Warm congratulations on the successful launch of SVOM!

Updates to the Einstein Probe mission

Weimin Yuan
National Astro. Observatories, CAS

on behalf of the Einstein Probe consortium

Image credit CAS/ESA

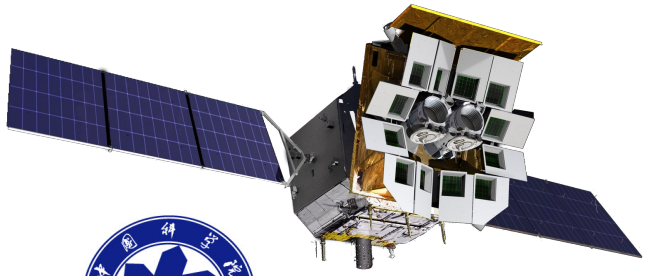
Einstein Probe (EP) mission

Goals a time-domain astro. mission

- Discover soft X-ray transients & monitor source variability with improved sensitivity
- Characterise transients/variables by quick X-ray follow-up onboard
- Disseminate transient alerts to astro. community in time

Milestones

- 2010- Lobster-eye R&D @ XIL/NAO (est. by S.-N. Zhang)
- 2012 Mission concept
- 2017/12 Adoption
- 2018 Joined by ESA & MPE; 2022 CNES
- 2022/07 Pathfinder *LEIA* launched
- 2024 Jan. 9 launch
- 2024/07 nominal mission (lifetime: 3 yr, goal 5 yr)



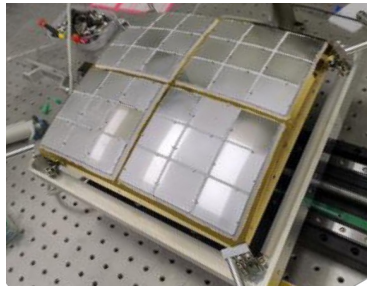
Instruments & spacecraft

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)
Effe. area: ~300 cm^2 @1keV (x 2 units)



WXT mirror & CMOS detectors (1 module)

Spacecraft

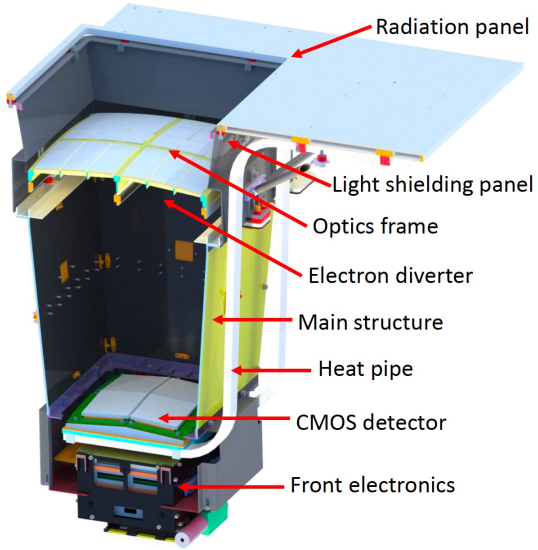
On-board data processing
Quick slew & autonomous follow-up

Telemetry

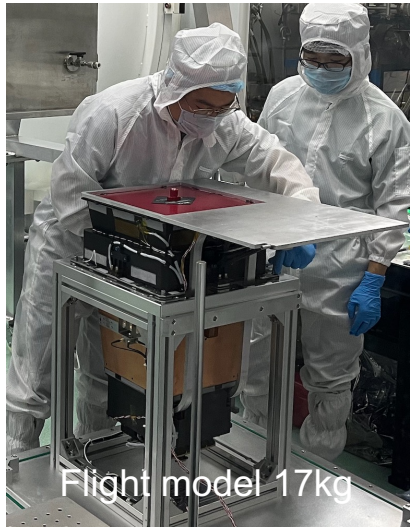
X/S-band (several hours)
BD (down/up-link; minutes)
VHF (down-link; minutes)

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

Wide-field X-ray Telescope

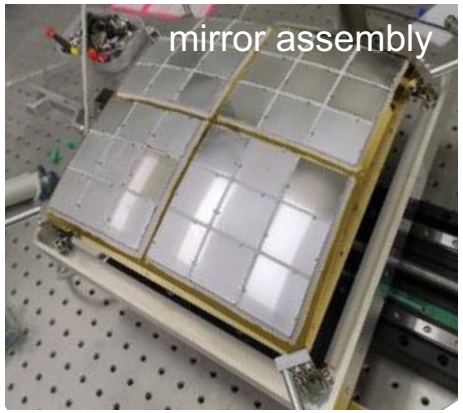


one module



Lead of LE mirrors
Chen Zhang (NAO/CAS)

WXT chief designer
Xiaojin Sun (SITP/CAS)



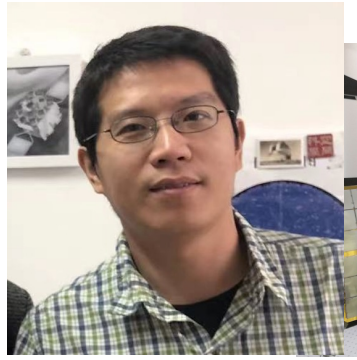
MPO plates (developed by NNVT jointly with NAO/CAS)

41mm x 41mm each

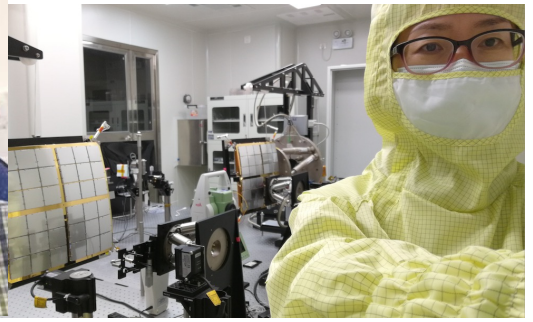
BI CMOS sensors

Time resolution 50ms

ΔE ~ 122eV @1.25keV



Instrument scientist &
lead of CMOS
Zhxing Ling (NAO/CAS)

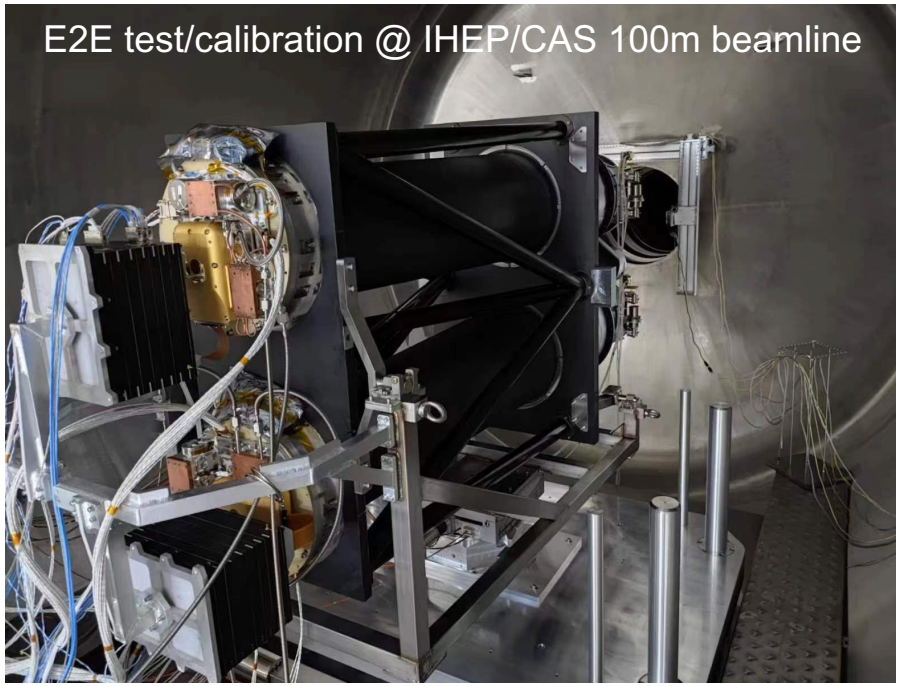


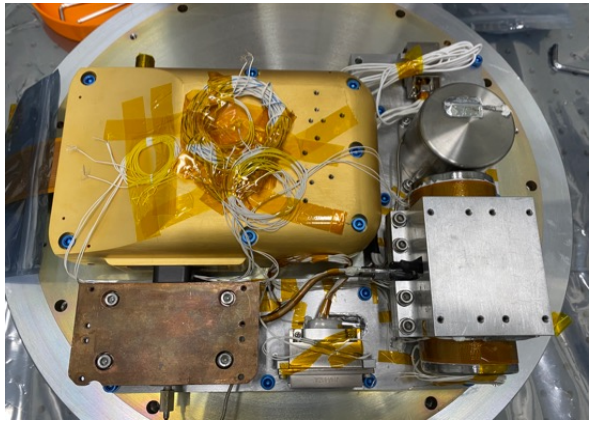
MA engineer
Yanfeng Dai (NAO)

Follow-up X-ray Telescope (FXT)

IHEP/CAS + ESA + MPE

- 2 Wolter-I mirror assemblies
  - ★ 1 by ESA (Media-Lario, eROSITA design)
  - ★ 1 by MPE (eROSITA FS)
- X-ray cameras (IHEP)
  - ★ PN-CCD detector modules by MPE based on eROSITA tech.

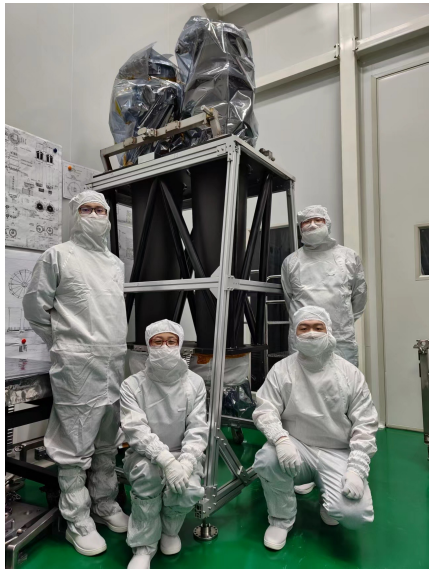




X-ray camera built @ IHEP/CAS

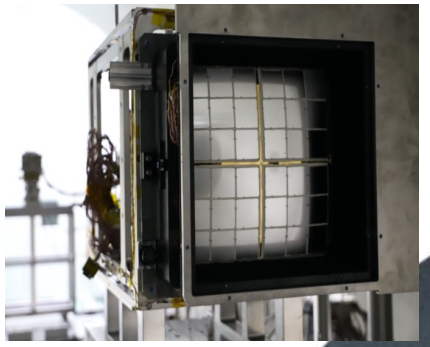
PI: Yong Chen (IHEP/CAS)

Camera lead: Weiwei Cui (IHEP/CAS)



FXT Delivered by IHEP team to MicroSAT on May 26

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

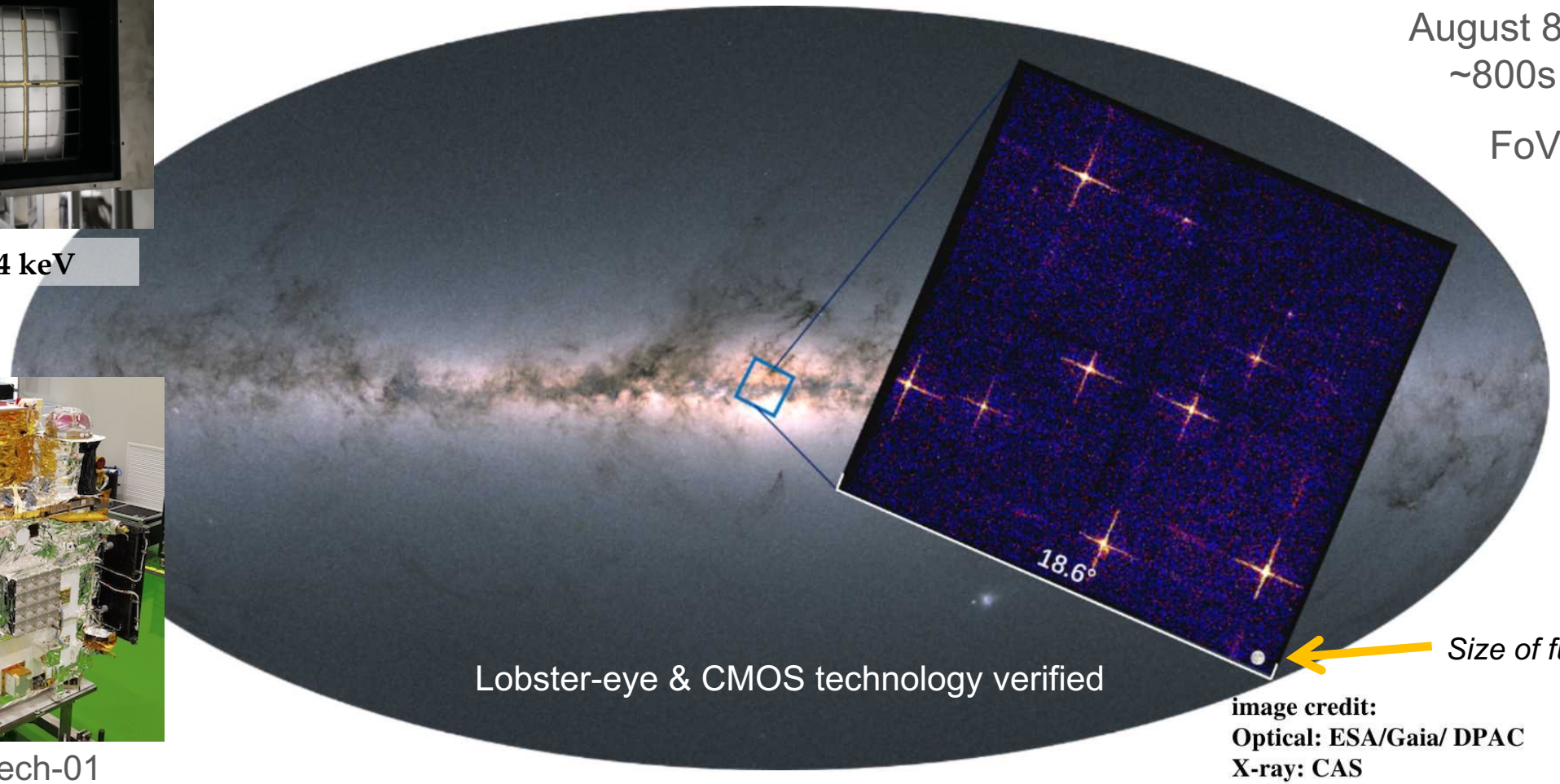


LEIA 0.5 – 4 keV

CAS's SATech-01 experiment satellite
Launched 2022-07-27
credit: MicroSAT

Instrument test observations
August 8-10, 2022
~800s exposure

FoV 340 deg^2



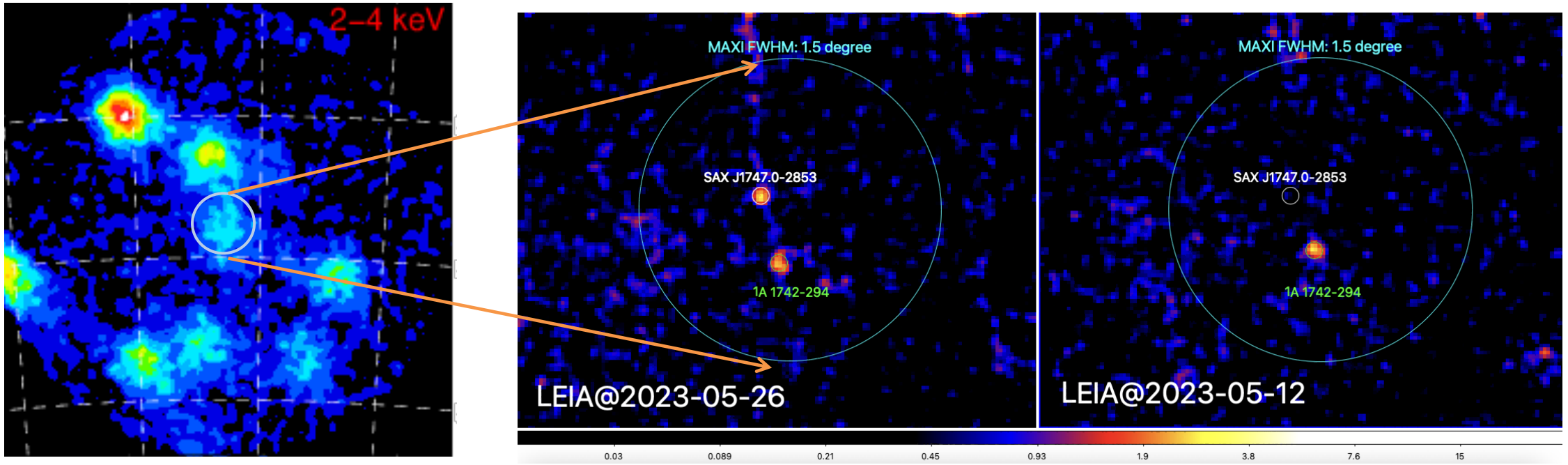
Frist wide FoV X-ray observations by a lobster-eye focusing X-ray telescope in orbit
Zhang et al. 2022 ApJL, 941, L2

LEIA: improved resolution & sensitivity for ASM

The brightening of SAX J1747.0-2853 around Galactic centre

MAXI image (PSF~1.5°)

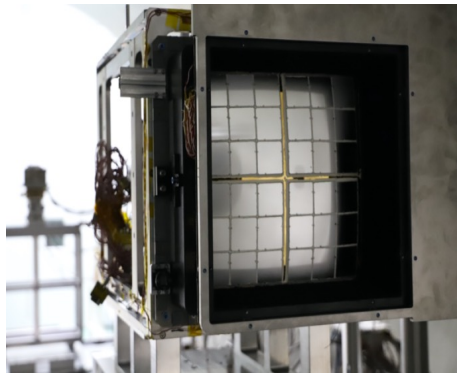
LEIA images (PSF~5')



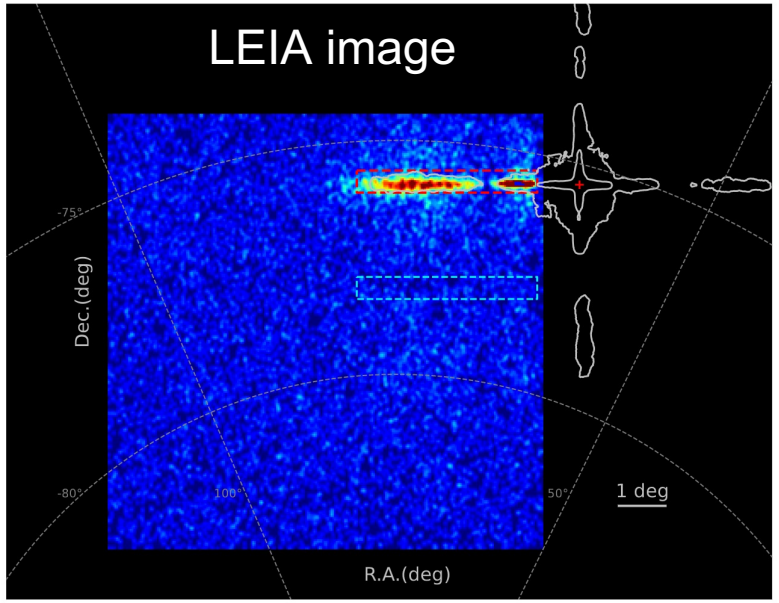
ATel #16061 Li D.Y, 2023 "*LEIA detected possible brightening of SAX J1747.0-2853* …"

Sensitivity (2-3) x10^{-11} erg/s/cm^2 (~1mCrab in 0.5-4keV) @1ks exposure
Source position uncertainties: ~ 2 arcmin (90% uncertainty)

LXT/GRB 230307A



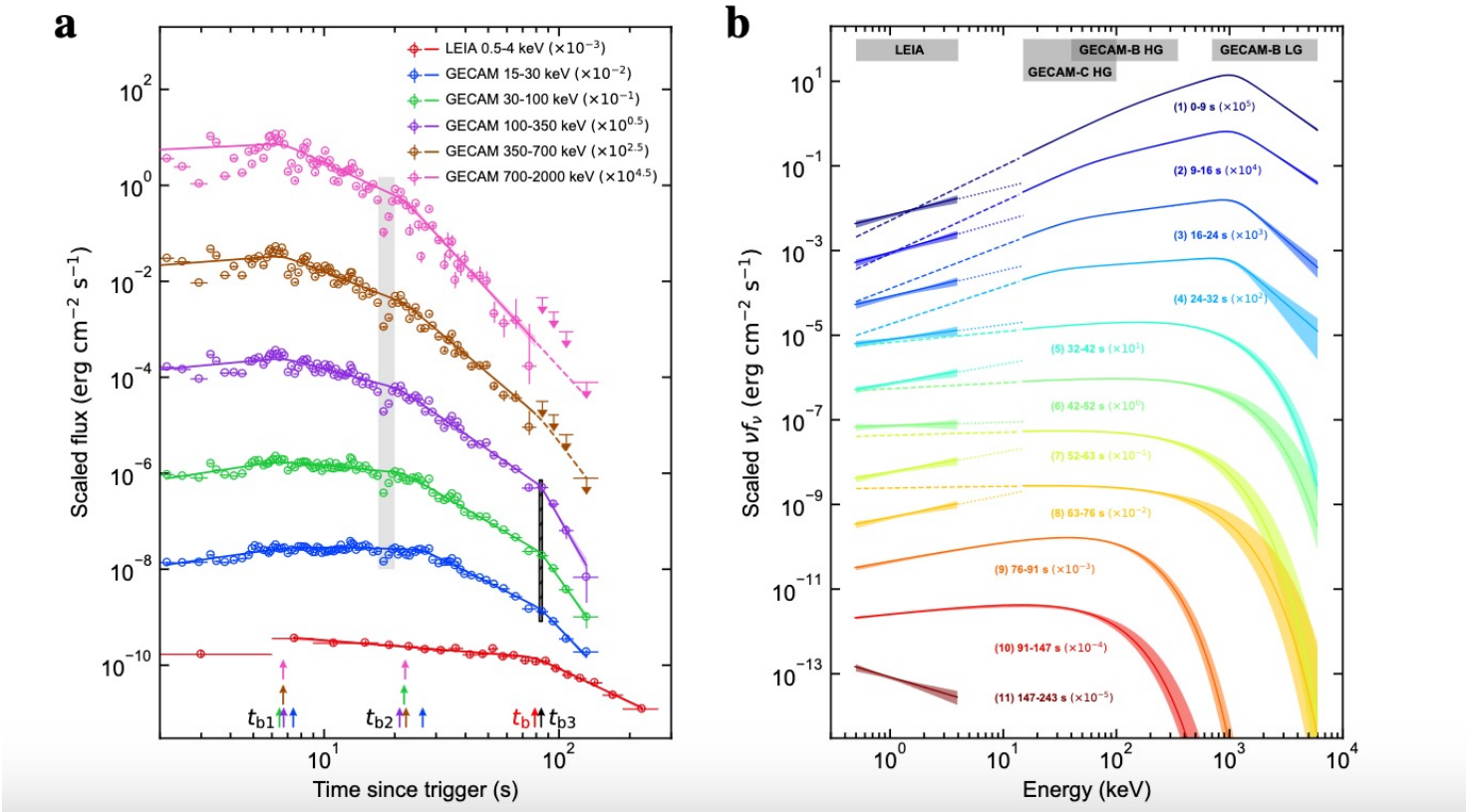
LEIA 0.5 – 4 keV



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



Sun H. et al. submitted arXiv:2307.05689

Launch of EP Jan. 9, 2024

height 592 km
orbital period 96min
inclination angle 29 deg.

LM-2C @Xichang

Status summary: commissioning phase

Most of the in-orbit verifications completed

- Spacecraft and payloads
- Satellite-ground interface & workflow (S/X-band, VHF, BD short-message system)

First light: WXT (Jan. 19), FXT (Feb. 22)

PV observations for one week (Mar. 22)

WXT calibration mostly completed; FXT calibration on-going

Automated FXT follow-up obs. triggered onboard achieved

Spacecraft & instruments working normally

- some minor anomalies are being resolved/improved

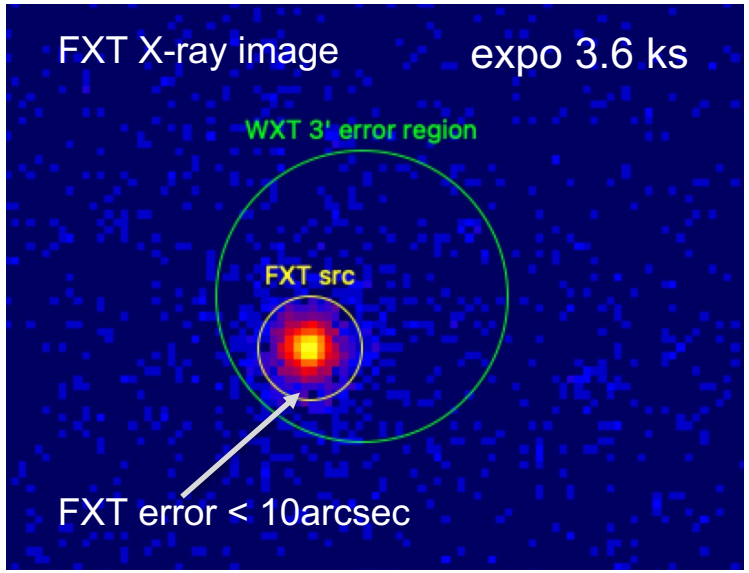
in-orbit calibration results in good agreement with on-ground calibrations for WXT and FXT

Commissioning completion: end of June

Start of science operations: expected July

Onboard trigger for FXT automated follow-up

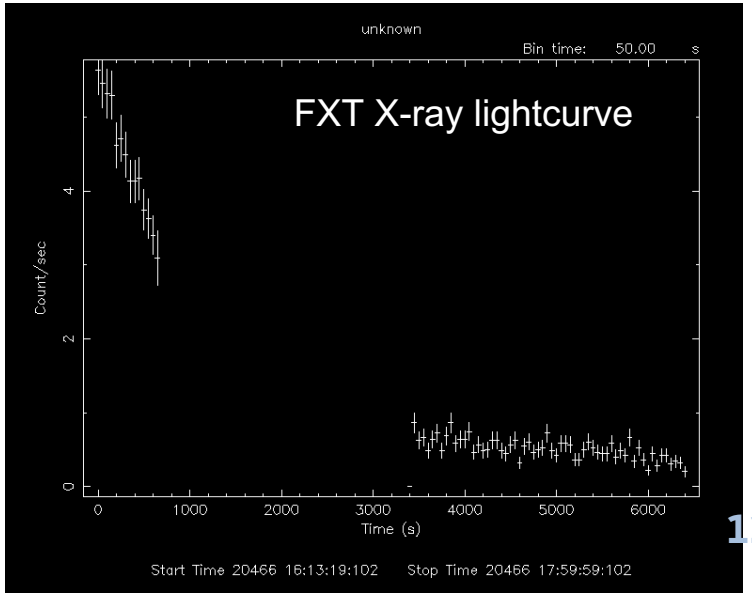
- June 5 UTC 16:10:30, WXT detected a fast transient EP240605a
- transient info downlink within minutes (BD & VHF)
- triggered FXT obs @ UTC 16:11:44
  - 1 min after triggering
  - FXT X-ray spectrum suggests a flaring star



alert information downlinked via BD

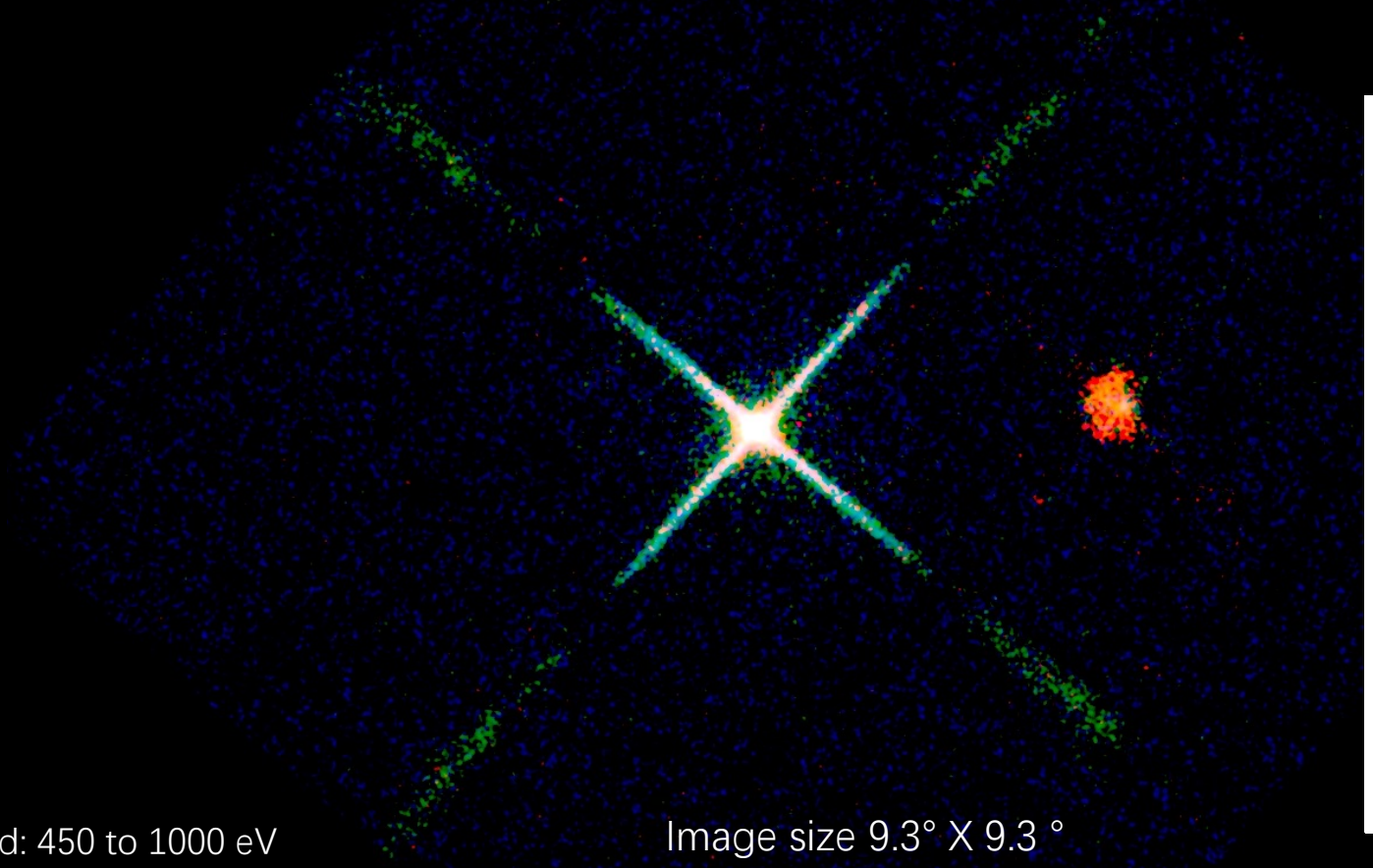
Beidou Alert: 01708918013 CMOS14

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



X-ray First light 2024 Feb. 19

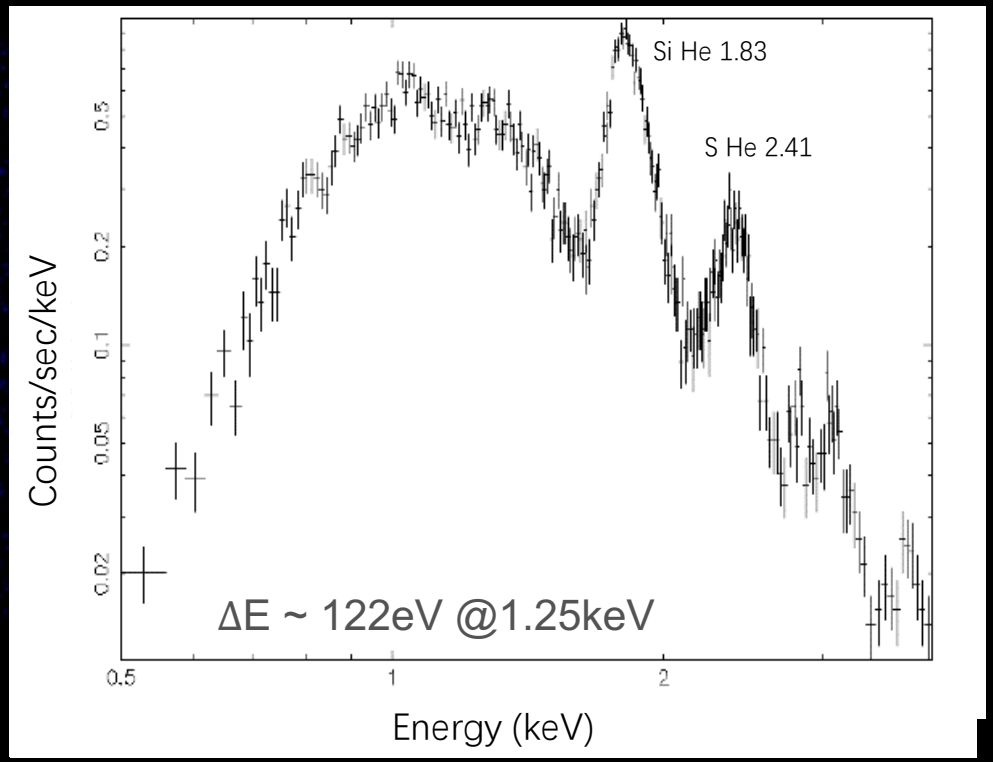
Cassiopeia A supernova remnant (nebula)



Red: 450 to 1000 eV
Green: 1000 to 2000 eV
Blue: 2000 to 5000 eV

Image size 9.3° X 9.3 °
exposure 22 kilo-seconds

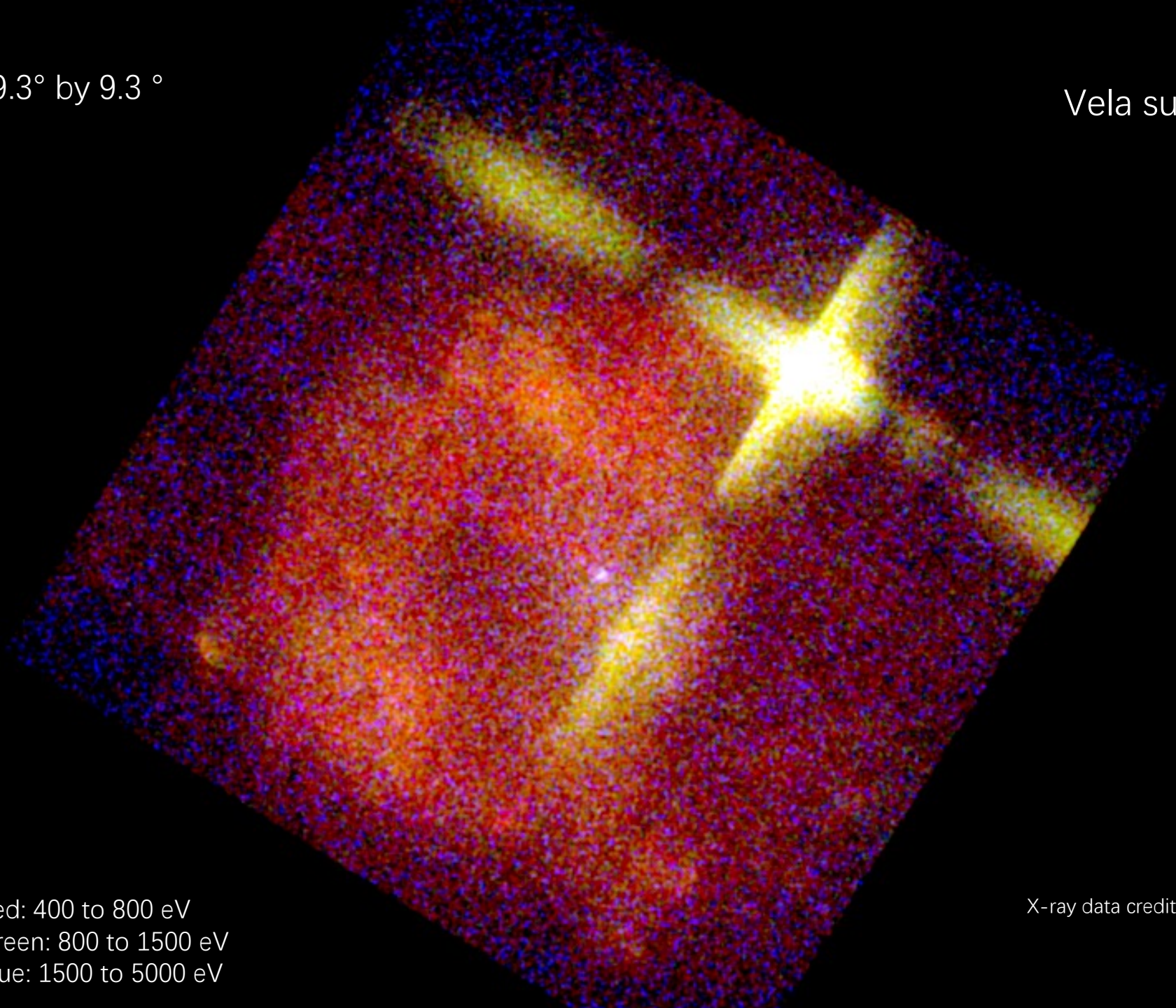
X-ray spectrum obtained at the same time



X-ray data credit: EPSC, image credit: Chen Zhang, Huaqing Cheng.

9.3° by 9.3 °

Vela supernova remnant X-ray (nebula)



exposure 9.3 kilo-seconds
mage size 9.3° X 9.3 °

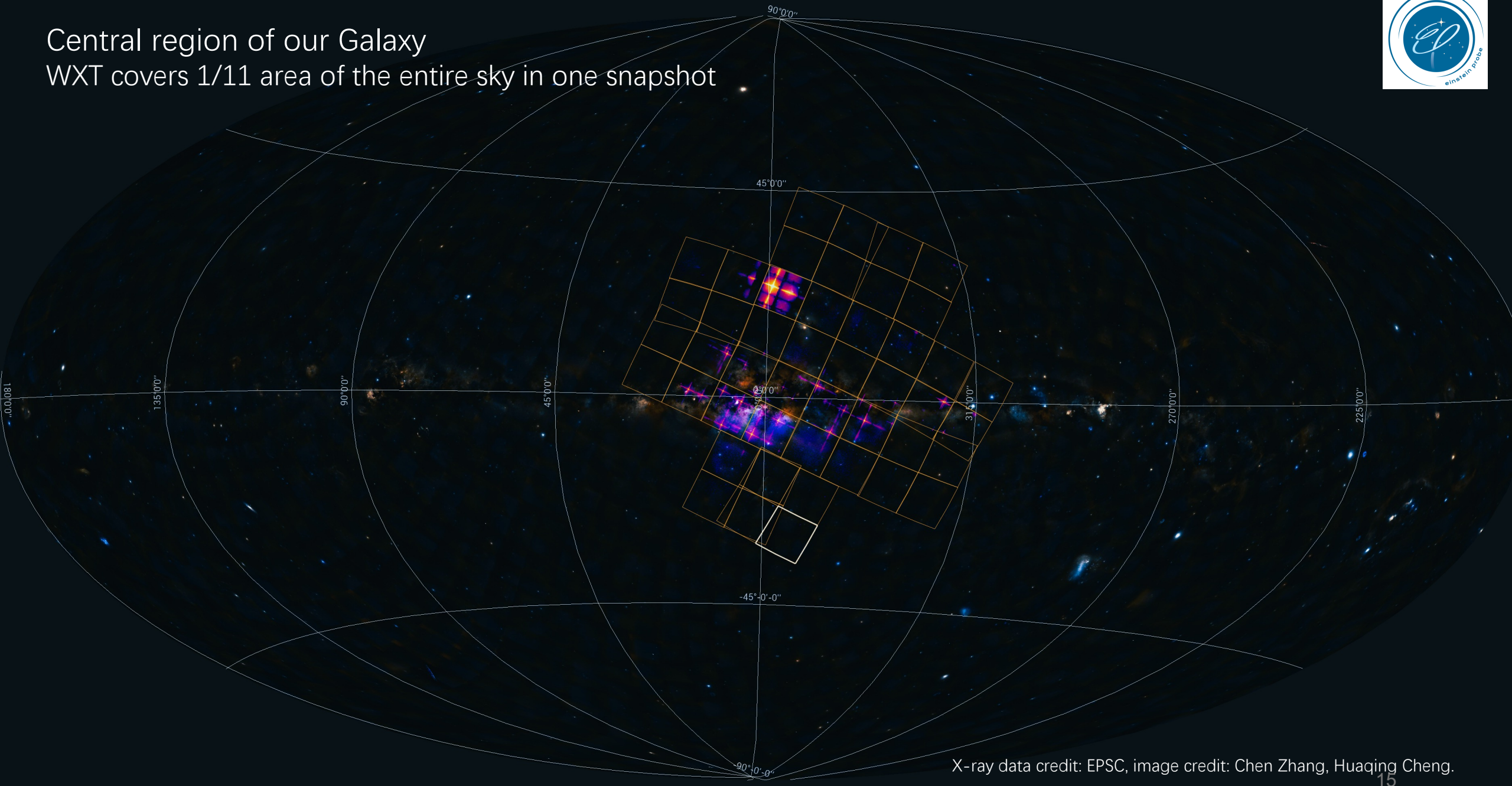
Vela supernova exploded about 11000 yr ago
936 light years to Earth

Red: 400 to 800 eV
Green: 800 to 1500 eV
Blue: 1500 to 5000 eV

X-ray data credit: EPSC, image credit: Chen Zhang, Huaqing Cheng.

Central region of our Galaxy

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

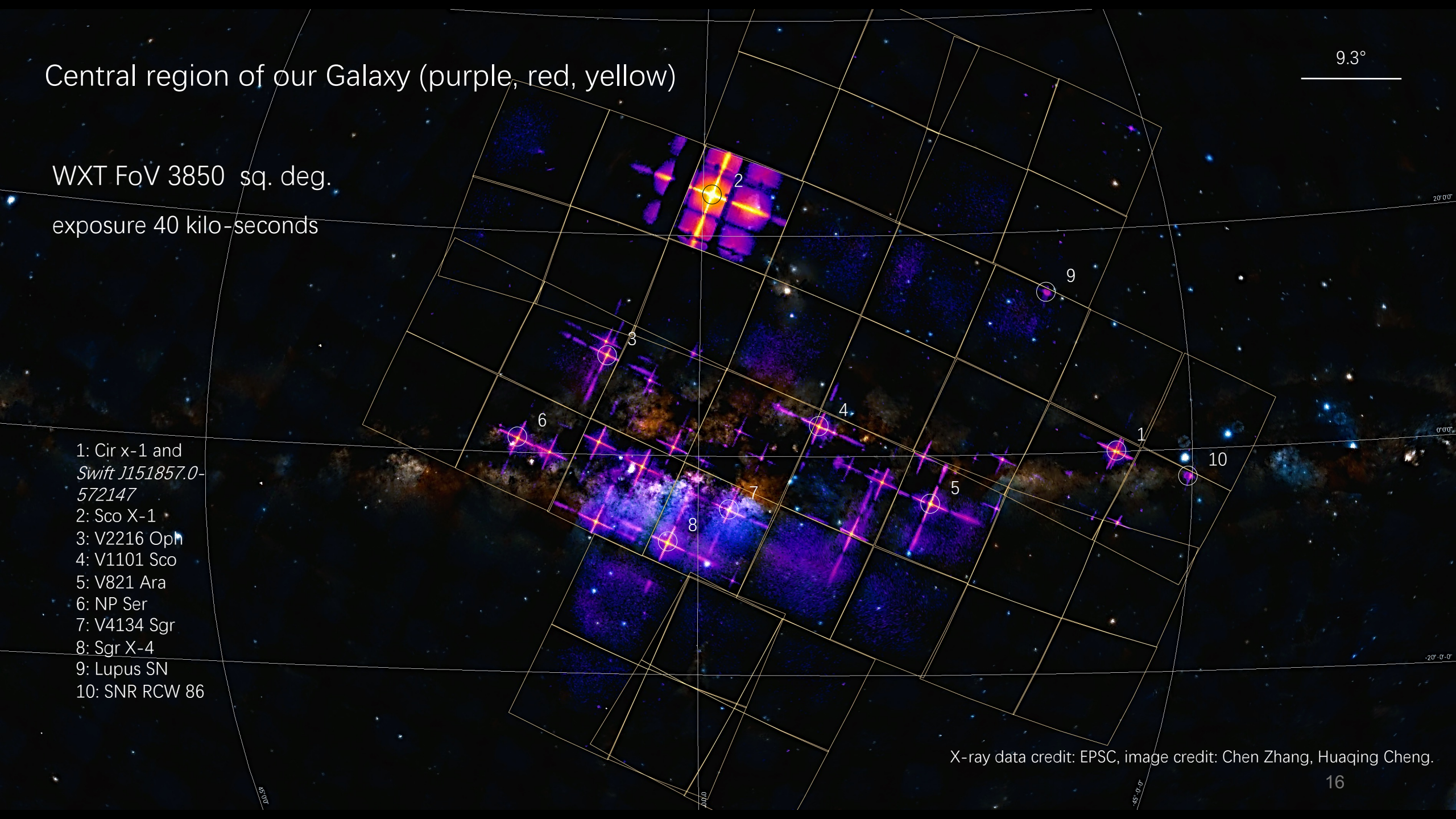


X-ray data credit: EPSC, image credit: Chen Zhang, Huaqing Cheng.

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

WXT FoV 3850 sq. deg.

exposure 40 kilo-seconds



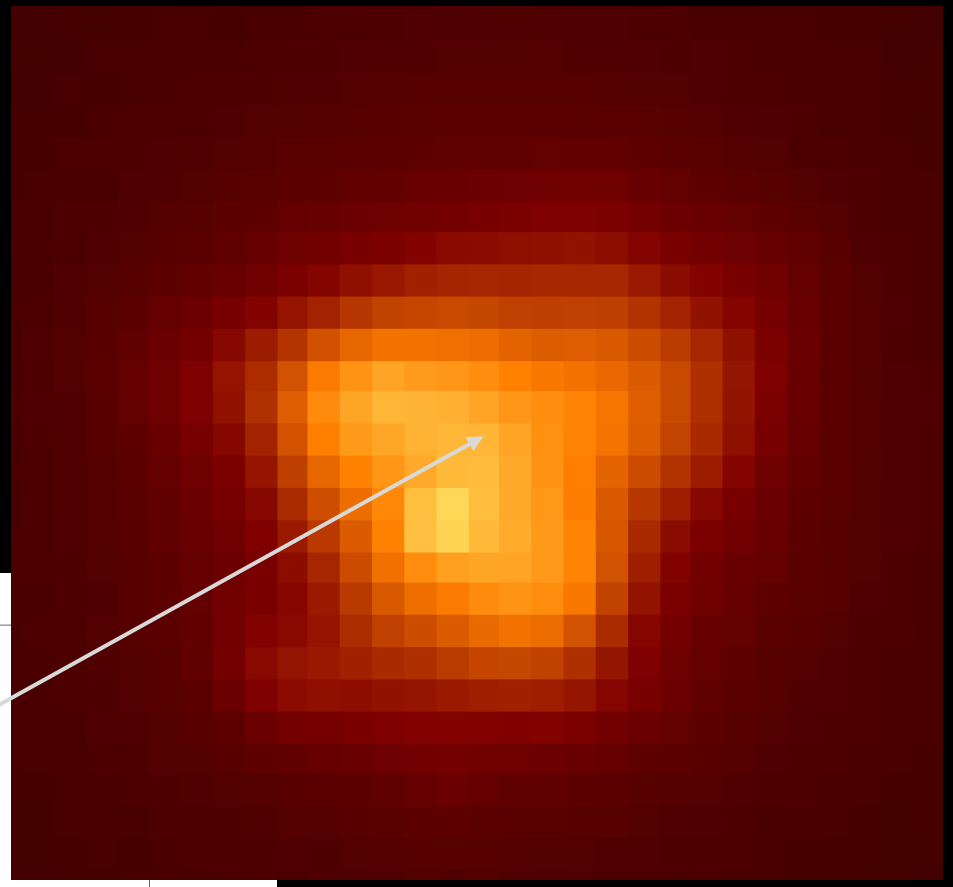
1: Cir x-1 and *Swift J151857.0-572147*
2: Sco X-1
3: V2216 Oph
4: V1101 Sco
5: V821 Ara
6: NP Ser
7: V4134 Sgr
8: Sgr X-4
9: Lupus SN
10: SNR RCW 86

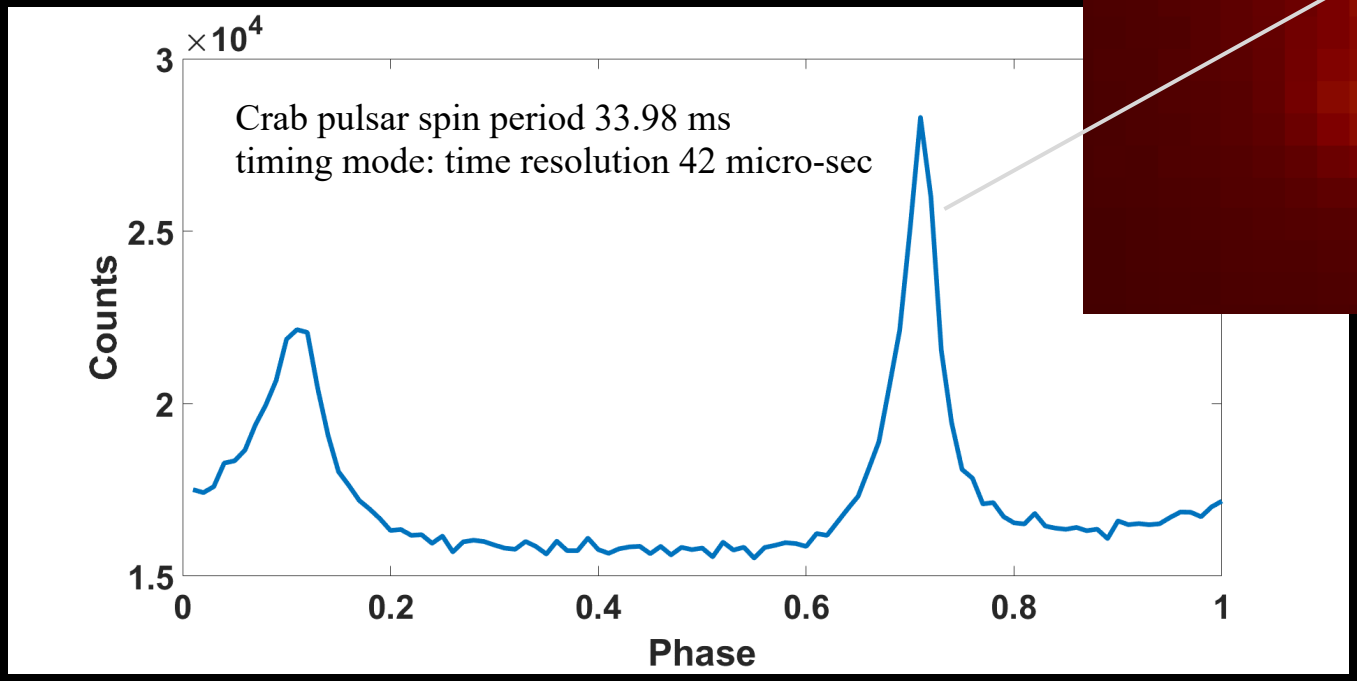
X-ray data credit: EPSC, image credit: Chen Zhang, Huaqing Cheng.

FXT X-ray First light

Crab nebula supernova remnant

Band 0.3-10 keV
Exposure 2600s

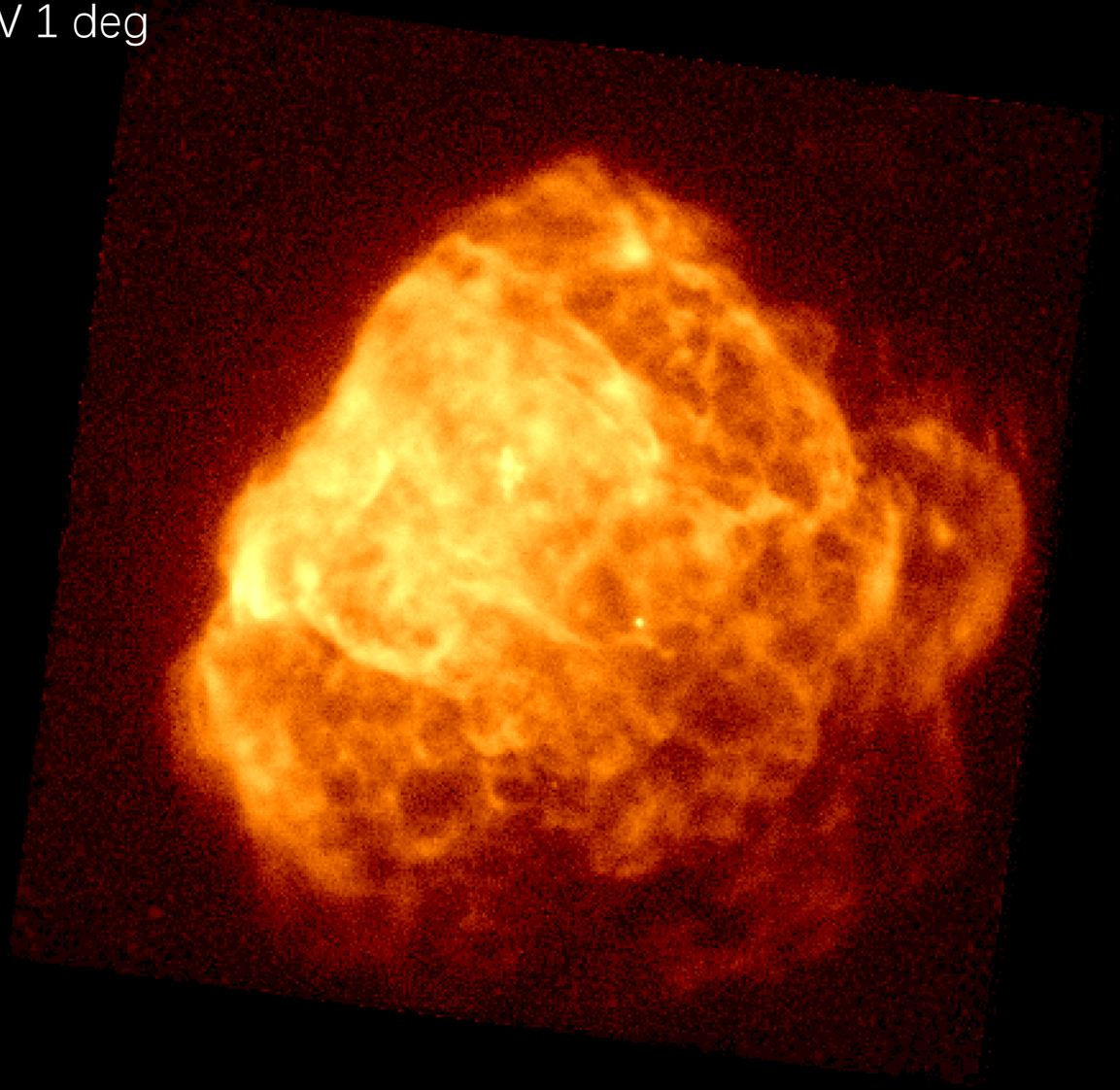




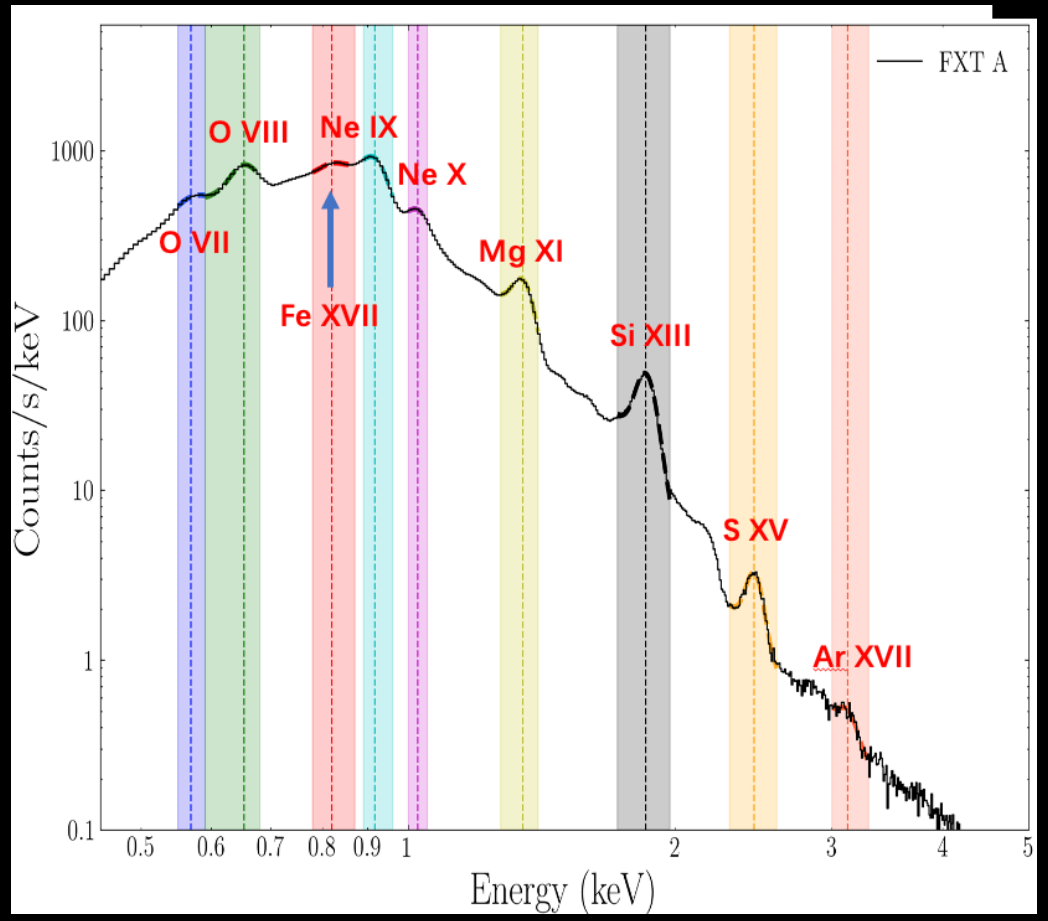
FXT X-ray First light (0.3-10 keV)

Puppis A supernova remnant (nebula)

FoV 1 deg



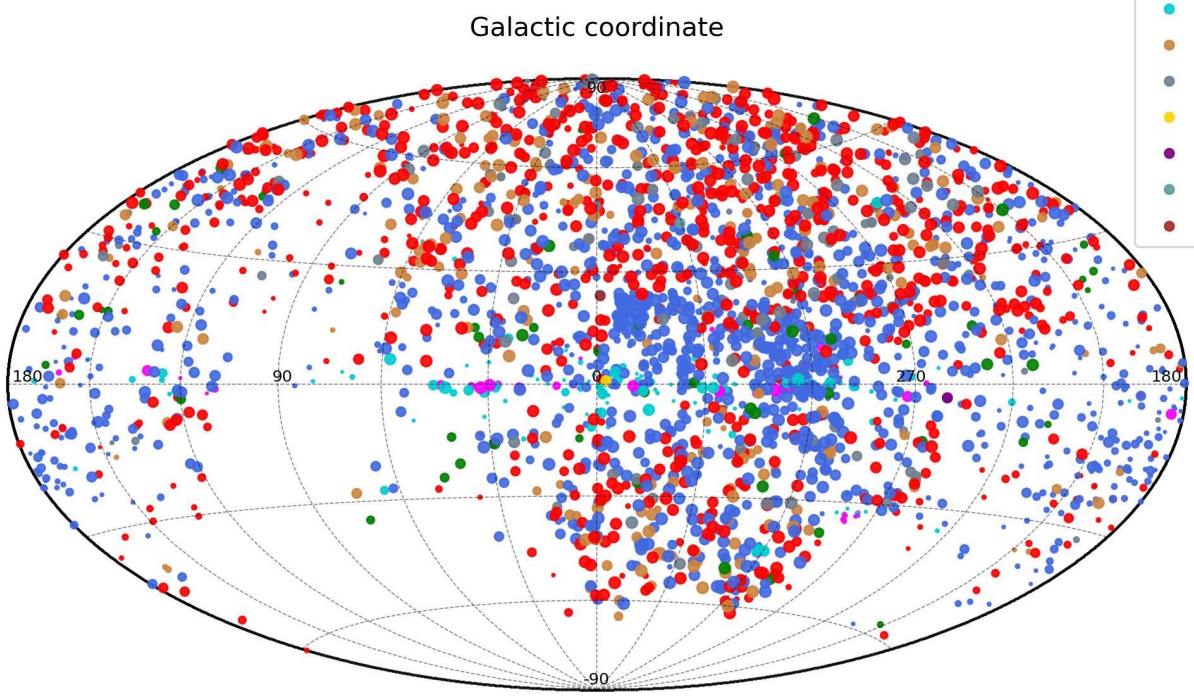
FXT X-ray spectrum obtained at the same time

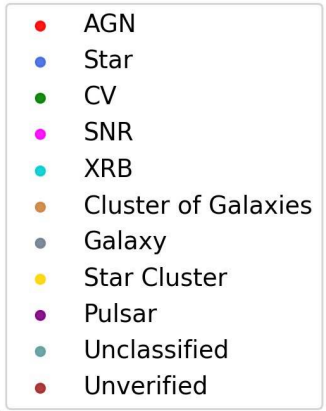


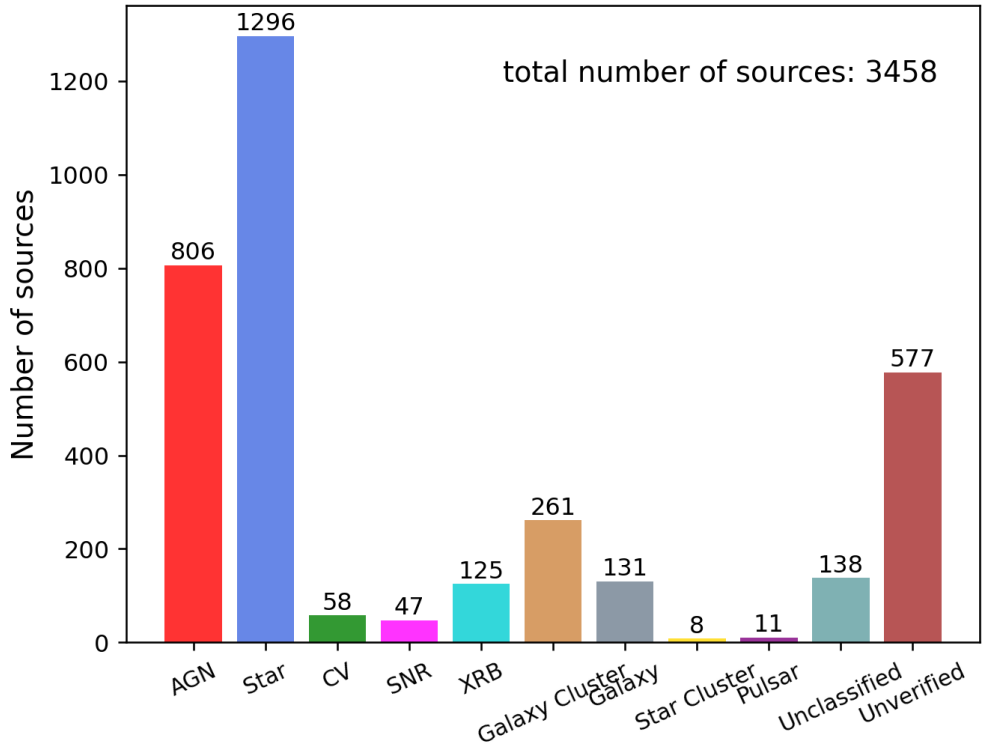
Statistics on X-ray sources detected with EP-WXT

total number of sources: 3458

as of last week





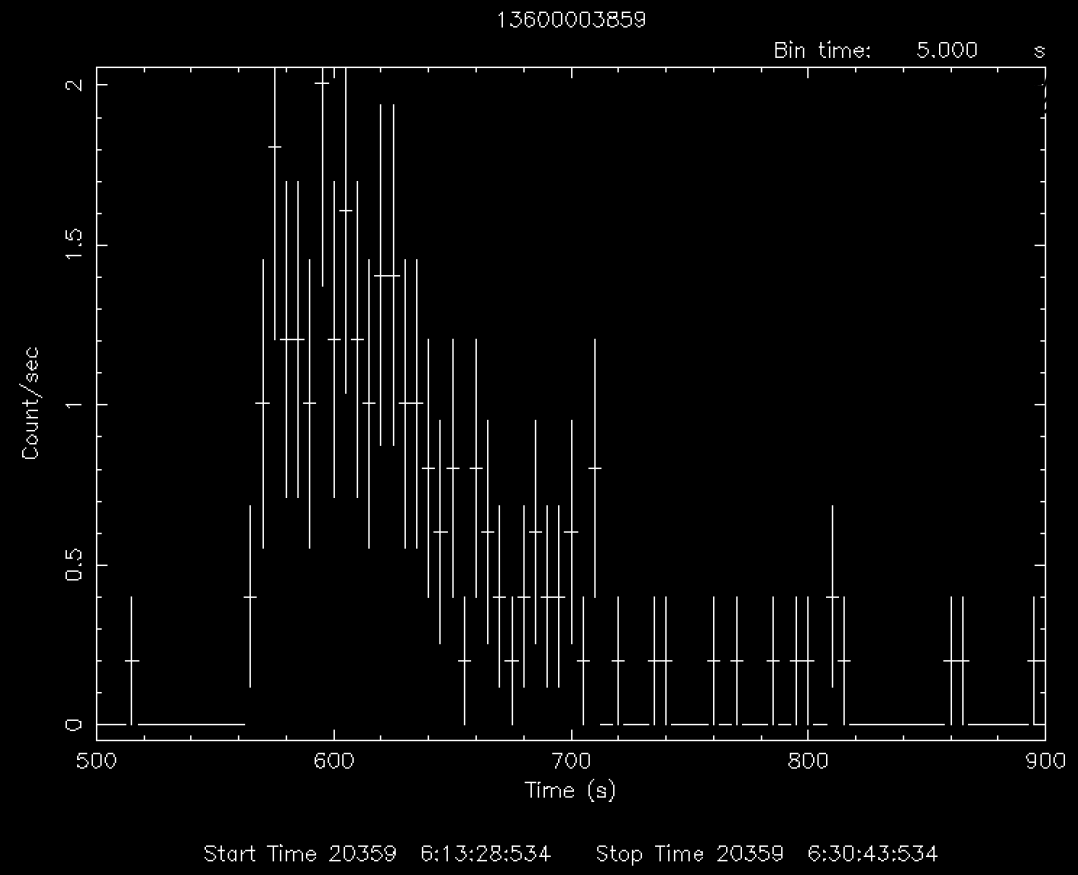


- known sources: 3458
- Transients： > 20 high S/N (> 100 low S/N)

EP240219a

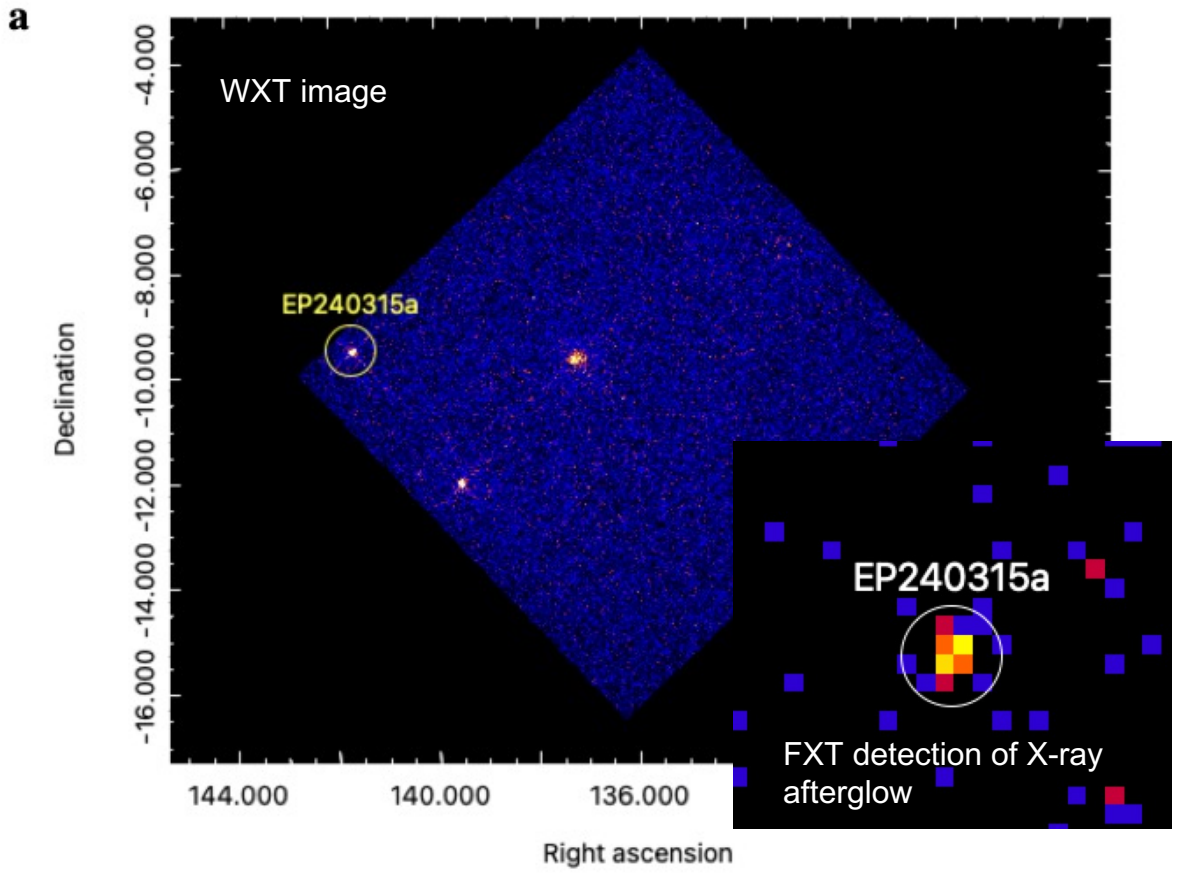
The first X-ray transient discovered by WXT on Feb 19, 2024, alert released on Astronomer's Telegram

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

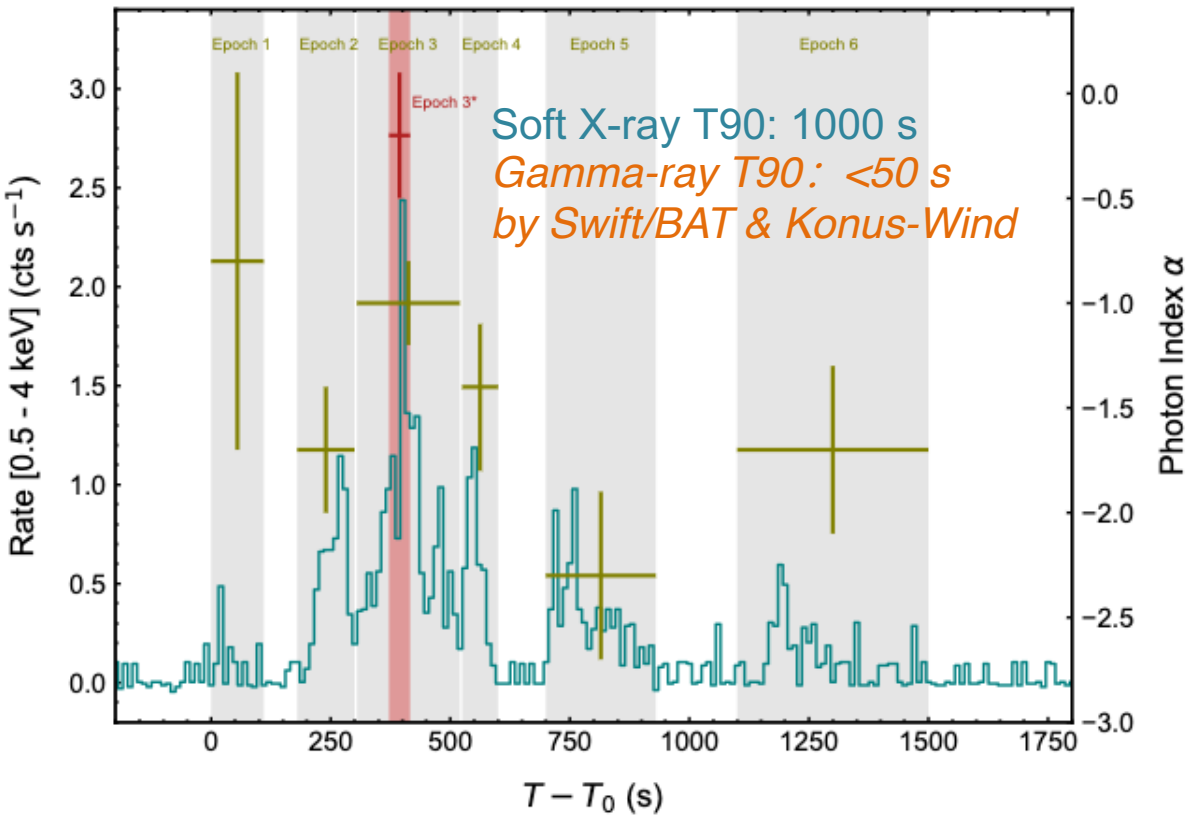


9.3° by 9.3 °, 1 time-frame = 33.3 sec

EP240315a: GRB @redshift 4.859



Onboard trigger, confirmed by on-ground analysis



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

Gillanders J.H., et al. arXiv:2404.10660 (ATLAS optical/radio counterpart, z)
Levan A., et al. arXiv.2404.16350 (Stargate optical pho. and spec., z)
Liu Y., et al. arXiv:2404.16425 (jointly with Swift, Konus-Wind, Stargate teams)

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

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

EP240414a: the quickest follow-ups

WXT onboard trigger (VHF/BD)
(Lian et al. GCN 36091)

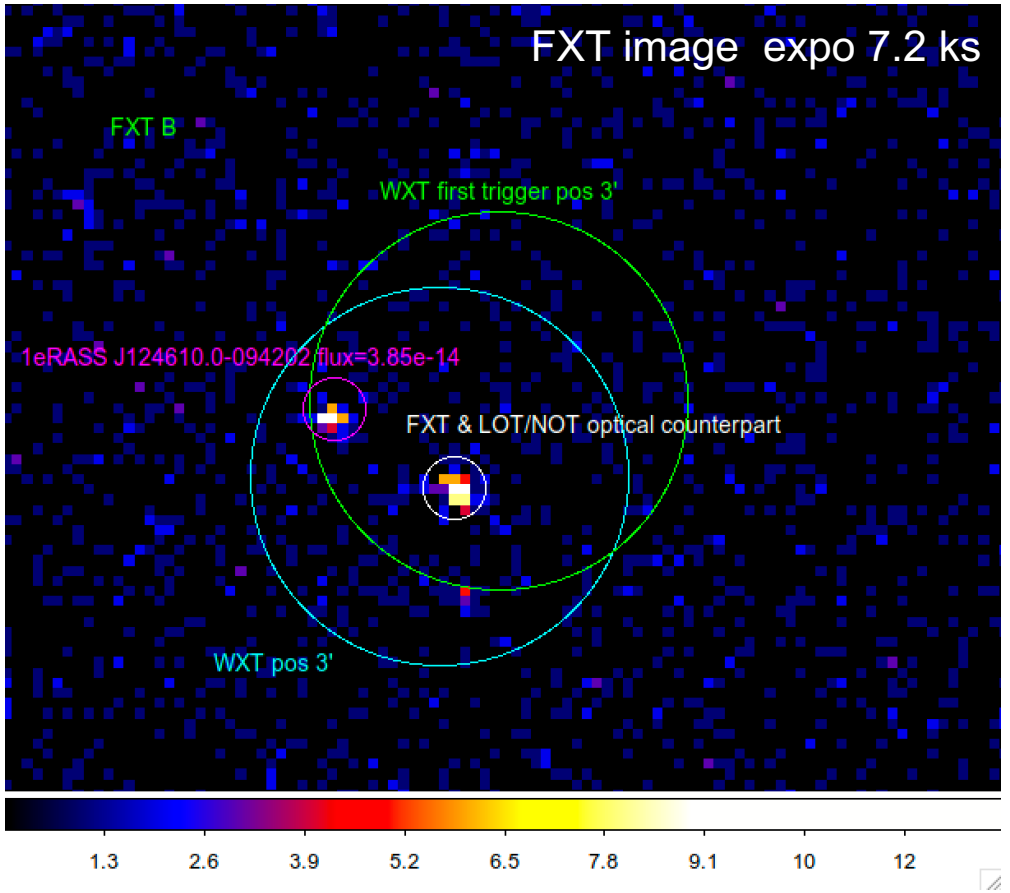
T0+ 2hrs: FXT follow-up (uplink ToO)

- 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

Onboard trigger for FXT automated follow-up

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- transient info downlink within minutes (BD & VHF)
- triggered FXT obs @ UTC 16:11:44
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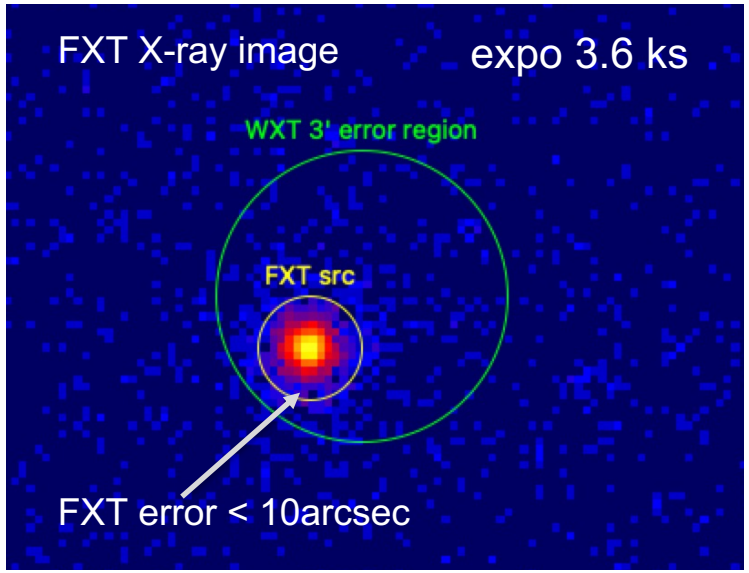

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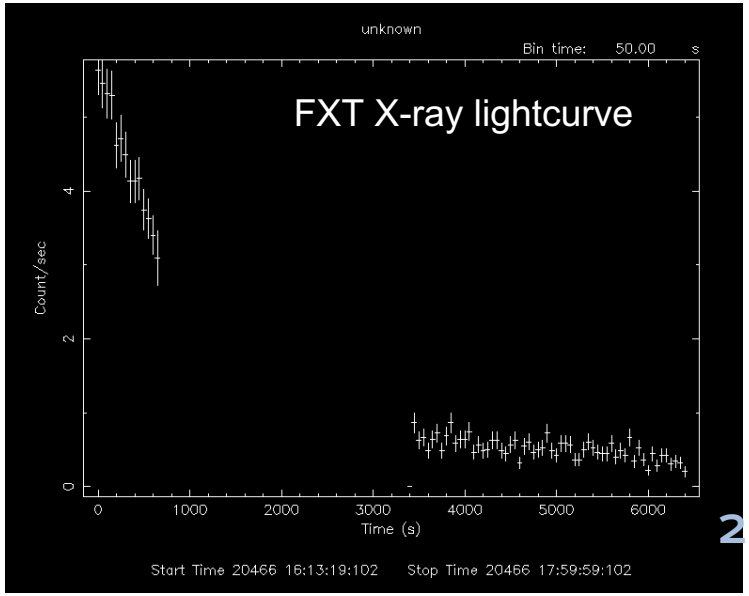
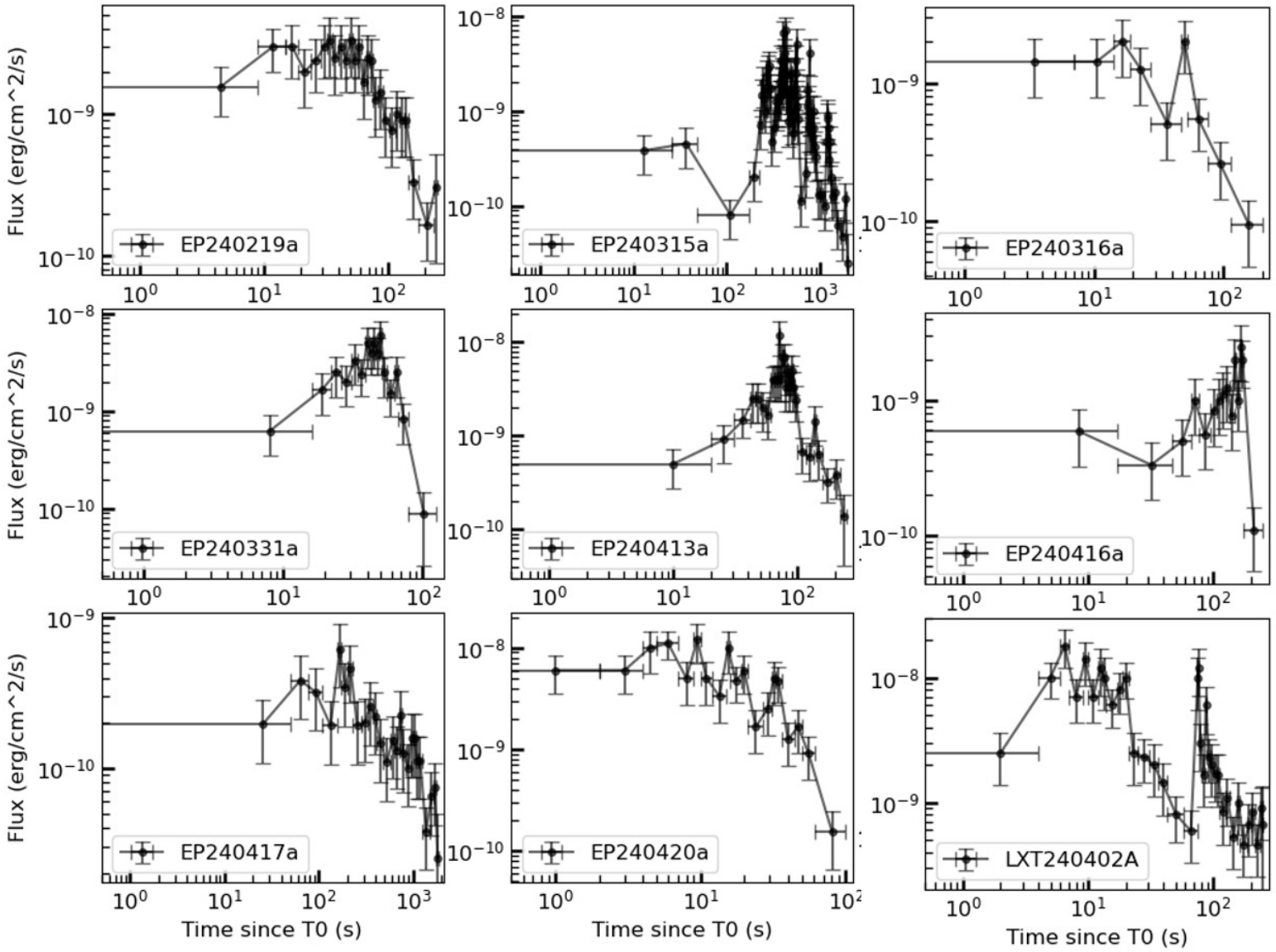


GRBs(4)/Fast X-ray transients (10) by EP & LEIA

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



Perspectives on GRB research

About 2/3 of the EP fast transients have no significant gamma-ray counterparts

- detecting GRB in soft X-ray: follow on the legacy of Beppo-SAX and HETE-2
- previously scarcely detected population, X-ray flash, X-ray rich GRB, ….

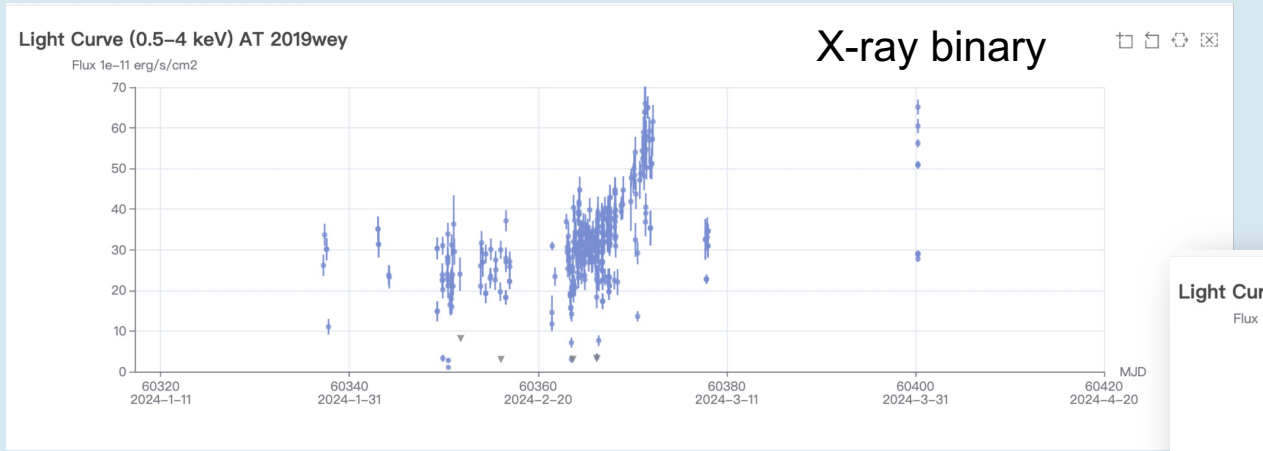
Soft X-ray prompt emission (possible new insight into GRB central engine activity)

- more extended (longer T90)
- complicated structure, multiple peaks

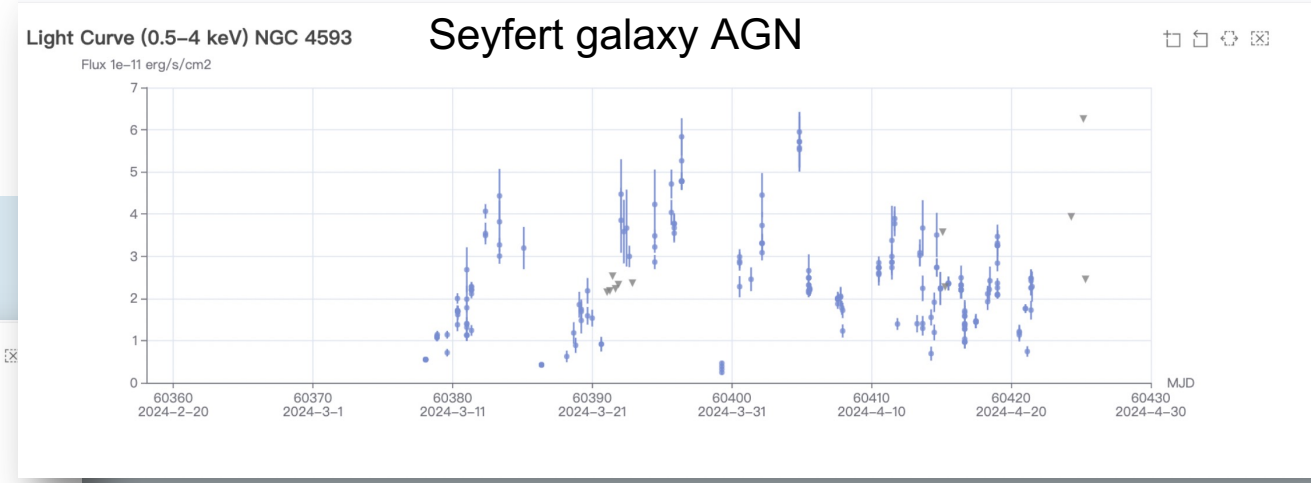
EP240315a: demonstrating the potential in detecting high-z GRB

- faint flux end of known high-z GRB, detectable at z~7.5 (Liu Y. et al. 2024, Levan et al. 2024, Gillanders et al. 2024)

Monitoring of known X-ray sources



X-ray binary



Seyfert galaxy AGN

blazar

Observation modes

Circular orbit

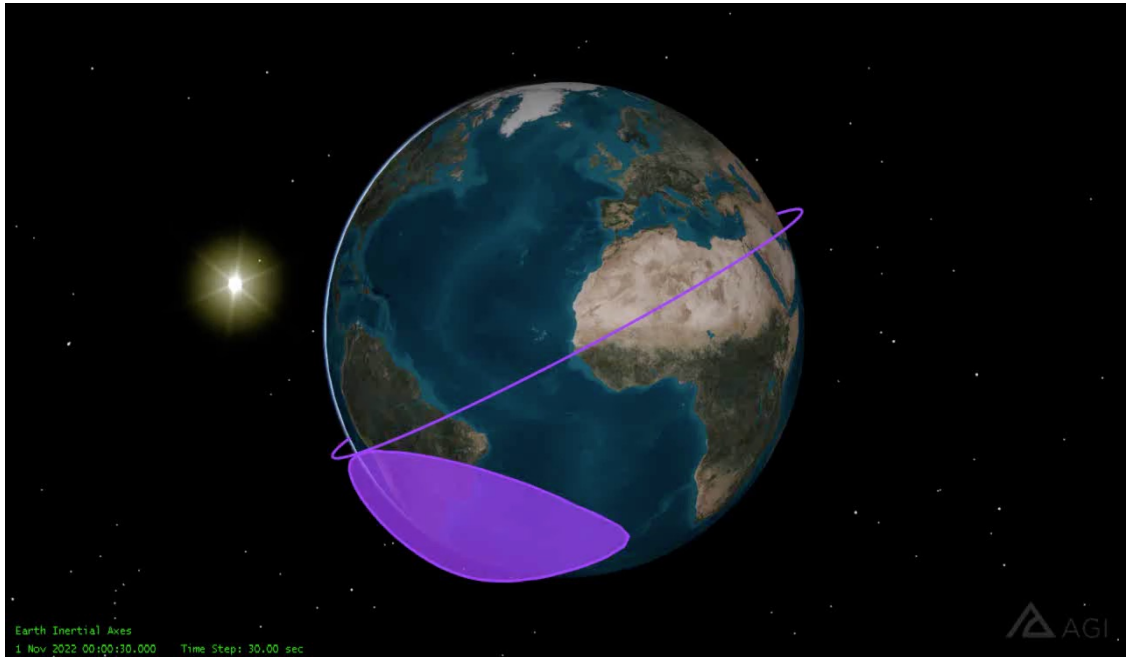
- Height 592km, period 96min
- inclination angle 29 deg.

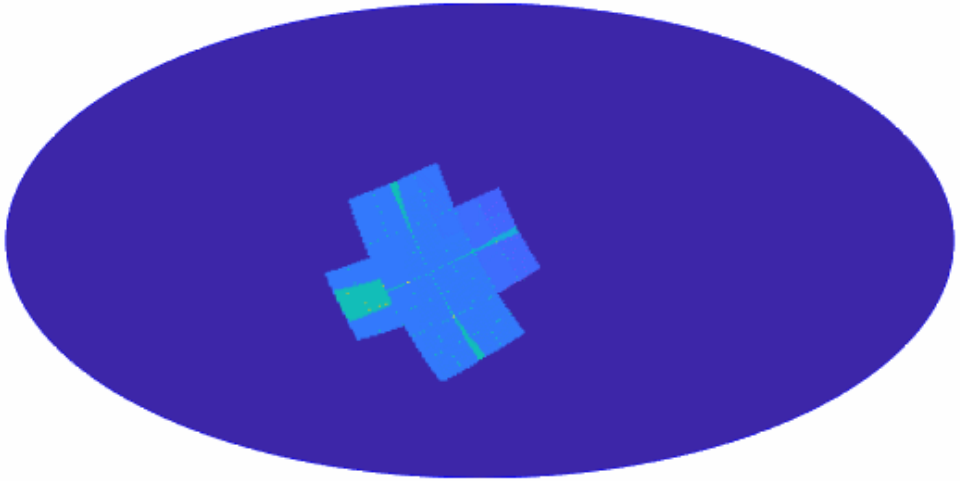
Observation modes

- Survey (primary WXT)
- Autonomous follow-up (FXT)
- ToO (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





Conclusion

EP in commissioning tests and calibration since launch on January 9

Most in-orbit performance verifications completed

Spacecraft & instruments working as expected

Some anomalies/challenges yet to be resolved or improved

> dozen fast X-ray transients (>100 faint ones) and other transients detected

Science operations expected to start in July, performance yet to be improved

Synergy with SVOM would maximise the scientific results of the two missions

Thanks to CNES and the SVOM team for joining the EP mission!
Look forward to synergy and collaboration between SVOM and EP!