EAS 2023, Krakow, July 10-14

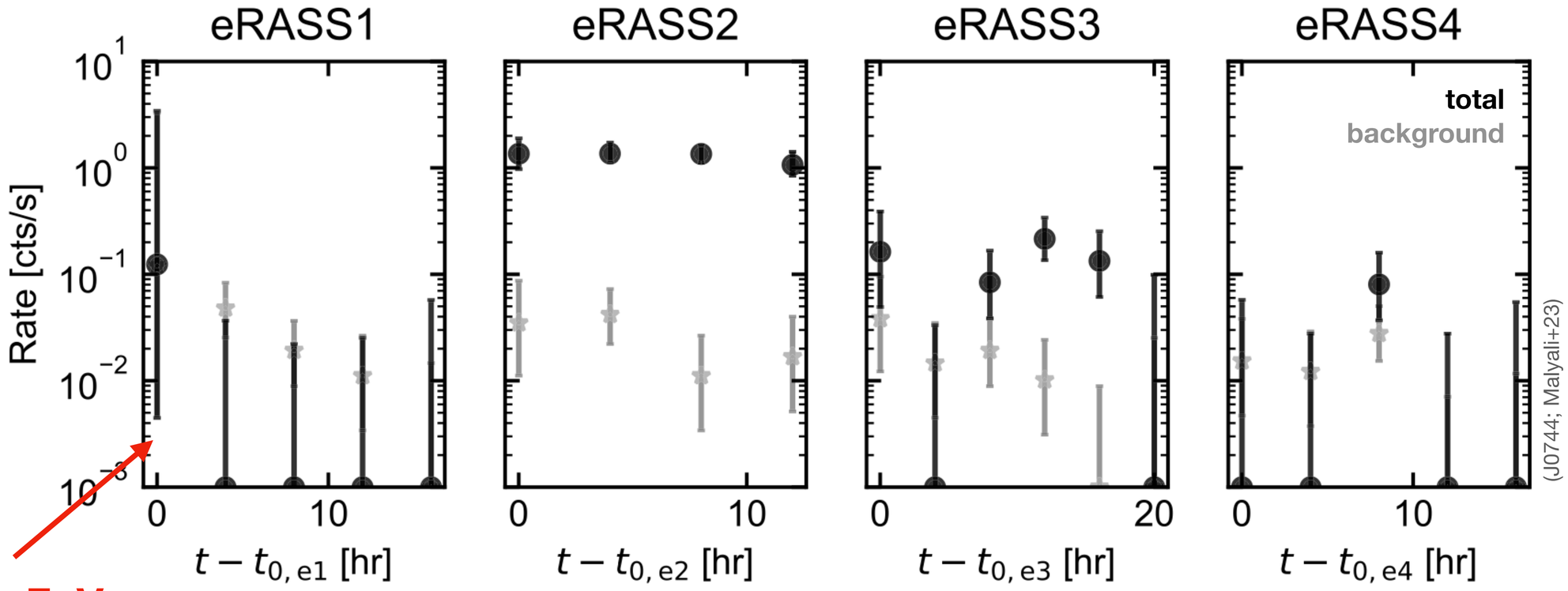
# Tidal Disruption Events with Uncovered by eROSITA

## Overview & some Highlights

**Zhu Liu** (Max Planck Institute for Extraterrestrial Physics)
w/ I. Grotova, A. Malyali, A. Merloni, A. Rau (all MPE) & D. Homan, M. Krumpe (both AIP) + many more

# eROSITA’s capabilities for TDE searches

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




**40s: scan over FoV**

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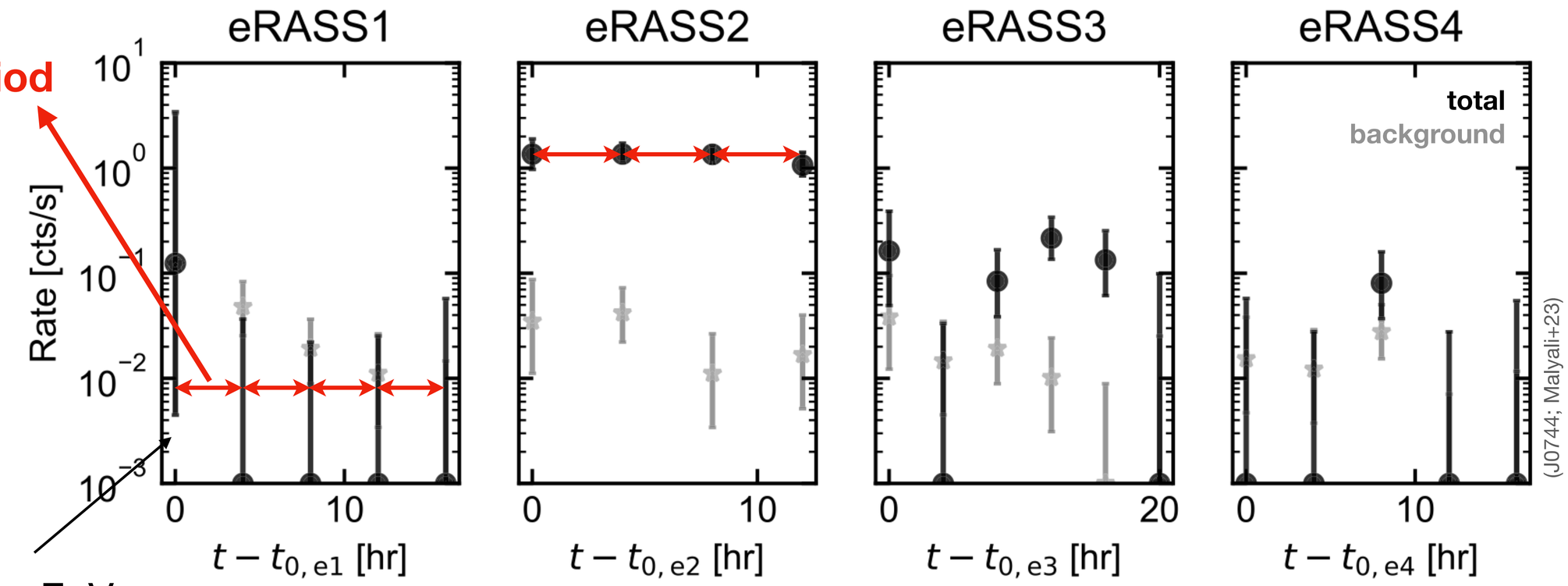


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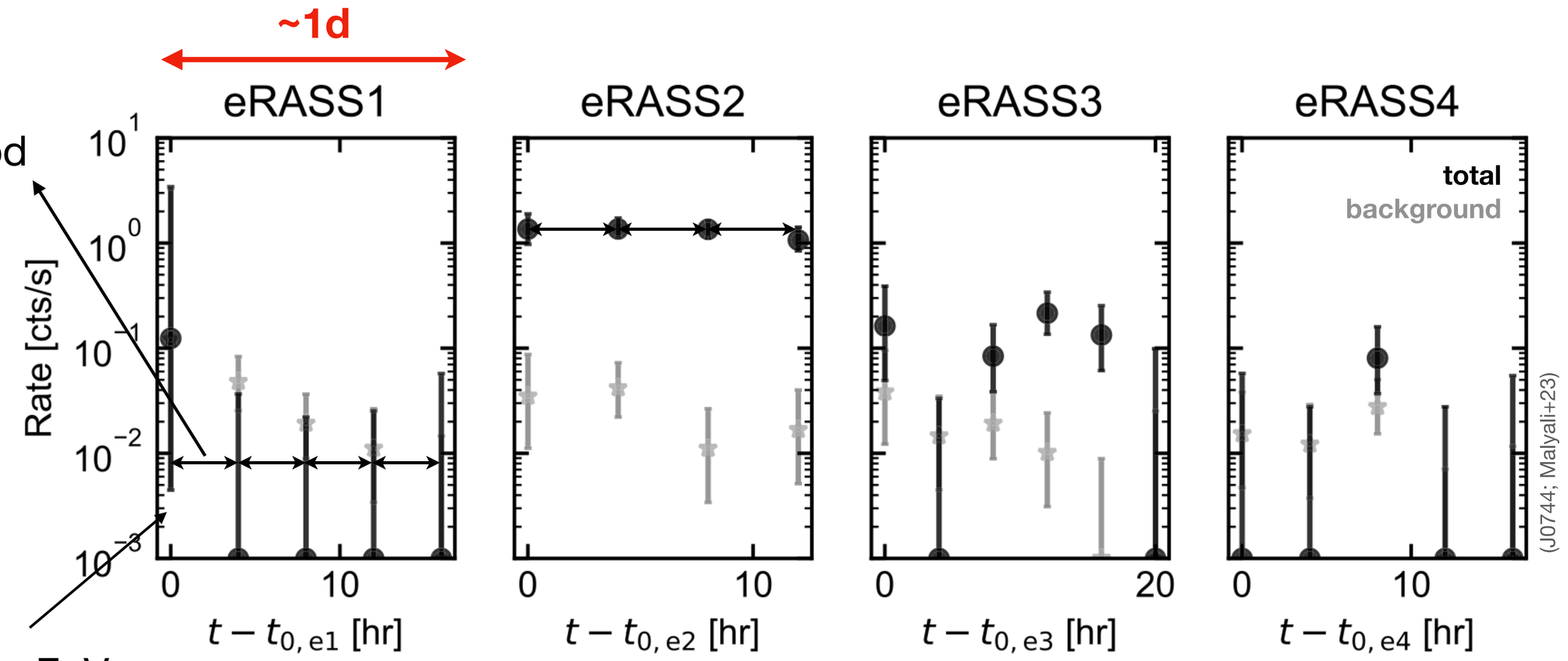

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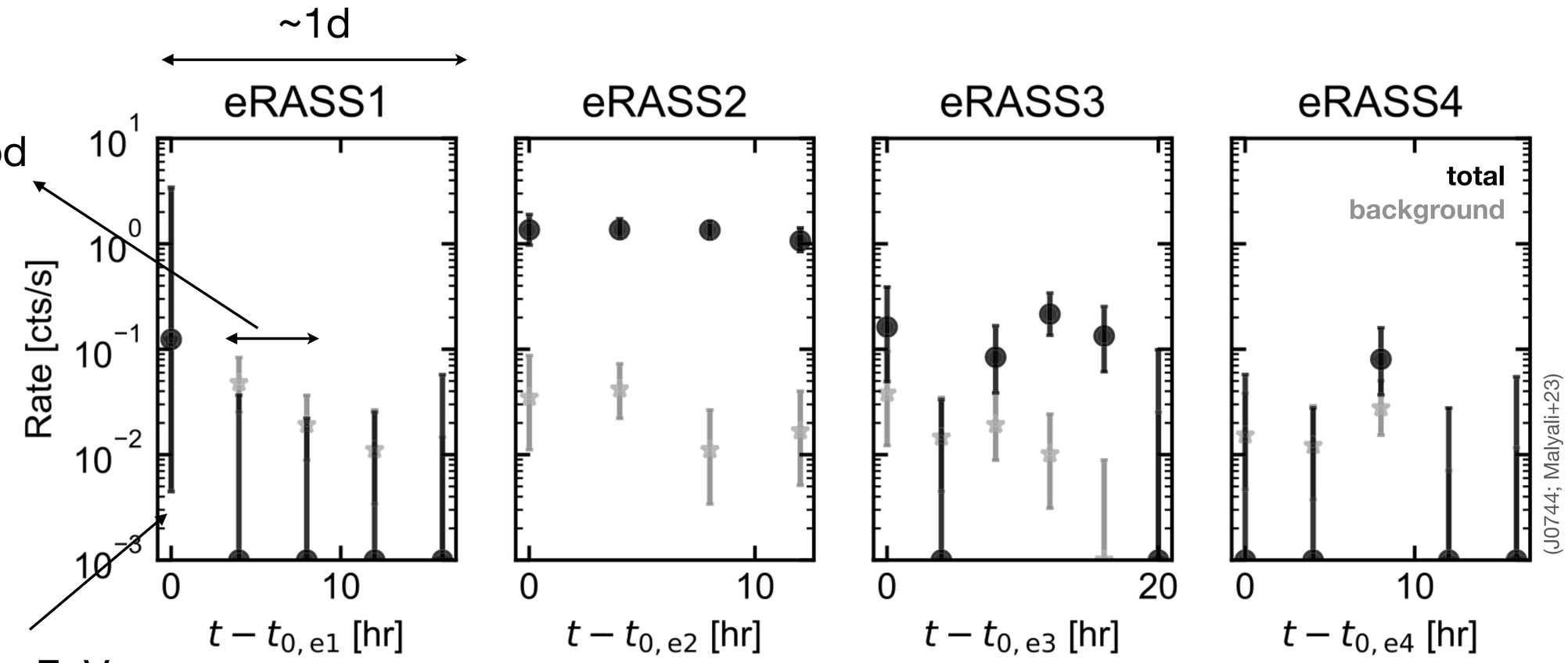


**180d: next survey**

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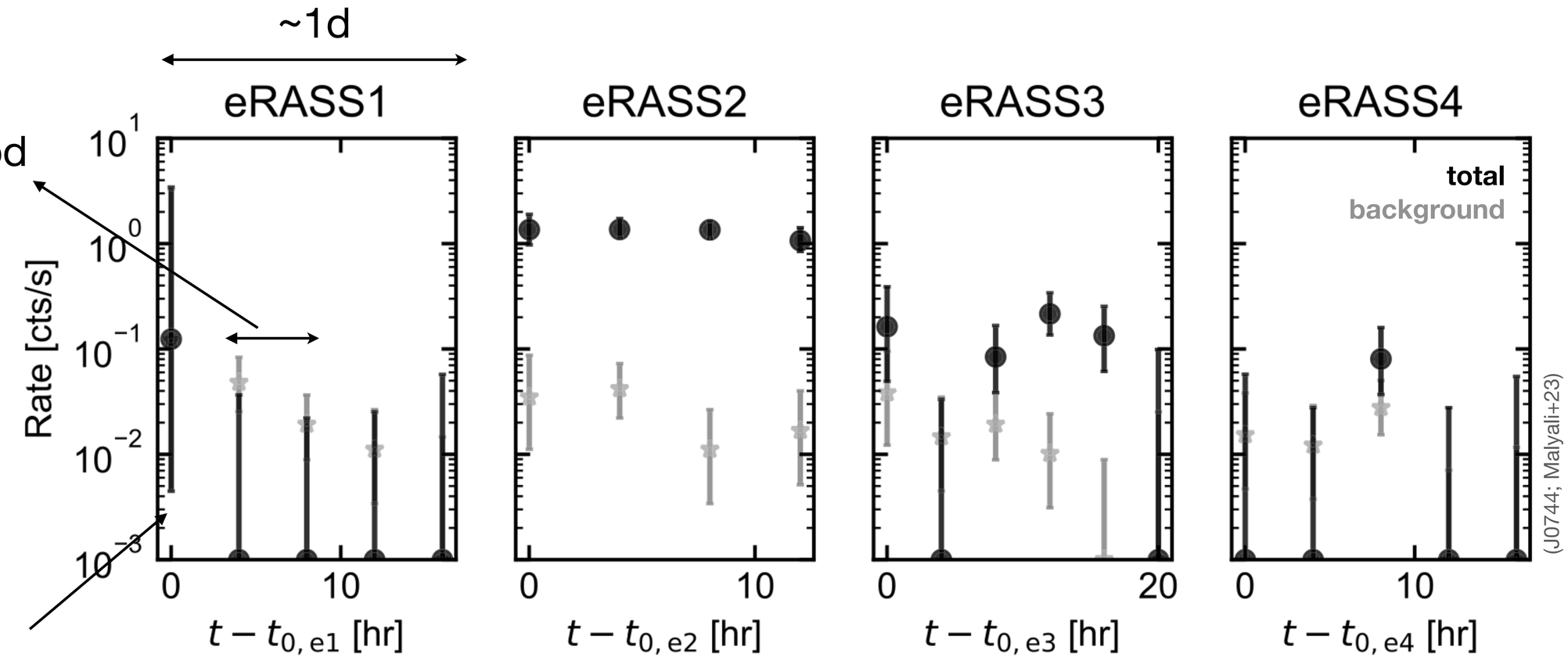

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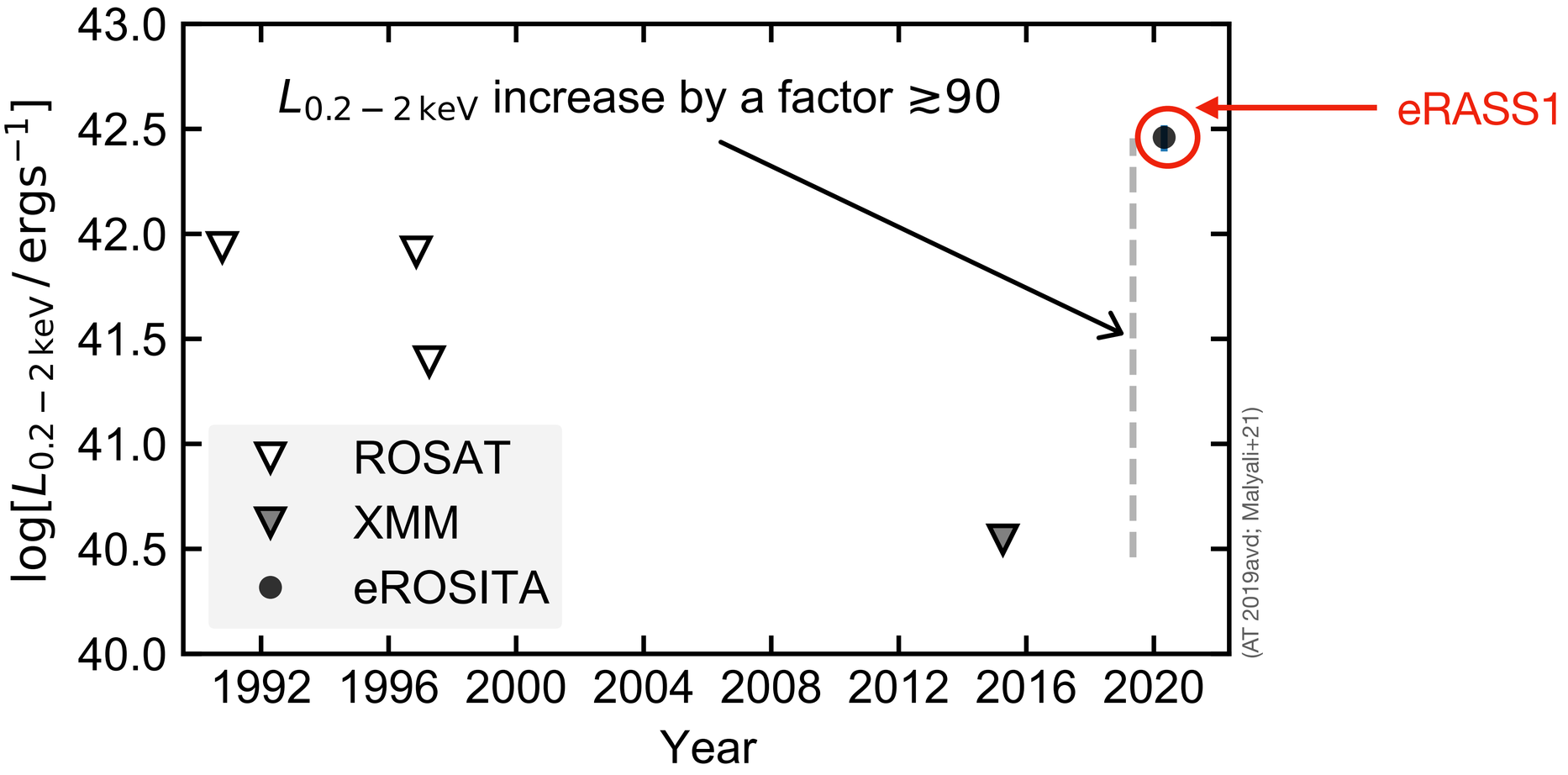


**1-30yr: comparison with XMM and other missions**

## For X-ray emitting TDEs, eROSITA is:

- a discovery machine
- with excellent soft X-ray response
- with accurate localisation (~few “)
- but sparse light curve sampling (~180d)

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- enables population studies based on a systematic selections of a large samples of X-ray TDEs (e.g., Sazonov+21, Grotova+ in prep.)
- initiates detailed studies of individual sources facilitated via comprehensive multi-wavelength follow-up (incl. XMM) (e.g., Malyali+21, 23a, 23b, 23c (in prep.), Homan+23, Liu+23)

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Note, eROSITA data are split between German (west in gal. coord.) and Russian (east) consortia. German Half results are presented here.

# TDE Selection & Road to Population Study

# TDE selection from eRASS1 and eRASS2

(Grotova+ in prep)

1. **eRASS1** & **eRASS2** source catalogues
   >1 Million each
   → Variability catalogue **Amplitude,Sig.>4**
   ~2400

# Optical counterparts & AGN/star removal

(Grotova+ in prep)

1. **eRASS1** & **eRASS2** source catalogues (>1 Million each) → Variability catalogue **Amplitude,Sig.>4** (~2400)

2. **NWAY LS10** counterparts → **Cuts (exclude stars & AGNs)** |BII| > 10, parallax significance < 3, W1 - W2 < 0.5, PSF cut, color cut (STAREX) (~700)

**NWAY:** Bayesian algorithm for cross-matching multiple catalogues (Salvato+21)
**LS10:** Legacy Survey DR10 (https://www.legacysurvey.org)

# Candidate characterization and vetting

(Grotova+ in prep)

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   color cut (STAREX) ~700

3. **Archival X-ray data**
   → - XMM-Newton, ROSAT, Swift
   remove sources showing long-term variability

4. **Lightcurves**

5. **Spectral modelling**

6. **Optical data if available**

# Light curve analysis using eRASS1 to eRASS5

(Grotova+ in prep)

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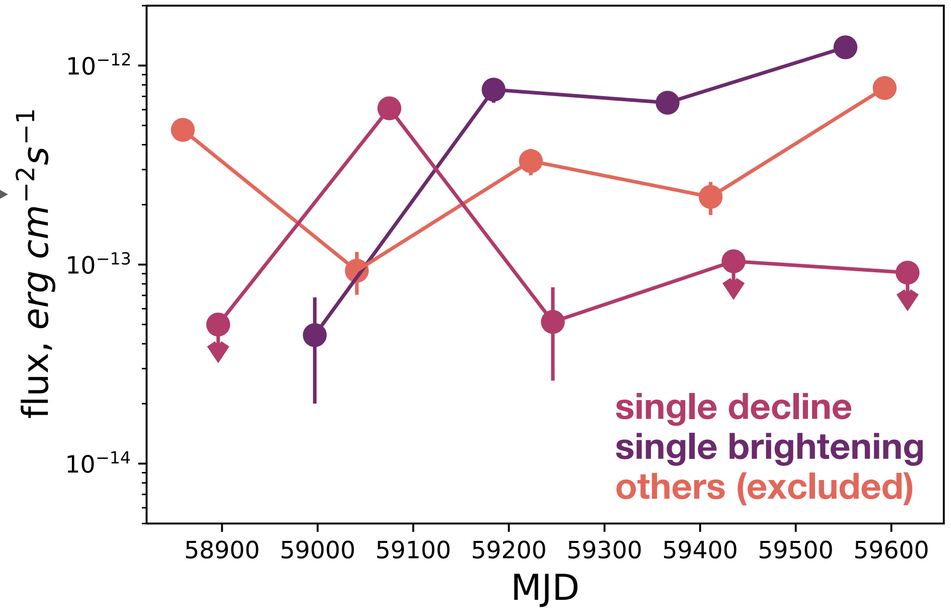
6. **Optical data if available**




~300 TDE candidates

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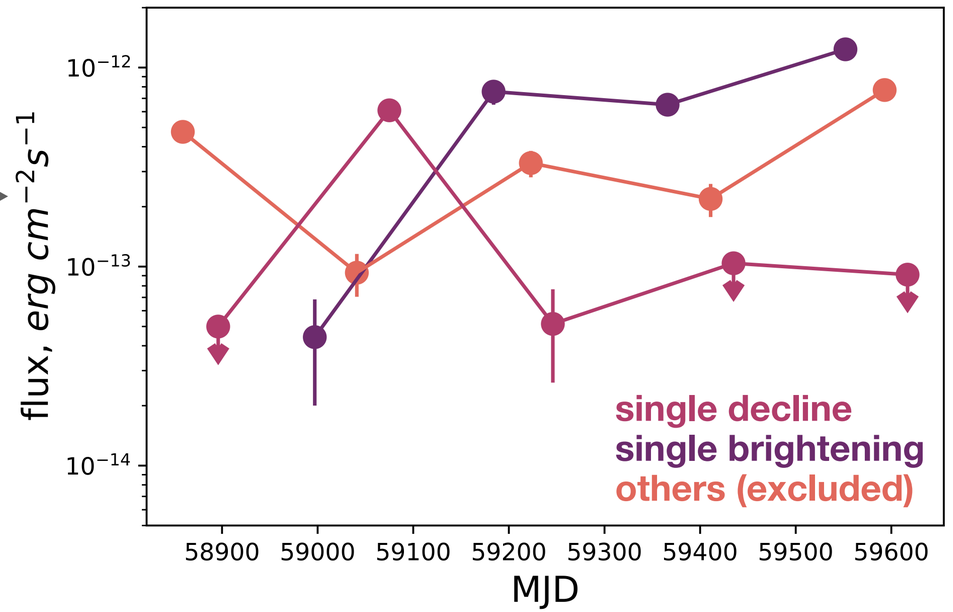
3. **Archival X-ray data**

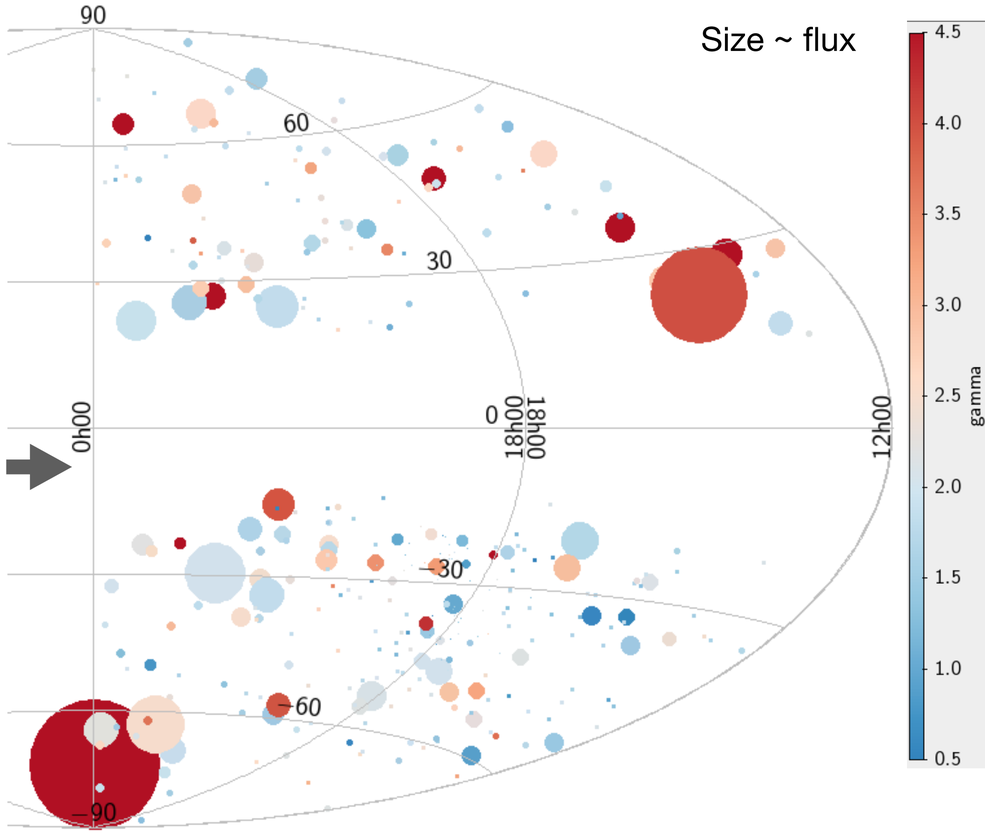
4. **Lightcurves**




5. **Spectral modelling**

6. **Optical data if available**

Size ~ flux

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# Golden Sample: super-soft X-ray spectra

(Grotova+ in prep)

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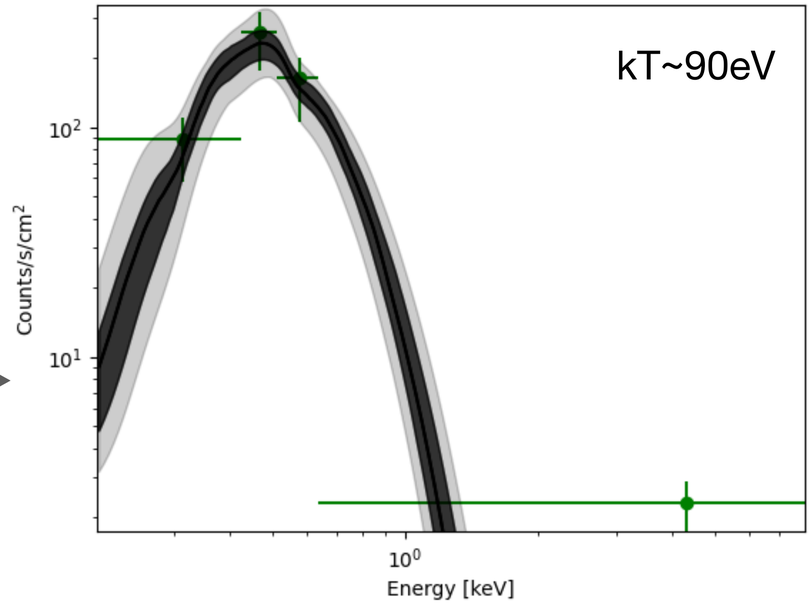
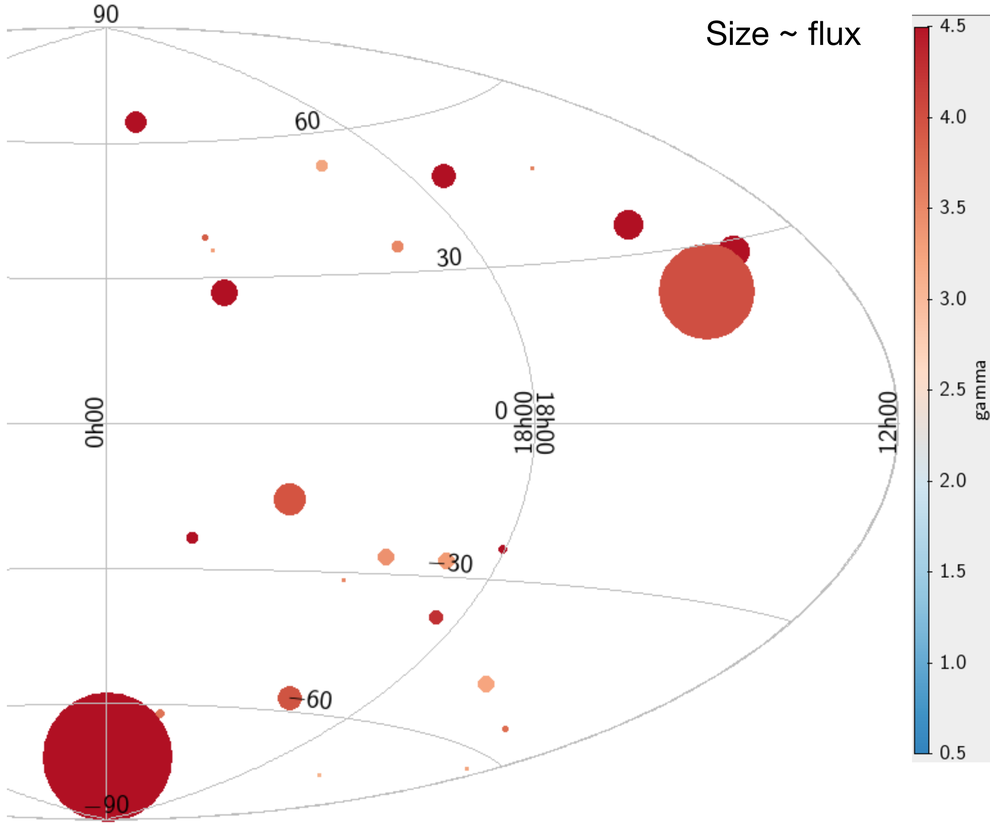



~25 Golden Sample

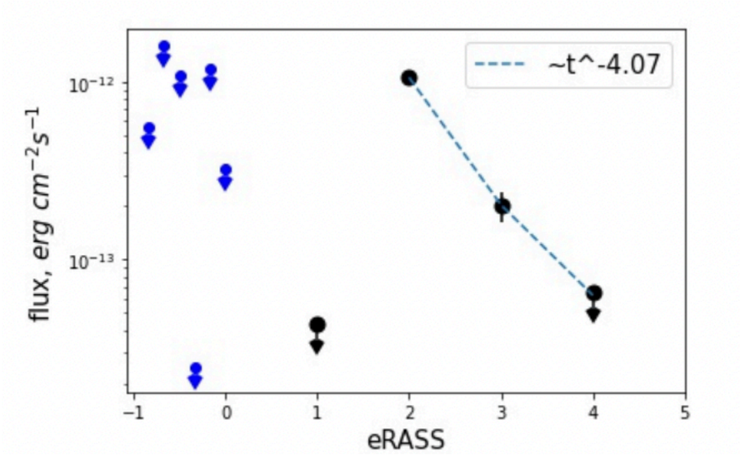
# Light curve analysis using eRASS1 to eRASS5

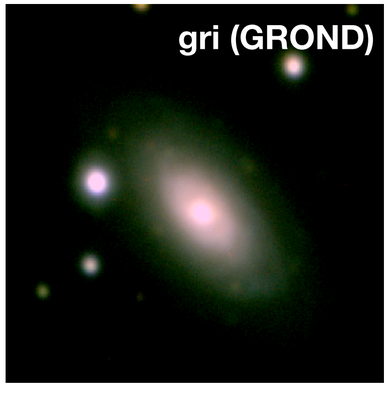
(Grotova+ in prep)

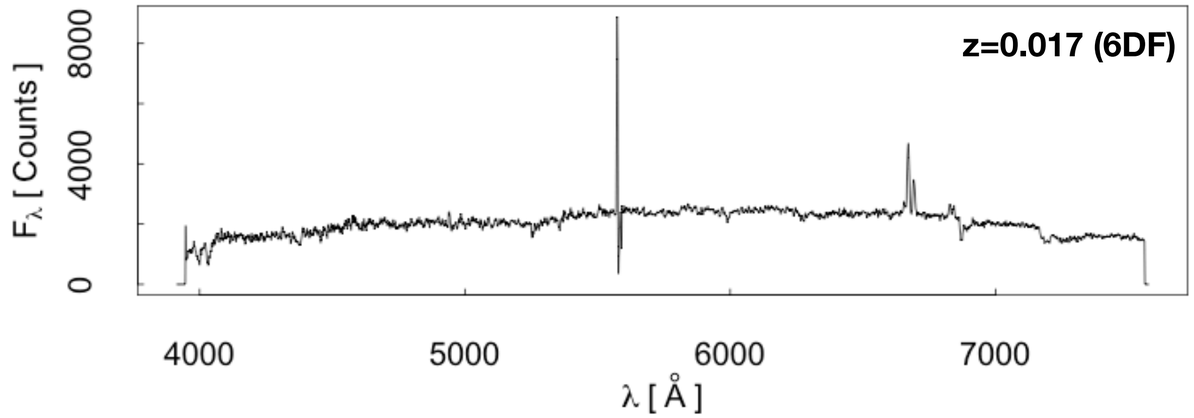
1. **eRASS1** & **eRASS2** source catalogues >1 Million each
2. **NWAY LS10** counterparts
3. **Archival X-ray data**
4. **Lightcurves**
5. **Spectral modelling**
6. **Optical data if available**

## Example: **“Golden” TDE candidate**

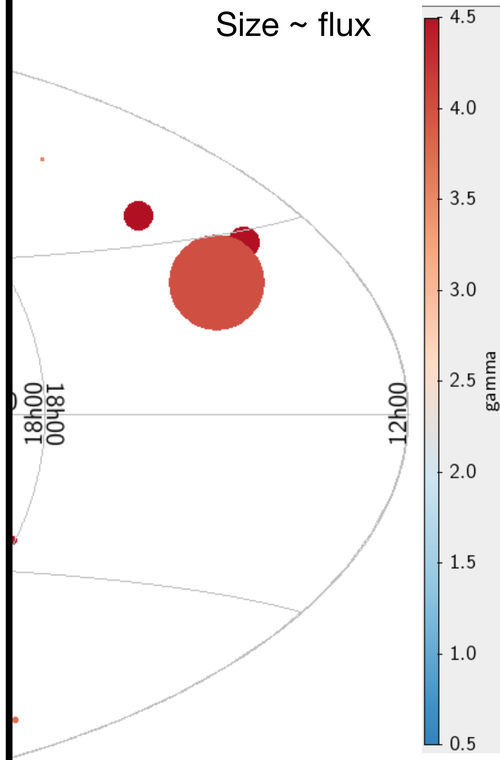
Amplitude = 24.4, Significance = 13.4, Γ= 3.9



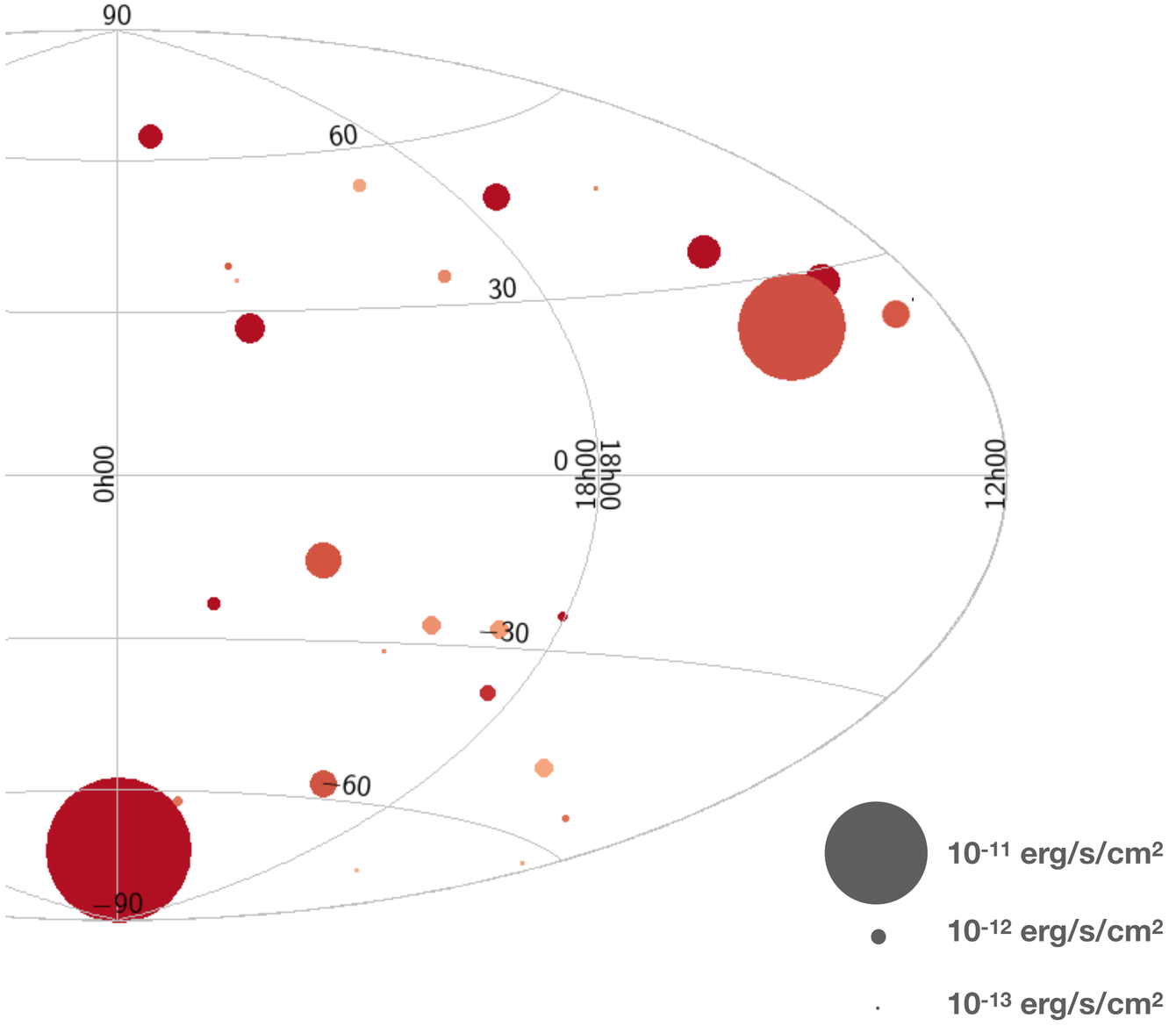




Size ~ flux



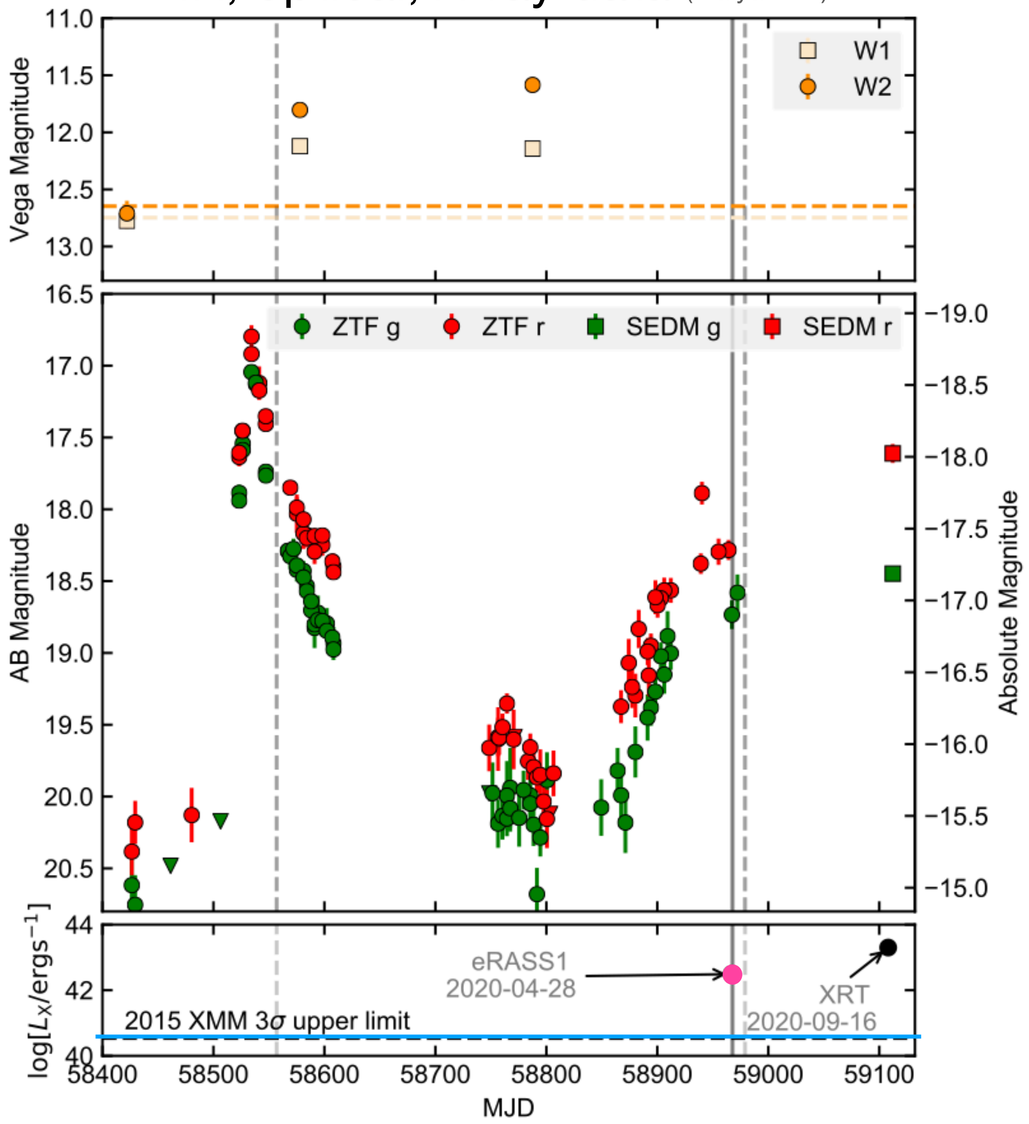

candidates

# Example Discoveries



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

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

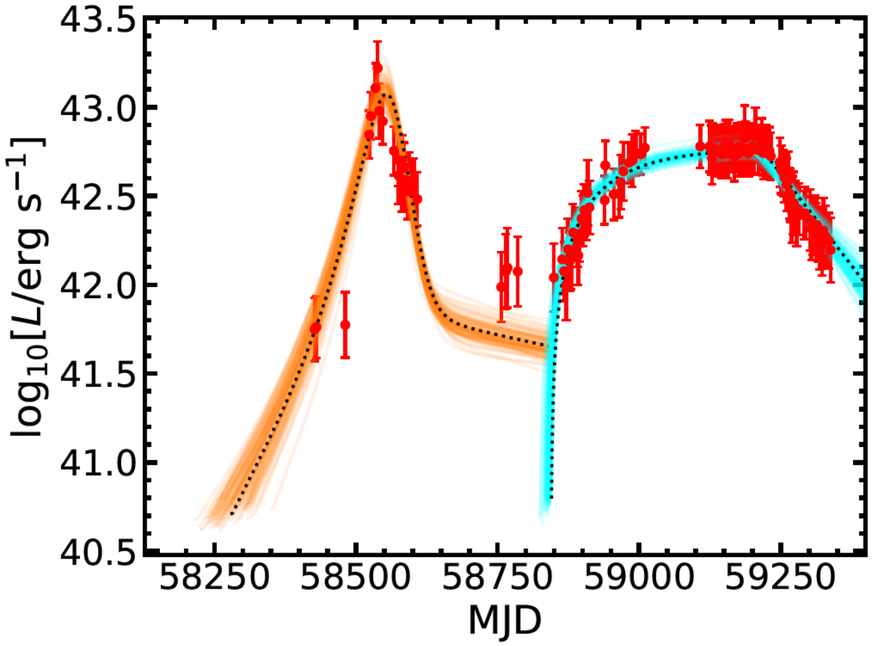



- eRASS1 discovery 600x above archival XMM limit
- TDE_like X-ray luminosity and spectrum (~85eV)

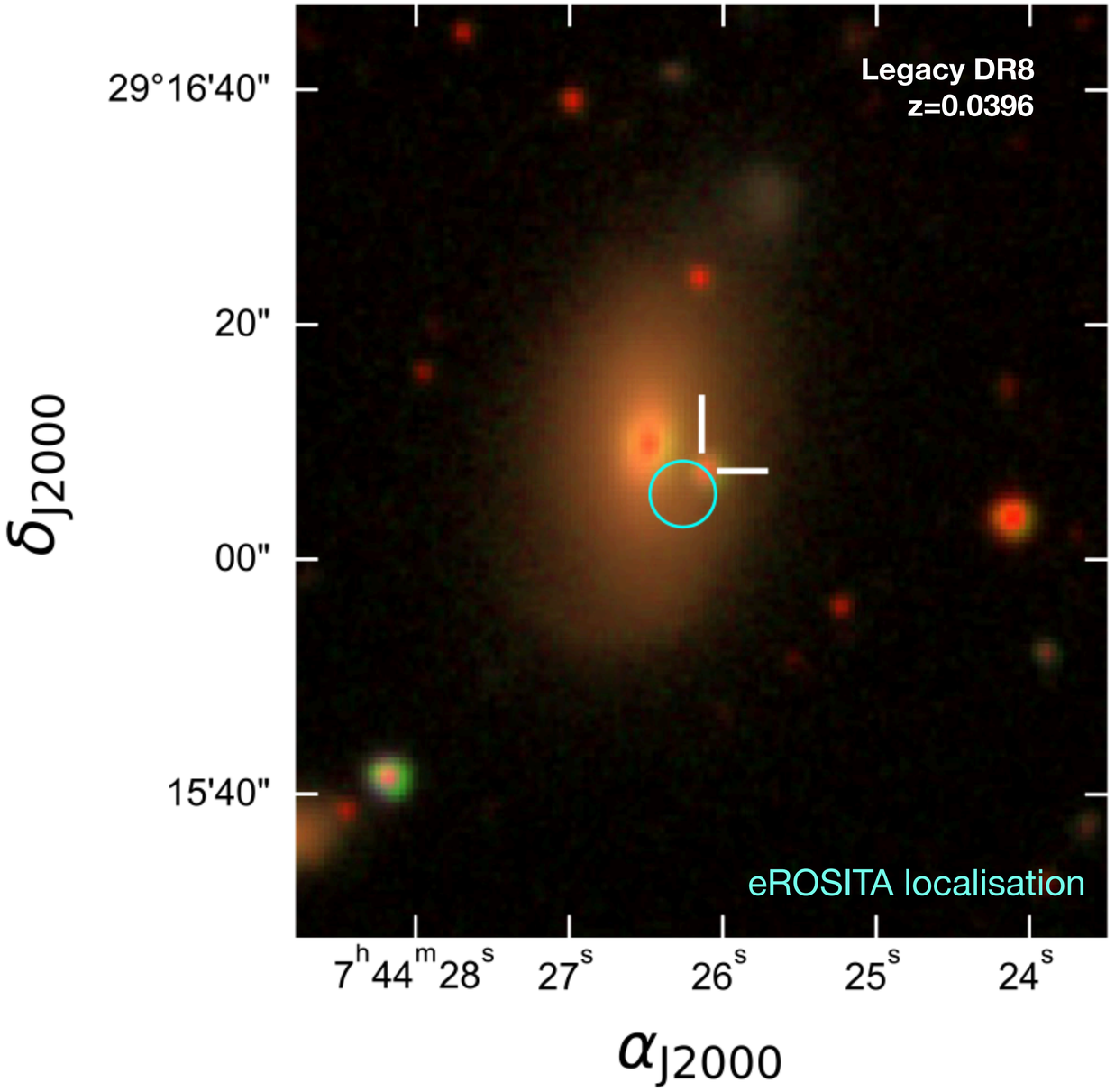
But

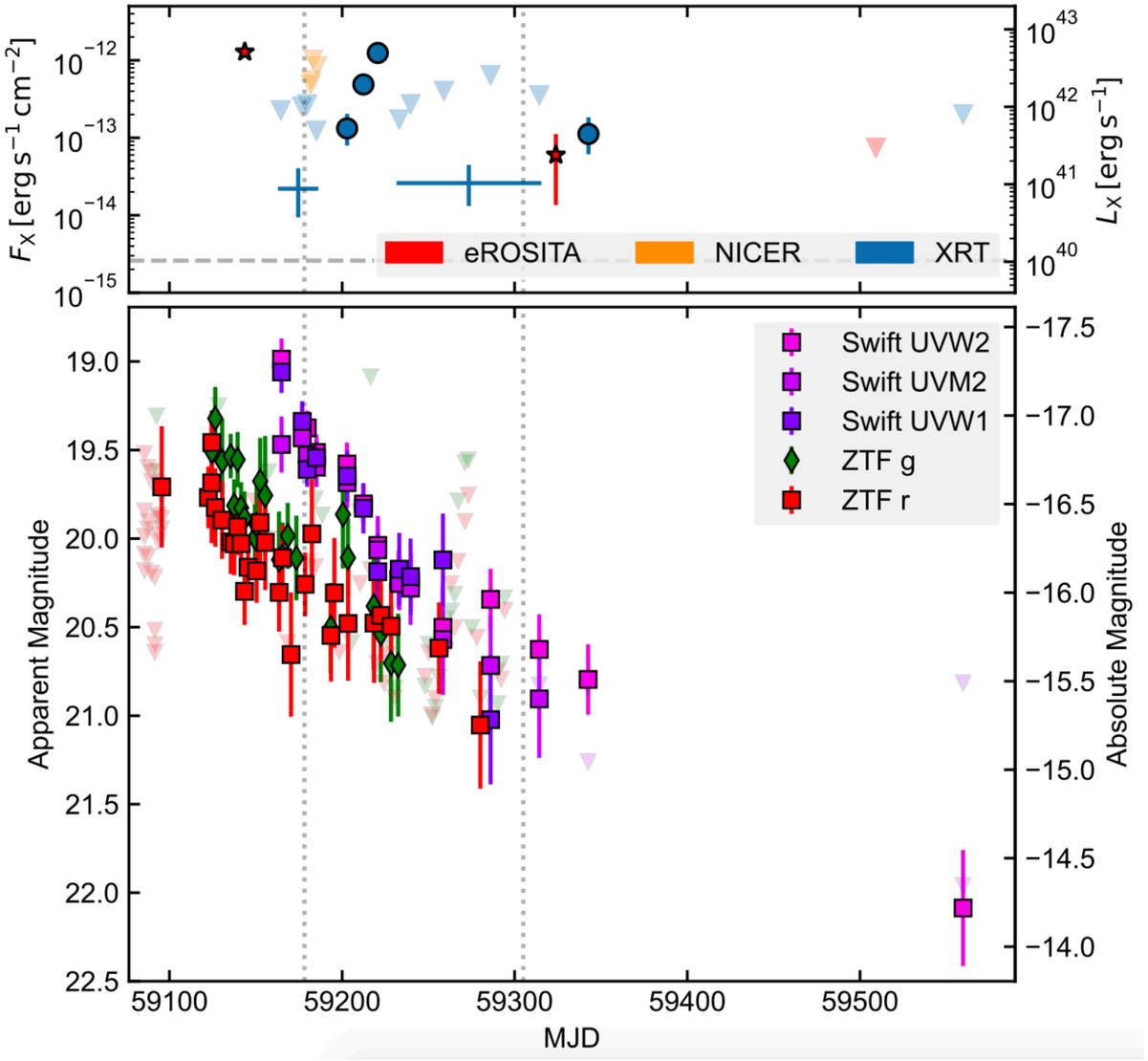
- double-peaked optical light curve
- Orange: self-crossing, i.e. circularisation of debris stream
- Cyan: Delayed accretion (cyan), consistent with X-ray detection

Model (Chen+22)



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

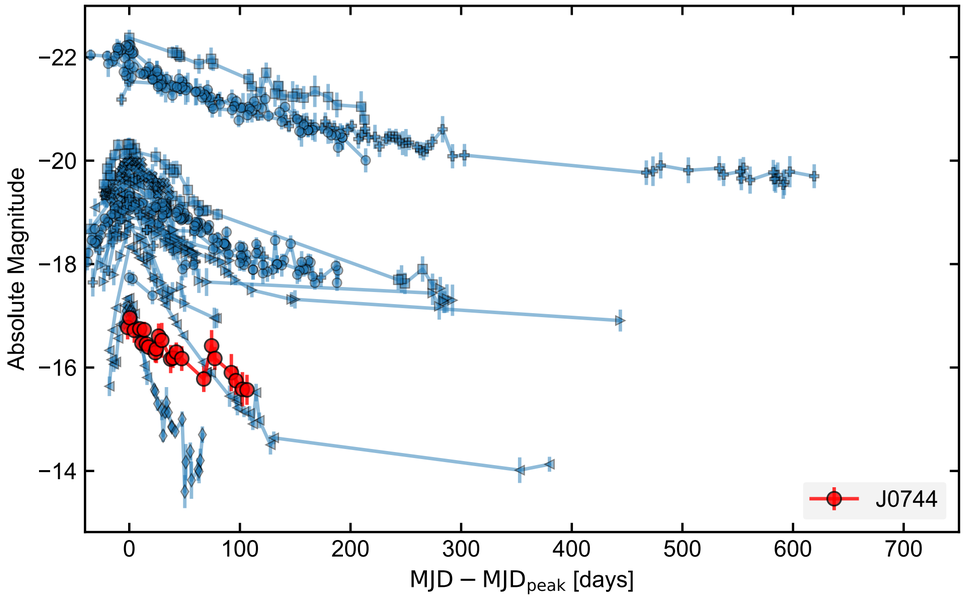


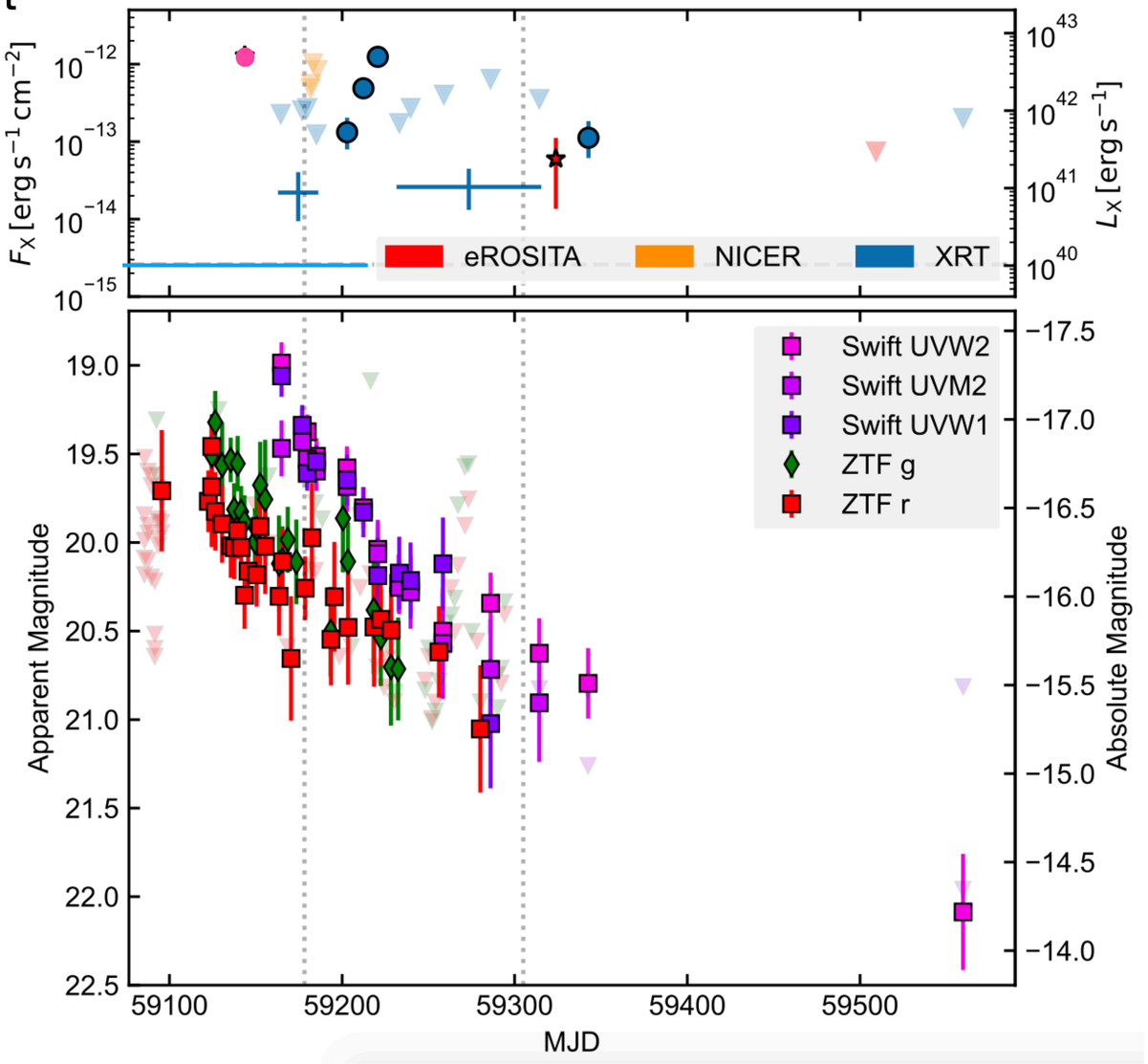



# eRASSt J074426.3+291606: faint/slow TDE in a dwarf galaxy (Malyali+23a)

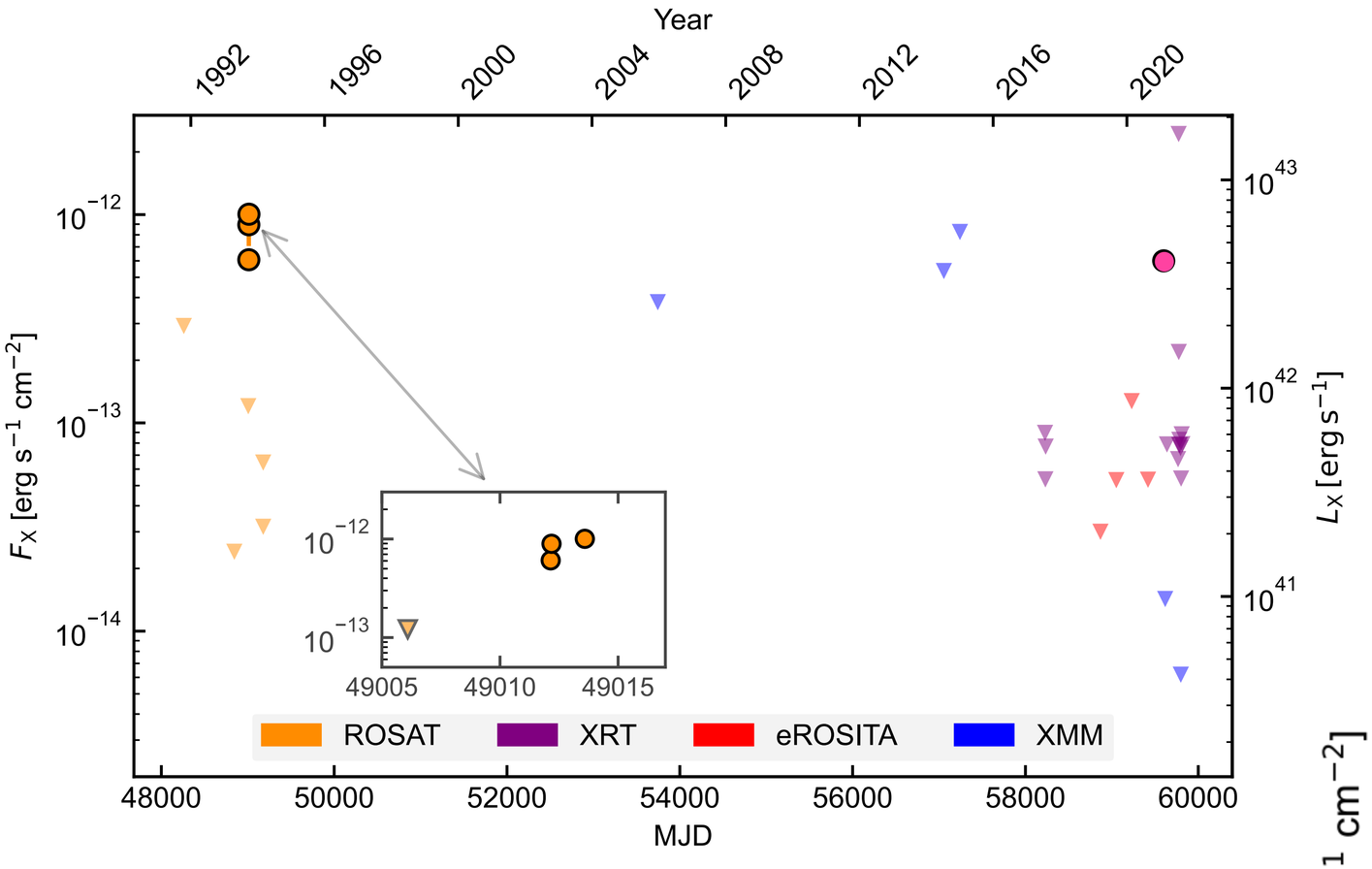
- eRASS2 discovery 160 above archival Chandra limit
- X-ray detection and optical peak suggest prompt disk formation
- Significant X-ray variability (x50) during decline interpreted as disk obscuration by unbound stellar debris

- Faintest optically-detected TDE, but slow!
- Dwarf galaxy hosts could lead to misclassifications as off-nuclear transients

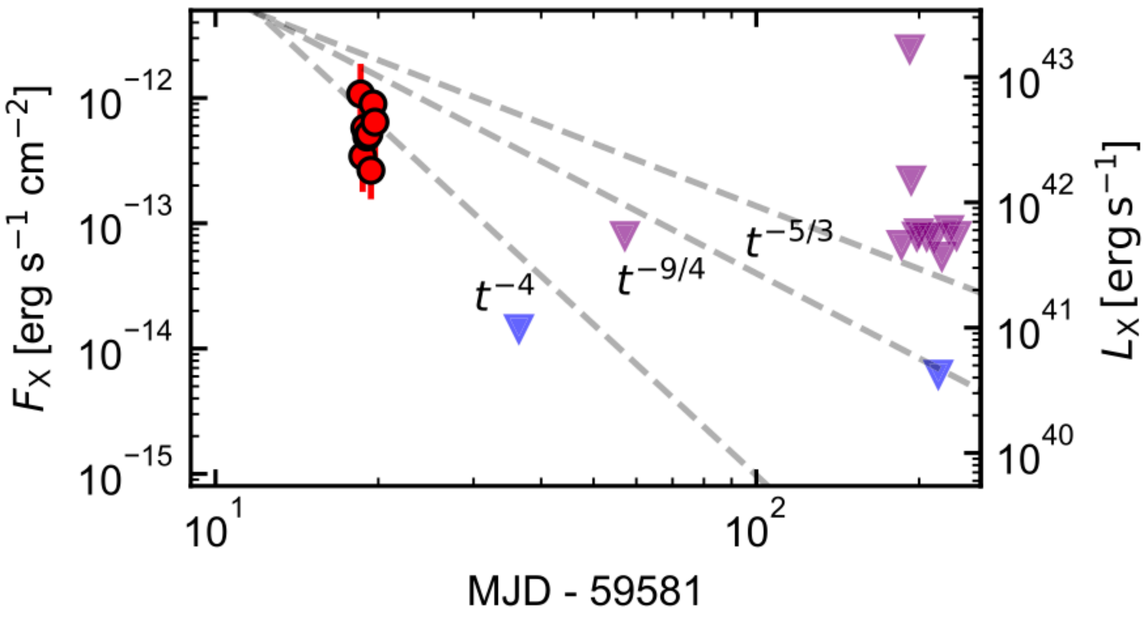


# RX J133157.6–324319.7: Reawakened ROSAT TDE (Malyali+23b)




- eRASS5 discovery >30yr after ROSAT reported TDE (Reiprich & Greiner 01; Hampel+22)
- z=0.052
- Decay by >factor of 40 within ~17d revealed by XMM
- No associated transient optical/UV emission



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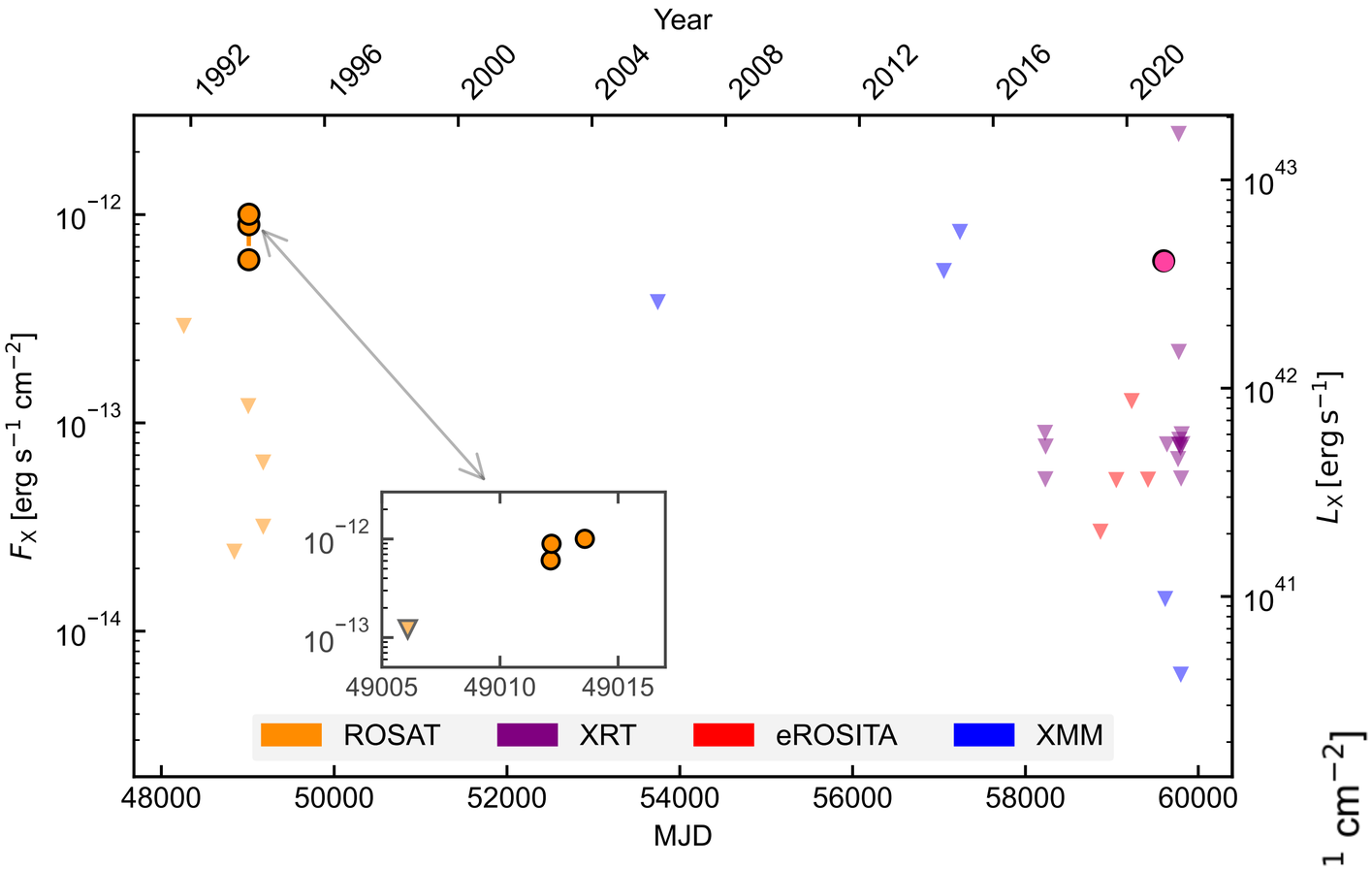


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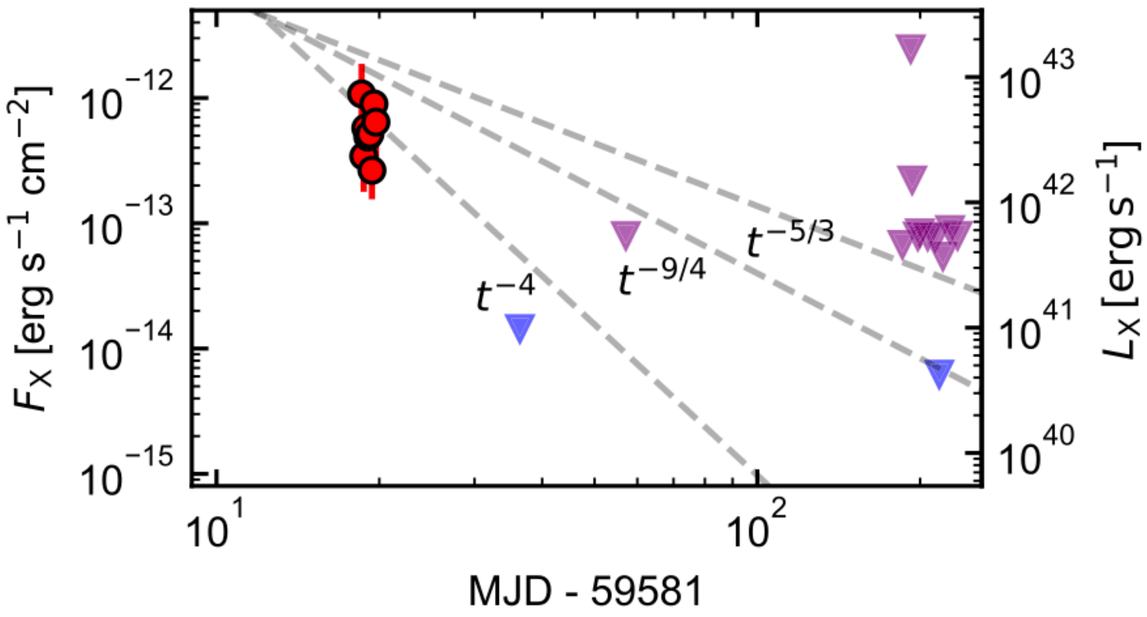
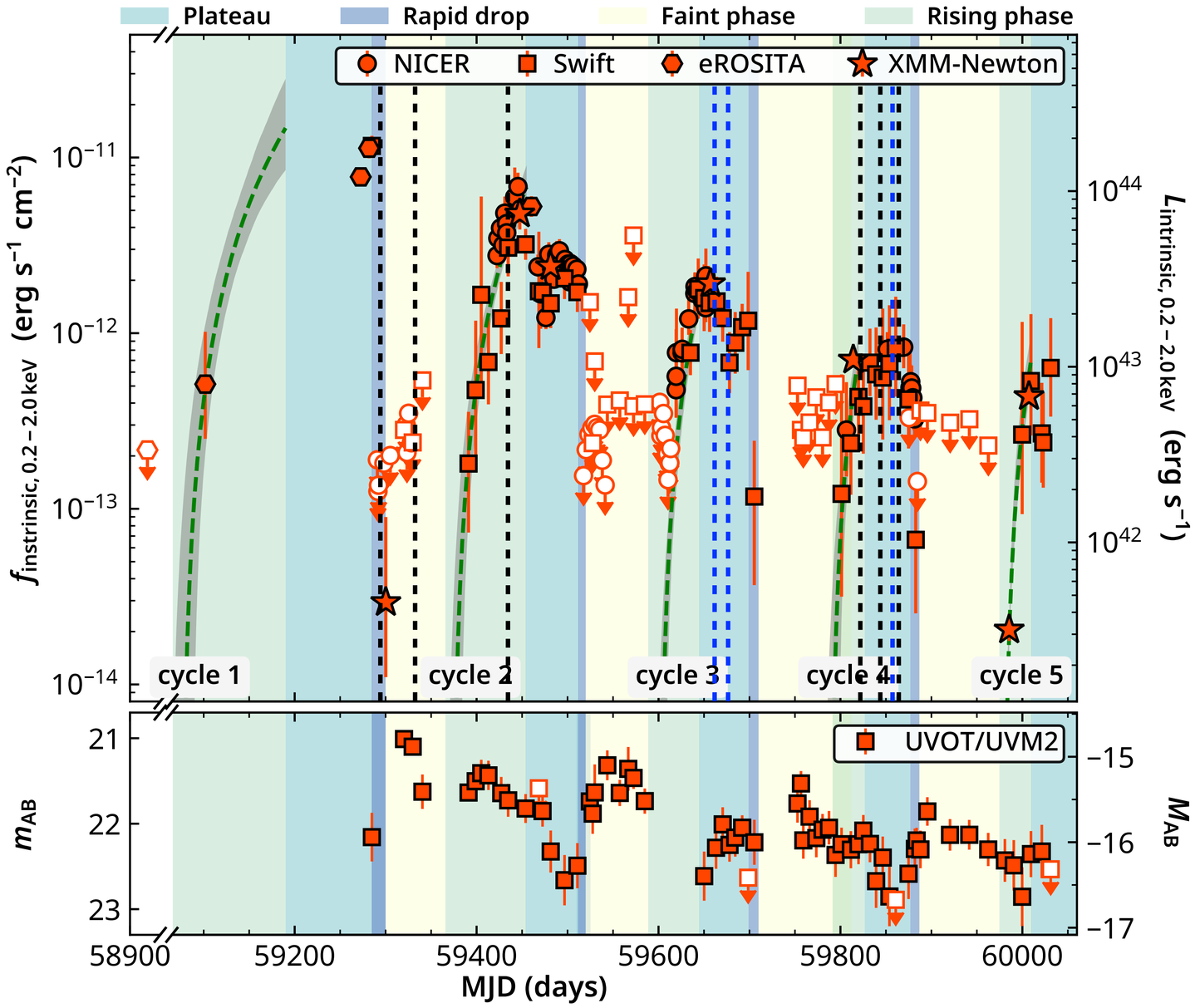



- 2nd TDE extremely unlikely (<5x10$^{-6}$)
- Favoured interpretation: partial, repeating TDE
- Steep decay suggests a star on an elliptical orbit, in agreement with theory (Ryu+20)

# J0456-20: a promising repeating partial TDE (Liu+23)



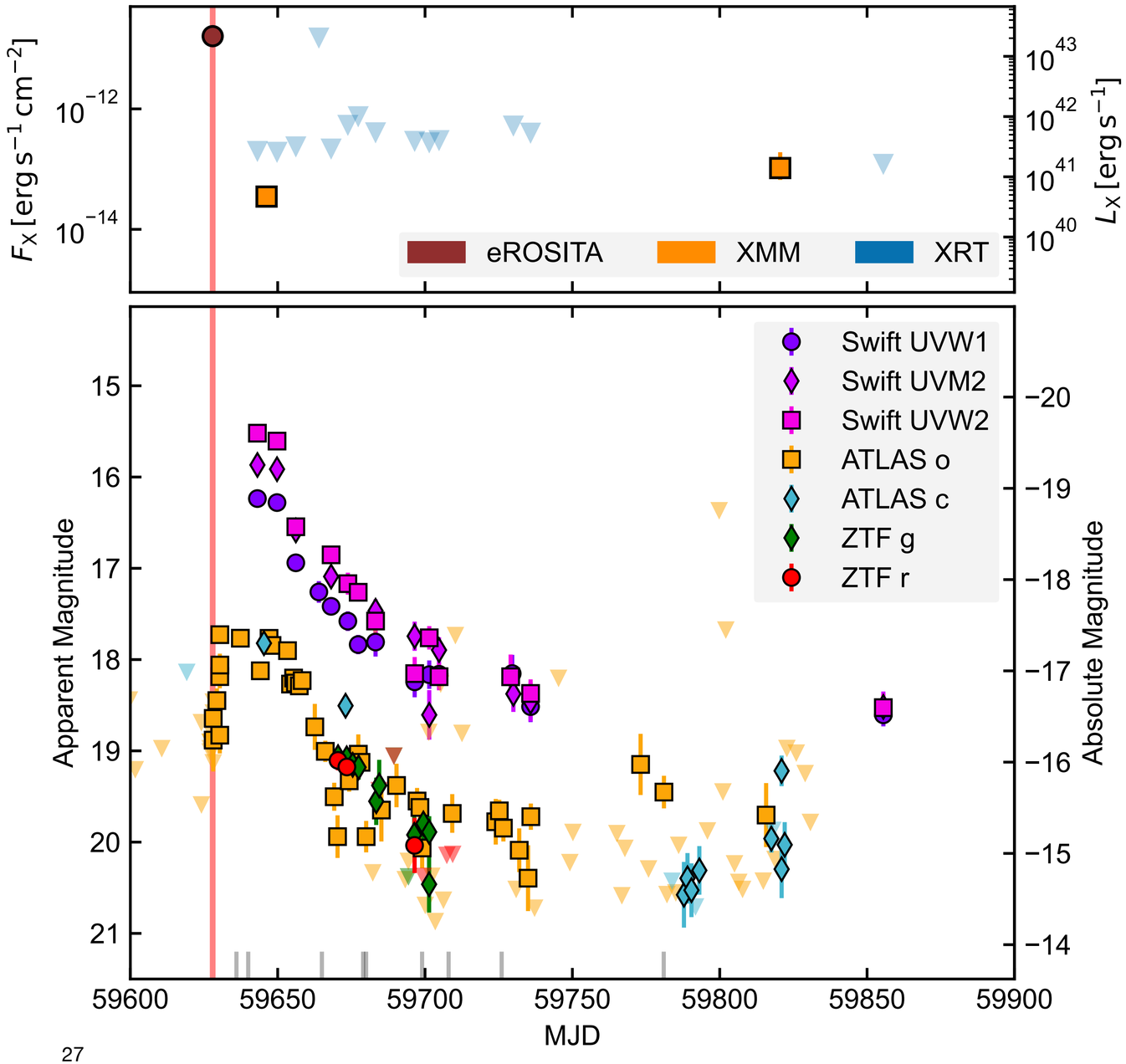

- Drastic X-ray flux drop: ~300 in 16 days
- Repeating X-ray and UV flares
  - X-ray: rising → plateau → drop → faint
  - Recurrence time of ~220 days
- Transient radio emission
  - Decreased by a factor of a few in 2 weeks
- A repeating pTDE as the most plausible explanation (5 in total, Payne et al. 2021, Malyali et al. 2023, Wevers et al. 2023, Webb et al. 2023)
- Variability: accretion state transitions
  - X-ray rising: soft state —> steep power law state; formation of the corona
  - X-ray drop: steep power law state —> soft state; destroy of the corona

# AT 2022dsb: Earliest X-ray detection (Malyali+, in prep.)

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

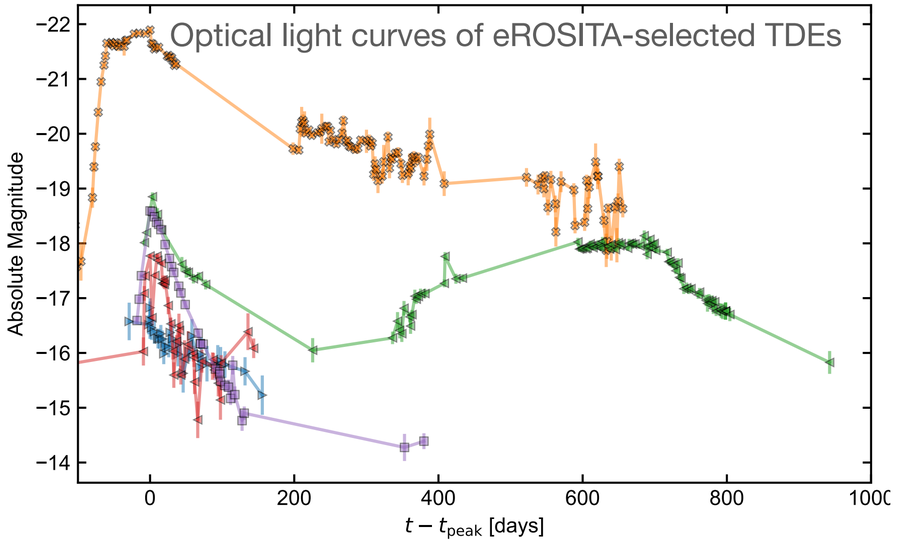


# Summary

1. **eROSITA enables X-ray selected TDE population studies**
   - ~25 very good TDE candidates per year (0.2-2 keV $F_x$>1x$10^{-13}$ erg/s/$cm^2$)
   - Increase of rate X-ray selected TDEs by order of magnitude with respect to pre-eROSITA era
   - No strong jetted TDEs identified (so far)

2. **eROSITA's TDEs show a rich diversity of X-ray behaviours:**
   - 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 TDE-like spectral features




*X-ray/UV follow-up has been vital to explore the richness of eROSITA-discovered TDEs*