Current and Near-Future (<2030) Space High Energy Astronomy Missions of China

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GRB&CE in Playa del Carmen, Mexico 2024.12.04

China's Space High Energy Astronomy Missions

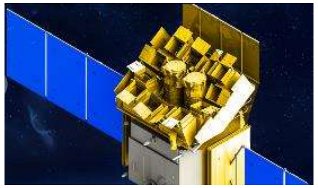
- **悟空DAMPE (2015)**
- **POLAR*(2016)**
- **Insight-HXMT*(2017)**
- **GECAM (2020-)**
- **EP (2024)**
- **SVOM (2024)**
- **POLAR-2*(2027)**
- **HERD*(2027?)**
- **eXTP*(2030?)**

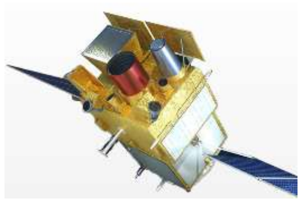

DAMPE 2015

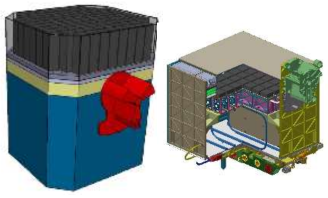

POLAR 2016


HXMT 2017

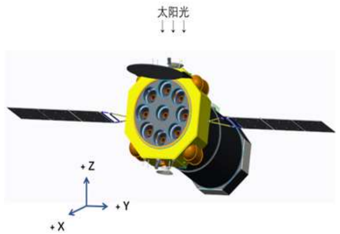

GECAM 2020-


EP 2024


SVOM 2024


POLAR-2 2027


HERD 2027?


eXTP 2030?

*Missions led by our teams in Particle Astrophysics Division/IHEP
Proposed missions ≥ 2030 not included, e.g., VLAST, CATCH, etc.

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 narrow FoV, 0.2-3 MeV as ASM)
- Status:
  - All instruments perform well
  - Focus on bright sources
  - Unrestricted number of ToOs
    - Response time: hours to days
    - *Ad hoc* ToO data public immediately
  - In Cycle 7: open for world wide
  - To stay in orbit for several more years

sciencemag.org

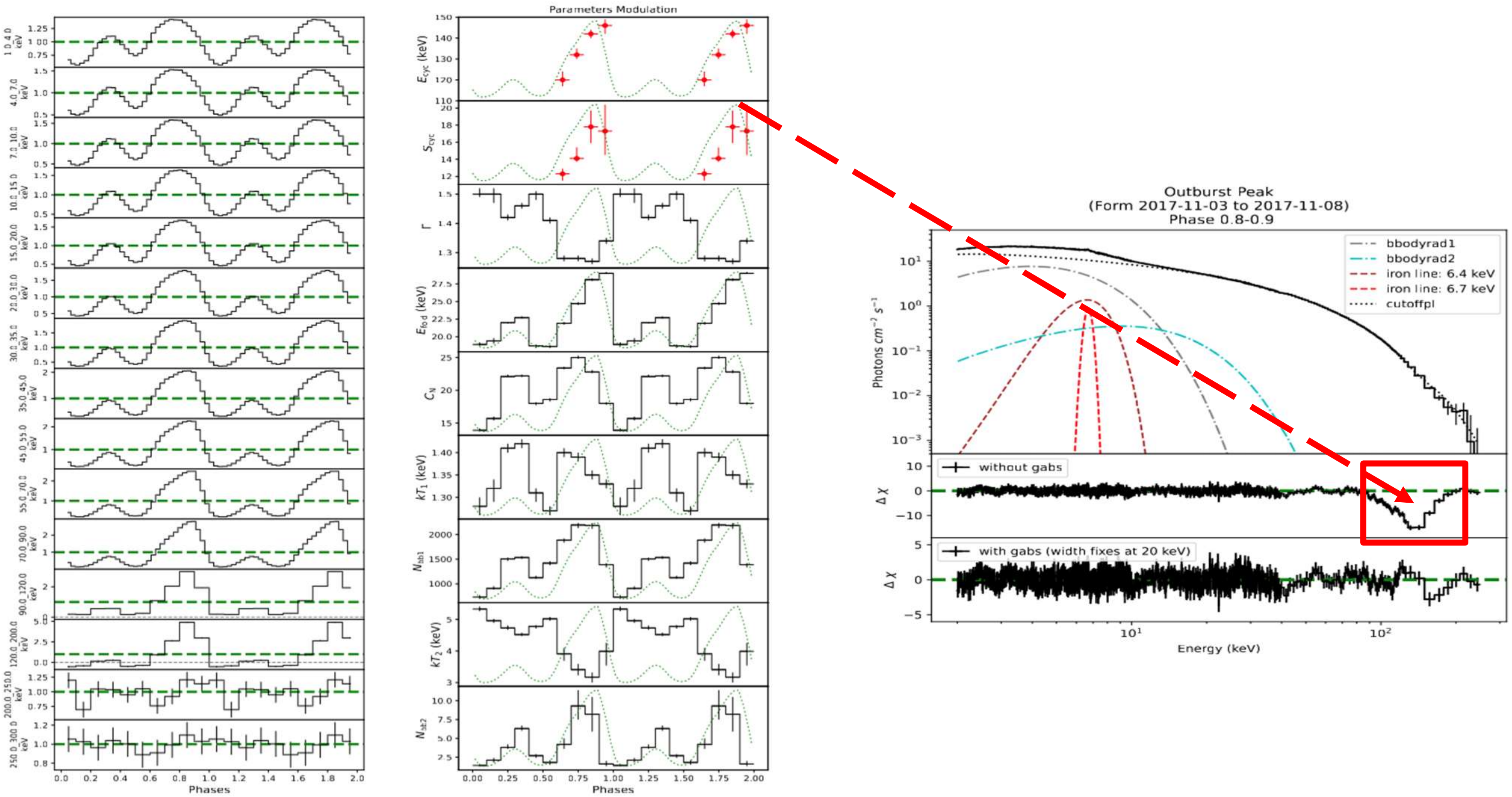
China successfully launches x-ray satellite | Science

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

4-5 分钟

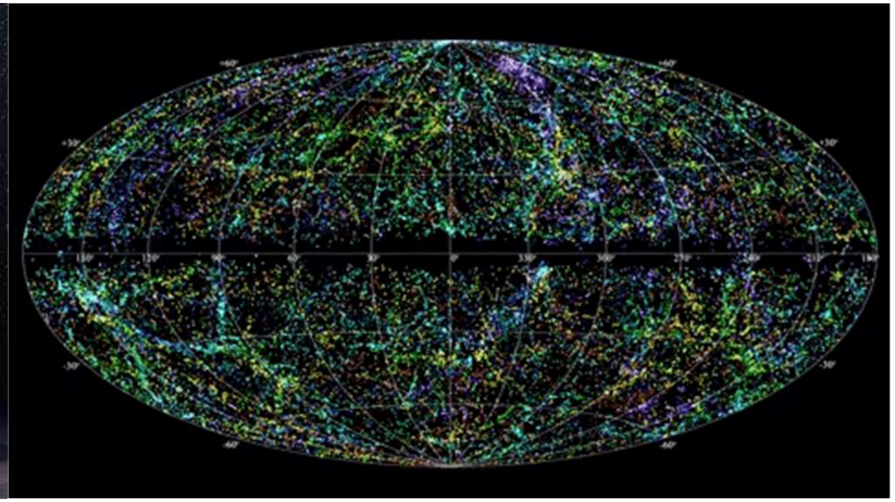
PI: Shuang-Nan Zhang (IHEP)

Highest-E Neutron star cyclotron absorption line



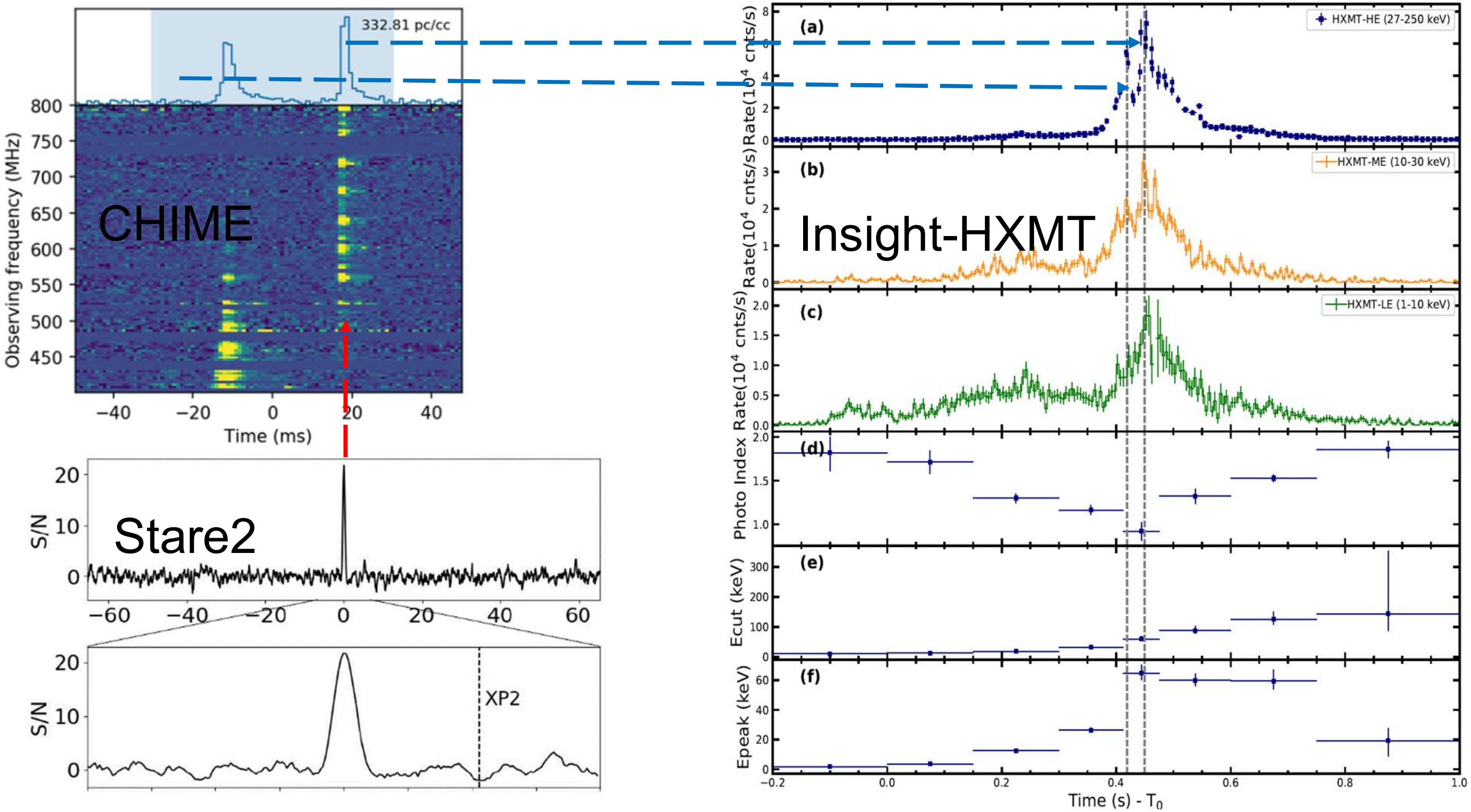
1st Galactic ultraluminous X-ray pulsar Swift 0243: 146 keV→1.6×10^{13} G >> ~10^12 G dipole B-field: evidence for multipole B-field? (Kong+2022)

Fast Radio Bursts



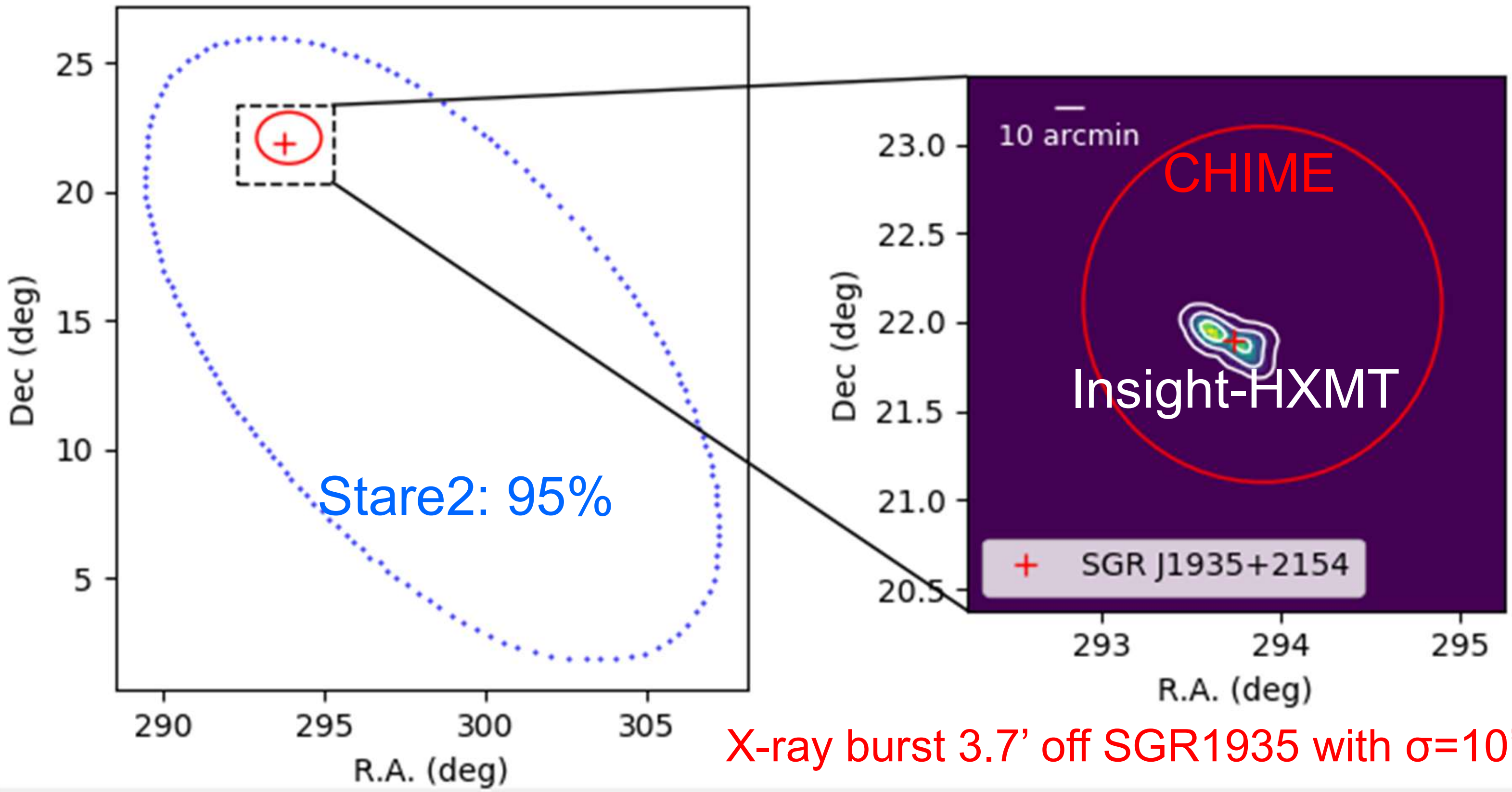
First reported in 2007 (Lorimer et al. 2007): bright millisecond radio pulses, random arrival direction and time, some repeat and even periodic, but counterpart or radiation at any other wavelengths not known, until April 28th, 2020.

Historic event on April 28th 2020



CHIME/FRB Collaboration+; Bochenek+; Li+, 2021, Nature Astronomy

Localization of the X-ray burst



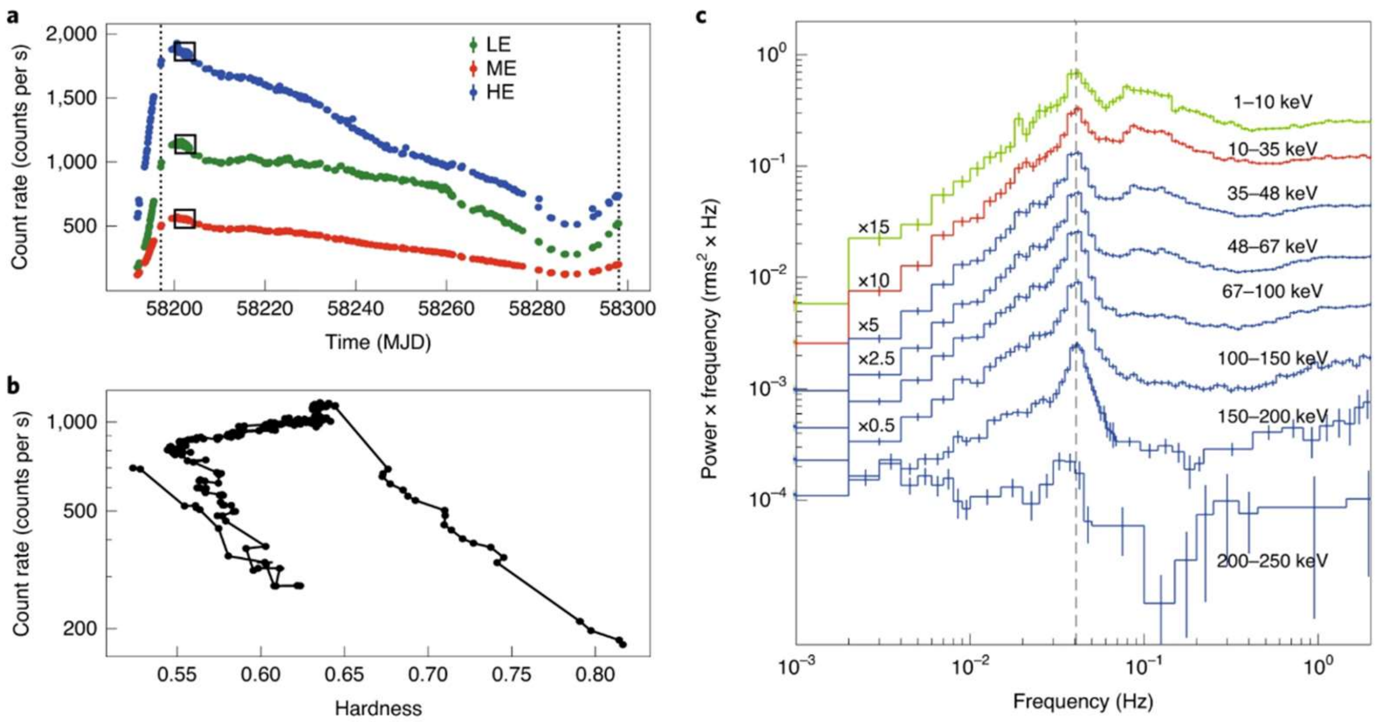
X-ray burst 3.7' off SGR1935 with σ=10''

Identification of the X-ray burst with SGR1935, Li+ (Insight-HXMT team), 2021, Nature Astronomy

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

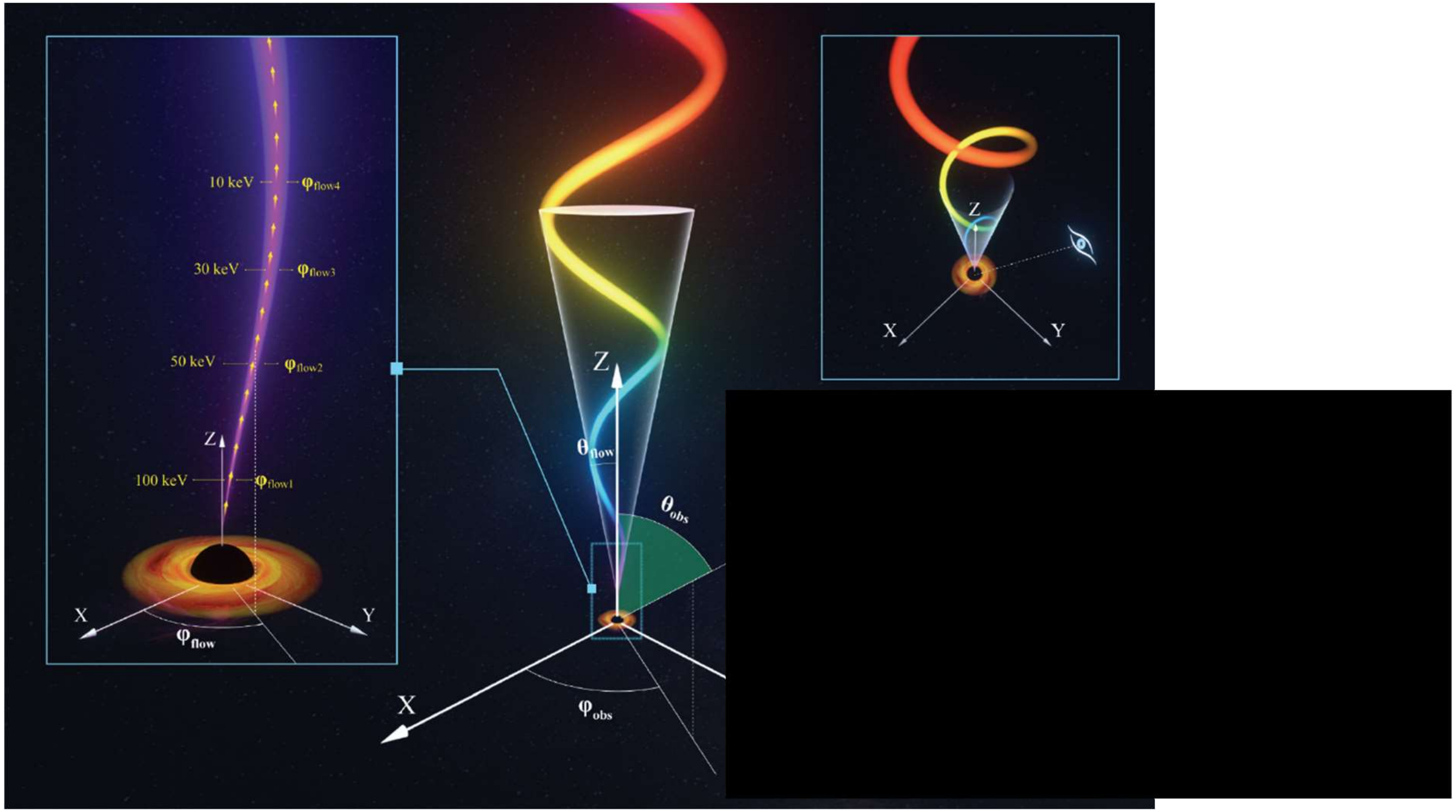
Fig. 1: Light curves, hardness–intensity diagram and power density spectra of MAXI J1820+070 in the X-ray hard state.

From: Discovery of oscillations above 200 keV in a black hole X-ray binary with Insight-HXMT



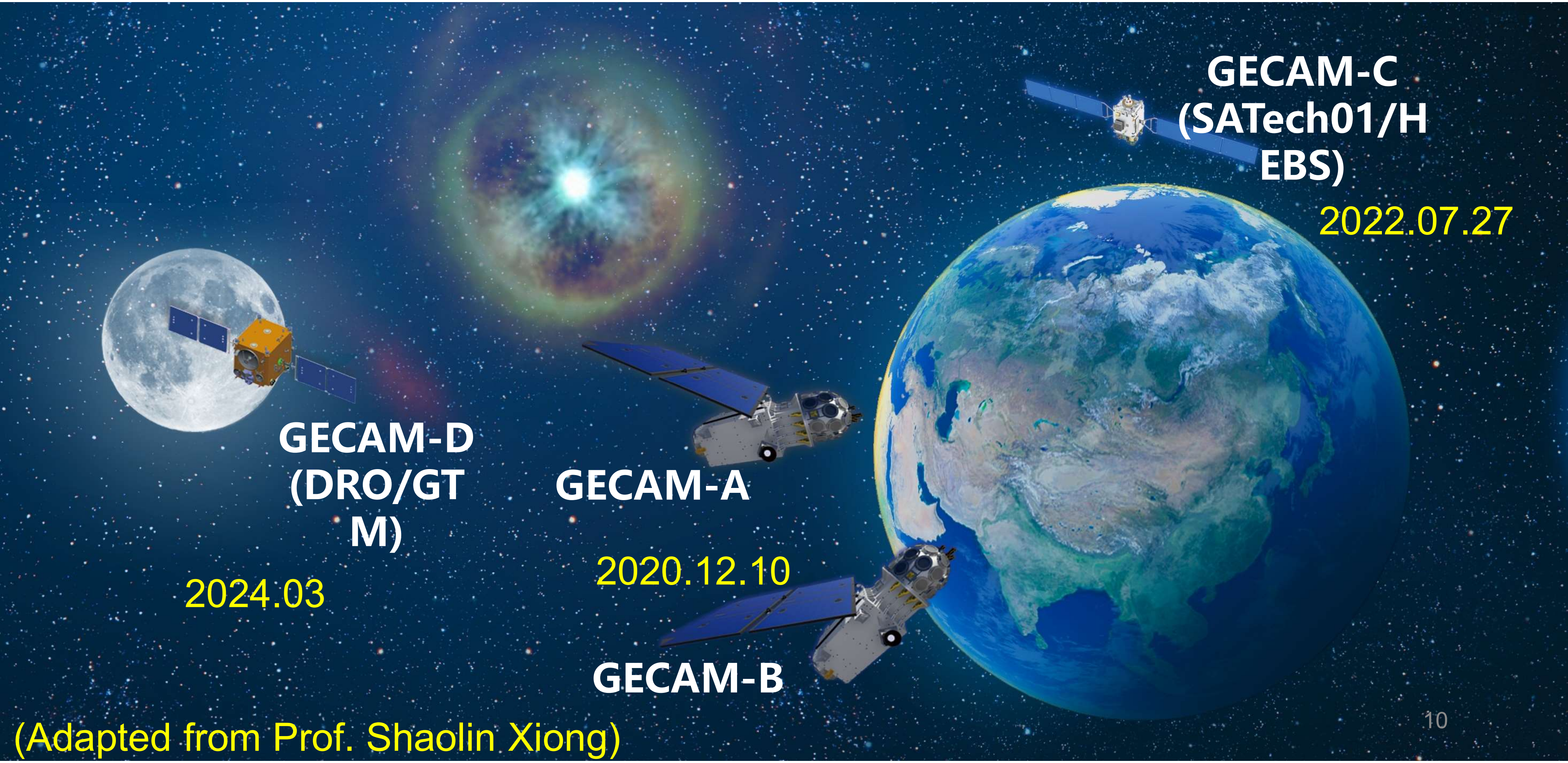
Ma, Tao, SNZ+ 2021, Nature Astronomy

New model of BH QPOs: L-T precession Jet

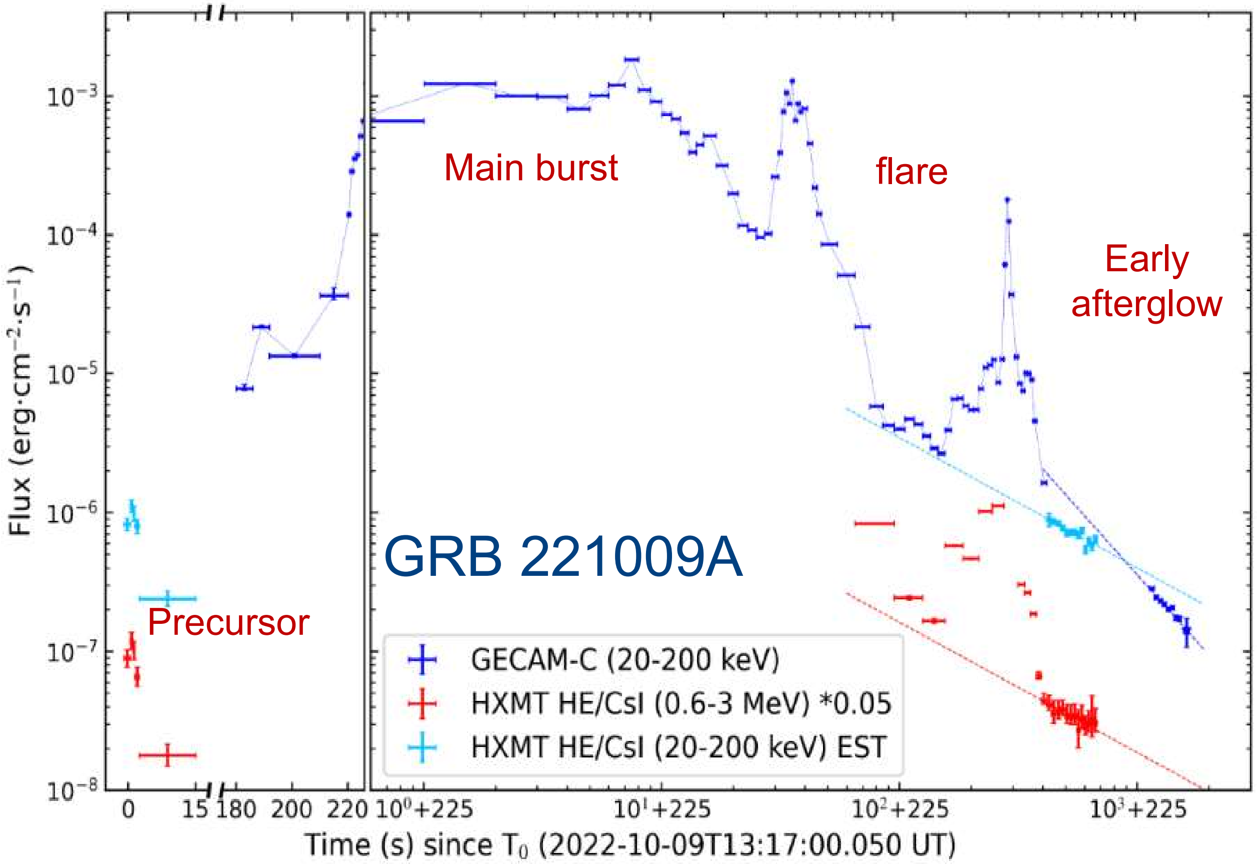


Ma et al. 2020, Nature Astronomy

GECAM Constellation



The brightest GRB: 221009A



HXMT and GECAM accurately observed the GRB: precursor, main burst, flare & early afterglow.

① Brightest > 50 times
② Largest isotropic energy 1.5×10^{55} erg
③ Early afterglow break: very narrow jet~0.7°
④ Jet corrected energy 10^{51} erg: normal
⑤ Also VHE gamma-rays detected by LHAASO

Early jet break: 950±50 s & highest E_{iso}~1.5x10^{55} erg

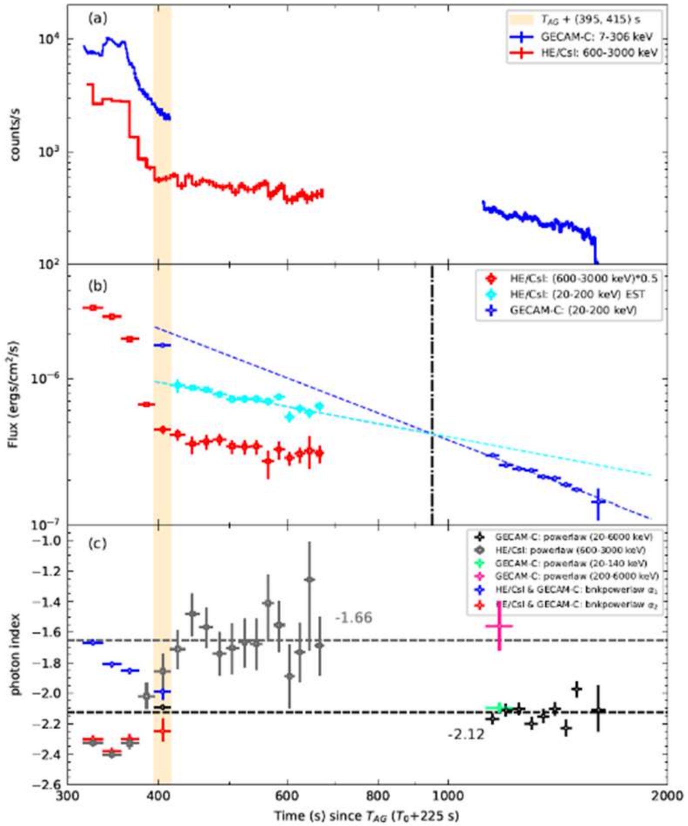


Figure 4: Evolution of light curve (Panel a), energy flux (Panel b) and photon index (Panel c) from flare-dominated phase to afterglow-dominated phase of GRB 221009A. The dashed lines are fit results to the HE/CsI light curve from T_0+600 s to T_0+900 s and GECAM-C light curve from T_0+1300 s to T_0+1860 s. The jet break time is estimated from a joint fit with broken power-law to the estimated 20-200 keV flux from T_0+600 s to T_0+900 s and the measured 20-200 keV flux from T_0+1300 s to T_0+1860 s.

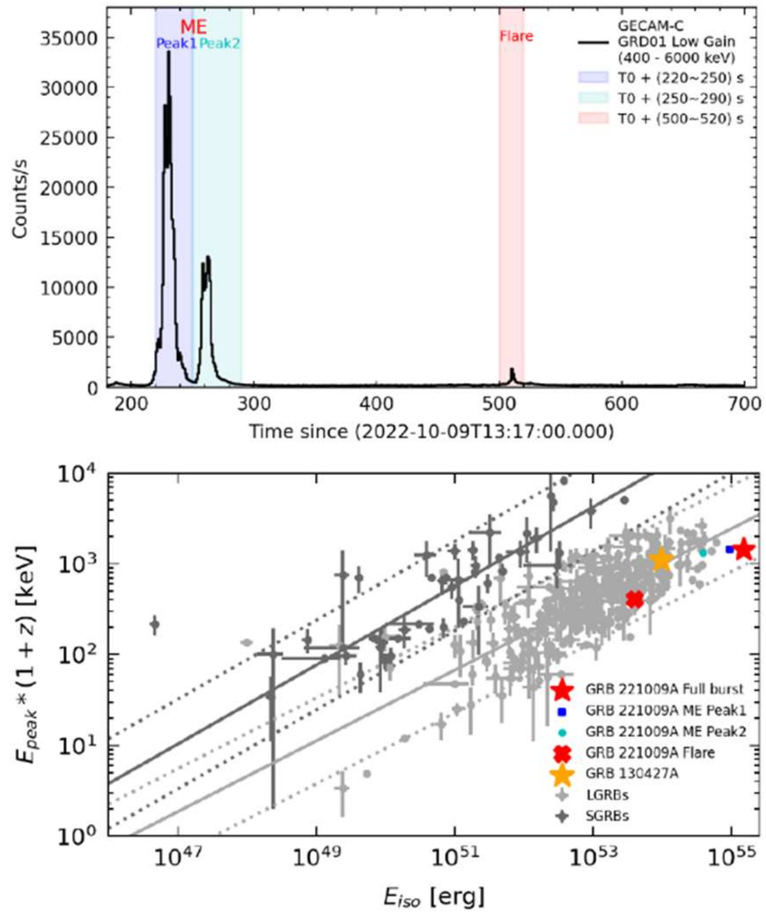
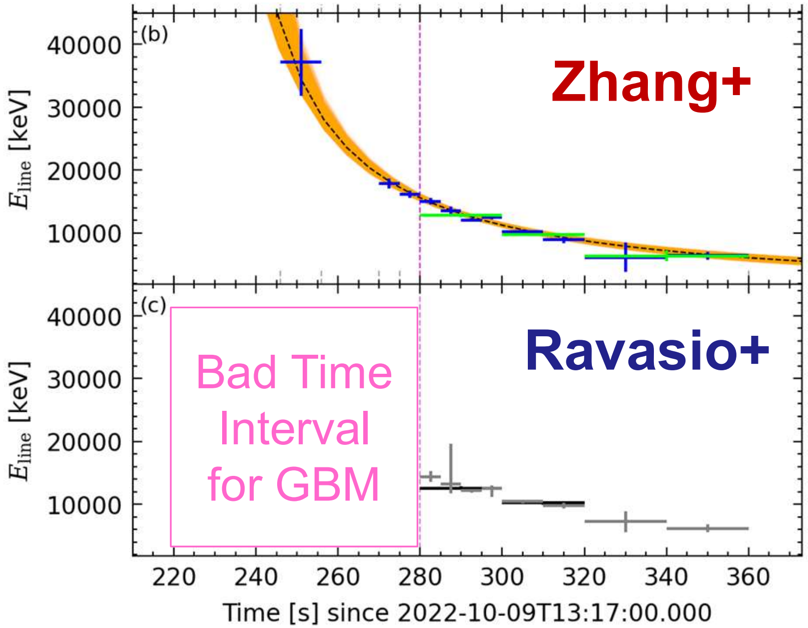


Figure 5: **Top Panel:** GECAM-C/GRD01 Low Gain light curve of GRB 221009A. **Bottom Panel:** Peak energy E_p and isotropic energy E_{iso} for GRB 221009A. The results for the two peaks in ME (Peak-1 and Peak-2) and the bright part of flare are also shown.

Two works on the MeV emission line

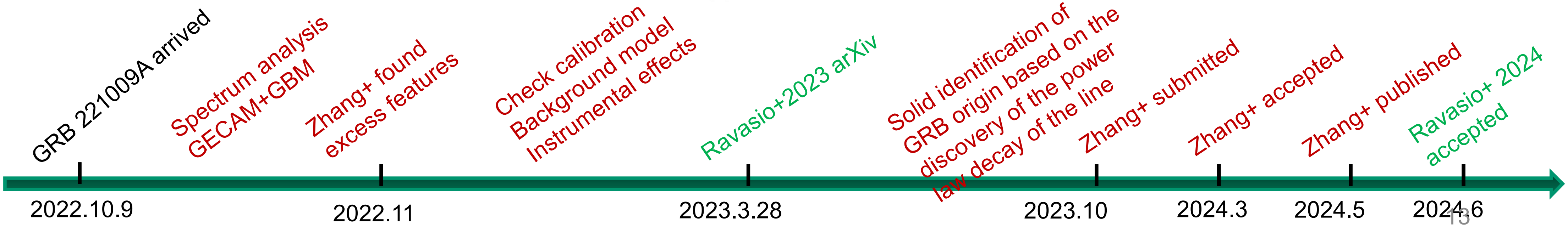
Yan-Qiu Zhang+

- GECAM-C + GBM BGO
  - low energy band of BGOs is suspicious and thus ignored
- Cross calibration of instruments
- Background: revisit orbits
  - well tested and verified
- Time range: Full burst including bright part
- Line energy: 37 MeV to 6 MeV
- Power law decay of line central energy and flux
- Nearly constant ratio of line width to line central energy



M.E. Ravasio+

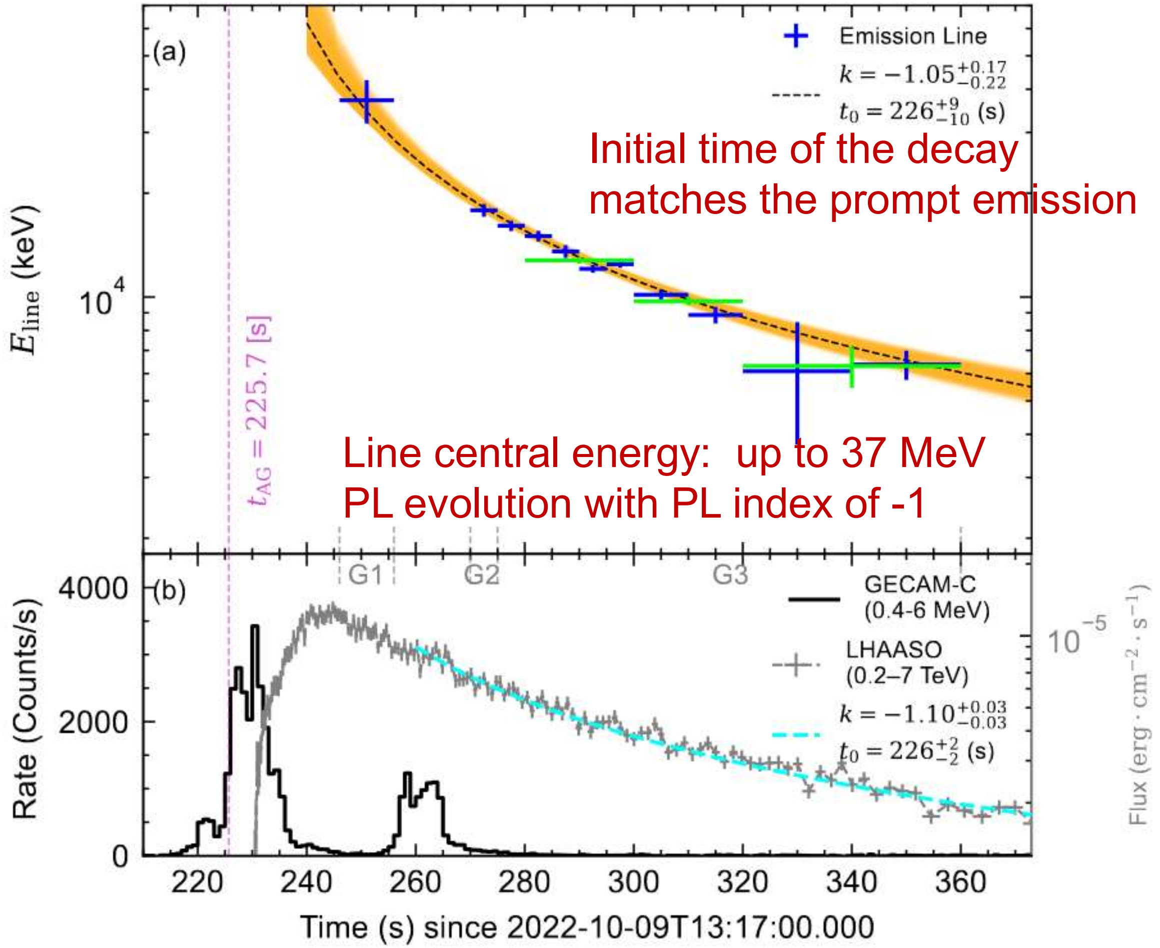
- GBM NaI + BGO
- Background: polynomial fit (up to 4th order)
- Time range: bright part of burst is excluded due to data issues
- Line energy: **12 MeV to 6 MeV**
- Temporal evolution of line
- Roughly constant line width



(Adapted from Prof. Shaolin Xiong)

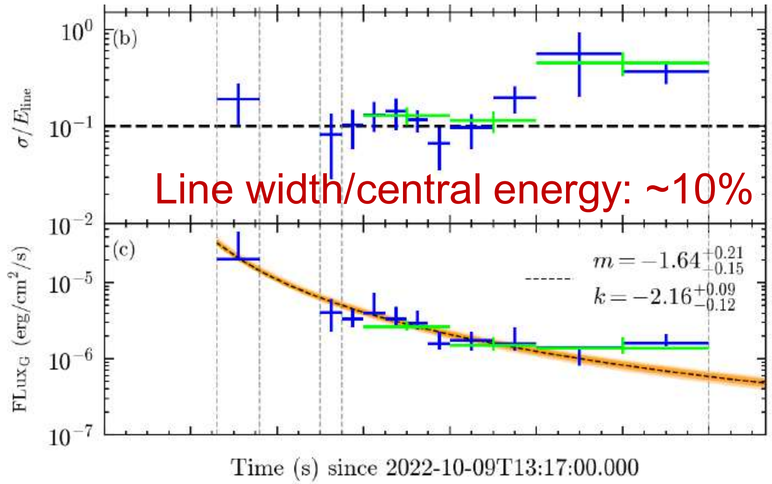
Power-law decay proves the GRB origin of the line

Y.-Q. Zhang, **SLX***, J.R. Mao*, S.-N. Zhang* et al., SCMPA, 2024



Initial time of the decay matches the prompt emission

Line central energy: up to 37 MeV
PL evolution with PL index of -1



Line width/central energy: ~10%

Line luminosity: up to 10^51 erg/s
PL evolution with PL index of -2

Brief Interpretations

- Doppler boosted e± pair annihilation 511 keV is the most natural and probable scenario
- Line energy PL index of -1 supports the high latitude effect but the HLE of a uniform jet is disfavored by the line flux PL index of -2
- Jet dynamics is possible, then an unusual $\Gamma \sim t^{-1}$

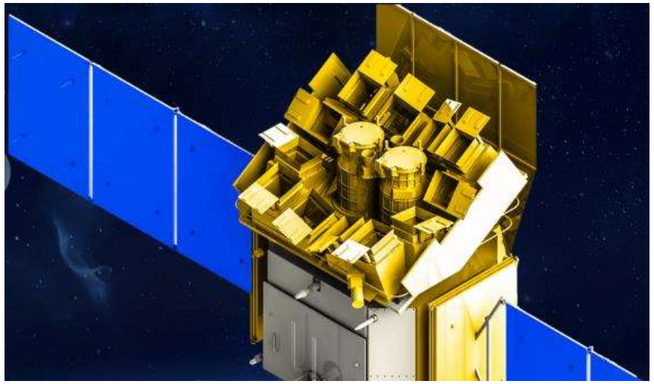
(Adapted from Prof. Shaolin Xiong)

The Einstein Probe (EP) mission

Mission Features

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

- **The first full scale 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: ~2024.1.09**



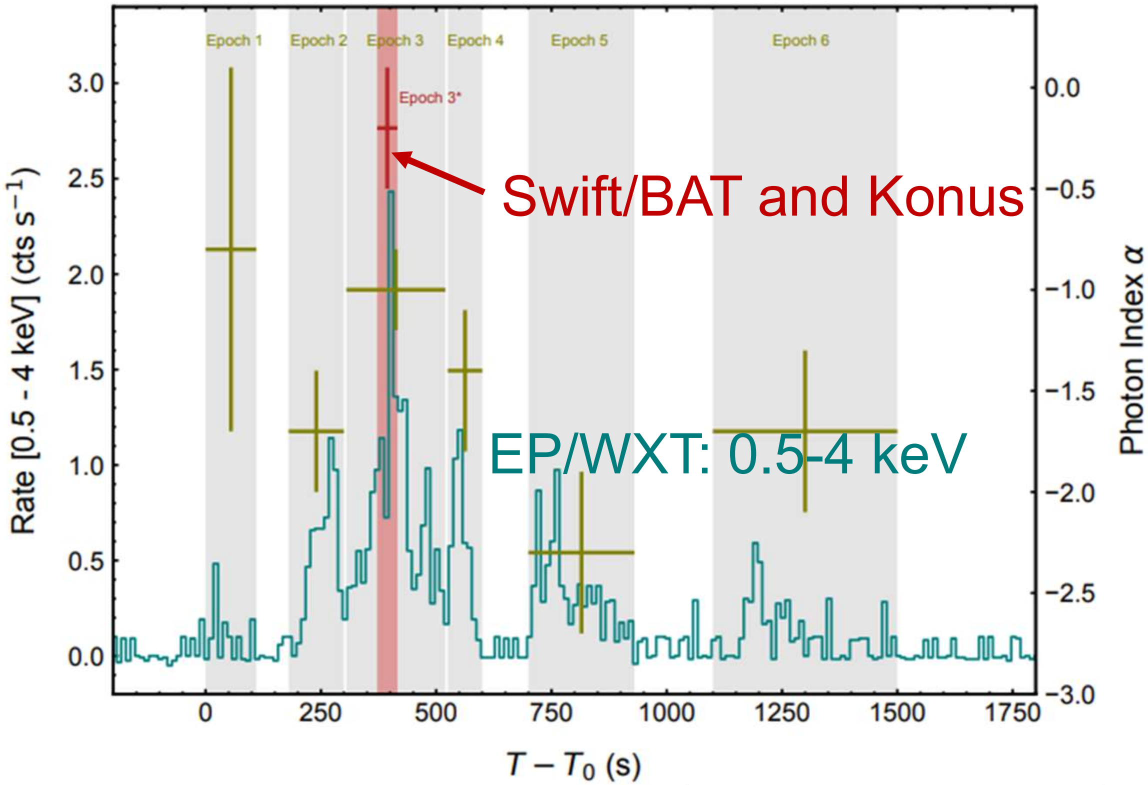
PI: Prof. Weimin Yuan, National Astronomical Observatories of China (NAOC)

(In 2009-2010, I created the X-ray Imaging Lab in NAOC to develop the Lobster-Eye optics and proposed the X-ray ASM for the China Space Station, the predecessor of EP; I also suggested the name "Einstein Probe"☺)

WXT discovered a high-Z GRB

EP240315a

- 2024-03-15T
- 20:15:19 onboard trigger
- 20:15:30 BeiDou alert received on ground
- 20:25:29 VHF下 light curve: strong variability
- 03-16T15:49:37 GCN
- 03-17T01:02:52 VLT: z=4.859 GRB
- 03-17T14:10:00 EP-FXT ToO afterglow detection



Liu+ 2024, NA in press ([arXiv:2404.1642)](arXiv:2404.1642)

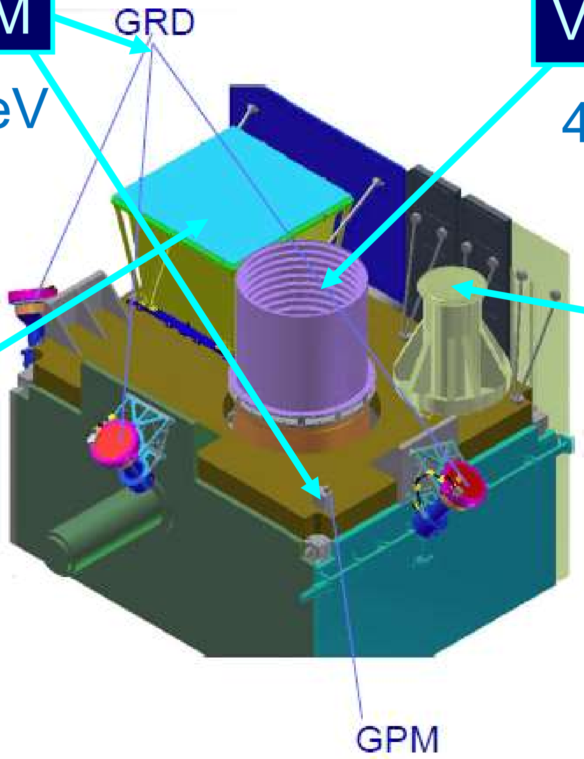
Prompt emission very different in X- & gamma-rays
Great potential for EP to study the early universe.

SVOM (Space Variable Object Monitor)

IHEP

GRM
30 keV-5 MeV

VT
400-650 nm, 650-950 nm



Eclairs
4-250 keV

MXT
0.3-5 keV

PIs: Jianyan Wei,
National Astronomical
Observatories of China;
Bertrand Cordier, CEA, France
Launch: 2024 June 22

450-900 nm
GWAC

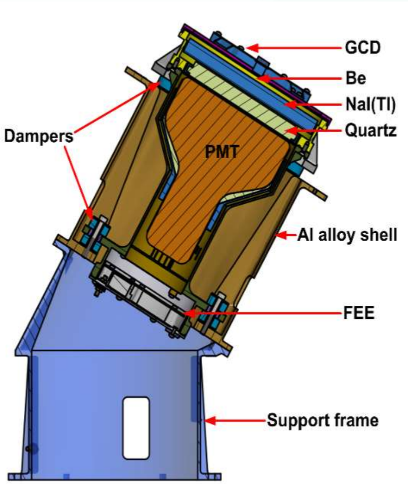
400-1700 nm
GFTs

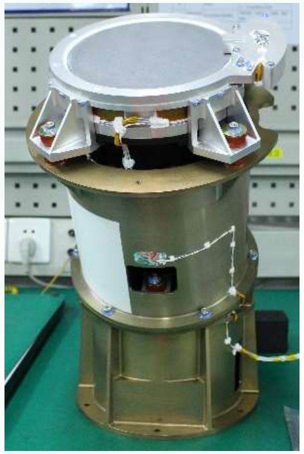
For more details:

17.50-18.15 Maria Grazia Bernardini The SVOM mission

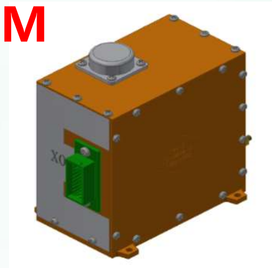
SVOM/GRM

GRD(GCD)





GPM



GRD (Gamma Ray Detector)：3GRDs, NaI + PMT

GCD (GRM Calibration Detector)： 3GCDs， ^{241}Am+PS+SiPM

GPM (GRM Particle Monitor)：PS+PMT

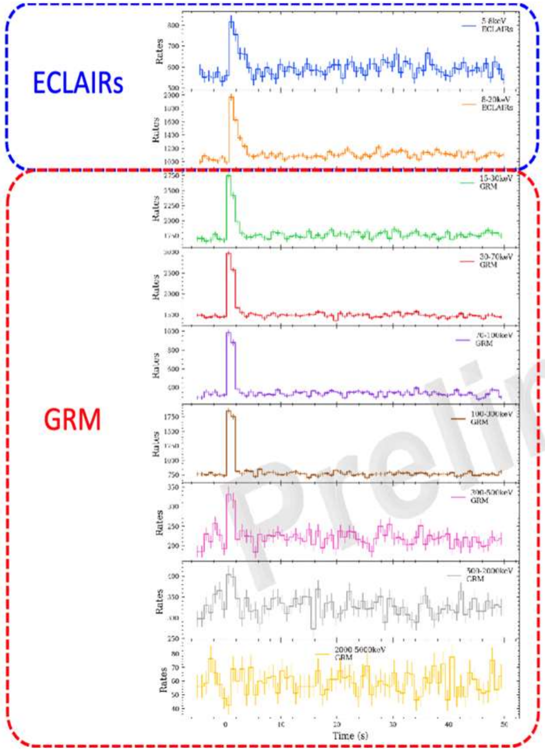
Overview of GRM in-flight observation

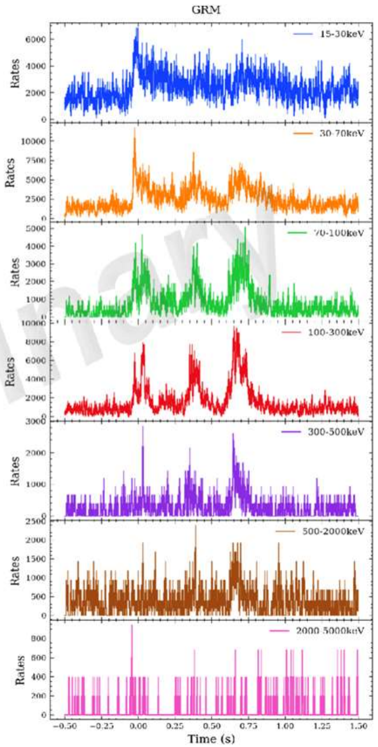
- **22th June launched, 24th June powered on, 27th June PMT HV on**
- As of 29th Nov., statistics of bursts detected by GRM
  - 57 GRBs: 44 long GRB + 13 short GRB
  - 6 SGR bursts
- GRB detection rate: ~130 GRBs/year
- 11 GRBs with redshift measurement

(Adapted from Prof. Shaolin Xiong)

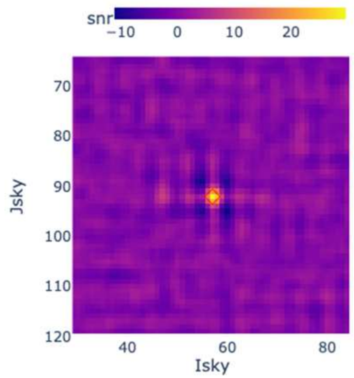
Joint observation: an example

- GRB 240821A: **GRM+ECLAIRs+VT+EP/FXT**

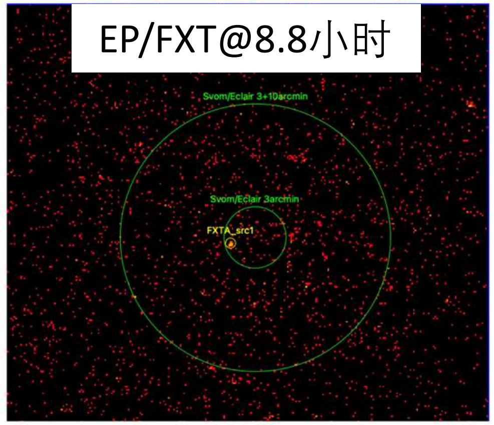


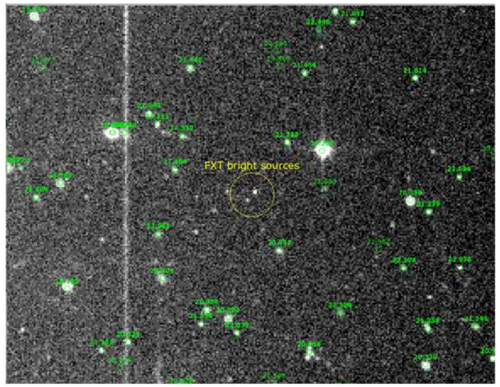


ECLAIRs image



T0: 2024-08-21T18:36:02Z
T90: 34.1 sec
RA, 354.257 deg
Dec : -10.151 deg
Error： 3+10 arcmin

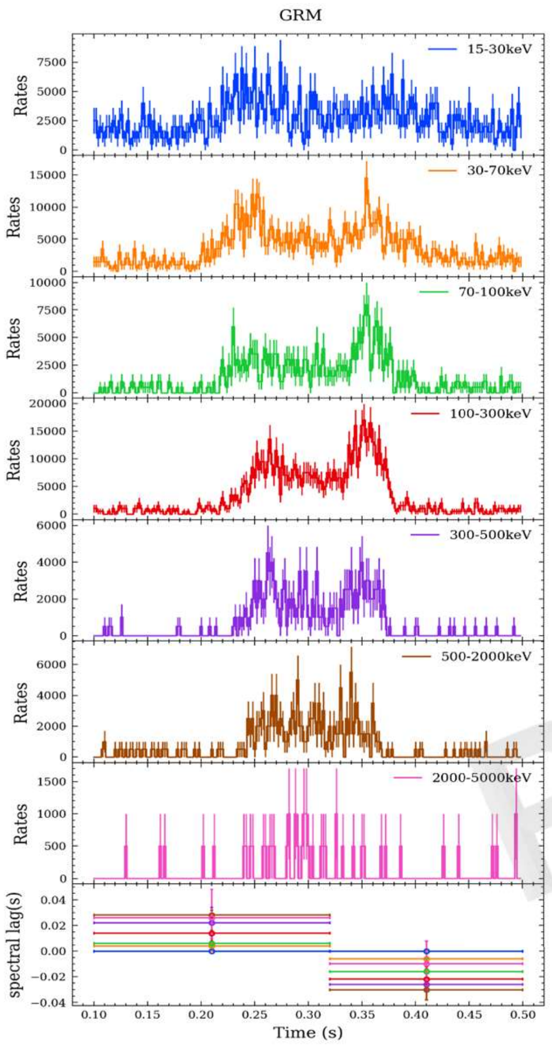


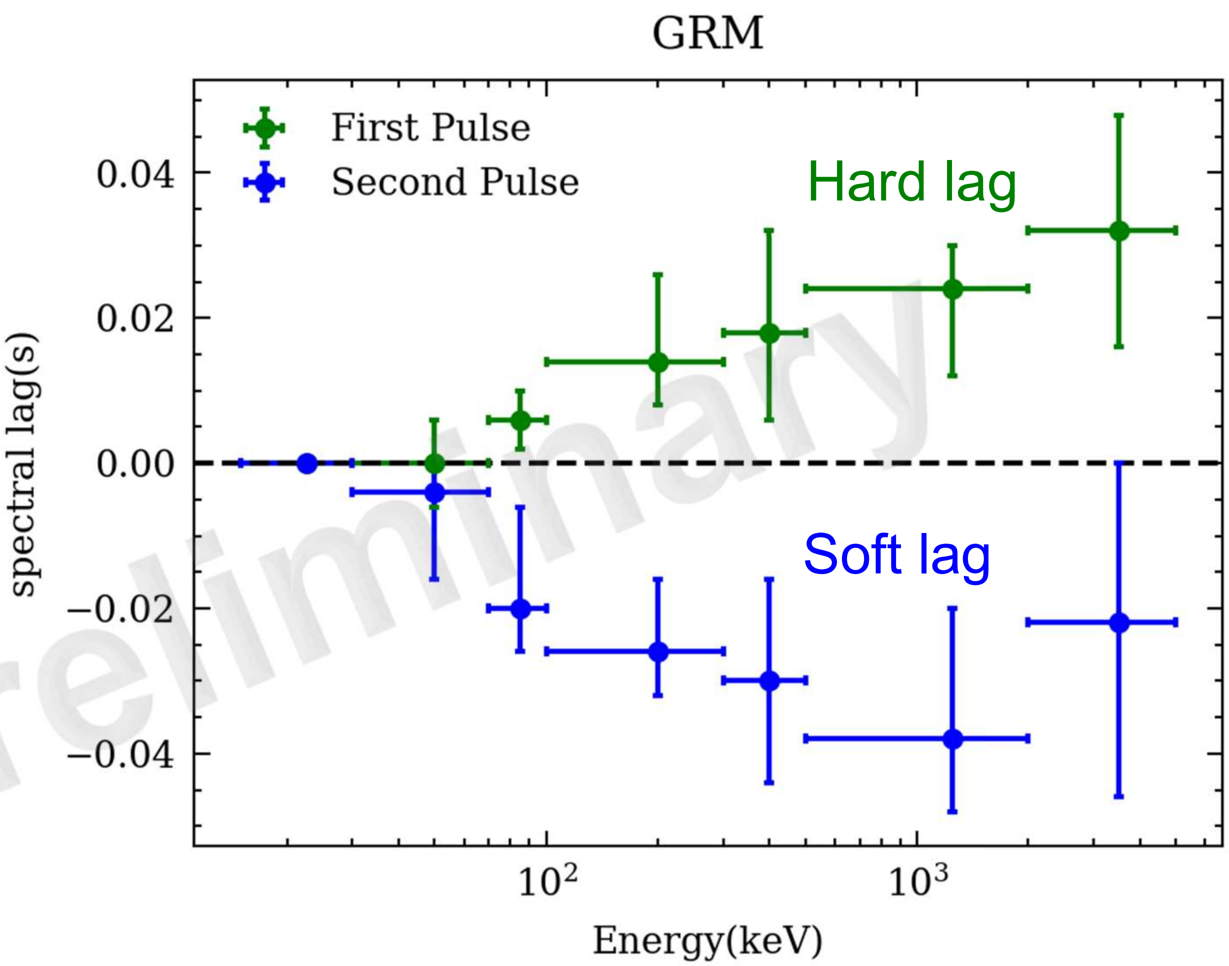


SVOM/VT@17hours
m=23 in one orbit

(Adapted from Prof. Shaolin Xiong) https://gcn.nasa.gov/circulars/37243 https://gcn.nasa.gov/circulars/37319

GRB 240715A: peculiar spectral lag?

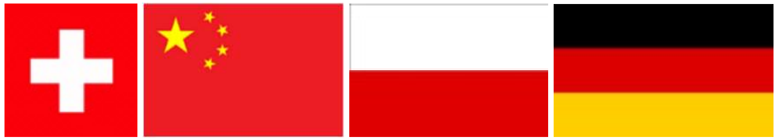




Results by Wenjun Tan@IHEP

(Adapted from Prof. Shaolin Xiong)

The POLAR-2 experiment



- Enhanced GRB polarimeter, successor of POLAR
- Officially selected by CSS through UNOOSA in 2019

Announcement of selection Jun./2019

UNITED NATIONS
Office for Outer Space Affairs

CMS

United Nations/China Cooperation on the Utilization of the China Space Station (CSS)

联合国/中国围绕中国空间站应用开展合作

Selected Experiment Projects to be executed on board the CSS for the 1st Cycle

Announced on the occasion of the 62nd Session of the Committee on the Peaceful Uses of Outer Space

12 June 2019 Vienna, Austria

第一轮合作入选项目

2019 年 6 月 12 日在奥地利维也纳举行的第 62 届和平利用外空委员会大会期间发布

I. Fully accepted experiment projects:

完全入选项目

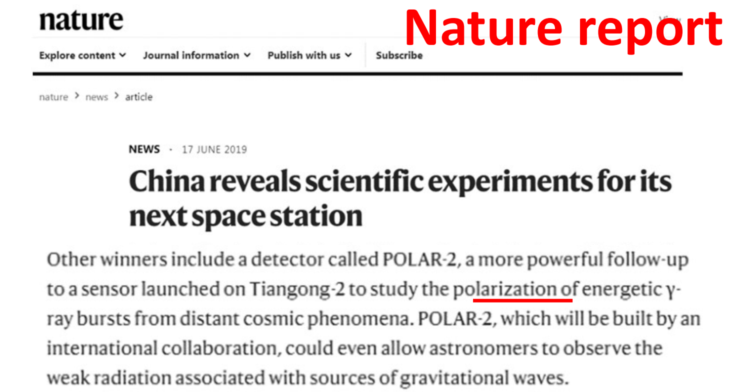
No.1: POLAR-2: Gamma-Ray Burst Polarimetry on the China Space Station

Building on the previous investigation on China's TG-2 space lab, this project aims to answer the most important open questions in astrophysics regarding the nature of Gamma-Ray Bursts (GRBs) by using the most promising investigation approach of polarization measurements allowing to observe even the weakest gamma-ray transients, such as those connected to gravitational waves.

It is an experiment project in astronomy in space. It was applied and will be implemented by four institutions from four countries, which are: The University of Geneva from Switzerland, the National Center for Nuclear Research of Poland, the Max Plank Institute for Extra-terrestrial Physics of Germany, and the Institute of High Energy Physics of Chinese Academy of Sciences.

第 1 个项目：POLAR-2：中国空间站上的伽玛暴偏振探测仪

Nature report



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NEWS · 17 JUNE 2019

China reveals scientific experiments for its next space station

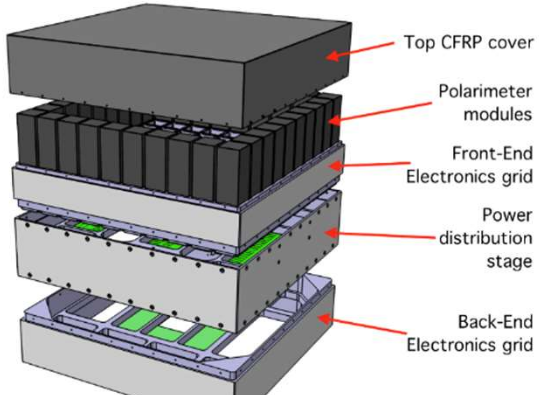
Other winners include a detector called POLAR-2, a more powerful follow-up to a sensor launched on Tiangong-2 to study the polarization of energetic γ-ray bursts from distant cosmic phenomena. POLAR-2, which will be built by an international collaboration, could even allow astronomers to observe the weak radiation associated with sources of gravitational waves.

Ceremony of MOU signing Nov./2019

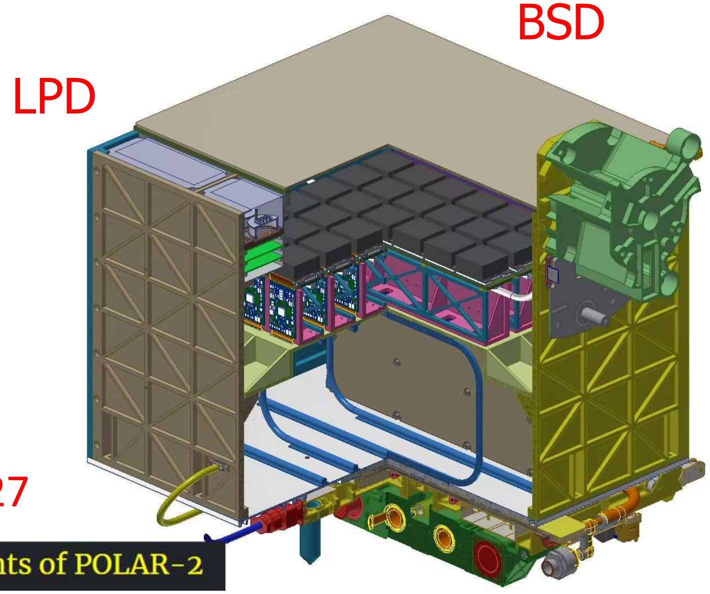
POLAR-2 current design of instruments

Polarimetry with largest FoV and broadest energy band

- ➢ High-energy Polarization Detector: HPD
- ➢ E-range for polarimetry: ~30-800 keV
- ➢ 100 modules, 6400 plastic scintillator bars
- ➢ Effective area: > 2000cm^2, > 1000cm^2 for Pol.
- ➢ FOV: ~50% sky
- ➢ Collaborations: UNIGE/IHEP/MPE/NCBJ
- ➢ Has been approved through United Nations



- ➢ Low-energy Polarization Detector: LPD, GXU, China
  - ~2-10 keV X-ray polarimetry
- ➢ Broad energy-band Spectrum Detector: BSD, IHEP/CAS, China
  - ~10-2000 keV for spectroscopy
  - Accurate GRB localization: < 1°
- ➢ Status: under final review for approval



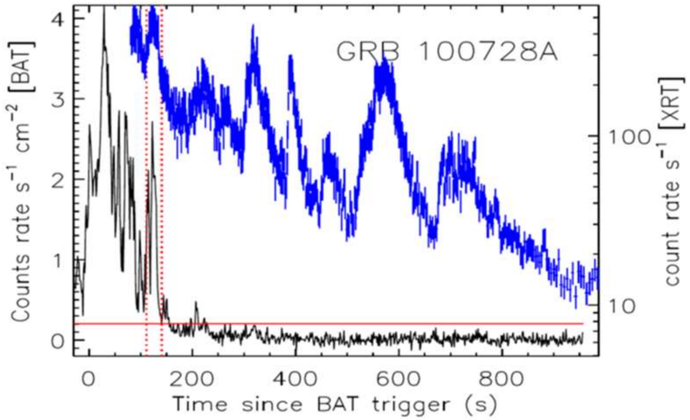
PIs: Shuang-Nan Zhang (IHEP), Xin Wu (UniGe); launch in 2027

For more details: 18.40-19.05 Johannes Hulsman Latest developments of POLAR-2

POLAR-2 will measure polarization of GRB and X-ray flares simultaneously

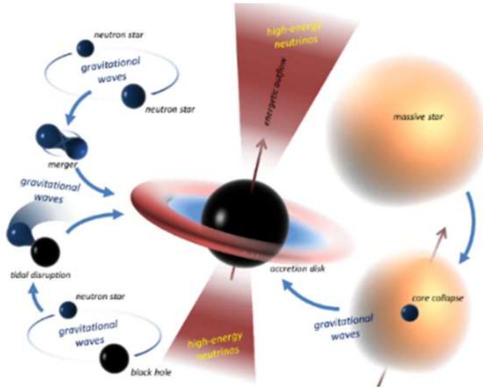
Unresolved GRB problems:

- Central engine and its evolution?
- Jet geometry and magnetic field topology?
- Particle acceleration and radiation in jet?

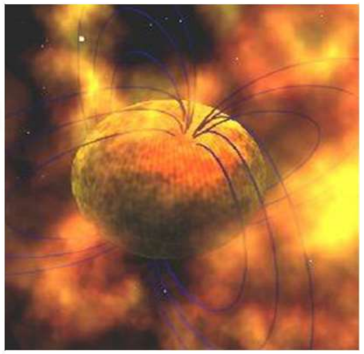


Simultaneous GRB and X-ray flare polarimetry may answer:

- Are the central engine, magnetic field topology and radiation mechanism the same between GRBs and X-ray flares?
- Is polarization evolution during a GRB common among GRBs?



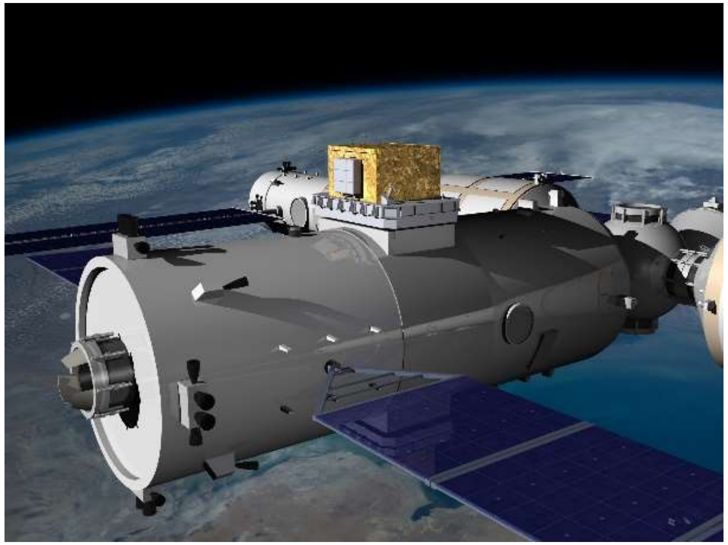
Super accretion BH/NS

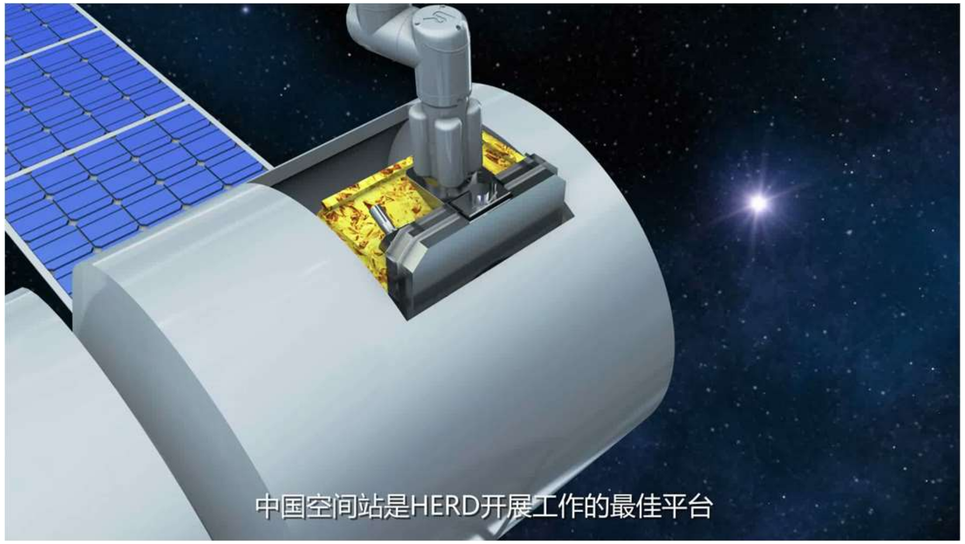


Magnetar

High Energy cosmic-Ray Detection (HERD)

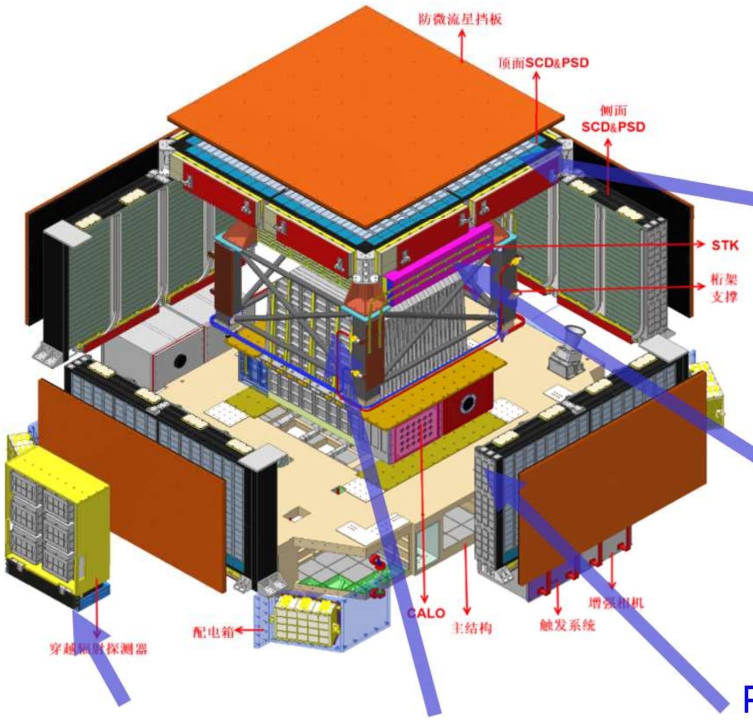
- HERD: flagship and landmark scientific experiment onboard the China's Space Station, China-led large international collaboration, ~2027
- Scientific goals
  - Dark matter search with high energy electrons and gamma-rays
  - Precise CR spectrum and composition measurements up to knee energy
  - High energy gamma-ray monitoring with large field of view





PI: Shuang-Nan Zhang (IHEP); Europe Coordinator: Giovanni Ambrosi (INFN, Perugia)

HERD current baseline design



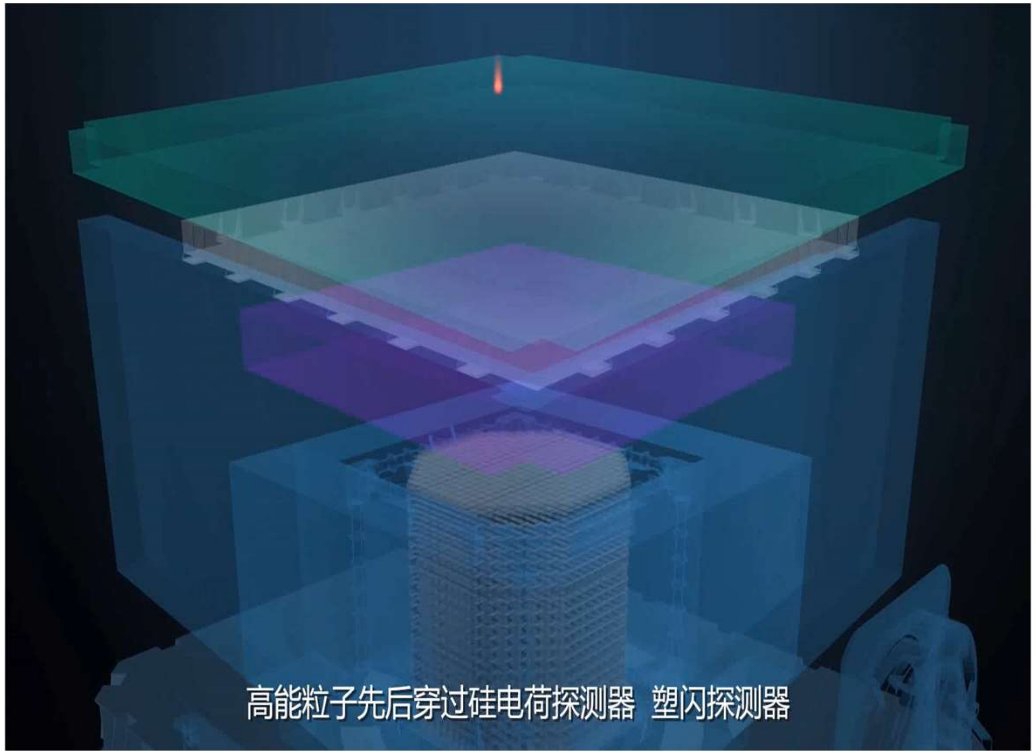
Silicon Strip
Charge
Detectors

Silicon Tracker
Tracks
γ conversion

Transition Radiation
Detector
TeV energy scale
calibration

3D Imaging
Calorimeter
Energy
Particle ID

Plastic
Scintillators
e/γ ID
Charge

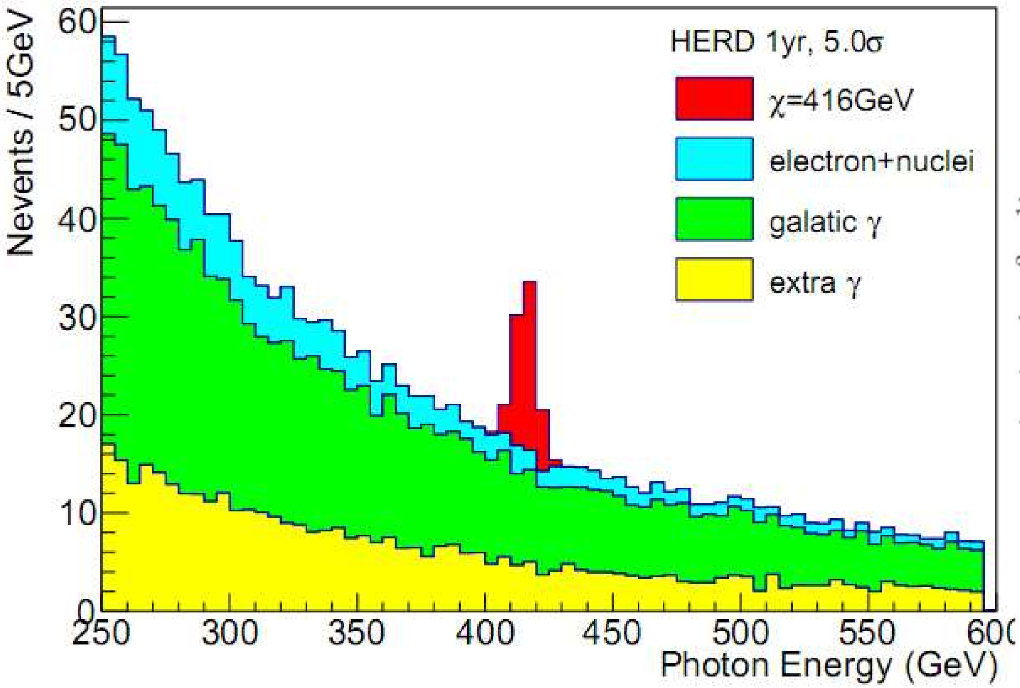


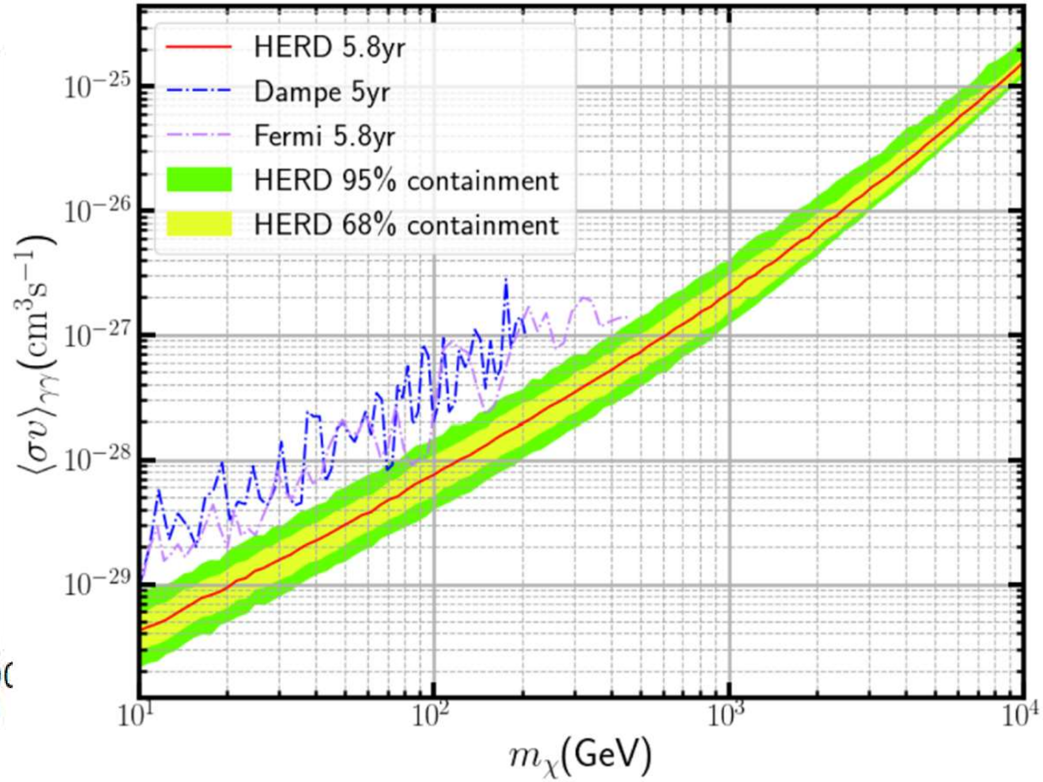
HERD specifications: gamma-ray monitoring capability

Particles Type	Measurements	Specifications
Charged particles	e acceptance	>3 m^2sr@200 GeV
	p acceptance	>2 m^2sr@100 TeV
	e energy range	10 GeV~100 TeV
	p energy range	30 GeV~5 PeV
	charge range	Z=1~28
	charge resolution	<0.15-0.2 c.u.
	e energy resolution	<1.5%@200 GeV
	p energy resolution	<25%@>100 GeV
Gamma-rays	γ energy range	0.5 GeV~100 TeV
	γ energy resolution	<1.5%@200 GeV
	γ angular resolution	<0.1° @10GeV, top incidence ~1° lateral incidence
	Field of view	~2π
	Data mode	Fast download with external trigger

Optimized for cosmic ray science with complementary gamma-ray capability.

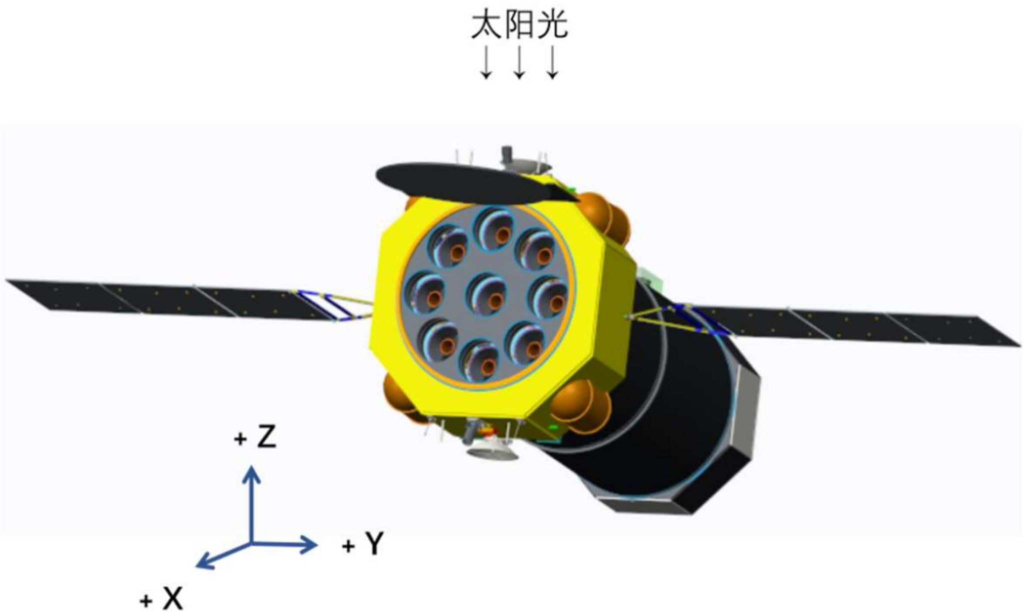
Expected HERD sensitivity to DM annihilation





HERD also has the largest FOV~2π to monitor the gamma-ray sky.

eXTP: enhanced X-ray Timing and Polarimetry Observatory



Observatory for X-ray Timing-Spectro-Polarimetry

- Important Sciences
  - Extreme gravity, magnetism, density
  - Neutron stars, black holes, etc
- Mission Profile
  - Orbit：5000km*116500km HEO
  - Weight：4.2 T
  - Launcher：CZ-3BE
  - Approved for launch in 2030

Main Payload	Configuration	Eff. area
Spectroscopy Focusing Array (SFA)	6 telescopes (5.25 m fl)	>0.3m²@6keV
Polarimetry Focusing Array (PFA)	3 telescopes (5.25 m fl)	>350cm²@2keV
Wide-field Wide-band Camera (W2C)	coded mask imager	160cm²@60keV

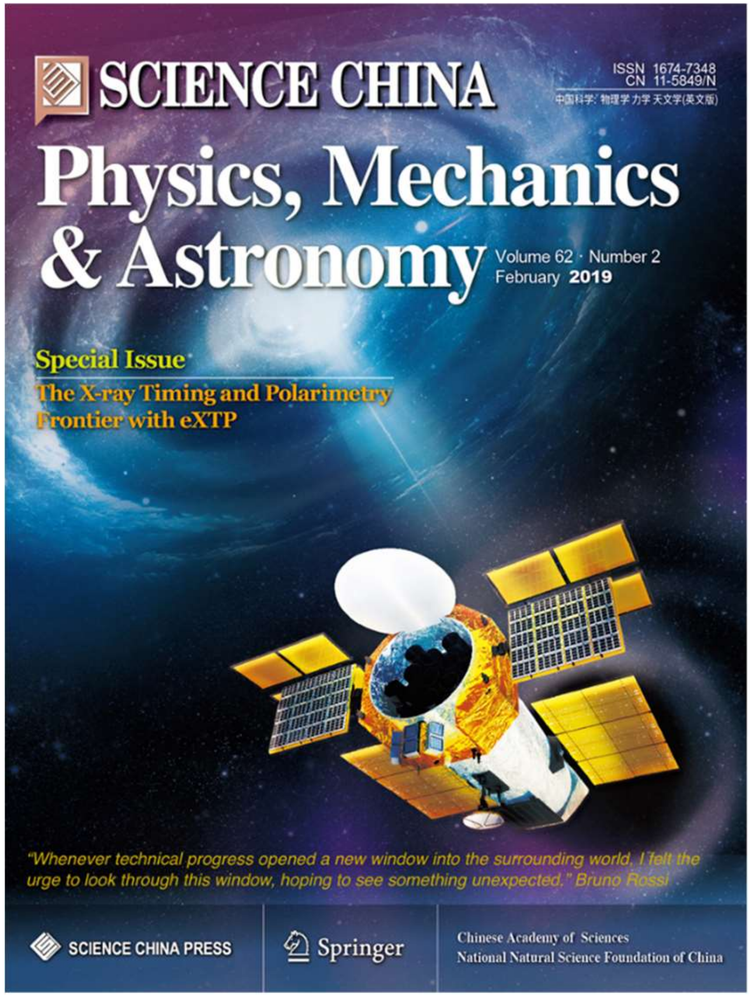
(Previous European instruments LAD and WFM dropped due to no-commitment from Europe)

PI: Shuang-Nan Zhang (IHEP); European coordinator for science studies: Andrea Santangelo (IAAT)

White papers on eXTP

Five refereed papers have been published in a special issue of SCIENCE CHINA Physics, Mechanics & Astronomy, Feb. 2019

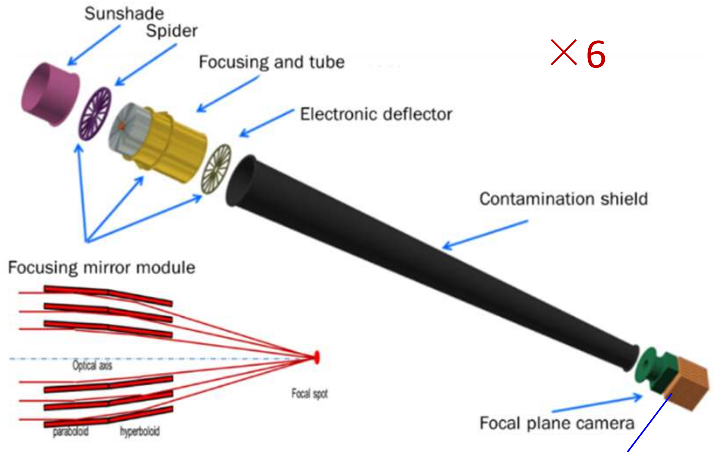
- S.-N. Zhang, A. Santangelo, M. Feroci, Y.P. Xu, et al., The enhanced X-ray Timing and Polarimetry mission - eXTP
- A. L. Watts, W.F. Yu, J. Poutanen, S. Zhang, et al., Dense matter with eXTP
- A. De Rosa, P. Uttley, L.J. Gou, Y. Liu, et al., Accretion in Strong Field Gravity with eXTP
- A. Santangelo, 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

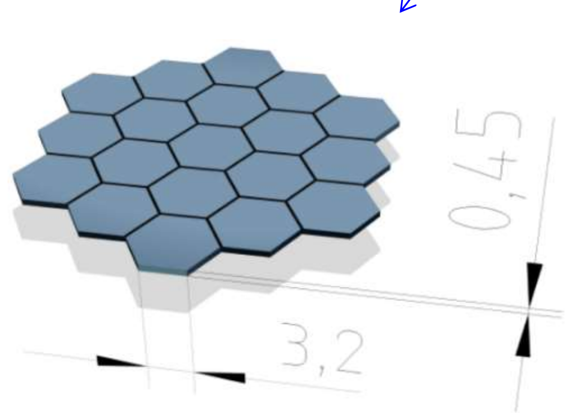


To be updated in June 2025 before Phase C

eXTP Payload: SFA – Spectroscopy Focusing Array

- Large collecting area achieved by multiple optics with short focal length.
- 6 grazing incidence Wolter-I optics with 5.25m F.L., 45-50 shells/module , D=60cm
- Non-imaging, 40″ (HPD), 3′ (W90), 16′ FoV
- 19-cell SDD array: multi-pixel to enable background subtraction
- Energy range: 0.5-10 keV
- Energy resolution: ≤ 150 eV @ 6keV
- Time resolution: 2μs
- Absolute timing accuracy: 2μs
- Dead time: < 5% @ 1Crab
- Sensitivity: 3.3×10^{-15} erg/cm^2/s (5σ, 10^6 s)

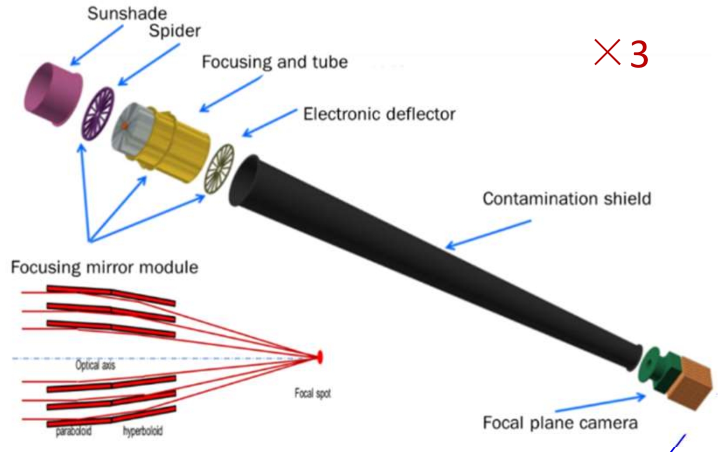


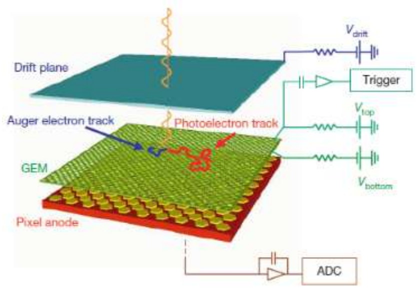


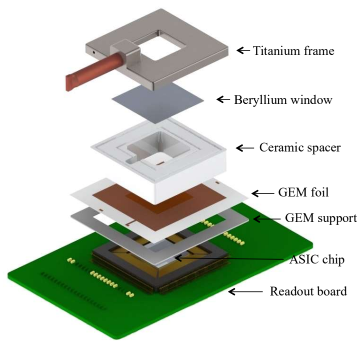
eXTP Scientific Payload: PFA – Polarimetry Focusing Array

- Large collecting area achieved by multiple optics with short focal length.
- 3 grazing incidence Wolter-I optics with 5.25m F.L., 45-50 shells/module, D=60cm
- Imaging, resolution ≤ 30″(HPD, goal 15″)
- Field of view: 9′x 9′
- Gas Pixel Detector (GPD): photo-electron tracking
- Energy range: 2-8 keV
- Energy resolution: ≤ 1.2 keV @ 6keV
- Time resolution: 10μs
- Absolute timing accuracy: 4μs
- MDP: < 1.7% (10^6s, 1mCrab)

×3





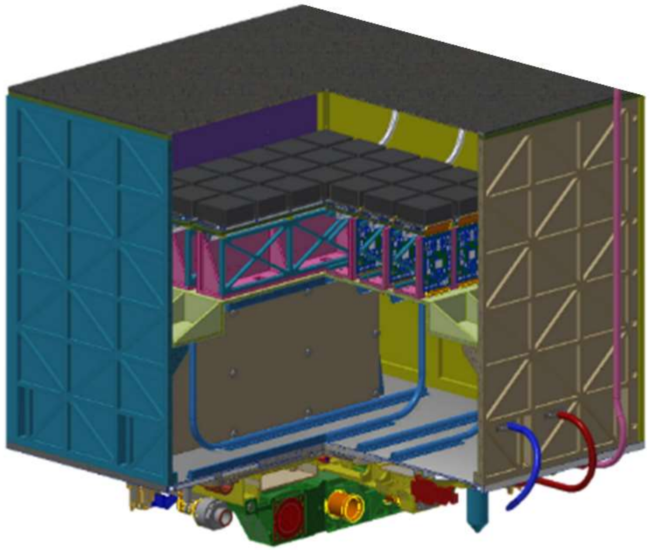


Designed by the INFN-Pisa group (Bellazzini et al.)

GPD

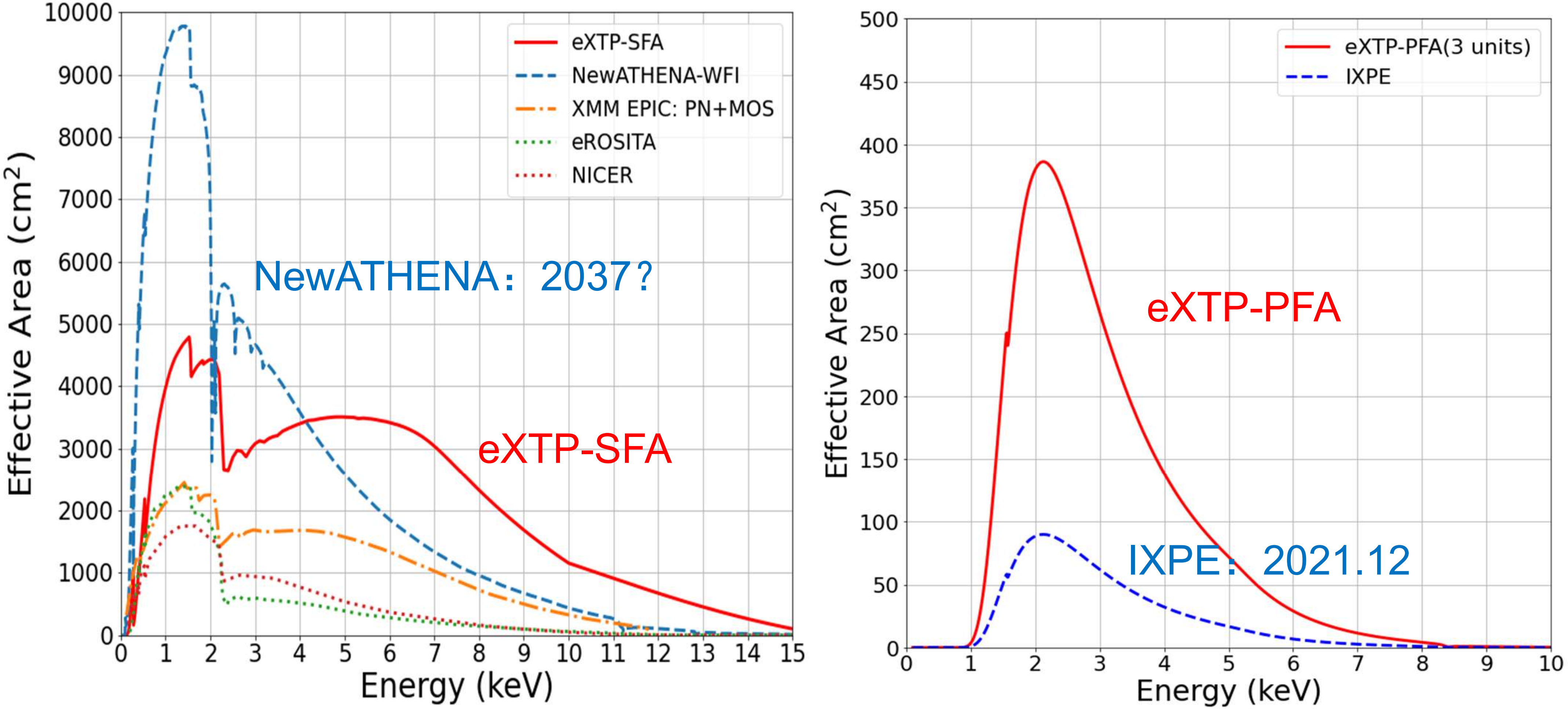
W2C: Wide-field Wide-energy band Camera

FoV: ~60°×60°
Angular Resolution: 20′
Position accuracy: 5′
Effective area: 160 cm² @ 60 keV
Sensitivity: 4 x10^{-7}erg cm^{-2}s^{-1} 10 - 1000 keV in 1 second
Energy range: 30-600 keV

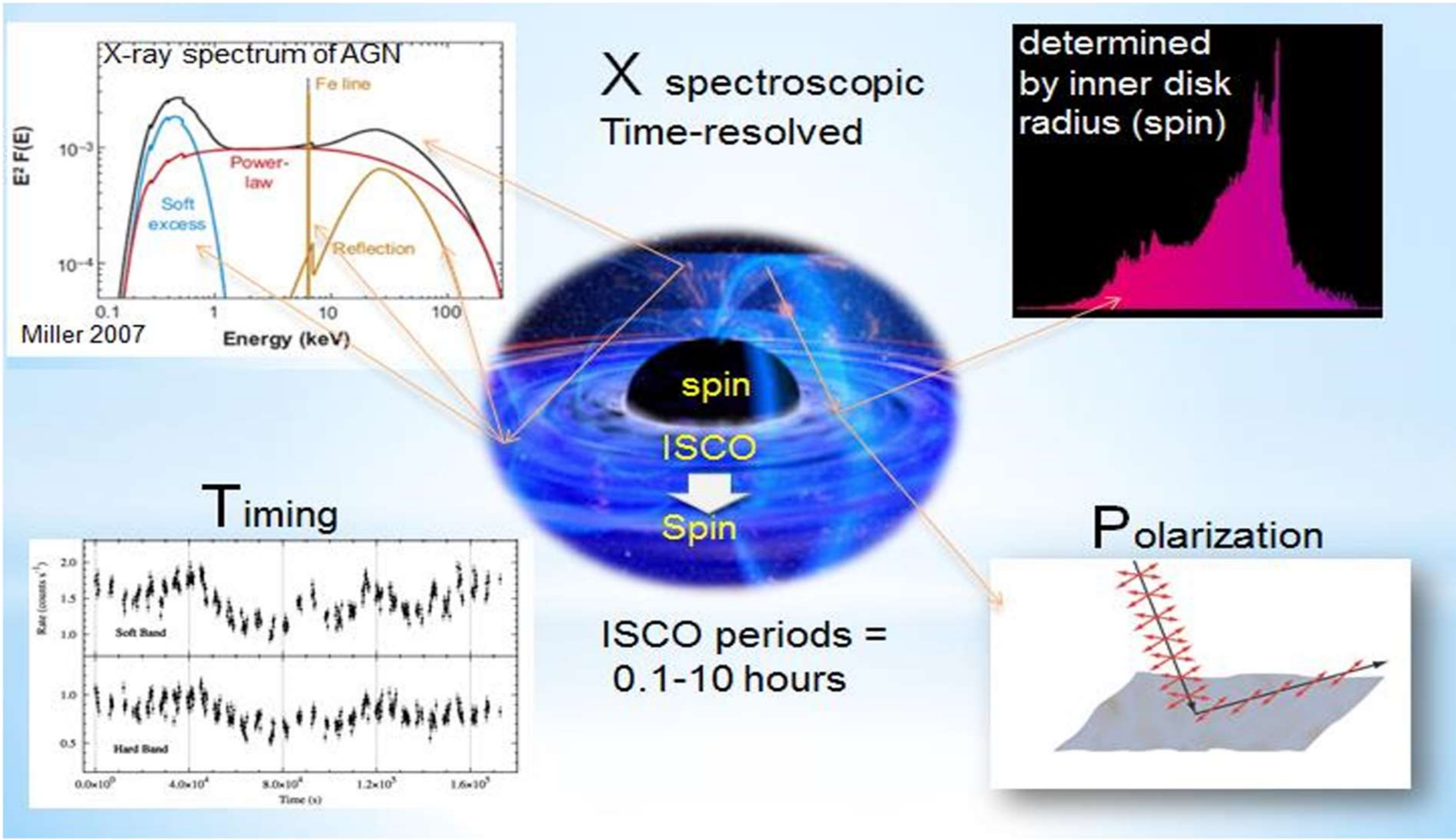


Code-mask imager (similar to SVOM/Eclairs)
Adapted from POLAR-2/BSD

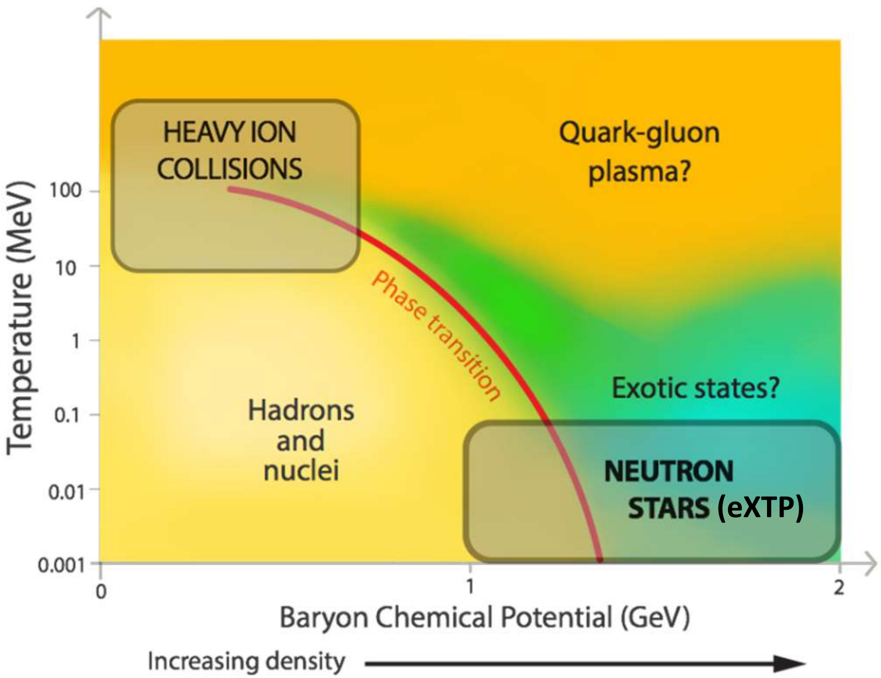
Effective area: SFA & PFA

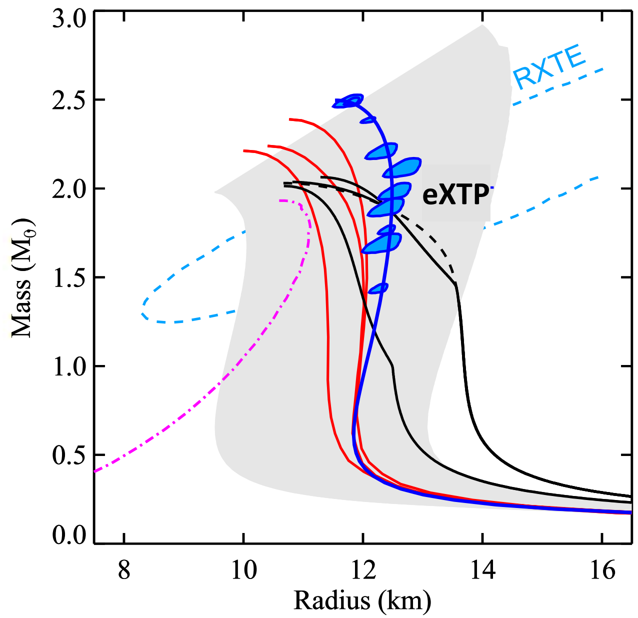


Spectro-Timing-Polarimetry on Accreting BHs



Neutron Stars EoS

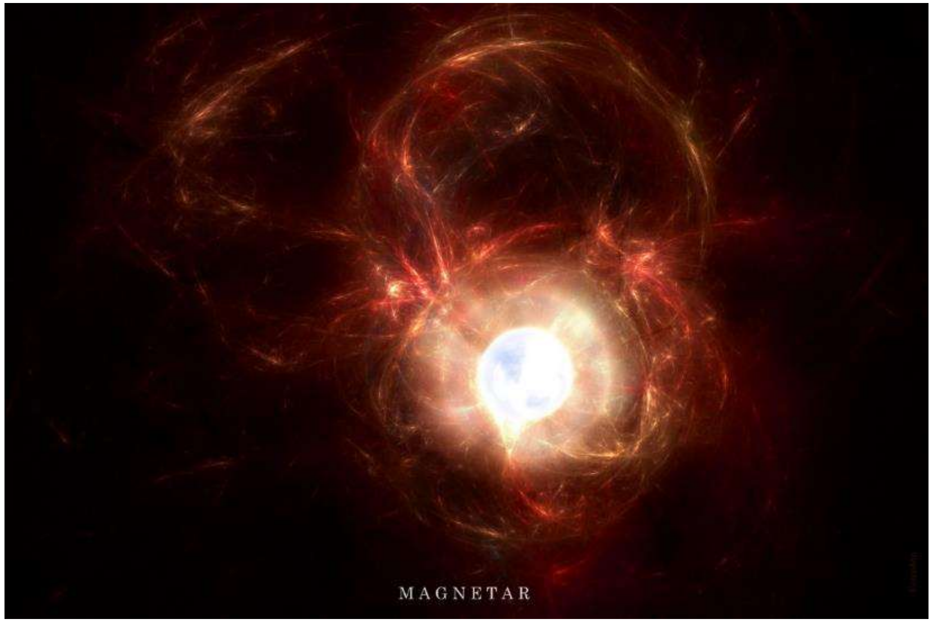




eXTP WILL STUDY **NUCLEONIC MATTER IN A UNIQUE REGIME**, AND **EXOTIC STATES OF MATTER (E.G., QUARK STARS)** THAT COULD NEVER EXIST IN THE LABORATORY.

USING ONLY KNOWN SOURCES, PULSE PROFILE MODELLING MEASUREMENTS WILL **MAP THE M-R RELATION** AND HENCE THE **EQUATION OF STATE (EOS)**.

Extreme Magnetism

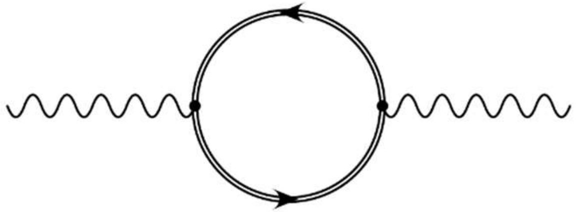


Test Quantum Electro-Dynamics effects → vacuum fluctuations: *is the propagation of light in vacuum modified by the magnetic field?*

Accreting Pulsars and *Magnetars hosts neutron stars with magnetic fields of* ***10^{12-15} Gauss***

Strongest magnetic fields in lab.

10^5 Gauss



$$\Delta n = \frac{\alpha}{4\pi}\frac{2}{15}\left(\frac{B}{4.4 \times 10^{13}\ \mathrm{G}}\right)^2$$

Has this been detected by IXPE? Maybe, as the predicted *vacuum resonance,* but needs eXTP to study further . (Lai, D. 2023, PNAS)

IXPE + X vs. eXTP (more friendly on GRBs)

- IXPE + X
  - Difficult to re-schedule multiple missions
  - Low flexibility in response to transient sources and GRBs
  - Earth occultation: joint observations are not really simultaneous
- eXTP
  - All (NFIs and W2C) point to the same target
  - Fast re-pointing to transients and GRBs: <10 min for 30° (difficult for a large satellite)
  - Almost no telemetry limit for bright sources
- IXPE + X cannot fulfill the job
  - if the source has variability on orbital timescale (~90 min)
  - if one tries to study short-term variability (Δt < ~90 min)
- For the same source, eXTP allows for
  - polarimetry at a better timing/energy/phase resolution (~5 times better)
- eXTP is more than a larger IXPE+X

(Adapted from Hua Feng)

Summary: China is active in space high energy astronomy

- DAMPE, POLAR, Insight-HXMT, GECAM, EP pathfinder, EP and SVOM launched in 2015/16/17/20/22/2024
  - Insight-HXMT is very flexible in ToOs and monitoring bright transients with high cadence and long observations; GECAM as ASM has good low energy response & near real-time alert capability; EP with large FoV & deep X-ray monitoring; SVOM as multiwavelength observatory with quick & deep X-ray/optical follow-up capabilities.
- POLAR-2 to be launched in ~2027
  - POLAR-2 for broad band GRB polarimetry.
- Two large future missions in 2027-2030, with GRB capability
  - HERD: mainly on cosmic rays, also provides wide field gamma-ray (0.5 GeV to 100 TeV) sky monitoring, on China's Space Station, 2027?
  - eXTP: To provide X-ray spectral-timing-polarimetry, space X-ray observatory, 2030?

Welcome to join POLAR-2, HERD & eXTP science teams!