A First Optical Characterization of Tidal Disruption Events

Arcavi et al. 2014, ApJ, 793, 38

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LCOGT & KITP
University of California, Santa Barbara

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 (maybe) $t^{-5/3}$ decline

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

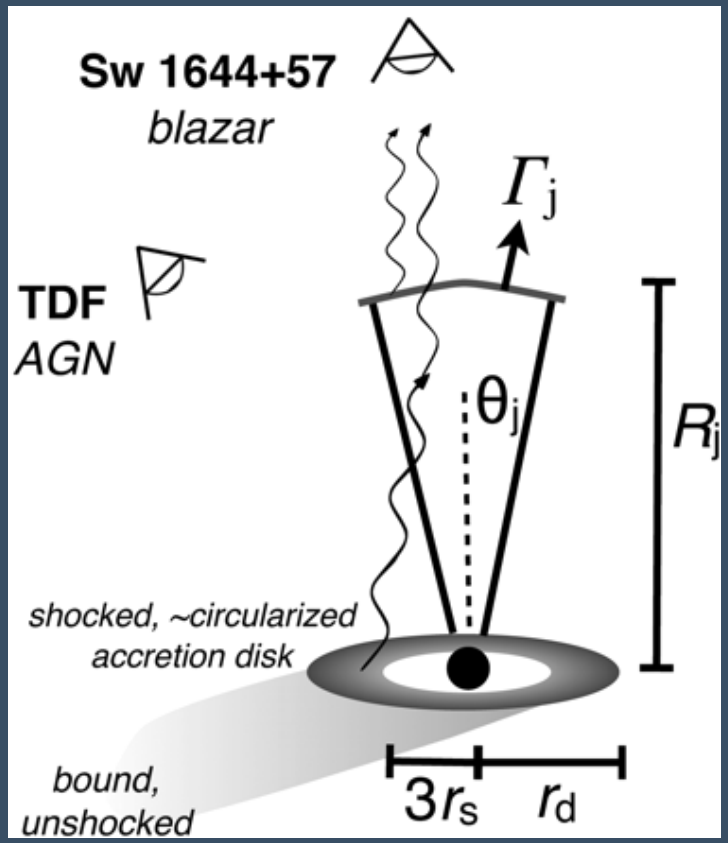
PS1-10jh (Gezari et al. 2012)

UV / Optical
No X-rays

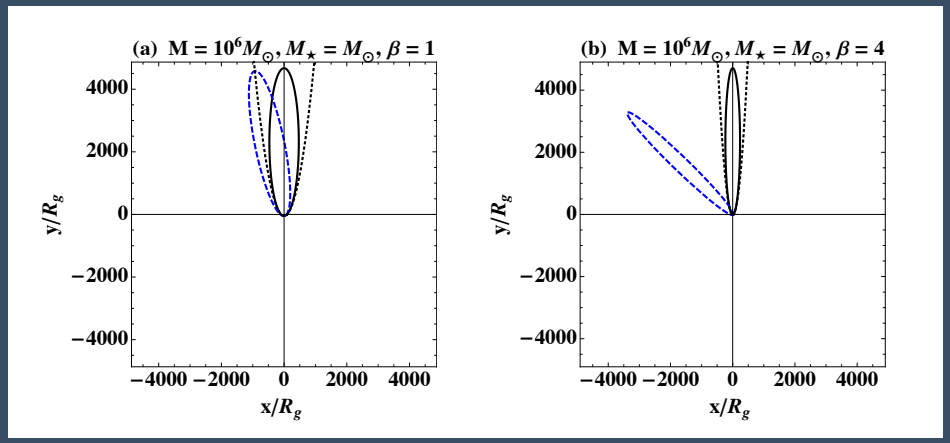
Hot blackbody (30,000K)
Smooth rise and fall light curve
$\sim t^{-5/3}$ decline

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

TDEs: Why Two So Different Types of Candidates?



Bloom et al. (2011): Viewing angle effect



Dai et al. (2015): β (penetration factor) effect

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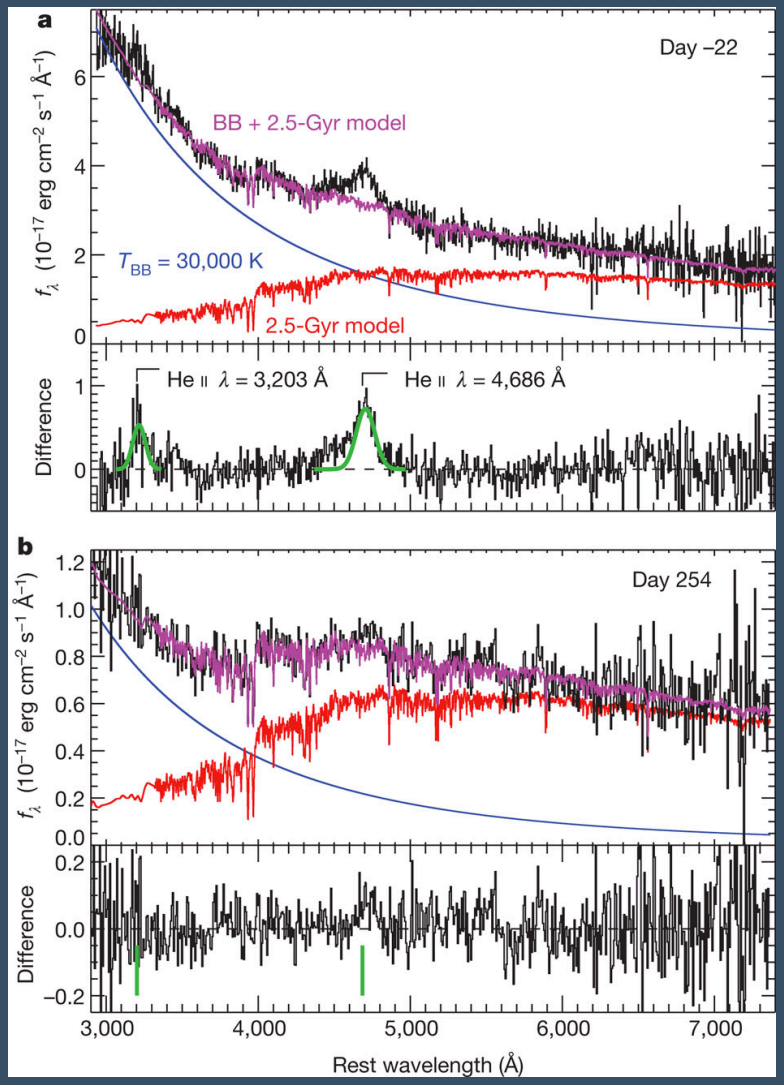
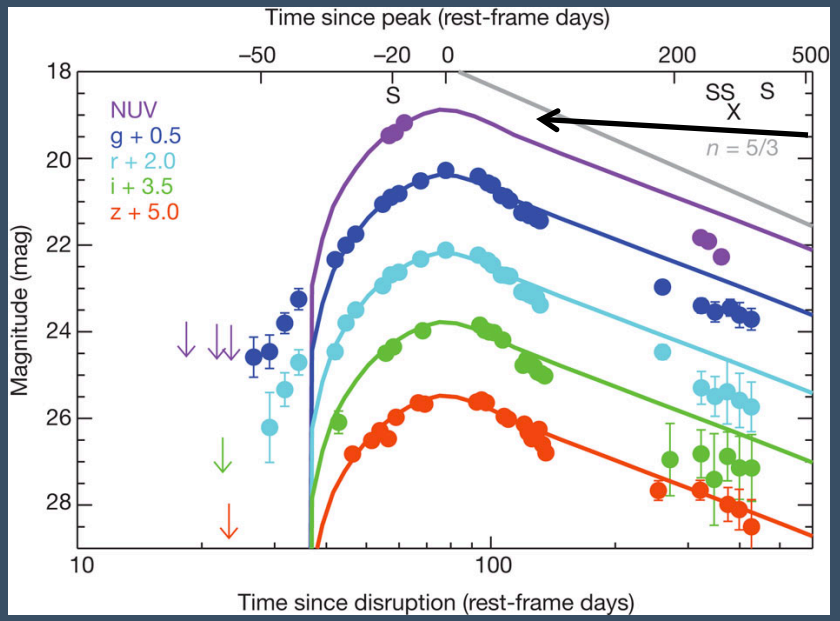
PS1-10jh: The First Optical / NUV TDE

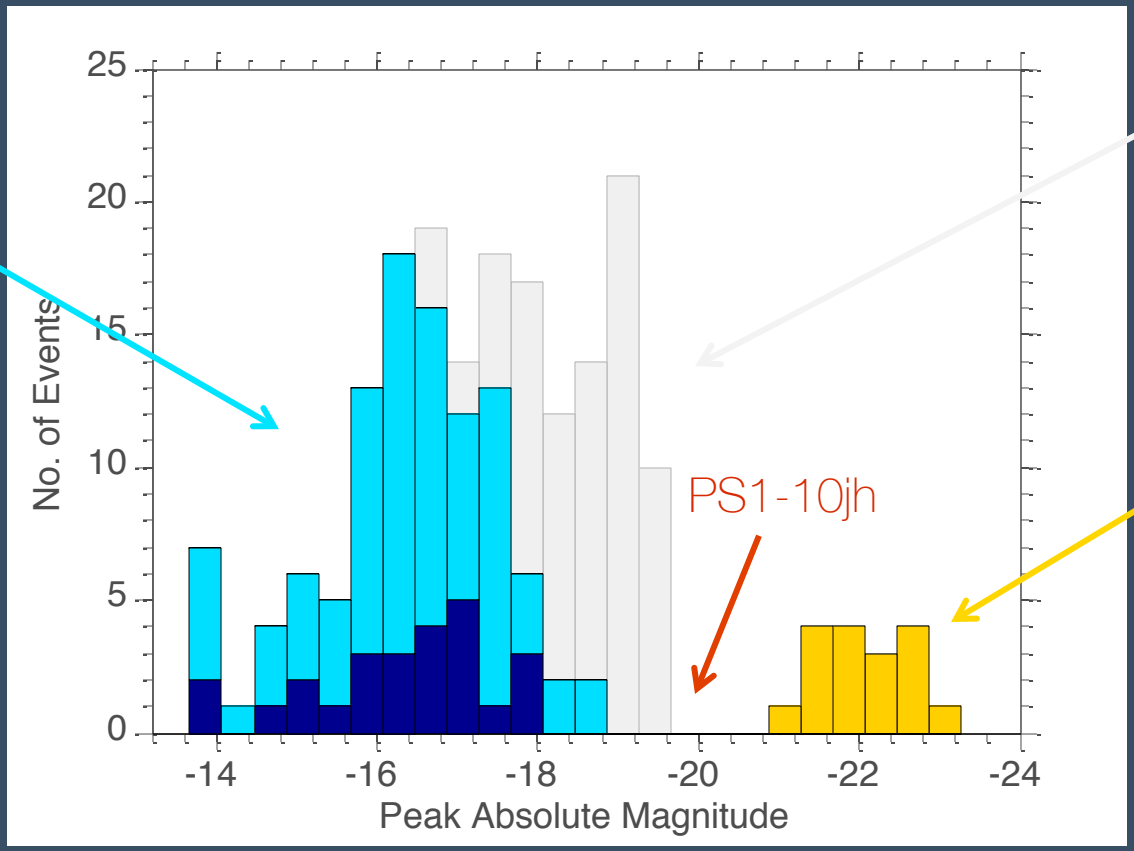




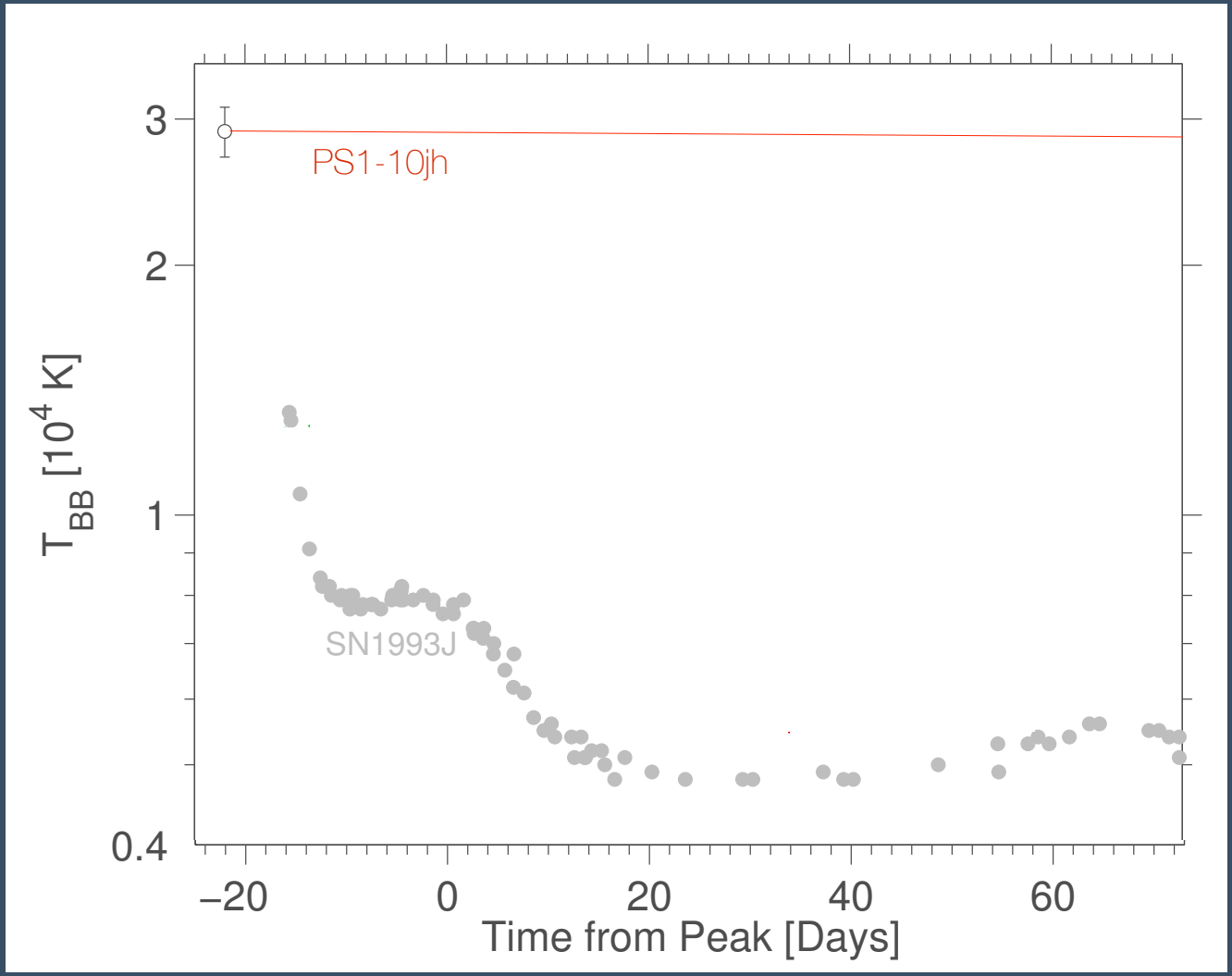
-20

Gezari et al. (2012)

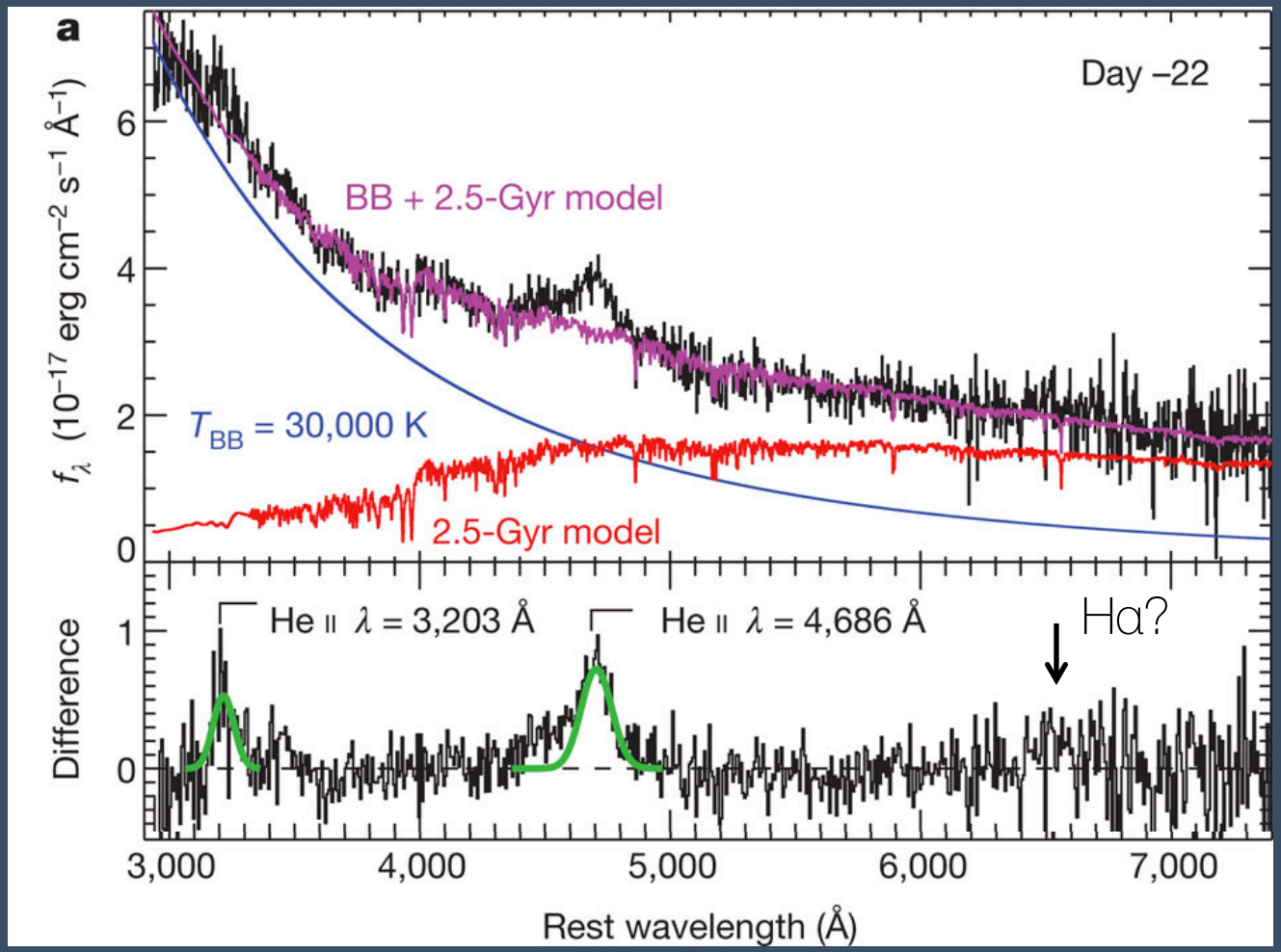
PS1-10jh: Brighter Than Core Collapse Supernovae



PS1-10jh: Hotter Than Core Collapse Supernovae



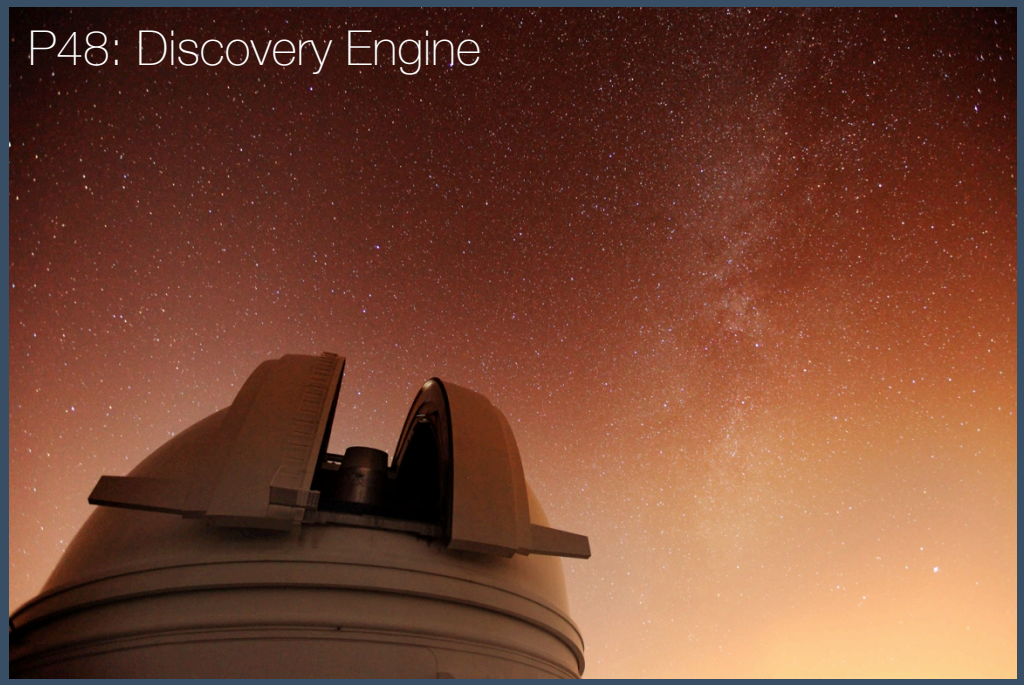
PS1-10jh: Spectra Not Like Any Known Supernova



Why no hydrogen from the disrupted star?

Gezari et al. (2012)

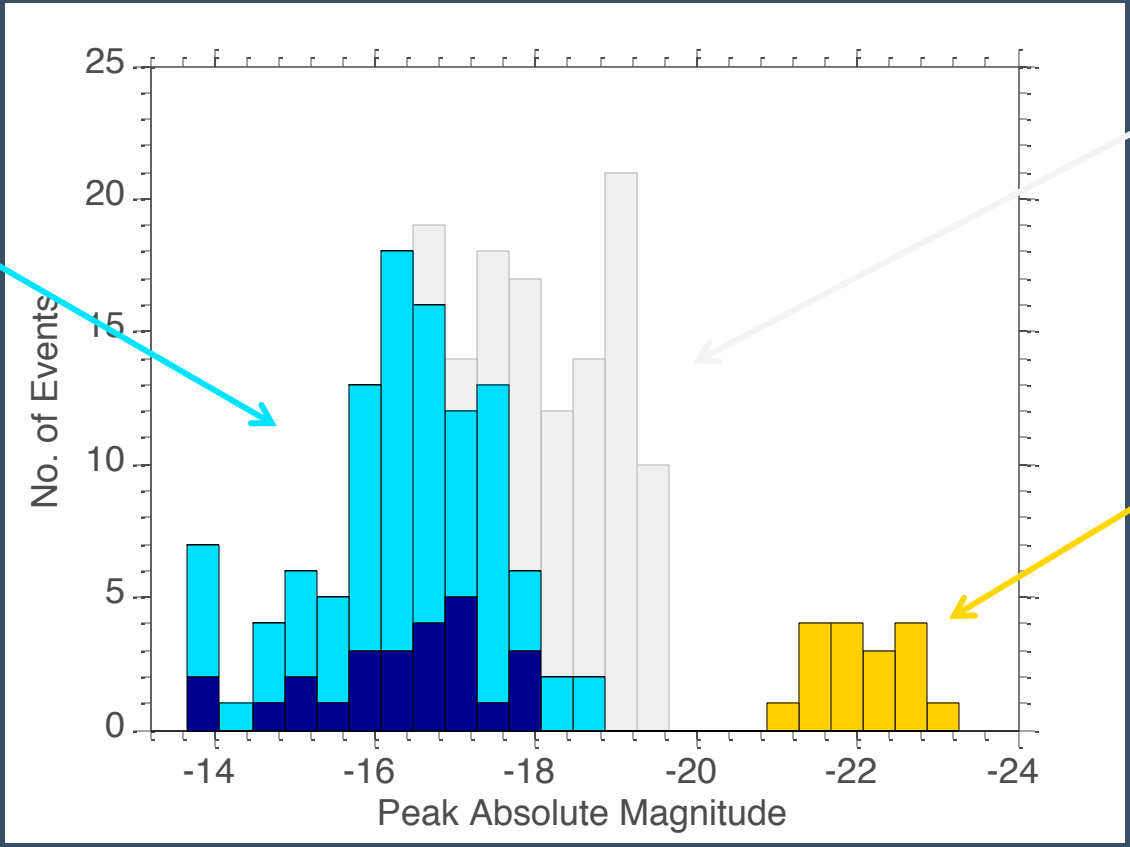
The Palomar Transient Factory (PTF)



Since 2009 found ~2000 supernovae and other transients
Expect to find ~13 TDEs per year (van Velzen et al. 2011)

PTF: Are There Events Between SNe and SLSNe?

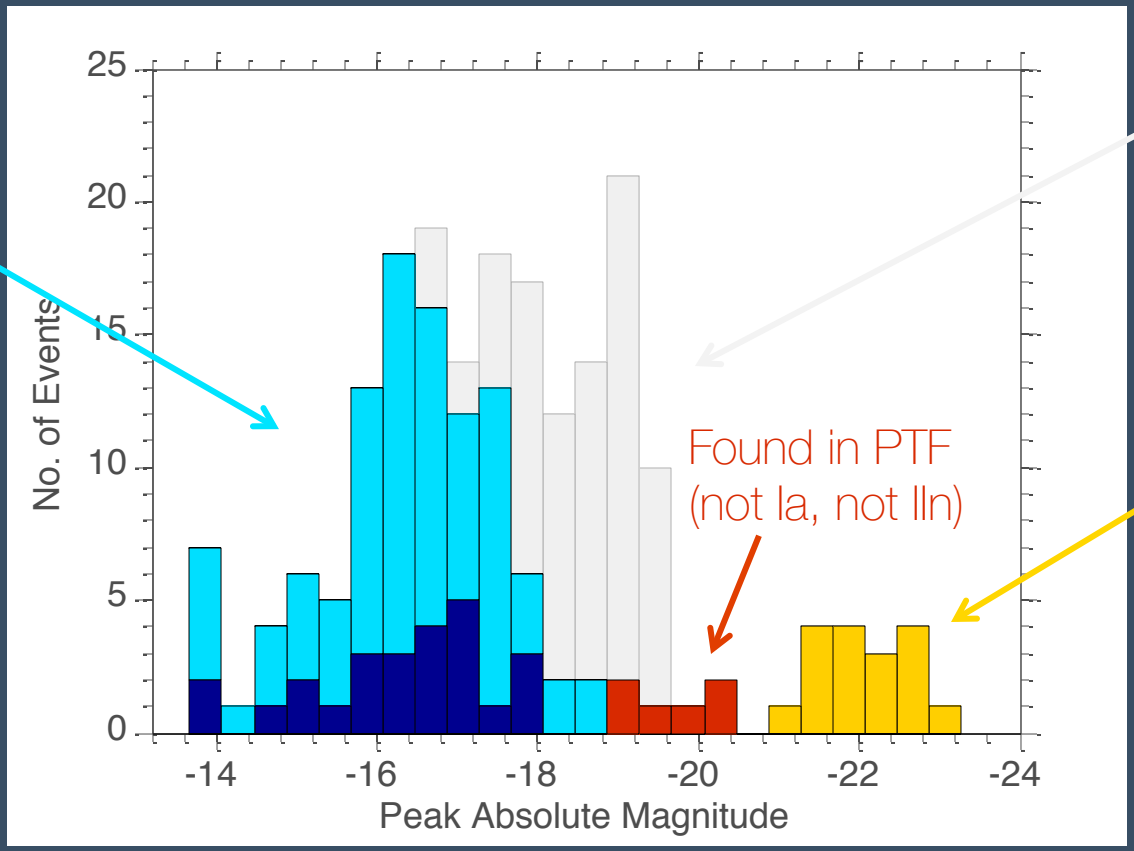
SNe II + Ib/c
(Li et al. 2011)



SNe Ia
(Li et al. 2011)

SLSNe
(Gal-Yam 2013)

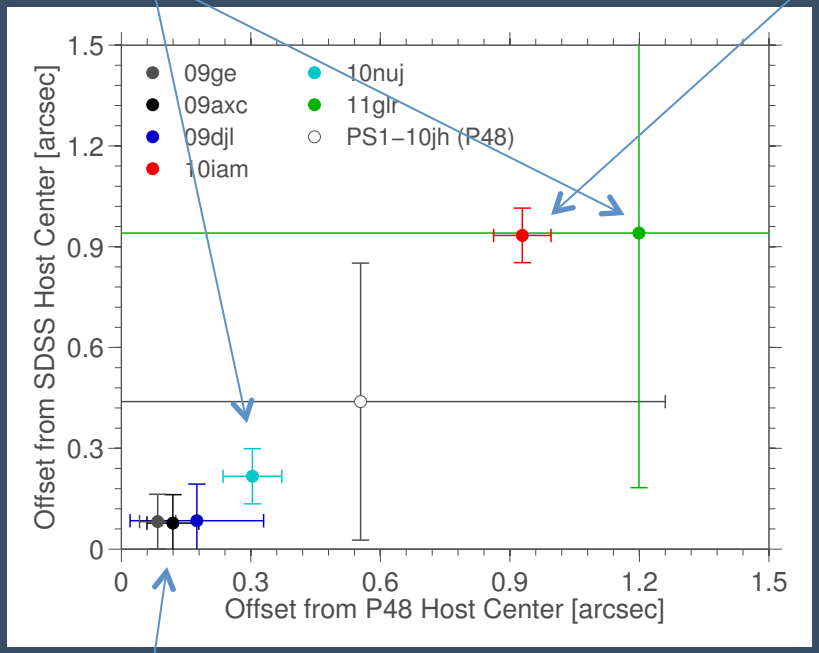
PTF: Are There Events Between SNe and SLSNe?

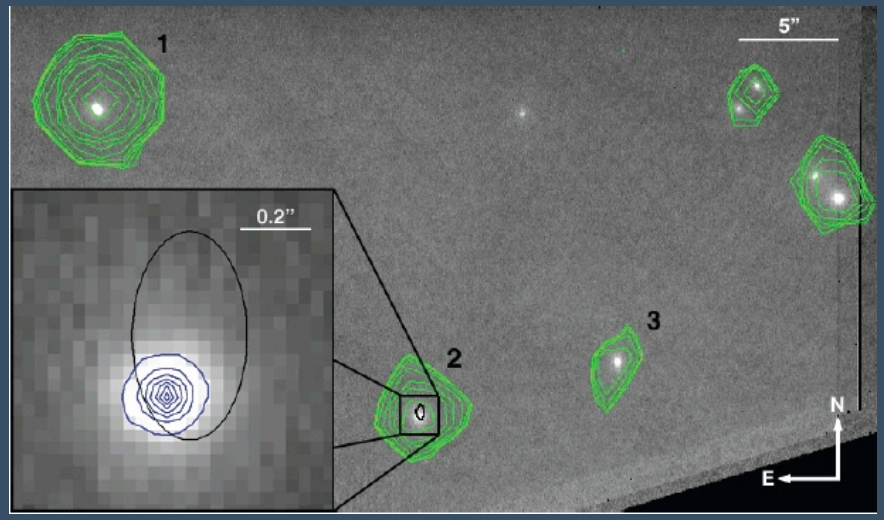


Three PTF Events Coincident With Their Host Center

Can't tell:
PTF10nuj (d=2.6)
PTF11glr (d=1.2)

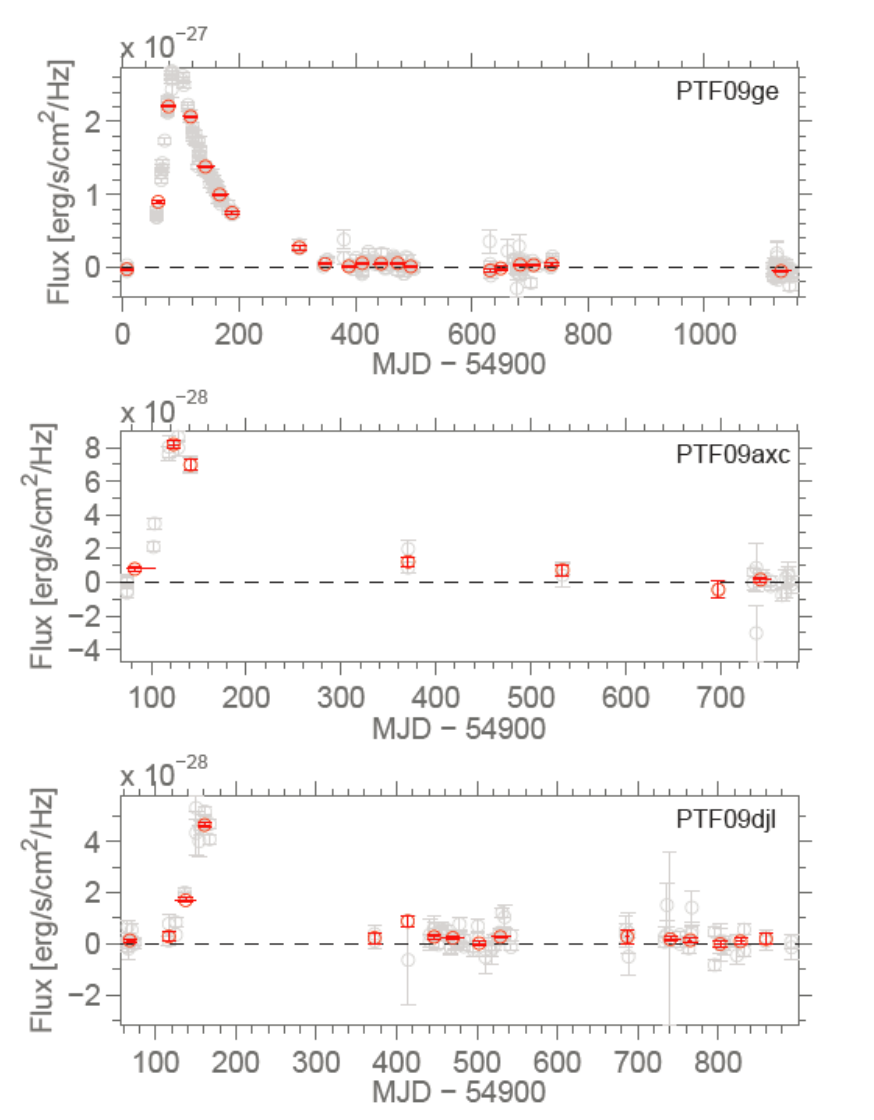
Off-center:
PTF10iam (d=11.4)





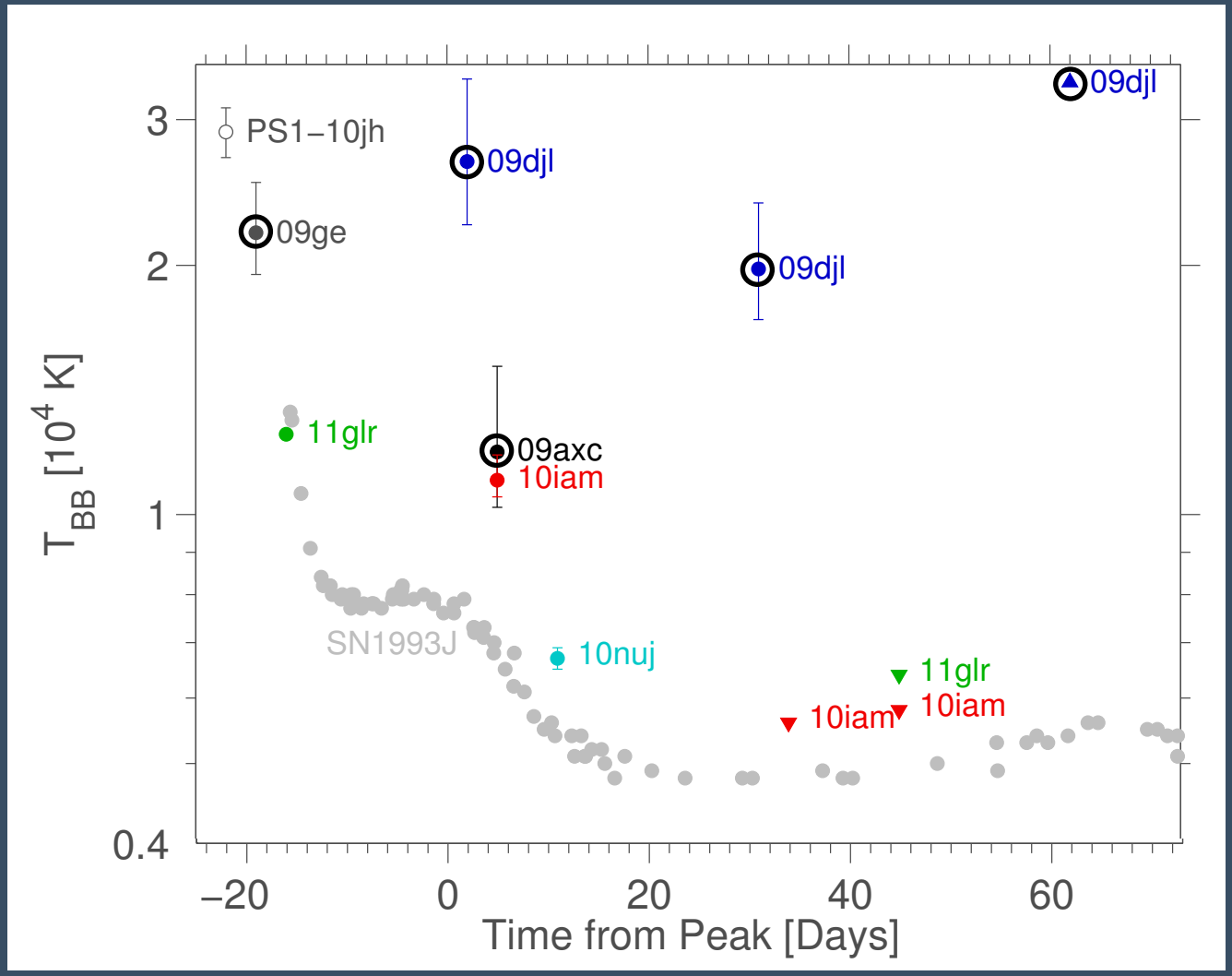
Coincident with center to <0.5 kpc:
PTF09ge (d=1.0)
PTF09axc (d=0.9)
PTF09dah (d=0.8; confirmed with AO)

The Central Events Are Not Likely AGN

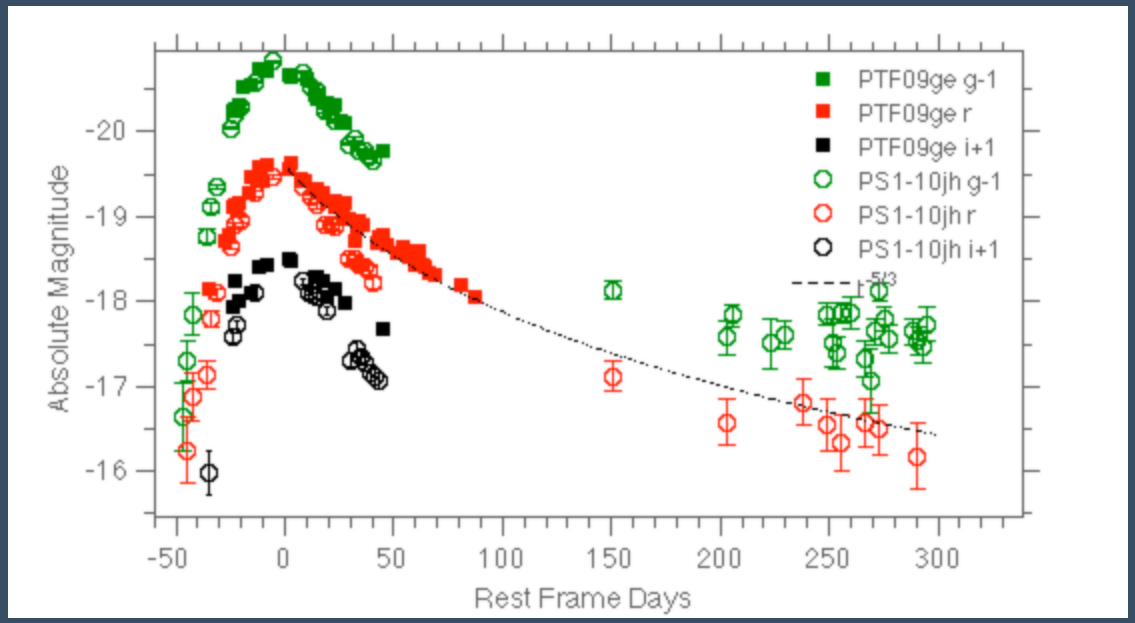


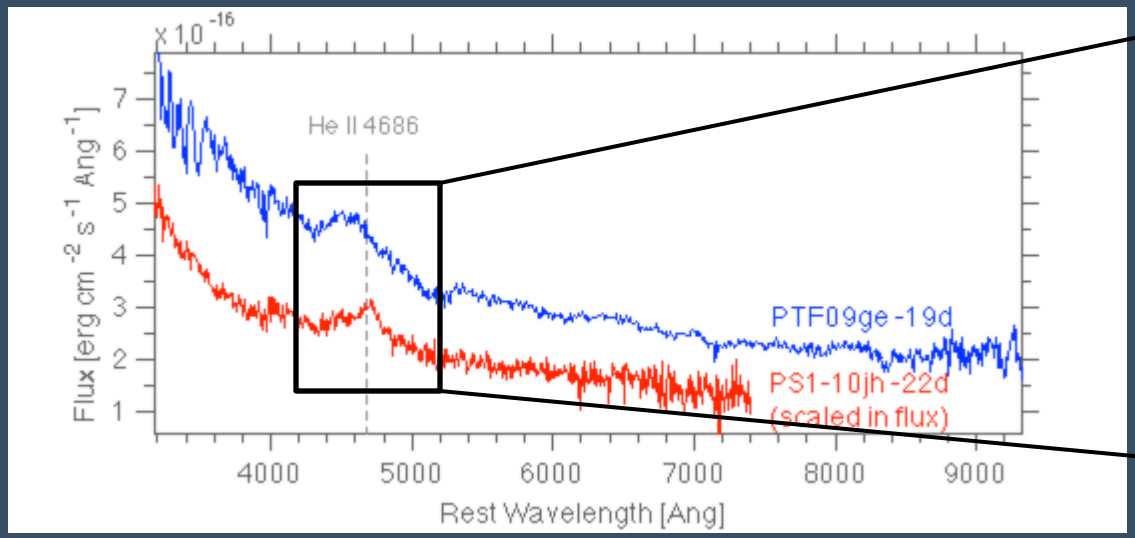
- No recurrent activity
- Outburst spectra not like AGN
- Host spectra not like AGN

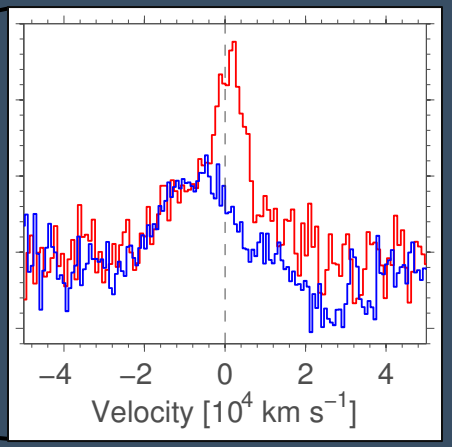
The Central Events Are Also Hotter Than SNe



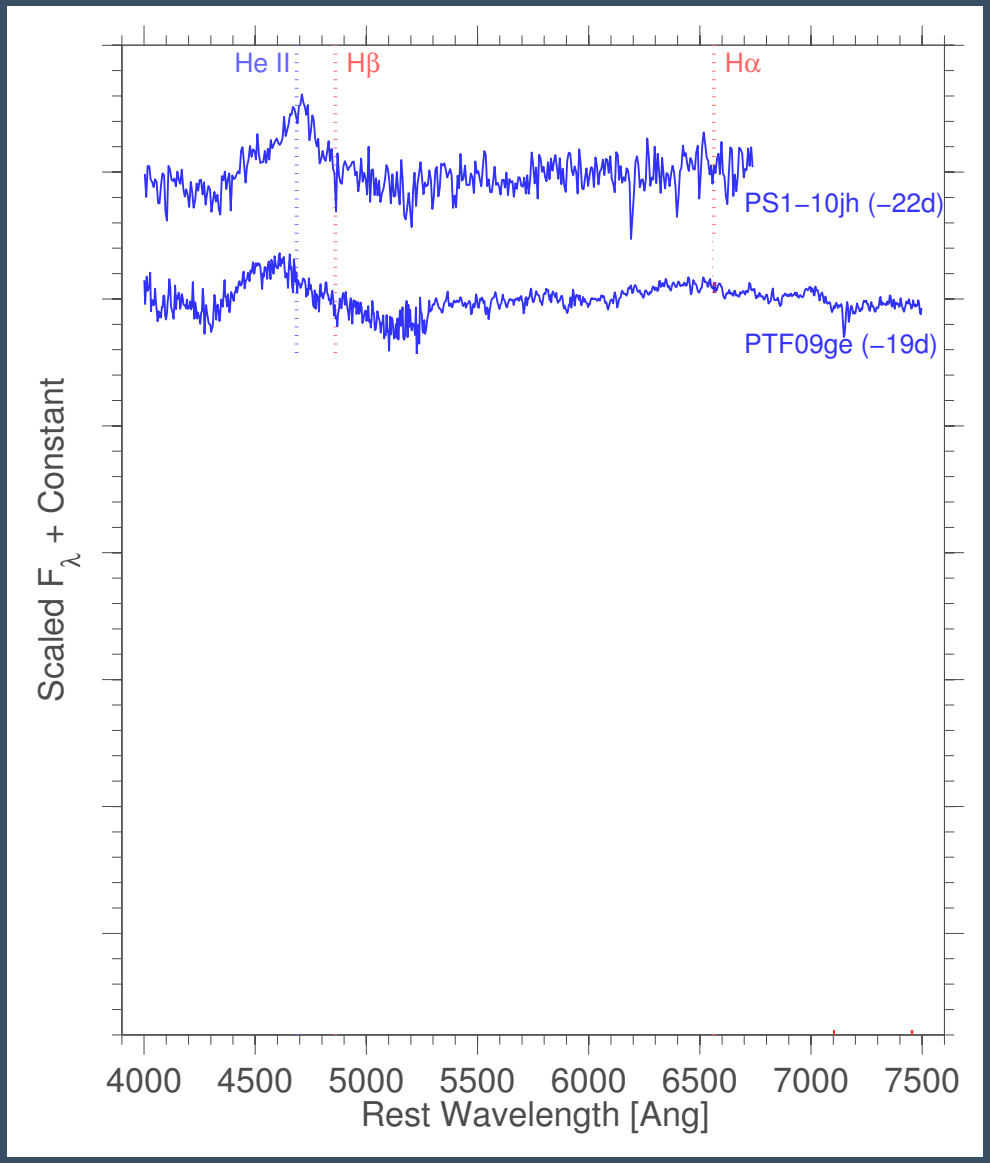
PTF09ge is Almost Identical to PS1-10jh







First Steps in the TDE Atlas



Gezari+ 12

Arcavi+ 14

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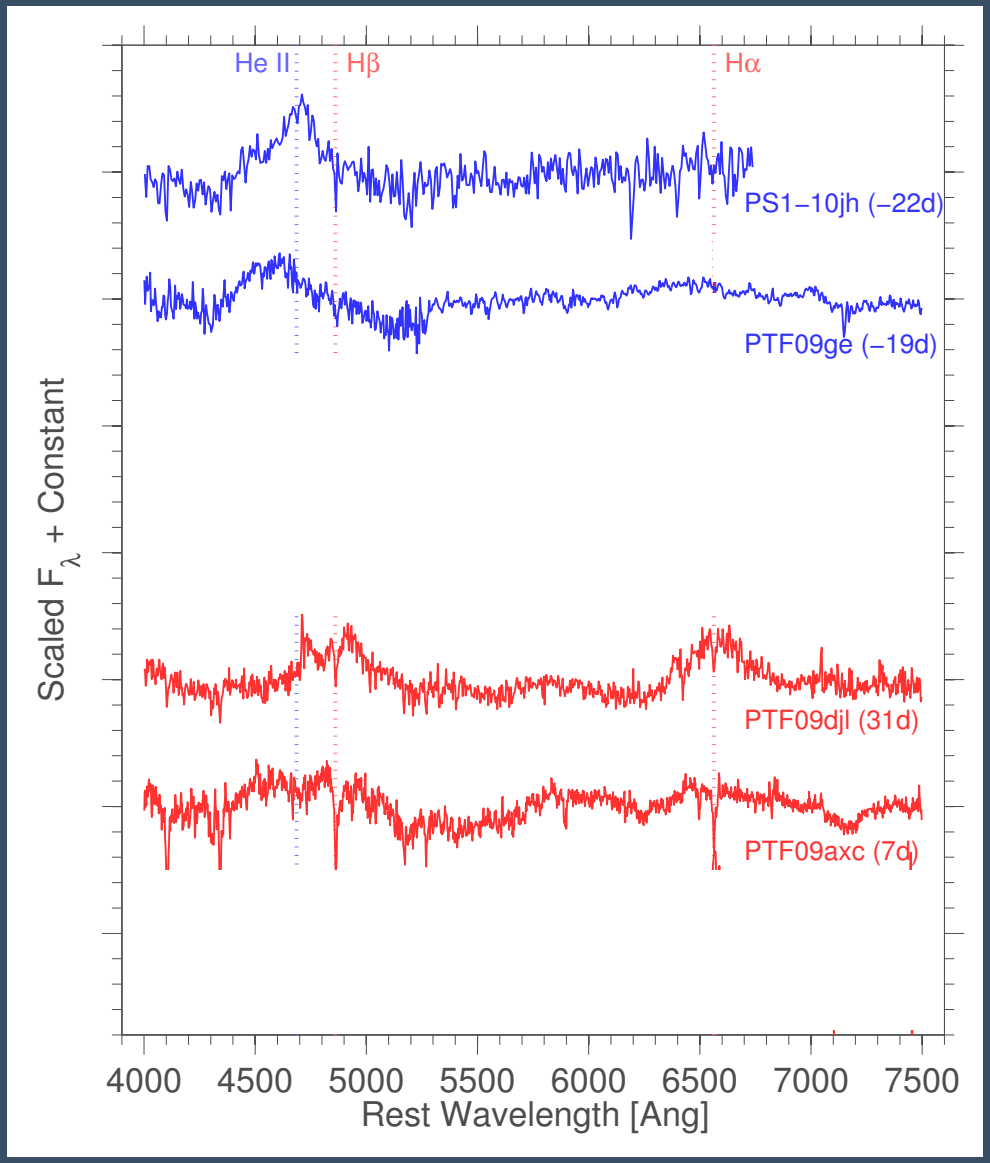

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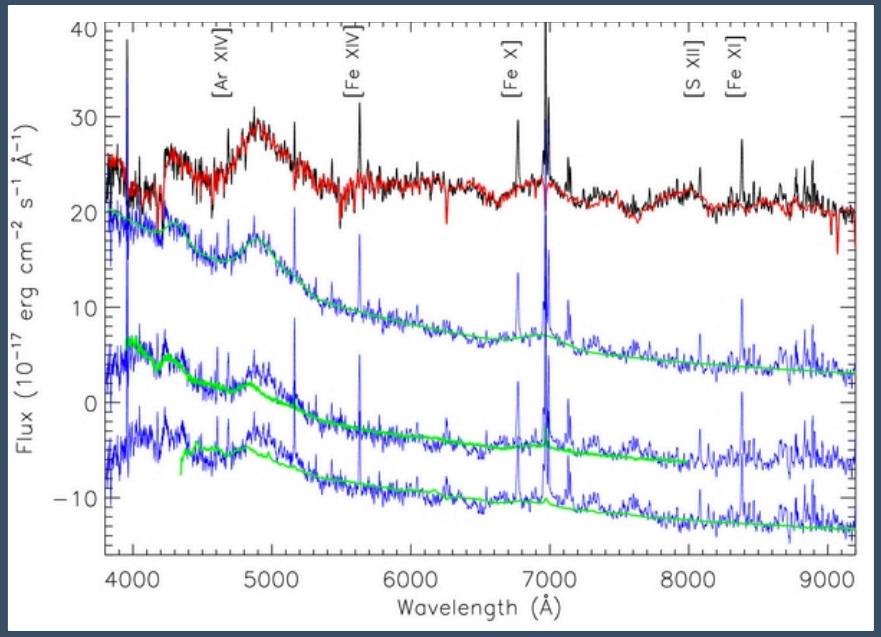
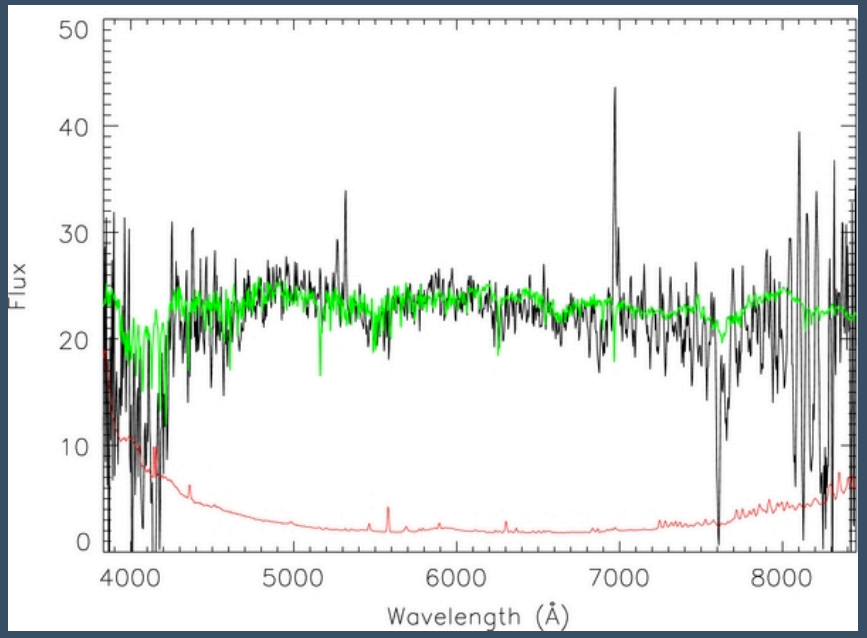
The Little-Known TDE Candidate SDSS J0748



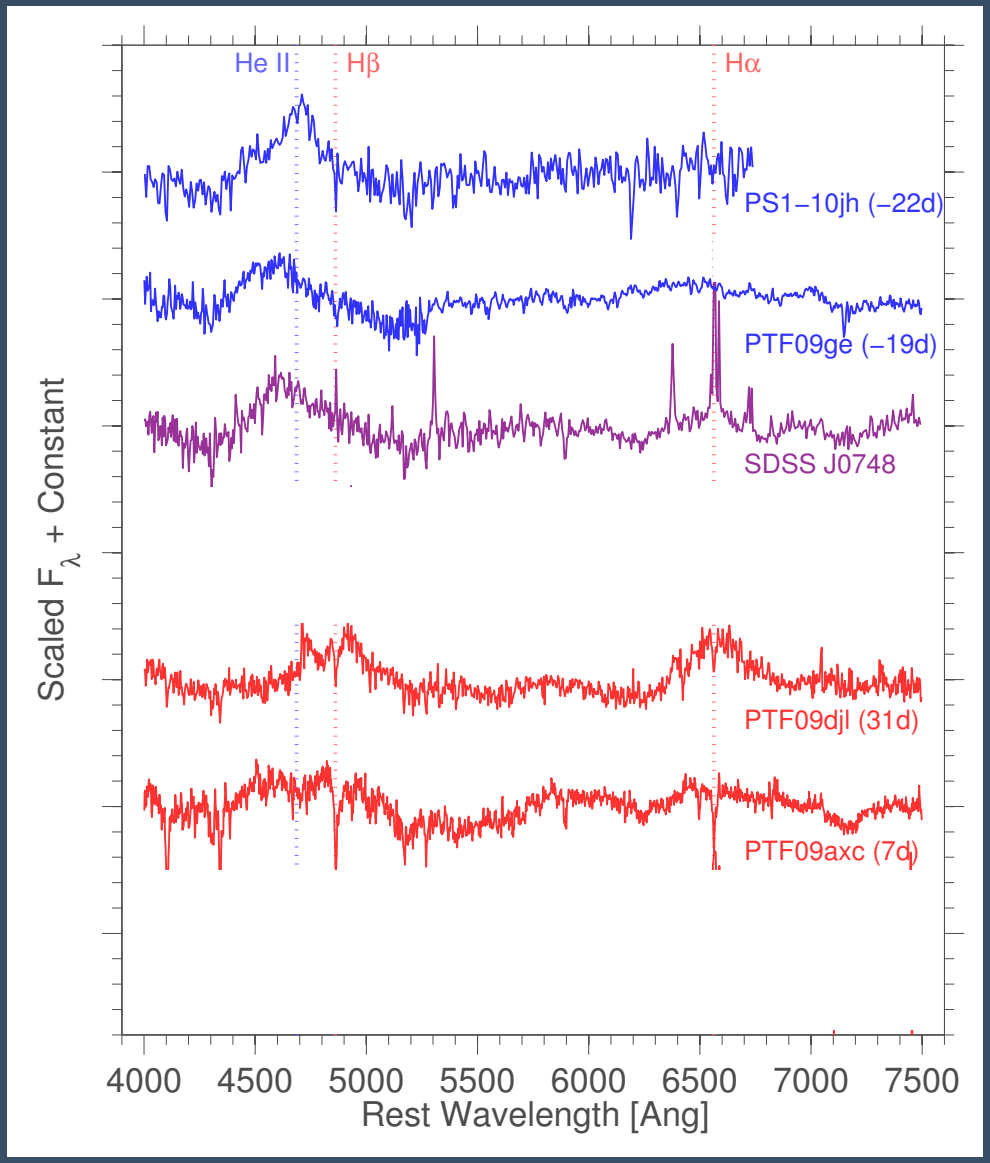
SDSS spectrum from Feb 2004 with various fits



Xinglong spectrum Mar 2009 shows broad features were transient

Wang et al. (2011)

First Steps in the TDE Atlas



Gezari+ 12

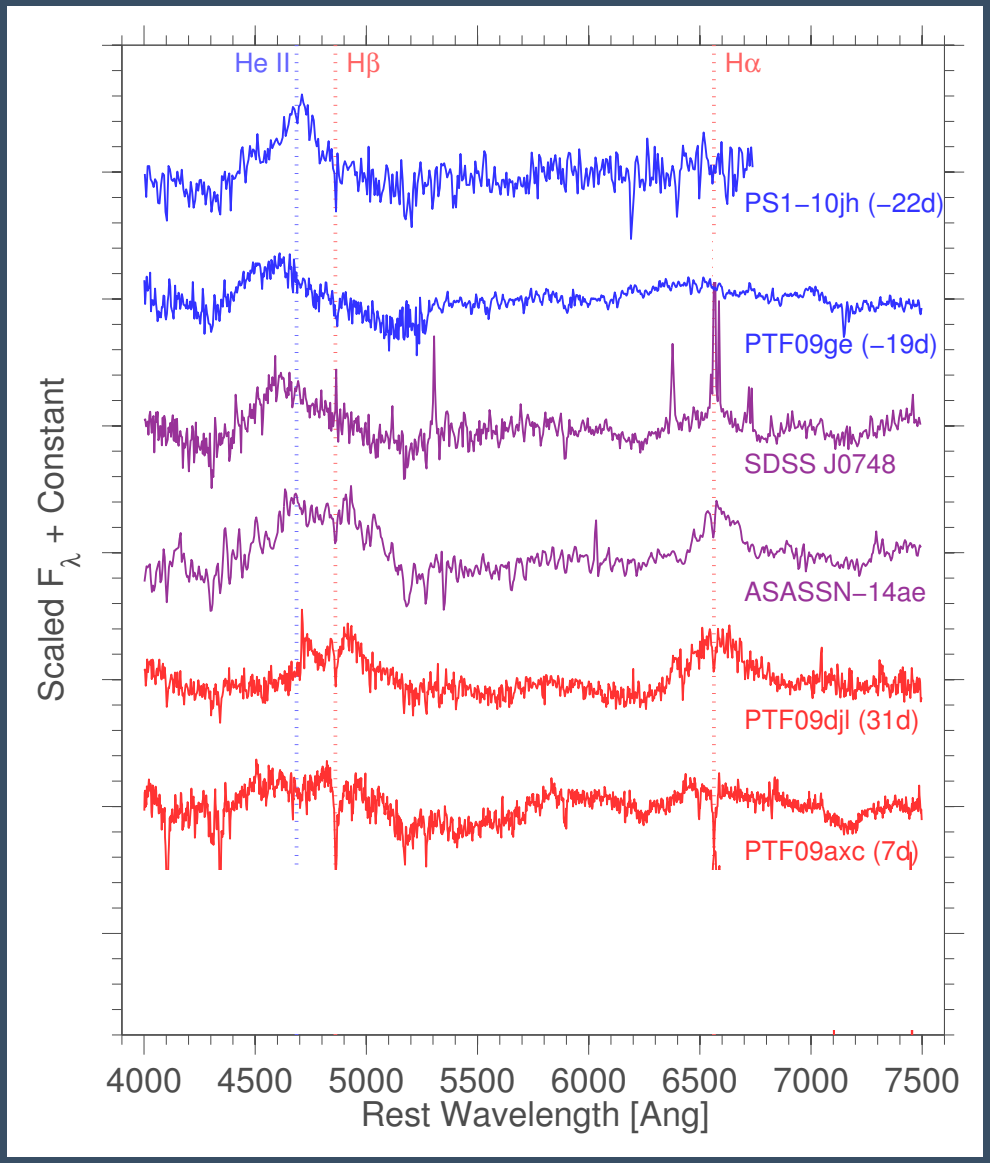
Arcavi+ 14

Wang+ 11

Arcavi+ 14

Arcavi+ 14

First Steps in the TDE Atlas



Gezari+ 12

Arcavi+ 14

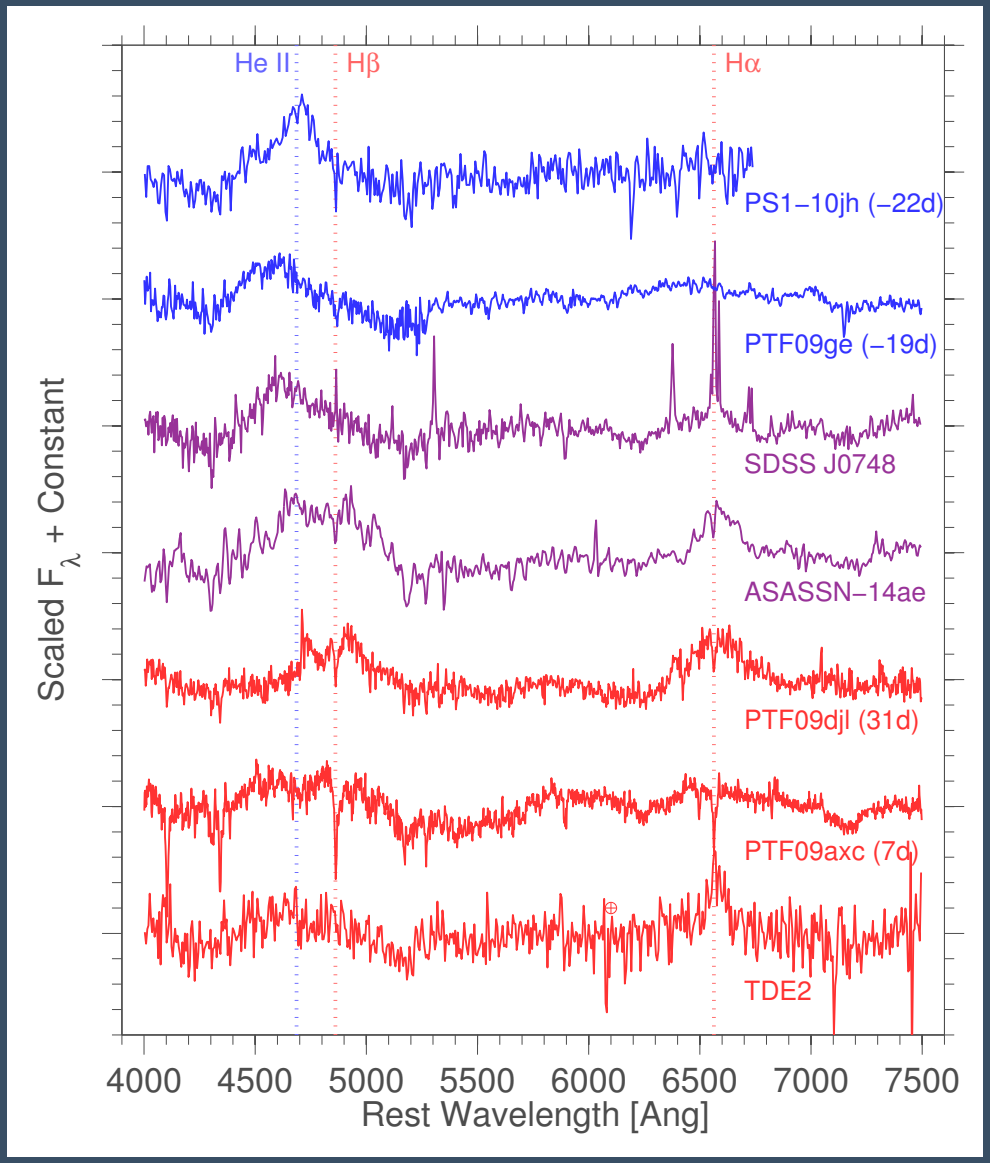
Wang+ 11

Arcavi+ 14
Holoien+ 14

Arcavi+ 14

Arcavi+ 14

First Steps in the TDE Atlas: a H/He Continuum



Gezari+ 12

Arcavi+ 14

Wang+ 11

Arcavi+ 14

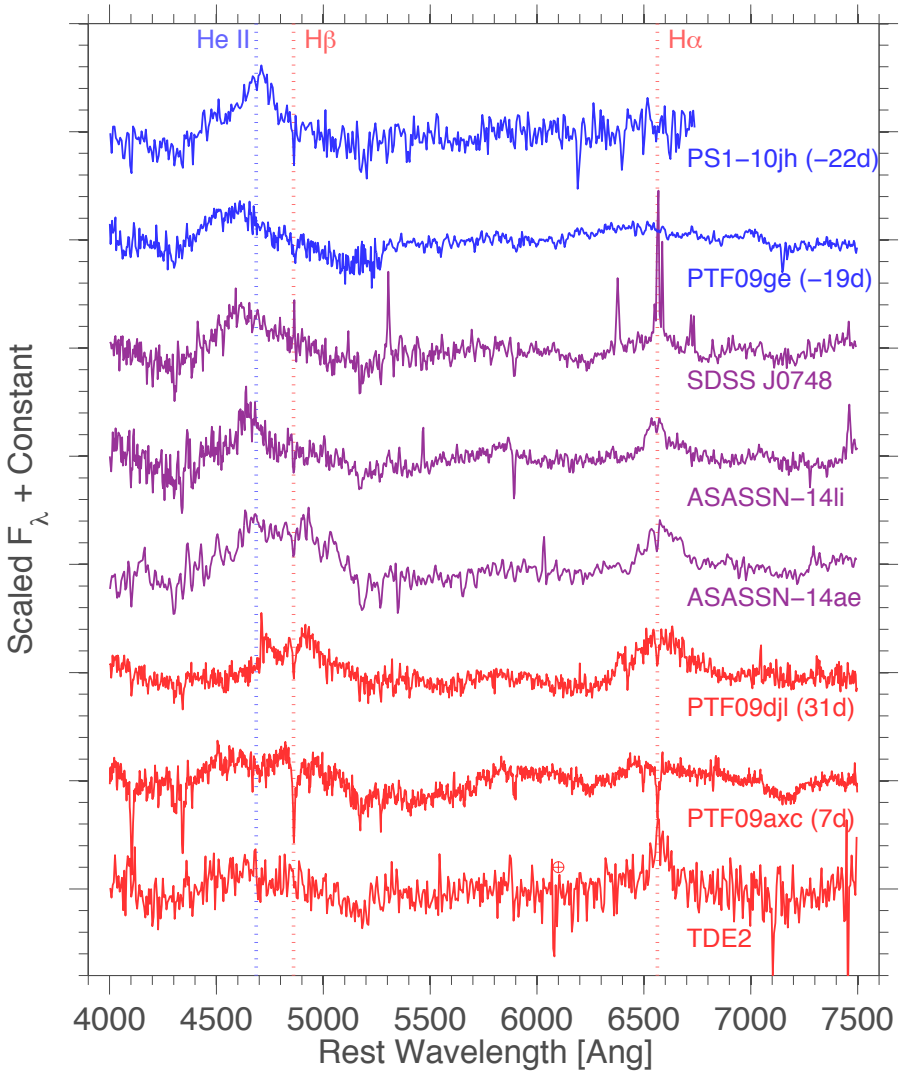
Holoien+ 14

Arcavi+ 14

Arcavi+ 14

van Velzen+ 11

First Steps in the TDE Atlas: a H/He Continuum



Gezari+ 12

Arcavi+ 14

Wang+ 11

Holoien+ 15

Arcavi+ 14

Holoien+ 14

Arcavi+ 14

Arcavi+ 14

van Velzen+ 11

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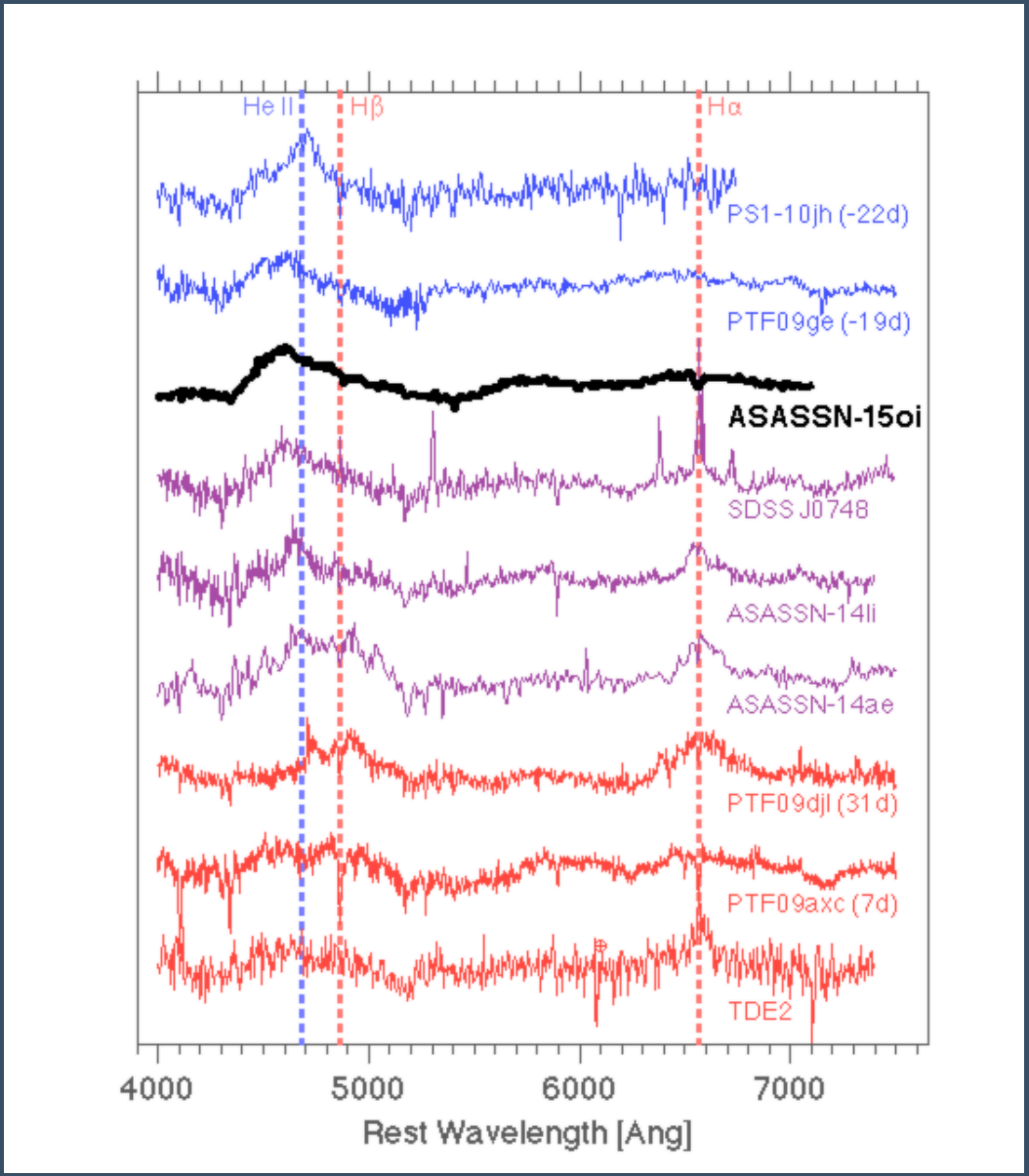


Gezari+ 12

Arcavi+ 14

←Active now

Wang+ 11

Holoien+ 15

Arcavi+ 14

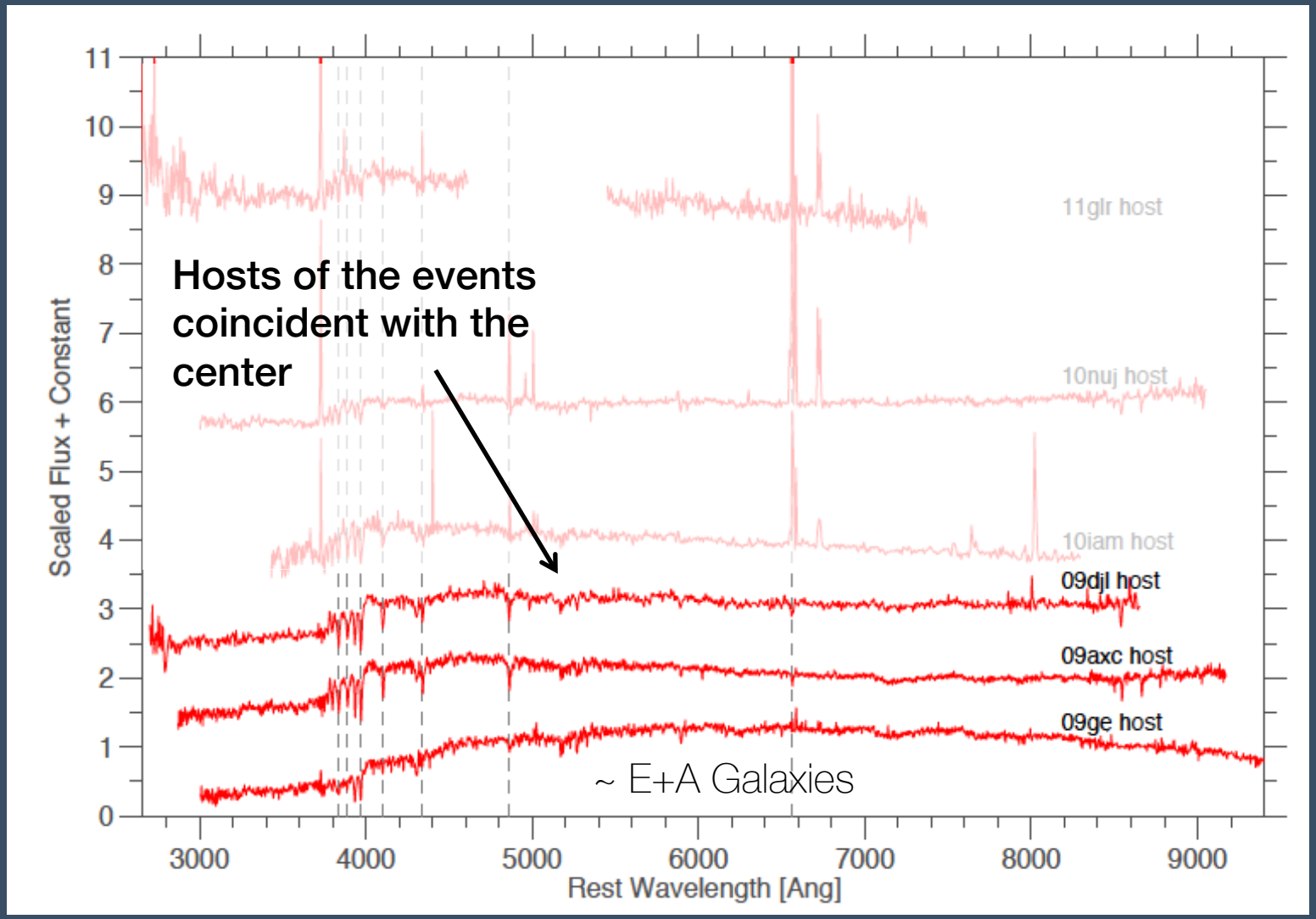
Holoien+ 14

Arcavi+ 14

Arcavi+ 14

van Velzen+ 11

Almost Exclusively in Post-Merger Hosts



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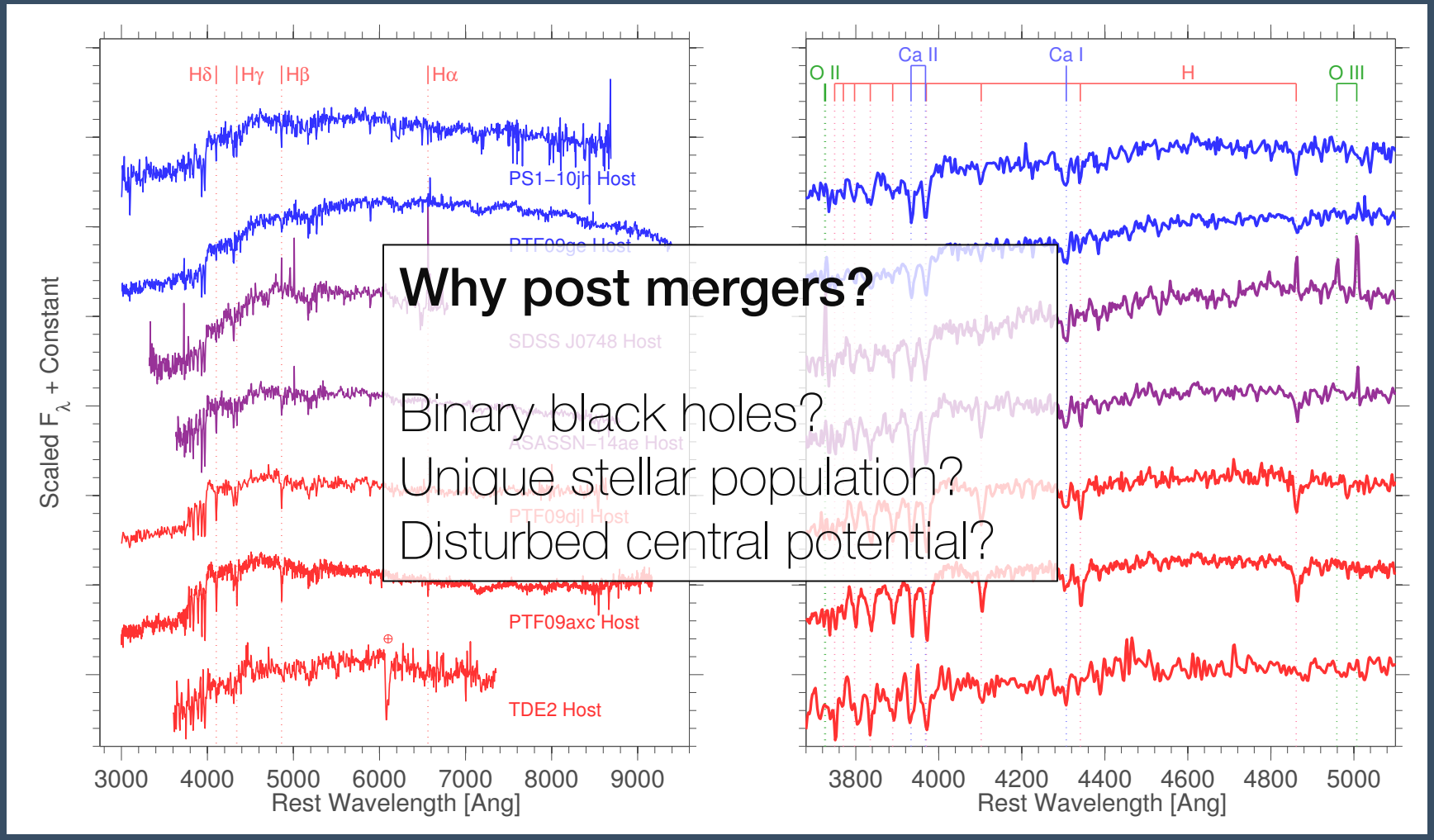


This is Not What We Expect Accretion to Look Like

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 $T_{eff} \sim 10^5\,\mathrm{K}$ (reprocessing material?)

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

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 reprocessing material
OR
seeing the circularization, *before* the accretion (Piran et al. 2015)

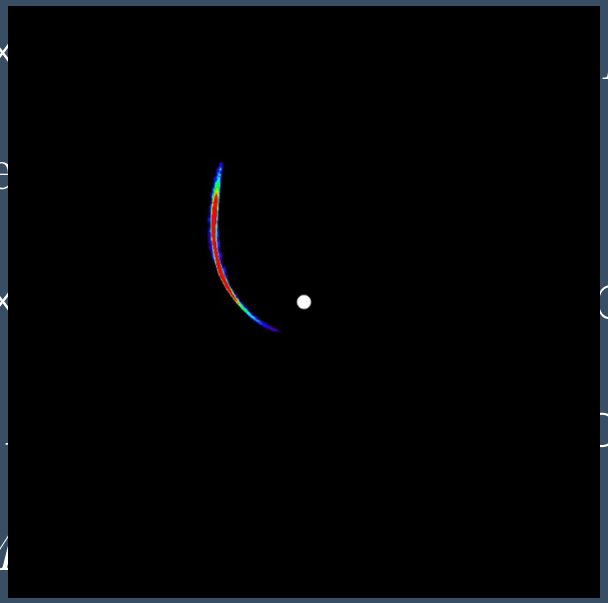
But from accretion ex $\left(\frac{}{H,6}\right)^{-3/2}\ \mathrm{erg\,s^{-1}}$

But $0.1 M_\odot c^2 \sim 10^{53}$ e

But from accretion ex rocessing material?)

But $R_T \sim 7 \cdot 10^{12} R_*^{-1/3}$ ocessing material?)

But at R_T: $v \sim 4 \cdot 10^4 M$

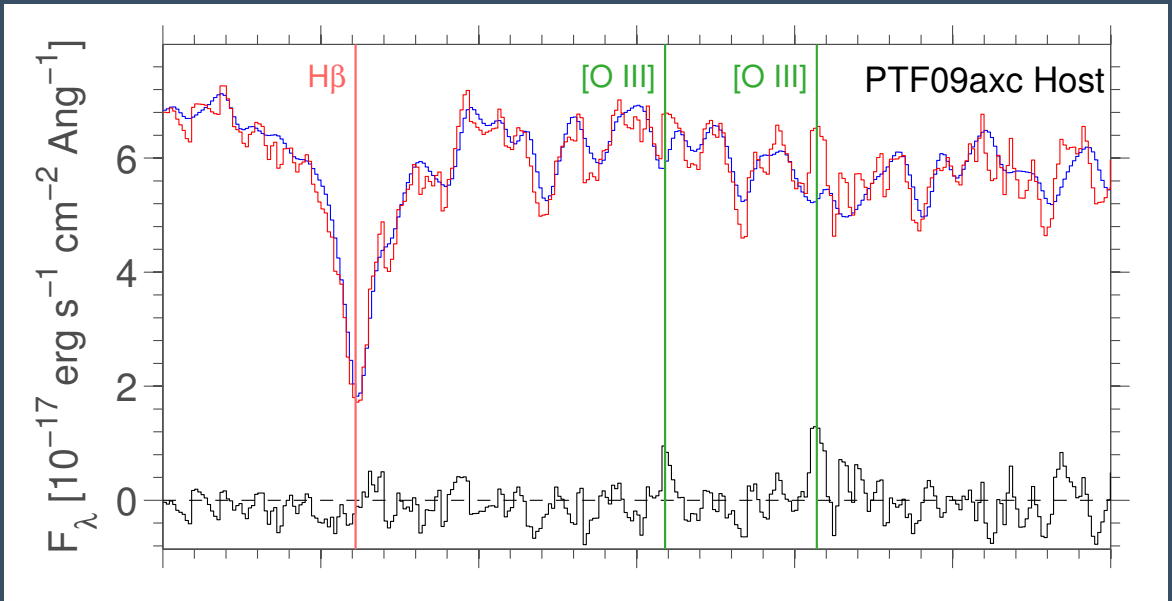


An X-ray Detection Five Years After PTF09axc

$$L_{0.3-10\mathrm{keV}} = 7.13^{+12.22}_{-3.06} \times 10^{42}\ \mathrm{erg\ s^{-1}}$$

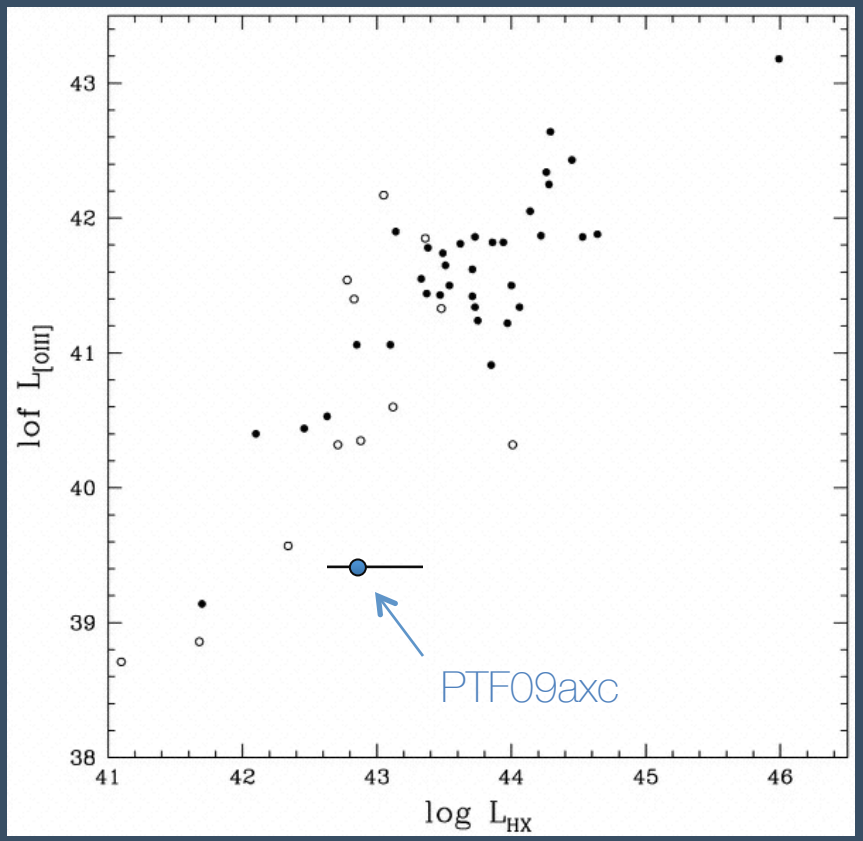
This is also the only PTF TDE candidate with host [O III] emission:

$$L_{[OIII]} = 2.4 \pm 0.3 \times 10^{39}\ \mathrm{erg\ s^{-1}}$$



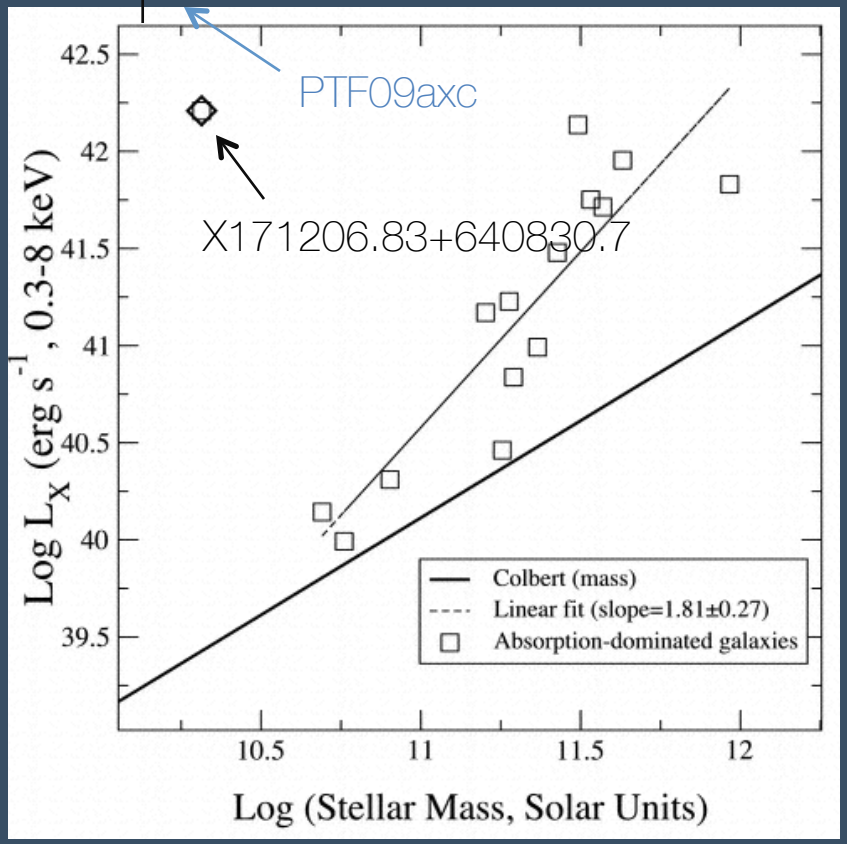
An X-ray Detection Five Years After PTF09axc

Are the x-rays from an AGN?



Heckman et al. (2005), nearby AGNs

Are the x-rays from an accreting binary?



Hornschemeier et al. (2005), non-AGNs

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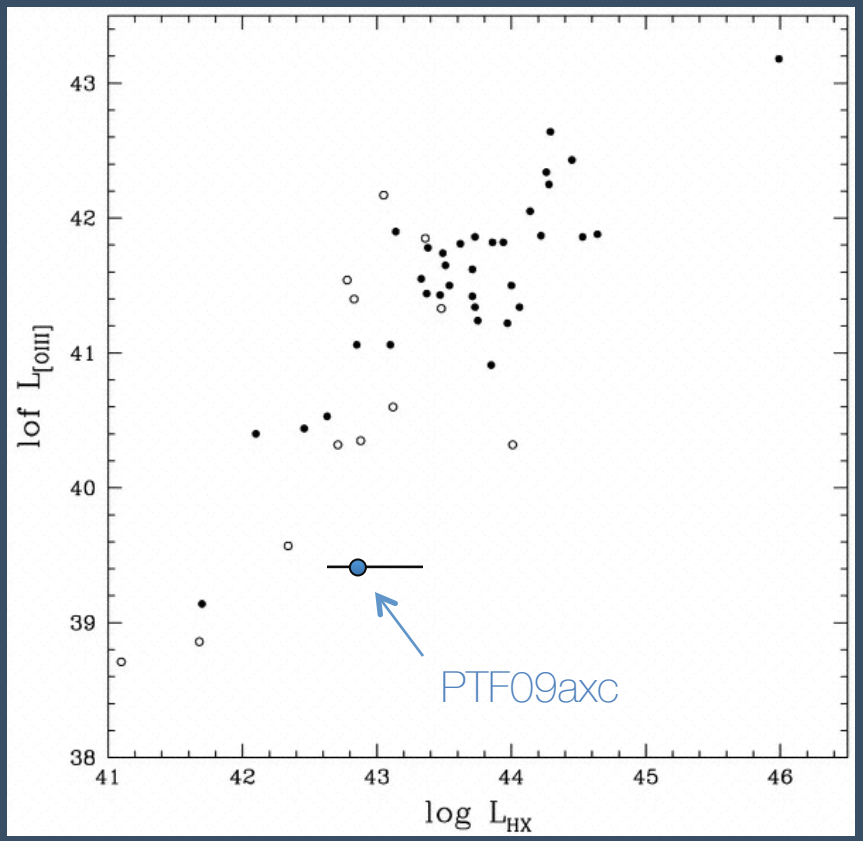

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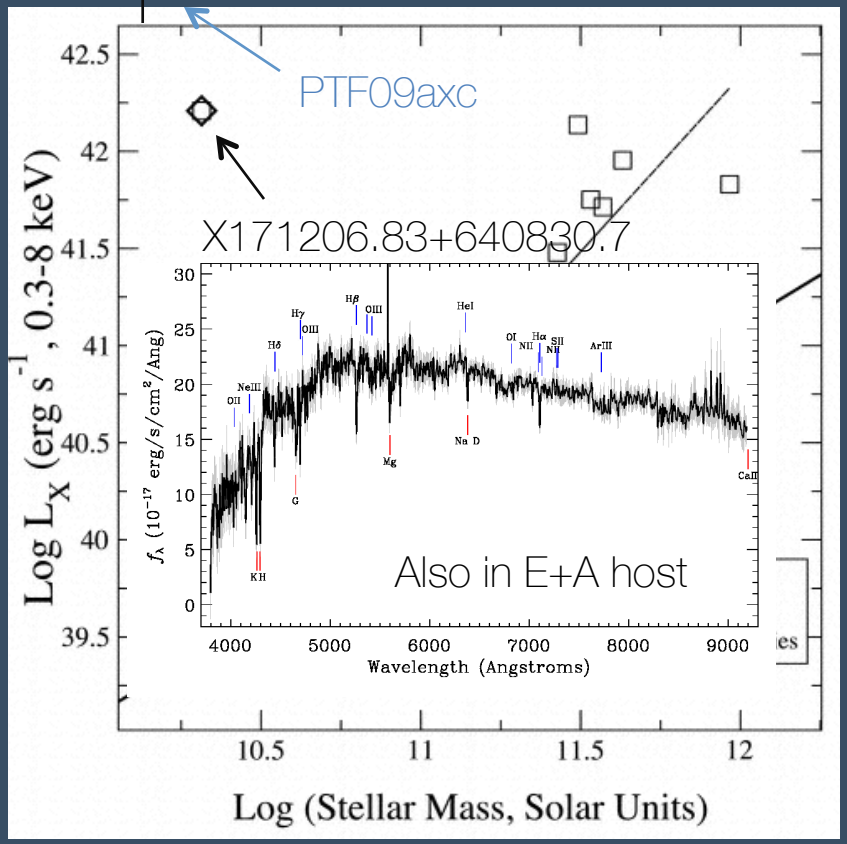

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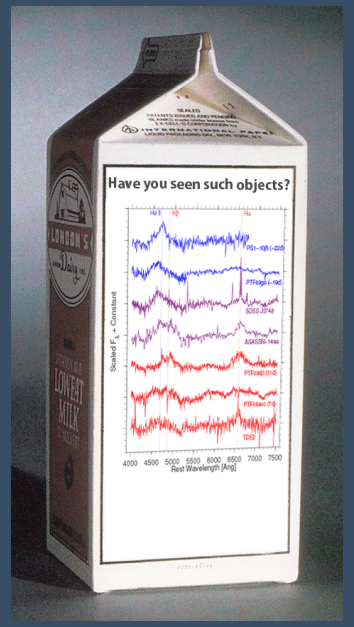
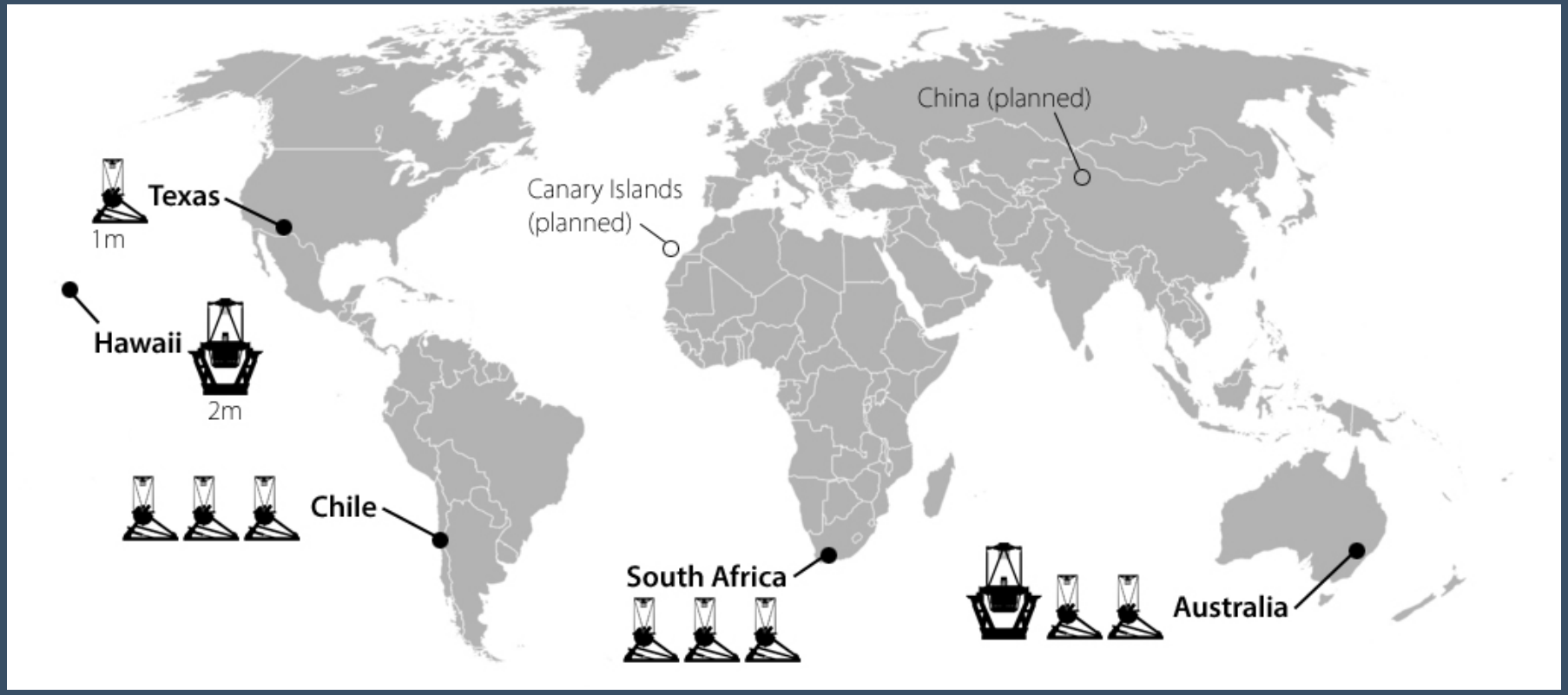
What's Next? More Data

- Monitoring past events for second flare:
  - *Swift* monthly visits 1 year after ASASSN-14ae
  - Monitoring x-rays from PTF09axc

- More events, densely sampled:
  - Discovery: iPTF, LSQ, PSST, ASAS-SN, Gaia, OGLE
  - Classification: LCOGT, PESSTO



LCOGT: A Worldwide Network of Robotic Telescopes



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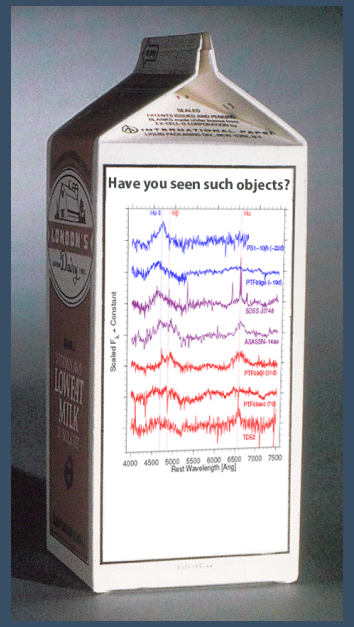
    Swift + VLA (X-ray, UV, radio)



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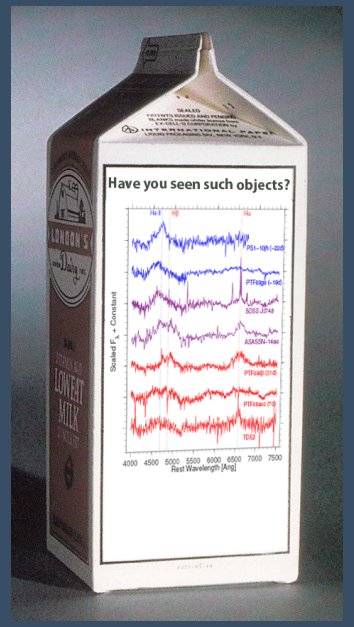
- Monitor E+A Galaxies: SEATiDE



Summary

Key Results:

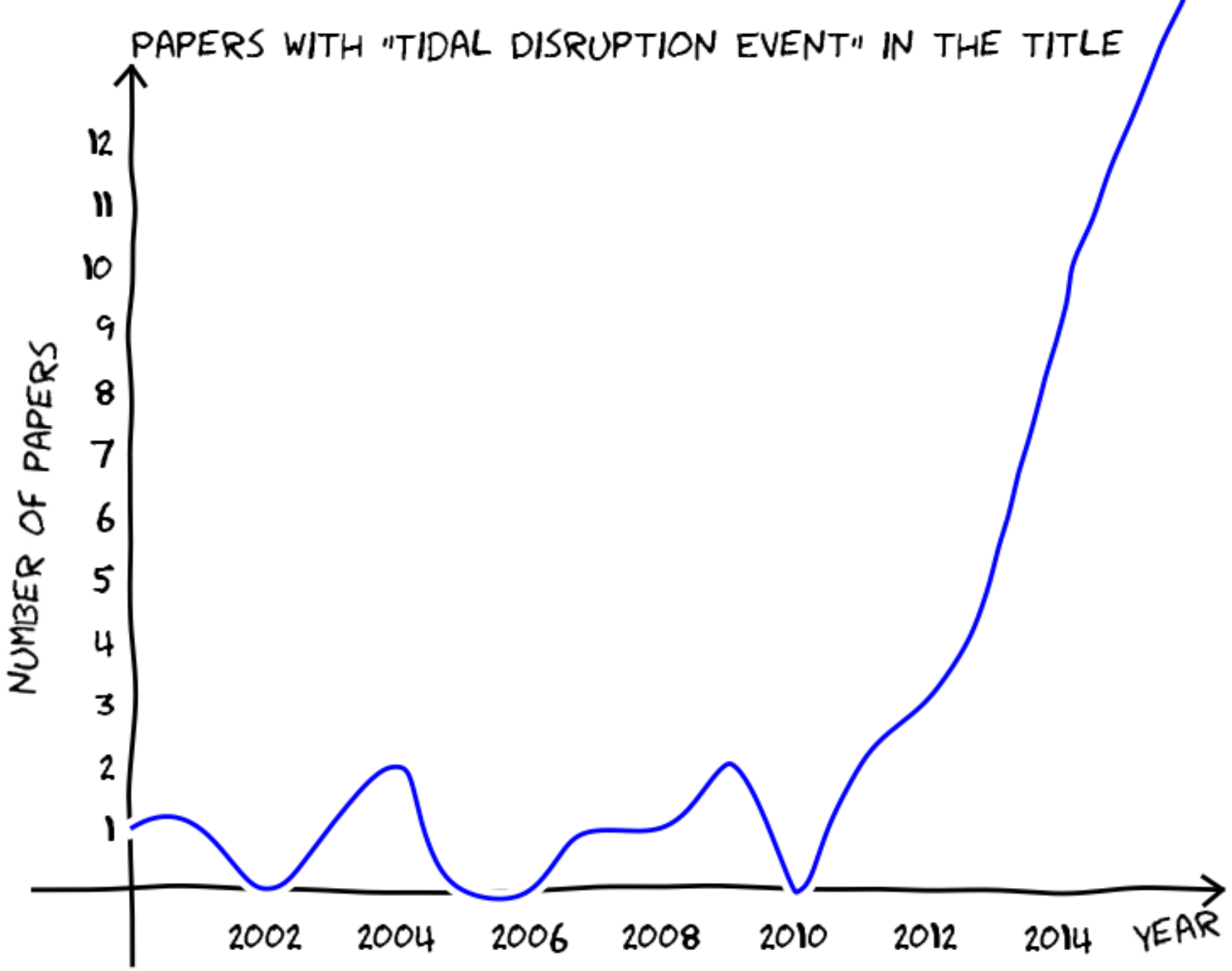
- Find three new TDE candidates in PTF and identify a continuum of H/He-rich spectral classes
- Most TDE candidates are in possible post-merger hosts

Future Observations:

- More and more events are turning up (now that we know what to look for).
- Dedicated *Swift*, VLA, LCOGT time, PESSTO also on board

New Questions:

- Are we seeing circularization or reprocessed accretion?
- What is the physical explanation for the spectral diversity and line profiles?
- Why the preference for post-merger hosts?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