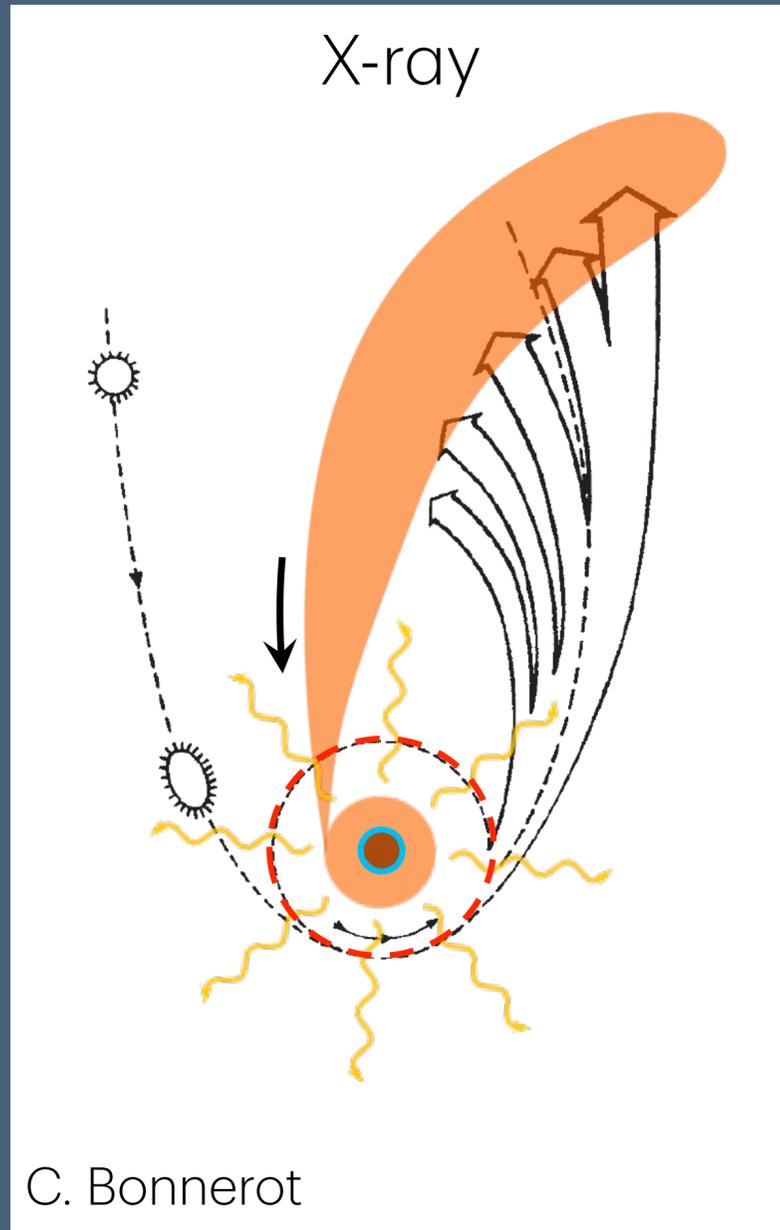


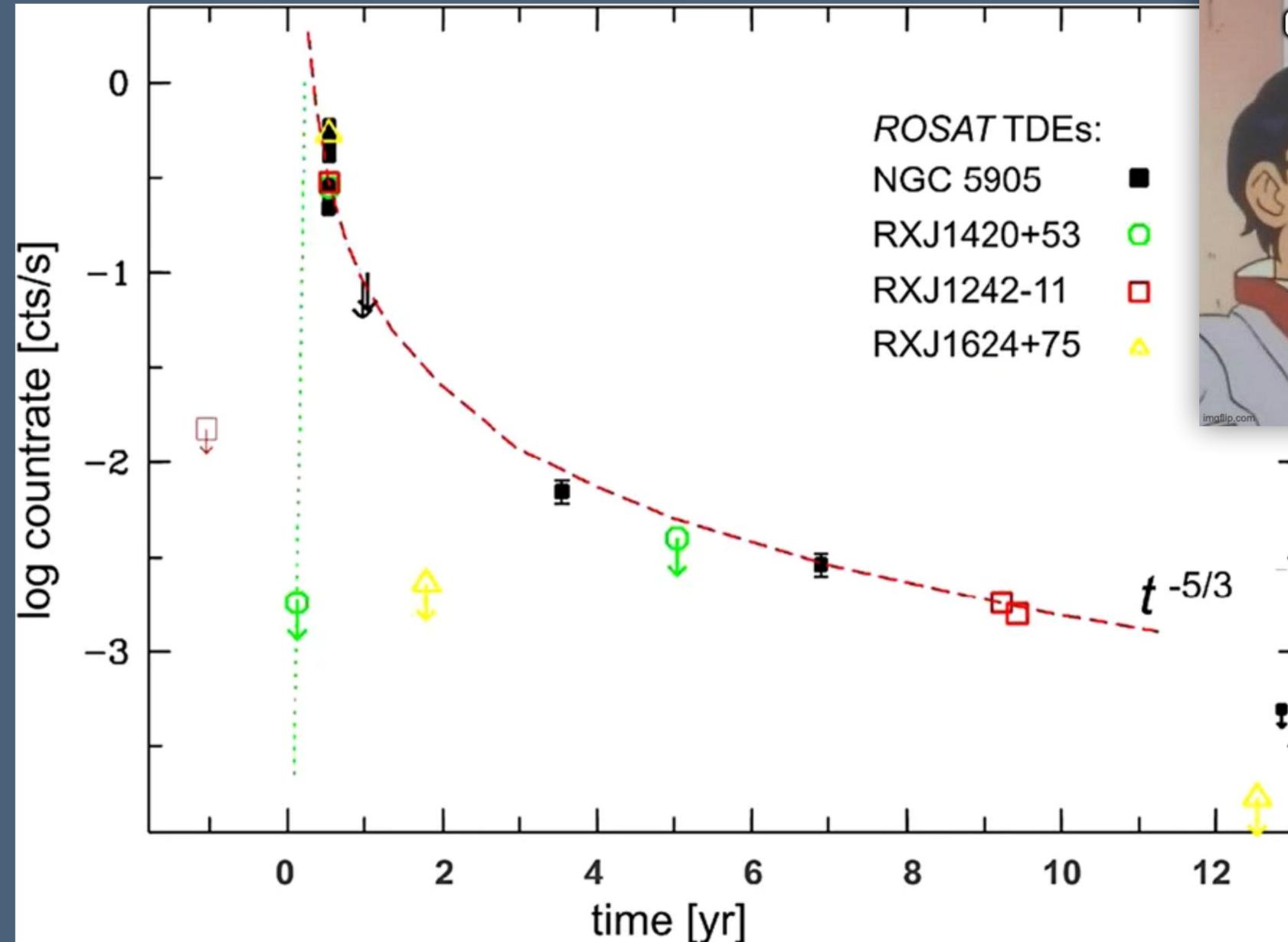
New Discoveries & Challenges in Understanding Optical/UV TDEs

Iair (“ya-eer”) Arcavi, Tel Aviv University

Naive TDE expectation: See x-rays from an accretion disk



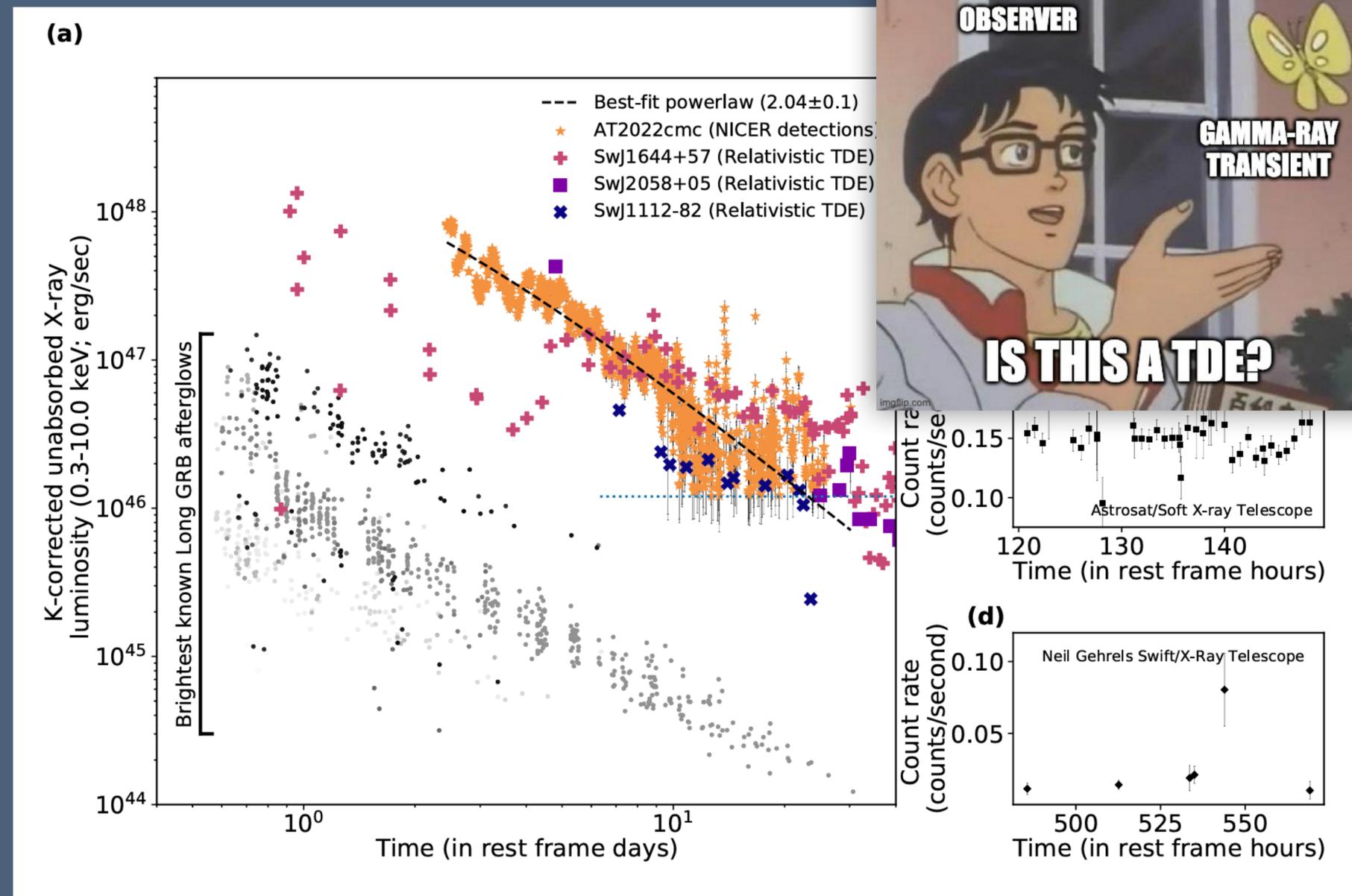
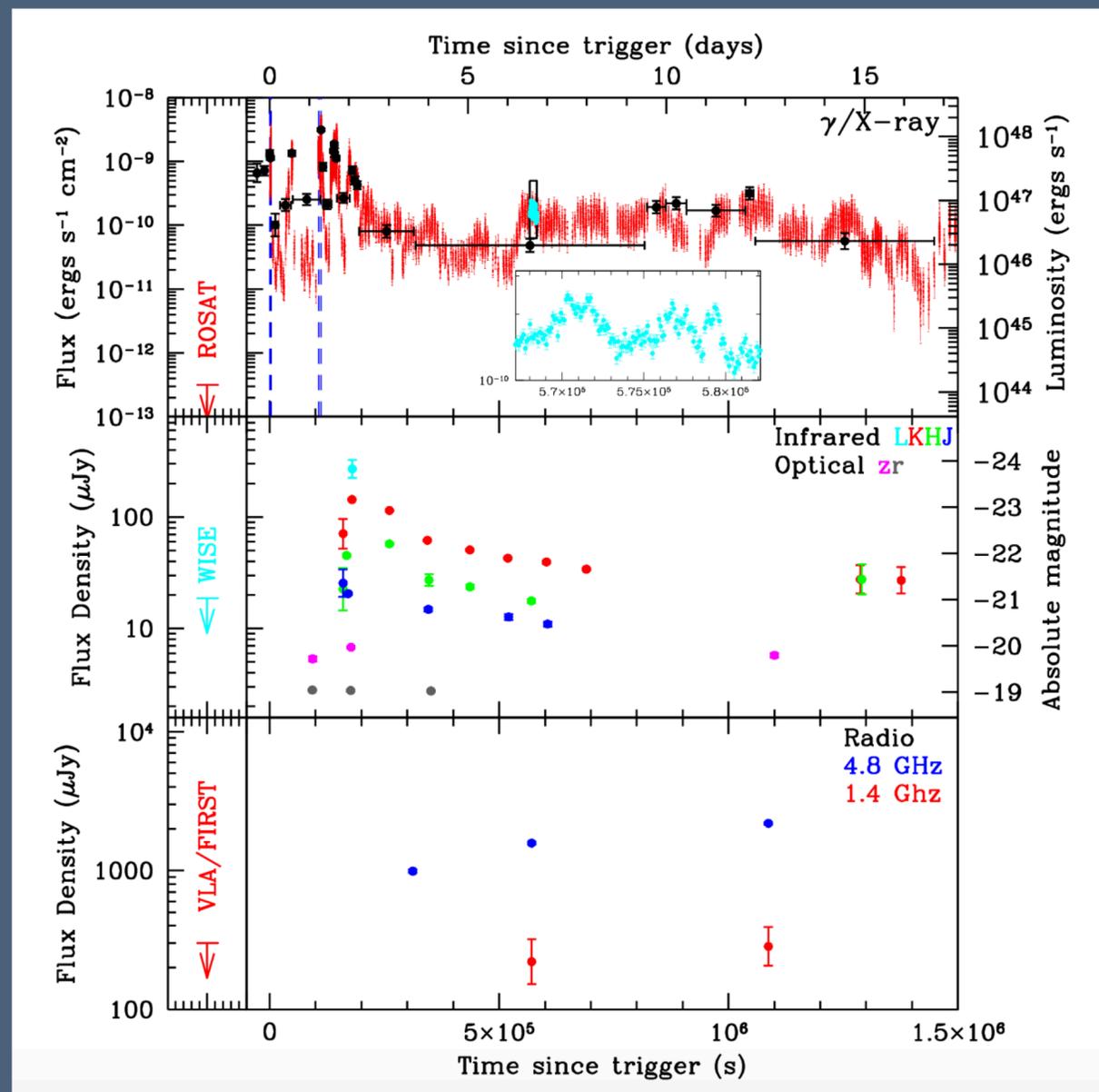
Accretion disk



Komossa and Bade (1999), Komossa (2004)

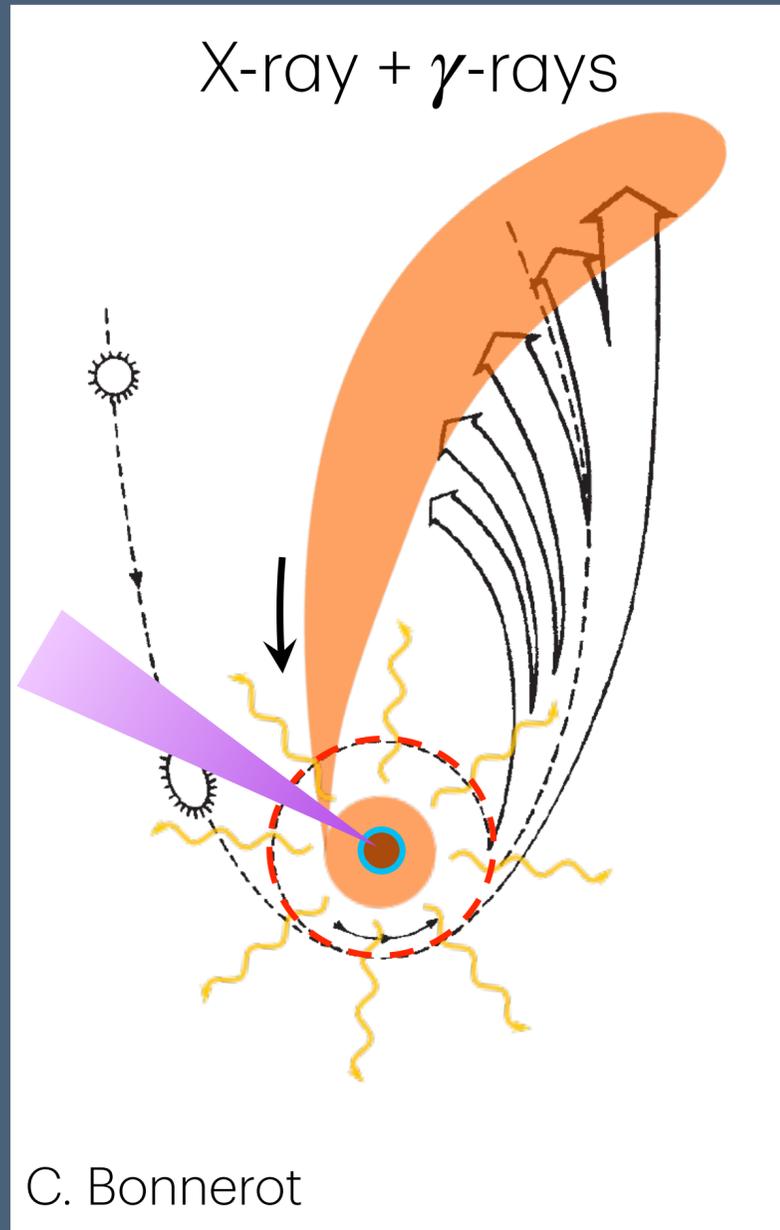


Surprise! TDEs as ultra-long gamma-ray bursts



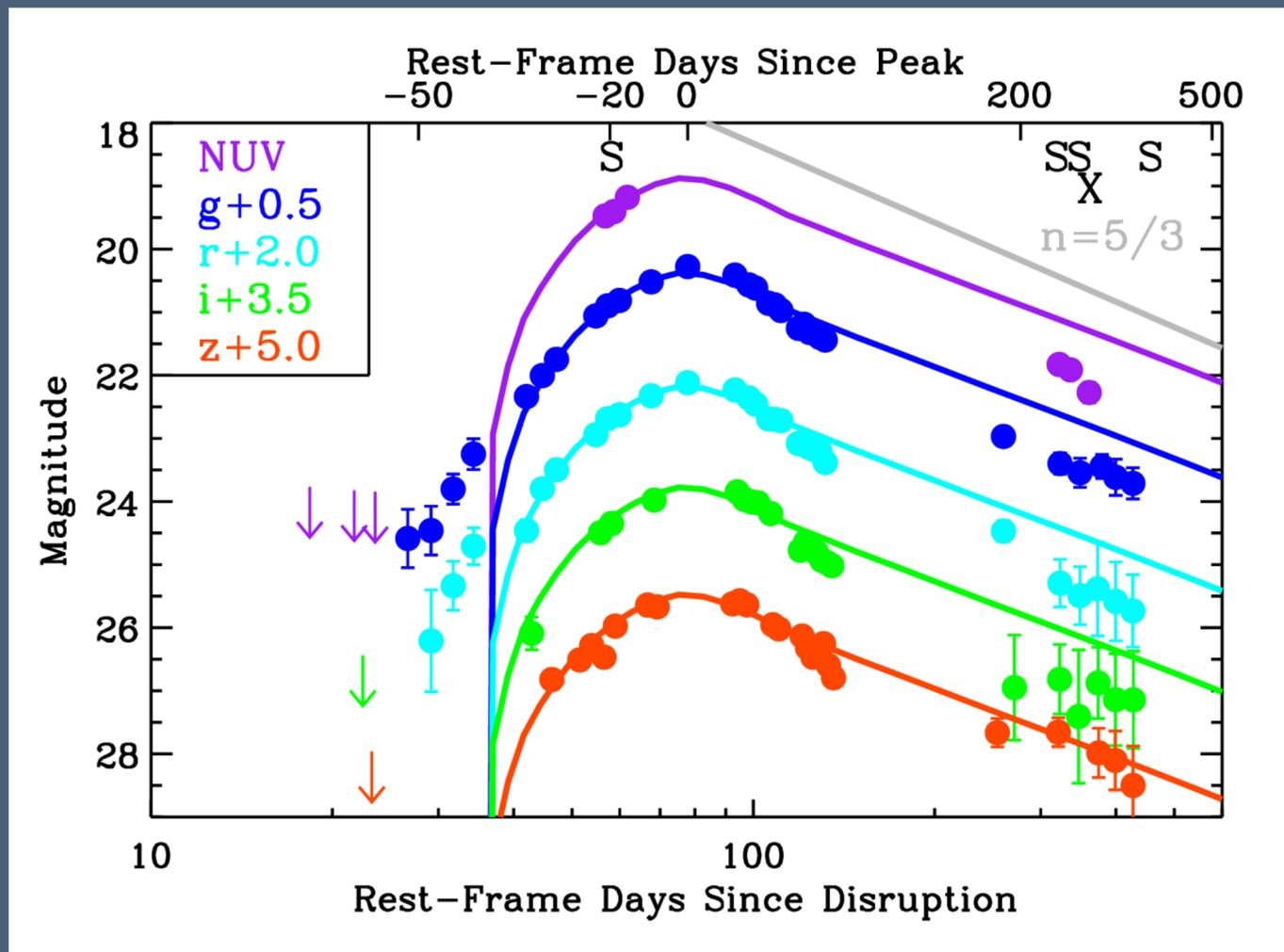
Zauderer et al. (2011), Bloom et al. (2011), Burrows et al. (2011), Levan et al. (2011), Cenko et al. (2012), Pasham et al. (2015), Brown et al. (2015), Andreoni et al. (2023), Pasham et al. (2023)

Some TDEs have jets that produce gamma rays

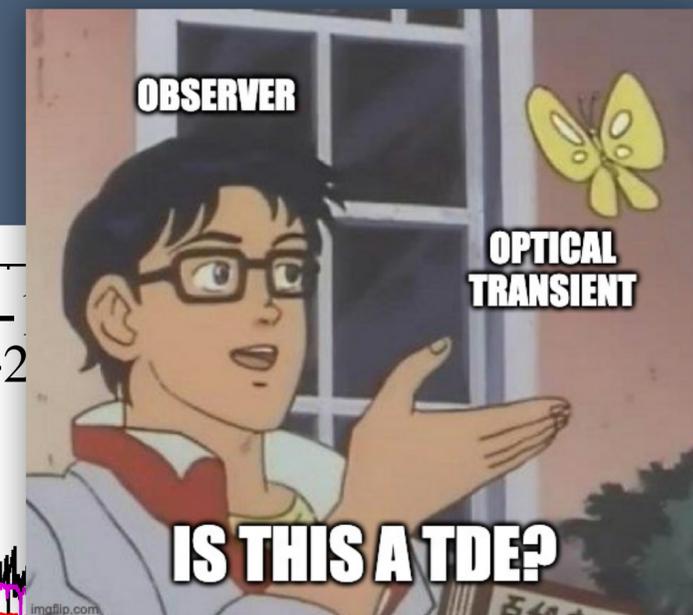
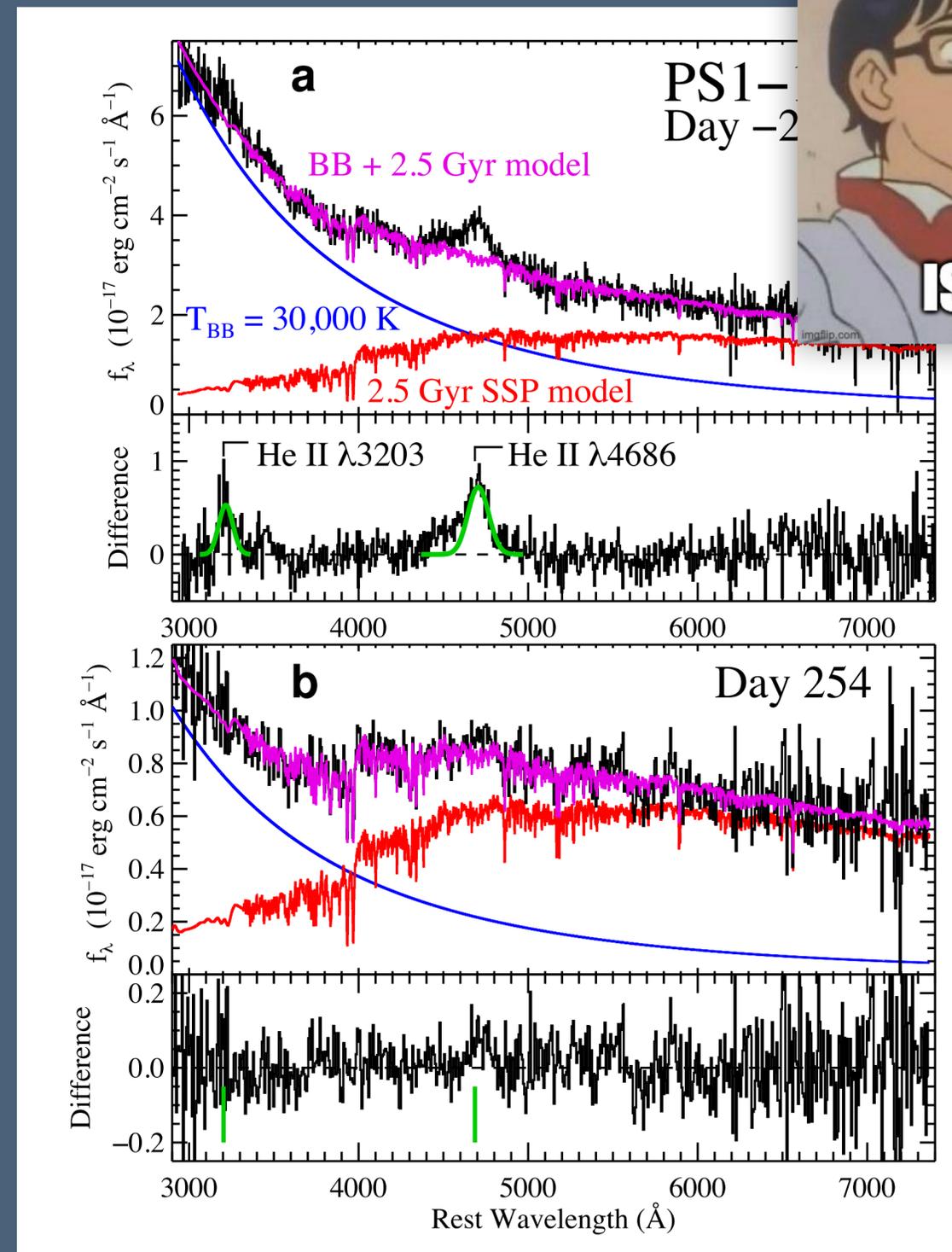


Accretion disk + jet

Surprise II! TDEs in the optical/UV



Gezari et al. (2012)





TDES

TDES EVERYWHERE

The optical/UV event can't be a TDE

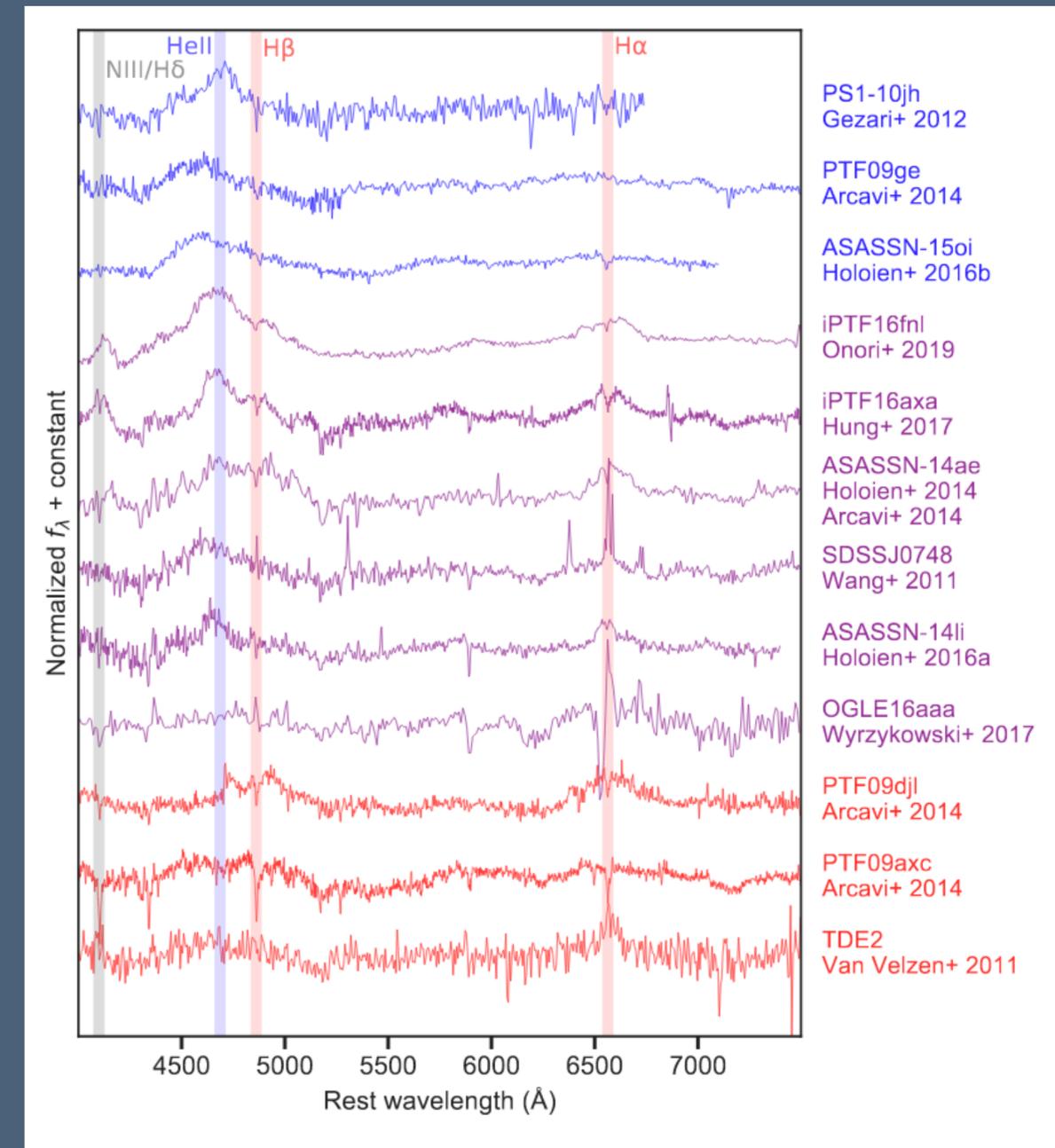
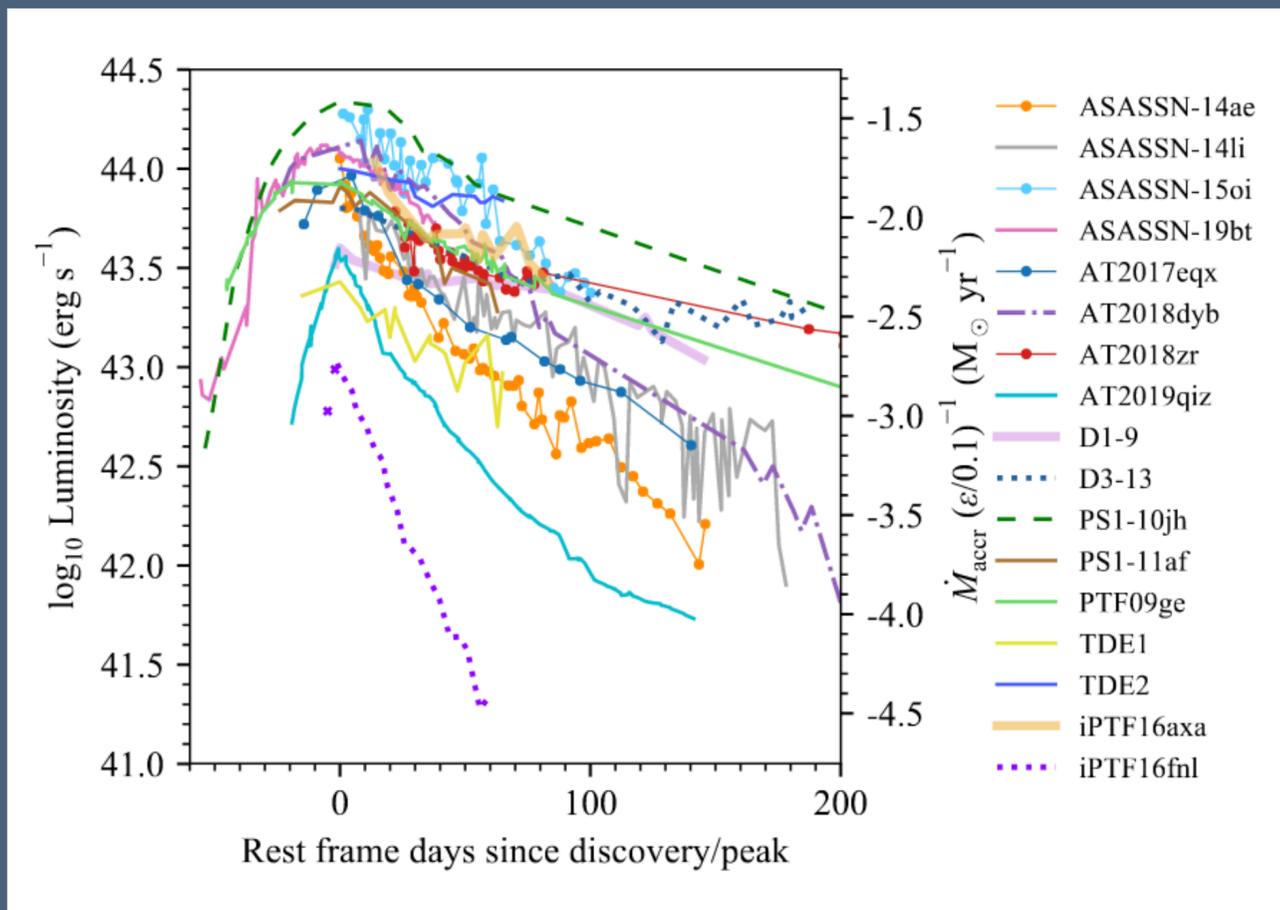
| | Expected from accretion | Observed | |
|--------------------------|---|----------------------|---|
| | Center of galaxy | Center of galaxy | ✓ |
| | $L \propto t^{-5/3}$ | $L \propto t^{-5/3}$ | ✓ |
| | $T \sim 10^5 - 10^6$ K | $T = 3 \cdot 10^4$ K | ✗ |
| | $R \sim R_T \sim 10^{13}$ cm | $R \sim 10^{15}$ cm | ✗ |
| “Missing energy problem” | $E \sim 0.1 M_{\odot} c^2 \sim 10^{53}$ erg | $E \sim 10^{51}$ erg | ✗ |
| | Evolving temperature | Constant temperature | ✗ |
| | H from the star | No H in some cases | ✗ |

PS1-10jh-like optical/UV class: Hallmark He II emission

Luminous in the optical and UV (10^{44} erg/s)

Blue (20,000-30,000K)

Broad (10,000's km/s) H and/or He II emission

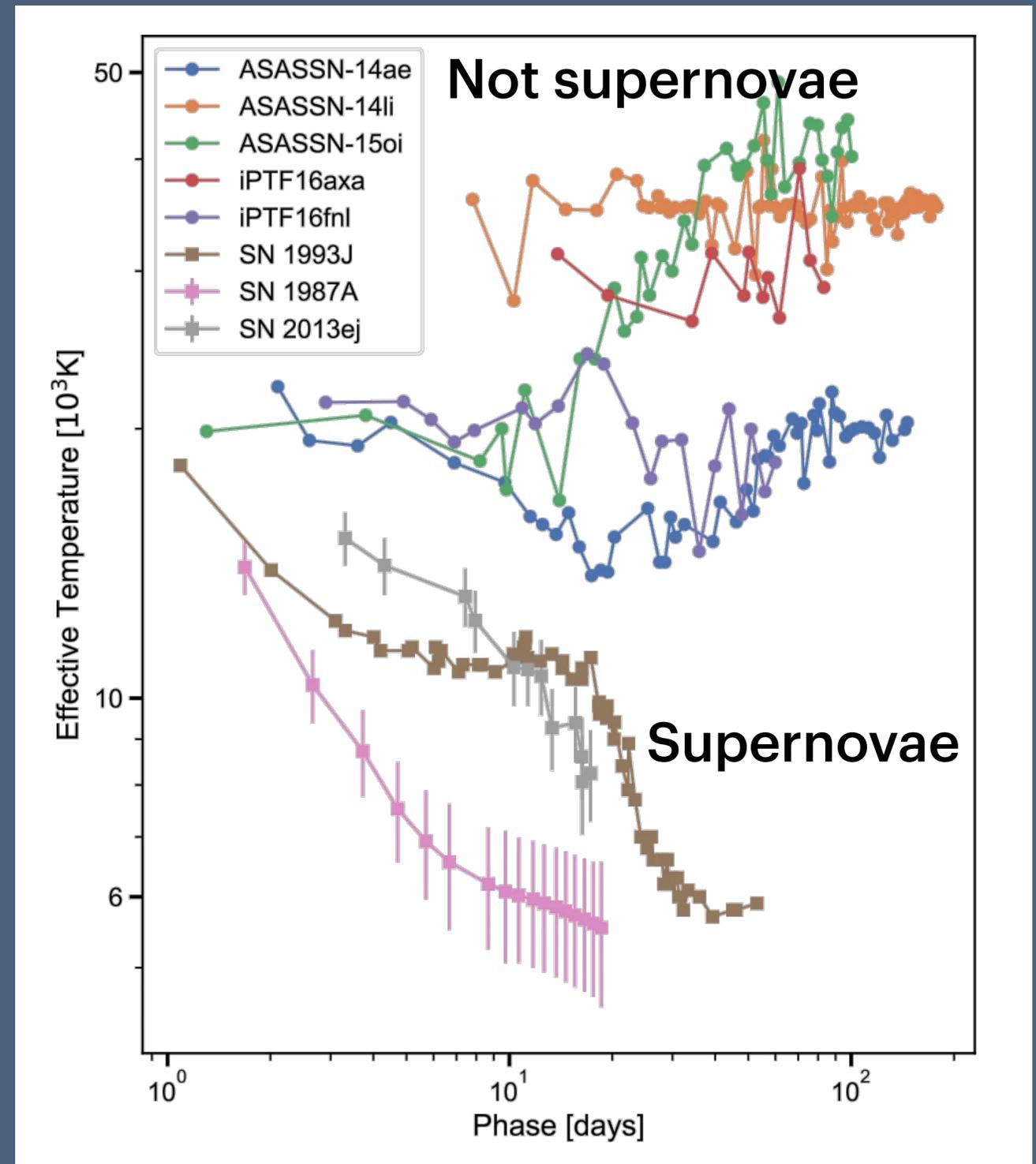


van Velzen et al. (2020); see also Gezari et al. (2012), Arcavi et al. (2014), Gezari et al. (2021), van Velzen et al. (2021), Hammerstein et al. (2023), Yao et al. (2023)

Are these supernovae? (no)

Supernovae cool within days, these transients remain hot

Plot from Zabludoff et al. 2020; Data from Hung et al. 2017, Holoien et al. 2014, 2016a,b, Menzies et al. 1987, Richmond et al. 1994, Valenti et al. 2014



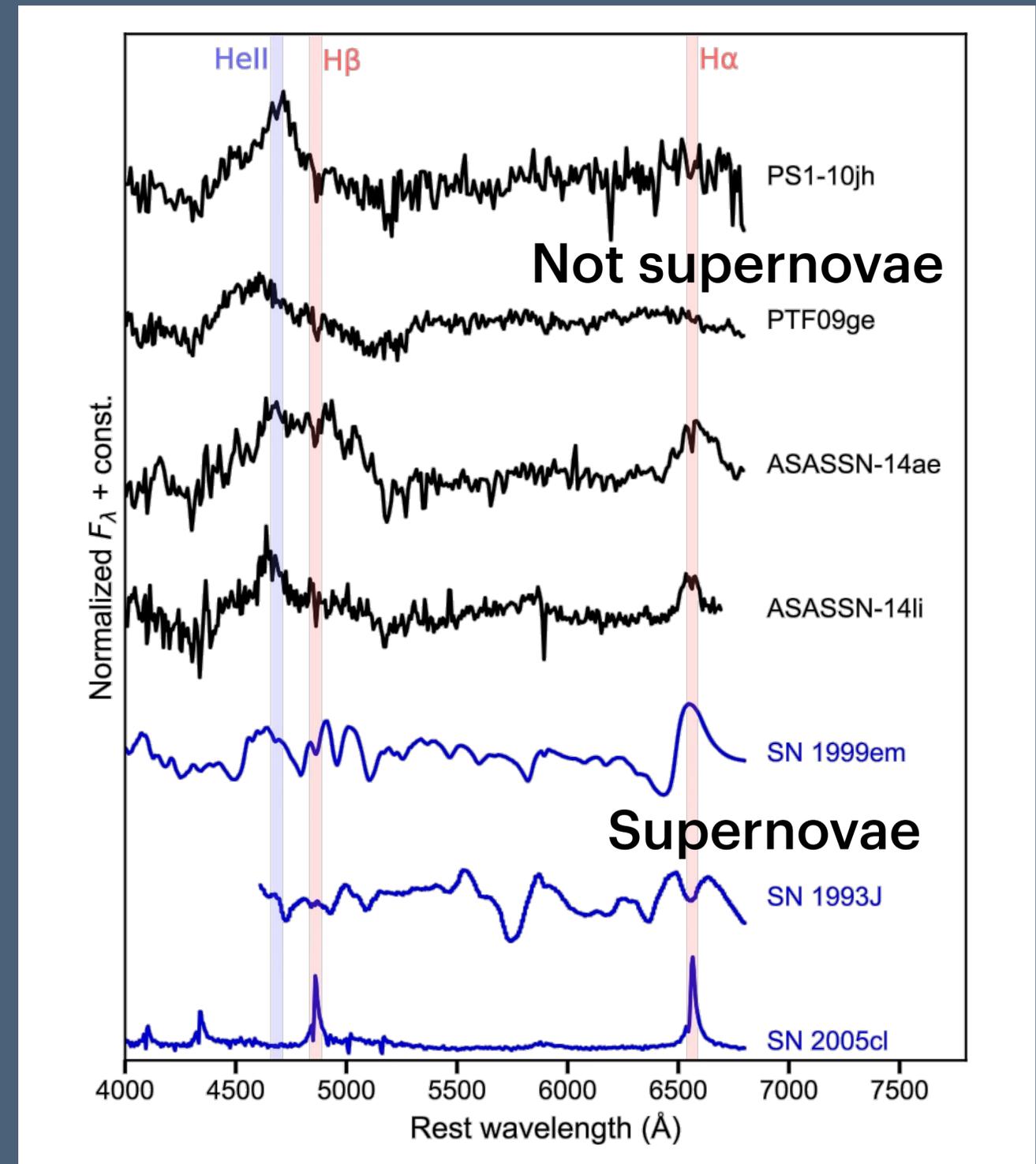
Are these supernovae? (no)

Supernovae cool within days, these transients remain hot

Supernovae show p-cygni features from expanding ejecta, these transients show only emission.

Supernovae don't show He II

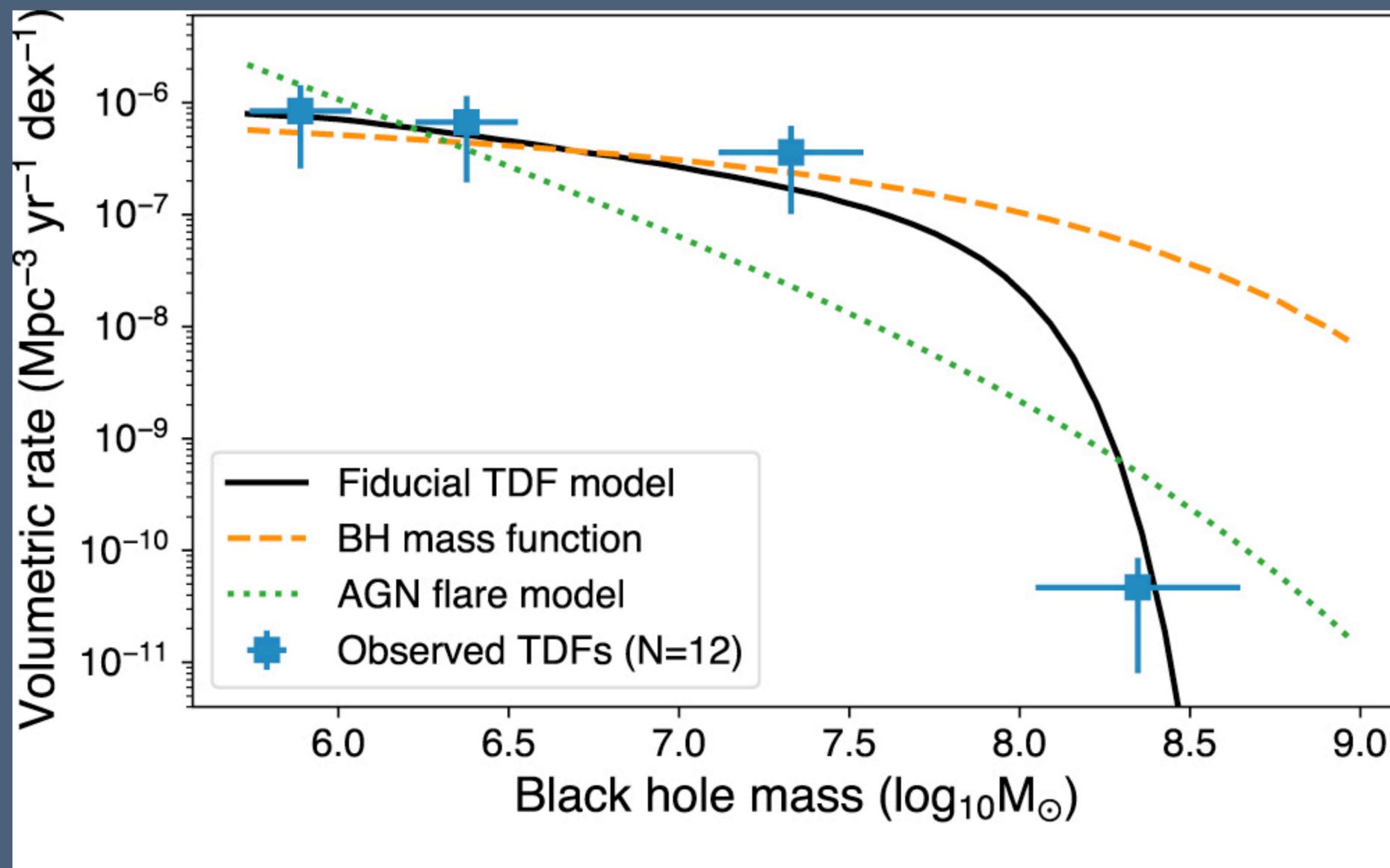
Plot from Zabludoff et al. 2020; Data from
Gezari et al. 2012; Arcavi et al. 2014,
Holoien et al. 2014, 2016b, Kiewe et al. 2012,
Barbon et al. 1995, Leonard et al. 2002



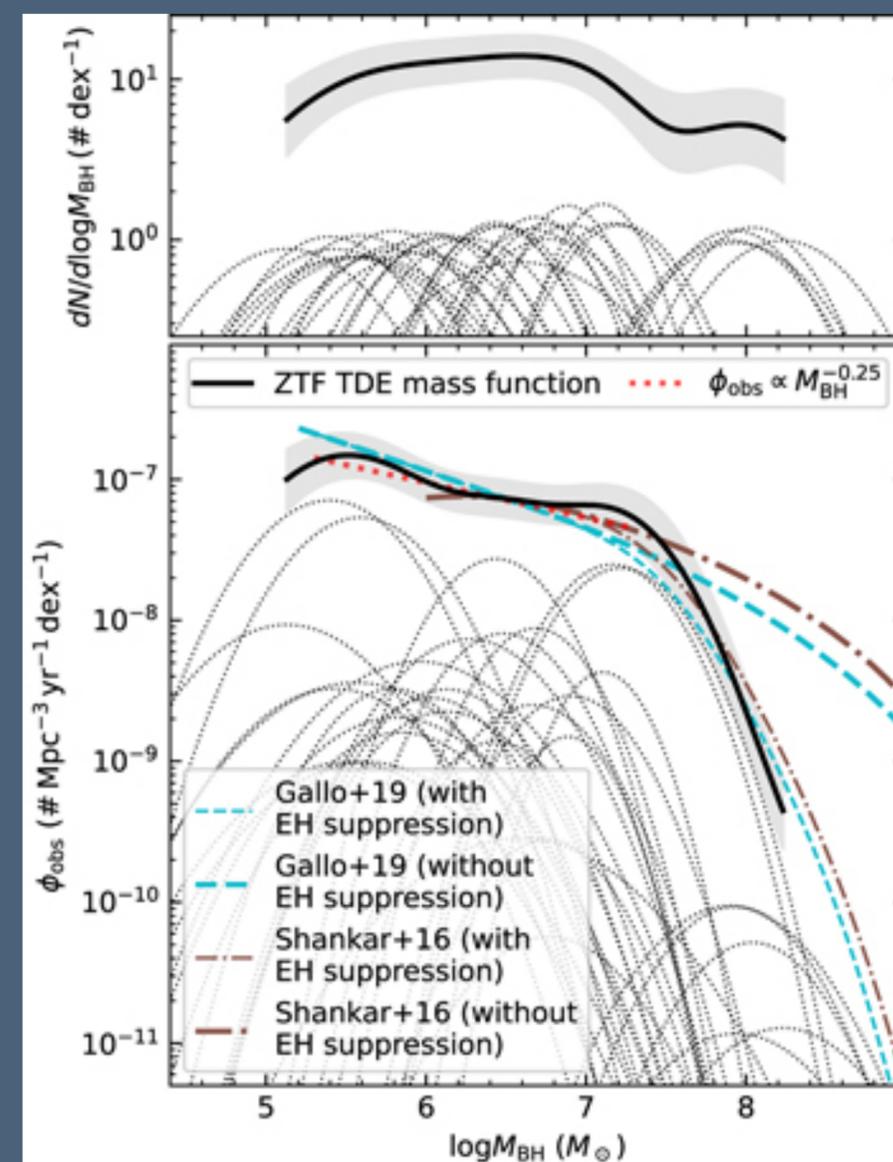
PS1-10jh class very likely TDEs

All in the centers of non-star forming quiescent galaxies

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



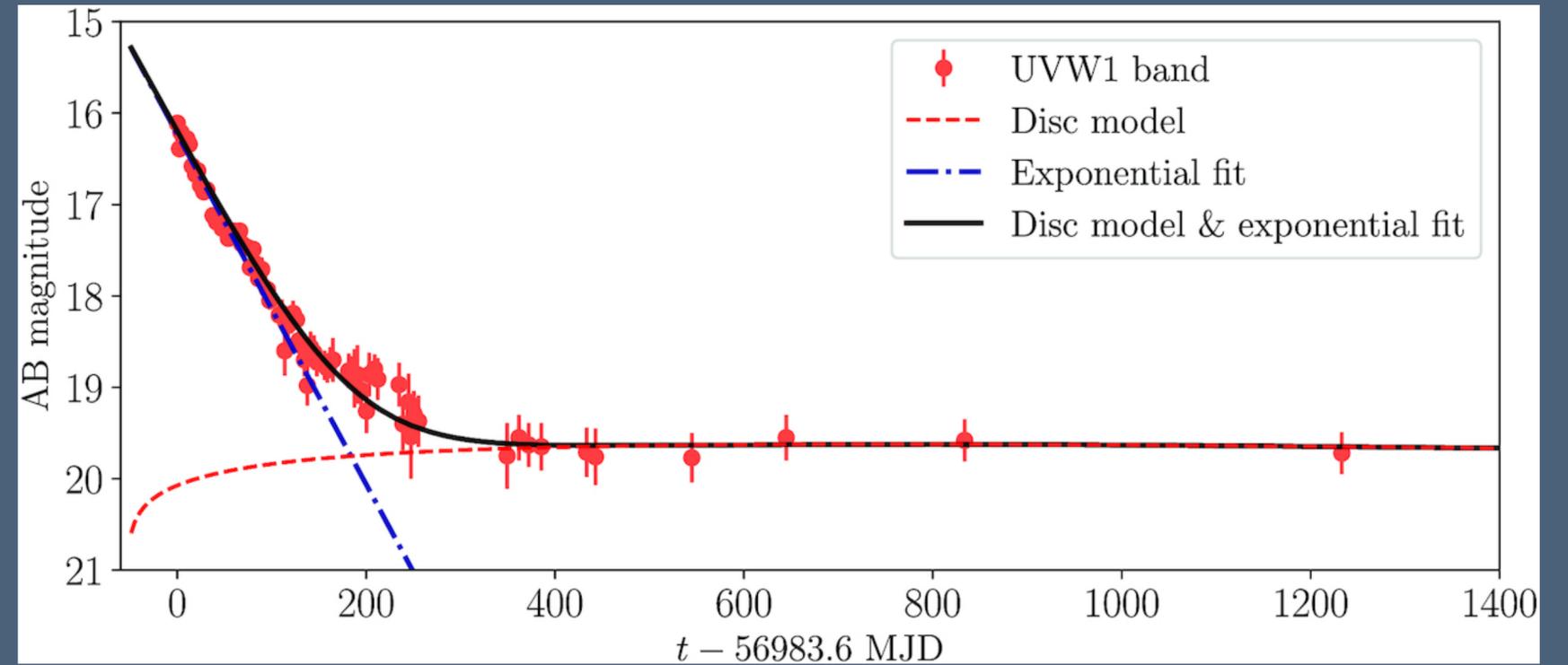
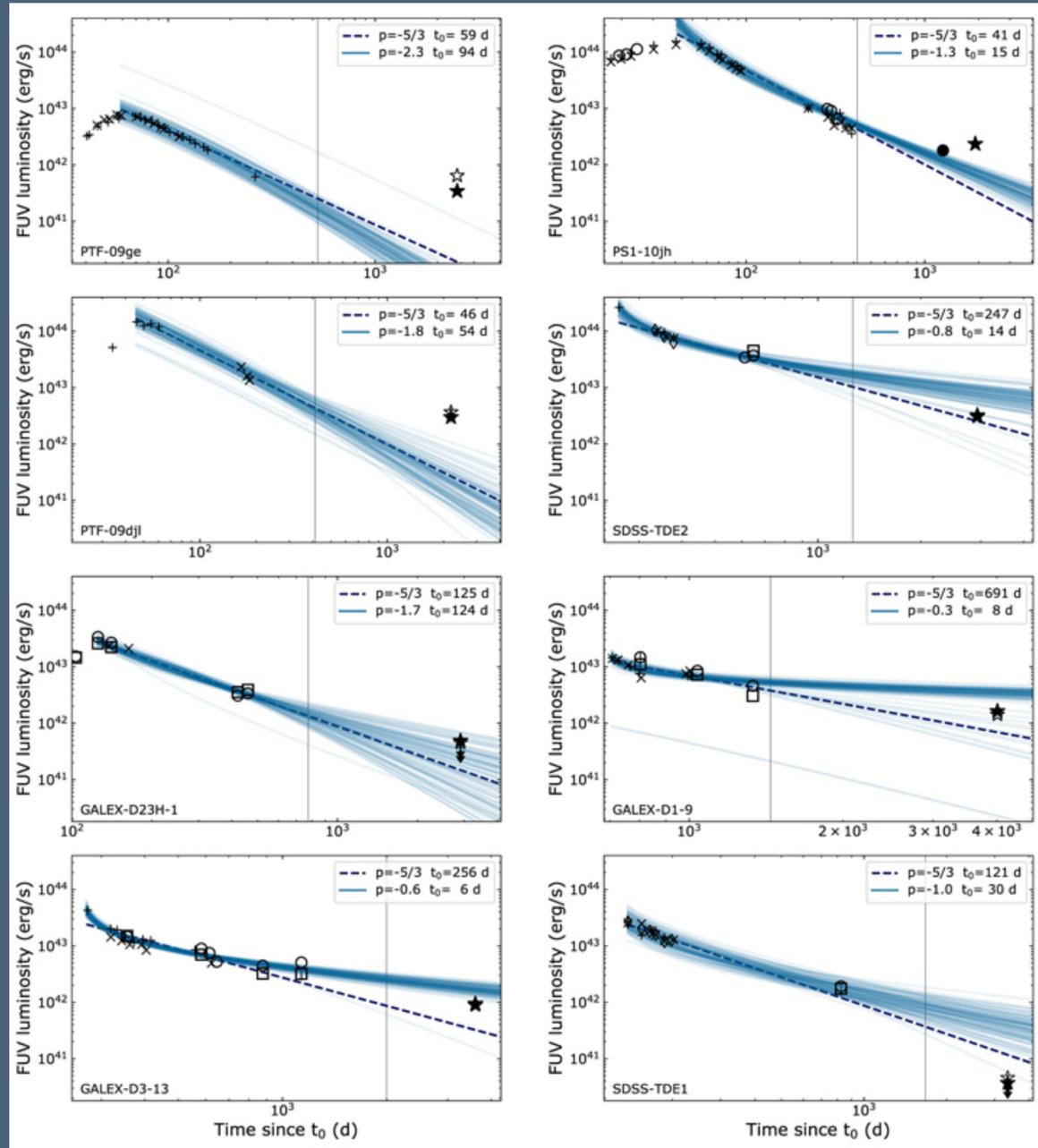
van Velzen (2018)



Yao et al. (2023)

PS1-10jh class very likely TDEs

Evidence for expanding accretion disk



Mummery & Balbus (2020)

So how can they be TDEs?

Expected from accretion

Center of galaxy

$$L \propto t^{-5/3}$$

$$T \sim 10^5 - 10^6 \text{ K}$$

$$R \sim R_T \sim 10^{13} \text{ cm}$$

“Missing energy problem”

$$E \sim 0.1 M_{\odot} c^2 \sim 10^{53} \text{ erg}$$

Evolving temperature

H from the star

Observed

Center of galaxy

$$L \propto t^{-5/3}$$

$$T = 3 \cdot 10^4 \text{ K}$$

$$R \sim 10^{15} \text{ cm}$$

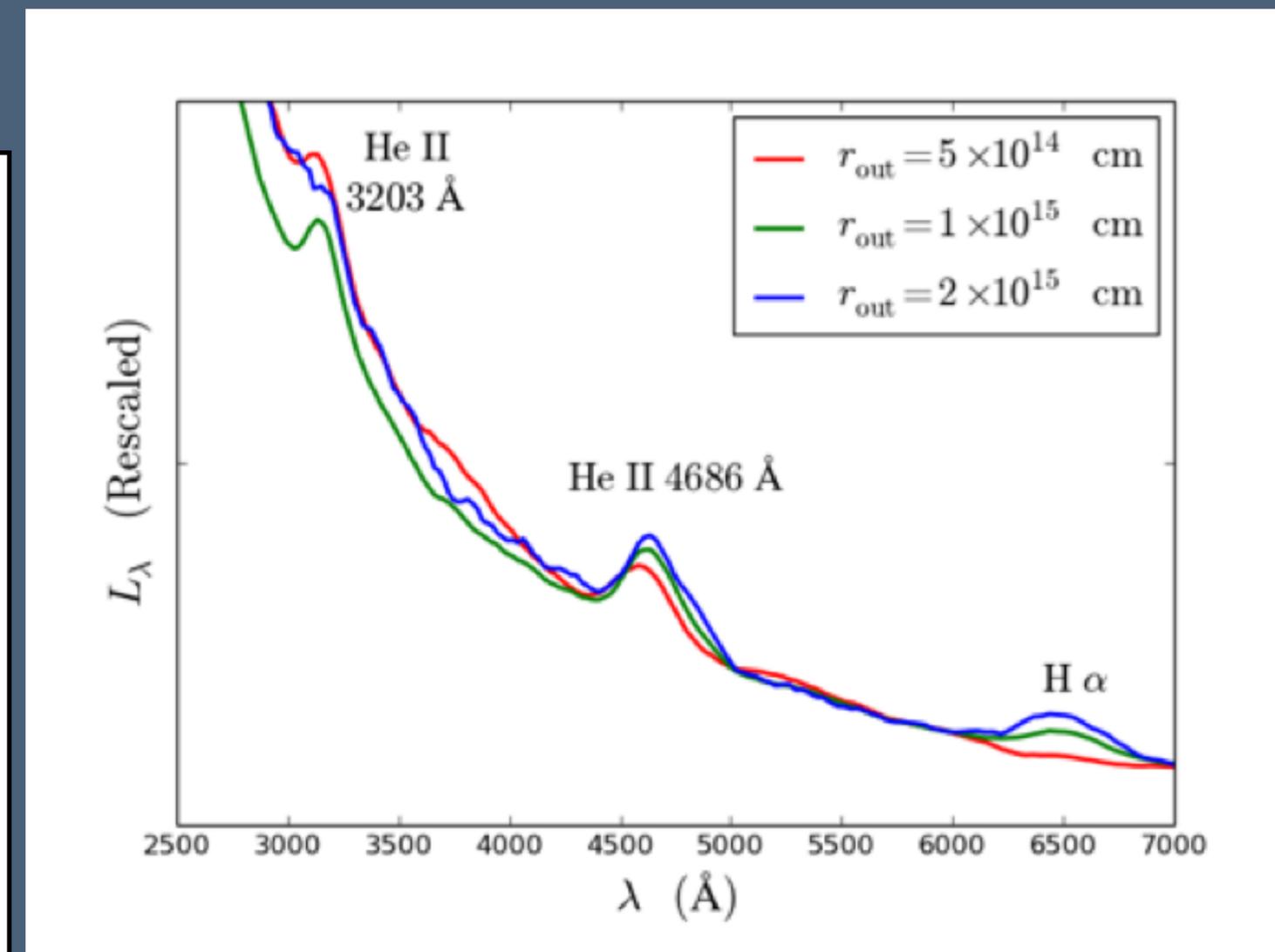
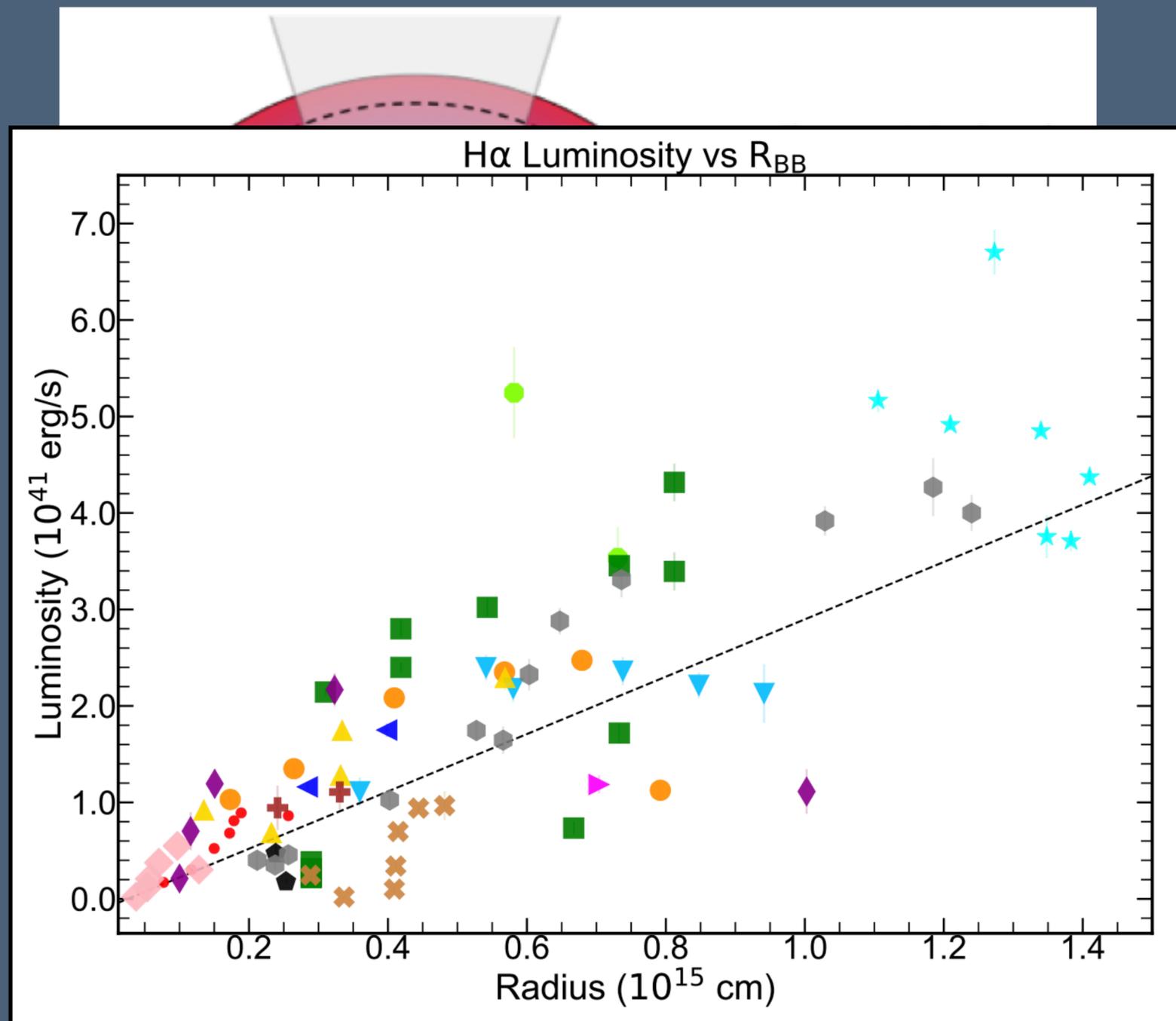
$$E \sim 10^{51} \text{ erg}$$

Constant temperature

No H in some cases



Emission mechanism 1: Reprocessing material



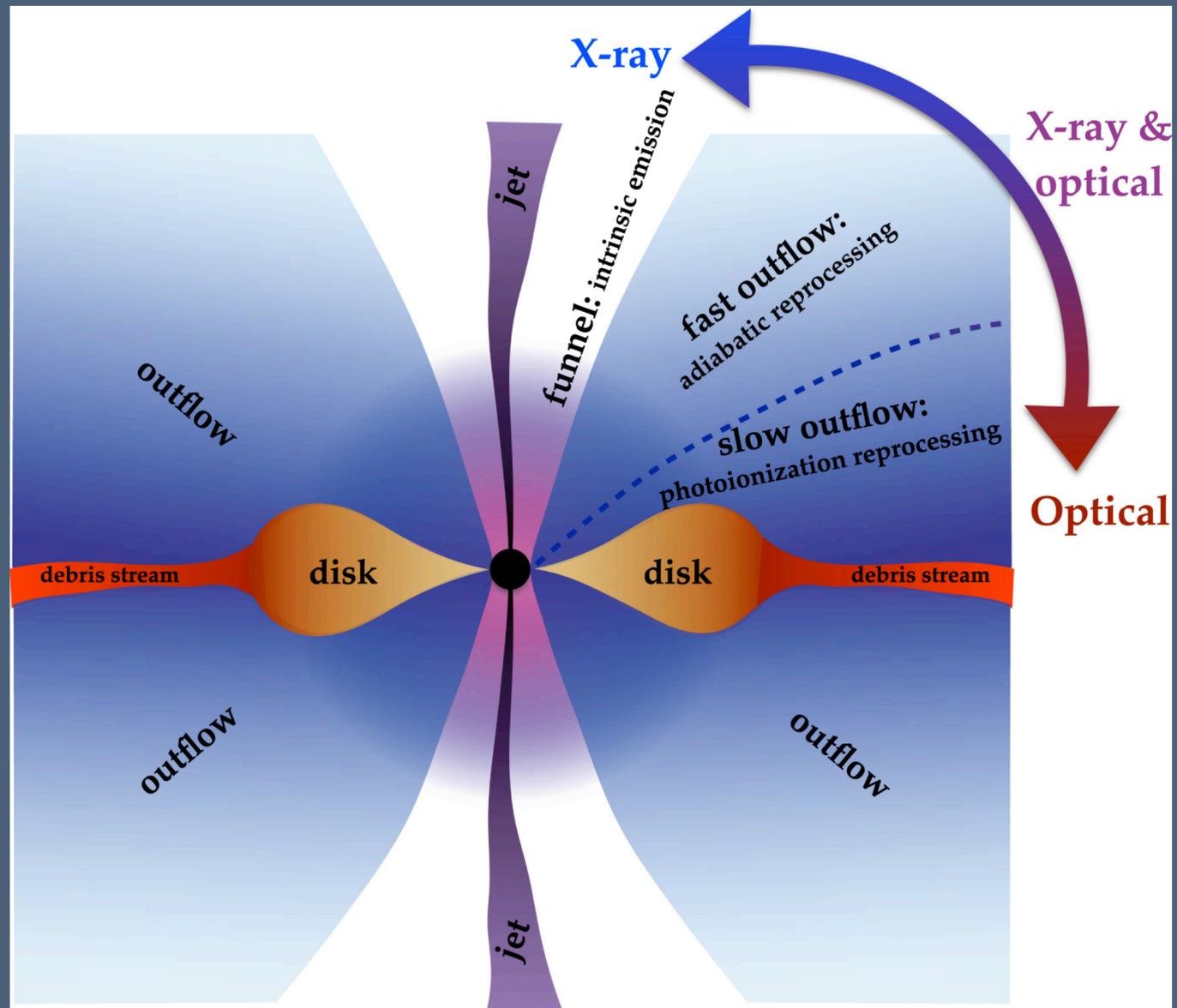
Roth et al. (2016); see also Guillochon et al. (2013)

Charalampopoulos et al. (2022)

2. The large radii

3. The lack of hydrogen in the spectra

Emission mechanism 1: Reprocessing material



Dai et al. (2019)

The presence of reprocessing material also unifies X-ray and optical/UV events as a viewing angle effect.

Emission mechanism 2: Circularization

WD-BH encounter

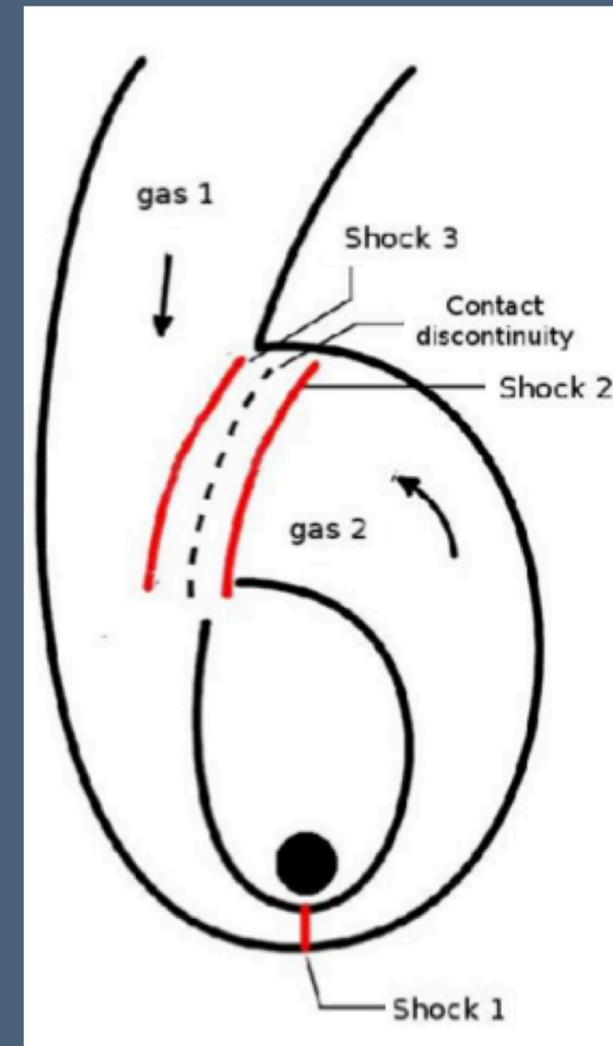
| | |
|----------------|---------------------------|
| masses (sol.) | 0.2 (WD) & 1000 (BH) |
| in. separation | 50 (in 1.E9 cm) |
| hydrodynamics | SPH (4 030 000 particles) |
| EOS, gravity | Helmholtz, N |
| nucl. burning | red. QSE-network (Hix 98) |
| simul. time | 5.4 min |
| color coded | column density |
| penet. factor | 12 |

coding, simulation, visualisation: S. Rosswog

GR precession causes the star to collide with itself at apocenter

These “outer shocks” explain:

1. The low temperatures
2. The large radii
3. The mechanism by which the material circularizes in order to accrete to the black hole



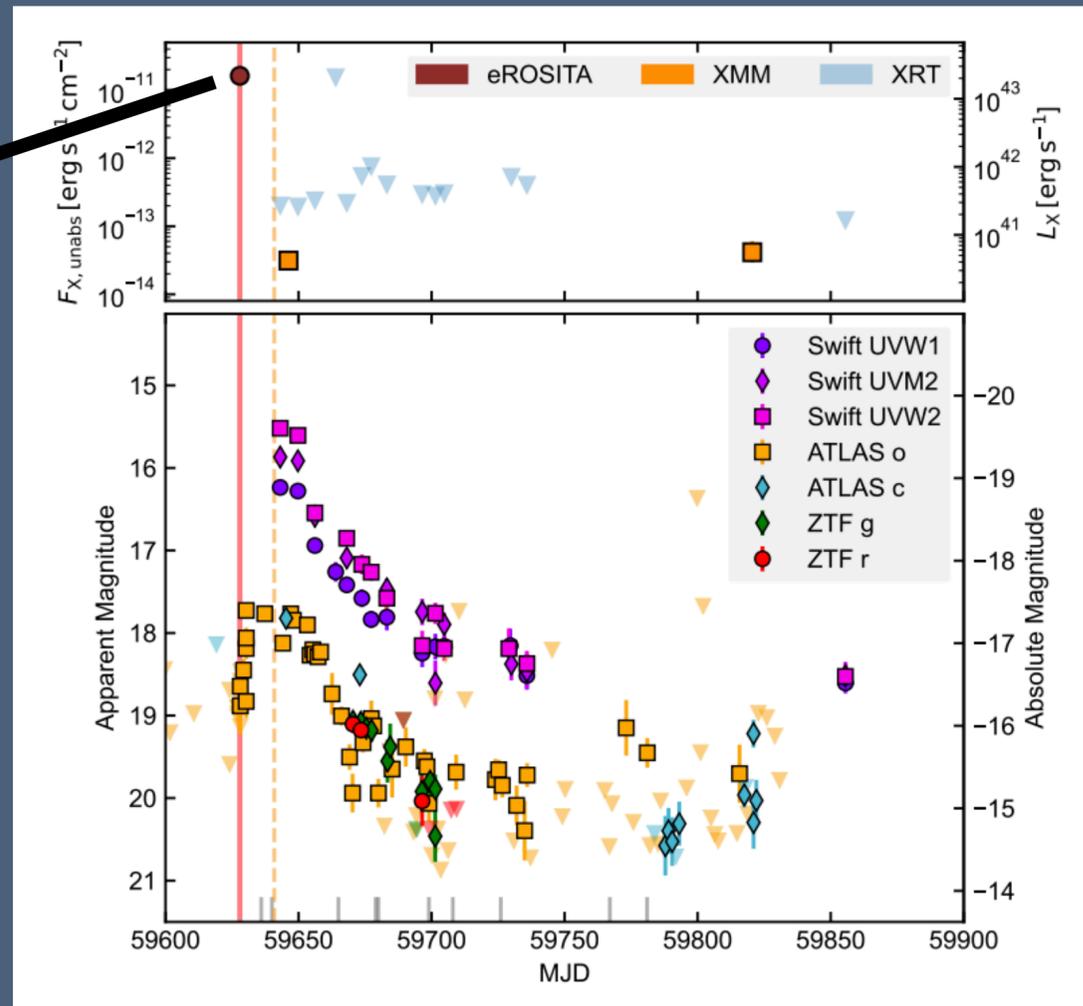
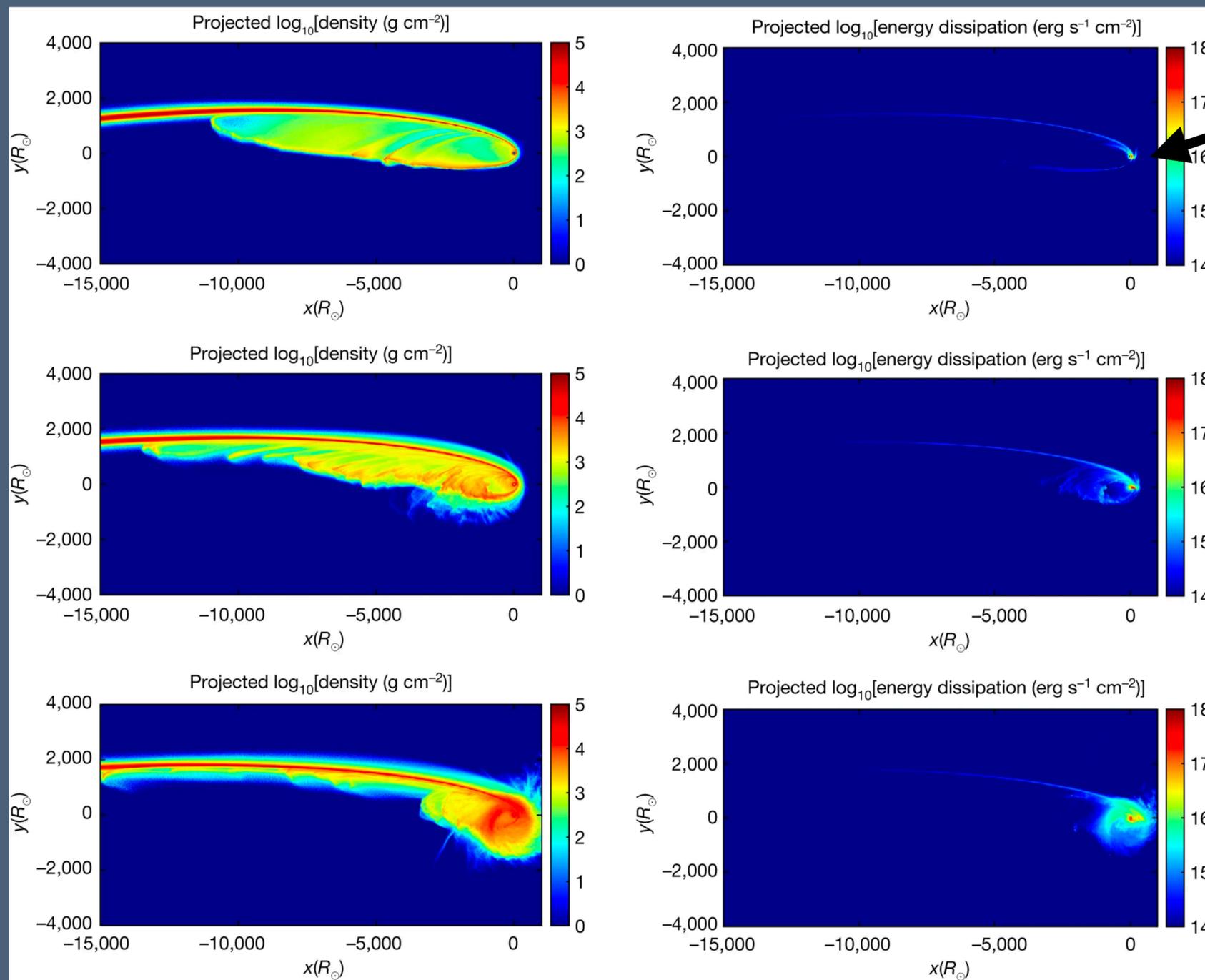
Piran et al. (2015)

Rosswog et al. (2008)

Emission mechanism 3: Stream-disk shocks

Density

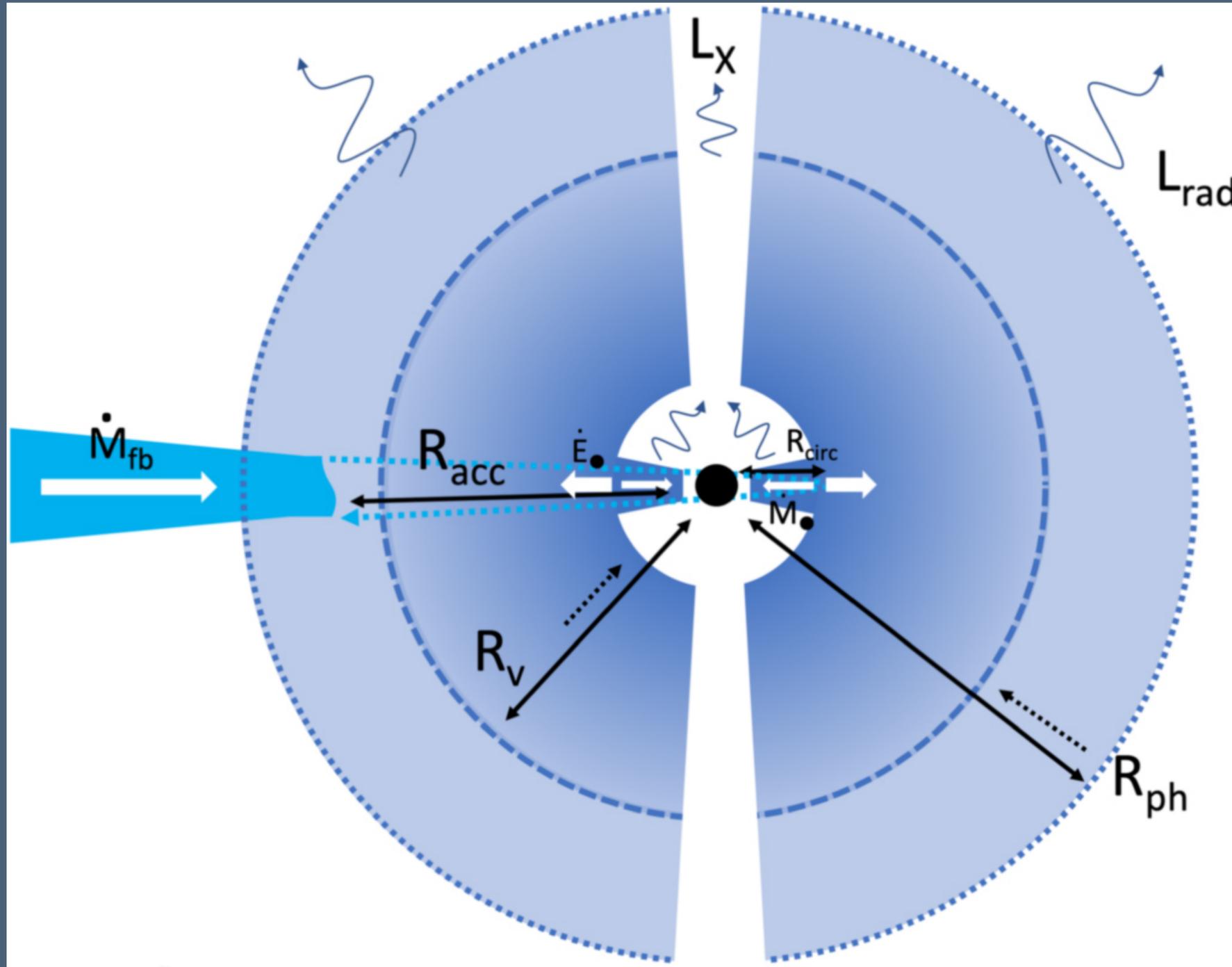
Energy dissipation



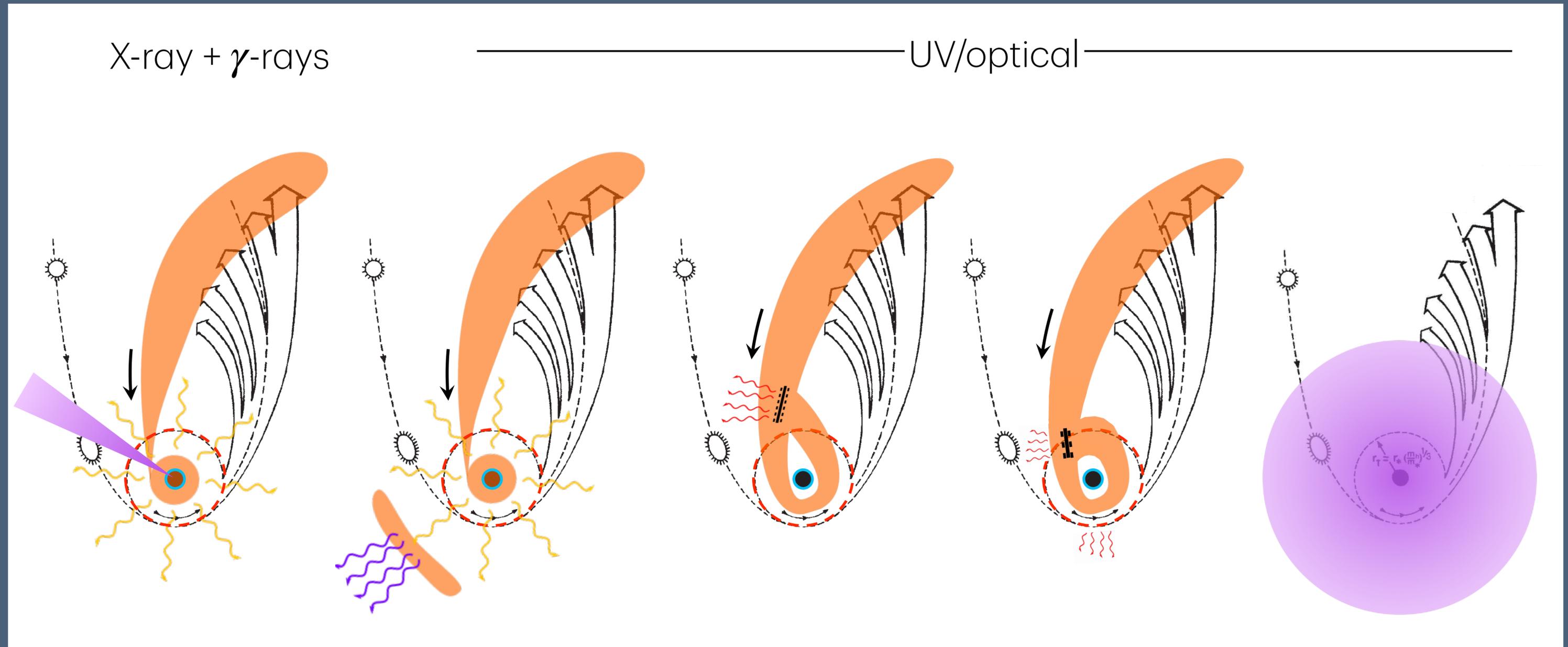
Malyali et al. (2023)

Steinberg & Stone (2024)

Emission mechanism 4: Cooling envelope



Multiple proposed mechanisms to produce optical/UV



Accretion disk + jet

Reprocessed accretion disk

Outer shocks

Stream-disk shocks

Cooling Envelope

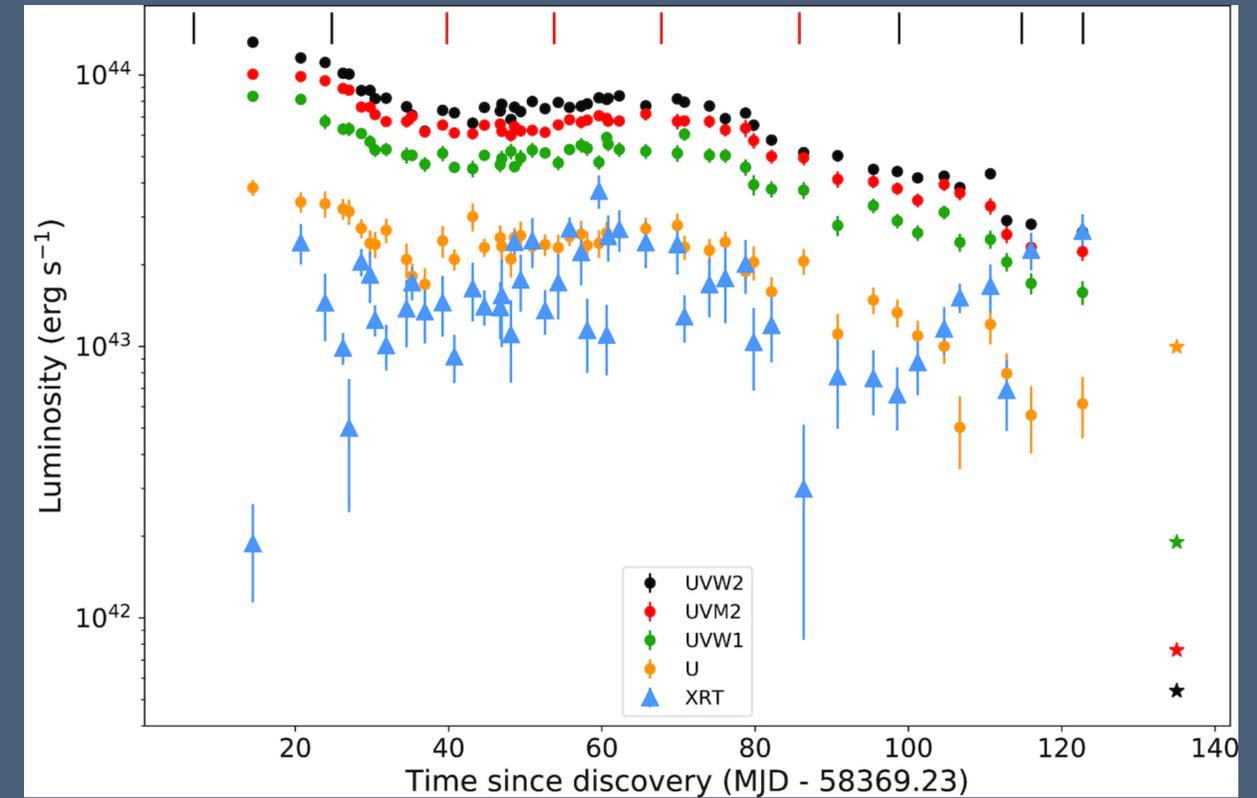
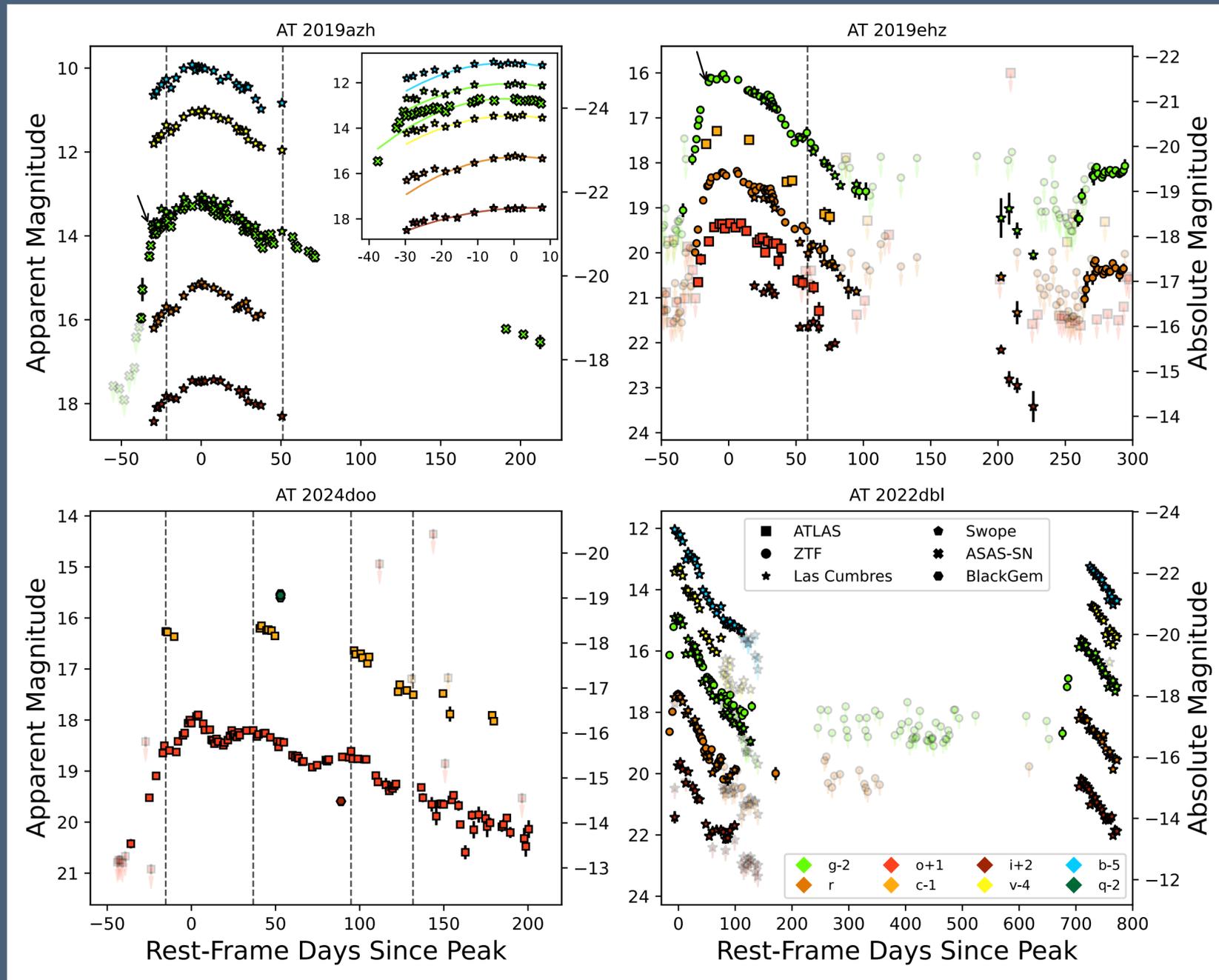
Guillochon et al. (2013),
Dai et al. (2021)

Piran et al. (2015),
Ryu et al. (2020)

Sternberg & Stone
(2024)

Metzger (2022)

Photometric diversity within the PS1-10jh class



Wevers et al. (2019)

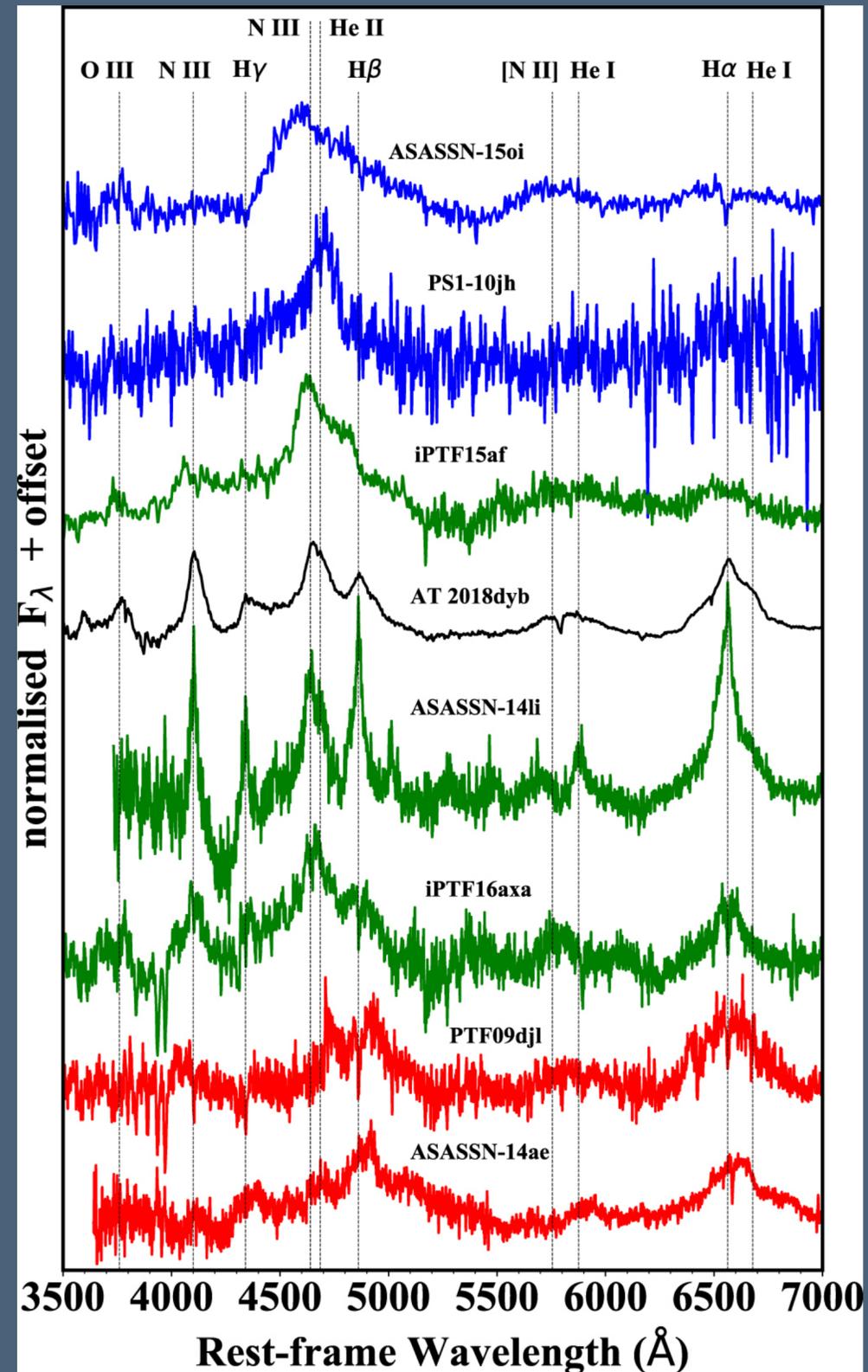
Faris et al. (2024); Makrygianni et al. (2025); Faris et al. (in prep)

Spectral diversity within the PS1-10jh class

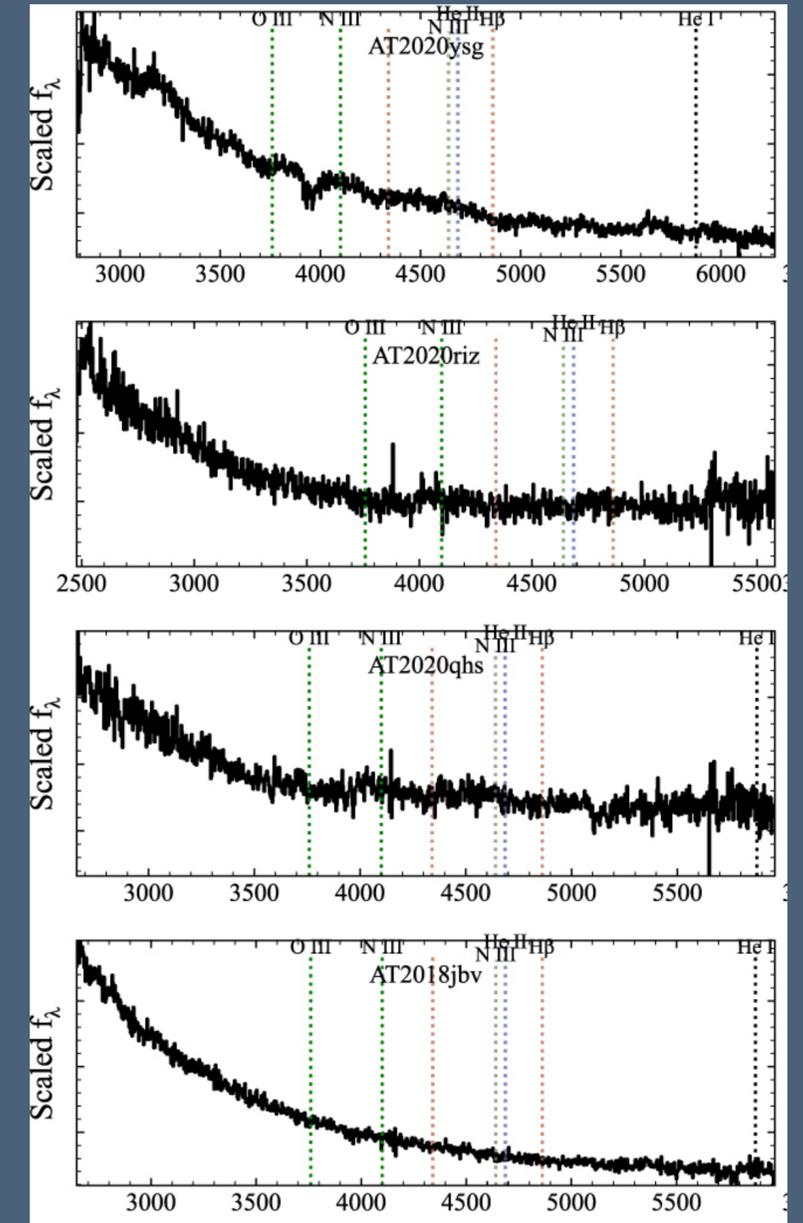
He-dominated

TDEs with
N III / O III

H-dominated



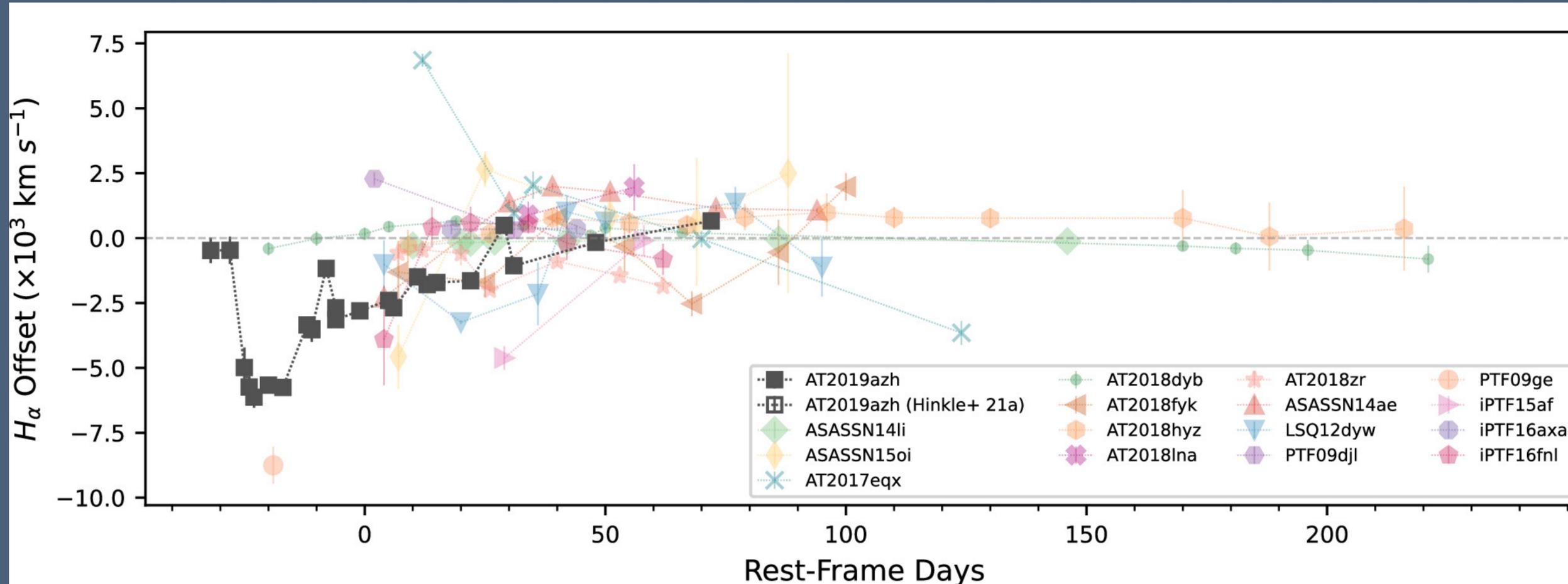
Featureless



Hammerstein et al. (2023)

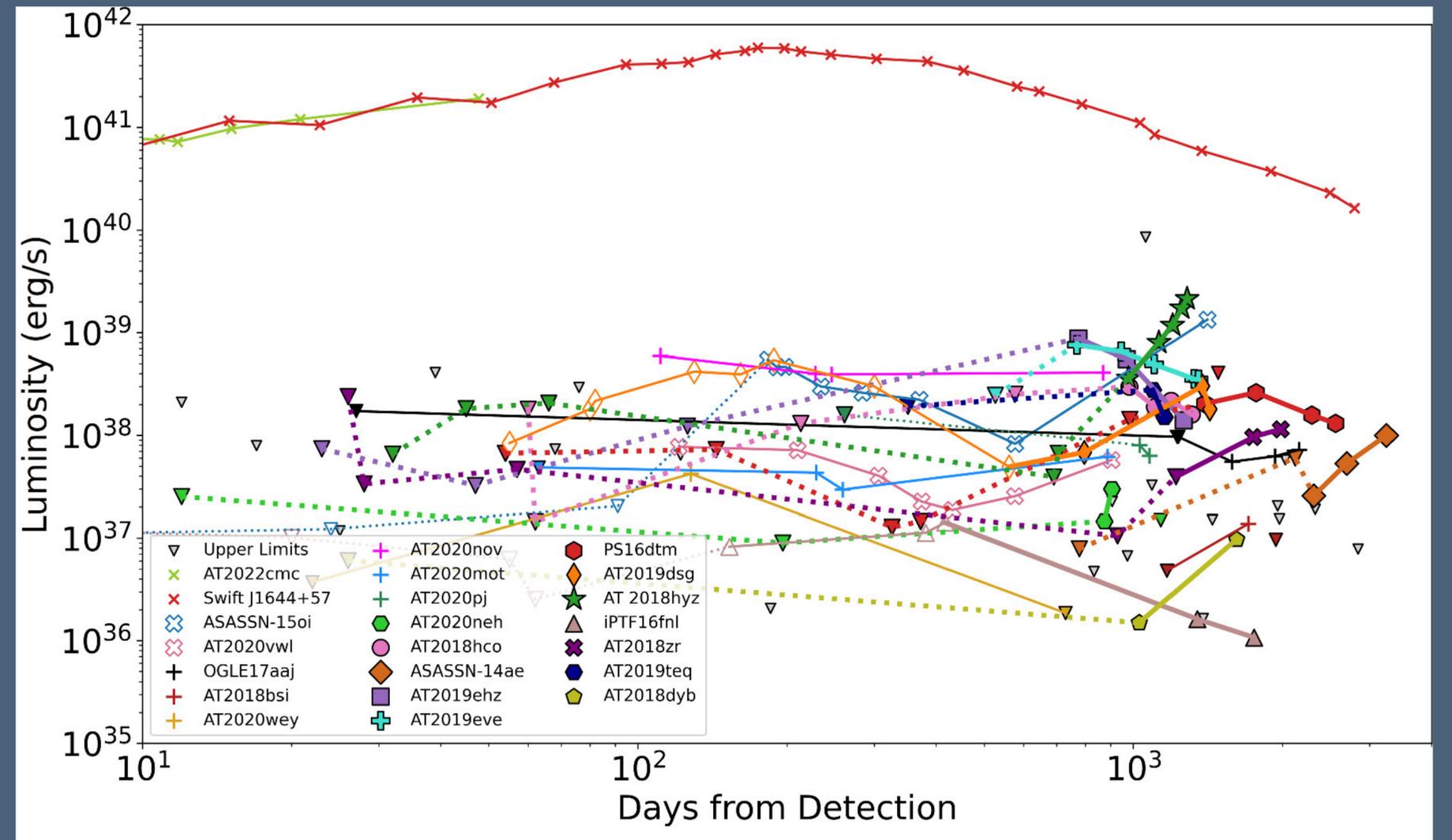
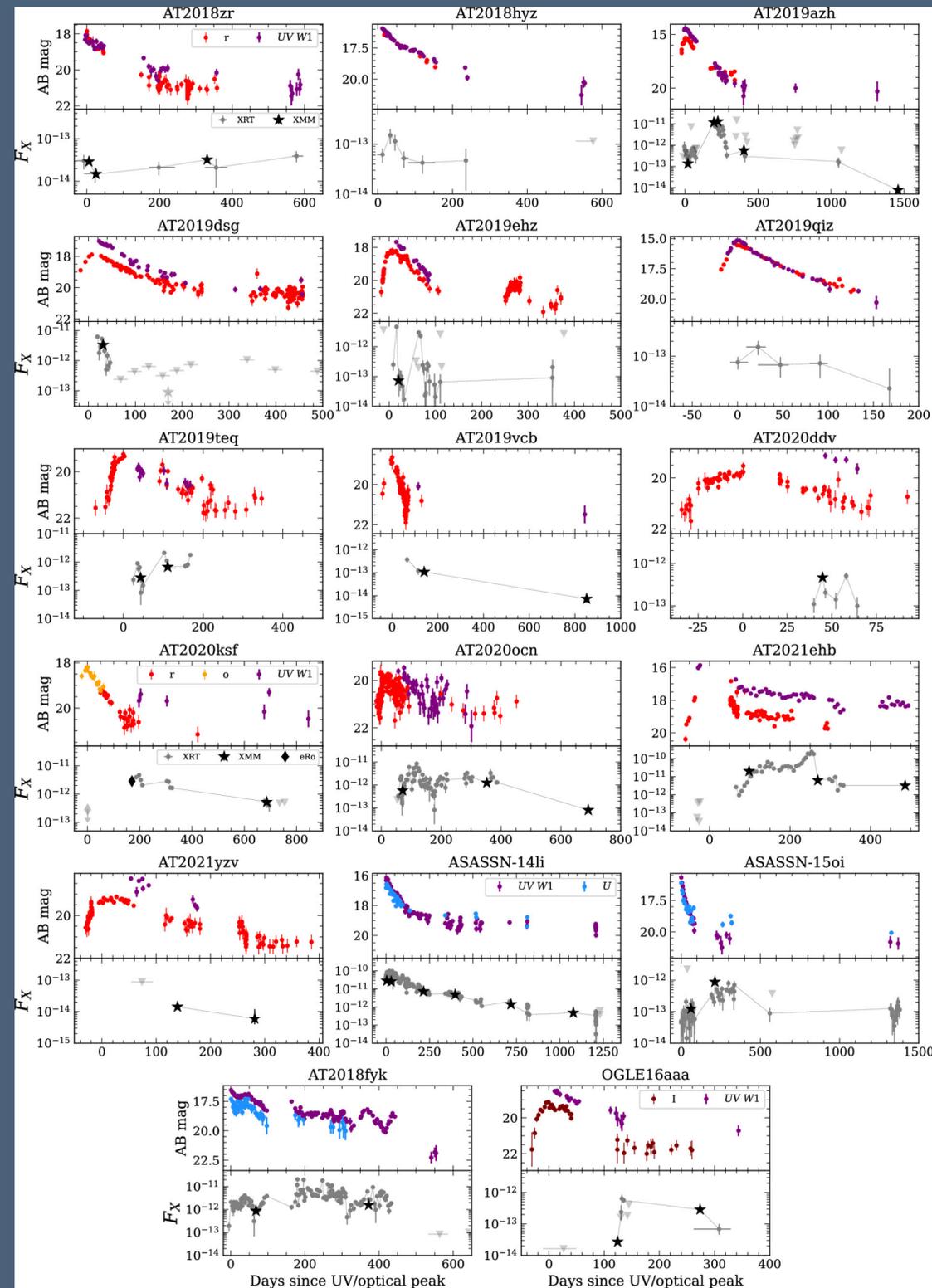
Plot: Leloudas et al. (2019), Data: Gezari et al. (2012), Arcavi et al. (2014) Holoien et al. (2014, 2016), Leloudas et al. (2019)

Spectral diversity within the PS1-10jh class



Faris et al. (2024)

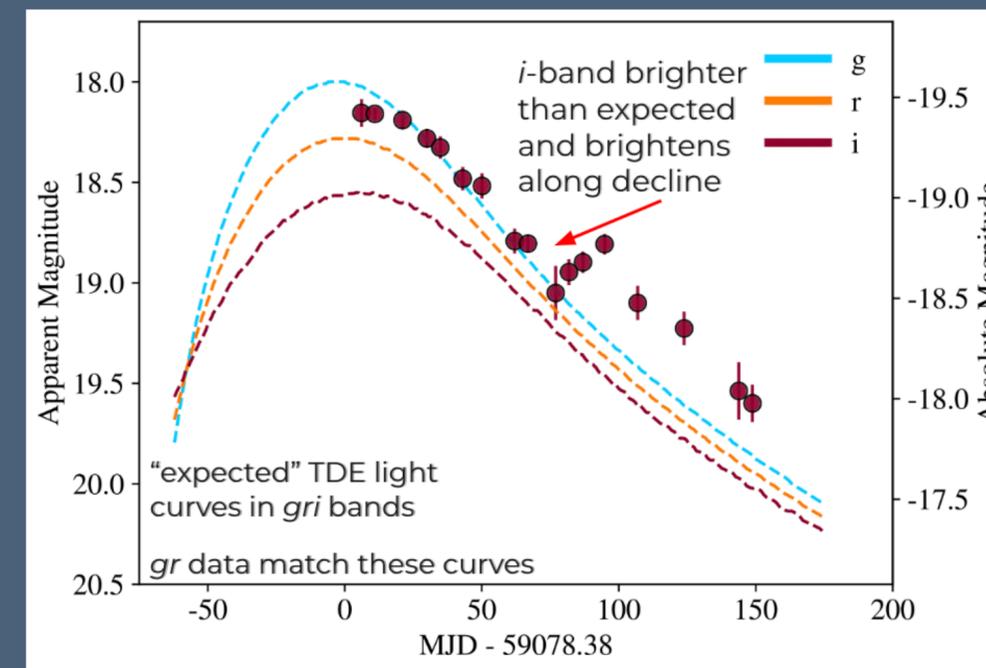
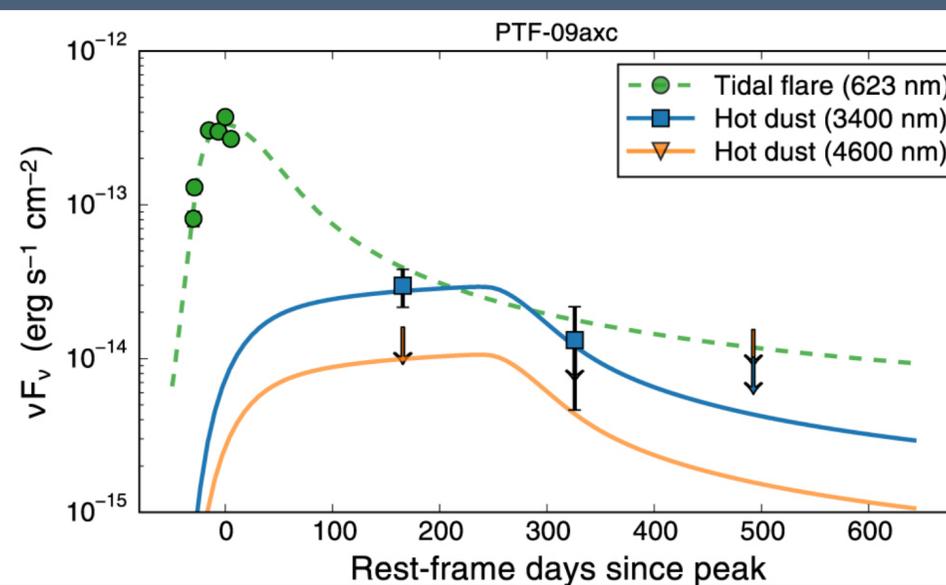
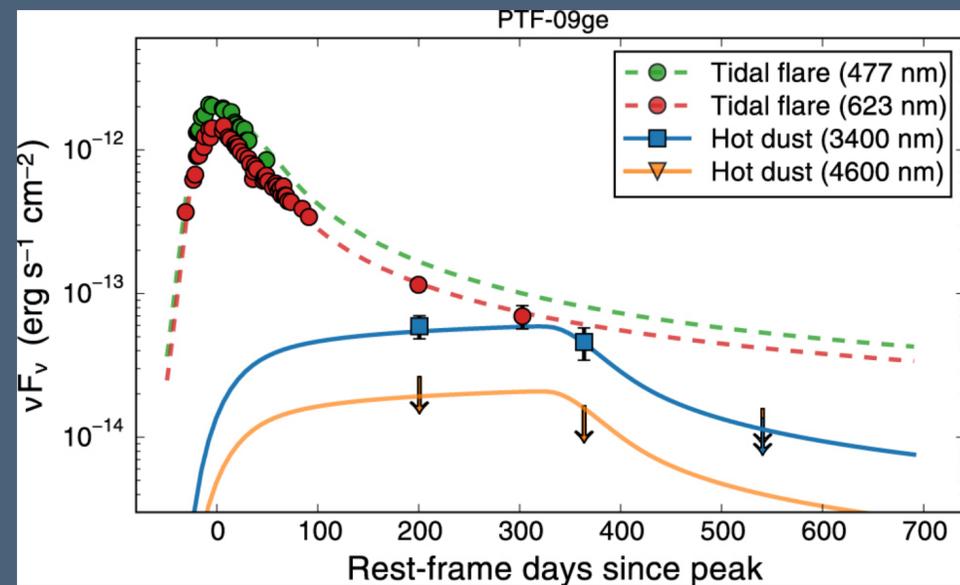
Multiwavelength diversity within the PS1-10jh class



Plot: Cendes et al. (2024), Data: Cendes et al. (2021a,b, 2022, 2024), Horesh et al. 2021, Stein et al. (2021), Andreoni et al. (2022), Goodwin et al. 2023a,b), Cendes et al. (2024)

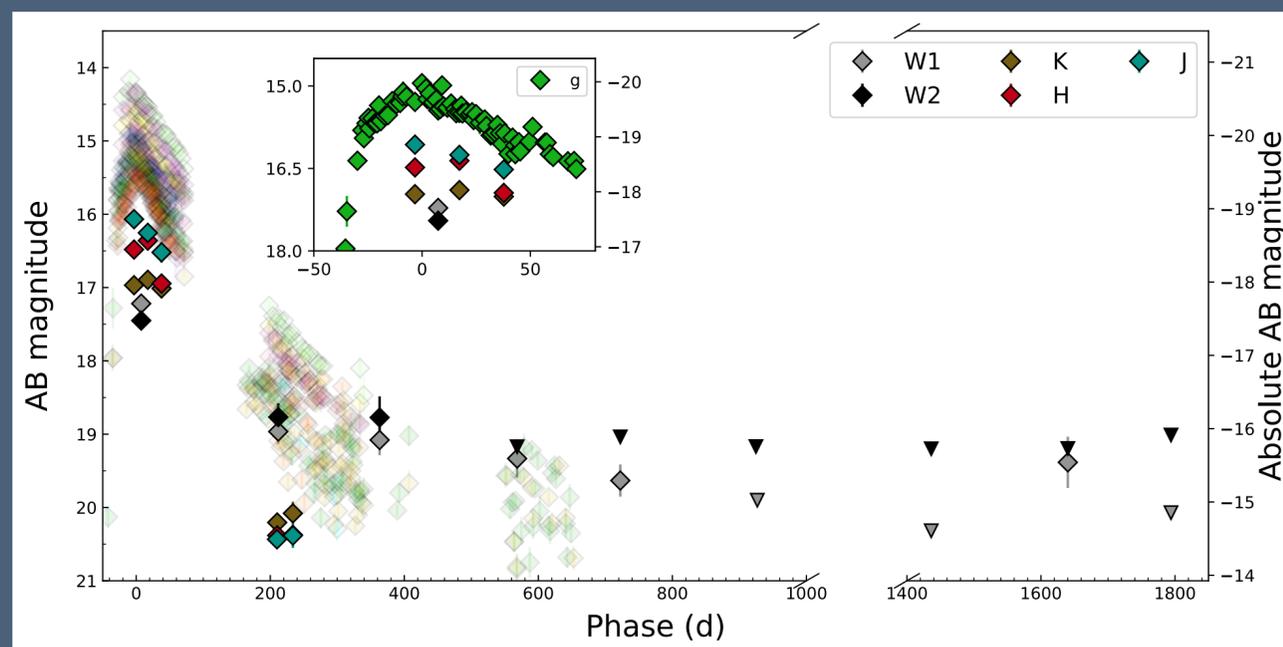
Guolo et al. (2024)

Multiwavelength diversity within the PS1-10jh class



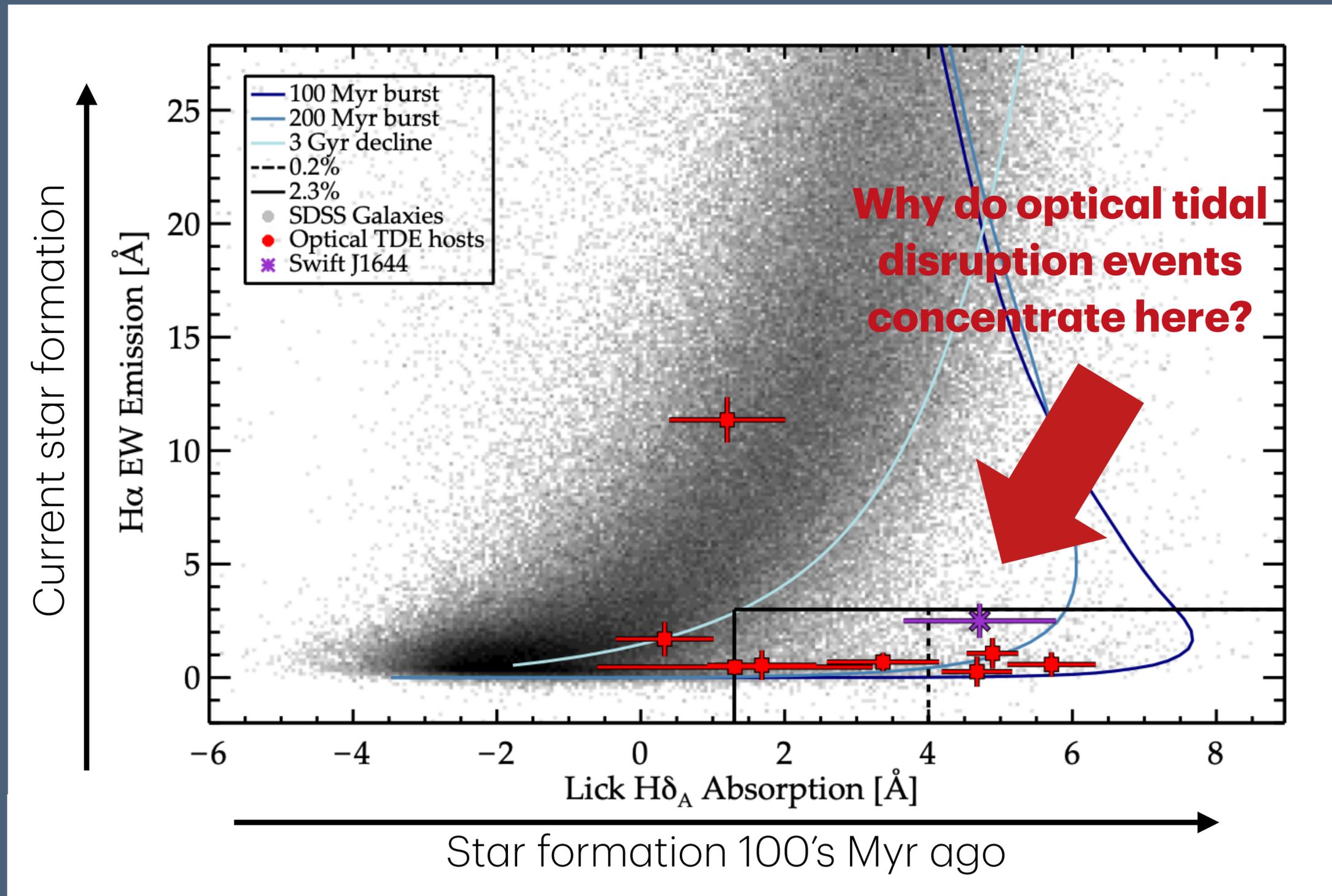
van Velzen et al. (2016); see also Jiang et al. (2021)

Newsome et al. (2024a)



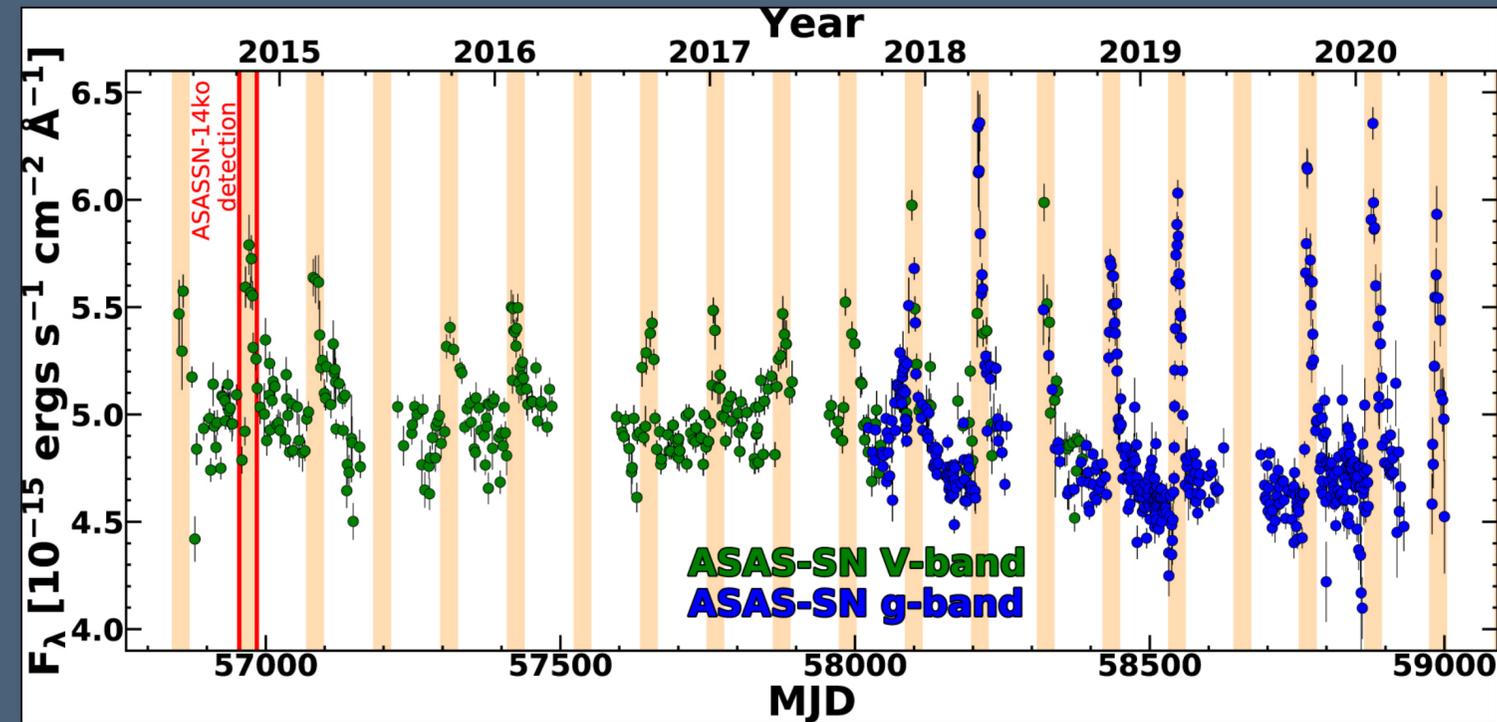
Reynolds et al. (2025)

Surprising uniformity in host galaxy properties



French, Arcavi,
Zabludoff (2016); see
also French et al. (2020)

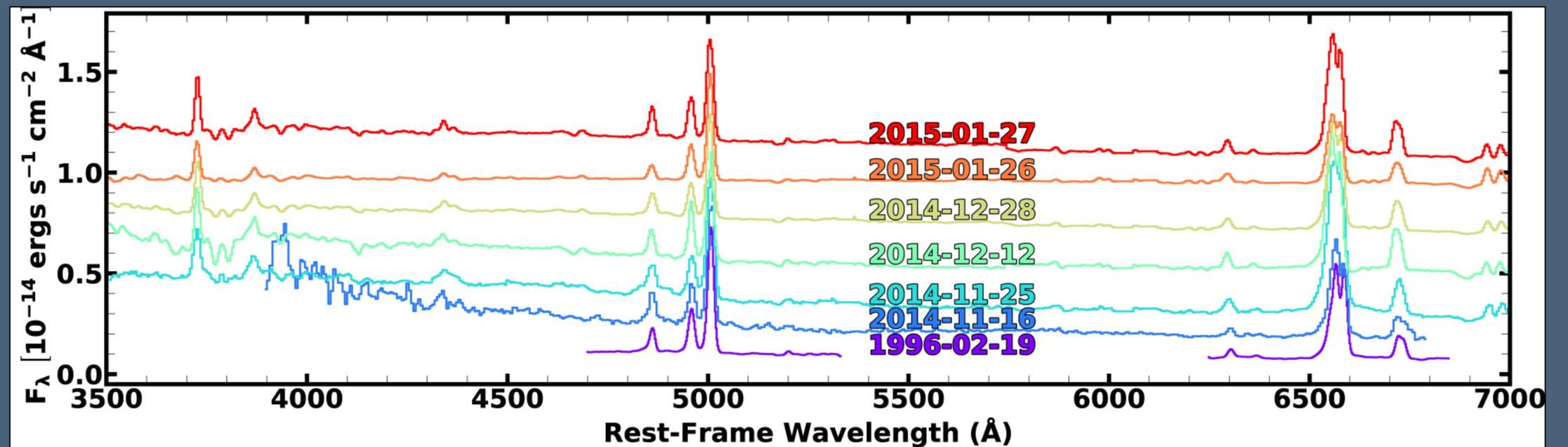
Repeating TDEs? ASASSN-14ko



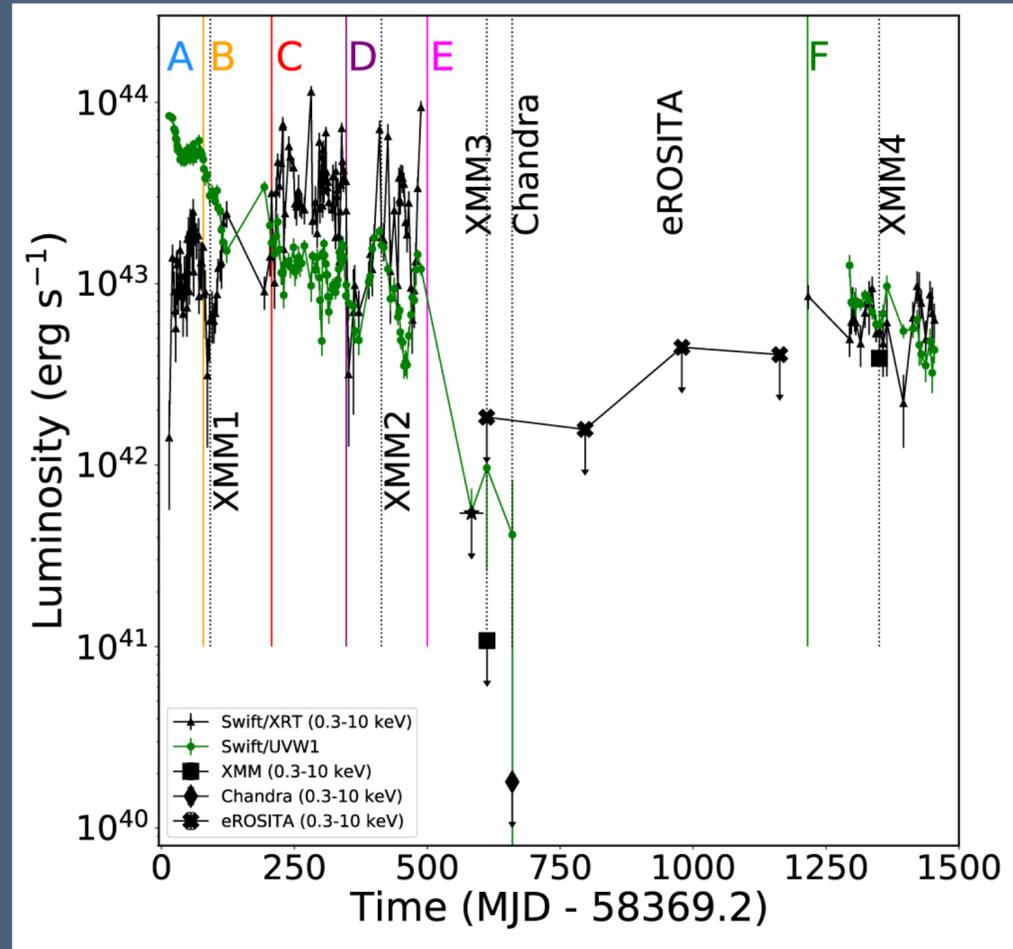
Payne et al. (2021)

114-day period, decreasing with time

HOWEVER: Spectra not the same as PS1-10jh class, some other phenomenon?



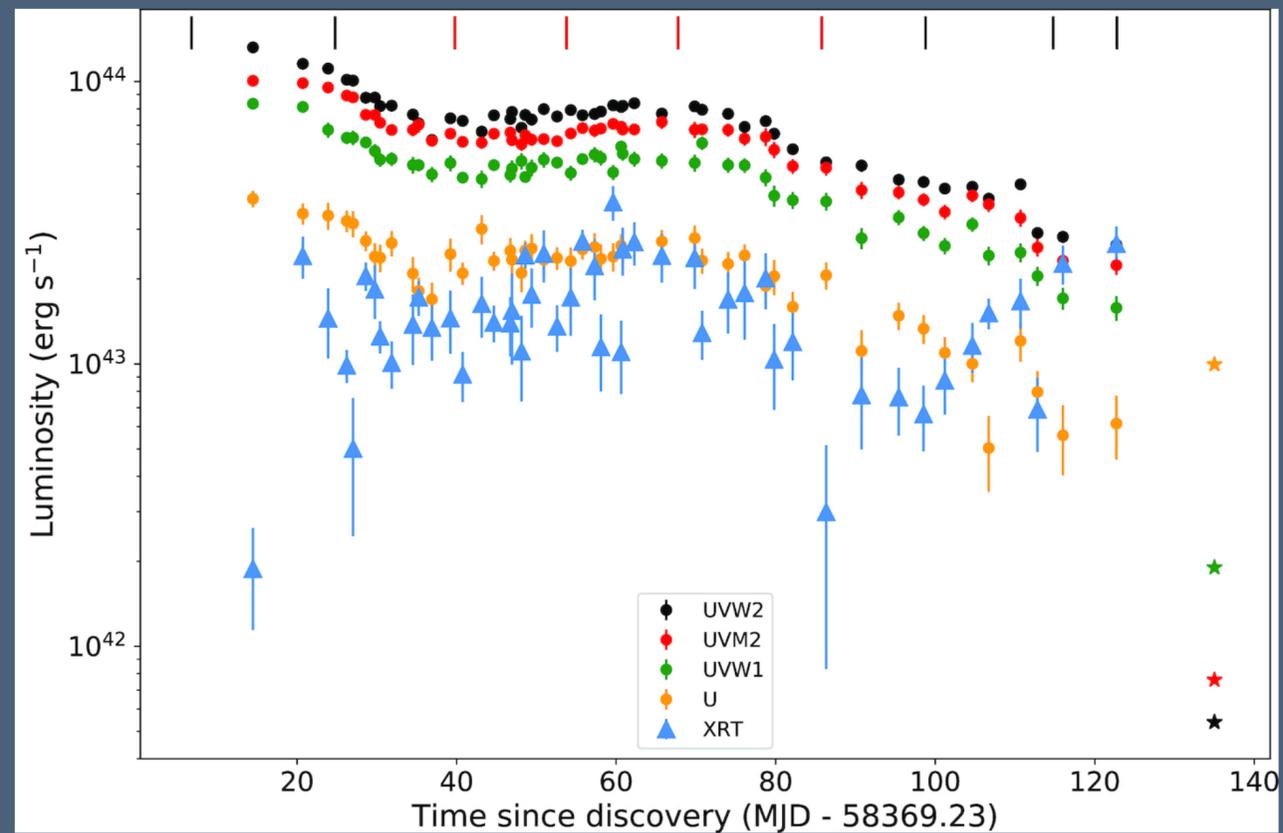
Repeating TDEs? AT 2018fyk



Wevers et al. (2023)

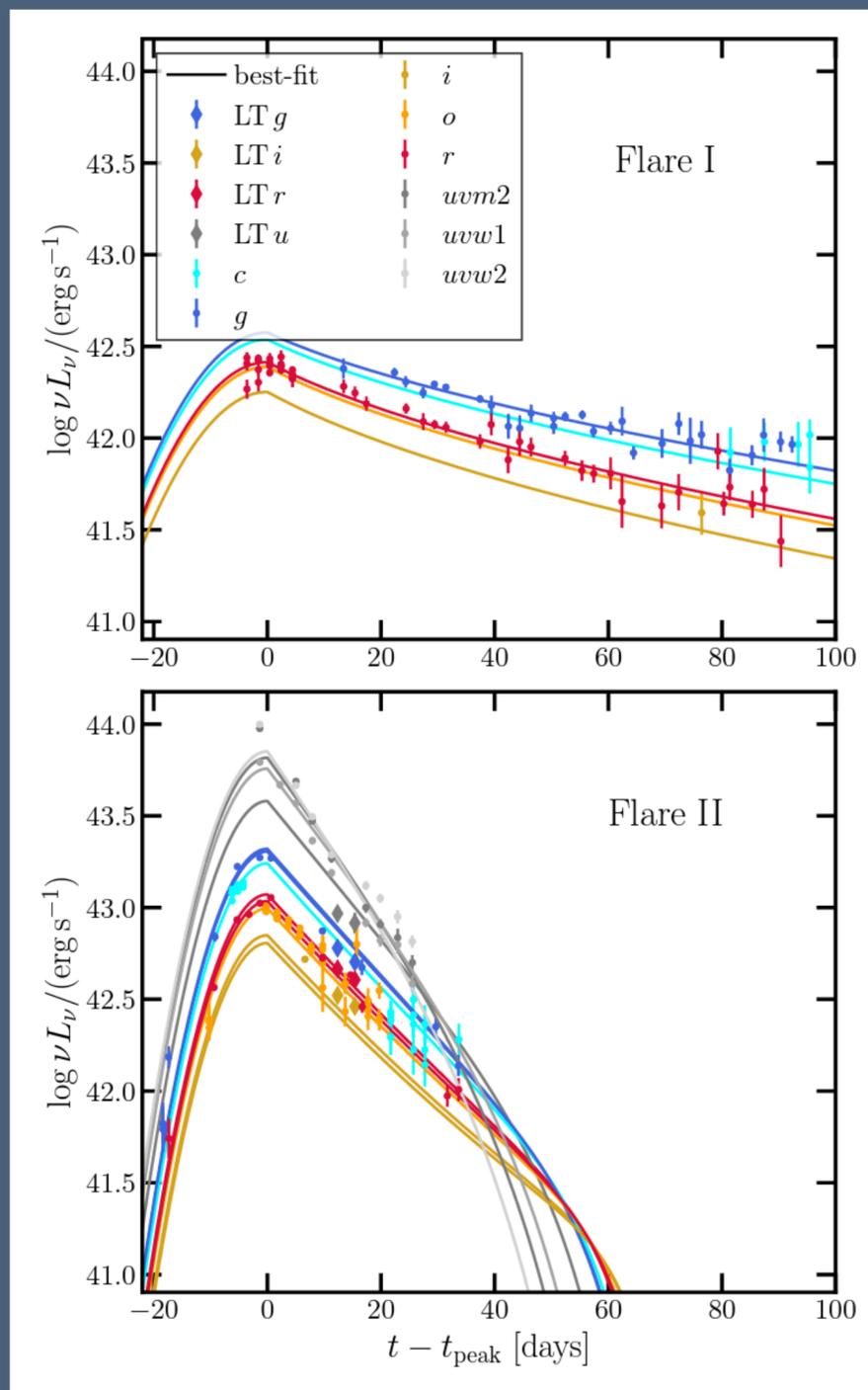
Similar to PS1-10jh class, re-brightening seen in the X-ray and UV

HOWEVER: First optical flare was unusual: re-brightened + Fe features



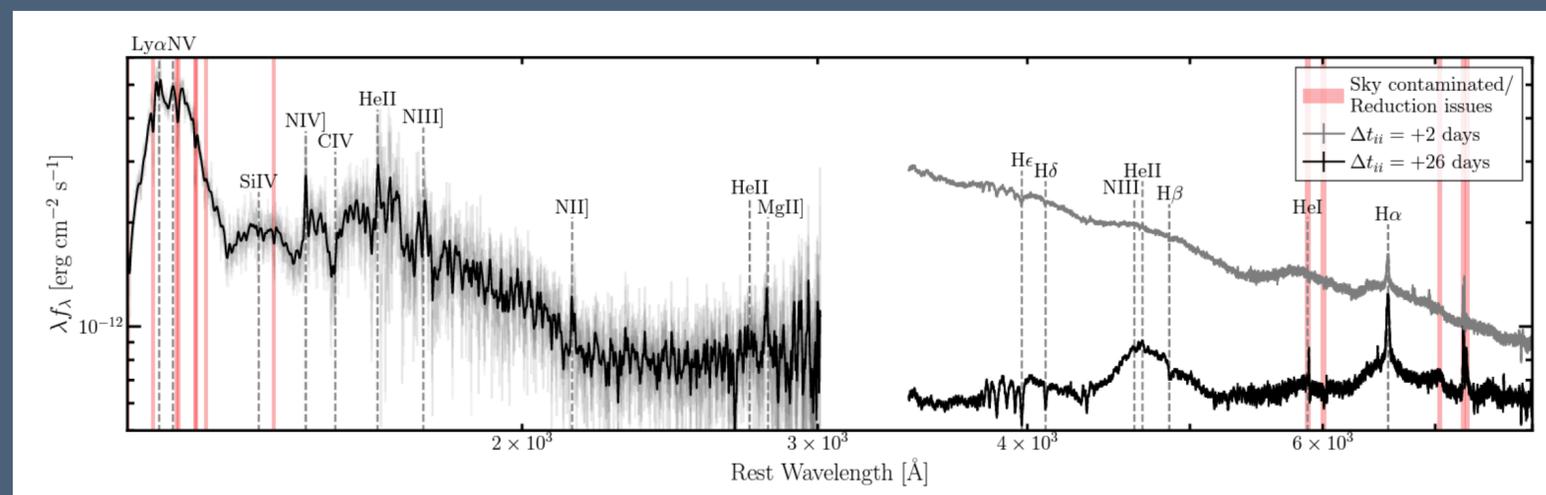
Wevers et al. (2019)

Repeating TDEs? AT 2020vda



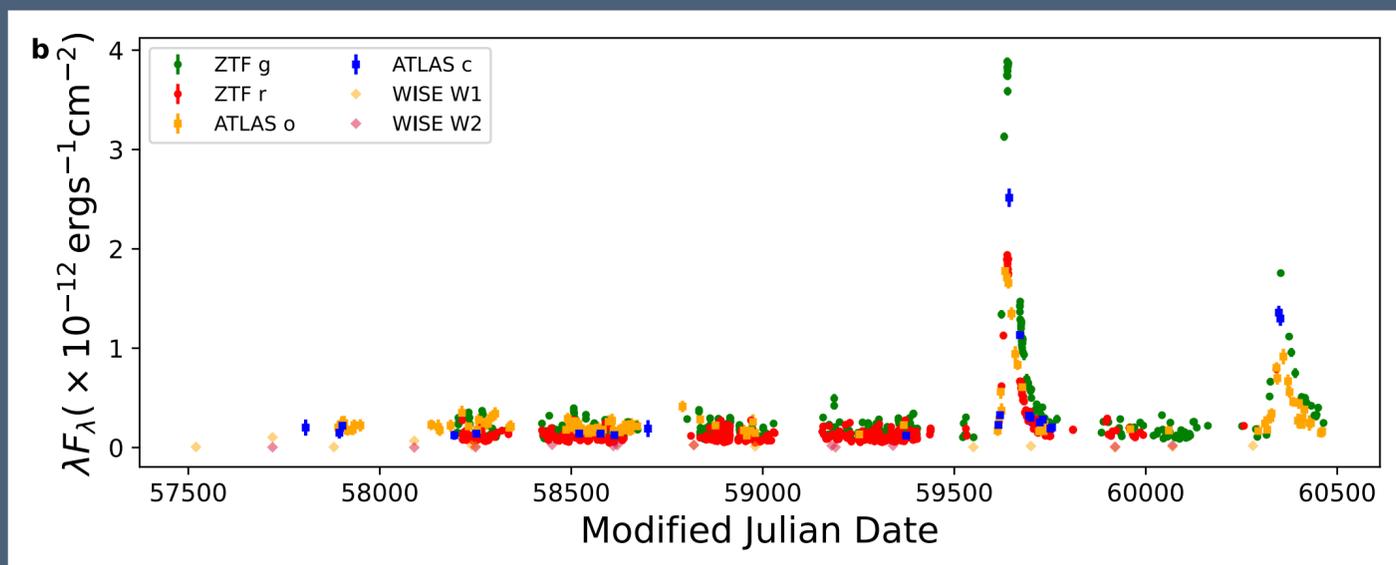
Second flare is a bonafide PS1-10jh class event.

HOWEVER: First flare different from second, no spectrum, and $\sim 1\text{-}10\%$ chance of two unrelated TDEs given post-starburst host $H\delta_A$ absorption.



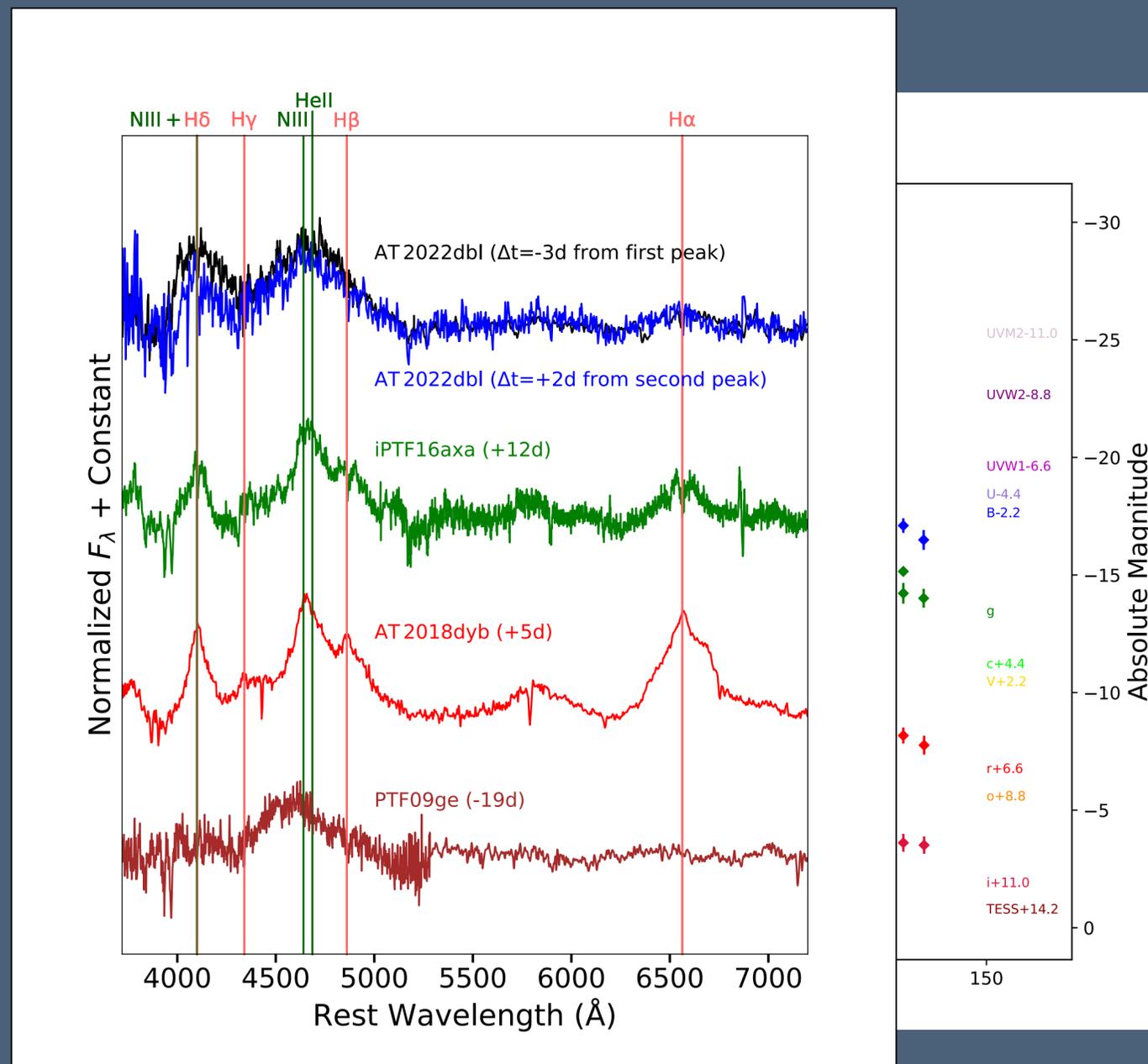
Repeating TDEs: AT 2022dbl

The first standard PS1-10jh class TDE to robustly repeat: big implications



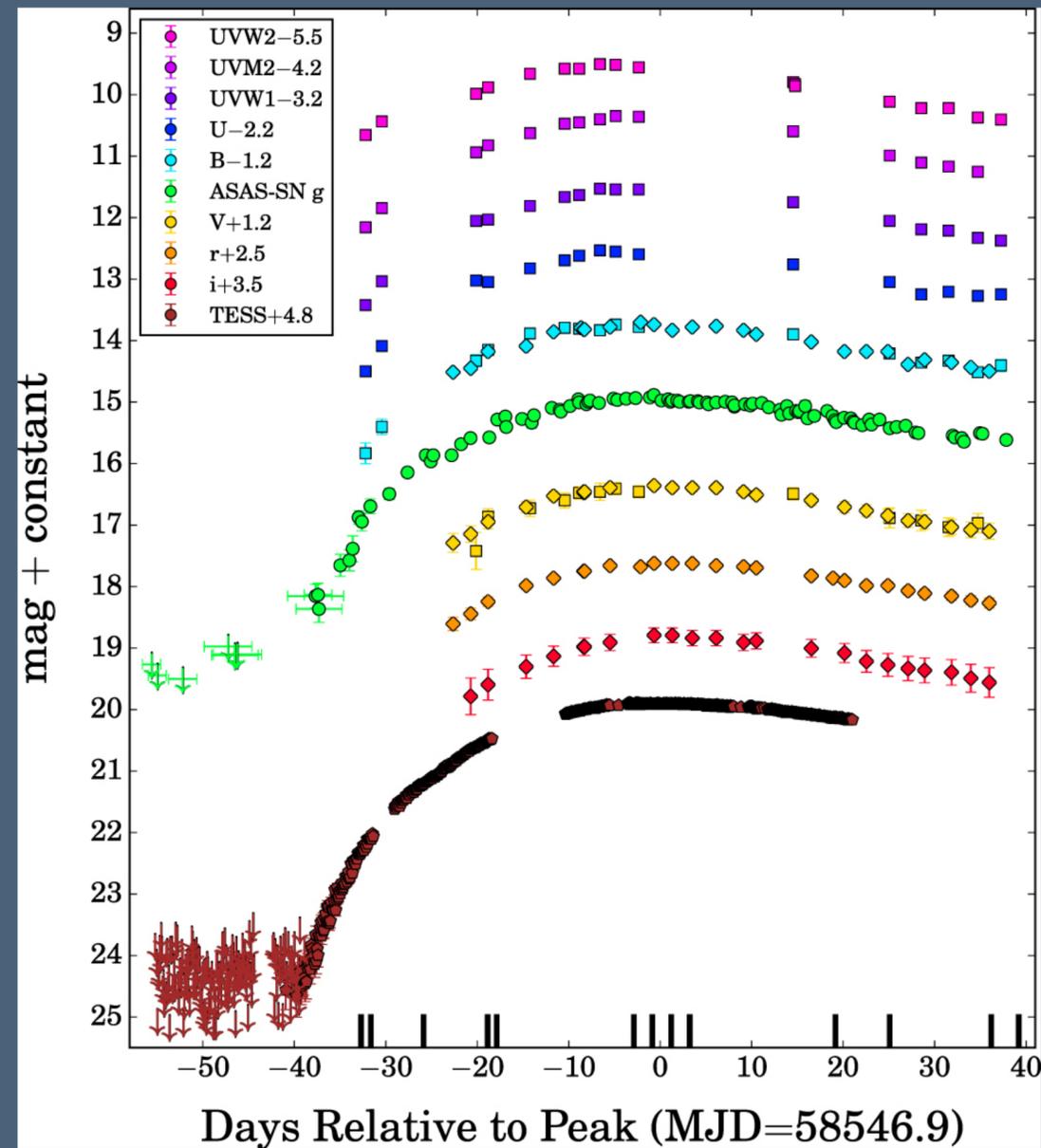
Makrygianni, Arcavi et al. (2025); Lin et al. (2024), Hinkle et al. (2024)

Host implies $\ll 1\%$ chance of two unrelated TDEs within 700d



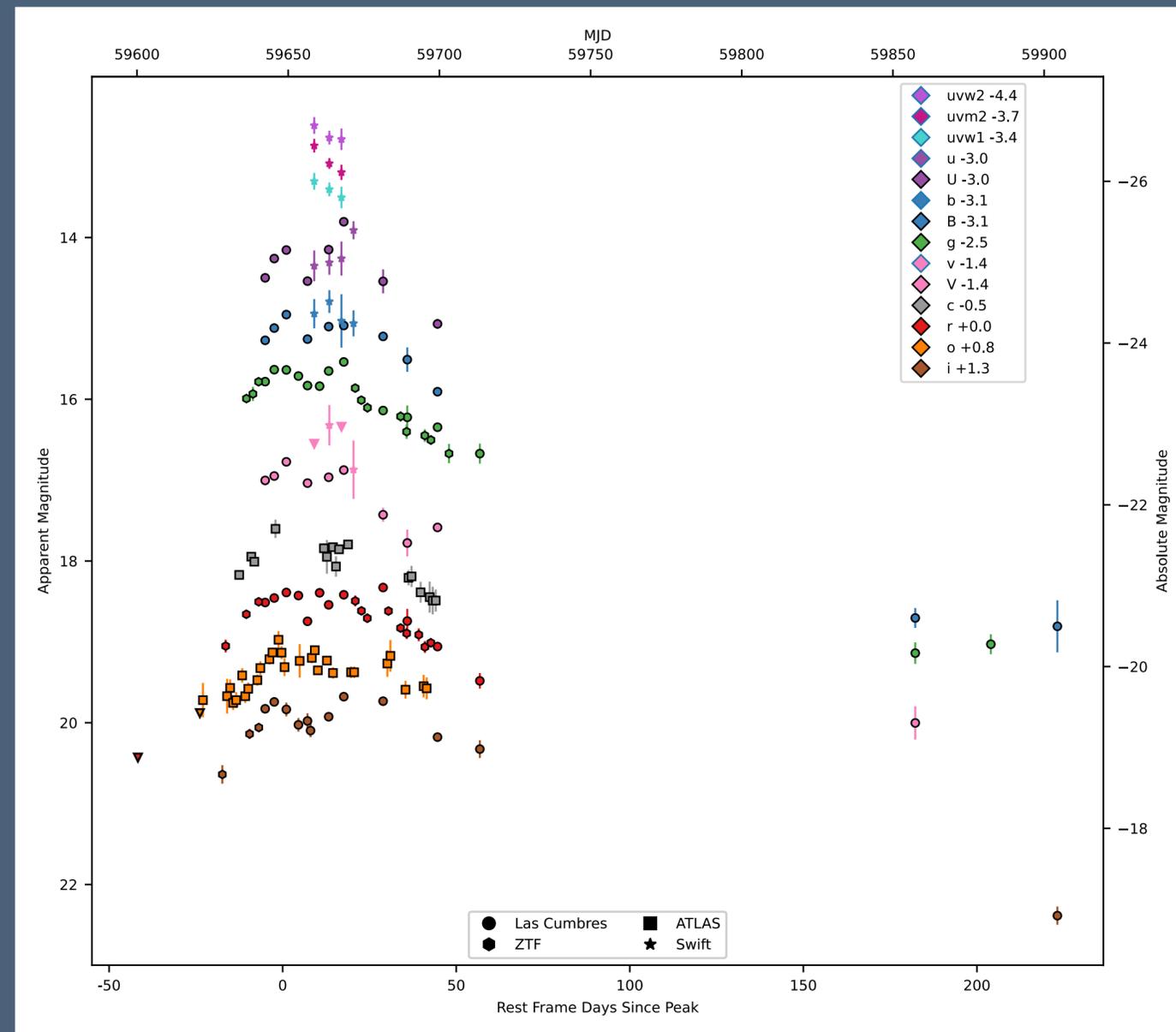
TDEs in AGN: AT 2019ahk and AT 2022csn

AT 2019ahk



Holoien et al. (2019)

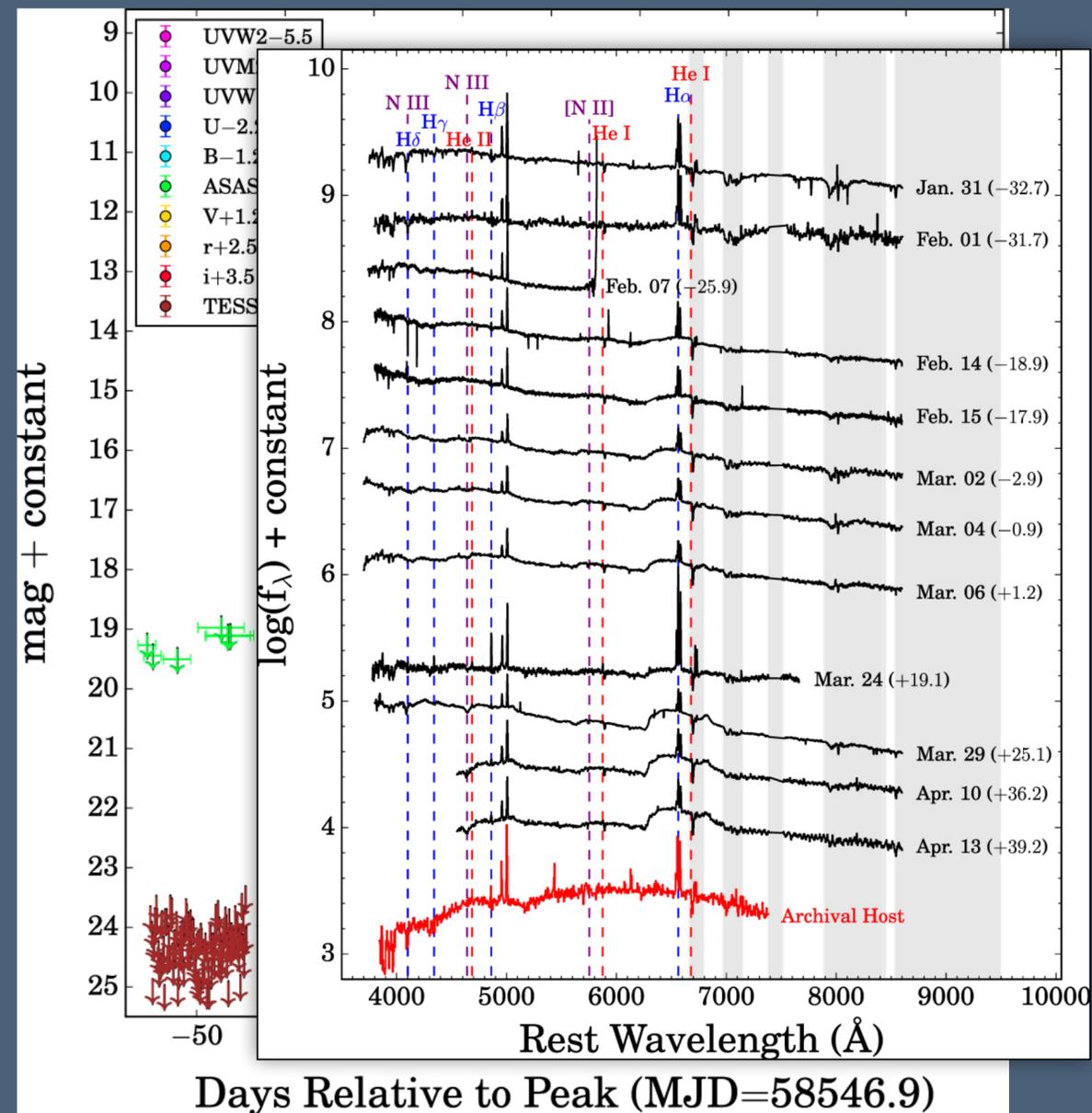
AT 2022csn



Dgany et al. (in prep)

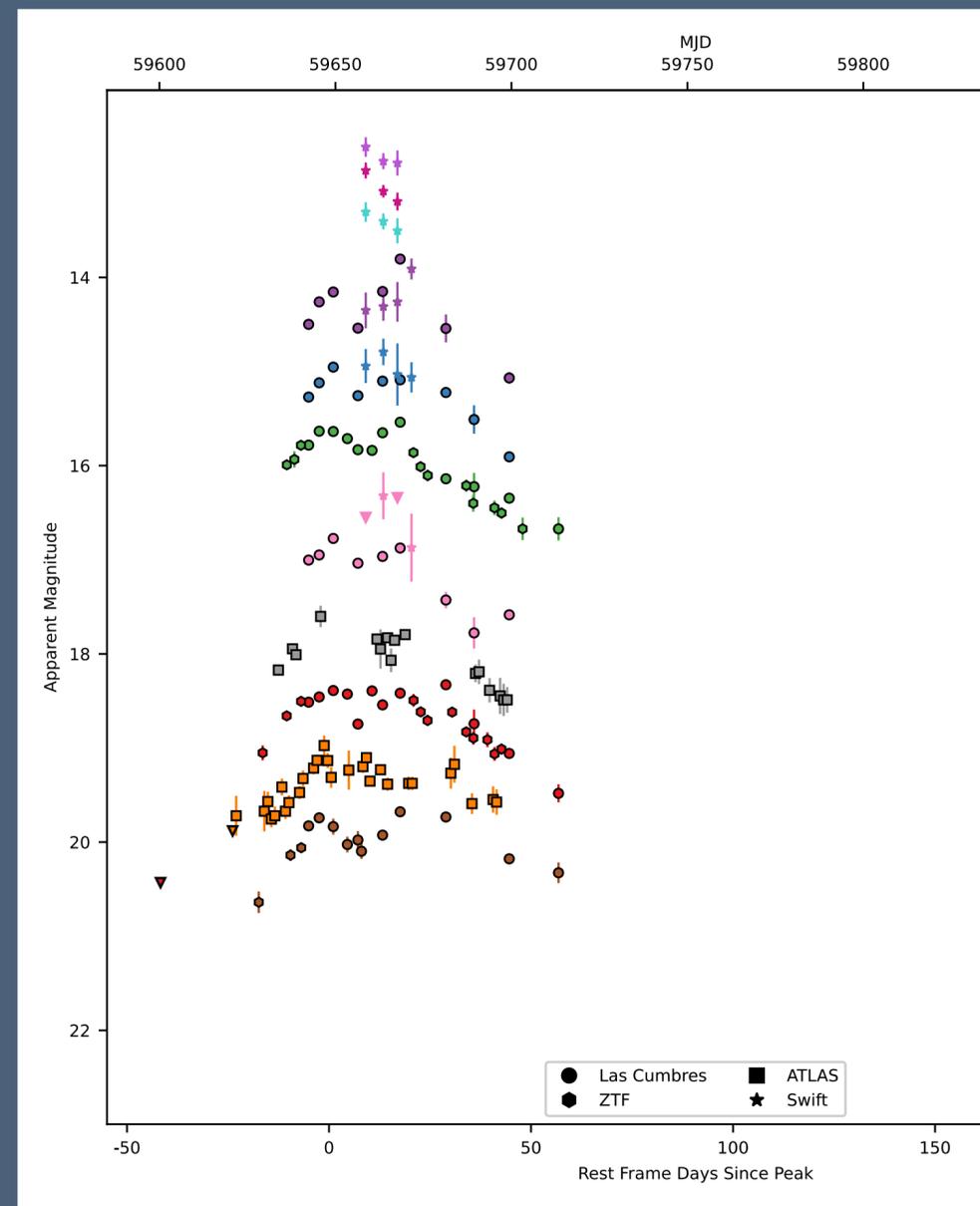
TDEs in AGN: AT 2019ahk and AT 2022csn

AT 2019ahk

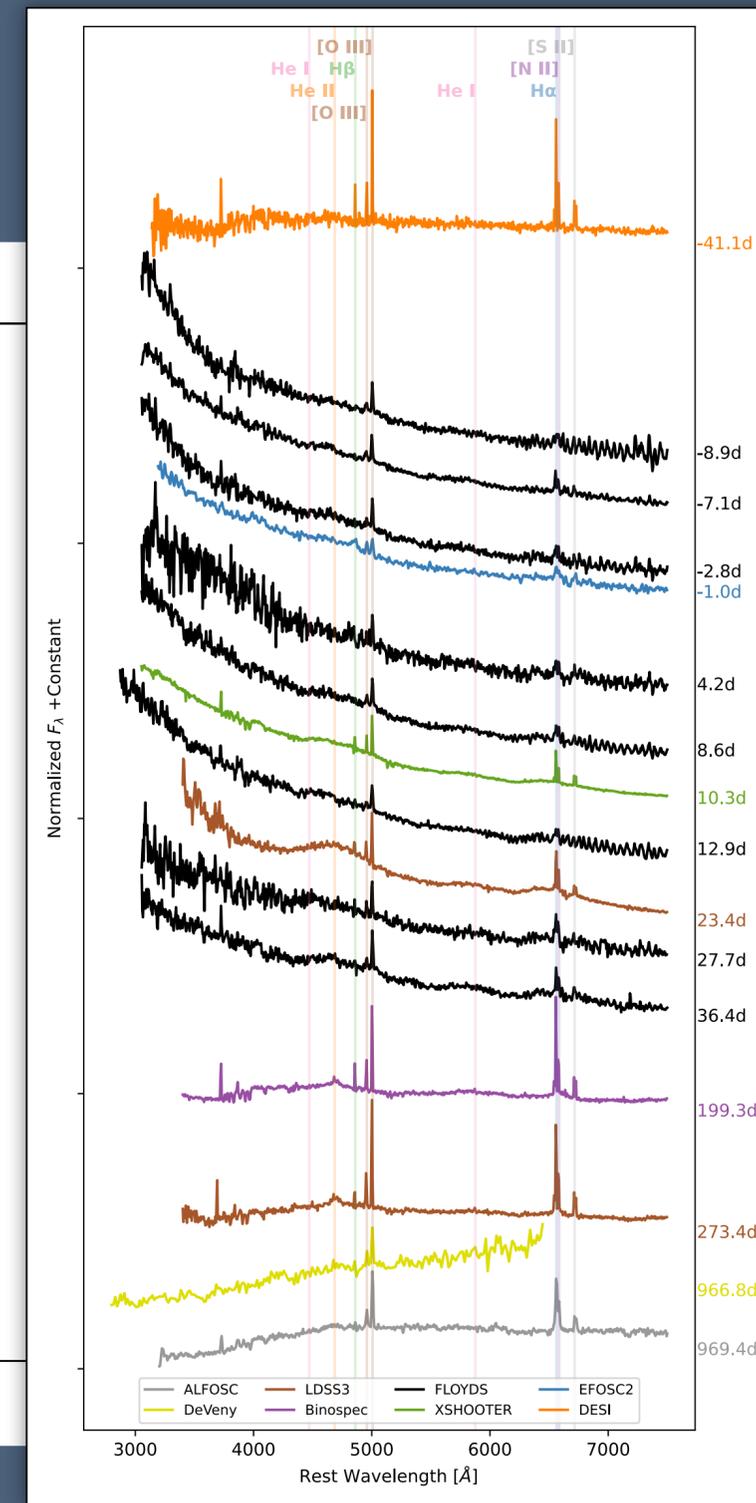


Holoien et al. (2019)

AT 2022csn

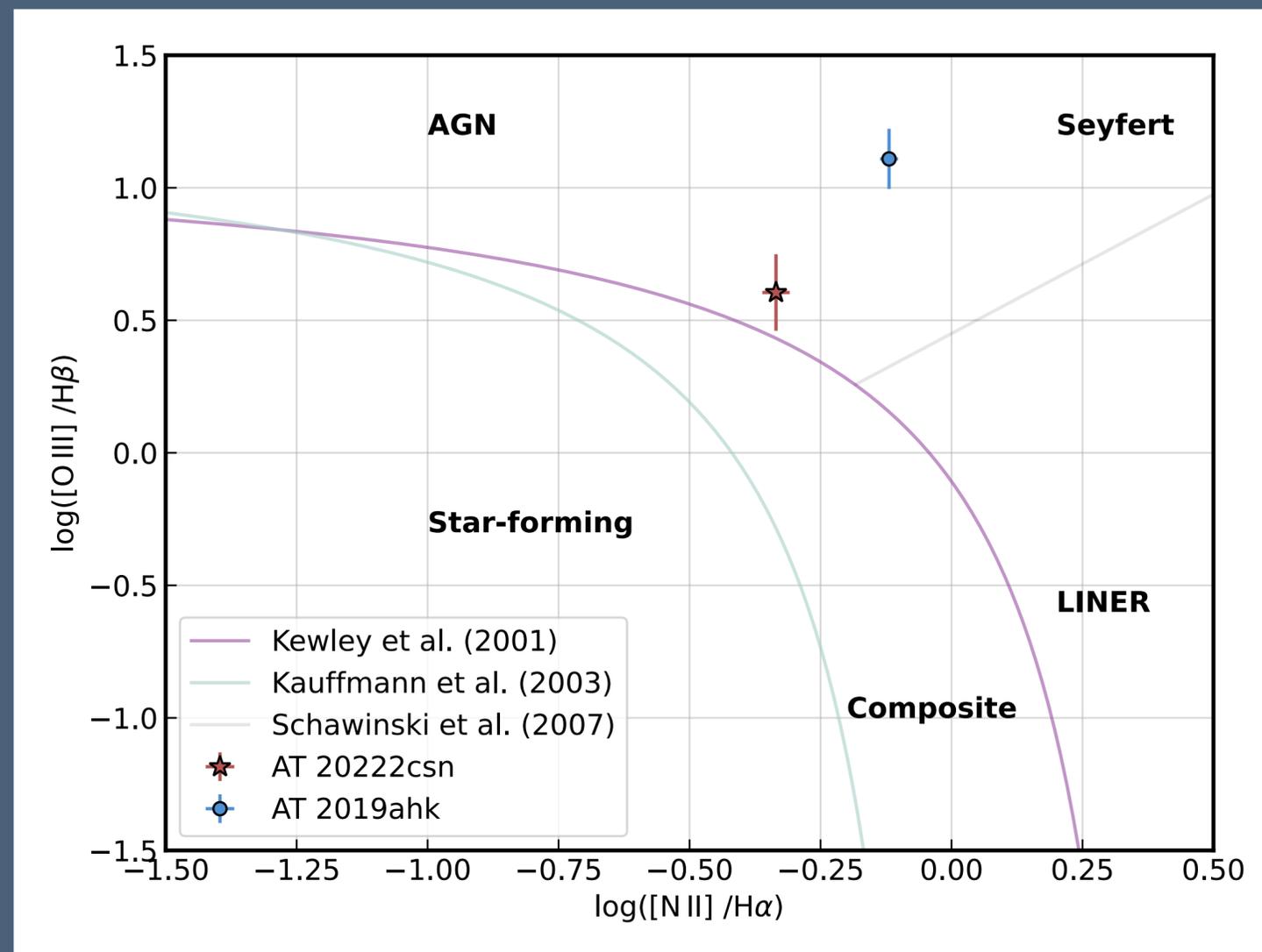
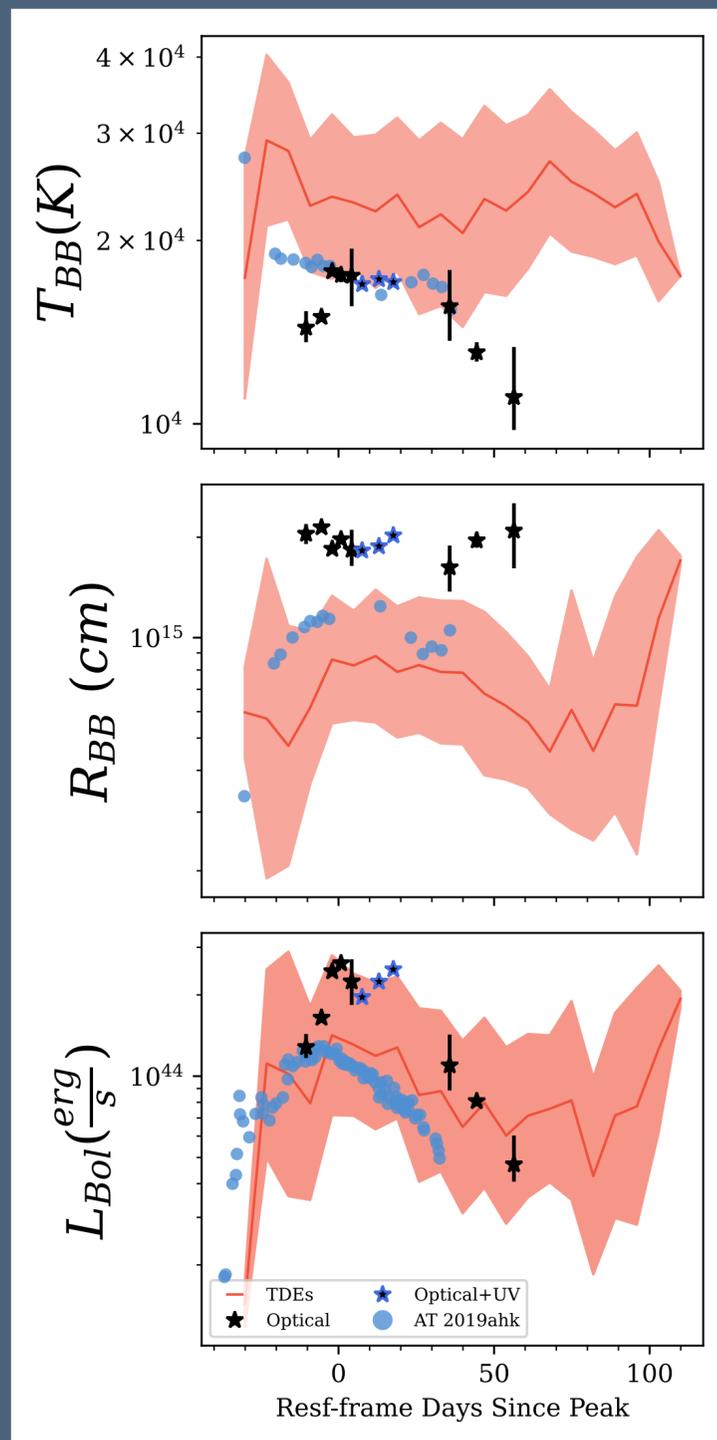


Dgany et al. (in prep)

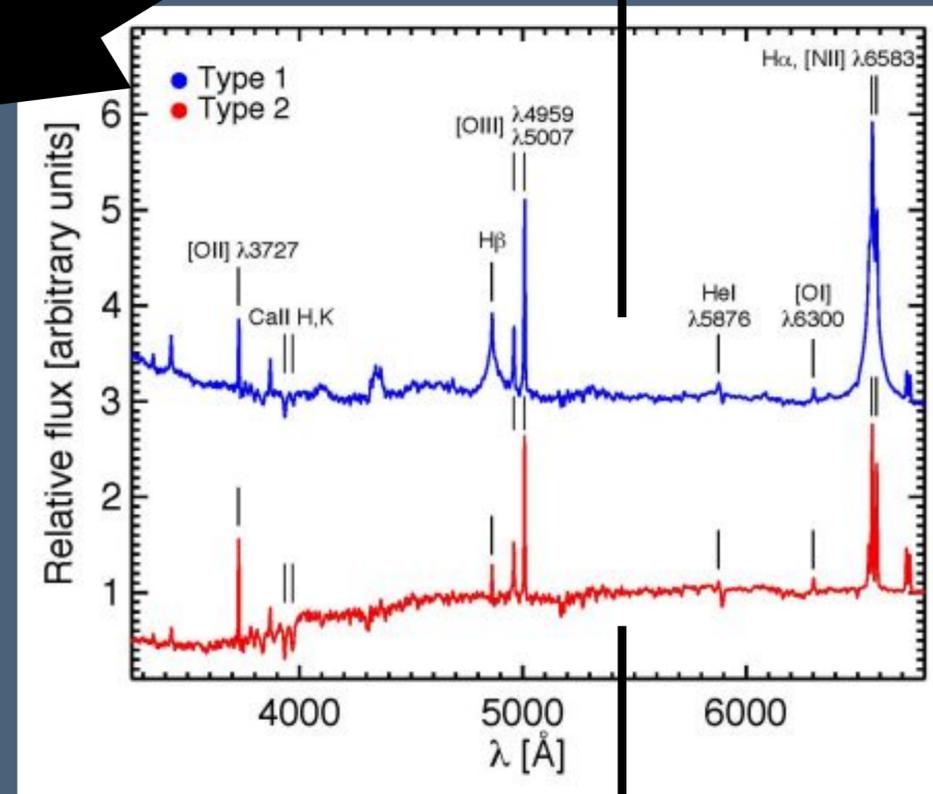
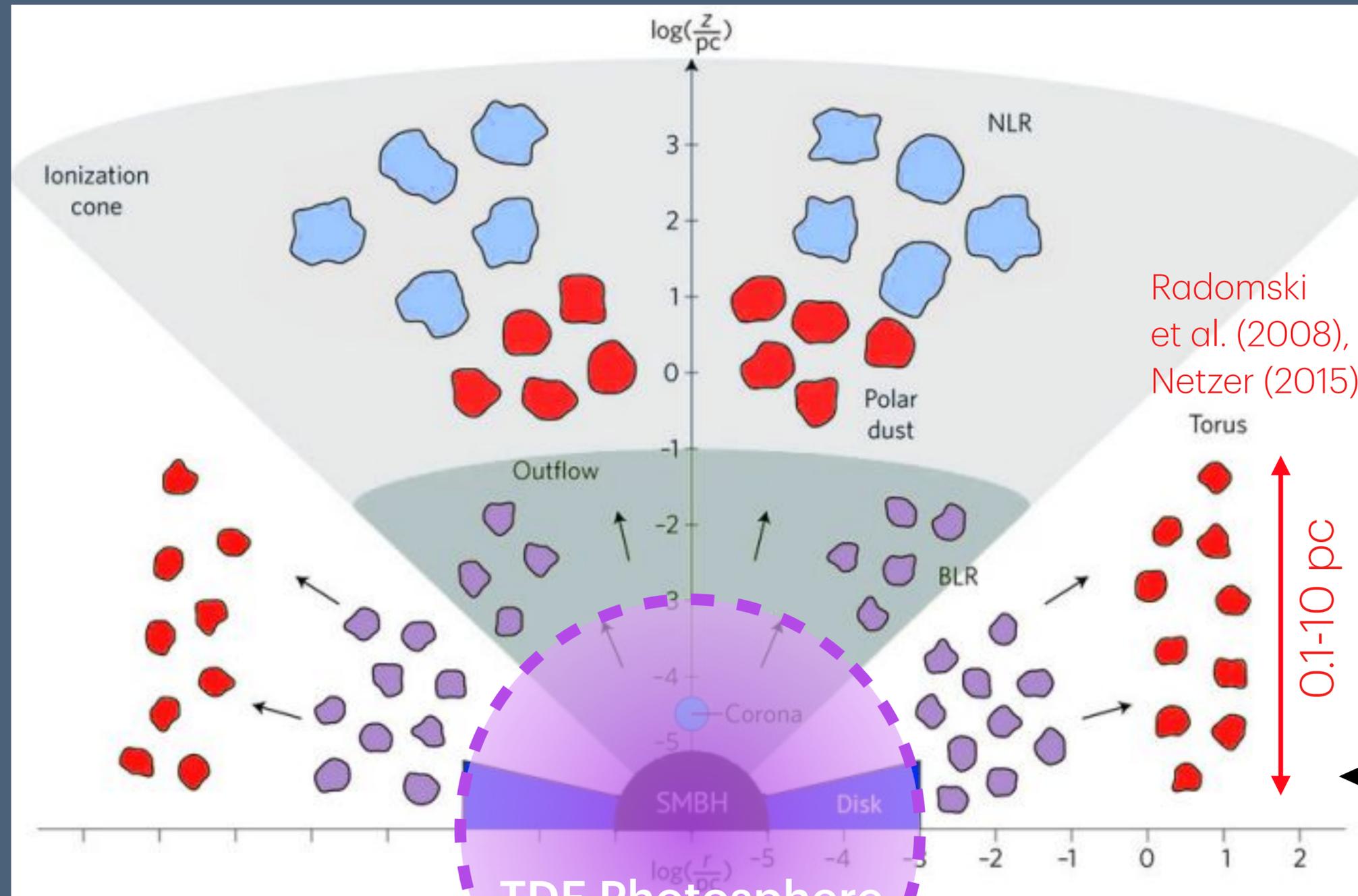


TDEs in AGN: AT 2019ahk and AT 2022csn

Could the interaction between the TDE and AGN disk produce the peculiar photometric properties of 2019ahk and 2022csn?



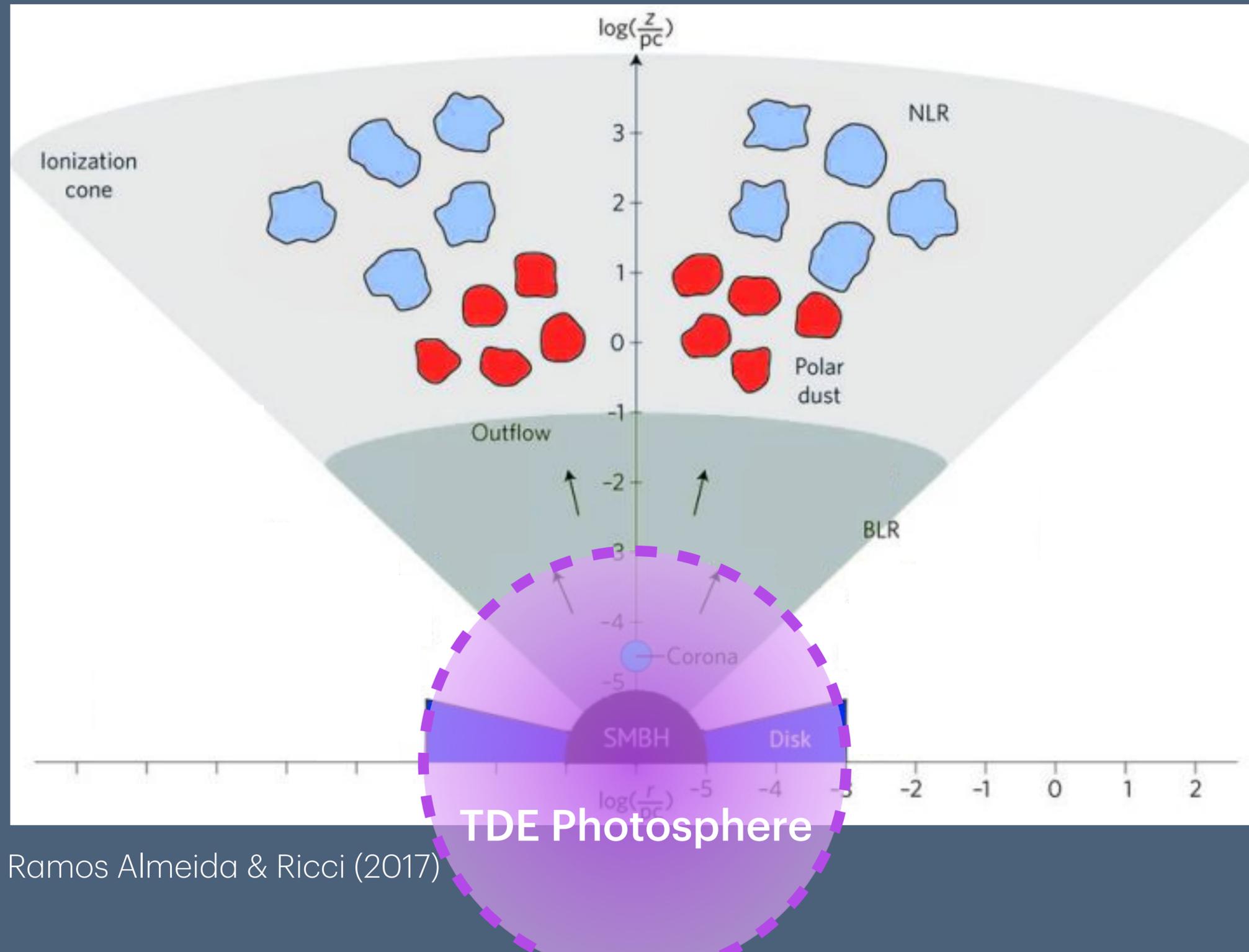
Wait! How would a TDE be visible in a Type II AGN?



0.1-10 pc

Wait! How would a TDE be visible in a Type II AGN?

True Type II AGN?

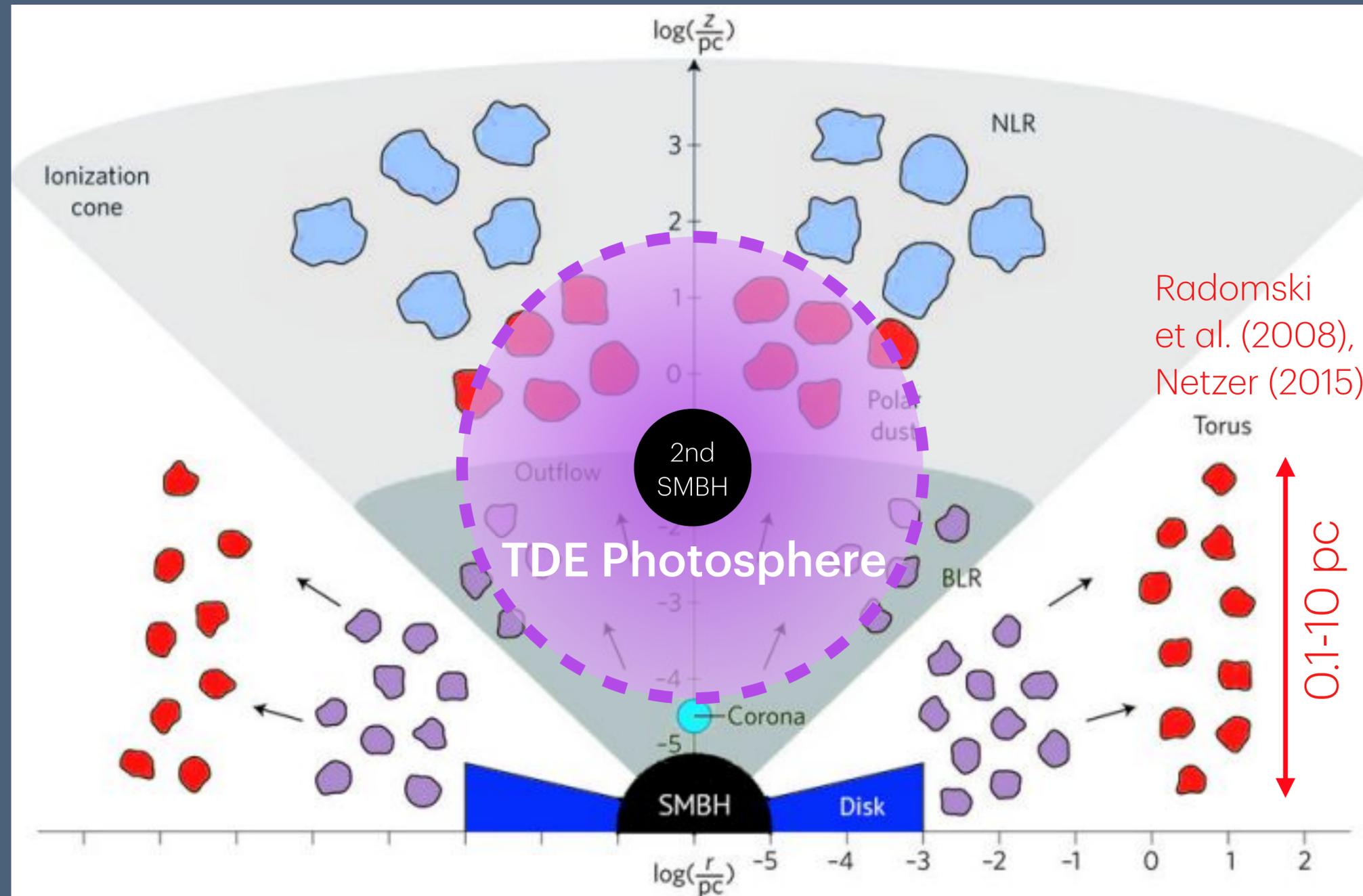


Ramos Almeida & Ricci (2017)

Wait! How would a TDE be visible in a Type II AGN?

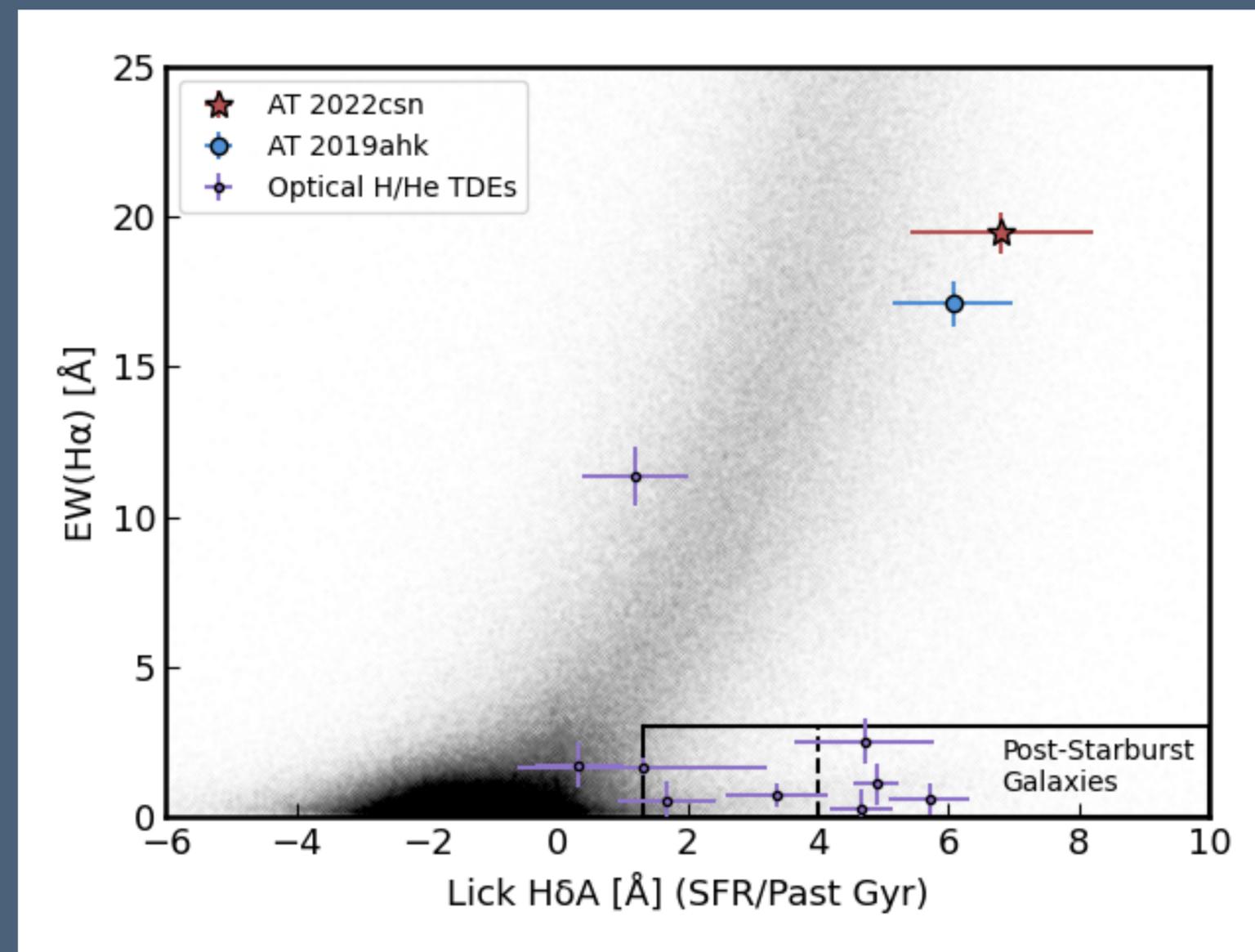
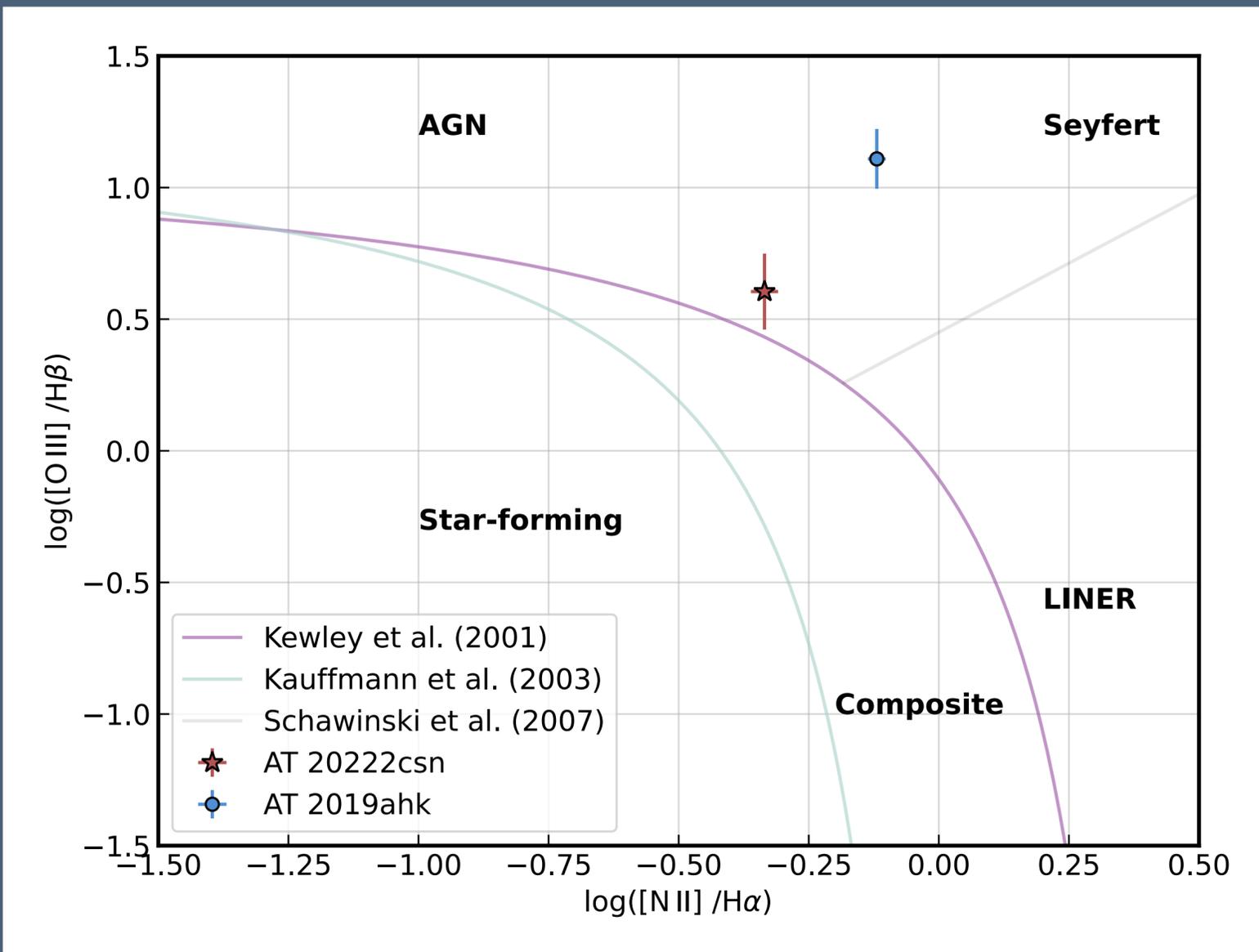
True Type II AGN?

Offset SMBH in a binary?

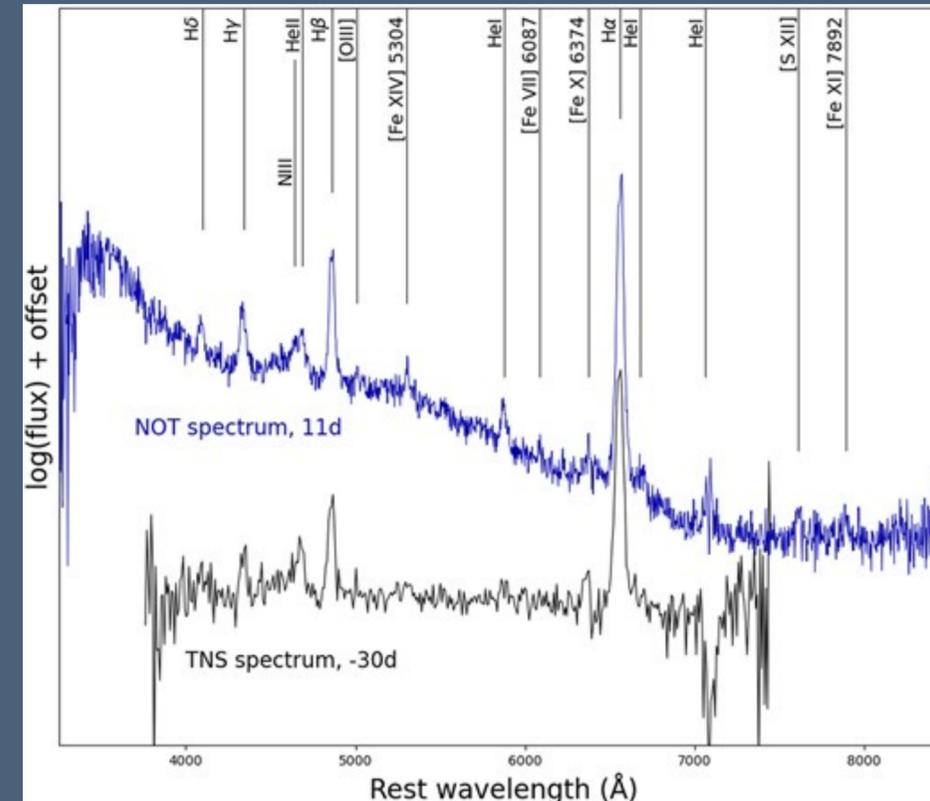
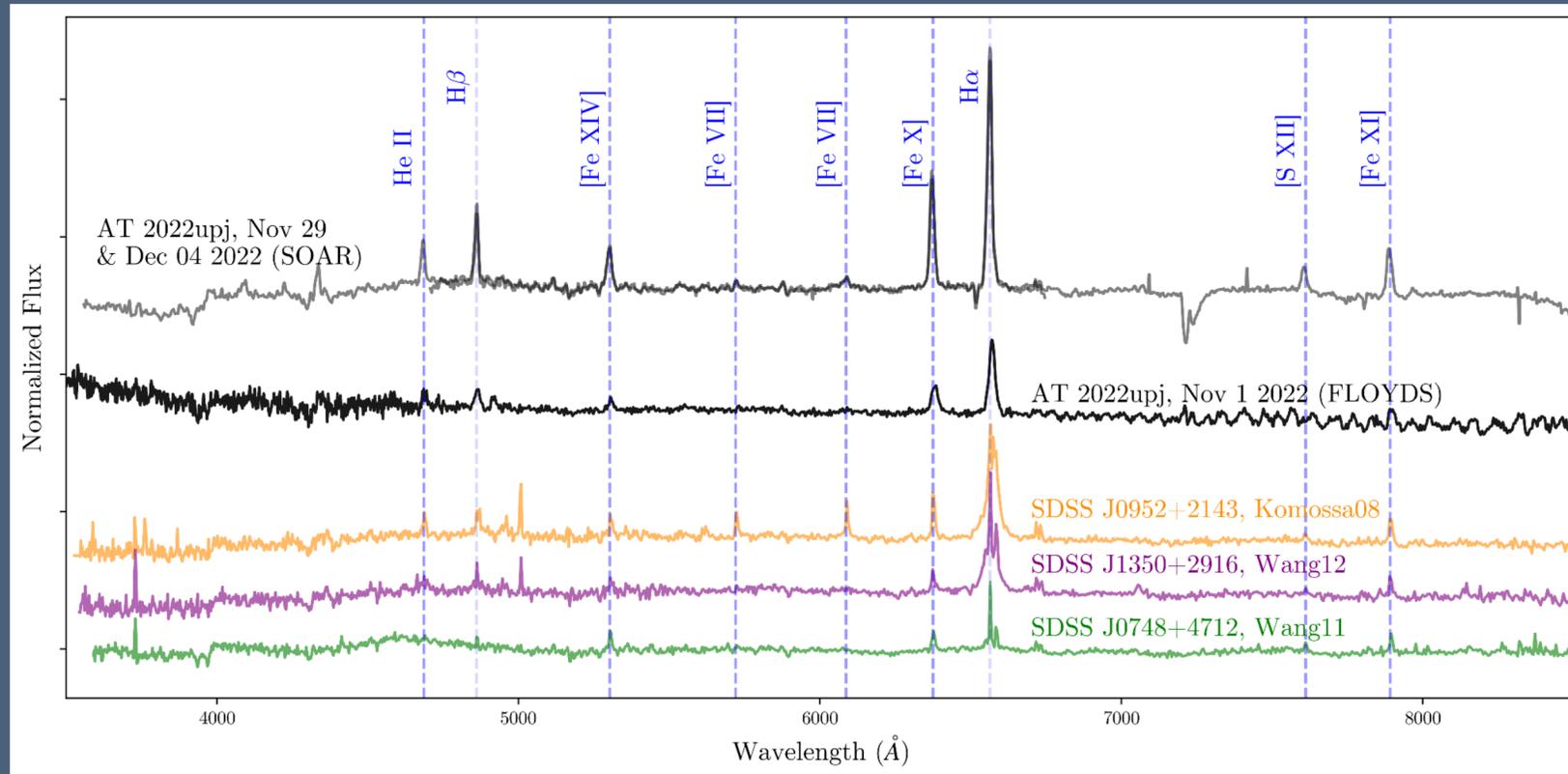


TDEs in AGN? Or are they SPOGs?

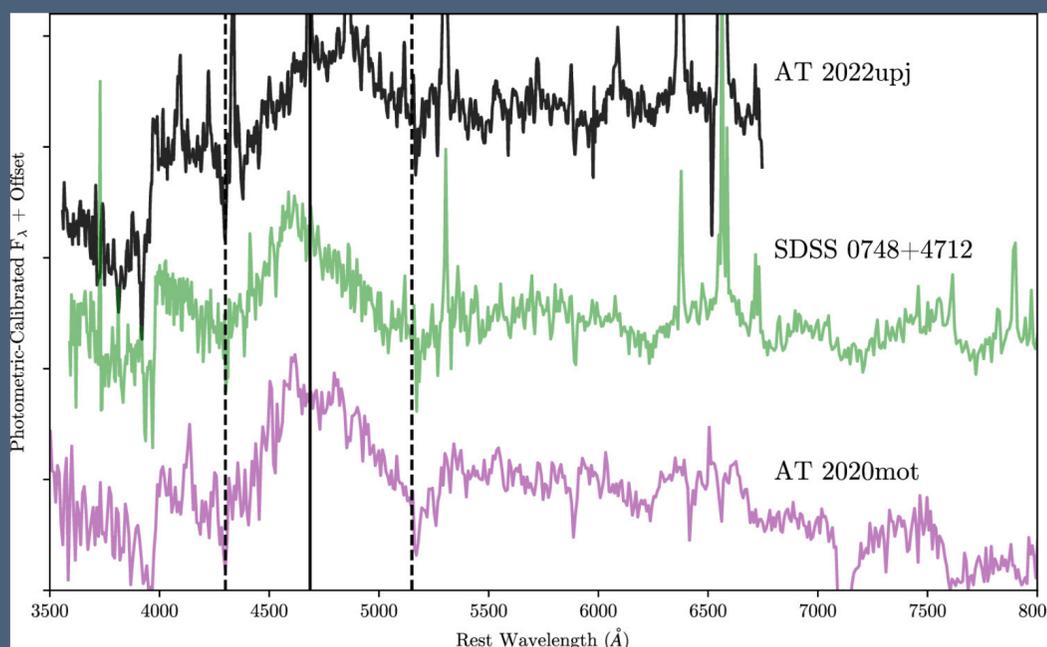
No AGN at all?



Extreme coronal line emitters as echoes of TDEs?

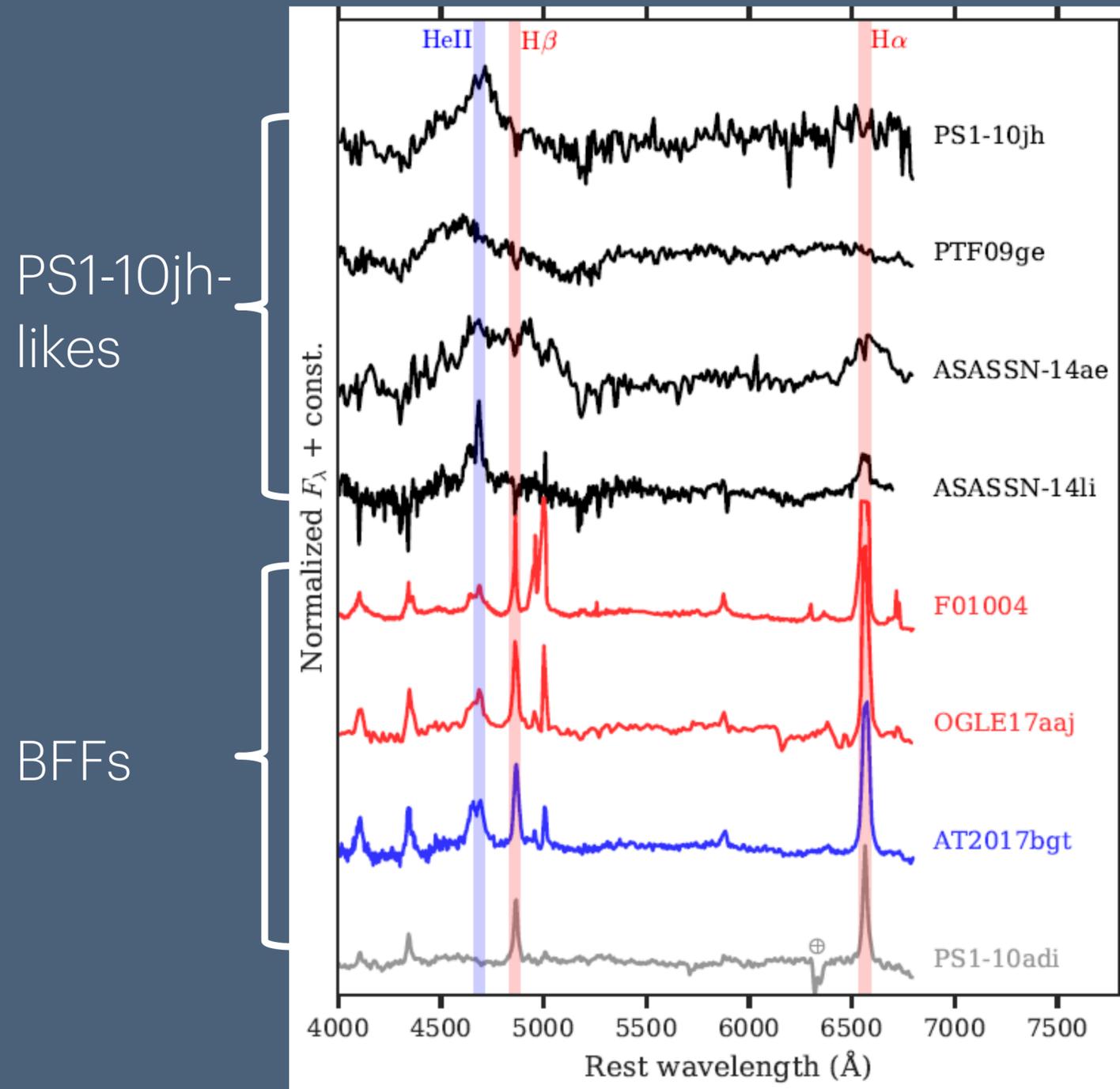


Koljonen et al. (2024)

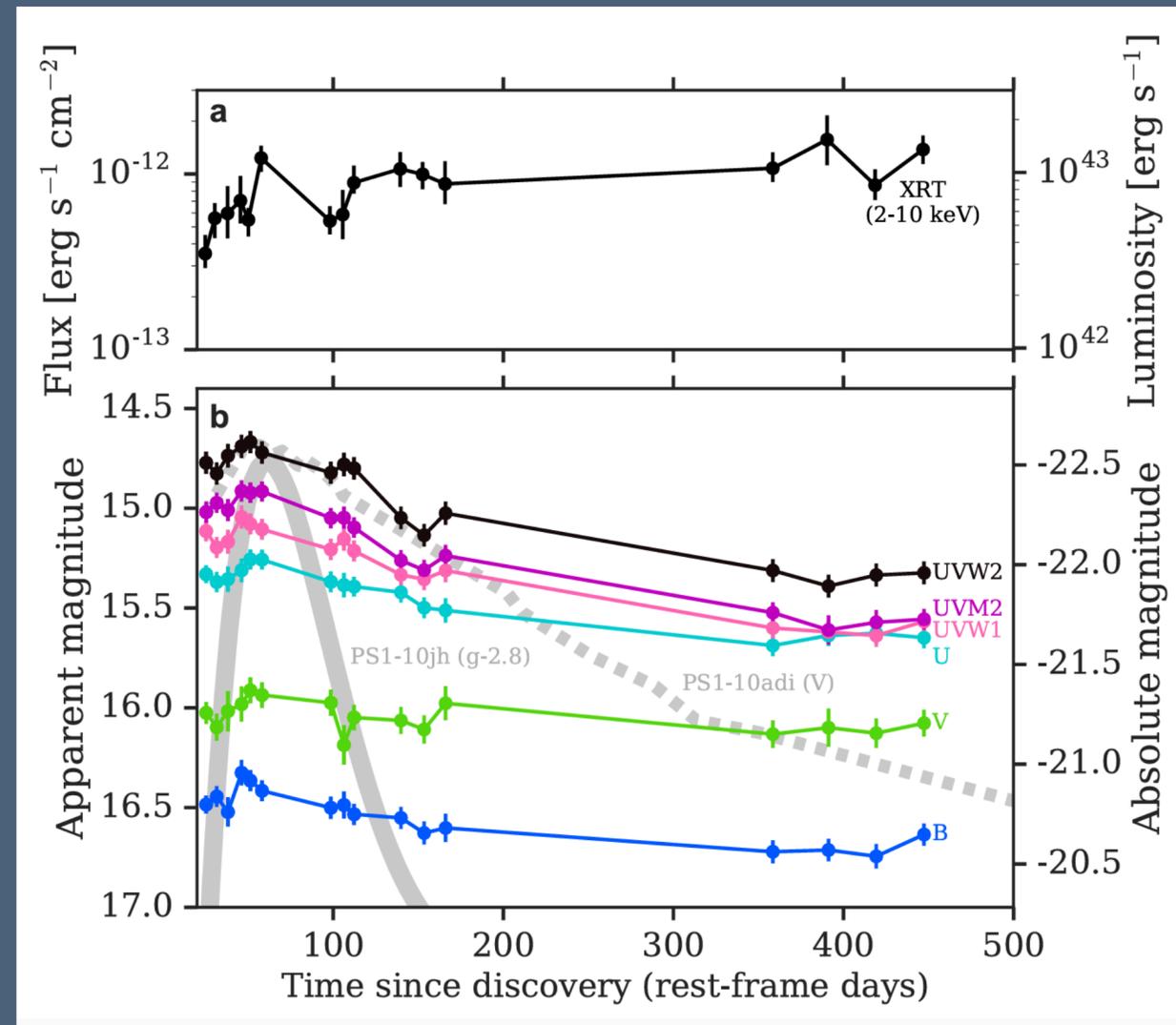


Newsome et al. (2024)

Second optical class: Bowen Fluorescence Flares (BFFs)

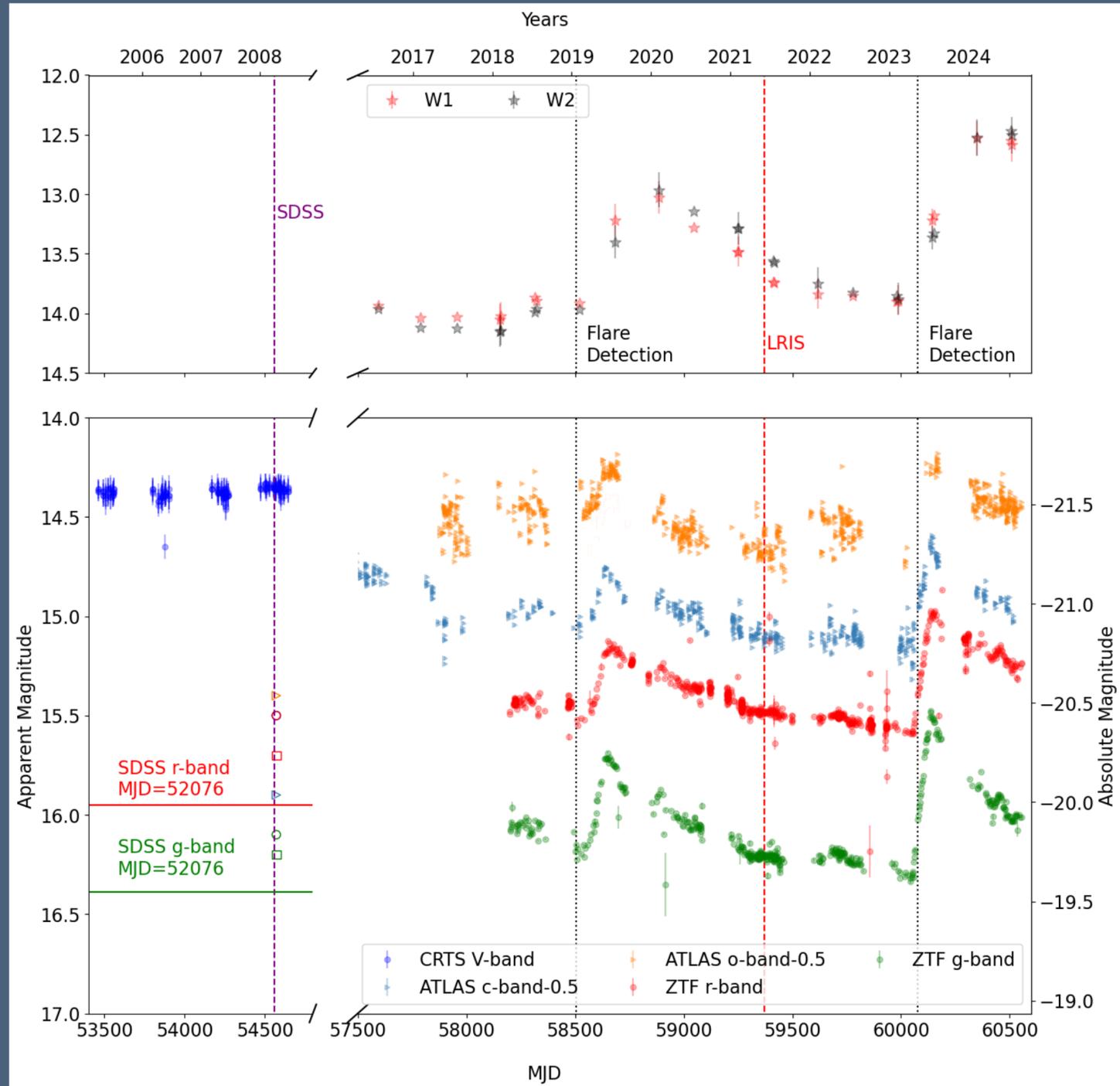


Trakhtenbrot et al. (2019a)



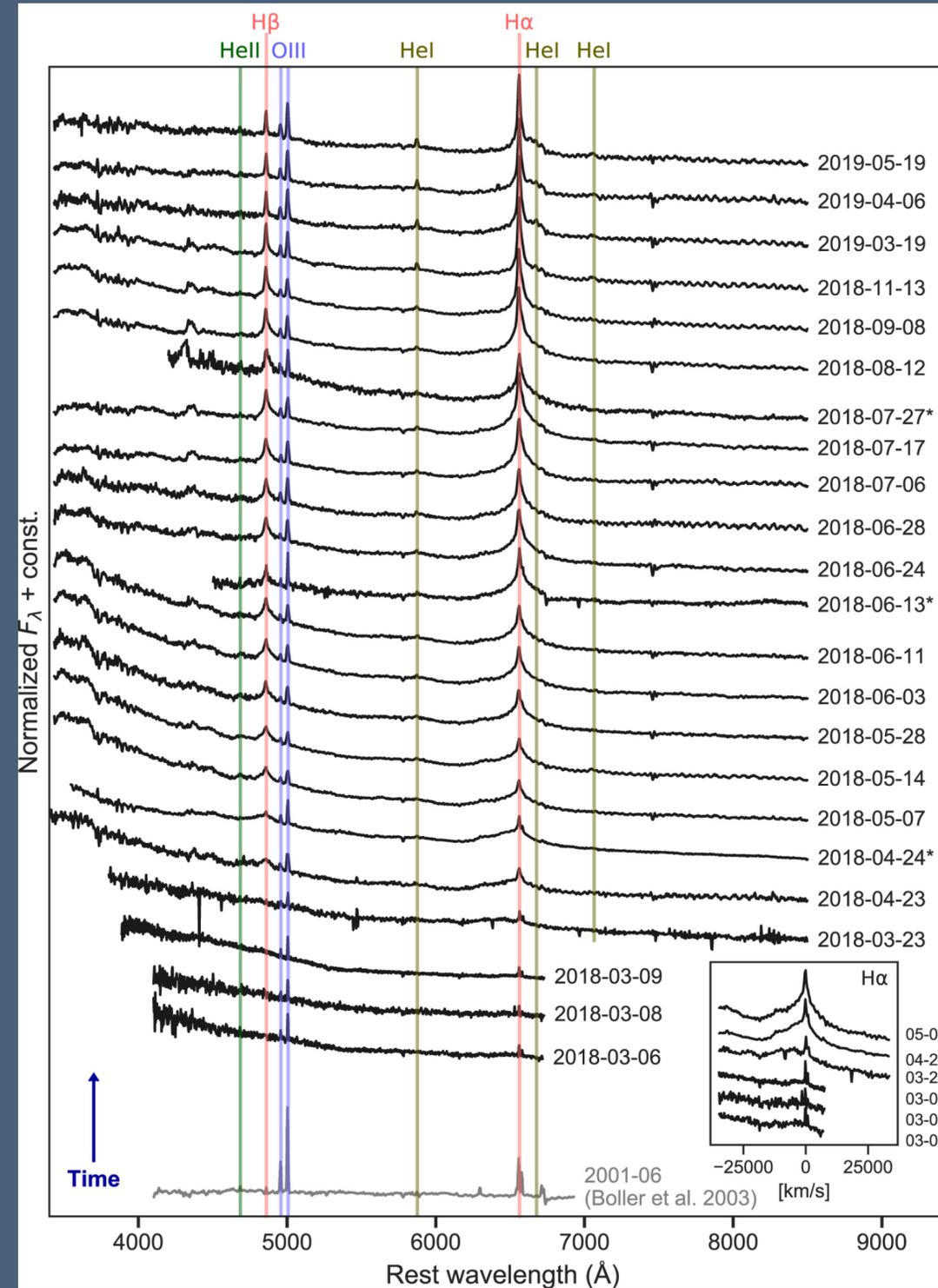
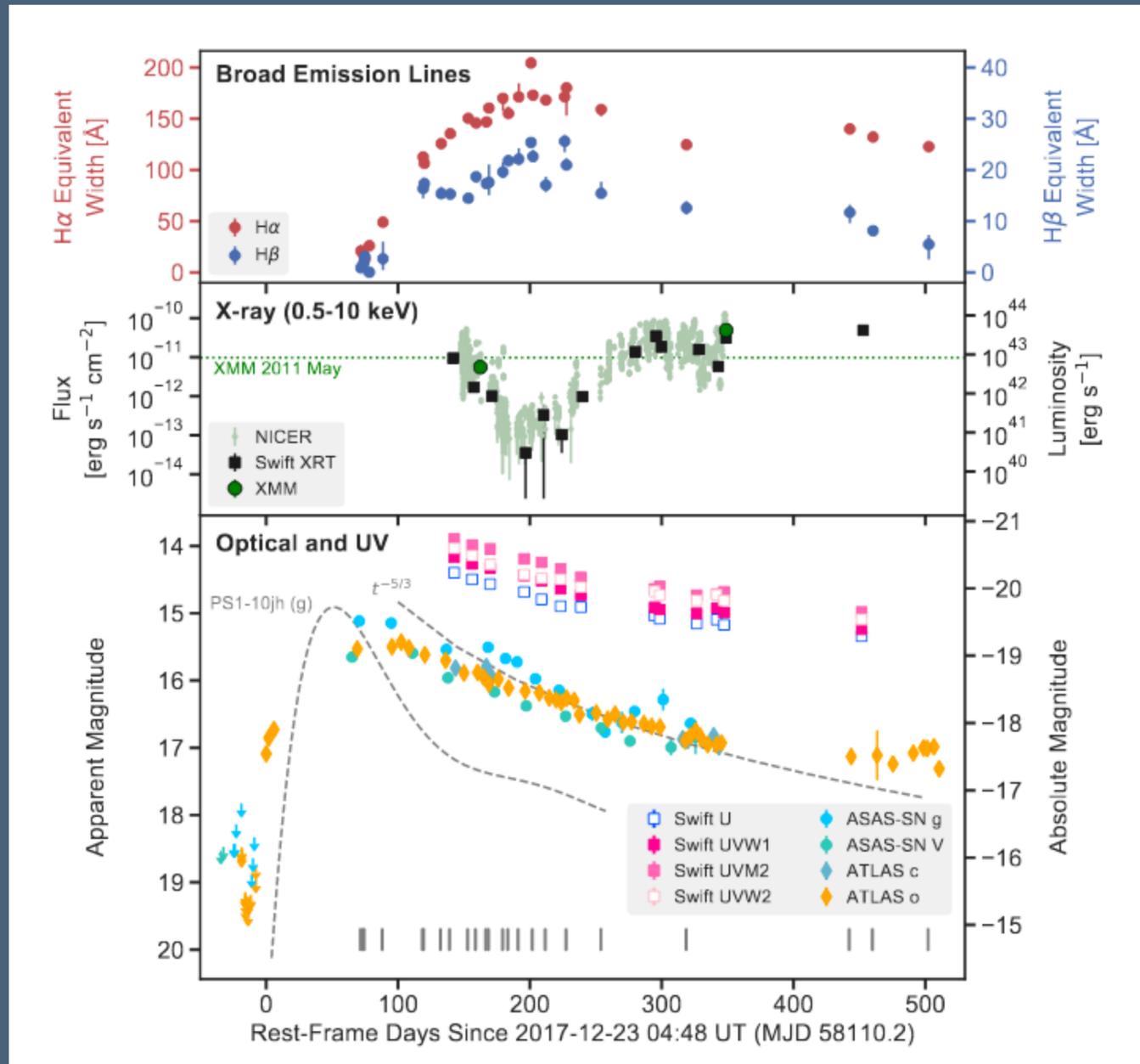
Talks by: Marzena Sniegowska, Pietro Baldini

Repeating BFFs?



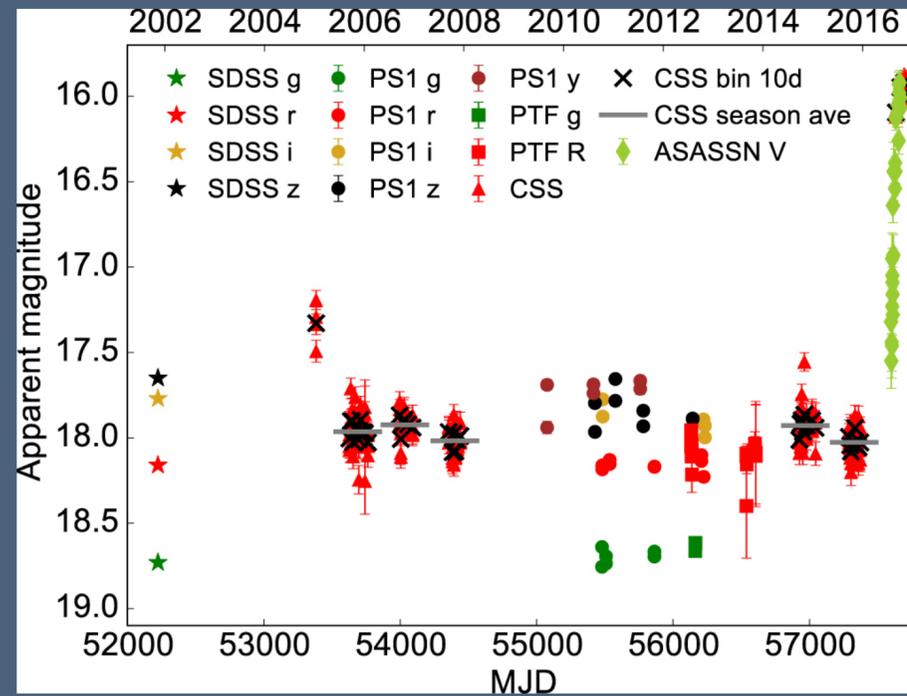
Sniegowska et al. (2025)

Third optical class? Changing look AGN

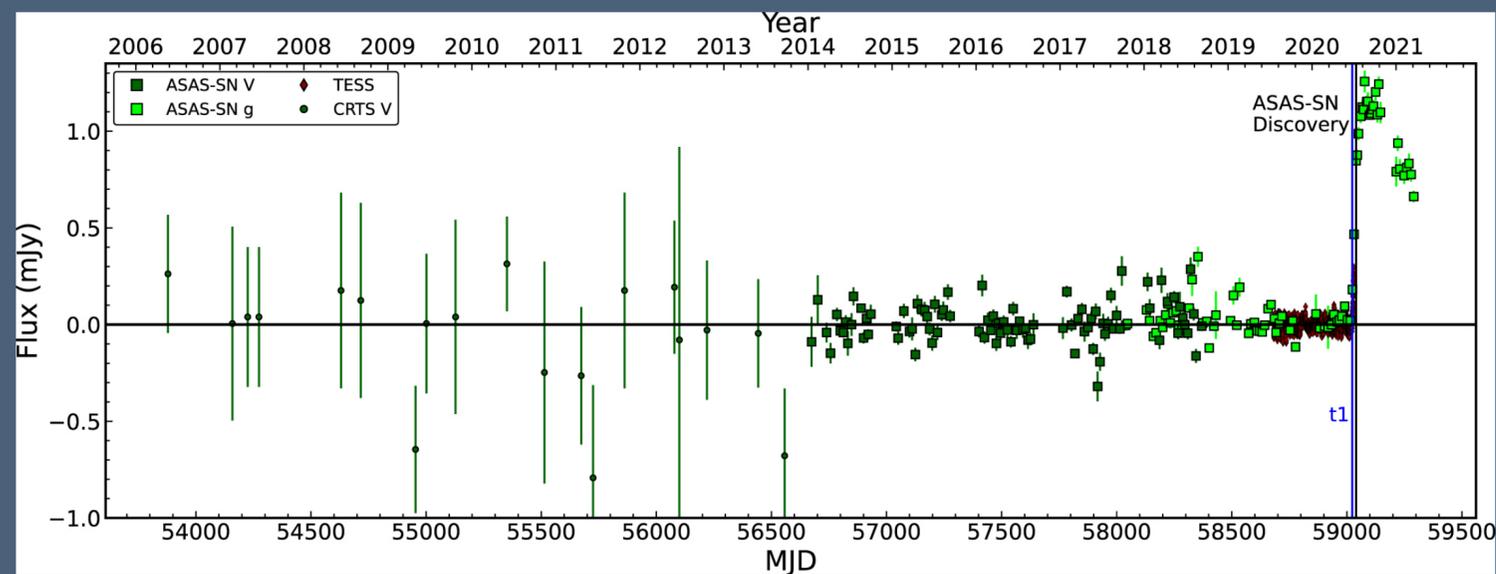
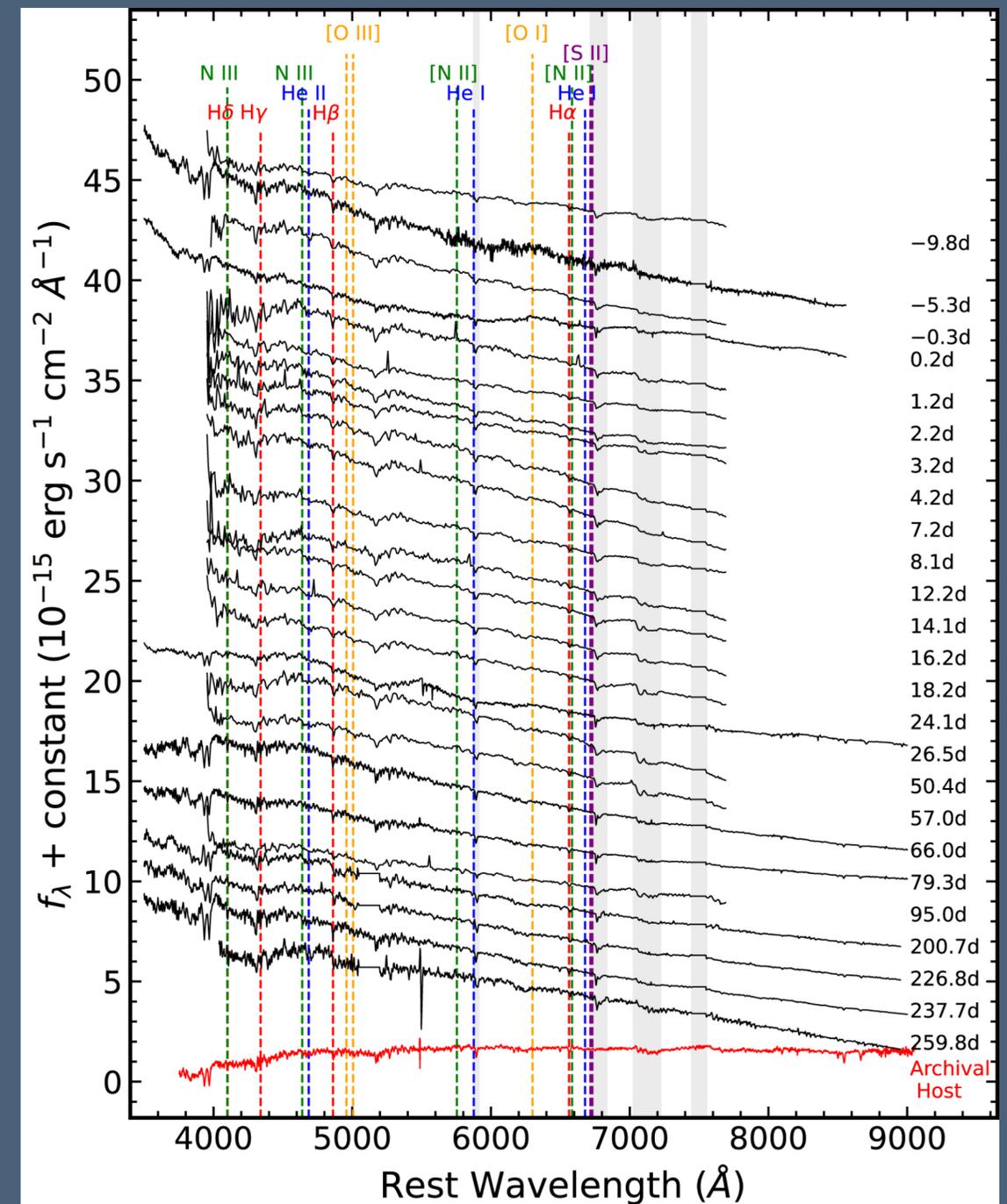
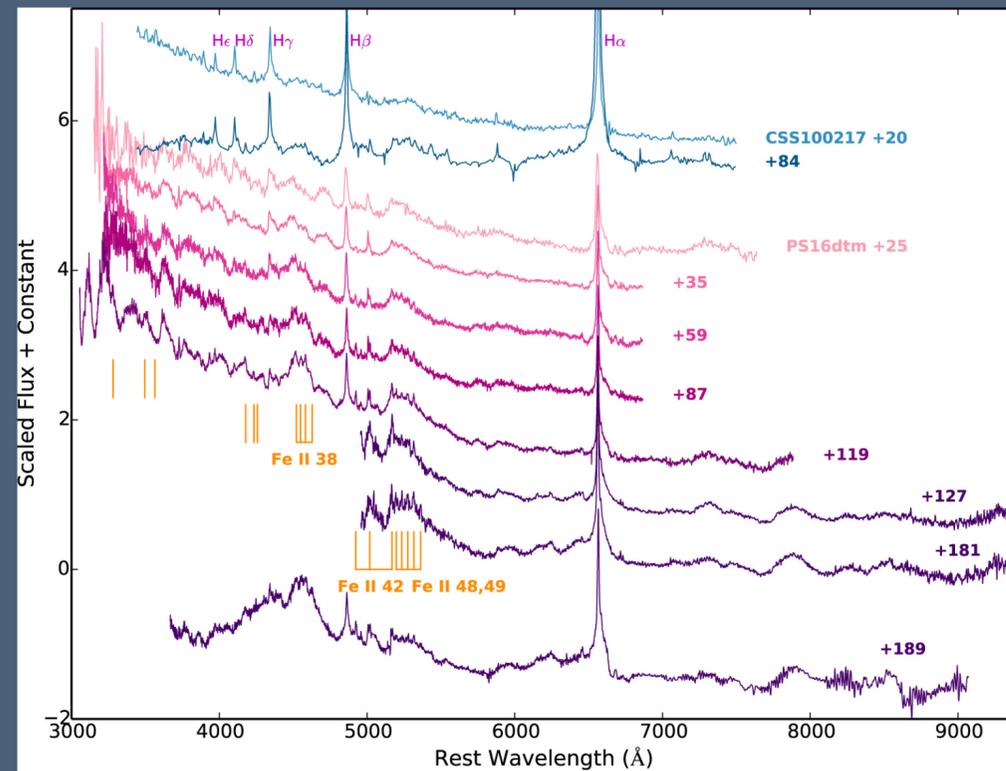


Trakhtenbrot et al. (2019b)

Fourth optical class: Ambiguous Nuclear Transients (ANTs)

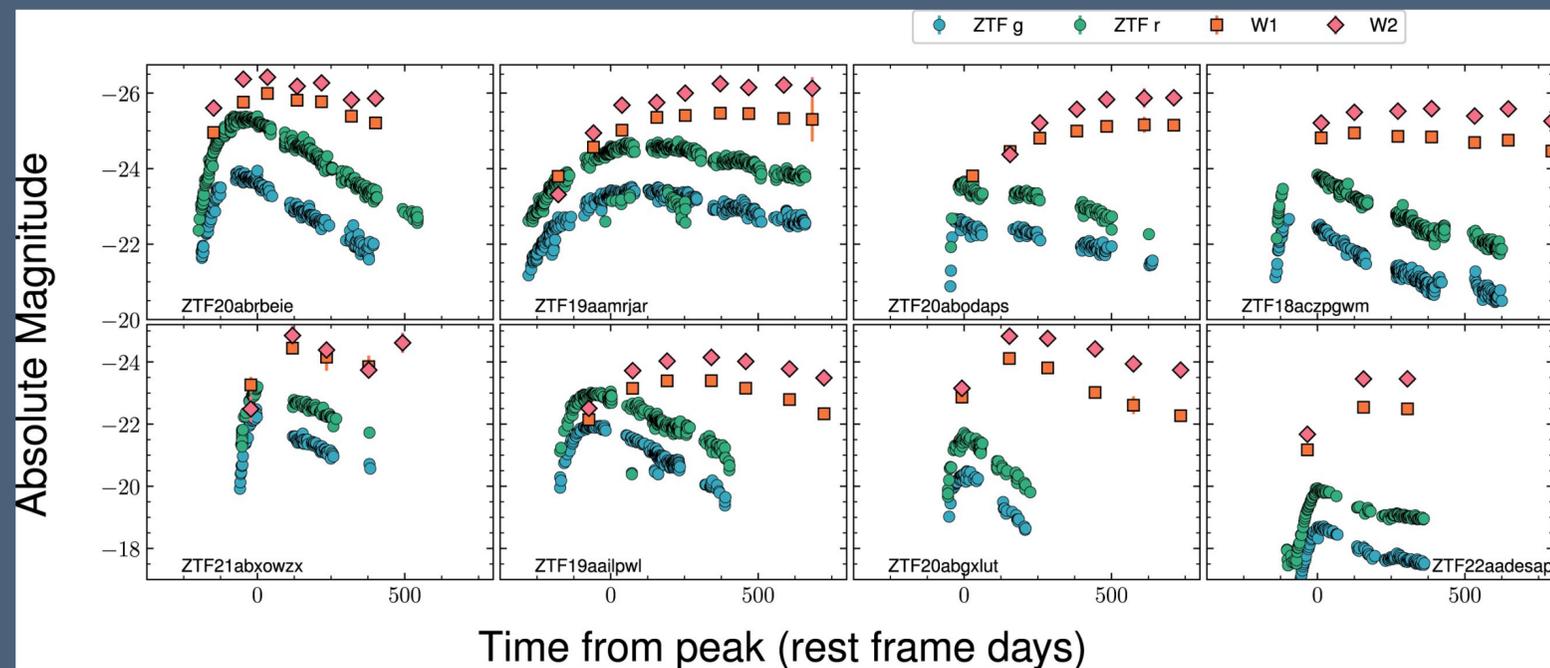


Blanchard et al. (2017)

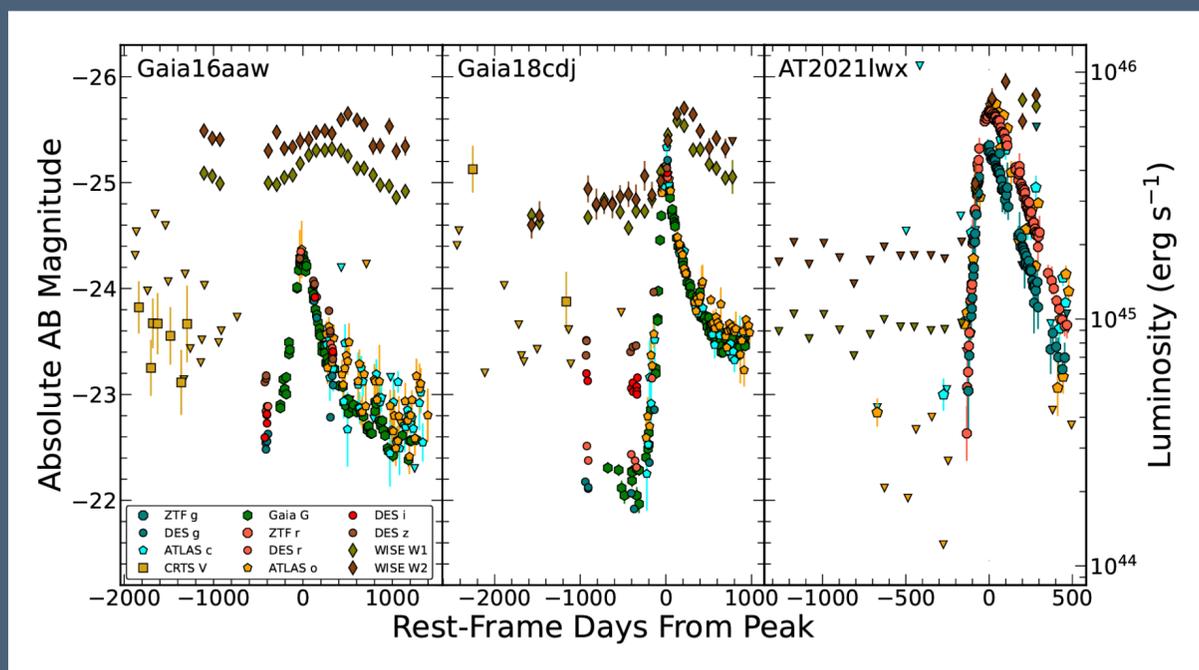
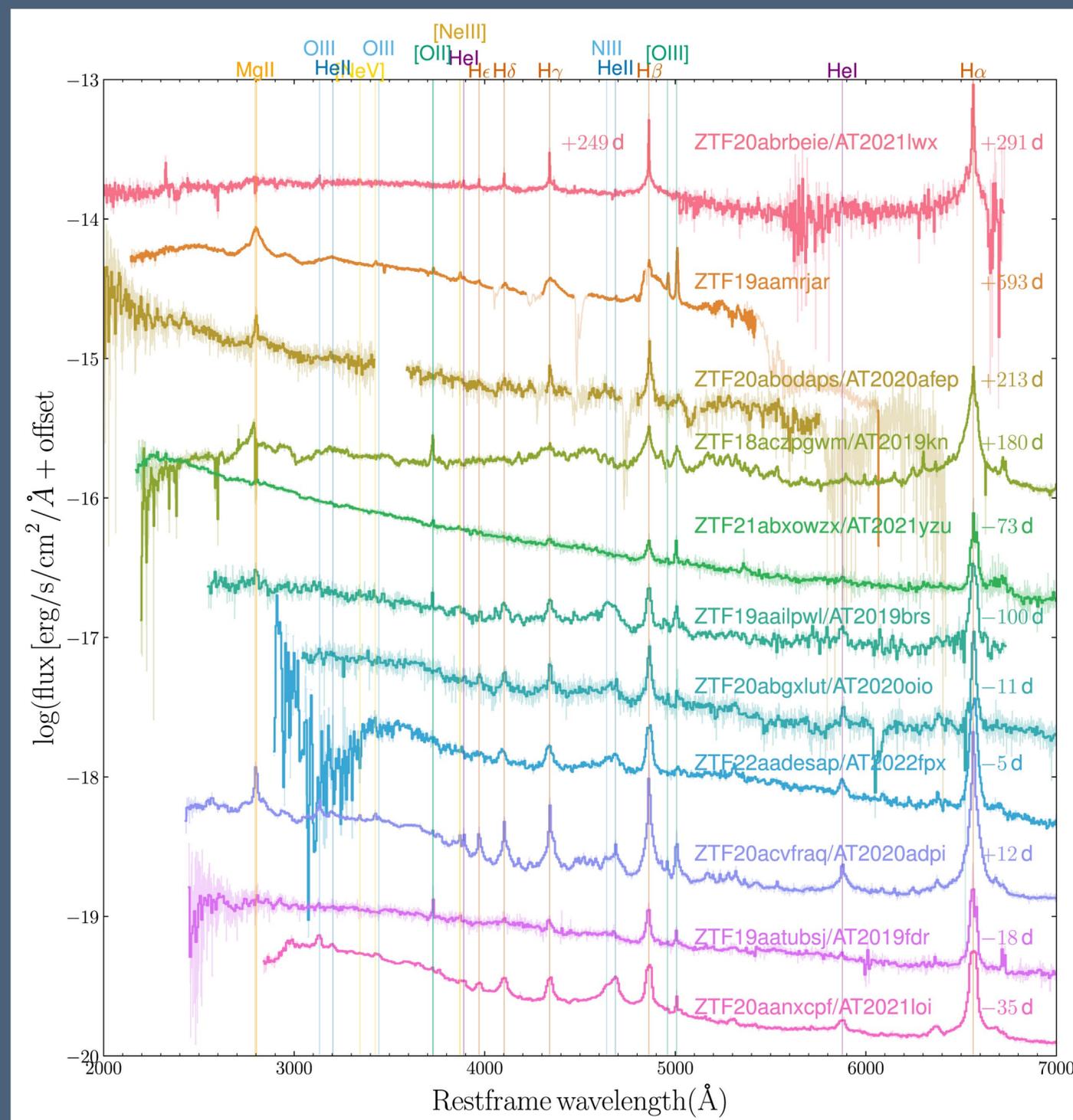


Hinkle et al. (2022)

Fifth optical class: Extreme ANTs (ENTs)

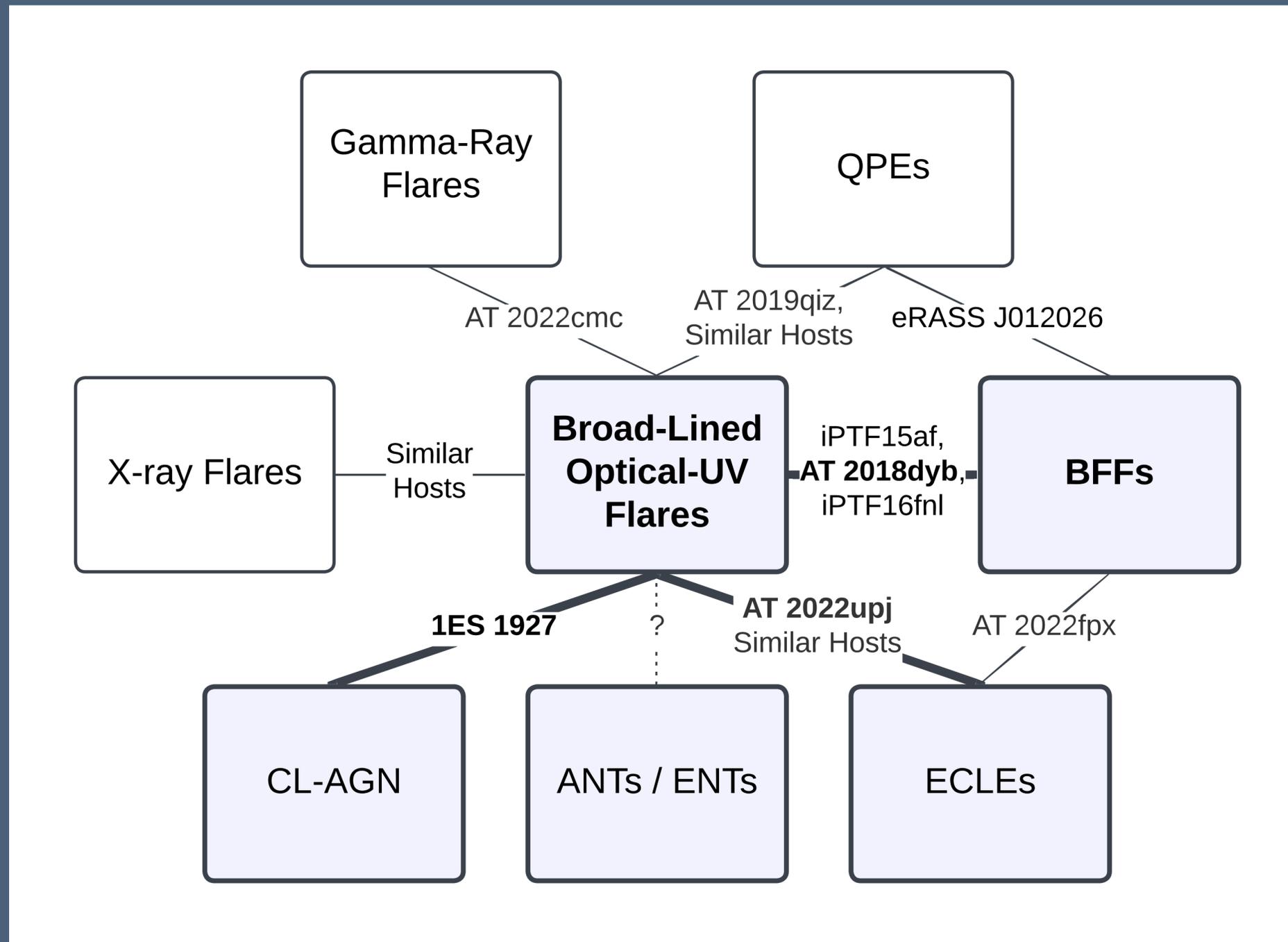


Wiseman et al. (2025)

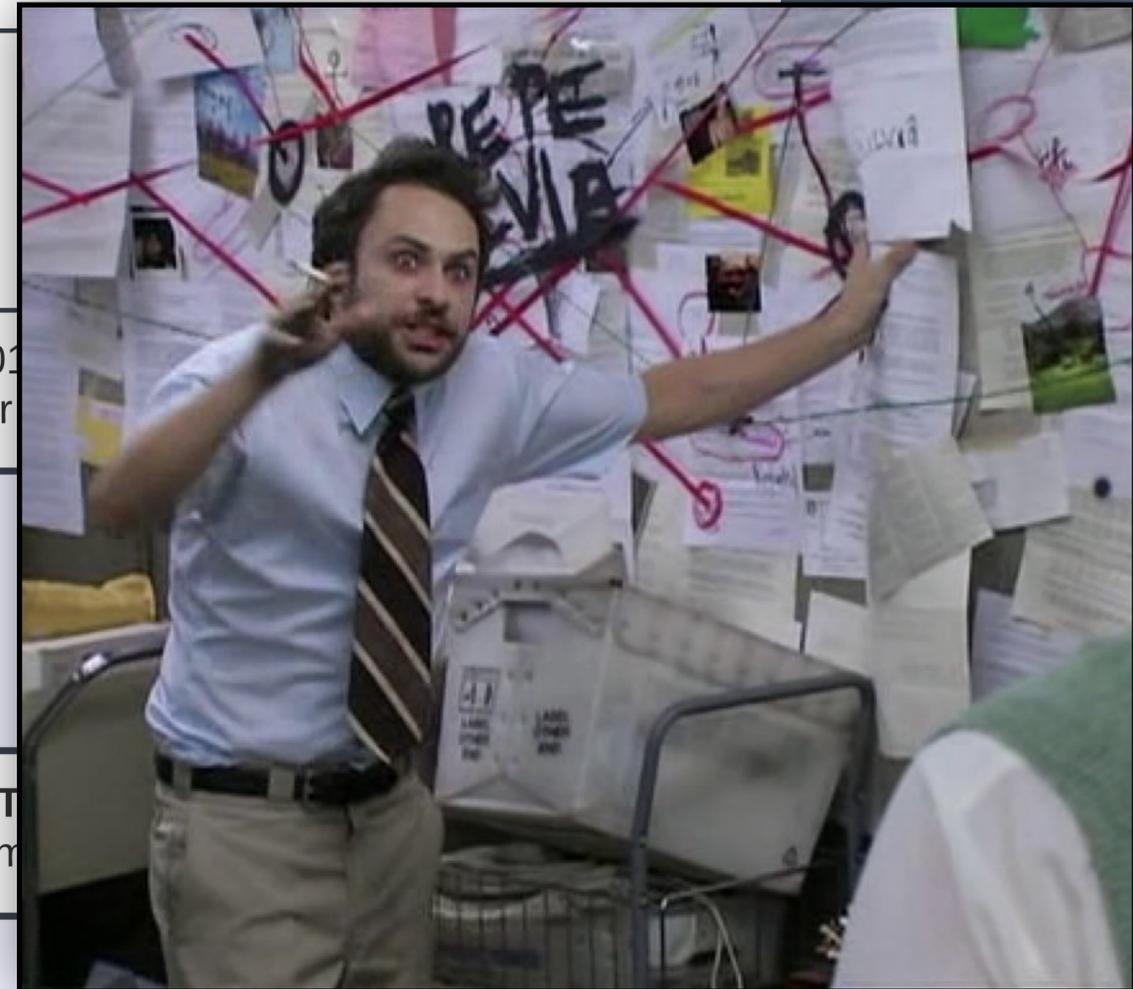
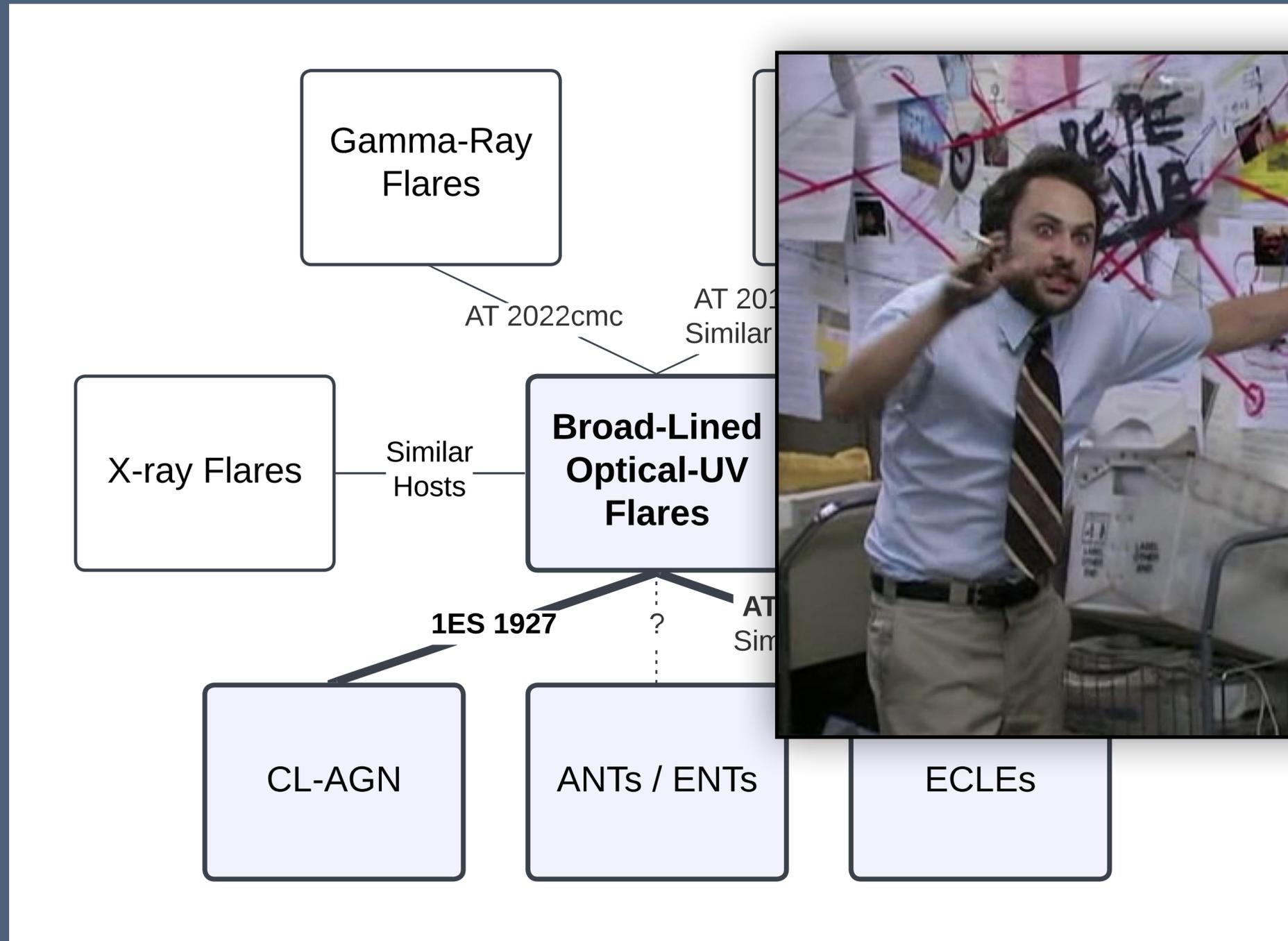


Hinkle et al. (2024)

There's a Zoo of Nuclear Transients Out There

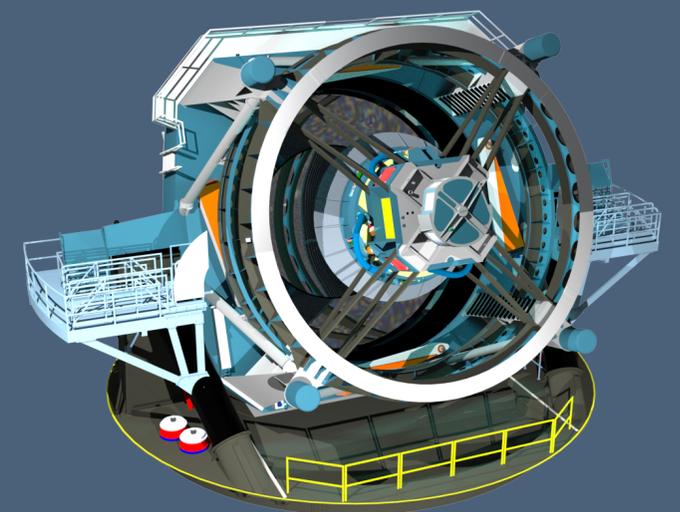


There's a Zoo of Nuclear Transients Out There

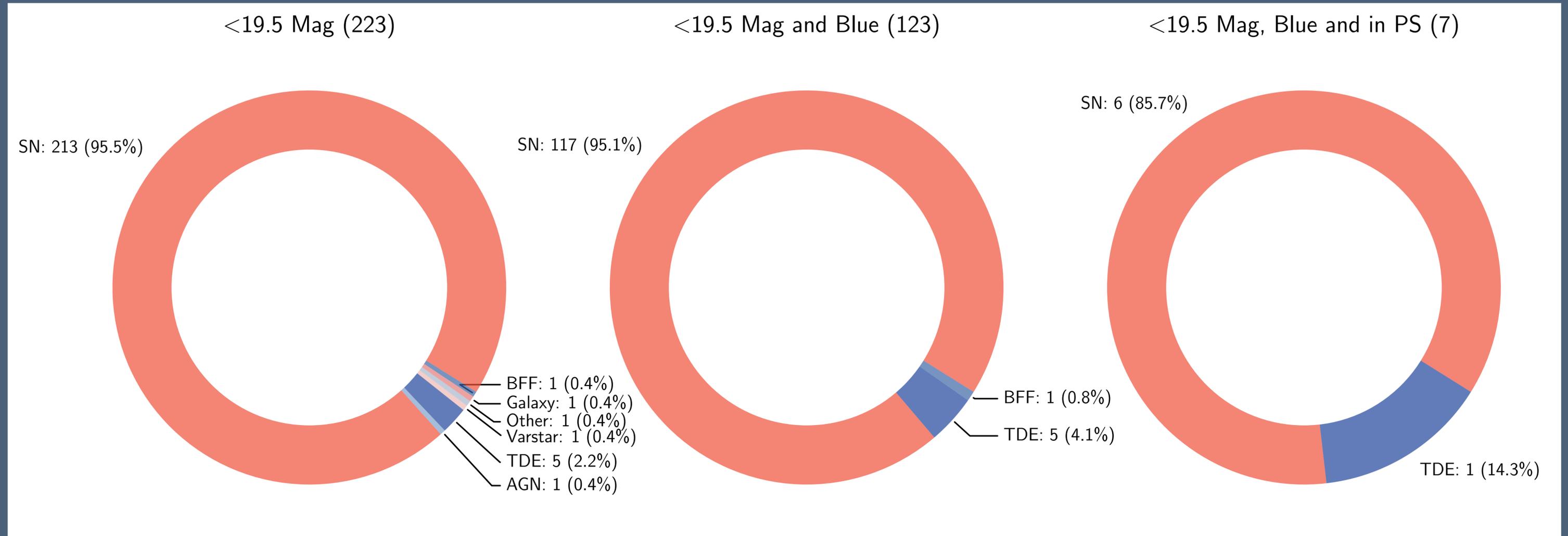


Main Challenge to Observers:

Increase the sample x10-100



Rubin promises thousands of TDEs but contamination large



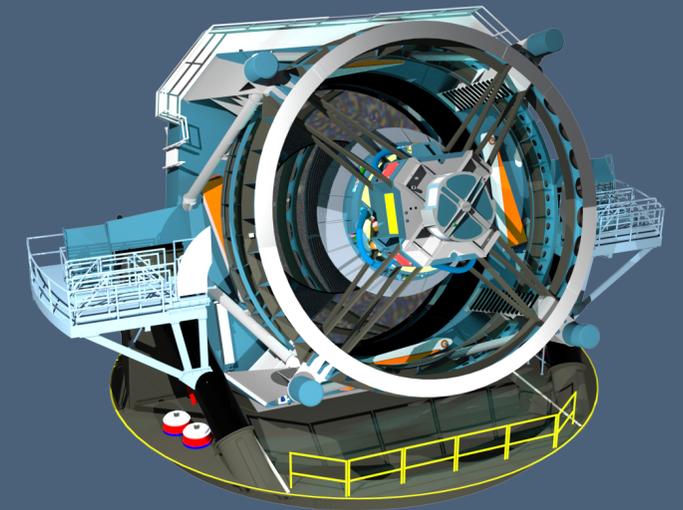
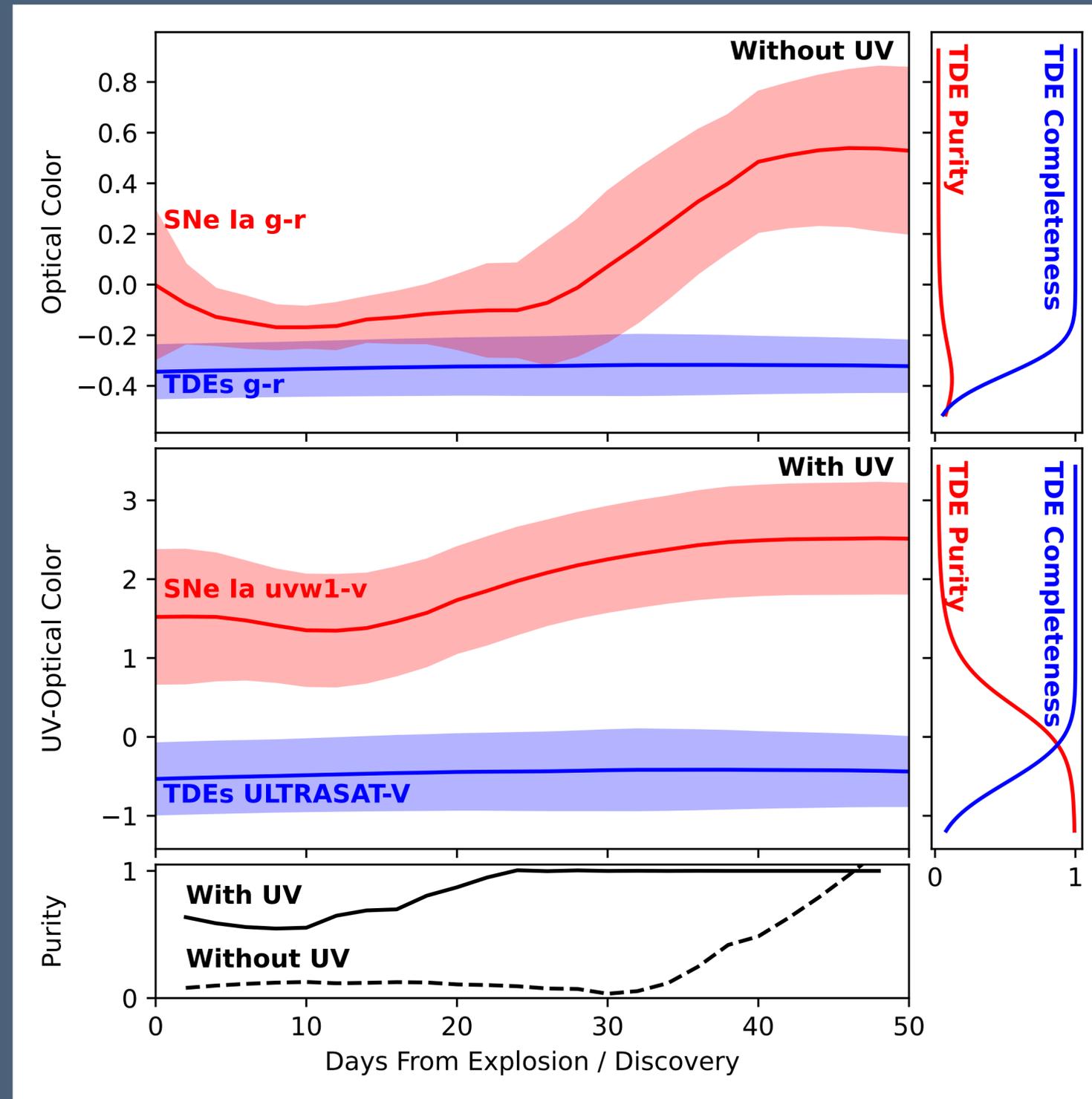
Dgany, Arcavi et al. (2023)

LSST + Ultrasat to remove SN Ia contamination

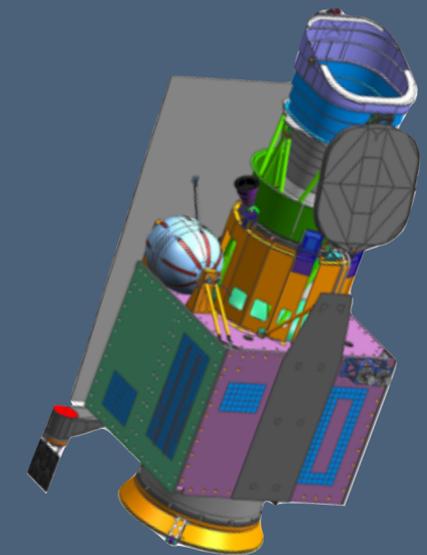
Optical: TDEs & SNe Ia mixed

Optical+UV: TDEs & SNe Ia separated

Adding UV provides much purer TDE sample from early times



Rubin LSST



ULTRASAT

At least seven classes of things identified as TDEs: X-ray flares, certain ultra-long GRBs, optical/UV 10j-likes, ECLEs, BFFs, ANTs, ENTs.
Many tantalizing links but based on small samples.

Intra-class diversity: Structured light curves, repeating 10jh-likes, TDEs in Type II AGN? repeating BFFs, late-time radio flares, X-ray diversity..

Main observational challenge is to get 10-100x the sample: Will have Rubin, but contamination likely to be overwhelming.

Multi-wavelength solutions: Optical+UV to select events, X-ray to help discern emission mechanism (and for QPEs), radio to probe outflows, IR to reveal SMBH environments, ...