The nature of the X-ray emission from TDEs

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with:
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Luminous accretion powered flare

X-rays

UV Opt

Log Flux

Wavelength (Å)

1  10  100  1000

3x10^5 K

e.g., Ulmer (1999)
Many TDE discoveries

Over 70 TDE candidates listed in the literature.

But the number detected is constantly growing due to archival studies, and current observational surveys.

For a constantly updated list see: https://tde.space/
Why look at X-rays from TDEs?

- Directly probe accretion activity/structure.
- Minimise confusion between other optical transients such as SNe.
- Recurring/incoherent X-rays reveal AGN activity rather than TDE.

(see Auchettl et al. (2017), arXiv:1703.06141)
X-ray emission of all TDE candidates

Auchettl et al. (2017), arXiv:1611.02291

X-ray Luminosity 0.3–2.0 keV (erg s⁻¹)

Date of Observation (years)
Grading X-ray TDEs

- **X-ray TDEs**
  - X-ray light curve well defined
  - Light curve decays monotonically on timescale of months to years.
  - Max. luminosity is >2 orders of magnitude larger than preflare limits.
  - Flare consistent with centre of host.
  - No evidence of AGN activity, while GRB/SNe origin ruled out.

- **Likely X-ray TDEs**
  - Similar to X-ray TDEs, but light curve more sparsely sampled thus a shape is not well constrained

- **Veiled X-ray TDEs**
  - No X-ray emission, but detected in optical and has properties consistent with that of a TDE.
## Grading X-ray TDEs

### Table 1

|----------|-----------|-------------|--------------|-------------|--------------|----------|

### X-ray TDEs

- **ASASSN-14li**
- **Swift J1644+57**
- **Swift J2058+05**
- **XMMSL1 J0740-85**

### Grading X-ray TDEs

- Likely X-ray TDEs
- Veiled X-ray TDEs

### References

- **2MASX J0249**
- **3XMM**
- **NGC247**
- **OGLE16aaa**
- **PTF-10iya**
- **SDSS J1201**
- **SDSS J1311**
- **SDSS J1323**

### Annotations

- **ASASSN-14ae**, **ASASSN-15lh**, **D1-9**
How do X-ray TDEs decay?

Auchettl et al. (2017), arXiv:1611.02291
How do X-ray TDEs decay?

The diagram shows a histogram of the powerlaw index (n) for different categories of X-ray TDEs:

- **Fall-back**
- X-ray TDEs
- Likely X-ray TDEs

The powerlaw index (n) is indicated with different colors and line styles:

- Blue dashed line for Early Time
- Red dashed line for Late Time

The powerlaw index (n) is marked with a vertical pink line at -5/3.
How do X-ray TDEs decay?

-4/3-19/16

Disk accretion

Auchettl et al. (2017), arXiv:1611.02291

X-ray TDEs

Likely X-ray TDEs

Early Time

Late Time

Powerlaw Index (n)
How do X-ray TDEs decay?

Auchettl et al. (2017), arXiv:1611.02291

-5/12

Disk emission

Histogram

Powerlaw Index (n)

-3 -2 -1 0 1

X-ray TDEs
Likely X-ray TDEs
Early Time
Late Time
How do X-ray TDEs decay?

- Disk emission
- Fall-back

Powerlaw Index (n)

-5/3 -4/3 -19/16 -5/12

X-ray TDEs
Likely X-ray TDEs

Transition from fall-back to disk dominated with time

Auchettl et al. (2017), arXiv:1611.02291
Black hole masses of X-ray TDEs?

Auchettl et al. (2017), arXiv:1611.02291

- Swift J1644+57
- Swift J2058+05
- SDSS J1201
- IGR J17361
- SDSS J1323
- ASASSN-14li
- 3XMM
- OGLE16aaa
- XMMSS1
- NGC247
- 2MASX J0249

$M_{\text{BH}} = 10^5 M_\odot$

$M_{\text{BH}} = 10^6 M_\odot$

$M_{\text{BH}} = 10^7 M_\odot$

$L_{\text{edd}} (10^7 M_\odot)$

$L_{\text{edd}} (10^6 M_\odot)$

$L_{\text{edd}} (10^5 M_\odot)$
Isotropic luminosities

$1 \ M_\odot$ Main Seq. Star, $\beta=2$

$M_\text{BH} = 10^5 M_\odot$

$M_\text{BH} = 10^6 M_\odot$

$M_\text{BH} = 10^7 M_\odot$

$L_\text{edd}(10^5 M_\odot)$

$L_\text{edd}(10^6 M_\odot)$

$L_\text{edd}(10^7 M_\odot)$

Super-Eddington

Sub-Eddington

$\log_{10}(L_90 / \text{erg/s})$

$\log_{10}(M_90 \ M_\odot)$

$\log_{10}(t_{90} / \text{s})$

Auchettl et al. (2017), arXiv:1611.02291
Gap in isotropic luminosities?

1 $M_\odot$ Main Seq. Star, $\beta=2$

Super-Eddington

Gap?

Sub-Eddington

$\log_{10}(t_{90})$ [s]

$\log_{10}(L_{90}) = 0.1M_\odot c^2$ [erg/s]

$M_{BH} = 10^5 M_\odot$

$M_{BH} = 10^6 M_\odot$

$M_{BH} = 10^7 M_\odot$

Swift J1644+57

Swift J12058+05

SDSS J1201

IGR J17361

SDSS J1323

ASASSN-14li

3XMM

XMMSL1

PTF-10iya

OGLE16aaa

NGC247

2MASX J0249

Auchettl et al. (2017), arXiv:1611.02291
**Clue # 1: Soft X-rays absorbed**

**Soft** = 0.3-1.0 keV
**Medium** = 1.0-2.0 keV
**Hard** = 2.0-10.0 keV

Same behaviour seen for Med vs. Soft

Significant variation in their soft 0.3-1.0 keV X-ray emission, compared to that seen in the medium and hard X-ray bands

Auchettl et al. (2017), arXiv:1611.02291
Clue # 2: X-ray to Opt. ratio

Super-Eddington TDEs have a X-ray to optical ratio $>>1$

Sub-Eddington TDEs have a X-ray to optical ratio $\sim 1$, and hardness ratios of $-1$ (i.e., very soft!)

[Graph showing luminosity comparison between X-ray and optical/UV regions]

Auchettl et al. (2017), arXiv:1611.02291
Gap in isotropic luminosities?

1 $M_\odot$ Main Seq. Star, $\beta=2$

Super-Eddington

Gap?

$\log_{10}(t_{90})$ [s]

$\log_{10}(L_{90}/[\text{erg/s}])$

$M_\odot$ Main Seq. Star, $\beta=2$

Auchettl et al. (2017), arXiv:1611.02291

$M_\odot$ Main Seq. Star, $\beta=2$
Reprocessing Valley

\[ \log_{10}(t_{90}) \text{[s]} \]
\[ L_{\text{peak}} \text{[erg/s]} \]

### Optical TDEs

<table>
<thead>
<tr>
<th>TDE</th>
<th>( M_{\text{BH}} \text{[10}^8 M_{\odot}] )</th>
<th>( L_{\text{peak}} \text{[10}^{43} \text{erg s}^{-1}] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS1-10jh</td>
<td>( 4^{+4}_{-2} )</td>
<td>( \gtrsim 22 )</td>
</tr>
<tr>
<td>PS1-11af</td>
<td>( 8 \pm 2 )</td>
<td>( 8.5 \pm 0.2 )</td>
</tr>
<tr>
<td>PTF09go</td>
<td>( 5.65^{+3.02}_{-0.68} )</td>
<td>( 85^{+50}_{-40} )</td>
</tr>
<tr>
<td>SDSS TDE2</td>
<td>( 2.45^{+1.55}_{-0.74} )</td>
<td>( 5.8^{+5.3}_{-3.3} )</td>
</tr>
<tr>
<td>ASASSN-14ae</td>
<td>( 2.69^{+0.66}_{-0.64} )</td>
<td>( 1.9^{+3.3}_{-1.4} )</td>
</tr>
<tr>
<td>PTF09axc</td>
<td>( 3.57^{+9.97}_{-2.96} )</td>
<td>( 12.7^{+23.1}_{-10.4} )</td>
</tr>
<tr>
<td>PTF09djl</td>
<td>( 3.57^{+9.97}_{-2.96} )</td>
<td>( 12.7^{+23.1}_{-10.4} )</td>
</tr>
</tbody>
</table>

\( L \sim 10^{43-44} \text{ erg/s} \)

\( L_{\text{edd}}(10^5 M_{\odot}) \)

Veiled X-ray TDEs (Optical/UV)

Super-Eddington

Sub-Eddington

Auchettl et al. (2017), arXiv:1611.02291

Imposter TDEs: AGN

Highly variable AGN produce flare-like emission that looks similar to that of a TDE, e.g., recurring flare emission from IC3599 is consistent with an AGN rather than multiple TDEs.

Difficult to differentiate between AGN and TDEs based on the change in luminosity as a function or pre-flare constraints or over short timescales.

Auchettl et al. (2017), arXiv:1703.06141
When we have lots of data...

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0.0 0.2 0.4 0.6 0.8 1.0

-5 0 5

$t-t_{\text{peak}}/\text{Max}[t-t_{\text{peak}}]$

Powerlaw Index \((-n)\)
When we have little data...

Auchettl et al. (2017), arXiv:1703.06141
Theoretical TDE LF derived by Milosavljevic et al. (2006) assumes $7 \times 10^{-4}$ galaxy$^{-1}$ yr$^{-1}$.

Much higher rate of TDEs compared to that currently inferred from observations!

Using TDE rate vs. BH mass relationship derived by Stone & Metzger (2016), we get a TDE rate of:

$$(0.5-4.7) \times 10^{-4}$ gal$^{-1}$ yr$^{-1}$$
Summary

- Canonical $t^{-5/3}$ not necessarily universal:
  - Emission transitions from fallback to disk dominated with time

- Super- and Sub-Eddington X-ray TDEs are separated by a “reprocessing valley” naturally populated by veiled X-ray (opt./UV only) TDEs.

- TDE flares decay more coherently than AGN flares.

- X-ray LF of TDEs imply:
  - TDE rate closer to theoretical expectation
  - TDEs contribute to BH growth at low redshifts