Observational Progress in Identifying and Characterizing Tidal Disruption Flares

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Tidal Disruption Flares (TDFs)

Luminous \((10^{44} \text{ erg s}^{-1})\), long-lived (> months), thermal \((10^5 \text{ K})\) flares from nuclei of otherwise quiescent galaxies
Early TDF Discoveries: X-Ray Selected

- Earliest events identified largely by ROSAT
- Agreed reasonably well with simple analytical models ($kT \sim 100$ eV, blackbody radius ~ tidal radius, $t^{-5/3}$ decay (though sparsely sampled))
- Subsequent X-ray discoveries have indicated additional diversity (see upcoming talk by Richard Saxton)

Komossa, 2015
Rise of Optical Time-Domain Surveys

Wide-field, high cadence optical transient surveys (Pan-STARRS, PTF, ASAS-SN) have revolutionized the search for TDFs.

7.1 deg camera on Palomar 48 inch Oschin Schmidt telescope

92 MPix
1.0 arcsec sampling
R=21 in 60 seconds
Rise of Optical Time-Domain Surveys

Summit of Palomar Mountain

P48 = discovery
P200 (Keck, Gemini) = Spectroscopy
P60 = Multi-color Imaging

Factory = fully automated, end-to-end discovery and follow-up
Observational Puzzles

- Low (and slowly evolving) temperature in optical/UV discovered TDFs
- Ubiquity of outflows (variety of velocities)
- Peculiar abundance patterns in optical (and particularly UV) spectroscopy
- Preferentially observed in “post-starburst” host galaxies
PS1-10jh: Cool, Constant Temperature

- PS1-10jh: Nucleus of non star-forming galaxy
- After removing host galaxy, blackbody continuum with $T \sim 2 \times 10^4$ K (factor of $>5$ lower than ROSAT events)
- No sign of color evolution for $>100$ (rest-frame) d
- Corresponding blackbody radius $\sim 10^{15}$ cm - a factor of 10-100 larger than the tidal radius!

Gezari et al., 2012
ASASSN-14li: At Least 2 BB Components

Comparable luminosity but varying temperature ⇒ distinct emitting regions!
Possible Explanations: Circularization and Reprocessing

1. Efficient circularization at large radii (due to relativistic precession) leads directly to emission at these distances (e.g., Shiokawa et al., 2015)

2. Reprocessing of inner accretion disk by outer layer of material yields large photosphere (e.g., Roth et al. 2015)
Outflows I: Relativistic TDFs

Sw J1644+57: A remarkable high-energy transient

Levan et al., 2011

Zauderer et al., 2011
Outflows I: Relativistic TDFs

- Star tidally disrupted by SMBH
- Resulting shocked, circularized accretion disk gives rise to thermal emission
- Launches collimated, relativistic jet powering non-thermal radio and (likely X-ray)
- In analogy with AGN, non-thermal component only visible for preferential viewing angles

Zauderer et al., 2011
Outflows II: Fast (but not relativistic)

ASASSN-14li: Radio

From broadband radio observations, measure outflow velocity of $\sim 20,000 \text{ km s}^{-1}$ and $E \sim 10^{48} \text{ erg}$

Alexander et al., 2016
Outflows III: Very low Velocity

Highly ionized gas, close to black hole (varies on few day time scales), velocities of few \textbf{hundred} km s$^{-1}$
Outflows IV: P Cygni profiles

Broad (~ 10000 km s), blue-shifted absorption of C IV, Si IV, Lyα (?); P Cygni like?
Abundance Patterns: PS1-10jh

- Strong, broad He II emission lines, but no corresponding Balmer H lines
- H-poor star disrupted?
- Complex photoionization conditions in emitting gas?

Gezari et al. 2012
Variable H-He Ratio in Optical Spectra

Arcavi+ 2014
Abundance Patterns: ASASSN-14li

First UV spectrum of a TDF (Cenko et al. 2016)
Abundance Patterns: ASASSN-14li

First UV spectrum of a TDF (Cenko et al. 2016)
Abundance Patterns: ASASSN-14li

No Mg II (and other low ionization lines) in emission or absorption

Cenko et al. 2016
Abundance Patterns: ASASSN-14li

N-rich Quasars: possible TDFs?? N over-abundance due to CNO processing in Sun-like star (Kochanek et al. 2016)

Cenko et al. 2016
Host Galaxies: Preference for Post-Starbursts

Factor of tens to hundreds over-abundant in “post-starburst” galaxies - post mergers?

French et al. 2016
Conclusions / Remaining Puzzles

❖ Why is the UV/optical emission seen from TDFs coming from such a large radius?
❖ What dictates the presence / speed of outflowing material in TDFs?
❖ How does the observed abundance pattern relate to physical conditions in the emitting gas?
❖ Why do TDFs occur preferentially in post-starburst galaxies?