Introduction to Insight-HXMT: China's first X-ray Astronomy Satellite

Shu Zhang, on behalf of

ShuangNan Zhang

on behalf of Insight-HXMT team

Institute of High Energy Physics
Chinese Academy of Sciences

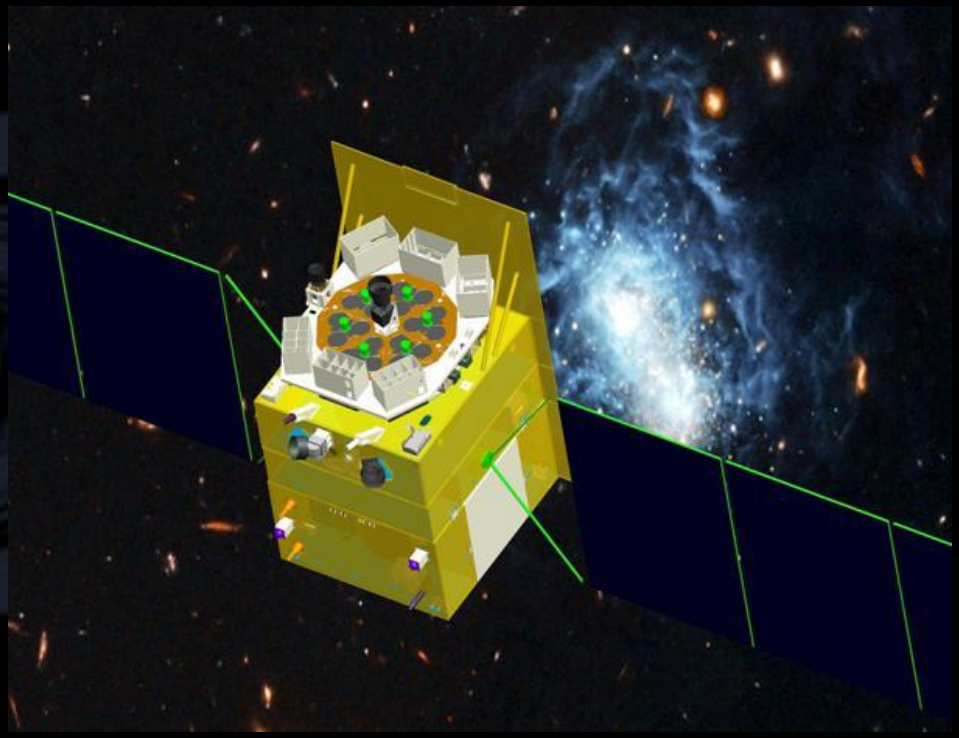
Outline

- Mission and payload
- Performed observations
- Preliminary results
- Summary

Mission and payload

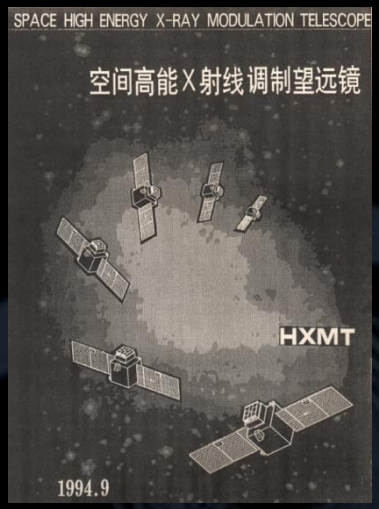
Hard X-ray Modulation Telescope (HXMT) satellite

- China's 1st X-ray astronomy satellite
- 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*"

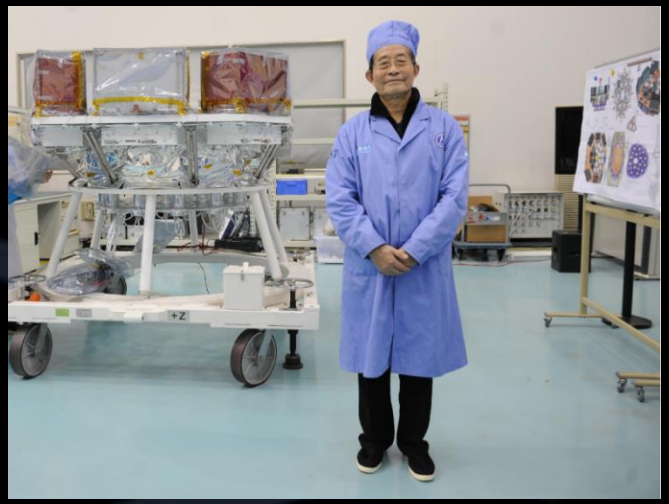


History of 慧眼Insight-HXMT

1970-80s balloon flight



1994 first proposal，2011 funded



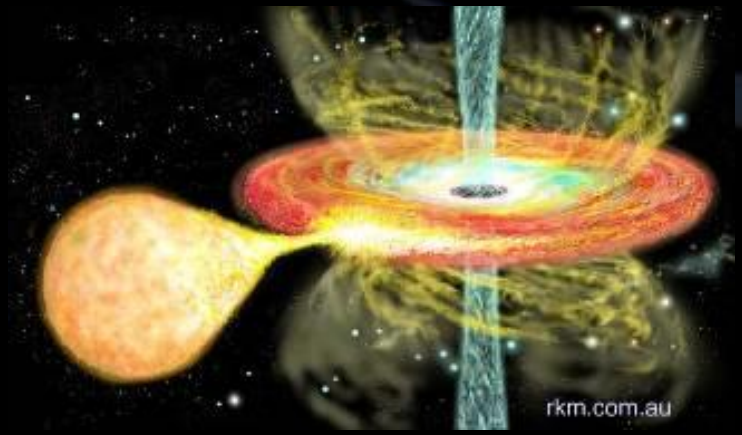
李惕碚院士Prof. Ti-Pei Li

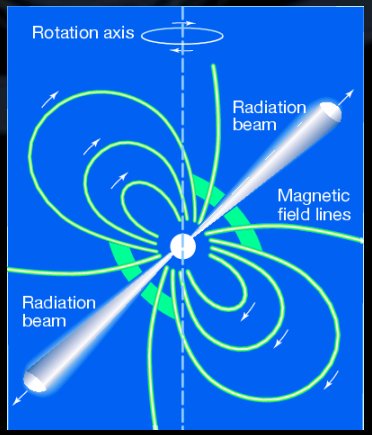
In honor of
何泽慧 Ho Zah-wei (1914-2011)
“慧眼” *Insight*

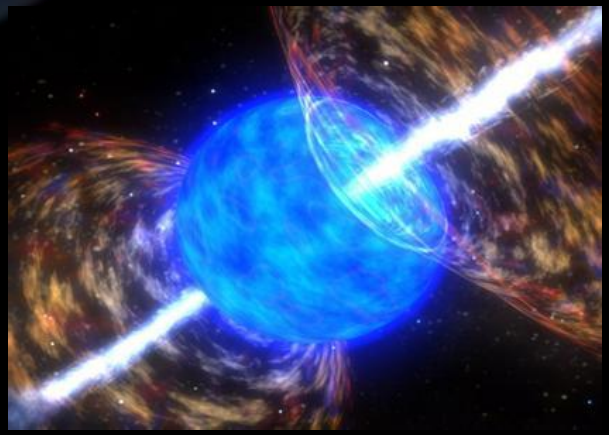
2017.6.15 Launched in Jiuquan, China

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, FRB, etc.



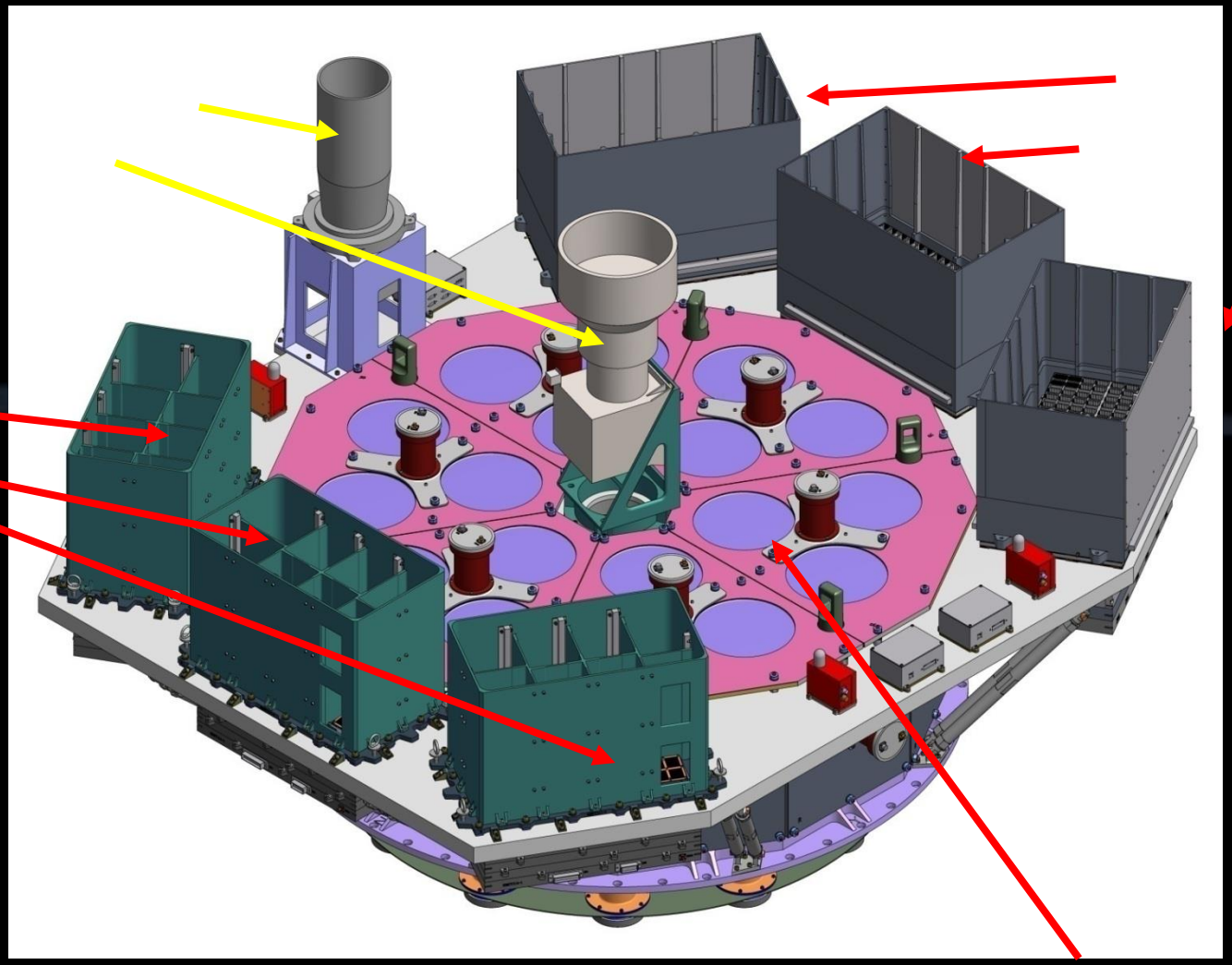




Science payloads

Star tracker

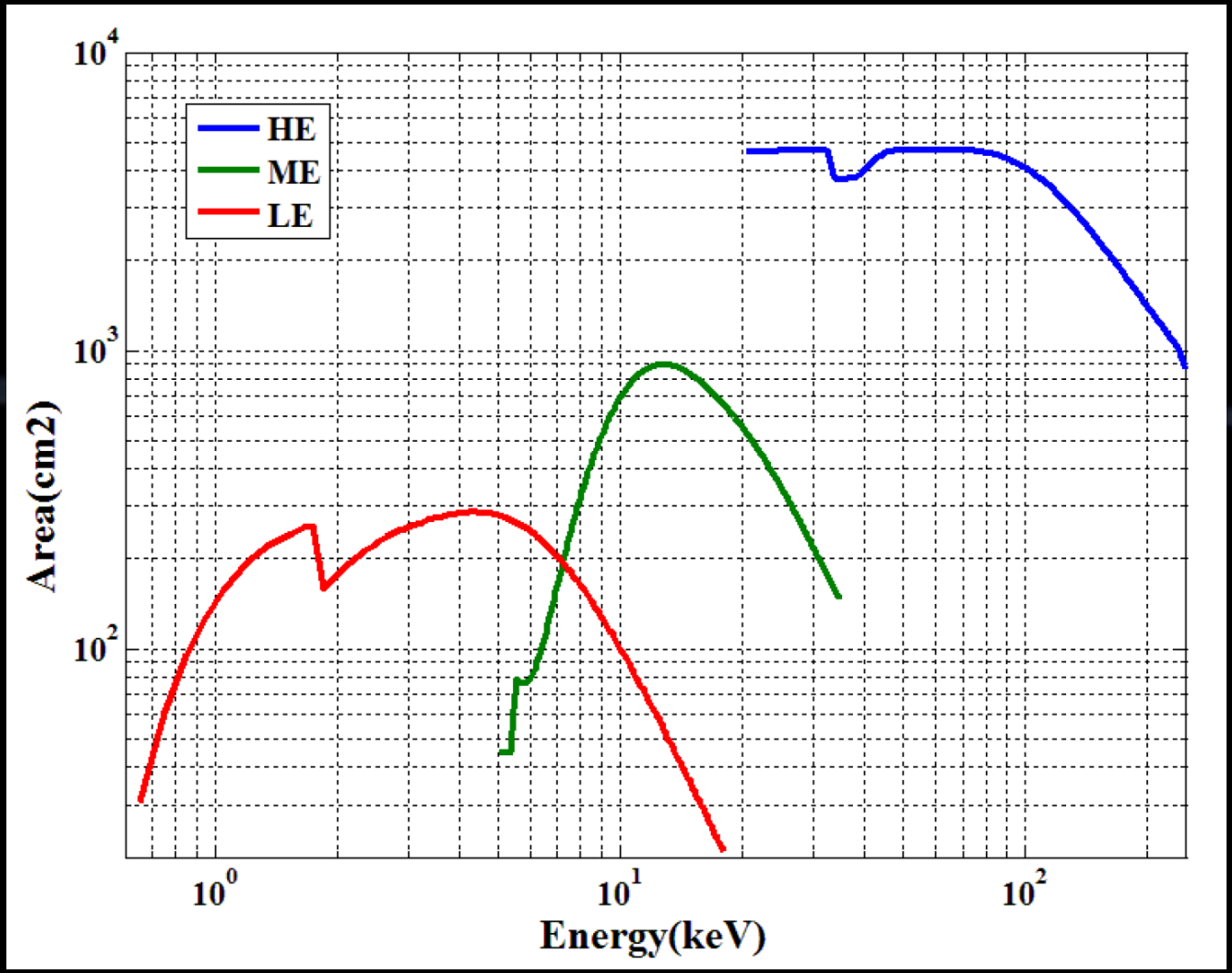
LE:SCD,1-15 keV, 384 cm^2



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

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

Effective area

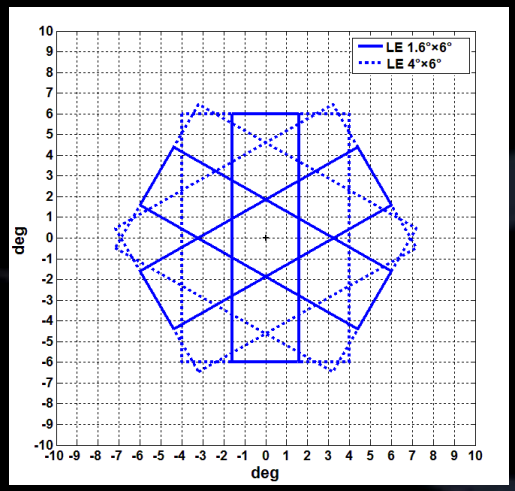


Comparison with other hard X-ray telescopes

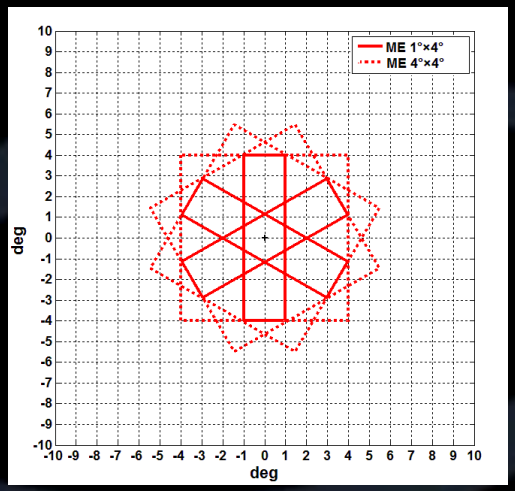
Insight-HXMT		RXTE	INTEGRAL/IBIS	SWIFT	NuSTAR
Energy Band (keV)	LE: 1-15 ME: 5-30 HE: 20-250	PCA: 2-60 HEXTE: 15-250	15-10000	XRT: 0.5-10 BAT: 10-150	3-79
Detection Area (cm^2)	LE: 384 ME: 950 HE: 5000	PCA: 6000 HEXTE: 1600	2600	XRT: 110 BAT: 5200	847 @ 9 keV 60 @ 78 keV
Energy Resolution (keV)	0.15@ 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

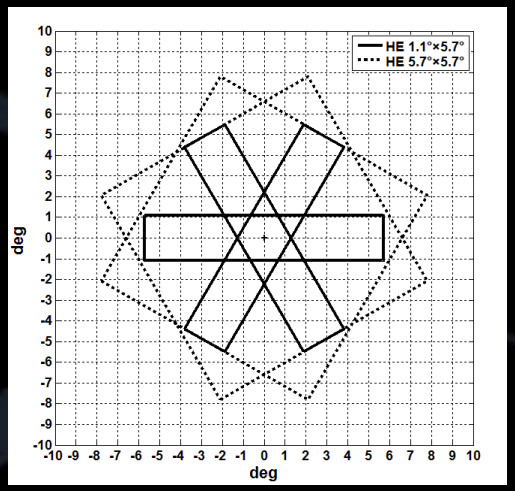
LE



ME



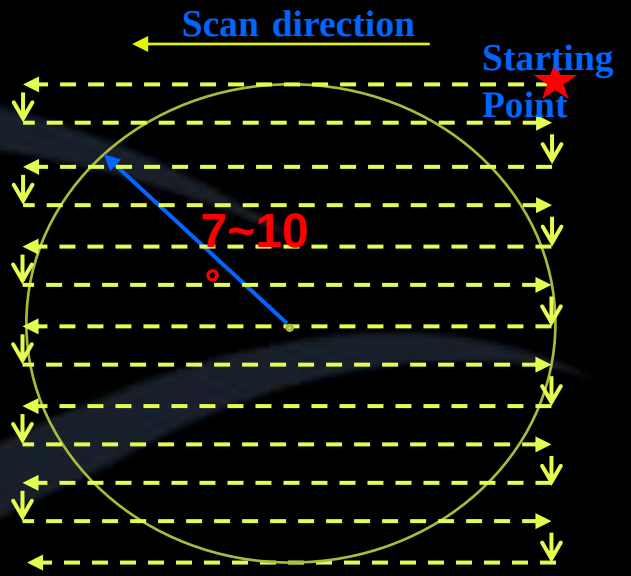
HE



	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 ˚

Observing Modes

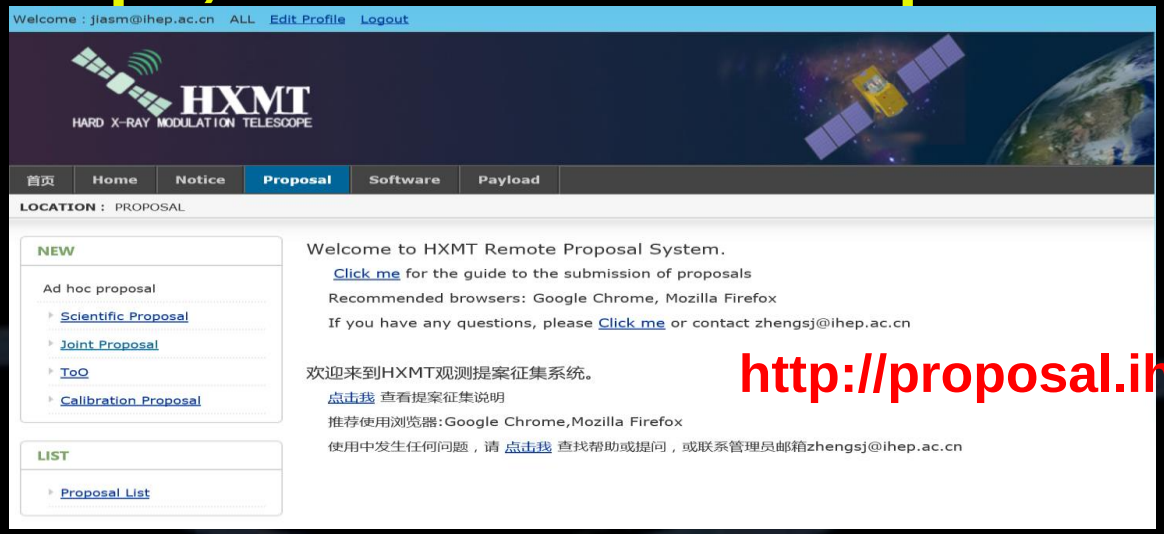
- **Pointing Observation:** Observing time: 96 mins~20 days
  - Spectrum
  - Variable properties
- **Small Area Scan:**
  - A square area of 14*14~20*20
    - Scan radius: 7~10 degree
    - Scan velocity: 0.01, 0.03, 0.06 deg/s
    - Scan step: 0.1~1 degree
    - Scan duration: 2 hours ~ 5 days
  - Galactic Plane Scan
  - Other interesting small areas



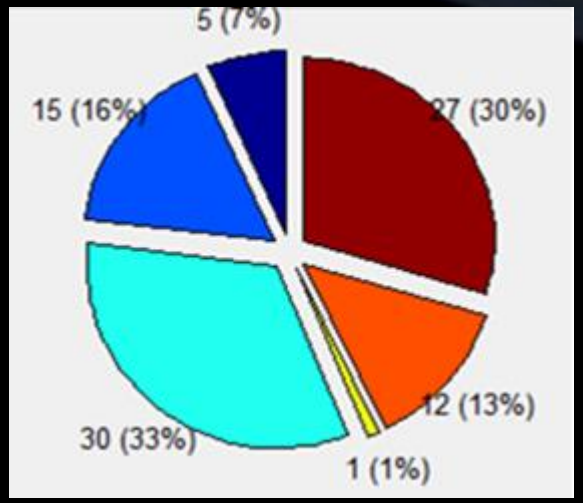
- **GRB Mode:** designed and implemented for HE
  - In this mode, the high voltage of the photo-multiplier tube (PMT) is reduced, so that the measured energy range of CsI goes up to 0.2-3 MeV.
  - **HE:** unique high-energy gamma-ray telescope to monitored the entire GW localization area and the optical counterpart, with the large collection area (~1000 cm^2) and microsecond time resolution.

Proposals of AO01

Aug.-Sept., 2016 : Call for Proposals (AO01)



http://proposal.ihep.ac.cn

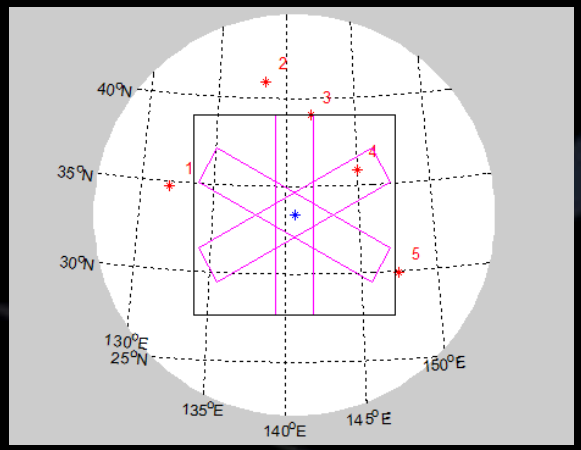


Total: 90 Proposals

- Galactic Plane Survey
- High Cadence Observation of BH and NS systems
- High Statistics Observation of BH and NS systems
- Synergy Observation with international telescopes
- Multi-wavelength Coordinated and Follow-up OBS
- Others

Proposals of AO 01

Oct., 2016 : Technical and Scientific evaluations



Technical Evaluation: HSOC

- Observation efficiency
- Effected by the sources around

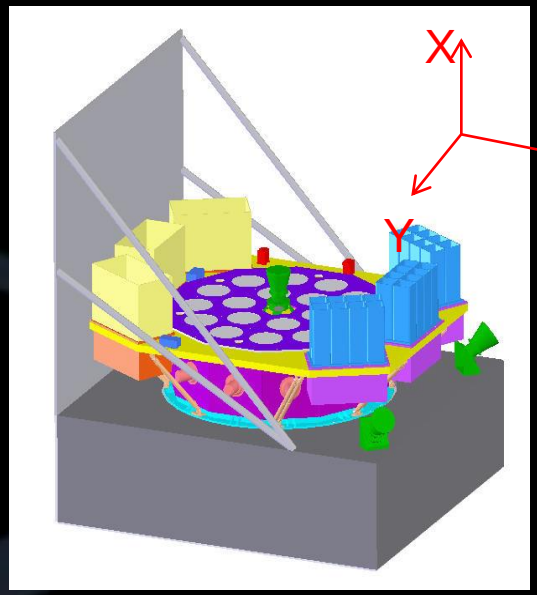
Scientific Evaluation: Science Committee

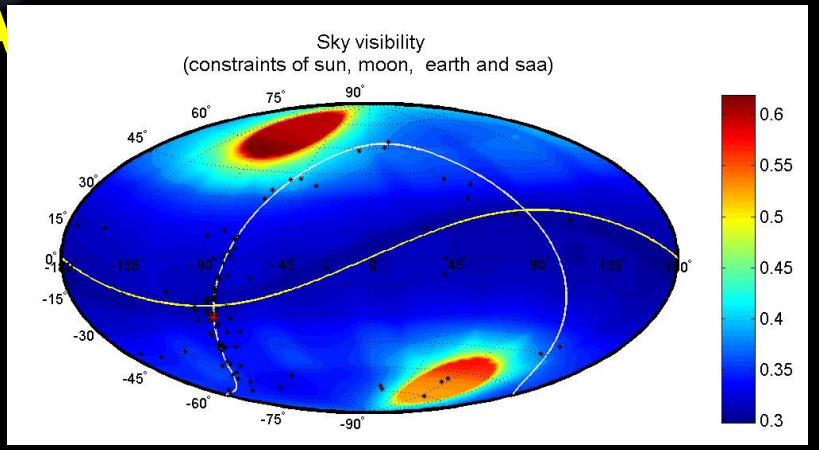
- Scientific goal suits HXMT

Grade		Mode	Number	times	Exposure time		
Normal	**A**	Point	42	290	5.8Ms	~136 days	**331 days**
		SAS	24	1271	16.1Ms	~195 days	
	B+C	Point	35	92	2.7Ms	~62 days	
ToO	**A**	Point	116		49Ms		1140 days
	B+C		65				
Total			282				

Observation Constrains

- **Thermal Control:**
  Limited FoV Orientation and Satellite Attitude
  - Solar avoidance angle > 70 °
  - X-Z plane < 10 °
- **Earth Occultation**
  - Almost every orbit
  - Last about 30 minutes
- **South Atlantic Anomaly (SAA**
  - 8~9 orbits per day
  - Last about 15 minutes
- **Moon avoidance angle:** > 6 °
- **Total efficiency:** ~ 50%





Target of Opportunity (ToO)

- **ToO alert**
  - * HXMT - Galactic Plan Scan
  - * Atel – Instant Email Notices
- **Check**
  - * Is HXMT contactable? (7-8 orbit/day)
  - * Information in Email
  - * Is it approved before?
- **Evaluation**
  - * Observation constrains
- **Project Scientist decision**
- **Urgent re-scheduling**
  - * Reschedule a ToO plan in 90 mins
- **Start observation**

ToO workflow

in 60 mins

> 4 hours

GW170817

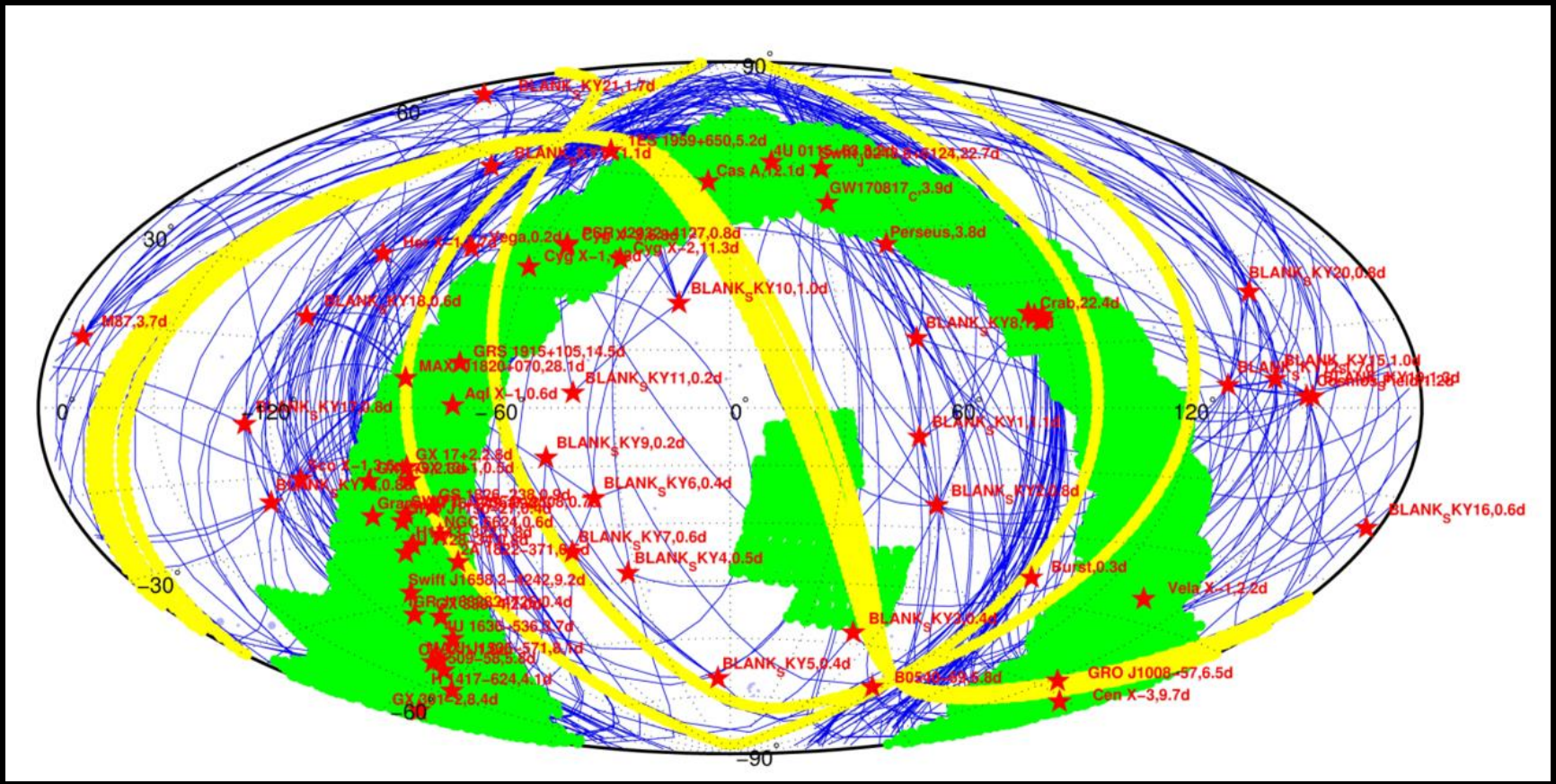
BJ 21:32
Project Scientist Uncertainty &Constrains observation scheme **00:00**
Too Plan **01:15**
02:23

Performed observations

Insight-HXMT Observations（till 2018.5.31）

	Mode	Type	Source Name	Obs. Frequency	Obs. Time（ks）
1	Point	SNR	Cas A	9	530
2		Pulsar	Crab	86	1530
3			PSR B0540-69	7	250
4			PSR B1509-58	12	310
5		BH Binary	Cyg X-1	12	270
6			Granat 1716-249	2	250
7			GRS 1915+105	24	720
8			GX 339-4	1	100
9			H 1743-322	15	180
10			MAXI J1535-571	18	430
11			MAXI J1543-564	1	80
12			MAXI J1820+070	61	1360
13			Swift J1658.2-4242	23	470
14		NS Binary	Aql X-1	3	30
15			Cen X-3	14	400
16			Cir X-1	6	100
17			Cyg X-2	22	540
18			Cyg X-3	15	390
19			GRO J1008-57	11	340
20			GRO1750-27	1	15
21			GS 1826-238	1	40
22			GX 301-2	15	400

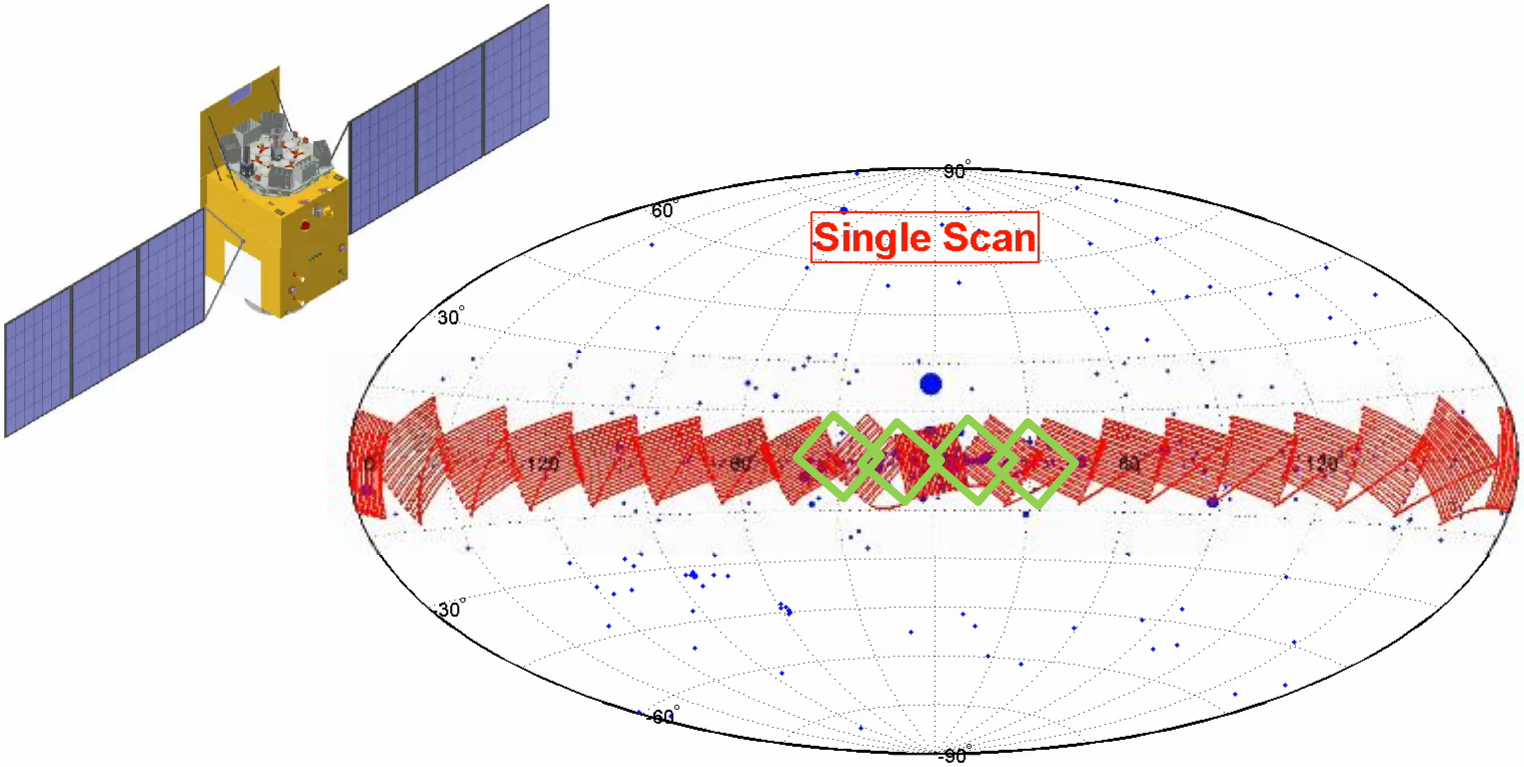
	Mode	Type	Source Name	Obs. Frequency	Obs. Time（ks）
23	Point	NS Binary	GX9+9	4	80
24			GX 13+1	1	30
25			GX 17+2	9	210
26			Her X-1	12	380
27			Sco X-1	6	180
28			Vela X-1	1	120
29			2A 1822-371	1	30
30			4U 1728-34	4	90
31			4U 0115+63	11	150
32			4U1636-536	19	200
33			PSR J2032+4127	4	40
34			NGC 6624	1	30
35			H 1417-624	21	210
36			IGR J16328-4726	2	20
37			Swift J1756.9-2508	1	40
38		TBD	Swift J0243.6+6124	97	1200
39		Extra-galactic	1ES 1959+650	25	255
40			Perseus	2	200
41			M87	4	180
42			Cosmos Field	4	80
43		BlankSky	21	84	840
44	Small Area Scan (SAS)	Crab Area		9	550
45		Galactic Plane	22 regions	324	3600



Red stars: point observation
Green regions: small area scan

Preliminary results

Galactic Plane Scan

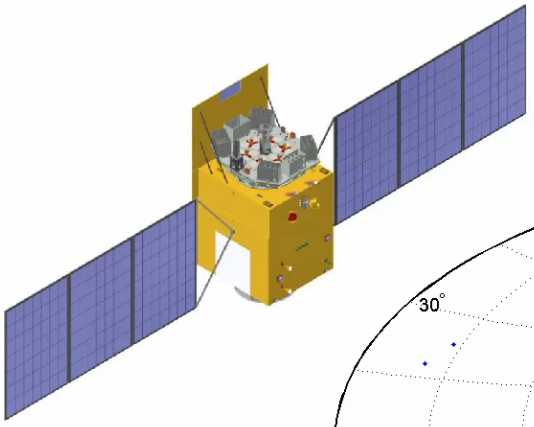


Galactic Plane: (20°*20°)*18 + (20°*20°)*4

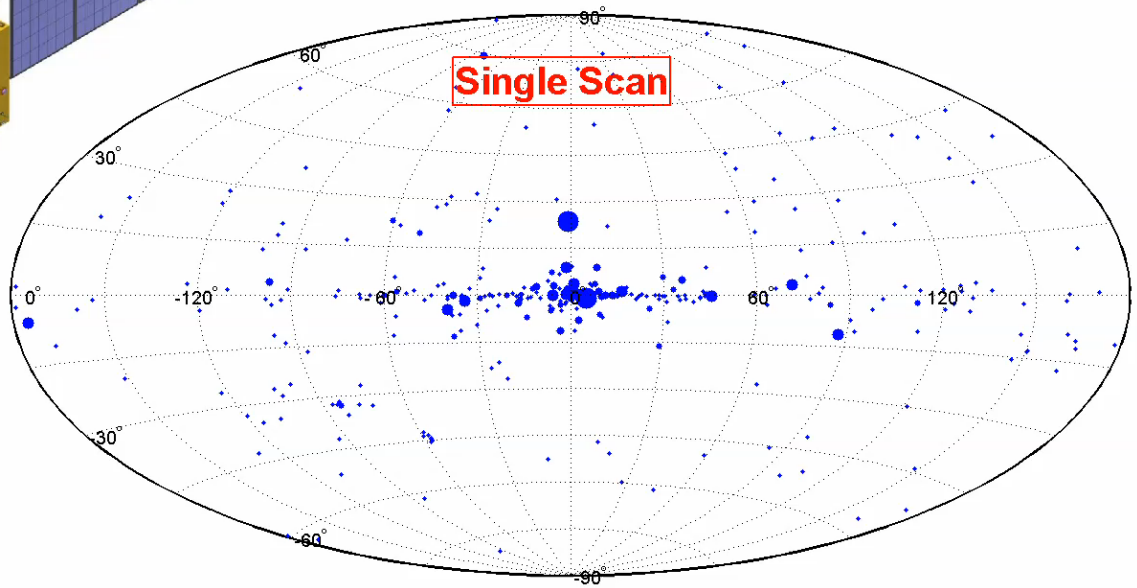
- 11 center regions: 90 times/year (-60°~60°)
- 11 outer regions: 10 times/year

Insight-HXMT scanning survey of the MW

✓Repeatedly scan the Milky Way plane

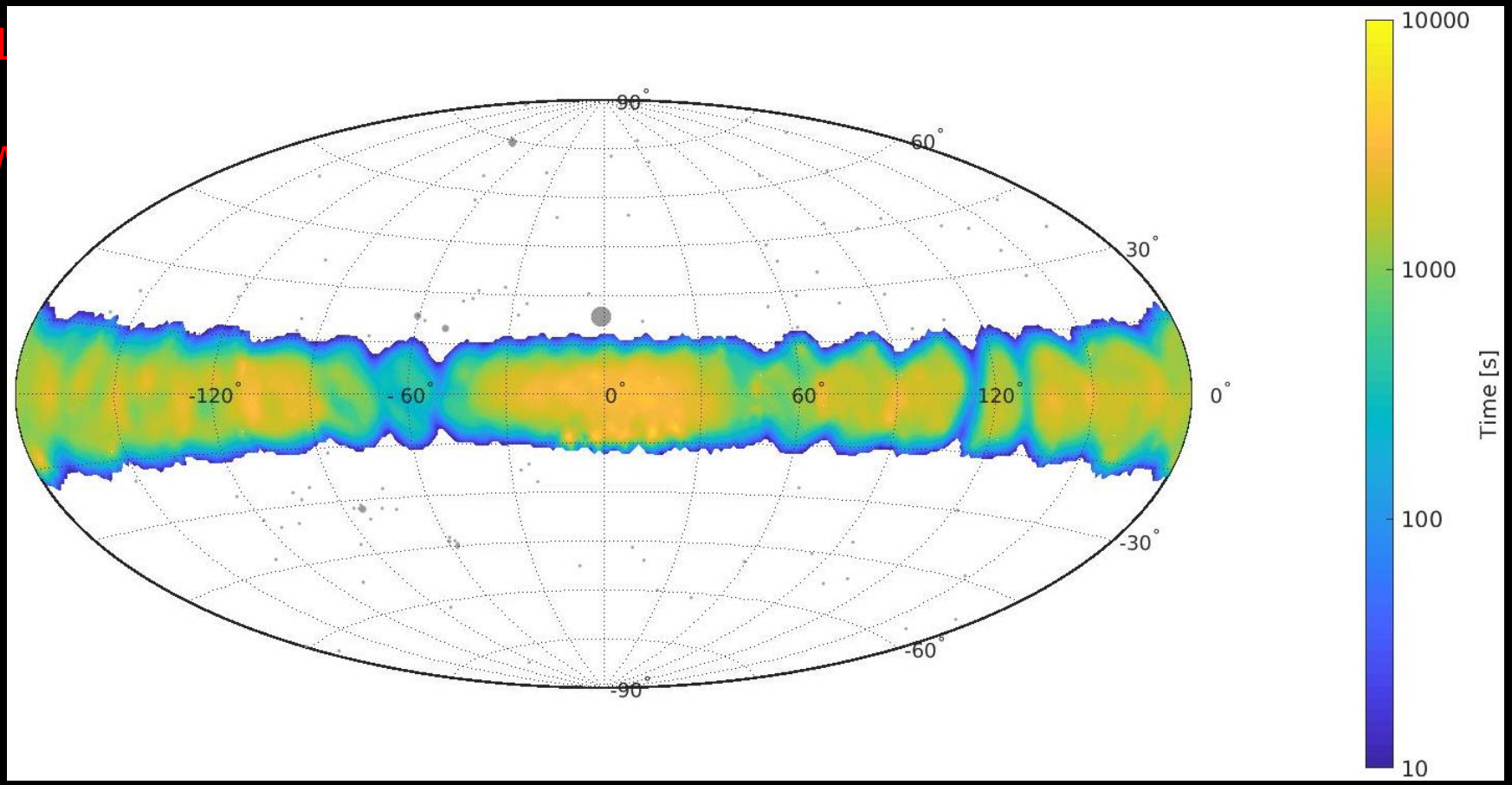


Single scan sensitivity: 3-10 mCrab
(spectral shape dependent)



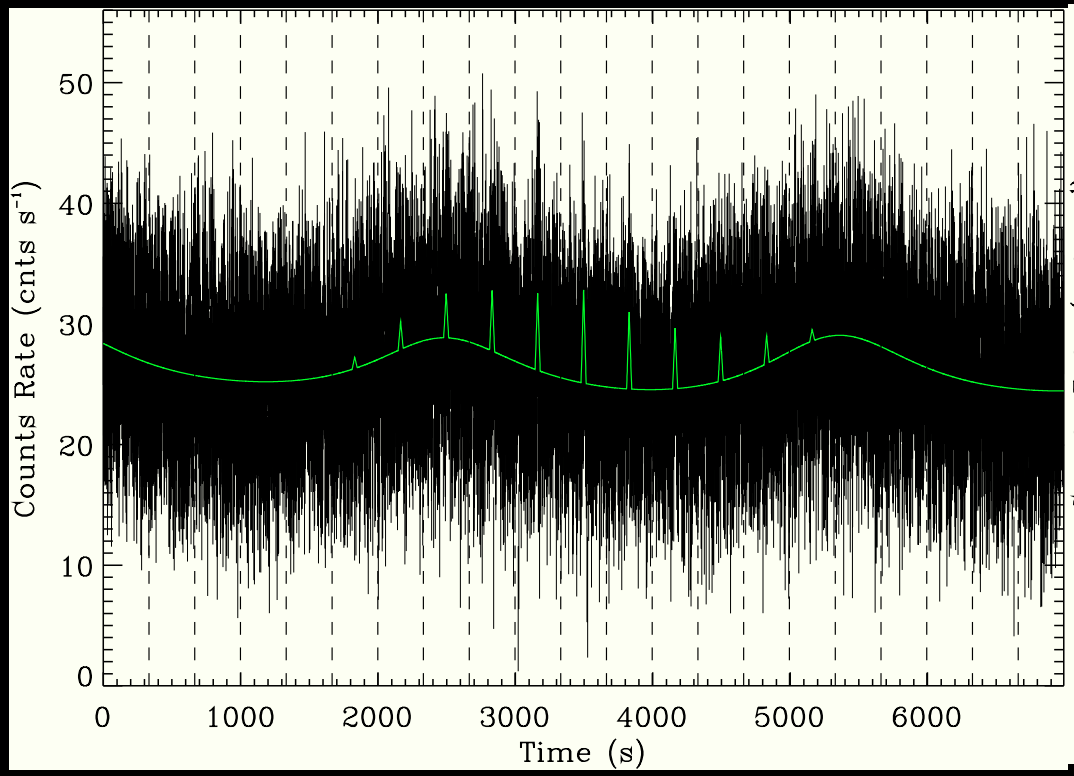
Galactic plane scanning survey

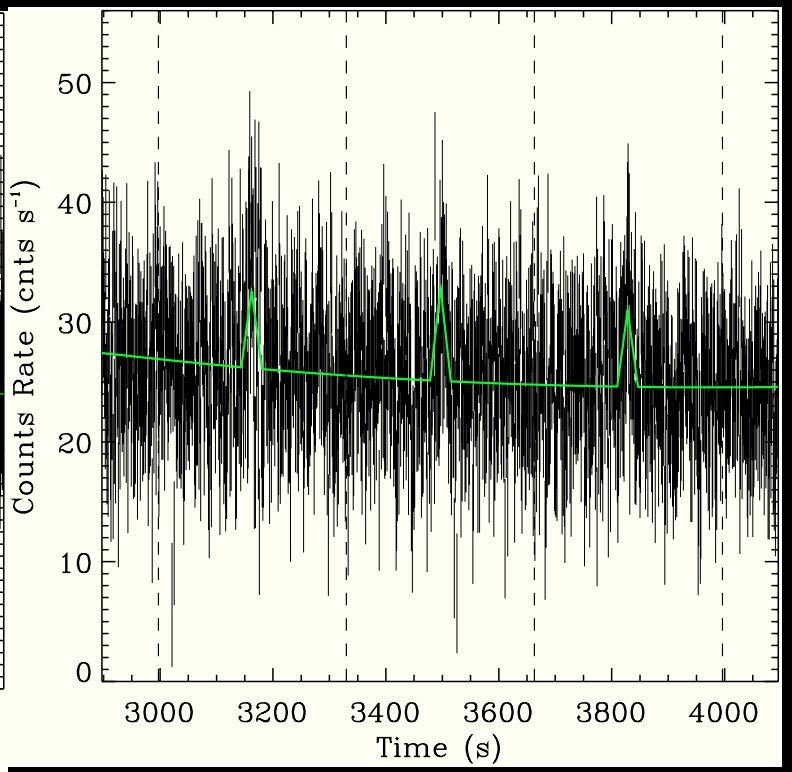
- ✓Exposure map up to 2018 March. 31



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

Point Spread Function fitting: simulation

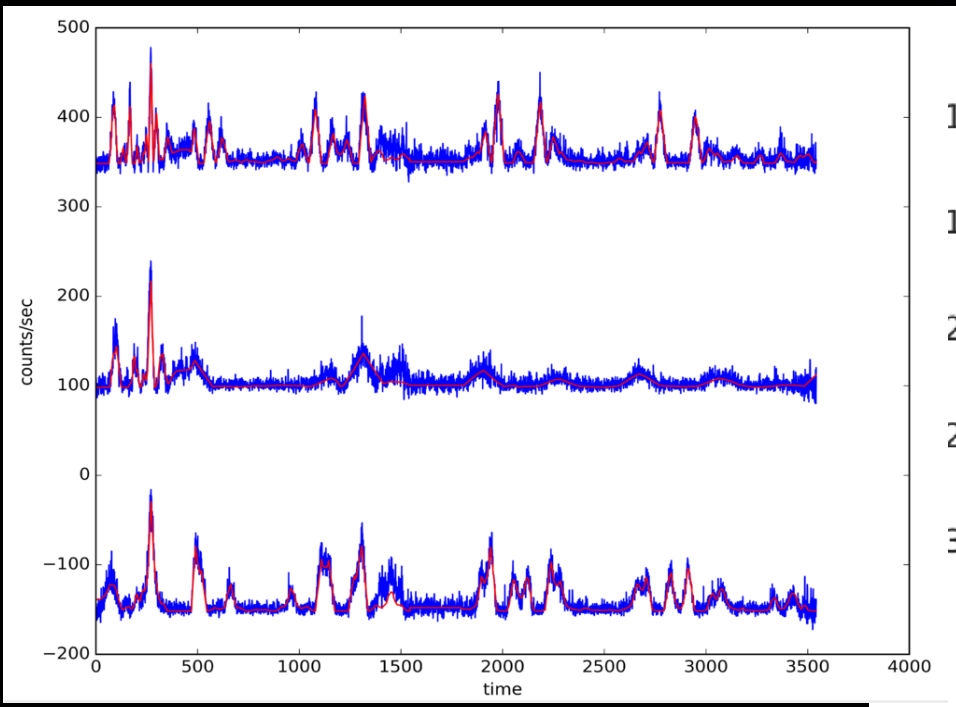


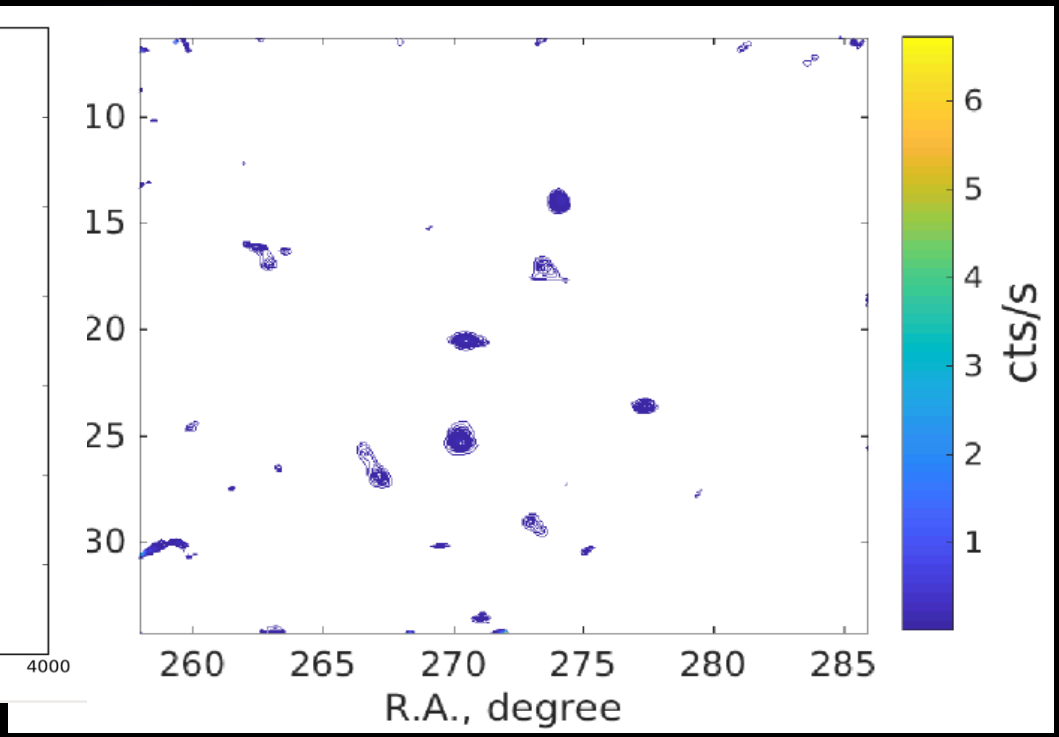


- ✓A group of peaks due to one source
- ✓Combine all FOVs to determine its position and flux

Observed light curve

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



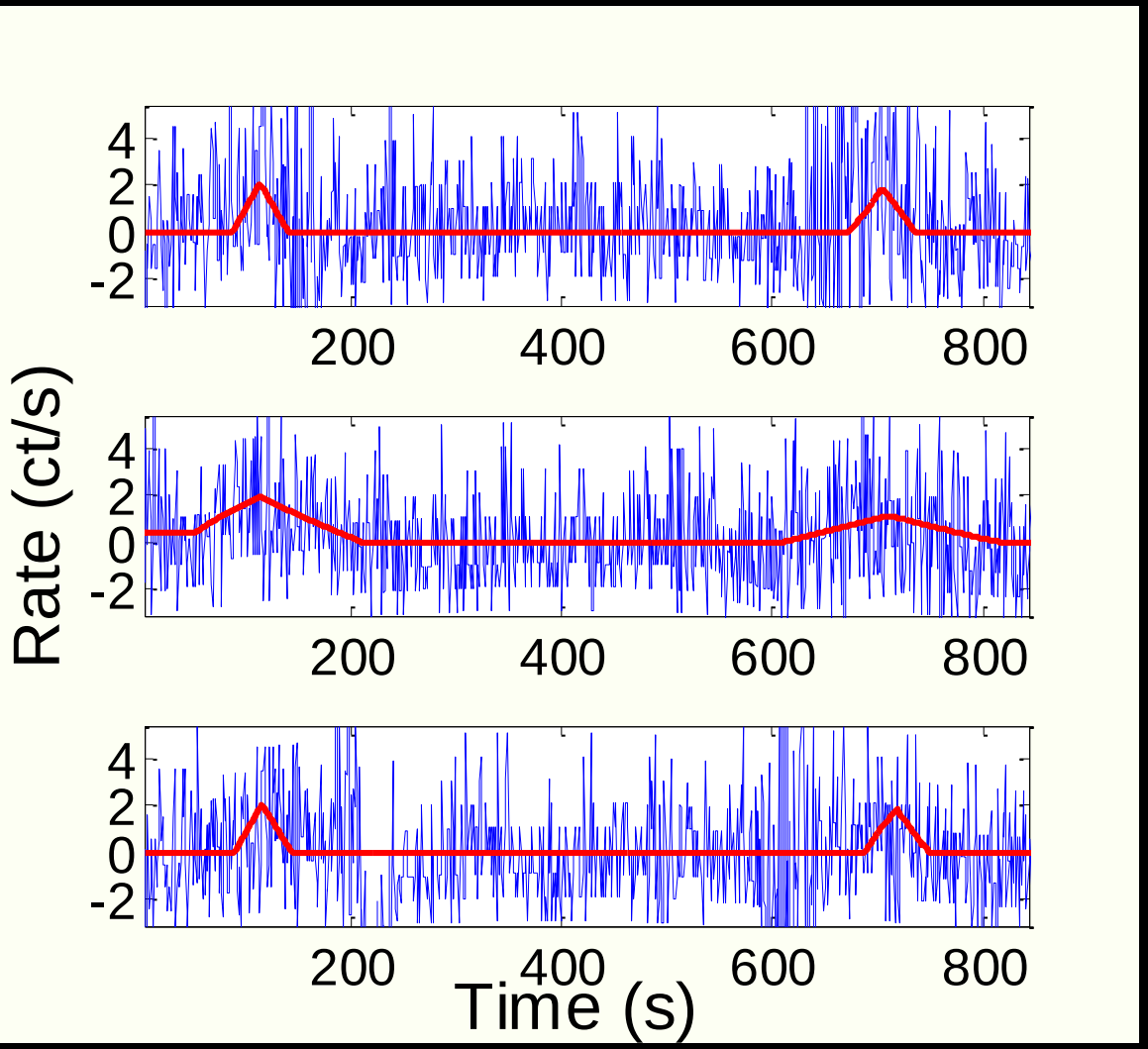


Direct Demodulation Method
(Li & Wu 1993)

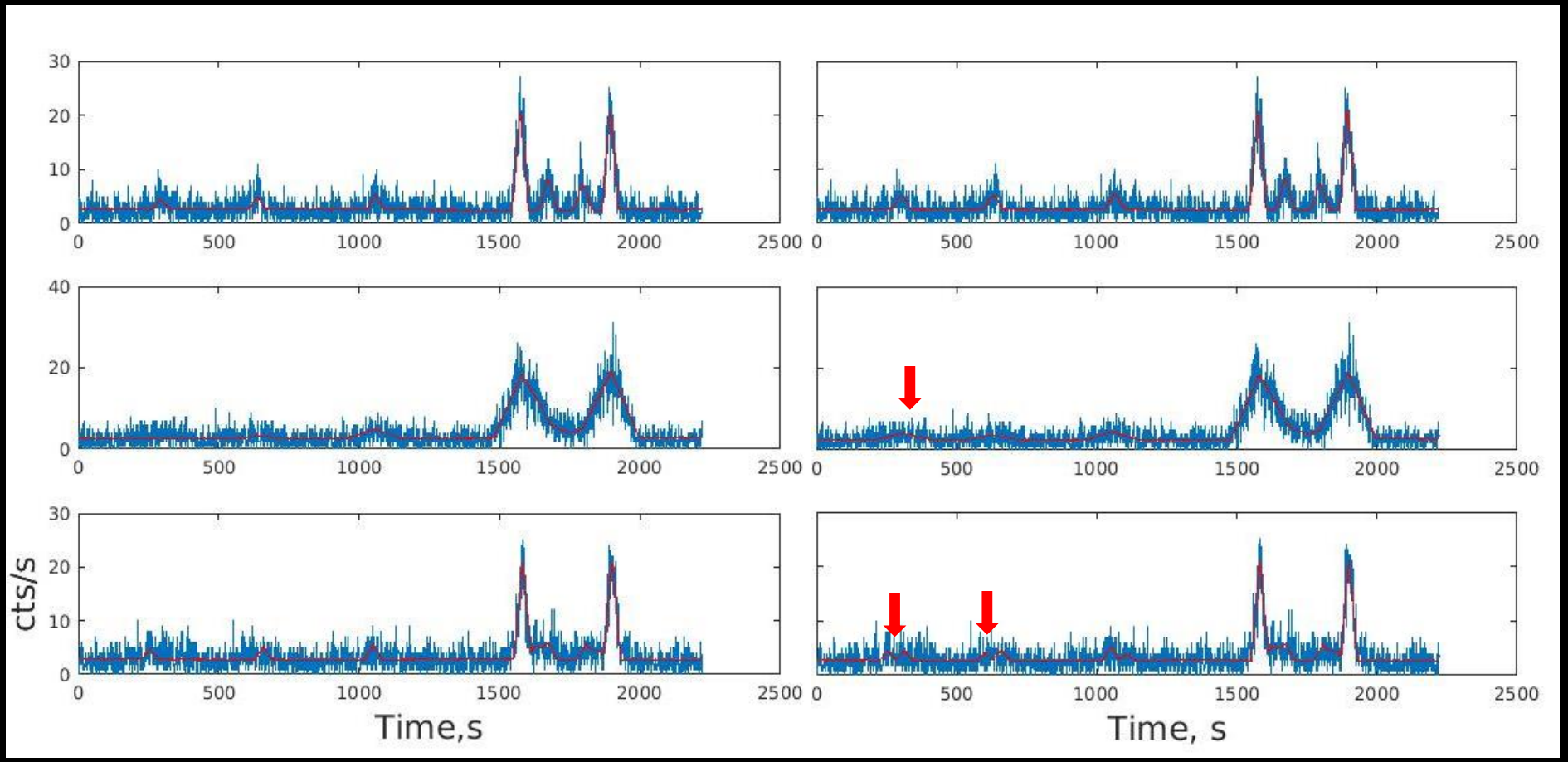
G21.5–0.9 (PWN)

- ✓Not in MAXI catalog
- ✓Detected by Insight at 8σ

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



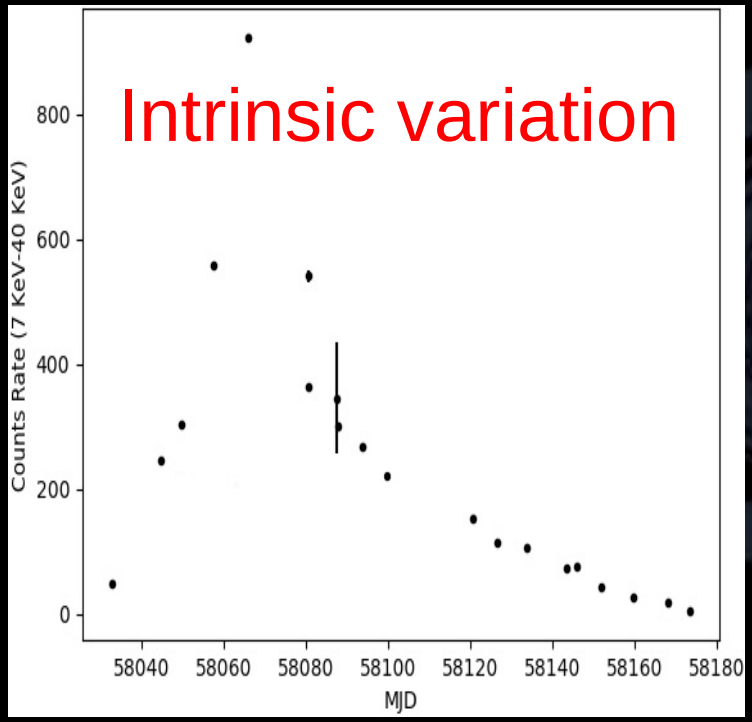
Possible new source detected in Galactic survey

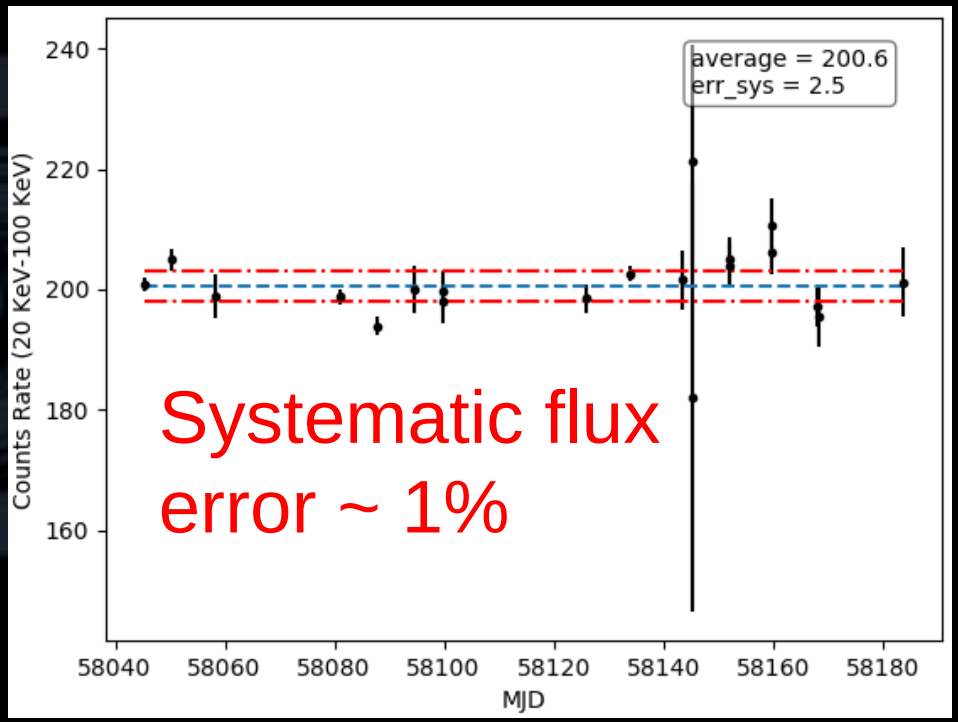


New source candidate：flux～7mCrab，～7.1σ

Long-term light curve monitoring

Monitor long-term variations of ~200 sources





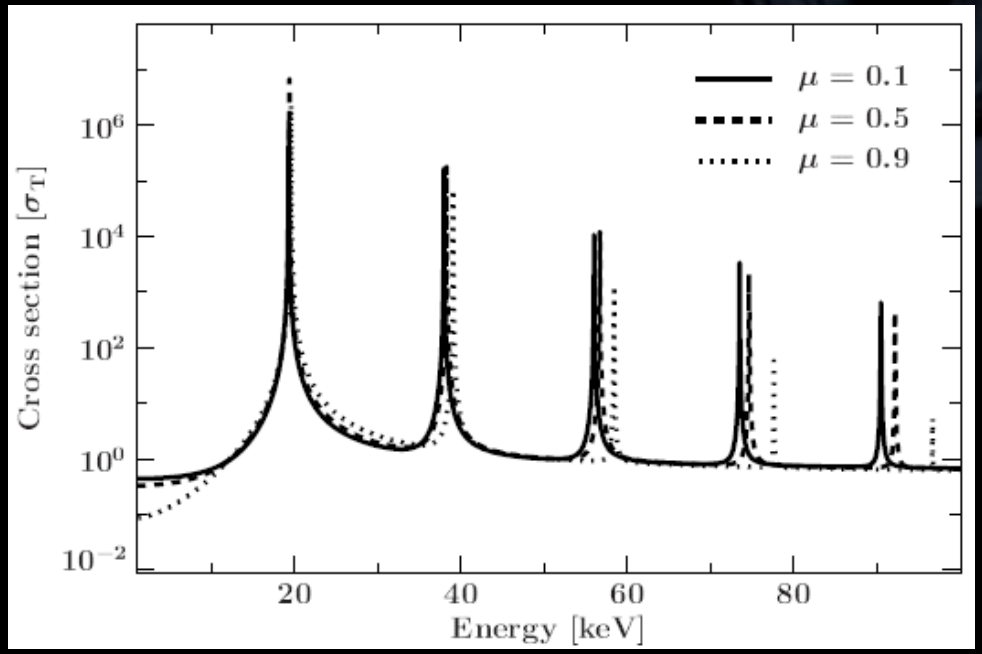
ME (7-40 keV)
Swift J0243.6+6124
Accreting pulsar

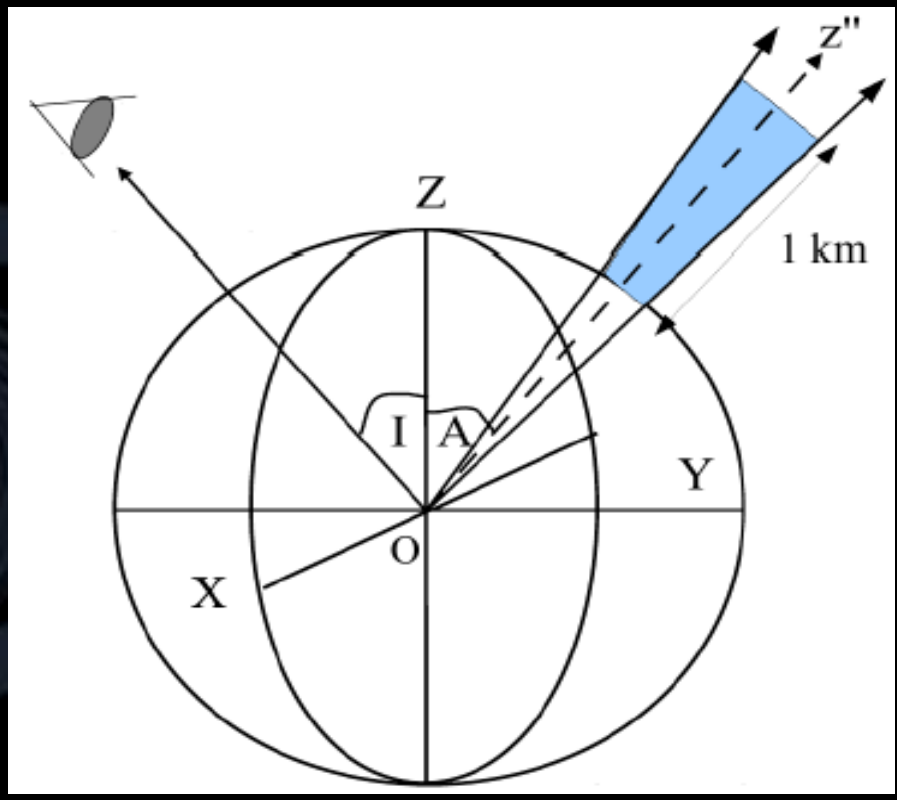
HE (20-100 keV)
Crab
Isolated pulsar

Neutron star cyclotron absorption line

- ✓Magnetic field
- ✓Accretion column

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

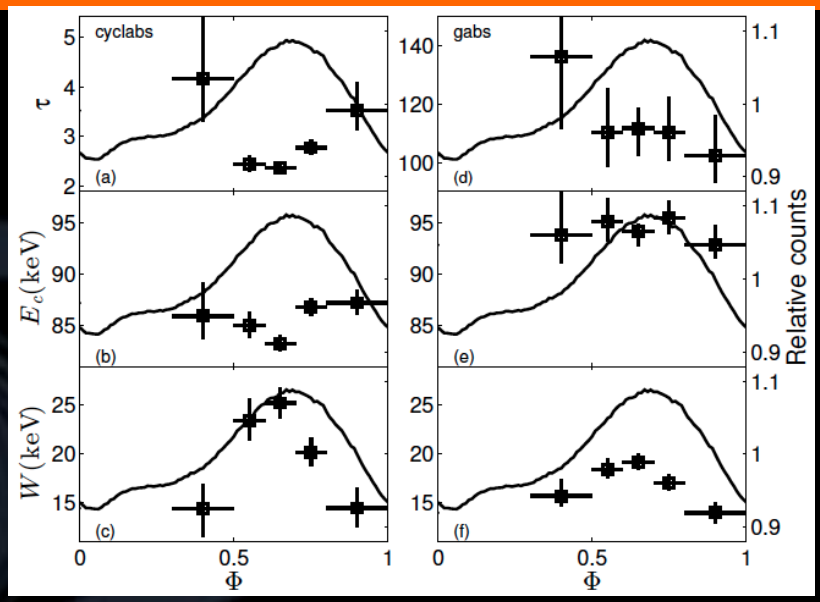


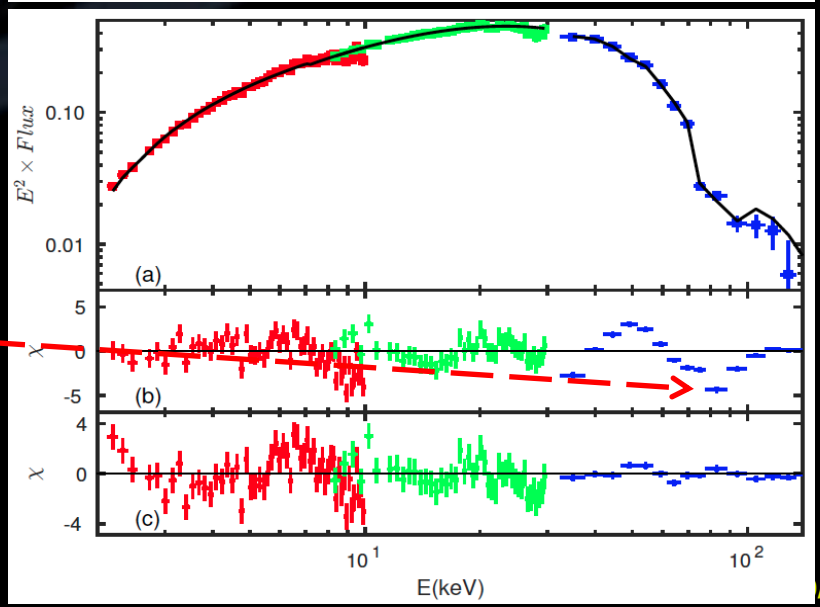


Maitra 2016

Neutron star cyclotron absorption line

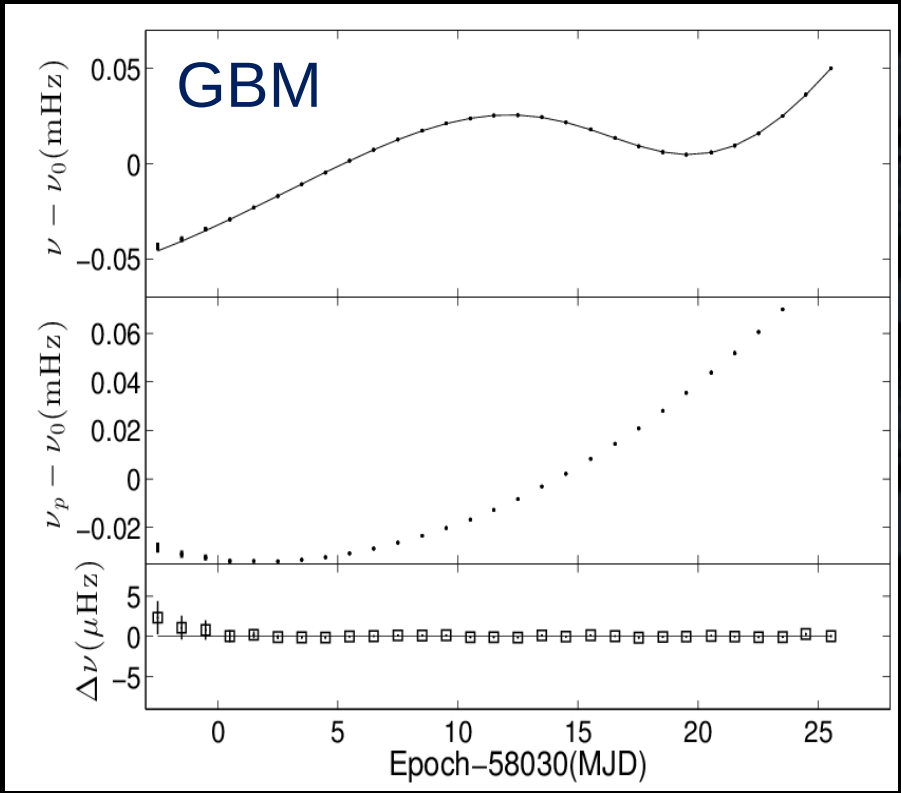
- GRO J1008-57： ~80 keV → highest *B* directly measured in the universe ~10^{13}, tentatively observed at ~ 4σ with NuSTAR & Suzaku
- 4 HXMT observations ~235 ks ~ 20σ detection

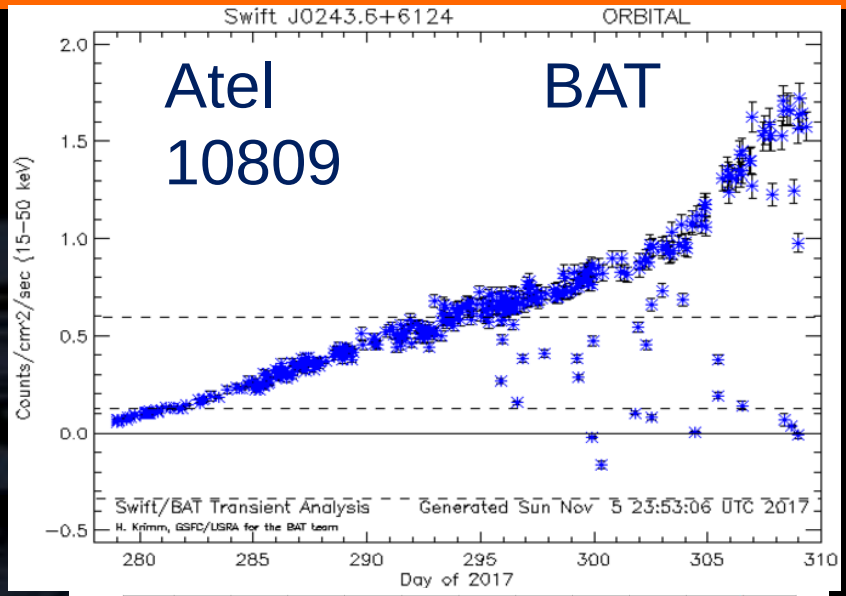


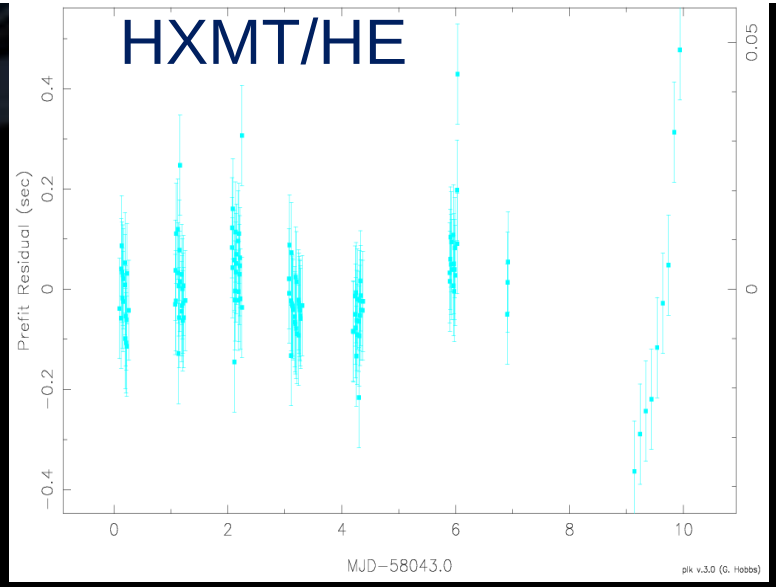


HXMT/HE one module,
17 modules ~ 20 σ

Accreting Pulsar: Swift J0243.6+6124

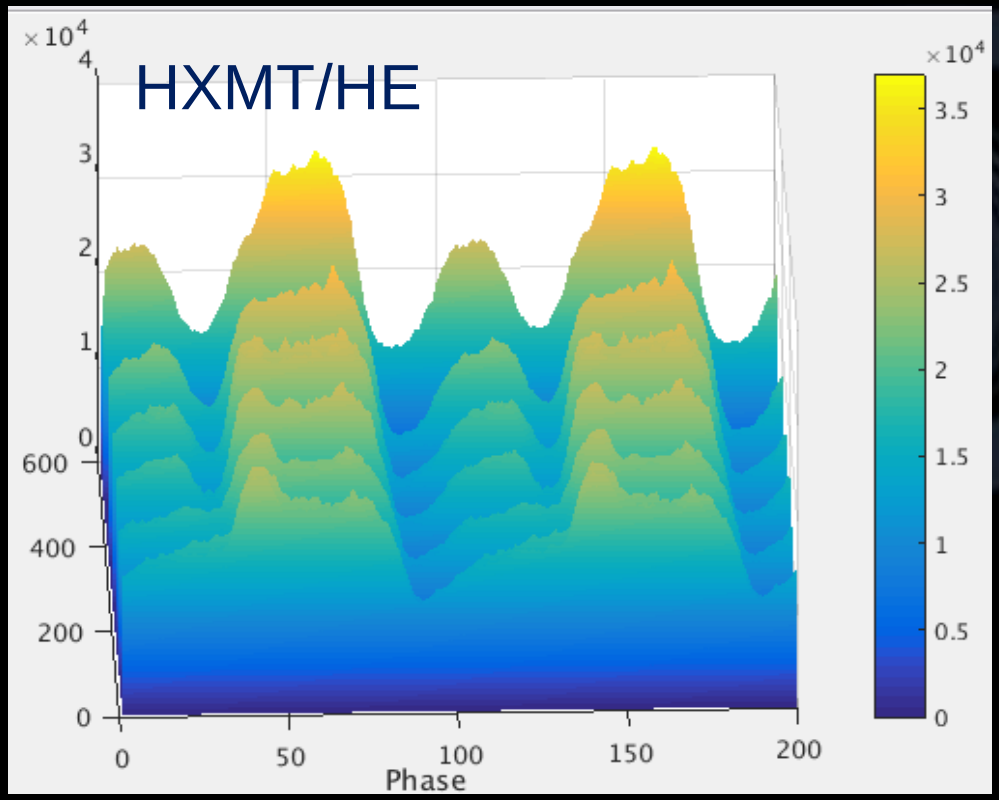




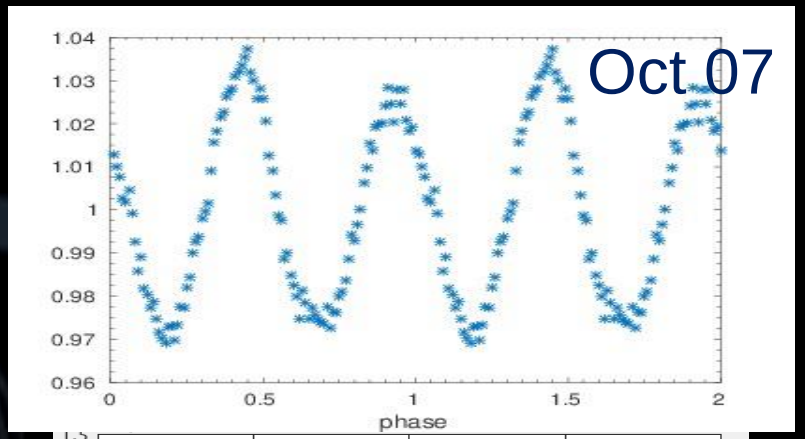


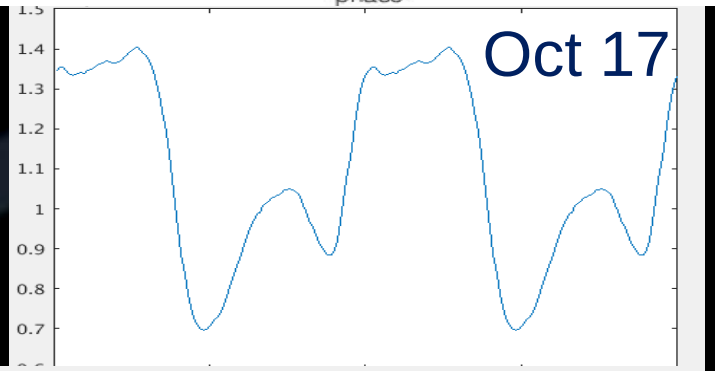
P= 9.86s,
Porb=~26d?

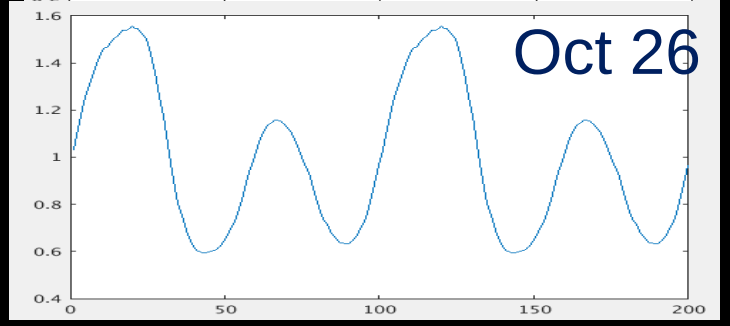
Accreting Pulsar: Swift J0243.6+6124



Oct 17-- Oct 23







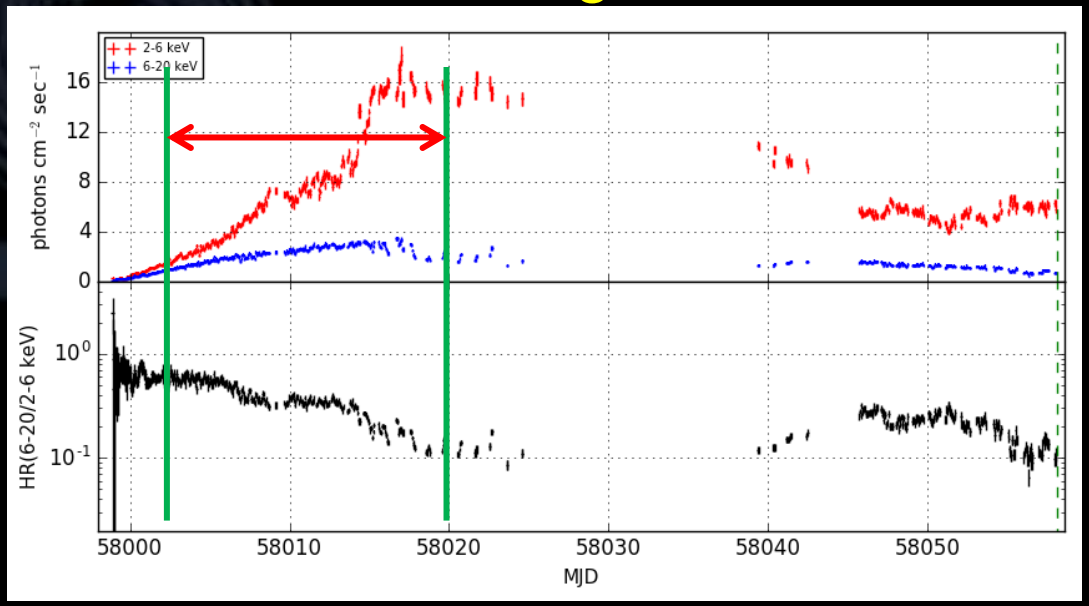
Black Hole Candidate MAXI J1535-571

- 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

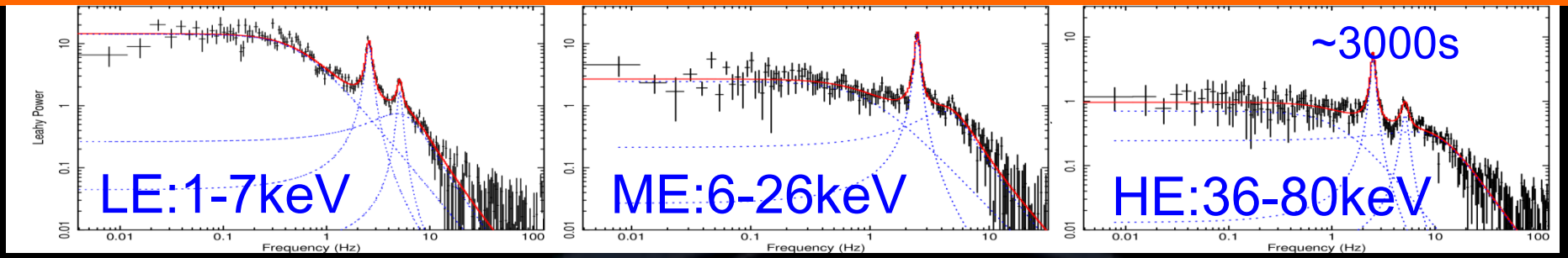
	Start Time	Exposure (ks)
1	2017/09/06 07:37:21	100
2	2017/09/14 04:56:05	8
3	2017/09/15 04:48:01	8
4	2017/09/16 06:15:31	8
5	2017/09/17 06:07:39	8
6	2017/09/18 02:48:56	8
7	2017/09/19 23:22:47	8
8	2017/09/21 02:26:27	150

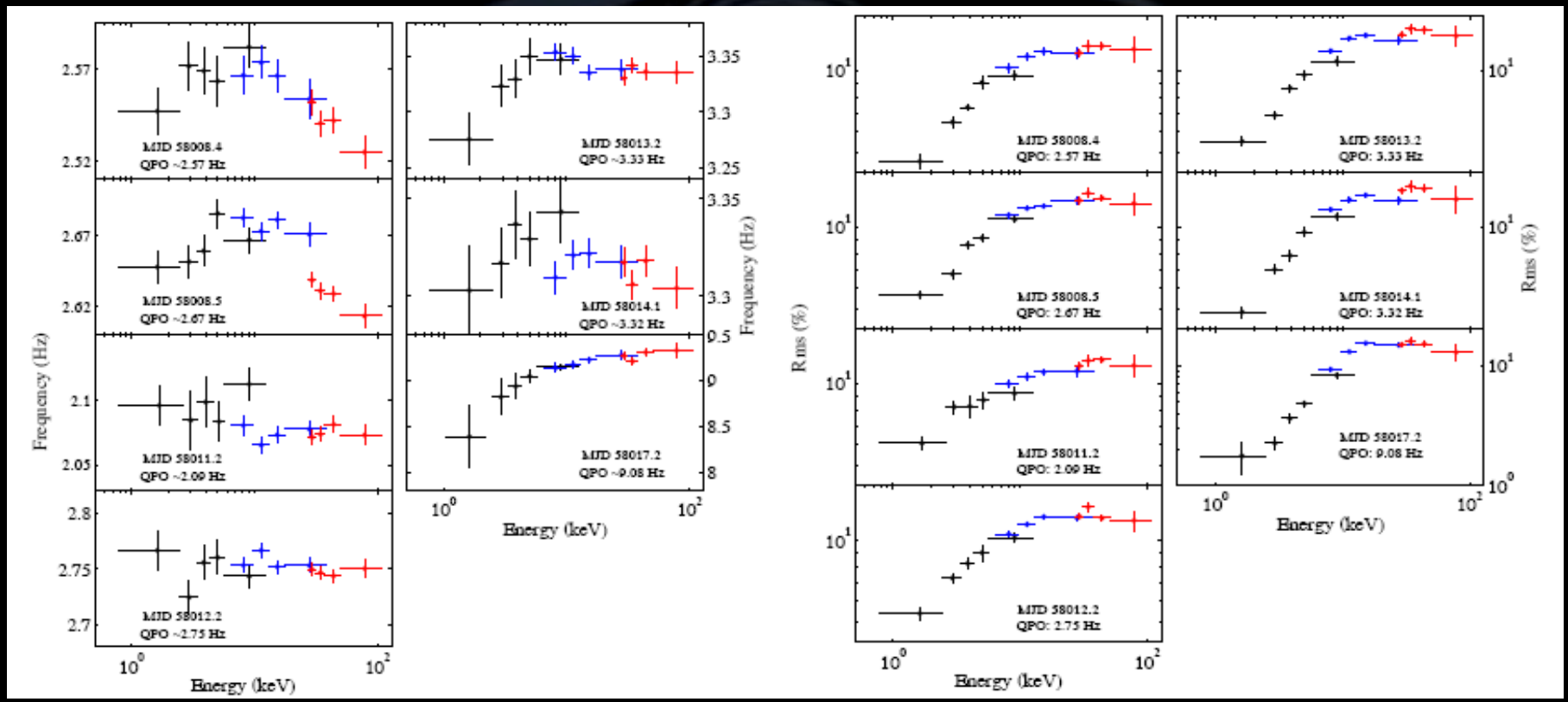
MAXI light curve



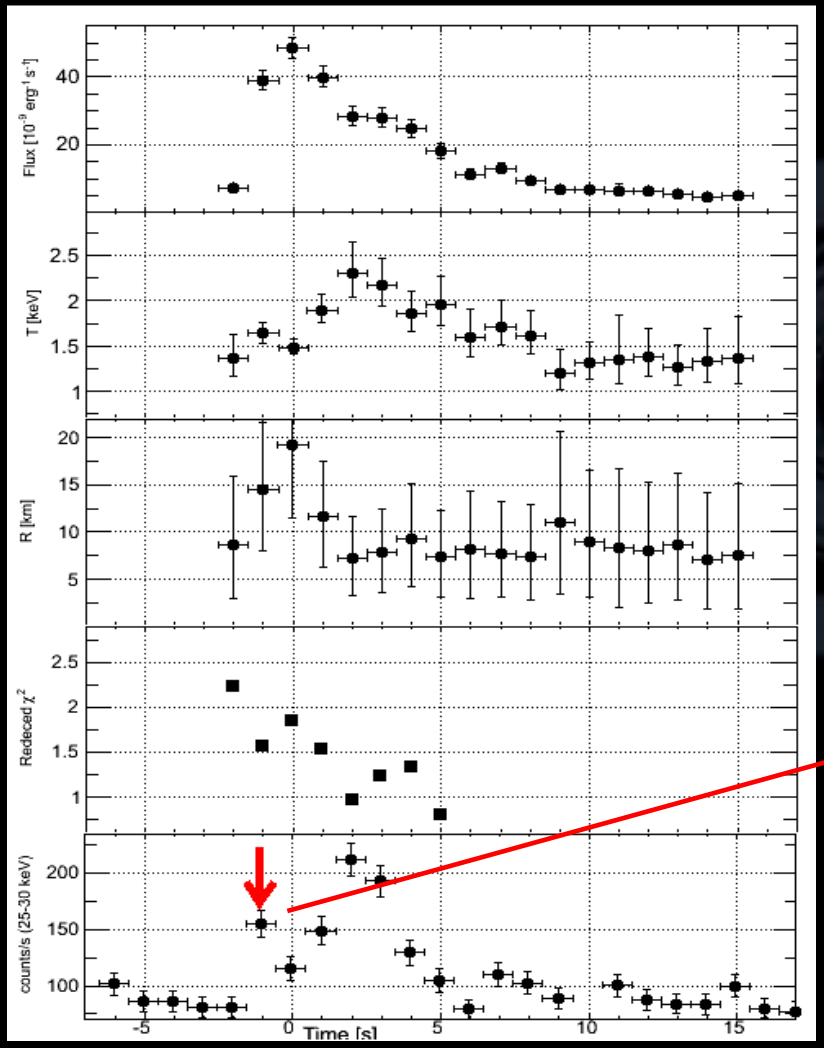
http://134.160.243.88/nakahira/1535monitor

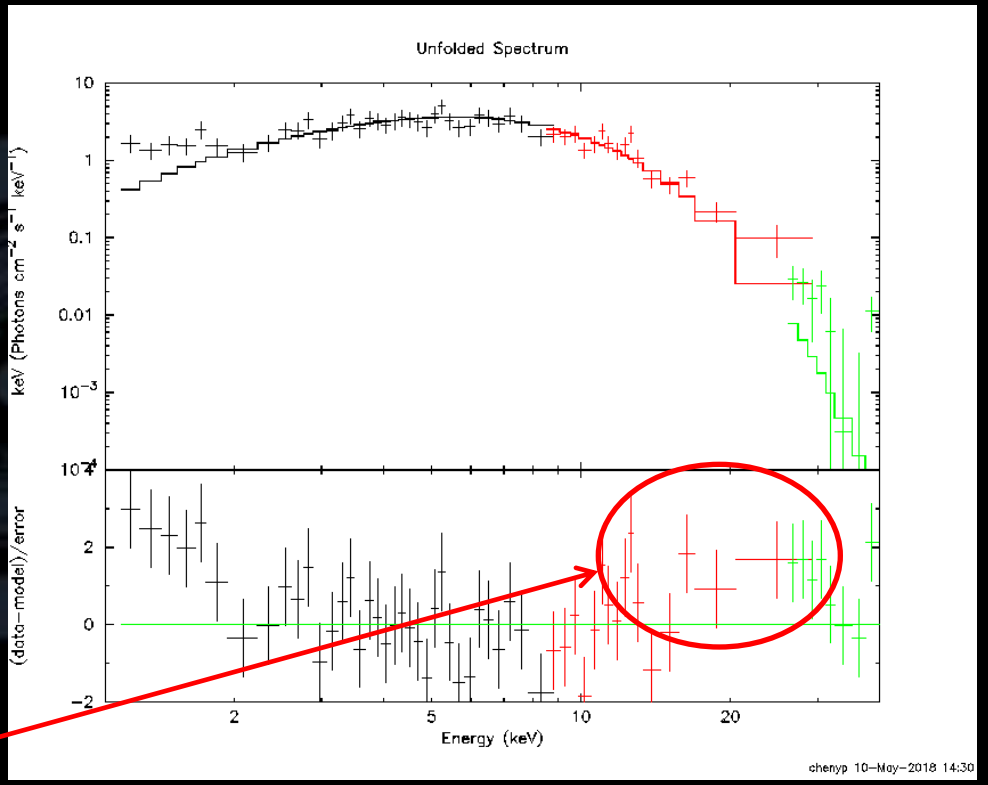
Insight-HXMT QPO observations





Hard X-ray burst hinted in the PRE burst

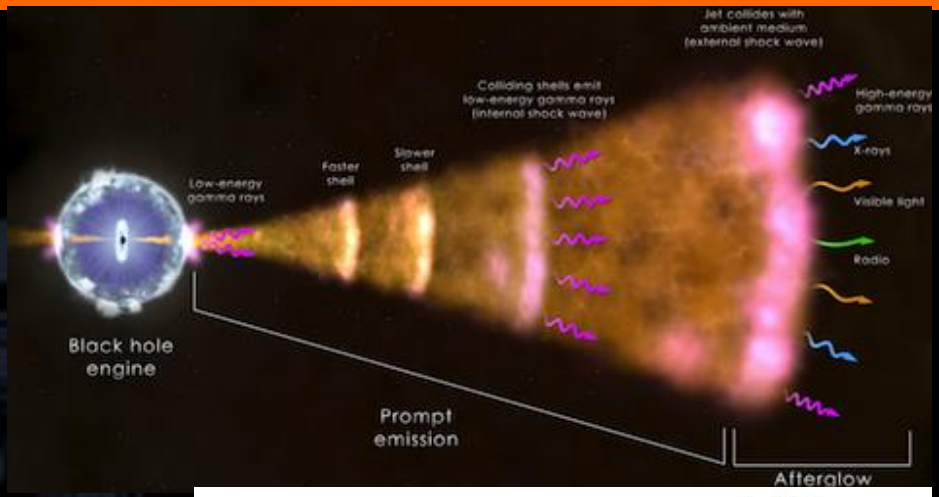


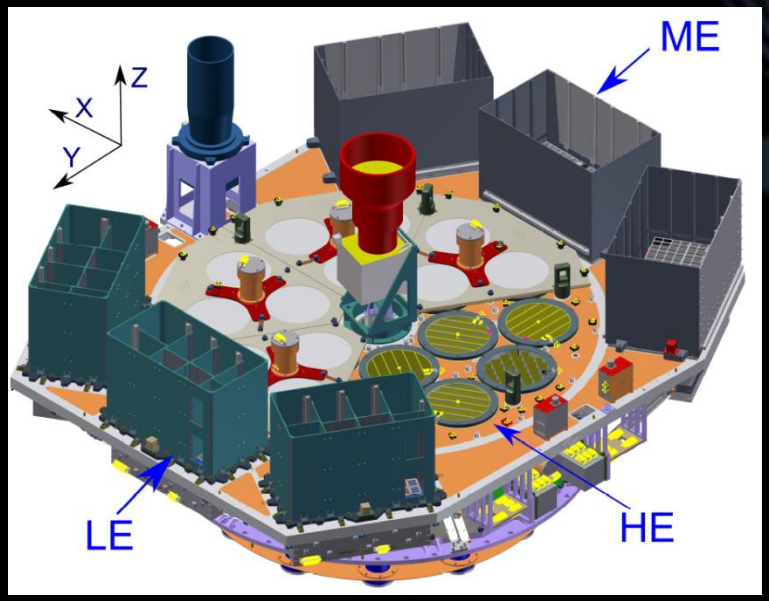


Insight-HXMT found for the first time from 4U1636-526 that, during PRE rising phase, additional hard X-ray burst is hinted (~5 sigma)

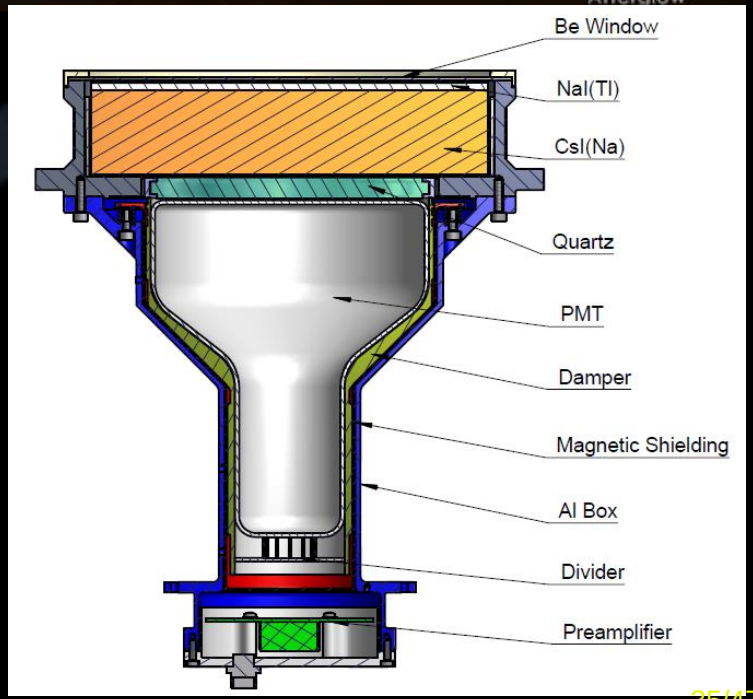
How to observe GRB (GW EM)?

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



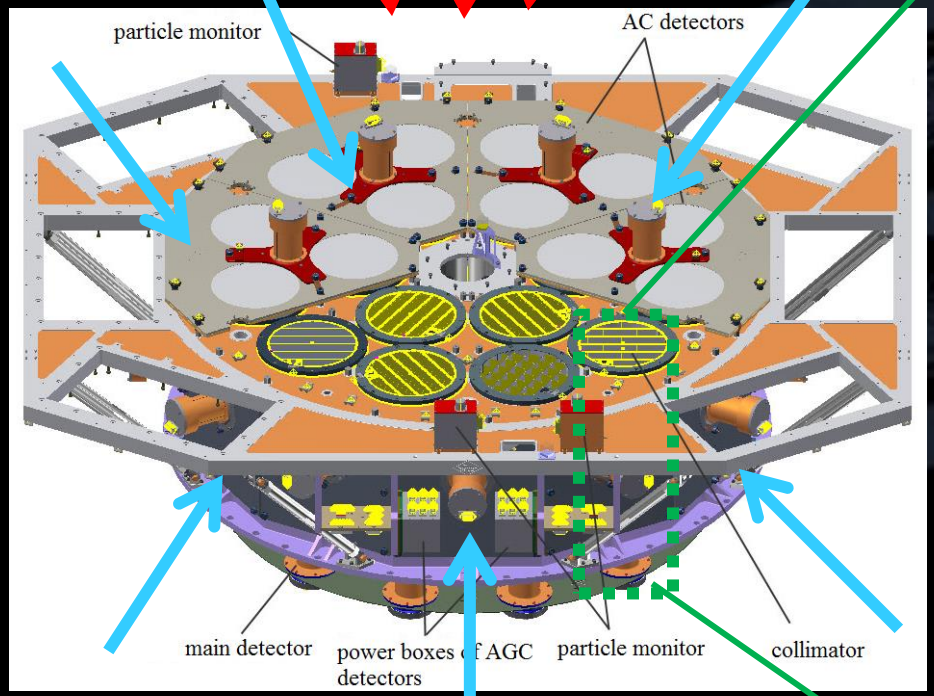


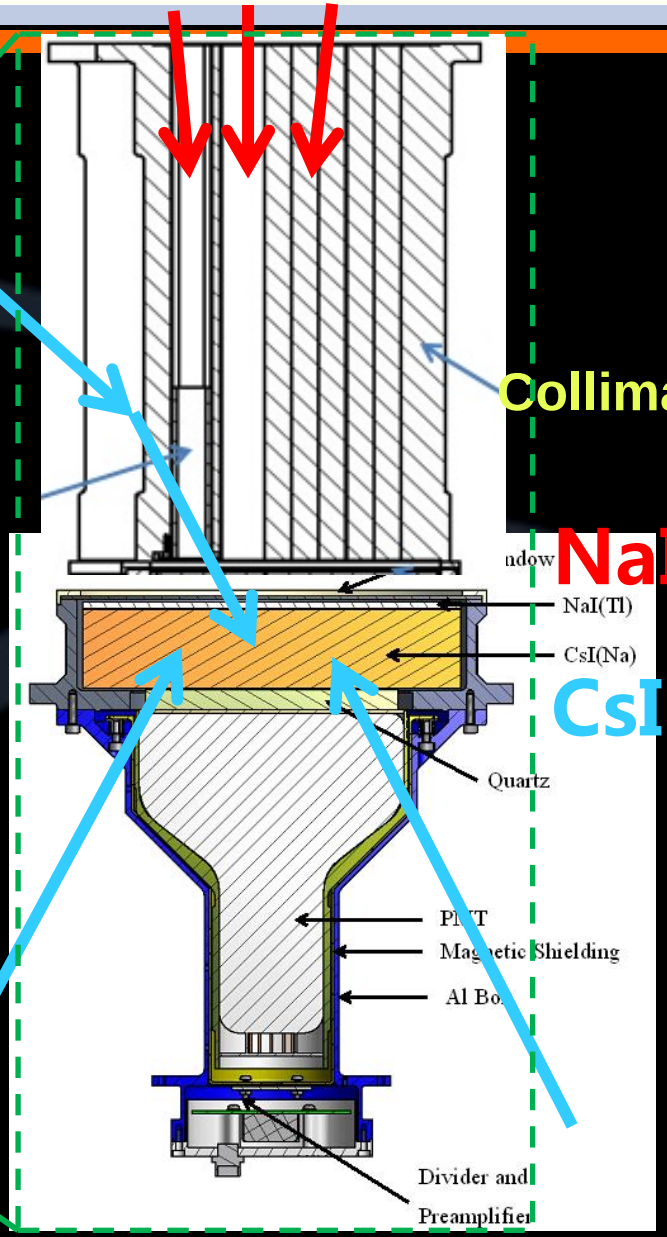
HE
NaI/CsI



Regular observation vs. GRB observation

X/gamma photons within FOV

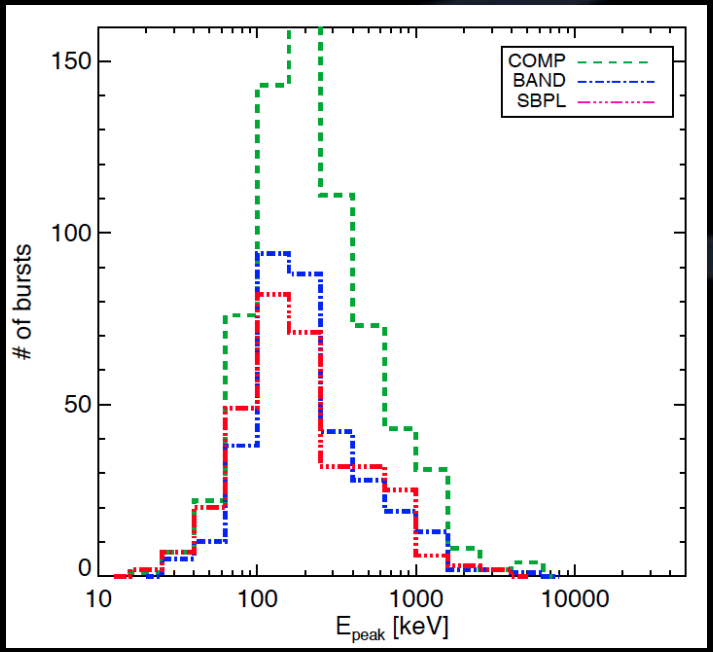




Gamma-rays (> ~200 keV)

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

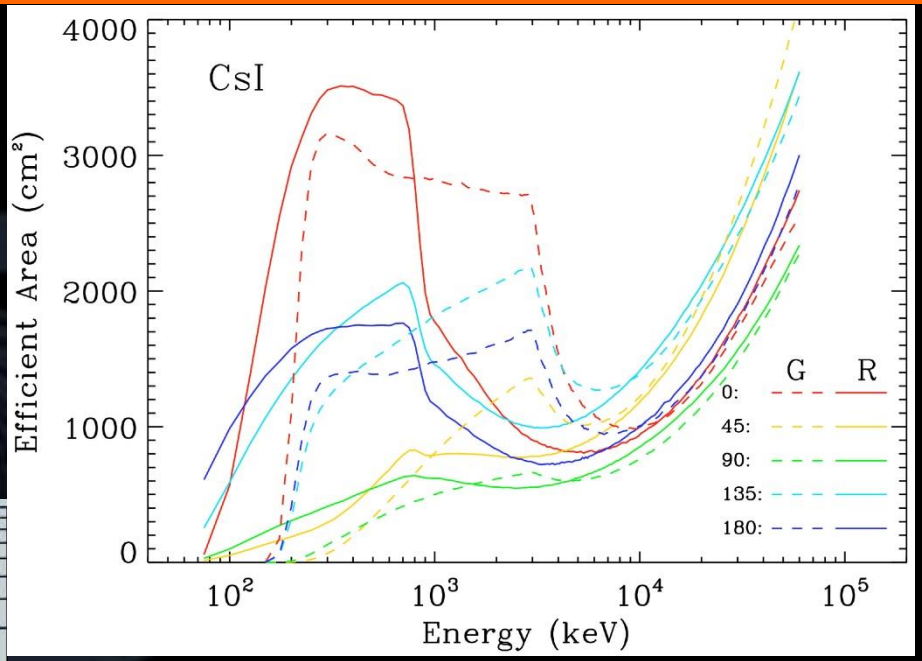


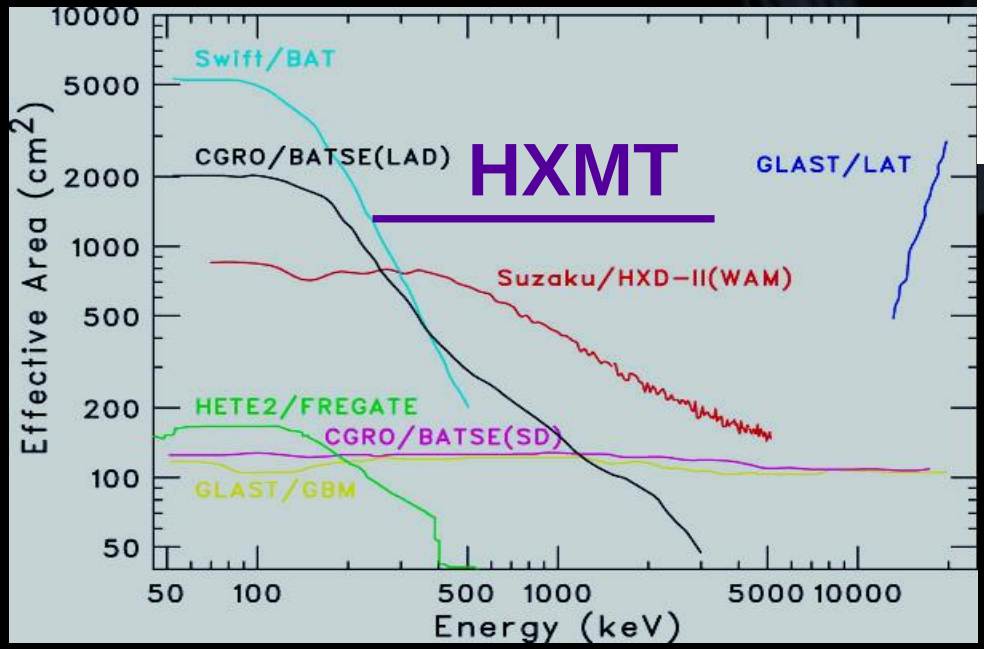
GRB Epeak measured by Fermi/GBM
（Gruber+, ApJS, 2014）

- **GRB mode better energy range:**
  - According to the simulation, det. efficiency is good for >200 keV
  - GRB Epeak distribution
- **GRB mode: ~30% 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 GRBs in **both** regular & GRB modes (lower HV for PMT)
- GRB monitoring FOV: all sky un-occulted by the Earth

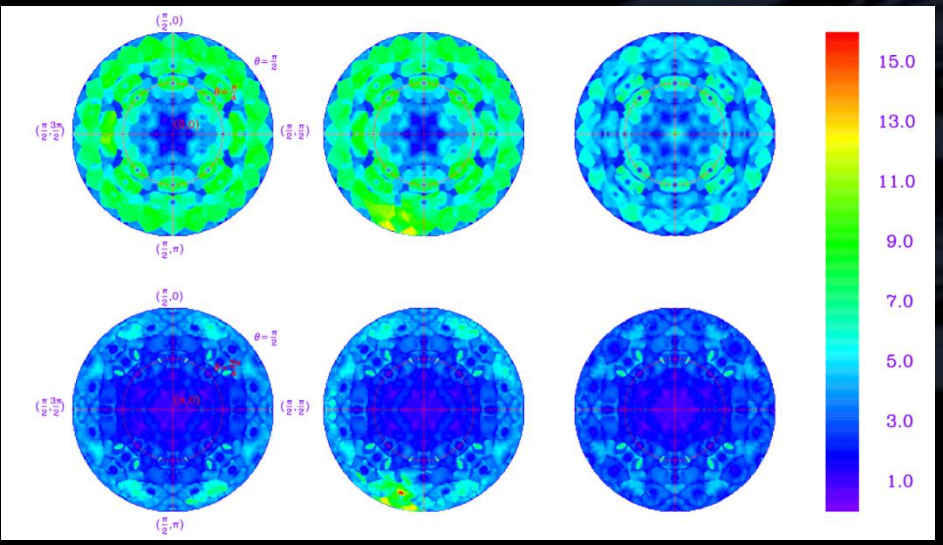




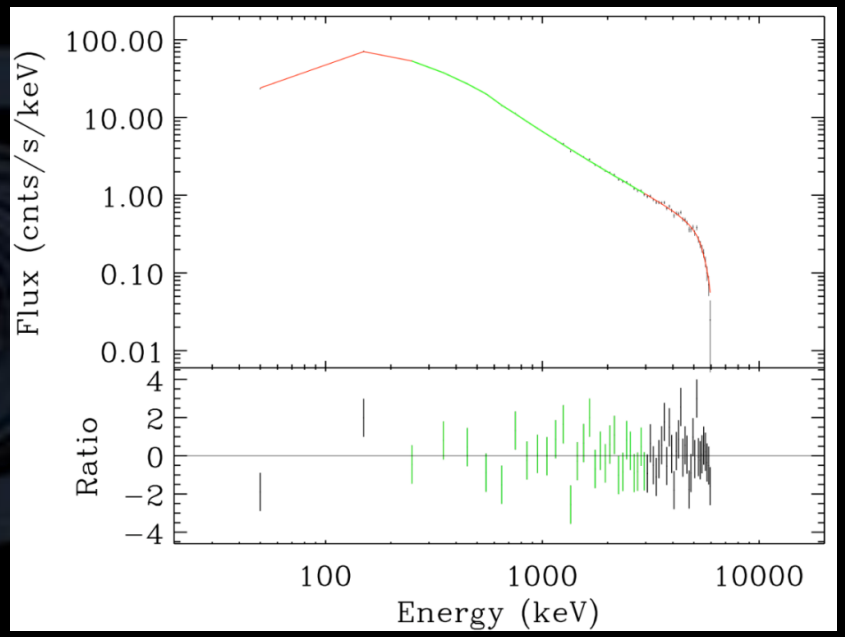
- 500~3000 cm^2 ~ MeV range with single photon counting and energy measurement, ~largest ~ MeV GRB monitors ever flown

GRB & GW EM: Location & Spectroscopy

- **Wide FOV (~60% all-sky) and large eff. area (1000 cm^2) in μs**
- Temporal analysis with high statistics
- Location accuracy: ~5 deg
- Spectral analysis (Epeak)



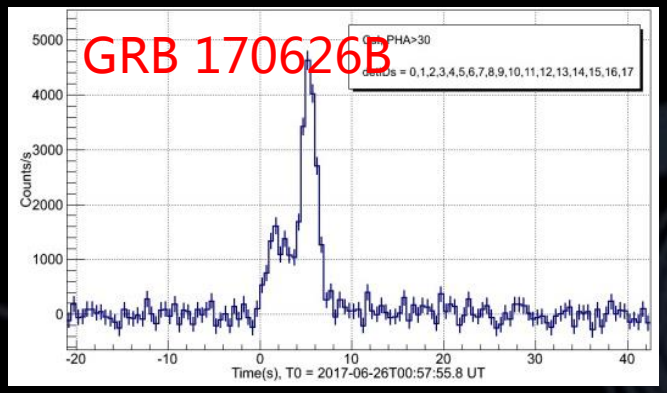
Localization accuracy

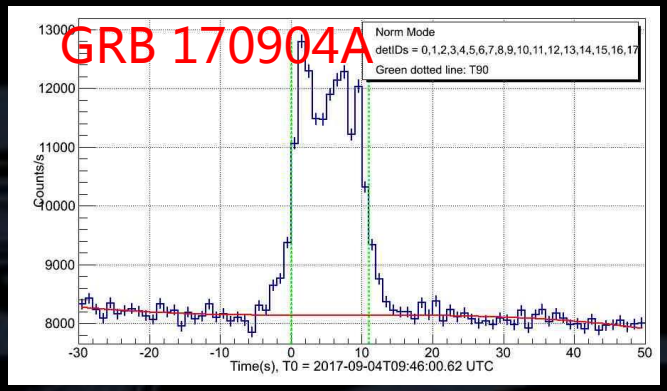


Fluence: 1E-4 erg/cm2, 10 s
Input：Alpha=0, beta=-1.5, Epeak=1000 keV
Measured：0.02+-0.12, 1.51+-0.01, 1004.6+- 68 keV

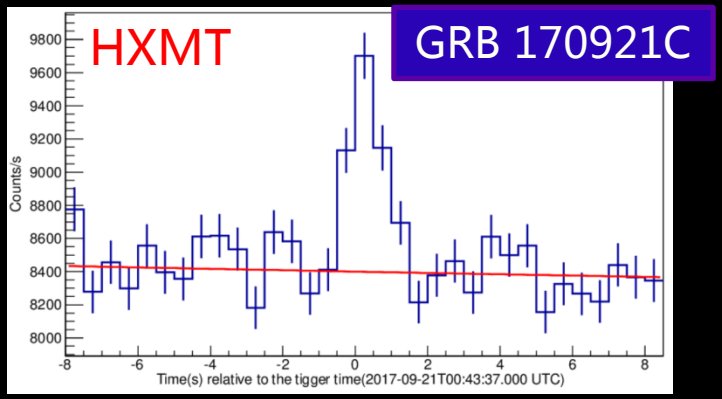
GRB Advantages

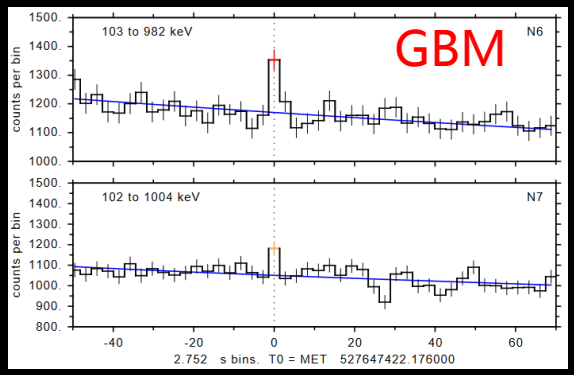
- ✓Large area: abundant photons → timing

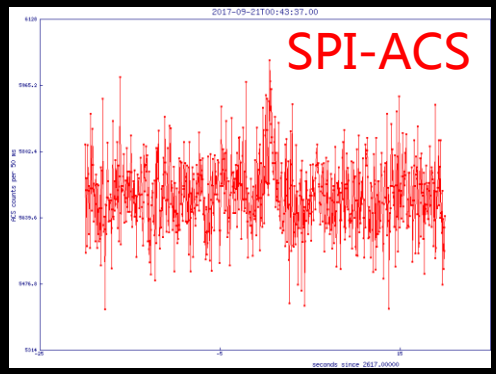




- ✓Sensitive @MeV: short/hard GRBs
  - ✓Sig: HXMT=12，GBM=8，SPI-ACS=4 (no spectrum)

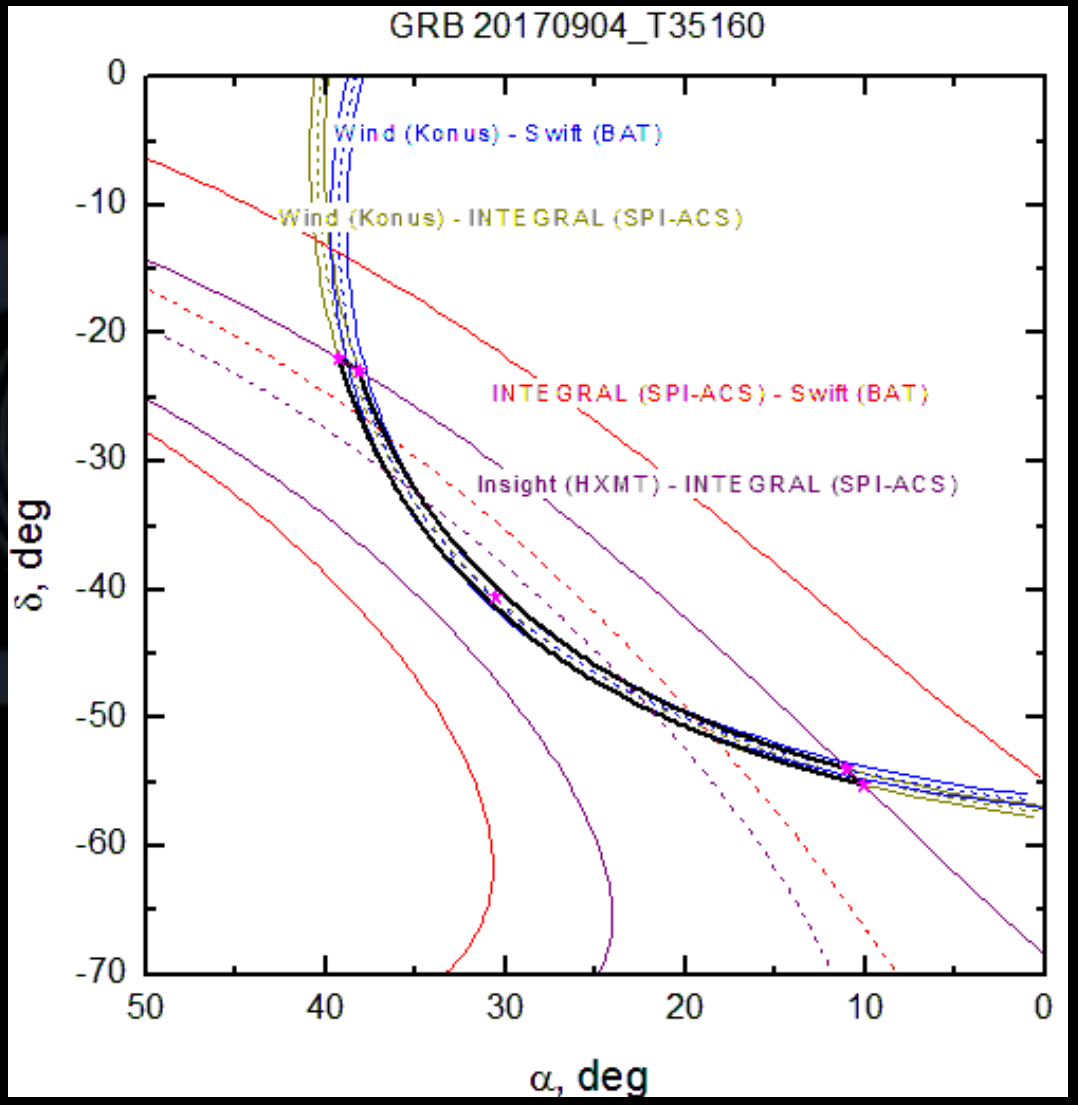






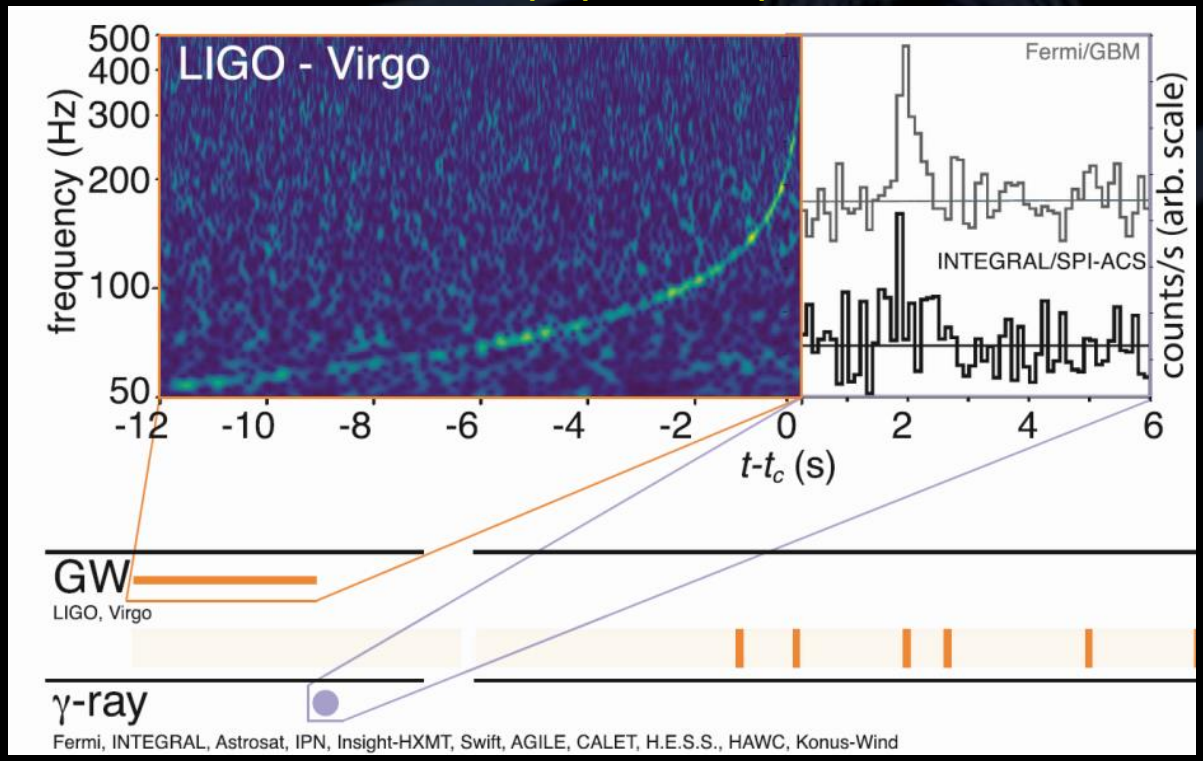
Joined Inter-Planetary Network (IPN）

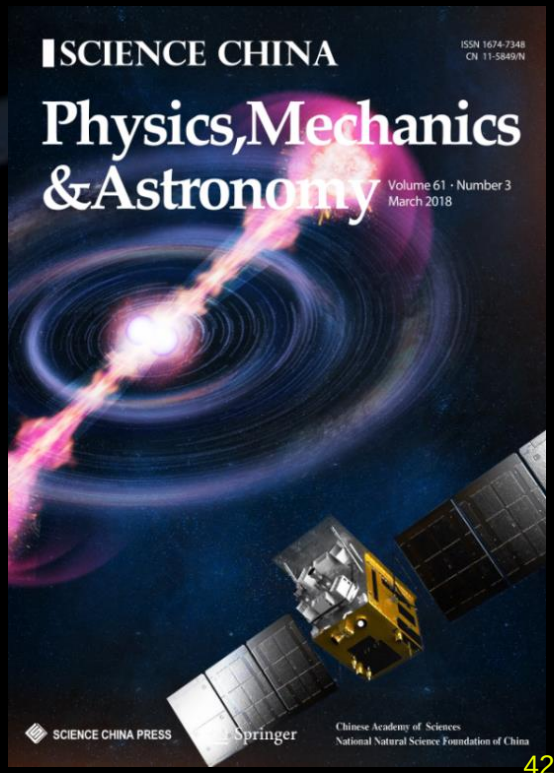
- ✓IPN: All major GRB detectors, near earth, L1, Mars orbit; *Insight*-HXMT is one of them, with Fermi, Swift, INTEGRAL, Wind-Konus, etc.



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

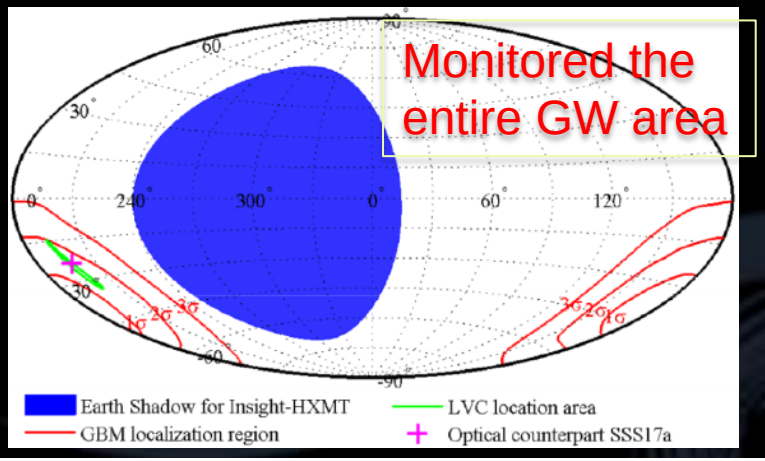
The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20 https://doi.org/10.3847/2041-8213/aa91c9

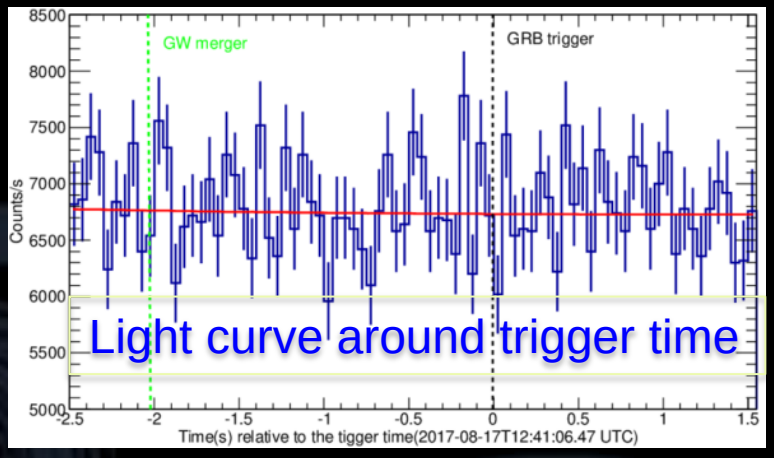
Multi-messenger Observations of a Binary Neutron Star Merger

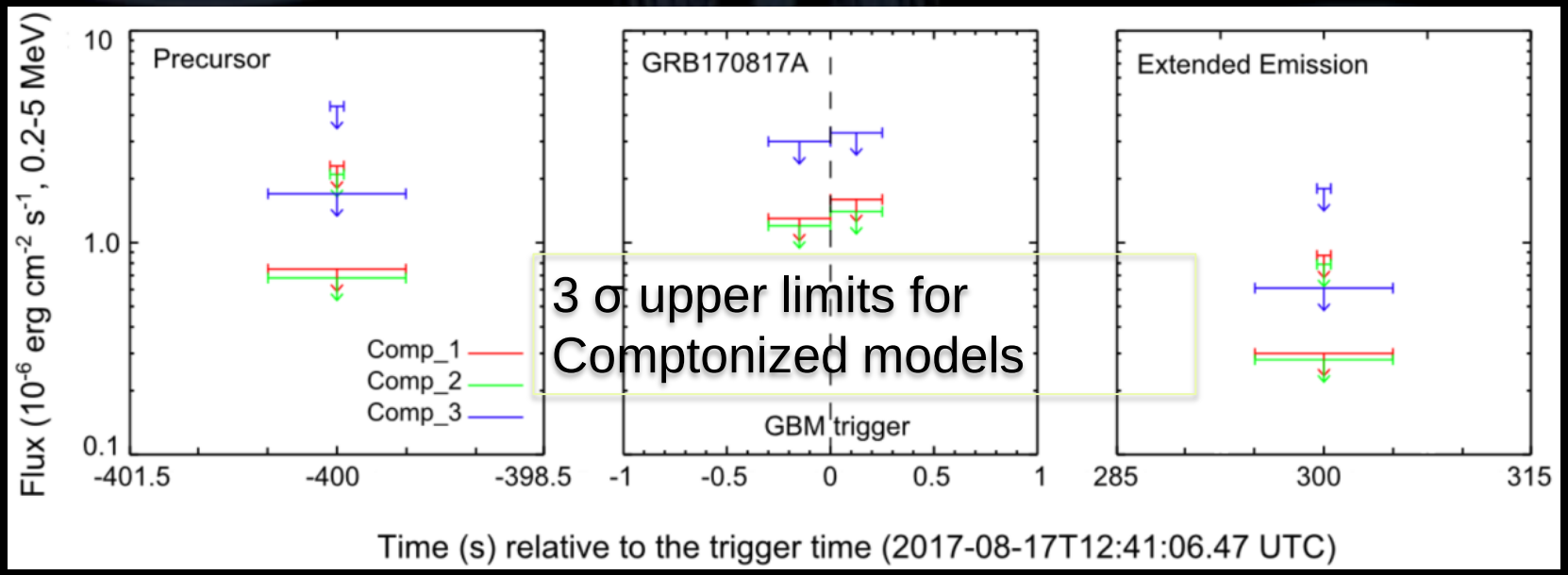
LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-Hxmt Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration 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.)

Received 2017 October 3; revised 2017 October 6; accepted 2017 October 6; published 2017 October 16

Insight-HXMT observation to GW-EM

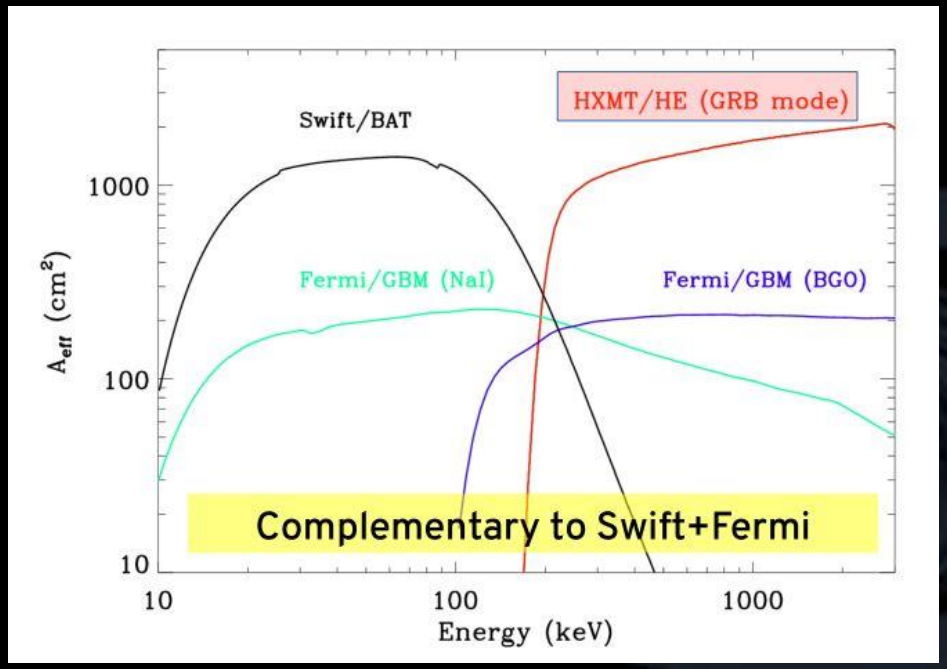


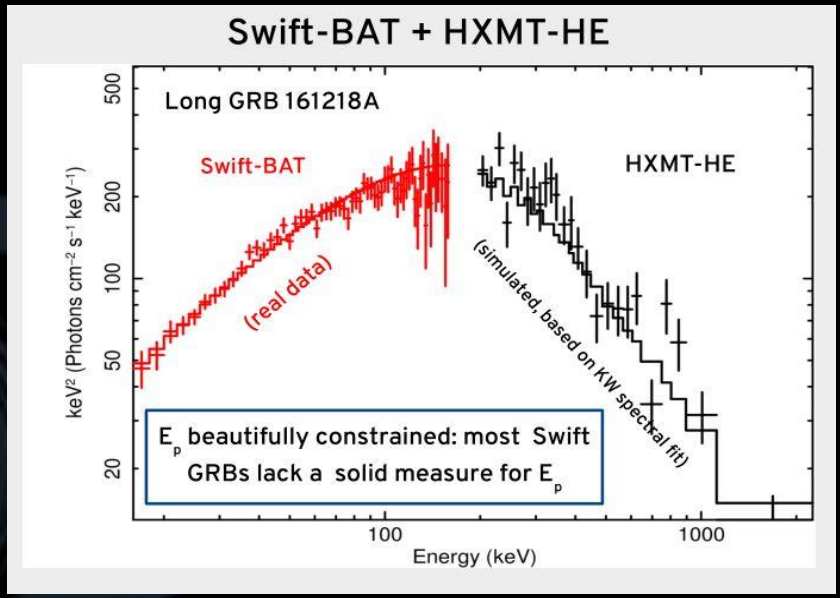


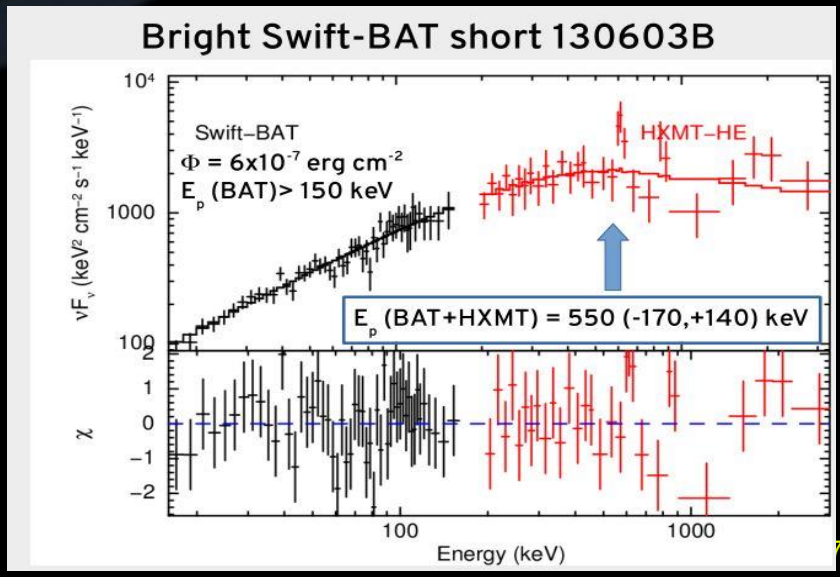


T. P. Li, et al, Sci. China-Phys. Mech. Astron. 61(3), 031011 (2018)

Prospect of GRB observations with joint missions





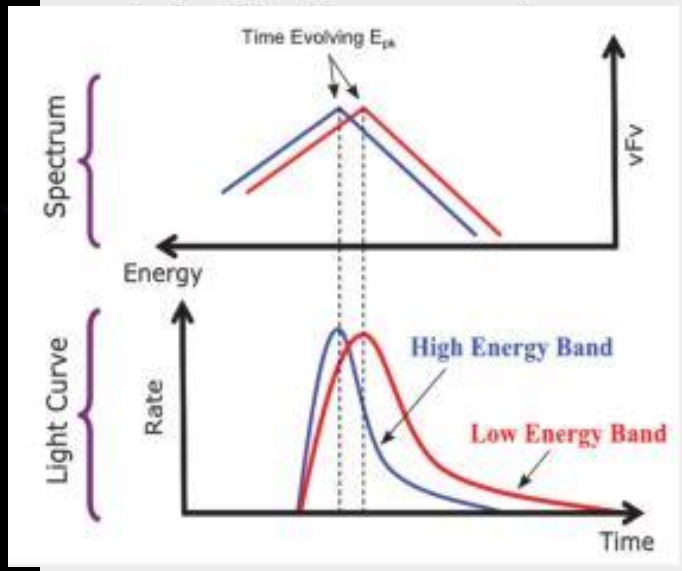


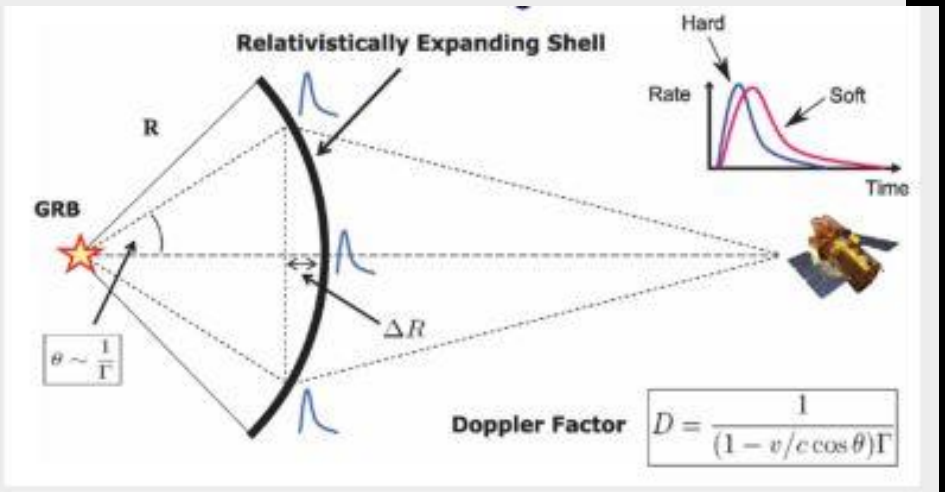
- ✓ Robust measurement of Epeak;
- ✓ sGRB coupled with GW.

(From Cristiano Guidorzi's talk , collaborator of HXMT in Ferrara University lead by Prof. Filippo Frontera) (see MG 15, parallel session HE3)

Prospect of GRB observations with joint missions

The added value of Insight-HXMT





Ukwatta+ (2011)

The unrivalled effective area above 300 keV of Insight-HXMT holds a great promise

(From Cristiano Guidorzi's talk) (see MG 15, parallel session HE3)

Summary

- ✓ *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
    - ✓ GRB mode when in Earth shadow or HE not used: 0.2 to 5 MeV
- ✓ 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.