

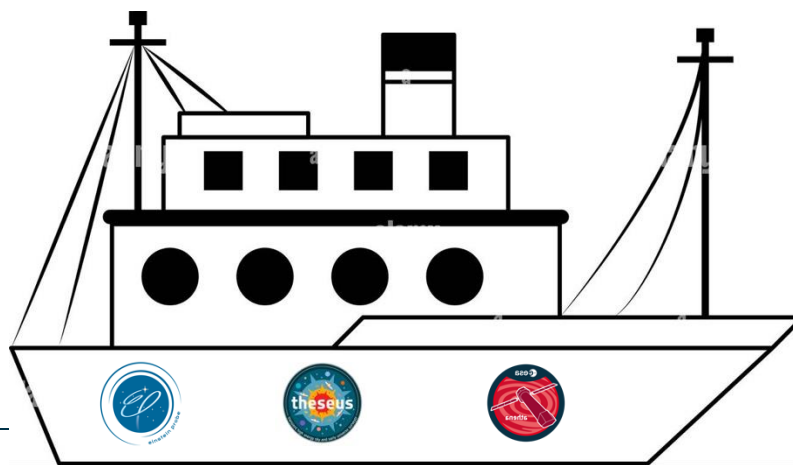


I'M ACTUALLY
LEAVING TO FOCUS
ON OTHER PROJECTS





- 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 → Einstein Probe : THESEUS : NewAthena = 25% : 25% : 50%





Status and scientific capability of the Einstein Probe mission

Erik Kuulkers (ESA/ESTEC)

on behalf of the Einstein Probe consortium

slides credit: Weimin Yuan (Einstein Probe PI)

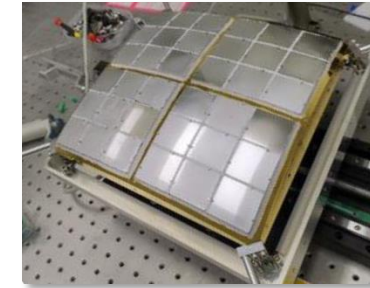
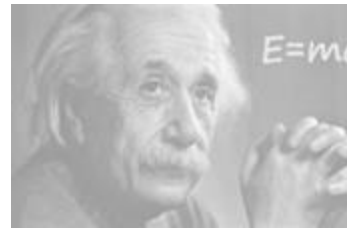
Einstein Probe - instruments & spacecraft



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



WXT mirror & CMOS detectors (1 module)

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 cm² @1keV (x 2 units)



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)

Einstein Probe launch: 9 January 2024

height 592 km
orbital period 96 min
inclination angle 29 deg

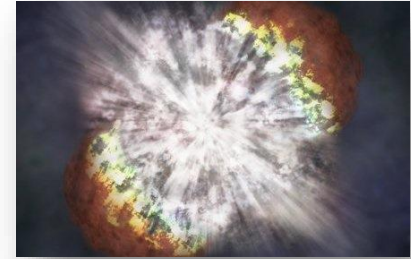


Long March-2C @ Xichang

Einstein Probe: Main science objectives



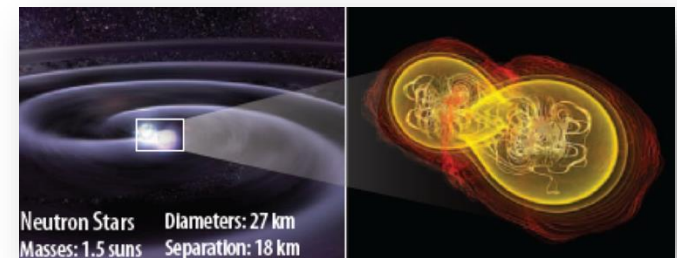
Systematic survey of soft X-ray transients and variability of X-ray sources with unprecedented combination of sensitivity and cadence



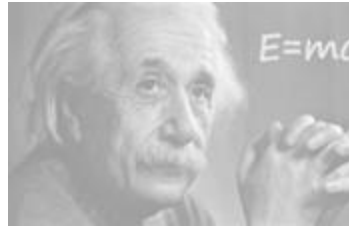
Discover otherwise quiescent **black holes** at almost all astrophysical mass scales and other compact objects by capturing their transient X-ray flares



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



Einstein Probe mission



Milestones

2010 -> Lobster-eye R&D @ XIL/NAO (est. by Prof. S.-N. Zhang)

2012 -> Mission concept

2017 Dec -> **Adoption by CAS**

2018 -> Joined by **ESA & MPE**; 2022 **CNES**

2022 July -> WXT pathfinder **LEIA** launched

2024 Jan 9 -> EP **launch**

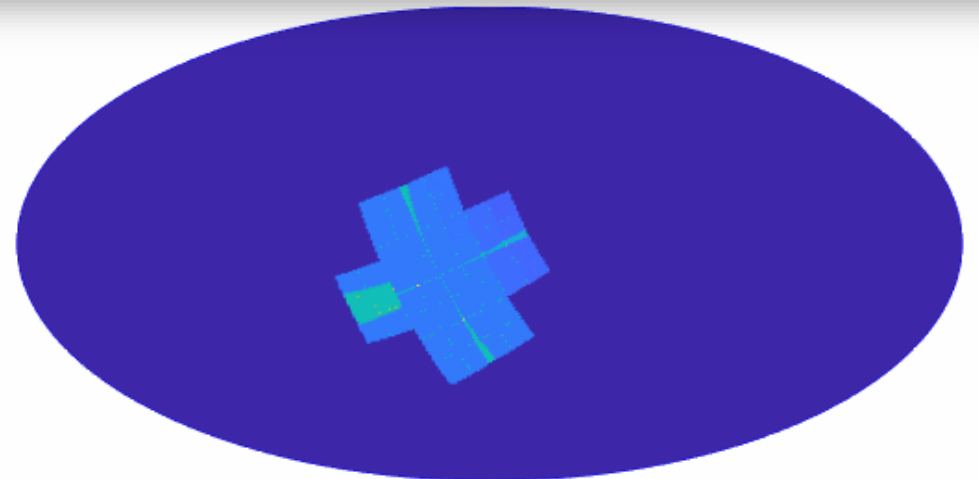
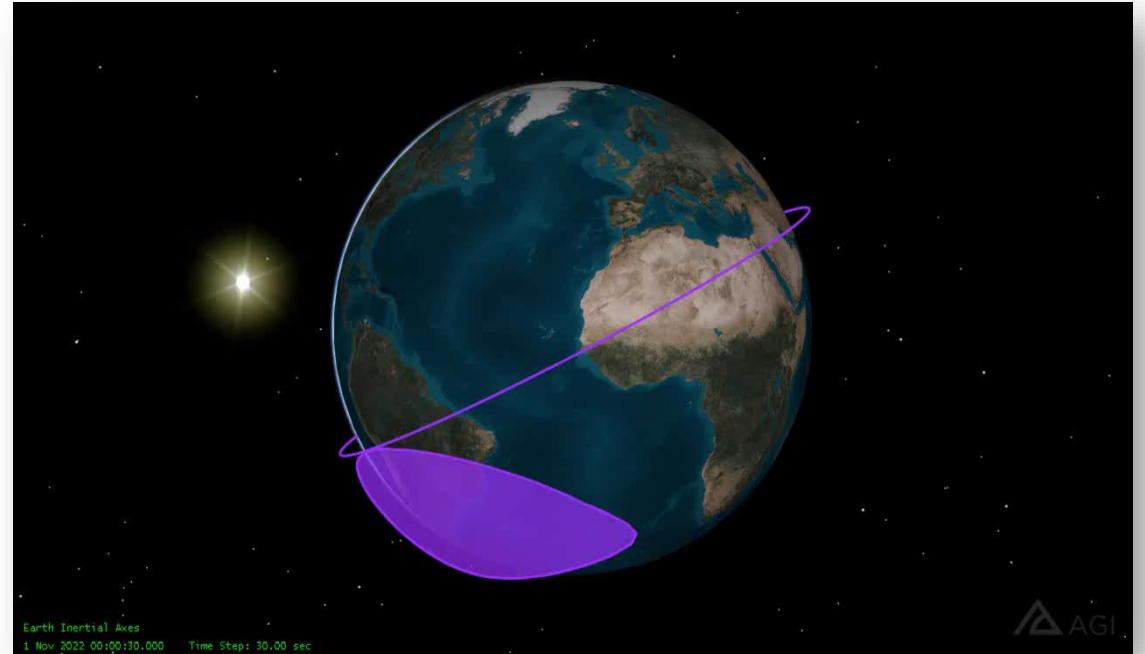
2024 Jan-Jul -> Commissioning & calibration

2024 July -> Nominal mission (lifetime: 3 yr, goal 5 yr)



Observation modes

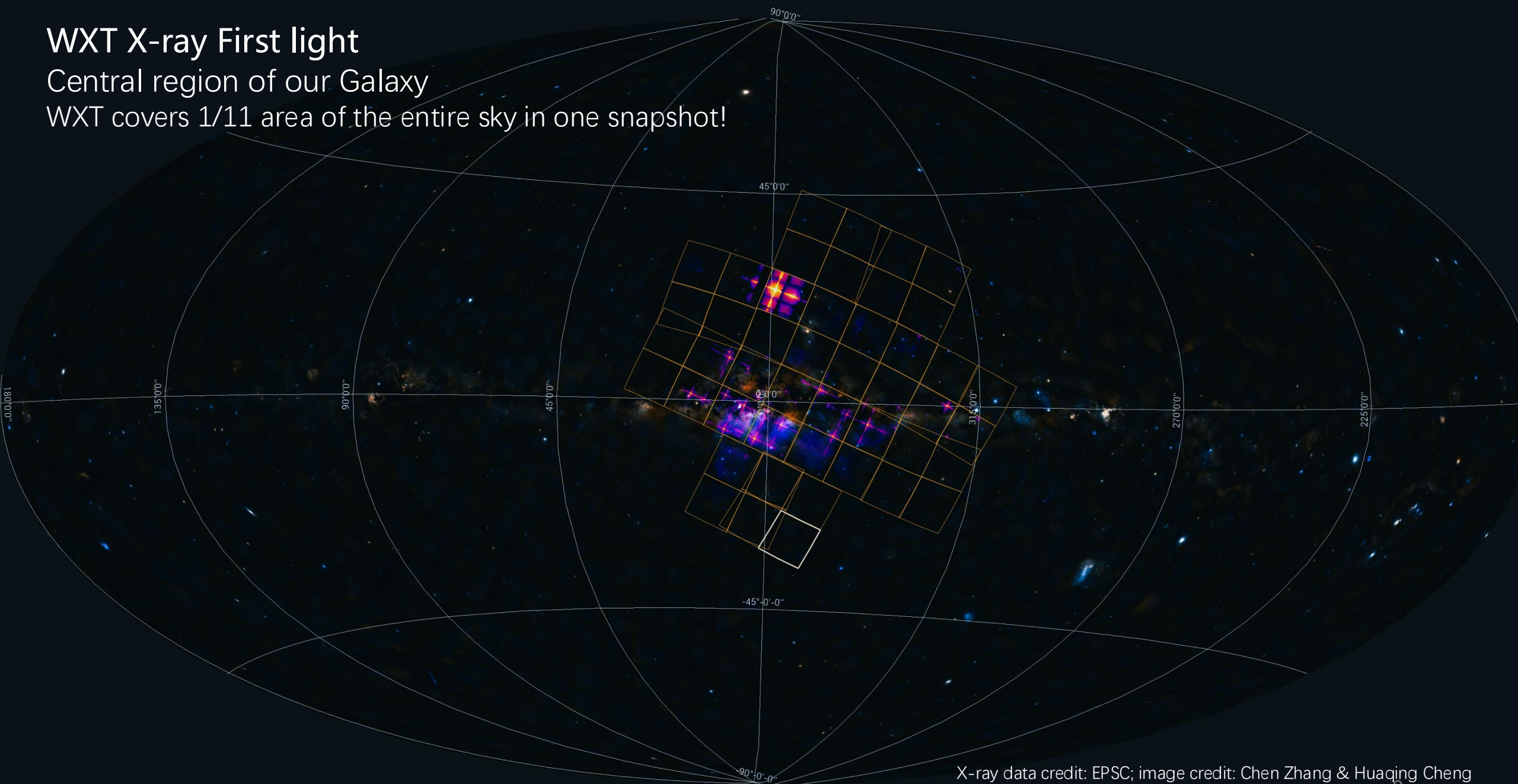
- ❏ Circular orbit
 - Height 592 km, period 96 min
 - inclination angle 29 degrees
- ❏ **Observation modes**
 - Survey (primary WXT)
 - Autonomous follow-up (FXT)
 - Target-of-Opportunity (FXT, WXT)
 - Calibration
- ❏ **WXT survey mode**
 - Pointing to night sky
 - 3 pointings/orbit, ~20 min each
 - ~ $\frac{1}{2}$ sky covered in 3 orbits (~5 hr)
 - Whole sky coverage in $\frac{1}{2}$ 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!



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

WXT Field-of-View: 3850 sq. deg.
= 1/10th of the whole sky!

exposure 40 kilo-seconds

INTEGRAL/IBIS FCOV
= 1/4 WXT module

9.3°

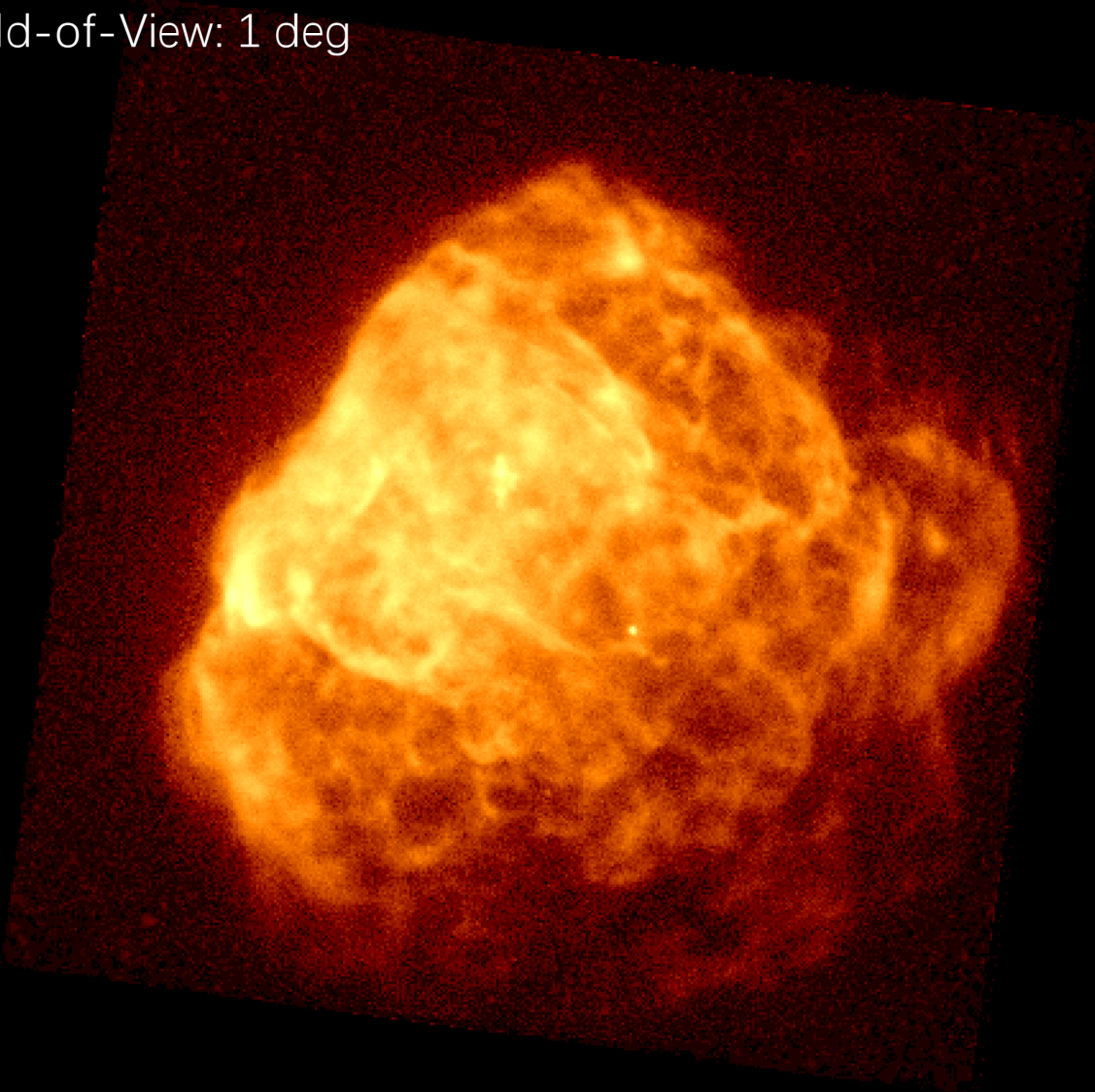
- 1: Cir X-1 & Swift J151857.0-572147
- 2: Sco X-1
- 3: V2216 Oph
- 4: V1101 Sco
- 5: V821 Ara
- 6: NP Ser
- 7: V4134 Sgr
- 8: Sgr X-4
- 9: Lupus SN
- 10: SNR RCW 86

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

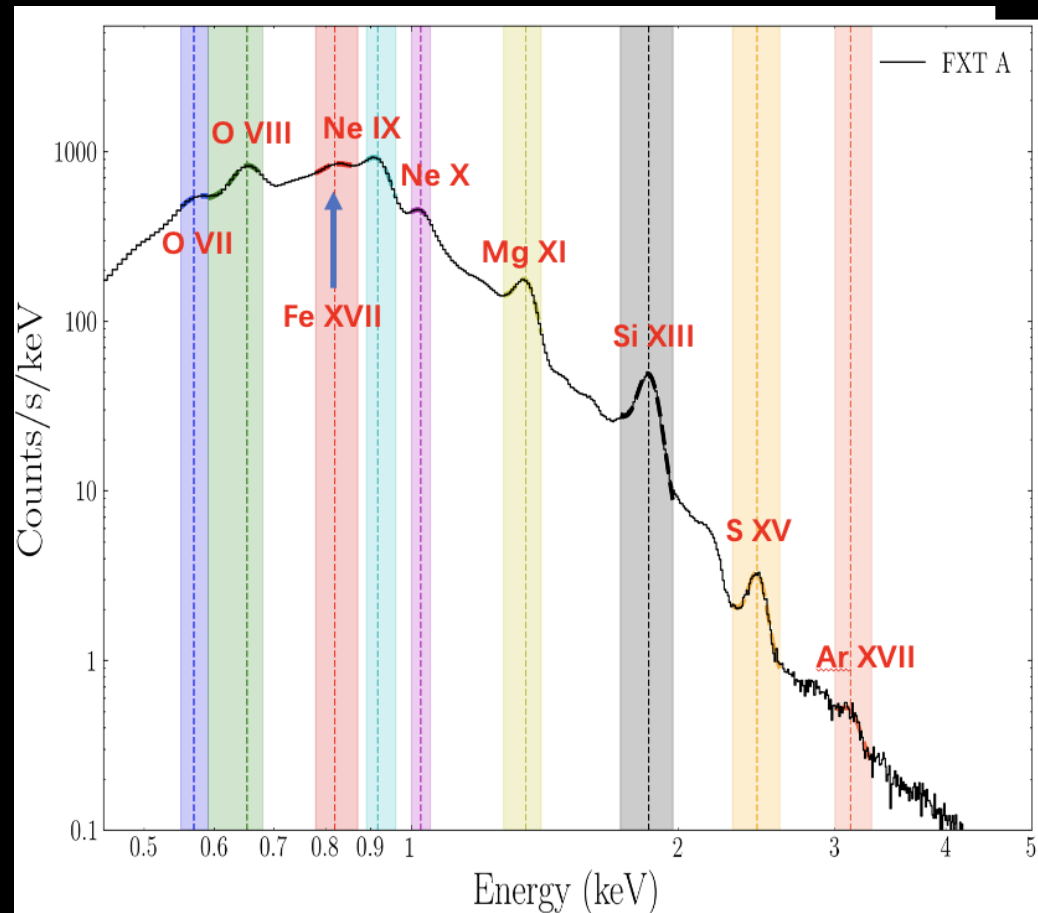
FXT X-ray First light (0.3-10 keV)

Puppis A supernova remnant (nebula)

Field-of-View: 1 deg



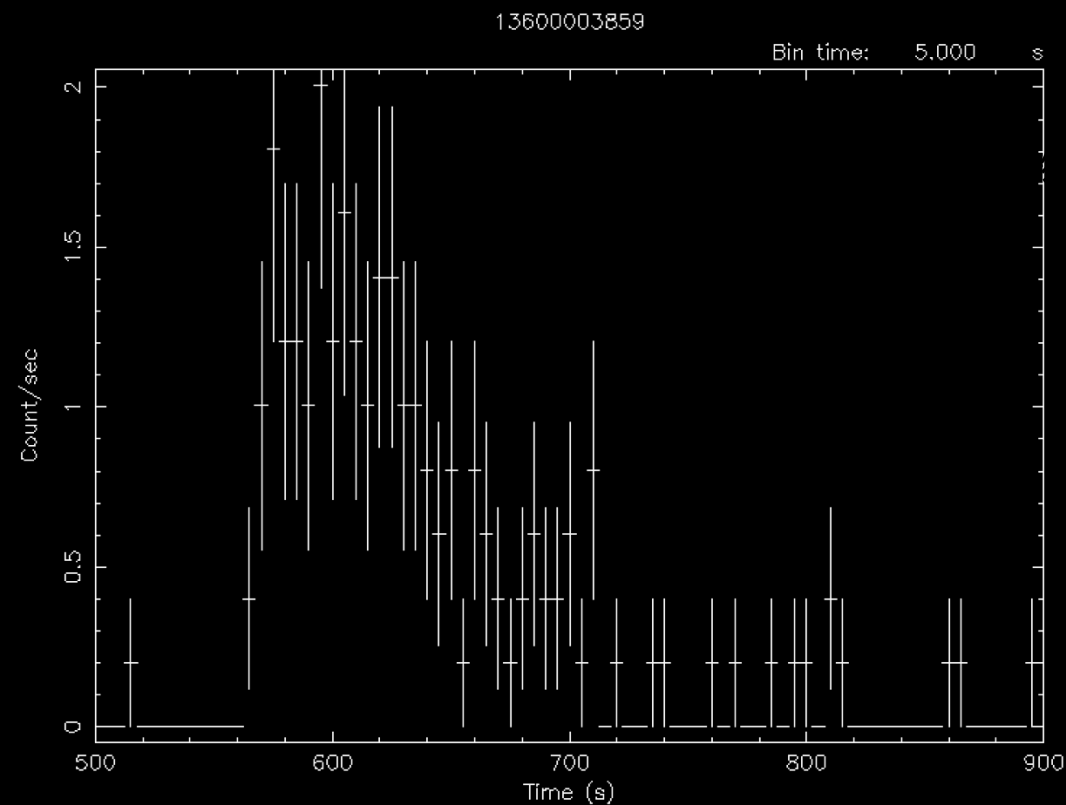
FXT X-ray spectrum obtained at the same time



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+3 days)
- Possibly an X-ray rich GRB



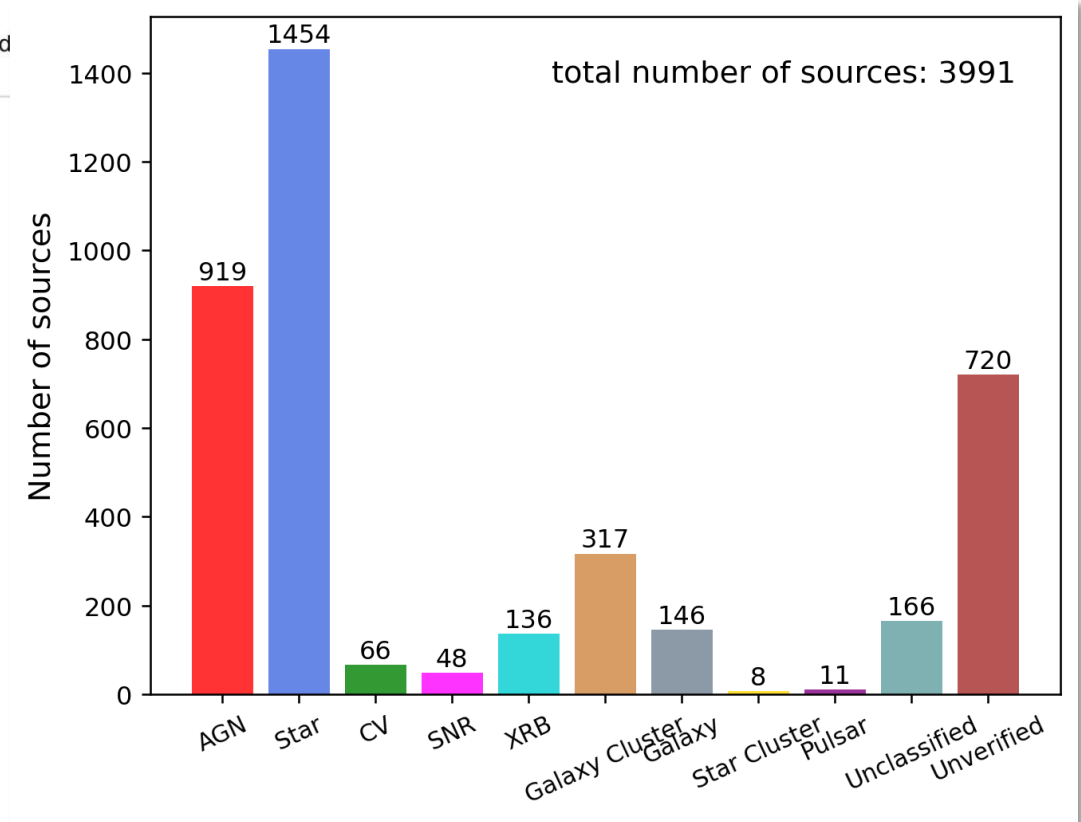
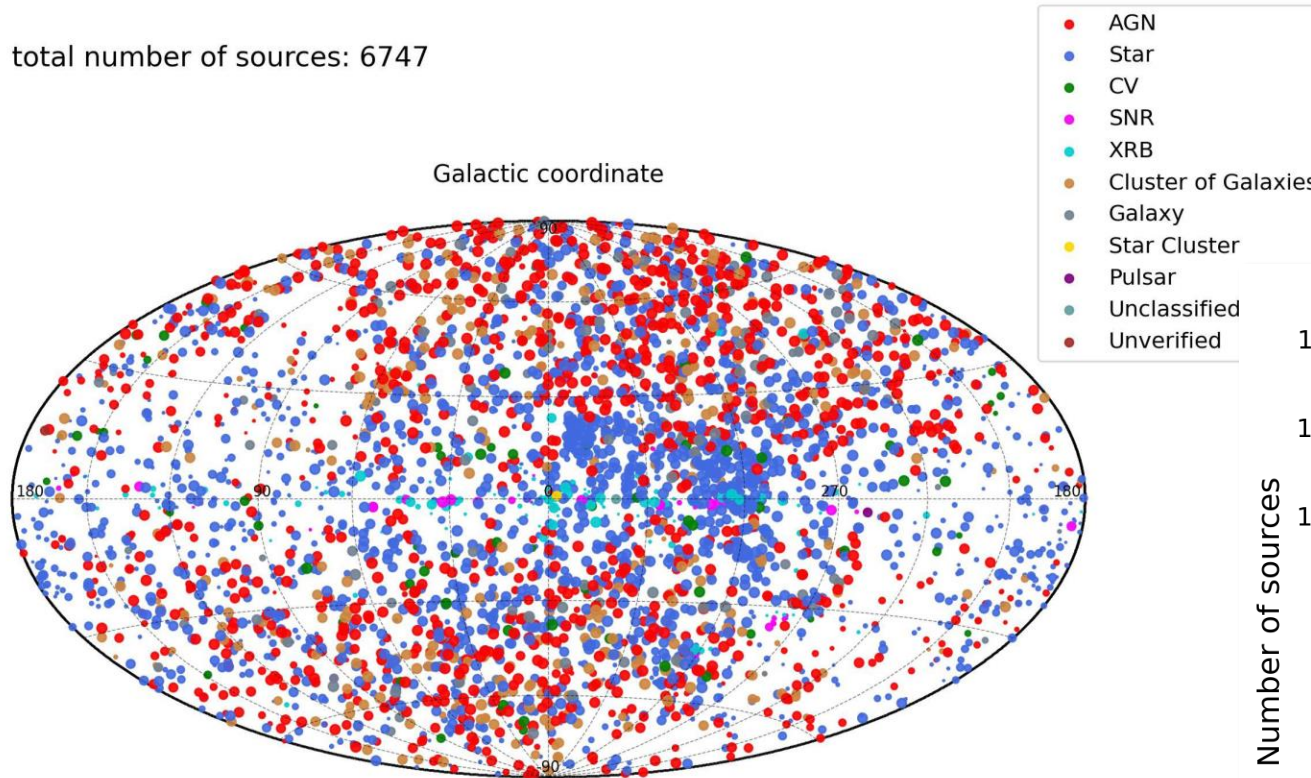
Start Time 20359 6:13:28:534 Stop Time 20359 6:30:43:534

9.3° by 9.3°, 1 time-frame = 33.3 sec

Yin et al. ApJL in press (arXiv:2407.10156)

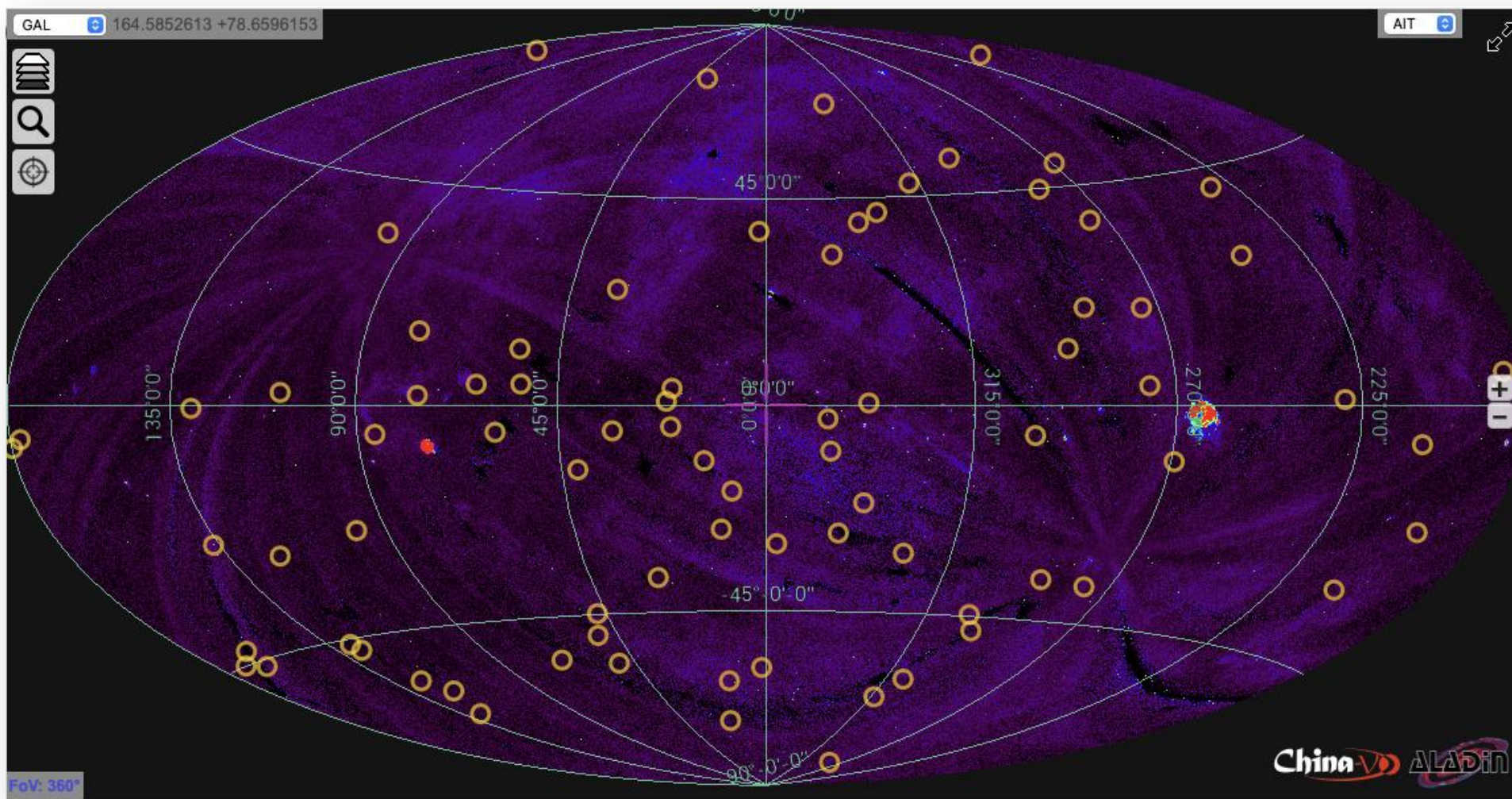
Statistics on X-ray sources detected with EP

total number of sources: 6747

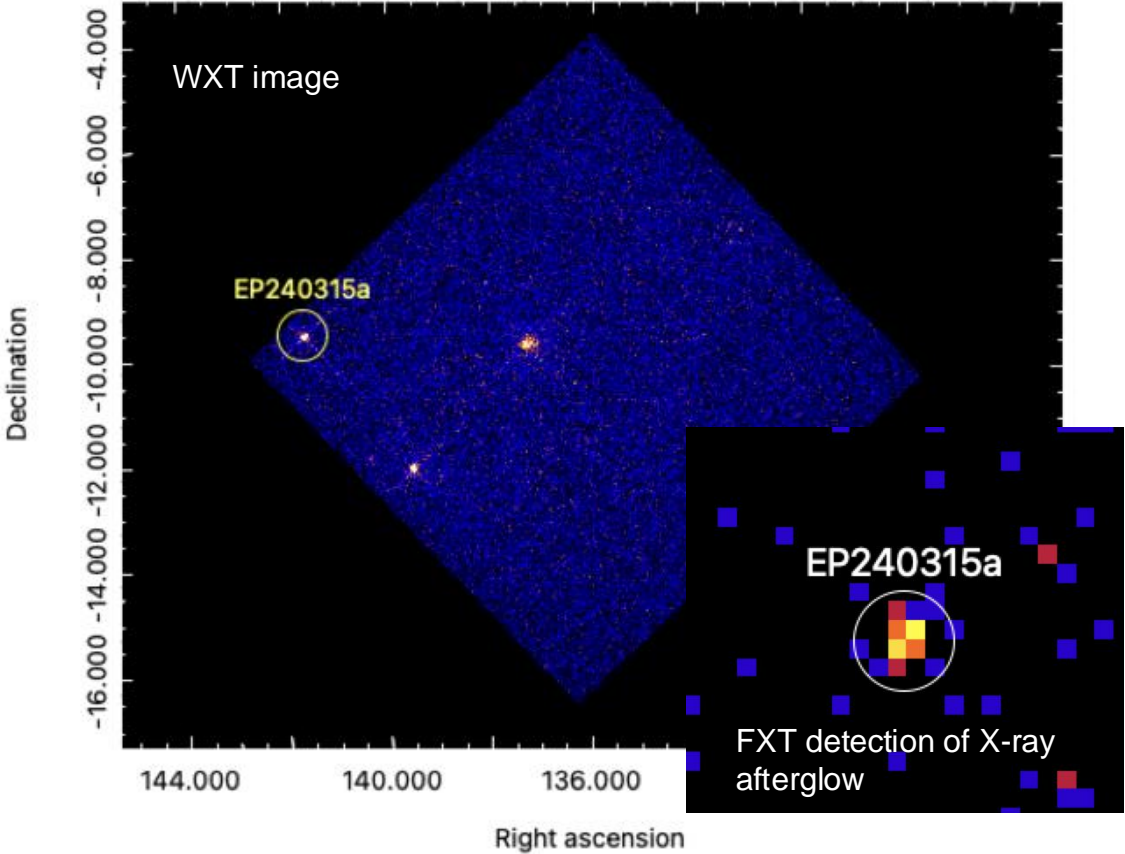


- Bright sources detected with WXT: 6747
- Transients: 55 with high S/N (3200 with low S/N)
- Stellar flares: 488
- New X-ray sources detected with FXT: ~20,000

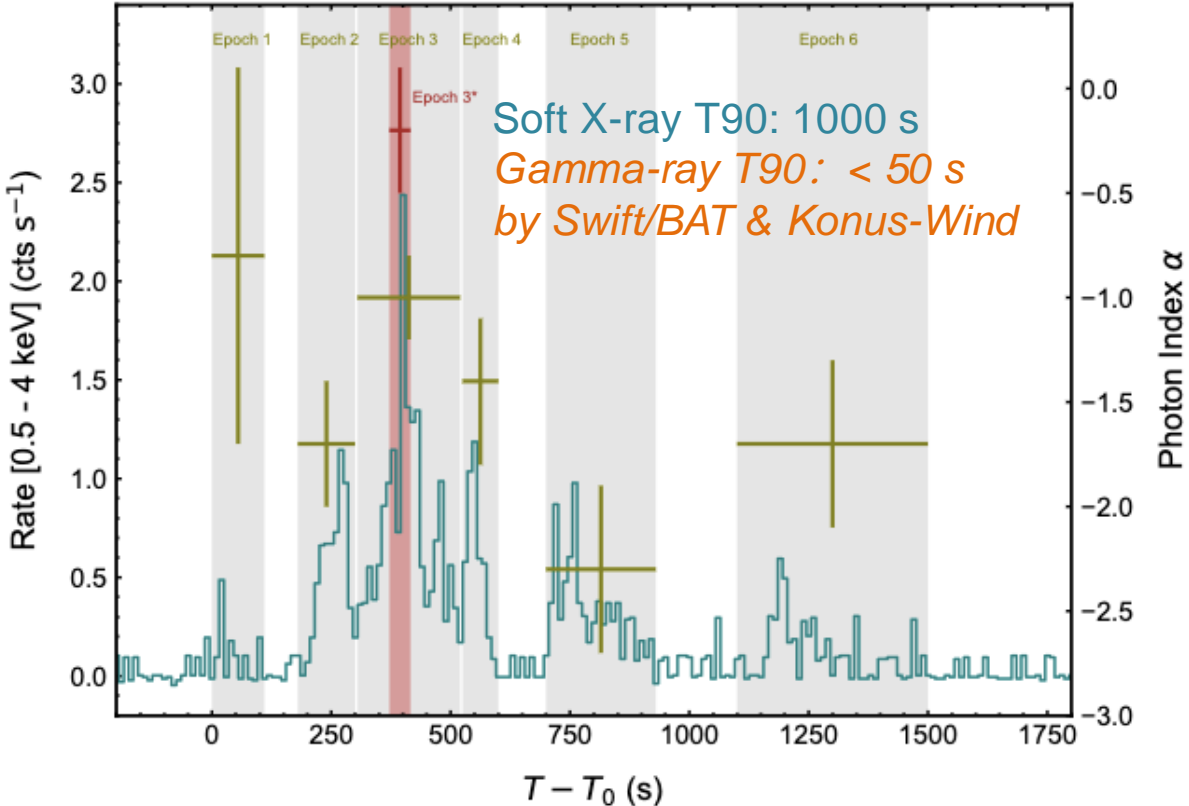
Transients detected with EP-WXT (high S/N)



EP240315a: GRB @ redshift 4.859



Onboard trigger, confirmed by on-ground analysis



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

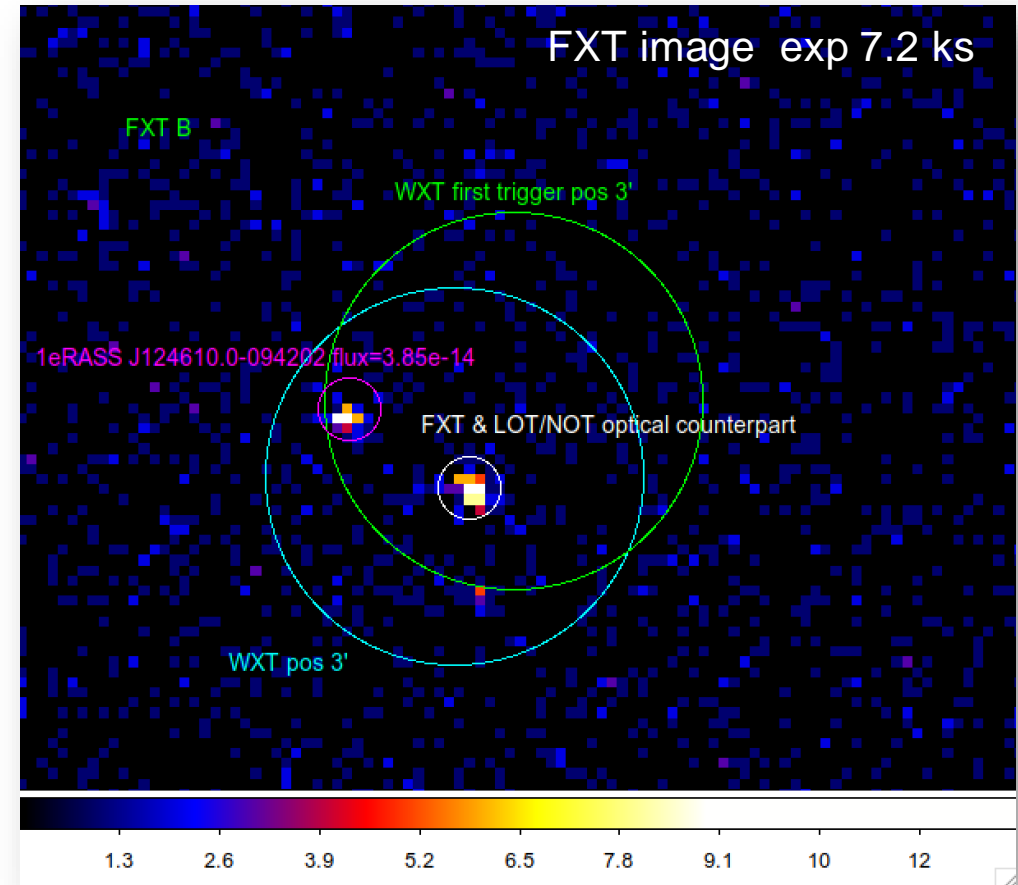
Gillanders et al. arXiv:2404.10660 (ATLAS optical/radio counterpart, z)
 Levan et al. arXiv:2404.16350 (Stargate optical photometry and spectrum, z)
 Liu et al. arXiv:2404.16425 (EP jointly with Swift, Konus-Wind, Stargate teams)

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!

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

EP240605a: onboard trigger for FXT automated follow-up

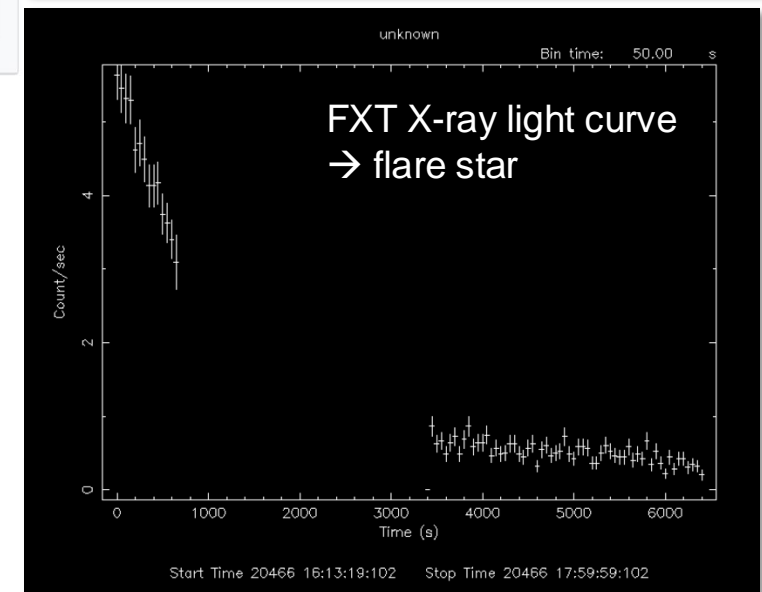
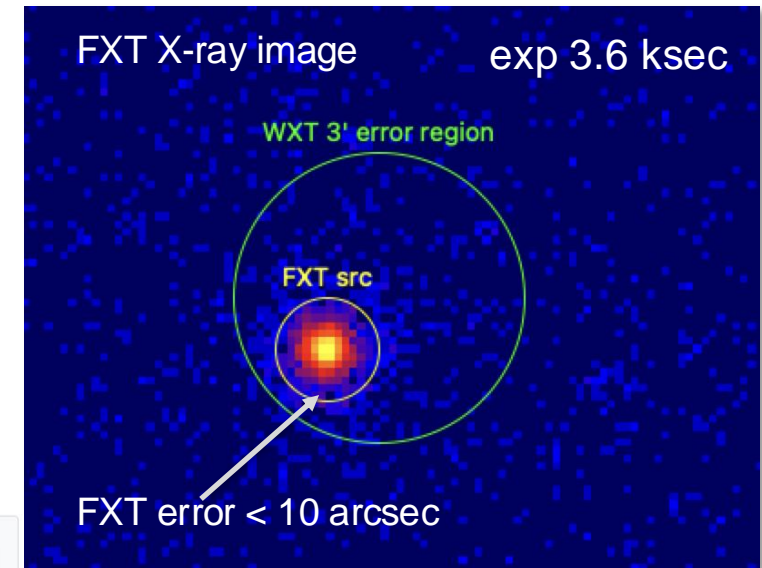
- 1st successful test: EP240605a 5 June UTC 16:10:30
- transient info downlink within minutes (Beidou & VHF networks)
- triggered FXT observation @ UTC 16:11:44
→ ~1 min after alert!

Alert information downlinked via Beidou network:

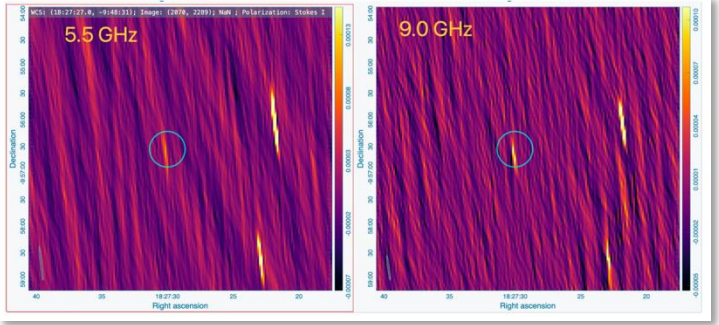
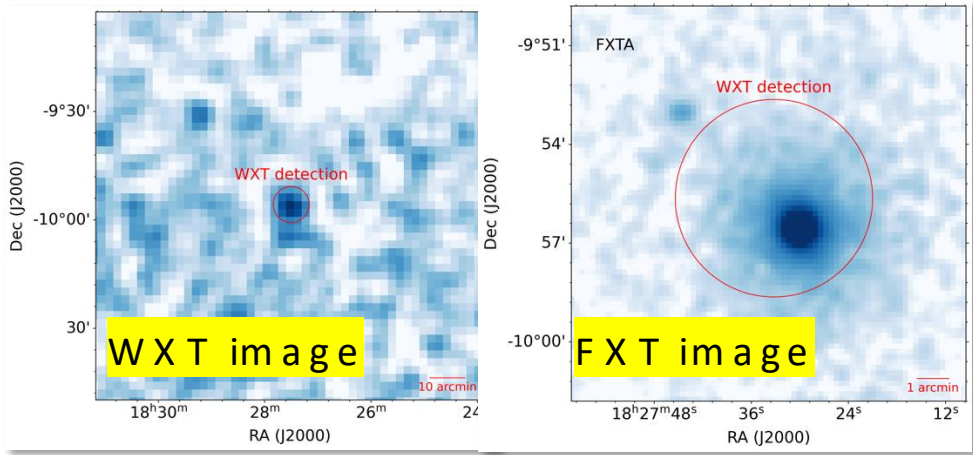
Beidou Alert: 01708918013 CMOS14

RA, Dec	19.907, -68.695
RA (HMS), Dec (DMS)	01h19m37.7s, -68d41m42.0s
Observation Time (UTC)	2024-06-05 16:00:40
X	2674.2
Net Rate	0.06
Significance	8.1

Galactic l, b	299.095, -48.223
1 σ Pos Err (arcmin)	0.692
Trigger Time (UTC)	2024-06-05 16:10:30
Y	3576.6
Variance ?	13.34
HR ?	0.18



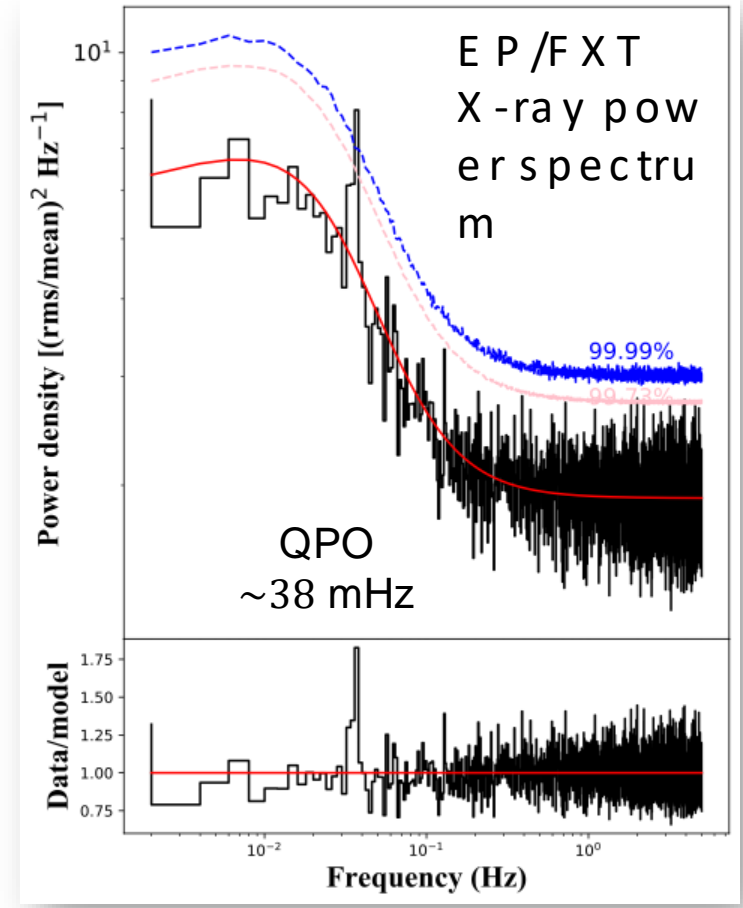
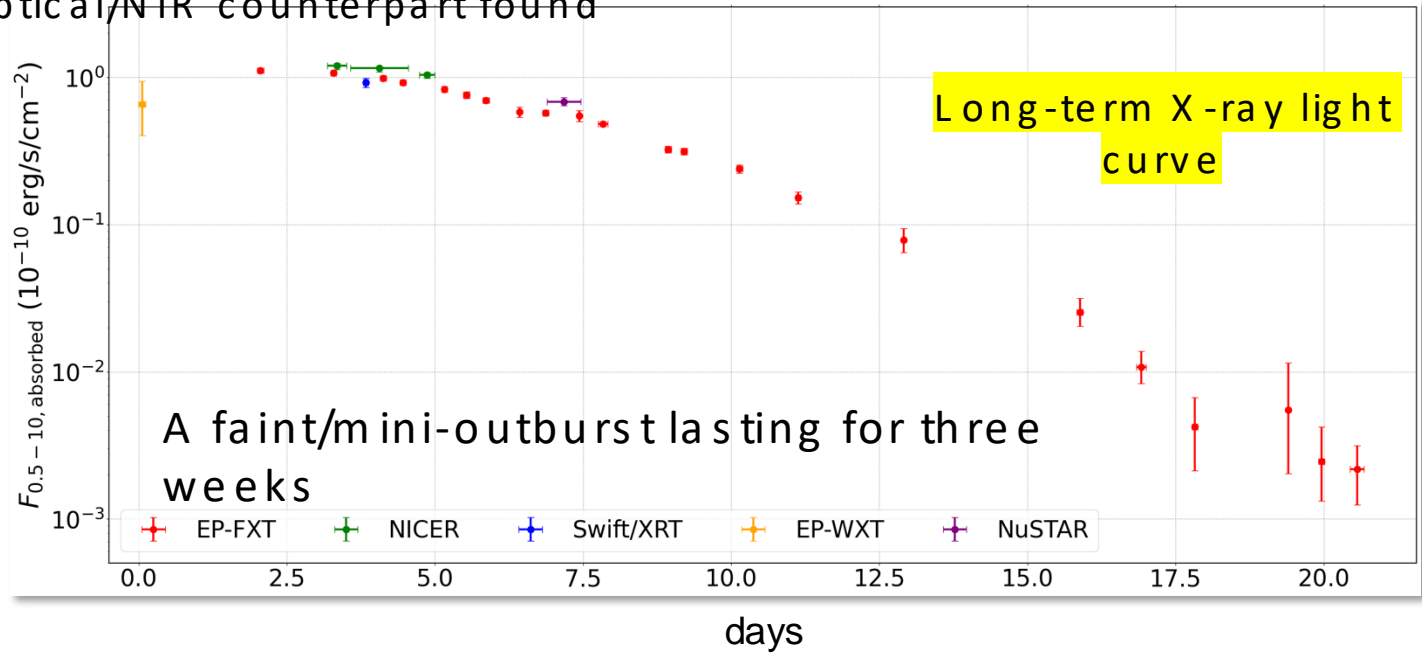
EP240904a: a new X-ray binary (BH?)



radio: flat spectrum & X-ray bright state → a compact jet

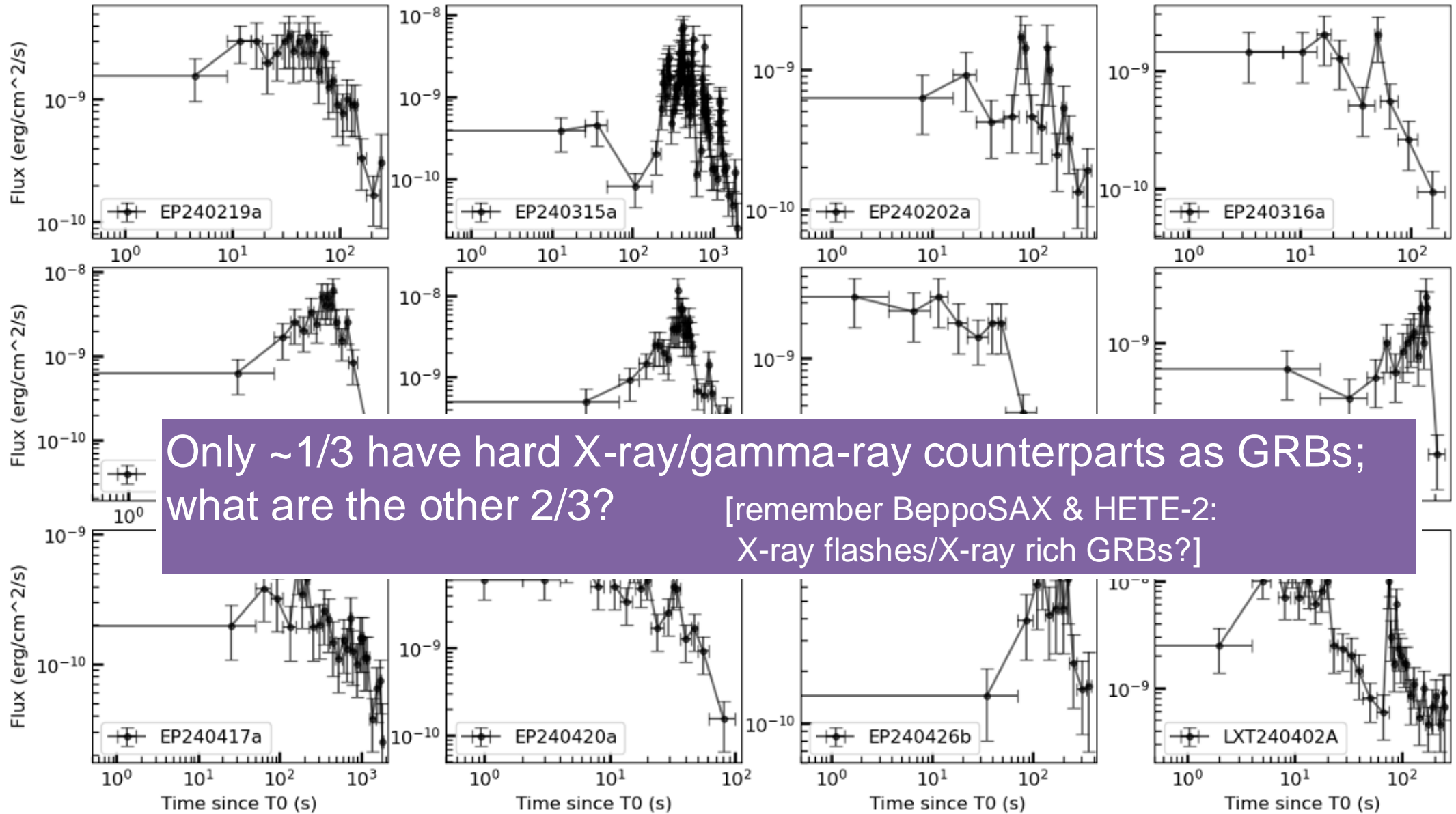
X-ray spectrum: power-law

EP J182730.0-095633: ATels # 16805, 16807, 16817, 16825; no optical/NIR counterpart found



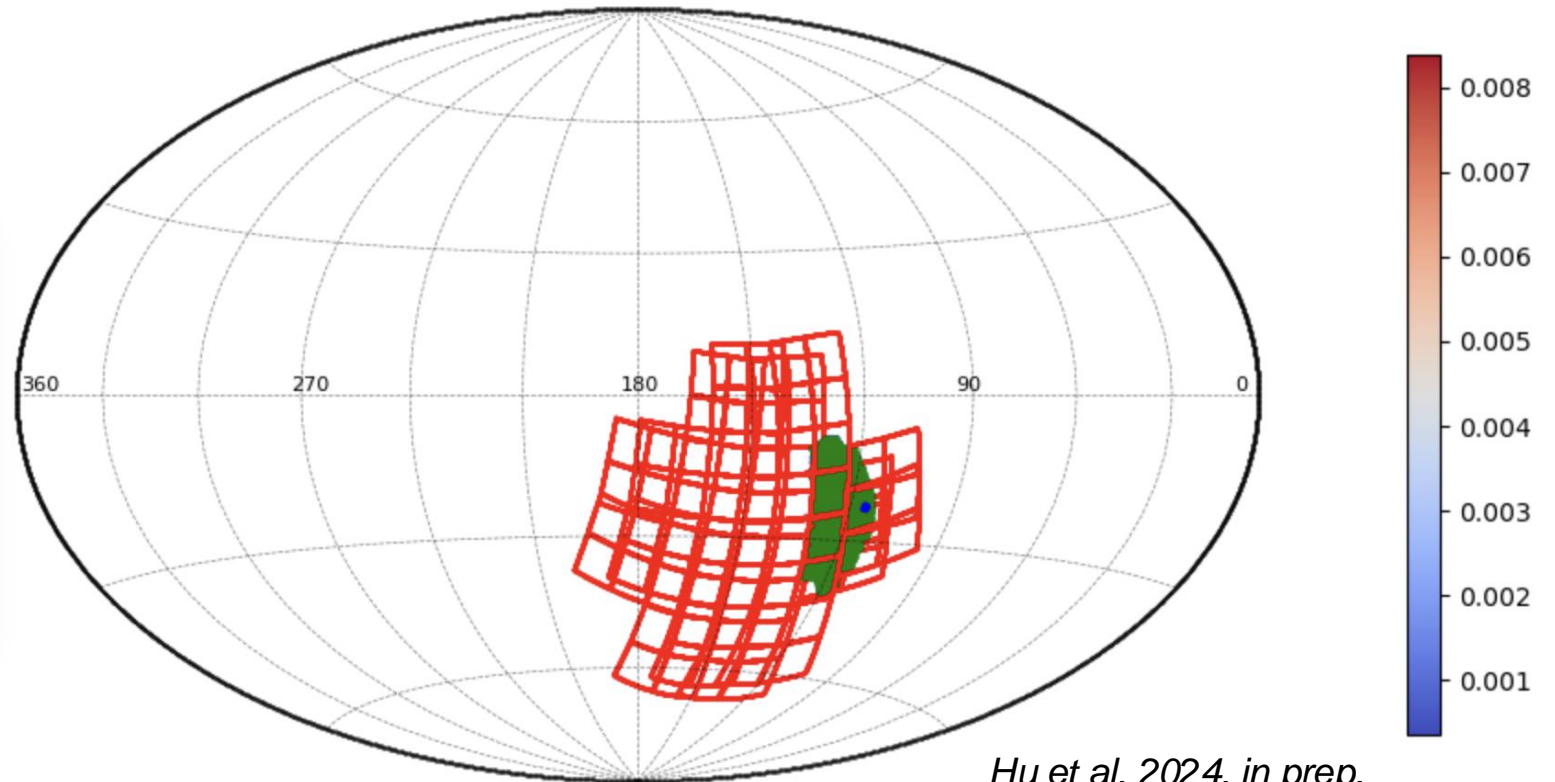
EP team, in prep.

Example light curves of EP fast transients



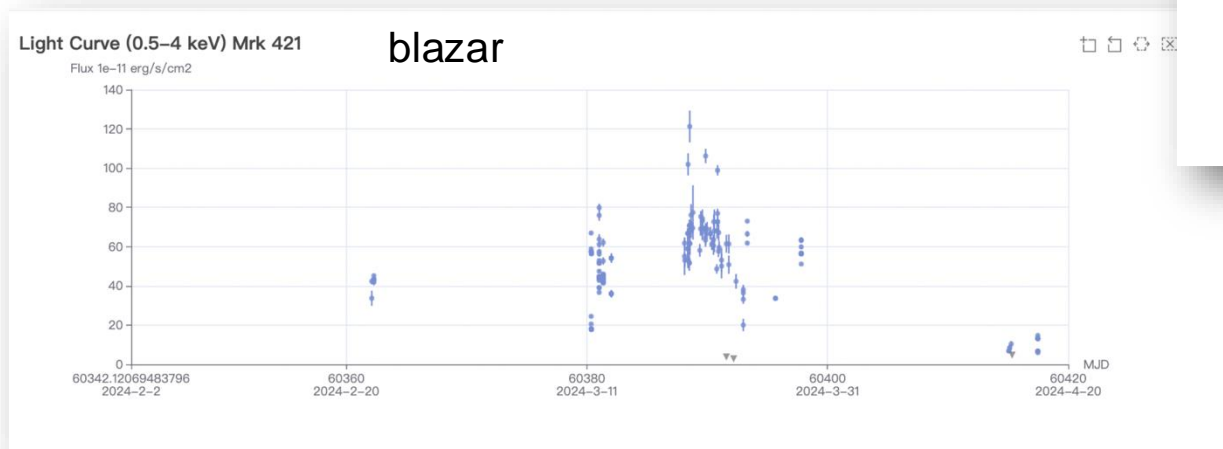
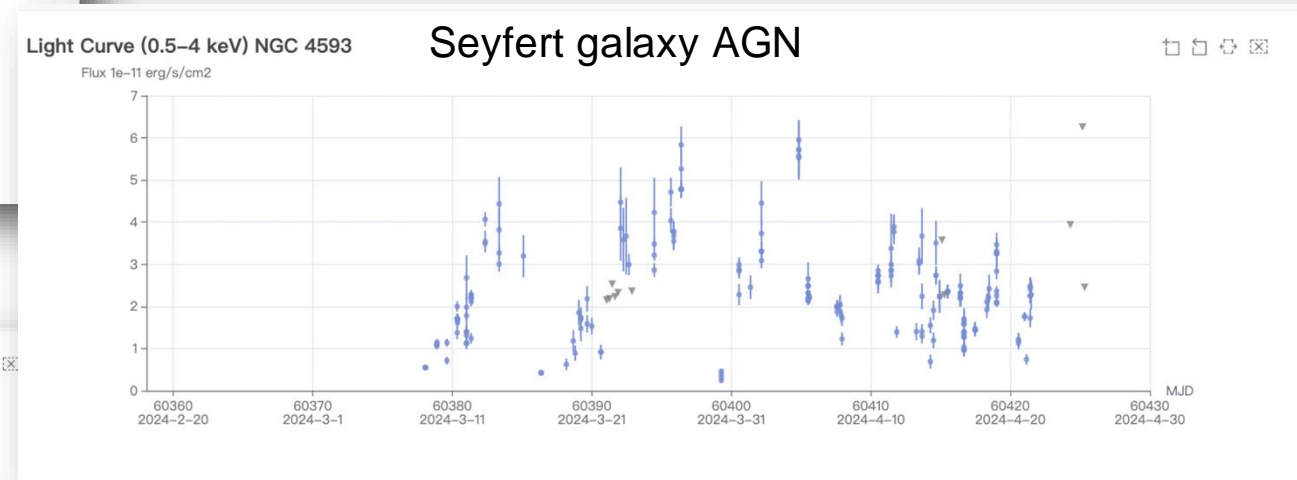
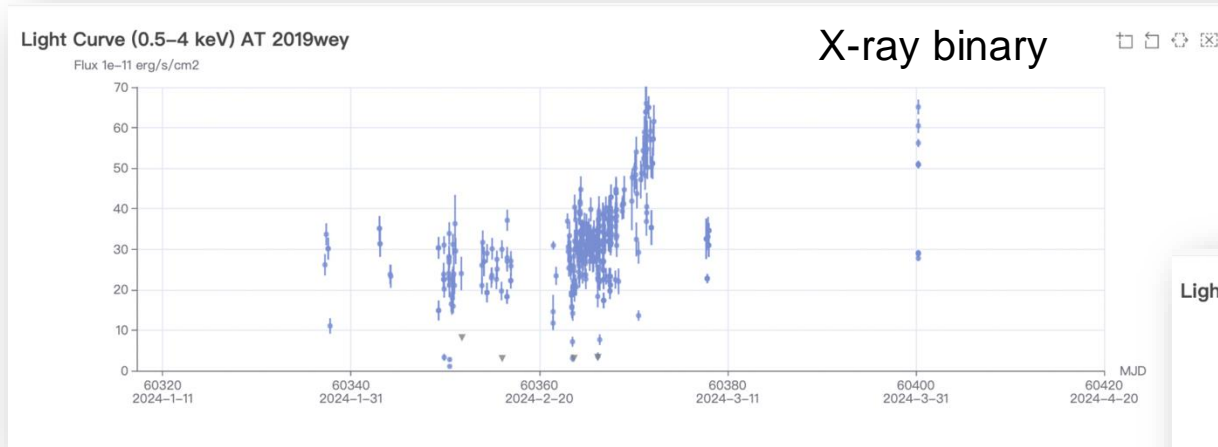
GW event S240422ed: search for potential X-rays

- On 22 April: 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.

WXT monitoring of known X-ray sources

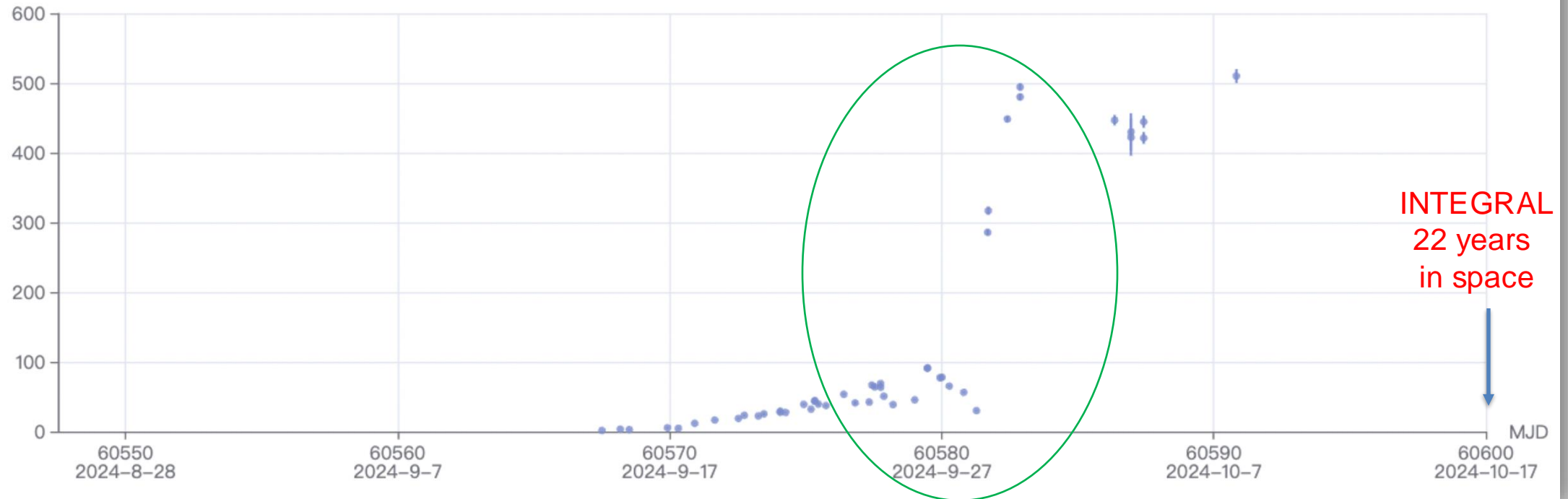


WXT monitoring of known X-ray sources: NS X-ray binary Aql X-1



Light Curve (0.5–4 keV) Aql X-1

Flux 10^{-11} erg/s/cm²



INTEGRAL
22 years
in space

recent outburst of Aql X-1

Einstein Probe: Summary

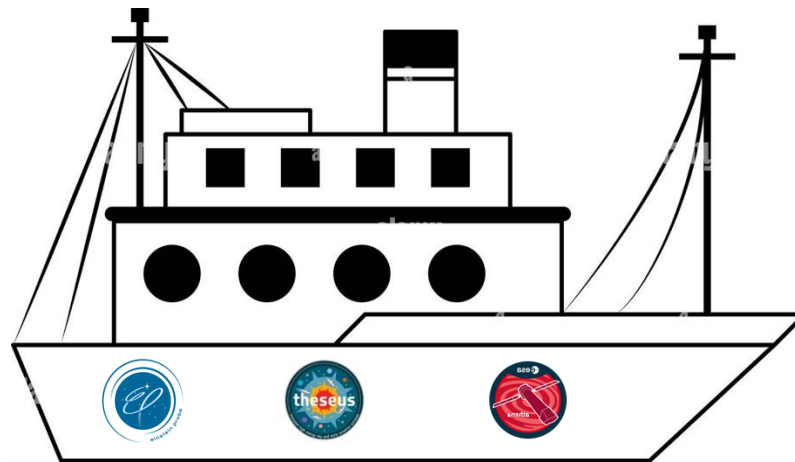


- Since launch on 9 January 2024, EP's performance verifications & calibrations completed
- Spacecraft & instruments working as expected
- Nominal science operations just started since July 2024; **>100 GCNs/ATels issued**
- ~55 X-ray transients with high S/N (>100 faint ones) have been detected
- A wide range of targets: GRB, SN, TDE, WD+NS+BH in our and nearby galaxy, and more
- Monitoring the activity of a sample of known sources
- A newcomer with great scientific potential in time-domain X-ray astronomy

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

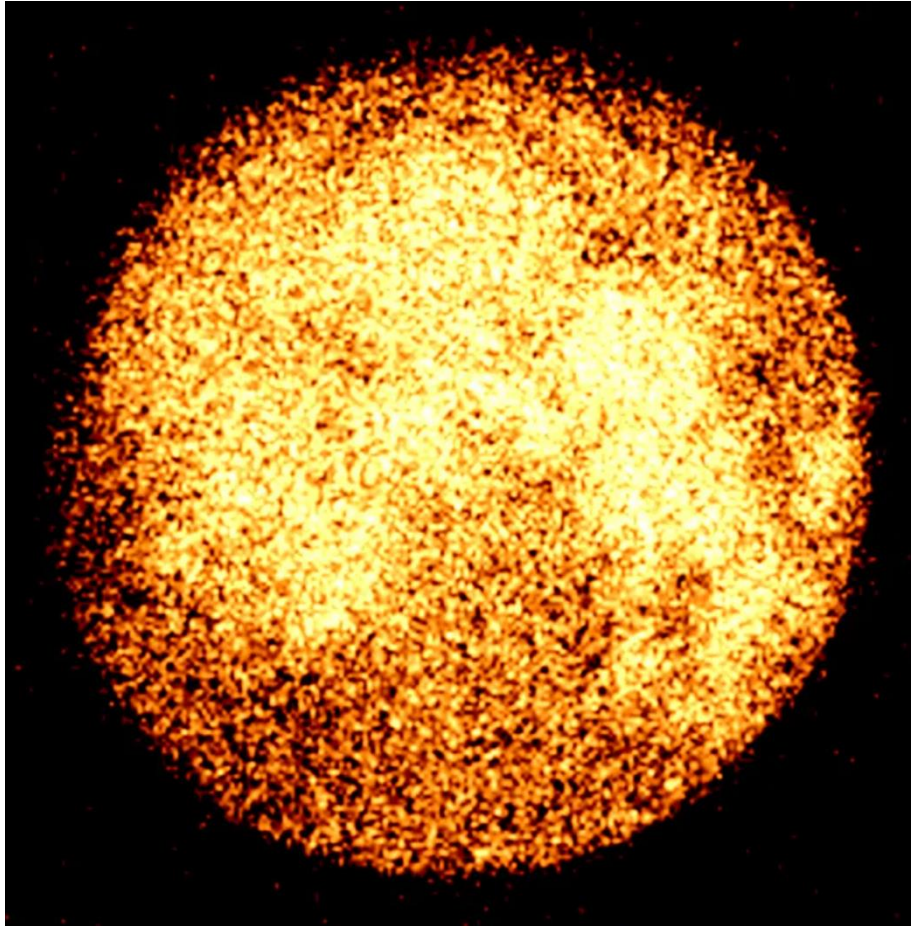


Thank you



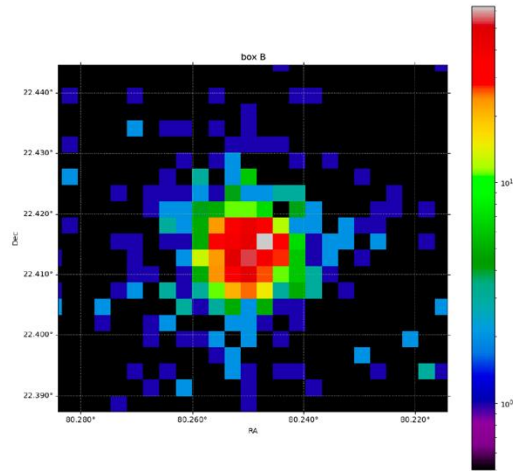


X-ray image of the Moon observed with EP-FXT

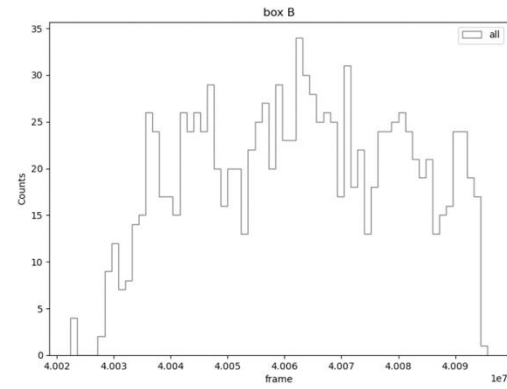


Impact of a Solar flare on Jupiter & Saturn observed with EP-FXT

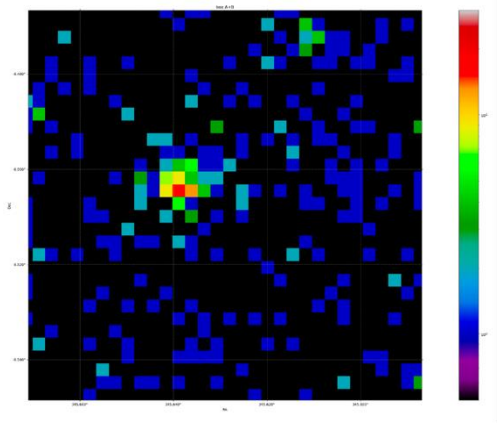
Jupiter



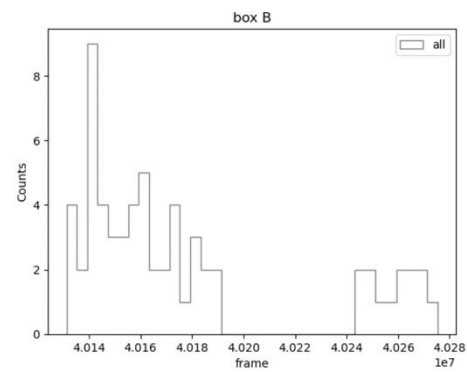
light curve



Saturn



light curve





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

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	-