Insight-HXMT: China's 1st X-ray Astronomy Satellite

Launched on June 15th, 2017

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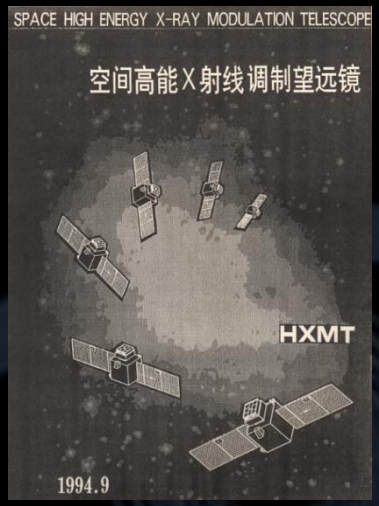
Chinese Academy of Sciences

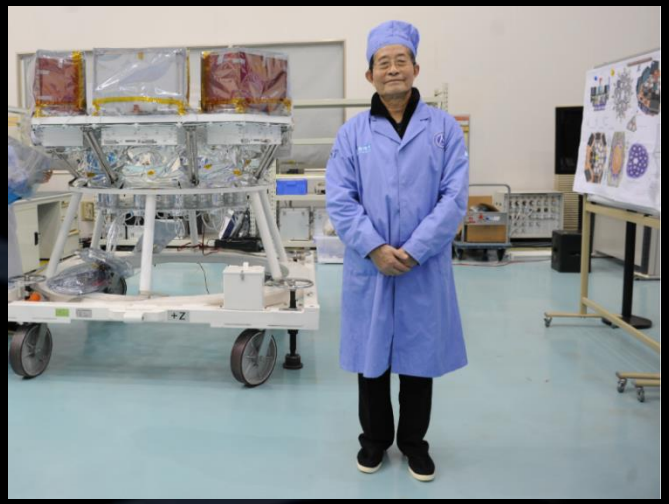

Hard
X-ray
Modulation
Telescope
慧眼*Insight*-HXMT

History of 慧眼Insight-HXMT

1970-80s balloon flight



1994 first proposal, 2011 funded



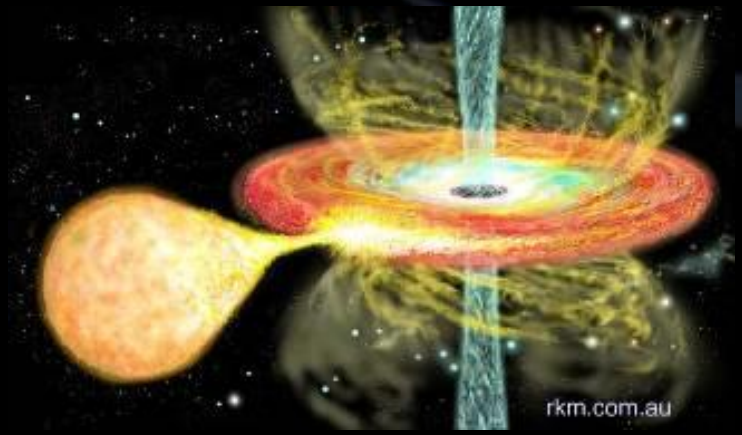
李惕碚院士Prof. Ti-Pei Li

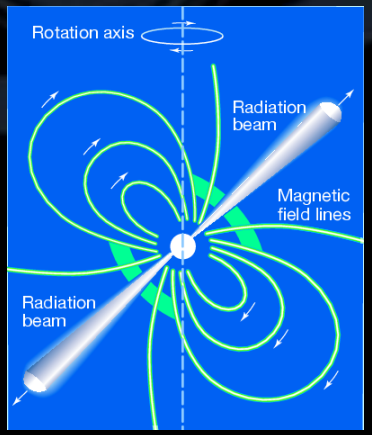
In honor of
何泽慧 Ho Zah-wei (1914-2011)
“慧眼” *Insight*

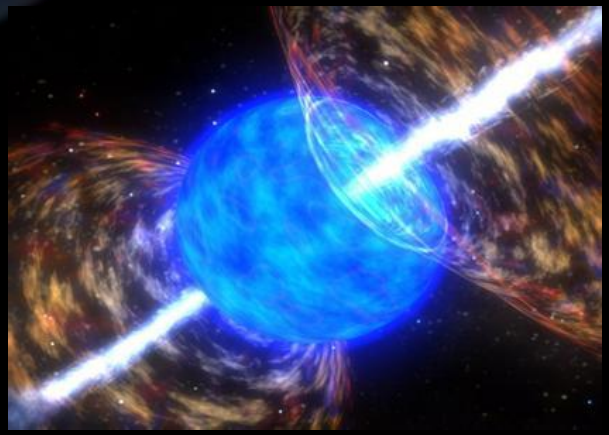
2017.6.15 Launched in Jiuquan, China

Core sciences

- ✓ 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
- ✓ Multi-wavelength Observations with other telescopes
- ✓ GRBs and GW EM, HEN, FRB, etc.



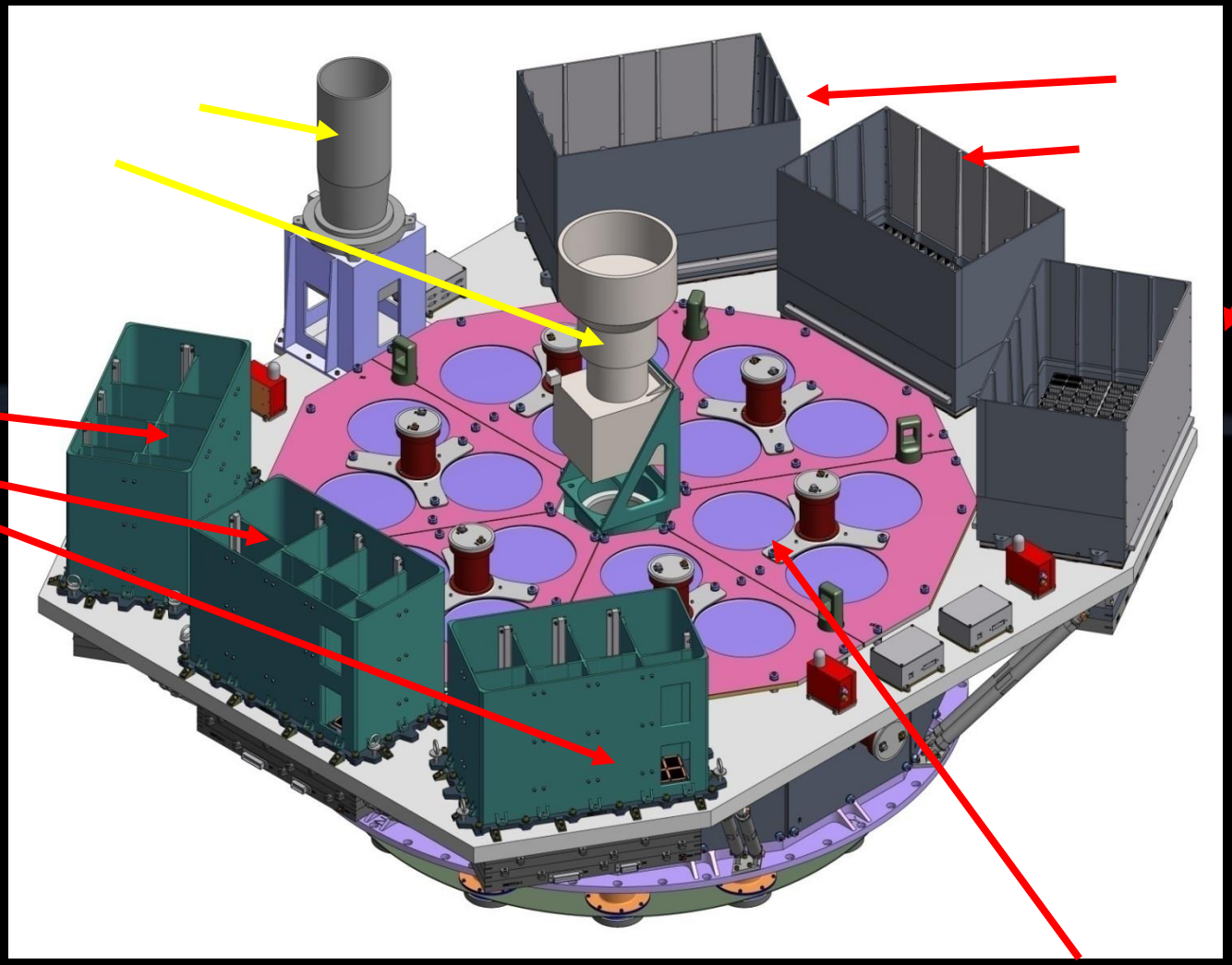




Science payloads

Star tracker

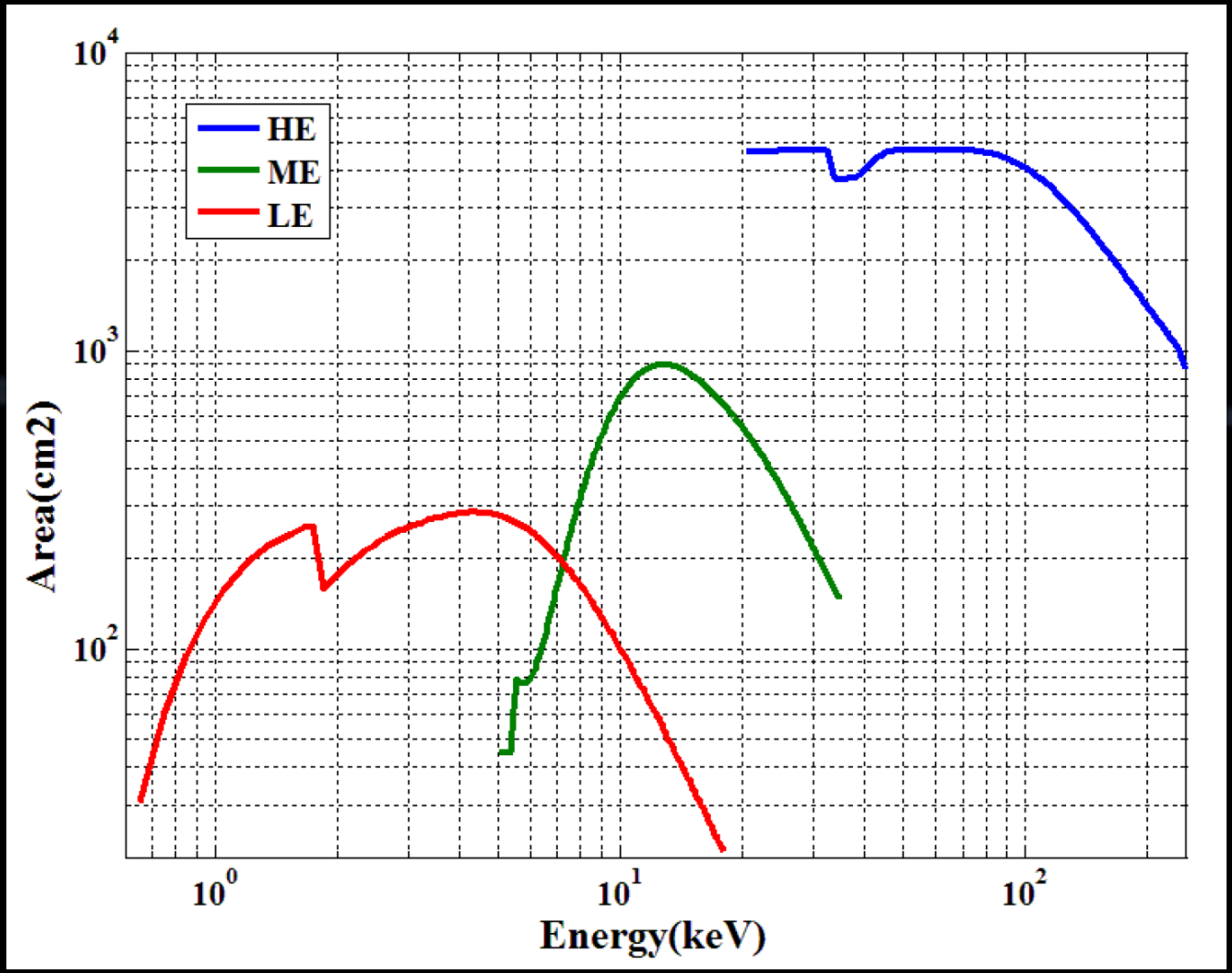
LE:SCD,1-15 keV, 384 cm^2



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

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

Effective area

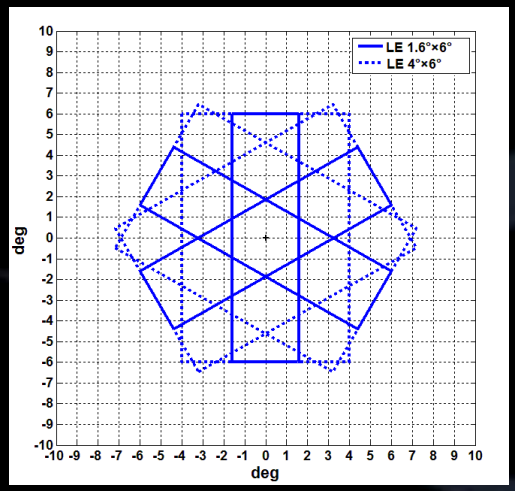


Comparison with other hard X-ray telescopes

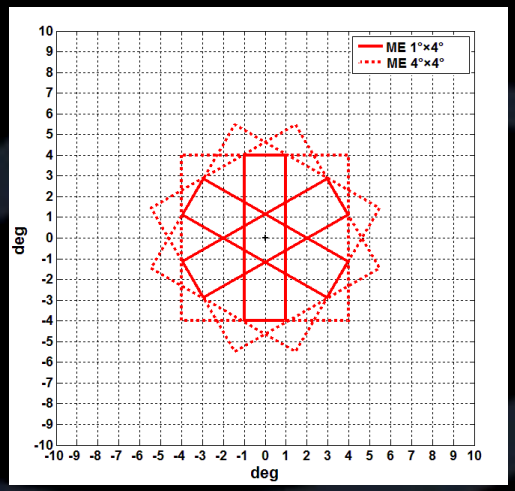
	HXMT	RXTE	INTEGRAL/IBIS	SWIFT	NuSTAR
Energy Band (keV)	LE: 1-15 ME: 5-30 HE: 20-250 200-3000	PCA: 2-60 HEXTE: 15-250	15-10000	XRT: 0.5-10 BAT: 10-150	3-79
Detection Area (cm^2)	LE: 384 ME: 950 HE: 5000	PCA: 6000 HEXTE: 1600	2600	XRT: 110 BAT: 5200	847 @ 9 keV 60 @ 78 keV
Energy Resolution (keV)	0.15@ 6 keV 2.5@20 keV 10@60 keV	1.2@6keV 10@60 keV	8@ 100 keV	0.15 @ 6 keV 3.3 @ 60 keV	0.9 @ 60 keV
Time Resolution (ms)	LE: 1 ME: 0.18 HE: 0.012	PCA: 0.001 HEXTE: 0.006	0.06	XRT: 0.14, 2.2,2500 BAT: 0.1	0.1

Fields of View of Different Collimators

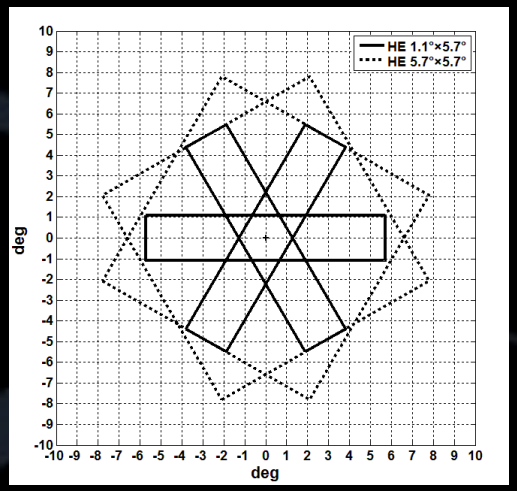
LE



ME

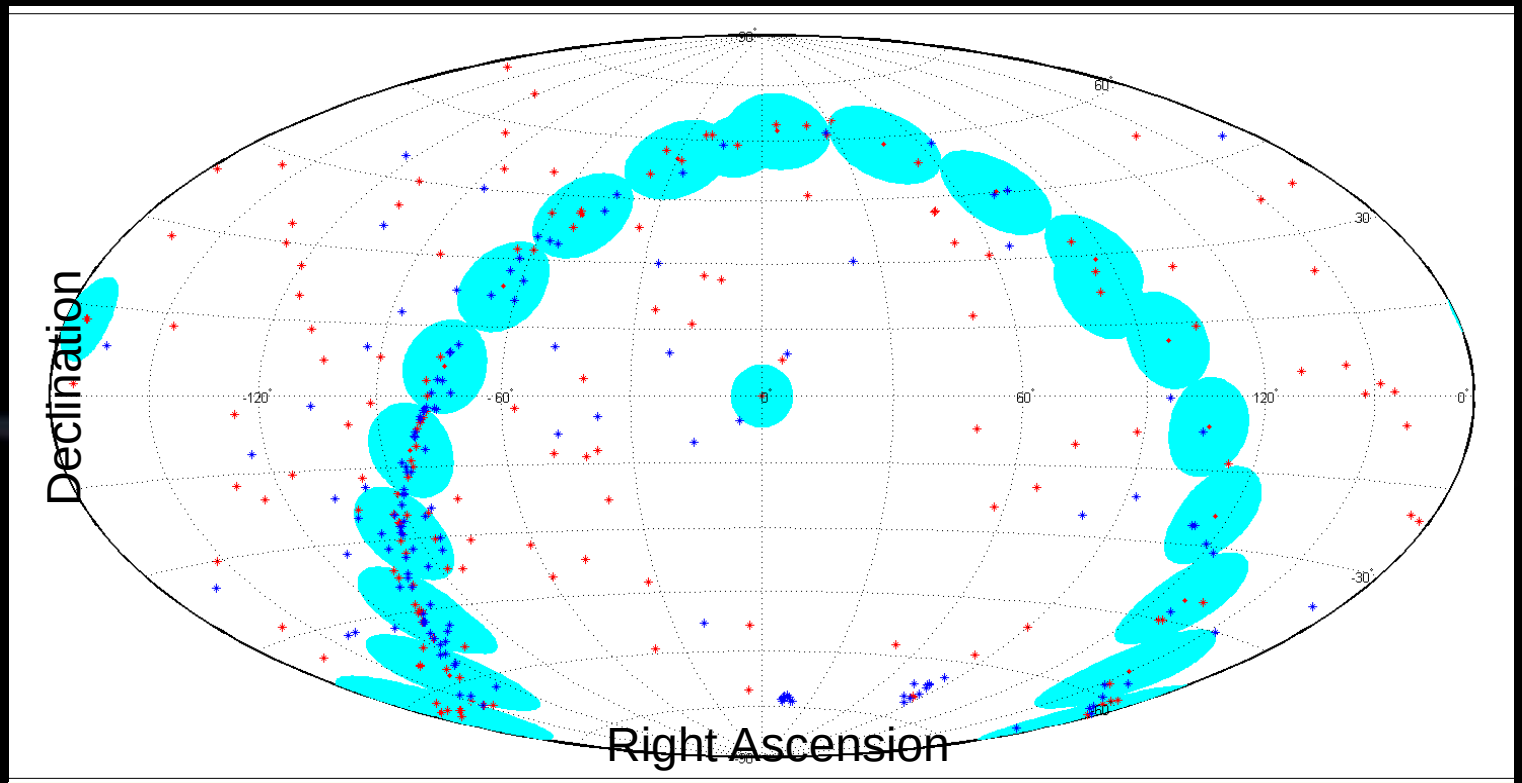


HE



	LE	ME	HE
Small FoV	1.6 ˚x 6 ˚	1 ˚x 4 ˚	1.1 ˚x 5.7 ˚
Large FoV	4 ˚x 6 ˚	4 ˚x 4 ˚	5.7 ˚x 5.7 ˚

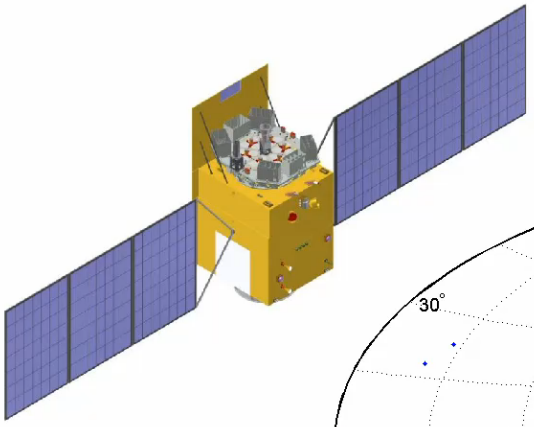
1st yr observation program: since July, 2017



From *Insight*-HXMT AO-1：Regular; ToO; scanning

Insight-HXMT scanning survey of the MW

✓Repeatedly scan the Milky Way plane



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

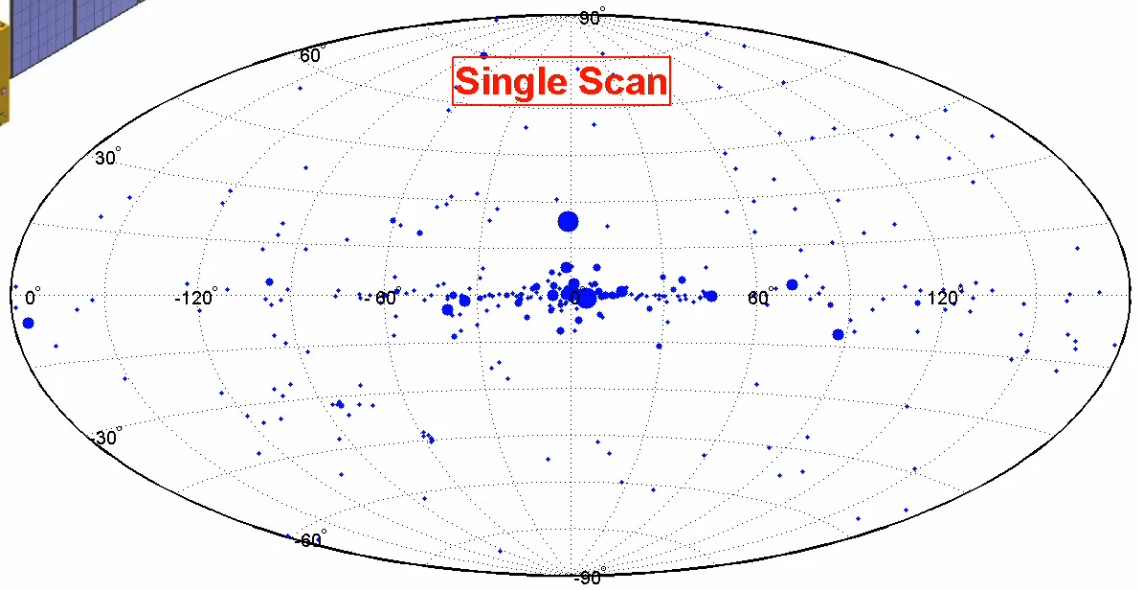
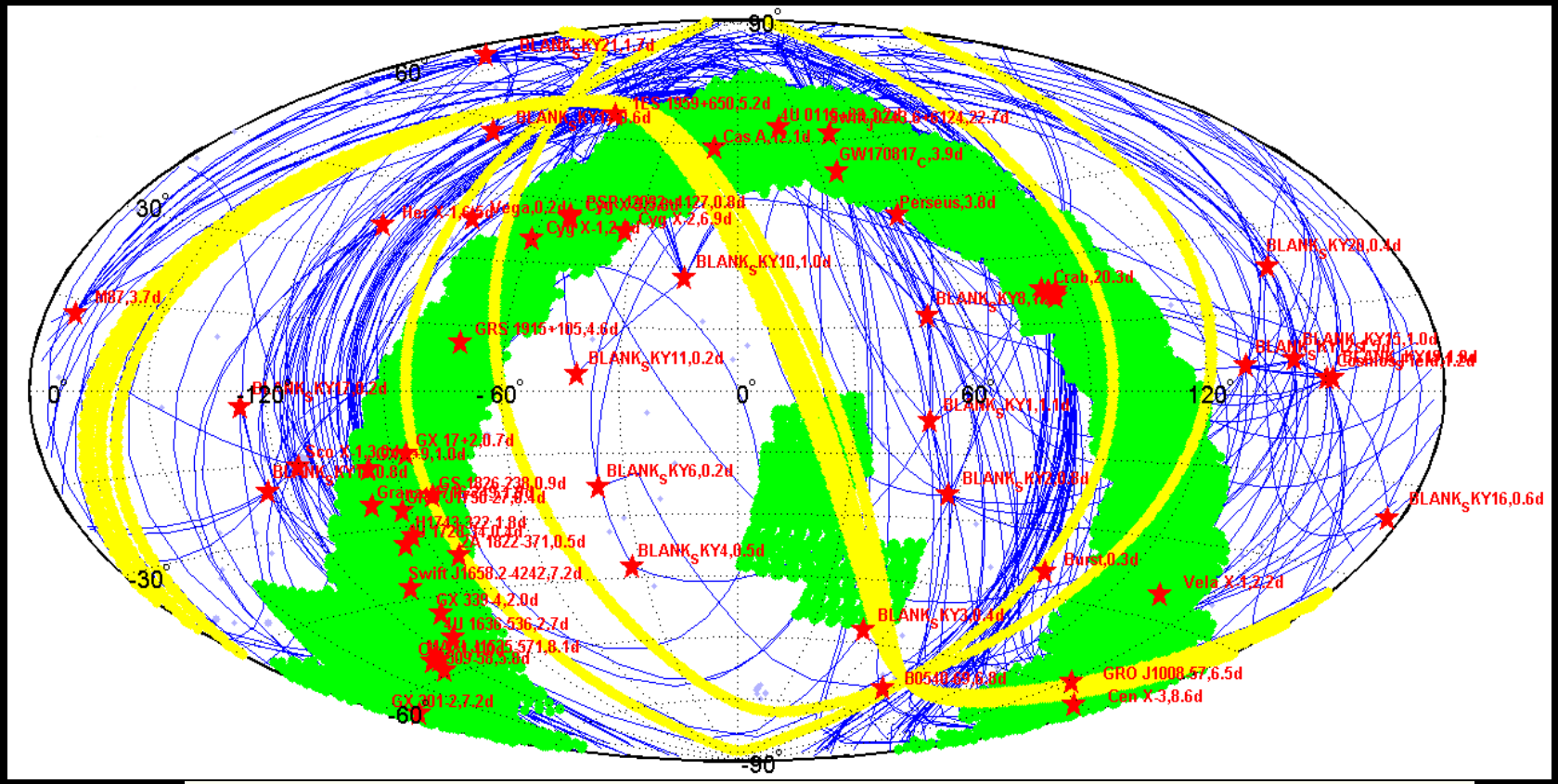


Table of HXMT observations

	Mode	Type	Source Name	Times
1	Point	Pulsar remnants	Cas A	9
2		Pulsar	Crab	76
3			PSR B0540-69	7
4			PSR B1509-58	12
5		BH Binary	Cyg X-1	9
6			Granat 1716-249	2
7			GRS 1915+105	6
8			GX 339-4	1
9			H 1743-322	15
10			MAXI J1535-571	17
11			MAXI J1543-564	1
12			MAXI J1820+070	1
13			Swift J1658.2-4242	21
14		Extra-galactic	1ES 1959+650	25
15			Perseus	1
16			M87	4
17			Cosmos Field	4

	30de	Type	Source Name	Times
18	Point	NS Binary	Cen X-3	3
19			Cir X-1	1
20			Cyg X-2	12
21			Cyg X-3	11
22			GRO J1008-57	11
23			GS 1826-238	1
24			GX 301-2	7
25			GX 17+2	5
26			Her X-1	5
27			Sco X-1	3
28			Vela X-1	1
29			4U 1728-34	2
30			4U 0115+63	11
31			4U1636-536	7
32			PSR J2032+4127	64
33		TBD	Swift J0243.6+6124	97
34		BlankSky	16	48
35	SAS	Crab Area		9
36		Galactic Plane	22 regions	284

Distribution of HXMT observations

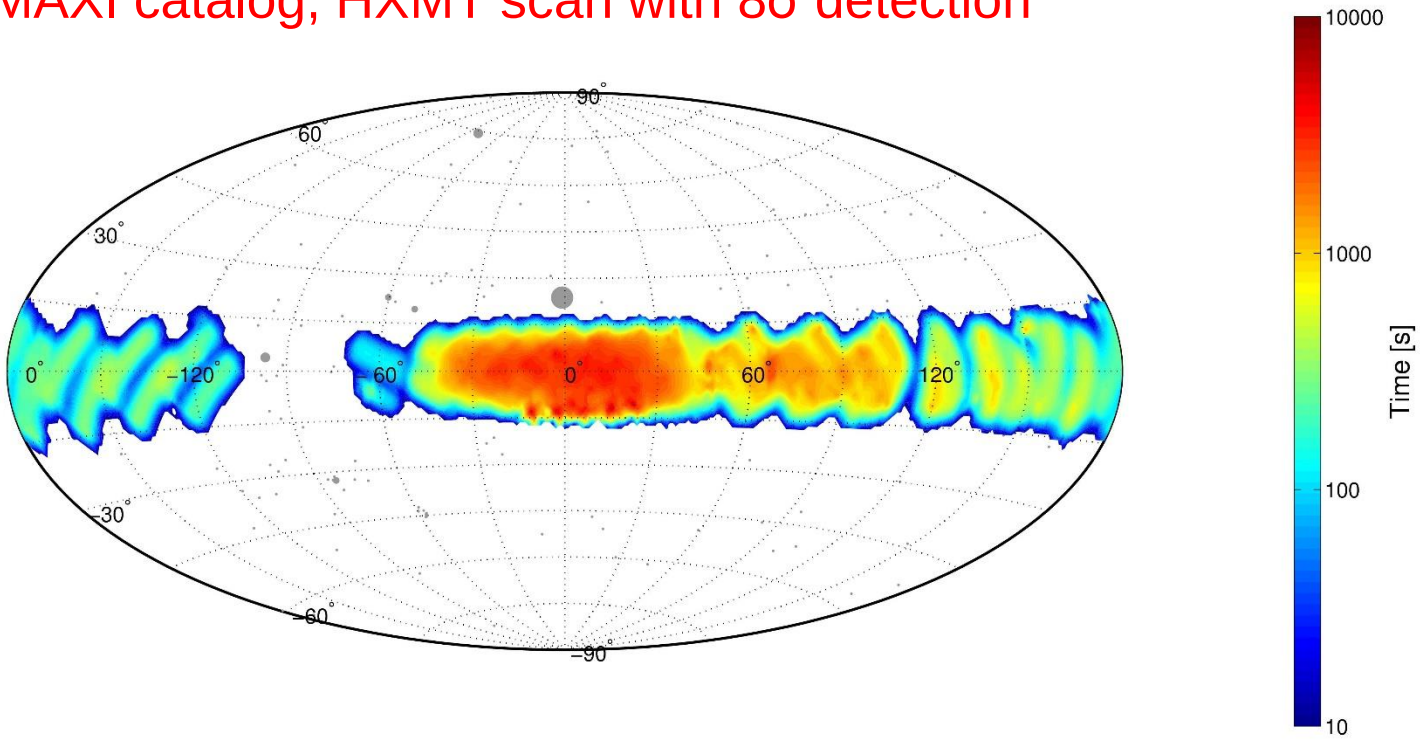


Red stars: pointed observations
Green regions: small area scan
Blue lines: slew between different pointing obs.
Yellow belts: test of the all-sky scanning mode

Galactic plane scanning survey

✓Exposure map up to Nov. 27

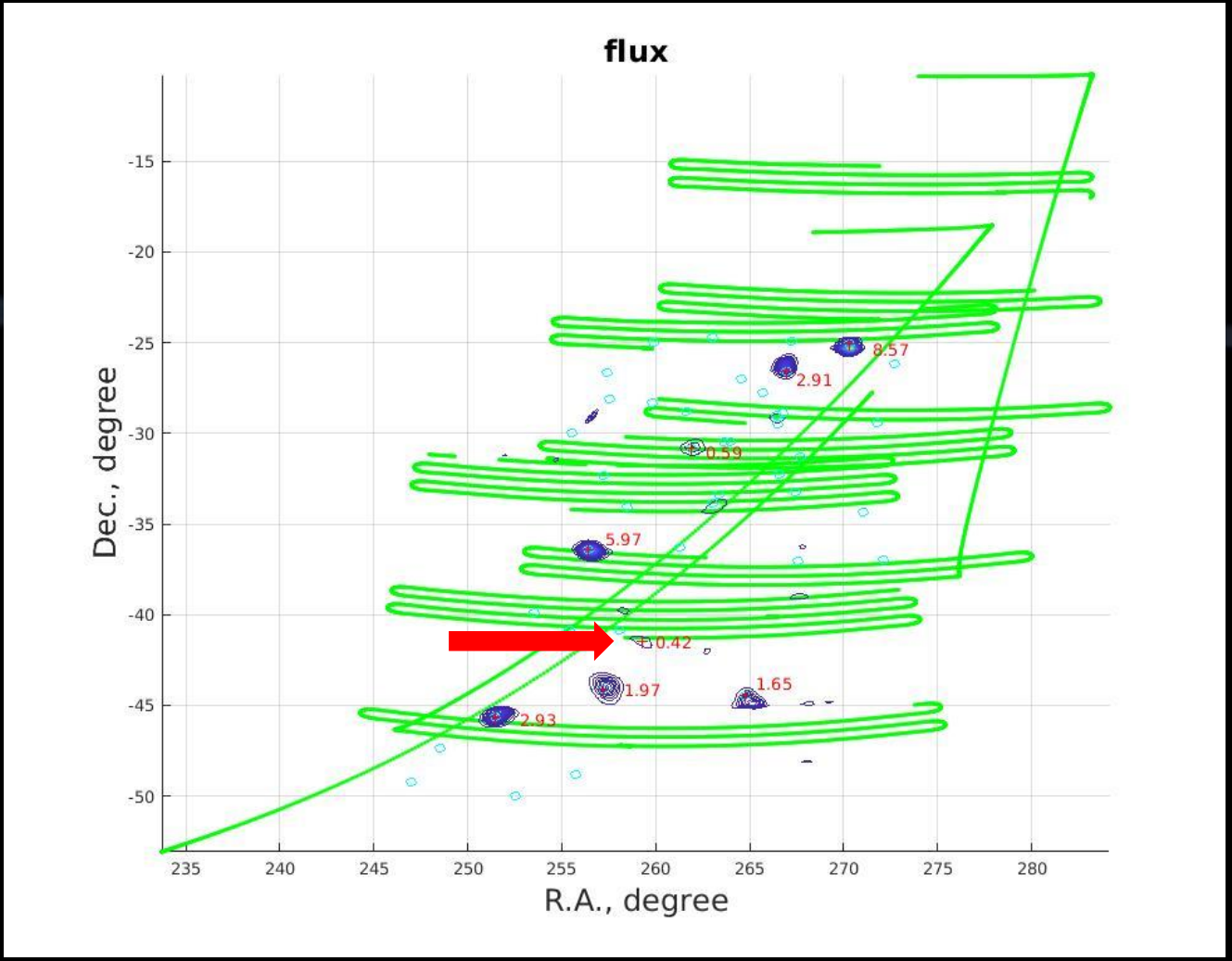
single scan sensitivity ~5 mCrab (5σ) , e.g., G21.5–0.9 (pulsar wind nebula) not in MAXI catalog, HXMT scan with 8σ detection



MAXI sensitivity: single scan 130 mCrab, one day 20 mCrab (5σ)

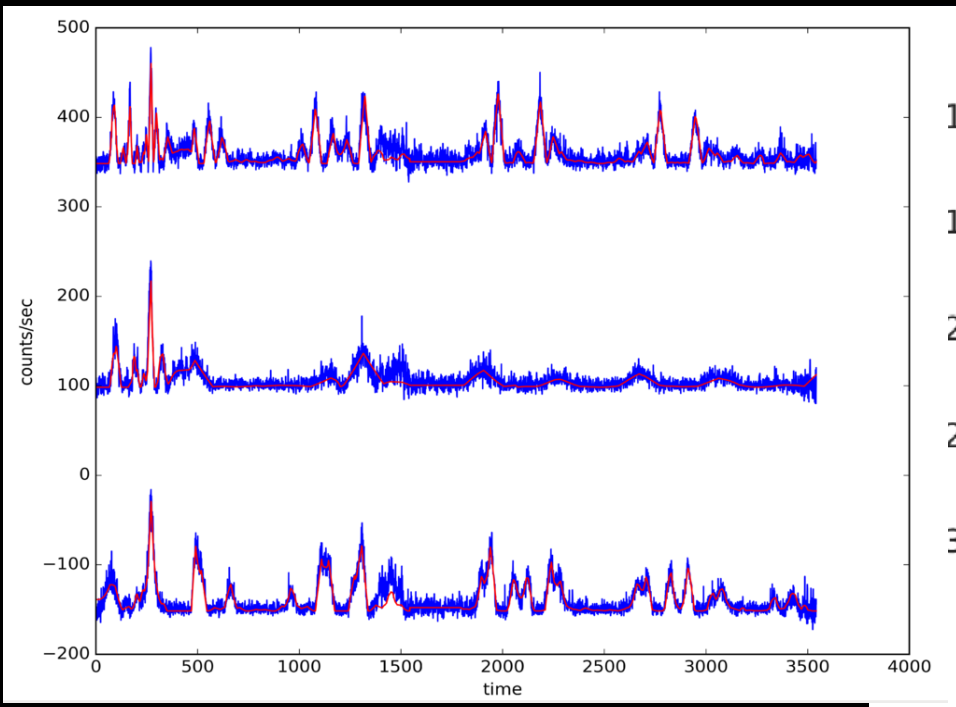
Galactic plane scanning survey

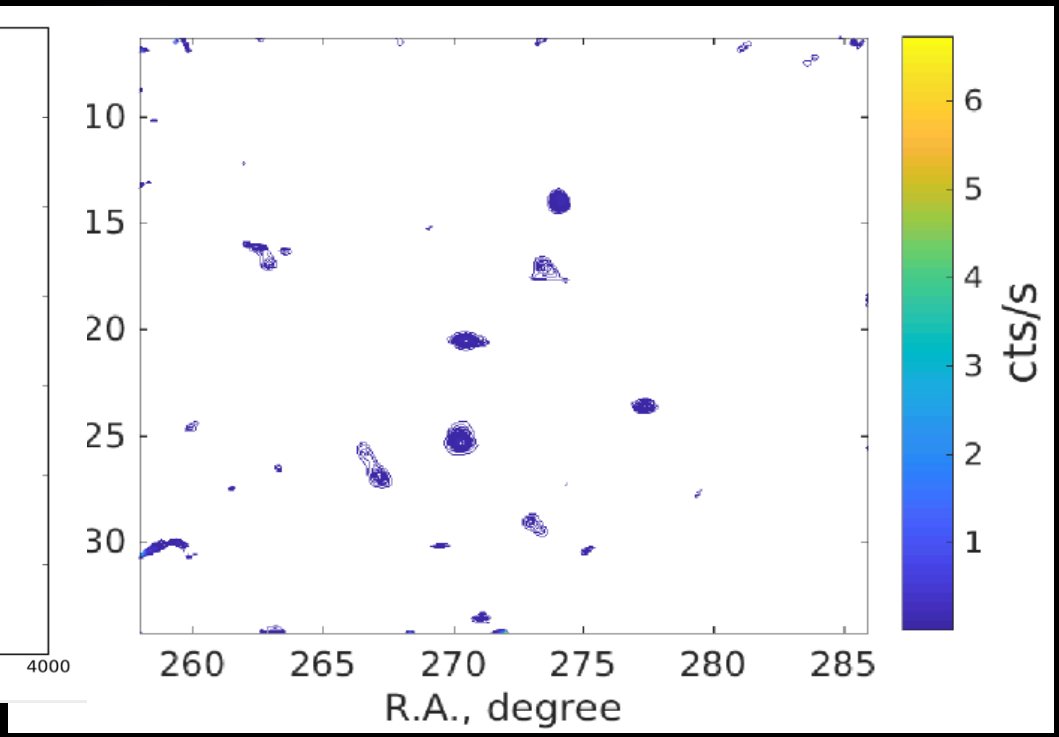
✓New source candidate: (259.28, -41.49) , 0.42 cts/s, 6.7σ.



Observed light curve

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



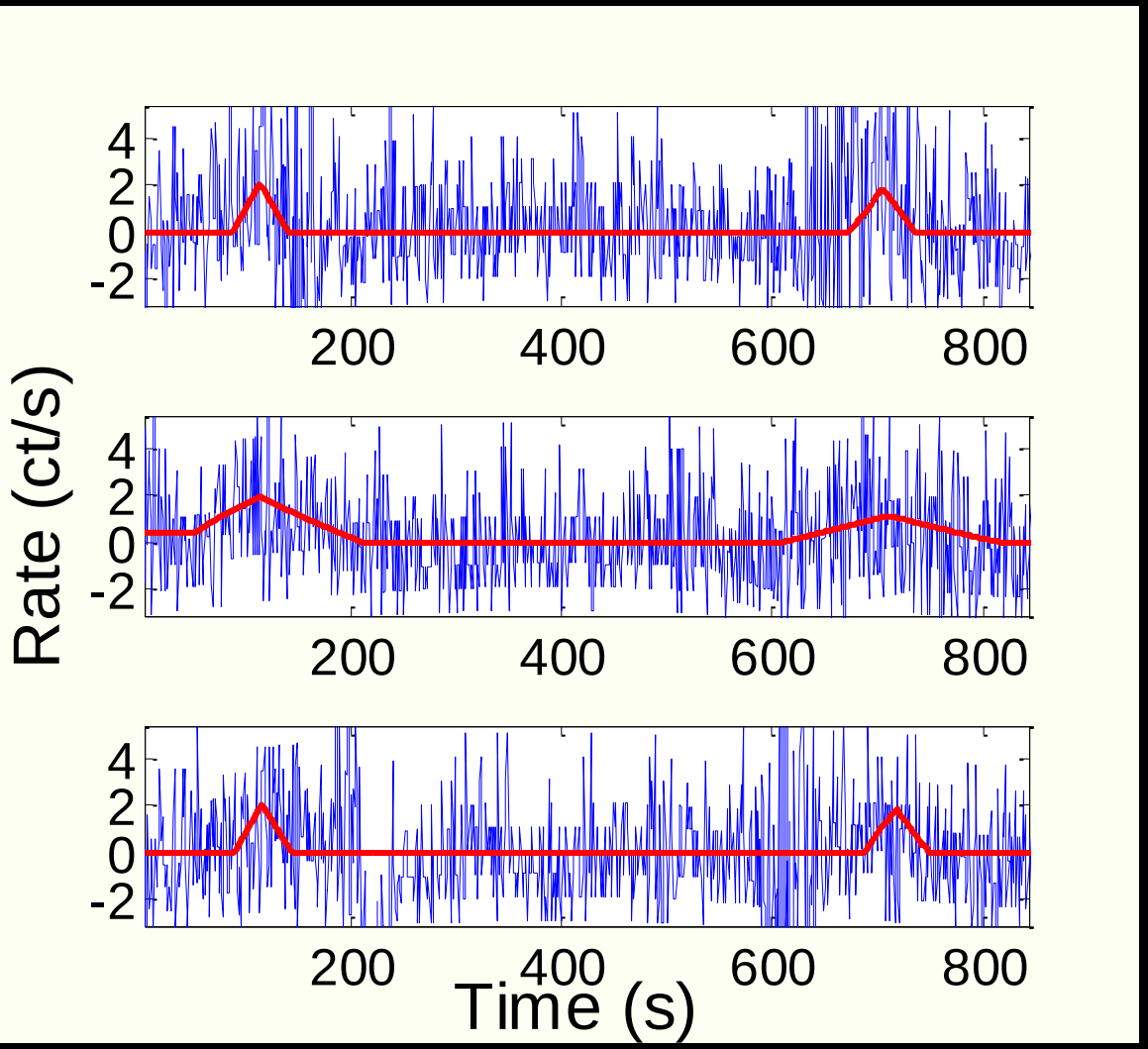


Direct Demodulation Method
(Li & Wu 1993)

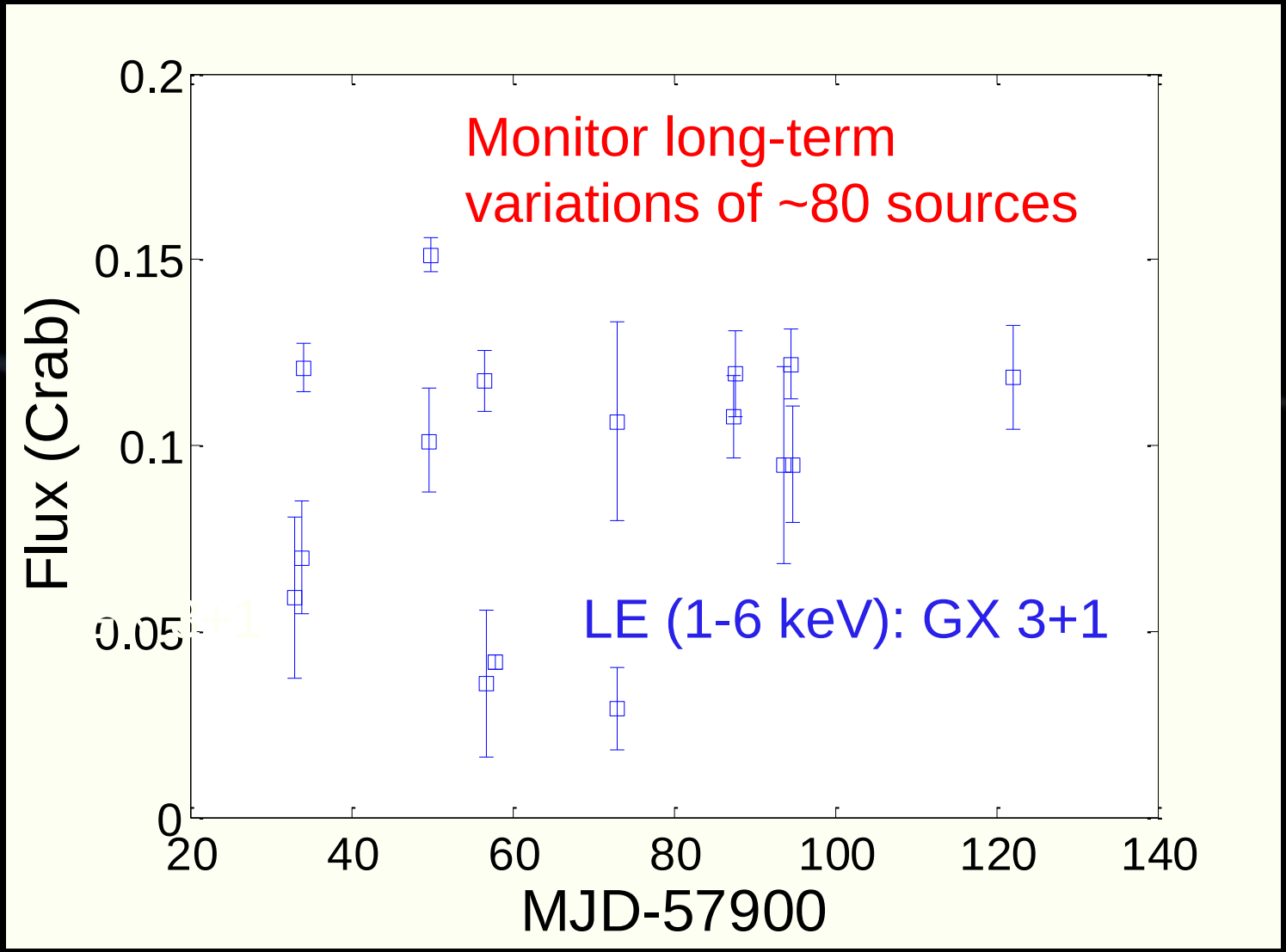
G21.5–0.9 (PWN)

- ✓Not in MAXI catalog
- ✓Detected by Insight at 8σ in one scan (~ 3 hours)

MAXI sensitivity: one orbit 130 mCrab (5σ) one day 20 mCrab (5σ)



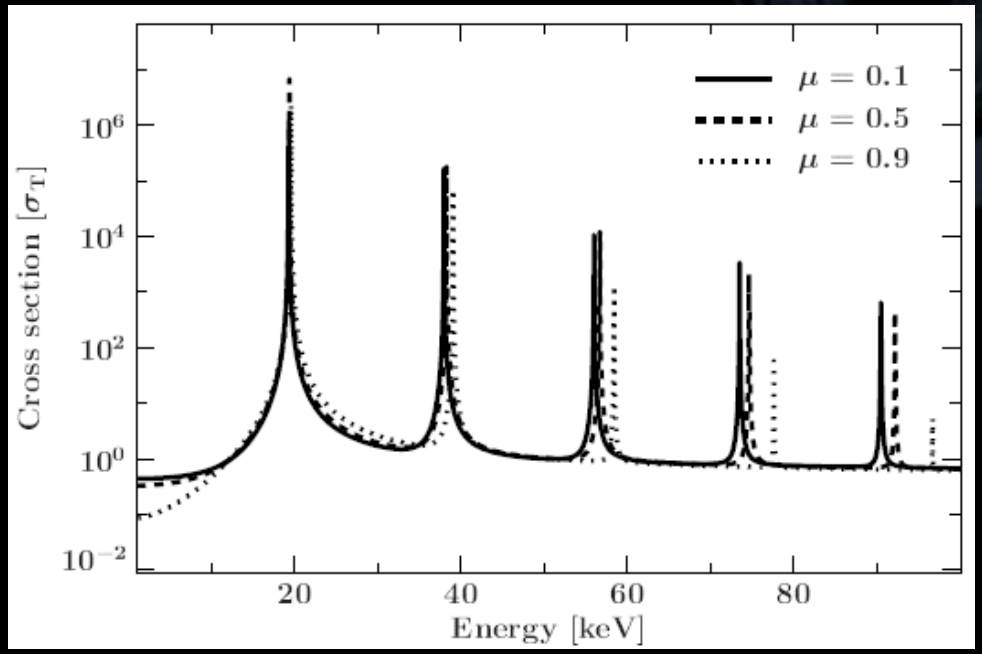
Long-term light curve

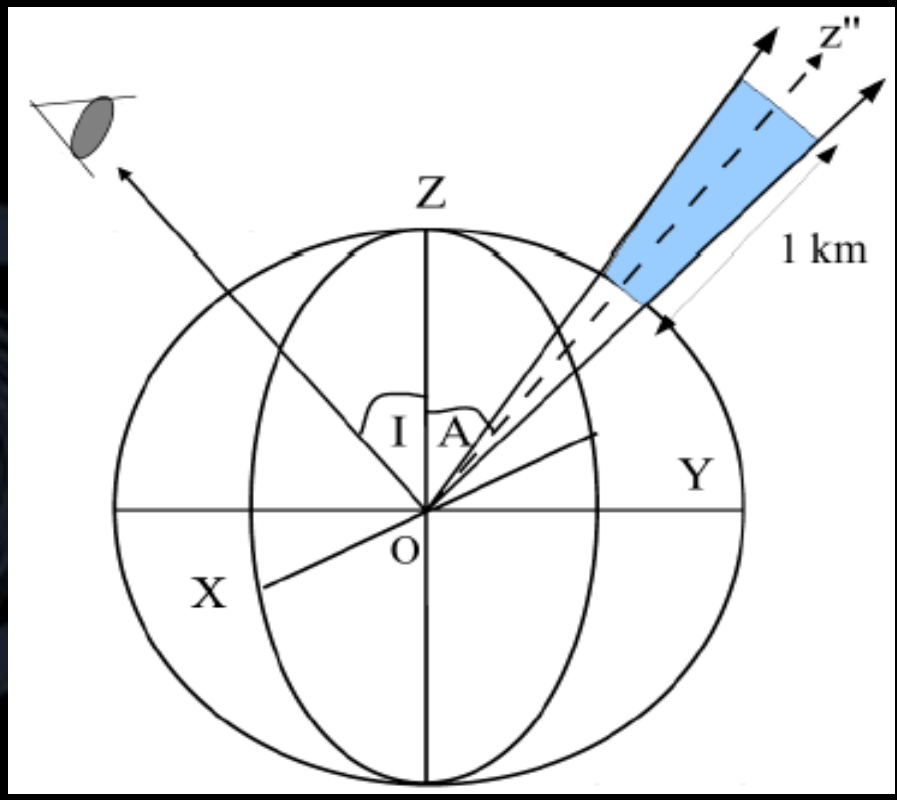


Neutron star cyclotron absorption line

- ✓Magnetic field
- ✓Accretion column

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

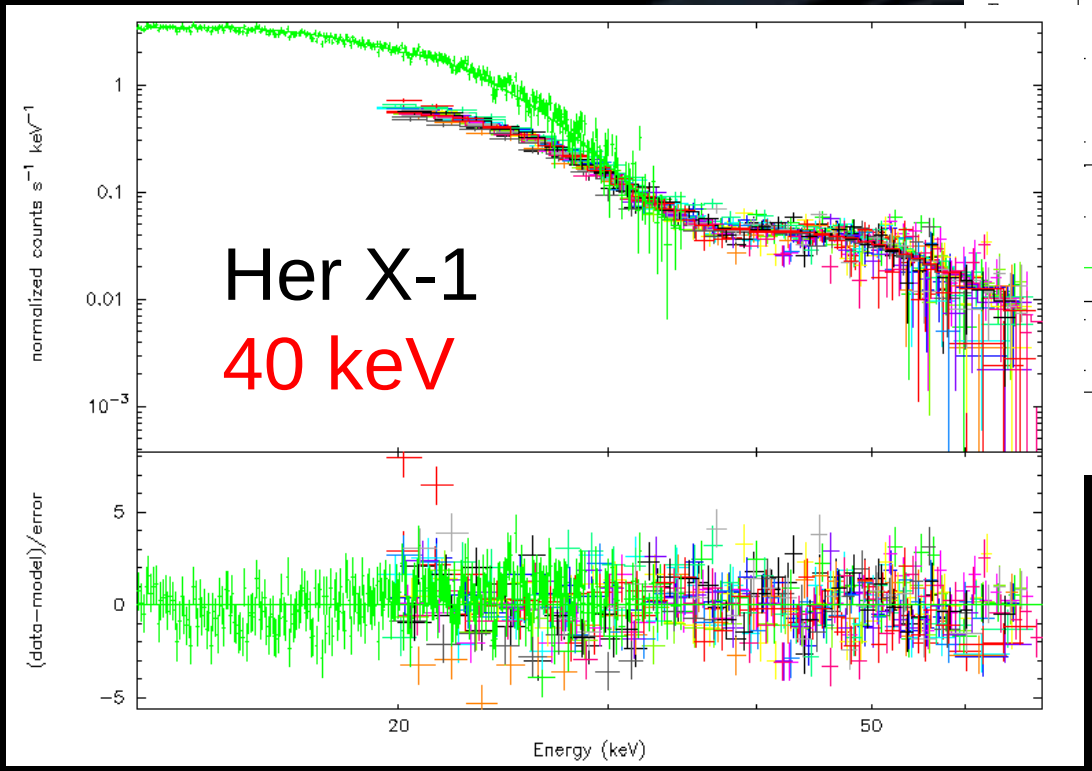


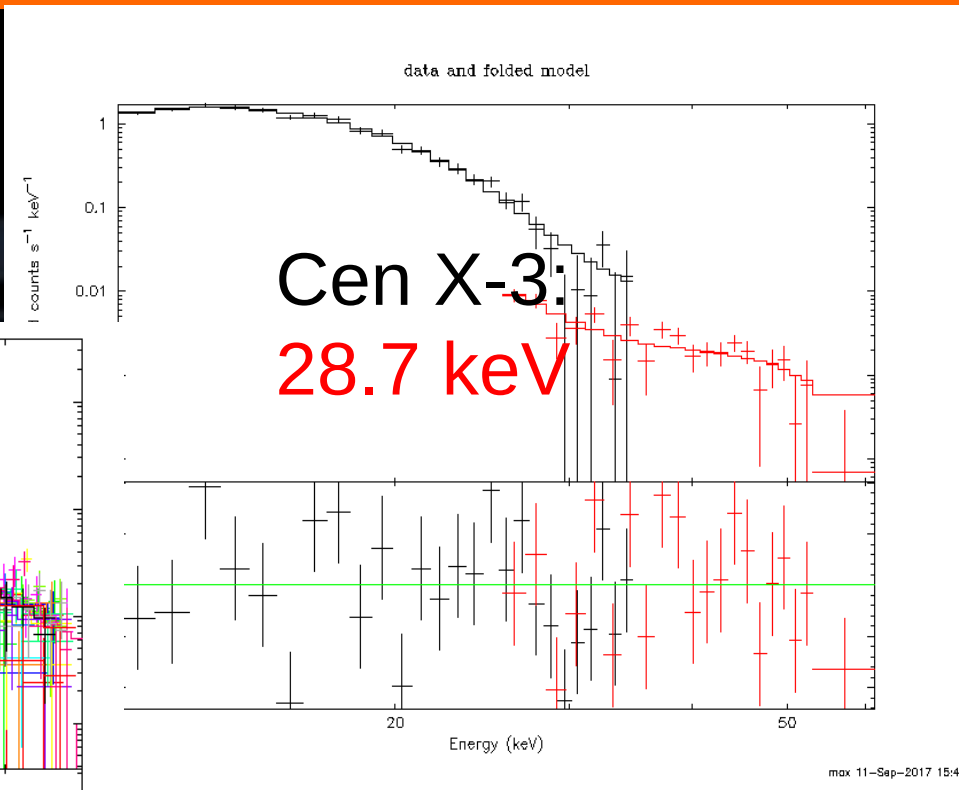


Maitra 2016

Neutron star cyclotron absorption line

- ✓Cen X-3
- ✓Her X-1



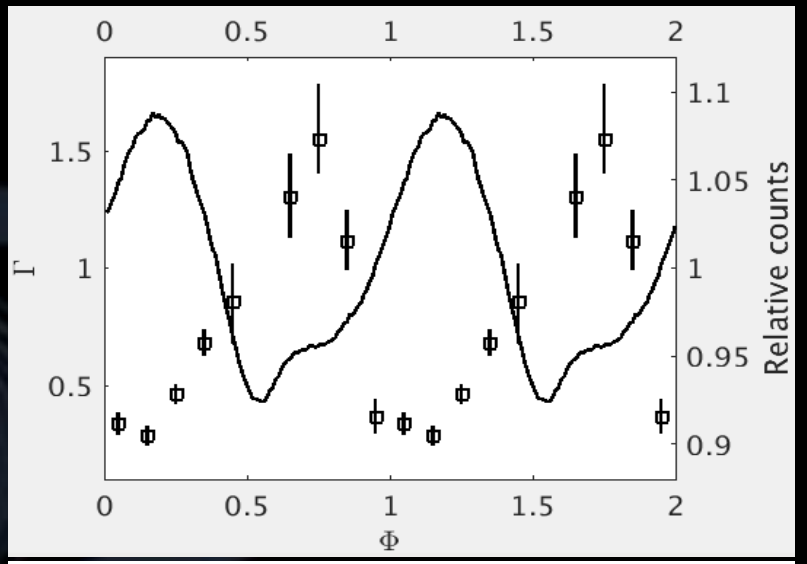


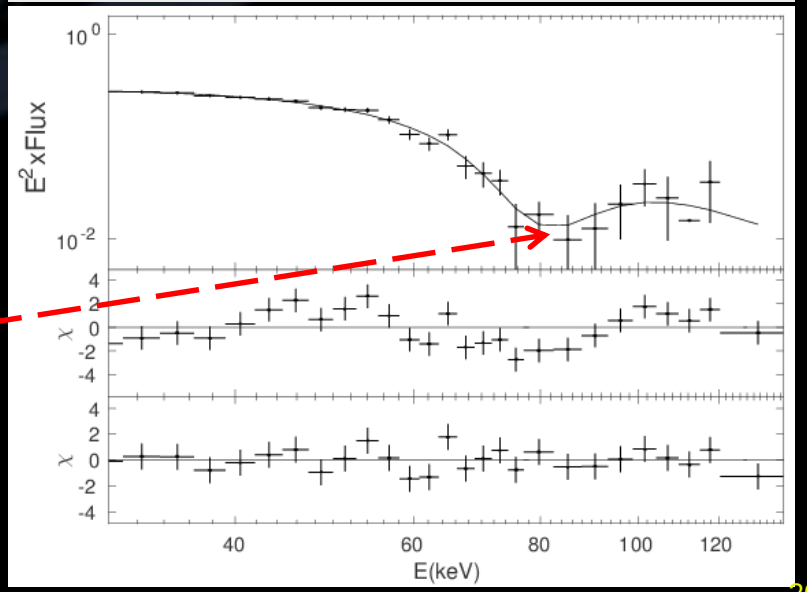
Pulsed spectrum !

Neutron star cyclotron absorption line

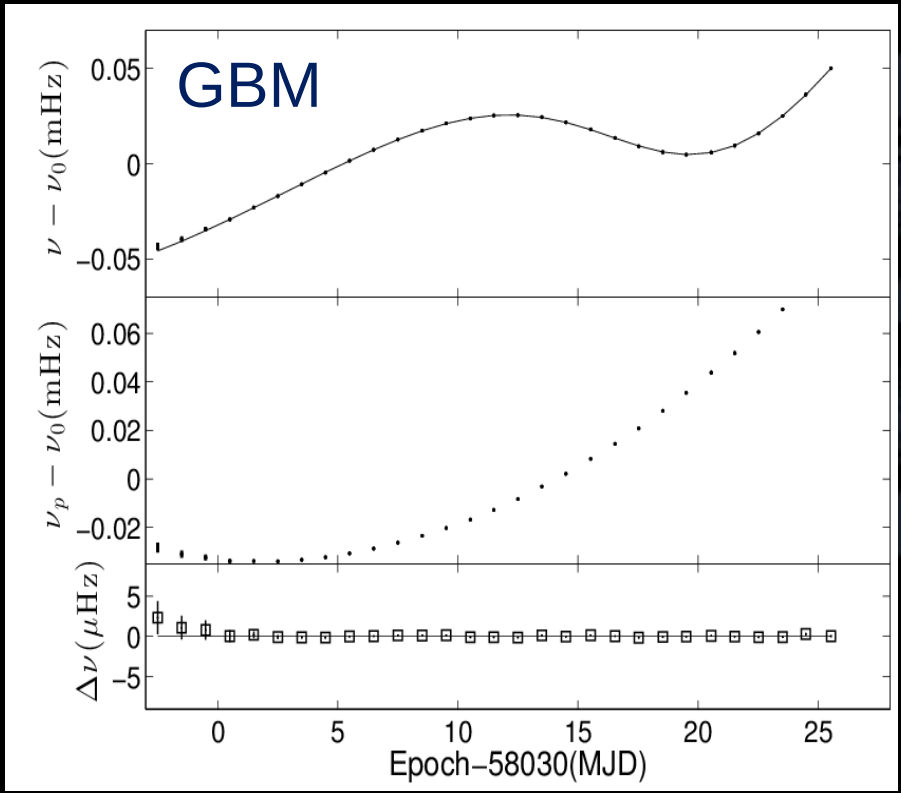
- GRO J1008-57：~80 keV → highest *B* directly measured in the universe ~10^{13}, tentatively observed at ~ 4σ with NuSTAR & Suzaku
- 4 HXMT observations ~235 ks ~ 20σ detection

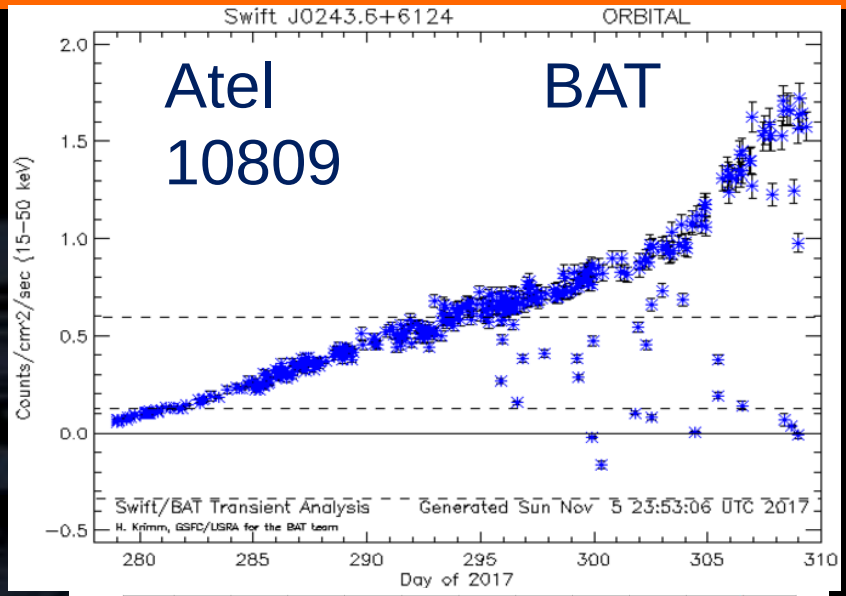
HXMT/HE one module,
17 modules ~ 20 σ

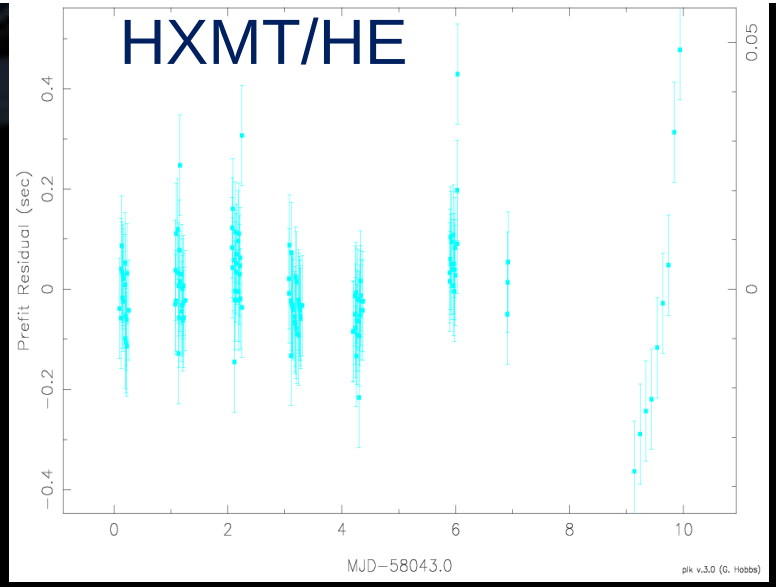




Accreting Pulsar: Swift J0243.6+6124

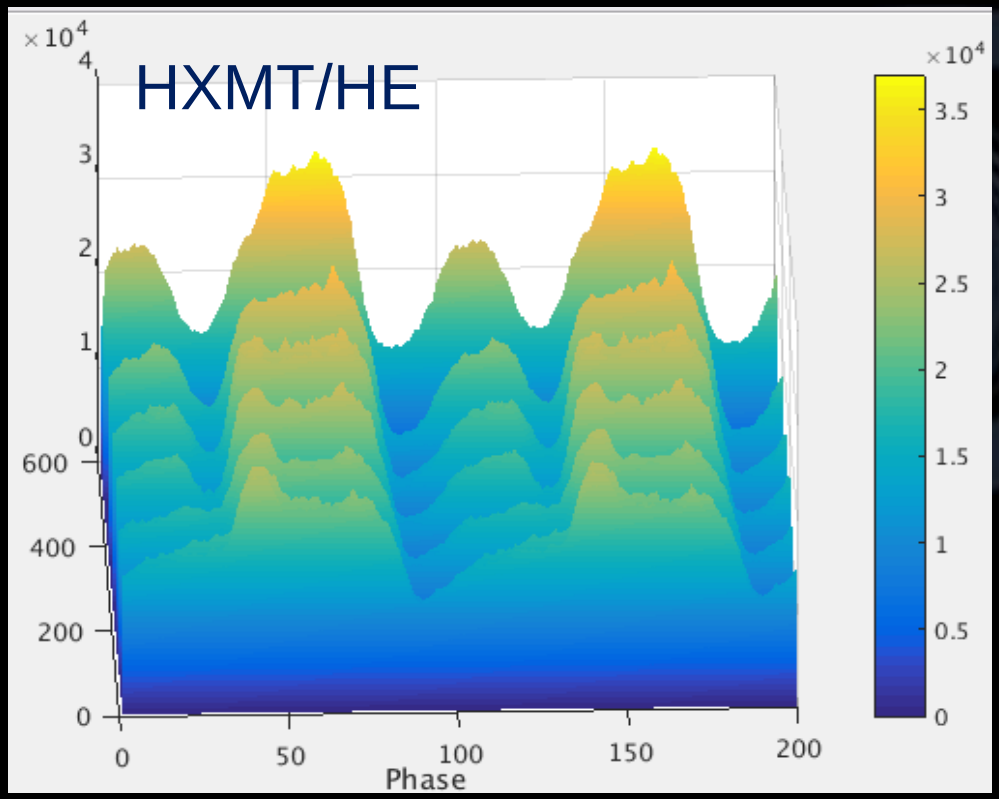




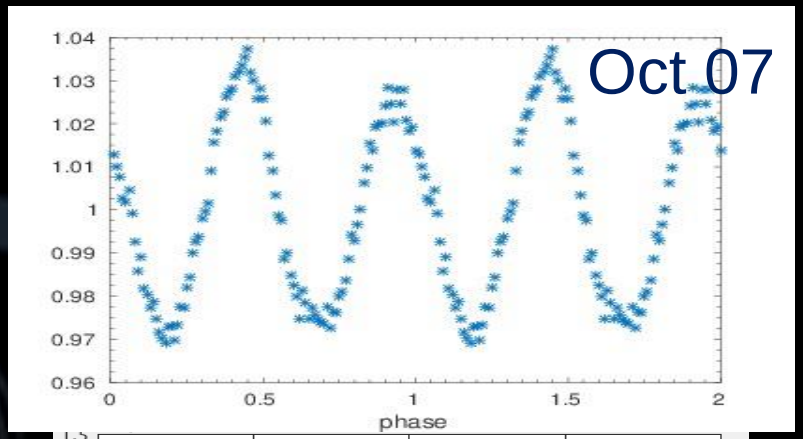


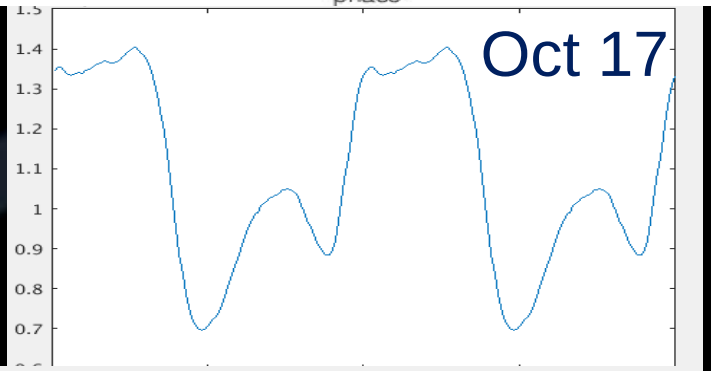
P= 9.86s,
Porb=~26d?

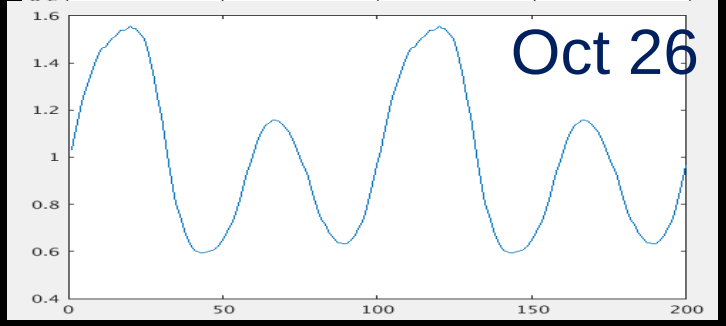
Accreting Pulsar: Swift J0243.6+6124



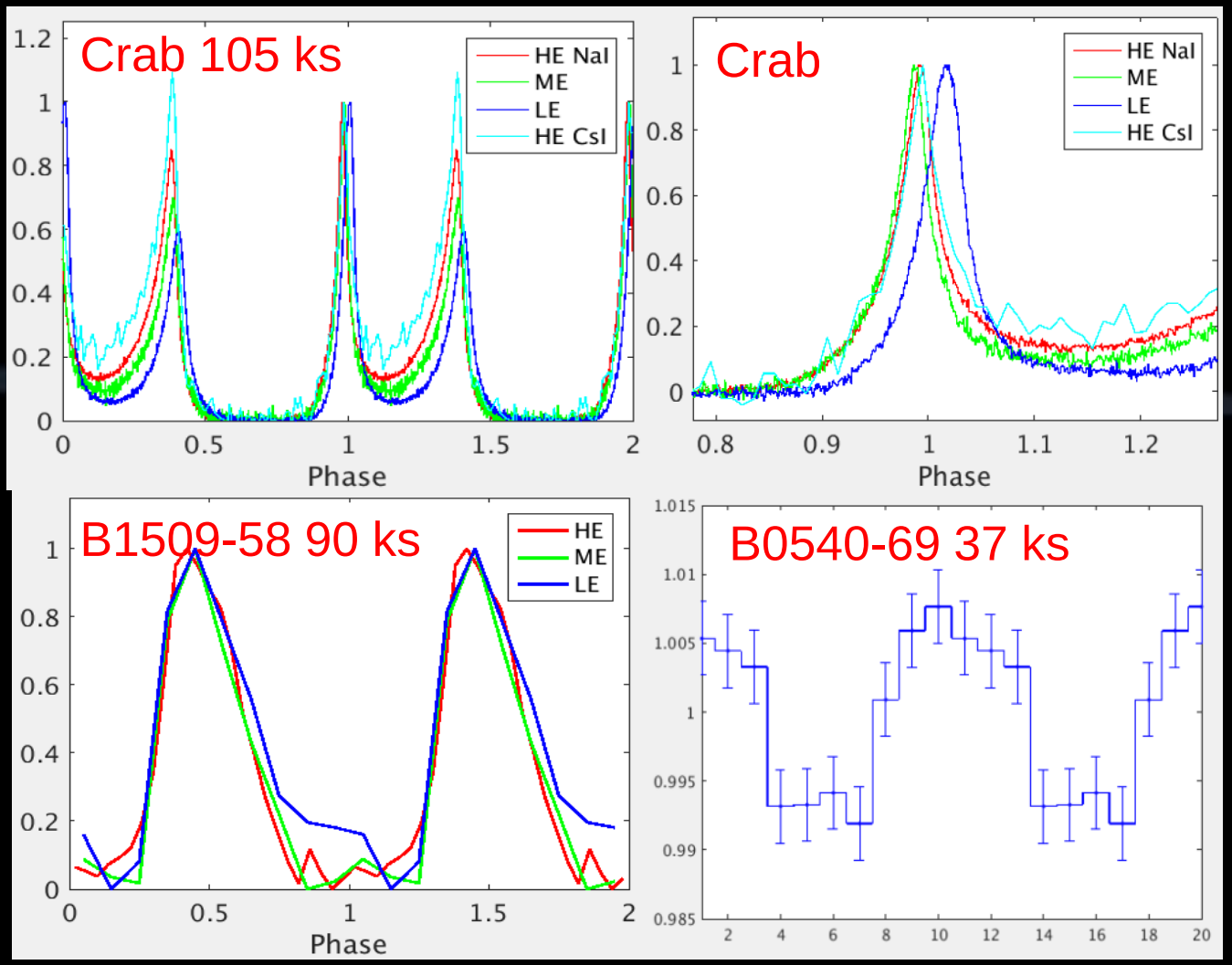
Oct 17-- Oct 23



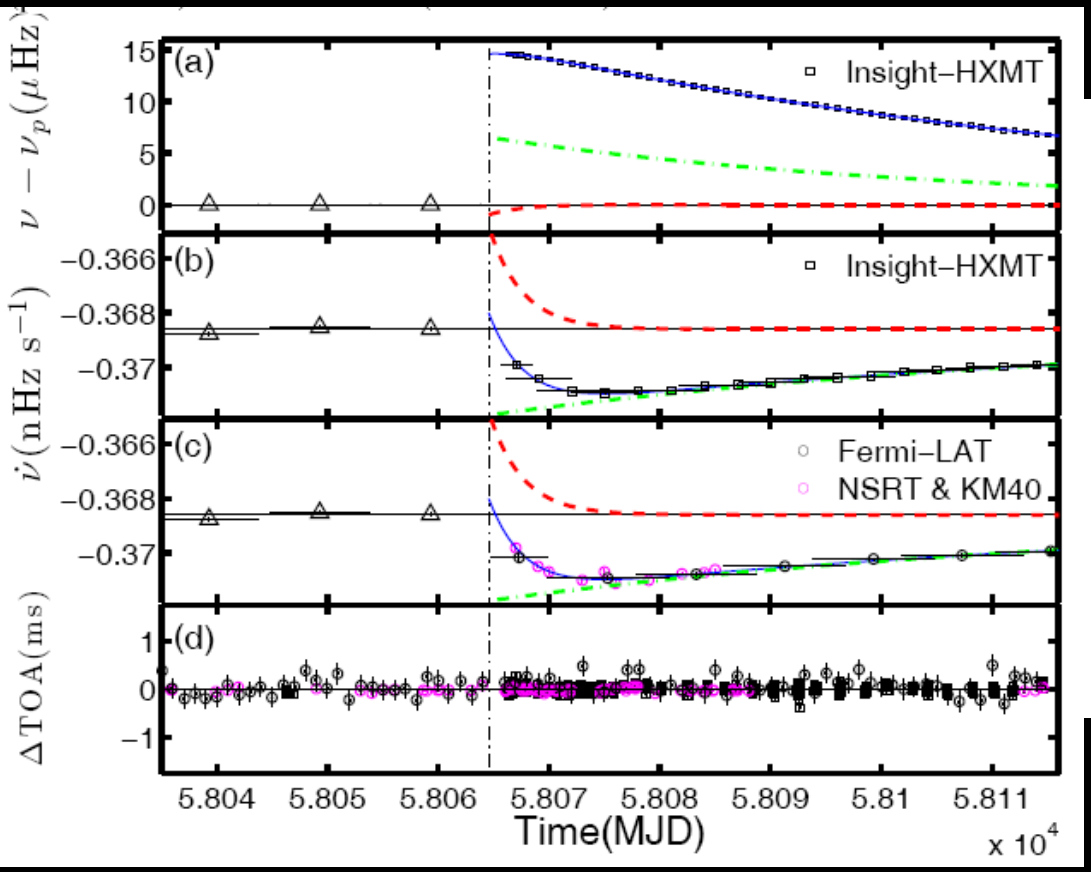


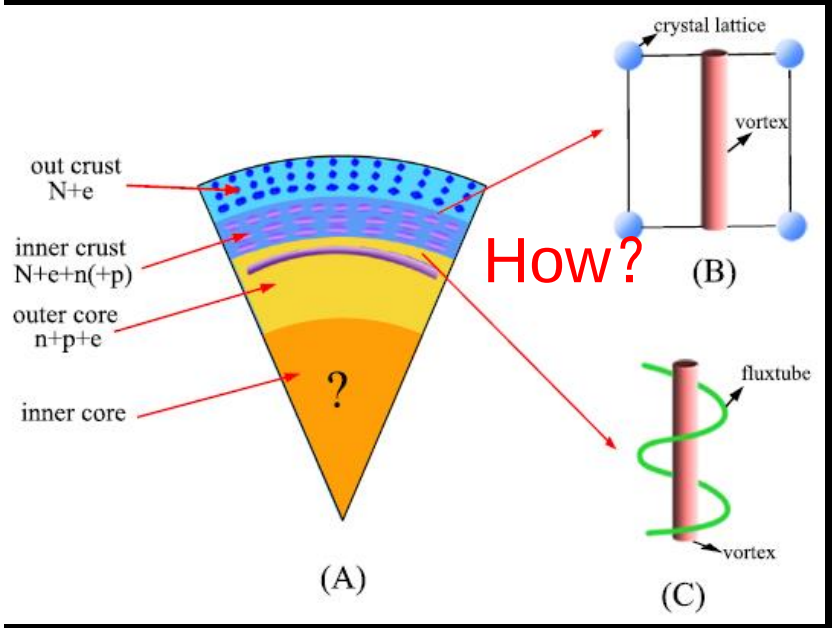


Isolated millisecond pulsars



Largest glitch of the Crab pulsar





Only observed two times before.

1st X-ray observation with Insight-HXMT.

Mechanism unclear.

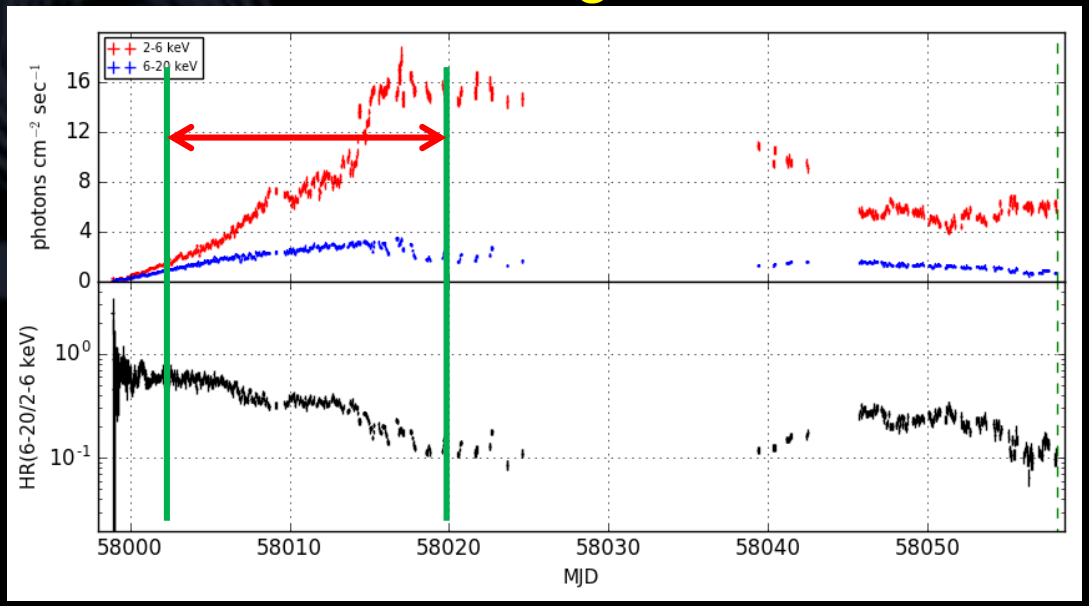
Black Hole Candidate MAXI J1535-571

- Detected by MAXI and Swift on 2017 September 02 (ATel #10699 & 10700)
- (R.A., Dec) = (233.83, -57.23)
- BH Candidate
  - MAXI: >L_{Edd} of NS (ATel #10708)
  - ATCA: radio (ATel #10711)

Insight-HXMT Observations

	Start Time	Exposure (ks)
1	2017/09/06 07:37:21	100
2	2017/09/14 04:56:05	8
3	2017/09/15 04:48:01	8
4	2017/09/16 06:15:31	8
5	2017/09/17 06:07:39	8
6	2017/09/18 02:48:56	8
7	2017/09/19 23:22:47	8
8	2017/09/21 02:26:27	150

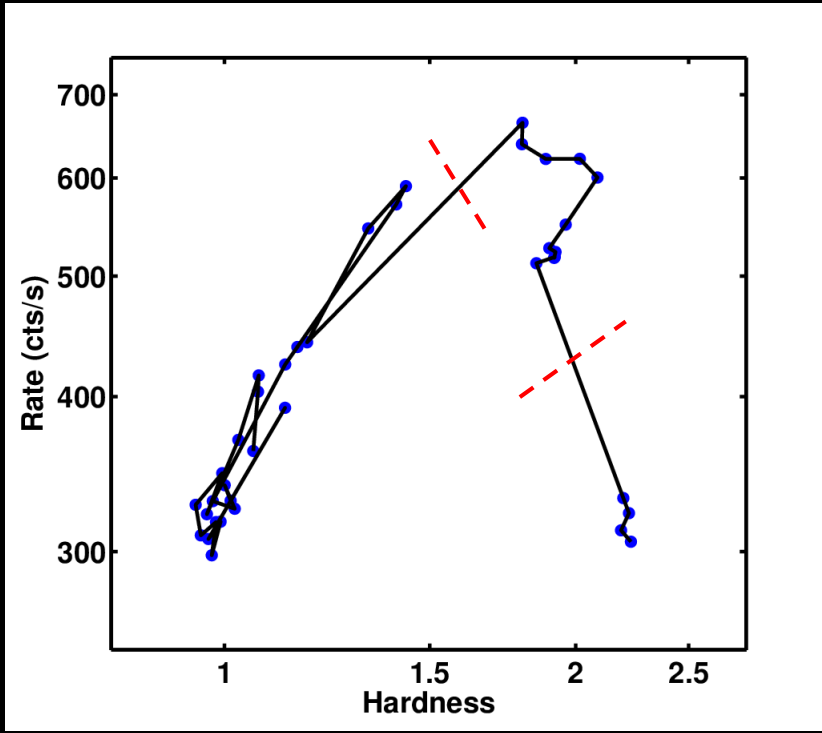
MAXI light curve



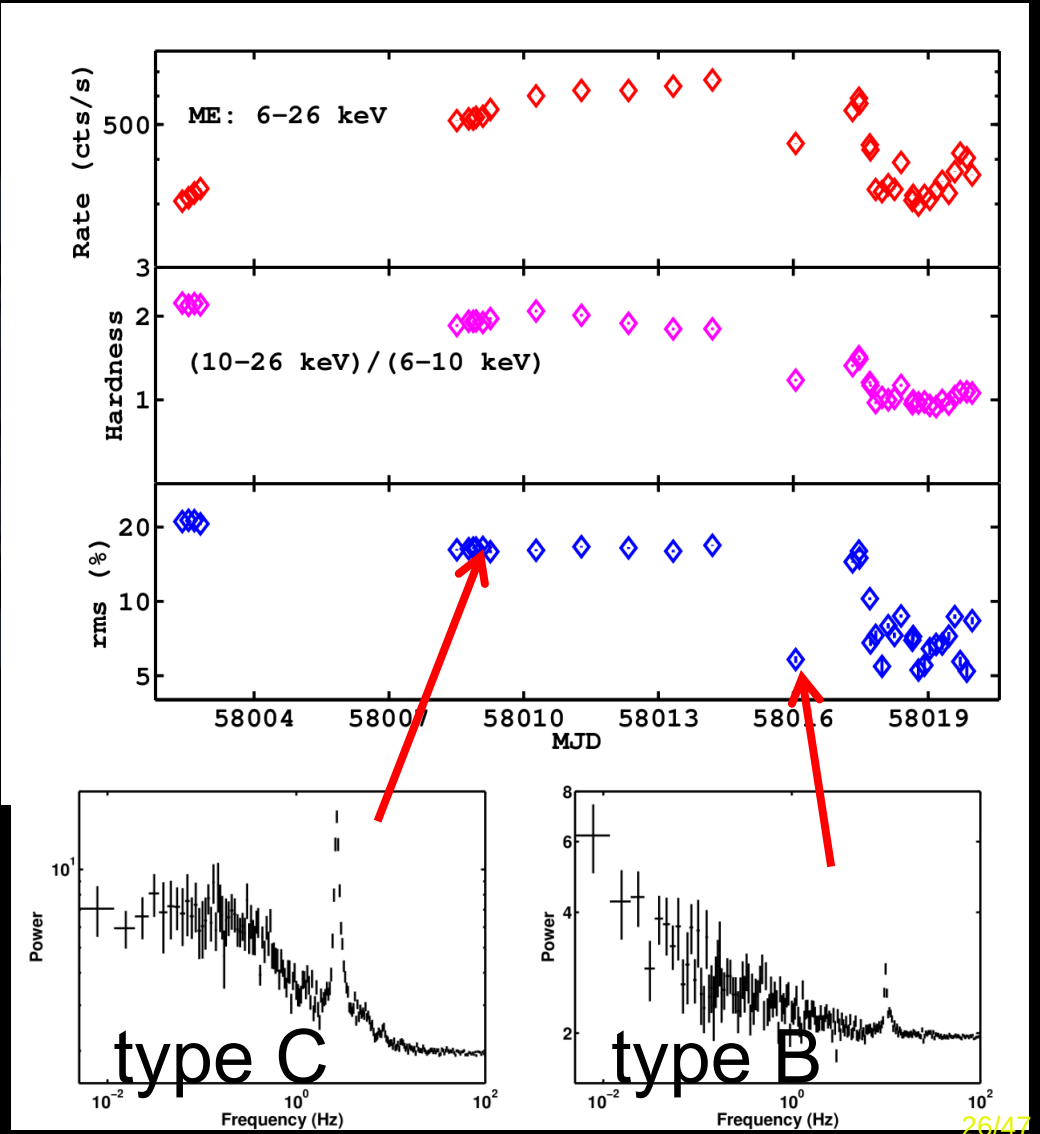
http://134.160.243.88/nakahira/1535monitor

Black Hole Candidate MAXI J1535-571

The outburst evolution

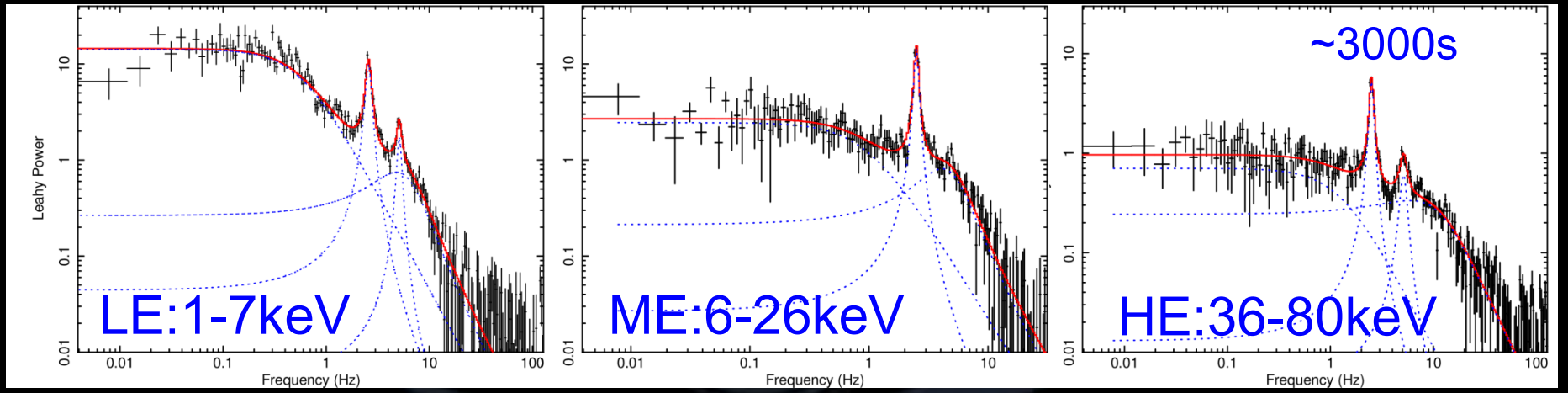


Hardness-Intensity diagram corresponding to the points in right panel.



Black Hole Candidate MAXI J1535-571

Power Density Spectra

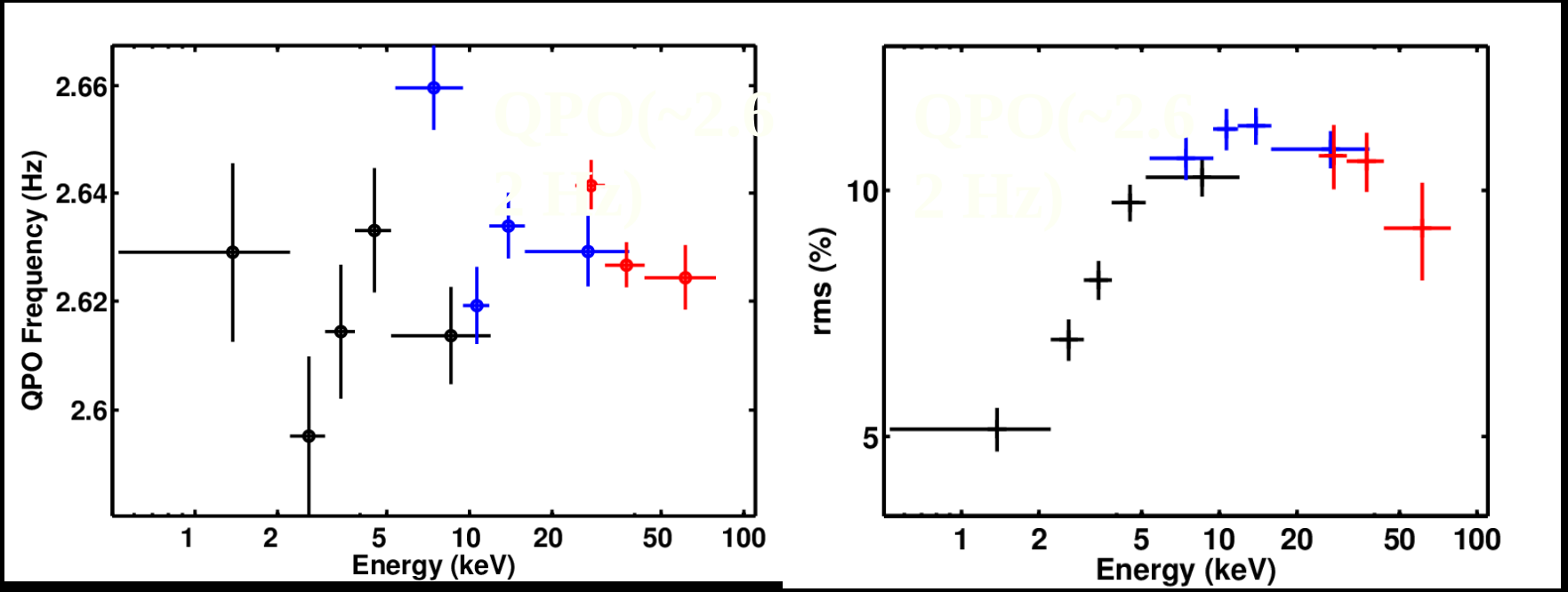


- noise components: two Lorentzian shapes
- QPOs: one Lorentzian each

High-frequency QPOs: No significant peaks

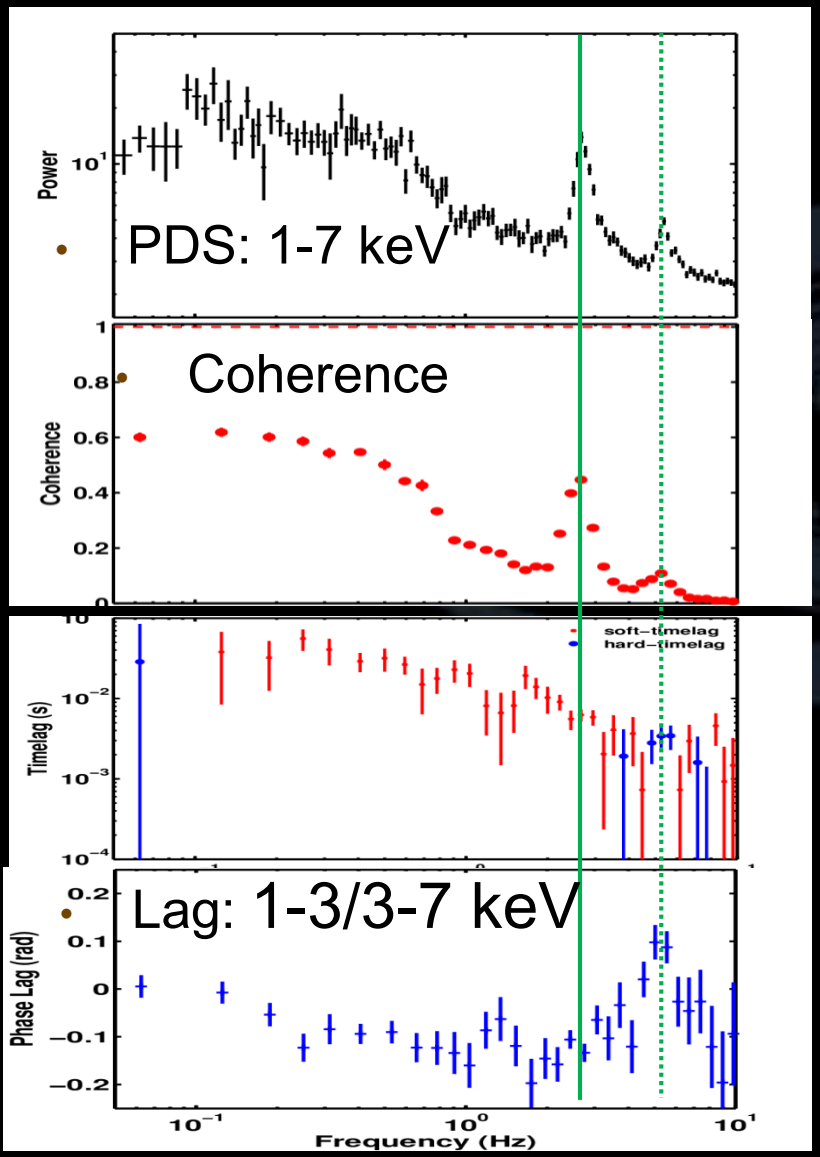
Black Hole Candidate MAXI J1535-571

Energy dependent QPO properties



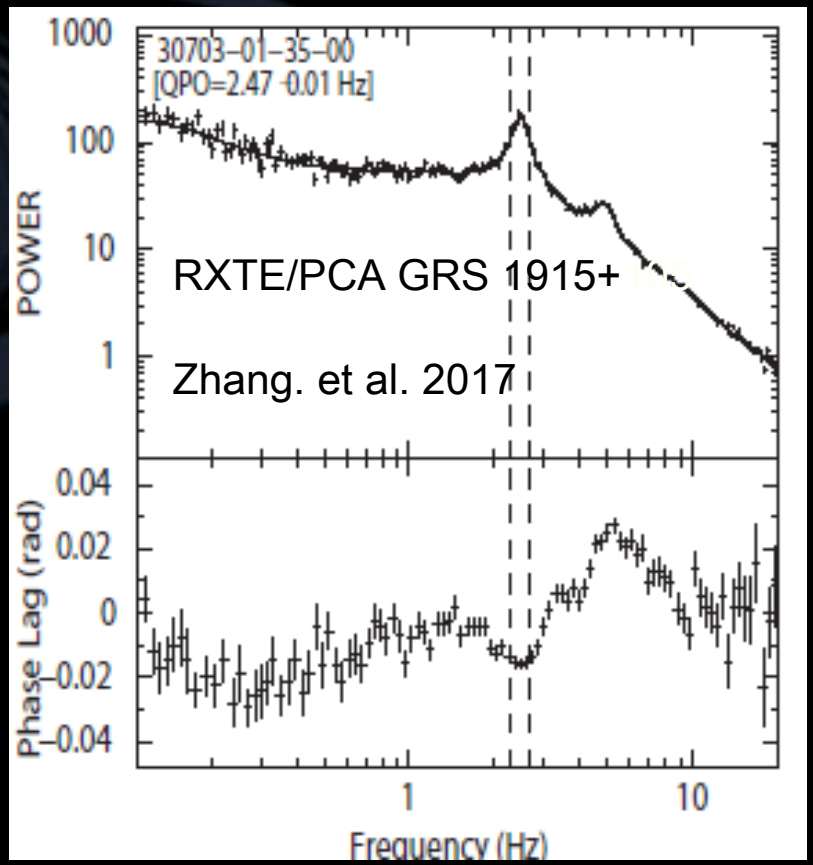
- The larger effective area at higher energies reveals that the QPO rms spectrum is non-monotonic and beyond ~20 keV the rms decreases with energy

Black Hole Candidate MAXI J1535-571



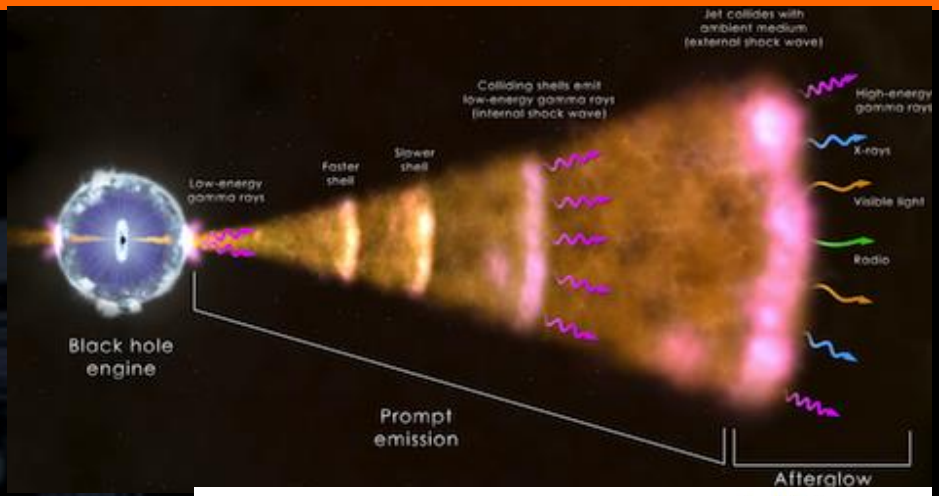
TIME LAG

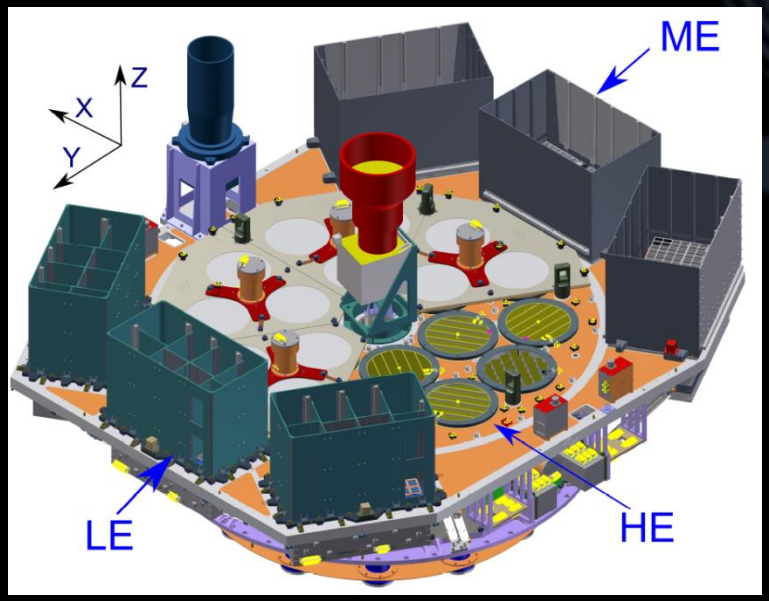
- Fundamental QPO: soft lag
- Harmonic: hard lag



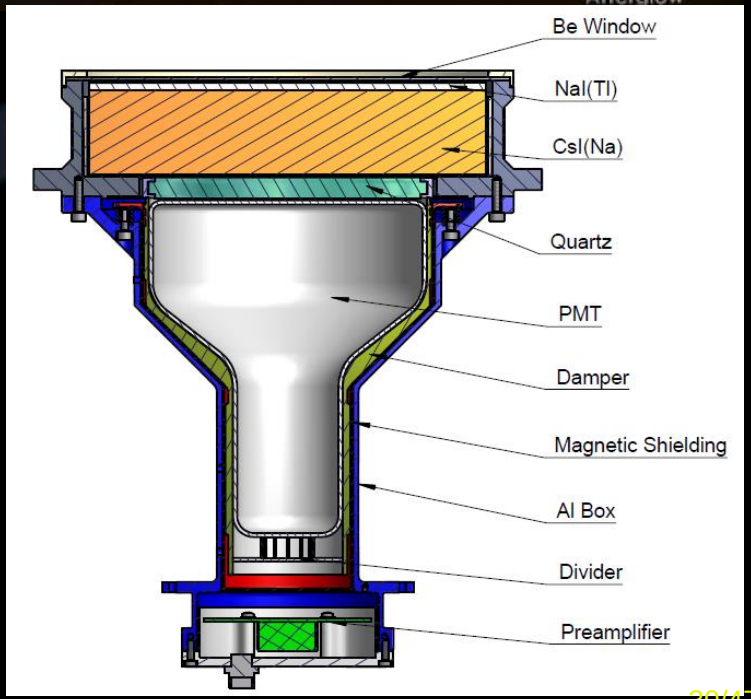
How to observe GRB (GW EM)?

- ✓Original design
  - ✓afterglow emission
  - ✓LE (0.5-10 keV), scanning
- ✓Extended capability
  - ✓prompt emission
  - ✓CsI detector of HE



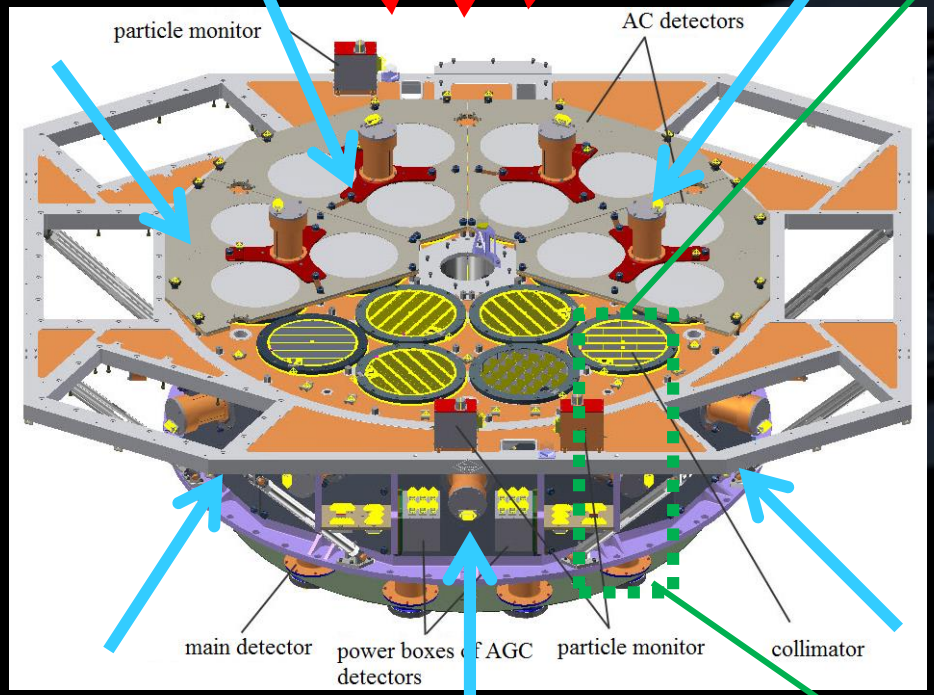


HE
NaI/CsI

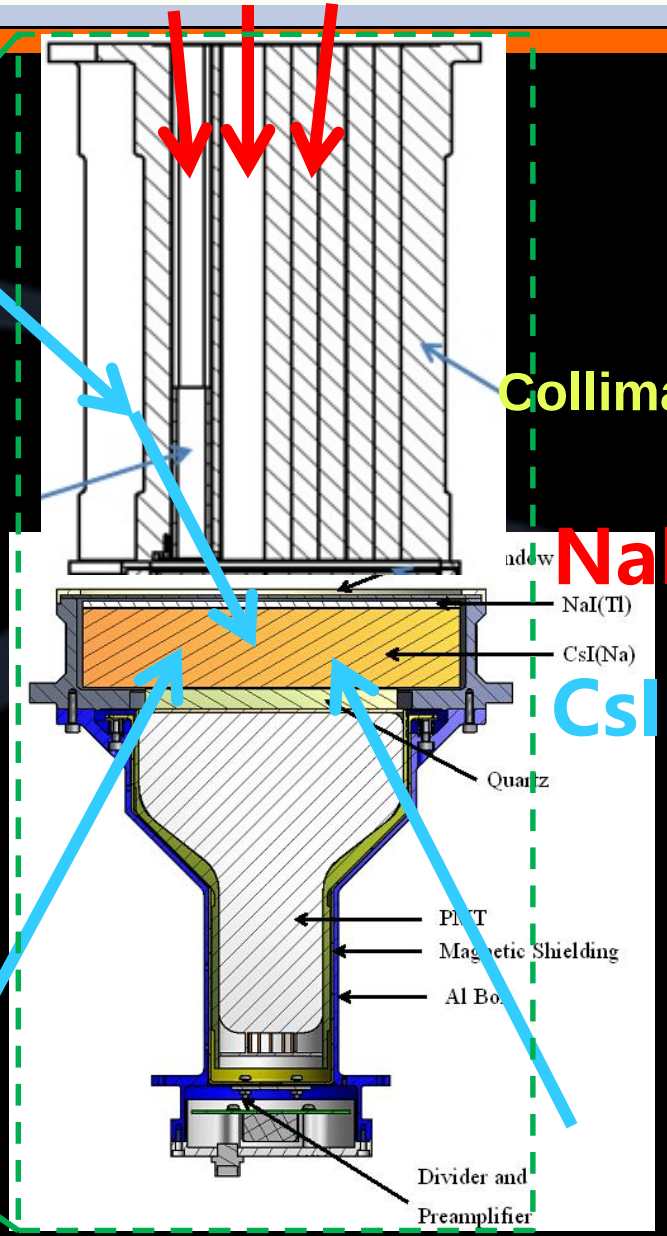


Regular observation vs. GRB observation

X/gamma photons within FOV

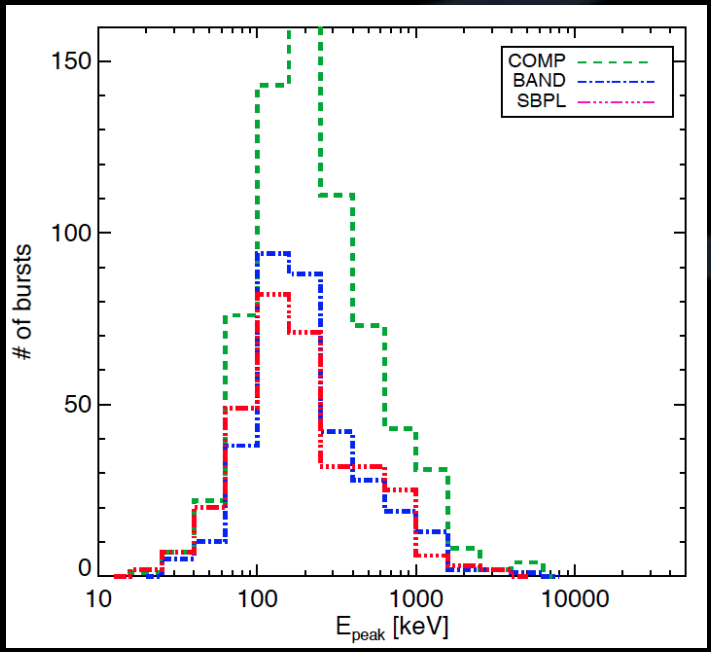


Gamma-rays (> ~200 keV)



Dedicated working mode for GRB

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

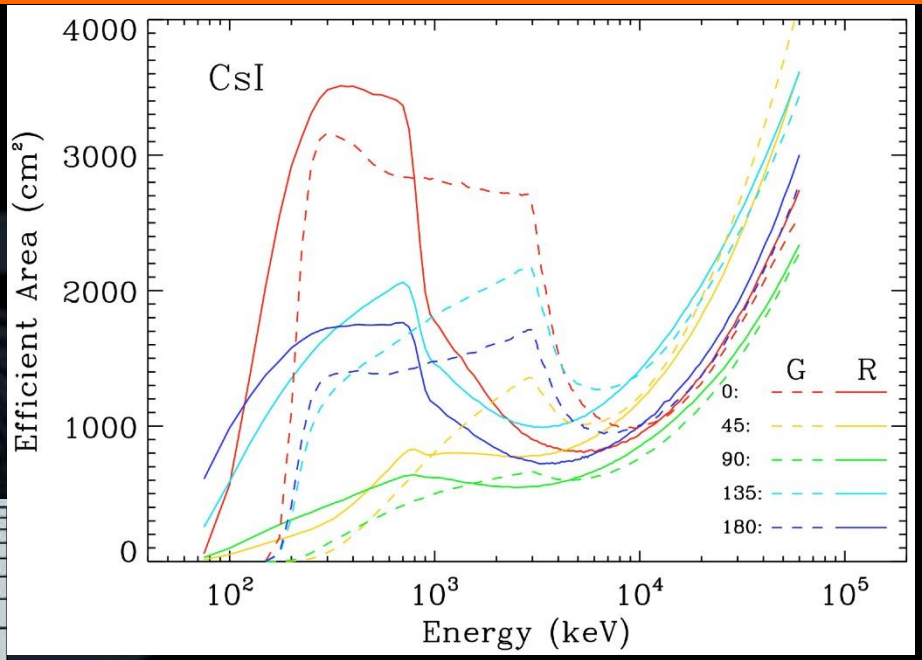


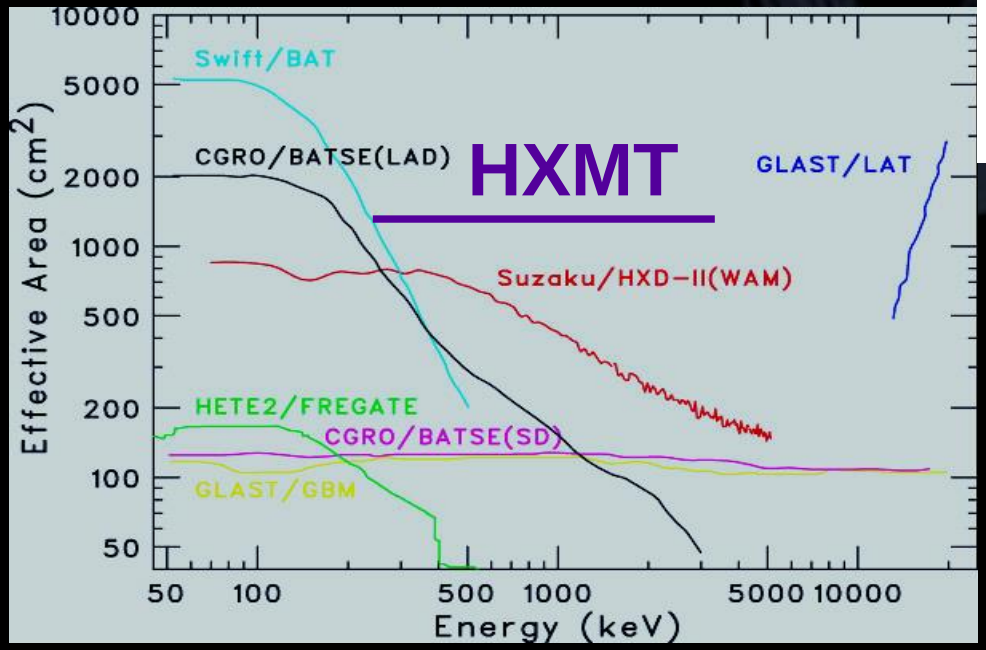
GRB Epeak measured by Fermi/GBM
（Gruber+, ApJS, 2014）

- **GRB mode better energy range:**
  - According to the simulation, det. efficiency is good for >200 keV
  - GRB Epeak distribution
- **GRB mode: ~30%(TBC) 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

- Can detect GRB in **both** regular & GRB modes (lower HV for PMT)
- GRB monitoring FOV: all sky un-occulted by the Earth

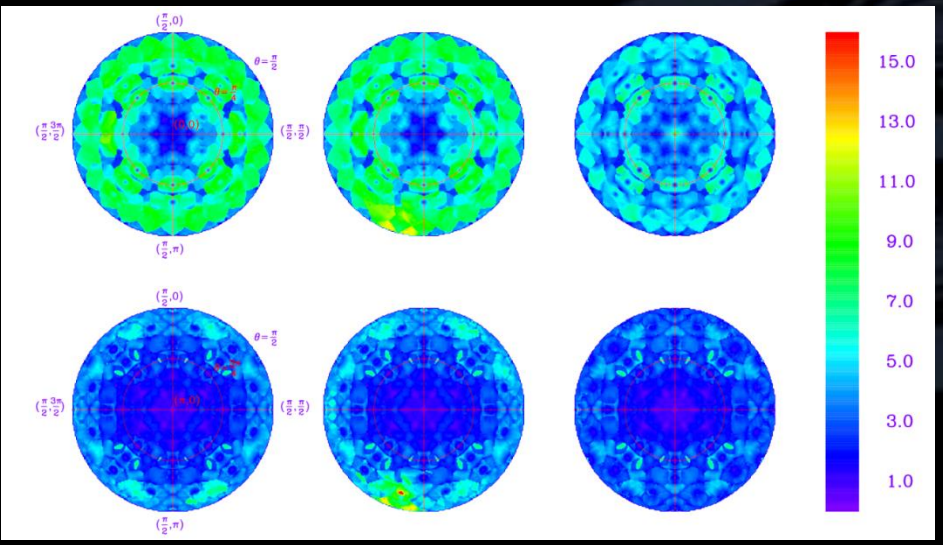




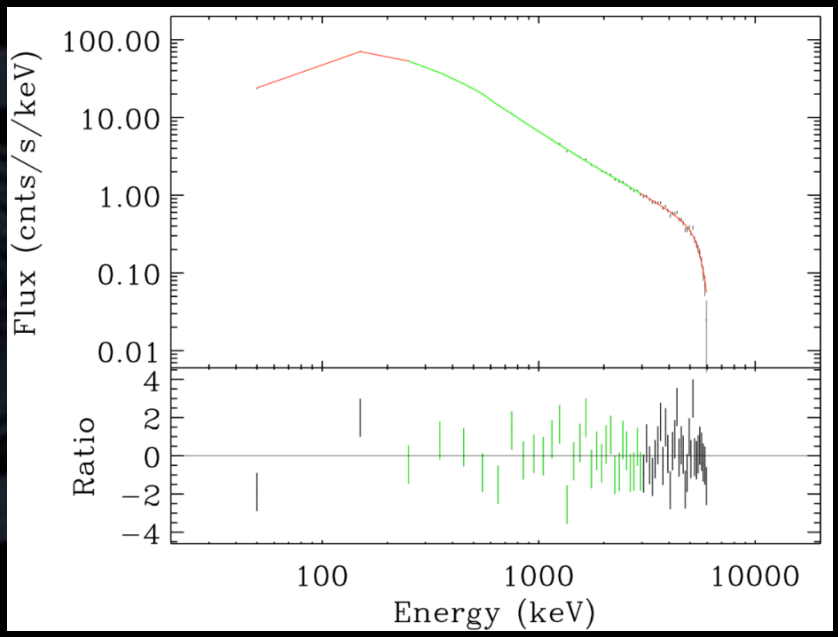
- 500~3000 cm^2 ~ MeV range with single photon counting and energy measurement, ~largest ~ MeV GRB monitors ever flown

GRB & GW EM: Location & Spectroscopy

- **Wide FOV (~60% all-sky) and large eff. area (~1000 cm²) in μs**
- Temporal analysis with high statistics
- Location accuracy: ~5 deg
- Spectral analysis (Epeak)

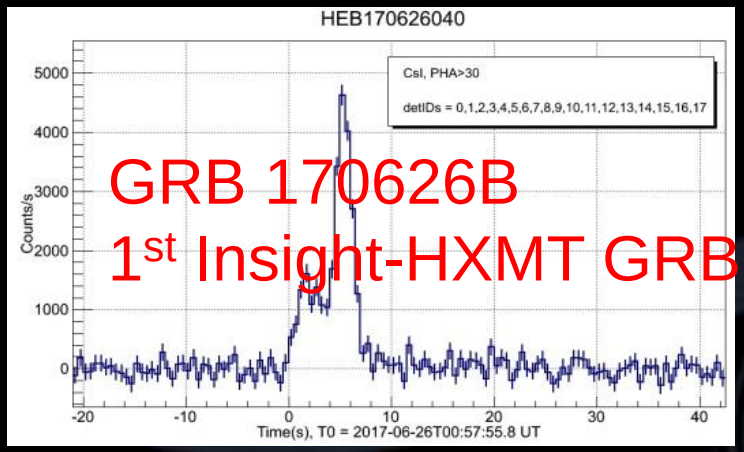


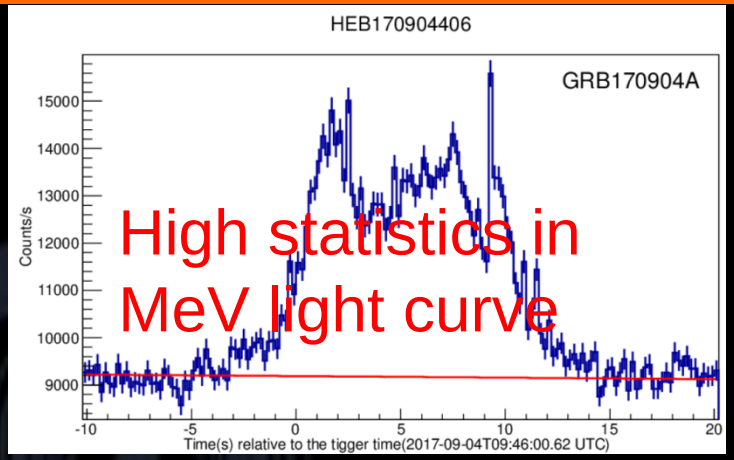
Localization accuracy



Fluence: 1E-4 erg/cm2, 10 s
Input：Alpha=0, beta=-1.5, Epeak=1000 keV
Measured：0.02+-0.12, 1.51+-0.01, 1004.6+- 68 keV

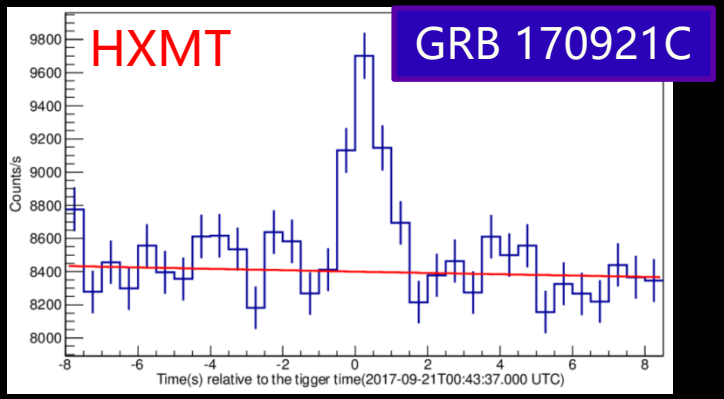
GRBs detected

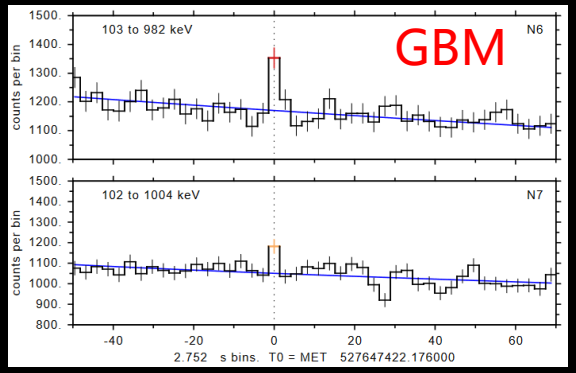


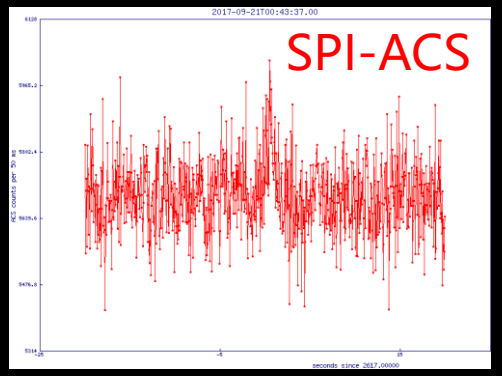


>60 GRBs detected ~100/yr

- ✓ Sensitive @MeV: short/hard GRBs
  - ✓ Sig: HXMT=12，GBM=8，SPI-ACS=4 (no spectrum)

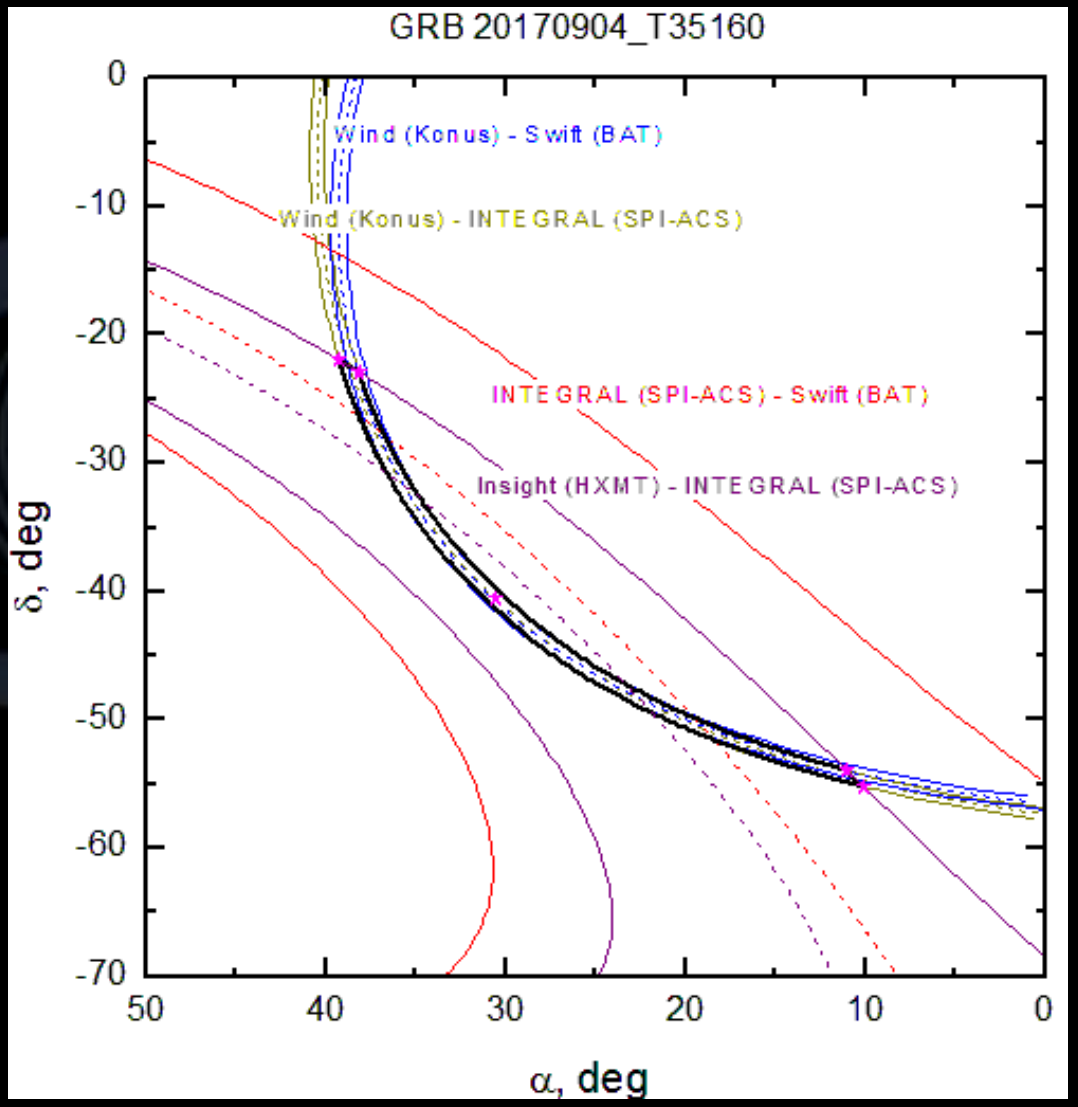






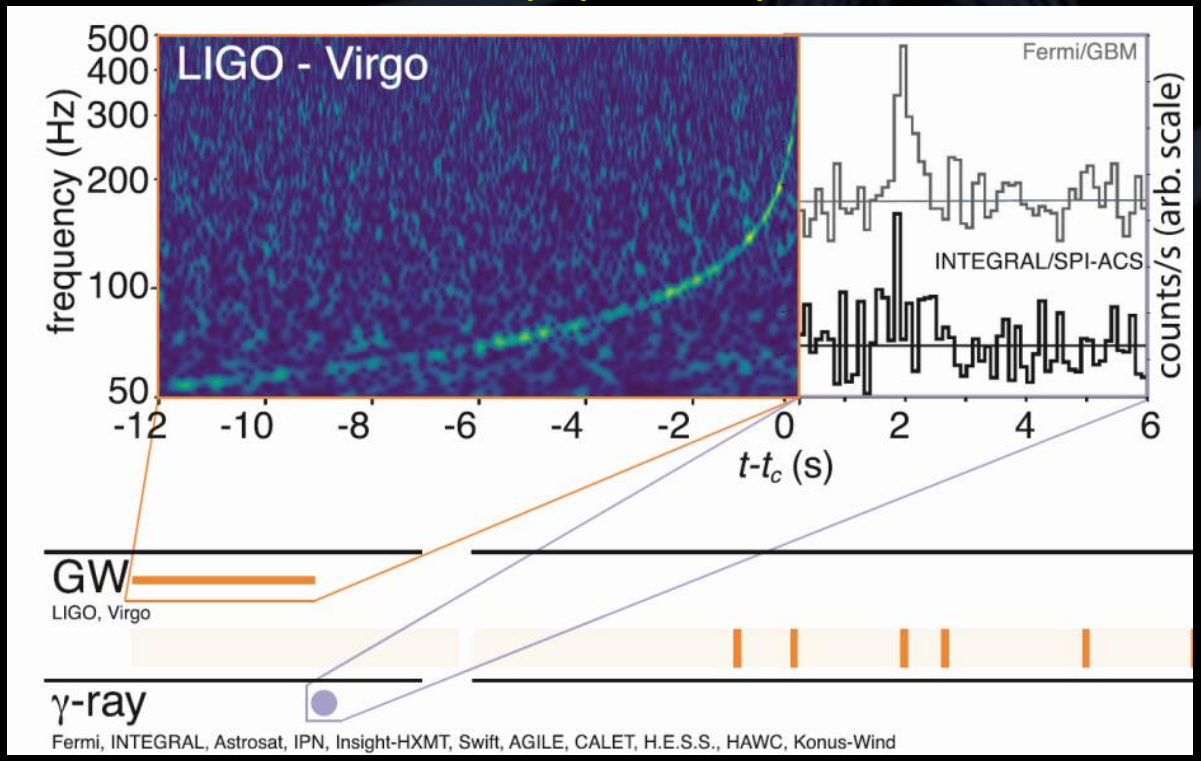
Joined InterPlanetary Network (IPN）

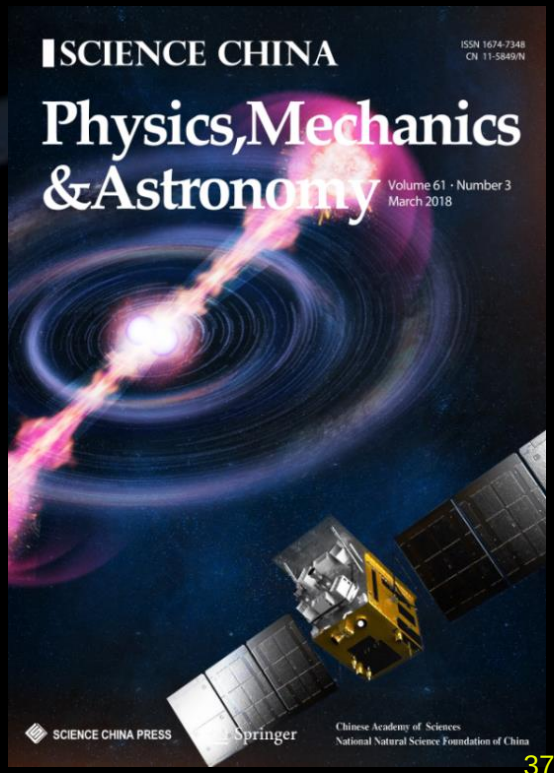
- ✓IPN: All major GRB detectors, near earth, L1, Mars orbit; *Insight*-HXMT is one of them, with Fermi, Swift, INTEGRAL, Wind-Konus, etc.



GW EM observations

- ✓ **Monitored 6 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

- ✓ 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

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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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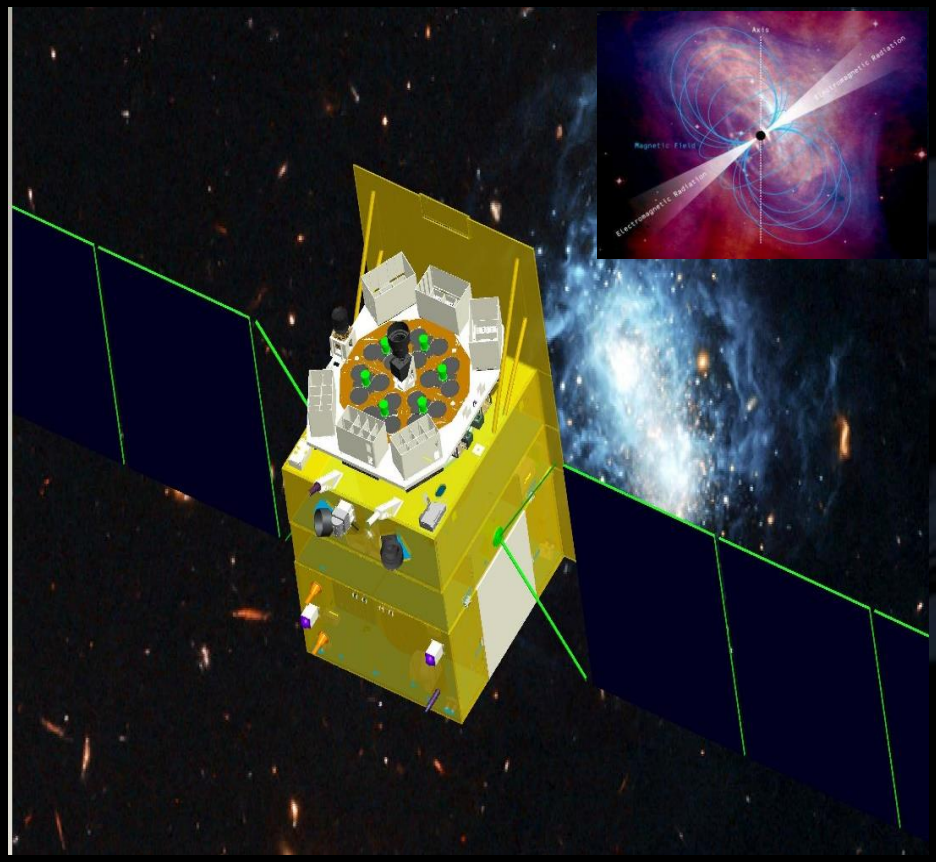
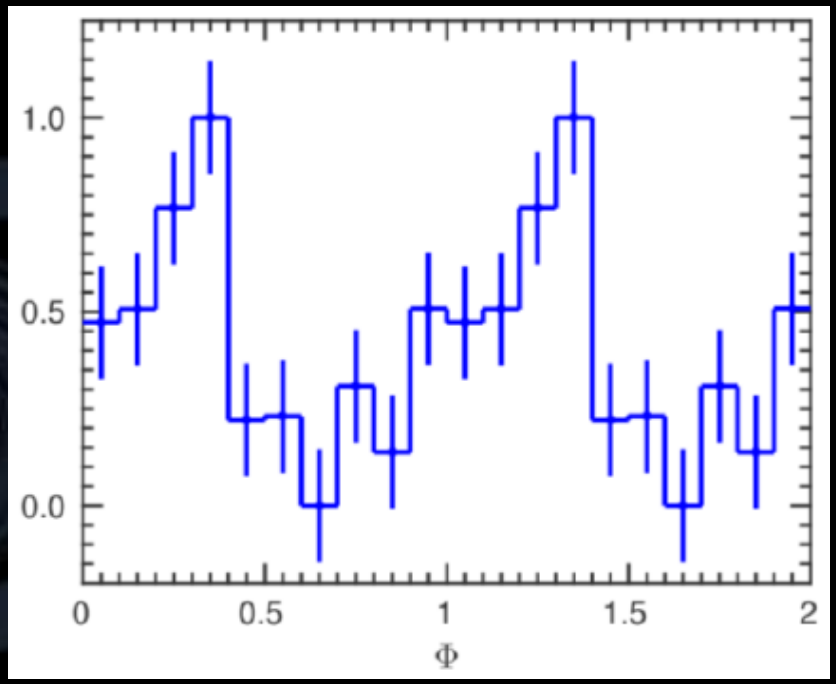
Calibration with Crab pulsar for GW170817

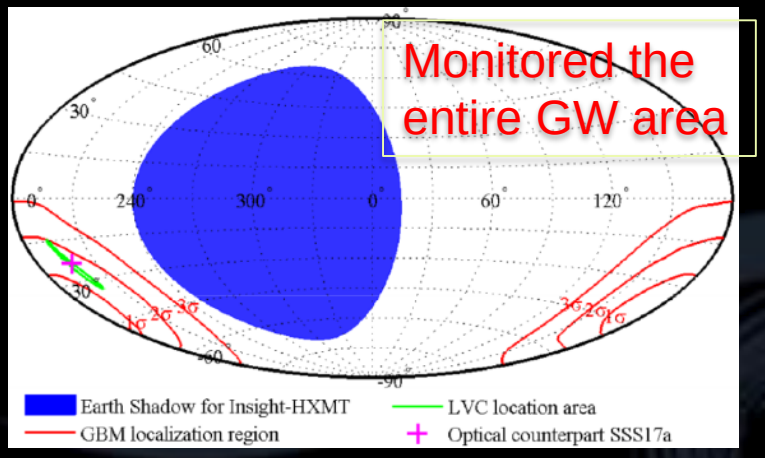


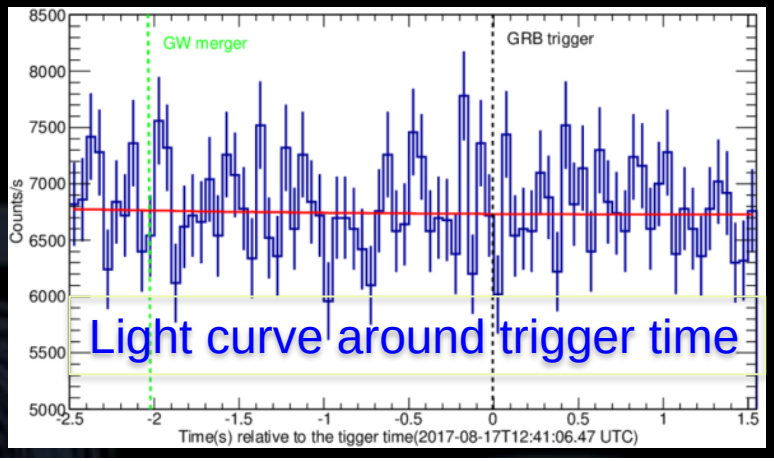


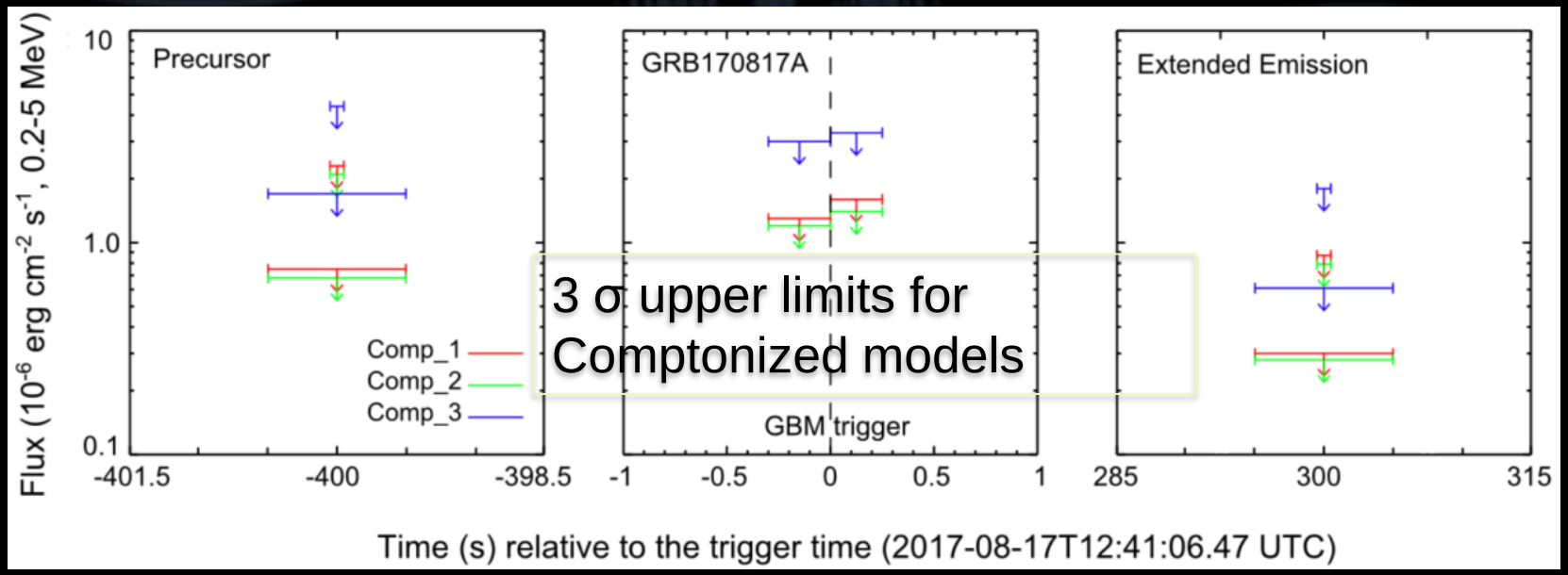
Pulse profile of Crab in GRB monitor (CsI)

Dedicated calibration observation: Crab set in the same incident direction as GW170817

Insight-HXMT observation to DNS GW-EM



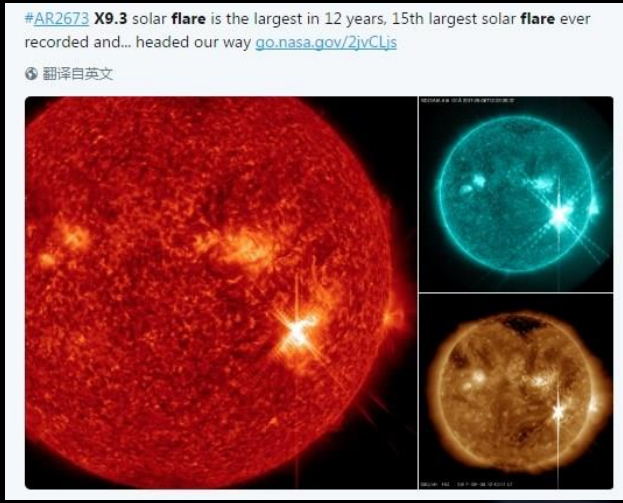


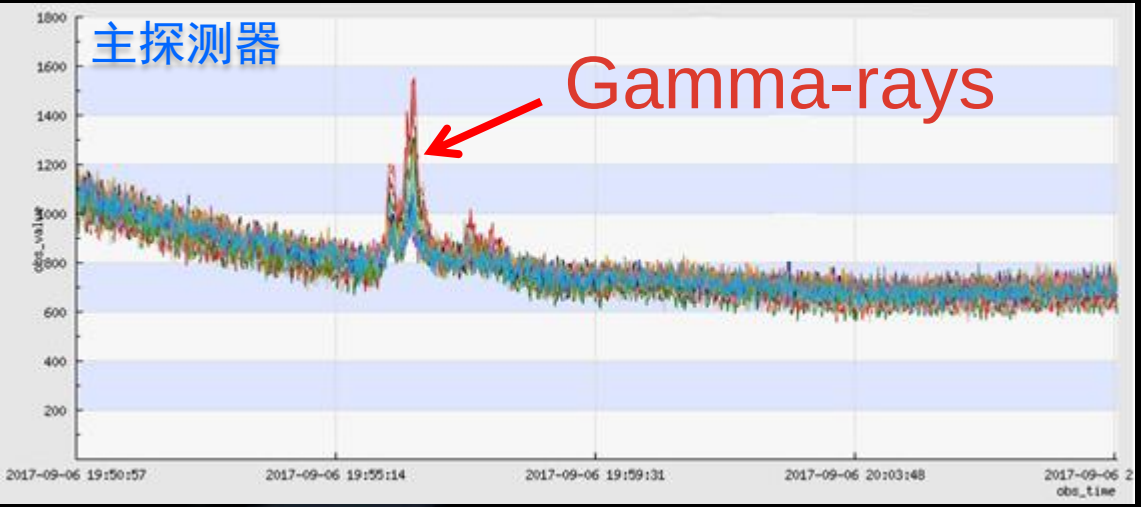


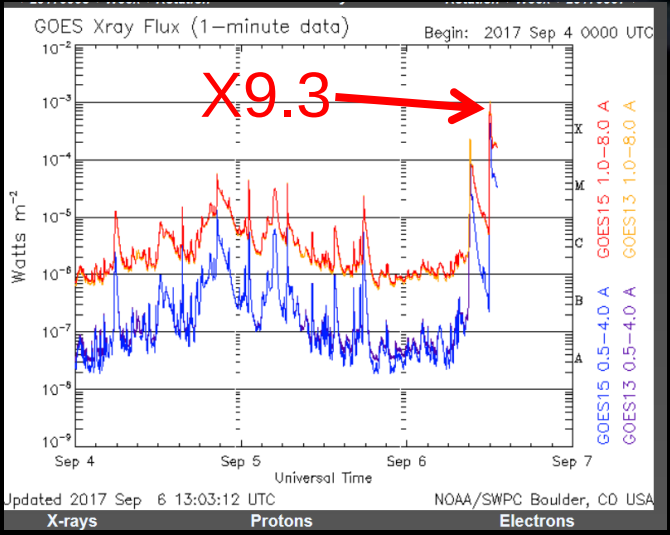
T. P. Li, et al, Sci. China-Phys. Mech. Astron. 61(3), 031011 (2018)

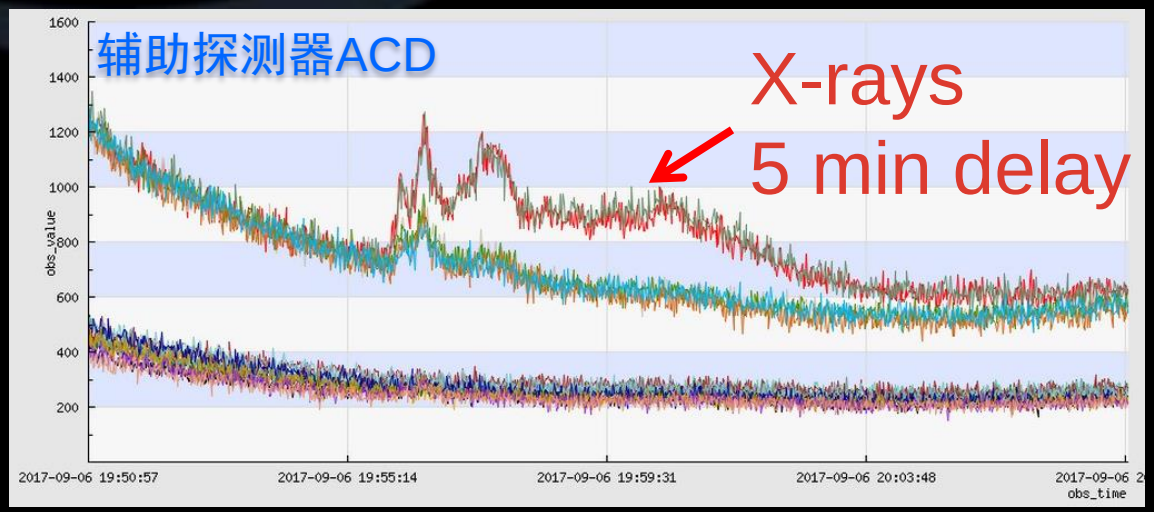
The brightest solar flare in 12 years

✓Prompt gamma-rays and delayed X-rays









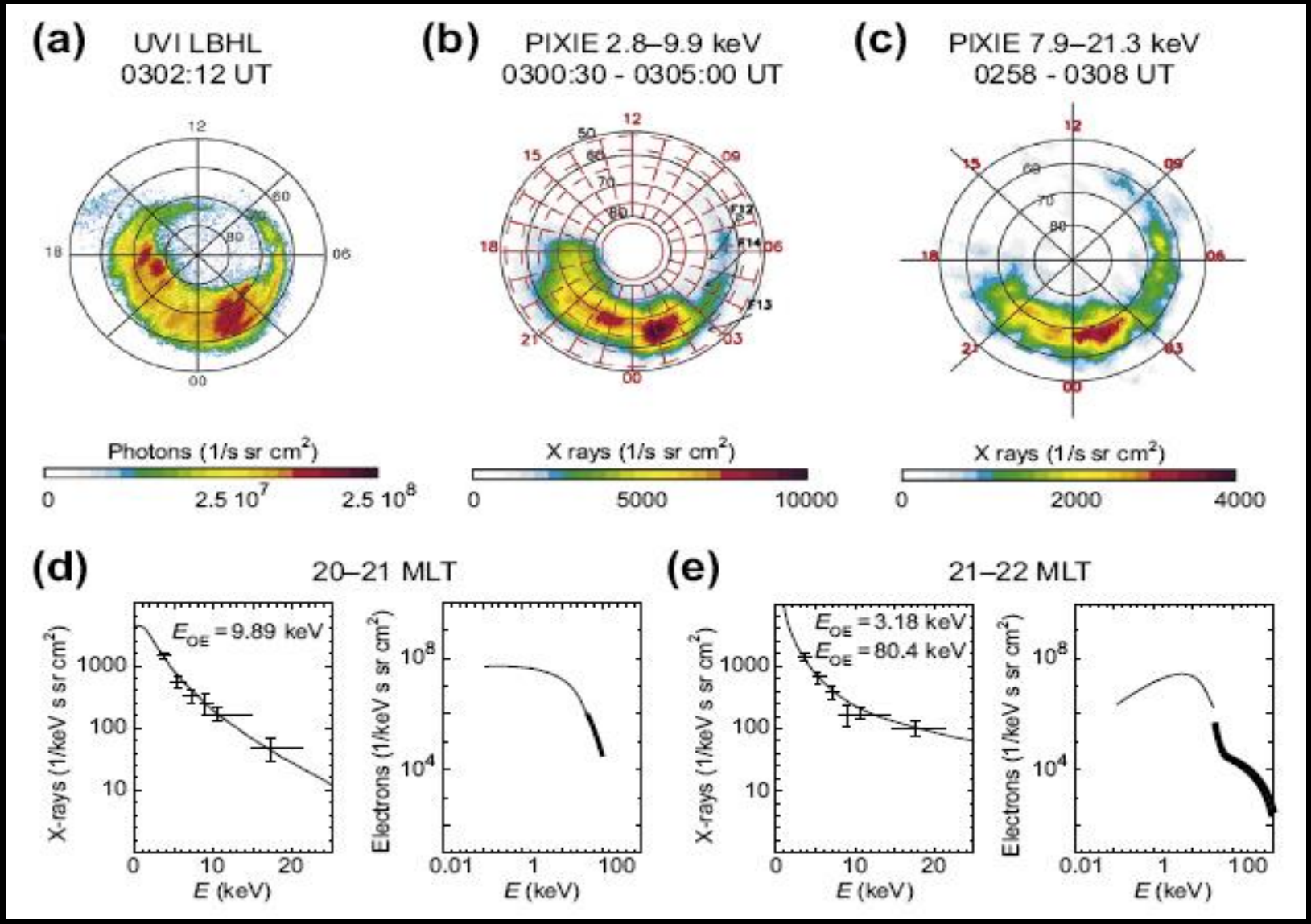
X-ray emissions from planets

Table 2. Characteristics of X-ray emissions of Jupiter, Saturn, and Earth

Planet	Emitting Region	Emitted Power[a]	Special Characteristics	Major Production Mechanism
Earth	Auroral atmosphere	10-30 MW	Correlated with magnetic storm and substorm activity	Bremsstrahlung from precipitating electrons
	Non-auroral atmosphere	40 MW	Correlated with solar X-ray flux	Scattering of solar X-rays
Jupiter	Auroral atmosphere	0.3-1 GW	Pulsating (~30-60 min) X-ray hot spot in north; in south emitted from a band ~180° wide in longitude	Ion precipitation (outer magnetosphere and/or solar wind) + electron bremsstrahlung
	Non-auroral atmosphere	0.3-2 GW	Relatively uniform over the disk, correlated with solar X-rays	Scattering of solar X-rays + ring current ion precipitation (?)
Saturn	Auroral and non-auroral atmosphere	0.1-0.4 GW	Correlated with solar X-ray flux	Scattering of solar X-rays + Electron bremsstrahlung (?)

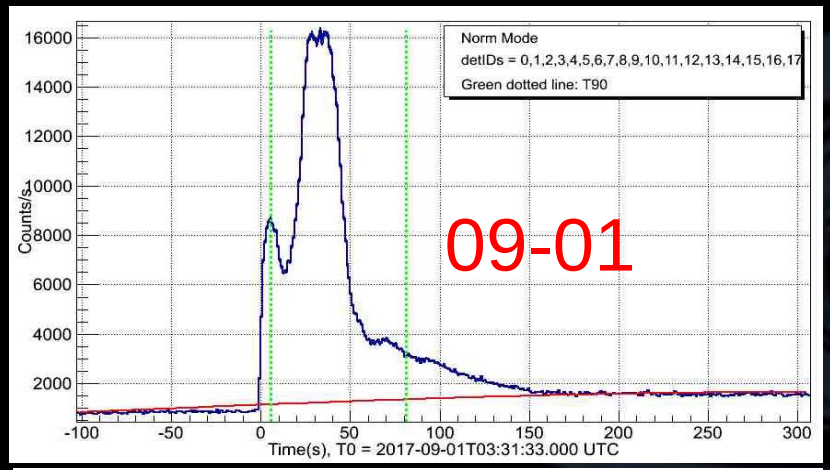
[a]The values quoted are "typical" values at the time of observation. X-rays from all bodies are expected to vary with time. For comparison the total X-ray luminosity from the Sun is 10^{20} W.

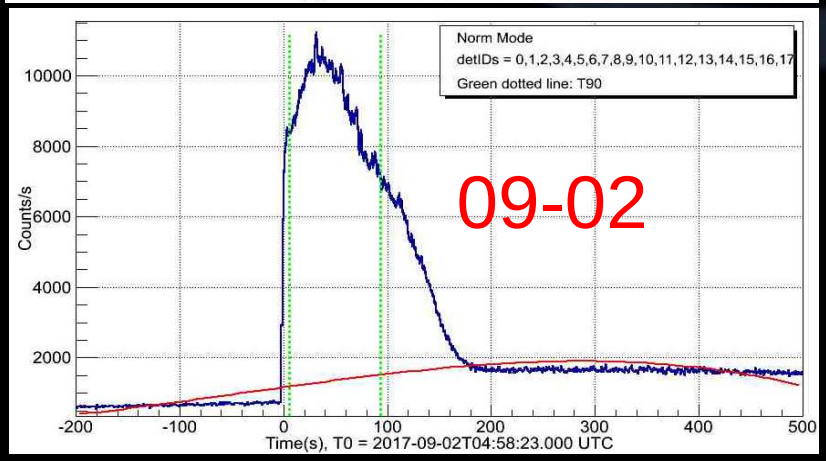
POLAR observations of aurora

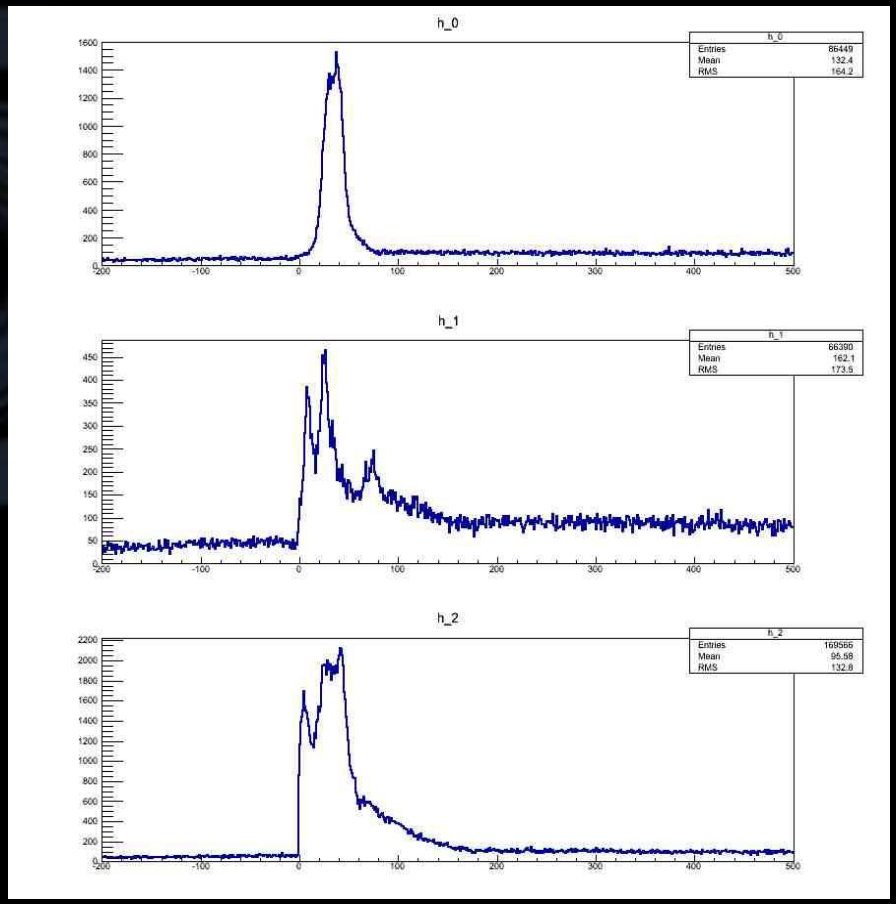


Peculiar HXMT events from NMP direction

- ✓ Observed on 2017-09-01 & 02 & 03 with HE & ME, significant and different flux modulation in detectors with different FOV

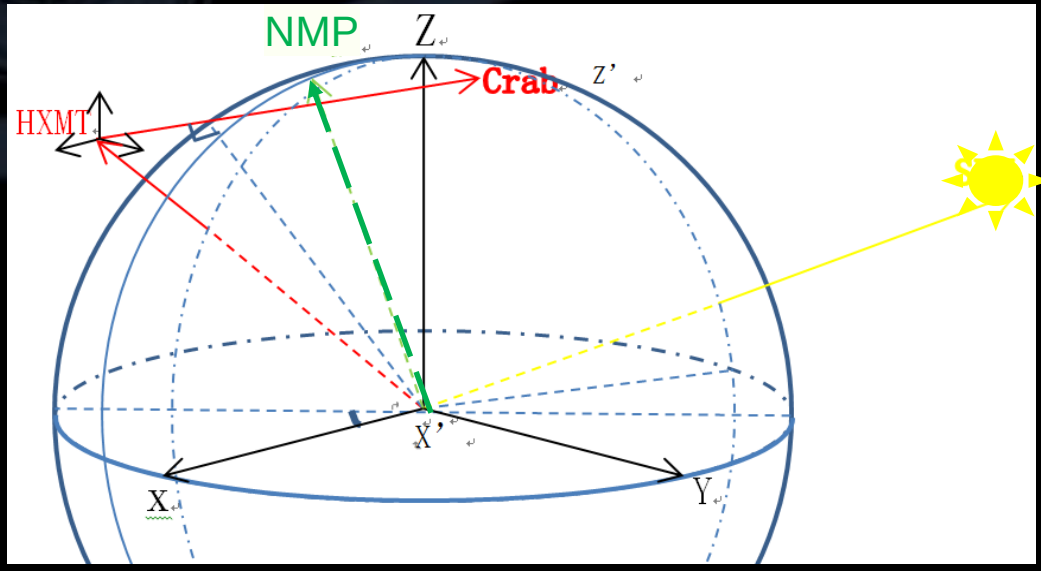






Possible origins of the peculiar events

- ✓Main characteristics
  - ✓Quiet Sun in 3 days
  - ✓Soft spectrum < 100 keV
  - ✓Thermal Brem. ~30 keV
  - ✓Significantly extended
  - ✓09/01 event brighter but shorter than 09/02 event, very faint on 09/03
  - ✓Possibly observed in the same direction several times earlier, but much fainter
- ✓Possible origins
  - ✓Non-astrophysical source
  - ✓Pointed to North Magnetic Pole, so possibly related to aurora (DMSP-F6 in 1984, INTEGRAL in 2015, ~hours), > 100 km above ground



Comparison with previous aurora X-rays

- ✓Similarities
  - ✓Likely from NMP region
  - ✓Extended and variable
  - ✓Thermal bremsstrahlung spectrum ~ 10s keV
- ✓Differences
  - ✓About 10^2-10^3 times fainter in power (assuming isotropic emission) than 10-30 MW observed before
  - ✓Possibly much longer: ~3 days vs. hours
  - ✓Nearly transverse observation direction vs top-down view from high altitude satellites → non-isotropic emission processes?

Summary and outlook

- ✓*Insight*-HXMT is China's 1st X-ray astronomy satellite.
  - ✓1-15, 5-30, 20-250 keV and 200-5000 keV (all-sky monitor mode)
- ✓*Insight*-HXMT PV & calibration: June 15 to Nov. 15, 2017
  - ✓1/3 total time in Galactic plane scan and monitoring
  - ✓Many bright sources observed: BHs & NSs
  - ✓Many ToOs executed: ~hours response time possible
  - ✓Dozens GRBs observed, GW EM followed
  - ✓Solar flares and peculiar events from MNP direction
- ✓Has started regular science operation for 4+ years
- ✓Collaborations welcome: three ways
  - ✓Partner institutions that contributed to *Insight*-HXMT
  - ✓Coordinated multi-λ observations: space & ground
  - ✓Apply and join our teams

http://www.hxmt.org/ for all information.