The Final Season Reimagined: 30 Tidal Disruption Events from the ZTF-I Survey

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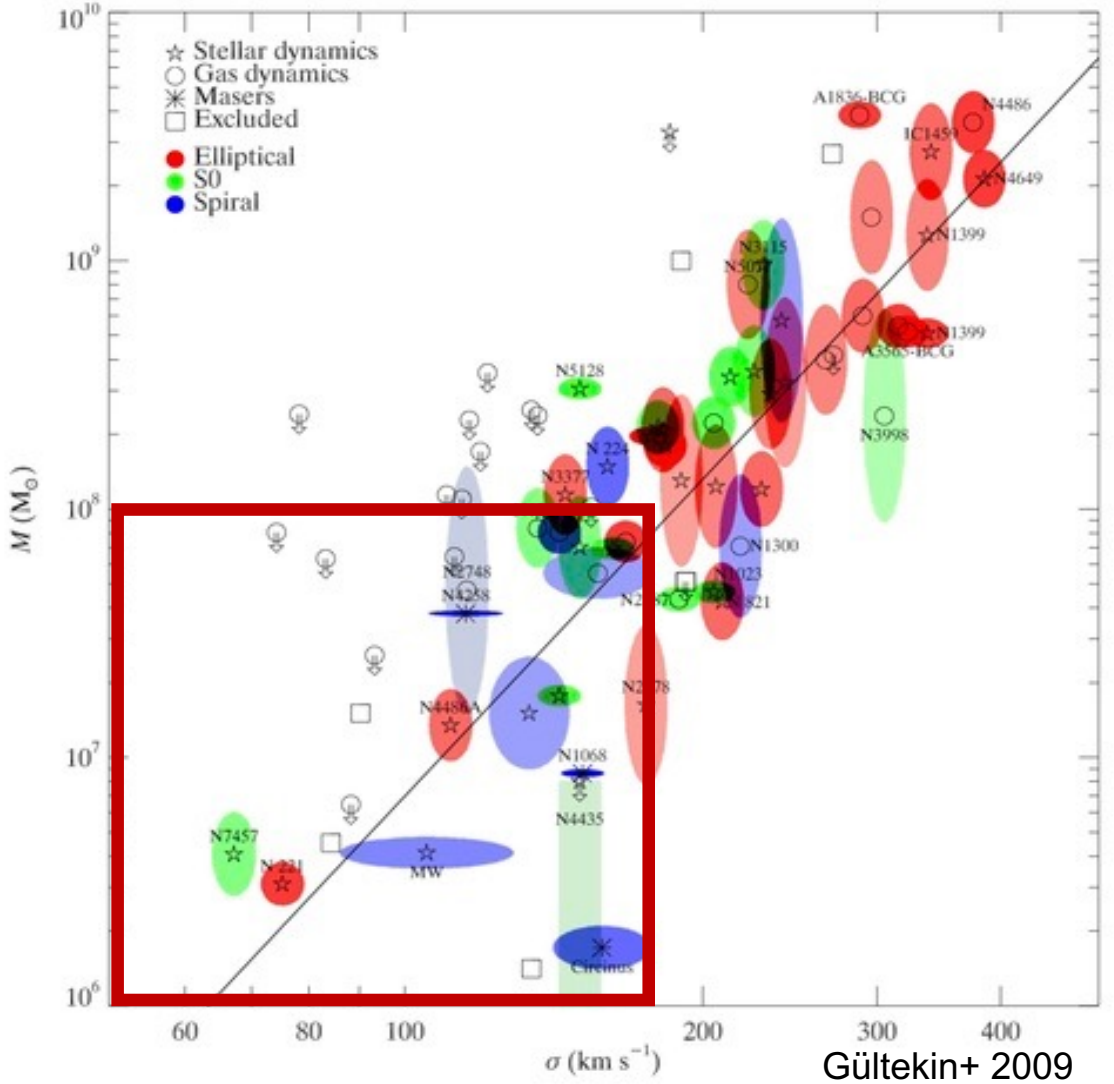
ZTF Team Meeting - May 2022

Massive black holes can be studied relatively well… if they are close and/or bright!

- What is the black hole occupation fraction, particularly in lower mass galaxies?
- How do massive black holes form and grow?
- How do massive black holes and their host galaxies evolve together?

What about distant and/or dormant black holes?

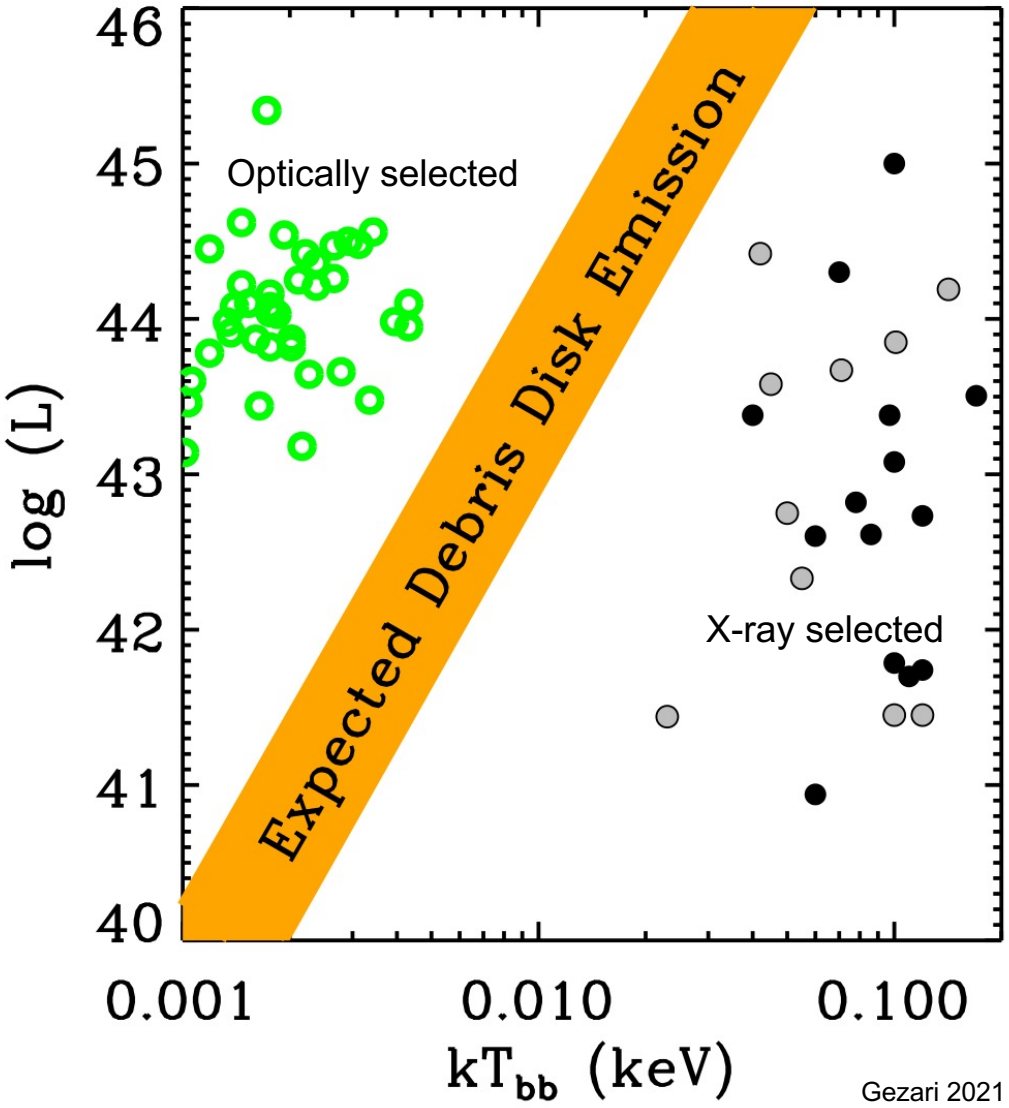
Tidal disruption events can fill in gaps in our knowledge about massive black holes, particularly on the lower mass end.



Gültekin+ 2009

What's the problem?

- Classical TDE picture:
  - Thought to be X-ray dominated events, accretion disks emitting in soft X-ray and EUV
- Lots of events discovered in the optical, often with no accompanying X-ray emission
- Optical/UV properties are surprising

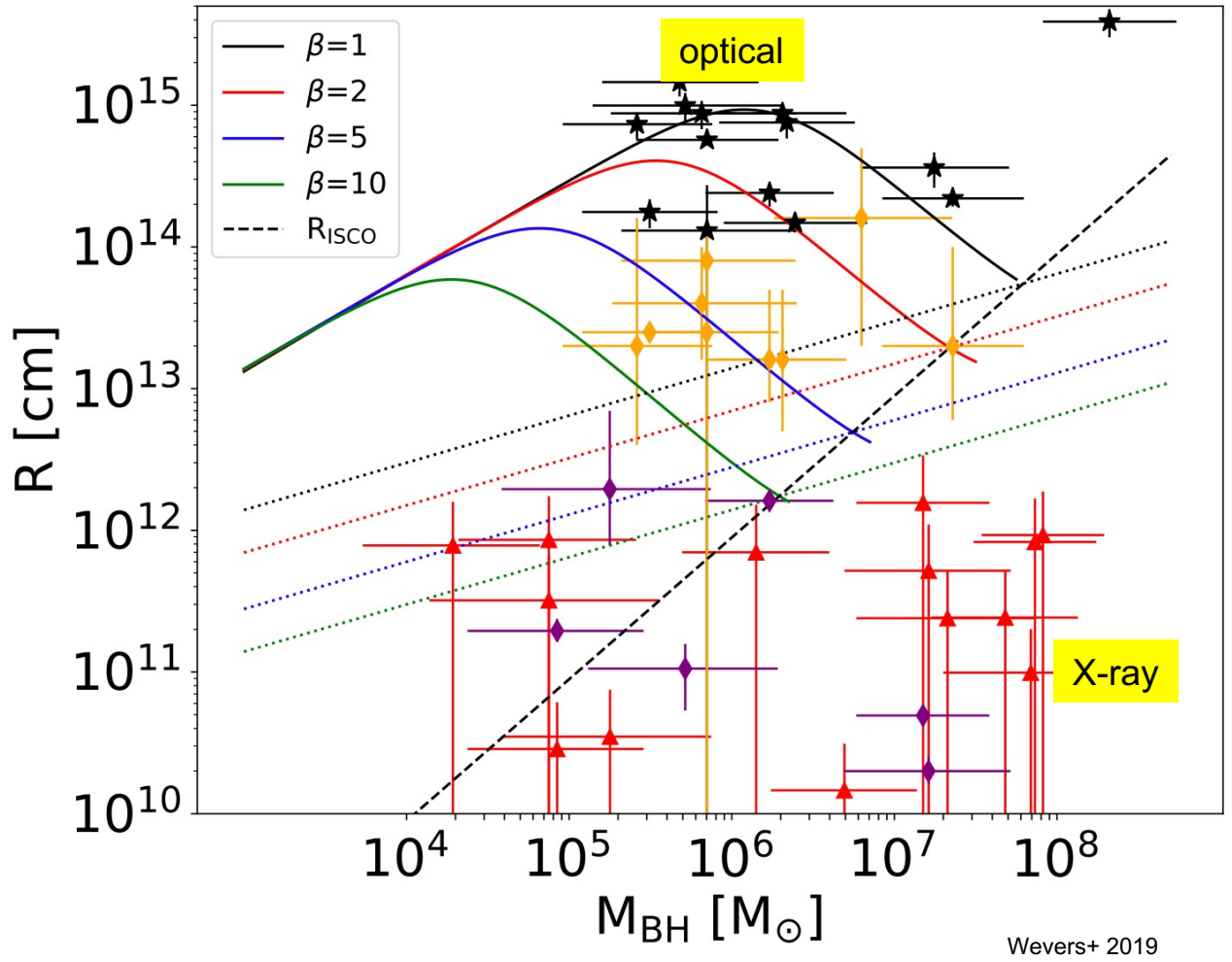


Gezari 2021

What's the problem?

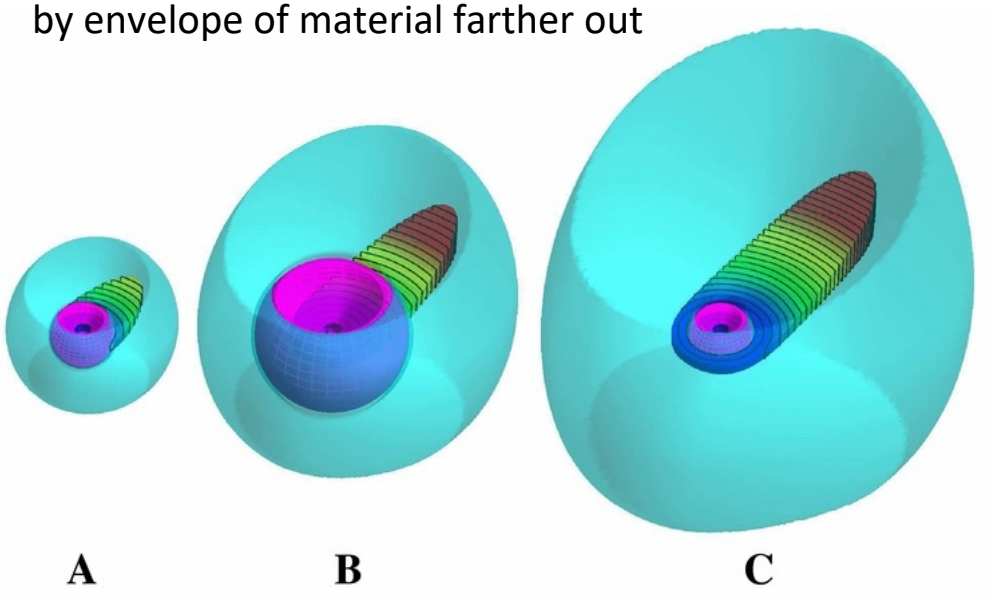
- Blackbody radii from UV/optical emission are far too large for standard accretion disk, closer to self intersection radius of tidal debris

Where does the optical/UV emission come from?

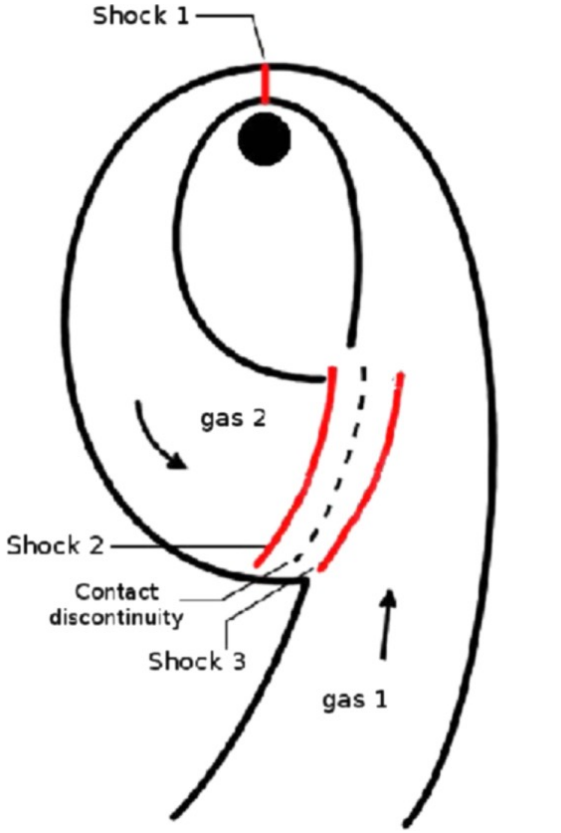


Solutions to the puzzling nature of TDE emission

Reprocessing of X-ray emission from accretion disk to UV and optical wavelengths by envelope of material farther out

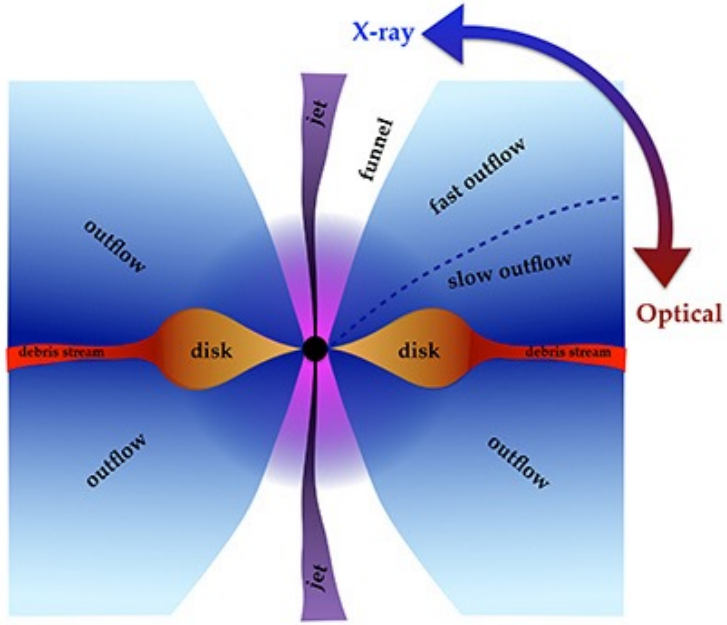


Guillochon+ 2014



Piran+ 2015

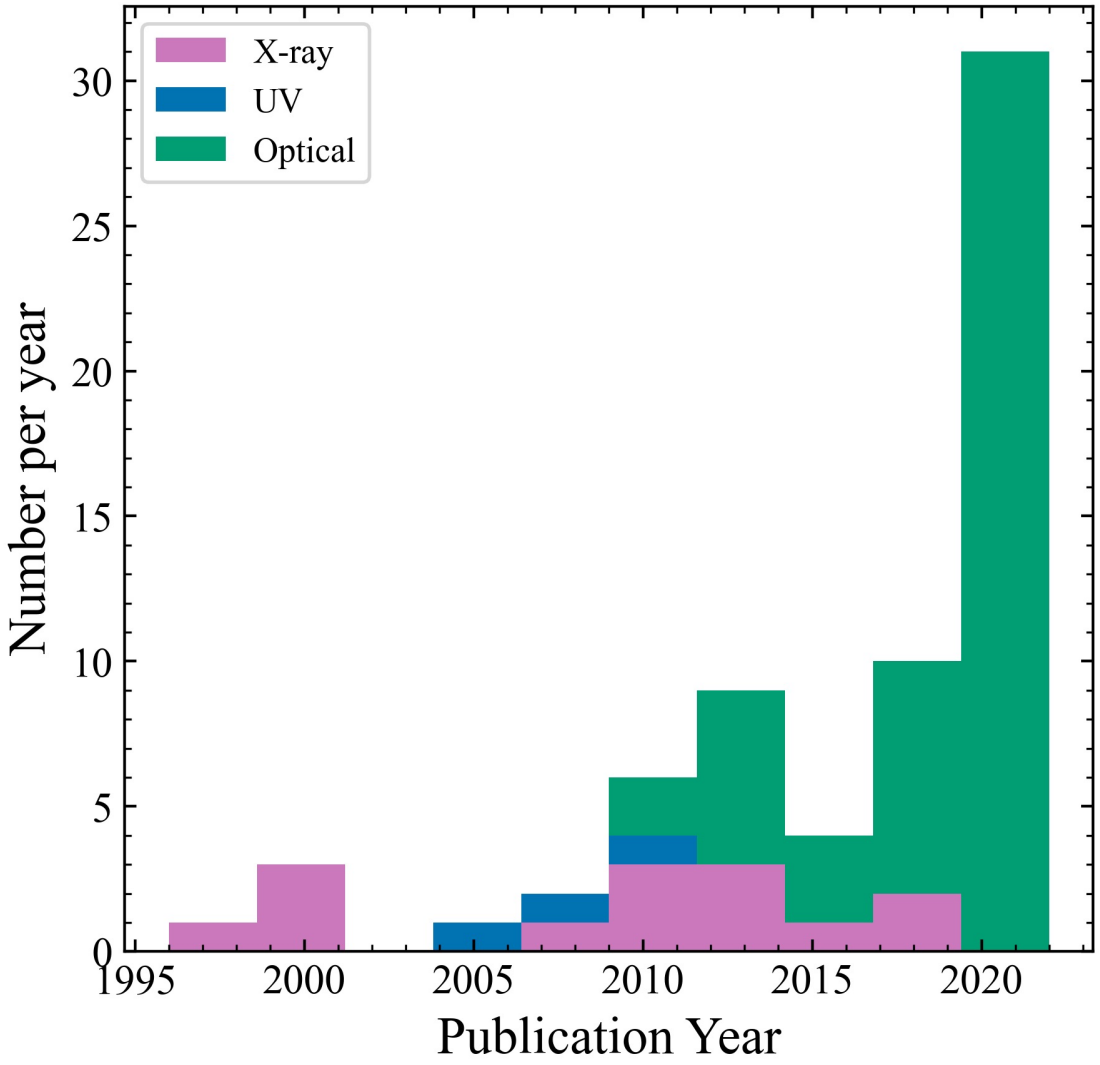
Viewing angle effects where X-ray emission is seen along poles but is reprocessed through an outflow at other angles



Dai+ 2018

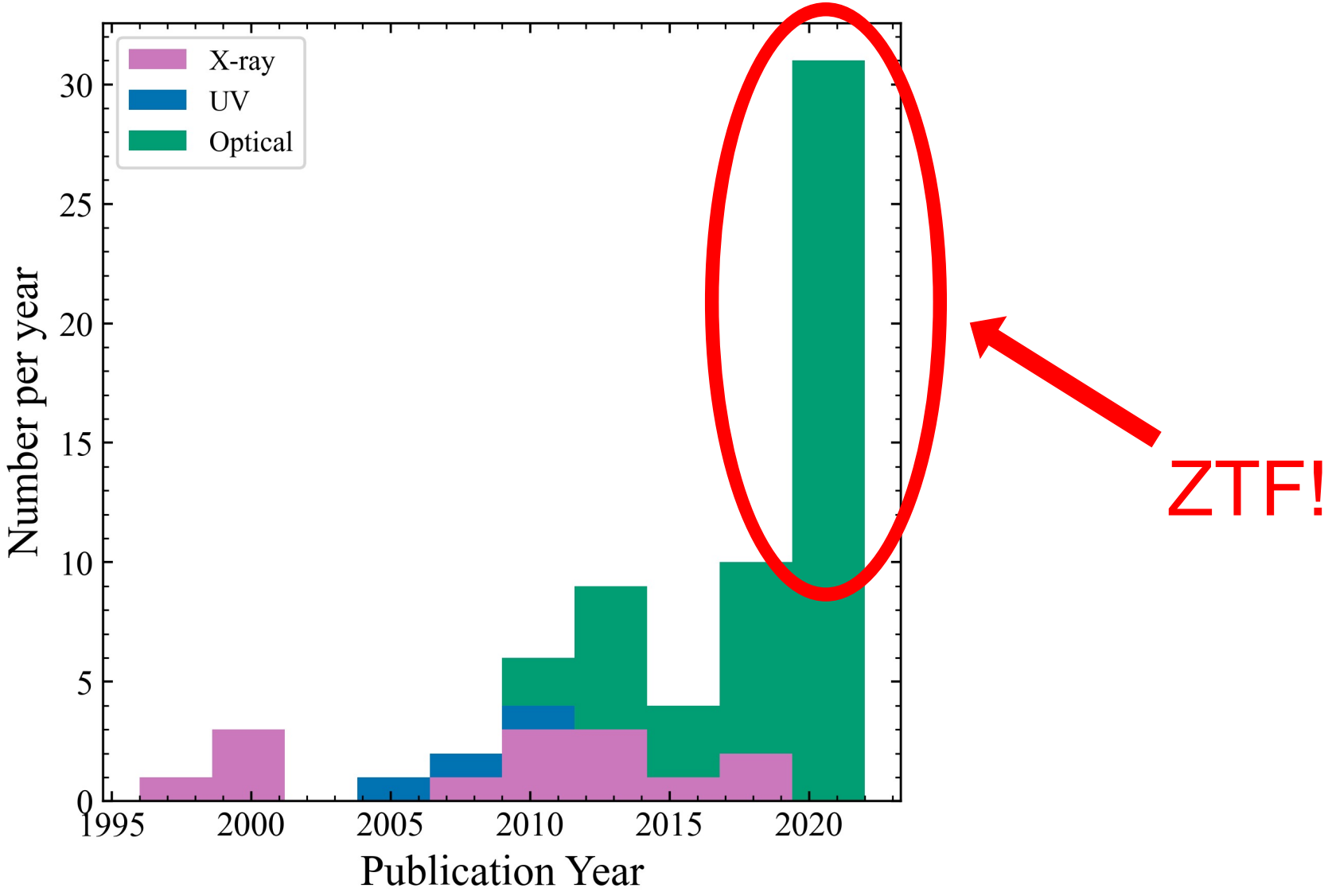
Shocks from stream-stream collisions of tidal debris which produce the UV/optical emission

Larger samples of TDEs will help us investigate these proposed solutions.

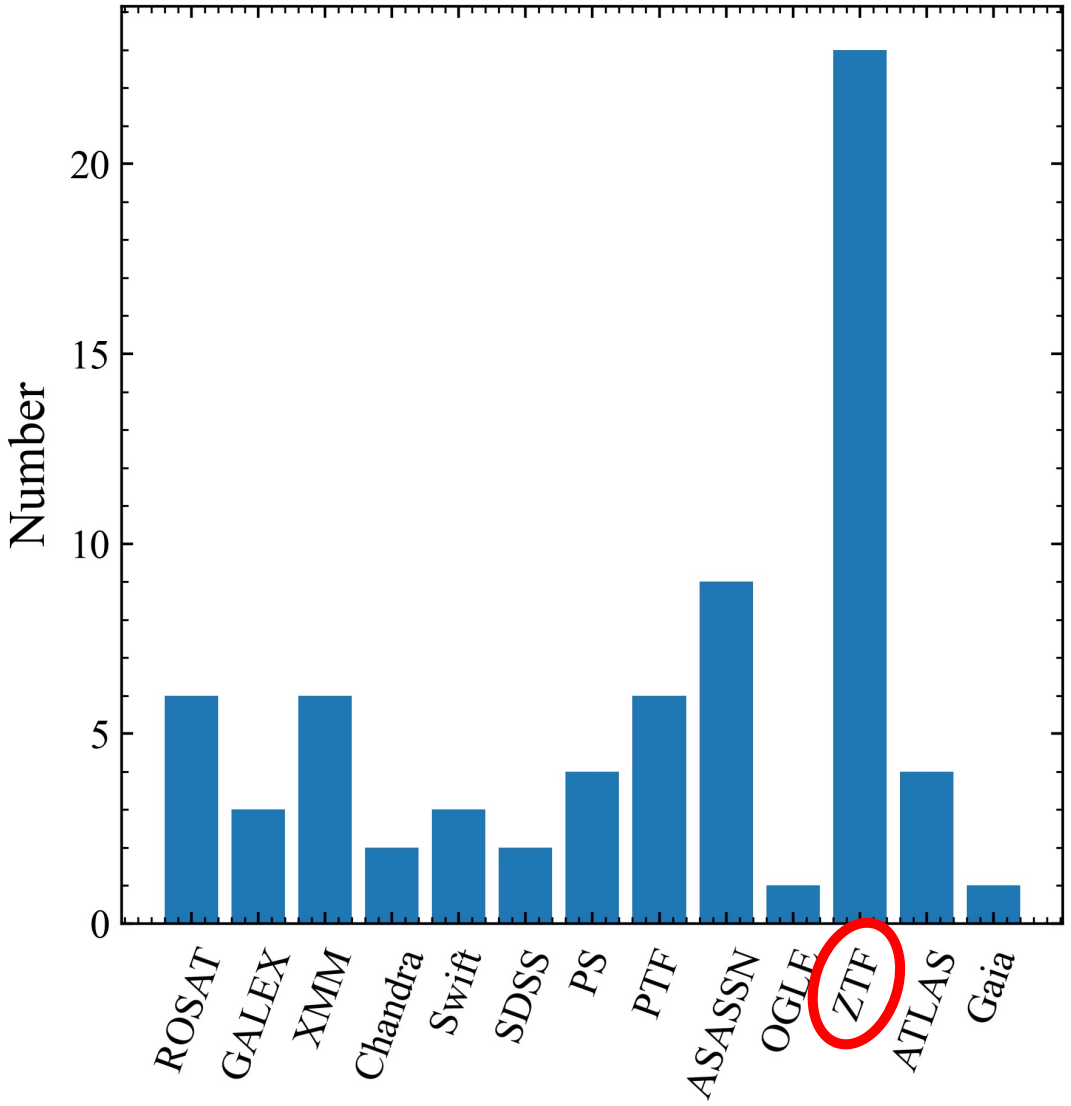


data from Gezari 2021 + Hammerstein 2022

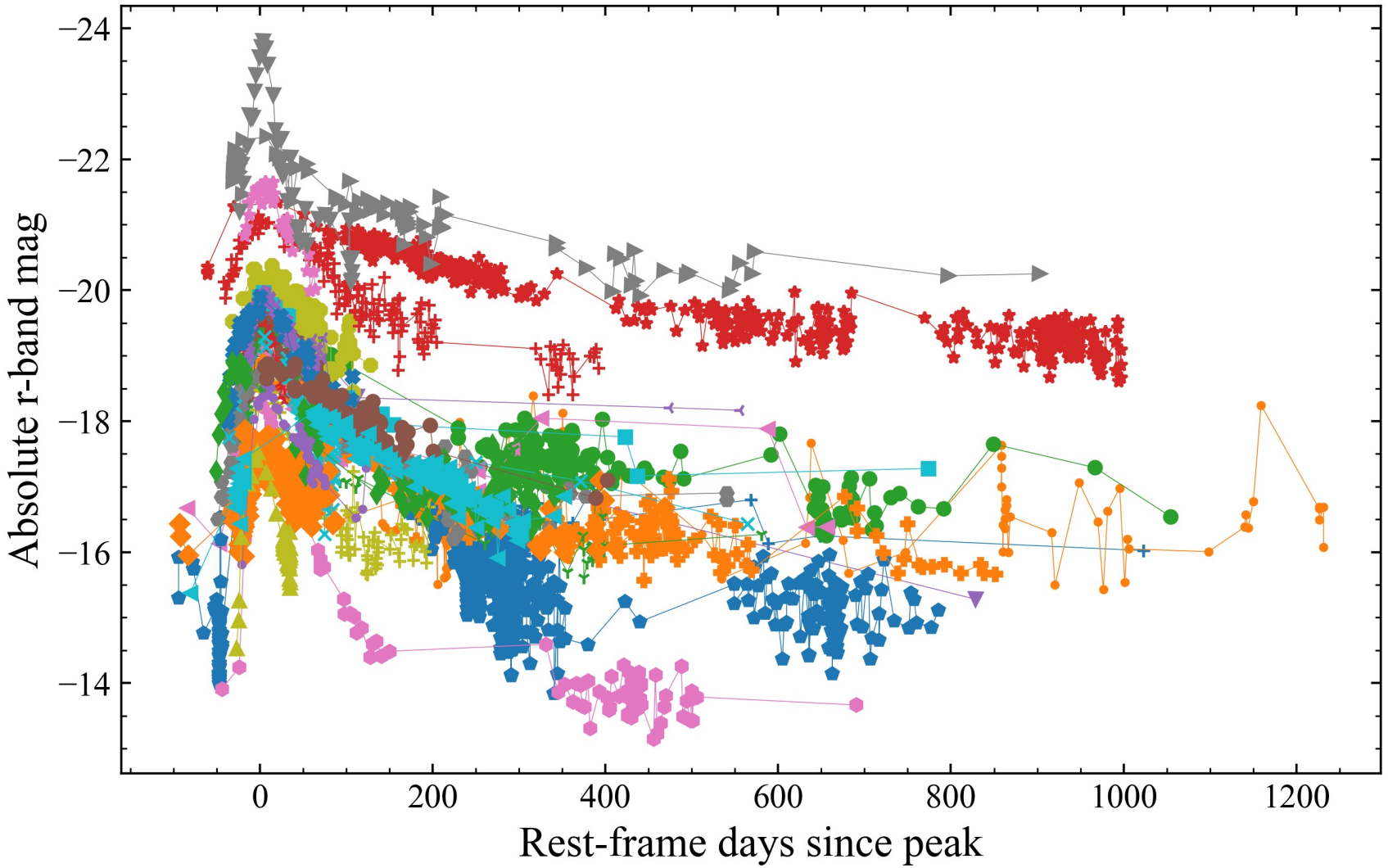
ZTF is leading the way in these discoveries!



ZTF is responsible for 33% of discovered TDEs!

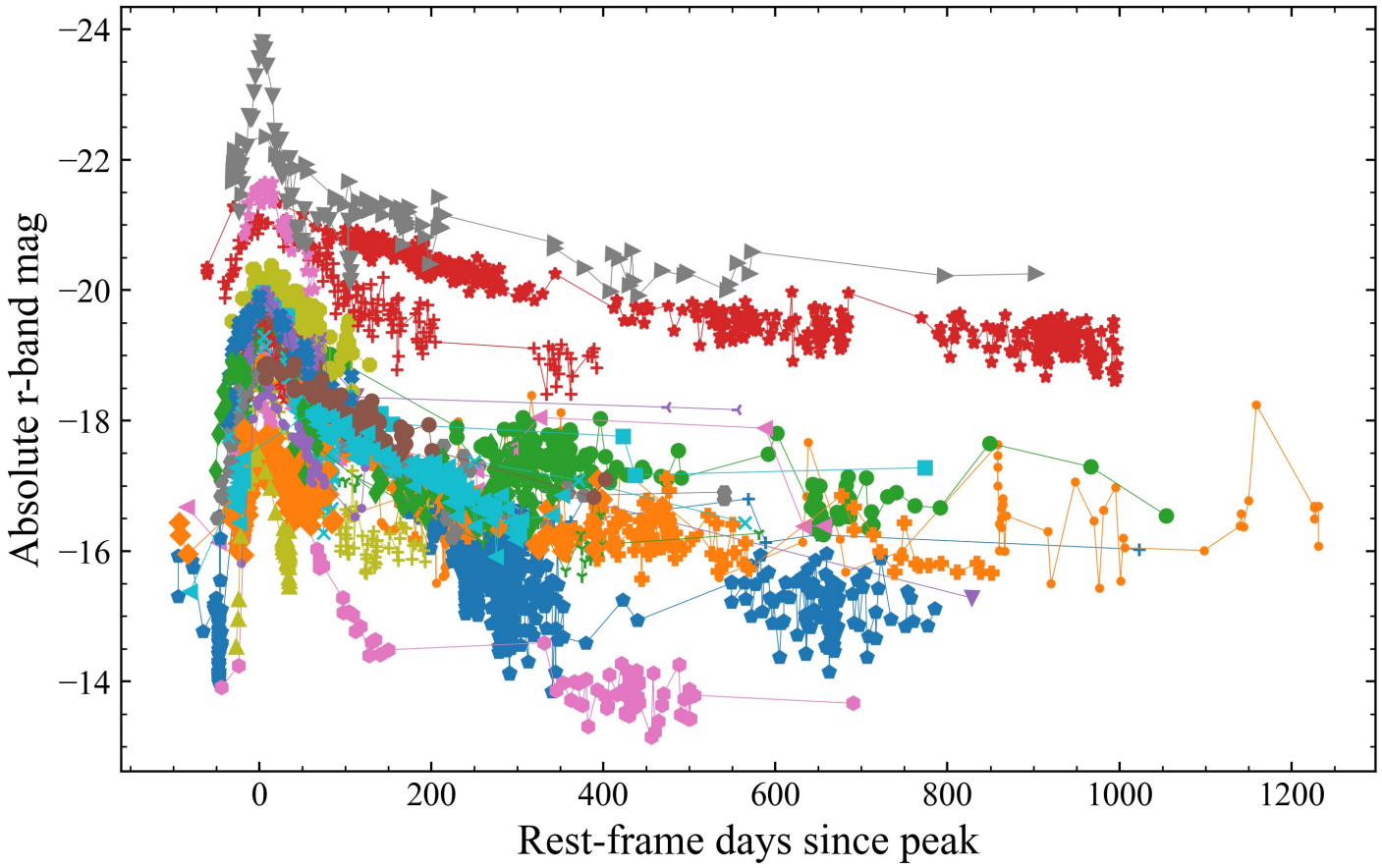


30 Tidal Disruption Events in the ZTF Phase I Survey



ZTF-I TDE Stats

- 30 TDEs discovered
  - 6 TDE-H
  - 17 TDE-H+He
  - 3 TDE-He
  - 4 TDE-featureless
- $0.015 \leq z \leq 0.435$
- $9.49 \leq \log(M_{gal}/M_{sun}) \leq 11.23$
- All have ≥ 1 epoch of *Swift*/UVOT + XRT coverage
- Some with pre-peak spectra and *Swift* coverage



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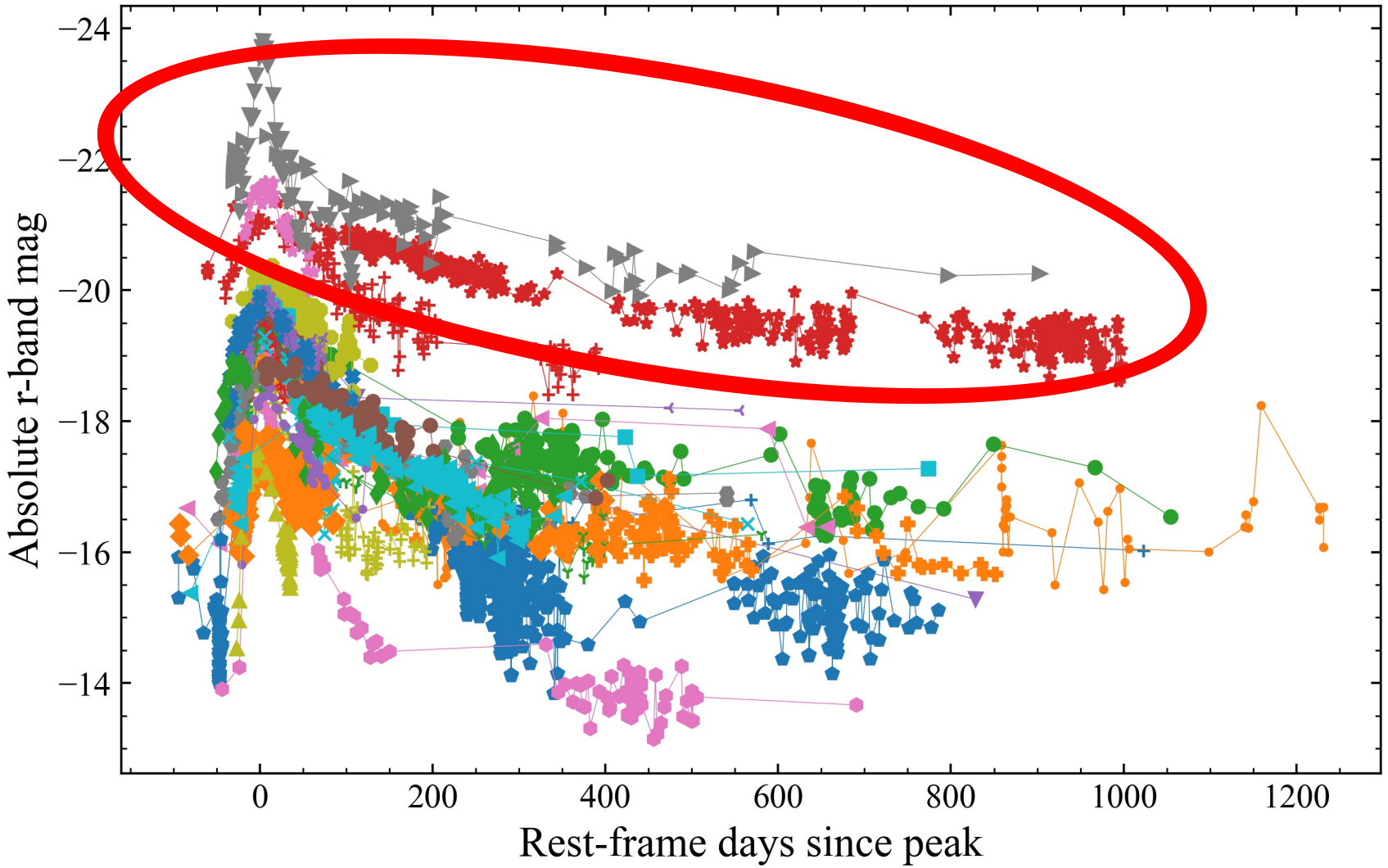
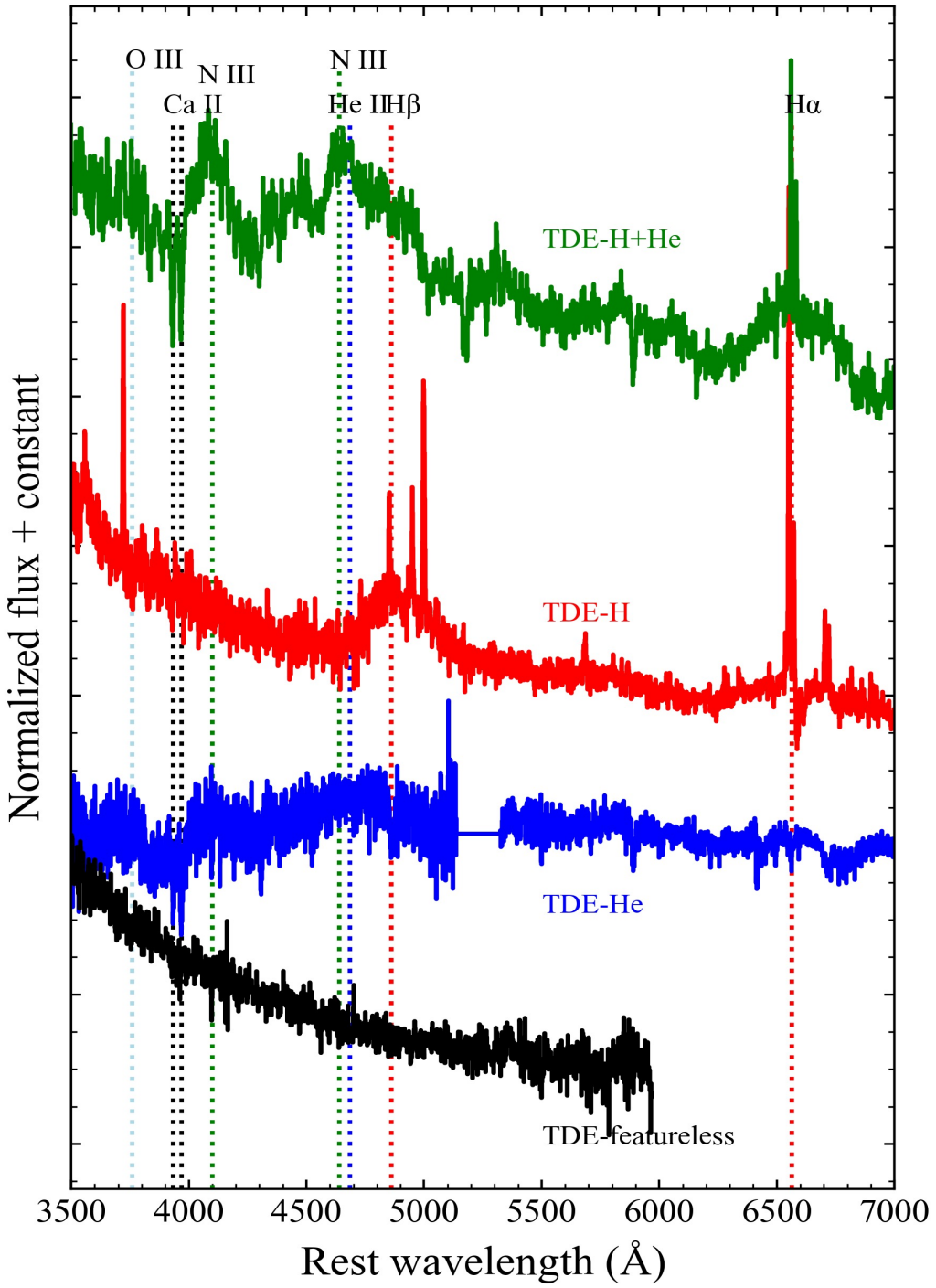


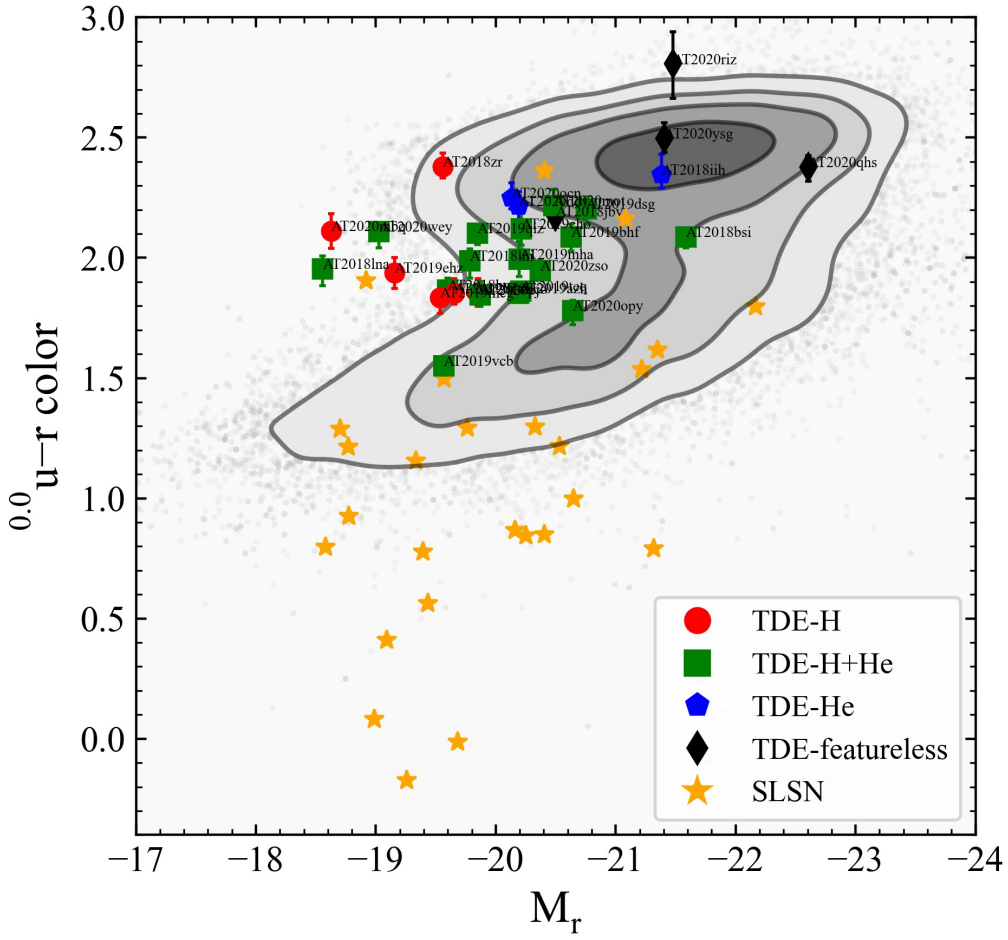
TDE Spectral Types

- 3 TDE spectral classes (van Velzen+ 2021)
  - TDE-H
  - TDE-He
  - TDE-H+He
- TDE-featureless (new!)
  - Pass the nuclear transients filter
    - Nuclear
    - Blue in $g - r$
    - Acceptable rise/fade timescales
  - Luminous (M_r = -21 – -24 with typical TDE ~ M_r = -20)
  - No broad TDE-like lines in spectra, redshift confirmed from host stellar absorption lines
  - How do we know these are TDEs?

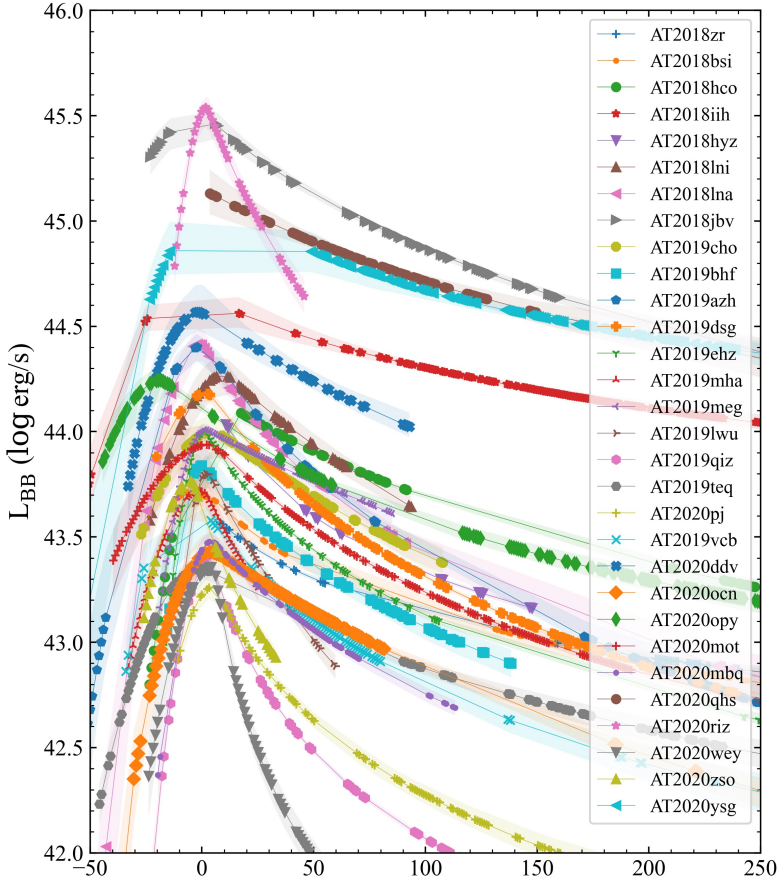


How do we know these featureless events are TDEs?

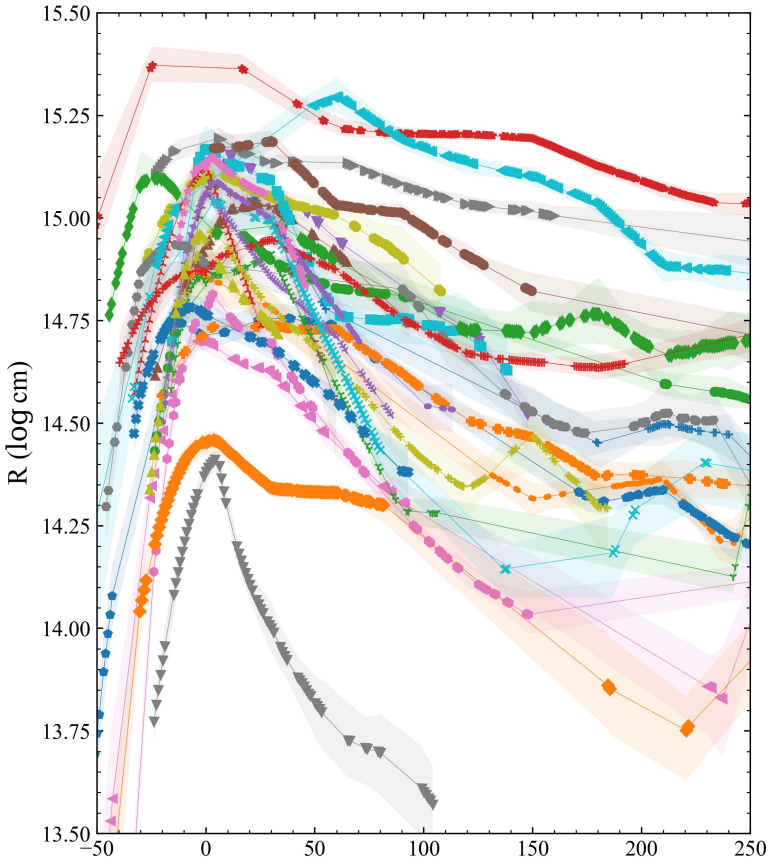
- Could they be AGN?
  - No AGN-like variability in the past
  - Spectroscopic features unlike other CLAGN
- Could they be supernovae?
  - Some SLSN have featureless spectra at early times
  - TDE-featureless no spectral evolution
  - Host galaxies are entirely different



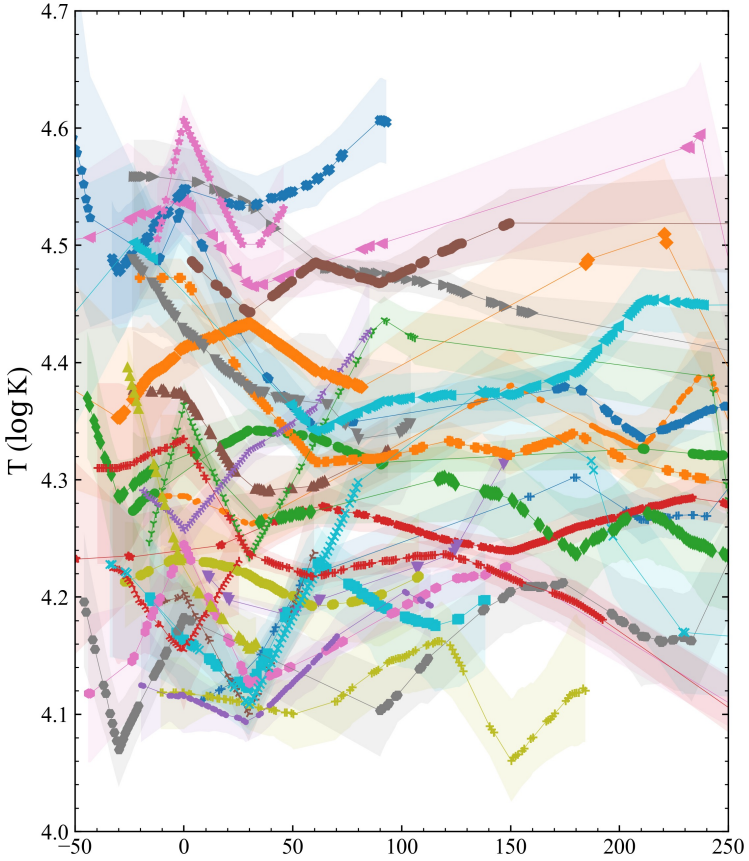
Results of Light Curve Fitting



L(t)

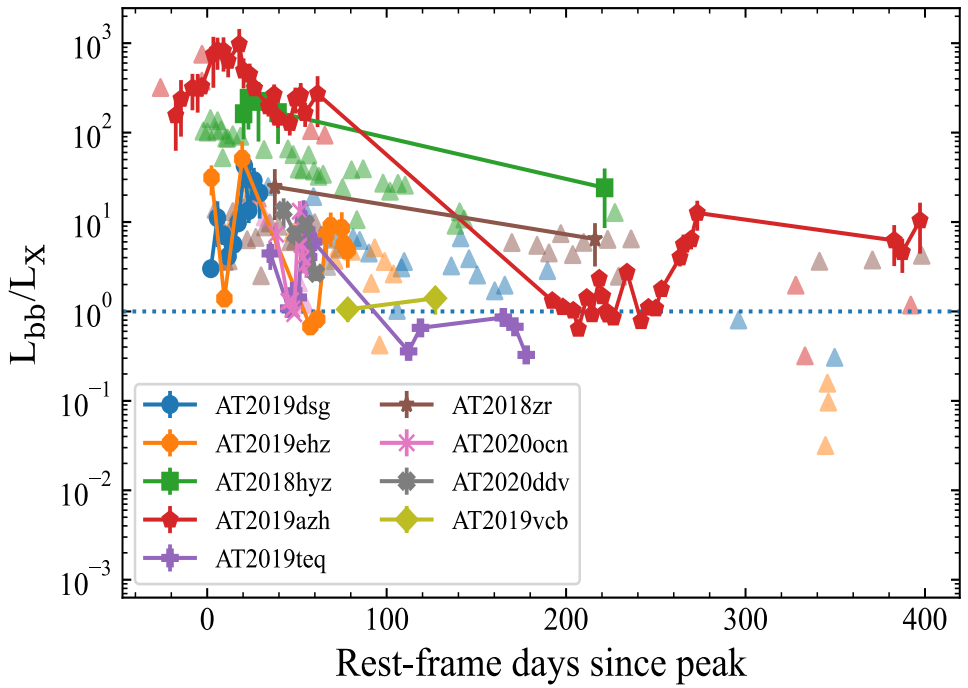


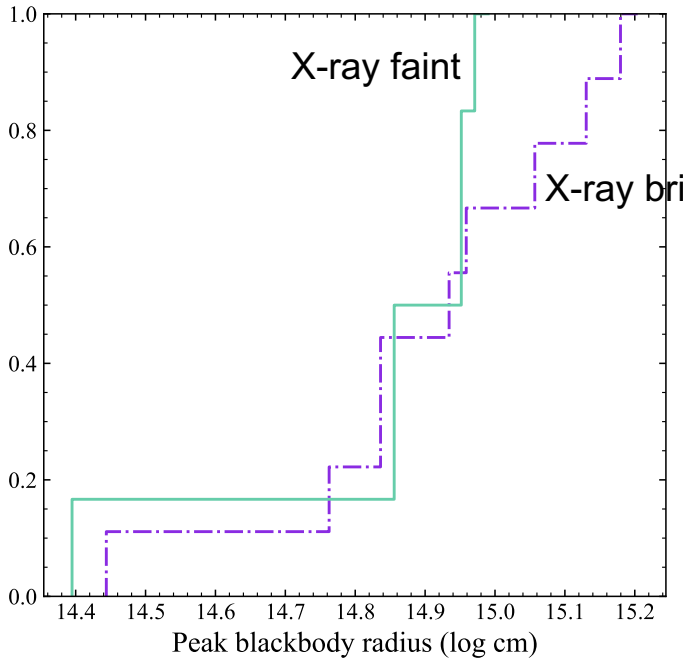
R(t)

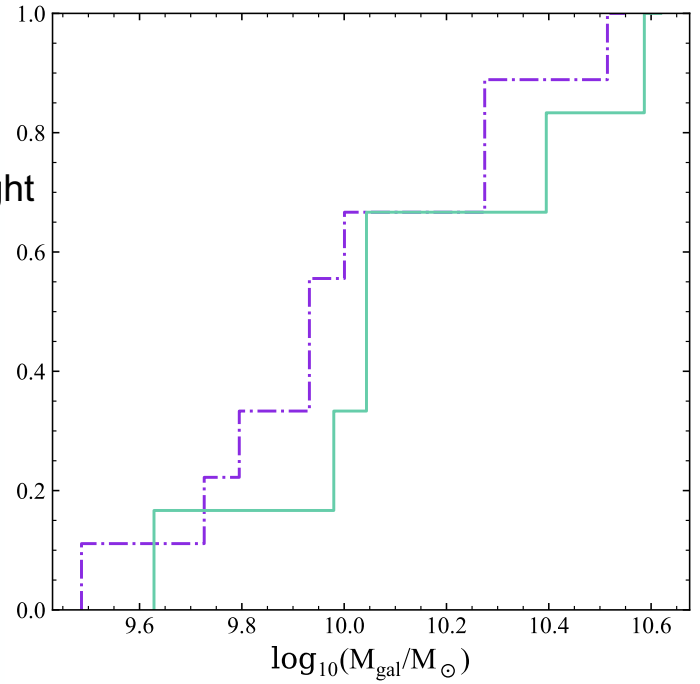


T(t)

What can the X-ray bright TDEs tell us?







Hammerstein+ 2022

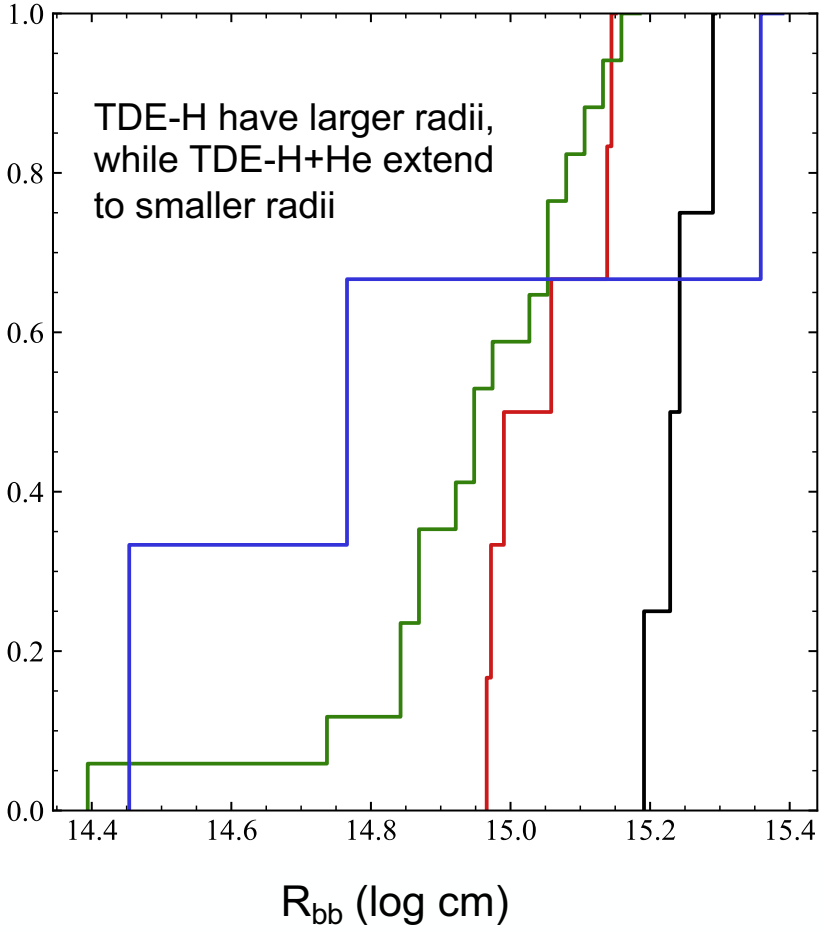
Optical-to-X-ray ratio decreases over time

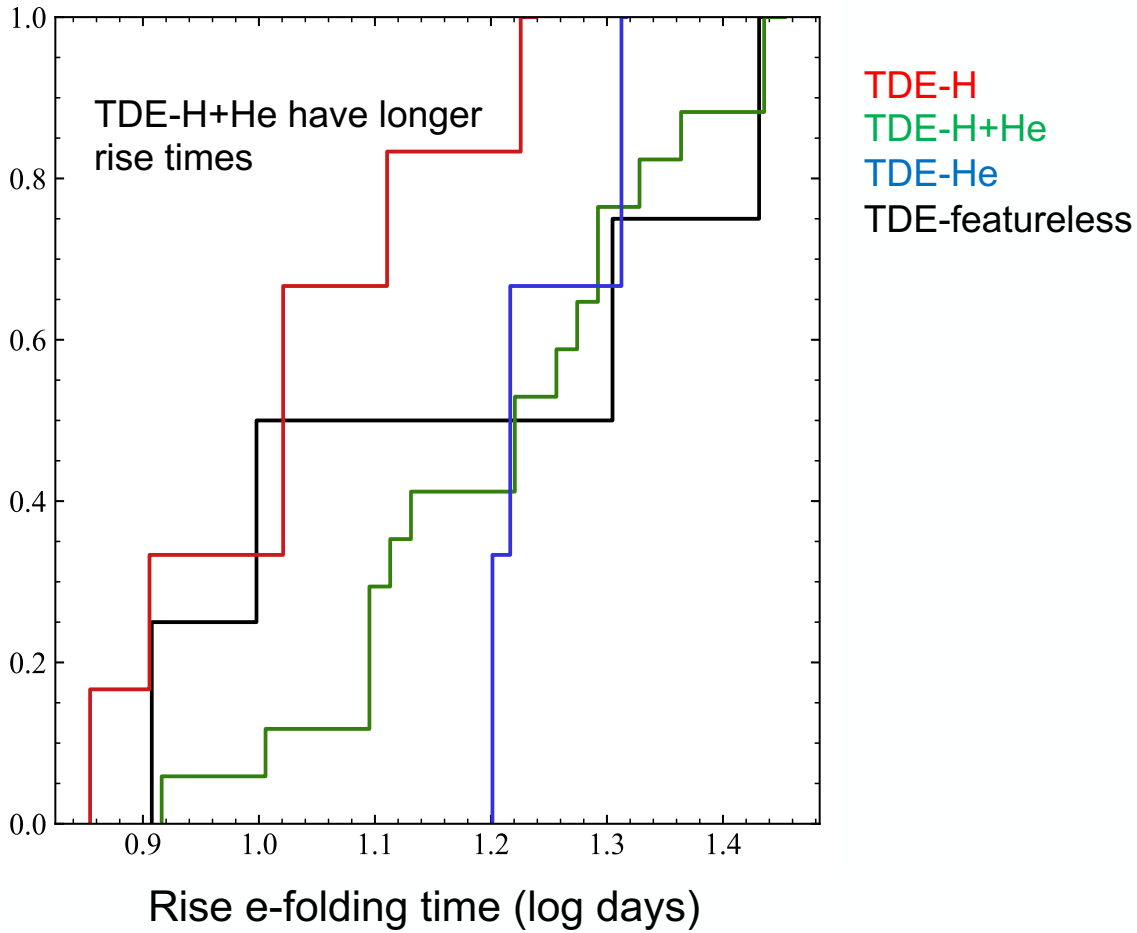
No differences in host galaxy properties between X-ray bright and X-ray faint

Few differences in light curve properties, surprisingly no difference in radius

→ viewing angle model favored?

What can the differences between spectral types tell us?

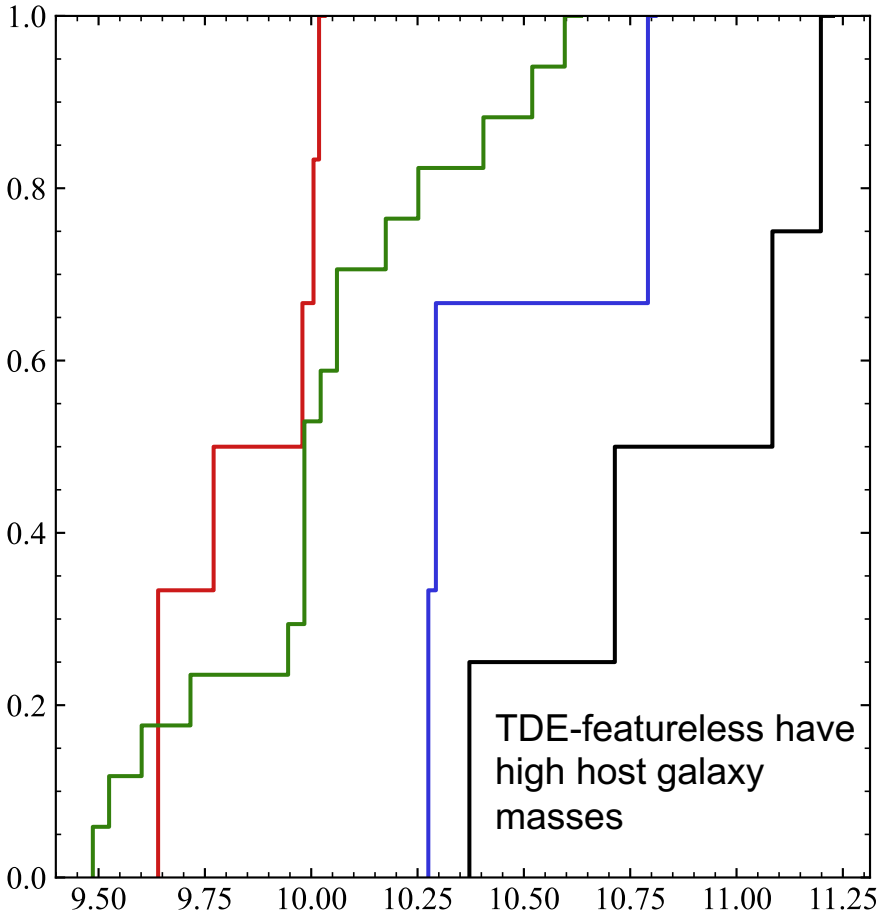




- Confirmed results from van Velzen+ 2021: TDE-H+He can reach higher densities at smaller radii and produce Bowen fluorescence lines
- Rise timescale determined by diffusion of photons through tidal debris, further confirmed by lack of correlation between rise time and host mass

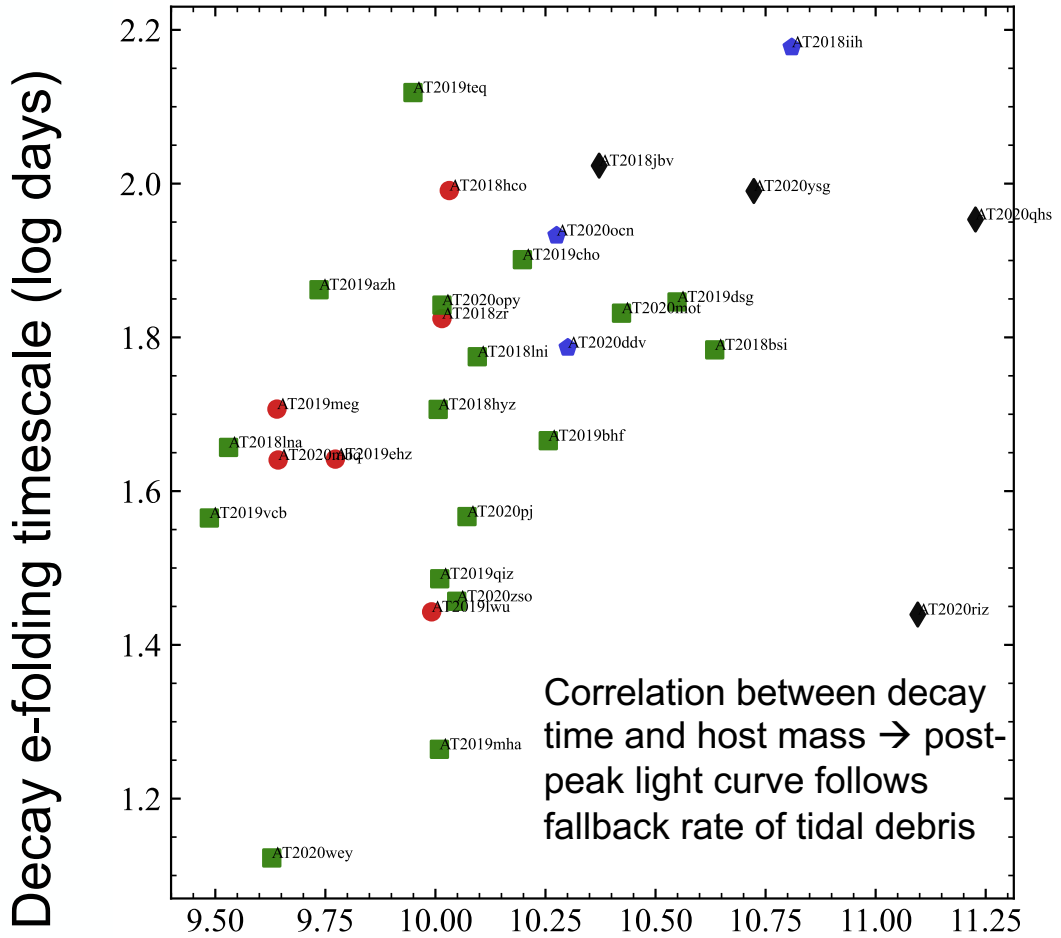
Differences in Host Galaxy Masses

TDE-H
TDE-H+He
TDE-He
TDE-featureless



Host galaxy stellar mass (log M_{sun})

Hammerstein+ 2022

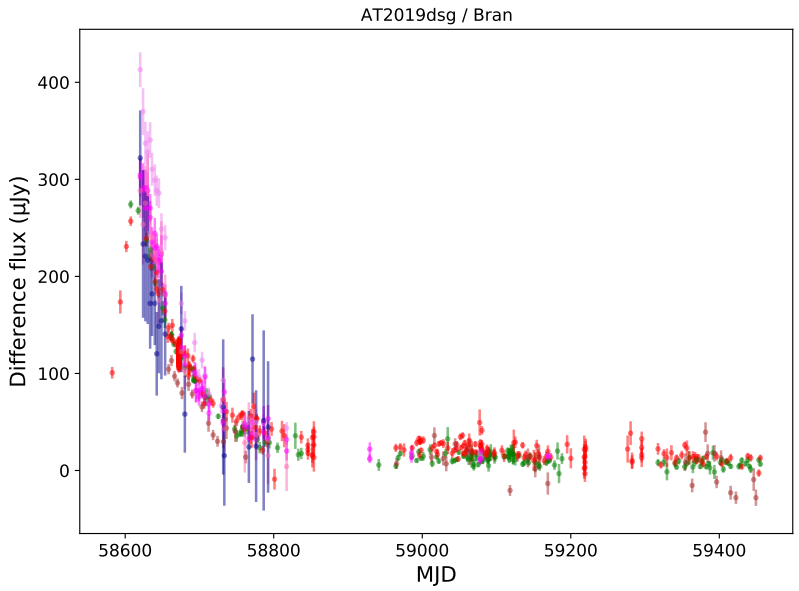


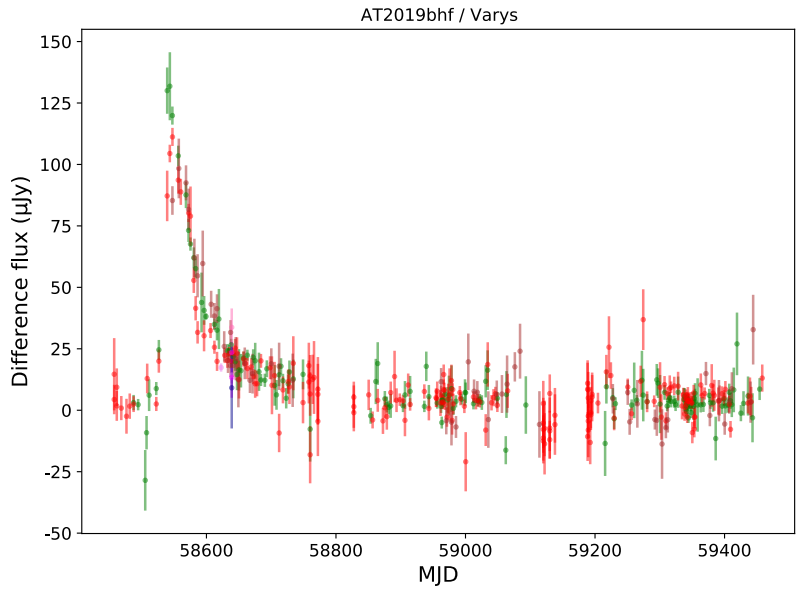
Host galaxy stellar mass (log M_{sun})

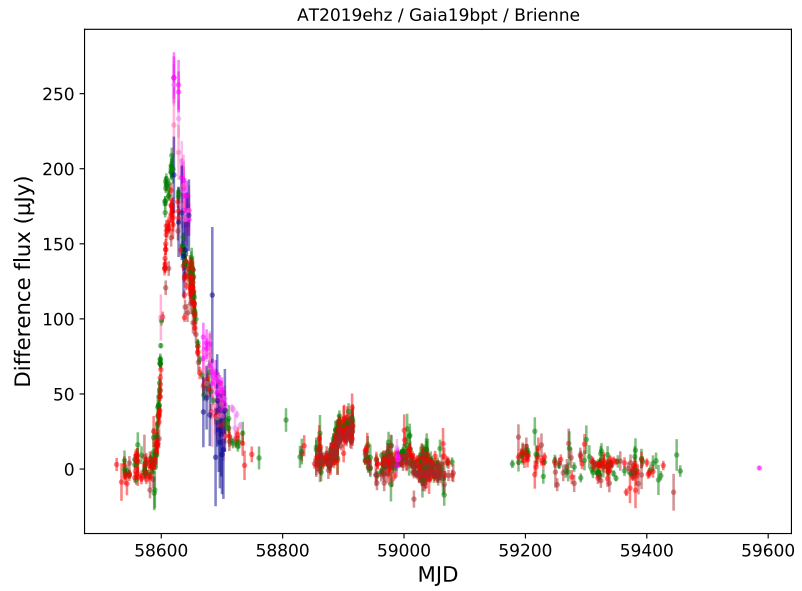
Light curve shapes

Classify TDE light curves into 3 distinct shapes:

- TDE-power law (TDE-PL): well-fit by simple power law
- TDE-plateau (TDE-P): show plateaus at late times
- TDE-structured (TDE-S): show significant residuals as compared to a simple power law fit







Hammerstein+ 2022

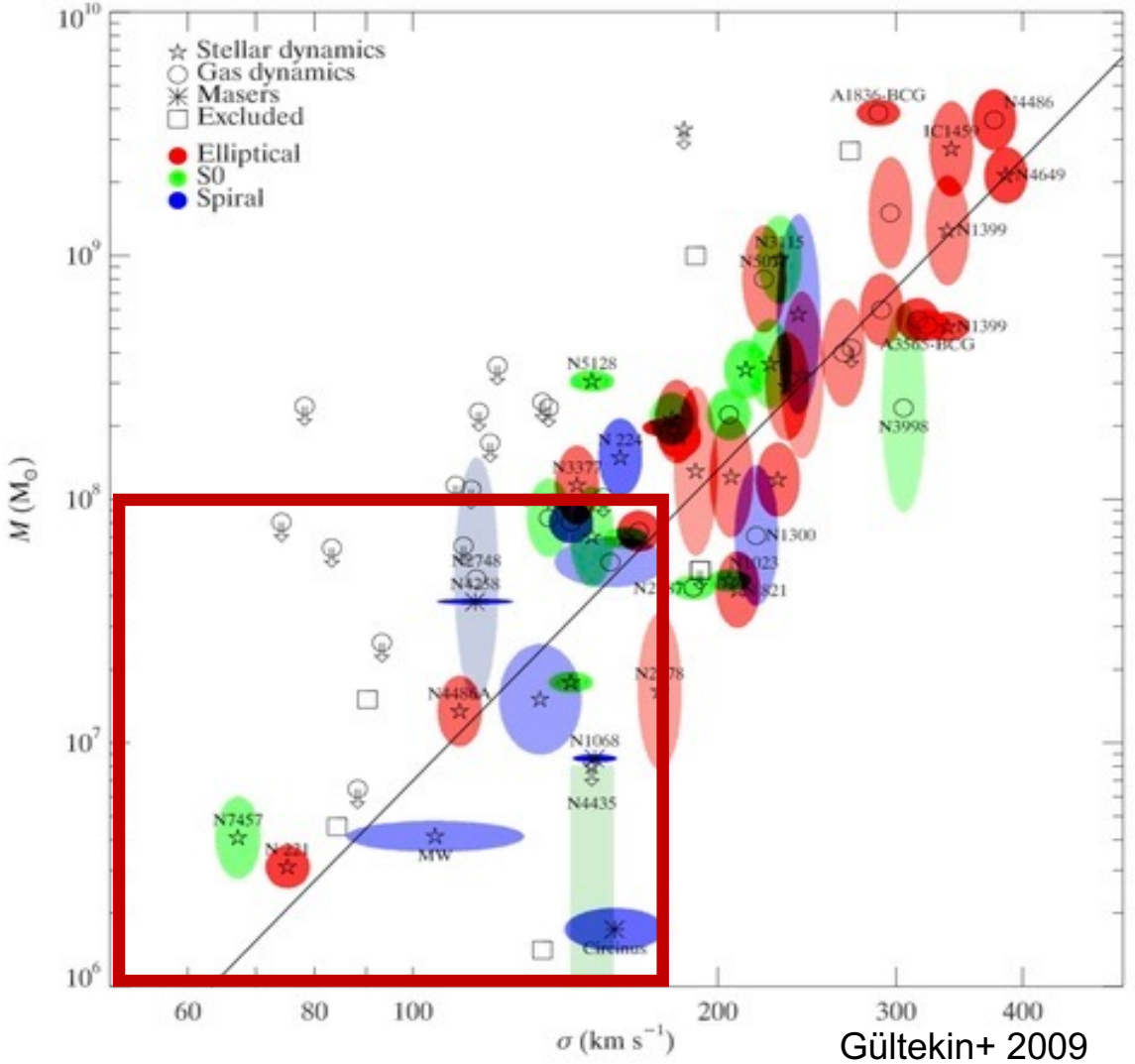
Summary

- ZTF is leading the way in TDE discoveries!
- We have found a new spectral classification for TDEs, TDE-featureless, which show no broad lines in their spectra, but are like TDEs in light curve properties.
- Differences between X-ray bright and faint TDEs can help determine which emission models are favorable.
- TDE light curves can be classified into shapes.

Backup Slides

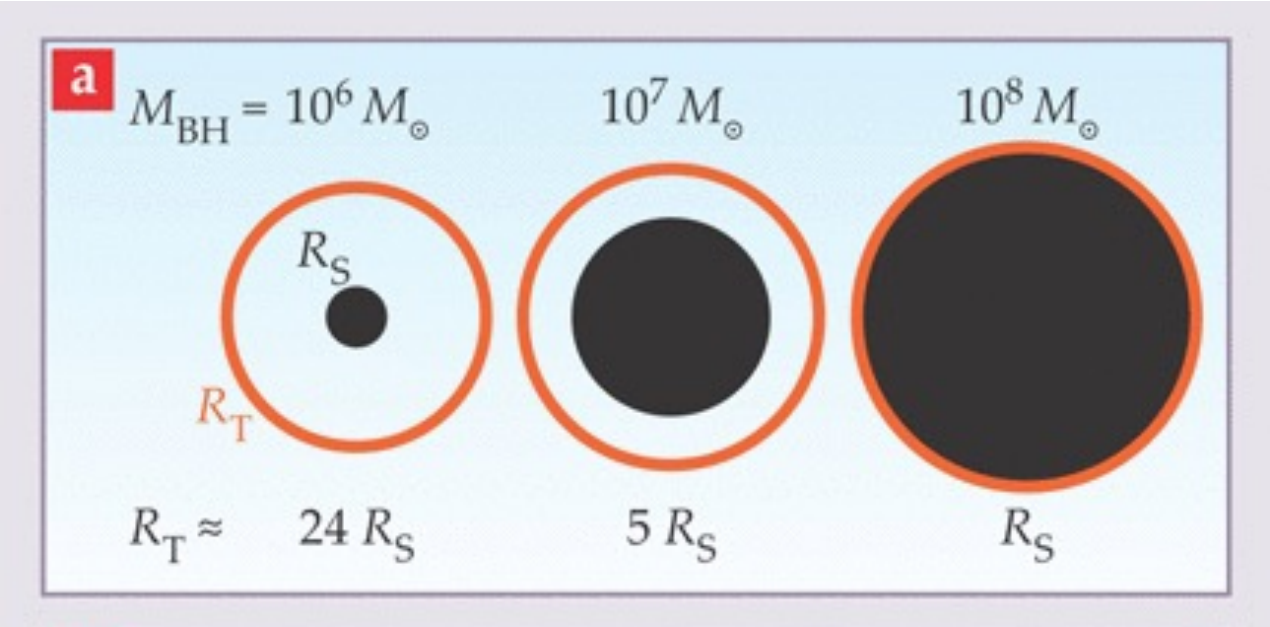
TDEs signal the presence of a massive black hole and illuminate the accretion process, and disk and jet formation processes.

- TDEs point towards lower mass SMBHs
  - $r_{\mathrm{tidal}} \propto {M_{\mathrm{BH}}}^{1/3}$ but $r_{\mathrm{s}} \propto M_{\mathrm{BH}}$
  - Potential to discover intermediate mass black holes
- Accretion disk formation and accretion phases happen over relatively short human timescales
- TDE light curves can potentially be used for independent measures of black hole mass

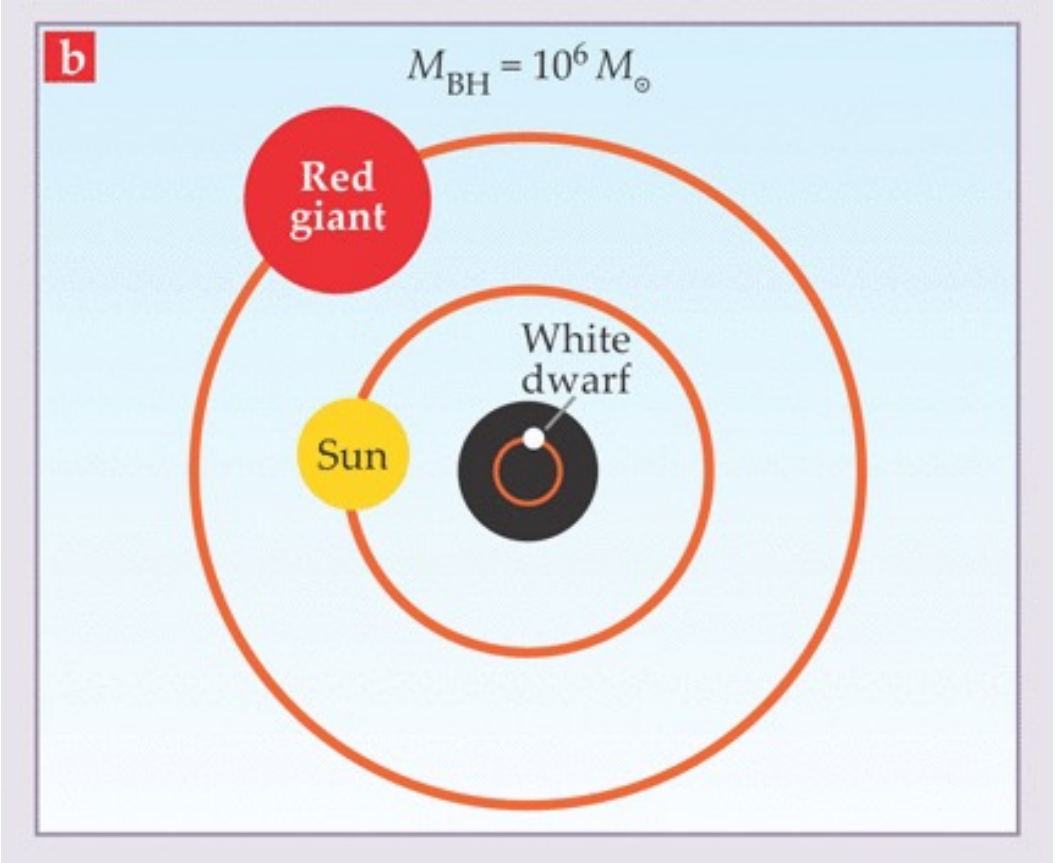


Gültekin+ 2009

How close does a star have to get?



Gezari 2014



Black holes larger than 10^8 M_{sun} disrupt a solar-type star within the event horizon → no observable flare!

- Tidal disruption events around black holes > 10^8 M_{sun} must be around spinning black holes

Tidal disruptions of white dwarf stars must be around intermediate mass black holes!

How close does a star have to get?

Star is disrupted when tidal forces are stronger than the self gravity of the star

Tidal force = Star's self-gravity

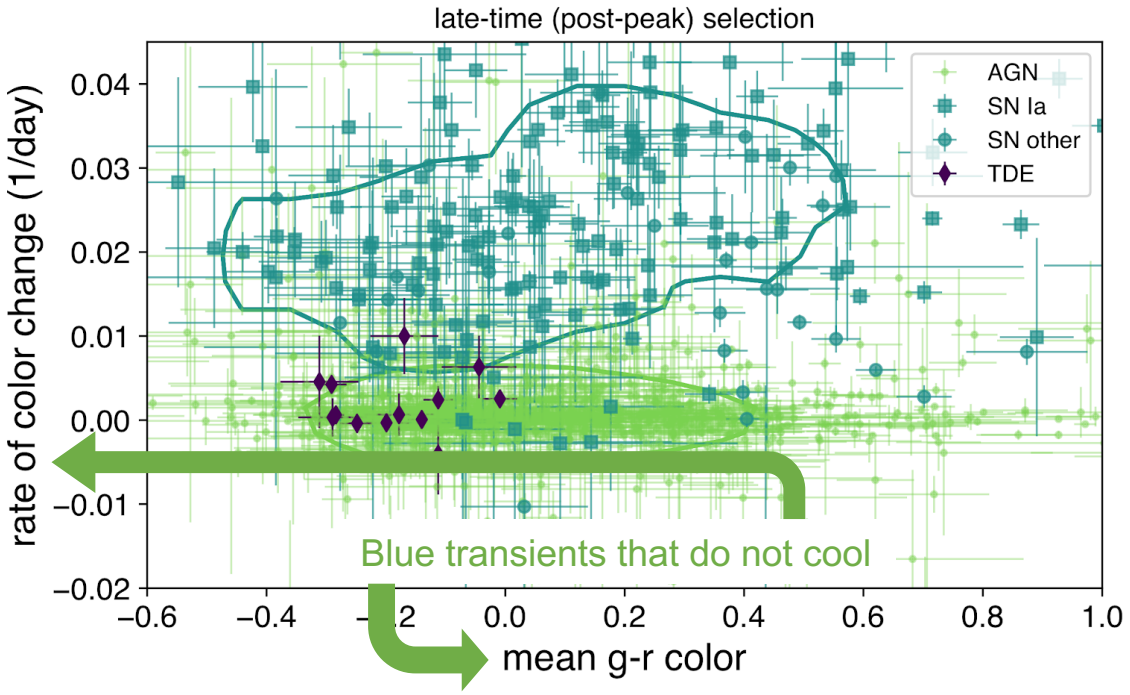
$$\frac{GMR_*}{r^3} = \frac{Gm_*}{R_*^2}$$

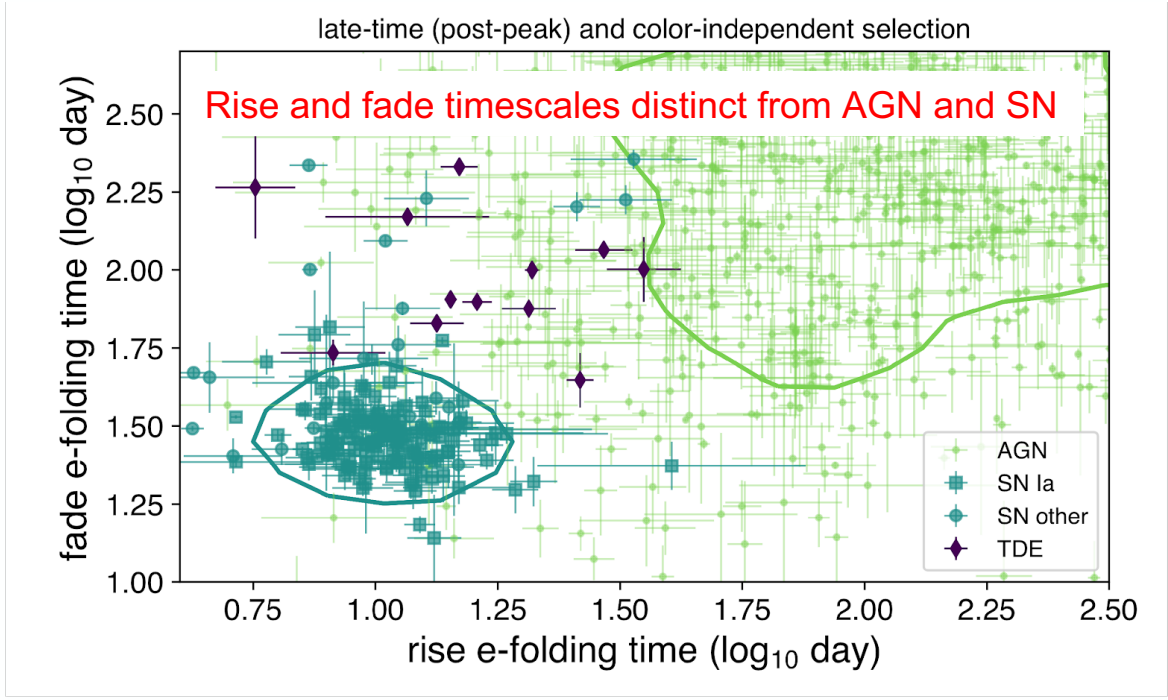
$$r_T \approx R_* \left(\frac{M_{\rm BH}}{m_*}\right)^{1/3}$$

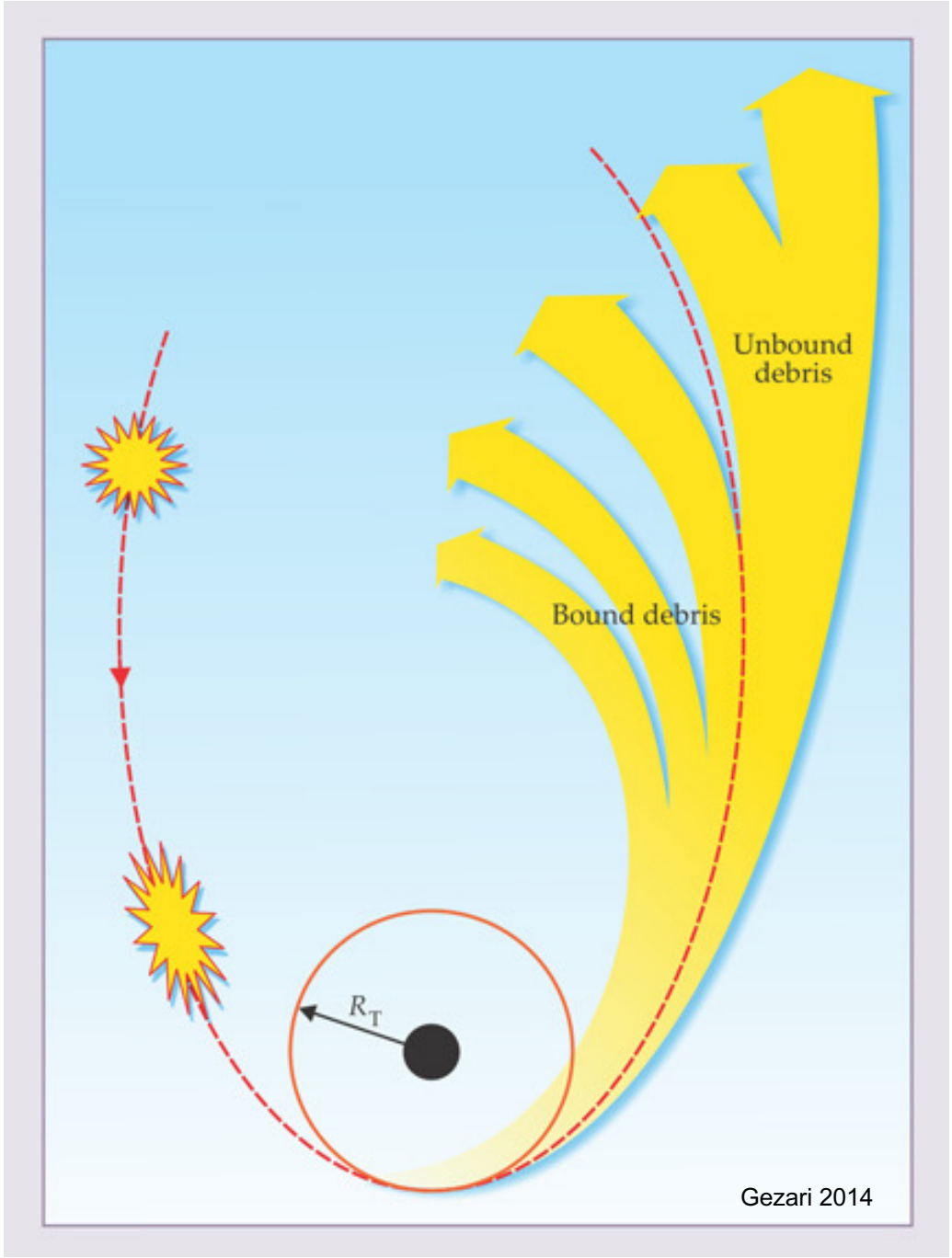
Tidal disruption radius

Efficient filtering of the ZTF alert stream

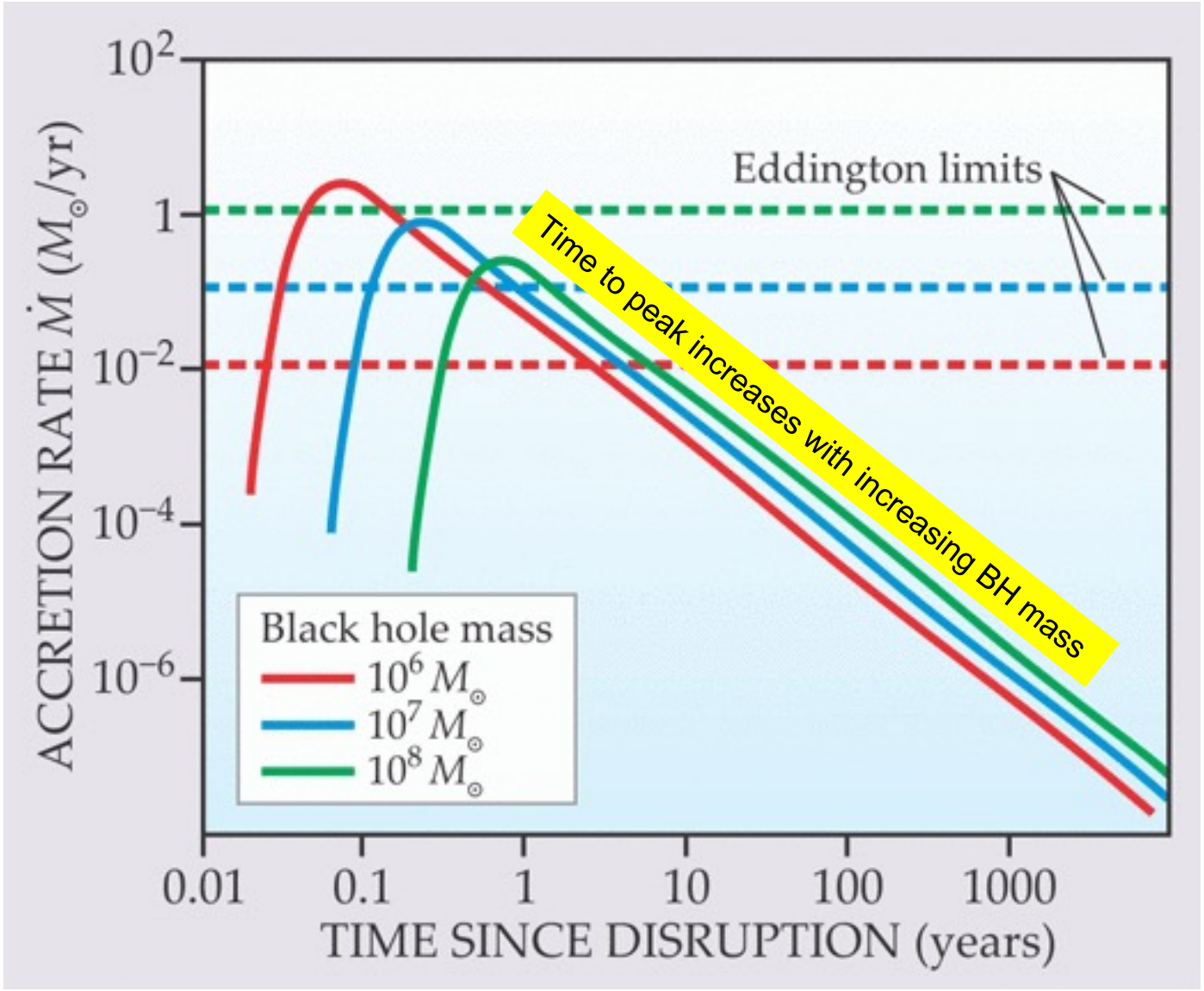
Searching for nuclear transients < 0.5” from galaxy nucleus
Rule out known AGN with catalogs and WISE colors/variability
Even among nuclear transients, TDEs are distinct!
Create a sample small enough for spectroscopic follow-up





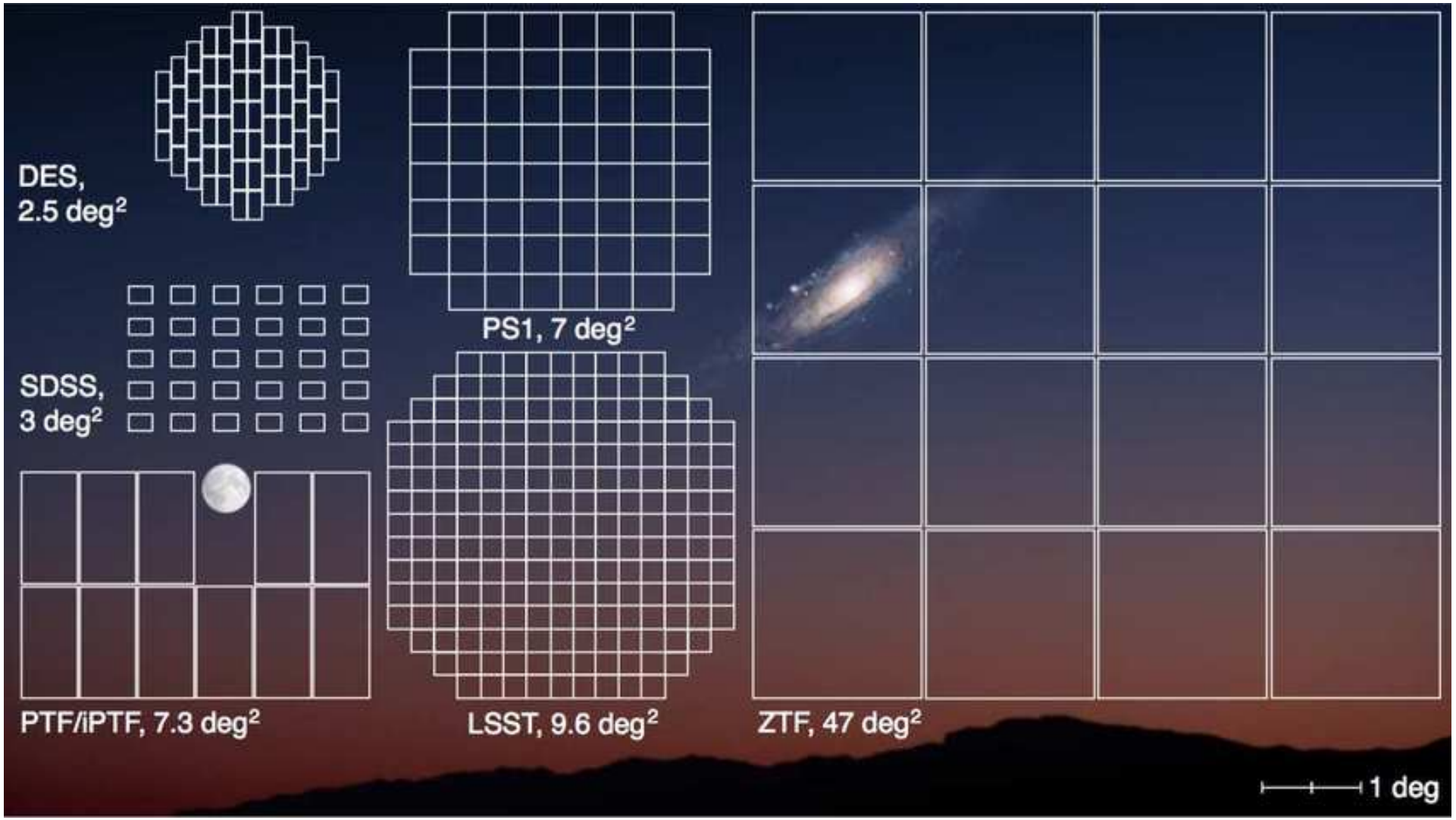

Unbound
debris
Bound debris
R_T
Gezari 2014

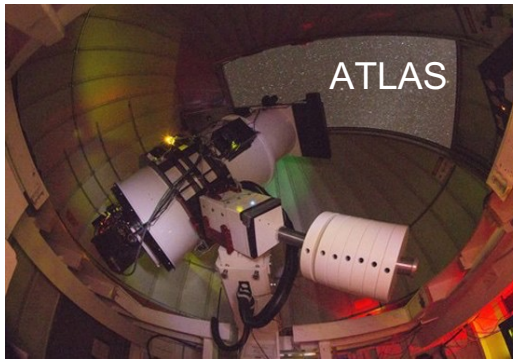
TDE light curves can be used to weigh black holes… in theory!

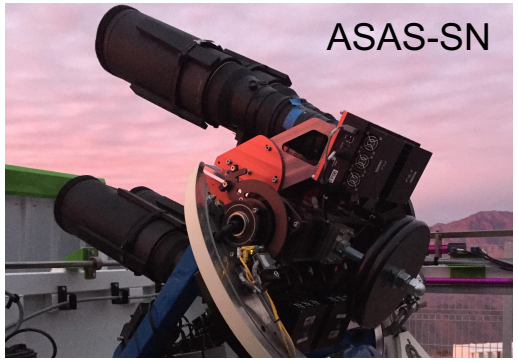


Gezari 2014, adapted from De Colle+ 2012

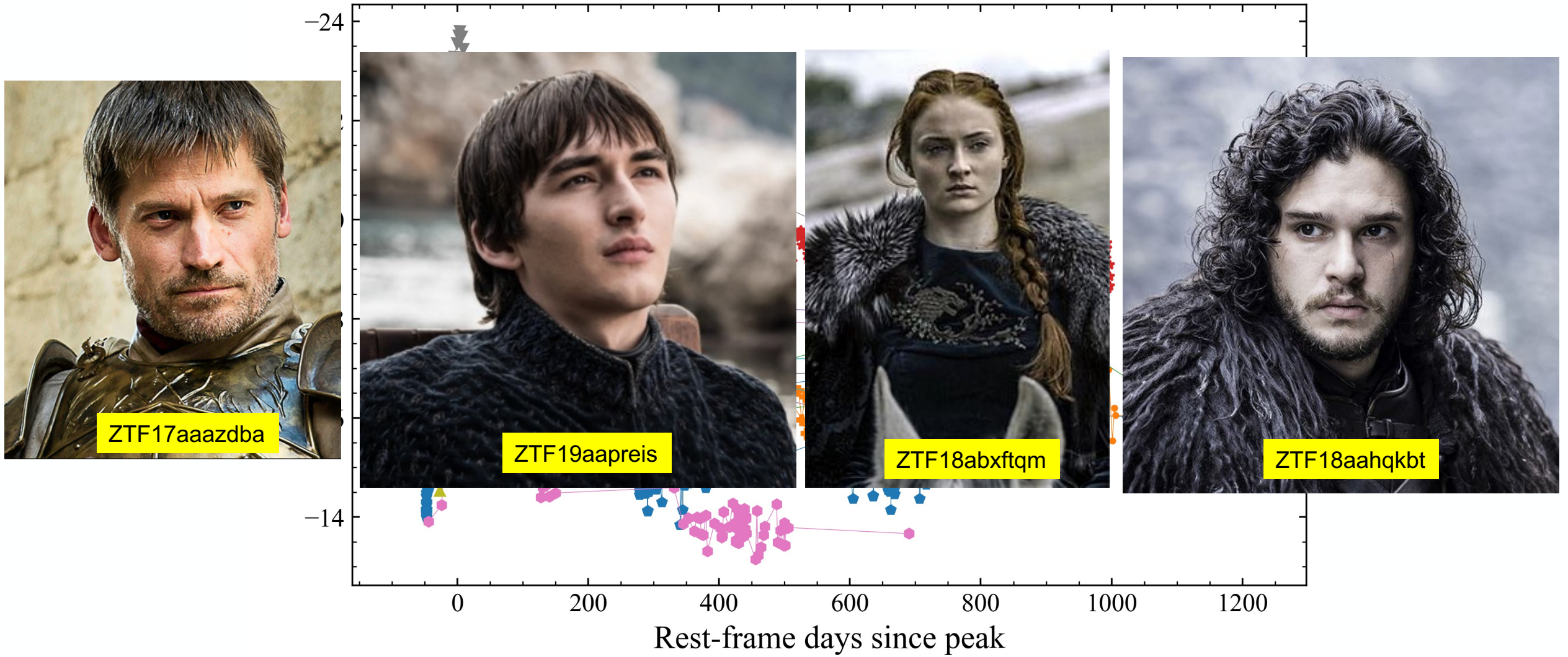
The Era of All-Sky Surveys





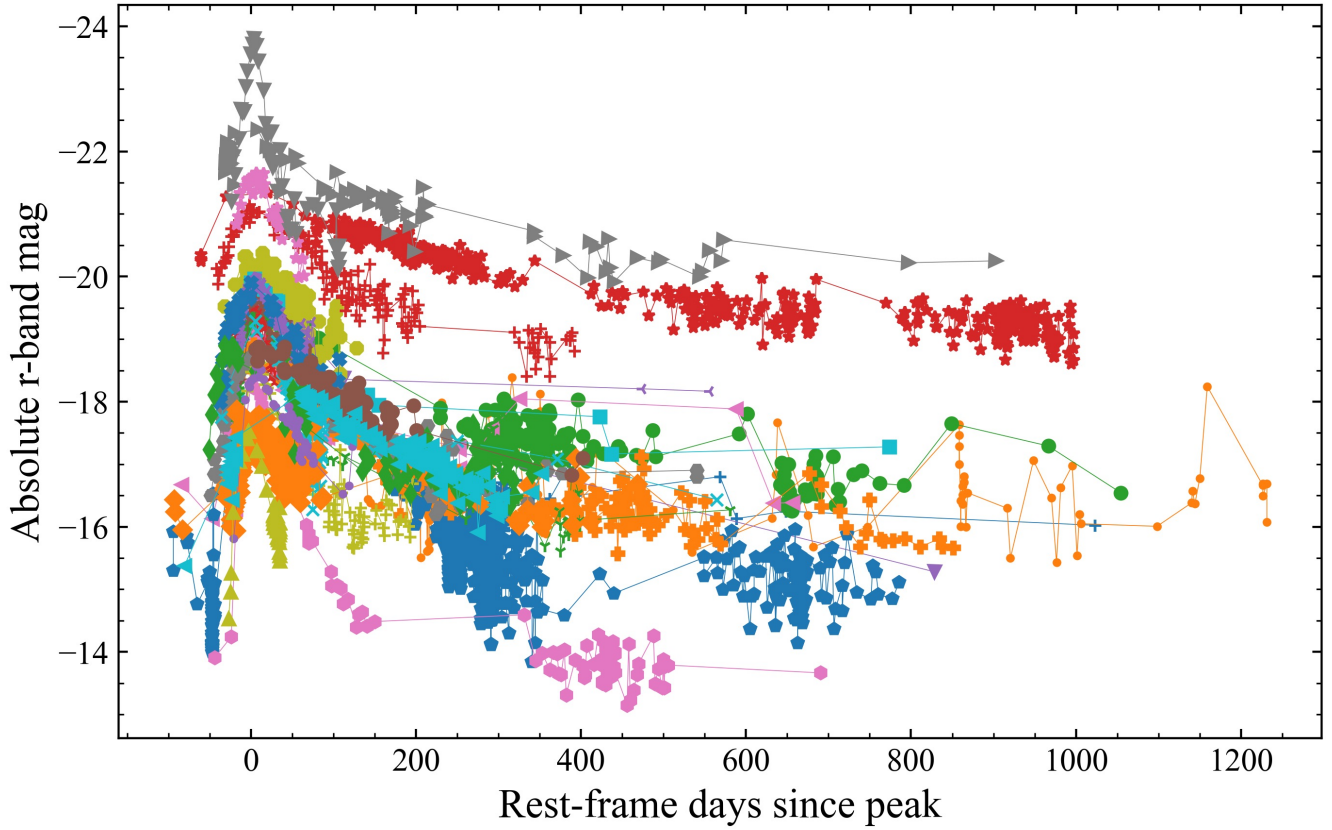


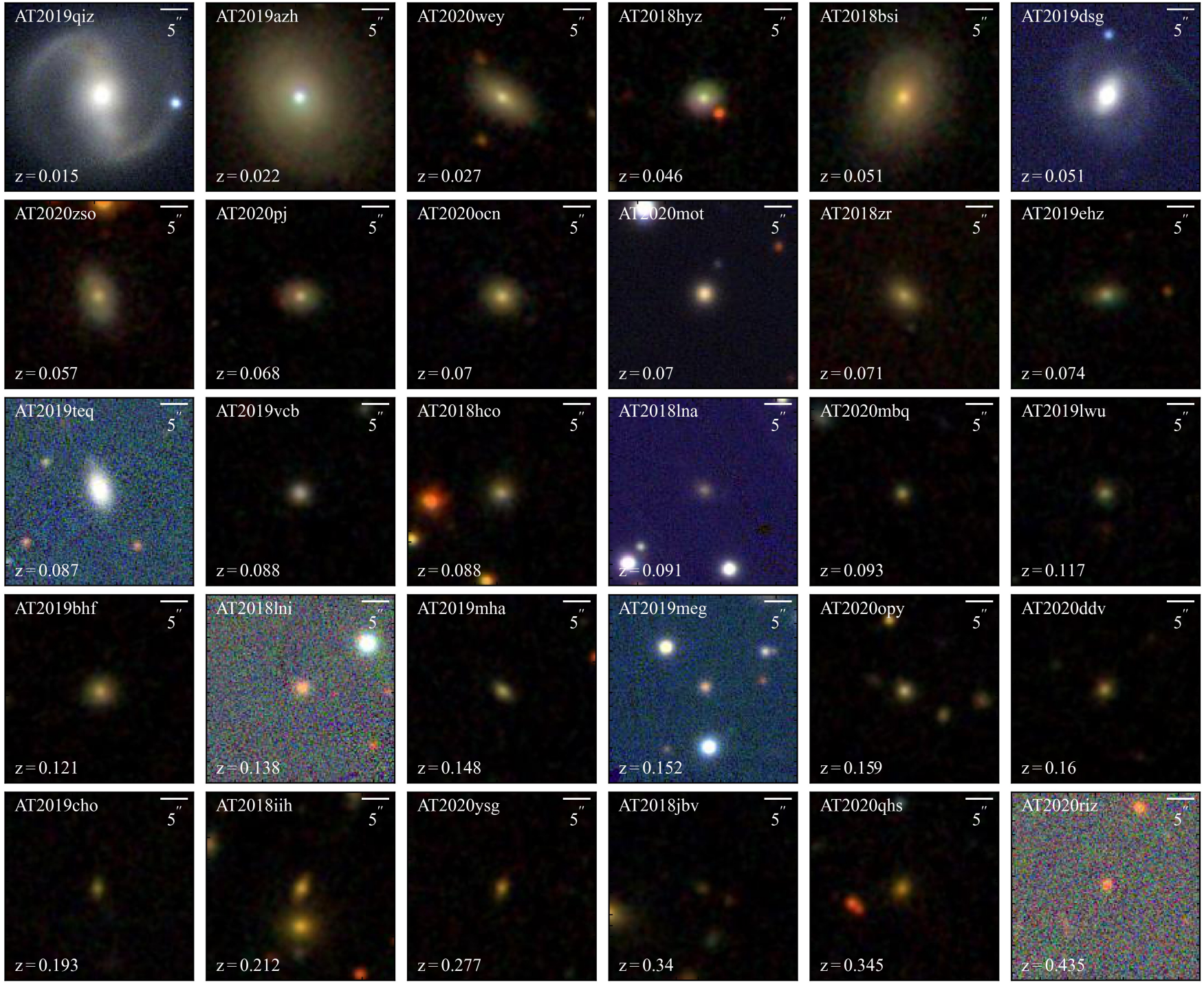
30 Tidal Disruption Events in the ZTF Phase I Survey



30 Tidal Disruption Events in the ZTF Phase I Survey

- Pre-peak discoveries, spectra, and *Swift* UVOT/XRT coverage
- More TDEs with well-sampled rises than ever before
- Spread across **four** TDE spectral classes
- Forced photometry yields TDE detection out to > 3 years post-peak
- 9 X-ray detected events
- Largest sample of systematically discovered TDEs, enabling population studies of optically selected TDEs

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AT2020ysg
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AT2018jbv
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AT2020qhs
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AT2020riz
z = 0.435
5″

Light curve shapes

Classify TDE light curves into 3 distinct shapes:

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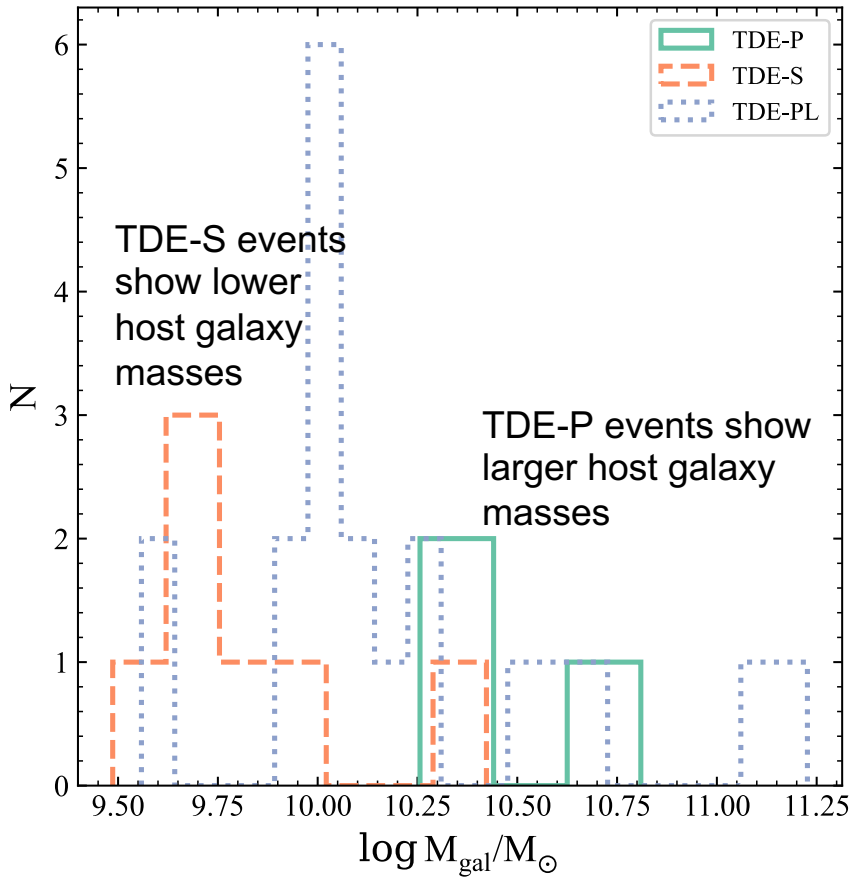

Hammerstein+ 2022