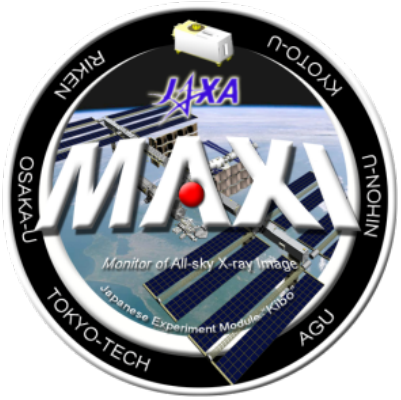


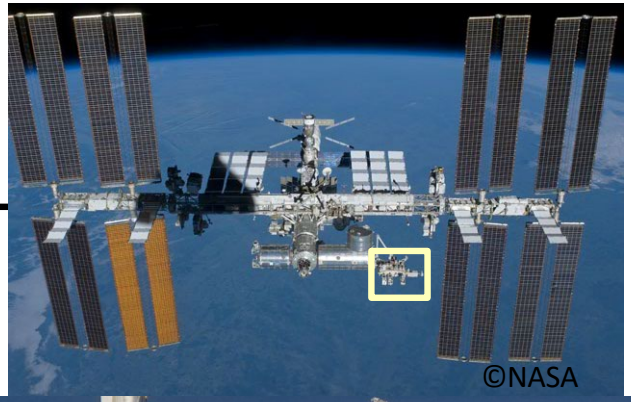
Monitor of All-Sky X-Ray Image (MAXI) — an X-ray all-sky monitor on the International Space Station —

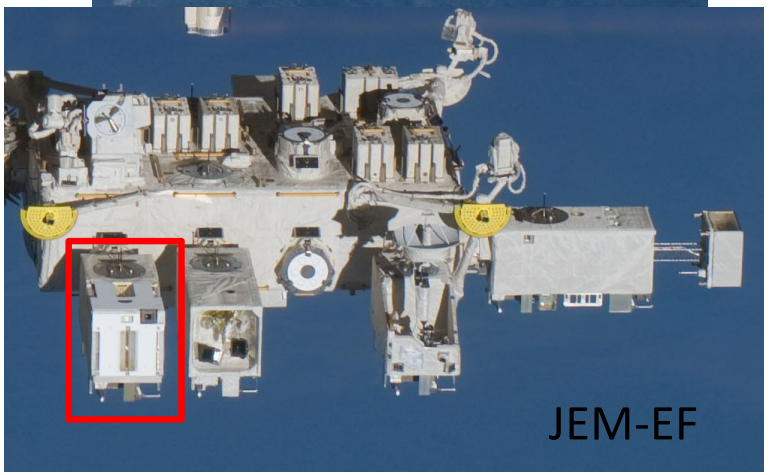
Nobuyuki Kawai (Tokyo Tech)

AMON Sixth Workshop, Chiba, May 2019

Tokyo Tech

MAXI mission

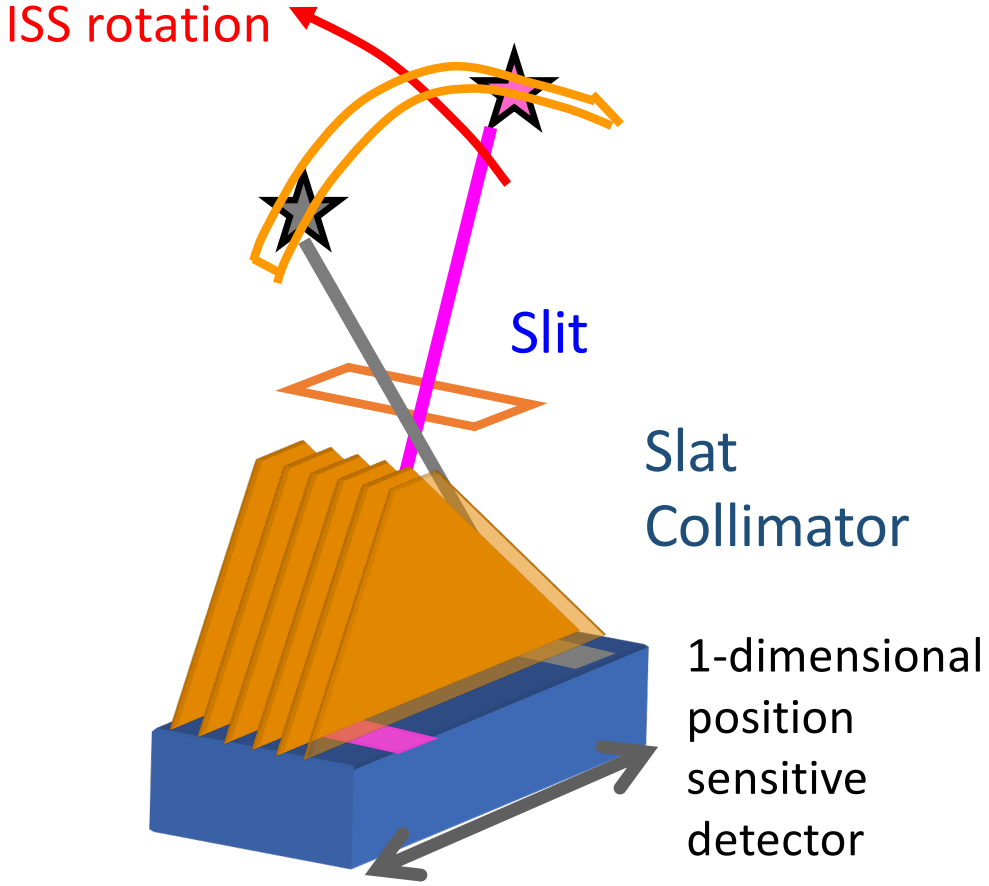


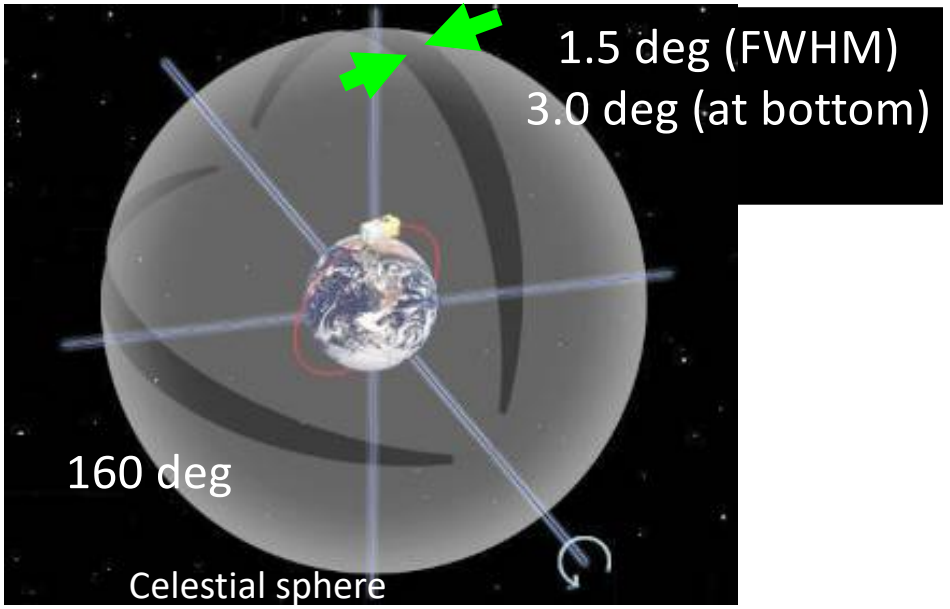


- MAXI (Monitor of All-sky X-ray Image)
- Observation started in August 2009
- Two scientific instruments
  - Gas Slit Camera (GSC) 2-20 keV
  - Solid-state Slit Camera (SSC) 0.7-10 keV
  - GSC has larger effective area and covering sky
- **Large FoV observing whole sky**
  - MAXI can cover entire sky
- **All-time monitoring**
  - Data before the trigger are available
- **Alert system in real-time**
  - Transient events can be searched automatically
  - Real time alert via MAXI mailing lists, 265 subscribers

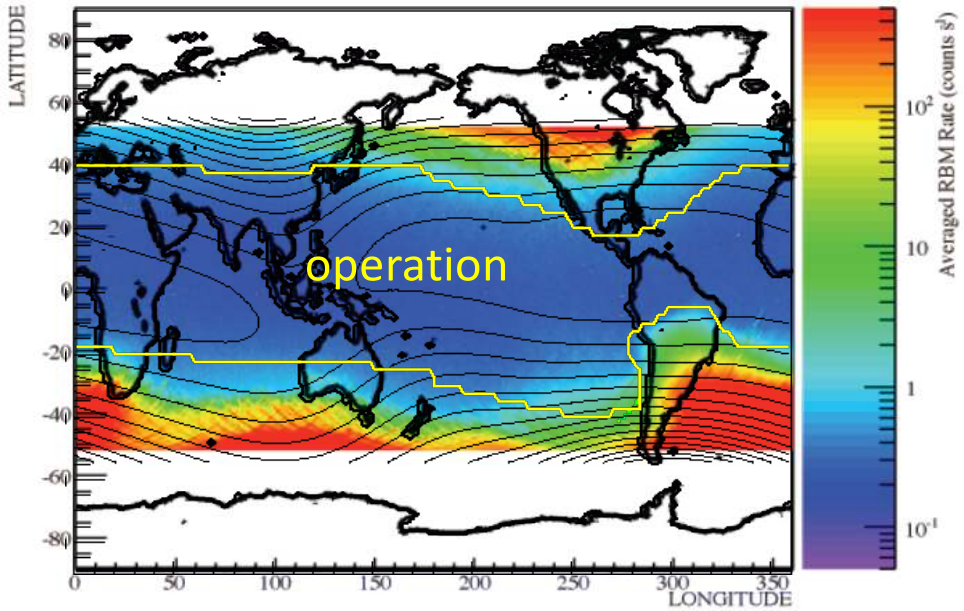
Leading "Time domain astronomy"

Scans with
Slit + Slat collimator





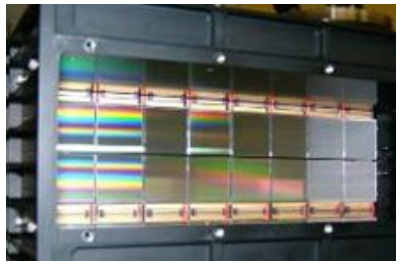
Charged Particle Background Rate



Operating in low-latitudes

proportional counter

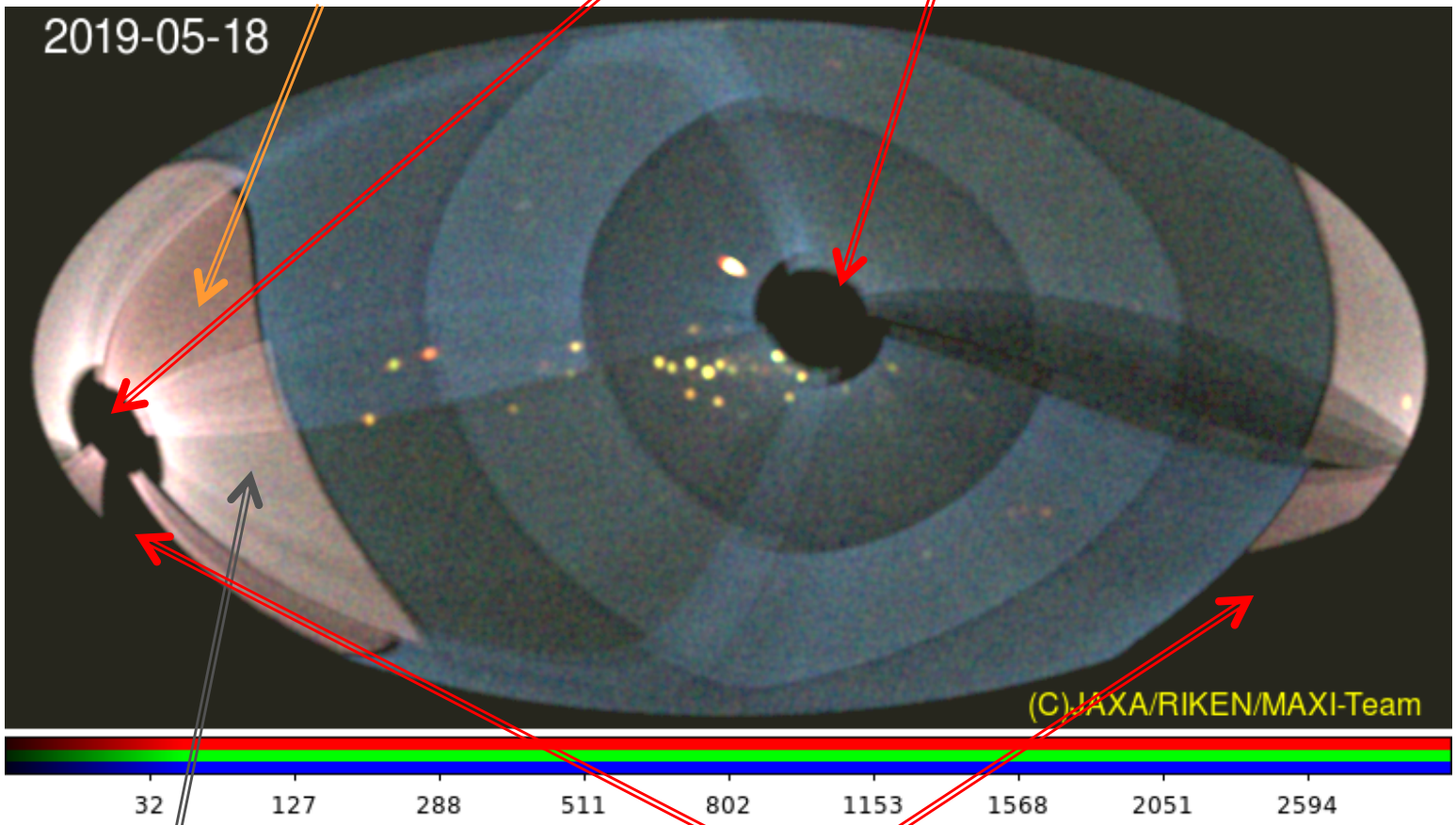
X-ray CCD



Example Daily Coverage (GSC, one-day)

Scan poles (r = 10 deg.) moves with the orbital precession period of 70 days.

GSC 6 (degraded)



GSC 3 (degraded sensitivity with a damaged anode)

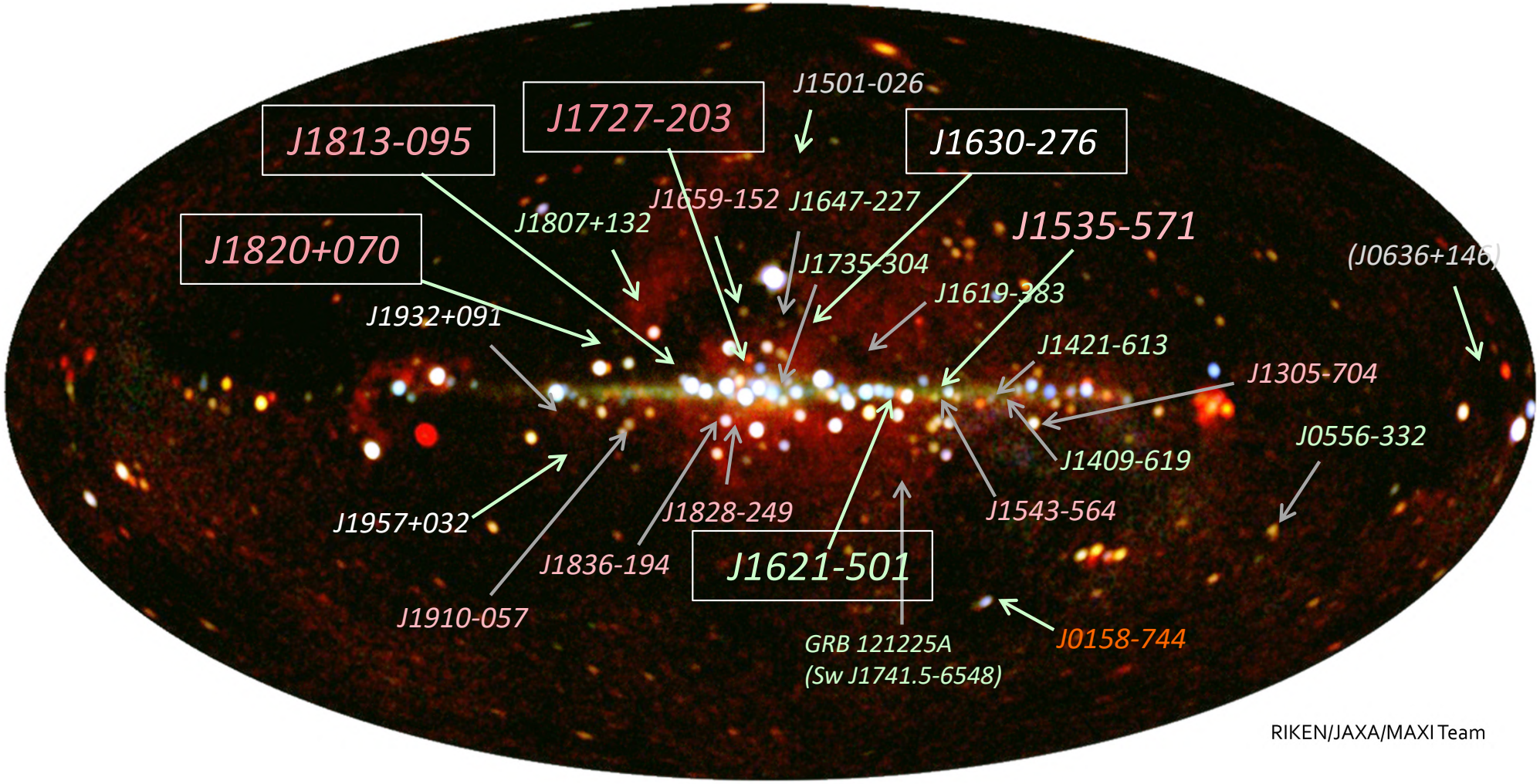
Sun avoidance (5 deg.)

Galactic coordinates

http://maxi.riken.jp/ v5l

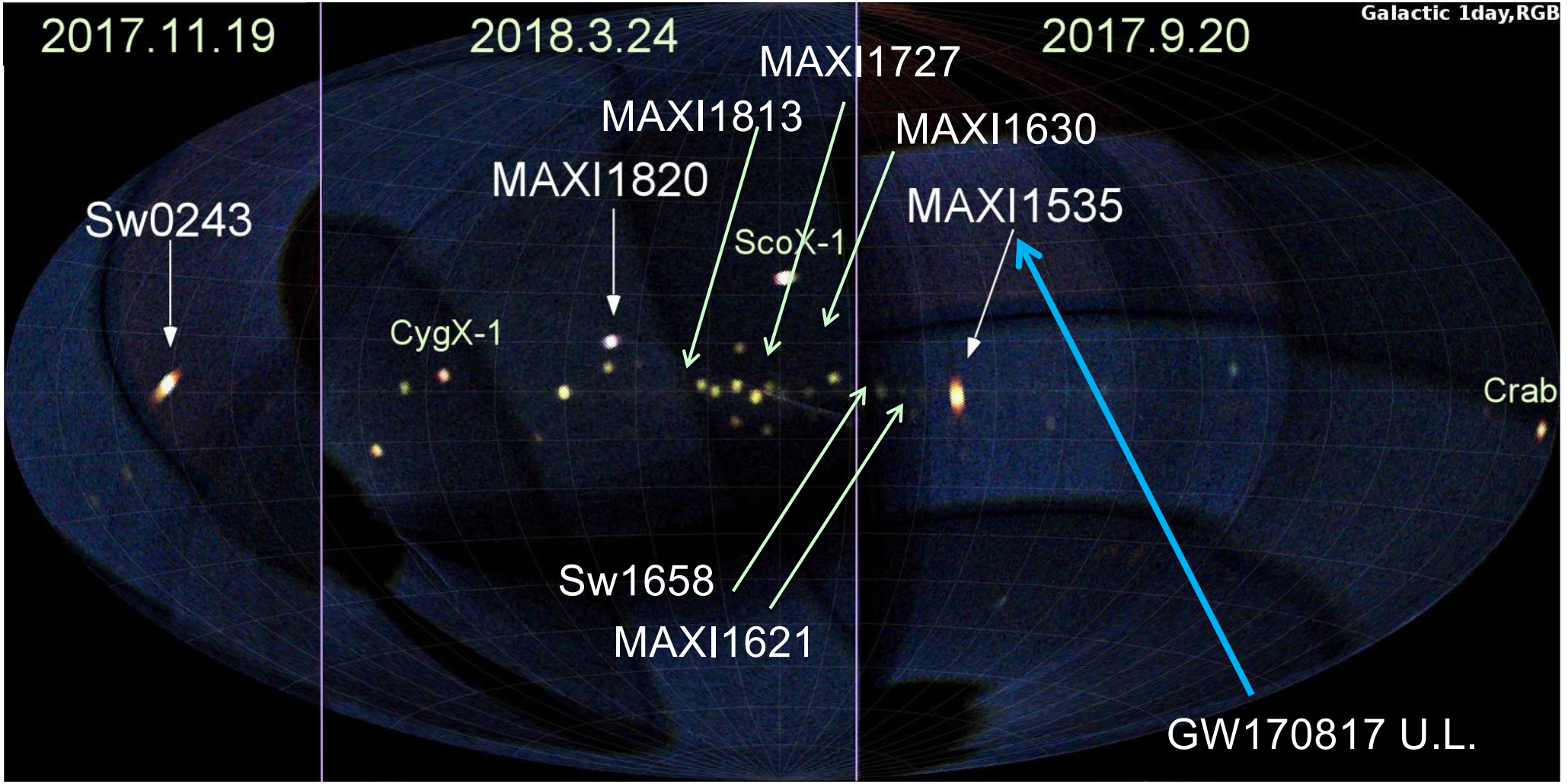
20+5 newly discovered X-ray transients

2009 – 2018 (excluding unID short transients)



Total 25 : 10 black holes, 13(-1) neutron stars, 1 white dwarf and 1(+1) unknown.

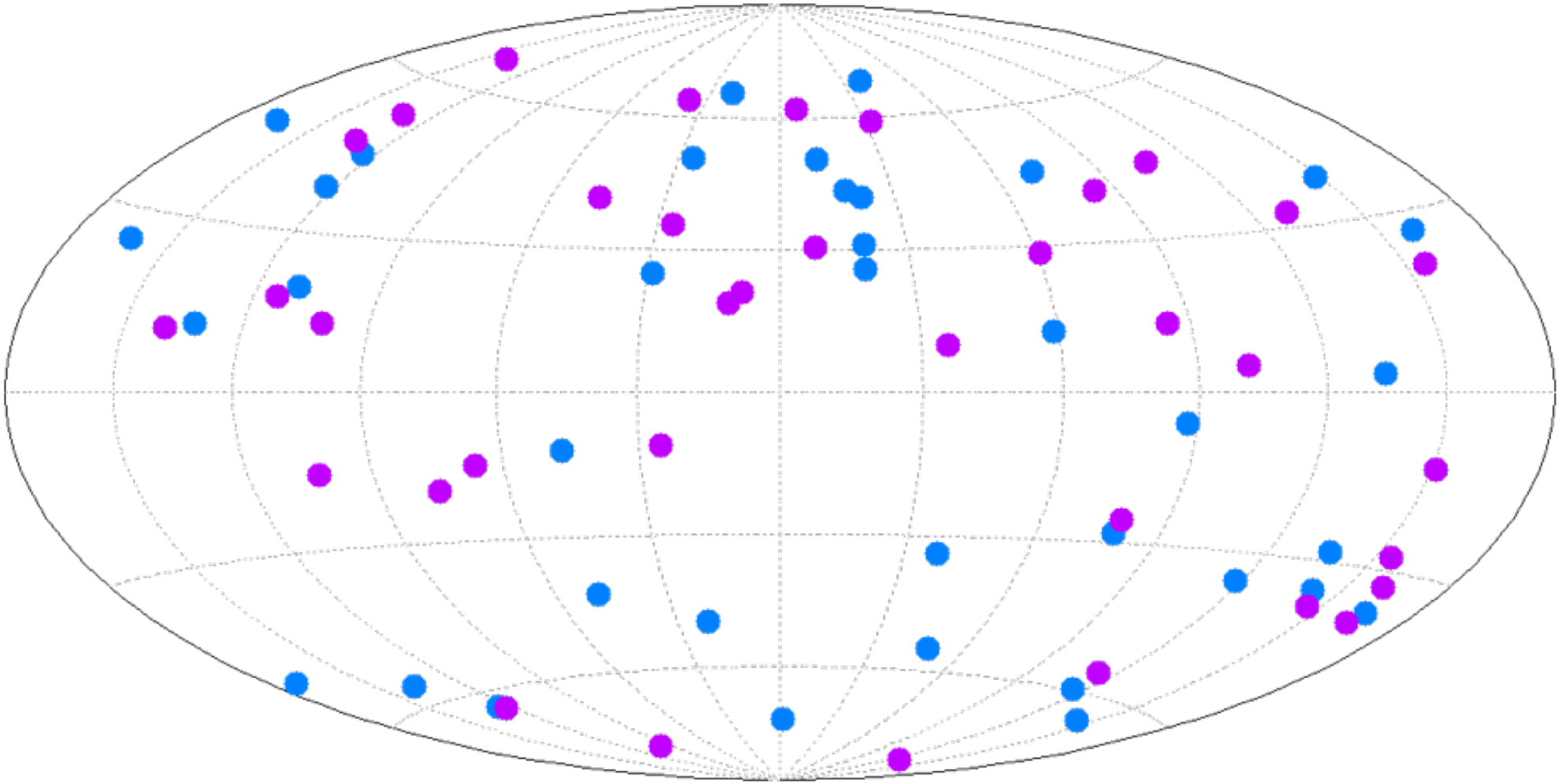
Recent Transients : 6(MAXI) +2(Swift)



Bright sources on daily images.

M1535, M1813, Sw1658, M1820, M1727 BH. M1621, M1630 NS-LMXB. Sw0243 BeXB

MAXI GRBs and transients (2—20 keV)



Serino et al. (2014)

http://maxi.riken.jp/grbs/

●: only MAXI (43)

●: MAXI + other (39 prompt + 7 afterglows)

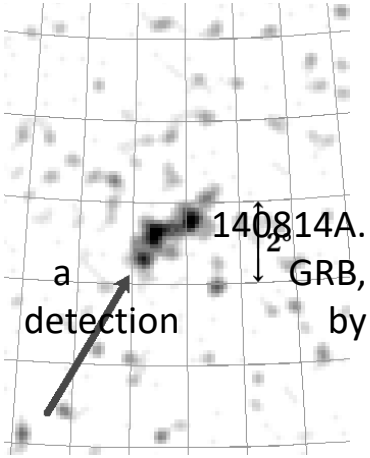
MAXI Unidentified Short Soft Transient (MUSST)

- Detected only in X-ray band (MAXI 2-10 keV) : Soft
  - No detection by Swift/BAT (15-50 keV)
- Fades out before Swift/XRT follow-up at a half day later : Short transient
- No detection by Swift/XRT ends up unidentified
  - MAXI localization (0.3deg) is insufficient for optical follow-ups.
- Rapid X-ray follow-up is desired while it is still bright
  (100 mCrab in 1 minutes, 1 mCrab in 20 minutes).

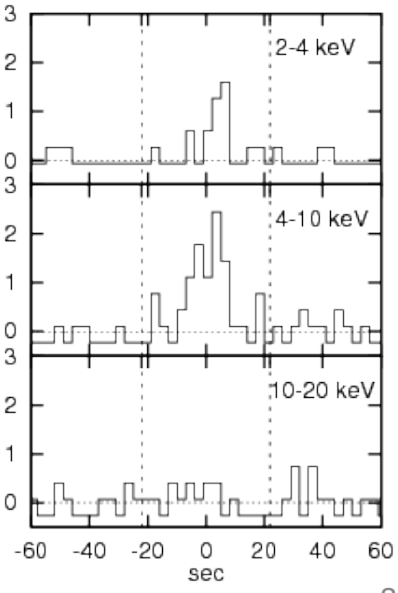
  ⇒ NICER

8 MUSSTs in 8 years of MAXI

name	l	b	flux [Crab]	reference
GRB 161123A	255.8	-69.6	0.1	Atel #8050
MAXI J1501-026	354.6	+46.8	0.44	Atel #7954
GRB 150428C	139.3	+11.2	0.2	GCN #17772
MAXI J1540-158	351.6	+30.6	0.1	GCN #17568
GRB 140814A	139.9	+66.4	1	GCN #16686
MAXI J0545+043	201.1	-12.6	0.2	ATel #6066
GRB 130407A	26.4	+35.6	4	GCN #14359
MAXI J1631-639	324.4	-10.8	0.12	ATel #3316



A MUSST, GRB 140814A. Reported as a GRB, but no detection by Swift follow-up. X-ray image at discovery and light curve in the scan. Soft (= no detection in 10-20keV) is a different point from a GRB.



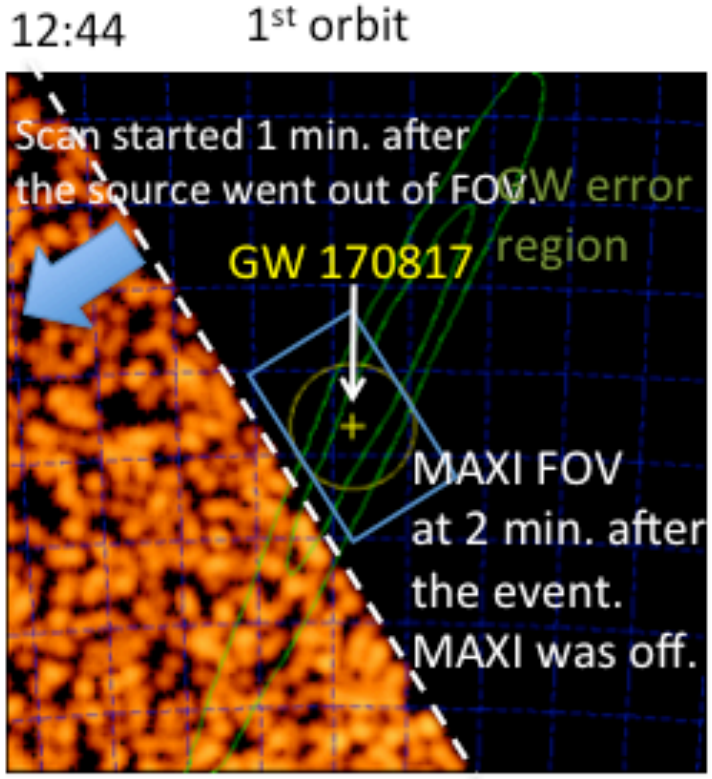
What are these short soft transients?

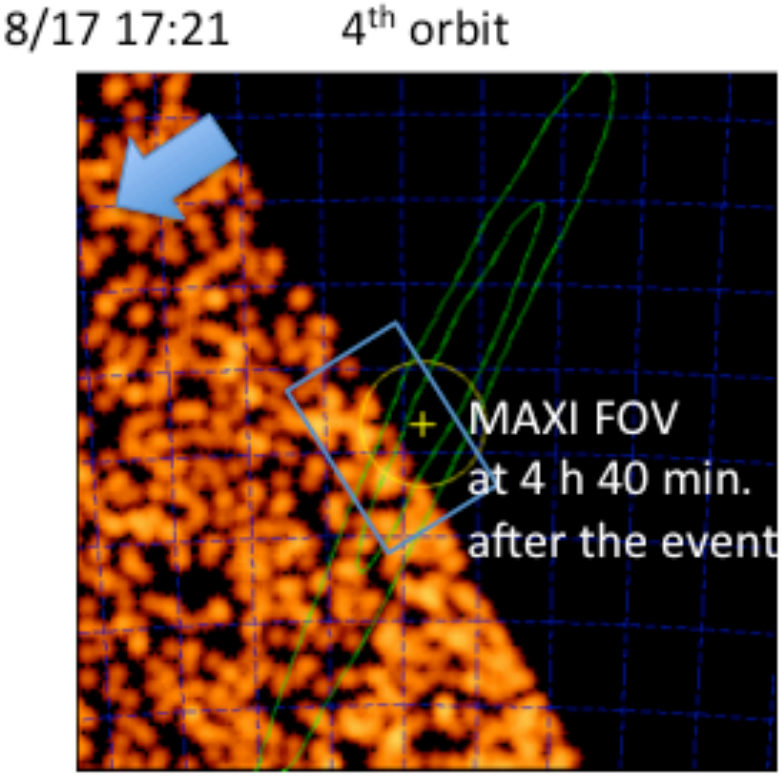
- gamma-ray bursts with very low E_{peak}
- low-luminosity GRB w/SN
  (~ SN2006aj/GRB060218)
- Choked GRB
- soft extended emission of short GRBs
  - neutron star merger — GW source (?)
- stellar flares
- igniting classical novae
- tidal disruption events
- SN shock breakout (~ SN2008D)
- very short AGN (blazar) flare
- …

GW 170817

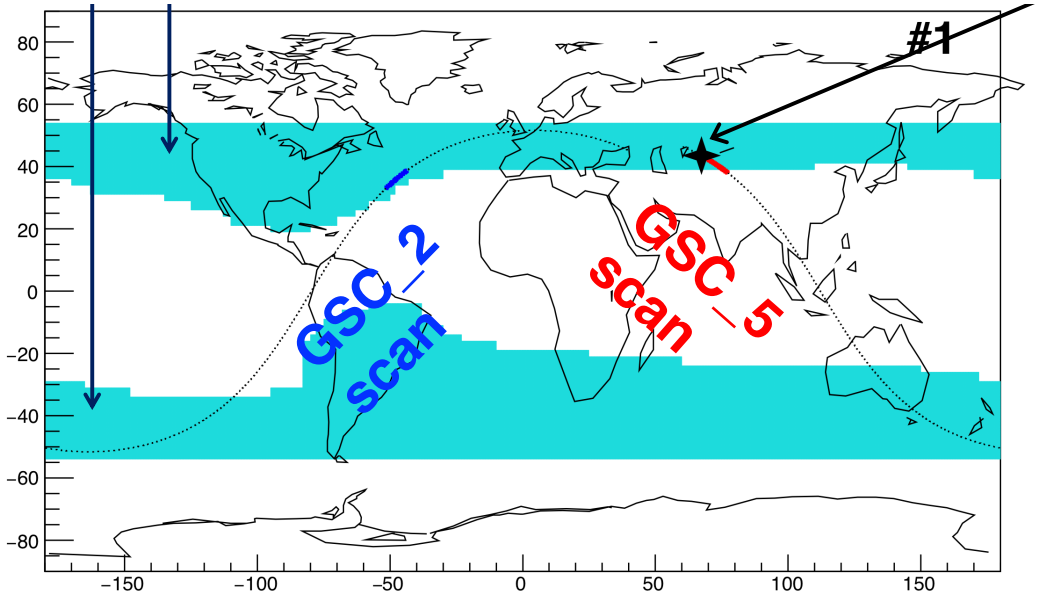
Sugita+ 2017

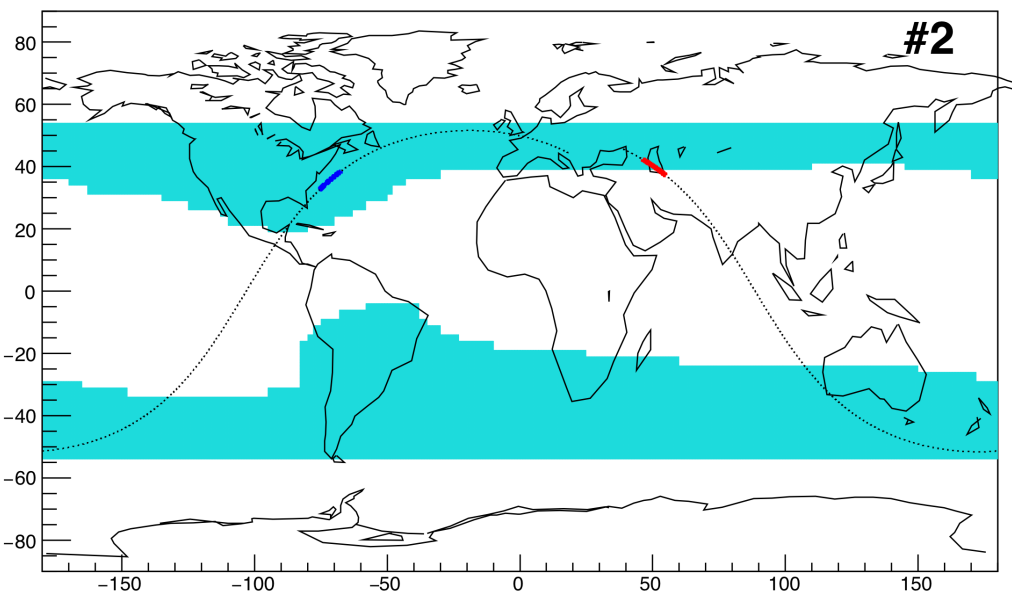
- 12:23 (-18 min pre GW) MAXI scanned the field with no detection
- 12:41 GW170817 (MAXI in high particle flux region)
- 12:44 MAXI resumed observation
- 17:21 (+4.6 hours post GW) first observation (partial)
- 18:55~ full coverage; no detection

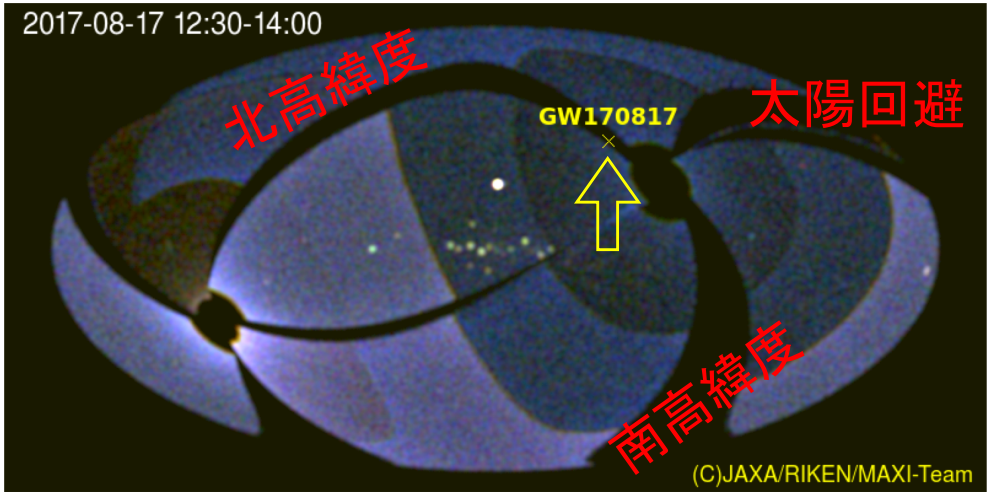


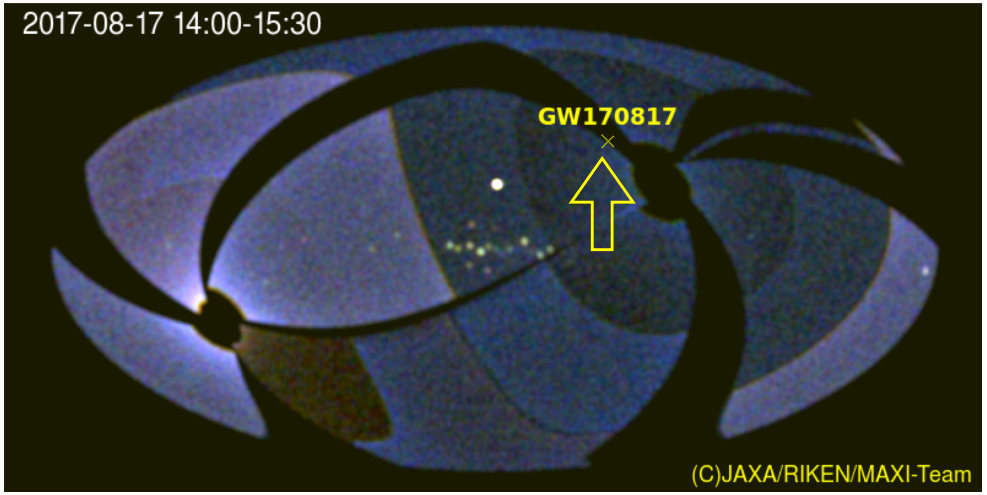


GW170817 orbit 1, 2

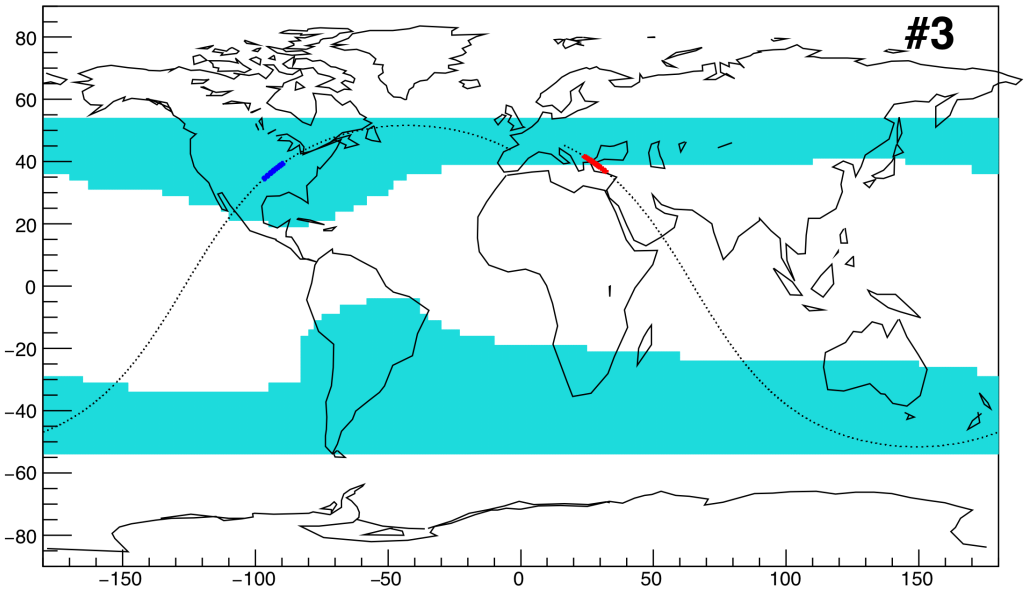


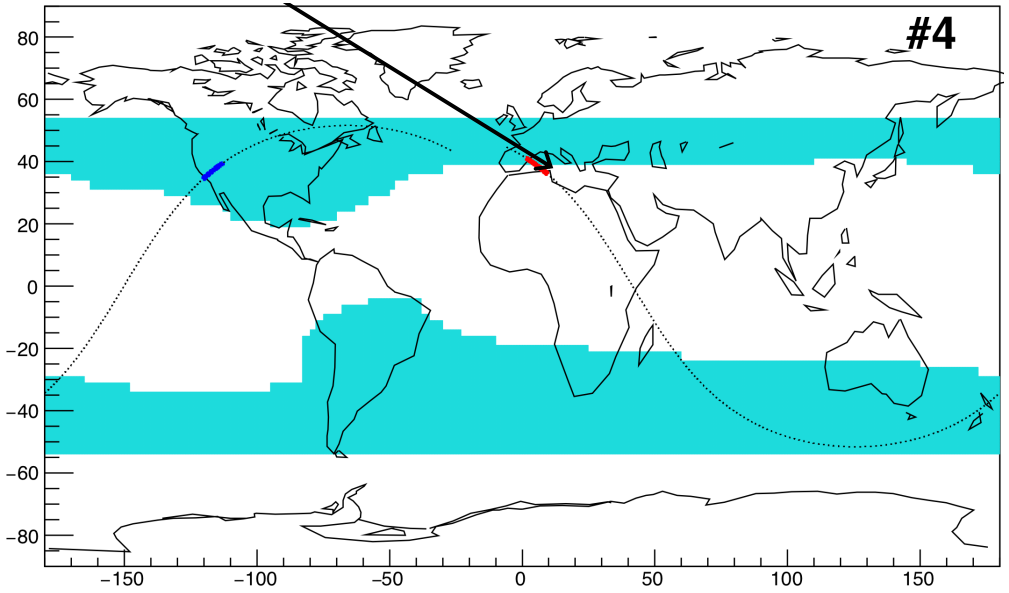


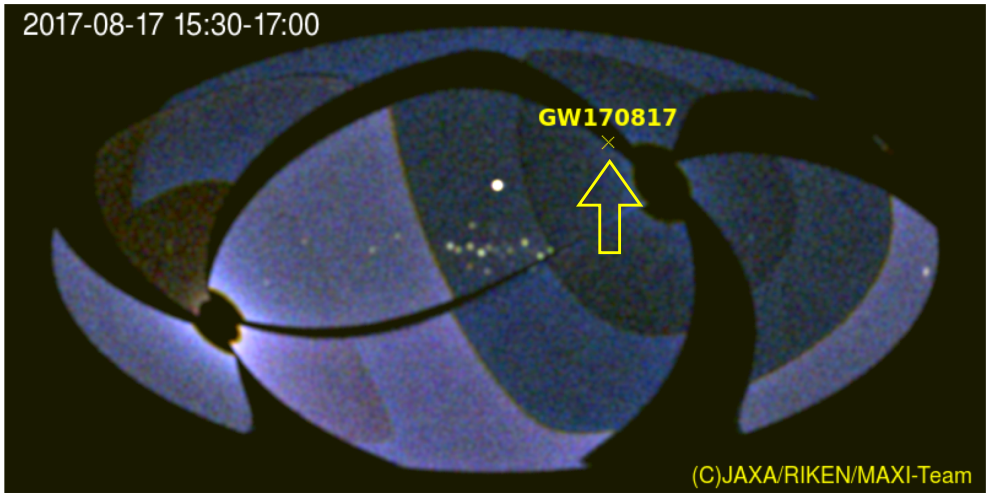


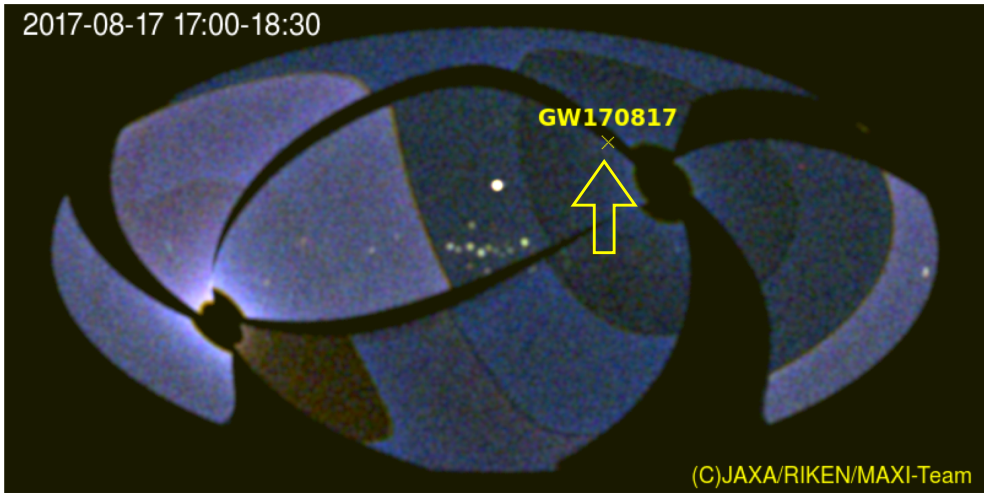


GW170817 orbit 3, 4



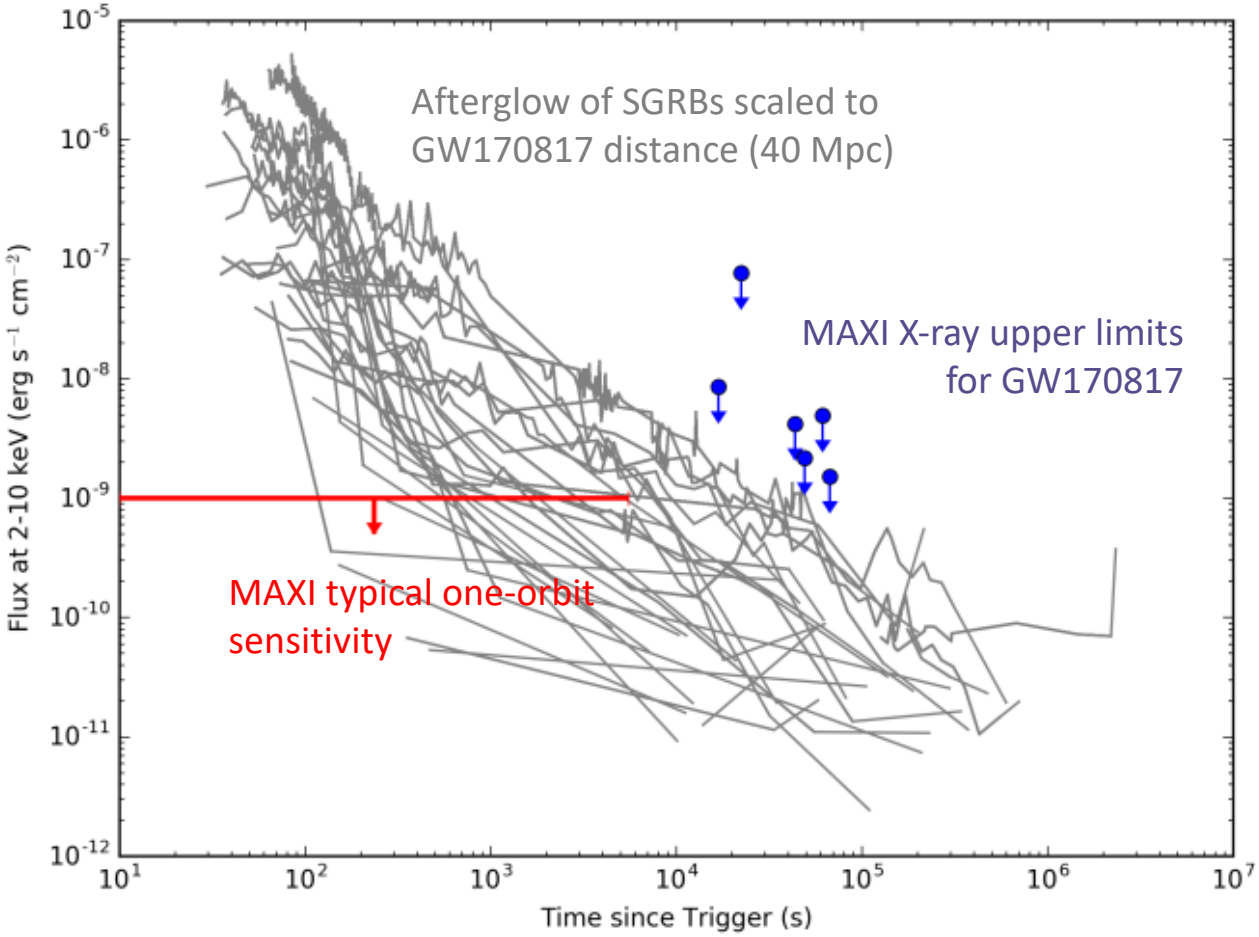


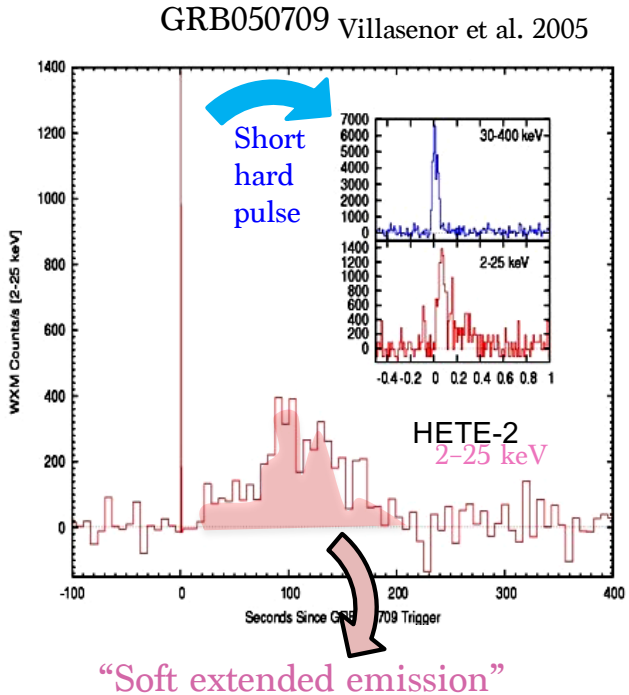




MAXI for GW counterpart search

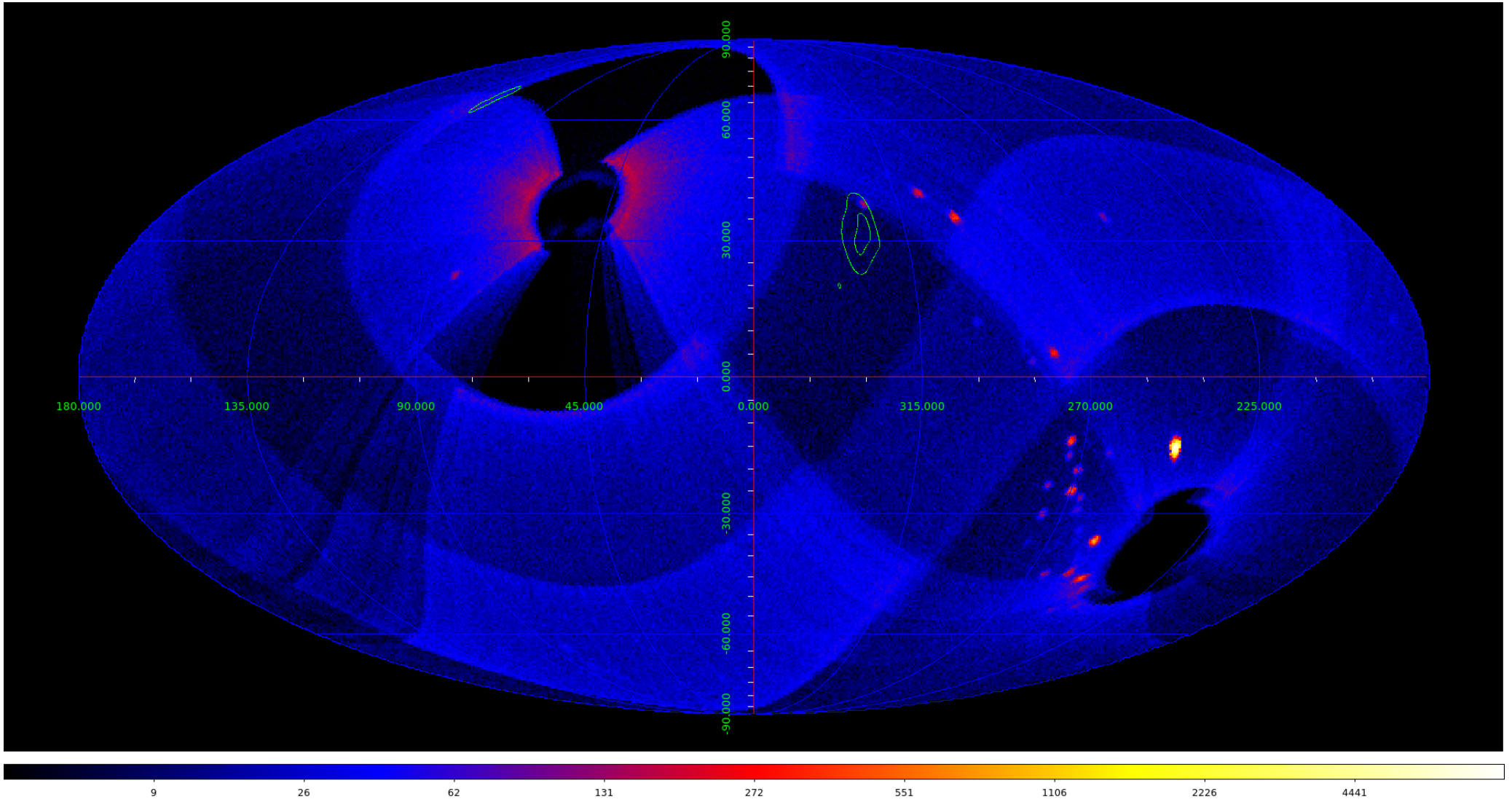
- MAXI has sensitivity to detect the “extended” X-ray emission and early afterglow of SGRBs, if observation takes place within an orbit (~85% of the whole sky)



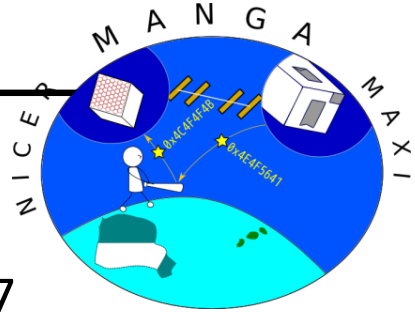


S190518bb


BNS 75%
Terrestrial
RETRACTED


90.000
60.000
30.000
0.000
-30.000
-60.000
-90.000
180.000
135.000
90.000
45.000
0.000
315.000
270.000
225.000
9
26
62
131
272
551
1106
2226
4441

MANGA : MAXI And NICER Ground Alert



NICER(Neutron star Interior Composition ExploER)

- a NASA/GSFC mission.
- Installed at ISS on June 2017
- Absolute time resolution : ～100 ns
- Energy resolution : 2% @6 keV
- Large effective area : >2000cm^2
  10 times higher than Swift/XRT

ToO observations of NICER provide accurate timing and spectroscopy of MAXI transients

According to the discussion between the MAXI and NICER team before NICER launch, **we already made 7 ToO observations in 6 months**.

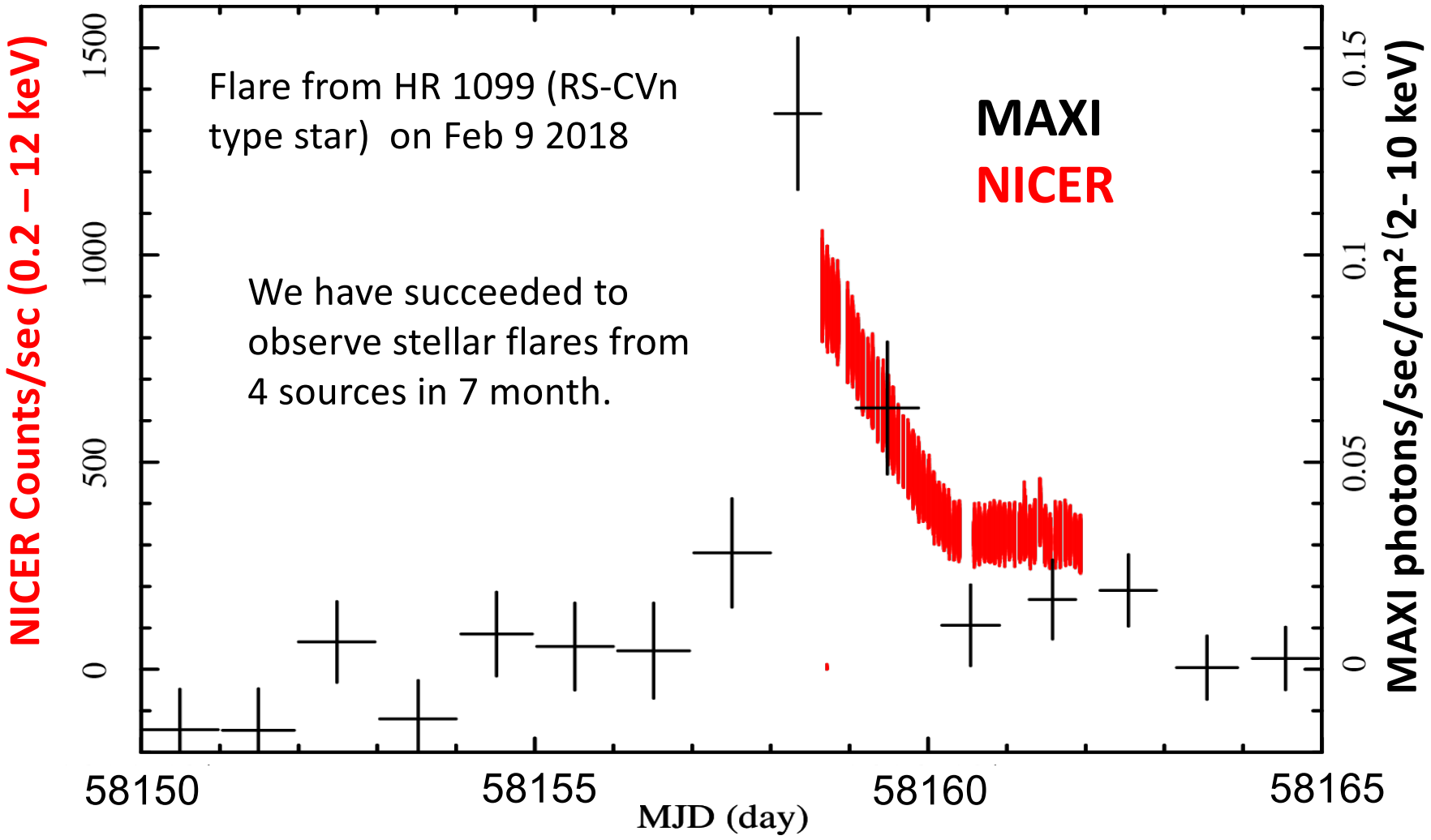
MANGA concentrates on hour-day phenomena such as
- Huge **stellar flare** from GT Mus (2017/07/18), HR1099 (2018/2/9), UX Ari (2018/2/22)
- **State transition** of MAXI J1535-571 (**MAXI new source**, Black hole binary) (2017/09/11)
-Swift J0243.6+6124 (**New source**, Neutron star binaries) (2017/10/01)
-MAXI J1621-501 (New source, possible NS-LMXB) (2017/10/19)

We will continue MANGA in such a rate (～once a month).
We will try to shorten the time delay aiming upto 20 minutes.

Stellar flare observation by MANGA

- MAXI can discover stellar flares but cannot get high quality data
- NICER cannot discover stellar flares but can get high quality data

The MAXI NICER relationship is quite complementally.



OHMAN (On-orbit Hookup of MAXI And NICER)

NICER : Mounted in June 2017

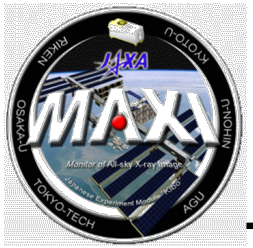
- Look at the source in X-ray, while it is still bright in X-ray.
- Rapid follow-up from 2 min. after discovery
- MAXI nova detection by onboard PC
- Convey information to NICER on ISS.

Survey discovery space in time-domain astronomy.

Rapid decaying objects.

- MUSST
- GW sources
- Orphan afterglow of GRB
- Stellar flares

MAXI: Already on orbit

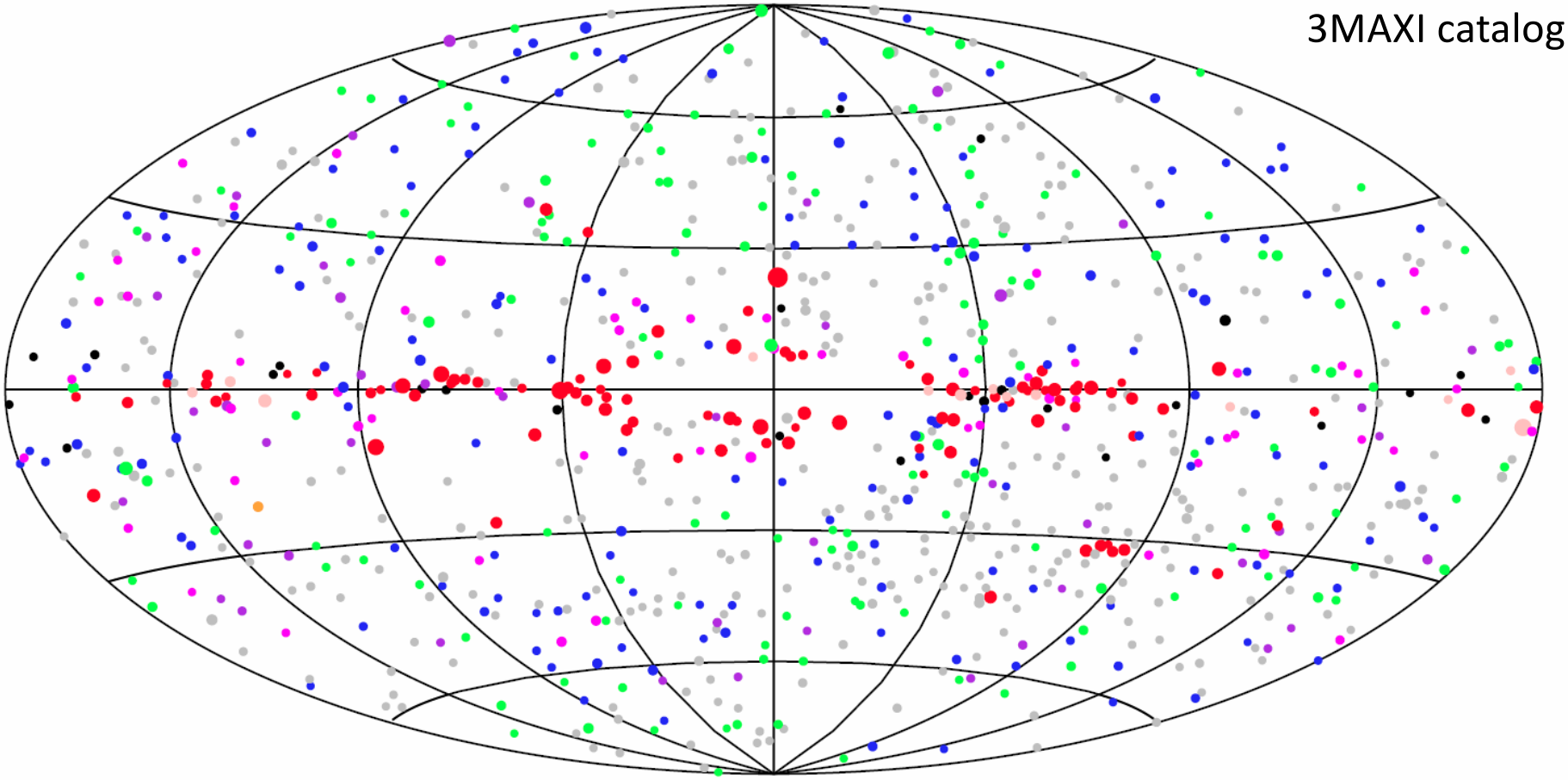


GSC catalog

Hori+ 2018 ApJS 235, 7
Kawamuro+ 2018 ApJS 238, 32

- We have produced new MAXI/GSC source catalogs based on the 7-year data from 2009 August to 2016 July. They will be published in two papers for low (214 sources) and high (682 sources) Galactic latitude regions.
- The sensitivity limit reaches ~0.4 mCrab for half of the whole sky, which is near the source confusion limit of MAXI/GSC.
- The two catalogs contain 896 sources in total, including a significant fraction of new unidentified objects.
- These are the deepest source catalogs covering the 4-10 keV band among all previous and on-going all-sky X-ray missions.
- The merit of 4-10 keV energy range is
  - It is free from the galactic absorption.
  - It is the energy range where blackhole and neutron star binaries emits most of the energy.
- MAXI scans thousands of times for a catalog.
  - It can correctly average the fluxes of variable sources.
  - It can make a variability catalog in one-month time-bin, for example.

GSC catalog



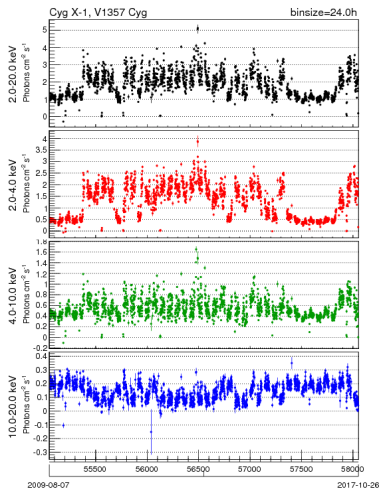
Seyfert **Quasar** **X-ray Binary** **CV** **SNR**

Cluster **Galaxy** **Pulsar** **Star** **Unidentified**

Data distribution

- MAXI data are public at MAXI Web. 403 sources are processed.
- 101 sources of them are processed every 4 hours.
- Ondemand process allows users to extract MAXI data from any sky region in any time period.
- Some contribution pages available.

MAXI HP http://maxi.riken.jp/



Light curve of sources

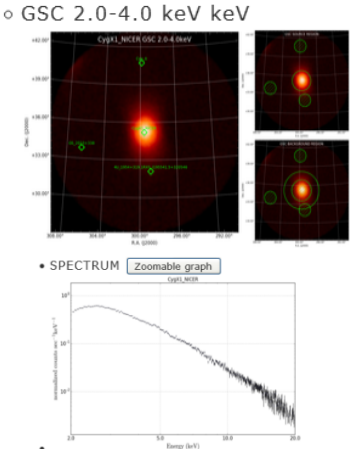
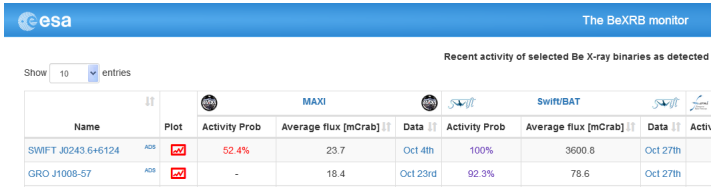
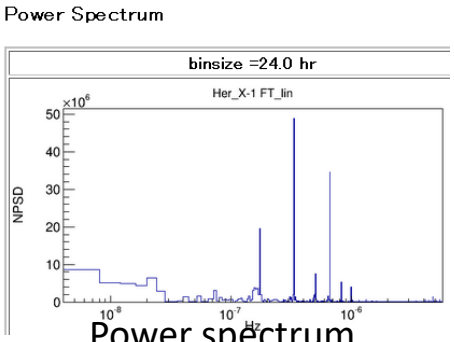


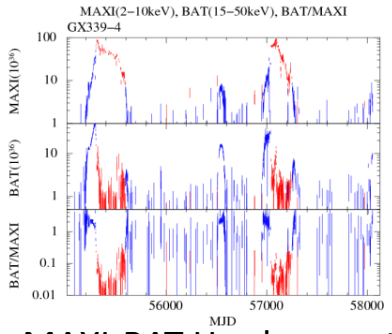
Image and spectrum by ondemand



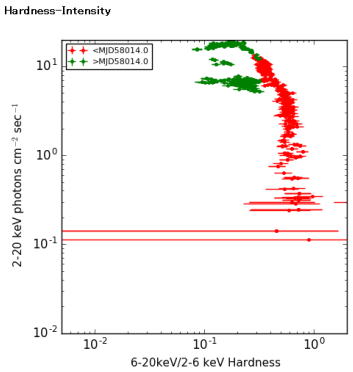
BeXRB monitor @ ESA



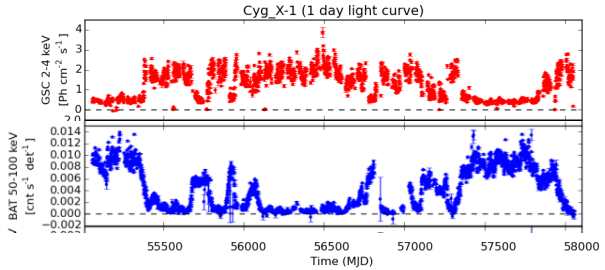
Power spectrum



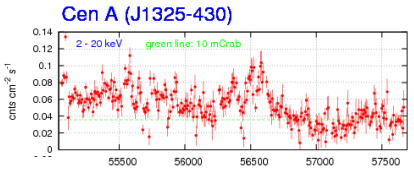
MAXI-BAT Hardness ratio



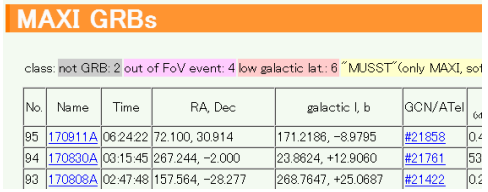
MAXI 1535 monitor



BAT-MAXI transient monitor



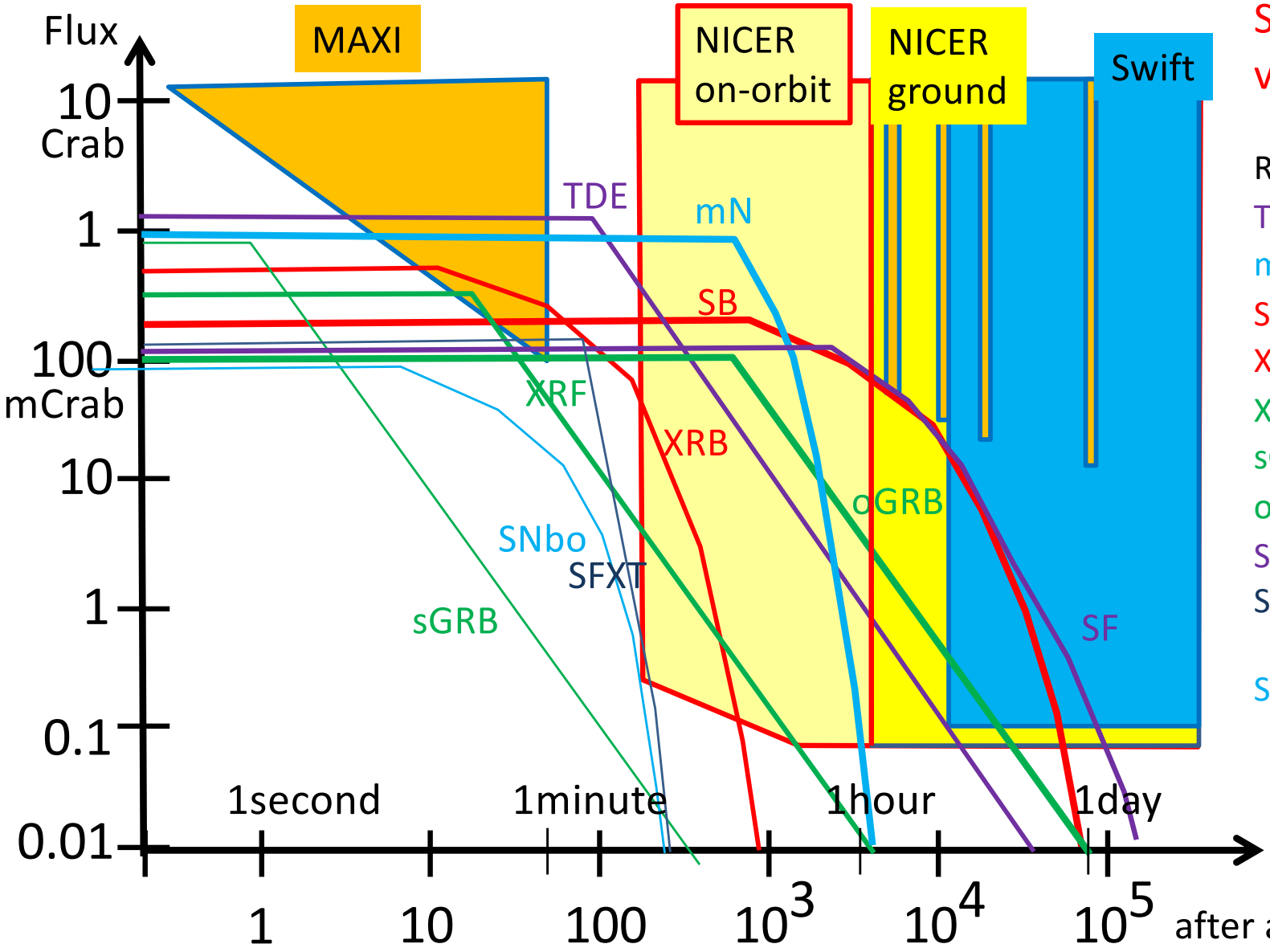
Weekly light curves



MAXI GRB list

Time-domain astronomy of Rapidly decaying X-ray sources

Rapidness of follow-up in X-ray and sensitivity



Swift follow up is very effective.

Rapidly decreasing obj.

TDE: as Sw1644

mN: massive Nova

SB: super burst

XRB: X-ray burst

XRF: X-ray flash

sGRB: short GRB

oGRB: orphan GRB

SF: stellar flare

SFXT: super giant fast X-ray transient

SNbo: super nova shock break out