NewAthena Webinar, 2026, April 28th

The eROSITA Population of Tidal Disruption Events

Arne Rau (MPE)

w/ P. Baldini, I. Grotova, A. Merloni (all MPE), A. Malyali (now private sector), Z. Liu (now Univ. of Hertfordshire), & many more

I - Tidal Disruption Events (TDEs)
II - eROSITA as a TDE discovery machine
III - Example Discoveries

Chapter I -
Tidal Disruption Events

Short History of TDEs before eROSITA

- Prediction from theory (Hills 75, Frank & Rees 76, Rees 88, …)
  - soft (~100eV) thermal transient lasting weeks to years with a decay following the fall back rate

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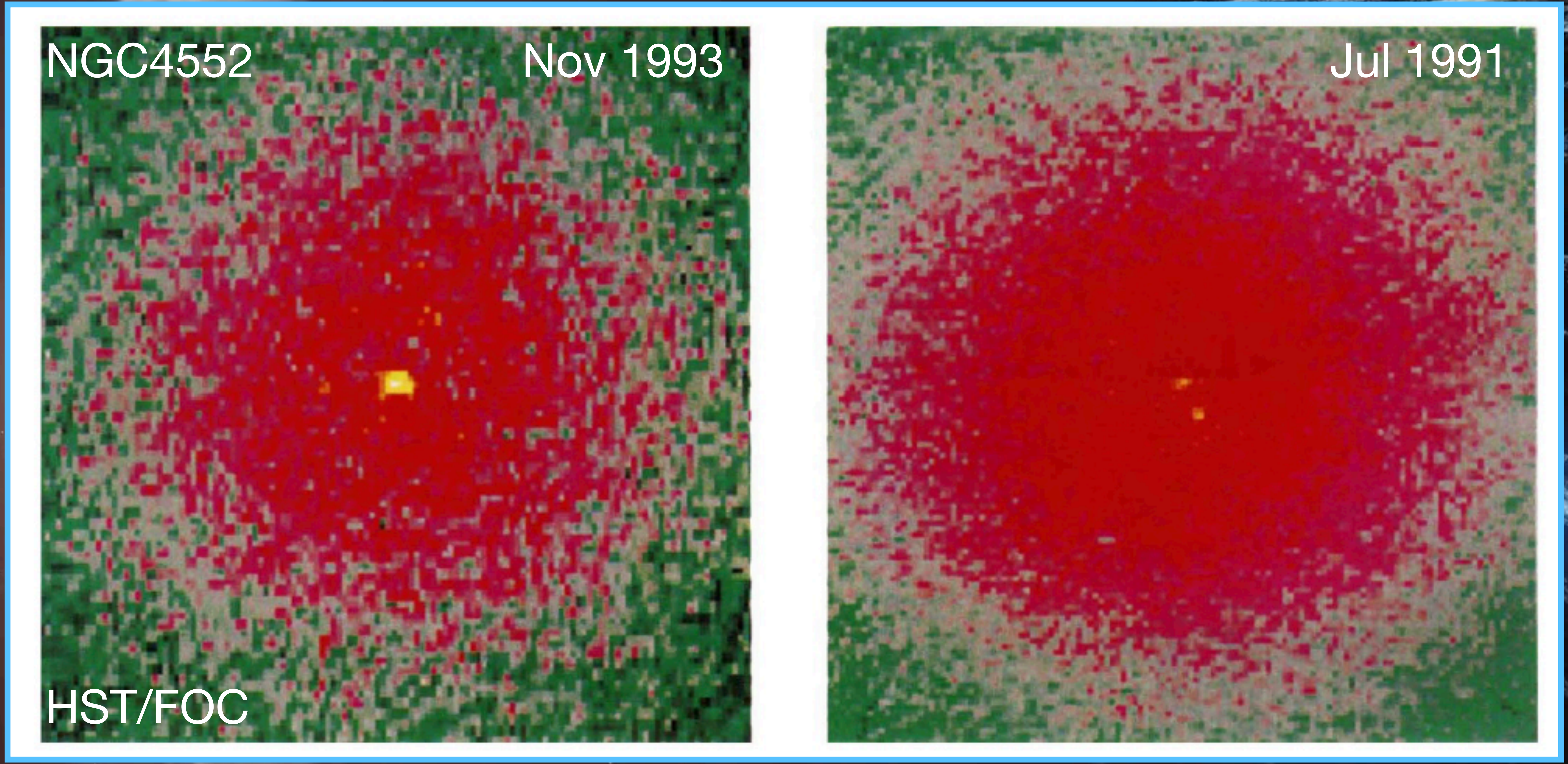

(Renzini+95)

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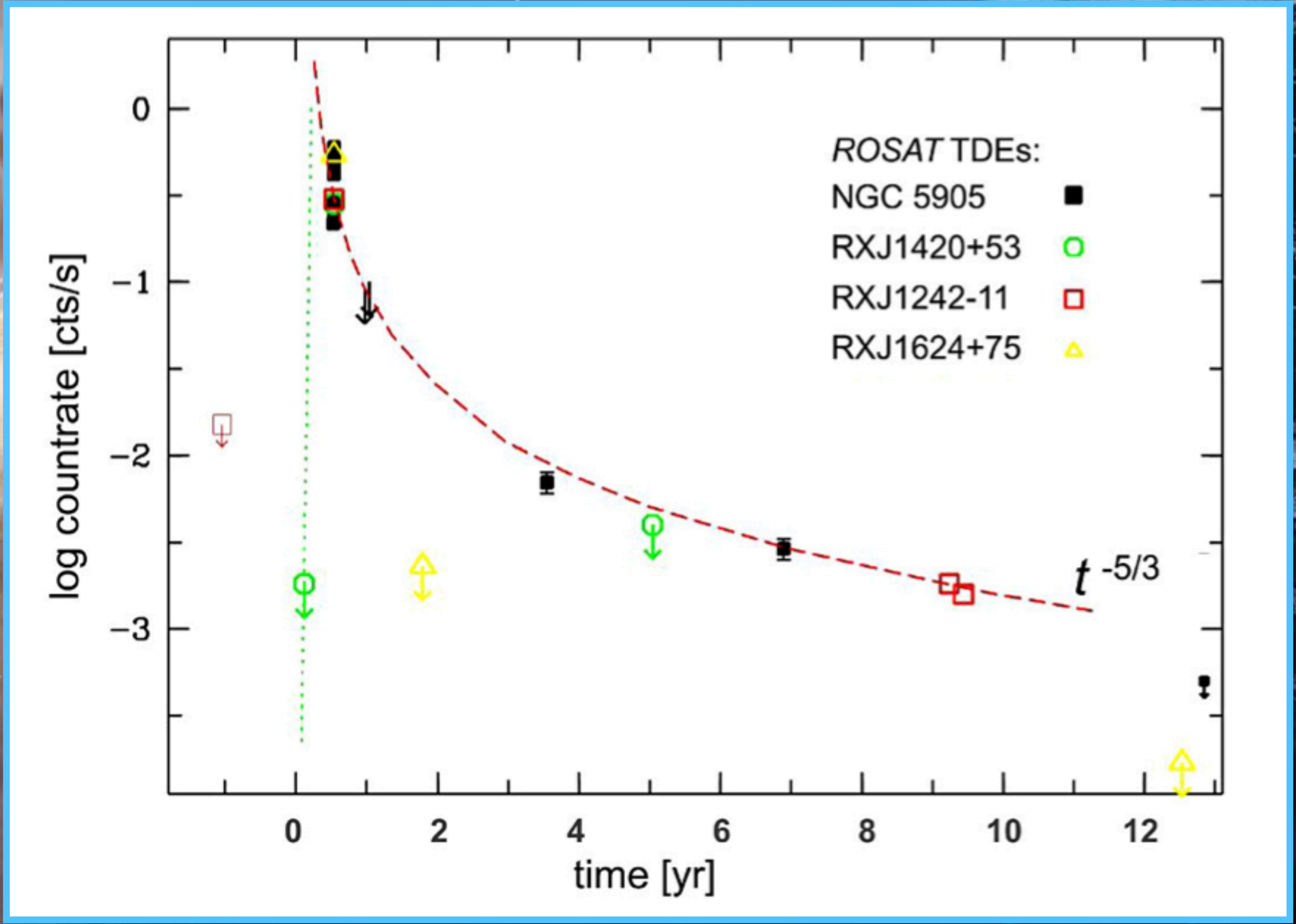

(Komossa 2015)

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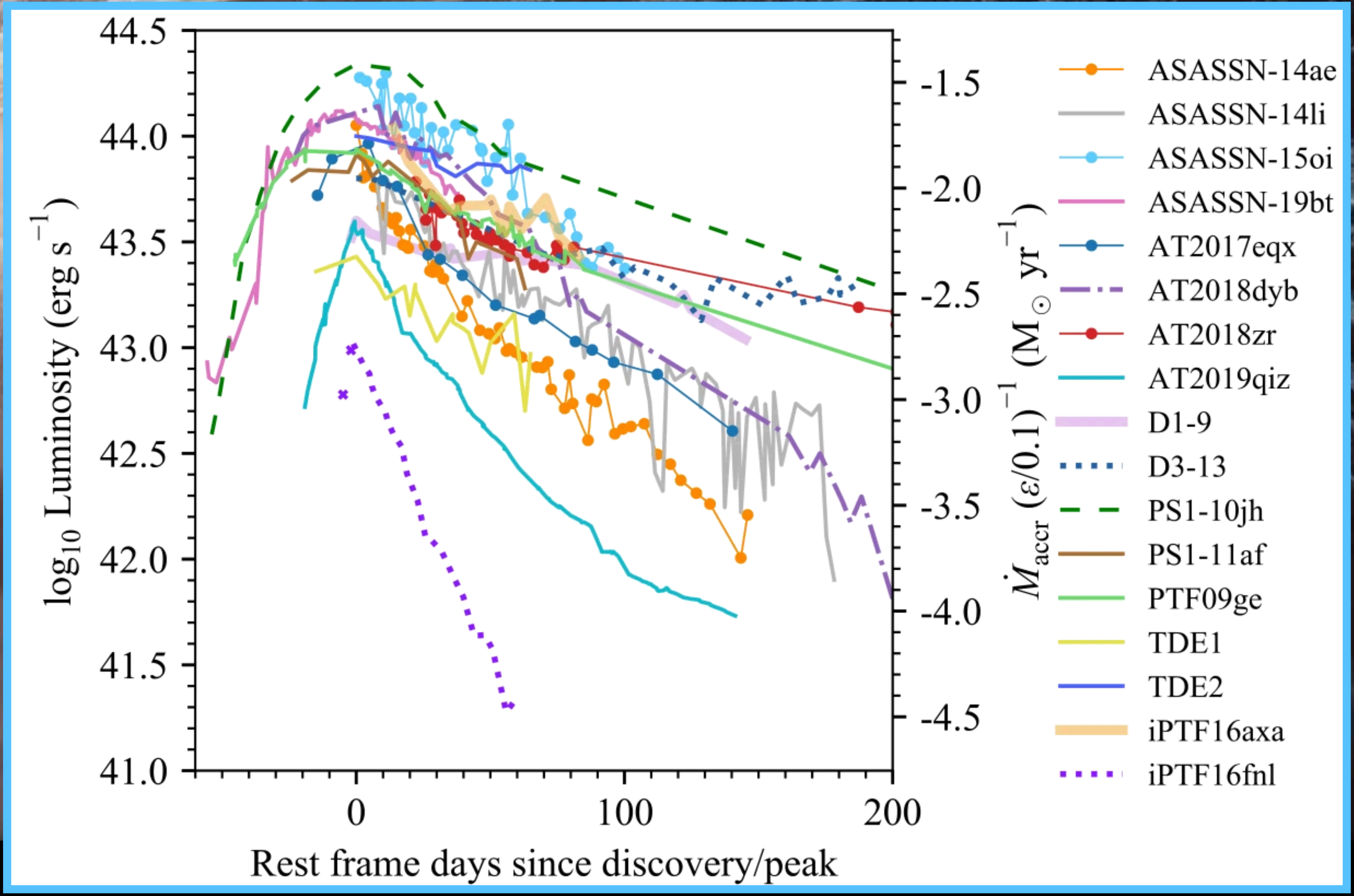
- ROSAT (e.g., Bade+96, Grupe+99, Komossa & Bade 99, Greiner+00, …)
- GALEX (Gezari+06,08,09)
- SDSS (e.g., Komossa+09, van Velzen+11, Wang+12)
- XMM, Swift, Chandra (e.g., Saxton+12,17, Bloom+11, Cenko+12, Maksym+10,13)
- PTF, ASAS-SN, ATLAS, PS, ZTF (e.g., Arcavi+14, Holoien+14,16,19, van Velzen+21)



(van Velzen 2020)

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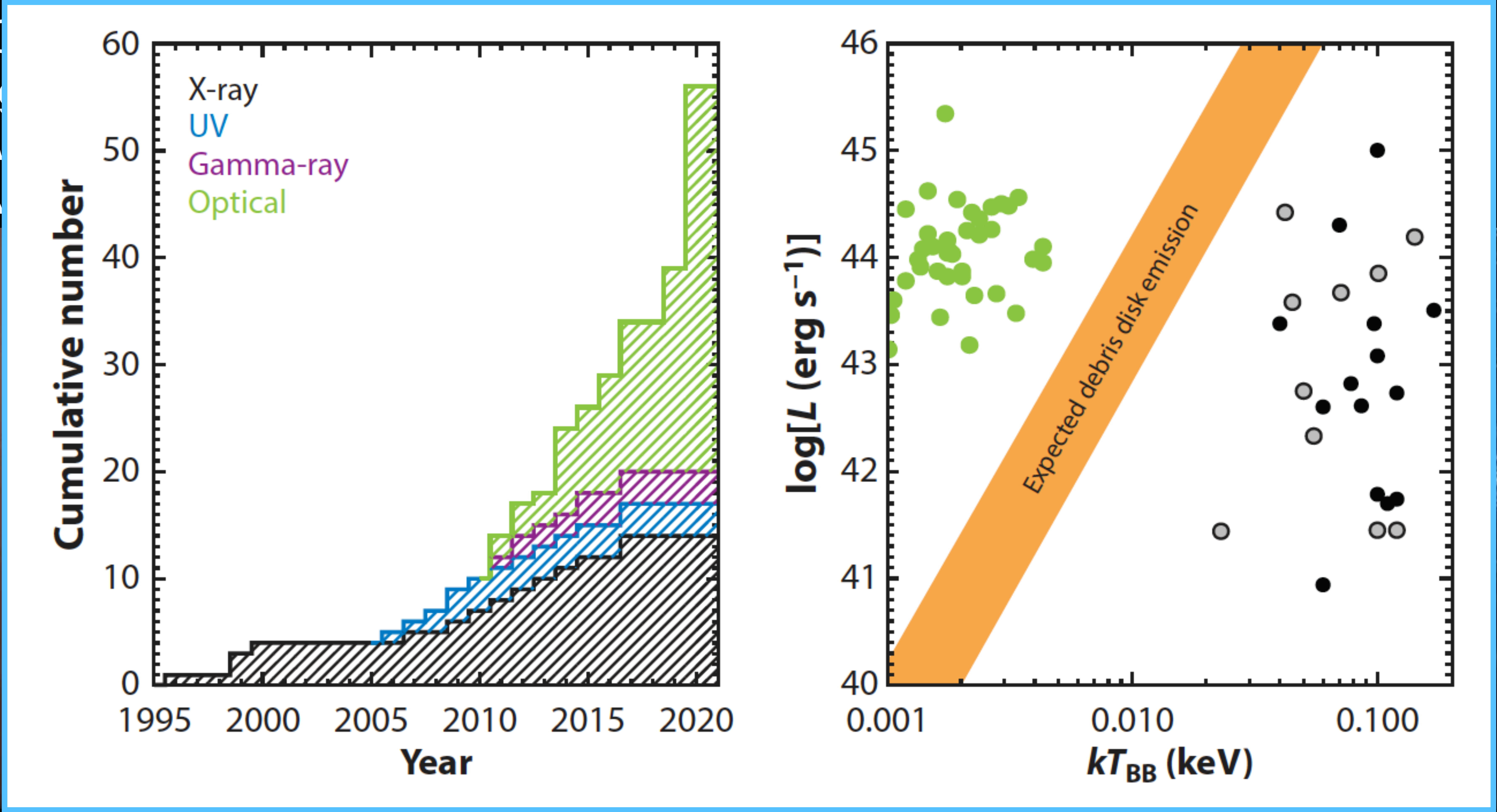
- XMM, Sw
- PTF, ASA

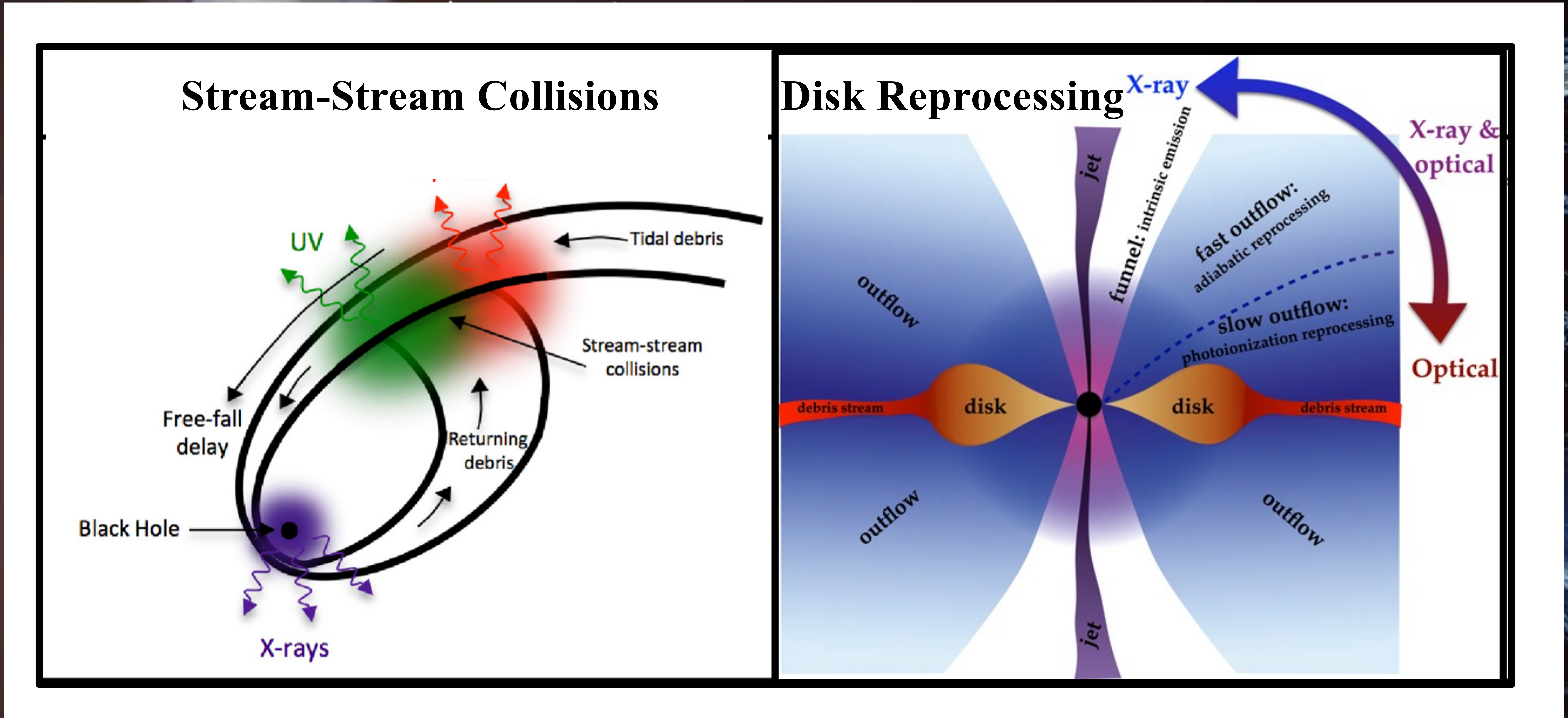


(Gezari 2021)

TDEs are physics laboratories …

What powers the X-ray and UV/optical emission?

Two Families of Models



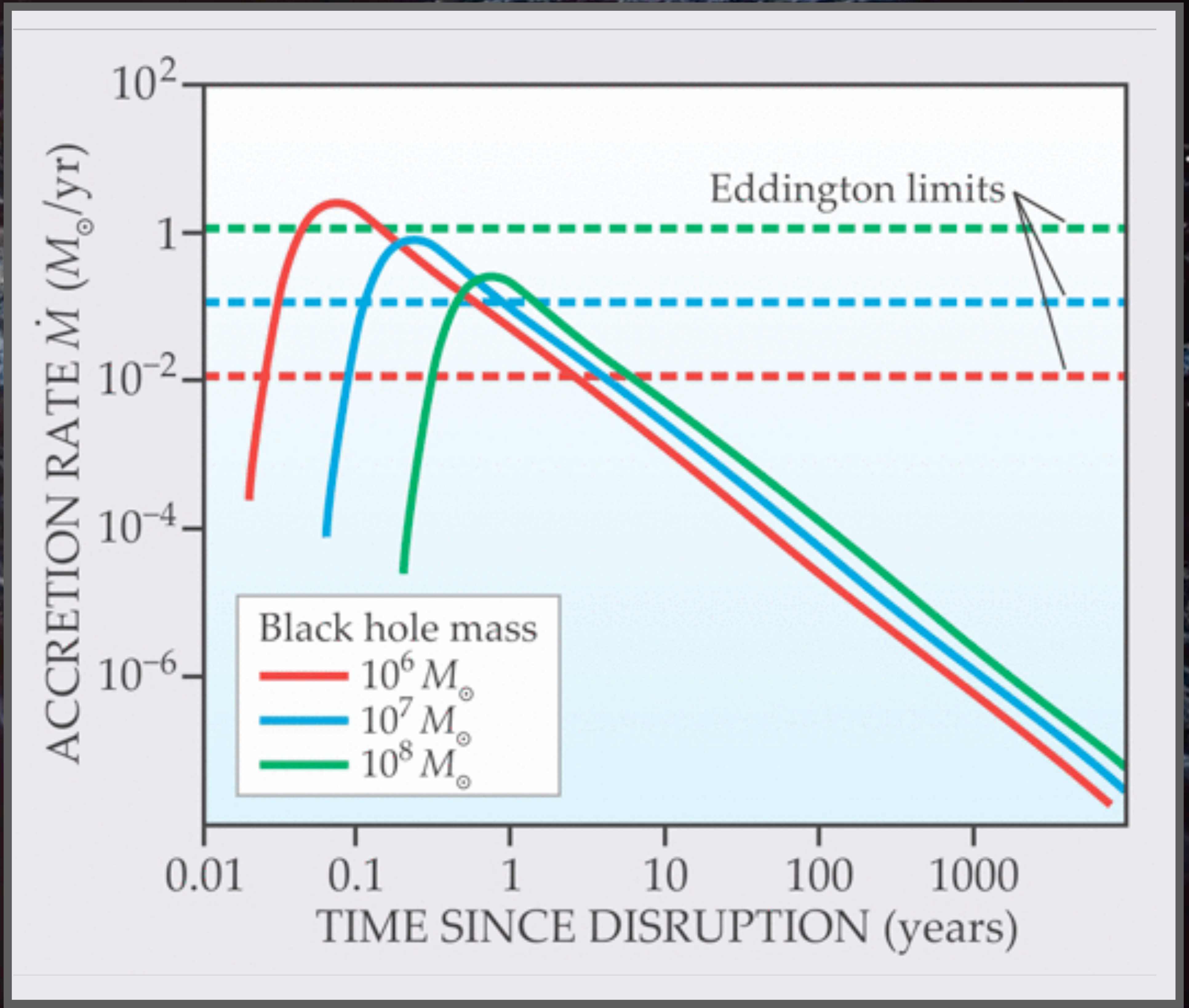
Circularization of Debris
Piran+ (2015), Jiang,Guillochon, & Loeb (2016),..

Reprocessing Envelope
Loeb & Ulmer (1997), Guillochon+ (2014), …

TDEs are physics laboratories …

… and probes of the nuclear regions of galaxies

(Gezari+ 2014)



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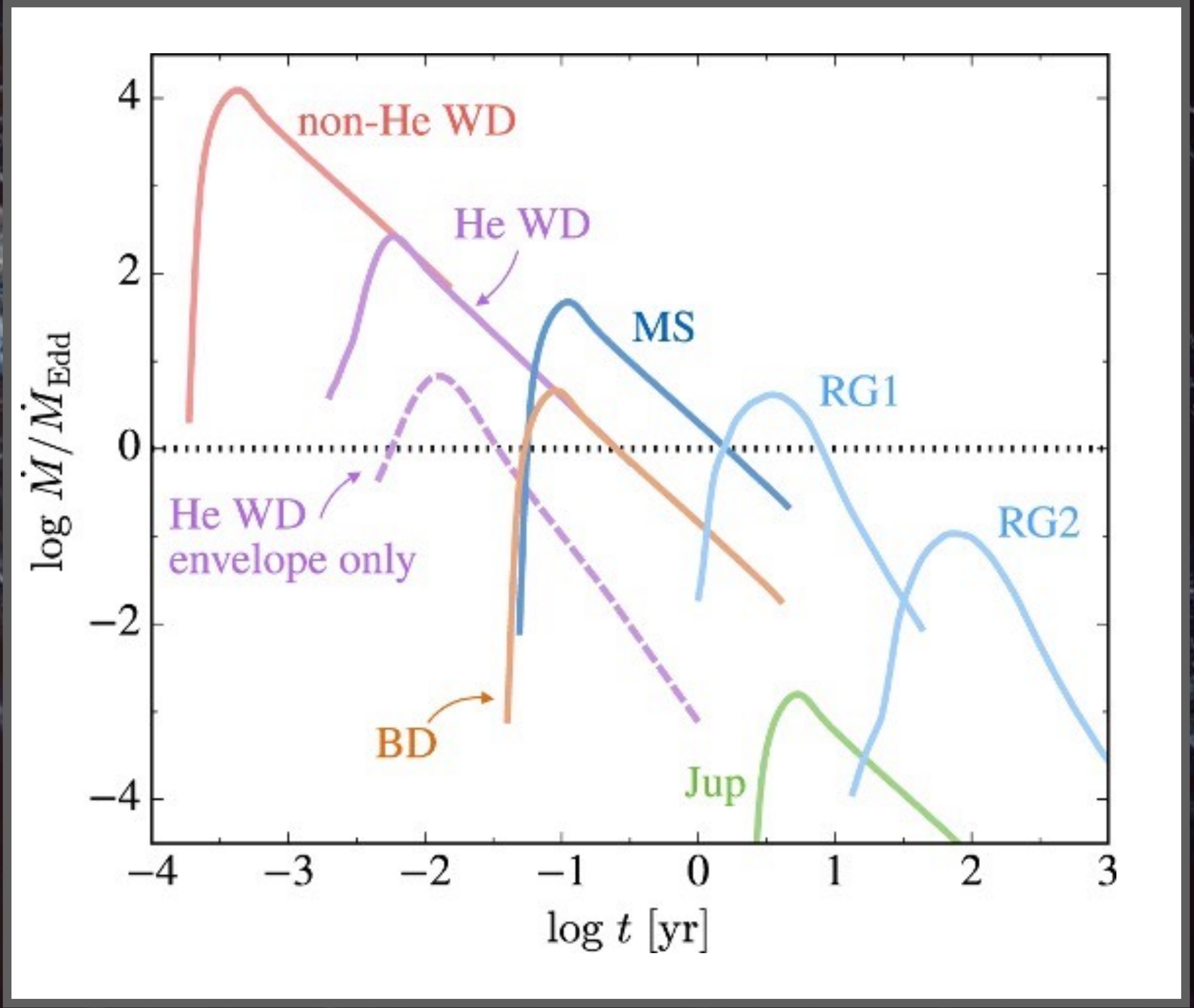
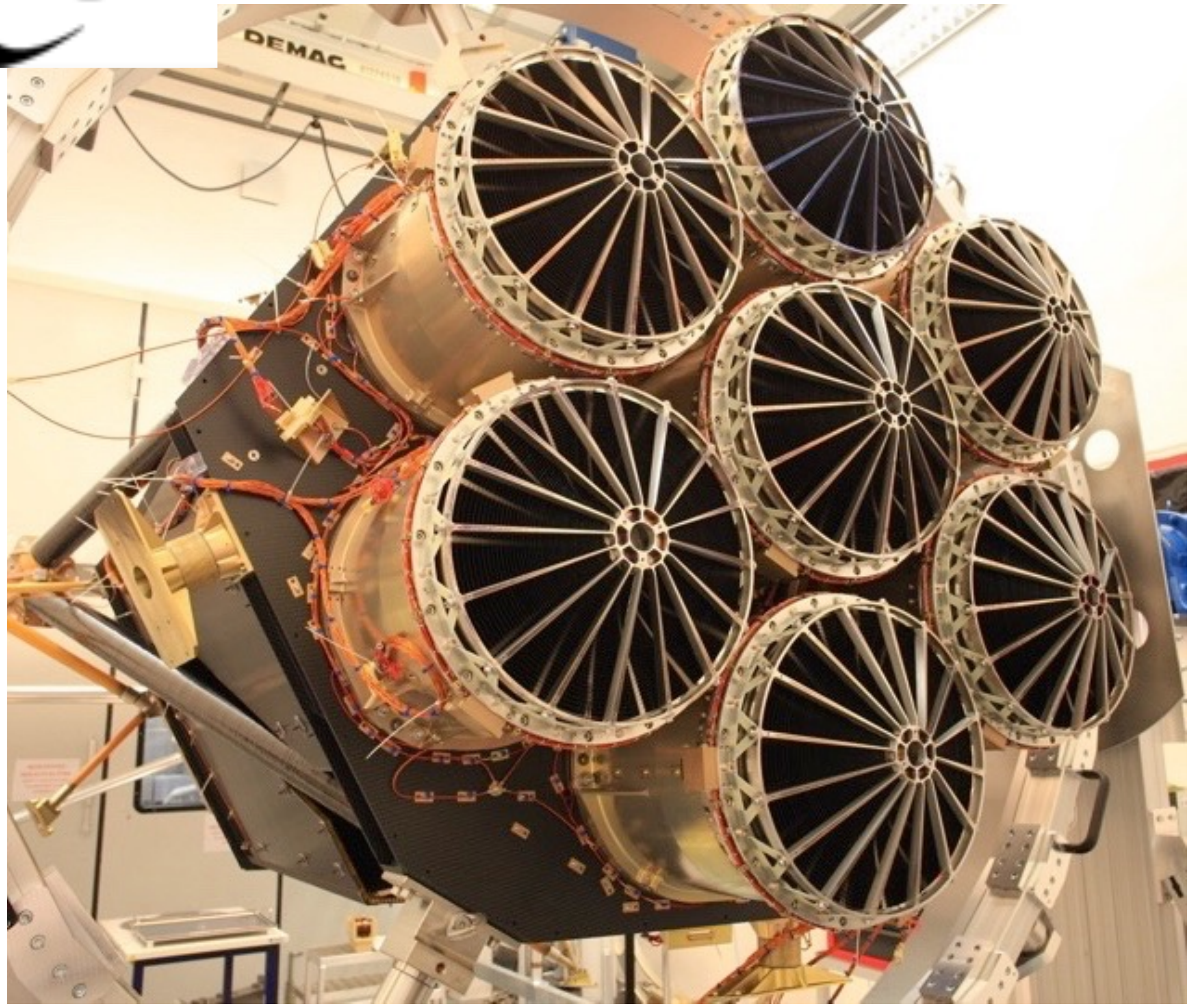
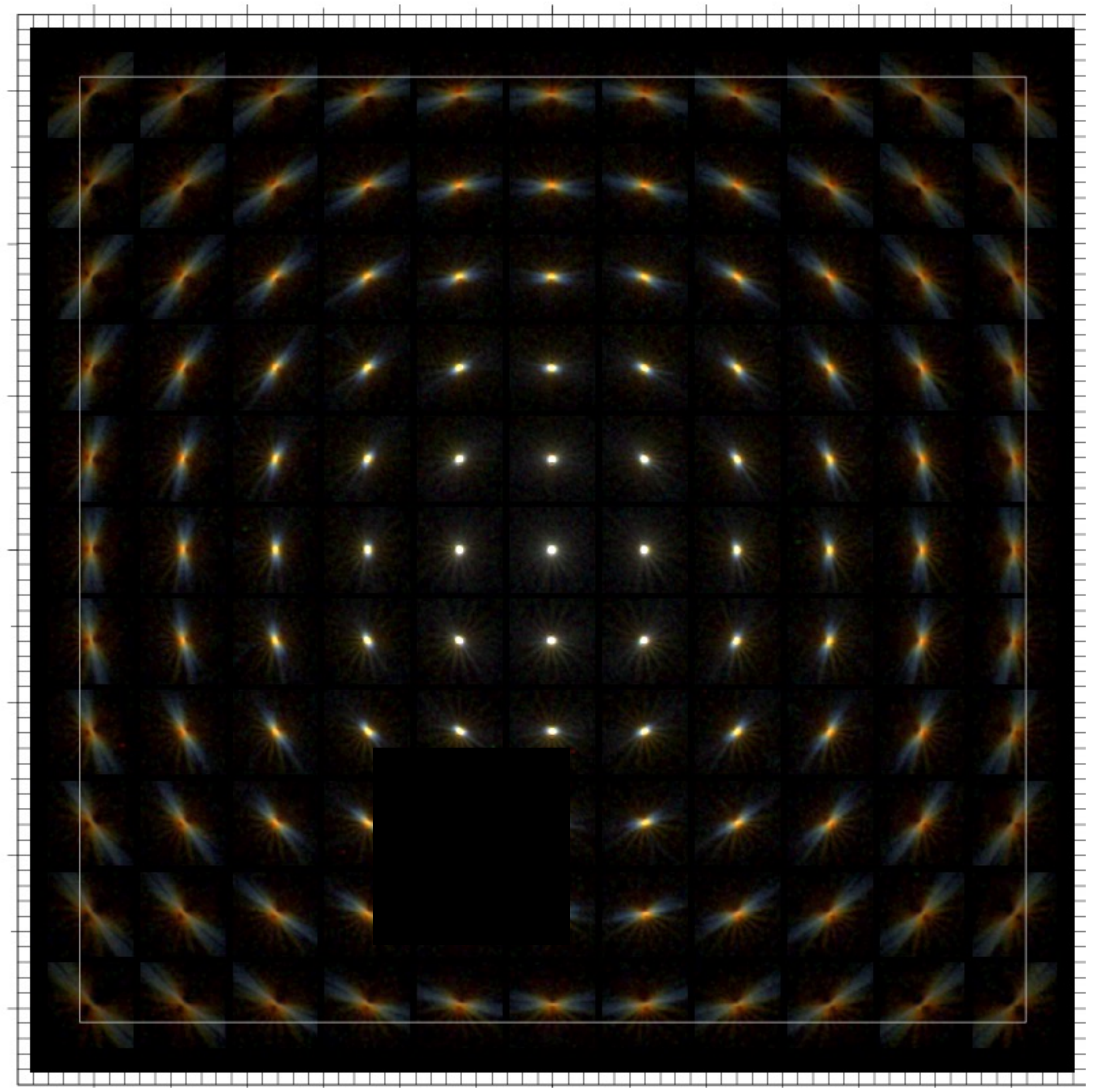
(Law-Smith+ 2017)

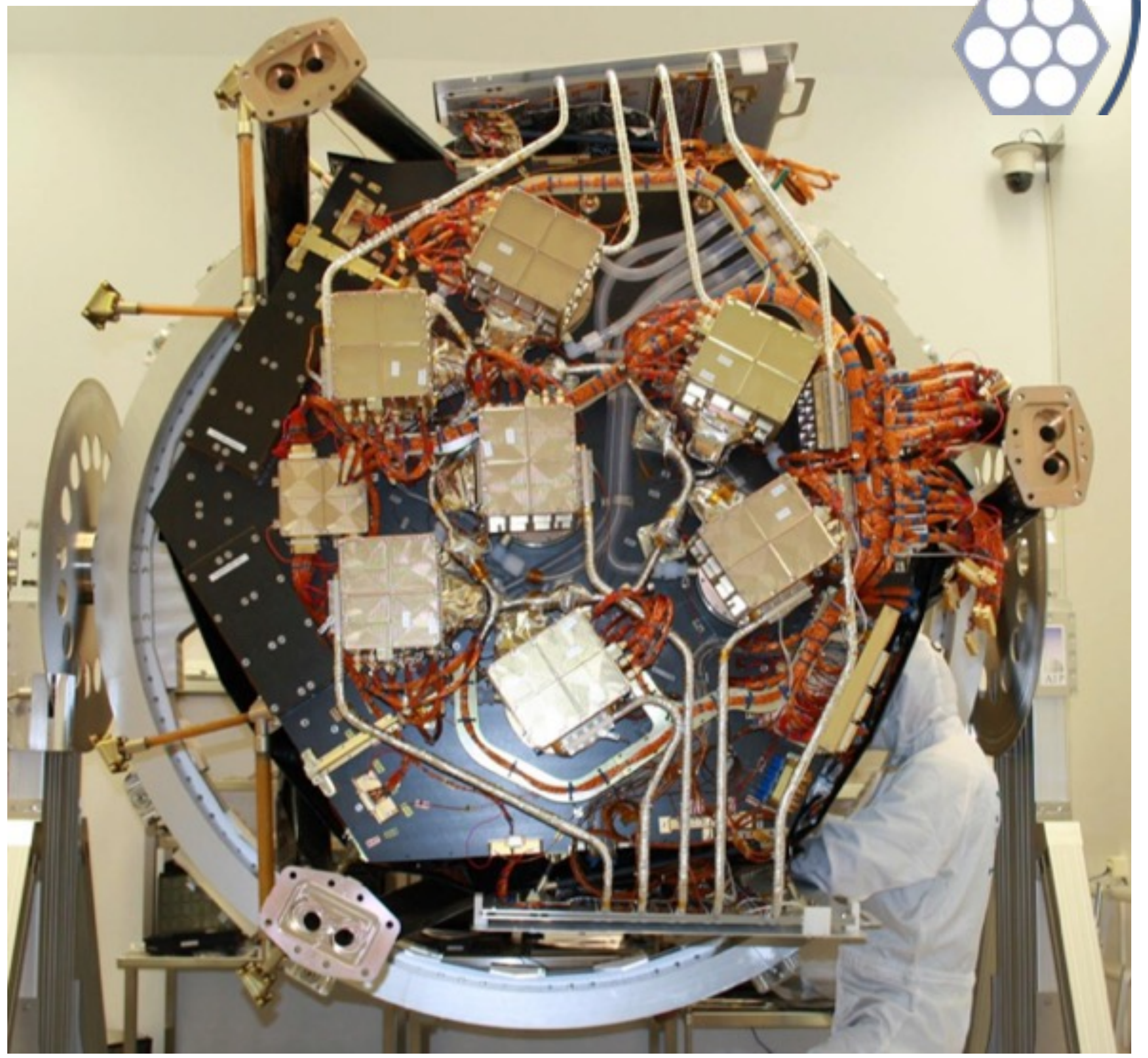


Chapter II -
eROSITA as a TDE discovery machine

eROSITA on SRG [Predehl et al. 2021]





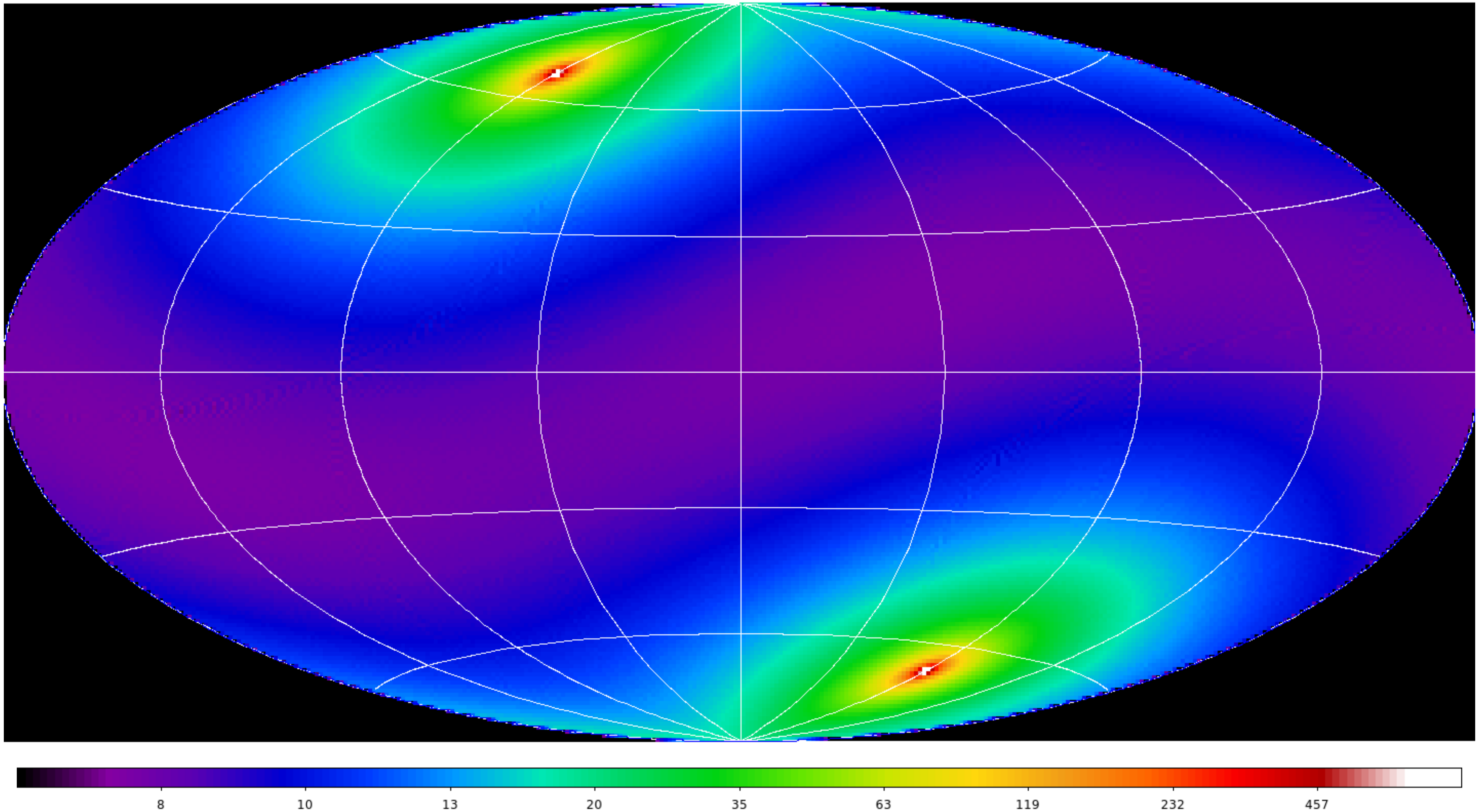


- Large Effective area (~**1300 cm^2 @1keV**, ~XMM-Newton)
- Large Field of view: **1 degree (diameter)**
- Half-Energy width **(HEW) ~18" (on-axis, point.); ~30" (FoV avg., survey)**
  - **Positional accuracy: ~4.5" (1σ)**
- X-ray baffle: **92% stray light reduction**
- pnCCD with framestore: 384x384x7~10^6 pixels (9.4"), no chip gaps, no 'out of time' events,
- **Spectral resolution** at all measured energies within specs (**~80eV @1.5keV**)

(Slide from A. Merloni)


The mirror systems collect
high-energy photons and fo
them on the CCD X-ray cam
DLR

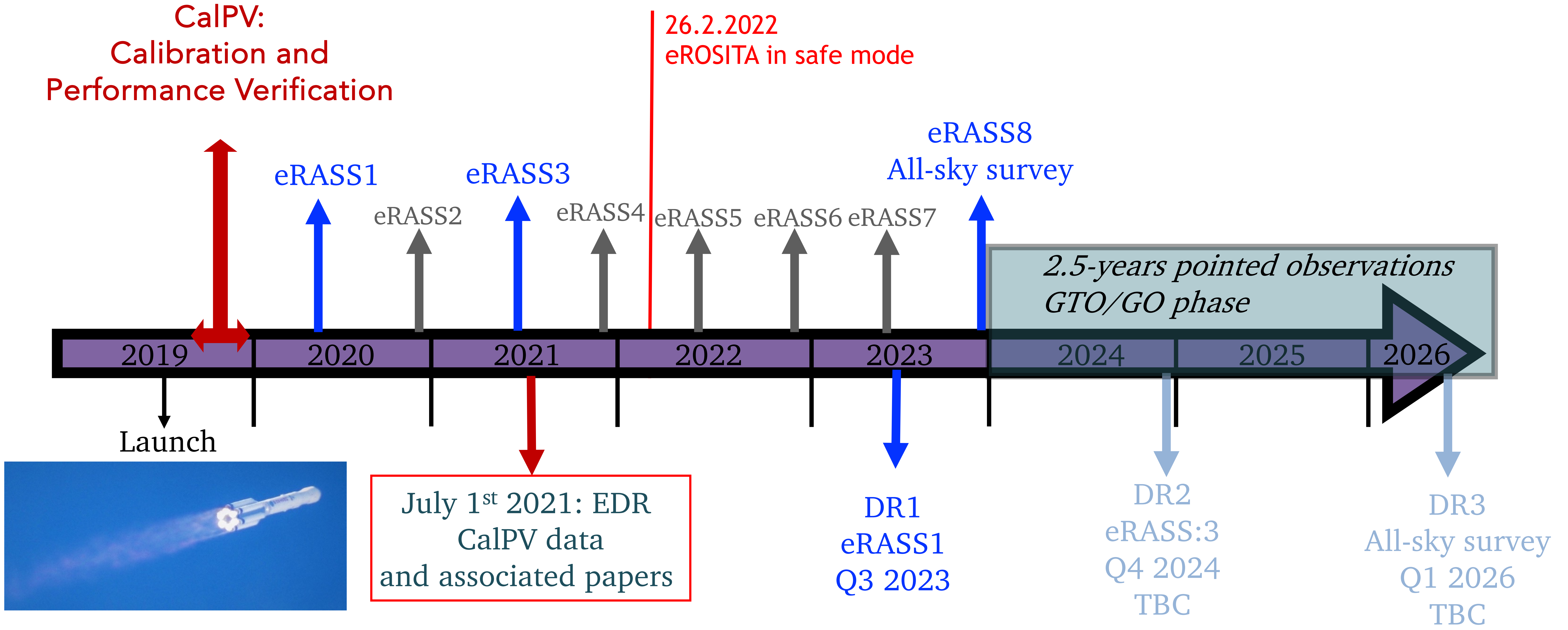
eROSITA: visits at sky position



- Over 4 yrs - 8-500 visits depending on sky position.
- Each visit consists of ~6 subsequent passes with ~40s exposure every 4hrs

SRG Programmatics

eRASS = eROSITA All-Sky Survey



- Early Data Release (EDR) in 2021: several fields, including eFEDS mini-survey
- DR1 on 31.1.2024
- DR2 (eRASS:3) in July 2026

(Slide adopted from A. Merloni)

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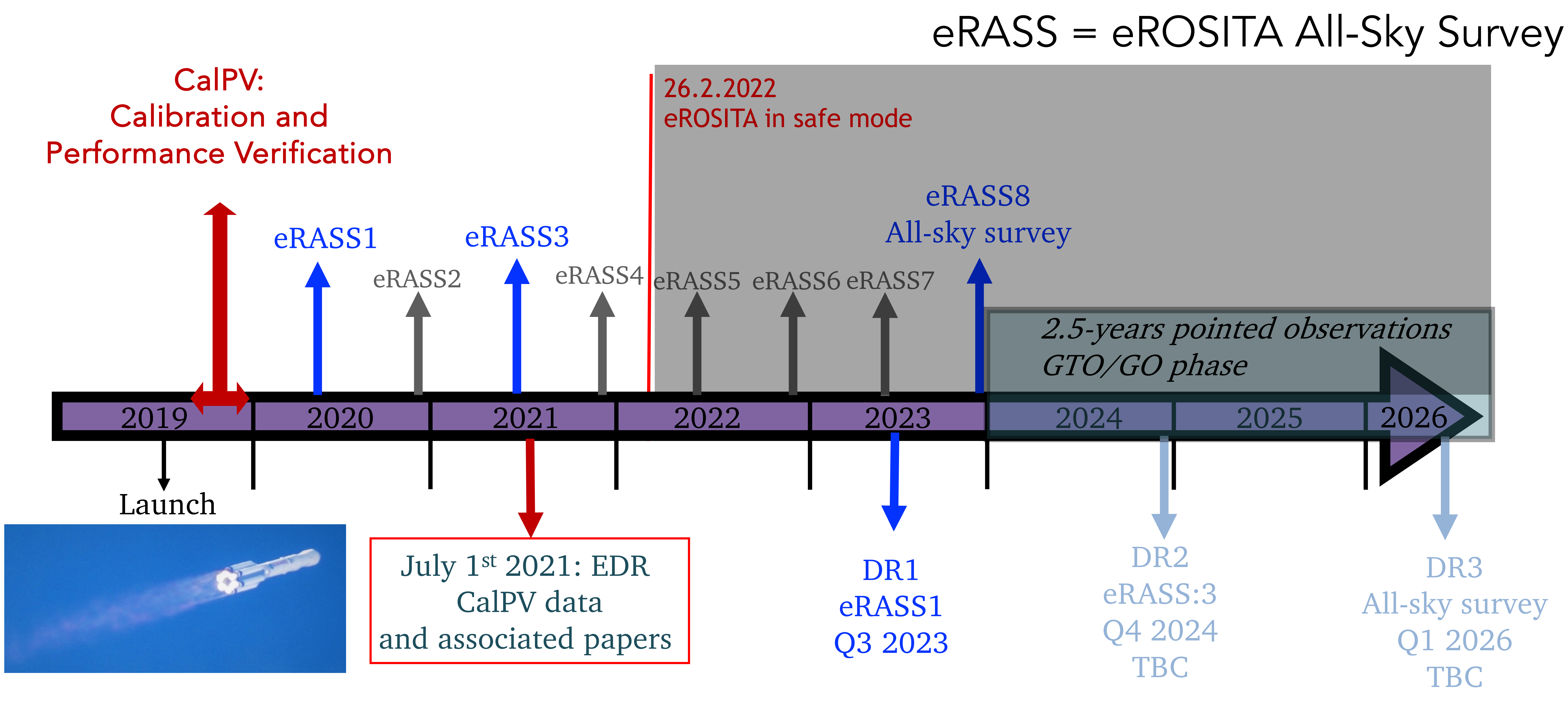

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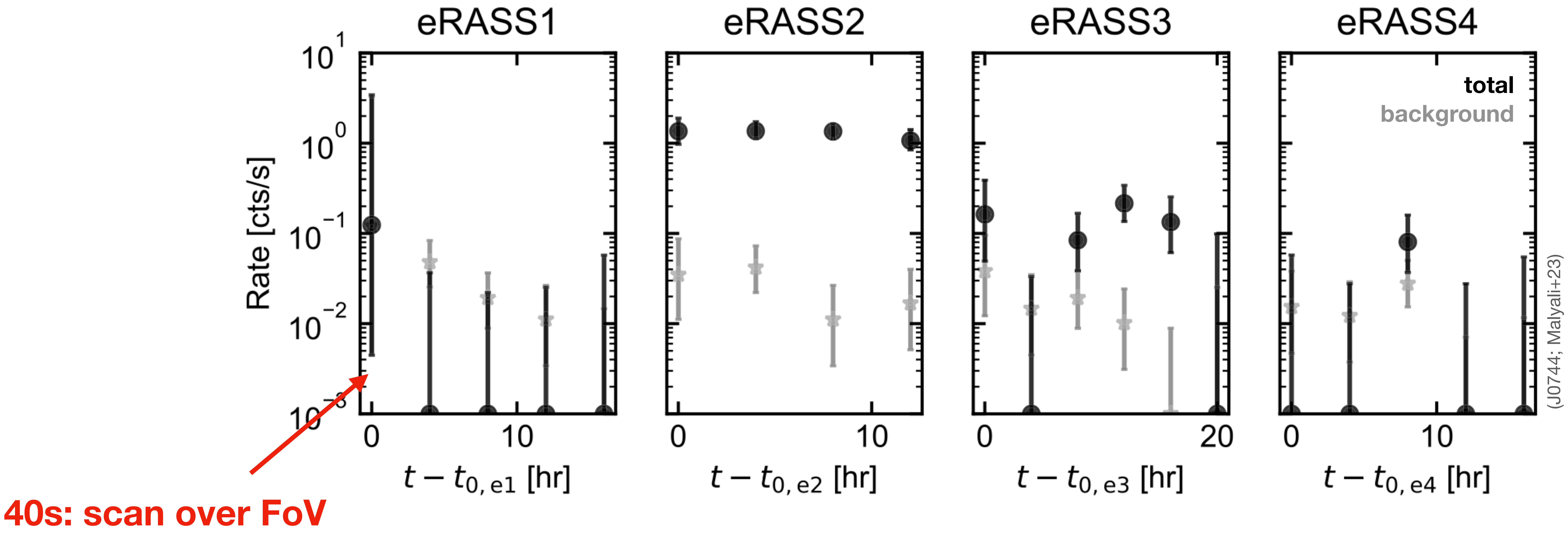
(Slide adopted from A. Merloni)

eROSITA's time domain capabilities during its 4.3 all-sky surveys (Dec'19- Feb '22)

(For more details on SRG/eROSITA (e.g., Predehl+21, Merloni+23))



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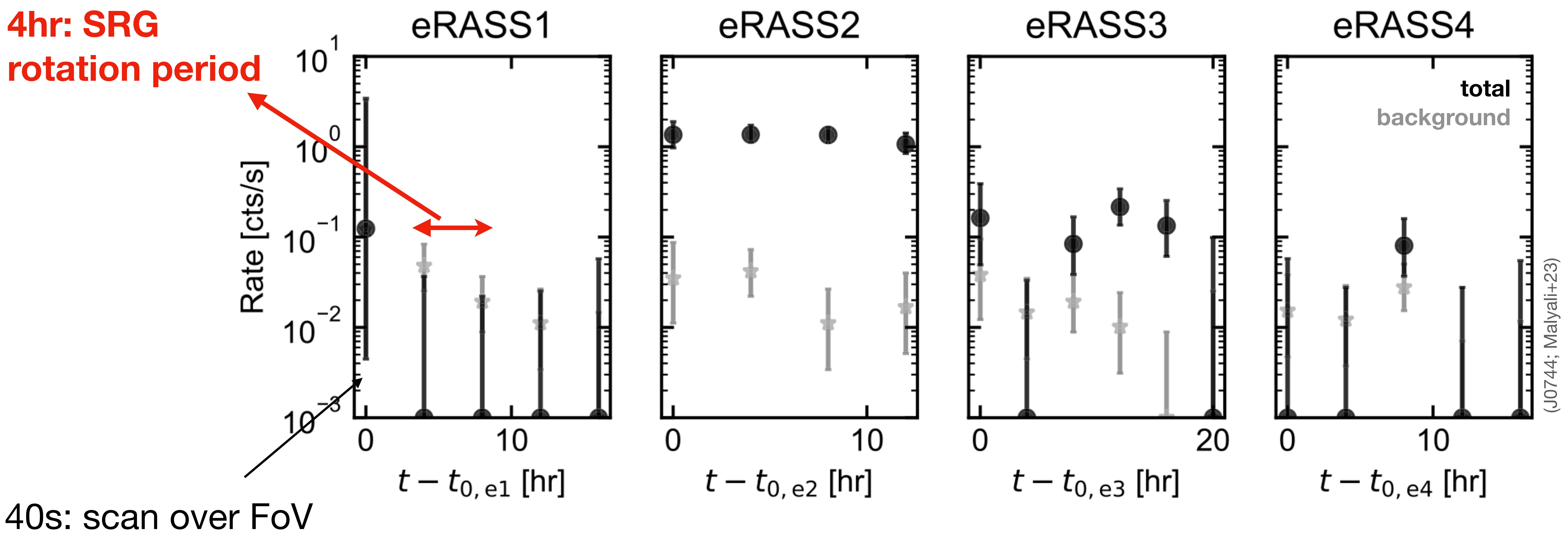

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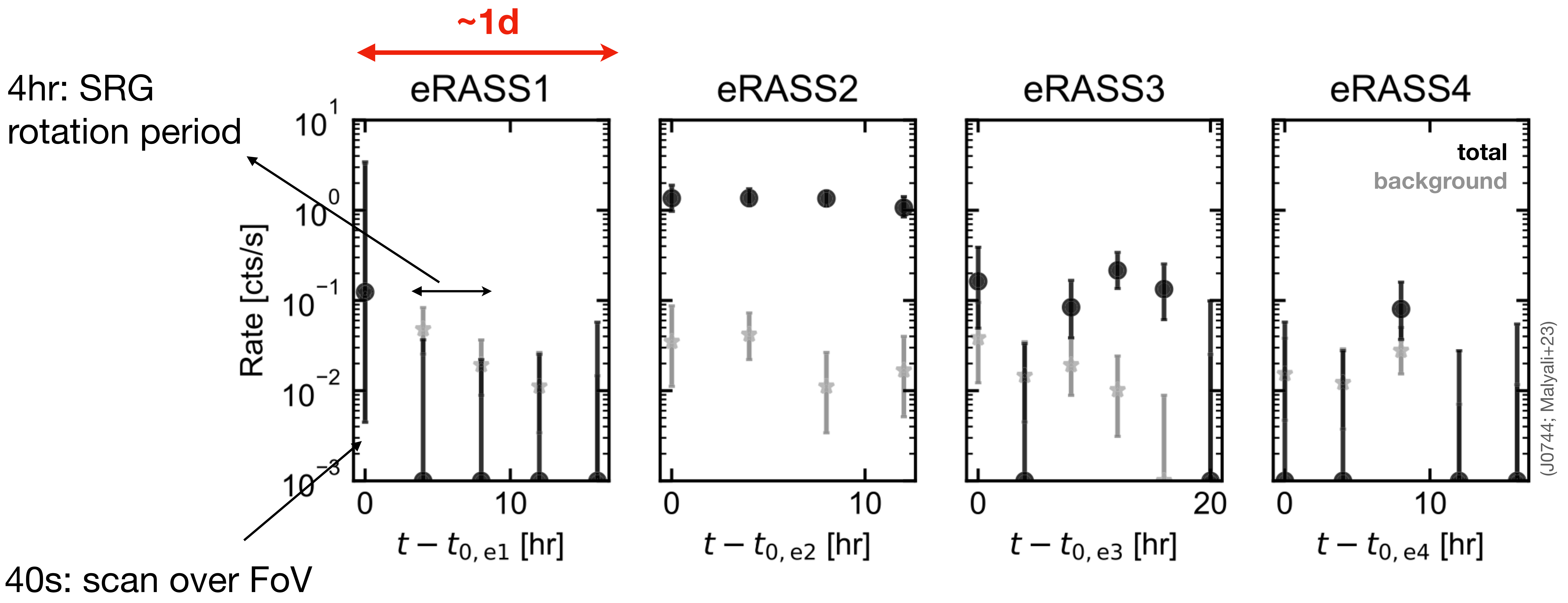

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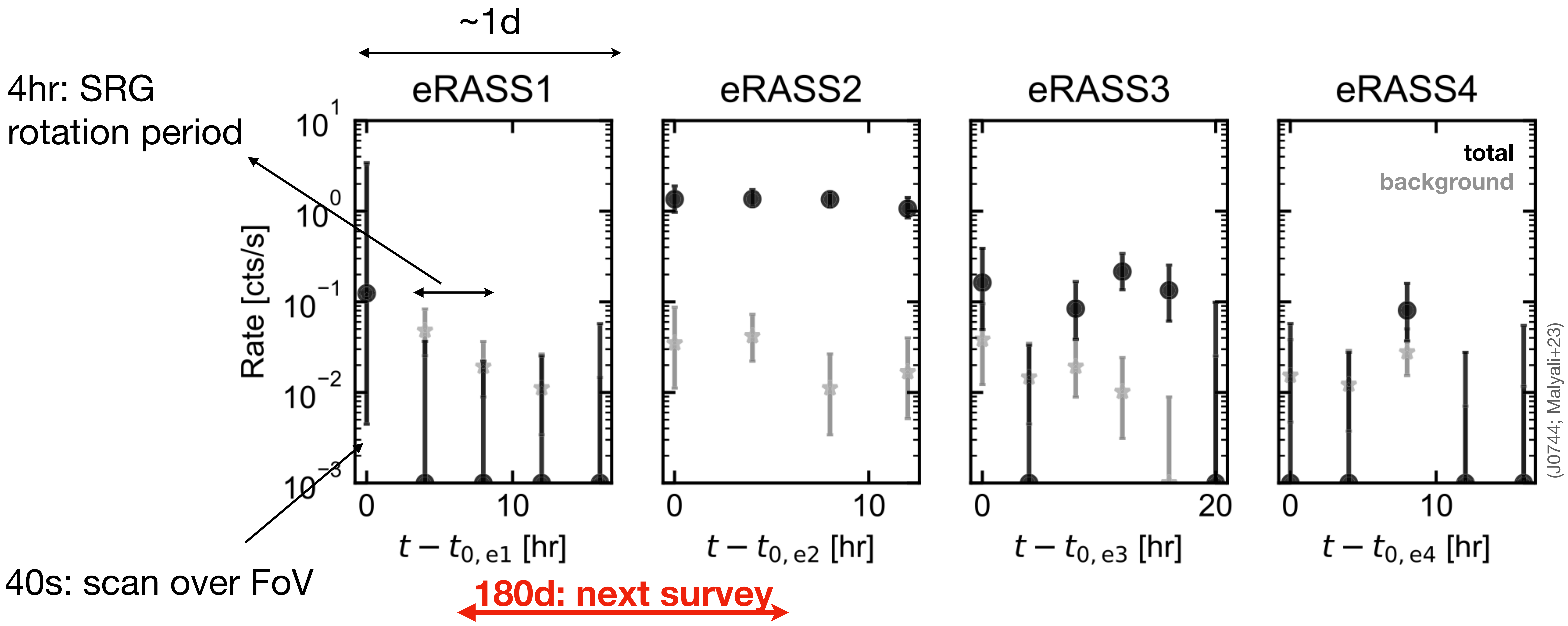

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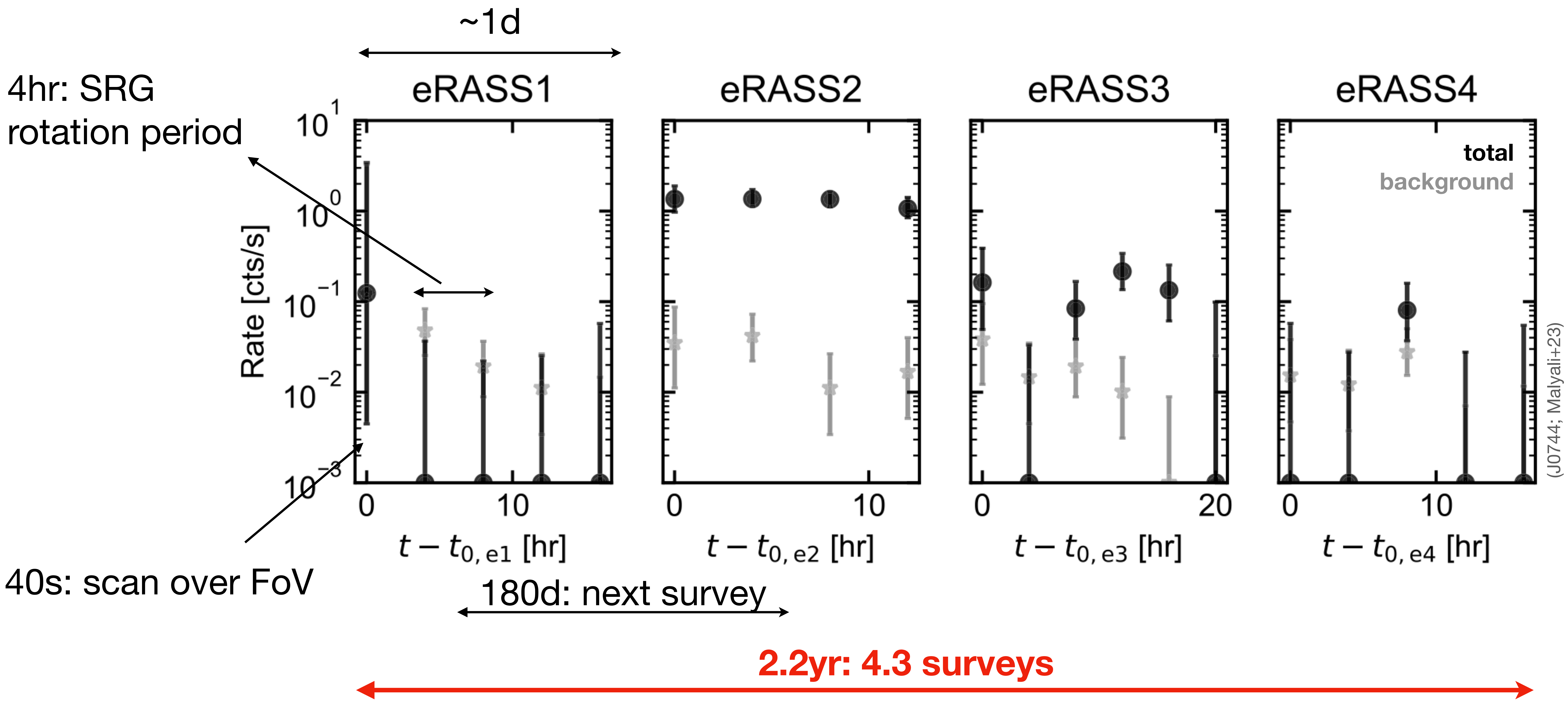

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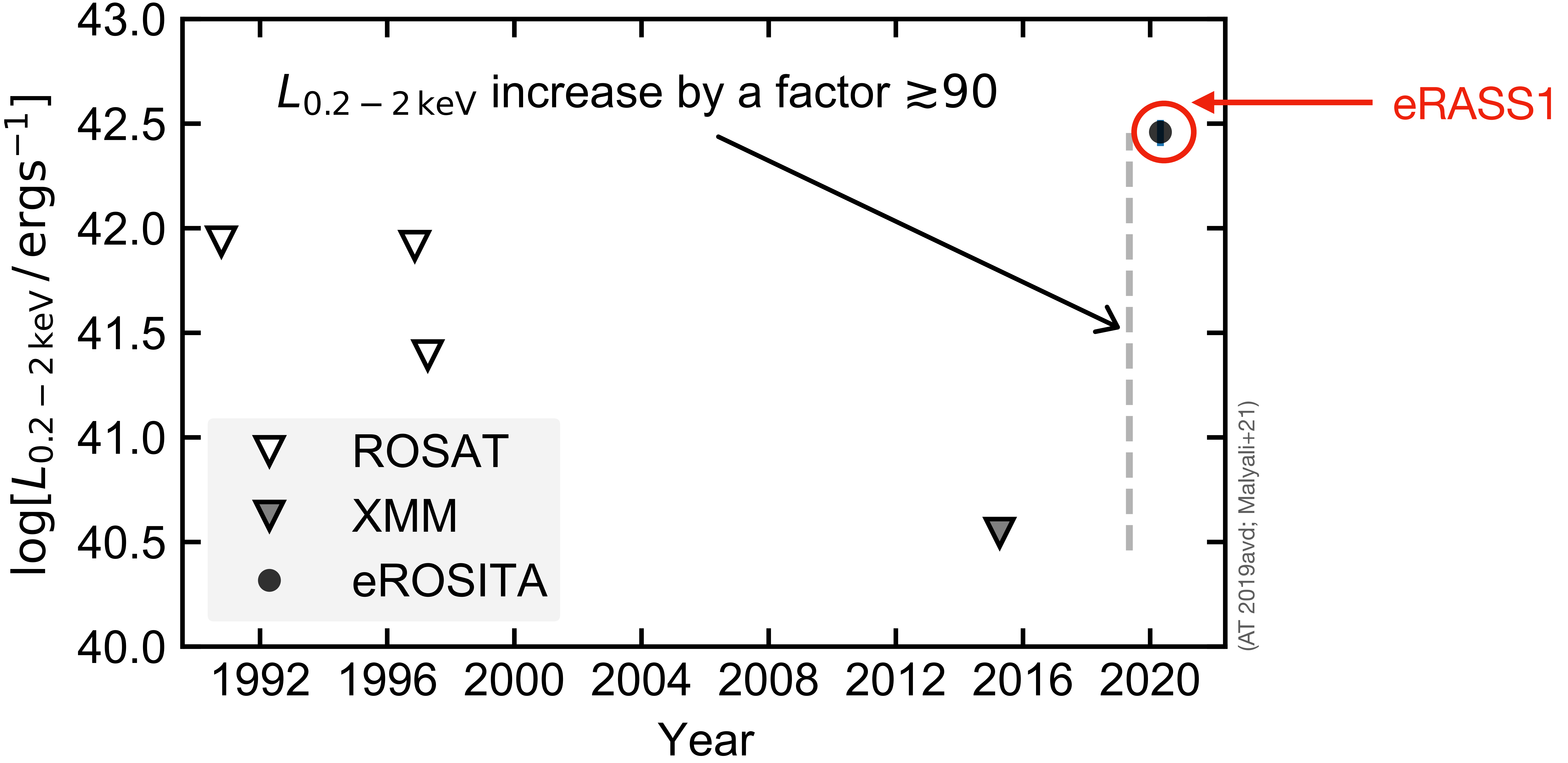
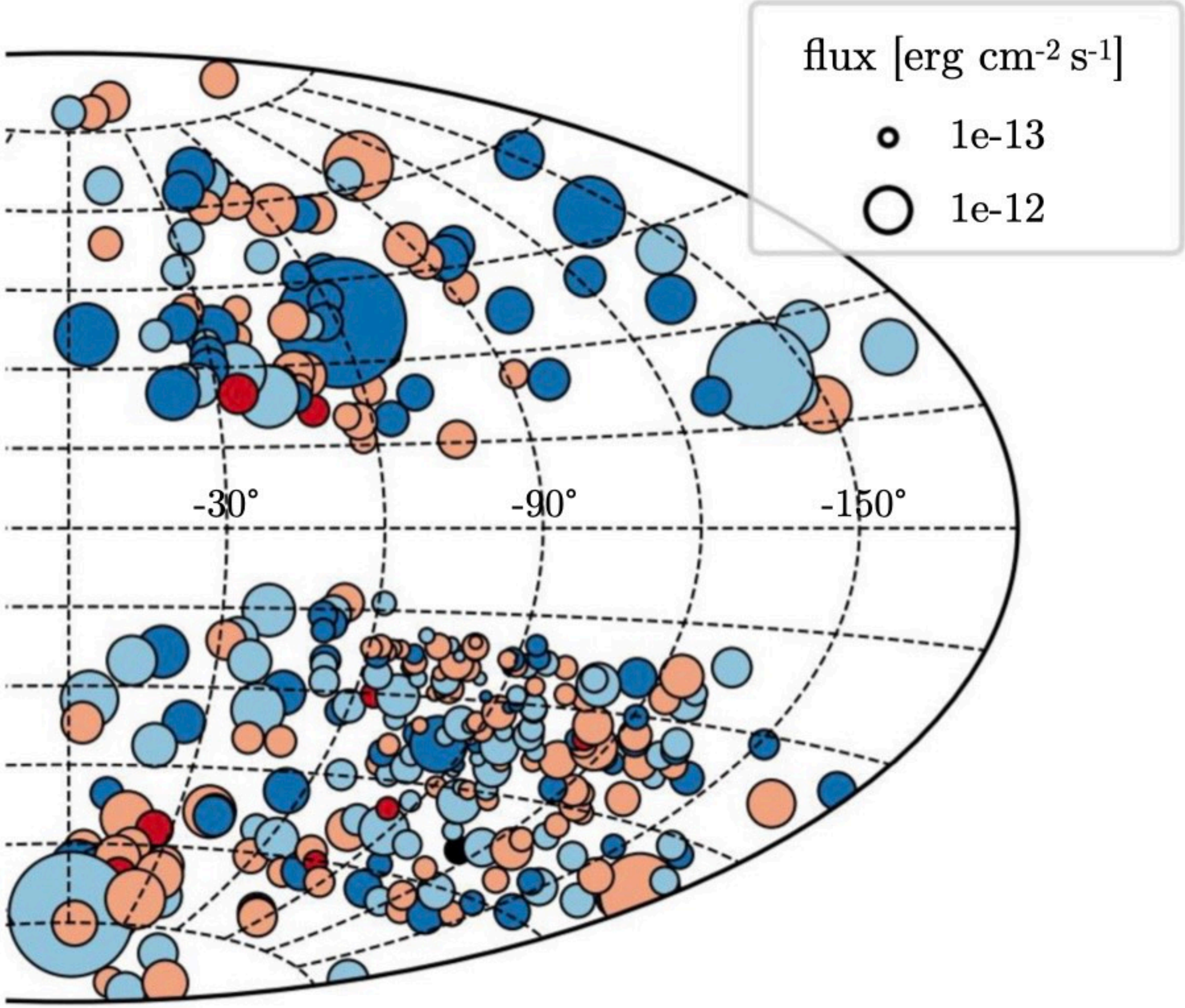


1-30yr: comparison with XMM and other missions

… And as baseline for the next X-ray surveys

TDE Selection & Population Study

Systematic selection of TDEs



Parent catalog: **eRO-ExTra**
Grotova,AR+2025a

- **304 transients and variables** from 1st & 2nd eROSITA all-sky surveys (Dec 2019 - Dec 2020) with amplitude > 4
- Extragalactic and non-AGN
- **Optical Counterparts** from Legacy Survey DR10 with redshifts
- X-ray lightcurve (eROSITA 2 or 2.5 years + archival) and spectral analysis

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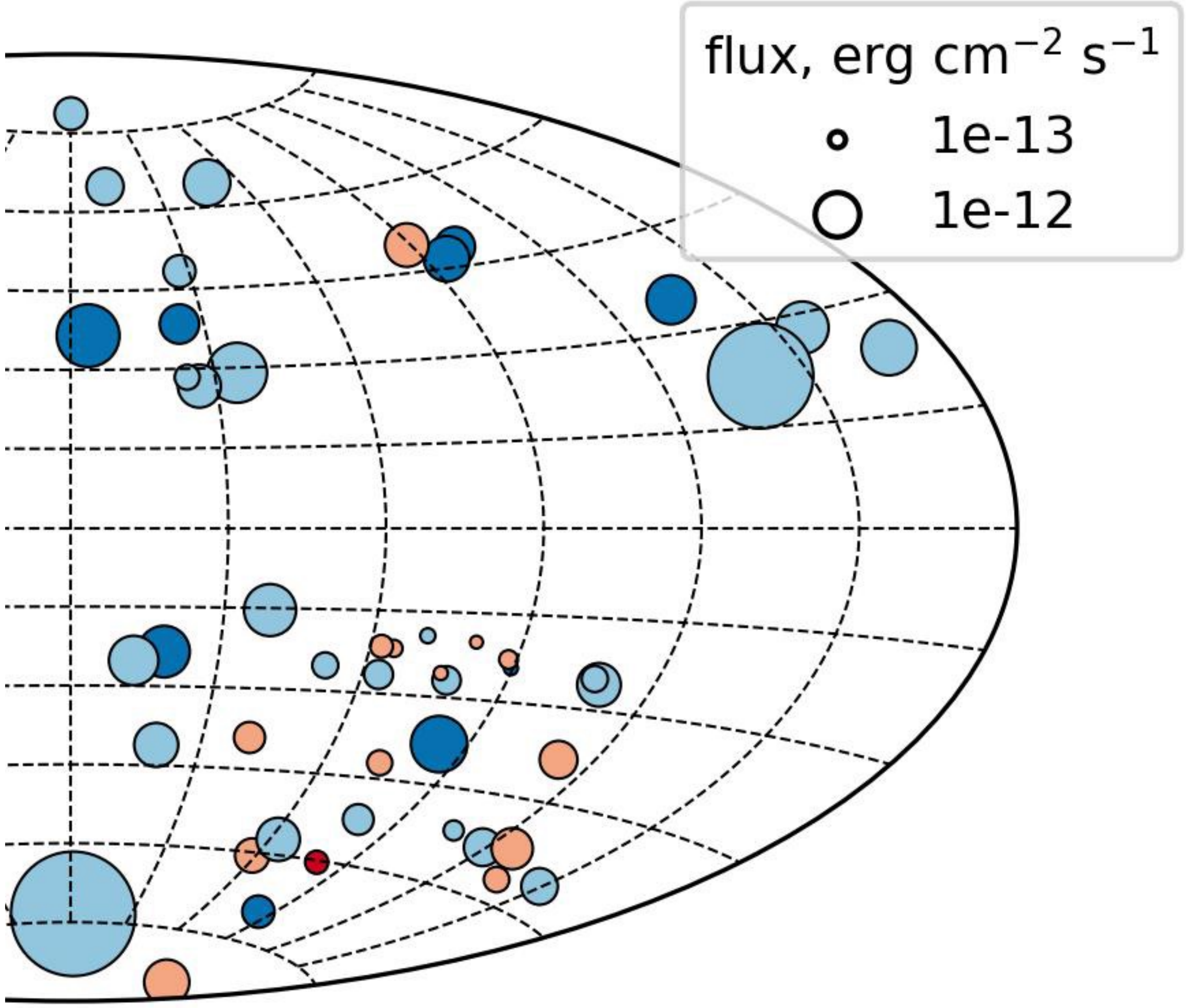

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Canonical TDE sample:

- Soft ($\Gamma > 3$)

Grotova,AR+2025b

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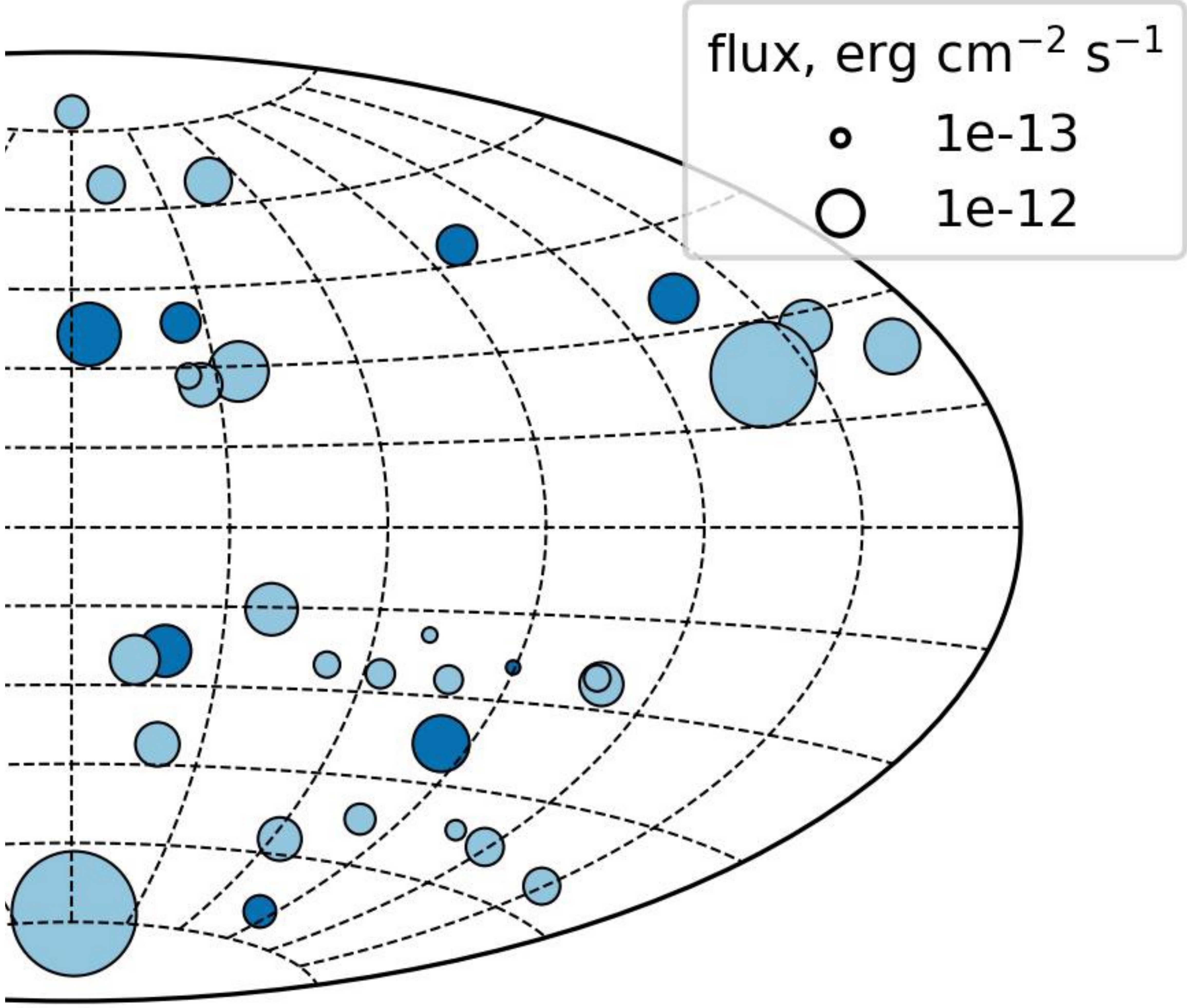

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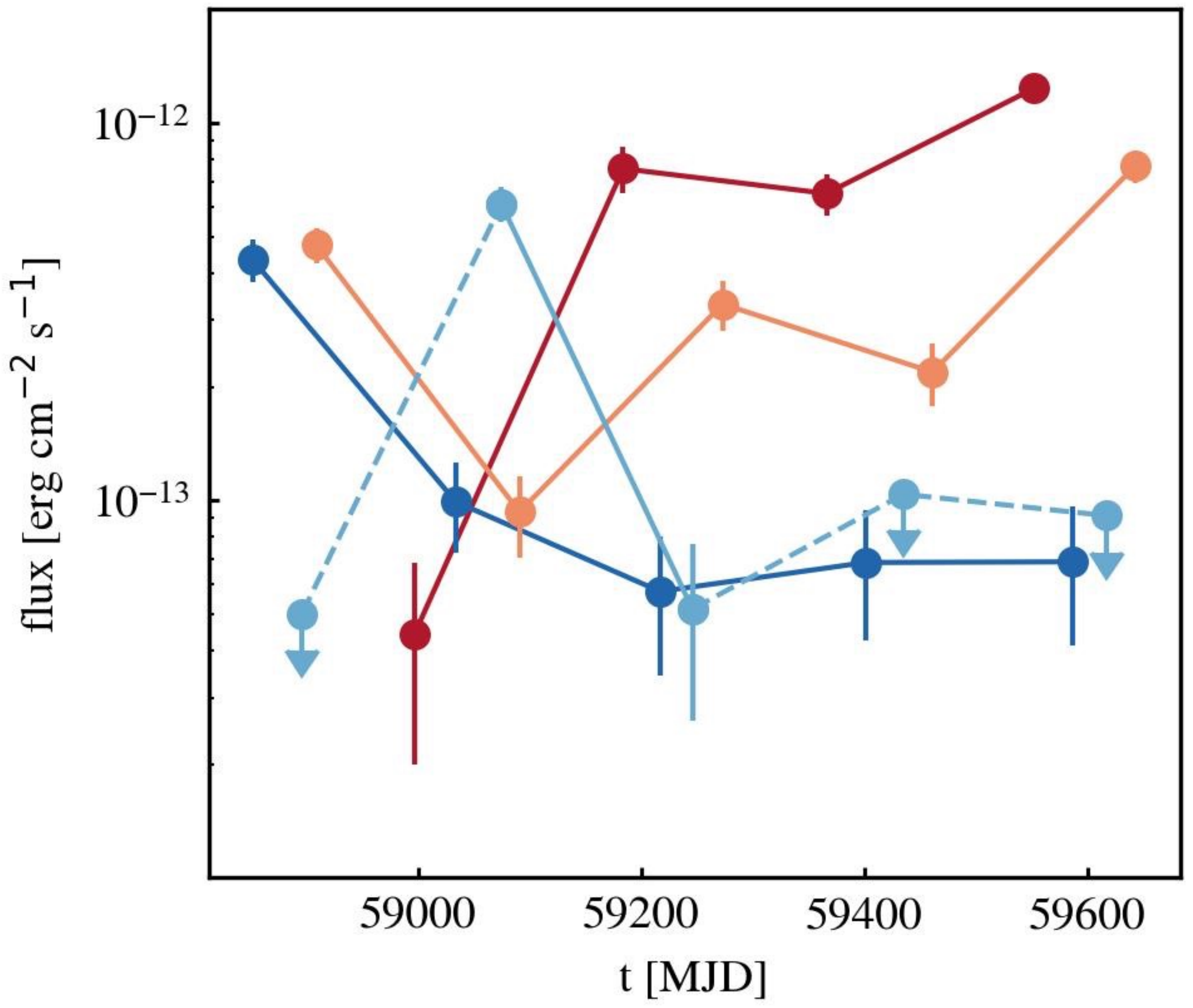
Canonical TDE sample:

- Soft ($\Gamma > 3$)
- Decaying or flaring
- Quiescent host

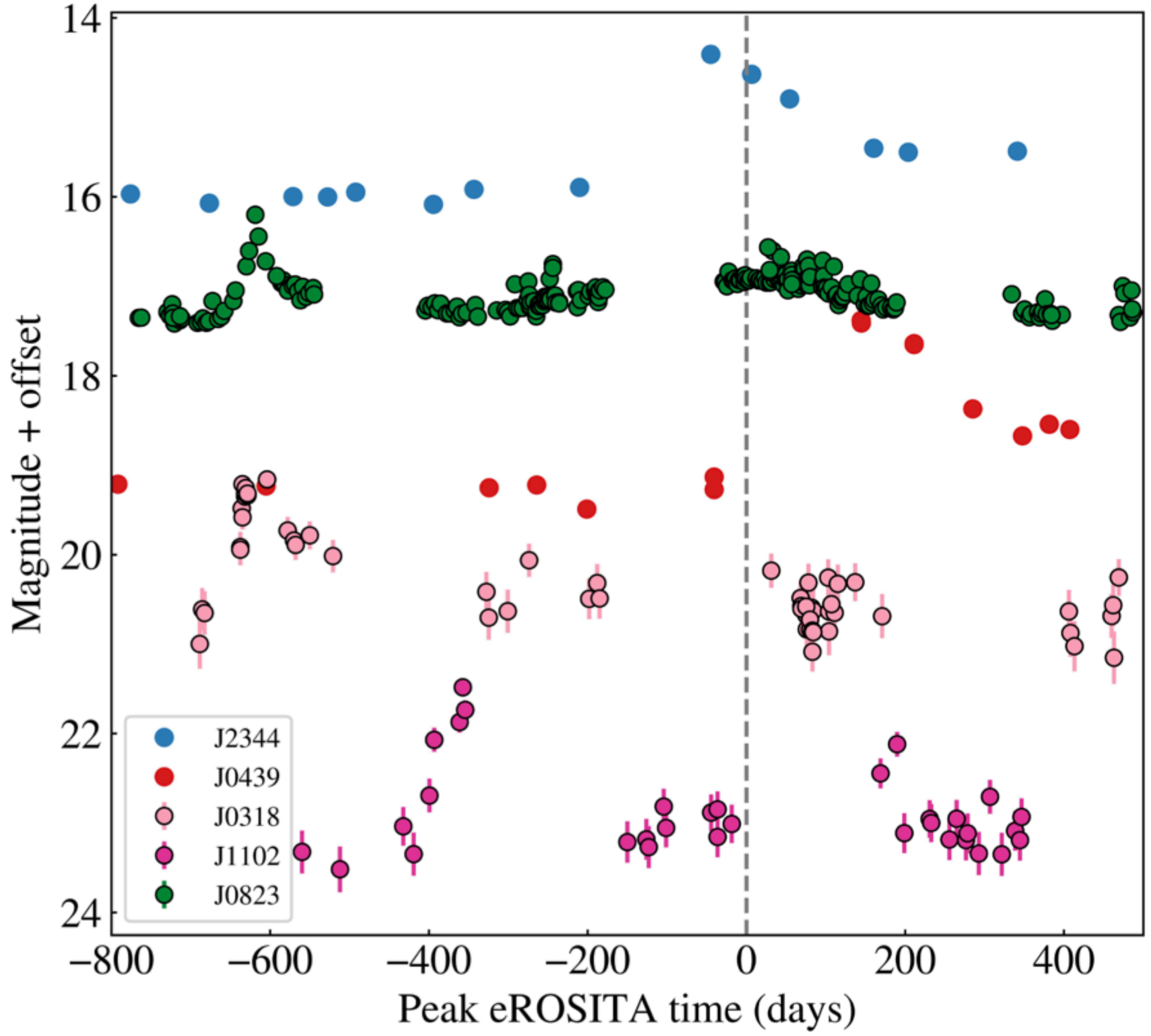


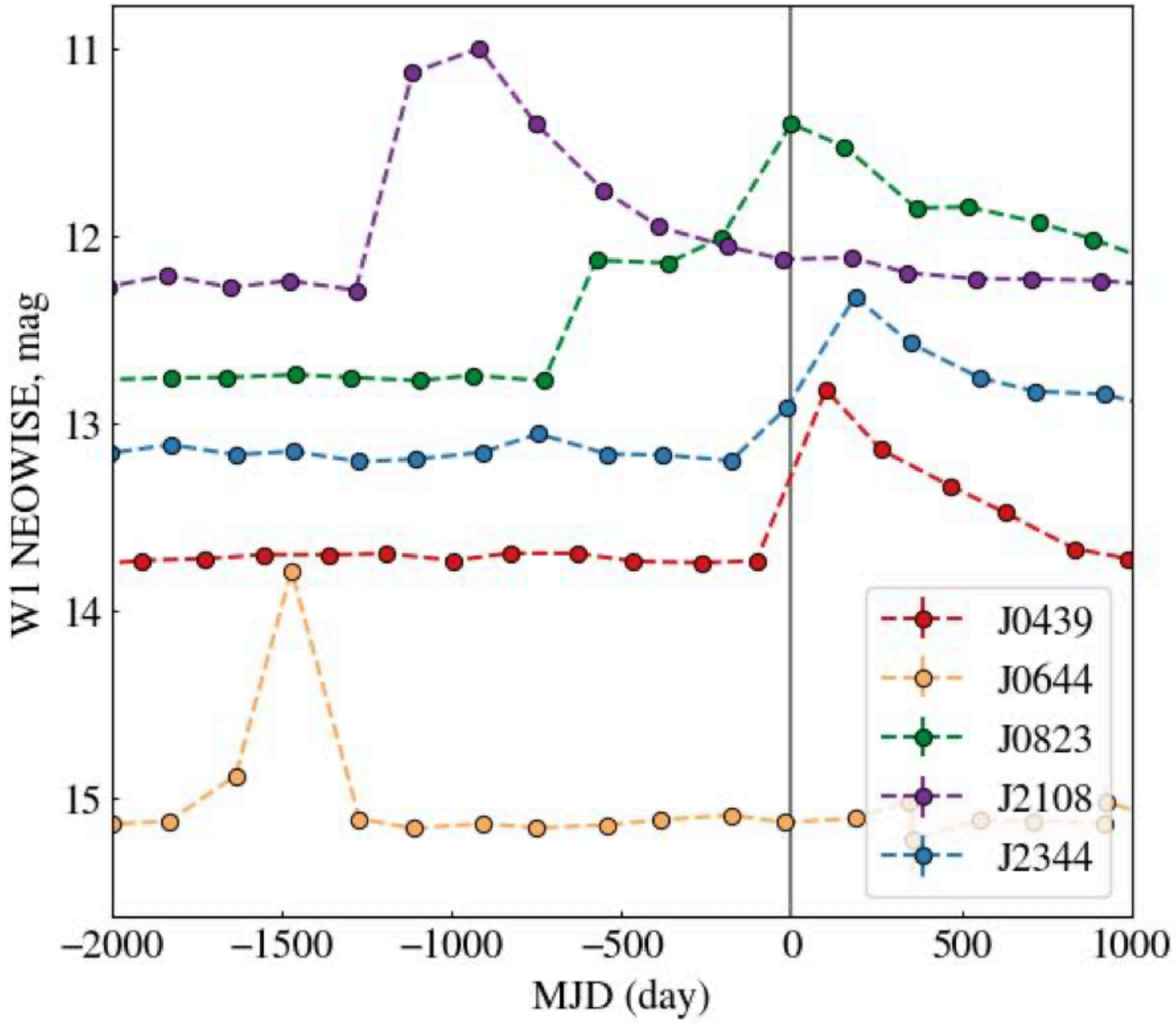
Example Host Galaxies of eROSITA TDEs

Images: Legacy Survey DR 10 - Red circles: eROSITA positions

Grotova,AR+2025b

OPTICAL AND IR PROPERTIES Not all are detected in optical or mid-IR

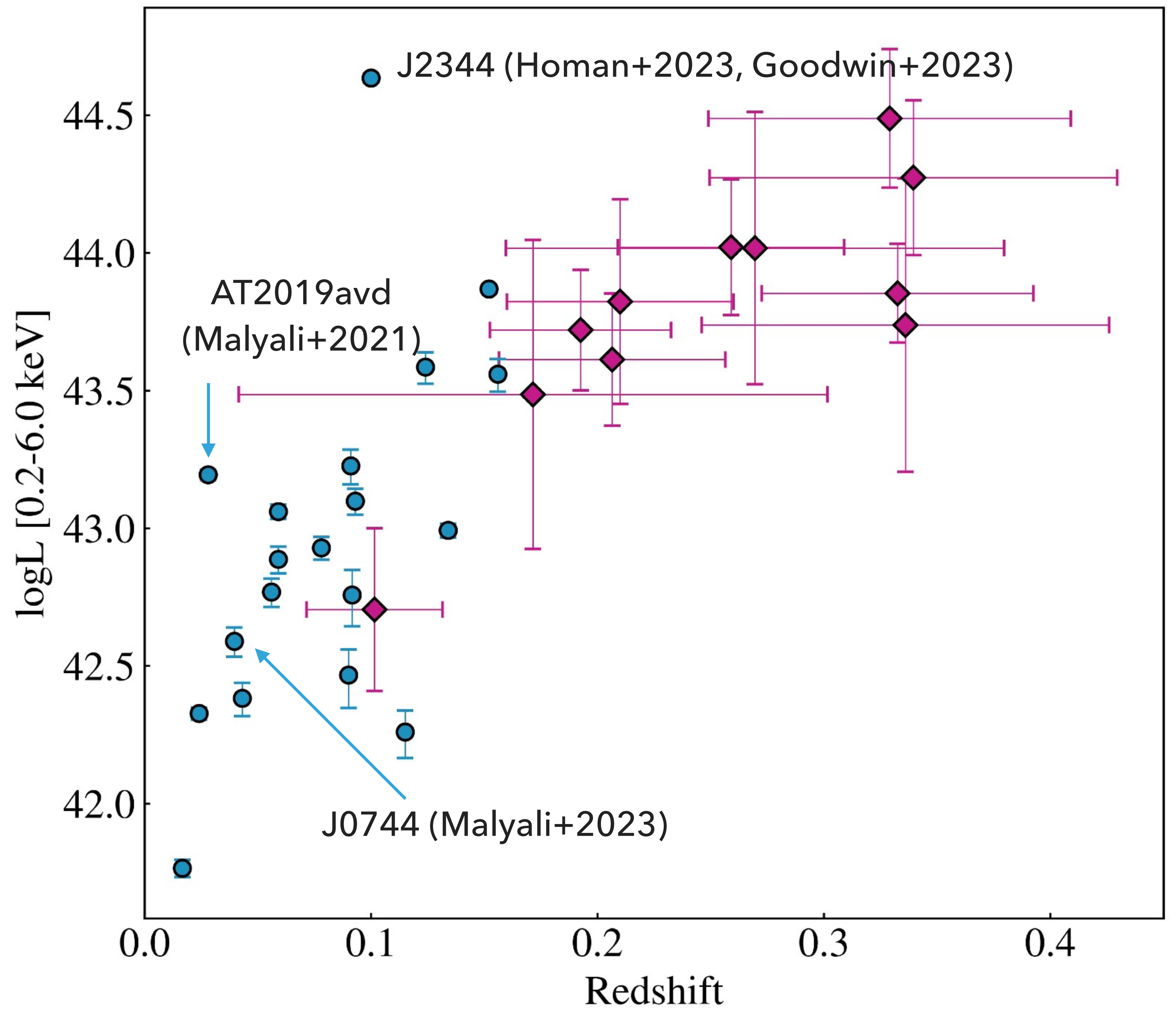


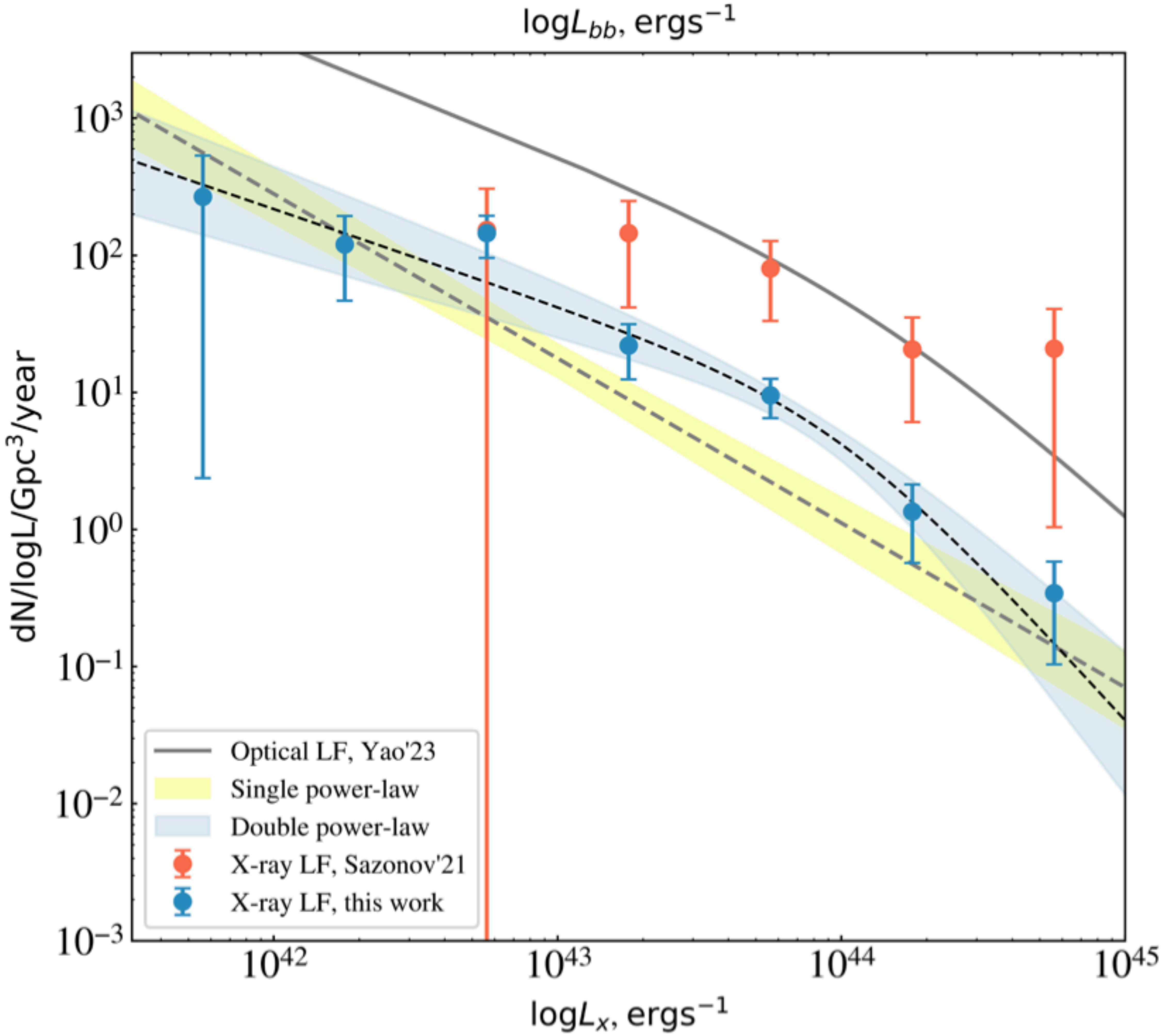


- Transient optical or IR behaviour detected for 14/31 sources
- Optical/IR emission peaked between years before and months after the X-ray peak

Grotova, AR+2025b

EROSITA TDE SAMPLE 31 candidates with z < 0.4



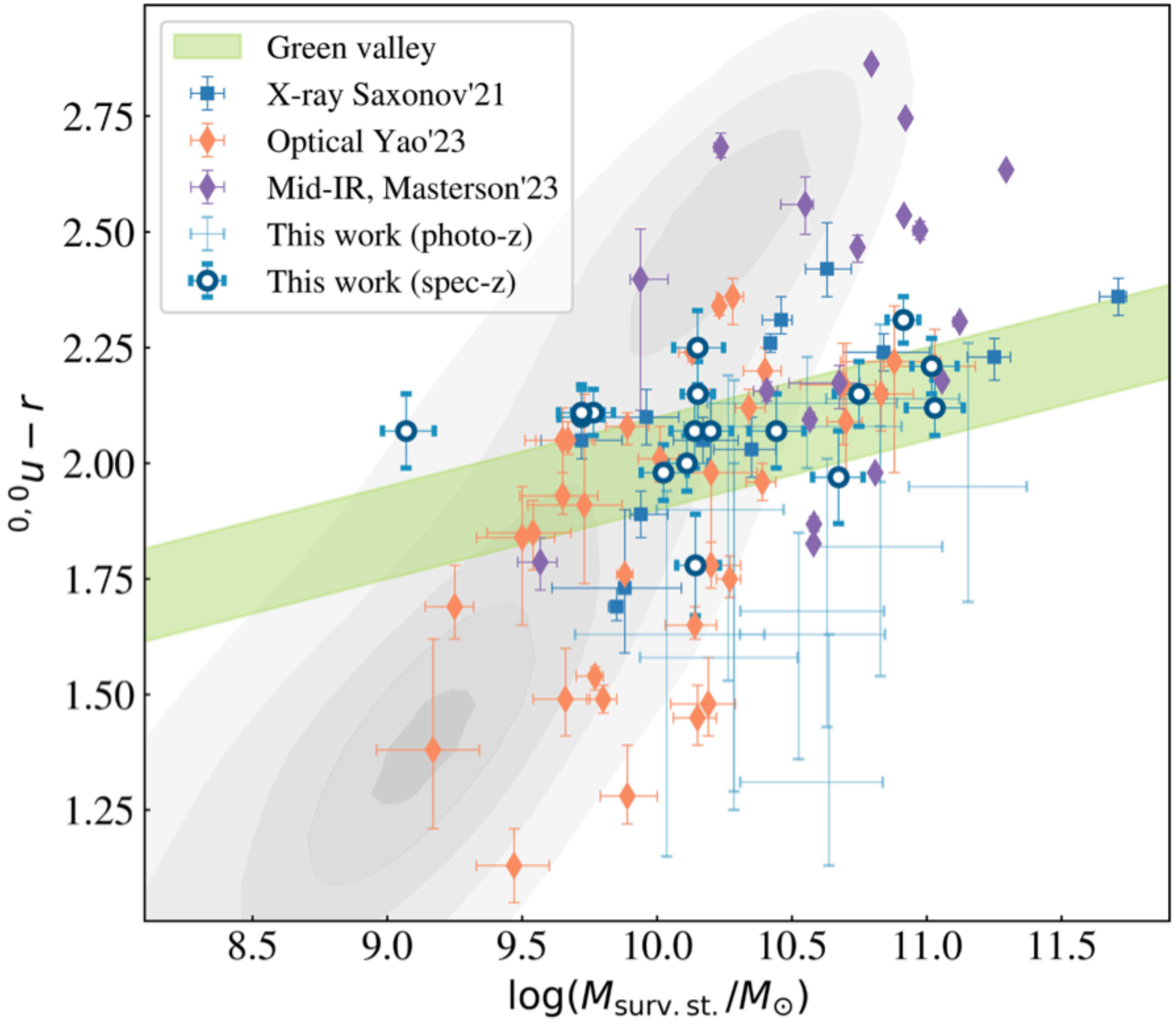


- Candidates **remain soft** throughout the evolution (2.5 years)
- One source becomes significantly harder (0.08 –> 0.35 keV). Might be associated with the formation of the corona.

- Rate $\approx (2.3^{+1.0}_{-0.8}) \times 10^{-7} Mpc^{-3} year^{-1}$ in 41.5 < logL < 45.0

Grotova, AR+2025b

HOST GALAXIES: GREEN VALLEY?



- ✓ Excess of X-ray and optically-selected TDE host in post-starburst galaxies (E+A)
- ✓ Preference for recent mergers?
- ✓ more stars filling the loss cone due to recent star formation or galaxy mergers
- ✓ Lack of detected TDEs in star forming galaxies may be caused by extinction

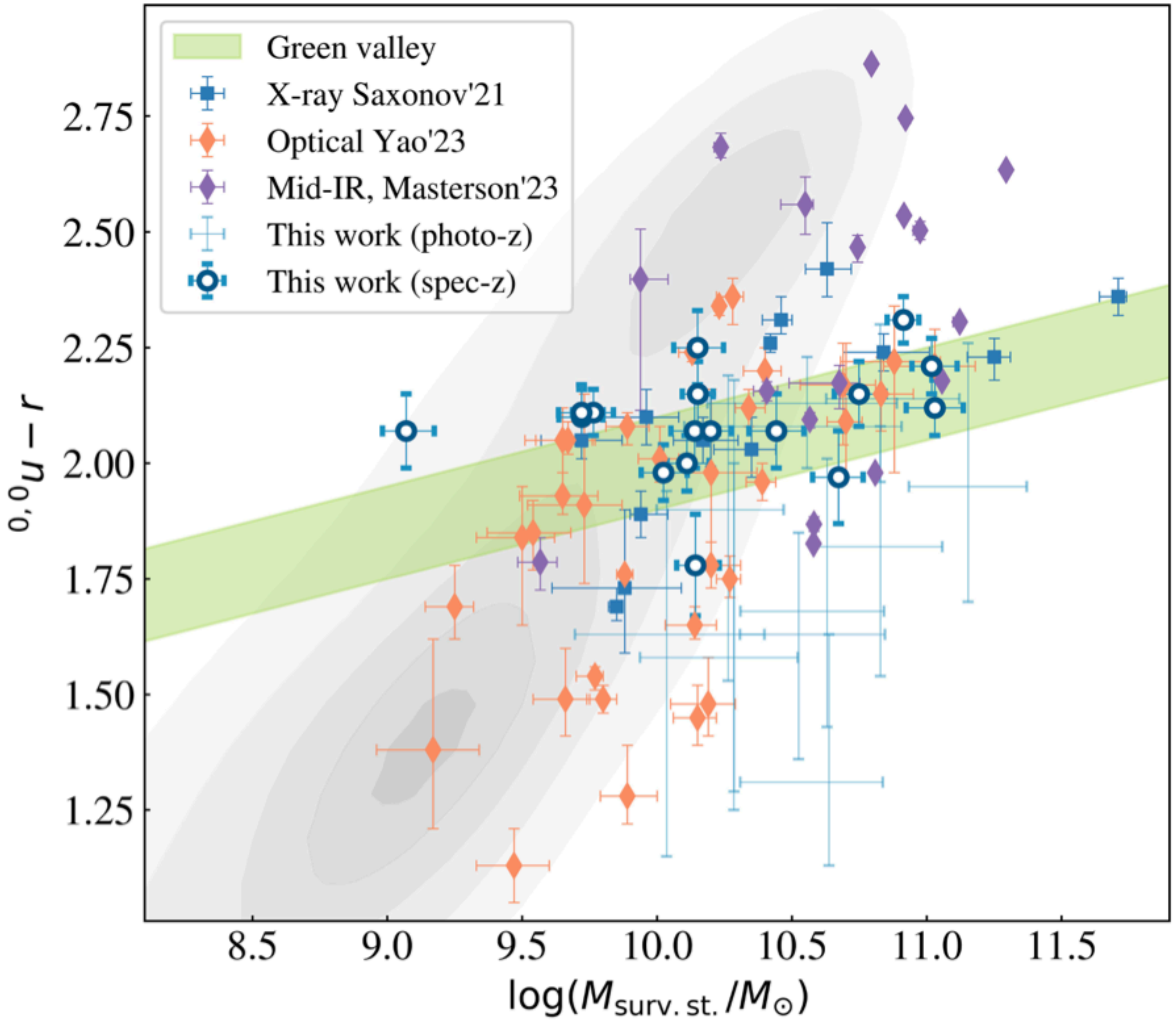
→ BH mass range
(relation from Reines & Volonteri 2015)

$$log(M_{BH}/M_{sun}) \approx 6.4 - 7.7$$

Grotova, AR+2025b

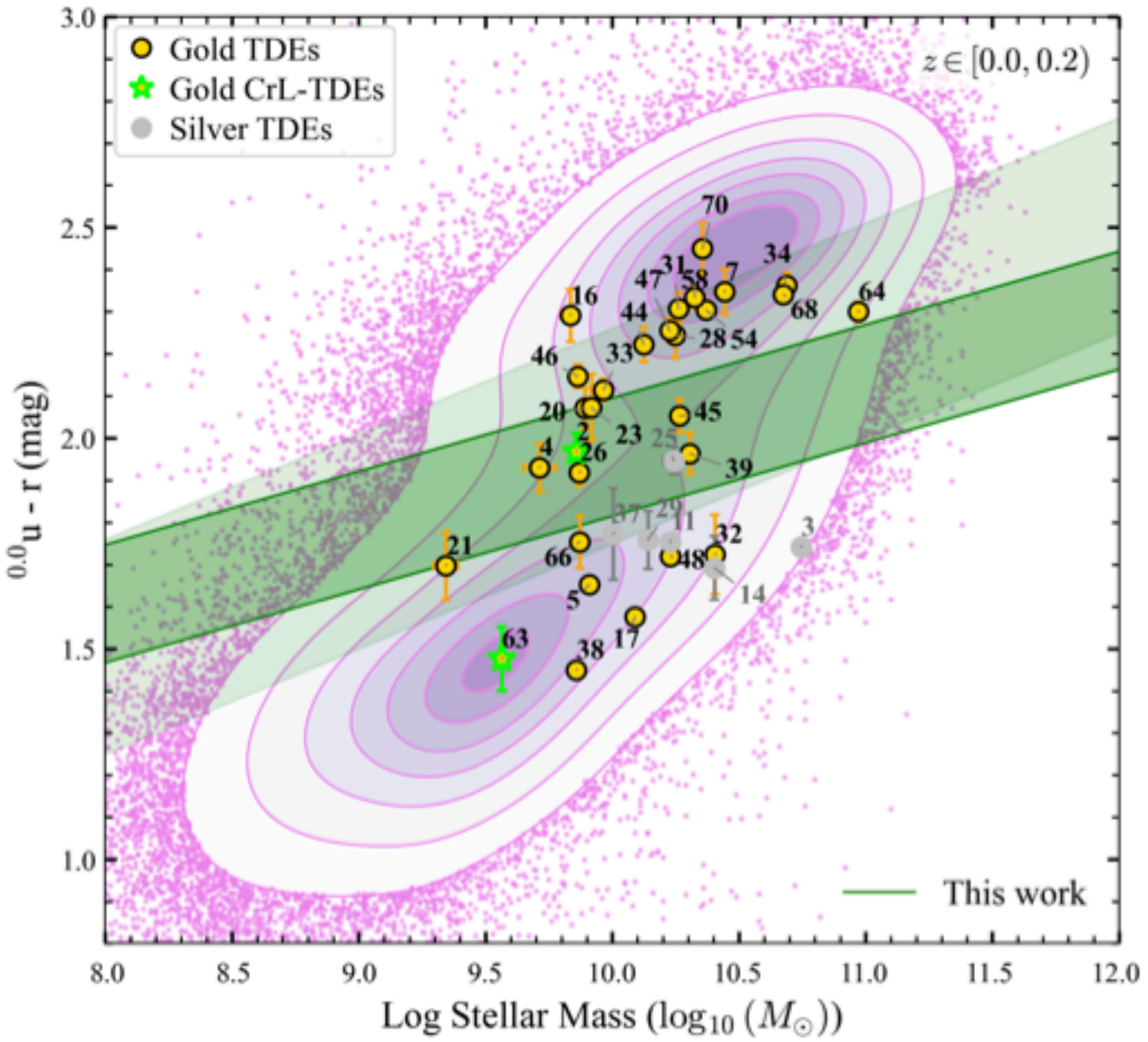
HOST GALAXIES: GREEN VALLEY?

31 TDEs from Western Galactic Hemisphere of eROSITA



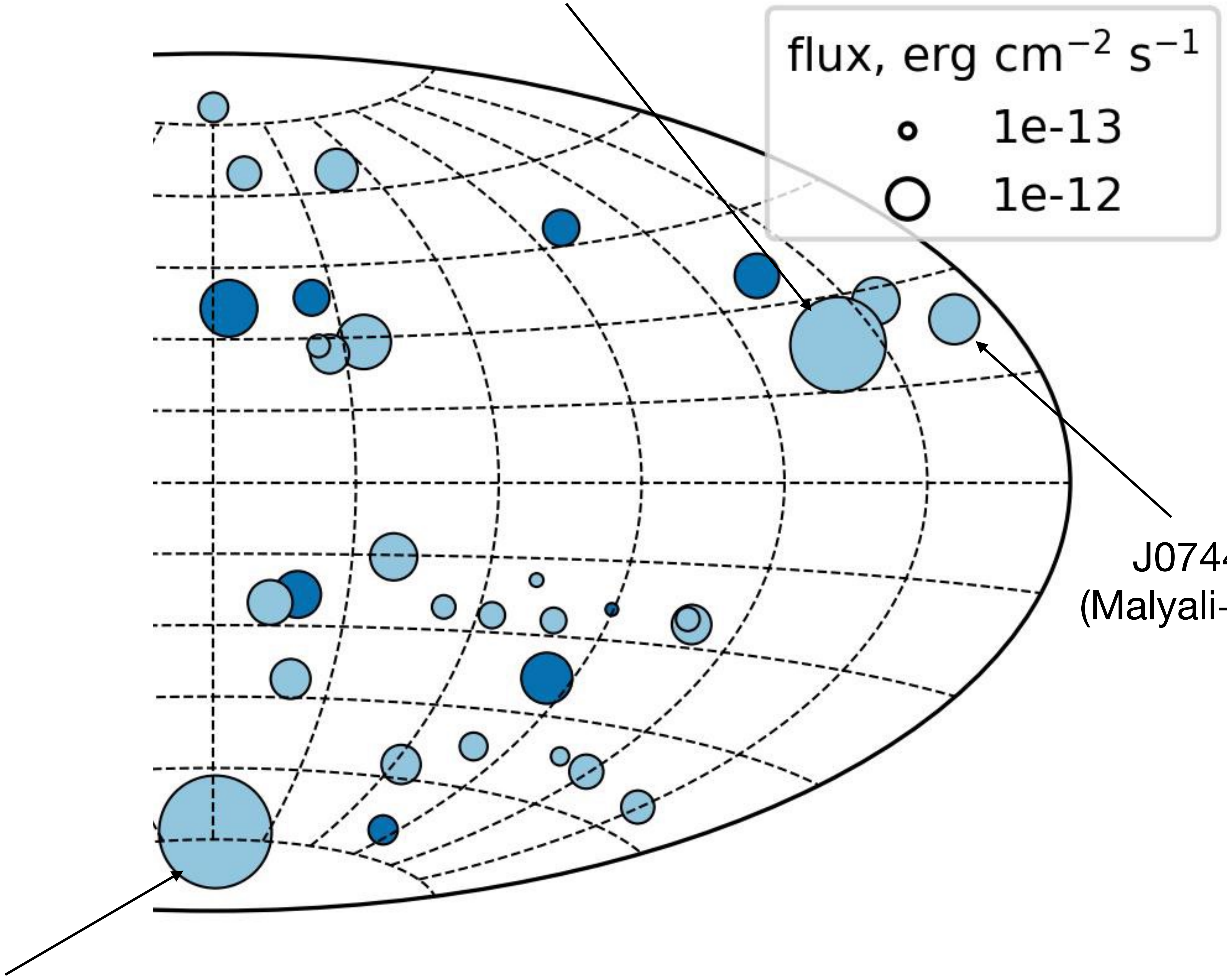
Grotova, AR+2025b

33 TDEs from Eastern Galactic Hemisphere of eROSITA

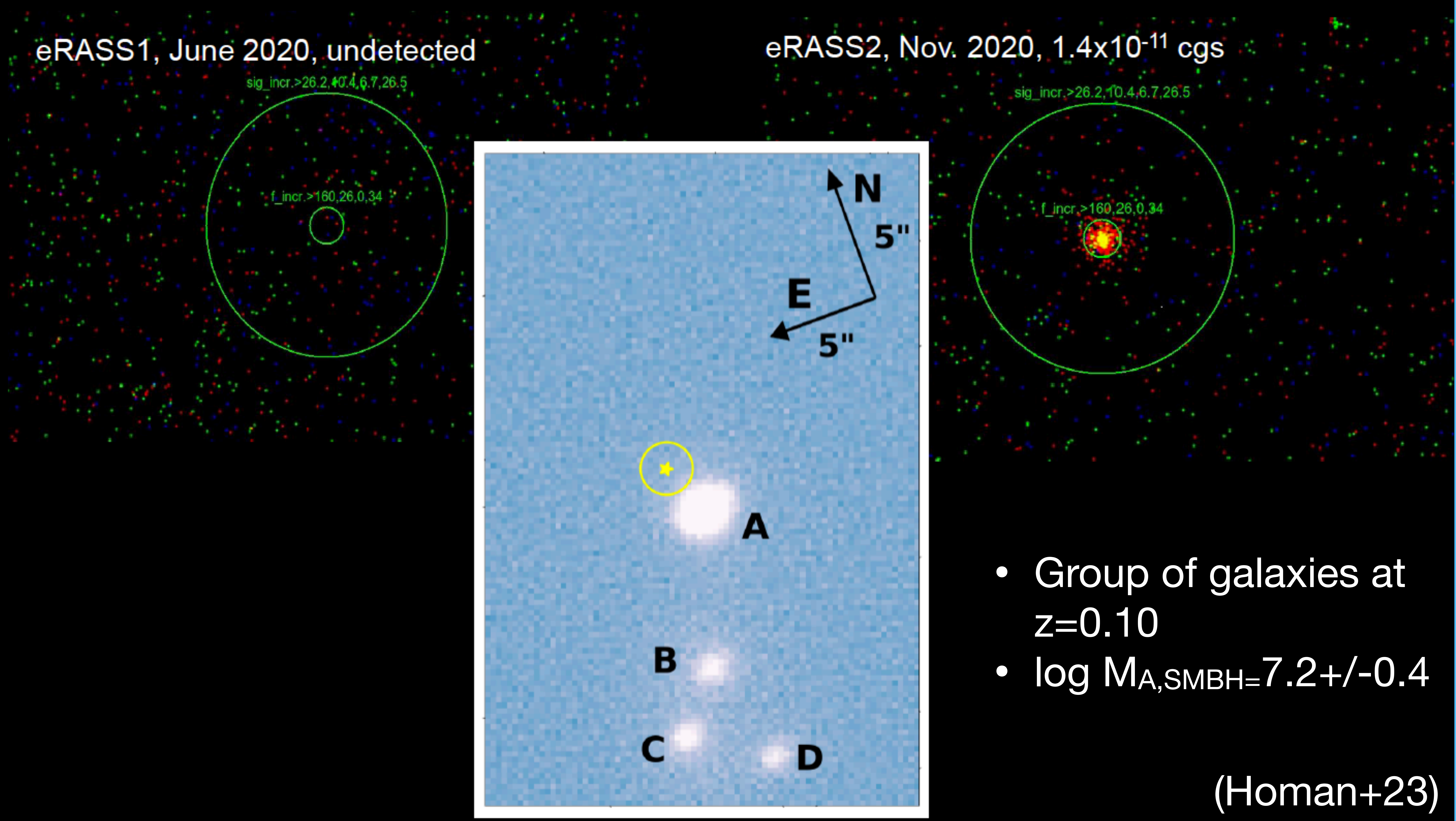


Zhang et al. 2026

Chapter III - Example Discoveries



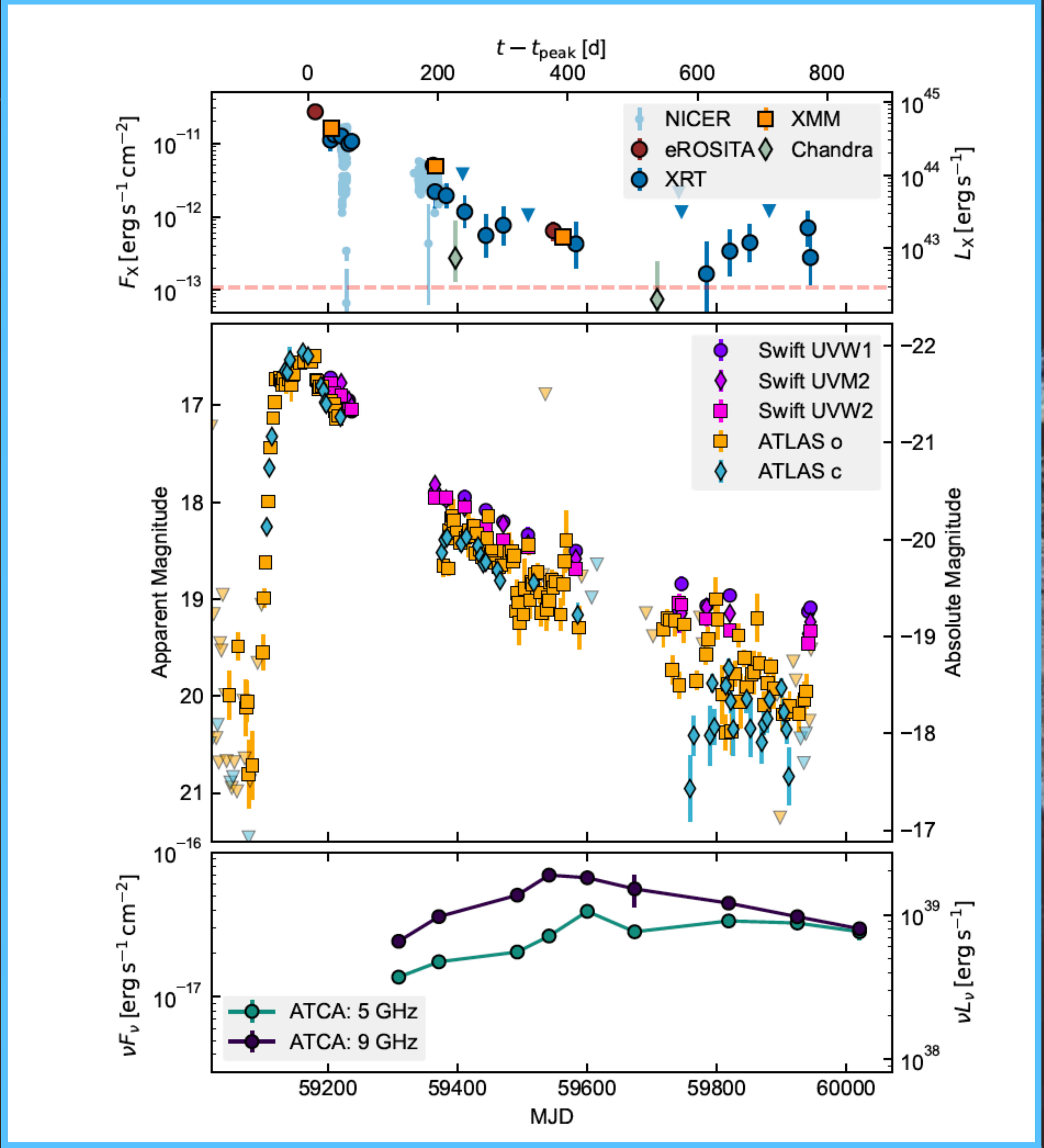
J2344 - The brightest (in flux) ignition event



- Group of galaxies at z=0.10
- log $M_{A,SMBH}$=7.2+/-0.4

(Homan+23)

J2344 - Bright in X-rays, UV, Optical, Radio



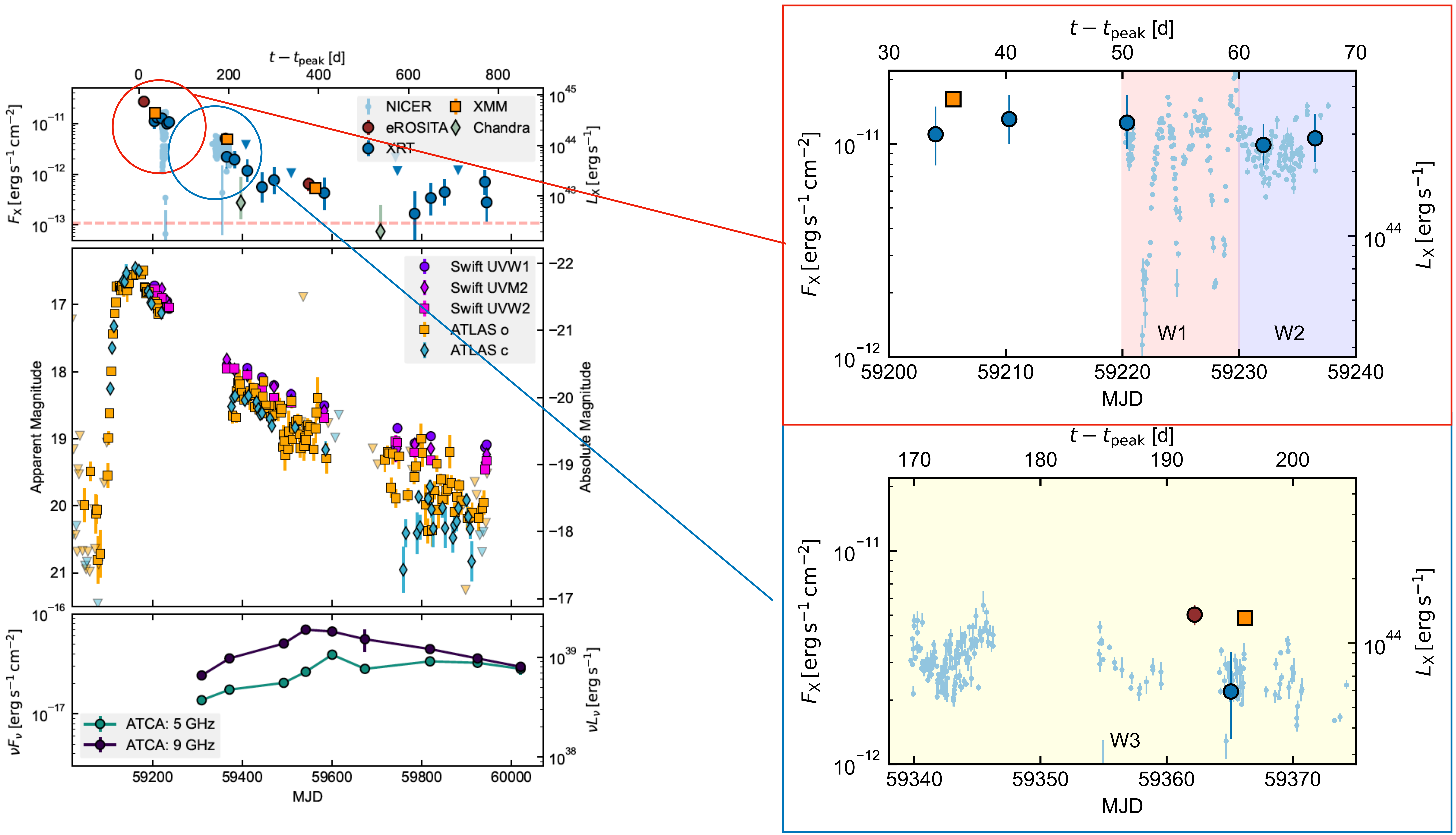
- highest-flux TDE candidate in eROSITA
- Among the most luminous X-ray-detected TDEs
- Independently discovered by Gaia (Homan+23)

- Ultra-soft (kT<100eV)

- ATCA radio lightcurve consistent with a single ejection of material launched coincident with optical flare (Goodwin+24)

(Malyali, AR+26)

3 day-timescale variability - Lense-Thirring precession of the inner accretion flow?



Malyali, AR+2026

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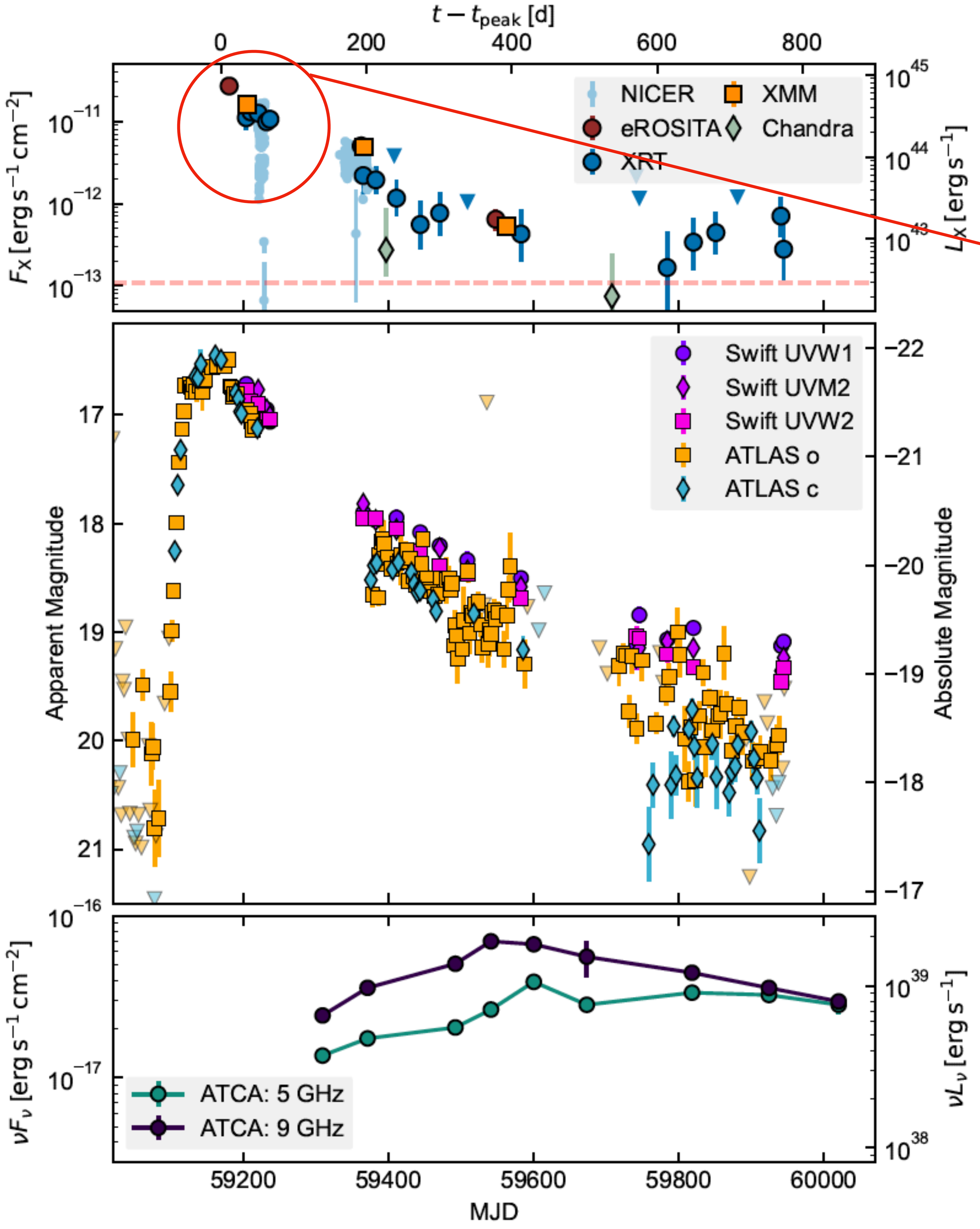
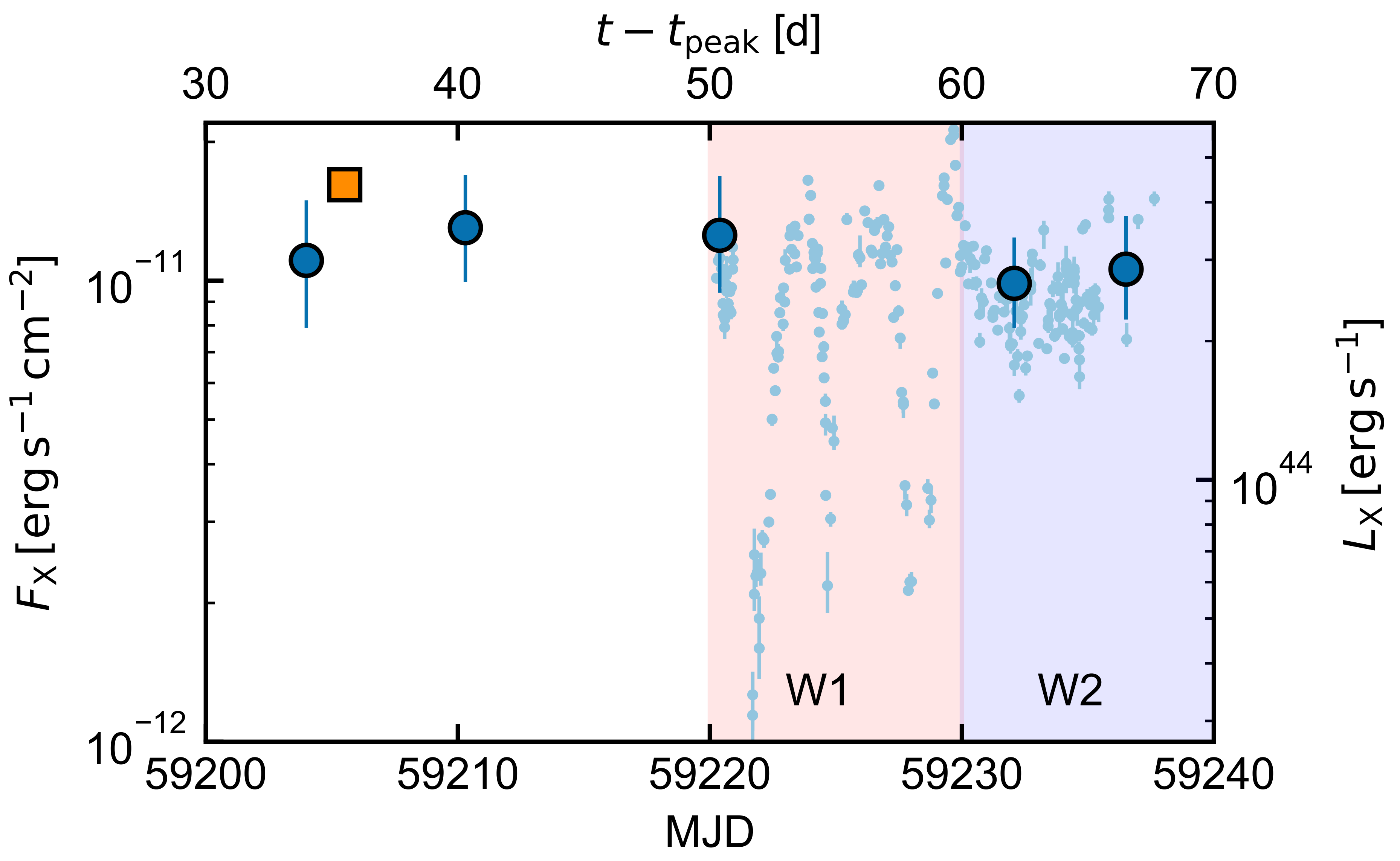
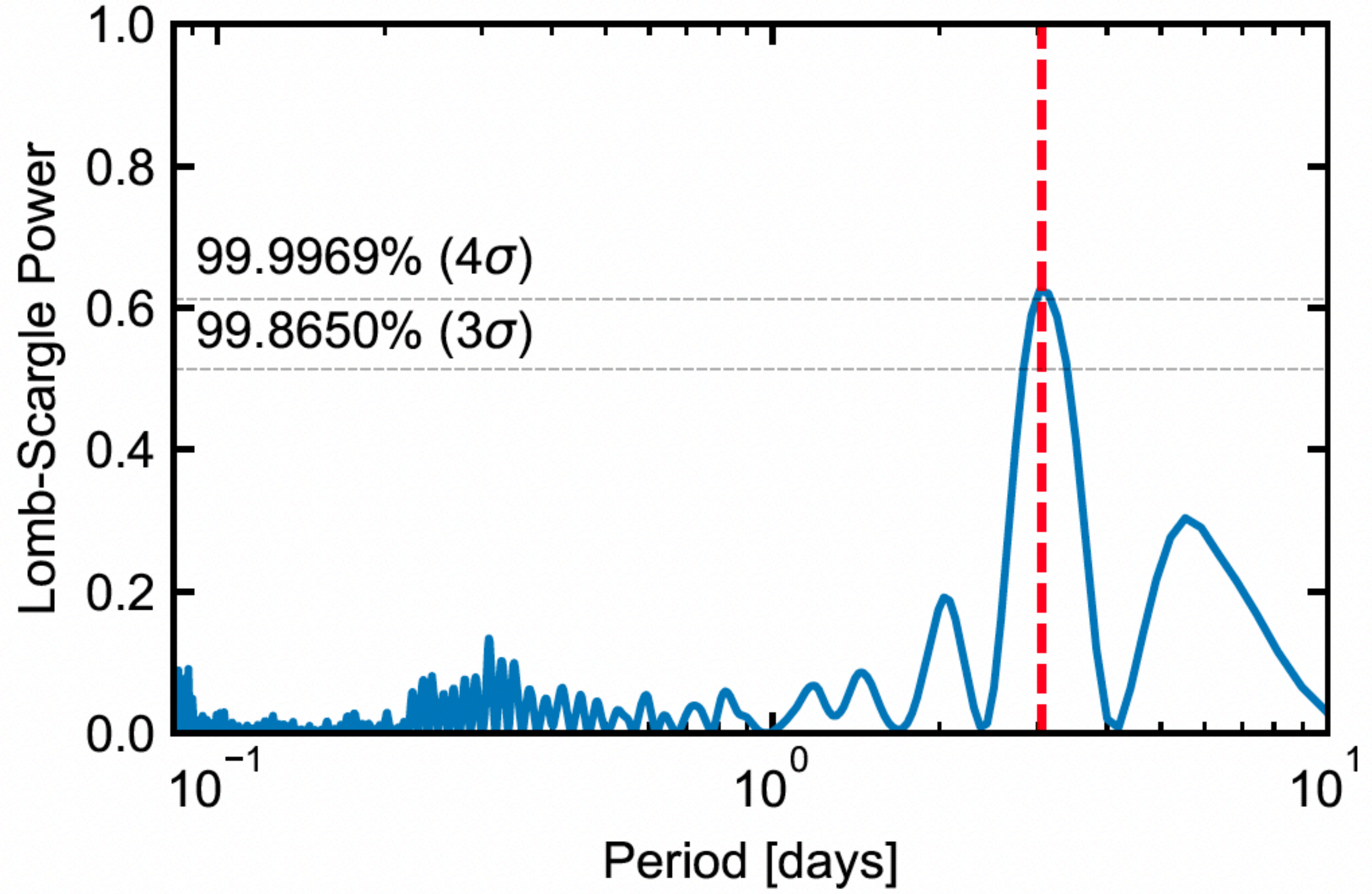


Malyali, AR+2026





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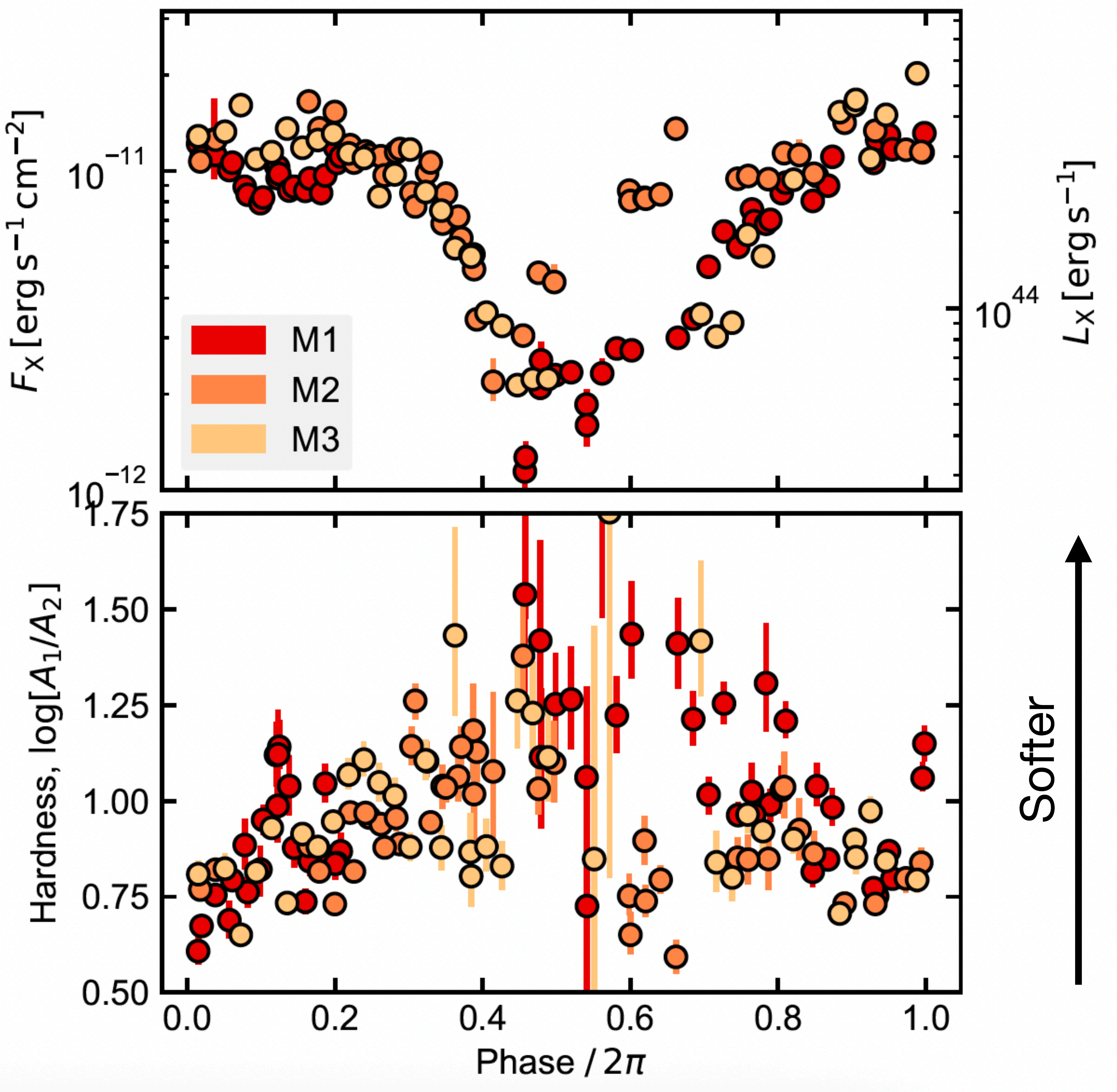
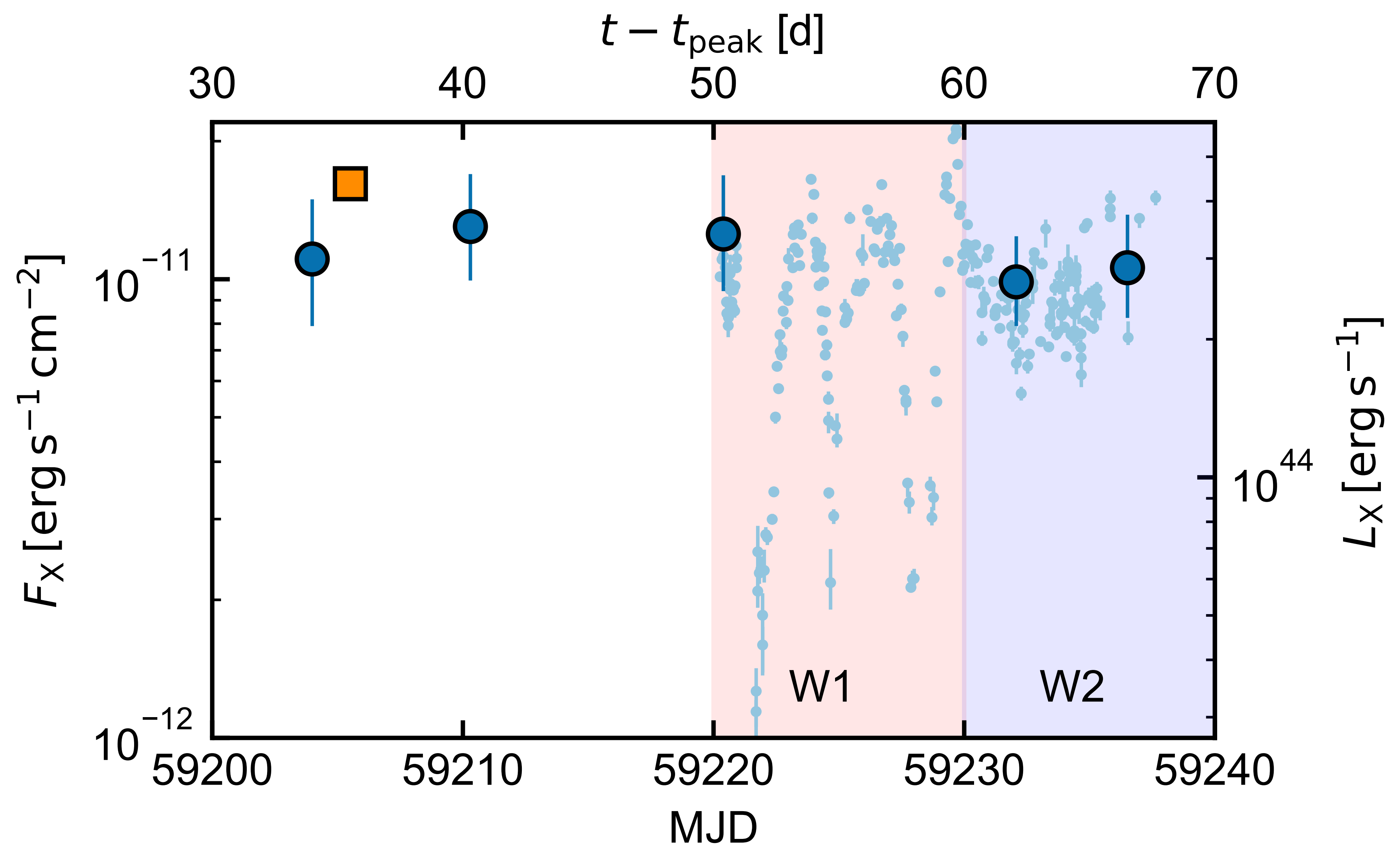
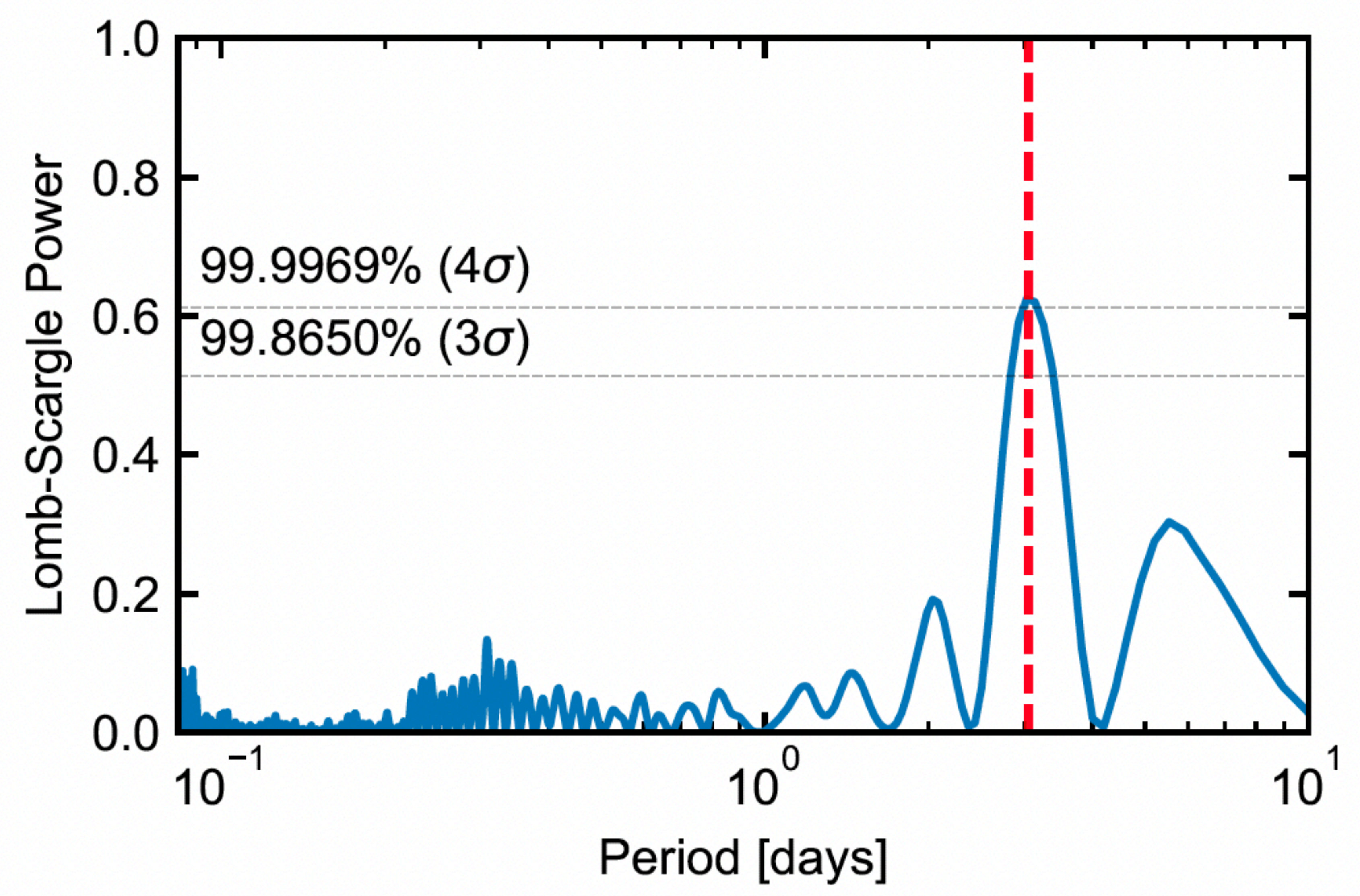


Malyali, AR+2026





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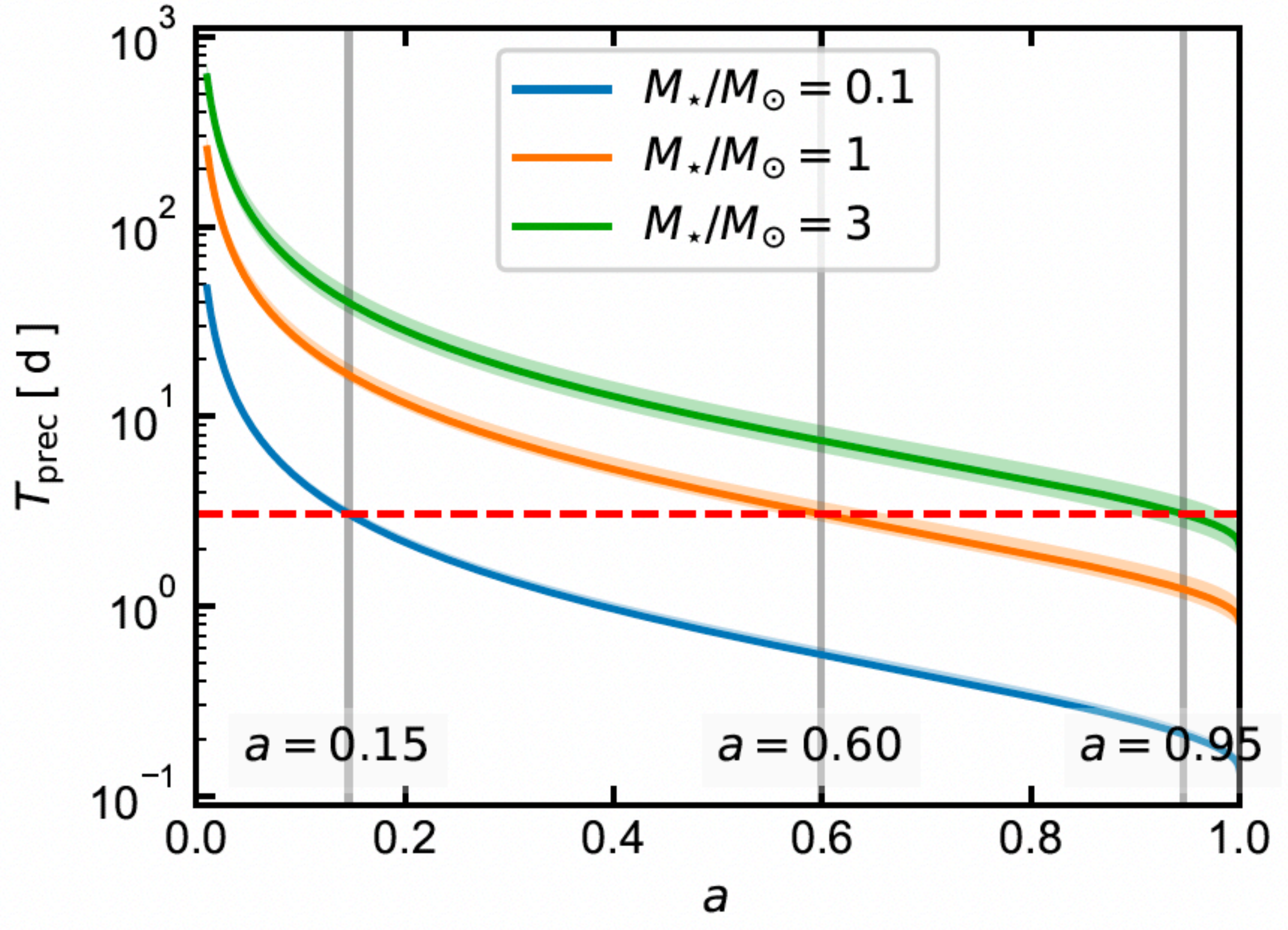
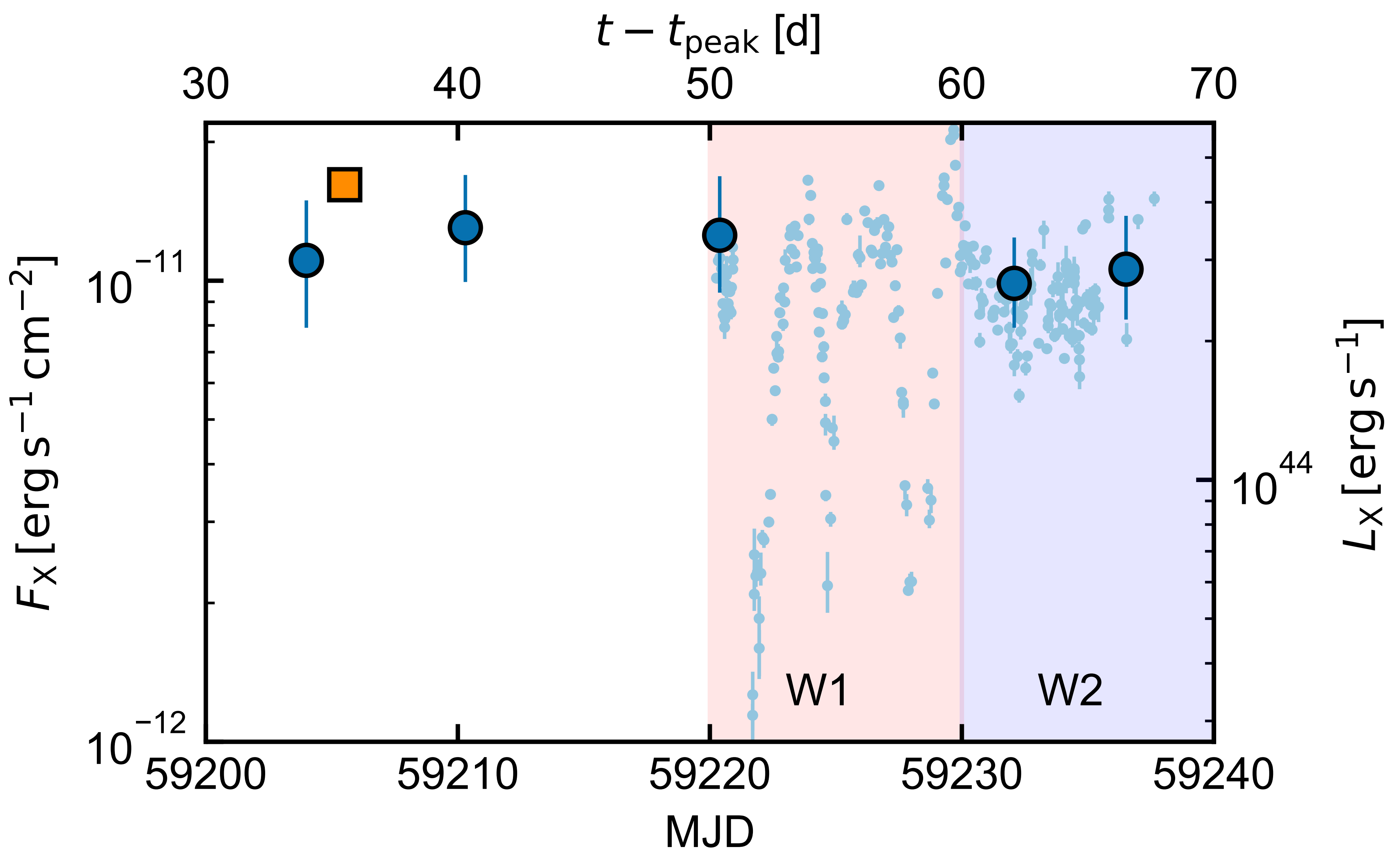
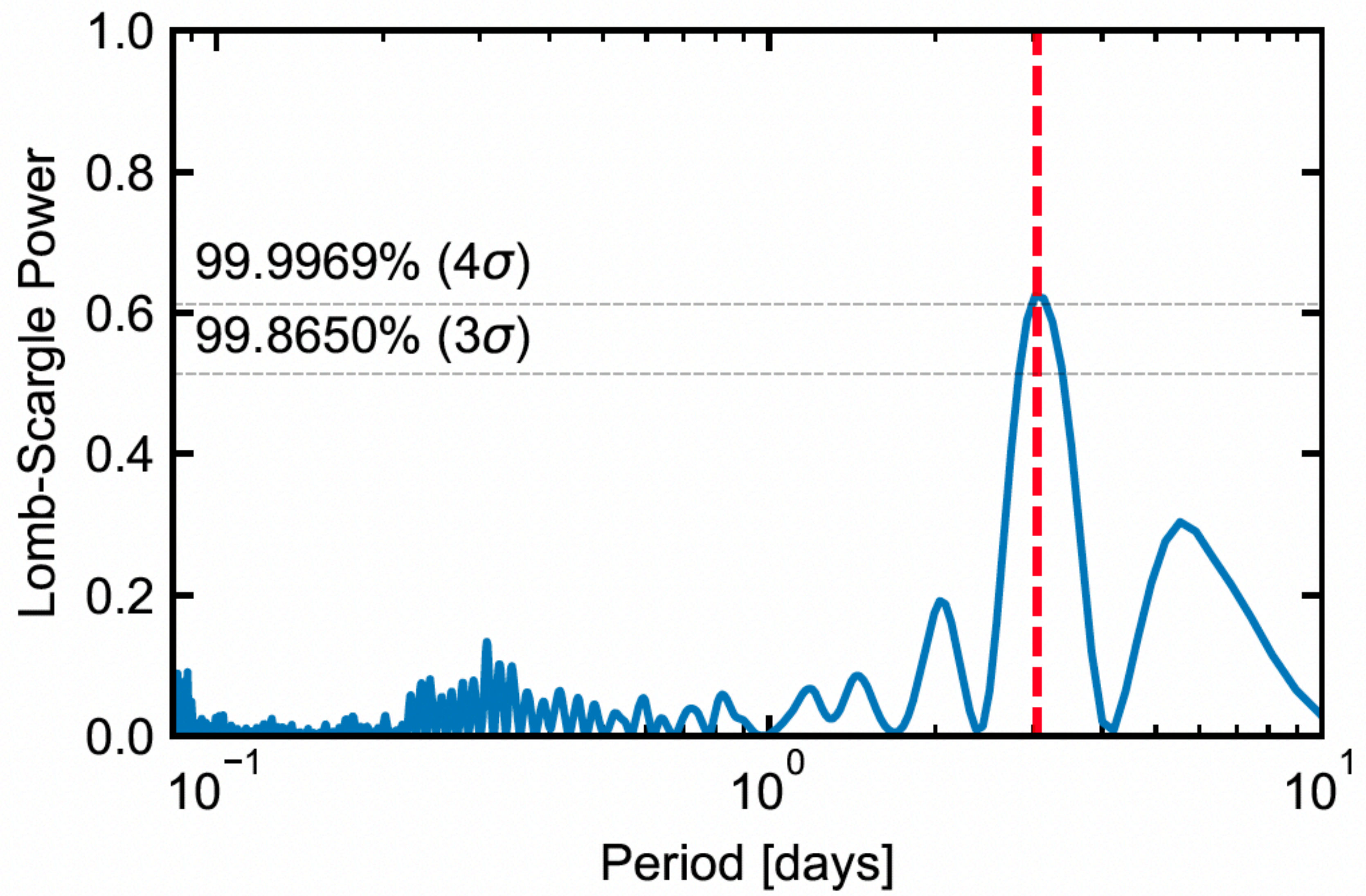


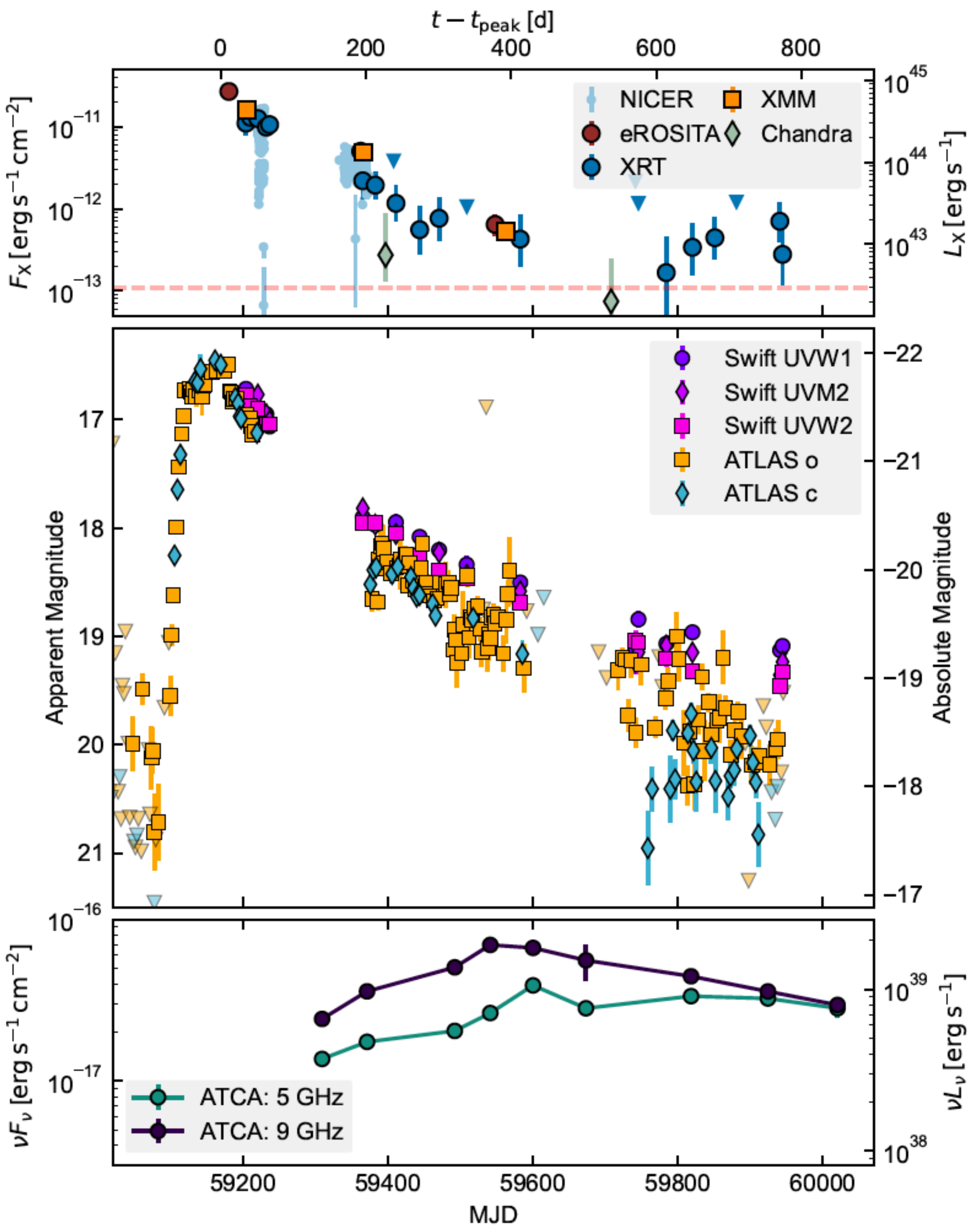




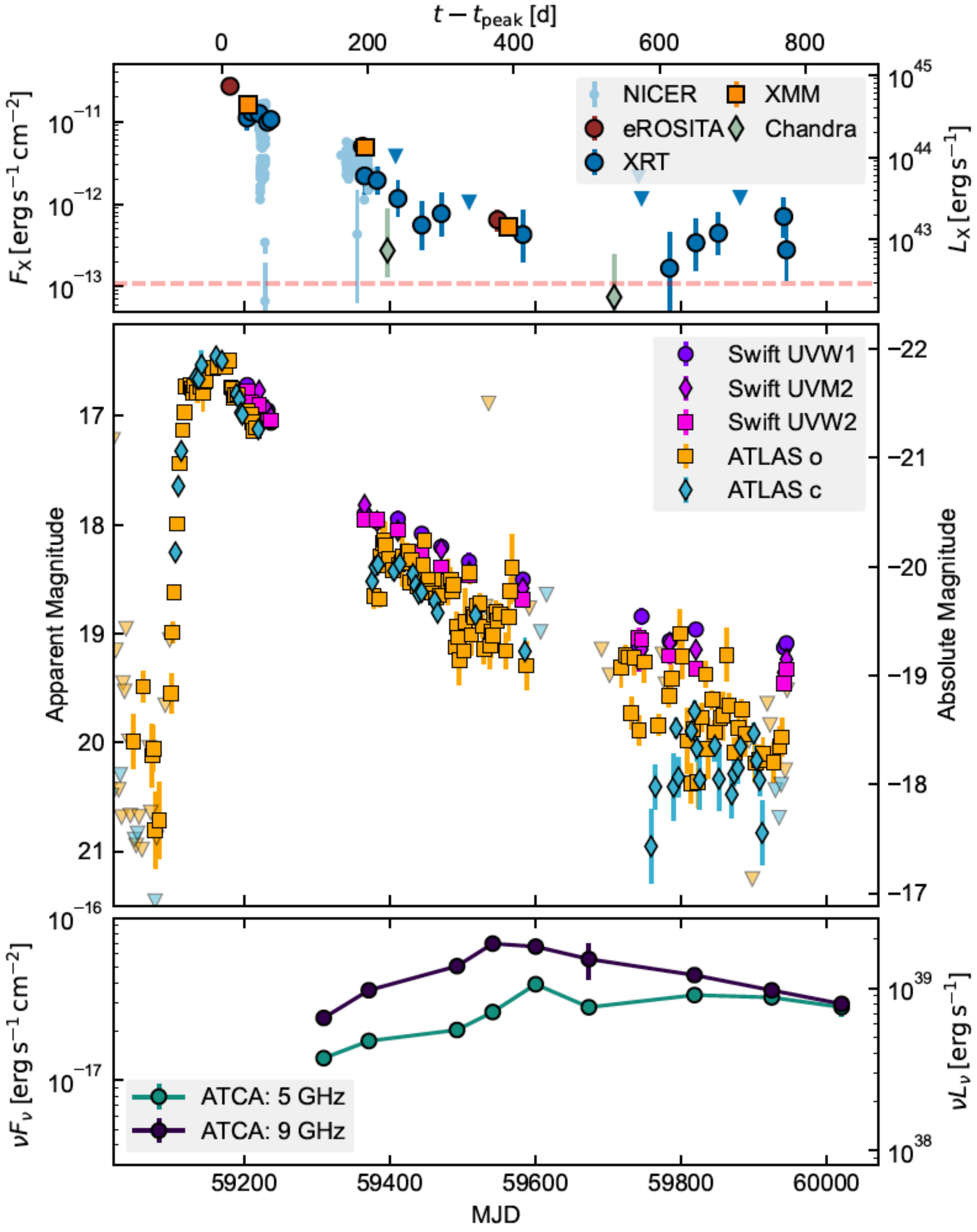
Precession time scale consistent with a=0.6 for 1-M_{sun} star and log M_{SMBH}=7.2 in J2344

Malyali, AR+2026

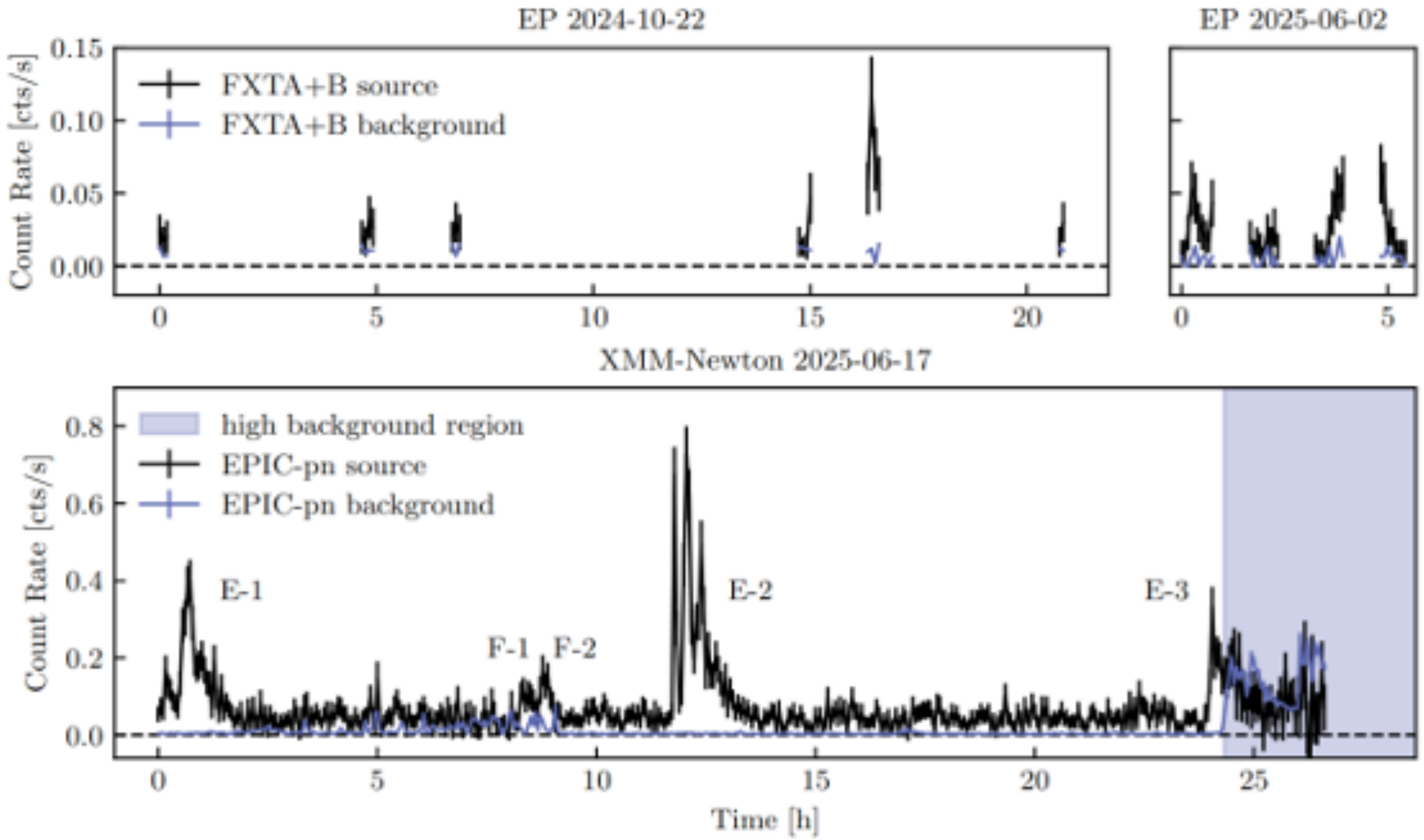
J2344 at late times



Quasi-Periodic Eruptions at late times?

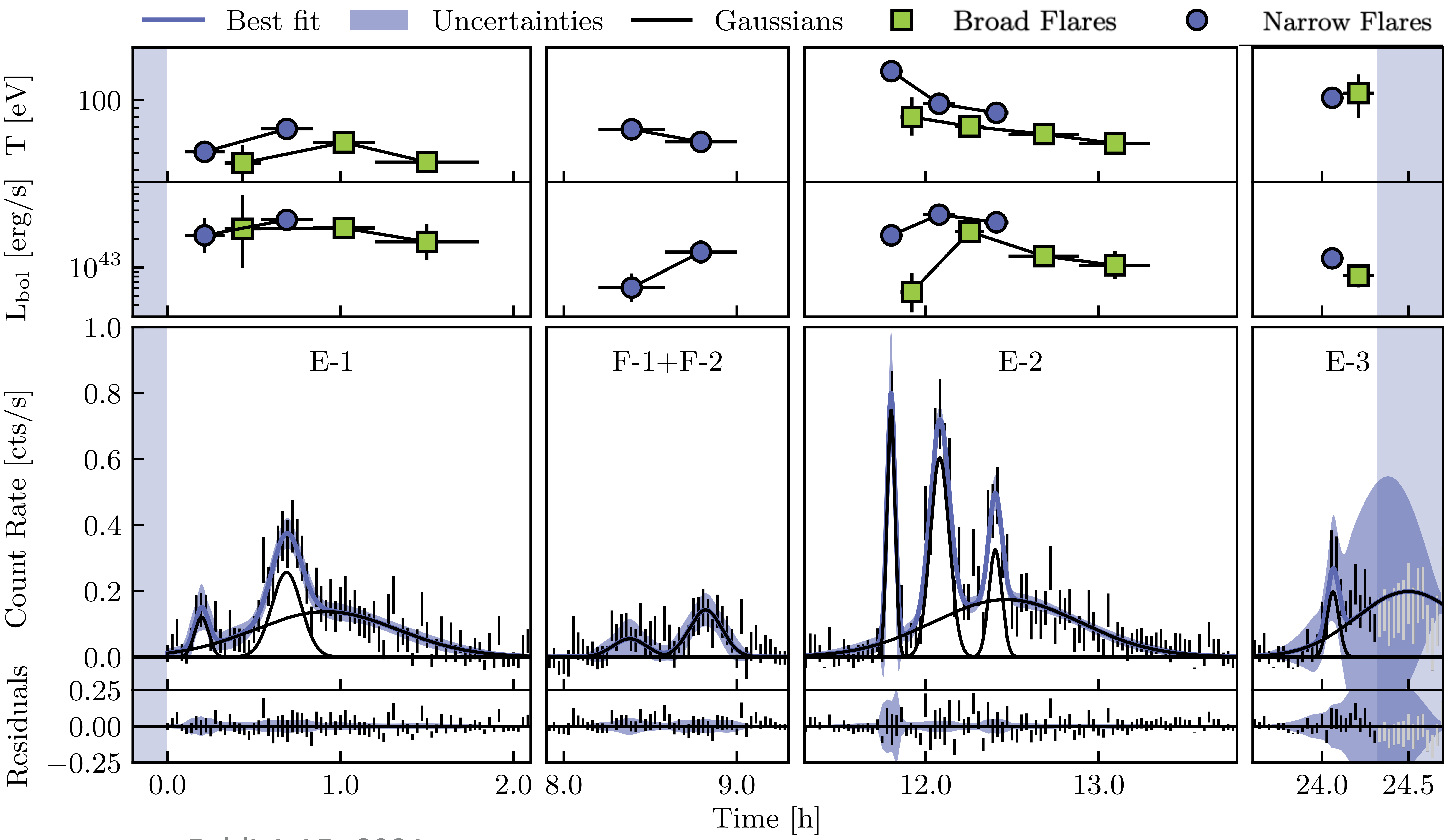


Follow-up with Einstein Probe and XMM revealed Quasi-Periodic Eruptions (QPEs) at t+4yr on ~11.7hr time scale for (at least) 8 months



Baldini, AR+2026

Narrow flares superimposed on ‘regular’ QPEs



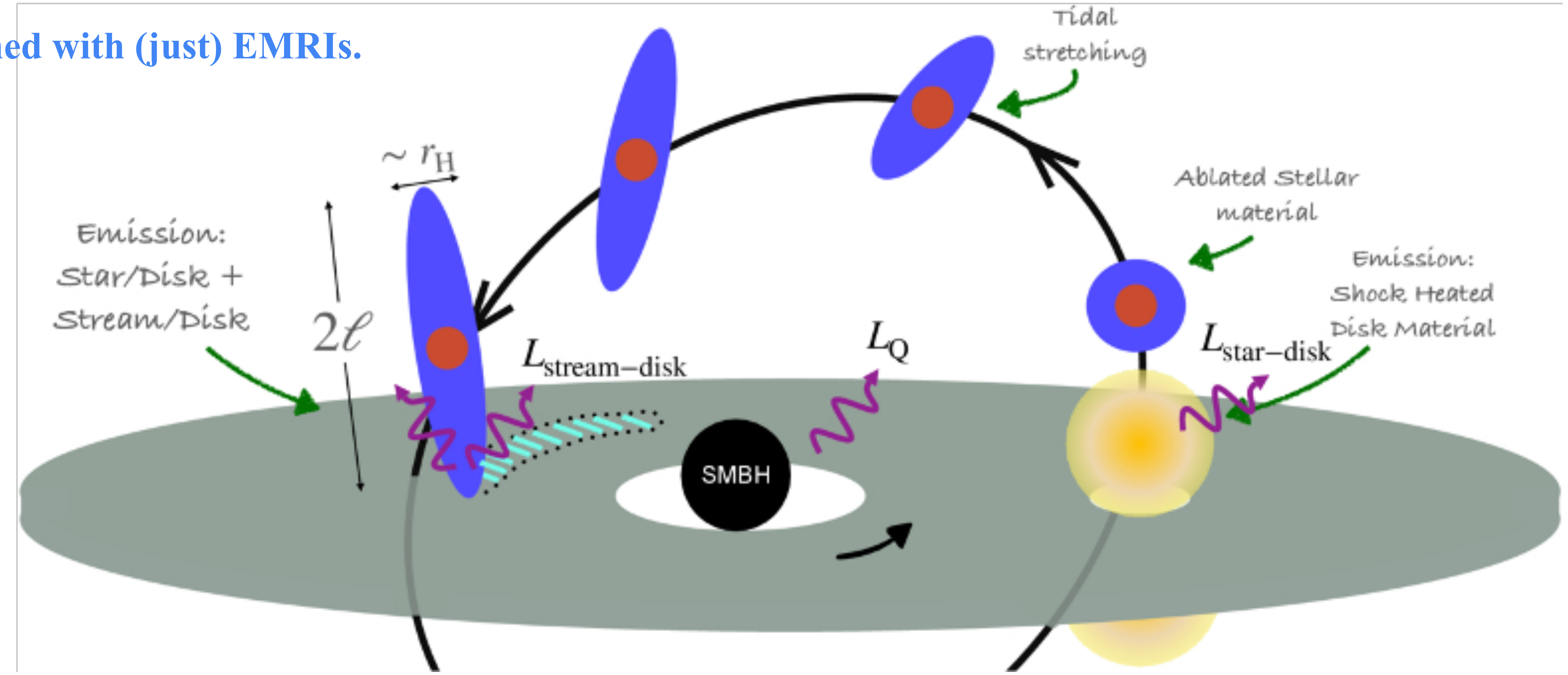
Baldini, AR+2026

Narrow flares superimposed on ‘regular’ QPEs

Within an EMRI framework:

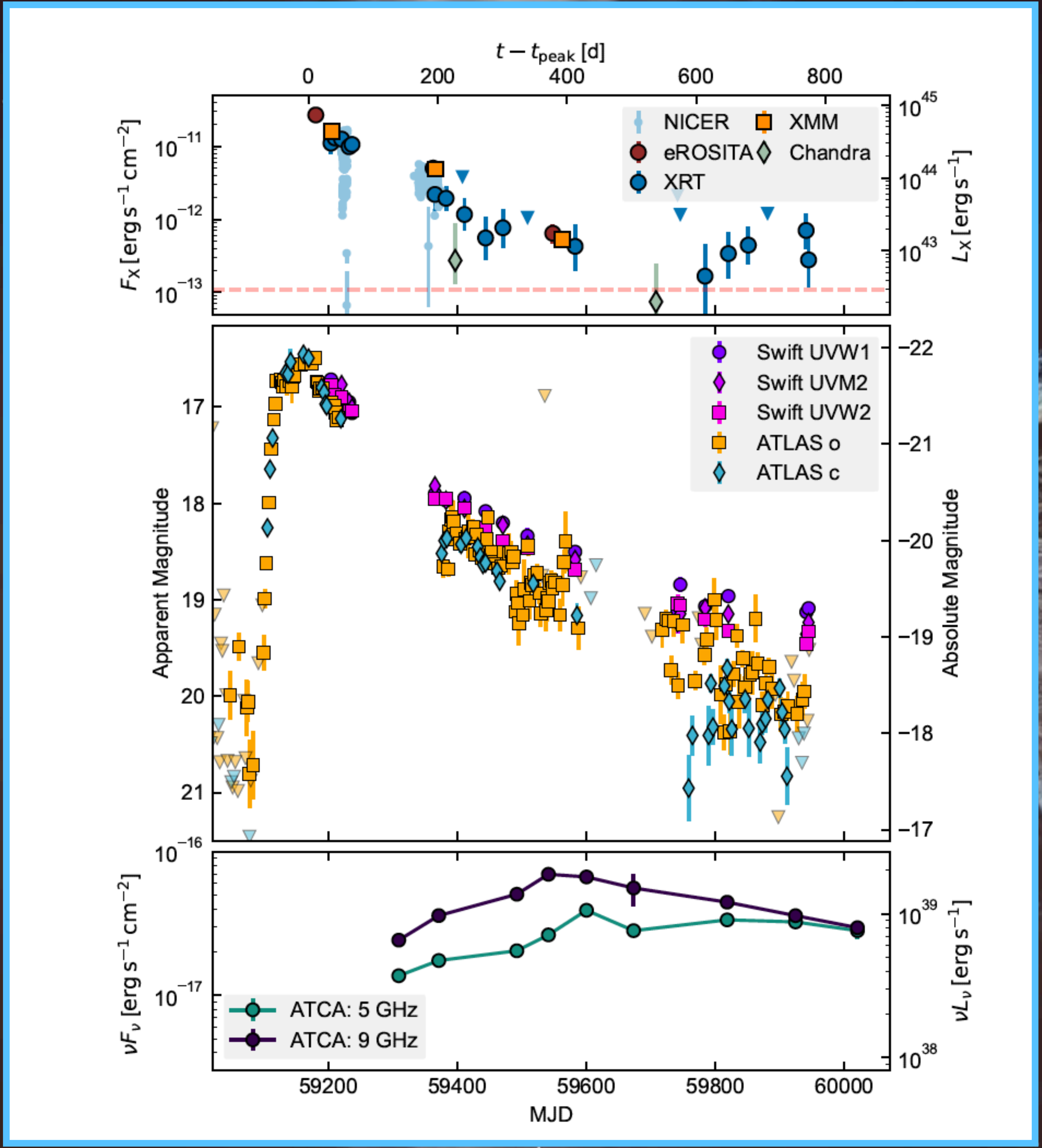
- **The perturbing object is a star getting stripped at each passage** (Linizal, Metzger & Quataert 25)
  - The ablated stellar debris can cool down and clump before each encounter with the disk, creating a discrete series of events.
- **The perturbing object is an intermediate-mass black hole** (~10^4 Msun).
  - As it plunges through the disk, it will accrete at super Eddington, producing flares at luminosities comparable to that of the QPEs (Lam+25)

It is possible that the QPEs in J2344 could not be explained with (just) EMRIs.



Linizal, Metzger & Quataert 25

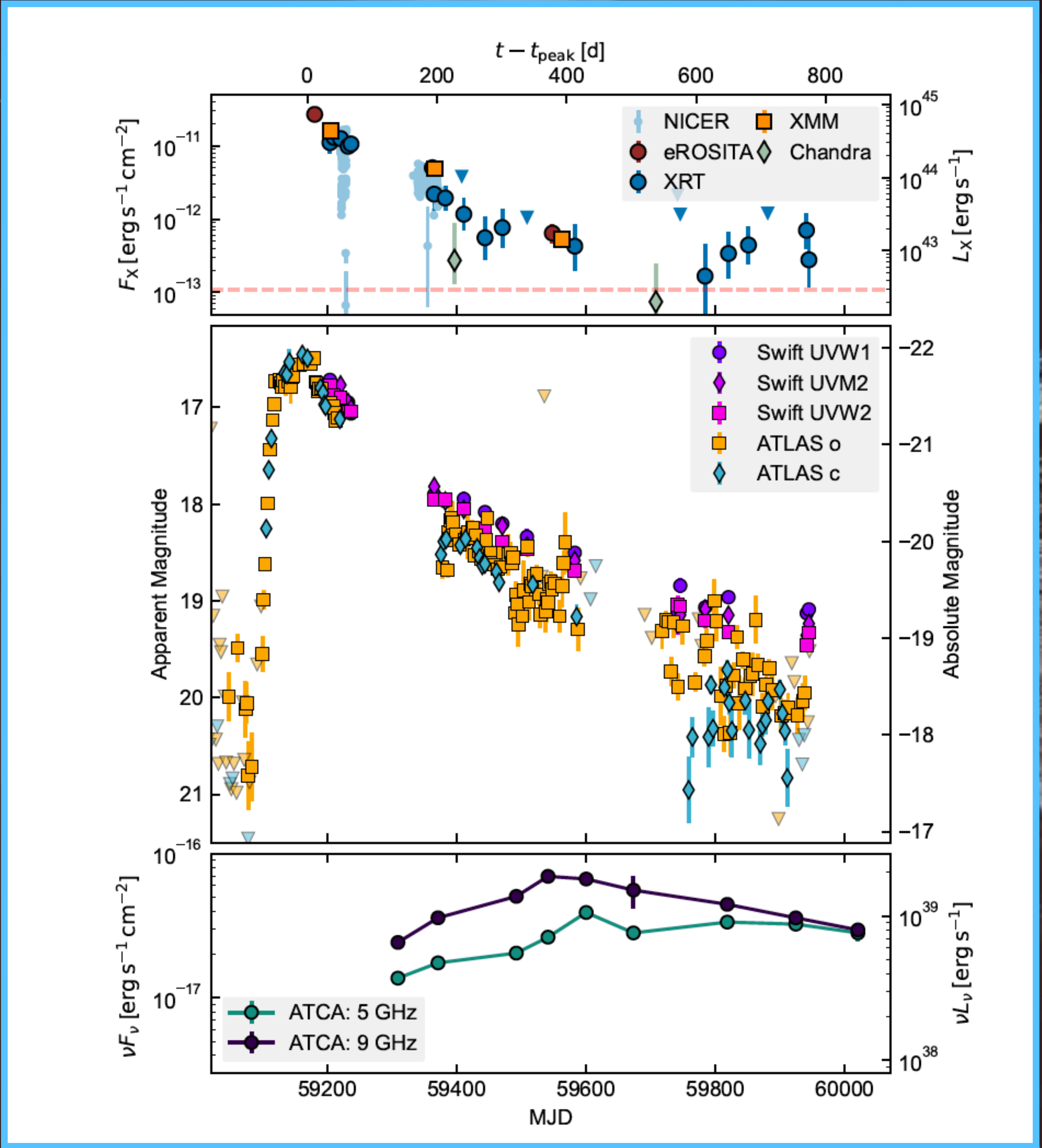
J2344



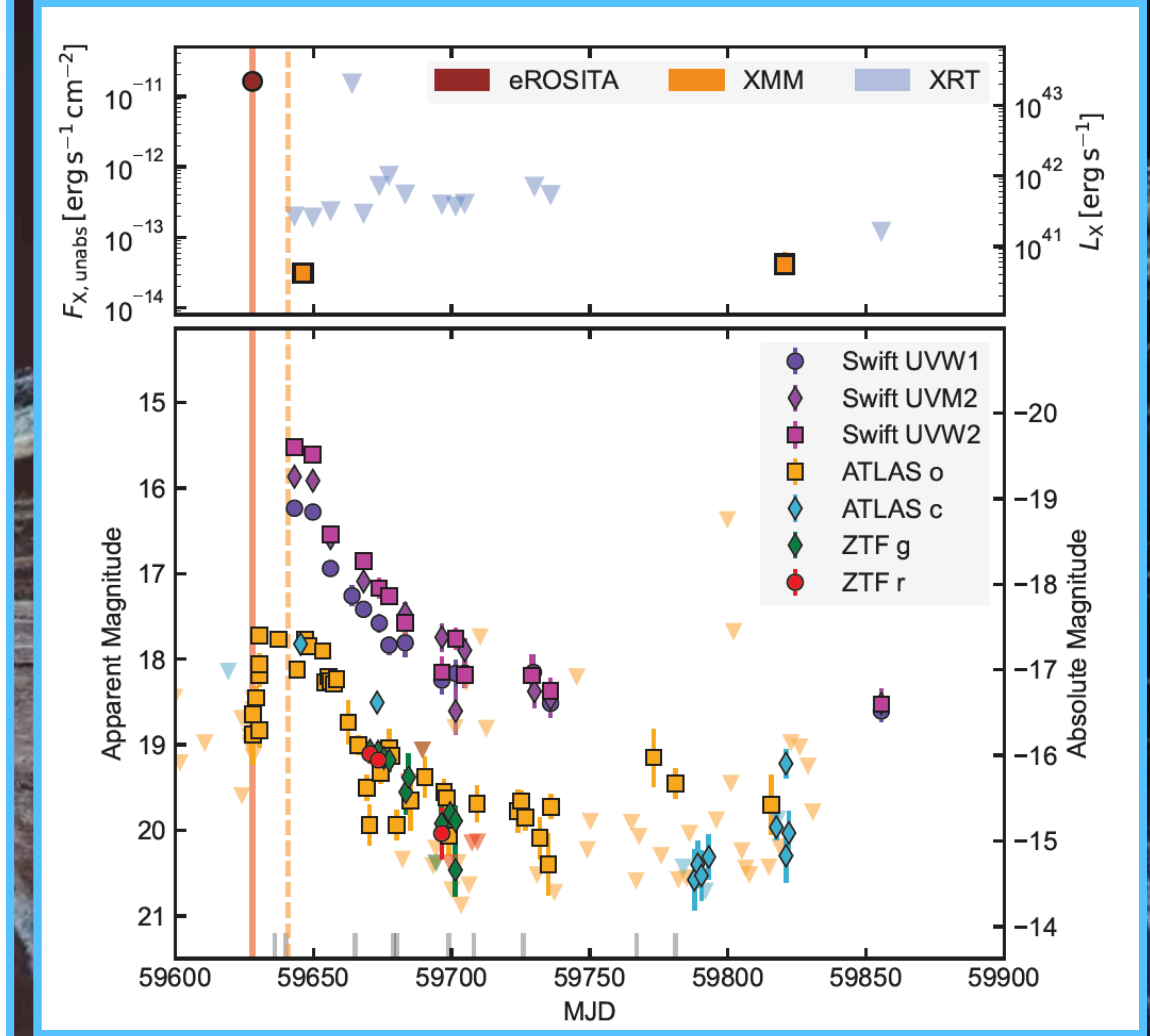
(Malyali, AR+26)

J2344

AT2022dsb



(Malyali, AR+26)



(Malyali, AR+24a)

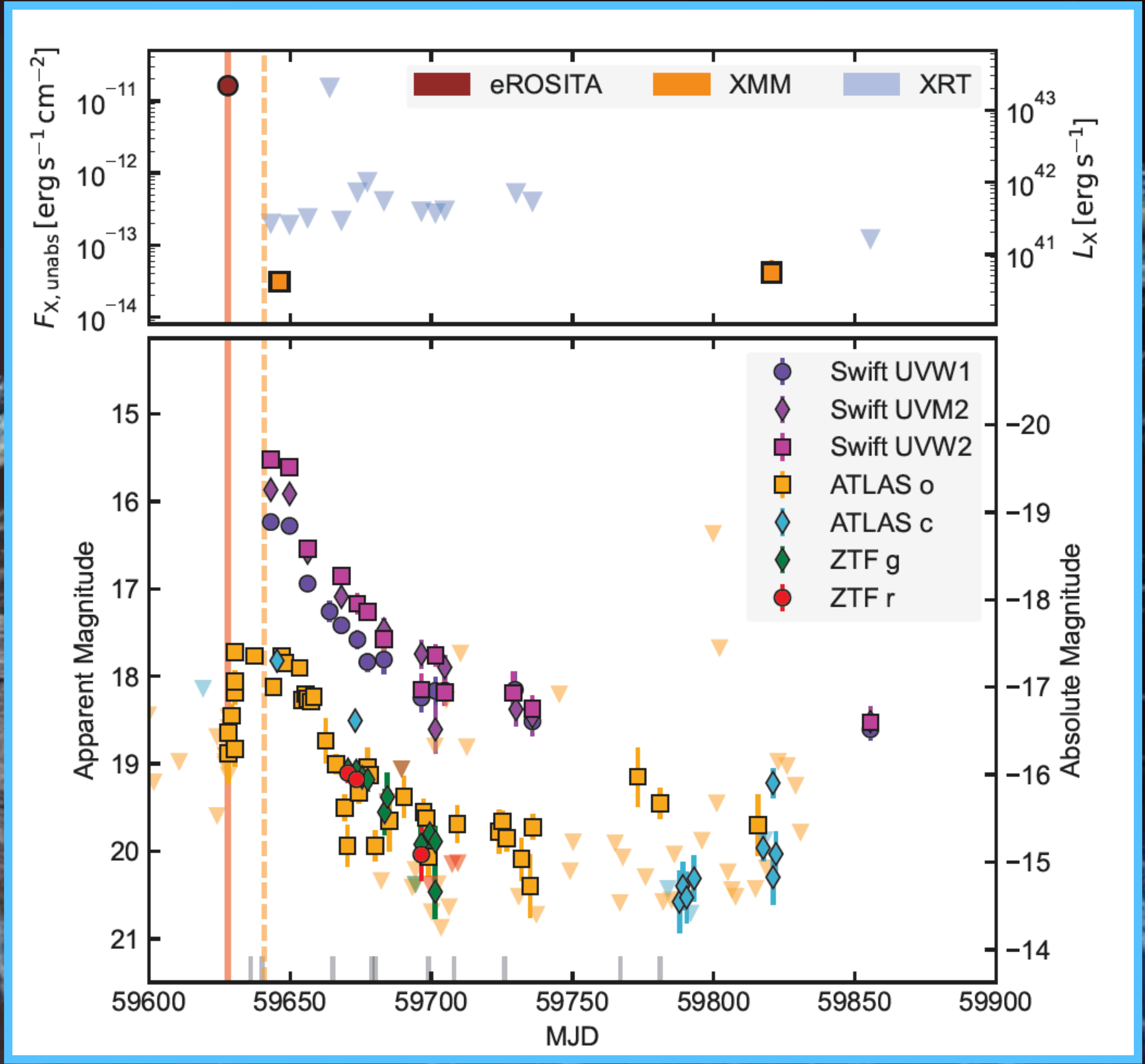
AT 2022dsb: Earliest X-ray detection

- eRASS5 discovery ~14d before optical peak (Liu+23)
- Ultra-soft (~45eV)
- Decay by >30 within ~19d revealed by XMM

- Outflow signatures detected in UV spectra (Engelthaler & Maksym 23), optical spectra, and radio

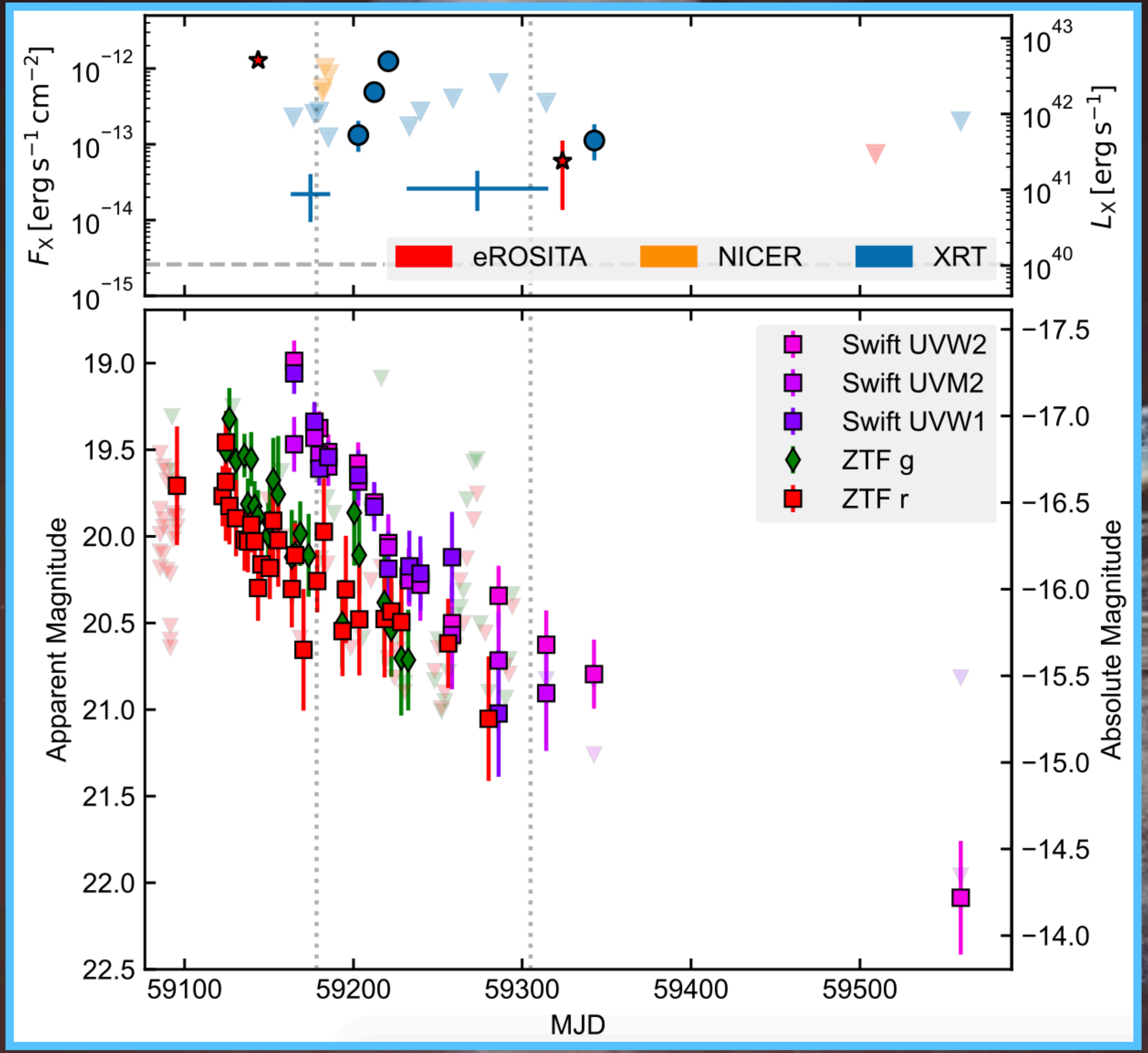
- Early X-ray detection consistent with 'nozzle shock' at pericentre

- Alternative: rapid accretion disk formation
- Fast X-ray decay interpreted as obscuration by outflowing thick debris
- Could explain other X-ray faint/non-detected optically-selected TDEs

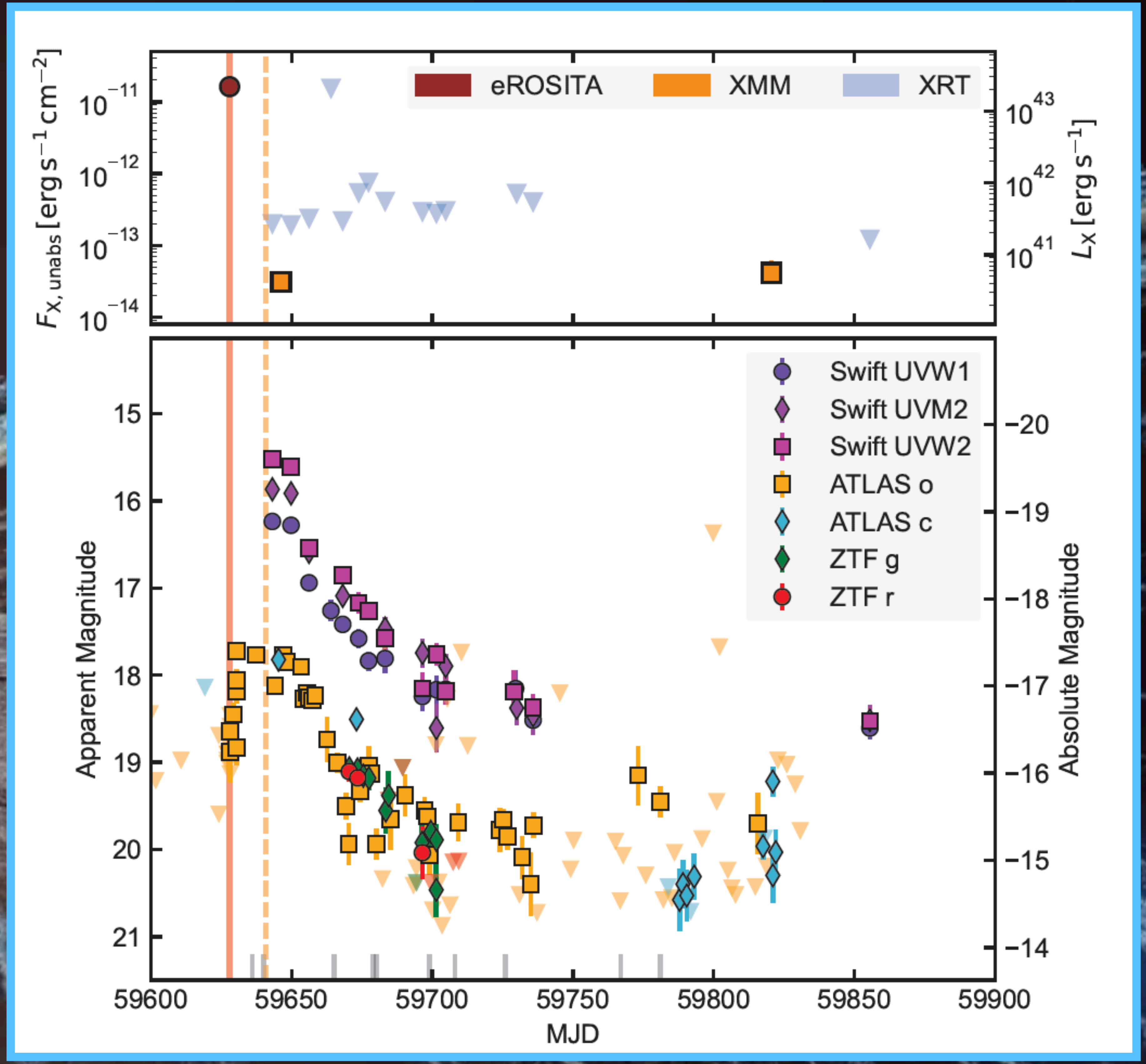


(Malyali, AR+24a)

eRASSt J074426.3+291606 AT 2022dsb

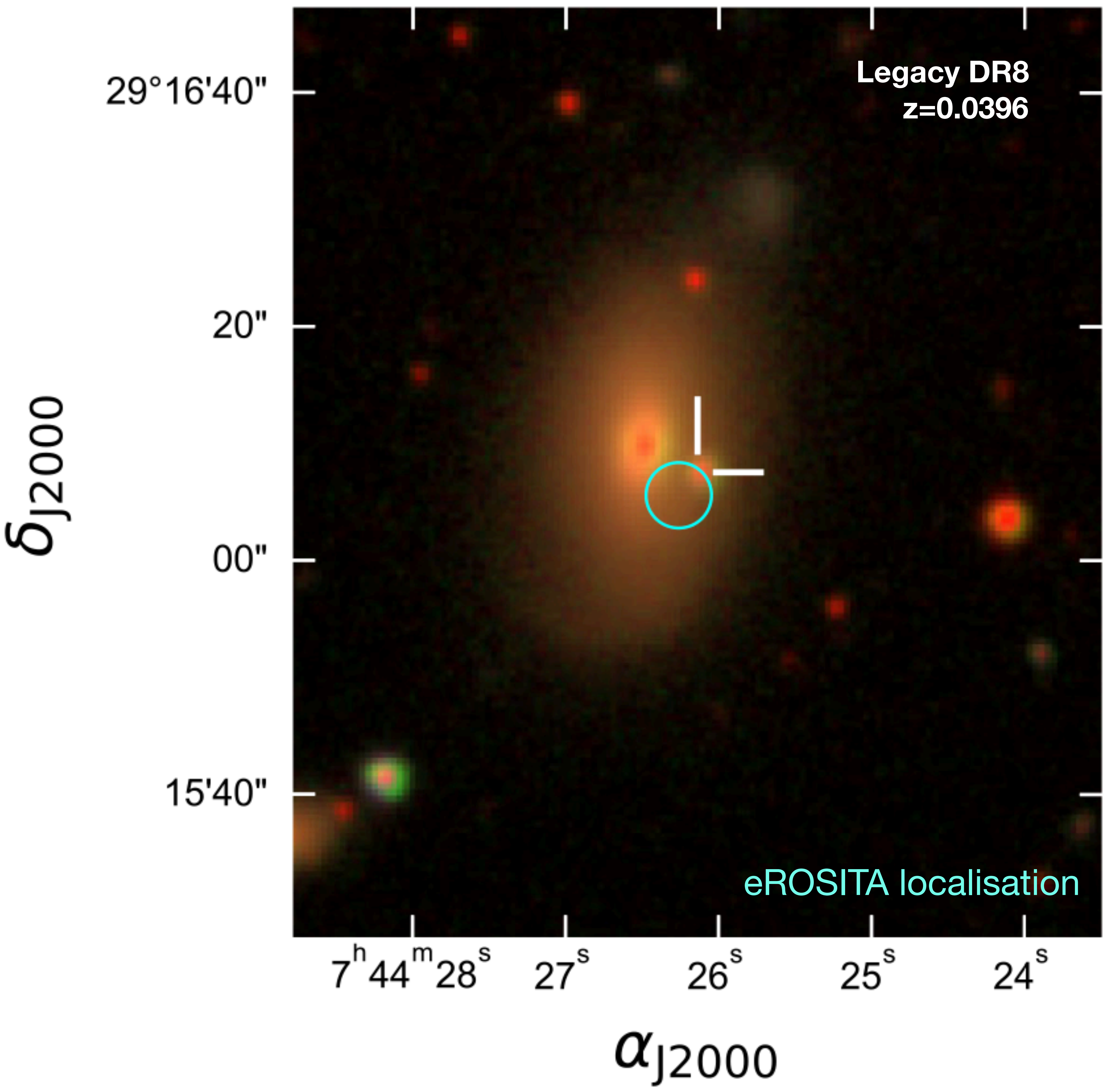


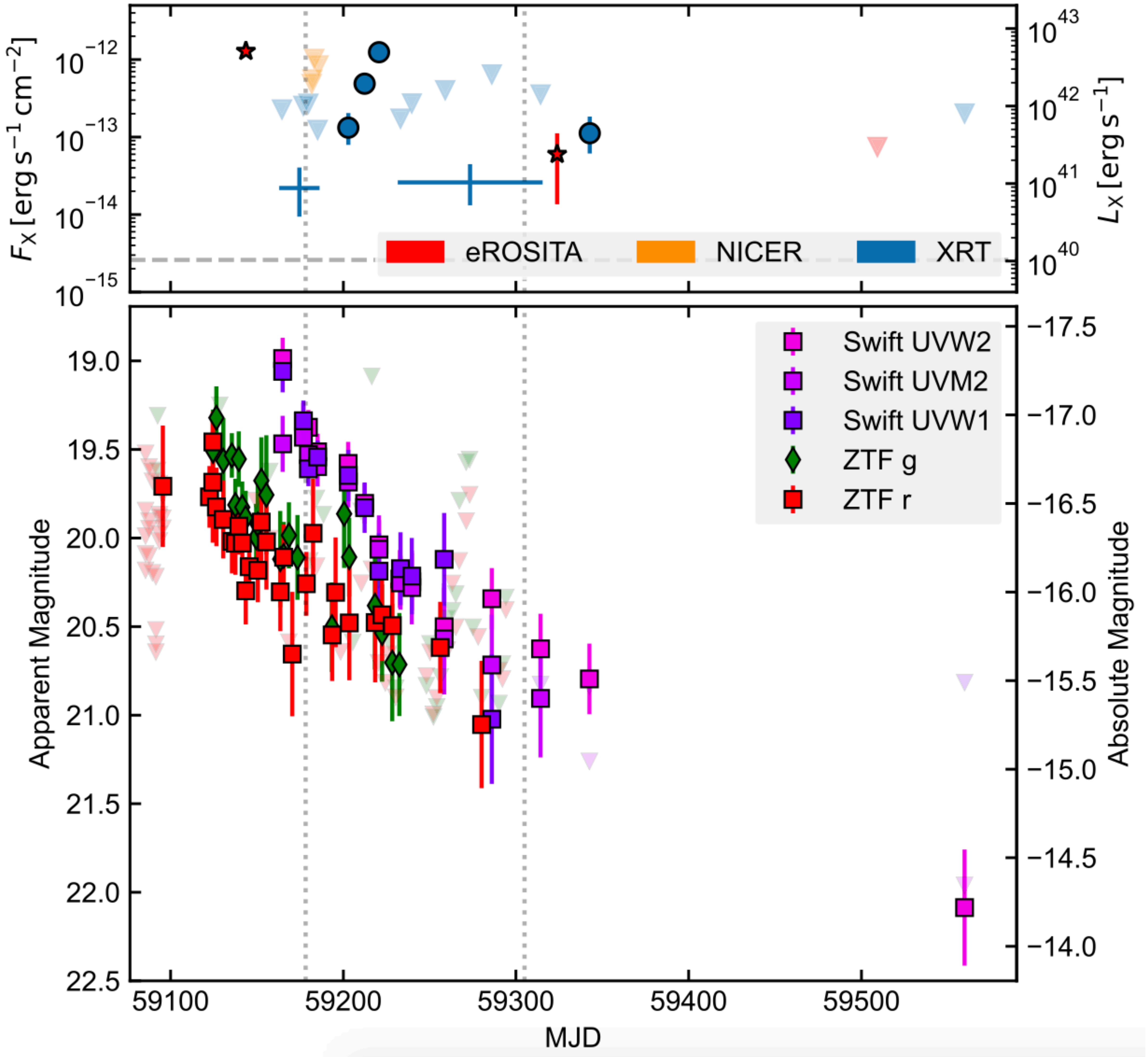
(Malyali+AR,+23a)



(Malyali, AR+24a)

eRASSt J074426.3+291606: faint/slow TDE in a dwarf galaxy (Malyali+23a)

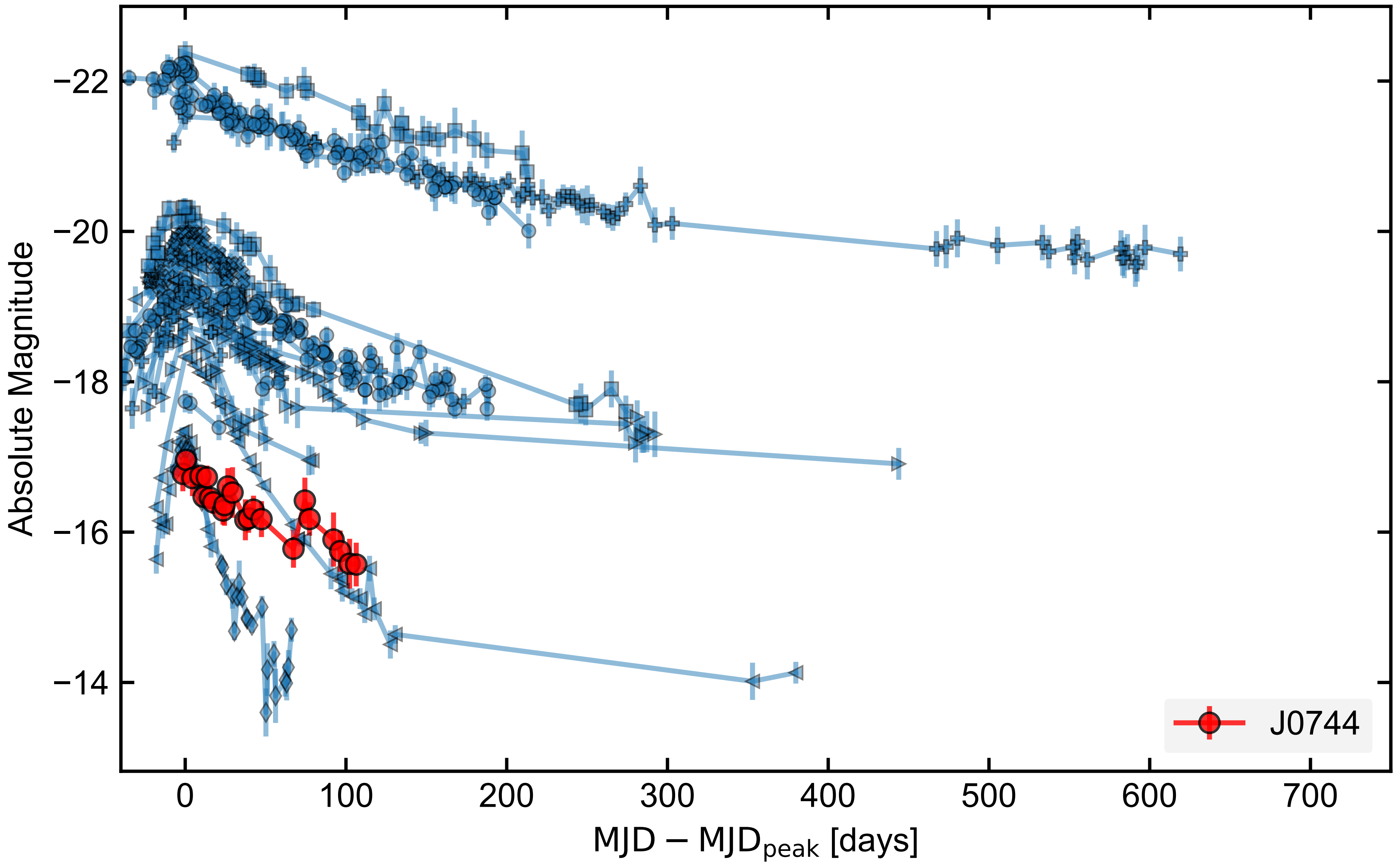


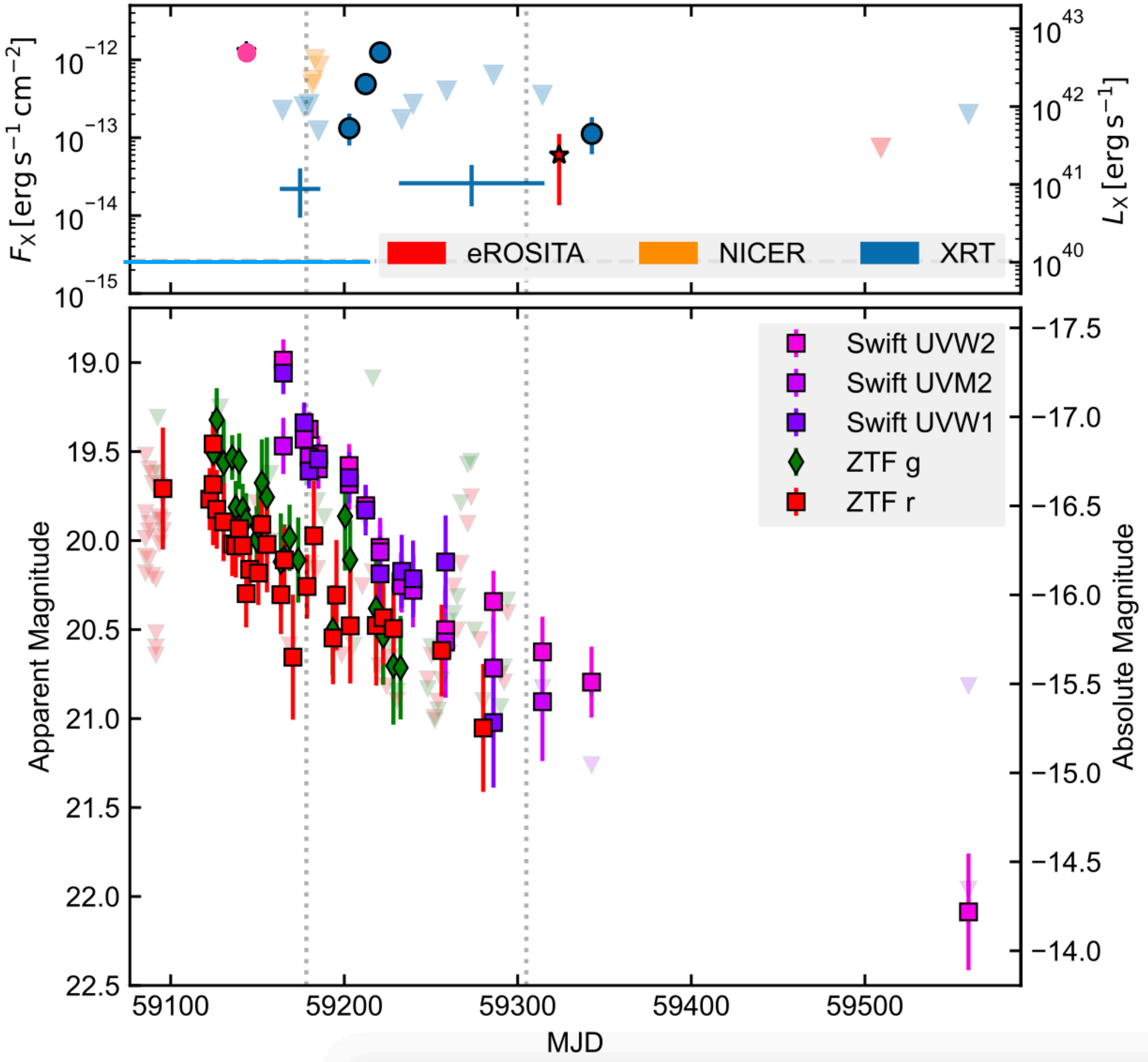


eRASSt J074426.3+291606: faint/slow TDE in a dwarf galaxy (Malyali+23a)

- eRASS2 discovery 160 above archival Chandra limit
- X-ray detection and optical peak suggest prompt disk formation
- Significant X-ray variability (x50) during decline interpreted as disk obscuration by unbound stellar debris

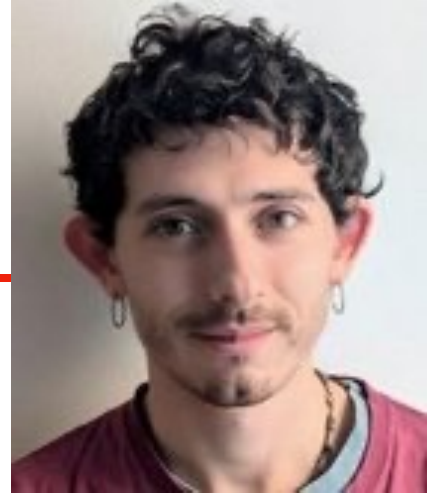
- Optically faint but slow!
- Dwarf galaxy hosts could lead to misclassifications as off-nuclear transients



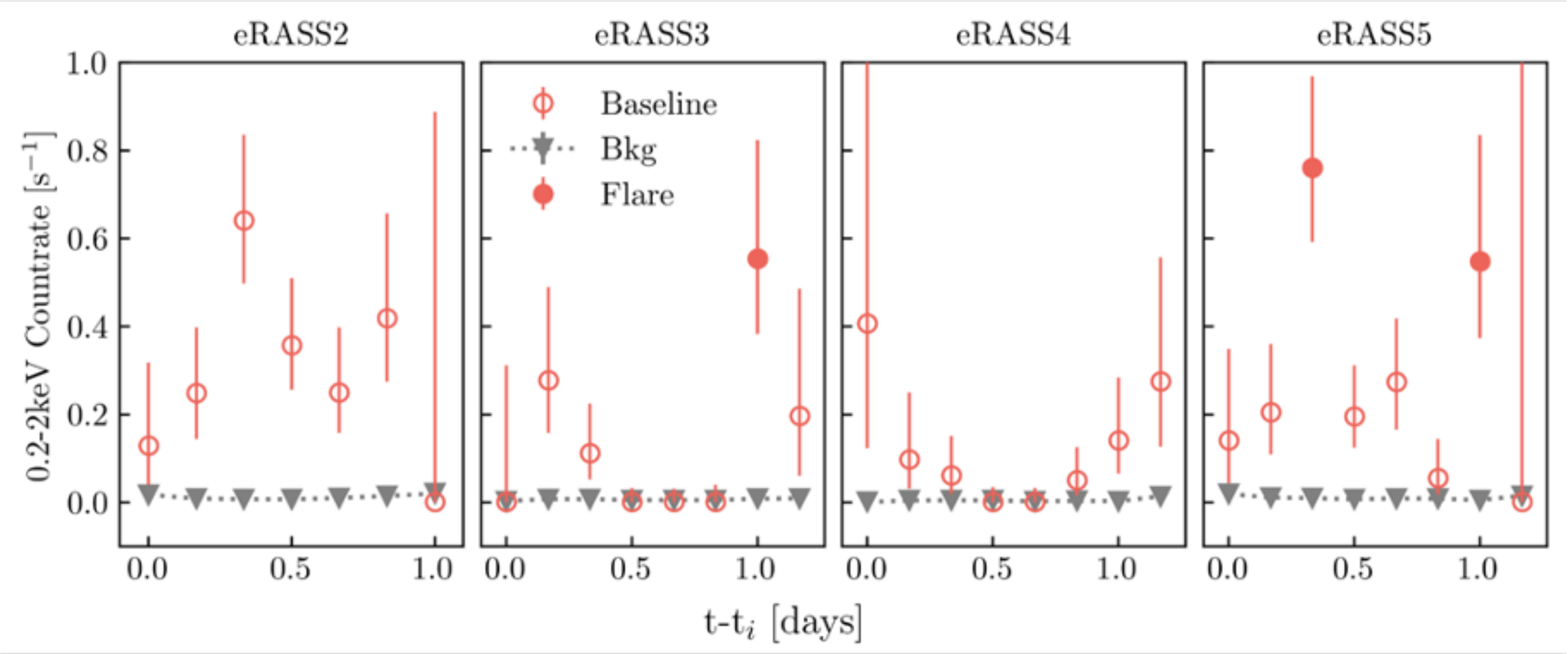


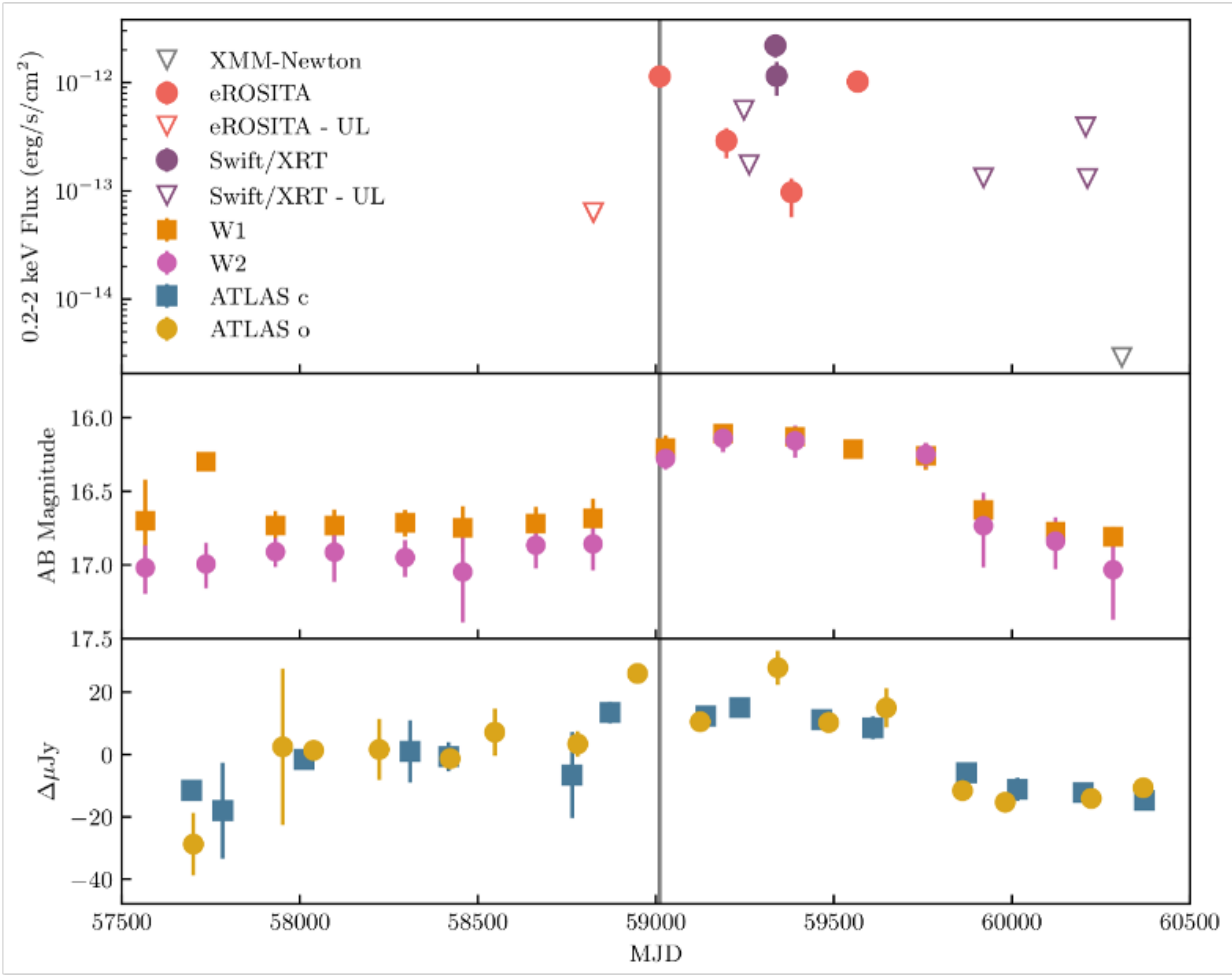
eRASS J012026-292727: highly variable on ~hour timescales

(Baldini, AR+25)



- eRASS2 discovery
- Significant short-time X-ray variability months after the peak
  - Infall of pre-existing gas?
  - Interaction of a third body with the newly ormed accretion disk?

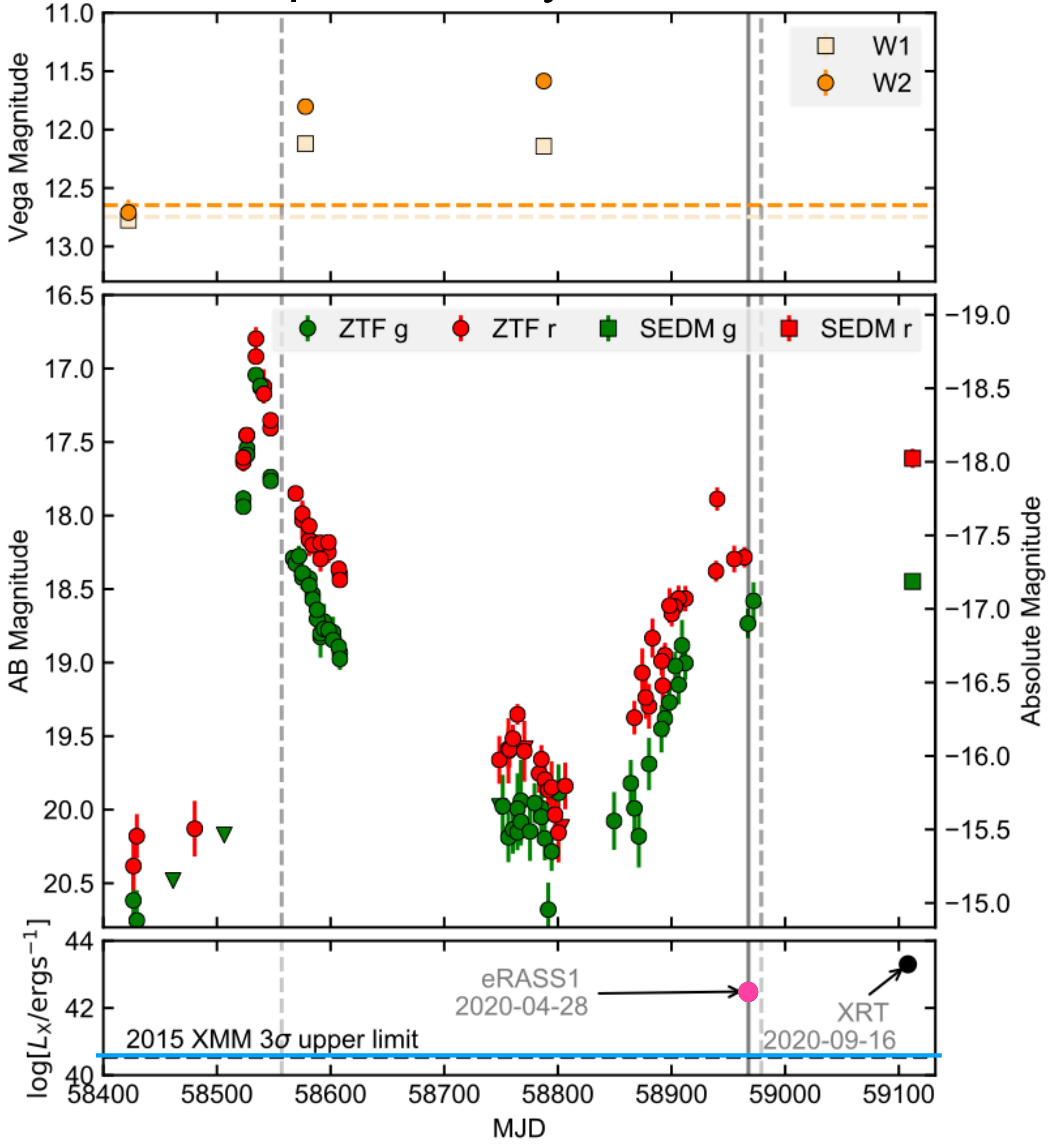




- Optical spectrum resembles Extreme Coronal Line Emitters (ECLE) and Bowen Fluorescence Flares (BFFs), connecting these classifications with TDEs

AT2019avd (eRASS1) - Double-peaked optical TDE (Malyali, AR+21)

IR, optical, X-ray data (Malyali+21)

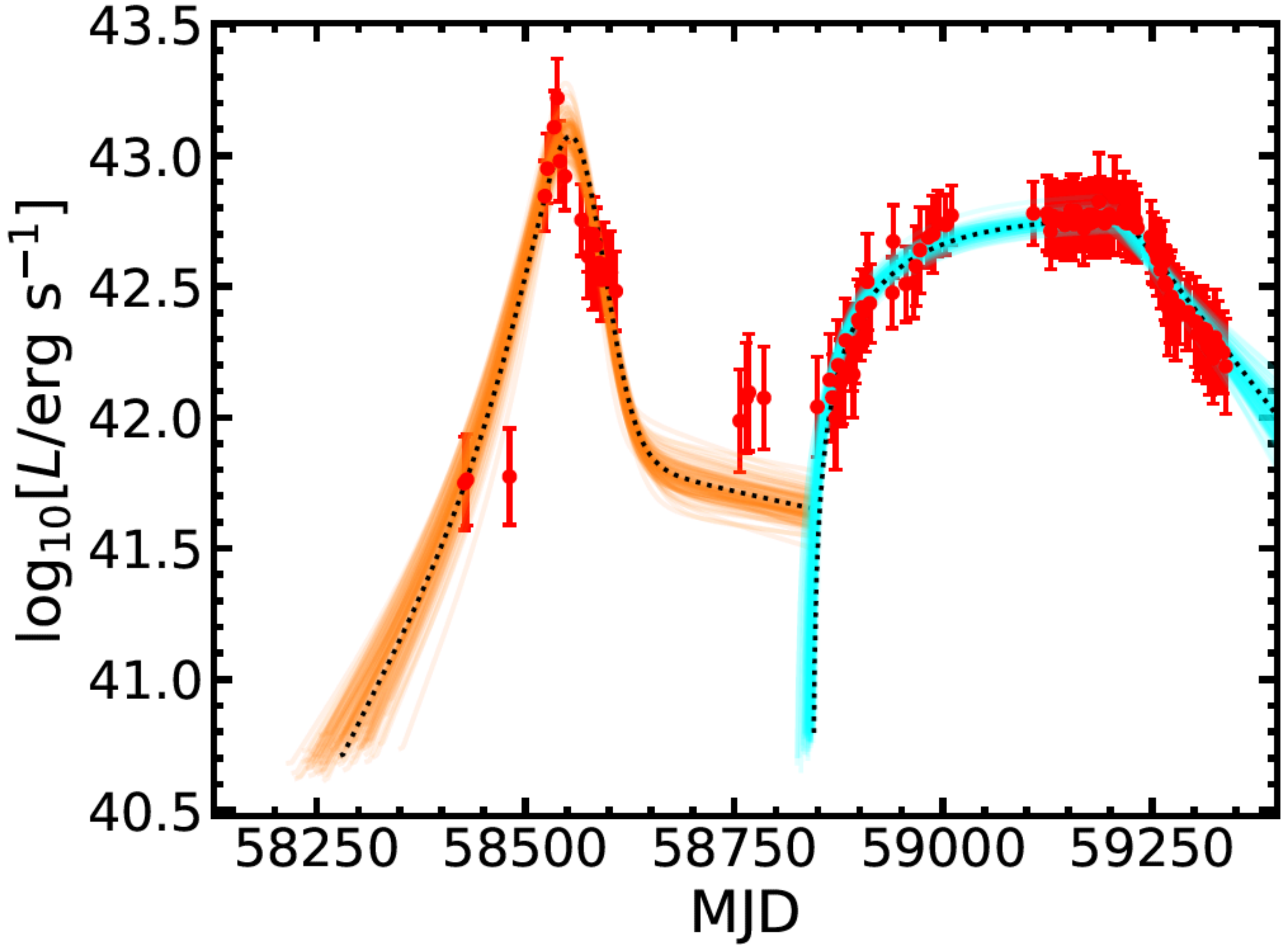


- eRASS1 discovery 600x above archival XMM limi
- TDE_like X-ray luminosity and spectrum (~85eV)

But

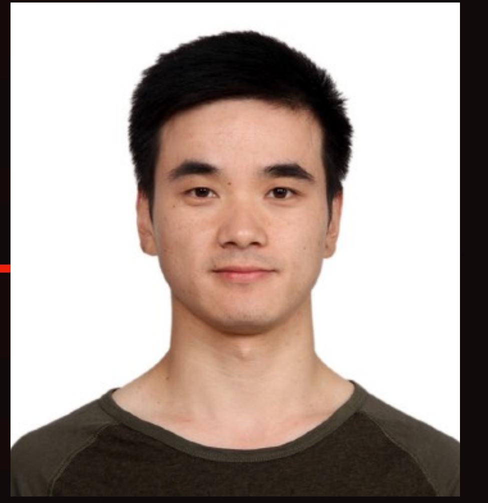
- double-peaked optical light curve
- Orange: self-crossing, i.e. circularisation of debris stream
- Cyan: Delayed accretion (cyan), consistent with X-ray detection

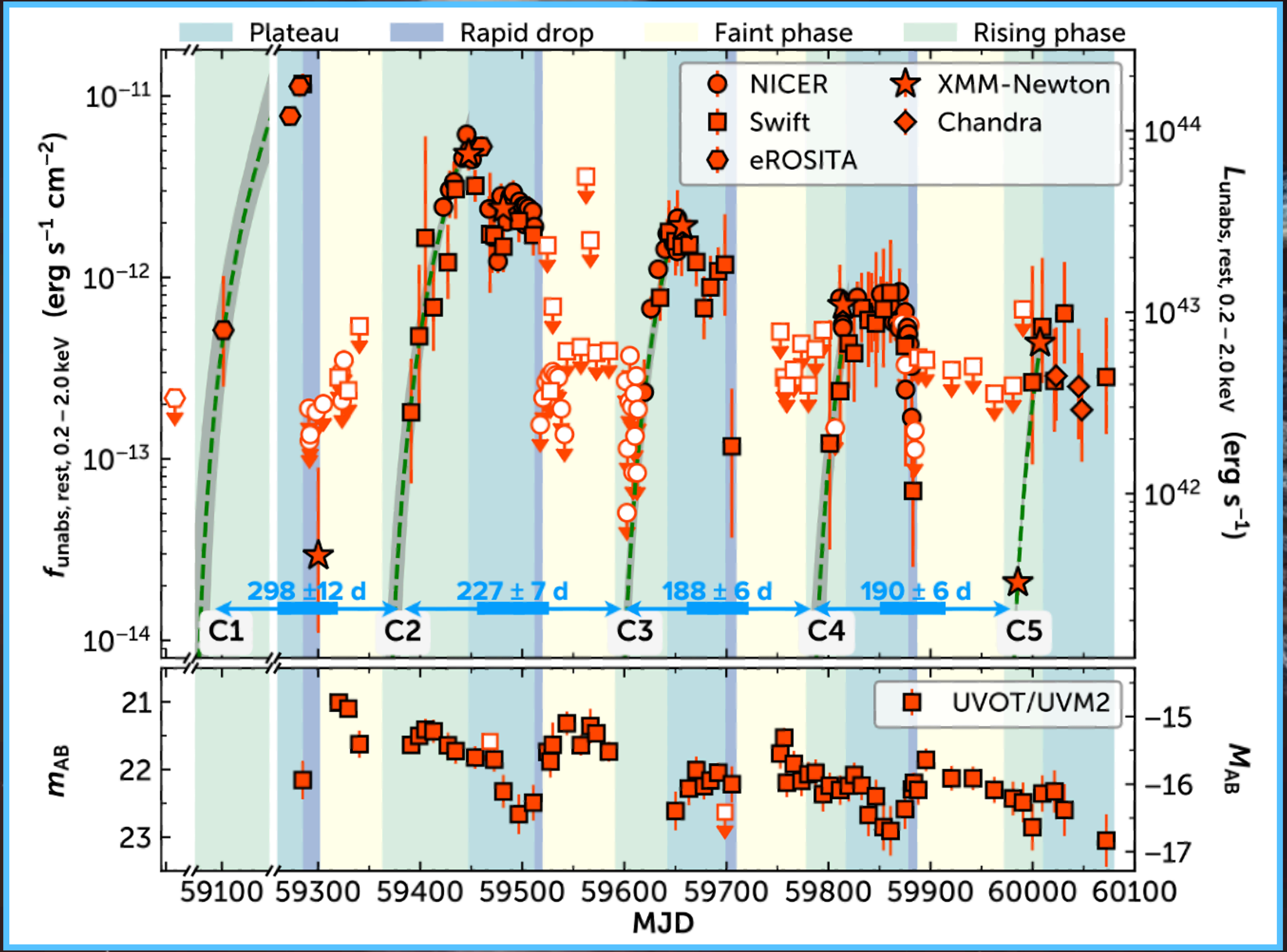
Model (Chen+22)



J0456 - Repeating partial TDE

(Zhu Liu+23,24)

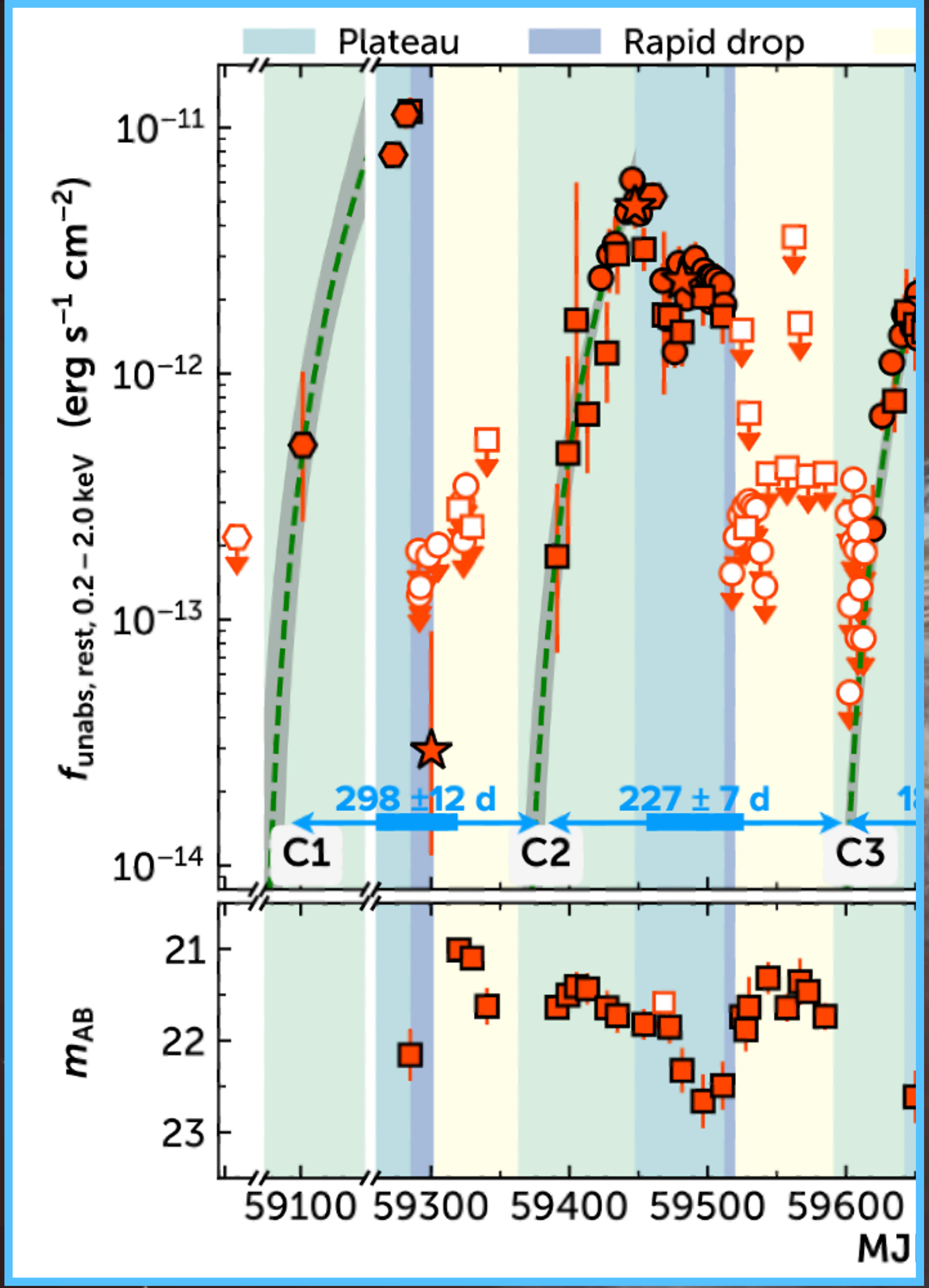


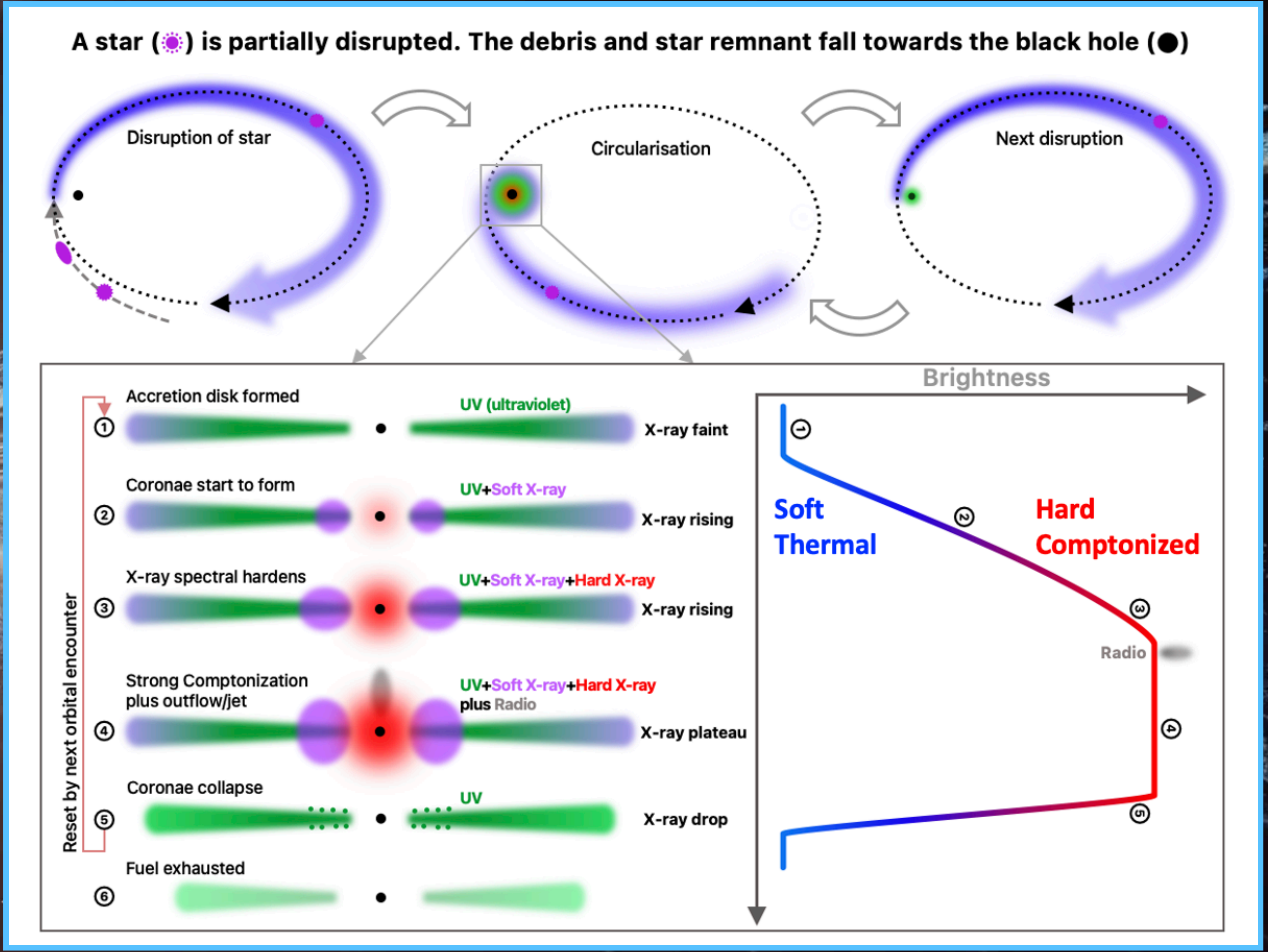


- z=0.077, M_{BH}~$10^7M_\odot$
- 5 repeating X-ray/UV flares
- Repeating transient radio emission
- No transient optical or MIR emission
- Most promising pTDE candidate (Payne et al. 2021, Malyali et al. 2023, Wevers et al. 2023, Webb et al. 2023)

- Evolving recurrence time (from ~300d to 190d) explained by changes in stellar orbit

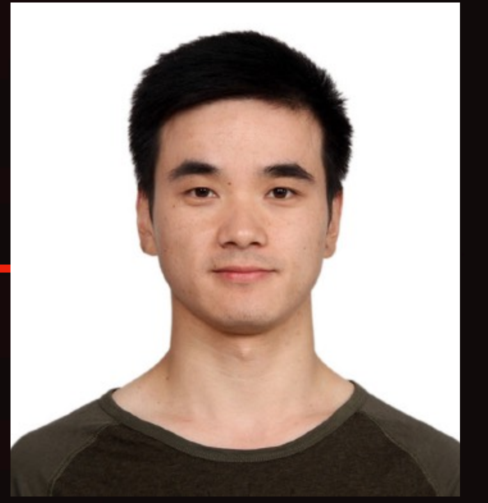
Spectral evolution suggests corona formation (months) and destruction (days).

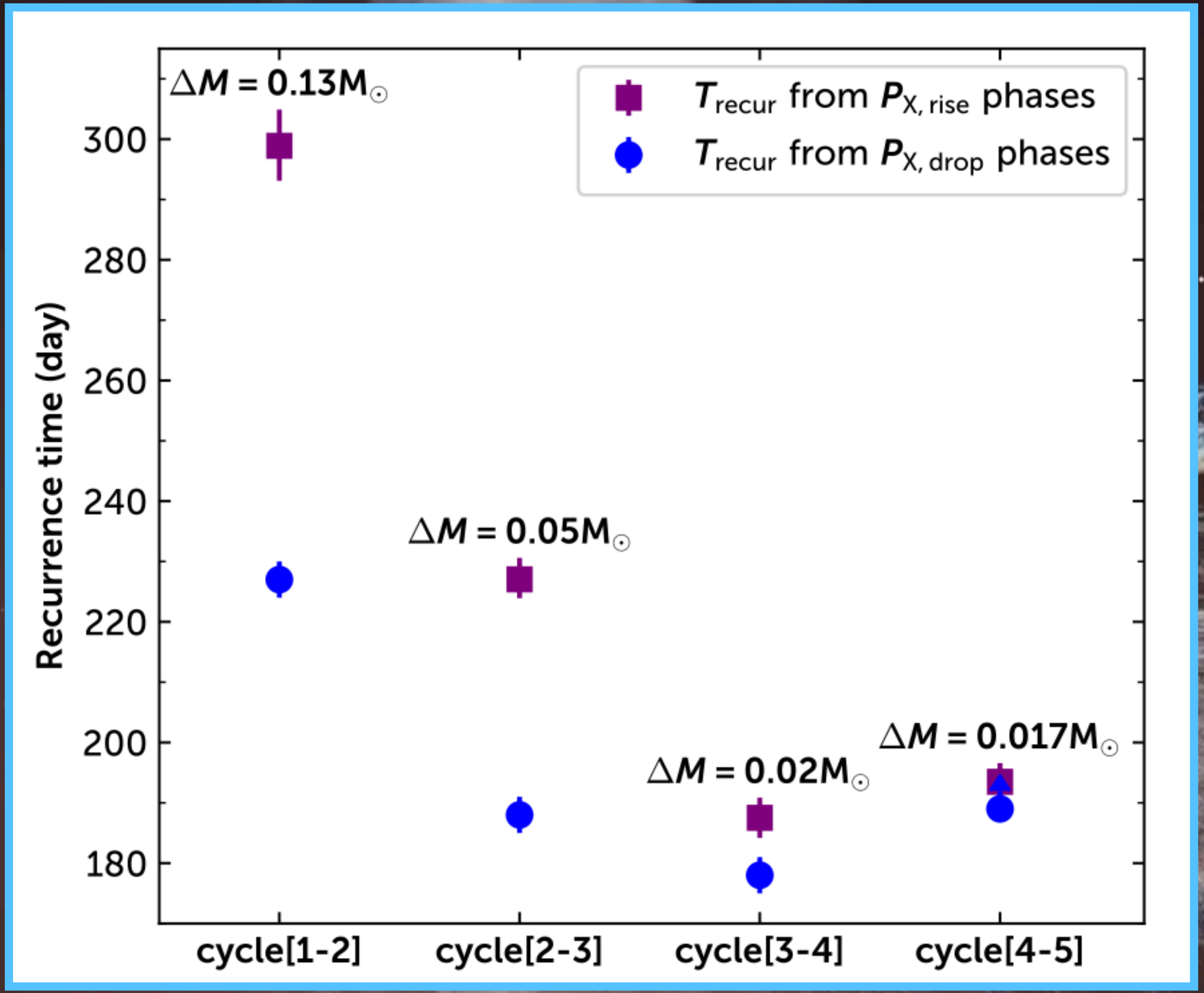


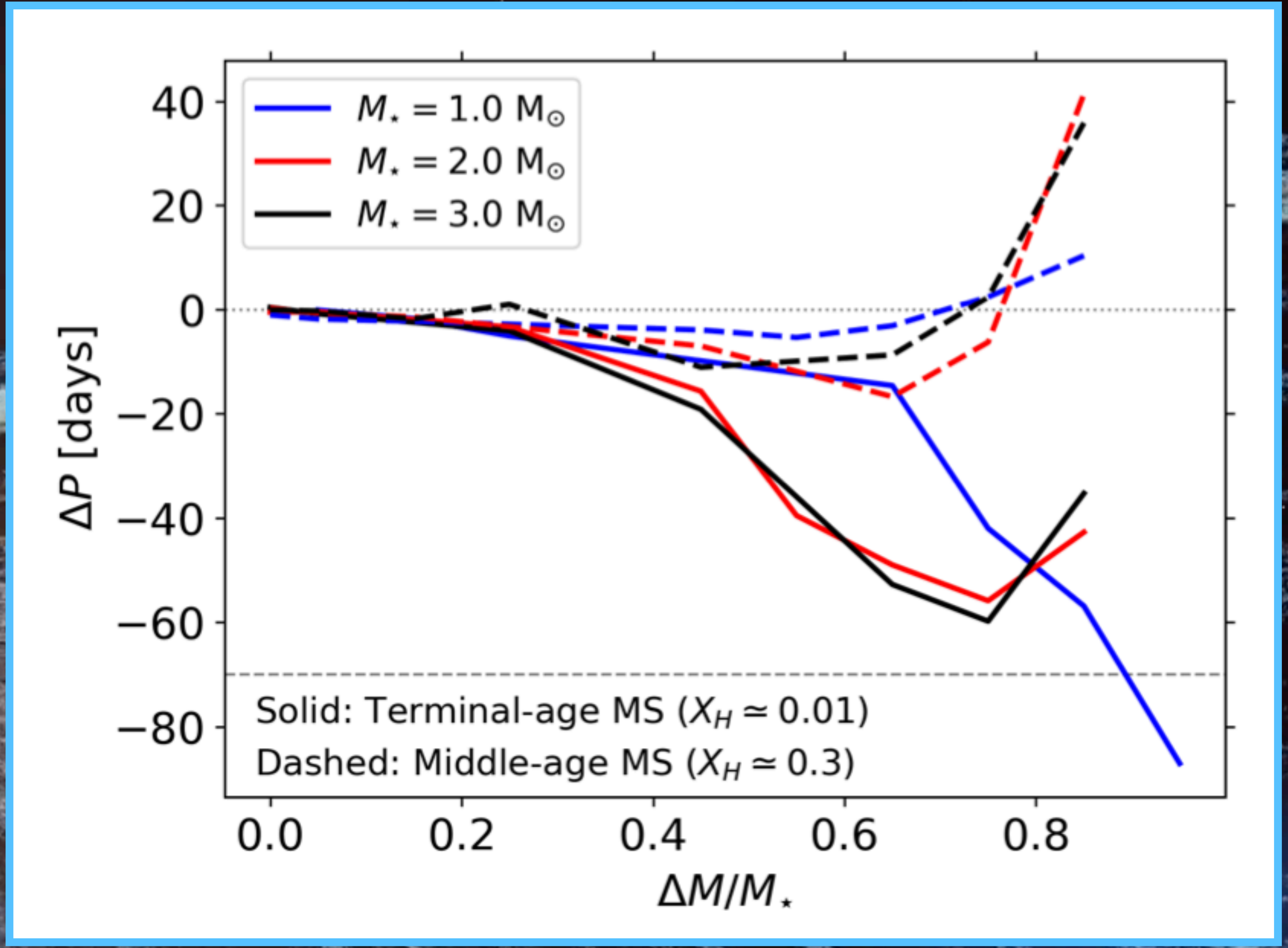


(Zhu Liu+23,24)

Recurrence Time Scale Evolution Probing Stellar Dynamics





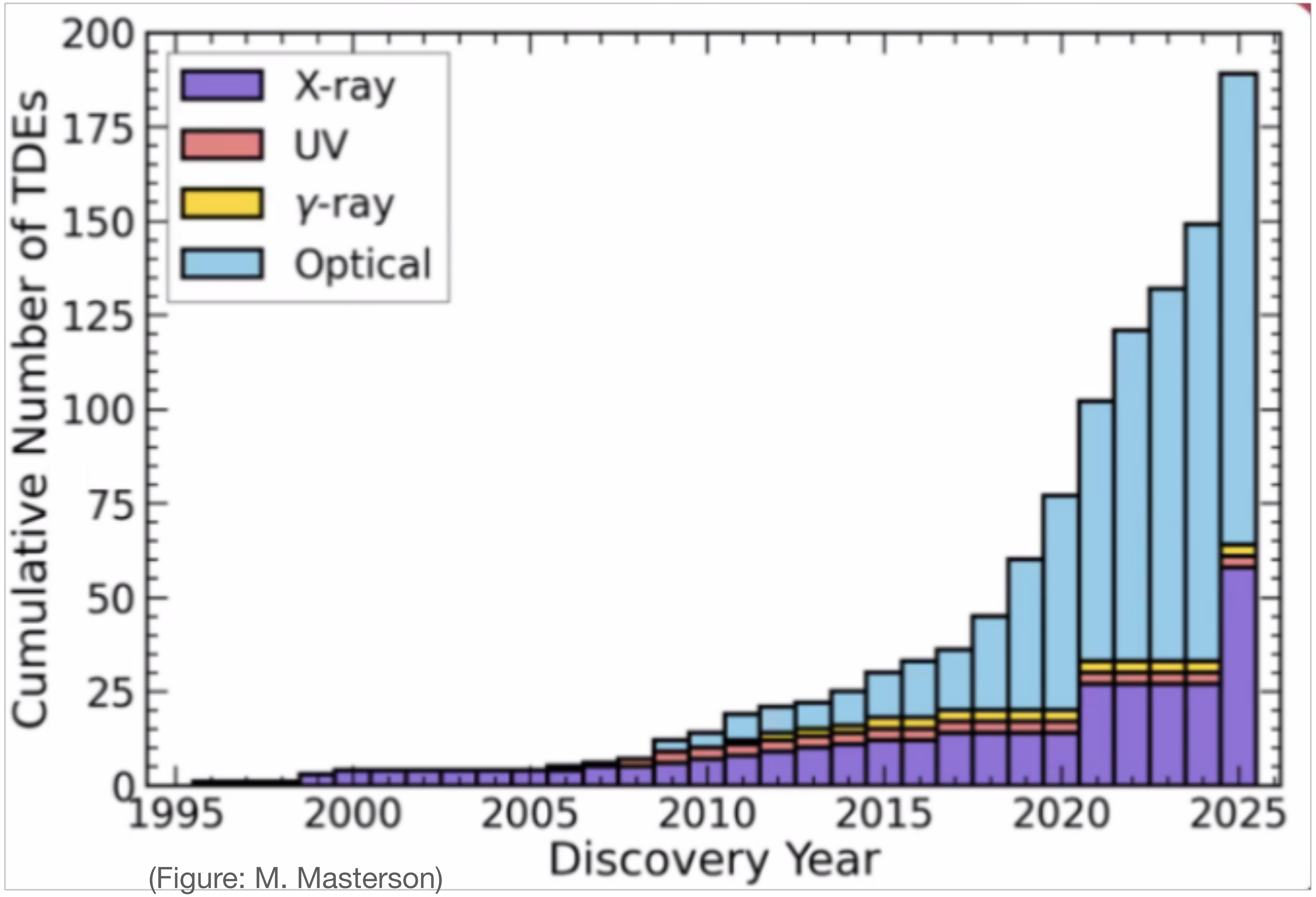


(Zhu Liu+24)

- Recurrence time constraints the initial mass of the star and the mass loss during each encounter
- Partial TDEs can be effective probes of stellar/gas dynamics around SMBHs beyond the Galaxy

Summary of Chapters

1. **eROSITA enables X-ray-selected TDE population studies** (Grotova+25a,b, Sazonov+21, Khorunzev+22, Zhang+26)
   - ~30 very good TDE candidates per year (0.2-2 keV, $F_X > 1 \times 10^{-13}$ erg/s/cm^2)
   - Increase in the rate of X-ray selected TDEs by an order of magnitude with respect to the pre-eROSITA era



(Figure: M. Masterson)

Summary of Chapters

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   - Increase in the rate of X-ray selected TDEs by an order of magnitude with respect to the pre-eROSITA era

2. **eROSITA's TDEs show a rich diversity of X-ray behaviours:** (Malyali+21,23a,23b,24,26,Homan+23, Liu+23,24, Baldini+25a,b)
   - X-rays can be peak before, after, or at the same time as the optical/UV maximum
   - X-rays can fade fast, slow, and/or show variability on a broad range of time scales and amplitudes
   - X-rays can show major repeated flares- due to repeated partial TDEs

3. **And similarly for their optical evolution:**
   - Fast/slow, double-peaked, or canonical
   - Majority (~70-90 %) shows no transient optical emission
   - Even smaller fraction (~5-10%) shows transient spectral features

4. **NewAthena's contribution to TDE studies:**
   - Extend population studies of X-ray selected TDEs to higher redshift and probe cosmic evolution (WFI)
   - Physics of accretion, outflows and winds (X-IFU)

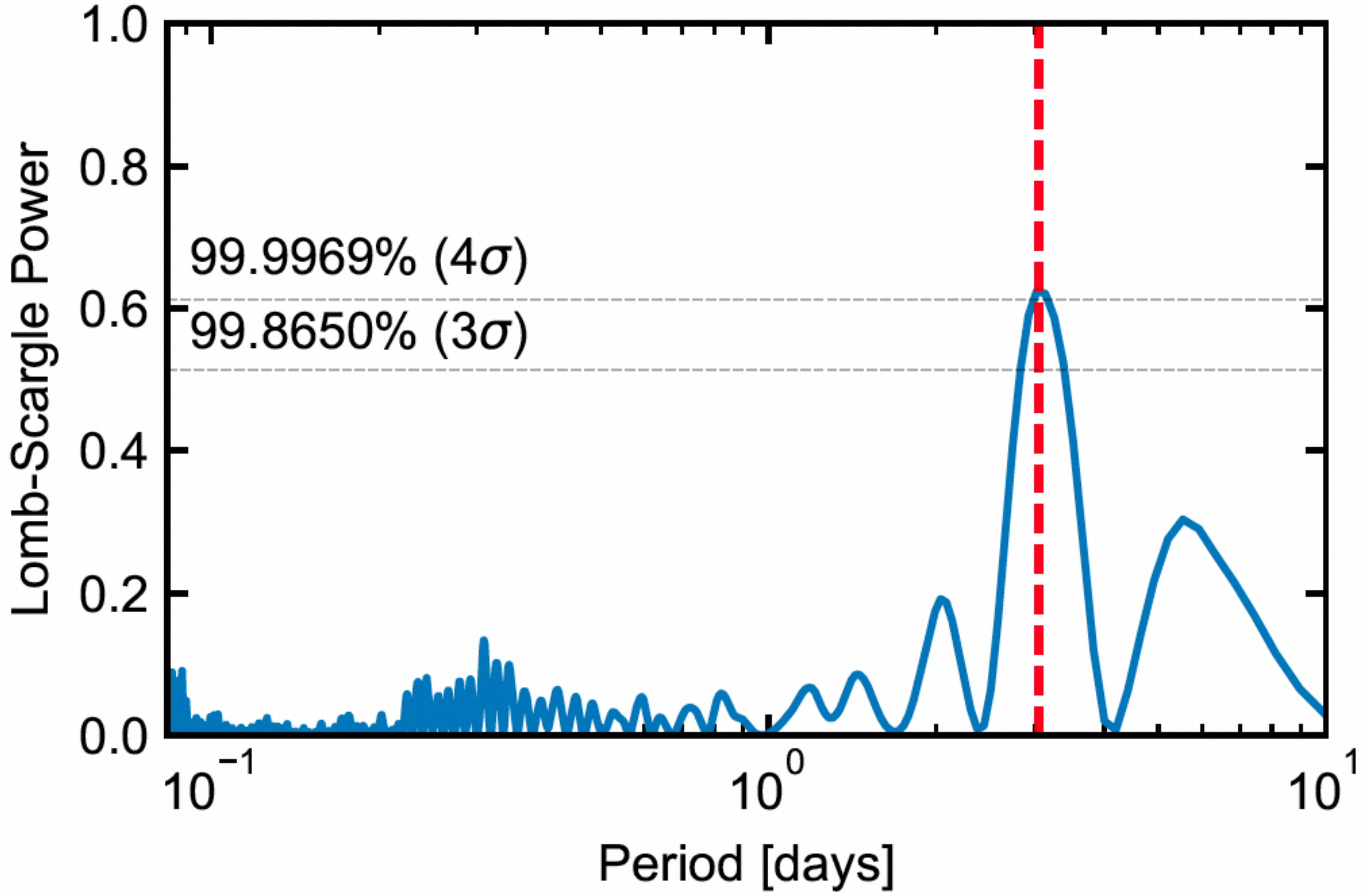
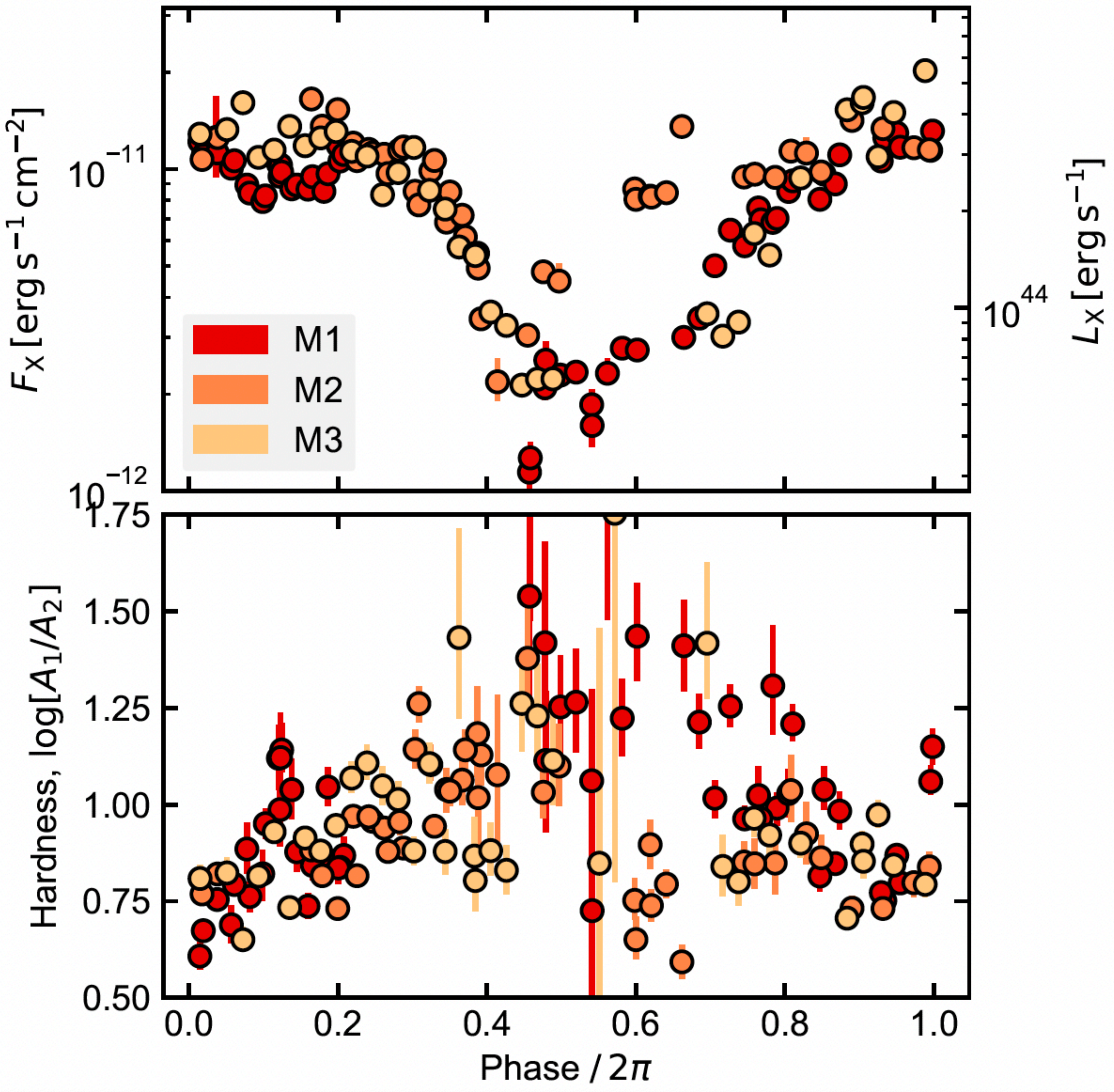
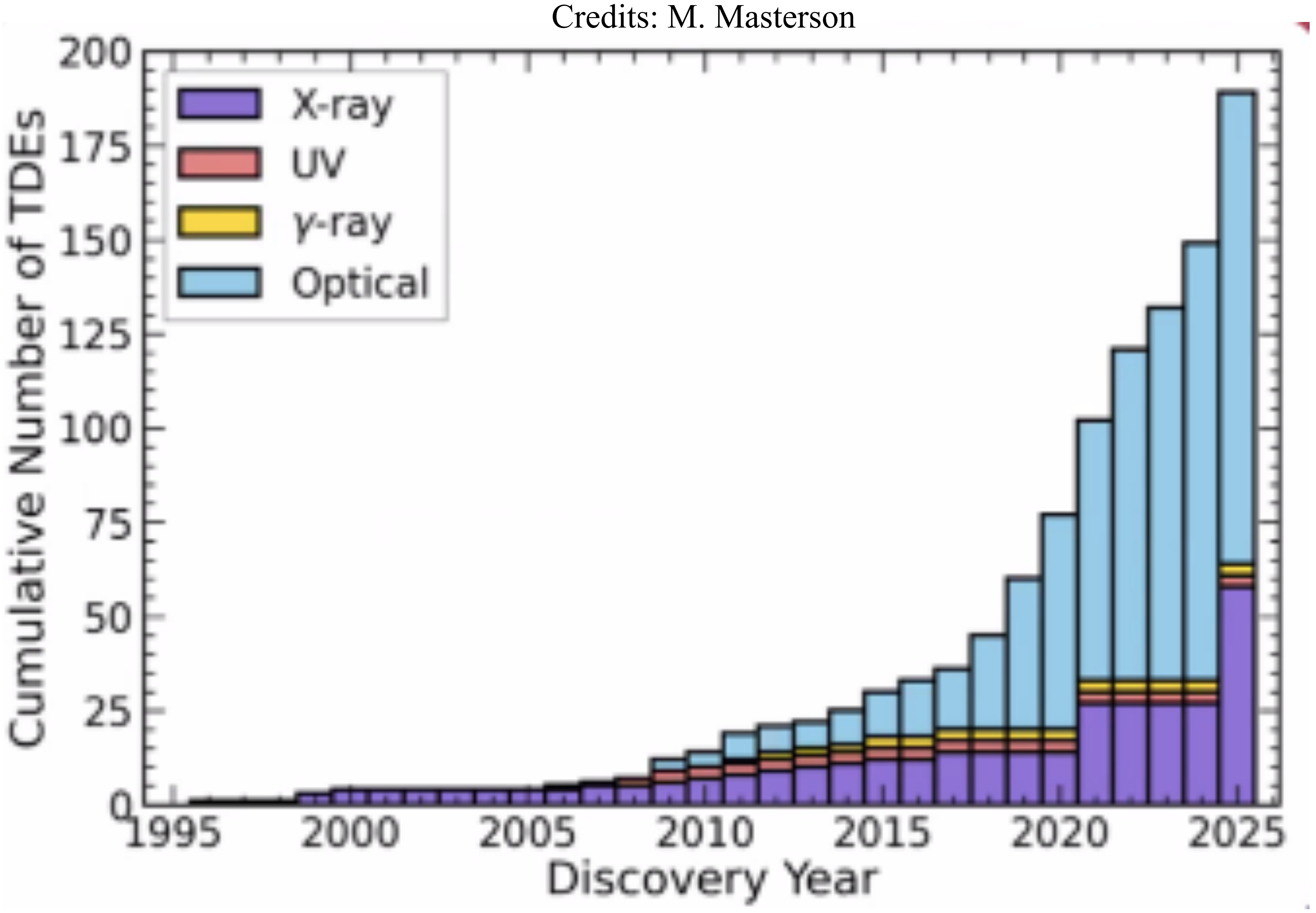
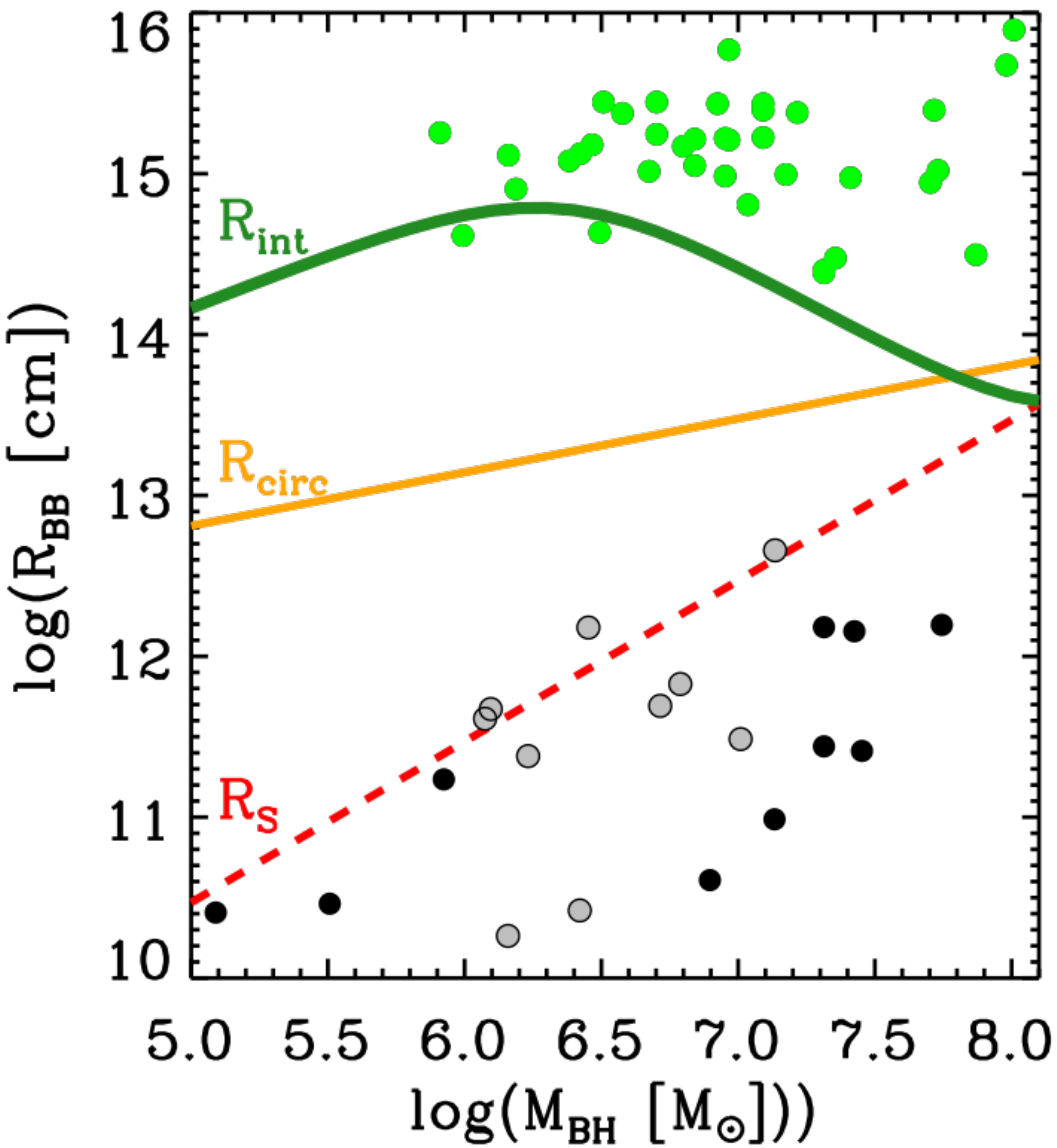


Fig. 7. LSP computed from the 0.2−2 keV light curve between MJD 59215 and 59240. The dashed red line marks the period $t_{\rm p} = 3.0^{+0.6}_{-0.4}$ days, inferred from the peak with maximum power. The two dashed grey lines mark the 0.998650 (≈3σ) and 0.999969 (≈4σ) upper quantiles of the distribution of maximum Lomb-Scargle powers computed from the synthetic light curves (Fig. D.4).



Credits: M. Masterson

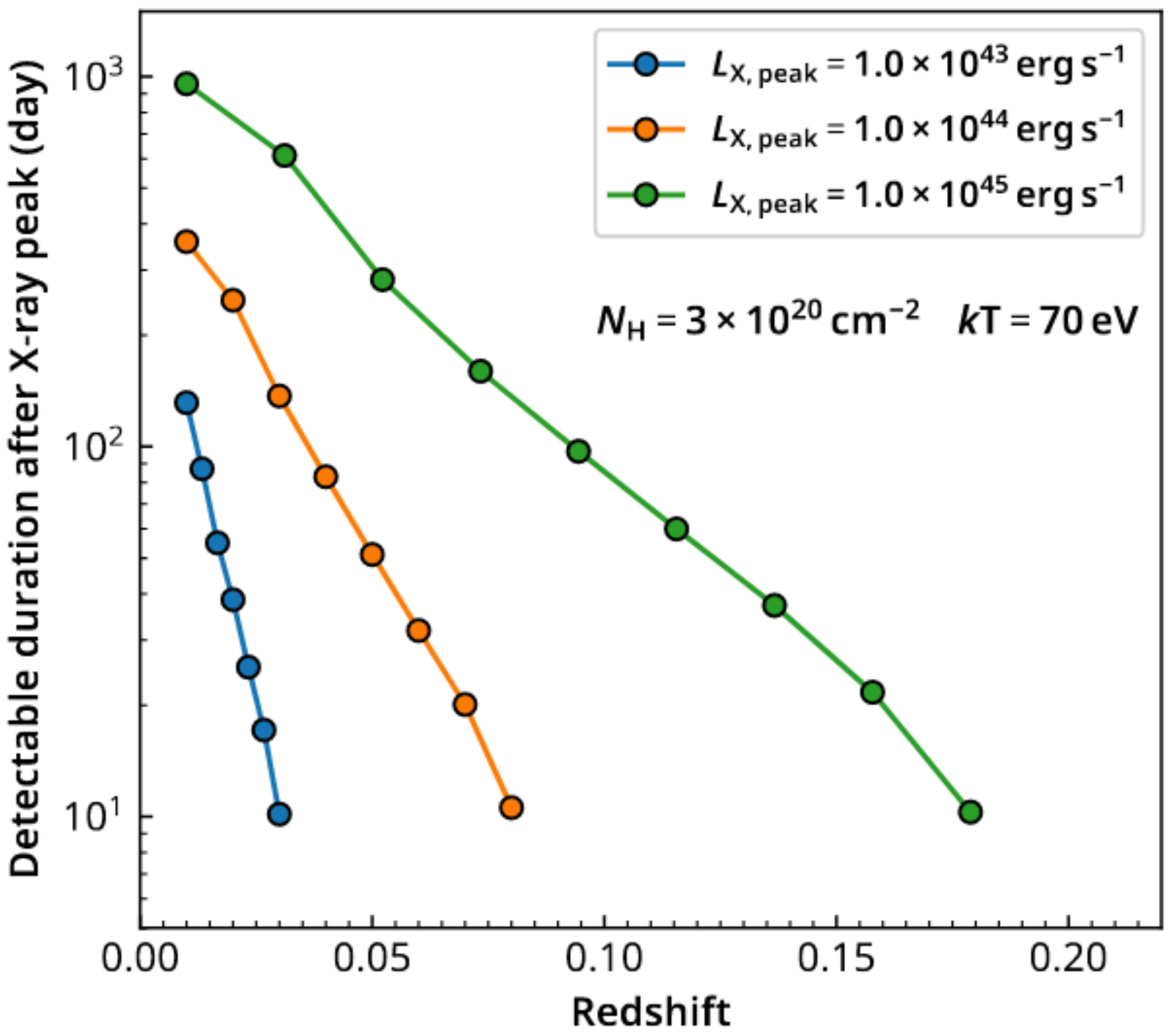


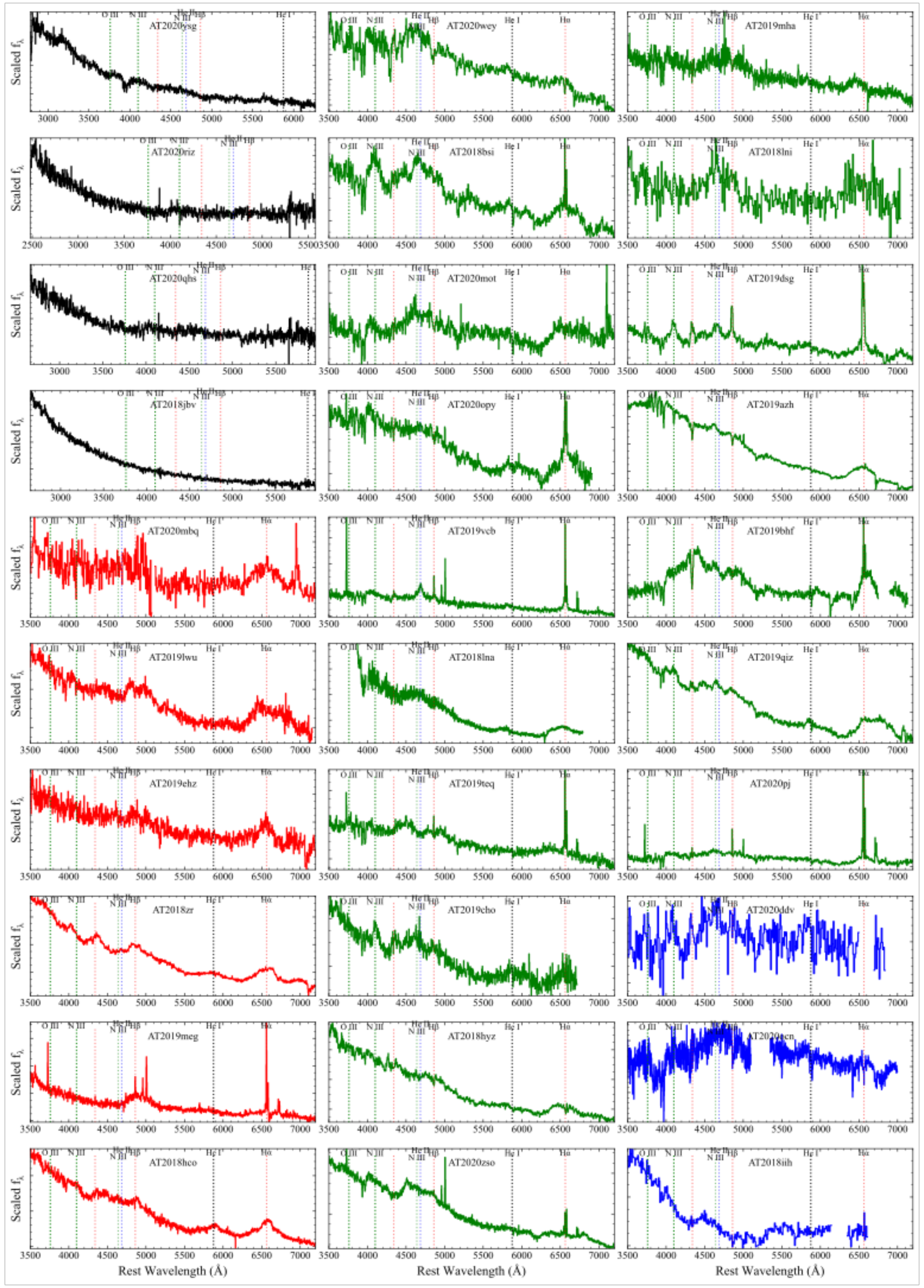


R_{int}: radius of intersection of debris streams near apocenter

R_{circ}: circularization radius (2x R_T)

R_S: Schwarzschild radius


$L_{X,peak} = 1.0 \times 10^{43}$ erg s^{-1}
$L_{X,peak} = 1.0 \times 10^{44}$ erg s^{-1}
$L_{X,peak} = 1.0 \times 10^{45}$ erg s^{-1}
$N_H = 3 \times 10^{20}$ cm^{-2} $kT = 70$ eV
Detectable duration after X-ray peak (day)
Redshift
10^1
10^2
10^3
0.00
0.05
0.10
0.15
0.20



ZTF TDE
Spectral Types

TDE-featureless

TDE-H

TDE-H+He

TDE-He

Hammerstein, van Velzen, Gezari+ 2022