“慧眼”-HXMT卫星亮点
Highlights of the *Insight*-HXMT satellite

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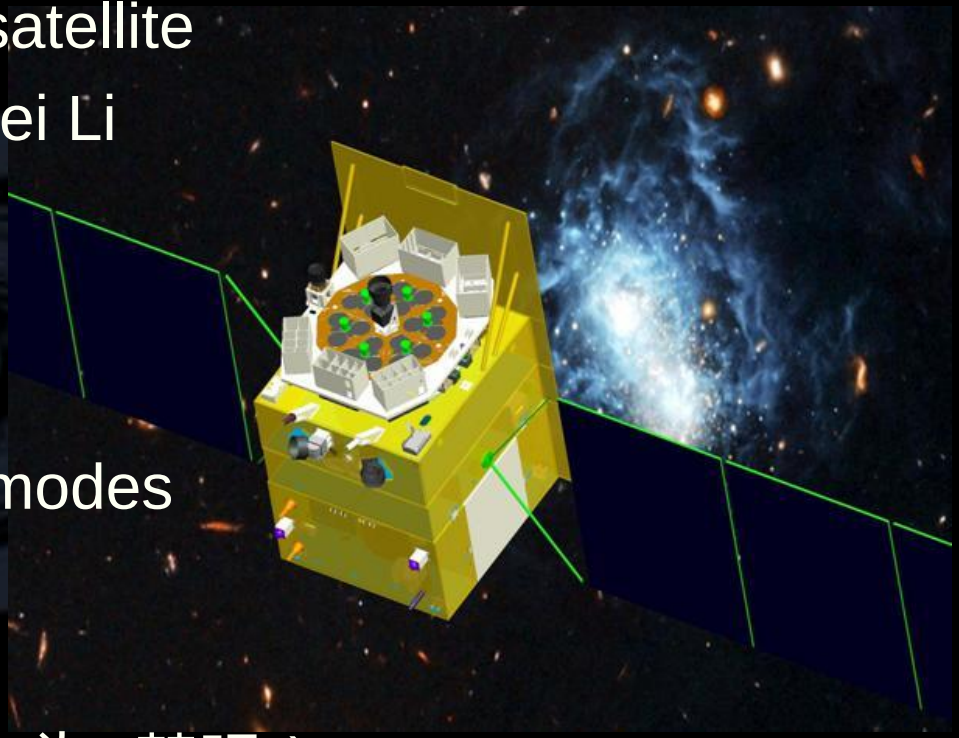
Trump on US election: we all have to learn Chinese if Biden wins!
OK, let’s do it…

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

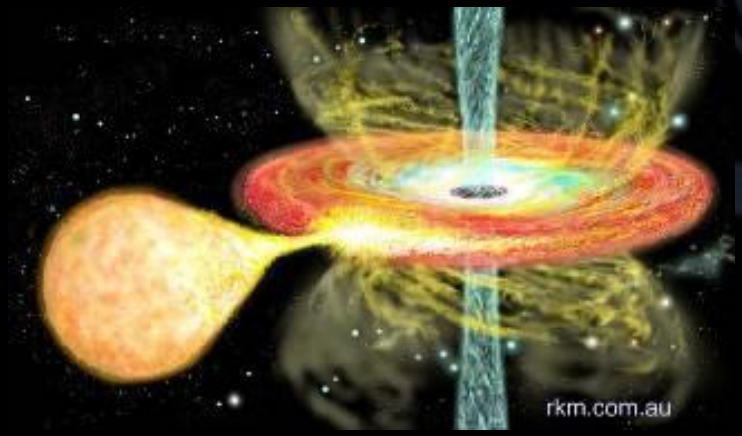
- China's 1st X-ray astronomy satellite
- Proposed in1993 by Prof. Tipei Li
- Selected in 2011
- Total weight ~2500 kg
- Cir. Orbit 550 km, incl. 43°
- Pointed, scanning and GRB modes
- Designed lifetime 4 yrs
- Launched on June 15th, 2017
- Dubbed "*Insight*"（发射后命名为 "慧眼"）

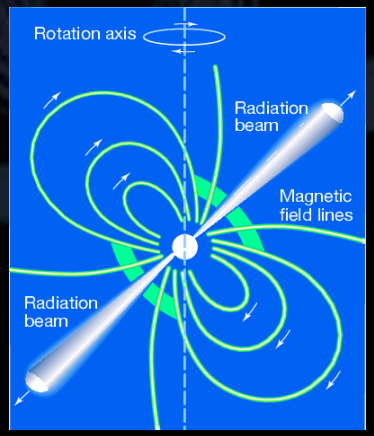


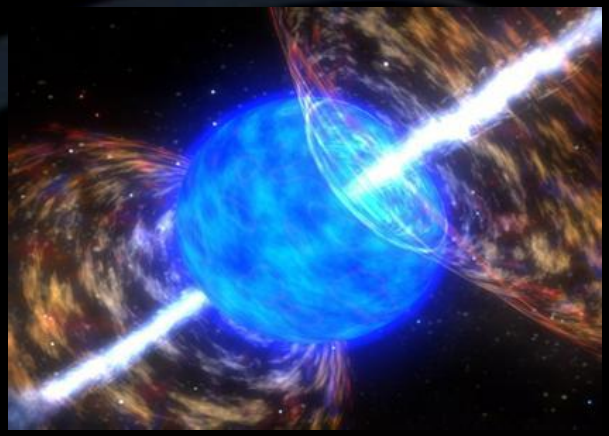
Zhang, S.-N. et al. Overview to the Hard X-ray Modulation Telescope (Insight-HXMT) Satellite. Science China Physics, Mechanics, and Astronomy 63, 249502 (2020)

Core sciences核心科学

- ✓ Galactic plane scan and monitor survey for more weak & short transient sources in very wide energy band (1-250 keV)
- ✓ Pointed observations: High statistics study of bright sources and long-term high cadence monitoring of XRB outbursts
- ✓ All sky monitor for GRBs & pulsars (0.2 – 3 MeV)





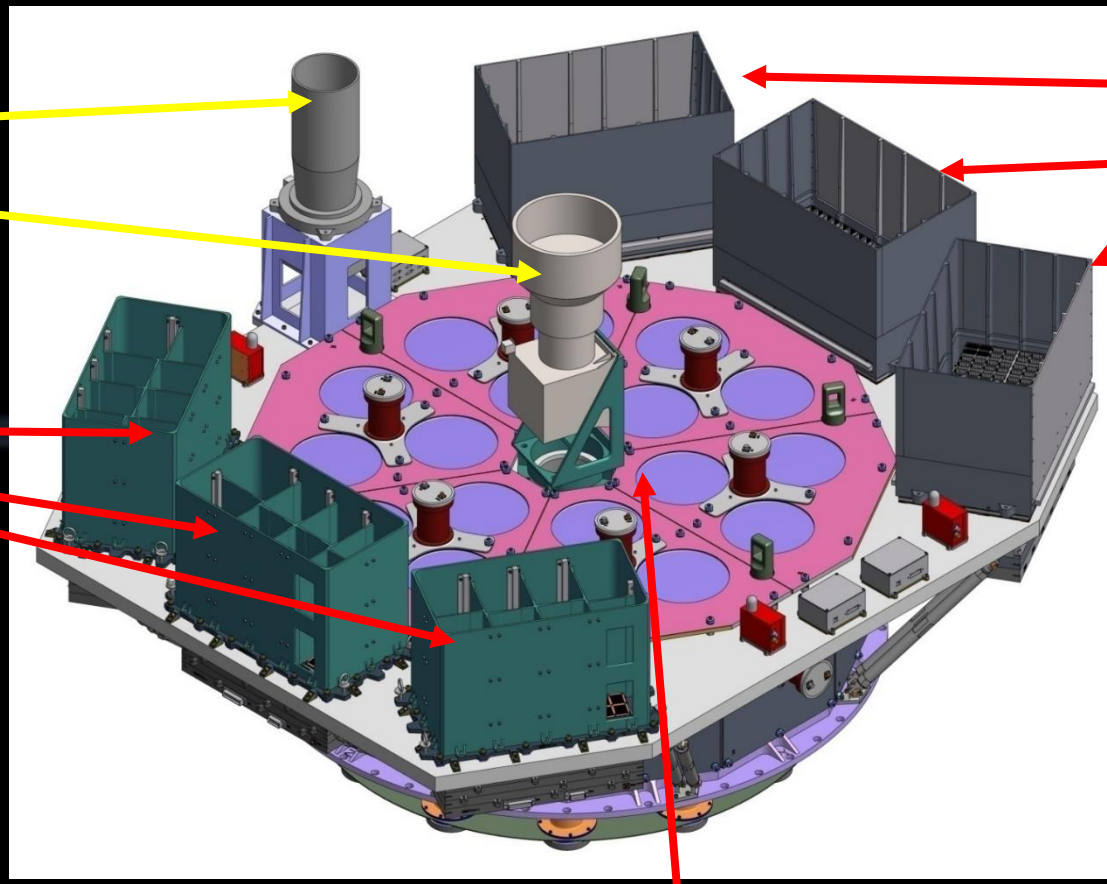


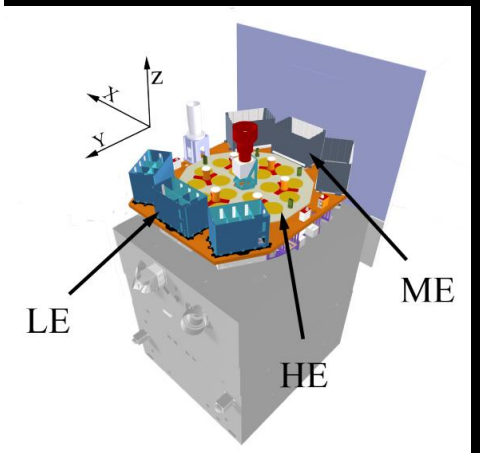
Science payload科学载荷

Star tracker

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

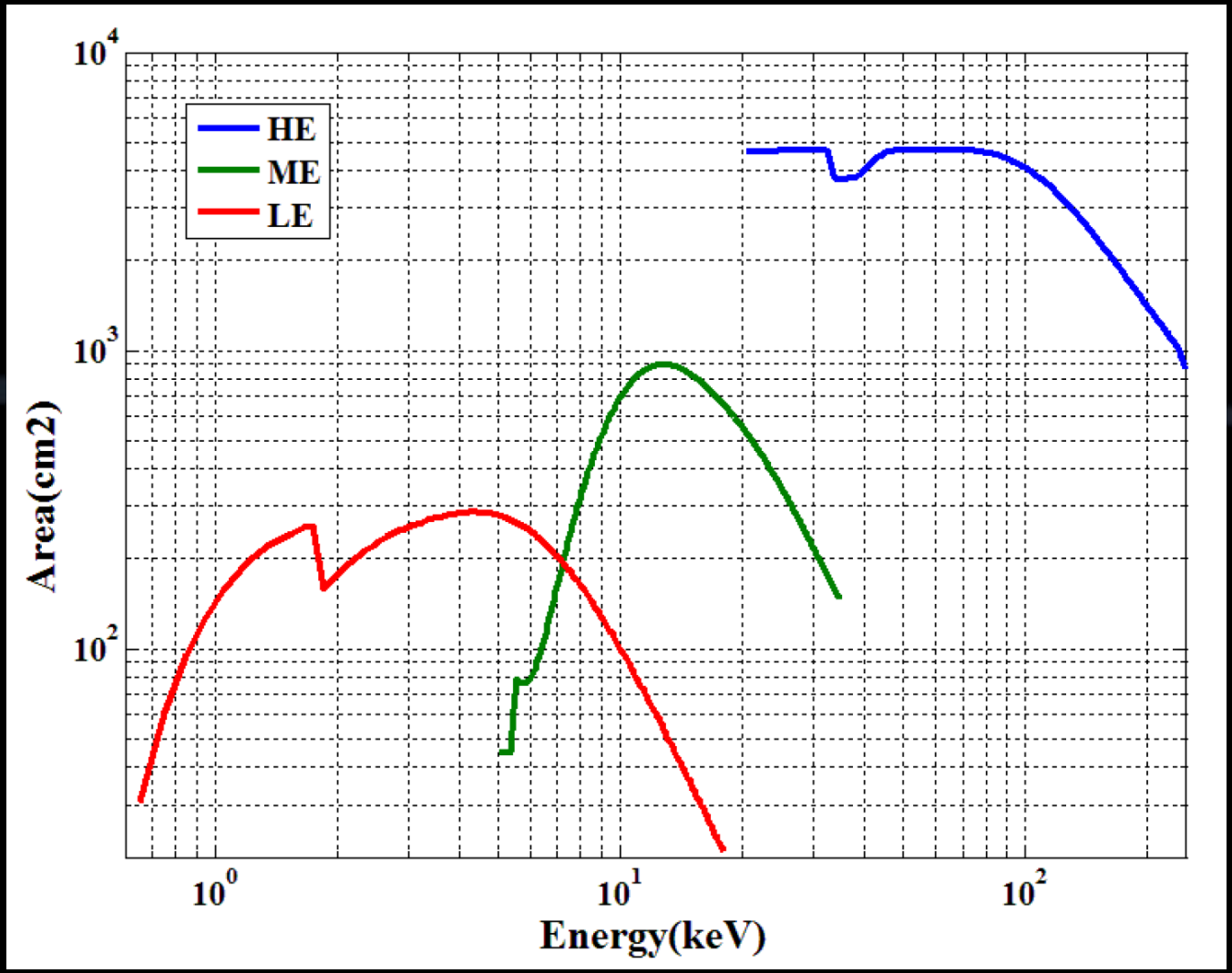
ME:Si-PIN,5-30 keV, 952 cm^2



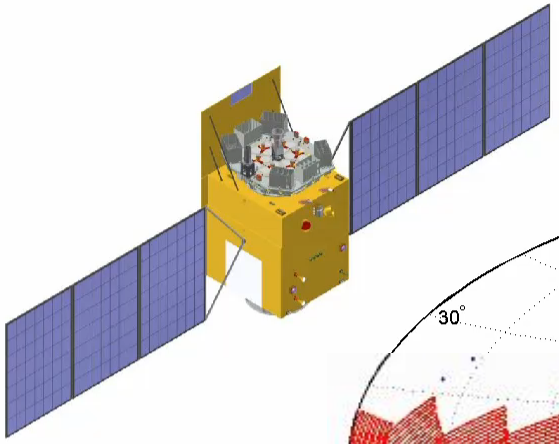


HE: NaI/CsI, 20-250 keV, 5000 cm^2

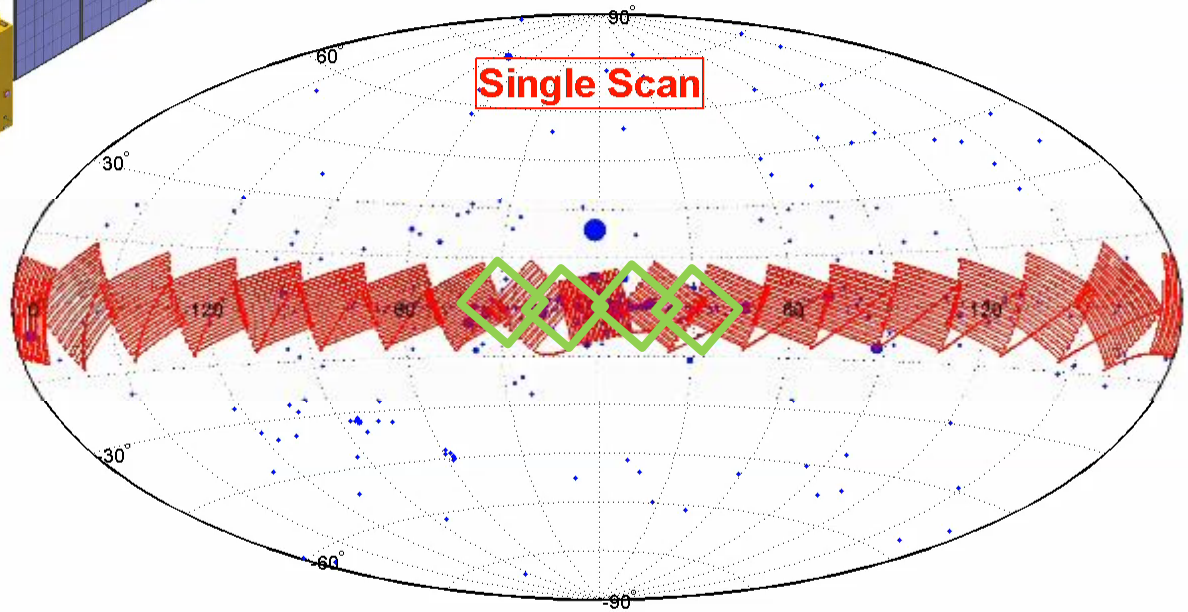
Effective area有效面积



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)



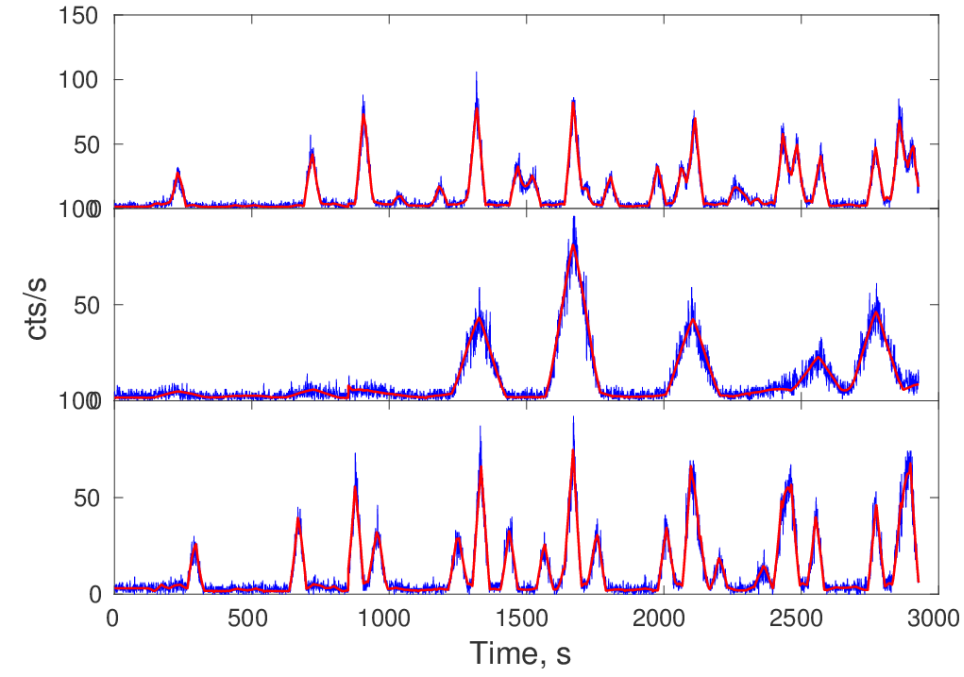
Galactic Plane: (20°*20°)*18 + (20°*20°)*4

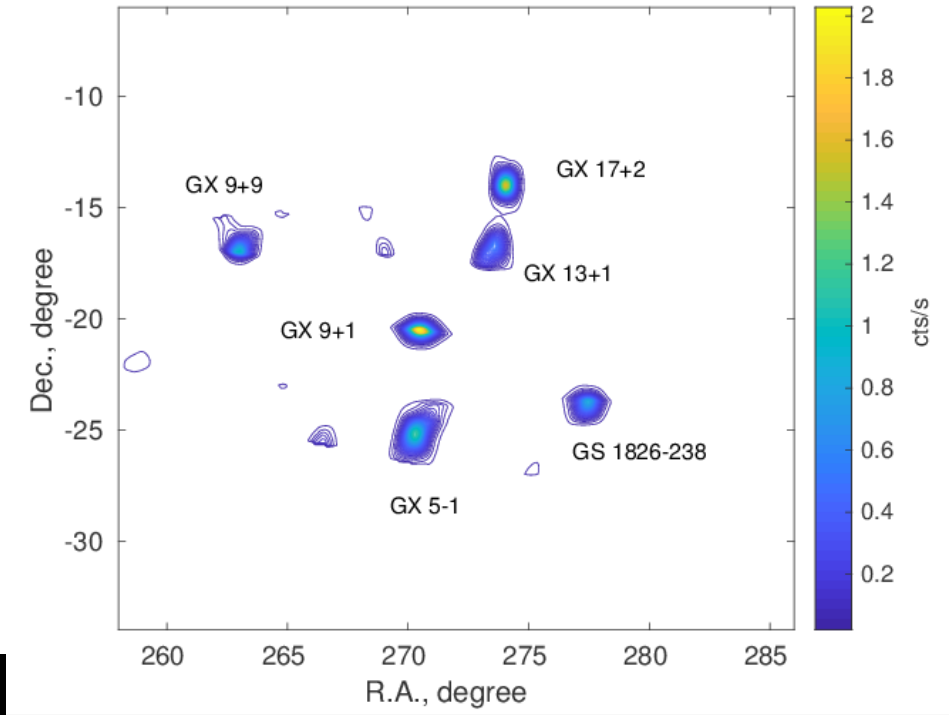
- 11 center regions: 90 times/year (-60°~60°), 11 outer regions: 10 times/year

Sai, N. et al., 2020

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

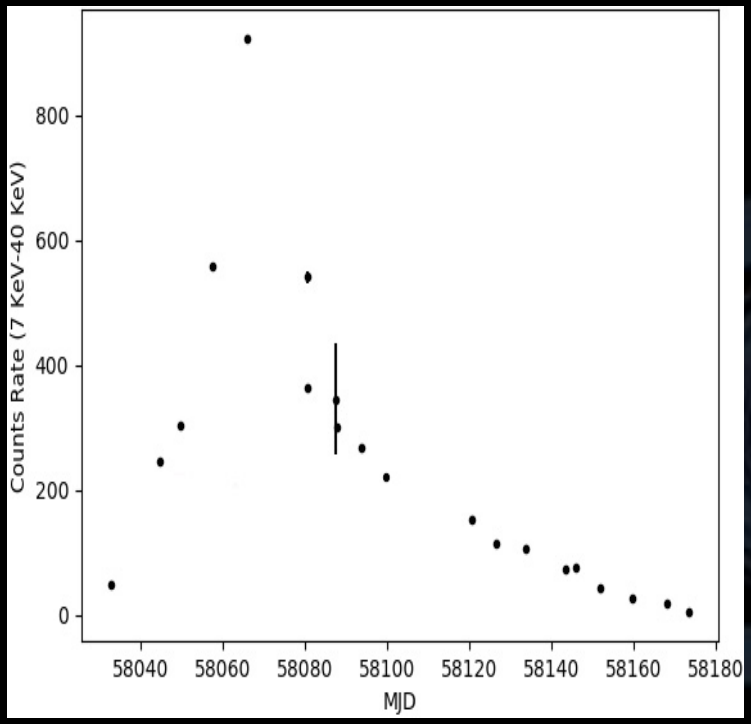
July 16 on Galactic center (LE 1-6 keV)





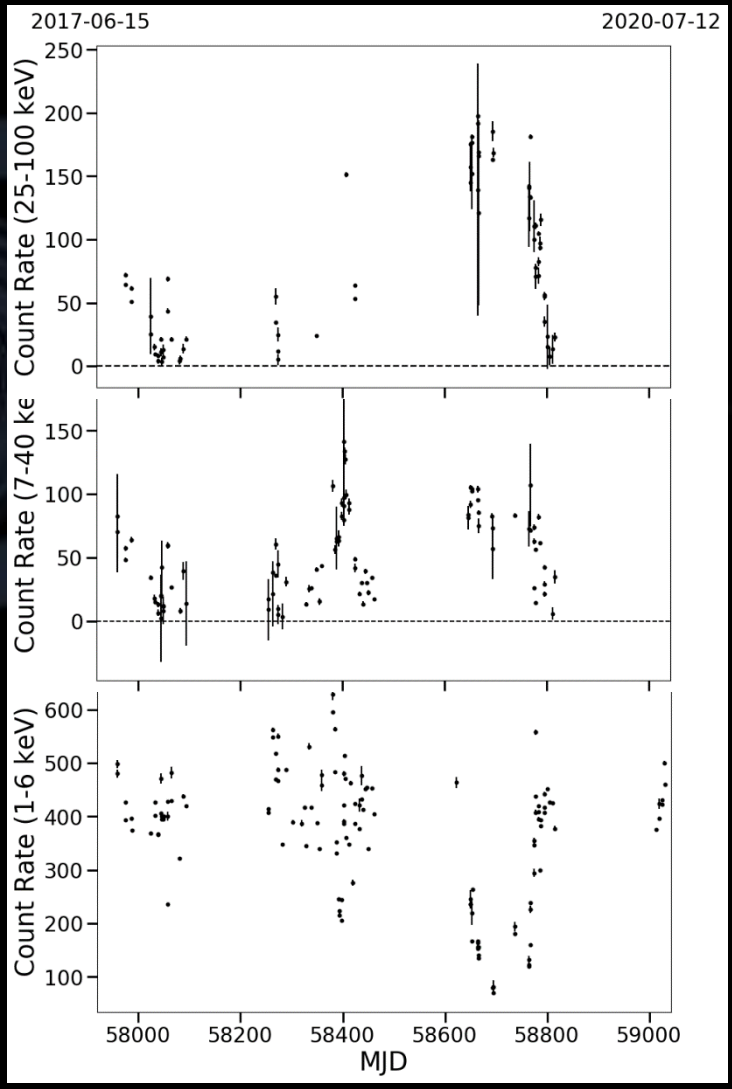
Direct Demodulation Method (Li & Wu 1993); Guan, J. et al., 2020

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

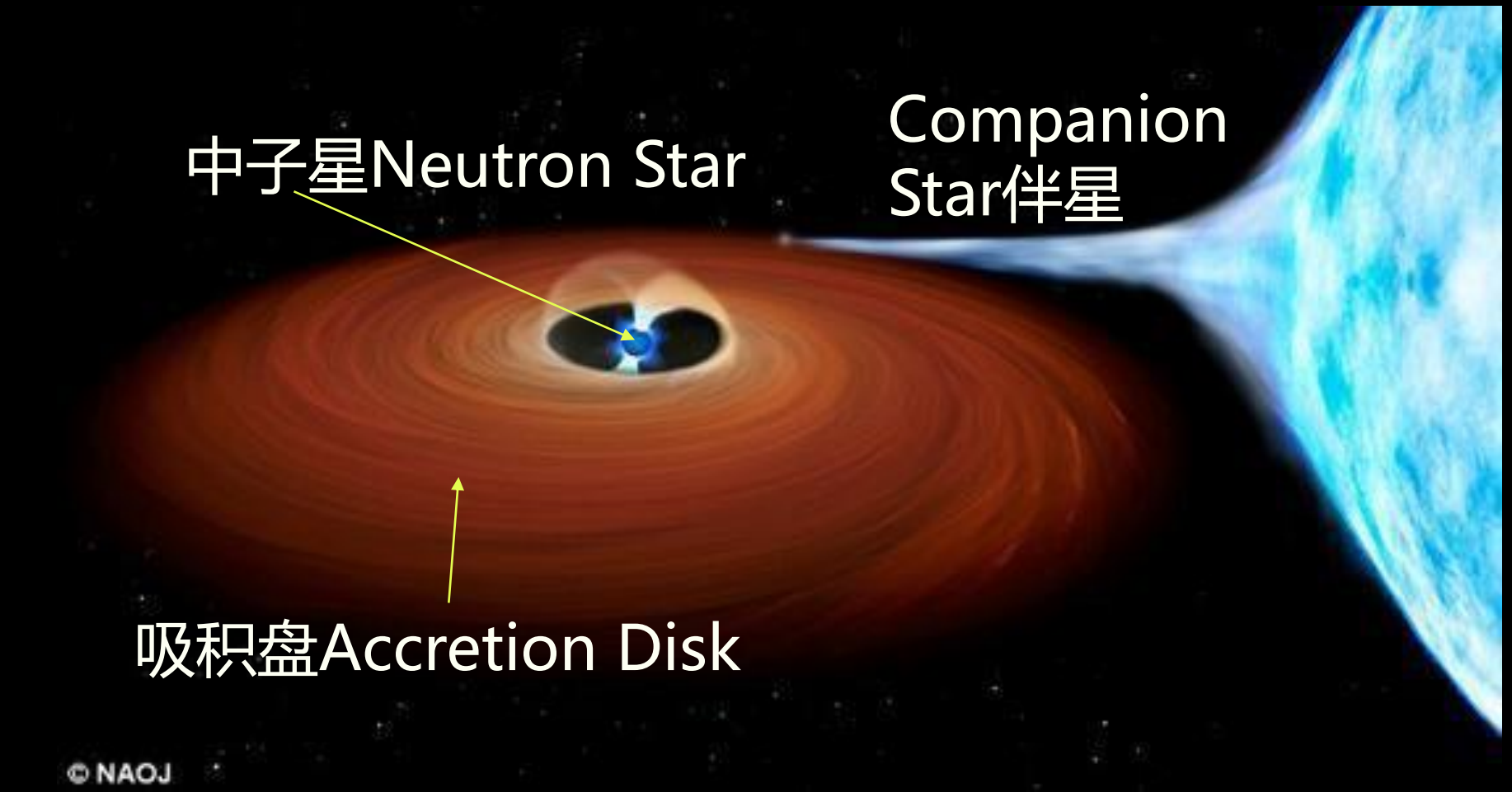


ME (7-40 keV):
Swift J0243.6+6124,
Accreting pulsar

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

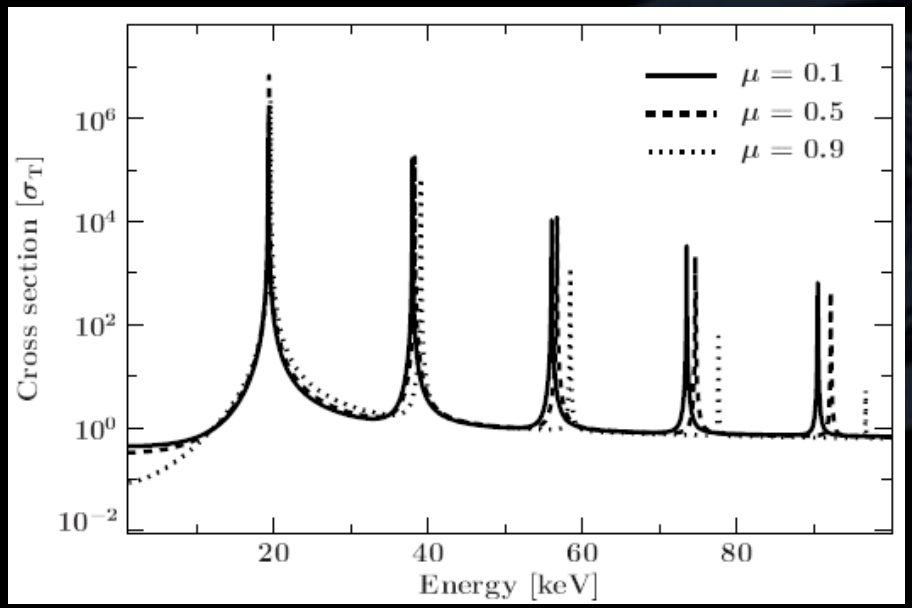


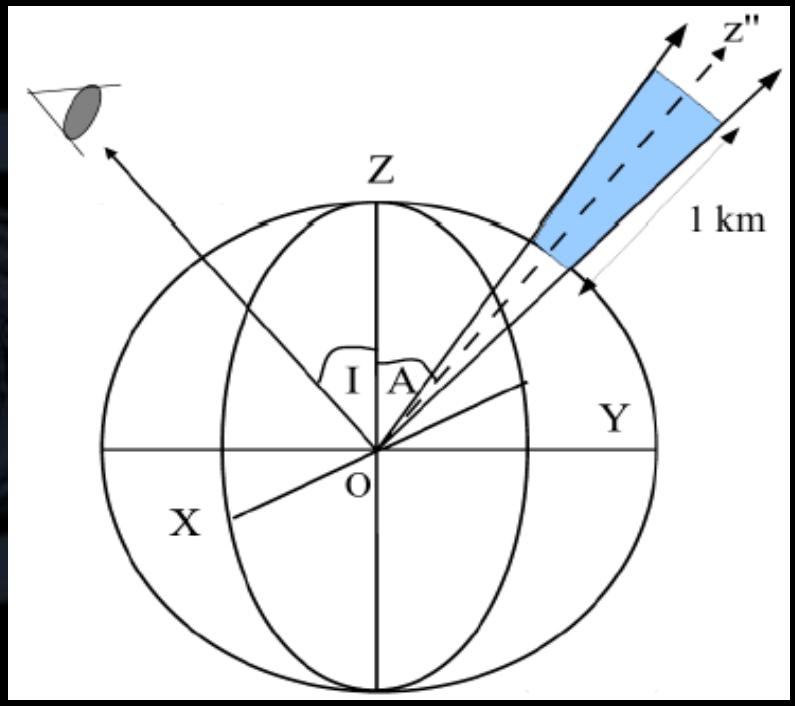
Extremely Complex Interactions in NSXBs
“吸积”中子星和吸积盘复杂的相互作用



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

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

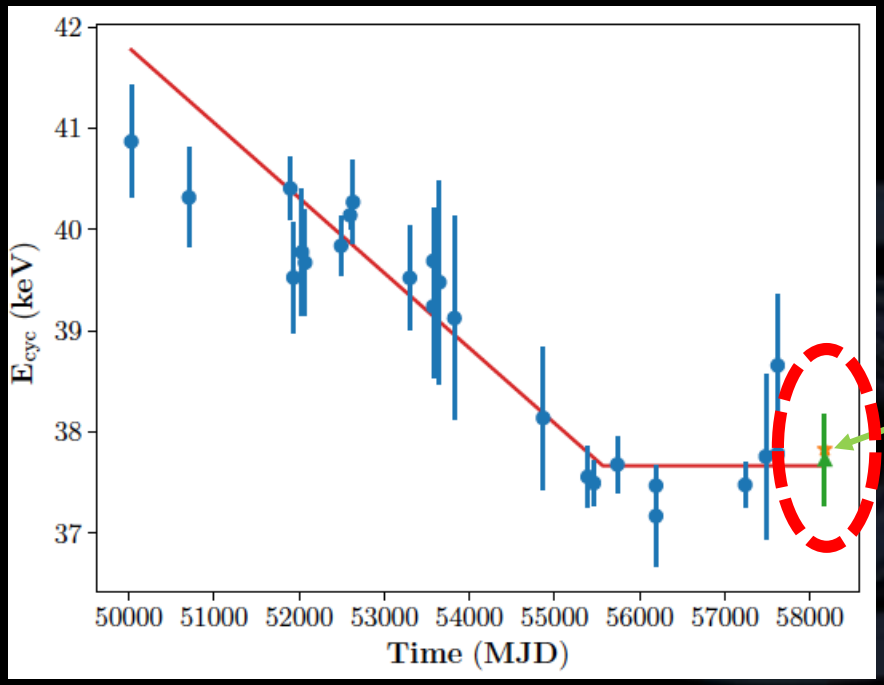


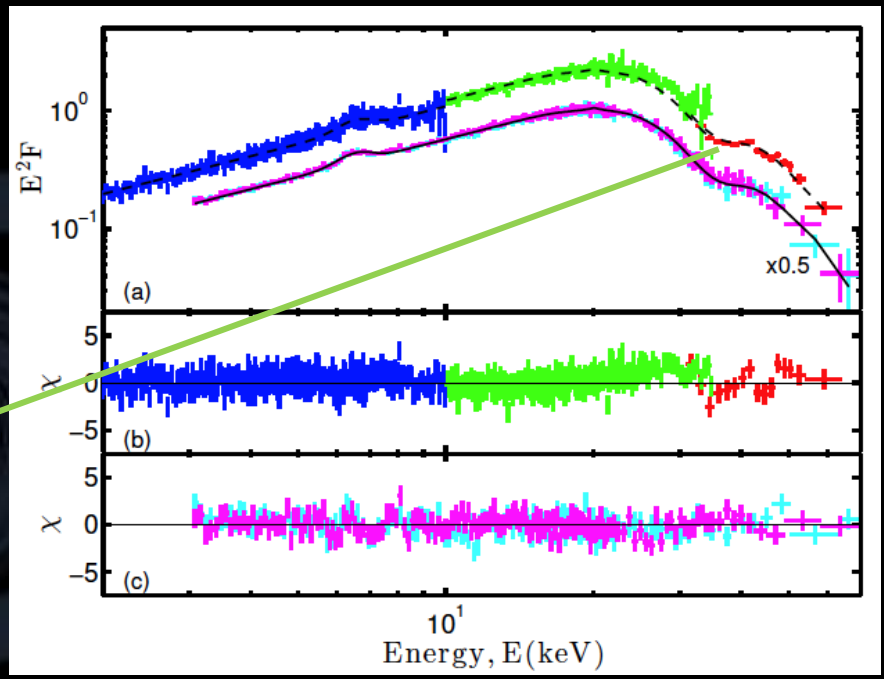


Maitra 2016

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。

Neutron star cyclotron absorption line of Her X-1
“慧眼”确认了中子星回旋吸收线能量停止减少





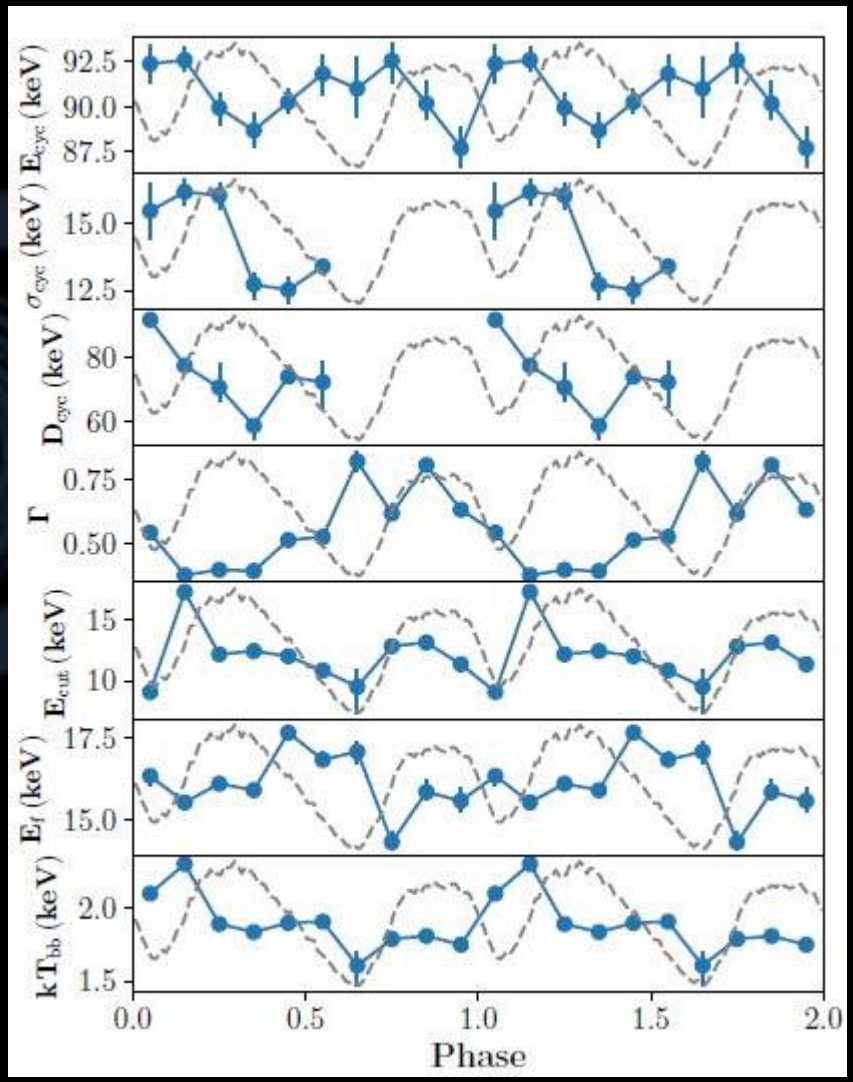
Constant cyclotron line energy in Hercules X-1 -- Joint Insight-HXMT and NuSTAR observations (@> 5 σ significance, Xiao et al. 2020

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

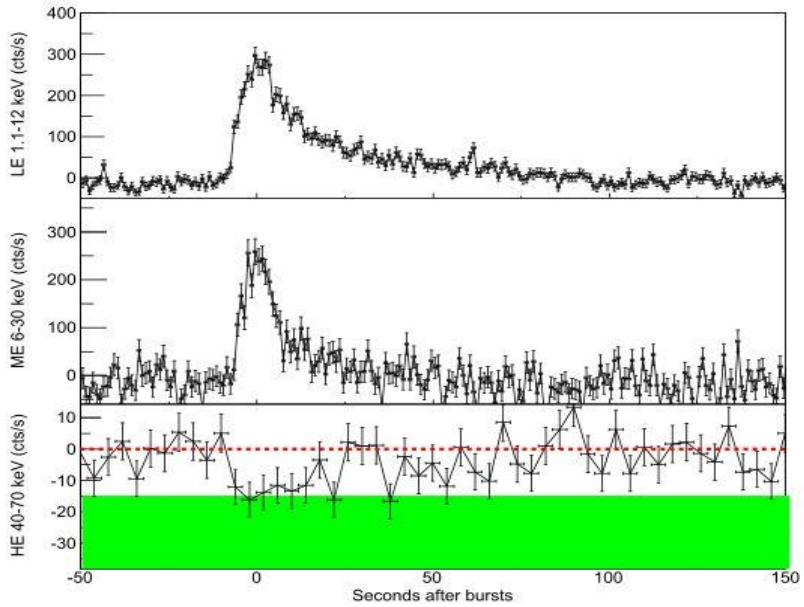
- GRO J1008-57：~90 keV → highest *B* directly measured in the universe ~10^{13}, ~ 4σ with NuSTAR & Suzaku ~79 keV
- 4 HXMT observations ~235 ks ~ 20σ detection

Allow for phase resolved and flux dependent studies

Ge et al. 2020



Corona cooled by *single* Type-I X-ray burst
“慧眼”发现中子星高温冕被单个X射线暴冷却



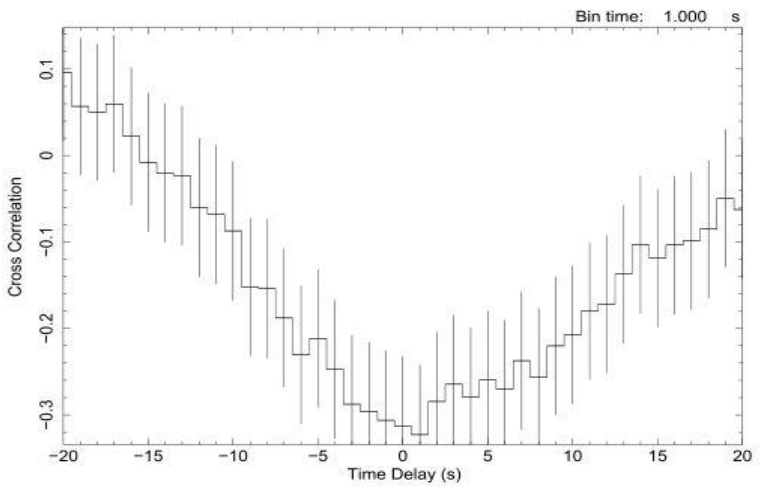
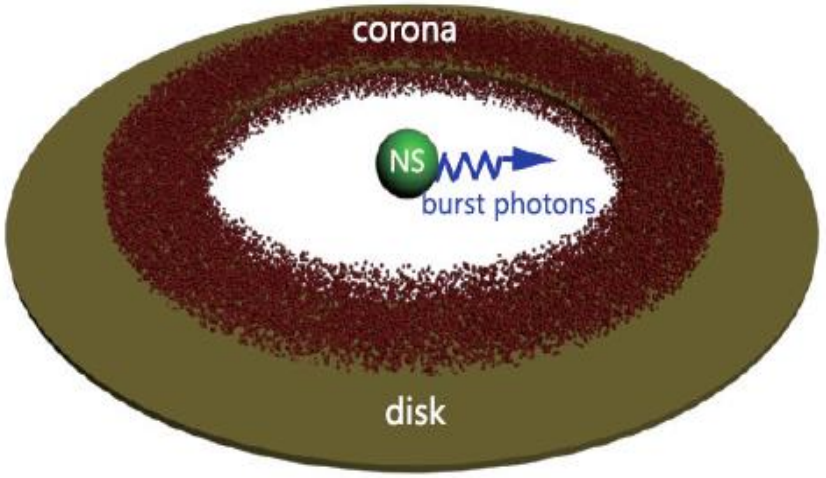
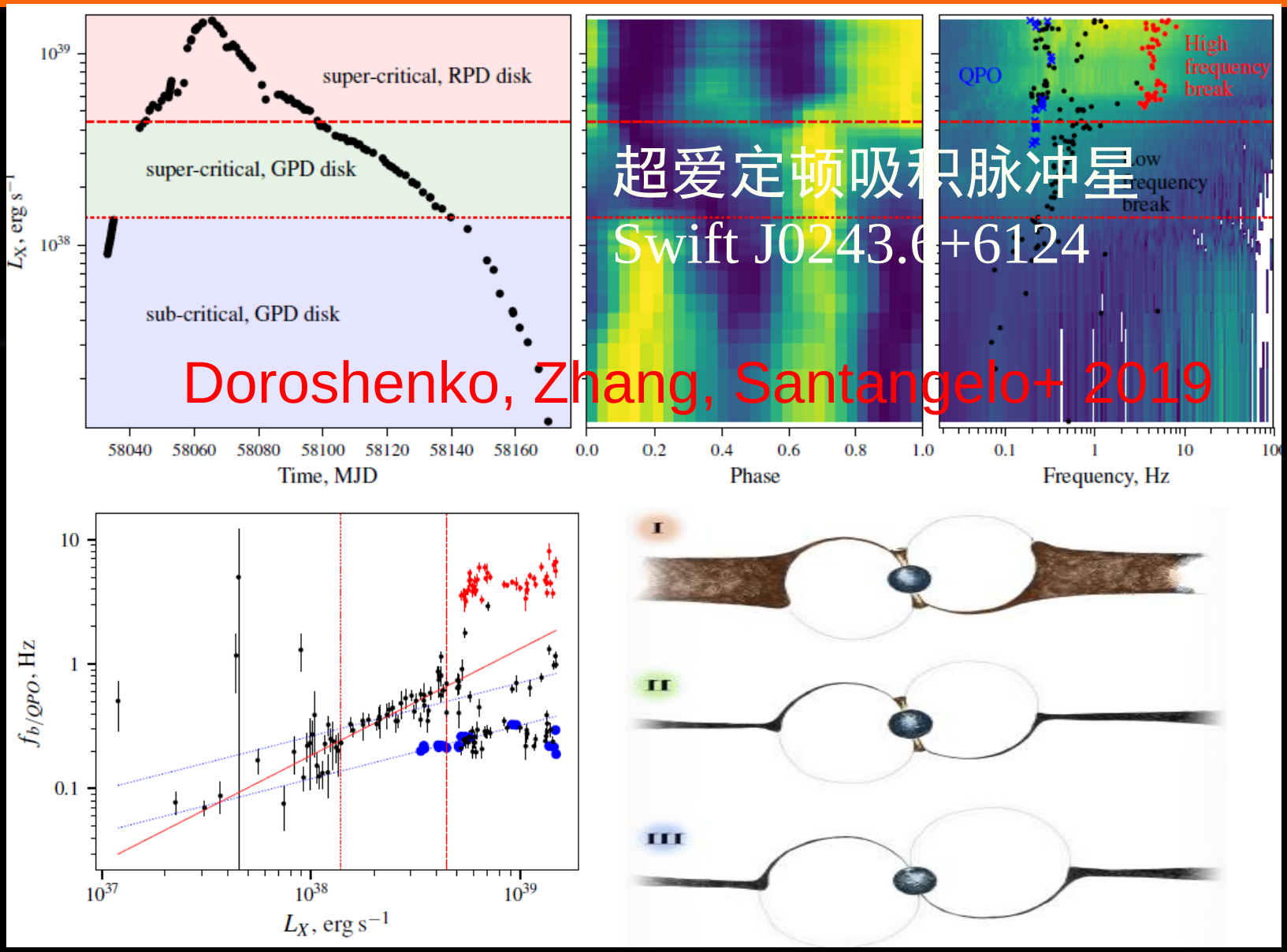


Figure 2. Left panel shows the LE, ME, and HE light curves of the burst in 1.1–12 keV, 5–30 keV, and 40–70 keV, respectively. The time bin for LE and ME is 1 s and HE is 4 s, the green zone in the bottom panel indicates the background level for HE detectors. The right panel shows the cross-correlation between the left panel's LE and HE re-extracted light curves with a time bin of 1 s.

Previously multiple bursts were added to see the cooling, but with Insight-HXMT it's seen in a single burst for the 1st time. 以前需要几十个暴叠加，慧眼单暴就显著看到（4U1636-536, Chen+2018, ApJL)



Insight-HXMT discovery of GPD to RPD transition
“慧眼”发现气压向辐射压转换的吸积盘

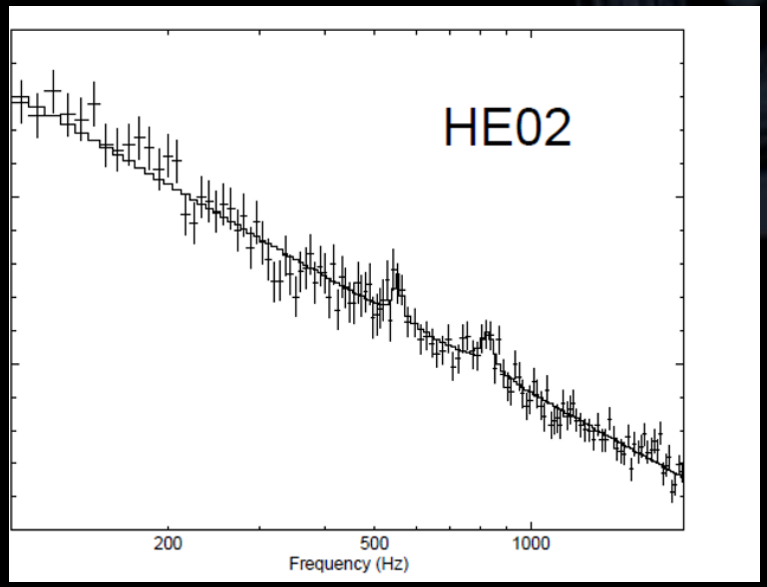


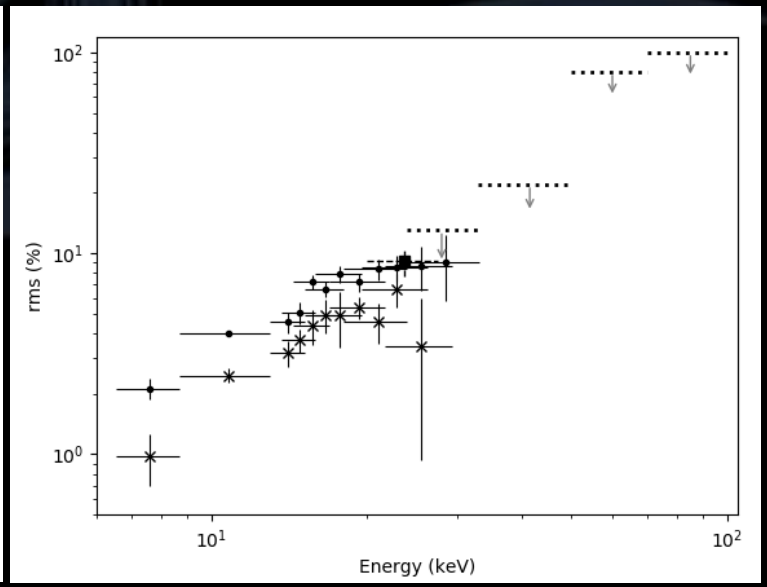
kHz QPOs>20 keV from Sco X-1 with Insight-HXMT
“慧眼”发现最亮X射线源的高能千赫兹准周期振荡

Discovery of Submillisecond Quasi-periodic Oscillations in the X-Ray Flux of Scorpius X-1

M. van der Klis[1], J. H. Swank[2], W. Zhang[2], K. Jahoda[2], E. H. Morgan[3], W. H. G. Lewin[3], B. Vaughan[4], and J. van Paradijs[5]

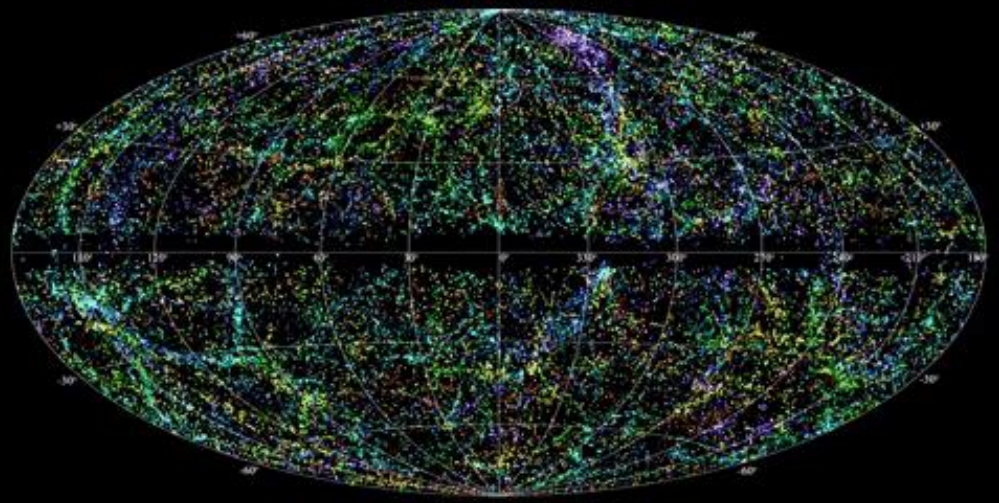
The Astrophysical Journal Letters, Volume 469, Number 1





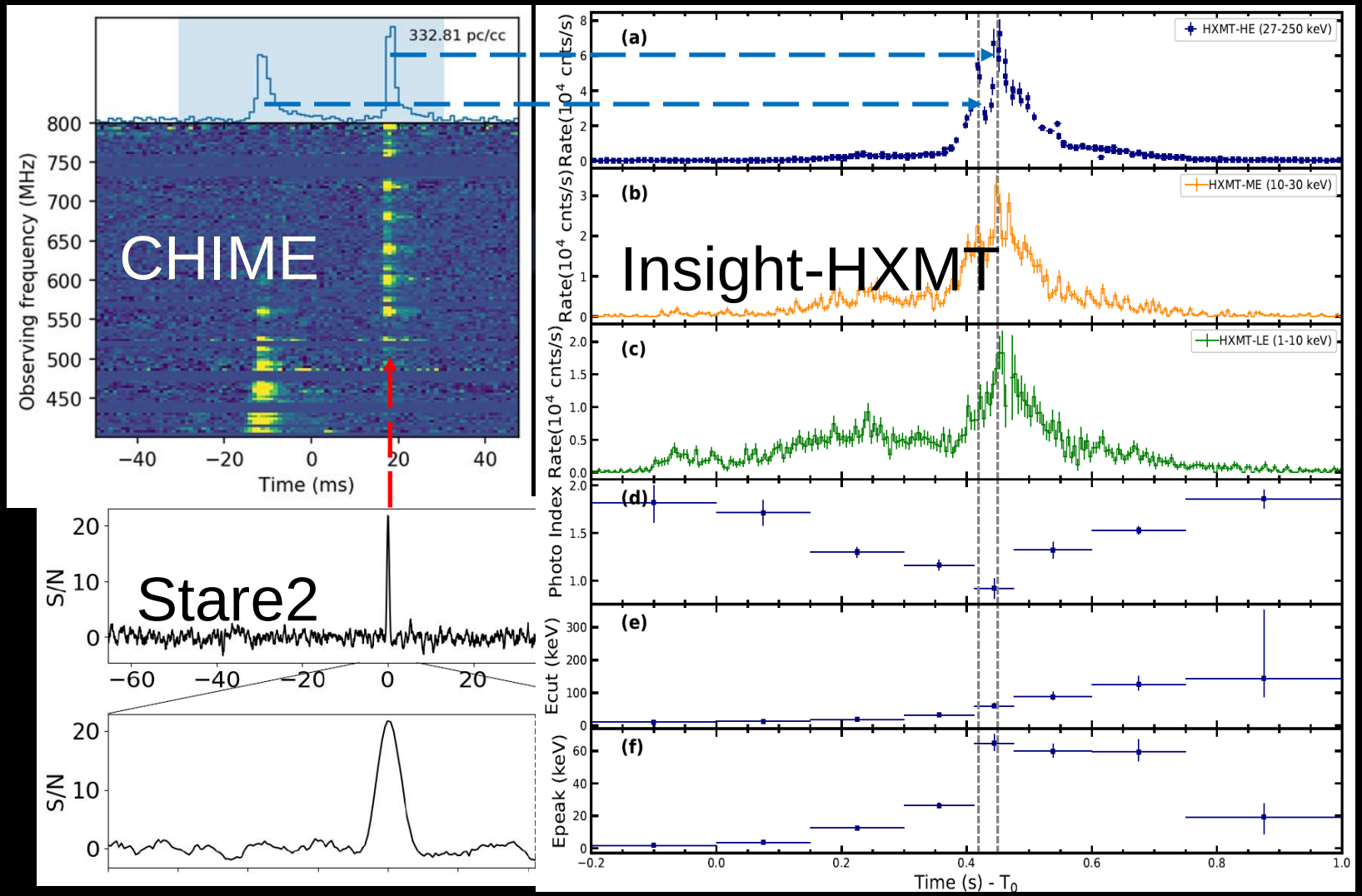
Insight-HXMT on Sco X-1 (Jia+ 2020, JHEAP, arXiv:1910.08382)

Fast Radio Bursts快速射电暴



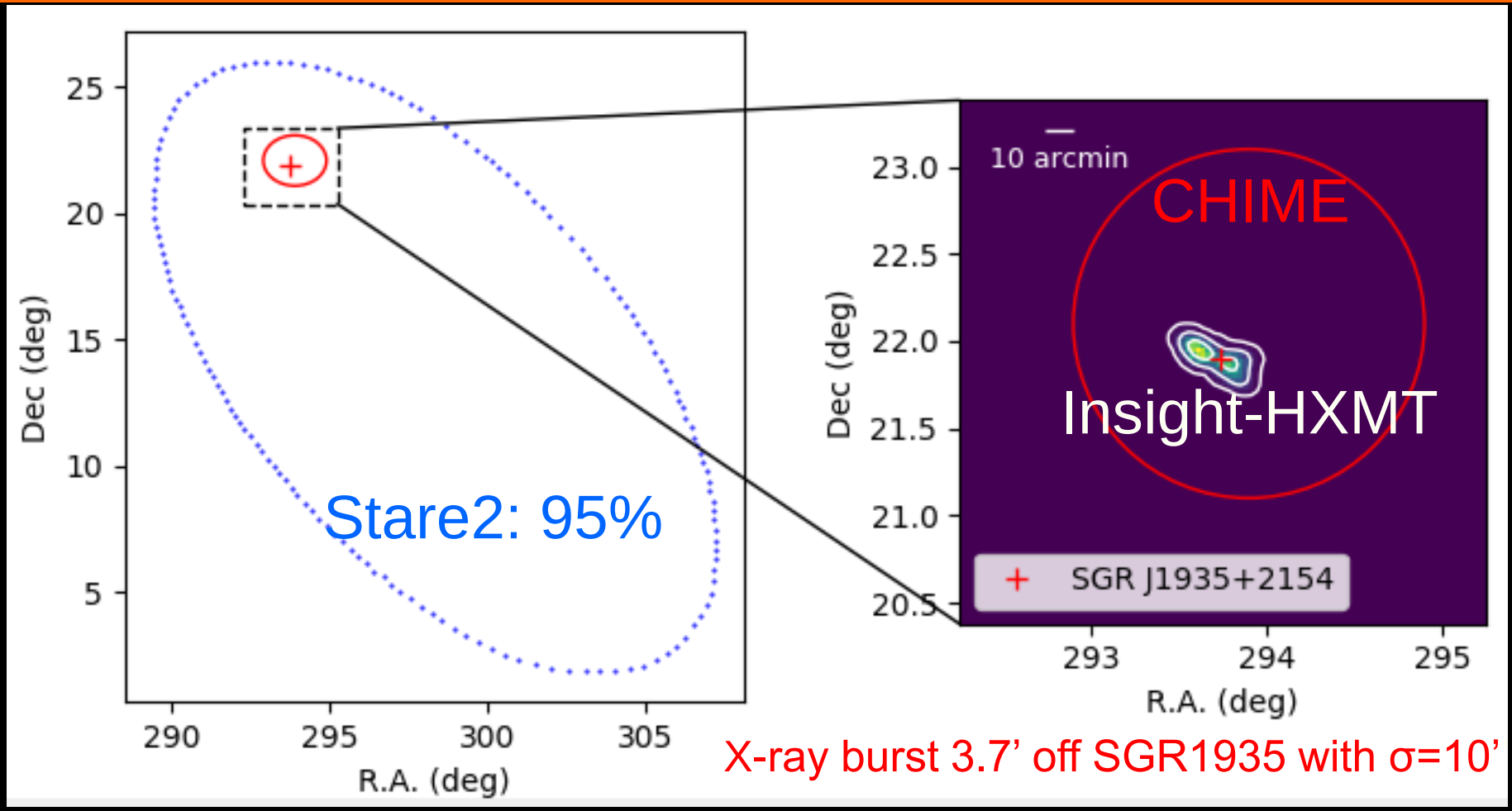
First reported in 2007 (Lorimer et al. 2007): bright millisecond radio pulses, random arrival direction and time, some repeat and even periodic, but counterpart or radiation at any other wavelengths not known, until April 28th, 2020.

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



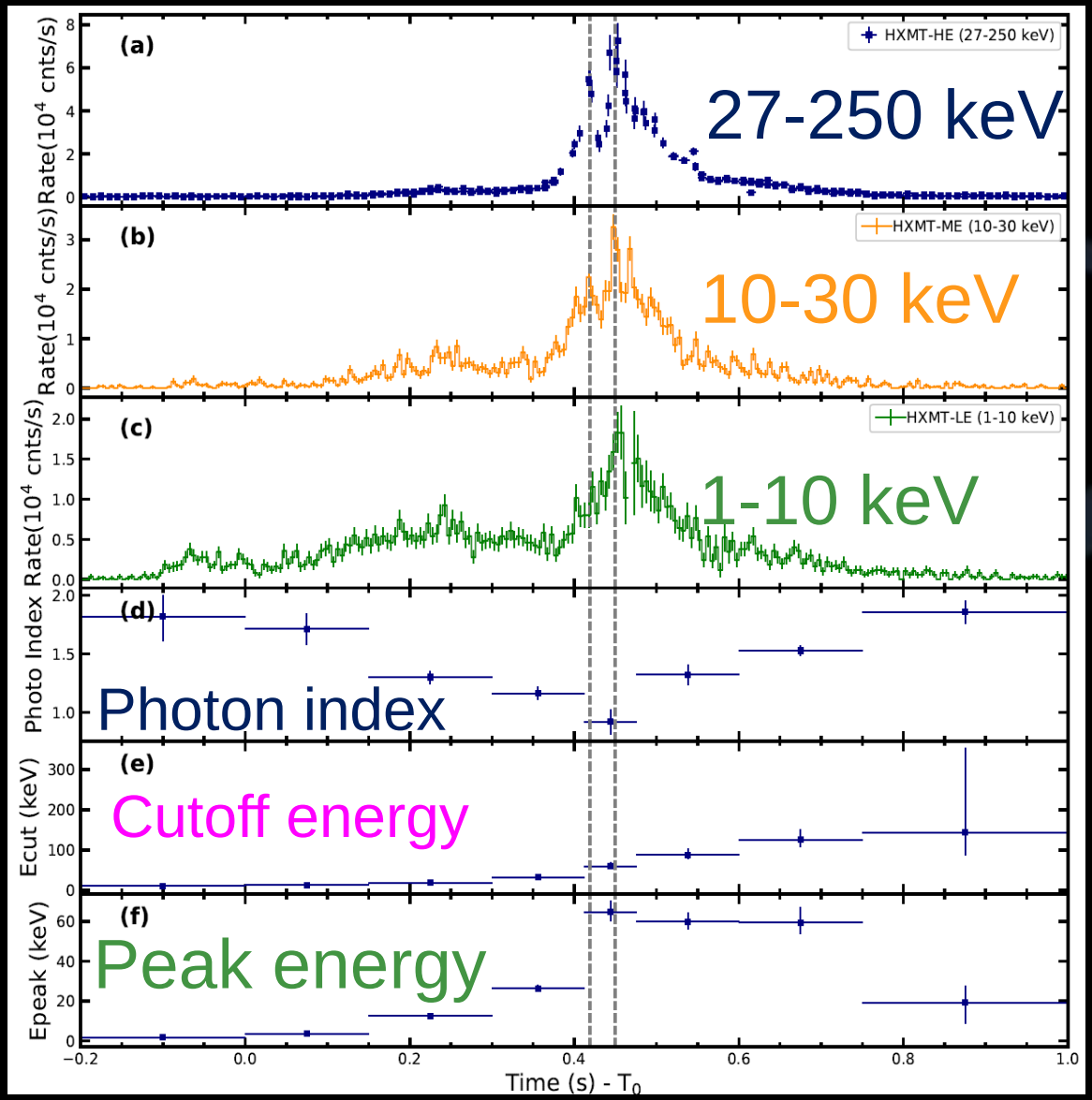
CHIME/FRB Collaboration+; Bochenek+; Li+, 2021, Nature Astronomy

Localization of the X-ray burst定位X射线暴



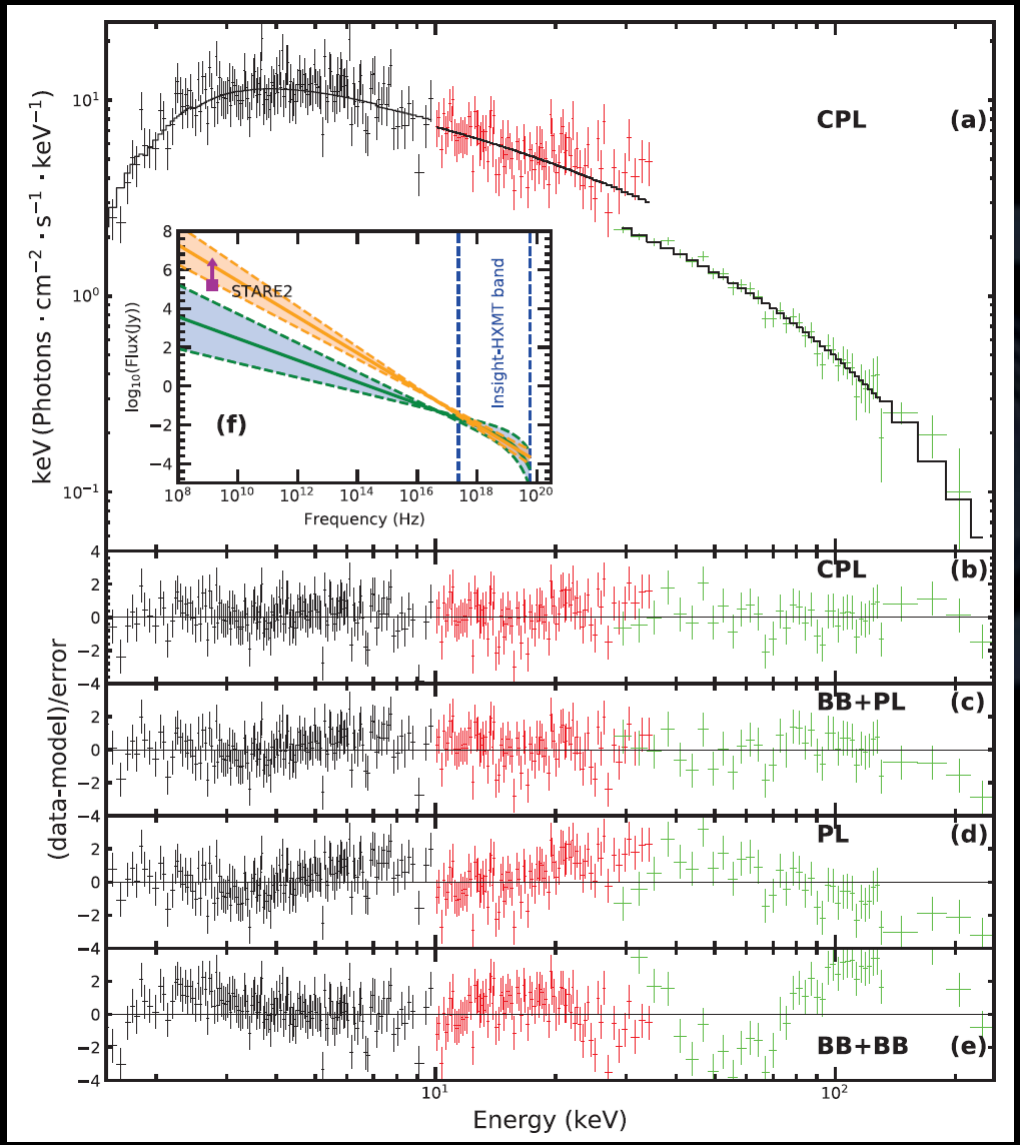
Identification of the X-ray burst with SGR1935, Li+ (Insight-HXMT team), 2021, Nature Astronomy

Insight-HXMT broad band light curves
慧眼宽能段光变



Two narrow X-ray peaks coinciding the twin radio pulses (30 ms separation), identification of the X-ray burst with FRB 200428: Insight-HXMT Atel #13696/GCN #27675, Li+ (Insight-HXMT team), 2021, Nature Astronomy

Insight-HXMT broad band spectrum
慧眼宽能段能谱



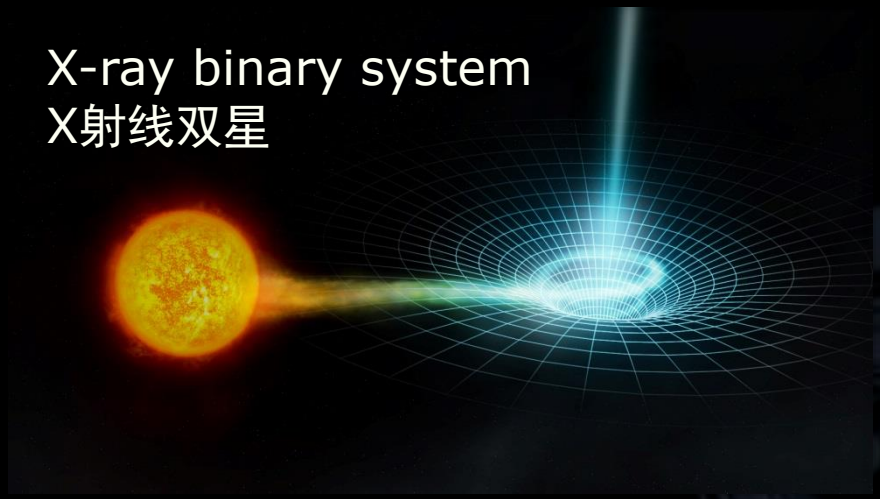
Both cutoff powerlaw & blackbody+powerlaw provide almost the same good fitting. BB+BB or PL rejected.

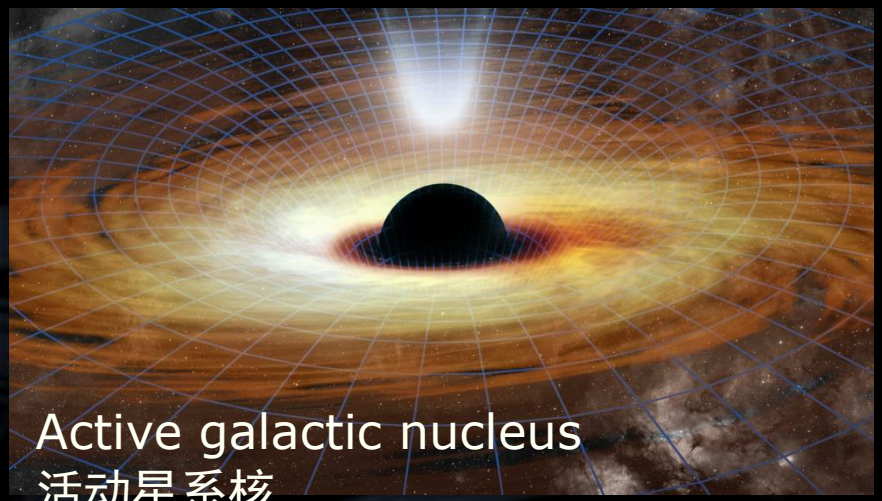
CPL: photon index ~1.6, Ecut~84 keV

BB+PL: Tbb~11 keV, photon index ~1.9

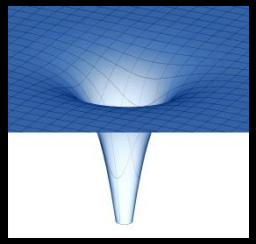
Li+ (Insight-HXMT team), 2021, Nature Astronomy

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

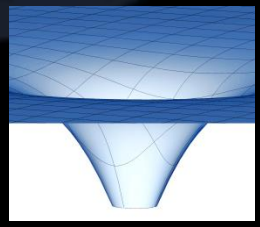




X-ray study covers wide mass range in uniform setting



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



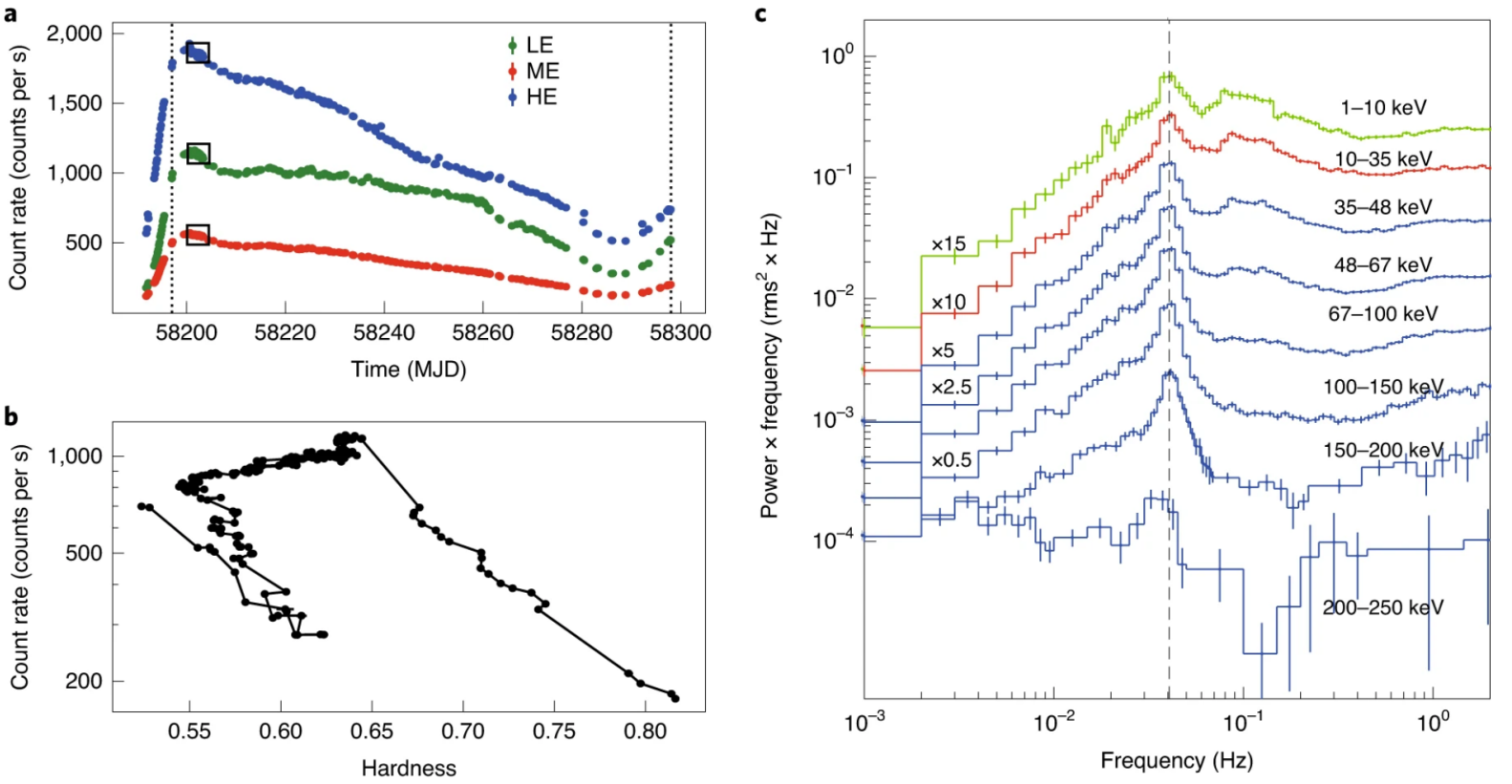
Supermassive black hole
Weakly curved spacetime
(~Solar)

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

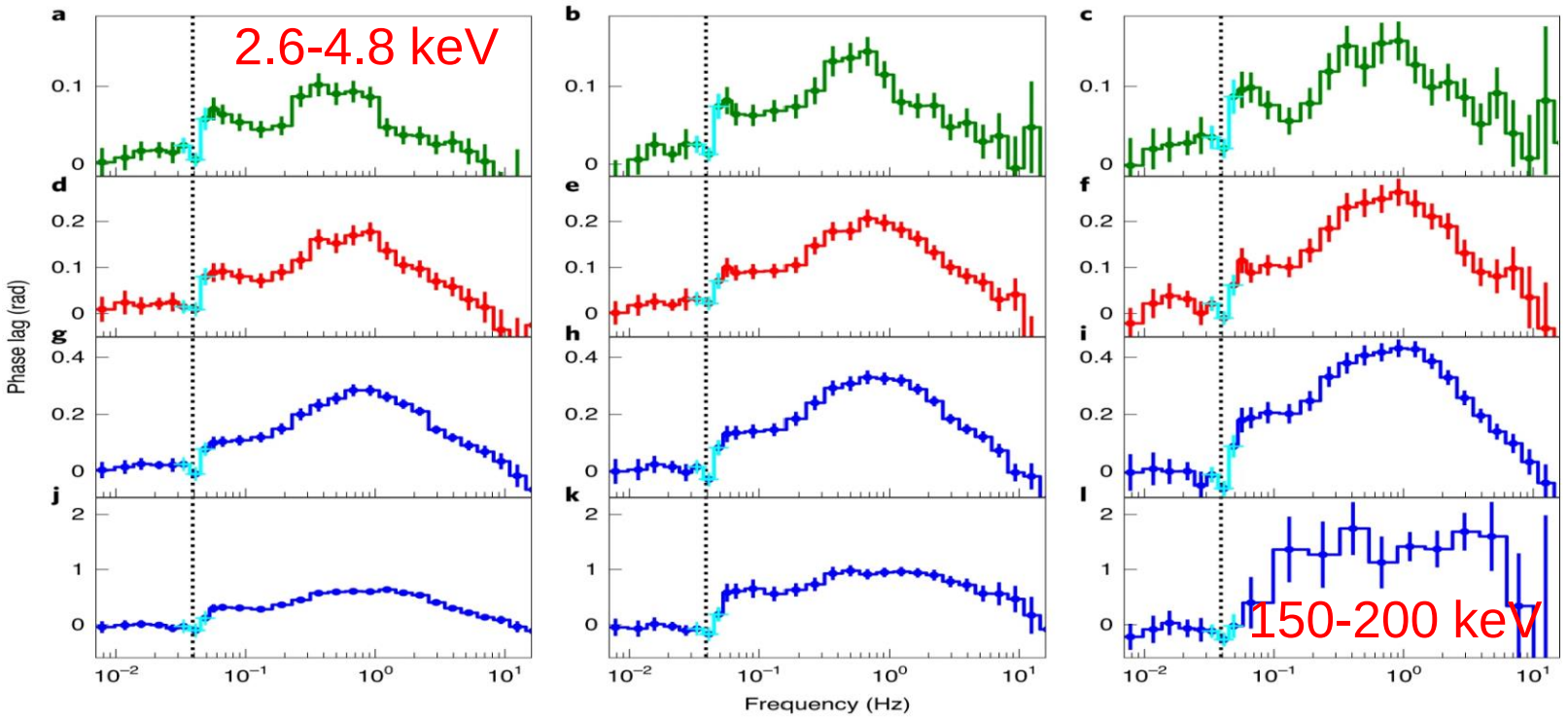


Ma, Tao, SNZ+ 2021, Nature Astronomy

Dip in the lag-freq. spectra at QPO

Fig. 2: Frequency-dependent phase-lag spectra for MAXI J1820+070 in different energy bands. All lags are relative to 1-2.6 keV; negative lag: behind

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



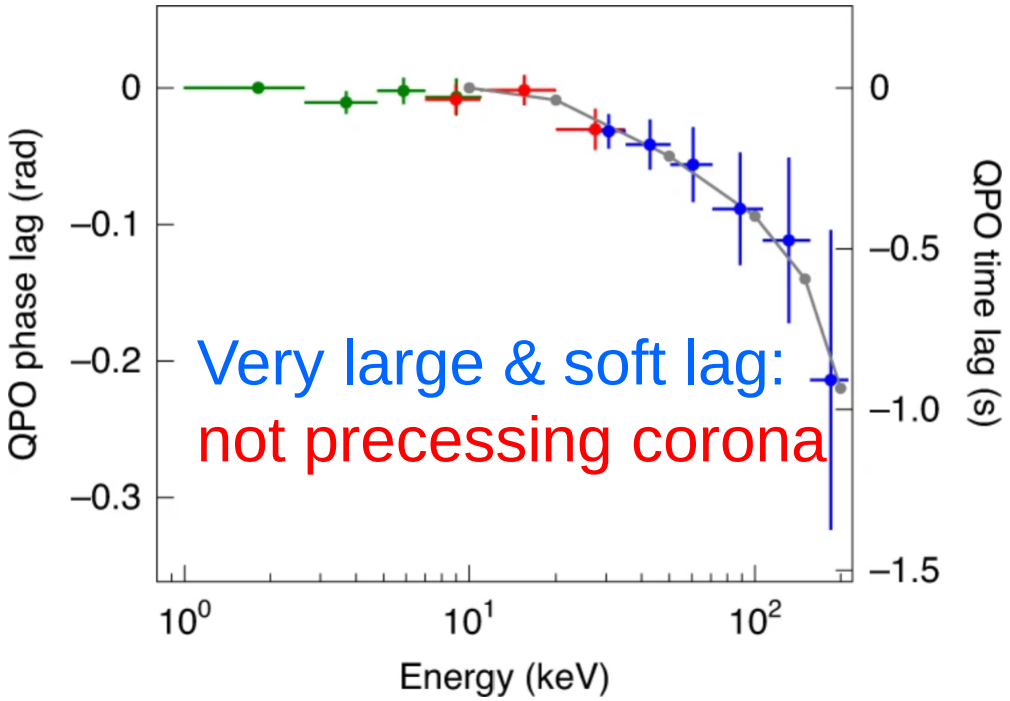
All spectra are relative to the 1–2.6 keV band for a typical observation taken on MJD 58199.5–58200.9 (ObsID P0114661003). **a**–**c**, Spectra for 2.6–4.8 keV (**a**), 4.8–7 keV (**b**) and 7–11 keV (**c**) from LE. **d**–**f**, Spectra for 7–11 keV (**d**), 11–23 keV (**e**) and 23–35 keV (**f**) from ME. **g**–**l**, Spectra for 25–35 keV (**g**), 35–48 keV (**h**), 48–67 keV (**i**), 67–100 keV (**j**), 100–150 keV (**k**) and 150–200 keV (**l**) from HE. To compare the results from different telescopes, we used some overlapping energy bands: **c** for LE and **d** for ME, and **f** for ME and **g** for HE. The frequency-dependent phase-lag spectra confirm consistency between different telescopes. The vertical dashed lines indicate the LFQPO frequency. In all cases, we observe a narrow dip-like feature (cyan points) at the LFQPO frequency. Error bars correspond to 1σ confidence intervals.

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.

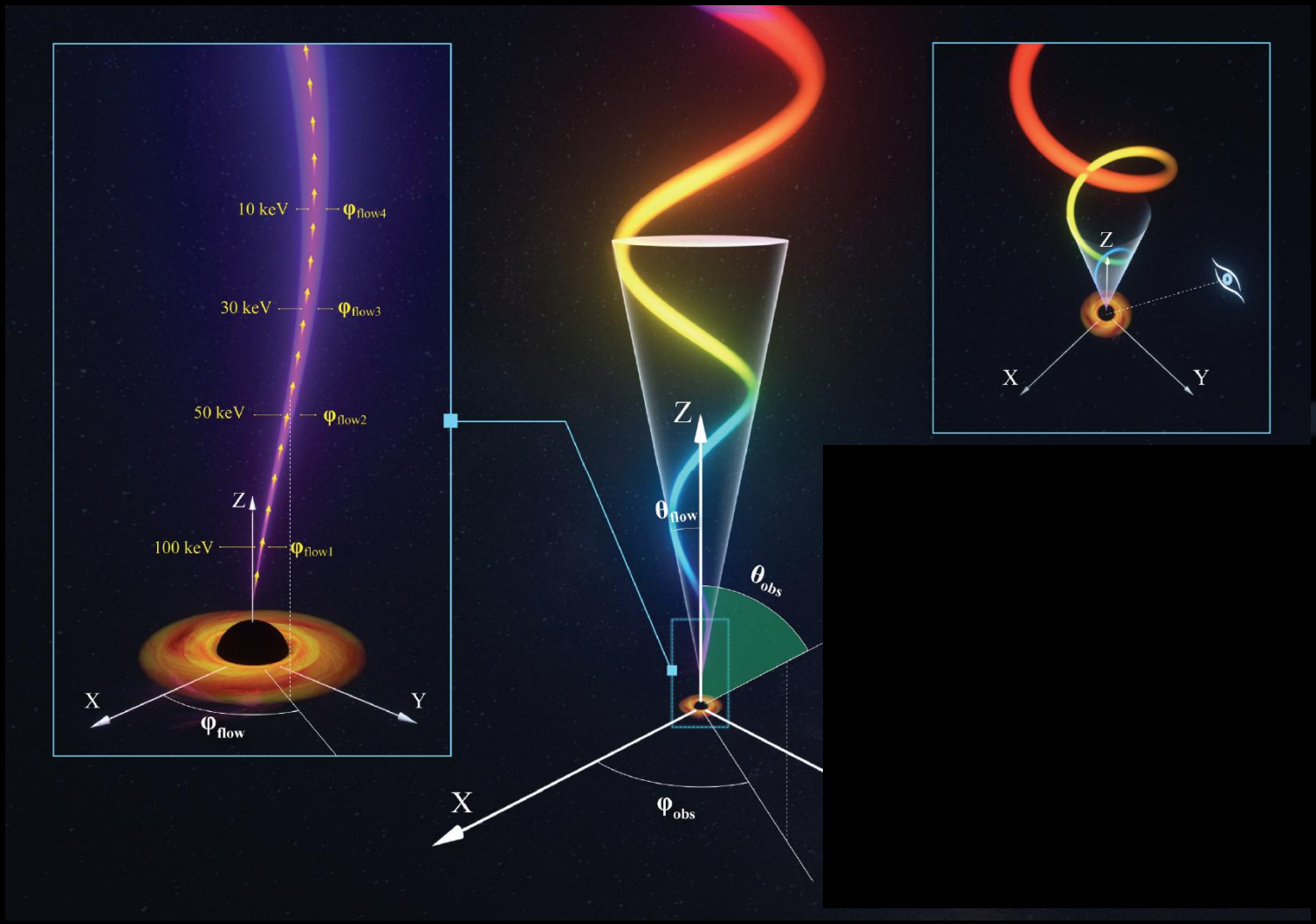
From: Discovery of oscillations above 200 keV in a black hole X-ray binary with Insight-HXMT



In the jet precession model, as the jet is curved, different parts of the jet have different $\varphi_{\rm flow}$ values (see Fig. 4), which causes the phase lags between different energies (green, LE; red, ME; blue, HE). The curvature of the jet ($\Delta\varphi_{\rm flow}$) 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

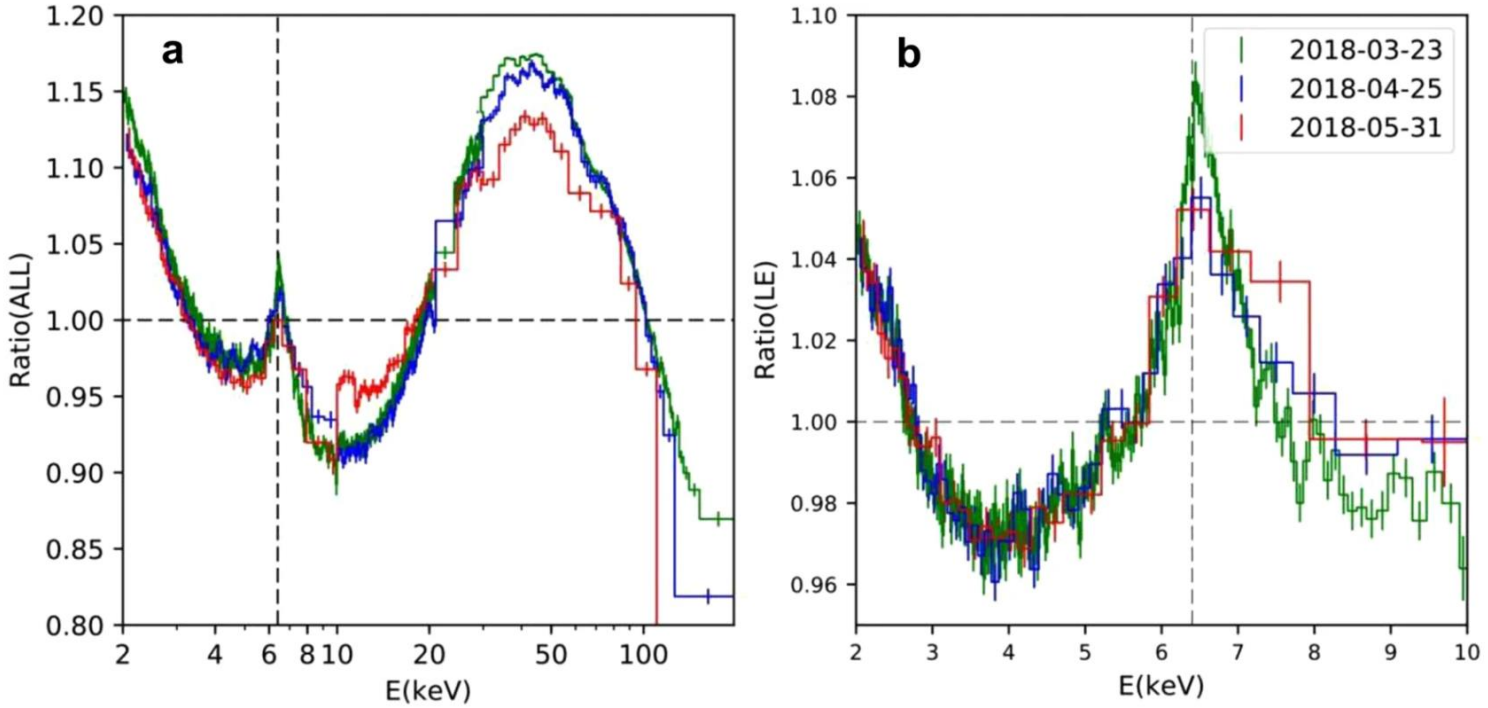


Ma et al. 2020, Nature Astronomy

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

Decreasing reflection contradicts contracting corona
慧眼观测到的反射减少与不久前发现的收缩高温冕矛盾

Fig. 3: Time-evolutions of the free parameters in the best-fitting of the spectral model (1).

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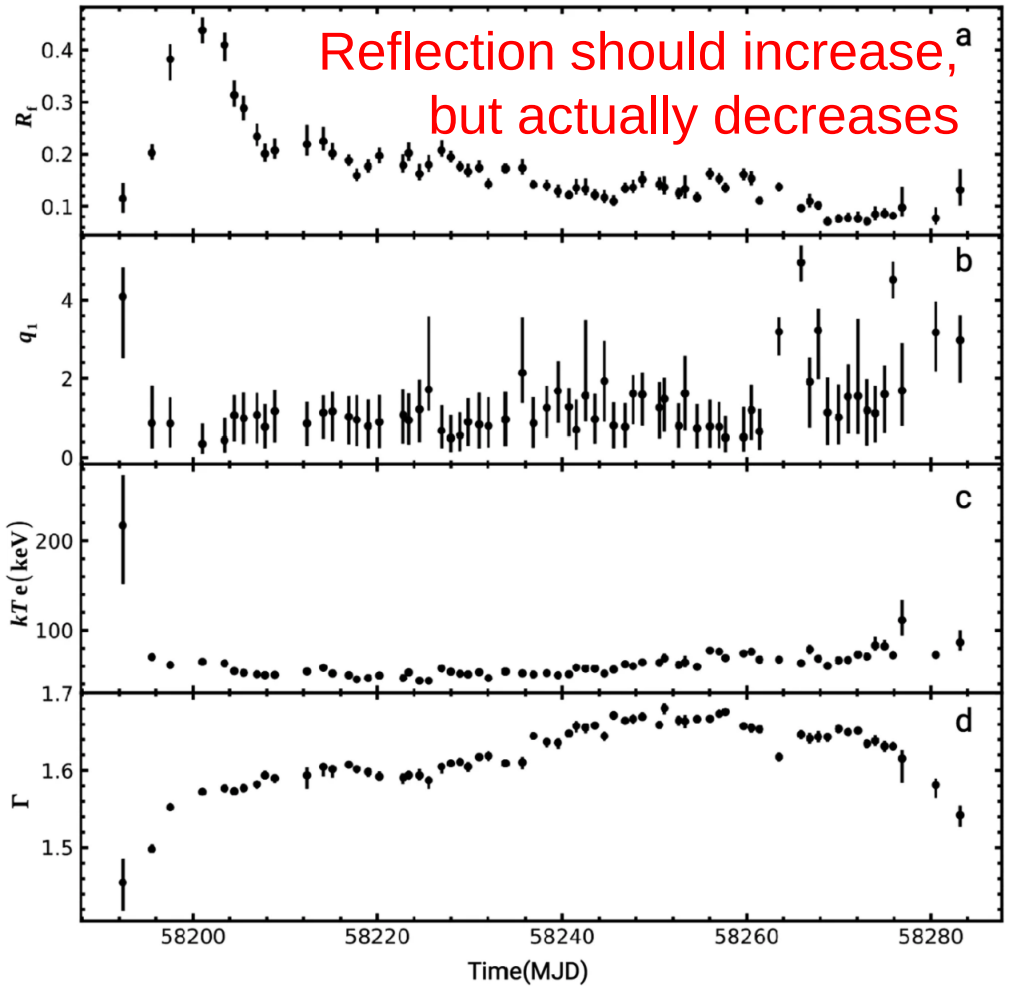
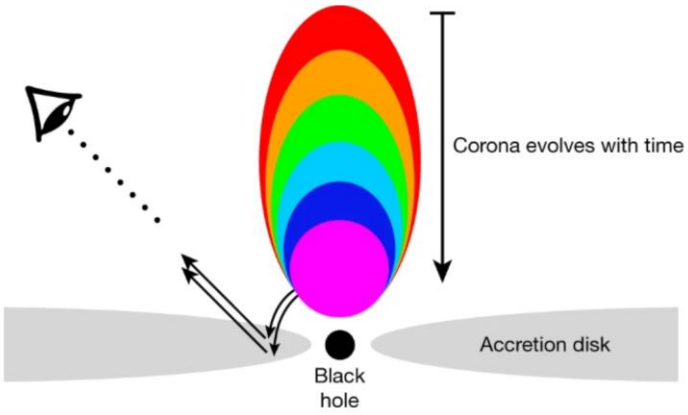


Fig. 4: Schematic of the proposed geometry.



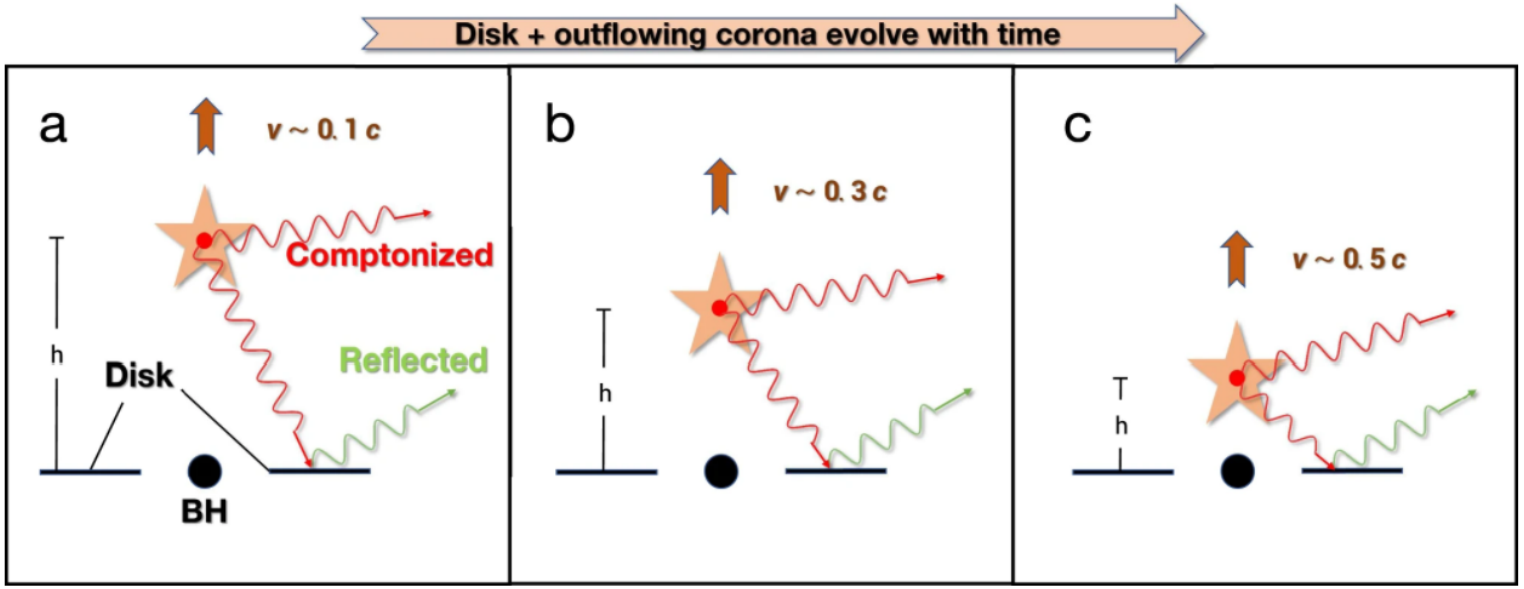
Shown is a schematic of the proposed geometry, evolving from a vertically extended corona at early times to a more compact corona at late times. The corona has a static core at small radii that is responsible for most of the flux irradiating the disk, and the constant shape of the broad Fe line is due to this static core. As the corona decreases in vertical extent, the coronal variability timescale shortens, causing the shift in the thermal reverberation lag to higher frequencies. The decrease in vertical extent of the corona is also responsible for the decrease in the equivalent width of the narrow component of the Fe line at 6.4 keV.

Kara+2020, Nature

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！

Fig. 5: Schematic of the proposed jet-like corona in the decay phase.

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

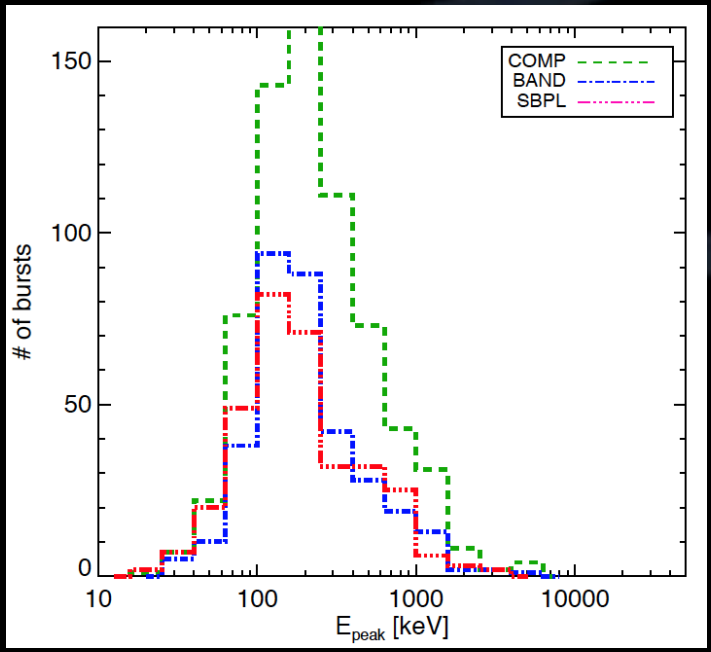


'BH' stands for Black Hole, and the symbol `star' represents the coronal region where the X-ray radiation comes from. The corona at height h can be understood as a standing shock where the material flowing through. The Comptonized hard photons (red arrow) from the corona illuminates the accretion disk, resulting in the observed reflection component (green arrow). Panel **a**, **b** and **c**, represents the peak, middle and end of the decay phase, respectively. As the corona contracts towards the black hole (e.g., from panel **a** to **b**) with decreasing height, the fitted reflection fraction decreases, which suggests that the bulk motion of the outflowing coronal material (sketched as an upward arrow) gets faster in the deeper gravitational potential well, with the increase of the outflowing velocity v in units of light speed c. Note that the values of v are not taken from the spectral fits, but for the sake of depicting faster outflowing corona.

You+2021, Nature Communications

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

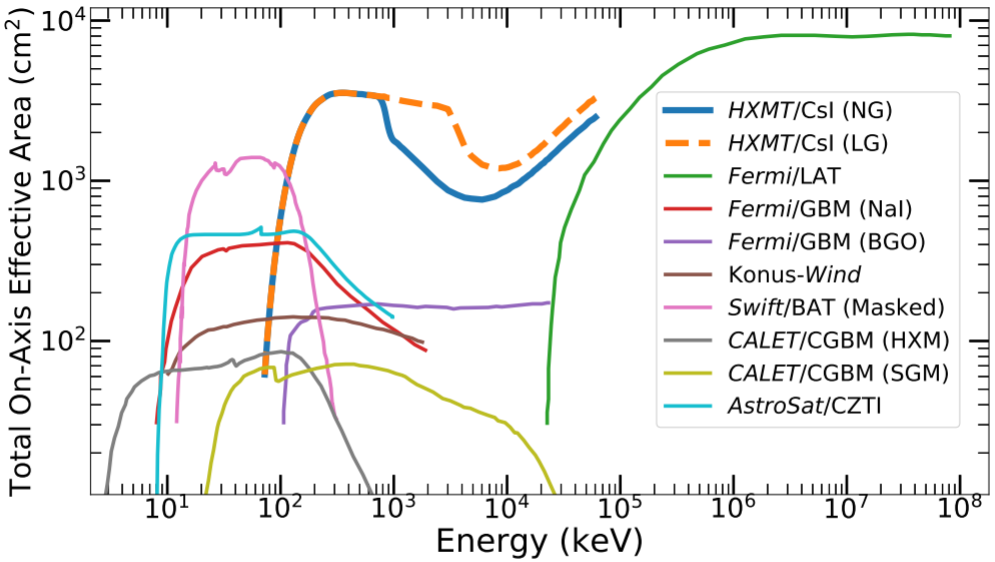


Figure 13: Effective areas of *HXMT*/CsI, *Fermi*/LAT, *Fermi*/GBM, Konus-*Wind*, *Swift*/BAT, *CALET*/CGBM and *AstroSat*/CZTI. The effective area of *Fermi*/GBM (NaI) is the averaged over the unocculted sky.

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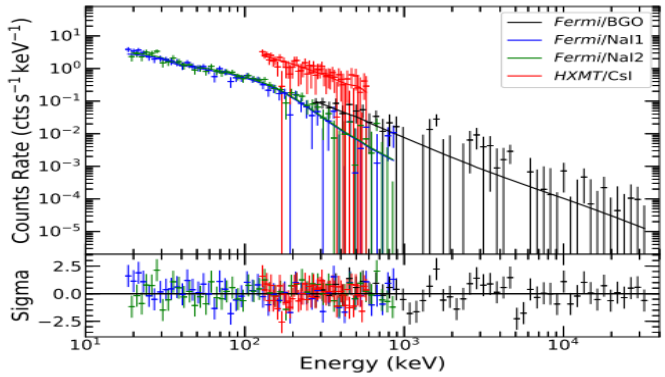
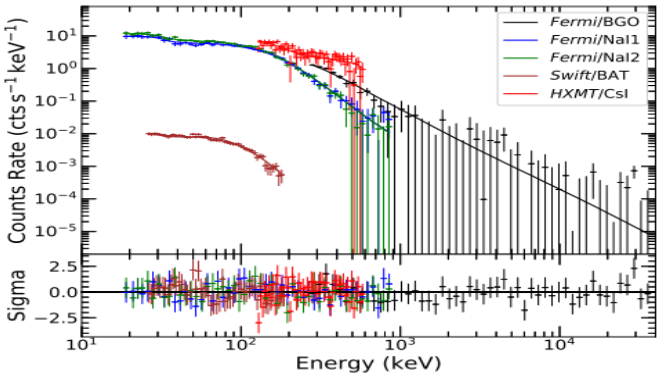
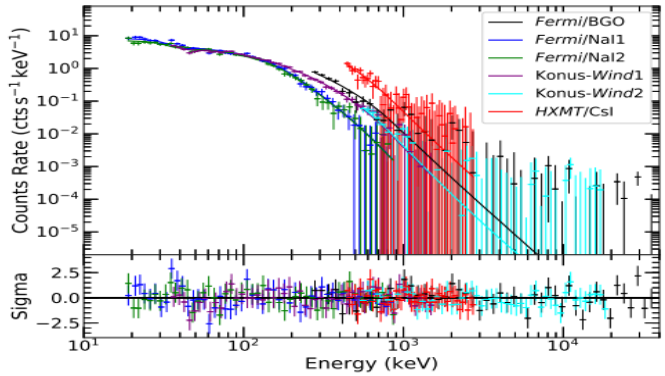
Multi-instrument GRB spectral fitting
多仪器伽马暴能谱拟合



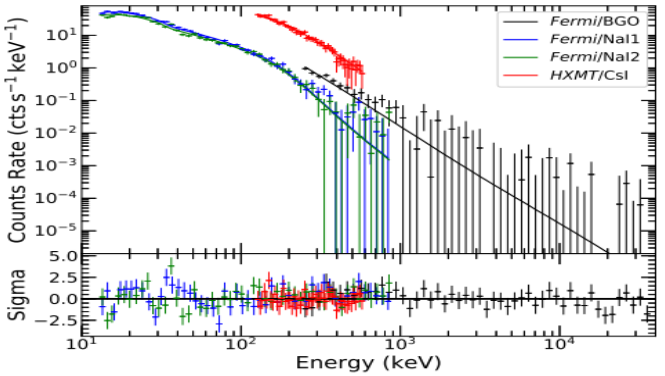
(c) GRB 180413A, NG mode



(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.

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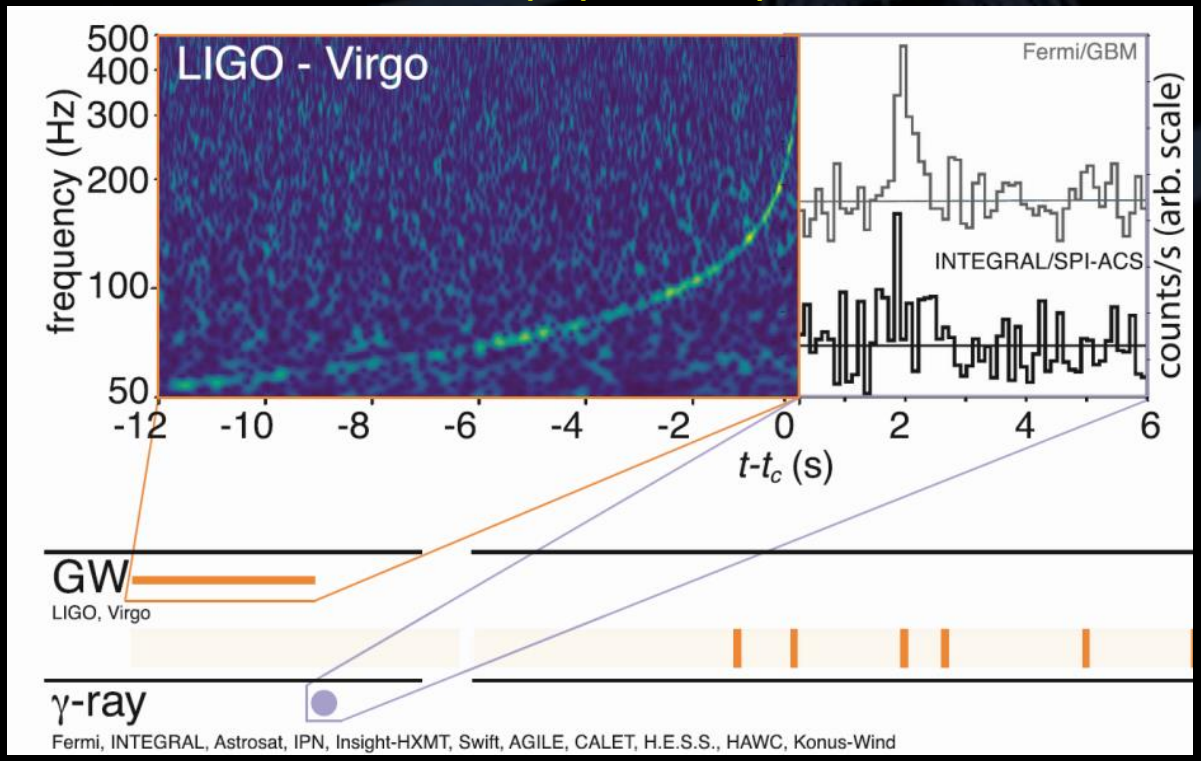
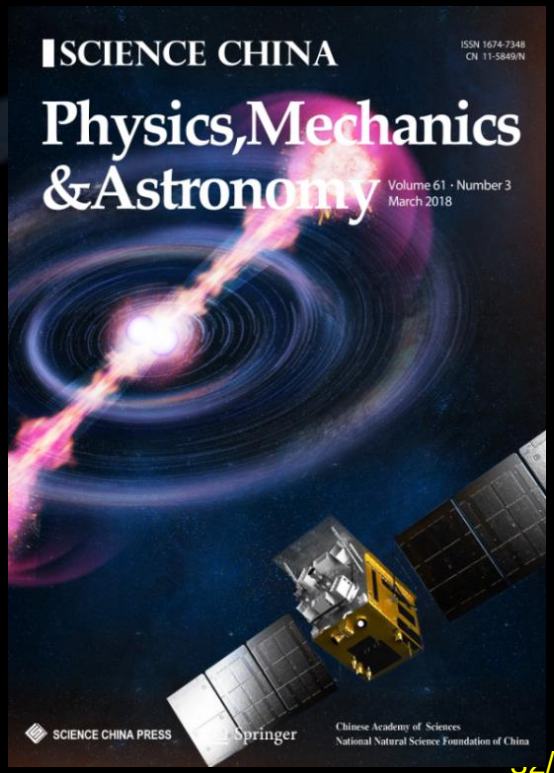
GW EM observations
“慧眼”的引力波电磁对应体观测

- ✓ **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

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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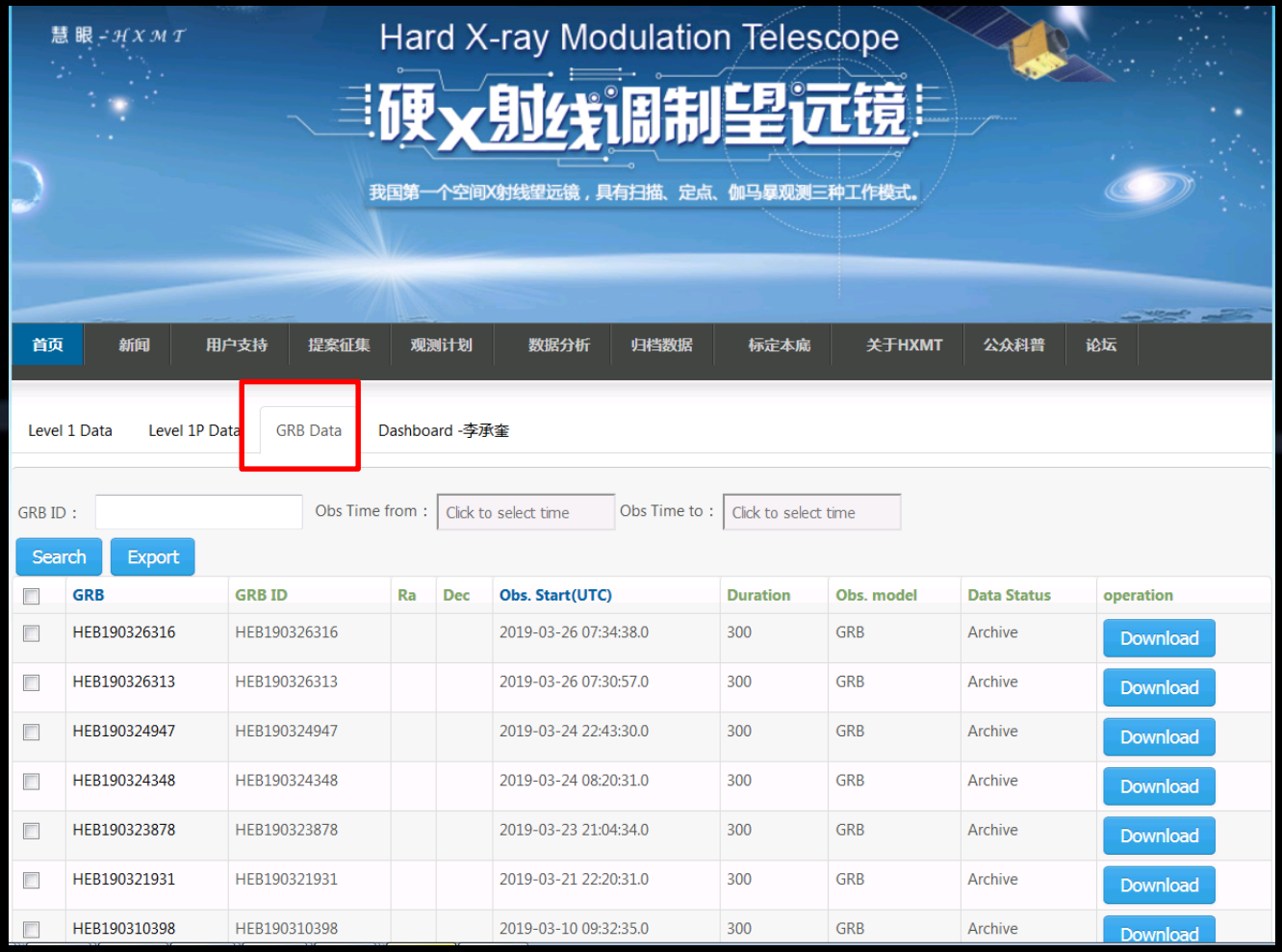
Insight-HXMT GRB data products
“慧眼”伽马暴数据产品（可以公开下载使用）



	GRB	GRB ID	Ra	Dec	Obs. Start(UTC)	Duration	Obs. model	Data Status	operation
	HEB190326316	HEB190326316			2019-03-26 07:34:38.0	300	GRB	Archive	Download
	HEB190326313	HEB190326313			2019-03-26 07:30:57.0	300	GRB	Archive	Download
	HEB190324947	HEB190324947			2019-03-24 22:43:30.0	300	GRB	Archive	Download
	HEB190324348	HEB190324348			2019-03-24 08:20:31.0	300	GRB	Archive	Download
	HEB190323878	HEB190323878			2019-03-23 21:04:34.0	300	GRB	Archive	Download
	HEB190321931	HEB190321931			2019-03-21 22:20:31.0	300	GRB	Archive	Download
	HEB190310398	HEB190310398			2019-03-10 09:32:35.0	300	GRB	Archive	Download

http://hsuc.ihep.ac.cn/web/hxmtdata/grb

Summary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 will be announced in April (more time than core program)
  - ✓Coordinated multi-λ observations: space & ground

hxmt.cn for all information and data download. Thanks!

ads: year:2017-2020 full:"HXMT"