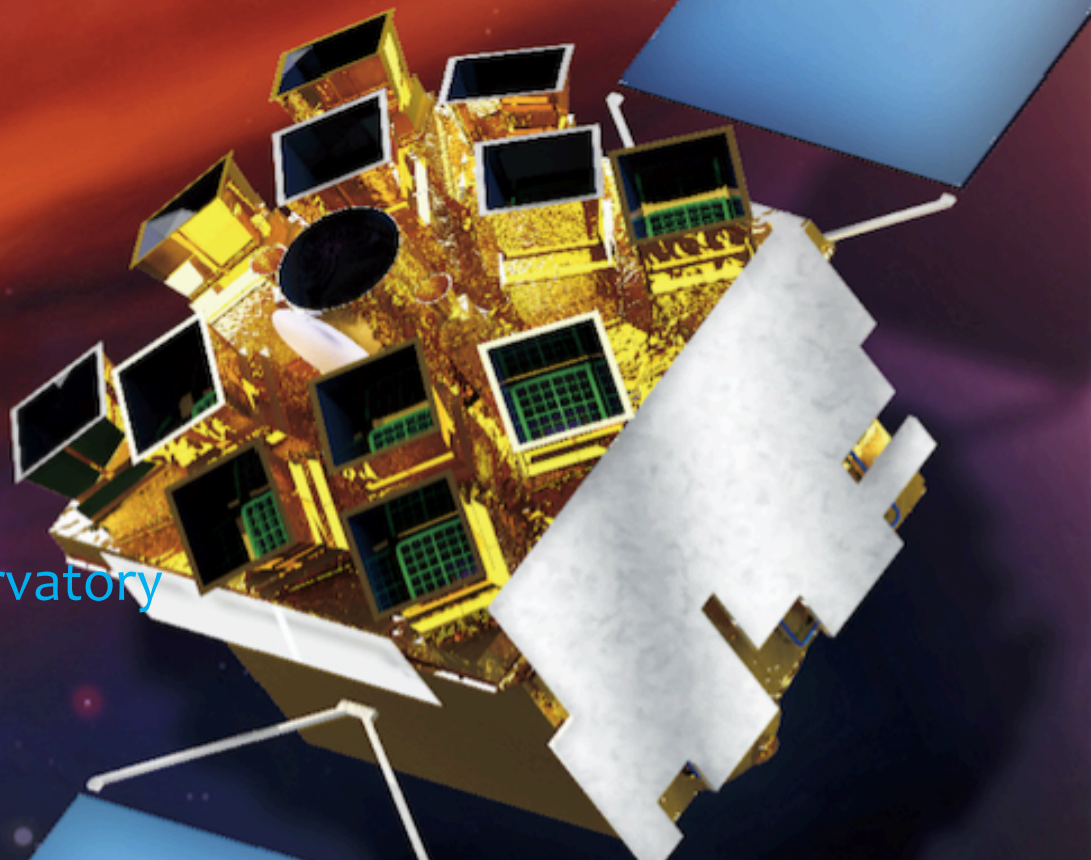
爱因斯坦探针：
探索变幻多姿的 X 射线宇宙专题

THE EINSTEIN PROBE MISSION

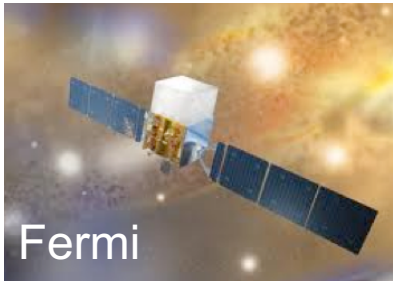


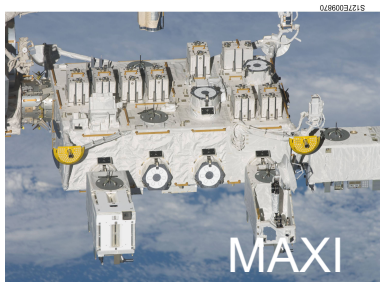
Weimin Yuan

National Astronomical Observatory (NAOC), CAS
and the Einstein Probe team

Scientific drivers for future X-ray sky monitoring

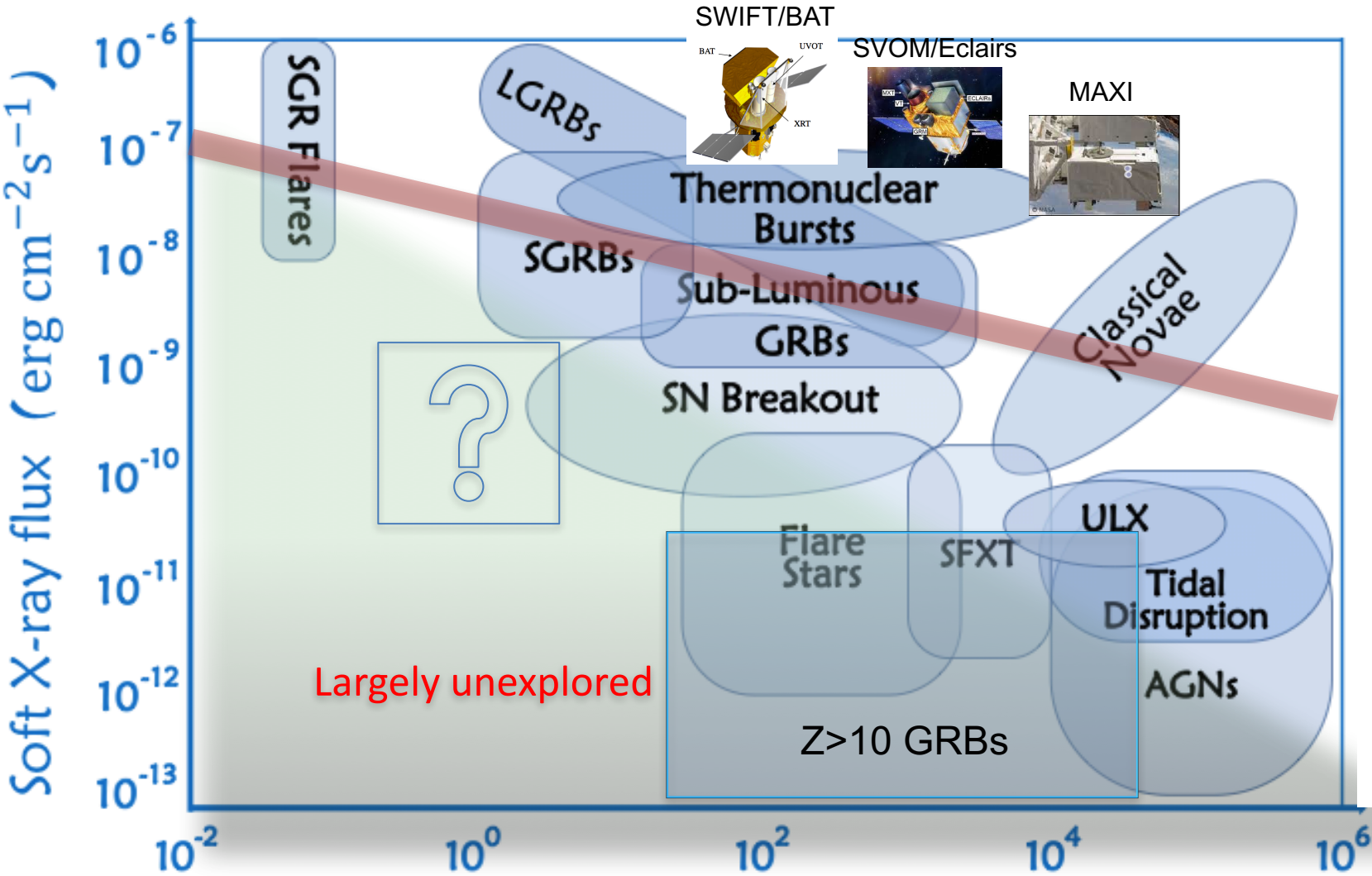
- X-ray transients and variables pervade the Universe
- A rich variety discovered, yet many not well understood





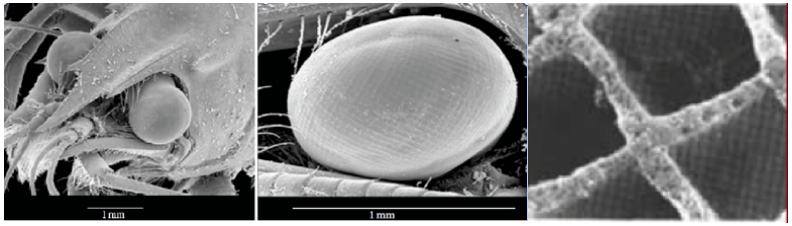
- New phenomena continue to be discovered and appeal for observational characterisation on a large scale, e.g.
  - Tidal disruption events (a few dozens)
  - Supernova shock breakouts (a few)
  - GRBs up to z > 7 - 9 (several)
  - EM sources of gravitational wave events (only 1)
- New types ?

Needs for more sensitive surveys of X-ray transients

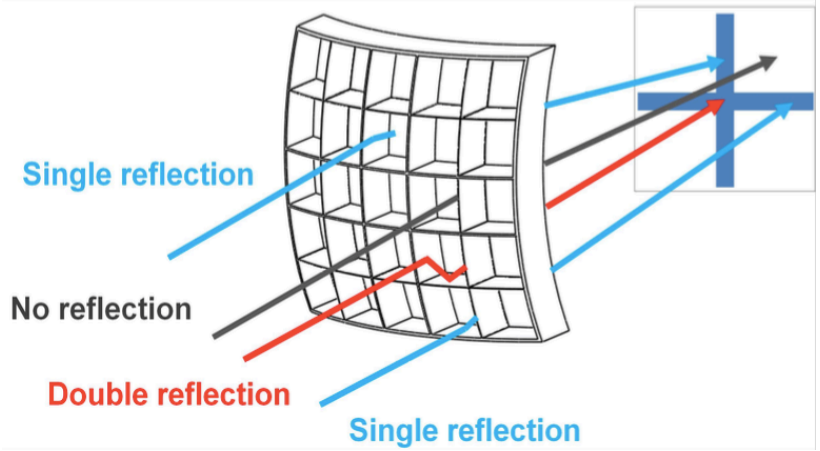


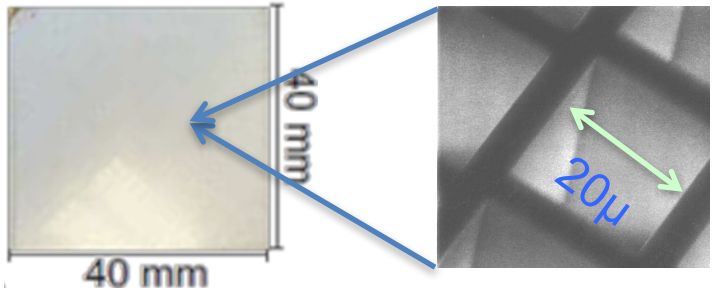
Requirements: higher sensitivity, large FoV, and high cadence

Lobster-eye micro-pore optics for wide-field imaging



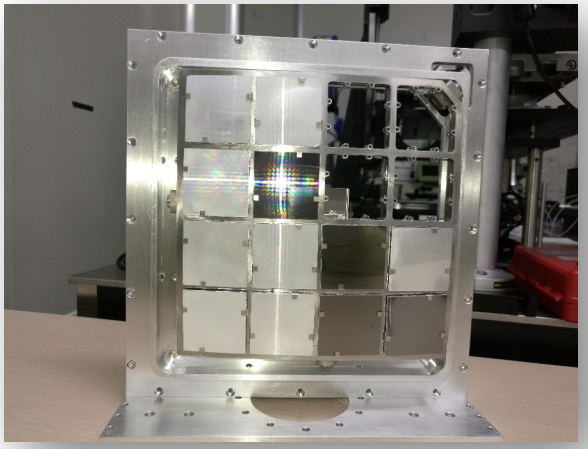
Structure of lobster eyes





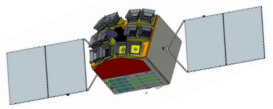
- True imaging
- Wide FoV (un-vignetted)
- Good ang. resolu.: a few arcmin
- High sensitivity
- Low weight

Ideal for X-ray wide-field monitor



A prototype lobster-eye MPO mirror assembly (NAOC/XIL)

The Einstein Probe (EP) mission



A mission for all-sky monitoring to discover and study high-energy transients and variability in the soft X-ray band

- Approved and fully funded in 2017 Dec.
- Engineering implementation started in 2017 Sep.
- Currently in Phase B
- planned launch: end of 2022

- Large Field of View 3600 sq. deg.; grasp: ~10,000 $deg^2.cm^2$
- Monitoring: soft X-ray band: 0.5-4 keV
- Sensitivity: > 1 order of magnitude higher than those in orbit
- Good angular resolution (~5' fwhm) and positioning accuracy (<1')
- Autonomous follow-up (<10 arcsec localisation; 0.5-10keV)
- Fast alert data downlink and (possible) fast uplink (ToO)

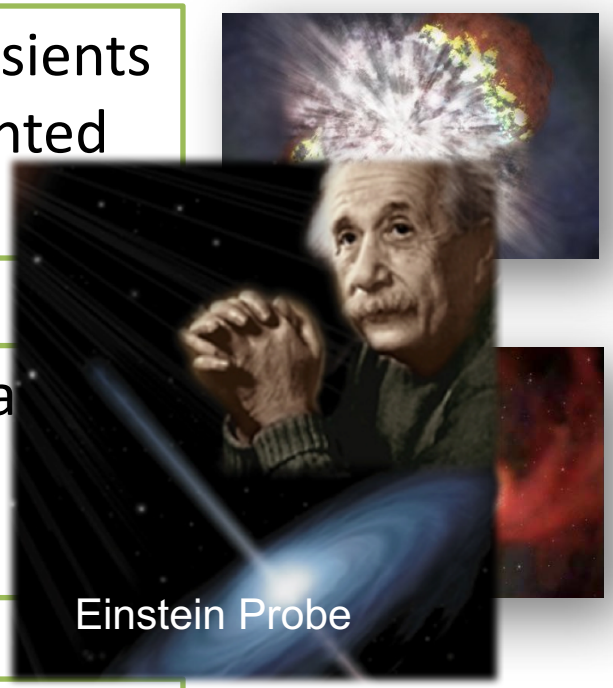
Main science goals

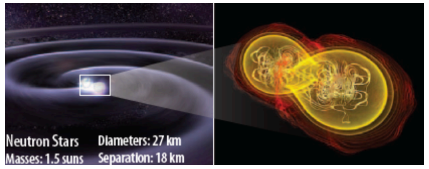
Carry out systematic survey of soft X-ray transients and variability of X-ray sources at unprecedented sensitivity and high cadence

Discover otherwise quiescent Black hole[illegible]t a[illegible] astrophysical mass scales and[illegible]t objects by captur[illegible]

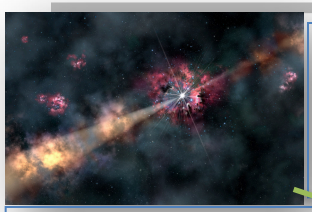
Detect[illegible]ize the electromagnetic-wave sources of gravitational-wave events by synergy with gravitational-wave detectors

Emerging new research frontiers!
Predictions of Einstein's GR





Wide range of topics: X-ray transients & variability

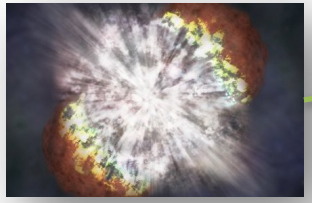


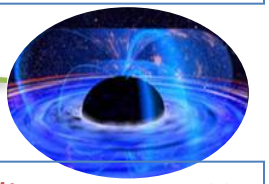
X-ray flash
& LL GRB
GRB physics

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

BH Tidal disruption
Quiescent MBH finder
BH accretion/jets
30-300/yr

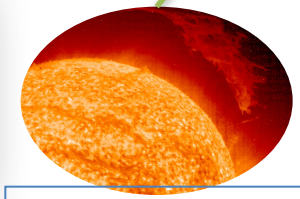
High-redshift GRB
Trace first stars/BH
Early universe
4-5 detection in 3yr

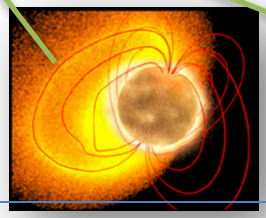


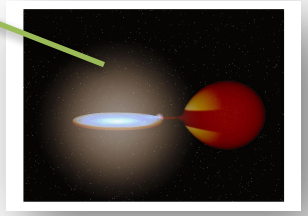


Intermediate-mass BH
BH physics/accretion

SN shock breakout
SN physics
Size of progenitors







BH X-ray binary
Extreme gravity
BH physics/accretion

Comets
charge exchange
emission

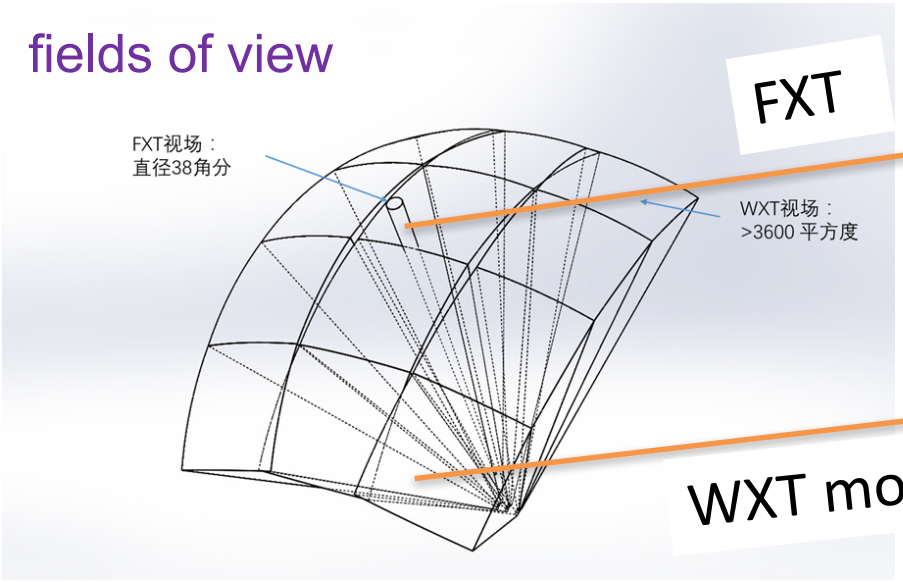
Star X-ray flares
Magnetic fields
Corona activity

SGR/magnetar
extreme
magnetic Field

Thermal nuclear burst
Neutron stars physics

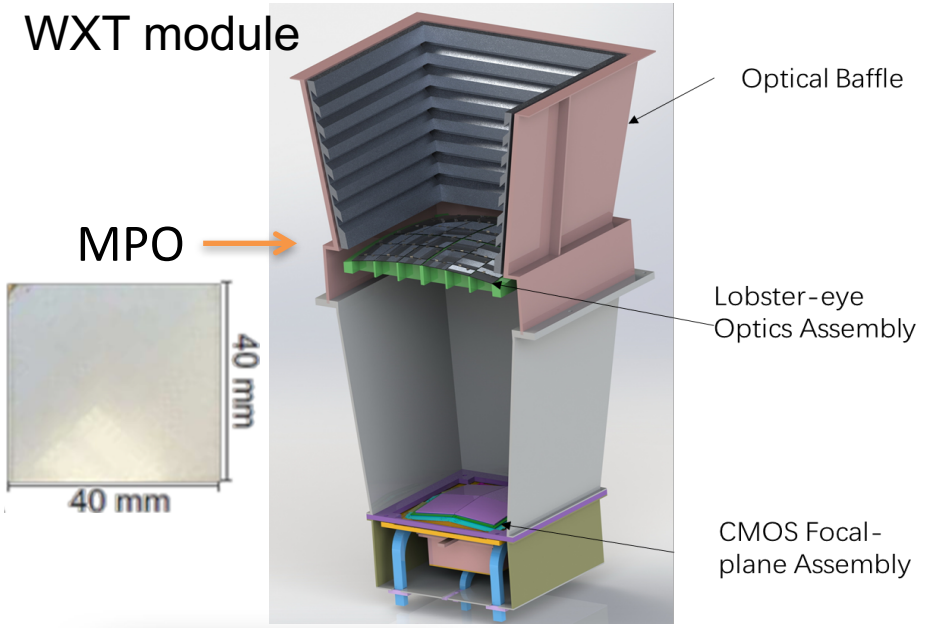
EP instruments and fields of view

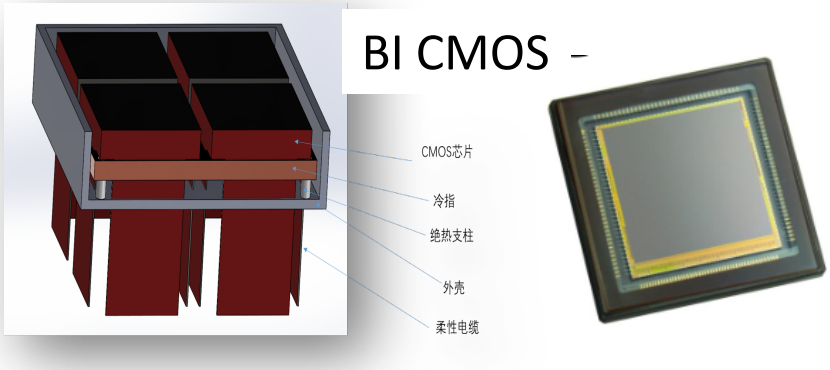
- Wide-field X-ray Telescope (WXT)
  - X-ray optics: lobster-eye MPO;
  - 12 modules; total FoV~ 3600 square degrees
- Follow-up X-ray Telescope (FXT)
  - X-ray optics: Wolter-1 type; FoV ~ 38 arcmin
  - Detector: CCD



Wide-field X-ray Telescope (WXT)

- X-ray optics: lobster-eye MPO (MPO plates, NNVT China)
- Detector: large format, BI s-CMOS array (G-pixel, China)
- Focal length: 375mm
- Eff. area: ~3cm² @1keV
- FoV: 3600 sqr. deg. (~1.1 sr)
- FWHM: ~ 5 arcmin
- Bandpass: 0.5-4 keV
- Lead: SITP & NAOC (CAS)

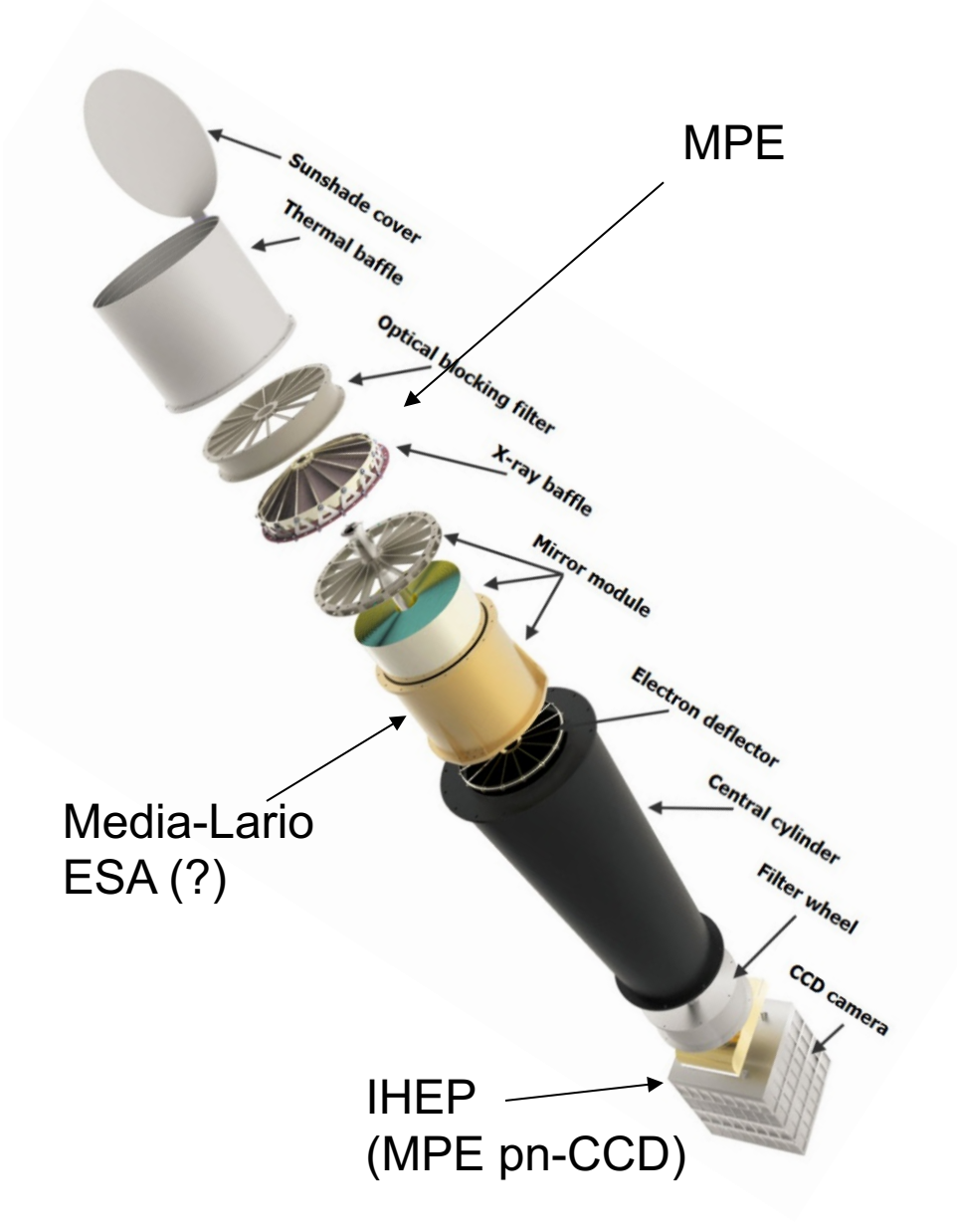




Challenge: the largest-format detector for focusing X-ray telescopes ever built

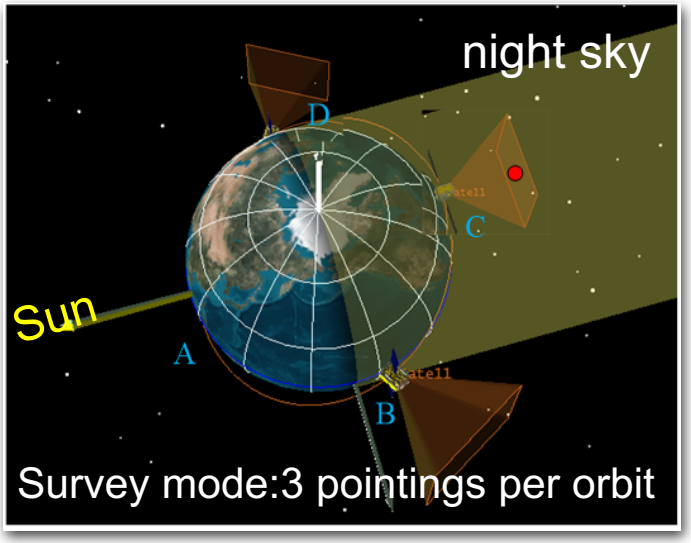
Fellow-up X-ray Telescope (FXT)

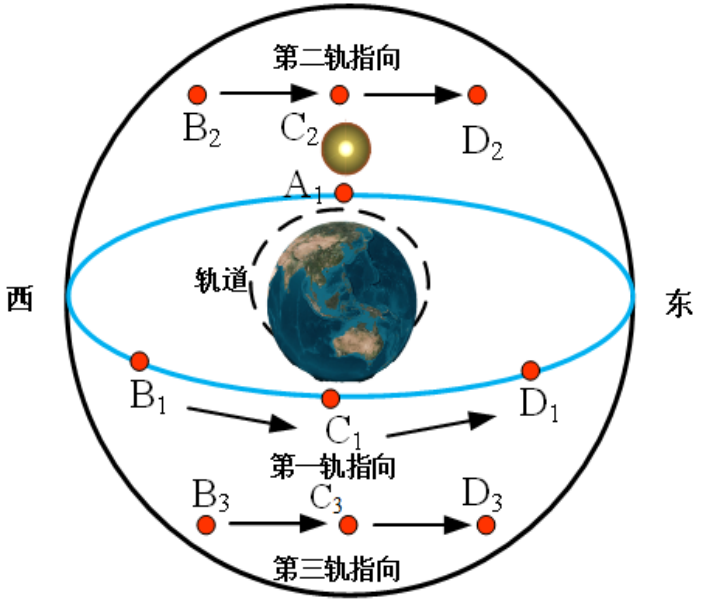
- X-ray mirror: Wolter-I
  - (Media Lario + MPE)
- Detector: PN-CCD (MPE+IHEP)
- Focal length: 1.6m
- Eff. area: 300cm² @1keV
- Spatial resolution (HPD): 30”
- FoV: ~38 arcmin
- Bandpass: 0.5-10 keV
- E-resolution: 170eV @1.25keV (120eV goal) FWHM
- Lead: IHEP (+MPE + ESA?)



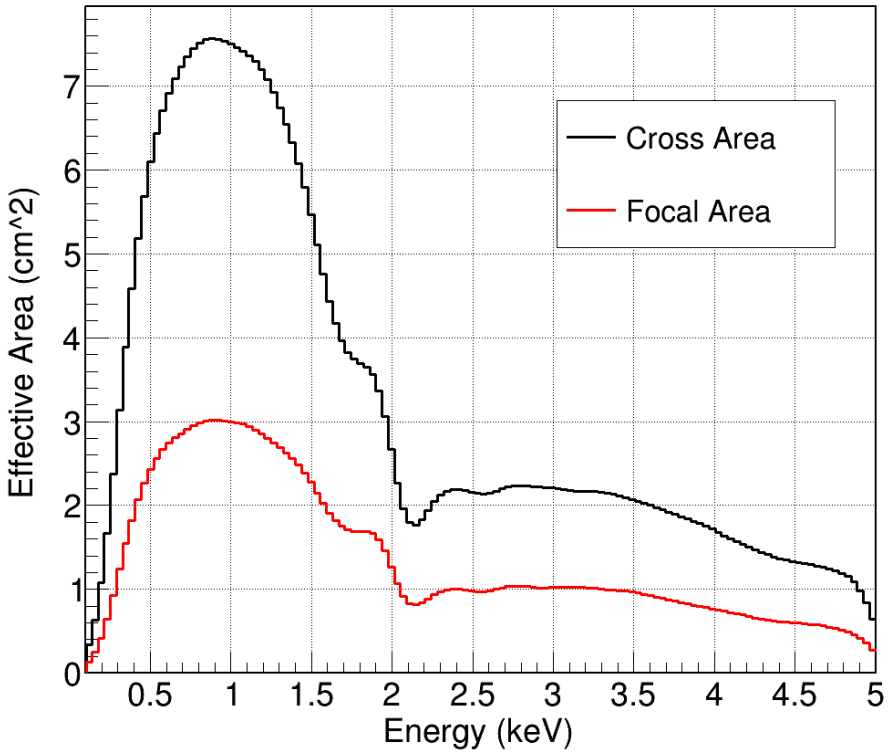
Mission profile

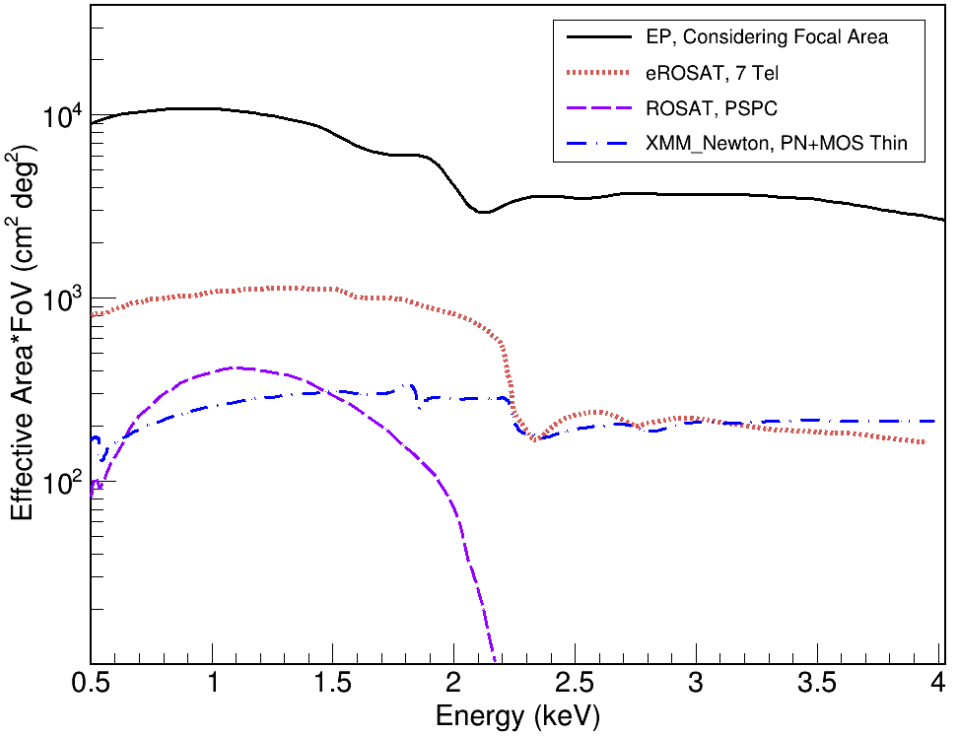
- Orbit: 550km (~97m), i = 29 deg
- Weight: ~1000kg, power ~900W
- Observation modes
  - **Survey**: 3 pointings per orbit to the night-sky, each ~20 min exposure
  - cover whole night sky in 3 orbits
  - **Autonomous follow-up**: FXT
  - **ToO** (fast ToO)
- On-board data reduction & transient search
- Alert data downlink/uplink
  - VHF network (French)
  - 'Beidou' system
- Nominal lifetime: 3 +2 years





WXT: simulated effective area & Grasp



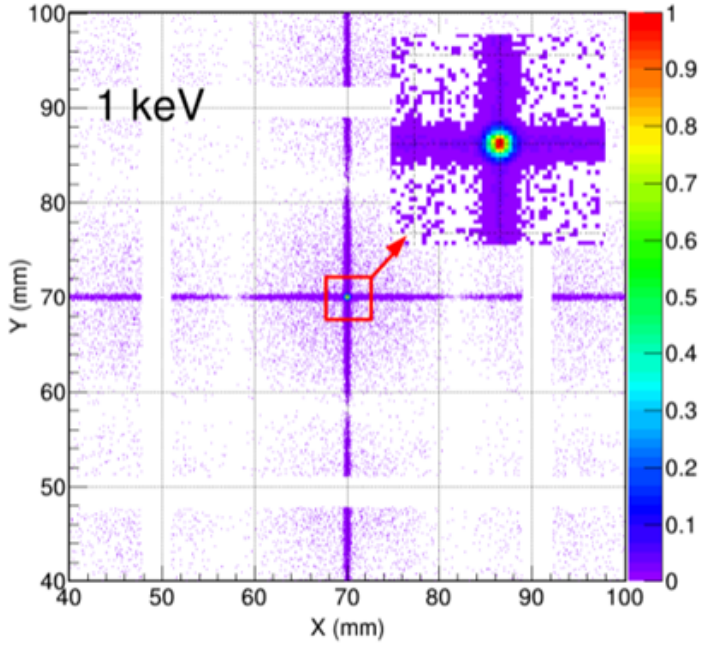


MPO: Ir coating
sCMOS detector 200nm Al coating

Zhao D. et al. 2017

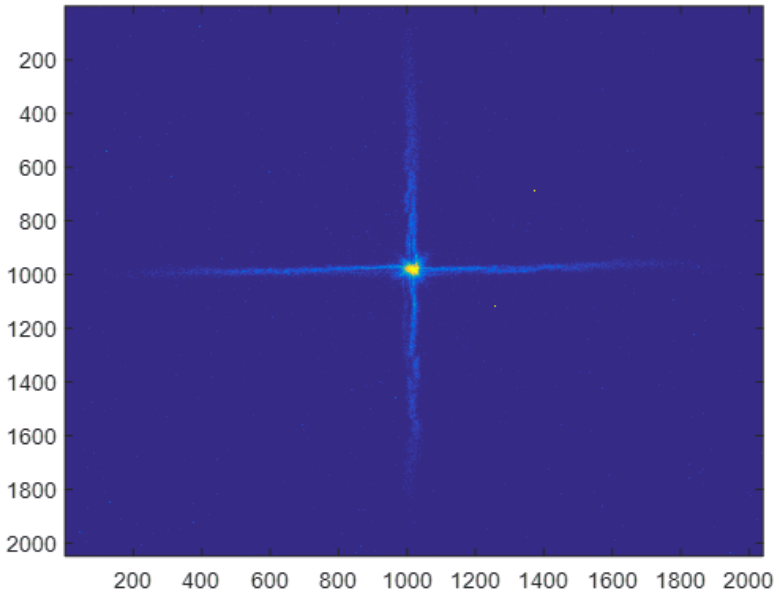
WXT: point spread function (PSF)

simulation



FWHM ~ 5 arcmin

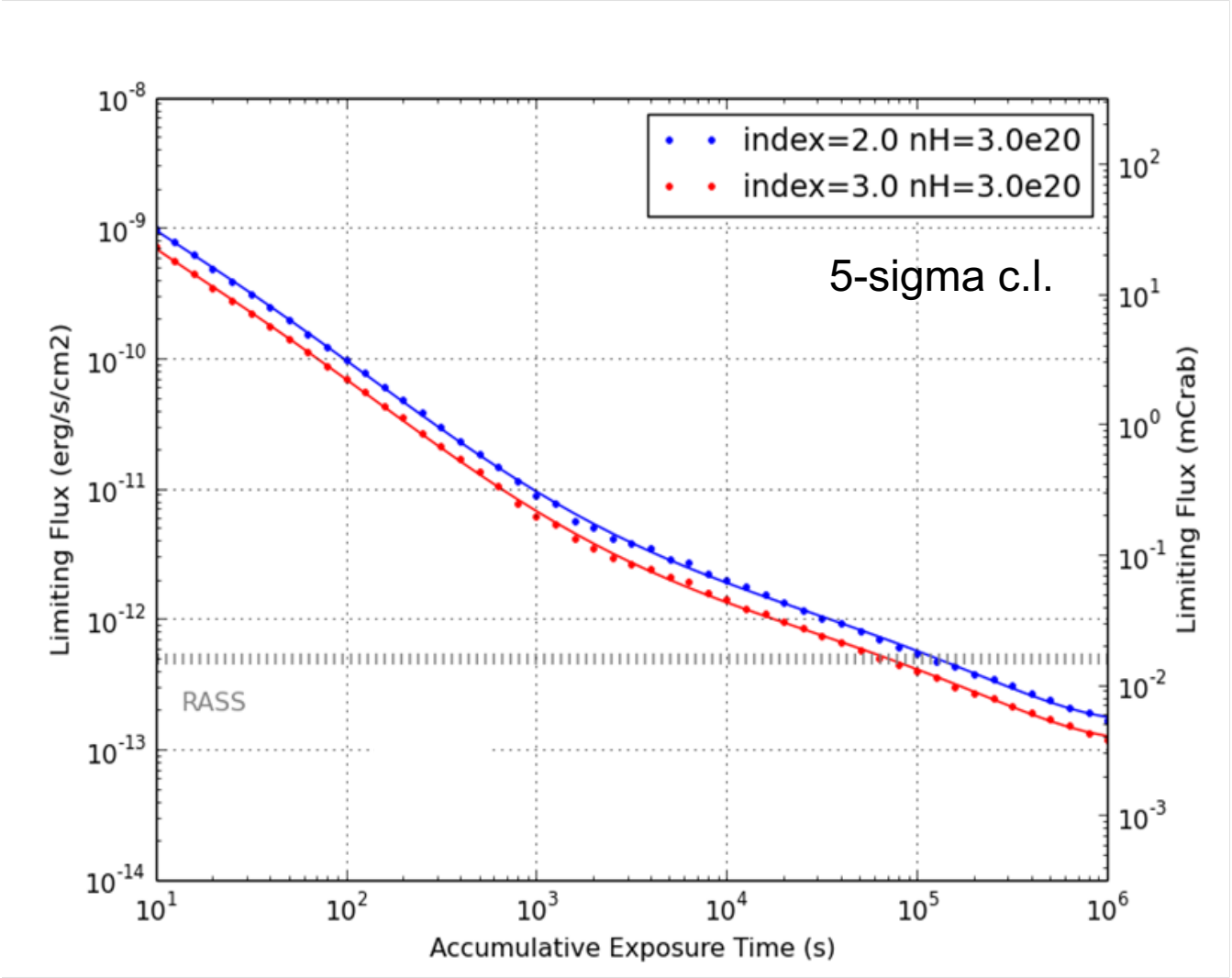
Measured (MPO plate)



FWHM ~ 5 arcmin

Zhao D. et al. 2017

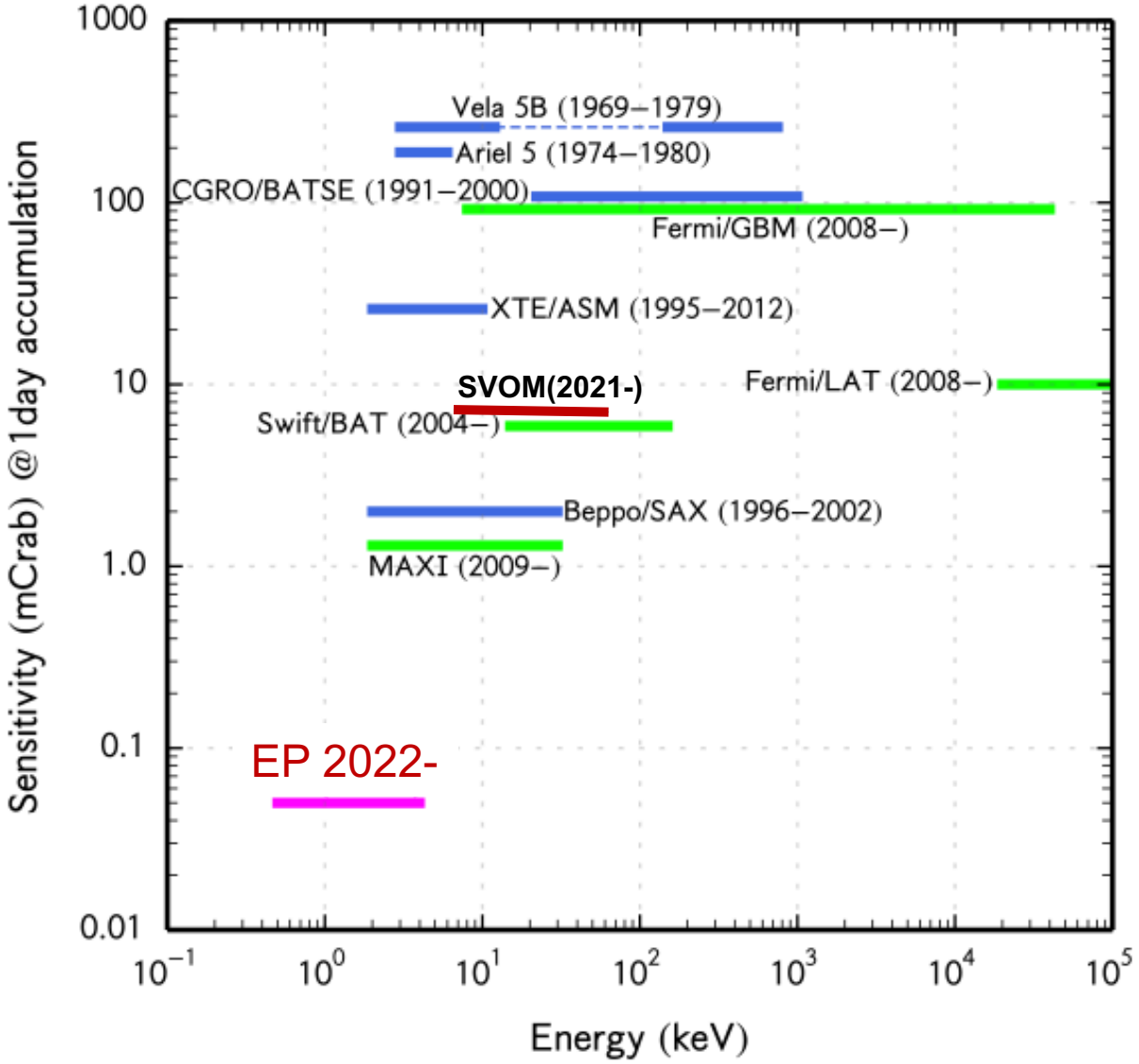
Simulated EP WXT sensitivity



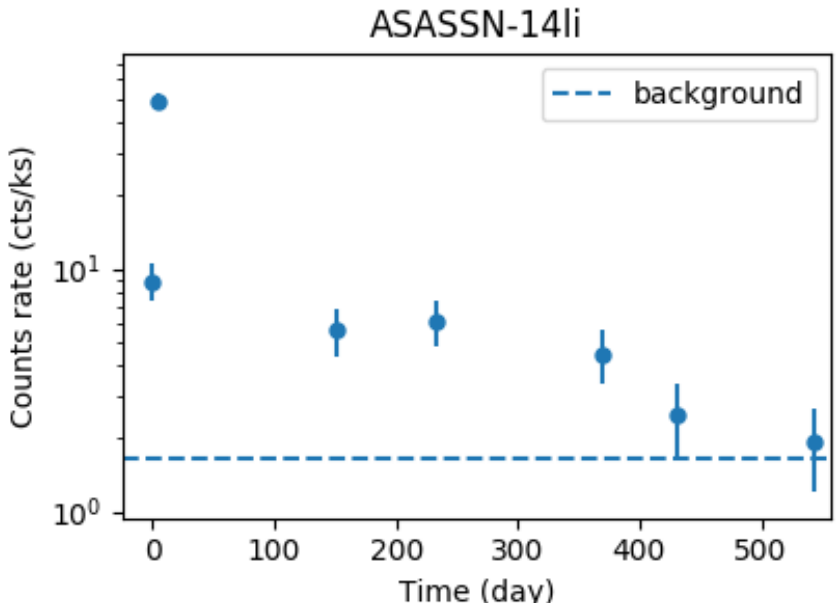
~ (0.3 – 1) mCrab at 1ks exposure

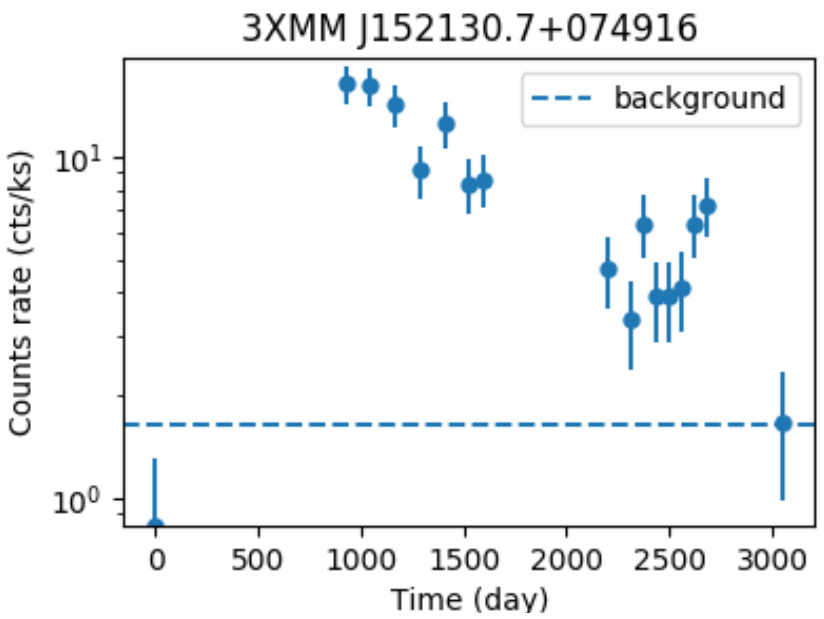
Zhao D. et al. 2017

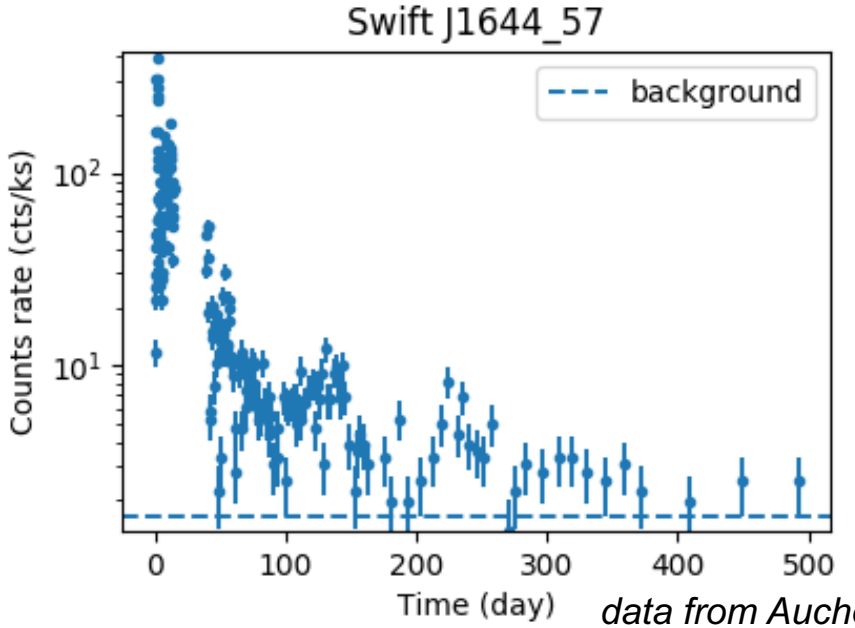
EP WXT sensitivity

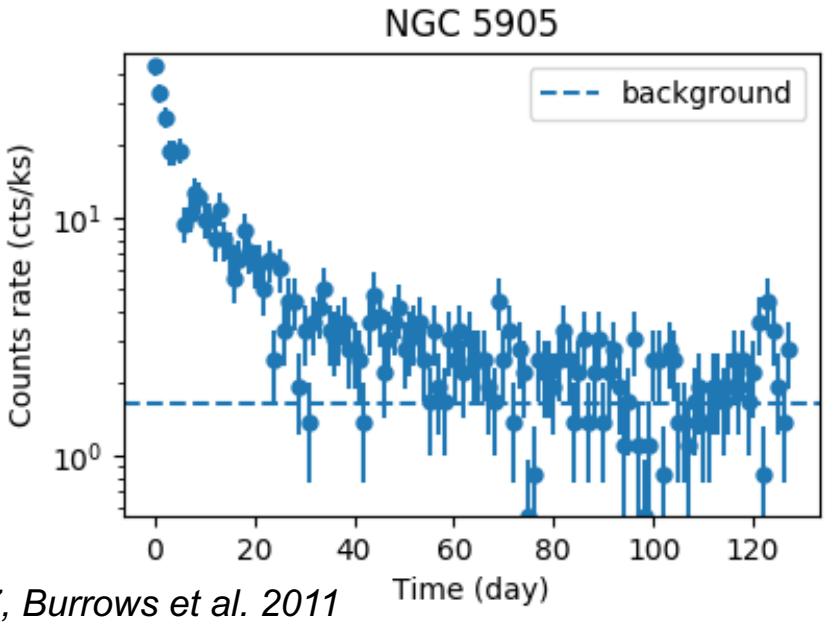


Simulated WXT light-curves for known TDEs





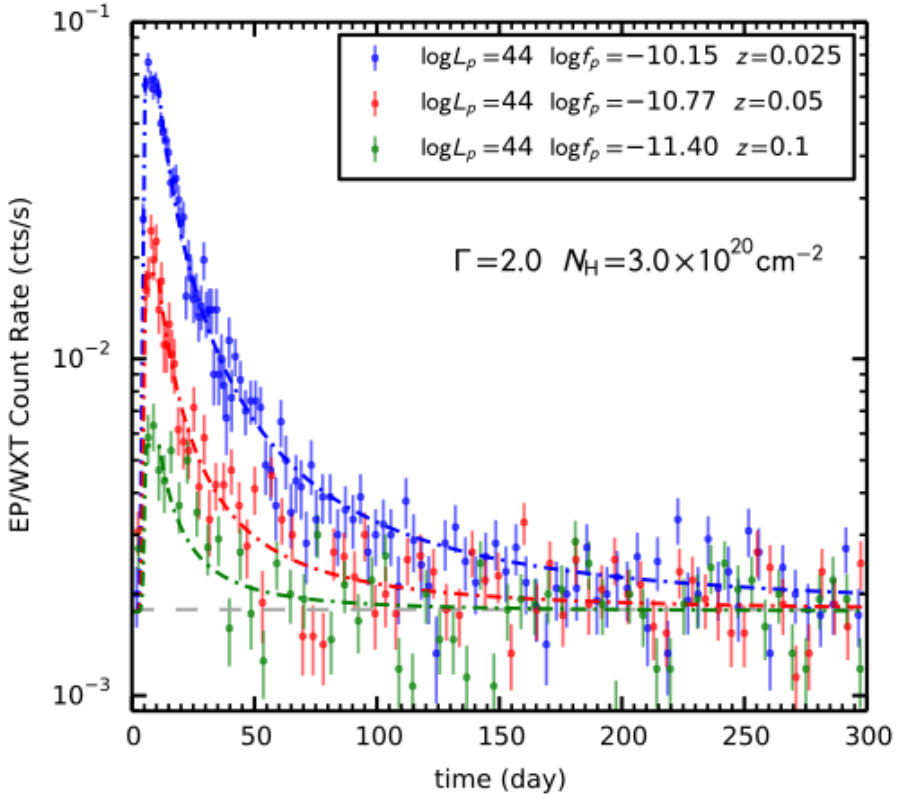




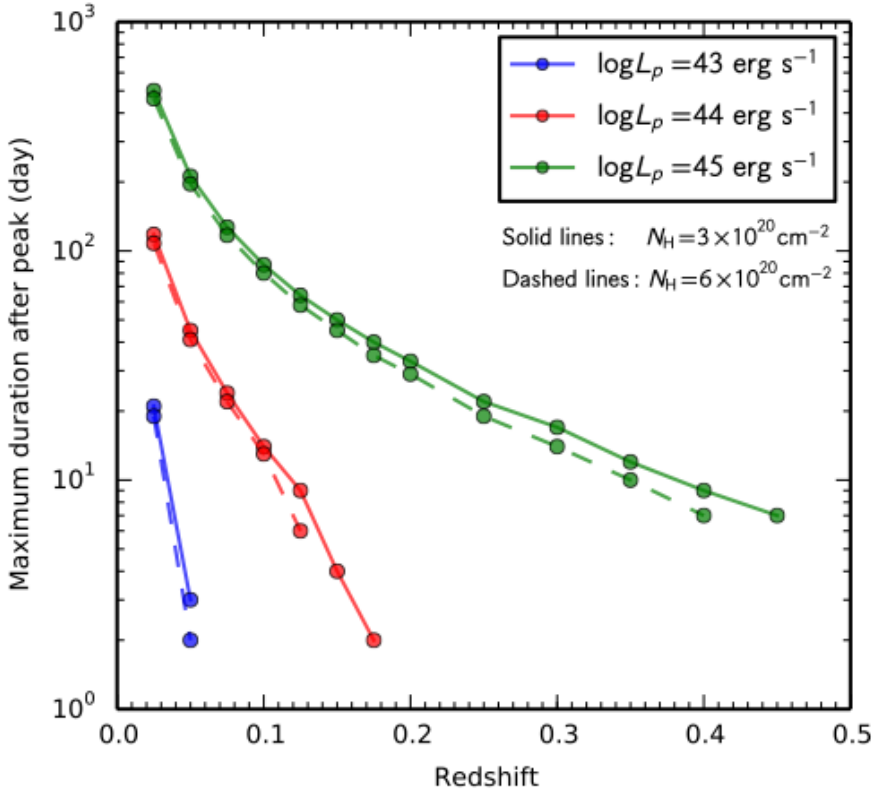
data from Auchetti 2017, Burrows et al. 2011

EP science capability: simulated detection of TDEs

Simulated WXT X-ray lightcurves of TDE

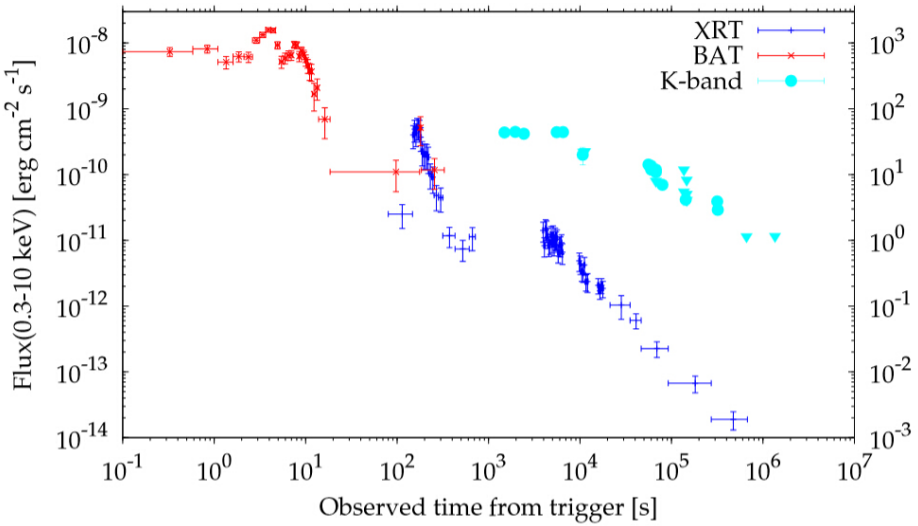


detectable duration of TDE flares vs. redshift



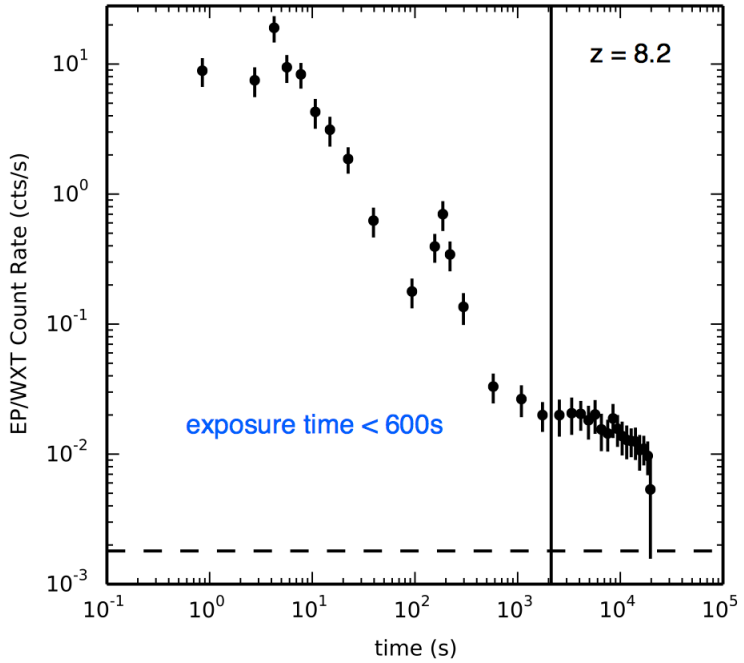
Important to catch the onset and rising phase of outbursts

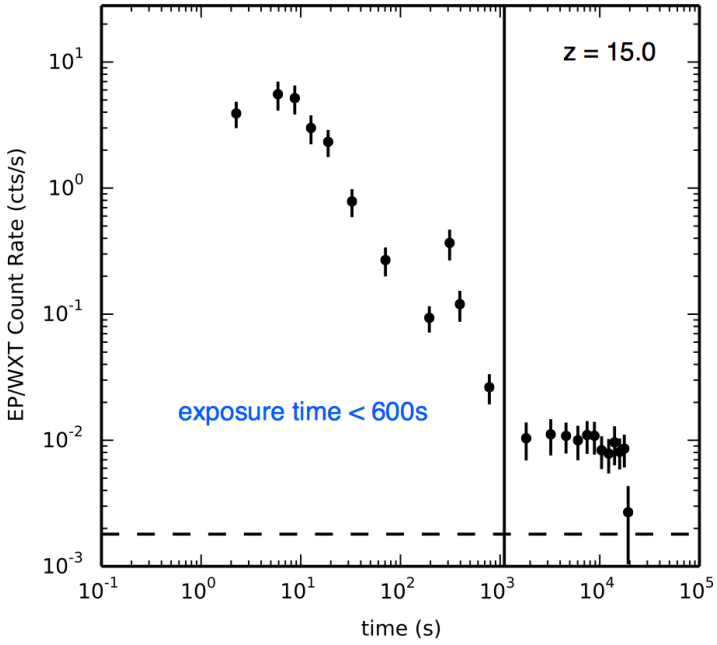
EP science capability: detectability of high-z GRBs



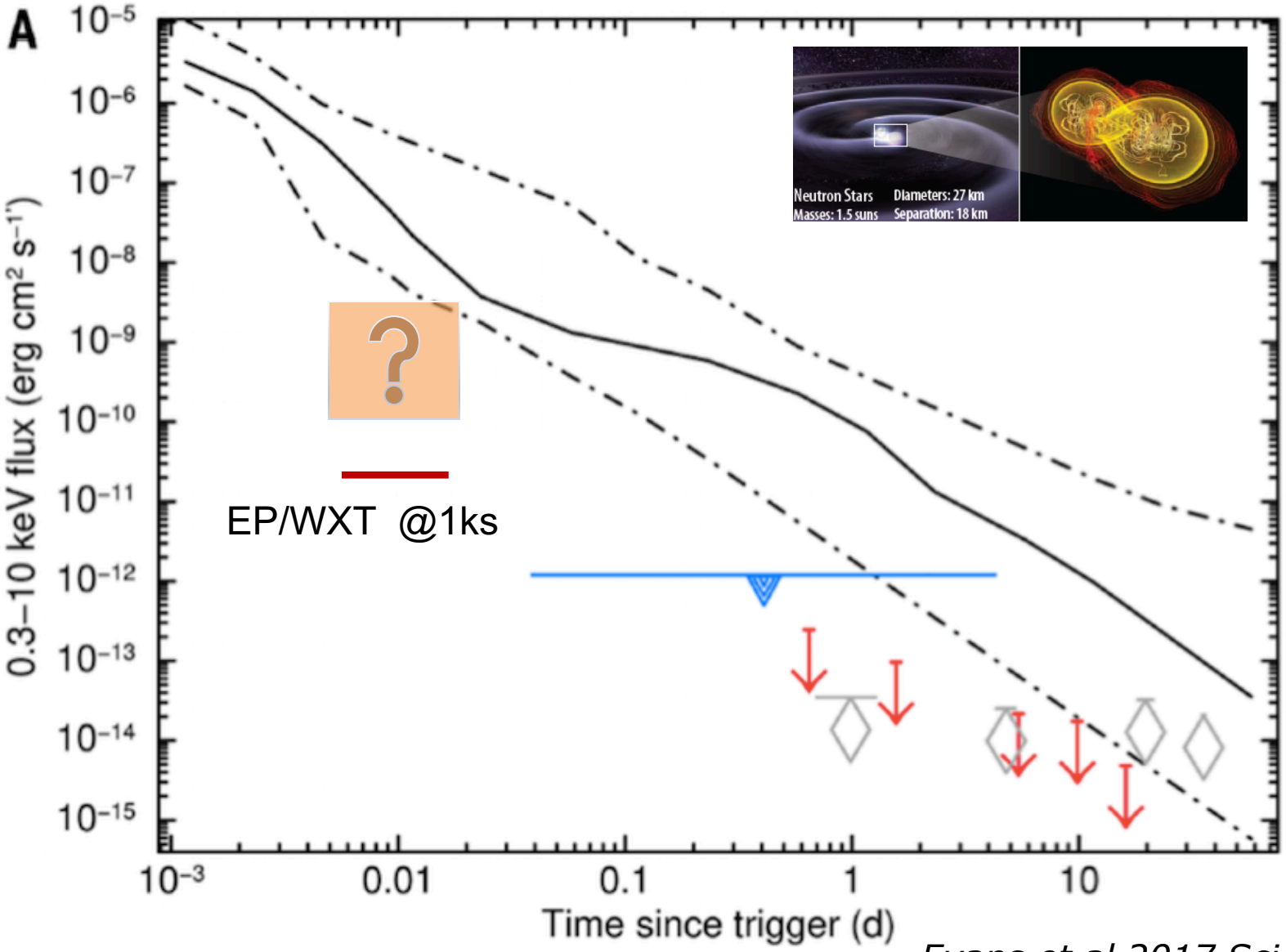
GRB090423 at z=8.2
Swift BAT/XRT
(Salvaterra el. al., 2009)

Simulated EP/WXT detections





EP science capability: X-ray from GW 170817 ?



Evans et al 2017 Science

Estimated detection rates for several types

Type of events	Estimated detections per year
Tidal disruption events (TDE)	20-120 (onset/peak)
TDE with jets	20 - 40
SN shock breakout	7
GRB $z > 6$ (8)	7 (3)
magnetar	1
X-ray flash	~ 10
Low-luminosity GRB	< 8
SFXT	~ 13

EP ground segment and data flow

RADI

NSSC

EP

Alert message

TC/TM

Beidou global positioning system

VHF network (TBD)

Stored PLM Data in X-Band

Ground Segment

ToO Data

Alert message

Alert message

X band Ground station

S-Band TT&C Ground Stations

Satellite Control Center (SCC)

TC/TM

Misson Center (MC)

ToO Request

Alert Message

Aux Data

Edited products

Data Archive

Space Science Data Center (SSDC)

Science Operation Center (SOC)

NAOC

IHEP

Requests, Data, QL, Products(long term)

Requests,Data, QL,Products

Science Data User Community

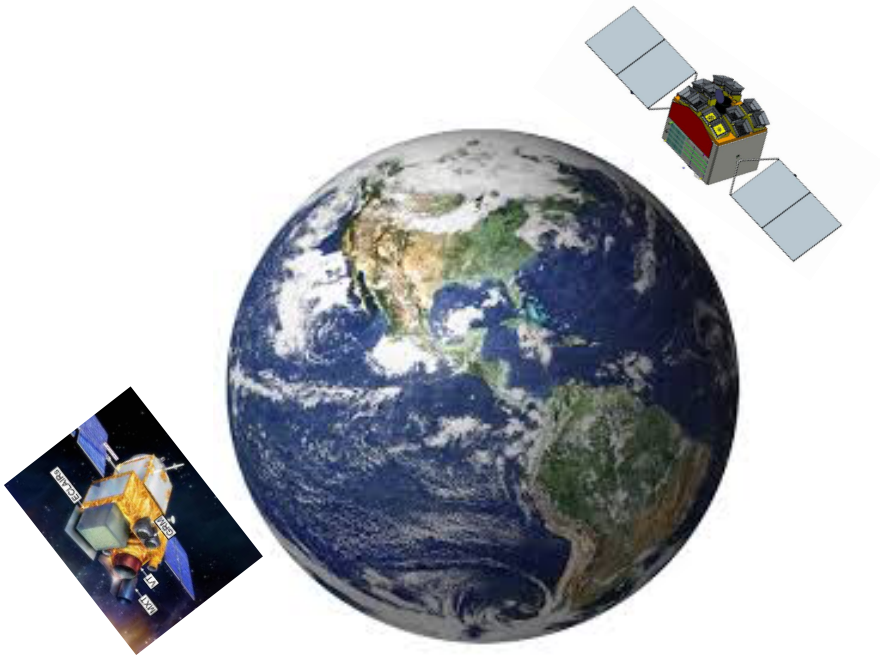
Potential international collaborations

- Max-Placnk-Instit. for extraterrestrial Physics, Germany
  - FXT CCD detector, FXT mirror mandrels, ……
- ESA
  - FXT mirror assembly, ground stations, ground segment (?), ……
- University of Leicester, UK
  - Optics, testing, etc.
- CNES/CEA, France
  - VHF network, system simulation

Synergy with SVOM

- The two missions are well complementary
  - Truly multi-waveband, better positioning by EP, ……
- Operating at same time (mostly)
- Coordinated observations will maximise science return

Maximise the study of source nature



Maximise finding more rare transients

Conclusion

- The X-ray sky is rich in violent cosmic events; unexpected new types of events always expected
- Time domain astronomy has come of a golden age of multi-wavelength & multi-messenger in next decade
- Lobster-eye MPO is a promising technology to look both deeper & wider in soft X-rays
- EP will be a unique and powerful mission in monitoring the X-ray sky, starting from 2022/23 for the following 5 years or more
- Synergy observations with SVOM is very interesting and promising. Look forward to collaboration with French colleagues

Thank you for your attention

Perfect venue, perfect rainbow, perfect workshop