

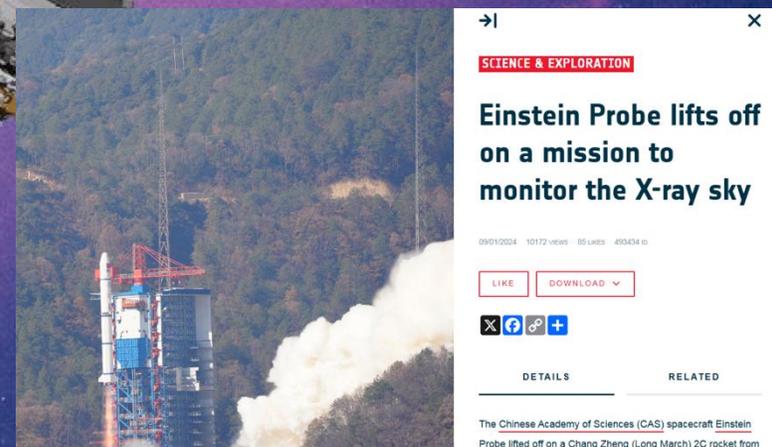
# Einstein Probe

exploring the dynamic  
X-ray universe

Weimin Yuan  
National Astro. Obs., CAS

Image credit CAS/ESA

launched 2024 Jan  
nominal operations since 2024  
Jul



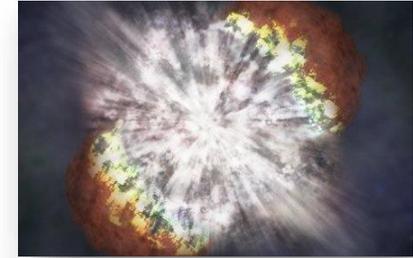


- 📄 Introduction to EP
- 📄 Science capabilities
- 📄 High-lights in the early phase of operations
  - Fast X-ray transients
  - Transients related to black hole and compact objects
  - multi-messenger observations (prospects)
- 📄 Summary

# Core science objectives



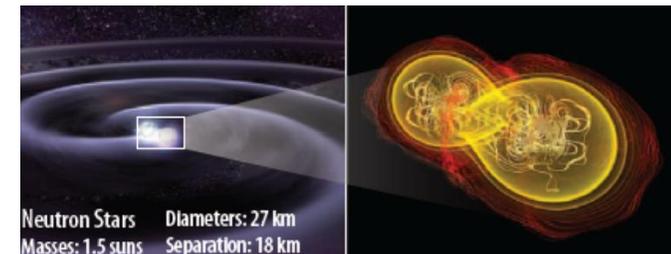
Systematic survey of transients and source variability in the soft X-ray band with unprecedented combination of sensitivity and cadence



Discover normally quiescent black holes and other compact objects by capturing their transient X-ray flares



Detect and localise the potential X-ray sources of gravitational wave events



## Wide-field X-ray Telescope

WXT (12 modules)



Lobster-eye MPO + CMOS  
FoV: > 3,600 sq deg (1.1 sr)  
Band: 0.5 – 4 keV  
Angular resolution: ~ 5' (FWHM)  
Sensitivity: ~1mCrab @1ks

## Follow-up X-ray Telescope

FXT (2 units)



Wolter-1 + pn-CCD (eROSITA)  
FoV: ~1 deg  
Band: 0.3 -10keV  
Angular resolution: 24" (HPD, on-axis)  
Effe. area: ~300 cm<sup>2</sup> @1keV (x 2 units)



## Spacecraft



On-board data processing  
Quick slew & autonomous follow-up

Fast satellite-ground 2-way communications in minutes



Chinese Beidou system  
VHF network  
Science data telemetry (hours)

# Instruments & spacecraft



WXT mirror & CMOS detectors (1 modul

e)



WXT chief designer  
Xiaojin Sun (SITP/CAS)



Lead of LE mirrors  
Chen Zhang (NAO/CAS)



WXT

FXT



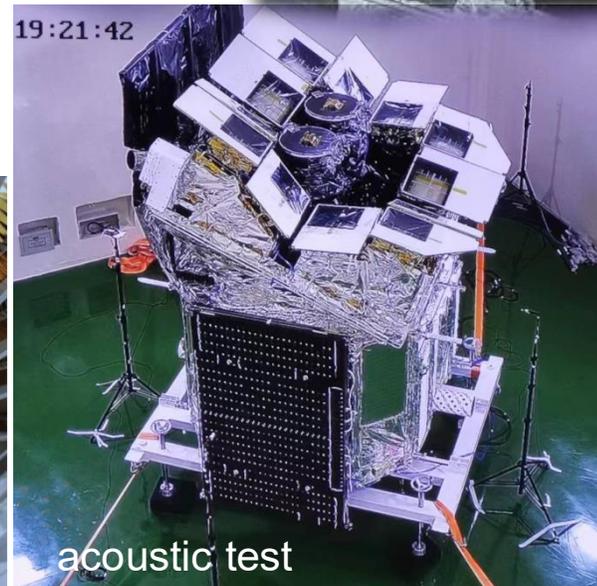
FXT FM built at IHEP/CAS



PI: Yong Chen  
(IHEP/CAS)



FXT mirror assembly FM  
(ESA/MediaLario/MPE)

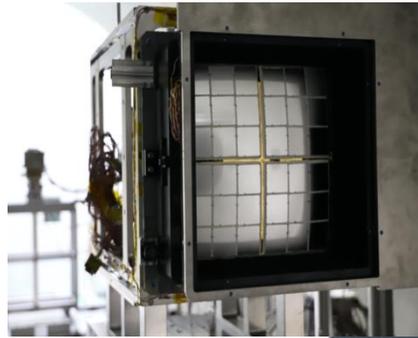


acoustic test



thermal vacuum test @ CAS

# EP-WXT pathfinder LEIA (Lobster Eye Imager for Astronomy)



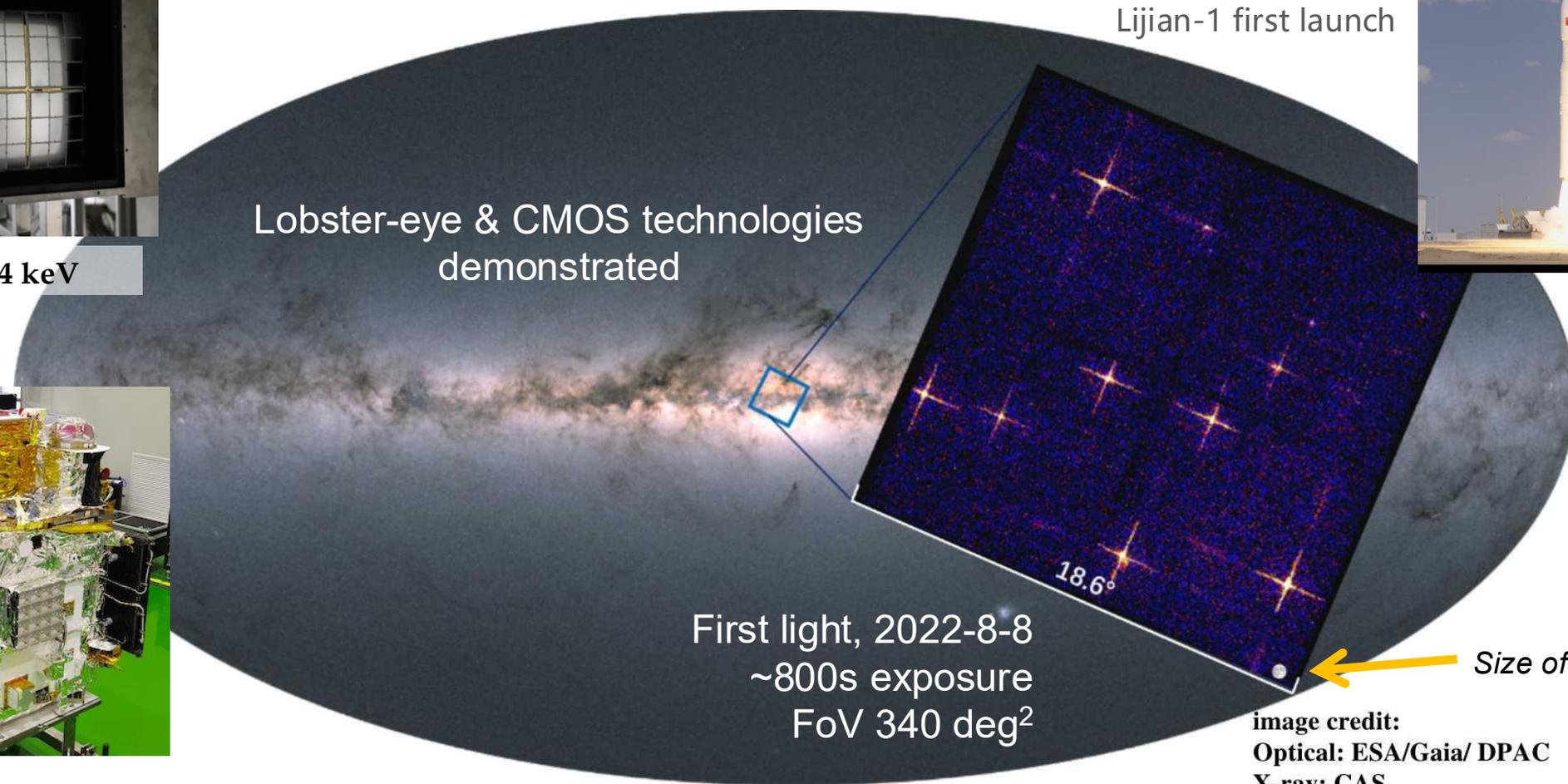
LEIA 0.5 - 4 keV



CAS's SATech-01  
experiment satellite  
credit: MicroSAT

Lobster-eye & CMOS technologies  
demonstrated

2022-07-27  
Lijian-1 first launch



First light, 2022-8-8  
~800s exposure  
FoV 340 deg<sup>2</sup>

18.6°

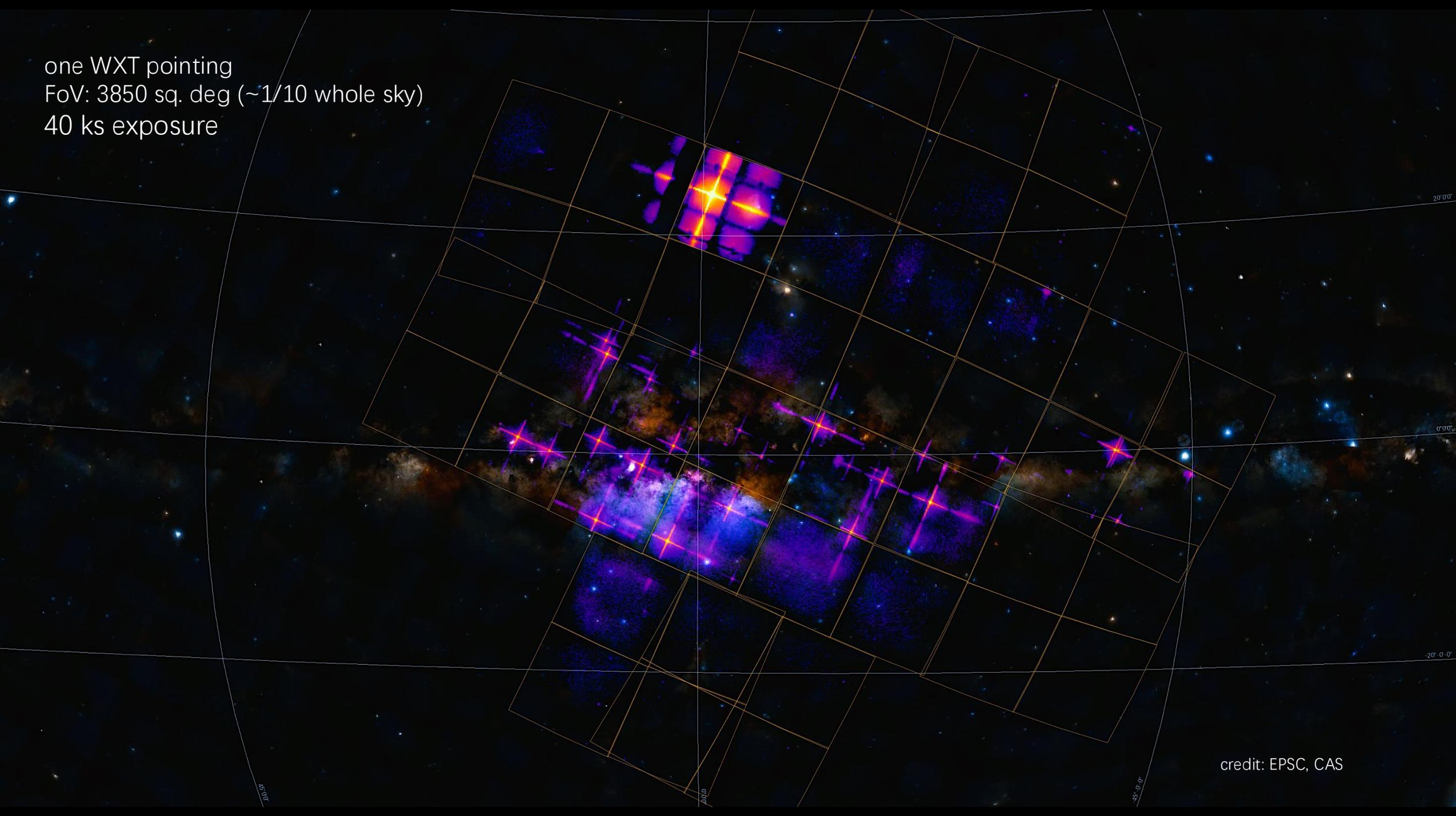
image credit:  
Optical: ESA/Gaia/ DPAC  
X-ray: CAS

Size of full Moon

*First wide FoV X-ray observations by a lobster-eye focusing X-ray telescope in orbit*

Zhang et al. 2022 ApJL, 941, L2

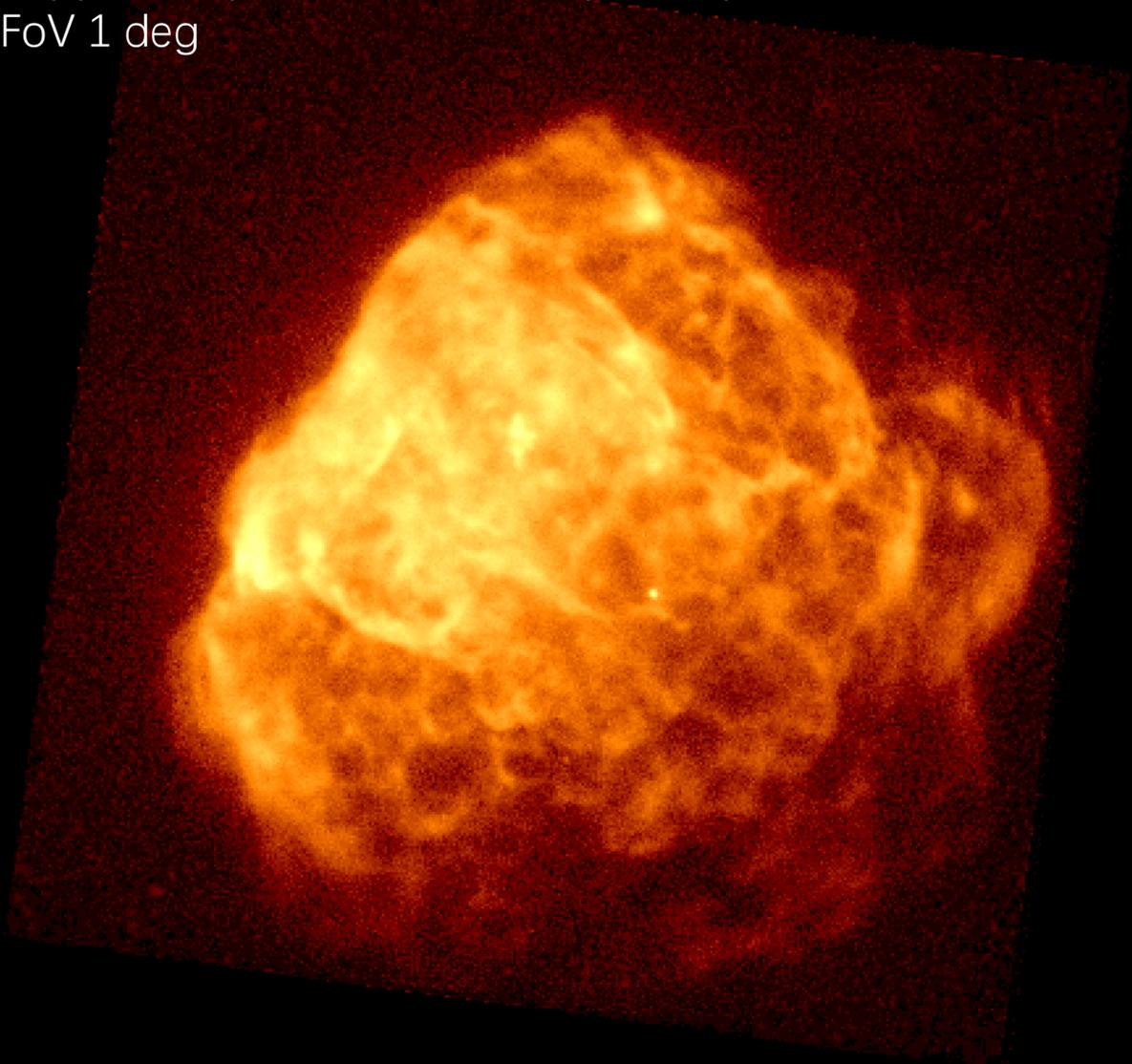
one WXT pointing  
FoV: 3850 sq. deg (~1/10 whole sky)  
40 ks exposure



credit: EPSC, CAS

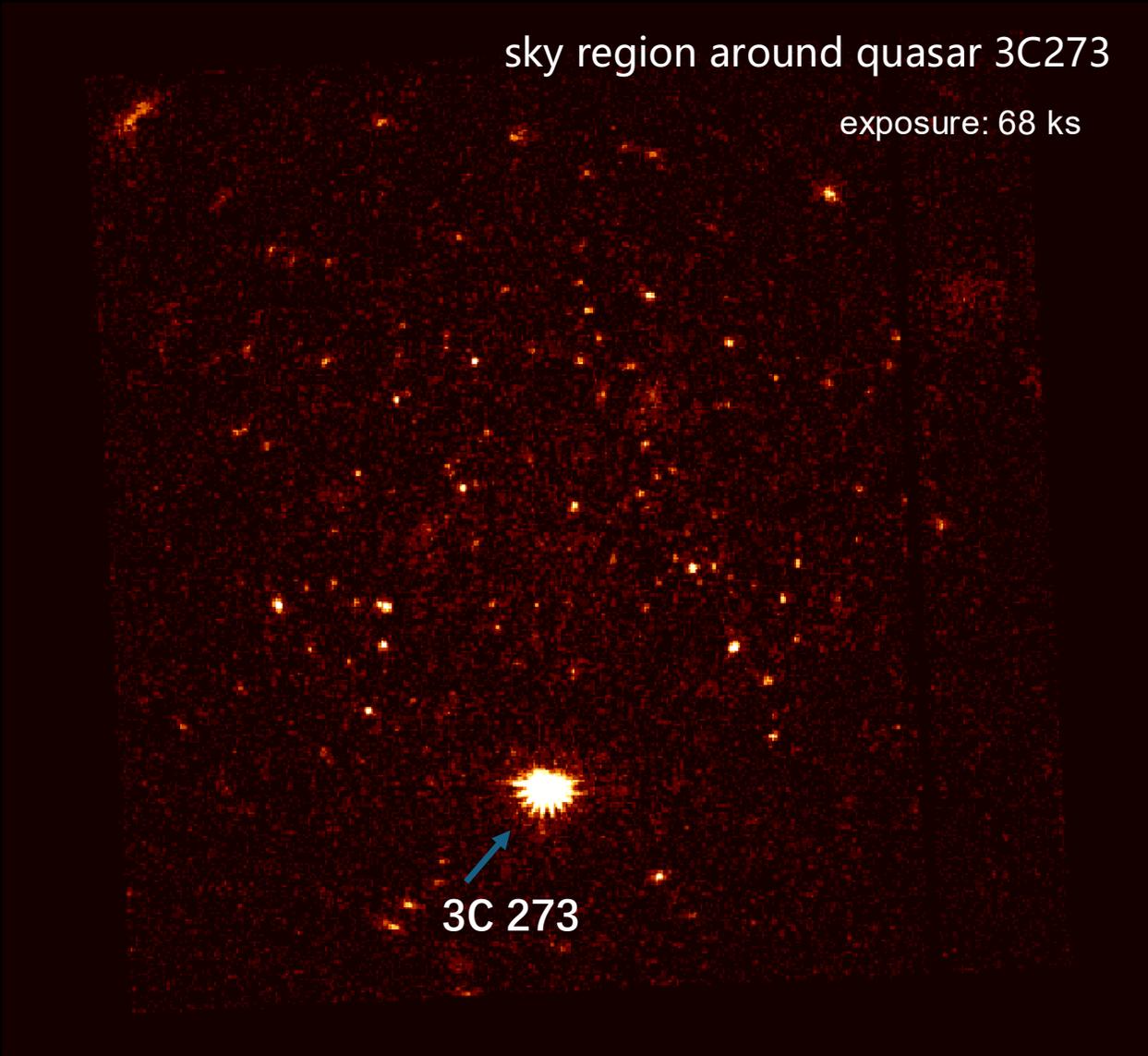
# FXT X-ray First light (0.3-10 keV)

Puppis A supernova remnant (nebula)  
FoV 1 deg



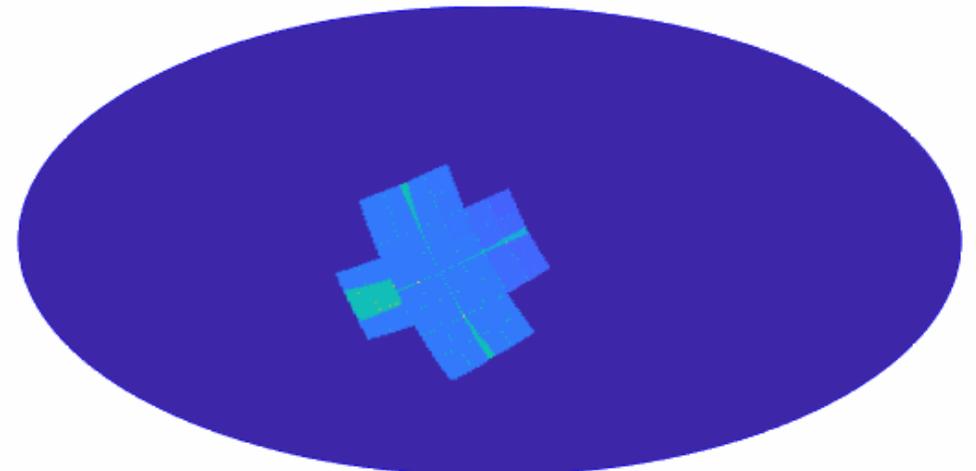
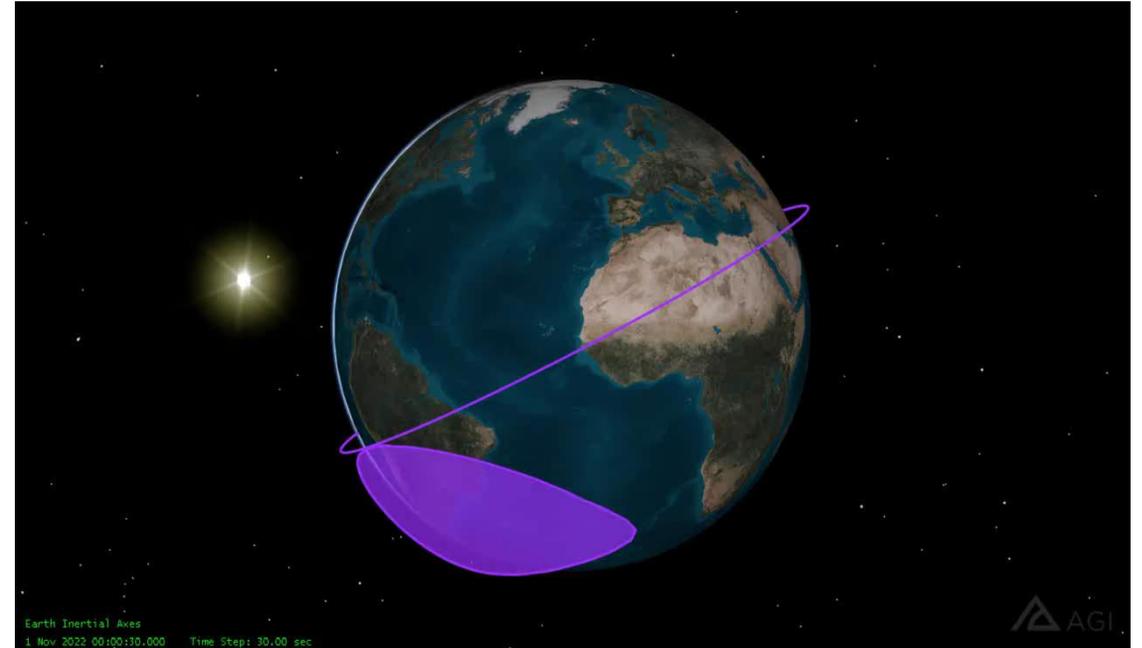
sky region around quasar 3C273

exposure: 68 ks

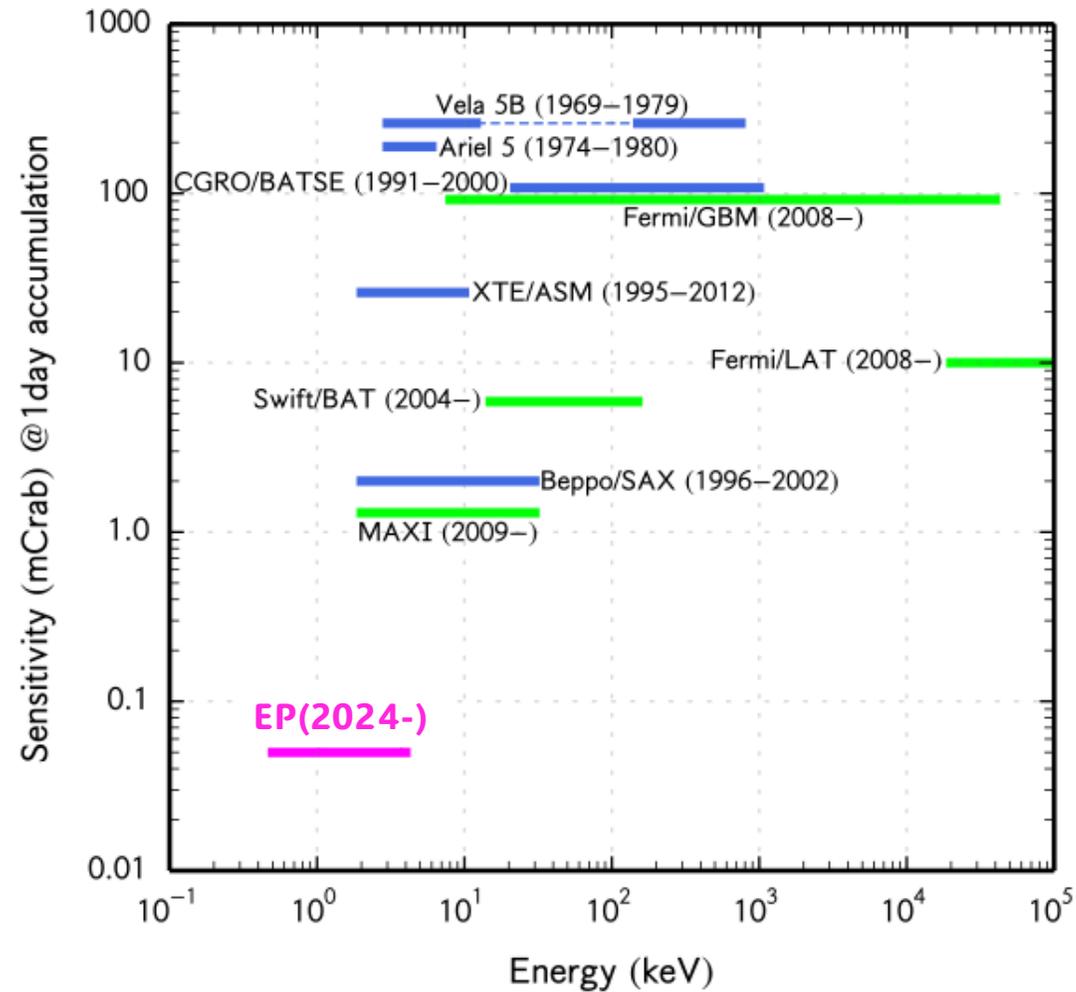
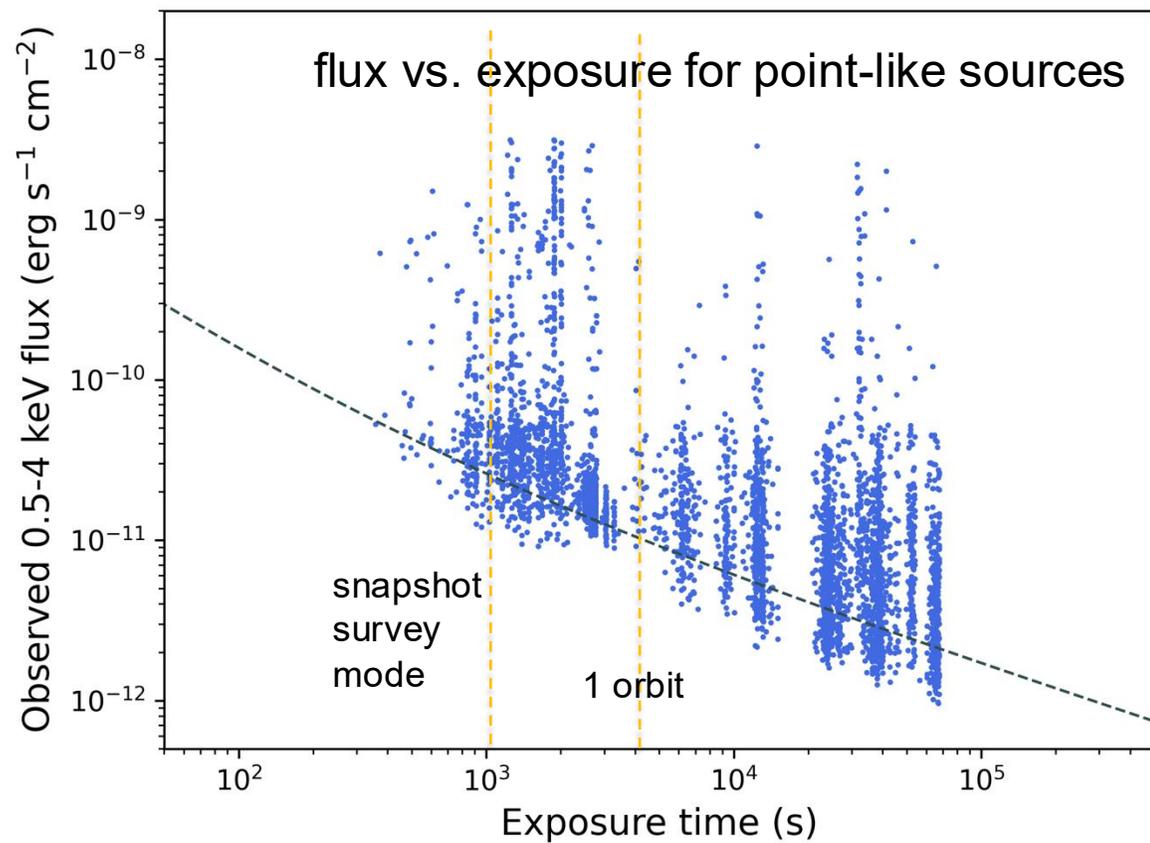


# Observation modes

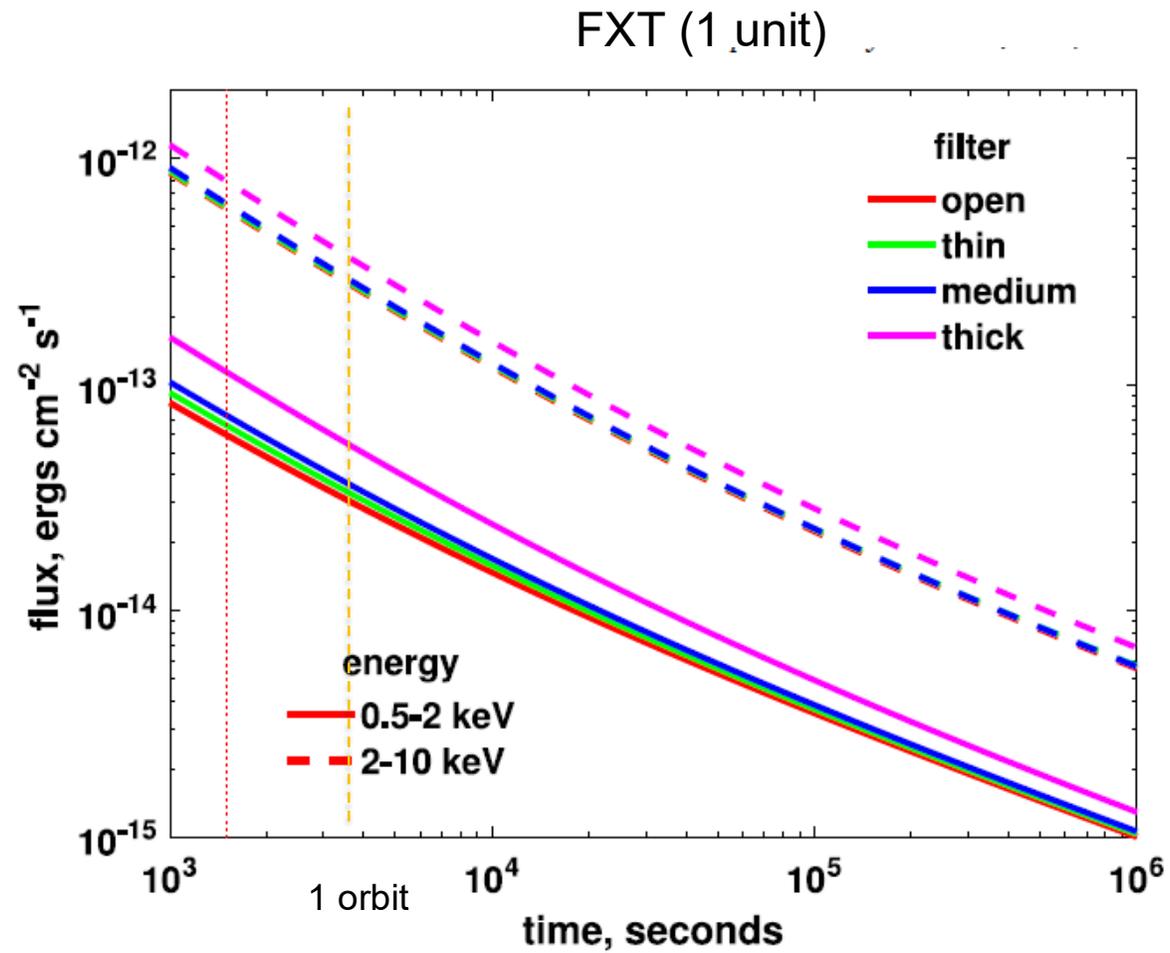
- ❏ Circular orbit
  - Height 592km, period 96min
  - inclination angle 29 deg.
- ❏ **Observation modes**
  - Survey (primary WXT)
  - Autonomous follow-up (FXT)
  - ToO (FXT, WXT) – quick response
- ❏ **WXT survey mode**
  - Pointing to night sky
  - 3 pointings/orbit, ~20min each
  - ~ 1/2 sky covered in 3 orbits (~ 5 hr)
  - Whole sky coverage in 1/2 year
  - FXT pointed to pre-selected targets



# Sensitivity of WXT

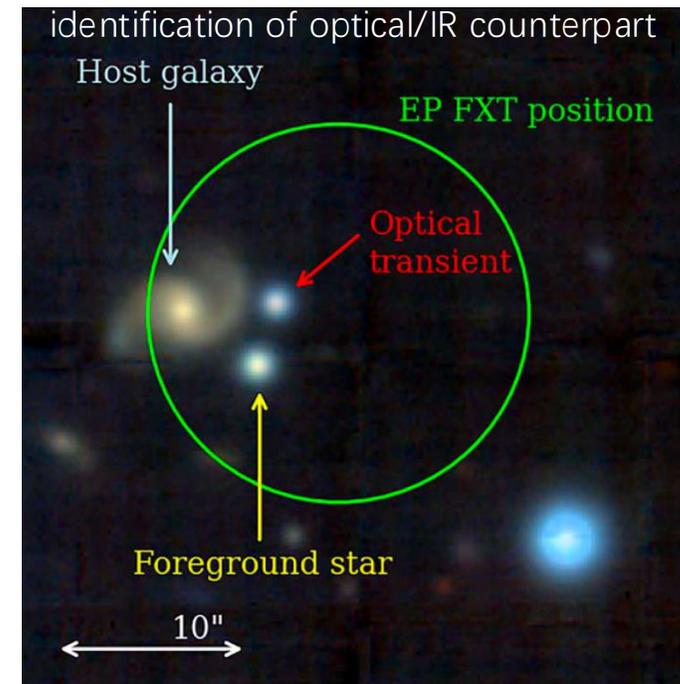
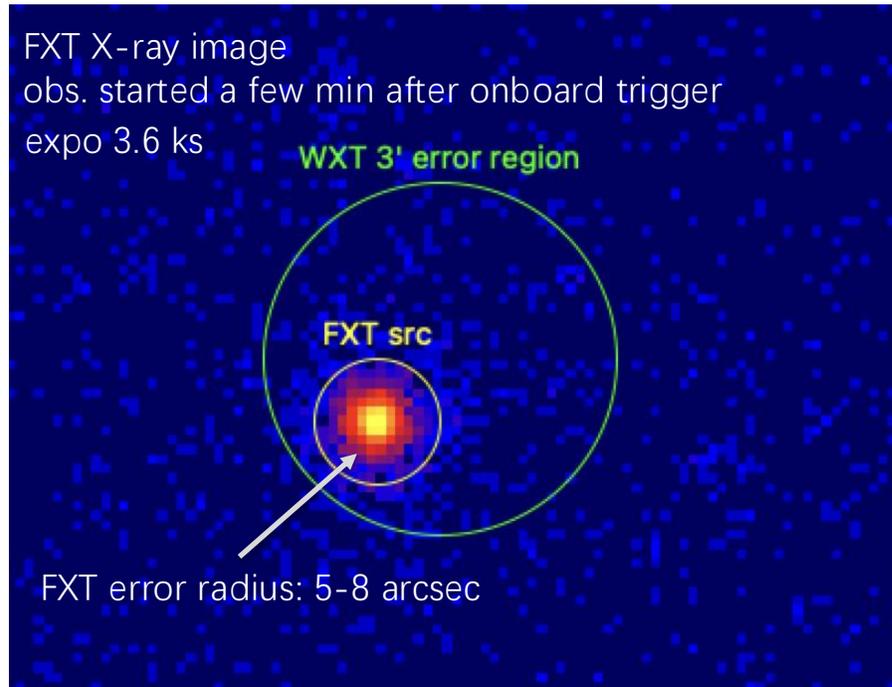


# Sensitivity of FXT



lowest particle background

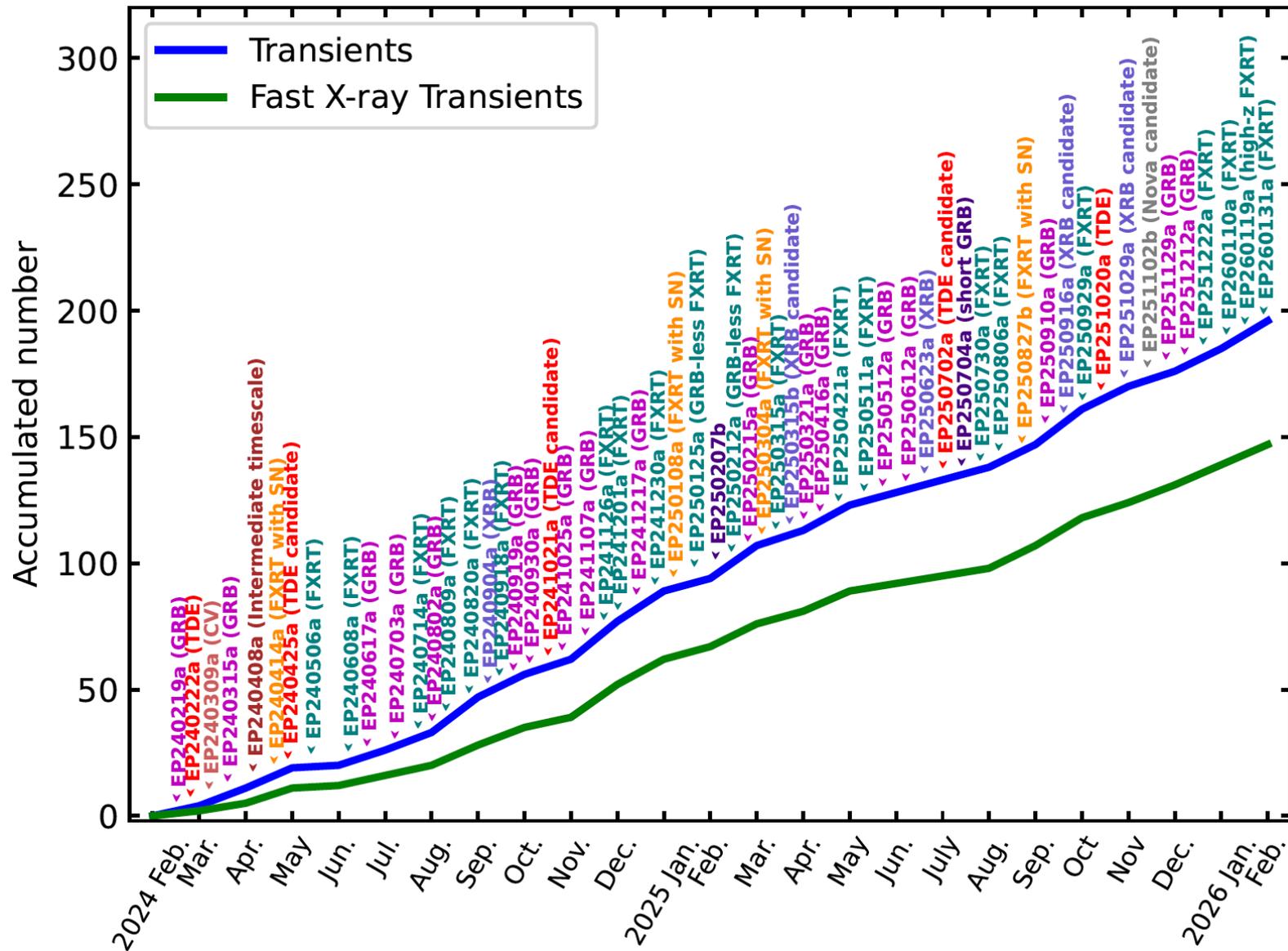
# FXT autonomous follow-up



onboard follow-up response: several minutes

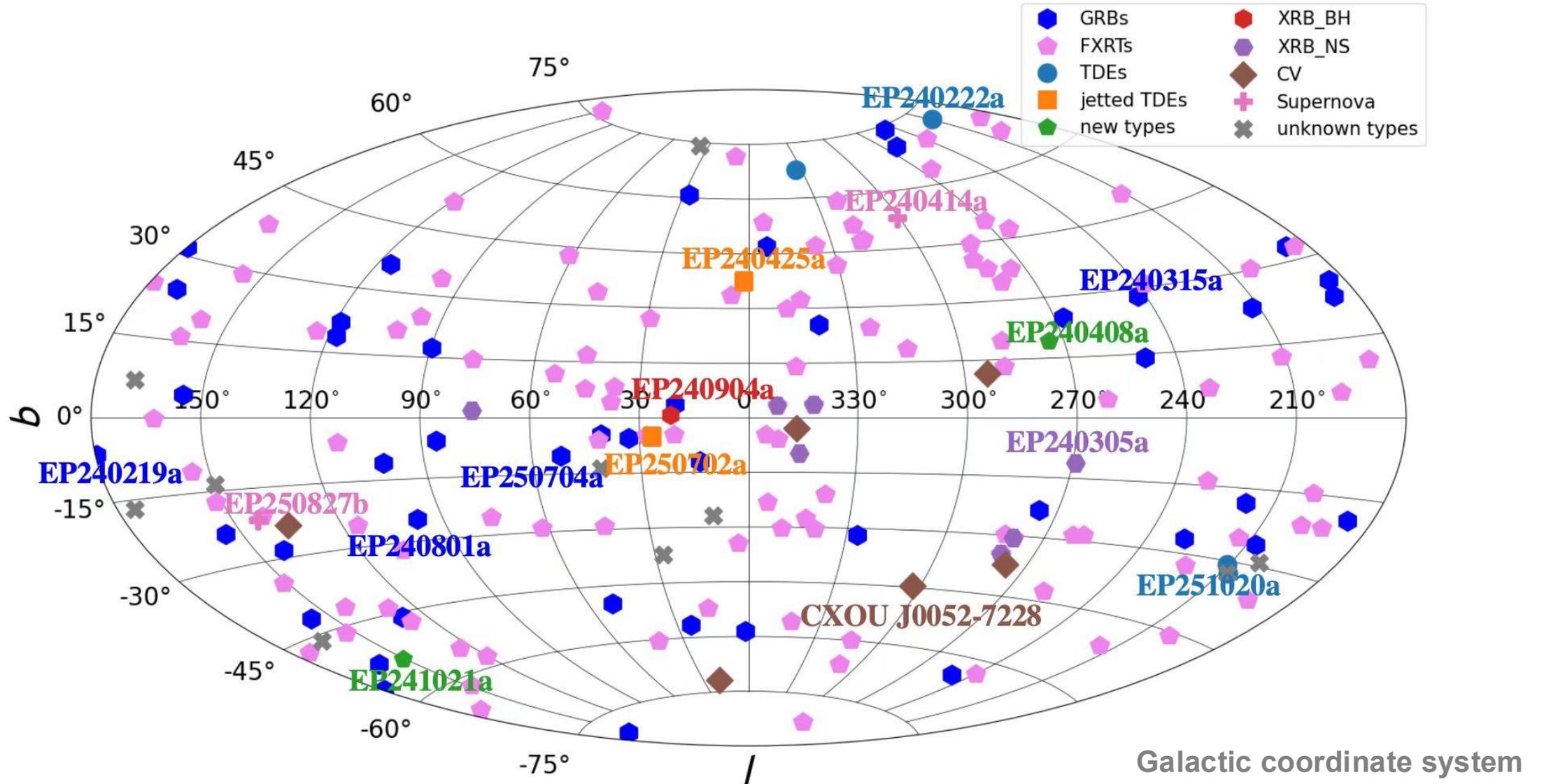
van Dalen et al. 2025

# EP X-ray transients



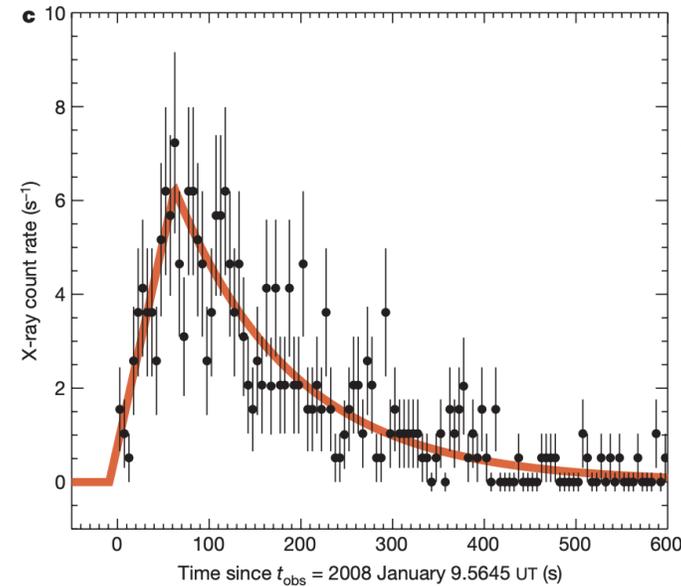
- 198
- ~150 EFXT
- various types
- > 463 GCN/ATel alerts
- enthusiastically responded by multiwavelength follow-ups worldwide --- crucial

# EP X-ray transients

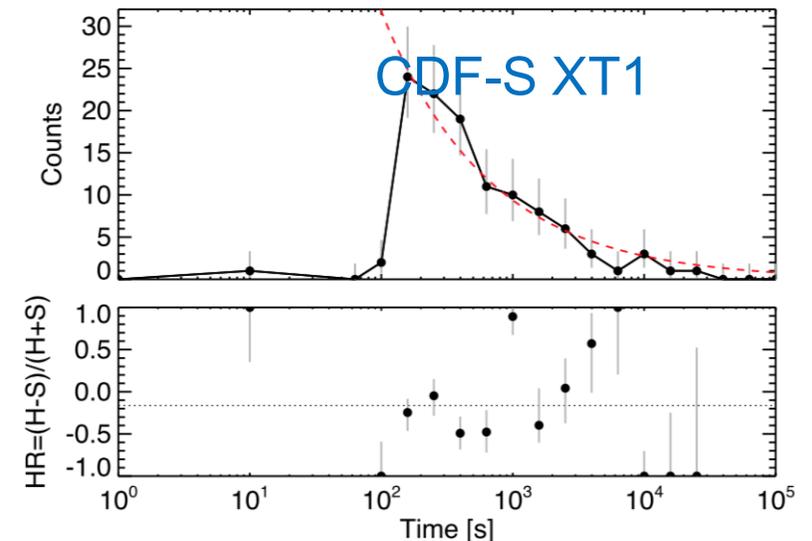
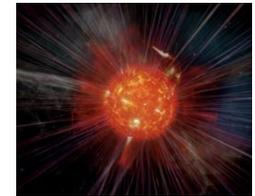


# Extra-galactic fast X-ray transients (EFXT)

- Fast X-ray transient mystery
  - bursts lasting from seconds to hours, found since 1970's
  - detected by wide-field & narrow-field (serendipitously) instruments
  - classifications, demography & origins remain unclear (stellar explosive process?)
- EP has detected **148 EFXT**
  - No-GRB (X-ray flash):  
99 (c.f. 30-40 before EP launch)
  - GRB in soft X-ray: new window



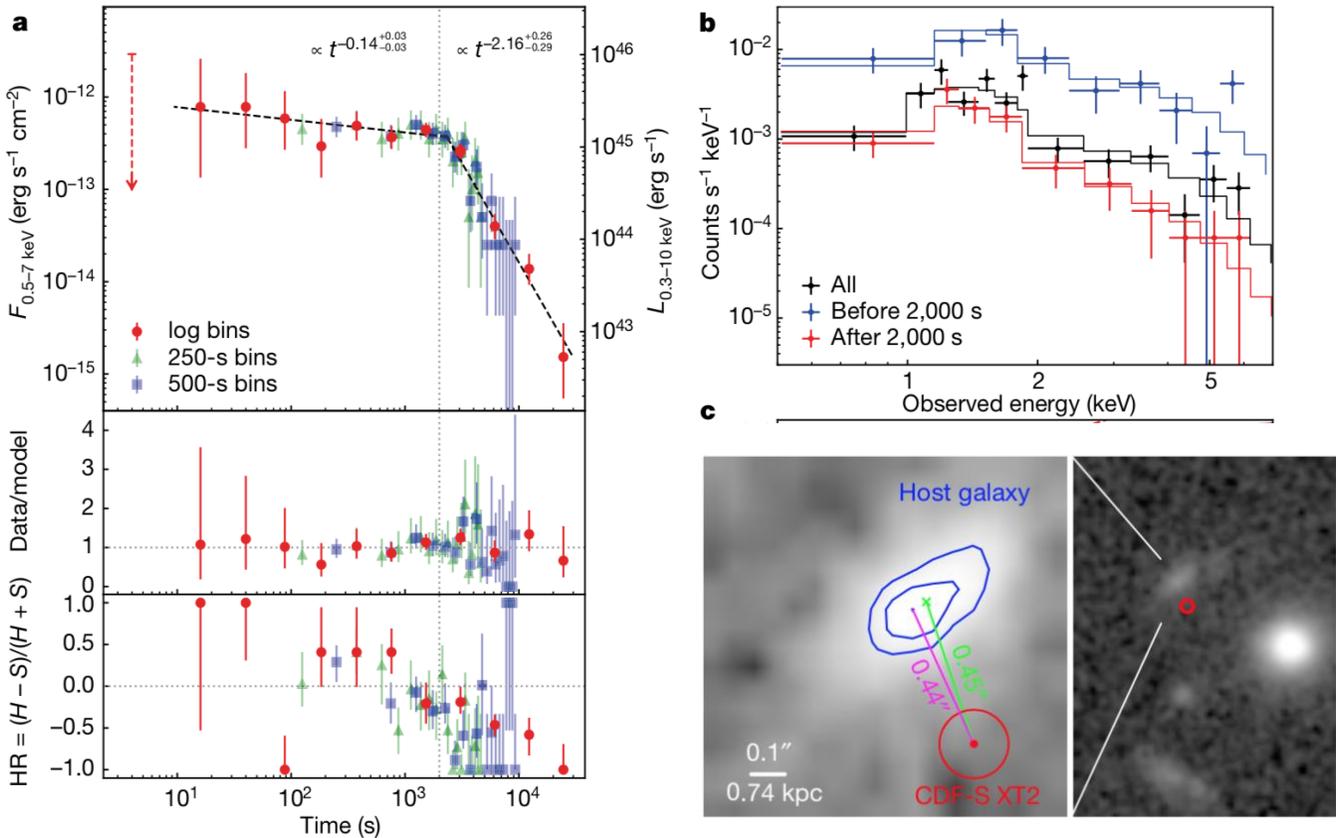
SN Shock breakout by Swift/XRT XRO 080109 (Soderberg+ 2008)



$z_{\text{ph}} \sim 2.23$ ,  $L_p \sim 6.8e46$   
erg/s Bauer et al. 2017

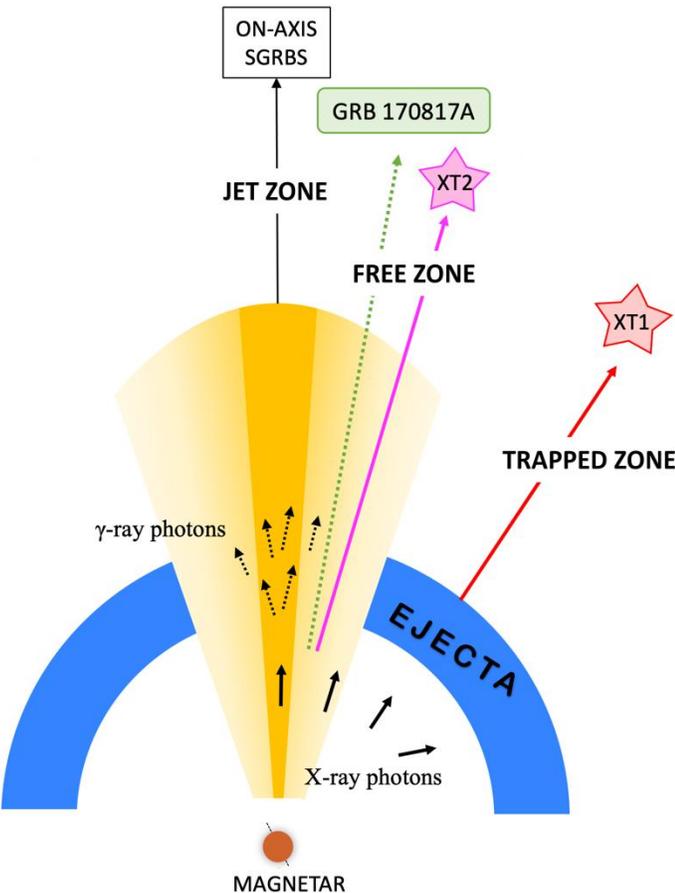
# EFXT: example

## CDF-S XT2



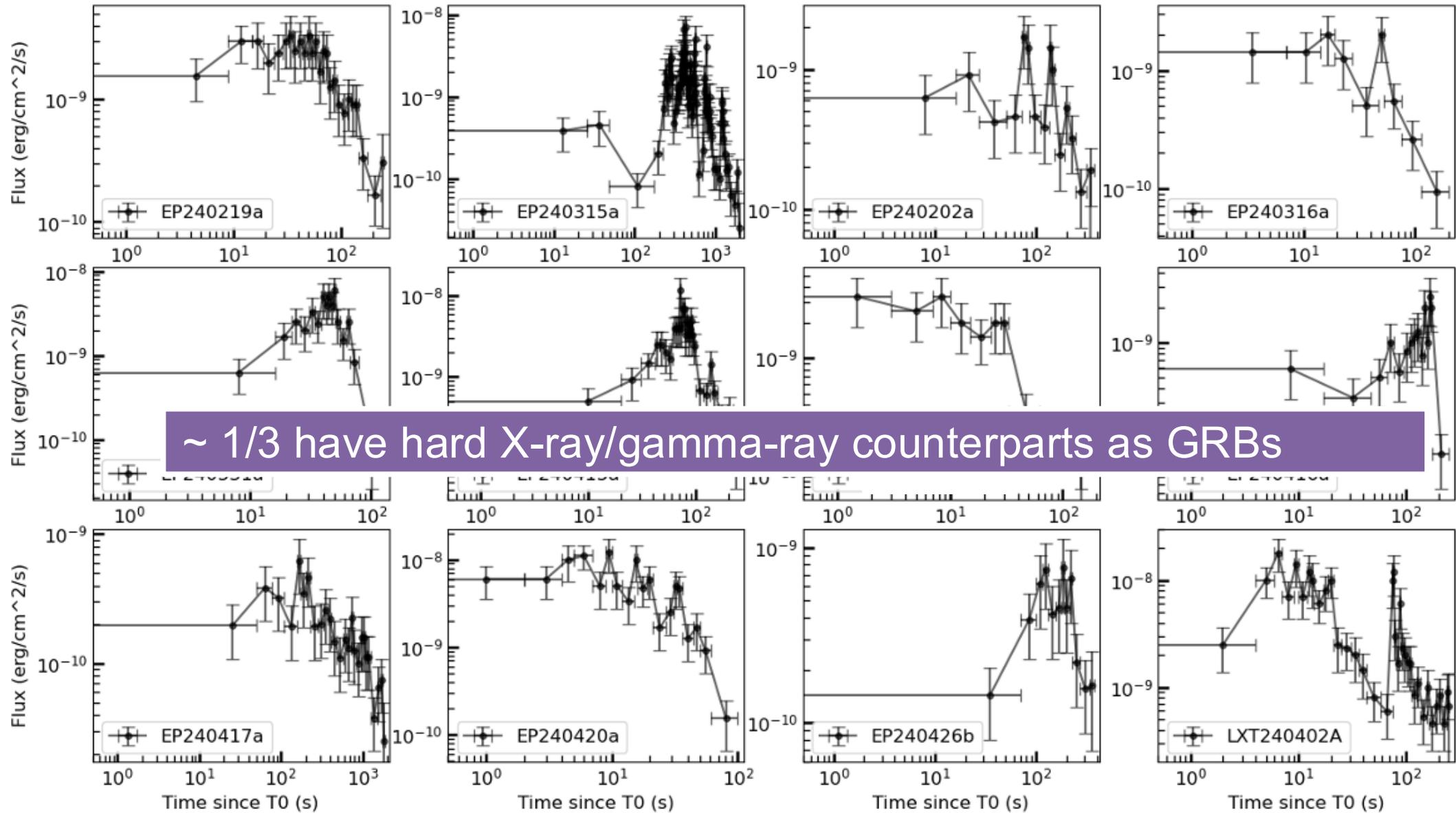
$z \sim 0.738, L_p \sim 3e45 \text{ erg/s}$  Xue et al. 2019

one of the models: driven by magnetar from BNS merger (both XT2 & XT1)



e.g. Zhang B., 2013, Sun et al. 2019

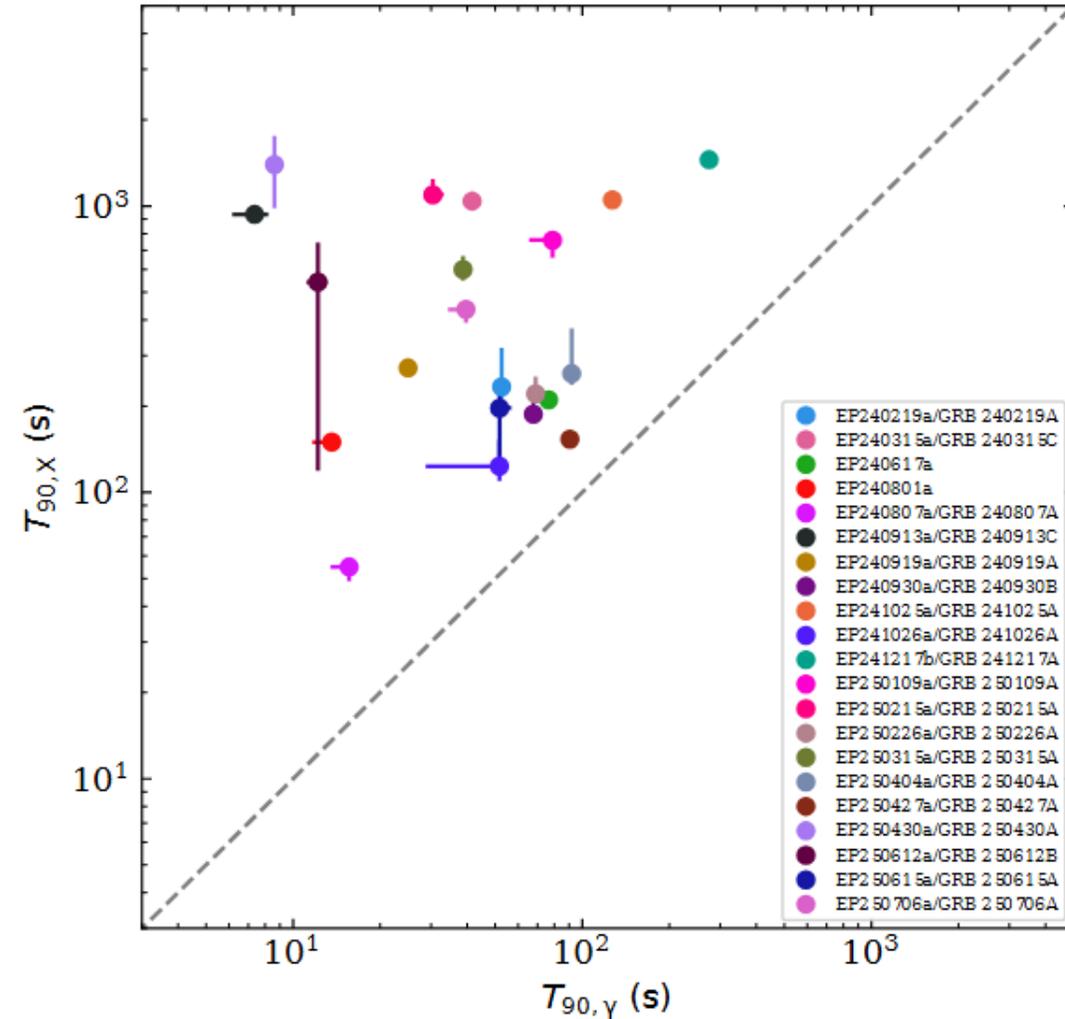
# Example light curves of EP fast X-ray transients



# Fast X-ray transients last longer than GRBs

X-ray and gamma-ray  $T_{90}$  distribution

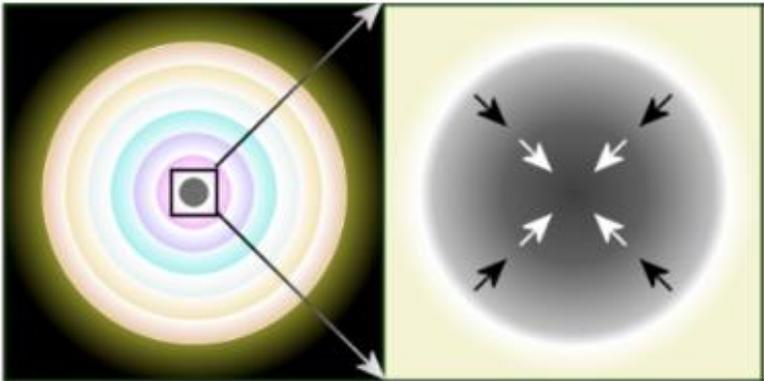
Duration: X-ray longer than gamma-ray for all events



# Possible origin of EFXT

massive star core-collapse

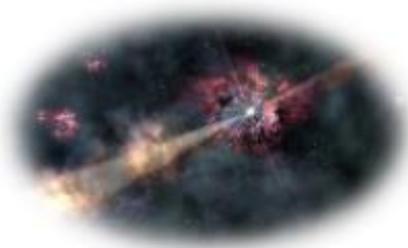
compact objects  
binary merger



GW-EM

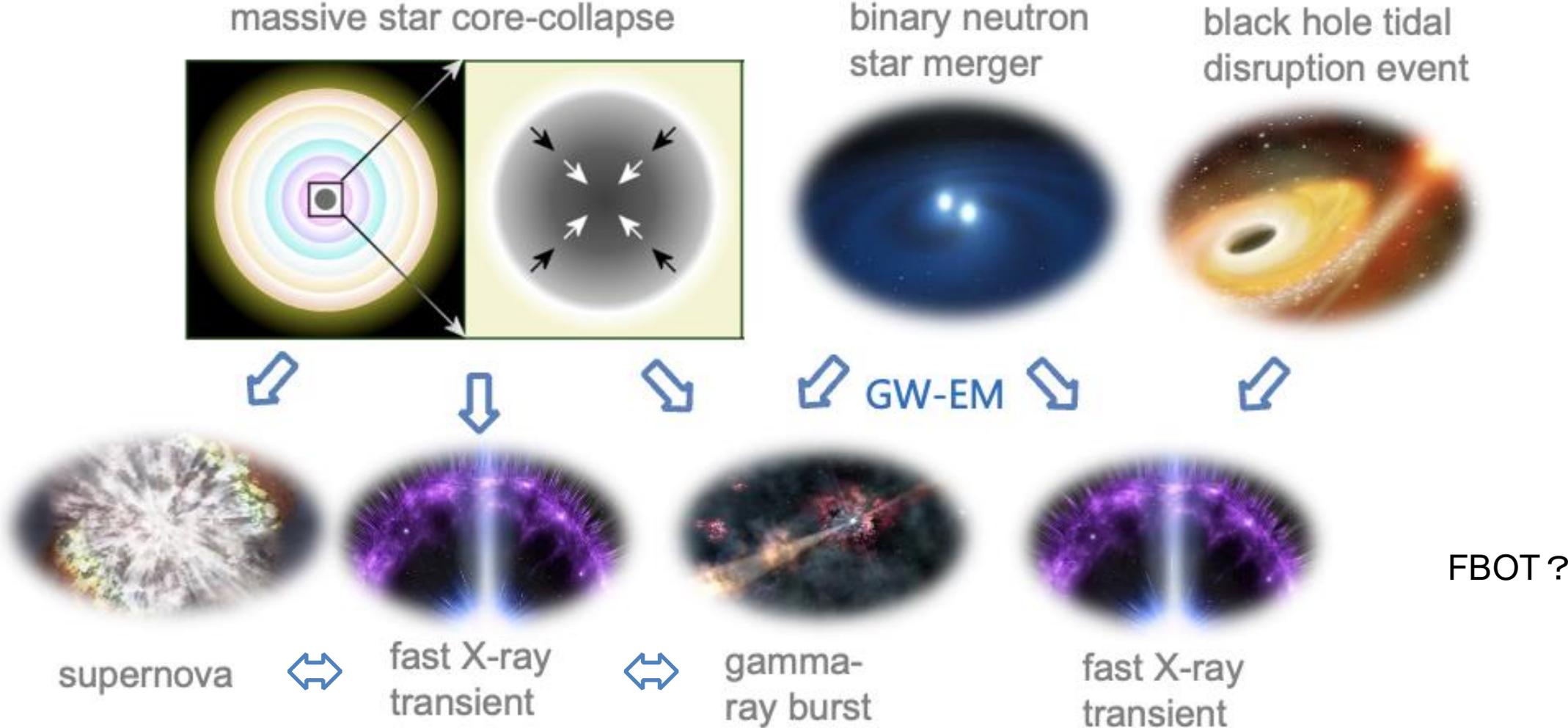


supernova



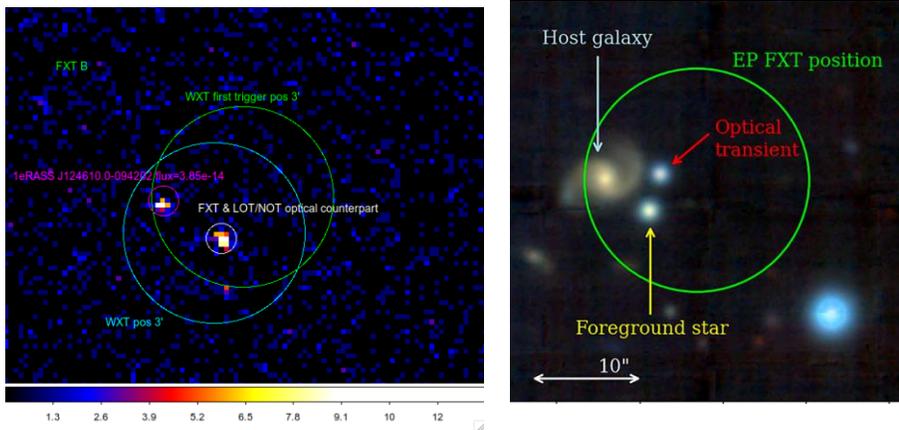
gamma-ray burst

# Possible origin of EFXT

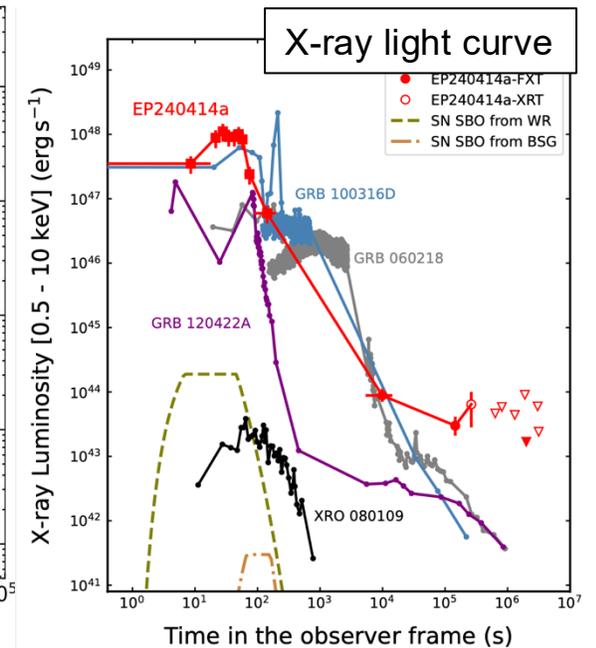
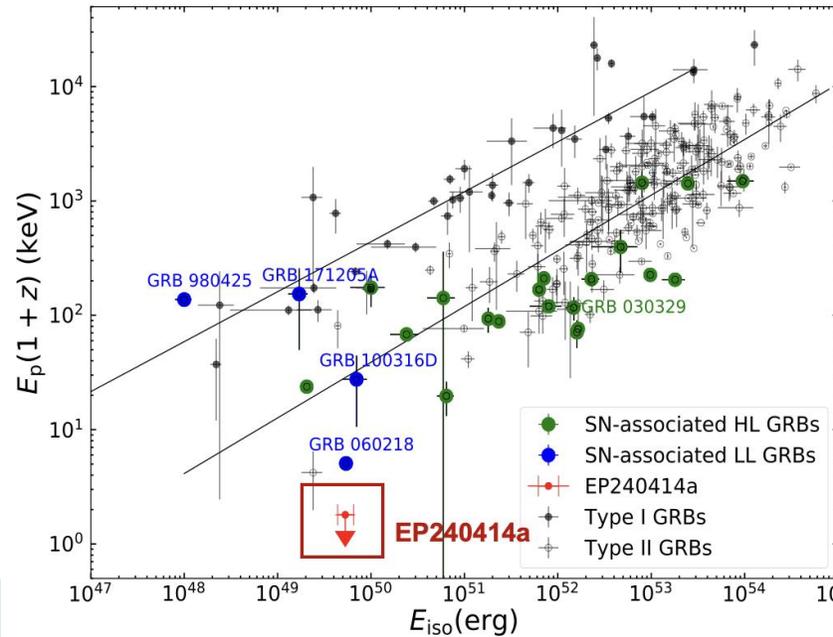
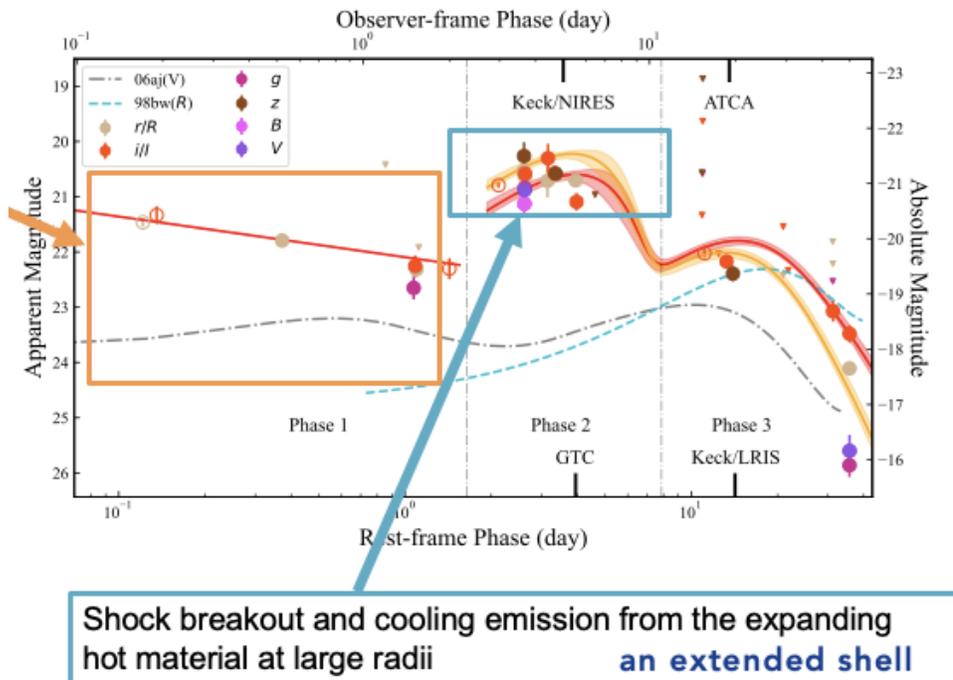


EP may reveal the diversity of the processes of collapsars and compact object mergers

# EP240414a: new fast X-ray transient with SN ?



- Associated with Ic-BL supernova 2024gsa  $z=0.4$
  - No GRB, very soft spectrum
  - possibly a new type of FXT
- => A weak relativistic jet that interacts with an extended shell surrounding the progenitor star**



# EP enabling multiple FXT-SN associations

8 confirmed FXT-SN, all Broad-line SN Ic

## EP250108a / SN 2025kg

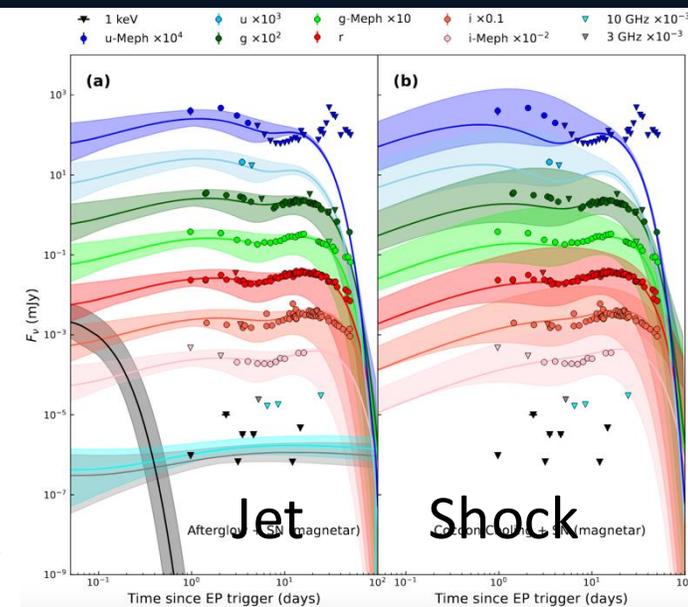
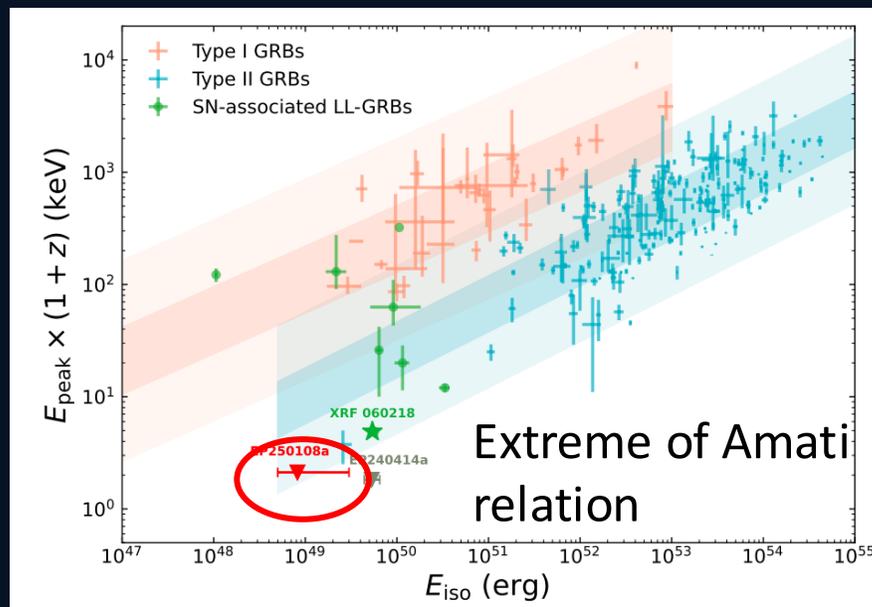
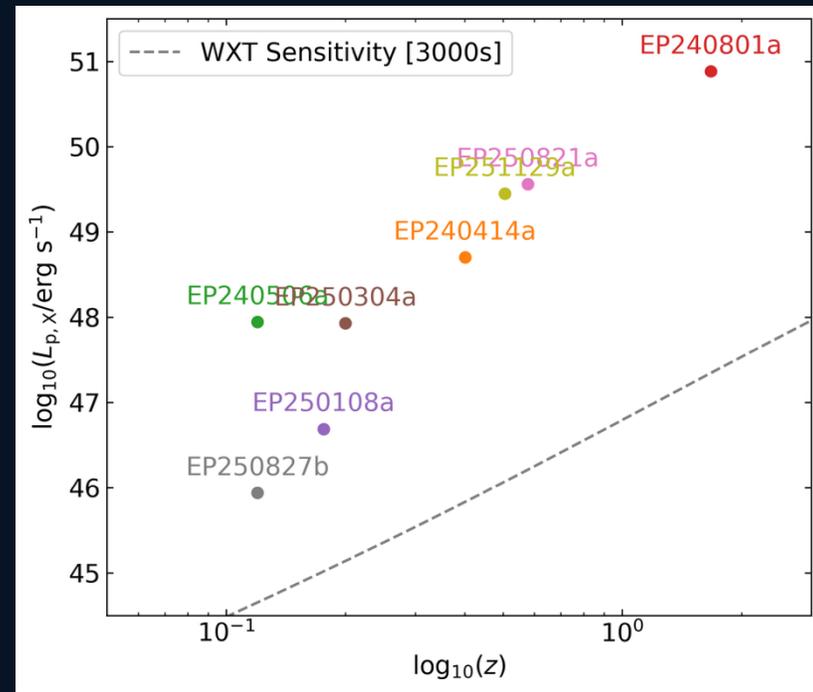
Type Ic-BL @  $z \approx 0.176$  (Li+ 2025)

Extremely soft/weak

X-ray flash

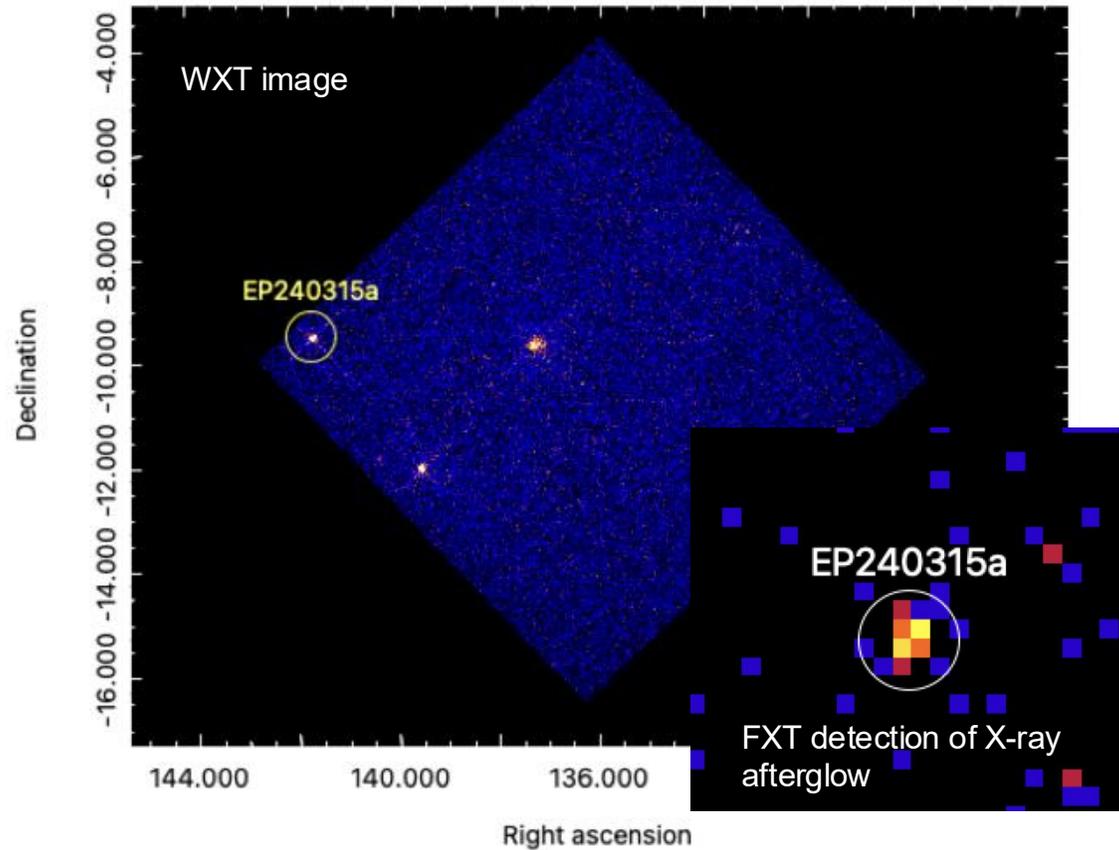
A relativistic outflow origin  
(jet or shock)

from Wenxiong Li (submitted)



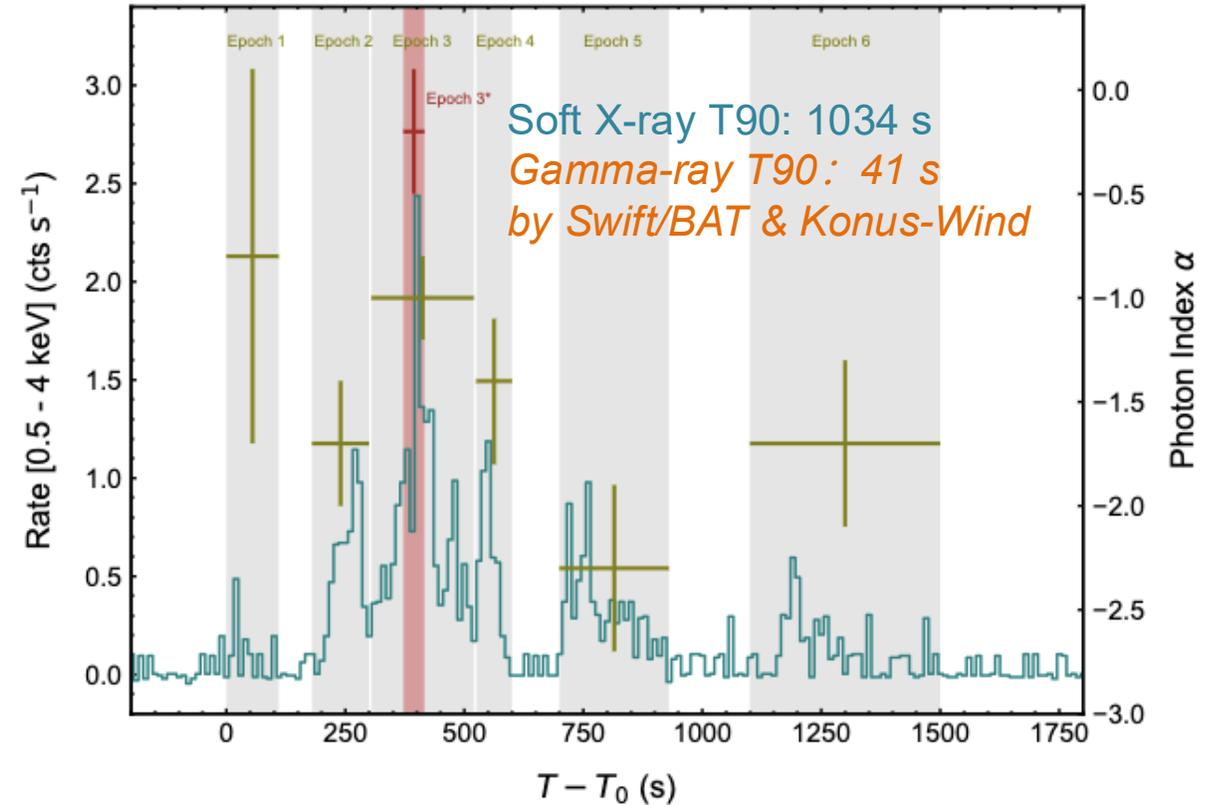
# EP240315a: GRB @redshift 4.859

a



Onboard trigger, confirmed by on-ground analysis

Liu Y., et al. 2025 Nature Astronomy, 9, 564  
 Levan A., et al. 2025 Nature Astronomy, 9, 1375  
 Gillanders J.H., et al. 2024 ApJ



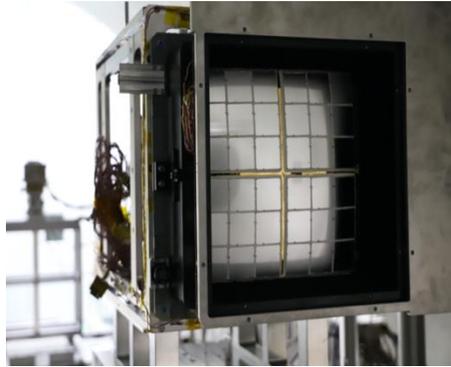
Marked difference in LC of soft X-ray and hard X/γ rays

redshift 4.859 measured by VLT (Levan et al. 2024)

detectable by WXT at  $z \sim 7.5$

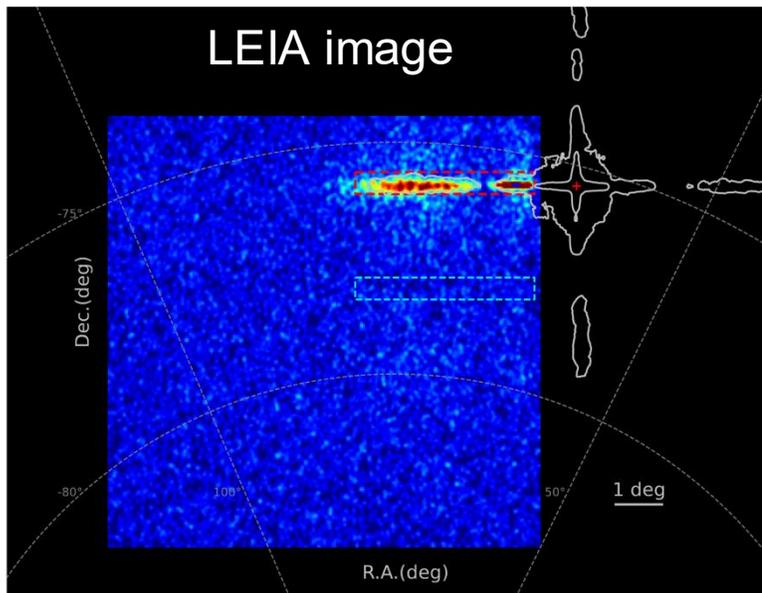
EP's potential of detecting high-z GRB !

# LXT 230307A: transient powered by NS merger

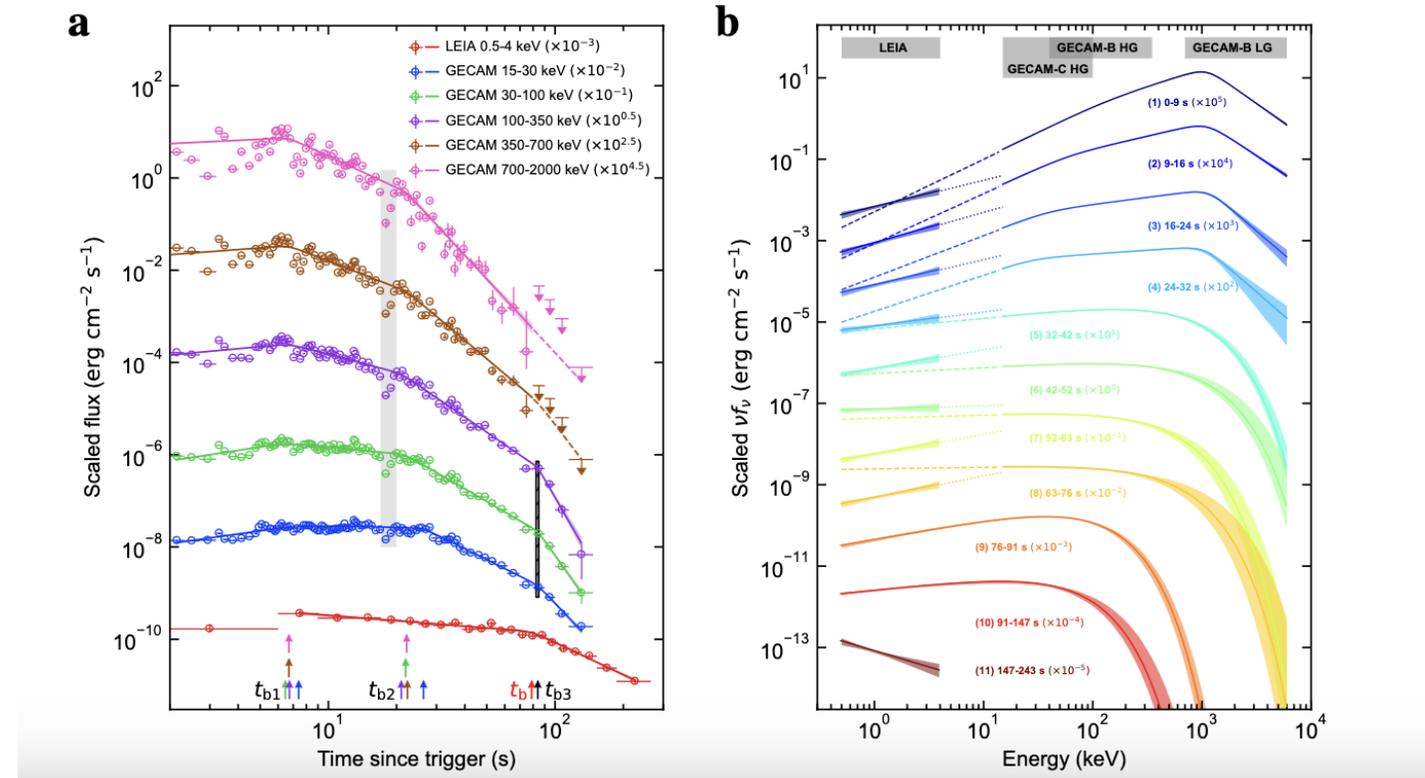


EP pathfinder LEIA 0.5 - 4 keV

- Hard X-rays and gamma-rays powered by relativistic jet
- Soft X-rays likely powered by a magnetar, emerging from burst onset
- Consistent with the association of kilonova signature found by JWST

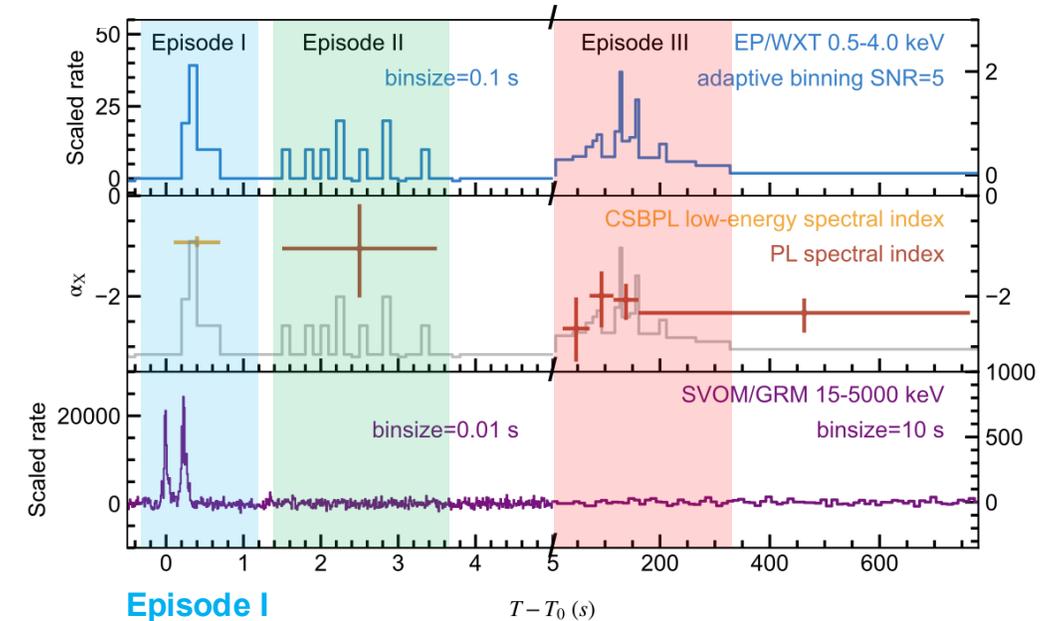
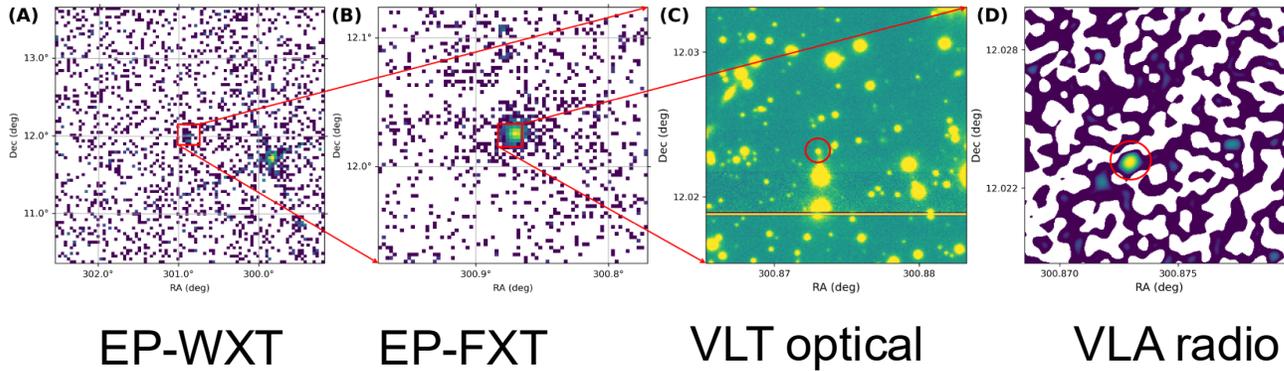


4



# EP250704a: Extended emission in merger-type GRBs

## EP250704a/GRB 250704B



**Episode I**  
 (~ 0.5 s)  
 initial X-ray hard spike  
 gamma-ray double spikes

**Episode II**  
 (~ 3 s)  
 extended X-ray hard bump  
 no gamma-ray

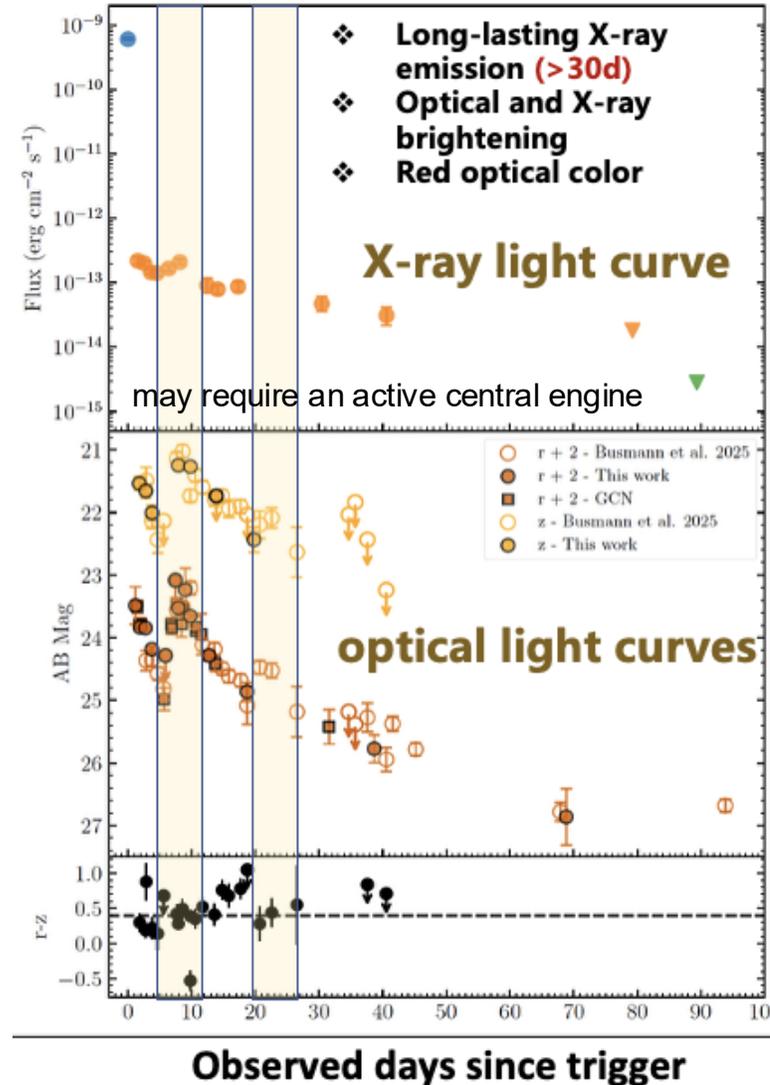
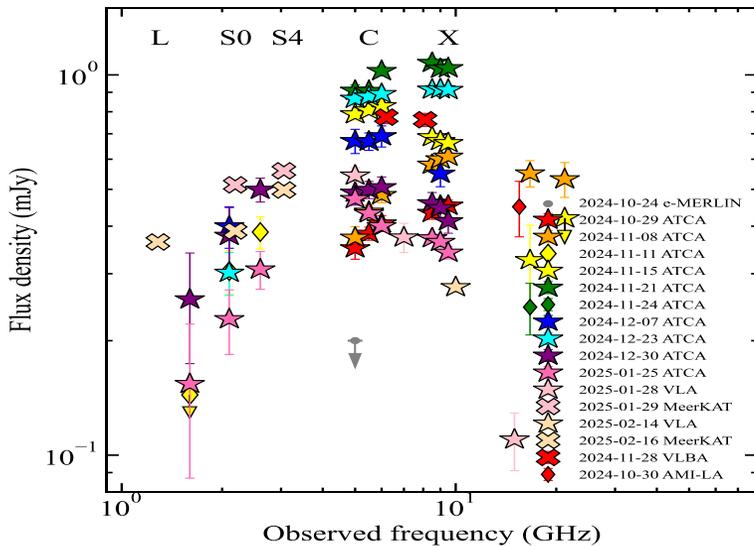
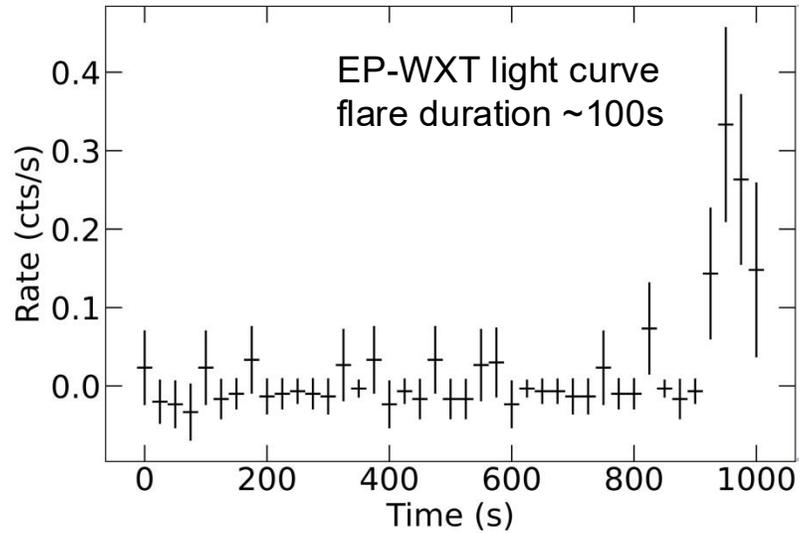
**Episode III**  
 (~ 540 s)  
 X-ray soft bump  
 no gamma-ray

A long-last soft X-ray prompt emission in a typical short gamma-ray burst, likely a common feature in merger-driven burst, and an X-ray counterpart of GW events

Li, A &. EP/SVOM Collaboration et al, 2026,  
 submitted , arxiv: 2601.14137

credit: Zhang B.B.

# EP241021a: a repeating partial TDE or a peculiar GRB?

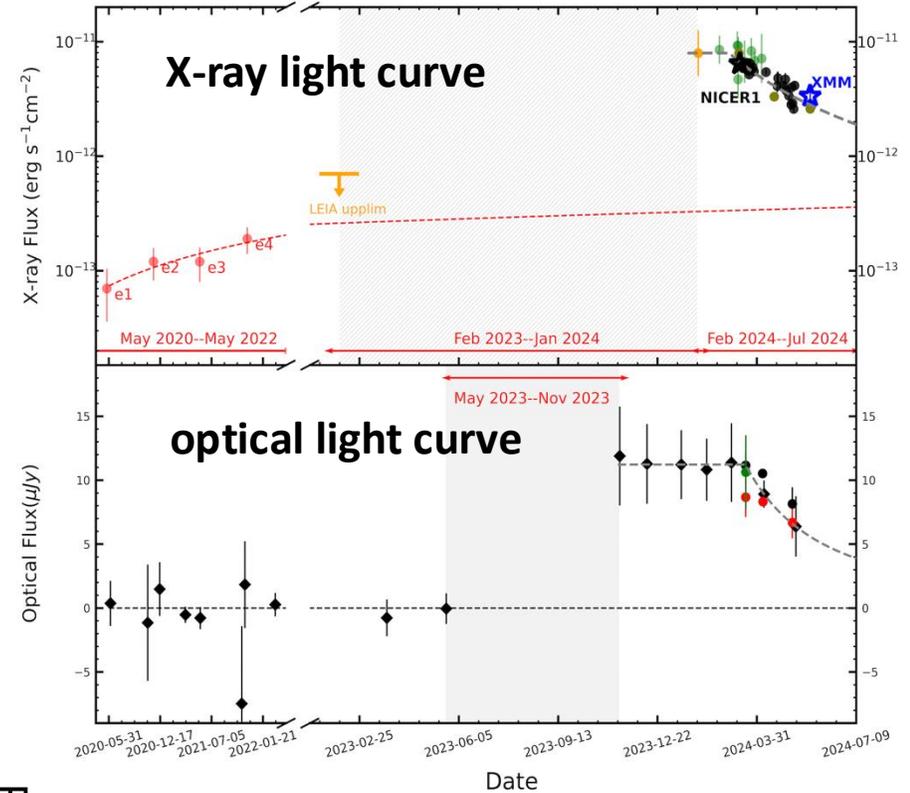
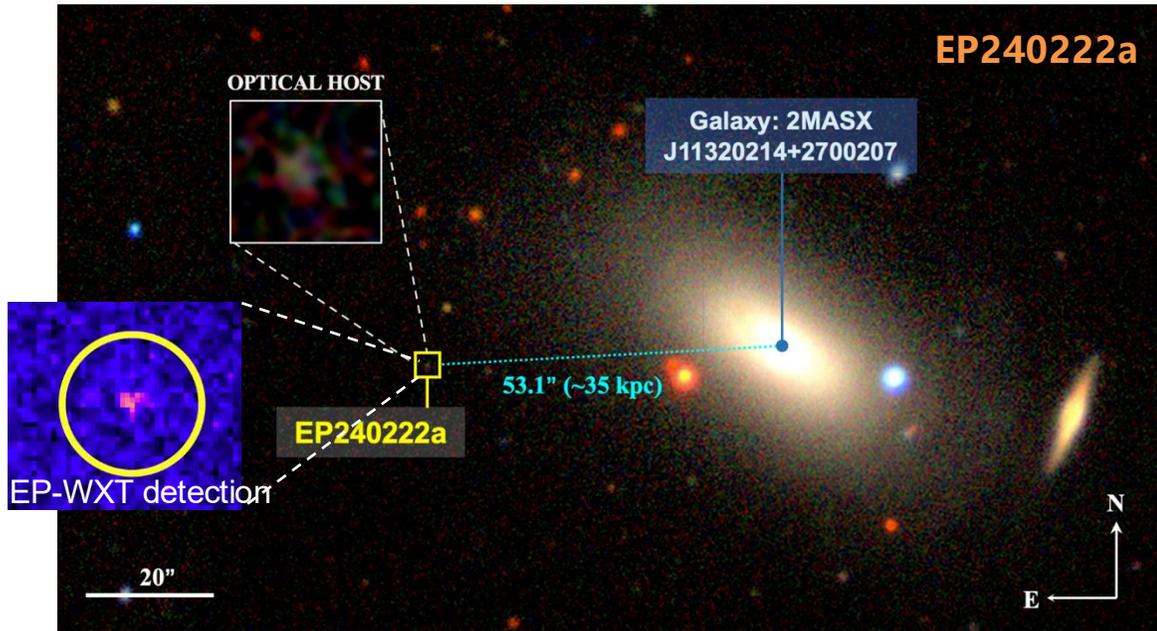


Possible scenarios:

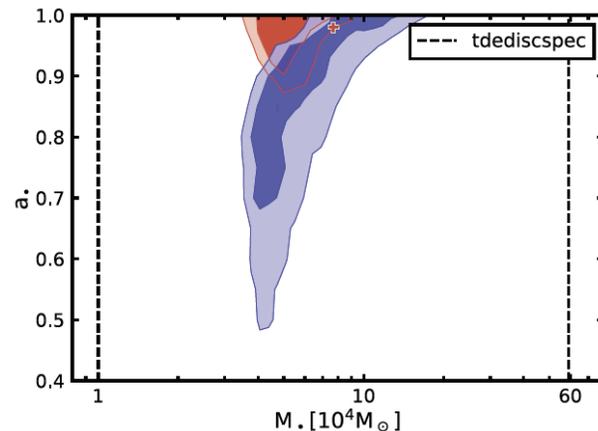
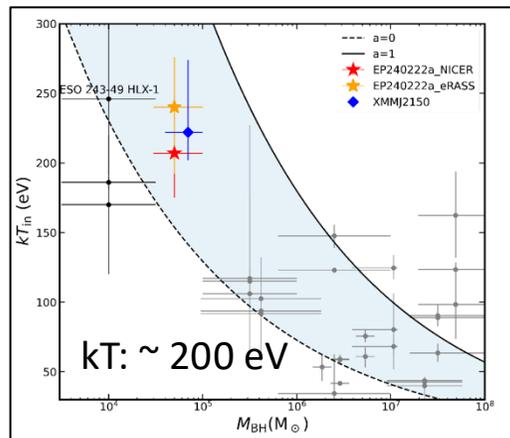
- repeating partial TDE by IMBH
- highly structured GRB jet
- choked jet with supernova shock breakout
- merger-triggered magnetar
- **new type of transients with months-timescales**

Shu, XW et al., 2025 ApJL, arxiv: 2505.07665  
 Busmann, M. et al. , arxiv:2503.14588  
 Gianfagna, G. et al., arxiv:2505.05444  
 Yadav, M. et al., arxiv:2505.08781  
 Wu, GL et al. arxiv:2505.12491

# EP240222a: TDE by IMBH in the halo of a large galaxy



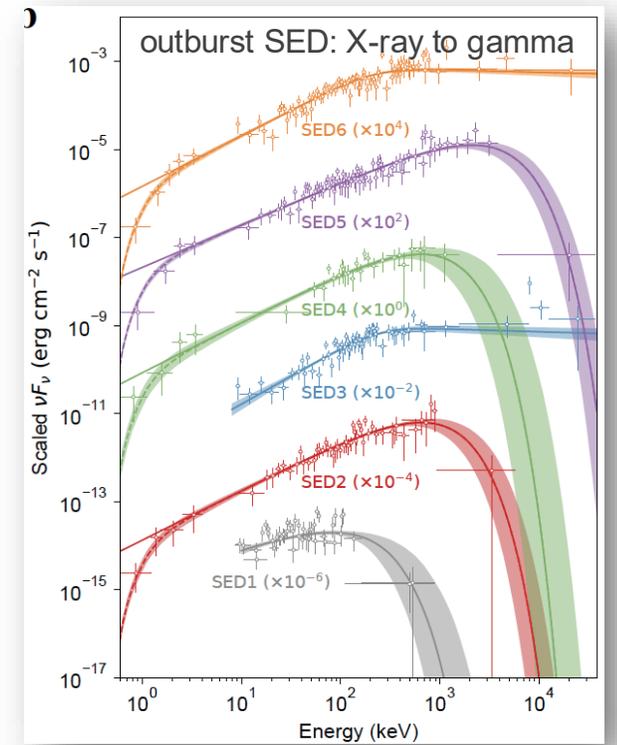
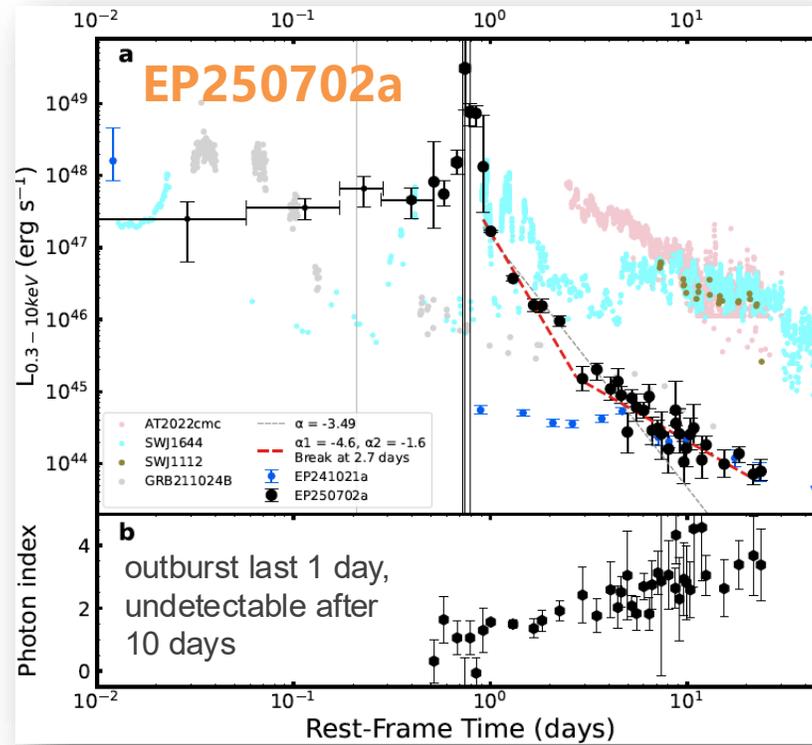
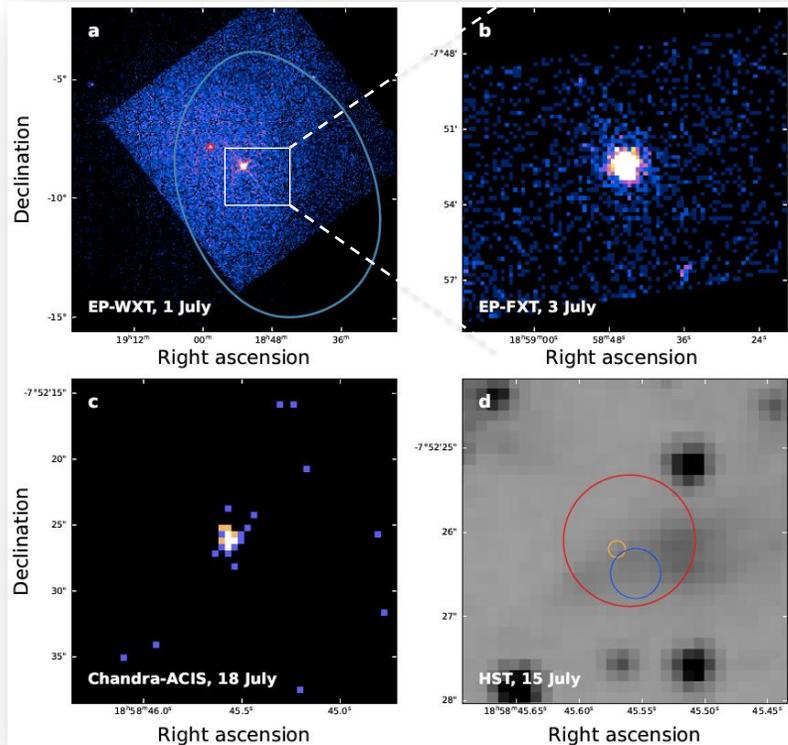
>4 years; off nucleus: 35 kpc from center of a massive galaxy



BH mass  $1e4-1e5 M_{\text{sun}}$   
 host stellar mass:  $\sim 1e7 M_{\text{sun}}$   
 (Jin et al. under review)

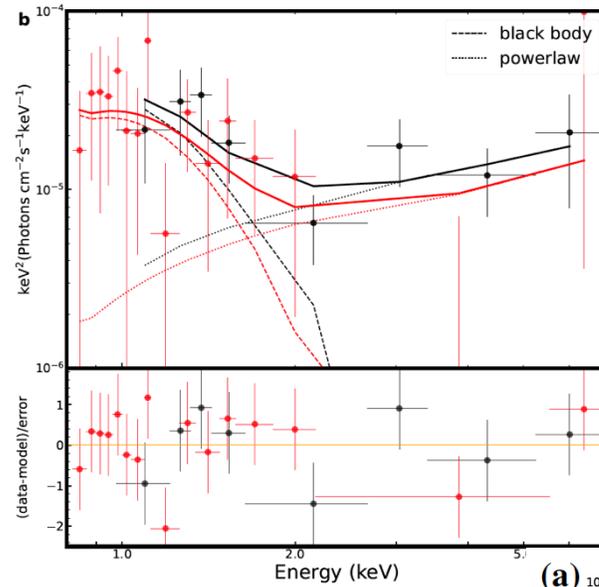
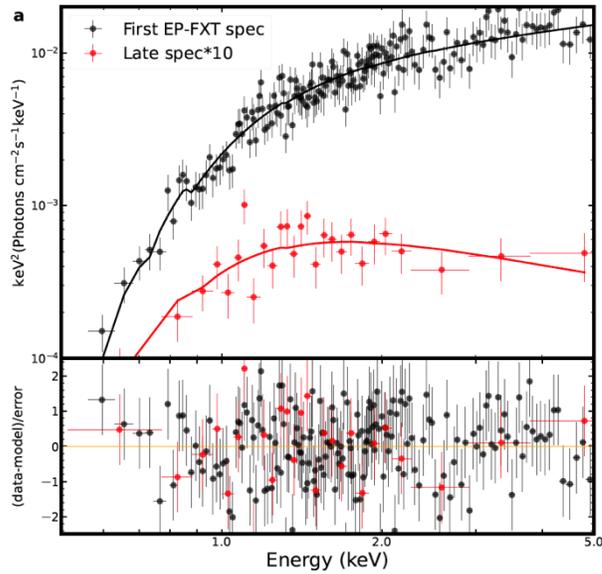
<https://arxiv.org/abs/2501.09580>

# EP250702a: first discovery of TDE of a white dwarf by IMBH ?



- Unprecedented lightcurve & spectra
- Relativistic jets

# EP250702a: first discovery of TDE of a white dwarf by IMBH ?



• power-law (jet)

$$\Gamma = 1.4^{+0.7}_{-0.8}$$

• blackbody

$$kT = 161^{+32}_{-30} \text{ eV}$$

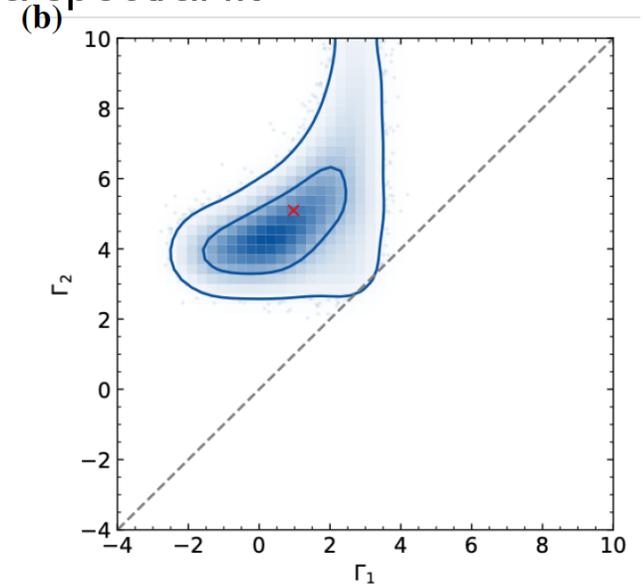
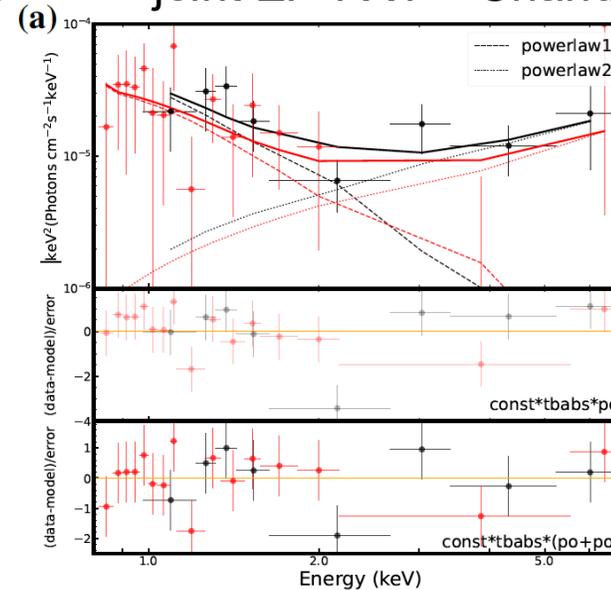
$$9.8 \times 10^{44} \text{ erg s}^{-1}$$

~100  $L_{\text{Edd}}$  for BH with

$$7.5 \times 10^4 M_{\odot}$$

- a soft X-ray component emerged at a later stage: accretion disc of highly super-Eddington
- TDE of a white dwarf by an IMBH?
- stellar-mass BH falling into a star?

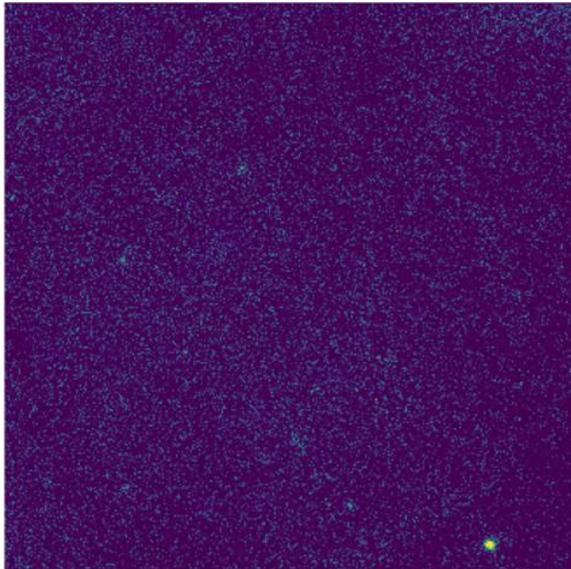
joint EP-FXT – Chandra spectral fit



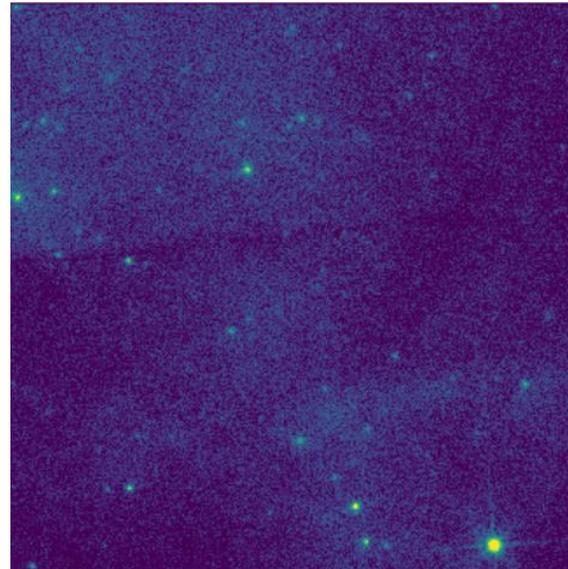
## Prospects: tidal disruption events

- Performance of WXT data stacking demonstrated, more TDEs are expected

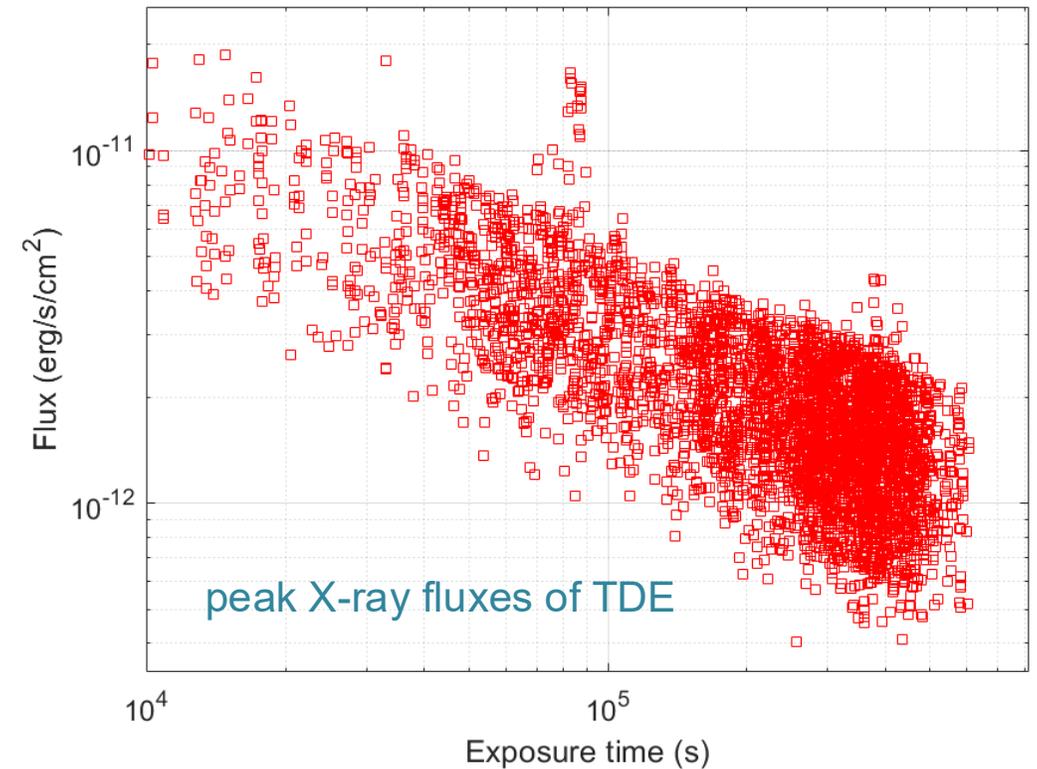
increasing sensitivity achieved by stacking data



1-day WXT

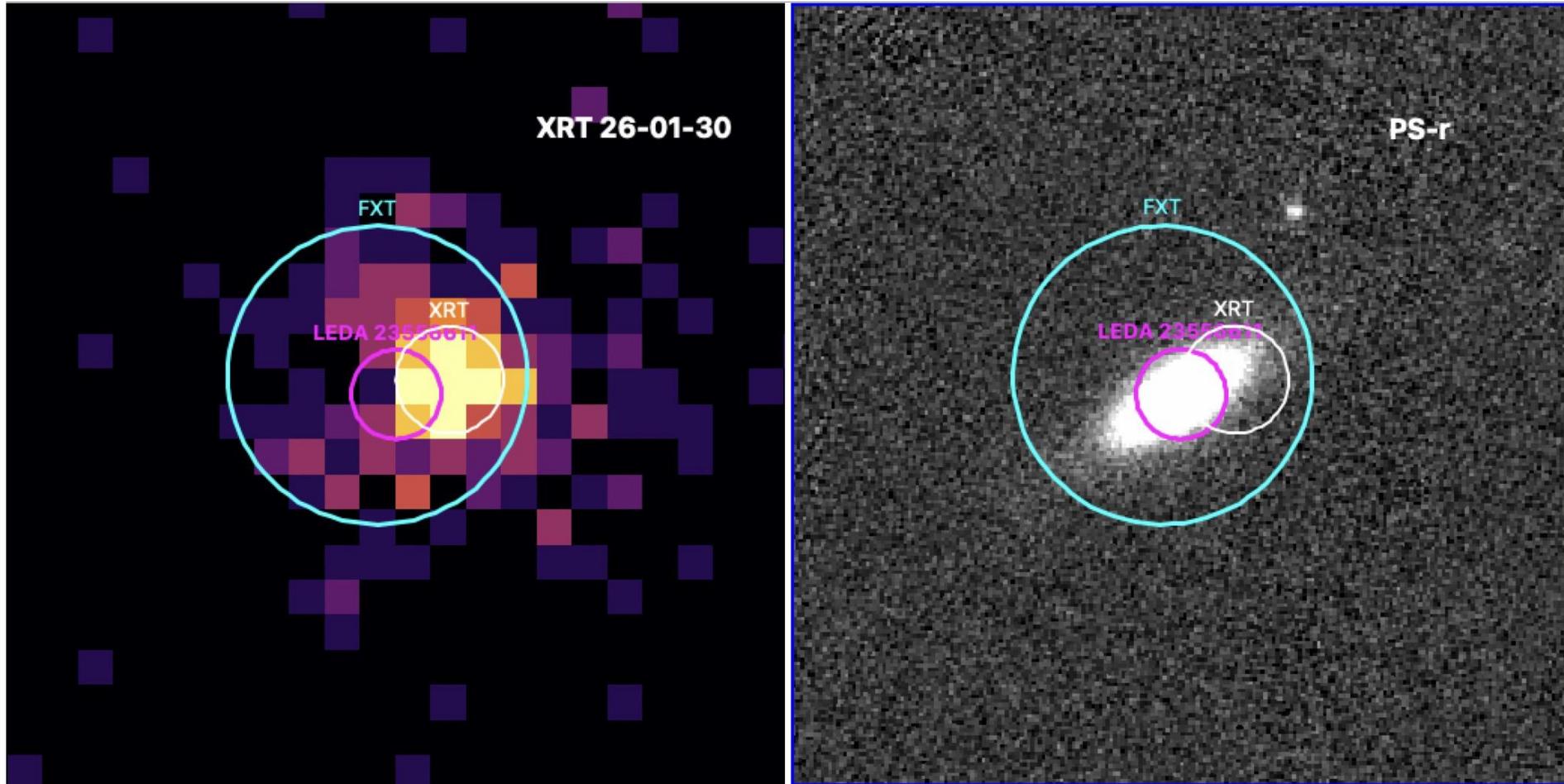


1-month WXT



## Prospects: tidal disruption events

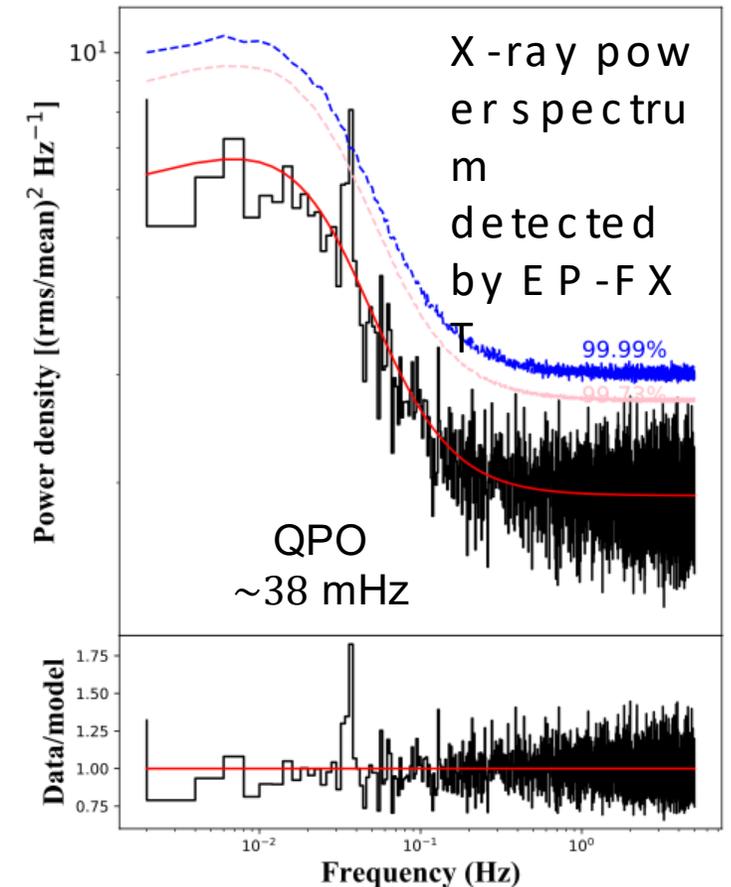
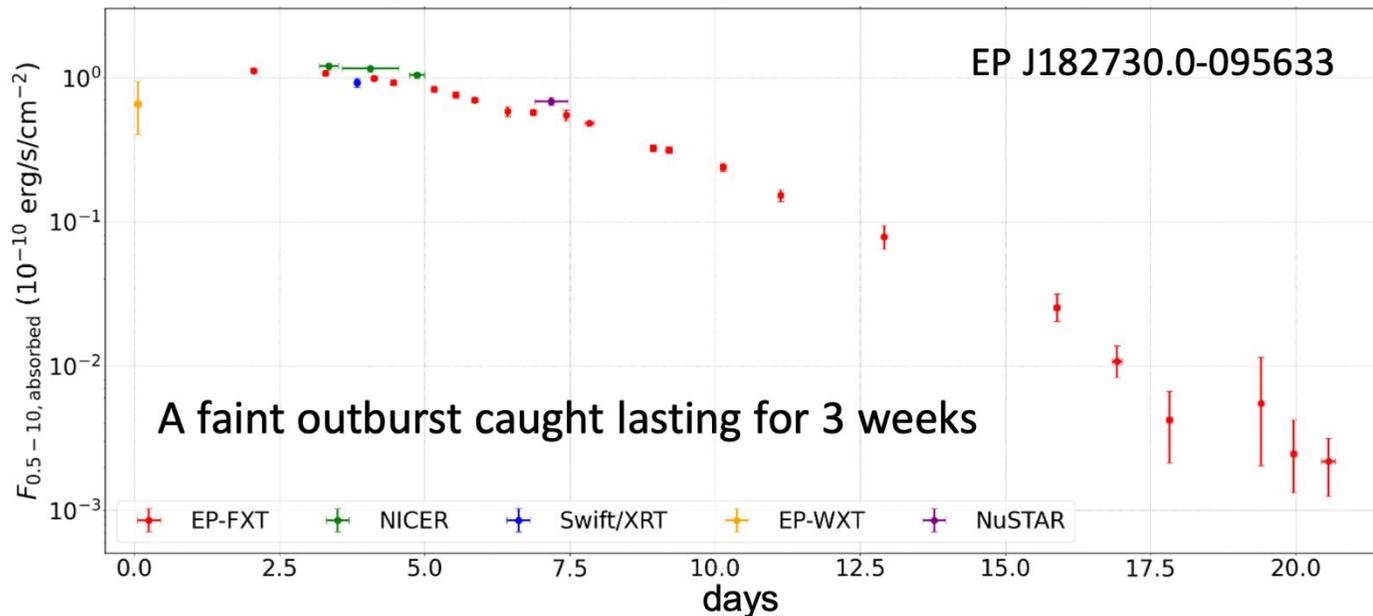
example of a TDE candidate found by data stacking



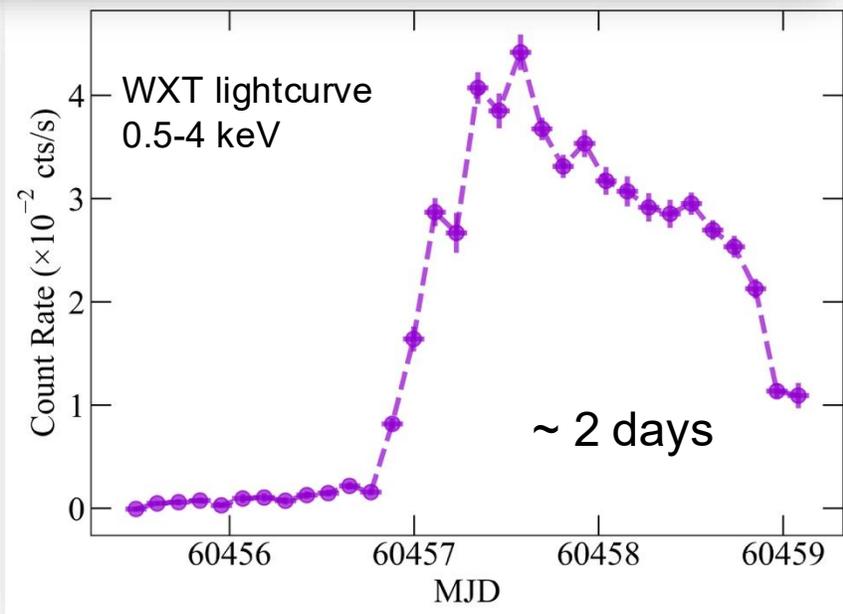
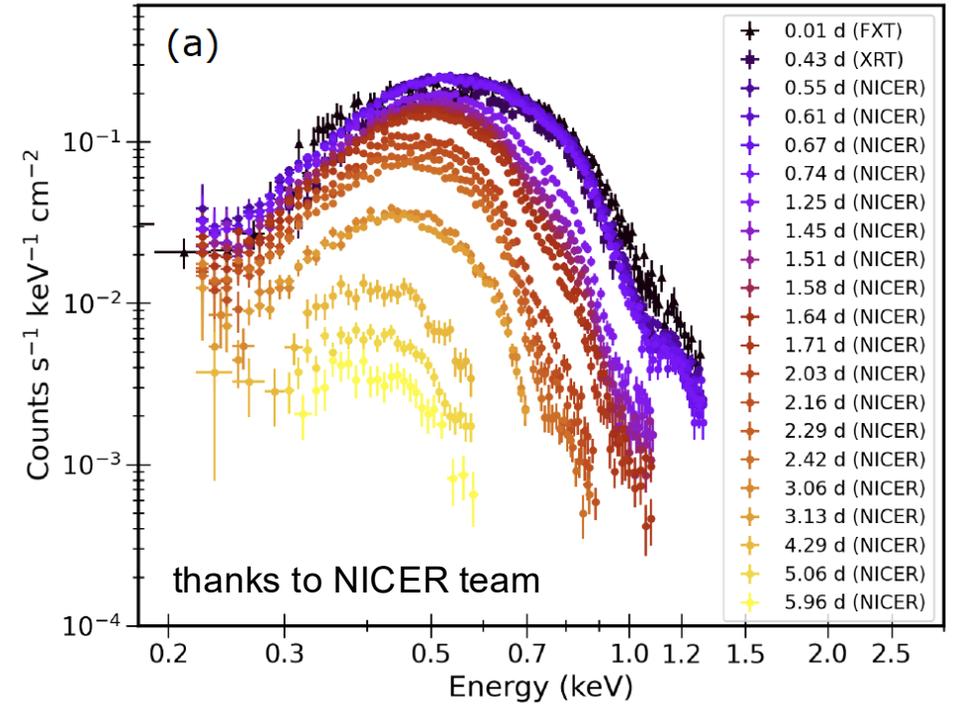
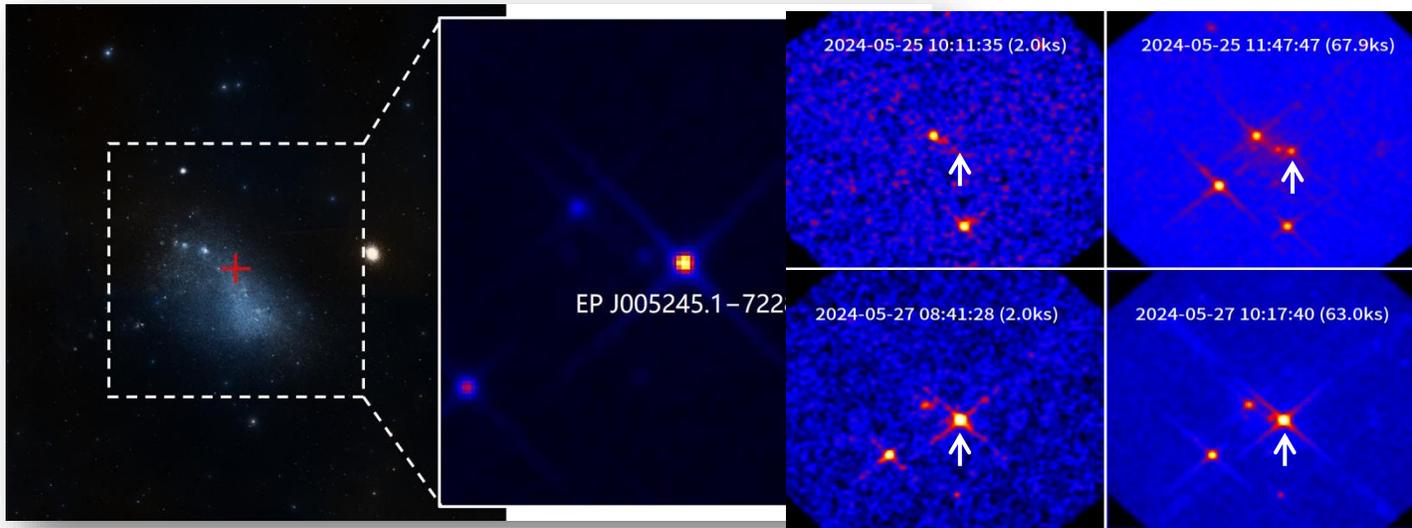
# Finding hiding stellar BH & compact objects

- Where are the hiding BH XRB in Galaxy? predicted  $10^3$  vs.  $< 100$
- Most in quiescent or faint activities, important to constrain stellar evolution, accretion
- EP has found 16 new XRB candidates (2 BH, 4 NS, ...)
- Very faint X-ray transients:  $\sim 5$  /year
- magnetars, fireball phase of novae, ...

a new BH binary candidate found by detecting its faint outburst

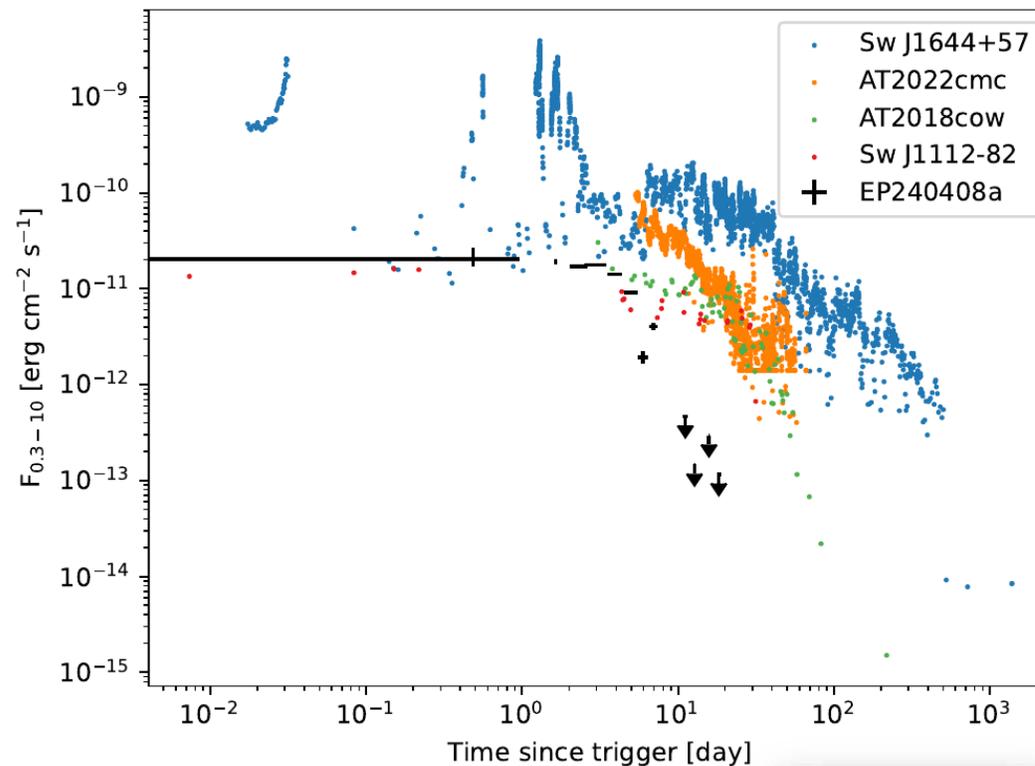
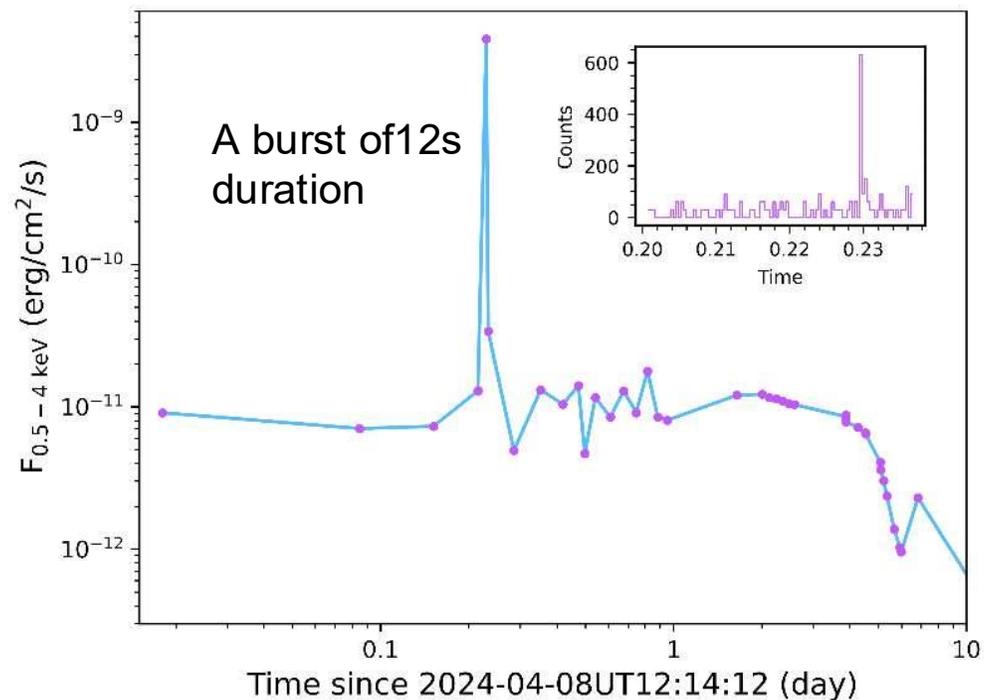
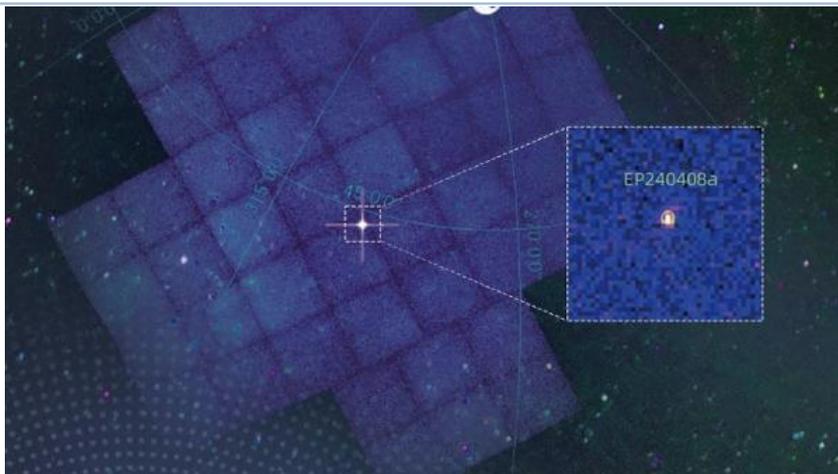


# An outburst in Small Magellanic Cloud: Be + WD



- CXOU J005245.0-722844 a weak Chandra source
- An X-ray outburst detected by [EP/WXT](#) (AteL#16631) and [Swift/XRT](#) (AteL# 16633), follow-up by NICER (AteL# 16636)
- very soft X-ray spectrum
- a rare class of Be binary system with a WD (7 previous)

# EP240408a: peculiar intermediate-timescale transient



Spectral and temporal properties different from known transients; possibly a new transient type or IMBH-jetted TDE?

Zhang W., et al. 2025 SCPMA..6819511Z  
O'Connor B., et al. 2025 ApJL



## Multi-messenger: UHE gamma-ray & cosmic rays

EP-FXT discovered one of the longest X-ray pulsar wind nebula tails associated with a LHAASO source.

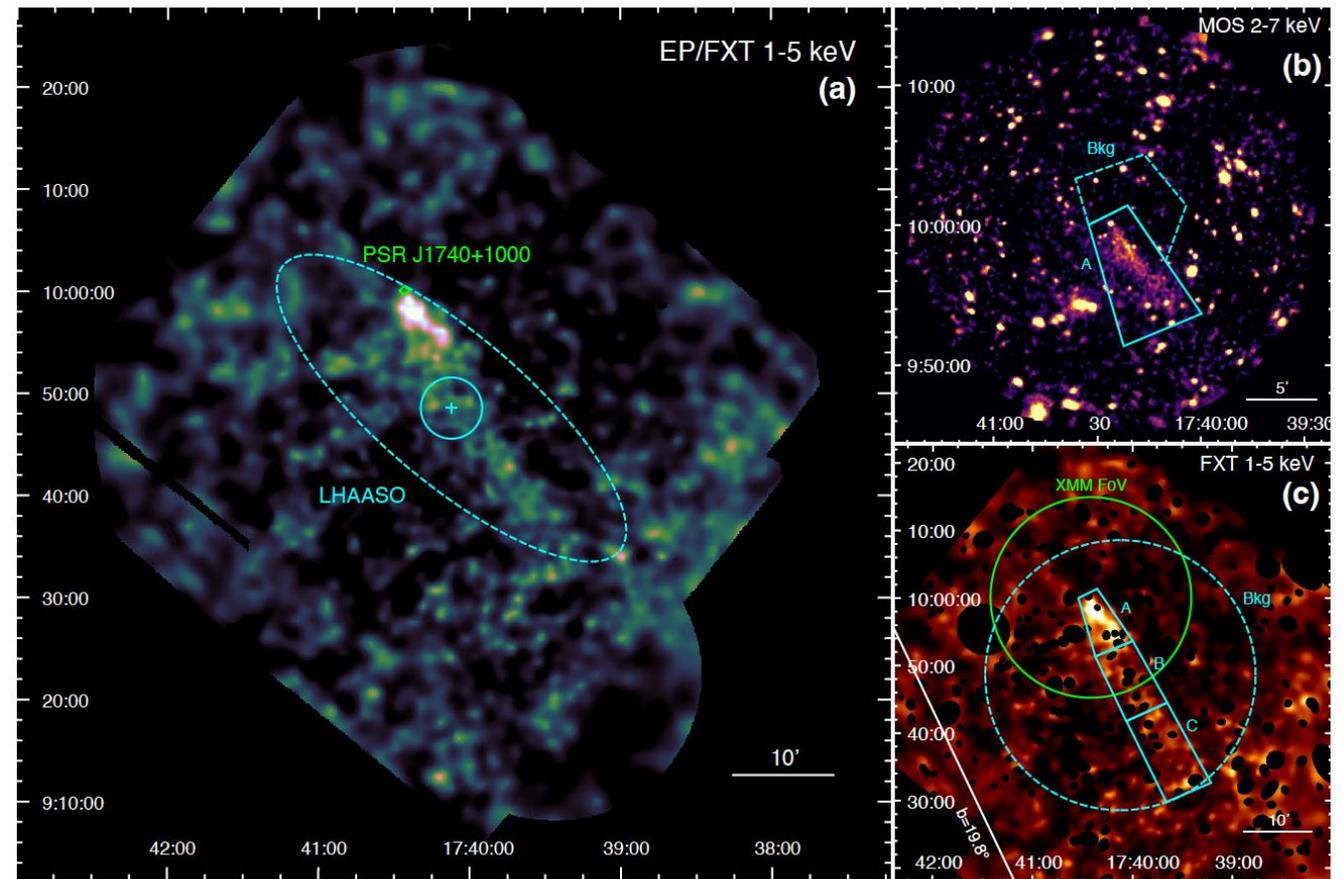
1LHAASO J1740+0948u:

~0.2° offset from the pulsar J1740+1000

70 ks EP-FXT observations uncovers a 32' tail, matching the LHAASO source location.

- the first unambiguous case of a gamma-ray pulsar tail
- UHE electrons can escape from the pulsar and anisotropically transport over at least ~10 pc
- X-ray and gamma-ray from a single population (via synchrotron & IC)

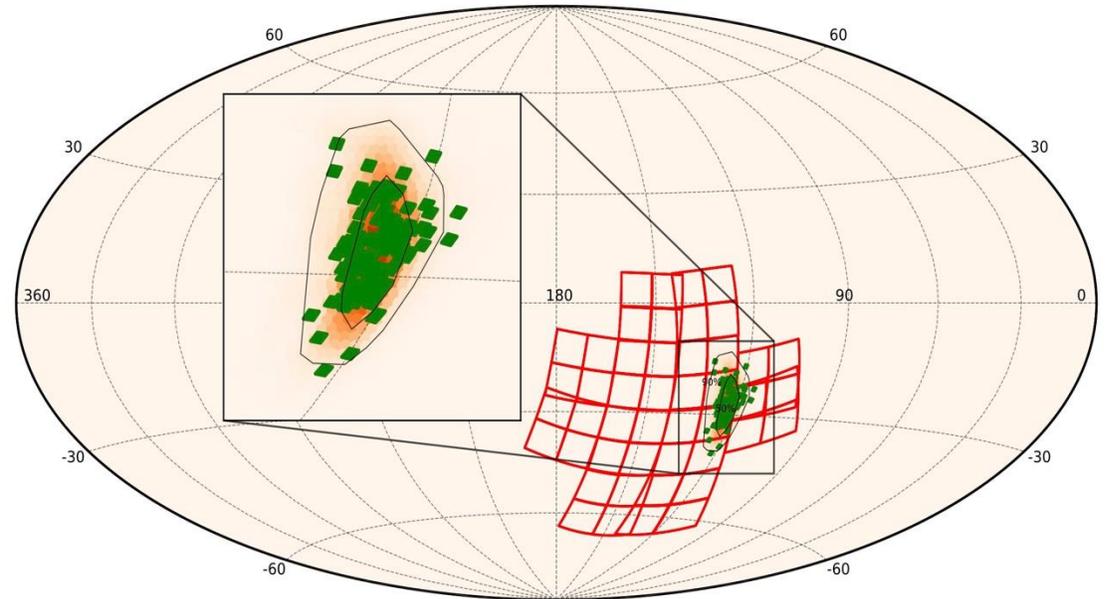
EP-LHAASO collaboration, to be submitted



**Figure 1.** X-ray images around the pulsar PSR 1740+1000 in celestial coordinators. (a): Point-like sources removed, background subtracted, vignetting corrected, adaptively smoothed FXT image in the 1–5 keV band, overlapped with the LHAASO  $\gamma$ -ray position (cross), position uncertainty (solid line), and  $2\sigma$  elliptical extension (dashed line). The position of PSR 1740+1000 is marked in green. (b): XMM-Newton 2–7 keV image with point-like sources remained. The solid lines encircle the source extraction region and the dashed lines encircle the background region. (c): same as (a) but with point-like sources masked. The solid lines encircle the three source regions marked as A, B, and C, respectively, and the dashed circle (excluding the source regions) encircles the sky background region. The green solid circle marks the field of view of XMM MOS shown in (b). The white solid line indicates the Galactic latitude at  $b = 19.8^\circ$ . The horizontal lines indicates the scale bars labeled with the angular sizes.

## Prospects: multi-messenger, GW events

- Important to search for EM counterparts of GW events
  - Only GW170817 so far
  - Counterparts of NS-BH never detected
- EP suited to search for X-ray sources associated with GW events
  - search for X-ray likely from newly formed magnetar
  - WXT: large FoV, good sensitivity
  - FXT: rapid response, 1deg FoV and depth
- EP has performed several searches, giving X-ray upper limits
- waiting for LIGO O5

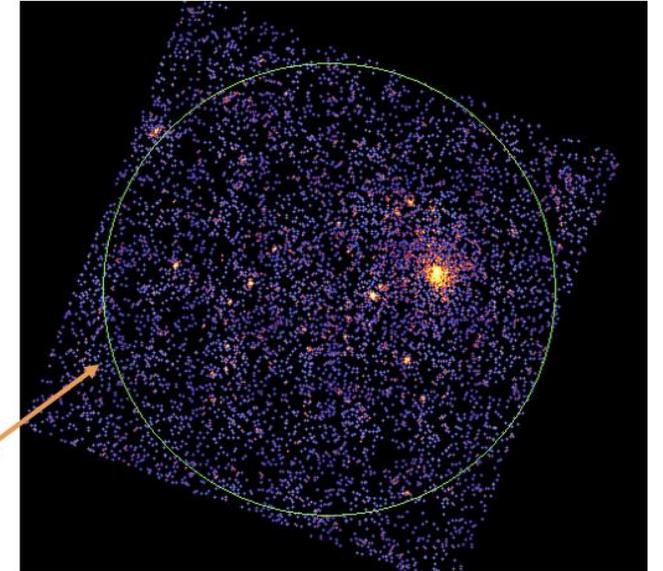


## Prospects: multi-messenger, neutrino events

- Significance of search for X-rays from neutrino events (e.g. Ice-CUBE)
- Questions:
  - origin of high-E neutrinos
  - acceleration of hadronic cosmic rays
- Possible sources ?
  - blazars/jets/TDE
  - low-luminosity GRB
- Why EP?
  - **WXT**: large FoV, high X-ray sensitivity, high cadence
    - collaboration with Chiba Univ.
    - ongoing
  - **FXT**: rapid response (matching FoV 1deg)

FXT (FoV 1 deg)  
IceCube-250706A  
(T0+40 min)

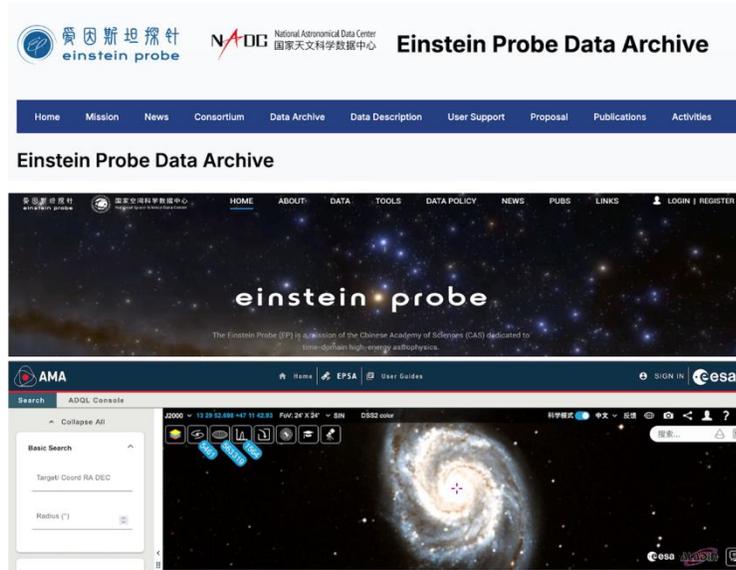
Error circle radius  
~ 0.5 deg



EP-FXT follow-up of an ICE-Cube neutrino event in 2025

# Release of First Batch of Einstein Probe Science Data

## National Astronomical Data Centre (NADC)



## National Space Science Data Centre (NSSDC)

2025年12月11日，国家天文科学数据中心、国家空间科学数据中心与天关卫星科学中心联合公开发布“天关”卫星首批科学数据。此次发布的数据涵盖了2024年7月11日开始科学运行后已达到保护期的后随X射线望远镜（FXT）的1至3级科学数据产品，包含1615个观测号，对深入研究恒星剧烈活动、黑洞及中子星等致密天体的形成、演化、并合等宇宙极端物理过程具有重要的科学意义。与此同时，欧洲空间局亦同步开放了“天关”卫星科学数据平台，该平台提供经过校准的“天关”卫星高级数据镜像。

General at National Astronomical Observatories, Chinese Academy of Sciences

### OPENING OF DATA ARCHIVES

**11 December 2025** EP Science Data are proprietary for a period of one year after which they shall be made publicly available. Access to data is described [here](#): There are two institutes in China operating archive interfaces, the [National Astronomical Data Centre \(NADC\)](#) and the [National Space Science Data Centre \(NSSDC\)](#). ESA has now opened the [Einstein Probe Science Archive \(EPSA\)](#) containing public, calibrated *high-level* data, i.e., calibrated data covering level 2 (events files) and level 3 (images, spectra, light curves); for details of ESA mirror archive, see [EPSA Documentation](#).

Data in EPSA are calibrated with the last *major* calibration release. If data need to be processed with the *latest* calibration version, level 1 data must be obtained from the [NADC](#) or [NSSDC](#) archives and processed with the EP Data Analysis software. Further, PIs of proprietary data need to obtain their data from the [NADC](#) archive. At this time, only the FXT data are released while the WXT are planned to be released early 2026.

### LAUNCH OF ESA WEBPAGES OF EINSTEIN PROBE

**19 July 2022** These ESA webpages with information about Einstein Probe see their first light.

## ESA's Einstein Probe Science Archive (EPSA)

# Summary



- ☞ The core science objectives have been largely fulfilled in 1.5-year nominal operations
  - fast X-ray transients, diversity of collapsars and compact binary mergers
  - discoveries of rare or long-predicted transients/objects (IMBH, WD-TDE, weak relative jet)
  - unexpected: EFXT-SN connection, new types of transients
- ☞ EP has the potential to revolutionise our understanding of fundamental processes in some specific types of transients via
  - consolidation of statistically meaningful samples
  - finding new types of transients in the wider discovery space
- ☞ WXT data release: expected in mid-2026
- ☞ Future: expected to deliver new discoveries & expand to new frontiers

<http://ep.bao.ac.cn>

[https://www.esa.int/Science\\_Exploration/Space\\_Science/Einstein\\_Probe\\_factsheet](https://www.esa.int/Science_Exploration/Space_Science/Einstein_Probe_factsheet)