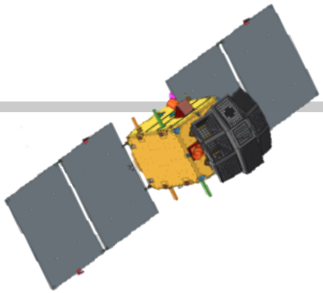





Einstein Probe

a small mission to explore the transient X-ray sky

Weimin Yuan

on behalf of the EP team

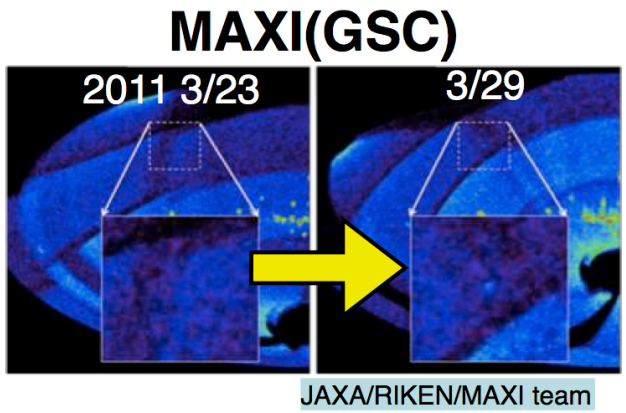
Key Lab of Space Astronomy & Technology of CAS
National Astronomical Observatories
Chinese Academy of Sciences

Outline

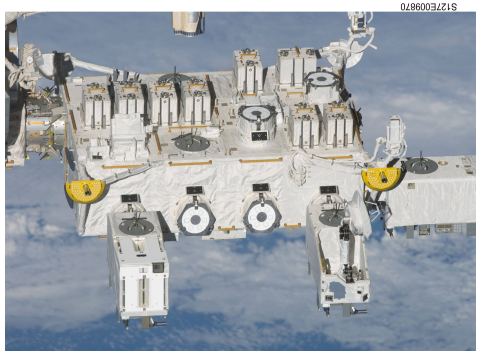
- Science drivers
- A novel X-ray focusing imaging optics: lobster-eye micro-pore optics
- Mission concept and simulated performance
- Expected scientific outcomes
- Summary

We have learned a lot by monitoring the X/γ-ray sky

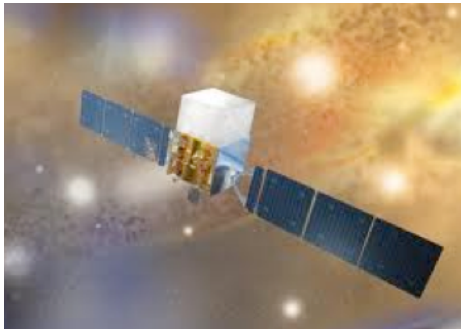
- New X-ray novae, black hole candidates
- GRBs up to z= 8-9
- Tidal disruption events: ~ two dozens
- Relativistic tidal disruption events (2-3)
- Supernova shock breakouts (a few)
- and more ……



Swift



MAXI



Fermi

Beyond 2020: a golden age yet to come …

Multi-wavelength

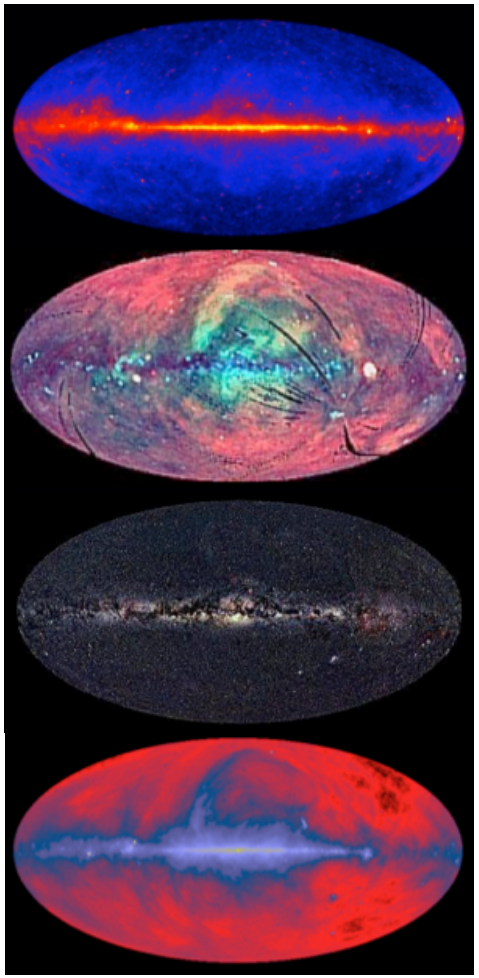
γ-ray

X-ray

optical

radio

Time



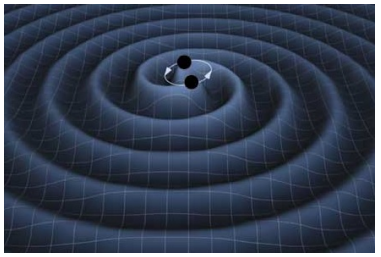
Soft X-ray ?

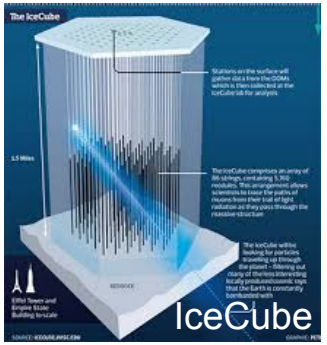
LSST

LOFAR、SKA

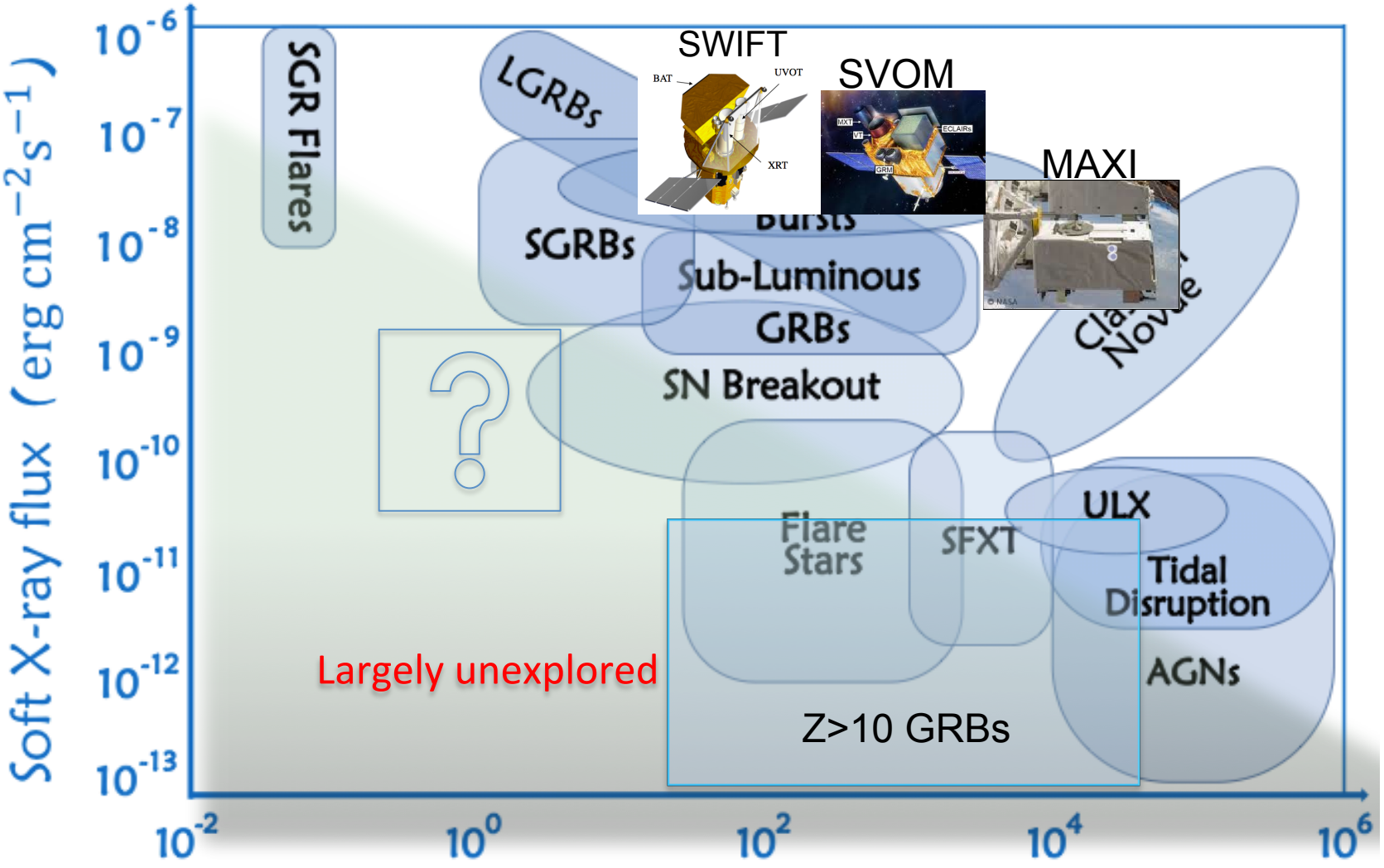
Multi-messenger

GW, neutrino





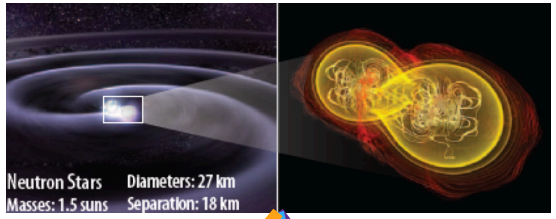
Need compatible, sensitive monitors in (soft) X-rays



Requirements: higher sensitivity and high cadence monitoring

Electromagnetic sources of gravitational wave events

NS–NS/BH–NS mergers



High frequency GW

GW

EM counterparts

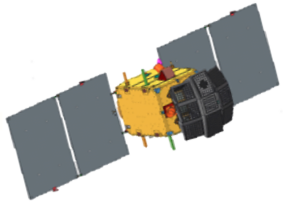
EM spectrum

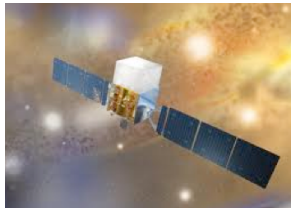
radio

IR/optical

X-ray

γ-ray



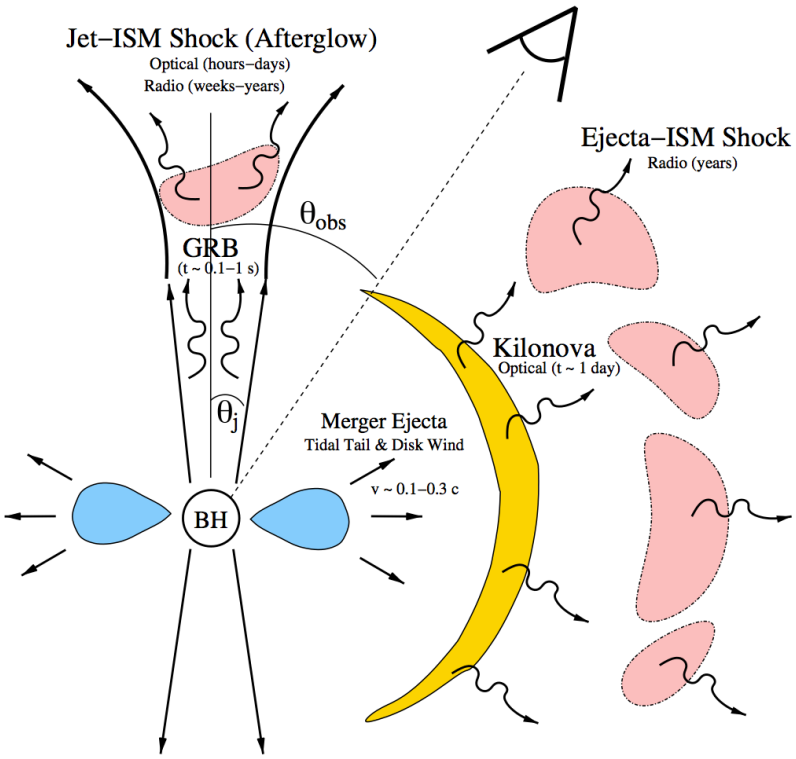


The significance is hard to overstated !

Possible EM radiation of NS-NS mergers

Merger product as BH

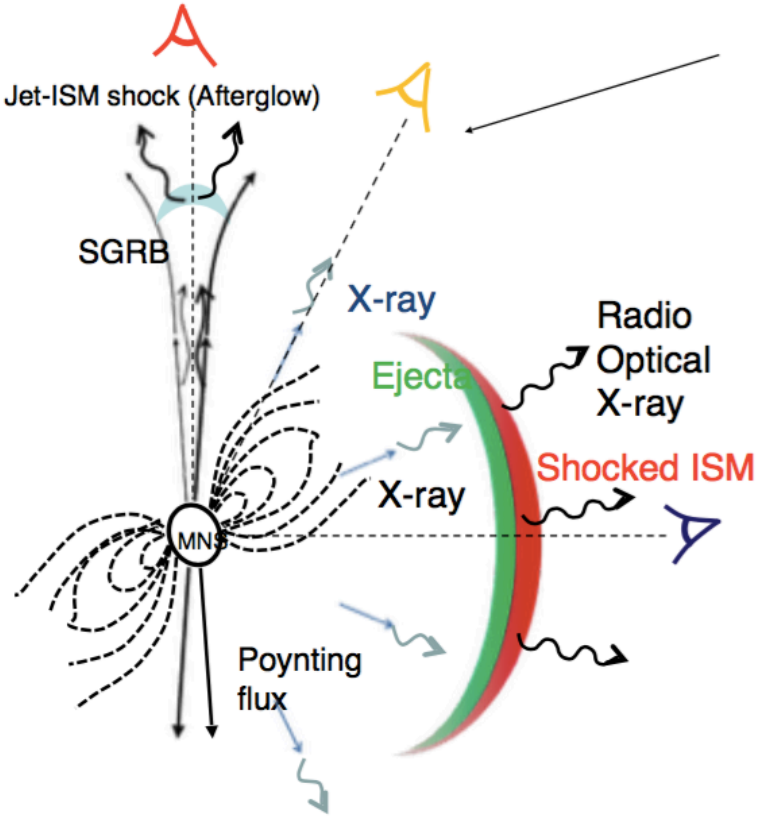
SGRB, optical/IR, radio



Metzger & Berger (2012)

(short-lived) supra-massive NS

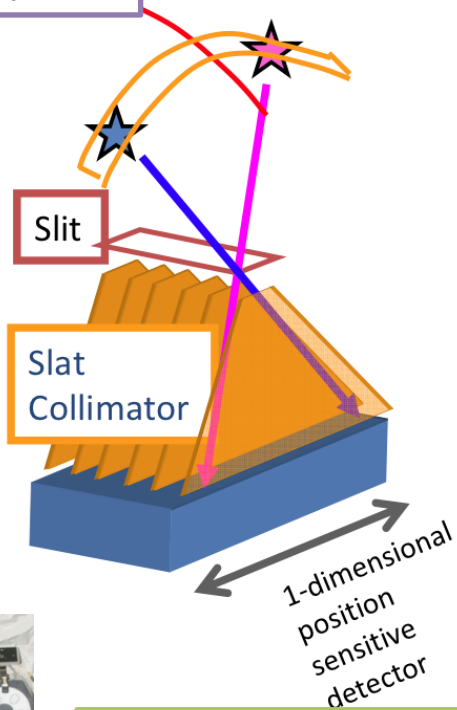
(quasi-isotropic) X-rays



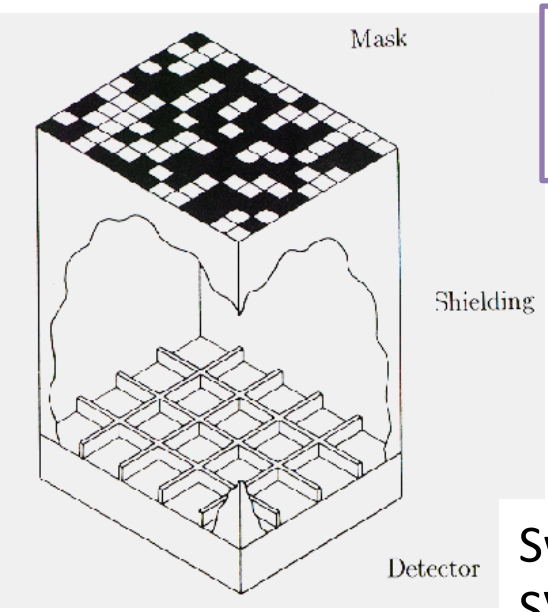
Zhang 2013, Gao et al 2013, Sun 2016

Conventional X-ray monitors – non-focusing

pinhole/slit



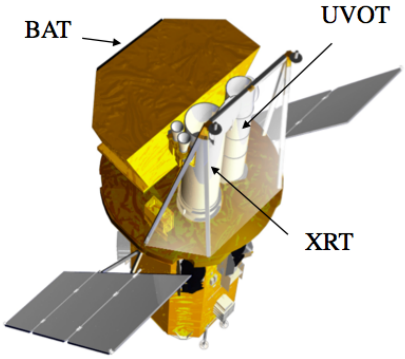
coded aperture



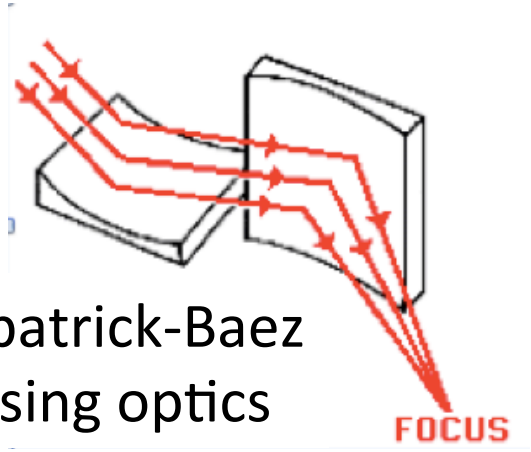
Swift/BAT
SVOM/Eclair

MAXI

- Relatively low spatial resolution (~ degrees)
- High background on detector
- Need focusing optics & wide-field

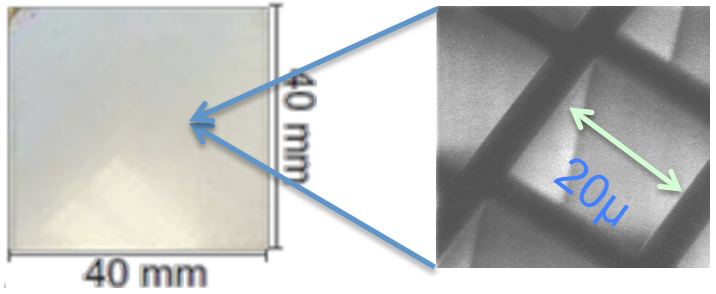


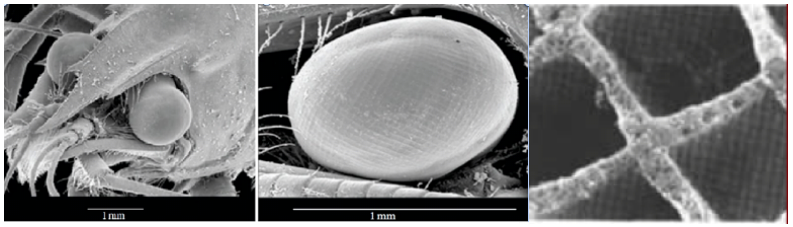
Lobster-eye micro-pore optics for wide-field imaging



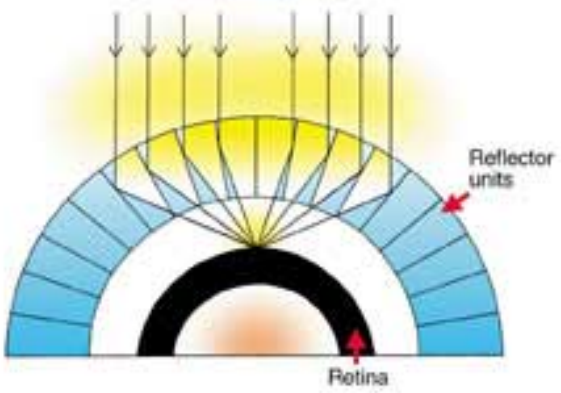
Kirkpatrick-Baez focusing optics

- Concept proposed by R. Angel in 1979
- Device industrialised in recent years





lobster eye in the optical

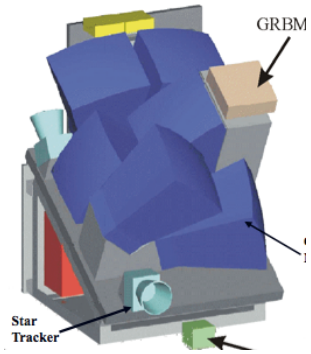


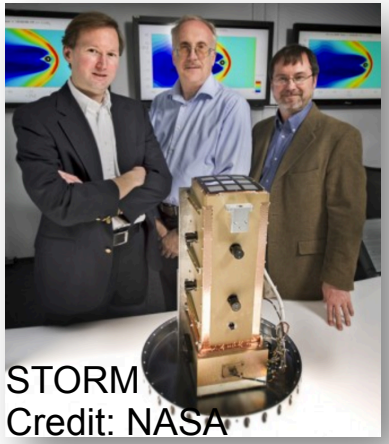
- True imaging
- Wide FoV, no vignetting effect
- Good angular resolution: ~ arcmin (c.f. ~ degrees for Swift, MAXI, …)
- High sensitivity
- Low weight

Ideal for X-ray wide-field monitor

Missions ever proposed, built and planned …

Lobster-ISS

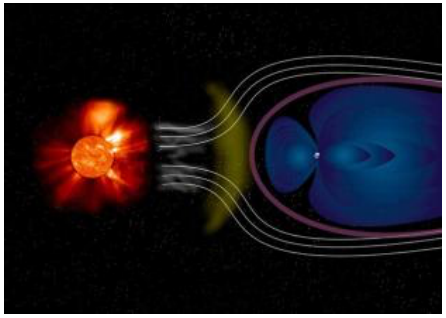


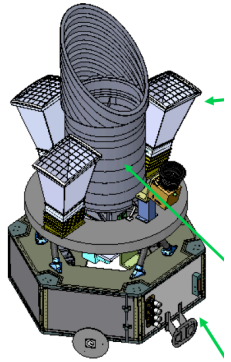


STORM
Credit: NASA

STORM/ CuPID/WASP

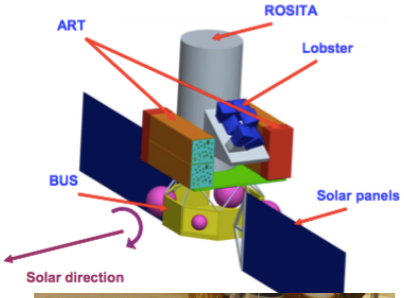
SMILE

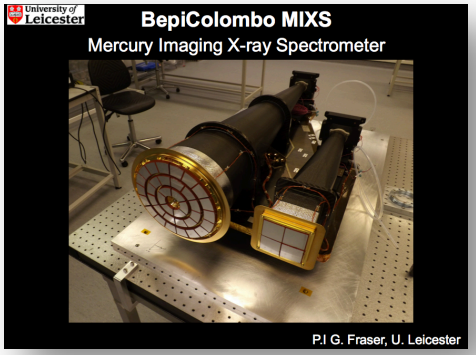




NASA/Lobster

Lobster-SRG

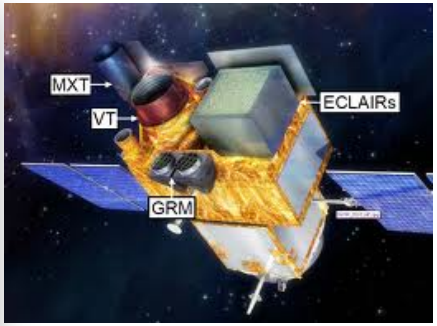


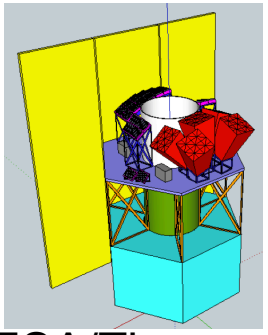


credit: Leicester Univ.

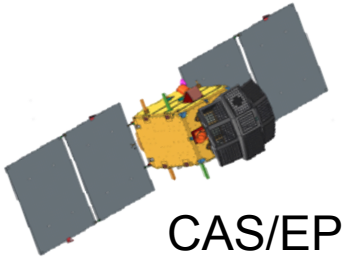
G.W. Fraser (1955-2014)

SVOM/MXT: MPO





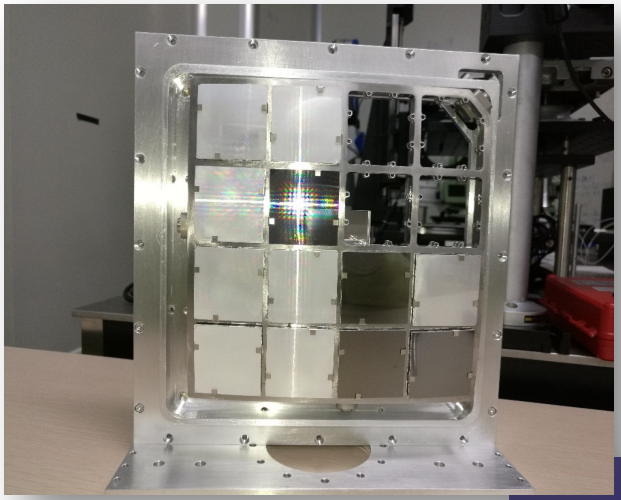
ESA/Theseus

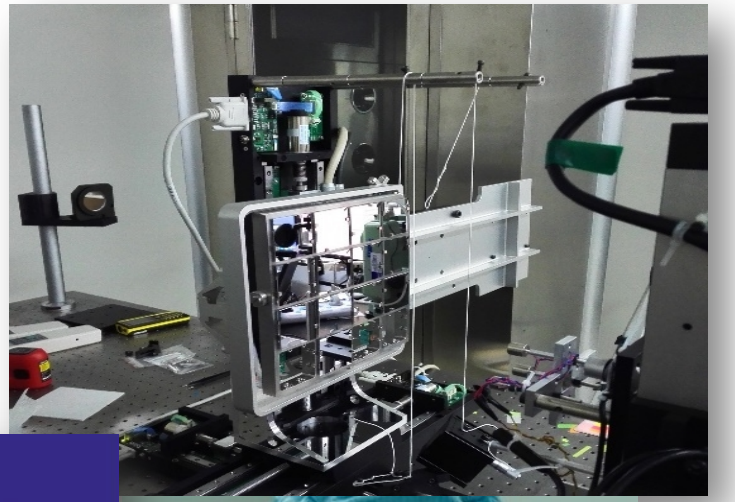


CAS/EP

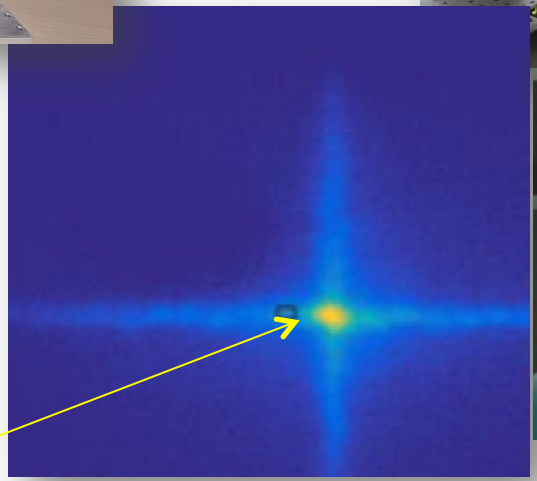
Development of X-ray MPO applications at NAOC

Development started form 2010 at X-ray Imaging Lab, NAOC
(led by Prof. Zhang S.N.)





Prototype MPO lobster-eye camera and X-ray image



true focal spot

Einstein Probe (EP)

Features

- A small mission for time-domain all-sky monitoring
- Soft X-ray band (0.5-4keV)
- High-energy transients and study variability
- >1 order-of-mag. more sensitive than those currently in orbit

Background

- Proposal submitted to CAS in 2013 Jan.
- Selected as a candidate mission funded for advanced study in July 2013
- Selected among 3 top candidate missions of priority in 2015

Team and collaboration

Space Science Division
National Astronomical Observatories of China (NAOC), CAS

Key Lab for Particle Astrophysics
Institute of High-energy Physics (IHEP), CAS

同濟大學
TONGJI UNIVERSITY

microsat

清華大學
Tsinghua University

University of Leicester

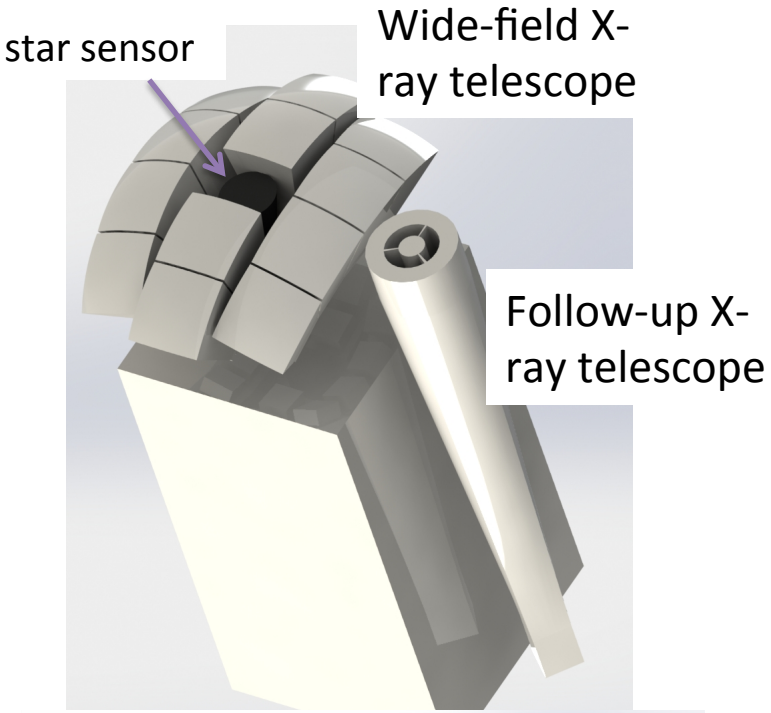
EP payload

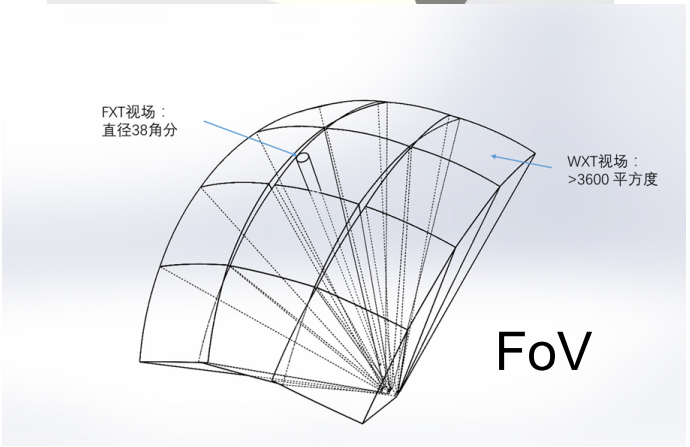
Wide-field X-ray telescope (WXT)

- X-ray optics: lobster-eye MPO
- Detectors: CMOS array
- Focal length: 370mm
- FoV: 3600 sqr. deg. (1.1 sr)
- FWHM: ~ 5 arcmin
- Bandpass: 0.5-4 keV

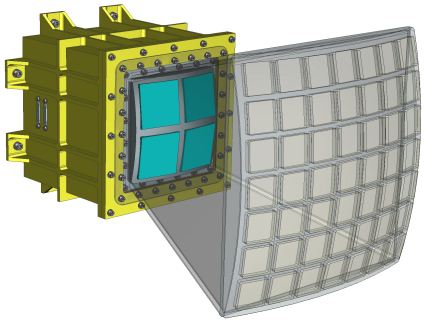
Fellow-up X-ray telescope (FXT)

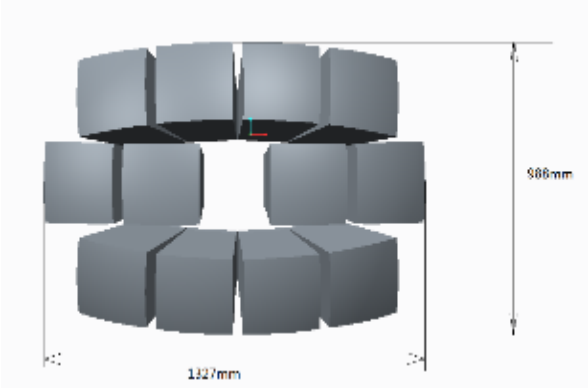
- X-ray optics: Wolter-I type
- Focal length: 2m
- Effective area: ~ 120cm^2 @1keV
- FWHM: ~3 arcmin
- FoV: ~30 arcmin
- Bandpass: 0.5-8 keV





Wide-field X-ray telescope



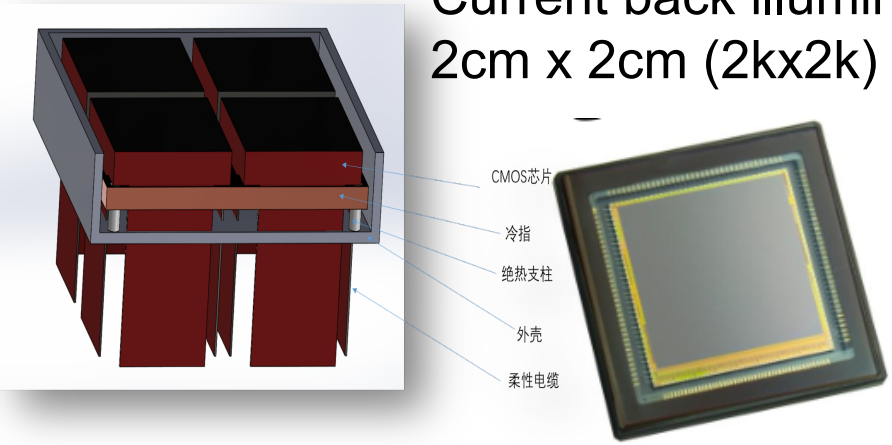


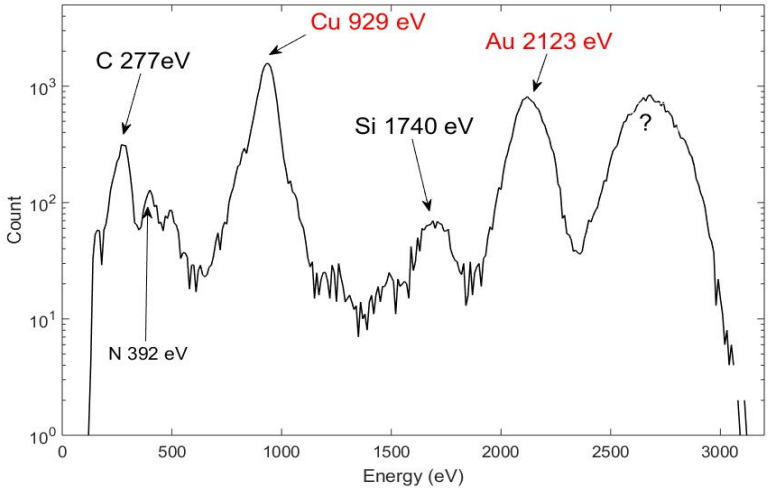
- 12 modules
- ~300 sq.deg. each
- Weight: 240kg
- Power: ~300W

Detector: back illuminated CMOS (Chinese)

energy resolution 210 eV
@ 5.9 keV @ room temp.

Current back illuminated
2cm x 2cm (2kx2k)

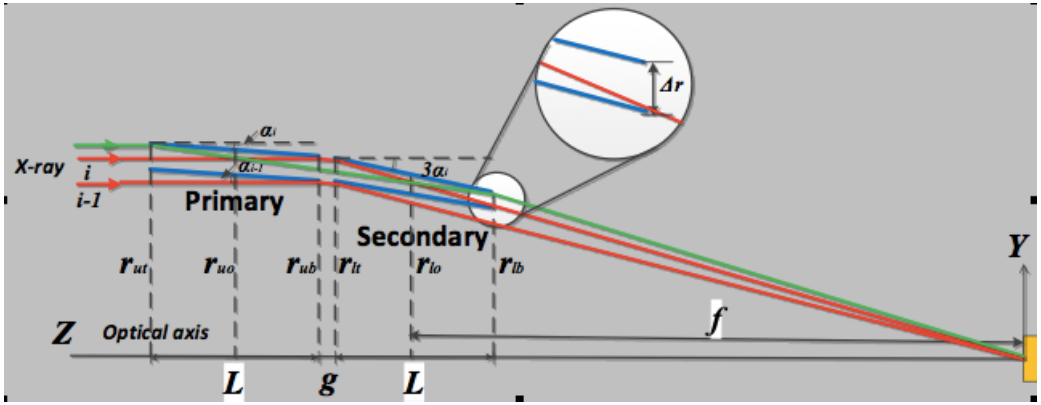


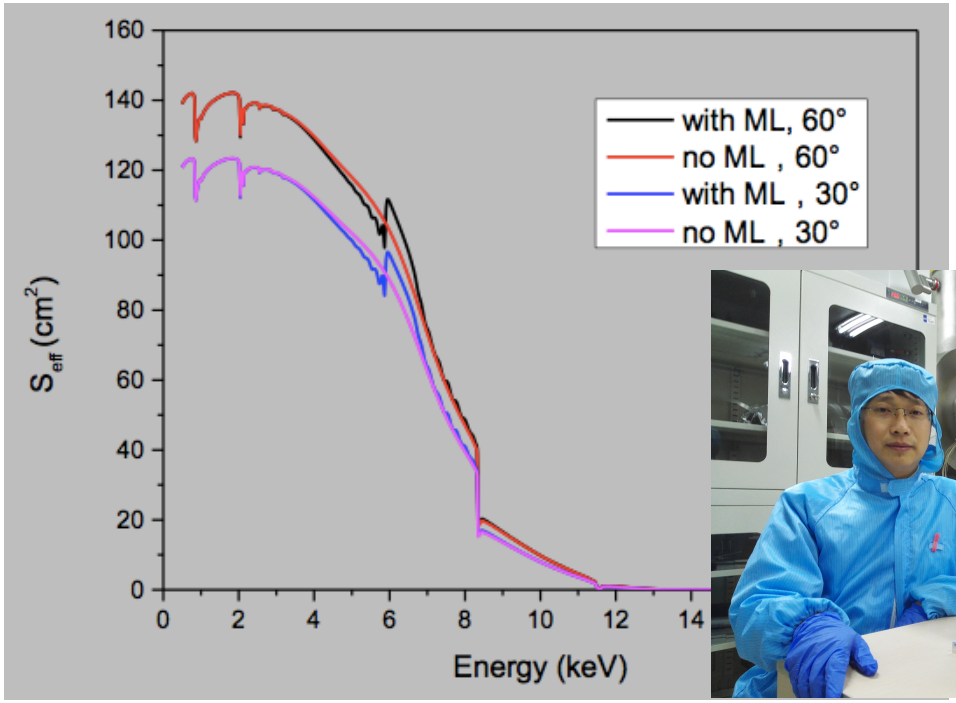


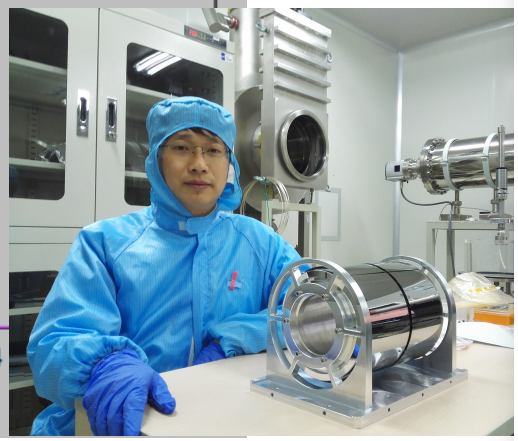
Goal: 6cm x 6cm 4kx4k

Follow-up X-ray telescope

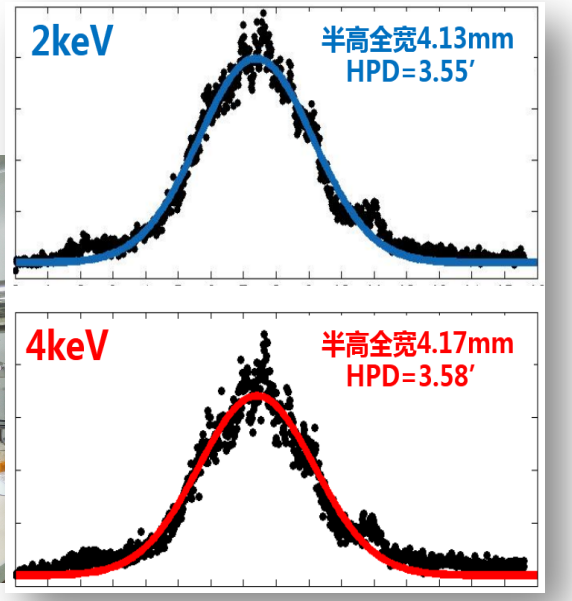
- Wolter-I type
- Slumped glass mirror (Tongji Univ., China)





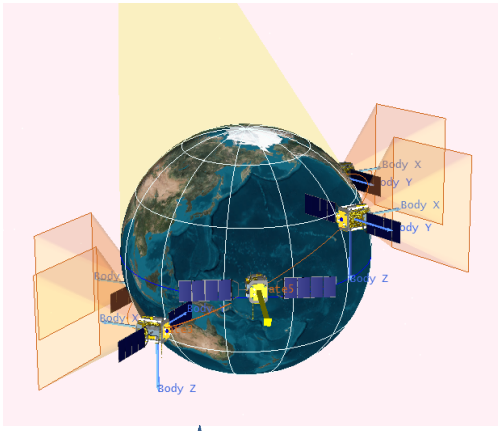


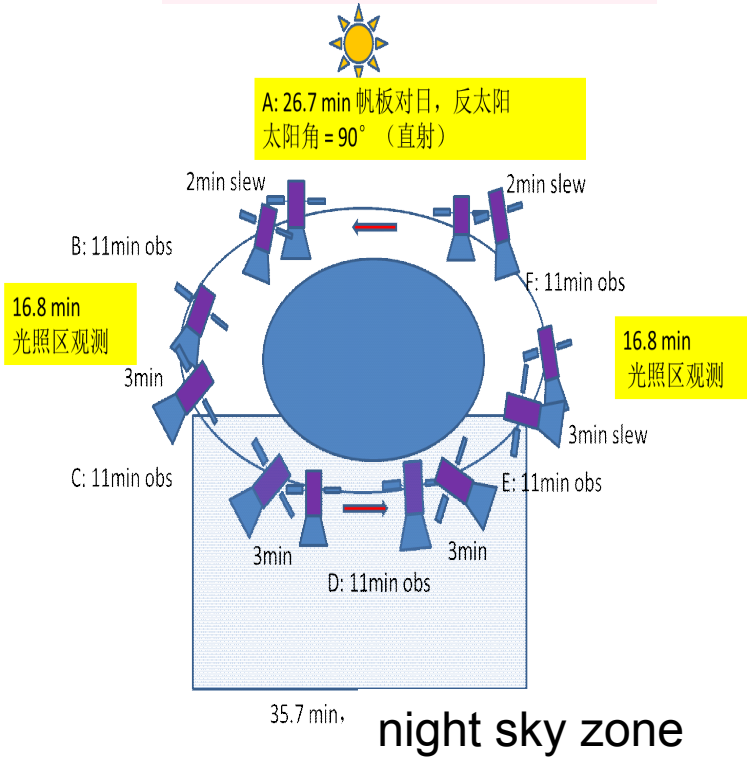
Angular resolution measured



Mission profile

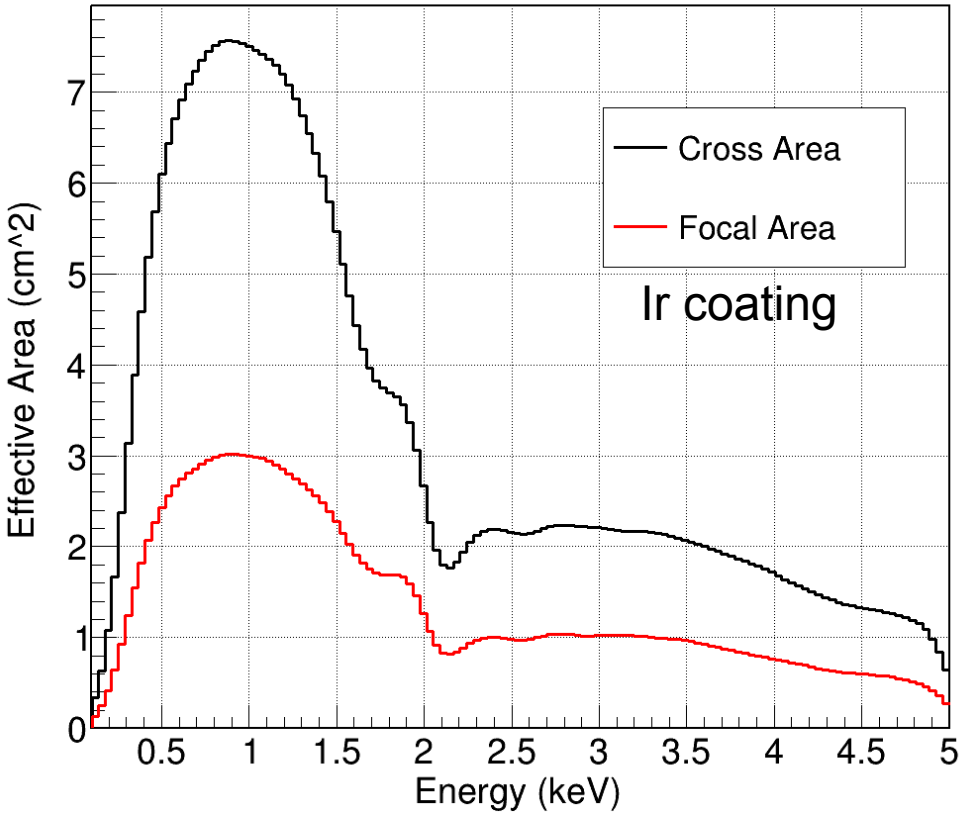
- Orbit: 600km, incl. < 30deg
- Observation mode
  - Survey mode: a series of pointings to the night-sky, each 11min exposure
  - cover the whole night sky in 3 orbits (97min each)
  - Follow-up mode: pointed observation with FXT (WXT remains operation)
  - Possible ToO mode (tbd)
- On-board transient data reduction
- Quick alert data downlink
  - VHF network (French)
  - Relay satellites (China)
- Nominal lifetime: 3 (+2) years





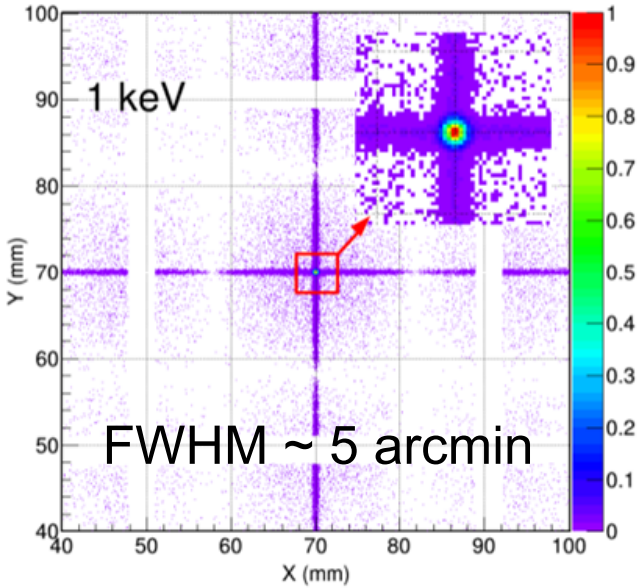
Simulated performance of WXT

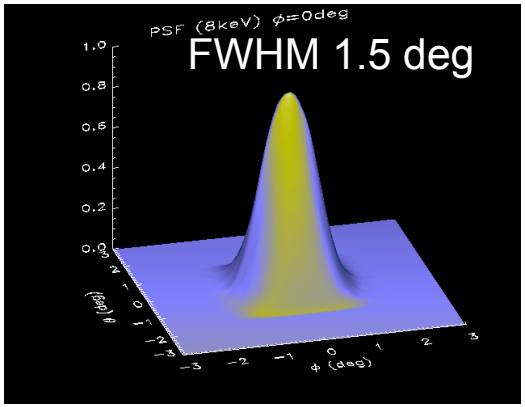
Effective area (simulated)



Zhao et al. 2014 SPIE (9144)

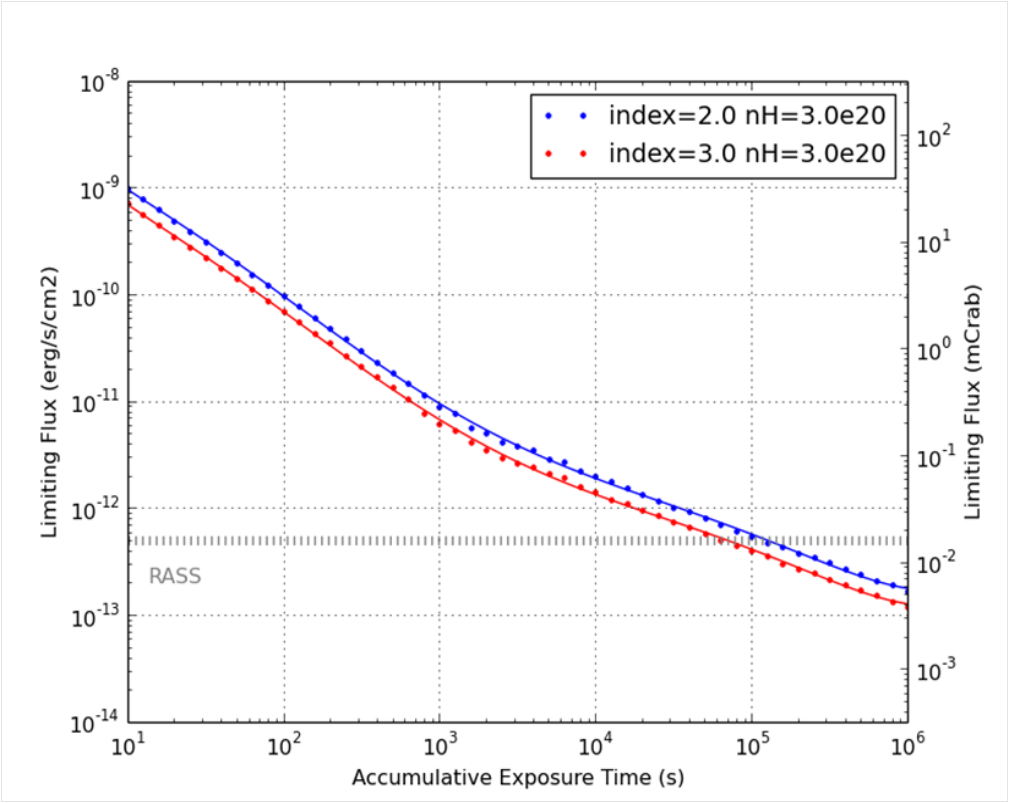
PSF (simulated)

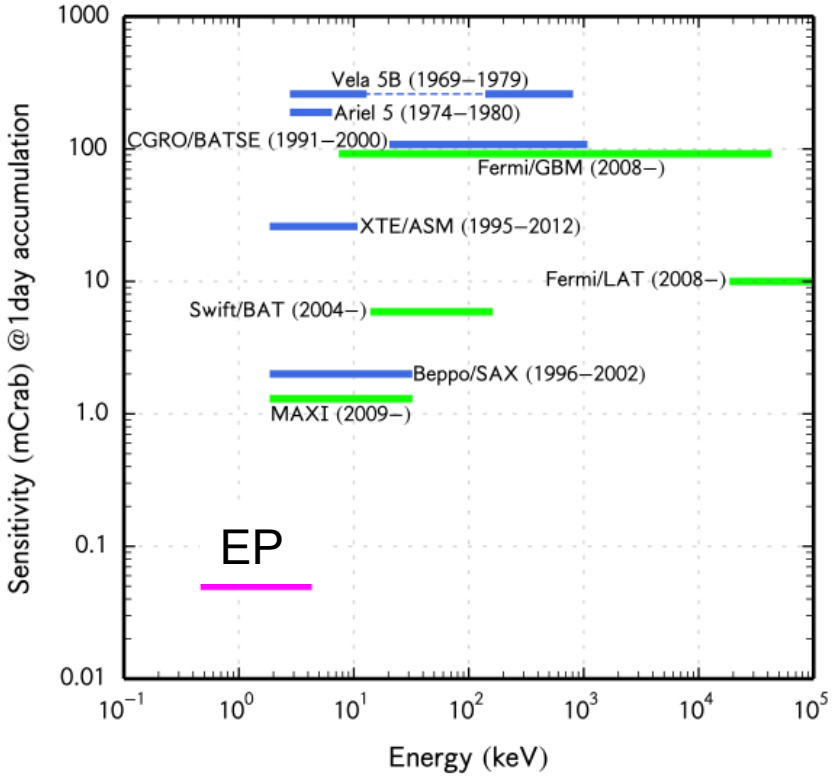




Simulated MAXI/GSC PSF @8keV
(Yuan W. et al. 2001)

Performance of EP WXT: senstivity



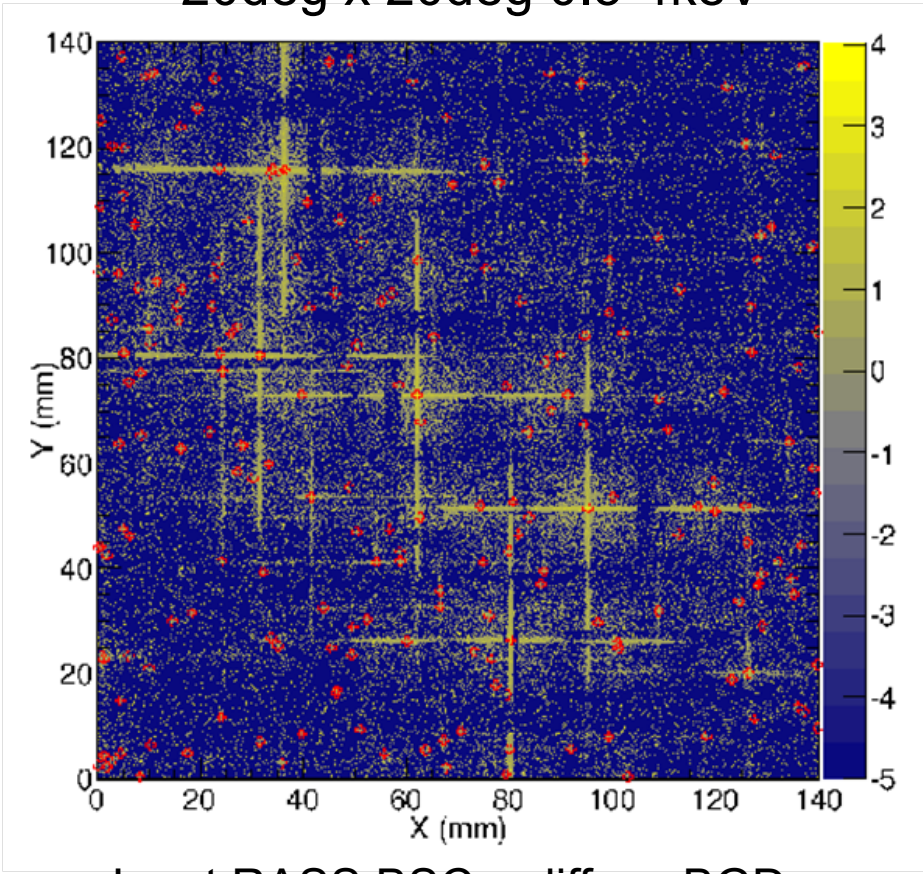


~0.3mCrab at 1ks exposure

Simulated X-ray sky images

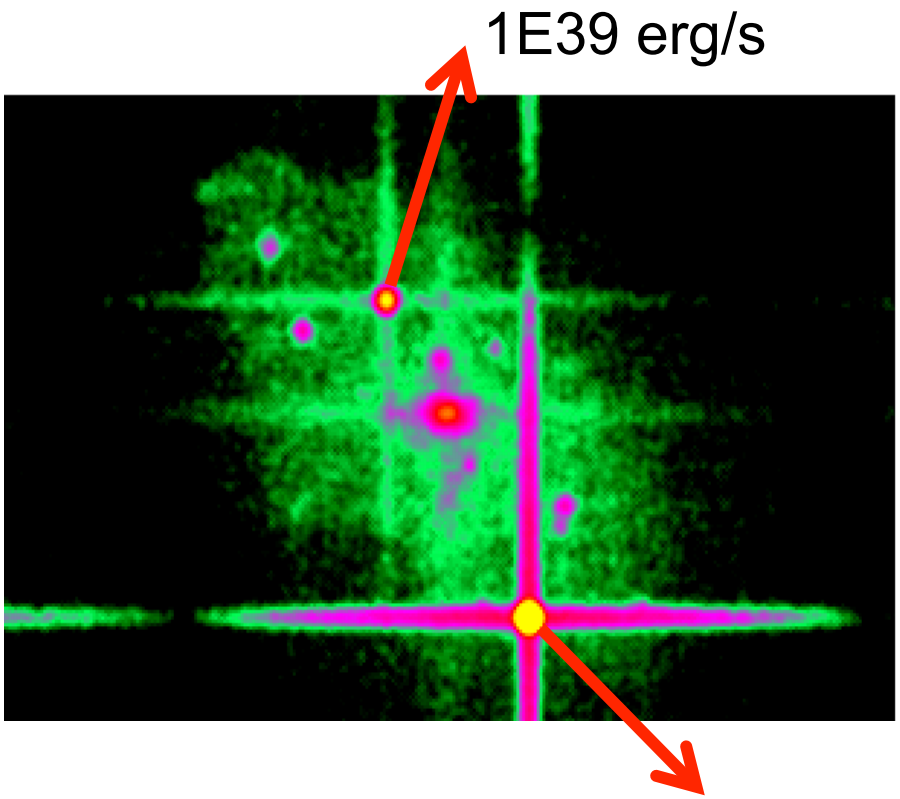
Simulated X-ray sky (500ks)

20deg x 20deg 0.5-4keV



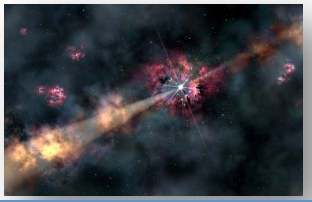
Input RASS BSC + diffuse BGD

M31 image with transients (500ks)

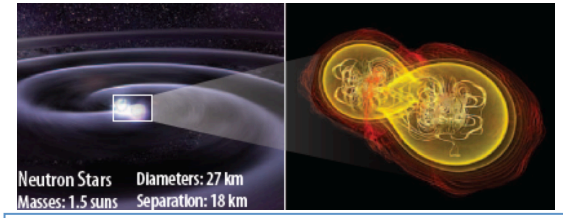


Zhao et al. 2014 SPIE

Wide range of scientific objectives: X-ray transients & variability



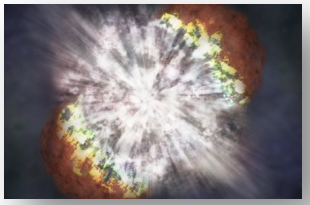
X-ray flash
& LL GRB
GRB physics

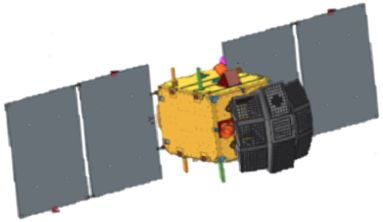


High-redshift GRB
Trace first stars/BH
Early universe

Neutron-star merger
EM counterparts of GW sources

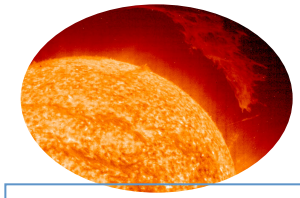
Active galactic nuclei
Extreme gravity, BH
accretion/jets/growth

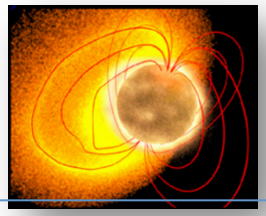


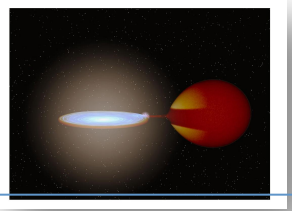


SN shock breakout
SN physics
Size of progenitors

BH Tidal disruption
Quiescent MBH finder
BH accretion/jets







Star X-ray flares
Magnetic fields
Corona activity

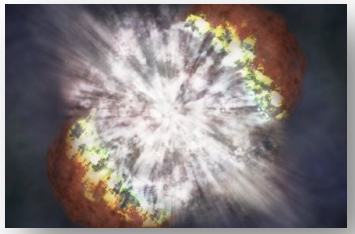
SGR/magnetar
extreme
magnetic Field

Thermal nuclear burst
Neutron stars physics

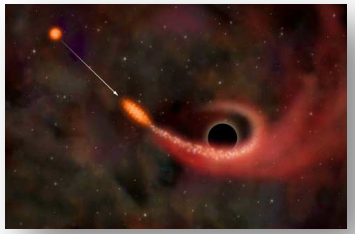
BH X-ray binary
Extreme gravity
BH physics/accretion

Core science goals

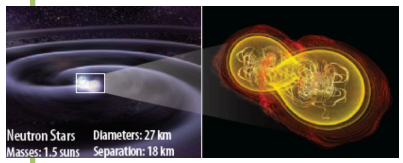
Systematic survey of soft X-ray transients and variability of X-ray sources at high sensitivity and high cadence



Uncover quiescent Black holes at all astrophysical mass scales and other compact objects via capturing their transient flares



Detect and localize electromagnetic-wave sources of gravitational-wave events by synergy with GW detectors

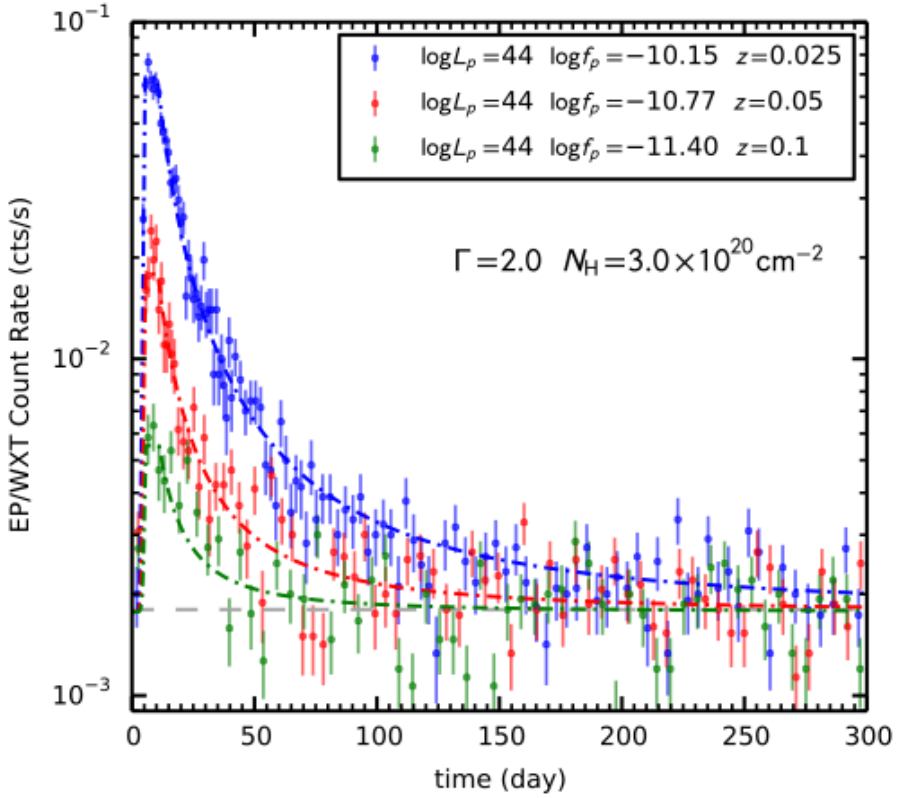


Estimated detection rates of selected transients

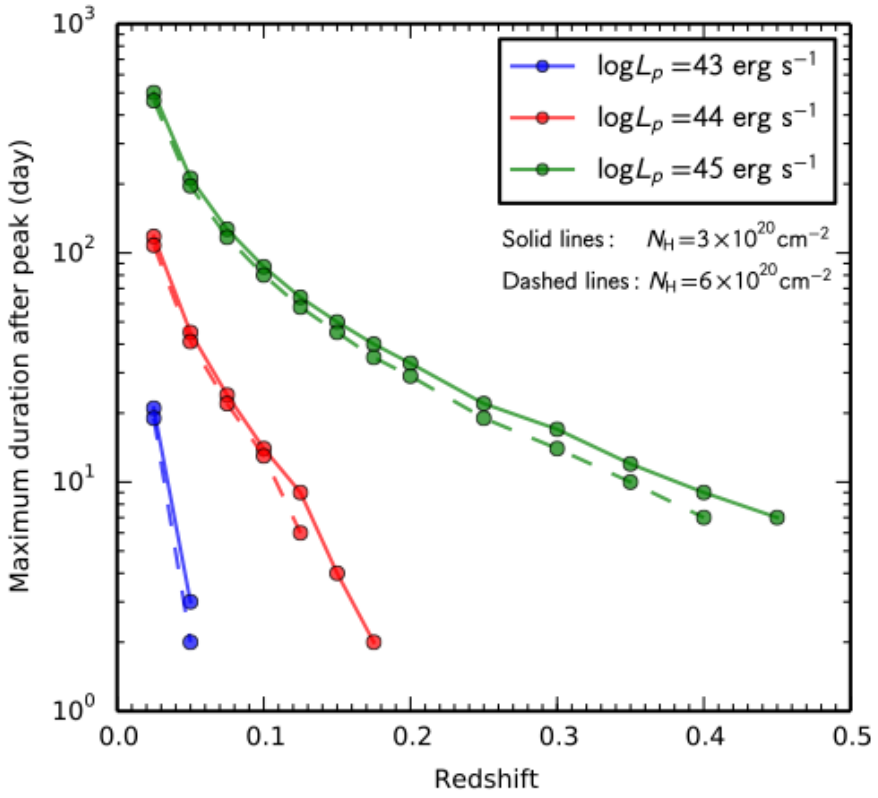
Type of events	Estimated detections per year
Tidal disruption events (TDE)	20-120
TDE with jets	20 - 40
SN shock breakout	7
GRB $z > 6$ (8)	7 (3)
magnetar	1
X-ray flash	~10
Low-luminosity GRB	< 8
SFXT	~ 13
Stellar flares	many

Simulated detection of TDEs with EP/WXT

WXT X-ray lightcurves of TDE



detectable duration of TDE flares vs. redshift



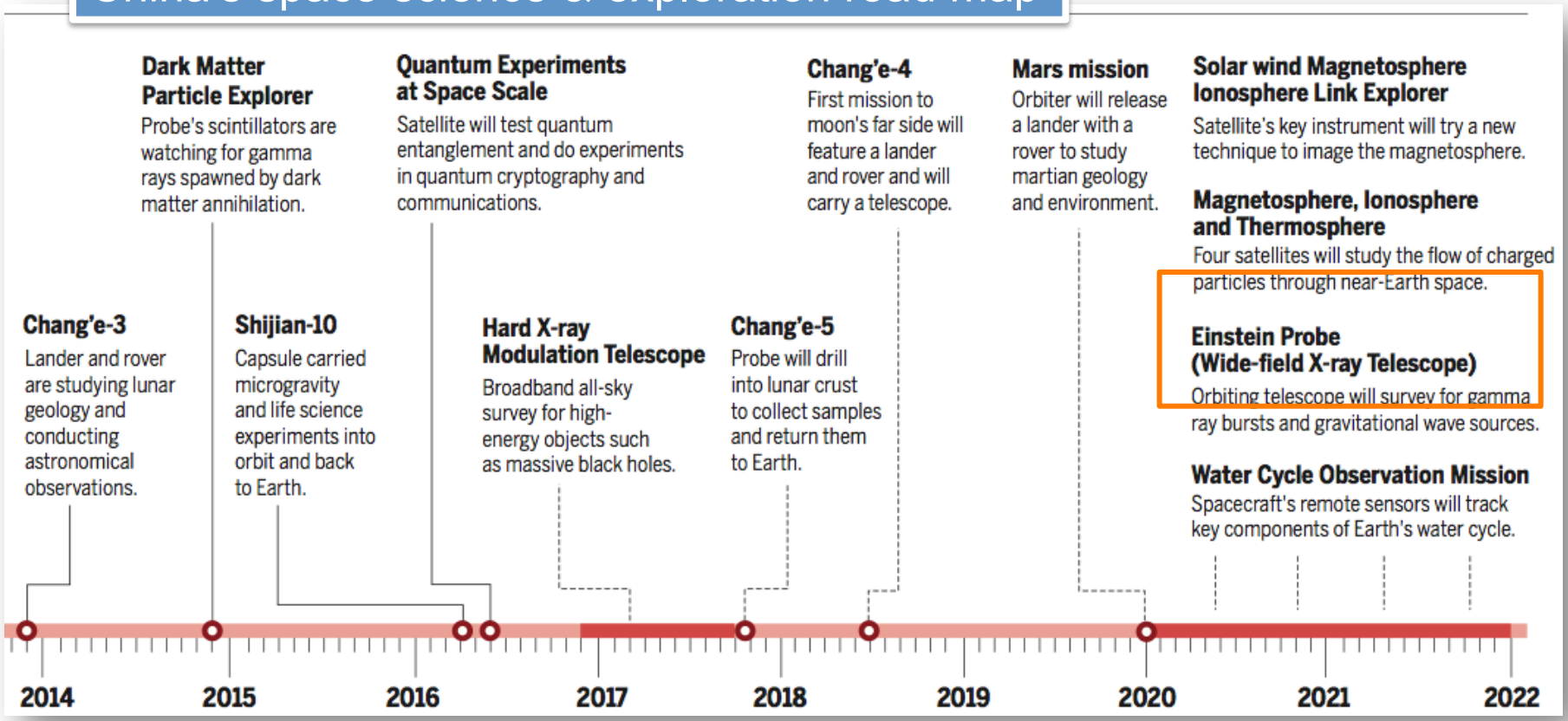
Important to catch the onset and rising phase of outbursts

Current status

- Nov. 2016, initiated the last phase of reviews to demonstrate the engineering feasibility of the whole mission system
- Formal approval expected in half a year; launch: 2021/22

China's space science & exploration road map

D. Normile 2016 Science



Summary

- Time domain astronomy has come of a golden age of multi-wavelength & multi-messenger
- New technology is needed to look both deeper & wider in soft X-rays
- MPO lobster-eye is a promising technique
- New discovery space will be explored, with Einstein Probe and other future missions ……
- Look forward to operation in synergy with MAXI

"Look deep into nature, and then you will understand everything better."

—— Albert Einstein

Thank you

http://ep.bao.ac.cn

Thanks to Matsuoka-sensei, Mihara-san, Kawai-san, Tamagawa-san, etc….