Status and scientific capability of the Einstein Probe mission

Erik Kuulkers (ESA/ESTEC)

on behalf of the Einstein Probe consortium

Image credit CAS/ESA

- 2002 – 2020: INTEGRAL Operations Scientist
- 2013 – 2023: INTEGRAL Project Scientist
- 2018 – Present: ESA Einstein Probe Project Scientist
- 2021 – Present: NewAthena Mirror Calibration Scientist
- 2022 – Present: THESEUS Study Scientist

- My job time → NewAthena : THESEUS : Einstein Probe = 50% : 25% : 25%

- Main scientific interest: X-ray transient/variable science
  [e.g., Type I X-ray bursts, GRBs, (transient) X-ray binaries]

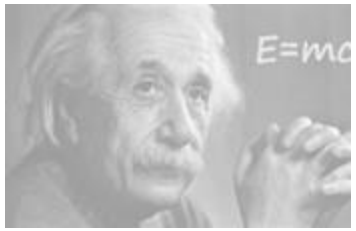
Instruments & spacecraft

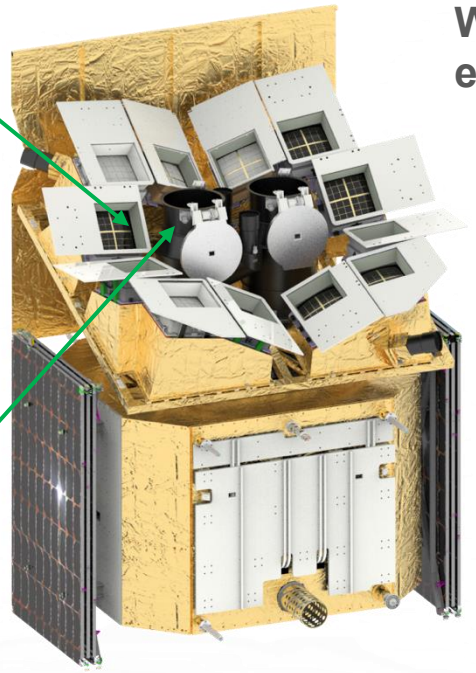
Wide-field X-ray Telescope
WXT (12 modules)

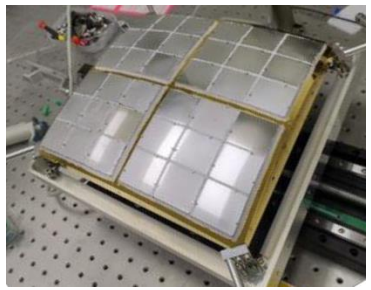
Lobster-eye MPO + CMOS
FoV: ~3,600 sq deg (1.1 sr)
Band: 0.5 – 4 keV
Resolution: ~5’ (FWHM)
Sensitivity: ~1mCrab @1ks

Follow-up X-ray Telescope
FXT (2 units)

Wolter-1 + pn-CCD (eROSITA)
FoV: ~1 deg
Band: 0.3 -10keV
Resolution: 24” (HPD, on-axis)
Eff area: ~300 cm^2 @1keV (x 2 units)







WXT mirror & CMOS detectors (1 module)

Spacecraft

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

Telemetry

X/S-band (several hrs)
Beidou (down/up-link; mins)
VHF (down-link; mins)

Yuan et al. 2022 *Handbook of X-ray and Gamma-ray Astrophysics*

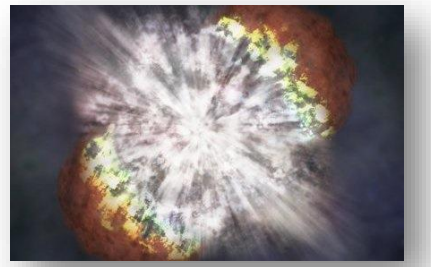
Einstein Probe launch: 9 January 2024

height 592 km
orbital period 96 min
inclination angle 29 deg

Long March-2C @ Xichang

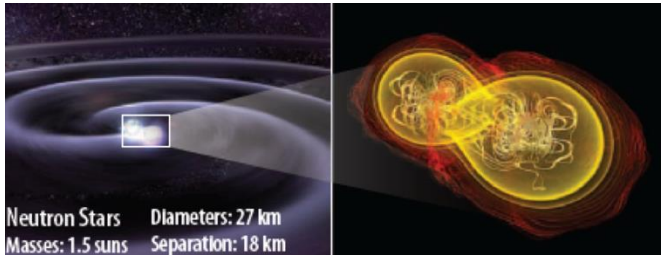
Einstein Probe: Main science objectives

Systematic survey of soft X-ray transients and variability of X-ray sources with unprecedented combination of sensitivity and cadence



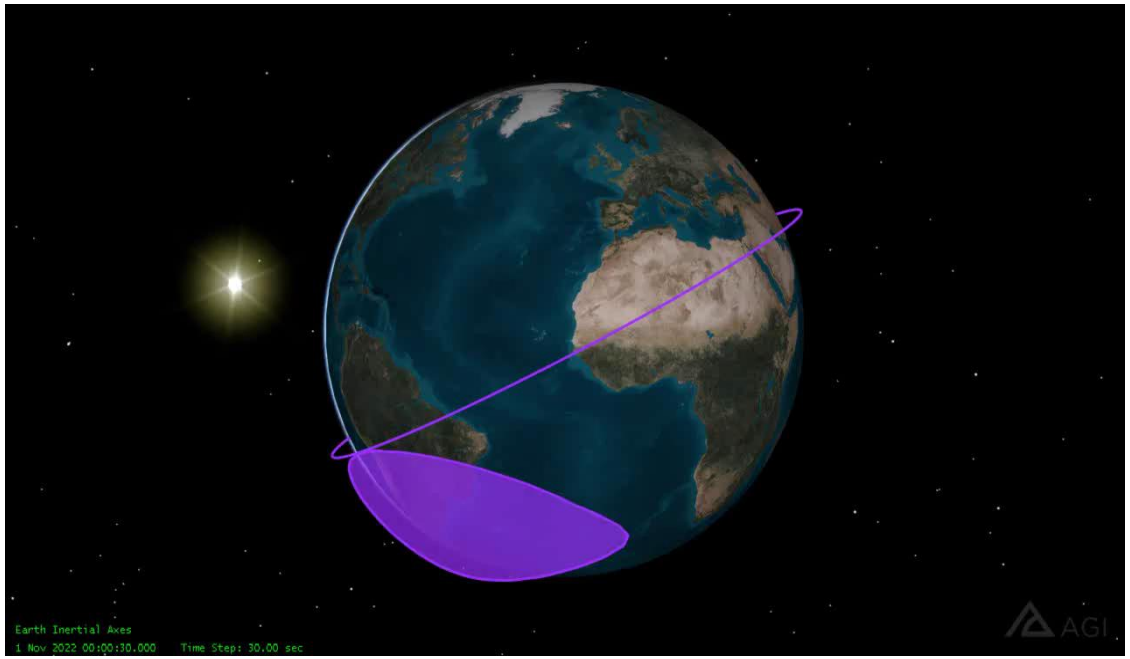
Discover otherwise quiescent black holes at almost all astrophysical mass scales and other compact objects by capturing their transient X-ray flares

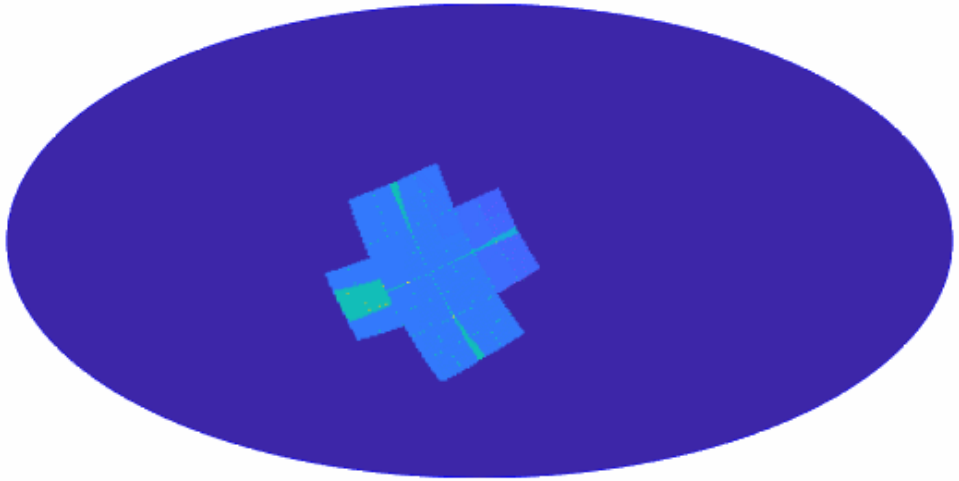
Detect and localise the electromagnetic-wave sources of gravitational-wave events by synergy with gravitational-wave detectors



Observation modes

- Circular orbit
  - Height 592km, period 96min
  - inclination angle 29 deg.
- **Observation modes**
  - **Survey (primary WXT)**
  - **Autonomous follow-up (FXT)**
  - **Target-of-Opportunity (FXT, WXT)**
  - **Calibration**
- **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 ½ year**
  - **FXT pointed to pre-selected targets**

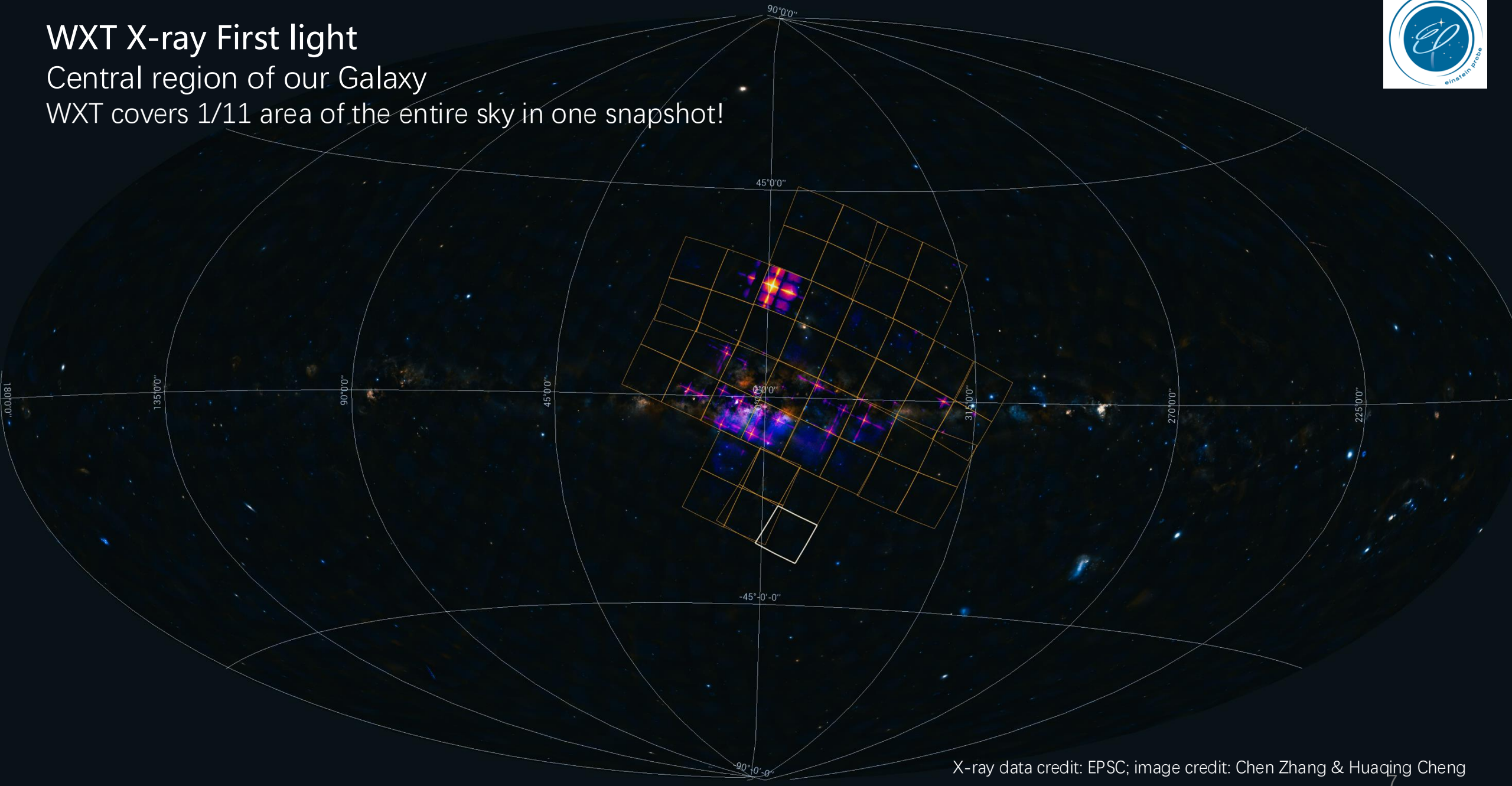




WXT X-ray First light

Central region of our Galaxy

WXT covers 1/11 area of the entire sky in one snapshot!

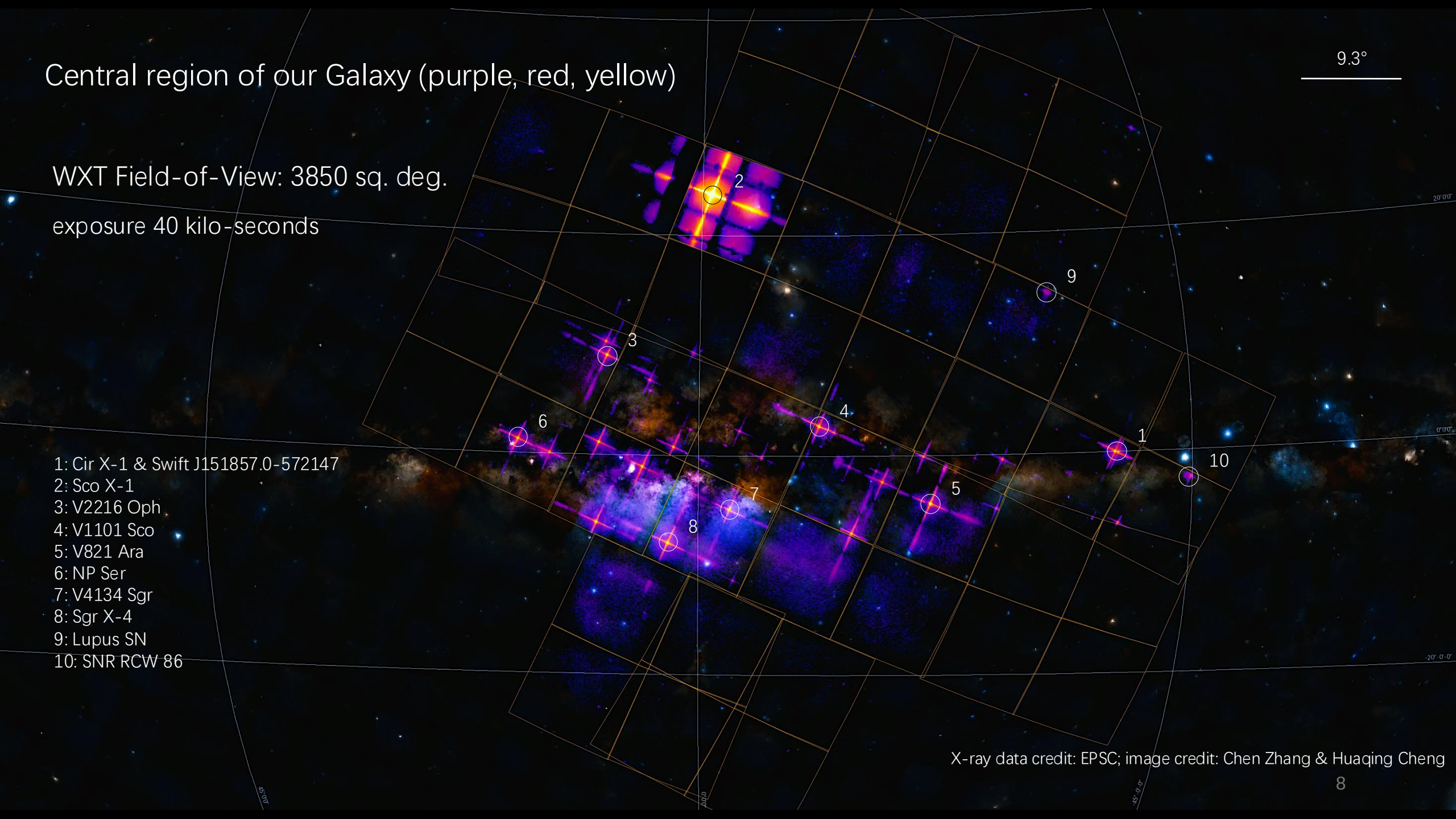


X-ray data credit: EPSC; image credit: Chen Zhang & Huaqing Cheng

Central region of our Galaxy (purple, red, yellow)

WXT Field-of-View: 3850 sq. deg.

exposure 40 kilo-seconds



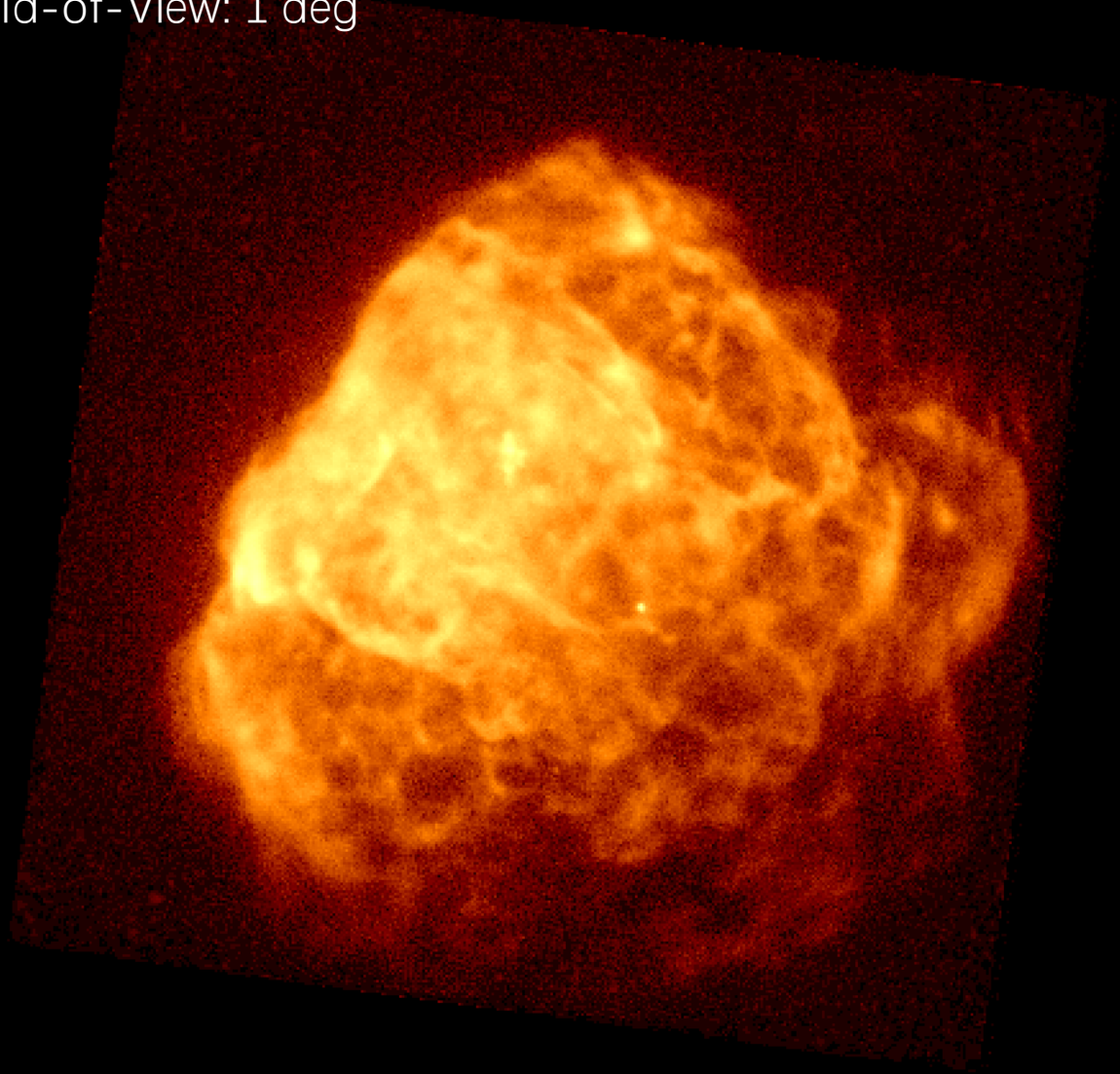
1: Cir X-1 & Swift J151857.0-572147
2: Sco X-1
3: V2216 Oph
4: V1101 Sco
5: V821 Ara
6: NP Ser
7: V4134 Sgr
8: Sgr X-4
9: Lupus SN
10: SNR RCW 86

X-ray data credit: EPSC; image credit: Chen Zhang & Huaqing Cheng

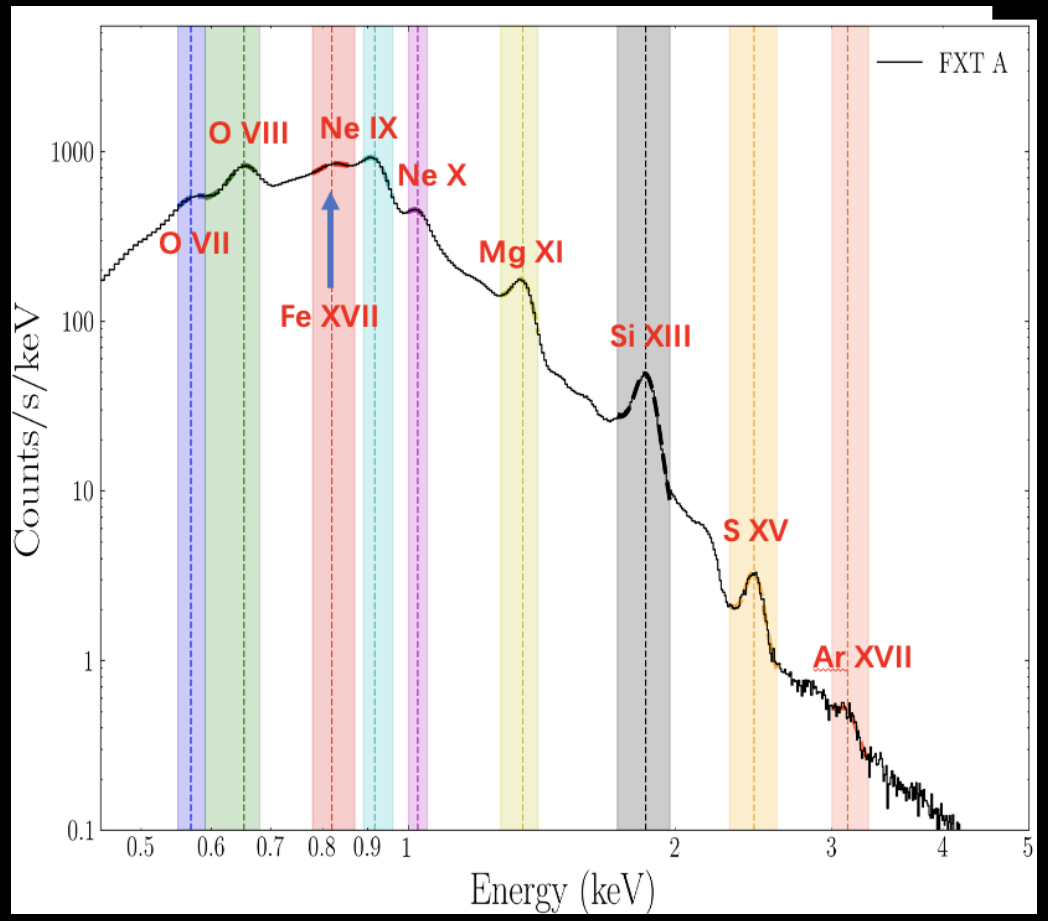
FXT X-ray First light (0.3-10 keV)

Puppis A supernova remnant (nebula)

Field-of-View: 1 deg



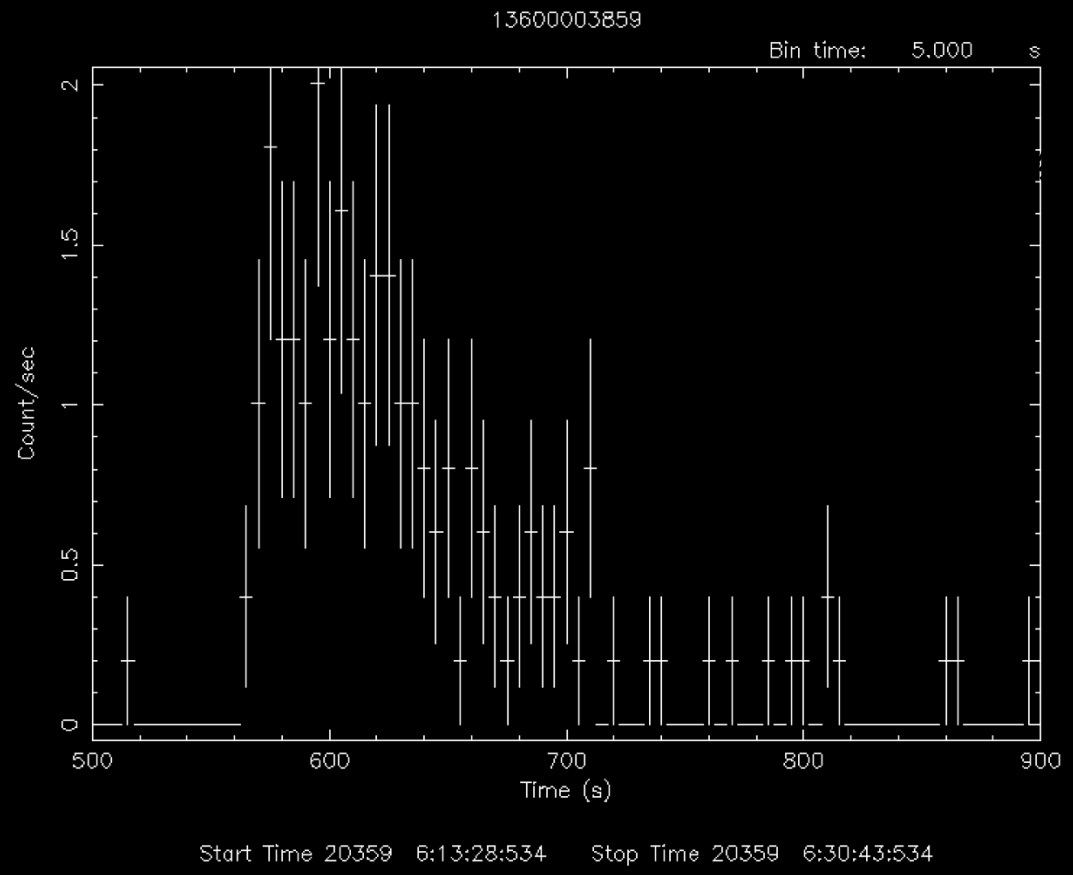
FXT X-ray spectrum obtained at the same time



EP240219a

First X-ray transient discovered by WXT on 19 Feb 2024; alert released as Astronomer's Telegram #16463

- Duration <200s
- ATel sent from EPSC: 1st EP alert! (ATel #16463; #16472)
- Subthreshold GRB signal found in Fermi/GBM data (ATel #16473;)
- Undetected by Swift/XRT 39 hours later
- No optical counterpart found (starting T0+3days)
- Possibly an X-ray rich GRB



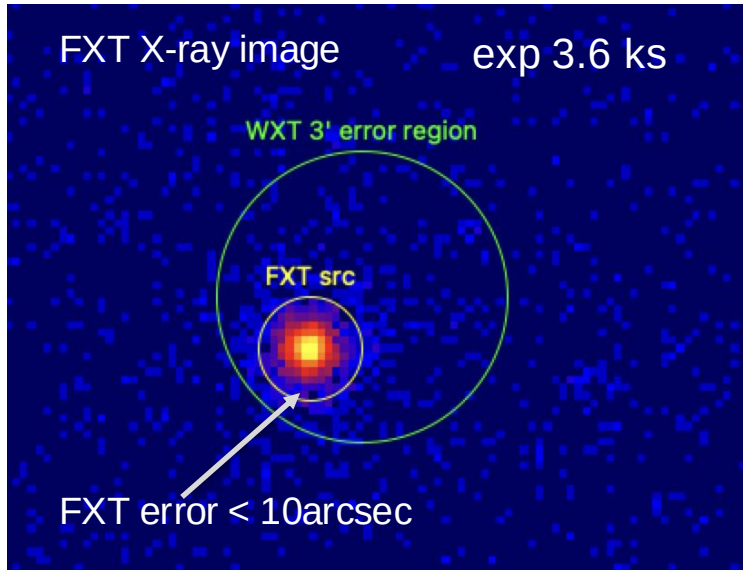
9.3° by 9.3 °, 1 time-frame = 33.3 sec

Yin et al. ApJL submitted (arXiv:2407.10156)

Onboard trigger for FXT automated follow-up

- 1st successful test: EP240605a June 5 UTC 16:10:30
- transient info downlink within minutes (Beidou & VHF networks)
- triggered FXT observation @ UTC 16:11:44

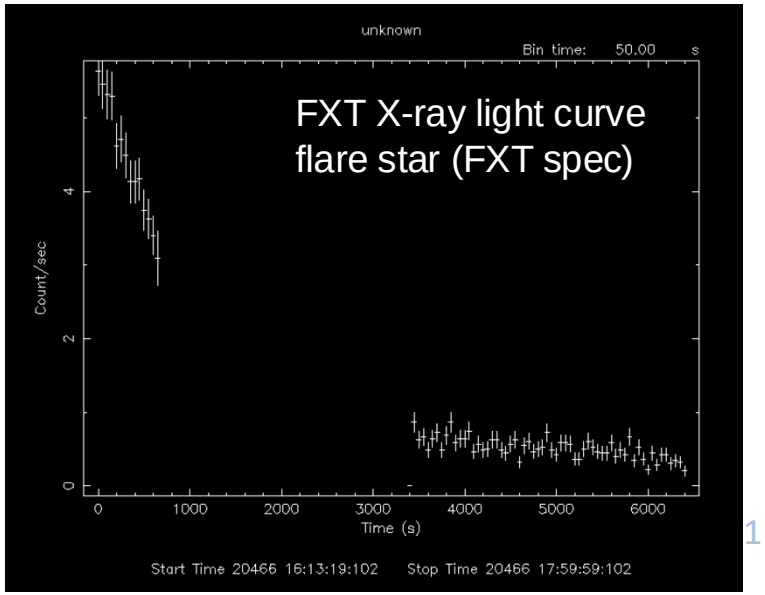
  → 1 min after alert!



Alert information downlinked via Beidou network:

Beidou Alert: 01708918013 CMOS14

RA, Dec	19.907, -68.695	**Galactic l, b**	299.095, -48.223
RA (HMS), Dec (DMS)	01h19m37.7s,-68d41m42.0s	**1 σ Pos Err (arcmin)**	0.692
Observation Time (UTC)	2024-06-05 16:00:40	**Trigger Time (UTC)**	2024-06-05 16:10:30
X	2674.2	**Y**	3576.6
Net Rate	0.06	**Variance**	13.34
Significance	8.1	**HR**	0.18



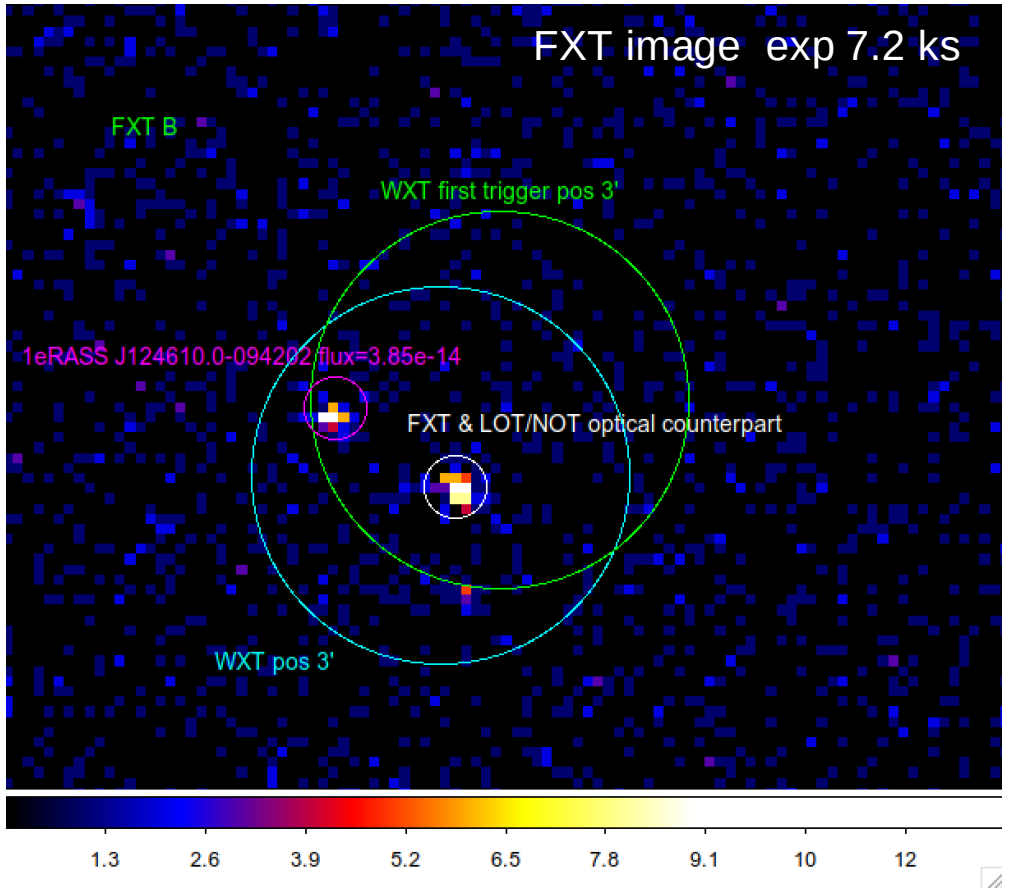
EP240414a: the quickest (multi-wavelength) follow-ups

- WXT onboard trigger (VHF/Beidou)
  (Lian et al. GCN #36091)

- T0+ 2 hrs: FXT follow-up (uplink ToO)
  A new source 1.5’ away

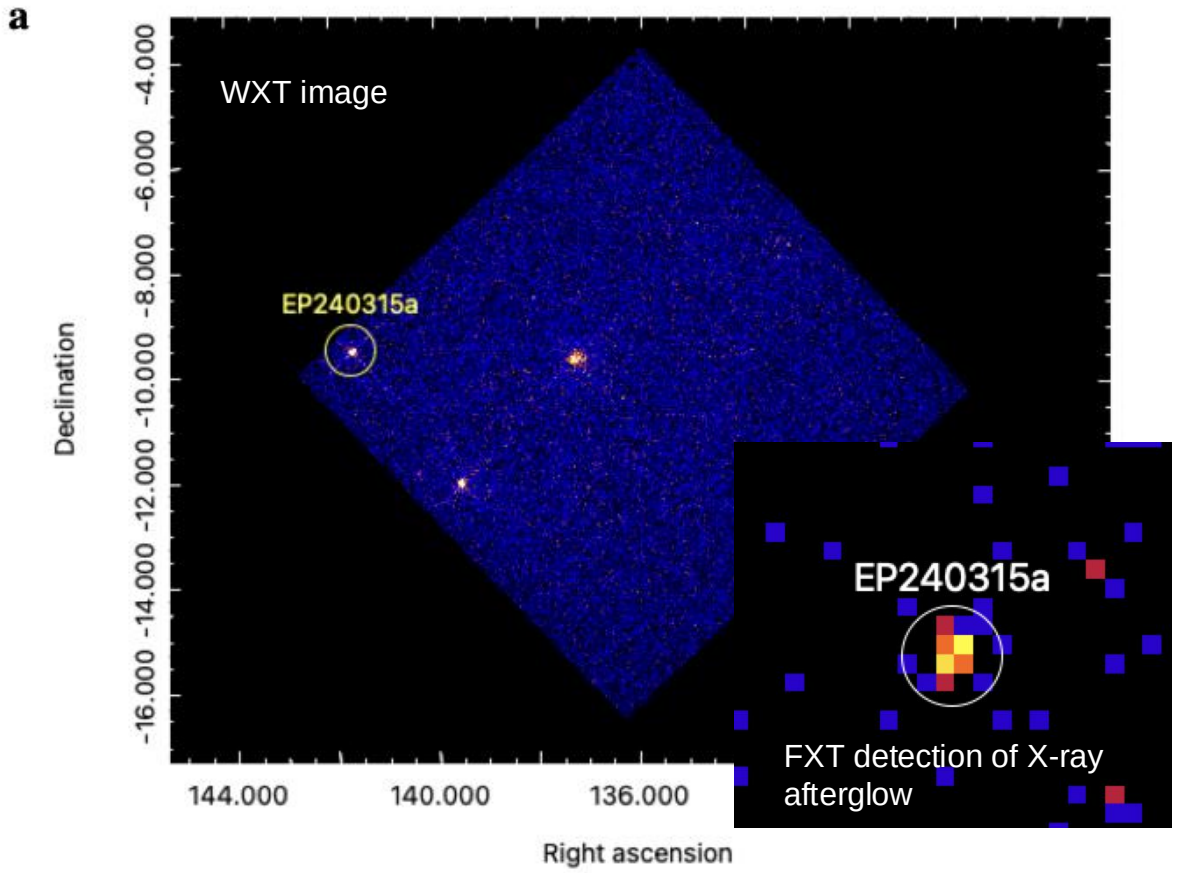
- Optical follow-up
  - LOT + 3.13 hr (AT2024gsa, r = 21.52 mag)
  - NOT +2.29 hr
  - GTC +5 hr
  - BOOTES-4/MET +5.56 hr
  - Pan-STARRS1 +2/3 d
  - GSP + 3.66 d

- Later time detection of associated supernova
  (Levan et al. GCN #36355)
- Host galaxy z = 0.41
- Projected offset ~25 kpc (Jonker et al. GCN #36110)

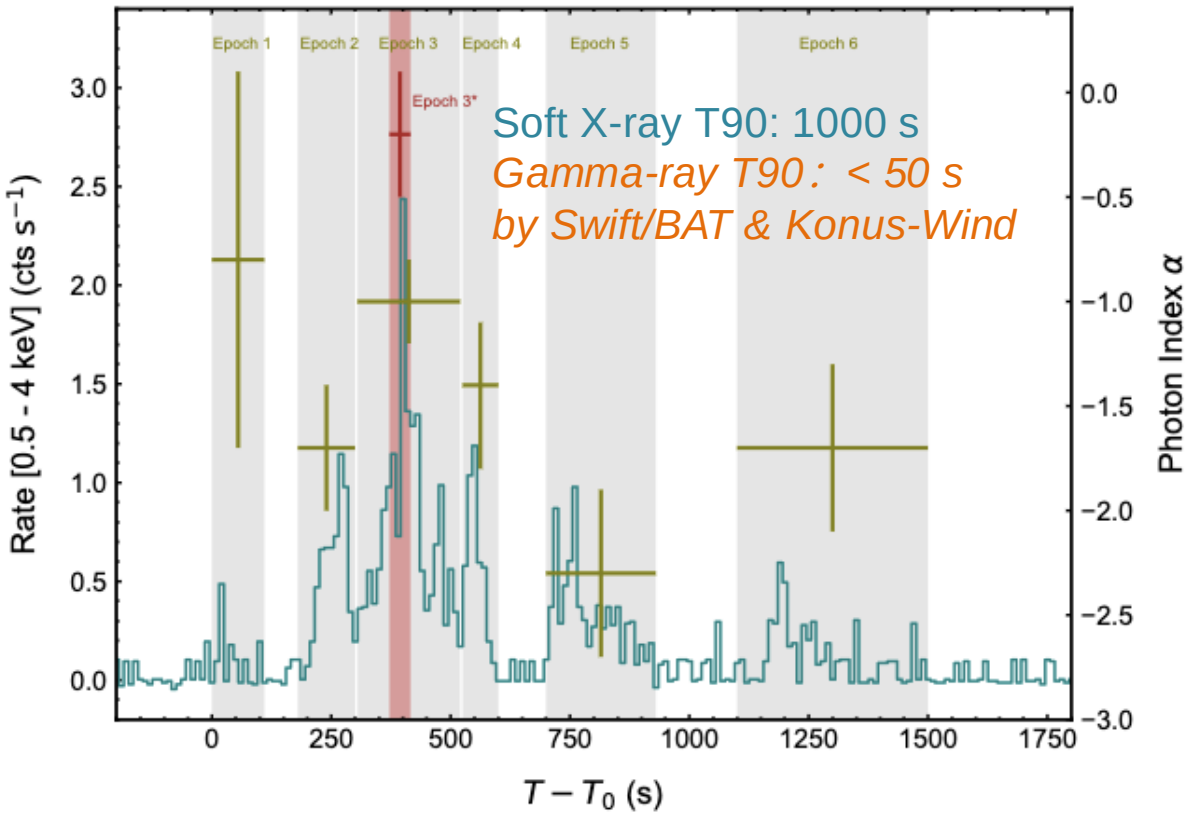


90% positioning errors
WXT: 2.1 arcmin
FXT: <10 arcsec

EP240315a: GRB @ redshift 4.859



Onboard trigger, confirmed by on-ground analysis



Marked difference in soft X-ray & hard X/γ ray light curve

Gillanders et al. arXiv:2404.10660 (ATLAS optical/radio counterpart, z)
Levan et al. arXiv:2404.16350 (Stargate optical photometry and spectrum, z)
Liu et al. arXiv:2404.16425 (jointly with Swift, Konus-Wind, Stargate teams)

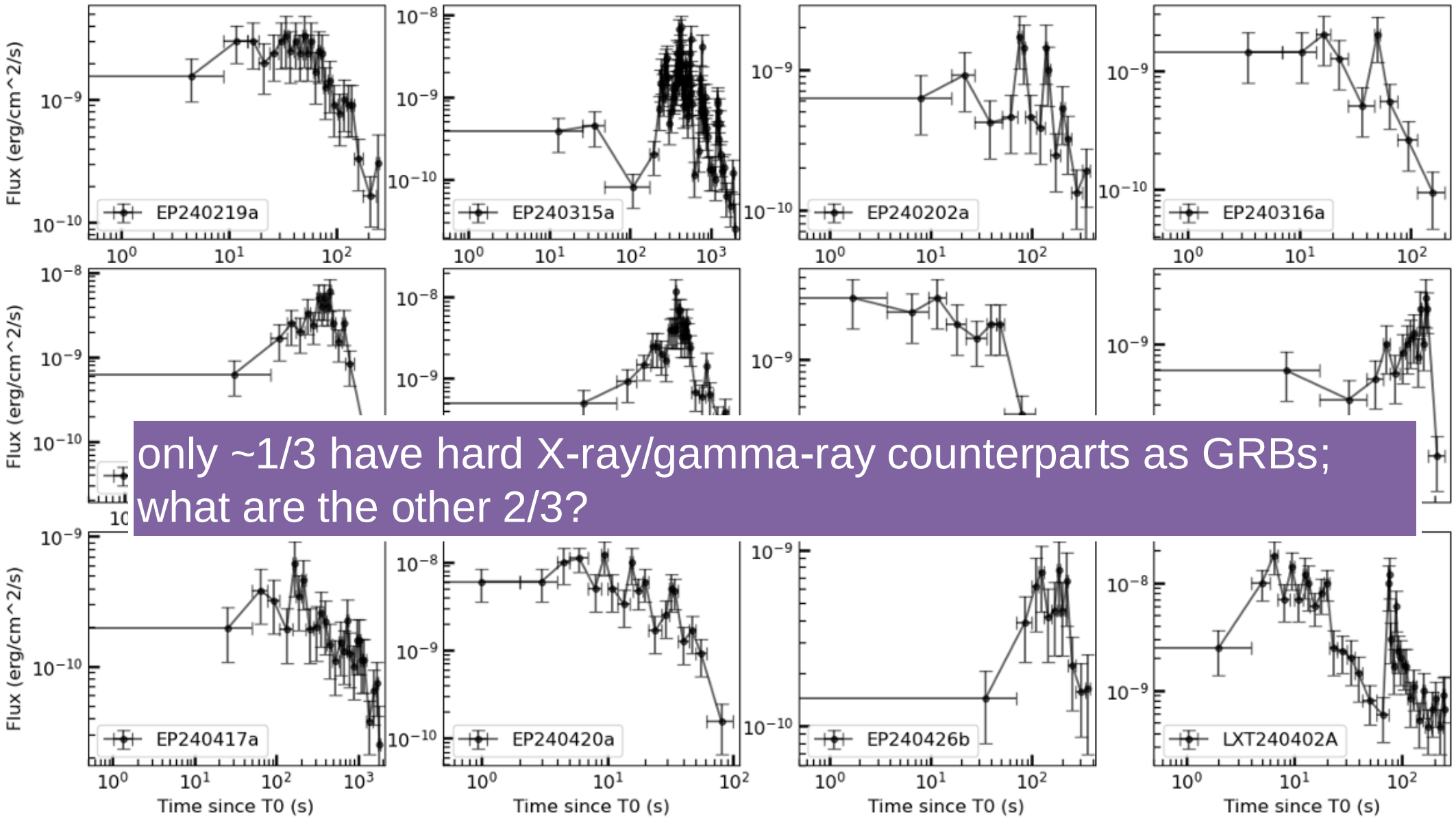
Redshift 4.859 measured by VLT (Levan et al. 2024)

Would be detectable by WXT at z~7.5
→ EP's potential of detecting high-z GRB!

Examples of fast X-ray transients detected by EP & LEIA (WXT pathfinder)

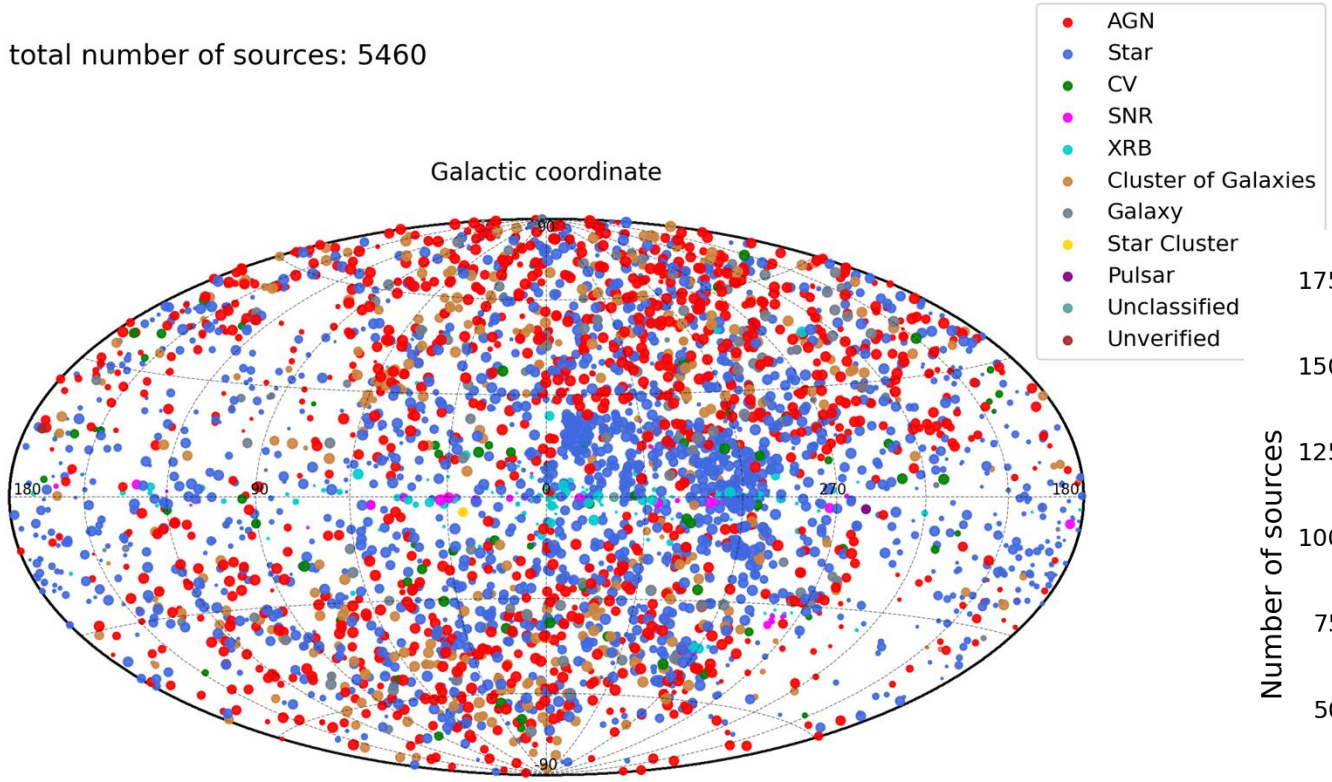
Transient	Duration	Peak Flux erg $cm^{-2}s^{-1}$	Fluence erg cm^{-2}	γ-ray counterpart	X-ray afterglow	Optical afterglow	z
LXT/GRB 230307A	~180 s	4E-7	2E-5	Y	Y	Y	0.065
EP240219a	~200 s	5E-9	1E-7	Y	X	N	-
EP240315a	~1600 s	3E-9	1E-6	Y	Y	Y	4.859
EP240202a	~300 s	4E-9	9E-8	N	N	N	-
EP240316a	~160 s	3E-9	1E-7	N	N	N	-
EP240331a	~100 s	4E-9	2E-7	N	possible?	N	-
LXT240402a	~200 s	3E-8	5E-7	Y	Y	Y	1.551
EP240413a	~200 s	7E-9	2E-7	N	possible?	N	-
EP240414a	~150 s	3E-9	2E-7	N (GBM off)	Y	Y	0.4
EP240416a	> 200 s	1E-9	1E-7	N (GBM off)	N	N	-
EP240417a	> 1500 s	3E-10	1E-7	N	N	N	-
EP240420a	~80 s	8E-9	3E-7	N	Y	Y	-
EP240426b	~300 s	9E-10	2E-7	N	N	N	-
EP240506a	~50 s	1E-8	5E-8	N	N	N	-

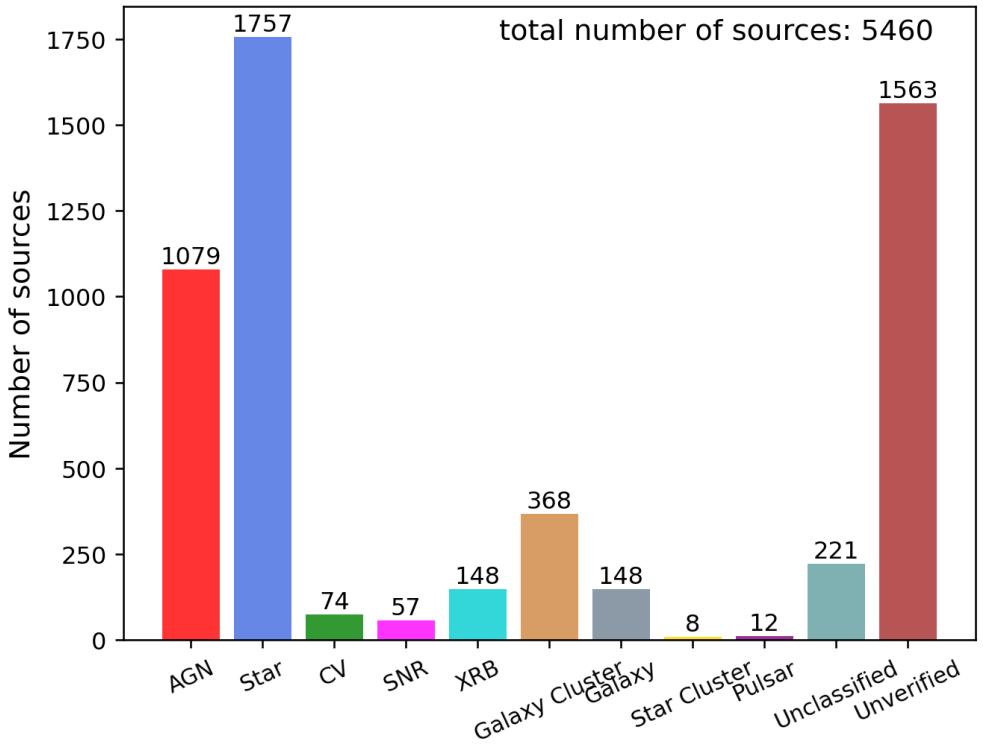
Example light curves of EP fast transients



only ~1/3 have hard X-ray/gamma-ray counterparts as GRBs; what are the other 2/3?

Statistics on X-ray sources detected with EP-WXT

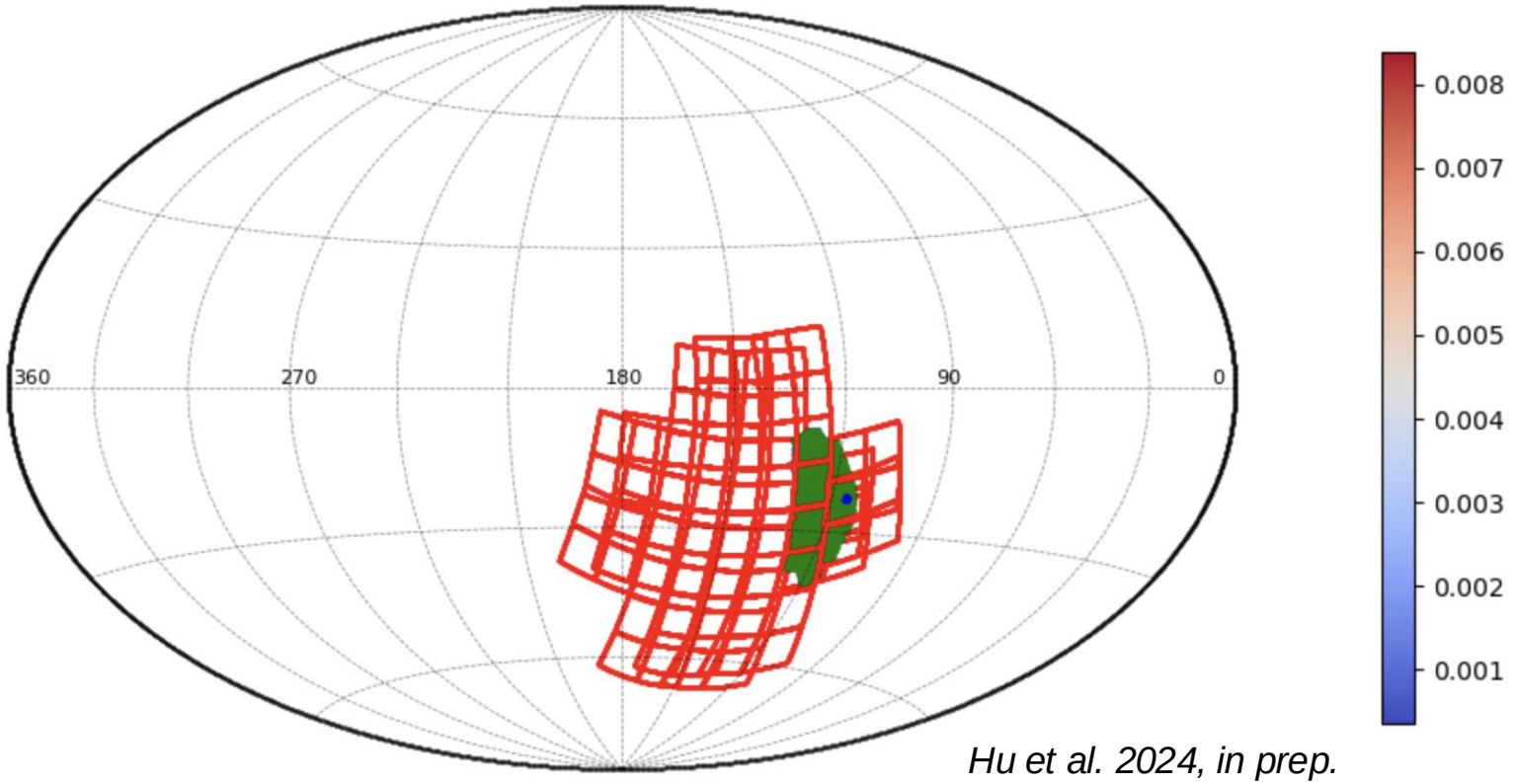




- Known bright sources detected: > 5000
- Transients: > 40 high S/N (more with low S/N)
- Stellar flares: > 400

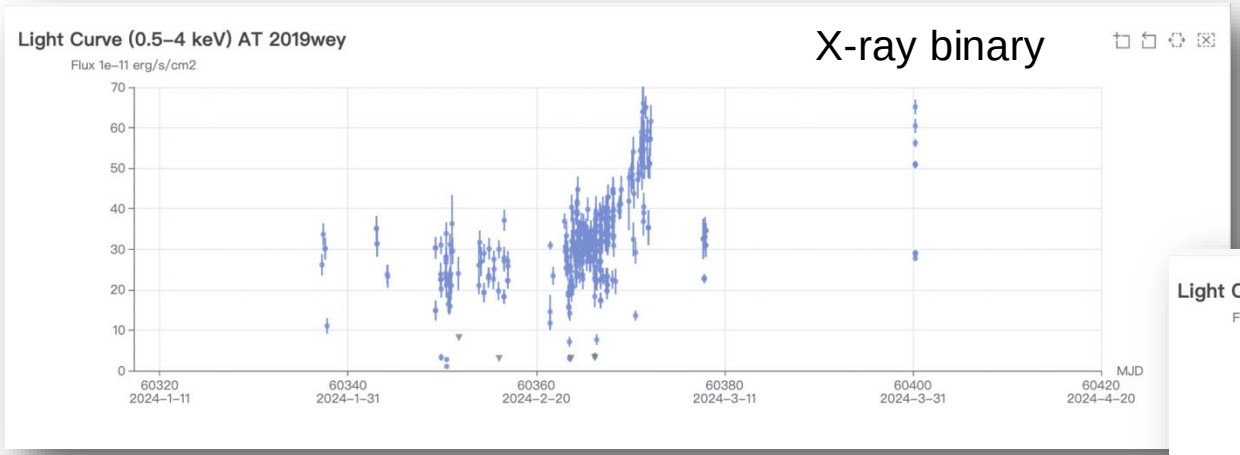
Search for potential X-rays from GW event S240422ed

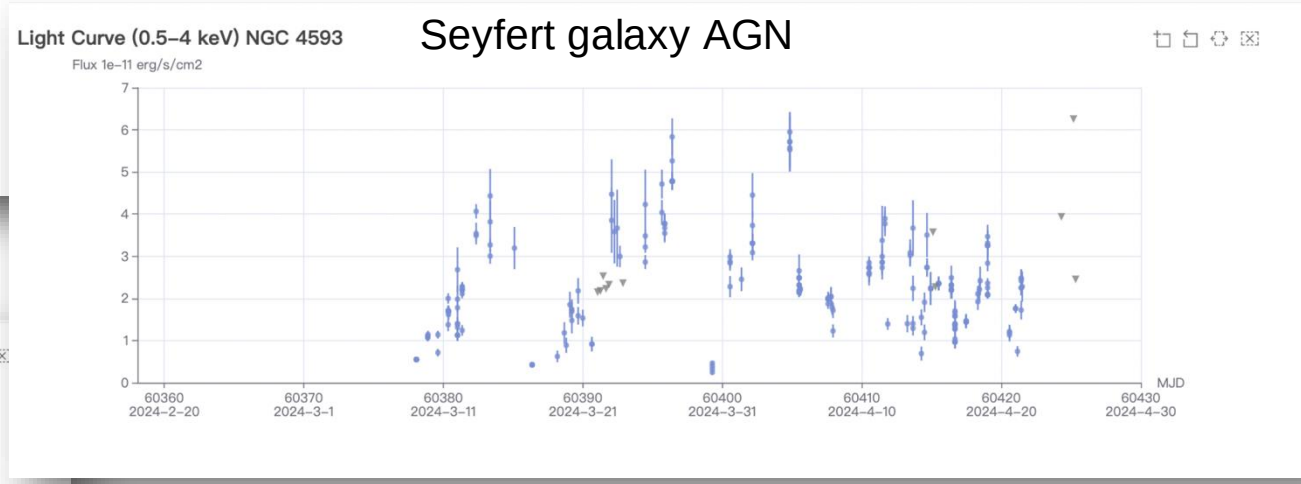
- On April 22, GW event NS+BH (>99%), 214 +/- 64 Mpc
- EP observations: started ~3 hrs after GW trigger (yet to be improved)
- Covered with WXT and set X-ray flux upper limits (GCNs #36270, #36277, #36282)
- Searched >100 galaxies with FXT



Hu et al. 2024, in prep.

Monitoring of known X-ray sources





Conclusions

- Since launch on 9 January 2024, EP's performance verifications & calibrations completed
- Spacecraft & instruments working as expected
- A sample of X-ray transients and flaring stars have been detected
- Nominal science operations just started in July
- A newcomer with great scientific potential in time-domain X-ray astronomy

http://ep.bao.ac.cn

https://www.esa.int/Science_Exploration/Space_Science/Einstein_Probe_factsheet

Thank you

Back-up slide: Alerts of transients, ToO & data

- Transient alerts
  - Onboard transient search and trigger unit
  - Alert information quick downlink： minutes
    - VHF (CNES/France)
    - BD system (China)
  - Alert information: release immediately to the community
    - source position, flux, time, spectral parameter
- ToO command uplink
  - Normal (S-band): < 1 day
  - Time critical (BD) < 10 min
- Science data
  - X-band telemetry: it takes about a few hours to reach EPSC
  - Will be made public (community outside EPST) after proprietary periods
  - Non-ToO data: one year
  - ToO by EP science team: 6 months
  - ToO by guest observers: released immediately