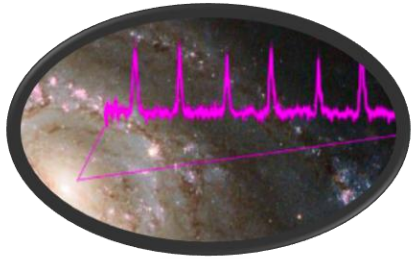
天关卫星和科学成果介绍

刘元
国家天文台

New high-energy transients & science questions

BH tidal disruption event

Demography of Black holes
How matter falls onto BH?
How jets form?



Quasi-periodic eruption

EMRI as GW sources?

High-redshift GRB

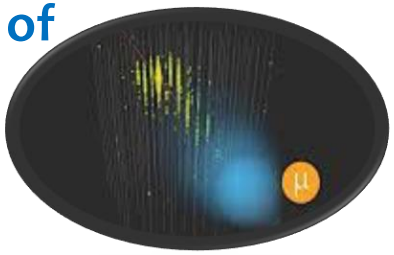
When first stars formed?
metal enrichment in early universe

Next generation X-ray monitors needed to see

- **deeper/further**
- **High cadence**

EM counterpart of neutrino events

How particles Accelerated?



Supernova shock breakout

Supernova physics & progenitors

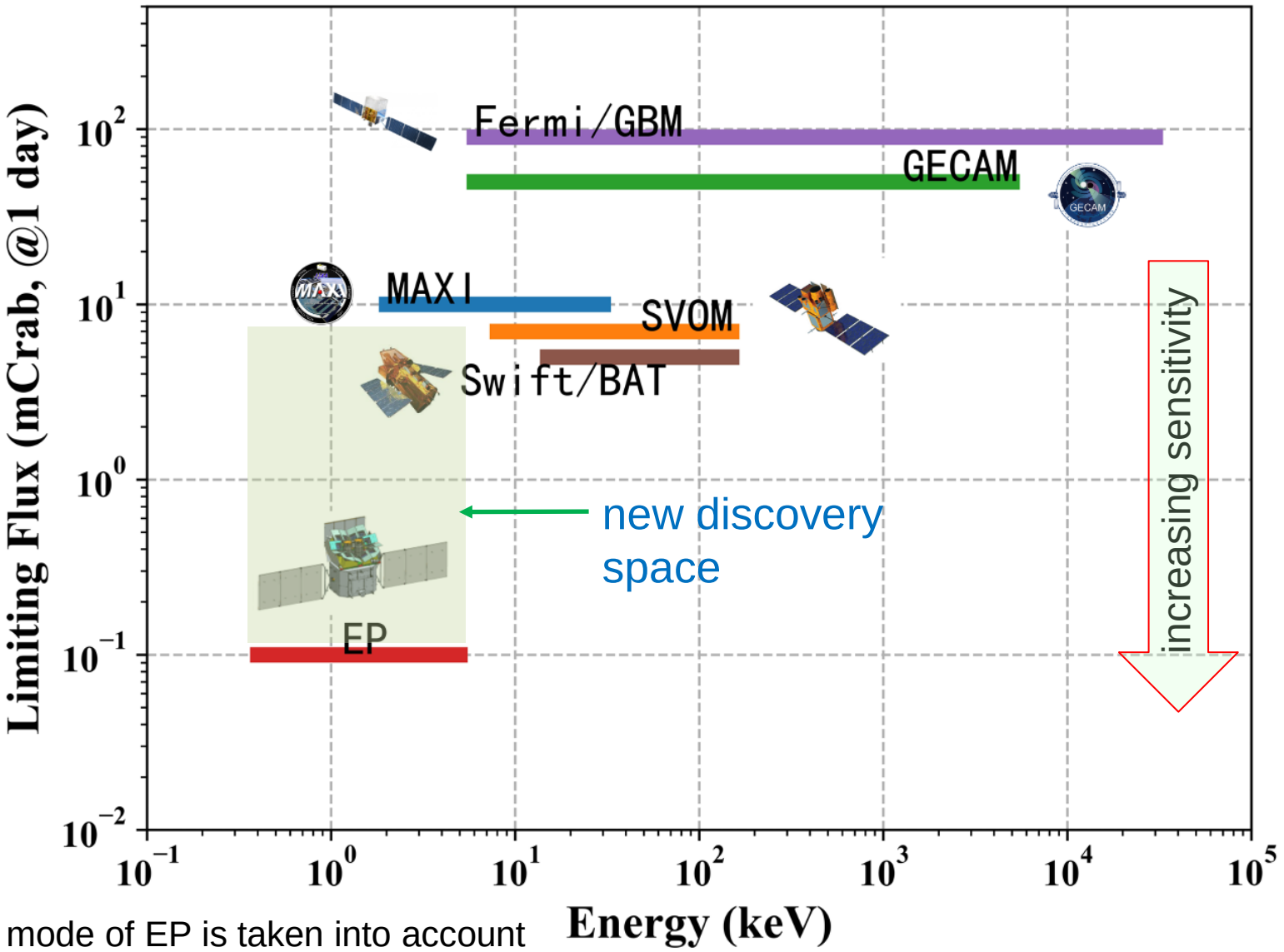
EM counterpart of gravitational waves

What are EM counterparts?
How compact objects merge?

Requirements for next generation X-ray ASM

- Higher sensitivity by 1 order of magnitude than those in orbits
- Large FoV (~ 1 str)
- Soft X-ray (0.5 keV)
- How ?

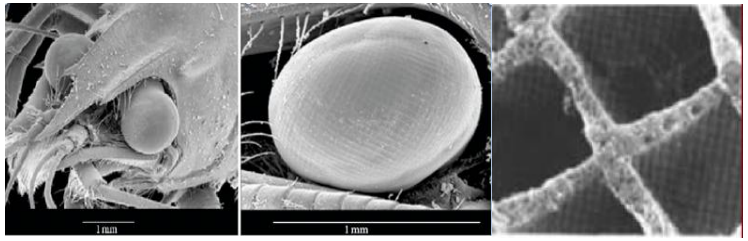
X-ray focusing imaging

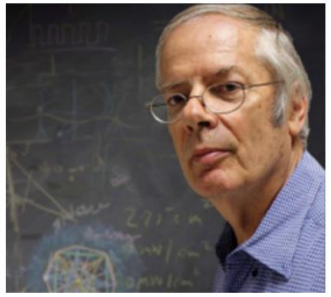


* For 1-day data taking. The sky survey mode of EP is taken into account

Lobster-eye optics for X-ray focusing imaging

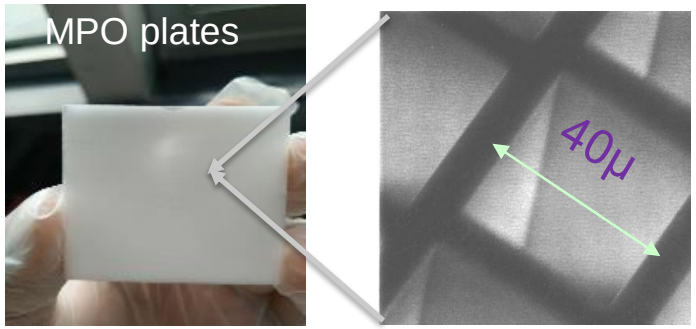
grazing incidence reflection by Lobster-eye Micro-Pore Optics (MPO)

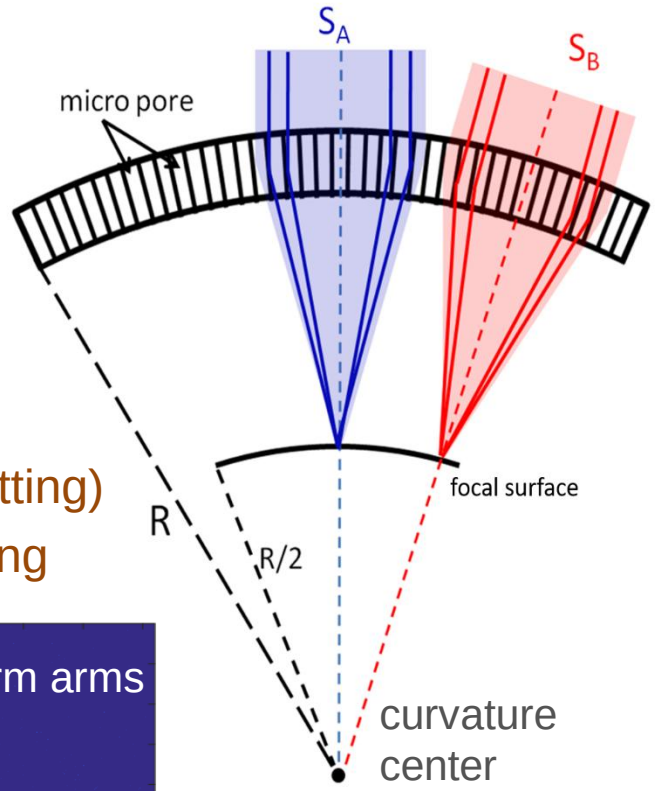




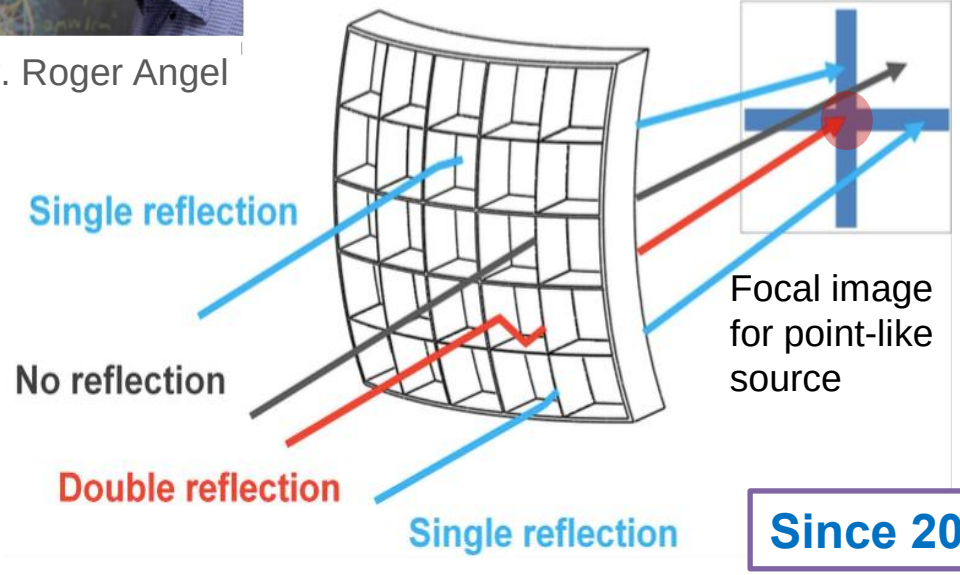
Dr. Roger Angel

image credit:
http://www.as.utexas.edu/lectures/great_lecture_twenty.html

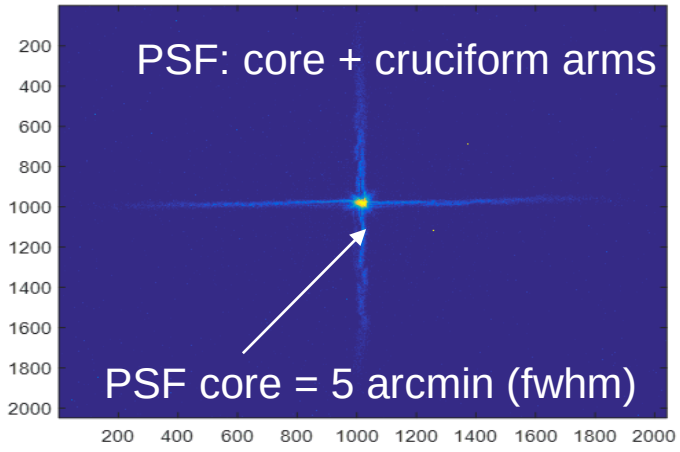




- Wide FoV (no vignetting)
- True focusing imaging



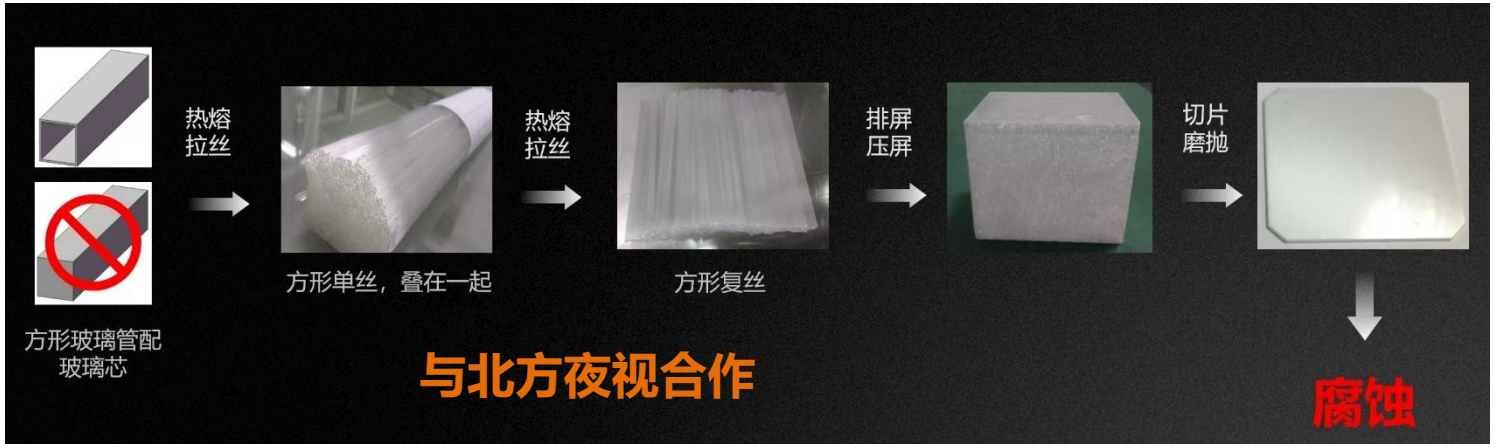
Focal image for point-like source

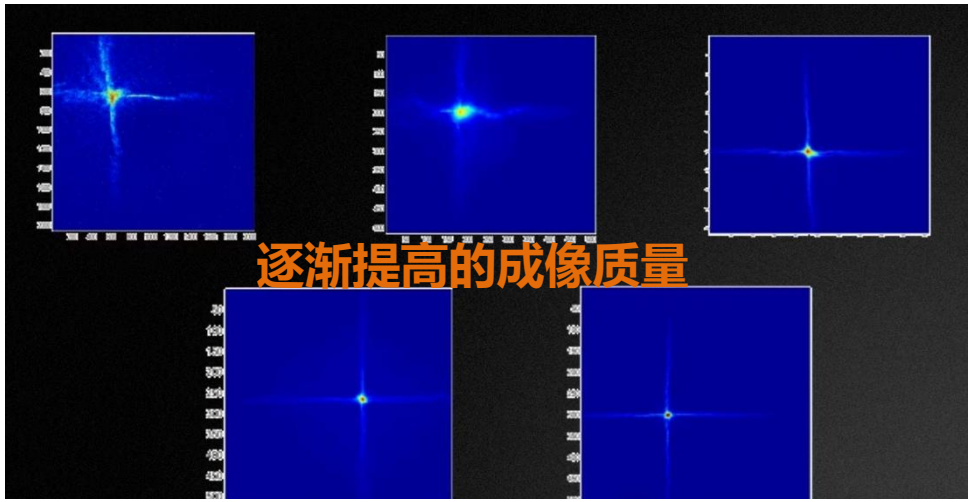


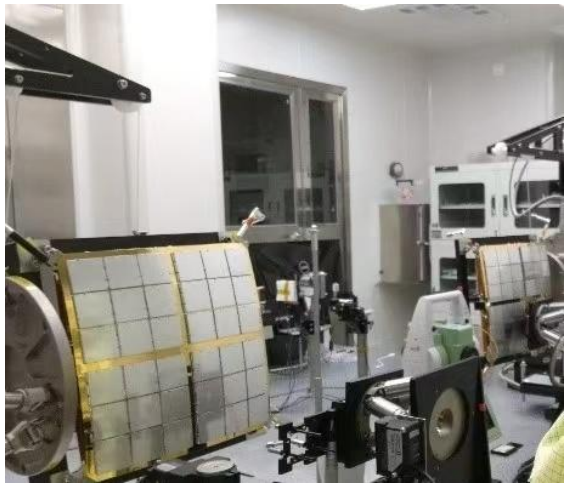
measured X-ray PSF mage @XIL/NAO/CAS

Since 2010, Lobster-eye R&D @ XIL/NAO/CAS (est. by S.-N. Zhang)

自主研发的龙虾眼微孔光学

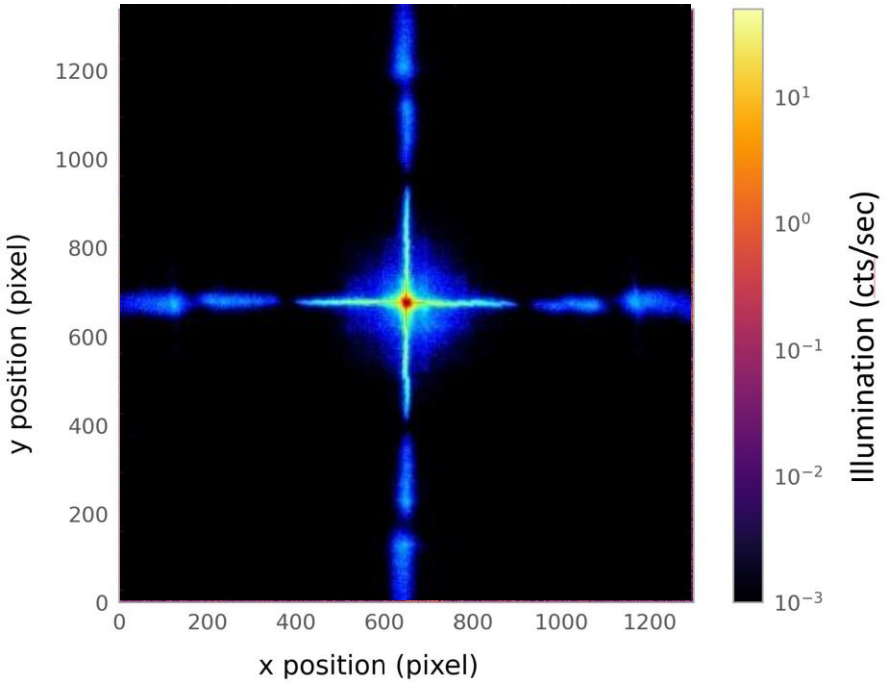






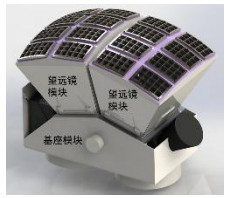
自动化装配

张臣 国家天文台



成像质量领先于国际同类设备

Brief history of EP 2013.1-2024.1 十一年磨一星



中国空间站 X 射线全天监视器 XASM

2010
X射线成像实验室 XIL
高能天体物理组

2011
XASM
项目论证

2012
XASM
项目建议书

2013.01
提交EP项目建议书，并入选背景型号

2015
EP通过遴选，成为中科院先导重点支持项目之一

2018
ESA、MPE加入

2022.07
LEIA 发射

2020.07
EP卫星系统进入初样研制

2023.08
EP卫星出厂

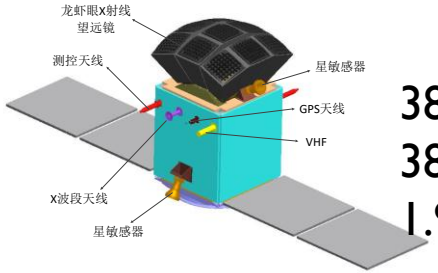
~1400kg
~1400W
> 3米

背景型号

工程阶段

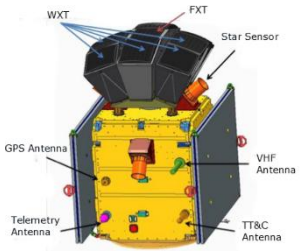
在轨测试定标

2012
提出EP项目



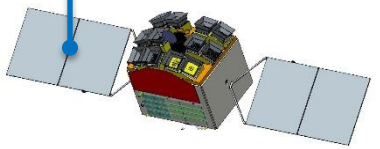
380kg
380W
1.9米

2014-2016
EP背景型号研制



采用
CMOS

2017.12
EP卫星正式通过工程立项



单 FXT 设计

2022.03
EP卫星系统进入正样研制

2022
cnes 加入

2024.1.9
发射

2024.7.10
科学运行

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)

Spacecraft

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

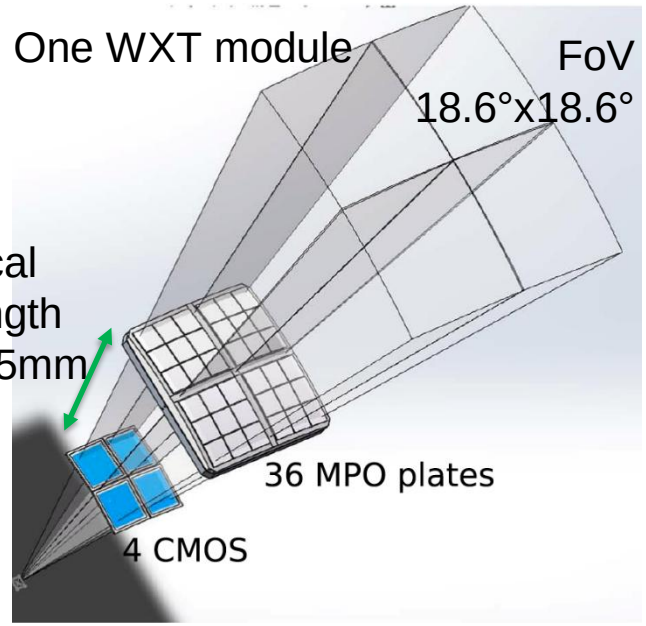
Telemetry

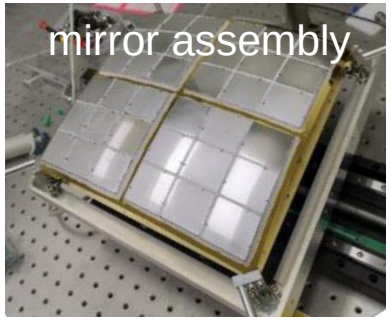
X/S-band (several hours)
BD (down/up-link; minutes)
VHF (down-link; minutes)

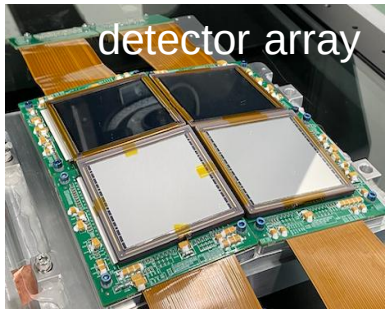
Yuan, et al. 2022 *Handbook of X-ray and Gamma-ray Astrophysics*

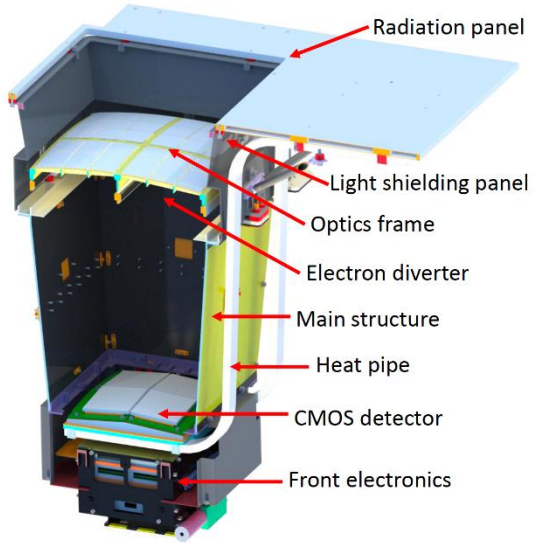
Wide-field X-ray Telescope (WXT)

Lobster-eye imaging system

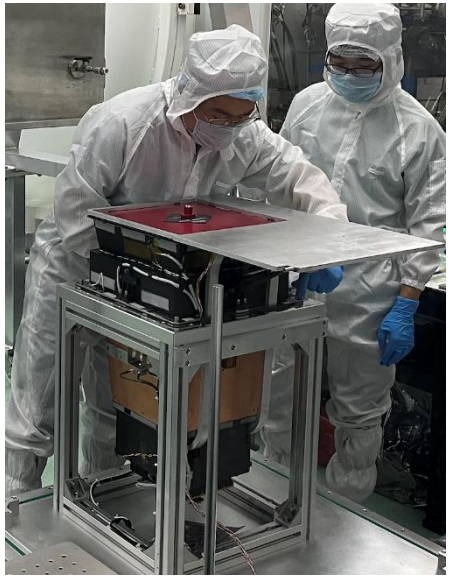








BI CMOS
6cm x 6cm
Time resolution 50ms
ΔE~122eV @1.25keV



Zhang et al. 2022 ApJL, 941, L2

EP-WXT in total

- **432 MPO plates**
- **48 CMOS (1728 cm^2)**

The largest focal detector array for X-ray focusing imaging telescopes

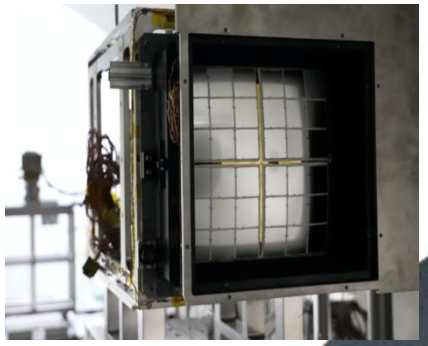
WXT chief designer
Xiaojin Sun
(SITP/CAS)

Lead of LE mirrors
Chen Zhang
(NAO/CAS)

Instrument scientist
Zhxing Ling
(NAO/CAS)

MA engineer
Yanfeng Dai (NAO/CAS)

EP pathfinder LEIA (Lobster Eye Imager for Astronomy)

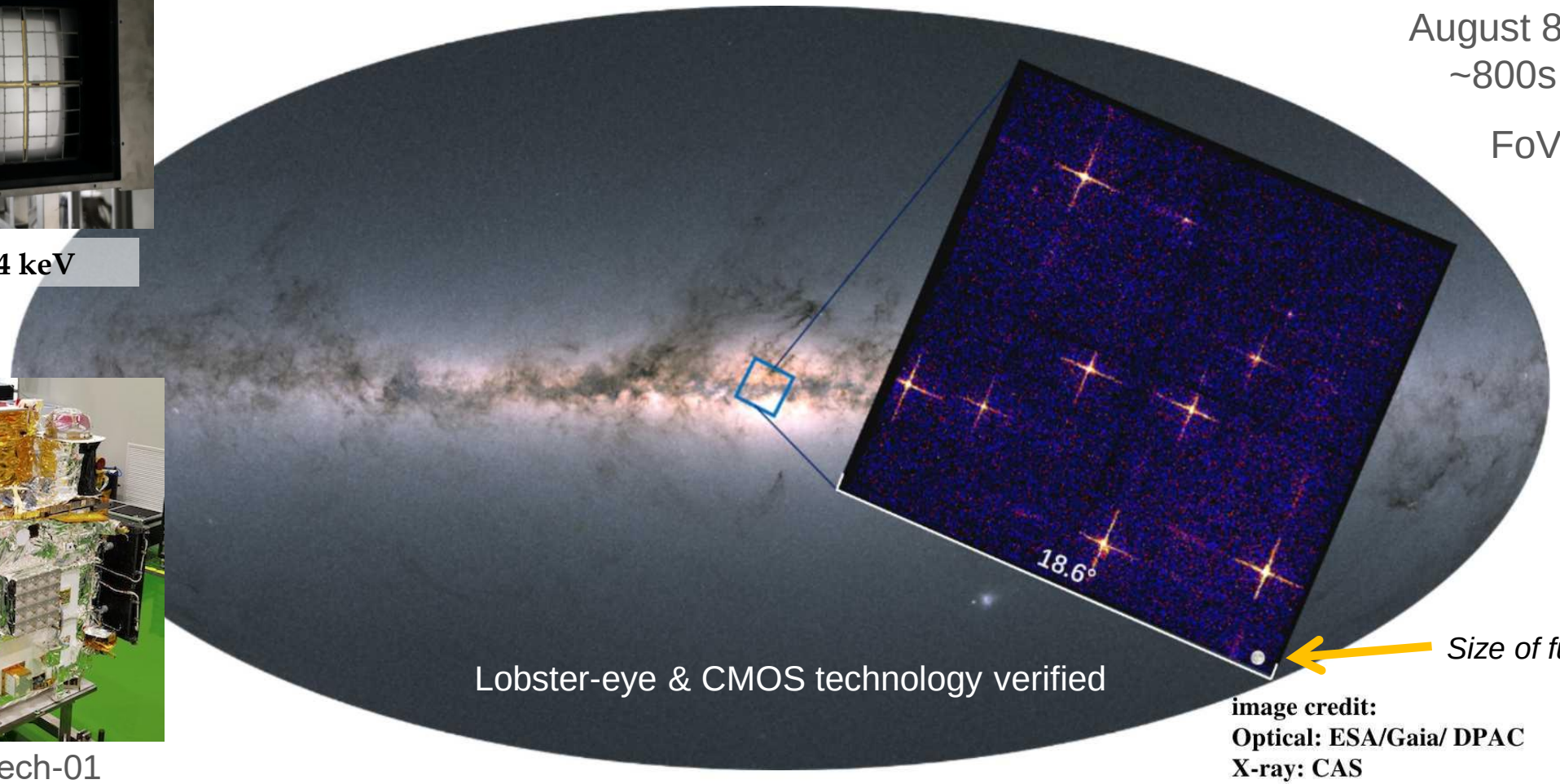


LEIA 0.5 – 4 keV

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

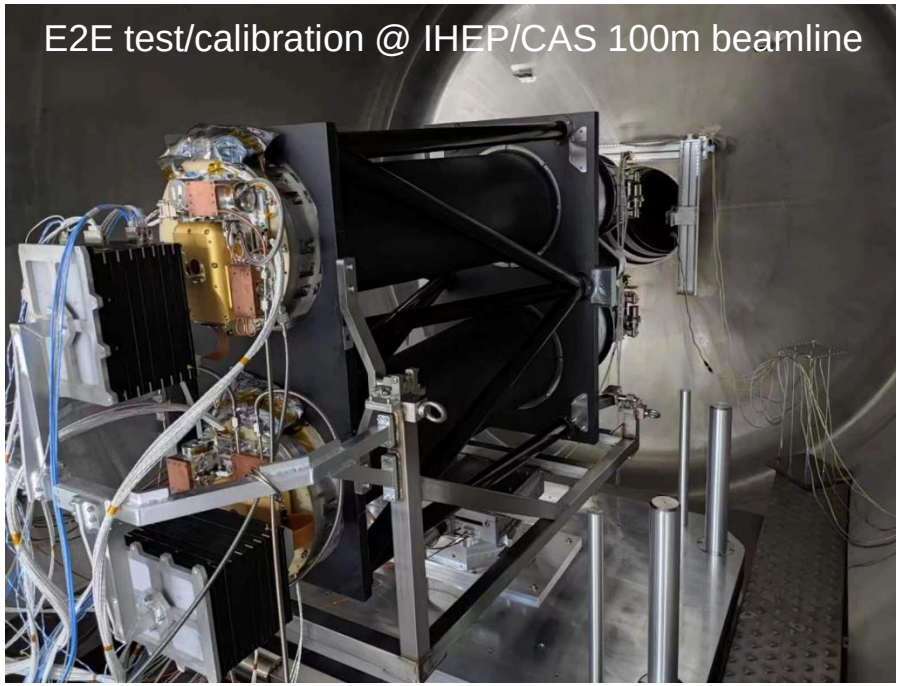


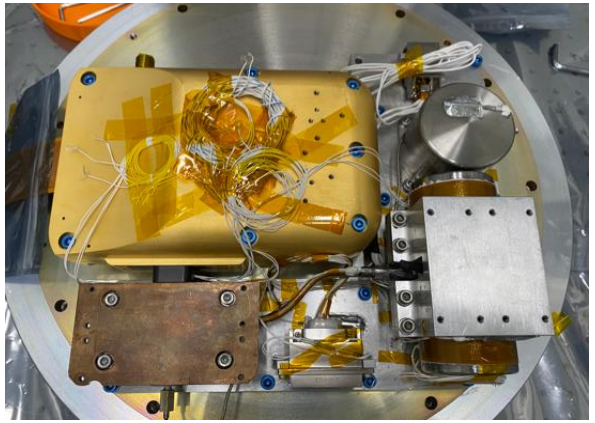
Frist wide FoV X-ray observations by a lobster-eye focusing X-ray telescope in orbit
Zhang et al. 2022 ApJL, 941, L2

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.





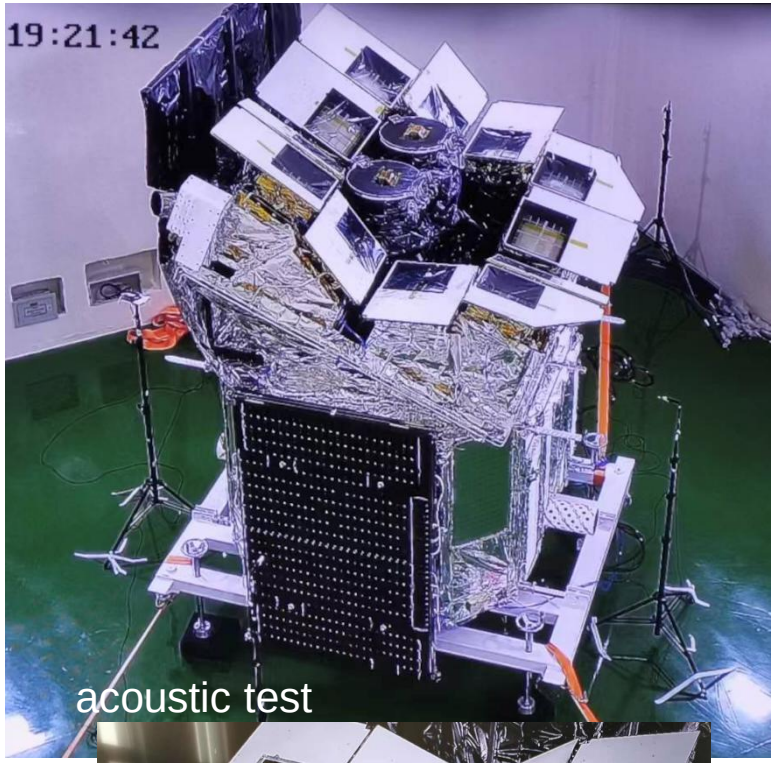
X-ray camera built @ IHEP/CAS

PI: Yong Chen (IHEP/CAS)

Camera lead: Weiwei Cui (IHEP/CAS)

FXT delivered by IHEP team to MicroSAT on May 26

EP satellite



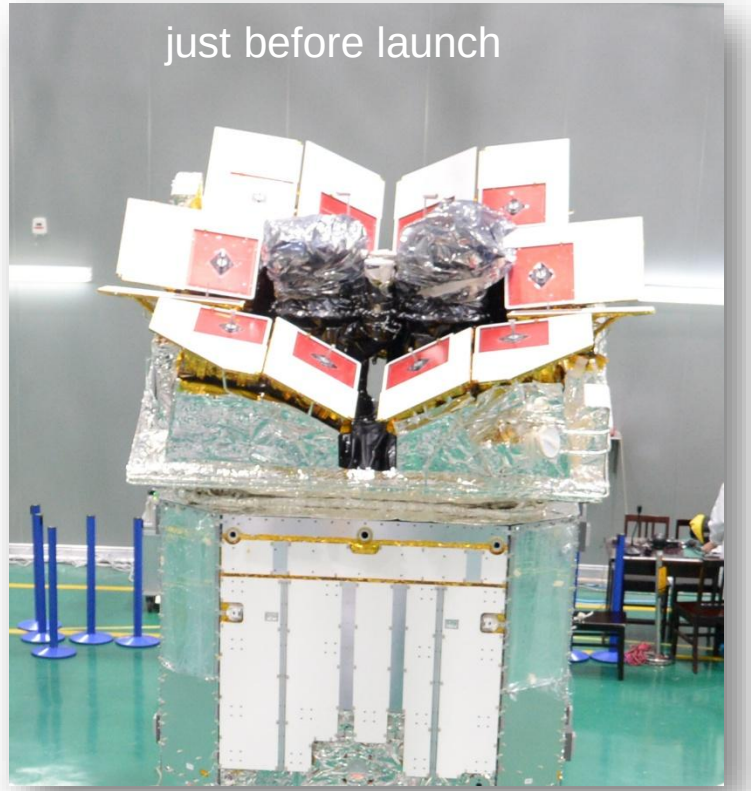
acoustic test


thermal vacuum tests

S/C developed @ MicroSat/CAS, Integration & tests

Satellite weight	1430 kg
Power	1150 W
Dimension	3.418(H) × 2.591(D) × 10.309(W) meters


thermal vacuum tests


just before launch

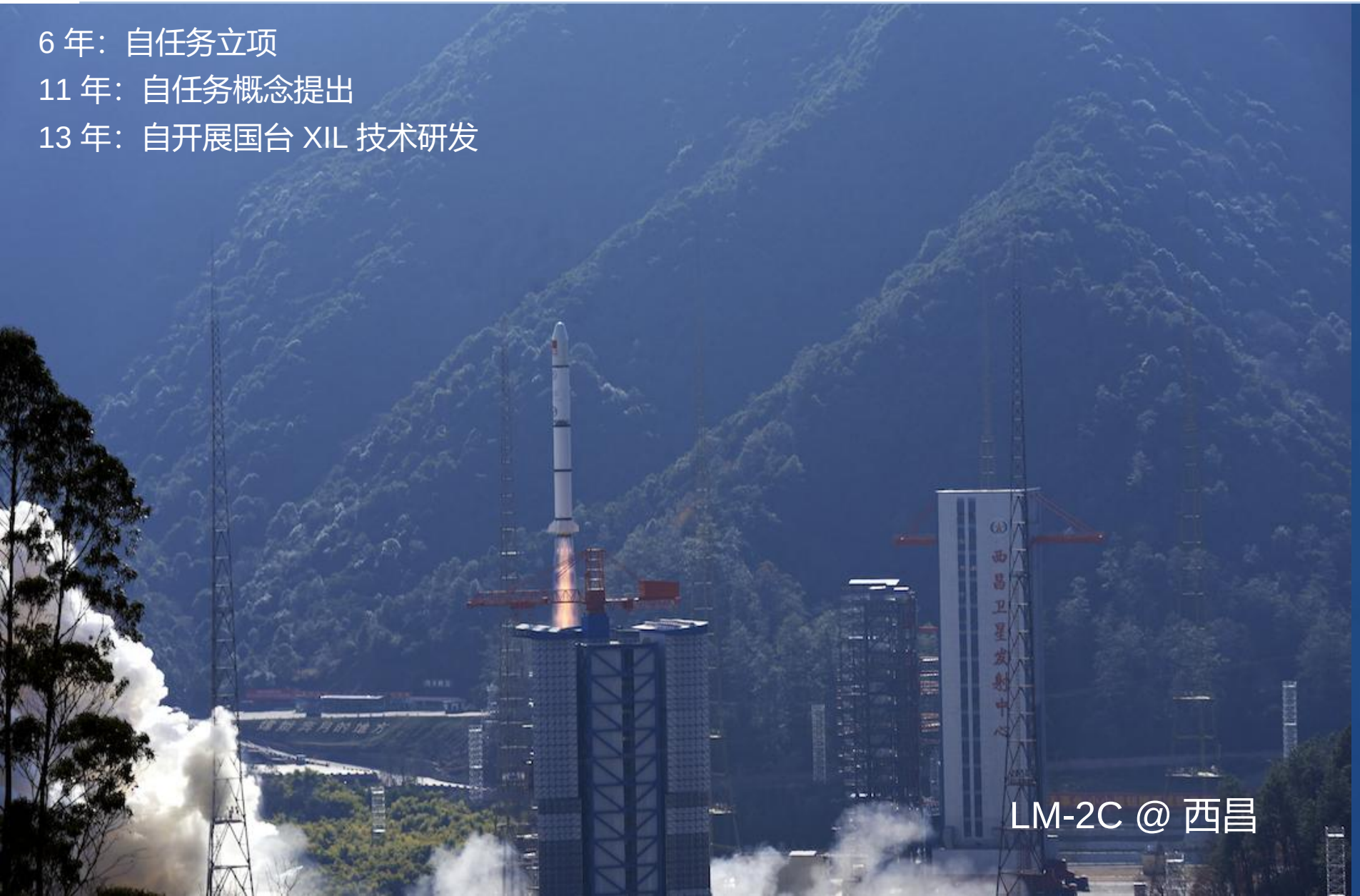
卫星团队

2024-1-9 EP卫星在西昌成功发射

6 年：自任务立项

11 年：自任务概念提出

13 年：自开展国台 XIL 技术研发



LM-2C @ 西昌

龙年大吉


XinhuaVideo

S/C-launcher separation

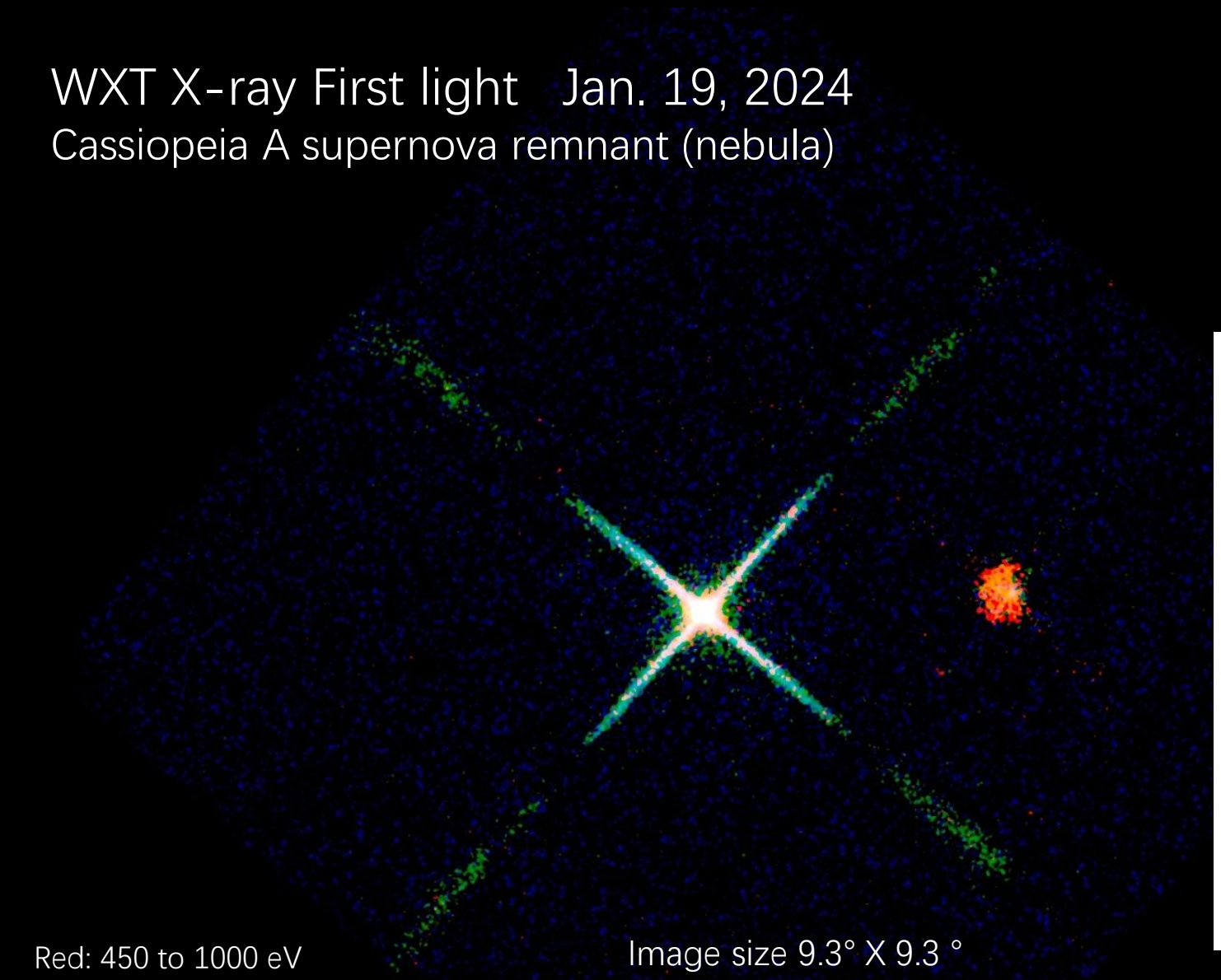
height 592 km

orbital period 96min

inclination angle 29 deg.

WXT X-ray First light Jan. 19, 2024

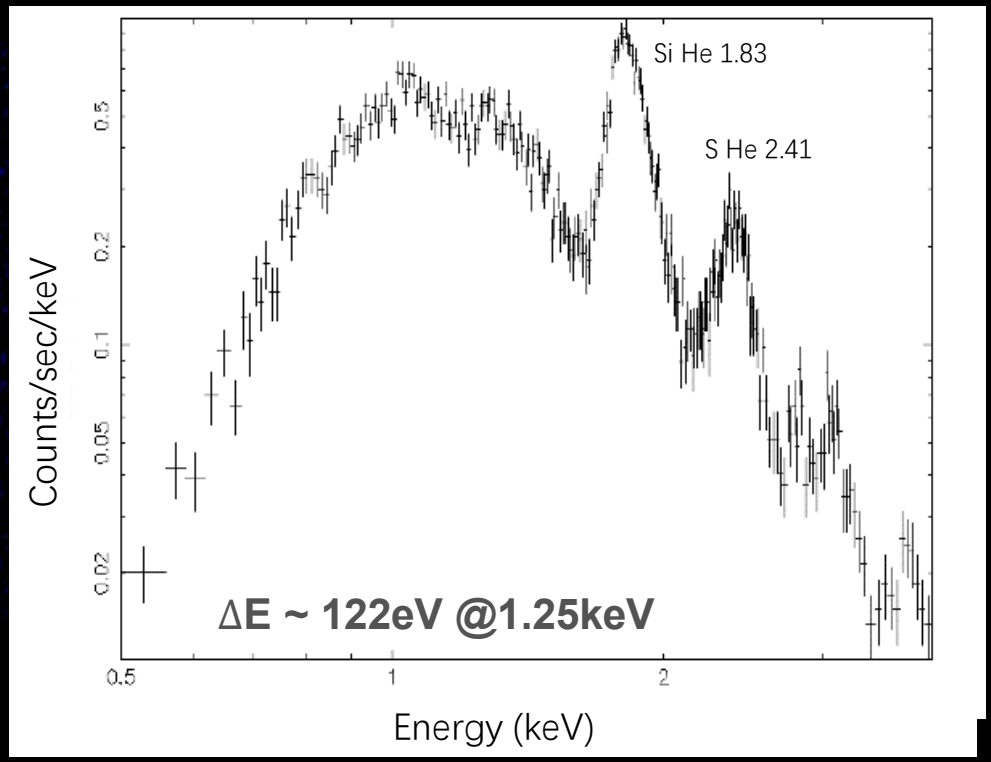
Cassiopeia A supernova remnant (nebula)



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

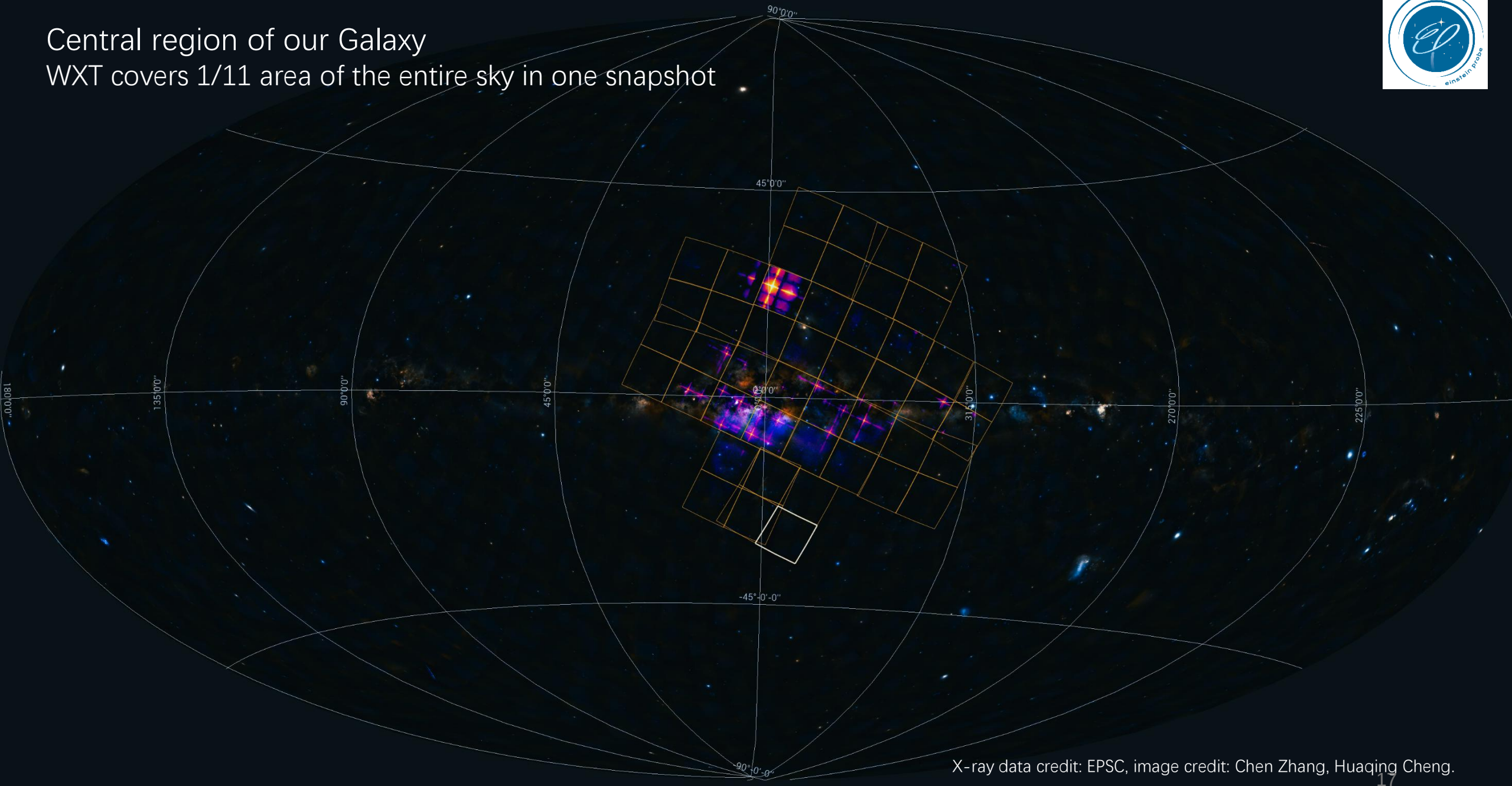
X-ray spectrum obtained at the same time



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

Central region of our Galaxy

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

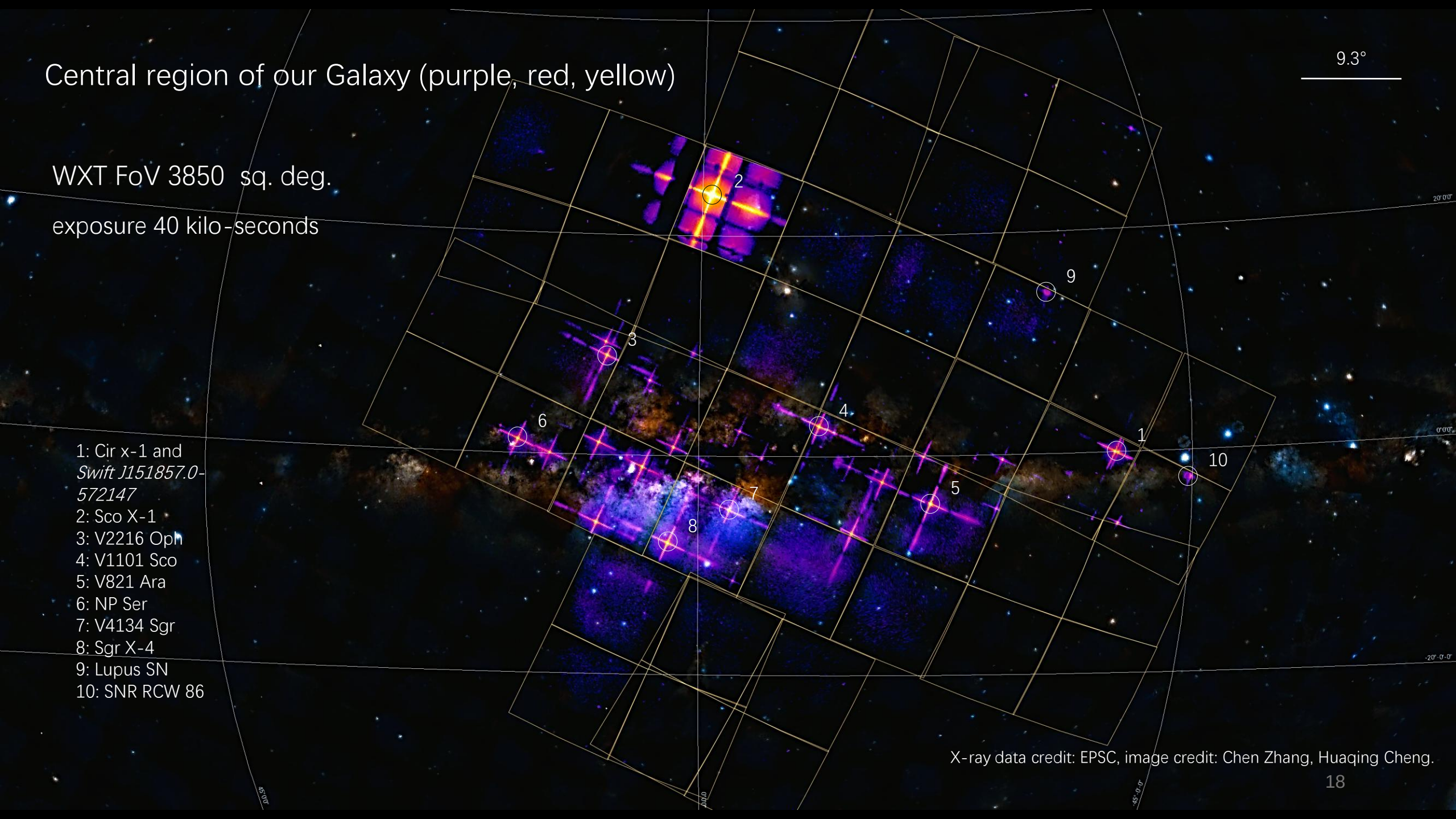


X-ray data credit: EPSC, image credit: Chen Zhang, Huaqing Cheng.

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

WXT FoV 3850 sq. deg.

exposure 40 kilo-seconds



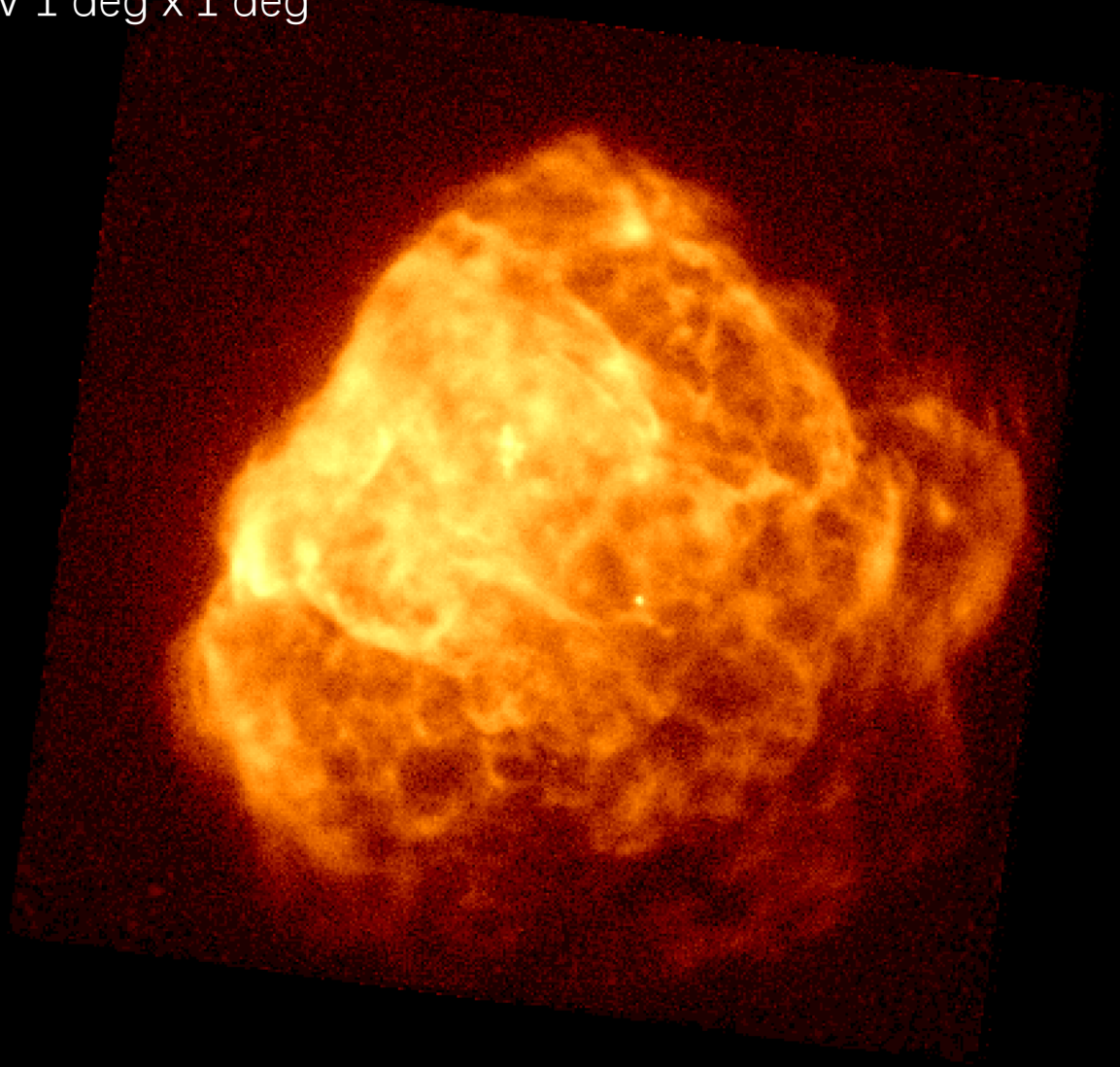
1: Cir x-1 and *Swift J151857.0-572147*
2: Sco X-1
3: V2216 Oph
4: V1101 Sco
5: V821 Ara
6: NP Ser
7: V4134 Sgr
8: Sgr X-4
9: Lupus SN
10: SNR RCW 86

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

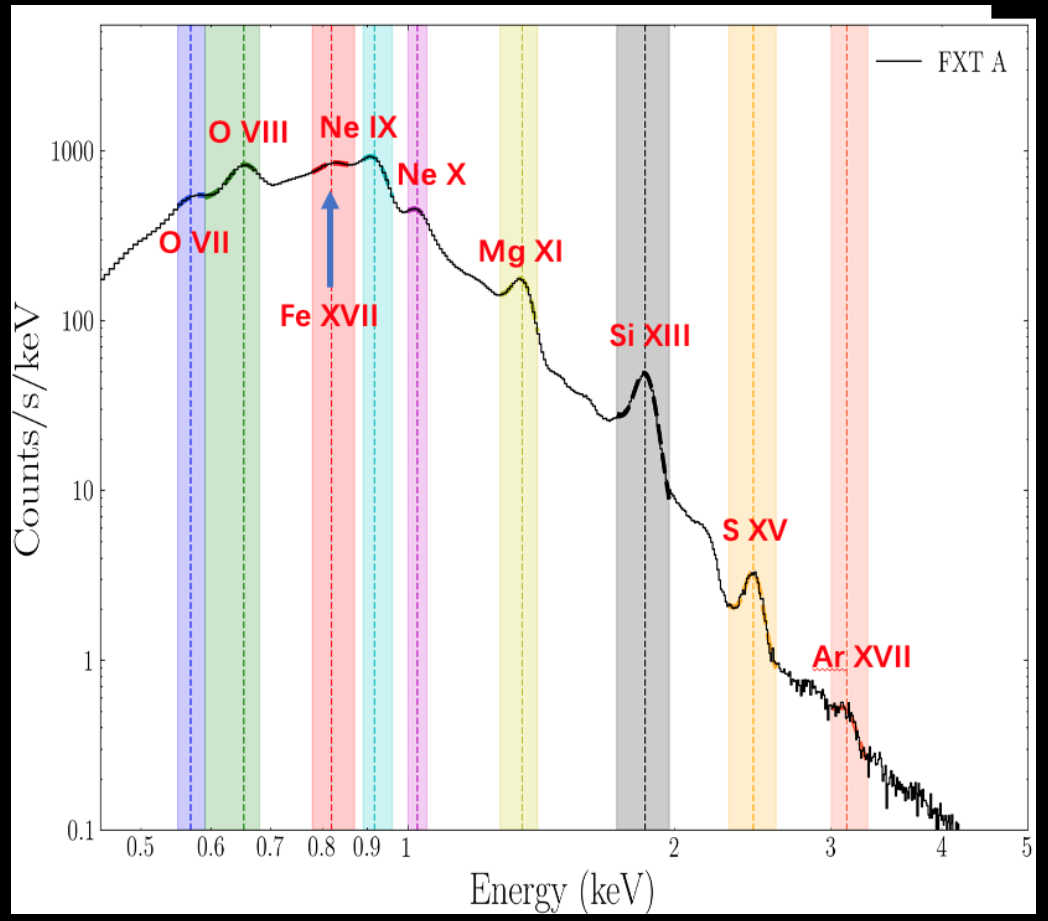
FXT X-ray First light (Feb 22., 2024)

Puppis A supernova remnant (nebula)

FoV 1 deg x 1 deg

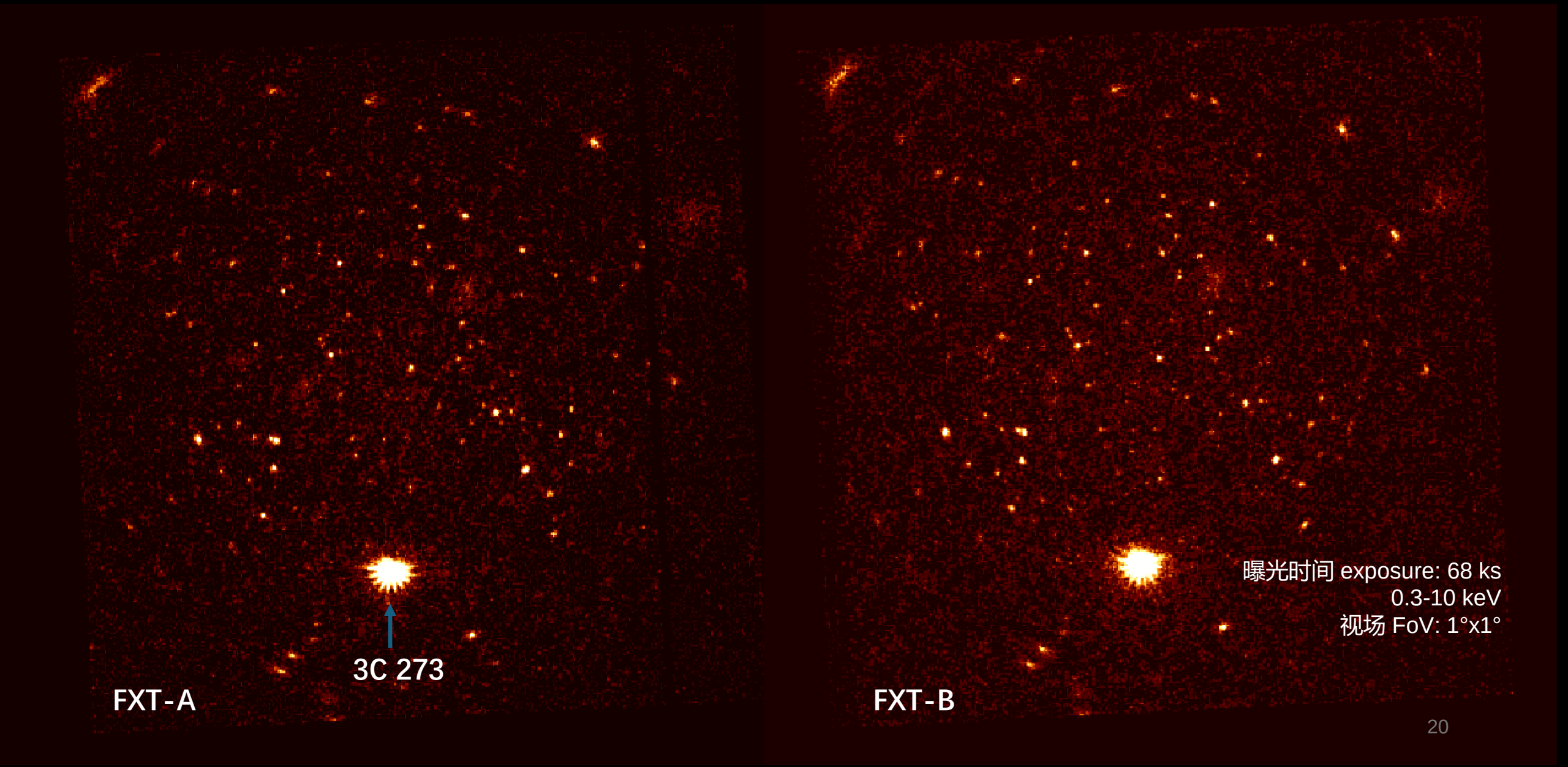


FXT X-ray spectrum obtained at the same time

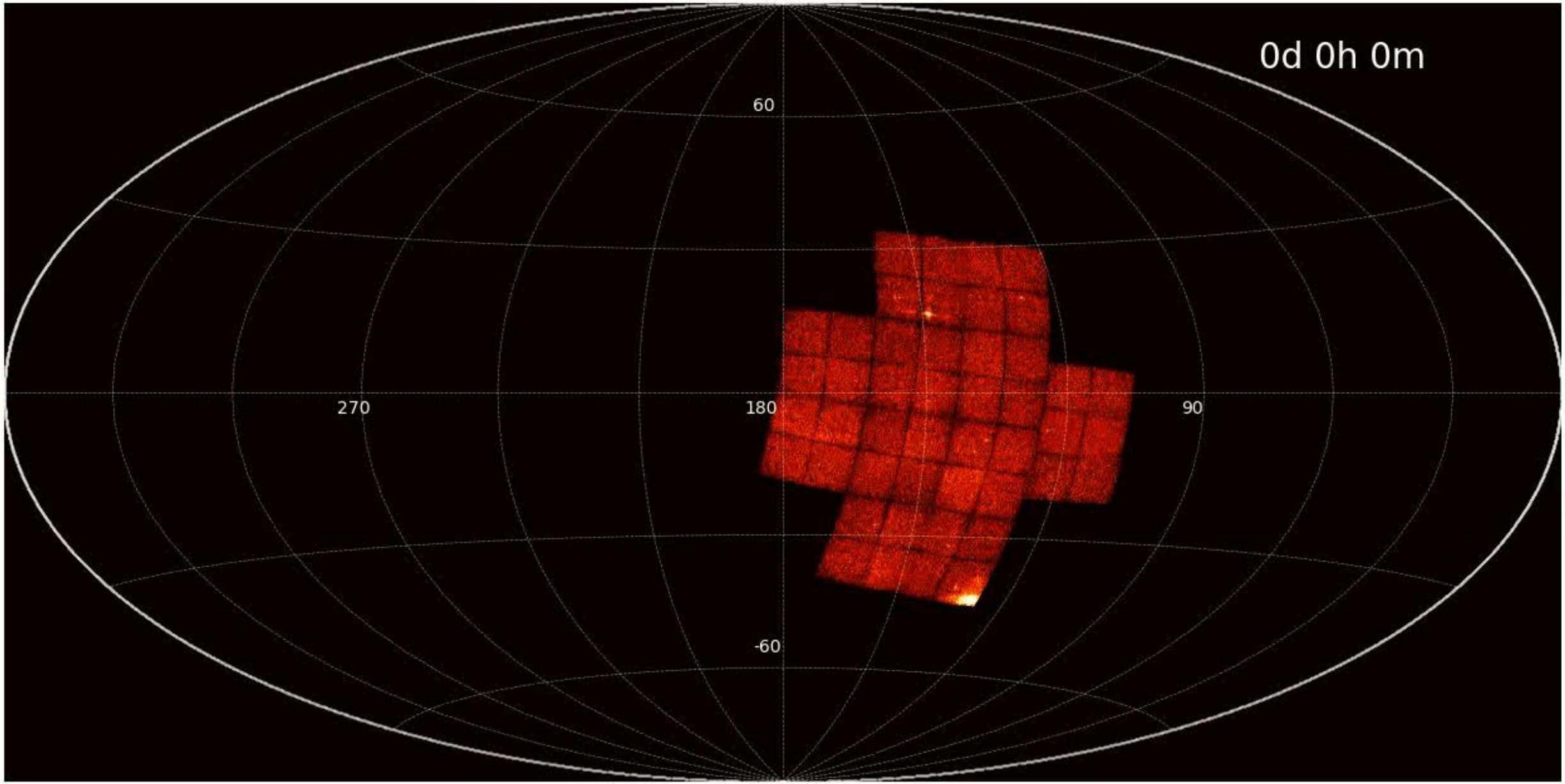


FXT 对类星体 3C 273 附近天区的X 射线观测图像

~100 新 X 射线源探测

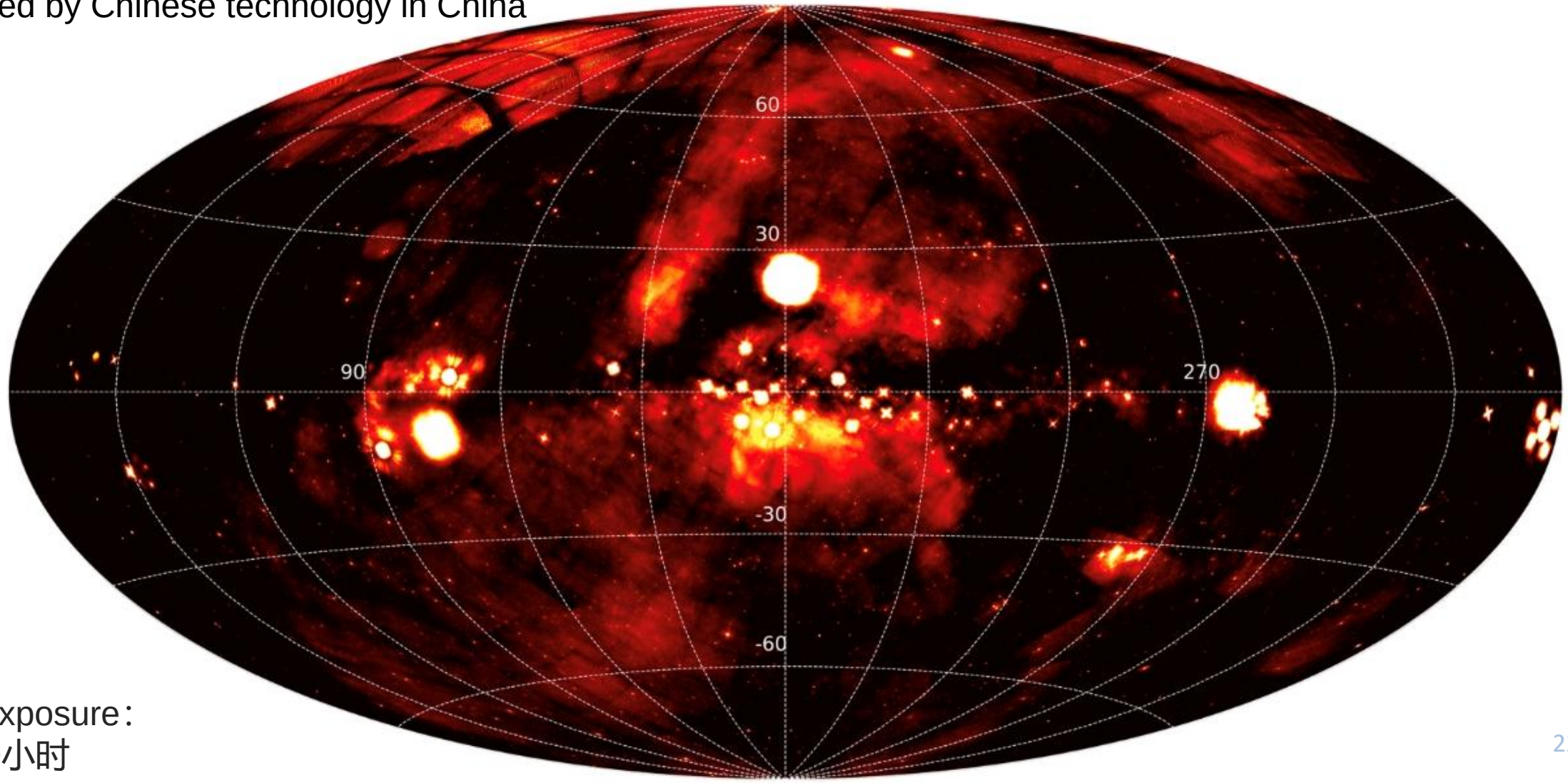


EP-WXT运行情况：1天的巡天监测



X-ray All-sky image obtained with WXT

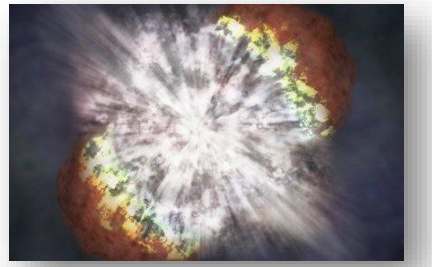
The 1st X-ray all-sky image obtained with instrument developed by Chinese technology in China



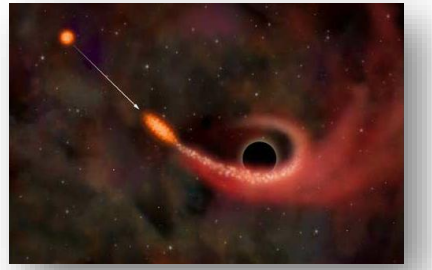
total exposure：
~2500小时

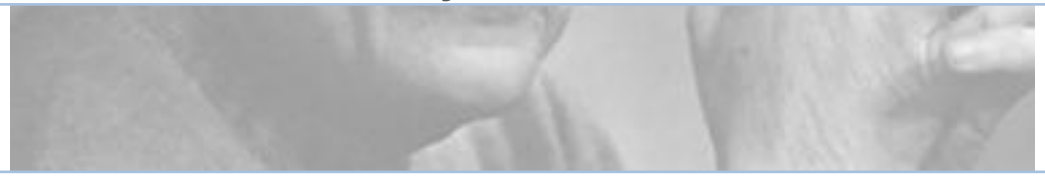
Main science objectives

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

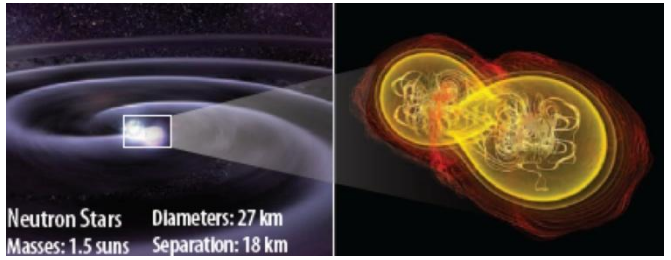


Discover otherwise quiescent black holes at almost all astrophysical mass scales and other compact objects by capturing their transient X-ray flares





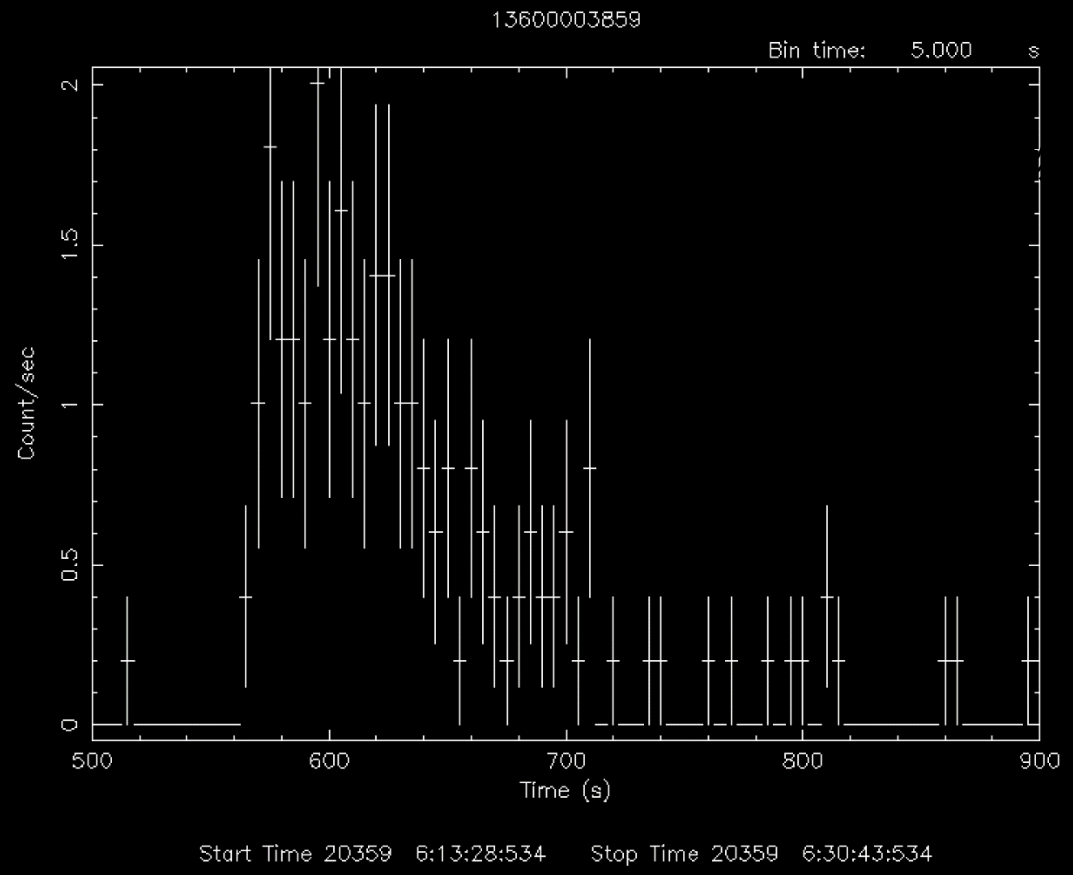
Detect and localise the electromagnetic-wave sources of gravitational-wave events by synergy with gravitational-wave detectors



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)
- Atel sent from EPSC: 1st EP alert!
- No optical counterpart found (starting T0+3days)
- An X-ray rich GRB

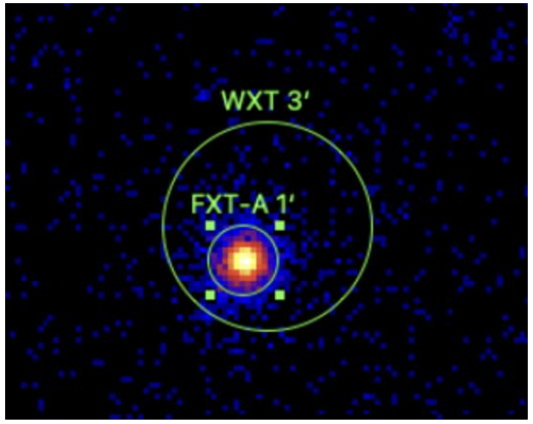


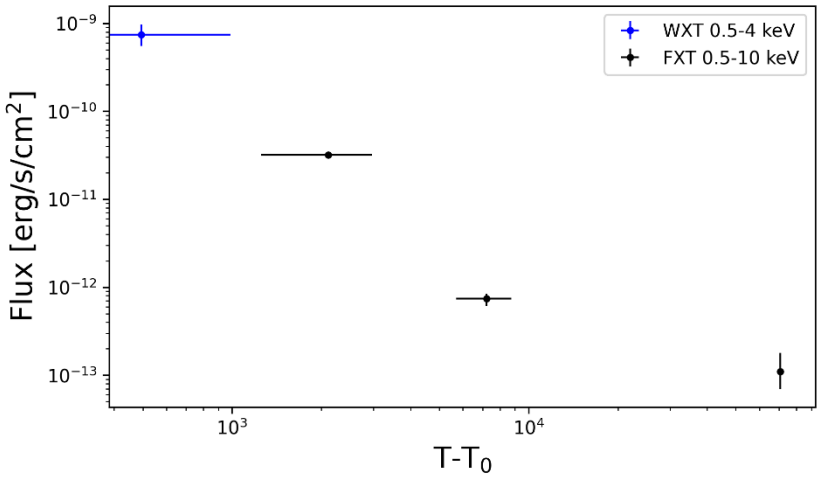
Yin et al. 2024 ApJL

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

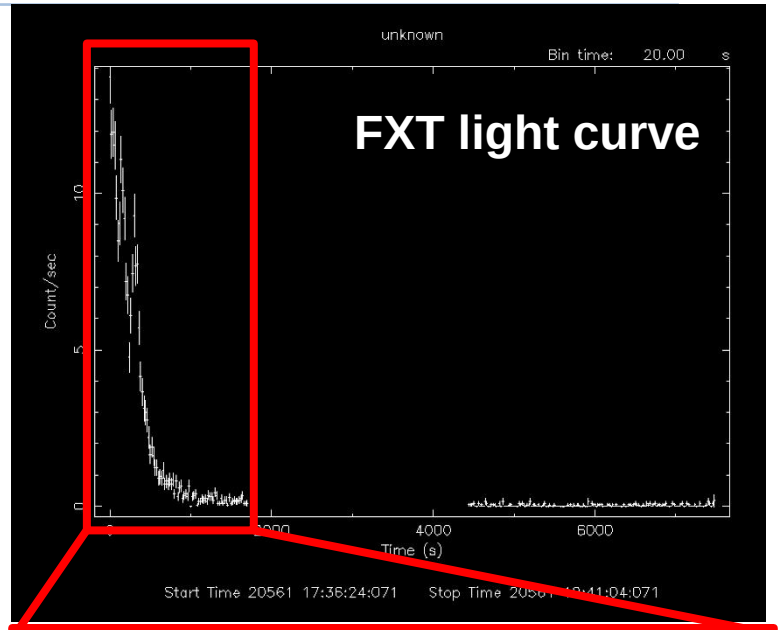
Fast X-ray Transients: EP240908a: a GRB

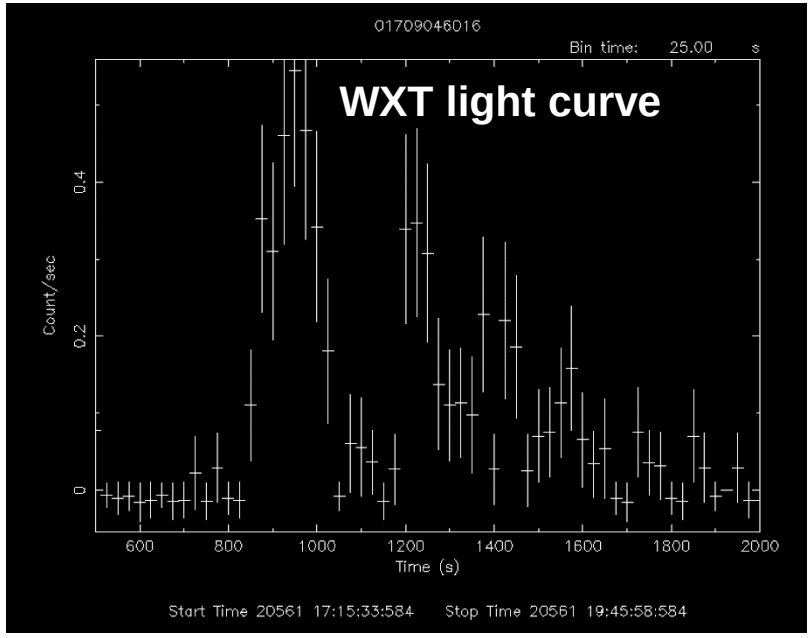
- WXT onboard trigger:
  - T0=2024-09-08T17:28:27 (UTC)
  - peak flux: ~1e-9 erg/s/cm^2
  - (EP team et al. GCN 37443)
- T0+7min: automated FXT follow-up
  - (EP team et al. GCN 37432)
- T0+19hrs: FXT follow-up
  - flux ~1.1x10^(-13) erg/s/cm^2
- optical afterglow candidate:
  - AB magnitude r ~ 24
  - (Quirola-Vasquez et al. GCN 37438)

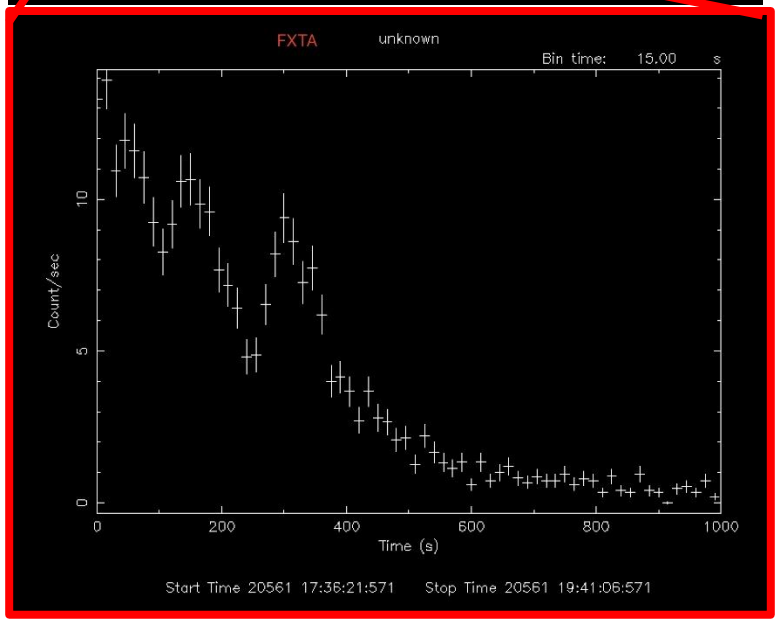




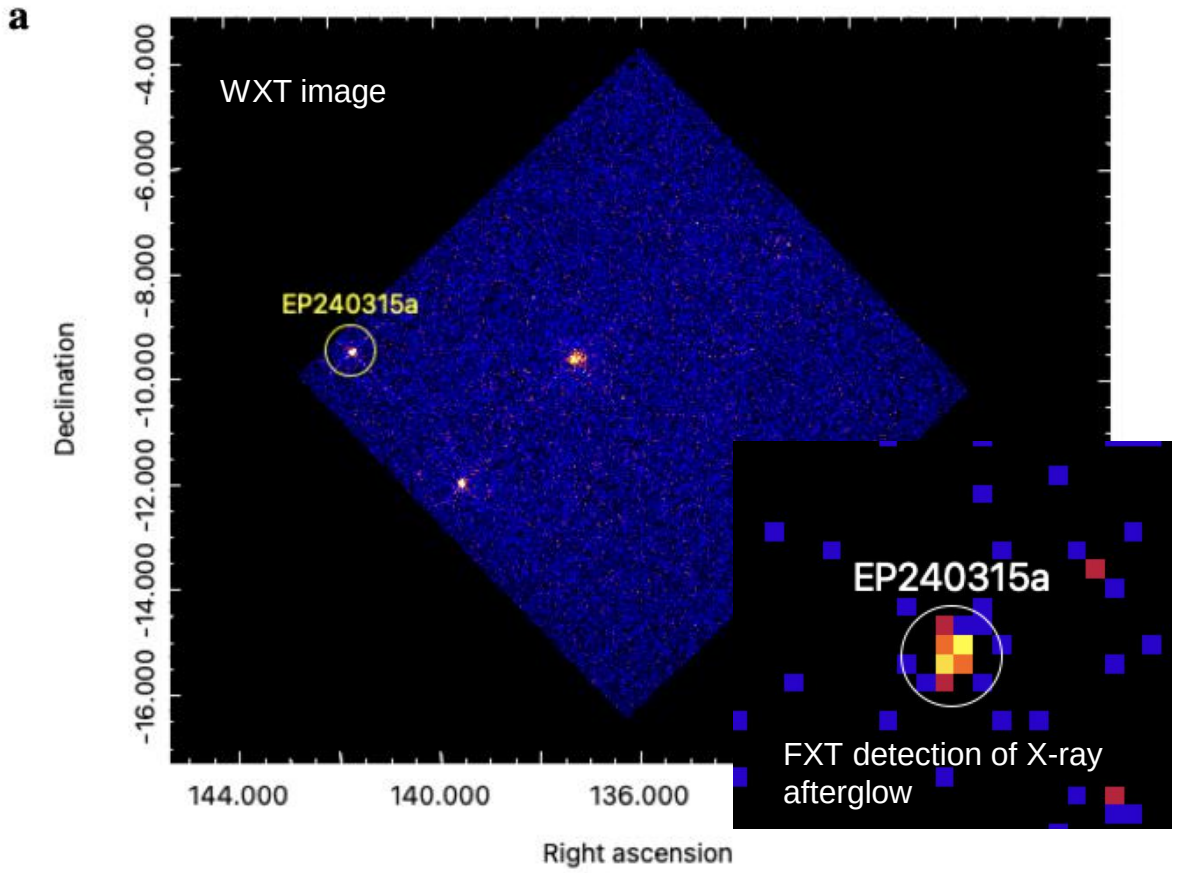
no gamma-ray burst counterpart



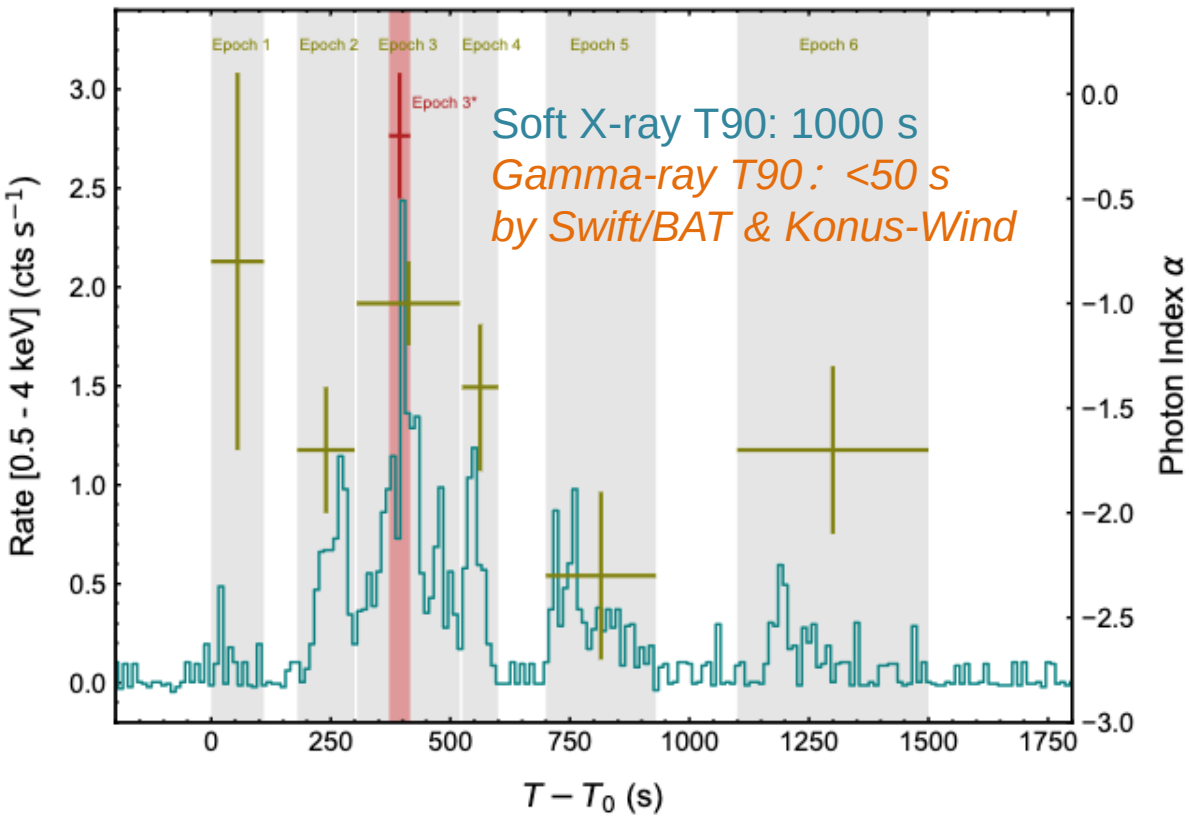




EP240315a: GRB @redshift 4.859



Onboard trigger, confirmed by on-ground analysis



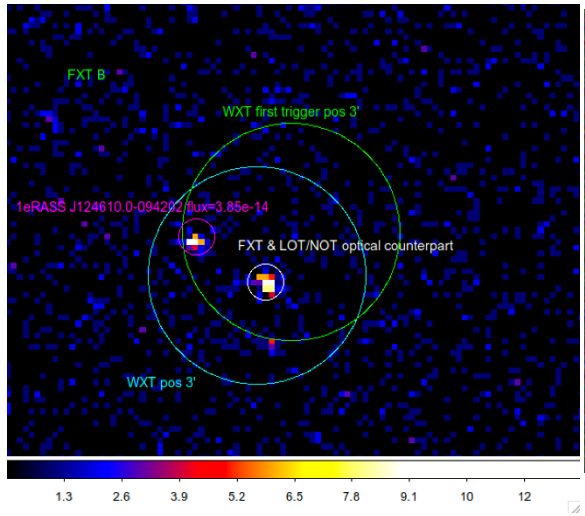
Marked difference in LC of soft X-ray and hard X/γ rays

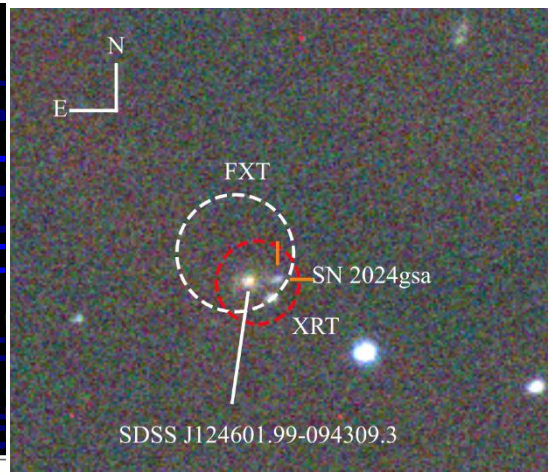
Gillanders J.H., et al. 2024 (ATLAS optical/radio counterpart, z)
Levan A., et al. 2025 (Stargate optical pho. and spec., z)
Liu Y., et al. 2025 Nature Astronomy

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: a new type of fast X-ray transient

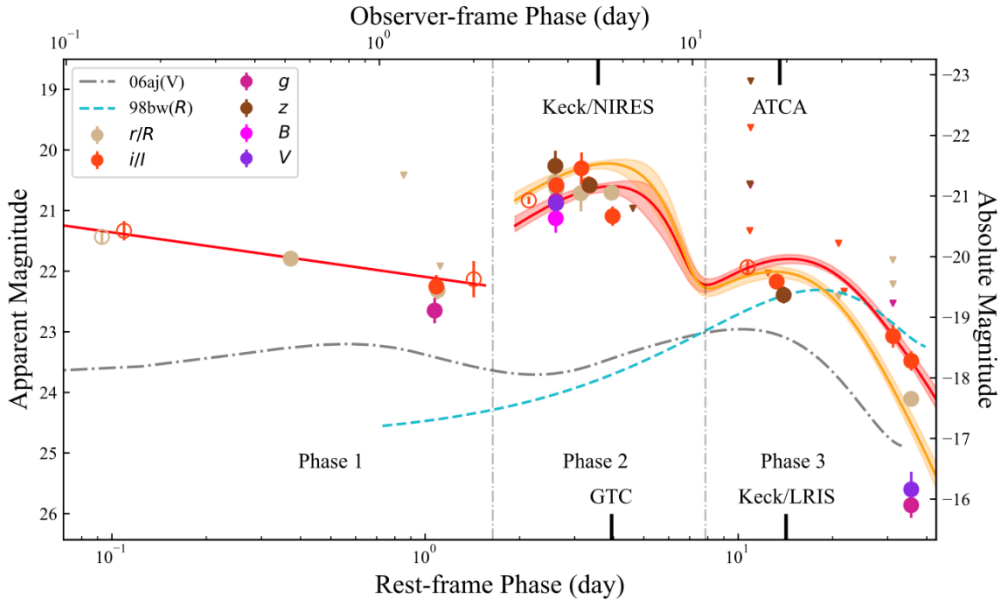


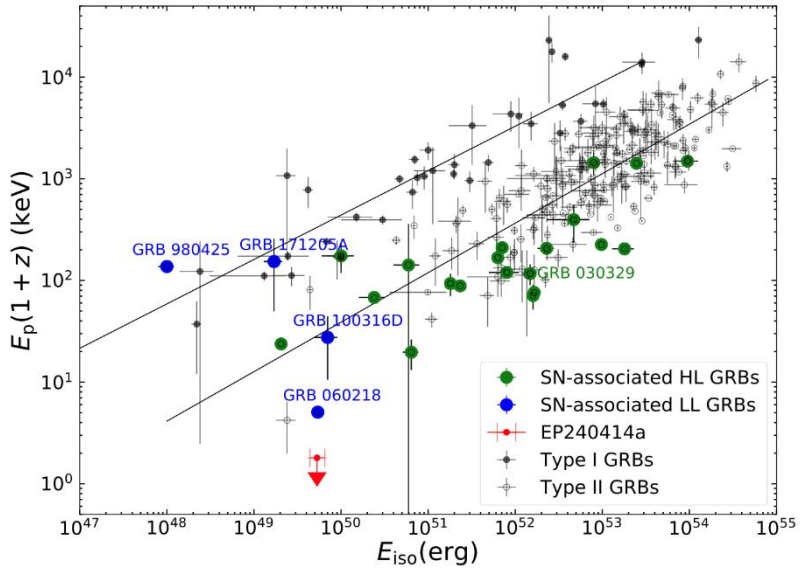


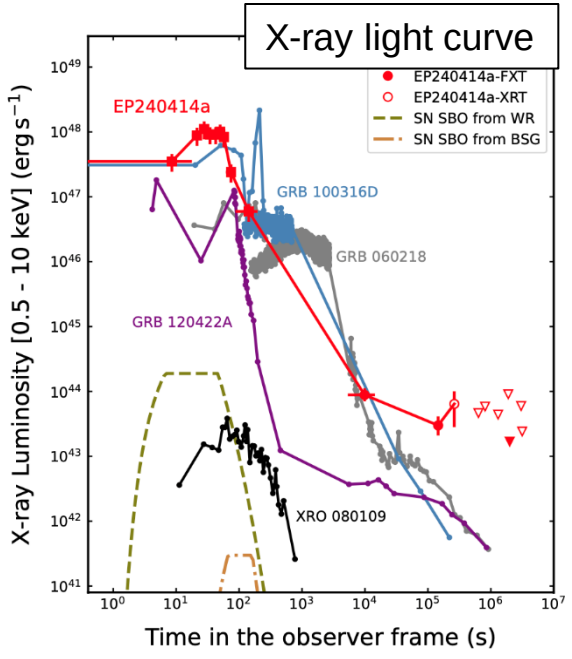
- Associated with Type Ic-BL supernova SN 2024gsa (z=0.4)
- No significant γ-ray signals associated
- Very soft energy spectrum Ep< 1.3 keV

=> A weak relativistic jet that interacts with an extended shell surrounding the progenitor star

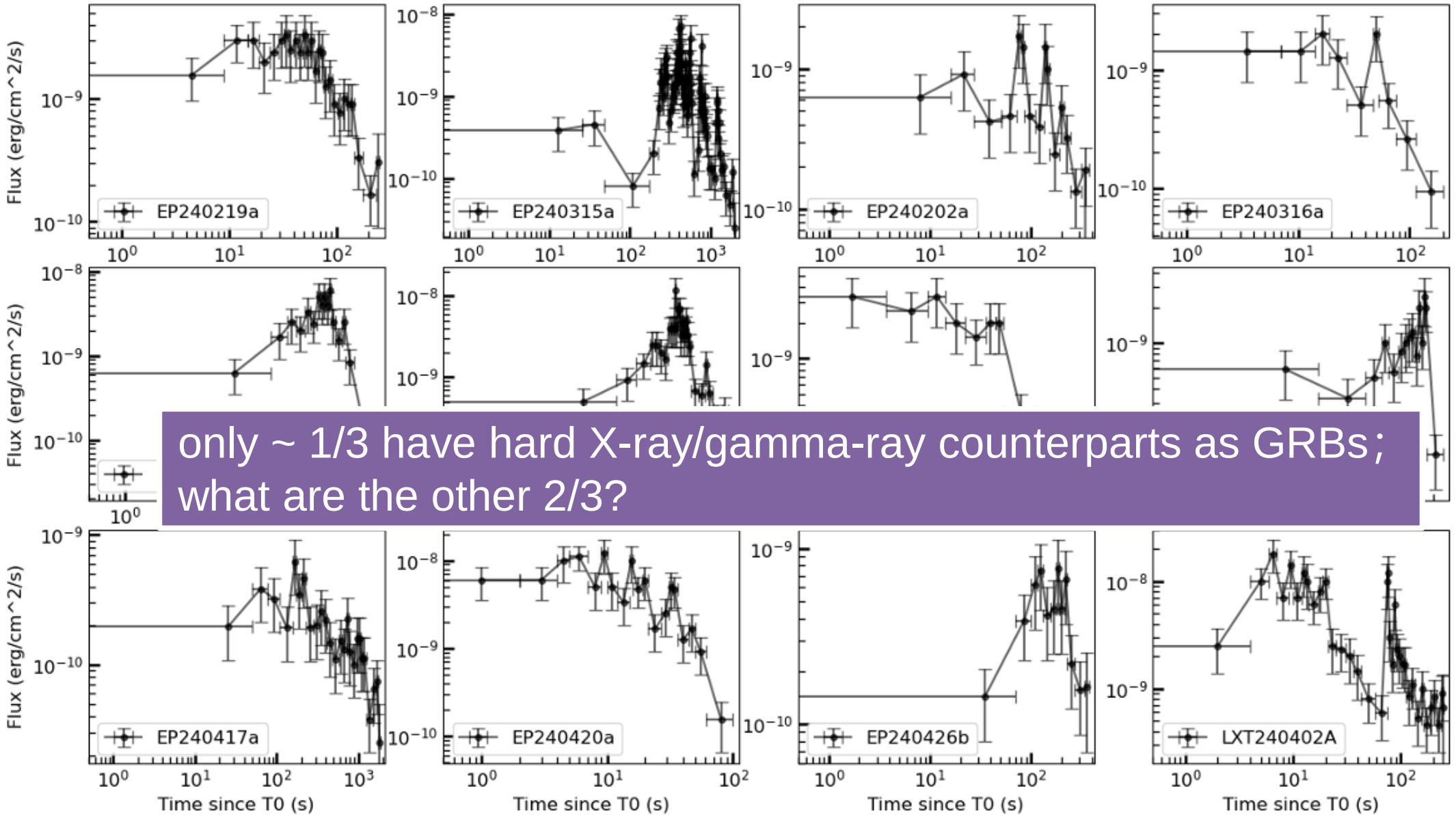
Sun et al. 2025 Nature Astronomy







Example light curves of EP fast transients

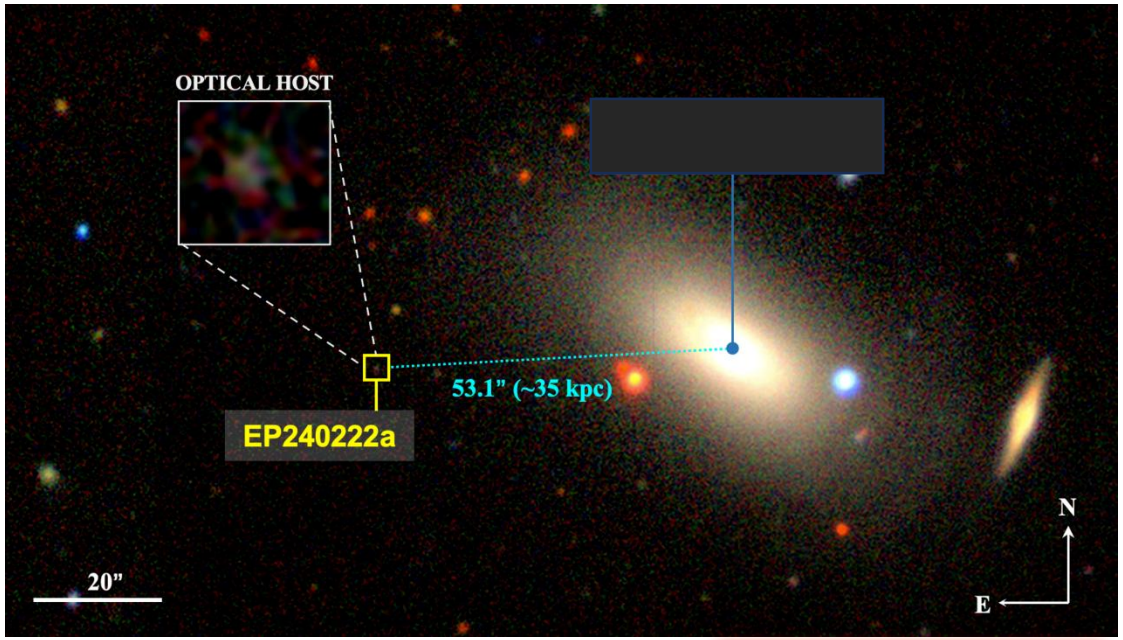


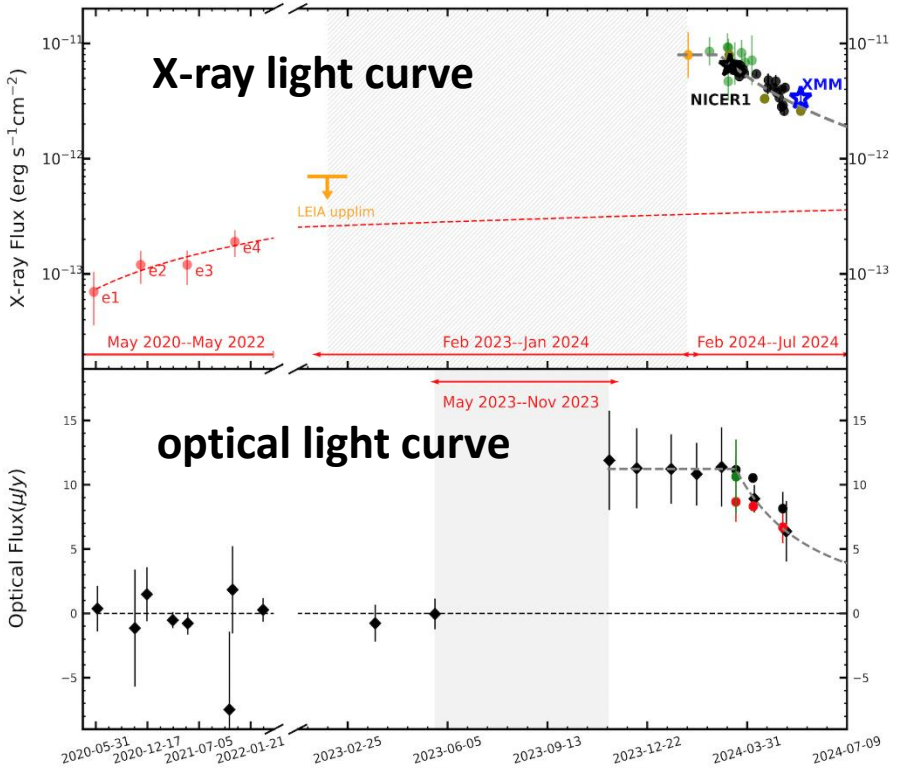
only ~ 1/3 have hard X-ray/gamma-ray counterparts as GRBs; what are the other 2/3?

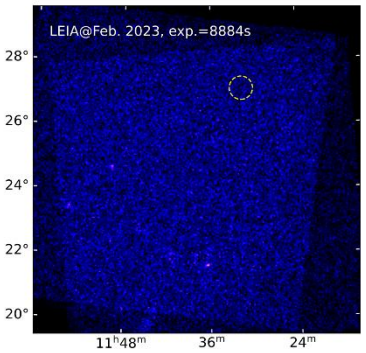
EP240222a: an IMBH-TDE candidate

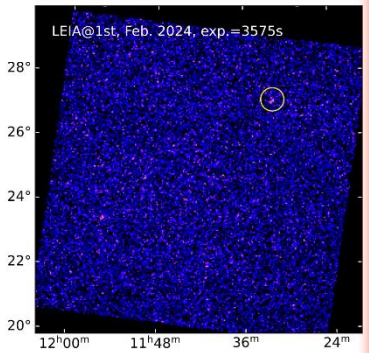
Time scale: >4 years

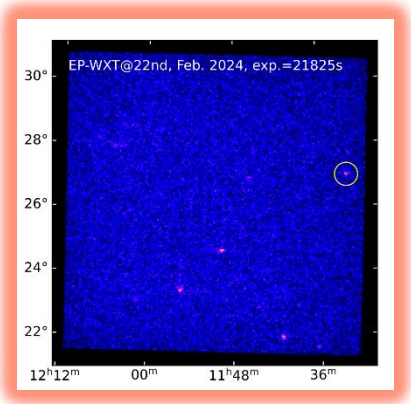
off center: 53” (~35 kpc) away from a massive galaxy

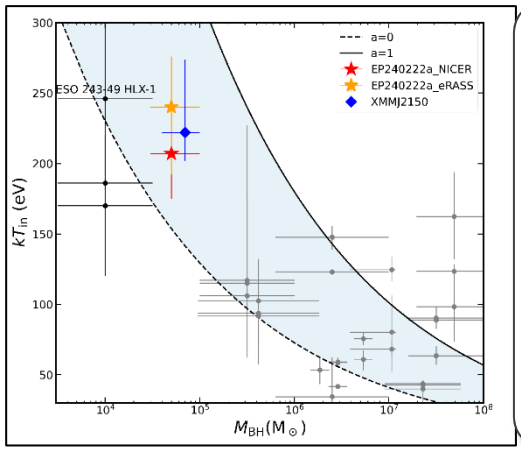


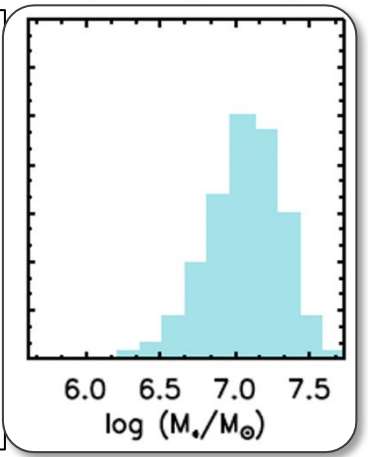












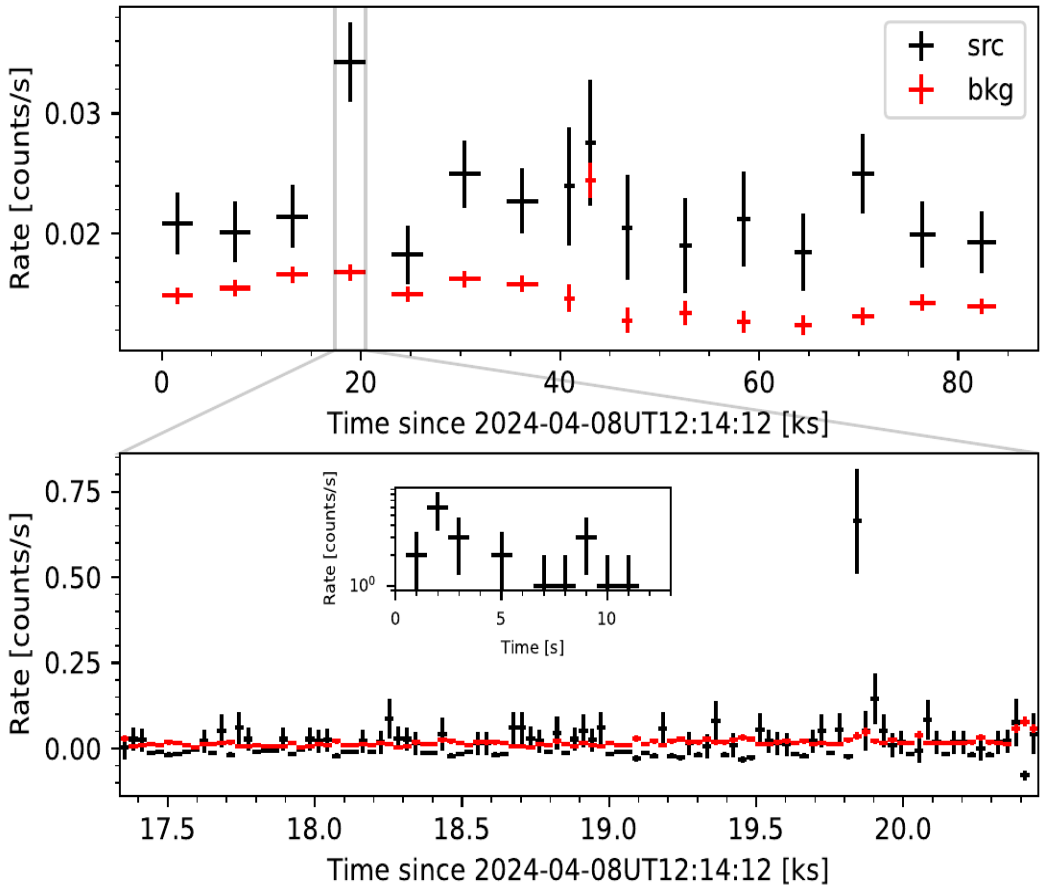
kT: ~ 200 eV

host stellar mass:

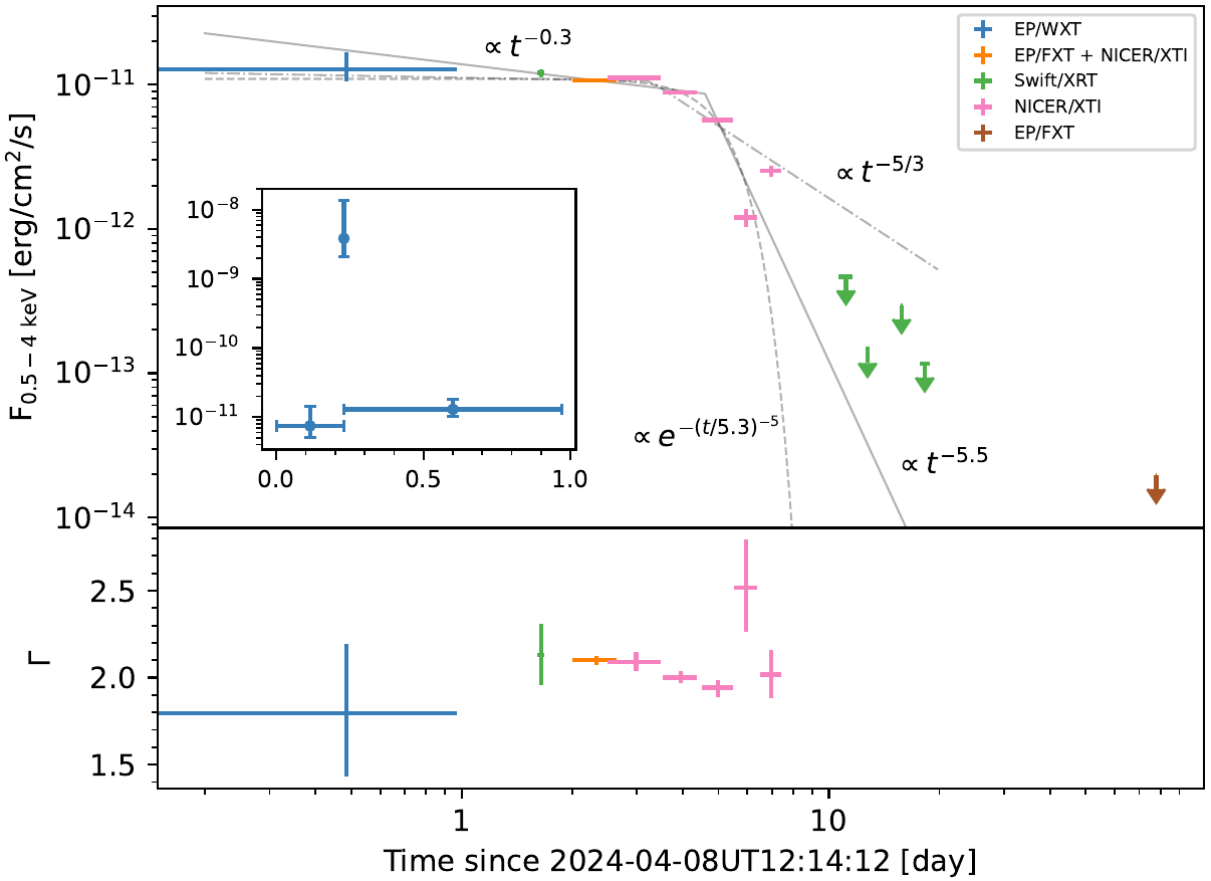
~1e7 Msun

Jin, Li, Jiang, Dai, submitted

EP240408a: peculiar intermediate-timescale transient



Broken-PL decay in the X-ray light curve



Persistent X-ray emission before flare:
hard to explain as a GRB

$$R_{\rm em} \lesssim 3.6 \times 10^{11} \frac{\delta}{1+z}\ {\rm cm}.$$

EP240408a : a new type of transient?

SCIENCE CHINA
Physics, Mechanics & Astronomy

• Article •

January 2024 Vol. 67 No. 1: 000000
https://doi.org/10.1007/s11433-024-2524-4

Einstein Probe discovery of EP240408a: A peculiar X-ray transient with an intermediate timescale

Wenda Zhang[1*], Weimin Yuan[1,2*], Zhixing Ling[1,2*], Yong Chen[3*], Nanda Rea[4,5*], Arne Rau[6*], Zhiming Cai[7], Huaqing Cheng[1], Francesco Coti Zelati[4,5], Lixin Dai[8], Jingwei Hu[1], Shumei Jia[3], Chichuan Jin[1,2], Dongyue Li[1], Paul O'Brien[9], Rongfeng Shen[10], Xinwen Shu[11], Shengli Sun[12], Xiaojin Sun[12], Xiaofeng Wang[13], Lei Yang[11], Bing Zhang[14,15], Chen Zhang[1], Shuang-Nan Zhang[3,2], Yonghe Zhang[7], Jie An[1,2], David Buckley[16,17,18], Alexis Coleiro[19], Bertrand Cordier[20], Liming Dou[21], Rob Eyles-Ferris[9], Zhou Fan[1,2], Hua Feng[3], Shaoyu Fu[1,2], Johan P. U. Fynbo[22,23], Lluis Galbany[4,5], Saurabh W. Jha[24], Shuaiqing Jiang[1,2], Albert Kong[25], Erik Kuulkers[26], Weihua Lei[27], Wenxiong Li[1], Bifang Liu[1,2], Mingjun Liu[1,2], Xing Liu[1,2], Yuan Liu[1], Zhu Liu[6], Chandreyee Maitra[6], Alessio Marino[4,5], Itumeleng Monageng[16,17], Kirpal Nandra[6], Jeremy Sanders[6], Roberto Soria[2,28,29], Lian Tao[3], Junfeng Wang[30], Song Wang[1,31], Tinggui Wang[32,33,34], Zhongxiang Wang[35,36], Qingwen Wu[27], Xuefeng Wu[37,33], Dong Xu[1], Yanjun Xu[3], Suijian Xue[1], Yongquan Xue[38,32,33], Zijian Zhang[8], Zipei Zhu[1], Hu Zou[1], Congying Bao[1], Fansheng Chen[12], Houlei Chen[39,2], Tianxiang Chen[3], Wei Chen[1,2], Yehai Chen[7], Yifan Chen[12], Chenzhou Cui[1,2], Weiwei Cui[3], Yanfeng Dai[1], Dongwei Fan[1], Ju Guan[3], Dawei Han[3], Dongjie Hou[3], Haibo Hu[1], Maohai Huang[1,2], Jia Huo[3], Zhenqing Jia[1], Bowen Jiang[40], Ge Jin[40], Chengkui Li[3], Junfei Li[12], Longhui Li[40], Maoshun Li[3], Wei Li[3], Zhengda Li[12], Tianying Lian[1,2], Congzhan Liu[3], Heyang Liu[1], Huaqiu Liu[7], Fangjun Lu[3], Laidan Luo[3], Jia Ma[3], Xuan Mao[1,2], Haiwu Pan[1], Xin Pan[1], Liming Song[3], Hui Sun[1], Yunyin Tan[41], Qingjun Tang[39,2], Yihan Tao[1], Hao Wang[3], Juan Wang[3], Lei Wang[42], Wenxin Wang[1], Yilong Wang[1,2], Yusa Wang[3], Qinyu Wu[1,2], Haitao Xu[41], Jingjing Xu[3], Xinpeng Xu[1,2], Yunfei Xu[1,2], Zhao Xu[40], Changbin Xue[41], Yulong Xue[12], Ailiang Yan[12], Haonan Yang[1,2], Xiongtao Yang[3], Yanji Yang[3], Juan Zhang[3], Mo Zhang[1], Wenjie Zhang[1], Zhen Zhang[1,2], Zhen Zhang[40], Ziliang Zhang[3], Donghua Zhao[1], Haisheng Zhao[3], Xiaofan Zhao[3], Zijian Zhao[3], Hongyan Zhou[43,44,34], Yilin Zhou[7], Yuxuan Zhu[3], and Zhencai Zhu[7]

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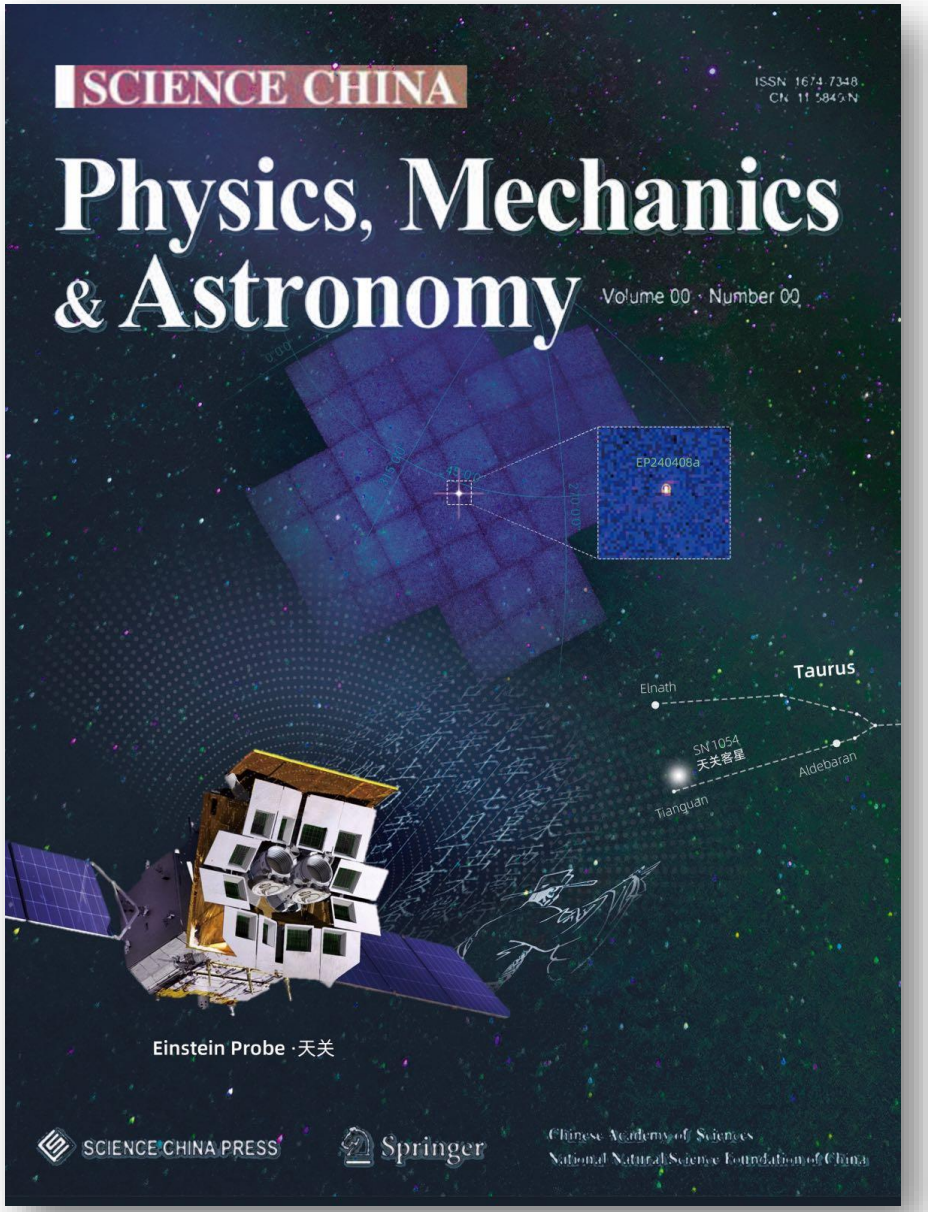
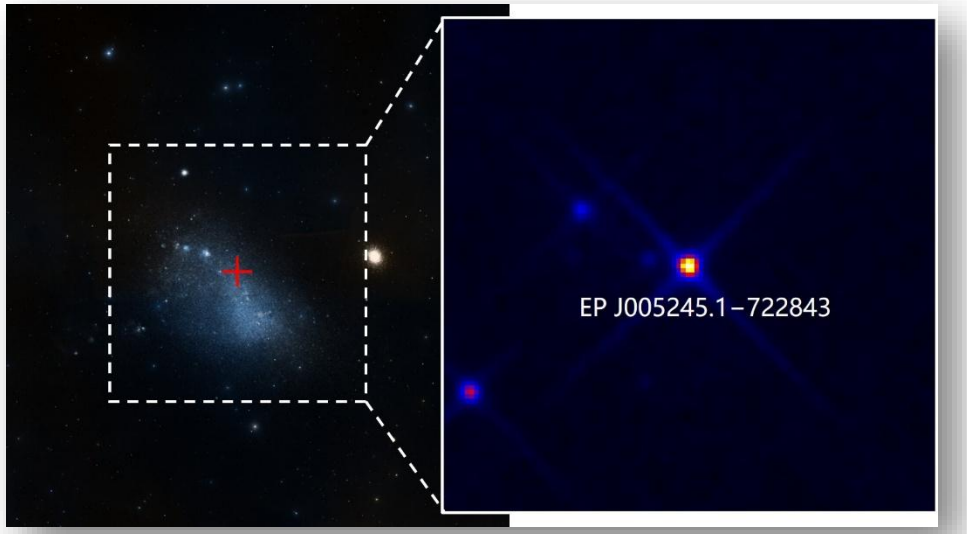
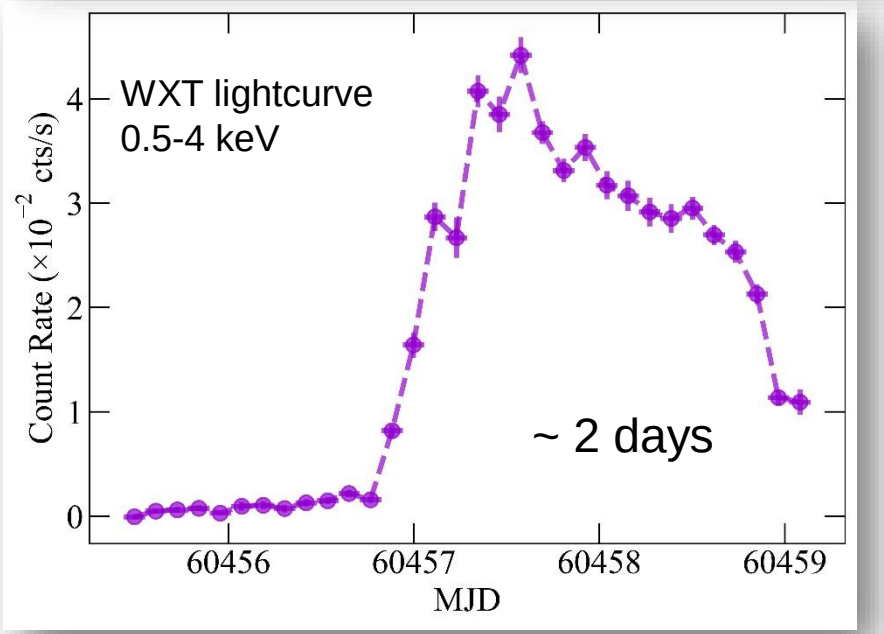
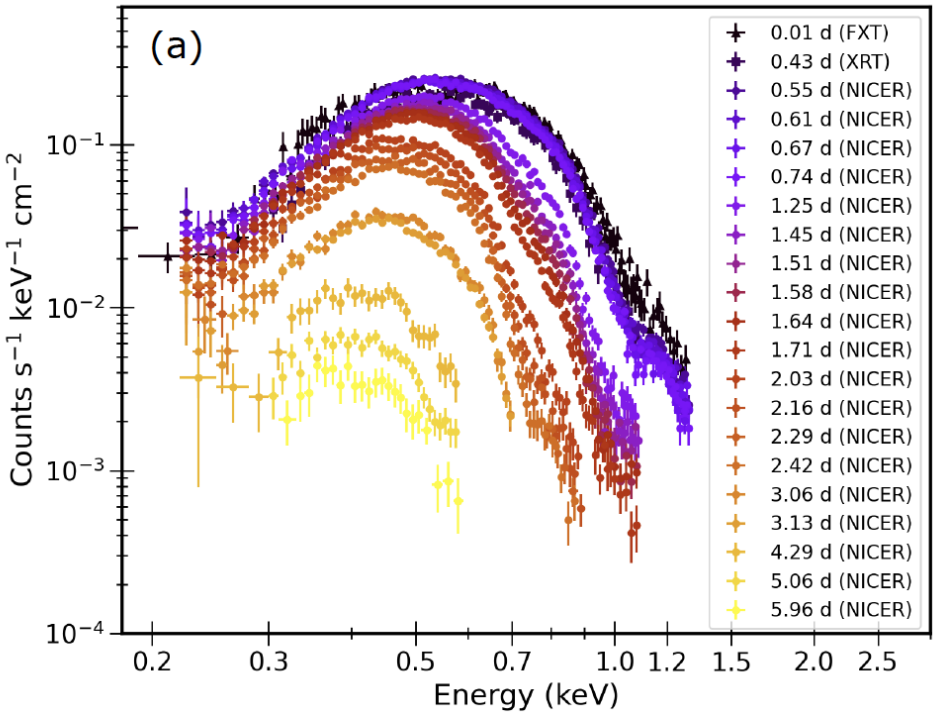


An outburst in Small Magellanic Cloud: Be + WD



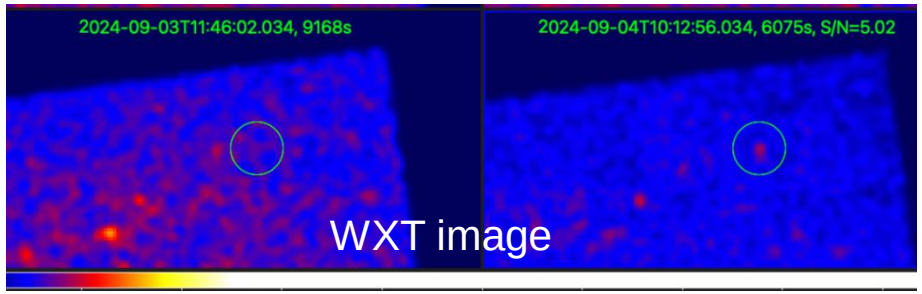


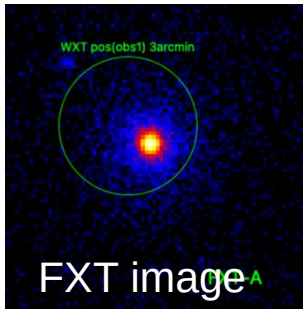


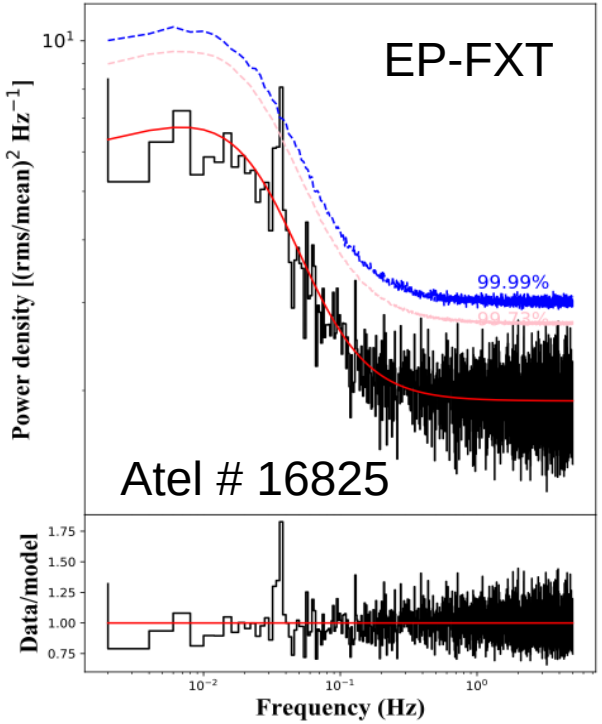
- CXOU J005245.0-722844 a weak Chandra source
- WXT detected its first X-ray outburst (Atel#16631)
- very soft X-ray spectrum
- also by Swift/XRT (ATeL# 16633), follow-up by NICER (ATeL# 16636)
- a possible Be binary system with a WD

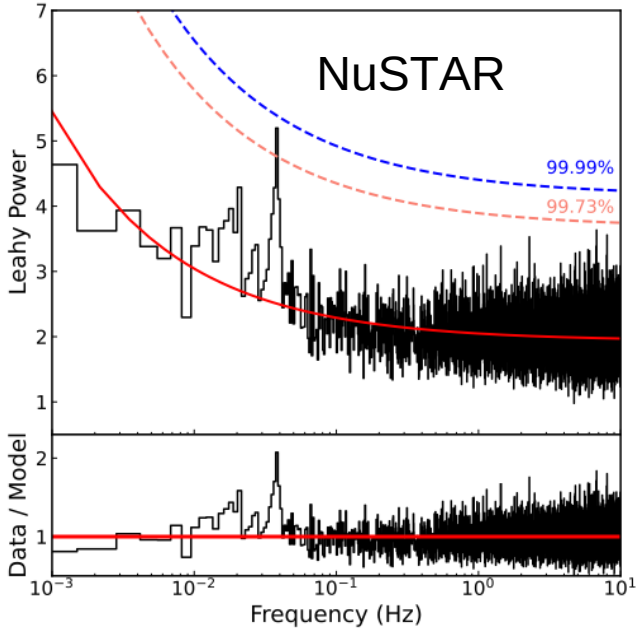
Marino, et al. 2025 ApJL

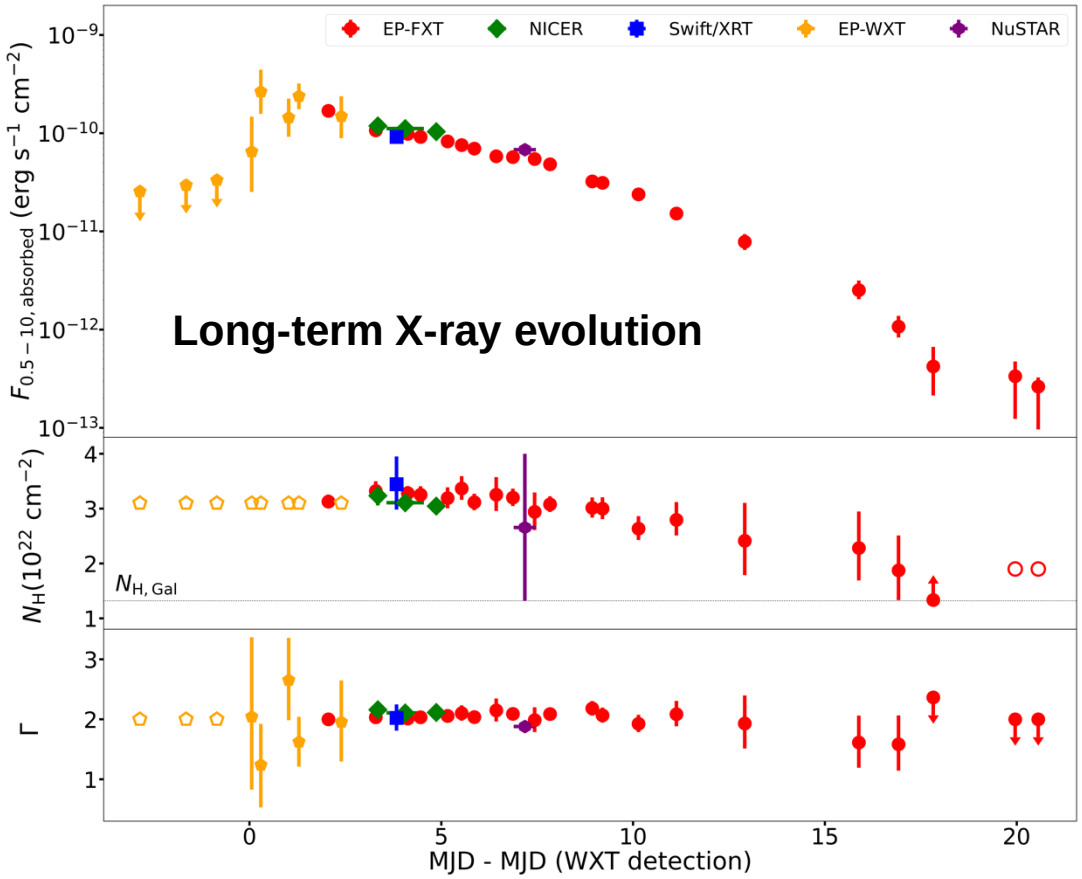
EP240904a: a new X-ray binary (BH?)







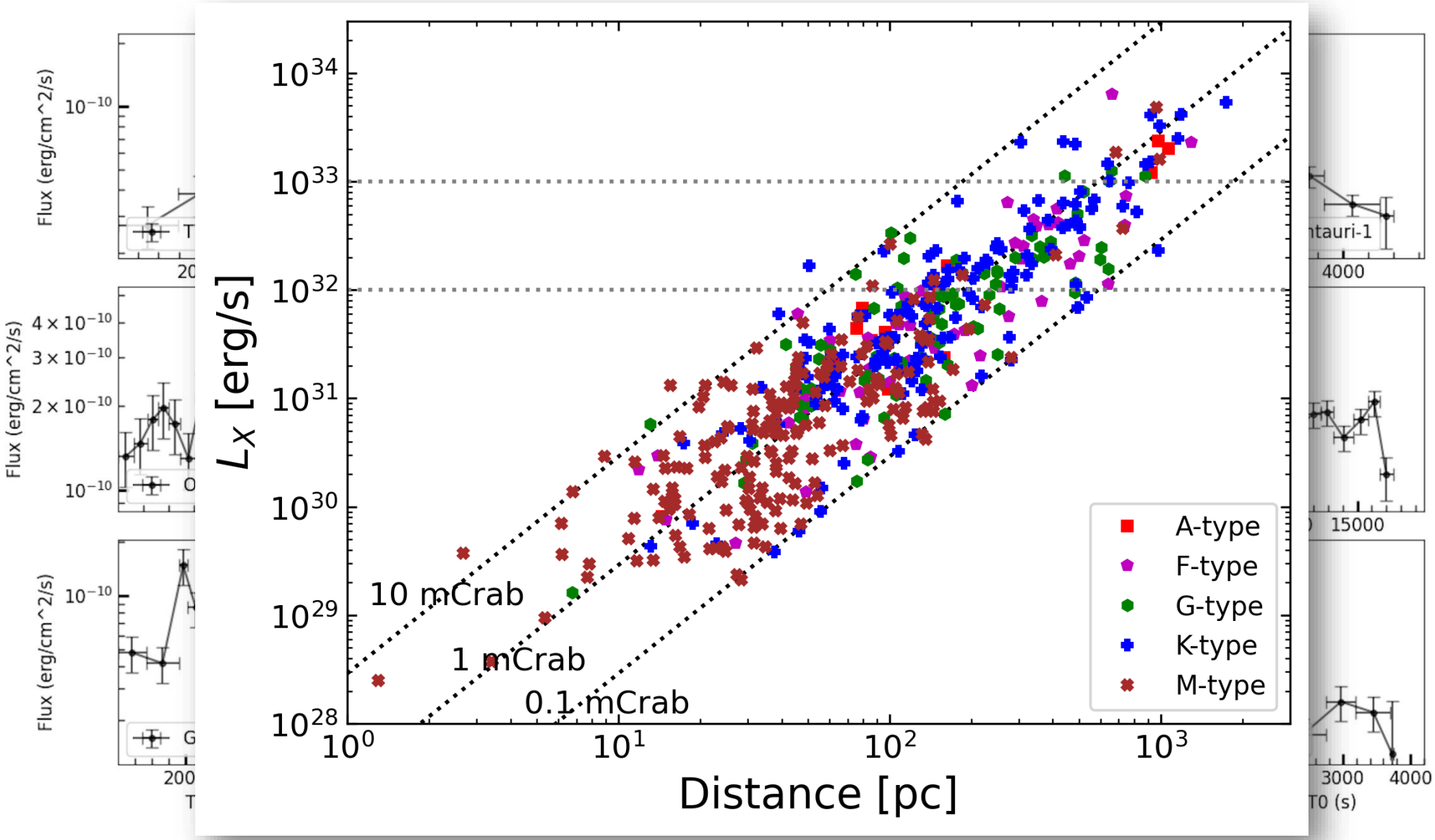




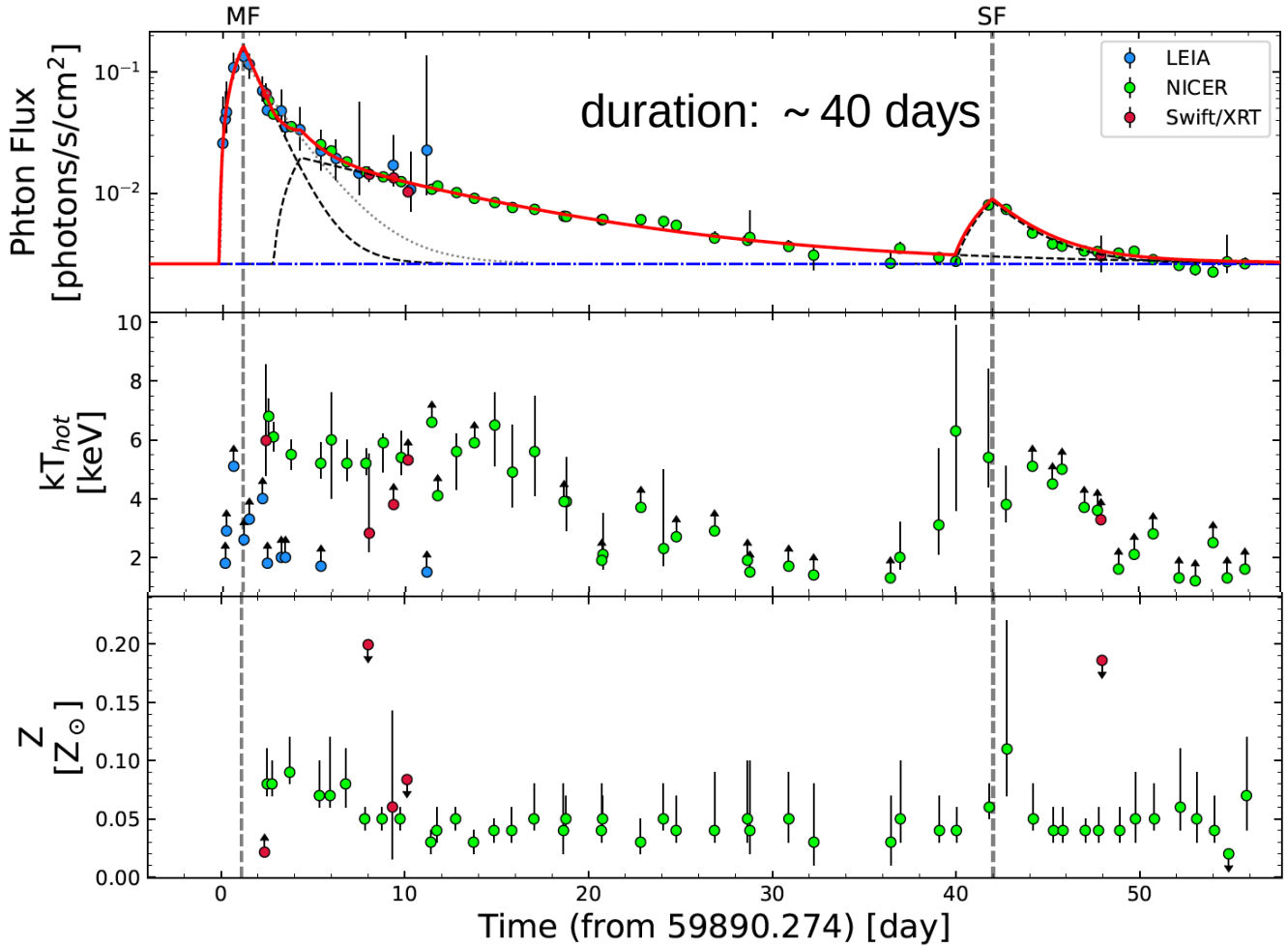
- 一个暗弱的 mini 爆发，持续 3 周，可能的mHz QPO
- 射电探测到致密喷流（X 射线高态）

Cheng, et al. 2025 ApJL

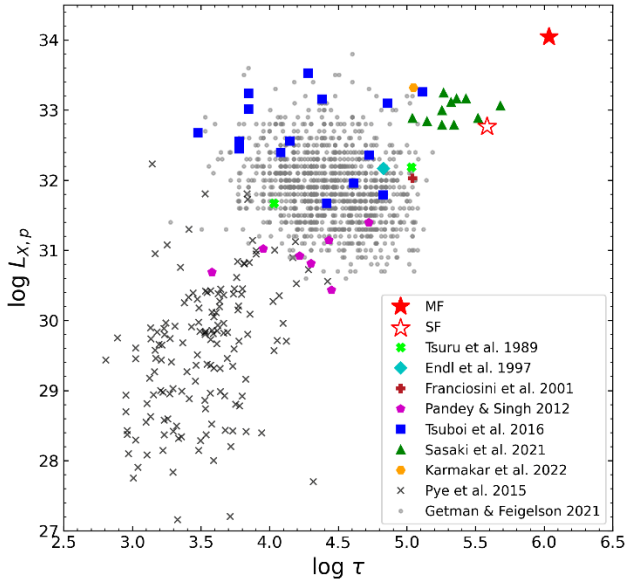
488 Stellar X-ray flares detected with EP-WXT

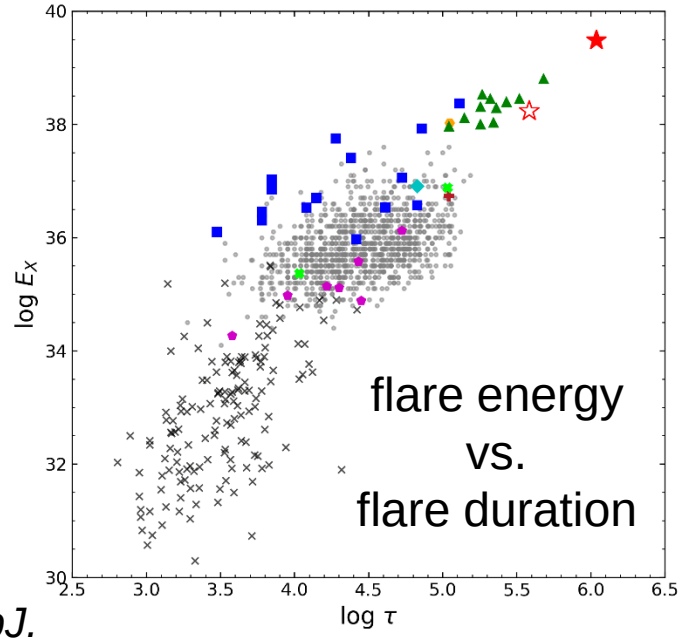


LEIA discovery of the most energetic & long-lasting stellar X-ray flare from RS CVn binary HD 251108



peak luminosity
vs.
flare duration



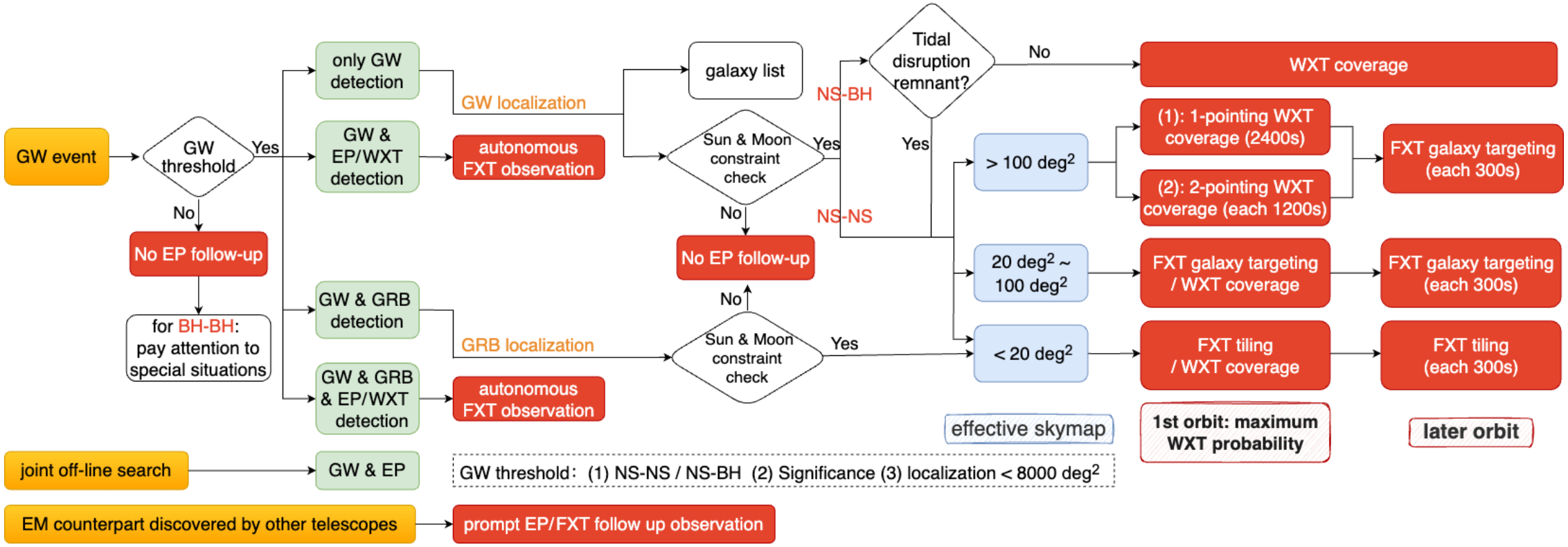


Peak L_X: 1.1E34 erg/s (0.5-4keV); Energy: 3E39 erg (0.5-4keV)

magnetic loop: ~1.9R_star; magnetic field ~ 50 Gauss

Mao X. et al. 2025 ApJ.

ToO-MM observing strategy



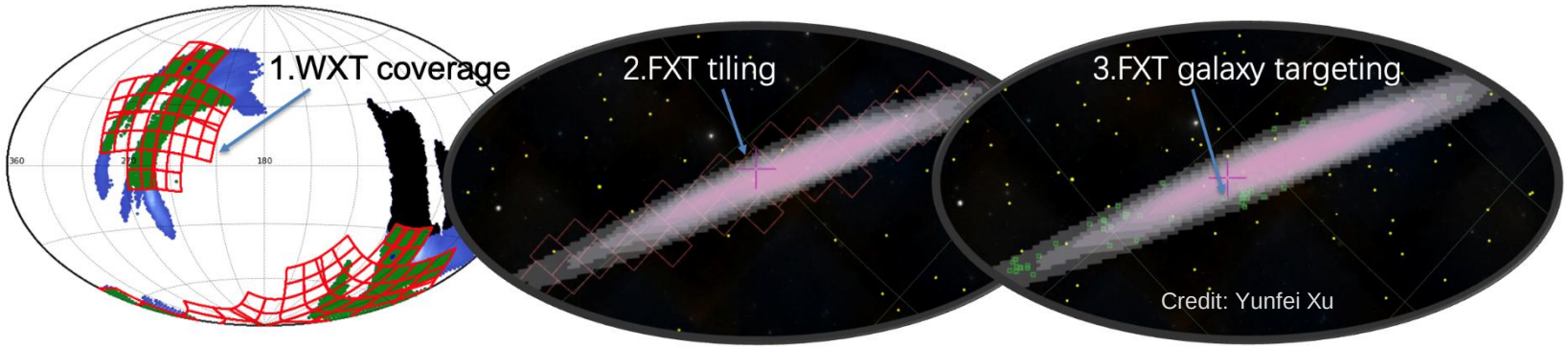


Figure: Jingwei Hu

ToO-MM automated uplink

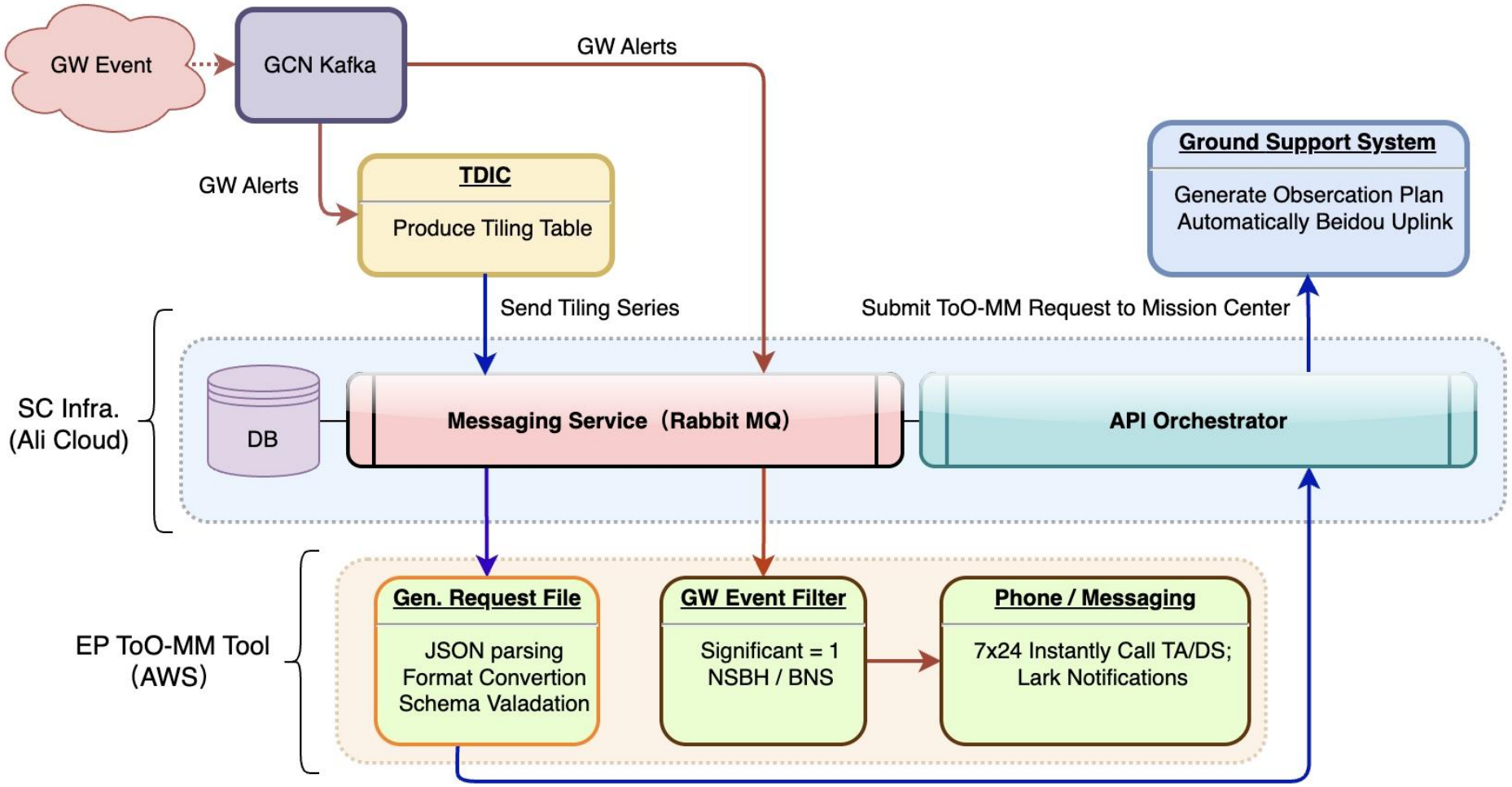


Figure: Mo Zhang Software: Yunfei Xu, Mo Zhang

S250206dm

S250206dm: T0=2025-02-06 21:25:30.439 UTC; NSBH (55%), BNS (37%); 373 +/- 104 Mpc; 90% area=547 deg^2

EP follow-up observations:

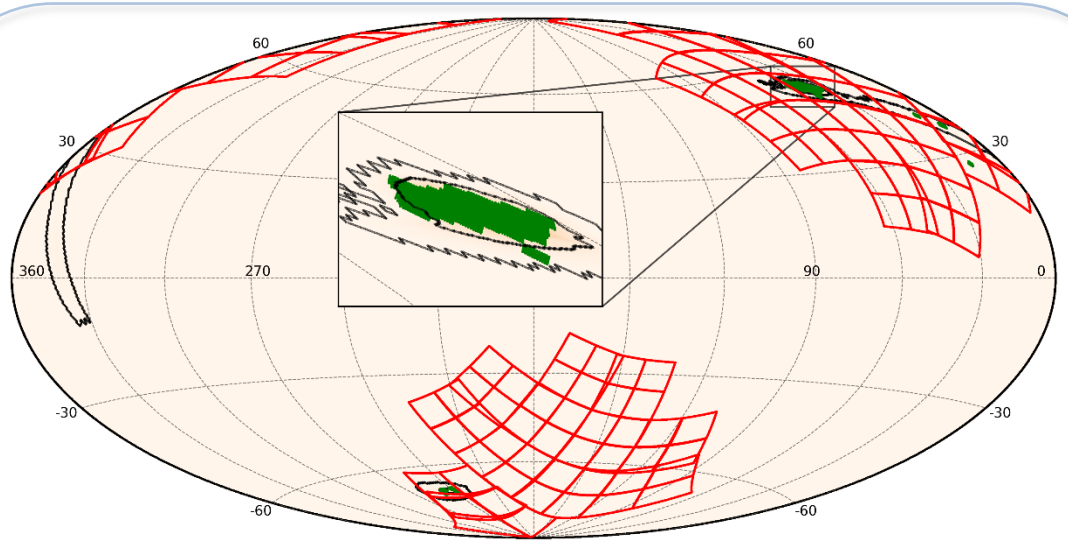
1^{st} round: 2×2400s WXT coverage + 100×300 s FXT targeting galaxies (2025-02-07T02:55:12Z ~ Feb. 8th)

2^{nd} round: 59×2000s FXT tiling (from Feb. 11th to 18th)

Search for transient or variable candidates in the FXT data (apparently associated with the galaxies):

found ~20 uncatalogued sources, two of which exhibit significant flux decay.

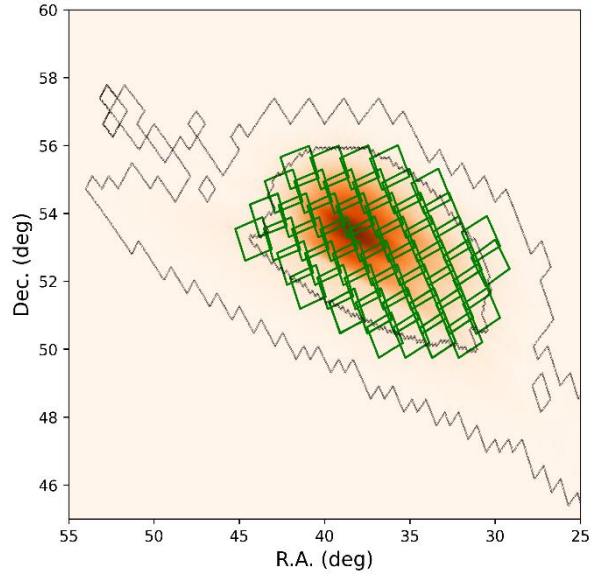
Detailed information: GCN Circular 39545; https://ep.bao.ac.cn/ep/cms/article/view?id=185



1^{st} : WXT covered 302 deg^2 within (55% of) the 90% GW area

WXT 0.5-4 keV flux limits: 1×10^{-11} erg $\mathrm{s}^{-1}\mathrm{cm}^{-2}$

FXT 0.5-10 keV flux limits: 3×10^{-13} erg $\mathrm{s}^{-1}\mathrm{cm}^{-2}$



2^{nd} : FXT covered 34 deg^2 within (89% of) the 50% GW area

FXT 0.5-10 keV flux limits: 5×10^{-14} erg $\mathrm{s}^{-1}\mathrm{cm}^{-2}$

Summary

- Since launch on January 9, 2024, EP's performance verifications & calibrations have completed
- Nominal science operations started since July 2024
- ~200 X-ray transients with high/SN (many faint ones) have been detected
- A wide range of targets: GRB, SN, TDE, WD+NS+BH in our and nearby galaxy, and more
- Monitored the activity of a sample of known sources
- 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

https://ep.bao.ac.cn

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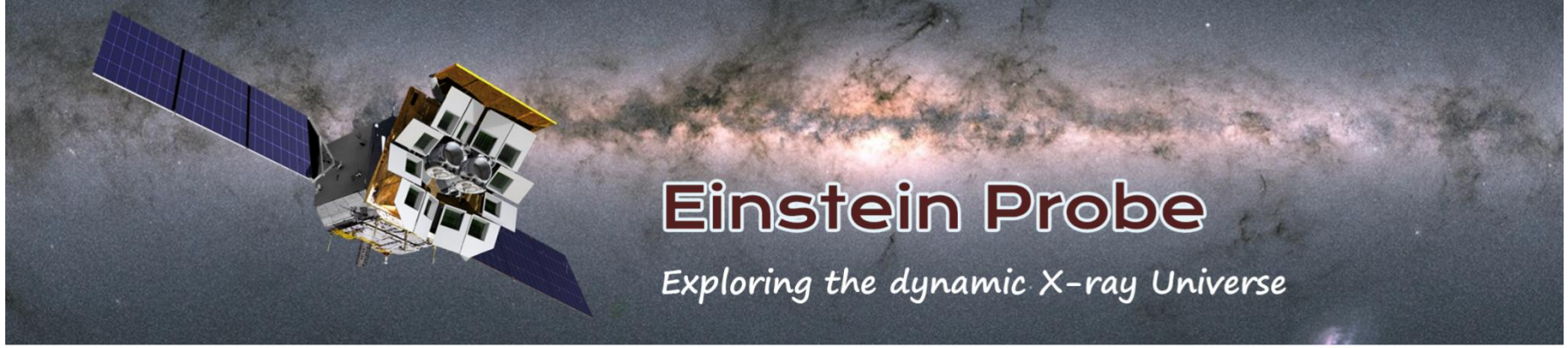
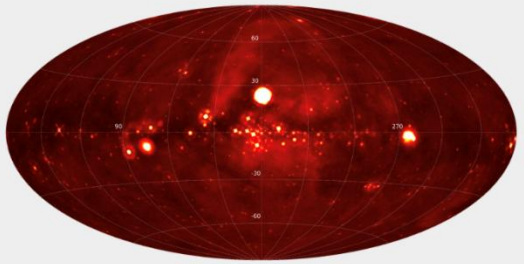
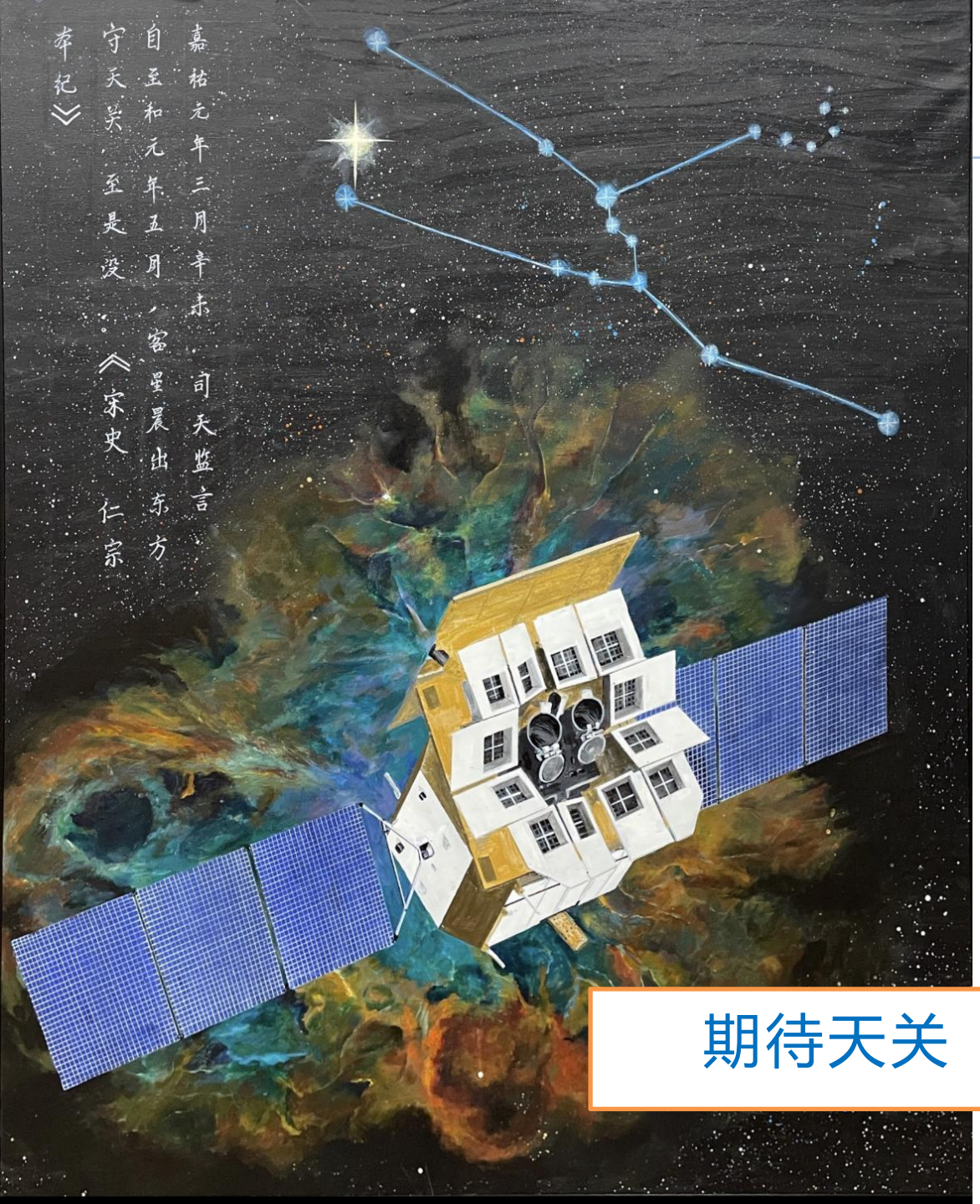


Overview

The Einstein Probe (EP) is a mission of the Chinese Academy of Sciences (CAS) dedicated to time-domain high-energy astrophysics. Its primary goals are to discover high-energy transients and monitor variable objects. To achieve this, EP employs a very large instantaneous field-of-view (3600 square degrees), along with moderate spatial resolution (FWHM ~5 arcmin) and energy resolution.





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期待天关（EP）卫星取得更多重要科学结果！