



中国科学院
CHINESE ACADEMY OF SCIENCES



Yuan Liu

Exploring the ever-changing X-ray Universe

Einstein Probe

National Astro. Observatories
Chinese Academy of Sciences

On behalf of EP consortium

New high-energy transients & science questions

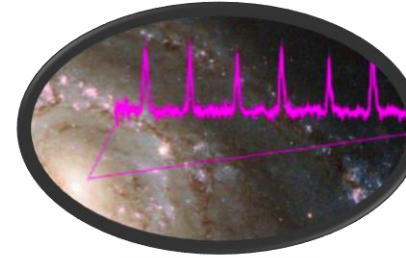
BH tidal disruption event

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



Quasi-periodic eruption

EMRI as GW sources?



Small numbers of known objects

High-redshift GRB

When first stars formed?
metal enrichment in early universe

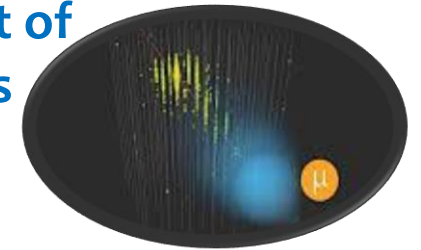


Next generation X-ray monitors needed to see

- deeper/further
- High cadence

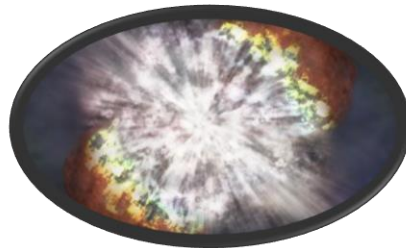
EM counterpart of neutrino events

How particles Accelerated?



Supernova shock breakout

Supernova physics & progenitors



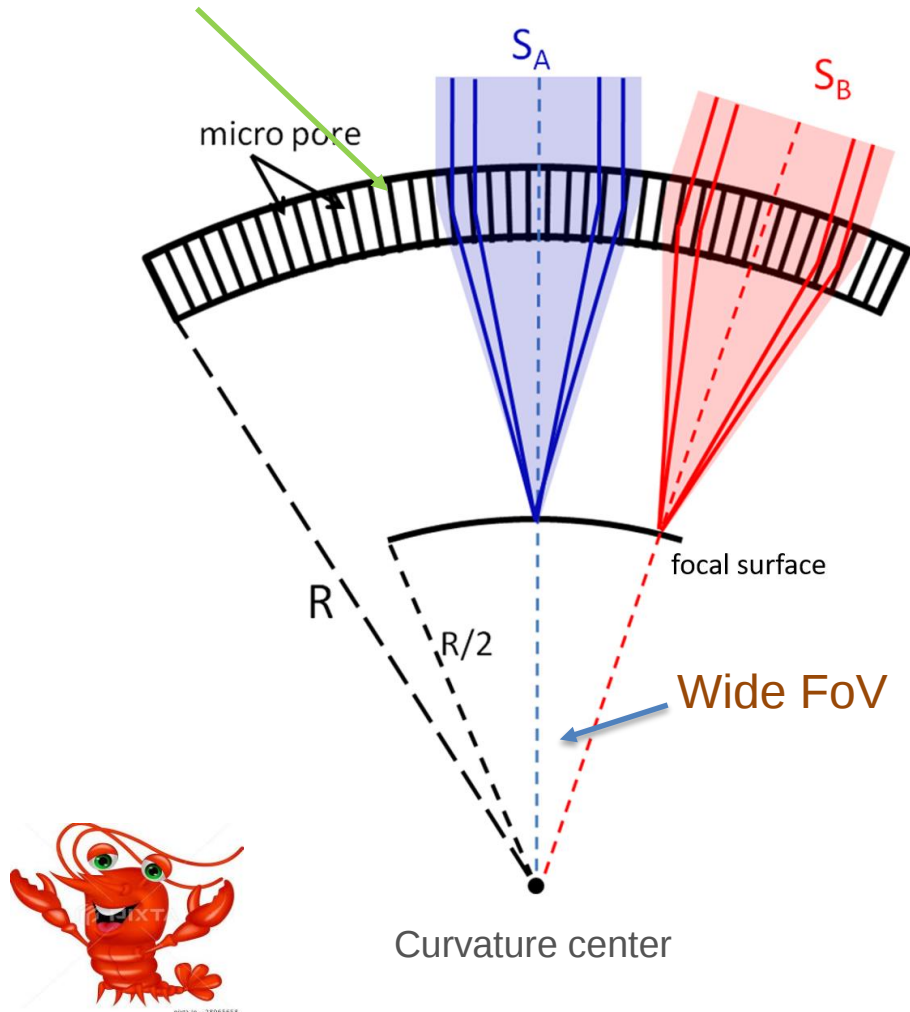
EM counterpart of gravitational waves

What are EM counterparts?
How compact objects merge?



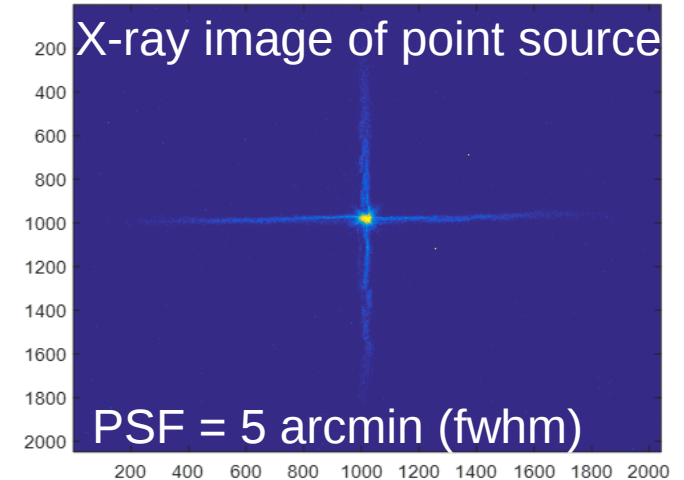
Lobster-eye micro-pore optics (MPO) for X-ray focusing

grazing incidence reflection



ideal optics for X-ray wide-field monitors

- * wide field of view
- * better angular resolution (5 arcmin)
- * higher sensitivity
- * optimised in soft X-ray



first proposed by R. Angel (1979); studied by a number of groups for many years e.g. Wilkins et al. (1989) ; Fraser et al. (1992); Kaaret (1992), also at NAOC since 2010

Einstein Probe (EP) mission of CAS

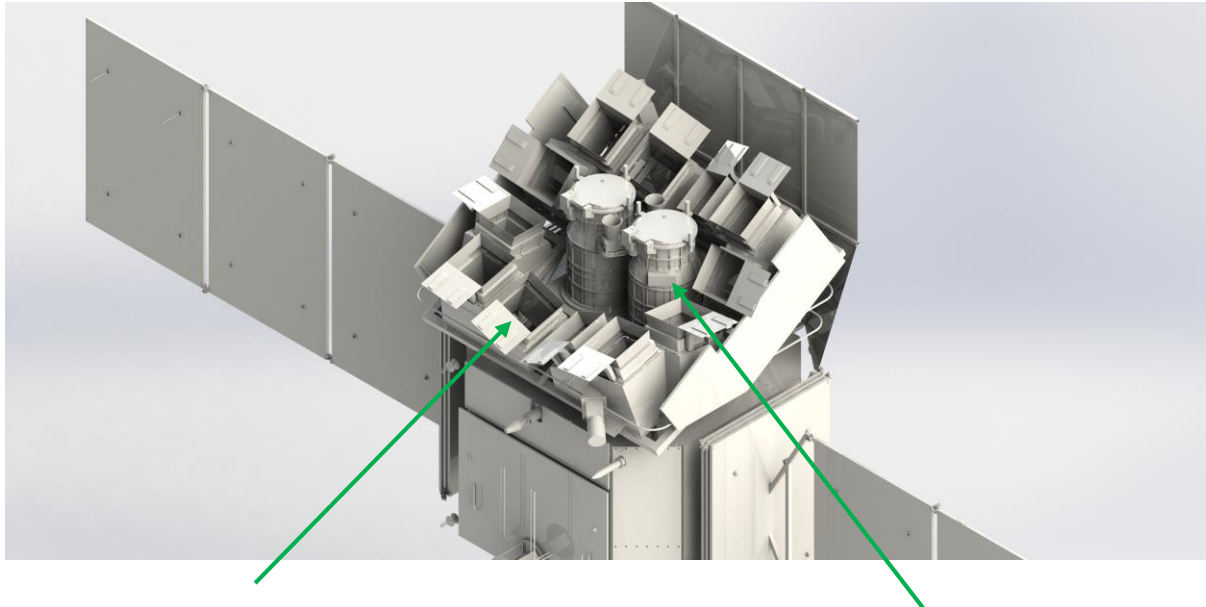


EP science goal
X-ray all-sky monitoring to discover & characterise high-energy transients, and to monitor variability of X-ray sources, at sensitivity > 1 order of magnitude better than current ones

- 2012: EP proposal
- Adoption: 2017-12
- CDR: 2022-03
- Current in phase D (Flight Model)
- Planned launch: by the end of 2023
- Lifetime: 3 years (goal 5 yr)
- International collaboration: ESA & MPE (+CNES)



Instruments & SC



Spacecraft



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

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



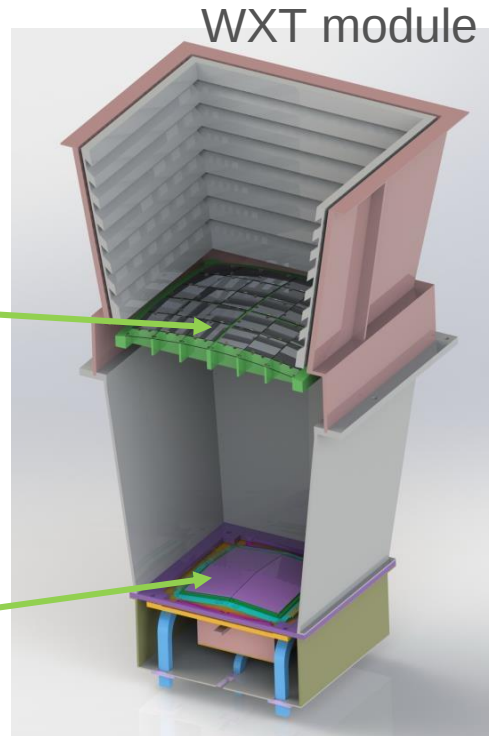
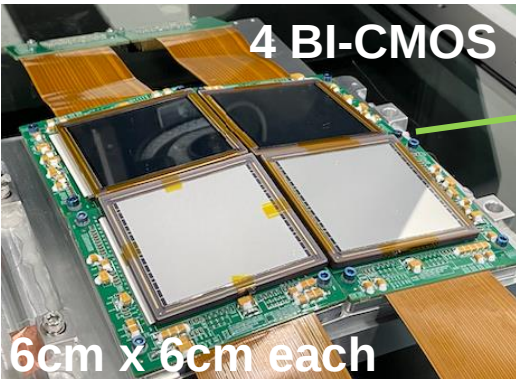
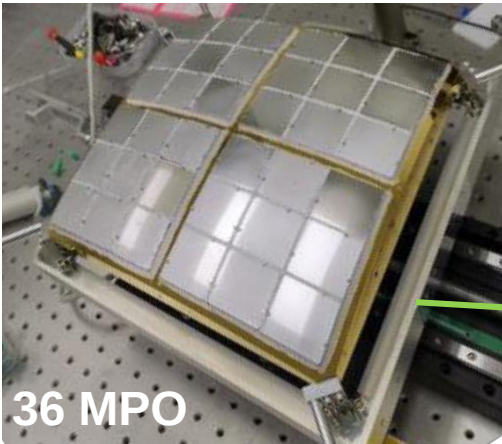
lobster-eye MPO
FoV: 3600 sq deg (1.1 sr)
band: 0.5 – 4 keV
spatial resolution: ~ 5' (FWHM)
sensitivity: tens times better than current

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



Wolter-1 optics
FoV: ~1 deg
band: 0.3-10 keV
effective area: 300 cm² @1 keV (1 unit)
spatial resolution: 30" (HPD on-axis)

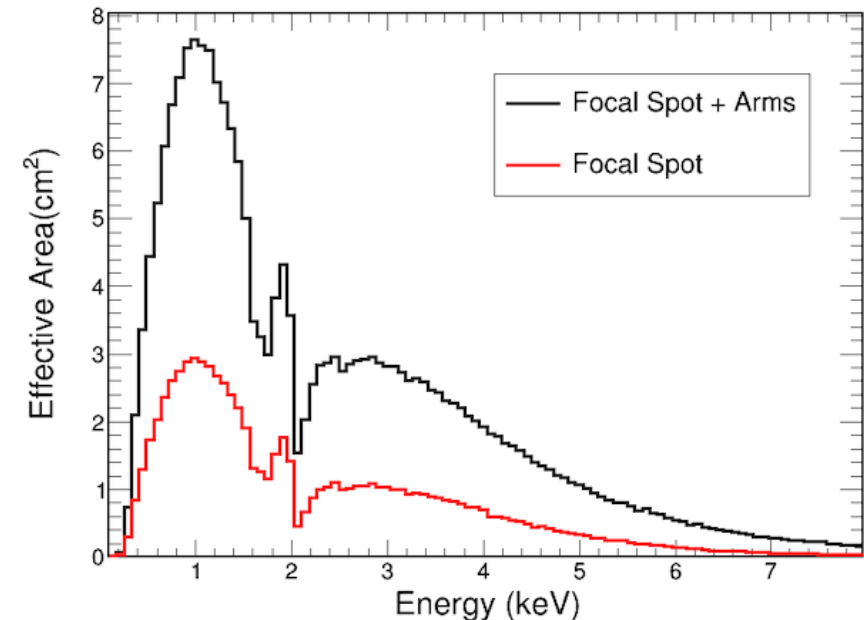
Wide-field X-ray Telescope (WXT)



Focal length 375mm

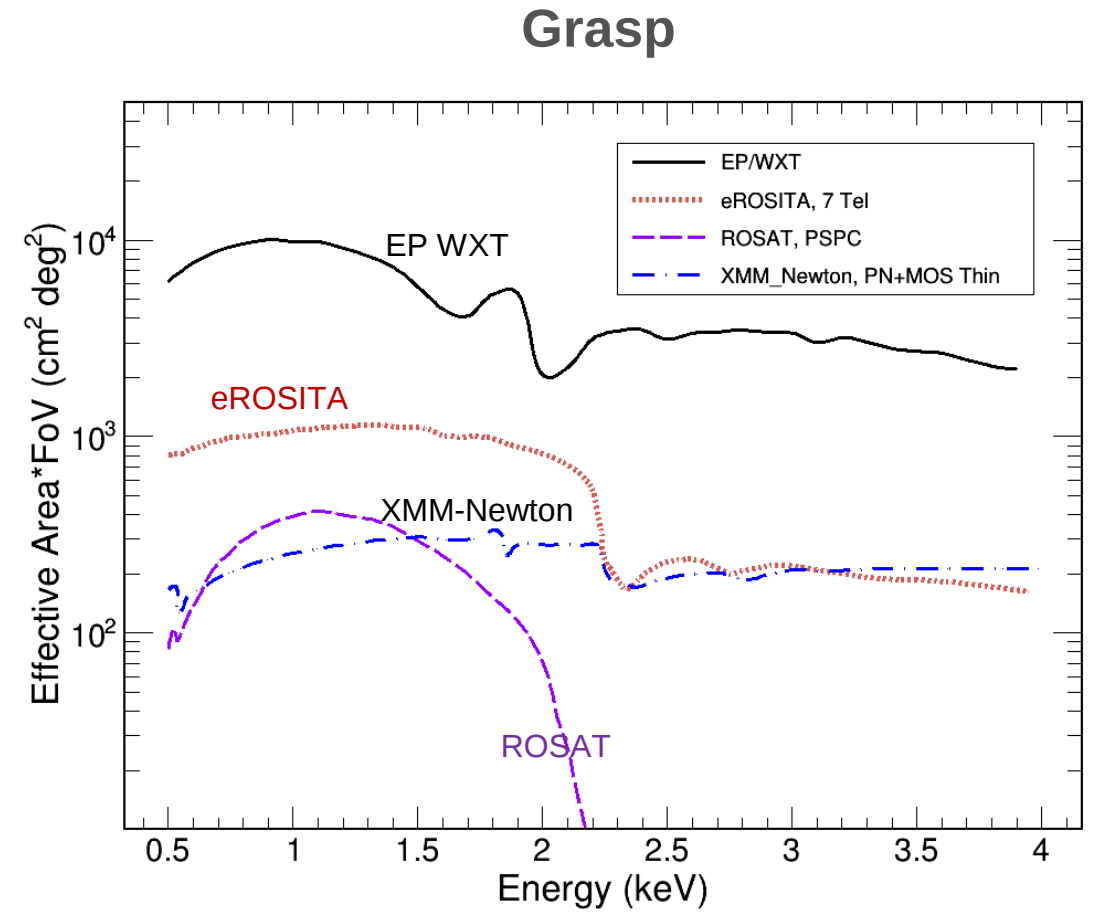
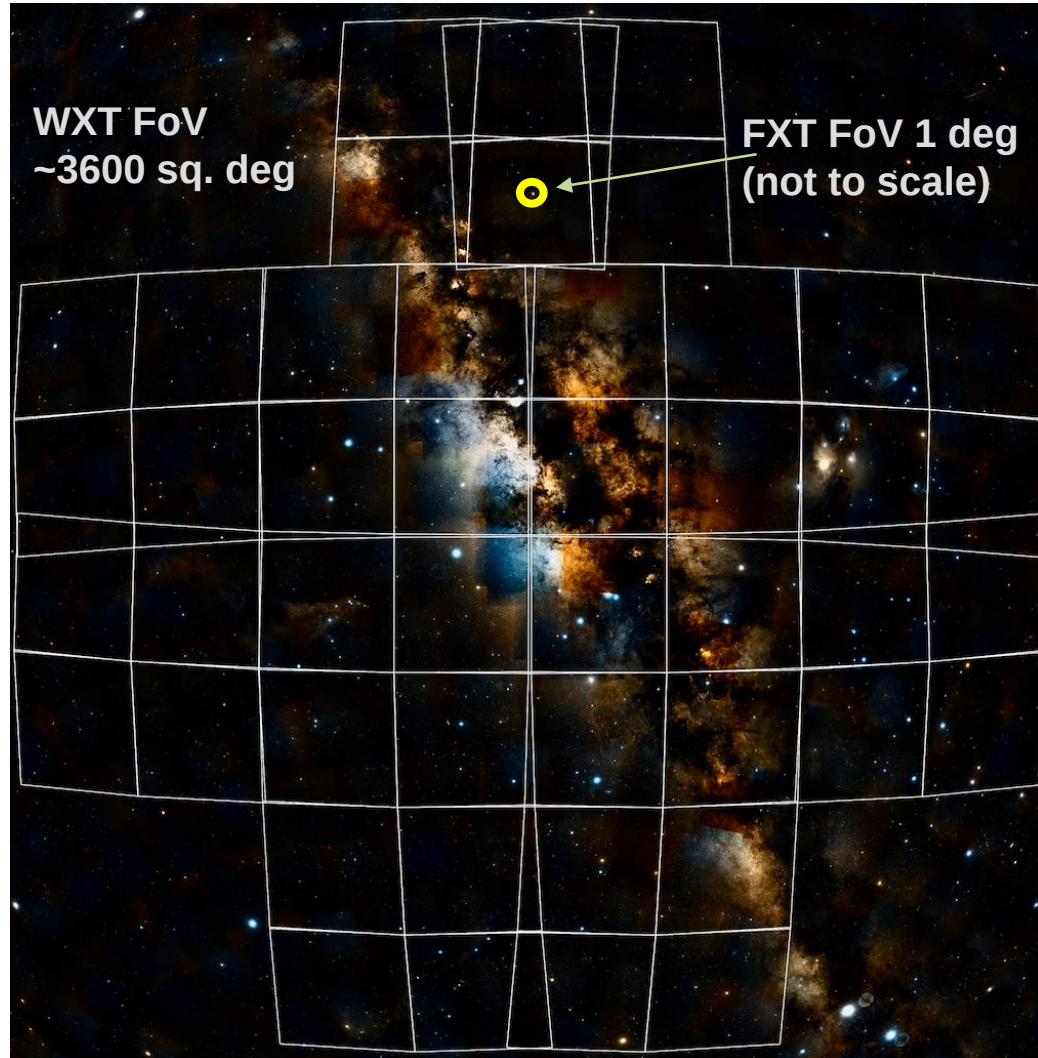
Technology challenges

- First large-FoV MPO telescope (432 plates)
- Large detector array (48 CMOS x 6 x 6 cm²)
- Use of CMOS as X-ray detectors in space
- Soft X-ray band



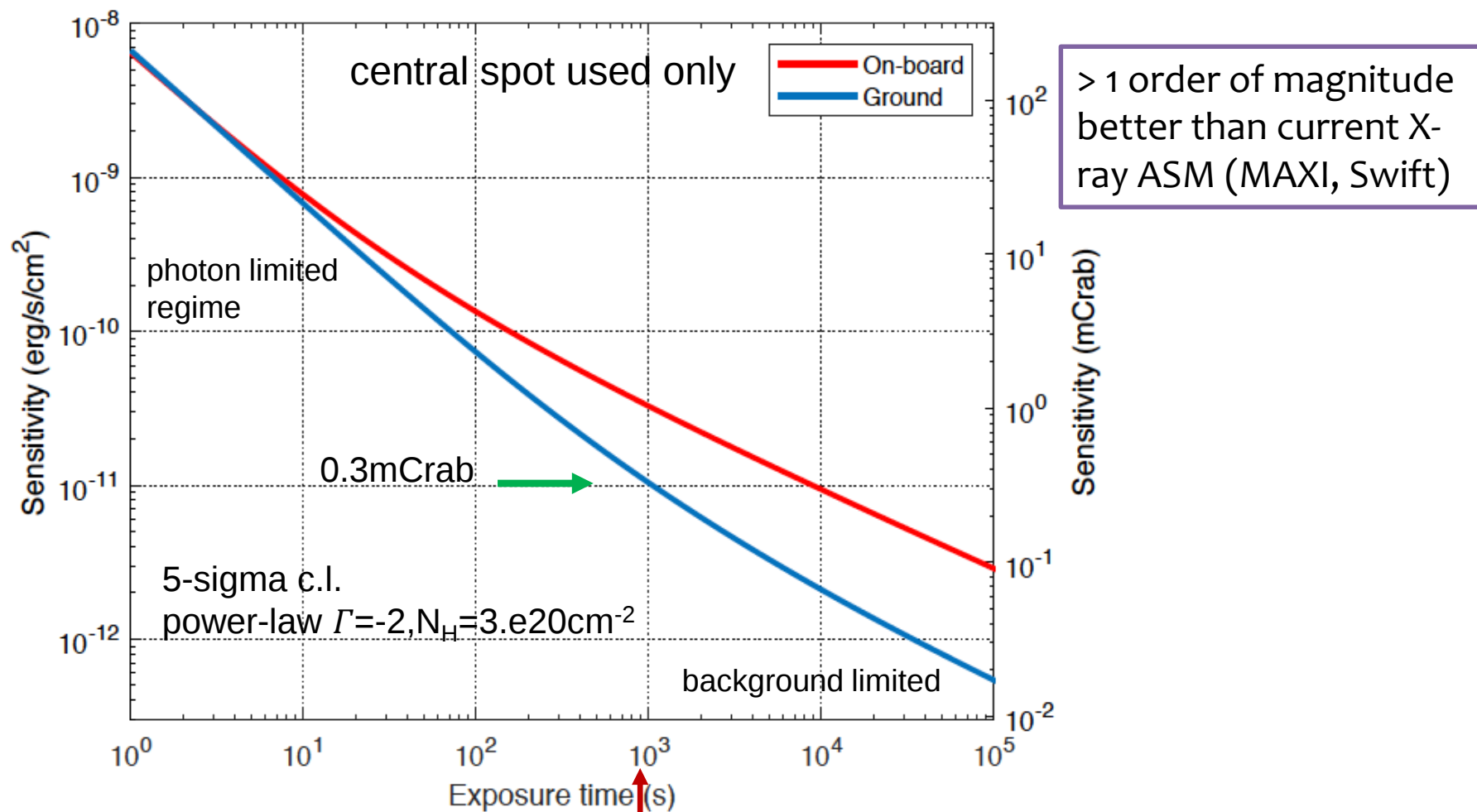
- development: CAS (SITP, NAO) + NNVT
- test/calibration: CAS & ESA
- WXT PI: X. Sun (SITP);
- Instr. Sci: Z. Ling (NAO); MA PI: C. Zhang (NAO)

WXT FoV & Grasp



Zhao D. et al. 2017

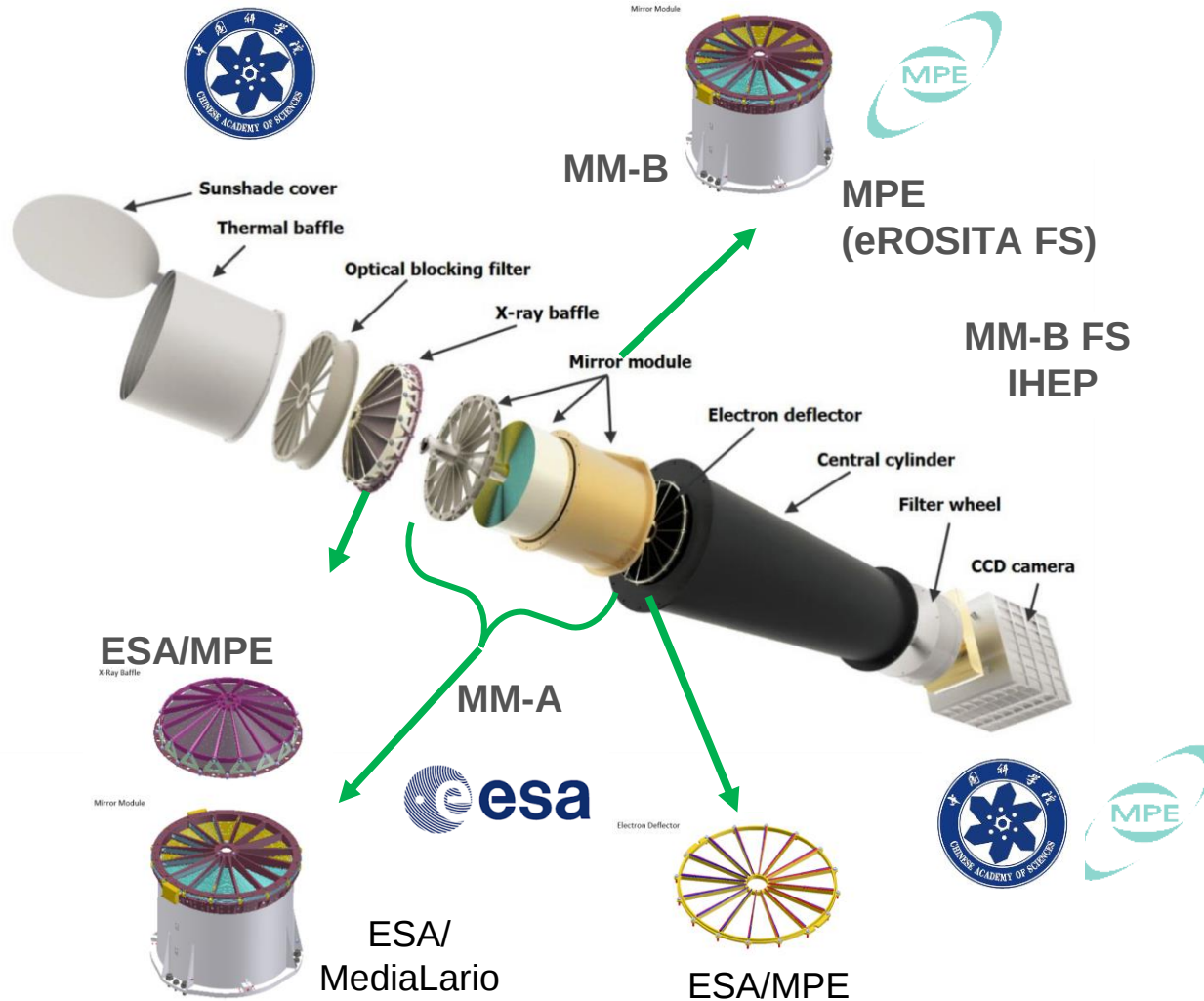
Simulated EP WXT sensitivity



~ 1 survey snapshot
background 3.3 counts @ central spot

Zhao D. et al. 2017

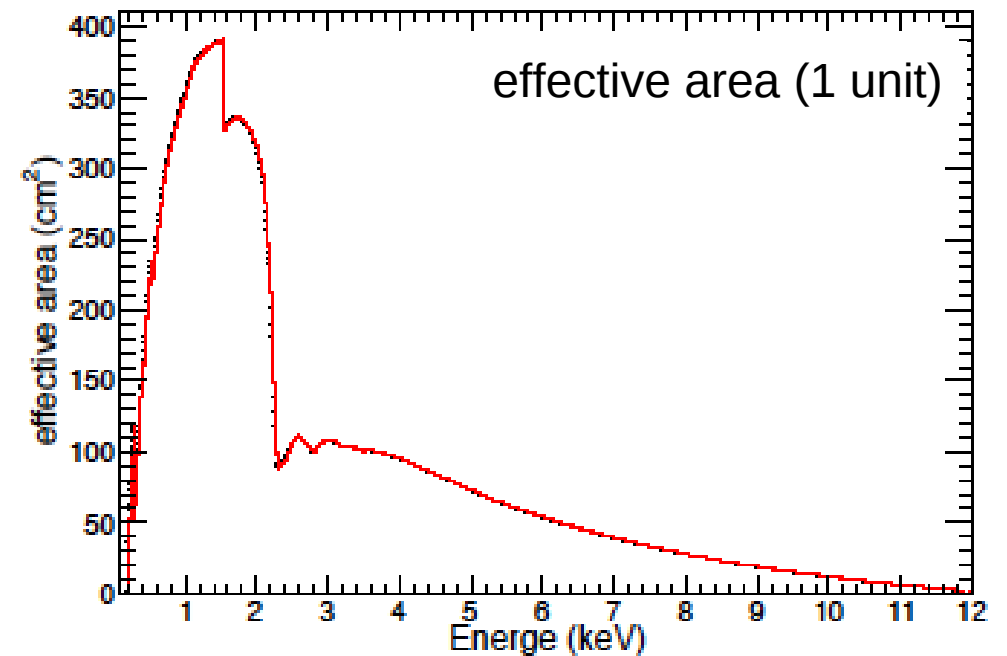
Follow-up X-ray Telescope (FXT)



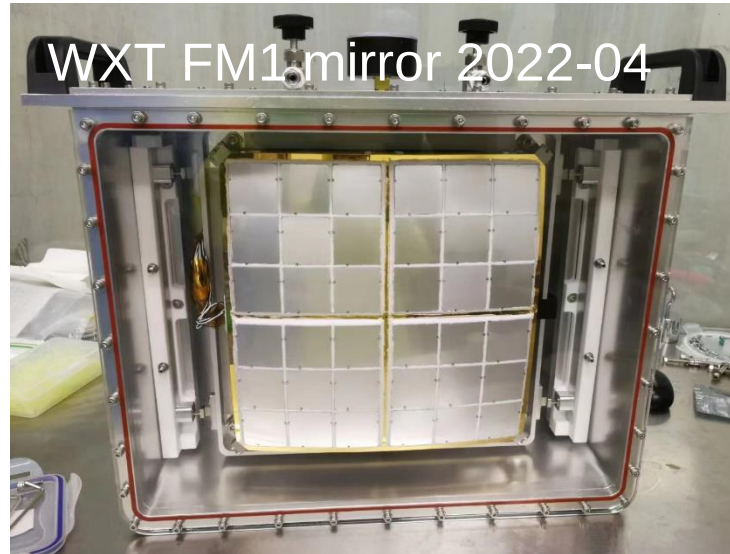
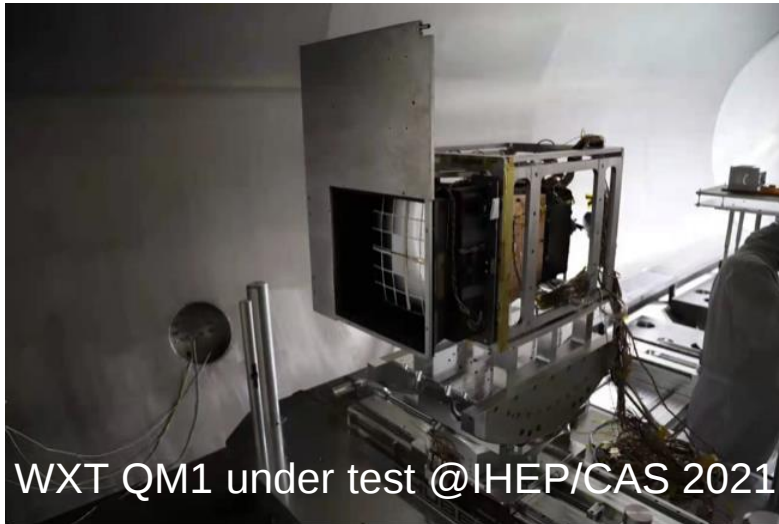
CAS/IHEP+ ESA + MPE

PI: Y. Chen (IHEP)

- X-ray optic
 - eROSITA design
 - ESA + MPE
- X-ray cameras
 - PN-CCD module (MPE)

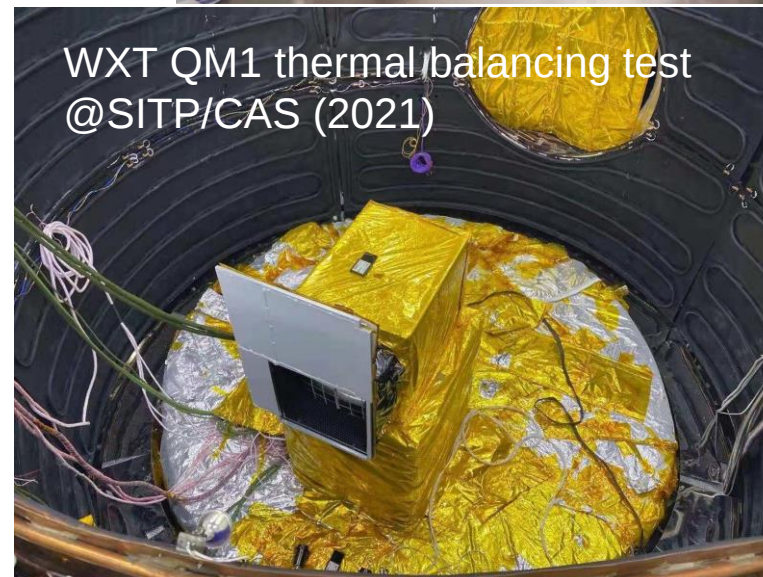


WXT status



Built and tested

- 2 QM of complete modules
- 2 FM mirror assemblies
- 1 FM complete module

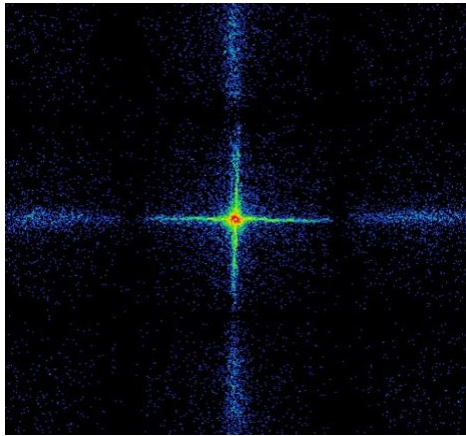


X-ray Test by ESA/MPE @Panter MPE 2021-04

WXT status

X-ray image of point source

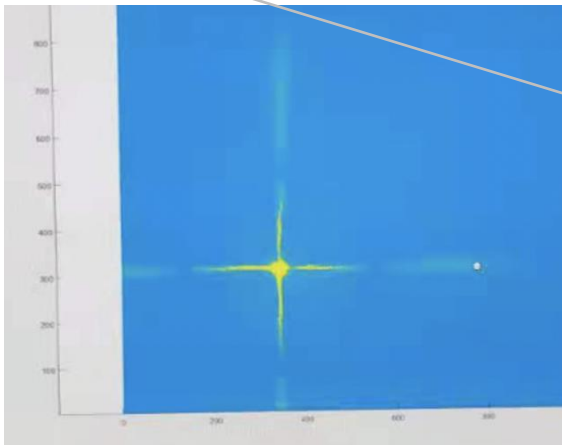
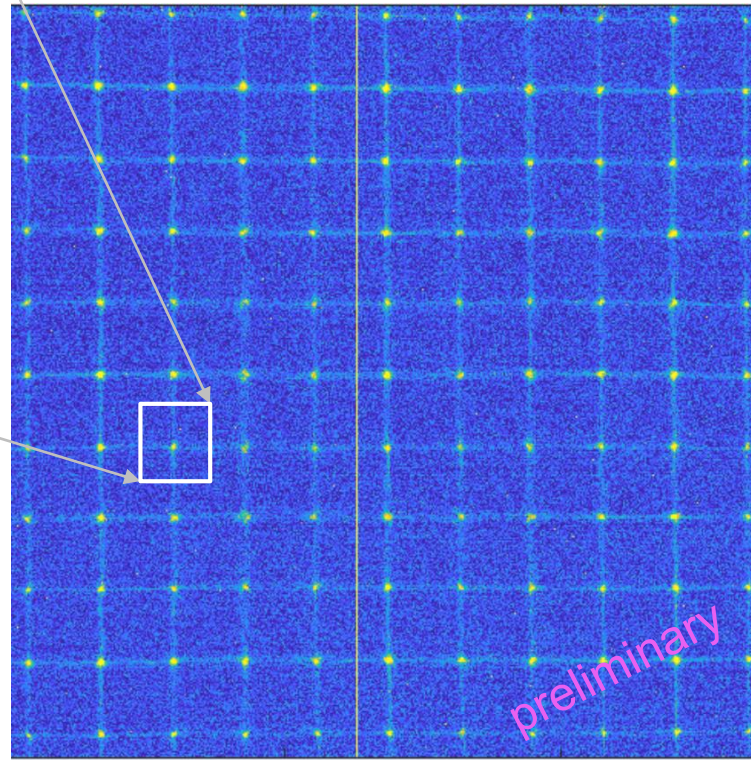
FWHM 4 - 5.5 arcmin



1/4 FoV of a WXT module MA

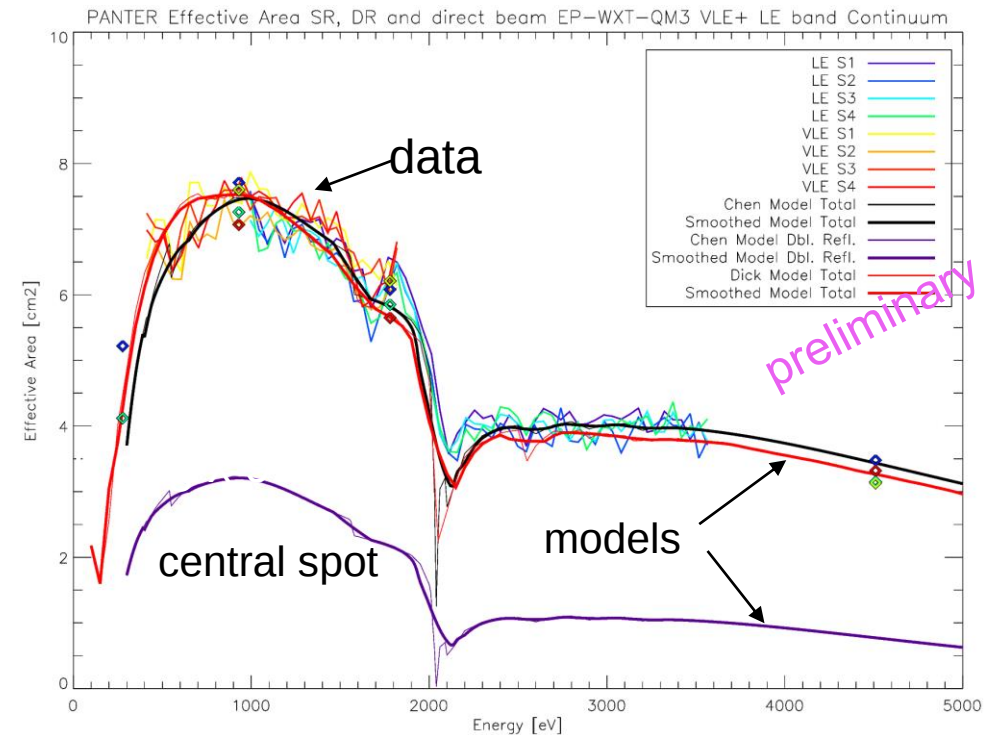
~ 9 deg x 9 deg

PSF images of point-source
from 121 directions



PSF for a complete WXT module

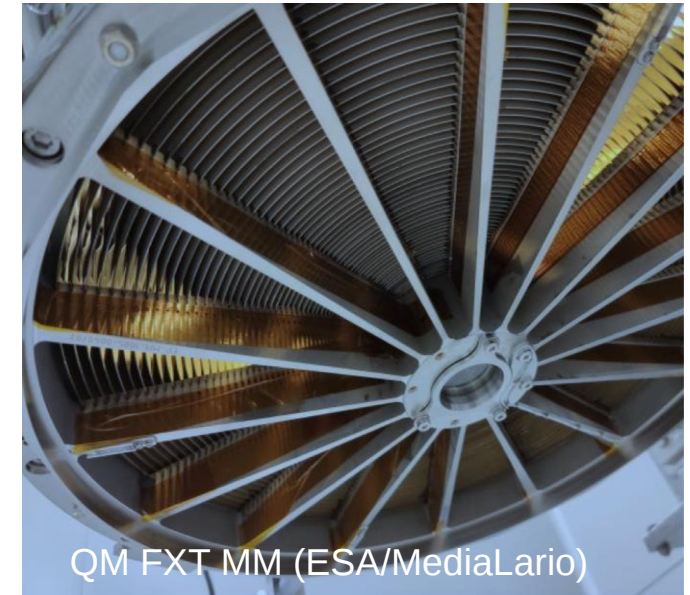
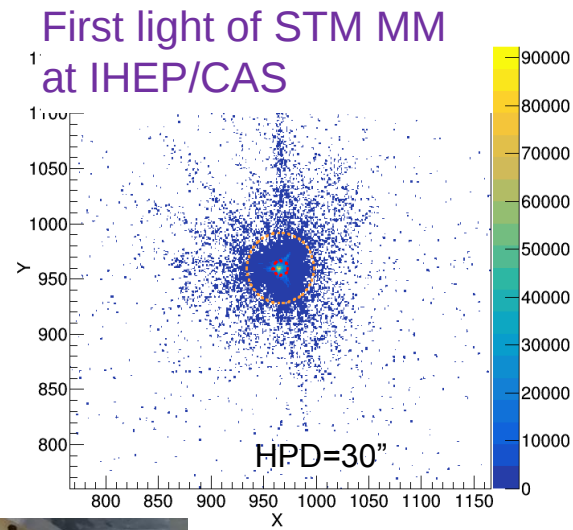
Measured effective area (cm² vs. energy)



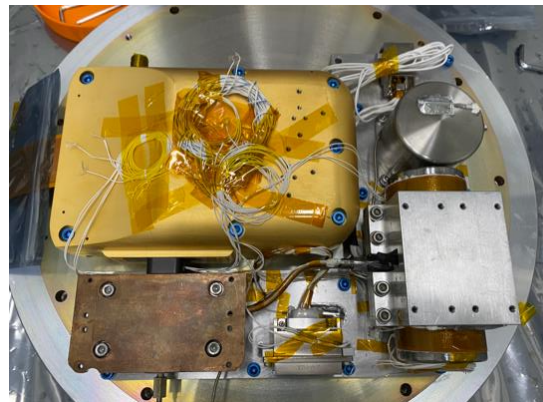
Credit: CAS/ESA/MPE

FXT Status

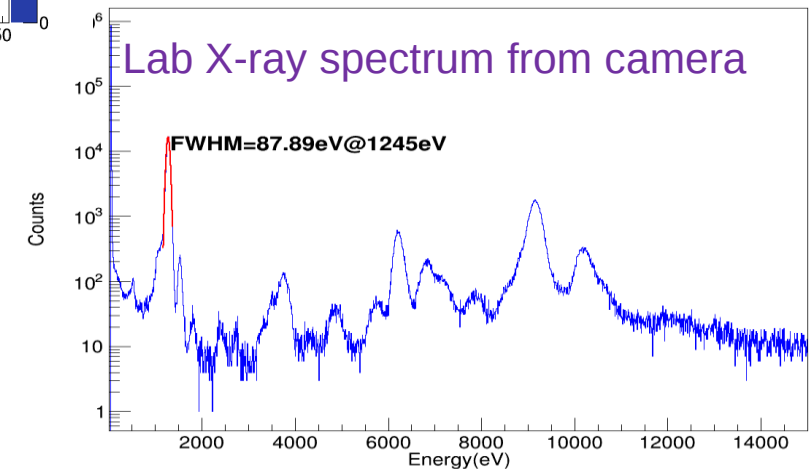
- X-ray camera QM built at CAS/IHEP (detector module from MPE)
- Joint test of STM of mirror module and camera QM at CAS/IHEP
- FM of mirror module (ESA/Media-Lario/MPE) delivered to CAS



Camera assembling at IHEP



X-ray camera QM



Satellite status: QM AIT

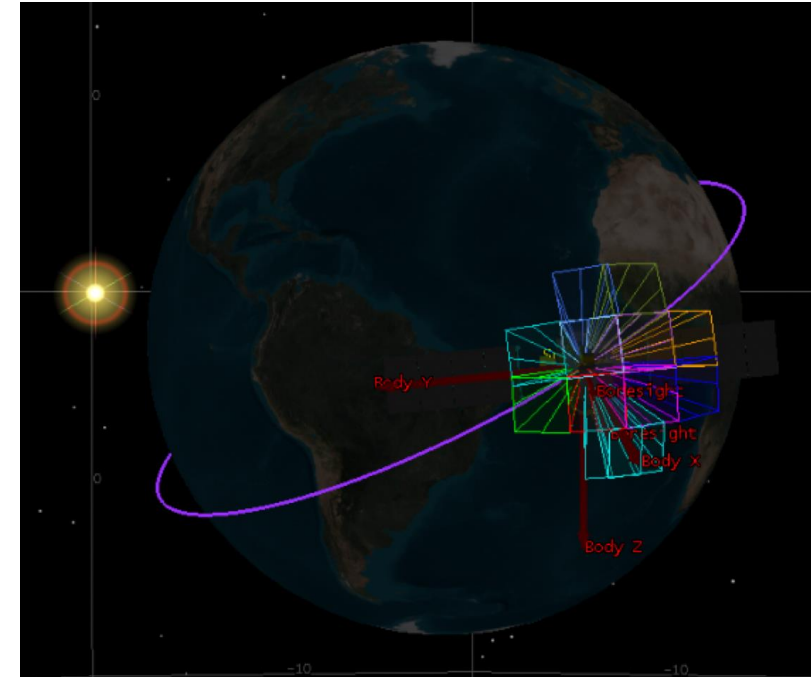
Satellite QM built and tested at MicroSat/CAS (2021-09/10)



Credit: MicroSat/CAS

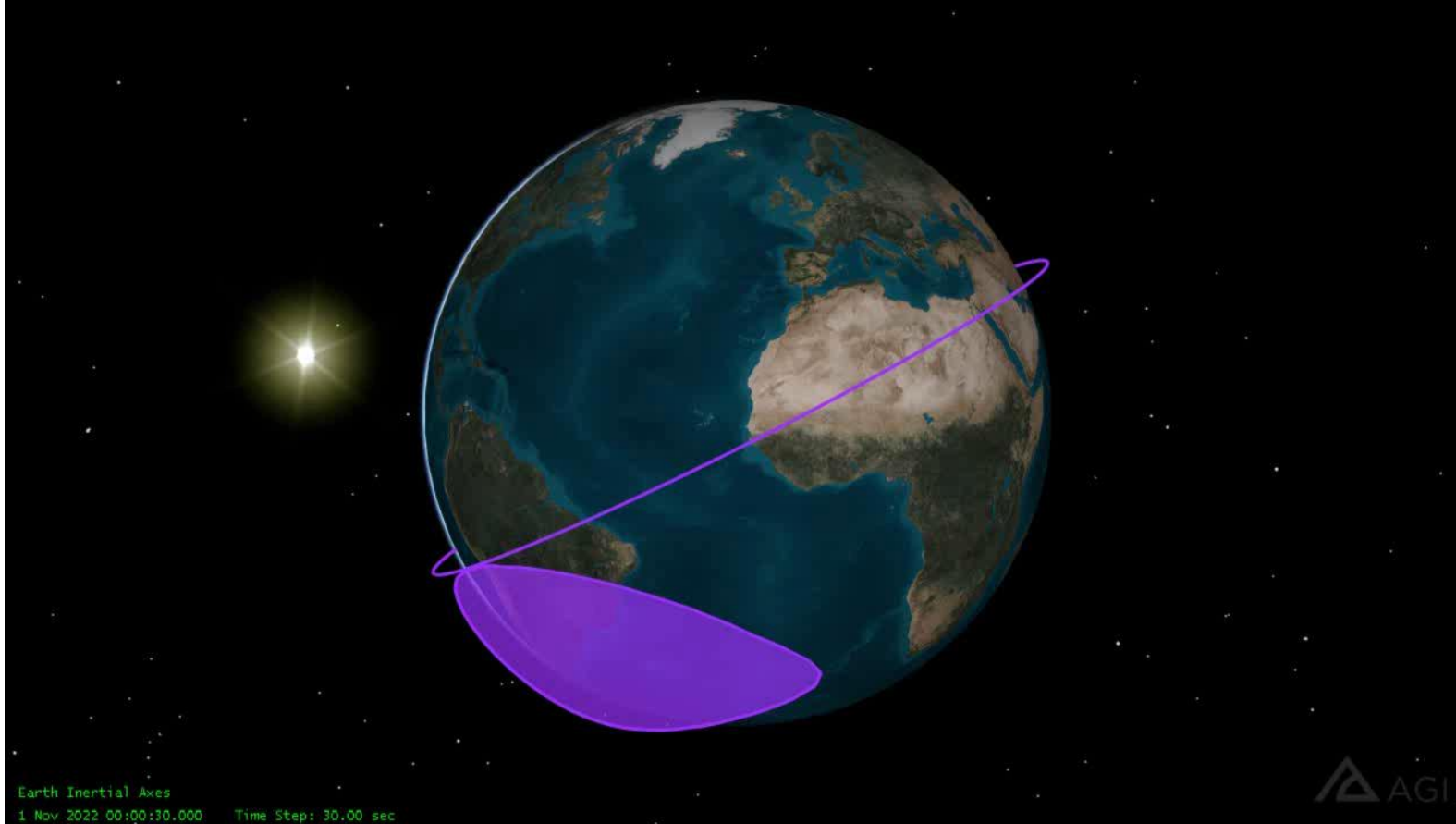
Mission profile

- Orbit: ~ 600 km (96min), incl. 29 deg
- Operation modes
 - **Survey (WXT)**
 - **Autonomous X-ray follow-up (FXT)**
 - **Target of opportunity (FXT, WXT)**
- Alert data rapid downlink
 - Beidou system (China)
 - VHF (CNES/France)
 - **Transient alert information to be released immediately and publicly**
- Target of opportunity command uplink
 - Normal (S-band): < 1 day
 - Time critical (Beidou): < 10 min

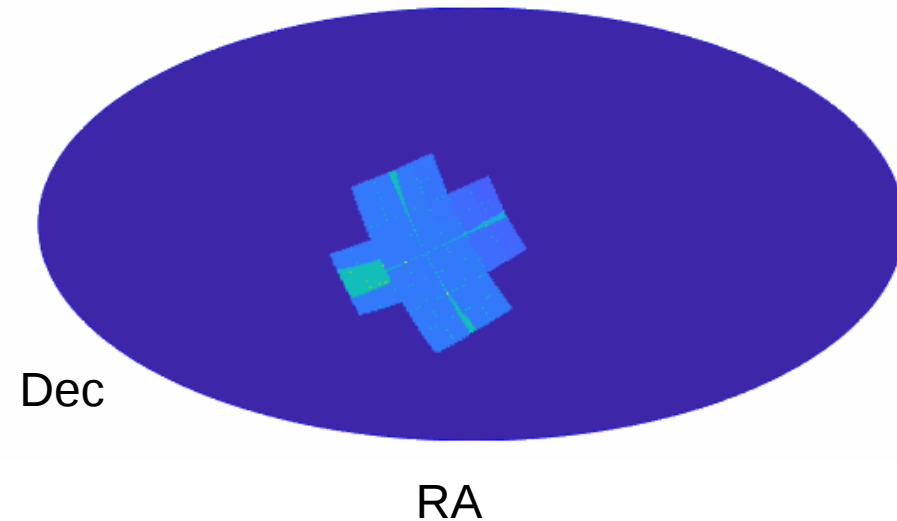


- EP Mission Centre @ NSSC/CAS
ESA (GS telemetry support)
- EP Science Centre @ CAS
NAOC+IHEP

EP all-sky survey mode



- anti-Sun pointings
- 3 snapshots per orbit, each ~20 min
- 3 orbits (~ 5 hr) cover half sky
- 1 day: ~ 45 snapshots



Main science objectives

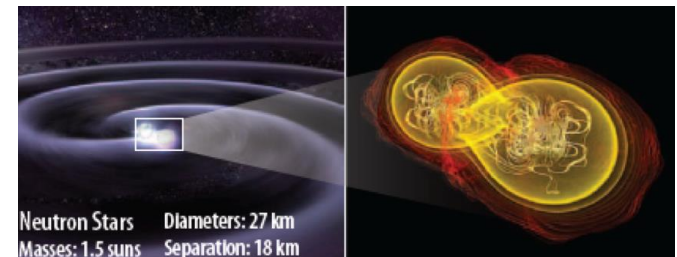
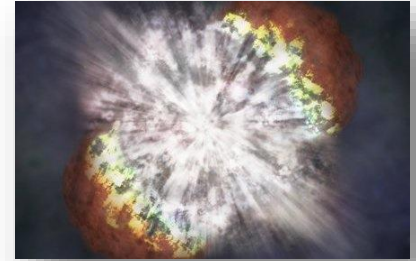
Systematic survey of soft X-ray transients and variability of X-ray sources at an unprecedented combination of high sensitivity and cadence



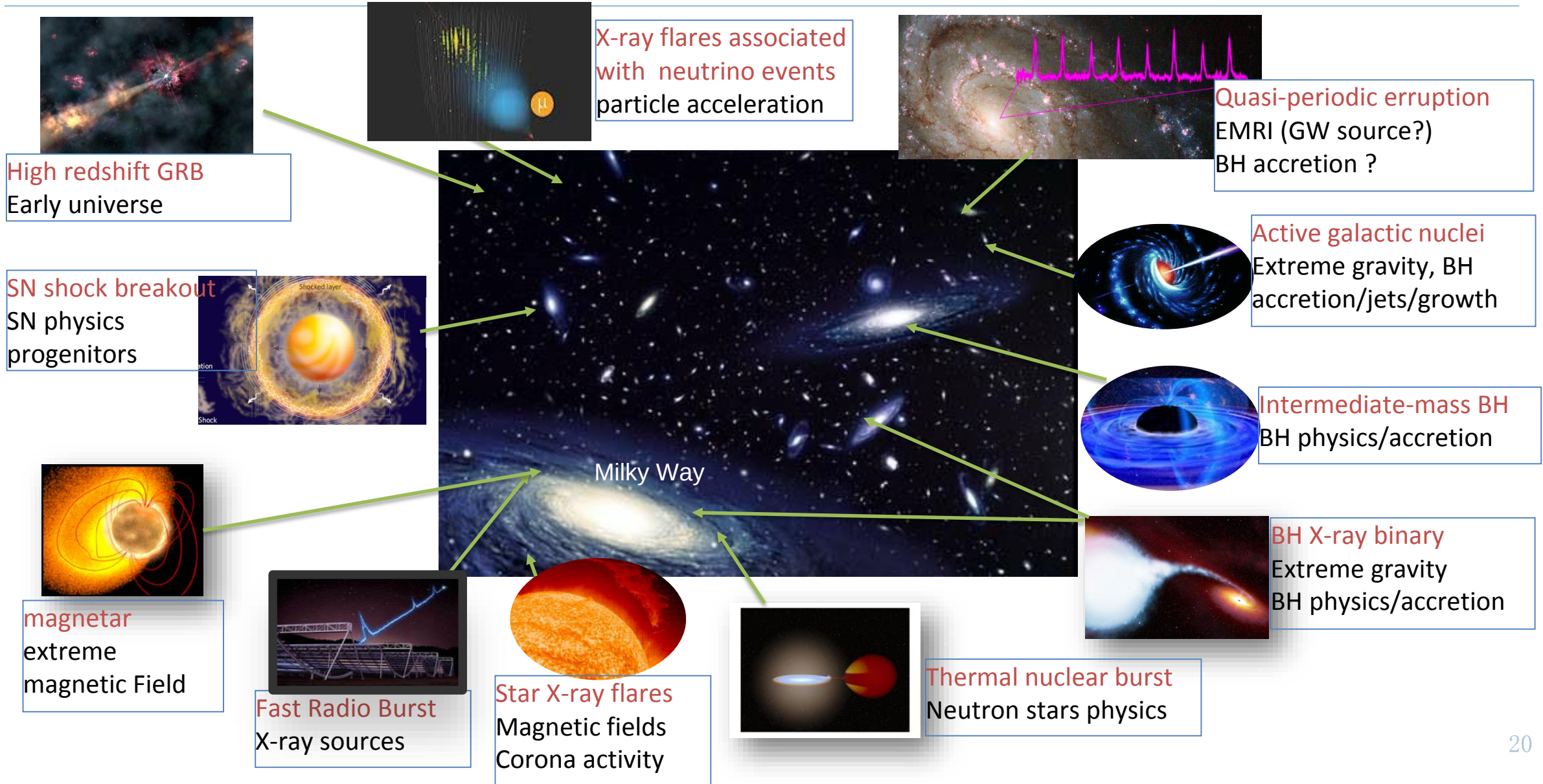
Discover otherwise quiescent **black holes** at almost all astrophysical mass scales and other compact objects by capturing their transient X-ray flares



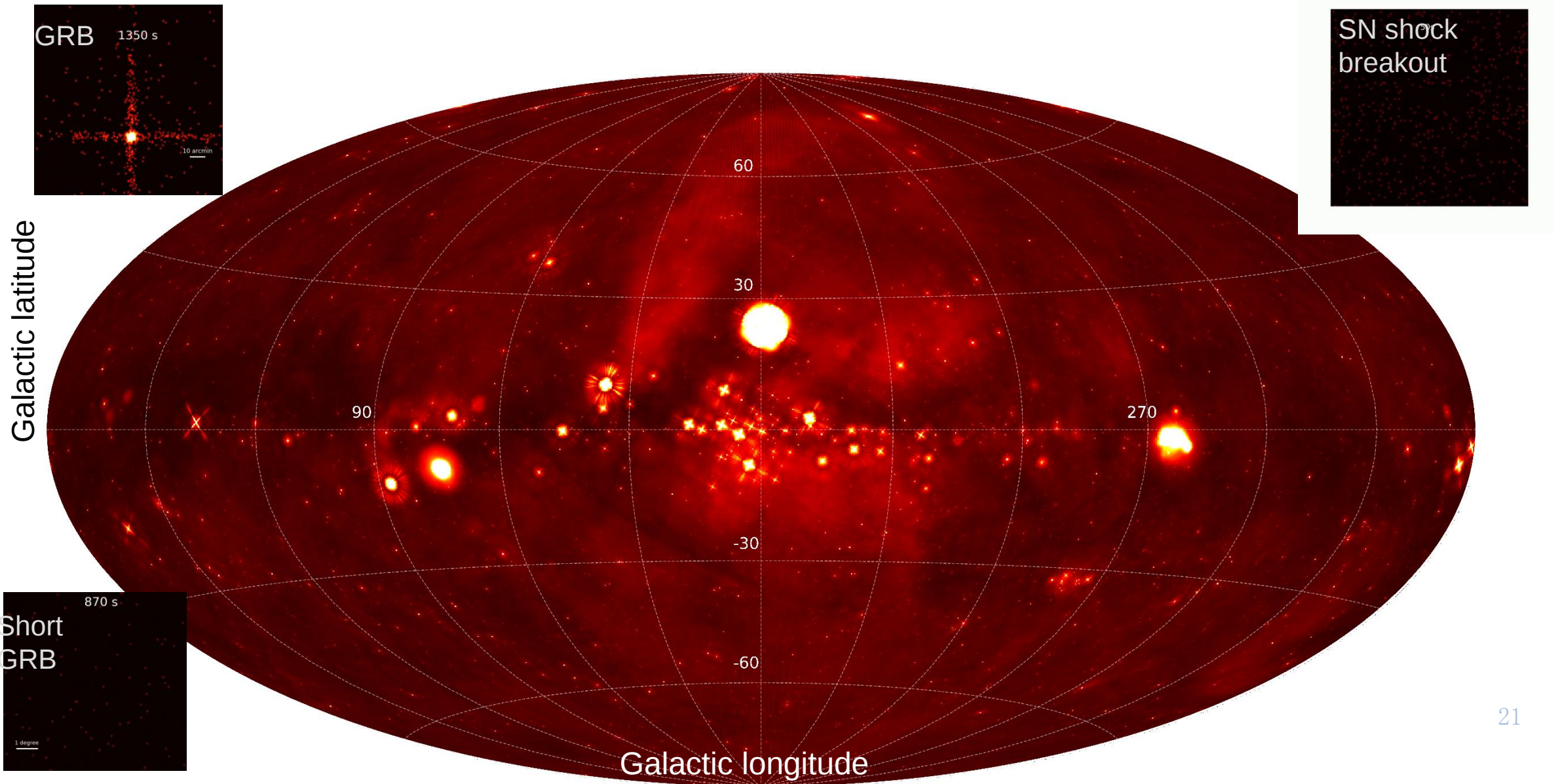
Detect and localise the electromagnetic-wave sources of **gravitational-wave** events by synergy with gravitational-wave detectors



Various classes of high-E transients & variability



Simulated all-sky image & transients in 1-year



Estimated detection rates for selected classes

Type of transients	Detections per year
--------------------	---------------------

Tidal disruption event (TDE)	10s - 100
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TDE with jet	several
--------------	---------

Supernova shock breakout	10 – 10s
--------------------------	----------

Long GRB	10s
----------	-----

High-z GRB ($z > 6-8$)	several
--------------------------	---------

challenging to
measure redshift !

Short GRB	10
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Low-luminosity GRB	10
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Magnetar	a few
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Stellar flares	a few 10^3
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AGN monitored daily / weekly	tens / hundreds
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transients per week

EP: >10

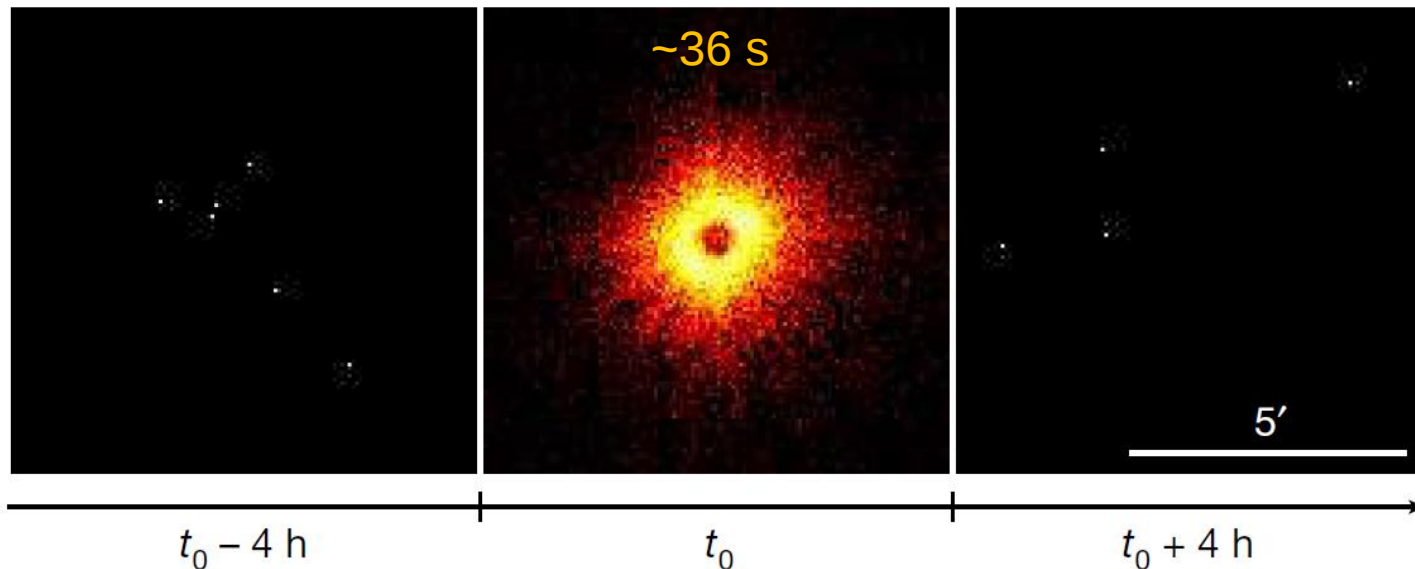
Swift: 2.5

MAXI: 0.8

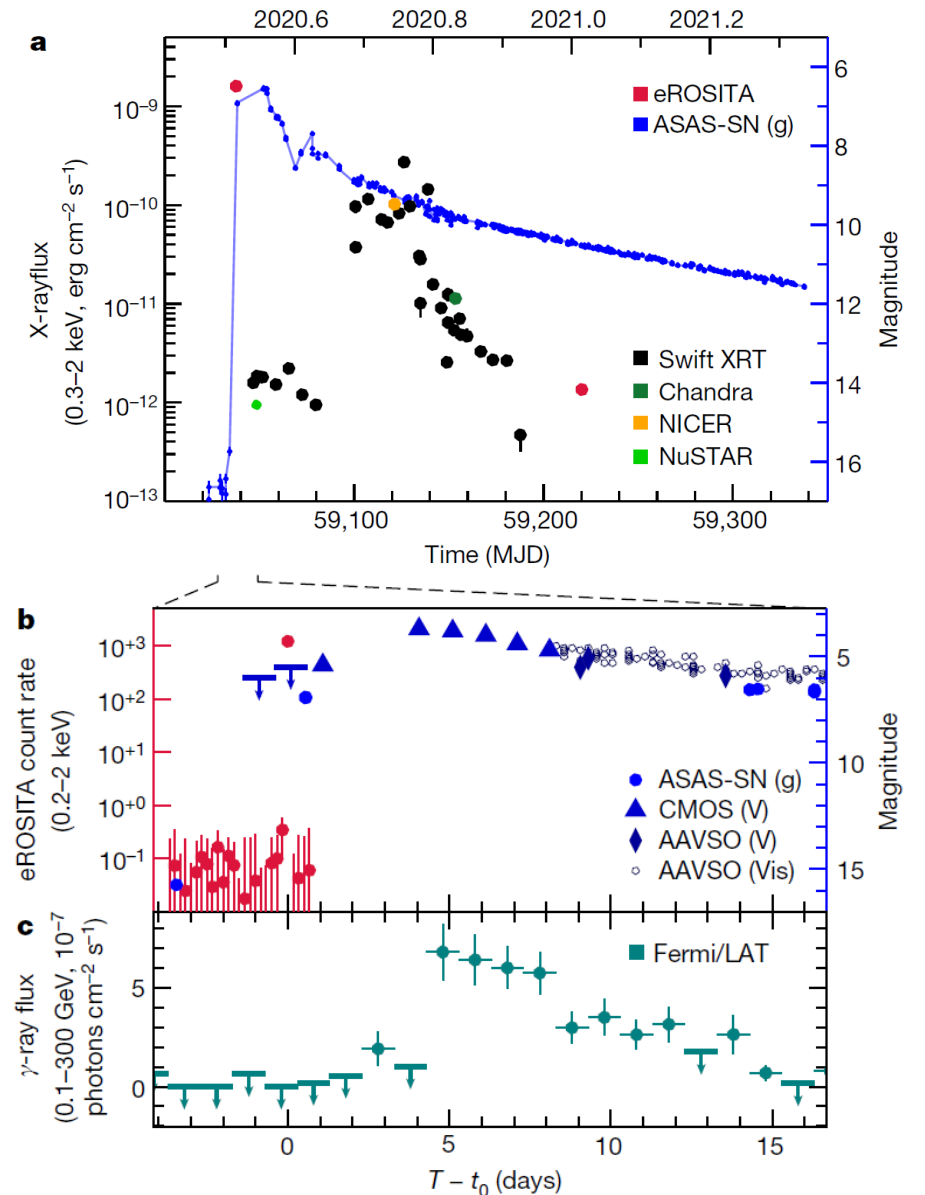
Note: subject to large
uncertainties...

The fireball phase of a nova (YZ Reticuli)

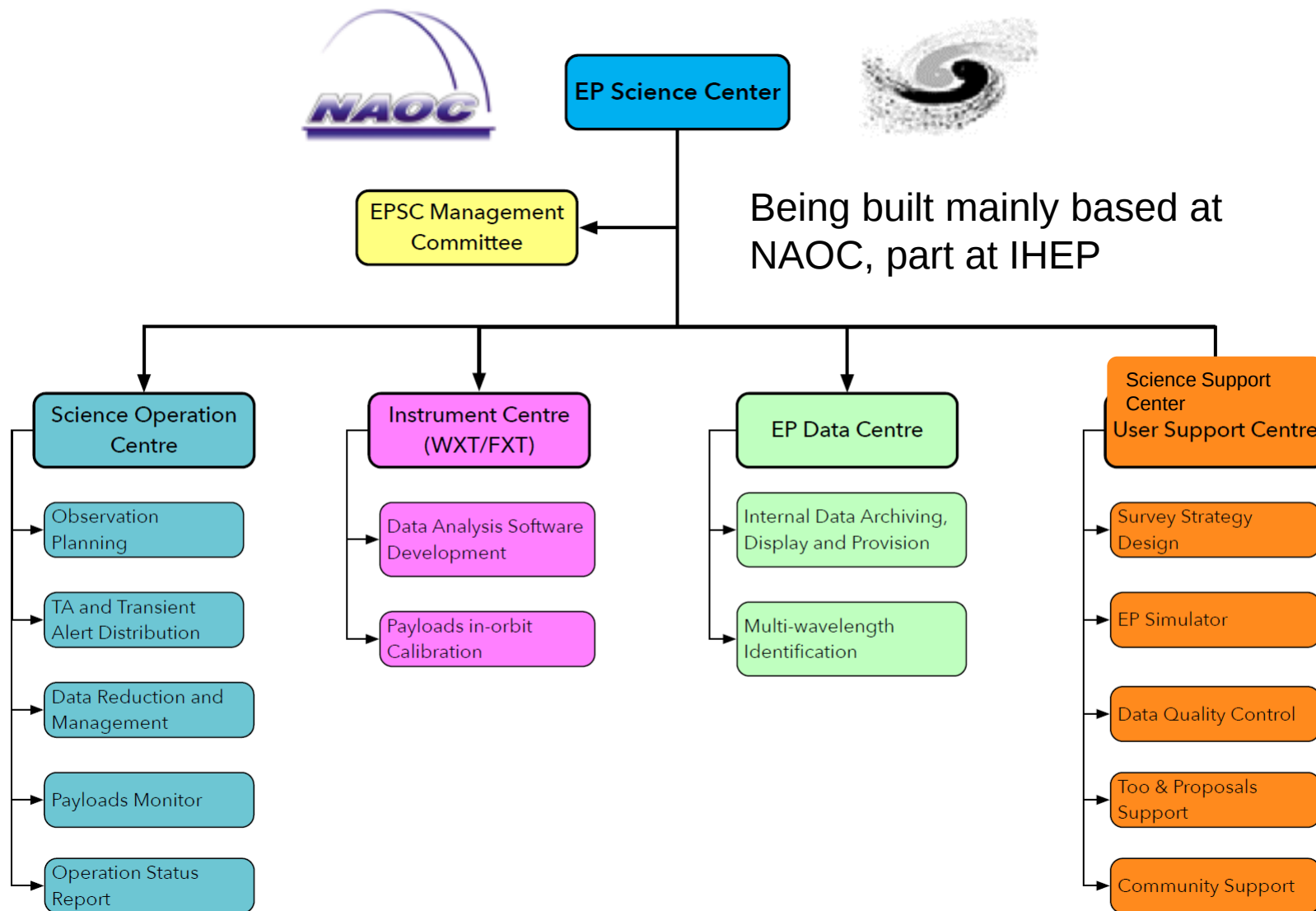
- A short, bright and soft X-ray flash before the nova becomes visible in the optical
- 6-12 h for 1.0 M_{sun}
- filled a gap in our understanding of how classical novae occur



König+2022



EP Science Center



Proposal Tools

■ Proposal submission and review

Proposal Management

Science Use Case Submission

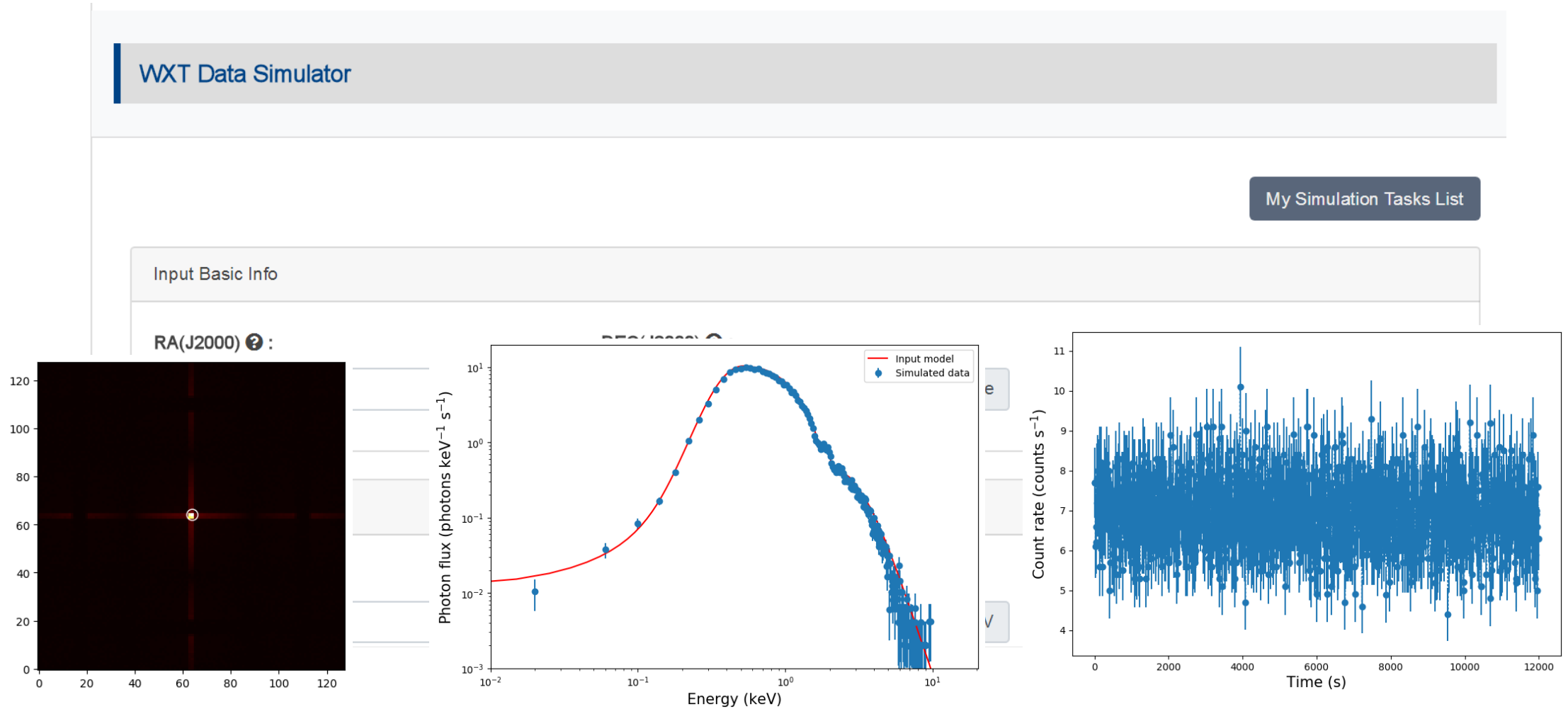
Proposal Content Filling

NO	Expiration(UTC+8)	PI-Name	Request(hours)	Status	Technical Review	Proposal	Peer Review
SQB-Test Season-0001	2022-05-29 00:00:00	Yunfei XU	0.2	Reviewed	View	View	Modify

Proposal Review Management

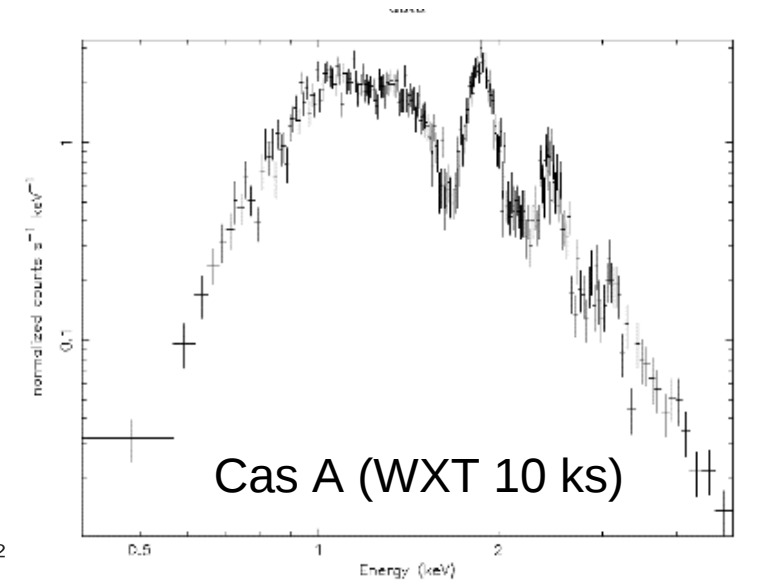
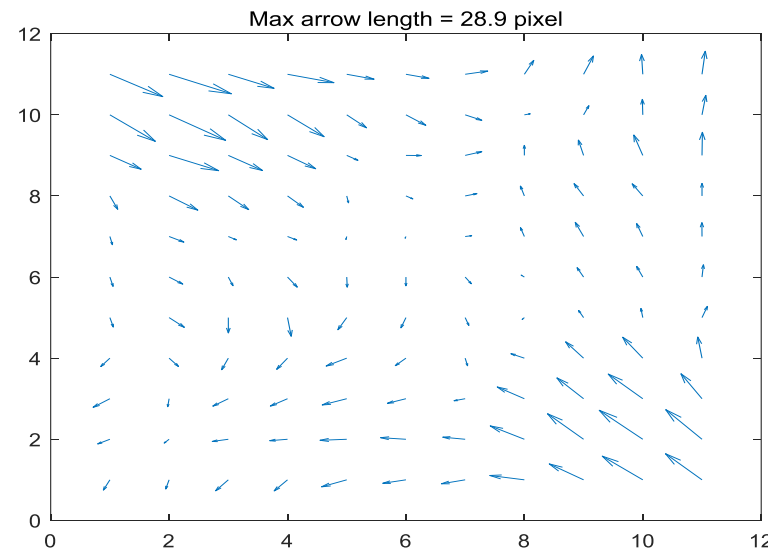
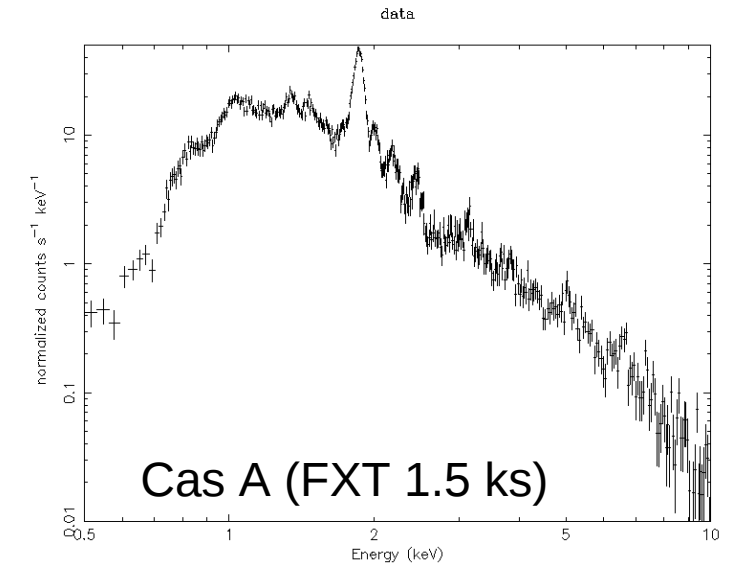
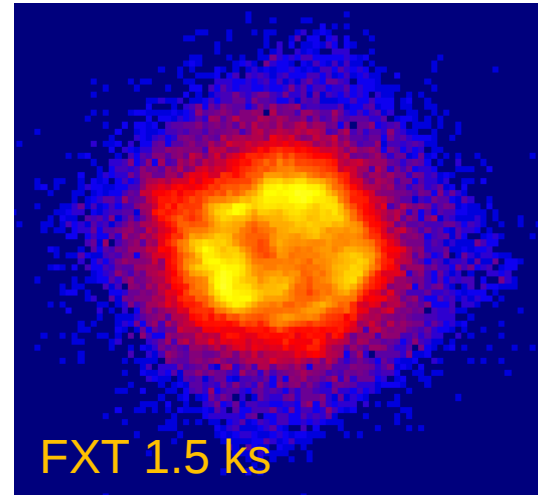
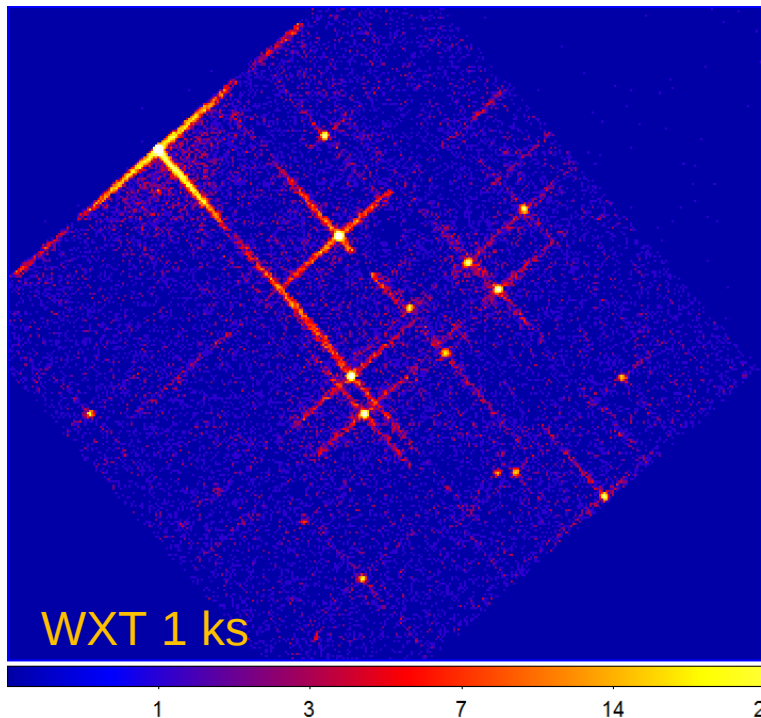
WXT online simulator

- Simple and quick



Data reduction software

- Define data products
- Build CALDB
- Develop and test software
- HEASARC framework



Transient database



Einstein Probe WXT Transients

The EP team has just performed a simulation for a on the satellite. The simulation mimics the equipment's c bursts (SGRBs), high-luminosity long gamma-ray bursts (HL-LGRBs), supernova shock breakout (SBO) ray bursts (HZ-GRBs), the bright sources m

The simulation data can be visualized and bro

Simulation Description

Last Updated at 2020-08

Three pointings observation per orbit

Two pointings observ

Observation Details

- **Observation mode:** Pointing observation in WXT Sky S
- **Observation Duration:** 2022.11-2023.10
- **Number of observations:** 16329
- **Data Volume:** 500GB
- **Simulation time:** 2.5 days under 55(64) cores

Input Samples

- **Known source:**
 - **ROSAT Point Source:** (1rxs + 2rxs)
 - **MAXI Source:** a total of 407, the number of arcmin) is 191
- **Transient:** TDE, SGRB, HL-LGRB, LL-LGRB, HZ-LGRB, SN-
- **Diffuse Radiation:** ROSAT diffuse radiation (0.09-0.2 ke

Exposure time



Einstein Probe WXT Transients

Source List

Explorer

Choose Observation Type:

two pointing observations

TDE

SGRBs

HL-LGRBs

LL-LGRBs

HZ-GRBs

J2000d

96.1901025 +50.2272813

Base image layer

DSS colored

Color map:

nativ

Reverse

Overlay layers

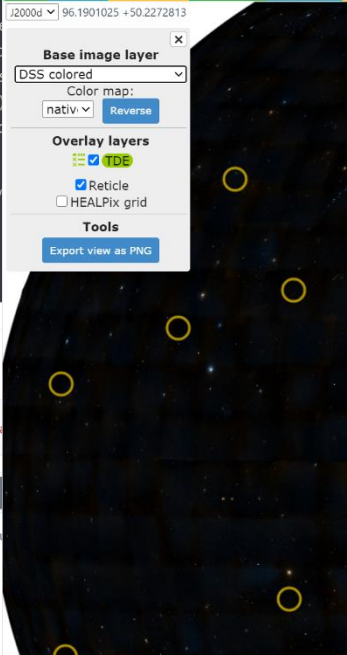
☒ TDE

☒ Reticle

☐ HEALPix grid

Tools

Export view as PNG



ID	Source Name	RA	Dec
3	MJ000240-320028	0.67	-32.0
16	MJ000914+384705	2.31	38.7
18	MJ001059-363610	2.75	-36.6
65	MJ003051-022022	7.72	-2.3
66	MJ003110+535736	7.79	53.5



Einstein Probe WXT Transients

Source List

Explorer

Choose Observation Type:

two pointing observations per orbit

TDE

SGRBs

HL-LGRBs

LL-LGRBs

HZ-GRBs

SN SBO

MAXI Known Sources

Lists of Transient: SGRB (two pointing observations per orbit) All 16 Rows

ID	Source Name	RA	Dec	Flux	Absflux	Cmosnum	SNR	OBS Number	Show Details																						
1	MJ000330-250202	0.88	-25.03	3.17e-9 erg·cm ⁻² ·s ⁻¹	8.92e-10erg·cm ⁻² ·s ⁻¹	24	43.26	1	Hide Details																						
Transient Image Light Curve Spectrum Spectrum First Spectrum Second Spectrum Stack Original <table><thead><tr><th>Source ID</th><th>Obs Id</th><th>X</th><th>Y</th><th>NH</th><th>Alpha</th><th>Beta</th><th>Epeak</th><th>Amplitude</th><th>Absflux</th><th>Cmosnum</th></tr></thead><tbody><tr><td>1</td><td>05010449001</td><td>765</td><td>2416</td><td>1.87e+20</td><td>-0.82</td><td>-2.06</td><td>814.94</td><td>4.85e-3</td><td>8.92e-10</td><td>24</td></tr></tbody></table> Hide Details										Source ID	Obs Id	X	Y	NH	Alpha	Beta	Epeak	Amplitude	Absflux	Cmosnum	1	05010449001	765	2416	1.87e+20	-0.82	-2.06	814.94	4.85e-3	8.92e-10	24
Source ID	Obs Id	X	Y	NH	Alpha	Beta	Epeak	Amplitude	Absflux	Cmosnum																					
1	05010449001	765	2416	1.87e+20	-0.82	-2.06	814.94	4.85e-3	8.92e-10	24																					
2	MJ010604-055655	16.52	-5.95	2.16e-9 erg·cm ⁻² ·s ⁻¹	3.62e-10erg·cm ⁻² ·s ⁻¹	1	21.17	1	Show Details																						
4	MJ012018-400151	20.08	-40.03	1.32e-9 erg·cm ⁻² ·s ⁻¹	1.29e-10erg·cm ⁻² ·s ⁻¹	8	14.95	1	Show Details																						
8	MJ021602+714922	34.01	71.82	7.09e-9 erg·cm ⁻² ·s ⁻¹	6.14e-10erg·cm ⁻² ·s ⁻¹	1	28.70	6	Show Details																						
10	MJ032433-032642	51.14	-3.45	6.61e-9 erg·cm ⁻² ·s ⁻¹	3.84e-10erg·cm ⁻² ·s ⁻¹	35	21.92	4	Show Details																						
11	MJ043247+245909	68.20	24.99	5.24e-9 erg·cm ⁻² ·s ⁻¹	4.07e-10erg·cm ⁻² ·s ⁻¹	37	16.13	1	Show Details																						
12	MJ044440+495403	71.17	49.90	1.57e-9 erg·cm ⁻² ·s ⁻¹	2.80e-10erg·cm ⁻² ·s ⁻¹	41	2.70	59	Show Details																						
14	MJ050139-692519	75.41	-69.42	1.23e-9 erg·cm ⁻² ·s ⁻¹	3.71e-11erg·cm ⁻² ·s ⁻¹	1	5.09	1	Show Details																						
16	MJ054819+492100	87.08	49.35	1.45e-9 erg·cm ⁻² ·s ⁻¹	1.33e-10erg·cm ⁻² ·s ⁻¹	8	8.81	1	Show Details																						
21	MJ074316+142638	115.82	14.44	7.27e-9 erg·cm ⁻² ·s ⁻¹	1.14e-10erg·cm ⁻² ·s ⁻¹	37	11.09	20	Show Details																						

Summary

- X-ray sky is rich in various classes of transients and variables
- Future of monitoring dynamic X-ray sky is promising, enabled by Lobster-eye MPO technology
- Einstein Probe will discover/characterise a large number of faint X-ray transients, and monitor source variability
- Follow-up by ground- and space-based telescopes are essential
- Synergy with other Multi-Wavelength & Multi-Messenger facilities offers great science opportunities

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

<https://www.bilibili.com/video/BV1mf4y1b7YJ>