Tidal disruption of stars by supermassive black holes: the X-ray view

- first TDE detections in X-rays ➔ ROSAT
- more recent events ➔ Chandra, XMM
- „relativistic“ tidal flares ➔ Swift
- high-ion. emission-line responses ➔ opt. surveys / SDSS

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tidal capture & disruption of stars by SMBHs

“The best diagnostic for a BH’s presence would be some inevitable concomitant that cannot be explained in any other way.” [Rees, Nature, 1988]
tidal disruption of stars – sources of radiation

- reprocessing from stellar & distant matter
- emi lines
- accretion phase, $L_{\text{Edd}}$
- jet formation?
- extreme squeezing of star, ign. of nucl. burning
- inspiral of comp. obj., GWs
- collision of unbound gas with ISM, SN-like
- stream-stream collisions
- shocks

see talks on TD theory: Luminet, Lodato, Guillochon, Ivanov et al.
tidal flares – initial X-ray discoveries with ROSAT

- $z = 0.011$
- $L_{\text{x,hi}} = 7 \times 10^{42} \text{ erg/s}$
- $\Gamma_{\text{x}} = -4.0$ or
  - $kT_{\text{bb}} = 0.06 \text{ keV}$
  - @ high-state
- $\Gamma_{\text{x}} = -2.4$ later

NGC 5905
- $z = 0.050$
- $L_{\text{x,hi}} = 9 \times 10^{43}$

RXJ1242-1119
- $z = 0.064$
- $L_{\text{x,hi}} = 2 \times 10^{44}$

RXJ1624+75
- $z = 0.147$
- $L_{\text{x,hi}} = 8 \times 10^{43}$

RXJ1420+53

Bade+ 96, Komossa & Bade 99
Komossa & Greiner 99, Grupe+ 99, Greiner+ 00
NGC 5905: X-ray lightcurve

high-state lightcurve during ~5d RASS coverage

$L_{\text{x, hi}} = 7 \times 10^{42}$ erg/s

[Bade, Komossa & Dahlem 96, Komossa & Bade 99]
NGC 5905: long-term X-ray lightcurve

[Komossa & Bade 99]
NGC 5905: optical follow-ups

ROSAT error circle on Calar Alto optical image

[Komossa & Bade 99]
NGC 5905: optical follow-ups

- ground-based optical spectroscopy, pre-flare, and post-flare (6 yrs): HII-type galaxy
- HST post-flare spectroscopy: faint [OIII]/Hbeta > 3  likely excited by the flare  (no permanent low-state hard X-ray emission!)

[Komossa & Bade 99, Gezari+ 03]
NGC 5905: radio follow-up

- does tidal disruption power a jet? ((does N5905 hide a blazar nucleus?))
- $\rightarrow$ no detection $\sim$ 6 yrs after X-flare: $f_{8.46\text{GHz}}$, VLA-A $< 0.15 \text{mJy}$

[Komossa 02 -- astro-ph/0209007]
**RXJ1242-1119**

- $L_{x,hi} = 9 \times 10^{43}$ erg/s
- $\Gamma_x = -5.1$

- no optical emission lines at all; no permanent AGN activity

- XMM spectroscopy: spectral hardening $\Gamma_x = -2.4$

- Chandra follow-up confirms fading; up to factor $1500$ (!!)

- amount of accreted stellar mass: $M > 1/100 \, M_{\text{Sun}}$

[Komossa & Greiner 99, Gezari+ 03, Halpern+ 04, Komossa+ 04]
tidal flares – initial X-ray observations

[from: K 02; astro-ph/0209007]

[Komossa & Bade 99, Grupe+ 99, Komossa & Greiner 99, Greiner+ 00, Halpern+ 04, Komossa+ 04, 12-prep]
so, then, _are_ these TDEs  ?
rejected alternatives:

- lensing? no (no achromatic var. obs.)
- AGN? no (no emi lines, no dust, no radio, no low-state X)
  no dusty WAs
  no blazar
  (likely) no disk instab.
- GRBs? no (none detected simultaneously)
- SN in dense medium? no (inefficient by orders of mag; hard spectr)
- ULX? no

[Komossa & Bade 99; see also Komossa 02]
main properties of the ROSAT giant X-ray flares

• $L_{x,\text{peak}}$ huge: up to several $10^{44}$ erg/s

• very soft X-ray spectra near peak ($kT_{\text{BB}} \sim 0.04-0.1$ keV); then hardening

• amplitudes of decline up to factor 1000-6000, after a ~decade (!!!)

• host galaxies are optically inactive, radio inactive, and X-ray inactive in low-state

• rapid rise; then decline consistent with predicted $t^{-5/3}$ law; plus quicker fading at $t>10$yr

all of these nicely match the order-of-mag predictions from TD theory, as e.g. given by Rees 1988, 90

[Komossa & Bade 99, Grupe+ 99, Komossa & Greiner 99, Greiner+ 00, Gezari+ 03, Halpern+ 04, Komossa+ 04 ]
tidal flares with Chandra and XMM-Newton

NGC 3599/ SDSSJ1323  TDXFJ1347-32  SDSSJ1311-01  2XMMiJ1847-63

- $z = 0.0028 \pm 0.088$
- $L_{x,hi} = 1 \times 10^{41} \text{ erg/s}$
- $6 \times 10^{42}$
- $0.037$
- $0.195$
- $0.035$
- $6 \times 10^{42}$
- $5 \times 10^{42}$
- $3 \times 10^{43}$
- in cluster Abell 3571
- in cluster Abell1689
- from XMM catalogue

- based on XMM slew-survey search
- Esquej+ 07, 08,
- Cappelluti+ 2009,
- Maksym+ 10,
- Lin+ 11
Tidal flares with Chandra and XMM-Newton

SDSS J1201+30

- $z = 0.146$
- $L_{x,hi} = 3 \times 10^{44} \text{ erg/s}$
- Based on XMM slew search
- Well-covered 1 yr lightcurve
- Non-thermal spec

[Saxton+ 12]

- RASS: $10^{-5}/\text{galaxy/yr}$
- CDF: $<10^{-4}/\text{galaxy/yr}$
- XMM slew: $2 \times 10^{-4}/\text{galaxy/yr}$

[rates ?]
### main X-ray properties of the X-ray-sel. TDEs

<table>
<thead>
<tr>
<th>ROSAT:</th>
<th>XMM/Chandra:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- $L_{x,\text{peak}}$ huge: up to sev. $10^{44}$ erg/s</td>
<td>- $10^{41}$ - sev. $10^{44}$ erg/s</td>
</tr>
<tr>
<td>- very soft X-ray spectra near peak $(kT_{\text{BB}} \sim 0.04-0.1 \text{ keV})$; then hardening with time</td>
<td>\checkmark  (one exception; better hard–X spectra now)</td>
</tr>
<tr>
<td>- amplitudes of decline up to factor 1000-6000</td>
<td>- up to fact. 100-1000</td>
</tr>
<tr>
<td>- host galaxies are optically <em>inactive</em></td>
<td>\checkmark  (when spectra available)</td>
</tr>
<tr>
<td>- decline consist.</td>
<td>\checkmark</td>
</tr>
</tbody>
</table>
then came Swift ......
discovery of “relativistic“ tidal flares with Swift

SwiftJ1644+57

- discovered with Swift BAT March 2011; no detection of “activity“ ever before March 25)
- \( L_{x,\text{isotropic}} = 10^{45} - 4 \times 10^{48} \text{ erg/s} \)
- peculiar lightcurve
- rapid variability, \( \Delta t \sim 100\text{s} \)
- \( z_{\text{host}} = 0.35, \) optically inactive
- NIR transient
- unresolved, variable, beamed radio emission

\( \Rightarrow \) rapid onset of a powerful jet, following tidal disruption

1 but see: talk by J. Grindlay on MAXI

[Bloom+ 11, Burrows+ 11, Zauderer+ 11, Levan+ 11, Barres de Almeida & De Angelis 11, Krolik+Piran 11, Cannizzo+ 11, Miller & Gueltekin 11, Metzger+ 11, Lei & Zhang 11, Saxton+ 12, and many more...]
„relativistic“ tidal flares with *Swift*

**SwiftJ2058+05**

- \( L_{x,\text{iso}} = 3 \times 10^{47} \text{ erg/s} \)
- rapid variability, \( \Delta t \sim 1000s \)
- \( z_{\text{likely-host}} = 1.19 \), optically inactive
- \( M_{\text{BH}} \approx 10^{7-8} \text{ M}_{\odot} \)
- luminous radio emi, likely beamed

\[ \rightarrow \text{many similarities with J1644} \]

\[ \rightarrow \text{second “relativistic” tidal flare} \]

[Cenko+ 11]
tidal flares in gas-rich environments: emission-line “echoes”

imagine, we could map a whole galaxy core, following one giant flare.....

(including, of course, the disrupted star itself)
emission-line „light echoes“

SDSSJ0952+2143

[Komossa+ 08, 09]
emission-line „light echoes“

- super-strong Fe lines & HeII
- fade dramatically, $\times 10$, in yrs

- very unusual Balmer profile; incl. redshifted broad comp., fading

- luminous MIR (Spitzer,10-20 $\mu$), $\sim 10^{43}$ erg/s

- but faint X-rays, $\sim 10^{41}$ erg/s, few yrs after 'SDSS' high-state

- no clear signs of permanent AGN

- various unusual emission-line properties:

[Komossa+ 08, 09]
emission-line „light echoes“

very narrow double-peaked “horns” in Balmer lines:

origin unclear. related to stellar debris ??

→ „light echoes“ from tidal flares illuminating surrounding ISM, and perhaps stellar material ?
→ cannot yet exclude, a previously unknown type of super-luminous (IIn) SNe, only found in galaxy cores ??

2-component high-ion. Fe and Hell:

[Komossa+ 08, 09]
emission-line „light echoes“

- 2nd case with super-strong Fe lines, up to [FeXIV] and [Ar XIV], but no [FeVII]
- plus unusual broad humps

- highest-ion lines have faded strongly 4-5 years later, while [OIII] increased by factor of 10

favored interpretation: tidal disruption of an evolved star, stripped by its H-envelope → He-rich core produces a strong, shifted HeII bump

SN argued to be unlikely

[T. Wang+ 11; see also Gezari+ 12, + her talk]
emission-line „light echoes“

- dedicated SDSS search for further extreme coronal line emitters:
  - 5 more found
  - all with very strong [FeX]-[FeXIV]
  - ~50% without [FeVII]
  - in relatively low-mass galaxies
  - 2 appear to be AGN, ~constant Fe
  - 3 have transient (fading) Fe lines; while [OIII] increases

→ same mechanism at work as in SDSSJ0952+2143

- rate: $\sim 10^{-5}$/yr /galaxy

[T. Wang+ 12, 13-in prep]
tidal flares in classical AGN?

are we now ready to search for them, and re-look at (one) previous AGN flares?
tidal flares in AGN ??

IC 3599

- 'classical' opt AGN before and after
- luminous X-ray outburst (RASS)
- accompanied by transient opt. lines

ph.ion. modelling of the emi-line response to the X-outburst of IC3599:

<table>
<thead>
<tr>
<th>Line</th>
<th>$I/I_{H\beta_{out}}$ observed</th>
<th>$I/I_{H\beta_{out}}$ modeled</th>
</tr>
</thead>
<tbody>
<tr>
<td>HeII 4686</td>
<td>0.36</td>
<td>0.38</td>
</tr>
<tr>
<td>H$\beta$ 4861</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>HeI 5876</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>[OIII] 5007</td>
<td>&lt; 0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>[FeX] 6375</td>
<td>0.37</td>
<td>0.45</td>
</tr>
<tr>
<td>[FeXI] 7892</td>
<td>0.23</td>
<td>0.36</td>
</tr>
<tr>
<td>[FeXIV] 5303</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>OI 8446</td>
<td>0.23</td>
<td>0.10</td>
</tr>
</tbody>
</table>

best-fit parameters:
log N $\sim$ 23,
log n $\sim$ 9, r$\sim$ 130 ld;

*typical for outer BLR / CLR*

[Komossa & Bade 97]

[Brandt+ 95, Grupe+ 95, Komossa & Bade 99]

see also: transient broad Hell line of NGC 5548, Peterson & Ferland, Nature, 1986 -- SN or TDE ? // transient Balmer-lines of NGC 1097; Storchi-Bergmann+ 97 -- accretion event or TDE ?
tidal flares in AGN ??

IC 3599

suggested possible explanations for IC3599:

→ extreme case of NLS1 variability ?
→ state-change, similar to gal. BHCs ?
→ TDE ?
→ thermal (or other) acc. disk instability ?
→ no SN

[Brandt+ 95, Grupe+ 95, Komossa & Bade 99]

→ we may now start searching for TDEs in classical AGN by looking for properties similar to the flares already seen in the non-active galaxies (esp.: super-softness of the X-ray spectra, decline law)

• 'classical' opt AGN before and after the luminous X-ray outburst (RASS)
• accompanied by transient opt. lines
summary

- stellar tidal disruption flares long predicted by theory. Key probe of SMBHs in non-active galaxies; of accretion & jet physics. 
  ~12 events discovered in X-rays.

- all “non-Swift” X-ray tidal flares share ~similar properties:
  - very soft X-ray high-state spectra
  - high $L_{x,\text{peak}}$ up to $> 10^{44}$ erg/s
  - giant amplitude of variability, up to factor 6000
  - from the cores of otherwise non-active galaxies
  - decline consistent with $t^{-5/3}$, esp. the well-covered lightcurves of NGC5905 & RXJ1242-1119

- the two Swift discoveries are markedly different in their giant peak luminosity, hardness, rapid variability, and evidence for beaming
  $\rightarrow$ “relativistic” tidal flares

- several cases of transient optical emission-lines (H, HeII, hi-ion Fe)
  $\rightarrow$ ISM, and stellar streams, excited by TD flares (?)

- wealth of future applications, when we find tidal flares in larger numbers & do rapid follow-ups and long-term monitoring