



# Monitor of All-Sky X-Ray Image (MAXI)

— an X-ray all-sky monitor on the  
International Space Station —

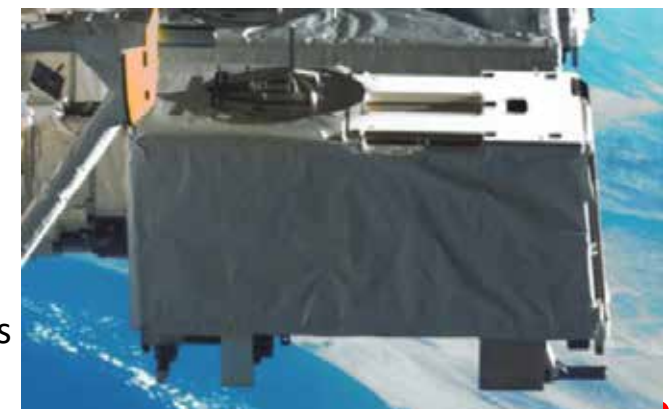
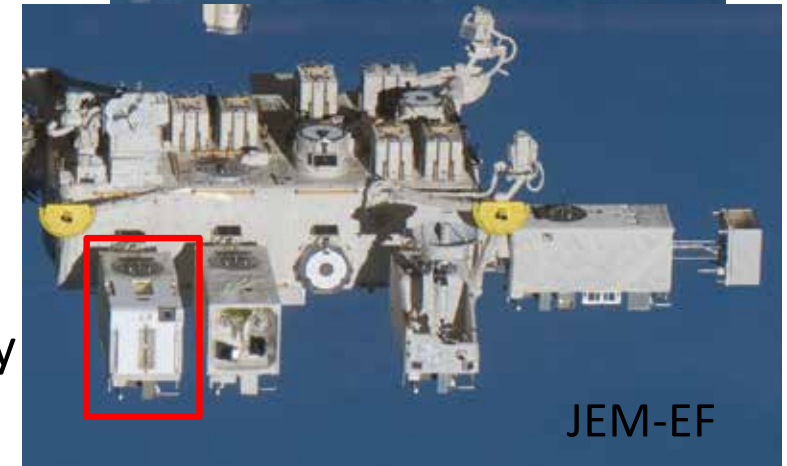
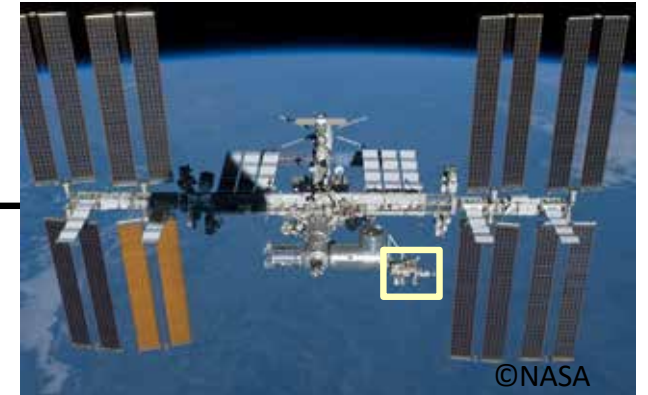
Nobuyuki Kawai (Tokyo Tech)

Time Domain Multimessenger , Nikko, January 2019



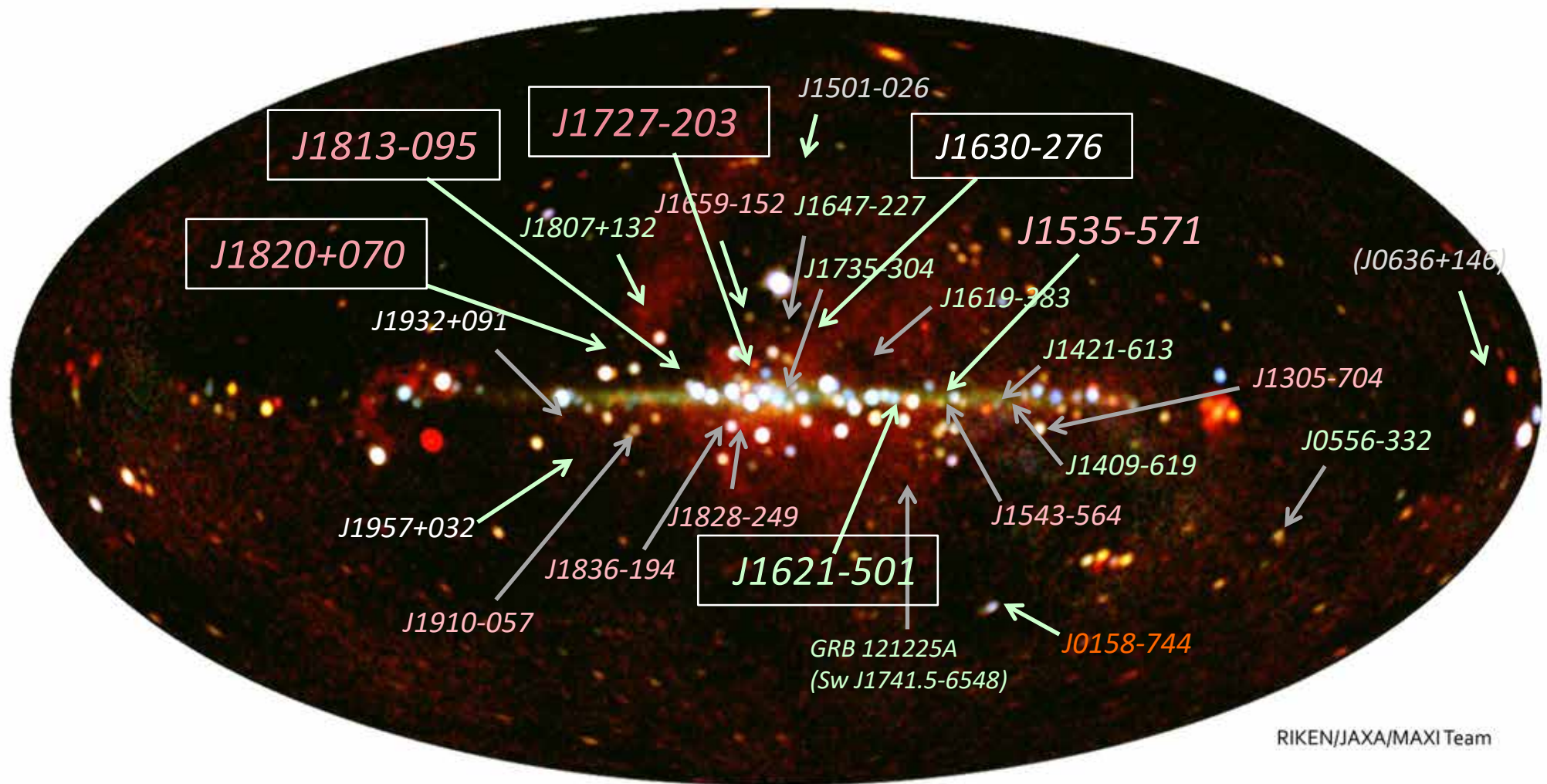
# 1. MAXI mission

- 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”



# 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.

# MAXI watches through the whole Galaxy.

12 kpc

8.5 kpc

$$F = \alpha L_{\text{Edd}} / 4\pi d^2$$

$\alpha = 0.01-0.04$  (Maccarone 2003)

*Soft-to-Hard Transition*

MAXI1828 (l, b) = (8.1, -6.5)  
d > 12 kpc !?

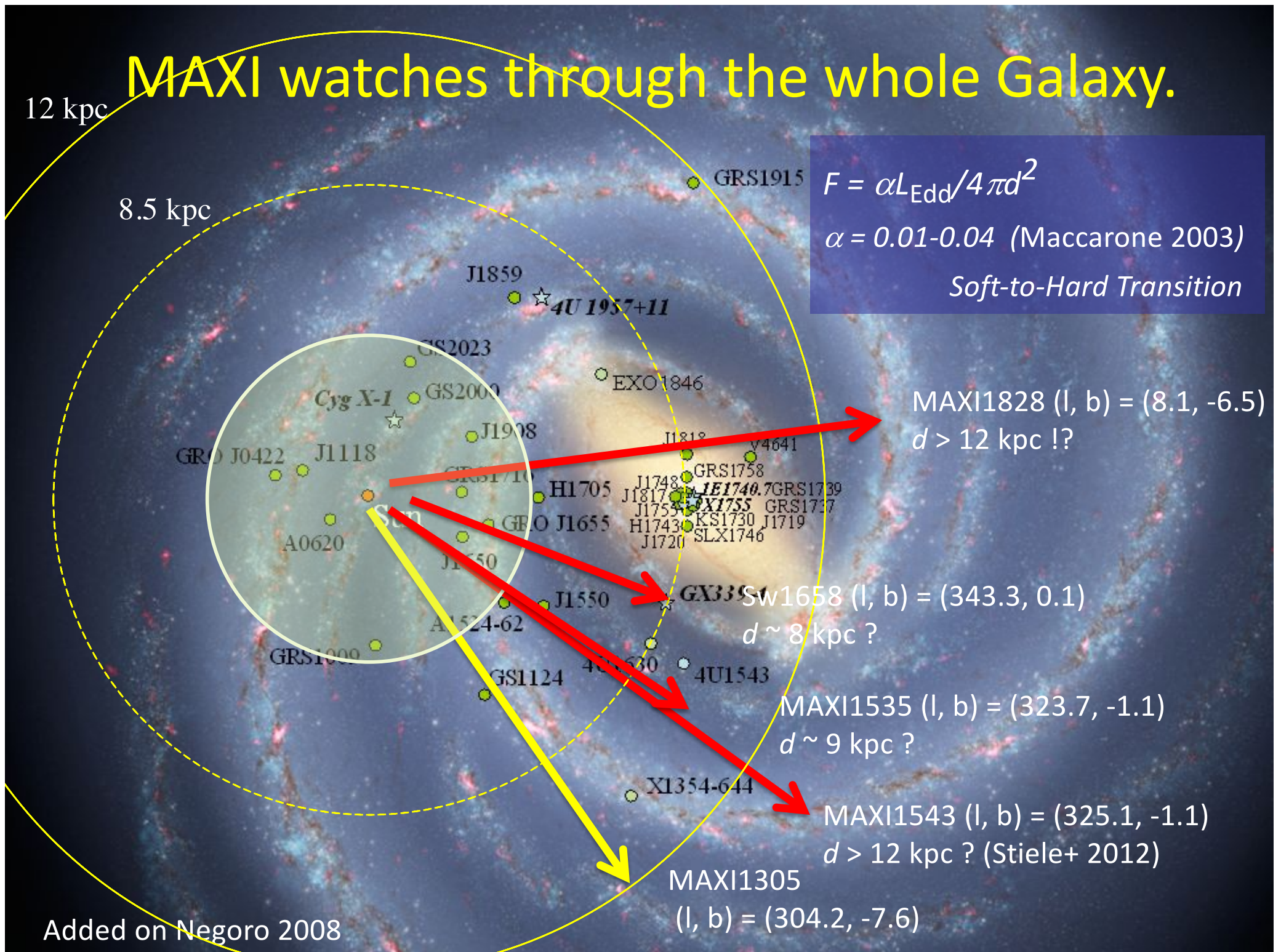
Sw1658 (l, b) = (343.3, 0.1)  
d ~ 8 kpc ?

MAXI1535 (l, b) = (323.7, -1.1)  
d ~ 9 kpc ?

MAXI1543 (l, b) = (325.1, -1.1)  
d > 12 kpc ? (Stiele+ 2012)

MAXI1305  
(l, b) = (304.2, -7.6)

Added on Negoro 2008



# Black Hole Binary — MAXI J1820+070

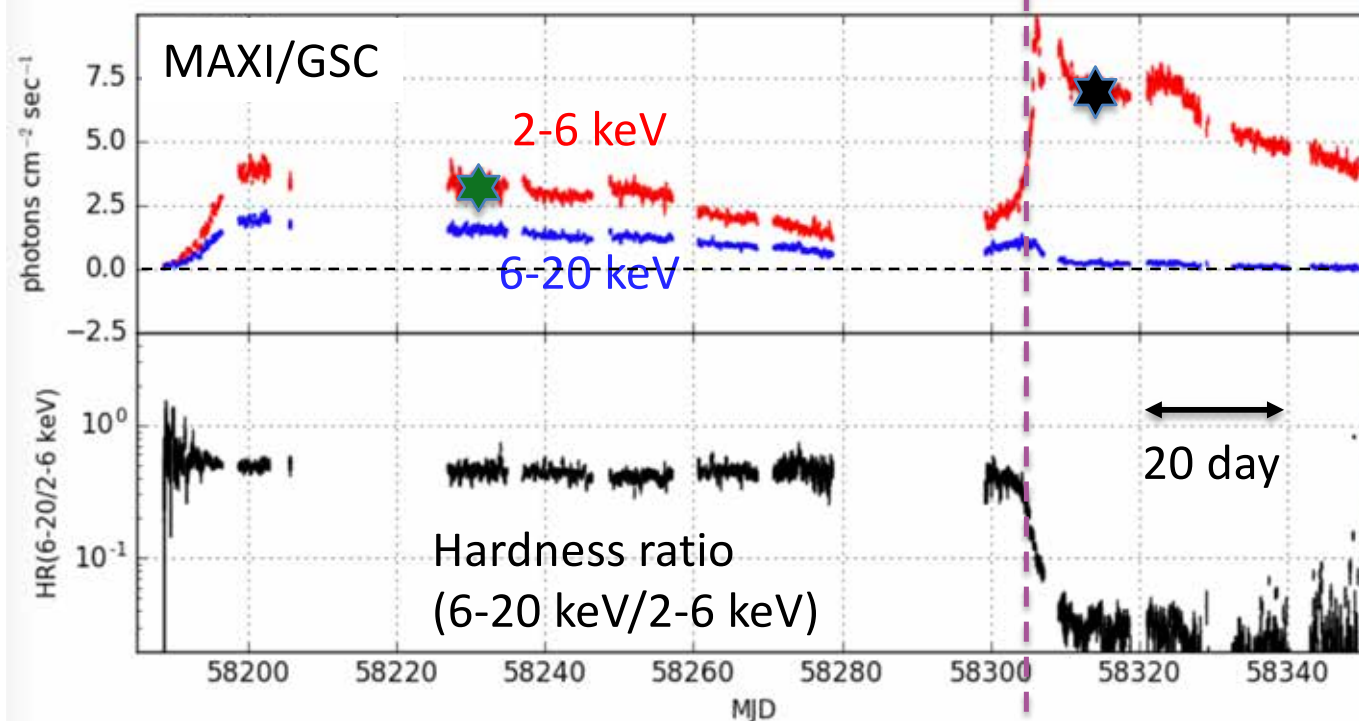
Discovery : March 11, 2018 (Kawamuro+ 2018 ATel #11399)

- Pre-discovery optical detection “ASASSN-18ey” March 5, 2018
- $(l, b) = (35.853, 10.160)$
- $N_{\text{H}} \sim 1 \times 10^{21} / \text{cm}^2$ ,  $A_{\text{v}} \sim 0.3$
- $D = 3 \pm 1$  kpc (Gandhi+ 2018, GAIA)

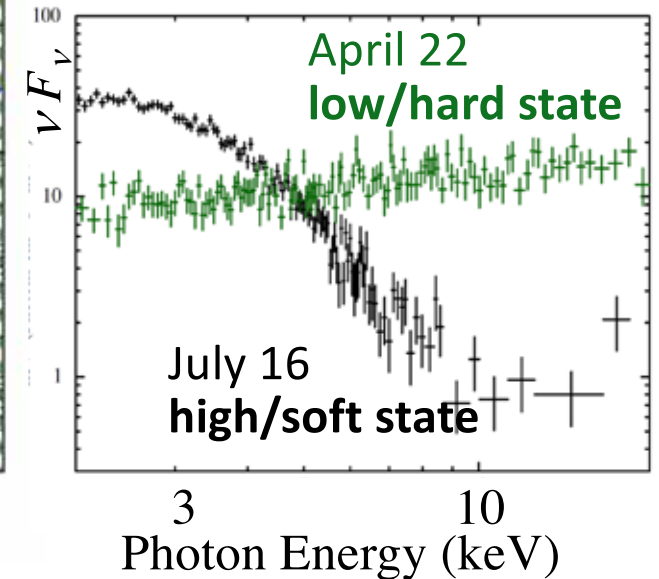
State Transition ( $T_0+120$  days)

Mar 11

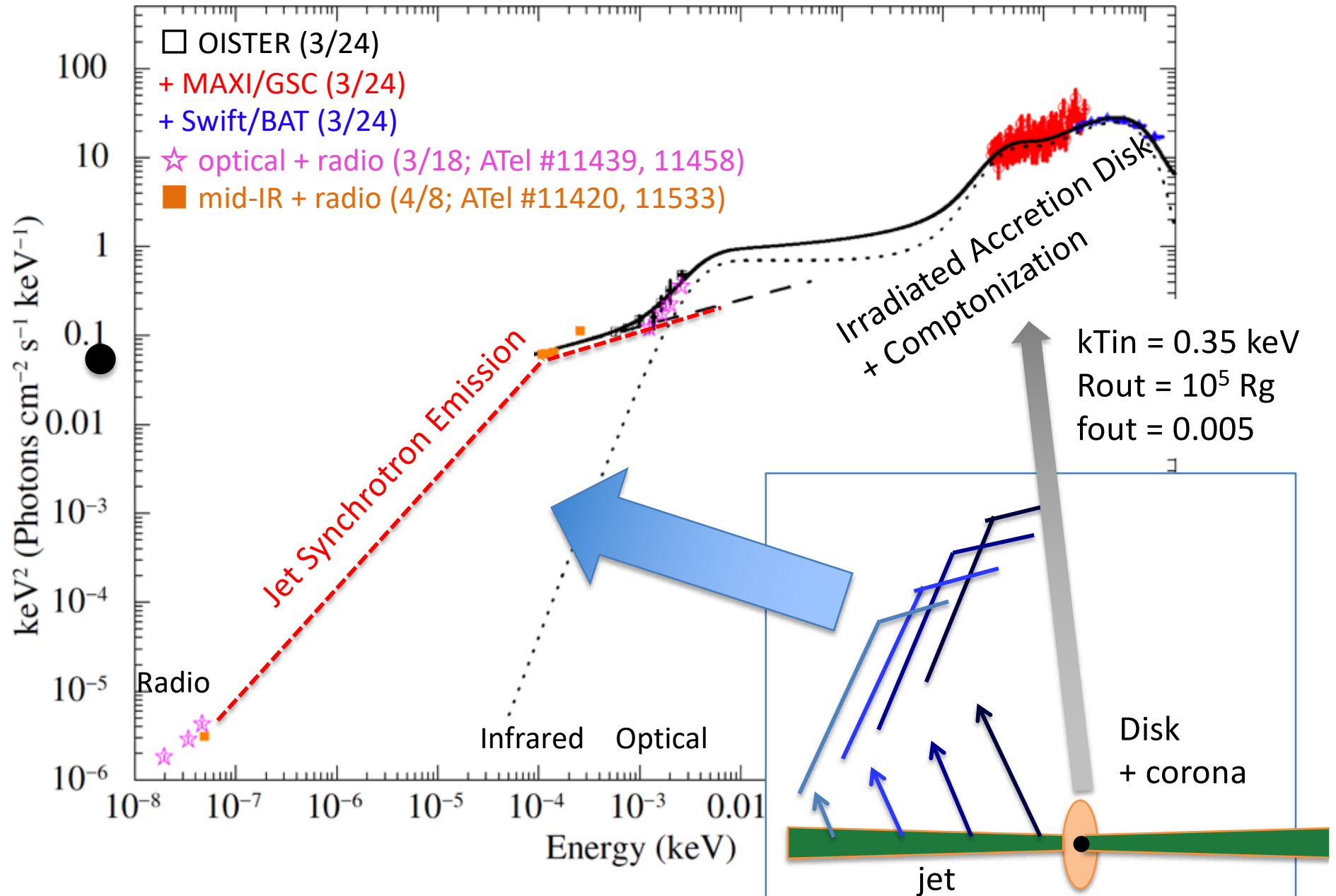
Early July



X-ray Spectrum (MAXI/GSC)



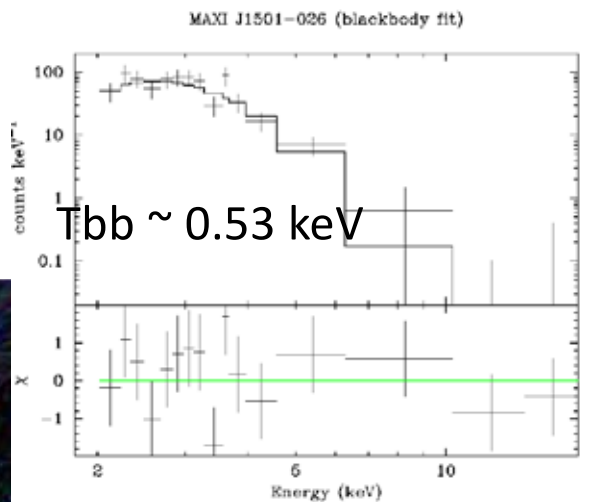
# Broadband Spectrum



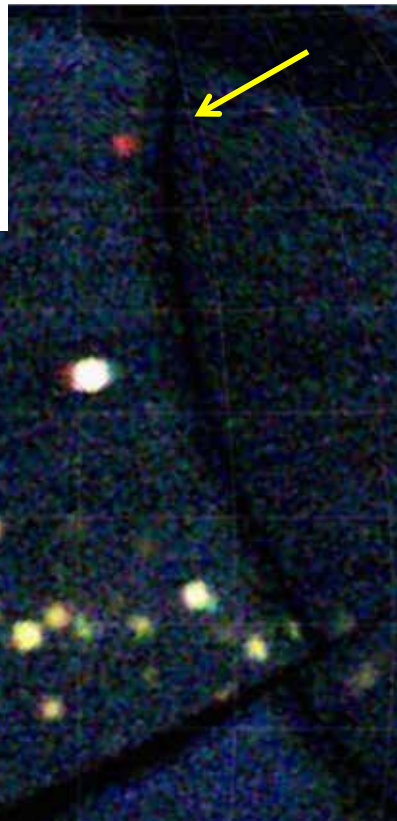


# Amazing Transients

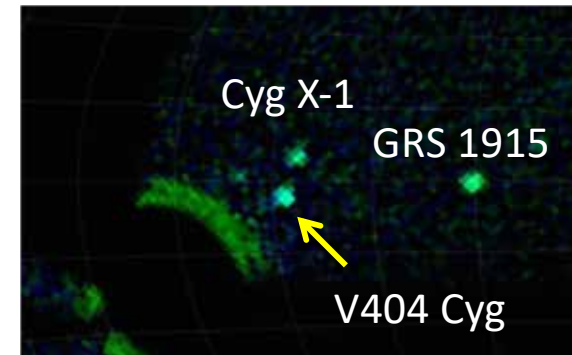
Short, soft X-ray transient **MAXI J1501-026** was discovered on 2015 Aug. 26.



Similar properties to MAXI J0157-744 (SSS), but neither X-ray (XRT) nor optical (KWFC) counterpart was detected.



**V404 Cyg** (GS 2023+338) woke up after 26 years on 2015 June 15. MAXI caught the source with a “degraded” camera **ACam 3**.

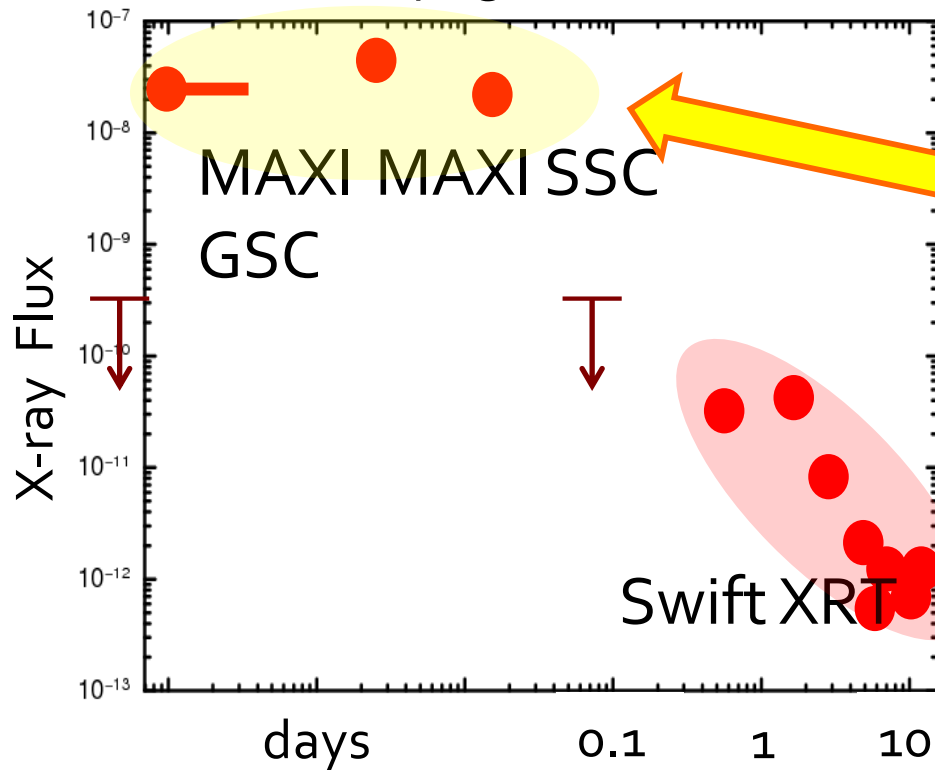


“First signs of renewed activity in V404 Cygni were spotted by the Burst Alert Telescope on NASA's Swift satellite, detecting a sudden burst of gamma rays, and then triggering observations with its X-ray telescope. Soon after, MAXI (Monitor of All-sky X-ray Image), part of the Japanese Experiment Module on the International Space Station, observed an X-ray flare from the same patch of the sky. These first detections triggered a massive campaign of observations from ground-based telescopes and from space-based observatories, to monitor V404 Cygni at many different wavelengths across the electromagnetic spectrum. As part of this worldwide effort, ESA's INTEGRAL gamma-ray observatory started monitoring the out-bursting black hole on 17 June” Taken from INTEGRAL@ESA web site



# MAXI J0158-744

X-ray light curve



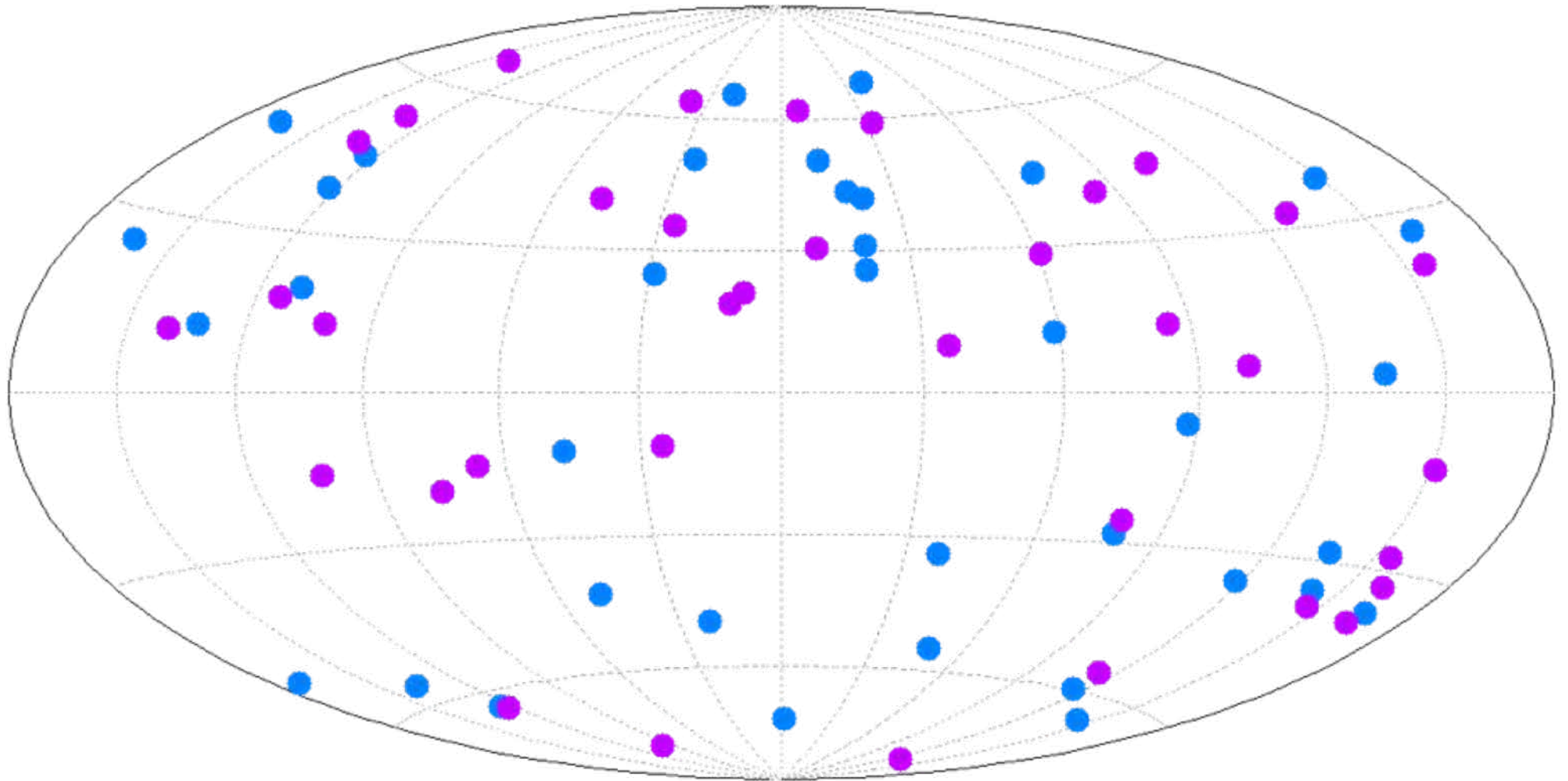
- Duration  $\approx$  hour
  - $(1300 \text{ s} < \Delta T < 1.1 \times 10^4 \text{ s})$
- Extremely luminous
  - $10^{40} \text{ erg / s}$
  - x100 solar mass Eddington luminosity
- supersoft X-ray source at late phase
  - white dwarf
  - classical/recurrent nova?
    - but  $\times 10^4$  more luminous than known nova X-ray emission
      - (shocked ISM? Li et al. 2012)

Morii et al. 2013



# MAXI GRBs and transients (2–20 keV)

---



- : only MAXI (43)
- : MAXI + other (39 prompt + 7 afterglows)

Serino et al. (2014)

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



# MAXI Unidentified Short Soft Transient (MUSST)

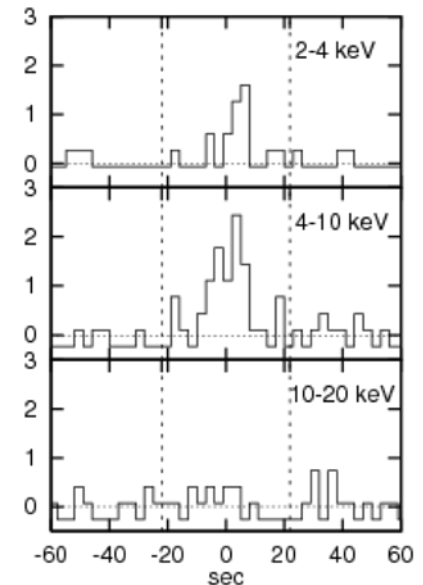
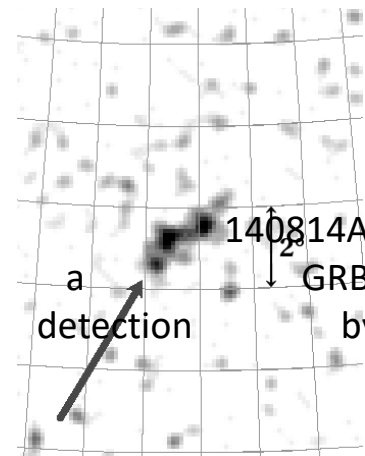
- Detected only in X-ray band (MAXI 2-10 keV) : **Soft**
  - No detection by Swift/BAT (15-50 keV)
- Fades out before Swift/XRT follow-up at a half day later : **Short transient**
- No detection by Swift/XRT ends up **unidentified**
  - MAXI localization (0.3deg) is insufficient for optical follow-ups.
- 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 Reported as a detection but no 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.



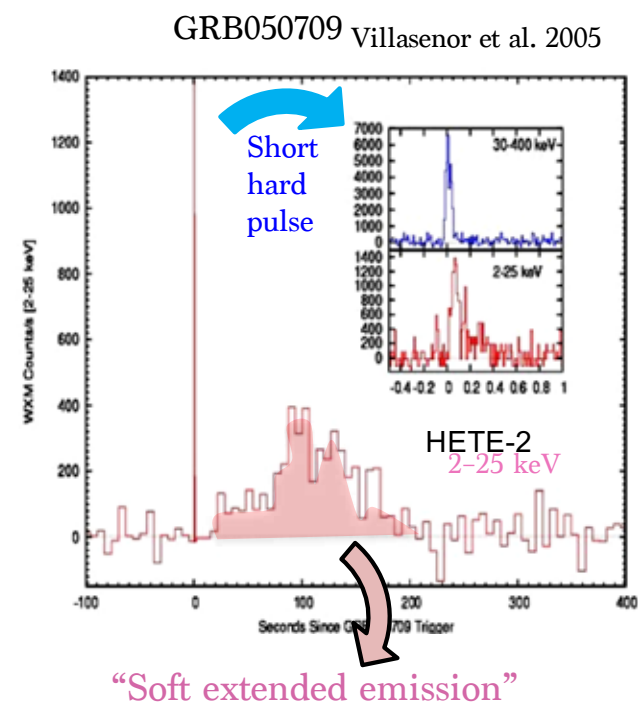
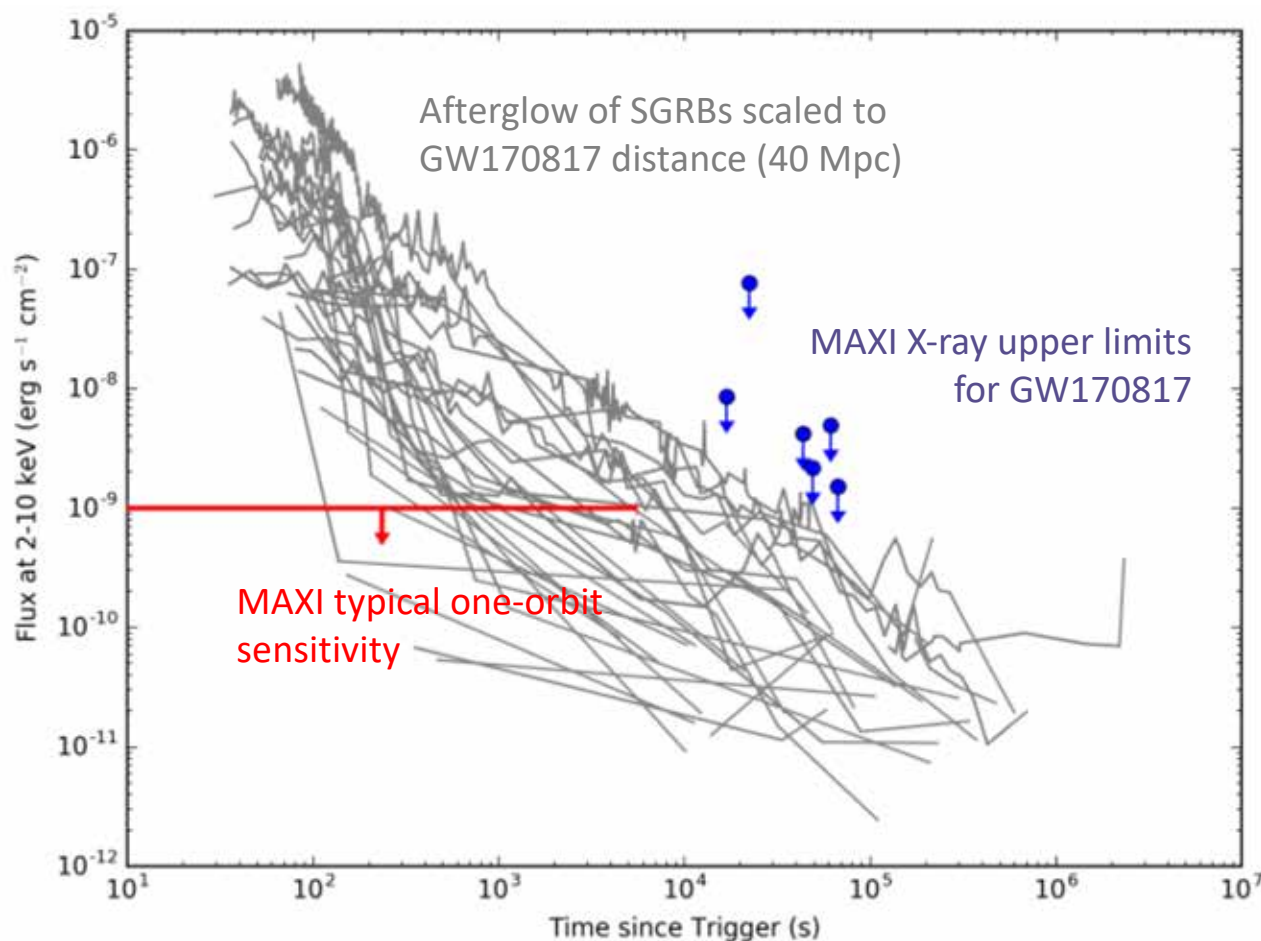
## What are these short soft transients?

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



# 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)



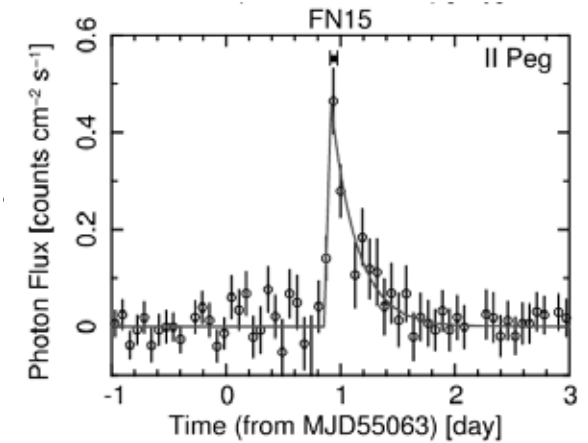


# Giant Stellar Flares

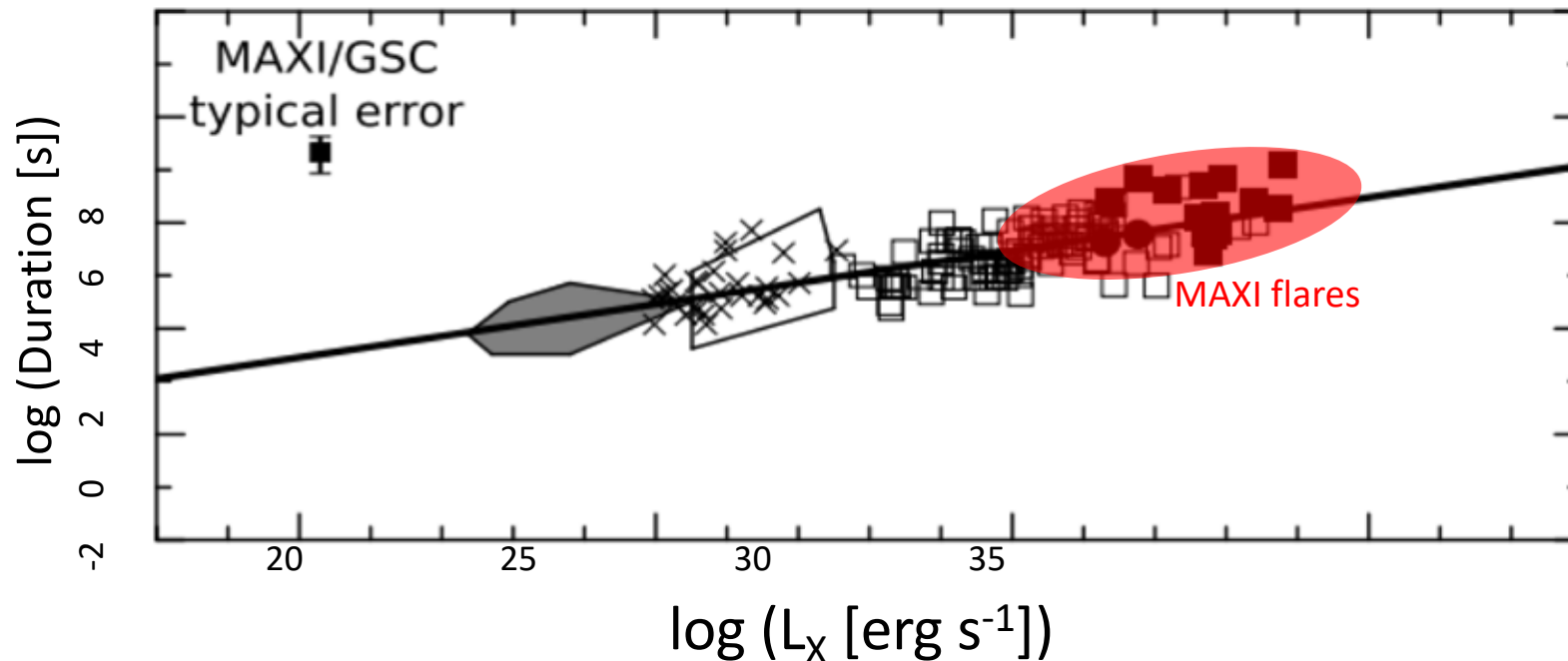
Tsuboi+ 2016

- MAXI detected 23 stellar flares in 2009 Aug - 2011 Aug.
- 2-6 orders of magnitude larger energies were observed in the flares detected with MAXI than those of solar flares

A universal correlation between  $L_x$  and duration time was found, which holds from solar micro flares to the MAXI giant flares.



MAXI giant flare from II Peg



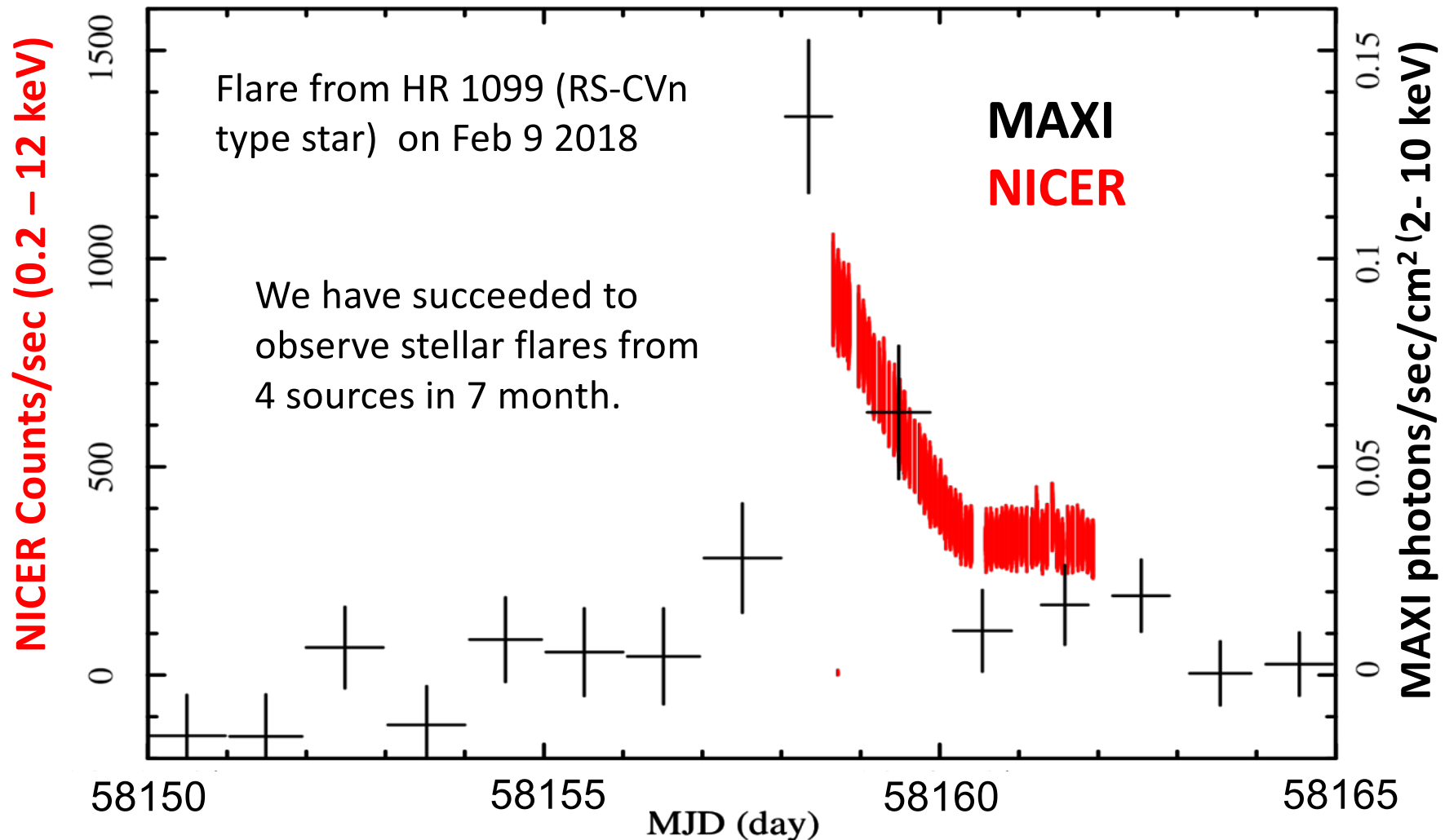


# Stellar flare observation by MANGA

- 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.





# GSC catalog

Hori+ 2018 ApJS 235, 7

Kawamuro+ 2018 ApJS 238, 32

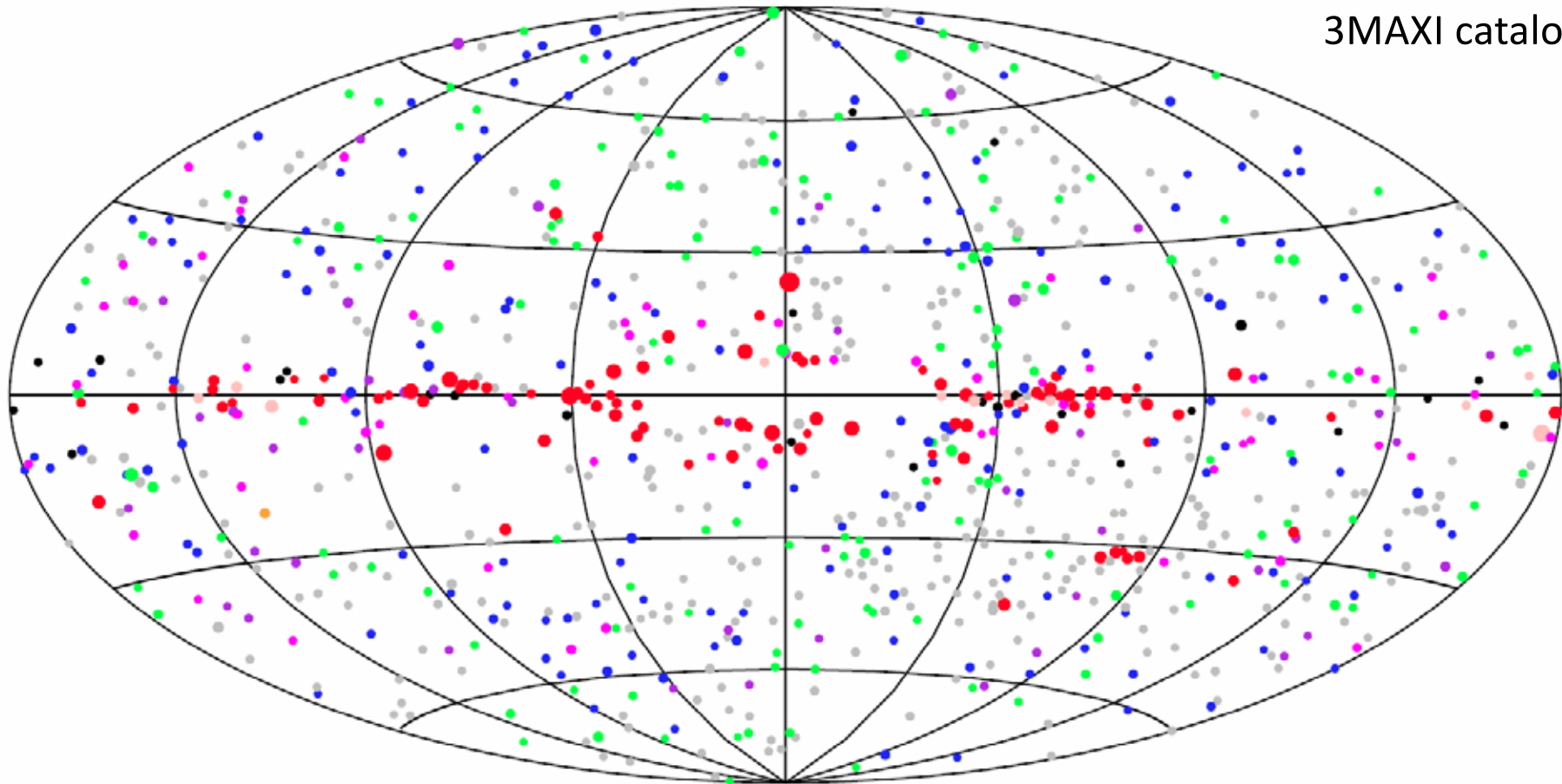
---

- 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  $\sim 0.4$  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

3MAXI catalog



Seyfert  
Cluster

Quasar  
Galaxy

X-ray Binary  
Pulsar

CV  
Star

SNR  
Unidentified



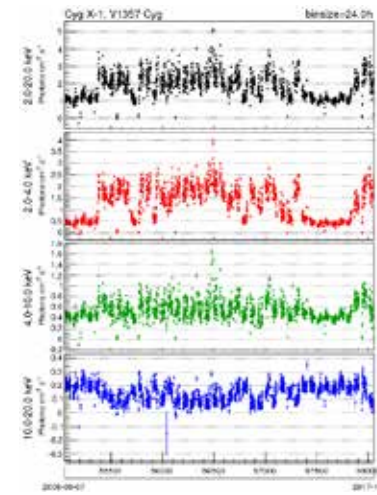


# Data distribution

- 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

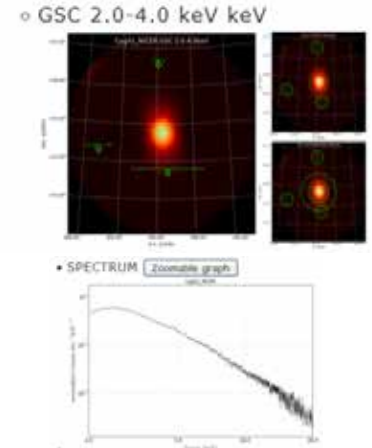


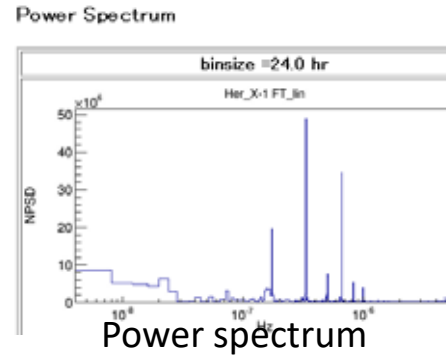
Image and spectrum by ondemand

The BeXRB monitor

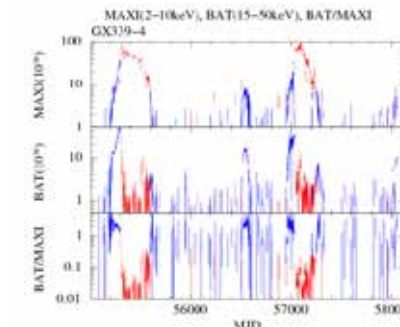
Recent activity of selected Be X-ray binaries as detected

Name	Plot	Activity Prob.	Average flux [mCrab]	Data	Activity Prob.	Average flux [mCrab]	Data	Acti
SWIFT_A040-B4124		52.4%	22.7	0314h	100%	3600.8	0312Ph	
1J021958-47		+	18.4	1012Ph	92.2%	79.8	0212Ph	

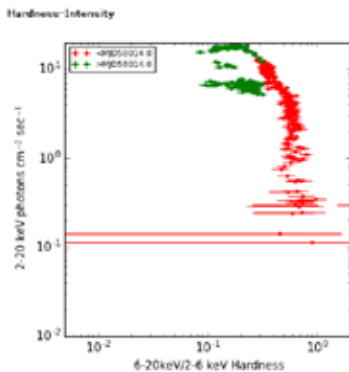
BeXRB monitor @ ESA



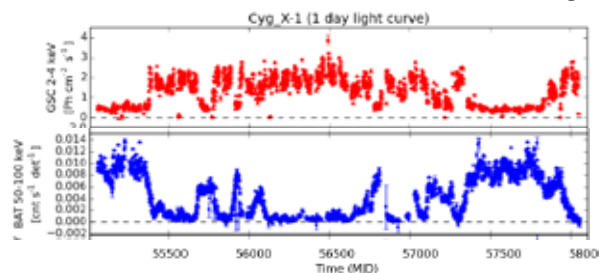
Power spectrum



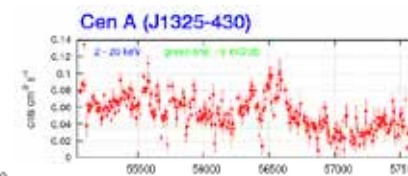
MAXI-BAT Hardness ratio



MAXI 1535 monitor



BAT-MAXI transient monitor



Weekly light curves

MAXI GRBs

```
class BatGRB & out of FoV event 4 low galactic lat: 6 "MUST" only MAXI so
```

No.	Name	Time	RA, Dec	galactic l, b	GCN/ATel
05	170611A	06:24:22.72	106, 30014	171.2186, -8.705	GCN185
04	170820A	03:15:45.267	244, -2.000	22.8824, +12.9080	GCN1761
03	170808A	02:47:48.157	564, -28.277	268.7847, +25.0687	GCN1492

MAXI GRB list



# Future: Time-domain astronomy of Rapidly decaying objects

Rapidness of follow-up in X-ray and sensitivity

