Highlights of the Insight-HXMT X-ray Satellite and future missions: GECAM, SVOM, EP, POLAR-2 and eXTP

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Particle Astrophysics Division
Institute of High Energy Physics
Chinese Academy of Sciences

Institute of High Energy Physics (IHEP)

1. Experimental Physics Division
2. Accelerator Division
3. Particle Astrophysics Division
4. Multi-disciplinary Research Division
5. Division of Nuclear Technology and Applications
6. Theoretical Physics Division
7. Computing Center

Total fulltime permanent staff: ~1500

Director: Yifang Wang (PhD in Italy)

Beijing Electron-Positron Collider

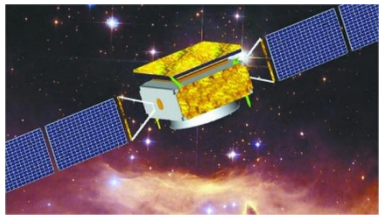
Particle Astrophysics Division

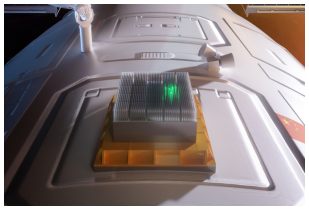
Fulltime permanent staff: 180

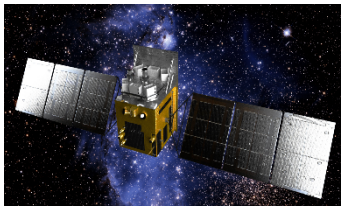
Director: Shuang-Nan Zhang (PhD in UK)

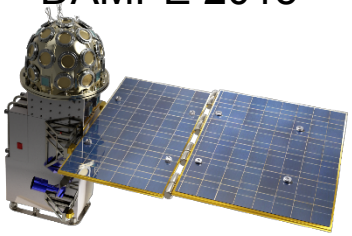
China's High Energy Astrophysics Missions

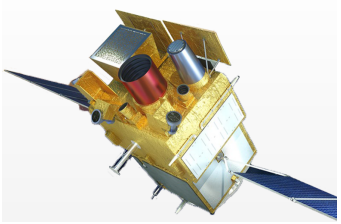
- DAMPE (2015)
- *POLAR (2016)
- *Insight-HXMT (2017)
- *GECAM (2020)
- SVOM (2021)
- EP (2022)
- *POLAR-2 (2024)
- *eXTP (2027?)
- *HERD (2025?)

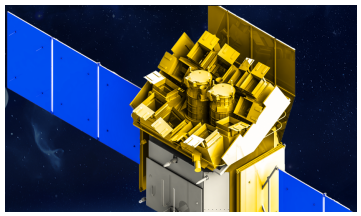

DAMPE 2015

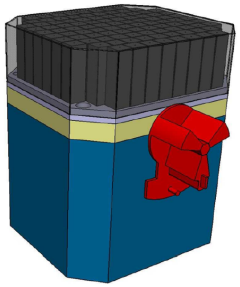

*POLAR 2016

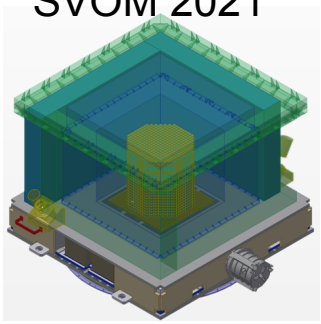

*HXMT 2017


*GECAM 2020


SVOM 2021


EP 2022


*POLAR-2 2024


*HERD 2025?

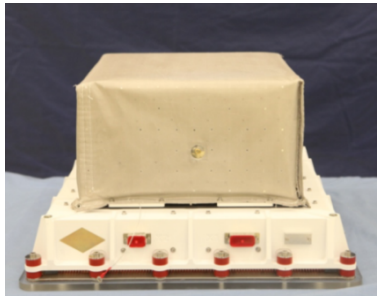

*eXTP 2027?

*IHEP the PI institution

高能所空间天文项目九宫格

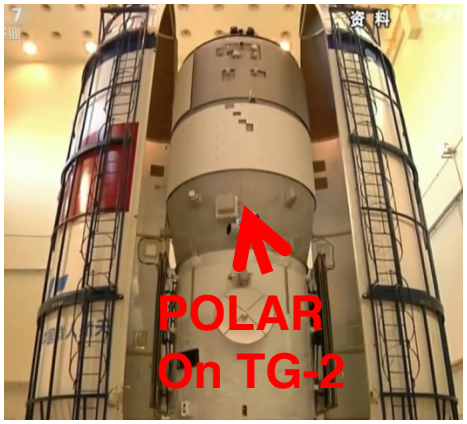
天极POLAR: GRB polarimeter

- China-Europe collaboration space program, onboard China's Space Lab., Sept. 15, 2016
- Most sensitive Gamma-Ray Burst polarimeter!
- Discovered 55 GRBs & obtained the largest sample o GRB polarization with high precision!



Detector

Electronics



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Chinese Academy of Sciences

ISDC

PAUL SCHERRER INSTITUT PSI

ANNECY lapp

nc bi

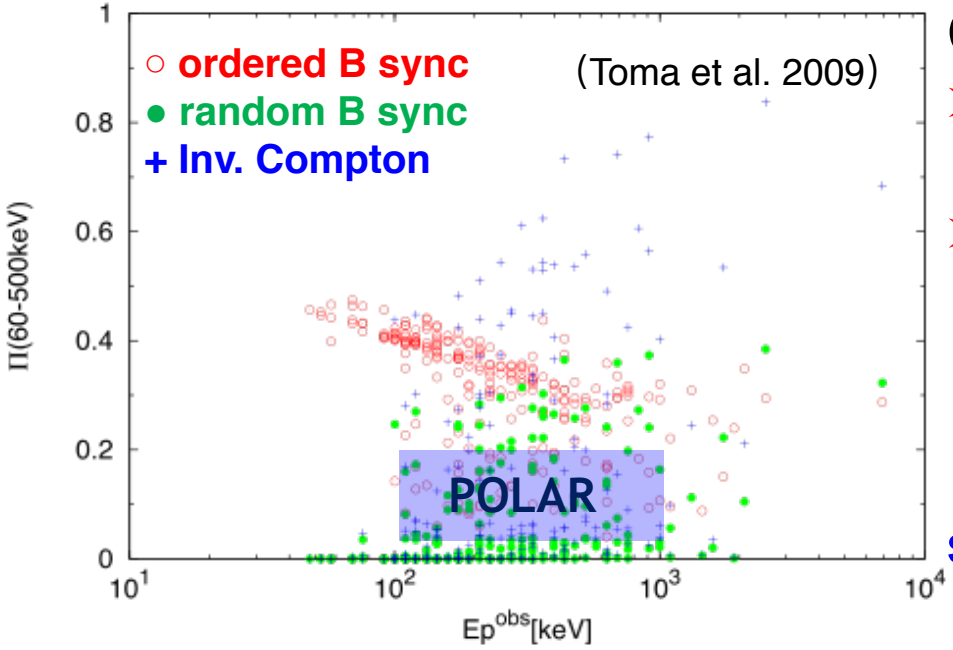
PIs: Shuang-Nan Zhang (IHEP), Martin Pohl & Xin Wu (UniGe)

POLAR's main results: contradicting most models

Table 1: Summary of the five GRBs selected (*in units of erg/cm^2 in 10-1000 keV)

GRB	T90 (s)	Fluence*	PD	Prob(PD<2%)	PD_{up}(99%)	PA(deg.)	PA Change
161218A	6.76	1.25×10^{-5}	9%	9%	45%	40	No
170101A	2.82	1.27×10^{-5}	8%	13%	31%	164	No
170127C	0.21	7.4×10^{-6}	11%	5.8%	67%	38	Unknown
170206A	1.2	1.34×10^{-5}	10%	12%	31%	106	No
170114A	8.0	1.93×10^{-5}	4%	14%	28%	164	Yes
170114Ap1	N/A	N/A	15%	8%	43%	122	N/A
170114Ap2	N/A	N/A	41%	0.49%	74%	17	N/A

170114A: 1st single peak GRB observed with pol. ang. evolution.



Comparison of obs. vs theory:

➢ POLAR's 5 GRB pol.
large-scale random B

➢ GRB 170114A pol.
Time-resolved high pol.
Time-integrated low pol
Pol. ang. varied significantly
→→ Large-scale B evolved significantly with time

Zhang et al. Nature Astronomy 2019

慧眼Insight-HXMT

- The 1st X-ray satellite in China, 06/15/2017
- Features:
  - Large effective area @ > 30 keV
  - High timing resolution: single event mode
  - Wide energy bands (1-250 keV, 0.2-3 MeV)
- Discoveries:
  - Strongest magnetic field of neutron star
  - Highest-energy oscillations in accretion disks around black holes
  - > 170 gamma-ray bursts

PI: Shuang-Nan Zhang (IHEP)

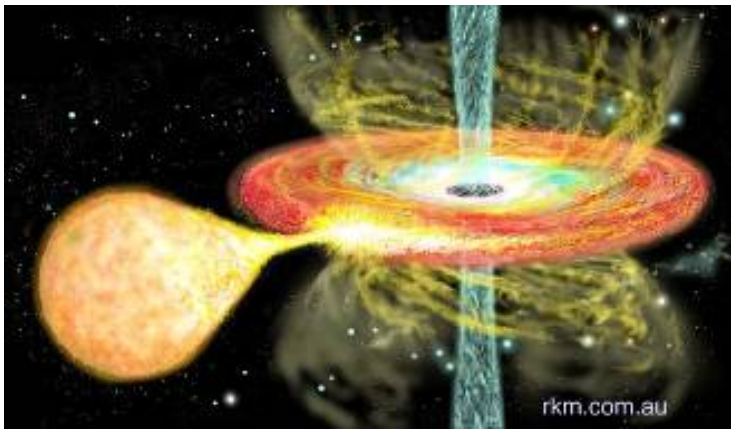
sciencemag.org

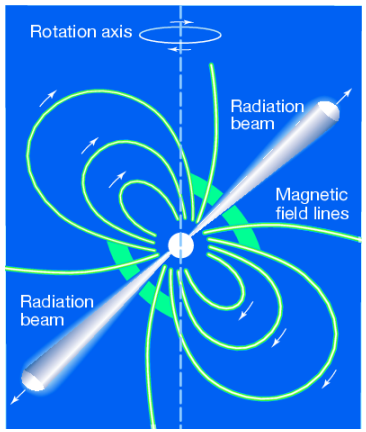
China successfully launches x-ray satellite | Science

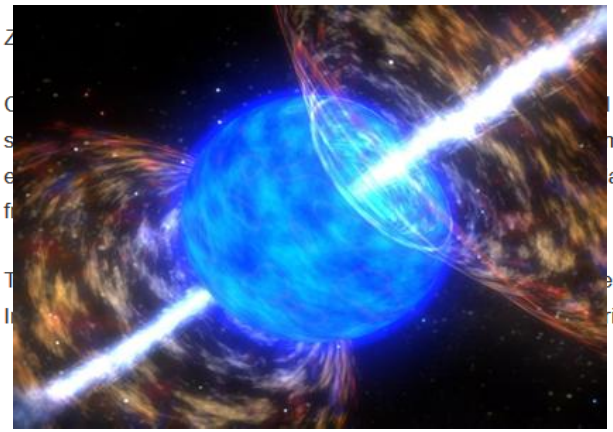
By Dennis NormileJun. 15, 2017 , 11:00 AM

4-5 分钟

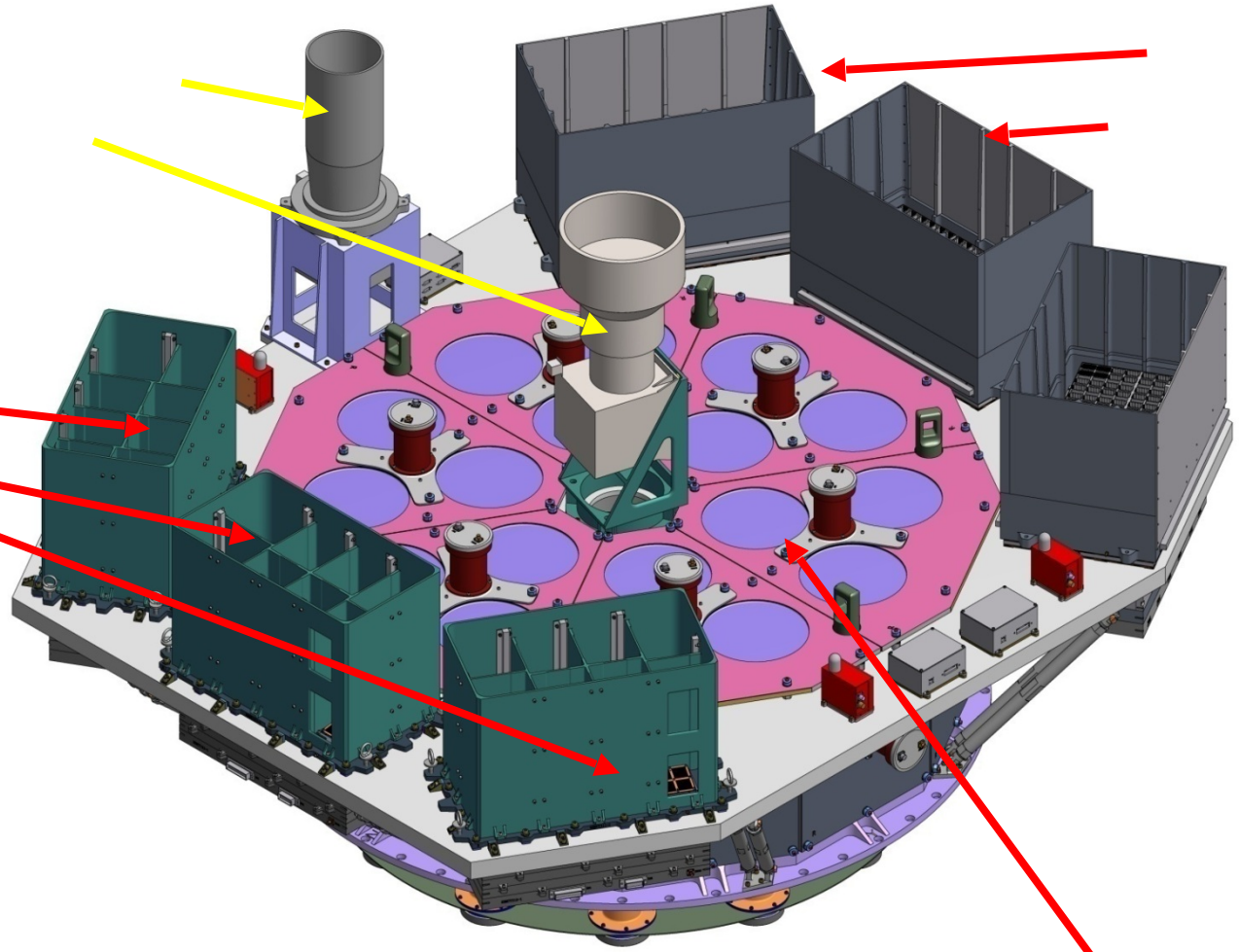
A rocket carrying China's new x-ray telescope blasts off.



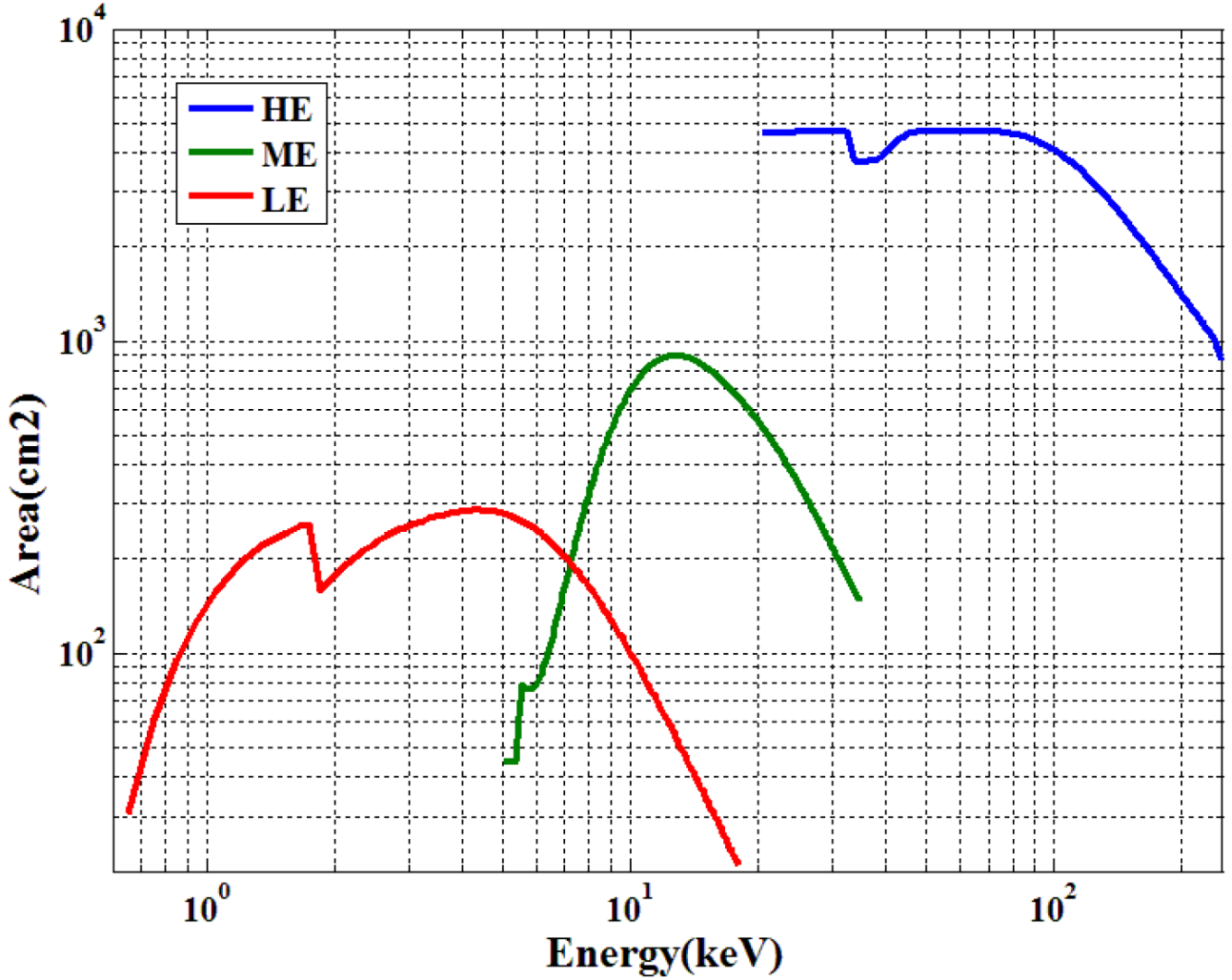




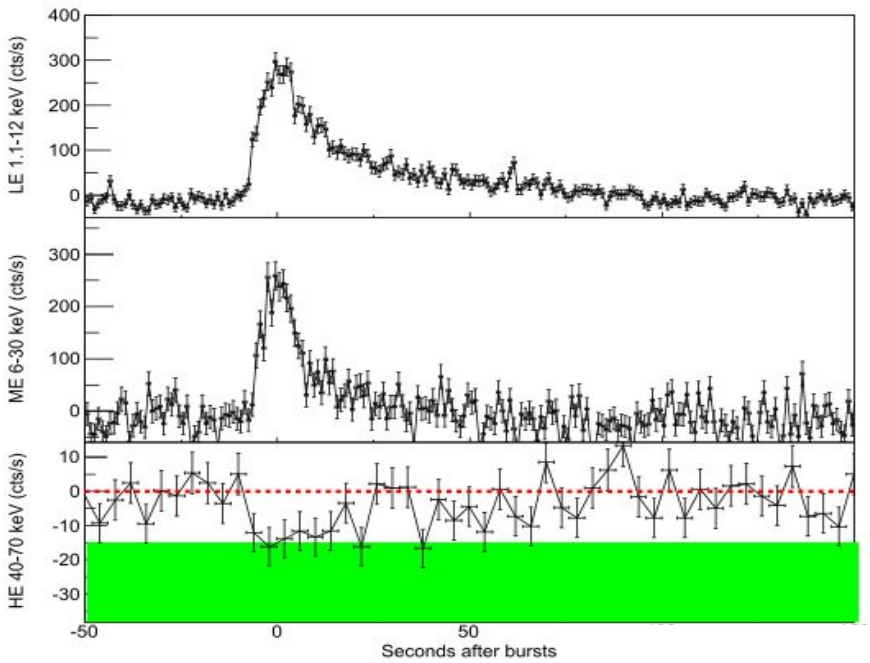
Science payloads



Effective area



Corona cooled by single Type-I X-ray burst



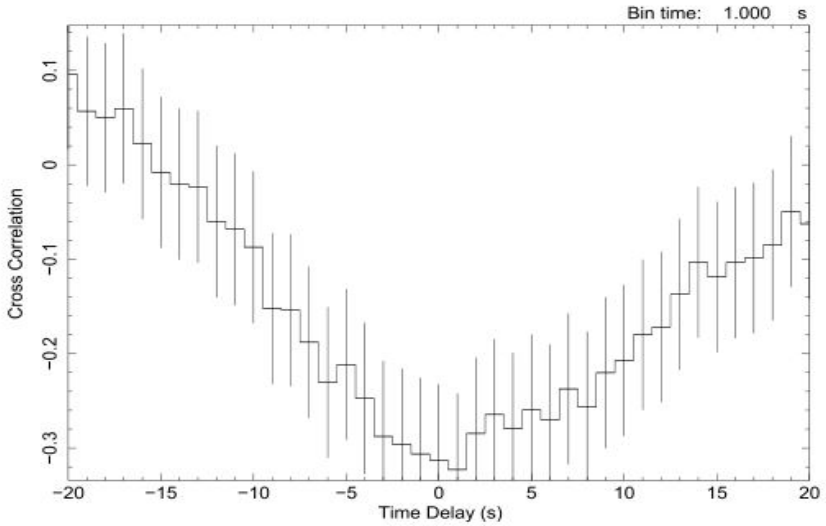
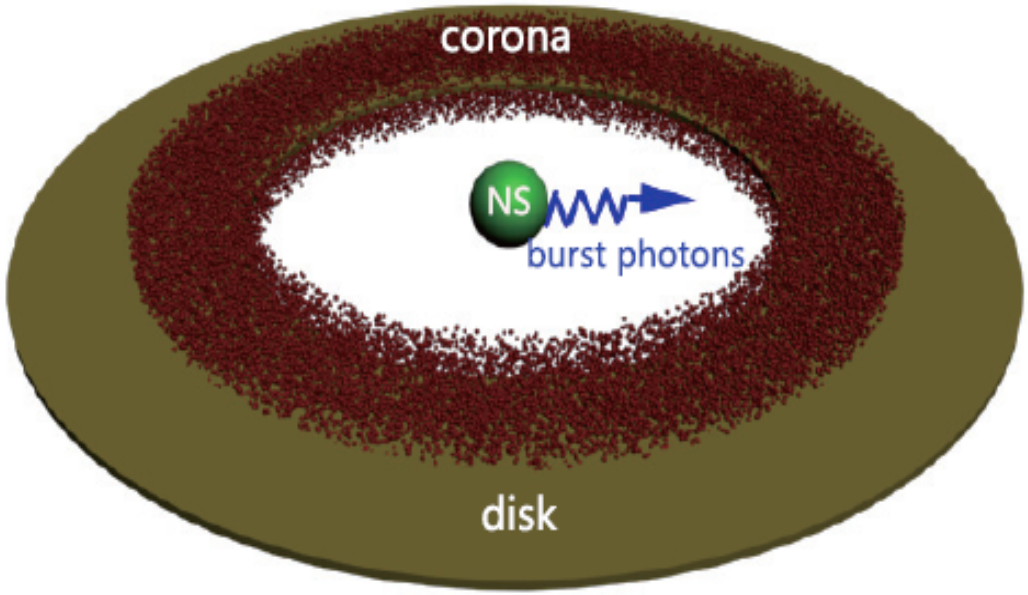
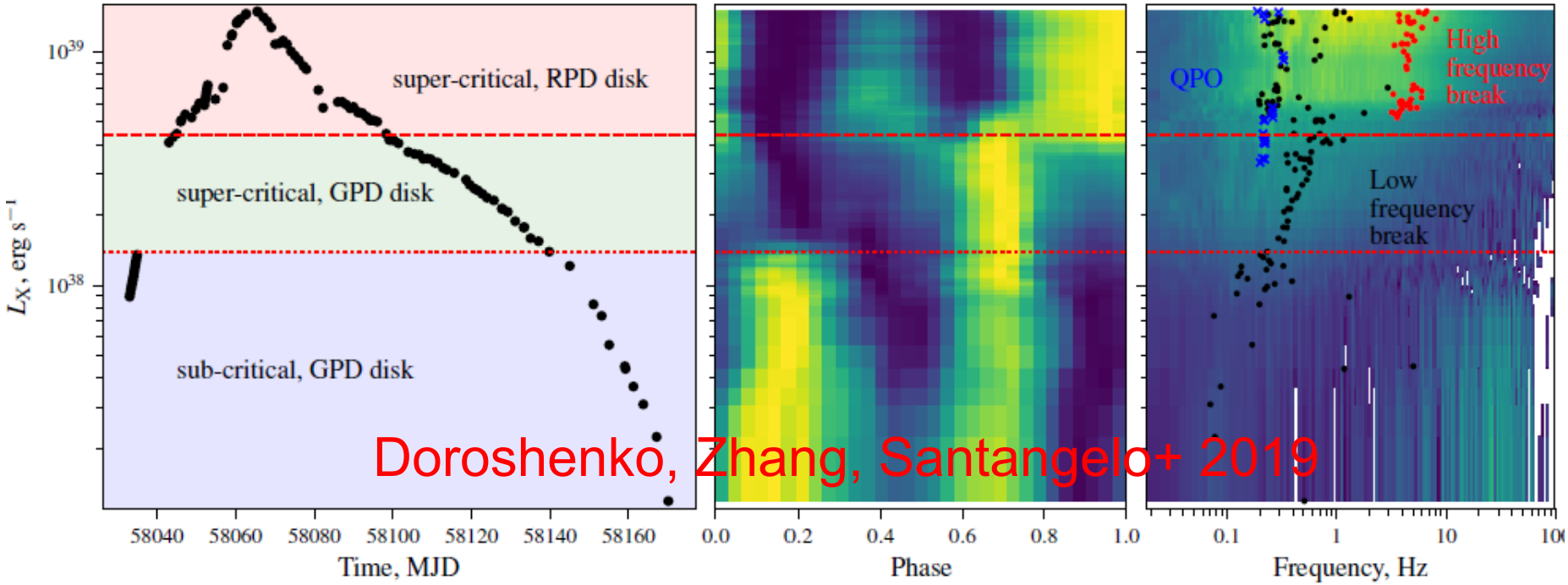


Figure 2. Left panel shows the LE, ME, and HE ligh
and HE is 4 s, the green zone in the bottom panel indi
LE and HE re-extracted light curves with a time bin

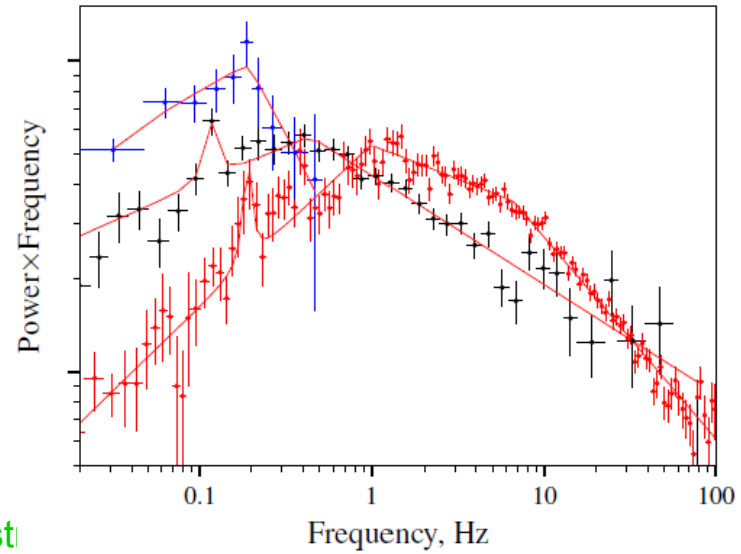
4U1636-536
Chen+2018, ApJL)

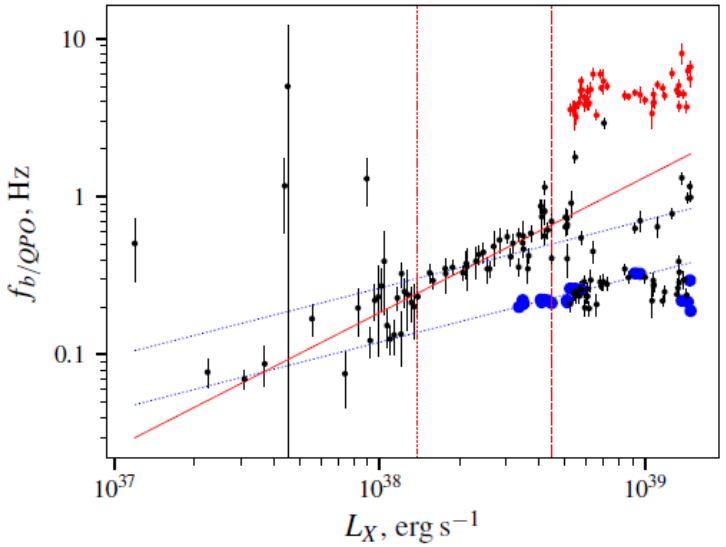


Hot disk of the Swift J0243.6+6124



Doroshenko, Zhang, Santangelo+ 2019

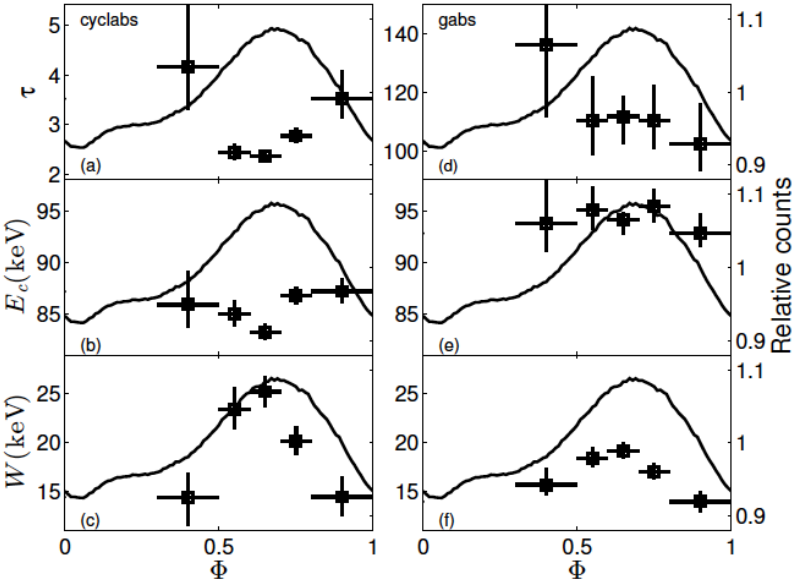


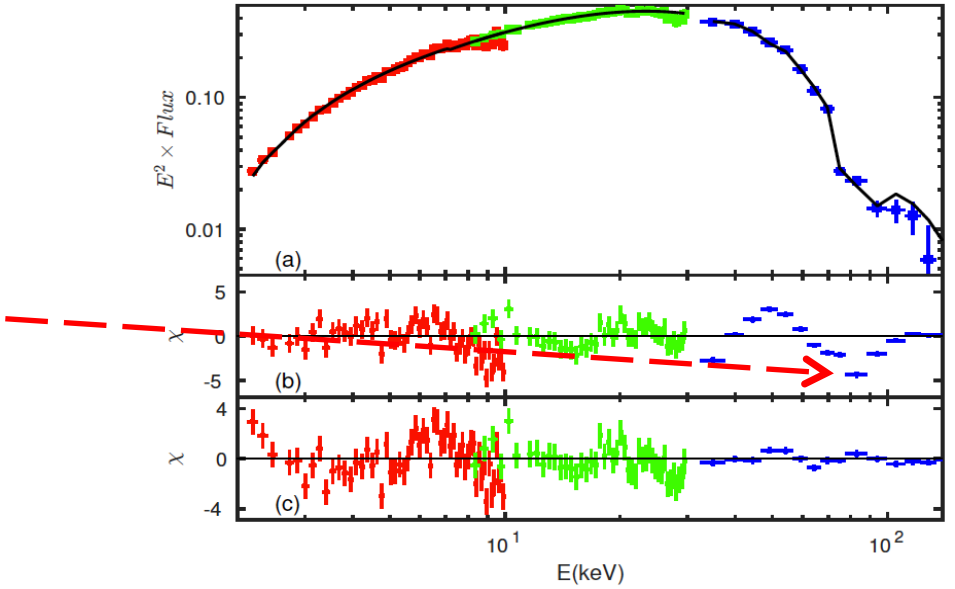


Neutron star cyclotron absorption lines

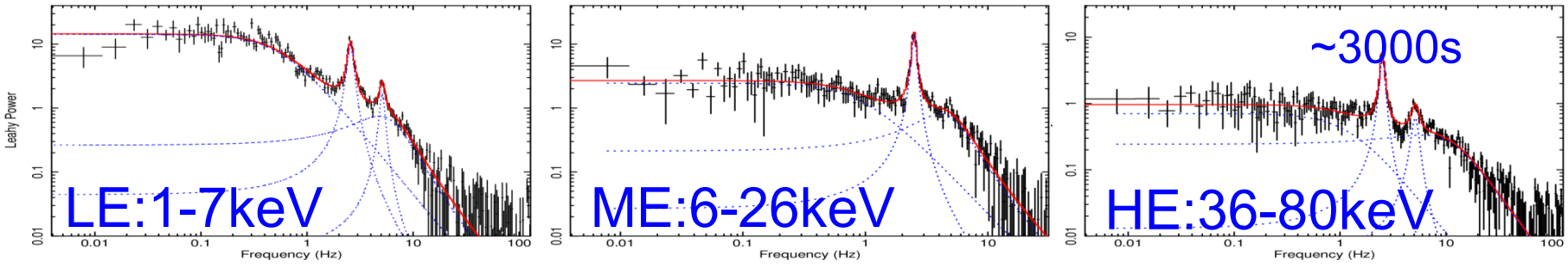
- GRO J1008-57： ~85 keV → highest (?) B directly measured in the universe ~10^{13}, ~ 4σ with NuSTAR & Suzaku
- 4 HXMT observations ~235 ks ~ 20σ detection

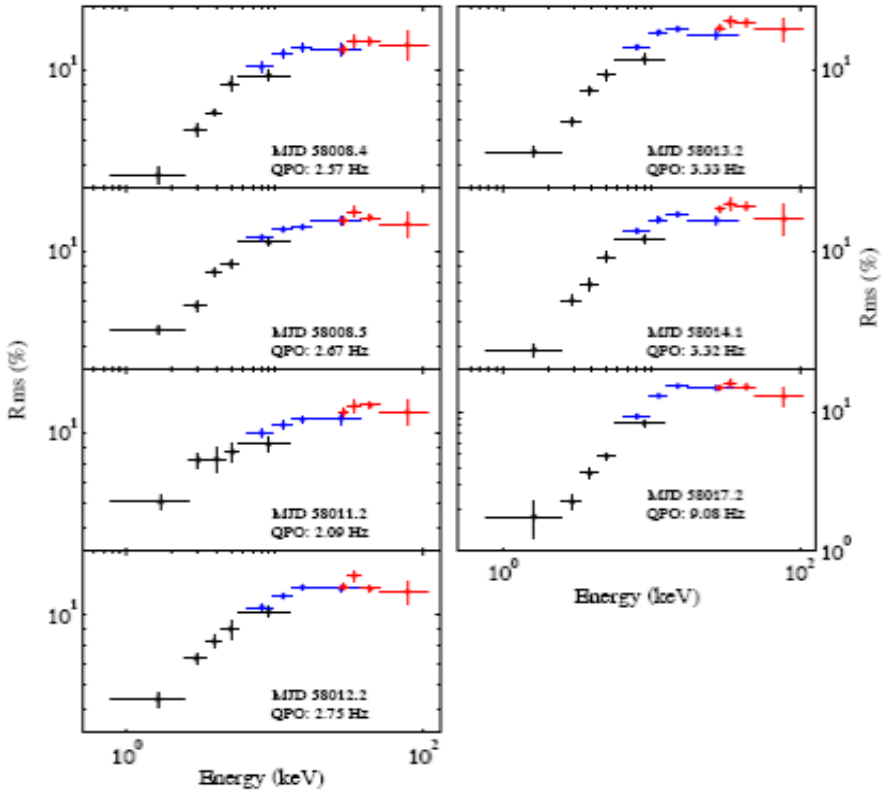
HXMT/HE one module, 17 modules ~ 20 σ
Allow for phase resolved and flux dependent studies

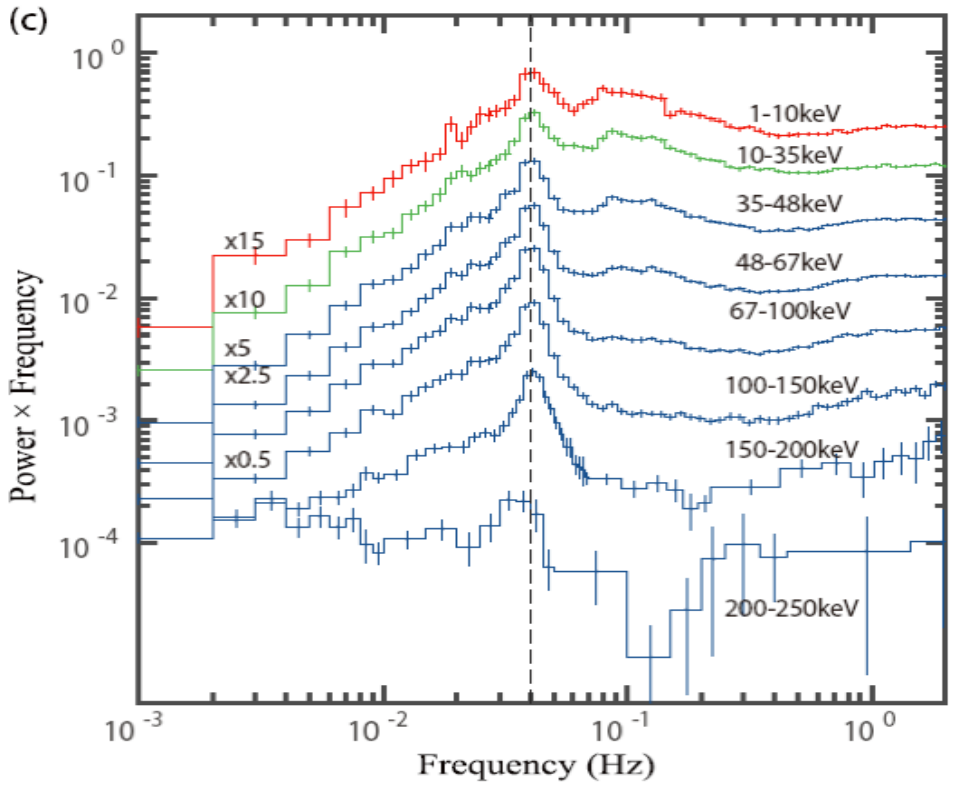




QPOs of BH binaries: < 30 keV → >200 keV



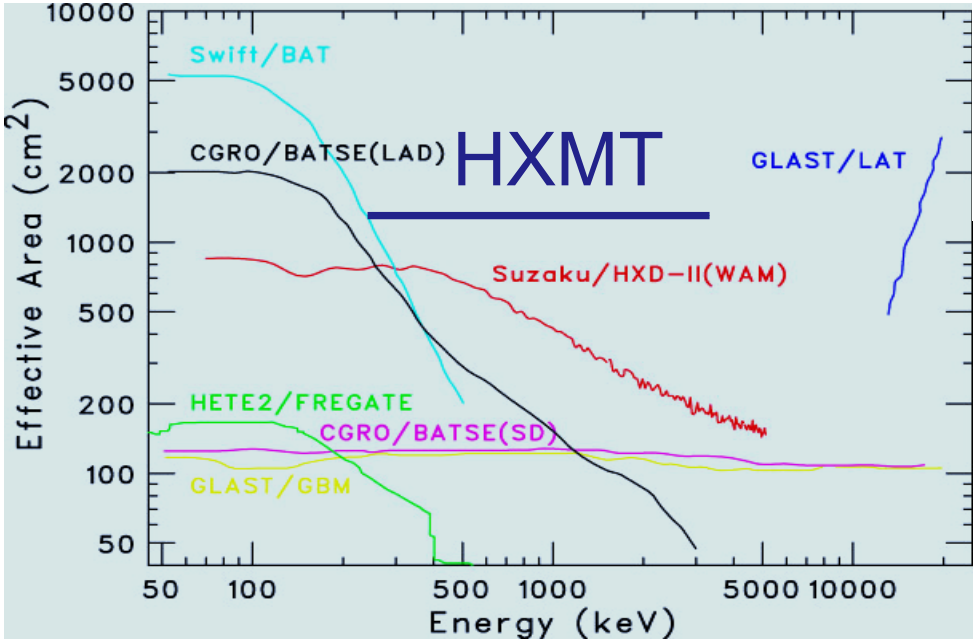


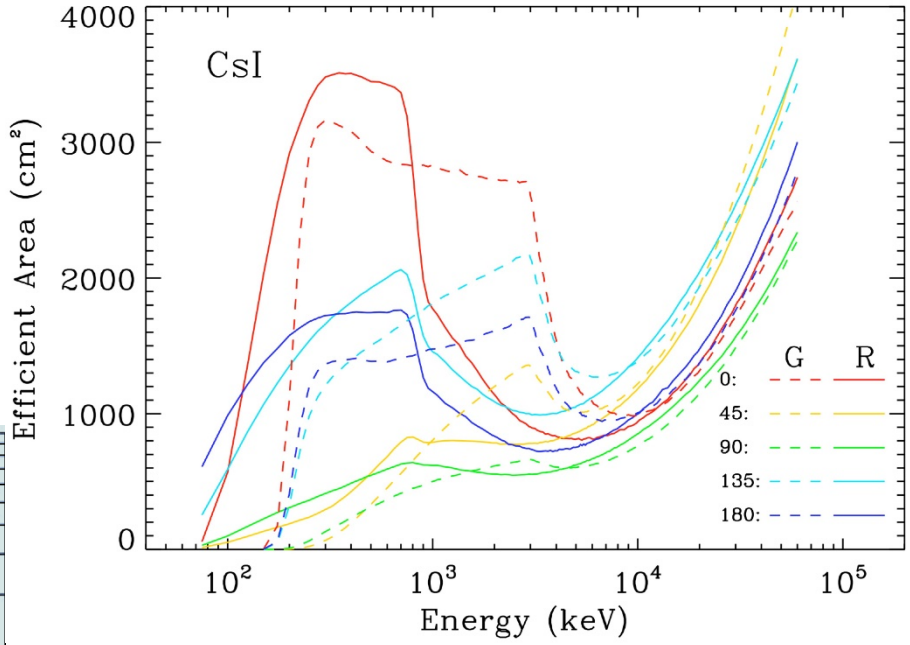


Huang et al. 2018; Ma et al. 2019

Effective Area for GRBs & Pulsars

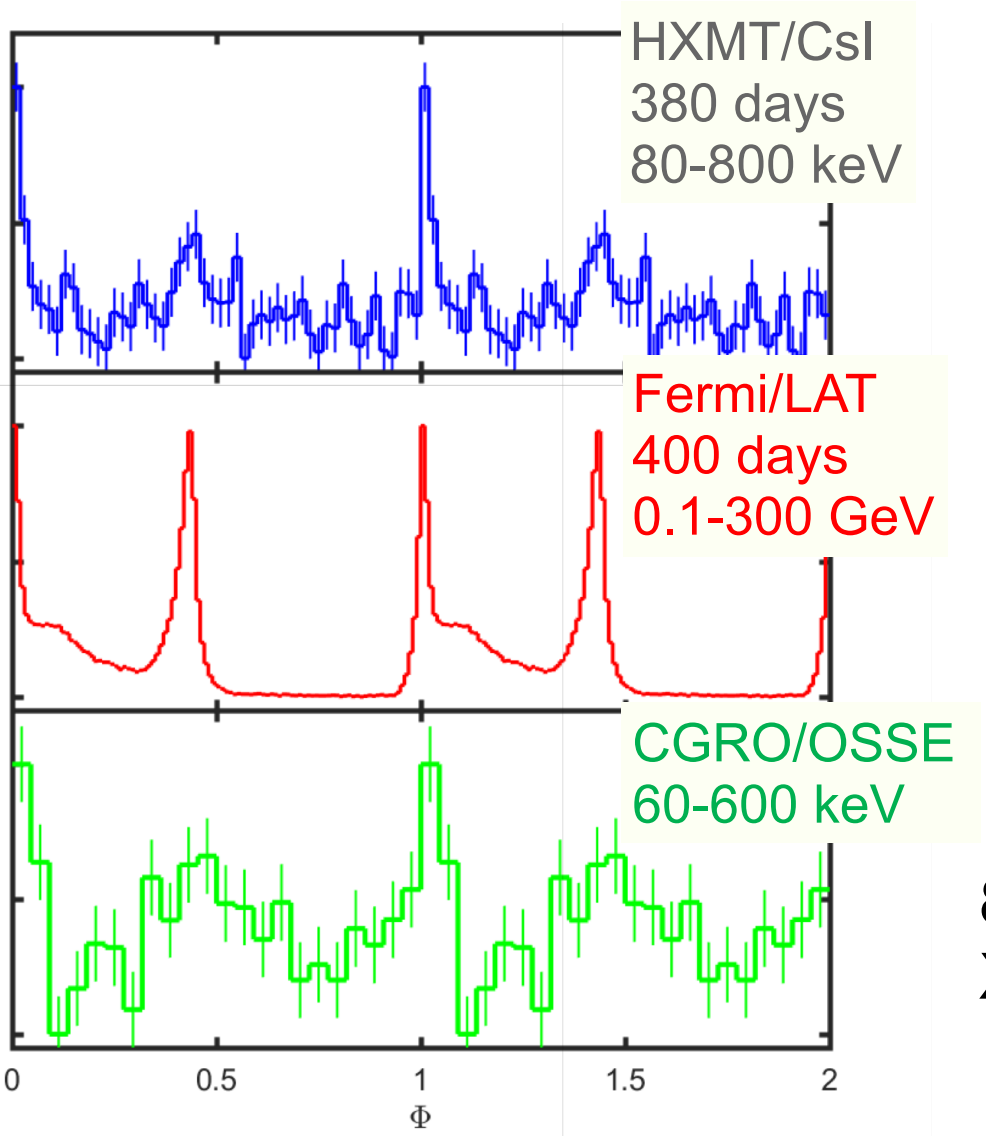
- GRB and pulsar monitoring FOV: all sky un-occulted by the Earth





- 500~3000 cm^2 ~ MeV range with single photon counting and energy measurement, ~largest ~ MeV GRB & pulsar monitor ever flown

MeV detection of the Vela pulsar



89 ms pulsar: radio, optical, X-ray, γ-ray

GRB Statistics

Year	2017							2018							
Month	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
All	2	10	9	12	8	8	8	11	8	7	11	6	8	7	4
short	0	3	5	3	5	2	1	1	1	1	3	2	2	2	0

Year	2018				2019			Total
Month	9	10	11	12	1	2	3	LG Mode：16；GCN：67/23 (1st)
All	4	4	5	6	7	6	12	163 gamma-ray bursts
short	1	0	2	1	0	2	2	39 short gamma-ray bursts

~100 GRBs/year @ ~MeV, ~¼ short GRBs > ~1/6 by GBM

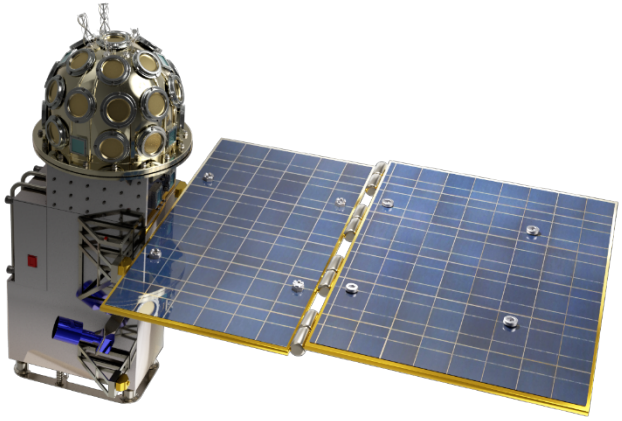
~ 1000 cm^2@0.2-3 MeV, ~μs timing resolution; but no real time data or online trigger, data delay of hours to days

GECAM

A leading mission in multi-messenger GW astronomy era

- **Sciences**
  - GW GRB (GW EM from keV to MeV)
  - Fast Radio Bursts (FRB), High Energy Neutrinos (HEN), GRB, Magnetar
- **Performance (better than existing ones)**
  - 100% all-sky FOV, high sensitivity, wide energy band, good localization (~1 deg)
- **Innovations**
  - Two small satellites, **ALL-TIME ALL-SKY**
  - BeiDou navigation system, **real-time data**
- **Mission of Opportunity**
  - Proposed in 2016, approved in 2018
  - **Plan to launch in 2020**, life time>3 yrs

GECAM星座

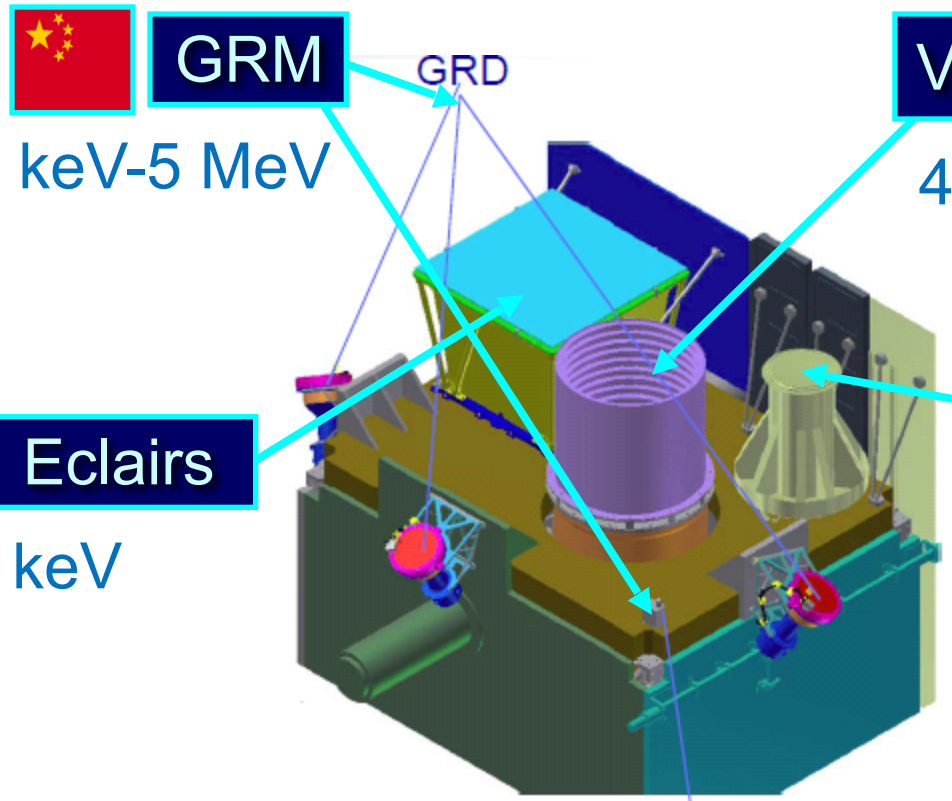


GECAM卫星

PI: Shaolin Xiong (IHEP)

SVOM (Space Variable Object Monitor)

IHEP



PIs: Jianyan Wei,
National Astronomical
Observatories of China;
Bertrand Cordier, CEA, France

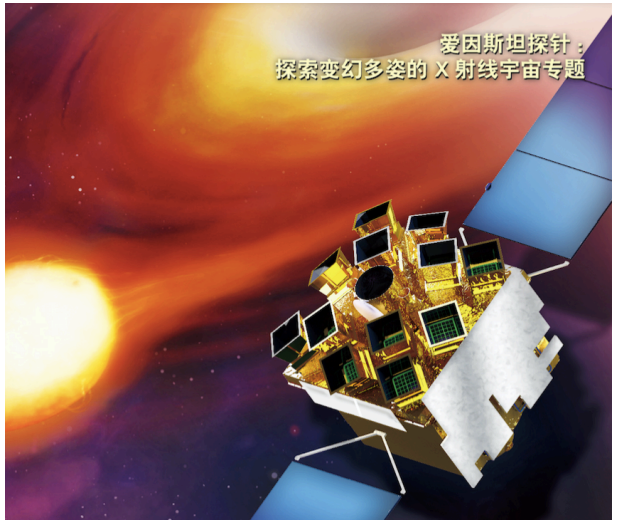
IHEP contribution to SVOM

- IHEP: GRM led by Shuang-Nan Zhang
- 2013-2018: Engineering model and space qualified model
- Launch Date: ~2021

	Spectral band	Field of View	Location Accuracy	GRBs/yr (Dect. Rate)
GRM	30 keV-5 MeV	2 sr	2-5 deg	~80
ECLAIRs	4-250 keV	2 sr	10 arcmin	~70
MXT	0.3-5 keV	65× 65 arcmin	30 arcsec	~90%
VT	400-650 nm 650-950 nm	26 × 26 arcsec	1 arcsec	~80%

The Einstein Probe (EP) mission

- The first mission that uses Lobster-eye optics to monitor transients in the soft X-ray band.
- Proposed in 2012, selected in the end of 2017
- Launch date: ~2022

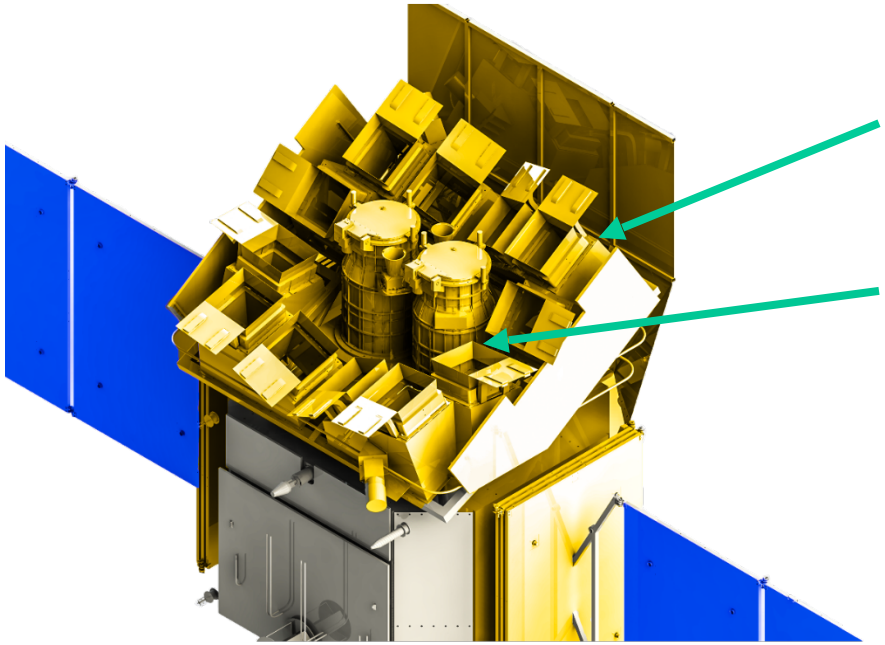


Mission Features

- Very wide FoV 1.1 sr (3600 sq. deg.) grasp: ~10,000 $deg^2.cm^2$
- Good angular resolution (~5') and positioning accuracy (<1')
- Soft X-ray band: 0.5-5 keV
- Sensitivity: >1 order of magnitude higher than current telescoeps
- Autonomous X-ray follow-up (<10 arcsec localisation)
- Fast alert data downlink and fast uplink for ToO (TBC)

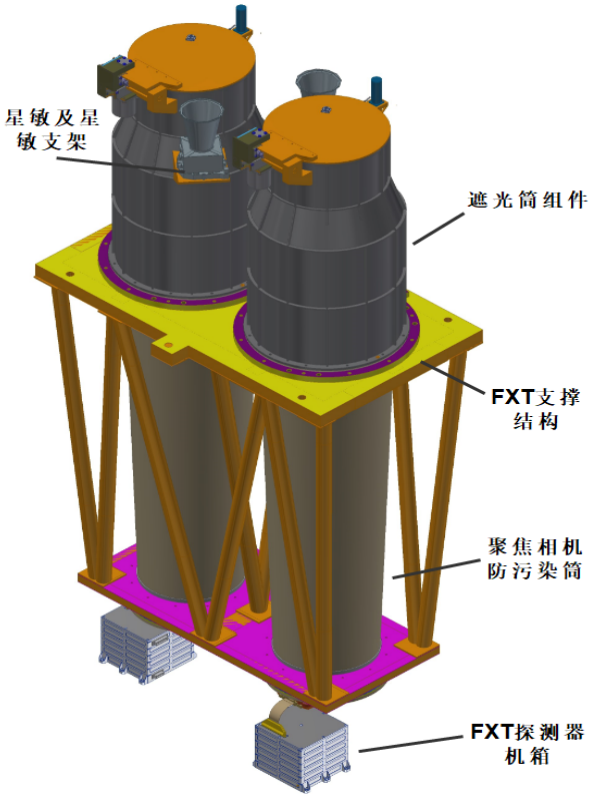
PI: Prof. Weimin Yuan, National Astronomical Observatories of China

IHEP contribution to EP



- WXT (Wied fov X-ray Telescope)
  - FOV: 3600 sq.deg.(1.1sr)
  - 0.5-5 keV
- FXT(Follow-up X-ray Telescope)
  - FOV: 30’
  - 0.3 – 10 keV

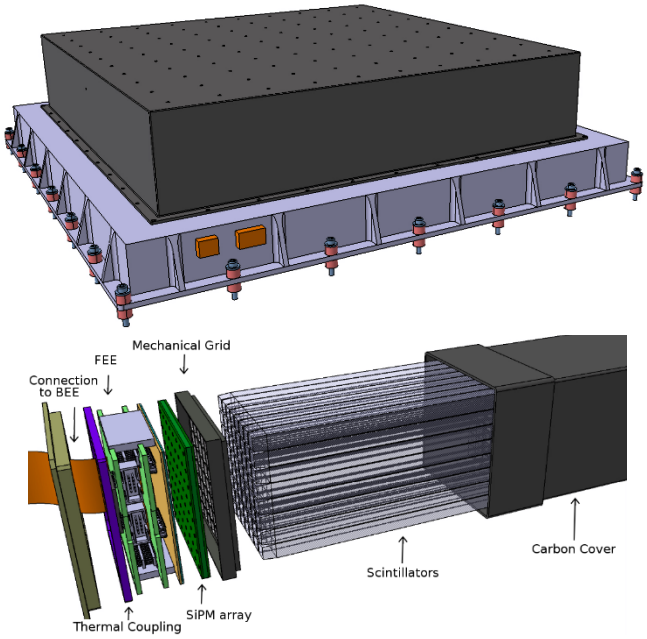
IHEP (Yong Chen and Fangjun Lu) X-ray telescope (FXT) in collaboration with ESA & MPE



POLAR-2 on China's Space Station

- Flight on-board China's Space Station
- Improvements from POLAR
- Consist of 6400 plastic scintillator bars, read out in groups of 64 by SiPM
- Each SiPM array has its own FEE with one ASIC and FPGA
- 800x800x200 mm, 80 kg

Selected on June 12, 2019

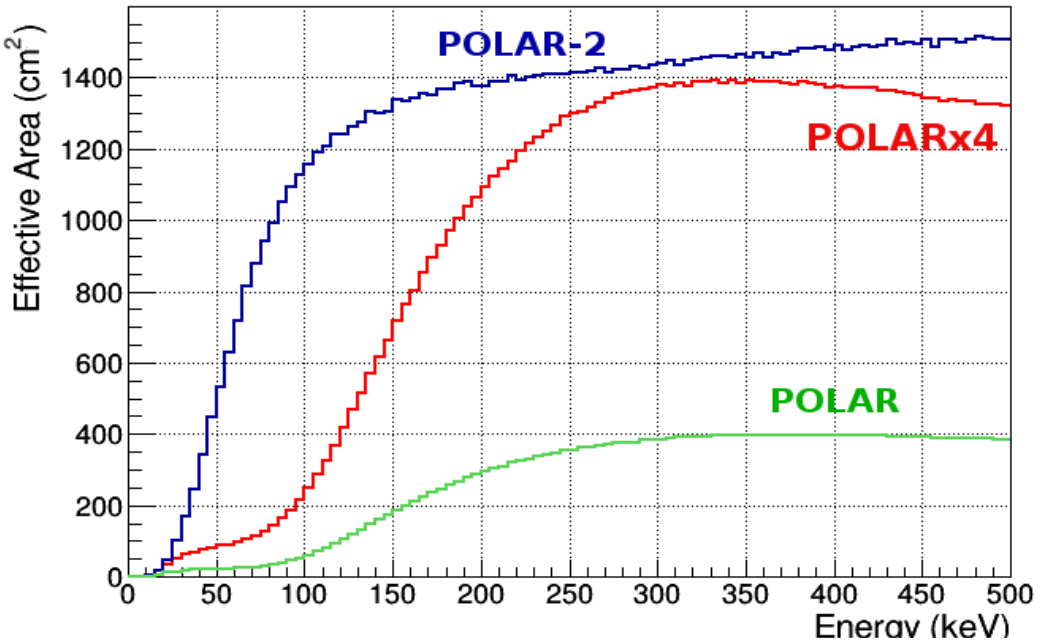


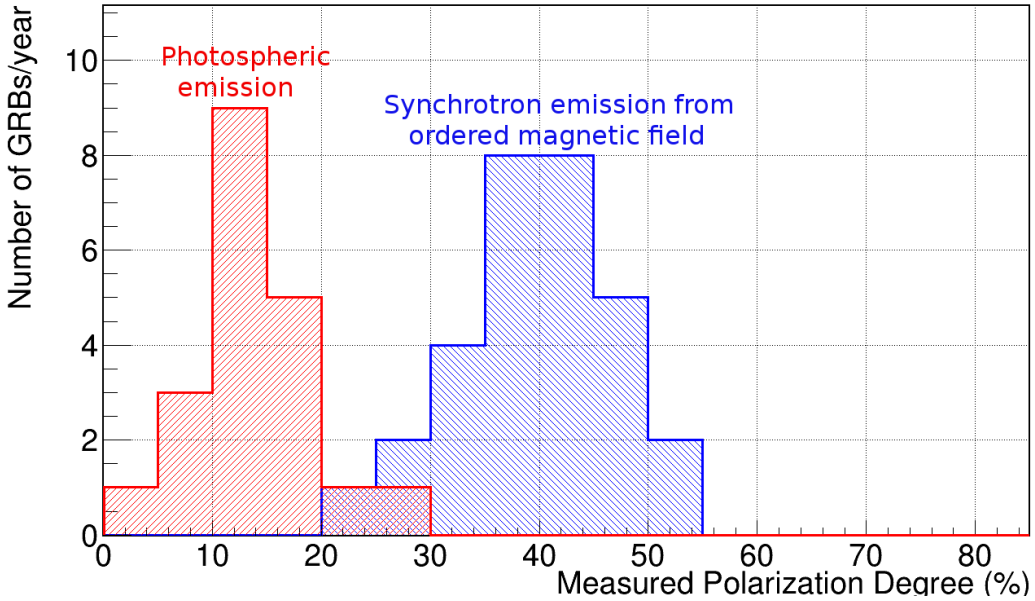
PIs: Xin WU (UniGE)
Shuang-Nan Zhang (IHEP)

UNIVERSITÉ DE GENÈVE
NCBJ
MPE
Institute of High Energy Physics
Chinese Academy of Sciences

POLAR-2 Performance

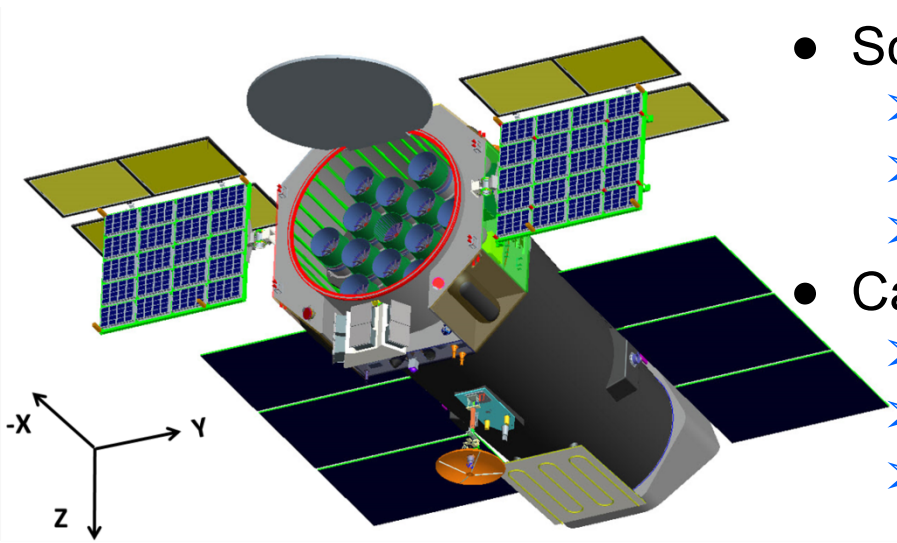
- 4 X POLAR + SiPM: much higher sensitivity
- more sensitive than Fermi-GBM: gravitational wave counter part searchers
- detailed polarization measurements 30 GRBs per year
- time resolved polarization measurements for 10 GRBs per year
- launch ~2024, operation for 2 years





eXTP: enhanced X-ray Timing and Polarimetry

--The next international flagship X-ray mission



一奇二星三极端

- Sciences
  - ➢ BH Singularity
  - ➢ Neutron or Quark Star?
  - ➢ Extreme gravity/magnetism/density
- Capabilities
  - ➢ Spectral, polarization, timing, imaging
  - ➢ Large eff. Area (~3.8 m²@6 keV)
  - ➢ High spec. resol.(<180 eV@6 keV)

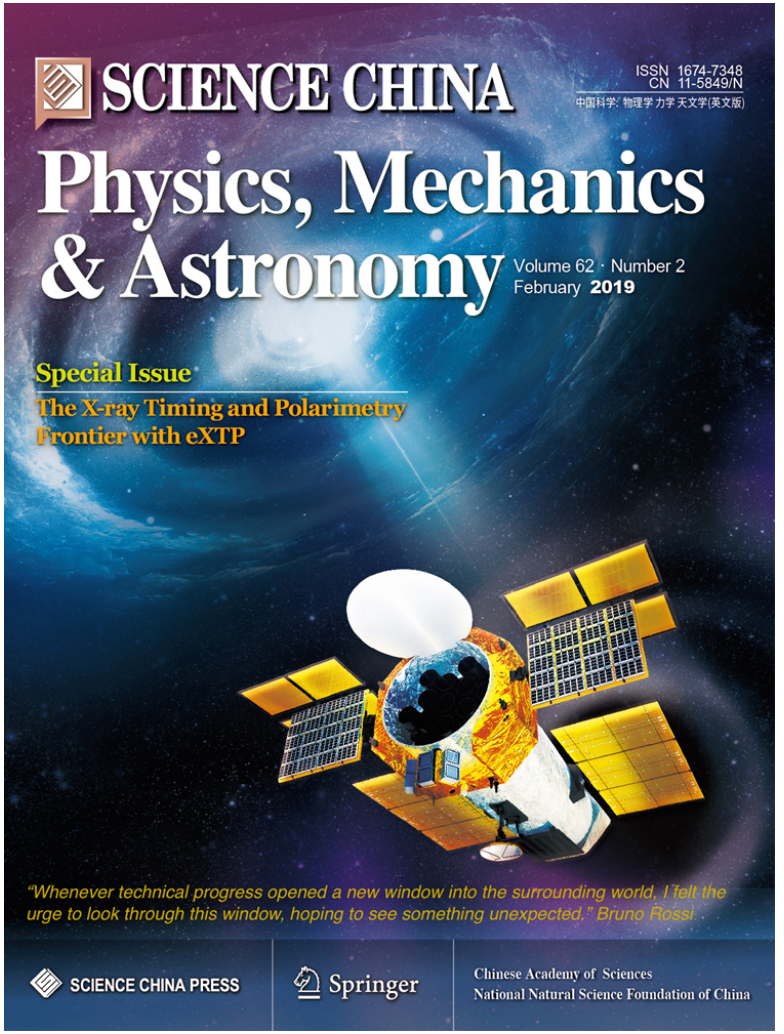
Payload	Configuration	Eff. area (m²)	Timing res. (μs)
Spectroscopy Focusing Array (SFA)	9 telescopes	0.54m²@1keV	10
Large Area Detector (LAD)	40 modules	3.4m²@8keV	10
Polarimetry Focusing Array (PFA)	4 telescopes	380cm²@3keV	500
Wide Field Monitor (WFM)	6 cameras	3.2 Sr (FOV)	10

PI: Shuang-Nan Zhang (IHEP); Europe: Marco Feroci (INAF, Rome)

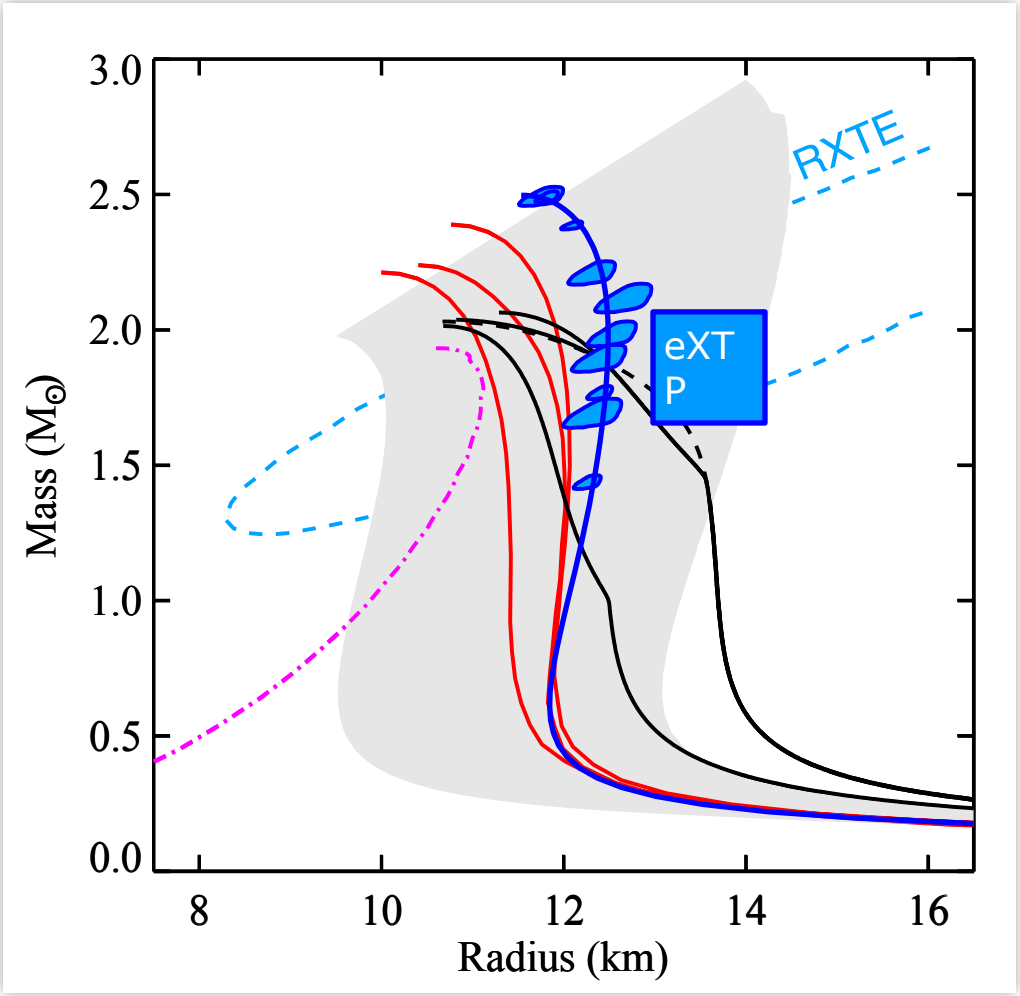
White papers on eXTP

Five refereed papers have been accepted for publication in a special issue of SCIENCE CHINA Physics, Mechanics & Astronomy

- S.-N. Zhang, A. Santangelo, M. Feroci, Y.P. Xu, et al., The enhanced X-ray Timing and Polarimetry mission - eXTP
- A. L. Watts, W.F. Yu, J. Poutanen, S. Zhang, et al., Dense matter with eXTP
- A. De Rosa, P. Uttley, L.J. Gou, Y. Liu, et al., Accretion in Strong Field Gravity with eXTP
- A. Santangelo, S. Zane, H. Feng, R.X. Xu, et al., Physics and Astrophysics of Strong Magnetic Field systems with eXTP
- J. J. M. in 't Zand, B. Enrico, J.L. Qu, X.D. Li, et al., Observatory science with eXTP



Spectral-Timing Mapping EOS with eXTP



Neutron or Quark Star?

Detailed simulations carried out to evaluate fitting procedure and accuracies (Lo et al. 2013, ApJ).

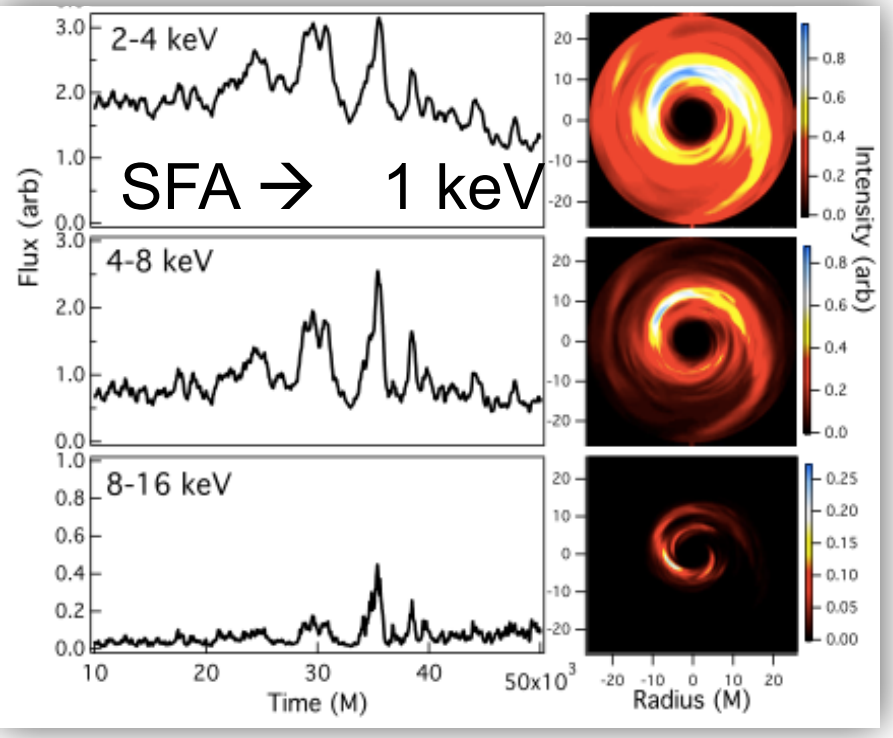
Few % accuracy needs ~10^6 photons: 3-4m^2 area crucial.

Multiple same-source cross-checks.

USING ONLY KNOWN SOURCES, EXTP'S PULSE PROFILE MODELLING MEASUREMENTS WILL MAP THE M-R RELATION AND HENCE THE EOS.

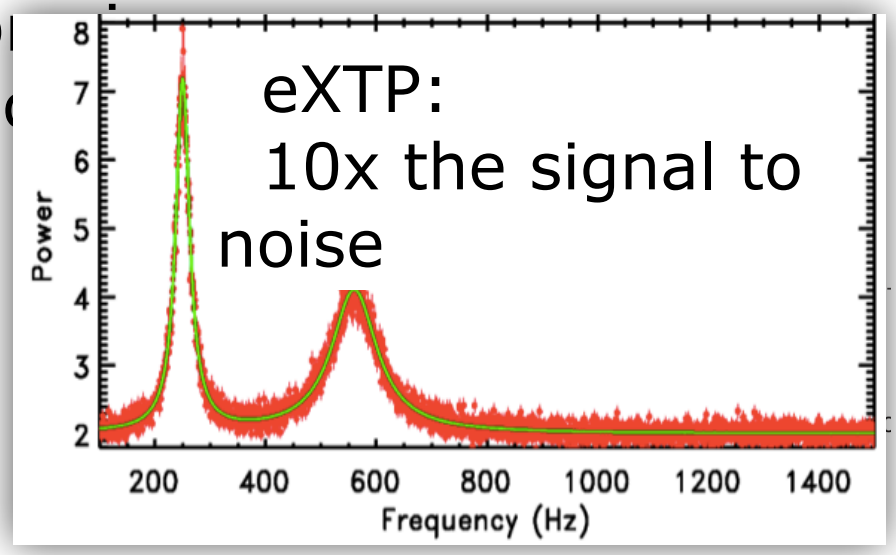
Spectral-Timing for strong field gravity

General Relativity predicts pr
orbital and epicyclic frequenc
at each radius



Wellons et al. 2013

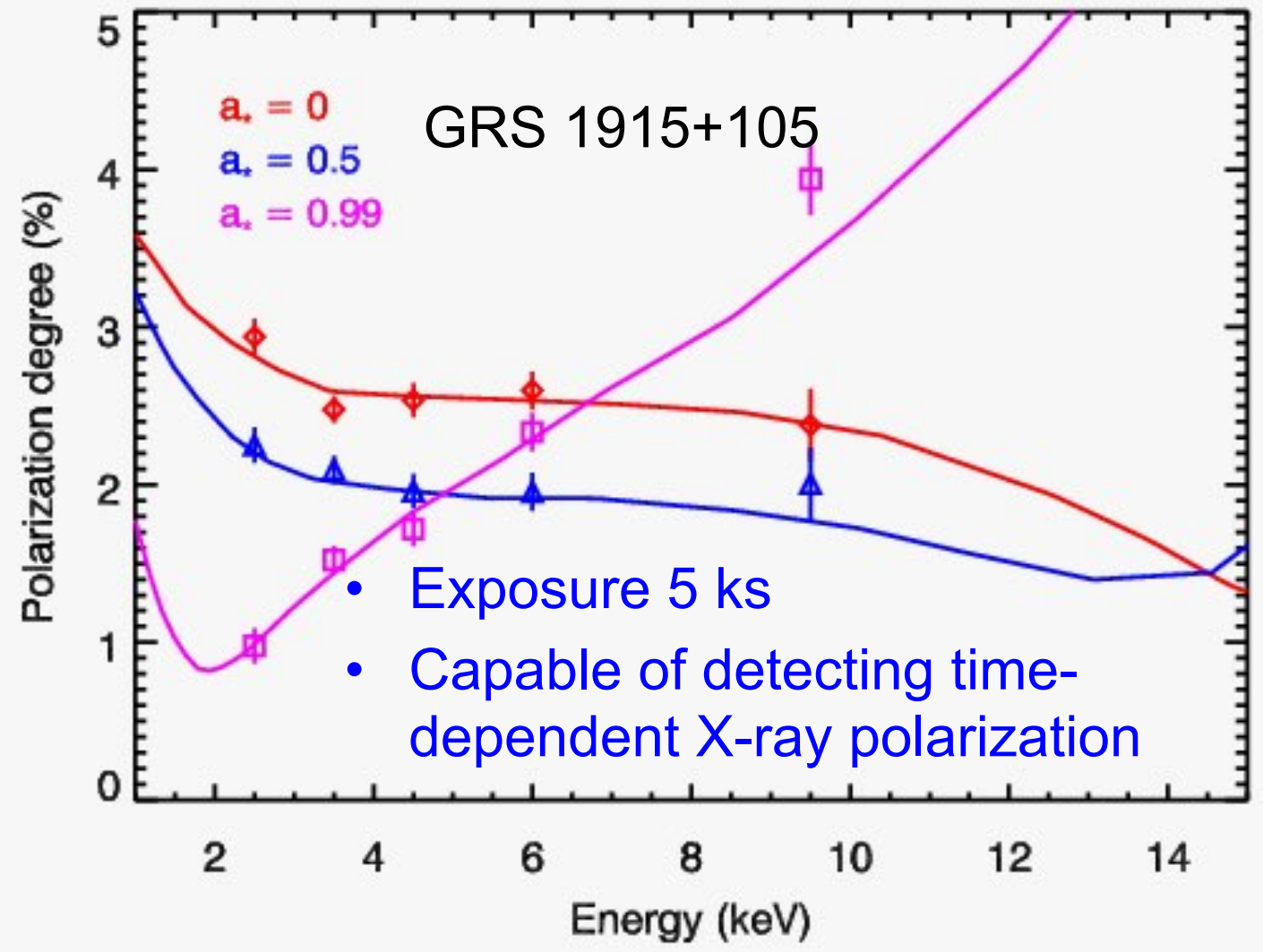
Orbiting inhomogeneities make frequencies observable



- Strong gravity dynamical frequencies just detected in current (RXTE) data
- eXTP diagnoses strong field gravity very precisely by:
  - timing of the flux variations
  - time resolved spectroscopy

  at very high signal to noise
- Uses known phenomena

Spectral-Polarimetry for BH spin

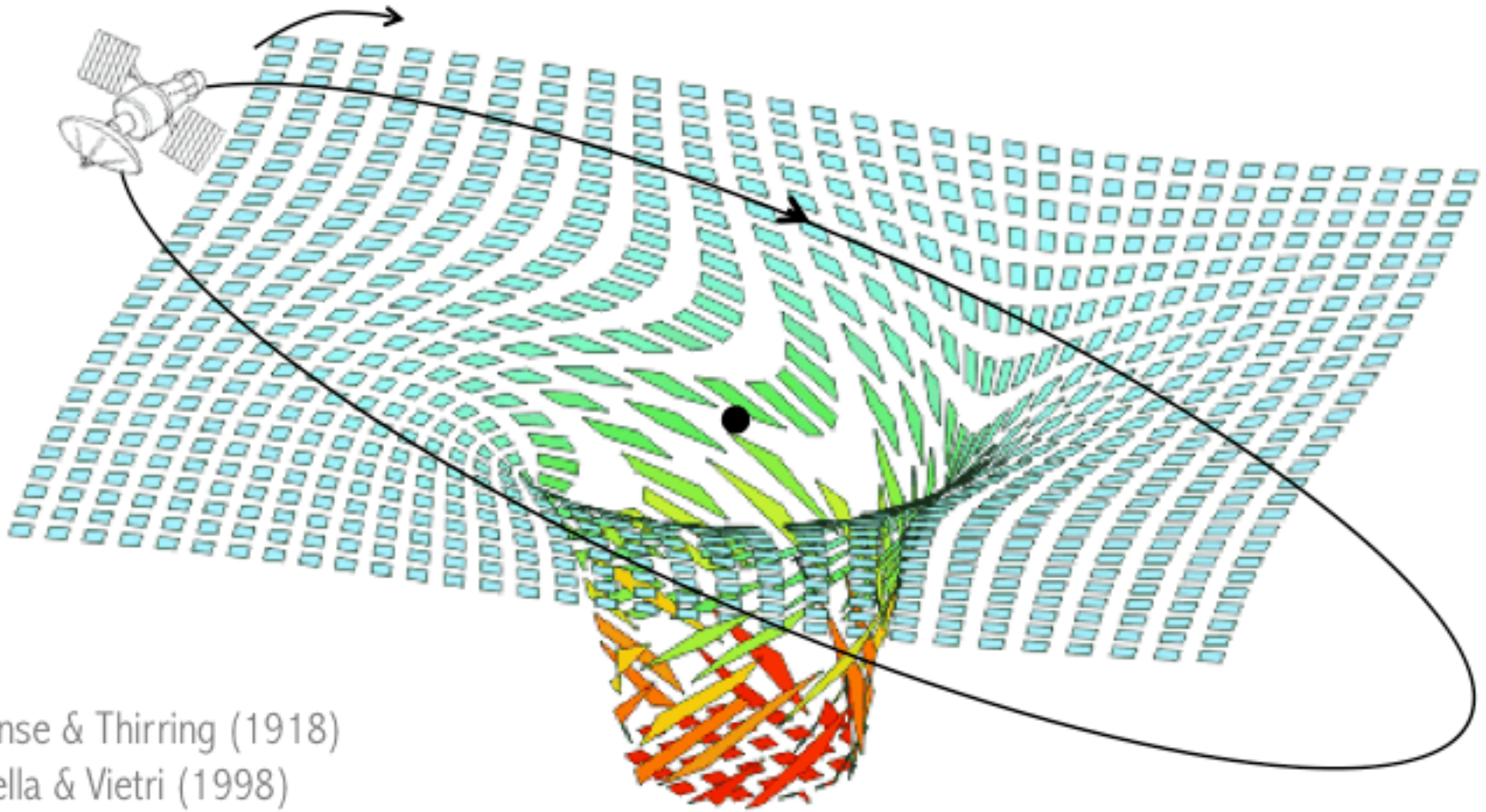


To be complemented by simultaneous SFA+LAD with Continuum Fitting & Fe-line BH spin measurement

Timing-Polarimetry for Frame Dragging

A spinning black hole **distorts** space and time

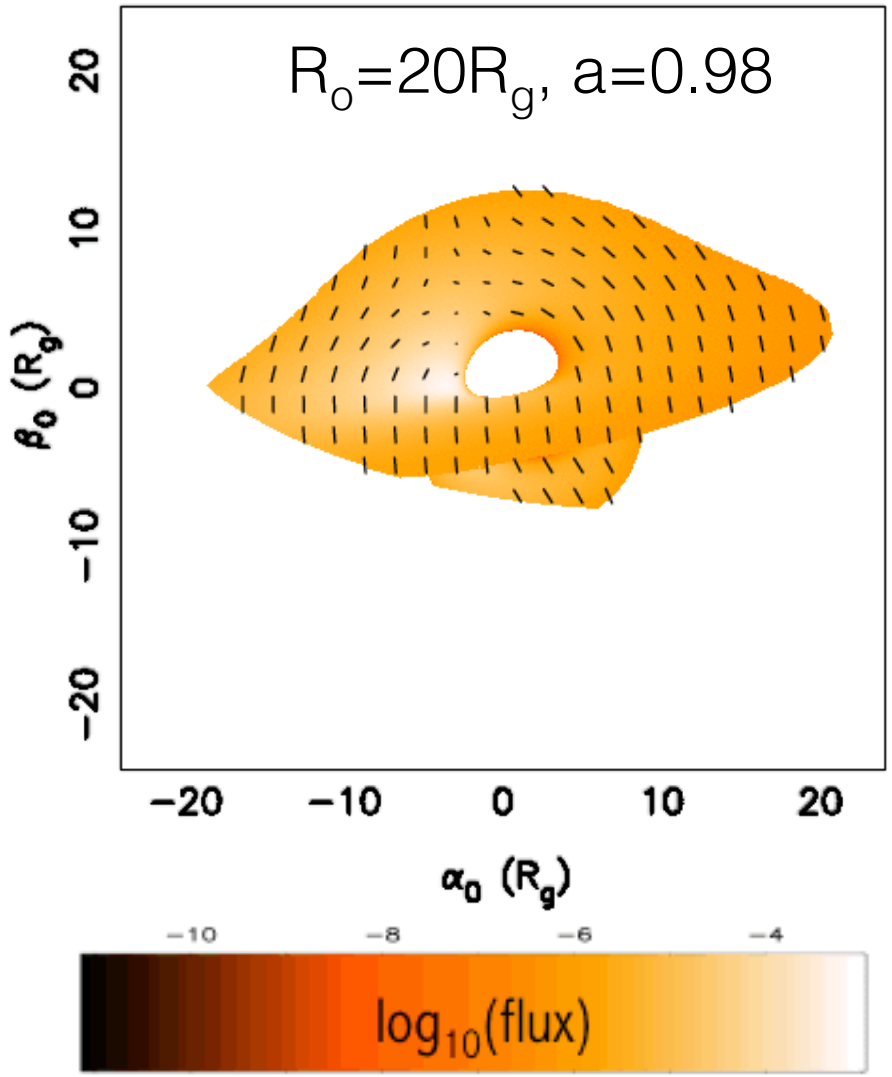
The satellite's motion is **influenced** by the spin of the black hole

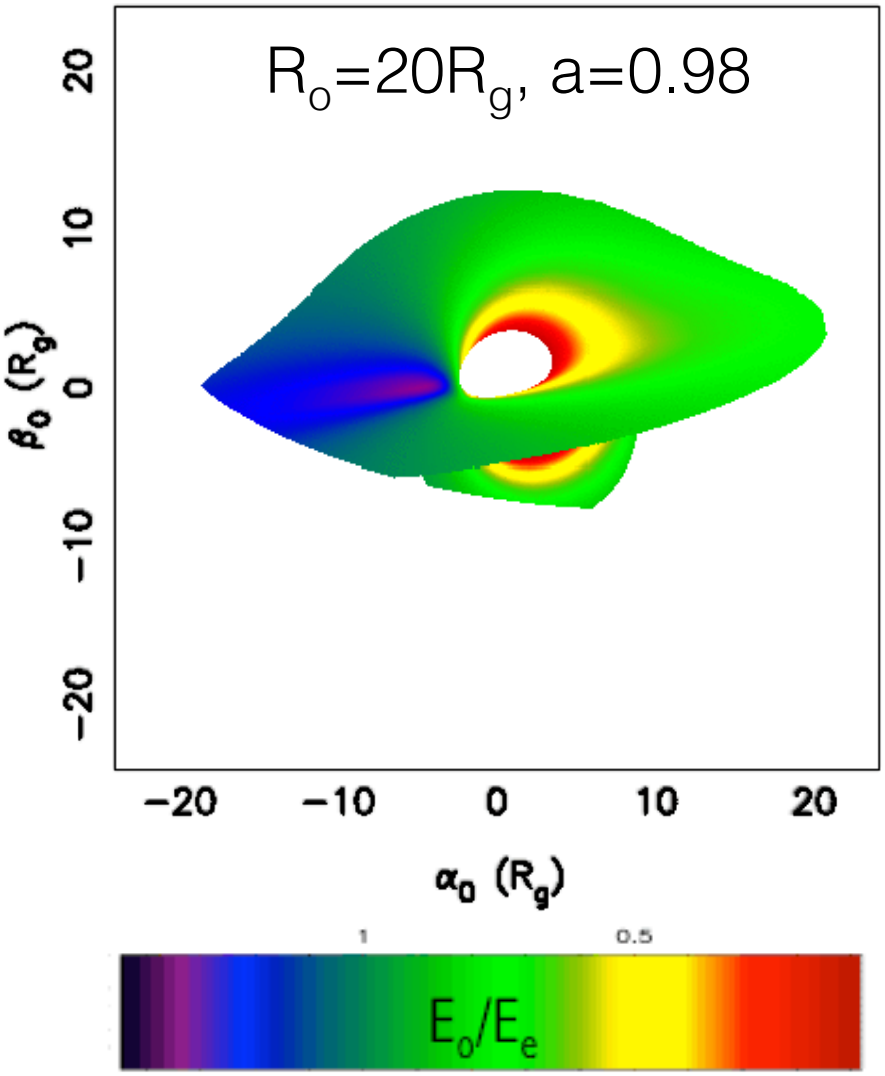


Lense & Thirring (1918)

Stella & Vietri (1998)

Movies: high inclination (i=70°)

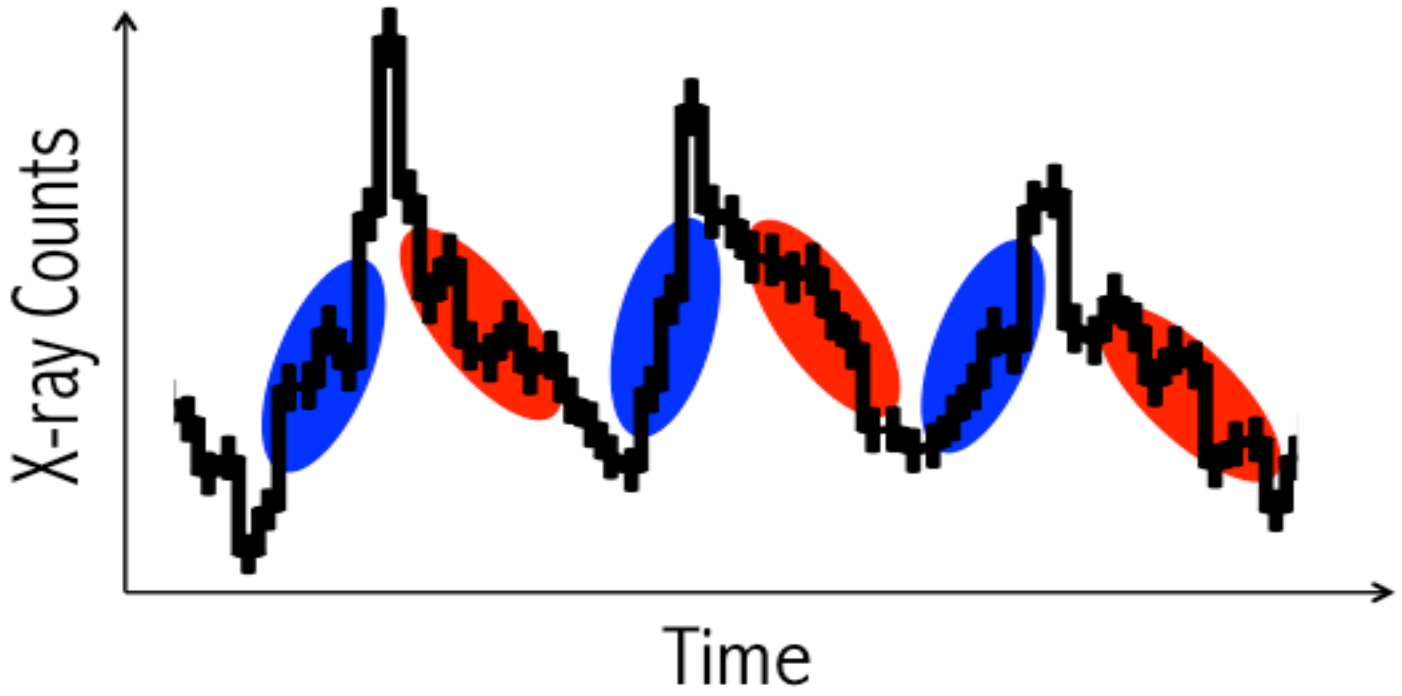




www.youtube.com/watch?v=ieZYYfCapJg&feature=youtu.be

Ingram et al (2015)

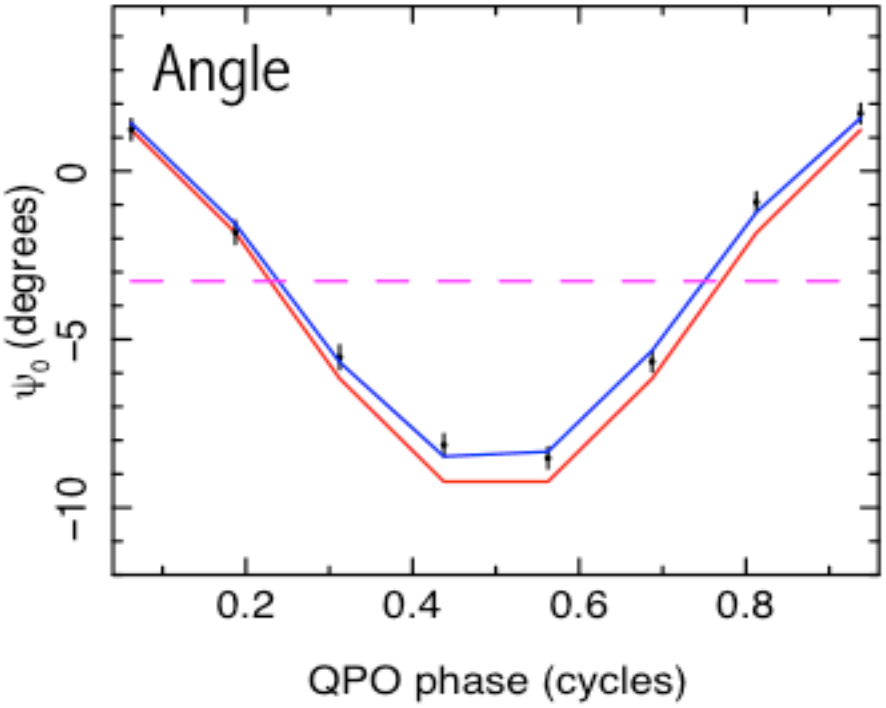
Phase folding

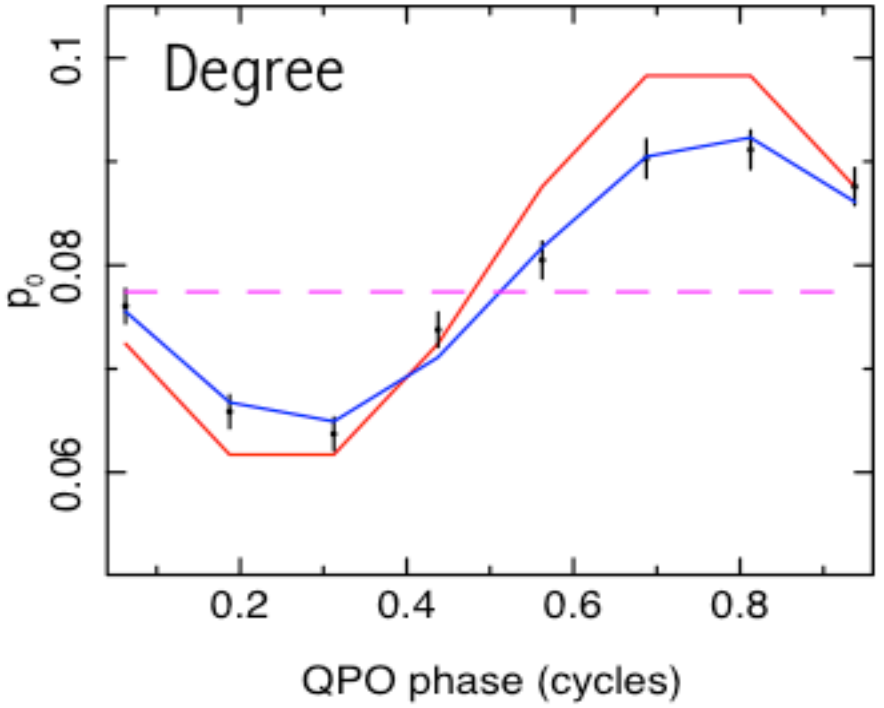


p_0 & ψ_0 p_0 & ψ_0

SFA & LAD → precise phasing

Phase folding: LAD+SFA+PFA



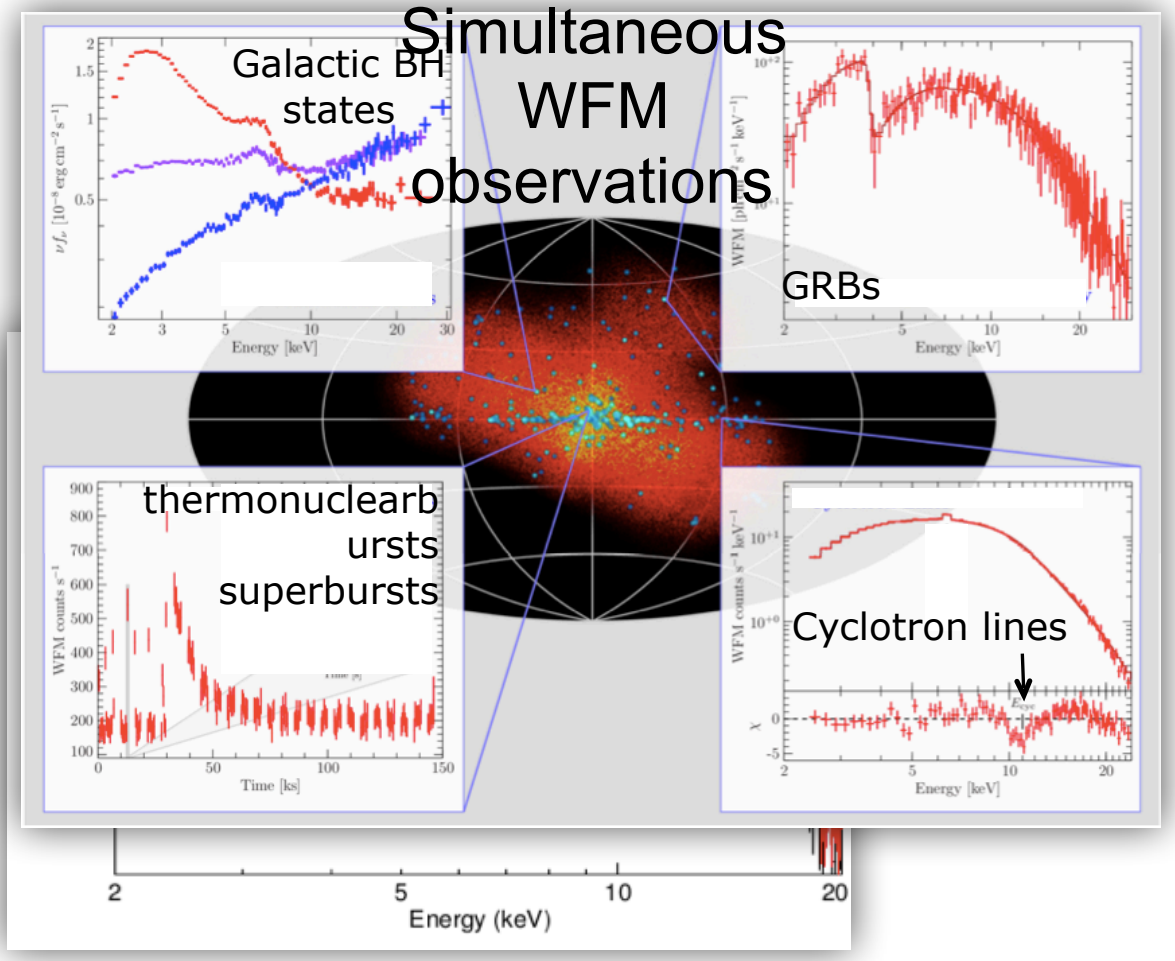


- 32.768ks exposure
- $\langle p_0 \rangle = 8\%$, $\sigma_{p0} = 1.4\%$, $\langle \psi_0 \rangle = -4$ degrees, $\sigma_{\psi_0} = 4$ degrees
- Flux = 1 photon $cm^{-2}s^{-1}$ assuming absorbed power-law with $\Gamma = 2$ and $N_h = 1 \times 10^{22} cm^{-2}$
- 40 LAD modules, 2 GPD units

eXTP observatory science

- Extreme-throughput with SFA & LAD
- Very wide angle monitoring with WFM

- Accretion physics
- Magnetospheric physics
- Thermonuclear bursts
- Magnetars
- Gamma ray bursts
- Tidal disruptions
- Cataclysmic variables
- Terrestrial γ-ray flashes
- Flare stars
- …



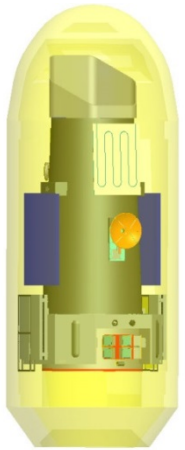
eXTP Scientific requirements

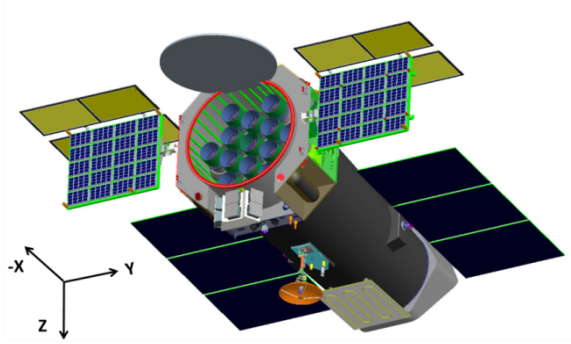
- Simultaneous spectral-timing-polarimetry observation of the time variable Universe in a wide X-ray energy band

Item	Requirement	Scientific drivers
Effective area	≥ 0.4 m^2 (focused) ≥ 3 m^2 (collimated)	EOS, BH spins, GR effect
Energy range	0.5-30 keV	Broadband spectrum, multi-wavelength variability, GR effect
Energy resolution	≤ 180eV@6 keV	Broad iron line measurement
Time resolution/accuracy	≤10μs / 2μs	Sub-millisecond variability
Polarimetry	MDP ~1.6%	Magnetic field, emission mechanism, emission geometry
Eff. Area for polarimetry	≥ 380cm^2@3keV	
Wide field monitoring	FoV ≥ 3 Sr	
Throughput	> 90% @10Crab	Bright sources

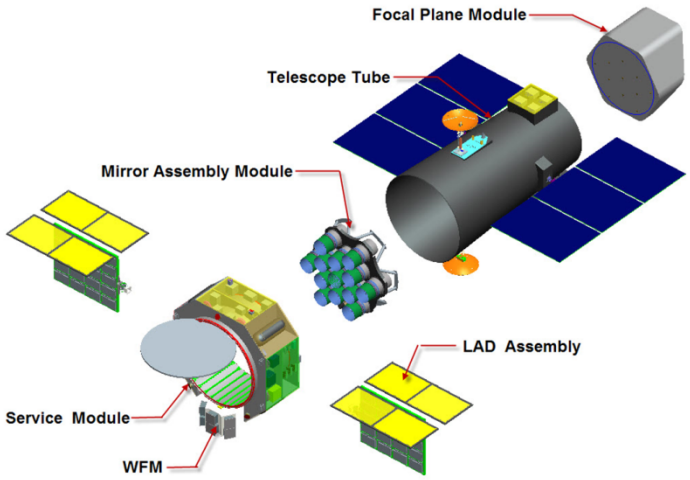
eXTP Mission overview

Parameter	Value
Orbit	550 km, inclination 0°
Pointing	3-axis stabilized, < 0.01°(3σ)
Launch	LM7 + upper stage, @Wenchang
Launch mass	4500 kg
Telemetry	3.2 Tb/day (X-band or Ka-band)
Burst alert	BeiDou Navigation Satellite System; VHF transmitter (SVOM); Tracking and Data Relay Satellite System
Ground Stations	Sanya (China), Malindi (Italy)
Mission duration	5 years (goal 8 years)
Launch date	~ 2027



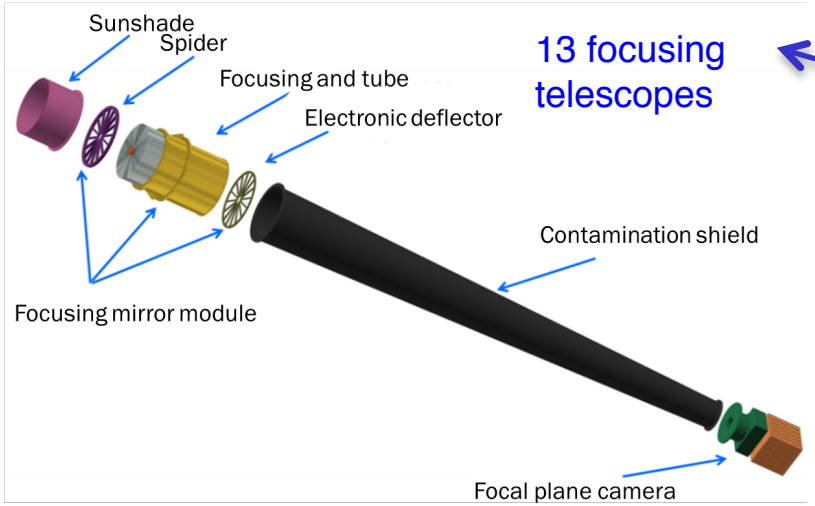


16.8 mm × 3.95 mm × 11.4m

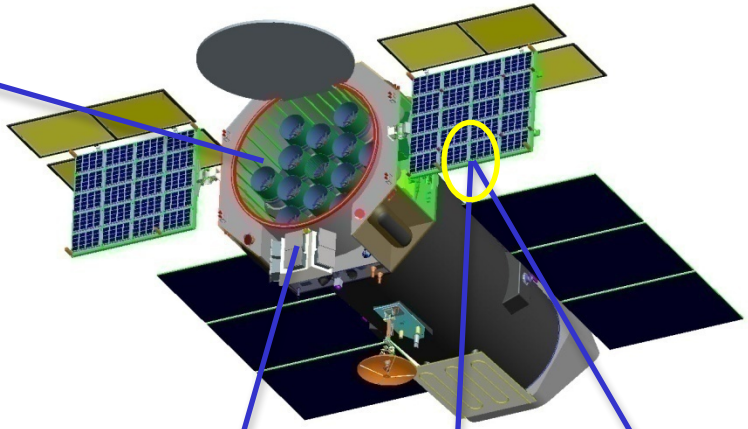


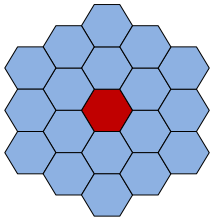
Accommodation concept by CAST

eXTP payload accommodation

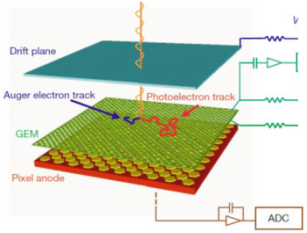


13 focusing telescopes

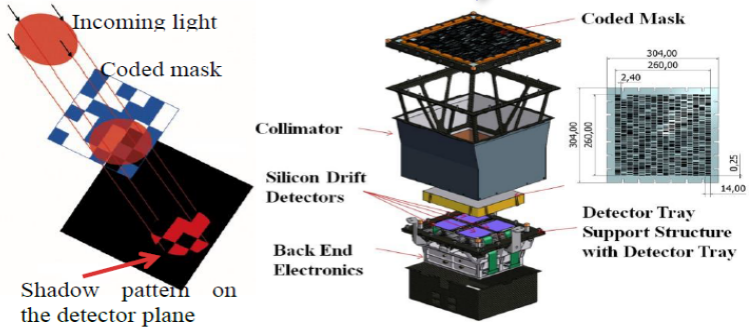




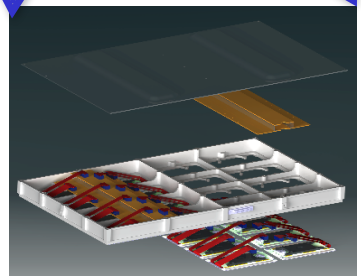
SDD camera (9)



GPD (4)



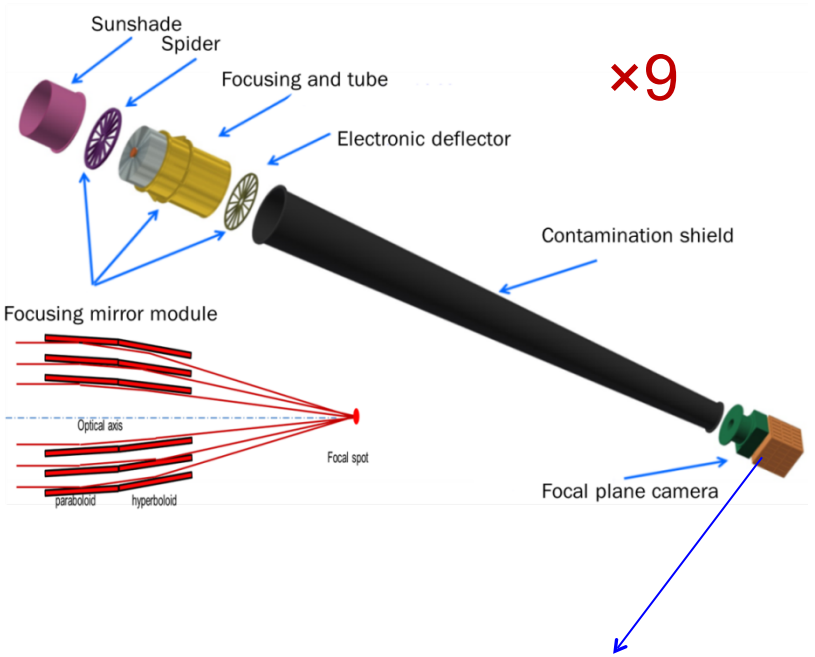
WFM cameras (6)

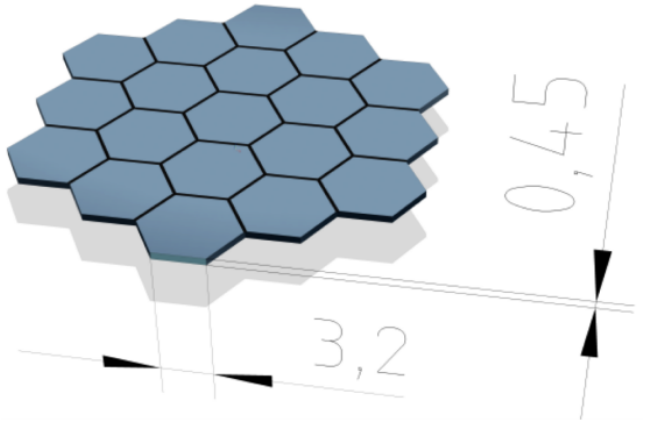


LAD modules (40)

eXTP Scientific Payload:
SFA – Spectroscopy Focusing Array

- Large collecting area achieved by multiple optics with short focal length.
- 9 grazing incidence Wolter-I optics with 5.25m F.L., 40 shells/module
- Non-imaging, 1′ (HPD), 3′ (W90), 12′ FoV
- 19-cell SDD array: multi-pixel to enable background subtraction
- Energy range: 0.5-10 keV
- Energy resolution: ≤ 180 eV @ 6keV
- Time resolution: 10μs
- Absolute timing accuracy: 2μs
- Dead time: < 5% @ 1Crab
- Sensitivity: 4.1×10^{-15} erg/cm²/s (3σ, 10ks)





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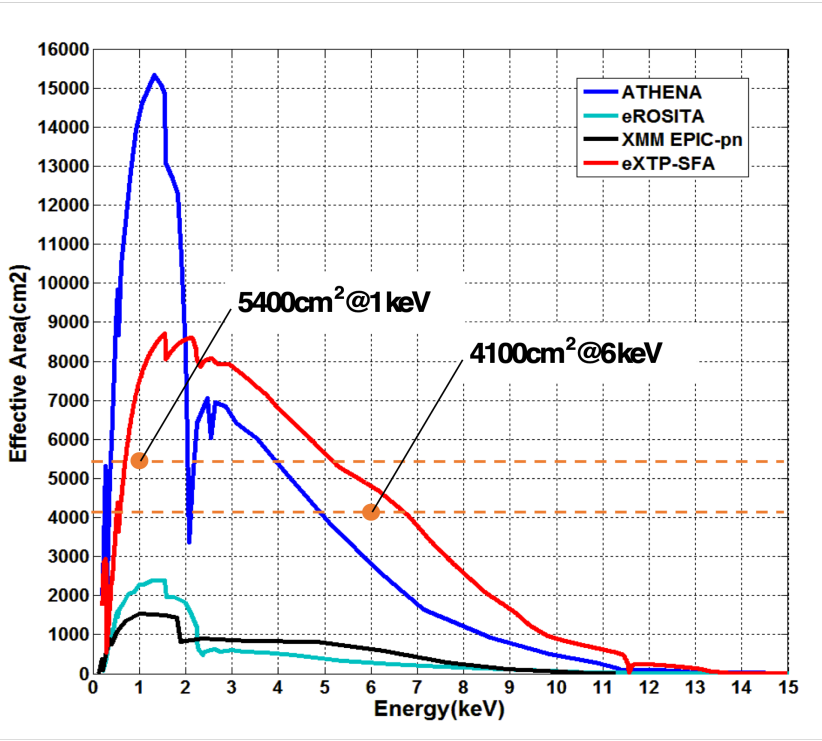
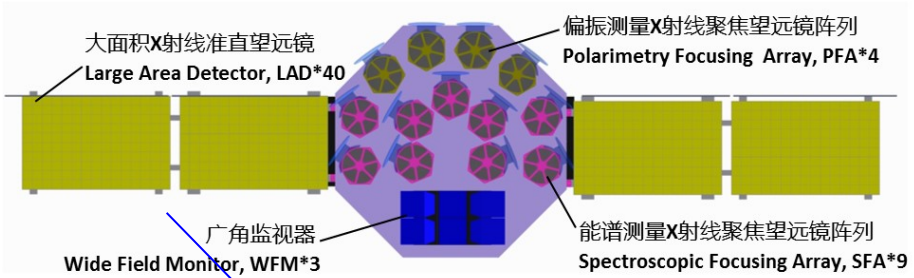
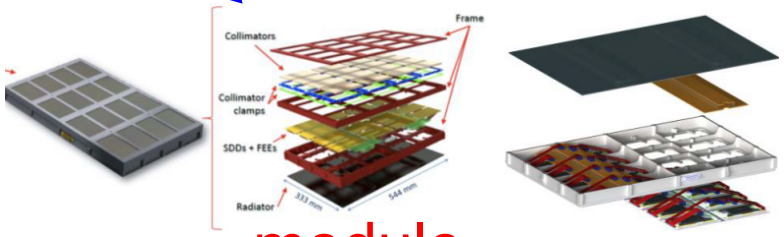


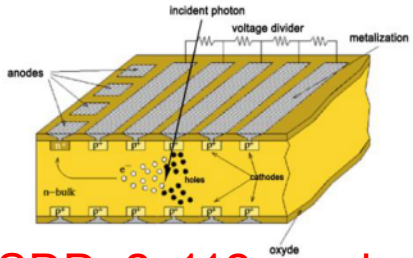
eXTP Scientific Payload: LAD – Large Area Detector

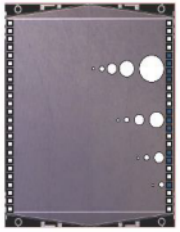
- Spectral and timing observation
- 40 modules on 2 deployable panels
- Collimated, large area SDD detector
- Energy range: 2-30 keV (goal 50keV)
- Energy resolution: < 240eV @ 6keV
- Field of View: 1°(FWHM)
- Time resolution: 10μs
- Absolute time accuracy: 2μs
- Dead time: < 0.5% @ 1Crab
- Background: < 3mCrab
- Total effective area: 3.4m² @ 8keV



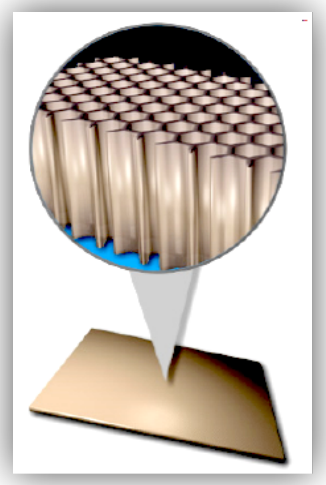


module





SDD: 2x112 anodes, pitch = 970μm



MCP collimator

Thermal/optical filter

eXTP Scientific Payload: LAD – Large Area Detector

- Spectral and timing observation
- 40 modules on 2 deployable panels
- Collimated, large area SDD detector
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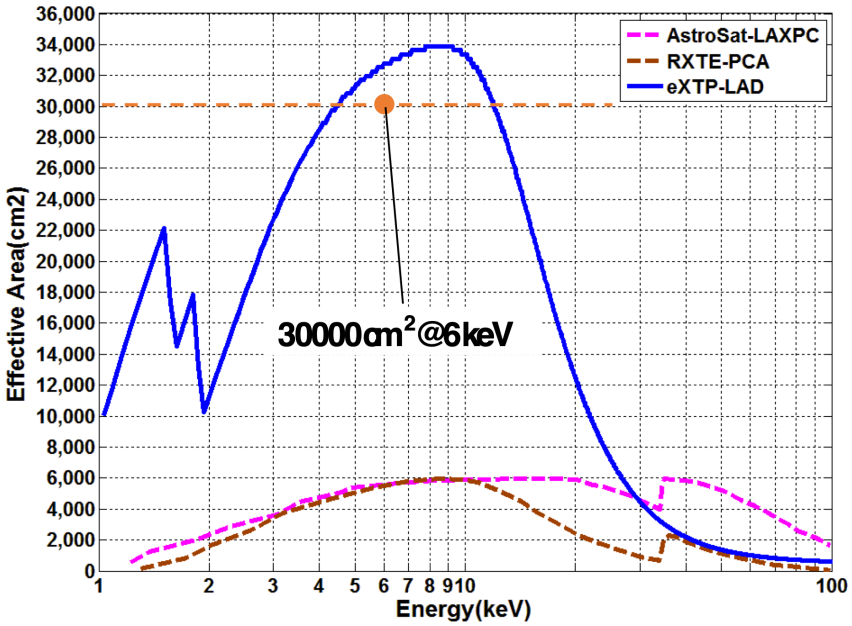
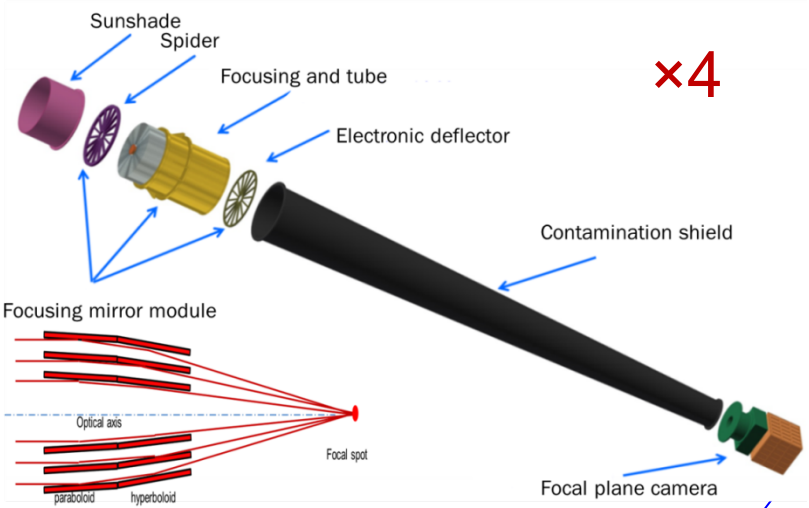
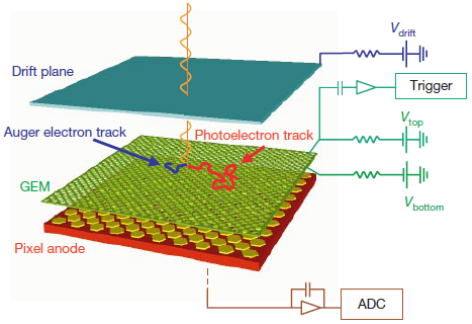


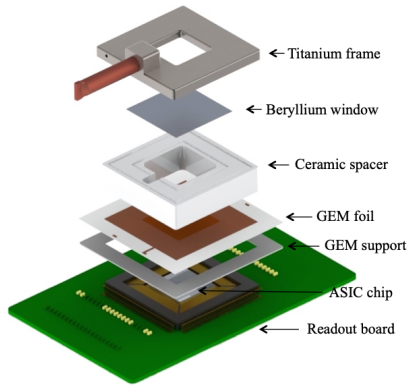
eXTP Scientific Payload:
PFA – Polarimetry Focusing Array

- Large collecting area achieved by multiple optics with short focal length.
- 4 grazing incidence Wolter-I optics with 5.25m F.L., 40 shells/module
- Imaging, resolution ≤ 30″(HPD, goal 15″)
- Field of view: 8′
- Gas Pixel Detector (GPD): photo-electron tracking
- Energy range: 2-8 keV
- Energy resolution: ≤ 1.8 keV @ 6keV
- Time resolution: 500μs
- Absolute timing accuracy: 2μs
- MDP: < 1.6% (10^6s, 1mCrab)





Designed by the INFN-Pisa group (Bellazzini et al.)



GPD prototype (Tsinghua)

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- Imaging, resolution ≤ 30″(HPD, goal 15″)
- Field of view: 8′
- Gas Pixel Detector (GPD): photo-electron tracking
- Energy range: 2-8 keV
- Energy resolution: ≤ 1.8 keV @ 6keV
- Time resolution: 500μs
- Absolute timing accuracy: 2μs
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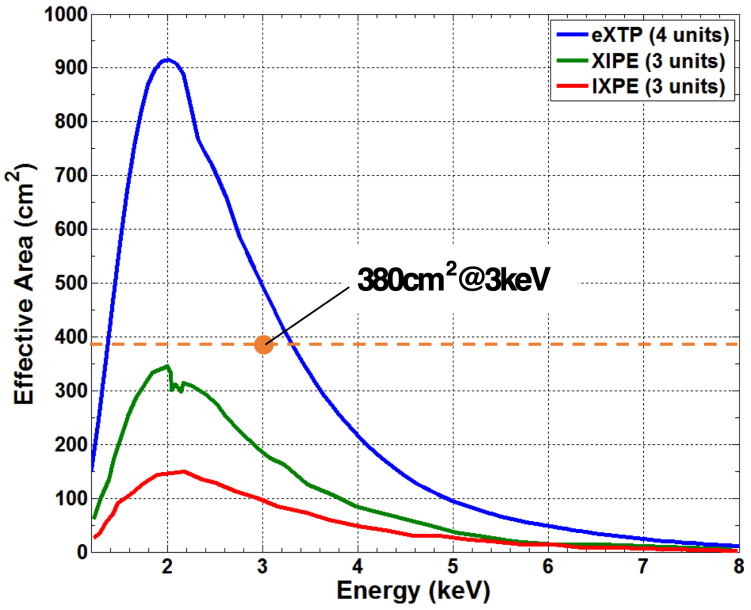
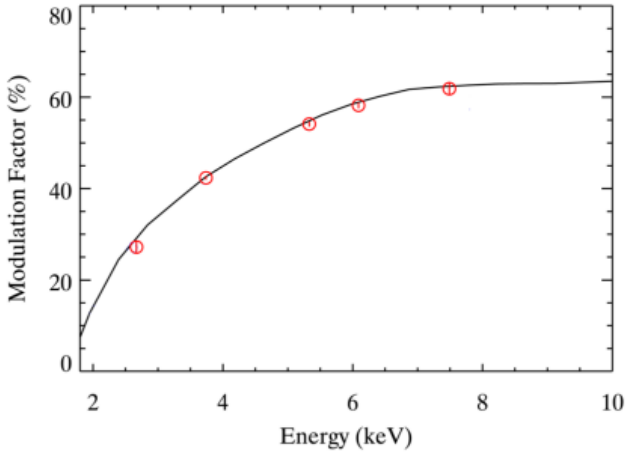
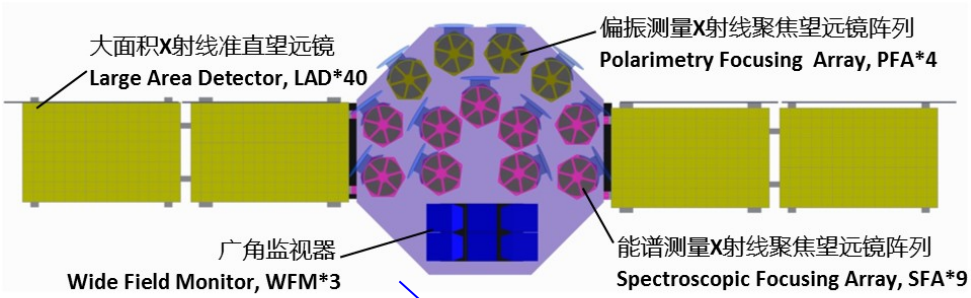
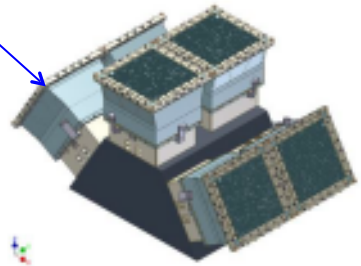


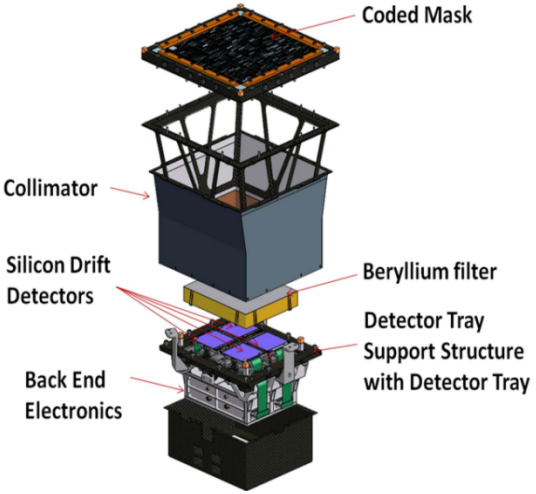


eXTP Scientific Payload: WFM – Wide Field Monitor

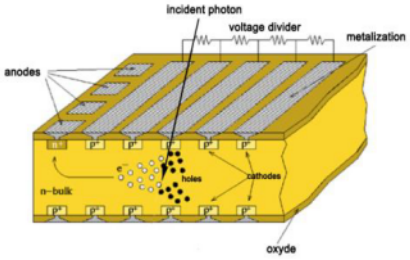
- 3 units (6 cameras)
- 2D Imaging, 5′ (FWHM) resolution
- Location accuracy: ≤ 1′
- Field of view: ≥ 3.2 Sr (at 20% response)
- Energy range: 2-50 keV
- Energy res.: ≤ 300eV @ 6keV
- Time resolution: 10μs
- Absolute time accuracy: 2μs
- Peak sensitivity (5σ): 1Crab (1s), 5mCrab (50ks)

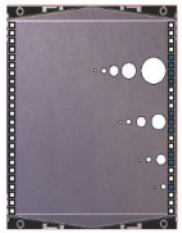




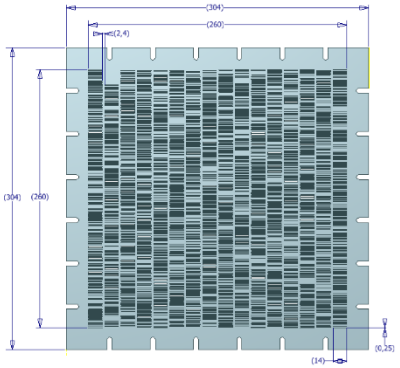


Camera module





SDD: 2x384 anodes, pitch = 169μm



1.5D coded mask

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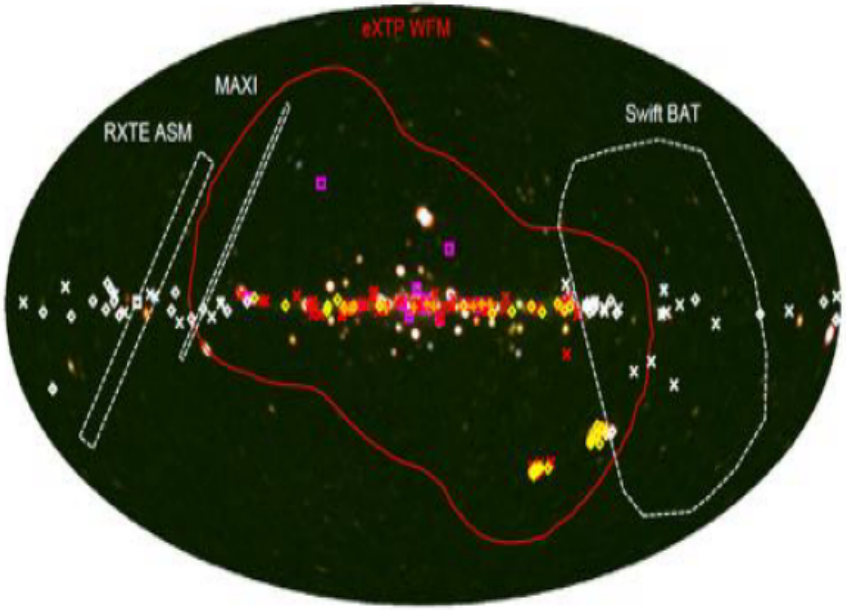

WFM field of View. (Background map courtesy of T. Mihara, RIKEN, JAXA, and the MAXI team)

Preliminary schedule of eXTP

- Phase A+ : March-Dec. 2018
  - Key technology/components development
- Phase B: Jan.2019-Dec. 2021
  - Preliminary definition
  - SRR (June 2020)
  - PDR
- Phase C (CDR): Jan. 2022 – Dec. 2023
- Phase D (FM): Jan 2024 – Mar. 2026
- Phase E1: Apr. 2026– Aug. 2027
  - Launch

Funded with > €50M in China by CAS through Dec. 2022

Summary

- Insight-HXMT launched in 2017 & working for XRBs in 1-250 keV, 0.2-3 MeV for GRBs, lots data public on hxmt.org
- GECAM, SVOM, EP, POLAR-2 & eXTP to be launched in 2020, 2021, 2023, 2024 & ~2027.
- eXTP will offer for the first time the most complete diagnostics of compact sources with excellent spectral, timing and polarimetry sensitivity in a single mission.
- Instrument configuration and system level studies have showed that eXTP is technically feasible.
- The eXTP Phase B has been started in China and some European countries, aiming for launch in late 2027.
- ~50% eXTP payload from Europe + possible ESA MoO.

Thank you for your attention!

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