Exploring the ever-changing X-ray Universe

Einstein Probe

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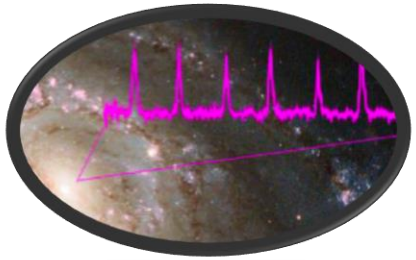
On behalf of EP consortium

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

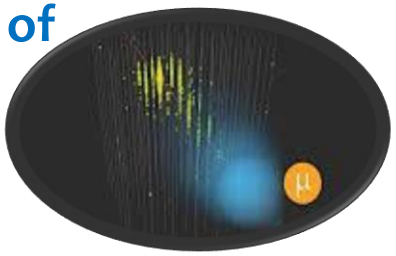
When first stars formed?
metal enrichment in early universe

Next generation X-ray monitors needed to see

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

EM counterpart of neutrino events

How particles Accelerated?



Supernova shock breakout

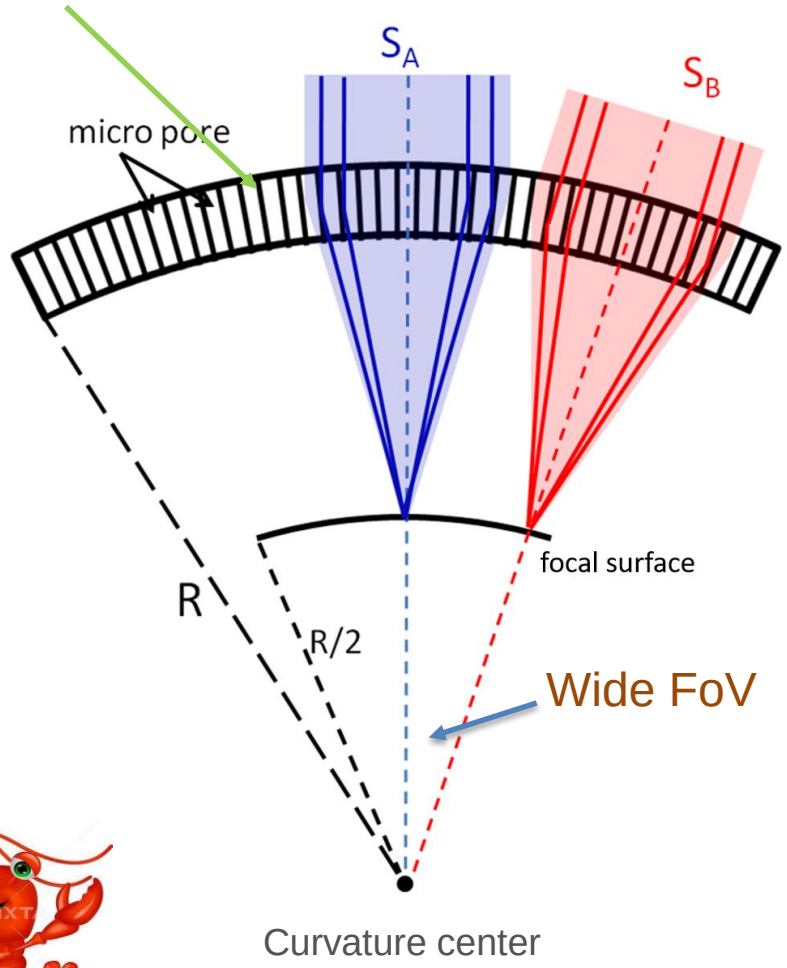
Supernova physics & progenitors

EM counterpart of gravitational waves

What are EM counterparts?
How compact objects merge?

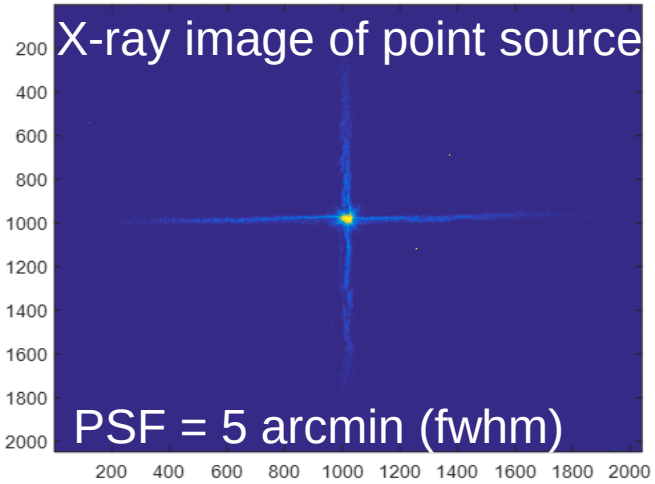
Lobster-eye micro-pore optics (MPO) for X-ray focusing

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

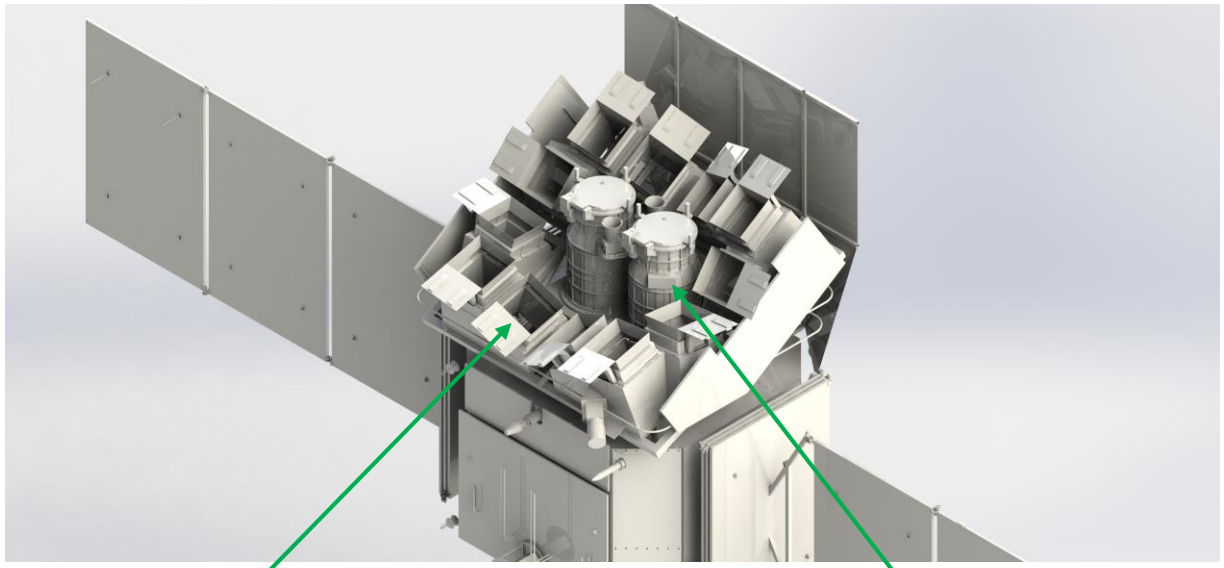
Einstein Probe (EP) mission of CAS

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

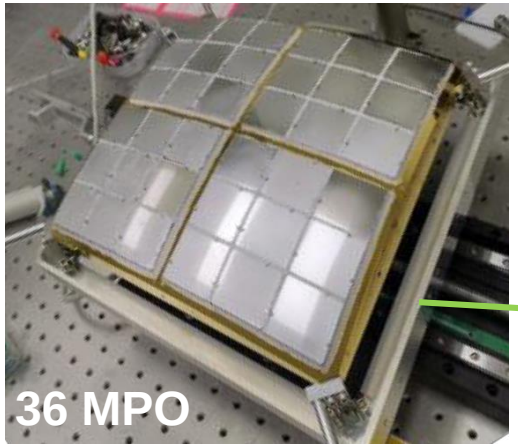
Wide-field X-ray Telescope
WXT (12 modules)

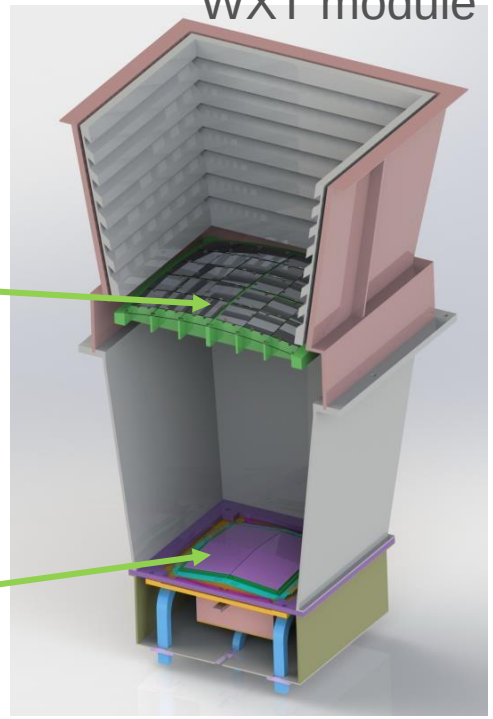
lobster-eye MPO
FoV: 3600 sq deg (1.1 sr)
band: 0.5 – 4 keV
spatial resolution: ~ 5’ (FWHM)
sensitivity: tens times better than current

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

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

Wide-field X-ray Telescope (WXT)



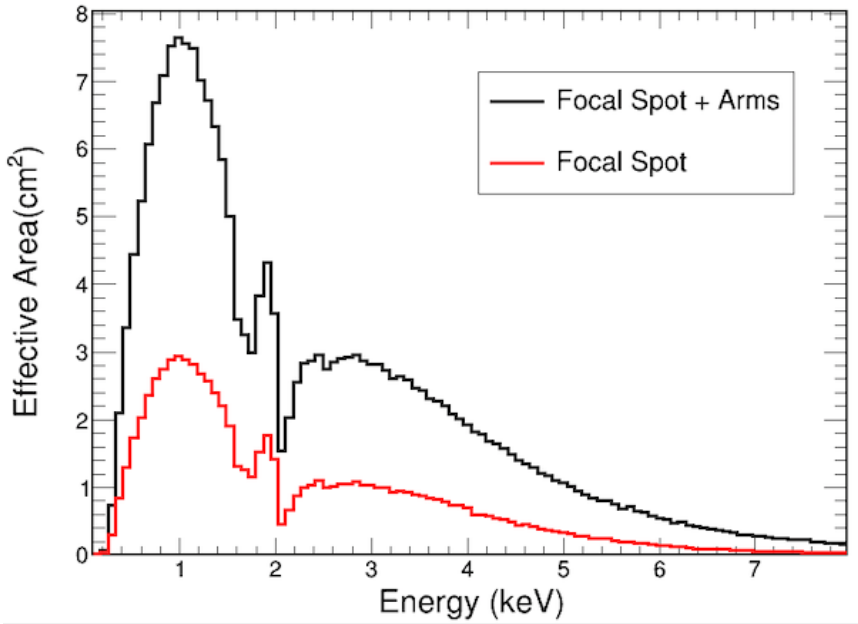


Focal length 375mm

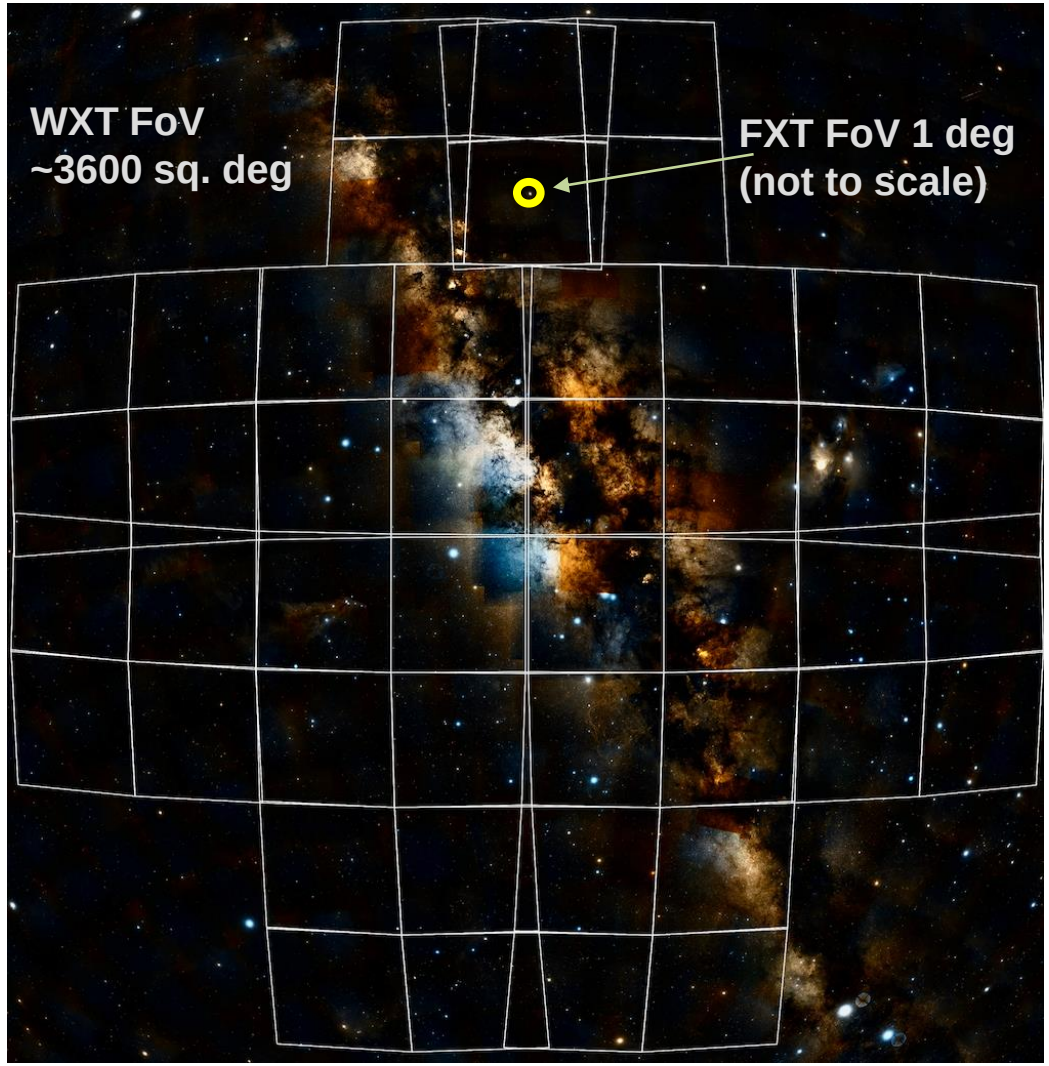
- development: CAS (SITP, NAO) + NNVT
- test/calibration: CAS & ESA
- WXT PI: X. Sun (SITP);
- Instr. Sci: Z. Ling (NAO); MA PI: C. Zhang (NAO)

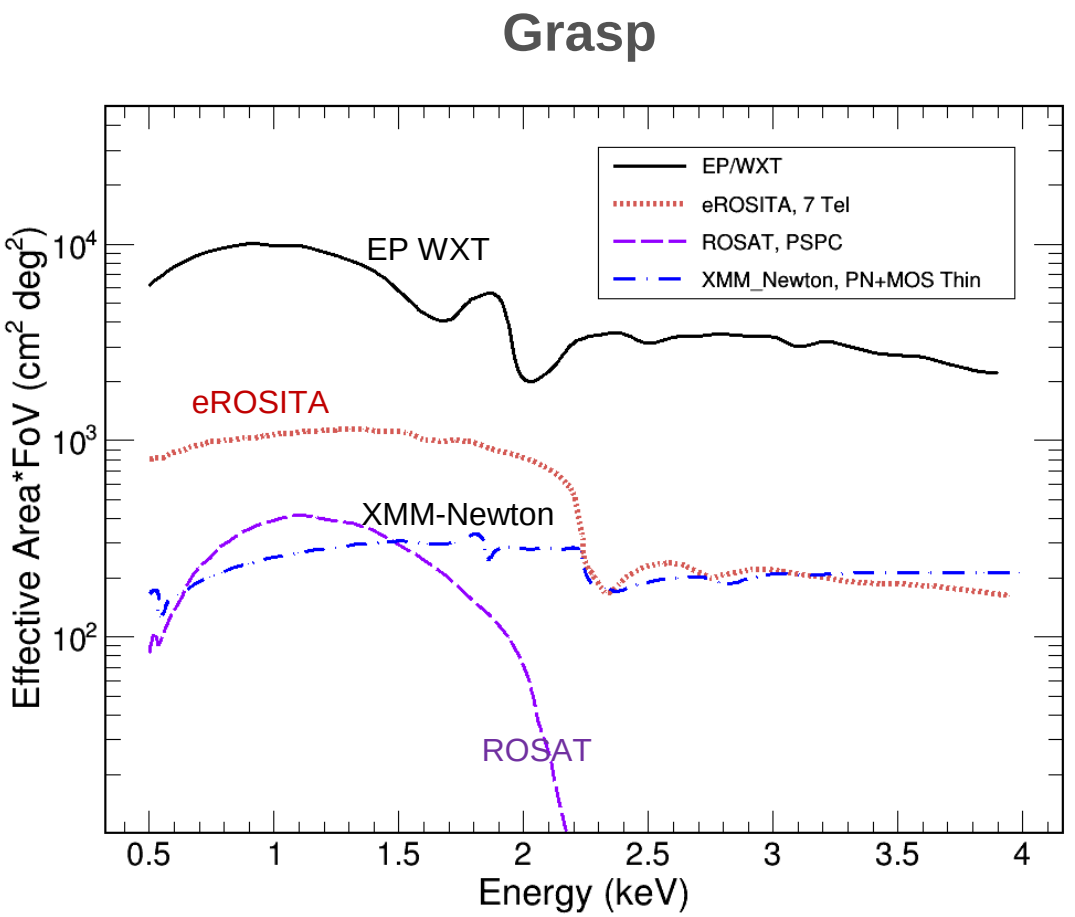
Technology challenges

- **First large-FoV MPO telescope (432 plates)**
- **Large detector array (48 CMOS x 6 x 6 cm^2)**
- **Use of CMOS as X-ray detectors in space**
- **Soft X-ray band**



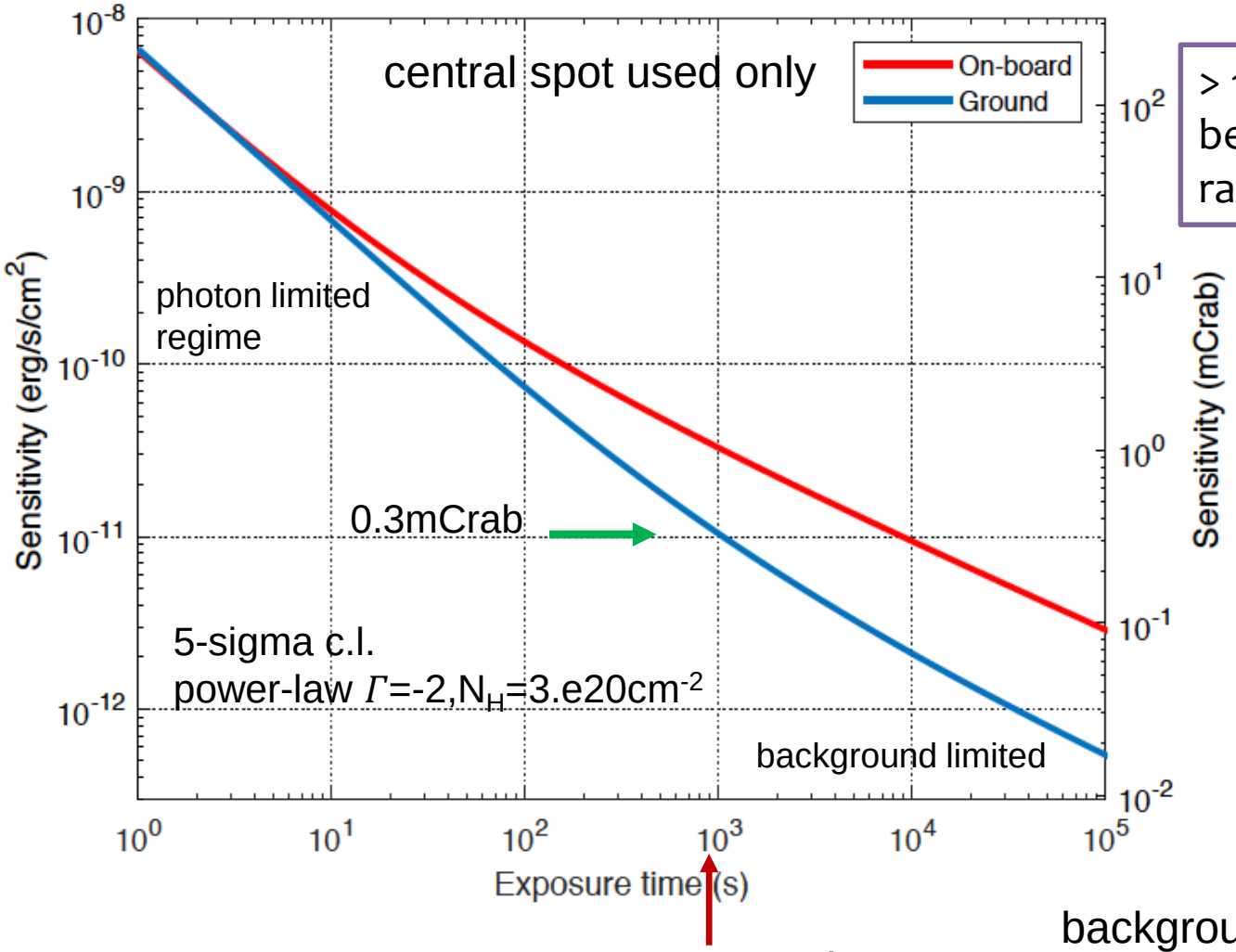
WXT FoV & Grasp





Zhao D. et al. 2017

Simulated EP WXT sensitivity



> 1 order of magnitude better than current X-ray ASM (MAXI, Swift)

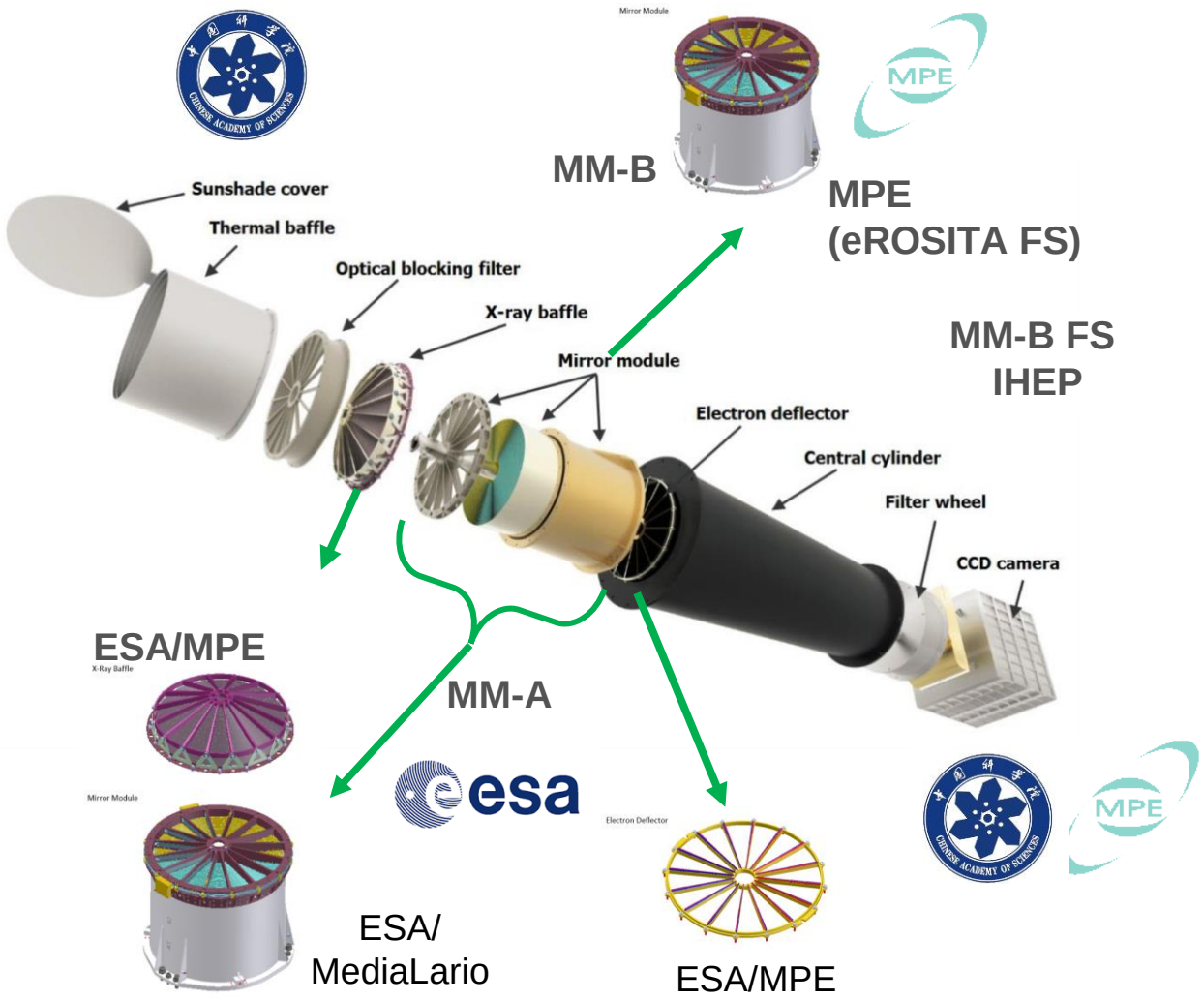
~ 1 survey snapshot

background 3.3 counts @ central spot

backgrounds : particles, diffuse background, with shielding

Zhao D. et al. 2017

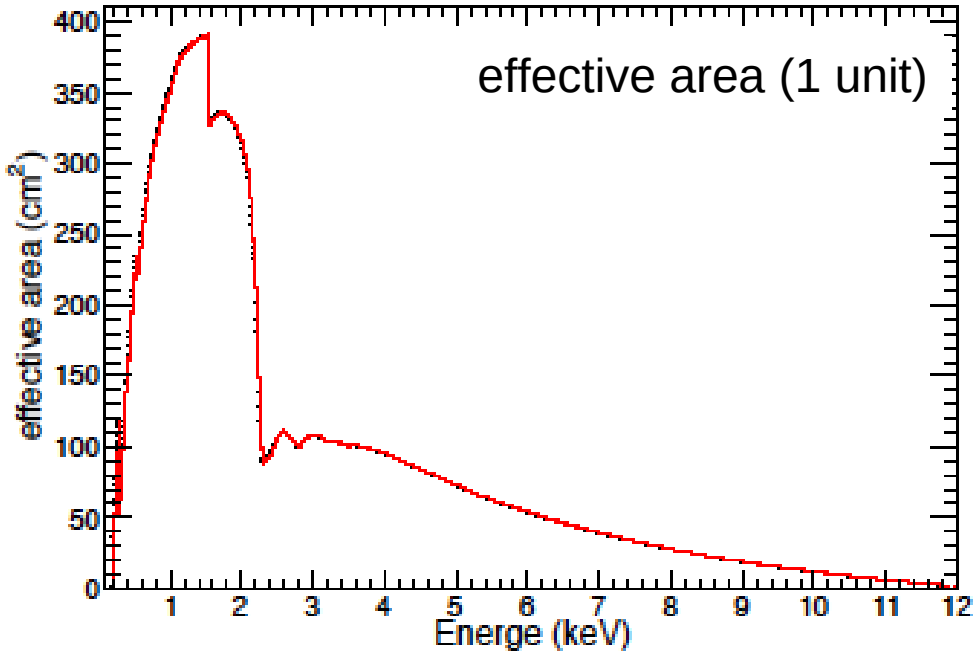
Follow-up X-ray Telescope (FXT)



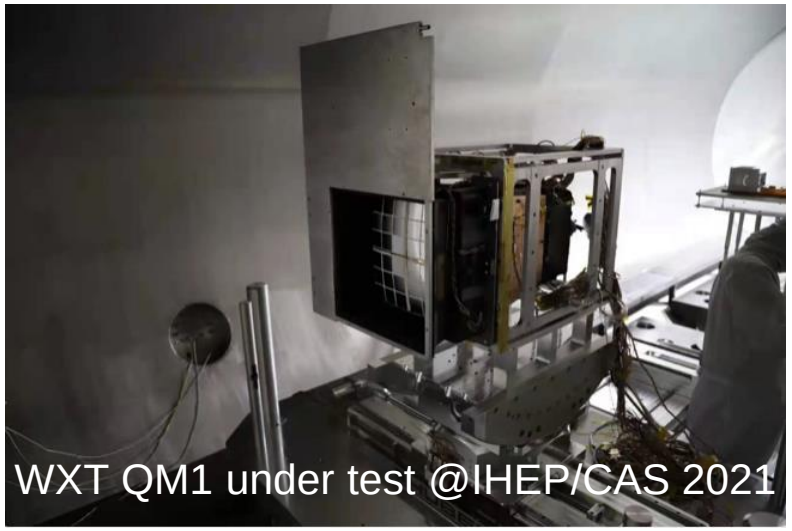
CAS/IHEP+ ESA + MPE

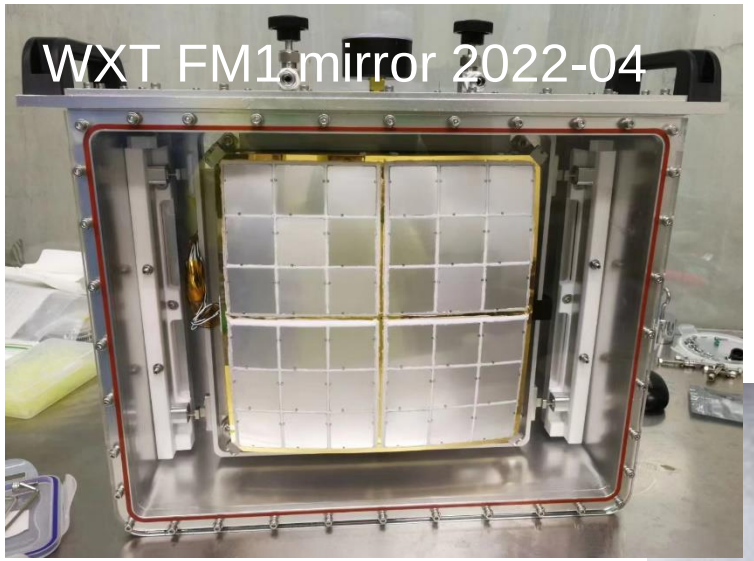
PI: Y. Chen (IHEP)

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



WXT status

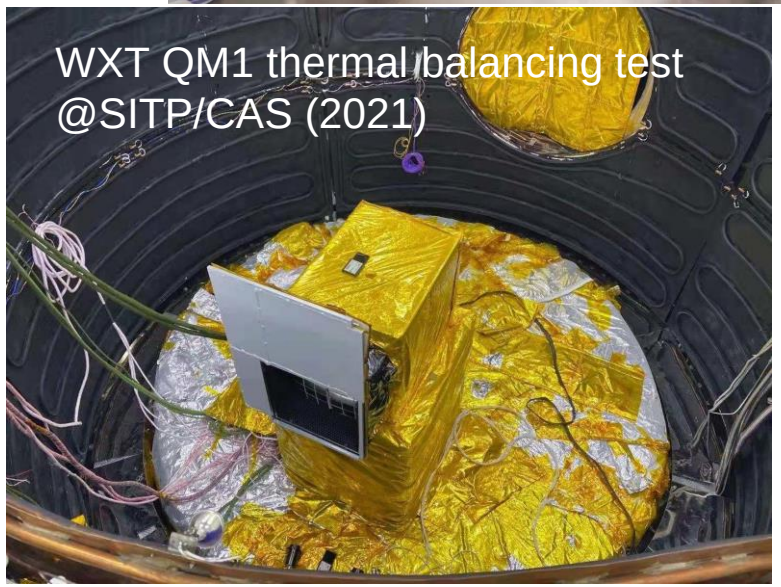

WXT QM1 under test @IHEP/CAS 2021


WXT FM1 mirror 2022-04

Built and tested

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


CMOS detectors @SITP/CAS


WXT QM1 thermal balancing test @SITP/CAS (2021)

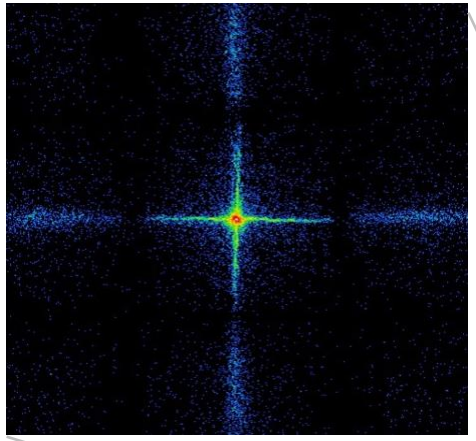

WXT MA QM3

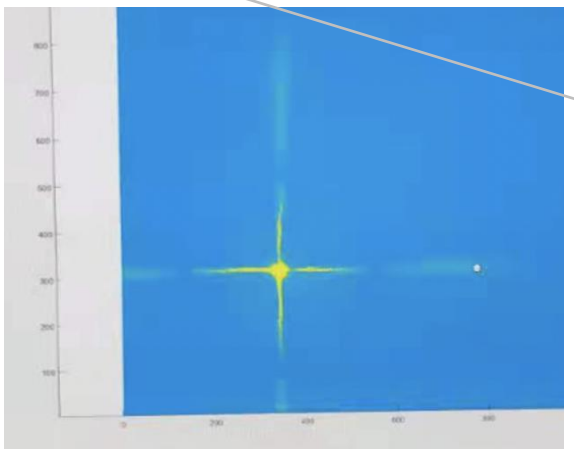
X-ray Test by ESA/MPE @Panter MPE 2021-04

WXT status

X-ray image of point source

FWHM 4 - 5.5 arcmin



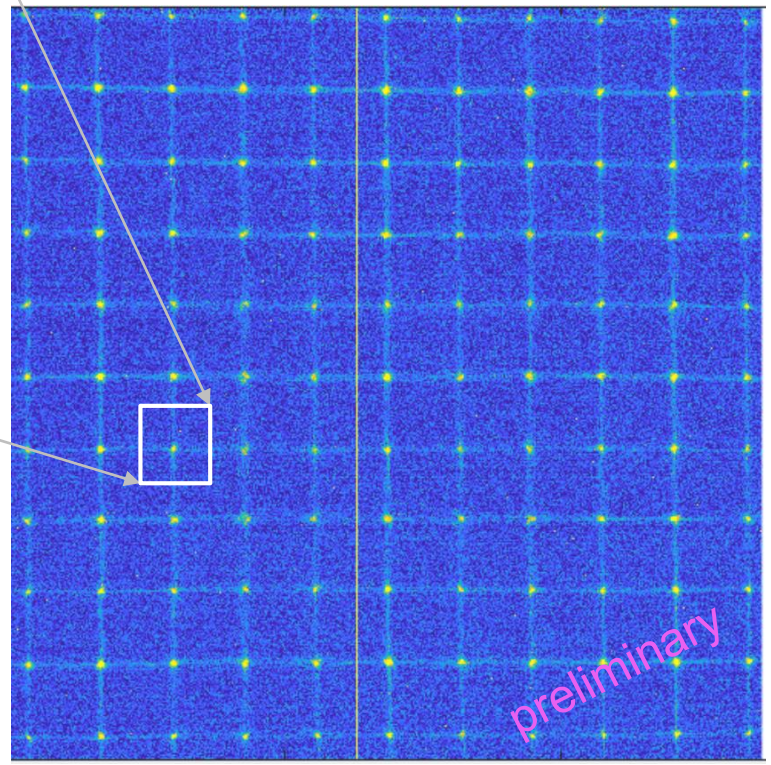


PSF for a compete WXT module

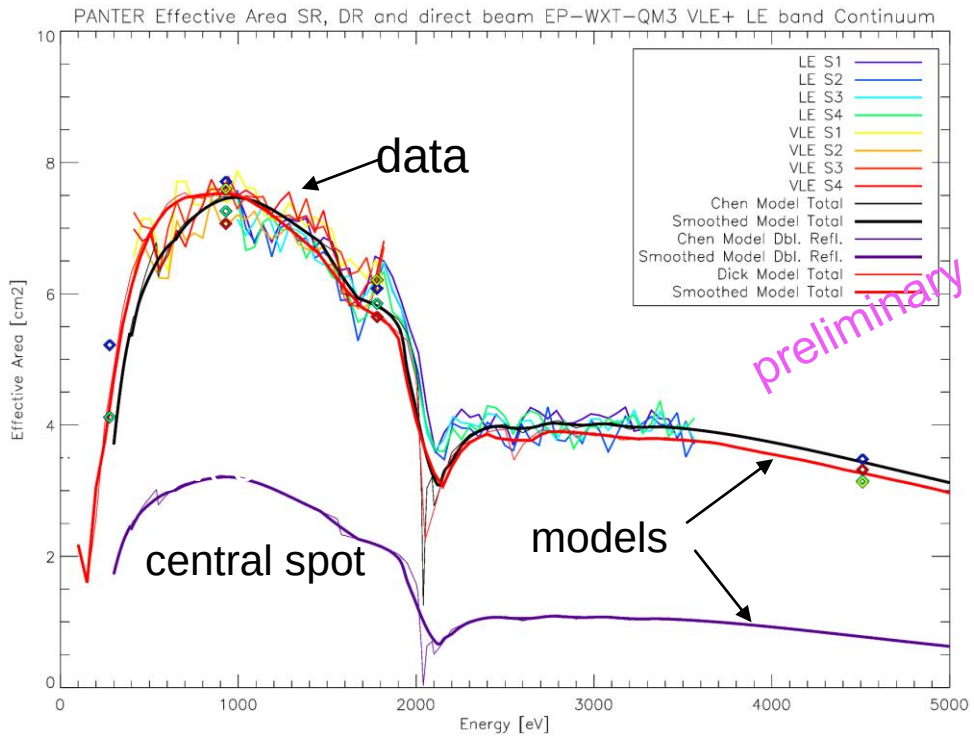
¼ FoV of a WXT module MA

~ 9 deg x 9 deg

PSF images of point-source from 121 directions



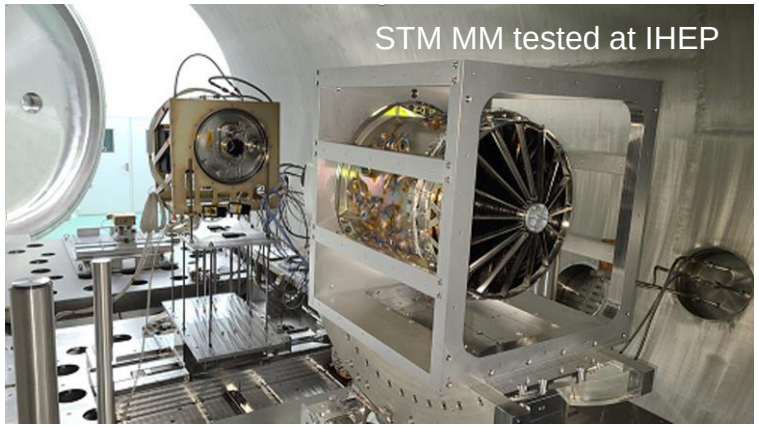
Measured effective area (cm^2 vs. energy)



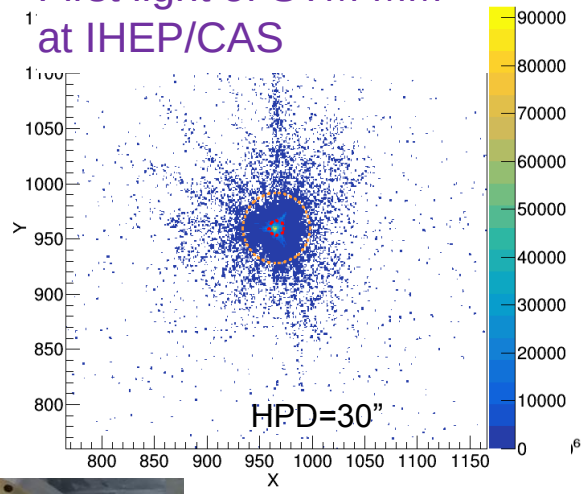
Credit: CAS/ESA/MPE

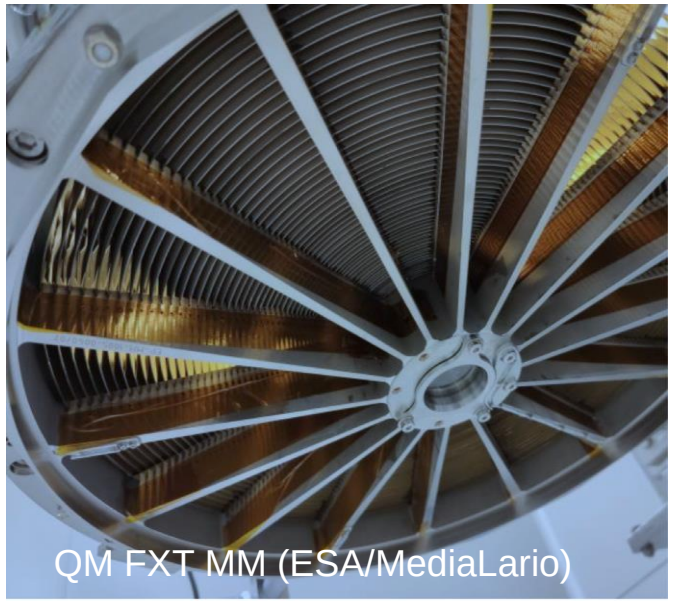
FXT Status

- 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

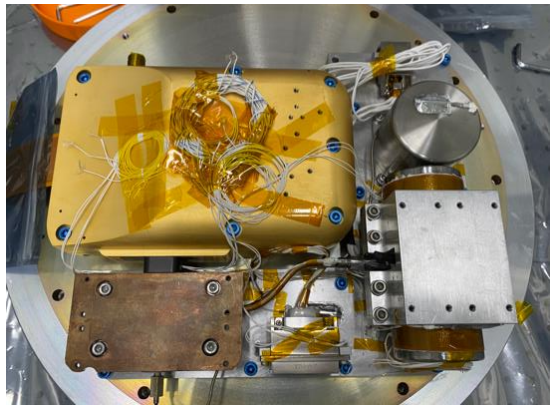


First light of STM MM at IHEP/CAS



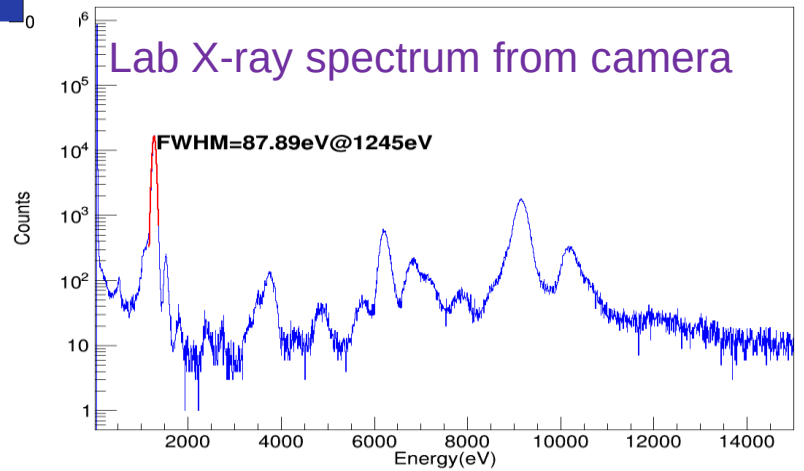


Camera assembling at IHEP



X-ray camera QM

Lab X-ray spectrum from camera



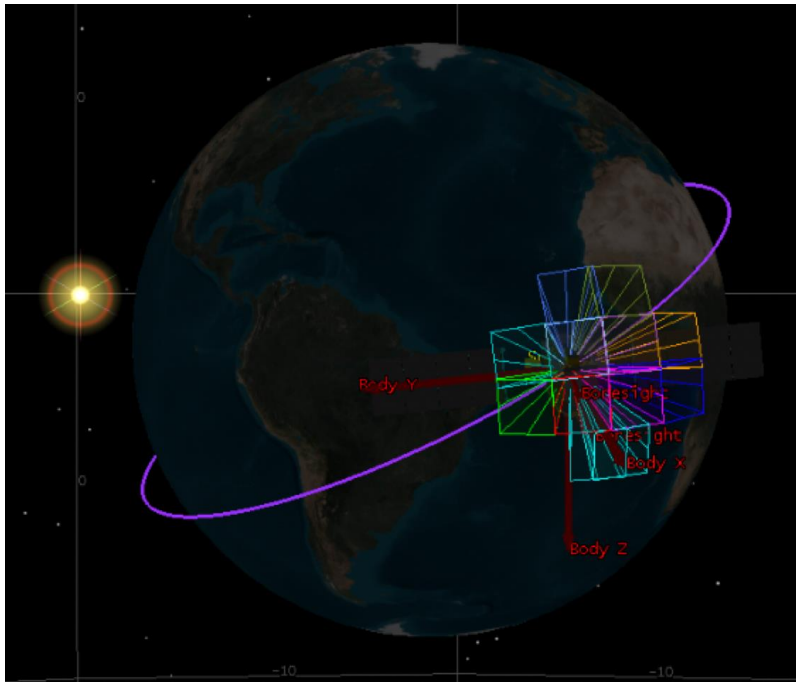
Satellite status: QM AIT

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

Credit: MicroSat/CAS

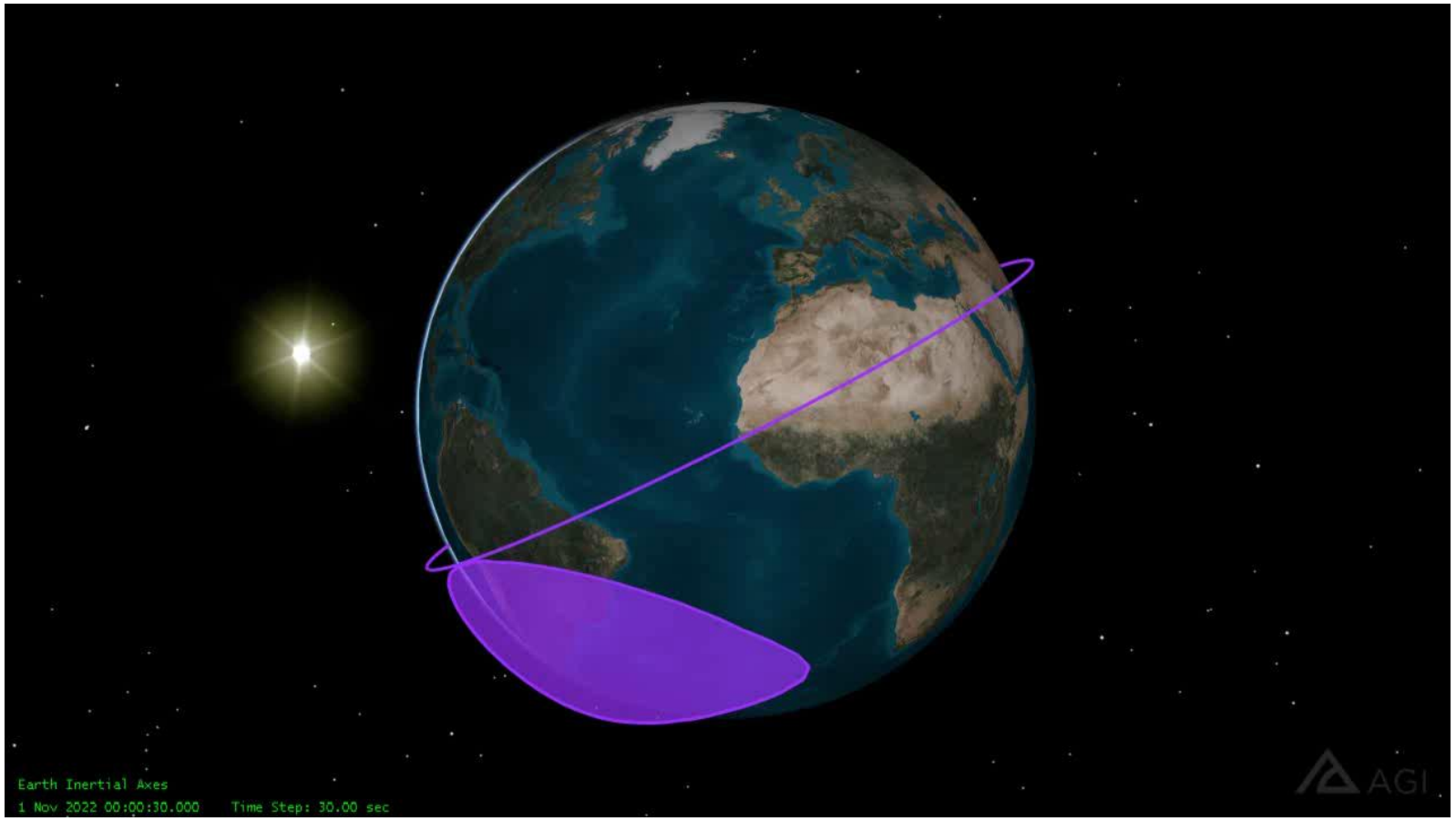
Mission profile

- 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

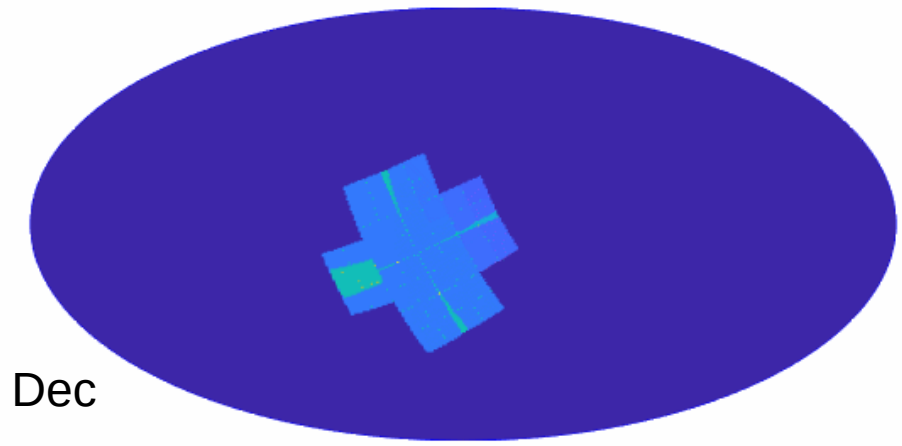


- EP Mission Centre @ NSSC/CAS
  ESA (GS telemetry support)
- EP Science Centre @ CAS
  NAOC+IHEP

EP all-sky survey mode

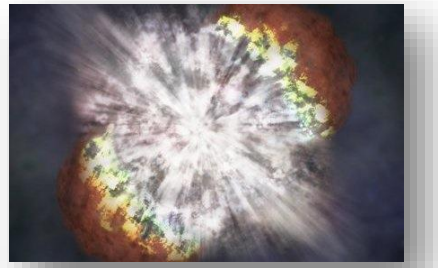


- anti-Sun pointings
- 3 snapshots per orbit, each ~20 min
- 3 orbits (~ 5 hr) cover half sky
- 1 day: ~ 45 snapshots

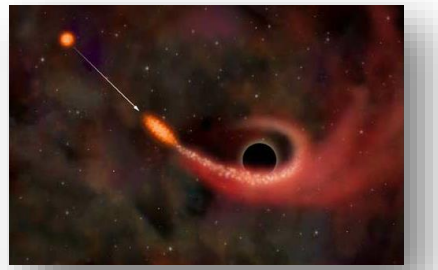


Main science objectives

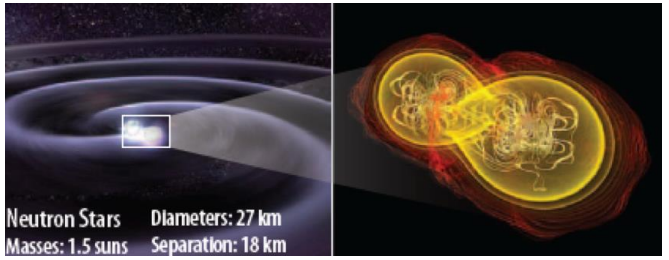
Systematic survey of soft X-ray transients and variability of X-ray sources at an unprecedented combination of high sensitivity and cadence



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

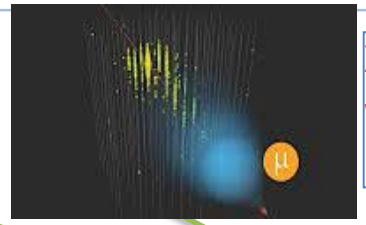


Detect and localise the electromagnetic-wave sources of gravitational-wave events by synergy with gravitational-wave detectors

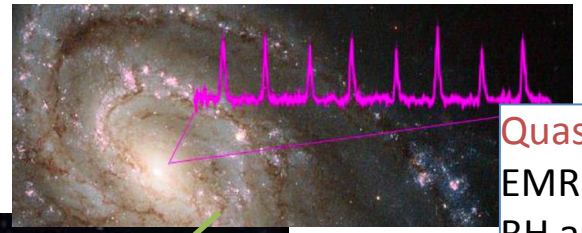


Various classes of high-E transients & variability

High redshift GRB
Early universe

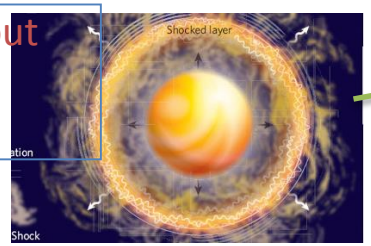


X-ray flares associated with neutrino events
particle acceleration



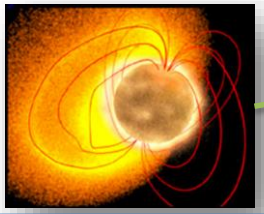
Quasi-periodic erruption
EMRI (GW source?)
BH accretion ?

SN shock breakout
SN physics
progenitors



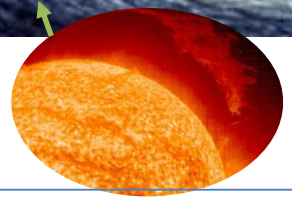
Active galactic nuclei
Extreme gravity, BH accretion/jets/growth

Intermediate-mass BH
BH physics/accretion

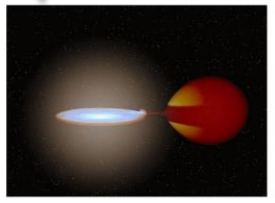


magnetar
extreme
magnetic Field

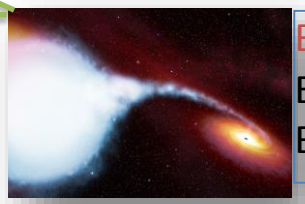
Fast Radio Burst
X-ray sources



Star X-ray flares
Magnetic fields
Corona activity

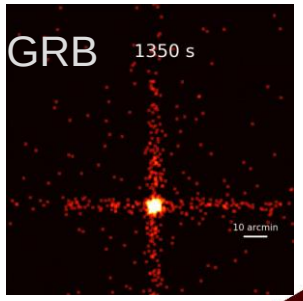


Thermal nuclear burst
Neutron stars physics



BH X-ray binary
Extreme gravity
BH physics/accretion

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
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

 # transients per week

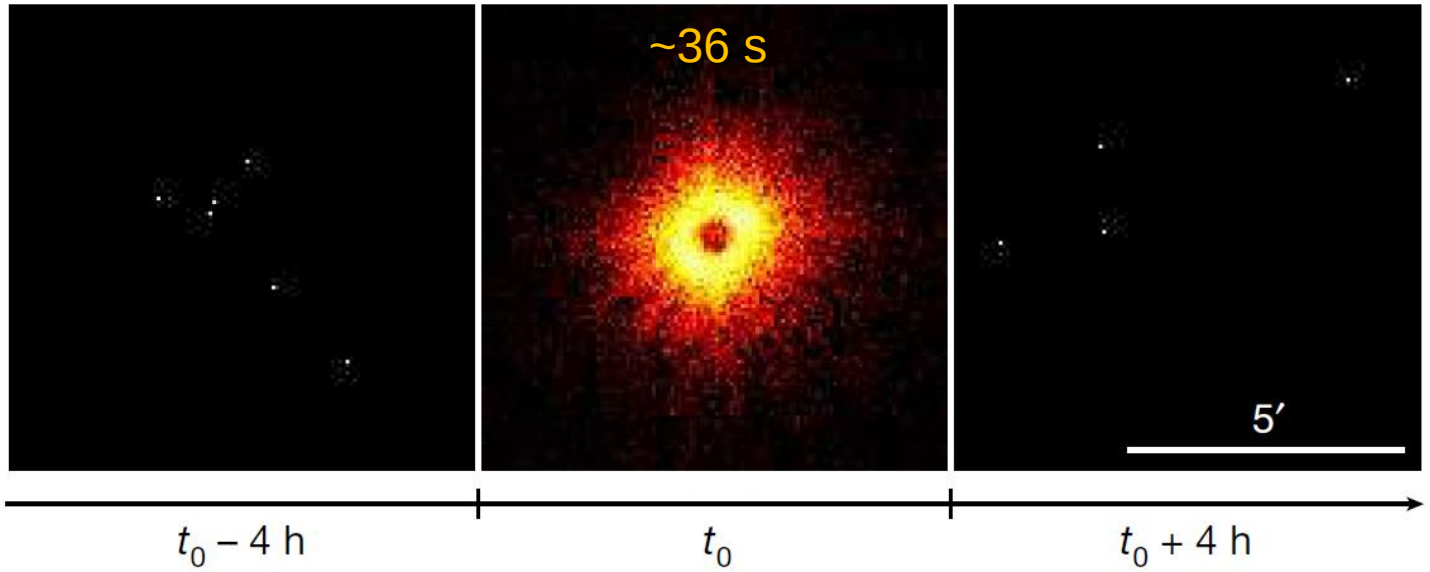
- EP: >10
- Swift: 2.5
- MAXI: 0.8

challenging to measure redshift !

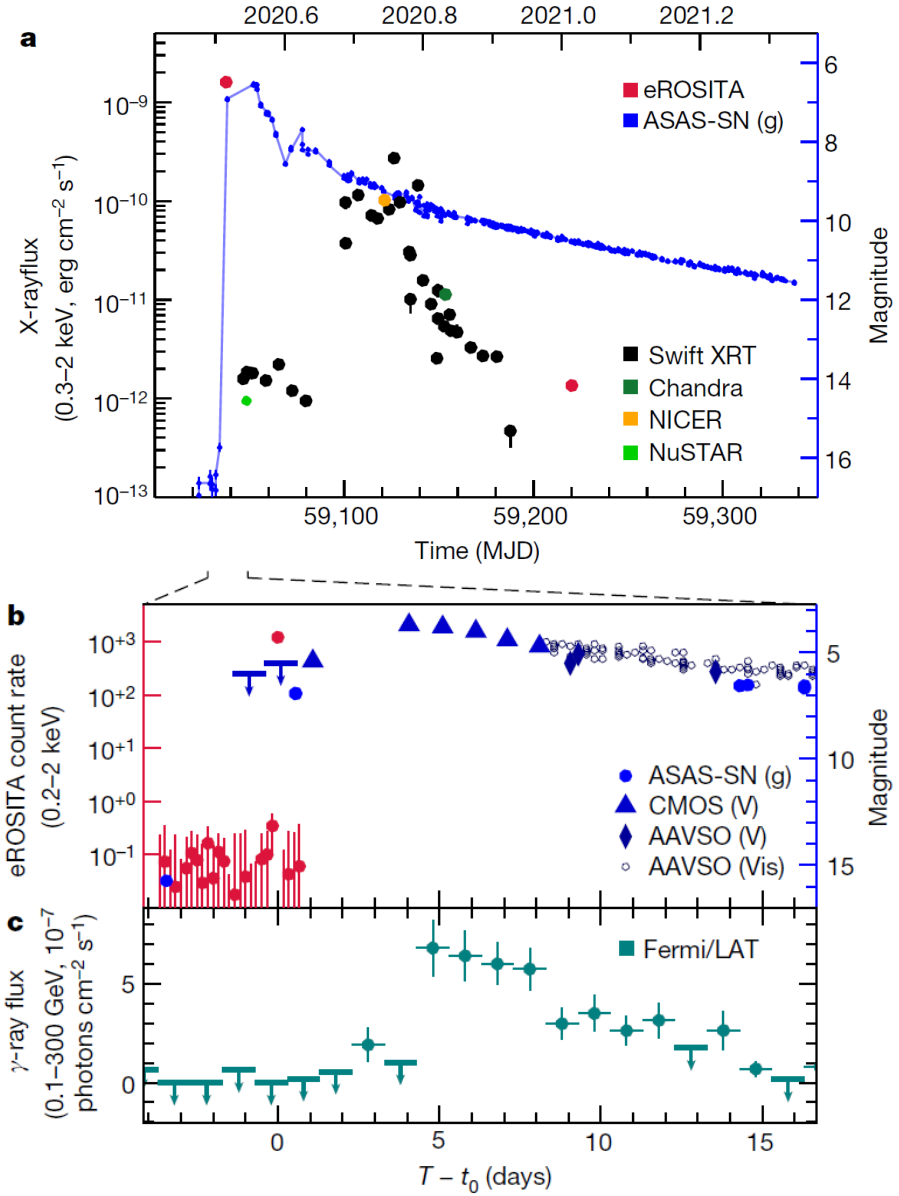
Note: subject to large uncertainties…

The fireball phase of a nova (YZ Reticuli)

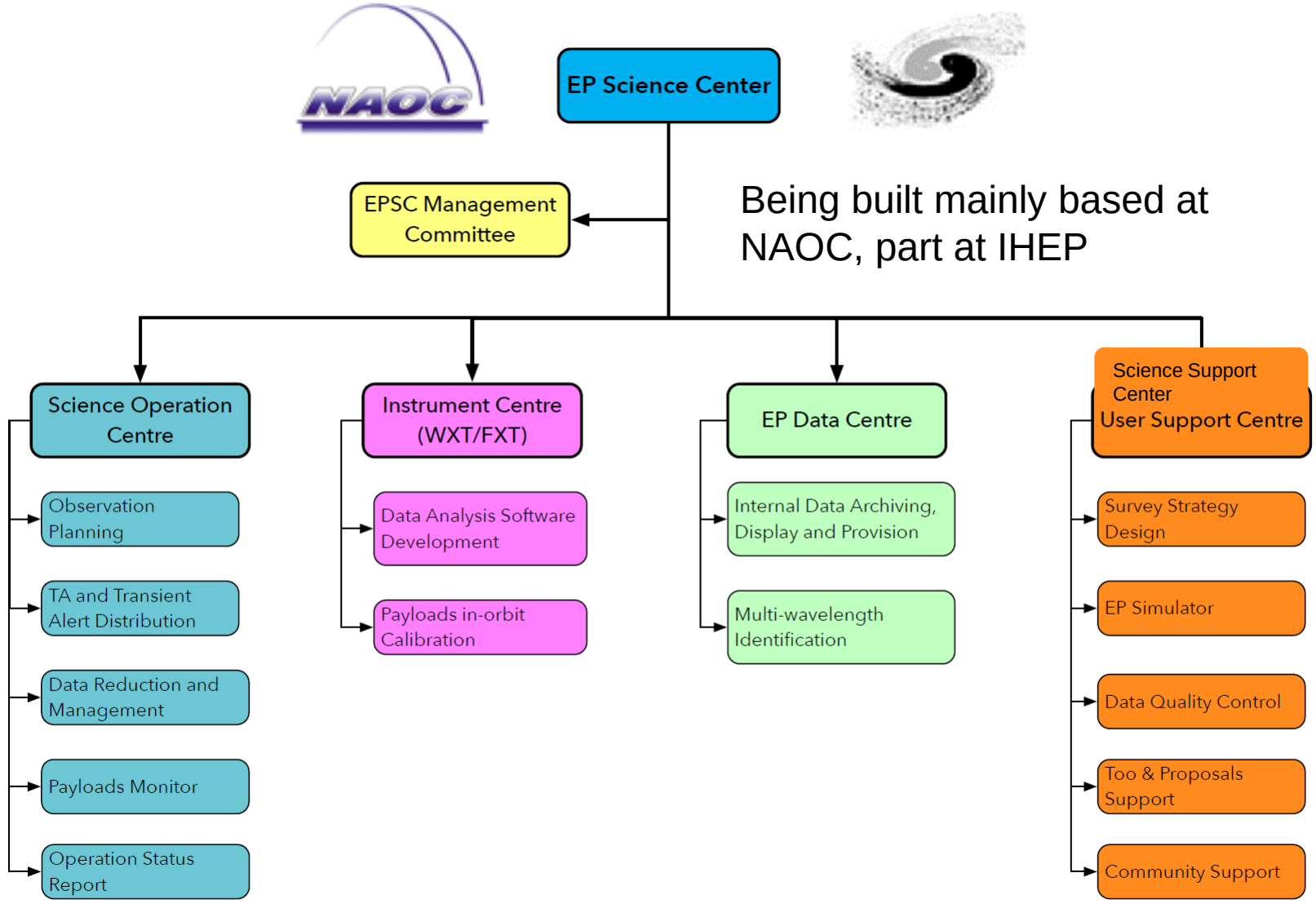
- A short, bright and soft X-ray flash before the nova becomes visible in the optical
- 6-12 h for 1.0 Msun
- filled a gap in our understanding of how classical novae occur



König+2022

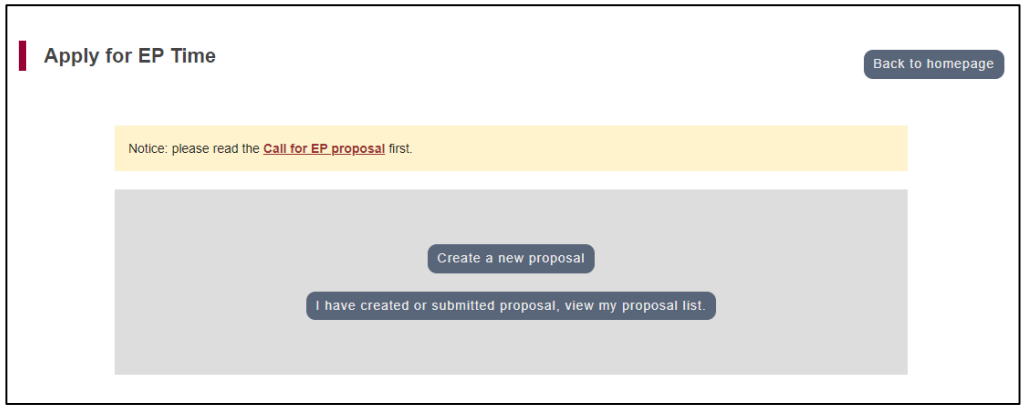


EP Science Center

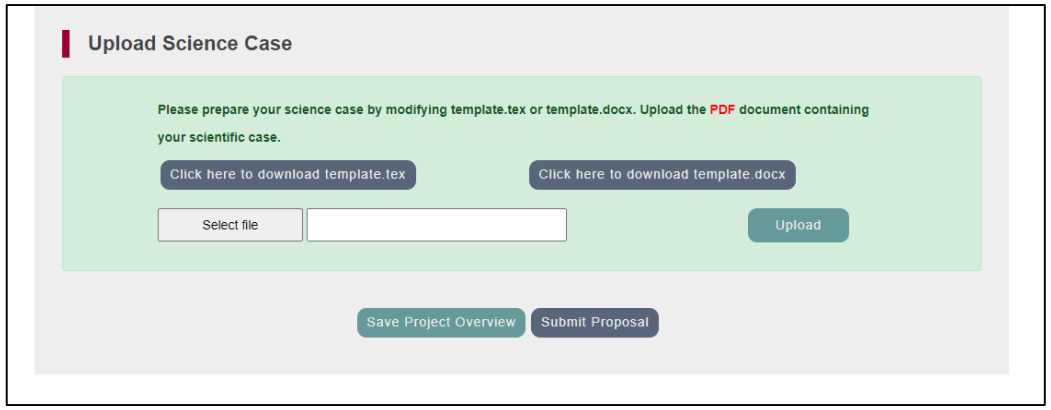


Proposal Tools

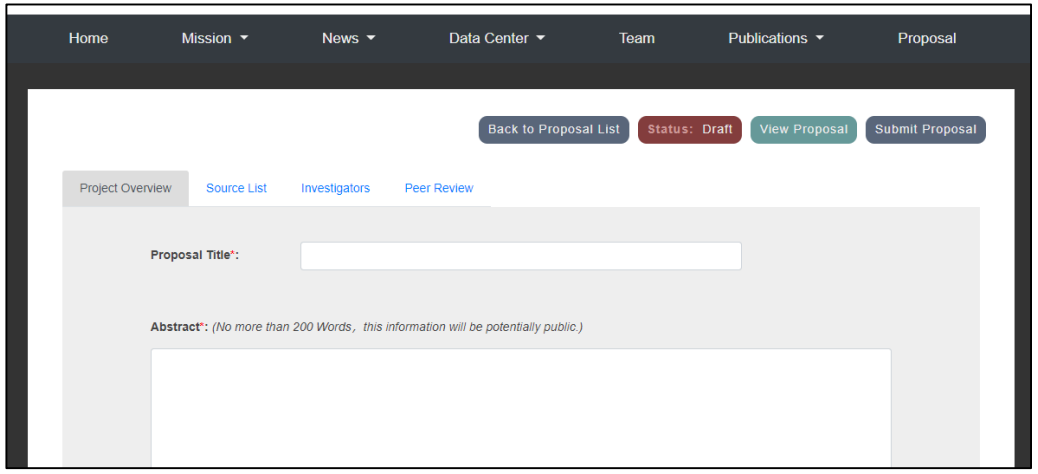
- Proposal submission and review



Proposal Management



Science Use Case Submission

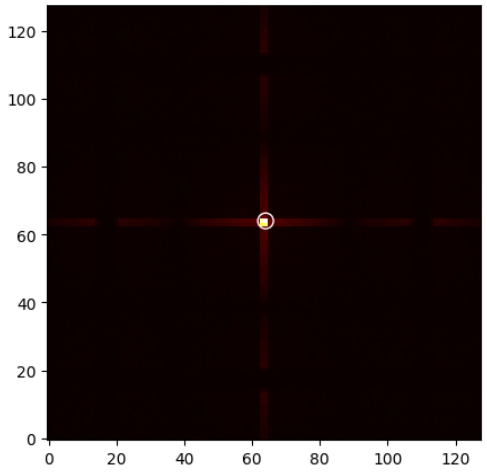


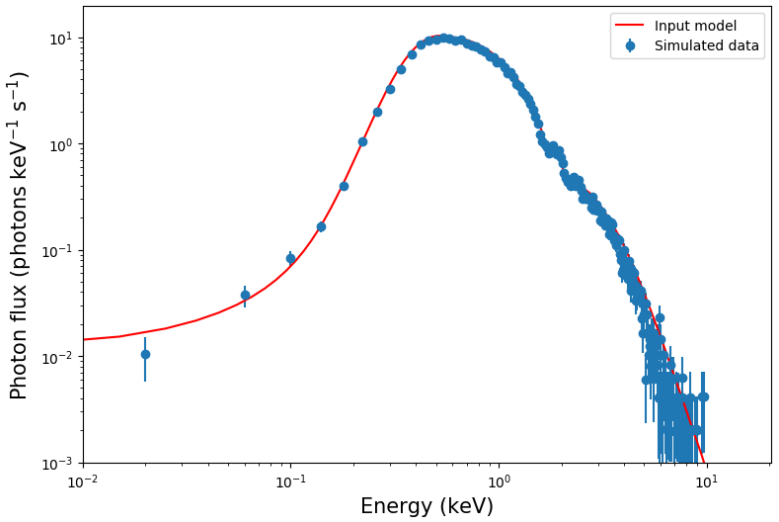
Proposal Content Filling

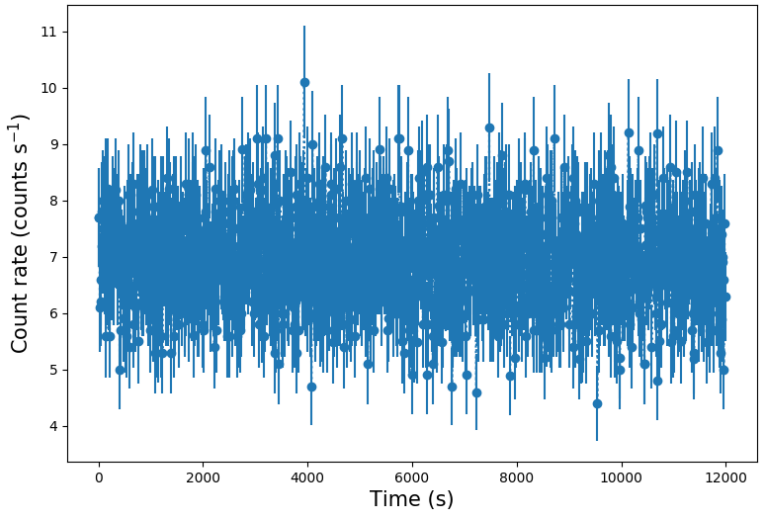
Proposal Review Management

WXT online simulator

- Simple and quick

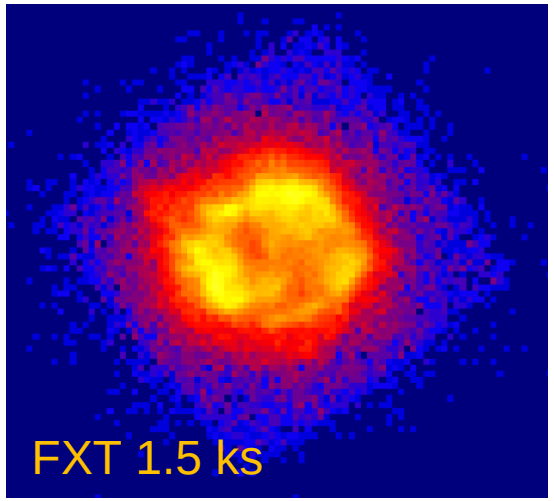


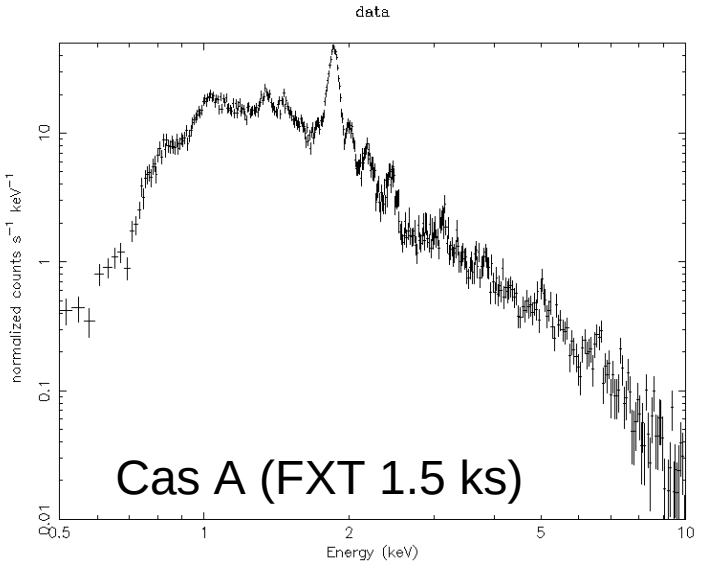


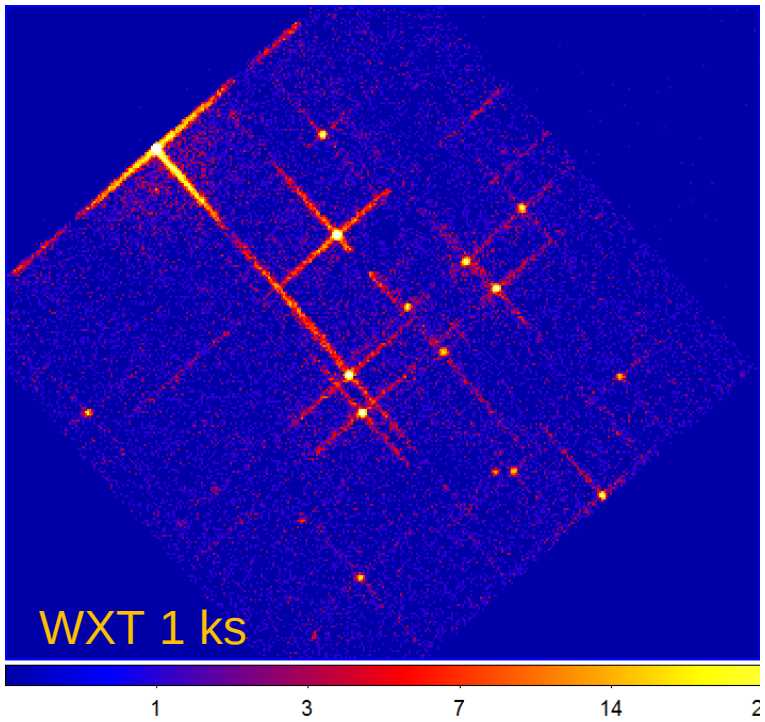


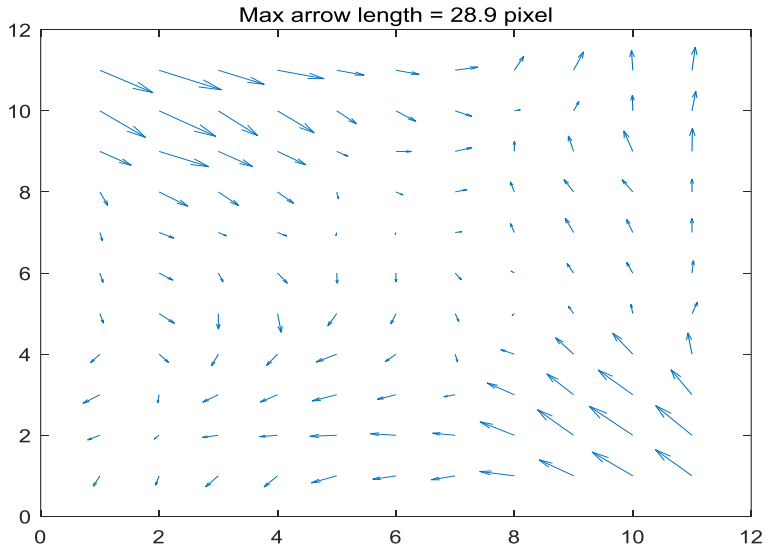
Data reduction software

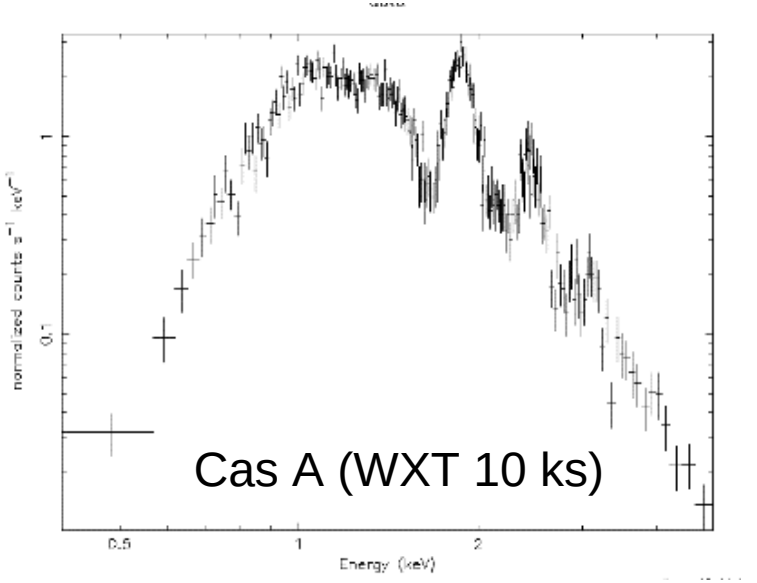
- Define data products
- Build CALDB
- Develop and test software
- HEASARC framework



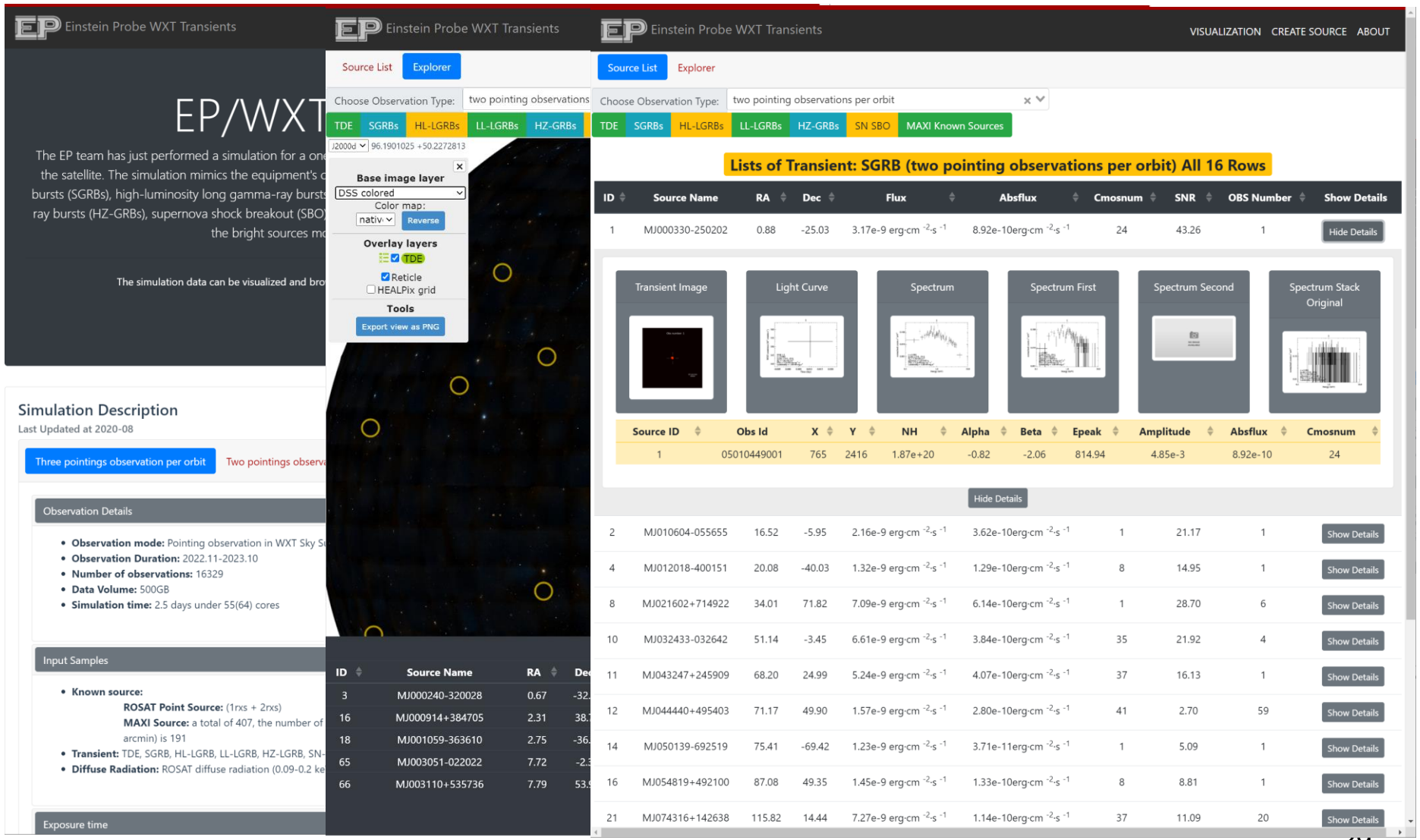








Transient database



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