Ultraviolet Transients from Supermassive Black Holes

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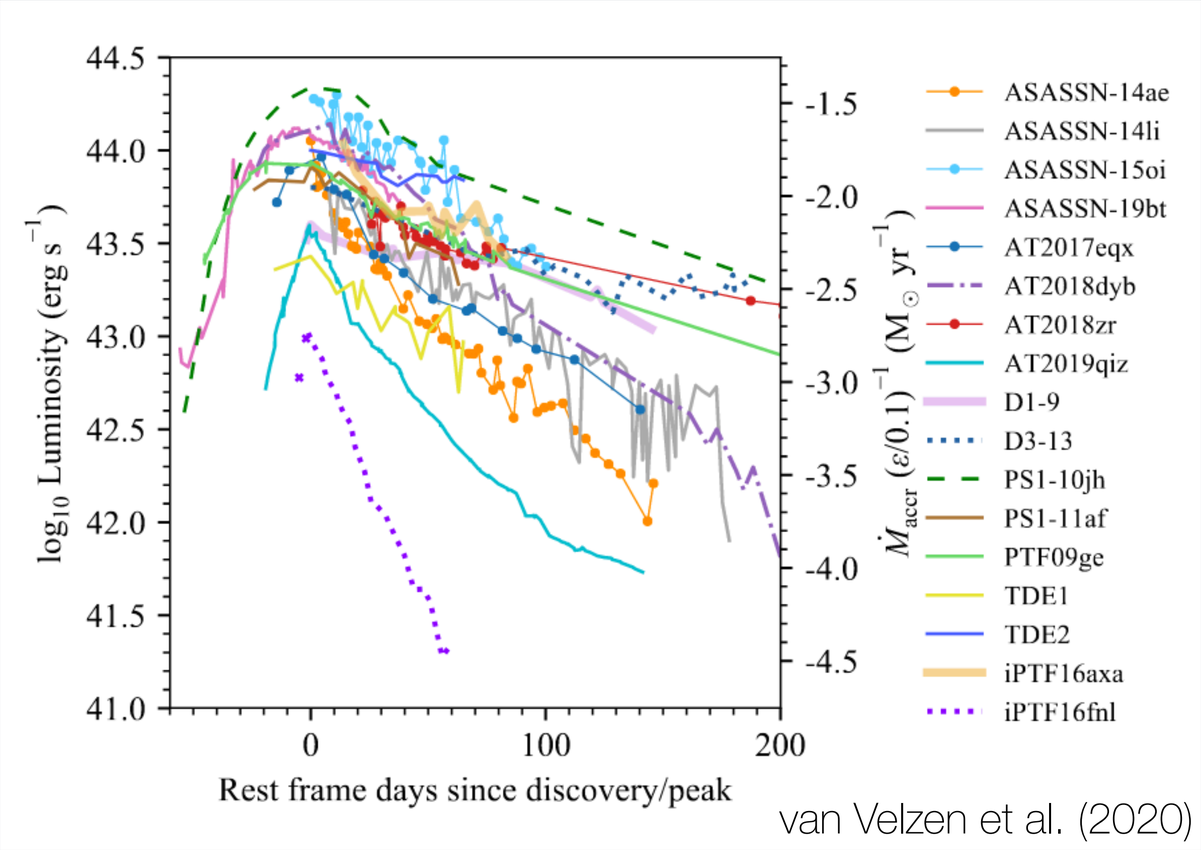
Tel Aviv University

Goal: Measure supermassive black hole properties and environments from transient events

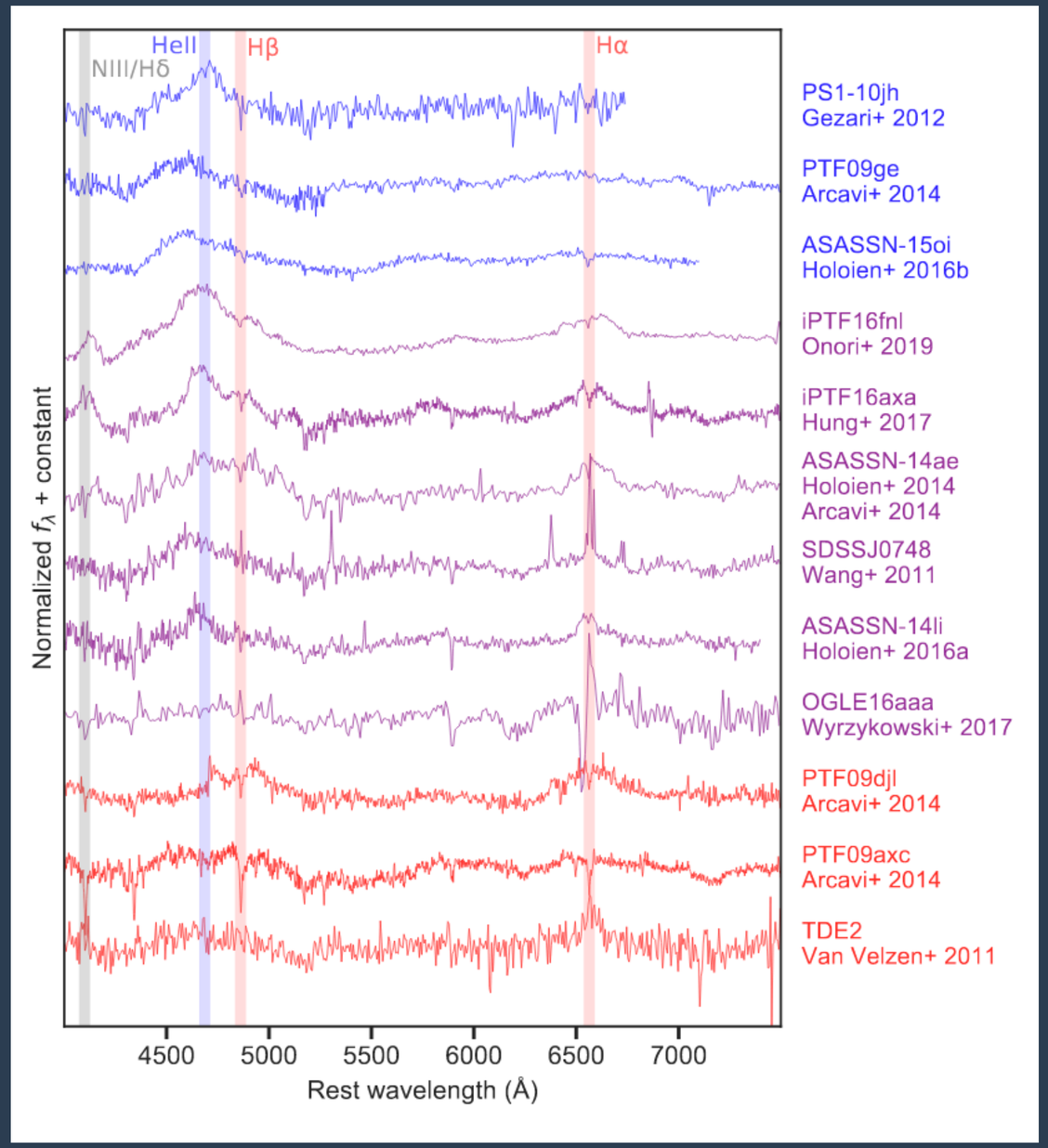
A New Class of Transients in Galaxy Centers

Luminous in the optical and **UV**, blue, with broad H and/or He II in their spectra

All in the centers of quiescent hosts



van Velzen et al. (2020)



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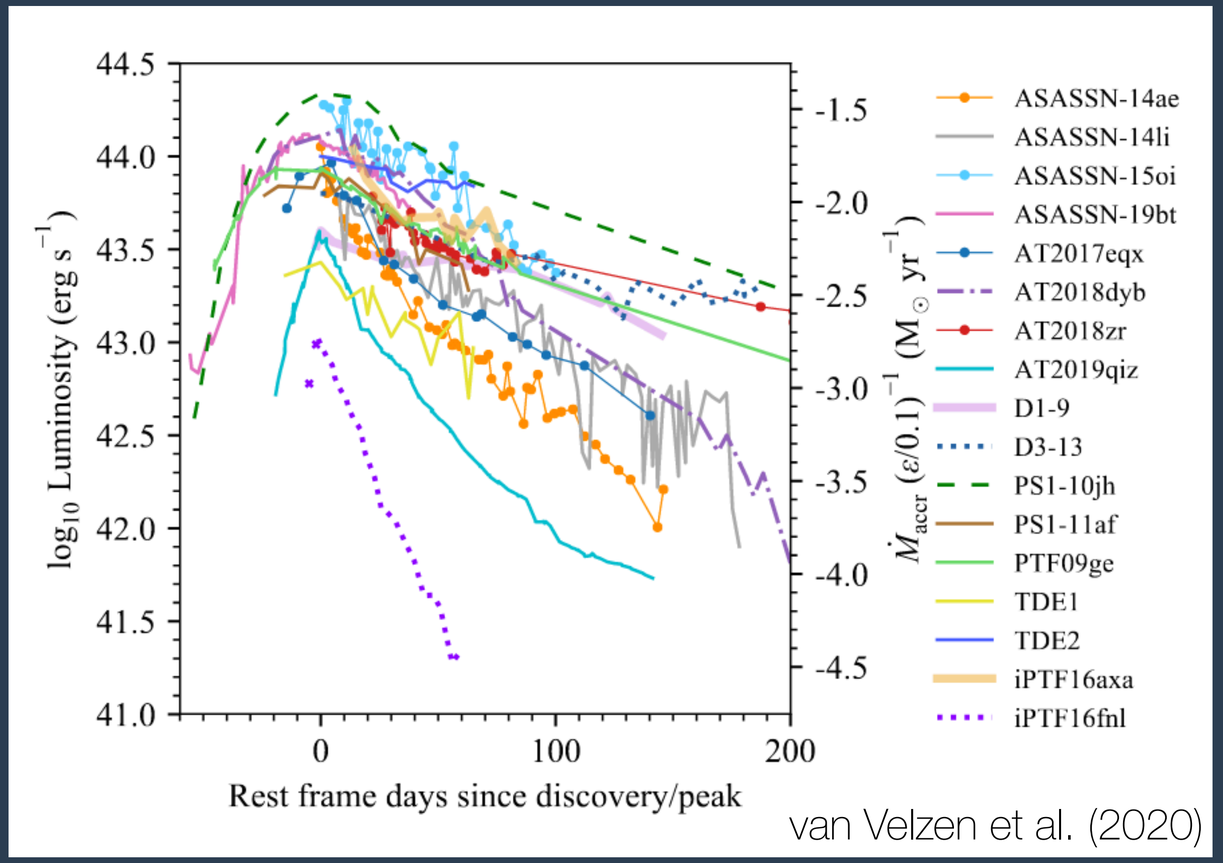

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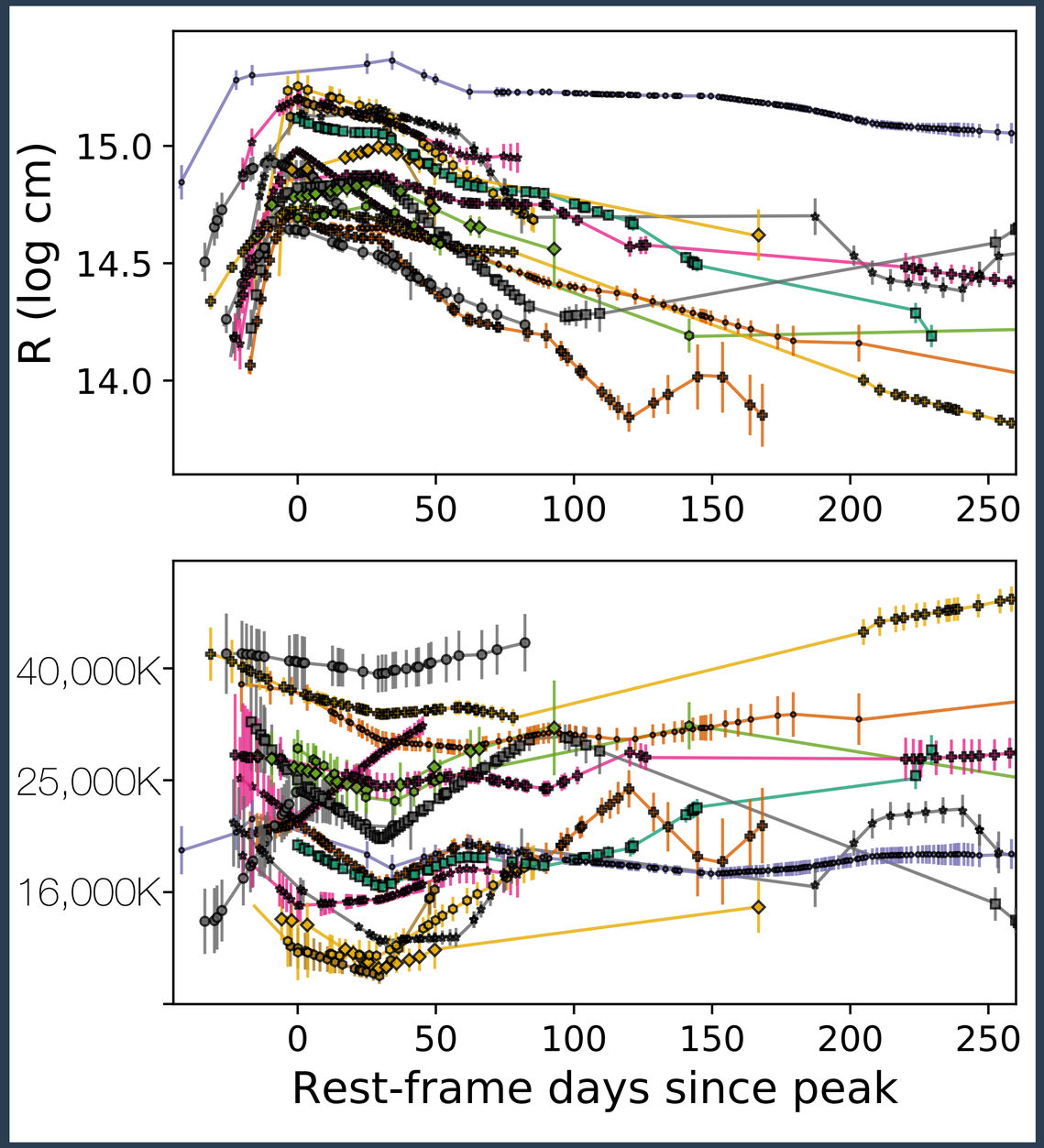
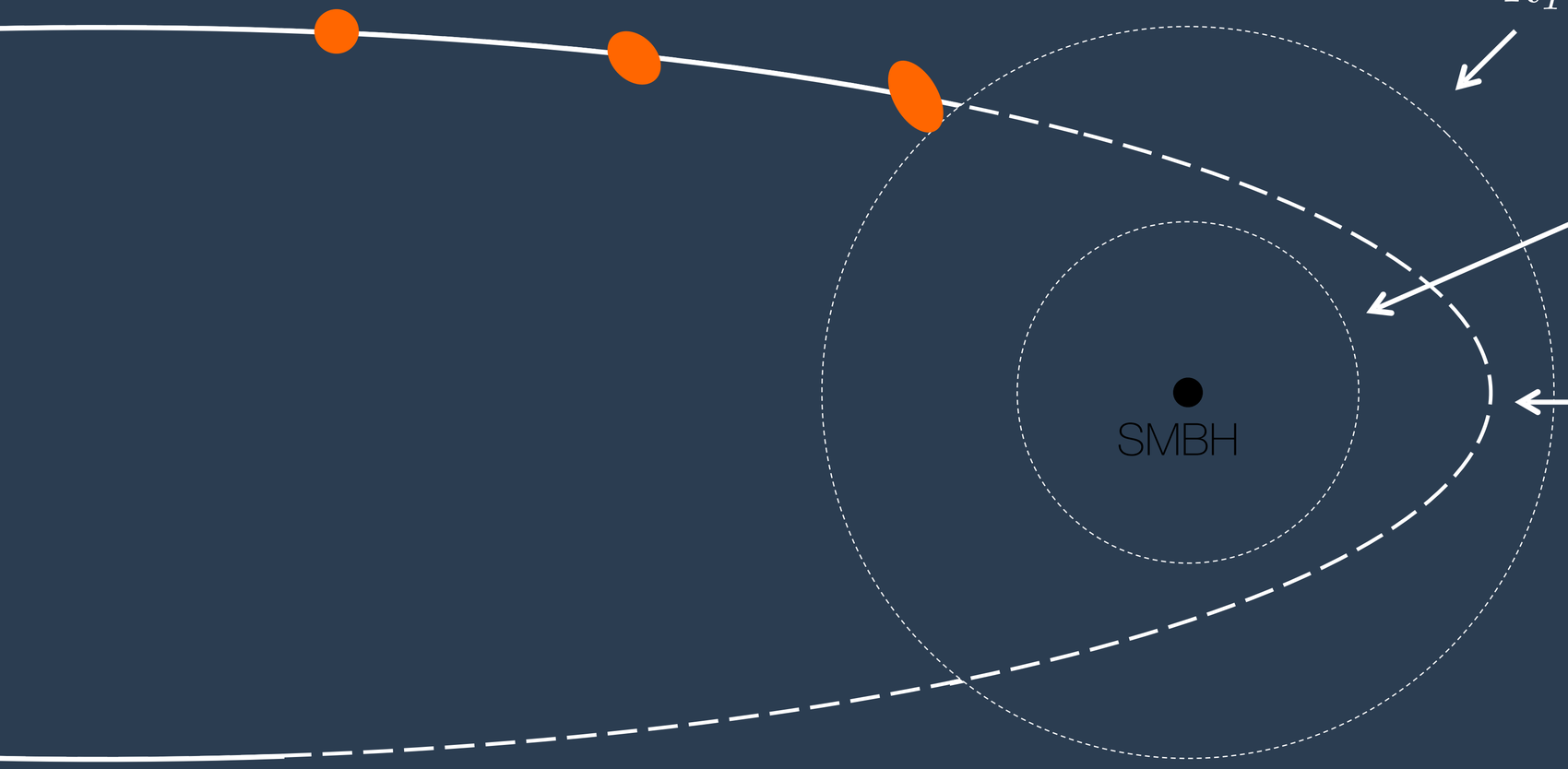


Tidal Disruption Events - Stars Torn Apart by Supermassive Black Holes



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

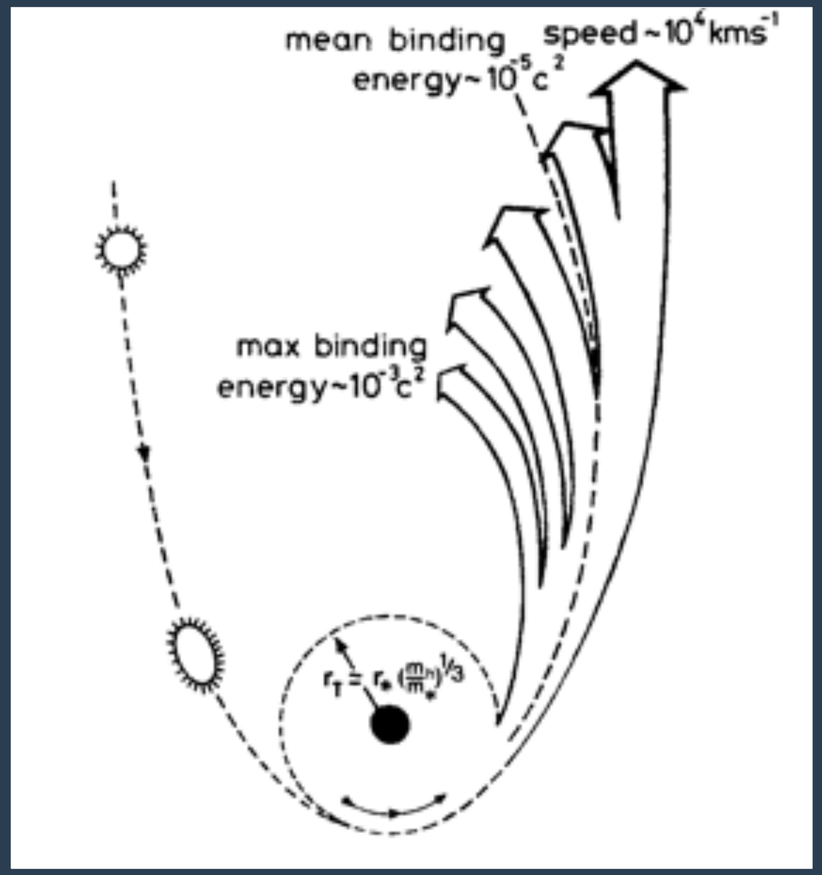
$$R_S = \frac{2GM_{BH}}{c^2}$$

R_p

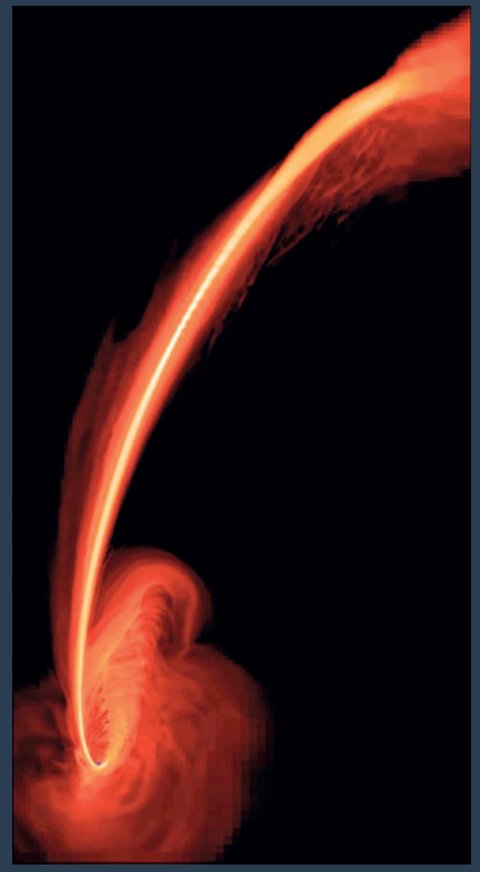
$\beta = R_T/R_p$

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

Tidal Disruption Events - Stars Torn Apart by Supermassive Black Holes

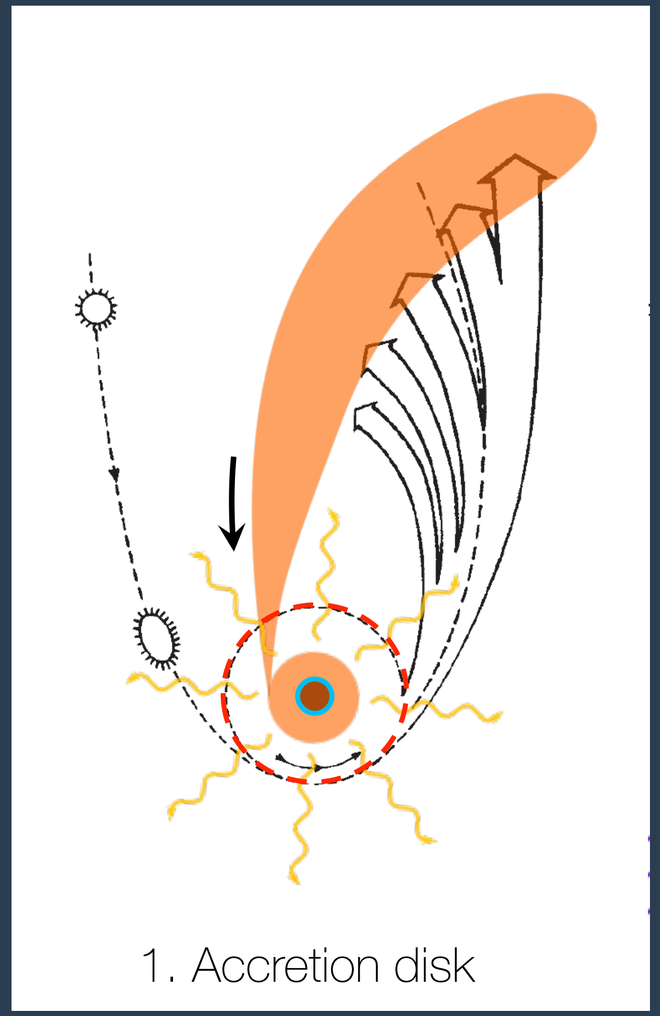


Rees 1988



NASA, S Gezari/JHU and J Guillochon/UCSC

What Will Emit Light in a TDE?



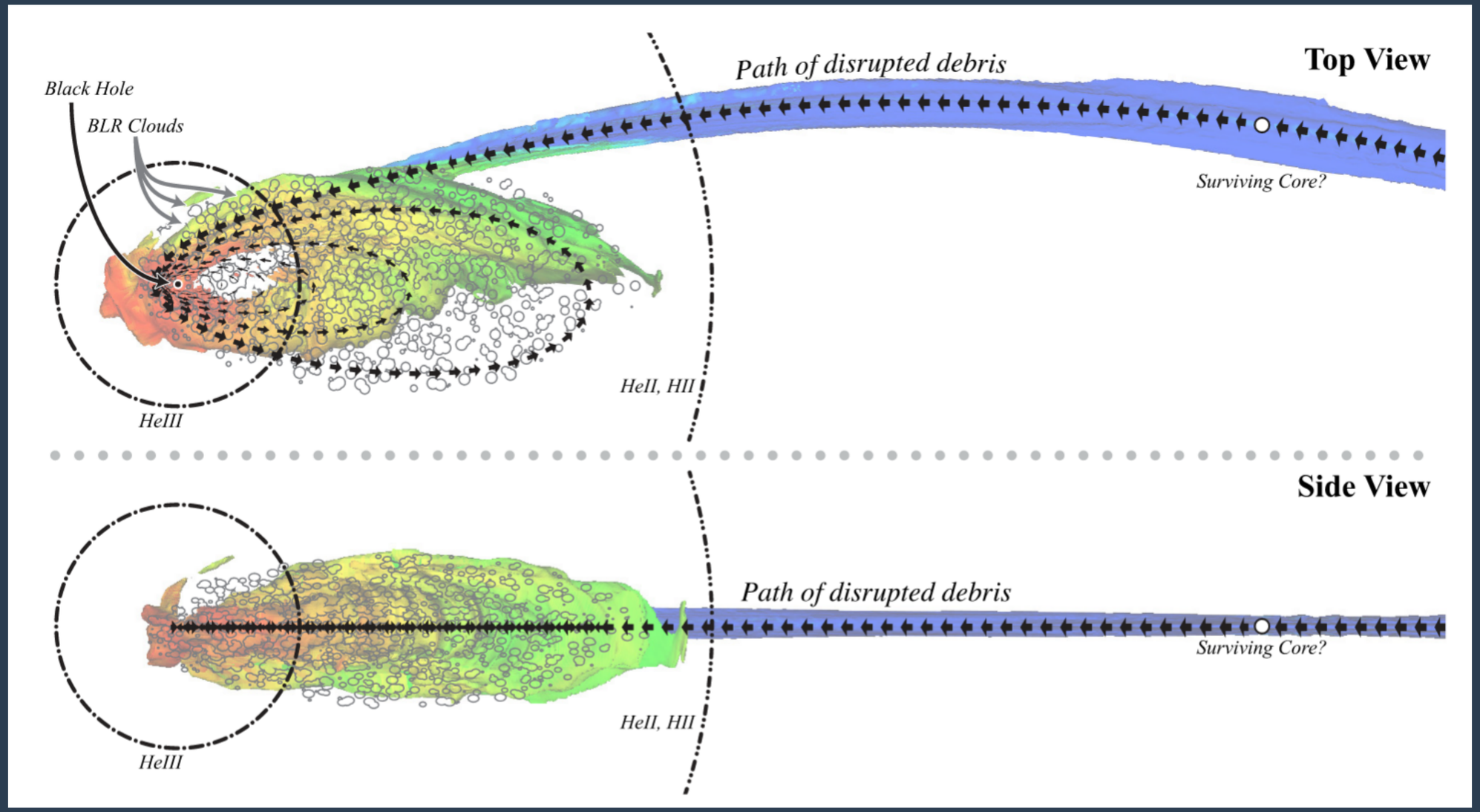
Courtesy C. Bonnerot

The New Class of Transients Did Not Fit Expectations

Expected (accretion)	Observed	
Center of galaxy	Center of galaxy	✓
$L \propto t^{-5/3}$	$L \propto t^{-5/3}$	✓
$T \sim 10^5 - 10^6\,\mathrm{K}$	$T = 3 \cdot 10^4\,\mathrm{K}$	✗
$R \sim R_T \sim 10^{13}\,\mathrm{cm}$	$R \sim 10^{15}\,\mathrm{cm}$	✗
$E \sim 0.1 M_\odot c^2 \sim 10^{53}\,\mathrm{erg}$	$E \sim 10^{51}\,\mathrm{erg}$	✗
Evolving Temperature	Constant Temperature	✗
Hydrogen from the star	Helium, No Hydrogen	✗

Puzzle I: Why do TDEs emit mostly optical & ultraviolet light?

Are We Looking Through Reprocessing Material?



Guillochon et al. 2014

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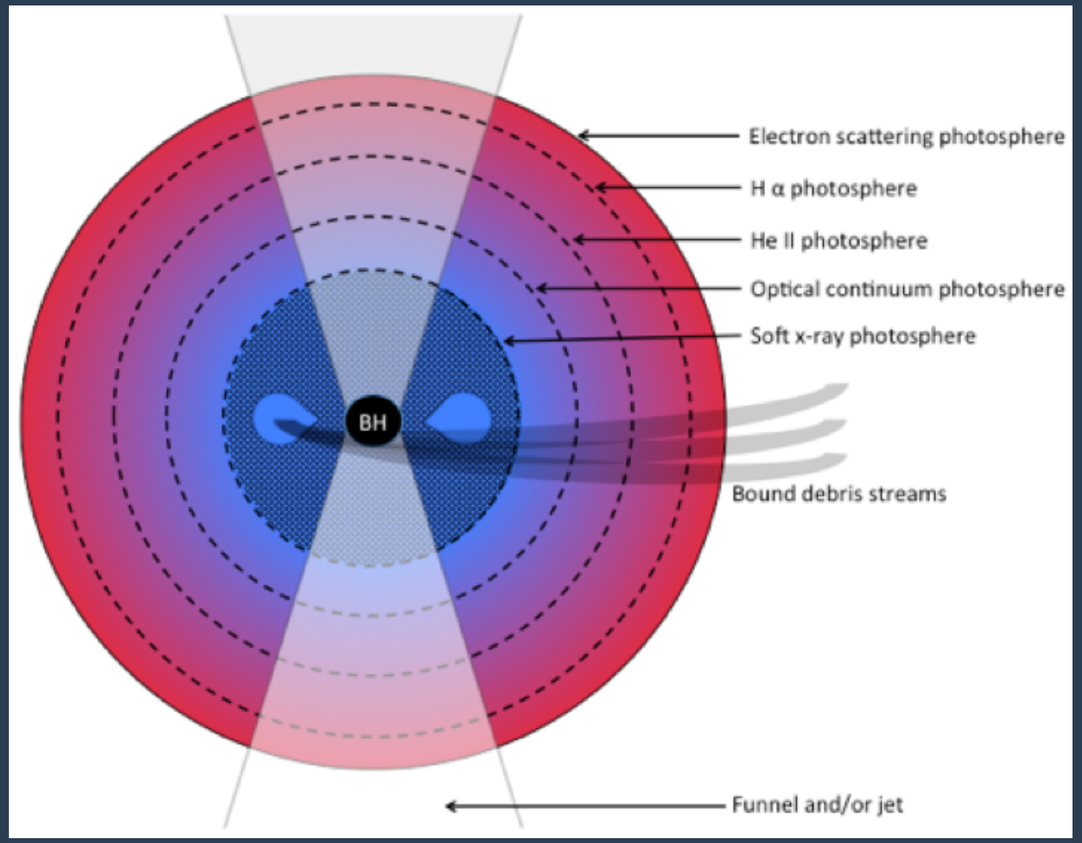
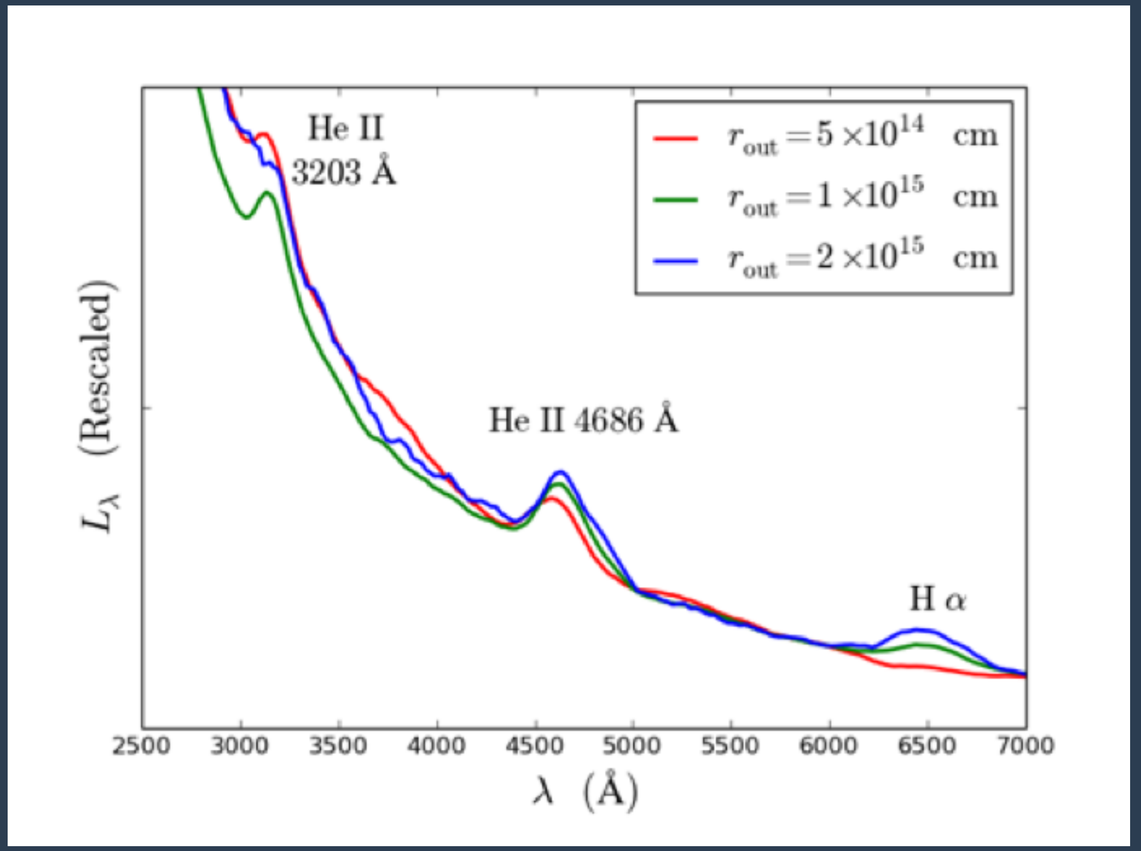


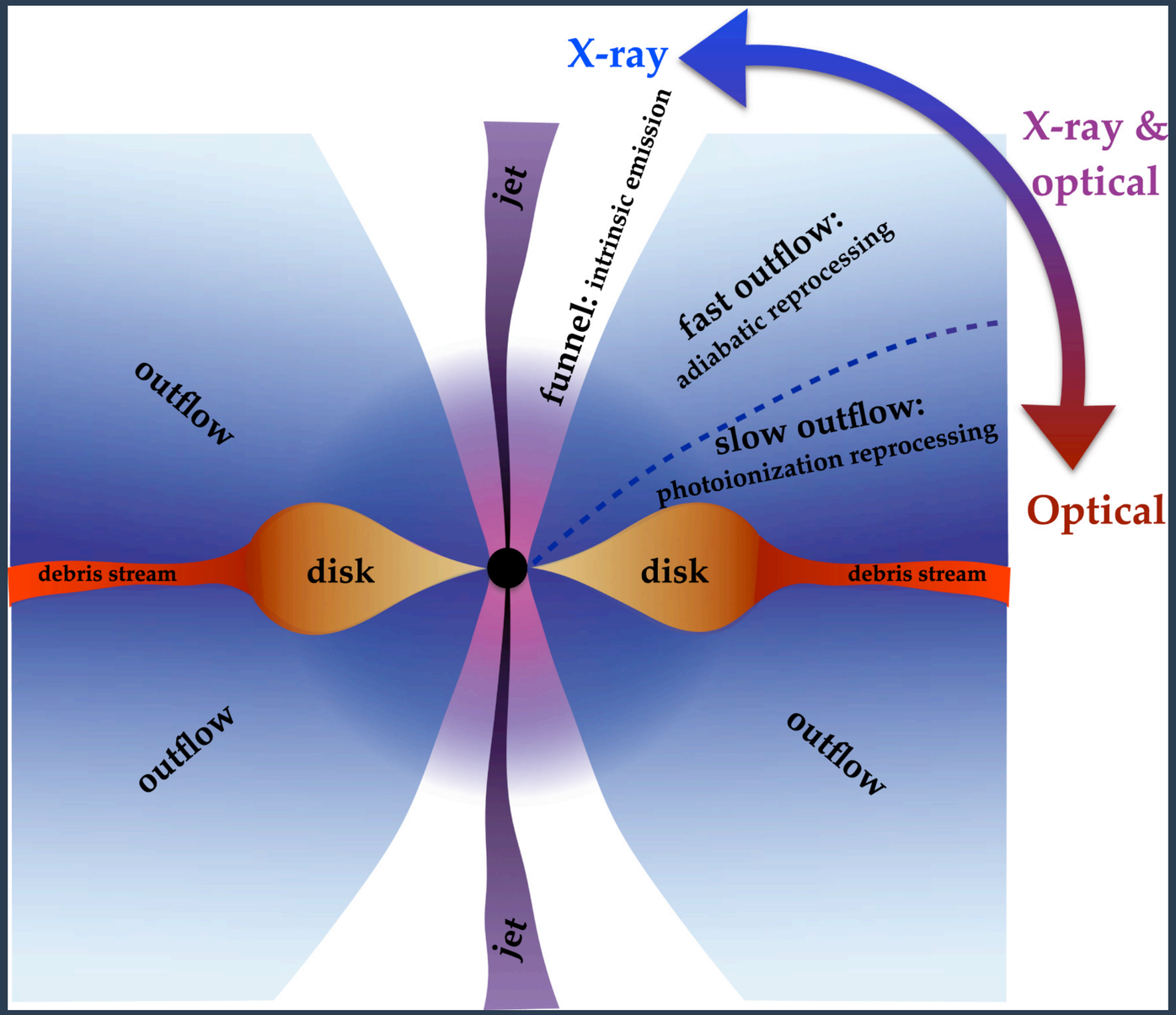


Roth et al. 2016

The presence of reprocessing material explains:

1. The low temperatures
2. The large radii
3. The lack of hydrogen in the spectra

Reprocessing Material as a Viewing Angle Effect

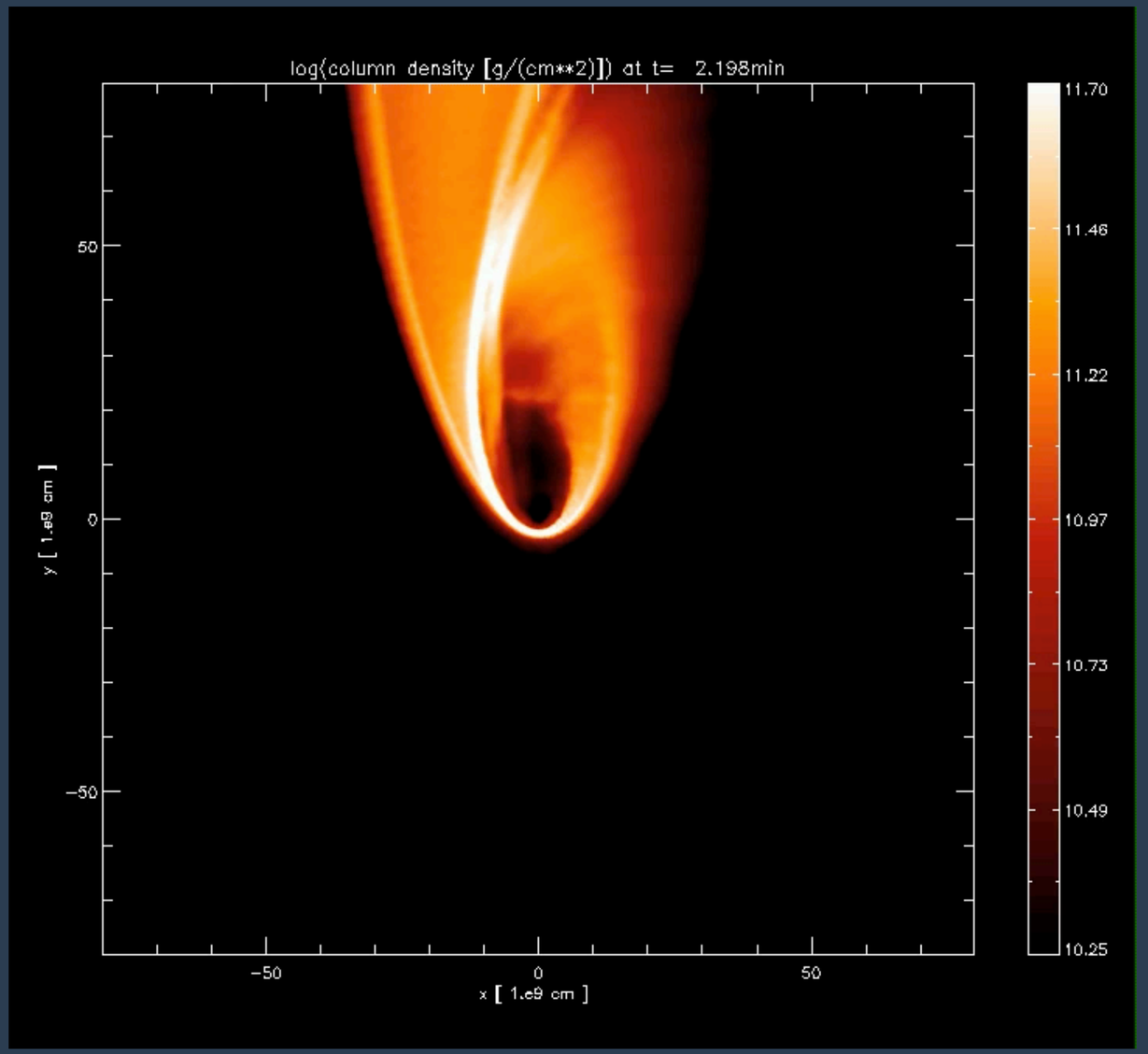


Dai et al. 2018

Puzzle I: Why do TDEs emit mostly optical & ultraviolet light?

Solution: We are seeing reprocessed accretion emission

But, Turns out Circularization Requires Outer Collision Shocks

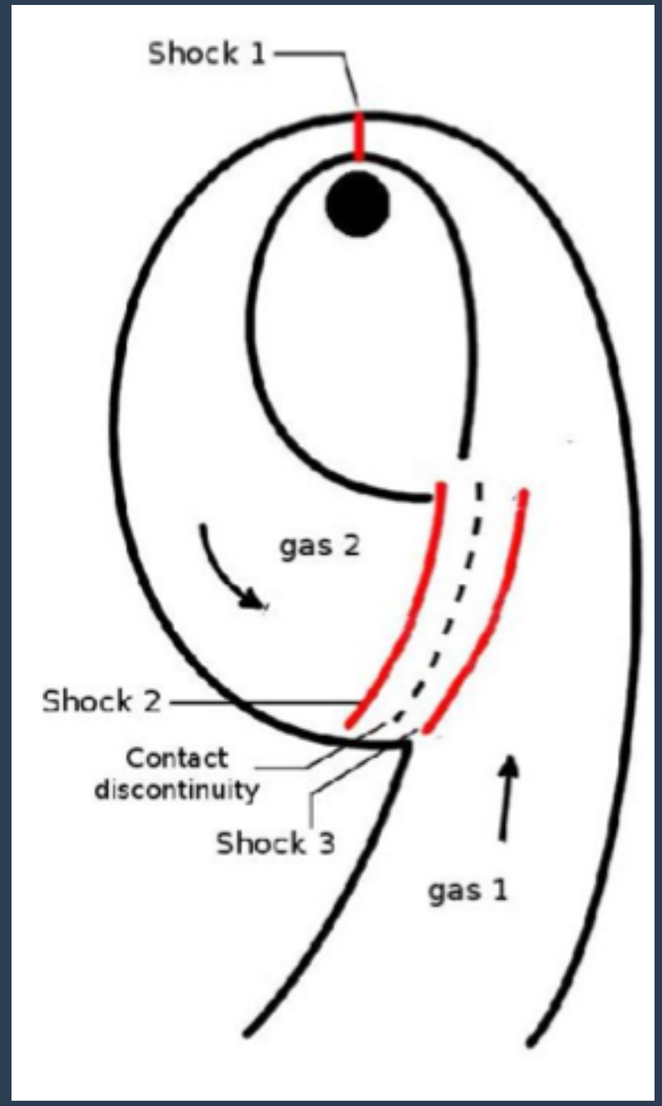


Rosswog et al. 2008

So, Are We Actually Seeing the Energy Lost in the Outer Shocks?

Self crossing 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

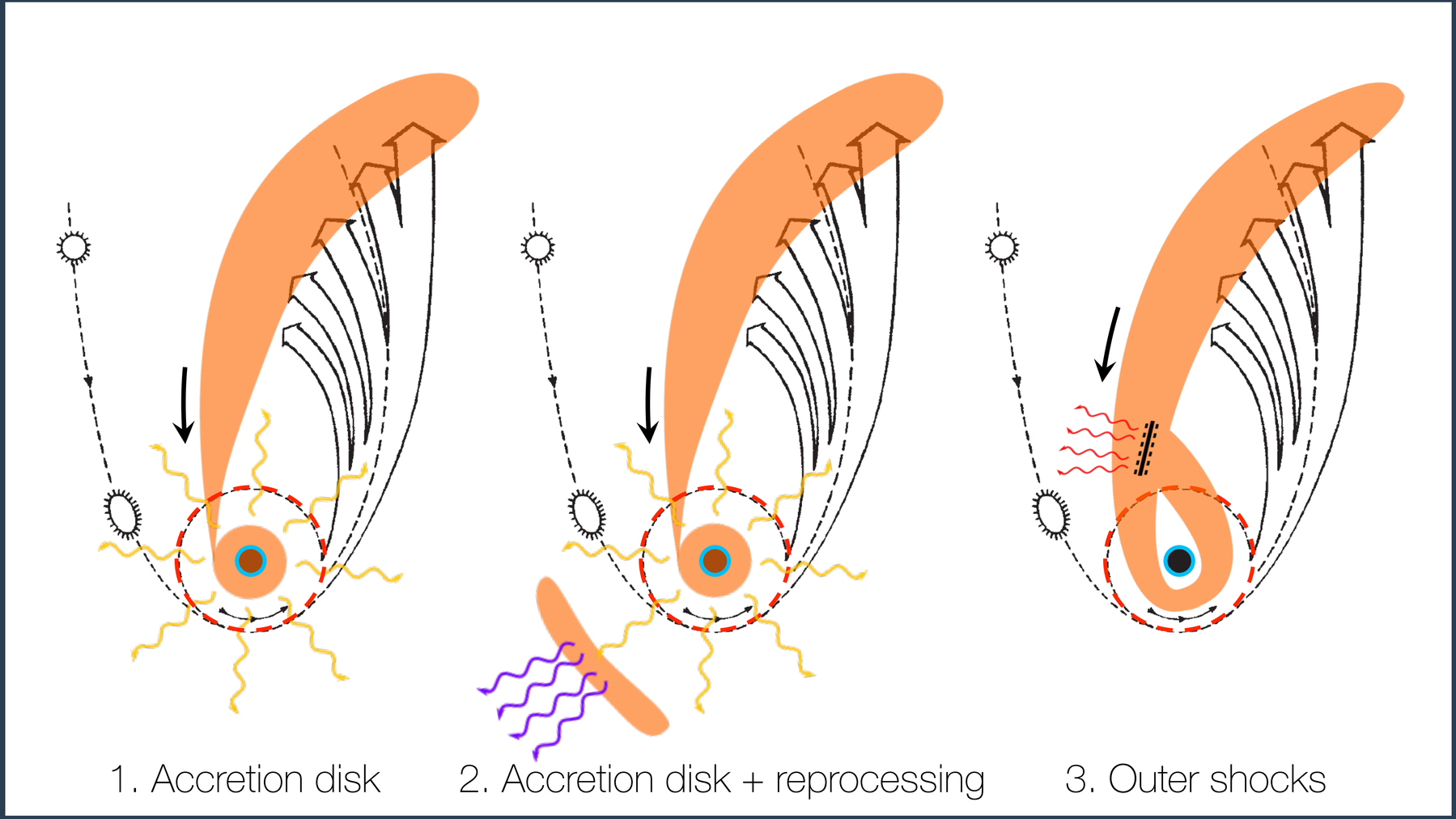


Piran et al. 2015

Puzzle I: Why do TDEs emit mostly optical & ultraviolet light?

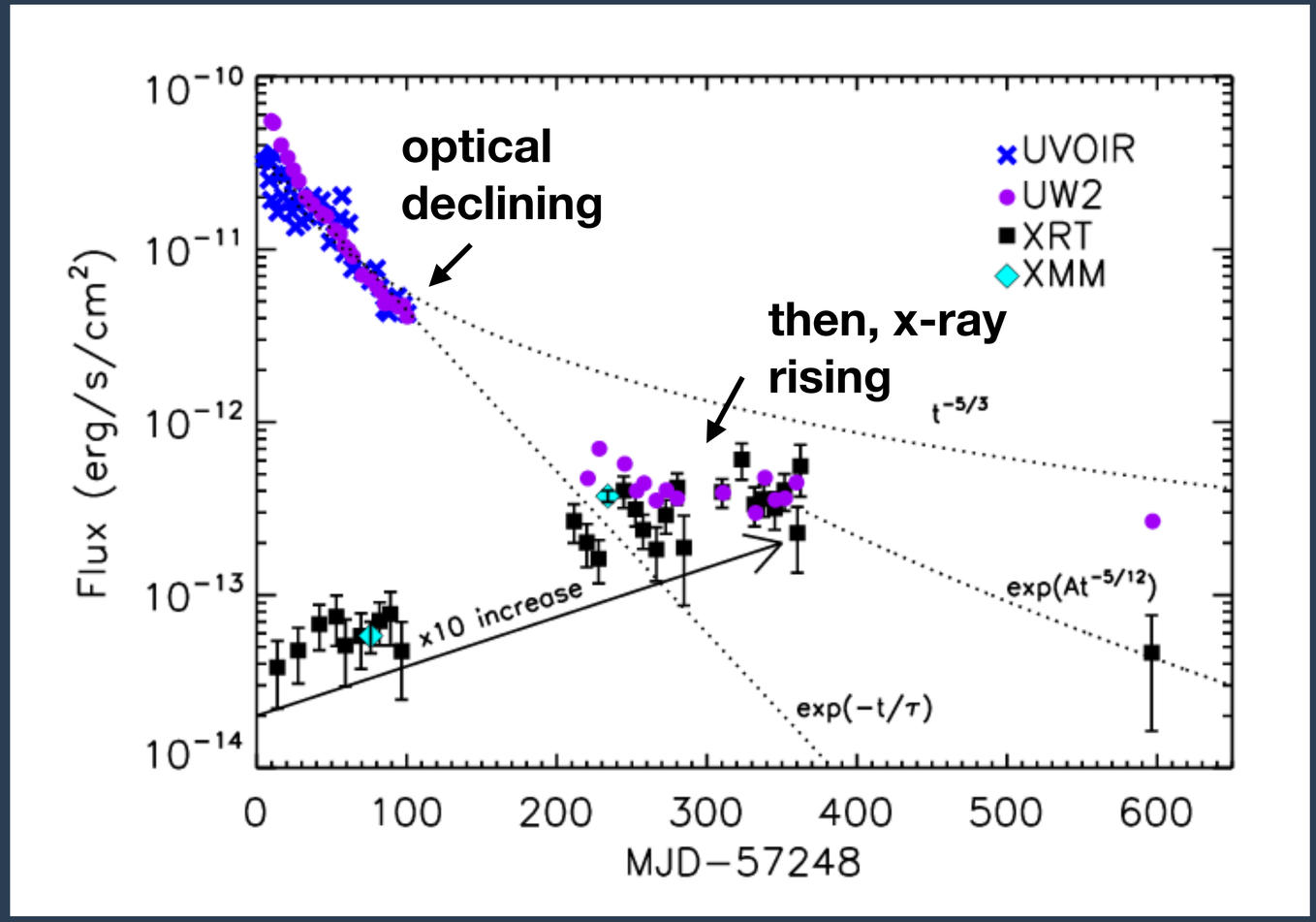
Solution: We are seeing emission from outer shocks

What Will Emit Light in a TDE?



Courtesy C. Bonnerot

Optical = Reprocessed Accretion OR Outer Shocks?



Gezari, Cenko & Arcavi 2017

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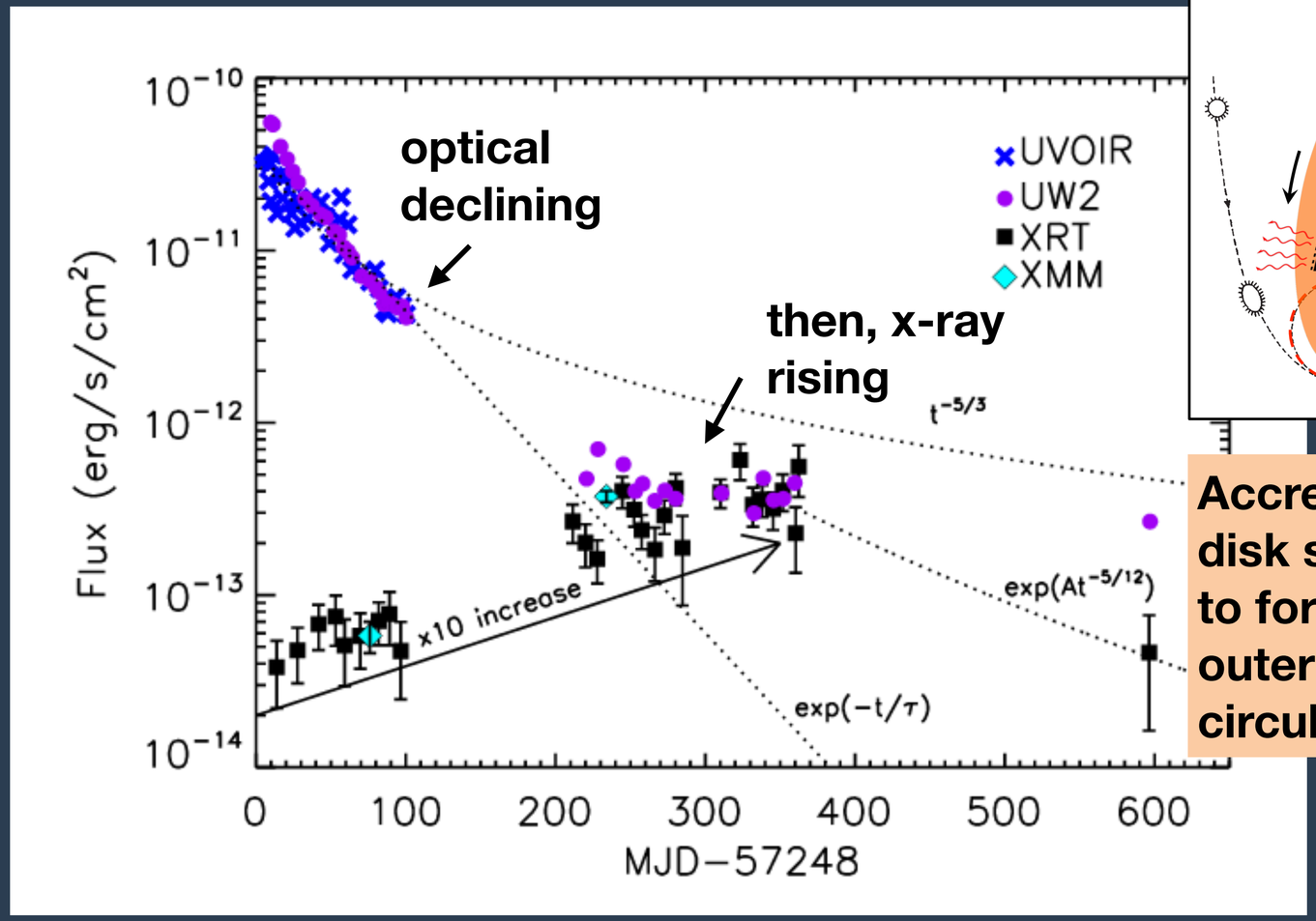

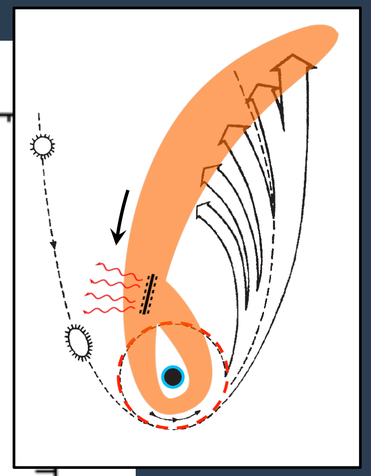

Accretion disk starting to form after outer shocks circularization

Gezari, Cenko & Arcavi 2017

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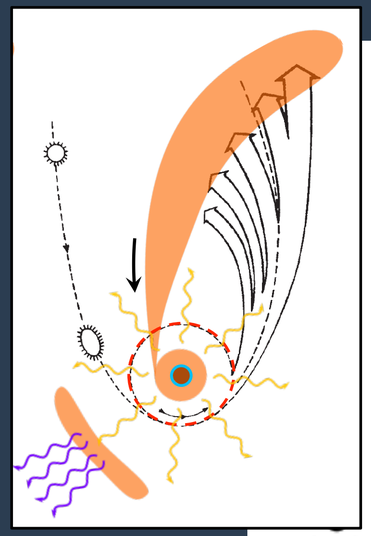
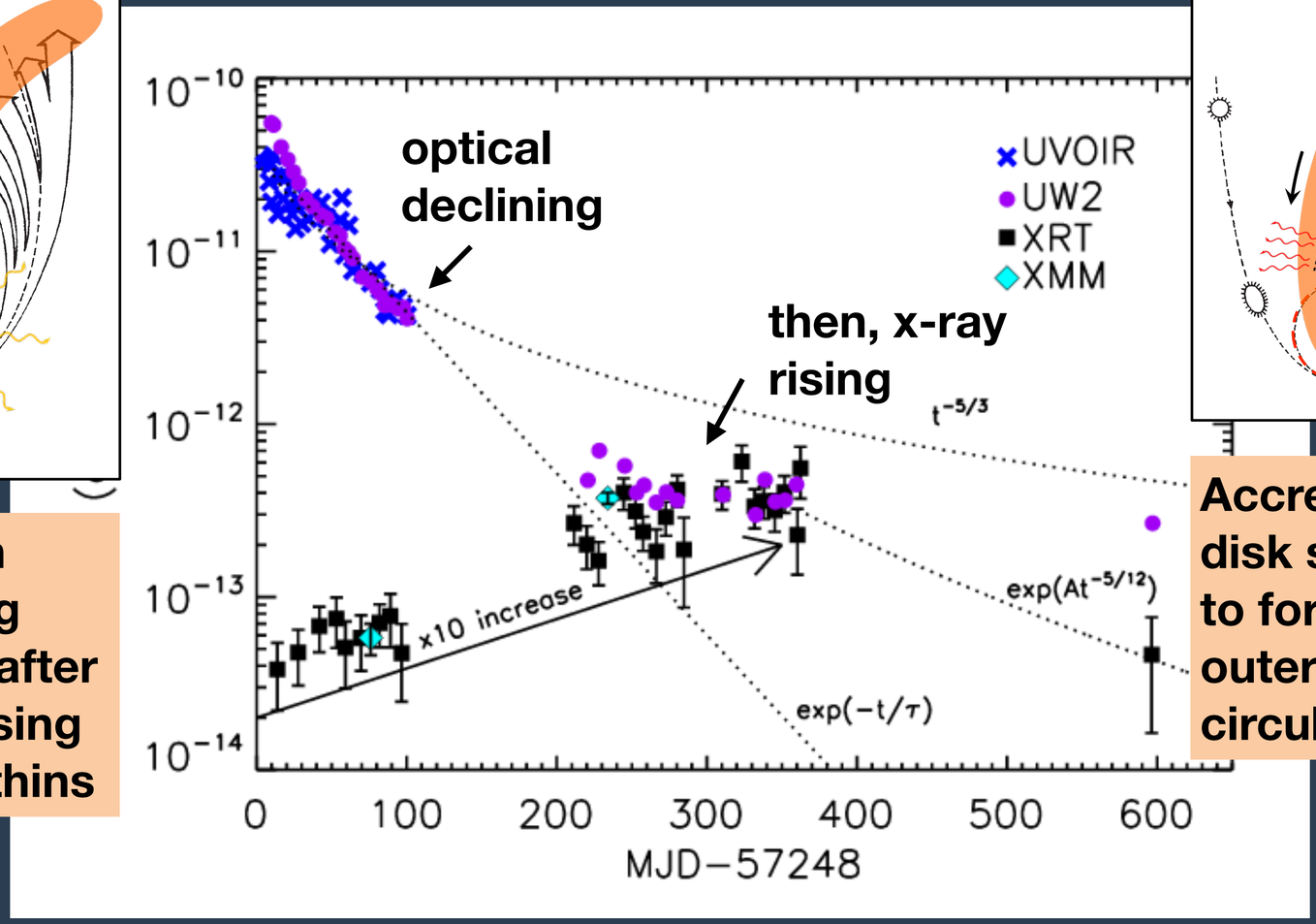
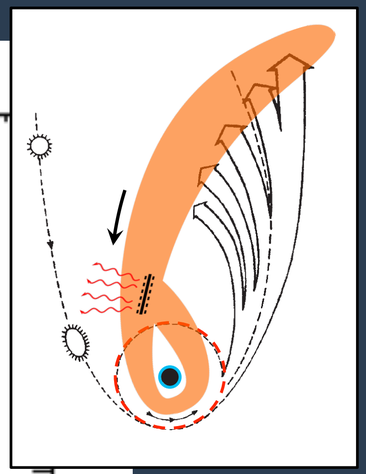


Accretion disk being revealed after reprocessing material thins





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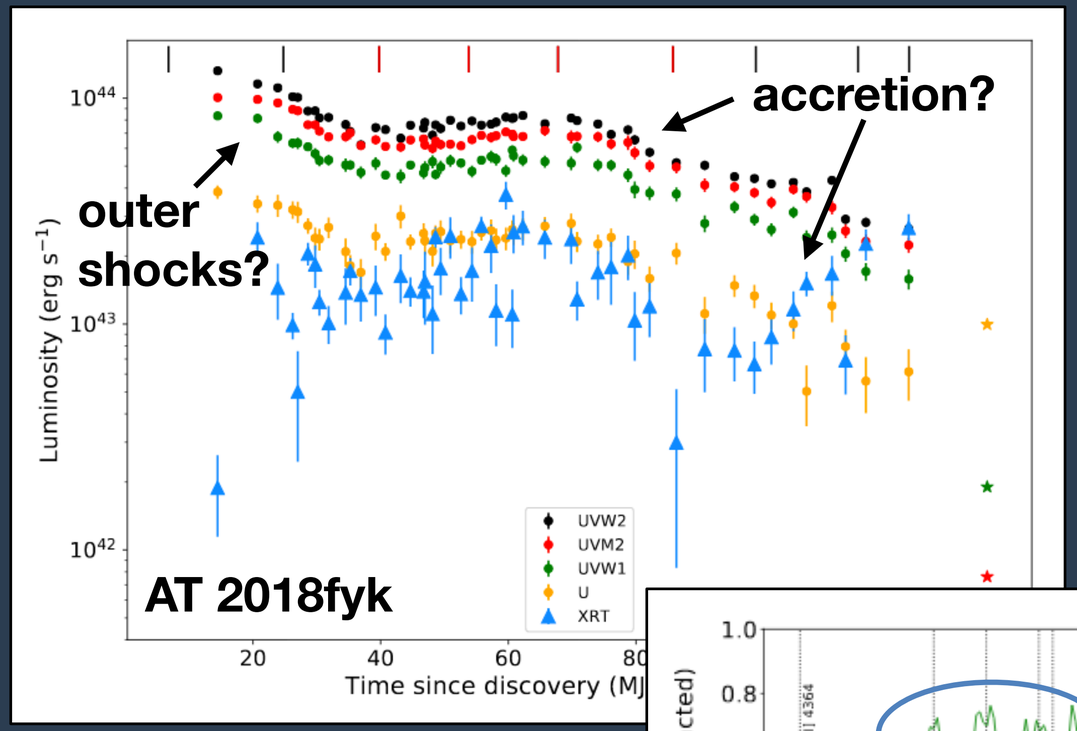
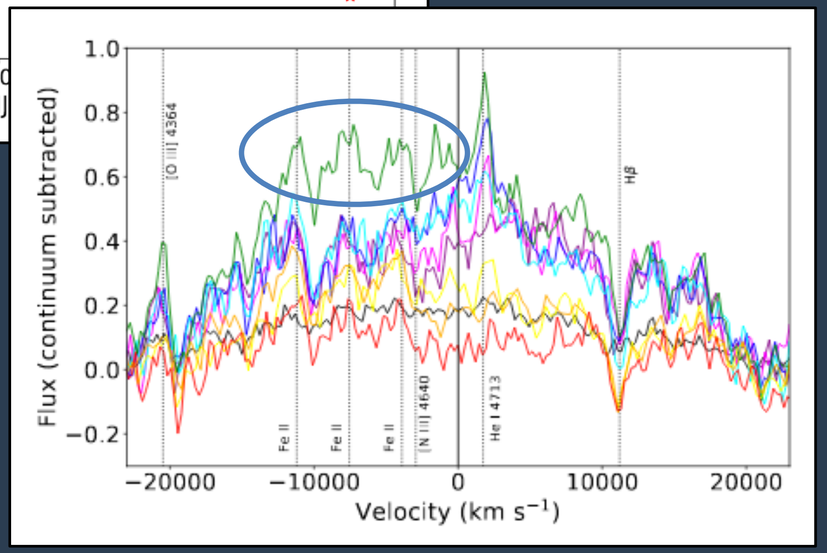
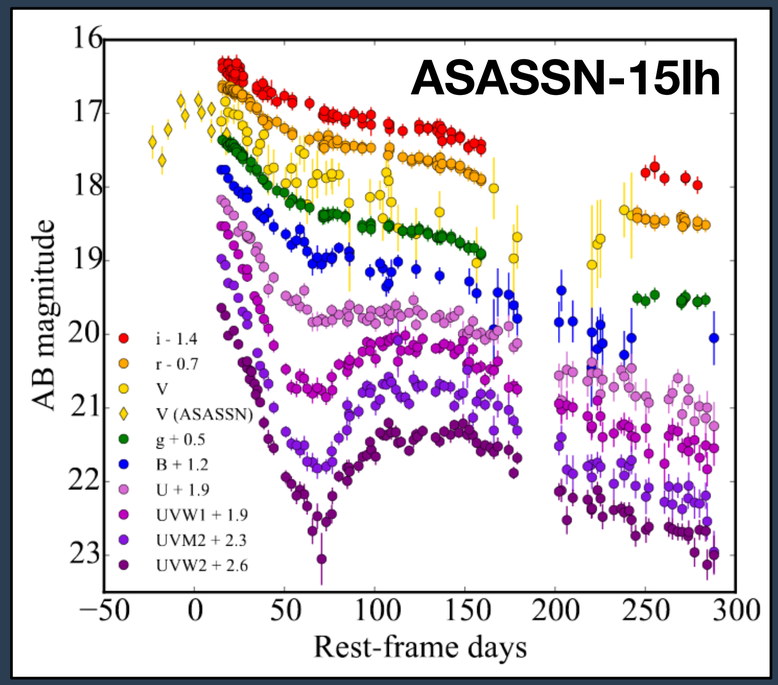


Wevers et al. 2019

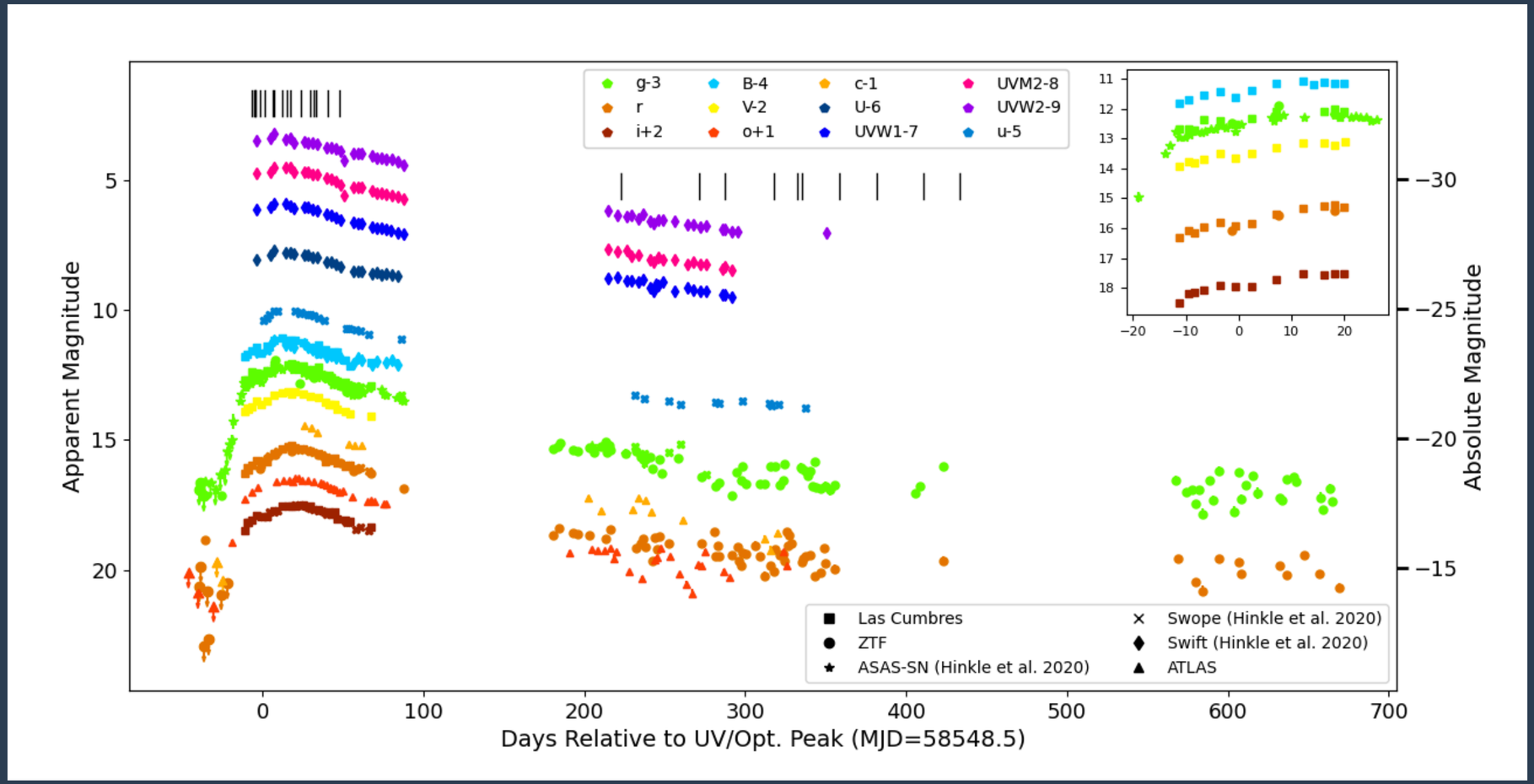




Leloudas et al. 2016

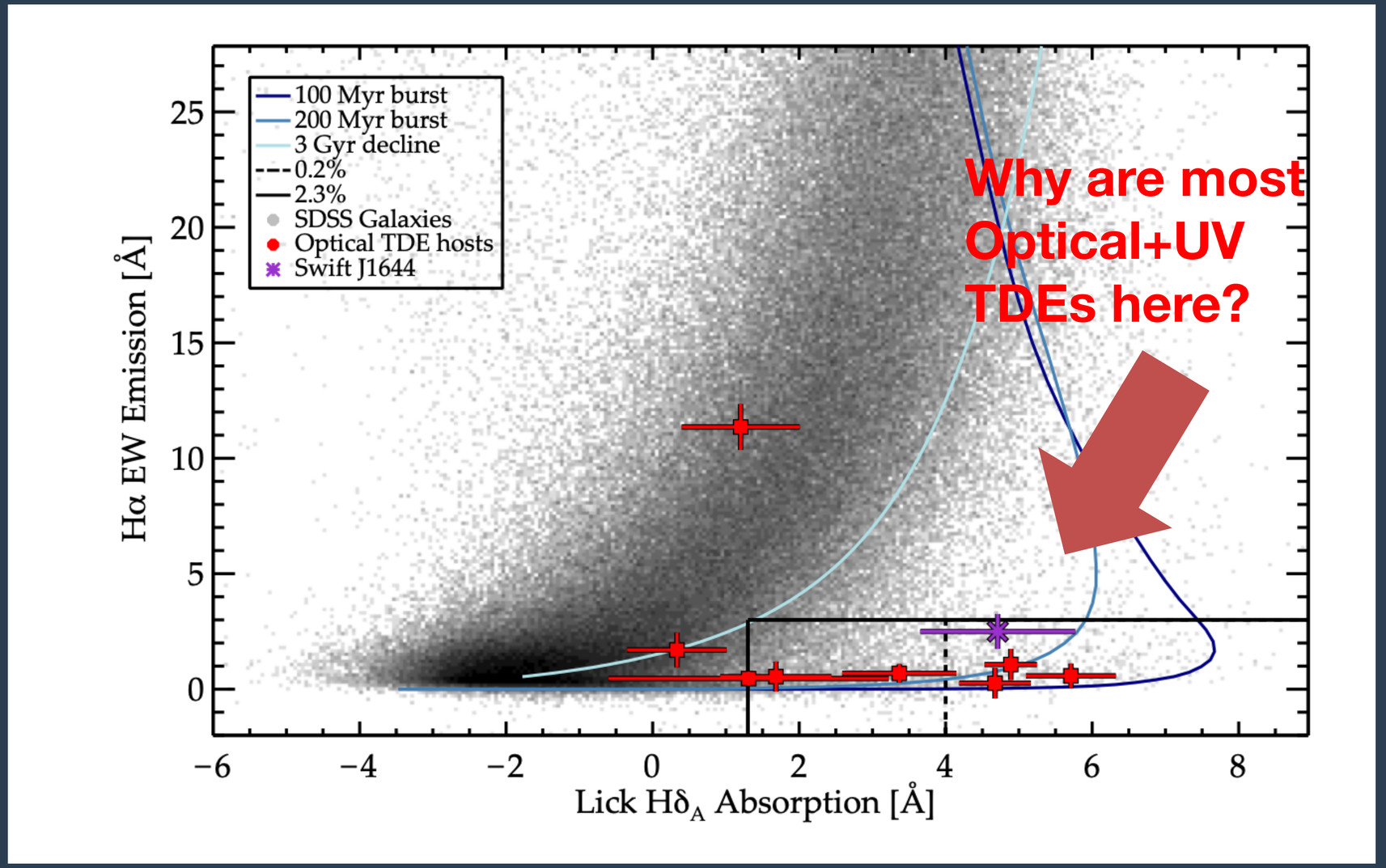
Optical = Reprocessed Accretion OR Outer Shocks?

Sara Faris



Faris et al. in prep.

Optical TDEs Prefer Post-Starburst Galaxies - Not Clear Why



French, Arcavi, Zabludoff 2016

Puzzle II: Why do TDEs prefer post-starburst galaxies?

Optical TDEs Prefer Post-Starburst Galaxies - Not Clear Why

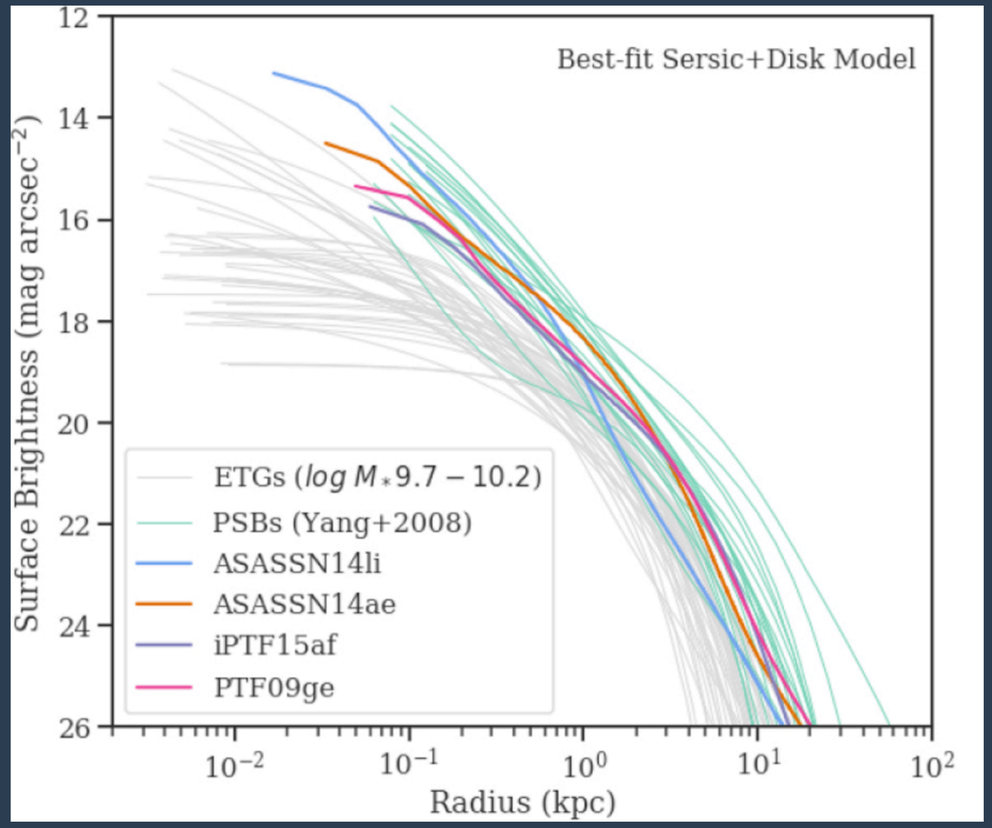
Extremely high density of stars in the galaxy nucleus?
Stone & van Velzen (2016); Stone et al. (2018); French et al. (2020)

Large numbers of massive stars?
Bortolas (2022)

Circumnuclear gas resevoirs?
Karas & Subr (2007)

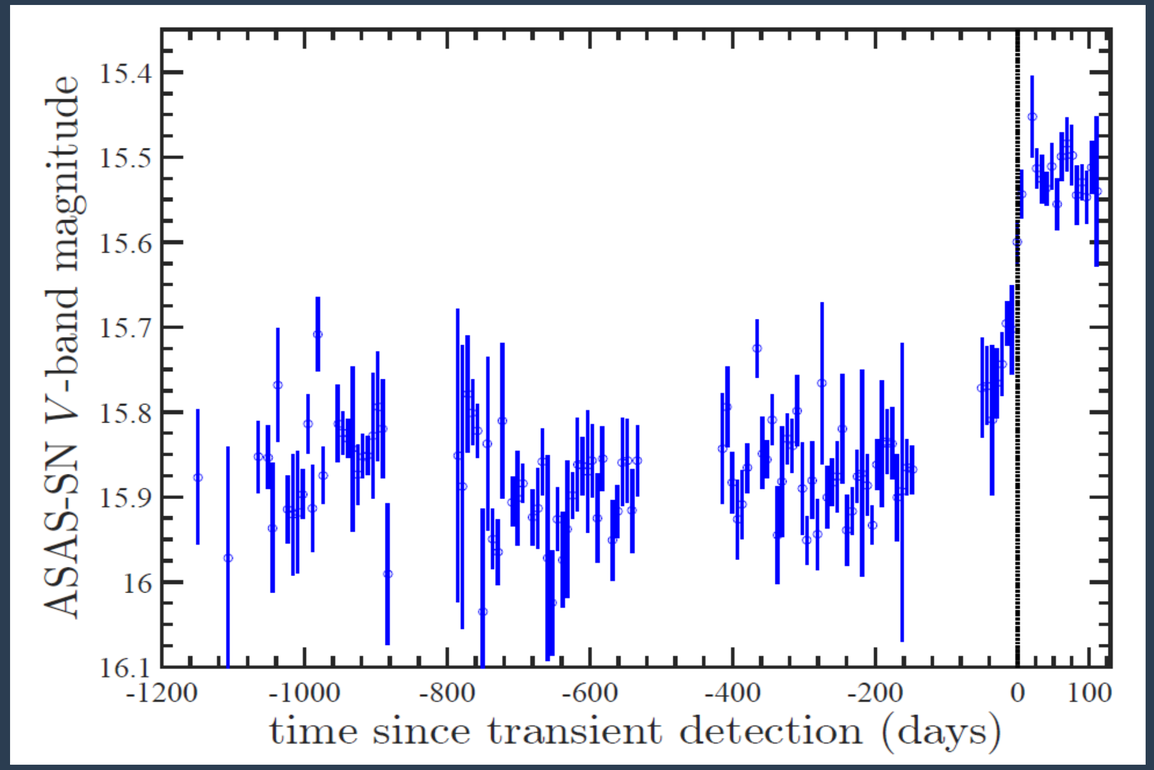
Massive cluster merging?
Arca-Sedda & Capuzzo-Dolcetta (2017)

Post-Merger Binary SMBH?
Li et al. (2015)



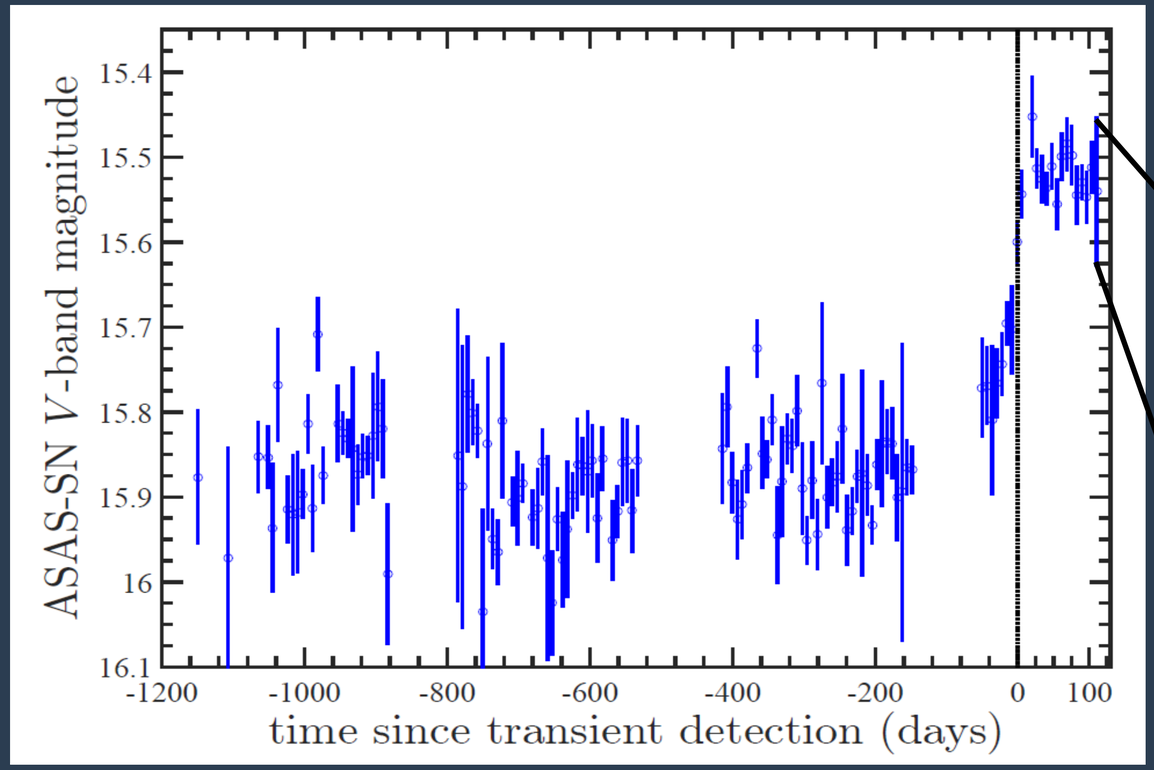
French, Arcavi, et al. 2020

A Second New Class of SMBH-Related Flares - Bowen Flares

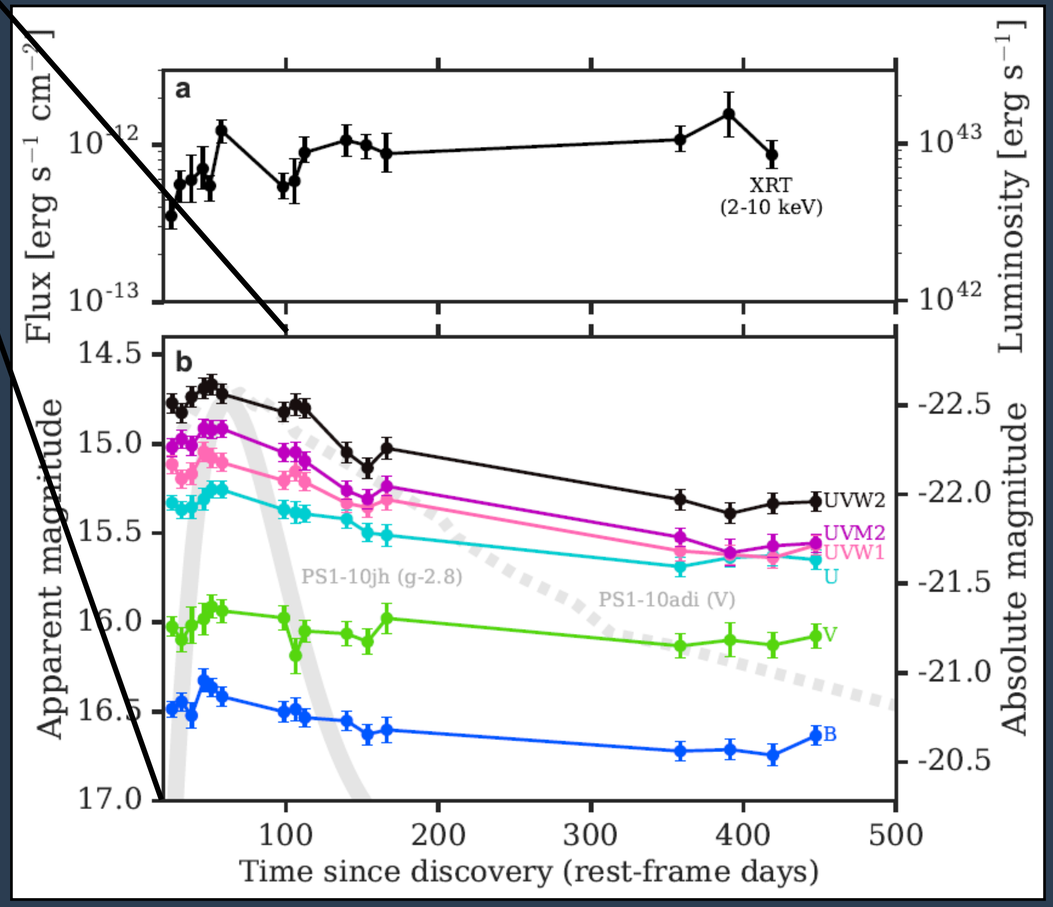


Trakhtenbrot et al. 2019a

A Second New Class of SMBH-Related Flares - Bowen Flares



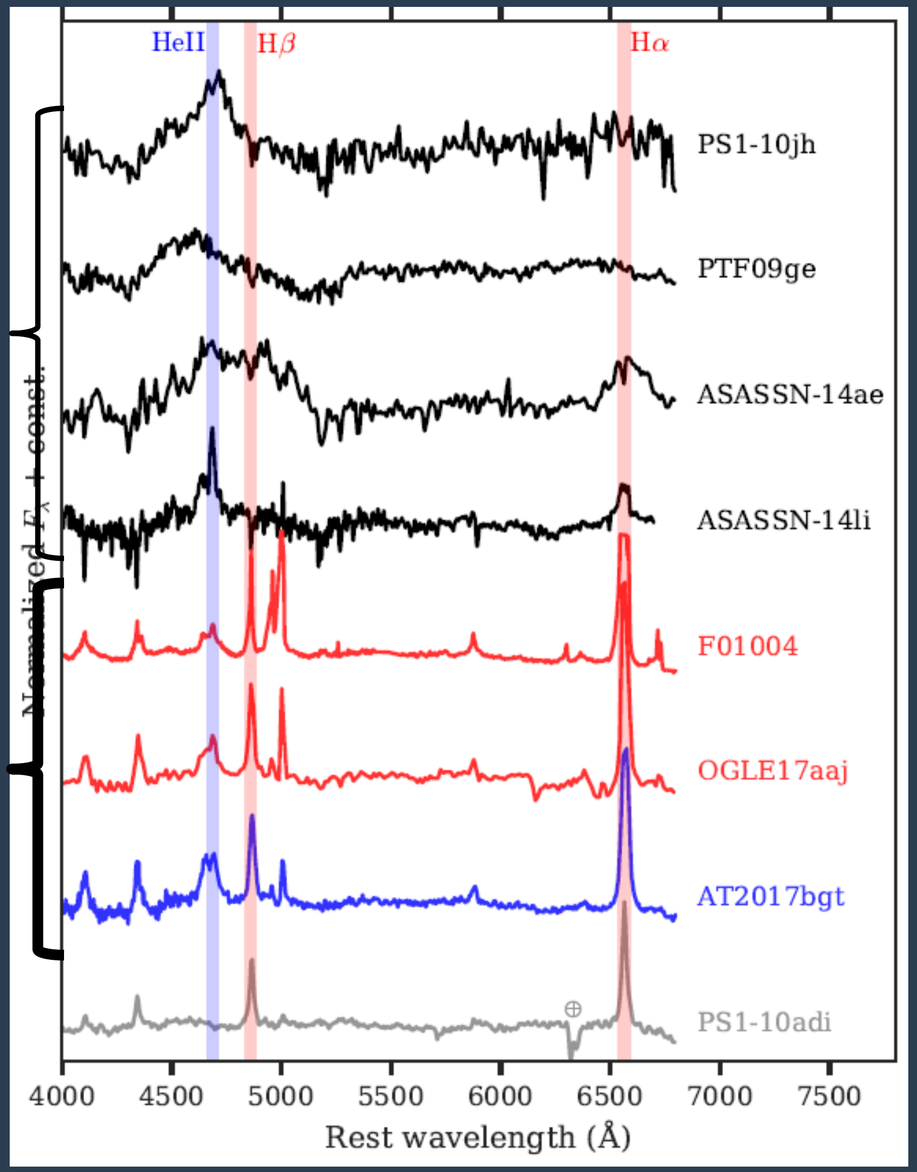
Trakhtenbrot et al. 2019a



A Second New Class of SMBH-Related Flares - Bowen Flares

TDEs (broad lines)

Bowen Flares (narrow lines)



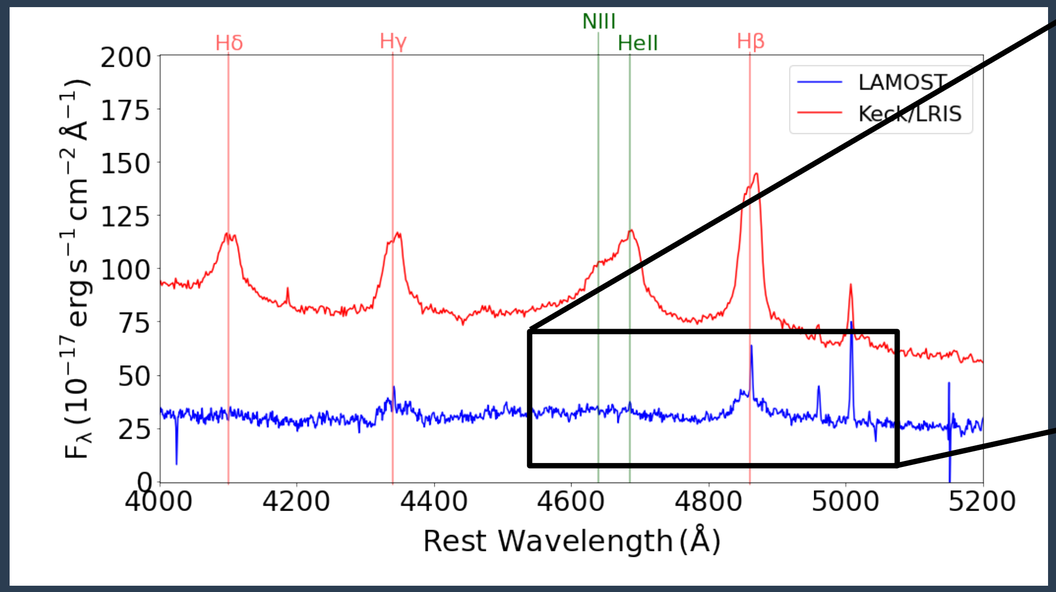
Trakhtenbrot et al. 2019a

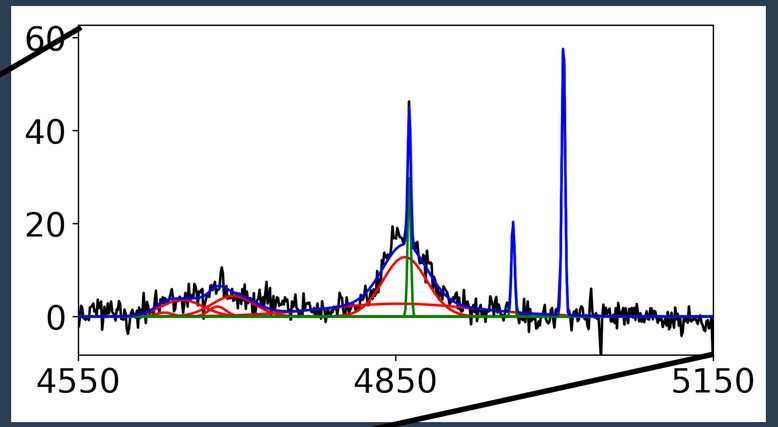
Bowen Flares May be Related to Pre-Existing AGN Disks

Lydia Makrygianni

AT 2021loi: A Bowen Fluorescence Flare with a Re-brightening Episode, Occurring in a Previously-Known AGN

Lydia Makrygianni [1], Benny Trakhtenbrot [1], Iair Arcavi [1,2], Claudio Ricci [3,4], Marco C. Lam [1], Assaf Horesh [5], Itai Sfaradi [5], K. Azalee Bostroem [6,7], Griffin Hosseinzadeh [6], D. Andrew Howell [8,9], Craig Pellegrino [8,9], Rob Fender, [10,11], David A. Green [12], David R. A. Williams [13] and Joe Bright [10]



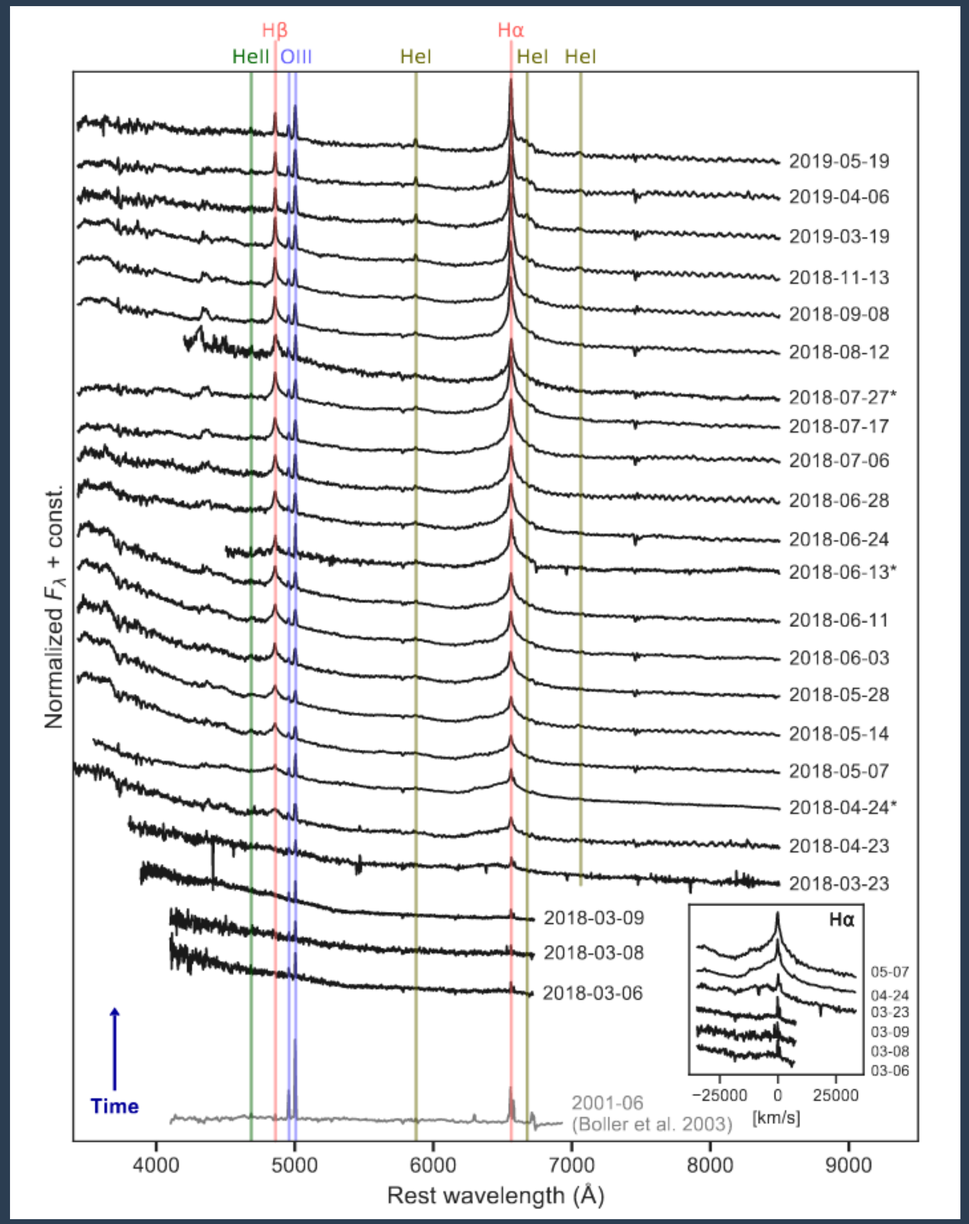


Pre-flare spectrum shows signs of AGN and Bowen features (which got stronger during the flare)

Makrygianni et al. submitted

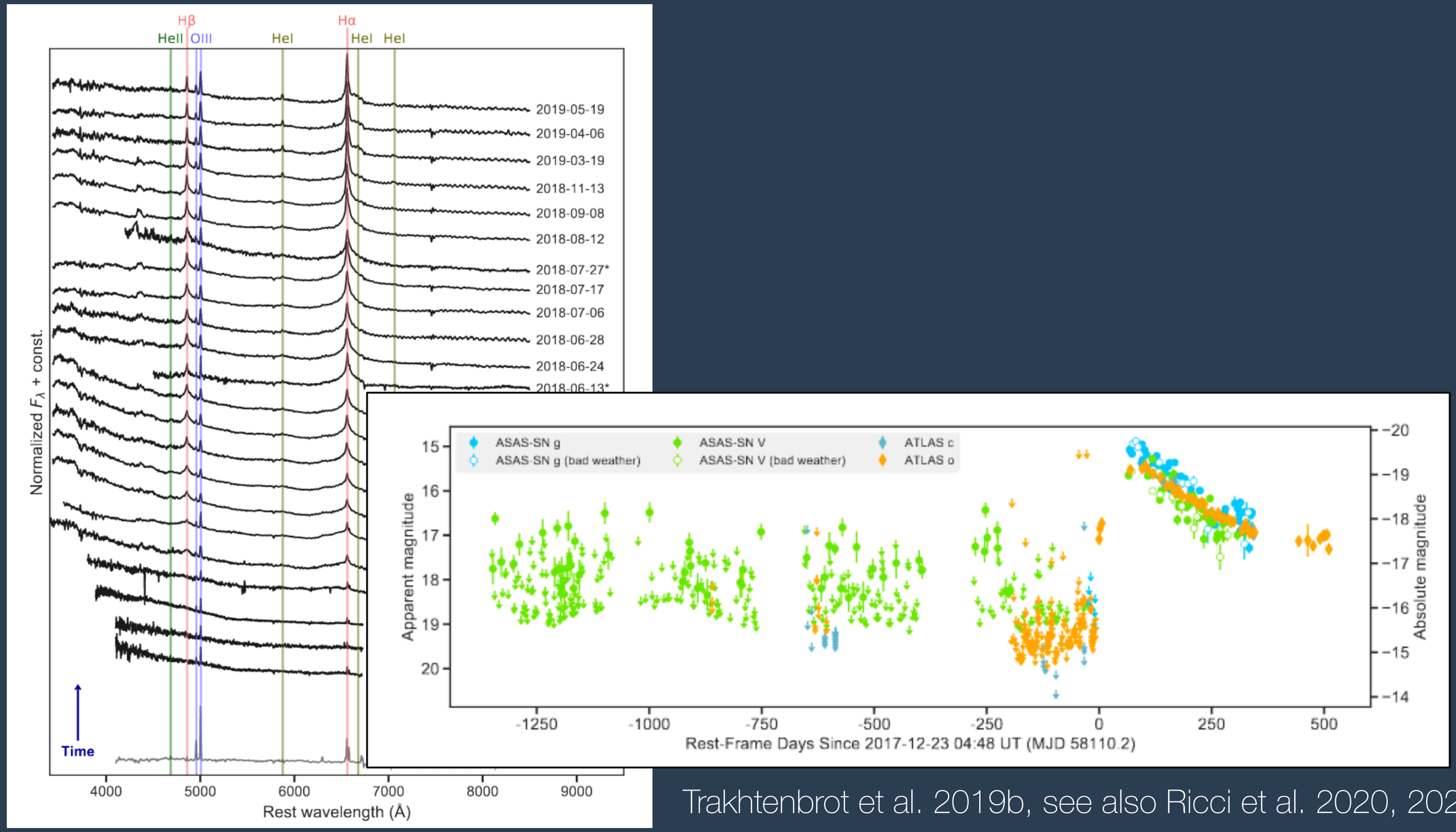
Puzzle IV: What is the nature of these “Bowen Fluorescence Flares”?

A TDE Triggering a Changing-Look AGN?



Trakhtenbrot et al. 2019b, see also Ricci et al. 2020, 2021

A TDE Triggering a Changing-Look AGN?



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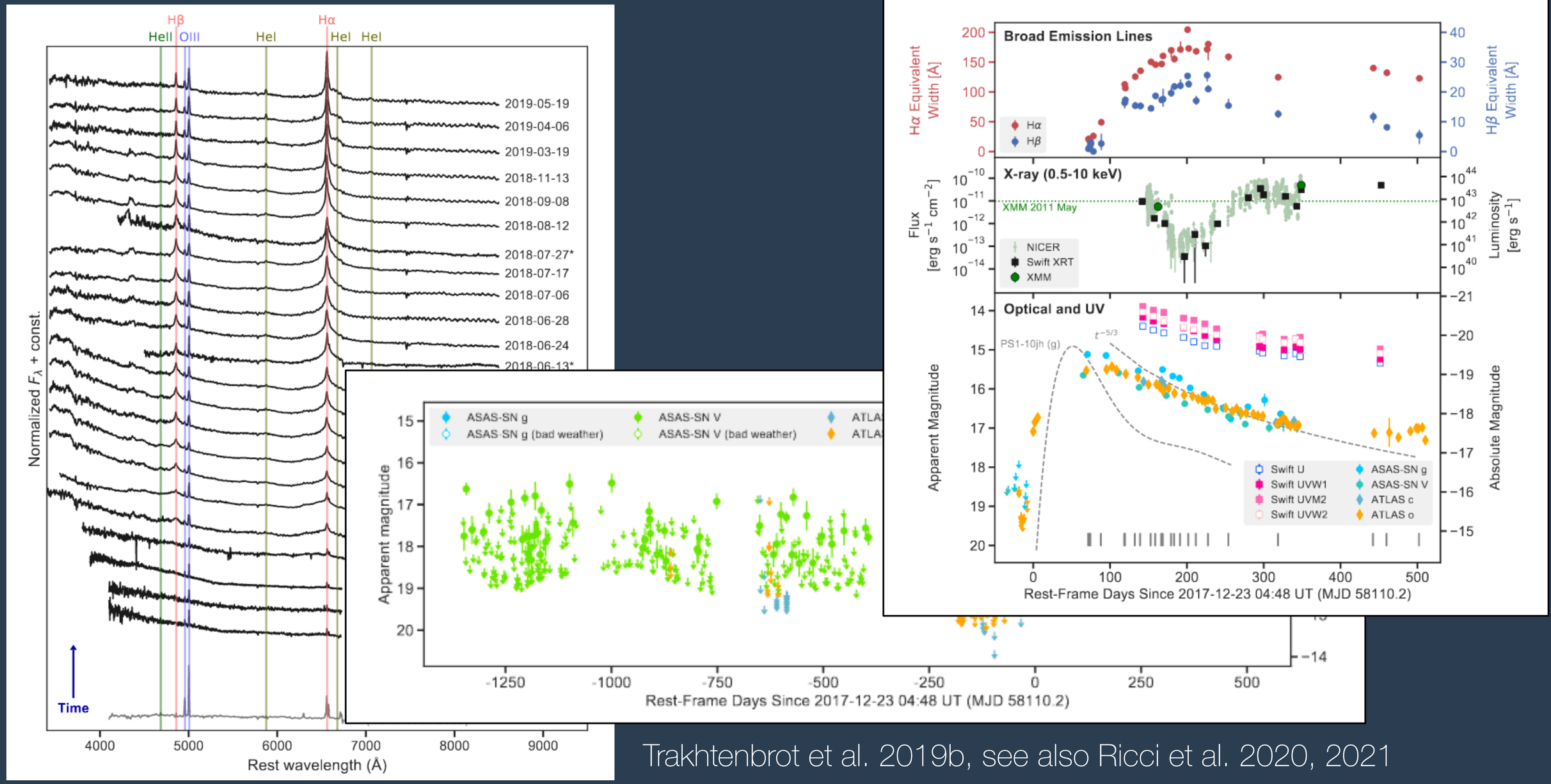
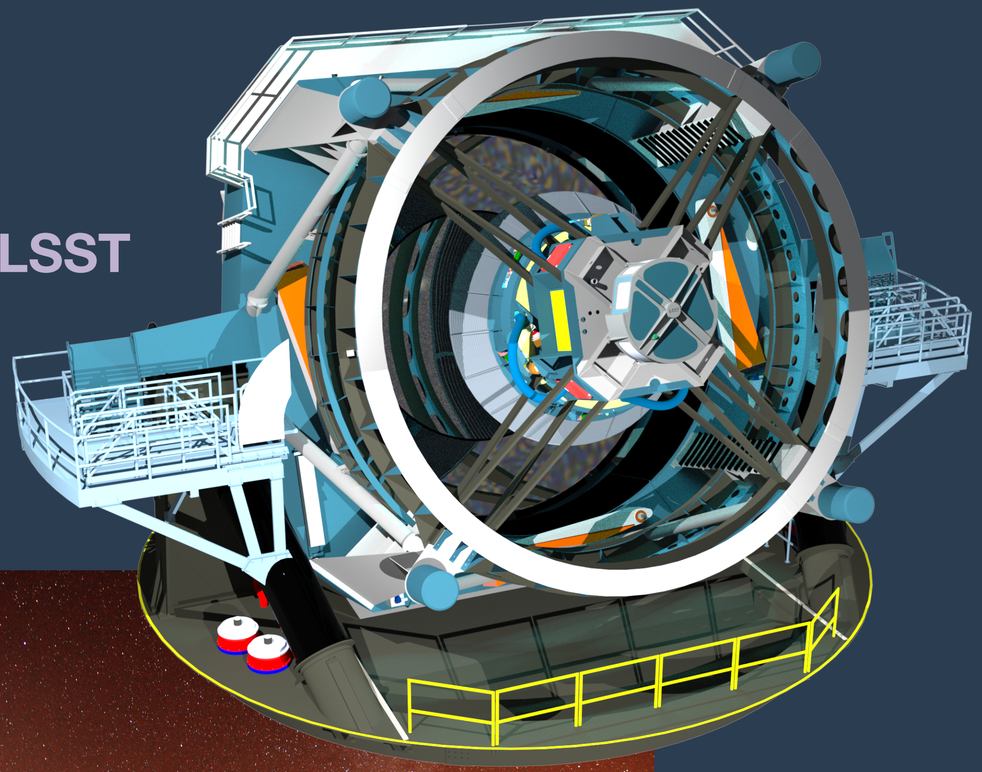


Trakhtenbrot et al. 2019b, see also Ricci et al. 2020, 2021

Challenge: How do we find more TDEs and other nuclear transients in order to solve these puzzles and learn about SMBHs?

New Transient Surveys Coming Online Find More and More Events

LSST

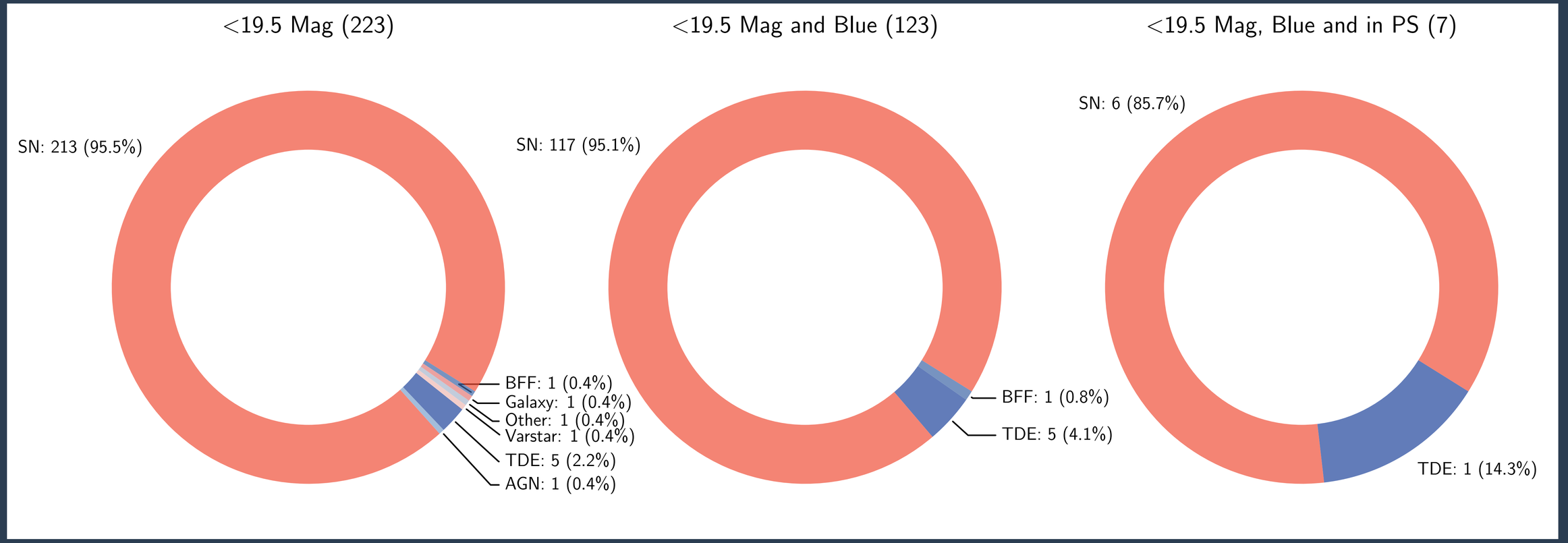


ZTF

BlackGEM

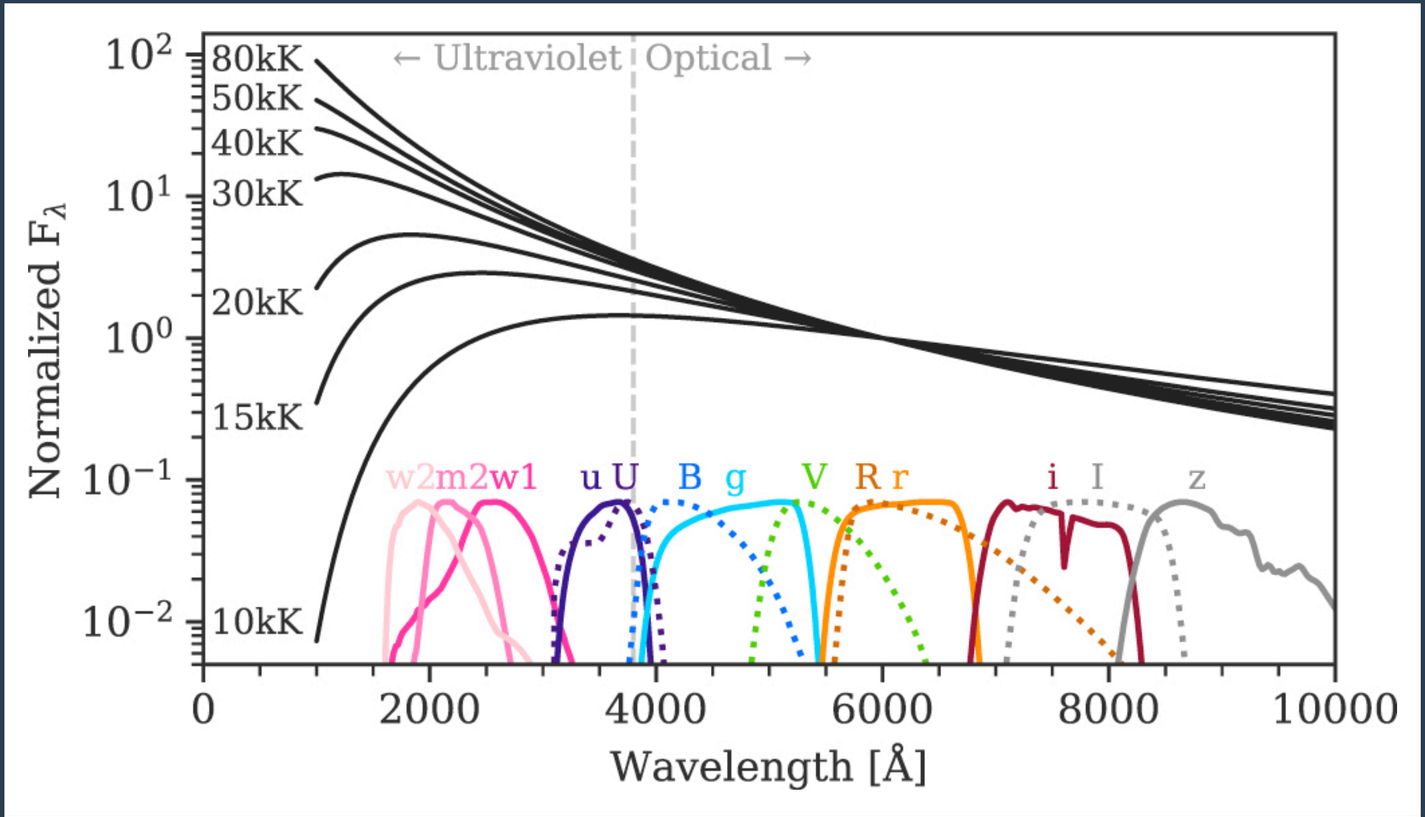
TDEs are only 2% of Transients in Galaxy Centers

Yael Dgany



Dgany et al. submitted

UV Imager = TDE Classification & Characterization Machine

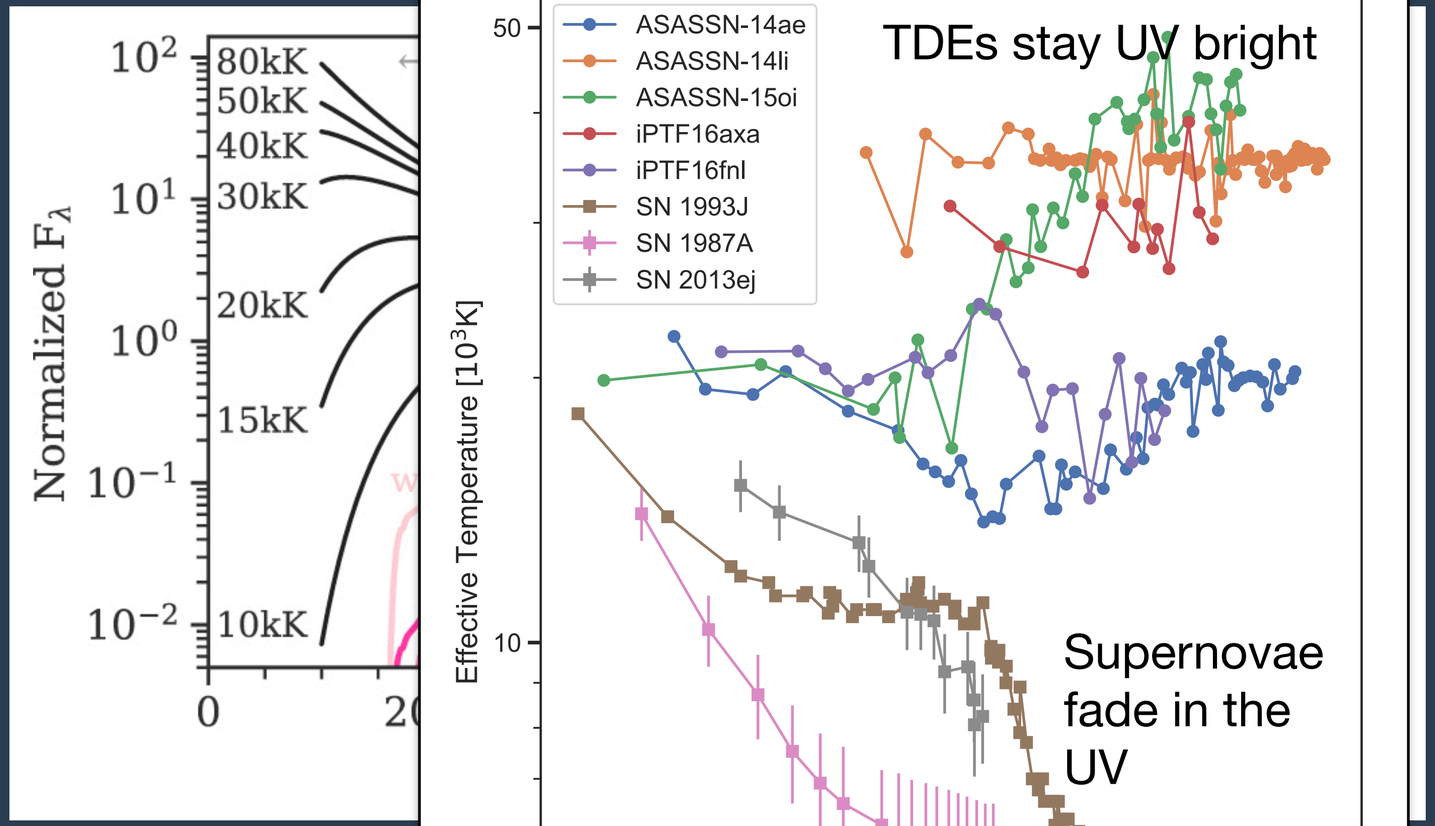


Arcavi 2022

TDEs are brighter, and their host galaxies fainter in the UV so are **much easier to find in the UV**

UV can distinguish the different temperatures, to **more accurately characterizing TDE emission**.

UV Imager = TDE Classification & Characterization Machine



Arcavi 2022

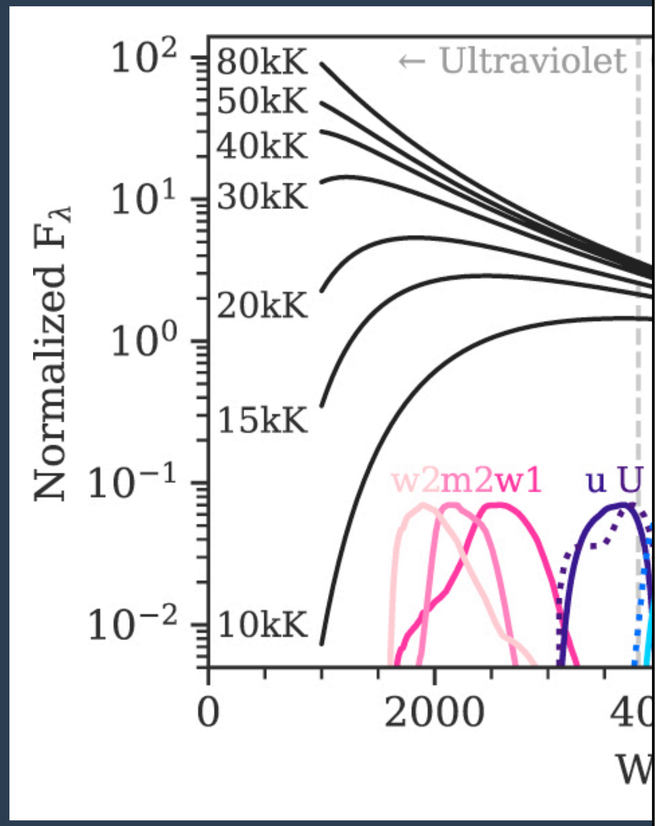
TDEs are brighter, and their host galaxies fainter in the UV so are **much easier to find in the UV**

UV can distinguish the different temperatures, to **more accurately characterizing TDE emission**.

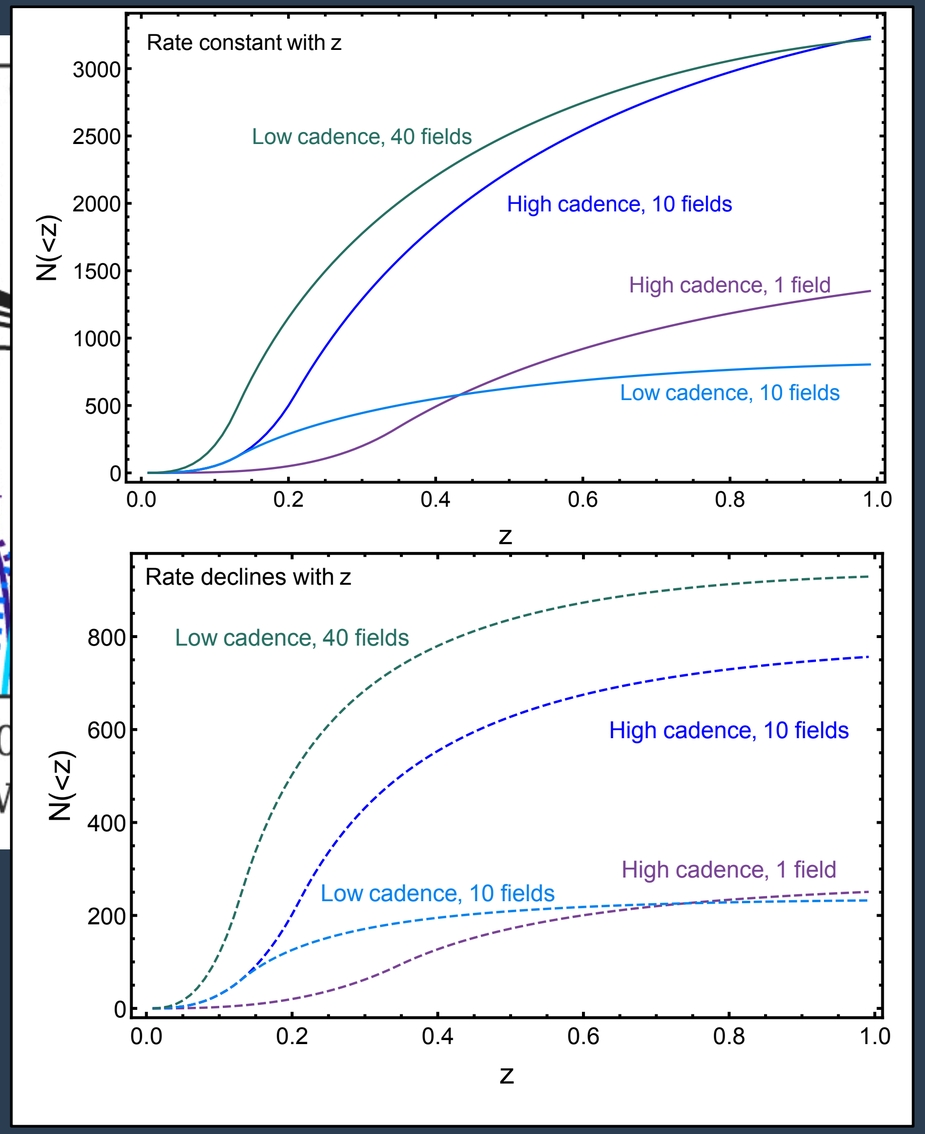
Supernovae cool while TDEs stay blue, so the **UV can distinguish the 2% TDEs from the 98% contaminants**

Zabludoff, Arcavi et al. 2021

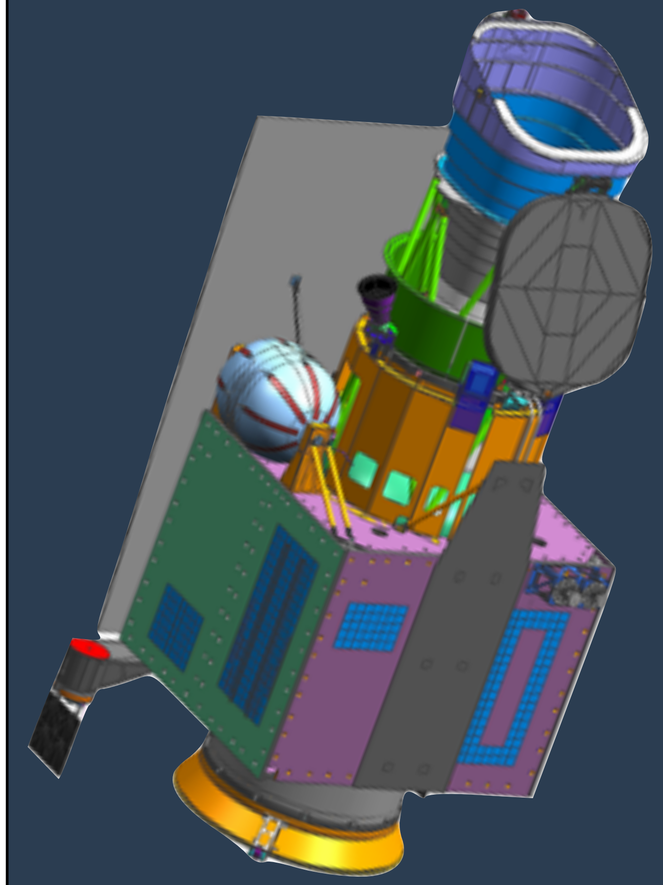
UV Imager = TDE Classification & Characterization Machine



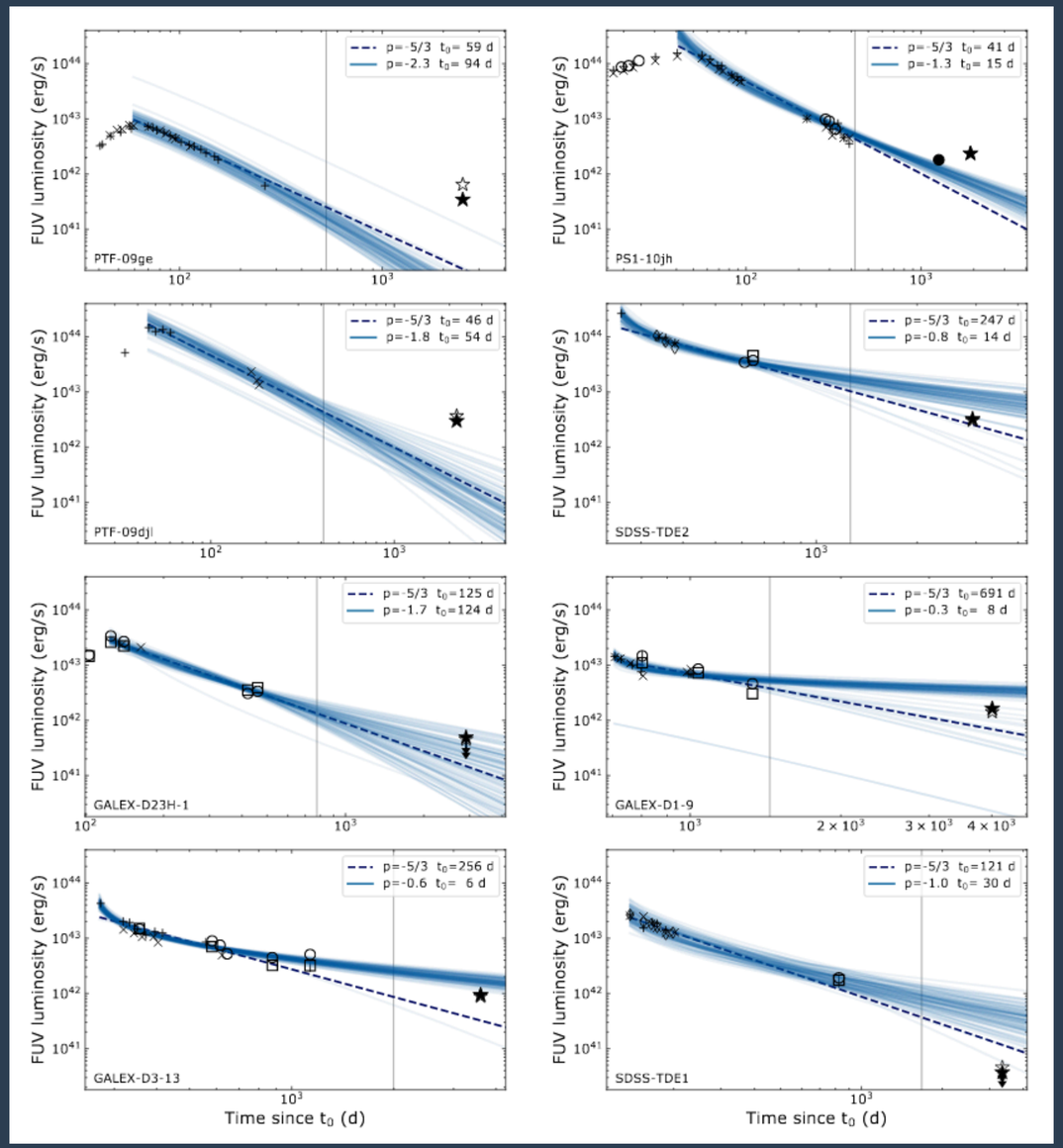
Arcavi 2022



Courtesy: N. Stone



UV Imager = TDE Classification & Characterization Machine



Some TDEs show **long-term UV emission**, perhaps related to a lingering accretion disk

van Velzen et al. 2019

Summary - Beginning to Scratch the Surface of SMBH Transients

A variety of UV transients that can teach us about SMBHs:

Optical Ultraviolet TDEs with puzzling emission mechanism(s) and host galaxy preference

Bowen Fluorescence Flares related to existing AGN disks?

Changing Look AGN Related Flares connected to TDEs?

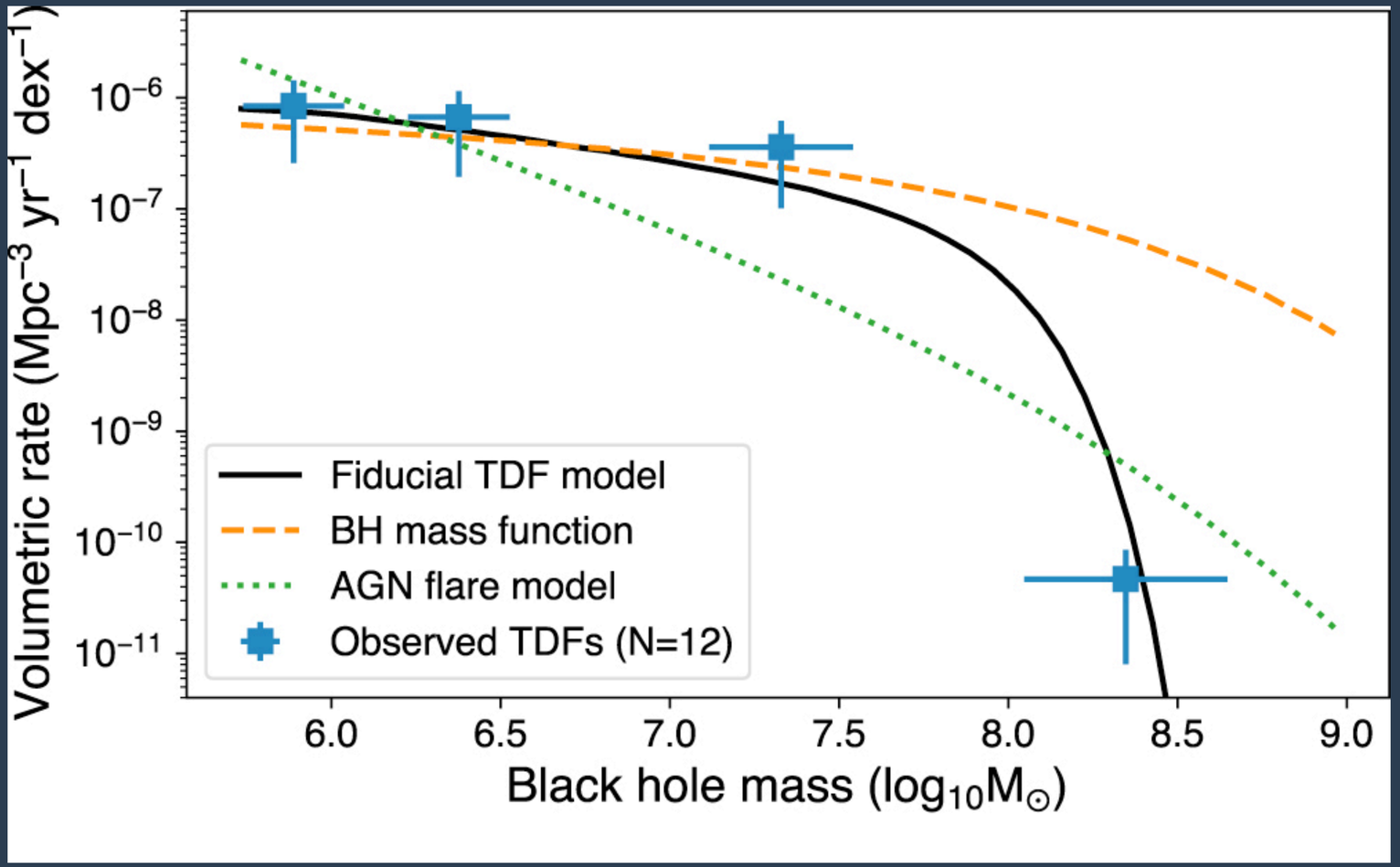
Hard to Find in Optical Surveys since rare and a lot of contamination.

Ultraviolet as the discriminant will build and characterize large samples.

We will be able to use SMBH transients to study the quiescent SMBH population, accretion physics, galaxy dynamics and more.

Puzzle III: Given all these puzzles, are these really tidal disruption events?

Evidence for Event Horizon in Rates of These Events



van Velzen 2018

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