

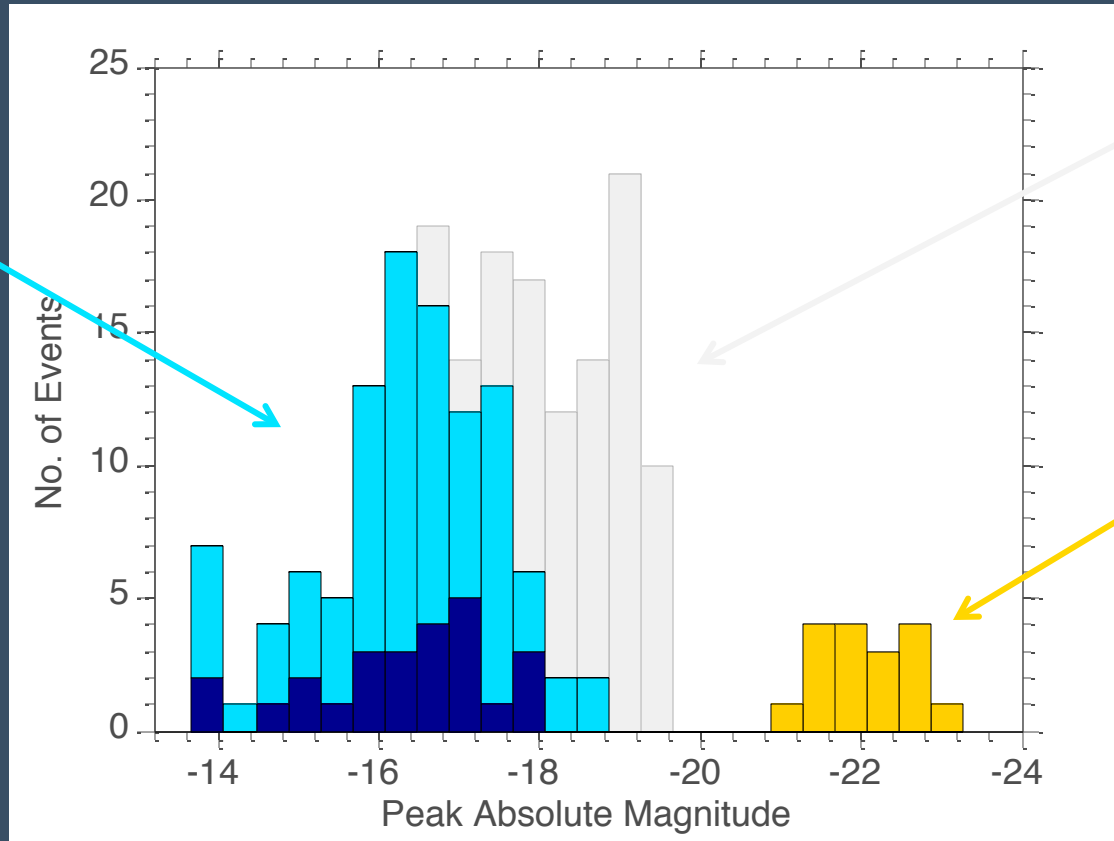
Continuous Spectral Classes of
Tidal Disruption Events
and Their Preference for E+A Galaxies

arXiv:1405.1415

laire ("ya-eer") Arcavi
LCOGT & KITP
University of California, Santa Barbara

Are there events between SNe and SLSNe?

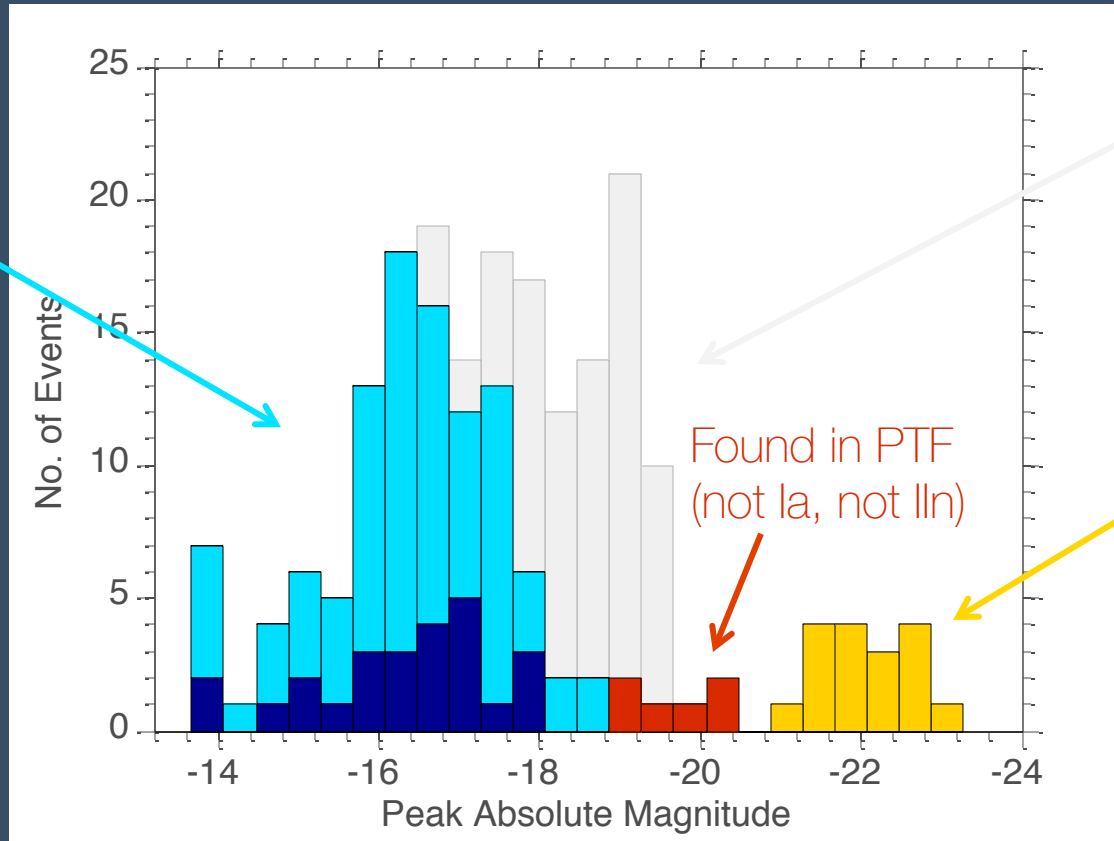
SNe II + Ib/c
(Li et al. 2011)



SNe Ia
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SLSNe
(Gal-Yam 2013)

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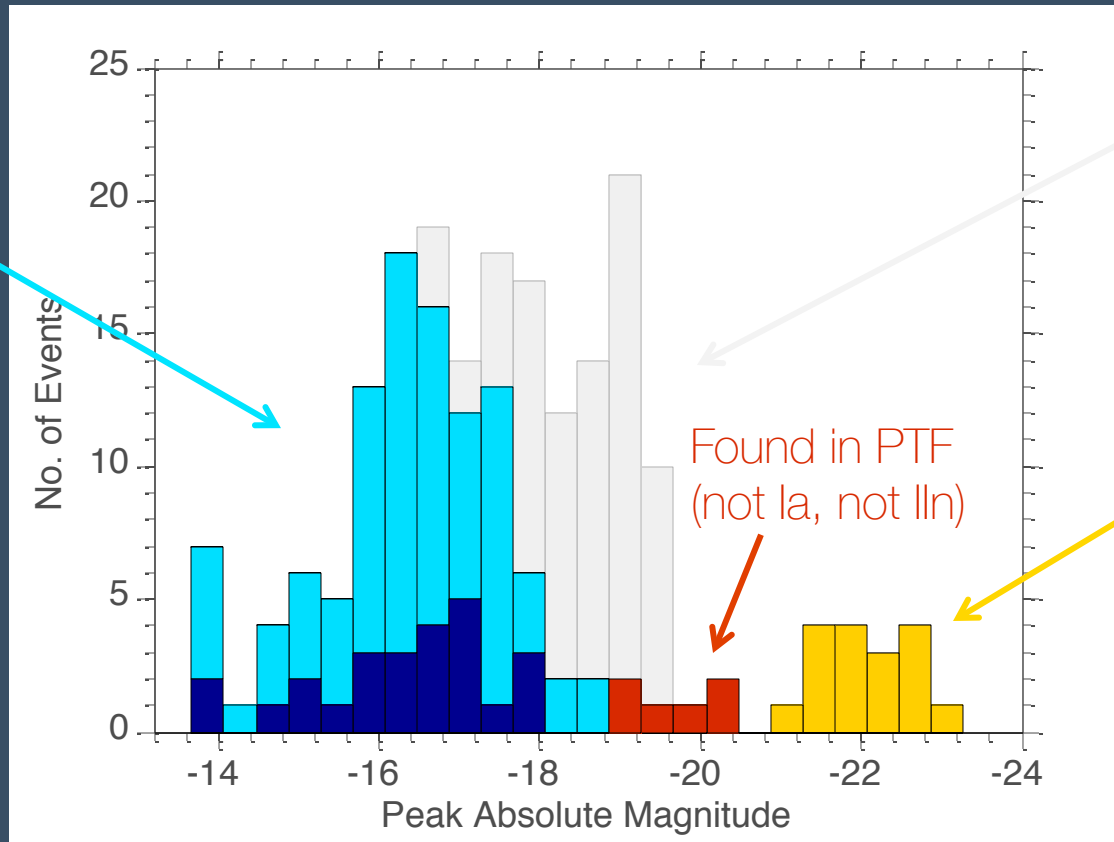
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Found in PTF
(not Ia, not II)

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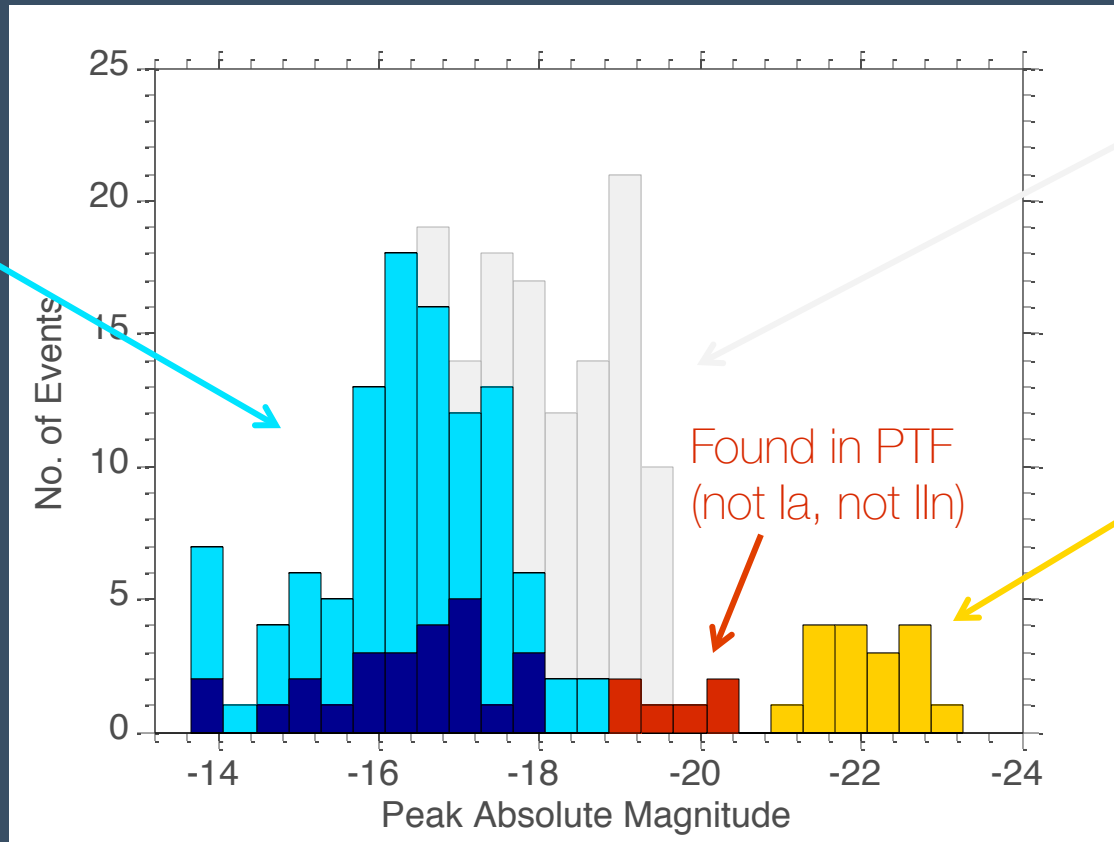
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Mini superluminous supernovae?

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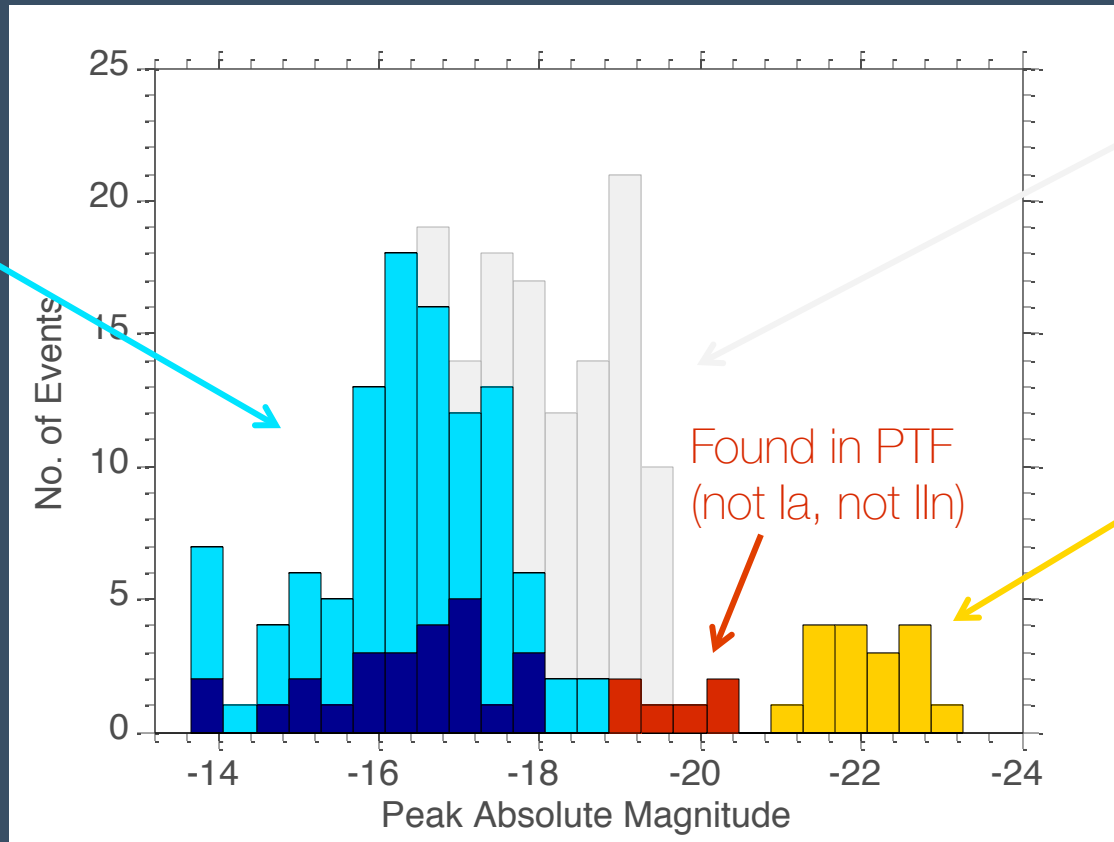
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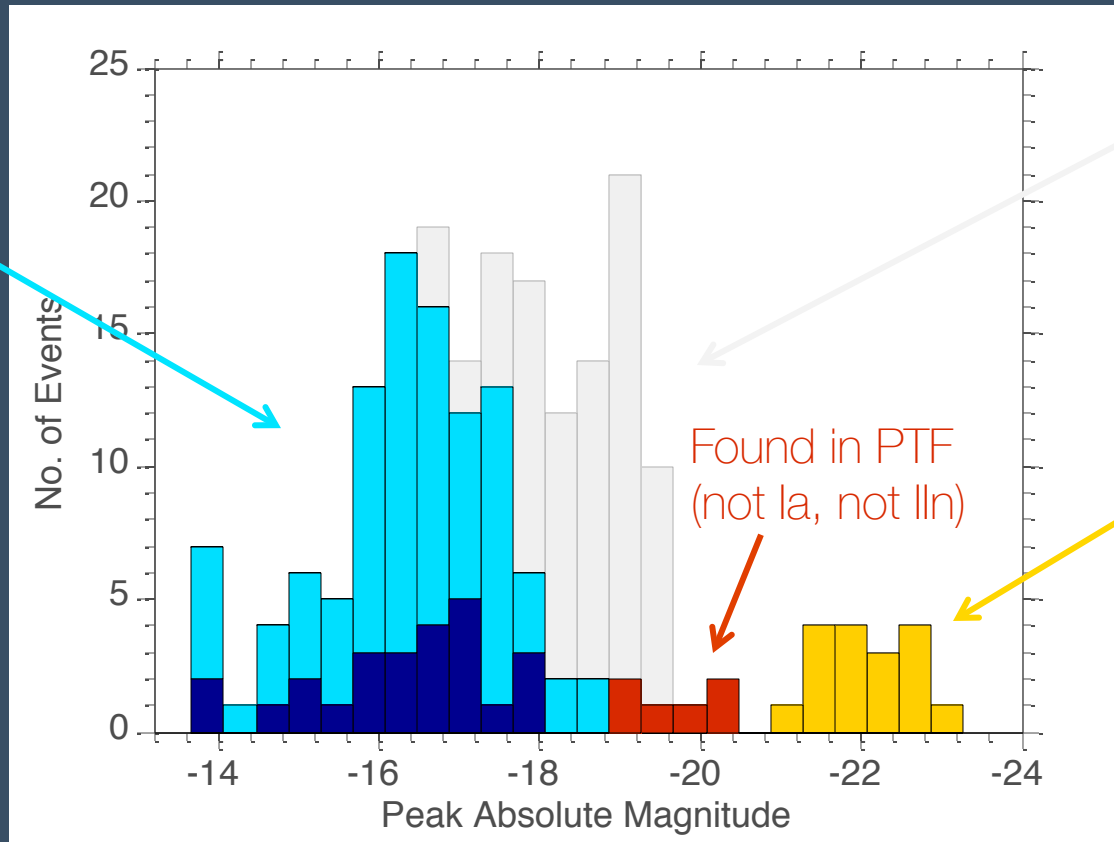
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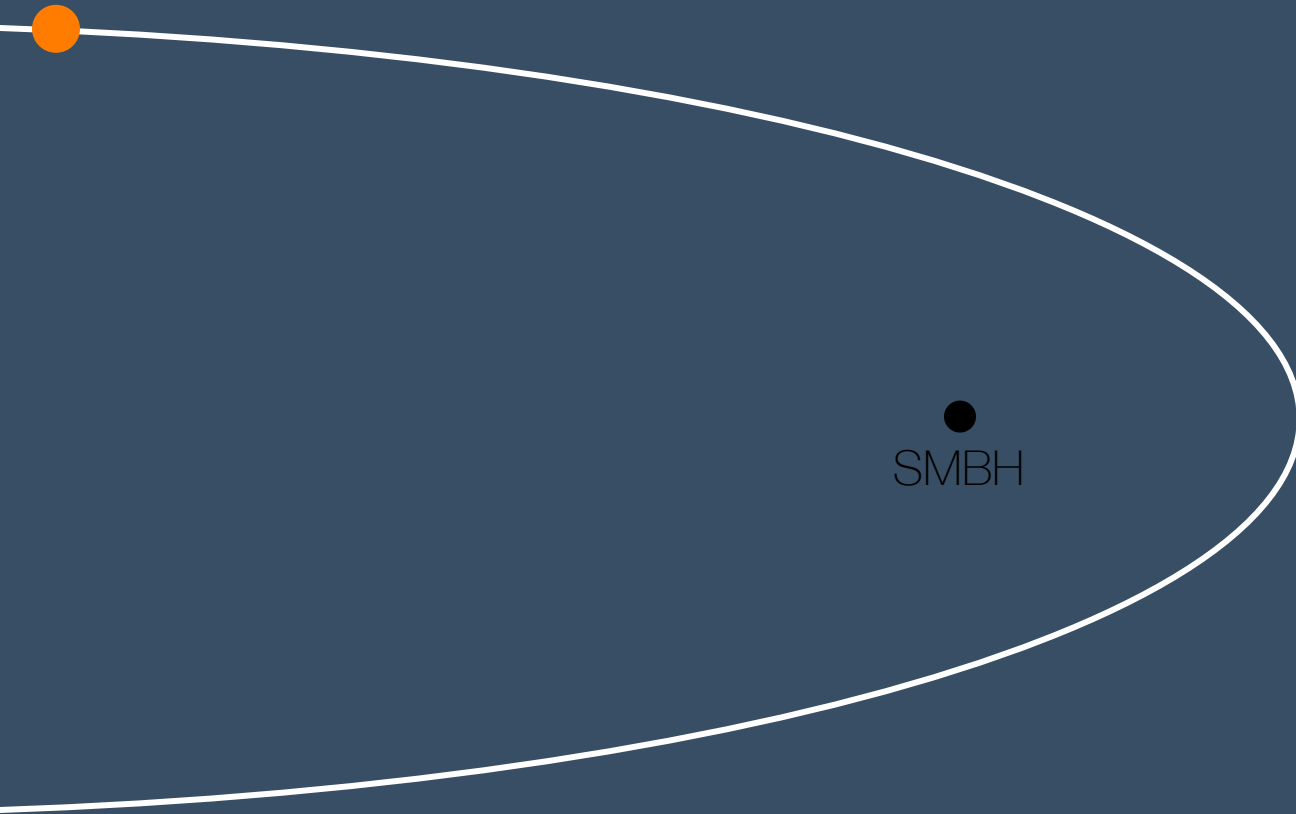
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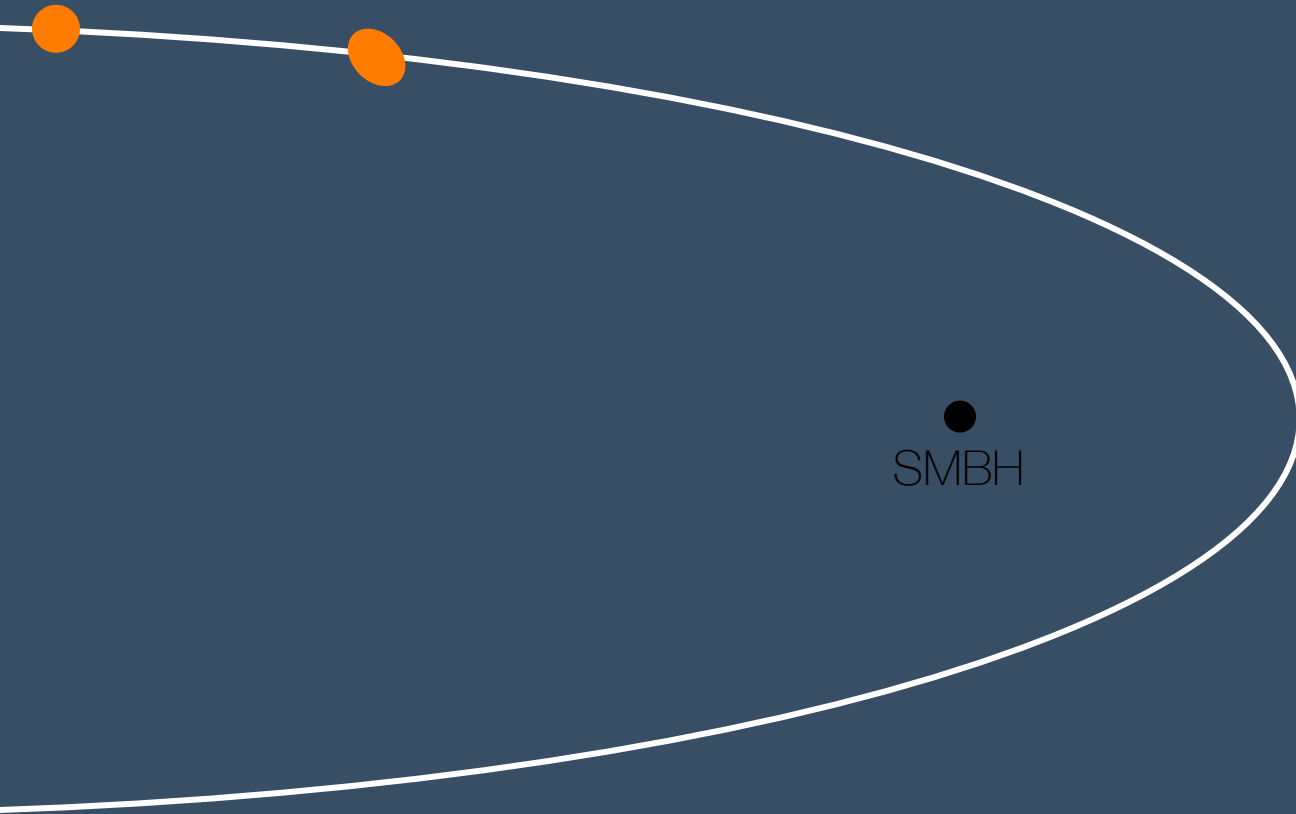
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TDEs?

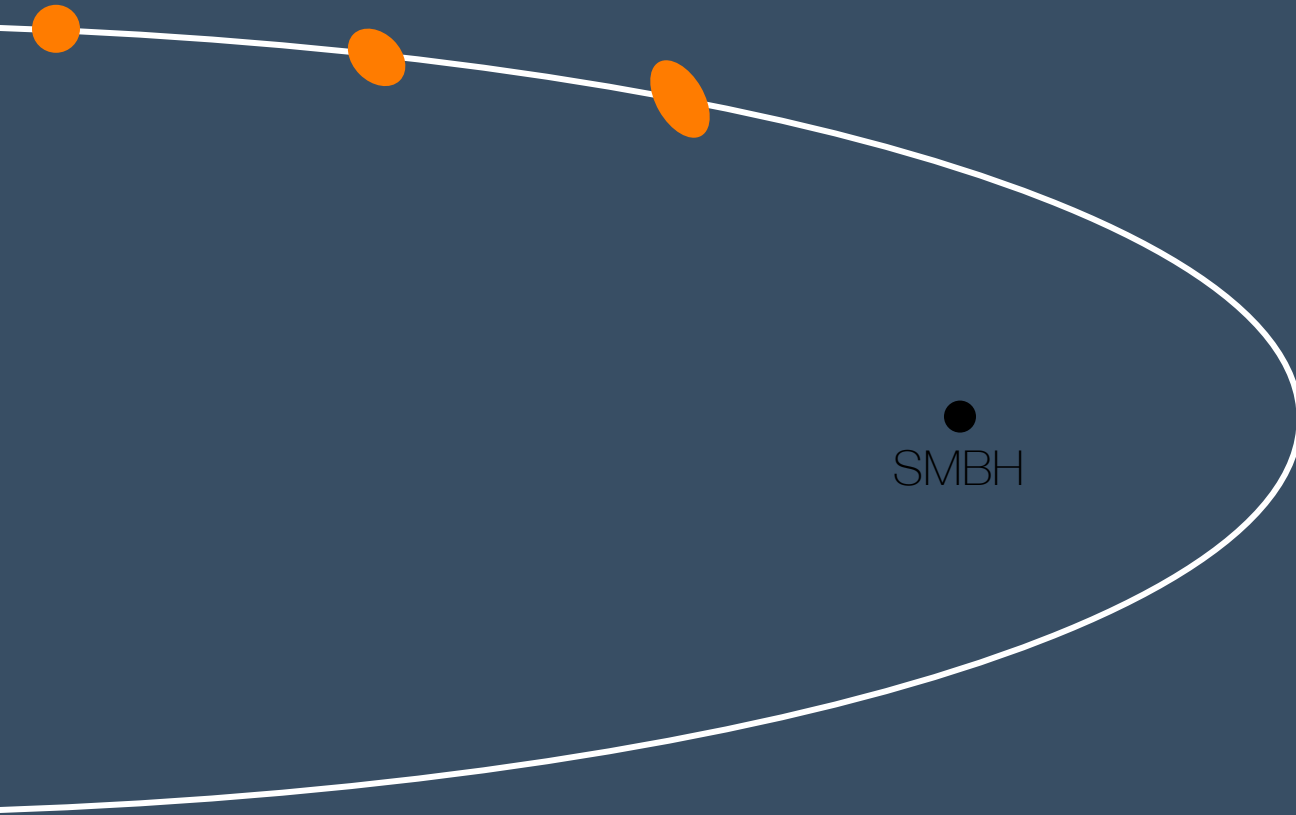
TDEs: important scales



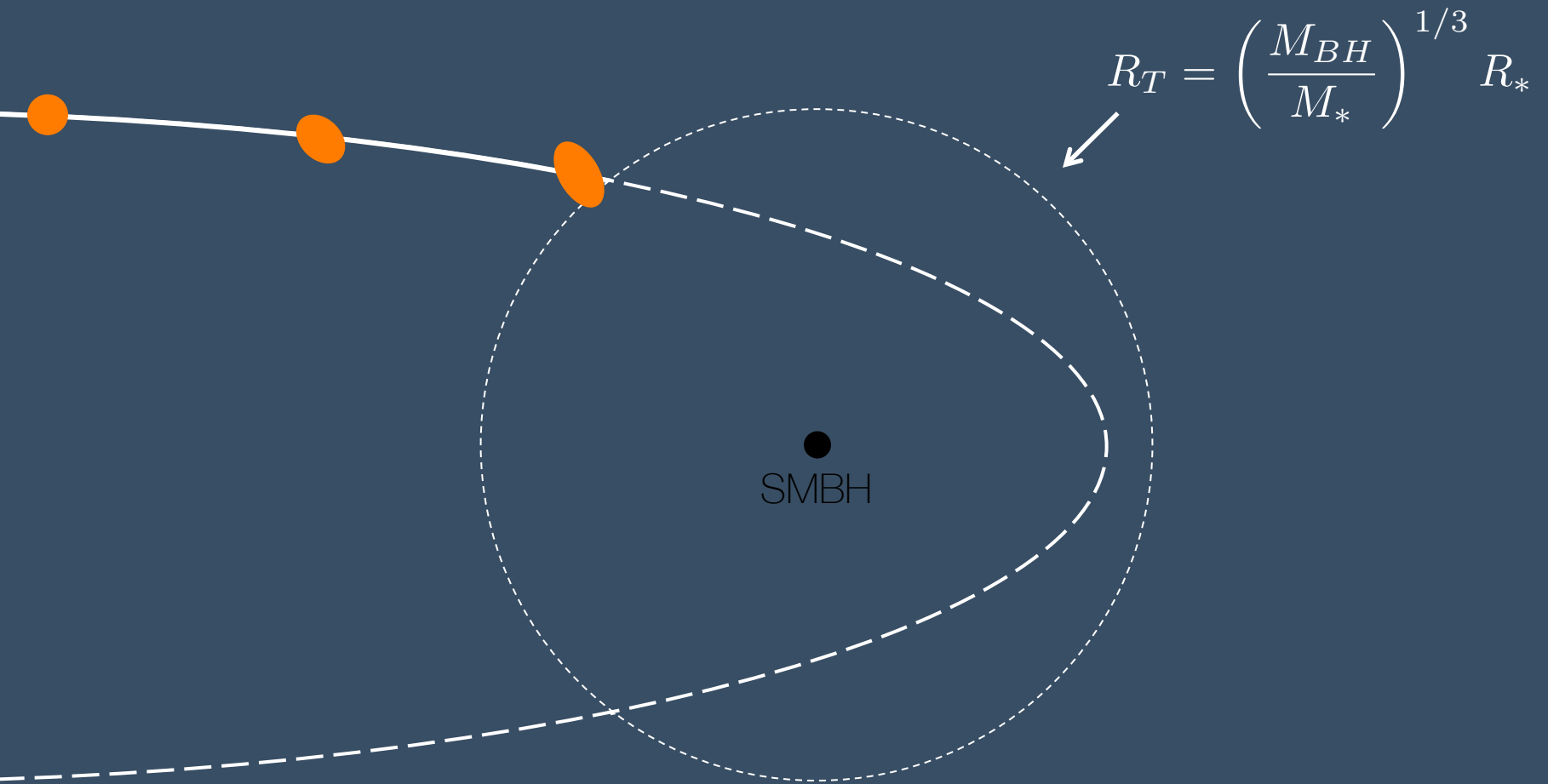
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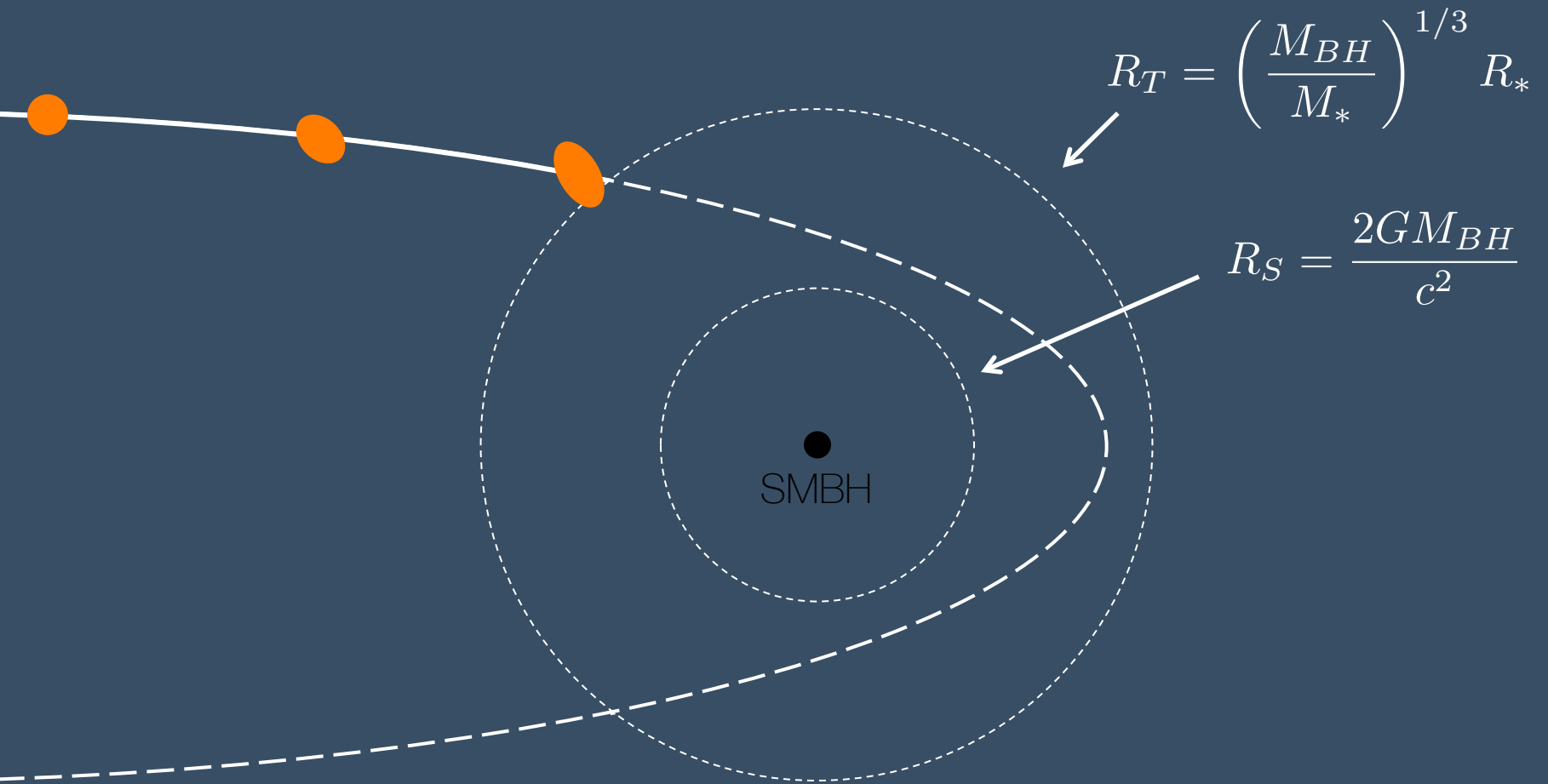
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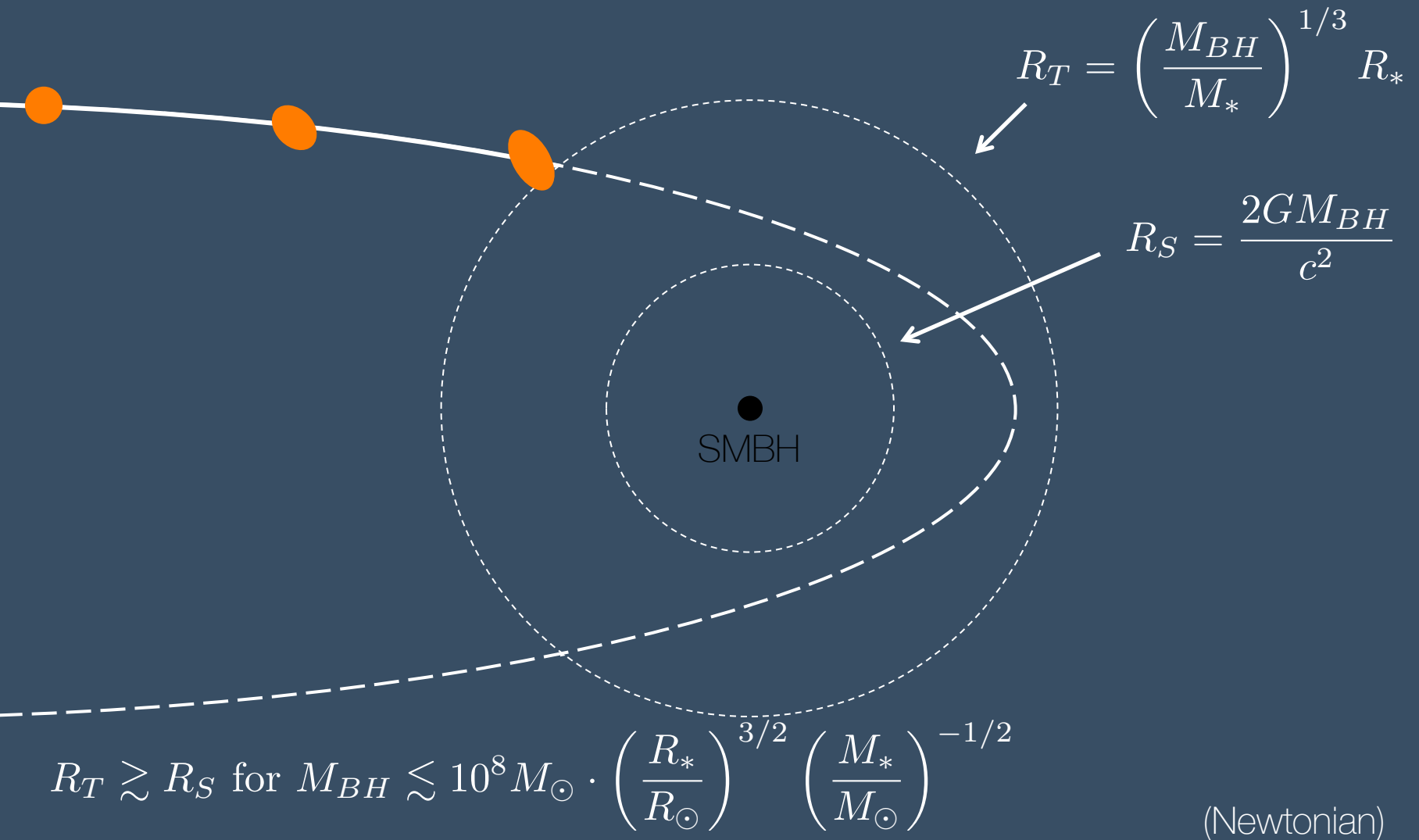
TDEs: important scales

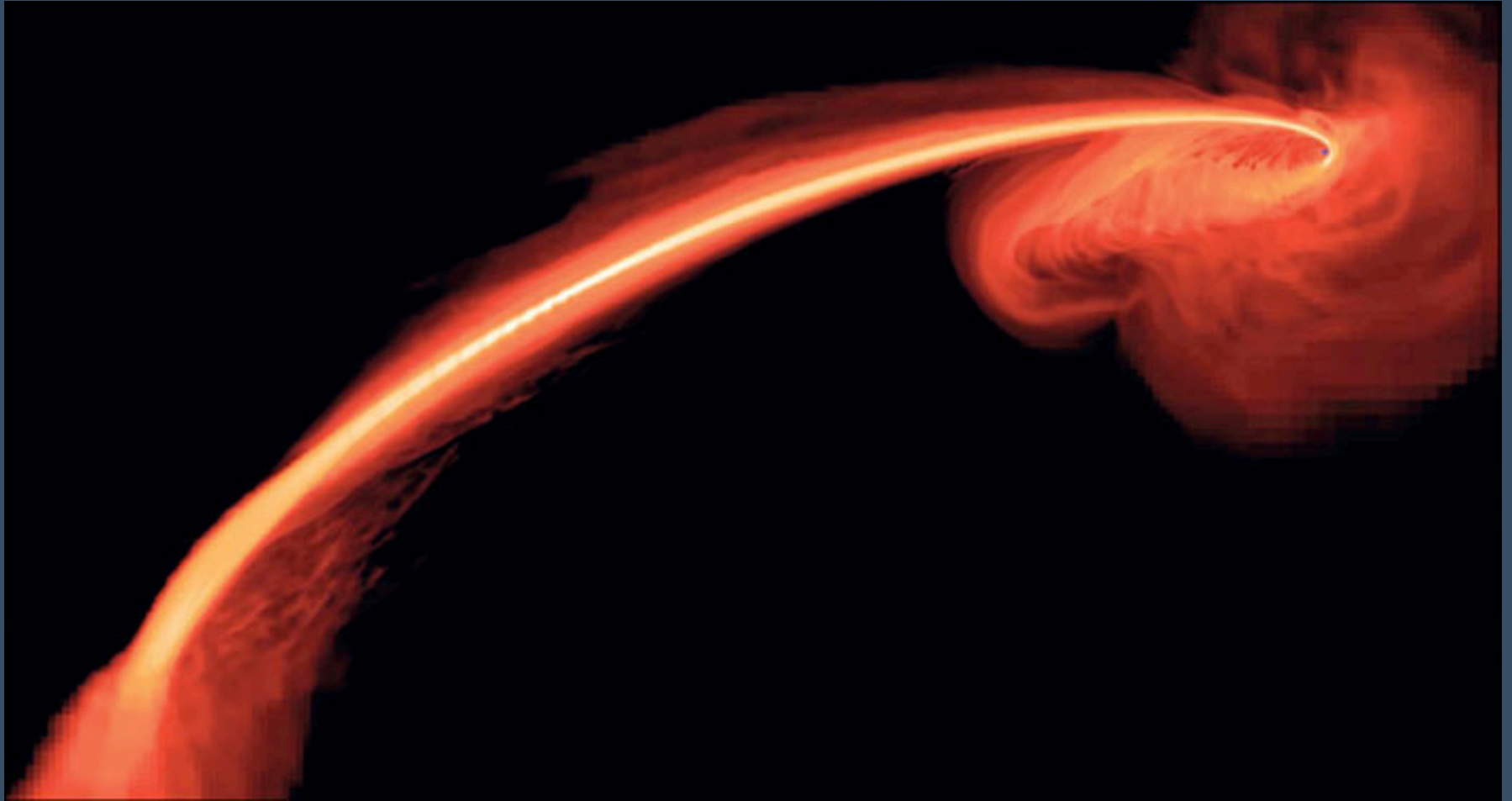


TDEs: important scales



TDEs: important scales





NASA, S Gezari/JHU and J Guillochon/UCSC

TDEs: Rare, and not sure what they should look like

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

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Strubbe & Quataert (2009) – Seeing emission processed by the fan of outflowing material.

Guillochon et al. (2014) – Seeing emission from infalling material, outflowing material is physically thin.

TDEs: ~20 candidates discovered so far

ROSAT (X-Rays) – 5 candidate events (Donley et al. 2002).

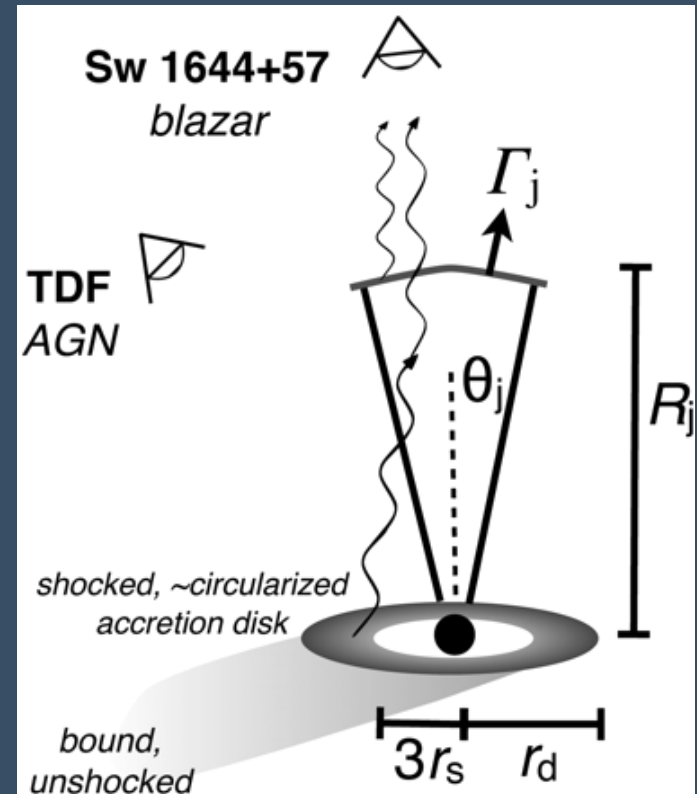
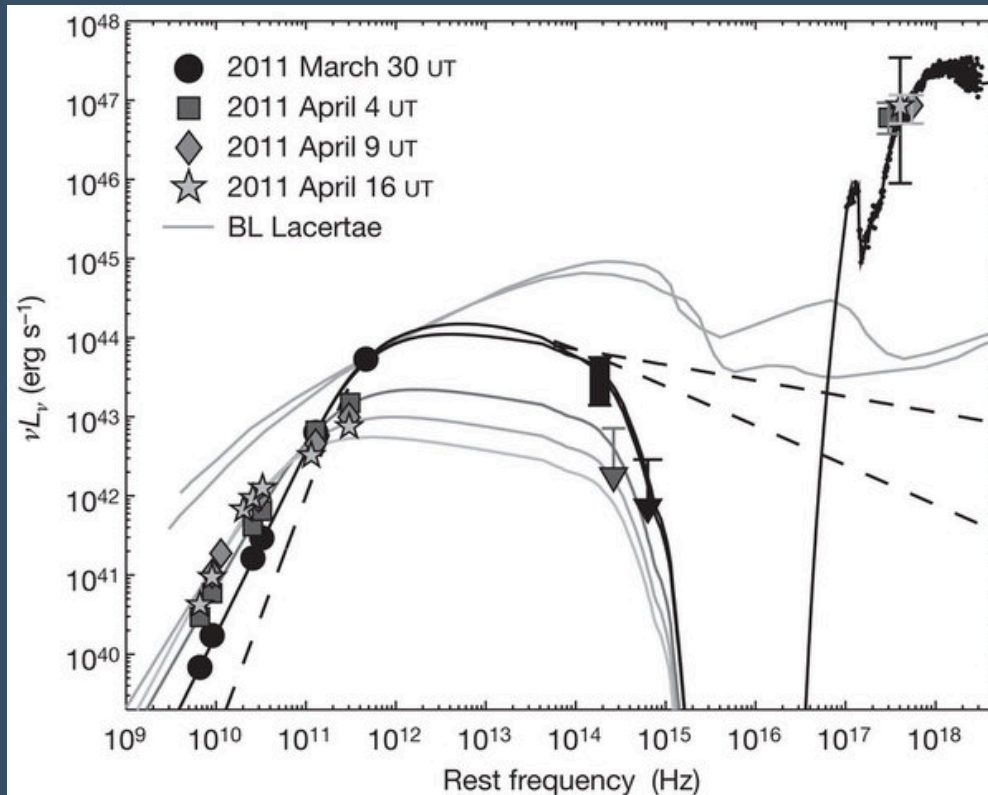
XMM-Newton (X-Rays) – 5 more candidates (Esquej et al. 2007).

SDSS (optical) – 2 candidates in Stripe 82 (van Velzen et al 2011).

Swift (γ -Rays detection + X-Ray followup) – 2 candidates (Burrows et al 2011, Cenko et al 2012).

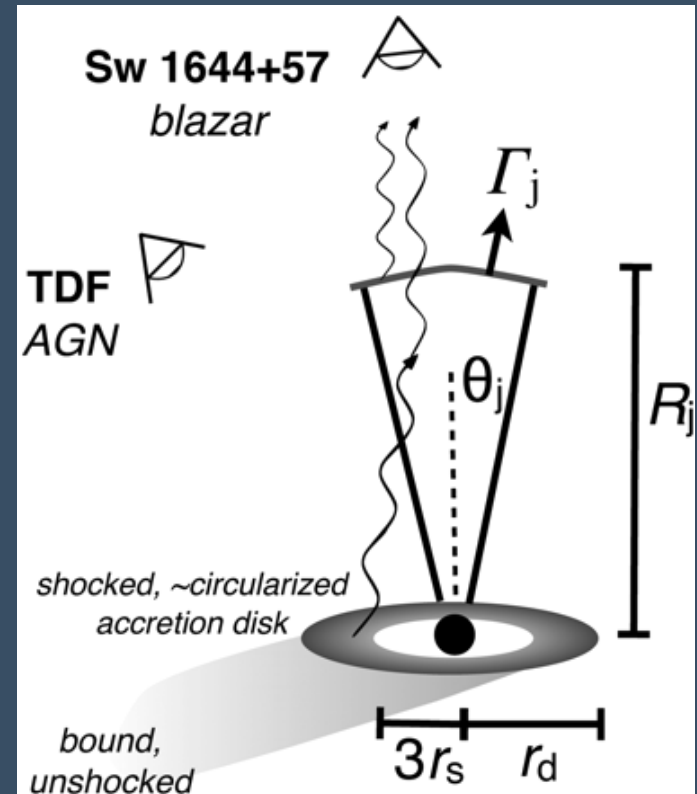
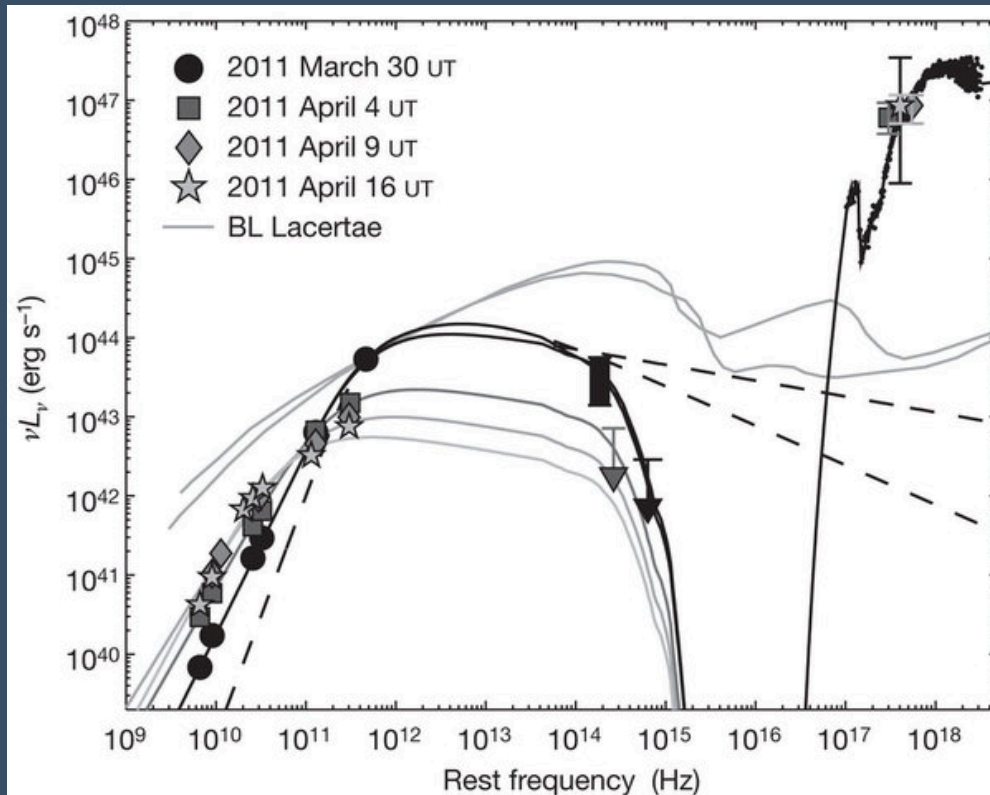
GALEX (UV) + CFHT (optical) + PS1 (optical) – another candidate (~year cadence light curve; Gezari et al. 2006), and recently PS1-10jh (Gezari et al. 2012).

Swift J1644: Best observed high-energy candidate



Zauderer et al. (2011), Bloom et al. (2011)

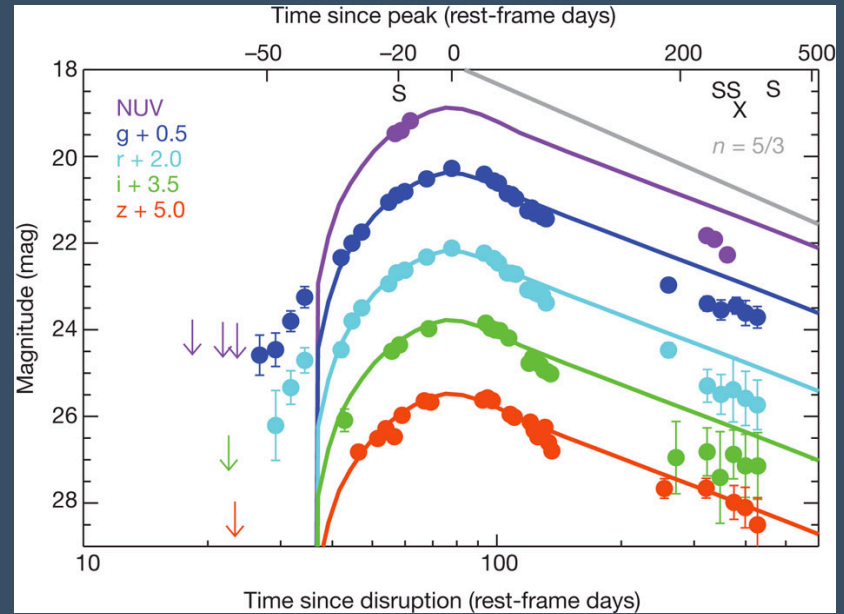
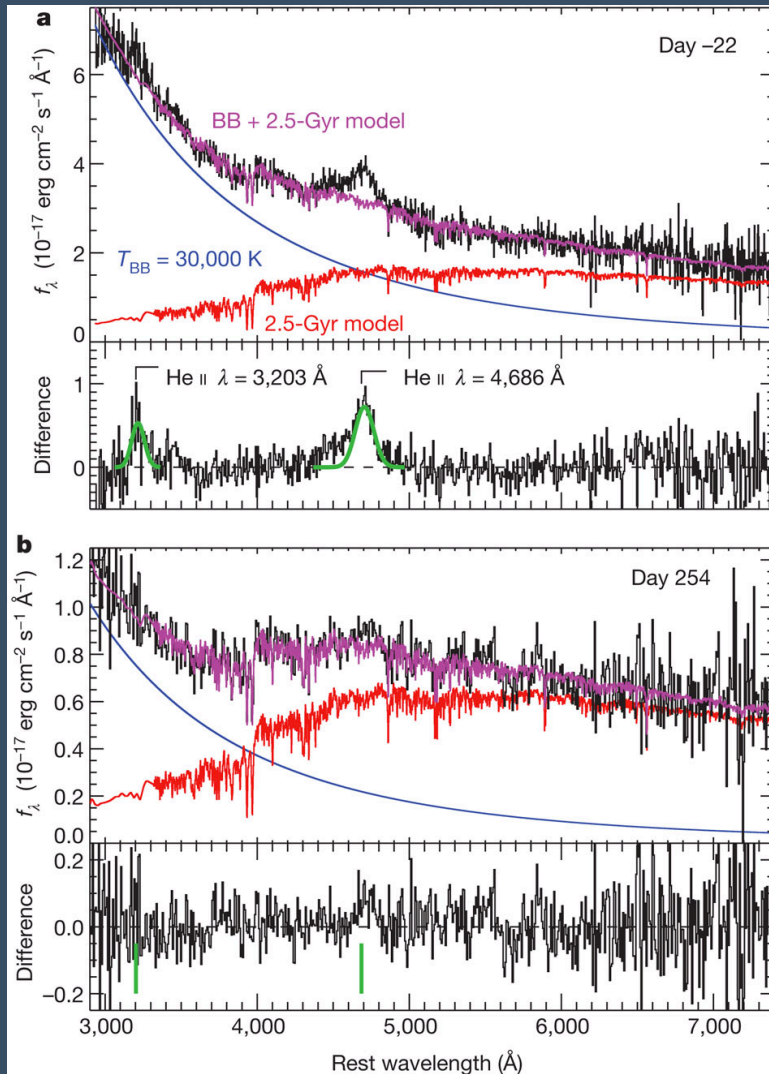
Swift J1644: Best observed high-energy candidate



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

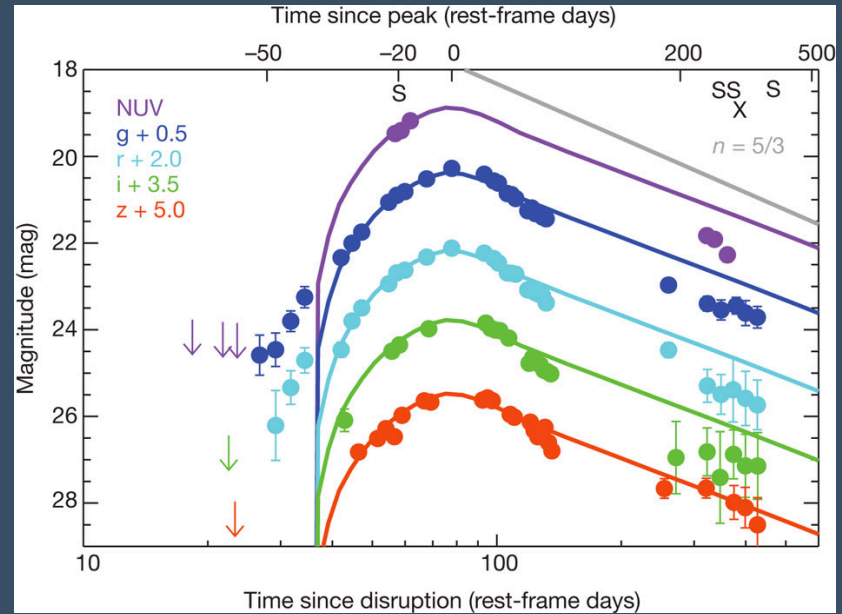
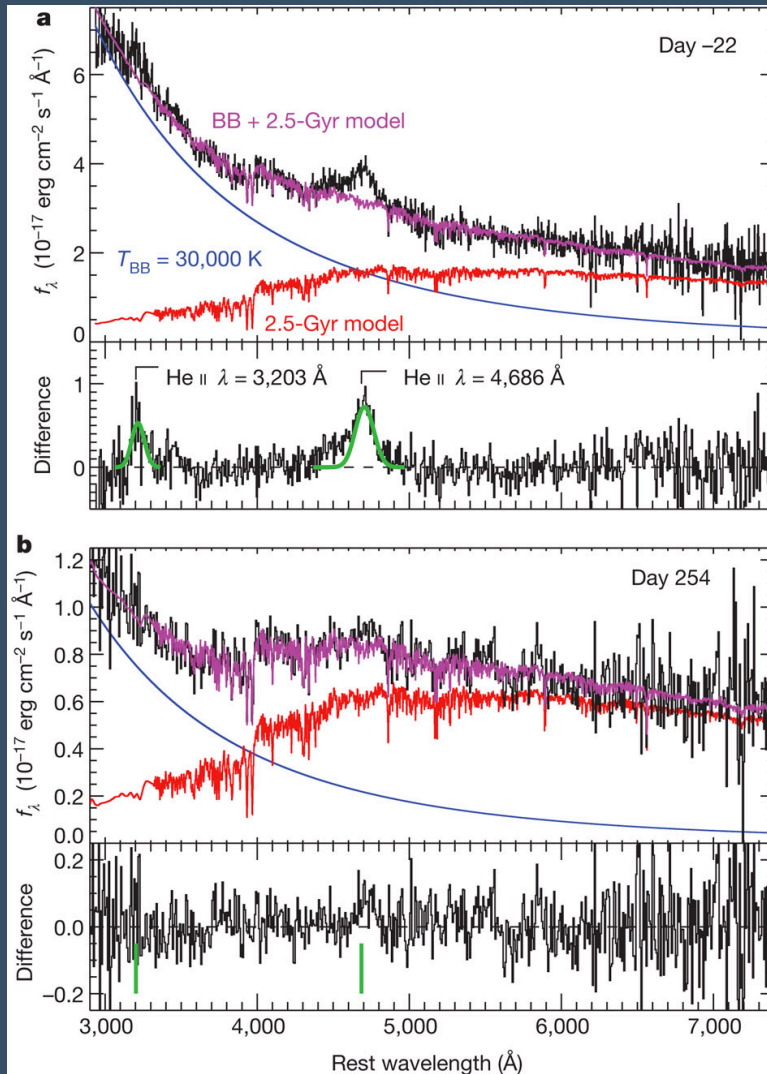
Zauderer et al. (2011), Bloom et al. (2011)

PS1-10jh: Best observed optical / NUV candidate



Gezari et al. (2012)

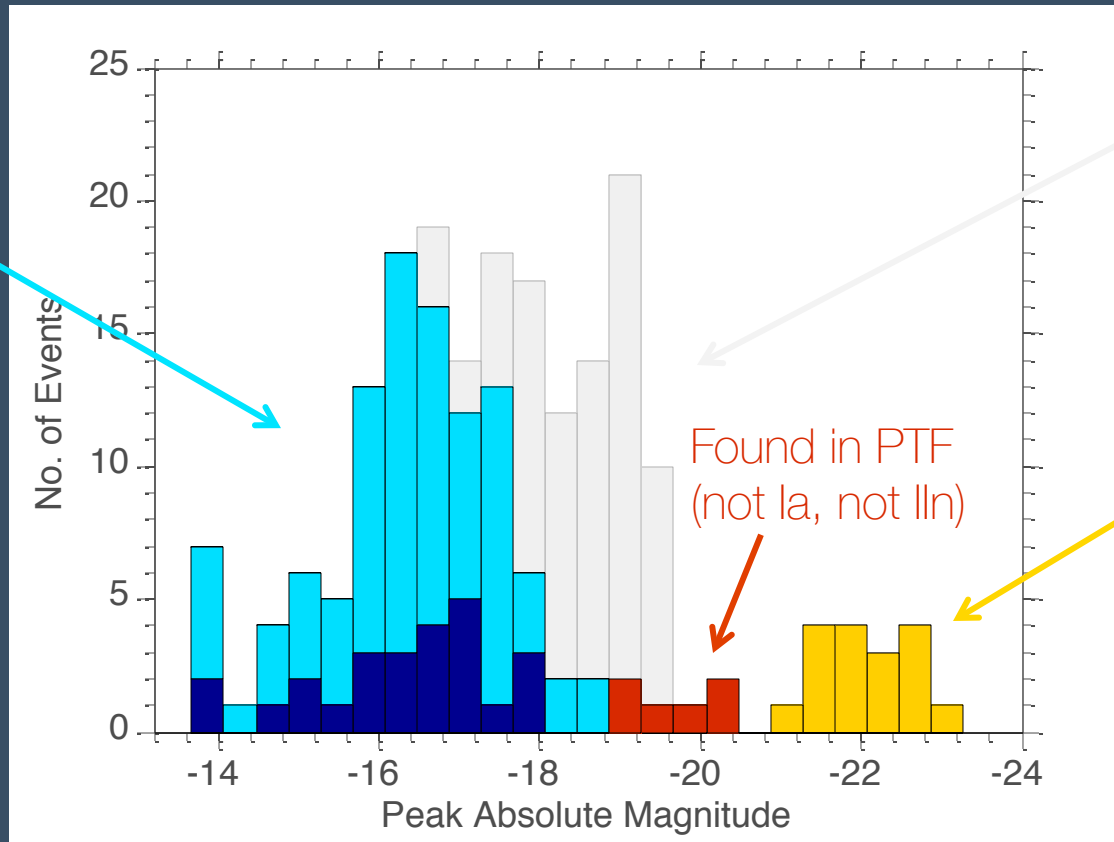
PS1-10jh: Best observed optical / NUV candidate



Expected to see H, not He, assuming main sequence star

Gezari et al. (2012)

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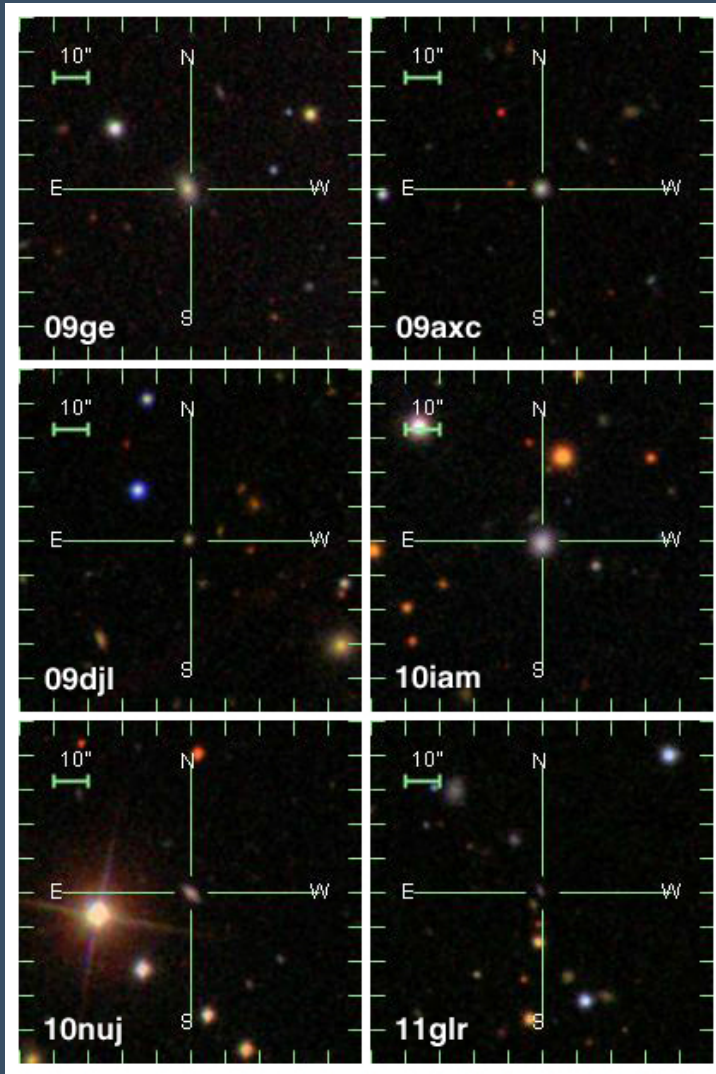
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Mini superluminous supernovae?
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Superluminous macronovae?

TDEs?

Six objects with blue spectrum and peak < -19



Q1: Are they in the centers of their hosts?

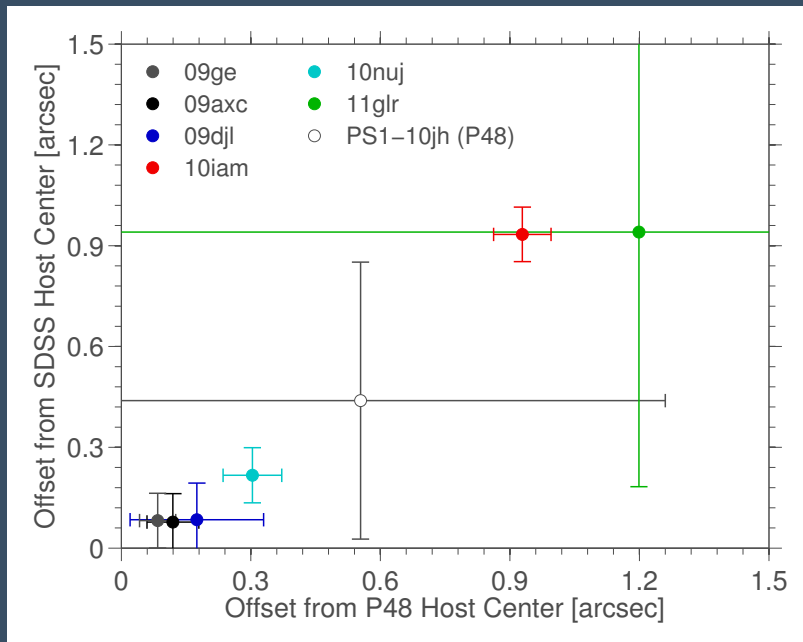
Q2: If so, are they AGN?

Q3: If not AGN, are they similar to other TDE candidates?

Q4: Can we learn anything new from them?

Q1: Are they in the centers of their hosts?

A1: Three are coincident with their host center



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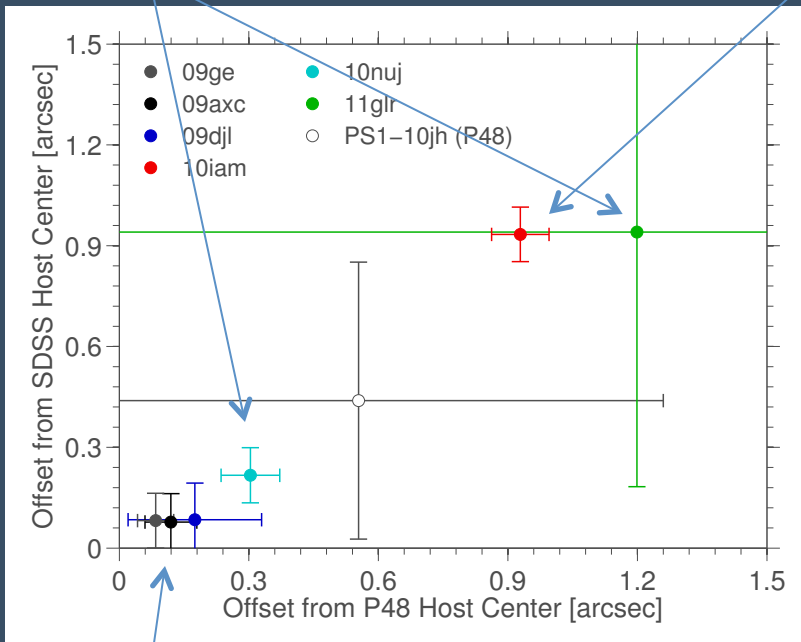
Can't tell:

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)

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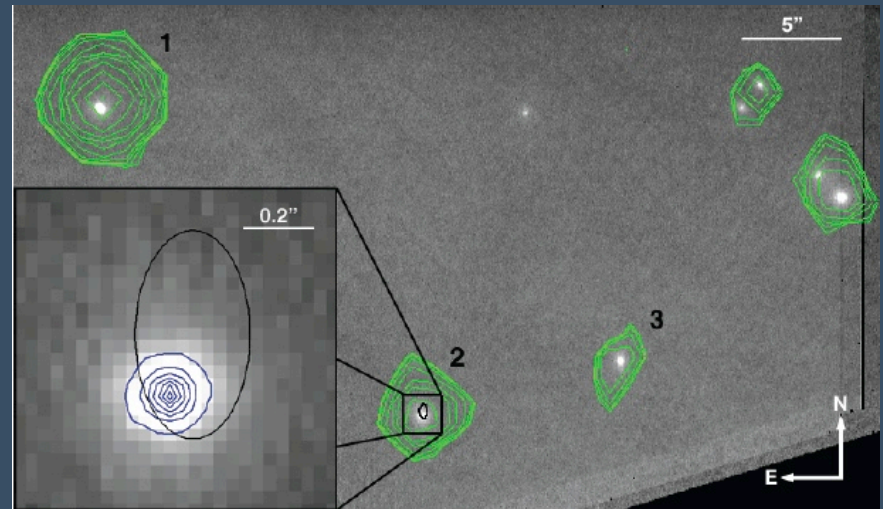
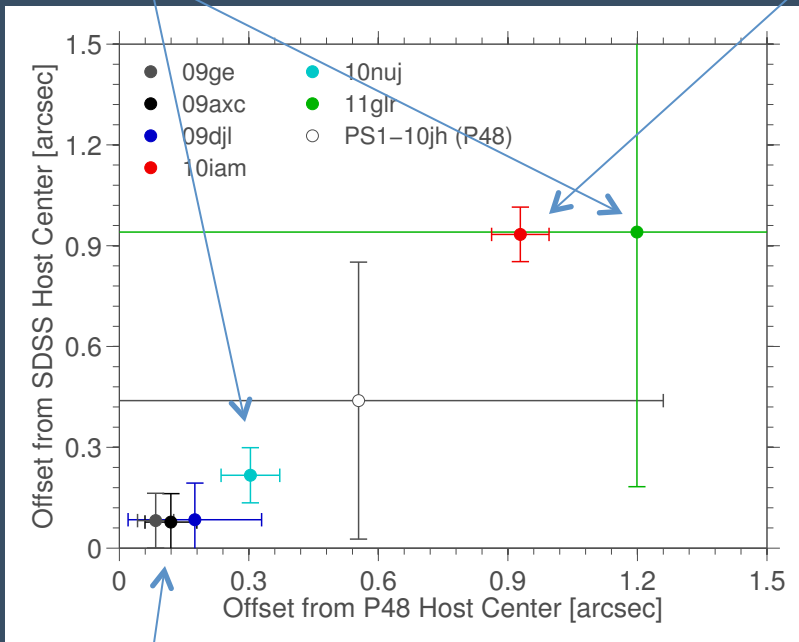
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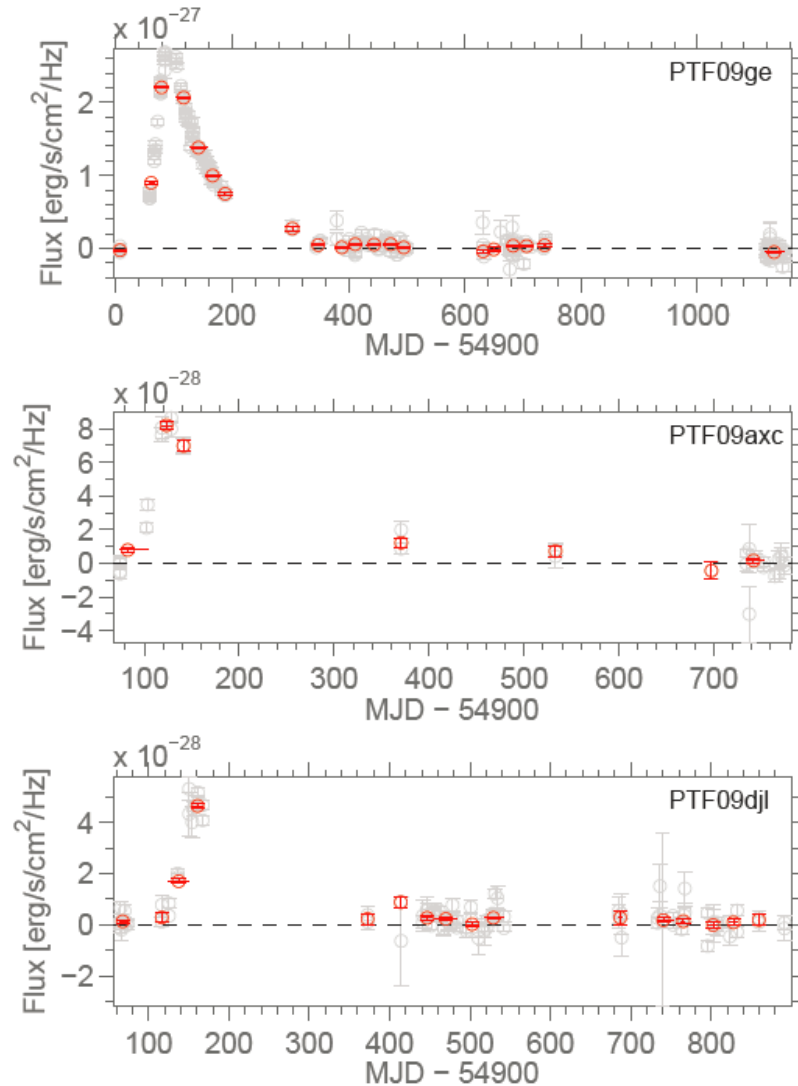
PTF09ge (d=1.0)

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Q2: Are they AGN?

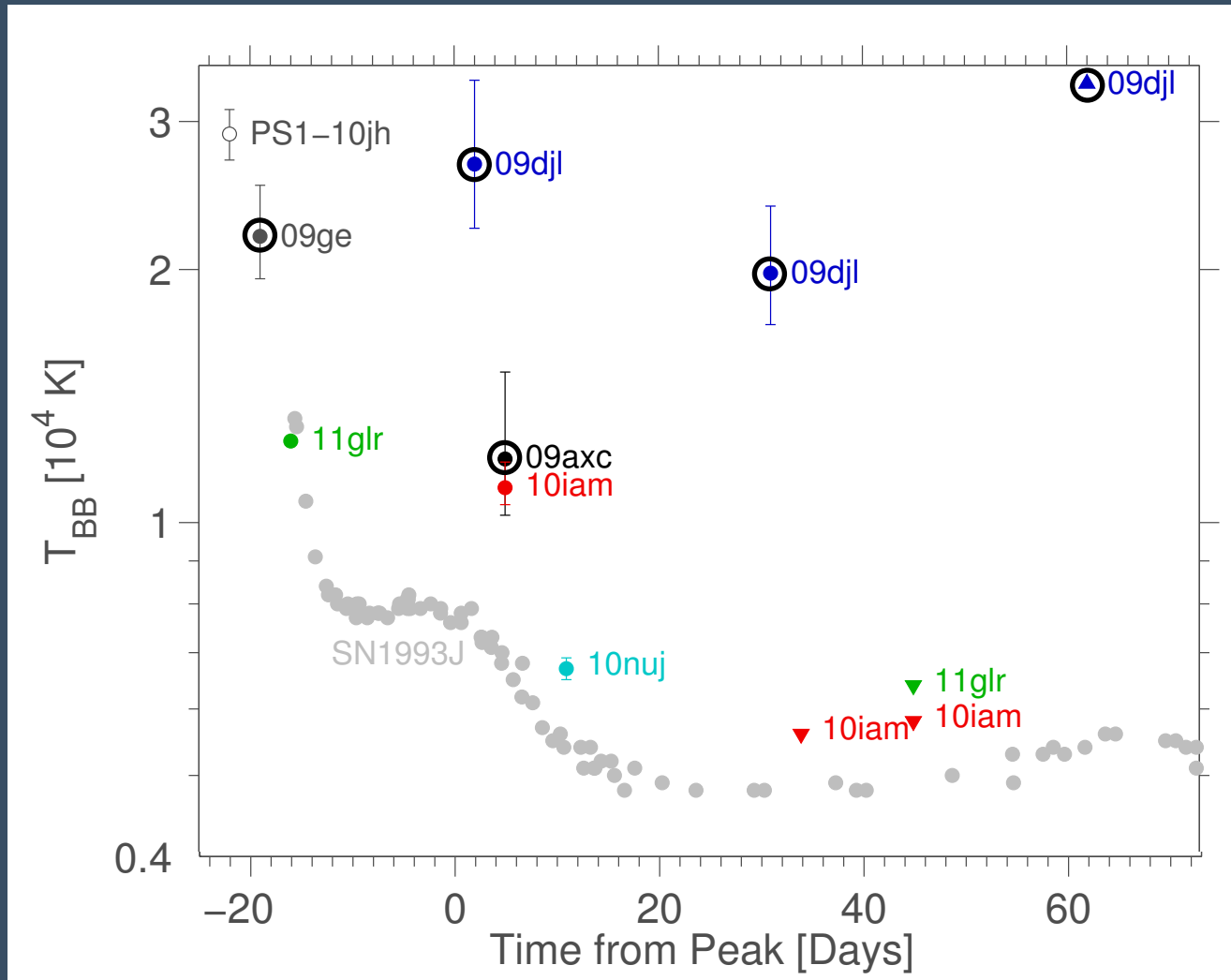
A2: Not Likely AGN



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

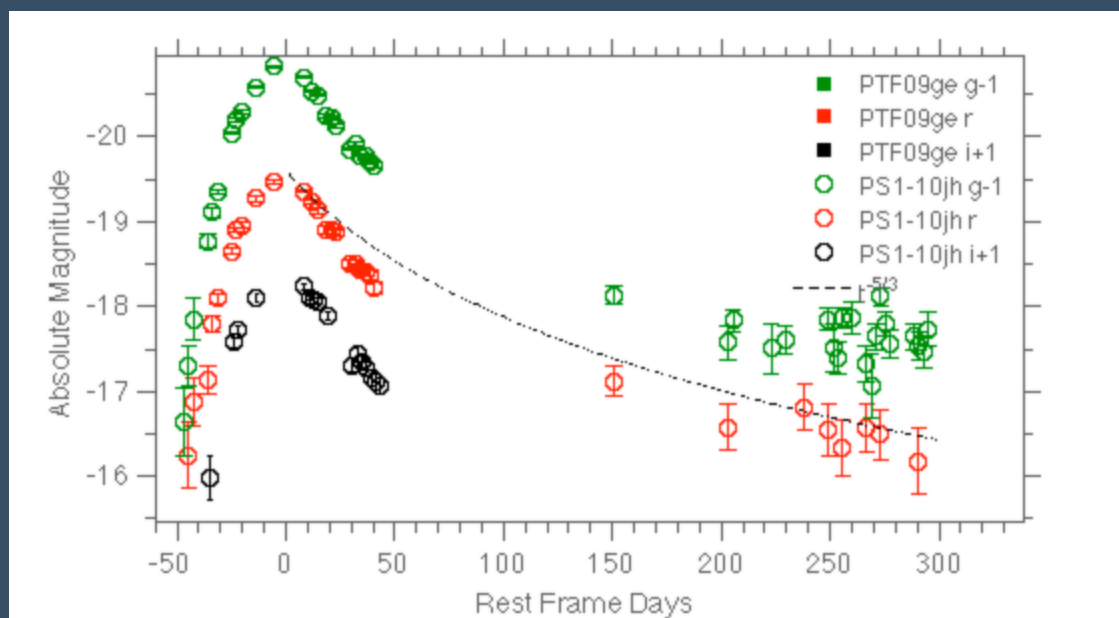
Q2: Are they AGN?

A2: The central events are also the hottest



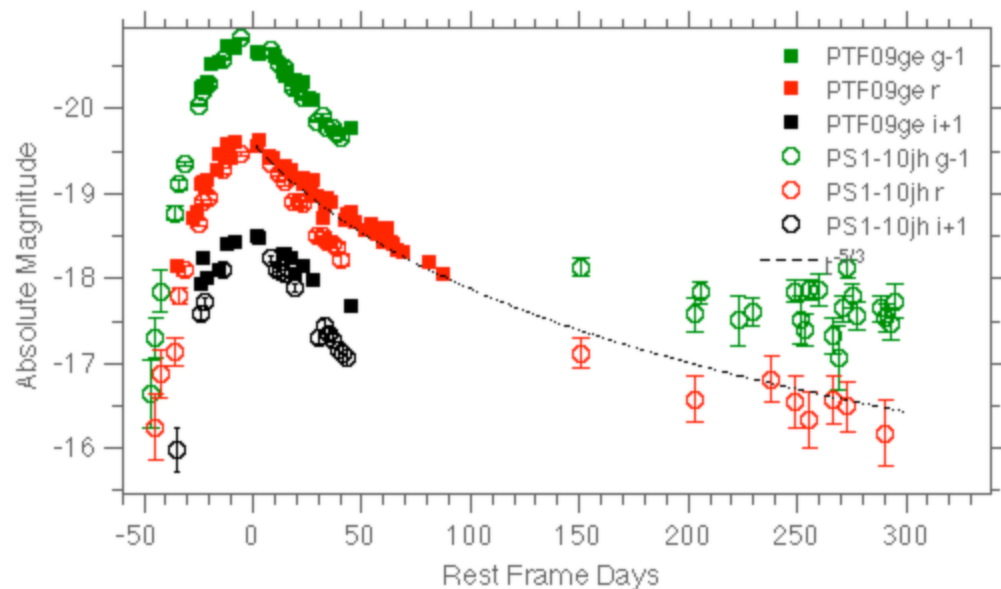
Q3: Are they similar to other TDE candidates?

A3: One is almost identical to PS1-10jh



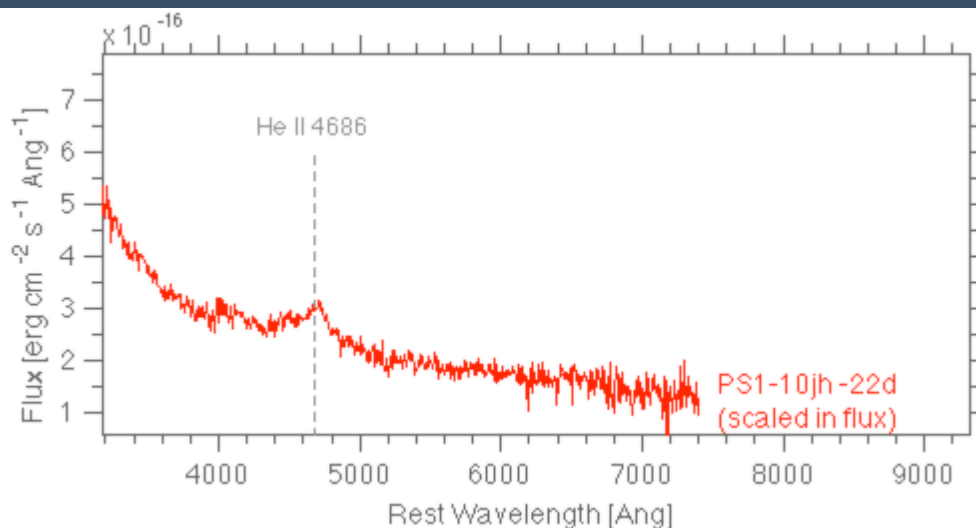
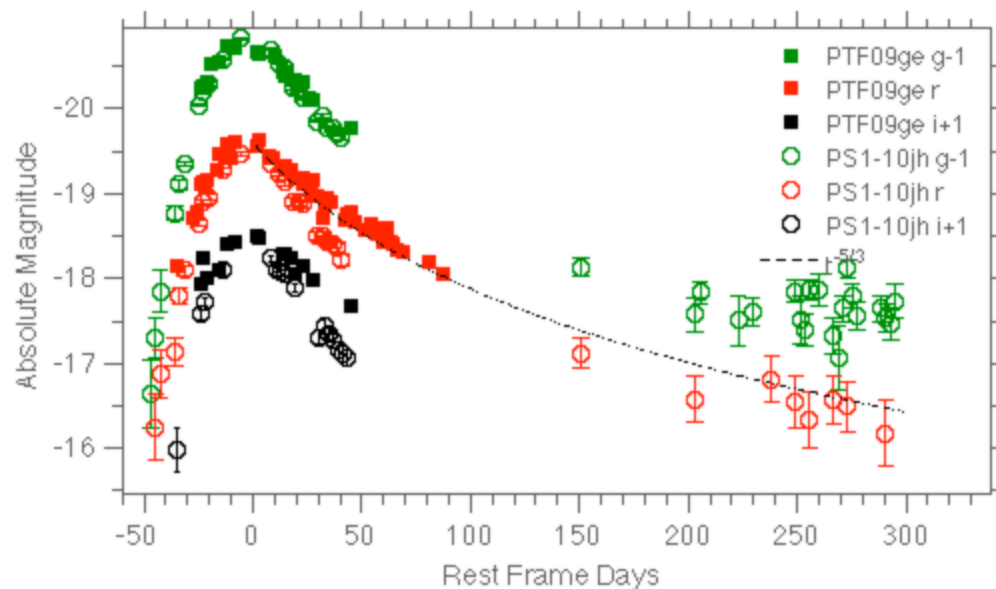
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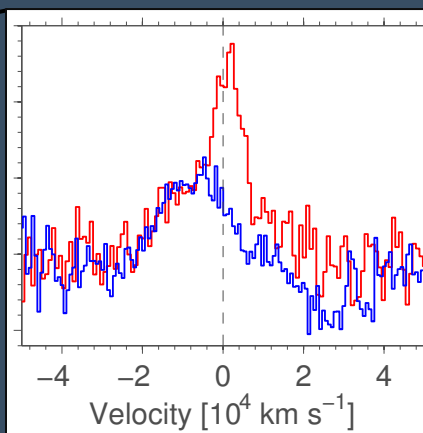
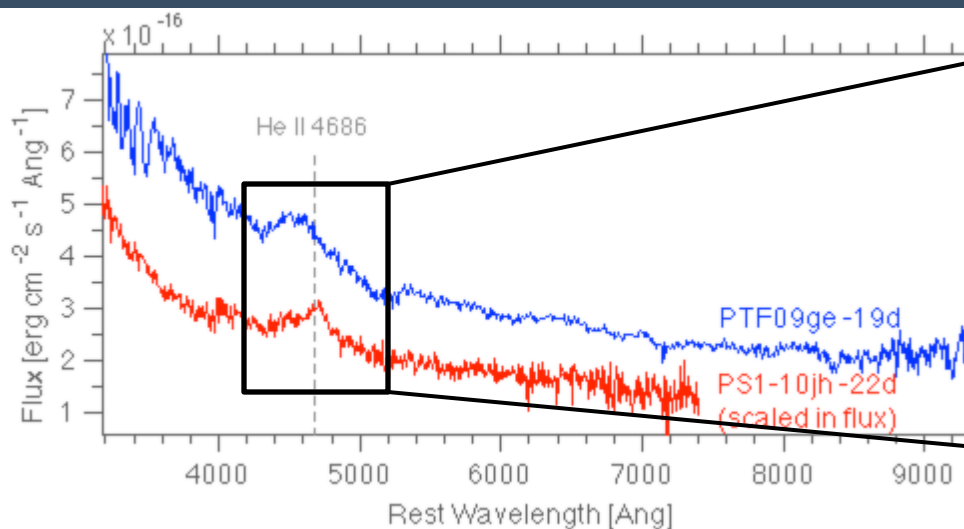
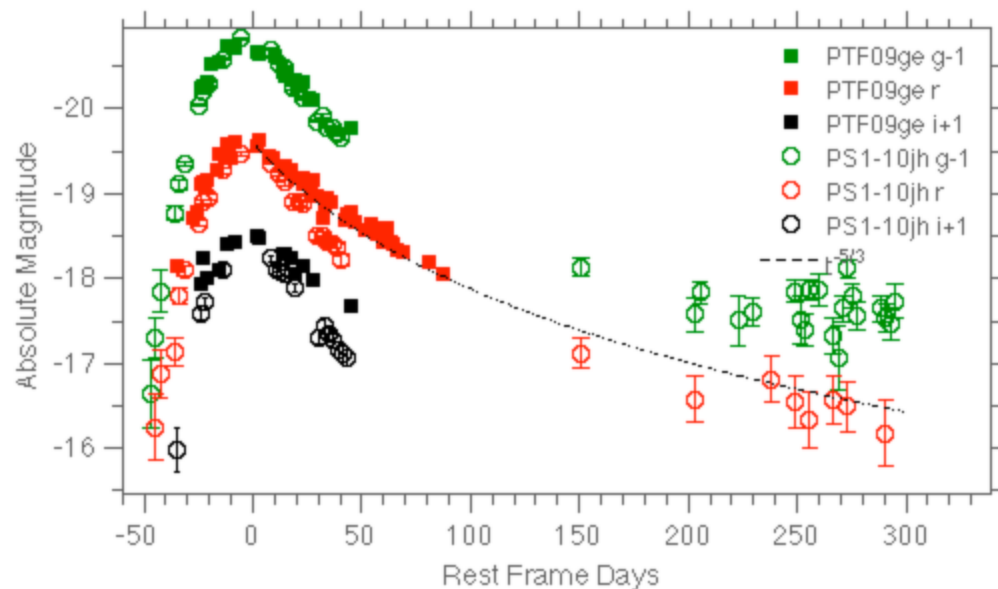
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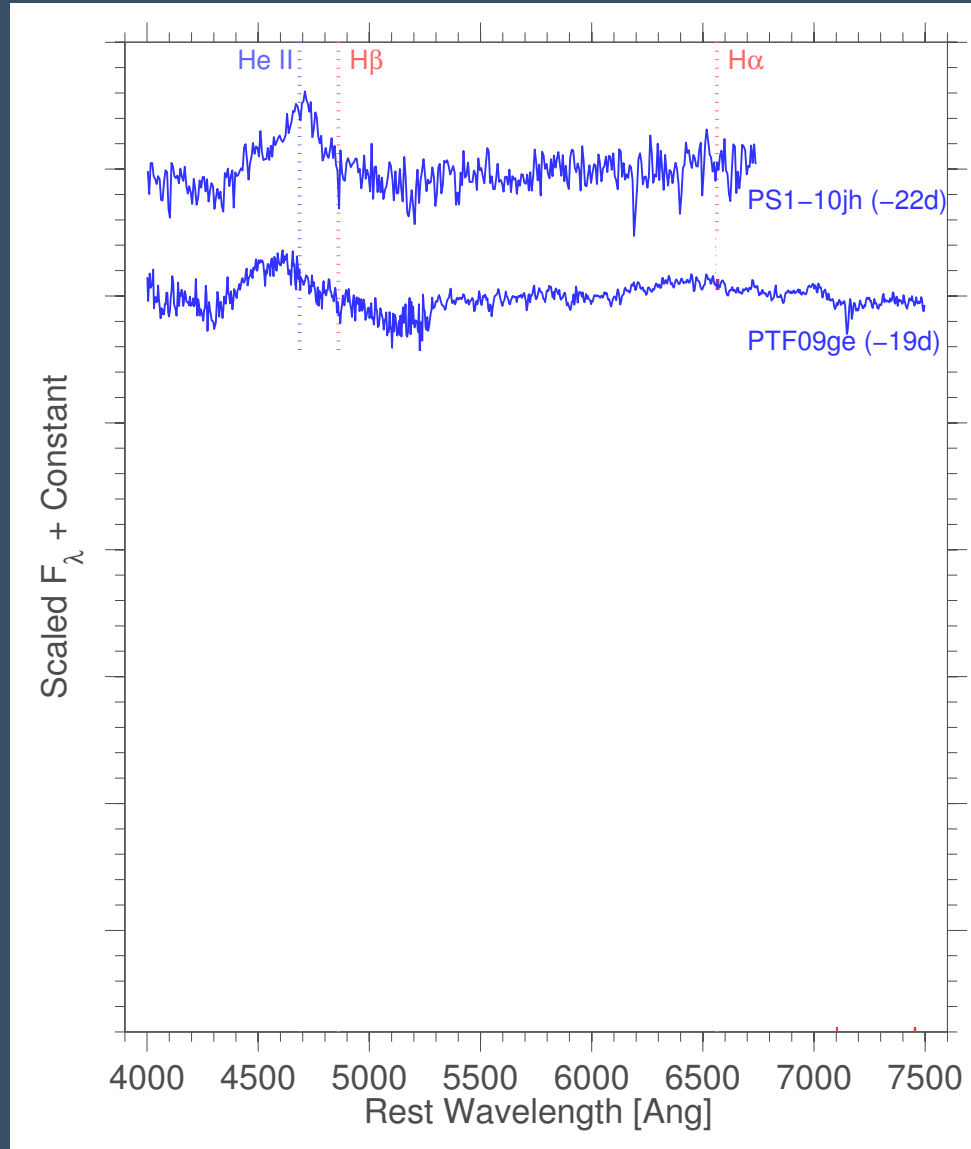
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Q3: Are they similar to other TDE candidates?

A3: Two of the PTF events show H emission

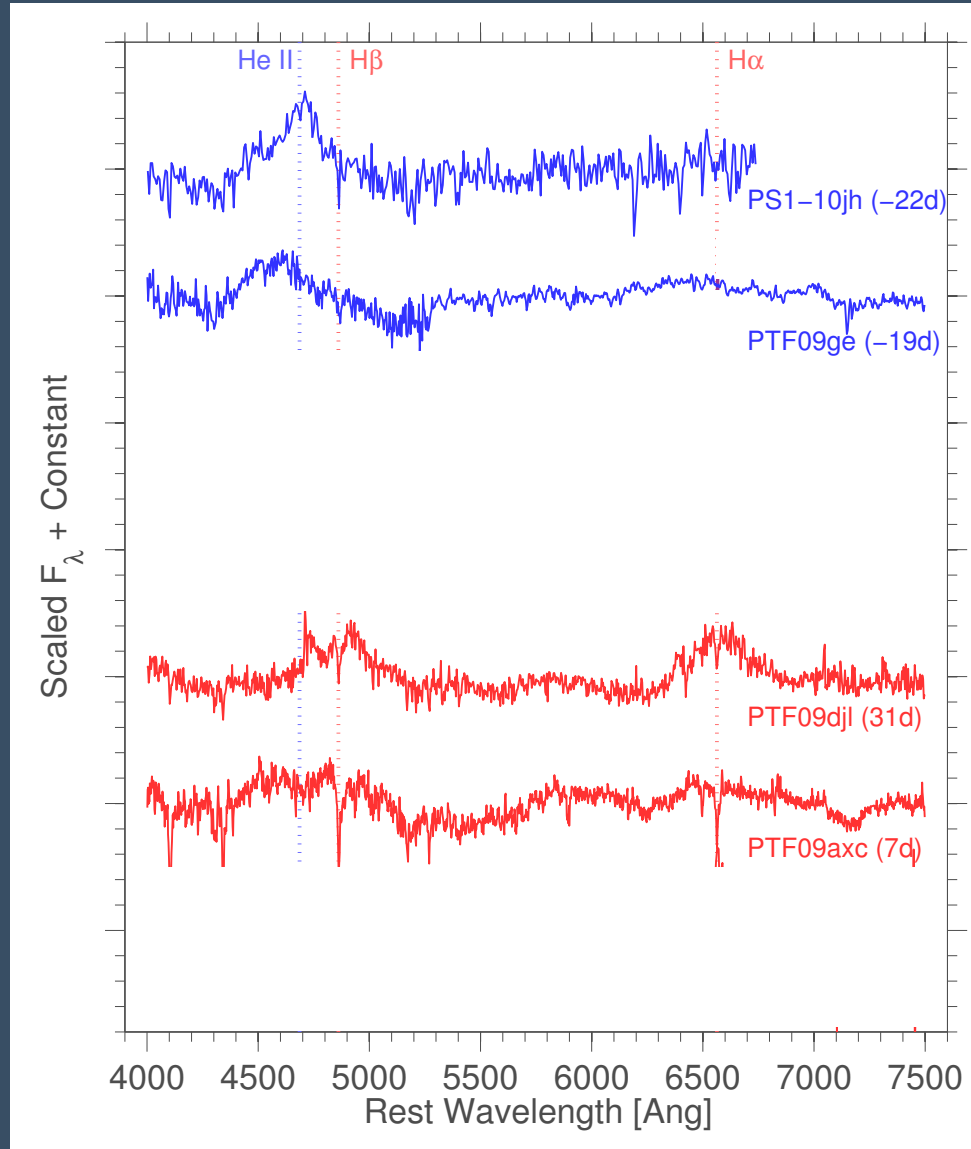


Gezari+ 12

Arcavi+ 14

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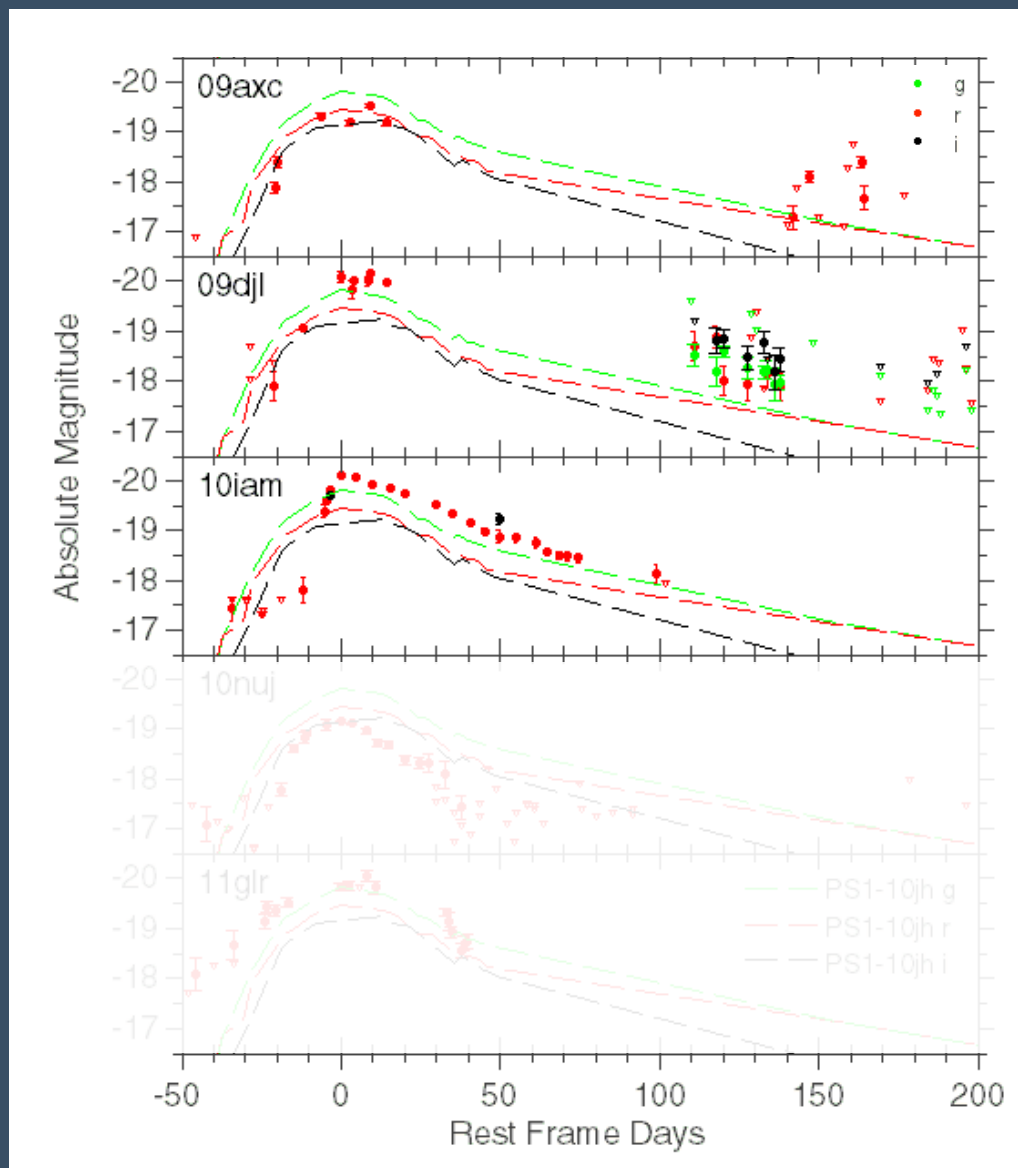
Arcavi+ 14

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Q3: Are they similar to other TDE candidates?

A3: Similar peak and decline rates in light curves

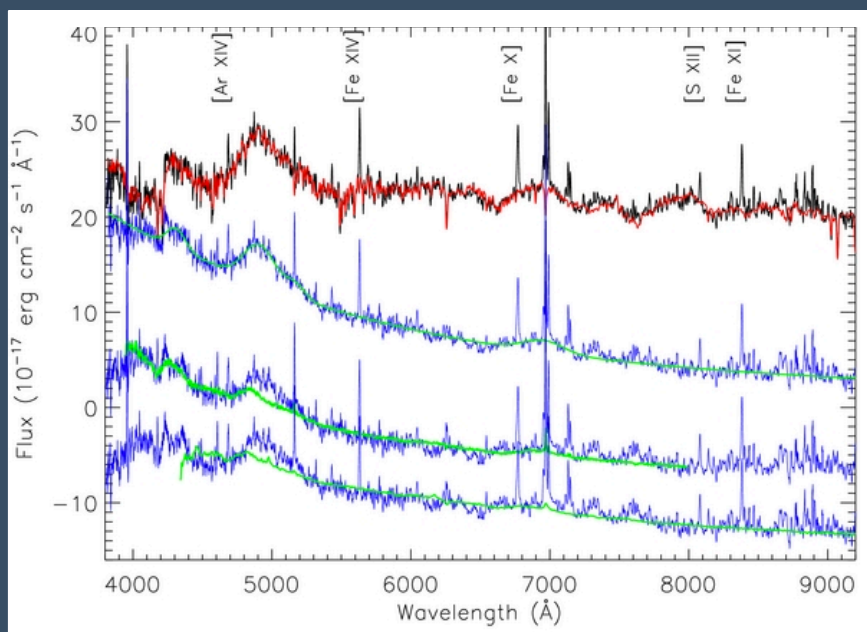


Coincident
with center

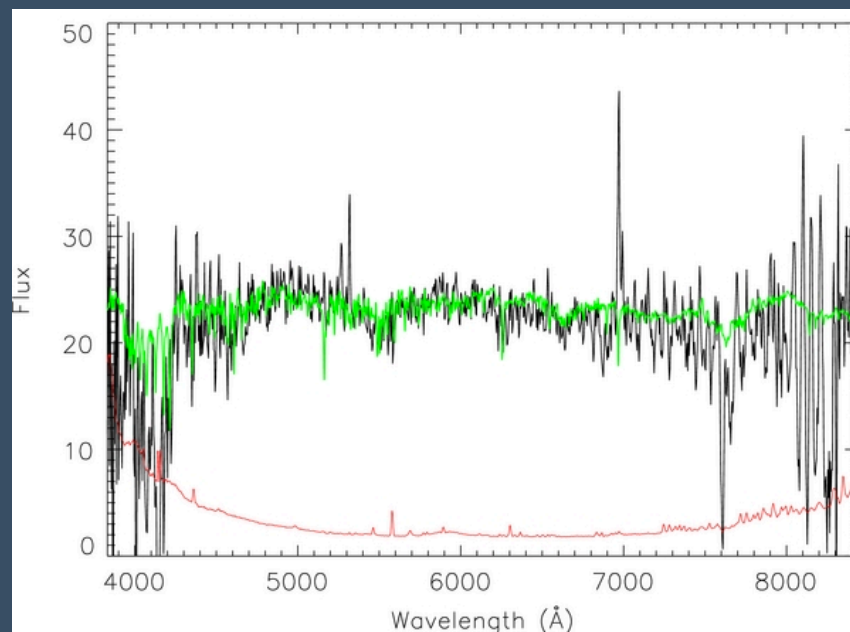
Off-center

Q3: Are they similar to other TDE candidates?

A3: The little-known TDE candidate SDSS J0748



SDSS spectrum from Feb 2004 with various fits

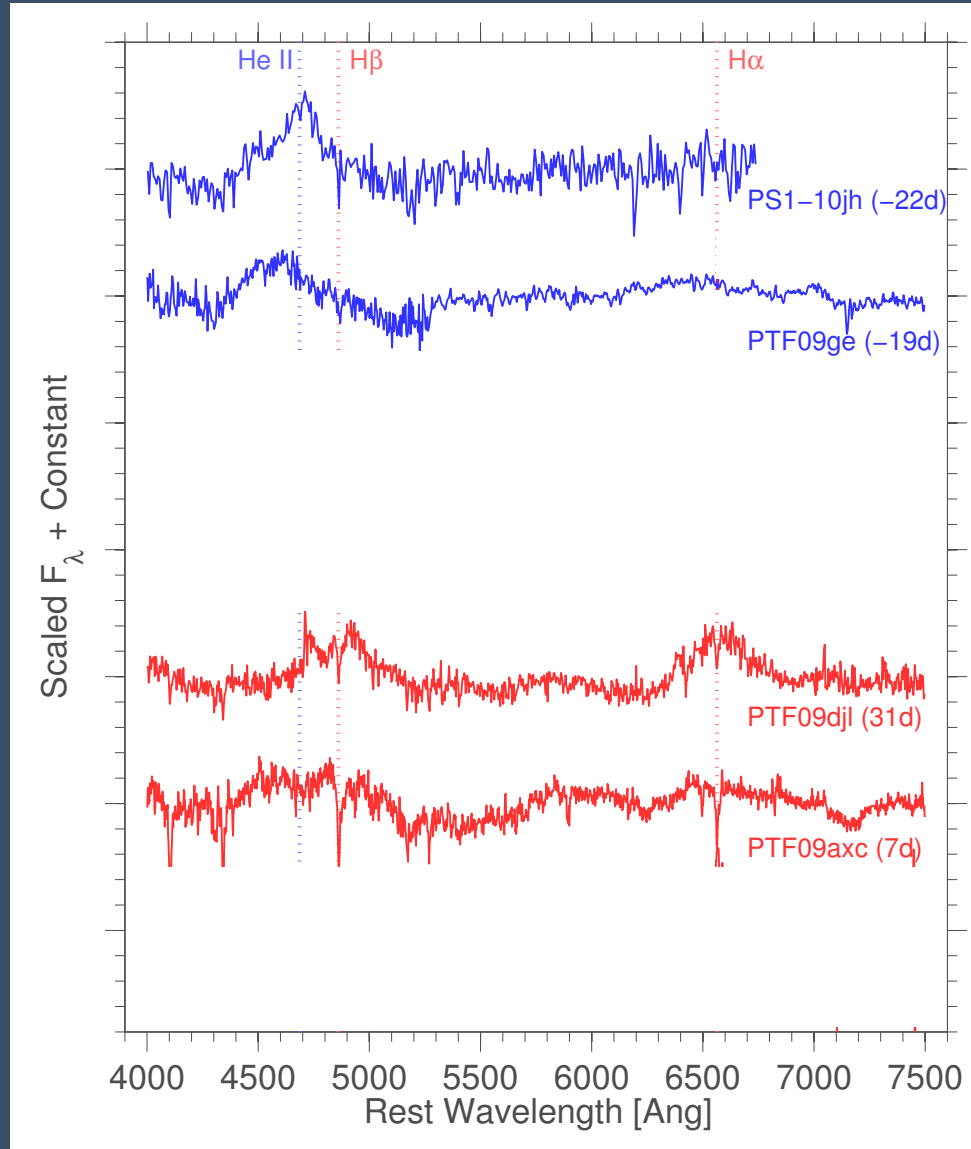


Xinglong spectrum Mar 2009 shows broad features were transient

Wang et al. (2011)

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Gezari+ 12

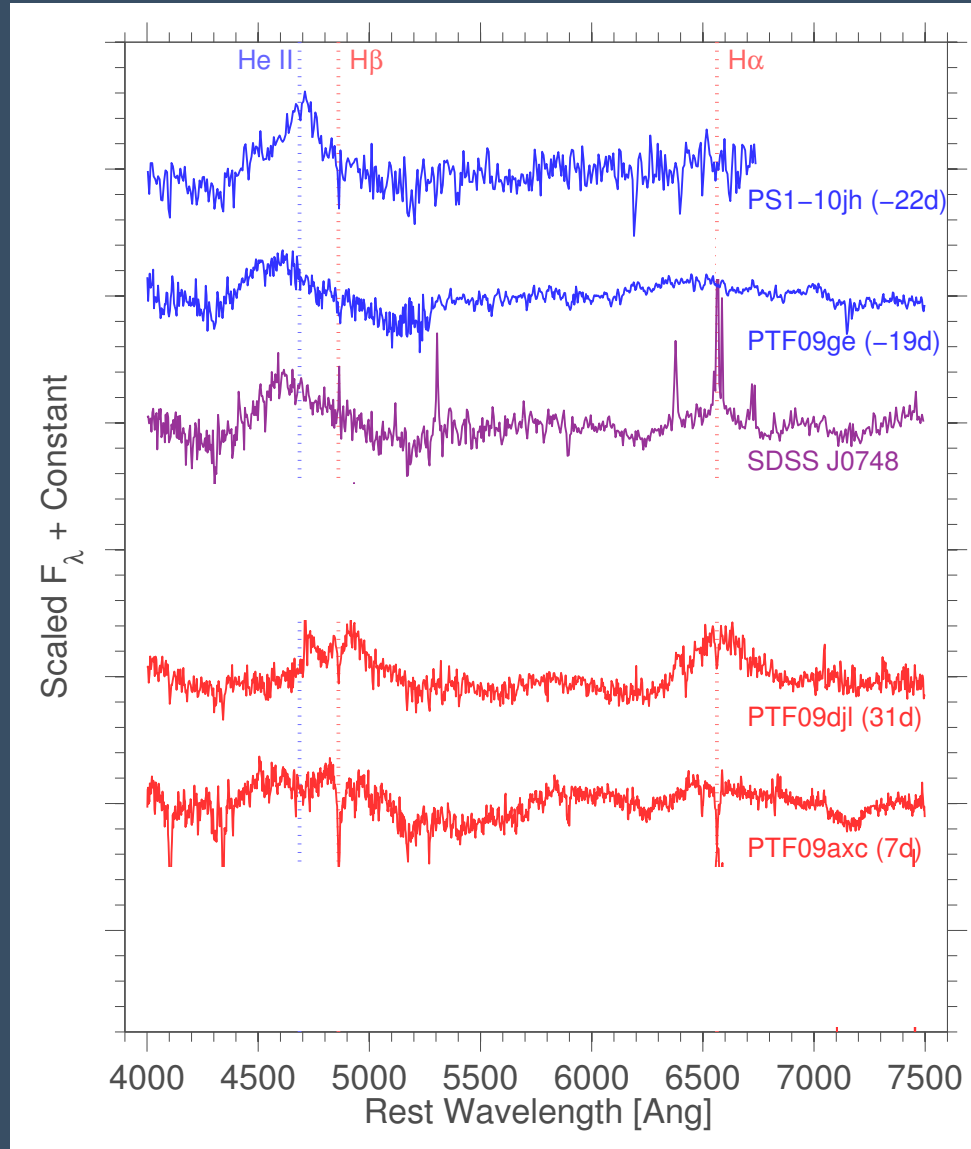
Arcavi+ 14

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Arcavi+ 14

Q3: Are they similar to other TDE candidates?

A3: SDSS J0748 shows strong He and some H



Gezari+ 12

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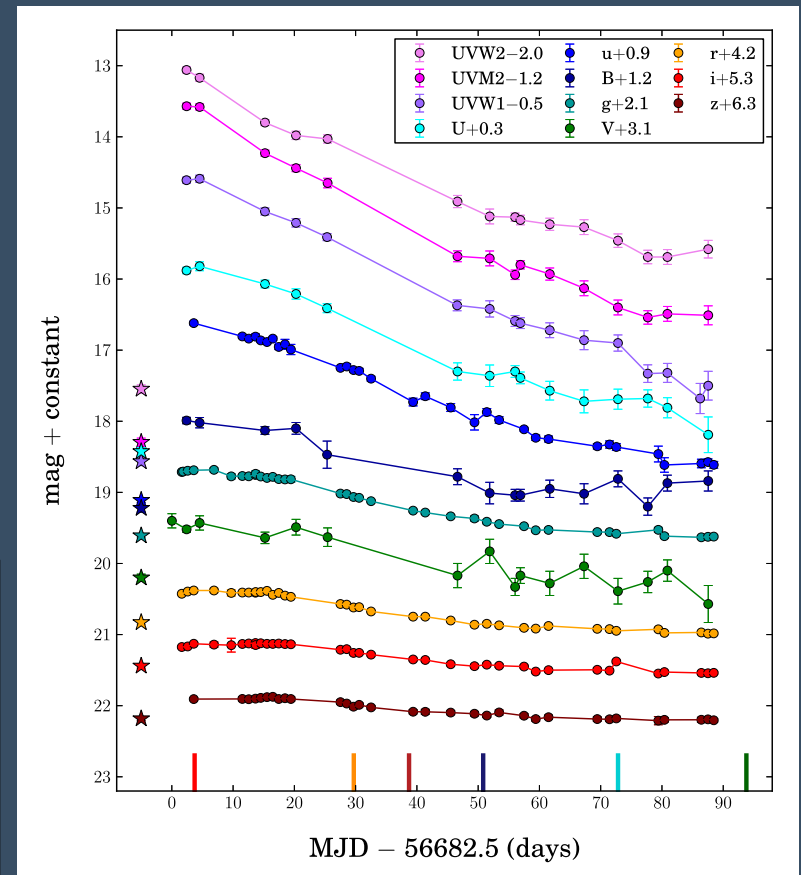
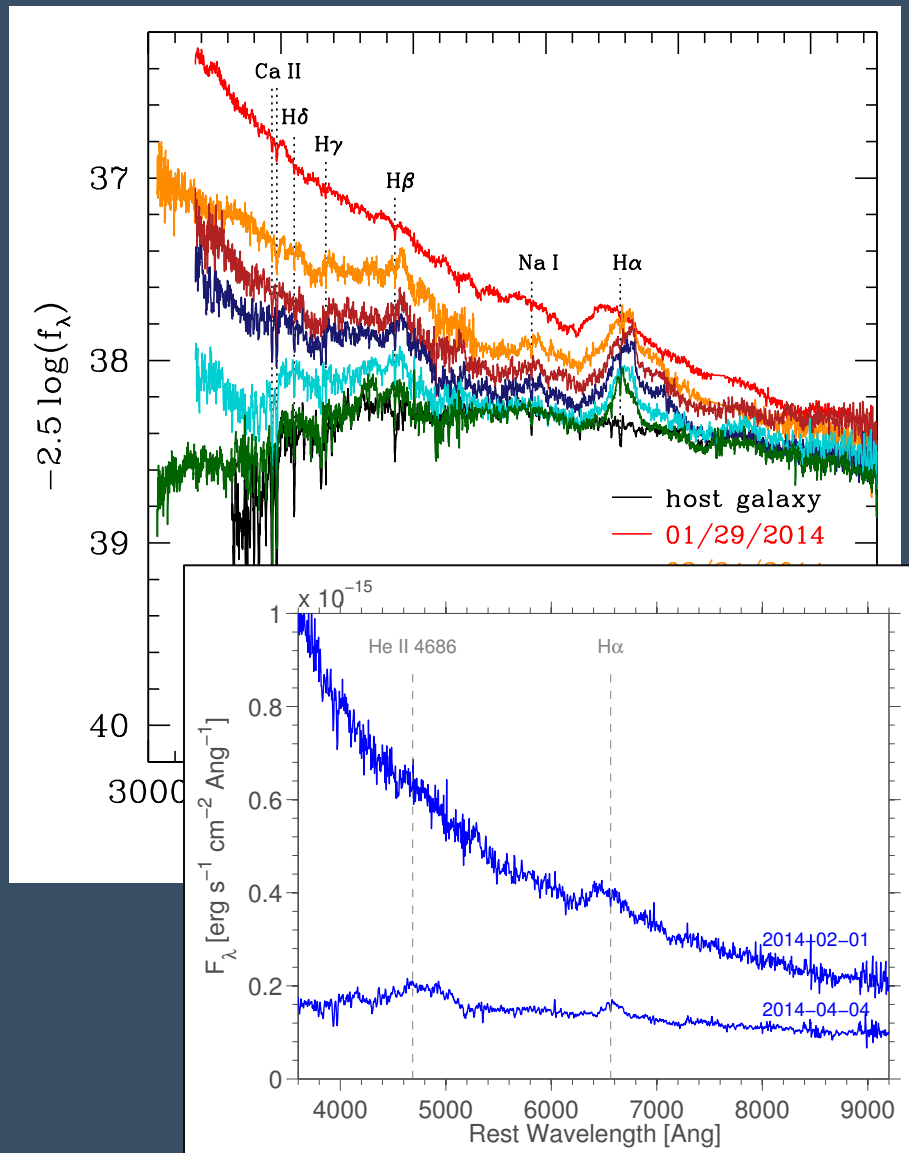
Wang+ 11

Arcavi+ 14

Arcavi+ 14

Q3: Are they similar to other TDE candidates?

A3: The most recent and near case, ASASSN-14ae

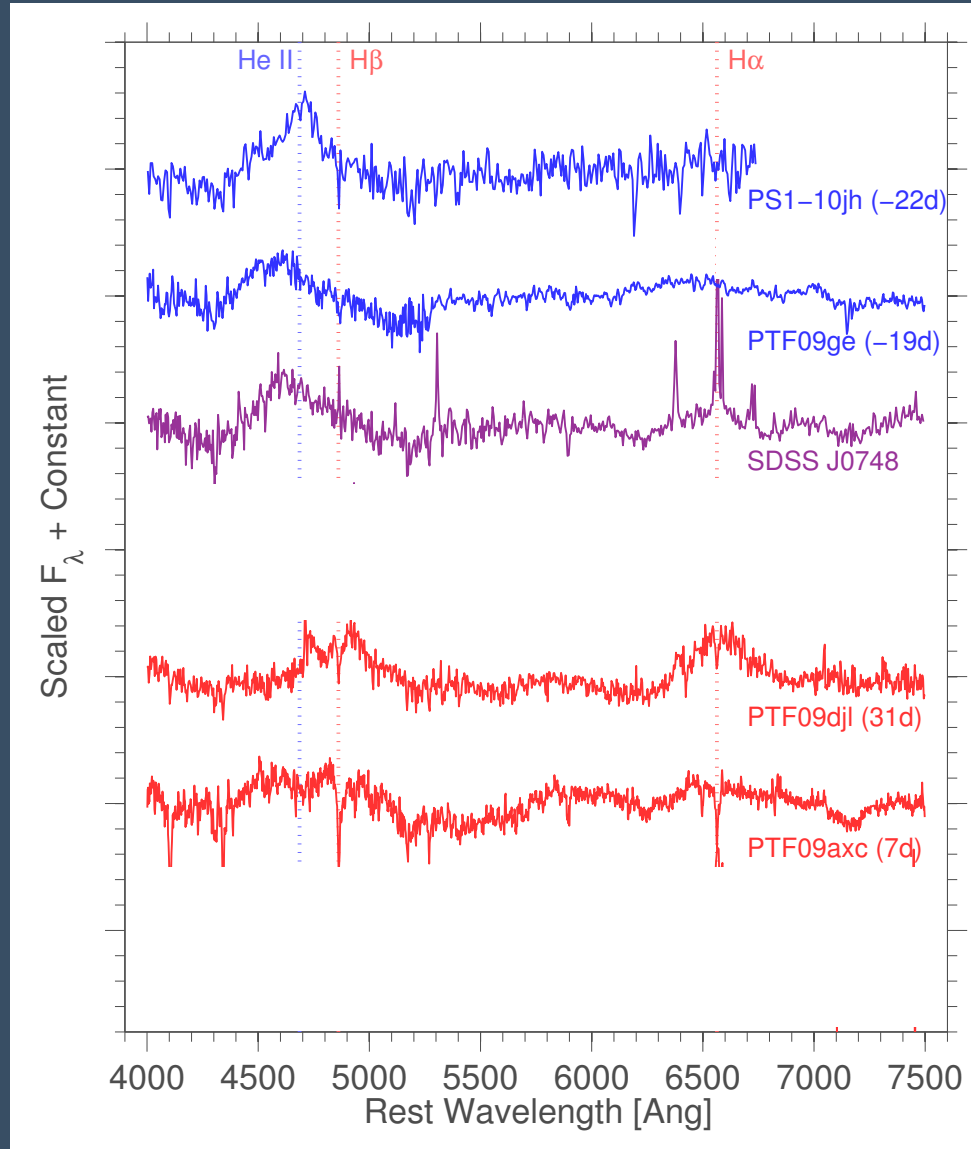


Holoien et al. (2014)

Arcavi et al. (2014)

Q3: Are they similar to other TDE candidates?

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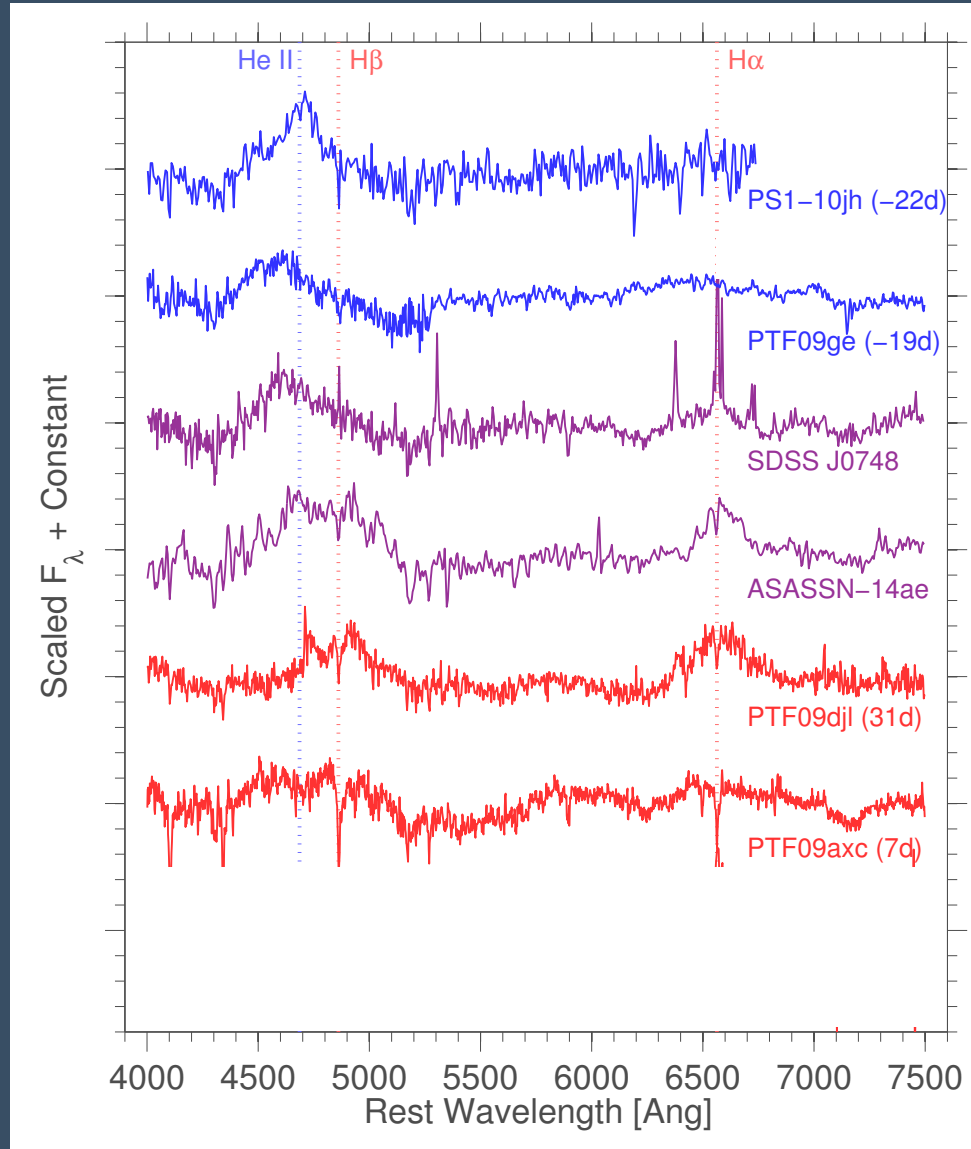
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A3: A continuum of He- to H-dominated spectra



Gezari+ 12

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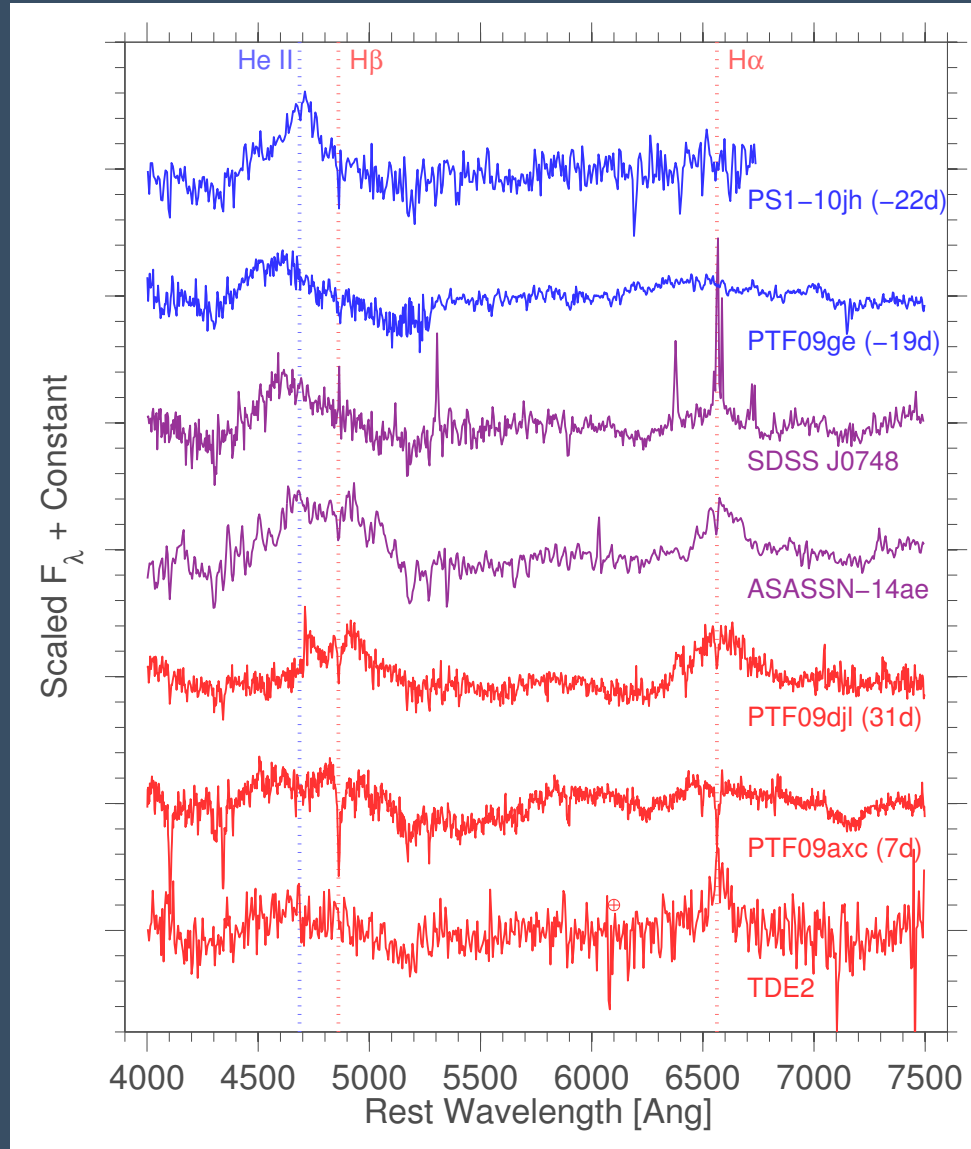
Holoien+ 14

Arcavi+ 14

Arcavi+ 14

Q3: Are they similar to other TDE candidates?

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Gezari+ 12

Arcavi+ 14

Wang+ 11

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Holoien+ 14

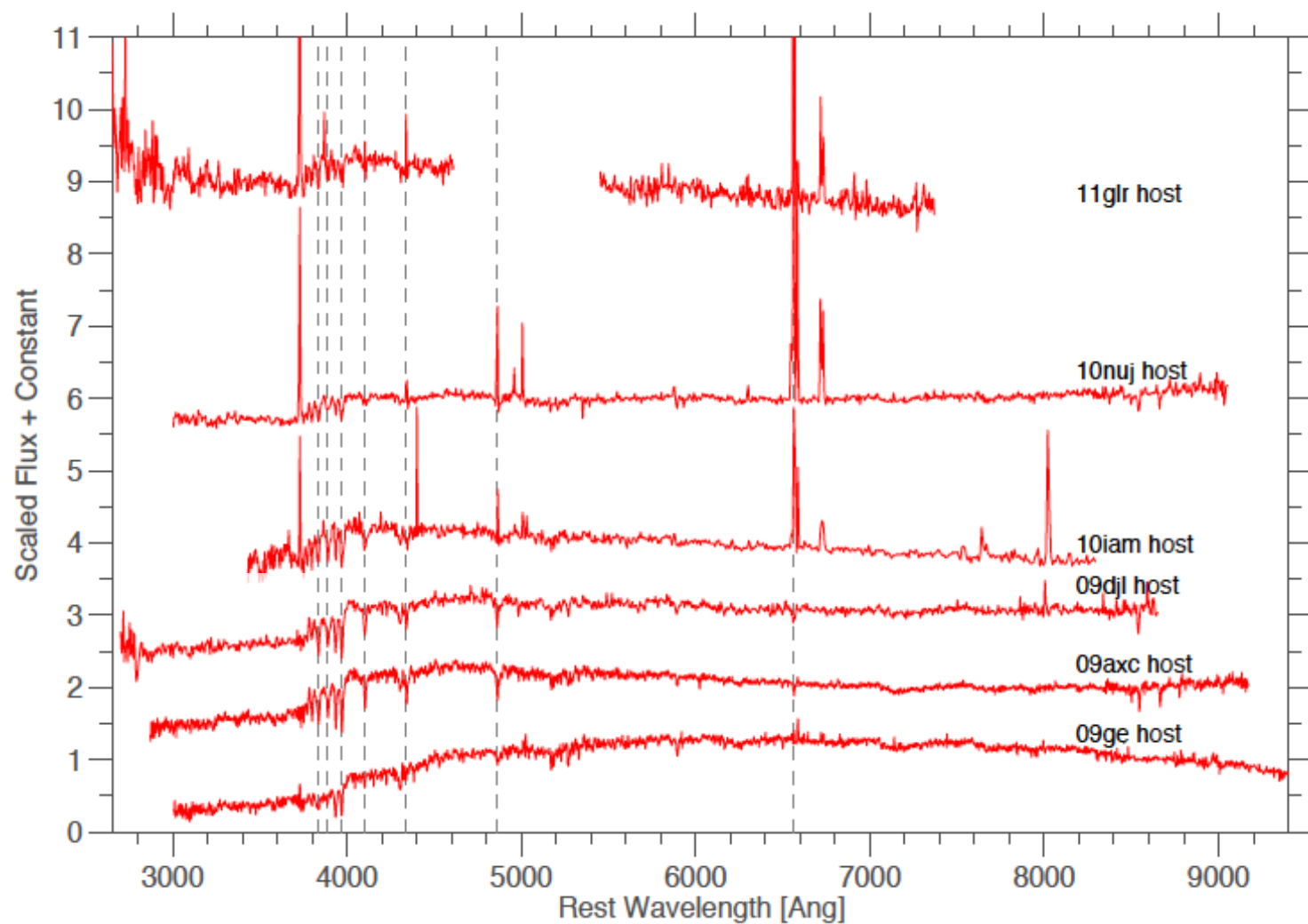
Arcavi+ 14

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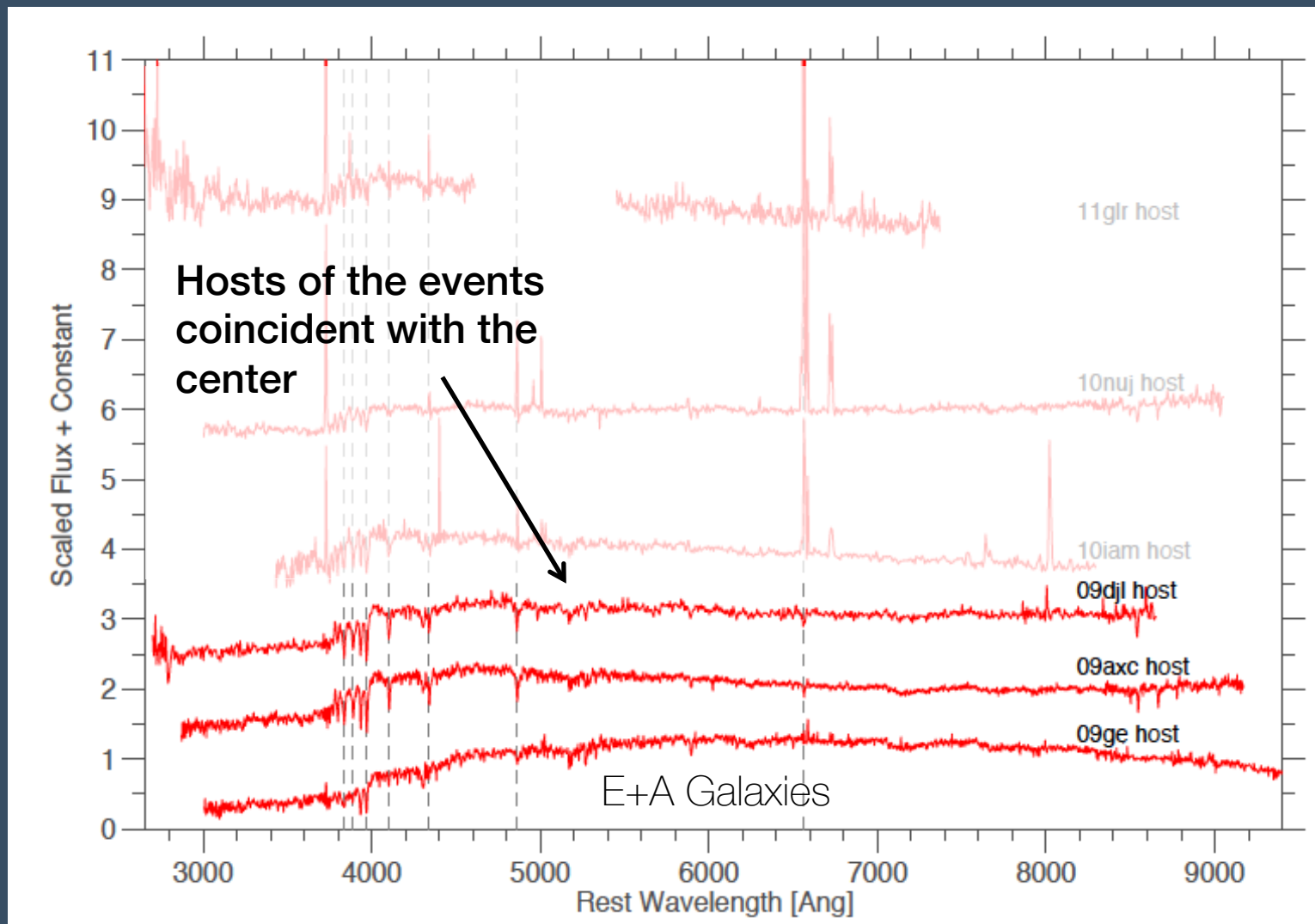
Q4: Can we learn anything new?

A4: Most in E+A (post-merger) hosts?



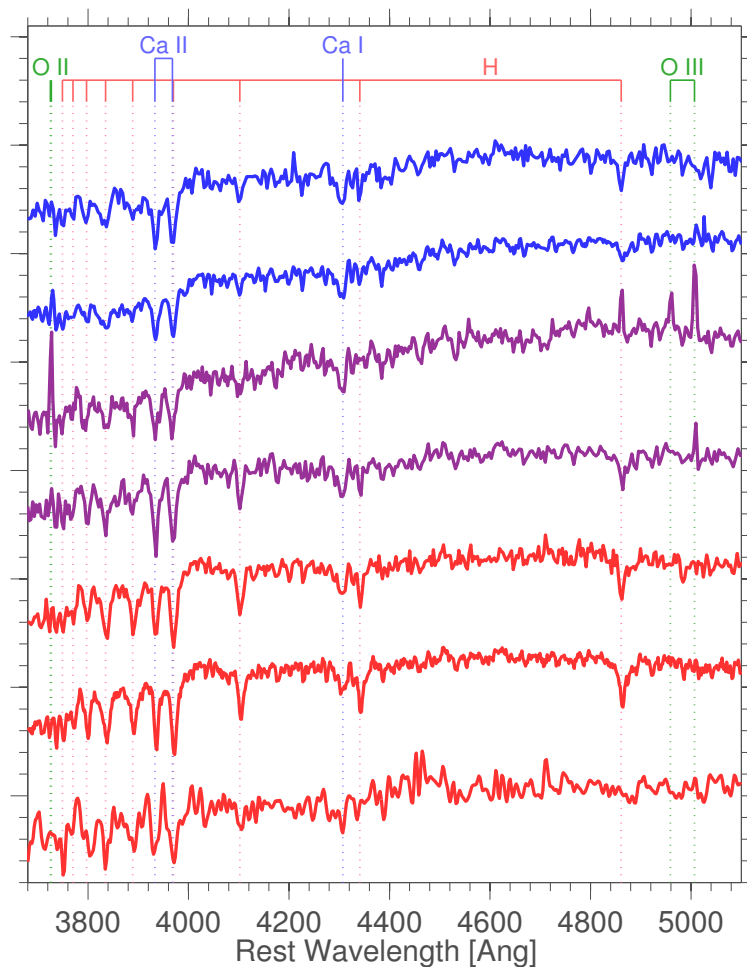
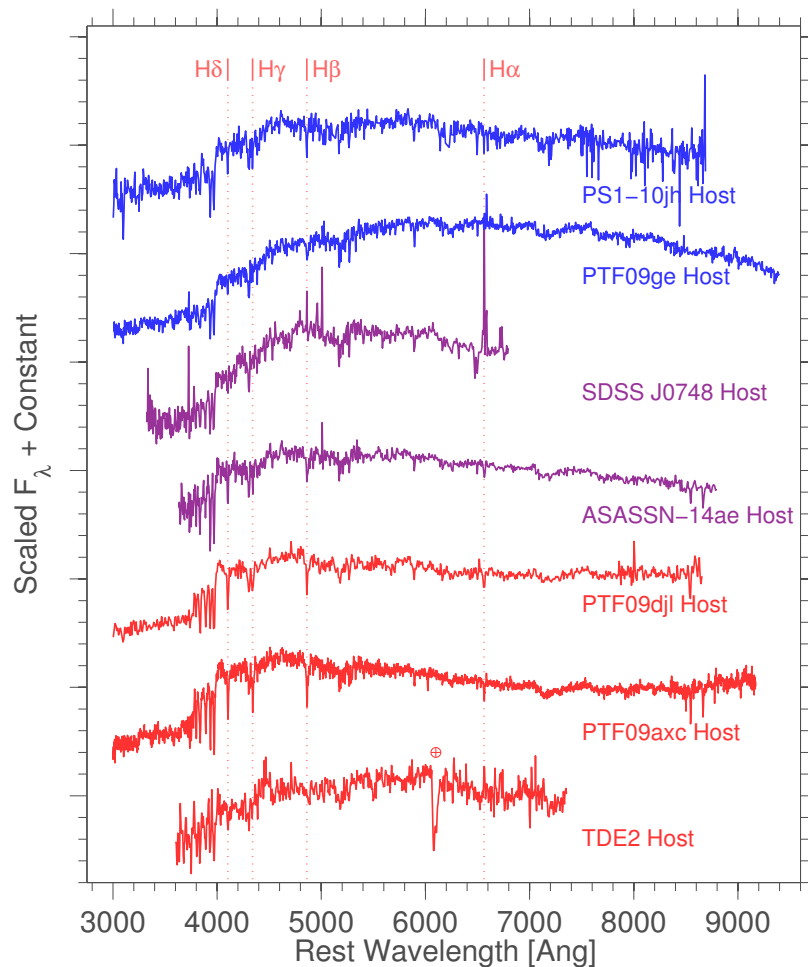
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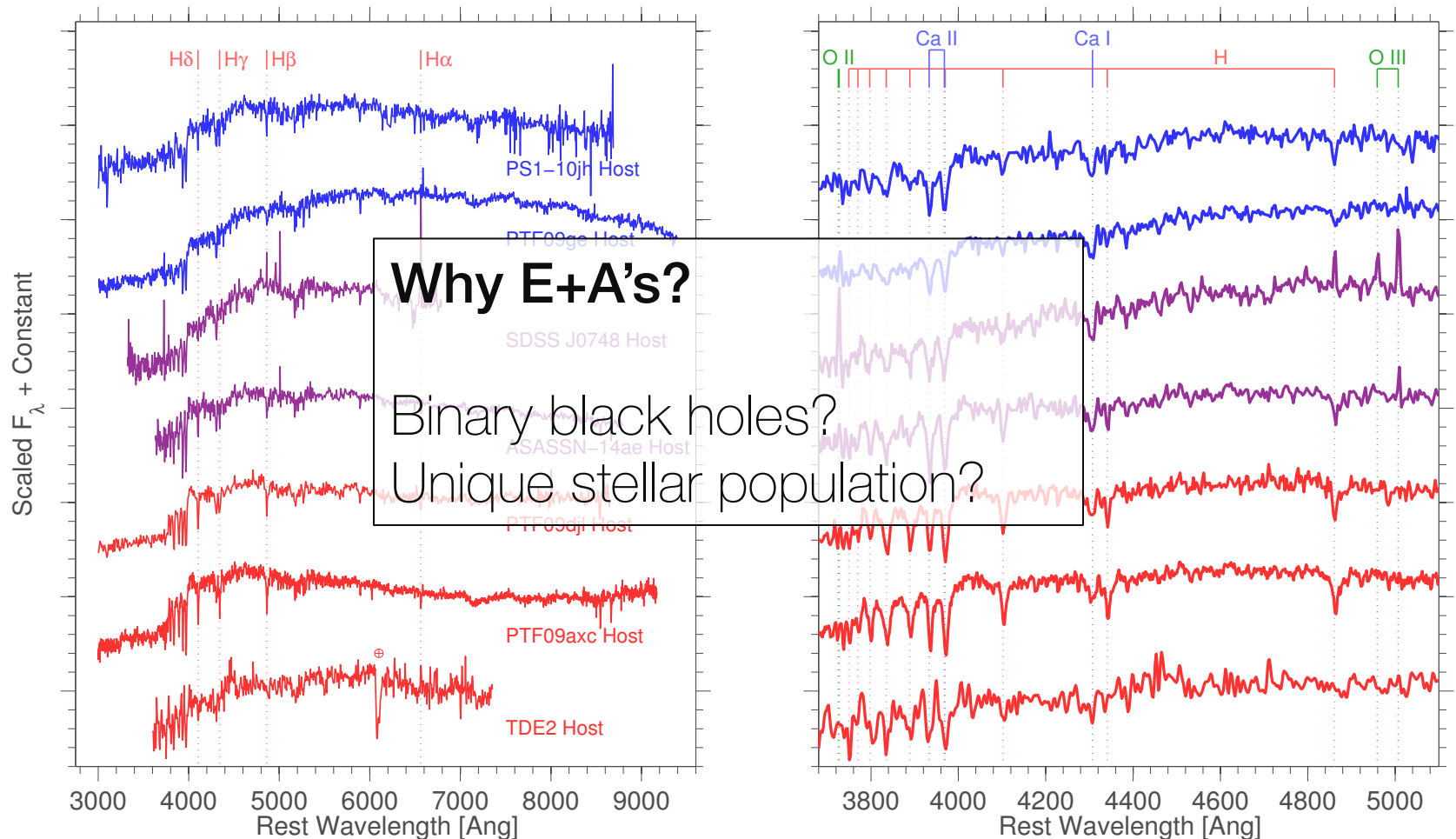
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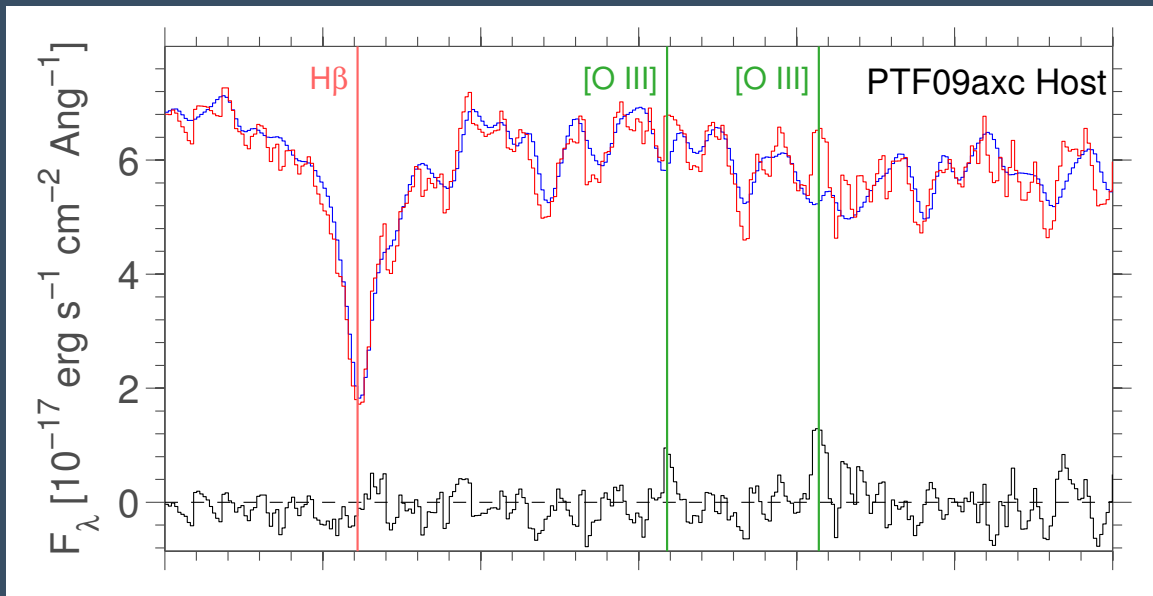
Q4: Can we learn anything new?

A4: X-ray detection at the position of PTF09axc

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

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

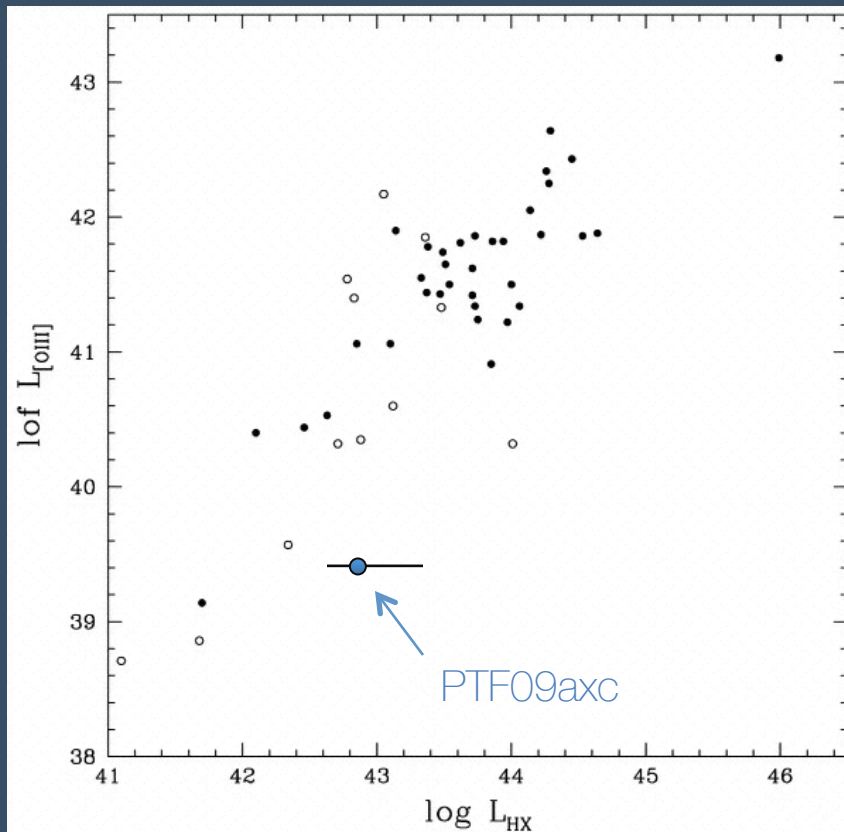
$$L_{[\text{O III}]} = 2.4 \pm 0.3 \times 10^{39} \text{ erg s}^{-1}$$



Q4: Can we learn anything new?

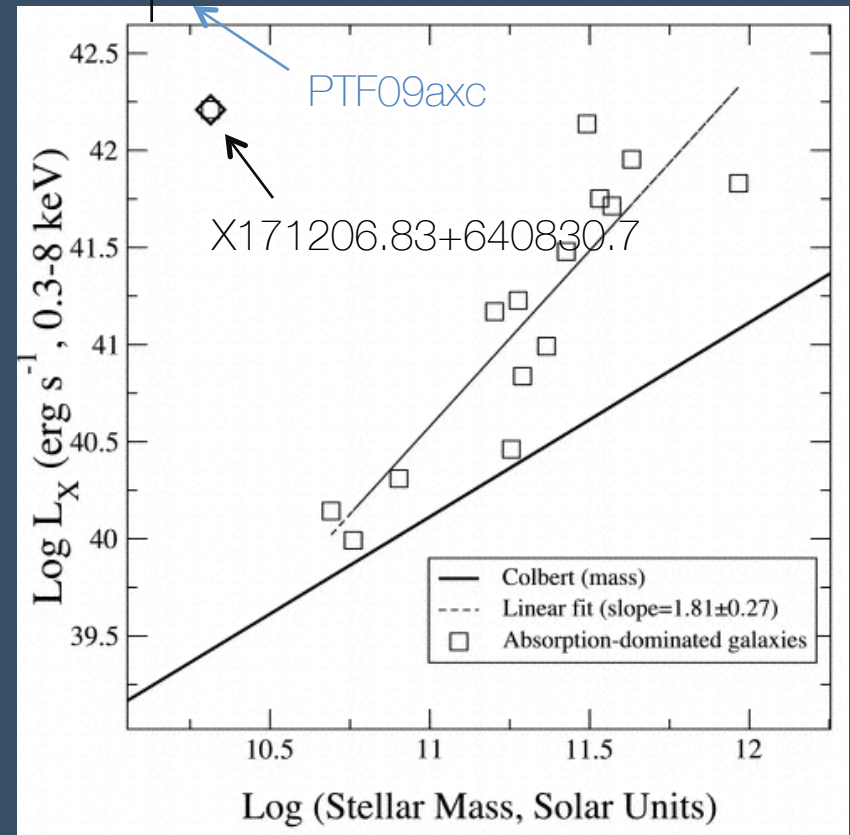
A4: X-ray detection at the position of PTF09axc

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

Finding more in iPTF

- Candidates in the center of their hosts (“nuclear”)
- Coherent light curve
- Not in AGN catalogues

Summary

Observations:

- Three new optical TDE candidates from PTF
- One is He-rich like PS1-10jh, two are H-rich counterparts
- New TDE candidate from ASASSN shows both He and H

Key Results:

- Together with SDSS J0748, find a continuous spectral class
- Most/all are in rare E+A hosts

New Questions:

- What is the physical explanation for the spectral diversity?
- Why the preference for E+A hosts?

A continuum of TDE types in E+A galaxies

E+A

~E+A

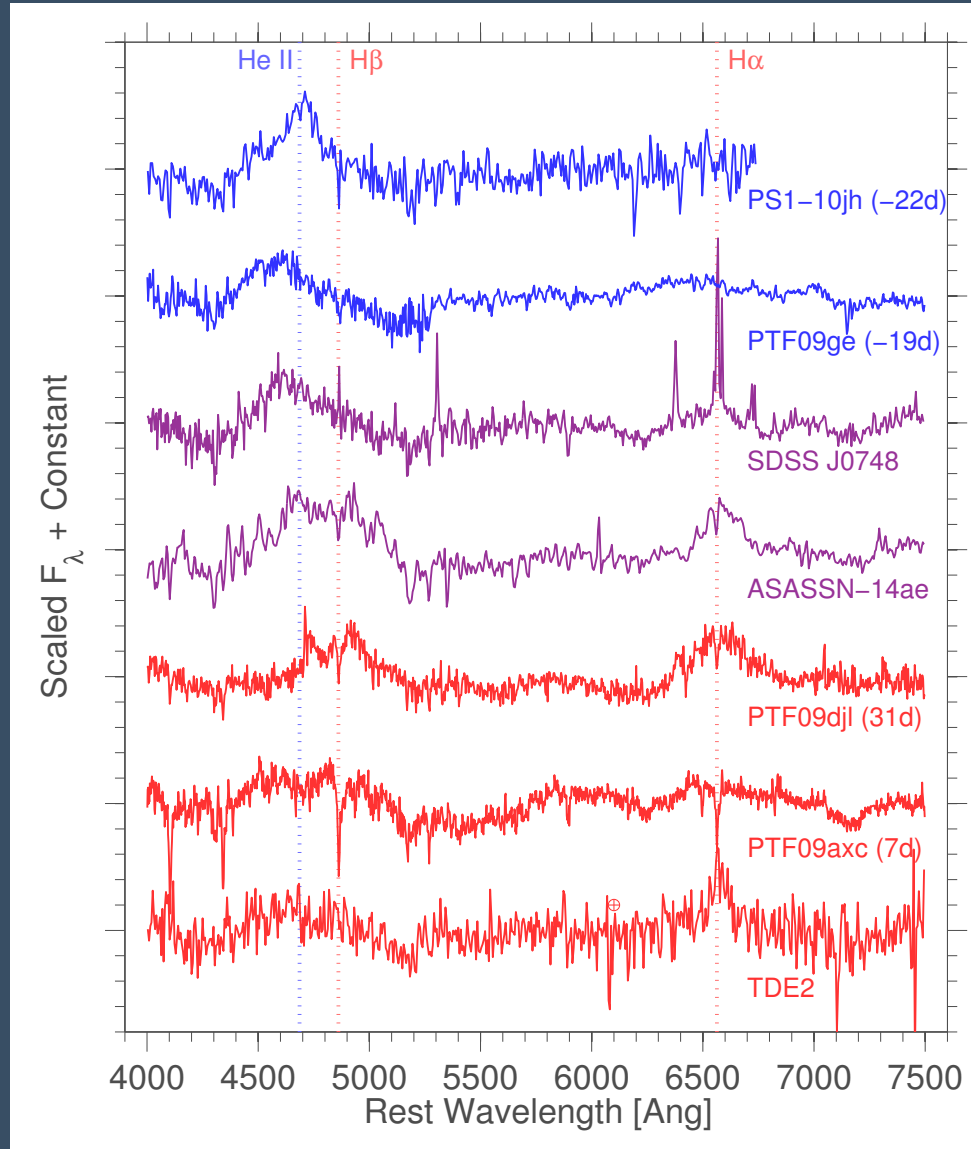
Complicated

E+A

E+A

E+A

?



Gezari+ 12

Arcavi+ 14

Wang+ 11

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Holoien+ 14

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van Velzen+ 11

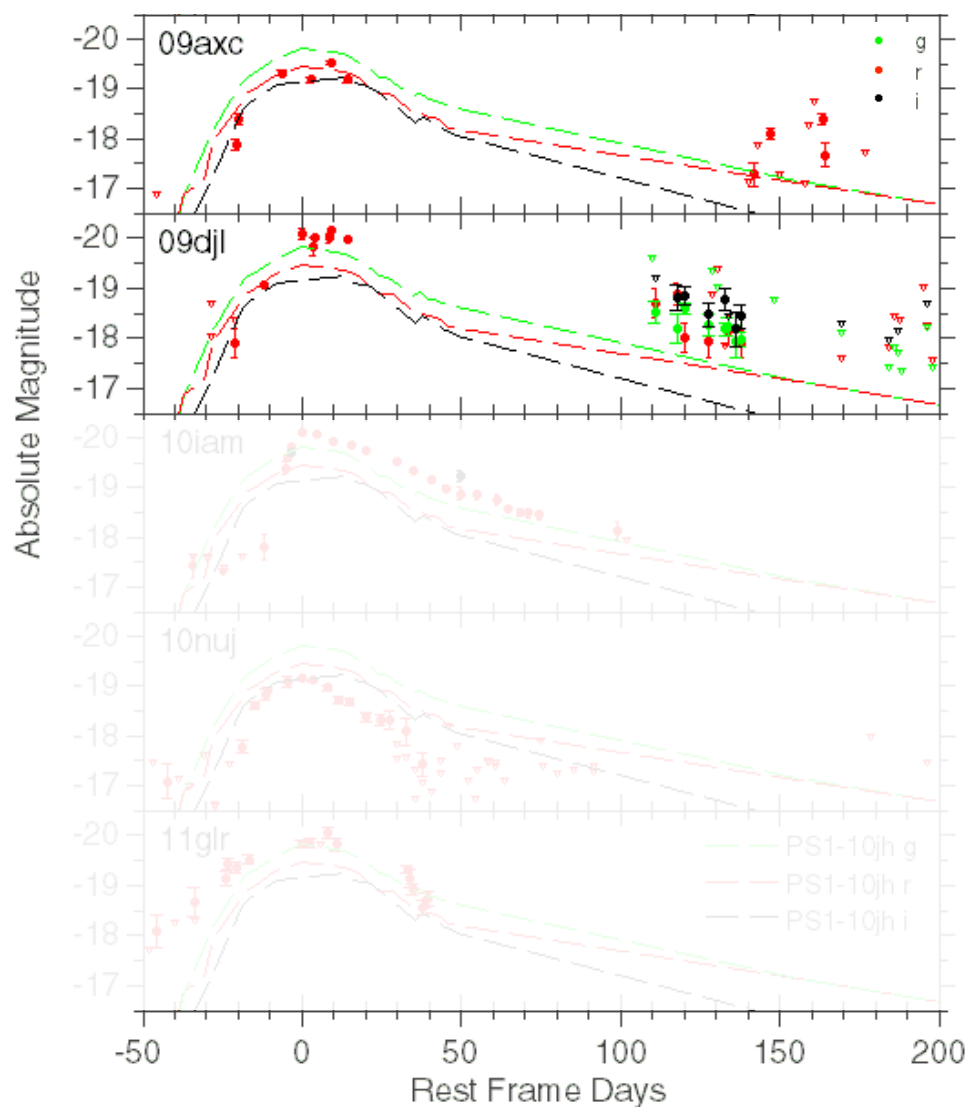
Q4: Can we learn anything new?

A4: The emerging classes and their properties

Name	Observed Energies	Spectral Features	Host Galaxy	Notes
PS1-10jh	Optical / NUV	He II	E+A	Gezari+ 12
PTF09ge	Optical	He II	~E+A	
SDSS 0748	No photometry	He II + some H	Complicated	Wang+ 11 Yang+ 13
ASASSN-14ae	Optical / NUV	He II + H	E+A	Holoien+ 14
PTF09axc	Optical	some He II + H	E+A	Weak X-rays, [O III]
PTF09djl	Optical	some He II+ H	E+A	Double peaked Ha
TDE2	No photometry	weak H	E+A?	van Velzen+ 11

Q3: Are they similar to other TDE candidates?

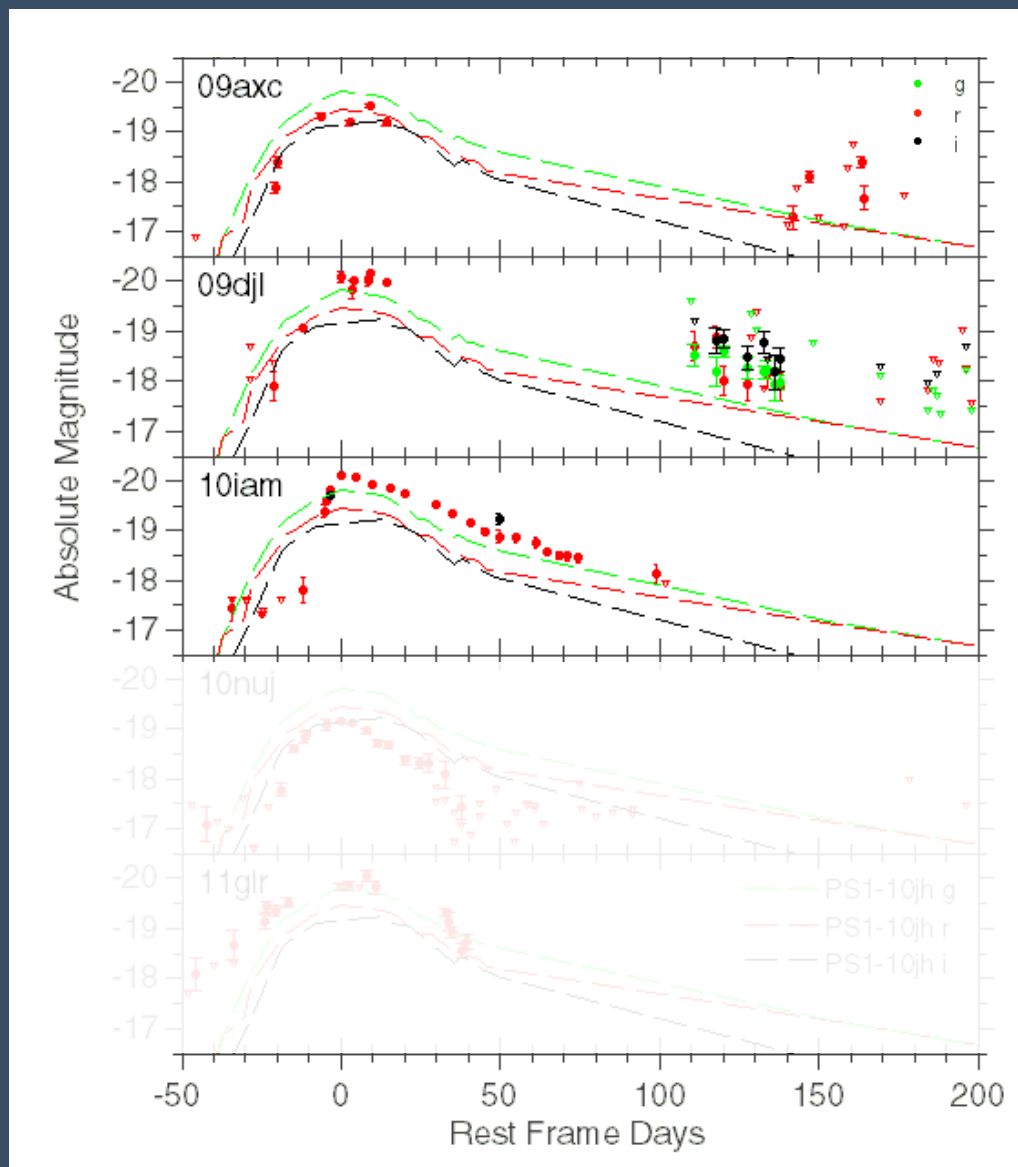
A3: Similar peak and decline rates in light curves



Coincident
with center

Q3: Are they similar to other TDE candidates?

A3: Similar peak and decline rates in light curves

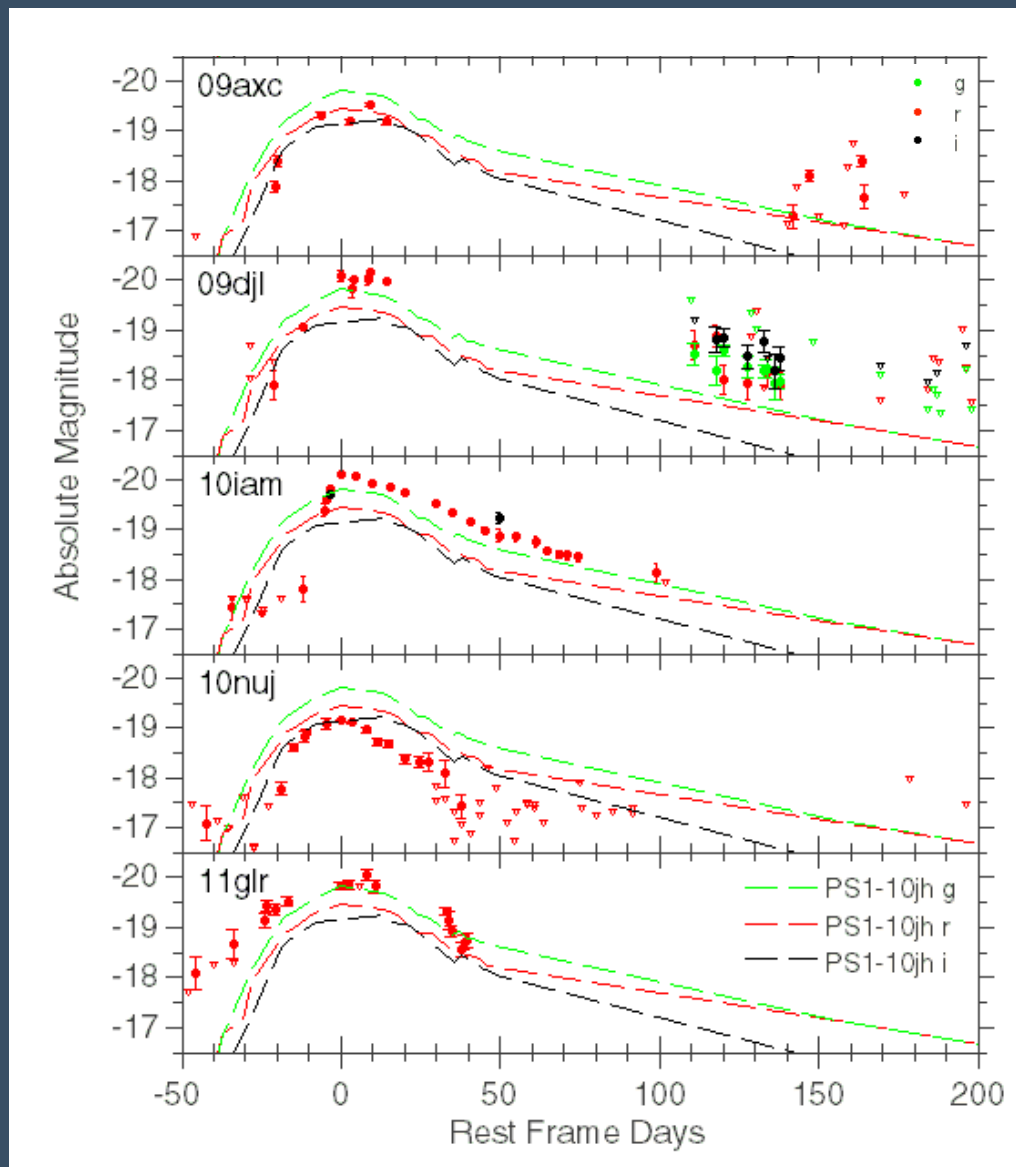


Coincident
with center

Off-center

Q3: Are they similar to other TDE candidates?

A3: Similar peak and decline rates in light curves

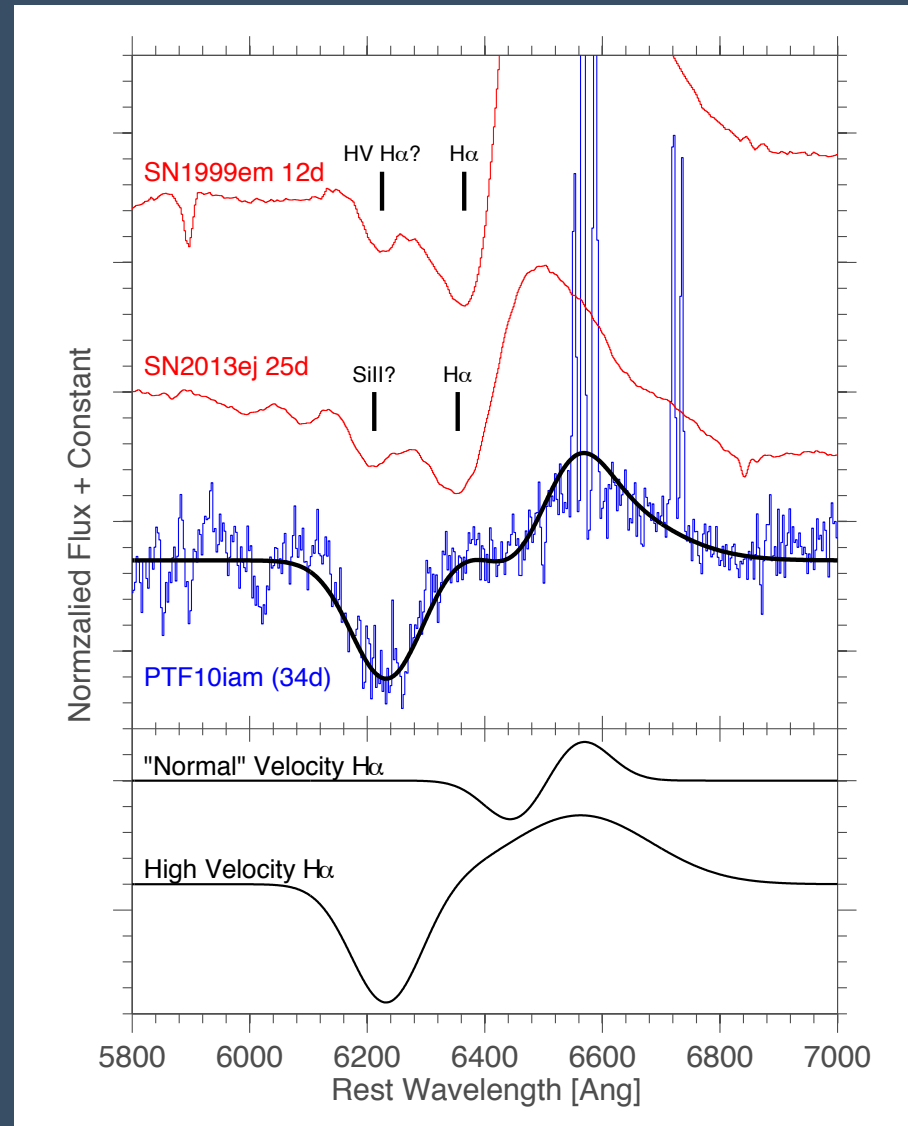


Coincident
with center

Off-center

Can't tell
precise
position

The off-center event shows a different spectrum



Q4: Can we learn anything new?

A4: Seeing bound or outflowing material?

Keplerian velocity for **bound** material at the tidal radius:

$$v_T \approx 43700 \left(\frac{M_{BH}}{10^6 M_\odot} \right)^{1/3} \left(\frac{\rho_*}{\rho_\odot} \right)^{1/6} \text{ km s}^{-1}$$

$$\begin{array}{c} \downarrow \\ v_T \propto (L_{\text{host}})^{\alpha/12} \rho_*^{1/6} \end{array} \quad \begin{array}{l} M_{BH} \propto \sigma_{\text{Galaxy}}^\alpha \\ L_{\text{Galaxy}} \propto \sigma_{\text{Galaxy}}^4 \end{array}$$

Velocity of most energetic **outflowing** material:

$$\approx 7500 \left(\frac{R_T}{R_P} \right) \left(\frac{M_{BH}}{10^6 M_\odot} \right)^{\frac{1}{6}} \left(\frac{M_*}{M_\odot} \right)^{\frac{1}{3}} \left(\frac{R_*}{R_\odot} \right)^{-\frac{1}{2}} \text{ km s}^{-1}$$

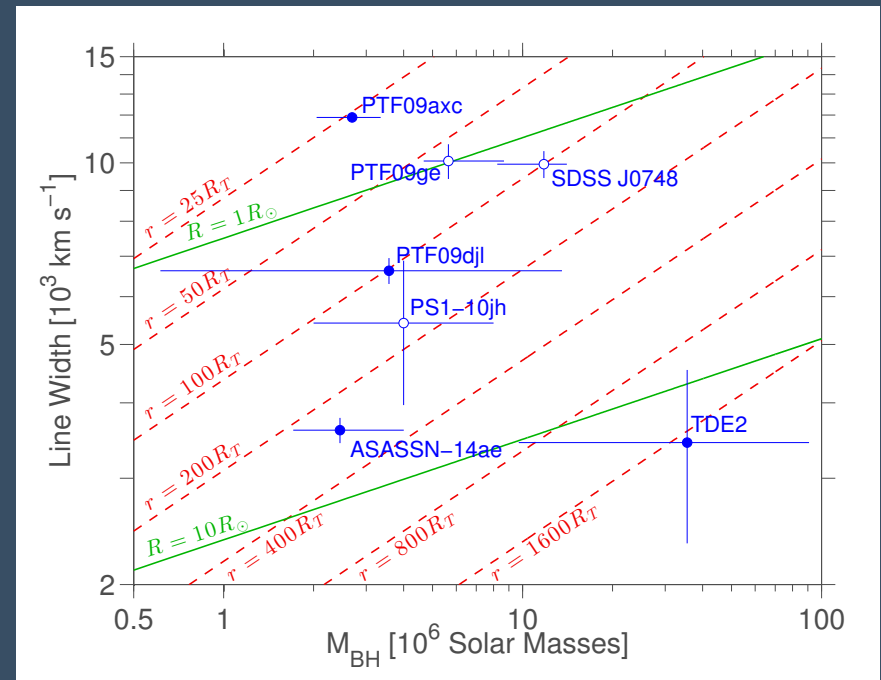
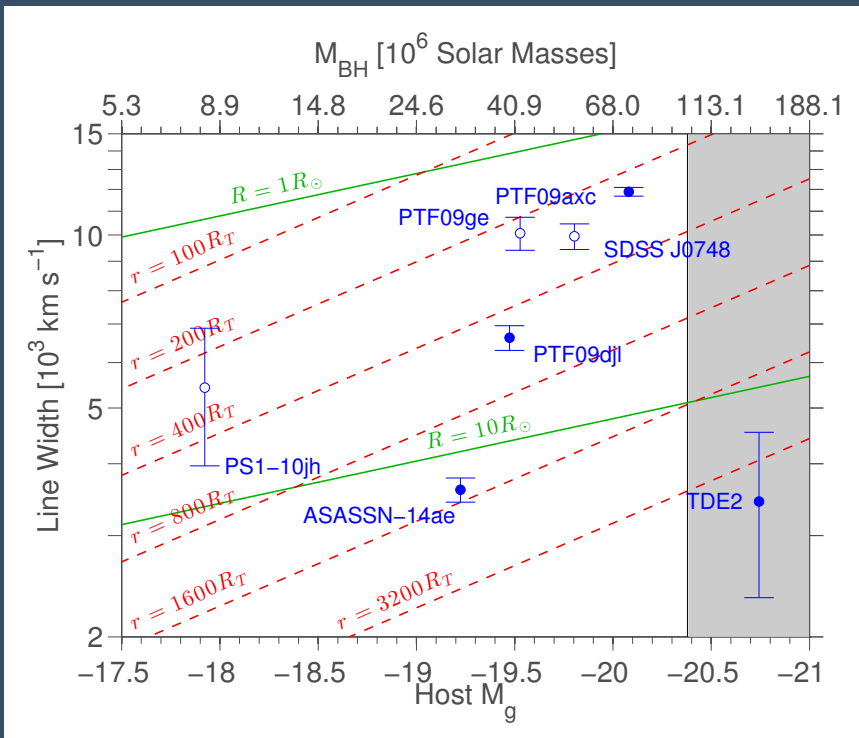
Strubbe & Quataert (2009)

Q4: Can we learn anything new?

A4: Can't constrain emission source from velocities

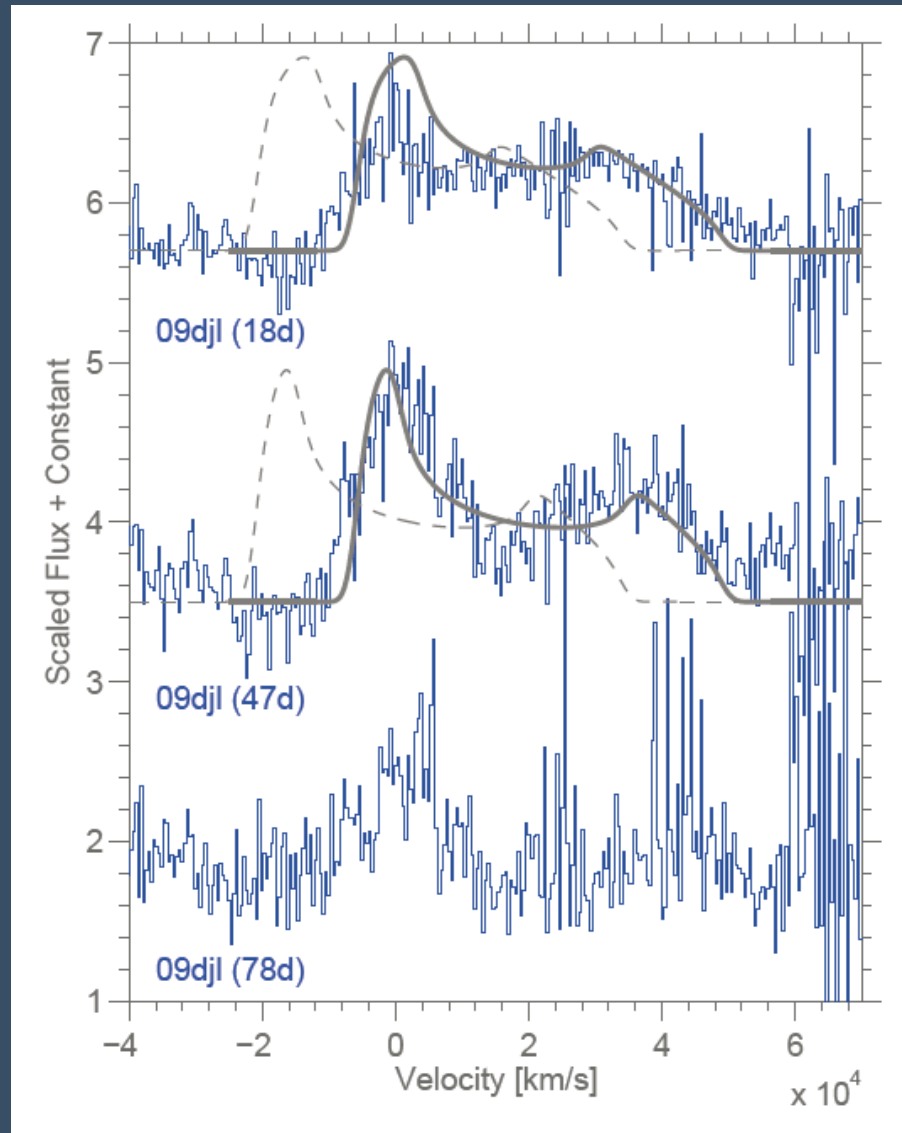
$$v_T \approx 43700 \left(\frac{M_{BH}}{10^6 M_\odot} \right)^{1/3} \left(\frac{\rho_*}{\rho_\odot} \right)^{1/6} \text{ km s}^{-1} \quad (\text{bound})$$

$$v_T \approx 7500 \left(\frac{R_T}{R_P} \right) \left(\frac{M_{BH}}{10^6 M_\odot} \right)^{1/6} \left(\frac{M_*}{M_\odot} \right)^{1/3} \left(\frac{R_*}{R_\odot} \right)^{-1/2} \text{ km s}^{-1} \quad (\text{outflowing})$$



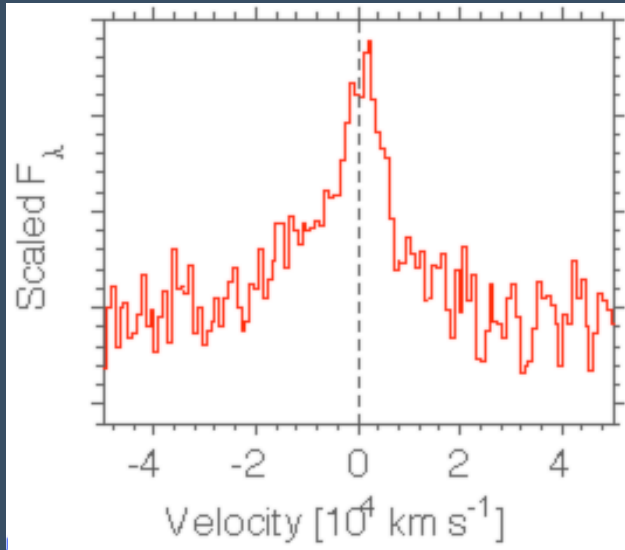
Q4: Can we learn anything new?

A4: Double Peaked H α profile for PTF09djl

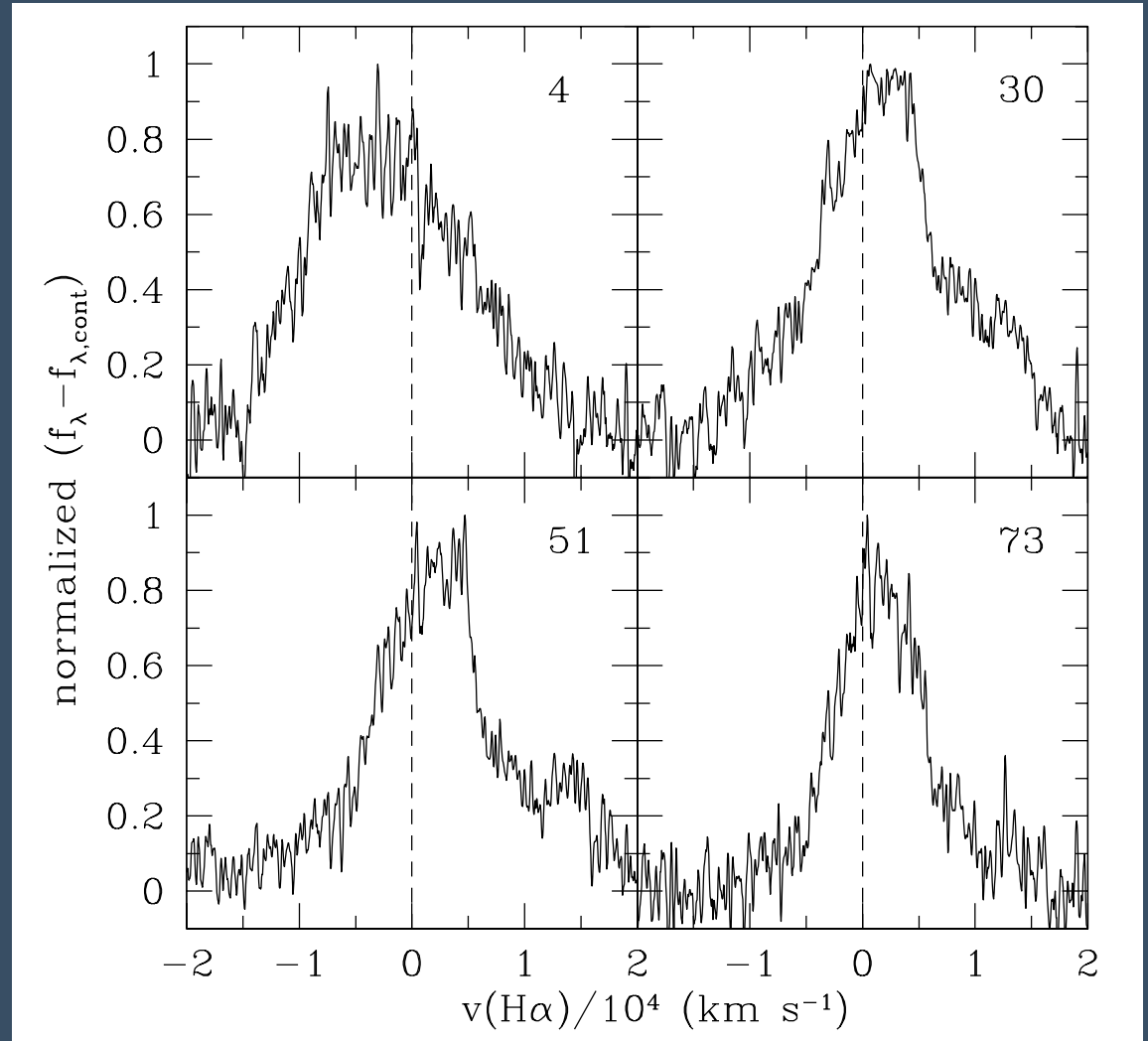


Q4: Can we learn anything new?

A4: Double component profiles?



He II from PS1-10jh
(Gezari et al. 2012)



Halpha from ASASSN-14ae (Holoien et al. 2014)

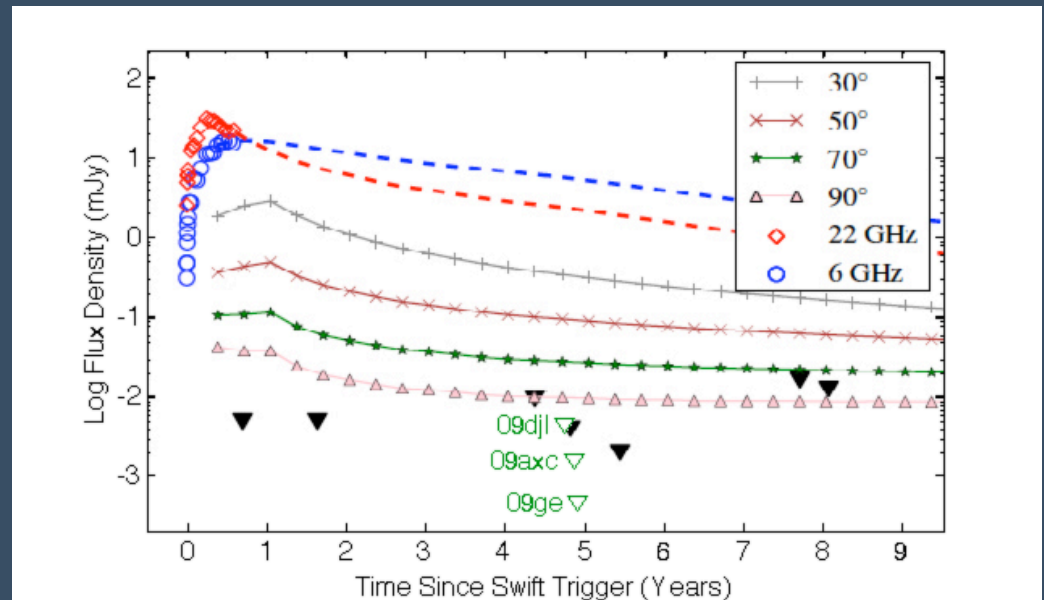
Q4: Can we learn anything new?

A4: Searching for radio emission

Only two TDE candidates ever detected in radio – both from Swift.

Seven more candidates not detected.

Not likely that all TDEs launch jets



van Velzen et al. (2013)