Tidal Disruption Events:
Probes of Accretion Physics and Black Hole Demographics

Yuhan Yao (姚雨含)
Miller Fellow, UC Berkeley
@32nd Texas Symposium, 2023 Dec 13

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Detailed X-ray Observations

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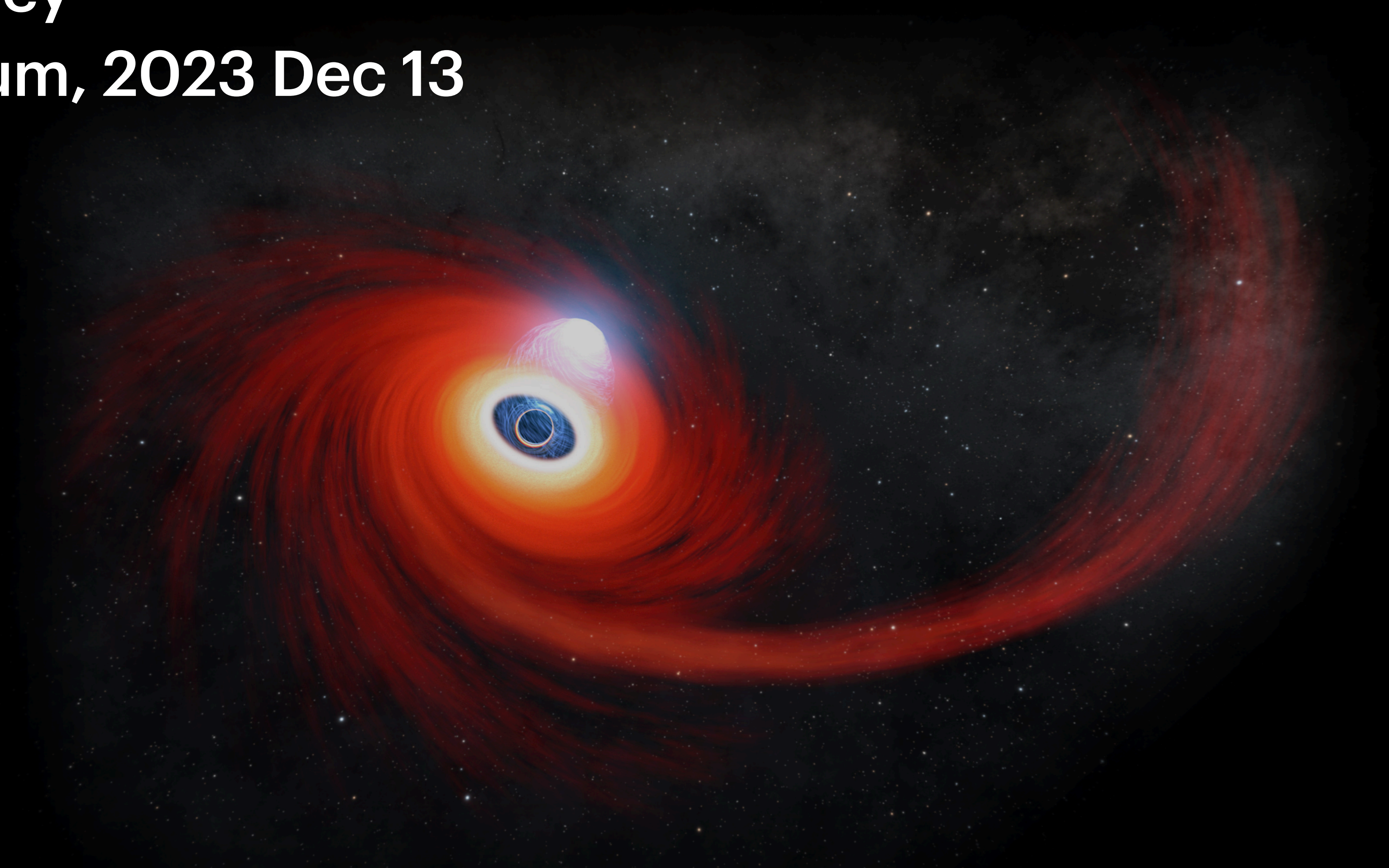

Tidal Disruption Events:
Probes of Accretion Physics and Black Hole Demographics

Detailed X-ray Observations — Large Optical TDE Samples

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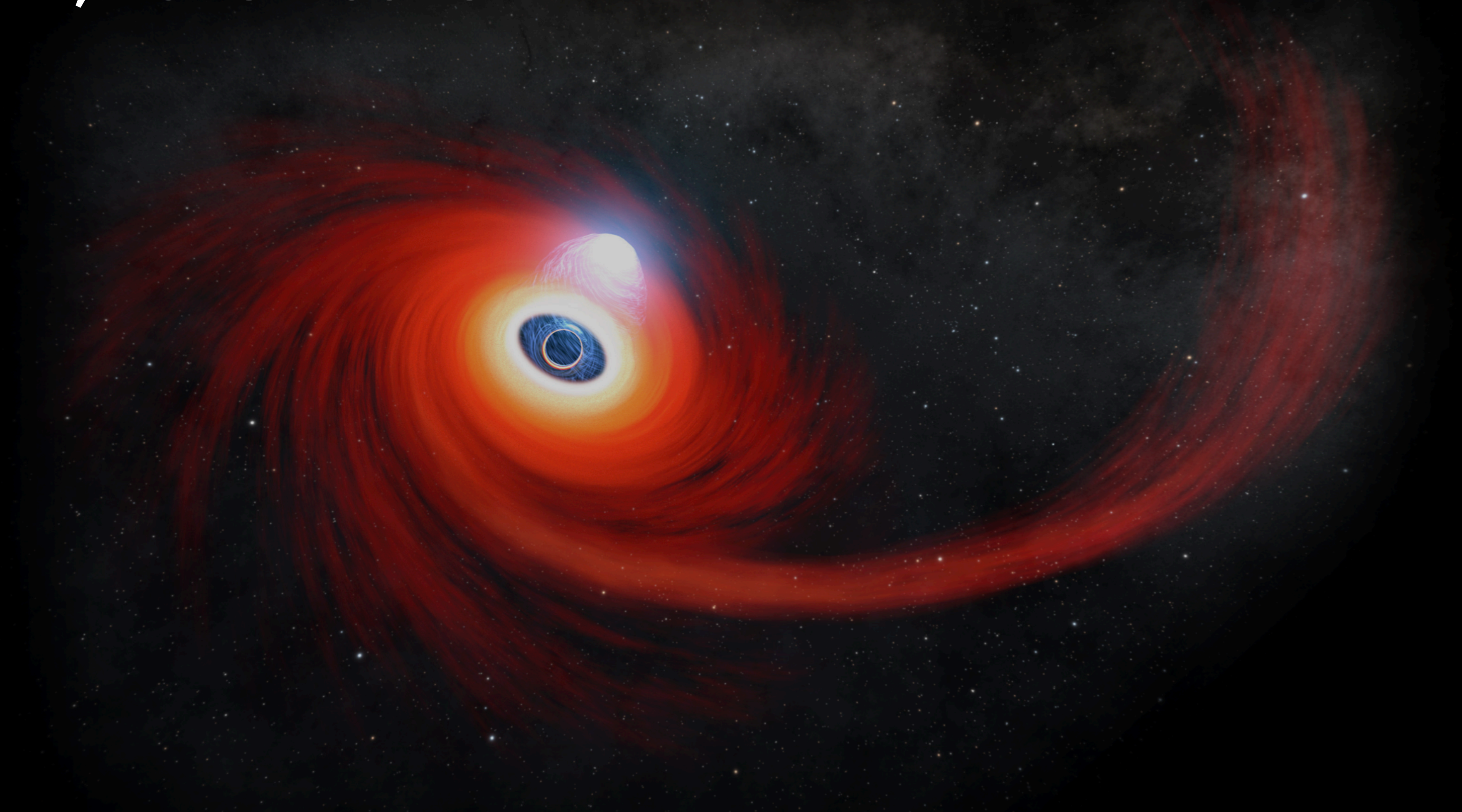
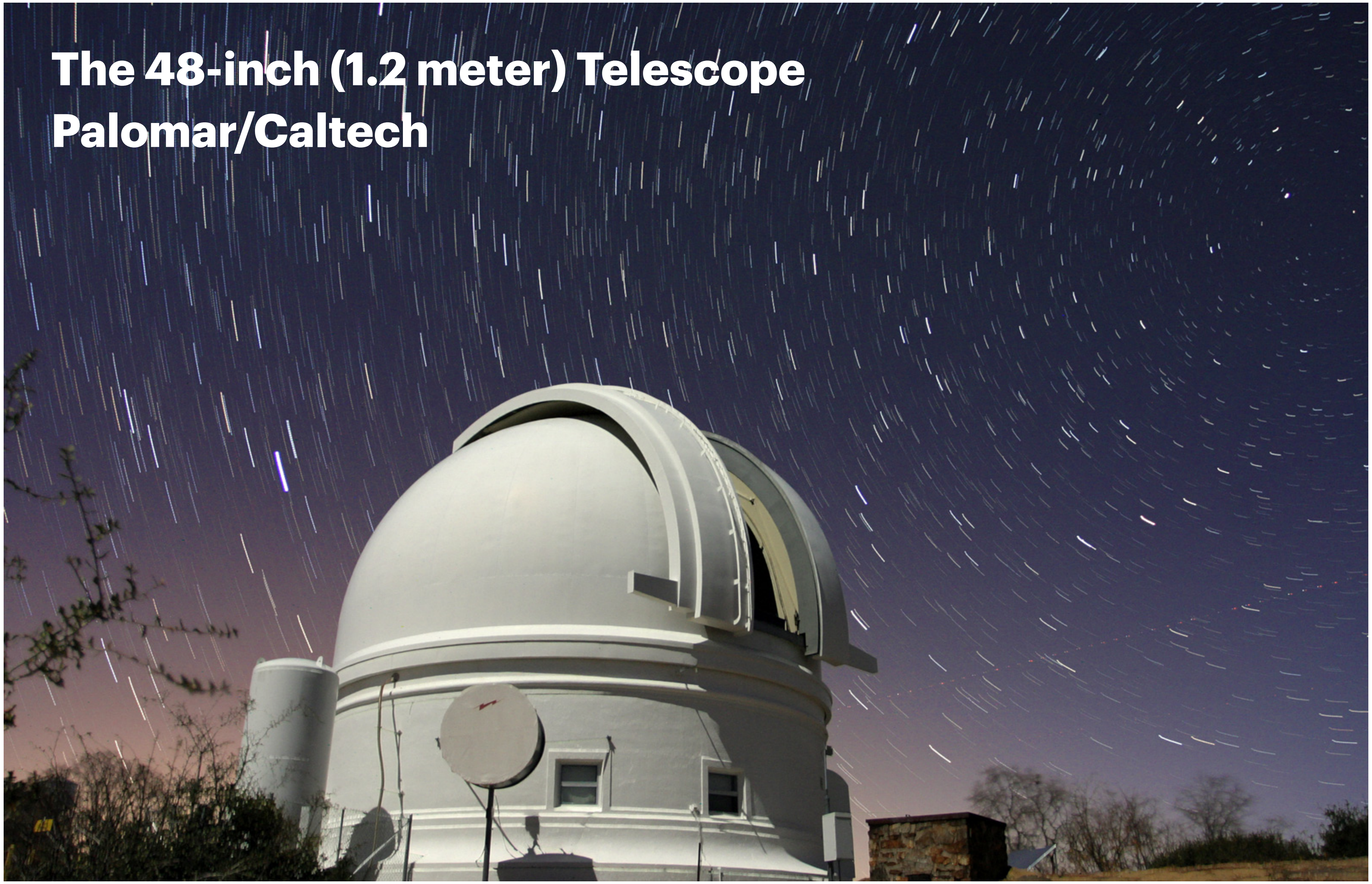


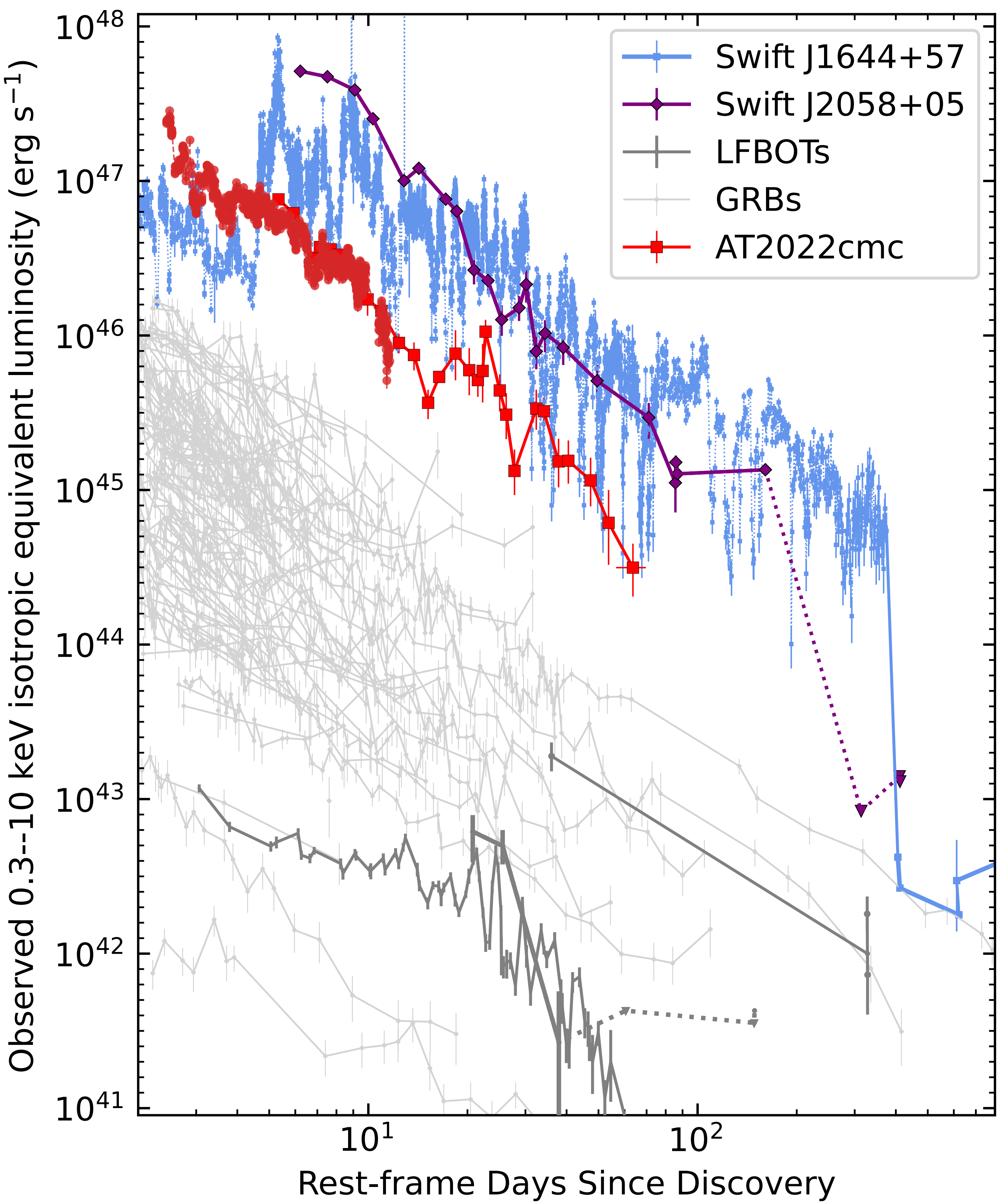
The Zwicky Transient Facility

Northern sky survey

- Sky area at dec>-30 deg
- Cadence: (g+r) every 2 days
- FoV: 47 deg^2, Limit AB mag ~ 20.5



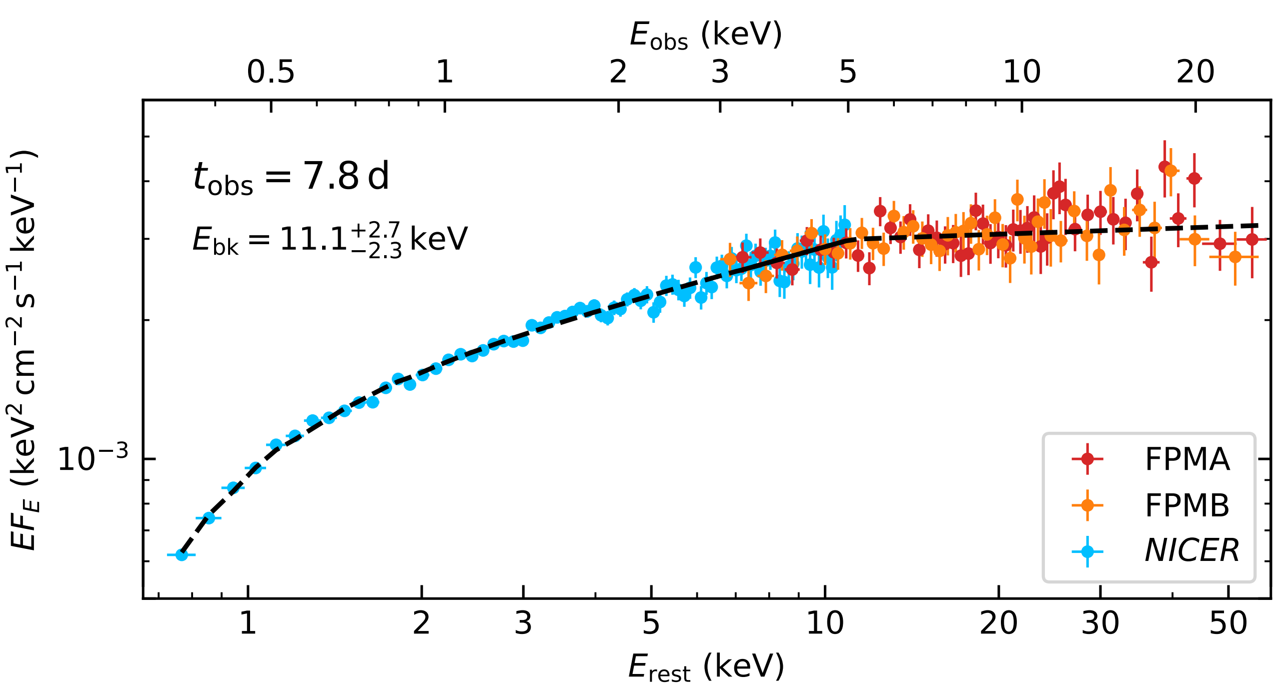
TDEs with on-axis relativistic jets

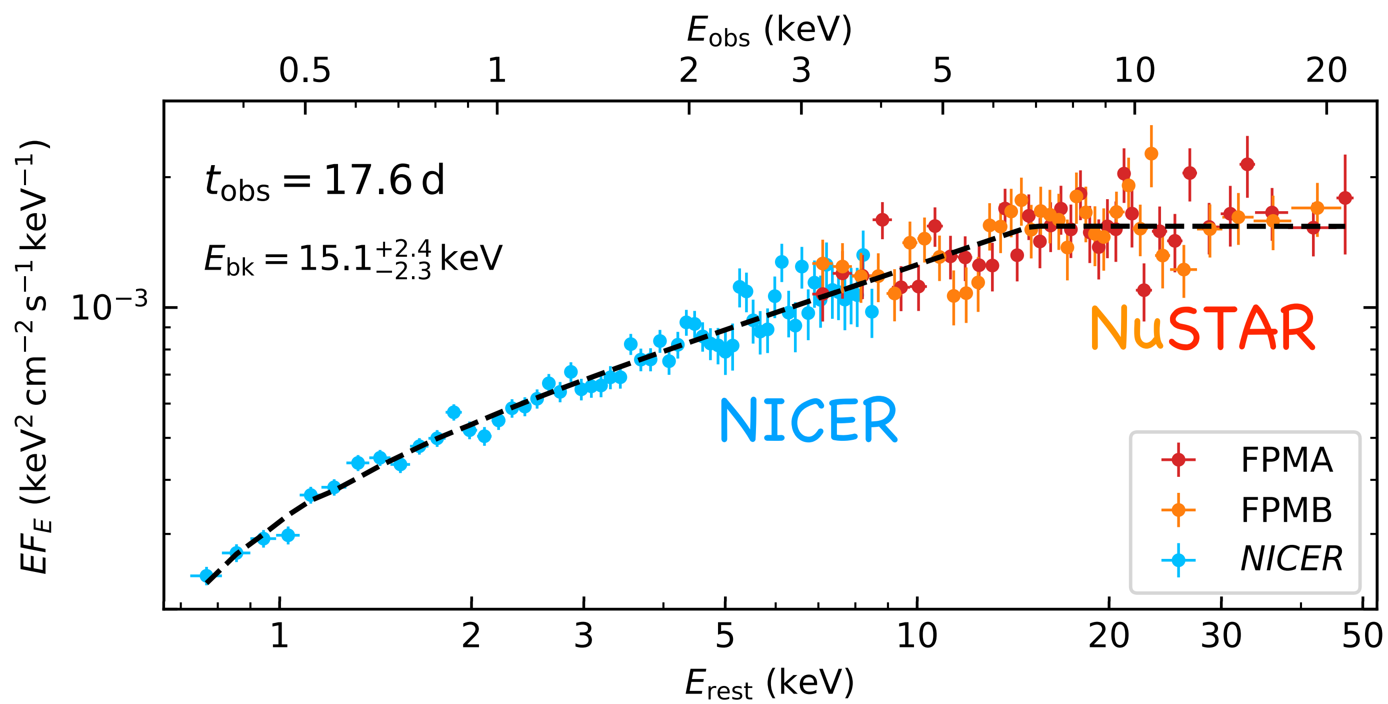


Three *Swift*-discovered events
(Burrows+2011, Bloom+2011, Levan+2011, Zauderer+2011, Cenko+2012, Pasham+2015)

AT2022cmc, z=1.193
Andreoni, Coughlin, Perley, **Yao**+2022, Nat
Pasham+2023, Nat Astro

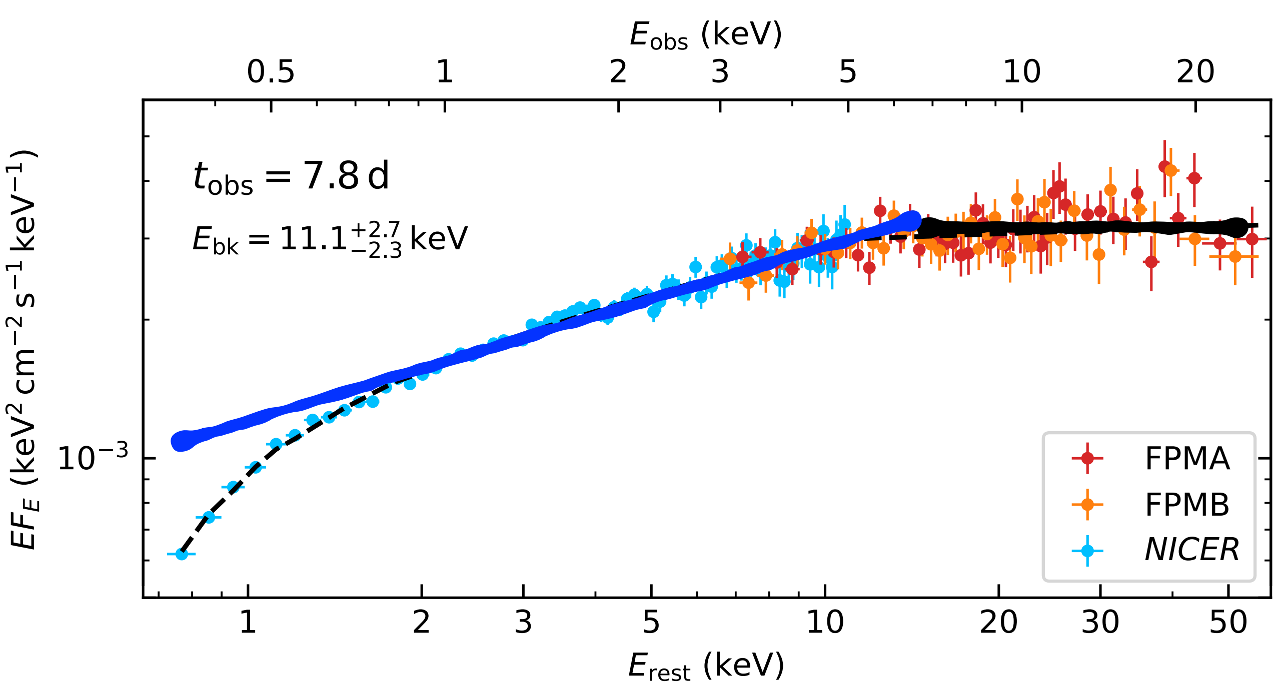
Jetted TDEs: Nature of X-ray Emission?

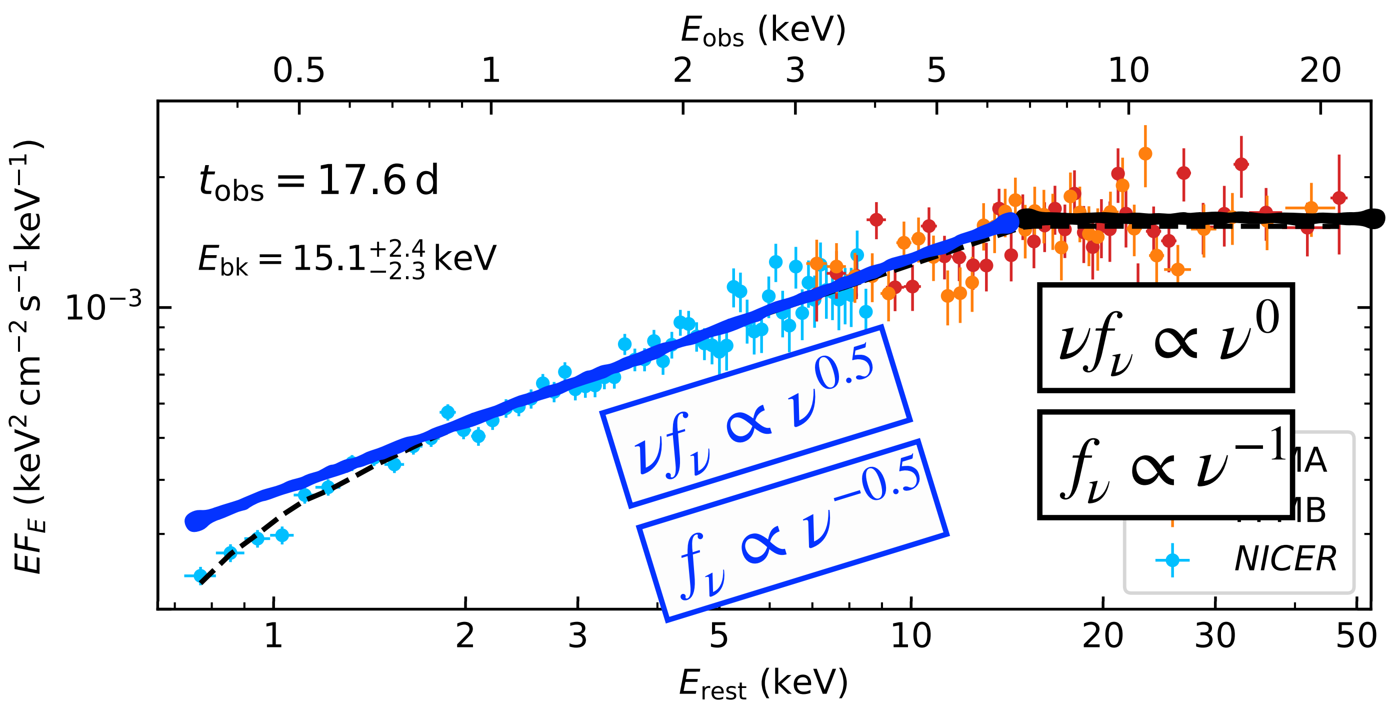




Yao, Lu+2023b, arxiv:2308.09834
AT2022cmc: the first jetted TDE observed with a focusing hard X-ray telescope (NuSTAR!)

Jetted TDEs: Nature of X-ray Emission?

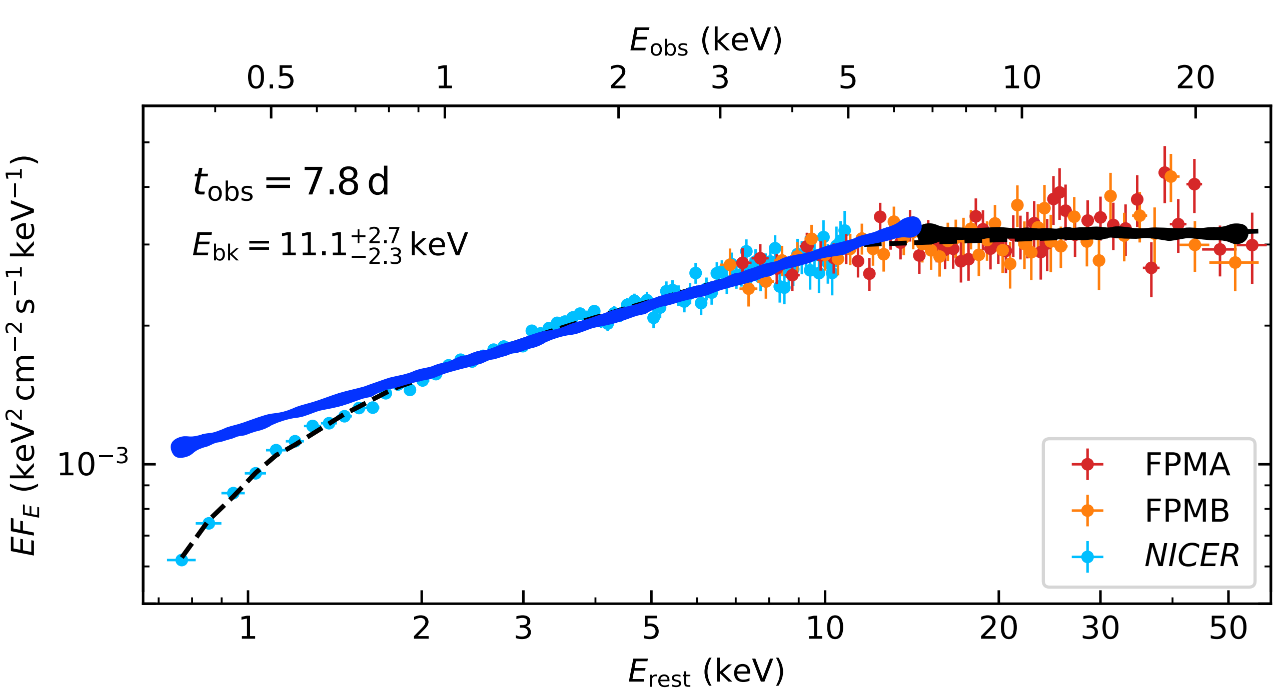


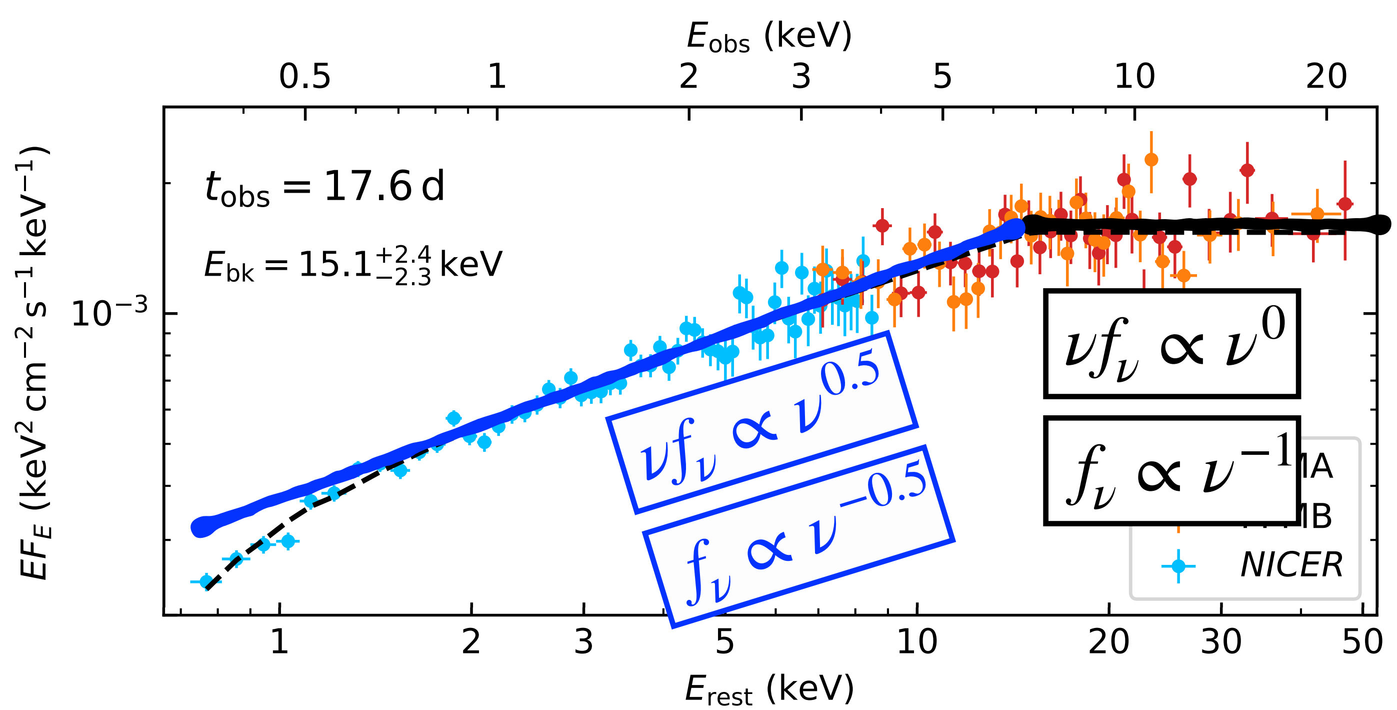


Yao, Lu+2023b, arxiv:2308.09834

AT2022cmc: the first jetted TDE observed with a focusing hard X-ray telescope (NuSTAR!)

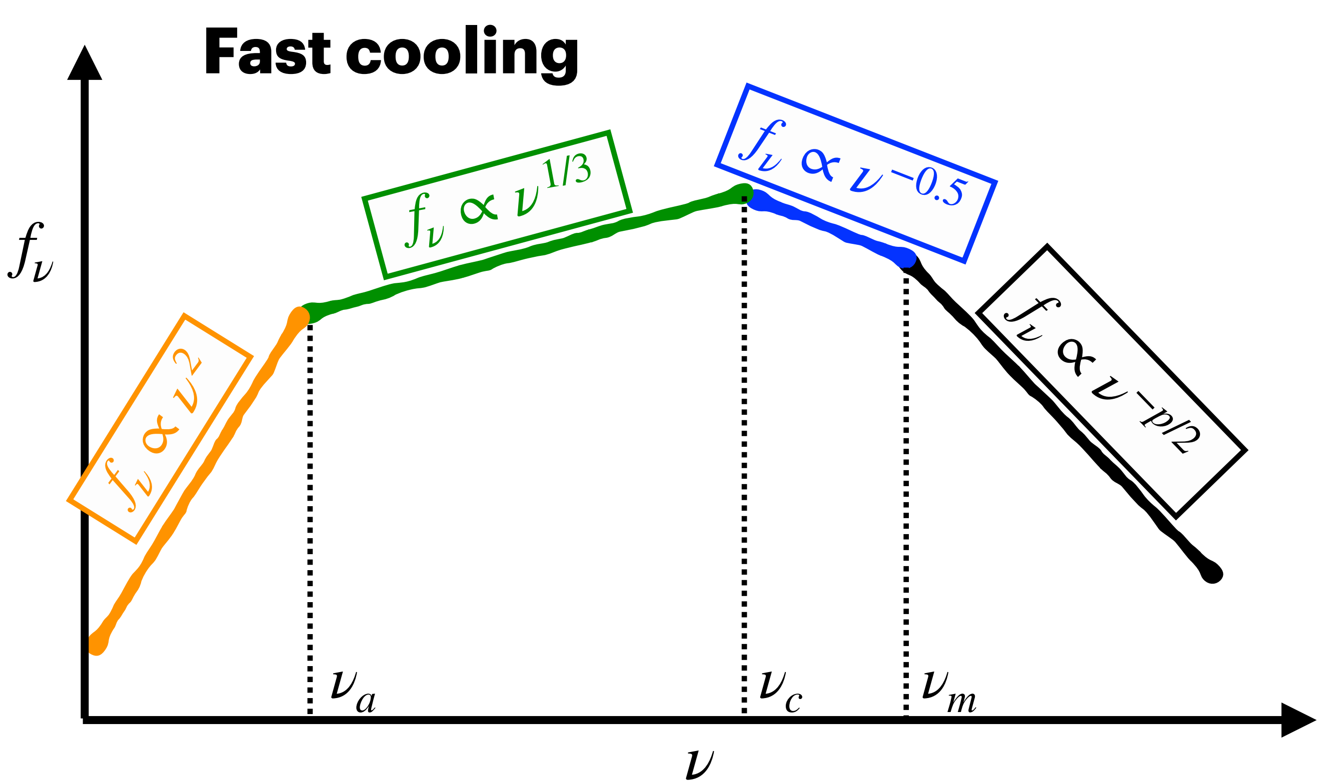
Consistent with a synchrotron spectrum (p=2)

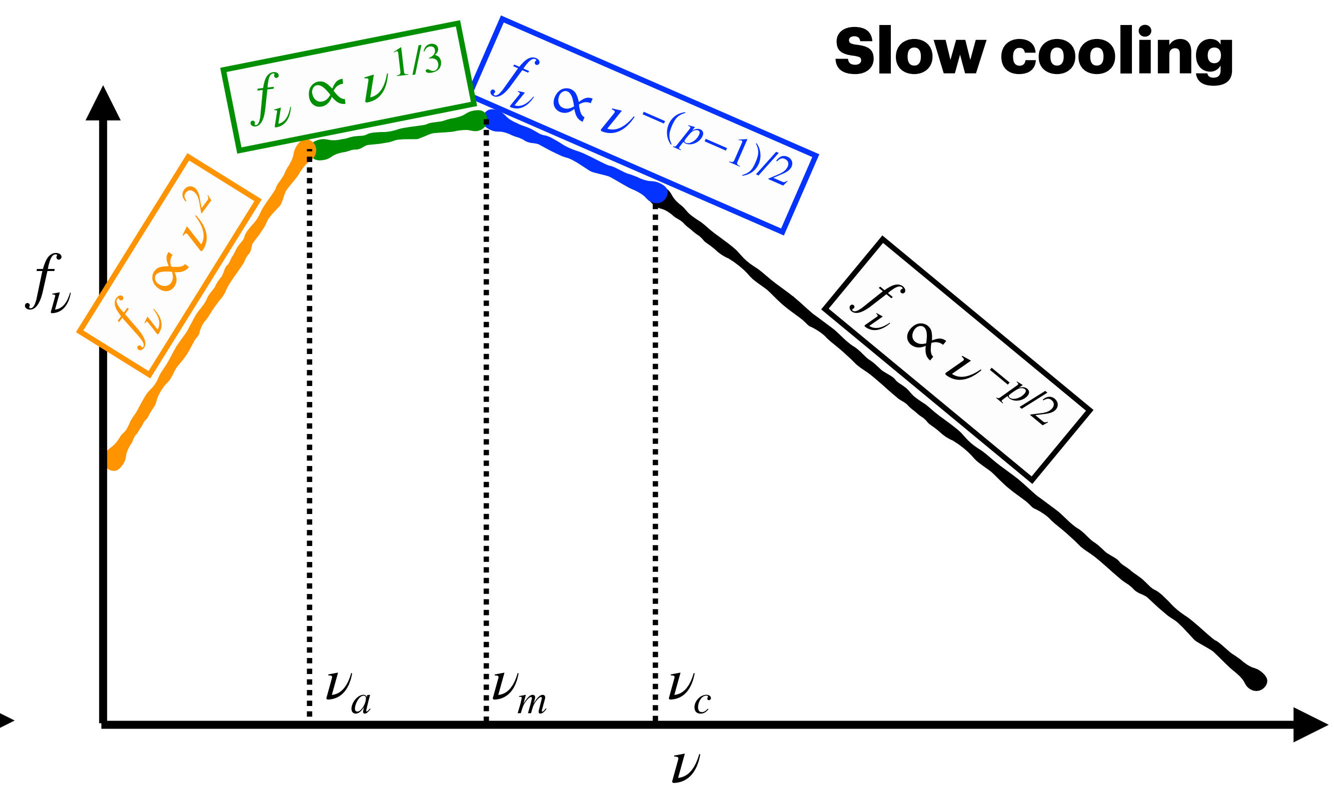




Sari+1998

Electrons are accelerated to: $N(\gamma) \propto \gamma^{-p} d\gamma \qquad \gamma_m < \gamma$



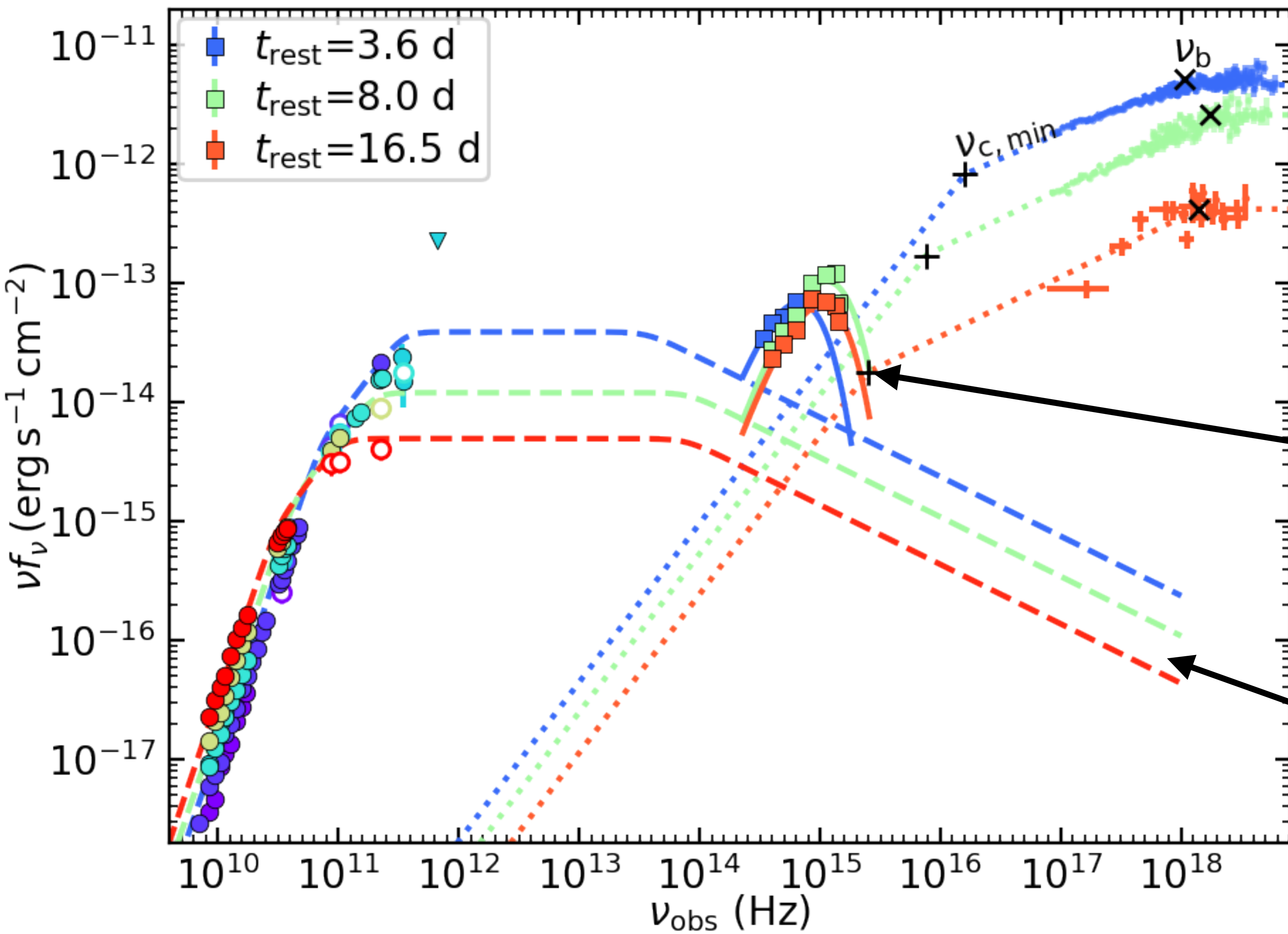


A synchrotron origin of the TDE jet

A <u>magnetically dominated</u> jet with high magnetization

Bulk Lorentz factor $20 \lesssim \Gamma_{jet} \lesssim 100$
Minimum electron Lorentz factor $10^4 \lesssim \gamma_m \lesssim 10^5$

Yao, Lu+2023b

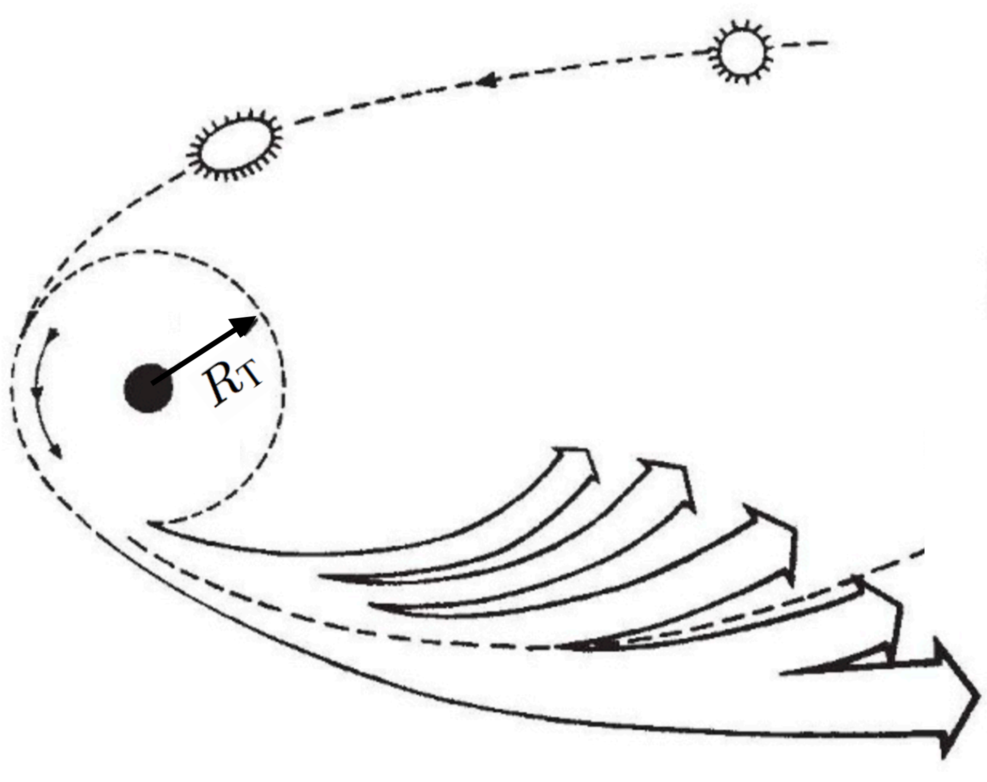


X-ray: prompt jet emission
"+": the minimum cooling frequency $\nu_{c,\,min}$
"x": the break frequency ν_b (can be either ν_c or ν_m)

UV/optical: thermal envelope
Blackbody L_{bb} ~ 10^{45} erg/s
R_{bb} ~ 10^{15} cm, T_{bb} ~ $10^{4.5}$ K

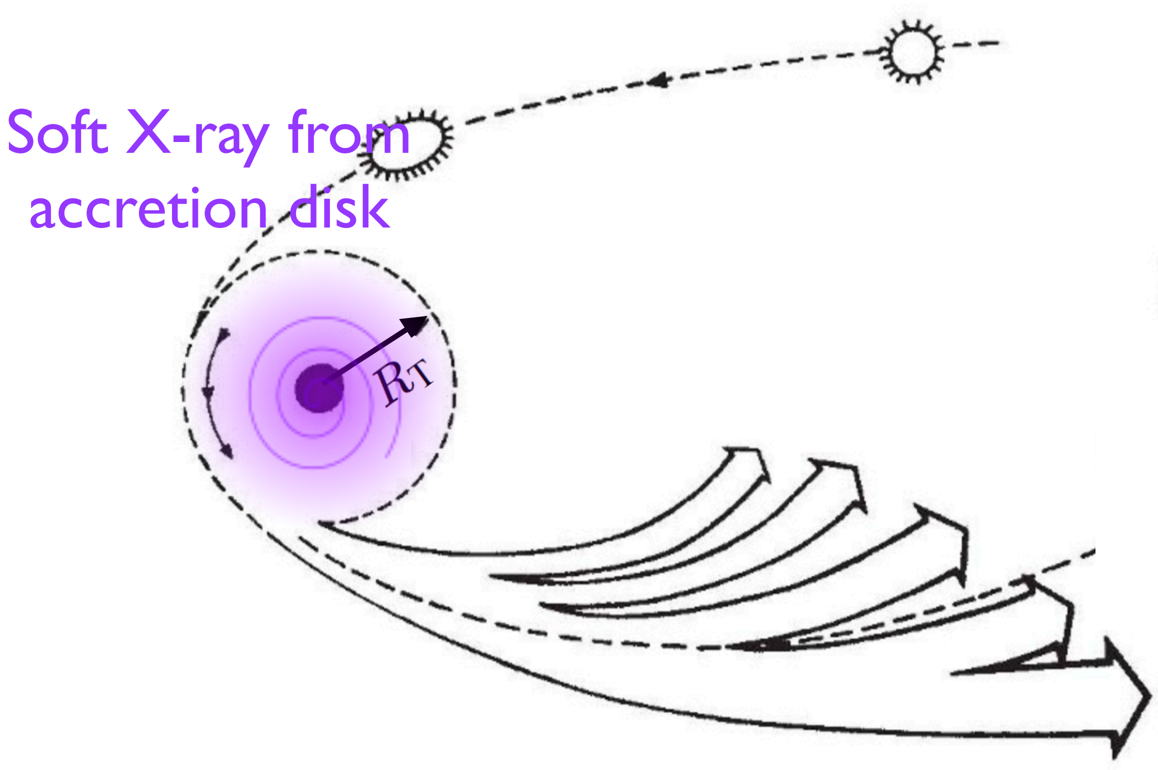
Radio/mm: external shock afterglow emission
Γ~3, r_{radio}~ 10^{17} cm,
total energy E_T ~ few x 10^{50} erg

Non-jetted TDE / Thermal TDE



Non-jetted TDE / Thermal TDE

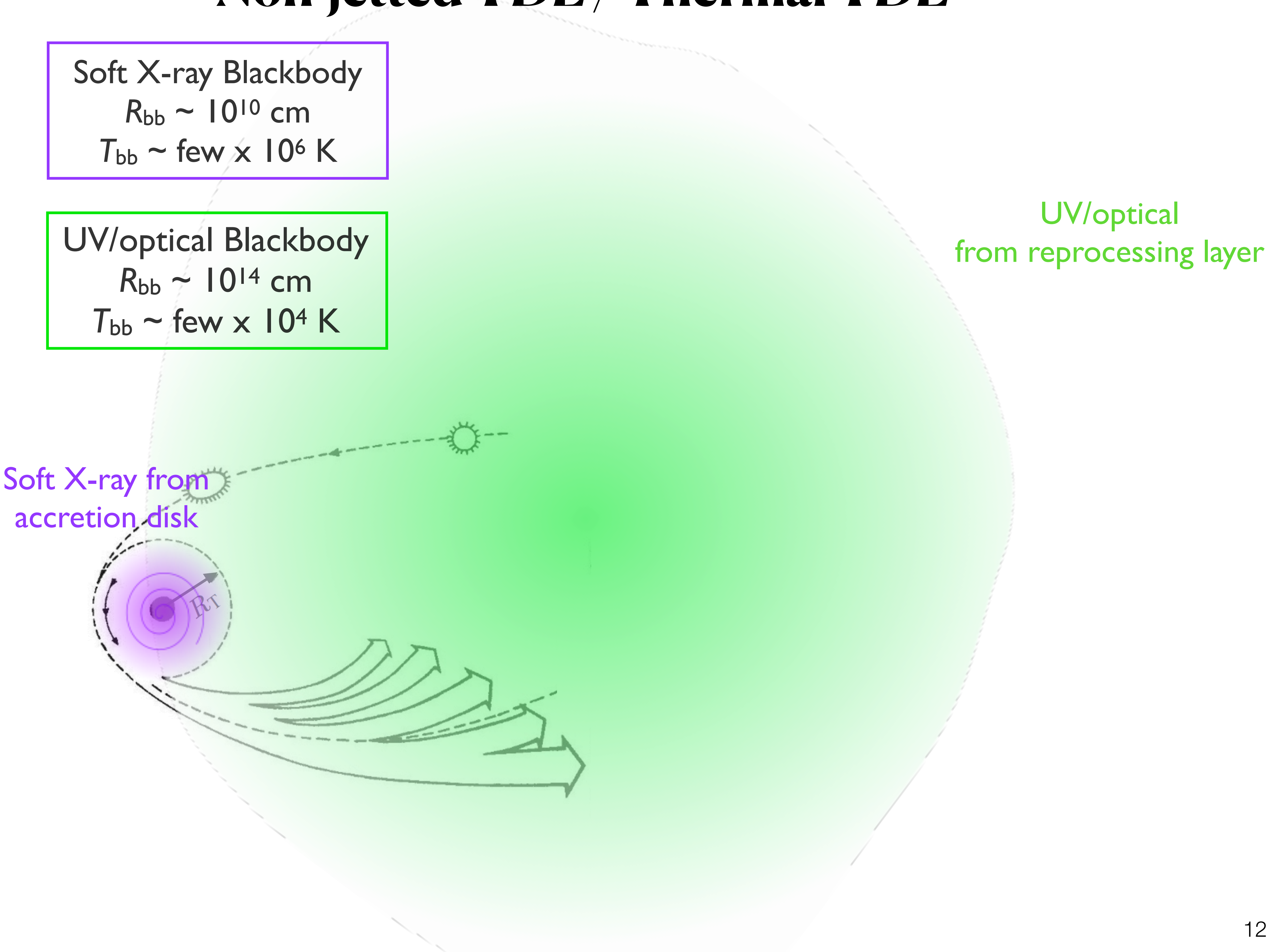
Soft X-ray Blackbody
$R_{bb} \sim 10^{10}$ cm
$T_{bb} \sim$ few x 10^6 K



Non-jetted TDE / Thermal TDE

Soft X-ray Blackbody
$R_{bb} \sim 10^{10}$ cm
$T_{bb} \sim$ few x 10^{6} K

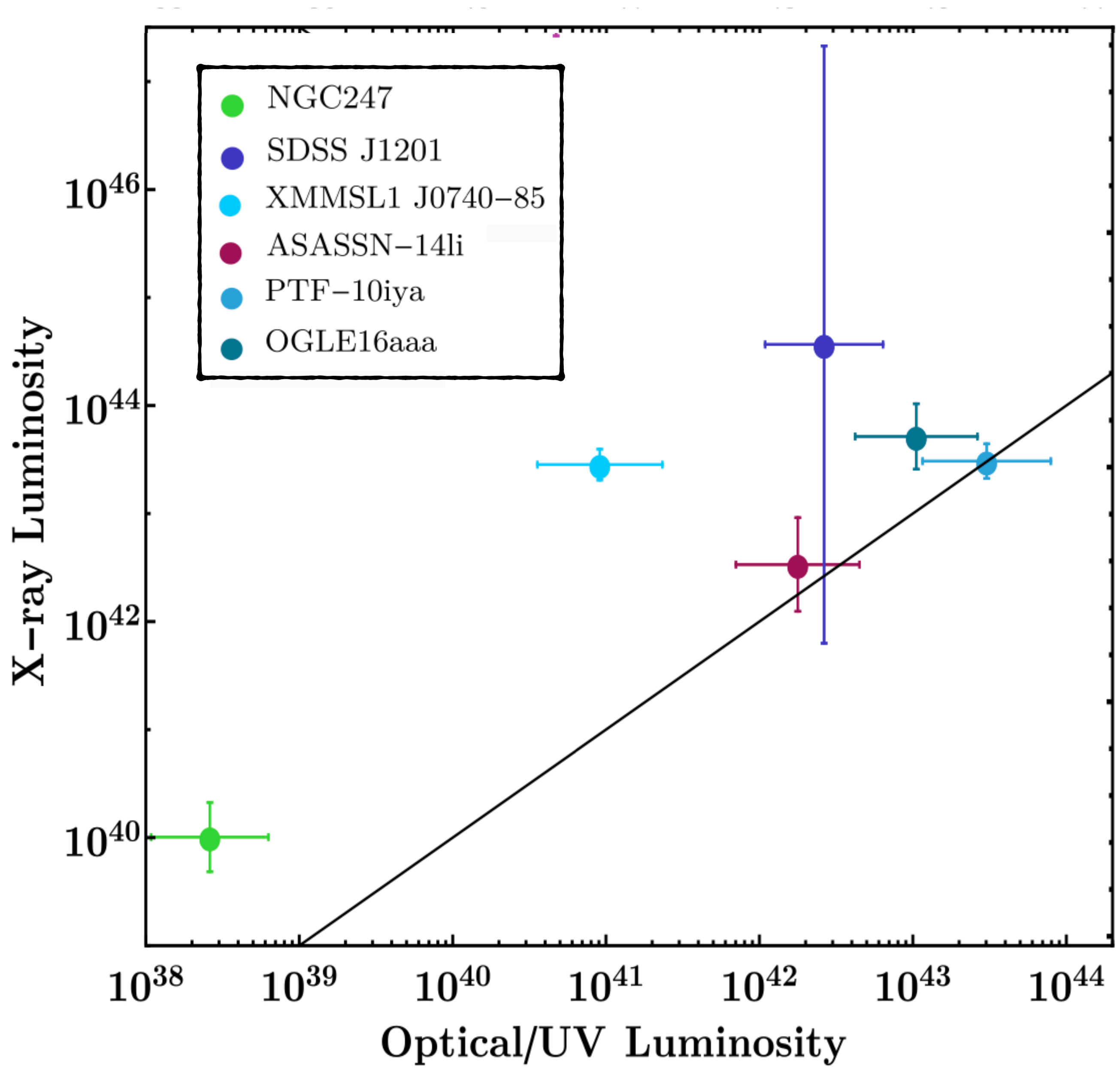
UV/optical Blackbody
$R_{bb} \sim 10^{14}$ cm
$T_{bb} \sim$ few x 10^{4} K



Landscape of thermal TDE discoveries ~6 yrs ago

X-ray: *ROSAT* survey in 1990/1991, serendipitous discoveries with sparse follow-up observations, only 6 events with simultaneous UV/optical monitoring

Auchettl+2017



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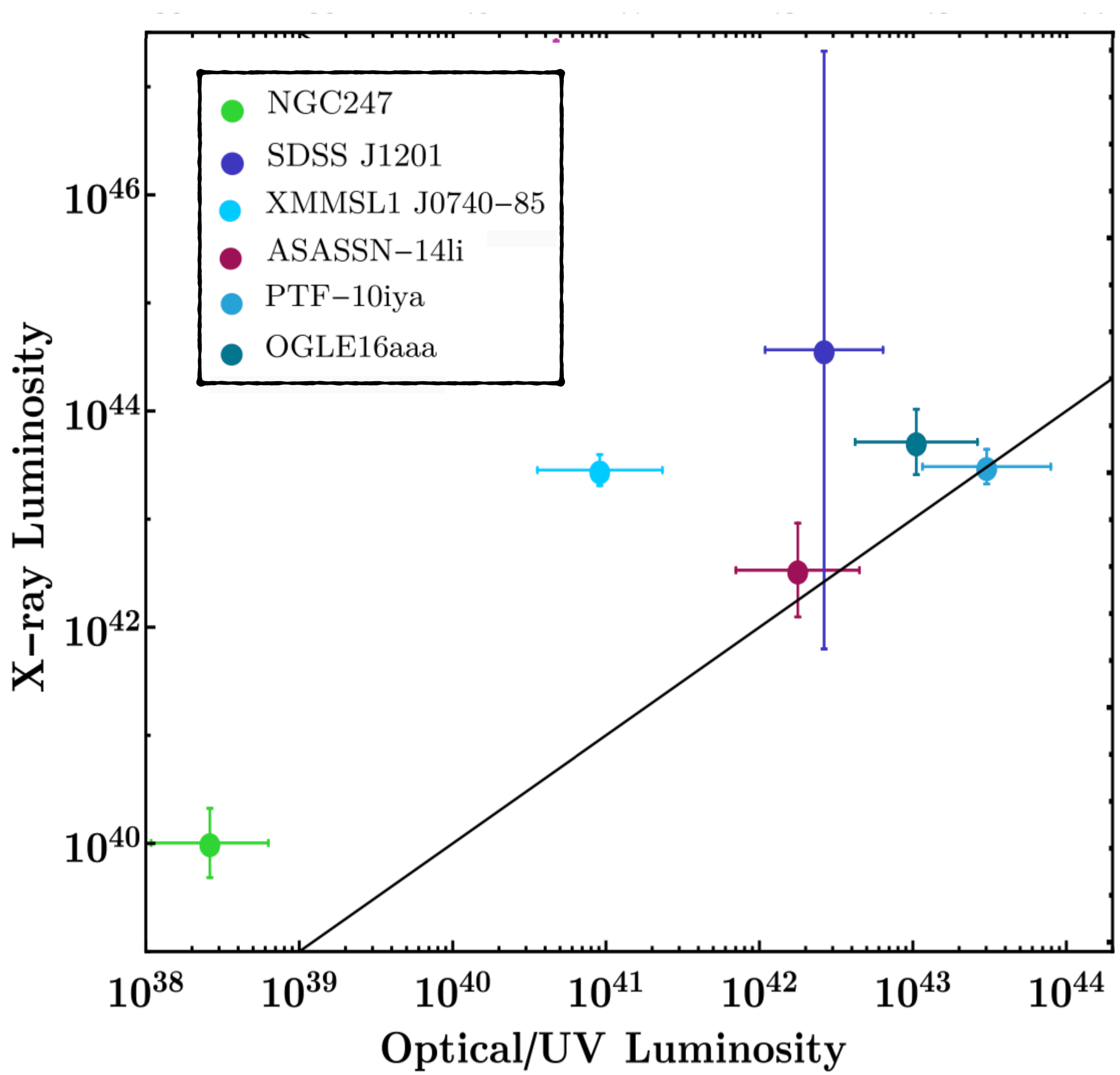
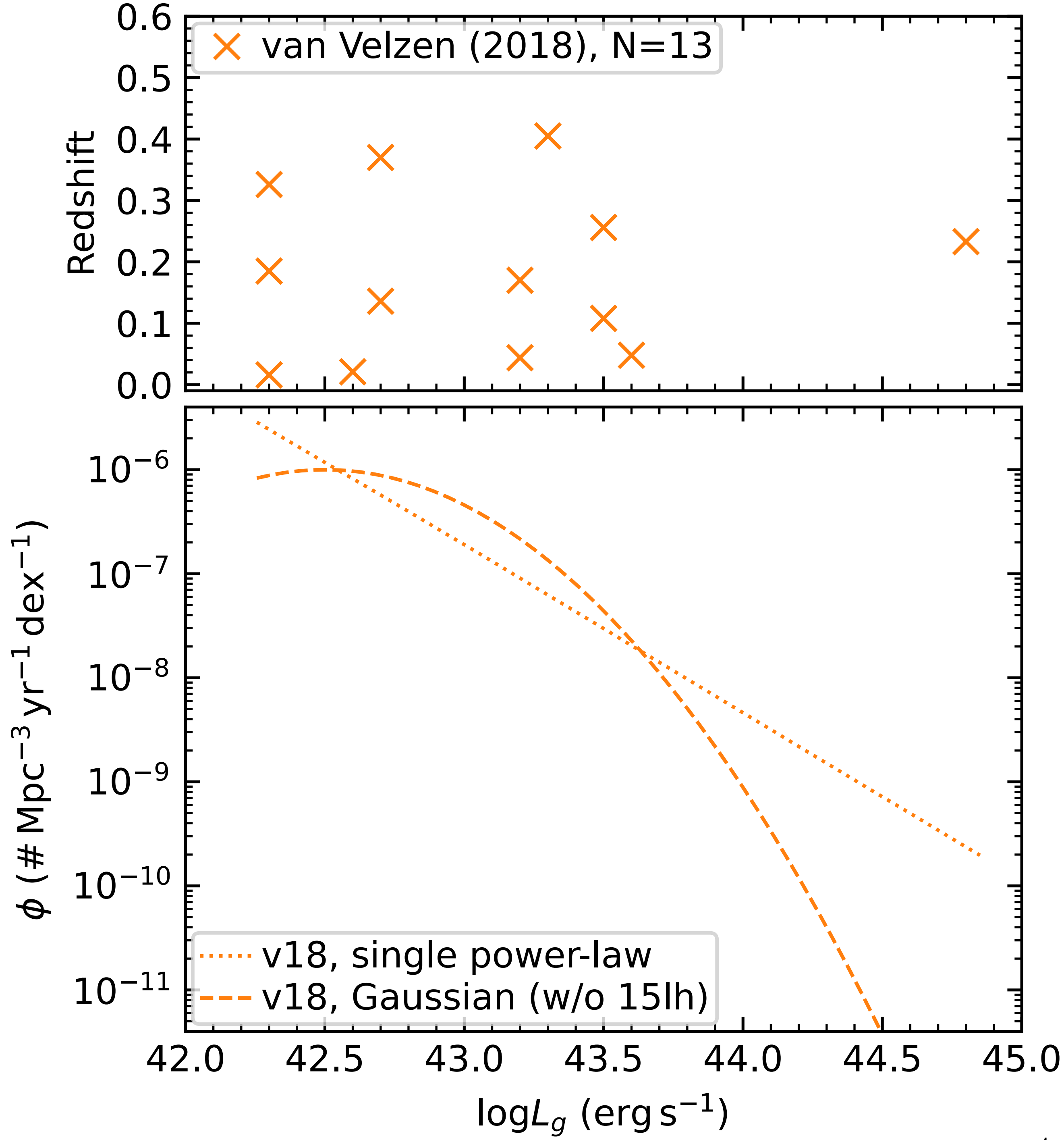


Optical: heterogeneous sample, 13 TDEs from 5 different sky surveys over ~10 yrs

van Velzen 2018

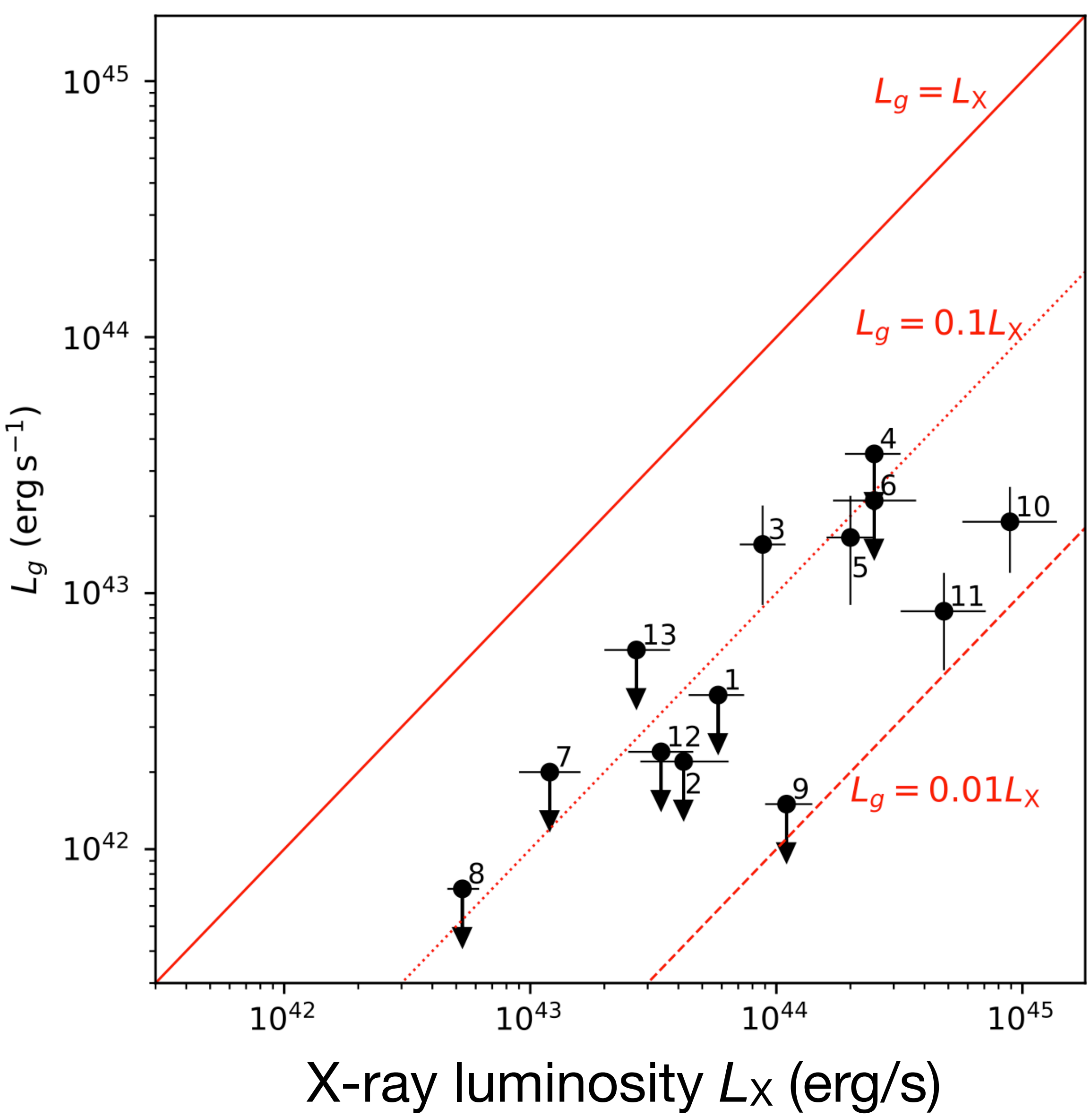


The surge in thermal TDE discoveries

X-ray: 13 TDEs from the *Spectr-Roentegen-Gamma (SRG)* eROSITA telescope

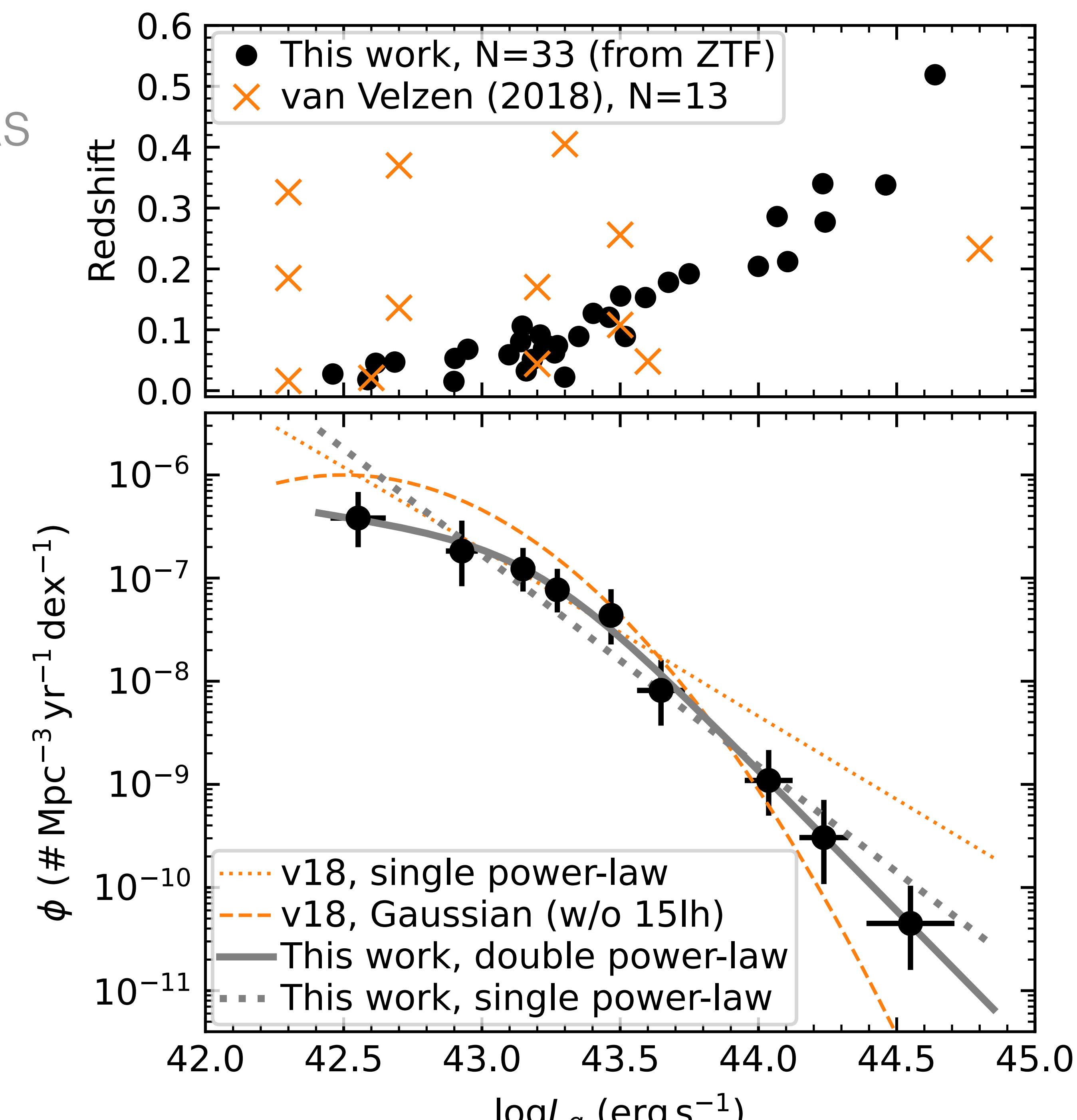
L_g obtained with ATLAS+ZTF forced photometry

Sazonov, Gilfanov, Medvedev, **Yao**+2021, MNRAS



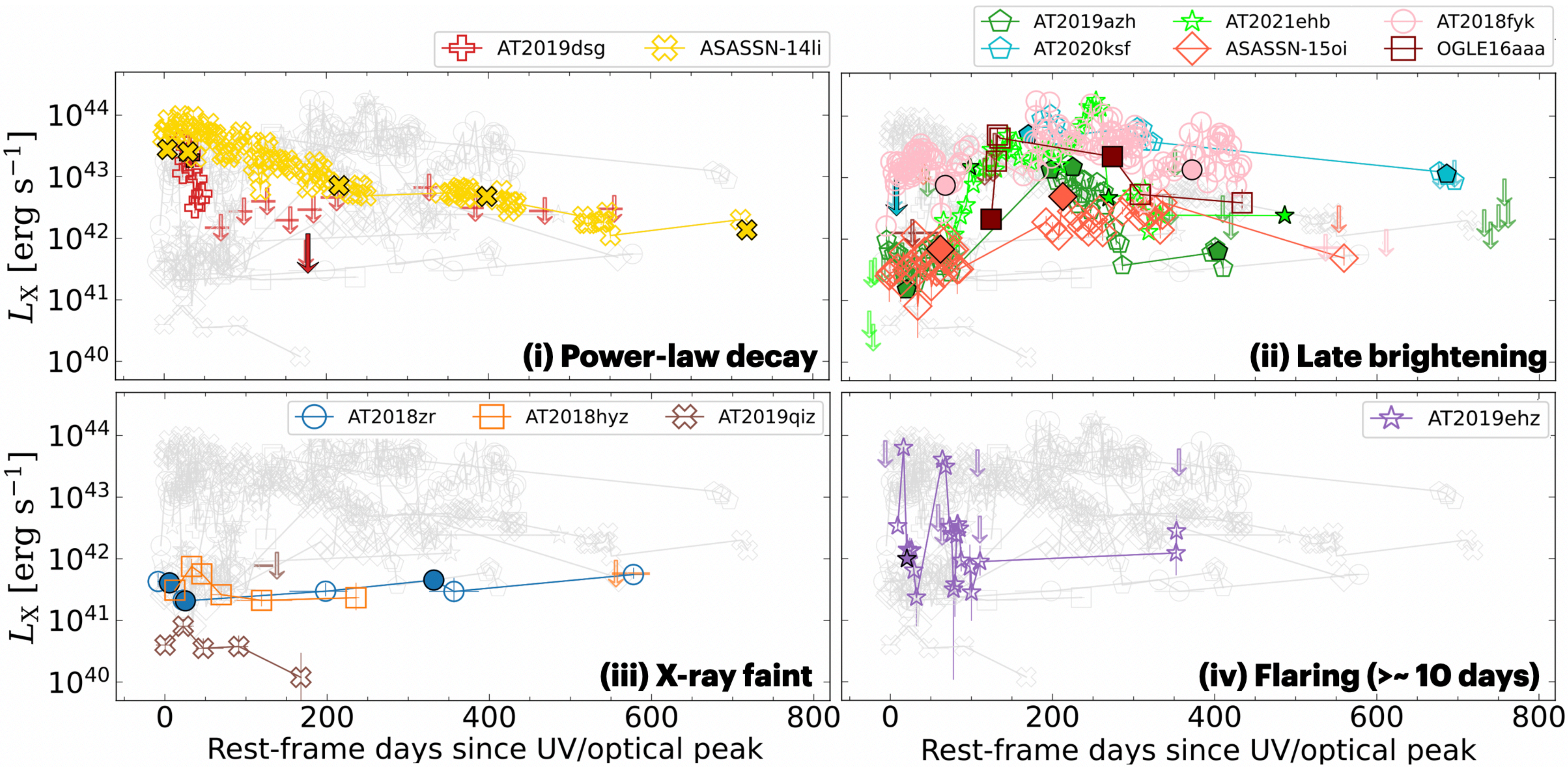
Optical: 33 TDEs (complete, flux-limited, 3 yrs) from ZTF

Yao+2023a ApJL



Surprises from high cadence X-ray Observations

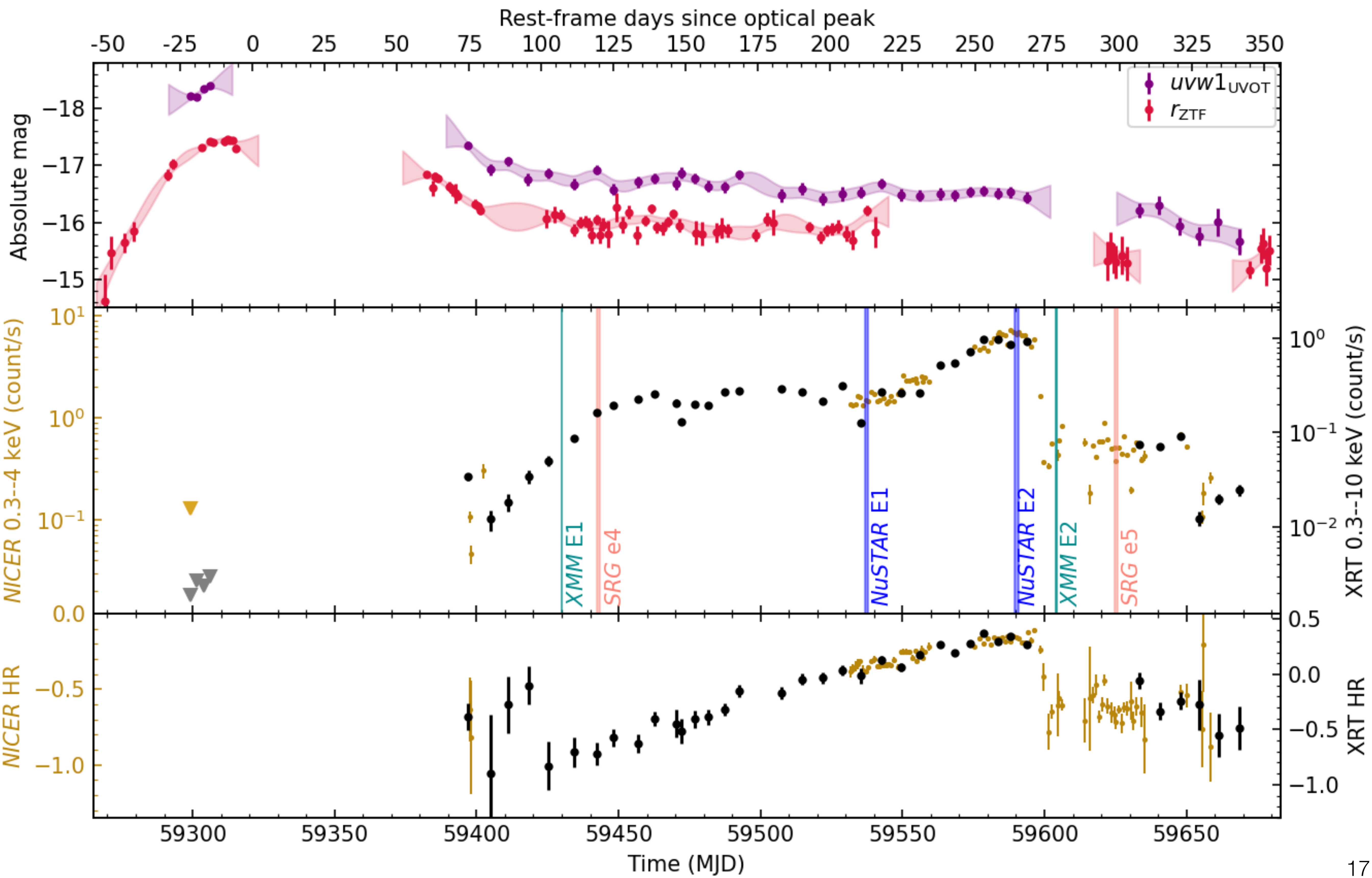
Guolo, Gezari, **Yao**+2023, arxiv: 2308.13019



AT2021ehb

z=0.018
$M_{BH} \sim 10^7 M_\odot$

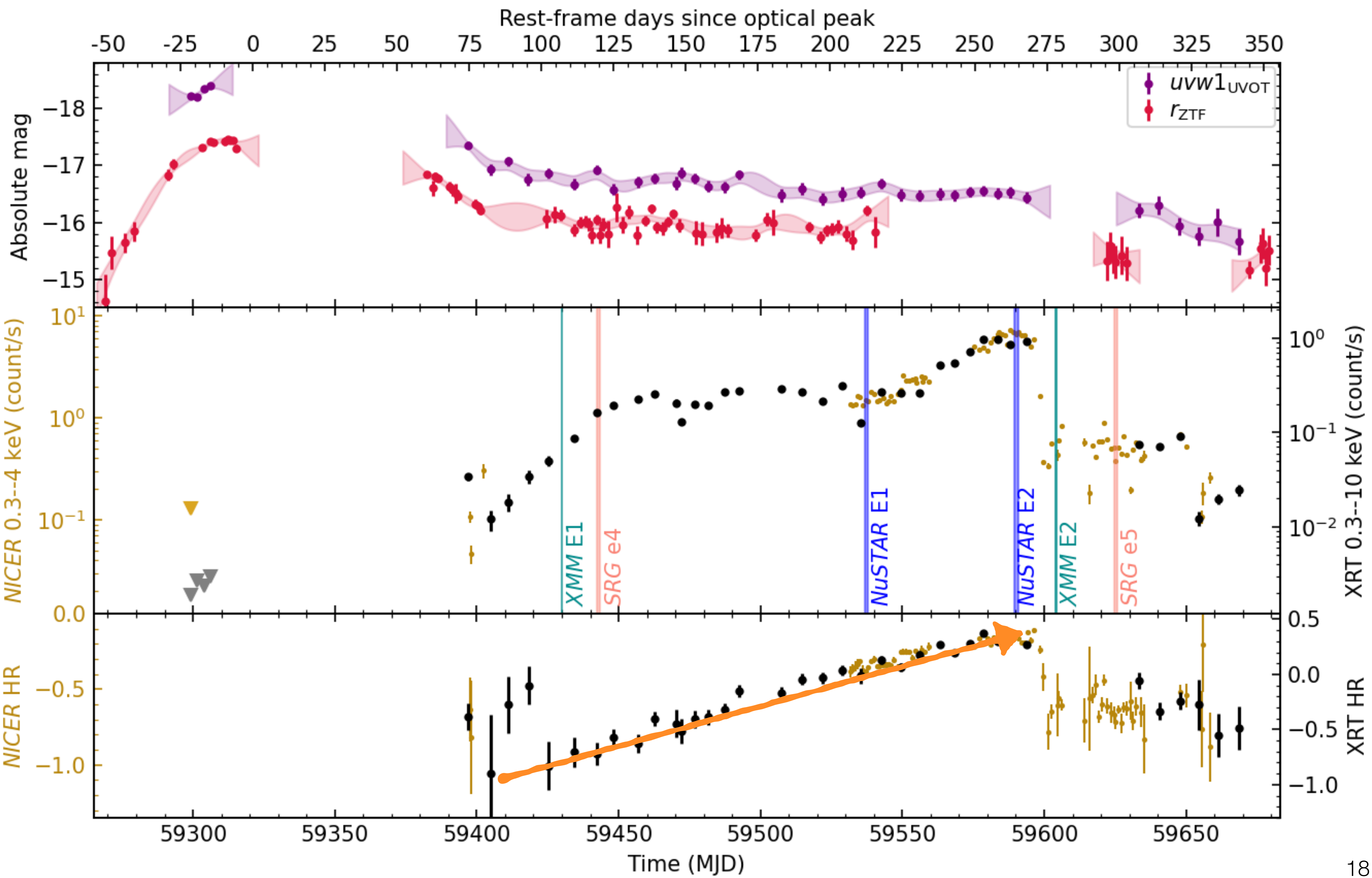
Yao, Lu+2022, ApJ



AT2021ehb

Soft→Hard:

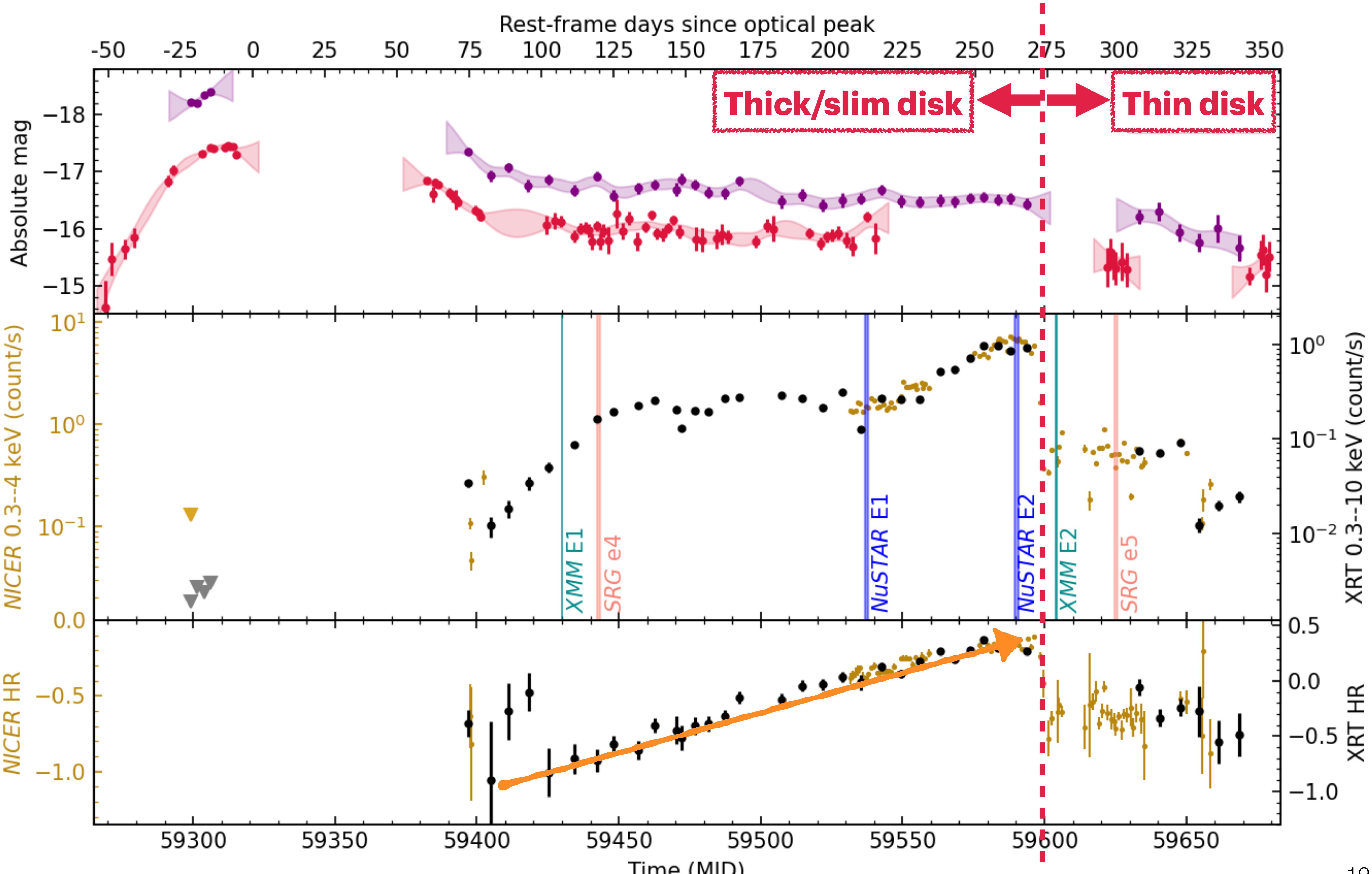
Gradual formation of corona



AT2021ehb

Soft→Hard: Gradual formation of corona

Hard→Soft (flux drop): Thick→thin disk transition

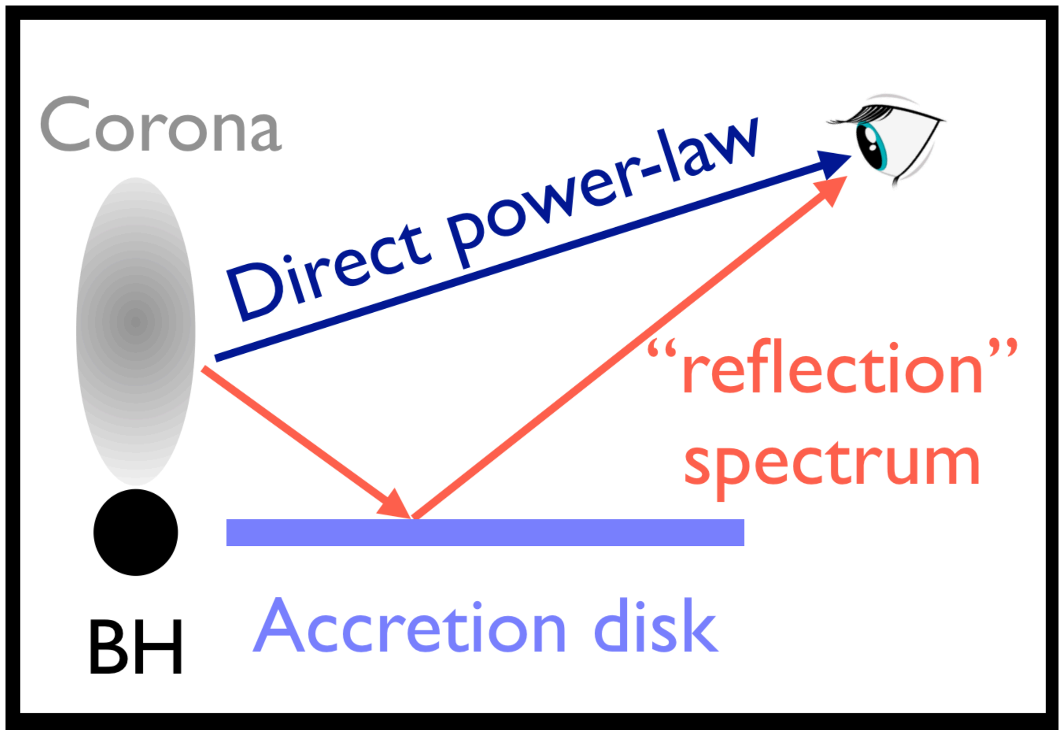


AT2021ehb in the super-Eddington hard state

Yao, Lu+2022

Typical hard-state AGN/XRB: $\log\xi \lesssim 3.5$

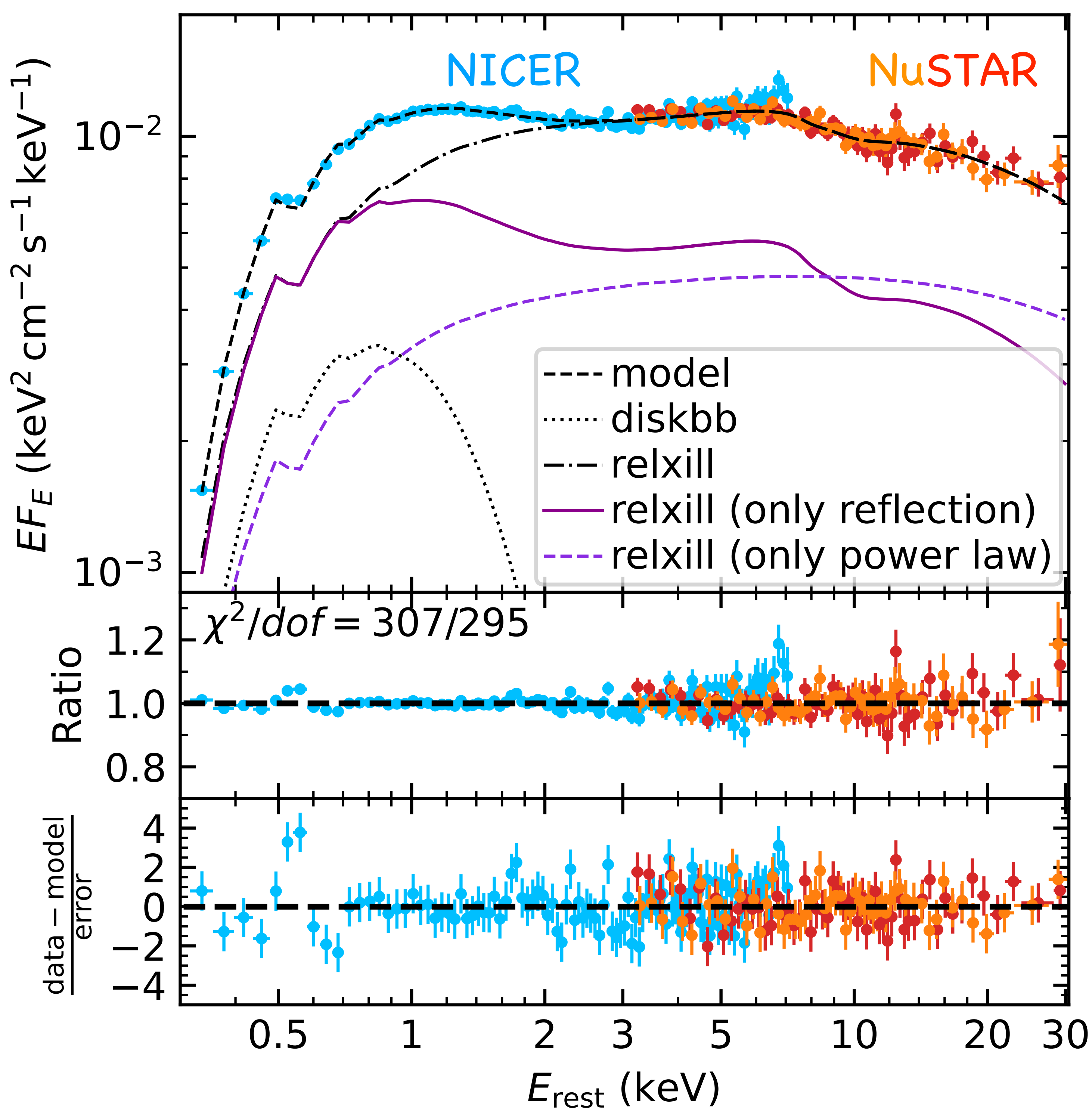
AT2021ehb (TDE): $\log\xi \approx 4$



$$\xi \equiv \boxed{\frac{L_{\rm ion}}{r^2}} \frac{1}{n}$$

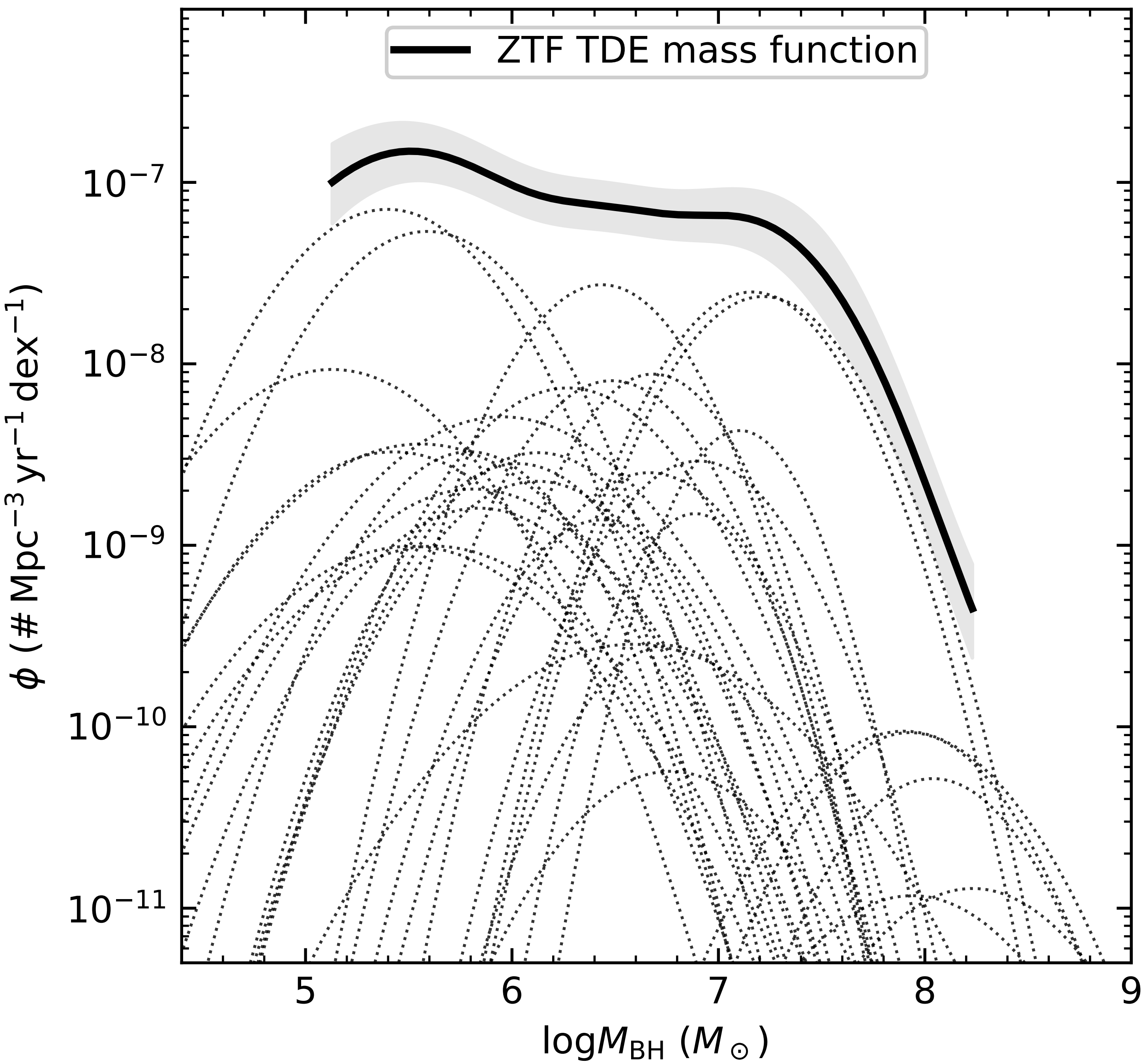
ionizing flux

gas density



From TDE rates to BH demographics

Yao+2023a



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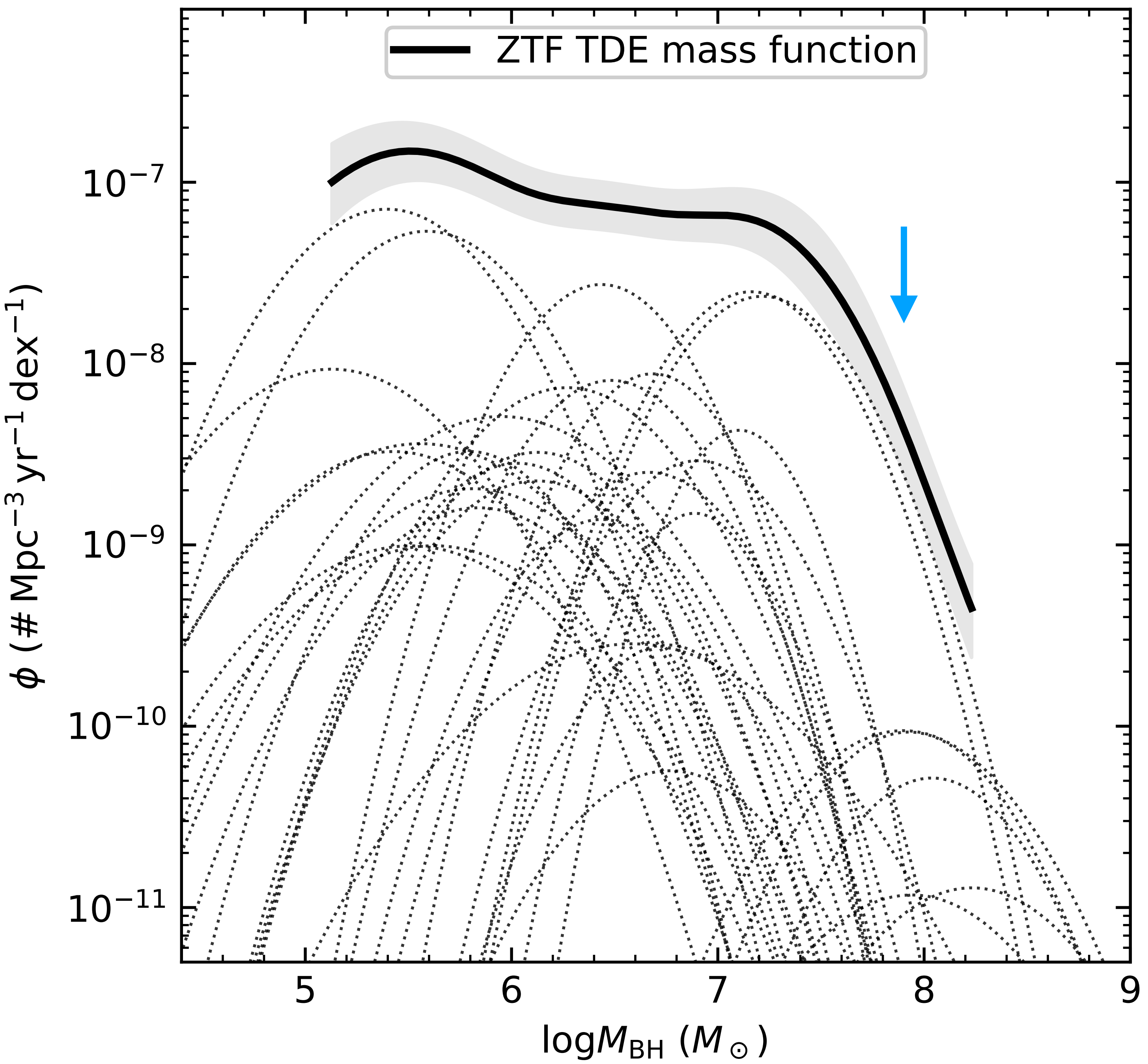

Yao+2023a

High-mass drop:

BH event horizon ($R_{\rm T} > R_{\rm S}$)

$$R_{\rm T} \sim 7 \times 10^{12} (M_{\rm BH}/10^6\, M_\odot)^{1/3}\,\mathrm{cm}$$
$$R_{\rm S} = 3 \times 10^{11} (M_{\rm BH}/10^6\, M_\odot)\,\mathrm{cm}$$

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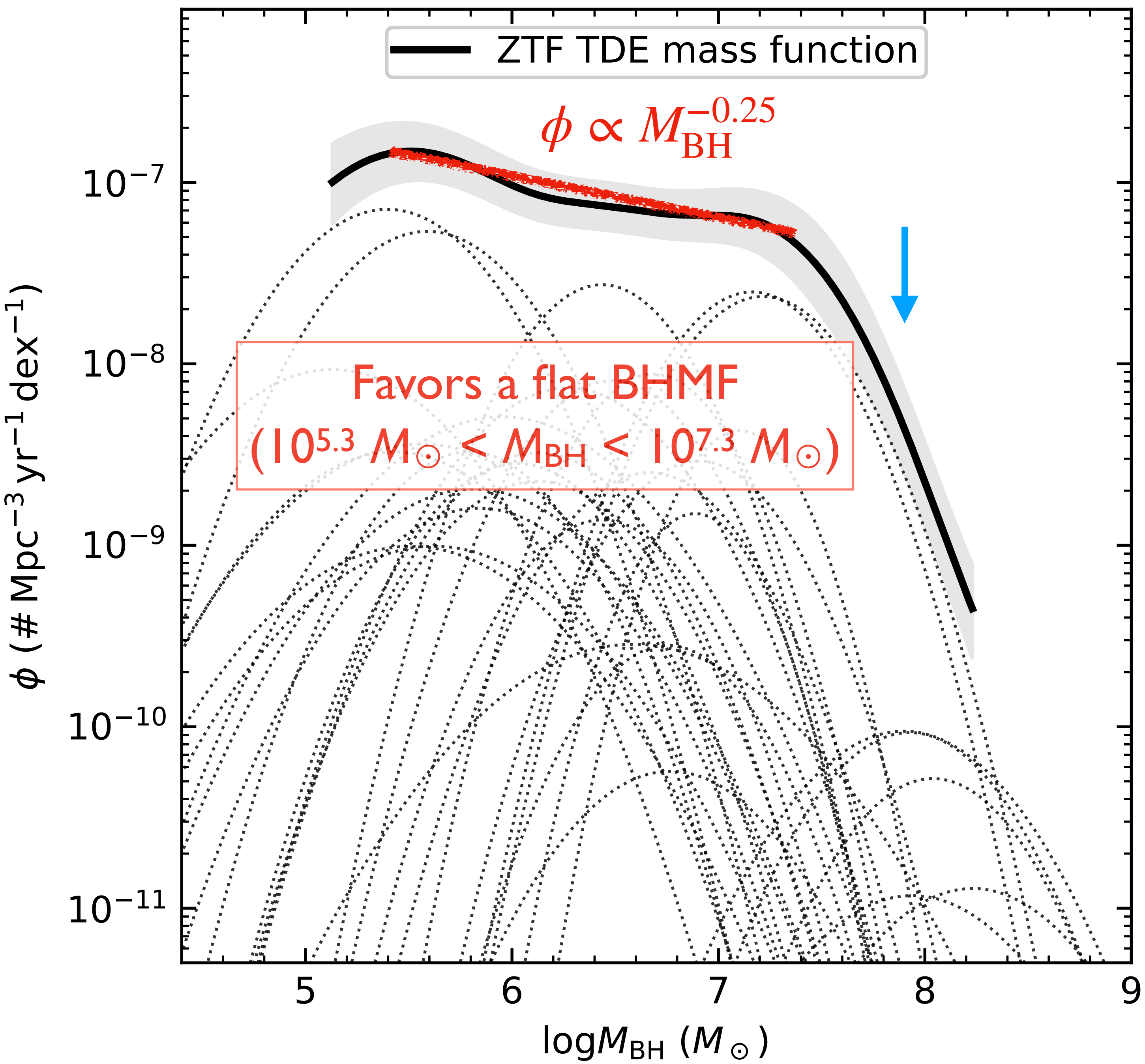

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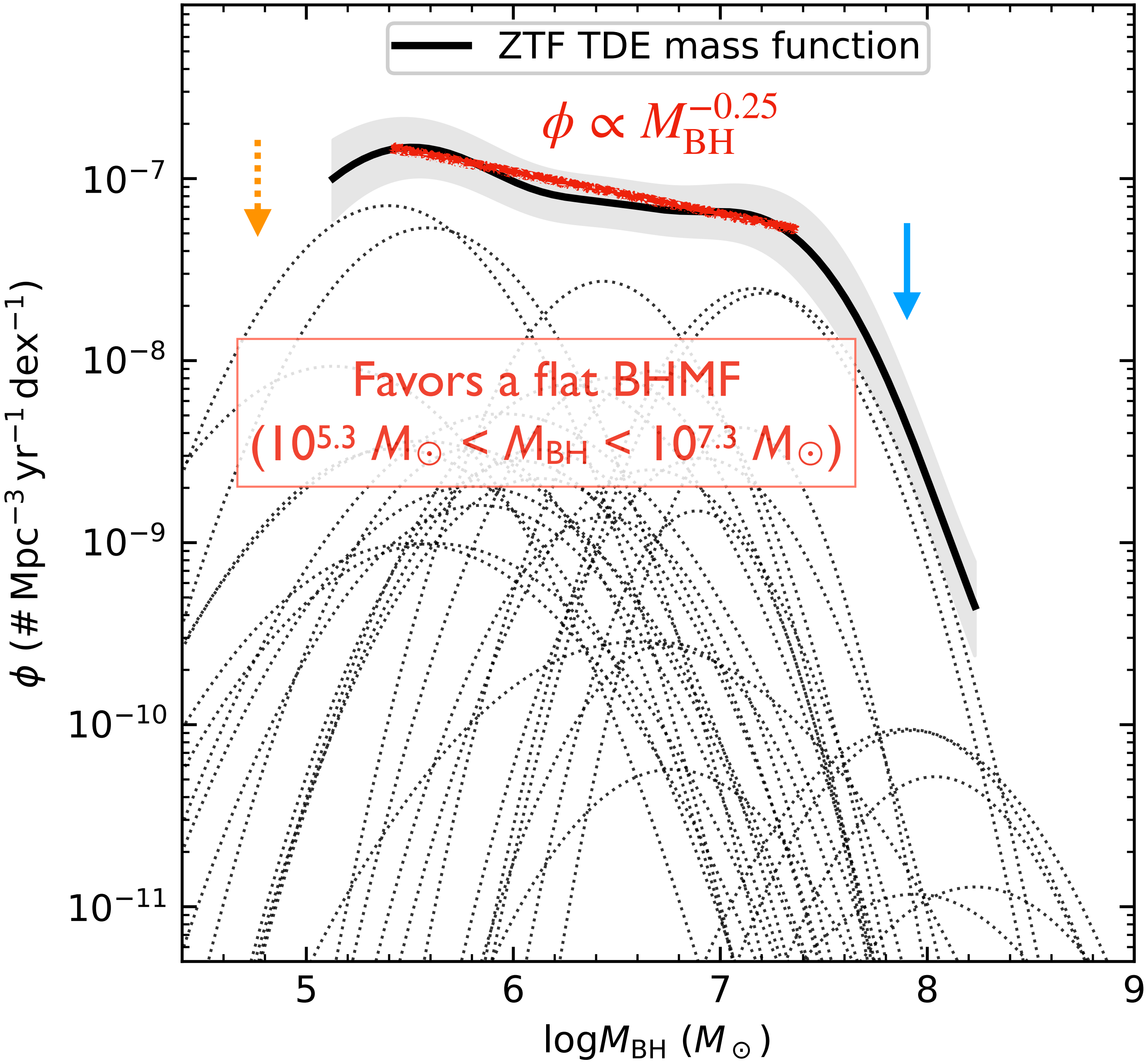
Middle range:

$$\phi(M_{\rm BH}) \approx \dot{N}_0 M_{\rm BH}^{-0.25} \boxed{\frac{dn_{\rm BH}}{d\log M_{\rm BH}}}$$

BH mass function (BHMF)

From TDE rates to BH demographics

Yao+2023a



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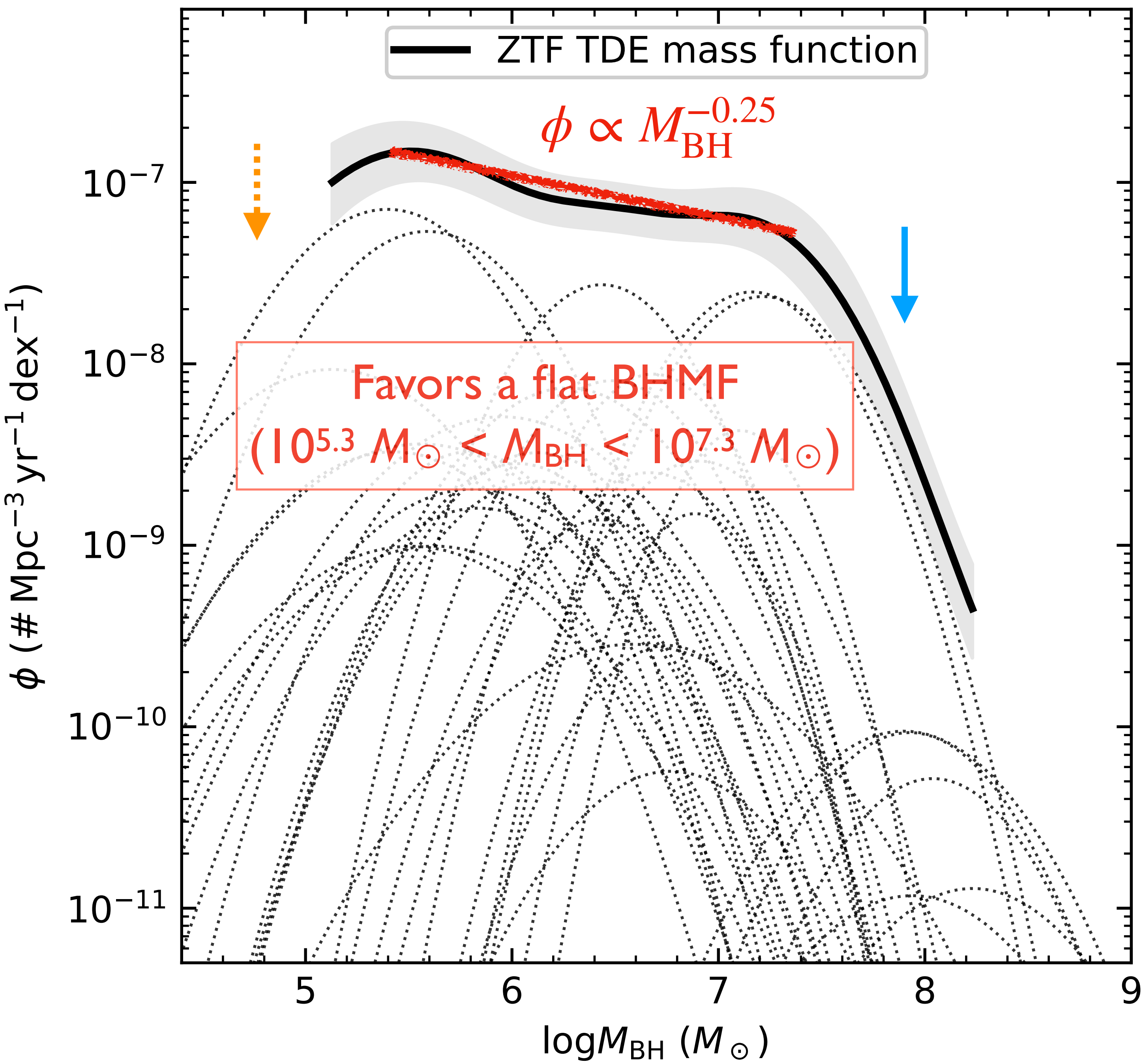
Low-mass dearth:

Not sensitive to TDEs with $L_{bb}<10^{43}$ erg/s and off-nuclear events

From TDE rates to BH demographics

Yao+2023a



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BH mass function (BHMF)

Low-mass dearth:

Not sensitive to TDEs with $L_{\rm bb} < 10^{43}$ erg/s and off-nuclear events

- Future surveys (i.e., VRO, *ULTRASAT*), ~10^3 TDEs (including sub-luminous events)
- Understand host galaxy preferences (observation & theory)
- Combine different populations of TDEs (selection in X-ray, UV/optical, IR & radio)

Summary

TDEs

Jetted

Four objects known

AT2022cmc

NuSTAR/NICER/Swift observations: X-ray is a broken power-law
→ a **synchrotron** origin of the jet **prompt** emission

Non-jetted Optical sample (**ZTF**): 33 TDEs from 3 yr

AT2021ehb (X-ray brightest)

Late-time **corona** formation, thick-to-thin state transition
NuSTAR+NICER: evidence of **relativistic reflection**

TDE **demography**

luminosity function: broken power-law
Favor a flat black hole mass function ($10^5\,M_\odot < M_{\rm BH} < 10^7\,M_\odot$)

TDE optical light curves

Yao+2023a