Constraints on radio jets from known stellar tidal disruption events

Do all TDFs launch jets?

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Tidal Disruption events and AGN outbursts workshop
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Learn from tidal disruption jets

• For single events:
  ‣ Disk + B-field
  ‣ Calorimetry

• Discovery:
  ‣ Radio not absorbed
  ‣ Upcoming radio transient surveys

• Accretion states
Black hole accretion modes

• Two accretion states, divided by Eddington rate

• Radio jets below \( \sim 2\% \dot{M}_{\text{Edd}} \)
  
  ‣ Observed for stellar mass accreting binaries (McClintock & Remillard 2004; Fender et al. 2004)
  
  ‣ Also the case for SMBHs? (Körding et al. 2006; Best & Heckman 2012)

• With TDEs we probe these rates for a single SMBH
Radio observations -- “Status of the field”

< 2011 No detections ≈3 events followed up

> 2011 Two detections (‘Swift events’), more followed up
Two models

- **External model** (Giannios & Metzger 2011; Metzger, Giannios, Mimica 2011)
  - Interaction of forward/backward shock with environment
  - On-axis (or isotropic)
  - Inspired by GRB afterglows

- **Internal model** (van Velzen, Falcke, Farrar 2010, van Velzen, Körding, Falcke 2011)
  - Emission from matter injected in the jet from the disk
  - Doppler boosting
  - Inspired by AGN jets
Standard AGN jet model

- **Conical jet model** (Blandford & Königl 1979)

- **Jet power is a linear function of disk luminosity** (Rawlings & Saunders 1991; Falcke & Biermann 1995)

- **Well constrained by observation**

\[
L_\nu = C_{\text{eq}} \delta^2 \int_{z_{\text{ssa}}}^{\infty} dz \, z^2 \epsilon_{\text{syn}}(z, \nu / \delta) \propto (q_j L_d)^{17/12}
\]

Körding et al. 2008

![Graph showing the relationship between accretion luminosity and jet luminosity](image-url)
Add time dependence

- Disk luminosity given by fallback rate

- Self-absorption radius sets the emission timescale

- Three scenarios for order of accretion modes

\[ q_j = \begin{cases} 
0.2 & \text{all times} \\
0.002 & \dot{M}(t) > 2\% \dot{M}_{\text{Edd}} \\
0.2 & t < t_{\text{fallback}} \end{cases} \]

- Radio-loud
- Eddington trigger
- Radio burst
Model light curves

\[ M_{\text{BH}} = 1 \times 10^7 M_\odot \]

- Green line: 10 GHz, always radio-loud (a)
- Blue line: 1.4 GHz, always radio-loud (a)
- Gray line: 200 MHz, always radio-loud (a)
- Blue dotted line: 1.4 GHz, loud for \( \dot{M} < 2\% \) (b)
- Blue dashed line: 1.4 GHz, burst (c)

jet luminosity (erg s\(^{-1}\) Hz\(^{-1}\))

\[ 10^27 \quad 10^28 \quad 10^29 \quad 10^30 \quad 10^31 \quad 10^32 \]

time since disruption (yr)

\[ 10^0 \quad 10^1 \]
Delay could explain existing non-detections
Jansky VLA observations at 5 GHz

<table>
<thead>
<tr>
<th>name</th>
<th>integration time</th>
<th>$\sigma(F_\nu)$</th>
<th>$\Delta t$</th>
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<tr>
<td>TD 04B</td>
<td>18</td>
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<td>PTF10iya</td>
<td>18</td>
<td>8</td>
<td>1.6</td>
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</table>

No detections
Exclusion for the external model

- Find largest jet angle consistent with non-detection

- Probability for at least one detection:
  - Always radio loud: 99.992%
  - Radio flare: 50%
  - Only below 2% Eddington: 33%
Sw 1644+57 late-time light curve

- few mJy after 10 yr! (if $\Gamma>1$)
- Scale to off-axis observers
  - Knowledge of frequency structure required
  - Assume ‘blob’

![Graph showing the late-time light curve of Sw 1644+57 with flux density (mJy) plotted against time (yr) for 22 GHz and 6 GHz frequencies. The graph includes curves for different energy scales: $E=10^{52}$, $E=3\times10^{52}$, and $E=10^{53}$, with EVLA sensitivity lines at 22 GHz (5σ) and 6 GHz (5σ).]
Sw 1644+57 off-axis: $\Gamma(t>1\text{yr}) = 2$

Probability zero detections = 0.1%
\[ \Gamma(t) = \sim t^{-0.2} \; ; \; \text{Sedov-Taylor if } \Gamma < 2 \]

Probability zero detections = 0.1%
Not all TDF launch jets?

• Radio upper limits for optically discovered TDF inconsistent with current jet models

• But optical TDF (may) have different:
  ‣ Environment
  ‣ Black hole mass; accreted matter
  ‣ Delay with respect to time of disruption
Good news: areal rate of Sw 1644+57

\[ R(F_\nu) \sim 10^{-3} \left( \frac{20 \text{ mJy}}{F_\nu} \right)^{3/2} \frac{\dot{N}_{\text{TDE}}}{10^{-5} \text{ yr}^{-1}} (1/\Gamma)^2 \text{ deg}^{-2} \]
Outlook

- Wait for Sedov phase of Sw 1644+57
- Analyze Sw 2058+05
- Include other non-detections
- Keep observing!
Lessons from multi-frequency radio data (Zauderer et al. 2011)

- ~days delay between 4.9 GHz and 6.7 GHz
- For conical jet:
  \[ z_{ssa} = z_0 \left( \frac{\nu}{\nu_0} \right)^{-1} \]
  \[ z_0 \sim 10^{-3} \text{ pc} \]
- Much smaller than equipartition for \( q_j = 0.2 \)
Predicted rate and observed upper limits
Sw 1644+57 off-axis: $\Gamma(t) = \sim t^{-0.2}$

Probability zero detections = 0.00%