Exploring the Extreme Universe with the *HERD* and *eXTP* missions

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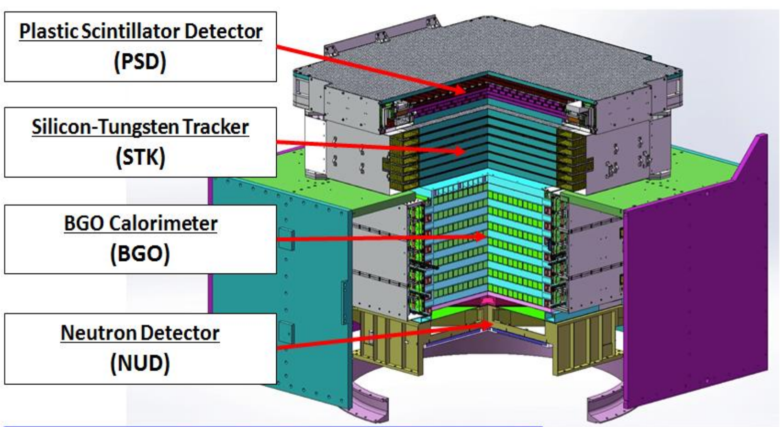
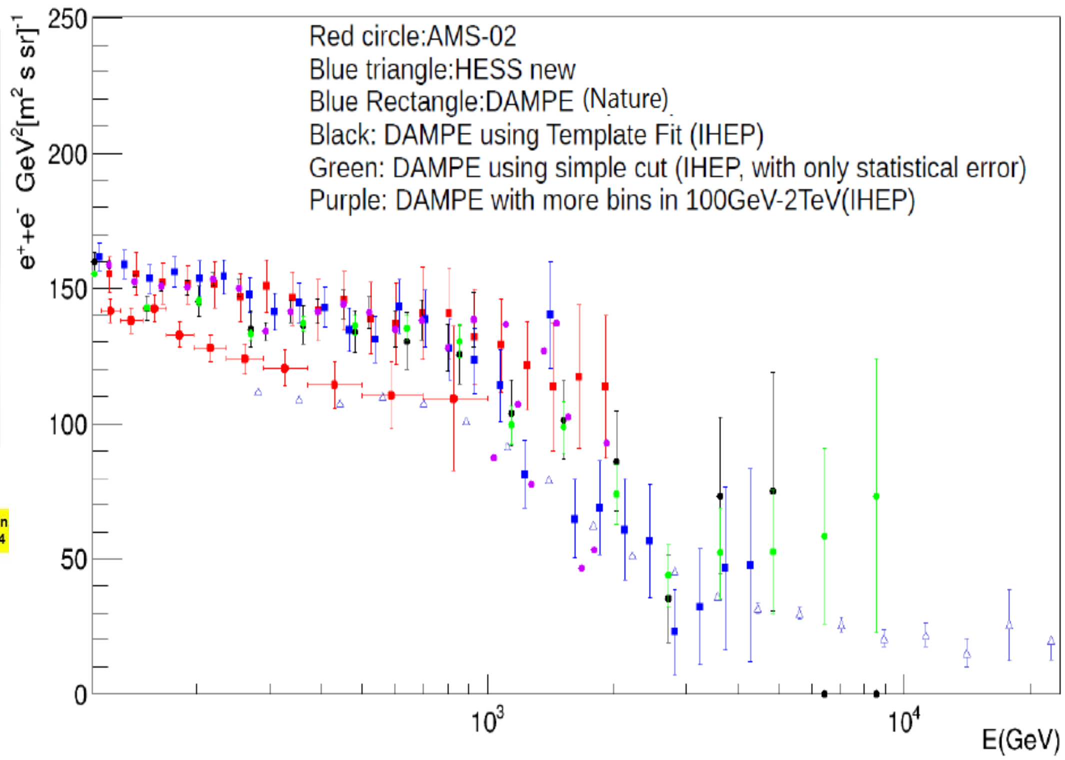
悟空DAMPE (Dark Matter Particle Explorer)

- China's first astronomical satellite, Dec. 17th, 2015.
- Made the most precise measurement of the high energy spectrum of cosmic electrons
- Possible evidence for dark matter particle, but debated



- Charge measurement (dE/dx in PSD, STK and BGO)
- Pair production and precise tracking (STK and BGO)
- Precise energy measurement (BGO bars)
- Hadron rejection (BGO and neutron detector)

J. Chang et al. DAMPE Collaboration Astroparticle Physics 95 (2017) 6–24

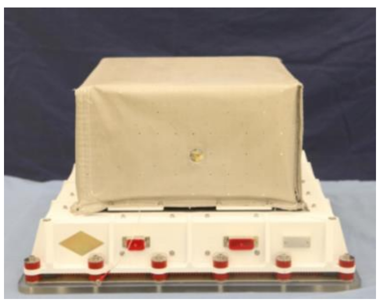


DAMPE 100 GeV-10 TeV电子正电子能谱结果

PI: Prof. Jin Chang, Purple Mountain Observatory, CAS

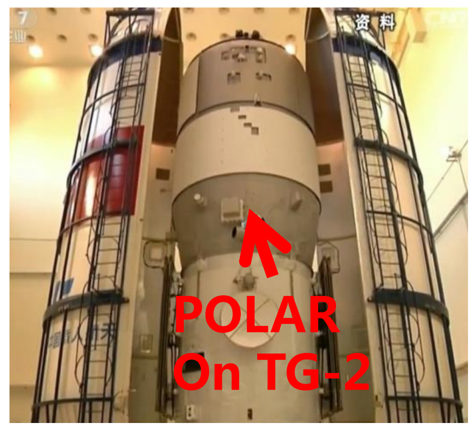
天极POLAR: GRB polarimeter

- 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 of GRB polarization with high precision!



Detector

Electronics



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Institute of High Energy Physics
Chinese Academy of Sciences

ISDC

PAUL SCHERRER INSTITUT PSI

ANNECY lapp

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

慧眼*Insight*-HXMT

- The 1st X-ray satellite in China, 06/15/2017
- Features:
  - Large effective area
  - High timing resolution
  - 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)

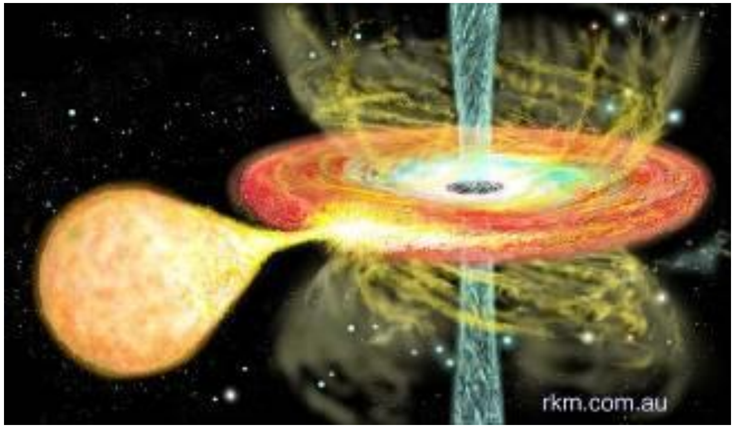
sciencemag.org

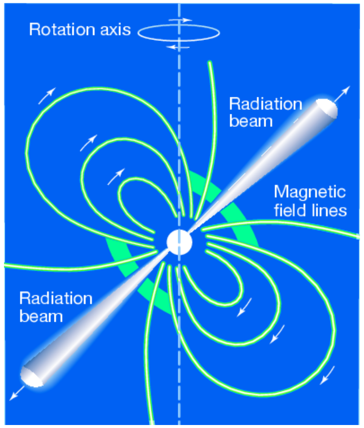
China successfully launches x-ray satellite | Science

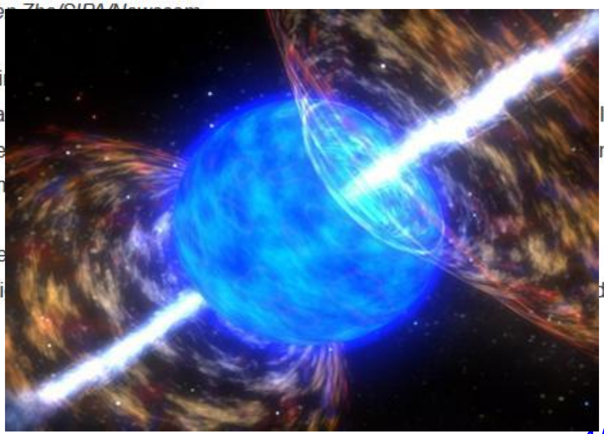
By Dennis NormileJun. 15, 2017 , 11:00 AM

4-5 分钟

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

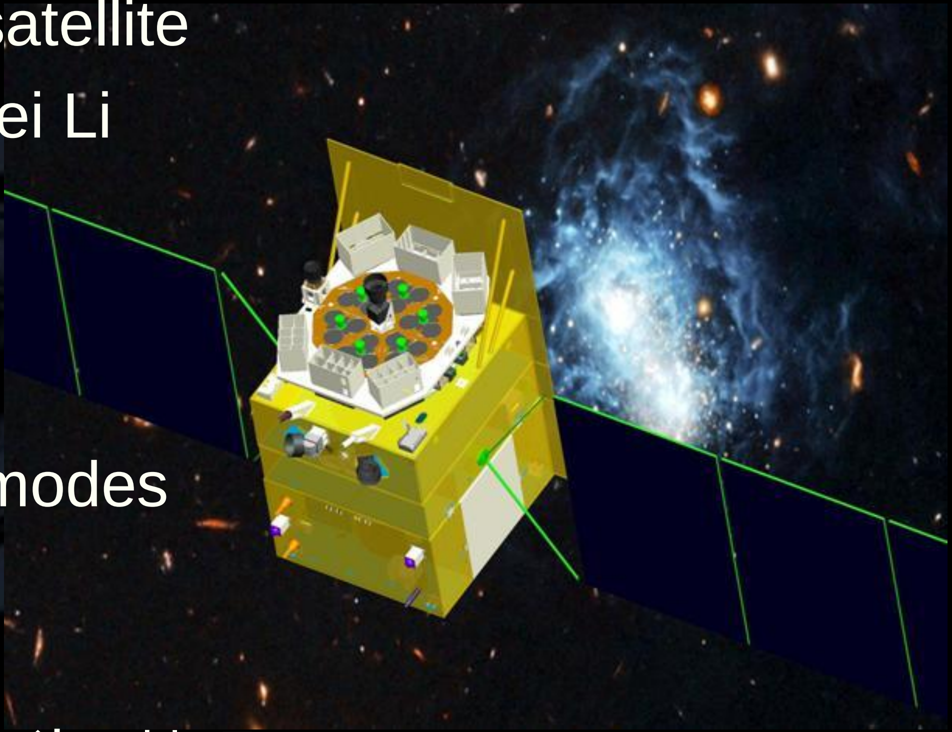






Hard X-ray Modulation Telescope (HXMT) satellite
硬X射线调制望远镜（HXMT）卫星

- China's 1st X-ray astronomy satellite
- Proposed in1993 by Prof. Tipei Li
- Selected in 2011
- Total weight ~2500 kg
- Cir. Orbit 550 km, incl. 43°
- Pointed, scanning and GRB modes
- Designed lifetime 4 yrs
- Launched on June 15th, 2017
- Dubbed "*Insight*" (发射后命名为 "慧眼")



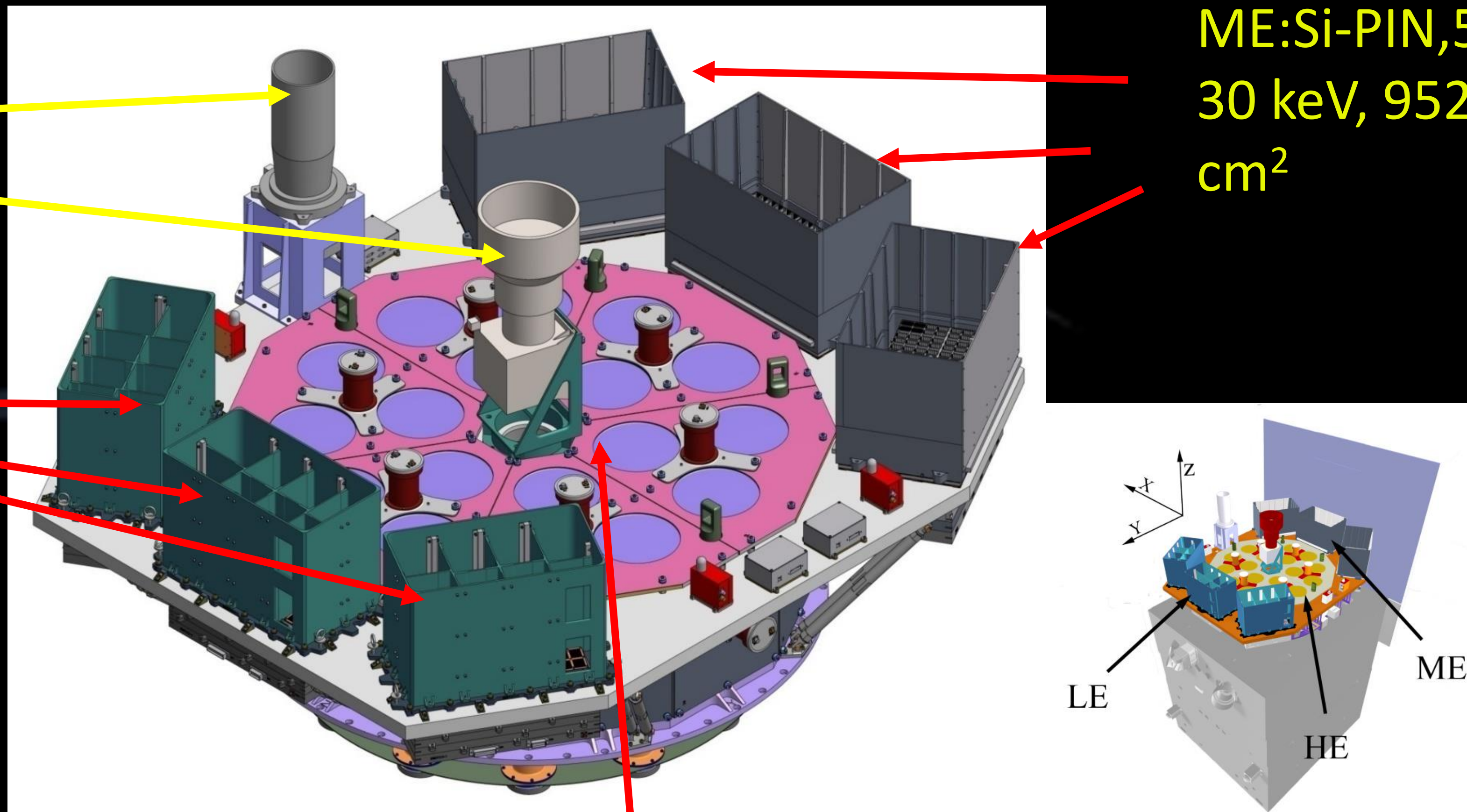
Zhang, S.-N. et al. Overview to the Hard X-ray Modulation Telescope (Insight-HXMT) Satellite. Science China Physics, Mechanics, and Astronomy 63, 249502 (2020)

Science payload科学载荷

Star tracker

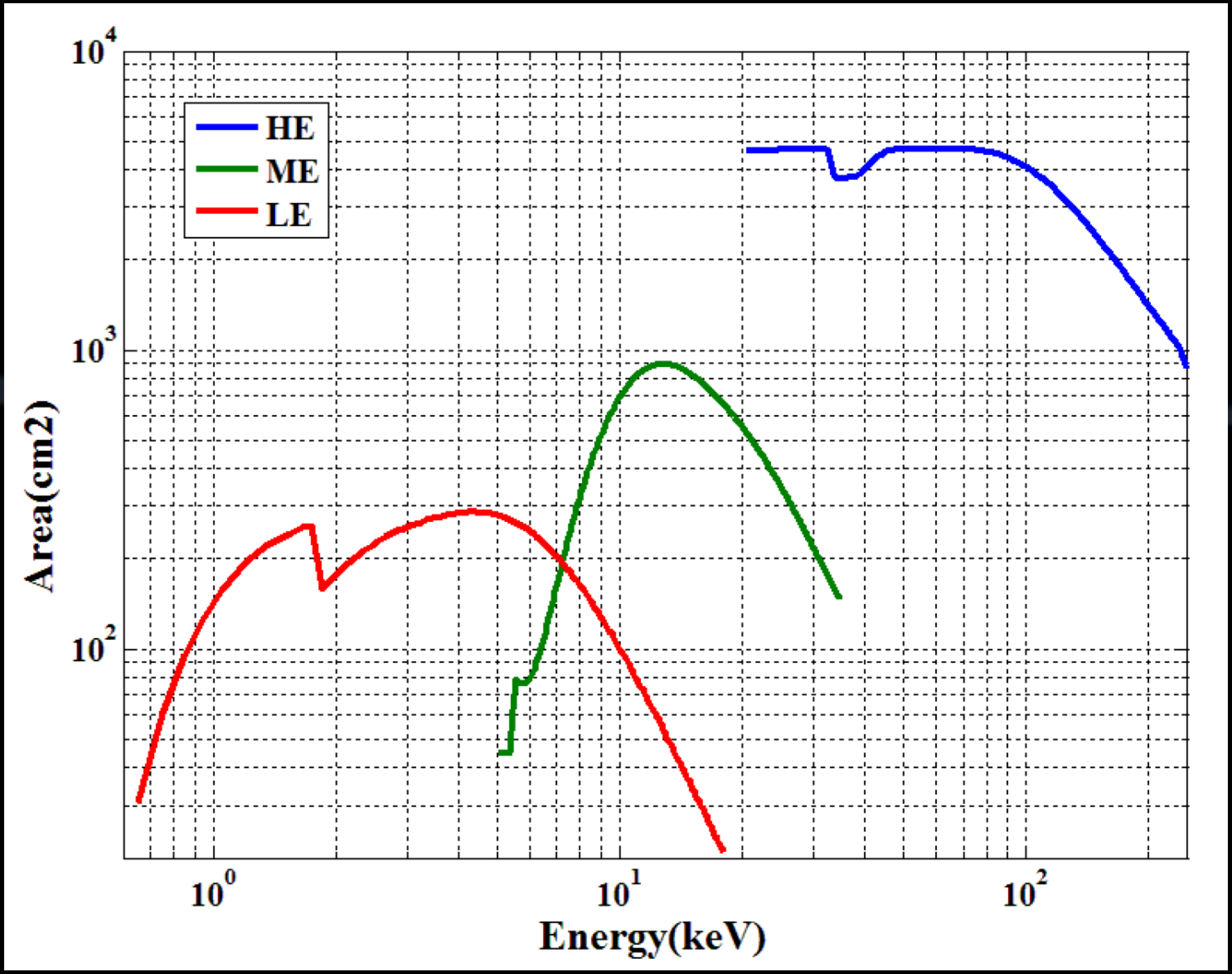
ME:Si-PIN,5-30 keV, 952 cm^2

LE:SCD,1-15 keV, 384 cm^2

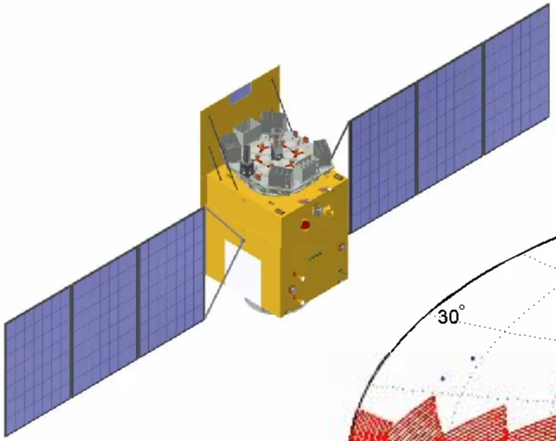


HE: NaI/CsI, 20-250 keV, 5000 cm^2

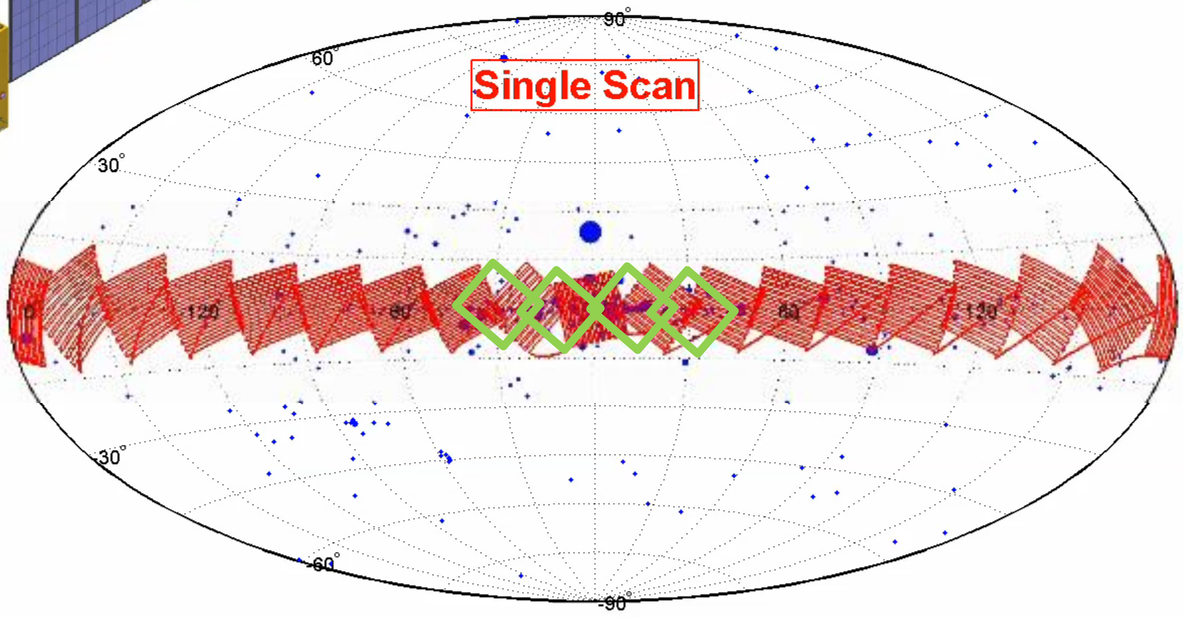
Effective area有效面积



Insight-HXMT scanning survey of the MW
“慧眼”对银道面的扫描巡天



Single scan sensitivity: 3-10 mCrab
(spectral shape dependent)



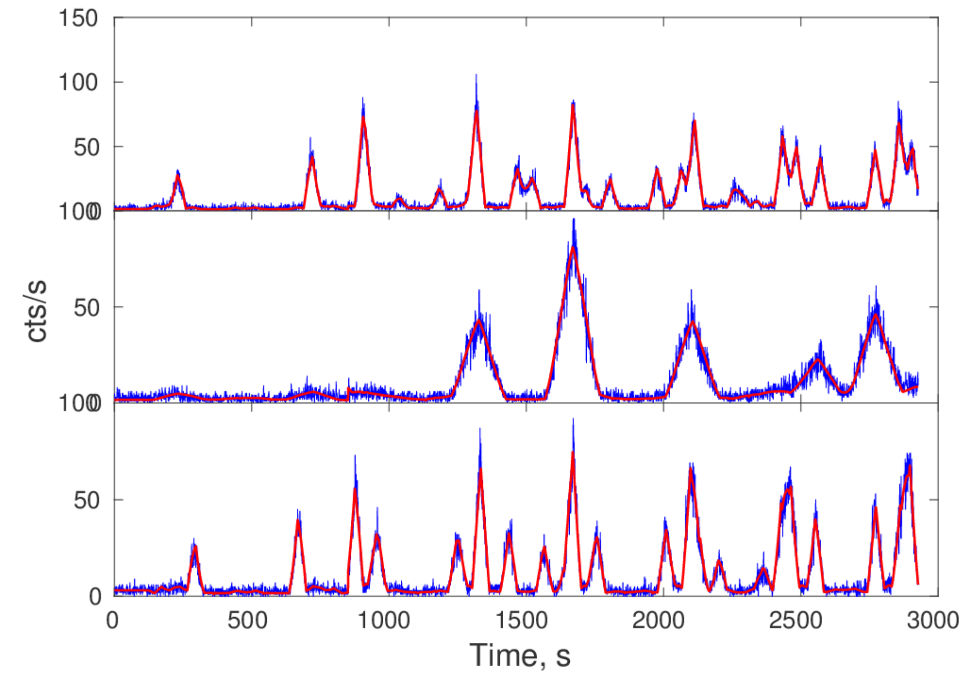
Galactic Plane: (20°*20°)*18 + (20°*20°)*4

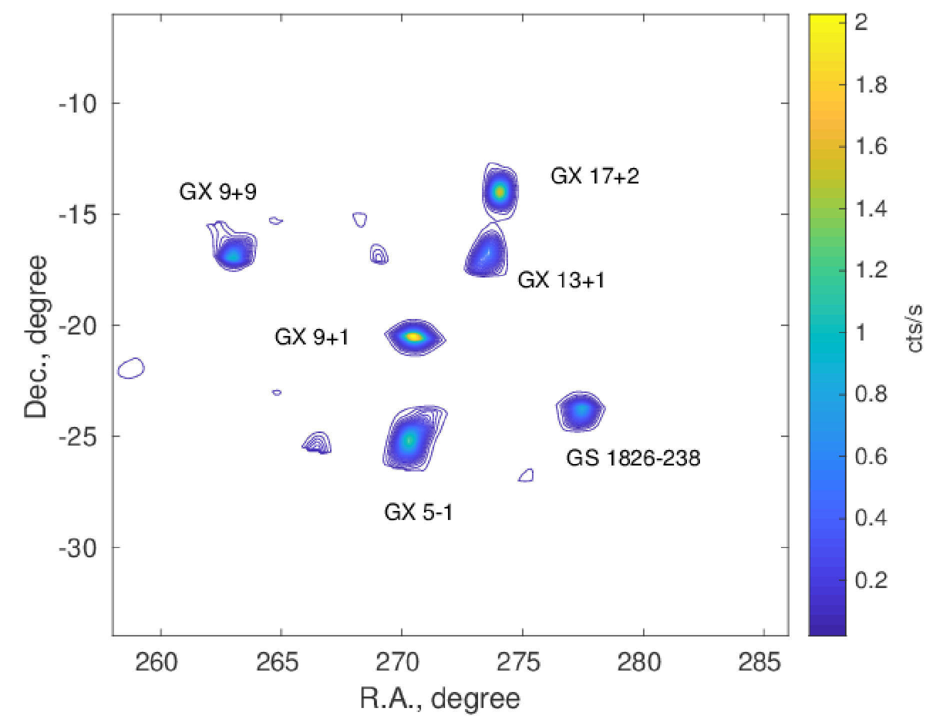
- 11 center regions: 90 times/year (-60°~60°), 11 outer regions: 10 times/year

Sai, N. et al., 2020

Scan light curve & reconstructed image
扫描光变曲线和重建的图像

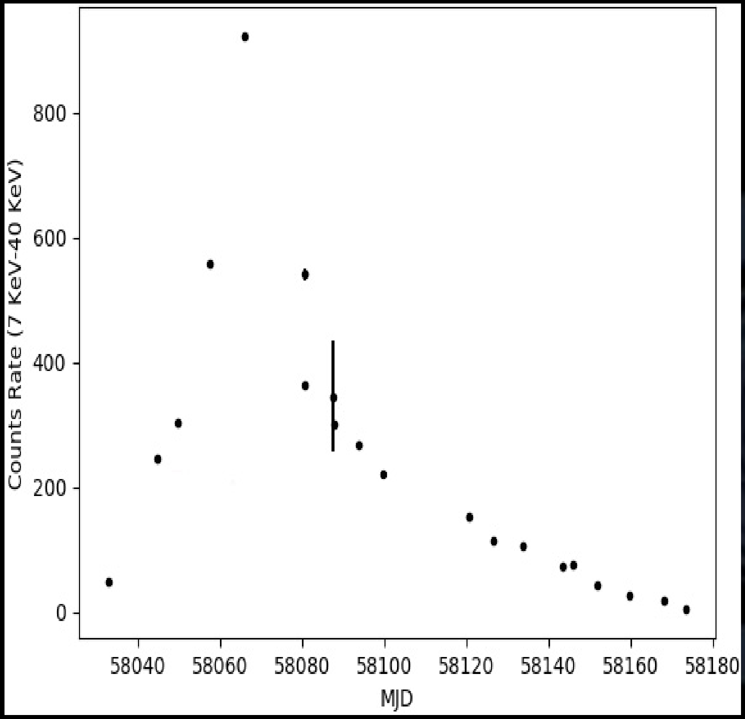
July 16 on Galactic center (LE 1-6 keV)





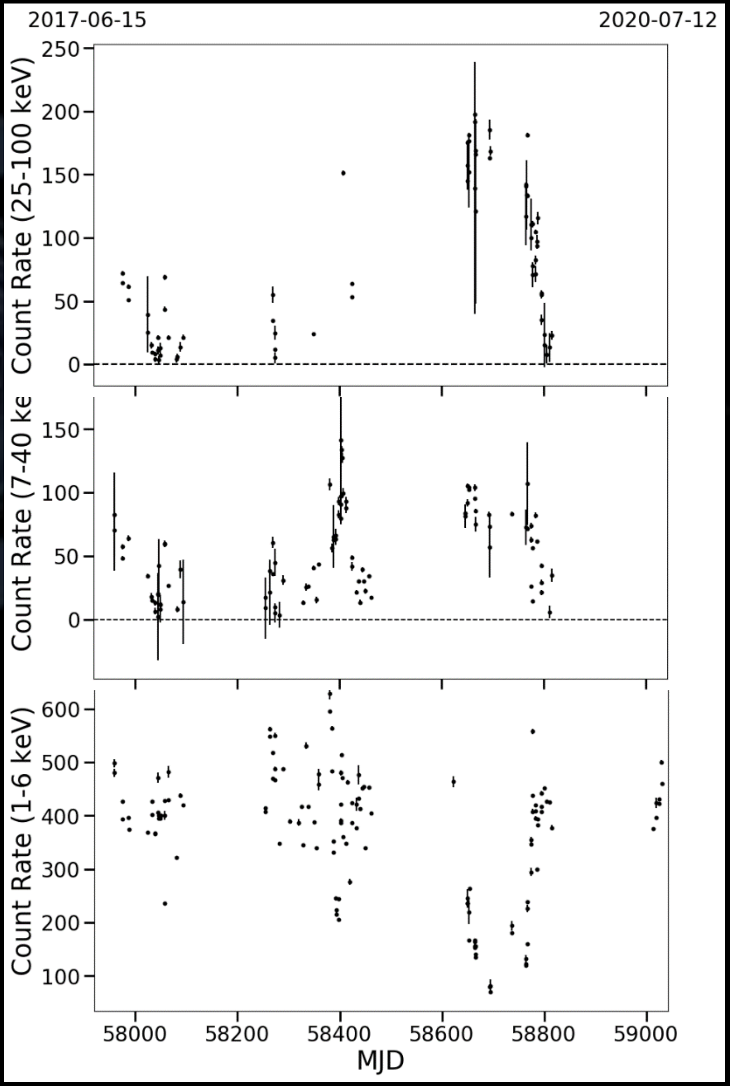
Direct Demodulation Method (Li & Wu 1993); Guan, J. et al., 2020

Long-term monitoring of ~200 sources
大约200个天体长期X射线光变曲线监测

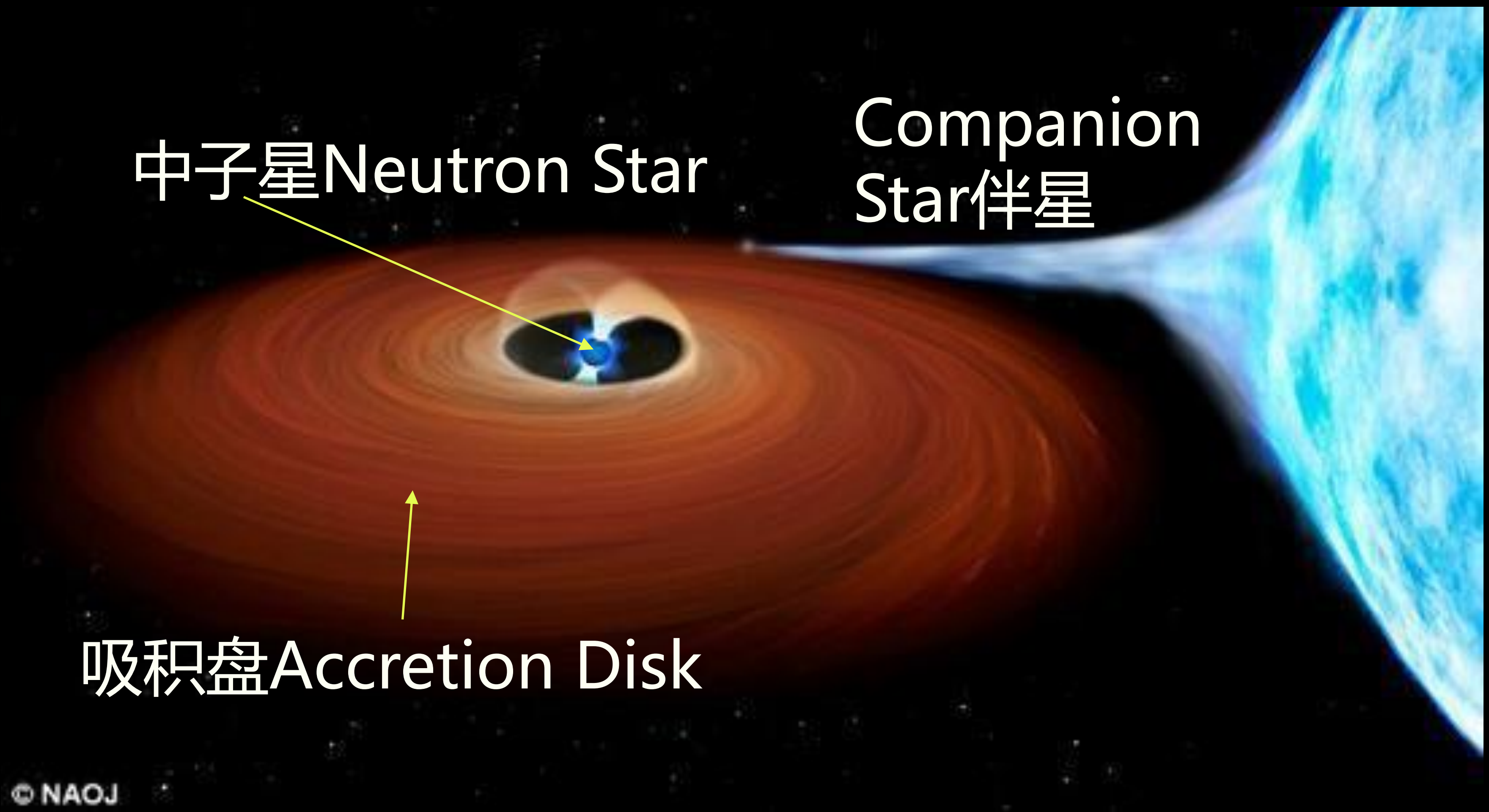


ME (7-40 keV):
Swift J0243.6+6124,
Accreting pulsar

1-250 keV: Cyg X-1, accreting BH

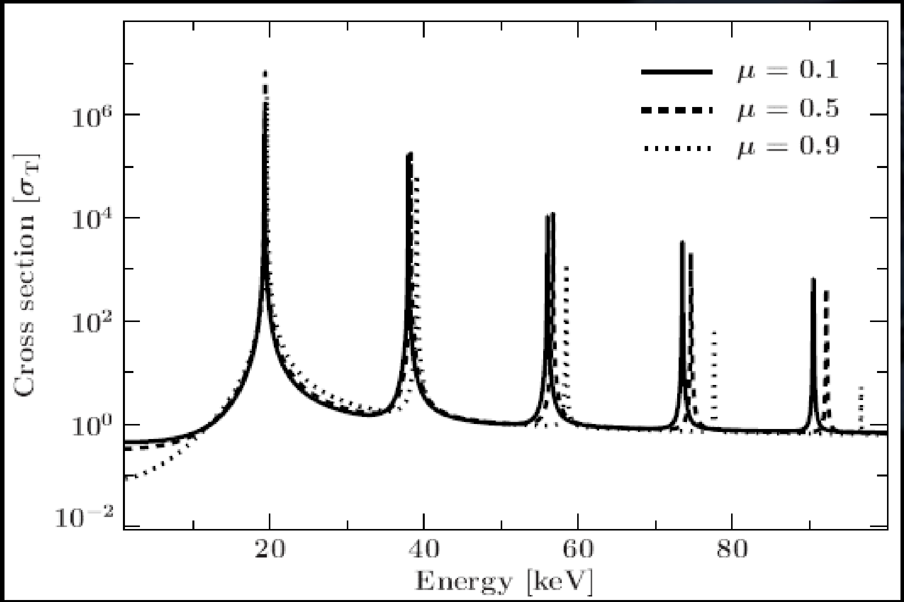


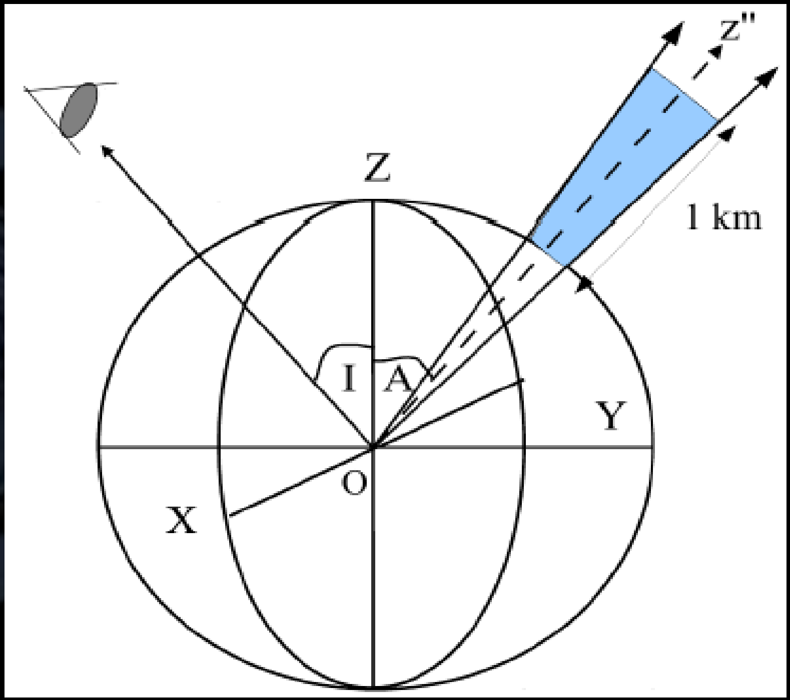
Extremely Complex Interactions in NSXBs
“吸积”中子星和吸积盘复杂的相互作用



Extreme Magnetism near Neutron Stars
中子星附近有宇宙最强磁场

$$E_n = (m_e c^2)\frac{\sqrt{1 + 2n\frac{B}{B_{crit}}\sin^2\theta} - 1}{\sin^2\theta} \times \frac{1}{1+z}$$





Maitra 2016

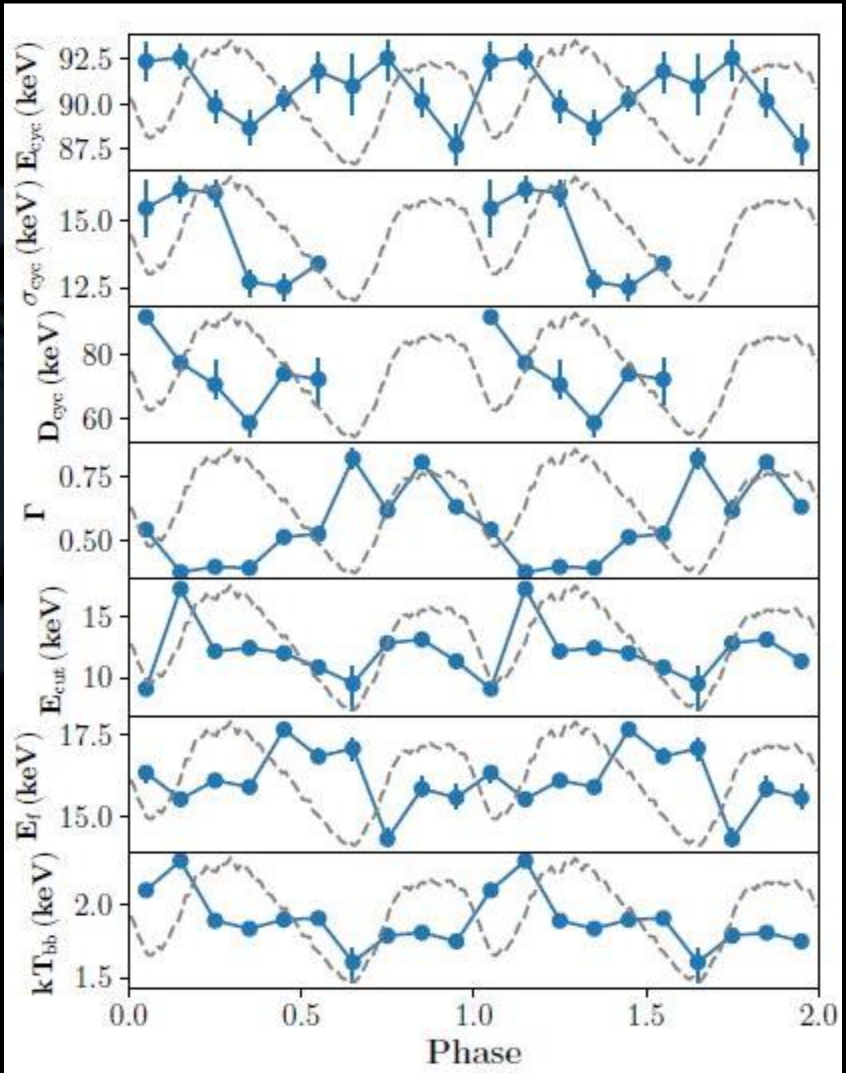
在强磁场中，高能电子围绕磁力线回旋运动呈现出量子态。光子被位于量子态的电子吸收，会形成回旋吸收线。回旋吸收线的能量直接对应着磁场强度，这是目前直接测量中子星磁场的唯一方法。

Highest-E Neutron star cyclotron absorption line
“慧眼”显著探测到最高能量的中子星回旋吸收线

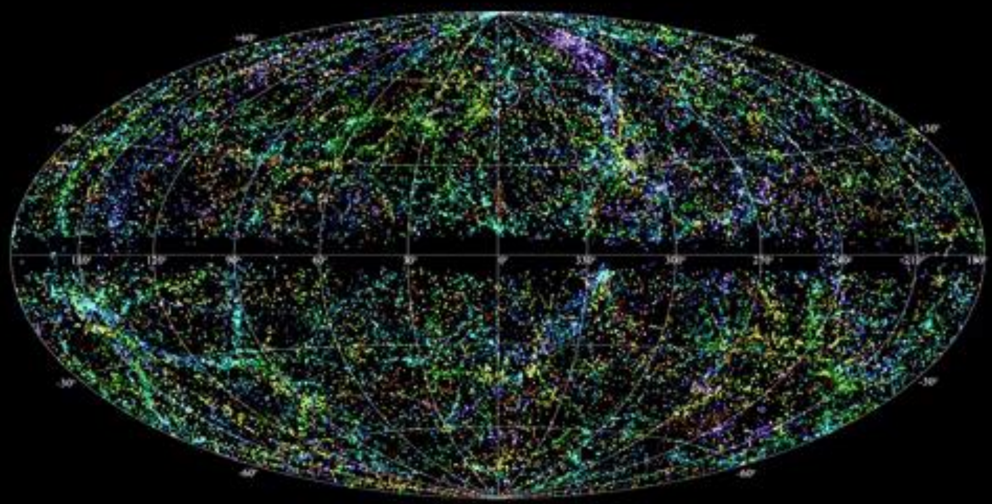
- GRO J1008-57：~90 keV → highest *B* directly measured in the universe ~10^{13}, ~ 4σ with NuSTAR & Suzaku ~79 keV
- 4 HXMT observations ~235 ks ~ 20σ detection

Allow for phase resolved and flux dependent studies

Ge et al. 2020

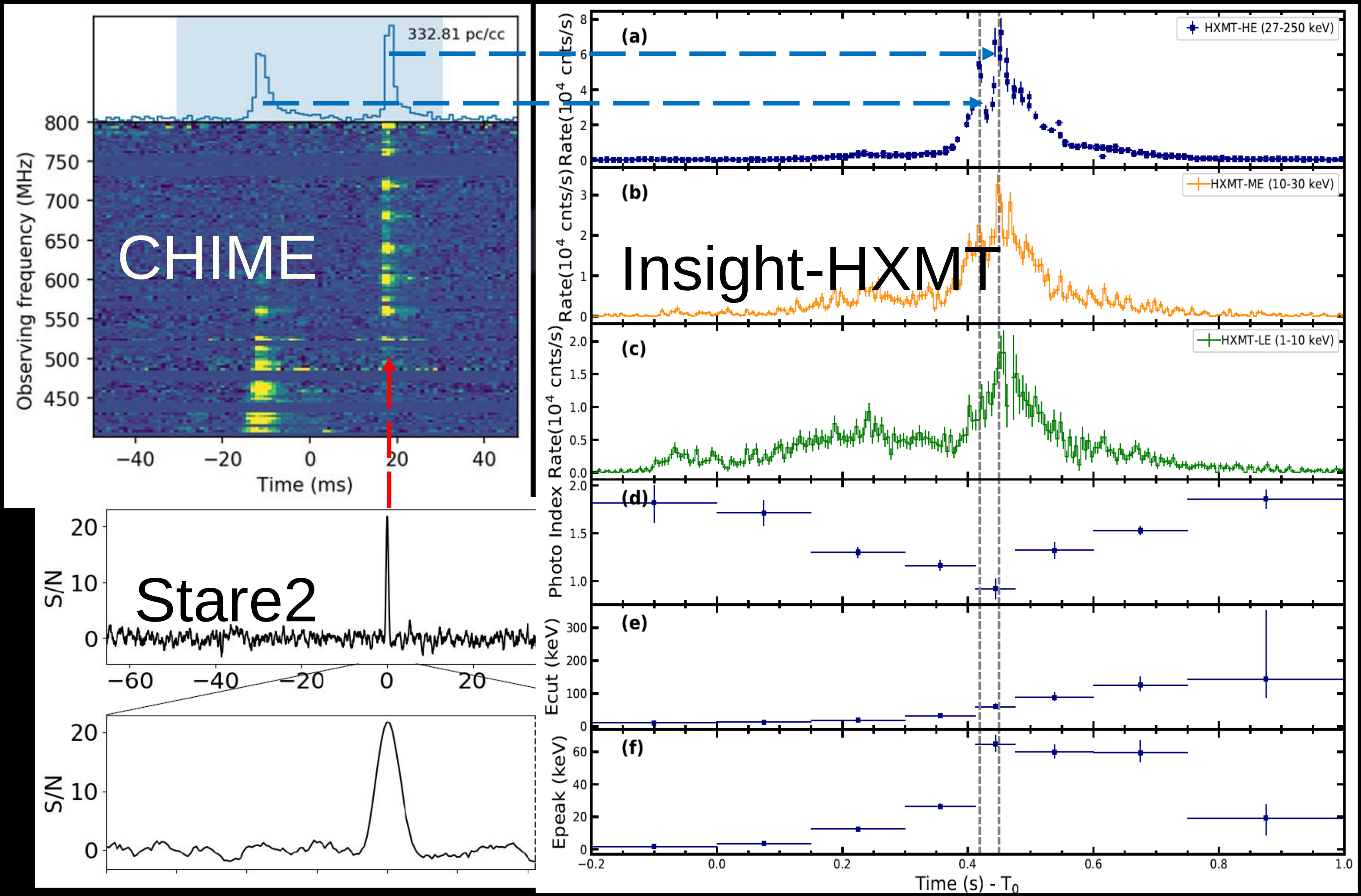


Fast Radio Bursts快速射电暴



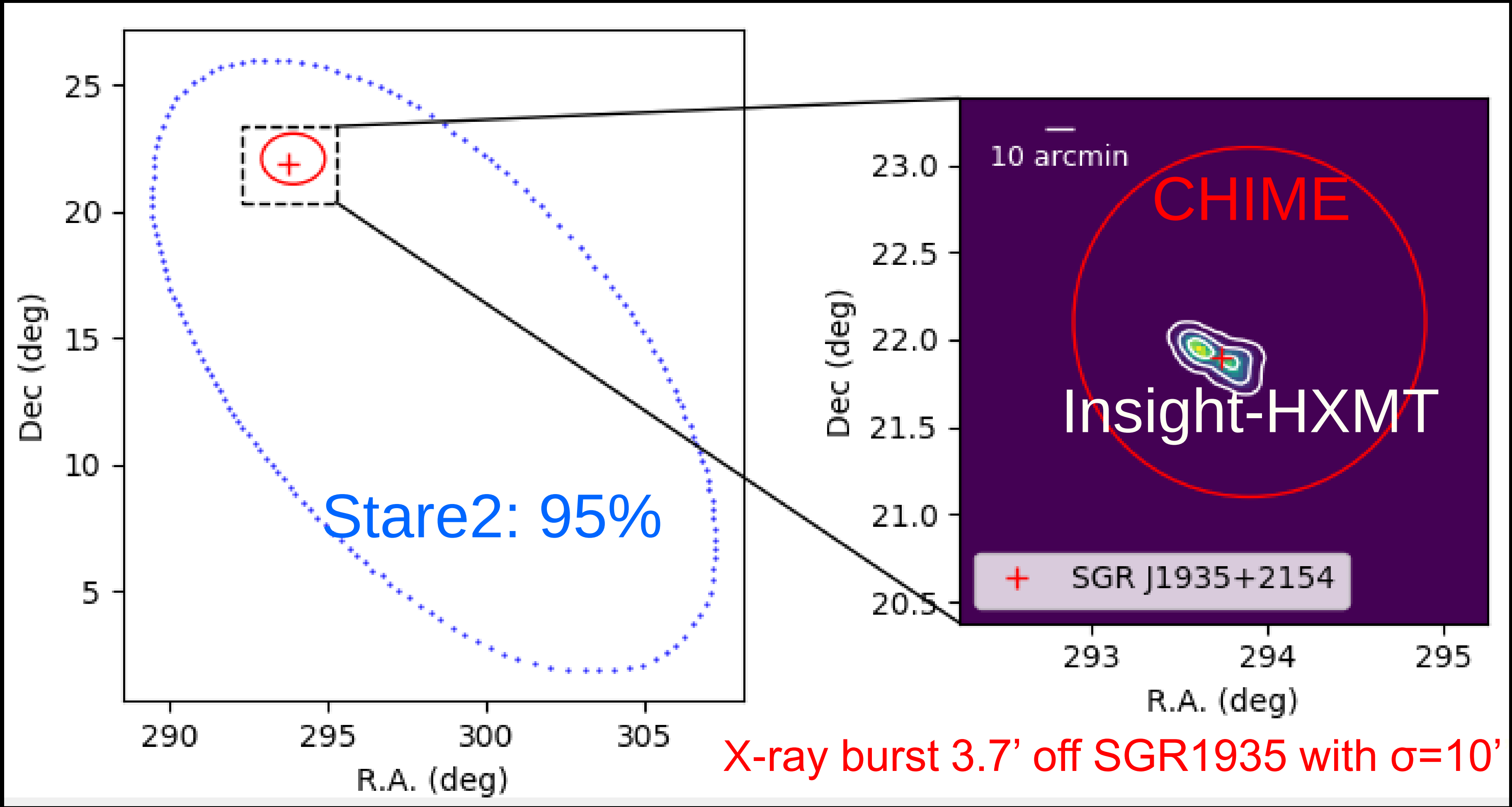
First reported in 2007 (Lorimer et al. 2007): bright millisecond radio pulses, random arrival direction and time, some repeat and even periodic, but counterpart or radiation at any other wavelengths not known, until April 28th, 2020.

Historic event on April 28th 2020
2020年4月28号的历史事件



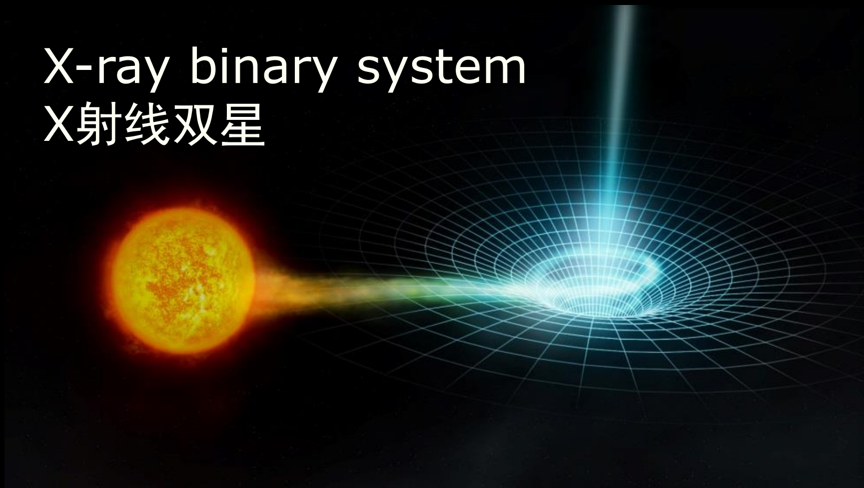
CHIME/FRB Collaboration+; Bochenek+; Li+, 2021, Nature Astronomy

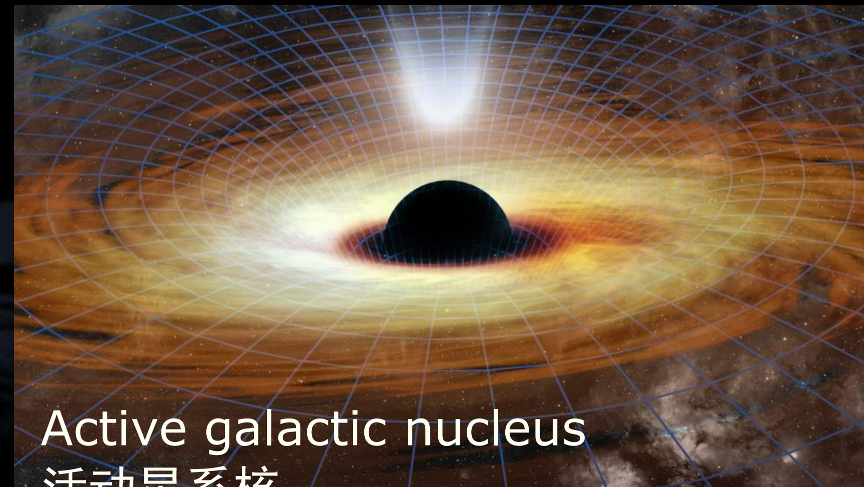
Localization of the X-ray burst定位X射线暴



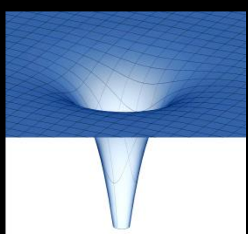
Identification of the X-ray burst with SGR1935, Li+ (Insight-HXMT team), 2021, Nature Astronomy

Extreme Gravity Near Black Holes
黑洞附近存在宇宙最强引力

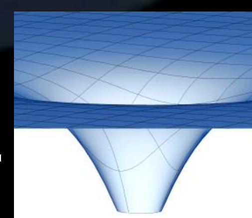




← X-ray study covers wide mass range in uniform setting →



Stellar mass black hole
(or neutron star)
Strongly curved spacetime.
(10^{16} times Solar)



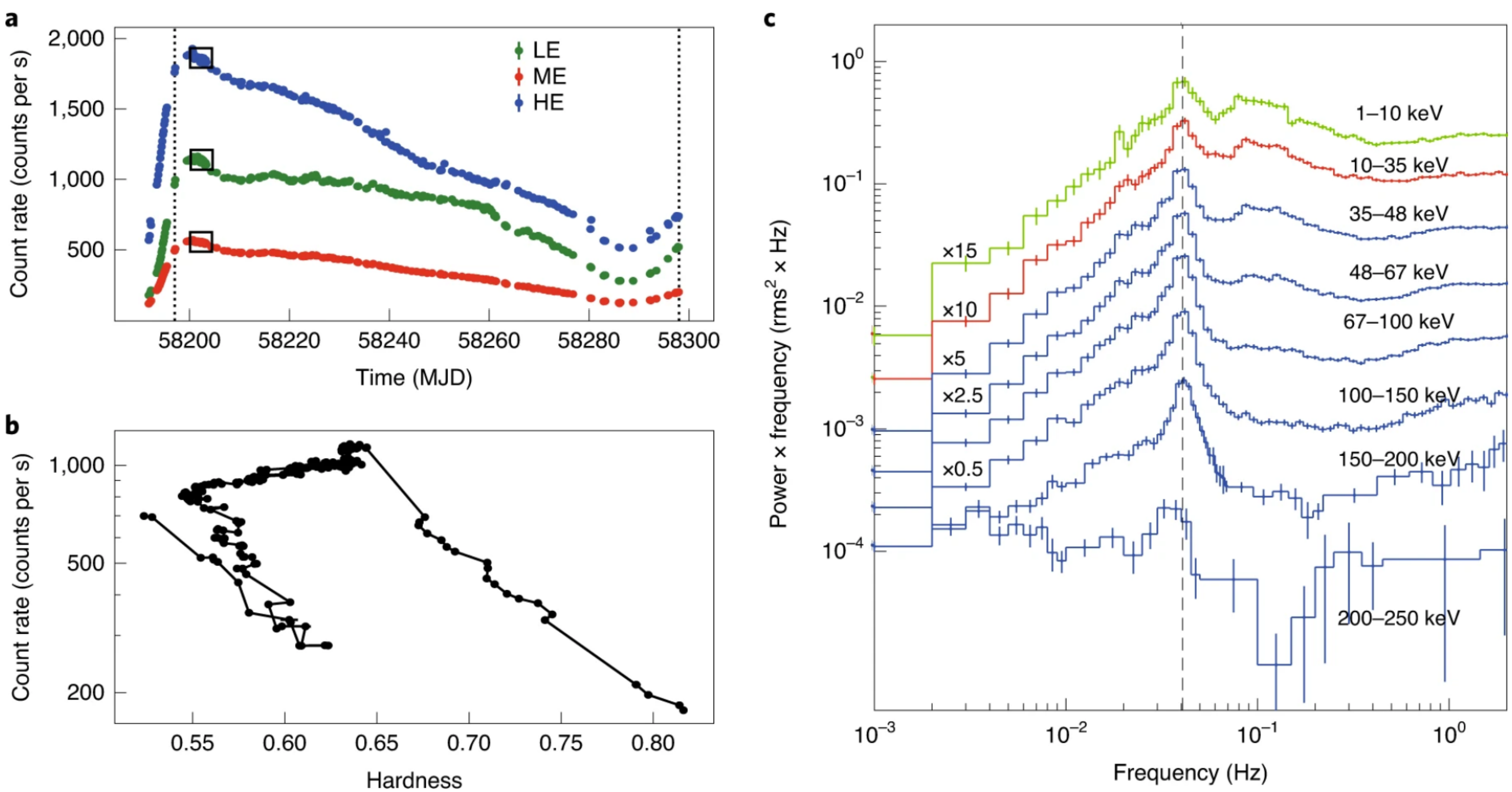
Supermassive black hole
Weakly curved spacetime
(~Solar)

TESTS OF GR PREDICTIONS IN THE STRONG FIELD REGIME OF GRAVITY.
COMPLEMENTARY TO GRAVITATIONAL WAVE EXPERIMENTS.

QPOs of BH binaries: < 30 keV → >200 keV
“慧眼”发现黑洞周围最高能量的准周期振荡

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

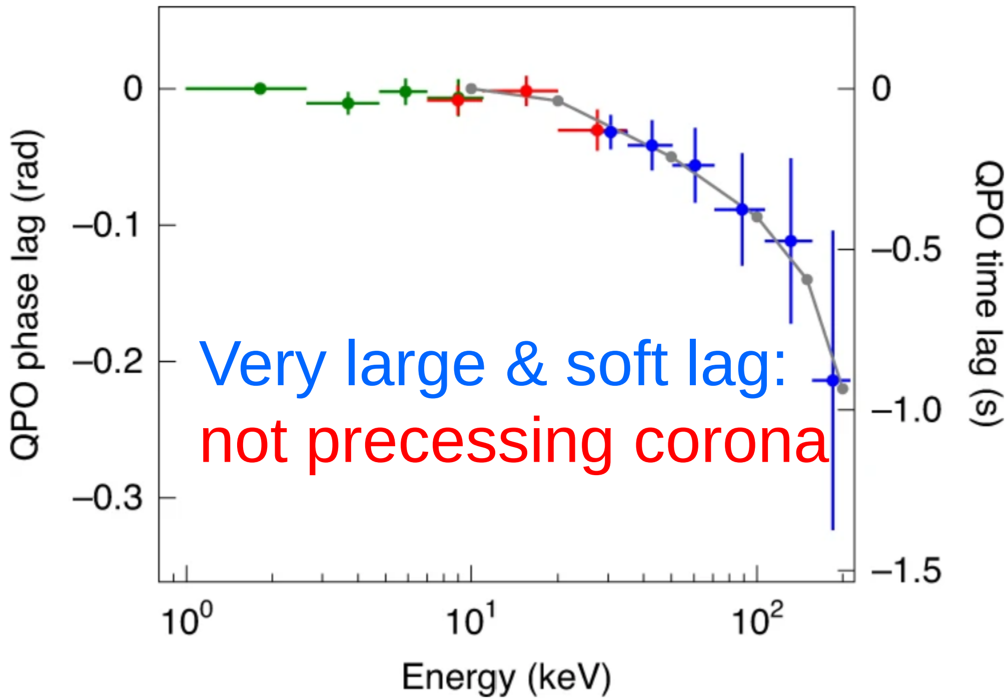


Ma, Tao, SNZ+ 2021, Nature Astronomy

Lag contradicts Comptonization delay in corona: Geometrical effect outside inner disk

Fig. 3: The evolution of the LFQPO phase lag as a function of photon energy for ObsID P0114661003.

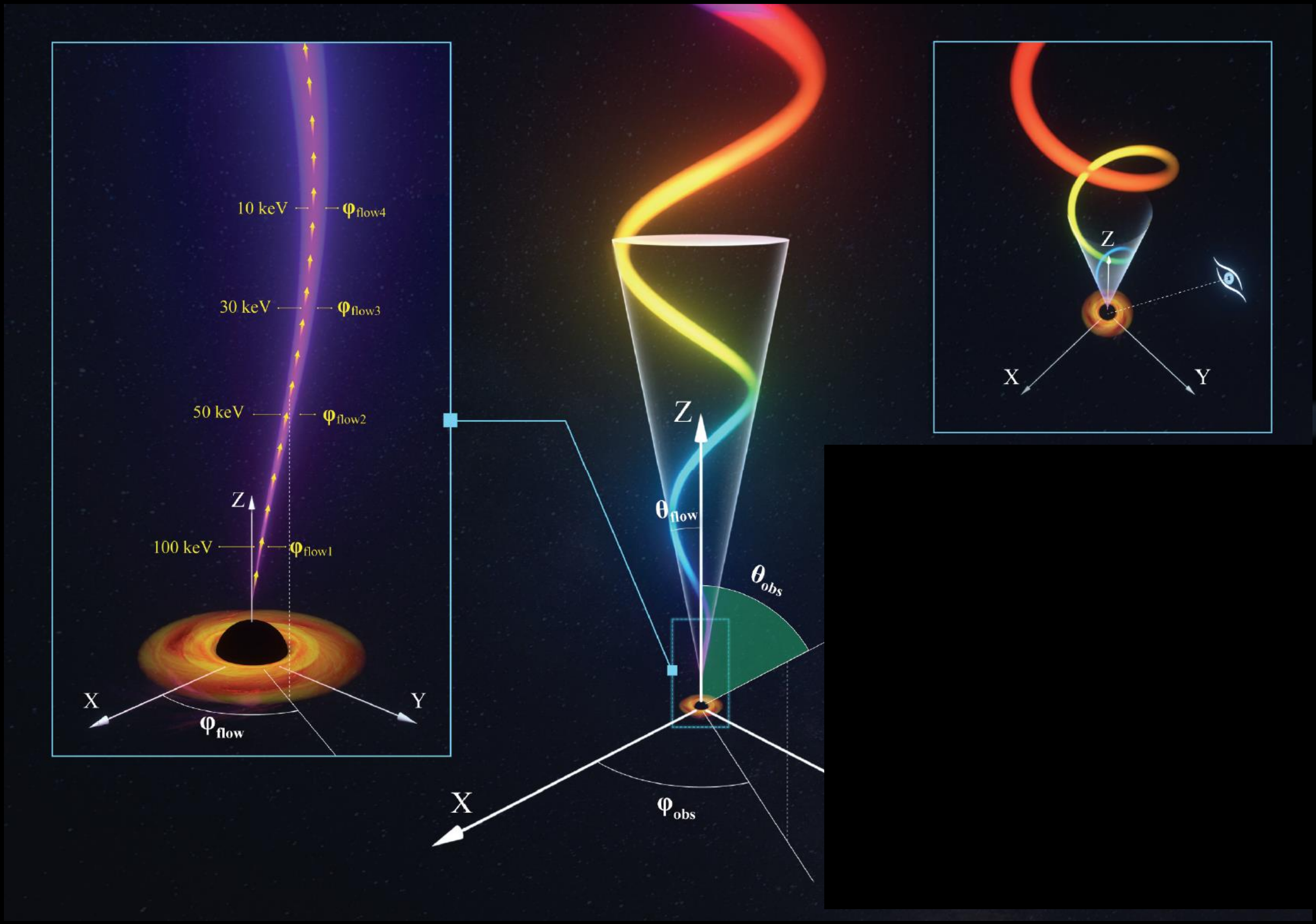
From: Discovery of oscillations above 200 keV in a black hole X-ray binary with Insight-HXMT



In the jet precession model, as the jet is curved, different parts of the jet have different φ_{flow} values (see Fig. 4), which causes the phase lags between different energies (green, LE; red, ME; blue, HE). The curvature of the jet ($\Delta\varphi_{\text{flow}}$) is tuned to match the observed phase lags (see the grey line). Error bars correspond to 1σ confidence intervals.

Ma, Tao, SNZ+ 2021, Nature Astronomy

New model of BH QPOs: L-T precession Jet
基于“慧眼”观测结果建立的黑洞喷流进动模型

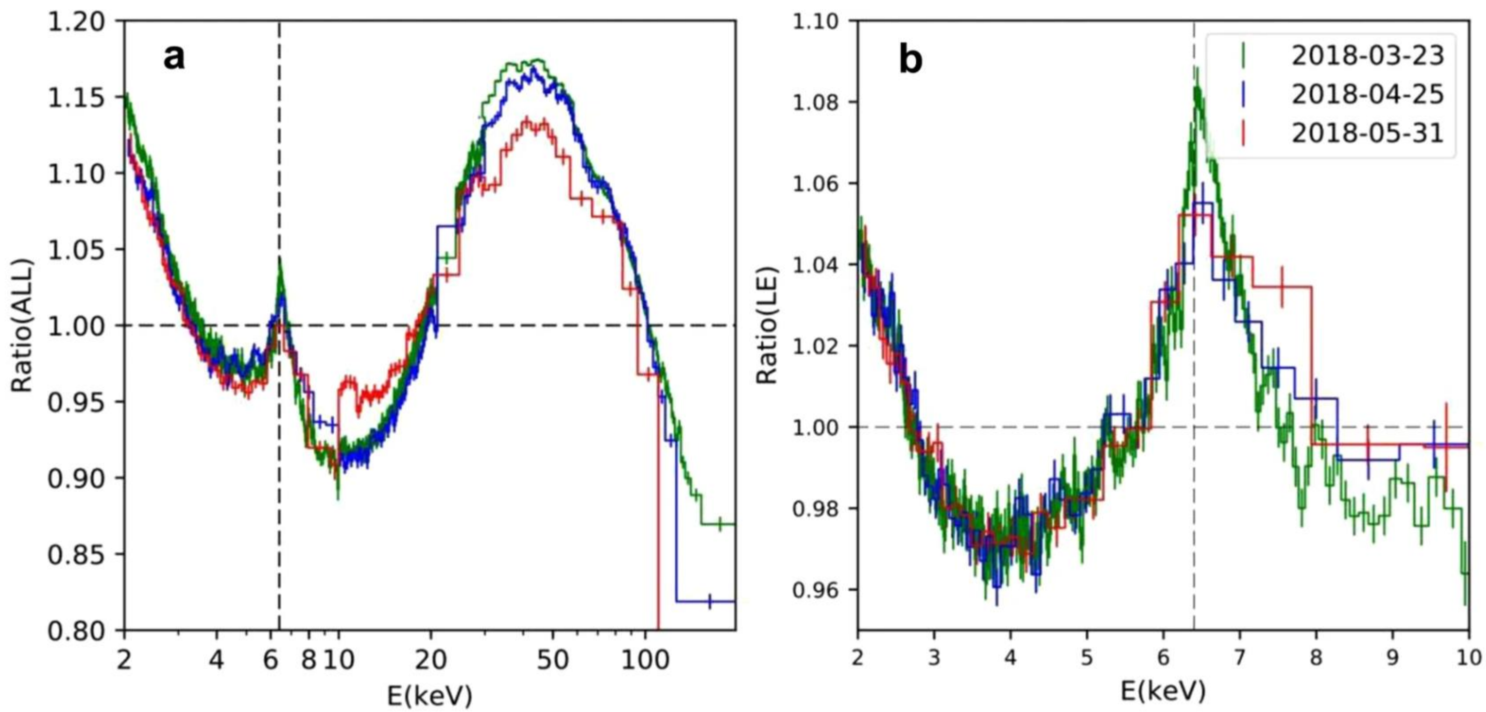


Ma et al. 2020, Nature Astronomy

Broad band energy spectra with Insight-HXMT
慧眼的宽能段能谱

Fig. 2: Ratio of the spectrum to the best-fitting cutoff power law.

From: Insight-HXMT observations of jet-like corona in a black hole X-ray binary MAXI J1820+070



a Ratio of the spectrum of three epochs to the best-fitting cutoff power law (cutoffpl in XSPEC) in 2–200 keV. Time runs from top to bottom, corresponding to the early, middle and late echo of this decay, i.e., 2018-03-23 (MJD = 58201, ObsID = P0114661003), 2018-4-25 (MJD = 58233, ObsID = P0114661028), 2018-05-31 (MJD = 58269, ObsID = P0114661060). **b** Ratio of the spectrum of the same epochs to the best-fitting power law in 3–10 keV. The vertical dashed line indicates the rest energy (6.4 keV) of the iron line. Fluorescence lines due to the photoelectric effect of electrons in the K-shell of silver are detected by the Si-PIN detectors of ME, which dominates the spectrum over 21–24 keV. Therefore, the spectrum over 21–24 keV is ignored.

You+2021, Nature Communications

The contracting corona is an X-ray jet!
慧眼发现收缩的高温冕实际上是X射线喷流！

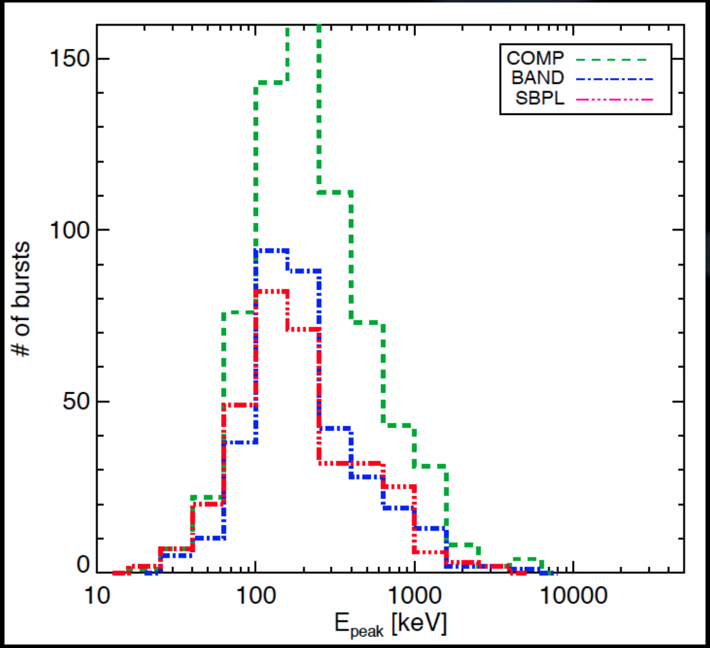
You+2021, Nature Communications

Panaroma of a BH's outburst
慧眼也“看到了”吸积黑洞爆发全景

Weng+ 2021, ApJL

Dedicated working mode for GRB
“慧眼”伽马暴专用观测模式（后增加功能）

Working Mode	NaI energy band (keV)	CsI energy band (keV)	Detector Setting
Regular mode	20-250	40-600	Normal HV
GRB/LG mode	100-1250	200-3000	Lower the PMT HV, turn off the AGC



GRB Epeak measured by Fermi/GBM
（Gruber+, ApJS, 2014）

- **GRB mode better energy range:**
  - According to the simulation, det. efficiency is good for >200 keV
  - GRB Epeak distribution
- **GRB mode: ~30% of obs. time**
  - When the targeted source is occulted by the Earth in pointed observation
  - When HE regular mode is not very useful in an observation

Effective Area for GRBs & Pulsars
针对伽马暴和脉冲星的有效面积

- Can detect GRBs in **both** regular & GRB/LG modes (lower HV for PMT)
- GRB 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

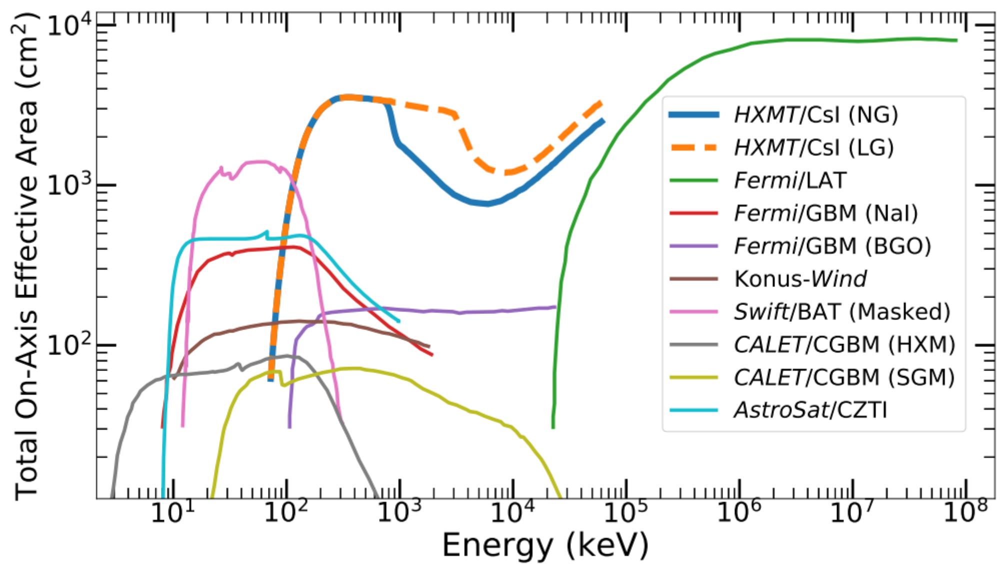
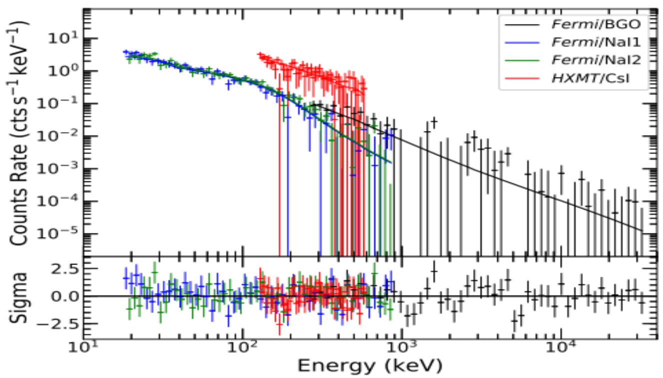


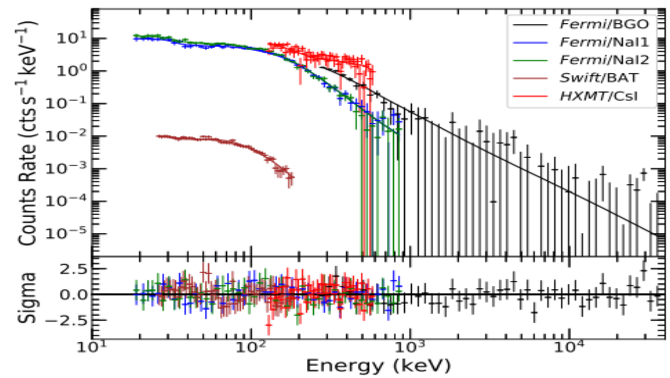
Figure 13: Effective areas of *HXMT*/CsI, *Fermi*/LAT, *Fermi*/GBM, Konus-*Wind*, *Swift*/BAT, *CALET*/CGBM and *AstroSat*/CZTI. The effective area of *Fermi*/GBM (NaI) is the averaged over the unocculted sky.

Luo et al. 2020

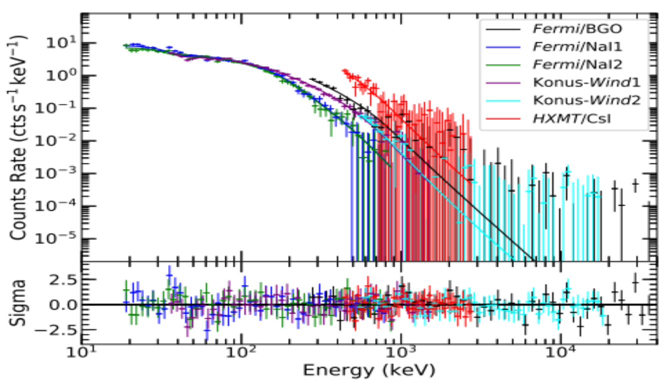
Multi-instrument GRB spectral fitting
多仪器伽马暴能谱拟合



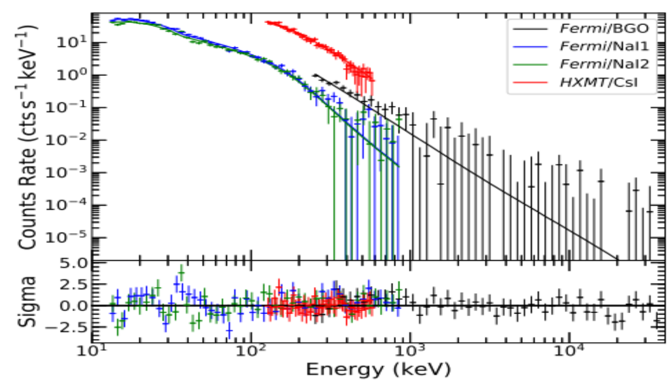
(c) GRB 180413A, NG mode



(d) GRB 180828A, NG mode



(e) GRB 181028A, LG mode



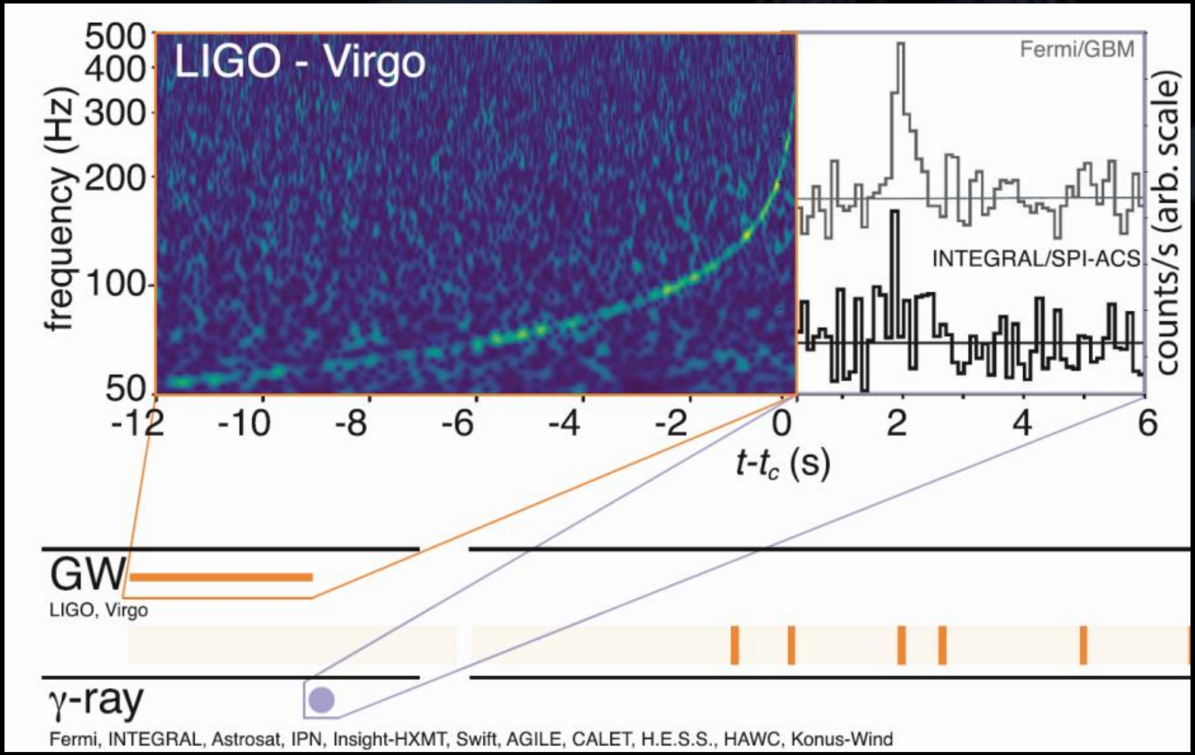
(f) GRB 181212A, NG mode

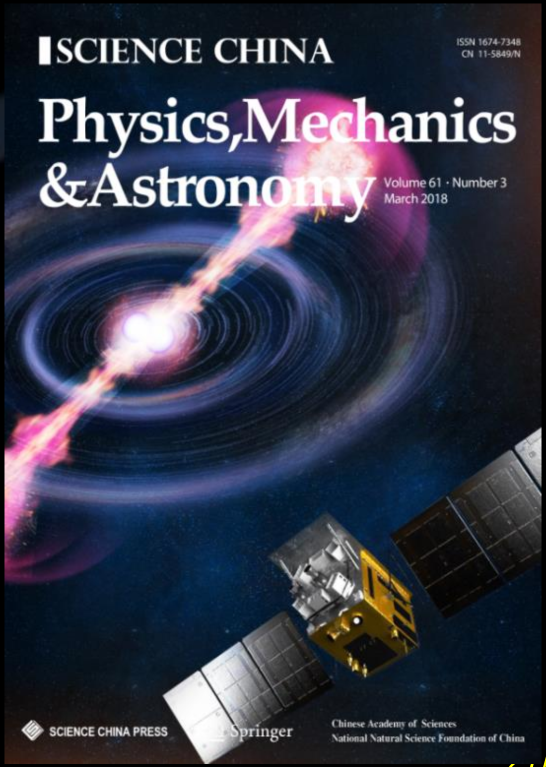
Figure 17: Joint spectral fitting of *HXMT*/CsI (red), *Fermi*/GBM BGO detectors (black), *Fermi*/GBM NaI detectors (blue and green), *Swift*/BAT (brown) and Konus-*Wind* (purple and cyan). In the joint fittings, the 18 *HXMT*/CsI spectra are merged and the merged spectrum are re-grouped to 50 energy bins for display clearly.

Luo et al. 2020

GW EM observations
“慧眼”的引力波电磁对应体观测

- ✓ **Monitored most GW triggers**
  - ✓ Reported observation results in LVC GCNs
- ✓ **Monitored the first BNS GW event GW170817**
  - ✓ GRB170817A was not detected in MeV range, including HXMT
  - ✓ Stringent upper limit constraint between 200 keV to 5 MeV
  - ✓ Joined the MMA paper and published detailed results in Science China





Insight-HXMT joined the MMA paper
“慧眼”加入了引力波多信使历史性论文

- ✓ Quick response, reported HXMT observation by LVC GCN
- ✓ Only 4 X/gamma telescopes monitored the GW source throughout the trigger time
  - ✓ *Fermi*/GBM, SPI-ACS, Konus-*Wind*, *Insight*-HMXT
  - ✓ HXMT has the largest eff. Area & time resolution in MeV
- ✓ Reported observation results in main context and table of MMA

The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20
https://doi.org/10.3847/2041-8213/aa91c9

CrossMark

Multi-messenger Observations of a Binary Neutron Star Merger

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-Hxmt Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT
(See the end matter for the full list of authors.)

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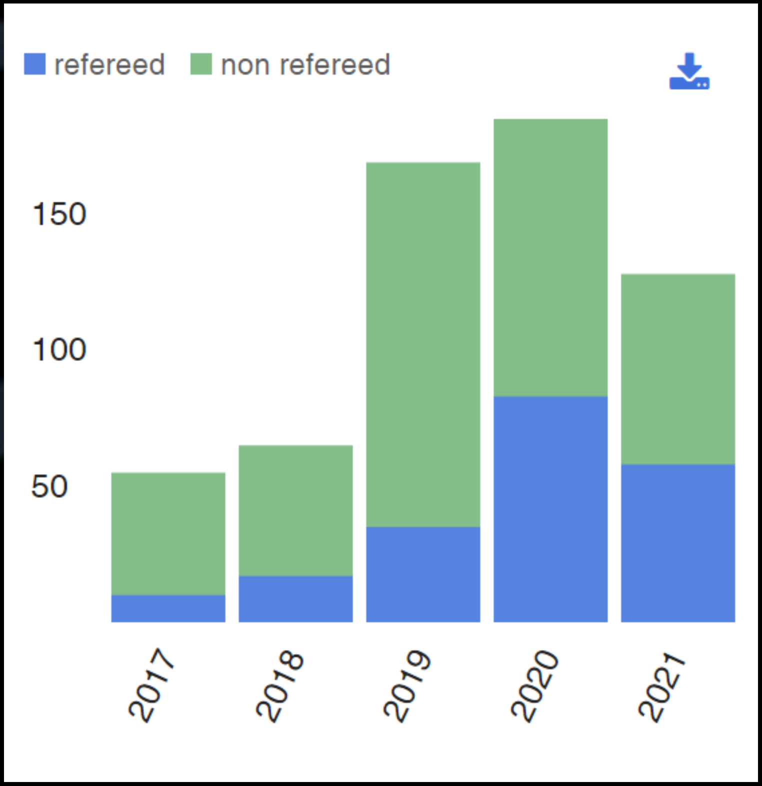
Insight-HXMT Summary慧眼总结

- ✓*Insight*-HXMT is China's 1st X-ray astronomy satellite.
  - ✓1-15, 5-30, 20-250 keV (pointed) and **0.2-3 MeV (all-sky monitor)**
- ✓An open small-observatory
  - ✓Core program: all scientists working in China (most data now public)
  - ✓Guest program: world-wide
    - ✓AO-4 started in 08/2021 (more time than core program)
  - ✓Coordinated multi-λ observations: space & ground

ads: year:2017-2021 full:"HXMT"



hxmt.cn for all information and data download.

Still 6 Problems of "Extreme Universe"

1. Extreme Origin: Big Bang extreme process → Dark matter to normal matter 6:1, but dark matter particles not found
2. Extreme Energy: Energies of cosmic rays > 10^8 in lab. accelerators, but extreme acceleration processes unknown
3. Extreme Sources: High energy γ-ray sources may be extreme accelerators, but need confirmation from surveys
4. Extreme Gravity： Black holes provide strongest gravity, but observations are still not sufficiently accurate
5. Extreme Magnetism: Neutron stars have strongest magnetic field, but vacuum fluctuations not observed
6. Extreme Density: Interior density of neutron stars is highest in the Universe, but quark or neutron matter?

"Exploring the eXtreme Universe (EXU)" International Mega-Science Program of China

Science Theme：Explore the eXtreme Universe (EXU)

Task 1: Space Station

- eXtreme Origin
- eXtreme Energy
- eXtreme Sources

China Space Station: **H**igh **E**nergy cosmic-**R**adiation **D**etector **(HERD)**

China initiated and leads, ~1/3 in kind contributions from ~10 European & other countries/regions

Task 2: Space Observatory

- eXtreme Gravity
- eXtreme Magnetism
- eXtreme Density

enhanced **X**-ray **T**iming and **P**olarimetry (**eXTP**) Observatory

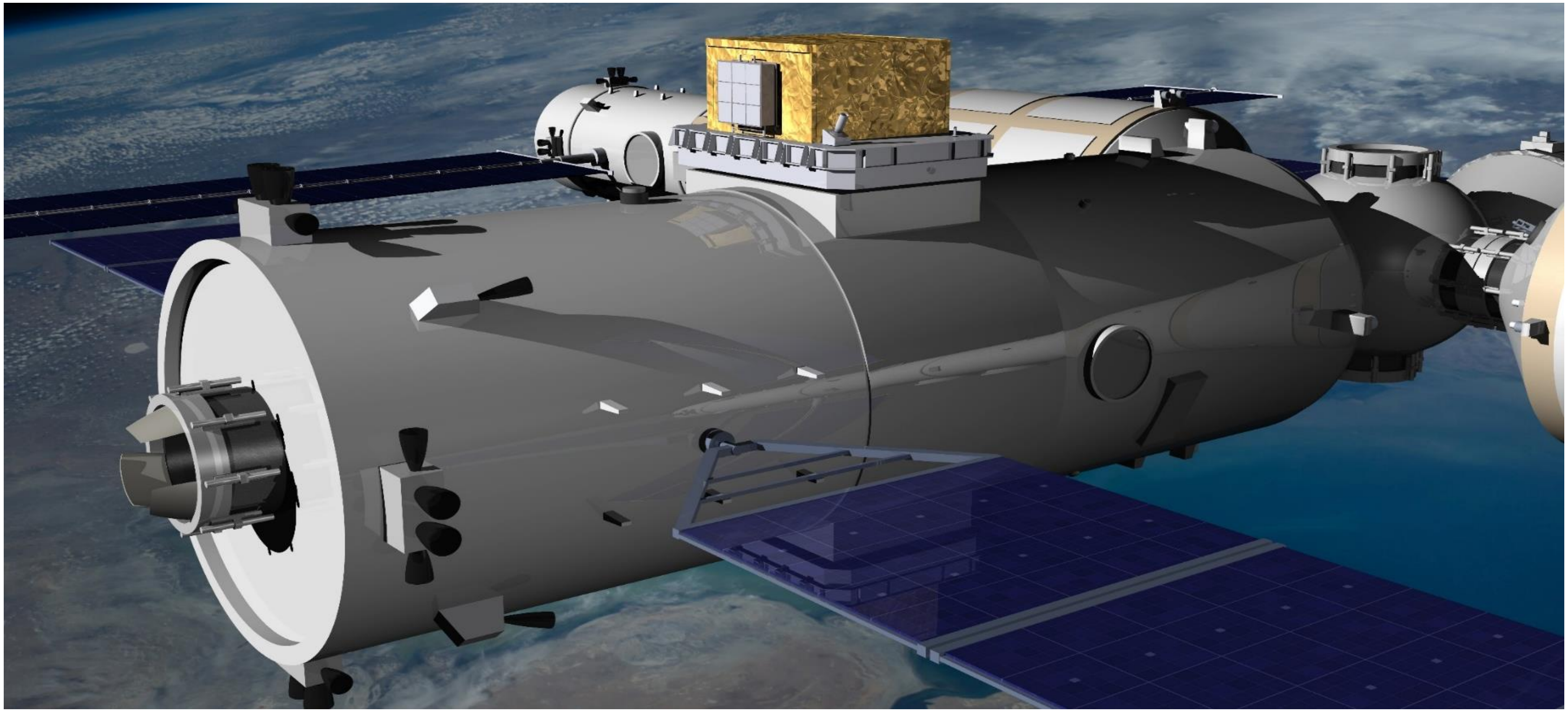
China initiated and leads, ~1/3 in kind contributions from ~20 European & other countries/regions

Project Scientist: Prof. Ming GAO, CSU/CAS; PI: Prof. Shuang-Nan Zhang (zhangsn@ihep.ac.cn), IHEP/CAS; **HERD** Europe coordinator: Dr. Giovanni Ambrosi (INFN/Perugia); **eXTP** Europe coordinator: Dr. Marco Feroci (INAF/Rome)

China welcomes participation and contributions from all!

High Energy cosmic-Ray Detection (HERD)

- HERD: flagship and landmark scientific experiment onboard the China's Space Station, 2027-2037.
  - Extreme Origin: dark matter search with unprecedented sensitivity
  - Extreme Energy: Precise cosmic ray spectrum and composition measurements up to the knee energy
  - Extreme Source: Gamma-ray monitoring and full sky survey



Extreme Origin: Search for Dark Matter

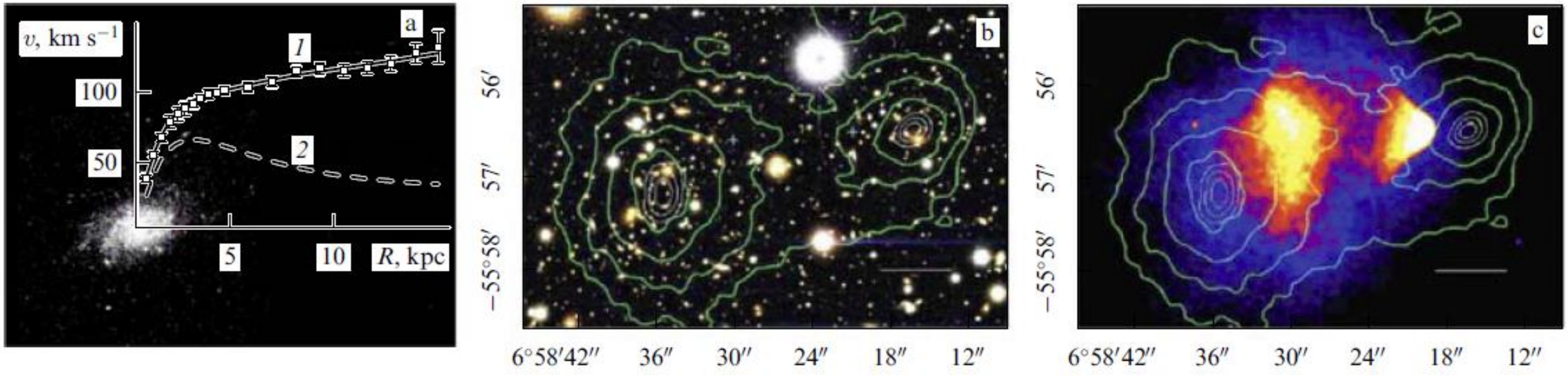
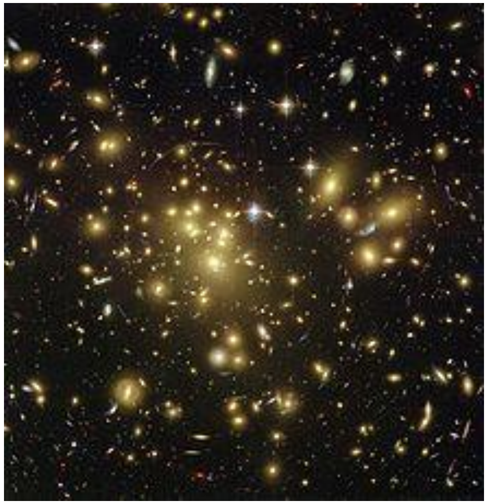


Figure 2. (a) Rotation curves for the M33 galaxy [4]: *1*, the observed curve, *2*, theoretical curve of the glowing galactic disk. (b) Optical and (c) X-ray images of cluster 1E0657-558 obtained with the Hubble and Chandra telescopes, respectively. The curves show mass density contours reconstructed by gravitational lensing [5]. Horizontal axes are the inclination angles, vertical axes are the ascention angles.

- Dark Matter exists
- Ratio of DM to ordinary matter generated from the extreme progress of the BIG BANG is 6:1.
- DM particle NOT found yet



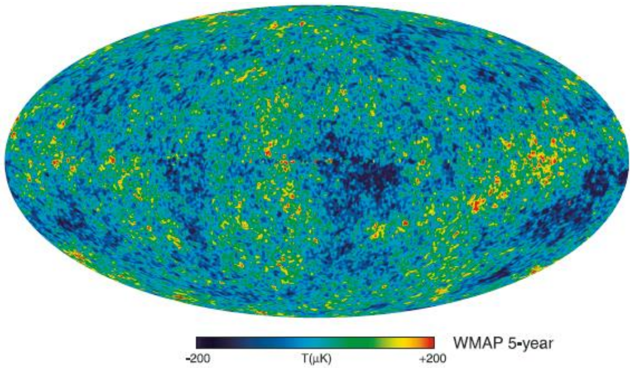
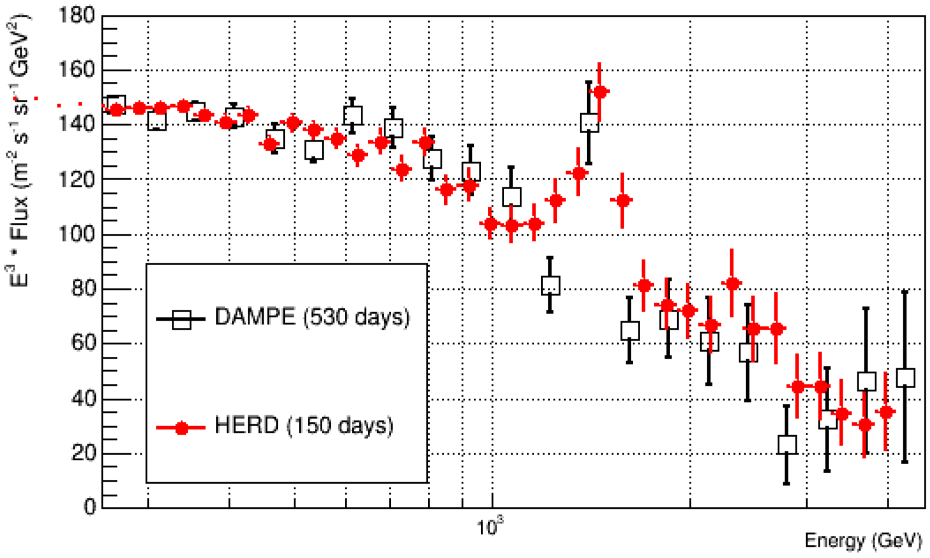
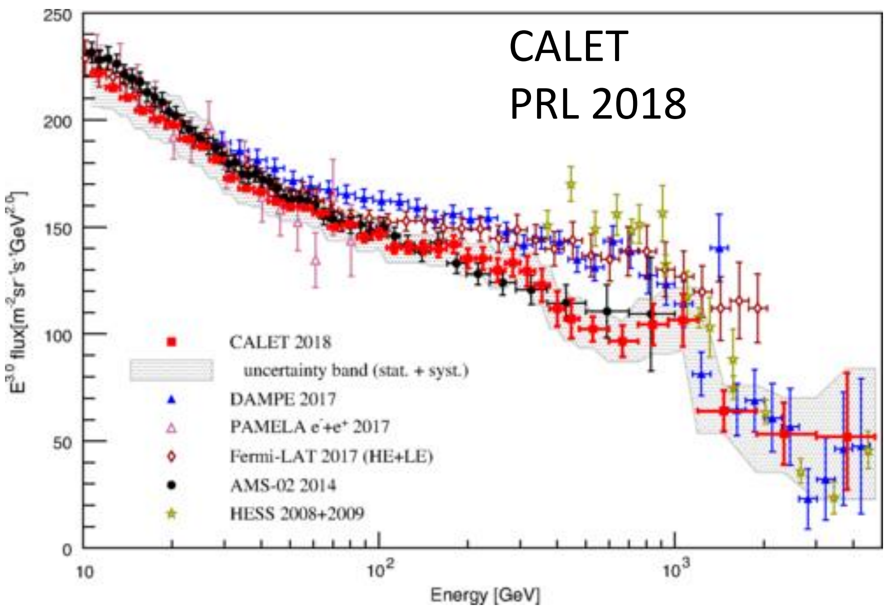


Figure 12. The foreground-reduced Internal Linear Combination (ILC) map based on the five year *WMAP* data.

e+/- spectrum: dark matter particle?

- HERD can confirm ~TeV features in the electron spectrum
- HERD can distinguish different origins of excess and new features in the electron spectrum.

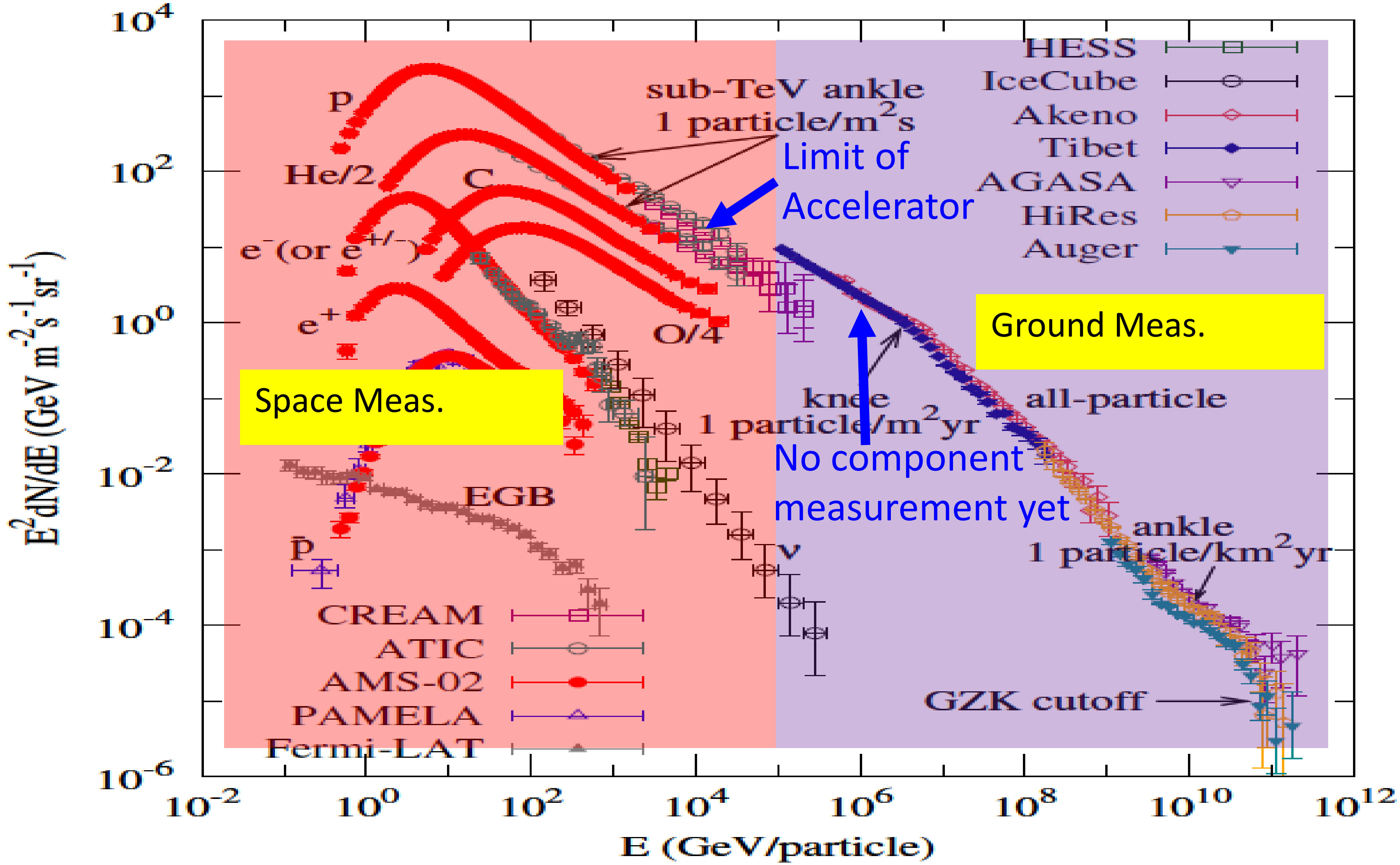




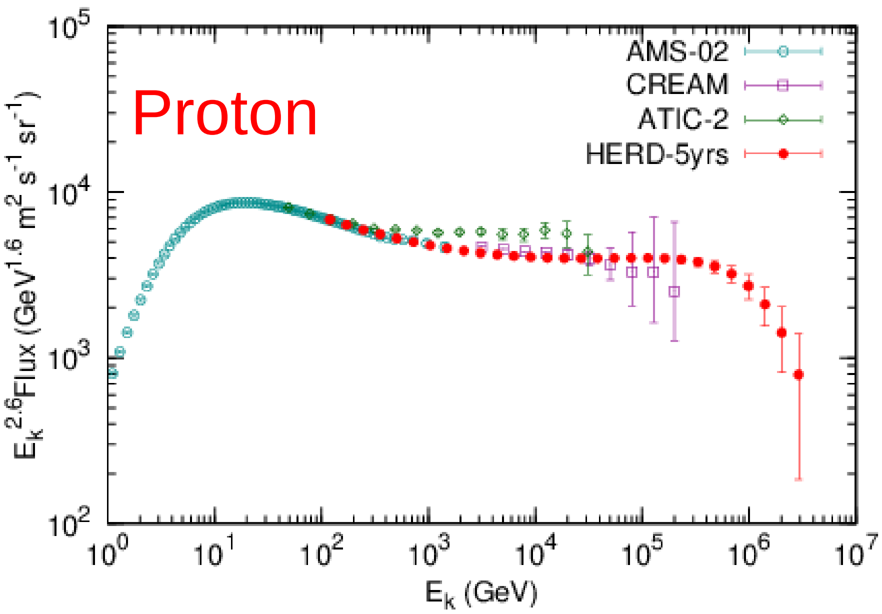
HERD could test the sharp peak at the DAMPE spectrum in half a year observation.

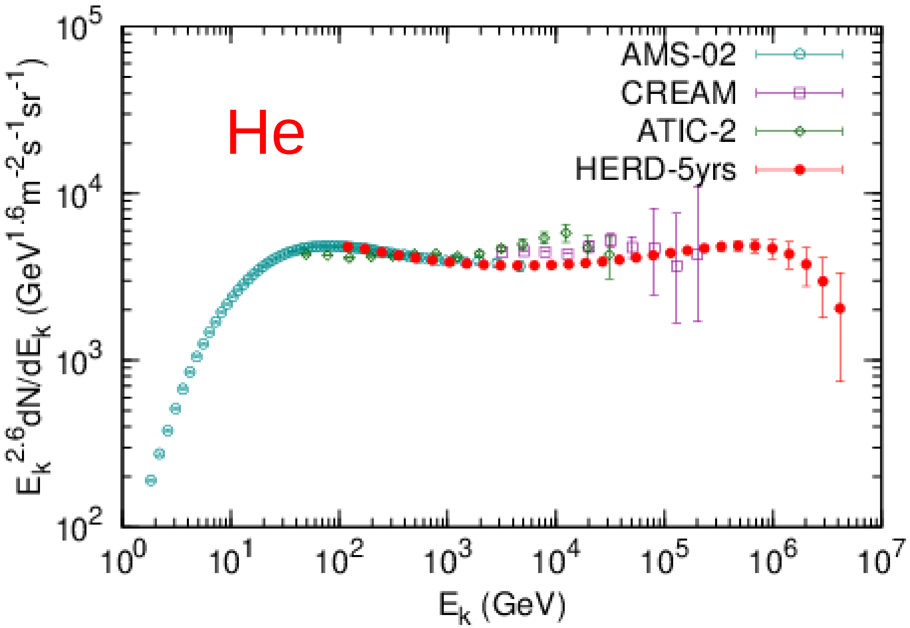
“The flux in the 1.4 TeV bin of DAMPE’s spectrum is not compatible with CALET results at a level of 4σ significance, including the systematic errors from both experiments.”

Extreme Energy: Cosmic-rays



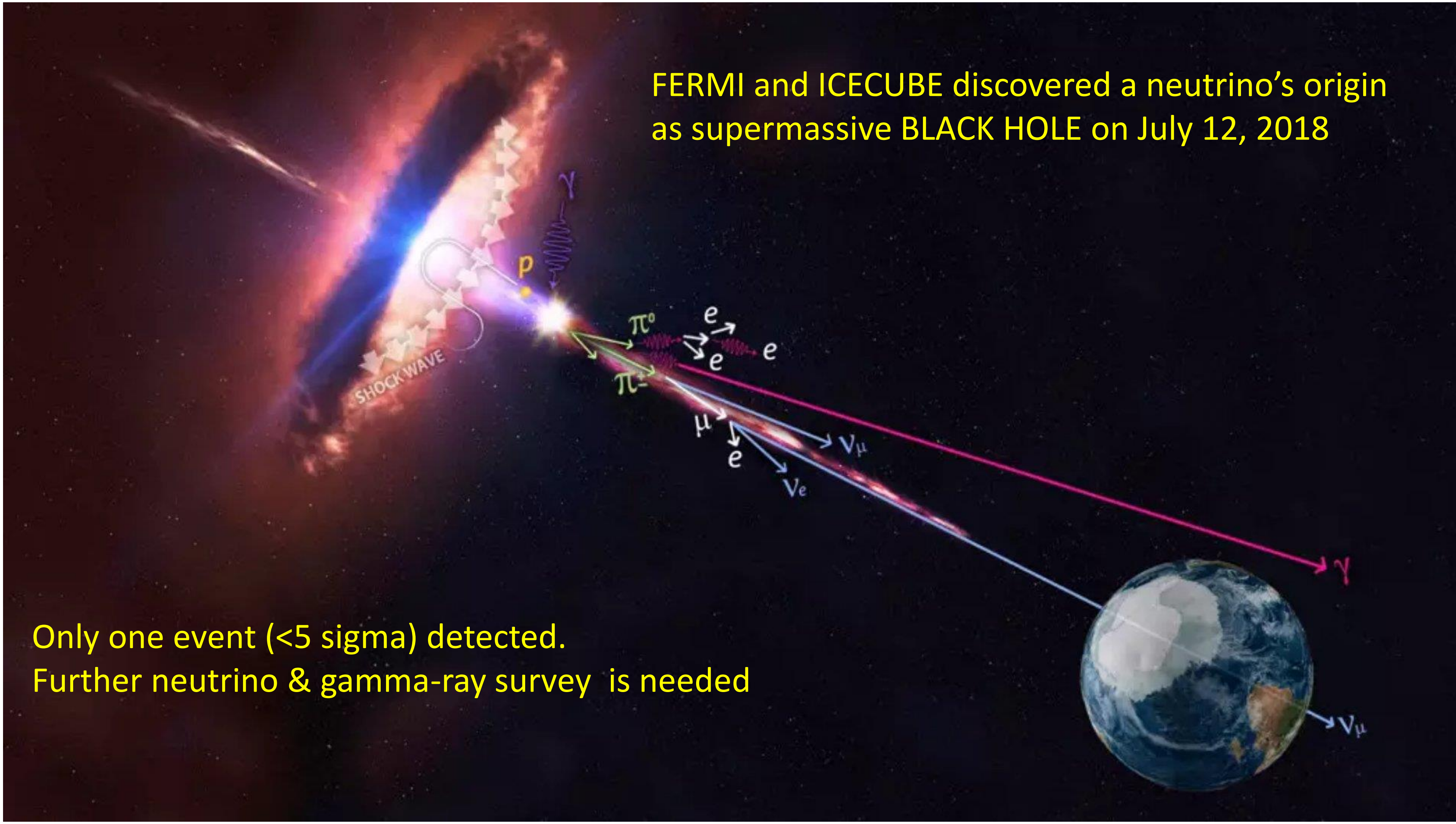
Expected HERD Proton and He Spectra





- Well extended to PeV energies
- Critically test any structures between TeV and PeV
- Clearly reveal the knee of light components (Z- or A-dependence)

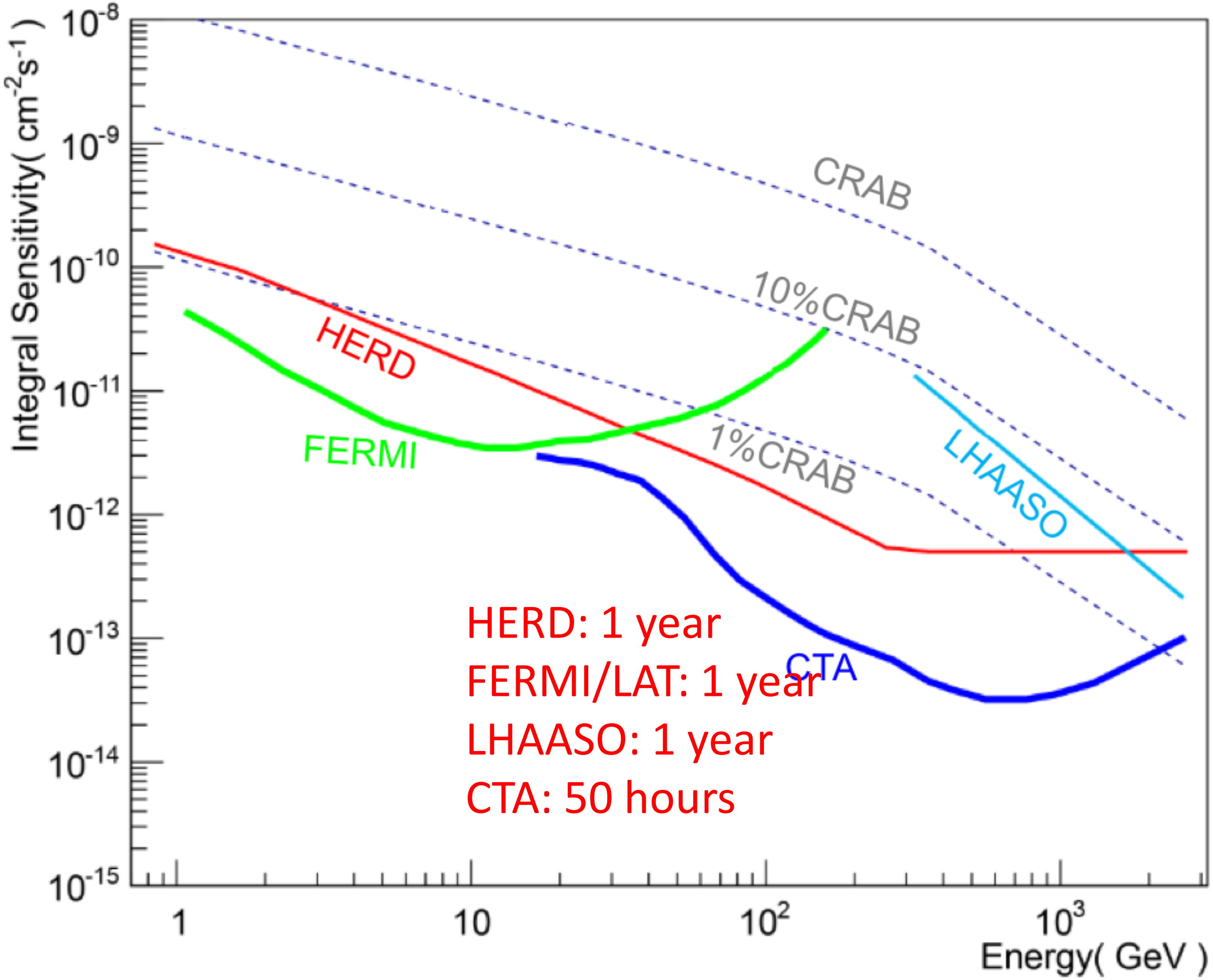
Extreme Sources: γ-ray monitoring & survey



FERMI and ICECUBE discovered a neutrino's origin as supermassive BLACK HOLE on July 12, 2018

Only one event (<5 sigma) detected.
Further neutrino & gamma-ray survey is needed

Gamma-ray sky survey



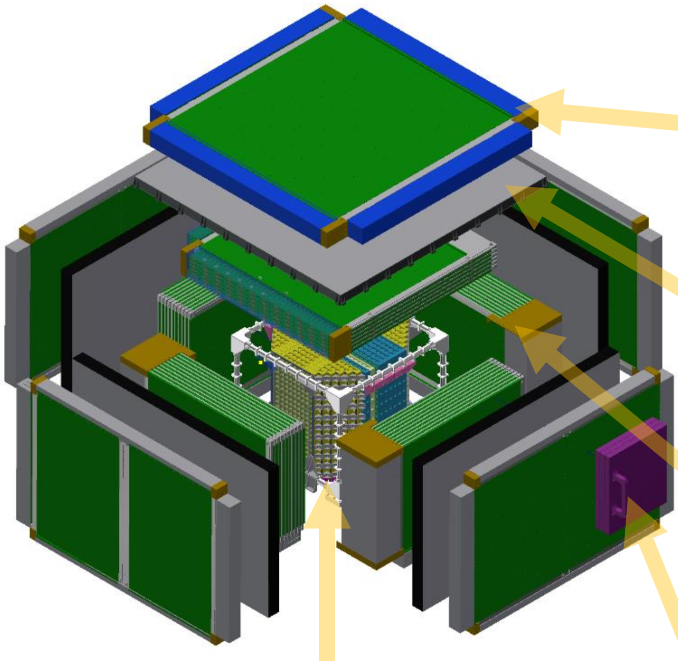
Expected HERD gamma-ray sky survey sensitivity (5σ)

HERD vs. other experiments

Experiment (time)	Energy (e/γ)	Energy (p)	ΔE/E (e/γ)	ΔE/E (p)	e/p ID	e accep. m^2sr	p accep. m^2sr
FERMI (2008)	1GeV-300GeV	30GeV-10TeV	10%	40%	10^3	0.9	<0.28
ISS-AMS02 (2011)	1GeV-1TeV	1GeV-1.8TeV	2%	-	10^6	0.12	0.12
ISS-CALET (2015)	1GeV-10TeV	50GeV-10TeV	2%	35%	10^5	0.12	--
DAMPE (2015)	5GeV-10TeV	40GeV-100TeV	≤1.5%	25-35%	$3*10^4$	0.3	0.04
HERD (~2027)	10GeV-100TeV 0.5GeV-100TeV (γ)	30GeV-PeV	1%	20%	10^6	>3 (10X DAMPE)	>2 (50X DAMPE)

HERD is a next generation experiment, following AMS02 and DAMPE, with much better performance on direct high energy e, p, gamma-ray detection.

HERD payload



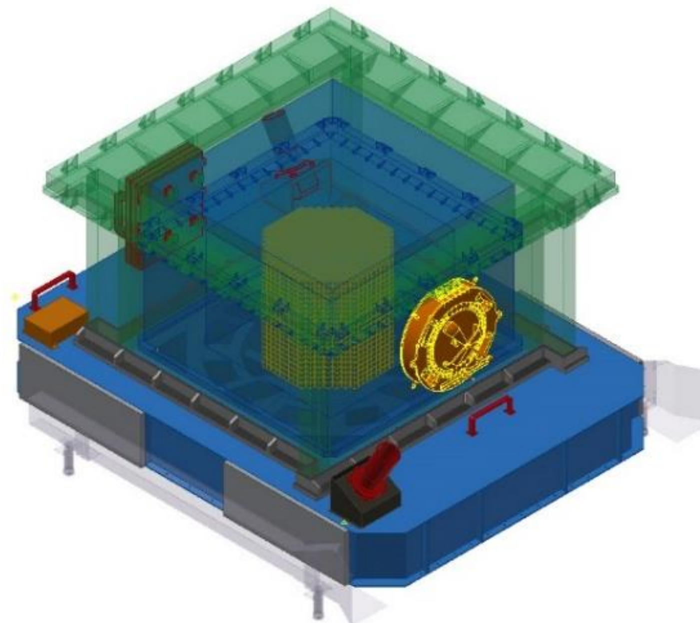
SCD
Z measurement

PSD
Gamma ID.
Z measurement

FIT
Tracking
Gamma conv.

TRD
TeV nuclei calibration

CALO
Energy measurement
Particle ID



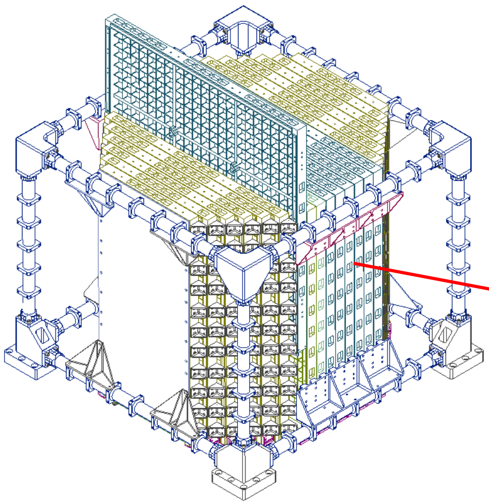
Payload Module

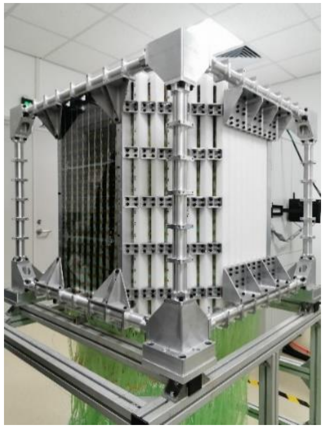
HERD responsibilities (preliminary)

Name	Responsible institutions
Payload Module	CSU, IHEP
CALO	IHEP, XIOPM, INFN Florence, CIEMAT
SCD	INFN Perugia, INFN Torino, IHEP, PMO etc
PSD	INFN Bari, INFN Pavia, INFN Lecce, GSSI, IHEP
TRD	Guangxi University
FIT	Univ. of Geneva, ICCUB
Ground calibration	IHEP, Guangxi Univ., INFN sections, Univ. of Geneva, CERN
Science center	CSU, IHEP, SDU, SWJTU, ASDC & INFN-CNAF
Sciences	IHEP, PMO, USTC, YNO, NAOC, SDU, GXU, TSU, PKU, NJU, YNU, SWJTU, HKU, Academia Sinica, and institutions from Italy, Switzerland, Spain, Germany, Denmark, Sweden, Russia, etc.

CALOrimeter

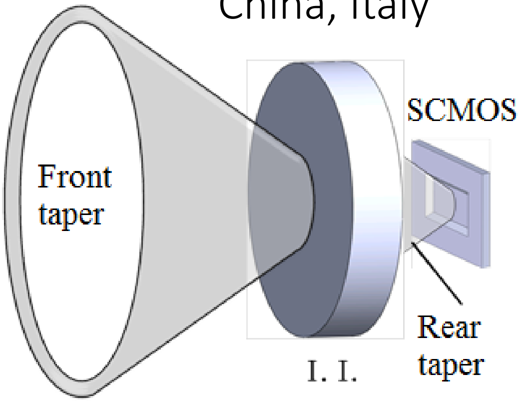
- CALOrimeter (3 N.I.L. and 55 R.L.)
  - ~7500 LYSO crystals
- Joint study on double readout of crystals is ongoing



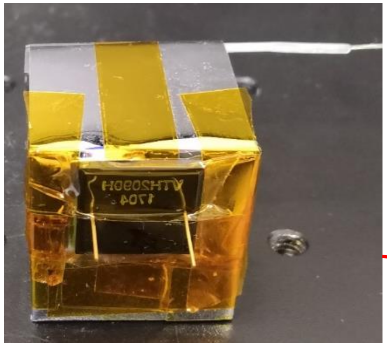


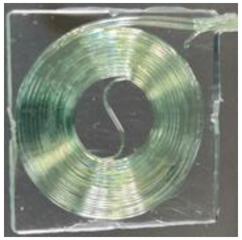
1:1 prototype

China, Italy



IsCMOS camera



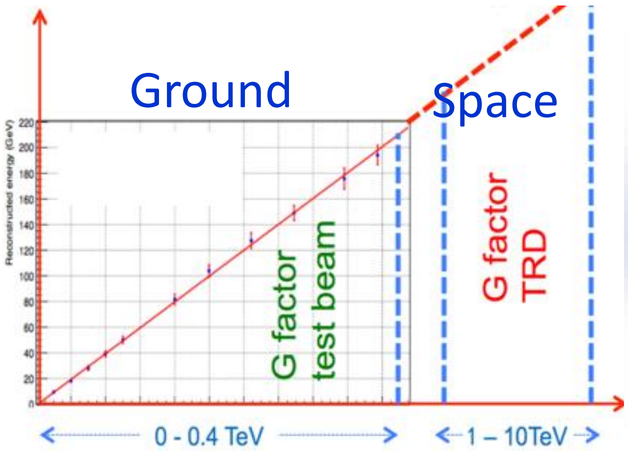


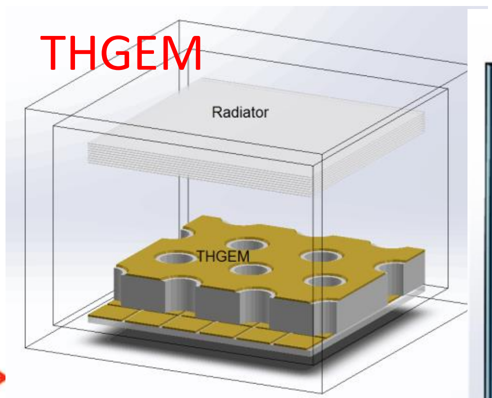
Crystal array	IHEP, CAS
Trigger system	IHEP, CAS
IsCMOS camera	XIOPM, CAS
PD SYSTEM	INFN Florence, Spain

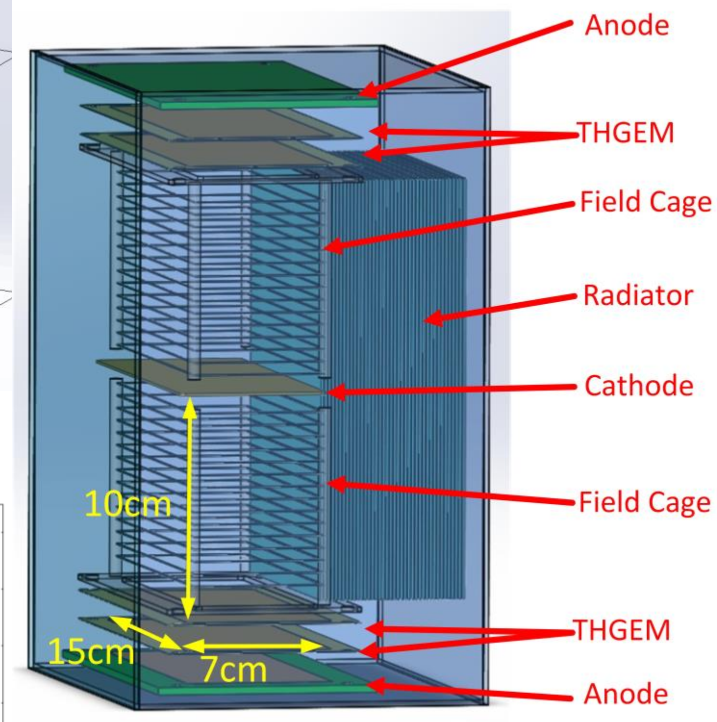
Transition Radiation Detector (TRD)

- Energy calibration of TeV nuclei

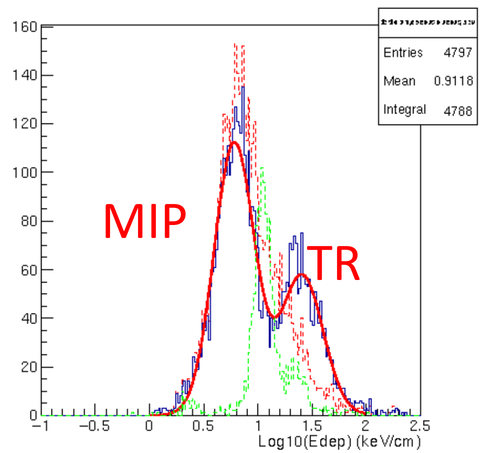
GXU, China



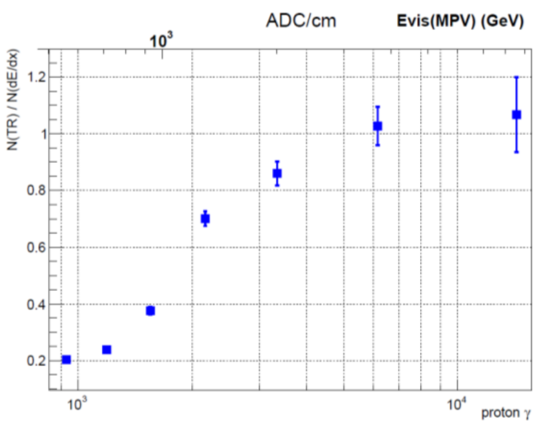




Side-on TRD



MWPC energy response to [2.25, 2.5] TeV protons



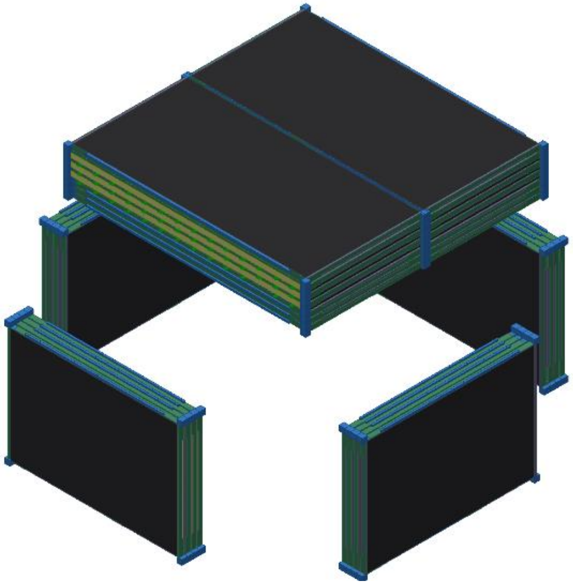
2 months simulated observation, ~6300cm^2 .

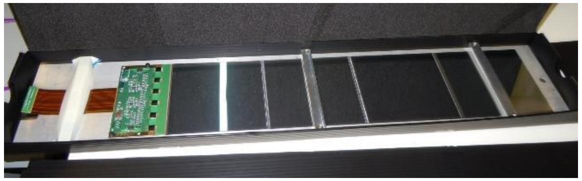
Silicon Charge Detector (SCD)

- Charge measurement

Italy

- Features of SCD
  - Located at outmost to avoid ion fragmentation
  - Large detection area
  - Z =1 to Z = 26
- 10 SSDs at most bonded in a row
- Customized SSD for large dynamic range
- Customized ASIC for large dynamic range
- INFN Perugia, INFN Torino, etc



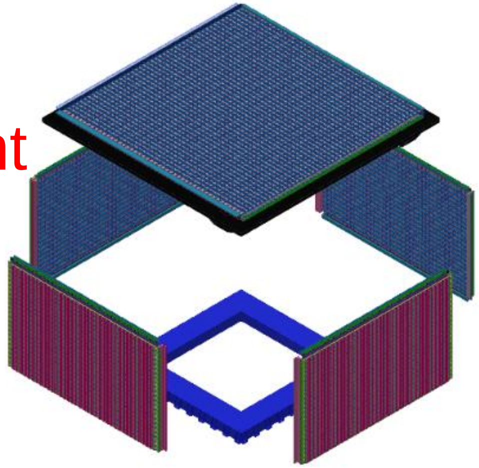


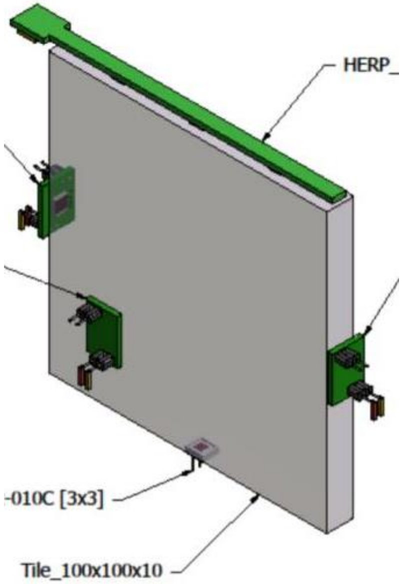
DAMPE STK ladder

Plastic Scintillation Detector (PSD)

Italy

- Gamma-ray ID.
- Charge measurement

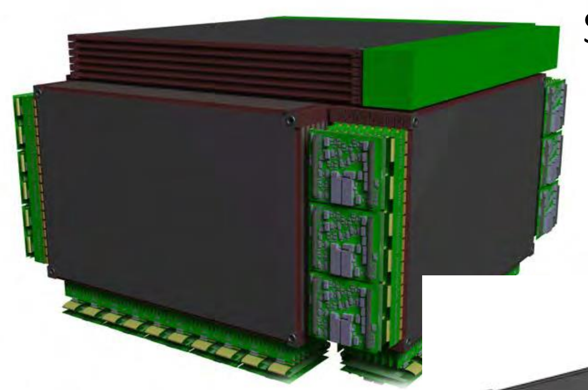




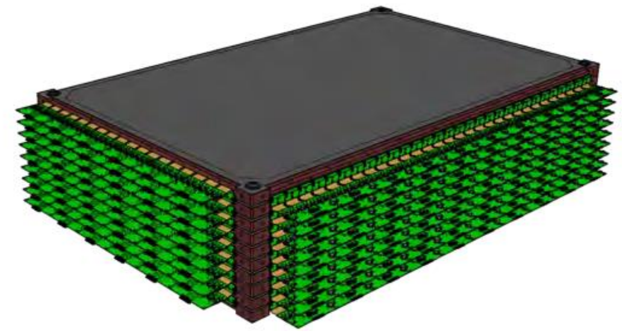
- Basic requirements
  - Full coverage of CALO for LEG trigger
  - Fast veto signal within 200ns
- Geometry of detection unit: Bar and/or tile
- PS readout by SiPMs
- INFN Bari, INFN Pavia, INFN Lecce, GSSI, etc.

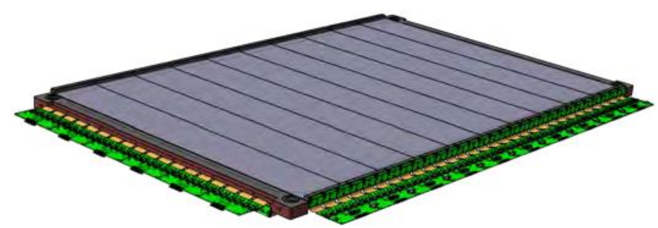
FIber Tracker (FIT)

- Tracking
- Charge measurement

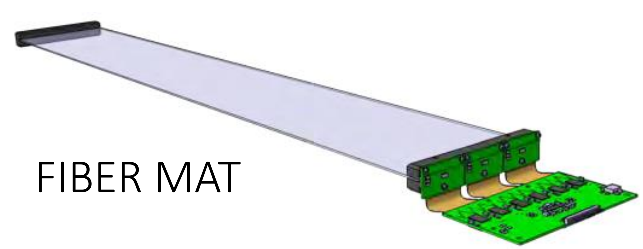


Switzerland, Spain





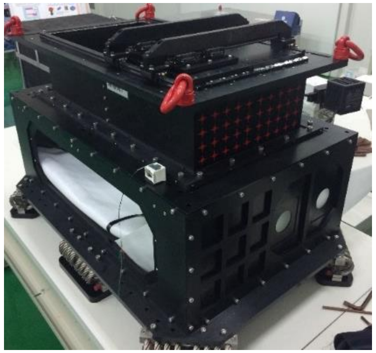
- Heritage of FIT
  - Based on LHCb & Mu3e technology
  - Robust design for high coverage ratio
- Diameter of scintillator fiber:~250um
- FIBER MAT is readout by SiPMs
- Univ. of Geneva, ICCUB



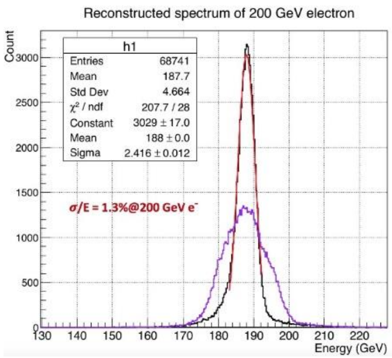
FIBER MAT

Joint study of key specifications of HERD payload

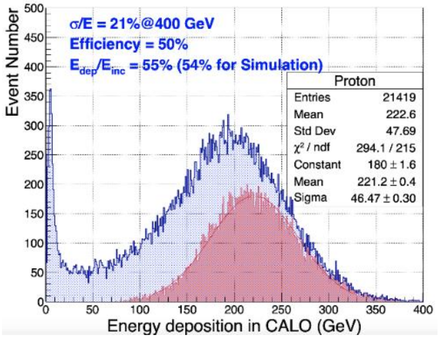
- Three rounds of CERN beam tests were carried out.
- The 2021 beam test was just approved: full HERD functionality



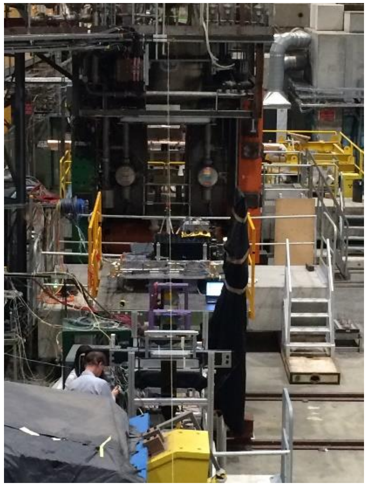
CALO prototype (500 LYSO)



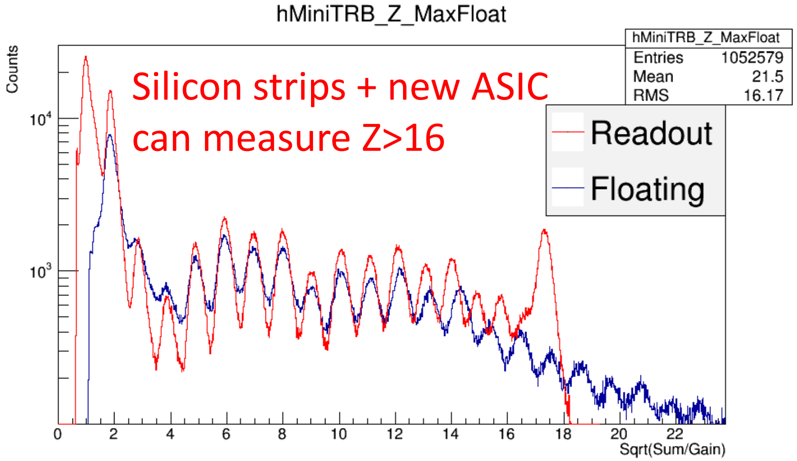
1.3%@200GeV e-

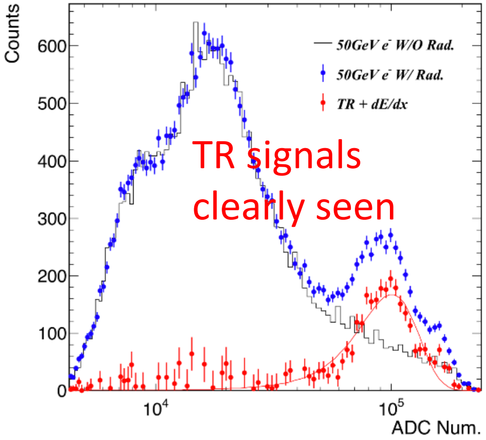


21.0%@400GeV proton

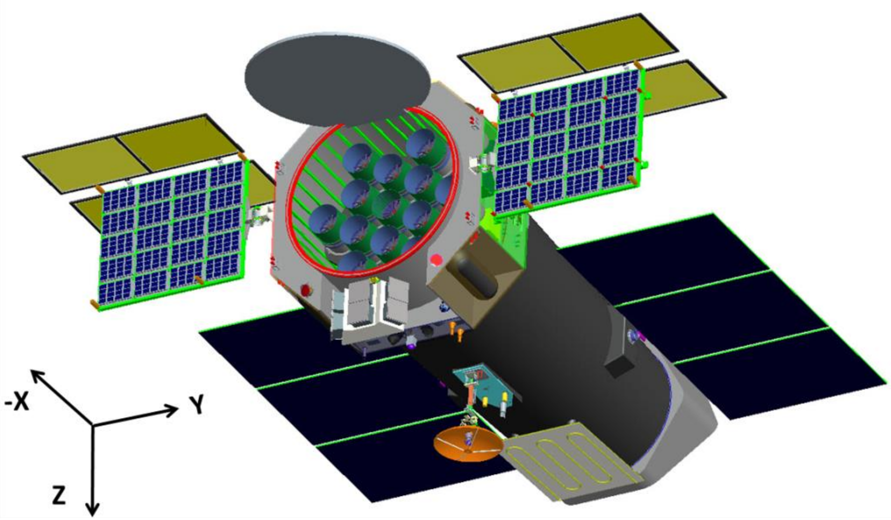


HERD prototypes at CERN





eXTP: enhanced X-ray Timing and Polarimetry



Next Generation Flagship Observatory

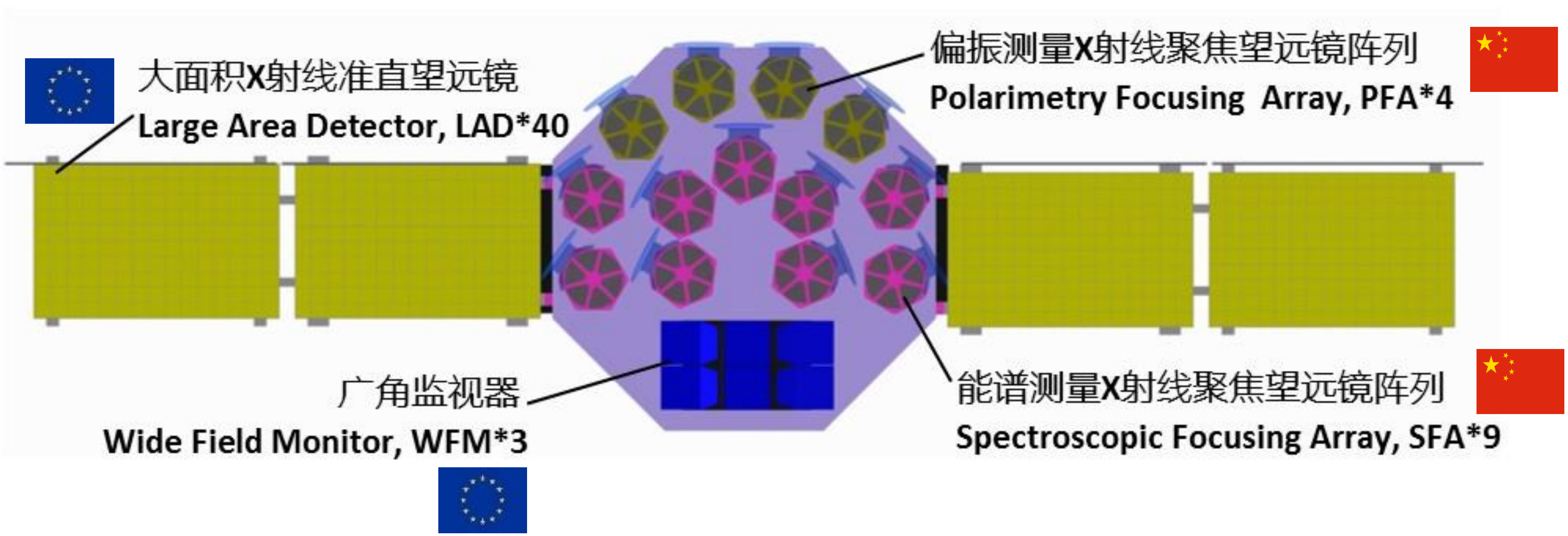
- Important Sciences
  - Extreme gravity, magnetism, density
  - Neutron stars, black holes, etc
- Cutting-edge technology
  - Large eff. Area (~3.8 m^2@6 keV)
  - High spectral resolution (<180 eV@6 keV)
  - Polarimetry

The next flagship X-ray space observatory: 2027-2037

Payload	Configuration	Eff. area (m^2)	Timing res. (μs)
Spectroscopic Focusing Array (SFA)	9 telescopes	0.54m^2@1keV	10
Large Area Detector (LAD)	40 modules	3.4m^2@8keV	10
Polarimetry Focusing Array (PFA)	4 telescopes	380cm^2@3keV	500
Wide Field Monitor (WFM)	6 cameras	3.2 Sr （FOV）	10
PI: Shuang-Nan Zhang (IHEP)			

eXTP payload configuration

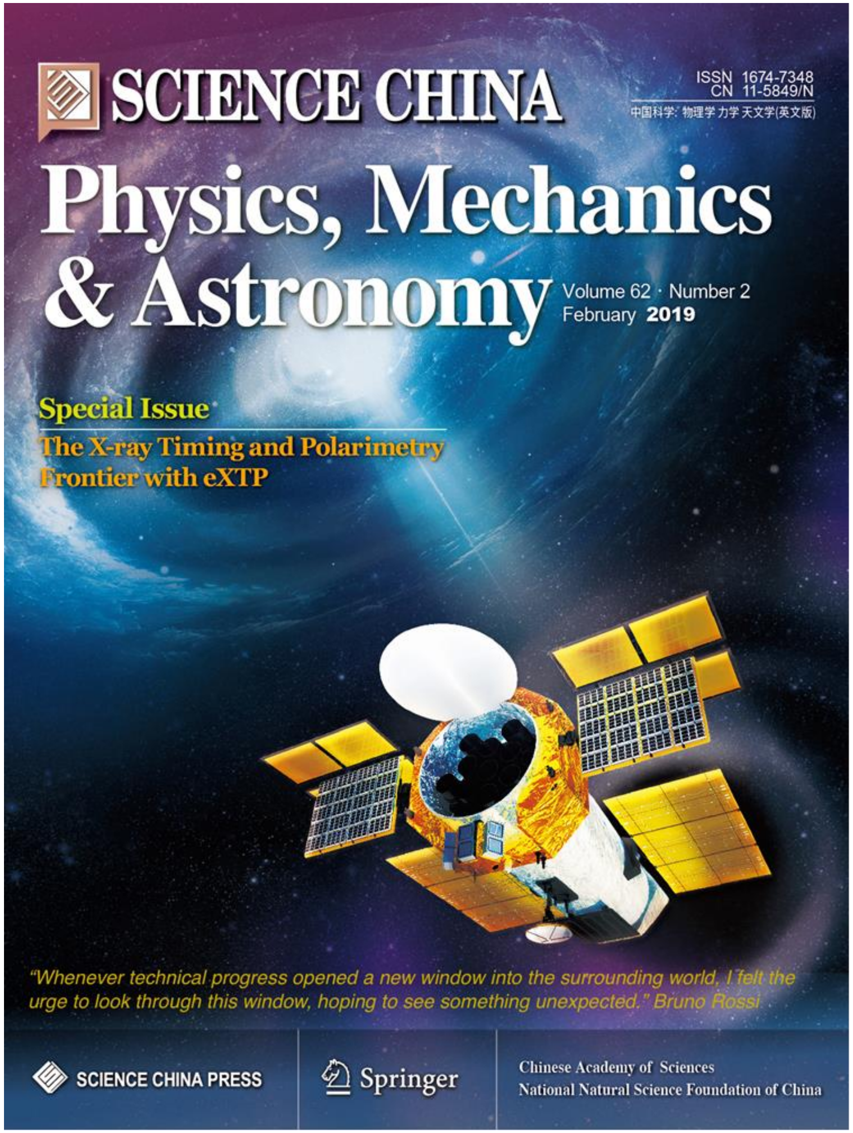
Payload	Configuration	Optics	Detector	Expected eff. area (m^2)	Time ref. (μs)
SFA - Spectroscopic Focusing Array	9 telescopes	Wolter-I	SDD	$0.74m^2$@2keV	10
LAD - Large Area Detector	40 modules	MCP collimator	SDD	$3.4m^2$@8keV	10
PFA - Polarimetry Focusing Array	4 telescopes	Wolter-I	GPD	$495cm^2$@3keV	500
WFM - Wide Field Monitor	6 cameras	1.5D coded mask	SDD	4.1Sr (FOV)	10



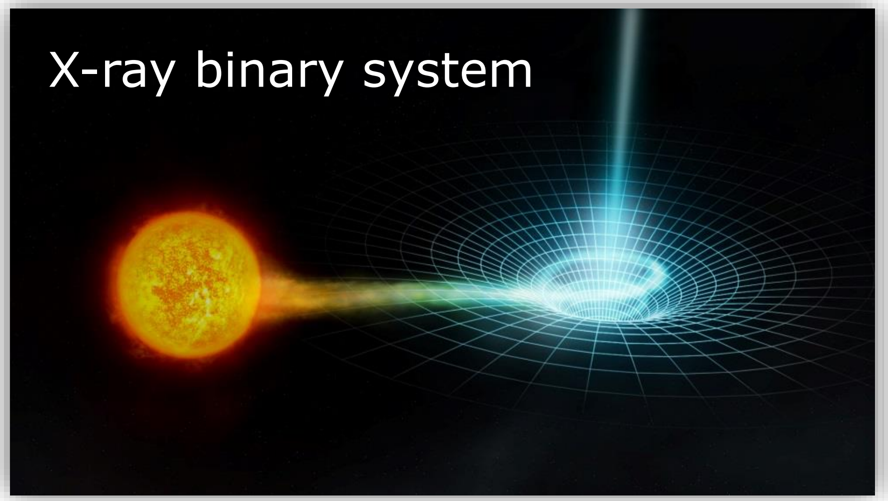
White papers on eXTP

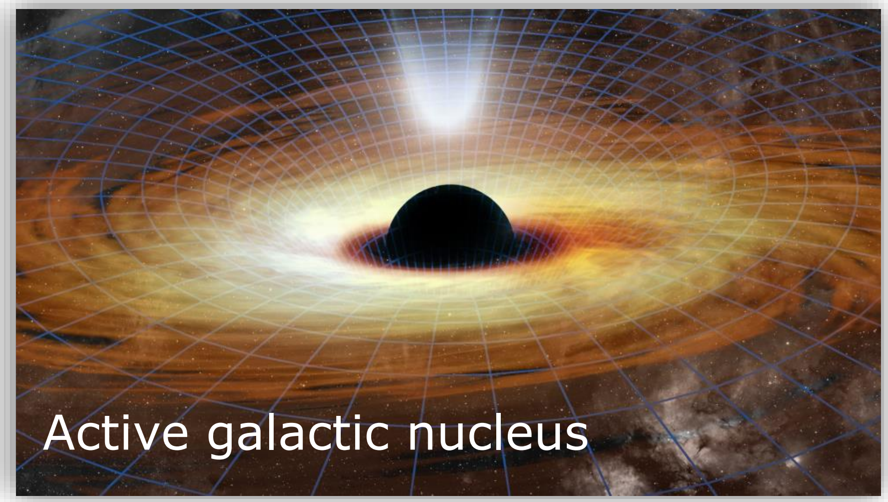
Five refereed papers have been published in a special issue of SCIENCE CHINA Physics, Mechanics & Astronomy, Feb. 2019

- 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

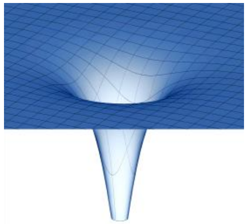


Extreme Gravity

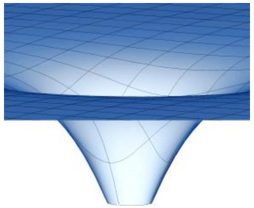




eXTP covers wide mass range in uniform setting



Stellar mass black hole
(or neutron star)
Strongly curved spacetime.
(10^{16} times Solar)

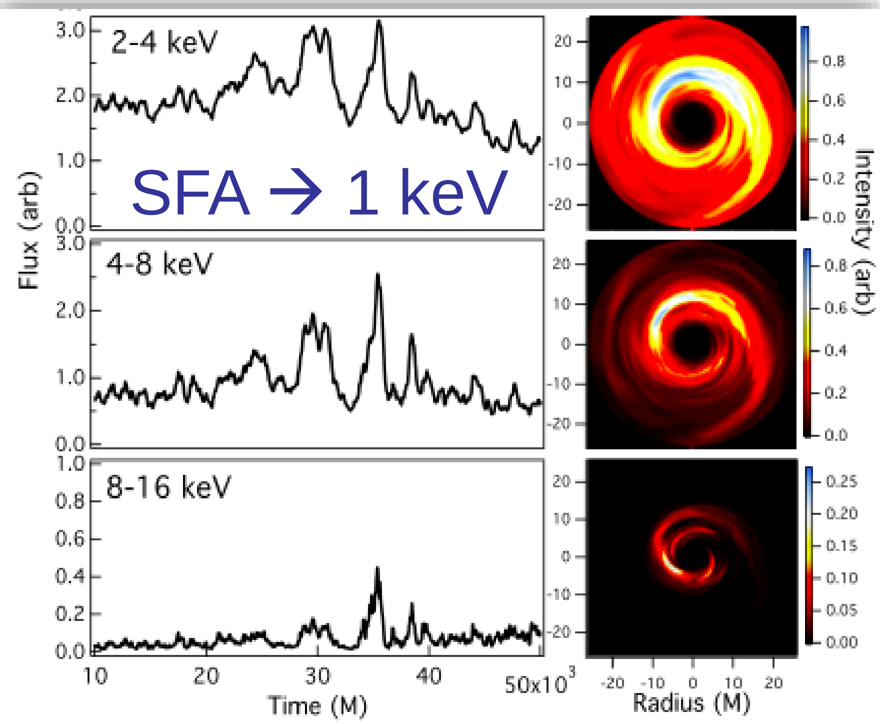


Supermassive black hole
Weakly curved spacetime
(~Solar)

TESTS OF GR PREDICTIONS IN THE STRONG FIELD REGIME OF GRAVITY.
COMPLEMENTARY TO GRAVITATIONAL WAVE EXPERIMENTS: eXTP PROBES *<u>STATIONARY</u> SPACETIME*

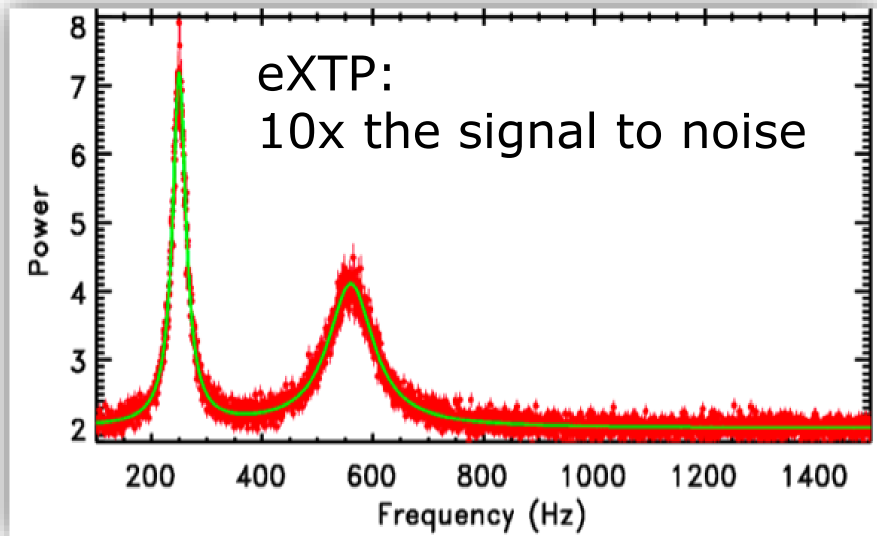
Spectral-Timing for extreme gravity

General Relativity predicts precise orbital and epicyclic frequencies at each radius



Wellons et al. 2013

Orbiting inhomogeneities make frequencies observable



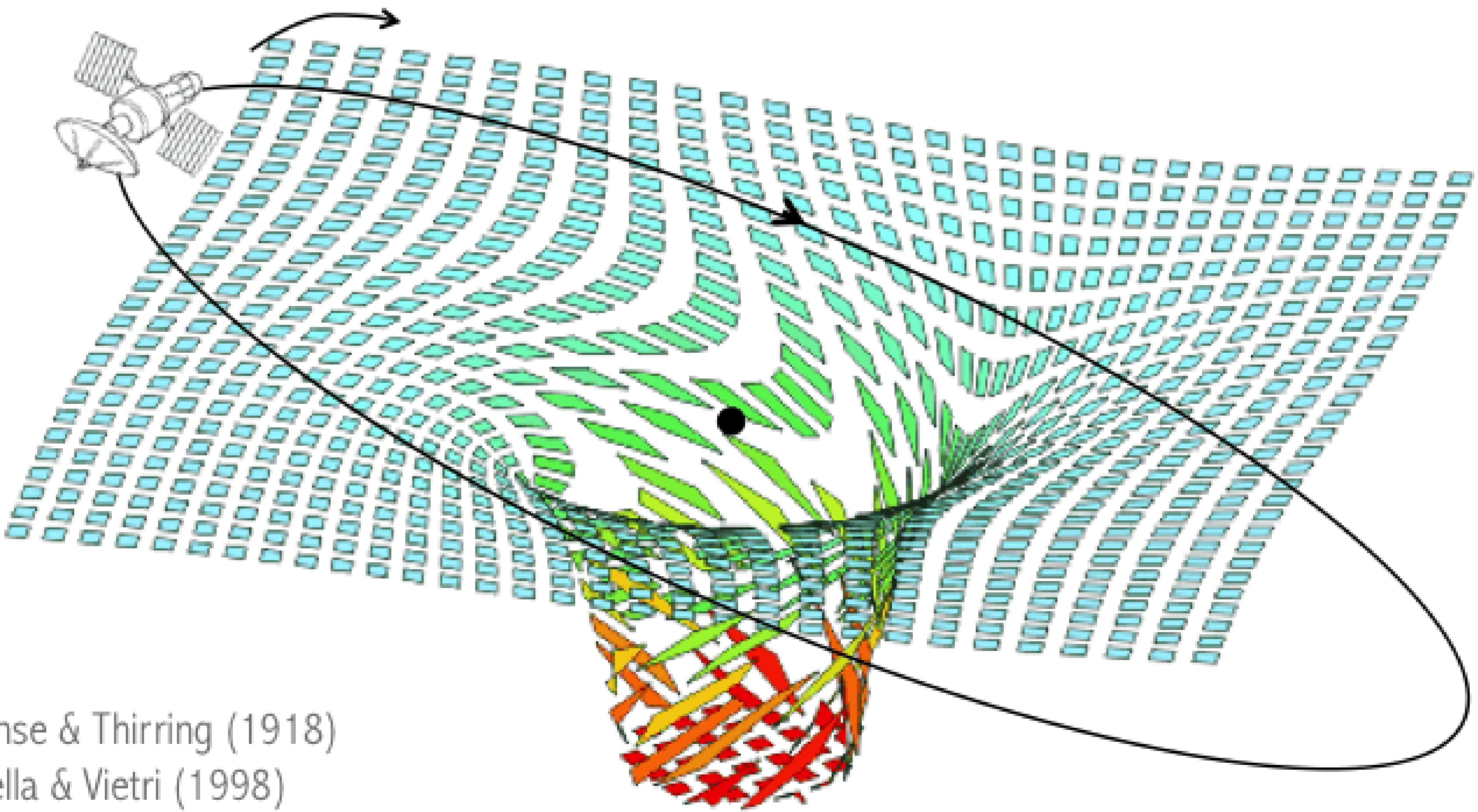
- Strong gravity dynamical frequencies just detected in current (RXTE) data
- eXTP diagnoses strong field gravity very precisely by:
  - timing of the flux variations
  - time resolved spectroscopy

  at very high signal to noise
- Uses known phenomena

Timing-Polarimetry for Frame Dragging

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

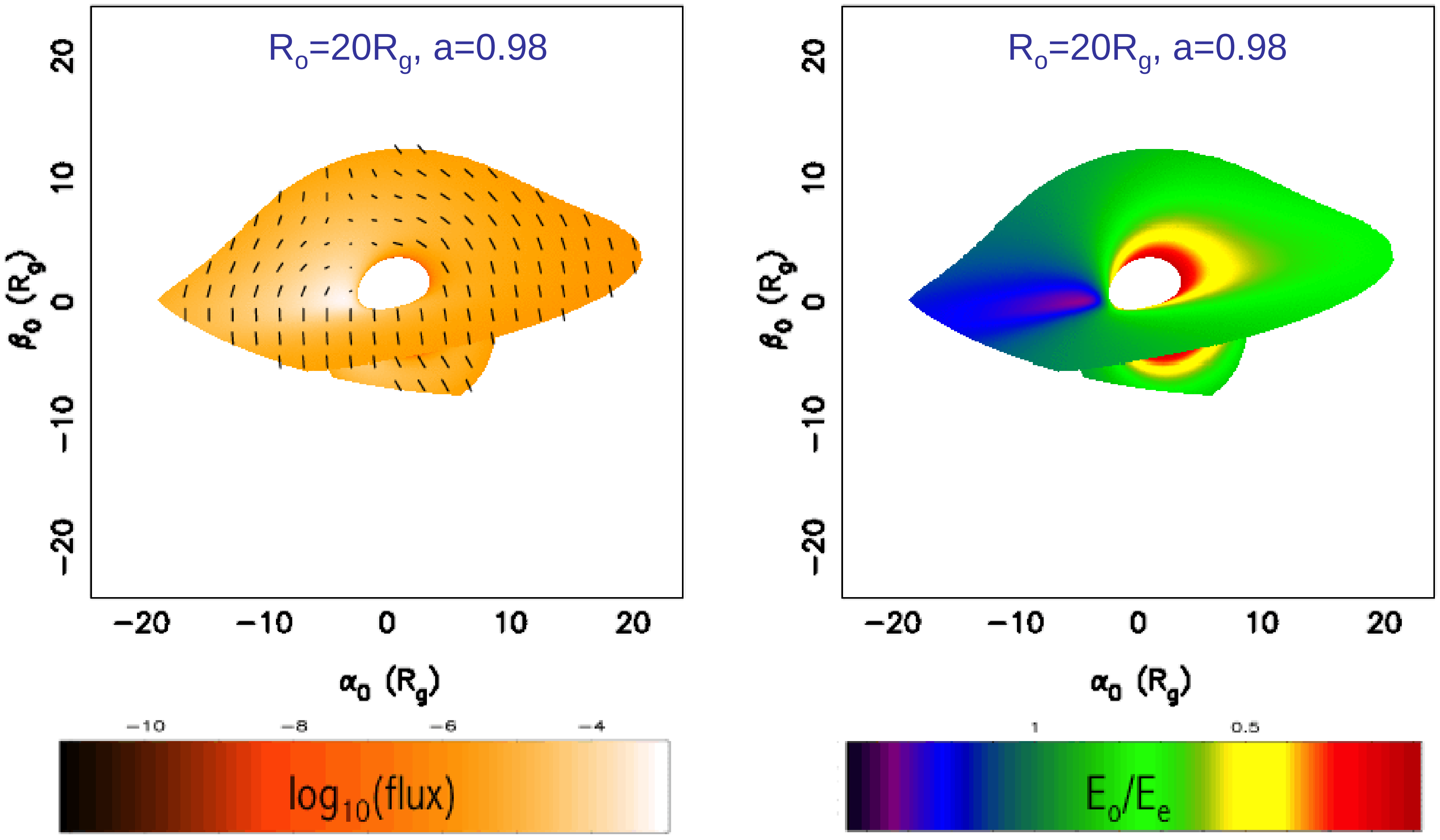
The satellite's motion is **influenced** by the spin of the black hole



Lense & Thirring (1918)

Stella & Vietri (1998)

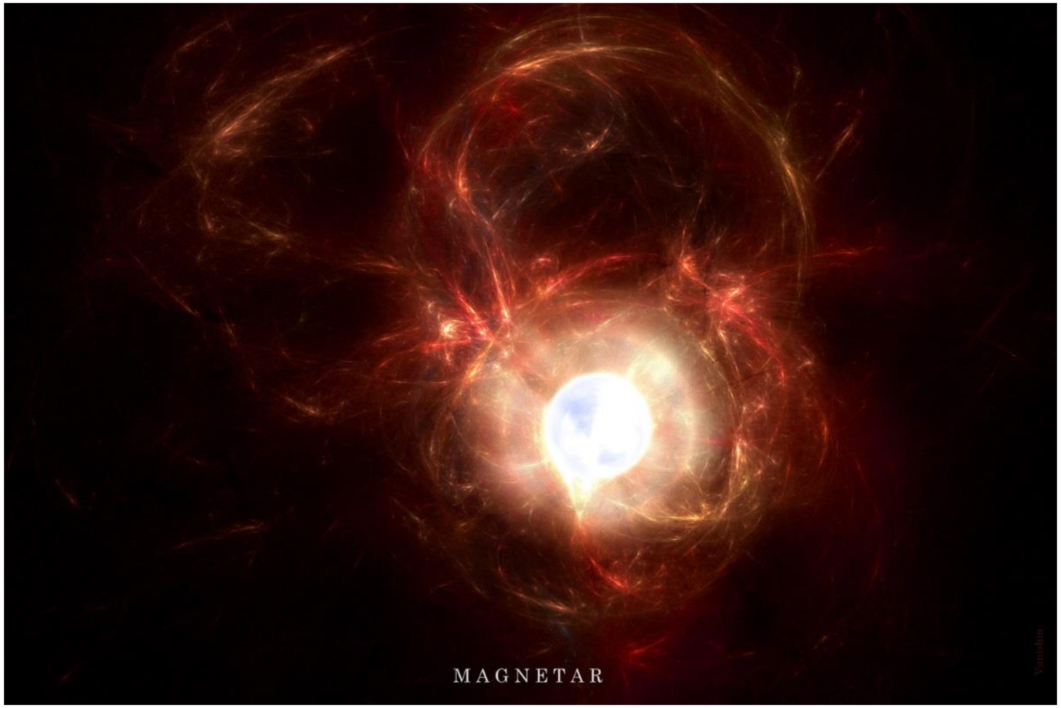
Movies: high inclination (i=70°)



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

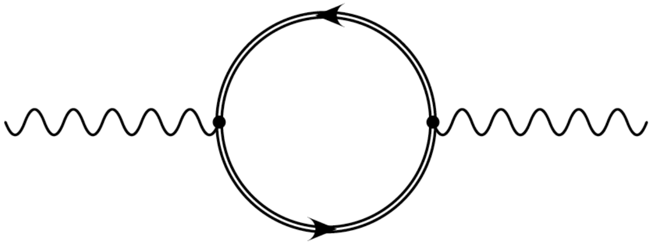
Ingram et al (2015)

Extreme Magnetism



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

Strongest magnetic fields in lab. ***10^5 Gauss***

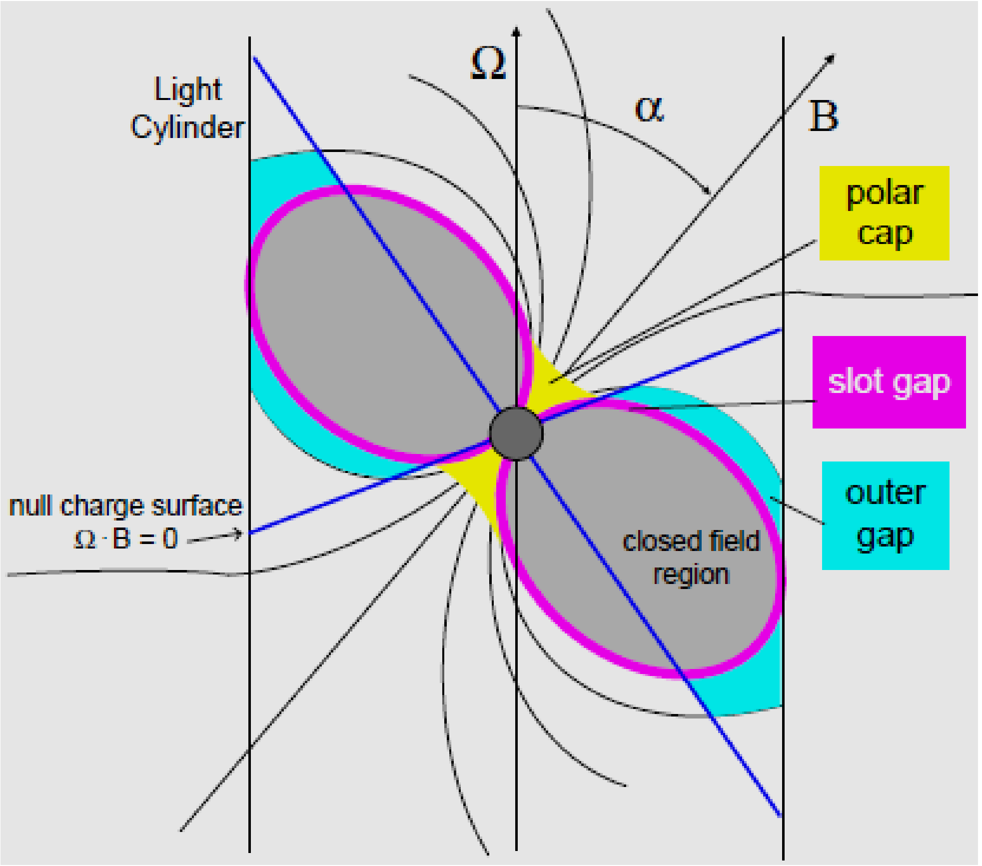


$$\Delta n = \frac{\alpha}{4\pi}\frac{2}{15}\left(\frac{B}{4.4\times 10^{13}\ \mathrm{G}}\right)^2$$

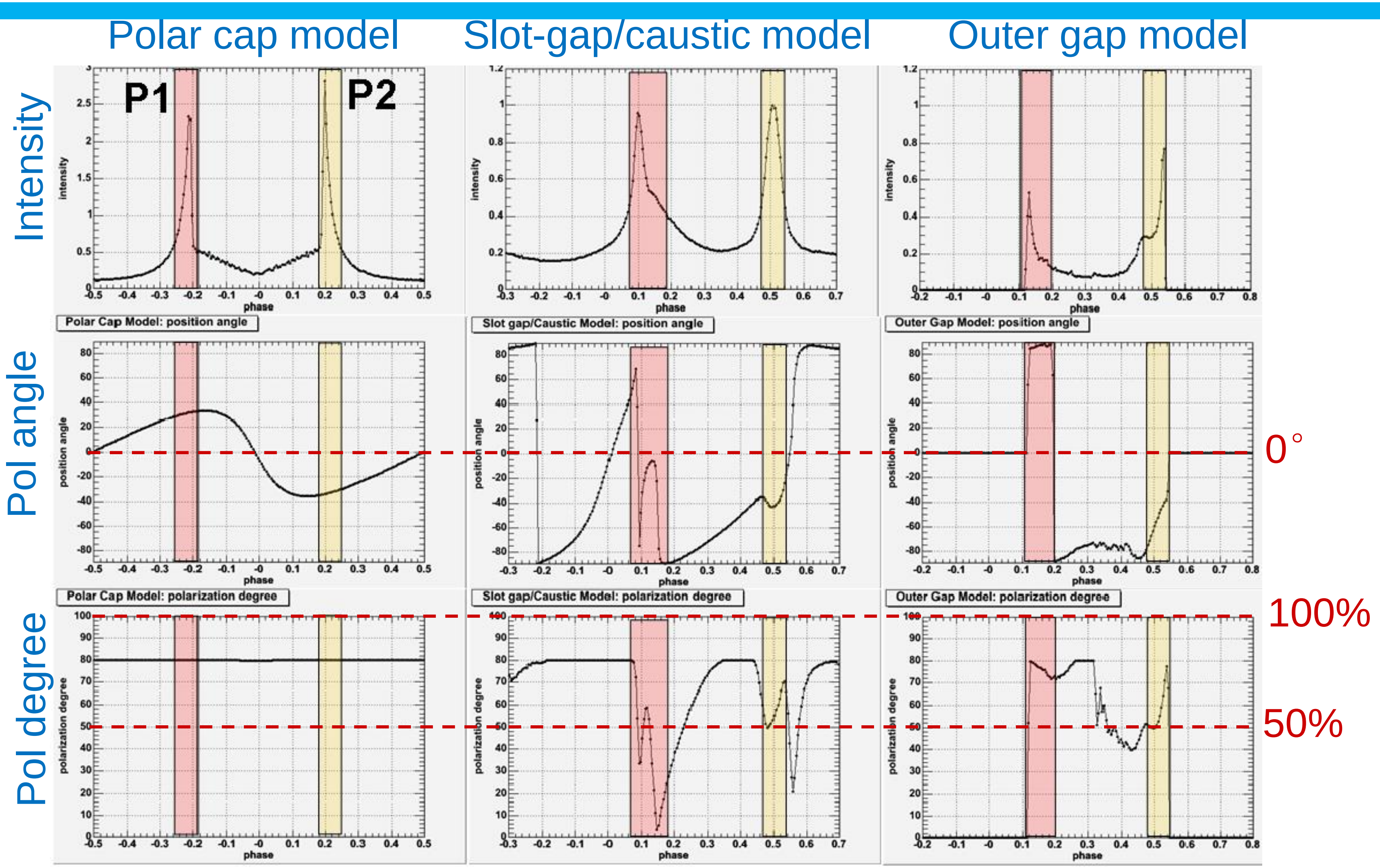
Test Quantum Electro-Dynamics effects → vacuum fluctuations: *is the propagation of light in vacuum modified by the magnetic field?*

Extreme magnetism: Rotation-powered pulsars

- Three competing models
  - Polar cap (Daugherty & Harding 1996)
  - Slot gap (Muslimov & Harding 2004)
  - Outer gap (Romani 1996; Takana 2007)

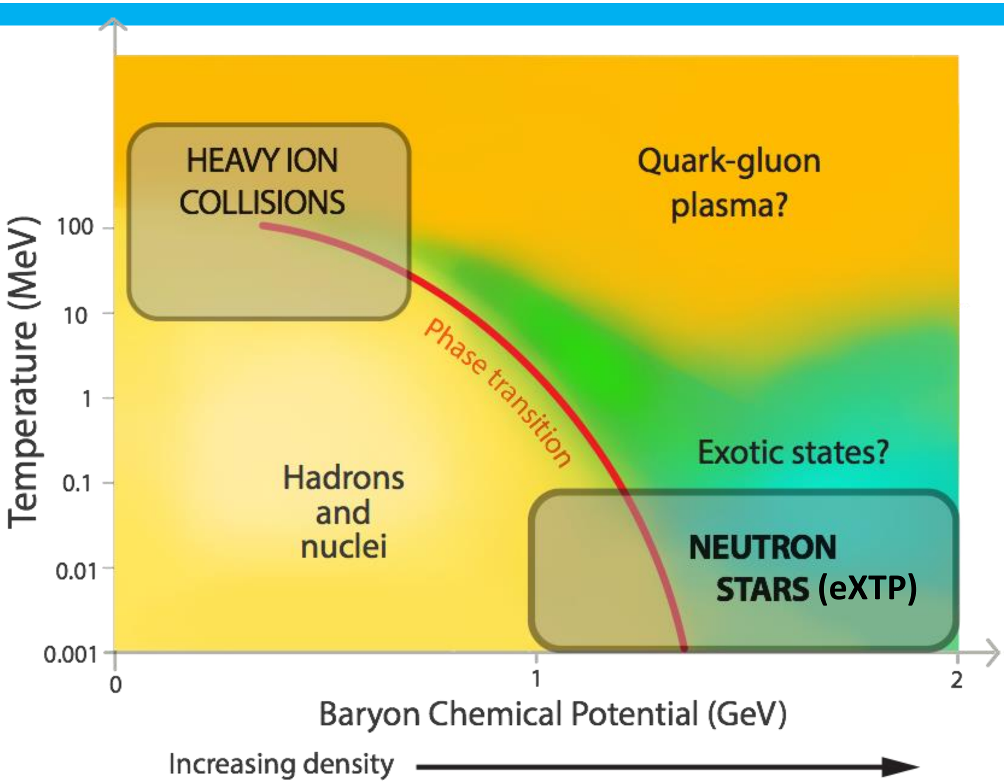


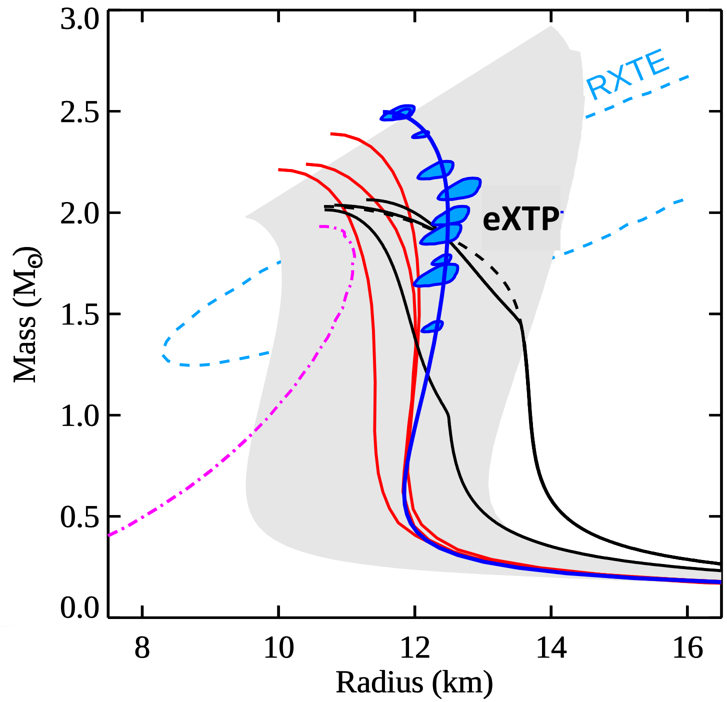
Timing-Polarimetry to Pulsars



SFA & LAD → precise phasing

Extreme Density: Neutron Stars EoS



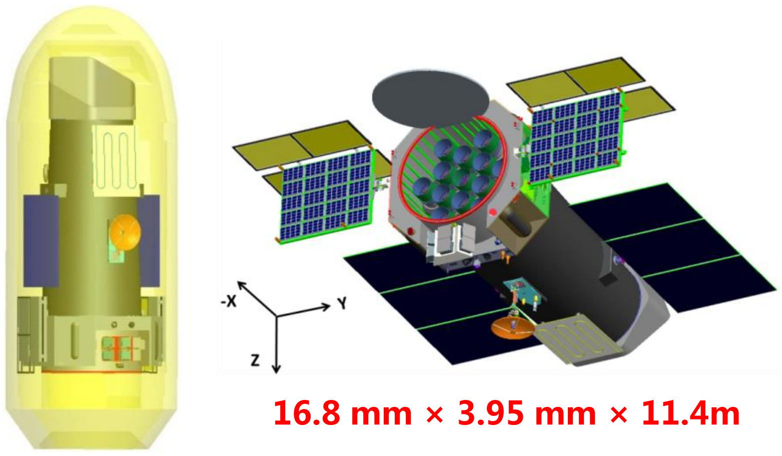


eXTP WILL STUDY **NUCLEONIC MATTER IN A UNIQUE REGIME**, AND **EXOTIC STATES OF MATTER (E.G., QUARK STARS)** THAT COULD NEVER EXIST IN THE LABORATORY.

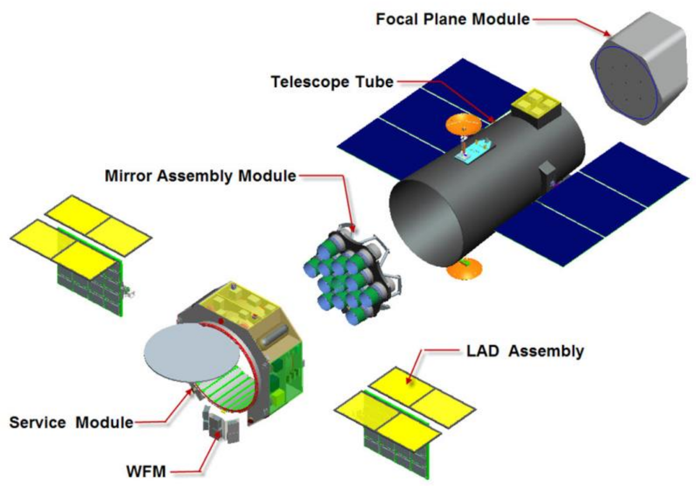
USING ONLY KNOWN SOURCES, PULSE PROFILE MODELLING MEASUREMENTS WILL **MAP THE M-R RELATION** AND HENCE THE **EQUATION OF STATE (EOS)**.

eXTP Mission overview

Parameter	Value
Orbit	550km, 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	~ 2025

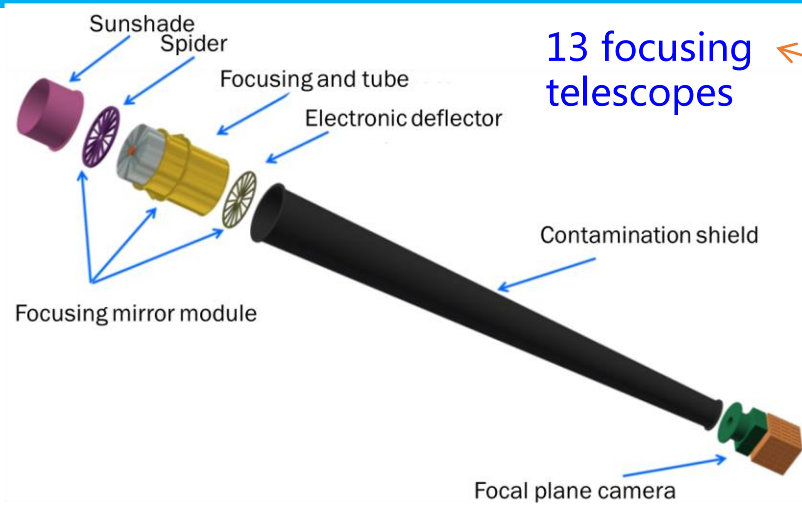


16.8 mm × 3.95 mm × 11.4m

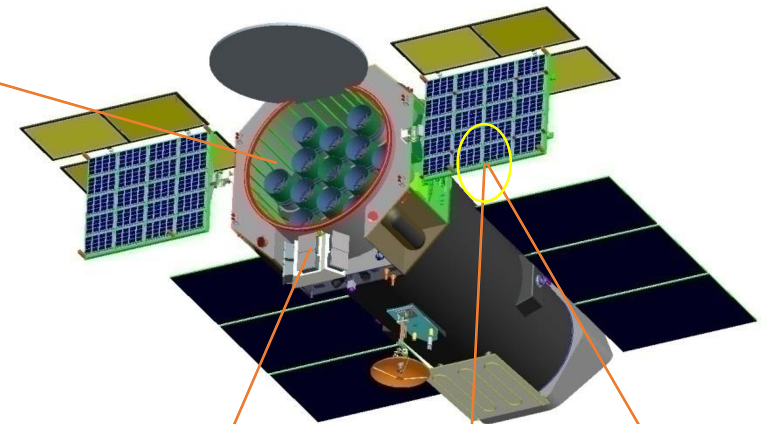


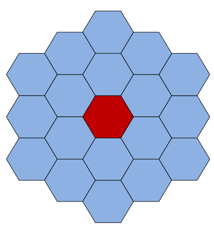
Accommodation concept by CAST

eXTP payload accommodation

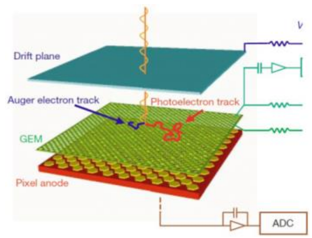


13 focusing telescopes

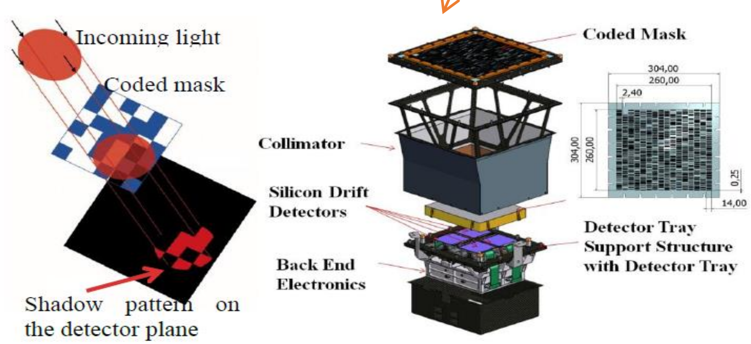




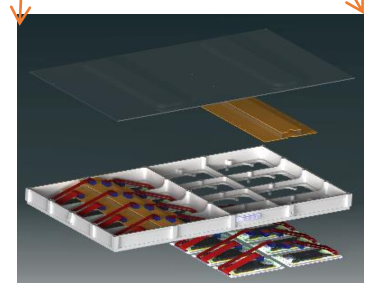
SDD camera (9)



GPD (4)



WFM cameras (6)

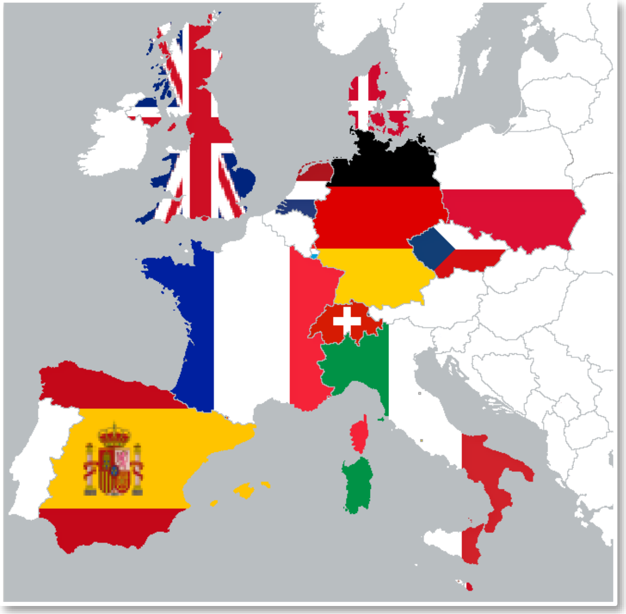


LAD modules (40)

International Partners in eXTP

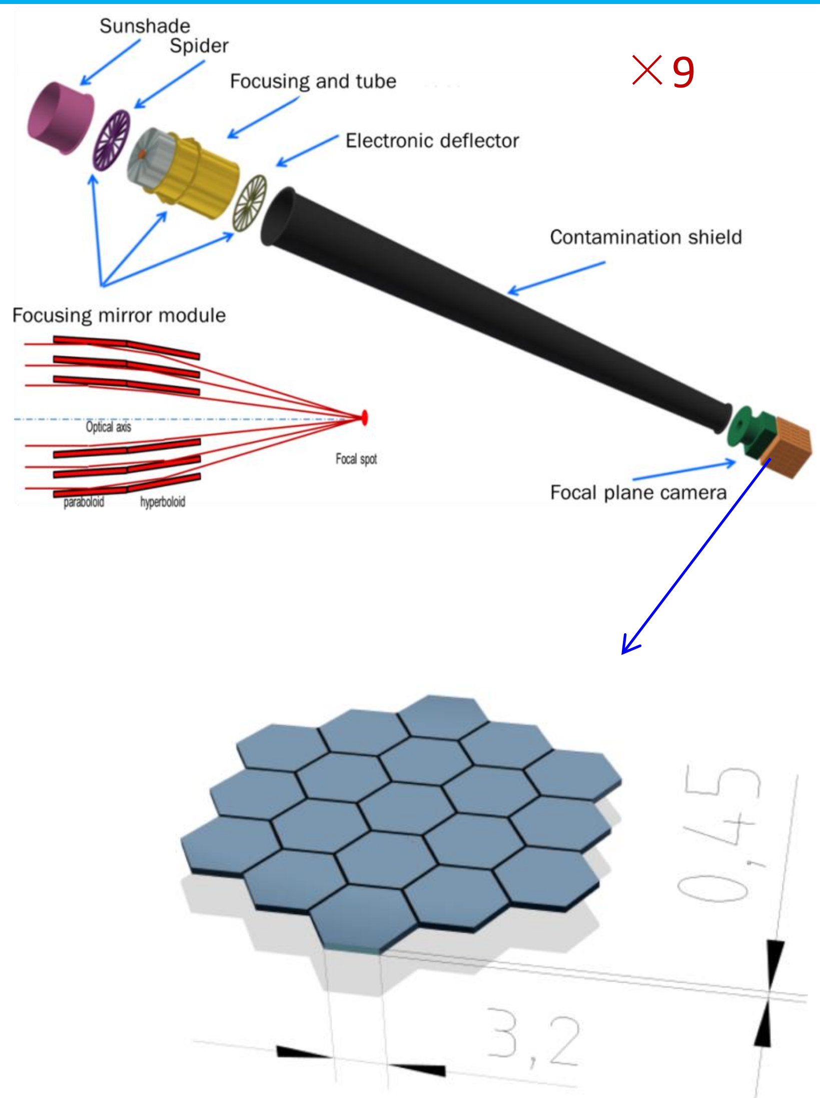
esa is considering eXTP MoO.

Nederlandse Onderzoekschool voor Astronomie



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: 4.1x10^{-15} erg/cm^2/s (3σ, 10ks)



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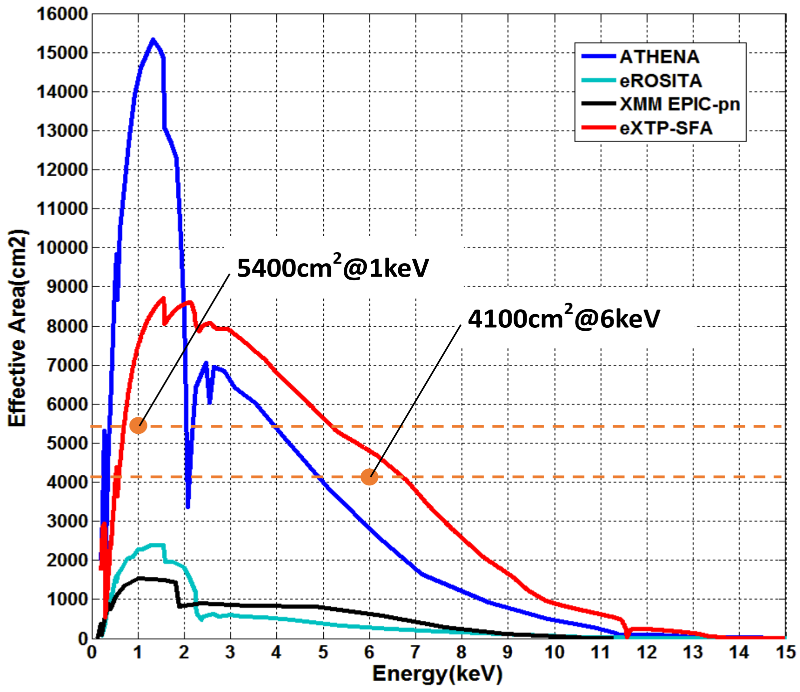
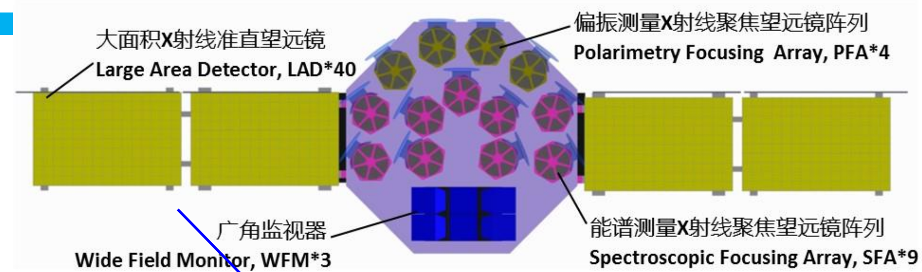
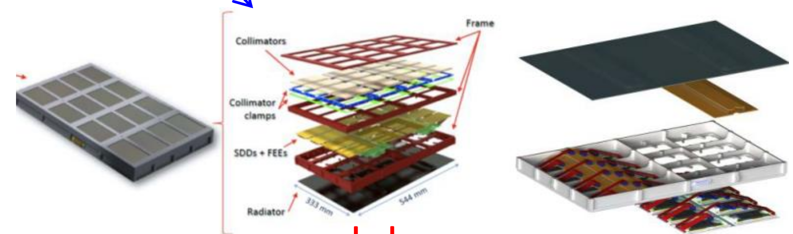


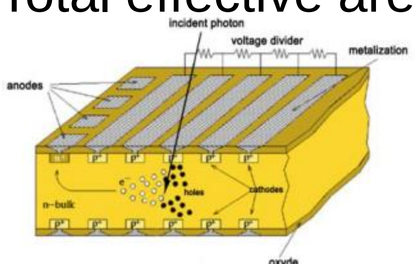
eXTP Scientific Payload: LAD – Large Area Detector

- 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: $3.4 m^2$ @ 8keV

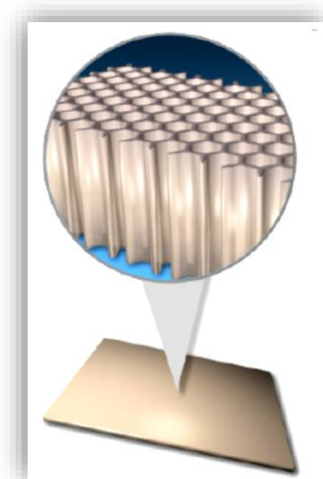




module



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
- Energy range: 2-30 keV (goal 50keV)
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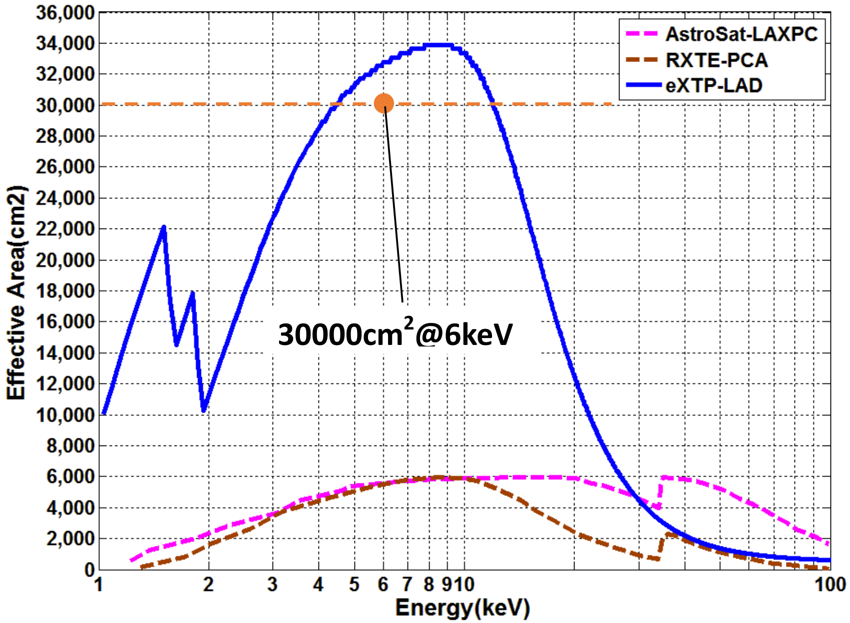
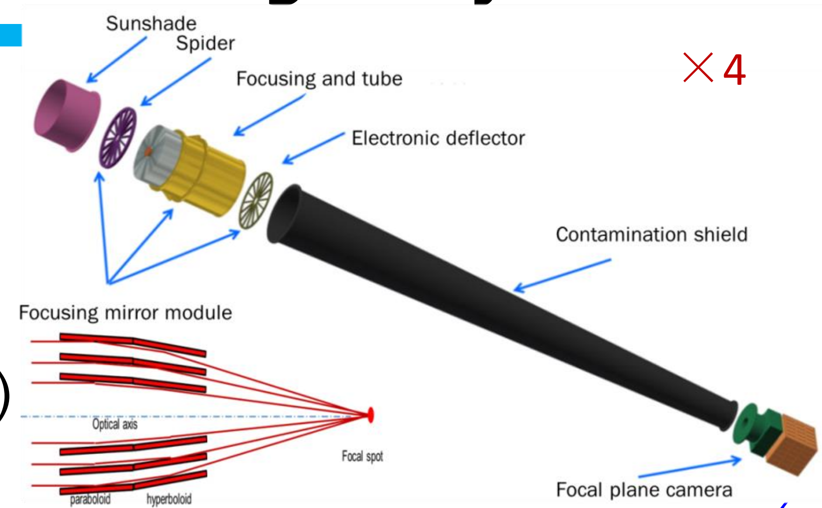
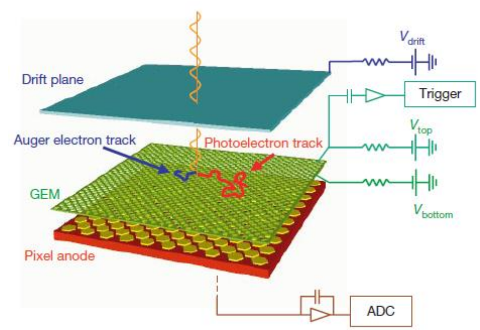


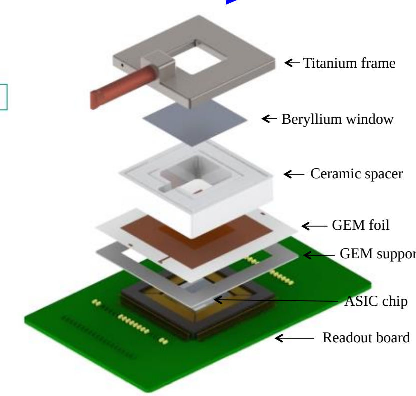
eXTP Scientific Payload:
PFA – Polarimetry Focusing Array

- 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)

eXTP Scientific Payload:
PFA – Polarimetry Focusing Array

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- 4 grazing incidence Wolter-I optics with 5.25m F.L., 40 shells/module
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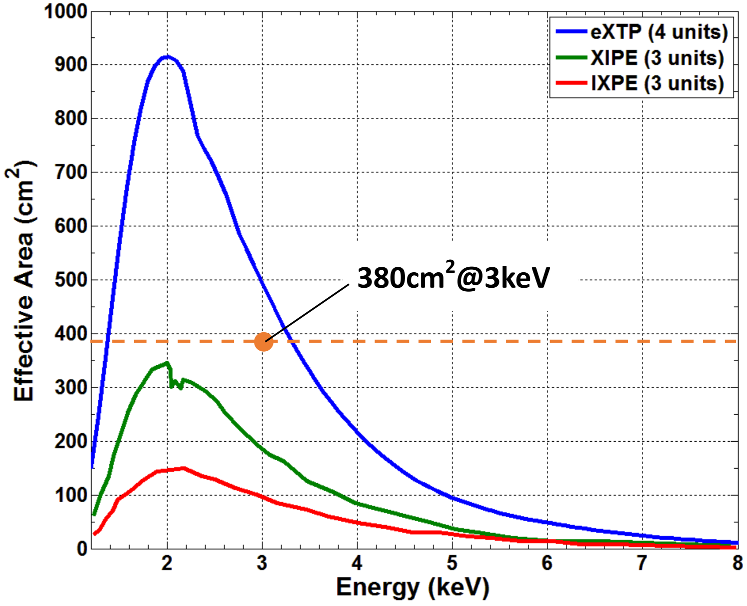
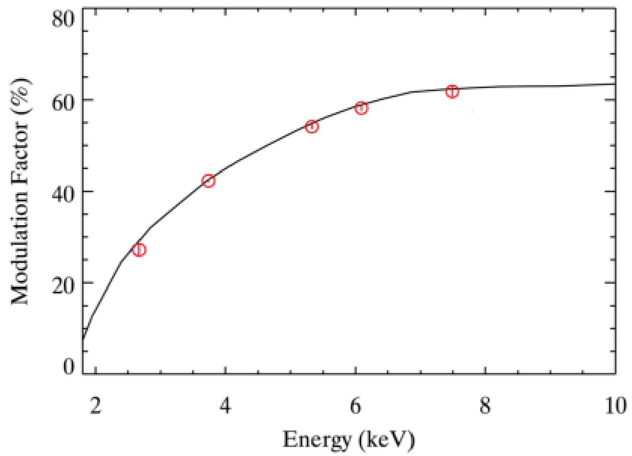
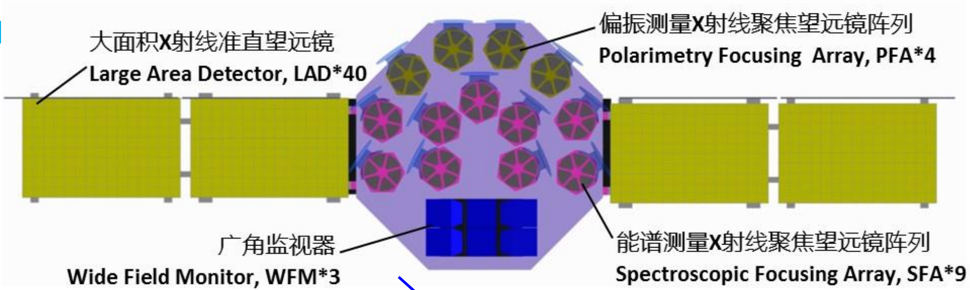
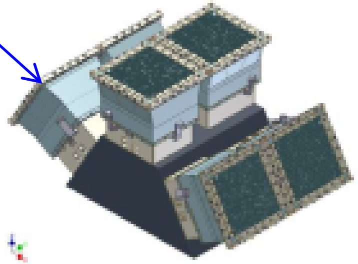


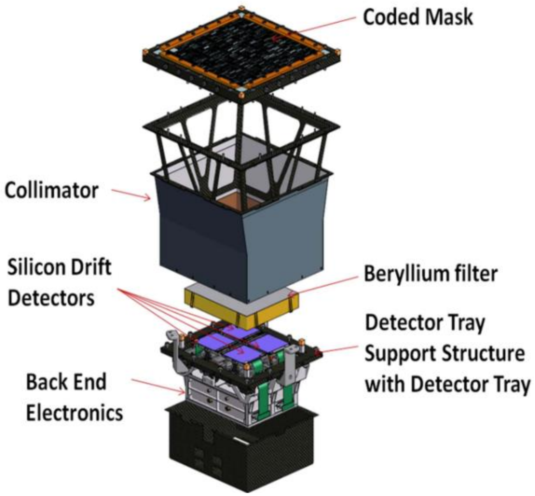


eXTP Scientific Payload: WFM – Wide Field Monitor

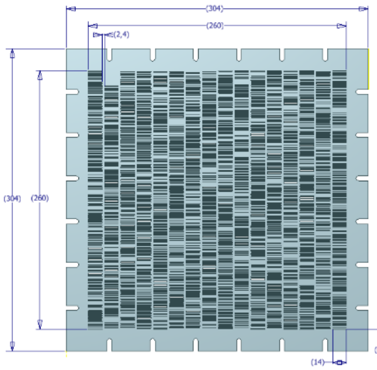
- 3 units (6 cameras)
- 2D Imaging, 5′ (FWHM) resolution
- Location accuracy: ≤ 1′
- Field of view: ≥ 3.2 Sr (at 20% response)
- Energy range: 2-50 keV
- Energy res.: ≤ 300eV @ 6keV
- Time resolution: 10μs
- Absolute time accuracy: 2μs
- Peak sensitivity (5σ): 1Crab (1s), 5mCrab (50ks)



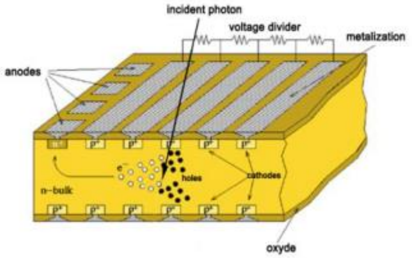




Camera module



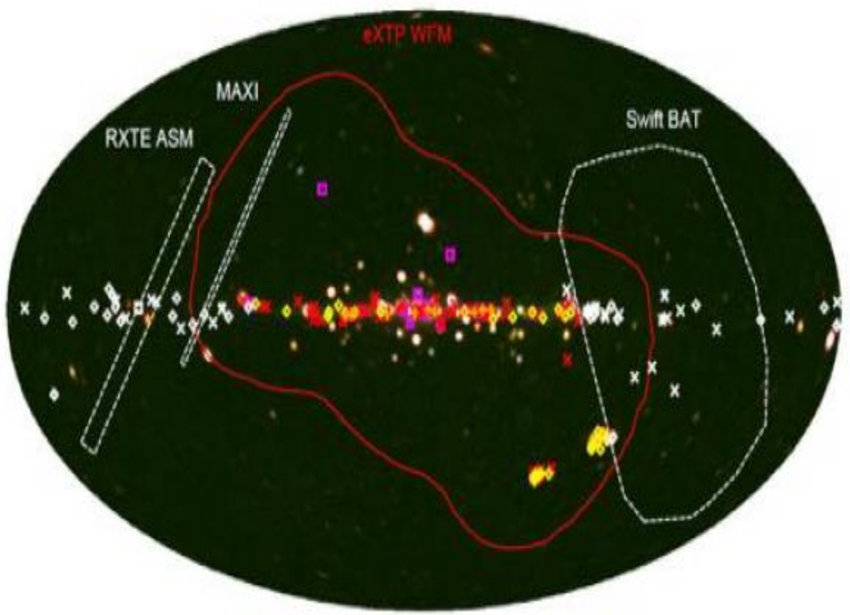
1.5D coded mask



SDD: 2x384 anodes, pitch = 169μm

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)



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

Summary

- DAMPE (2015), POLAR (2016) & Insight-HXMT (2017)
  - Major progresses made in exploring the extreme universe
- Still six important problems of extreme universe:
  - Origin, Energy, Source, Gravity, Magnetism, Density
- Two tasks with key international collaborations (~1/2 international payload) : ~500 scientists from ~ 100 institutions in ~ 20 countries & regions, ~2027 launch
  - High Energy cosmic-Radiation Detection (HERD) facility onboard China's Space Station (part of Italian Module)
  - enhanced X-ray Timing and Polarimetry (eXTP) space observatory

Many thanks for your attention!