Tidal Disruption Events & LSST

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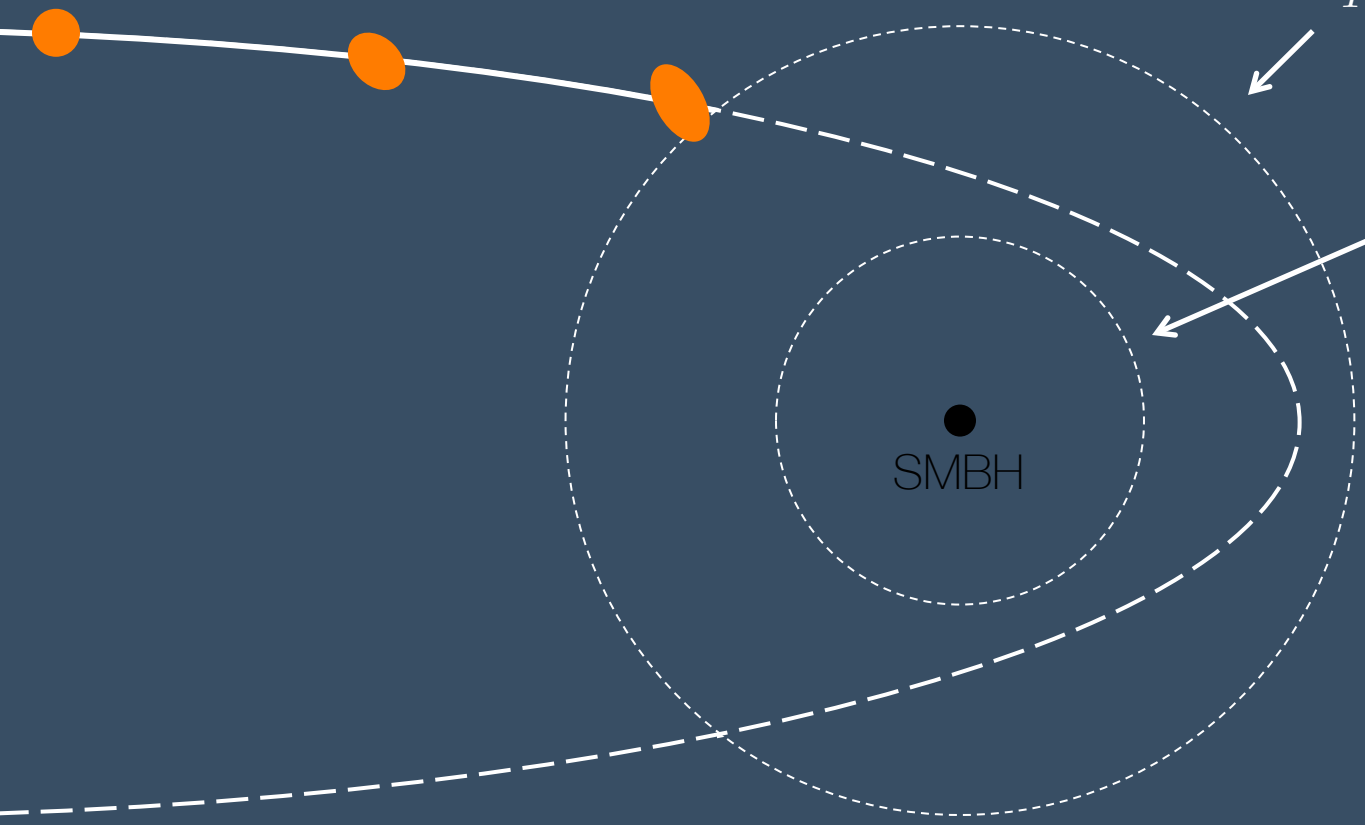
LCOGT & KITP
University of California, Santa Barbara

Important Scales



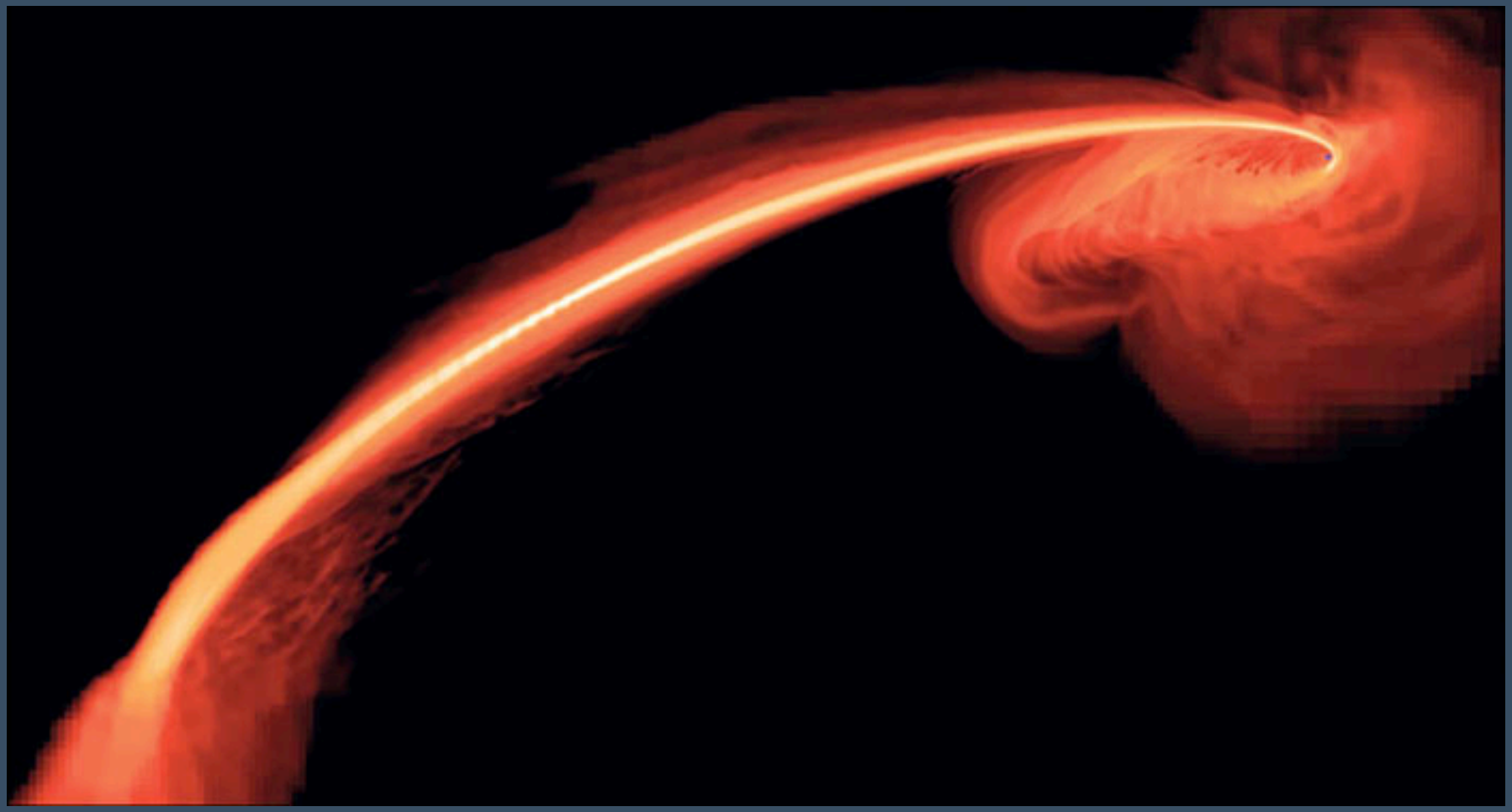
$$R_T = \left(\frac{M_{BH}}{M_*}\right)^{1/3} R_*$$

$$R_S = \frac{2GM_{BH}}{c^2}$$

$$R_T \gtrsim R_S \text{ for } M_{BH} \lesssim 10^8 M_\odot \cdot \left(\frac{R_*}{R_\odot}\right)^{3/2} \left(\frac{M_*}{M_\odot}\right)^{-1/2}$$

(Newtonian)

A Tidal Disruption Event (TDE) is Complicated



NASA, S Gezari/JHU and J Guillochon/UCSC

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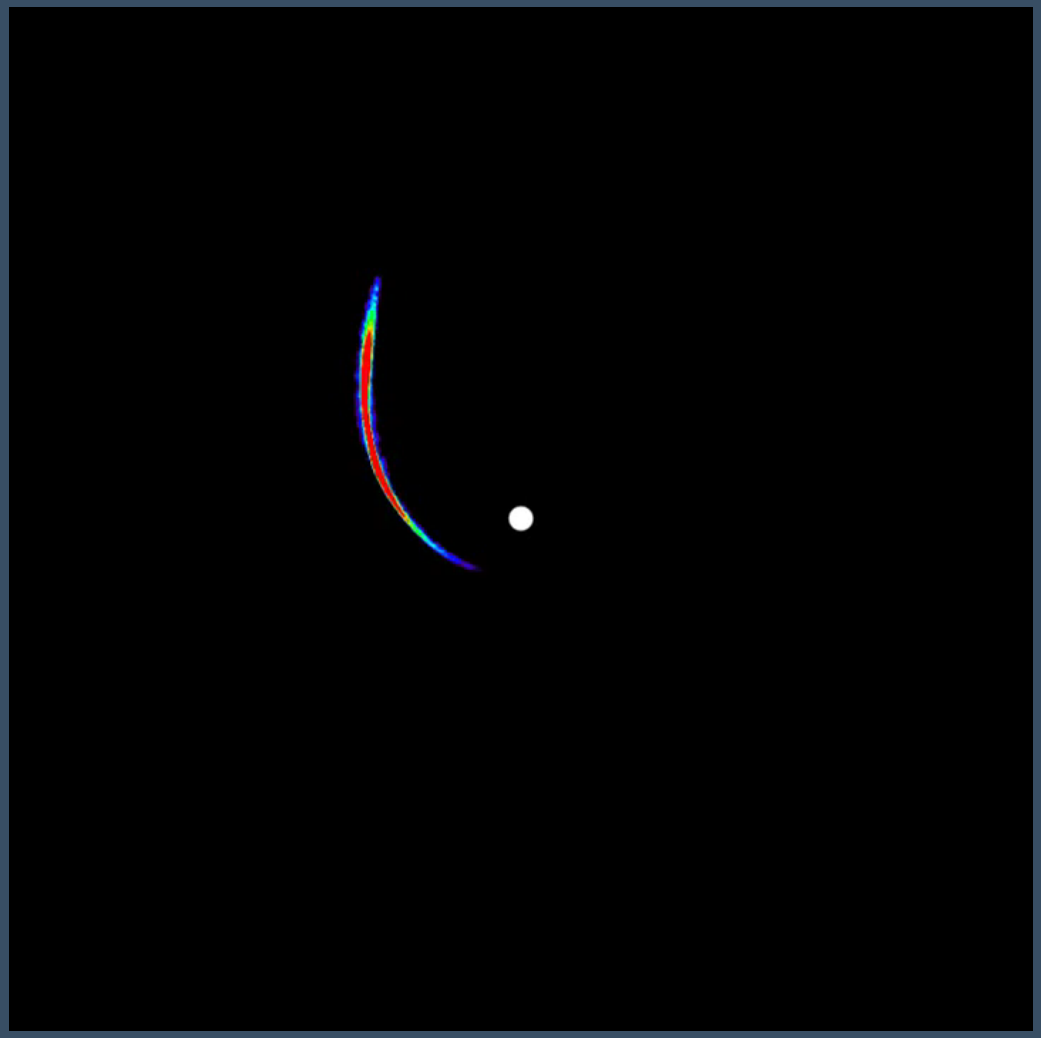

Bonnerot et al. 2015

TDEs Are Still Being Developed As Tools

TDEs can be used to study quiescent massive black holes (and the M-Sigma relation) **beyond the nearby Universe**

But first, we need to understand the events: what they look like and why, how are the TDE observables related to the SMBH properties

TDEs: Rare But Not a New Idea

Hills (1975) – A star could be disrupted by a massive BH.

Rees (1988), Evans & Kochanek (1989) – Half of the material is bound, half unbound, expect emission when the bound material falls back to the BH as $t^{-5/3}$.

Donley et al. (2002), Wang & Merritt (2004), Kesden (2012), Stone & Metzger (2014) – Rate is 10^{-4}-10^{-5} events per galaxy per year.

TDEs: No Well-observed Candidates Until 2010

ROSAT (X-Rays) – 5 archival candidates (Donley et al. 2002).

XMM-Newton (X-Rays) – 5 additional archival candidates (Esquej et al. 2007).

SDSS (optical) – 2 archival candidates (van Velzen et al 2011).

GALEX (UV) + CFHT (optical) – one candidate (~year cadence light curve; Gezari et al. 2006).

TDEs: Two Major Discoveries in 2011 and 2012

Swift J1644 (Bloom et al. 2011, Burrows et al. 2011, Levan et al. 2011, Zauderer et al. 2011)

Gamma and X-rays, radio
No optical

Non-thermal spectrum
Plateau in X-ray light curve
then $\sim t^{-5/3}$ decline

Additional events:
Swift J2058 (Cenko et al. 2012), Swift J1112 (Brown et al. 2015)

PS1-10jh (Gezari et al. 2012)

UV / Optical
No X-rays

Hot blackbody (30,000K)
Smooth rise and fall light curve
$\sim t^{-5/3}$ decline

Additional events:
Arcavi et al. 2014, Holoien et al. 2014, 2015

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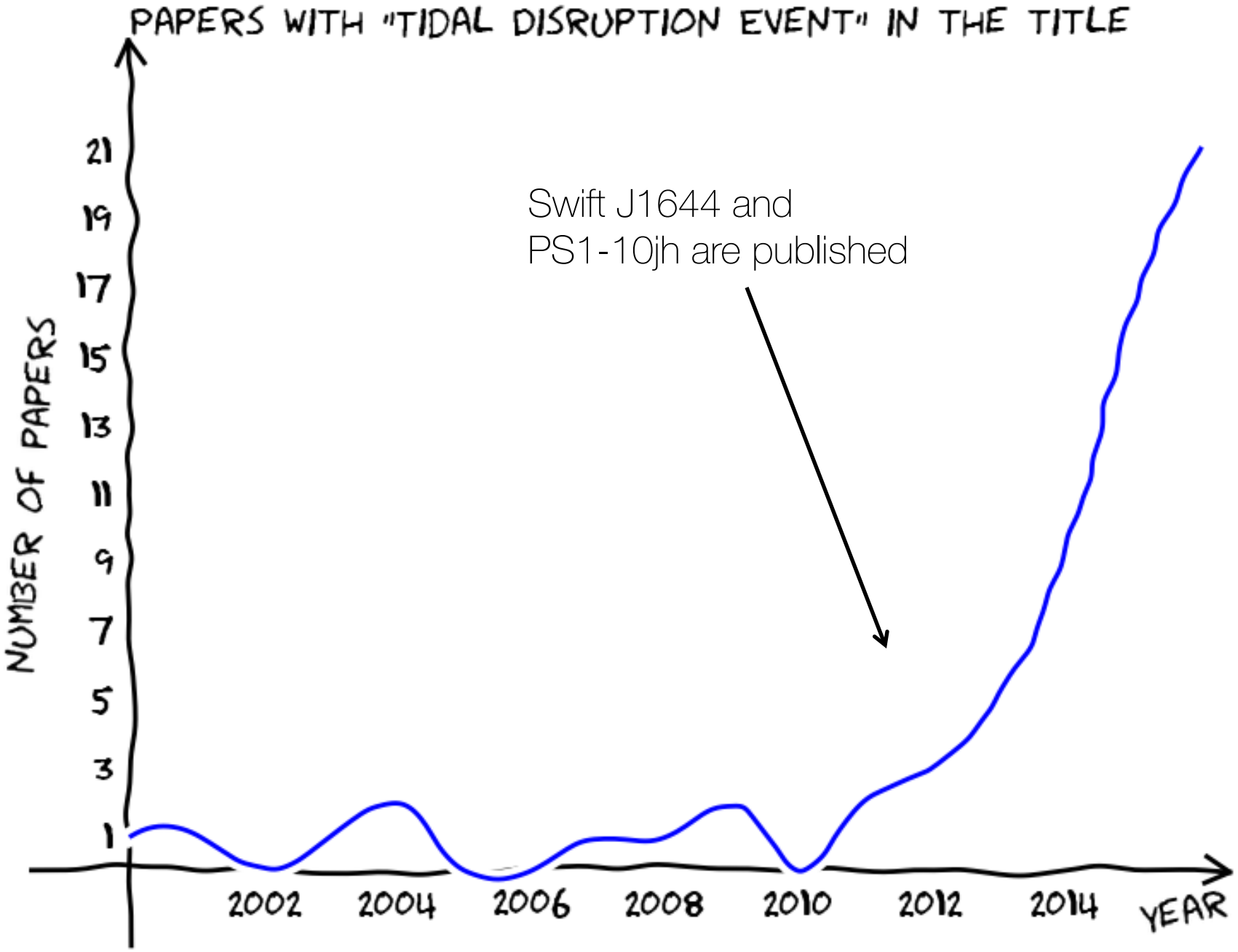
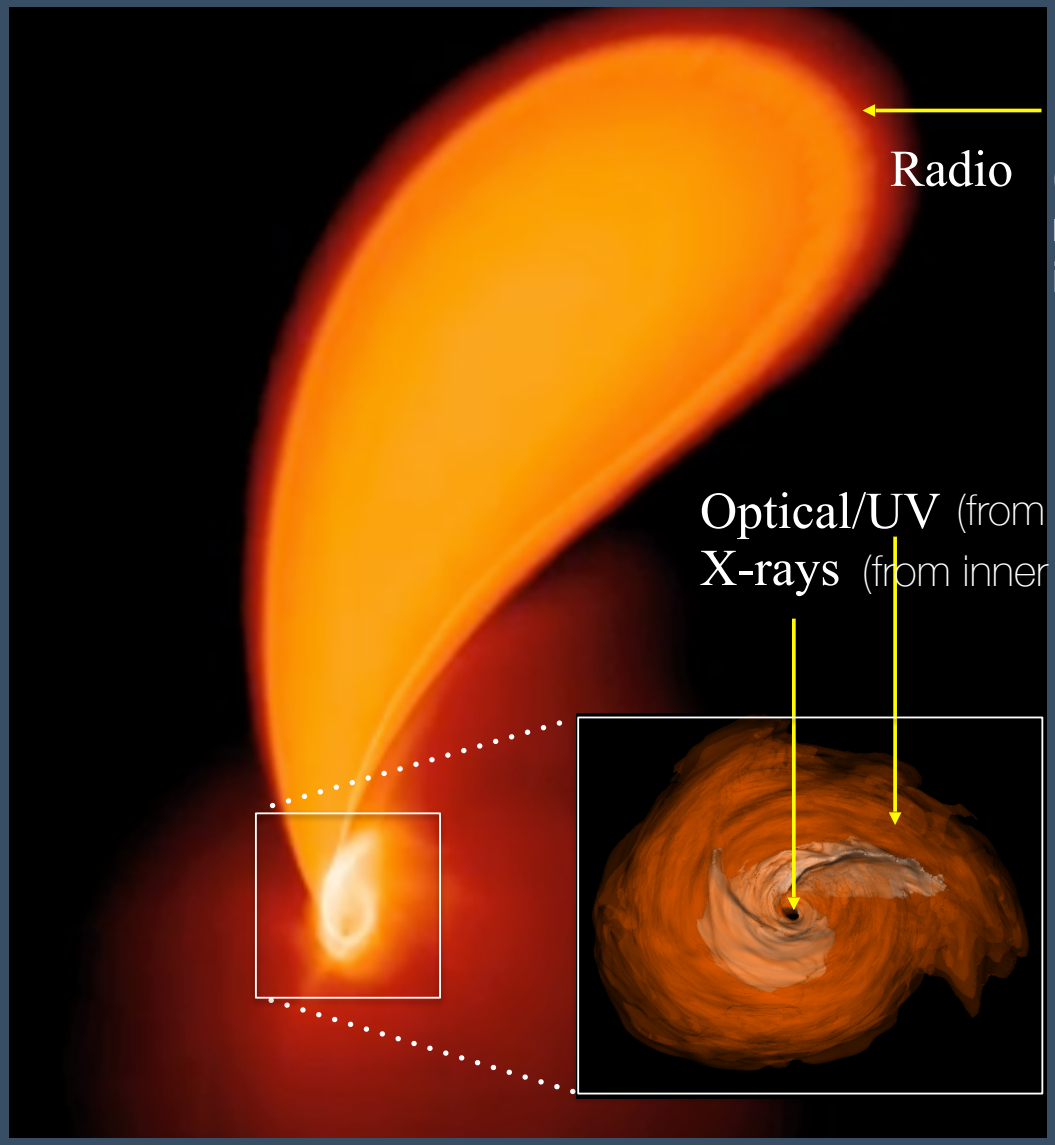

PAPERS WITH "TIDAL DISRUPTION EVENT" IN THE TITLE
NUMBER OF PAPERS
1
3
5
7
9
11
13
15
17
19
21
2002
2004
2006
2008
2010
2012
2014
YEAR
Swift J1644 and
PS1-10jh are published

TDE Emission Mechanism Still Uncertain



Krolik et al. 2016

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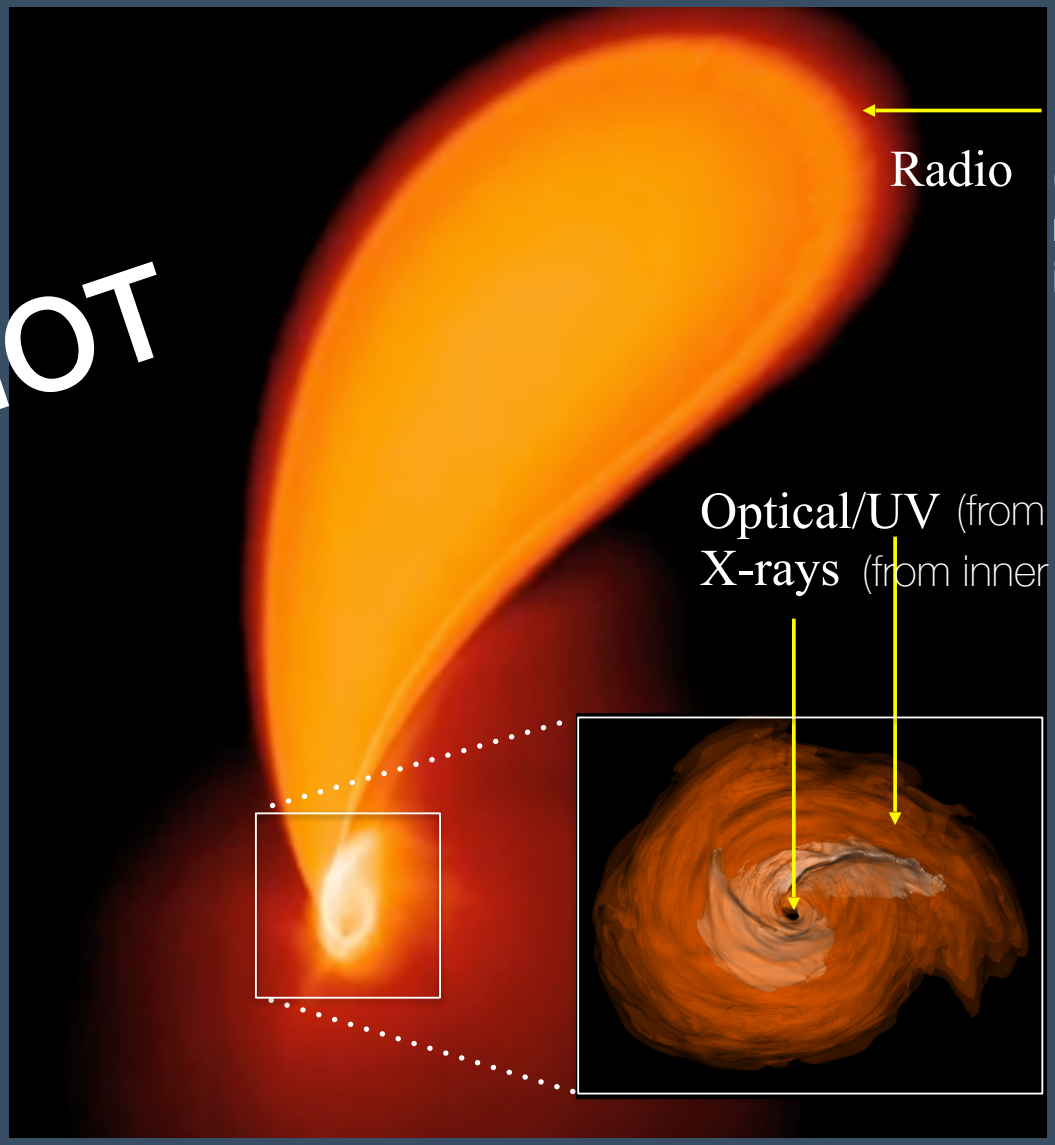

Krolik et al. 2016

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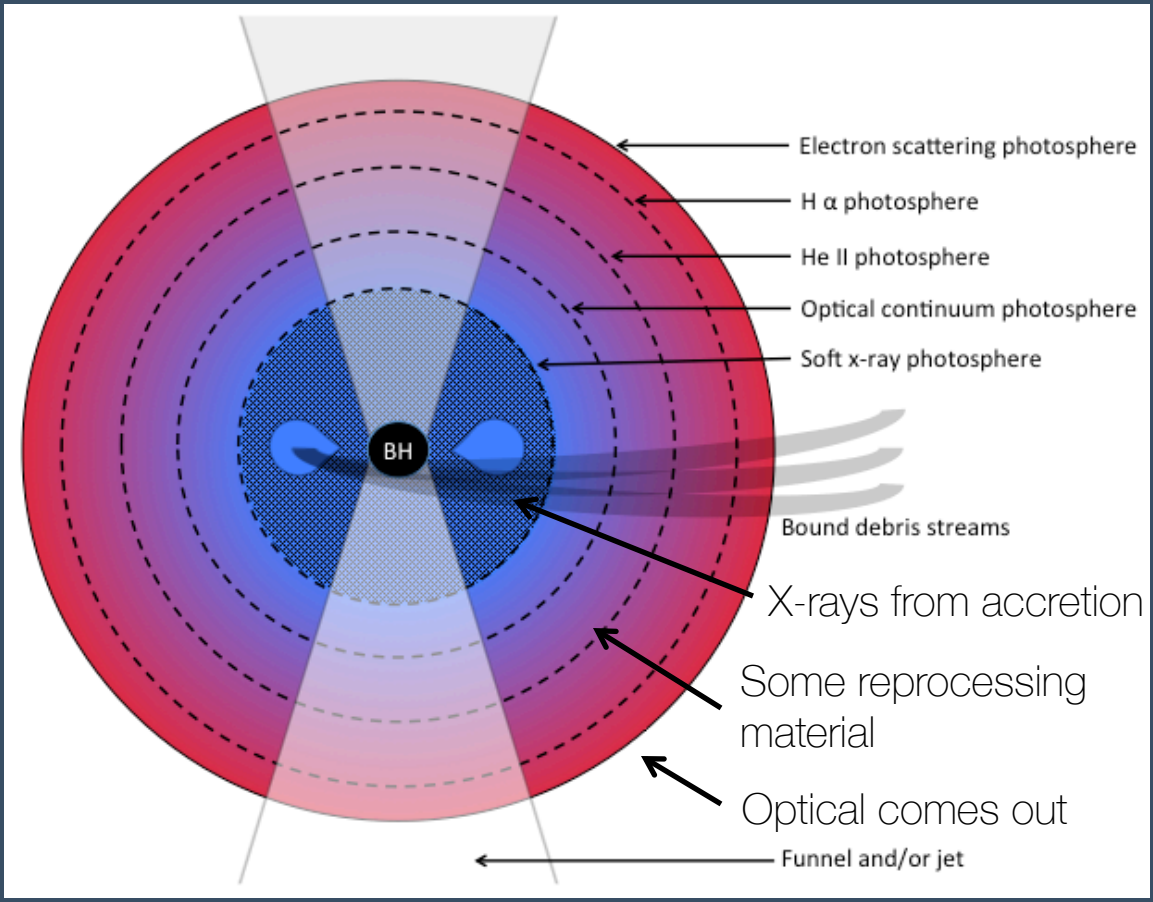
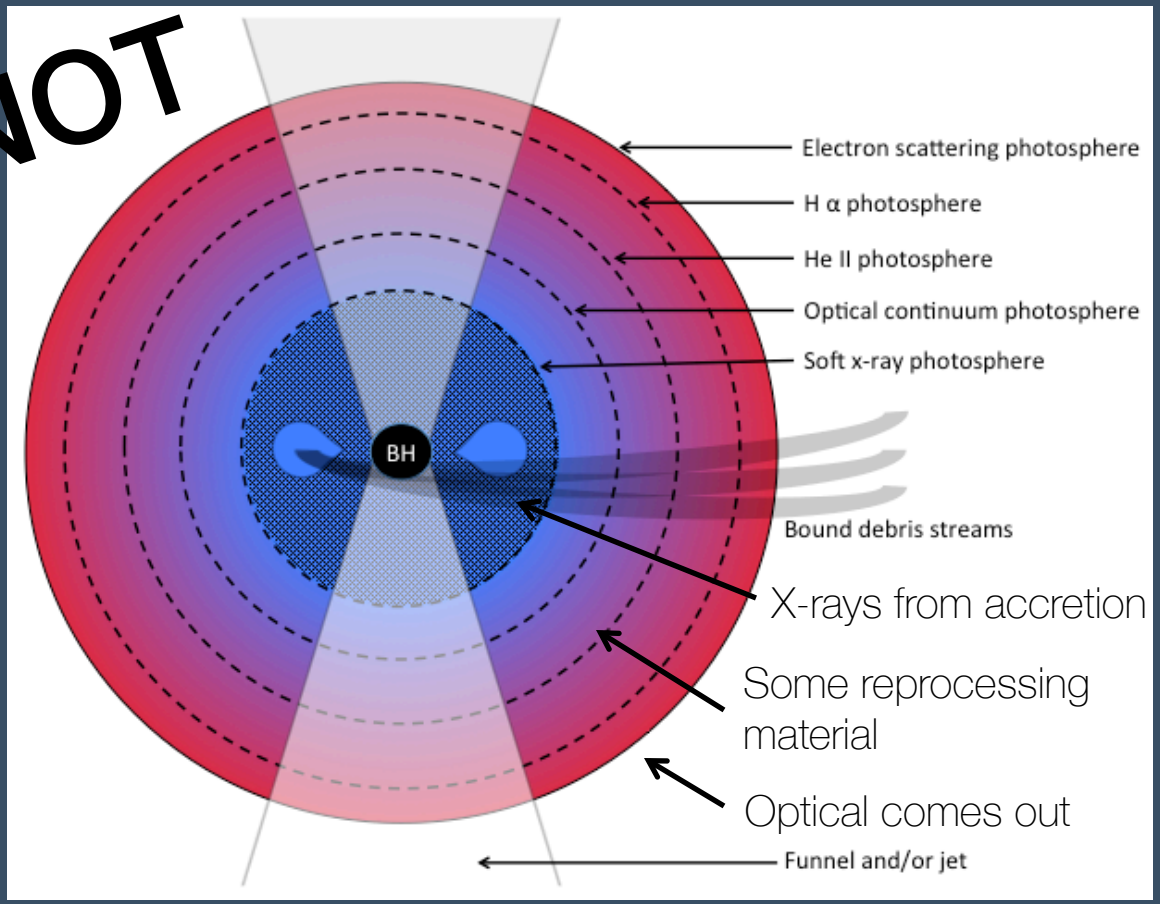


Krolik et al. 2016

TDE Emission Mechanism Still Uncertain

OR NOT



Krolik et al. 2016

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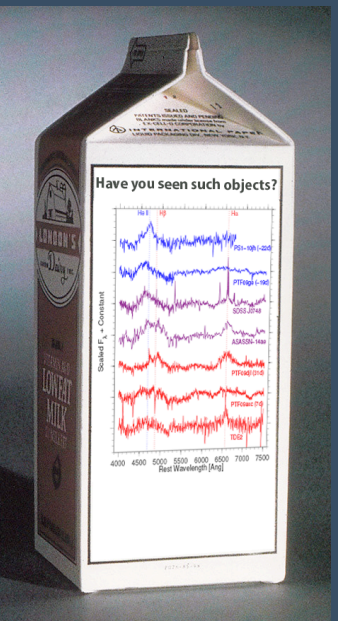
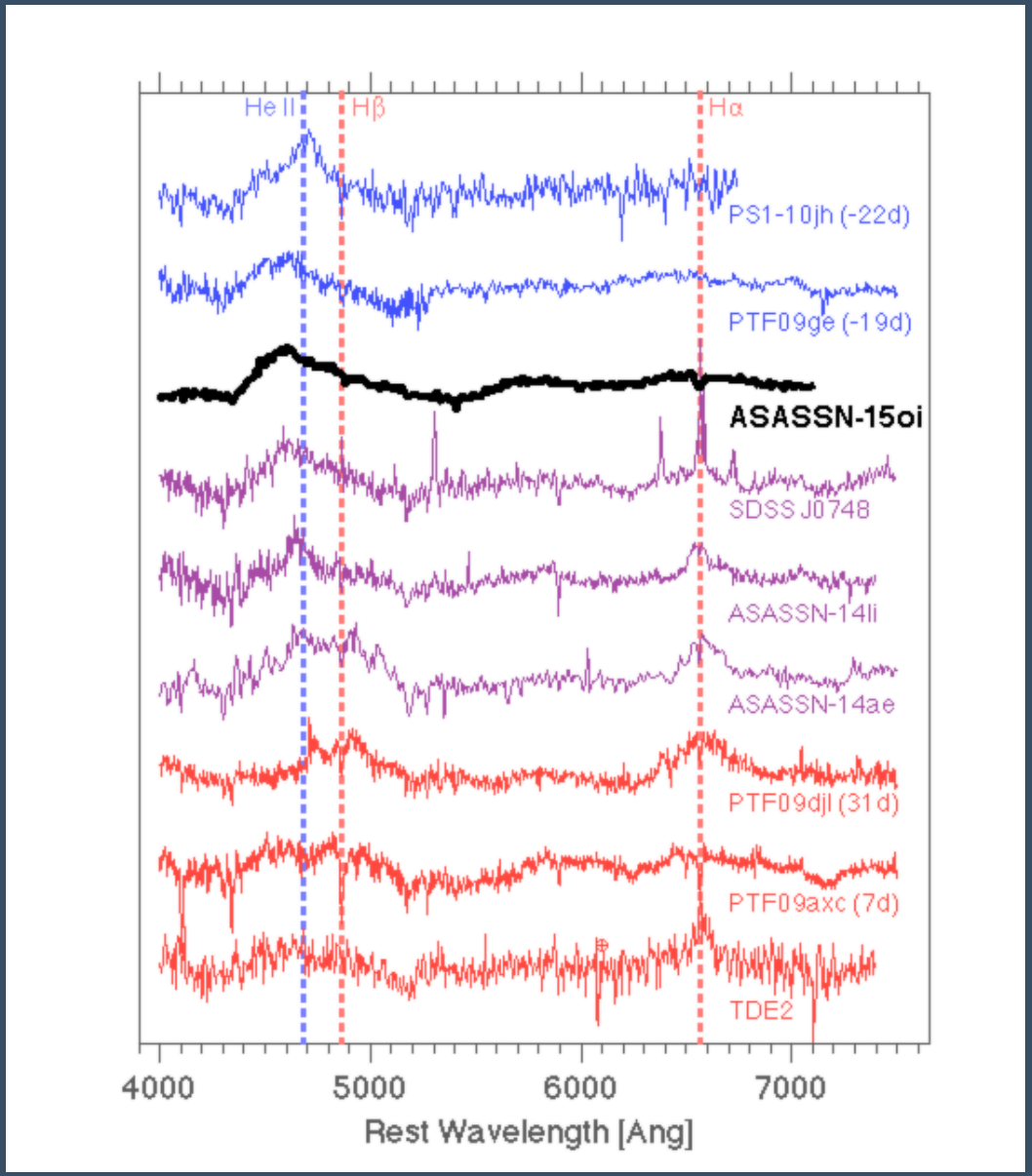
The First Atlas of Thermal TDEs





Gezari+ 12

Arcavi+ 14

Holoien+ 16

Wang+ 11

Holoien+ 15

Arcavi+ 14

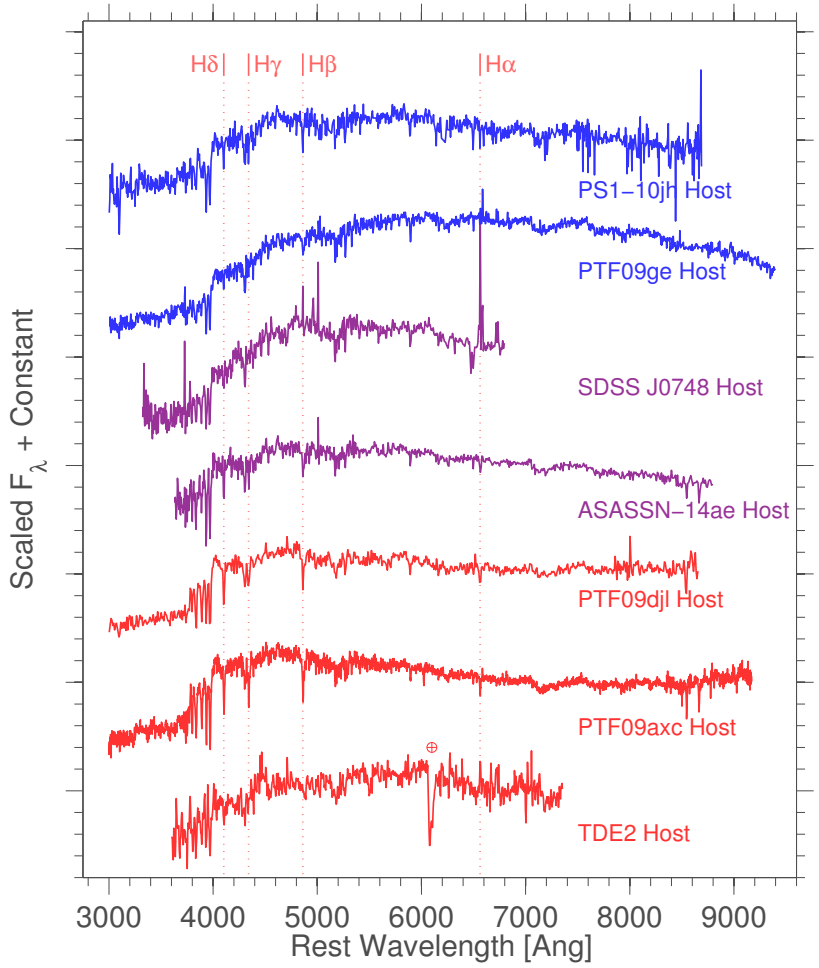
Holoien+ 14

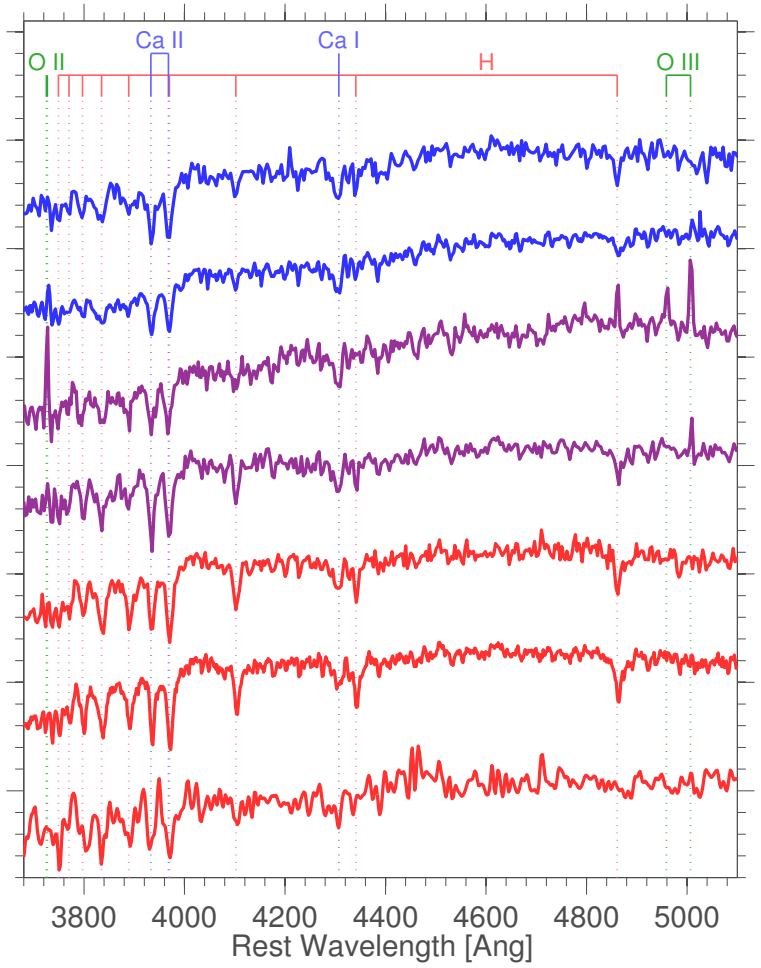
Arcavi+ 14

Arcavi+ 14

van Velzen+ 11

They're Almost All in Post-Starburst Galaxies!





Arcavi et al. 2014

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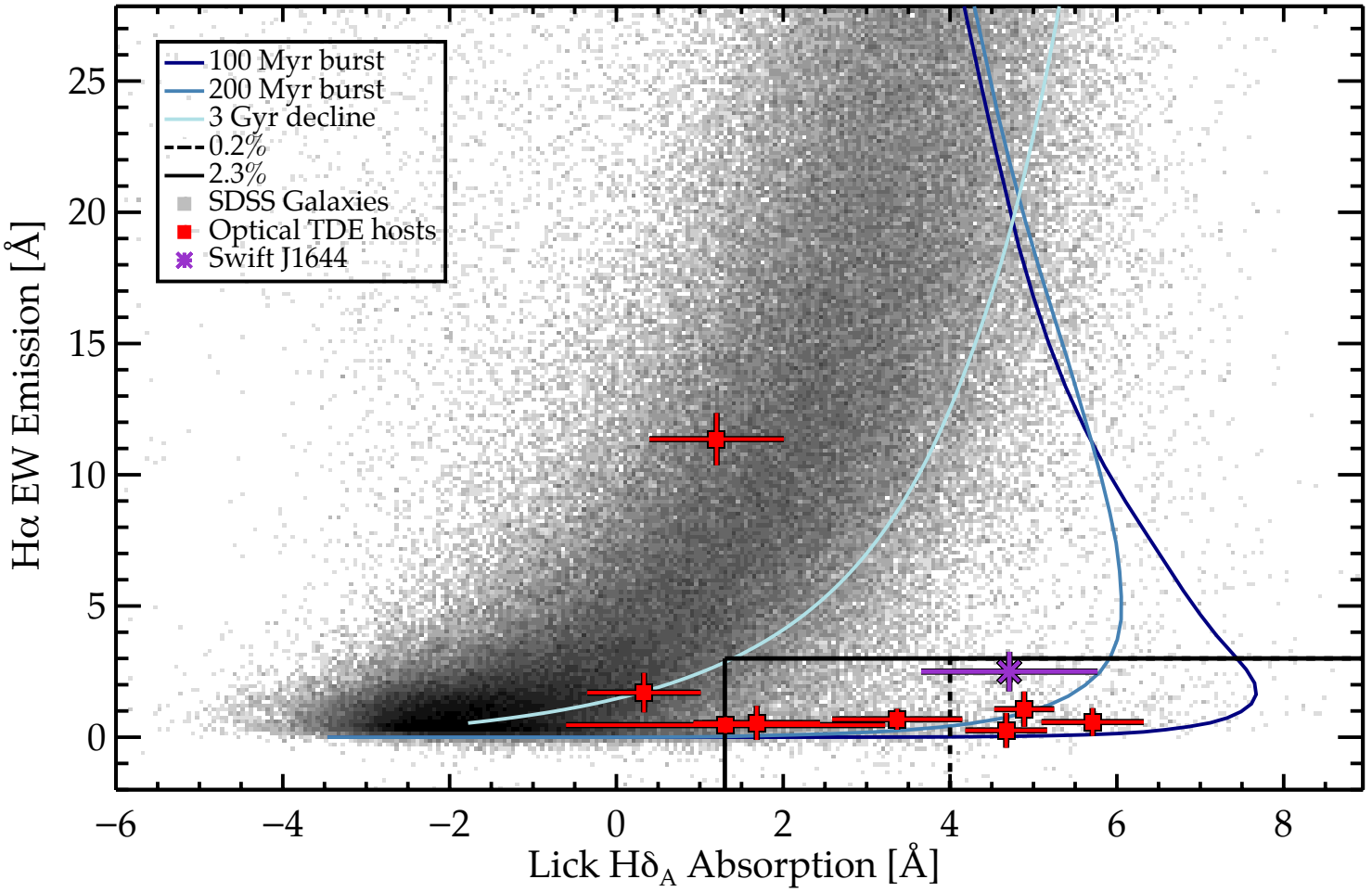


French, Arcavi, Zabludoff, 2016

How to Identify a TDE in a Transient Survey?

- In the center of its host: Image subtraction, host offset + error
- Hot for long: Colors for all visits, u-band crucial?
- Slowly evolving: Ok with relaxed cadence, up to ~week
- Not showing past AGN-like variability: History at position?
- Not in a known AGN host: X-ref galaxy catalogs
- Preference if peaking around mag -20: X-ref redshift catalogs
- Preference if in post-starburst: X-ref galaxy catalogs

What Will We Want to do with TDEs in the 2020s?

- Calculate black hole masses: What kind of cadences and bands can the TDE-fitting models tolerate?

- Correlate with host parameters: Co-addition for faint hosts, automatic bulge/disk parameters for resolved hosts?

- Measure TDE rates as functions of above: How tolerant is the luminosity function to irregular cadence?

- Look for optical signatures of high-energy TDEs: Co-observe with X-ray/UV telescopes? Recover sub-detection events? From deep stacks?

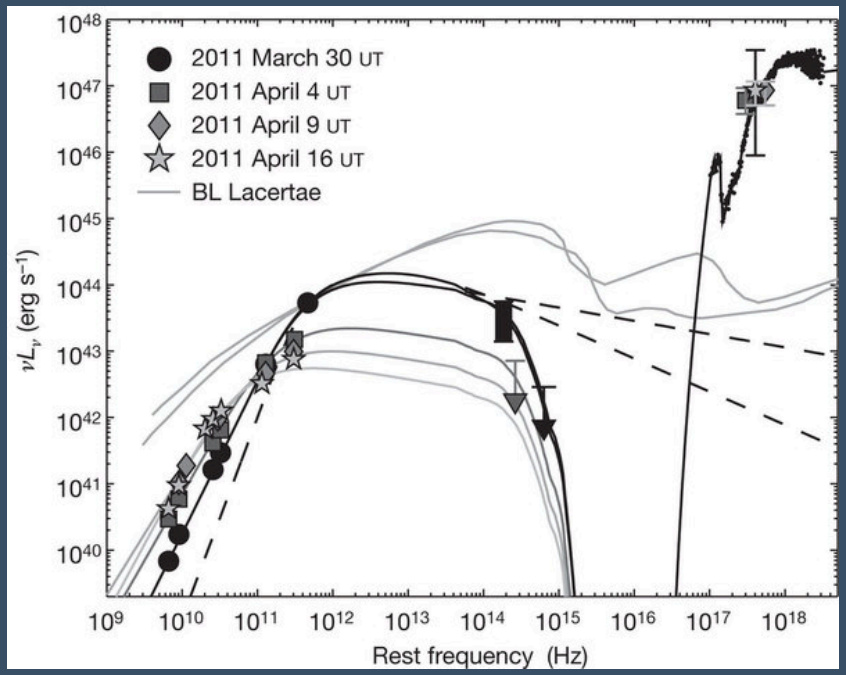
Tasks for the TDE Subgroup

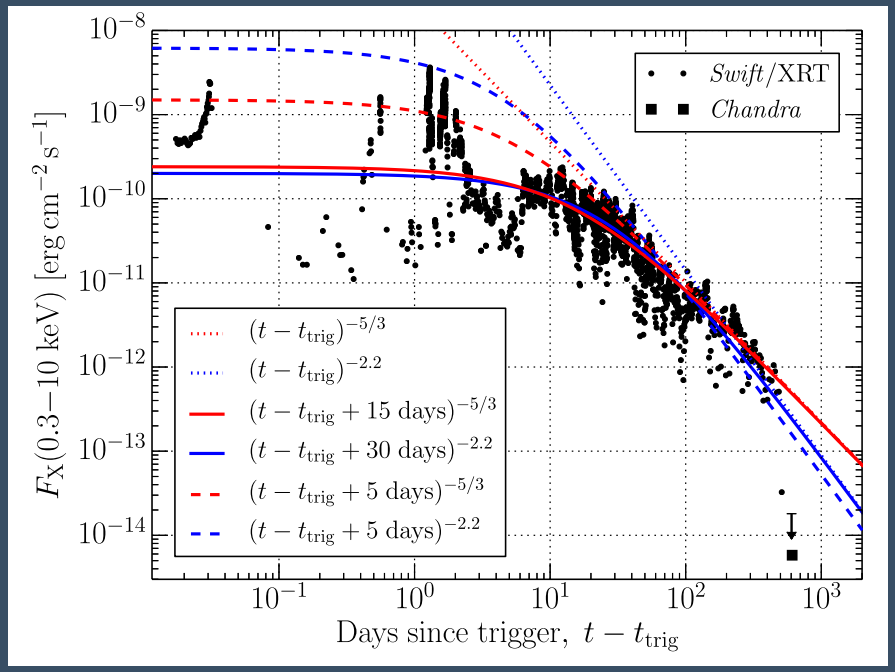
- Obtain a luminosity function for TDEs to check:
  - How does cadence affect black hole parameter modeling?
  - How does cadence affect rate calculations?
  - How do filters affect SN/TDE/AGN discrimination? How often do we need u-band if at all?

- What can we learn from TDEs just from photometry? Are there correlations between photometric and spectroscopic parameters?

- Can we identify likely TDE hosts by their color?

Swift J1644: High-energy TDE candidate



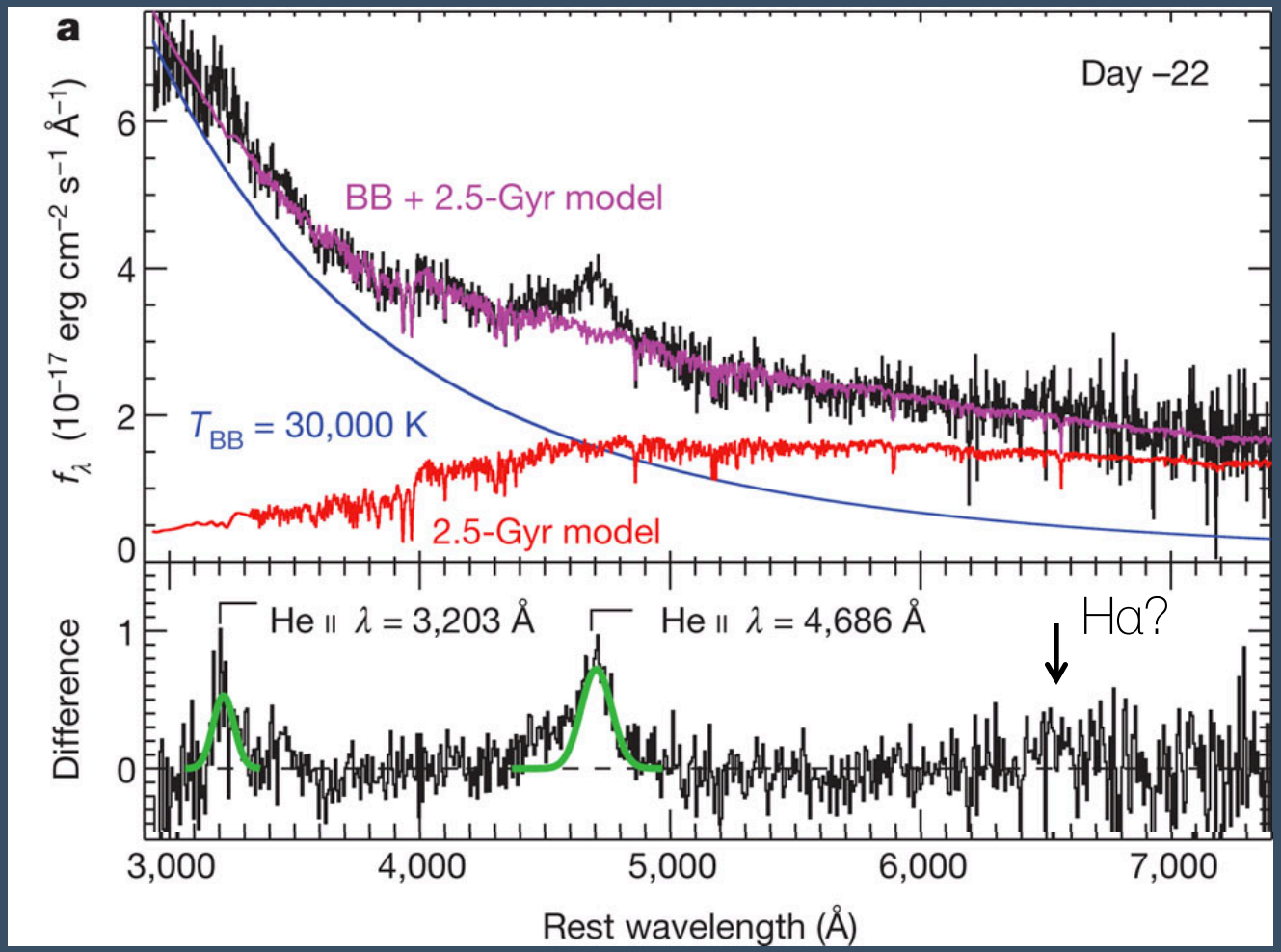


Radio IR X-ray

"… Sw 1644+57 initially displayed none of the theoretically anticipated (nor previously observed) TDF characteristics …"

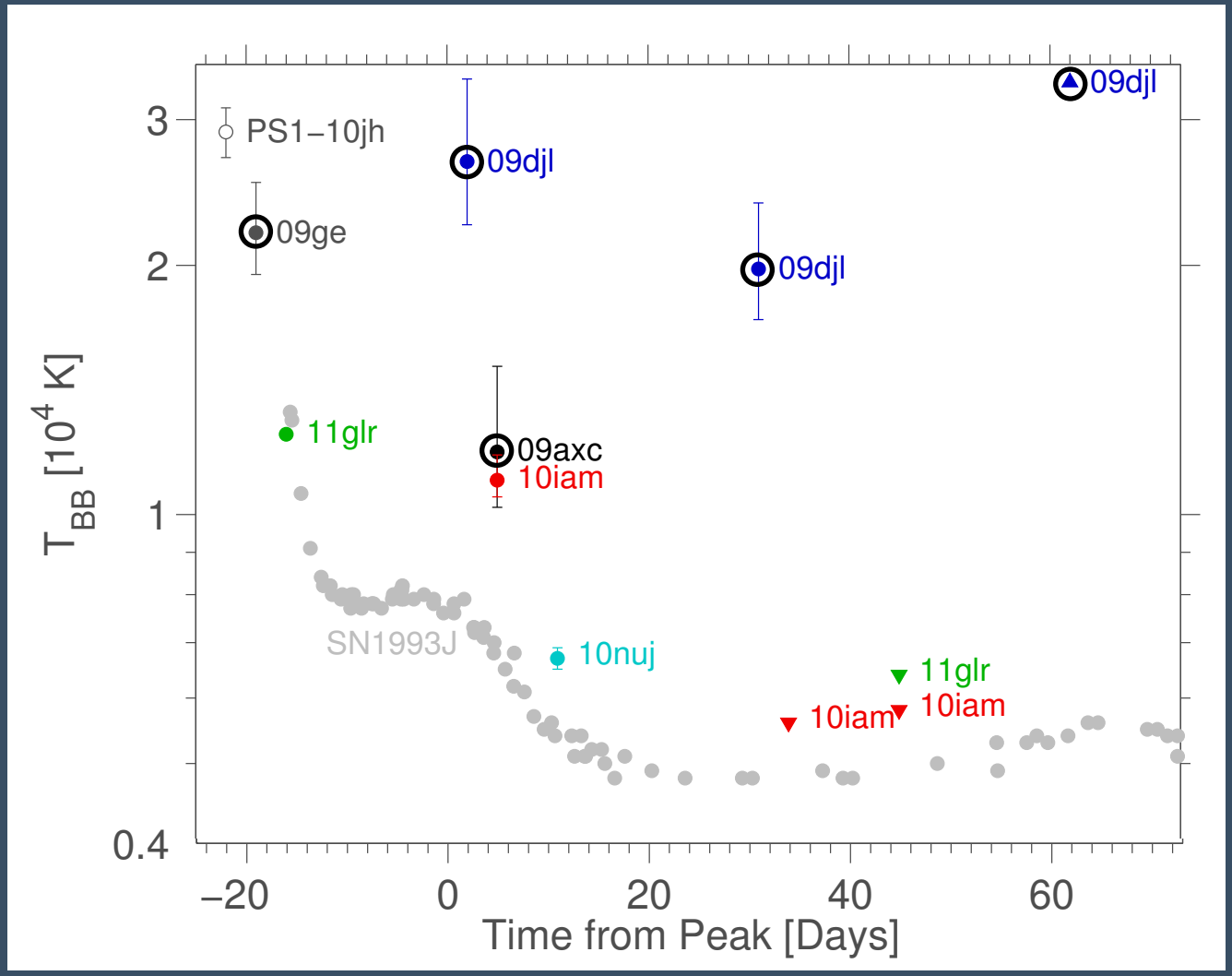
Zauderer et al. (2011), Bloom et al. (2011), Burrows et al. (2011), Levan et al. (2011), Tcheckovskoy et al. (2014)

PS1-10jh: Spectra Not Like Any Known Supernova

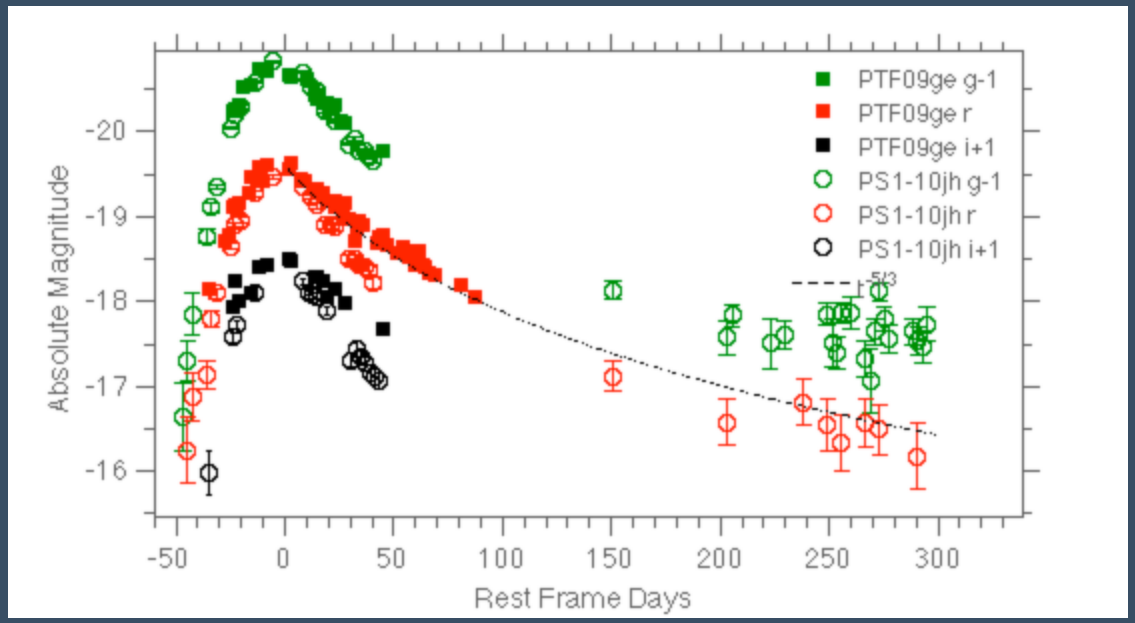


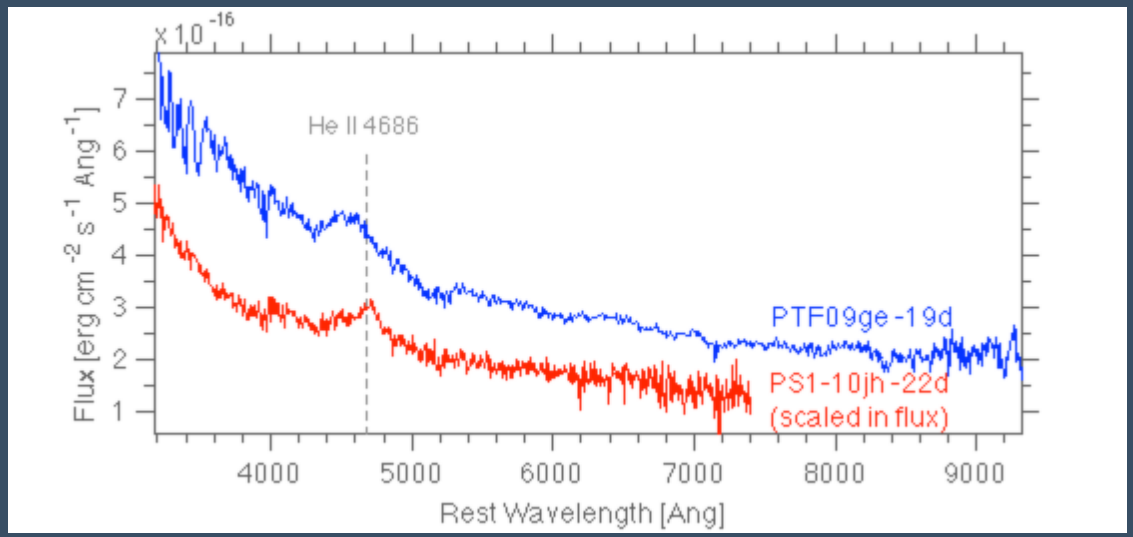
Gezari et al. (2012)

The Central Events Are Also Hotter Than SNe

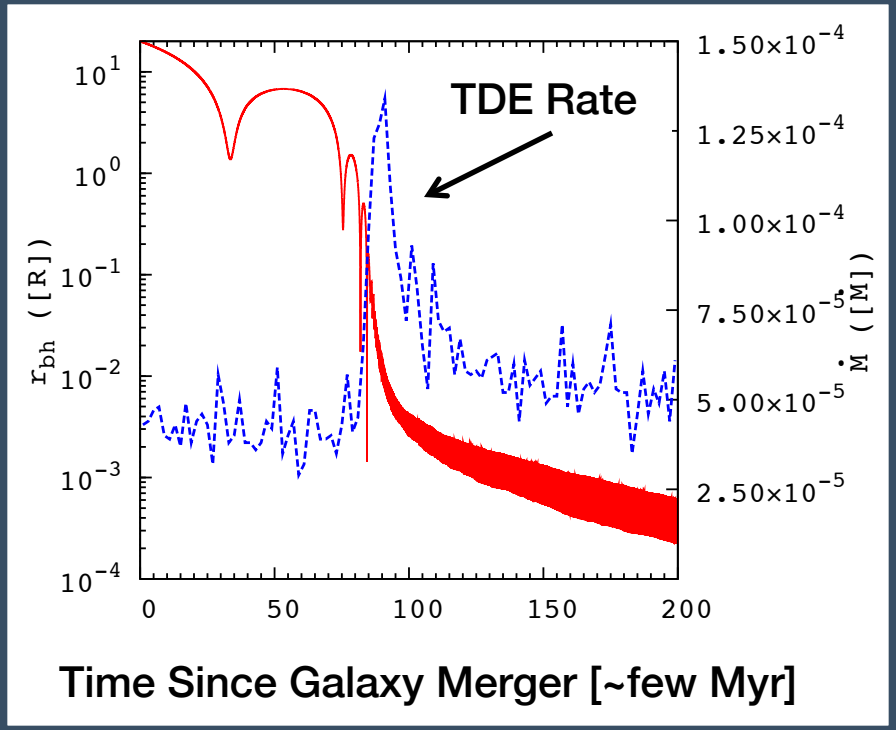


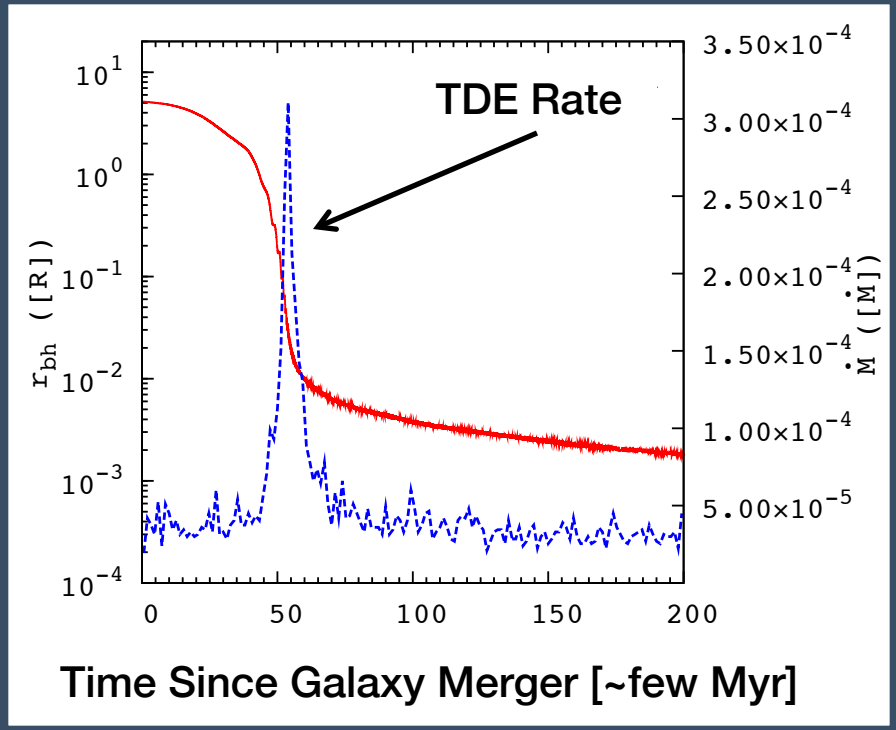
PTF09ge is Almost Identical to PS1-10jh





Are SMBH Binaries Increasing the TDE Rate?





Li et al. 2015

This is Not What We Expected TDEs to Look Like

Event	M_{BH} $(10^6 M_\odot)$	L_{peak} $(10^{43}\,\mathrm{erg\ s^{-1}})$	E_{tot} $(10^{51}\,\mathrm{erg})$	T_{BB} (@ ~peak) $(10^4\,\mathrm{K})$	R_{BB} (@ ~peak) $(10^{15}\,\mathrm{cm})$	Line Width $(10^3\,\mathrm{km\ s^{-1}})$	Host Type
SDSS J0748		n/a	n/a			10.0 ± 0.5 (He II)	?
PS-10jh	4^{+4}_{-2}	$\gtrsim 22$	$\gtrsim 2.1$	$\gtrsim 3$	$\gtrsim 0.6$	5.4 ± 1.5 (He II -22d)	E+A
PS-11af	8 ± 2	8.5 ± 0.2	0.41 ± 0.01	1.91 ± 0.08	0.95	No features	?
SDSS TDE2	$35.52^{+55.31}_{-25.80}$	4.1 ± 0.2 (g-band)	?	$1.82^{+0.07}_{-0.06}$	0.72	3.4 ± 1.1 (Hα)	E+A
PTF09ge	$5.65^{+3.02}_{-0.98}$	5.7	n/a	$2.19^{+0.33}_{-0.24}$	$0.59^{+0.16}_{-0.12}$	10.1 ± 0.7 (He II -19d)	E+A
PTF09axc	$2.69^{+0.66}_{-0.64}$	1.9	n/a	$1.19^{+0.32}_{-0.17}$	$1.14^{+0.41}_{-0.43}$	11.9 ± 0.2 (Hα 7d)	E+A
PTF09djl	$3.57^{+9.97}_{-2.96}$	12.2	n/a	$2.67^{+0.69}_{-0.43}$	$0.58^{+0.41}_{-0.21}$	6.5 ± 0.4 (Hα 2-62d)	E+A
ASASSN-14ae	$2.45^{+1.55}_{-0.74}$	8.2 ± 0.5	0.17	2.2 ± 0.1	$0.7 \pm .0.03$	3.6 ± 0.2 (Hα)	E+A

But from accretion expect $L_{peak} \sim 10^{47}\,(M_{BH,6})^{-3/2}\ \mathrm{erg\,s^{-1}}$

But $0.1 M_\odot c^2 \sim 10^{53}\,\mathrm{erg}$

But from accretion expect $T_{eff} \sim 10^5\,\mathrm{K}$

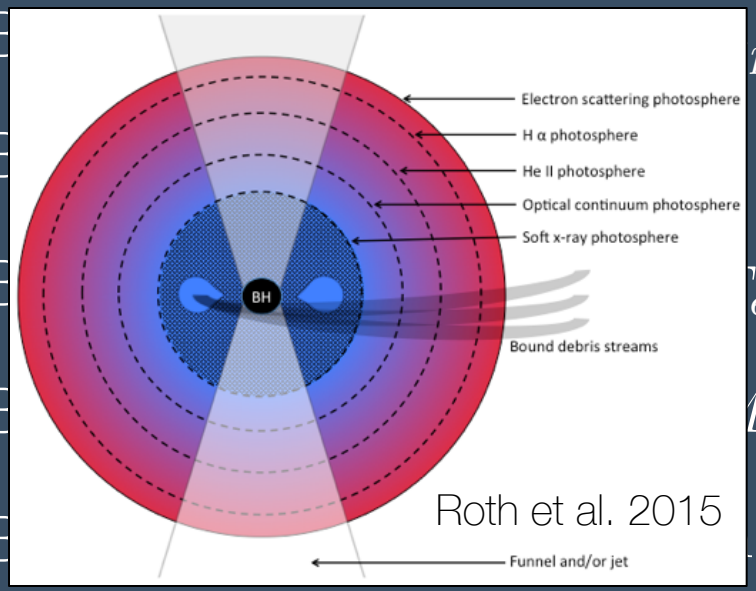
But $R_T \sim 7 \cdot 10^{12} R_*^{-1/3} M_{BH,6}^{1/3} M_*^{-1/3}\,\mathrm{cm}$

But at R_T: $v \sim 4 \cdot 10^4 M_{BH,6}^{1/3}\,\mathrm{km\,s^{-1}}$

This is Not What We Expected TDEs to Look Like

Event	Host Type
SDSS J07	?
PS-10jh	E+A
PS-11af	?
SDSS TD	E+A
PTF09ge	E+A
PTF09ax	E+A
PTF09dj	E+A
ASASSN-	E+A

Seeing the accretion emission through re-processing material
OR
maybe we're seeing the circularization, *before* the accretion



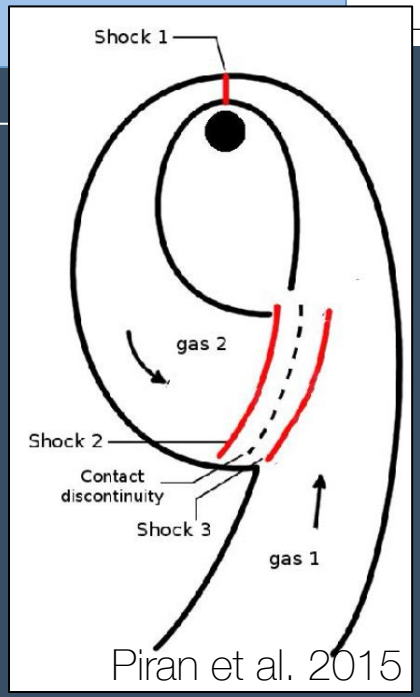
Roth et al. 2015

$peak \sim 10^{47}\,(M_{BH,6})^{-}$

$_{eff} \sim 10^{5}\,\mathrm{K}$

$M_{*}^{-1/3}\,\mathrm{cm}$

s^{-1}



Piran et al. 2015

What's Next? More Data

- Monitoring past events for second flare:
  - *Swift* monthly visits of a 1 year-old TDE
  - Monitoring x-rays from PTF09axc

- More events, densely sampled:
  - Discovery: iPTF, LSQ, PSST, ASAS-SN, Gaia, OGLE
  - Classification: LCOGT, PESSTO
  - Followup: LCOGT, Keck (optical)
    Swift + VLA (X-ray, UV, radio)

- Monitor post-starburst galaxies: SEATiDE

- Go back to the archives