Evolution of Tidal disruption events discovered by XMM-Newton

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  - Theory
  - Observational signatures & previous detections
  - Candidates selection
  - Follow-up observations
  - Alternative scenarios
  - Tidal disruption rate

- Summary/Conclusions

The ubiquity of SMBHs

- The paradigm that the cores of most, if not all, galaxies are occupied by SMBHs was predicted long ago.
- Quasars were more abundant in the early Universe at *z*~2 than at present, so dead quasar engines are expected to be enclosed in the nuclei of otherwise non-active galaxies.
- Alternatively to the stellar dynamics approach, an unavoidable consequence of the existence of remnant SMBHs at the nuclei of optically non-active galaxies is the detection of the *so-called* tidal disruption events.

Theory of Tidal disruption events

- A star orbiting a SMBH will be disrupted when approaching the BH tidal radius

$$R_T = \mu R_* \left(\frac{M_{BH}}{m_*}\right)^{1/3}$$ (Rees 1988)

- The process is expected to happen up to $M_{BH} \sim 10^8 M_{sun}$ (for a solar mass star).

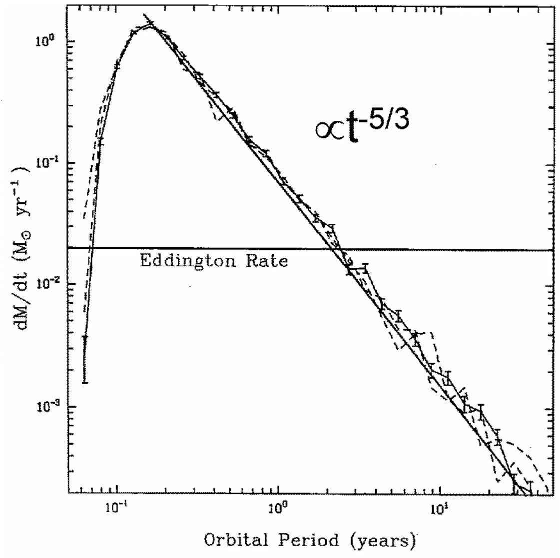
- Once disrupted, half of the stellar material is ejected and the remaining half will be bound, returning to pericentre and circularizing, a fraction of it will be accreted by the hole (~10%) (Ayal et al. 2000).

- Flare of radiation beginning when the most bound material returns to pericentre.

$$T_{bb}(3r_s) = 7\times10^5 \left(\frac{M_{bh}}{10^6 M_{sun}}\right)^{1/4} K \sim 60\ eV$$

➡ Peak in soft X-rays!

- By equating the energy of the released gas to the specific orbital energy: Tmin. Aplying physics of Keplerian orbits: luminosity declines as $t^{-5/3}$



(Evans & Kochanek 1999)

Observational Signatures

- Giant amplitude UV/EUV/X-ray flare – black body of kT=40-100 eV.

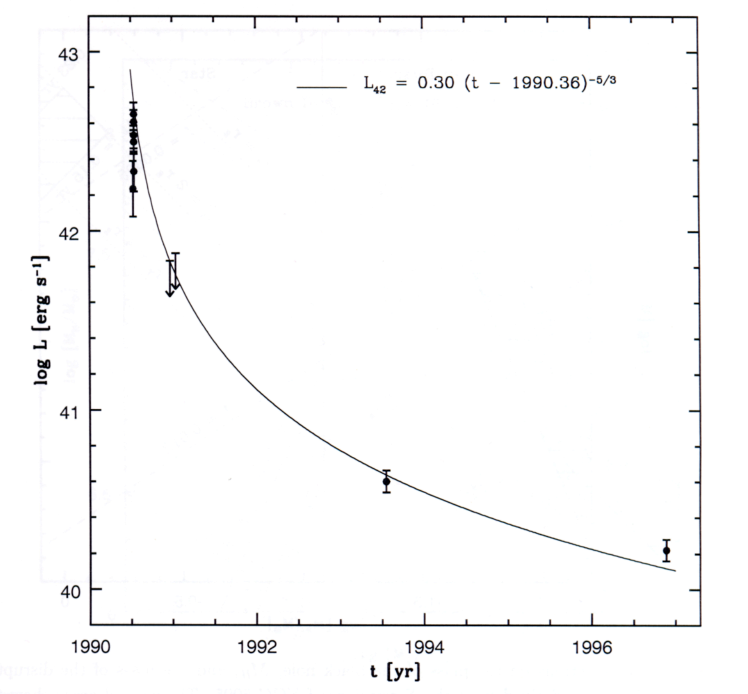
Identification based on the existence of two large area X-ray sky surveys of comparable sensitivities

(Komossa 2002)

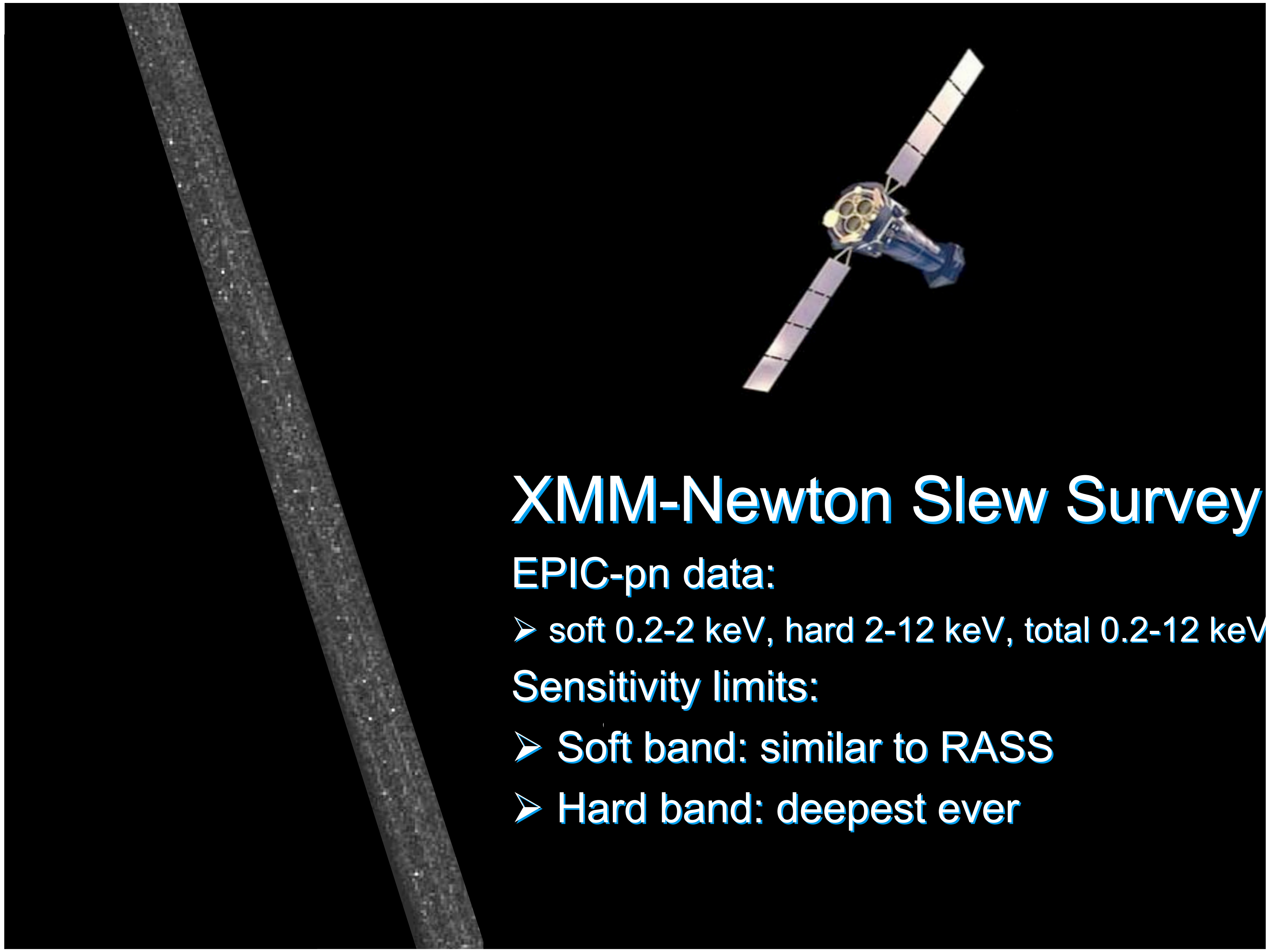
- Peak Luminosity $L_X = 10^{42} - 10^{44}$ erg s^{-1}
- Lasts a few weeks at peak luminosity and then falls off as $t^{-5/3}$

Previous detections:

- RX J1242.6-1119 (Komossa & Greiner 1999)
- RX J1624.9+7554 (Grupe at al. 1999)
- RX J1420.4+5334 (Greiner et al. 2000)
- NGC 5905 (Komossa & Bade 1999)
- TDXFJ134730.3-325451 (Cappelluti et al. 2009)
- 3 Galex sources (Gezari et al. 2007, 2008, 2009)



NGC 5905 (Li et al. 2002)



XMM-Newton Slew Survey

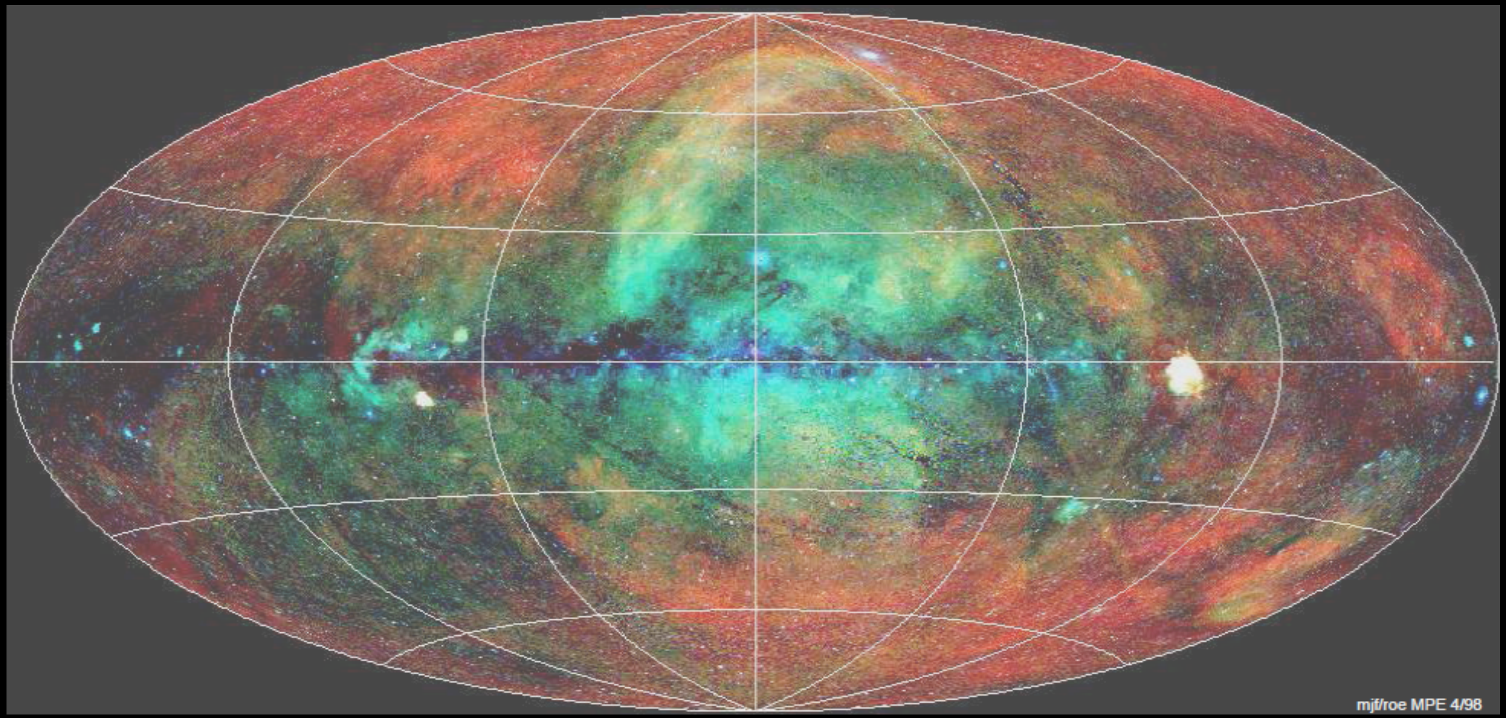
EPIC-pn data:

- soft 0.2-2 keV, hard 2-12 keV, total 0.2-12 keV

Sensitivity limits:

- Soft band: similar to RASS
- Hard band: deepest ever

XMM-Slew vs RASS

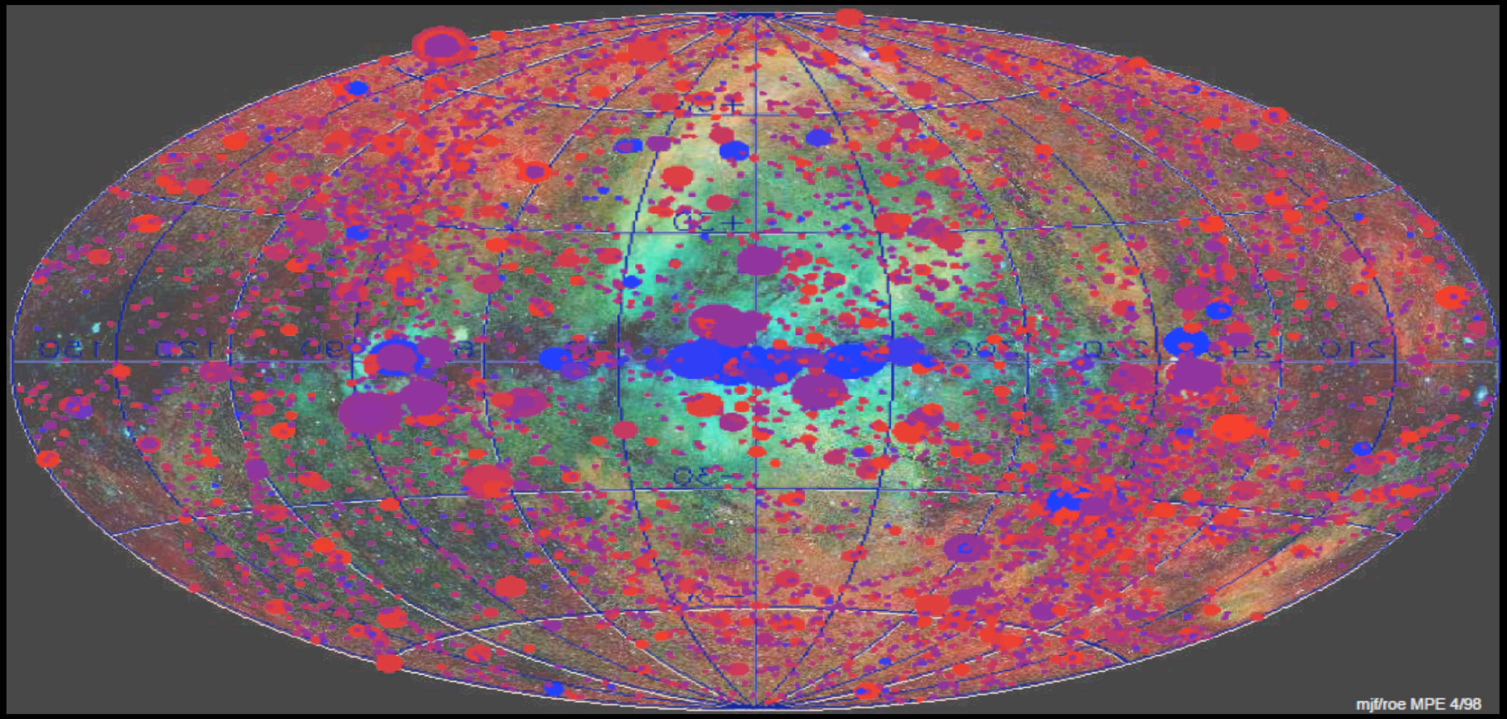


ROSAT: composite image RASS-PSPC maps of the diffuse soft XRB in the 0.1-0.4keV (red), 0.5-0.9keV (green), 0.9-2keV (blue) (Freyberg & Egger 1999).

Source	$L_{0.2\text{-}2keV}$ XMM/RASS-ul	$L_{0.2\text{-}2keV}$ (erg s^{-1})
NGC 3599	88	$5.1\text{x}10^{41}$
SDSS J132341.9+482701	83	$4.8\text{x}10^{43}$

Very soft sources (not detected in slew hard band) classified as normal galaxies, rough spectral shape as black body at kT=95 eV or power-law with $\Gamma\sim3$ → initial agreement with the tidal disruption model.

XMM-Slew vs RASS



ROSAT: composite image RASS-PSPC maps of the diffuse soft XRB in the 0.1-0.4keV (red), 0.5-0.9keV (green), 0.9-2keV (blue) (Freyberg & Egger 1999). XMM-slew: color code from red (soft) to hard (blue).

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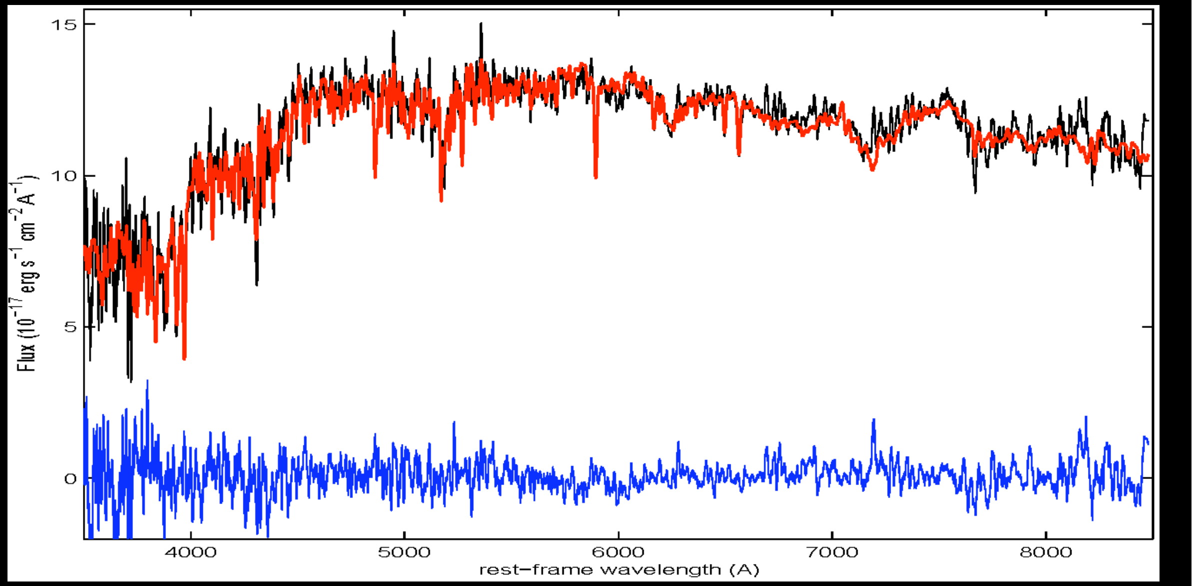
Optical data

SDSS J1323

z=0.0087

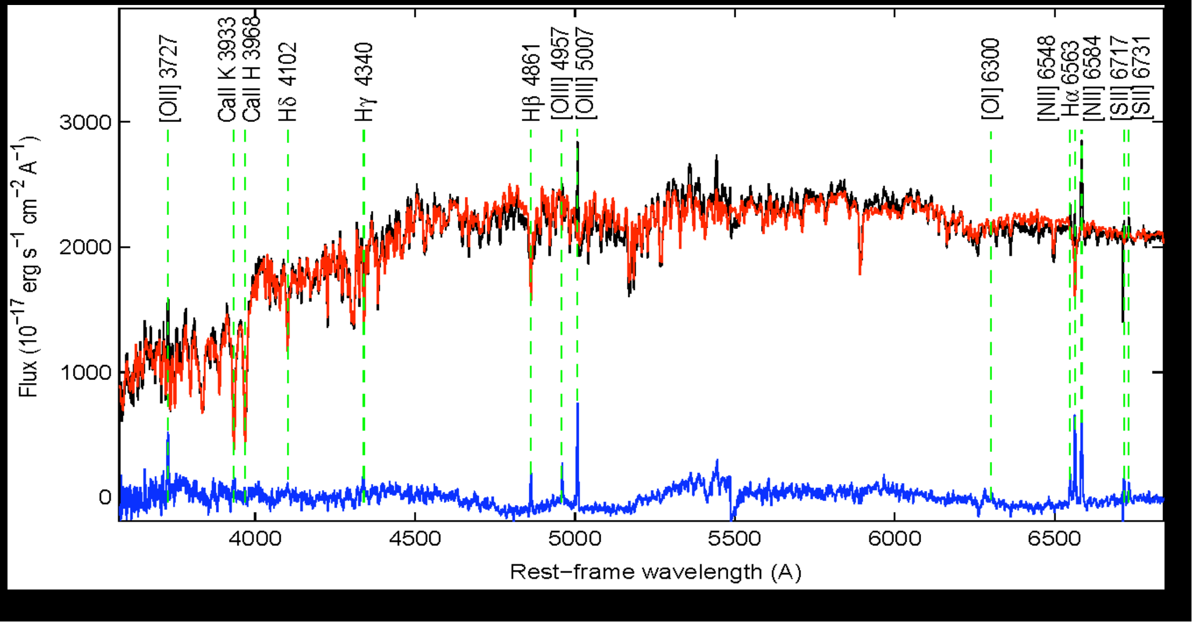
- Non-active galaxy



NGC 3599

z=0.0028

- LLAGN



Follow-up

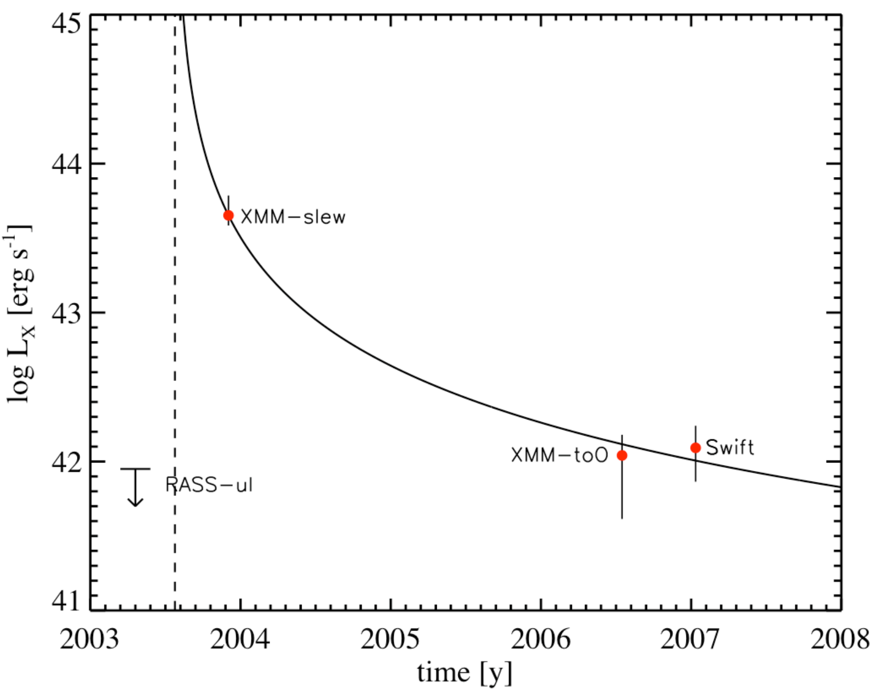
- Optical:
  - Do post-outburst spectra show any evidence of the disruption event?

- X-rays:
  - Is the temporal evolution following the $t^{-5/3}$ law?
  - Do sources harden in time?
  - Is the detected X-ray emission coming from the nucleus?

- Follow-up observations:
  - Optical: NOT/INT
  - X-ray: XMM-Newton (ToO) and Swift (Fill-in; PI: G.Hasinger). NGC 3599 recently observed with Chandra and XMM-Newton (PI: P.Esquej)

SDSS J1323

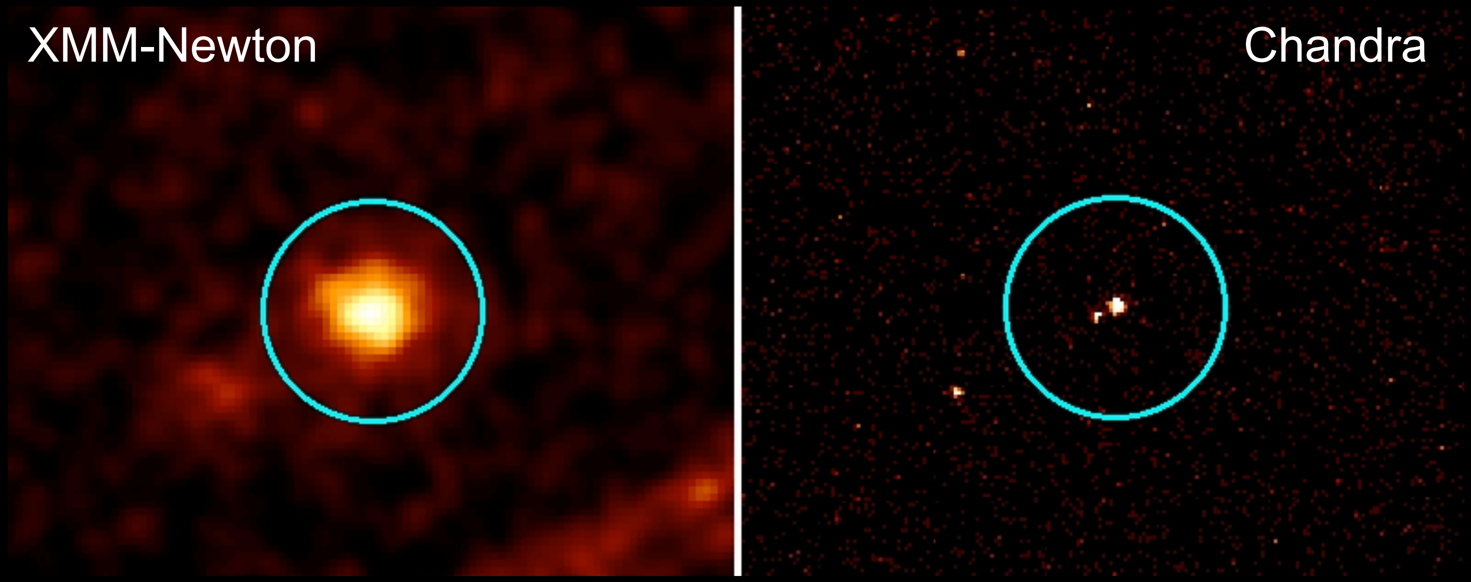
- Optical post-outburst spectra did not show any evidence of the disruption event.
- X-ray spectral analysis
  - Bbody (kT=62eV) + Powerlaw (Γ=1.4)
  - Hard tail detected
  - Hard luminosity in low state is still higher than estimation from [OIII]-$L_{2\text{-}10\mathrm{keV}}$ relationship (Netzer et al. 2006)



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

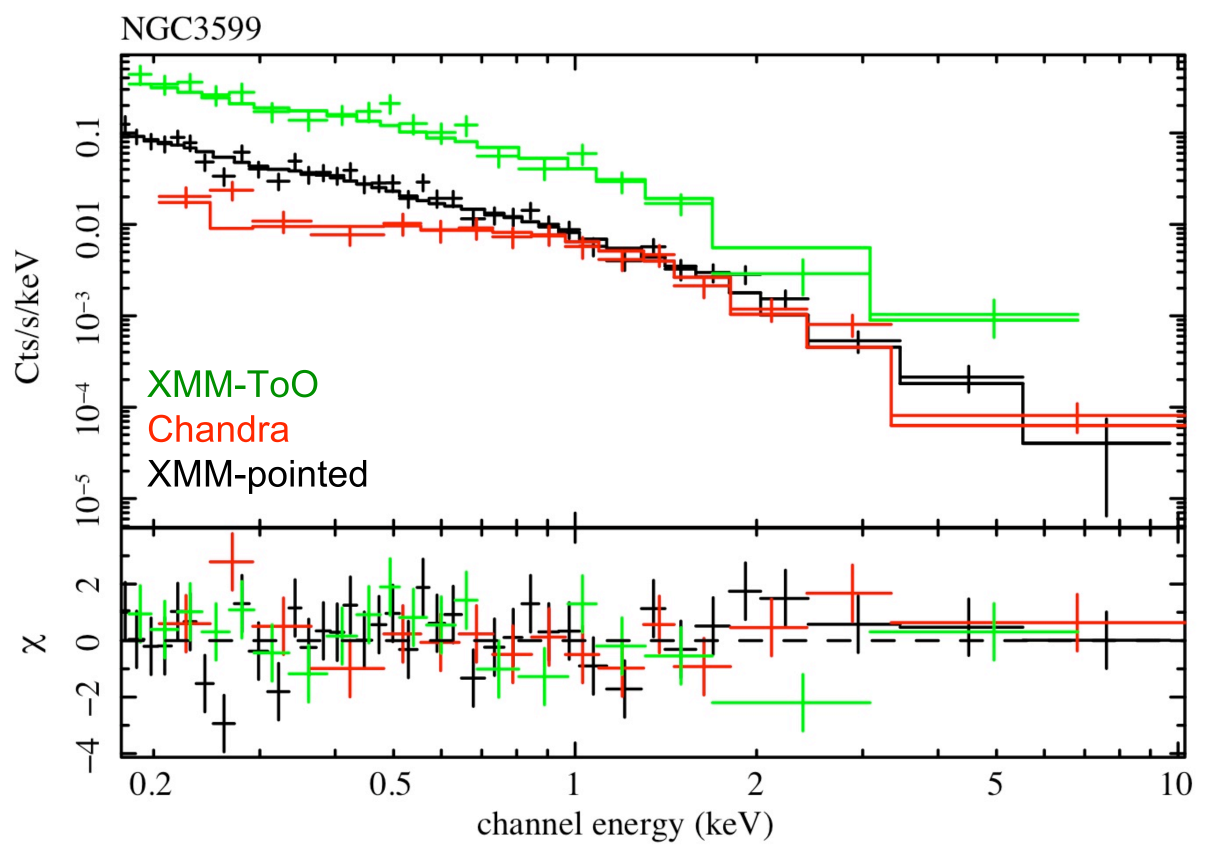
NGC 3599: X-ray imaging

XMM-ToO (mid-2006)
Swift (2007)
Chandra (2008)
XMM-Newton (2009)



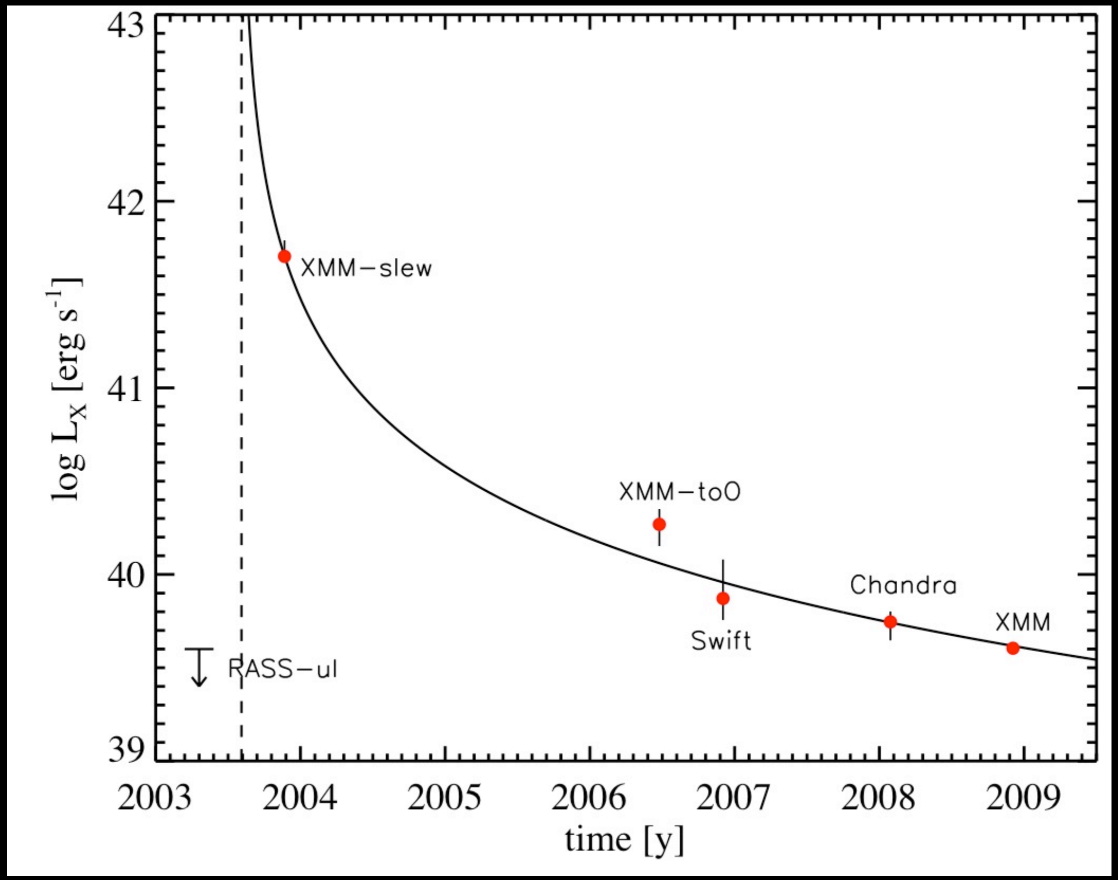
- Bright source coincident with the centre of the optical position
- Faint off-nuclear source at 3 arcsec (300 pc)

NGC 3599: spectral analysis



power-law (Γ=2.3) + black body (45 eV) + power-law (faint source)
Thermal or black body models not compatible with data

NGC 3599: X-ray light curve



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

Alternative scenarios

- Stellar objects: don't 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}
- Gravitational lensing event: same variability in optical and X-rays (no simultaneous observations)
- ULX within NGC 3599: L_X ~10^{39}-10^{40} erg s^{-1}, flux variation of 2-3, power-law shape (Γ=1.6-1.8).
- Accretion disk instability.
- Variations in the intrinsic radiation, changes in covering factor of the absorbing gas.

Properties of tidal events

Released energy:

$$\Delta E_{\mathrm{X}} = \int_t^{\infty} L_{\mathrm{X}}(t)\mathrm{d}t.$$

Total accreted mass:

$$\Delta M = \frac{\Delta E}{\epsilon c^2} \approx \frac{\Delta E_{\mathrm{X}}}{\epsilon c^2}$$

Radius emitting region:

$$R_{\mathrm{X}} = \left(\frac{f_{\mathrm{c}}^4 L_{\mathrm{X}}}{\pi \sigma T_{\mathrm{bb}}^4}\right)^{1/2}$$

(Ferrarese & Ford 2005)

Black hole mass:

$$M_{\mathrm{BH}} = 1.66(\pm 0.24) \times 10^8 M_{\odot} \left(\frac{\sigma}{200\ \mathrm{km\ s^{-1}}}\right)^{4.86(\pm 0.43)}$$

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

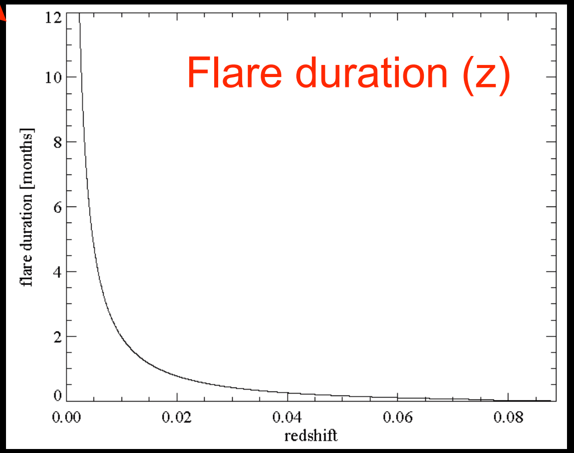
Assumptions:

- Tidal spectrum
  - bb (kT=70eV)
- Peak luminosity
  - L = 10^{44} erg s^{-1}

$$\frac{N\ events}{\int_0^{R_{\max}} A(r)\,t(r)\,dr} = 5.4\cdot 10^{-6}\,yr^{-1}Mpc^{-3} = 2.3\cdot 10^{-4}\,galaxy^{-1}yr^{-1}$$

Completeness distance (406 Mpc)

Area (16.5% of the sky)



Galaxy space density: ρ_{gal}

Tidal disruption rate

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-Tidal spectrum

bb (kT=70eV)

-Peak luminosity

$L = 10^{44}$ erg s^{-1}

$$\frac{N\ events}{\int_0^{R_{\max}} A(r)t(r)dr} = 5.4\cdot 10^{-6}\, yr^{-1} Mpc^{-3} = 2.3\cdot 10^{-4}\, galaxy^{-1} yr^{-1}$$

- Theoretical tidal disruption rate is ~10^{-4} -10^{-5} yr^{-1} (Wang & Merrit 2004), depending on the stellar density in the nuclear cusp and the SMBH mass.

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

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

Tidal disruption rate from slew survey lies in agreement with previous theoretical and observational predictions!

Summary/Conclusions and future

- Tidal disruption candidates in high-state agree with previous detections, X-ray light curves declined as $t^{-5/3}$ and no significant variation of optical spectra was observed (Esquej et al. 2007, 2008).

- Closest observations to maximum in hard X-rays showing apparent hardening with respect to high-state.

- X-ray emission from SDSS J1323 in low-state does not seem to be AGN related

- Although some AGN-related scenarios can not be ruled out, specially for NGC 3599, the tidal disruption model is fully consistent with observations.

- Important as they are the unambiguous probe of the existence of SMBH in otherwise non-active galaxies. They may contribute to the BH growth over cosmic times and the faint end of the AGN luminosity function.

- Fast data processing of incoming slews to perform fast follow-up of high variable sources.
- Future missions will allow the detection of new events to be obtained
- Possible future detection of GWs with LISA