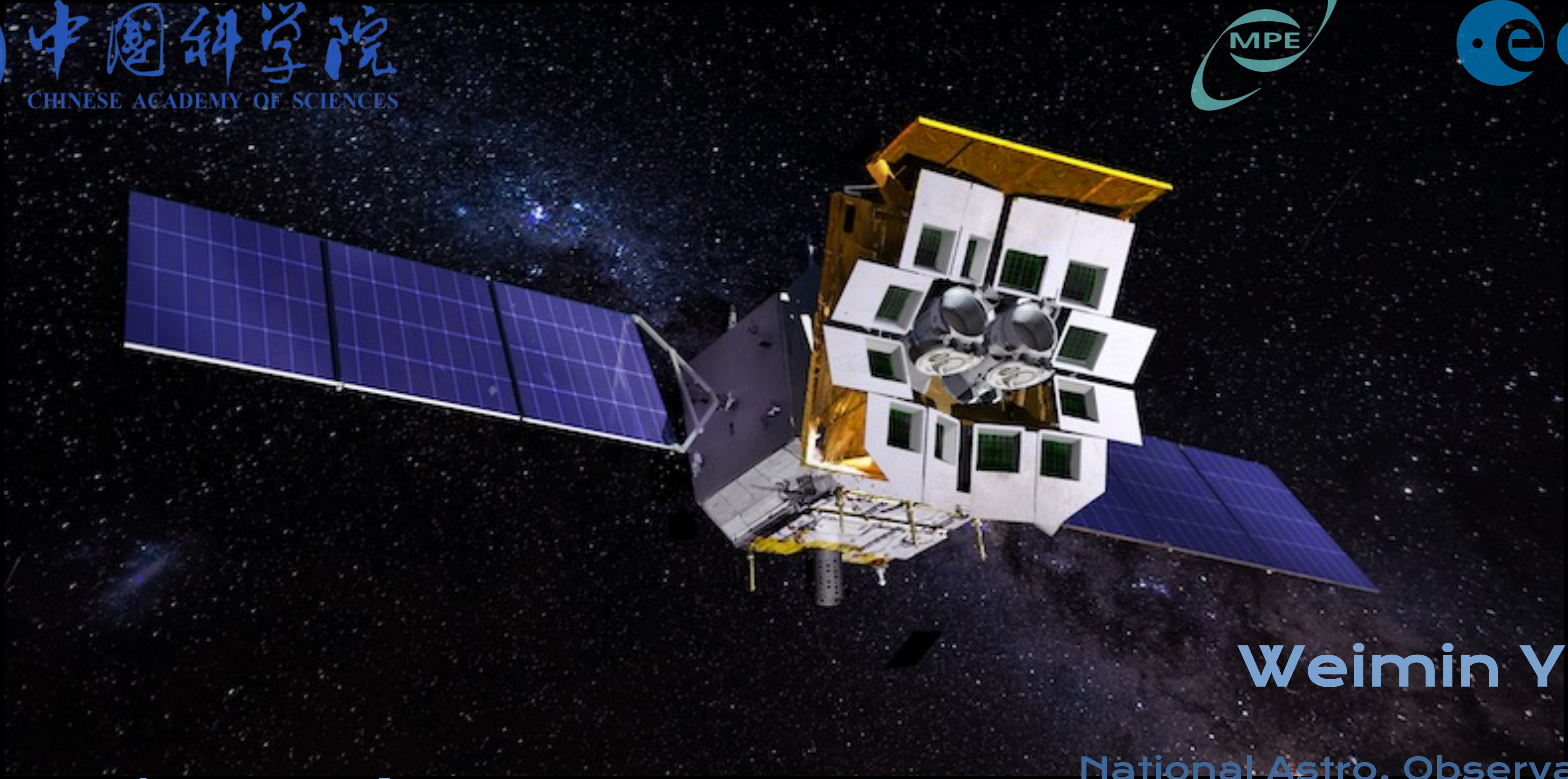


Einstein Probe

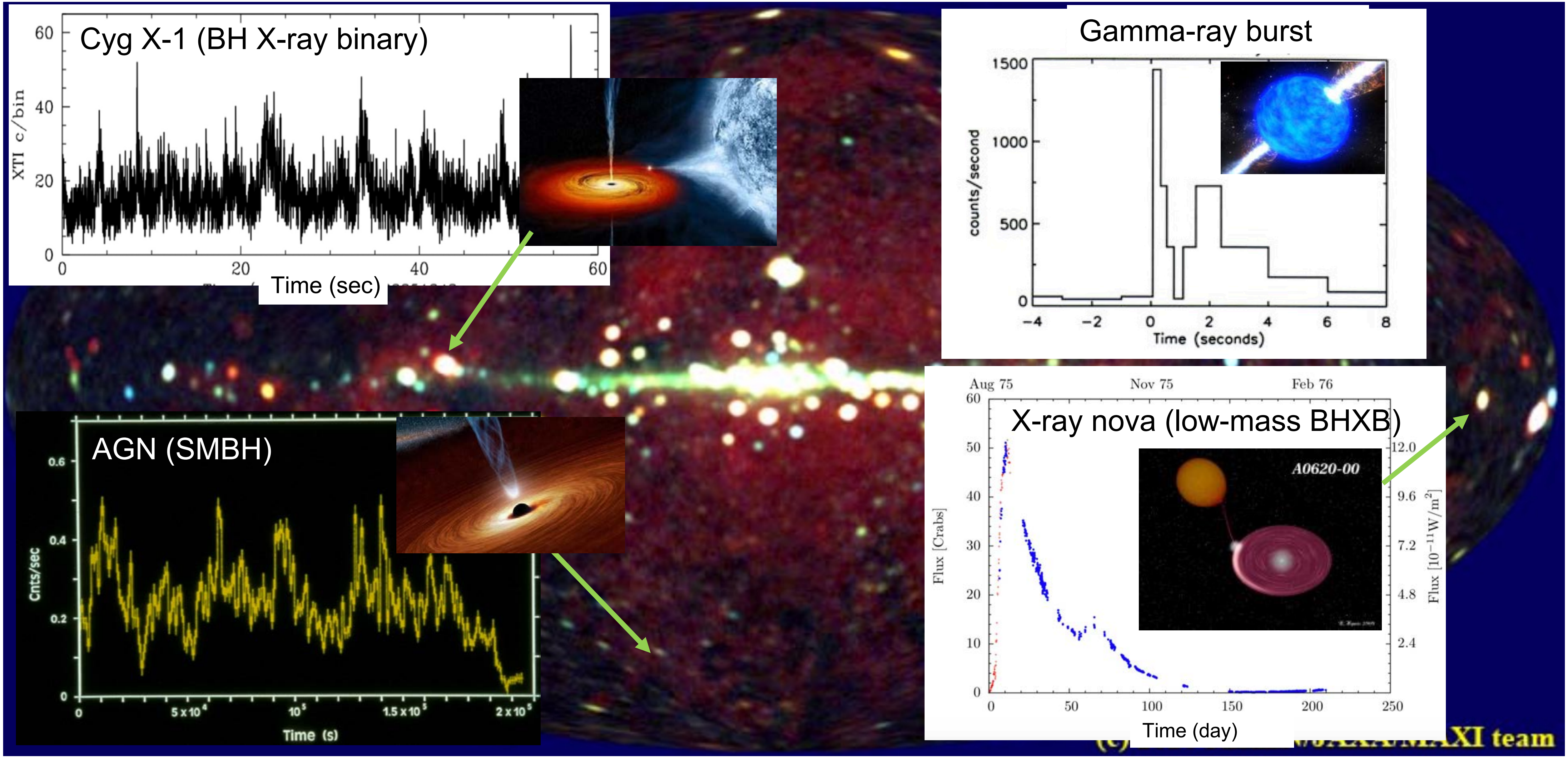
Exploring the dynamic x-ray universe

Weimin Yuan

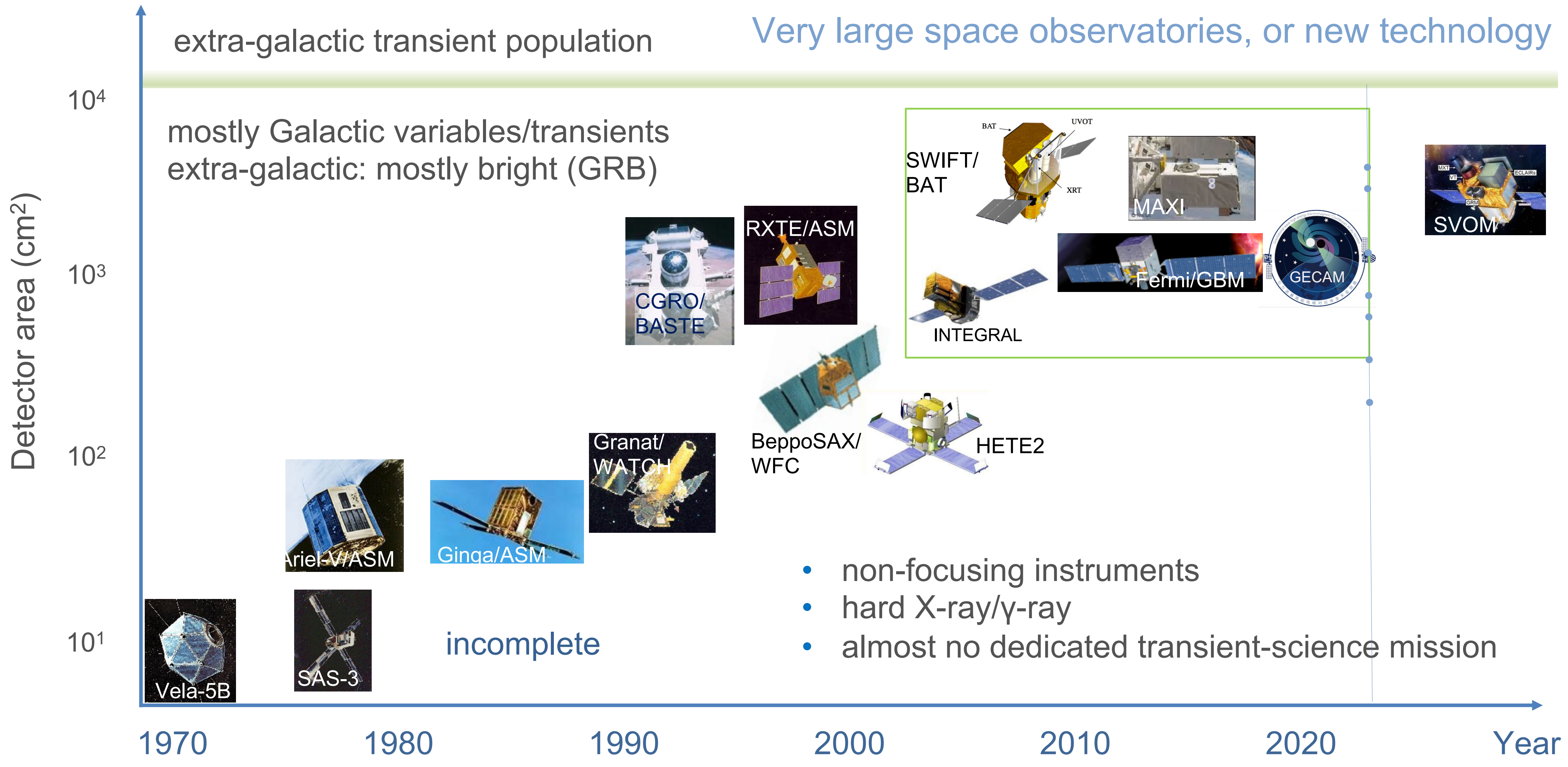
National Astro. Observatories
Chinese Academy of Sciences

On behalf of EP consortium

Variables & transients in X-ray sky

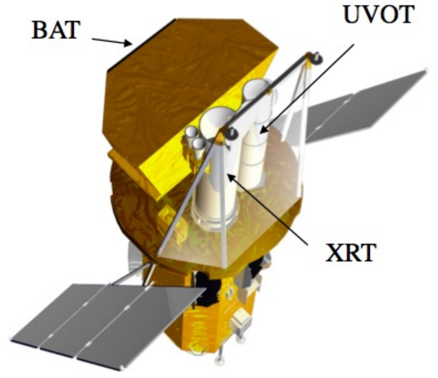


X/γ-ray wide-field monitors

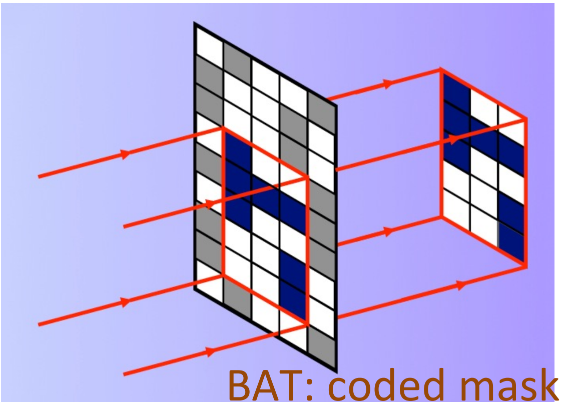


Current X-ray wide-field monitors in orbit

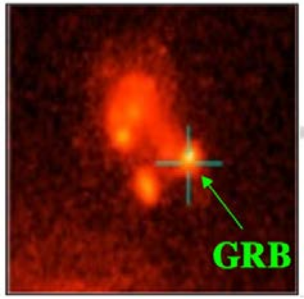
Swift (NASA 2004-)

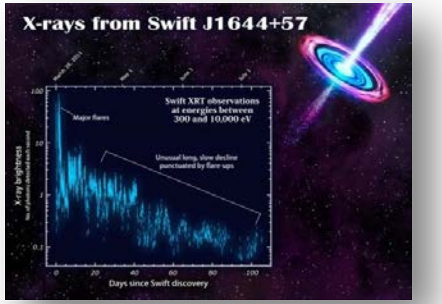


Credit: NSA/Gehrels

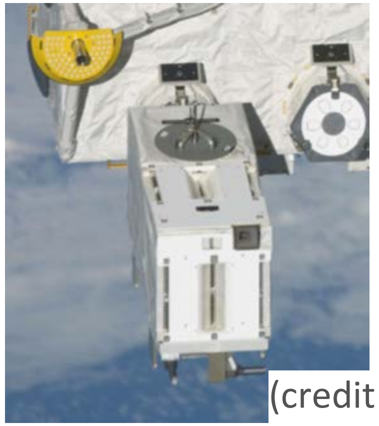


- GRB mission
- BAT: 14-300keV, FoV ~ 2 sr
- 2 GRB + 0.5 transients per week



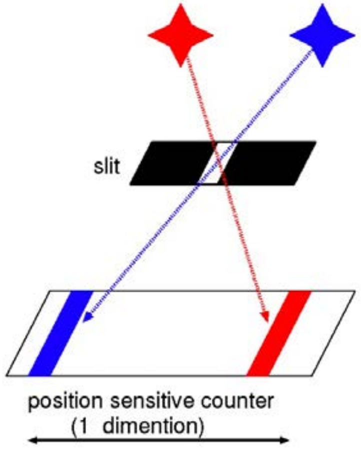


MAXI on ISS (JAXA 2009-)

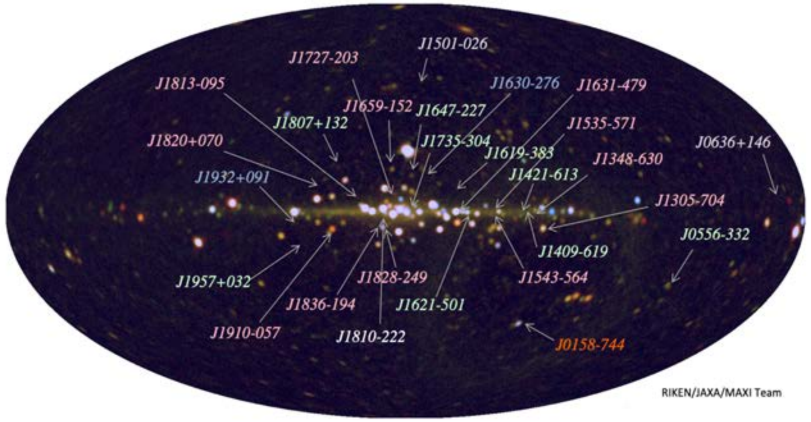


(credit: RIKEN/JAXA)

pinhole/slit camera



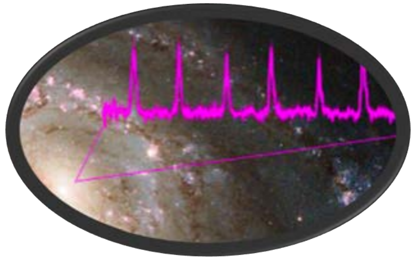
- 0.8 Transients per week (mostly Galactic)
- Monitoring large number of sources hourly/daily



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

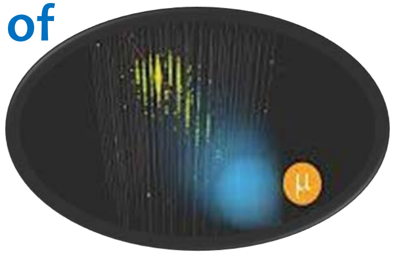
When first stars formed?
metal enrichment in early universe

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

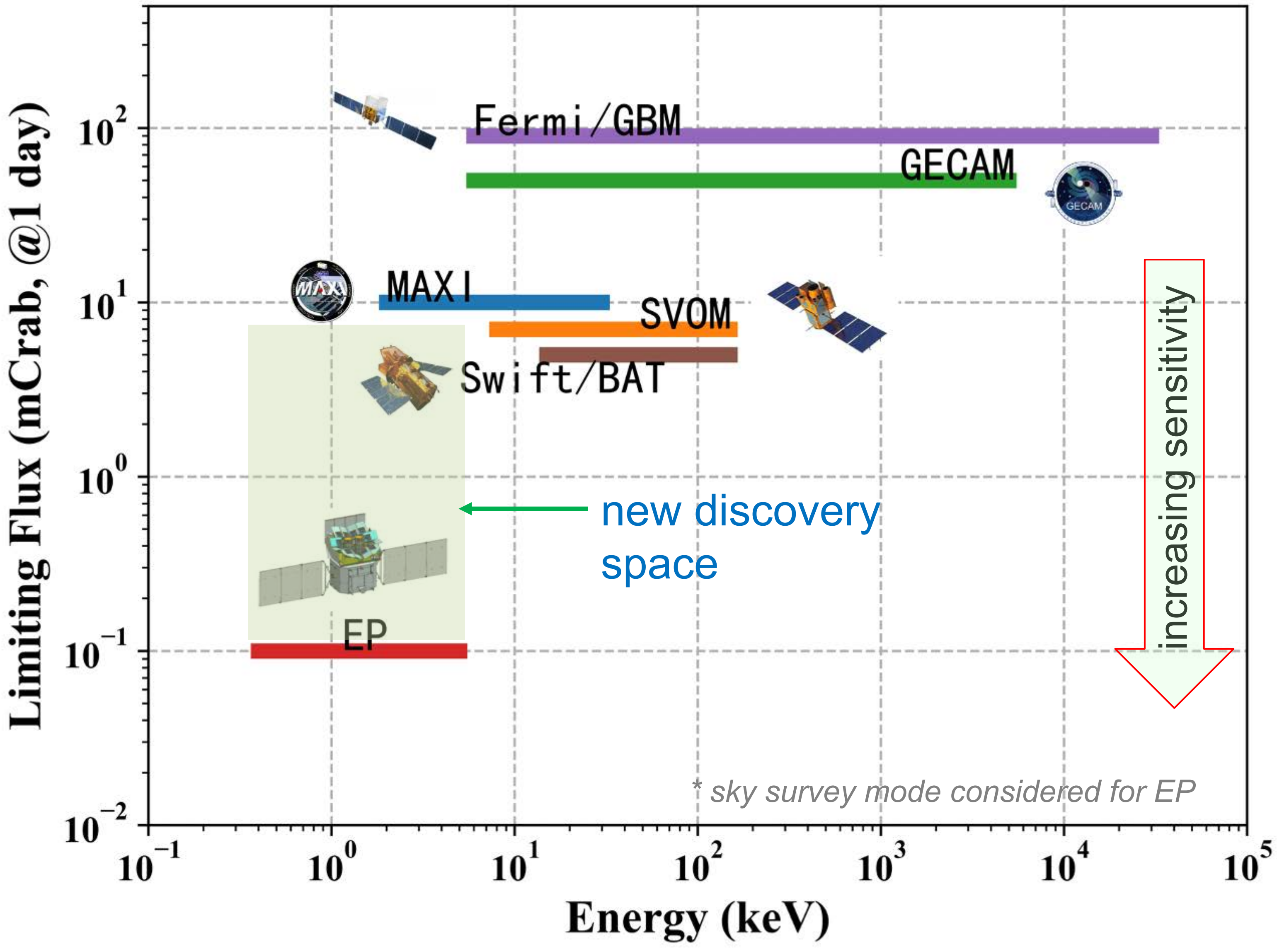
Higher sensitivity by 1-2 orders of mag. than those in orbits

Large FoV (~ 1 str)

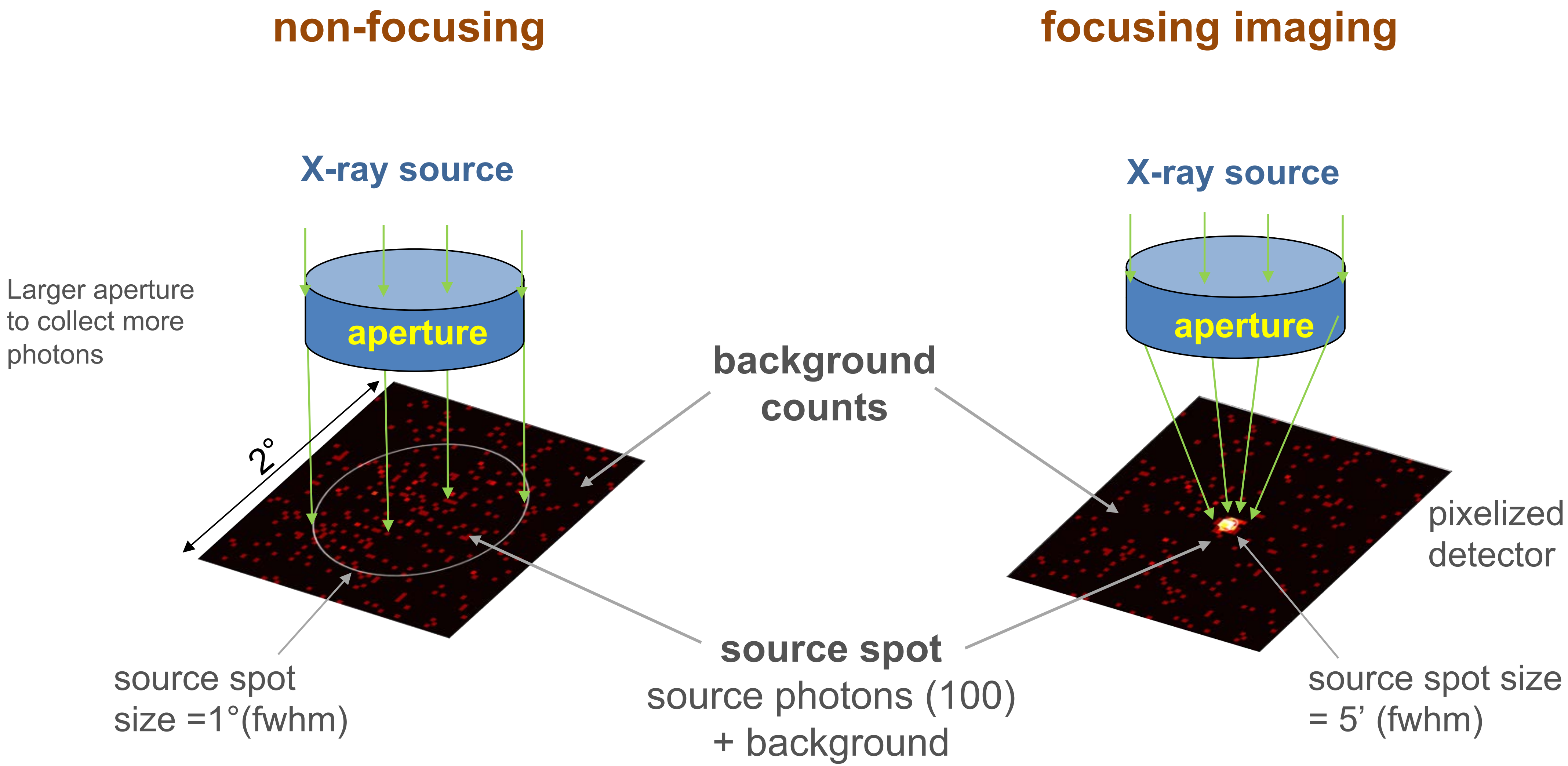
Soft X-ray (0.5keV)

How ?

A: X-ray focusing imaging



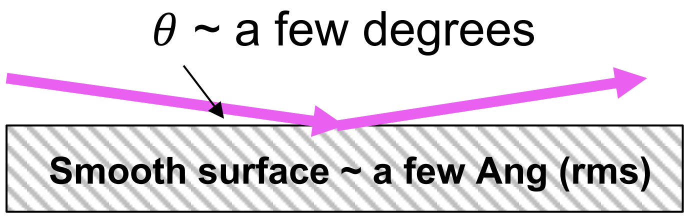
How X-ray focusing imaging improves sensitivity

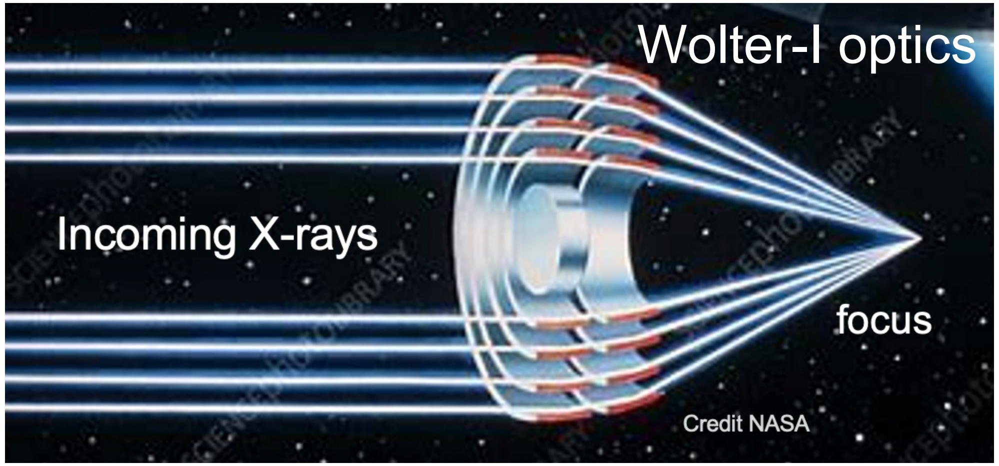


X-ray focusing imaging: Wolter-I optics

X-ray reflection by grazing incidence

Higher reflectivity for lower-E X-rays

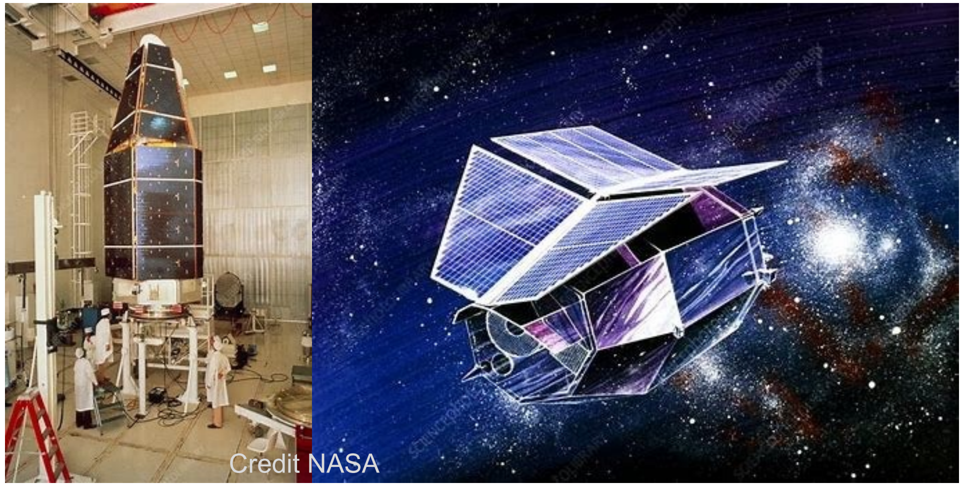




- high sensitivity
- small FoV (< 1-2 deg)

Frist: Einstein Observatory (NASA) 1978-1981

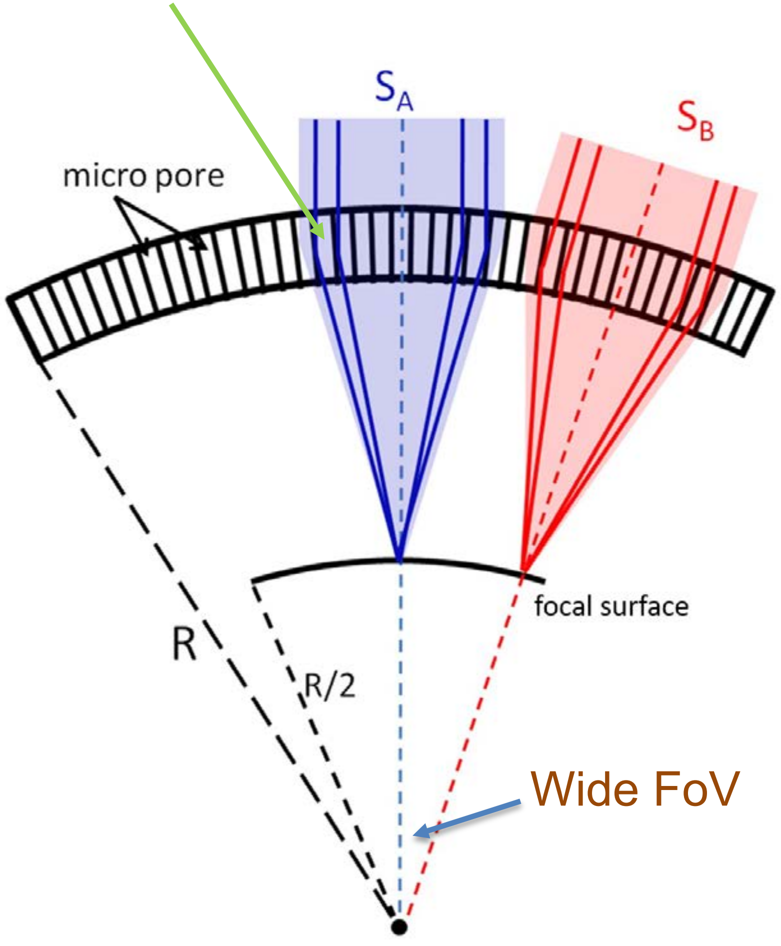
- 100 x more sensitive than Uhuru
- Revolutionzied X-ray astronomy



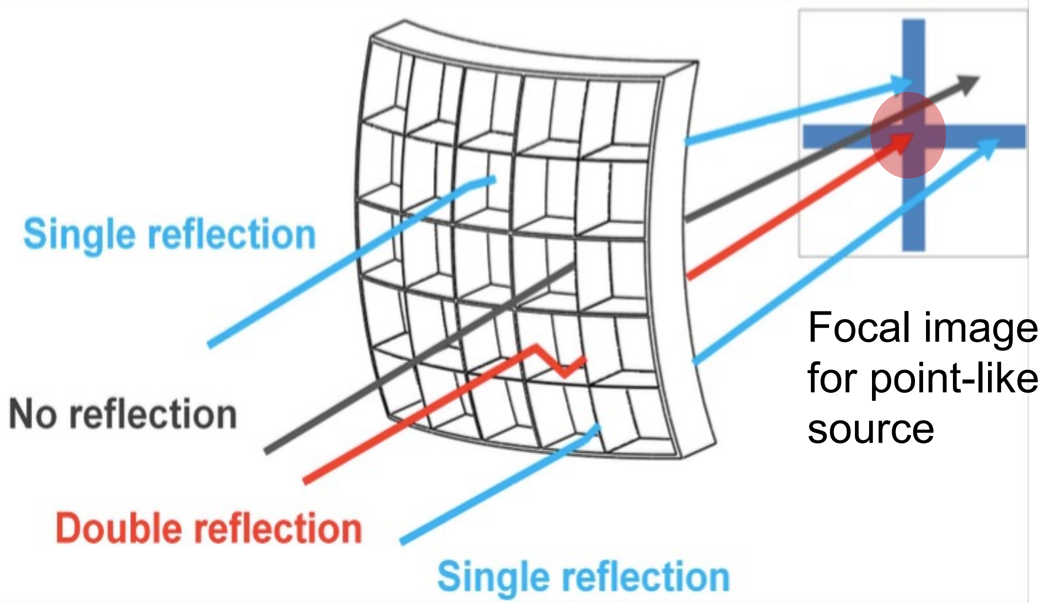
XMM-Newton, Chandra, NuSTAR, eROSITA…

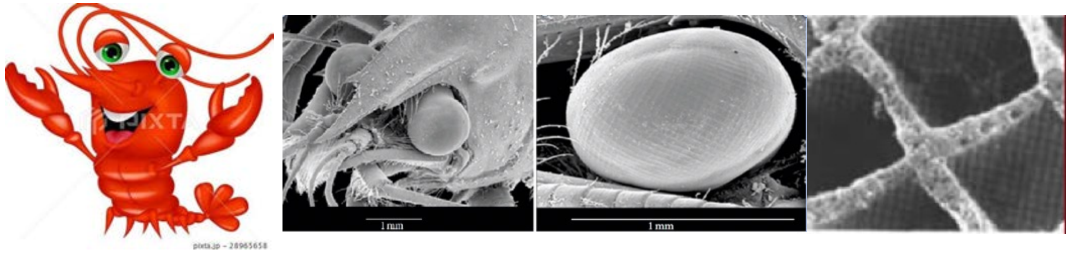
Lobster-eye micro-pore optics (MPO) for X-ray focusing

grazing incidence reflection



Curvature center



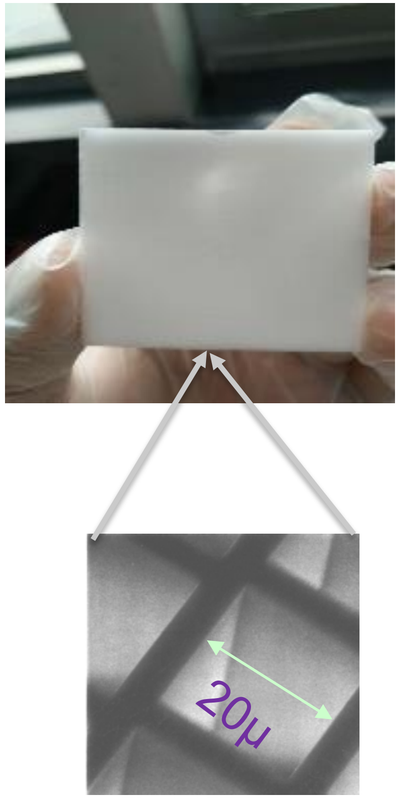


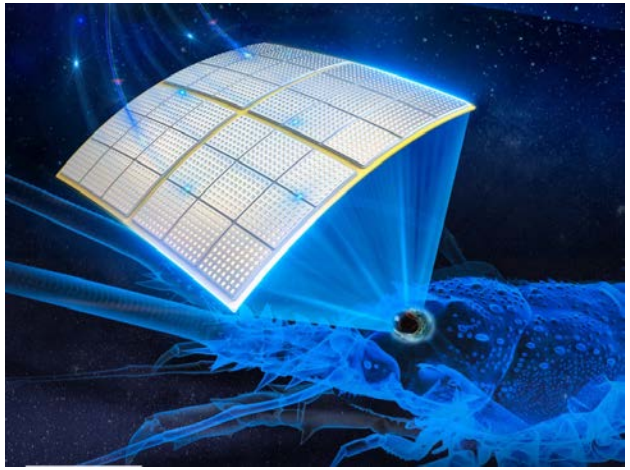
How do lobsters' eyes see the world?

lobster-eye micro-pore optics for X-ray focusing

Ideal optics for X-ray wide-field monitors

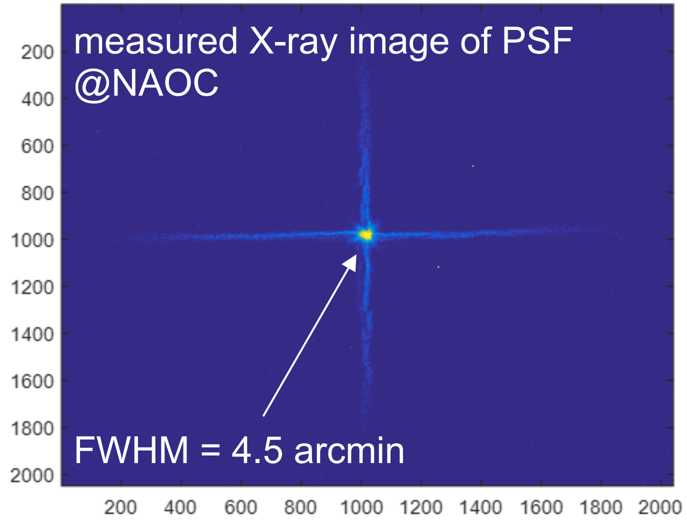
Wide FoV (uniform imaging)
True imaging
Arcmin angular resolution
Optimised for soft X-rays
Light weight





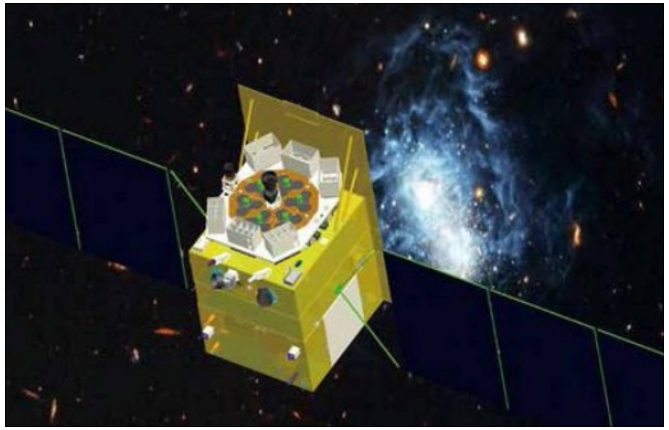
- *First proposed by R. Angel (1979)*
- *Studied by a number of groups for many years, e.g. Univ. Leicester, NASA, NAOC/CAS, …*

Wilkins et al. (1989) ; Fraser et al. (1992); Kaaret (1992)



Einstein Probe (EP) mission

HXMT-Insight (2017-)
CAS's 1st X-ray observatory

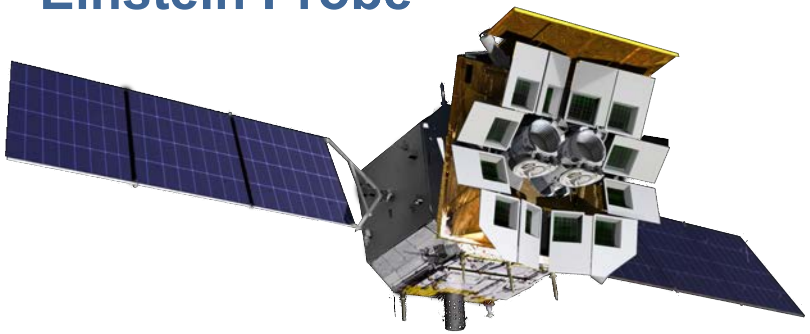


EP science goal

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

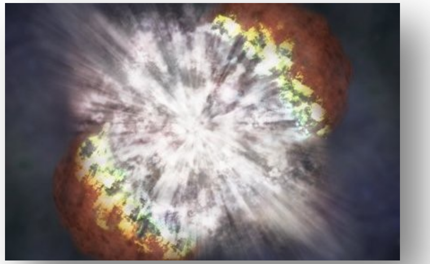
2010: X-ray ASM (CSS)
2012: EP proposal
Adoption: 2017-12
Now Phase C (performance validation)
Launch: planned 2022-12 (new 2023)
Lifetime: 3 years (goal 5 yr)
International collaboration: ESA & MPE

Einstein Probe



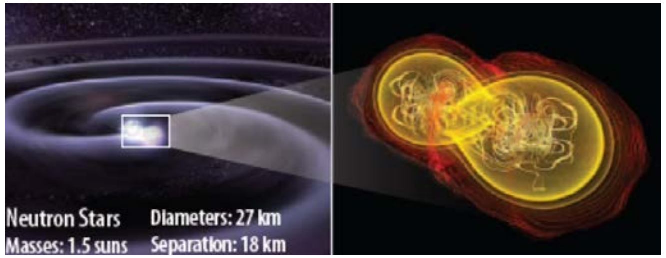
Main science objectives

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

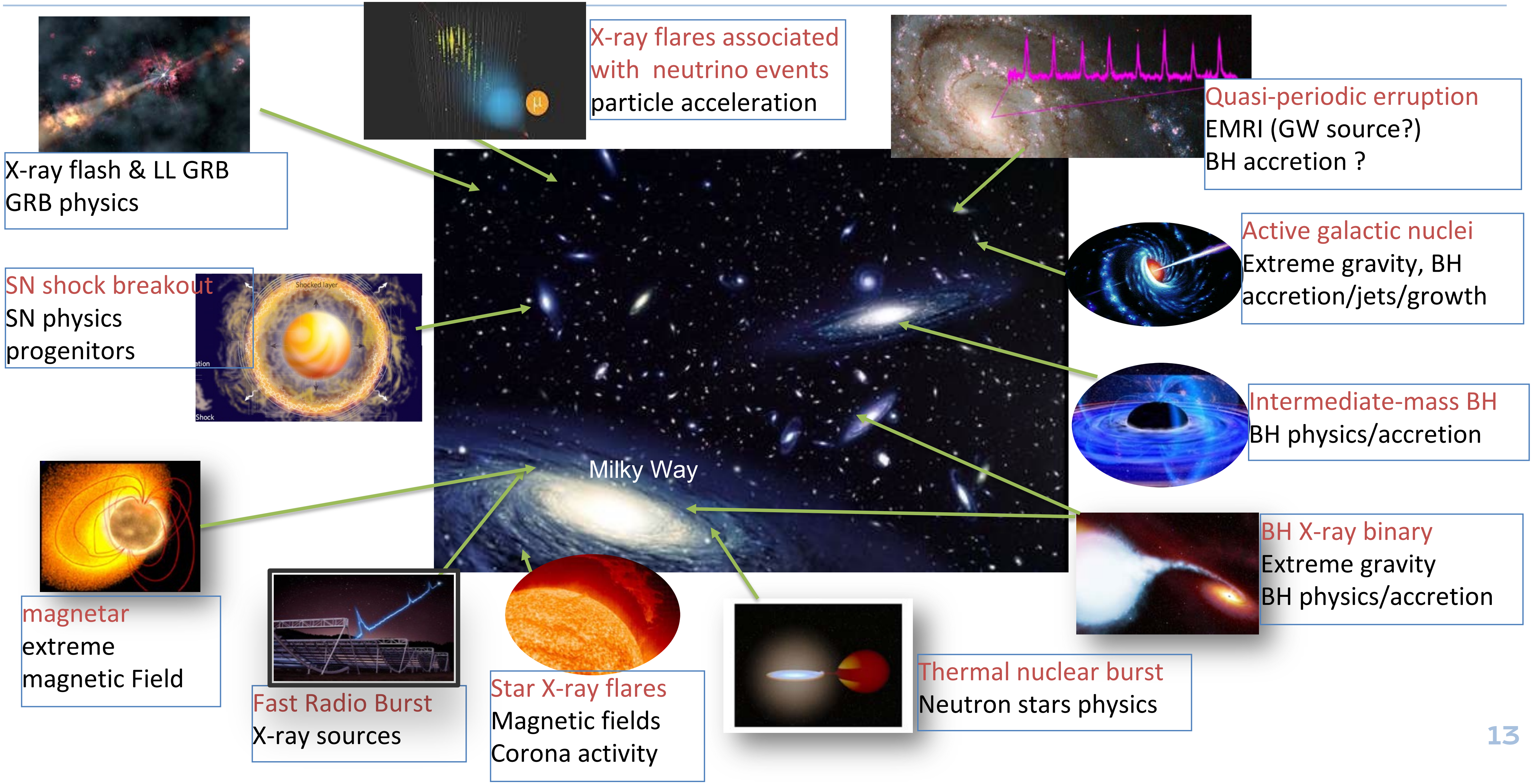


Discover otherwise quiescent black holes at almost all astrophysical mass scales and other compact objects by capturing their transient X-ray flares

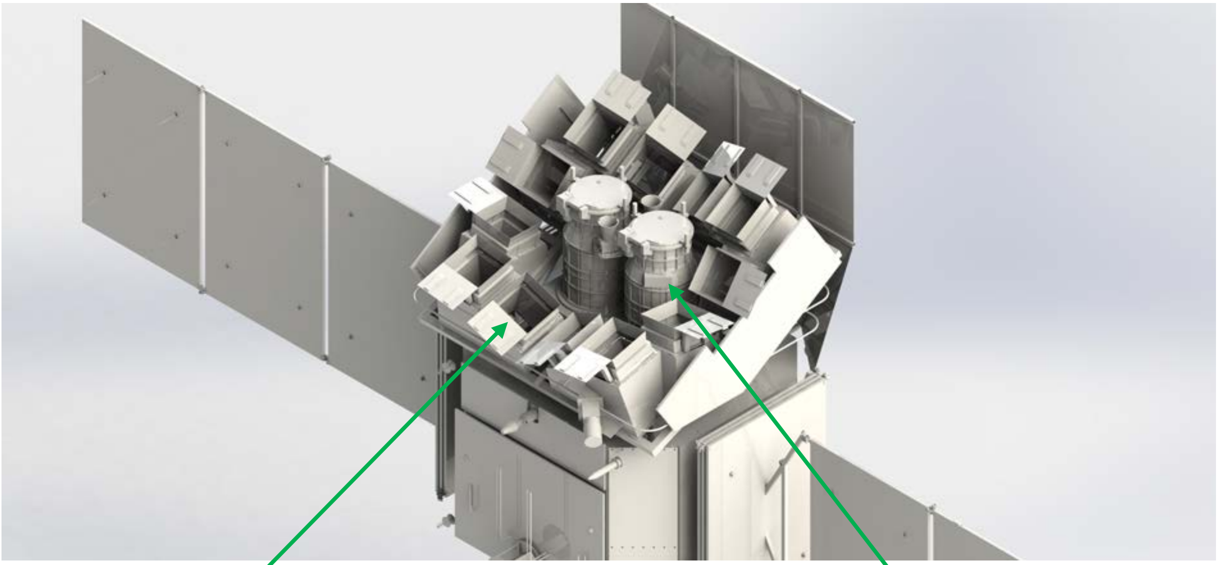
Detect and localise the electromagnetic-wave sources of gravitational-wave events by synergy with gravitational-wave detectors



Various classes of high-E transients & variability



Instruments & SC



Spacecraft

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

Wide-field X-ray Telescope

WXT (12 modules)

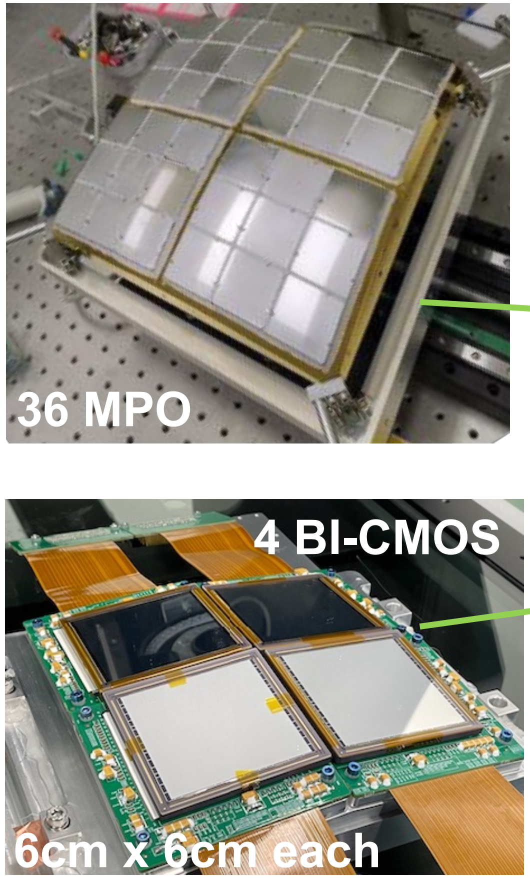
lobster-eye MPO
FoV: 3600 sq deg (1.1 sr)
band: 0.5 – 4 keV
spatial resolution: ~ 5' (FWHM)
sensitivity: > tens times better than current

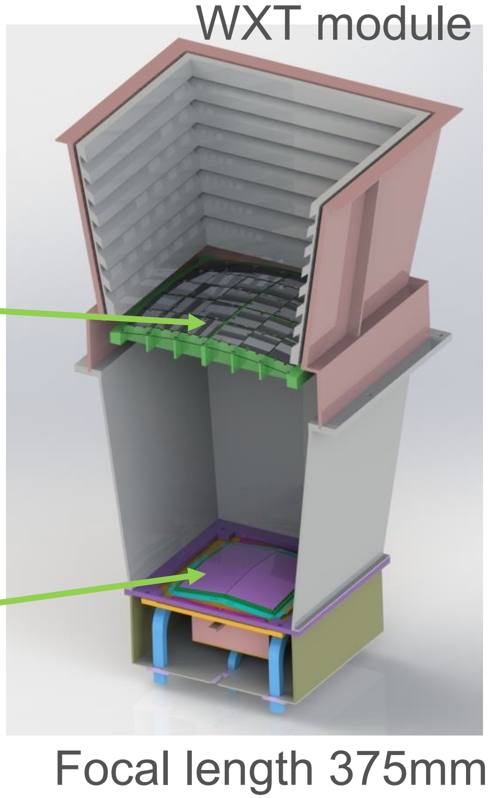
Follow-up X-ray Telescope

FXT (2 units)

Wolter-1 optics
FoV: ~1 deg
band: 0.3-10keV
effective area: 300cm^2 @1keV (1 unit)
spatial resolution: 30" (HPD on-axis)

Wide-field X-ray Telescope (WXT)

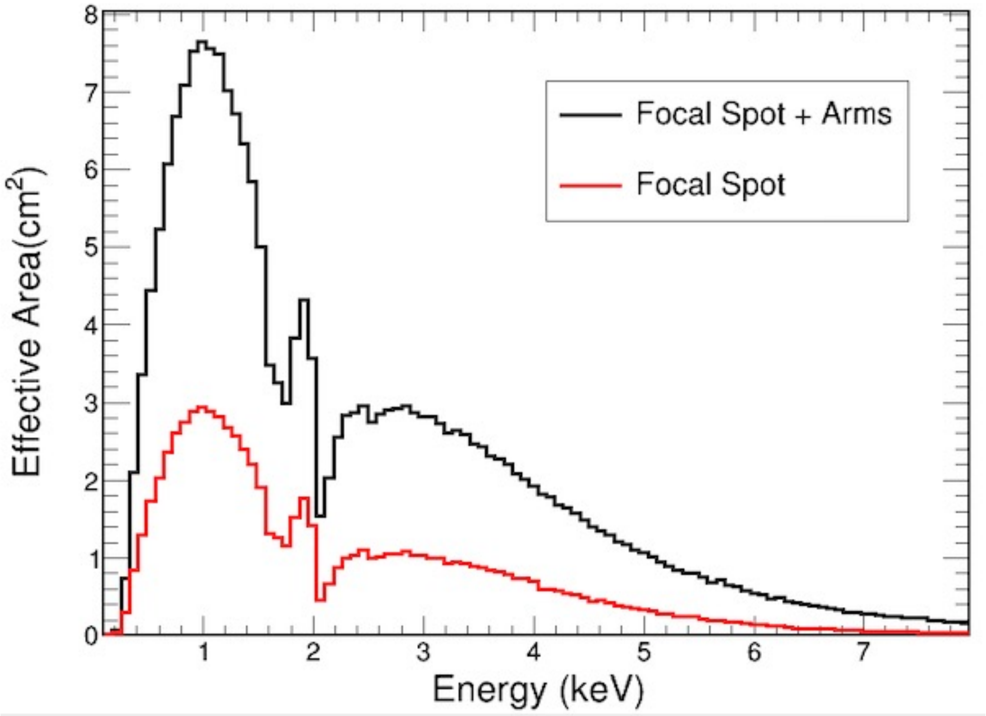




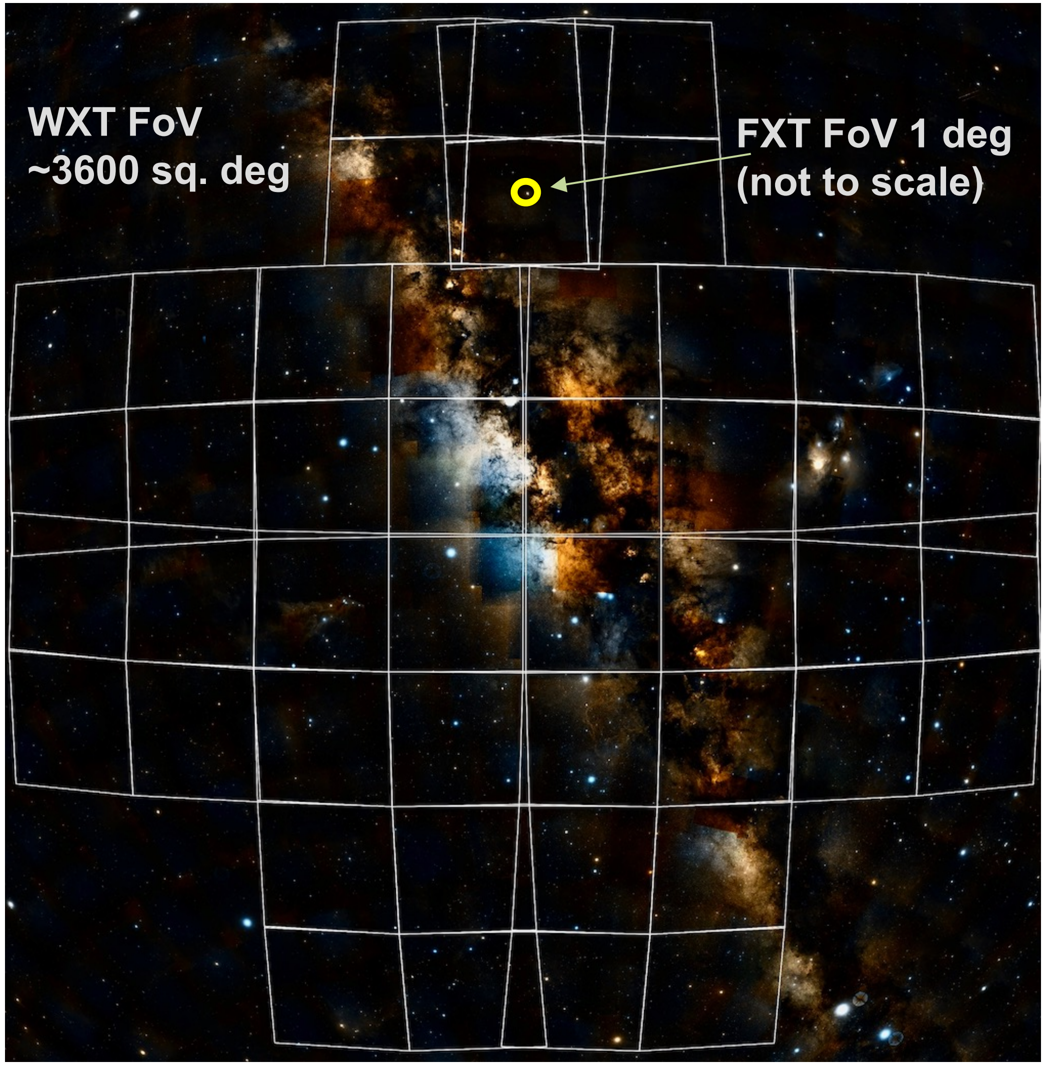
Development: CAS (SITP, NAO) + NNVT
Test/calibration: CAS & ESA
WXT PI: *Sun Xiaojin* (SITP);
Instr. Sci: *Ling Zhixing,* MA PI: *Zhang Chen* (NAO)

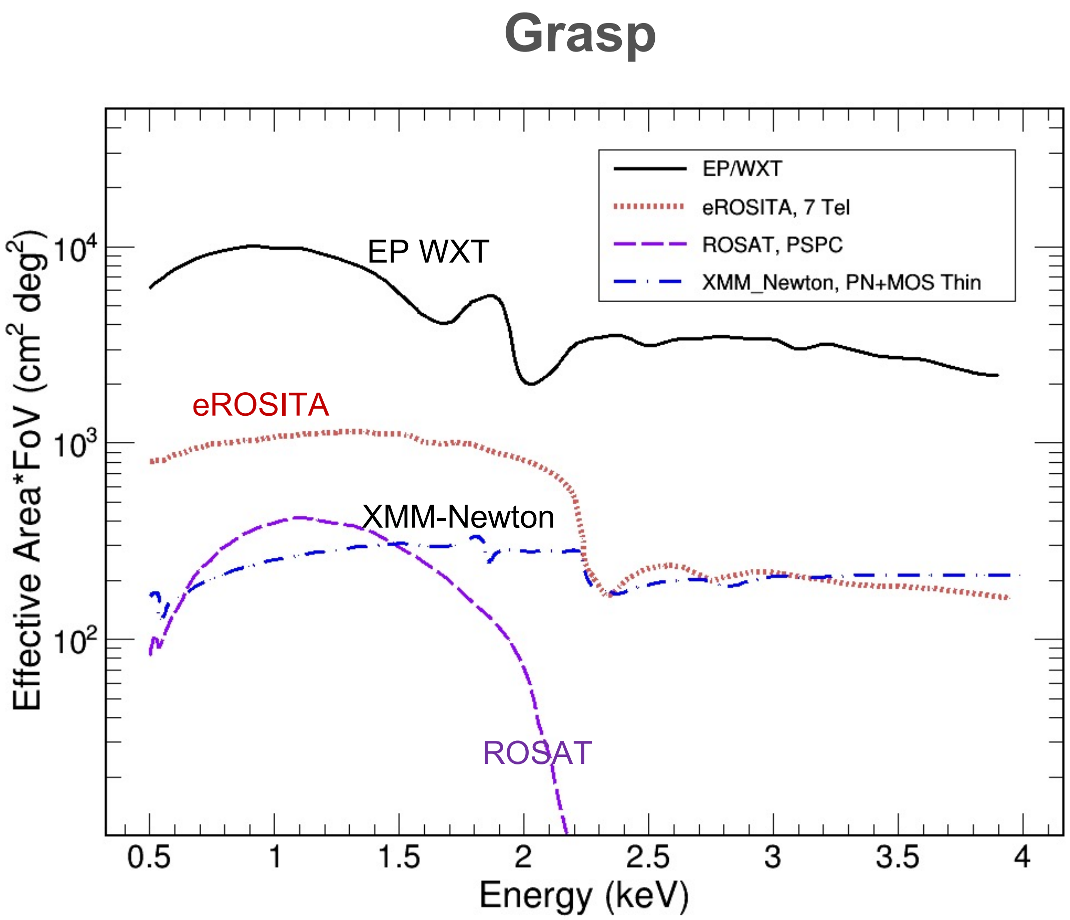
Technology challenges

- First large-FoV MPO telescope (432 plates)
- Large detector array (48 CMOS x 6 x 6 cm^2)
- Novel use of CMOS for space X-ray
- Soft X-ray band



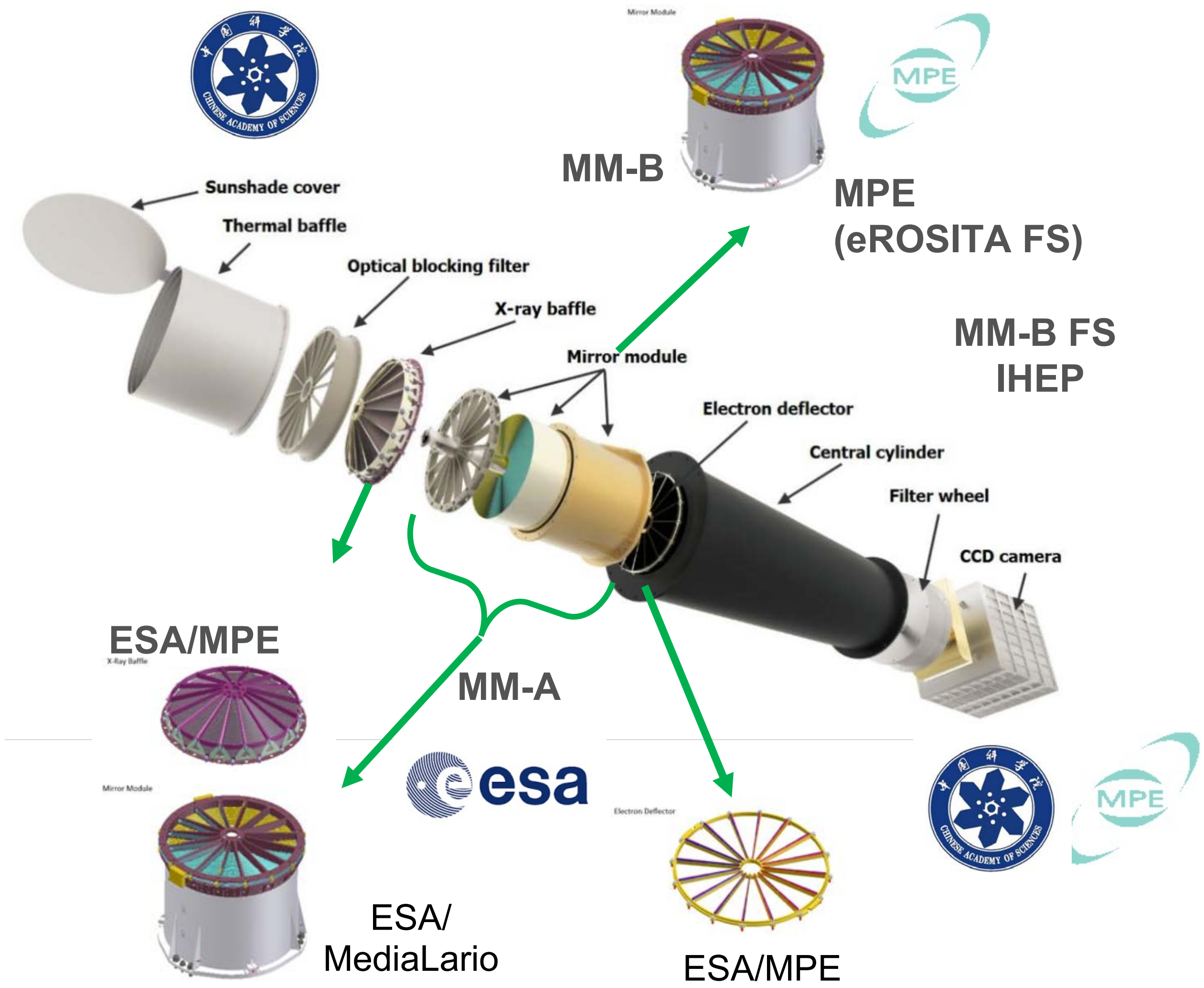
WXT FoV & Grasp





Zhao D. et al. 2017

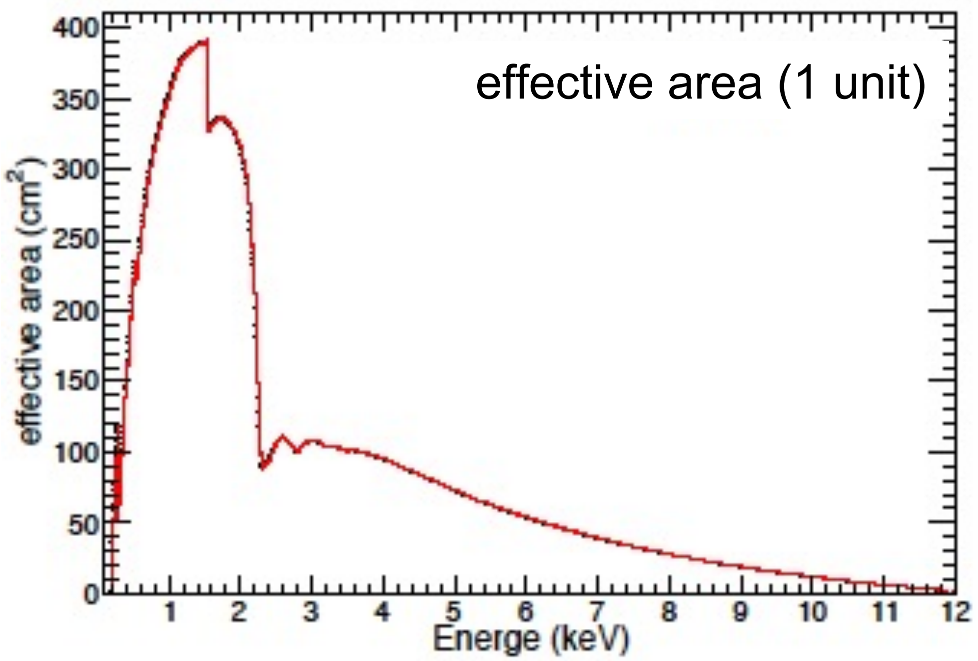
Follow-up X-ray Telescope (FXT)



CAS/IHEP+ ESA + MPE

PI: Y. Chen (IHEP)

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



Mission profile

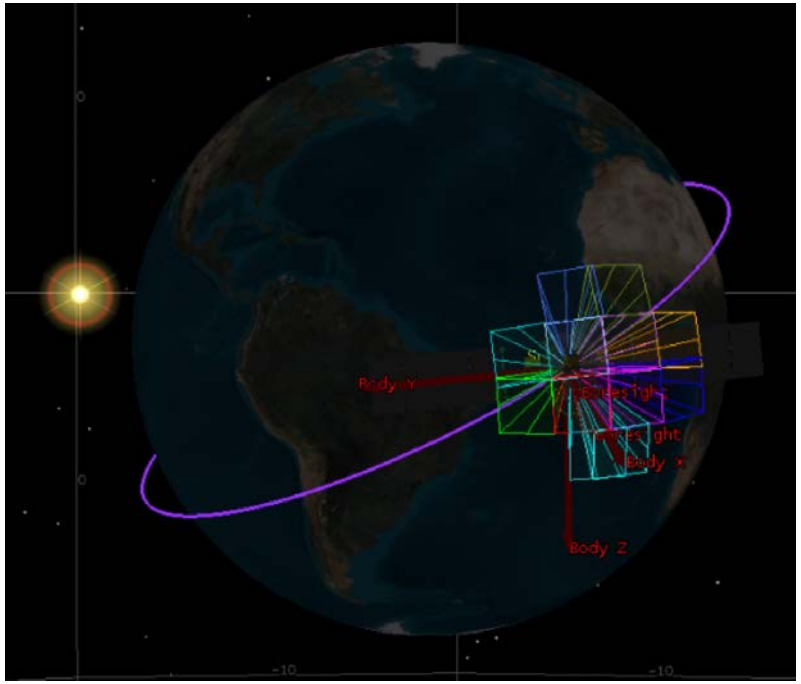
Orbit: ~ 600 km (96min), incl. 29 deg

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



Operation modes

- Survey (WXT)
- Autonomous X-ray follow-up (FXT)
- Target of opportunity (FXT, WXT)

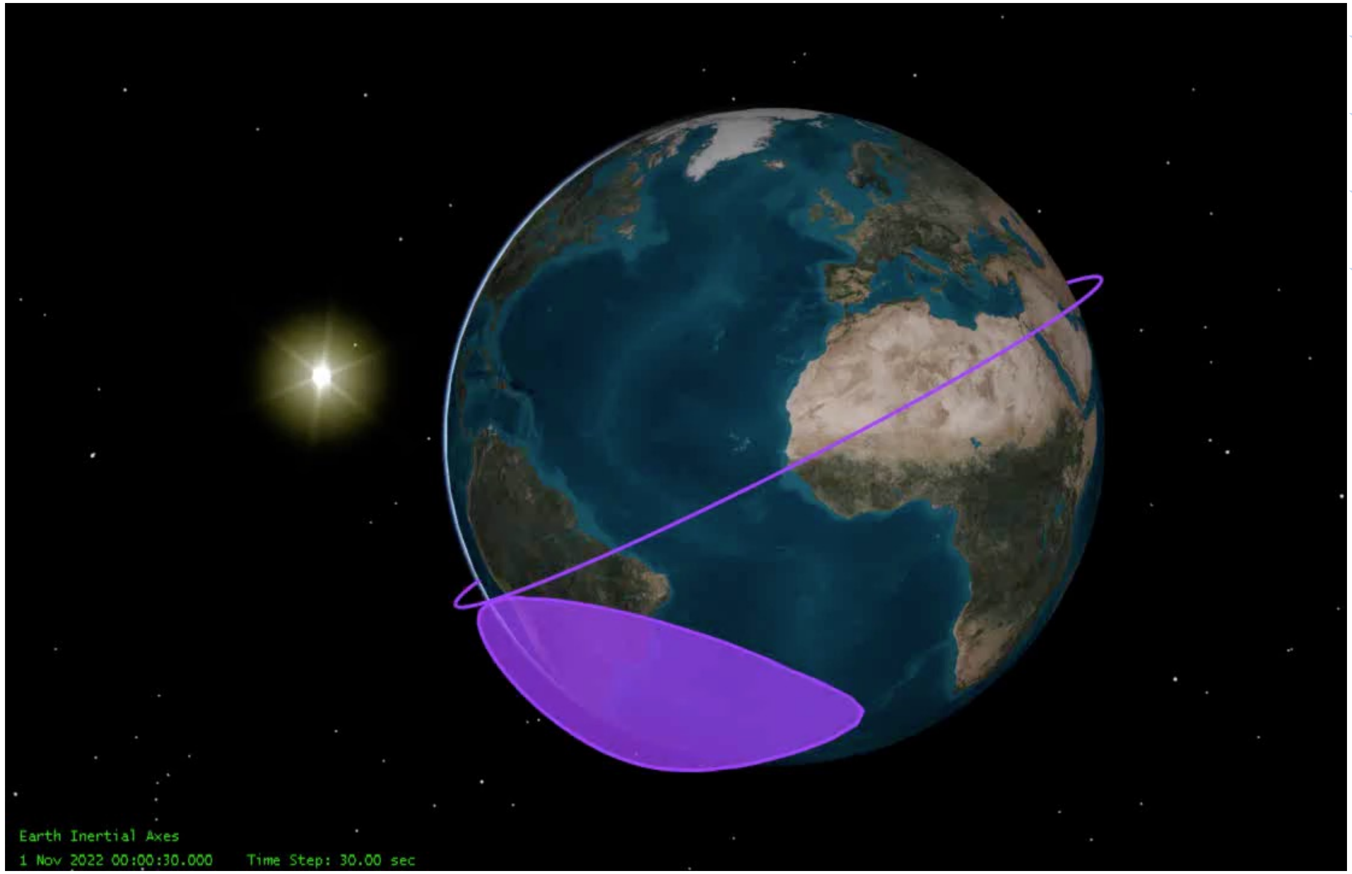
EP Mission Centre @ NSSC/CAS

- ESA (GS telemetry support)

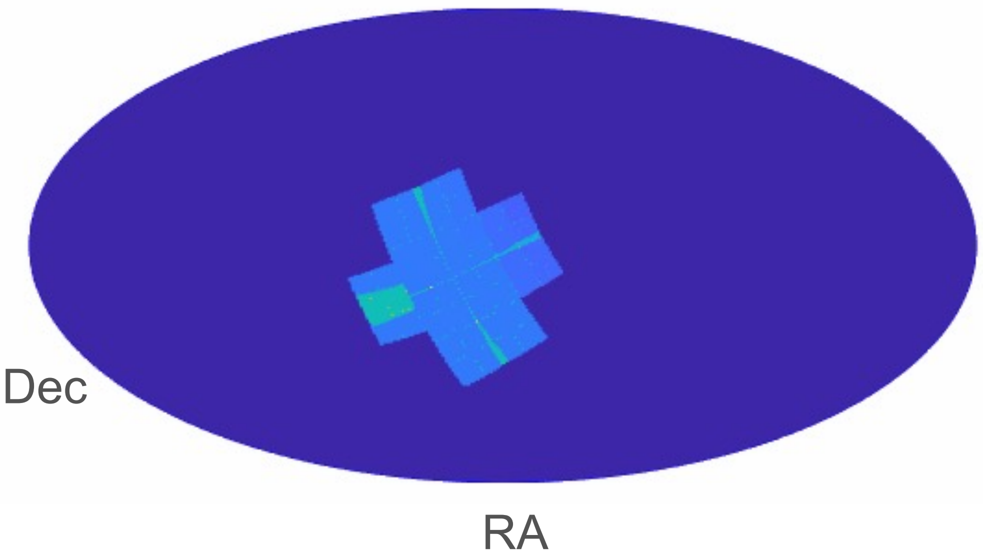
EP Science Centre @ CAS

- NAOC+IHEP

EP all-sky survey mode

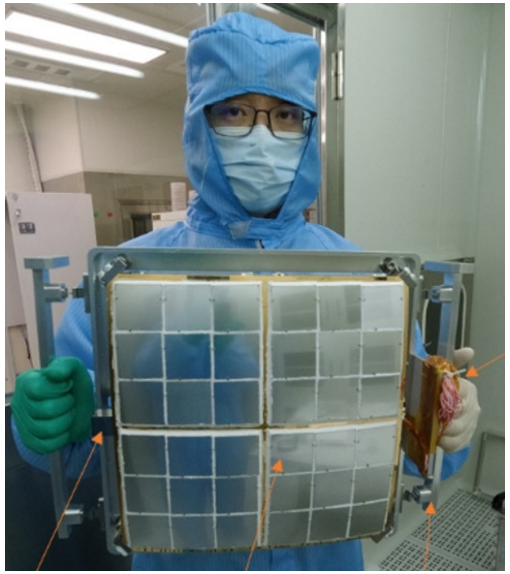


- anti-Sun pointings
- 3 snapshots per orbit, each ~20 min
- 3 orbits (~ 5 hr) cover half sky
- 1 day: ~ 45 snapshots

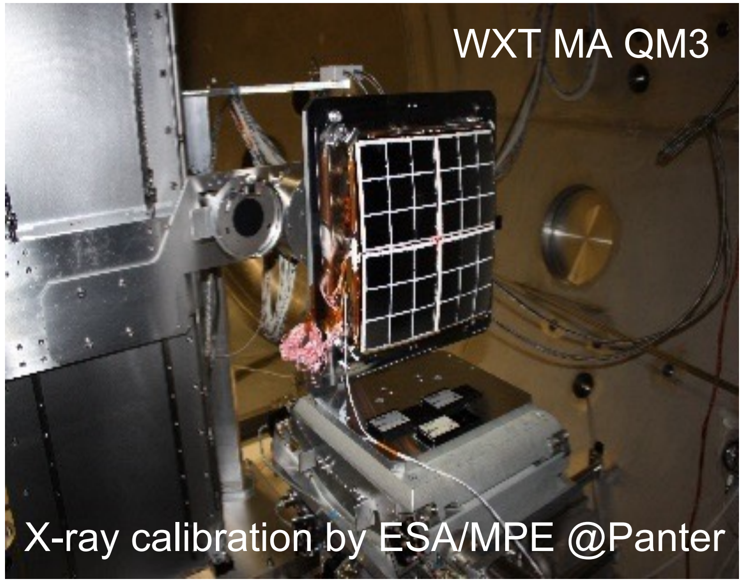


WXT status

3 QM of complete modules built, tested and calibrated (2021)

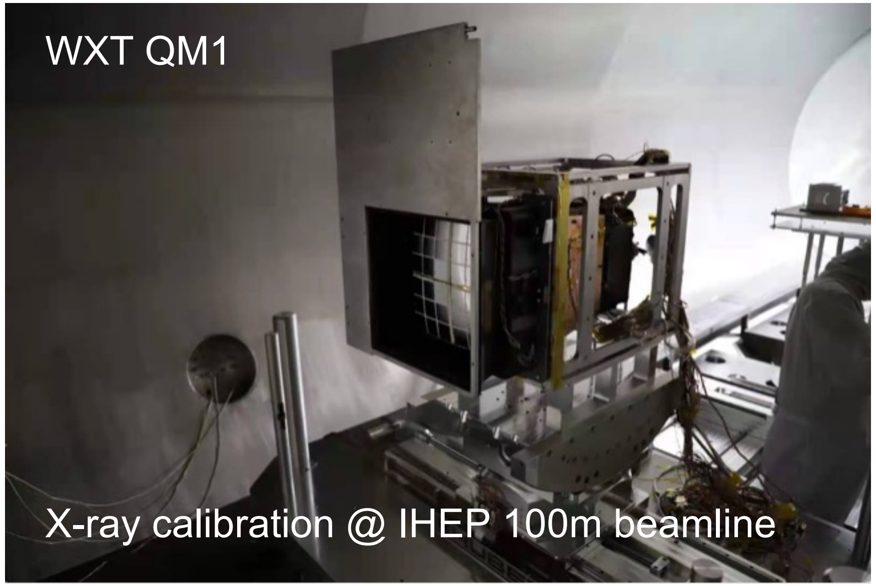


WXT MA QM (NAOC/CAS)



WXT MA QM3

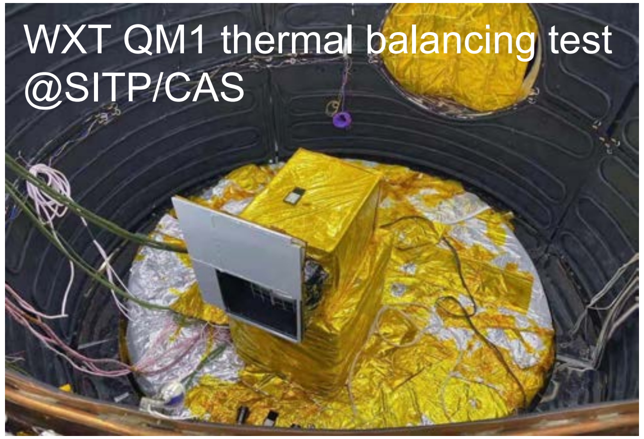
X-ray calibration by ESA/MPE @Panter



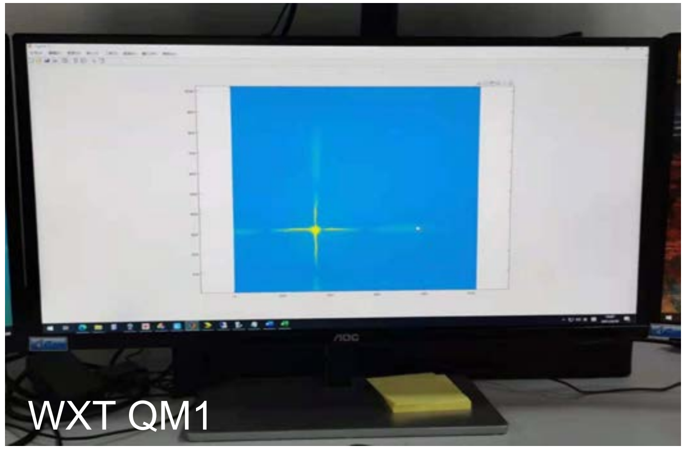
WXT QM1

X-ray calibration @ IHEP 100m beamline

CMOS detect
@SITP/CAS



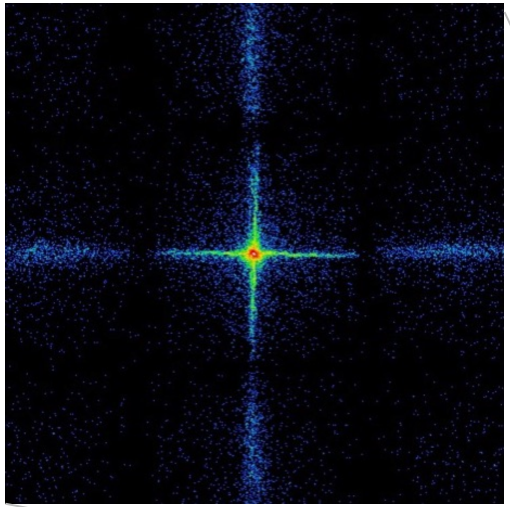
WXT QM1 thermal balancing test
@SITP/CAS



WXT QM1

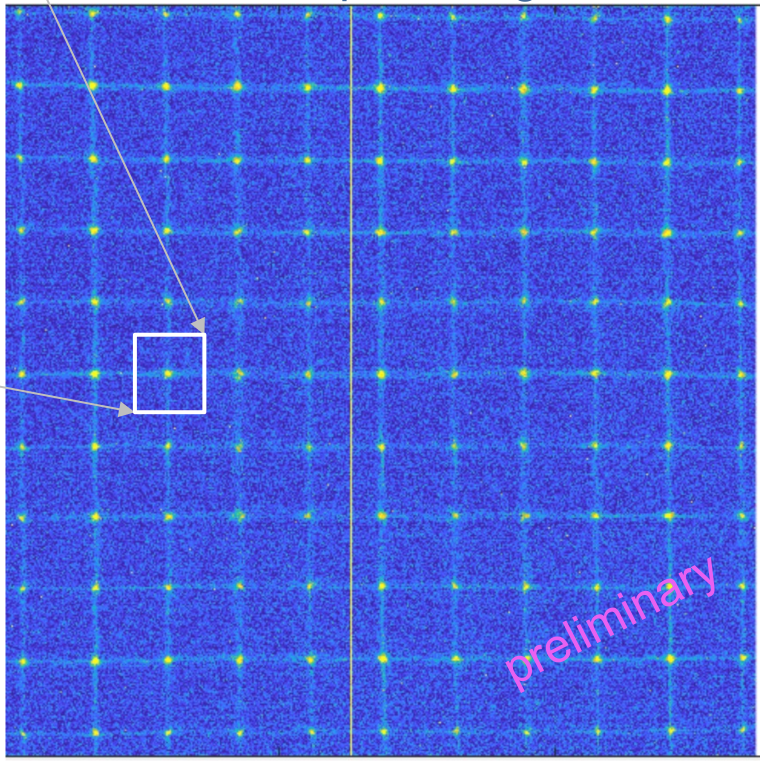
WXT status: Mirror assembly

X-ray image of point source

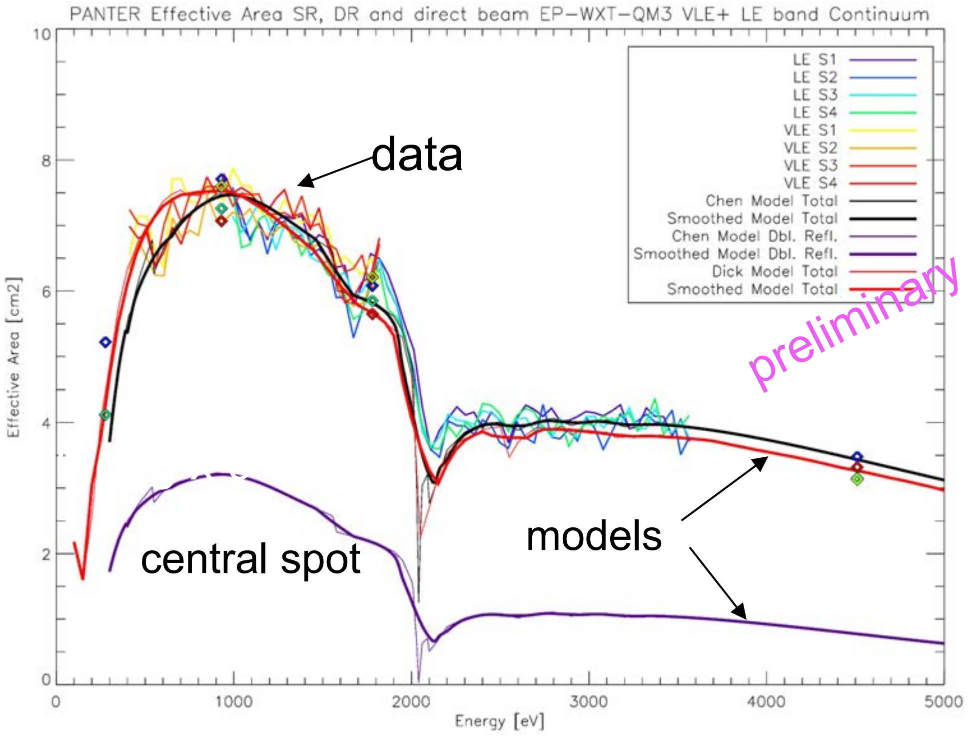


FWHM 4 - 5.5 arcmin

¼ FoV of a WXT module
9 x 9 square deg.



Measured effective area (cm^2 vs. energy)



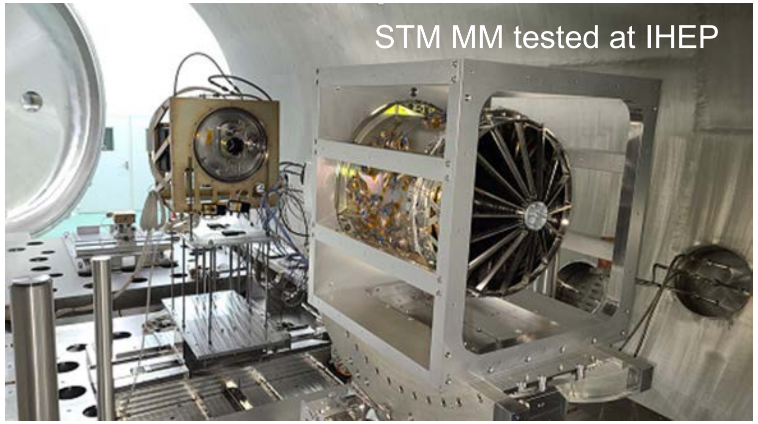
Credit: ESA/MPE/CAS

FXT Status

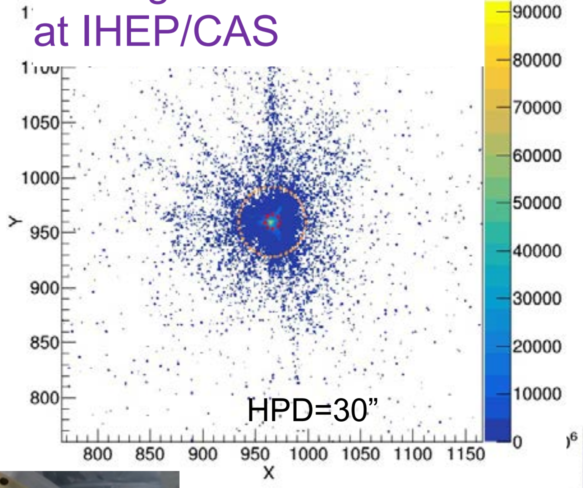
X-ray camera QM built at CAS/IHEP (detector module from MPE)

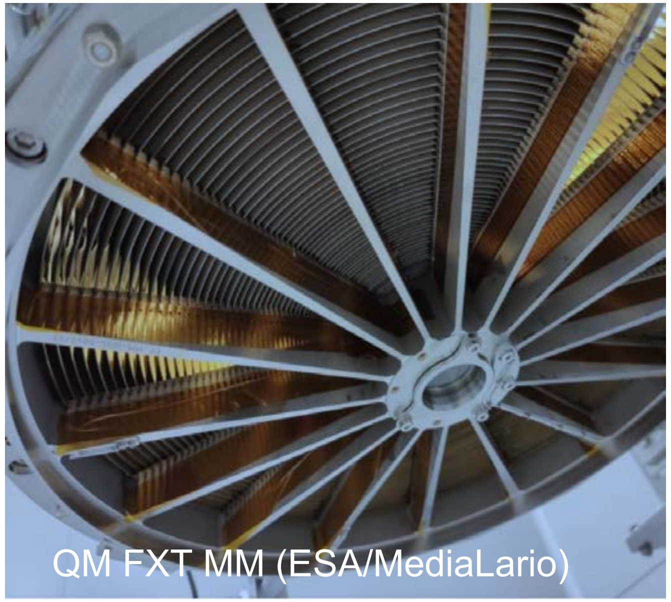
Joint test of STM of mirror module and camera QM at CAS/IHEP

QM of mirror module (ESA/Media-Lario) to be delivered to CAS soon

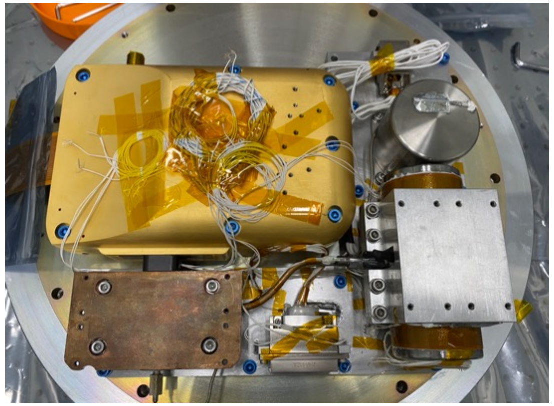

STM MM tested at IHEP

First light of STM MM at IHEP/CAS

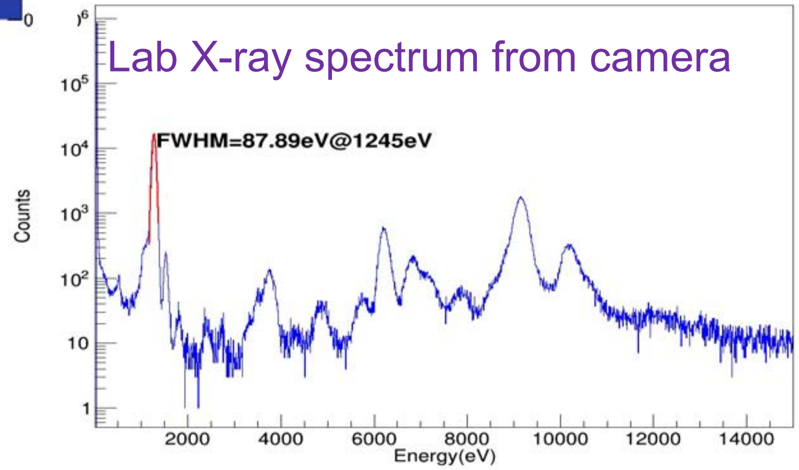



QM FXT MM (ESA/MediaLario)


Camera assembling at IHEP


X-ray camera QM

Lab X-ray spectrum from camera



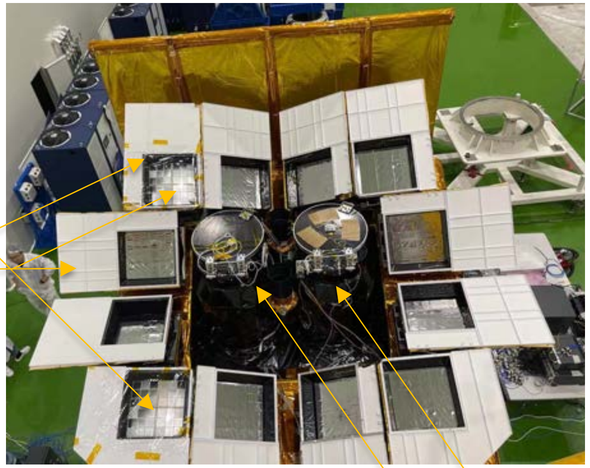
Satellite status: QM AIT

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

Chief designer Zhang Yonghe

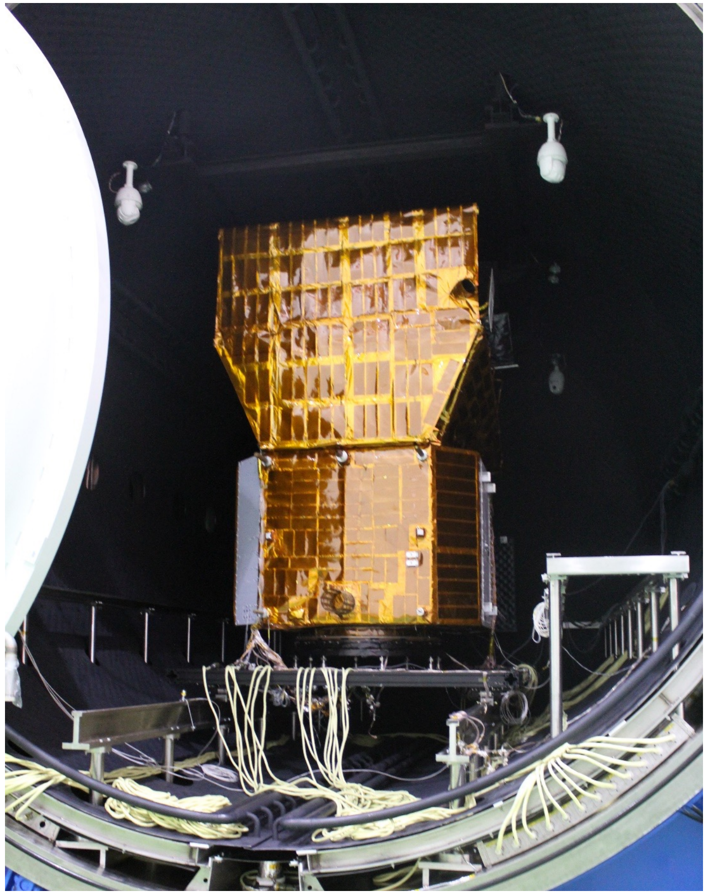
Mechanical tests

2 WXT QM
10 STM



1 FXT STM
1 FXT QM

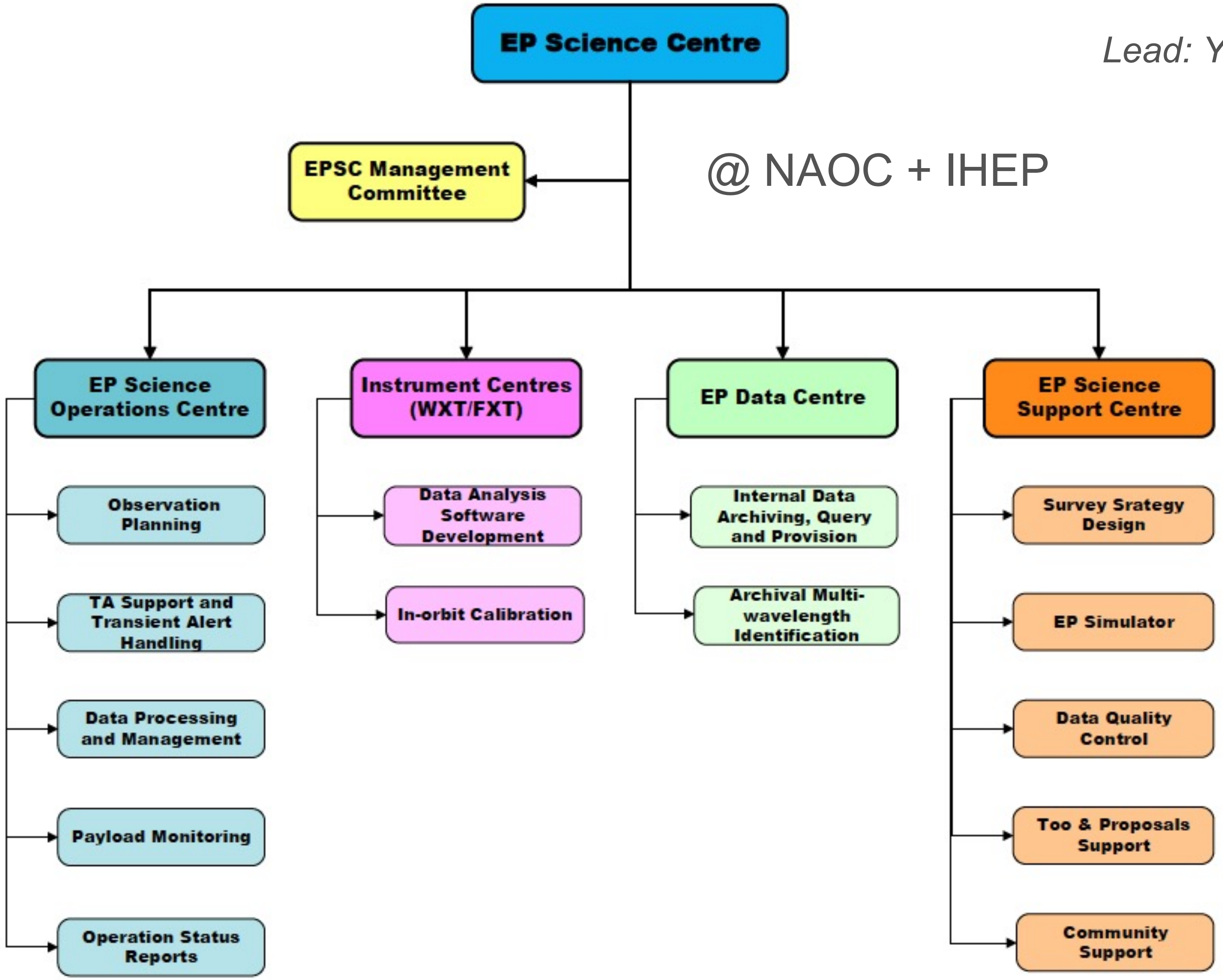
Credit: MicroSat/CAS



Thermal balancing & thermal vacuum tests

EP Science Centre

Lead: Yuan W. / Liu Yuan



EP Science Centre

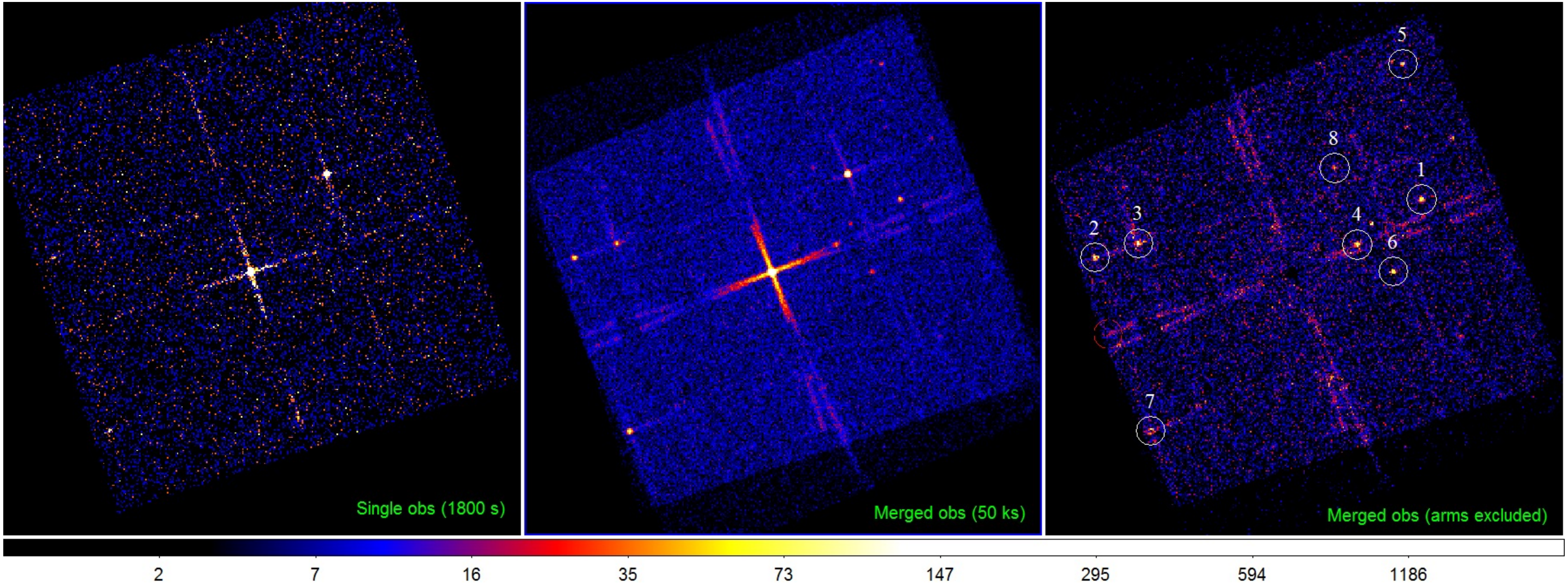
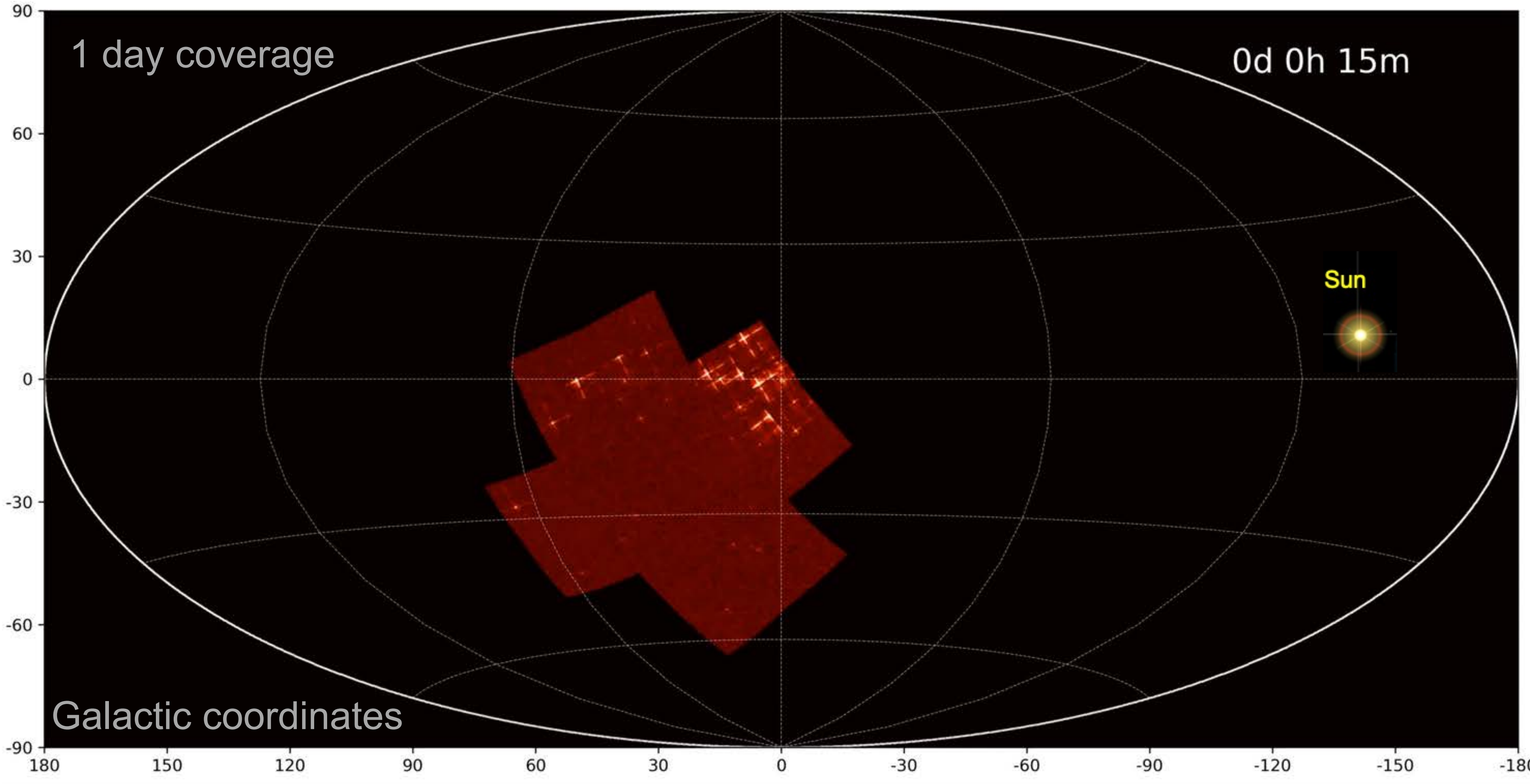


Image stacking and source detection for 1 WXT CMOS (9°x9°) *Liu Yuan, et al.*

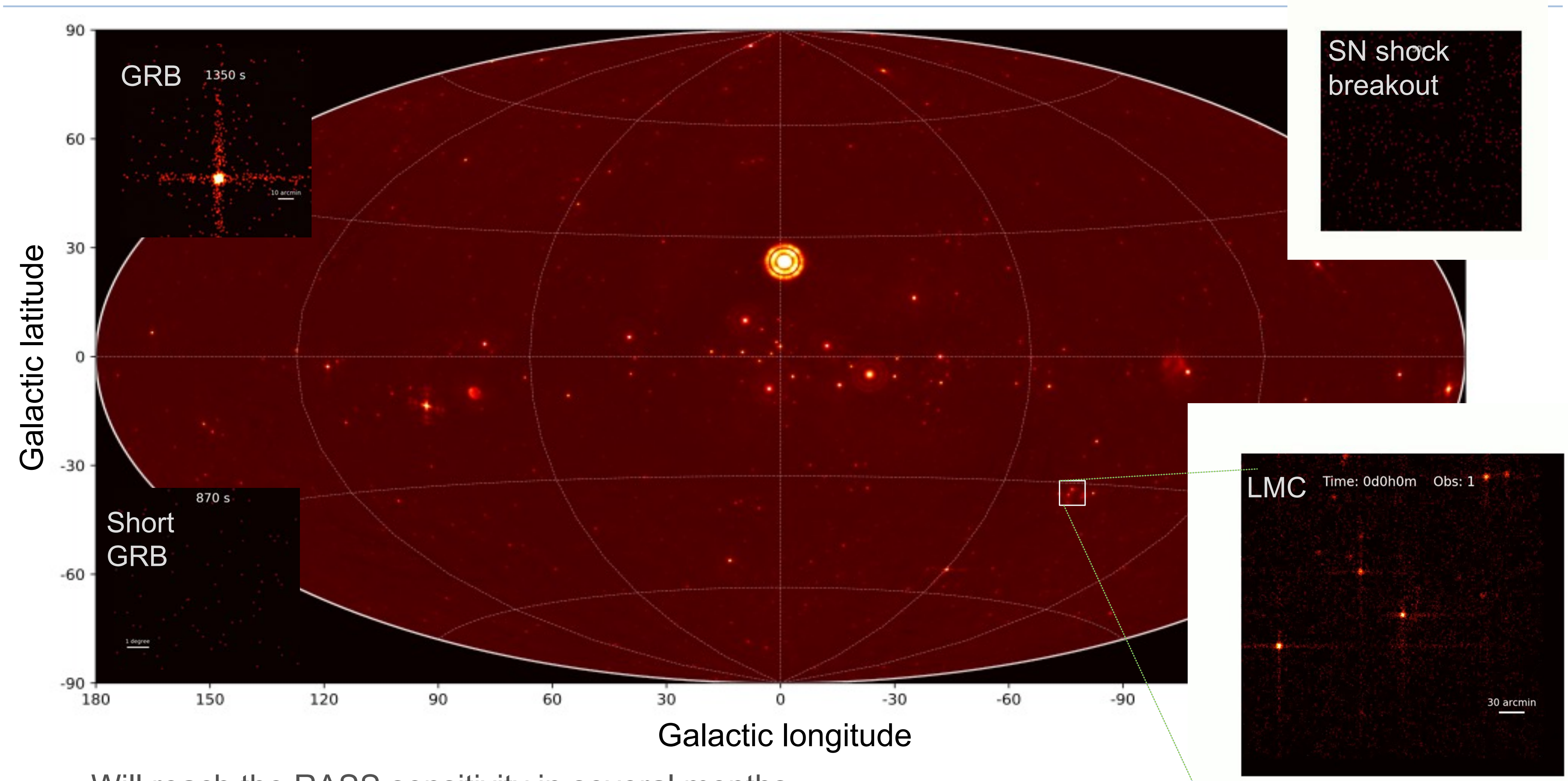
Simulation of 1 day survey with WXT



- In 3 orbits (~ 5hr) WXT covers most of the night sky
- Cover the whole sky in half year

Pan Haiwu, Zhao Donghua, et al.

Simulated all-sky image & transients in 1-year

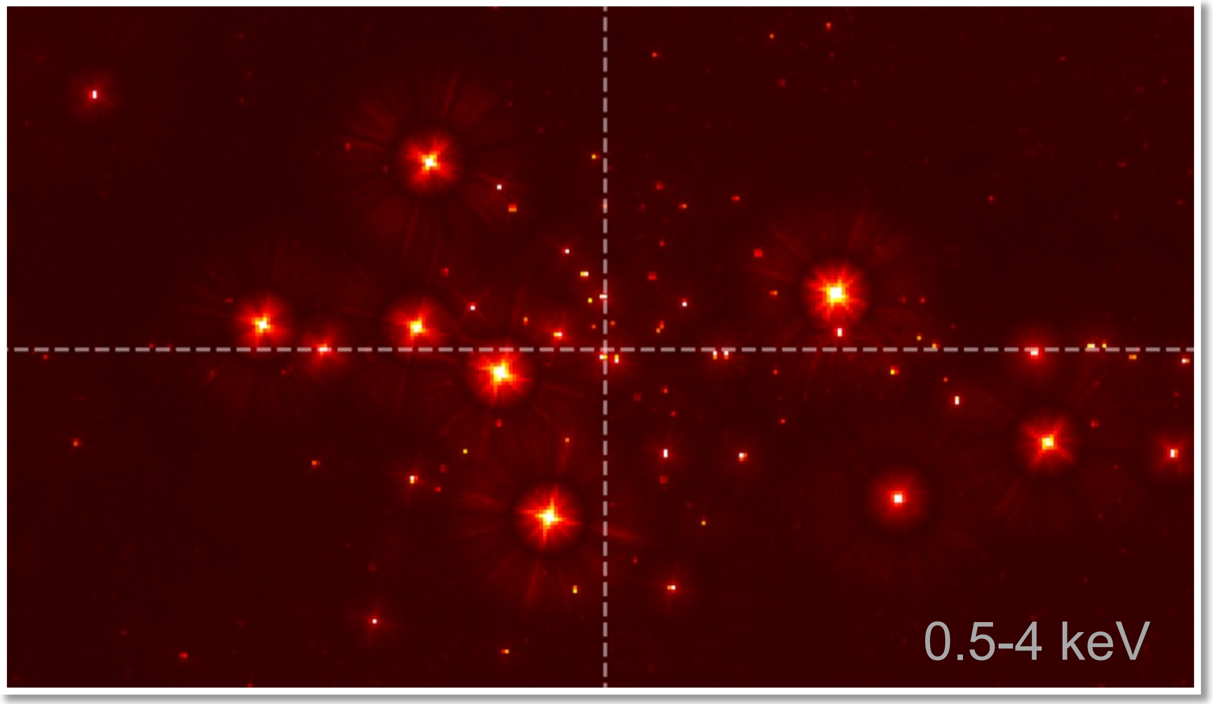


Will reach the RASS sensitivity in several months

Pan Haiwu, Zhao Donghua, et al.

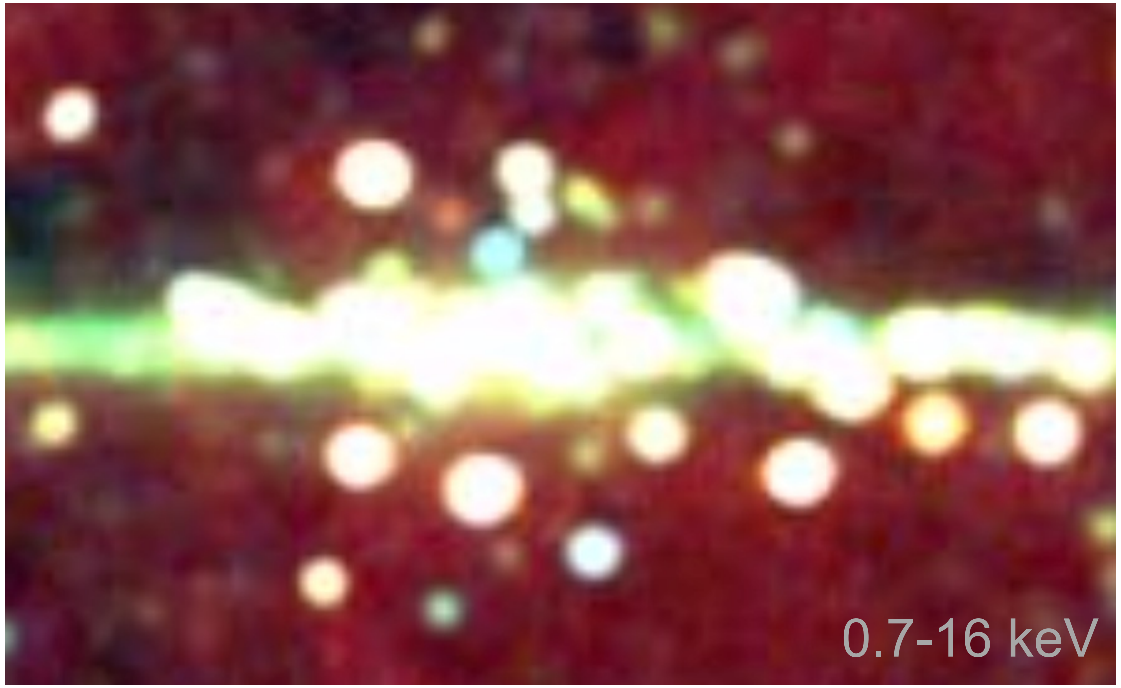
Simulated EP WXT images

Galactic center region (about 20°x 10°)



Credit: EP team

EP/WXT 1 year



Credit: RIKEN/JAXA/MAXI team

MAXI (10 year)

Estimated detection rates for selected classes

Type of transients	Detections per year
Tidal disruption event (TDE)	10s - 100
TDE with jet	several
Supernova shock breakout	10 – 10s
Long GRB	10s
High-z GRB (z > 6-8)	several
Short GRB	10
Low-luminosity GRB	10
Magnetar	a few
Stellar flares	a few 10^3
AGN monitored daily / weekly	tens / hundreds

challenging to measure redshift !

 # transients per week

EP: ~ tens (?)

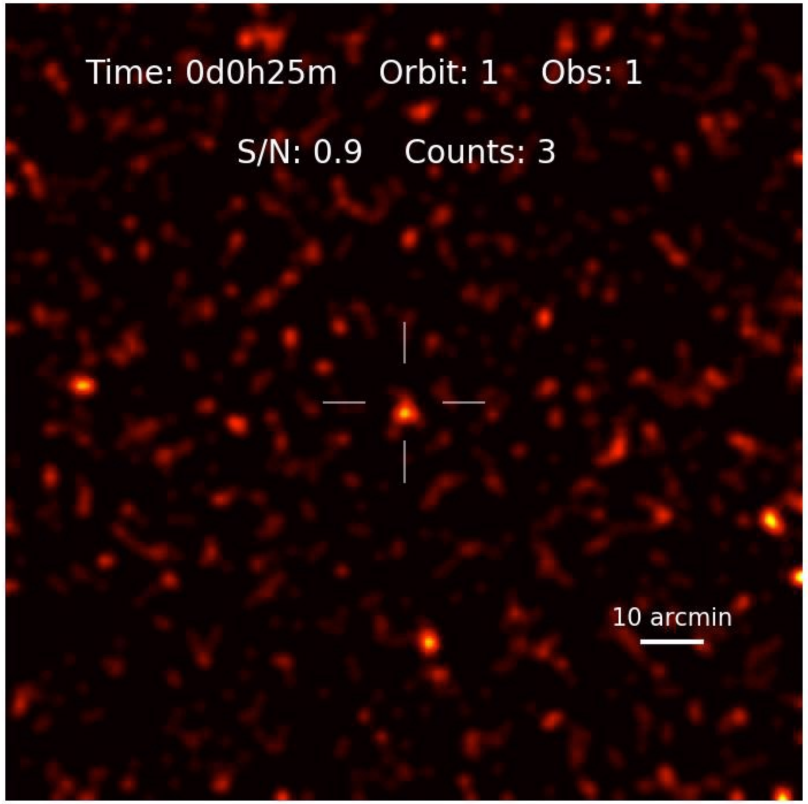
Swift: 2.5

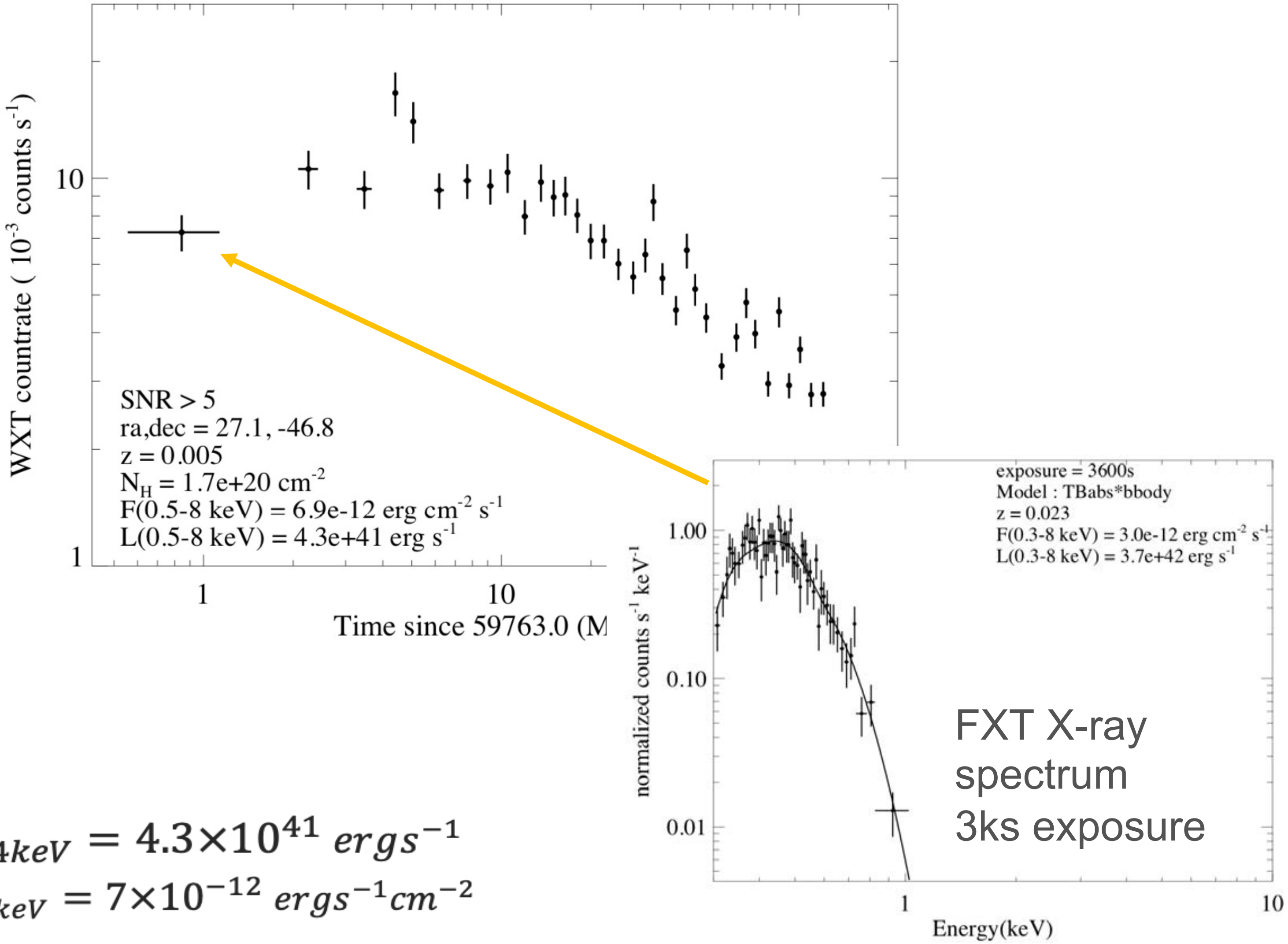
MAXI: 0.8

Note: subject to large uncertainties…

Example: simulated detection of a nearby TDE

simulation: a nearby TDE @ 21Mpc





$M_{BH} \sim 10^4\ M_{Sun}$ IMBH

$L_{0.5-4keV} = 4.3\times10^{41}\ ergs^{-1}$

$f_{0.5-4keV} = 7\times10^{-12}\ ergs^{-1}cm^{-2}$

EP consortium

Chinese Academy of Sciences

- Managed by CAS's National Space Science Centre (NSSC)
- Institutes: NAOC, IHEP, SITP, MicroSAT, NSSC, NNVT, IPC, HIT

European Space Agency (Mission of Opportunity)

- Hardware contribution (mainly FXT)
- Ground station support
- Science management support

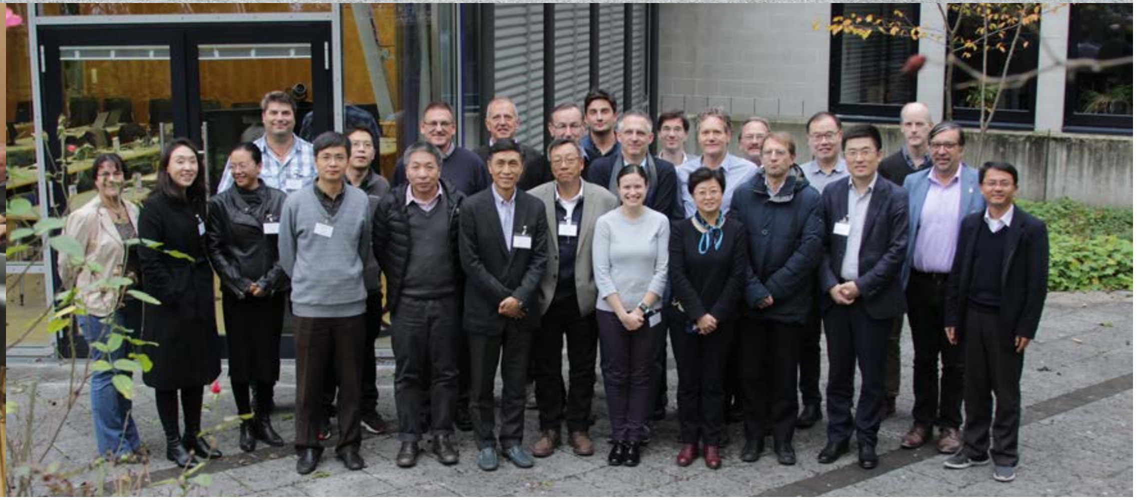
Max-Planck-Inst. for extraterrestrial Physics, Germany

- Hardware contribution (FXT)

CNES, France (collaboration in discussion)

- VHF network & support (contribution to EP Science Centre)

EP development team



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.nao.cas.cn

Welcome to join EP Science Team!