TDE demographics: impostors versus observations

Sjoert van Velzen
Hubble Postdoctoral Fellow
Johns Hopkins University

Glennys Farrar, Suvi Gezari, Julian Krolik, Peter Jonker, Nick Stone, Thomas Wevers

TDE17, Cambridge, Sep 14, 2017

image credit: NASA
TDF spectral energy distribution

Galaxy model
Archival data
Flare data

Radio
IR
optical/UV
EUV
soft X-ray

νLν (erg s⁻¹)

10⁹ 10¹⁰ 10¹¹ 10¹² 10¹³ 10¹⁴ 10¹⁵ 10¹⁶ 10¹⁷

Frequency (Hz)

νLν (erg s⁻¹)

10³⁷ 10³⁸ 10³⁹ 10⁴⁰ 10⁴¹ 10⁴² 10⁴³ 10⁴⁴

JET/OUTFLOW
Pasham & van Velzen
arXiv:1709.02882

DUST
(van Velzen+16)

??

DISK

Holoien+16, van Velzen+16, Alexander+16, Jiang+16
Reality for most current TDF candidates

**Galaxy model**
- Archival data
- Flare data

**Dust reprocessing**
- Small amplitude signal
  -但 important as it yields the bolometric flare luminosity

**Synchrotron emission**
- Correlates with X-ray light curve
  - Likely due to jet, powered by inner disk

**Thermal emission from inner accretion disk**
- Not detected for every optically-selected flare

**Large flux increase**
- With respect to host galaxy
  - Useful for discovery in optical surveys
  - But origin is currently unclear

---

**Diagram**

**νL_{ν} (erg s^{-1})**

**Frequency (Hz)**

- radio
- IR
- optical/UV
- EUV
- soft X-ray

**νL_{ν} (10^{37} - 10^{44})**

- ??
TDE locus in optical surveys (2010)

adapted from van Velzen et al. (2011)
TDE locus in optical surveys (2017)

adapted from van Velzen et al. (2011)
Alternative models / TDF Impostors

- Accretion disk instabilities (LINER $\rightarrow$ TDE)
  (Phinney’s talk; Saxton, Perets, & Baskin 2017)

- A new kind of SNe?
  (Saxton, Perets, & Baskin 2017)

- Collisions of stars on bound orbits (EMRIs)
  (Metzger & Stone 2017)
Goal of this talk

Demonstrate rate suppression due to the black hole horizon

(arXiv:1707.03458)

Kesden (2011)
Sample of 17 optical/UV TDEs from *non*-Seyfert galaxies
The optical TDE luminosity function (using $1/V_{\text{max}}$ method)

\[ \nu L_\nu \text{ g–band (log}_{10} \text{ erg s}^{-1}) \]

\[ \text{Volumetric rate (Mpc}^{-3} \text{ yr}^{-1} \text{ dex}^{-1}) \]

- Fiducial TDF LF
- Power-law LF
- Observed TDFs (N=13)

van Velzen (2017)
The TDE host galaxy black hole mass function

![Graph showing the relationship between the volumetric rate and black hole mass. The graph includes a black line labeled 'Fiducial TDF model', a dotted orange line labeled 'BH mass function', a dotted green line labeled 'AGN flare model', and a blue line labeled 'Observed TDFs (N=12)'. The x-axis represents black hole mass in units of log_{10} M_☉, while the y-axis represents the volumetric rate in units of Mpc^{-3} yr^{-1} dex^{-1}. There are data points and error bars for each line, indicating observed TDFs.]

van Velzen (2017); data from Wevers et al. (2017)
The TDE host galaxy black hole mass function

![Graph showing the TDE host galaxy black hole mass function. The graph plots the volumetric rate (Mpc⁻³ yr⁻¹ dex⁻¹) against the black hole mass (log₁₀Mʘ). The black line represents the Fiducial TDF model. The orange dashed line represents the BH mass function. The green dotted line represents the AGN flare model. The blue squares with error bars represent the observed TDFs (N=12). The graph includes a note indicating that the choice is contested.]
ASASSN-15lh

Superluminous SN
(Dong et al. 2016)

TDE from Kerr BH
(Leloudas et al. 2017)

Image credit: ESO
Next step: forward modeling

• **Input:** luminosity function
• **Apply survey limits**
• **Output:** flux-limited sample
Observed black hole mass distribution

• Median mass $\sim 10^6 \text{M}_\odot$
  (Wevers et al. 2017)

With horizon: good fit to data
Observed black hole mass distribution

- Median mass ~ $10^6 \, M_\odot$ (Wevers et al. 2017)
- No horizon: too many high mass flares
Observed black hole mass distribution

- Median mass ~ $10^6 M_\odot$ (Wevers et al. 2017)

- No horizon: too many high mass flares

- With horizon: good fit to data
  (see also Lu, Pawan, & Narayan 2017)
Observed galaxy stellar mass function

- Median mass $\sim 10^{10} \, M_\odot$
- AGN flares: too many at low mass
- Supernovae: too many at high mass

![Graph showing cumulative fraction of galaxy total stellar mass vs. log_10(M_\odot).]
Observed Eddington ratio distribution

- Appears capped near Eddington limit
- Any SNe model ruled-out
Take home message

• Lack of flares from high-mass BHs
• Reject (almost*) all TDE impostor models

*see next two talks…
Broader implications

*Assuming current optical/UV candidates are indeed TDEs

image: M.C. Escher
No clear sign of circularization inefficiency

Cumulative fraction

Black hole mass (log$_{10}$M$_{\odot}$)

- Without black hole captures
- Including black hole captures
- Observed TDFs (N=12)
Mean optical TDE rate

- Faint flares often missed
- Rate $\approx 10^{-4}$ galaxy$^{-1}$ yr$^{-1}$
- Similar to theoretical and X-ray rates
- Another argument against impostors
Conclusions

• High-mass turnover in the TDF mass function:
  • Evidence for a black hole event horizon
  • Inconsistent with TDE impostor scenarios
• Below Hills mass, TDF rate ~ constant:
  • No large circularization inefficiencies
• Steep optical luminosity function:
  • Due accreted mass: $M_{\text{star}}$ or $\beta<1$
  • Mean rate is $\approx 10^{-4}$ galaxy$^{-1}$ yr$^{-1}$
Backup slides
Summary of observations and emission mechanisms

- **Synchrotron emission**: correlates with X-ray light curve; likely due to jet, powered by inner disk.
- **Dust reprocessing**: small amplitude signal but important as it yields the bolometric flare luminosity.
- **Large flux increase with respect to host galaxy**: useful for discovery in optical surveys, but origin is currently unclear.

Graph showing emission across different frequencies (radio, IR, optical/UV, EUV, soft X-ray) with key emission mechanisms labeled.
Normalization of the different surveys

Number of flares = Survey duration x Area x Efficiency x Volume x Rate

<table>
<thead>
<tr>
<th></th>
<th>Number of flares</th>
<th>$z_{\text{max}}$</th>
<th>Survey duration x Area (yr deg$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GALEX</td>
<td>3</td>
<td>0.44</td>
<td>10</td>
</tr>
<tr>
<td>SDSS</td>
<td>2</td>
<td>0.14</td>
<td>200</td>
</tr>
<tr>
<td>ASAS-SN</td>
<td>4</td>
<td>0.02</td>
<td>80,000</td>
</tr>
</tbody>
</table>
Zoom to the BH mass function

![Graph showing the volumetric rate as a function of black hole mass](image)

The graph illustrates the relationship between the volumetric rate and black hole mass. The solid line represents the function $\dot{N} \propto M_{BH}^{0.3}$, and the dashed line represents $\dot{N} \propto M_{BH}^{0.5}$. The error bars indicate the uncertainty in the measurements.
The TDE host galaxy mass function

![Graph showing cumulative fraction against galaxy total stellar mass. The graph includes lines for AGN flares, nuclear SNe, and observed TDFs. The lines represent different scaling relations with mass, SFR, and BH mass.]
The light curve evolution of ASASSN-15lh in the rest frame. The data are from LCOGT (gri) and Swift (other filters), supplemented by the ASASSN V-band data. We have adopted a peak time at 5 June 2015 (MJD 57178.5). The light curves are shifted for clarity as indicated in the legend. Error bars represent 1 uncertainty.

The optical bands show a monotonic decline, but the UV bands show a rebrightening after 60 rest-frame days. A significant secondary dip is also observed in the bluest bands.