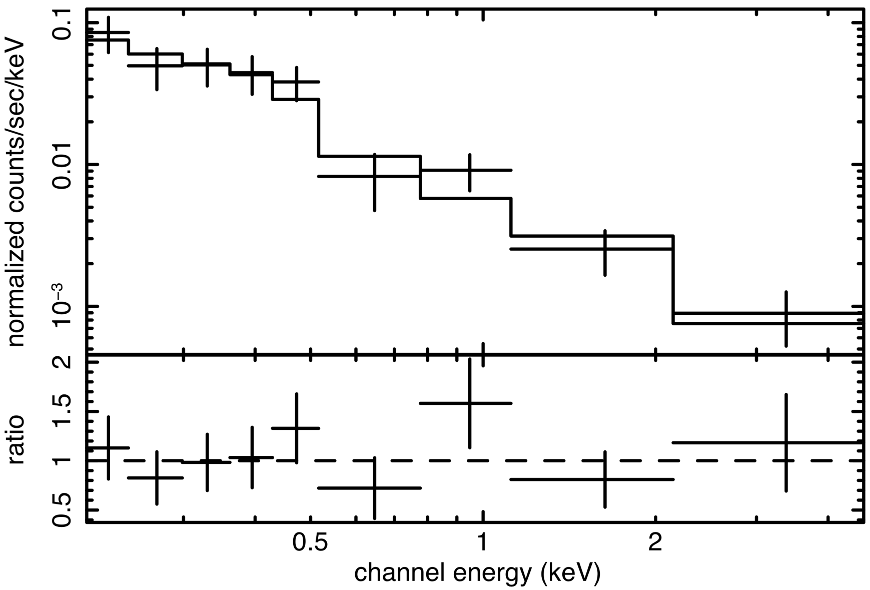
z = 0.087
Non-active galaxy

original data (SDSS)
stellar component
nuclear emission

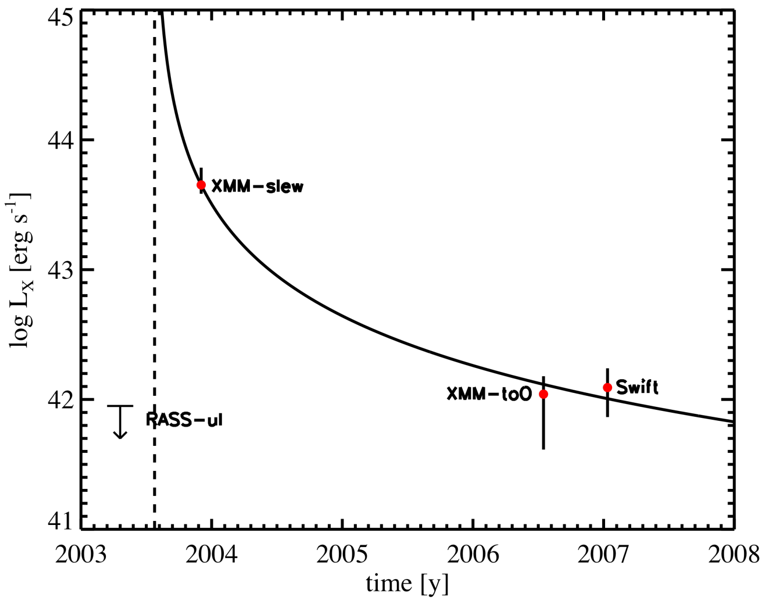
- Optical post-outburst follow-up at the NOT: No evidence of the disruption event.

SDSS J1323: X-rays follow-up

- XMM-Newton slew: no photons >2 keV
- XMM-Newton ToO (4.5 ks)
  - Bbody (kT=62eV) + Powerlaw (Γ=1.4)



X-ray light curve



- Swift (4 ks)

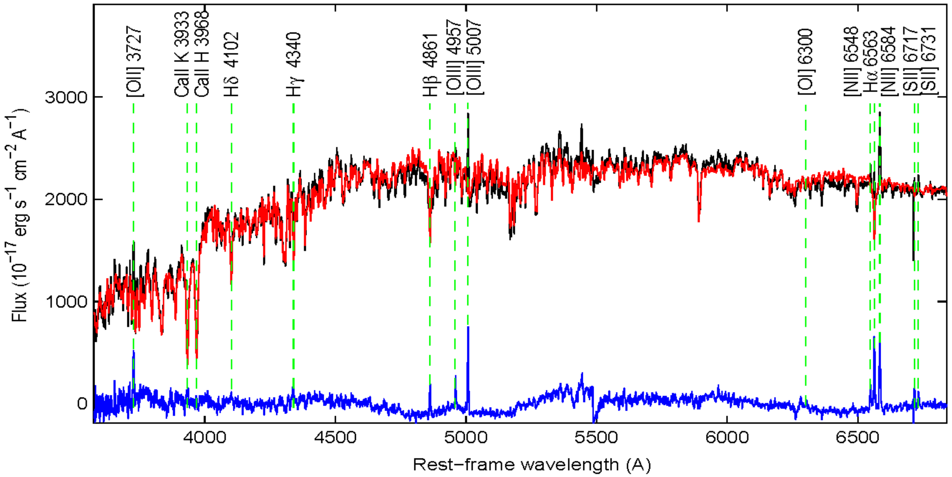
$$L_X = 8.1(\pm 2.9)\cdot 10^{42}\left[\frac{t-2003.56(\pm 0.10)}{1yr}\right]^{-5/3} erg\ s^{-1}$$

NGC 3599: Optical data

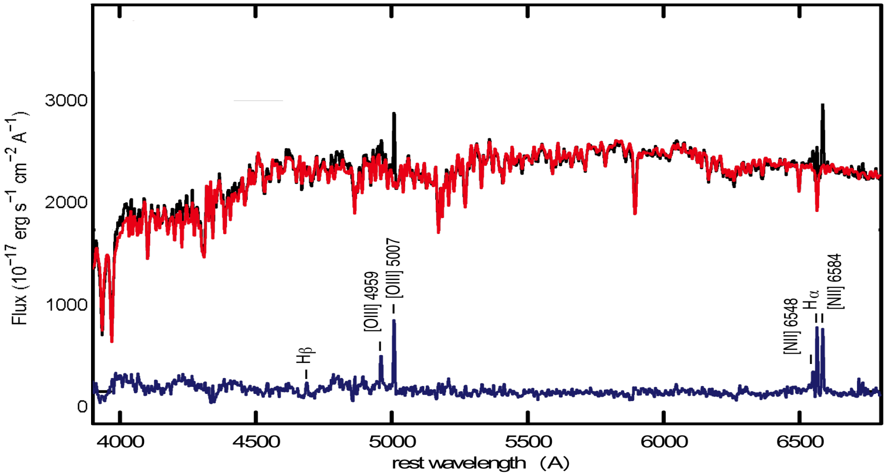
- z = 0.0028
- NELG – Seyfert/LINER

Pre-outburst spectrum

Post-outburst spectrum



Original data (black) from Caldwell et al. (2003)



Data (black) from INT observation

- Follow-up observations at the NOT and the INT. Post-outburst spectrum did not show any evidence of the disruption event.

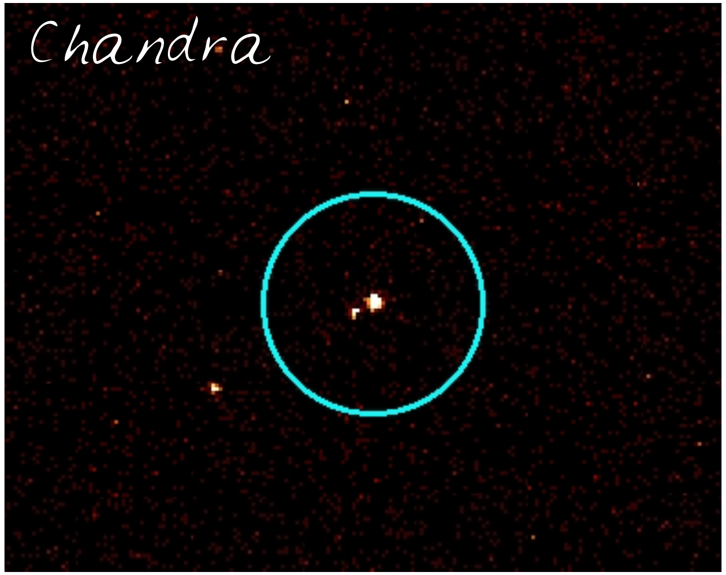
NGC 3599: X-ray follow-up

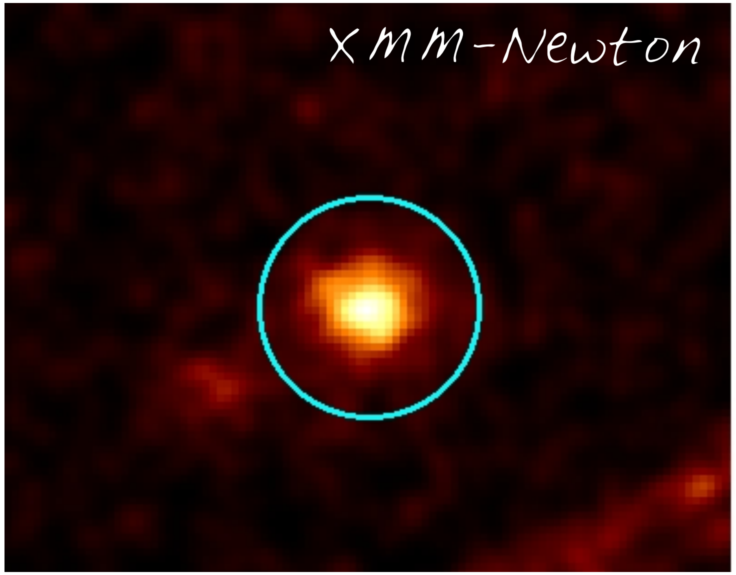
- XMM-Newton ToO (~4 ks)
- Swift - Fill-in time (~4 ks)

Esquej et al. 2008

- Chandra (~18 ks)
- XMM-Newton (~35 ks)

Esquej et al. in prep.

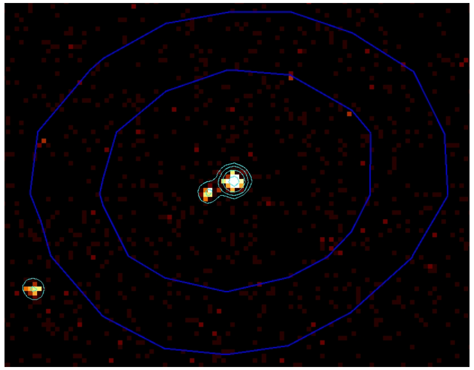




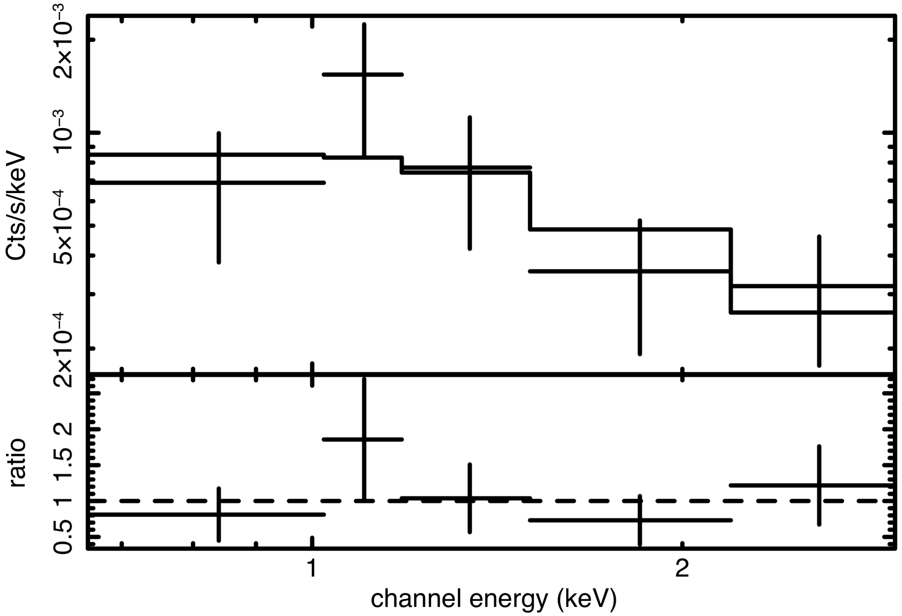
- Bright source coincident with the centre of the optical position
- Faint off-nuclear source at 3 arcsec (300 pc)

ULX within NGC 3599

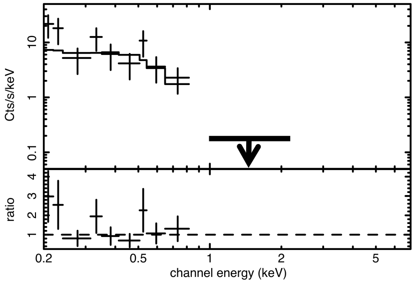
- Low statistics: 35 counts
- No photons below 0.4 keV
- Hard spectrum:
  - power-law with $\Gamma = 1.5$
- $L_X = 3 \times 10^{38}$ erg s^{-1}
- ULX in a low/hard state?
  - low luminosity, hard spectrum
  - A new (deeper) Chandra observation in needed.



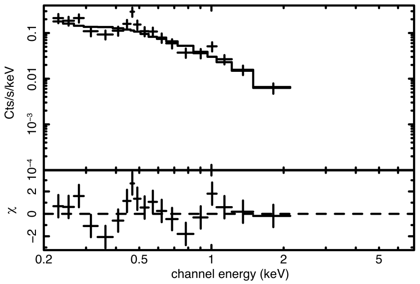
Chandra ACIS-S image of 40" x 50" centred on the optical position of NGC 3599. Optical DSS contours are overplotted in blue.



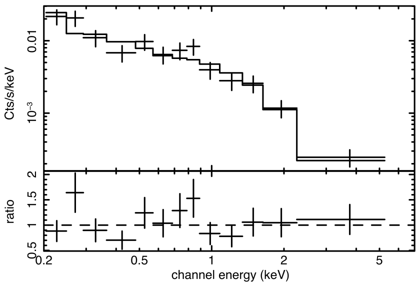
NGC 3599: X-ray spectra



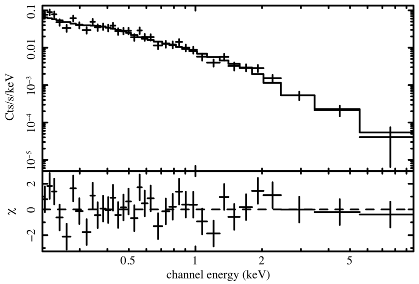
- XMM-Newton slew
  - Total counts: 50 cts (13 s)
  - Bbody (kT=95eV) or power-law (Γ=3)
  - $L_{0.2-2.0keV}=7 \times 10^{41}$ erg s^{-1}



- XMM-Newton ToO
  - Total counts: ~450 cts (4 ks)
  - Bbody (kT=20 eV) + power-law (Γ=2.8)
  - $L_{0.2-2.0keV}=2.0 \times 10^{40}$ erg s^{-1}; $L_{0.2-12keV}=2.2 \times 10^{40}$ erg s^{-1}



- Chandra (nucleus)
  - Total counts: ~200 cts (20 ks)
  - Bbody (kT=22eV) + power-law with (Γ=2.7)
  - $L_{0.2-2.0keV}=6.0 \times 10^{39}$ erg s^{-1}; $L_{0.2-12keV}=6.6 \times 10^{39}$ erg s^{-1}



- XMM-Newton
  - Total counts: ~1100 cts (36 ks)
  - Bbody (kT=42 eV) + power-law (Γ=2.7)
  - $L_{0.2-2.0keV}=3.7 \times 10^{39}$ erg s^{-1}; $L_{0.2-12keV}=4.9 \times 10^{39}$ erg s^{-1}

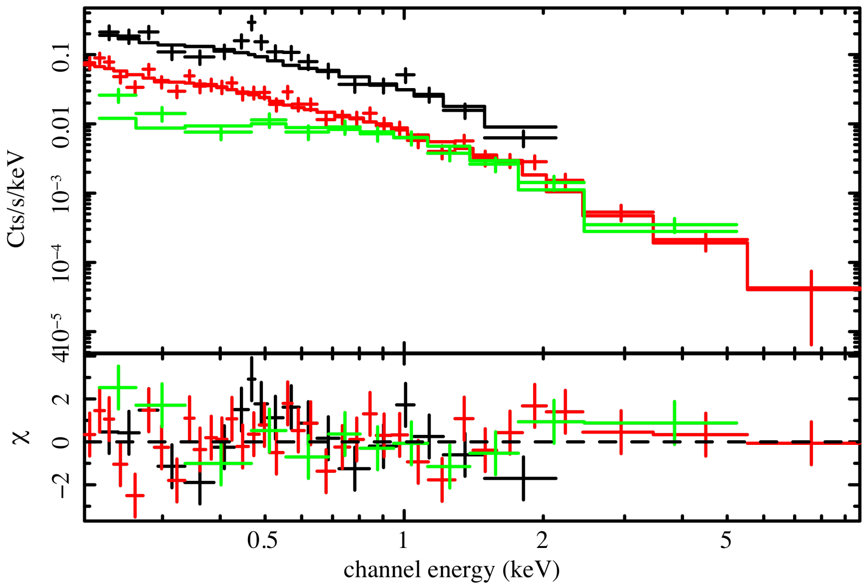
NGC 3599: X-ray data

No significant spectral evolution

Simultaneous fit of X-ray spectra:

Off-nuclear source

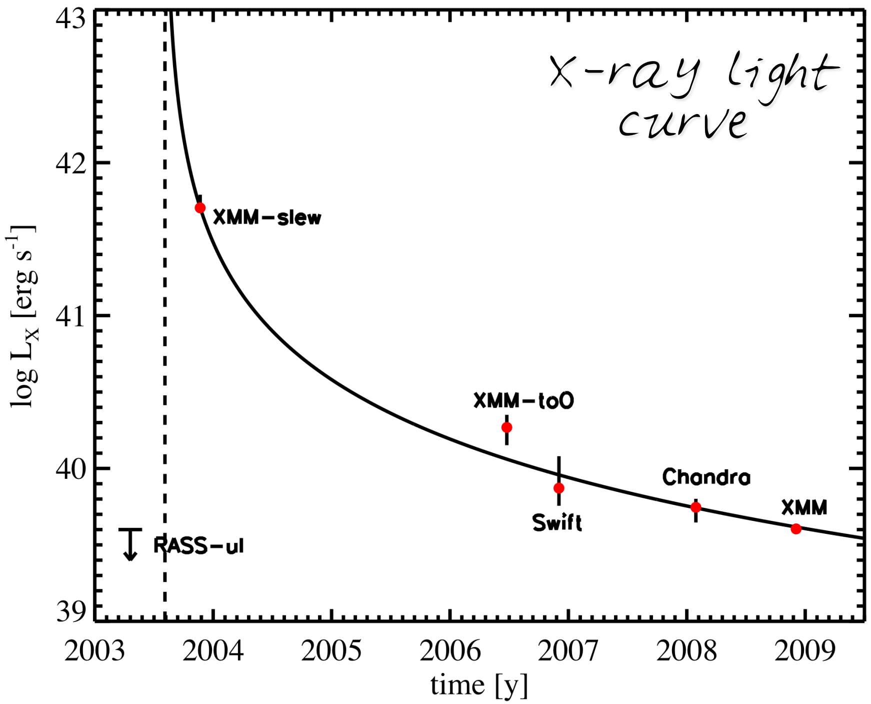
Nucleus: Bbody (kT=44 eV) + power-law (Γ=2.7)



XMM-ToO

Chandra

XMM-AO



$$L_X = 6.7(\pm 1.2) \cdot 10^{40} \left[\frac{t - 2003.59(\pm 0.04)}{1 yr} \right]^{-5/3} erg\ s^{-1}$$

Properties of tidal events

Released energy: $$\Delta E_X = \int_t^{\infty} L_X(t)\,dt$$

Total accreted mass: $$\Delta M = \frac{\Delta E}{\varepsilon c^2} \approx \frac{\Delta E_X}{\varepsilon c^2}$$

Radius emitting region: $$R_X = \left(\frac{f_c^4 L_X}{\pi\sigma T_{bb}^4}\right)^{1/2}$$

(Ferrarese & Ford 2005)

Black hole mass: $$M_{BH} = 1.66(\pm 0.24)\times 10^8 M_{sun}\left(\frac{s}{200\,km\,s^{-1}}\right)^{4.86(\pm 0.43)}$$

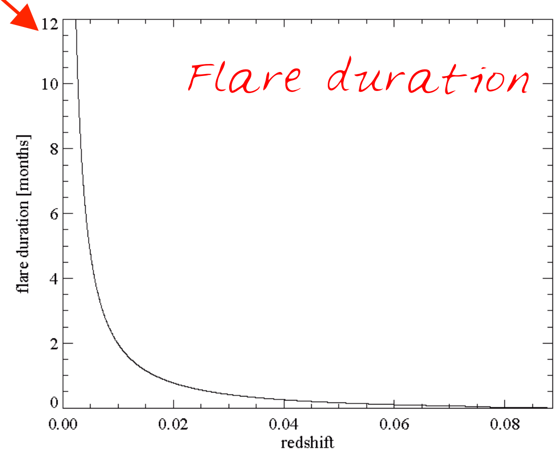
Source	ΔE_x (erg)	ΔM (M_{sun})	R_x (cm)	M_{BH} (M_{sun})
NGC 3599	7.1×10^{48}	4.0×10^{-5}	7.3×10^{11}	1.3×10^{6}
SDSS J1323	7.6×10^{50}	4.2×10^{-3}	6.8×10^{12}	2.2×10^{6}

Tidal disruption rate

$$\frac{N\,events}{\int_0^{R_{max}} A(r)\,t(r)\,dr} = 2.4\cdot 10^{-6}\,yr^{-1}Mpc^{-3} = 1.0\cdot 10^{-4}\,galaxy^{-1}yr^{-1}$$

Completeness distance (406 Mpc)

Area



Galaxy space density: ρ_{gal}

Tidal disruption rate

$$\frac{N\,events}{\int_0^{R_{max}} A(r)t(r)dr} = 2.4\cdot 10^{-6}\,yr^{-1}Mpc^{-3} = 1.0\cdot 10^{-4}\,galaxy^{-1}yr^{-1}$$

- Theoretical tidal disruption rate is ~10^{-4} -10^{-5} $galaxy^{-1}$ yr^{-1} (Wang & Merrit 2004)

$$G(M_{bh}) = 7\times 10^{-4}\,yr^{-1}\left(\frac{s}{70kms^{-1}}\right)^{7/2}\left(\frac{M_{bh}}{10^6 M_{sun}}\right)^{-1}\left(\frac{m_*}{M_{sun}}\right)^{-1/3}\left(\frac{R_*}{R_{sun}}\right)^{1/4}$$

- Observed disruption rate from ROSAT ~10^{-5} $galaxy^{-1}$ yr^{-1} (Donley et al. 2002)

Tidal disruption rate from slew survey lies in agreement with previous theoretical and observational predictions (Esquej et al. 2008)

Alternative scenarios

- Discarded:
  - Stellar objects: cannot reach so high luminosities
  - HMBX and supernovae: present strong hard X-ray emission and L_X up to 10^{40} erg s^{-1}
  - X-ray afterglow of GRB: no detected and follows a t^{-1}

- Still possible for NGC 3599:
  - ULX within NGC 3599
  - Accretion disk instability
  - Variations in the intrinsic radiation, changes in covering factor of the absorbing gas

Conclusions: Tidal disruption events

- Two candidates detected by XMM-Newton (previously only 5 in X-rays with ROSAT)
  - high-state properties agree with previous detections (soft spectral shape, high luminosity, huge variability)
  - Unprecedented broad band X-ray data
- No significant spectral evolution - X-rays and optical
- X-ray light curves declined as $t^{-5/3}$
- Tidal disruption rate agrees with previous predictions