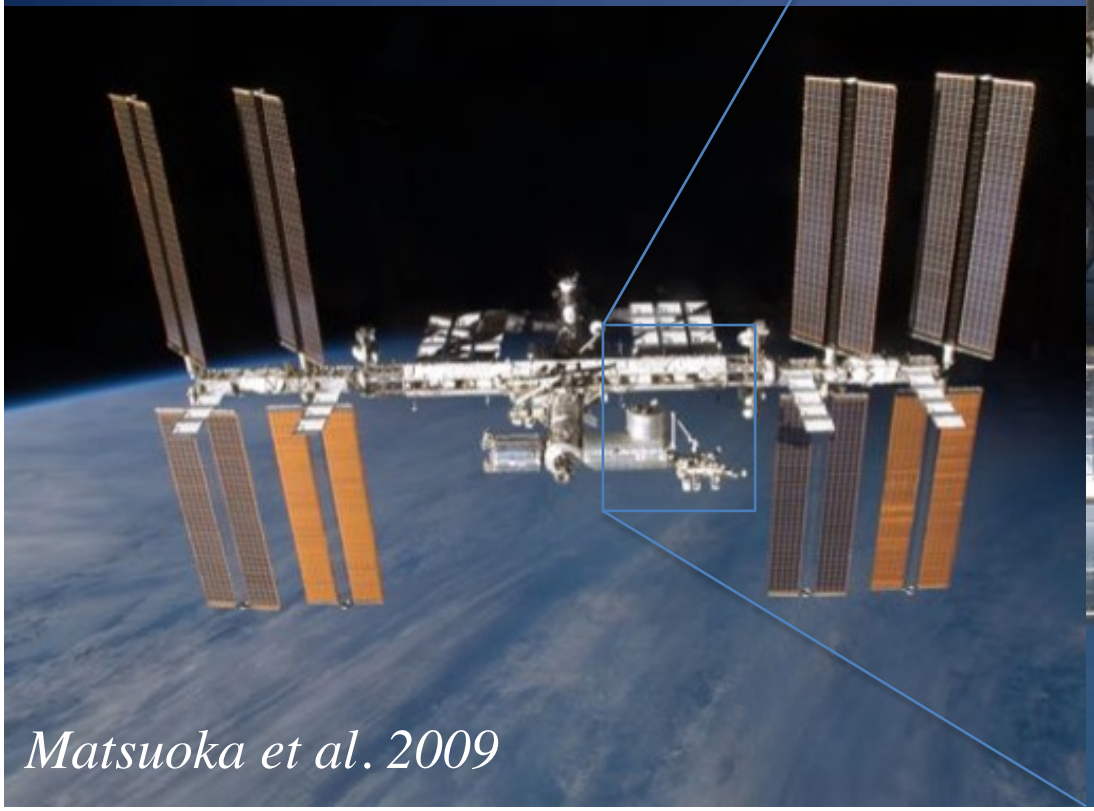
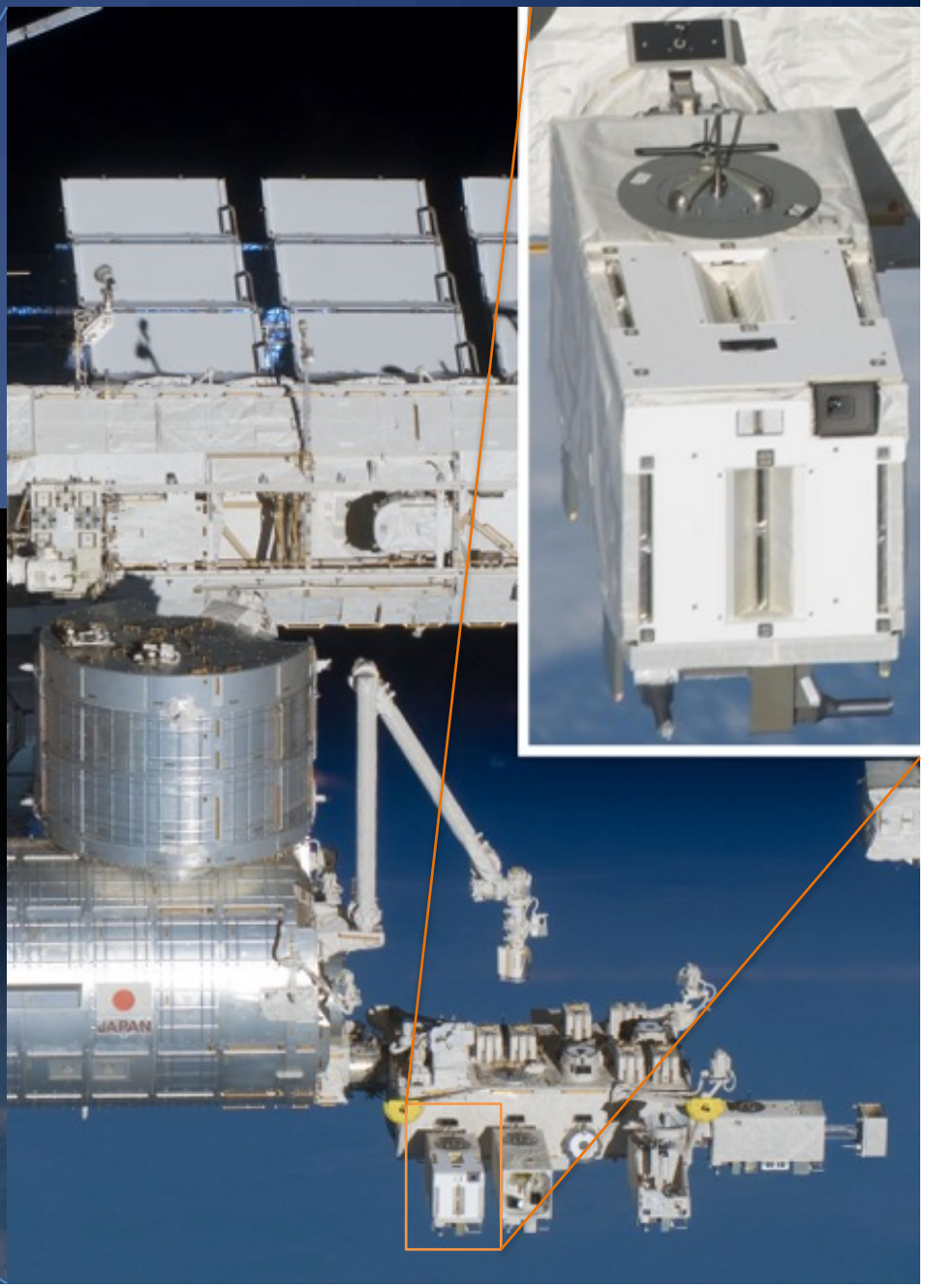
Monitoring High-Energy Transients with MAXI

Nobuyuki Kawai (Tokyo Tech)
on behalf of the MAXI Team

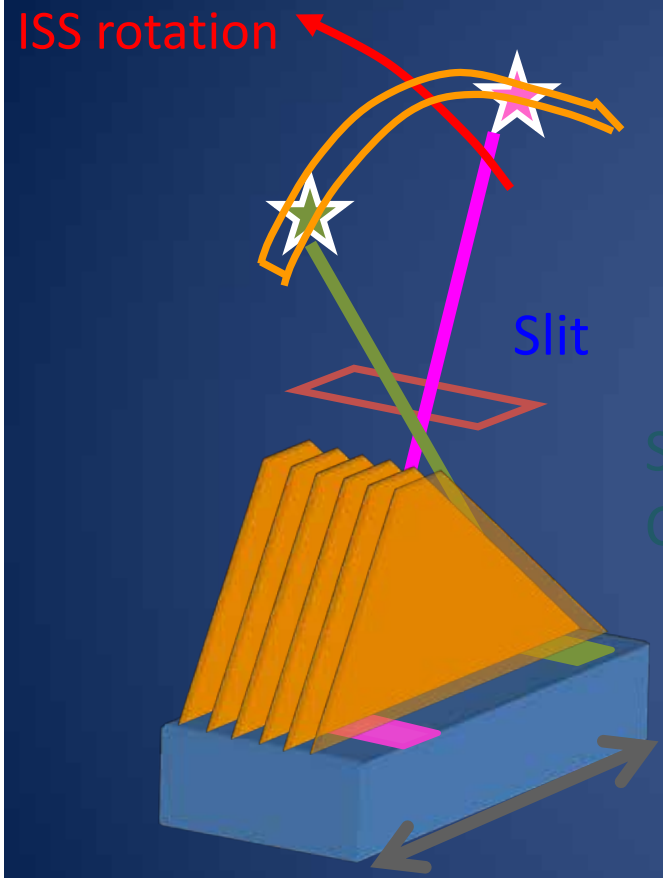
Monitor of All-Sky X-ray Image

- Mission started August 2009
- Ops approved until Mar 2018
- Real-time link ~70%

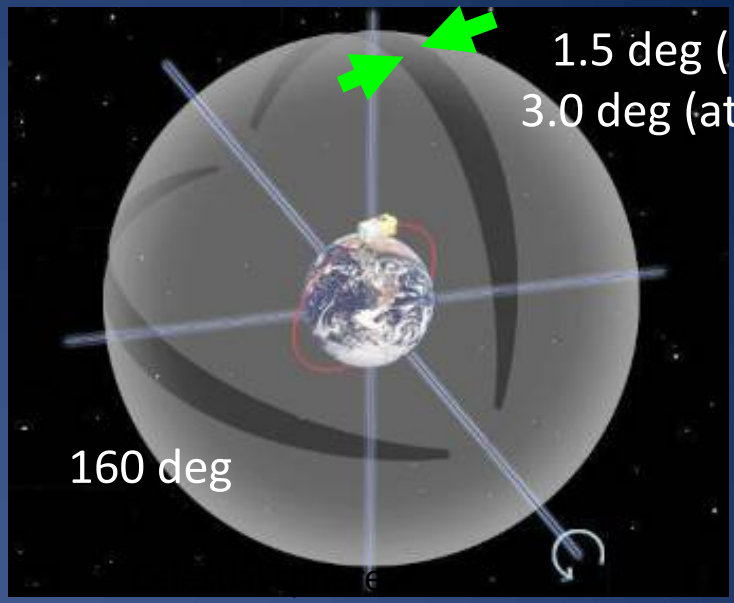




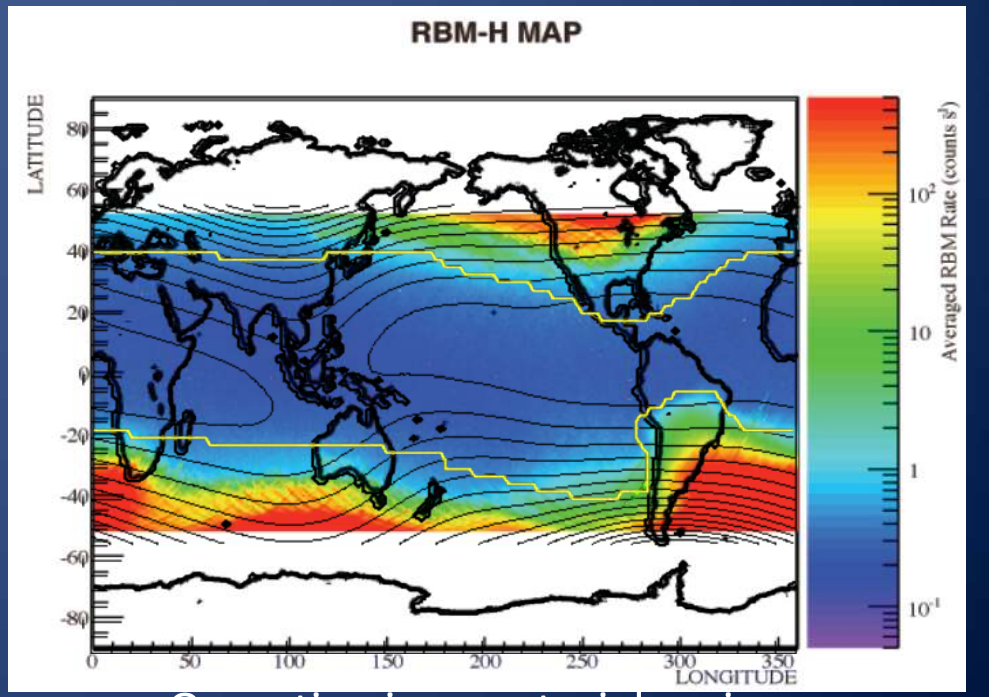
Scans with Slit + Slats collimator



1-dimensional position sensitive detector



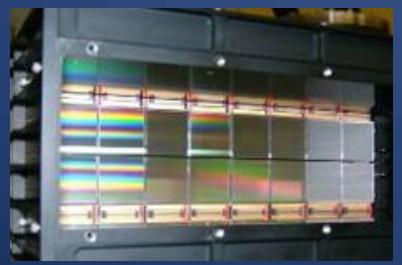
3



Operating in equatorial region

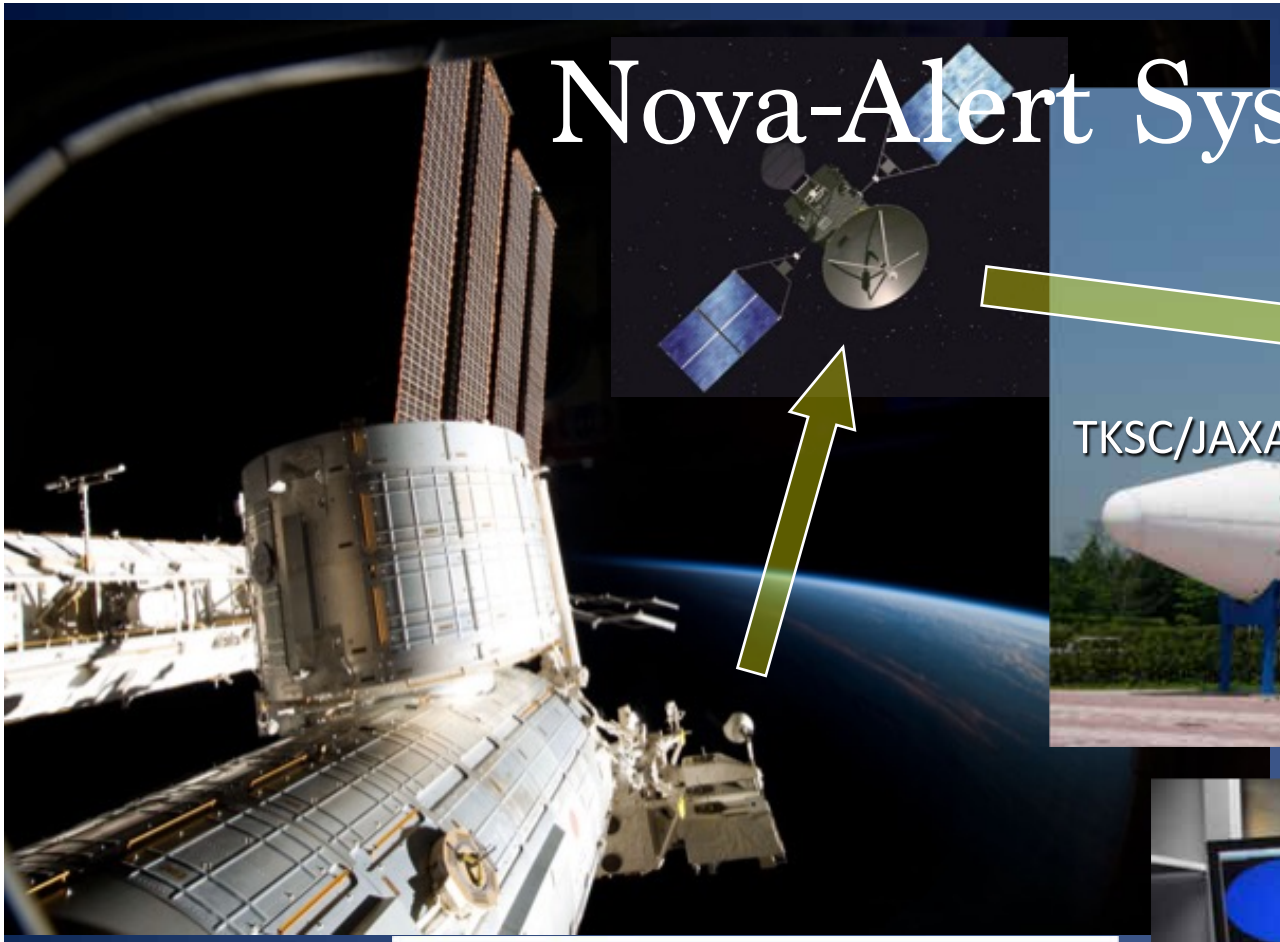
proportional counter

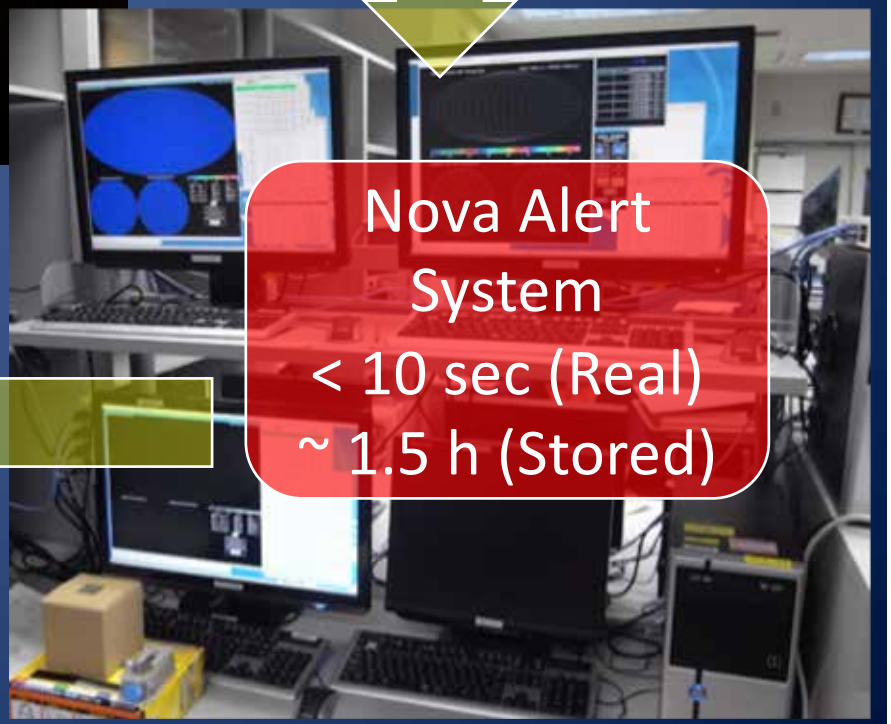
X-ray CCD



Nova-Alert System

Negoro+ 2016, PASJ





Nova Alert System
< 10 sec (Real)
~ 1.5 h (Stored)

RIKEN & MAXI MLs (& ATel/GCN)

Novae -- list --

ID	Image	Date	RA, Dec	com
5337375271 958473409 (Warning)		2010-05-21T10:36:34	(308.764, 37.464)	EXO 2030+375
5352037956 959732429 (Alert)		2010-06-05T00:20:14	(82.544, -66.334)	LMC X-4
5360024421 960424195 (Warning)		2010-06-13T00:29:40	(230.060, -57.227)	Cir X-1
5360277271 960453730 (Alert)		2010-06-13T08:41:55	(277.330, -24.044)	GS 1826-238
5360774677 960506625 (Alert)		2010-06-13T23:23:30	(230.037, -57.016)	Cir X-1
5363094768 960687741 (Warning)		2010-06-16T01:42:06	(52.055, -40.713)	Transient event
5365027798 [illegible] (Alert)		2010-06-18T01:28:17	(289.188, -5.447)	X-ray burst of 4U
[illegible] 961659391 (Warning)		2010-06-27T07:36:16	(84.738, 26.065)	A 0535+262
5378212885 962002493 (Warning)		2010-07-01T06:54:38	(189.997, -34.181)	likely to be an XRF

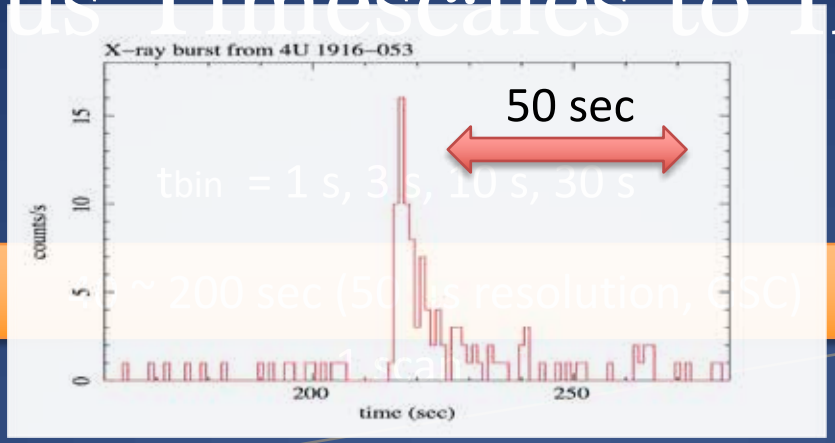
Various Timescales to Investigate

X, γ-ray bursts

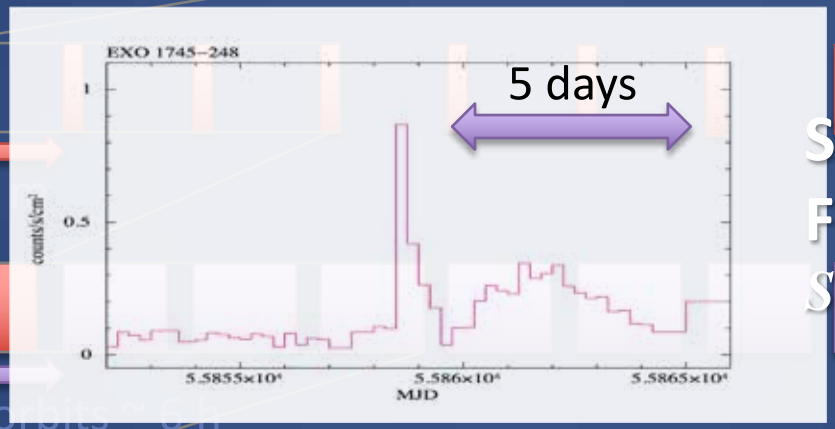
Superburst
SFXT
Star Flares

X-ray novae

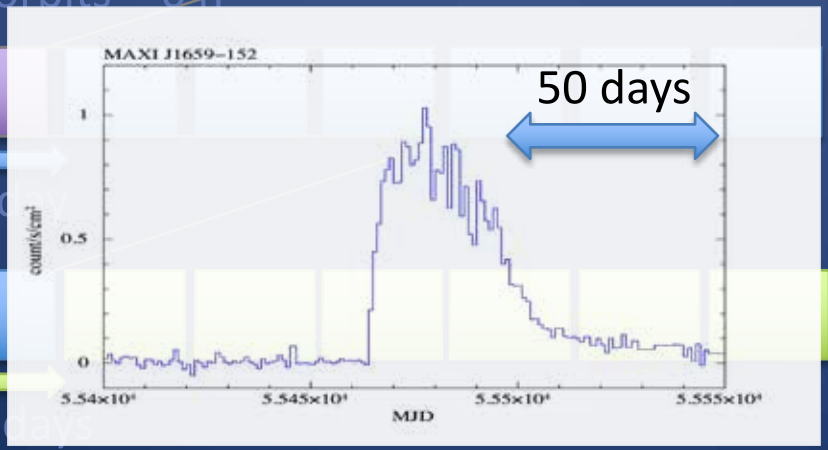
AGN Flares



X-ray burst
From 4U 1916-053



Superburst + Outburst
From EXO 1745-248
Serino+ 2012



BH Outburst
MAXI J1659-152
Negoro+ 2010,
Yamaoka+ 2011

X-ray New "MAXI" Transients/Novae

Negoro+ 2016

5(+1) X-ray novae were newly discovered in the last 3yrs.

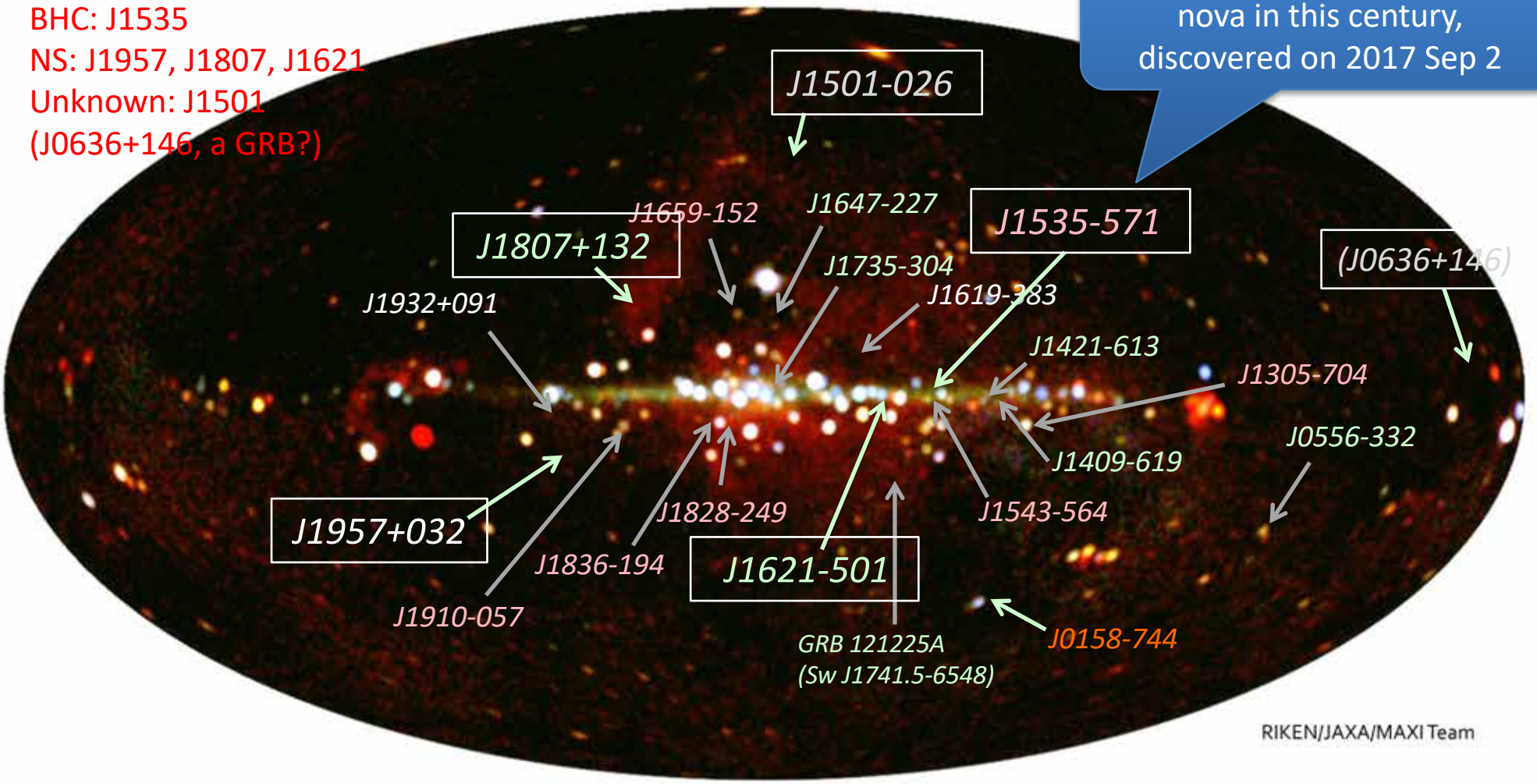
BHC: J1535

NS: J1957, J1807, J1621

Unknown: J1501

(J0636+146, a GRB?)

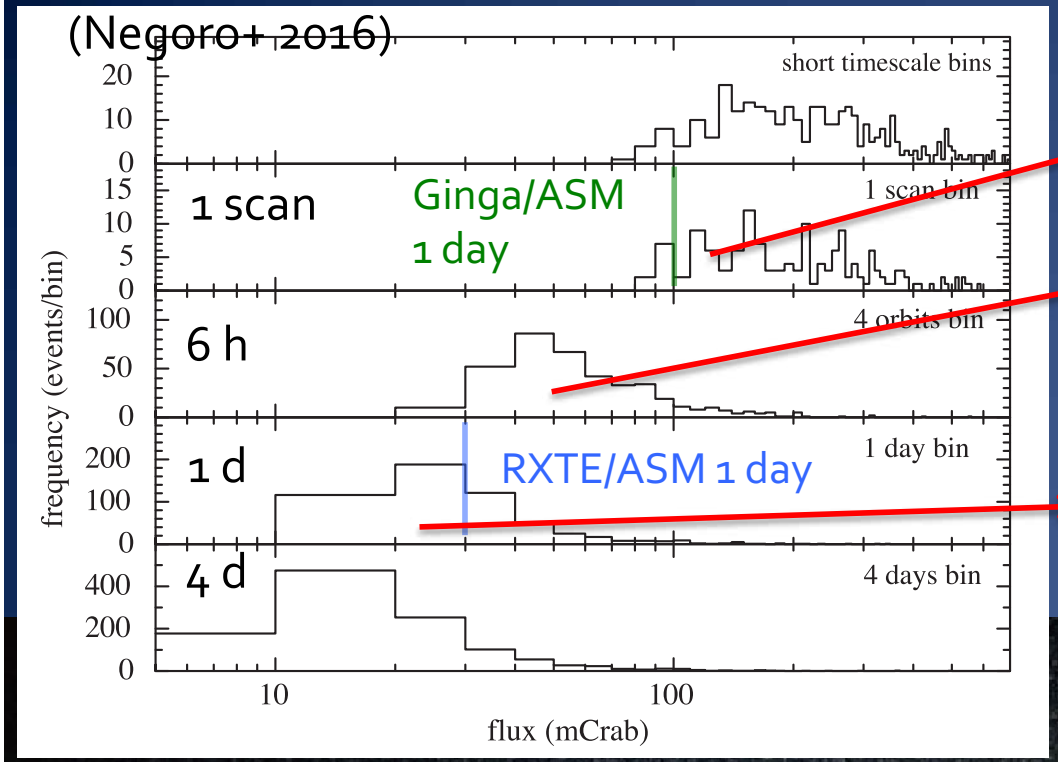
Brightest Black Hole X-ray nova in this century, discovered on 2017 Sep 2



Total 21 : 7 black holes, 11 neutron stars, 1 white dwarf and 1(+1) unknown.

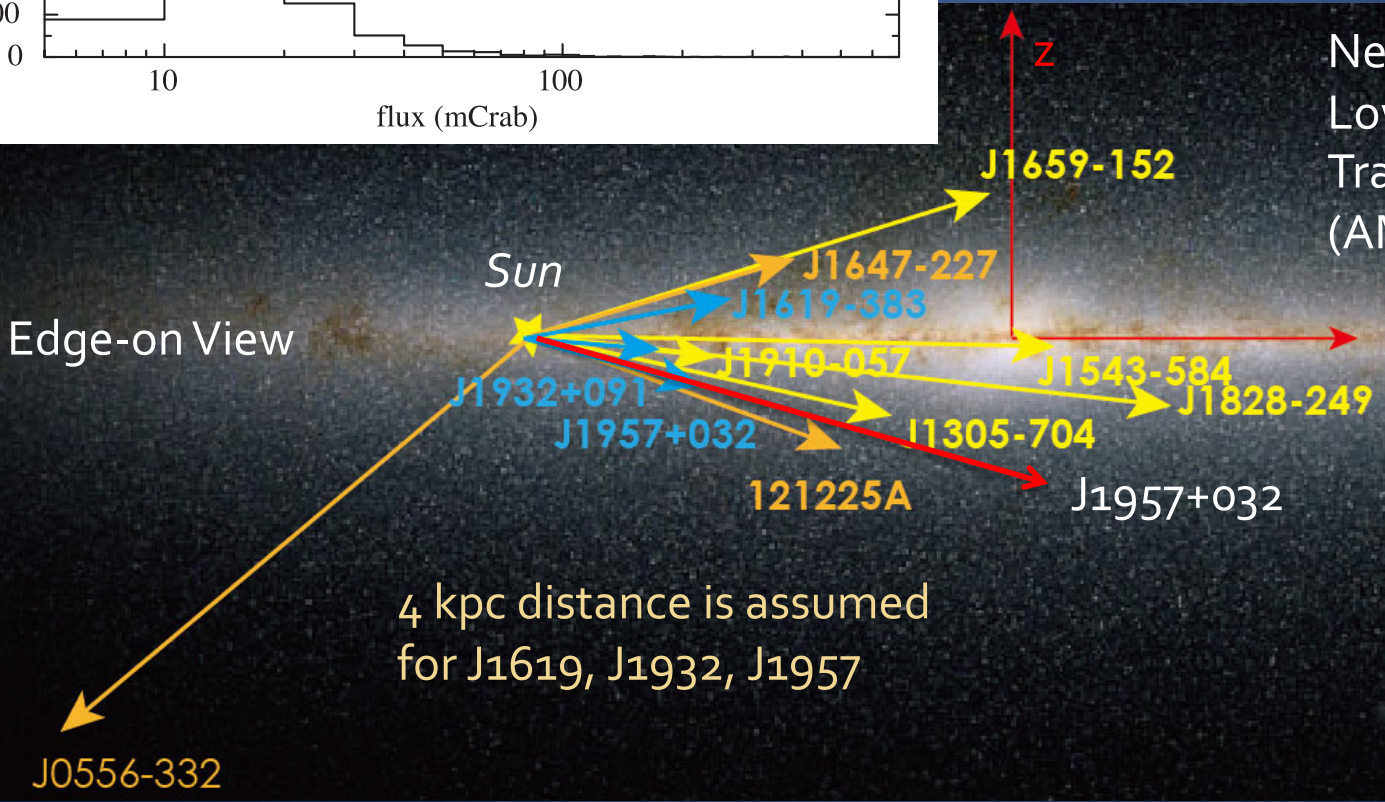
Flux distribution of alerts on different time scales

(Negoro+ 2016)



MAXI Transients

- XRB SLX 1735-269, IGR J1724-3257
  - + GRBs
- MAXI J0636+146, MAXI J1957+032
  - + Hyper Star flares, SFXTs, ...
- H 1743-322, 4U 1711-34, GRS [illegible]16+....
- 4U 0728-25



Edge-on View

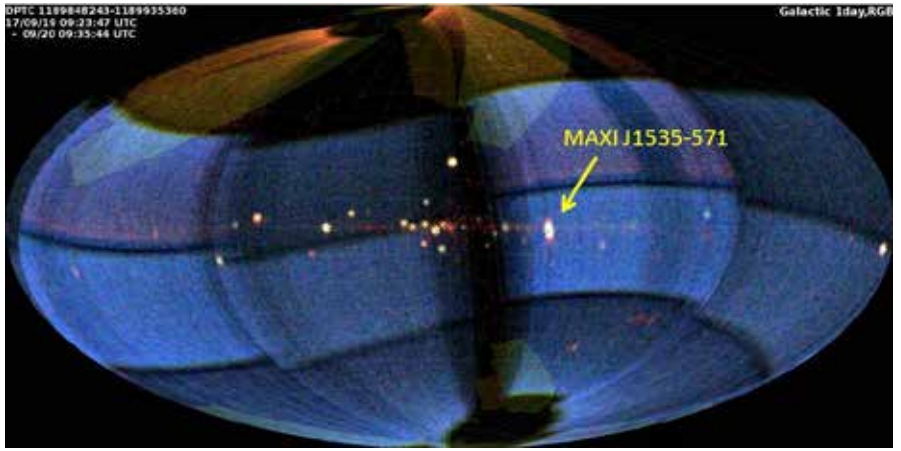
New class object in halo?
Low-mass Fast X-ray Transients (LFXT) !?
(AMXP ? Burst Only Src?)

4 kpc distance is assumed for J1619, J1932, J1957

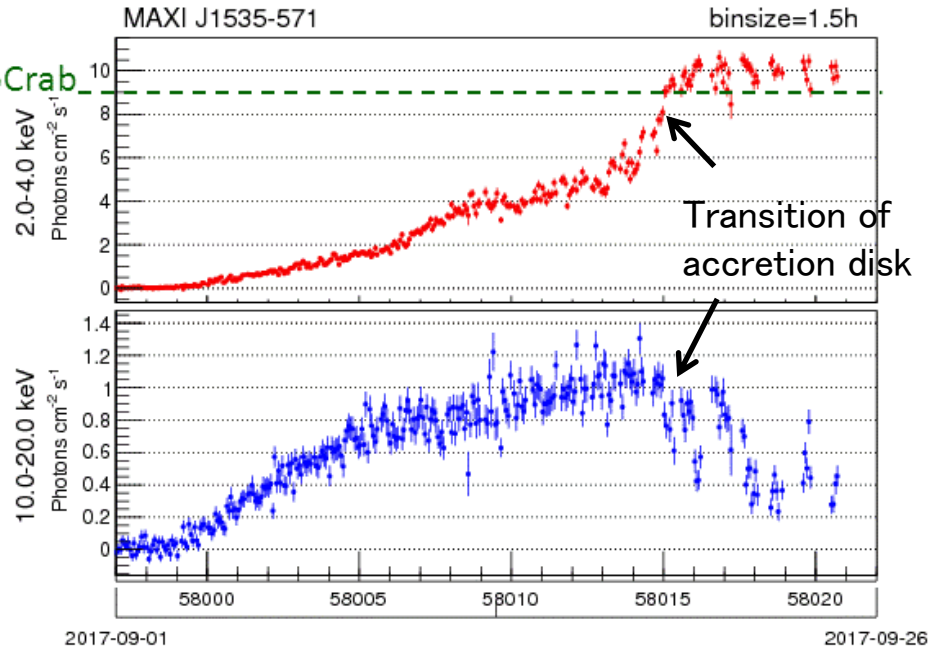
optical/radio follow-up essential

Blackhole binary : MAXI J1535-571

- MAXI detected an X-ray nova at 23:55UT on 2017 Sep 2. and named it **MAXI J1535-571** (ATel #10699). Four hour (20:00) before it, Swift had also detected it (GCN #21788). Five hours (14:41) before Swift, MAXI novasearch program had detected it automatically.
- MAXI J1535-571 increased the flux and reached 5 Crab on Sep 19. It was the brightest X-ray nova since MAXI was launched. It was the 7th brightest in history. In fact it was the brightest X-ray nova since 1999, that is, in the 21st century.
- Swift, NuSTAR, Chandra, NICER have observed MAXI J1535 as well as optical and infrared telescopes.
- NICER team reported a complex disk line in the spectrum and a QPO with good photon statistics.(ATel #10768)

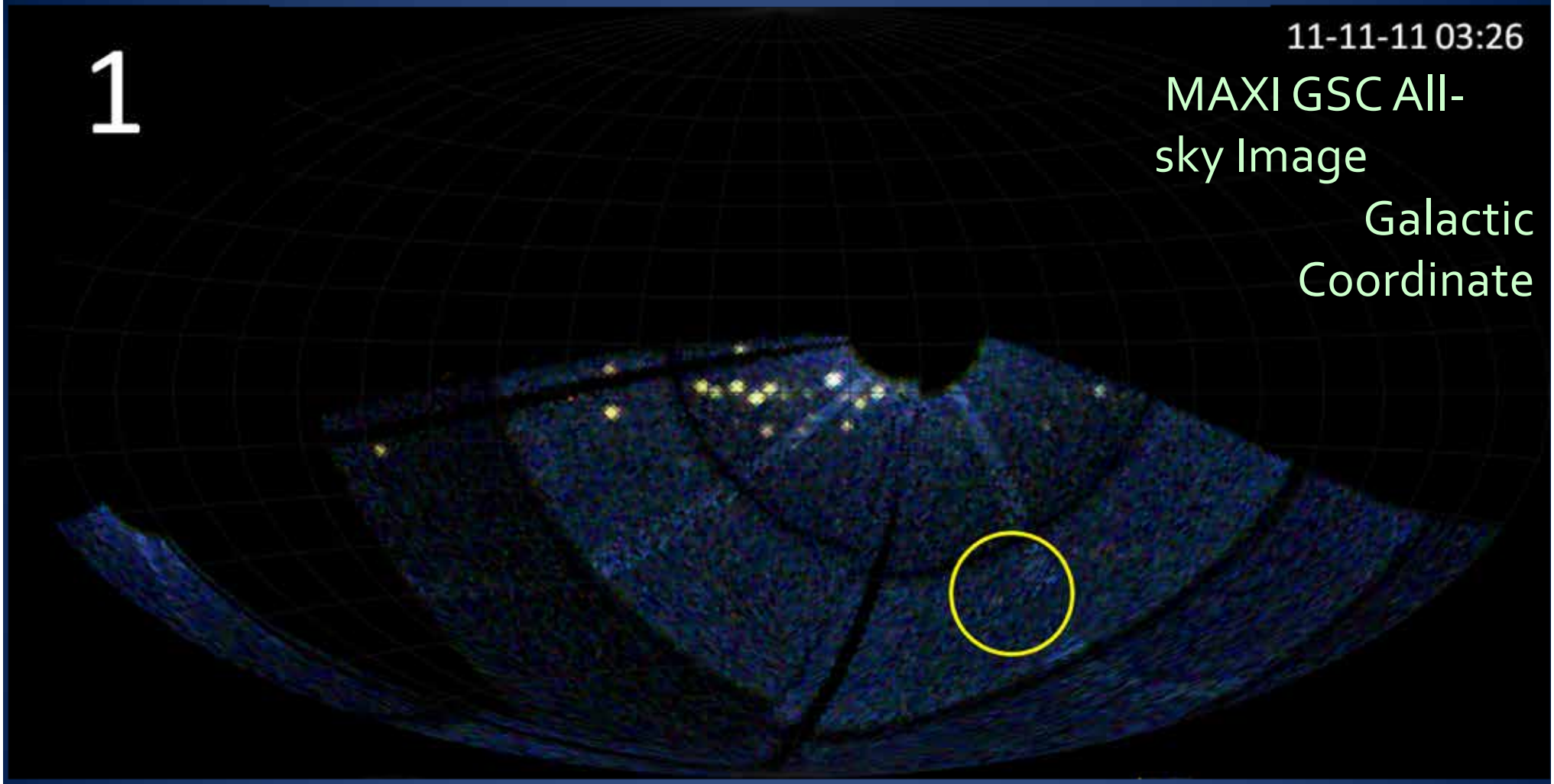


MAXI sky map on 2017 Sep. 19.



MAXI light curve of MAXI J1535-571

MAXI J0158-744: unique soft X-ray transient

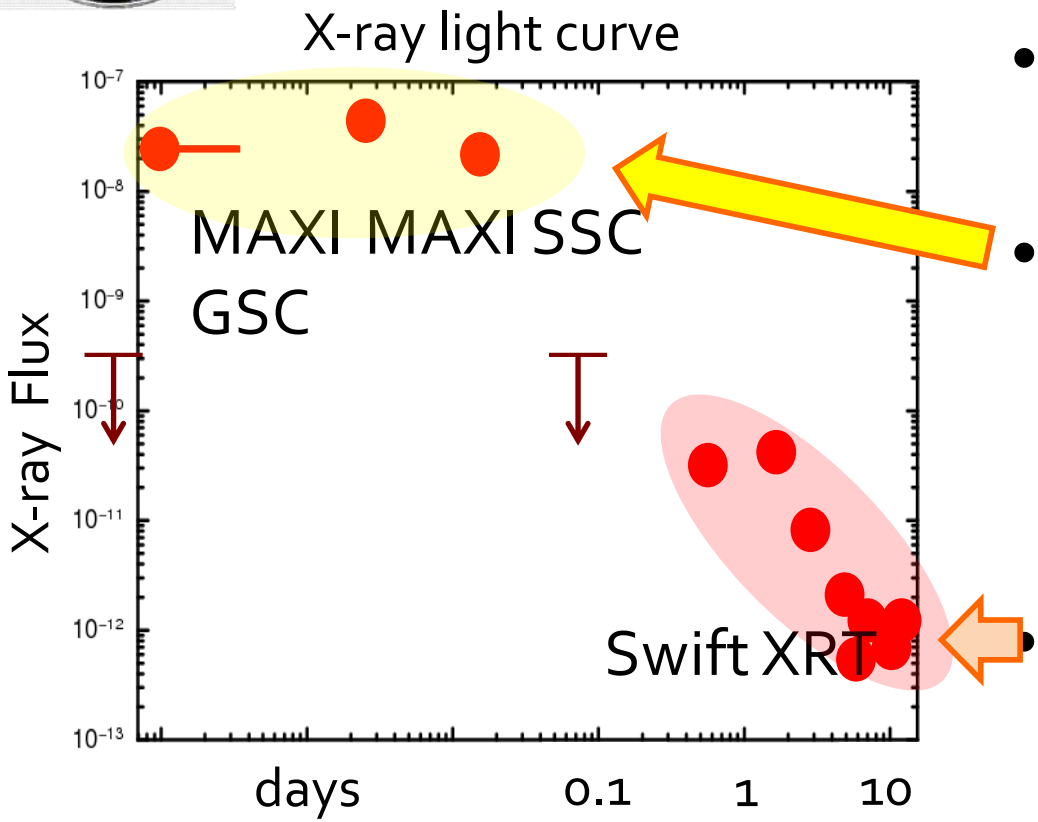


- 2011-11-11 05:05:59 (UT)
- GRB 111111A
- Soft X-ray transient (< 5 keV)

- Swift follow-up lead to identification to a star near SMC (Be star at 60 kpc)

Morii et al. 2013

MAXI J0158-744



- Duration ≈ hour
  - (1300 s <ΔT< 1.1 x 10^4 s)
- Extremely luminous
  - 10^{40} erg / s
  - x100 solar mass Eddington luminosity
- supersoft X-ray source at late phase
  - → white dwarf
  - classical/recurrent nova?
    - but x10^4 more luminous than known nova X-ray emission
      - (shocked ISM? Li et al. 2012)

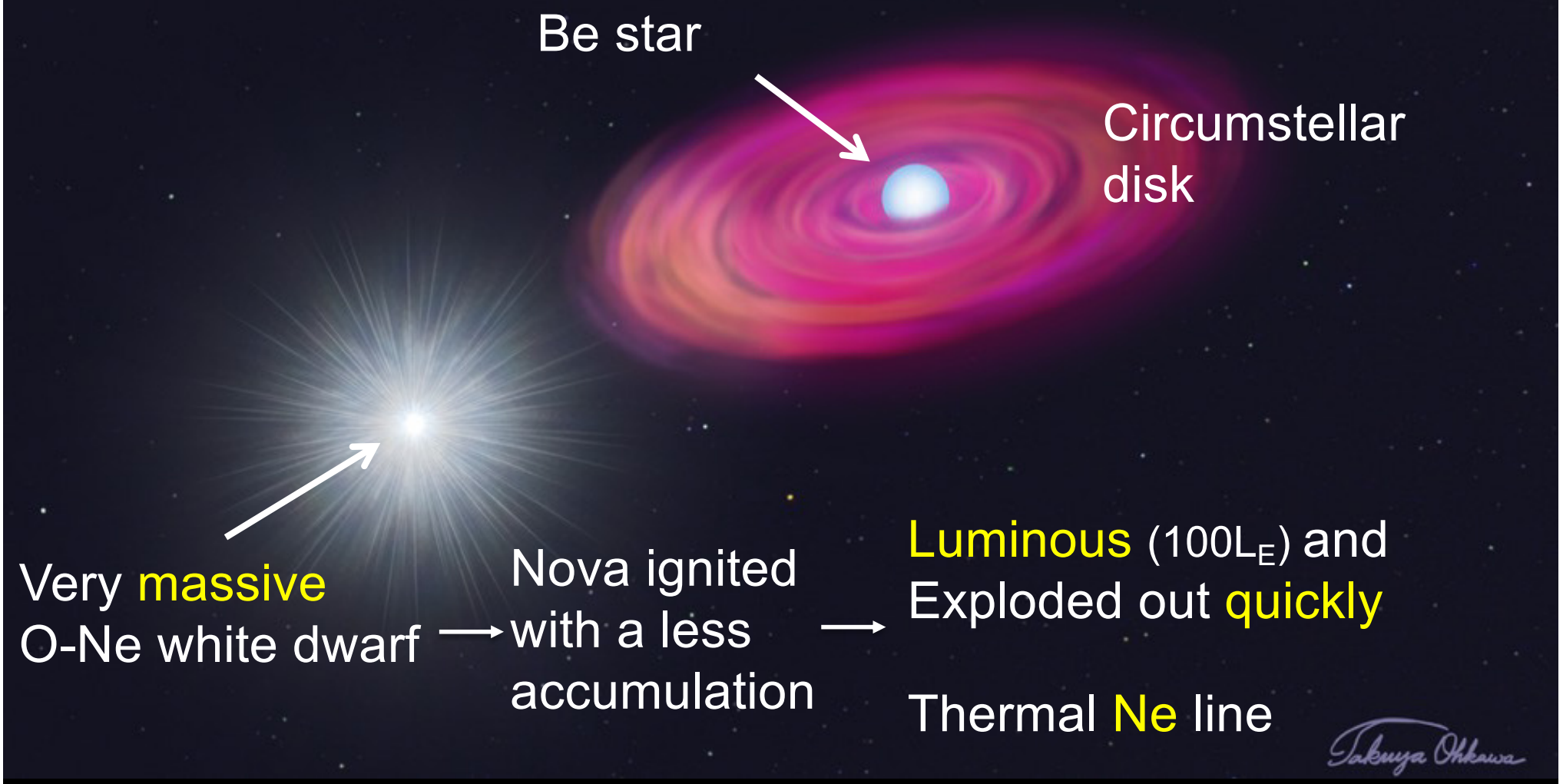
Morii et al. 2013

Nova (nuclear fusion) explosion

Morii et al. (2013)

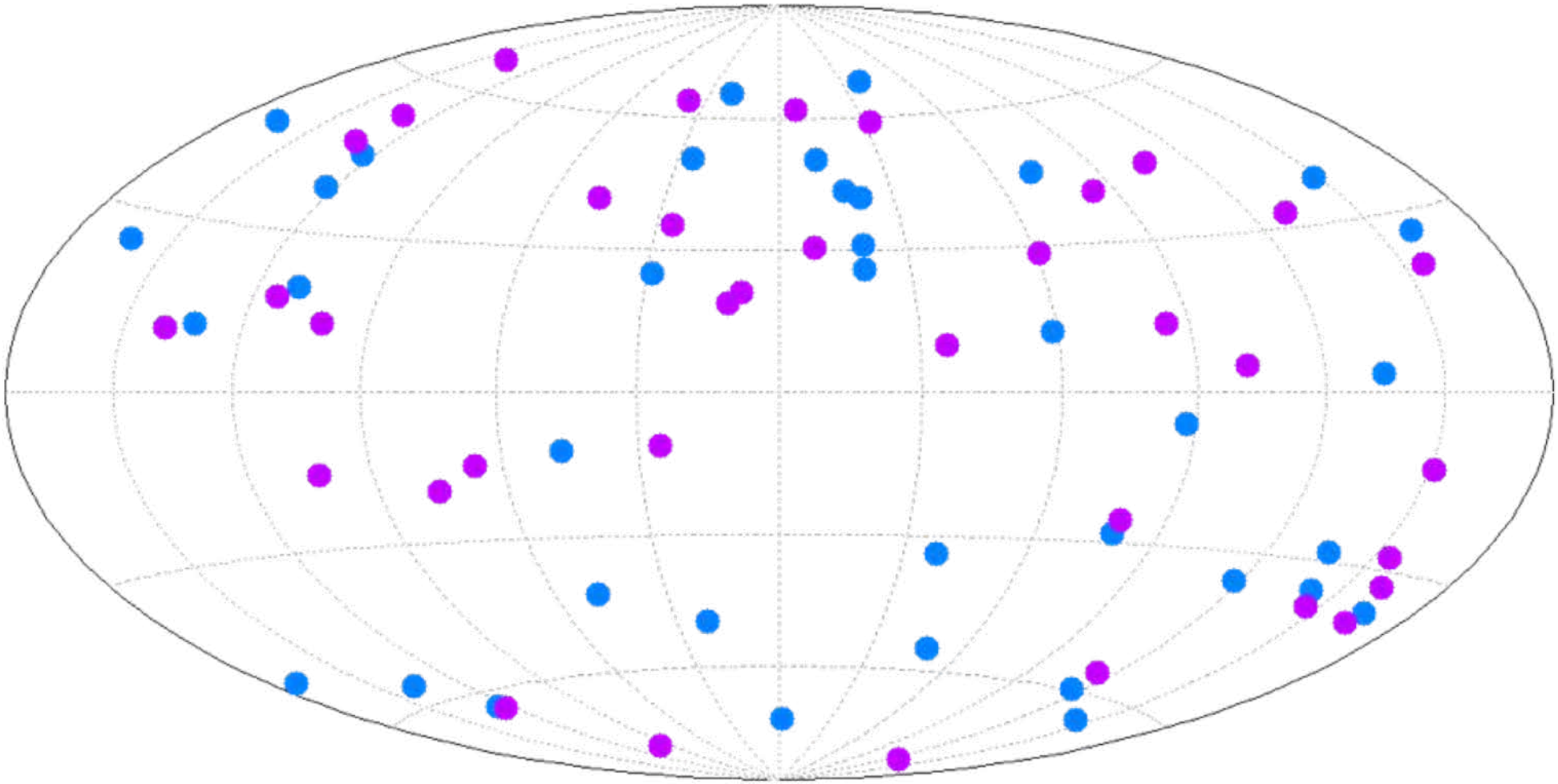
rare

WD-Be binary system (MAXI J0158-744)



Credit: Takuya Ohkawa

MAXI GRBs and transients (2—20 keV)



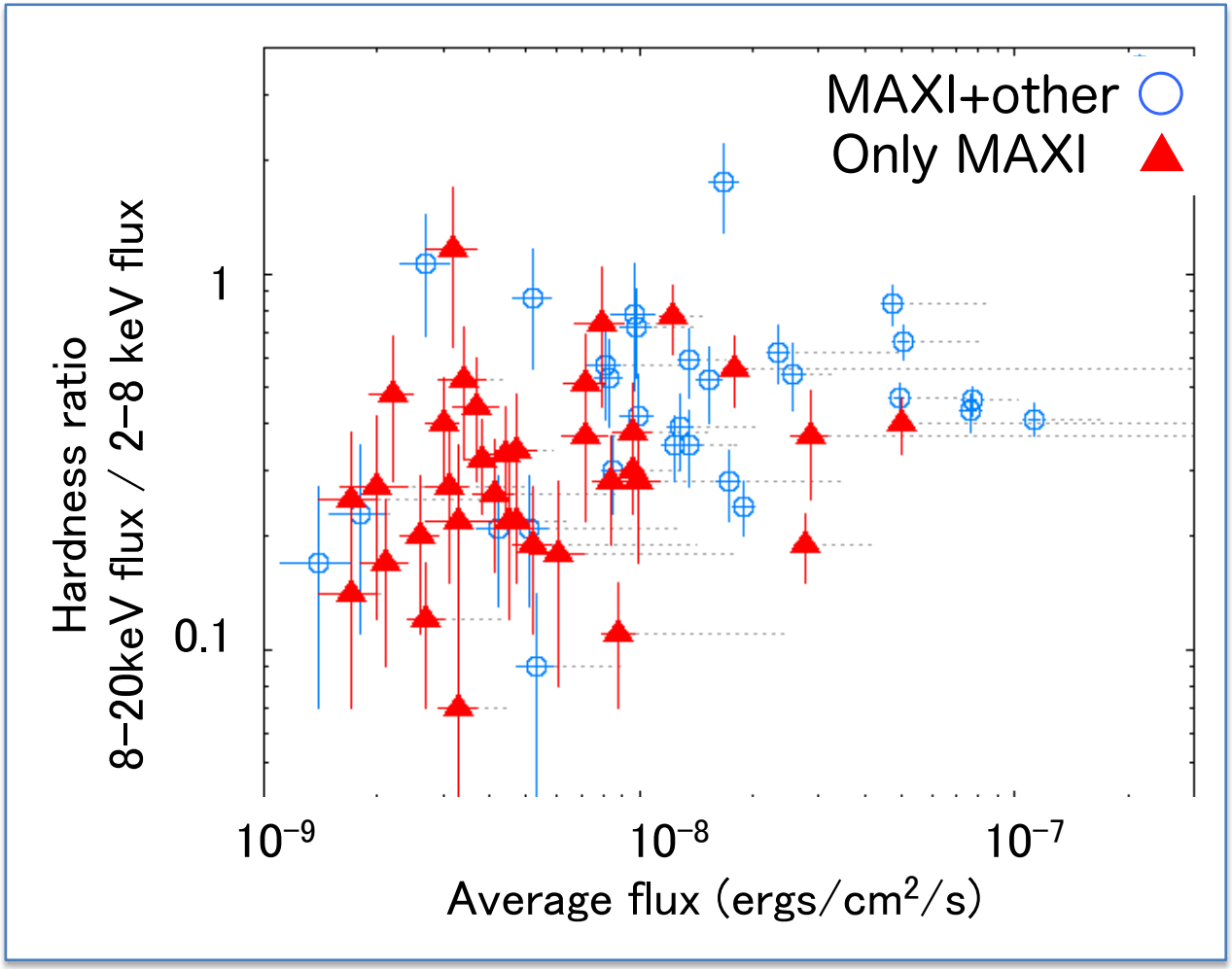
Serino et al. (2014)

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

●: only MAXI (43)

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

Flux and Hardness



1/2 of MAXI GRBs are "Only MAXI" events

Only MAXI GRBs tend to Soft and Dim

many of them are XRFs?

Slide by M. Serino

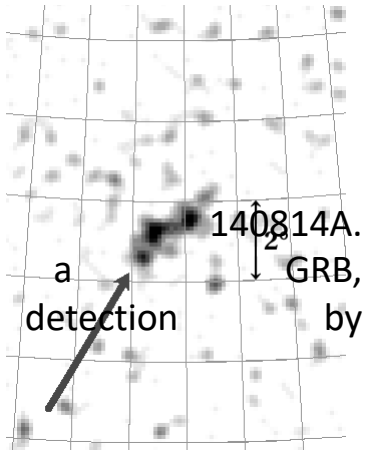
MAXI Unidentified Short Soft Transient (MUSST)

- 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).

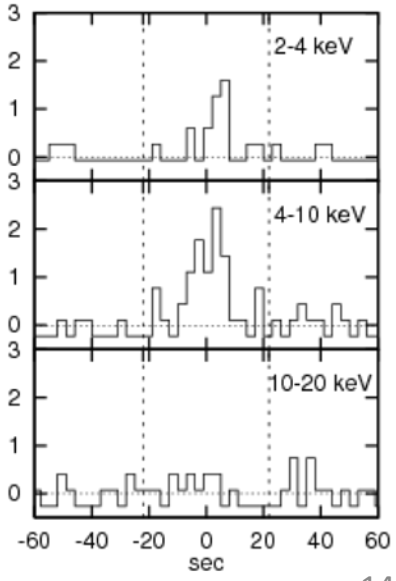
  ⇒ NICER

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



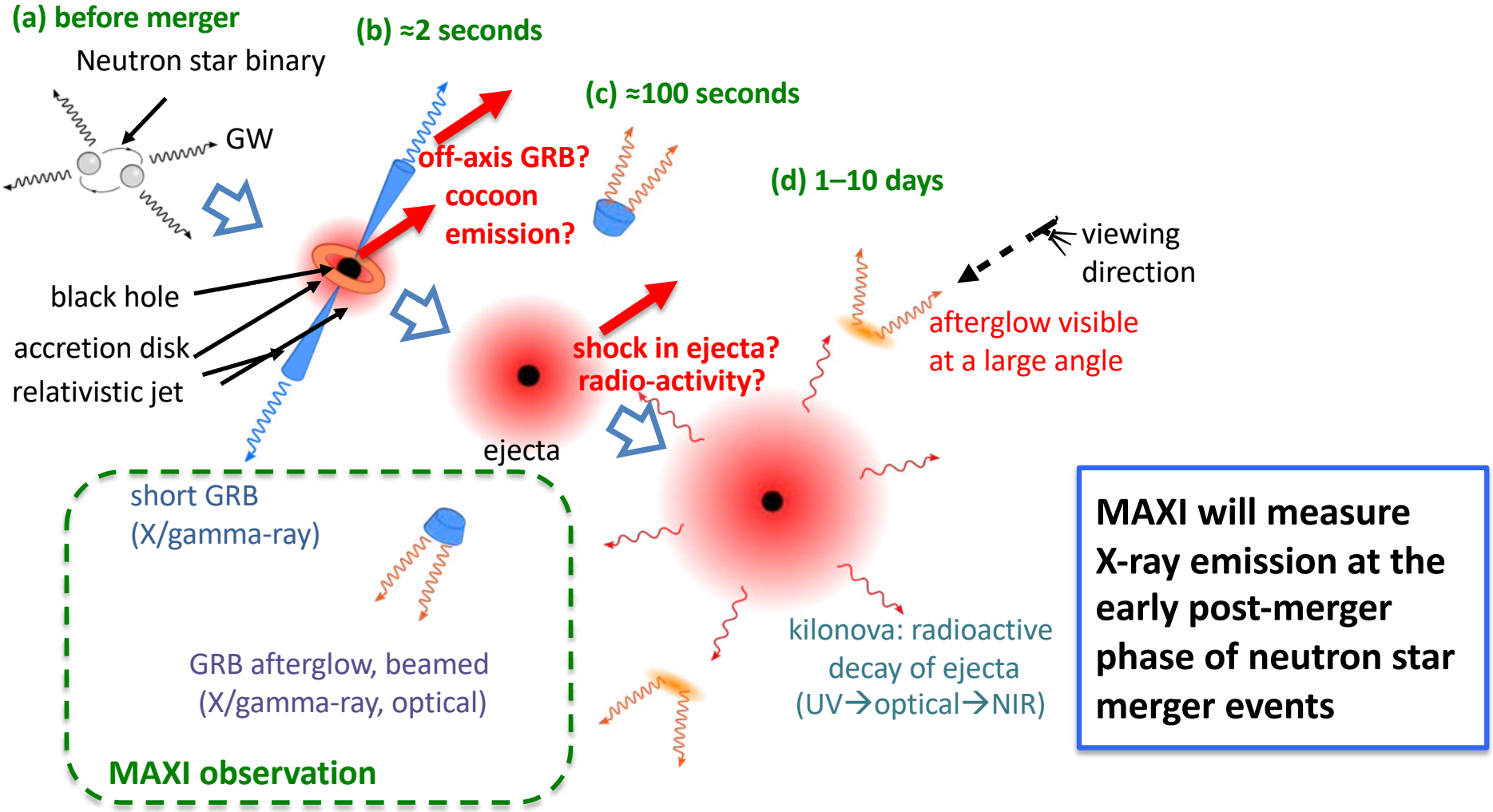
A MUSST, GRB 140814A. Reported as a GRB, but no detection by Swift follow-up. X-ray image at discovery and light curve in the scan. Soft (= no detection in 10-20keV) is a different point from a GRB.



What are these short soft transients?

- gamma-ray bursts with very low E_{peak}
- 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 event



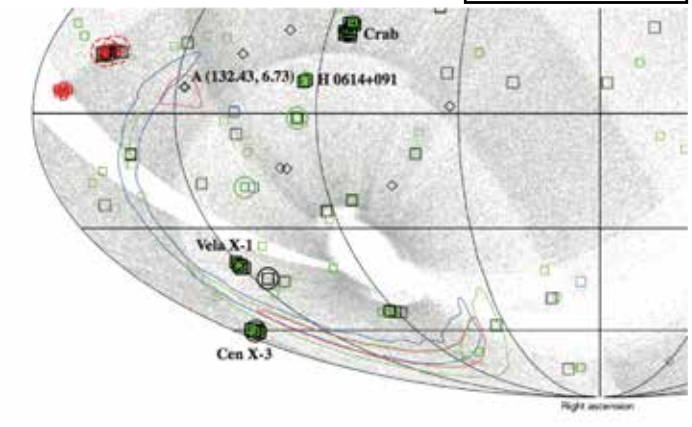
MAXI will measure X-ray emission at the early post-merger phase of neutron star merger events

Emission from Double Neutron Star Merger in time sequence and **possible X-ray emission processes**

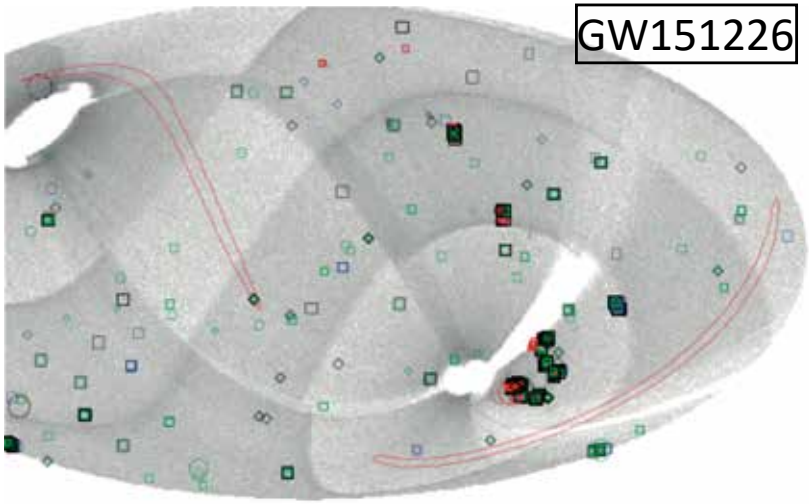
Framework of GW Analysis

- Nova-Alert system is always running regardless of GW event or not

GW150914



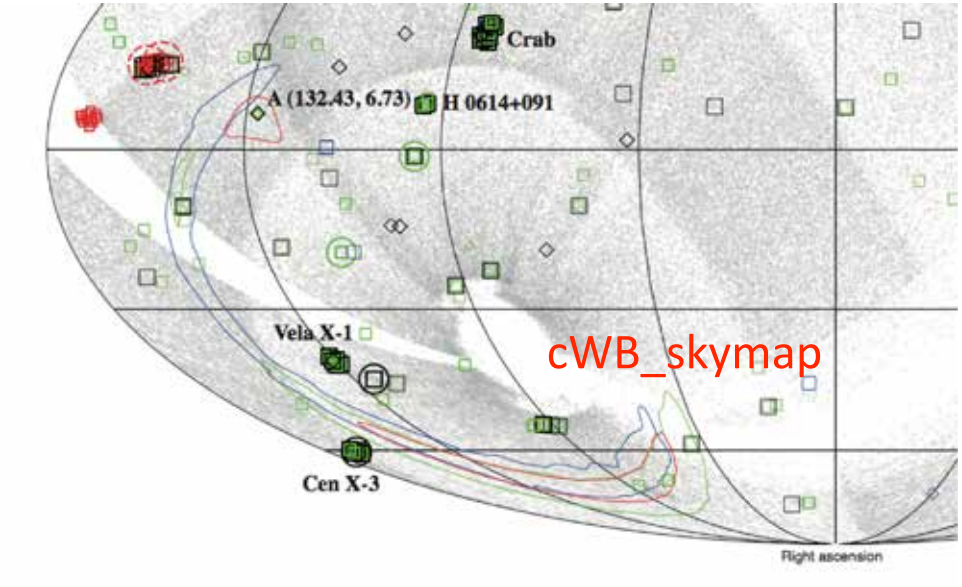
GW151226



- Search weak candidate and calculate X-ray flux upper limits from MAXI/GSC observation in the error region of GW event when we receive the GW skymap data from GraceDB

“X-ray upper limits of GW150914 with MAXI”

PASJ in press (Kawai et al.)



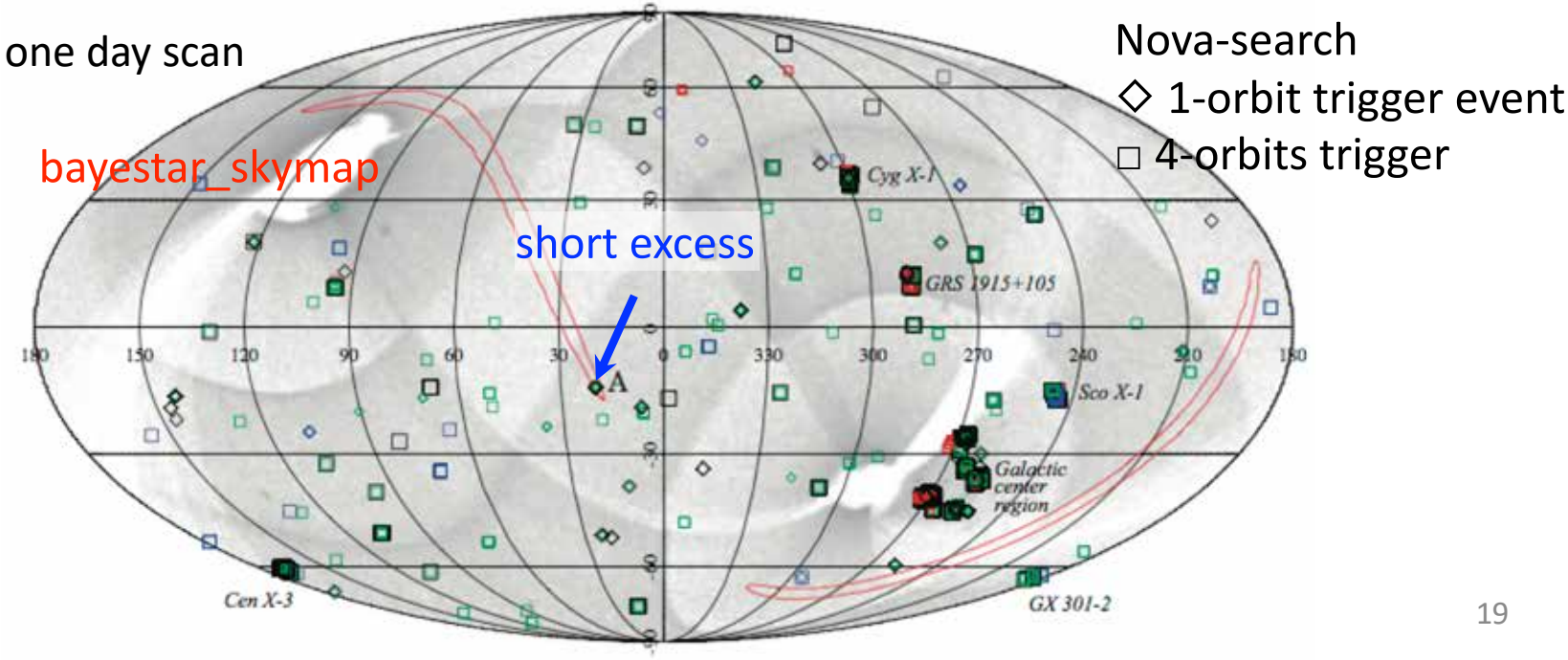
Nova-search
◇ 1-orbit trigger event
☐ 4-orbits trigger

- Triggered at 2015/09/14 09:50:45 UTC
- Scan in the GW error region started T0+4 to +25 min
- Scan in one-orbit covered 95% of cWB skymap region by 6 GSC cameras
- Nova-Alert detected no significant variability with 3 σ in the GW error region.

“X-ray upper limits of GW151226 with MAXI”

PASJ in press (Serino et al.)

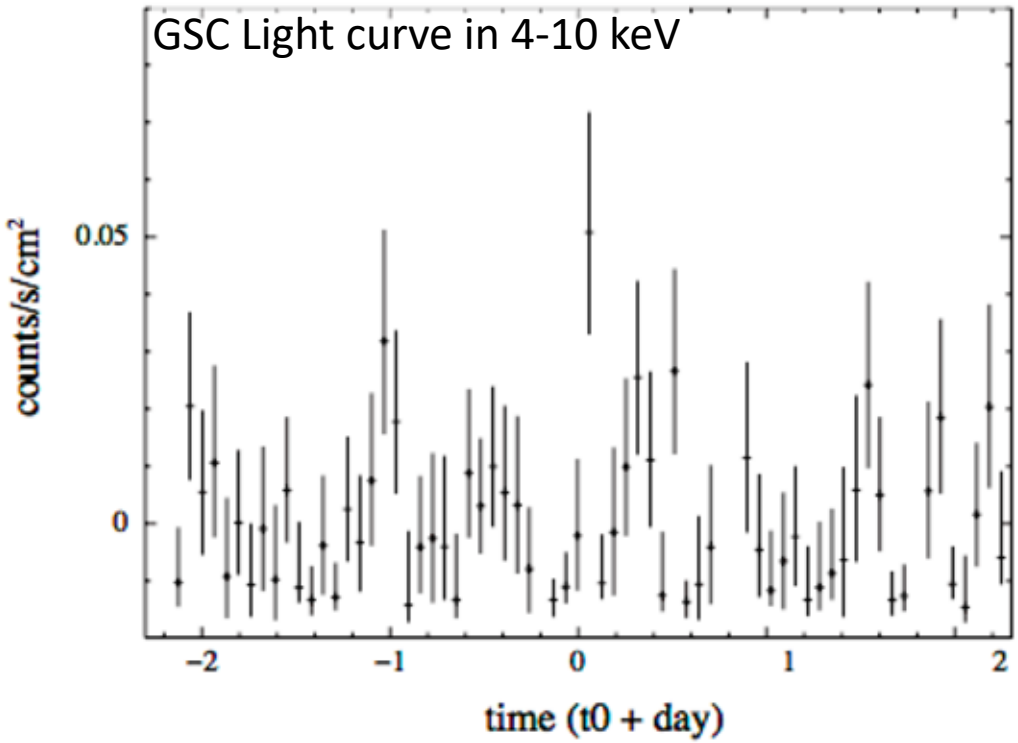
- Triggered at 2015-12-26 03:38:53.648 UTC
- At the trigger time, GSC was observed in the GW error region: cover 1% of the region at that time
- Scan in one-orbit covered 84.8% of bayestar skymap region by 6 GSC cameras
- Nova-Alert detected a short excess event with a low significance (2.85σ) from T0+5257 to 5260 sec



“X-ray upper limits of GW151226 with MAXI”

PASJ in press (Serino et al.)

Short excess in the GW error region

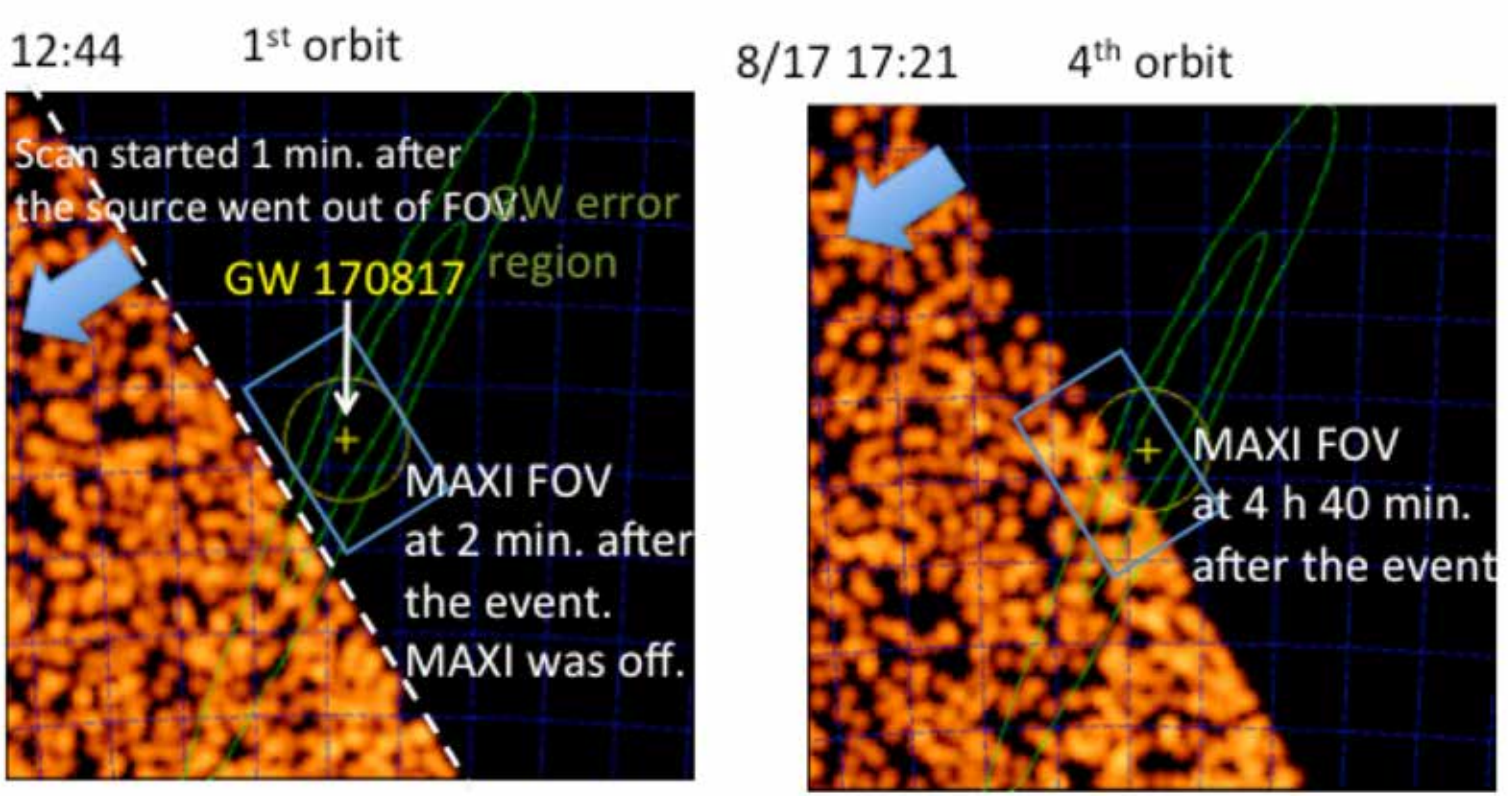


- (R.A., Dec): (19.913, −14.480 deg) with error of elliptical circle 0.46°,0.49° (+systematic 0.1°)
- X-ray flux: $5.1^{+2.1}_{-1.8} \times 10^{-2}$ counts cm^{-2}s^{-1} ~43 ±16 mCrab

GW 170817

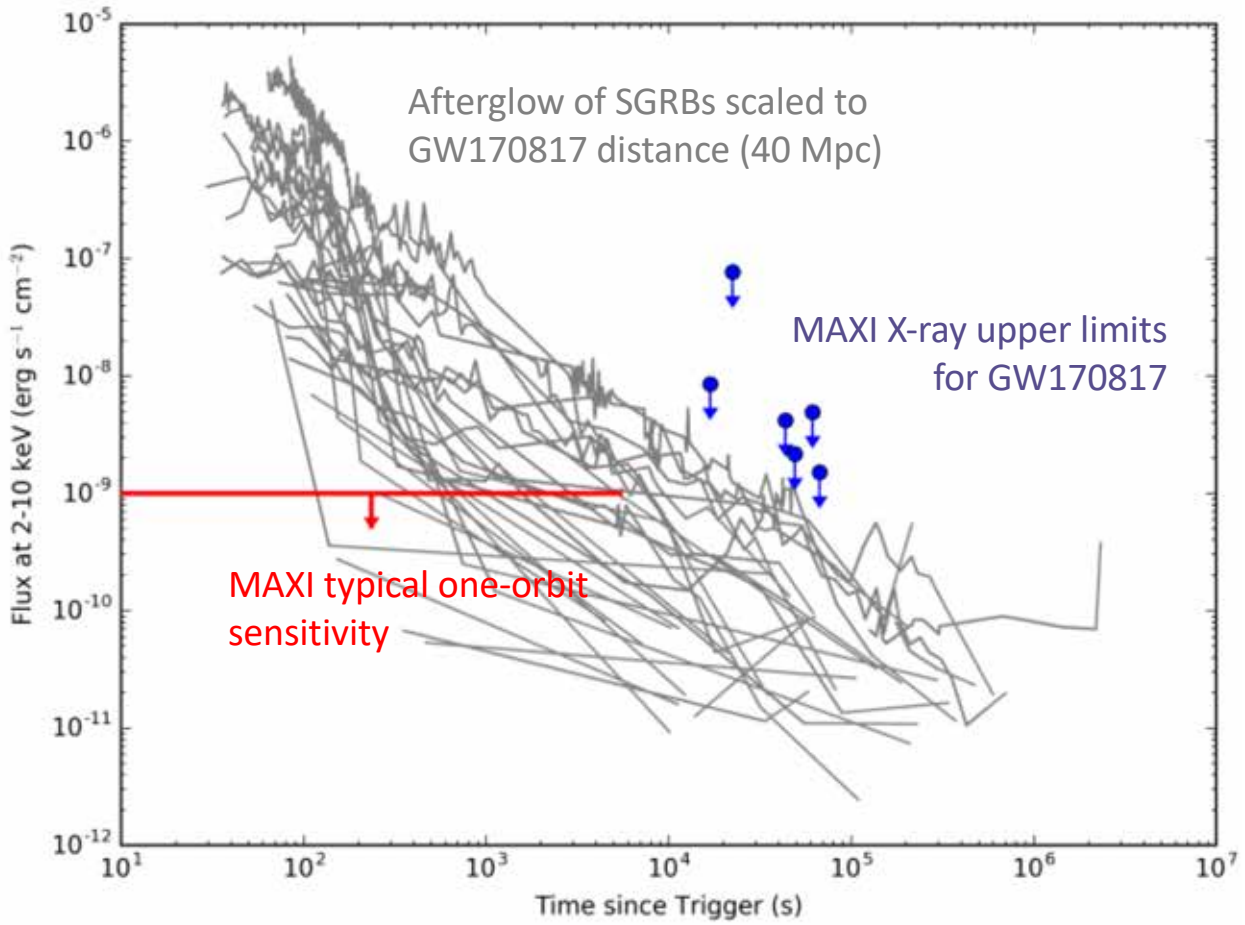
Sugita+ 2017

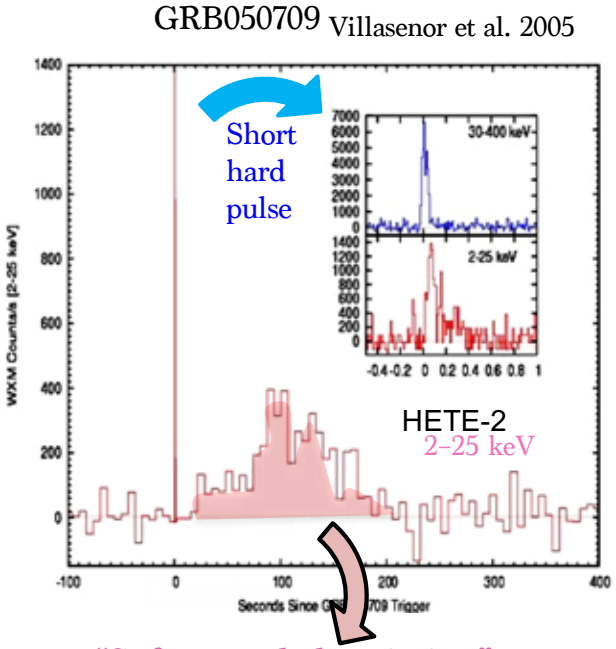
- 12:23 (-18 min pre GW) MAXI scanned the field with no detection
- 12:41 GW170817 (MAXI in high particle flux region)
- 12:44 MAXI resumed observation
- 17:21 (+4.6 hours post GW) first observation (partial)
- 18:55~ full coverage; no detection



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)





MAXI/GSC observations of IceCube-170922A and TXS 0506+056

ATel #10838; H. Negoro

We reexamine MAXI/GSC data for the high-energy neutrino event IceCube-170922A detected at 20:54:30.43 on 2017 September 22 (GCN #21916), and recently active blazer TXS 0506+056 in the IceCube error region (ATel #10791, #10792, #10794, #10799, #10801, #10817, #10830, #10831, #10833, also see ATel #10773, 17787).

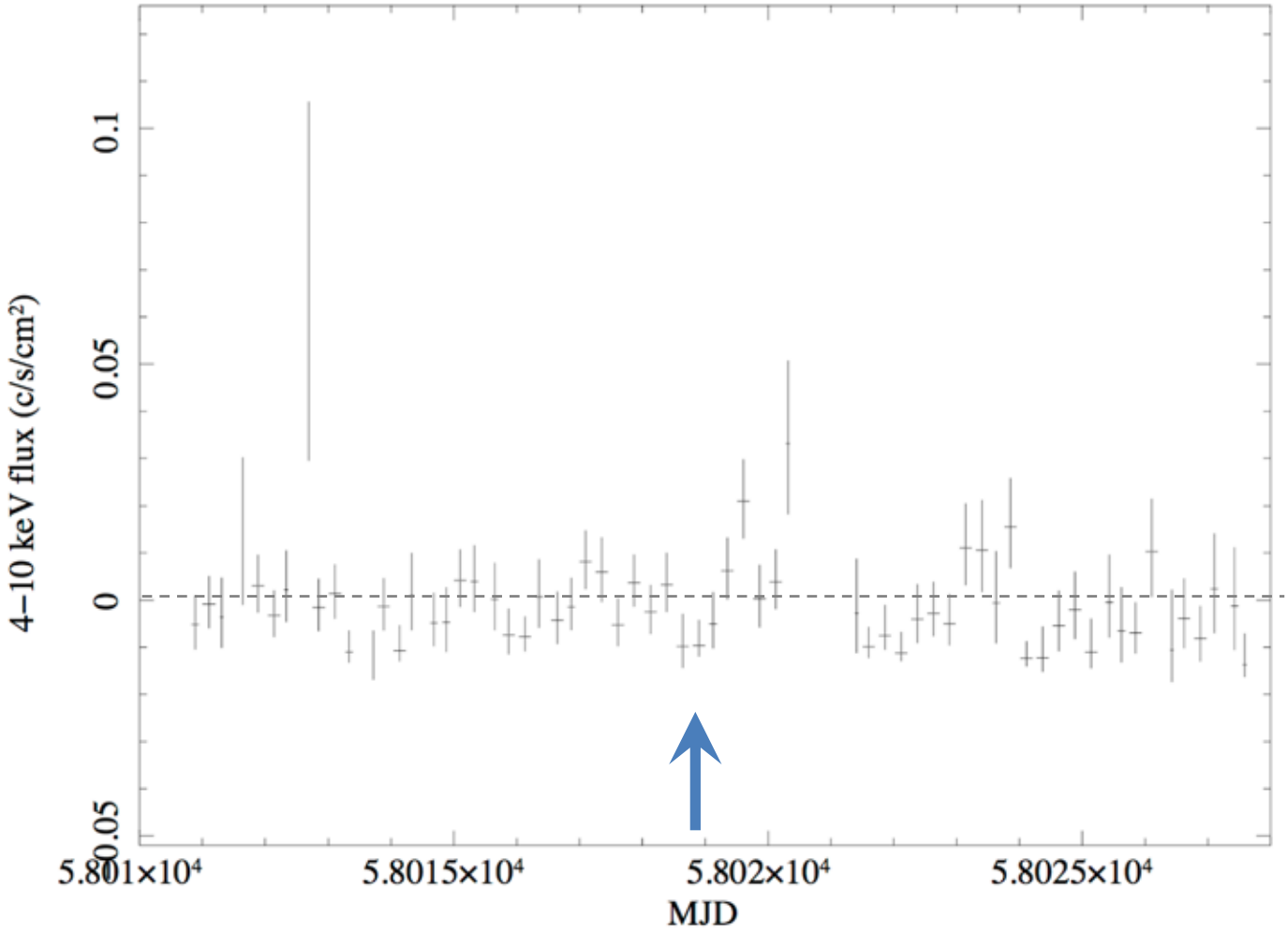
MAXI/GSC scanned the IceCube error region at 20:49 and 22:21 on September 22 before and after the event, and detected no significant X-ray enhancement. The 4-10 keV 1-sigma upper limits are both 16 mCrab.

We also produced 2-4 keV and 4-10 keV X-ray light curves at the position of TXS 0506+056 with the PSF-fit method (Morii et al. 2016, PASJ, 68, S11). The 4-10 keV X-ray light curve shows a flare-like event peaking at 0.040 (+0.022, -0.019) c/s/cm2 (~34 mCrab) in the scan transit at 16:53 on September 23, and the 4-10 keV X-ray flux averaged over 4 scans from 12:15 to 16:53 on September 23 is 0.021(+0.009, -0.008) c/s/cm2 (~ 18 mCrab, 2.6 sigma level detection). The 2-4 keV X-ray light curve, however, do not show similar excess for the above period. and the point-source is not so visible even in the 4-10 keV X-ray image.

Any flux excess corresponding to the Gamma-ray flare after September 15 (ATel #10791) is not recognized either in the 2-4 keV or 4-10 keV X-ray longterm light curve.

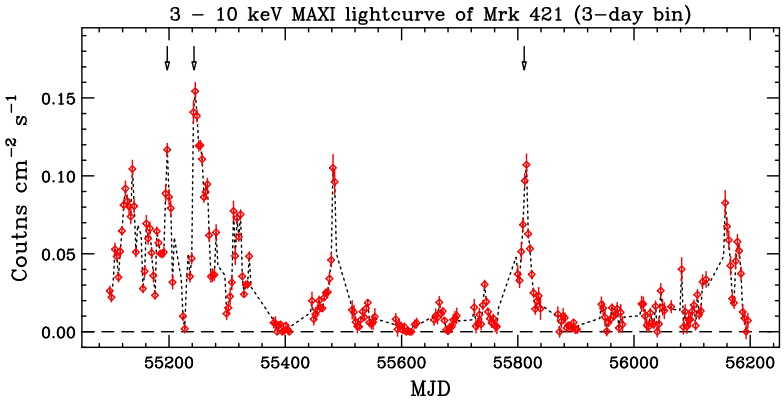
MAXI/GSC observations of IceCube-170922A and TXS 0506+056

ATel #10838; H. Negoro

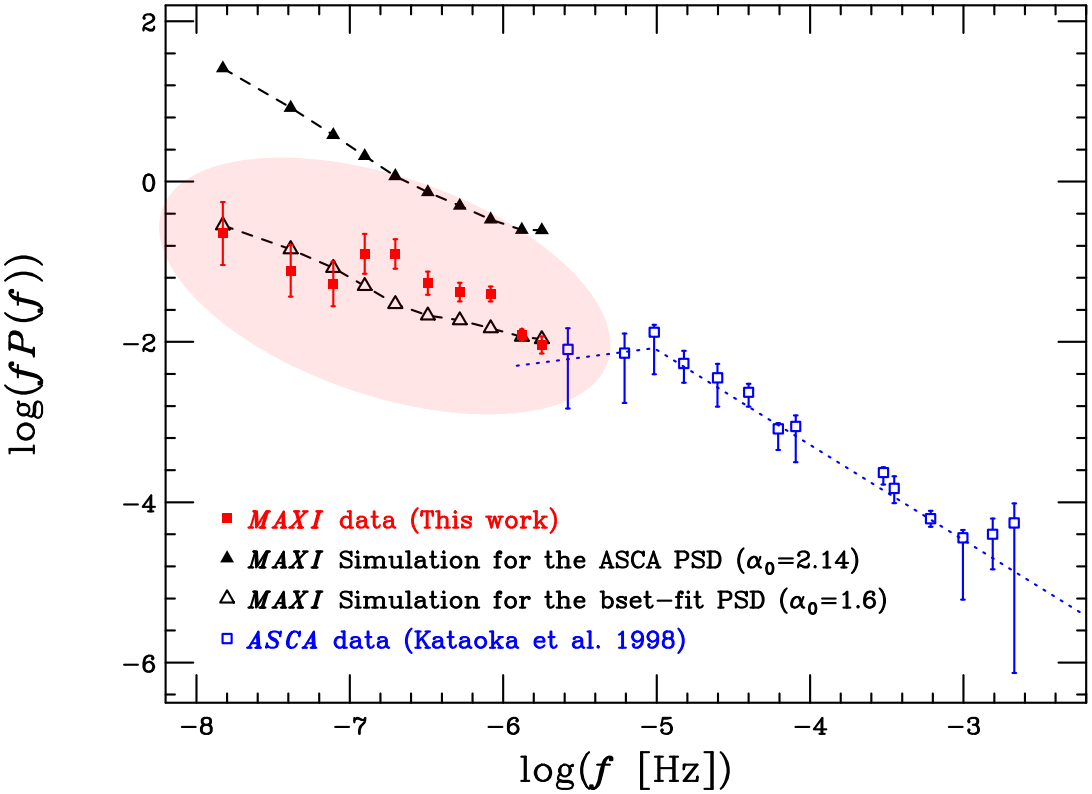


IceCube

Long-term monitoring of AGN: Mrk 421



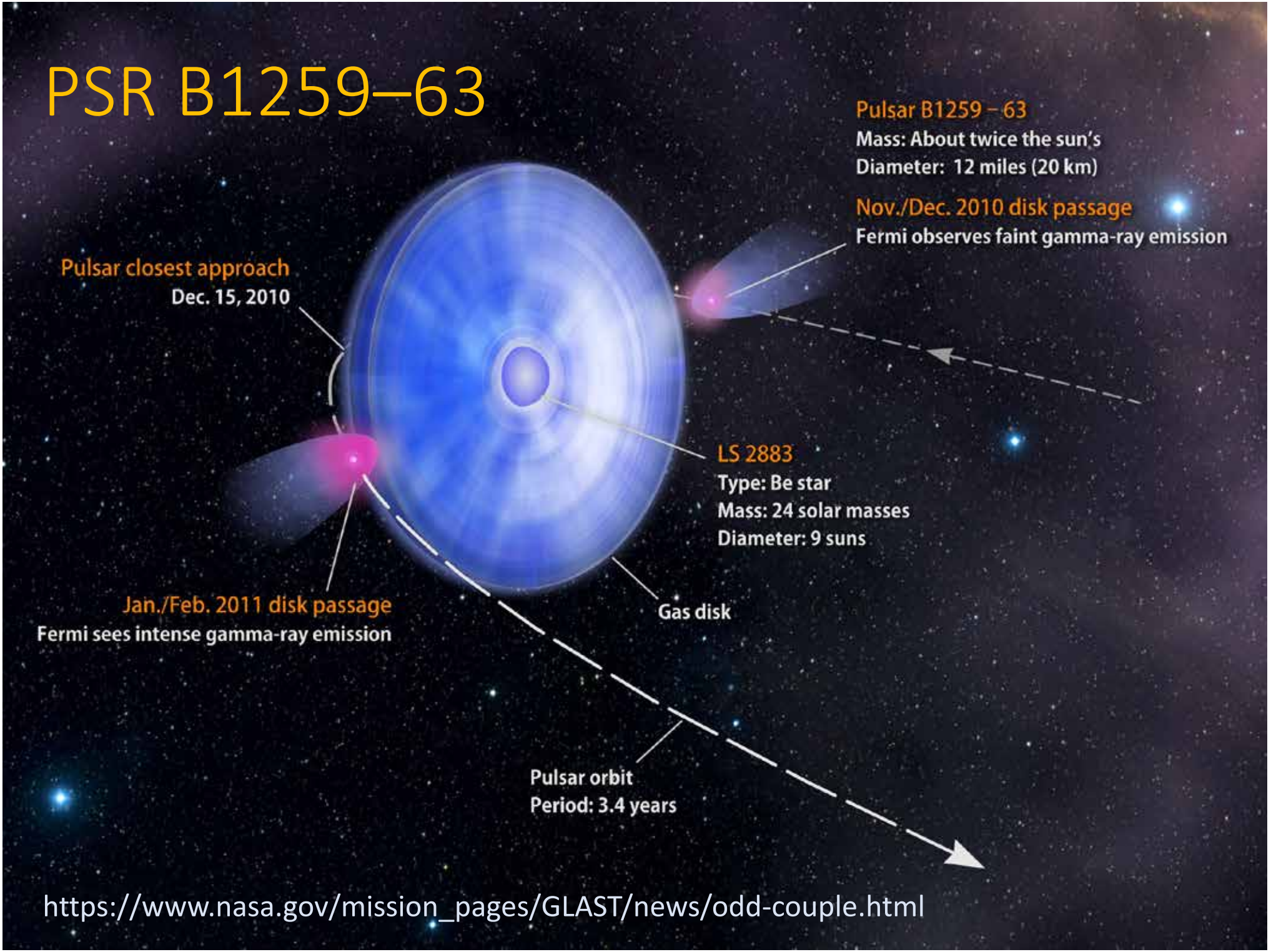
MAXI Light curve (3-10 keV) of the Blazar Mrk 421 for 3 years.



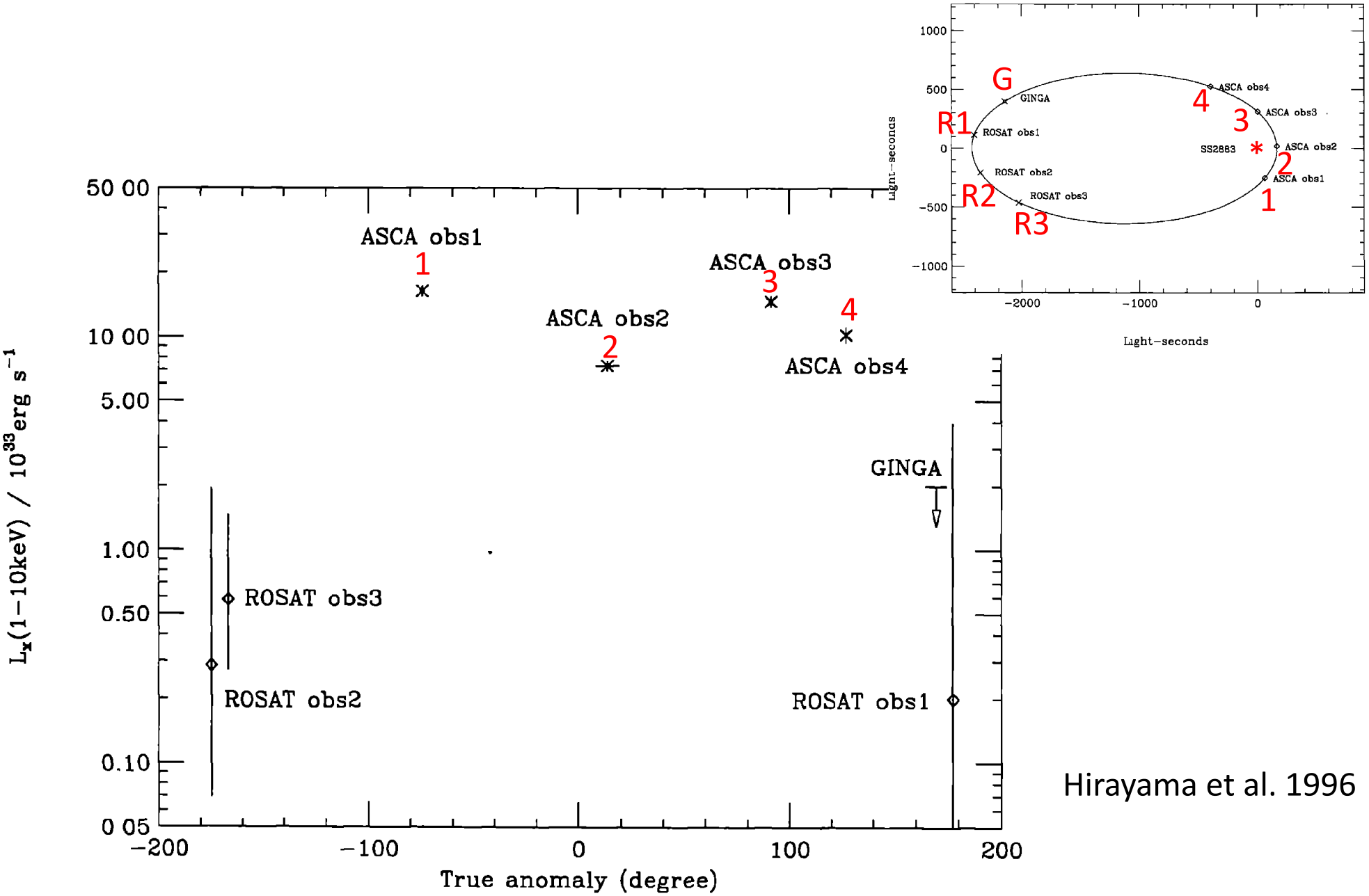
Power spectrum of Mrk 421 by MAXI.
It connects with the ASCA points at higher frequency after break.
White triangles with lines are simulation of a power law with index of 1.6.
Black triangle with lines are extrapolation of ASCA curve (index 2.14).

Isobe et al. (2014)

PSR B1259–63



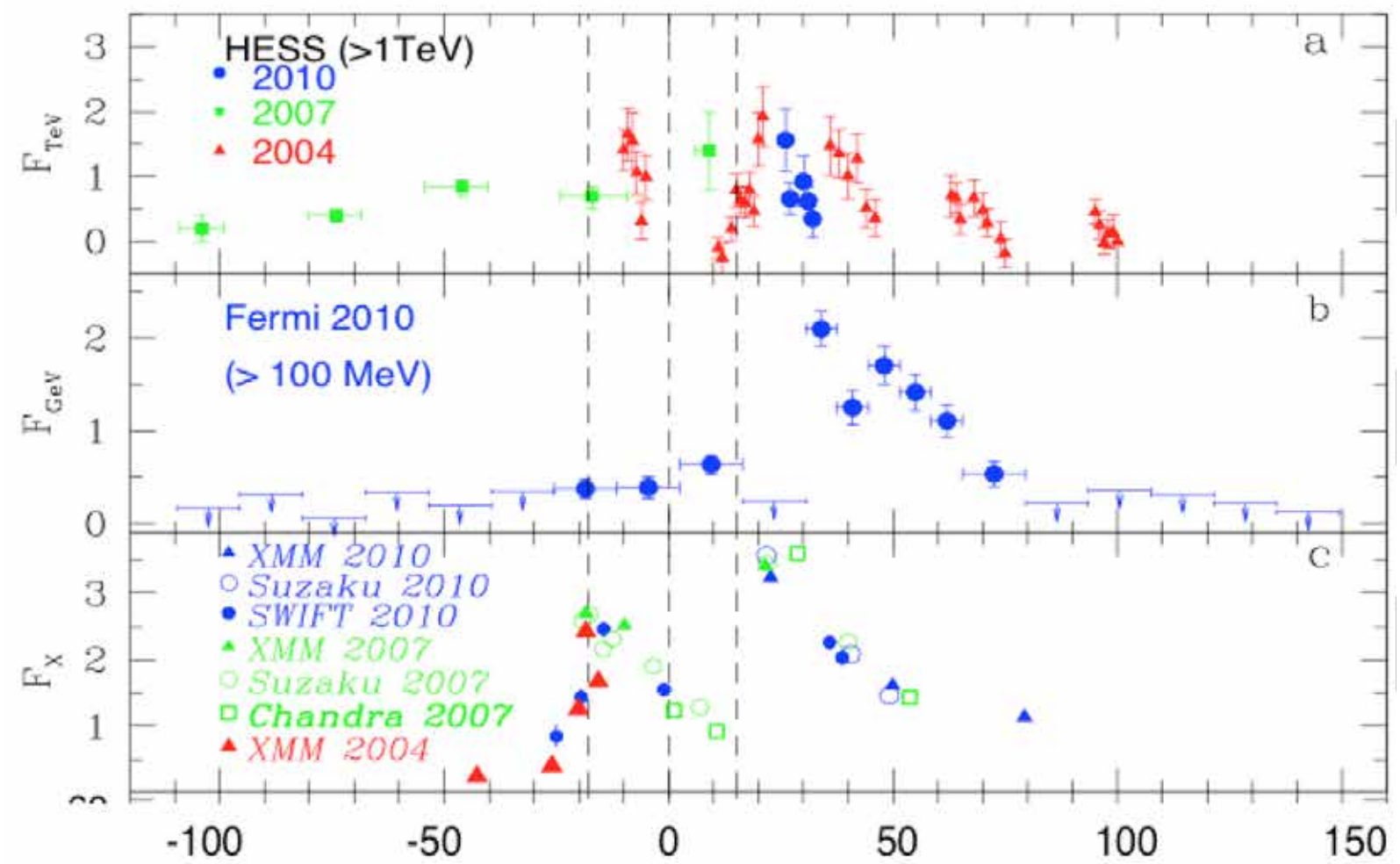
https://www.nasa.gov/mission_pages/GLAST/news/odd-couple.html



Hirayama et al. 1996

PSR B1259-63 X-ray flux vs. orbital phase

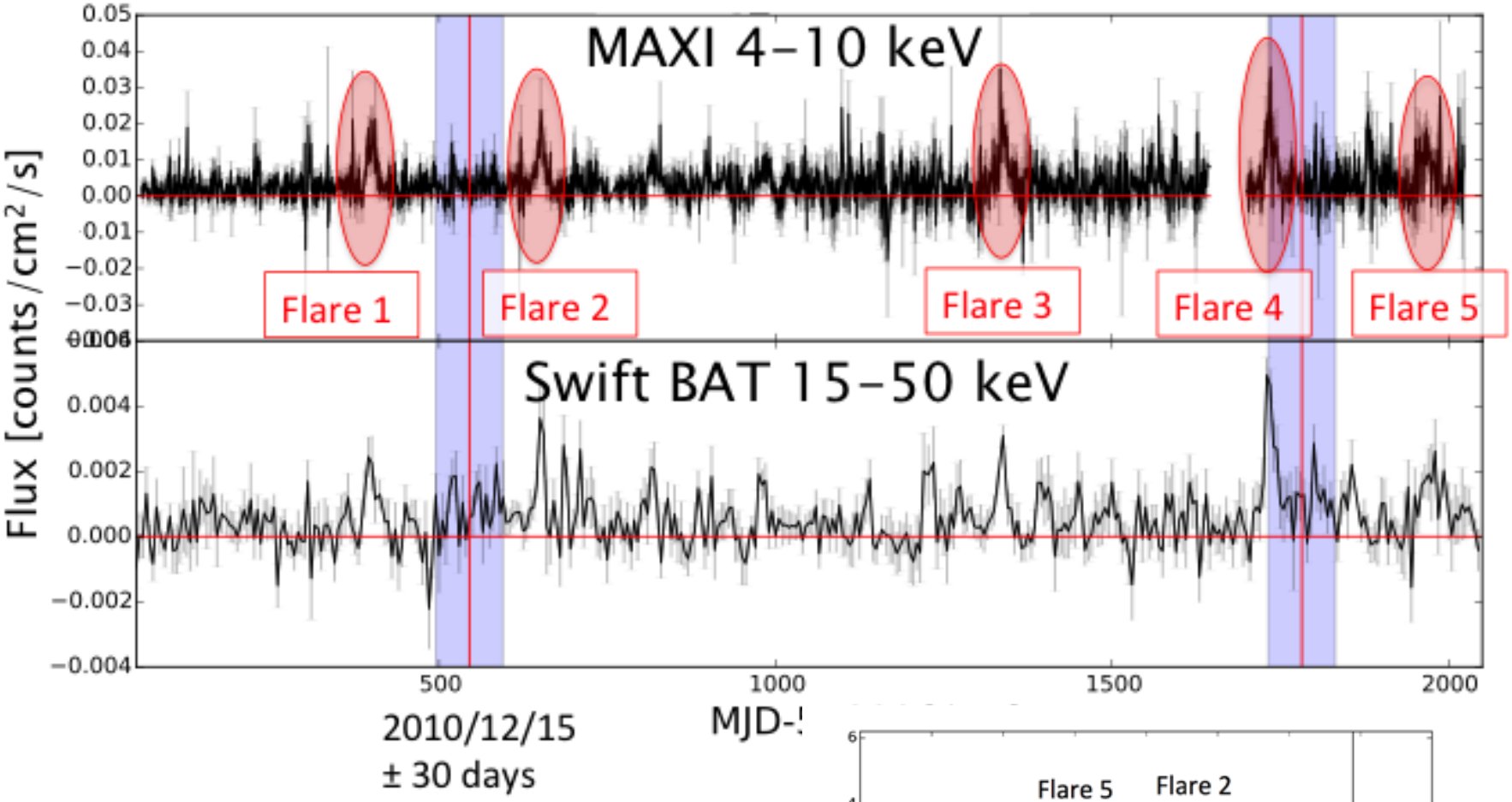
PSR B1259–63
gamma-ray and X-ray emission near periastron

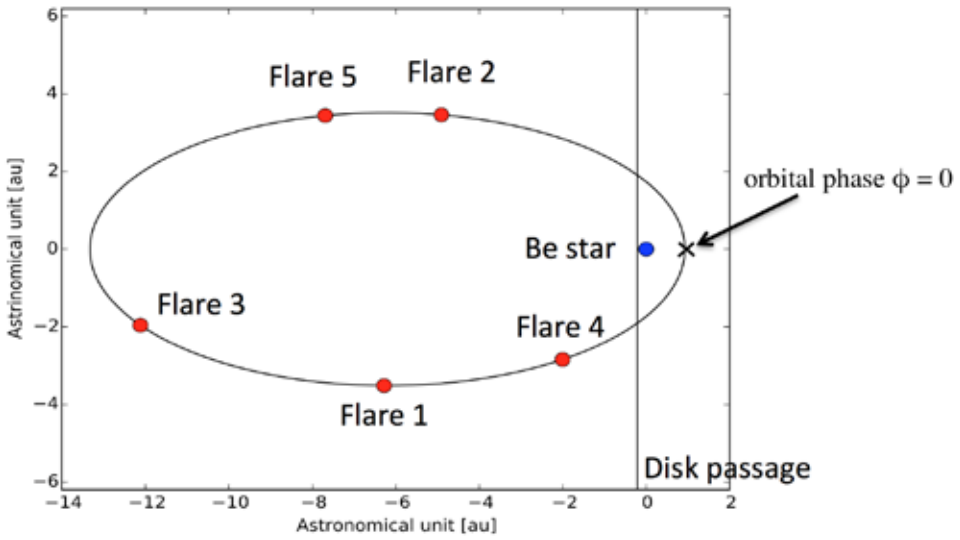


Days from Periastron

M. Chernyakova et al. (2014)

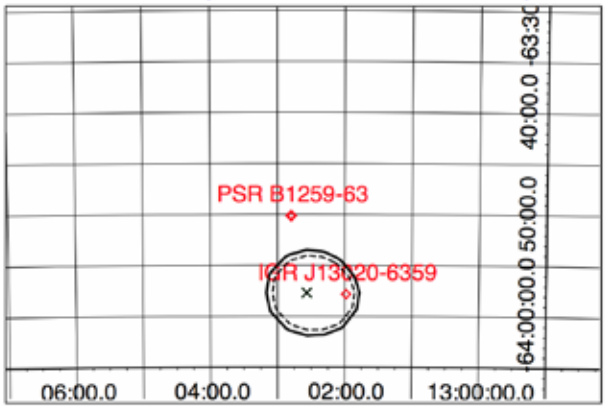
小野雄貴 (2017)





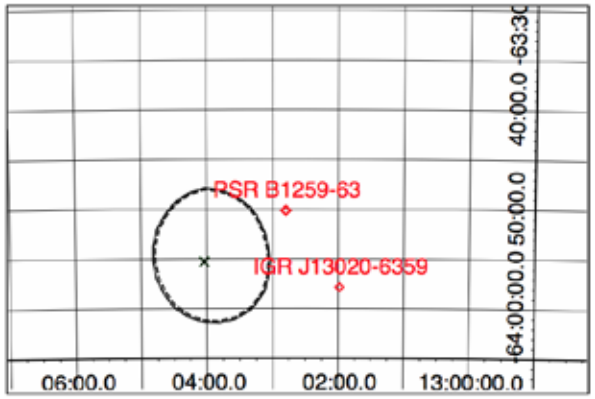
PSR B1259-63
X-ray light curve

Flare 1(MJD 55390-55410)



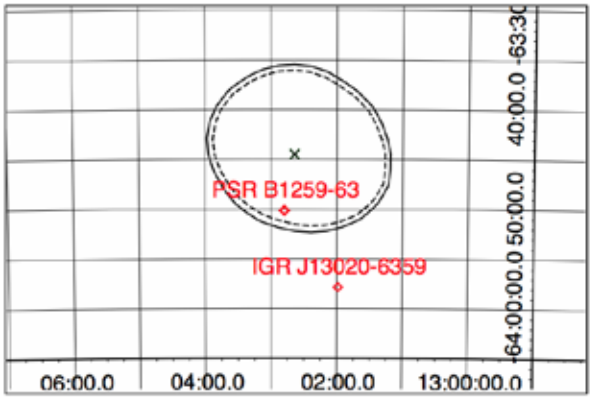
系統誤差 : 0.044°

Flare 2(MJD 55630-55670)



系統誤差 : 0.027°

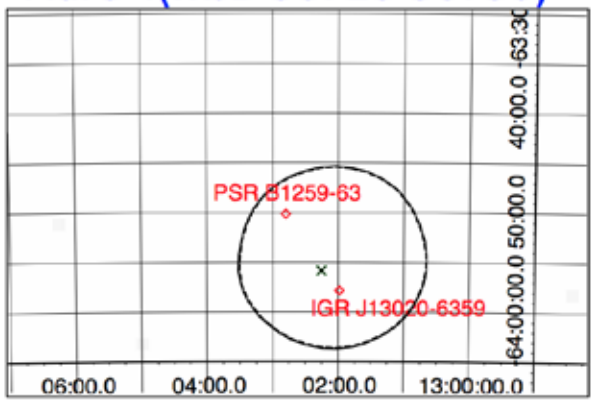
Flare 3(MJD 56330-56345)



系統誤差 : 0.053°

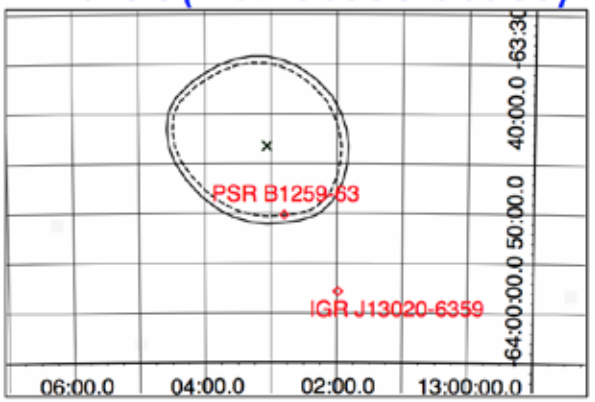
MAXI flare source positions

Flare 4(MJD 56720-56750)



系統誤差 : 0.021°

Flare 5(MJD 56950-56980)



系統誤差 : 0.056°

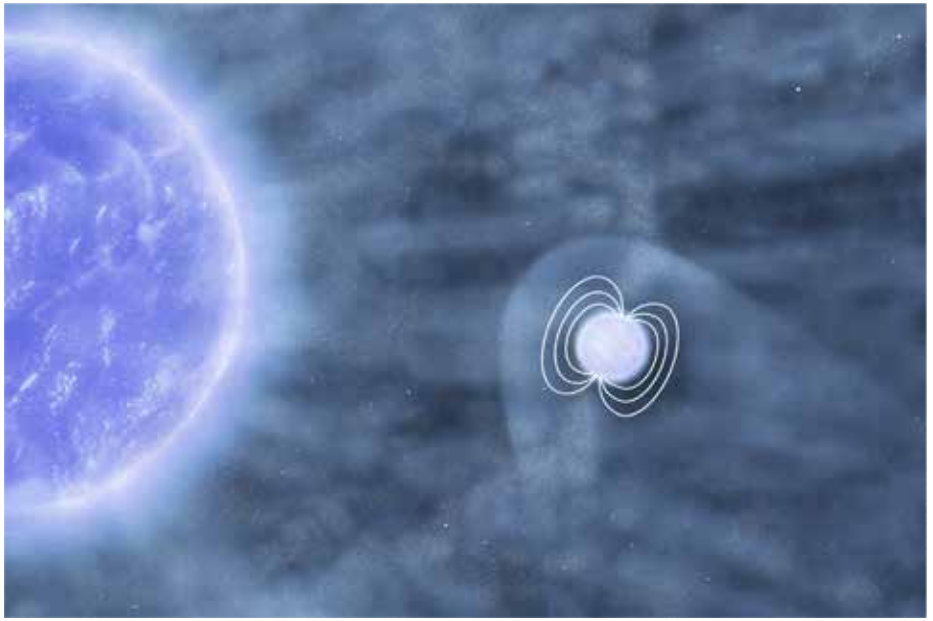
Flare ID	orbital phase ϕ	Flux (1-20 keV) $\times 10^{-10}$ erg cm^{-2} s^{-1}	$L_{1-20\mathrm{keV}}$ $\times 10^{35}$ [erg cm^{-2} s^{-1}]
Flare 2	0.085	$2.81^{+0.51}_{-0.60}$	$1.77^{+0.32}_{-0.37}$
Flare 3	0.641	$4.76^{+0.50}_{-0.71}$	$3.00^{+0.32}_{-0.45}$
Flare 4	0.962	$7.41^{+0.50}_{-2.31}$	$4.67^{+0.32}_{-1.46}$
Flare 5	0.148	$3.83^{+0.21}_{-0.73}$	$2.42^{+0.13}_{-0.46}$

小野雄貴 (2017)

x10 ASCA flux

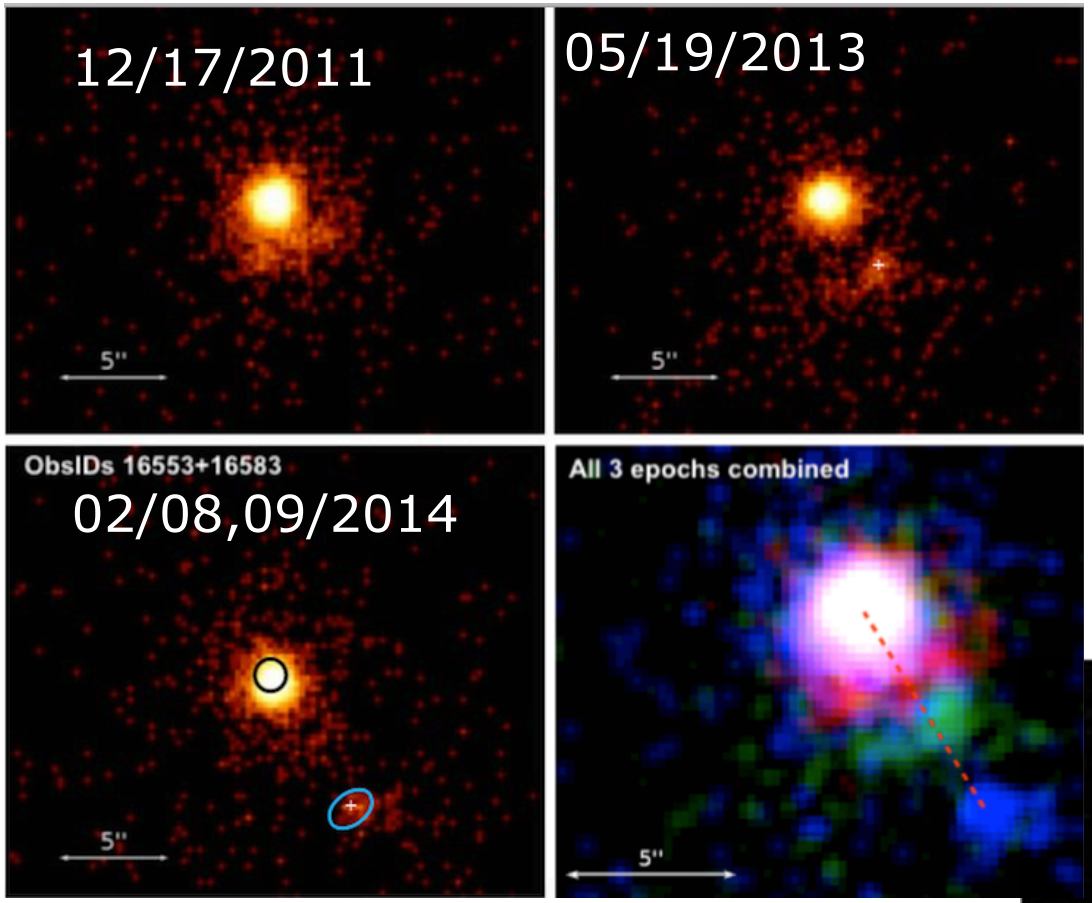
PSR 1259-63 flare

- Accretion unlikely due to propeller effect
- pulsar-stellar wind collision may be responsible
- required clump density/mass comparable to those found in Vela X-1 and Supergiant fast X-ray transients (SFXTs)



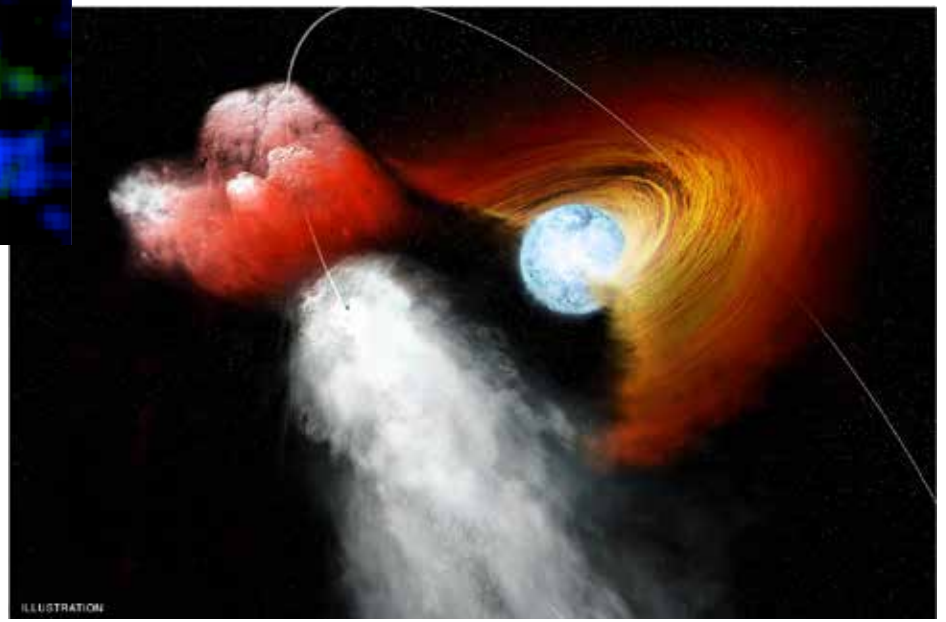
Animation of Supergiant Fast X-Ray Transient, IGR J18410-0535 (c) ESA

PSR 1259-63 – Chandra observations



Pavlov et al, 2015

http://chandra.harvard.edu/photo/2015/psrb1259/

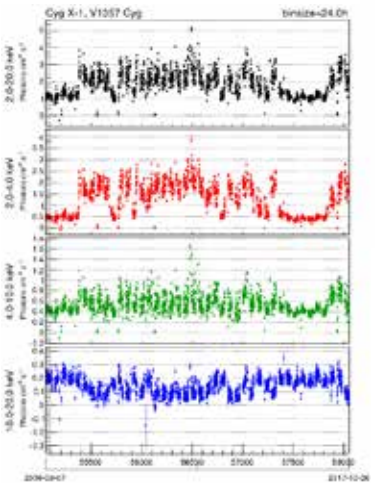


extended source moving at 0.07c

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

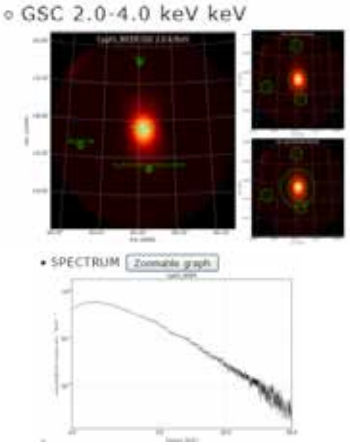
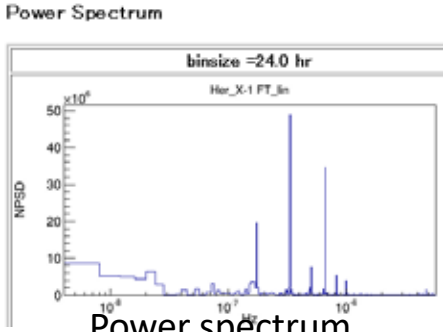
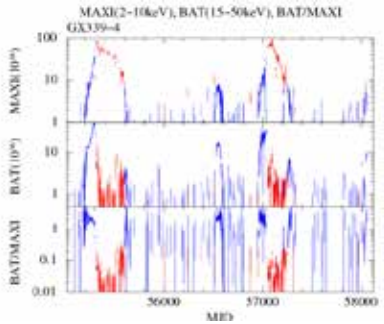


Image and spectrum by ondemand

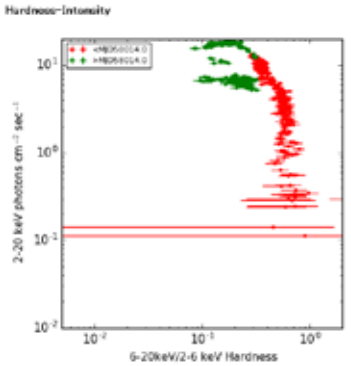
BeXRB monitor @ ESA



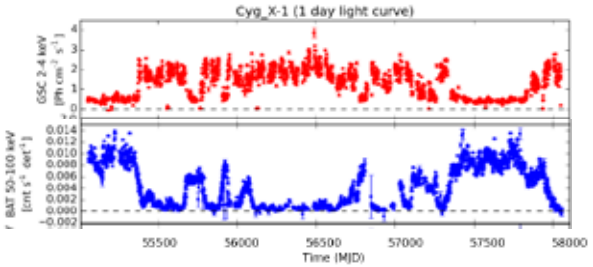
Power spectrum



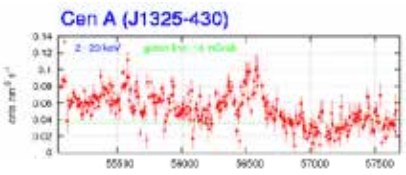
MAXI-BAT Hardness ratio



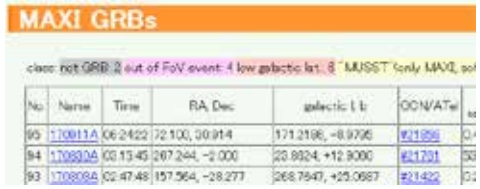
MAXI 1535 monitor



BAT-MAXI transient monitor



Weekly light curves



MAXI GRB list

publication statistics

- Number of refereed papers from previous evaluation (2014.11.25) to date (2017.10.31).

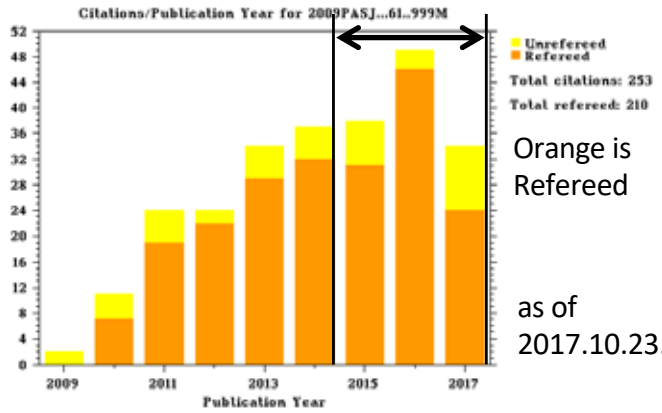
(a) By MAXI team member, using MAXI data

(b) By other than MAXI team member, using MAXI data

(c) By observations triggered by MAXI alerts, NOT using MAXI data

	Before previous evaluation 2009.8(2009.12)～2014.11		this extended period 2014.12～2017.11	
	5 yr	(/yr)	3 yr	(/yr)
(a)	41	(8.2)	25	(8.3)
(b)	68	(13.6)	76	(25.3)
(c)	106	(21.2)	126	(42.0)

this extended period



Orange is Refereed

as of 2017.10.23.

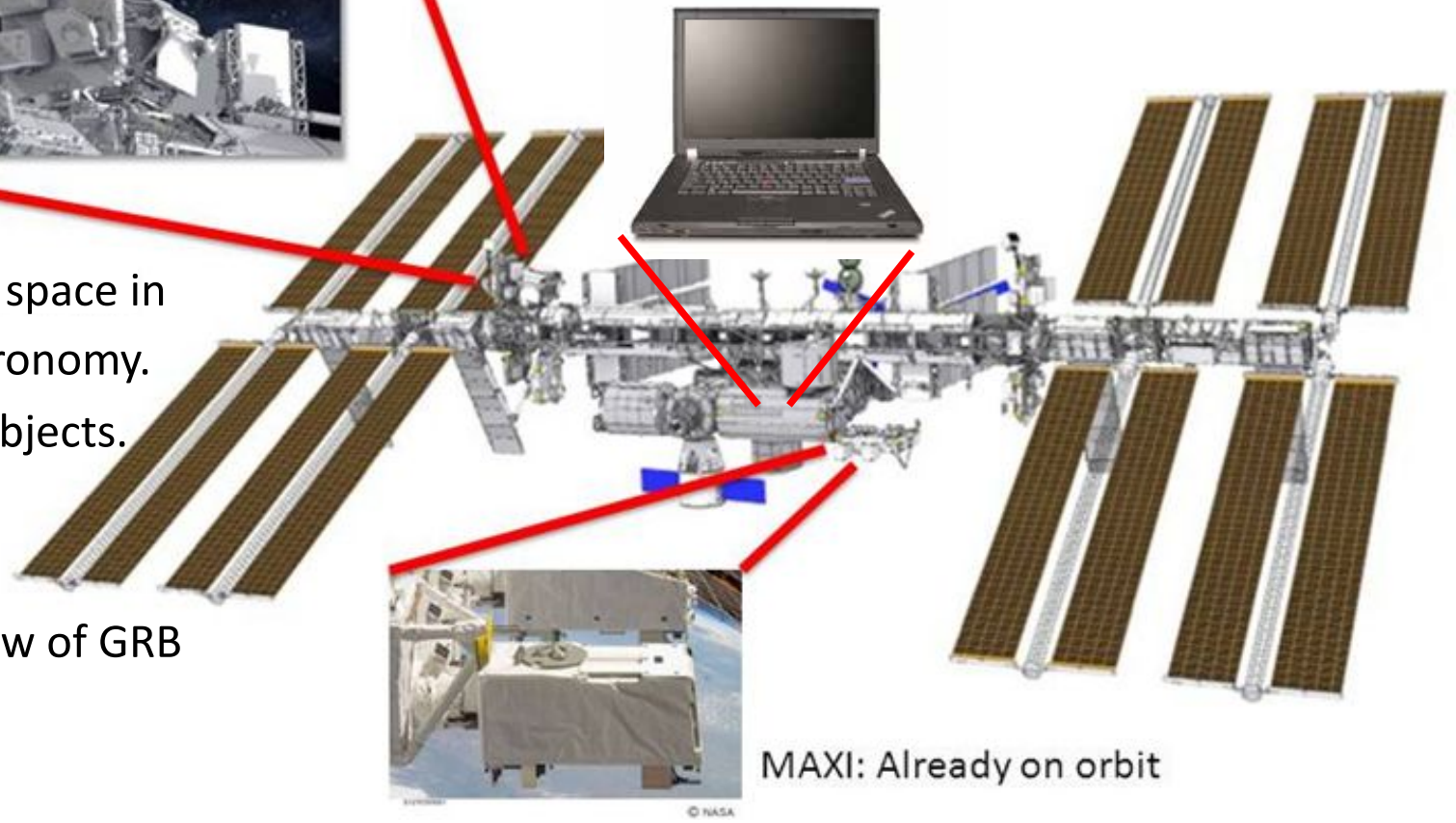
In this extended period, there are 105 papers in Proceedings of MAXI 7 yr conference (2016.12). They are non-refereed, and not counted in the figure.

- MAXI Instrument paper (Matsuoka et al. 2009) was awarded as PASJ excellent paper in 2014 March. The number of citation was about 100 in 4 years It keeps increasing to reach 210 now.
- The rate in this period is the same as before in (a) . Number of the MAXI team is almost the same.
- The rate is doubled in (b). MAXI data are more widely used by more scientists.
- The rate is also doubled in (c). Number of observations (=observers) triggered by MAXI Atel or GCN has increased.

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.

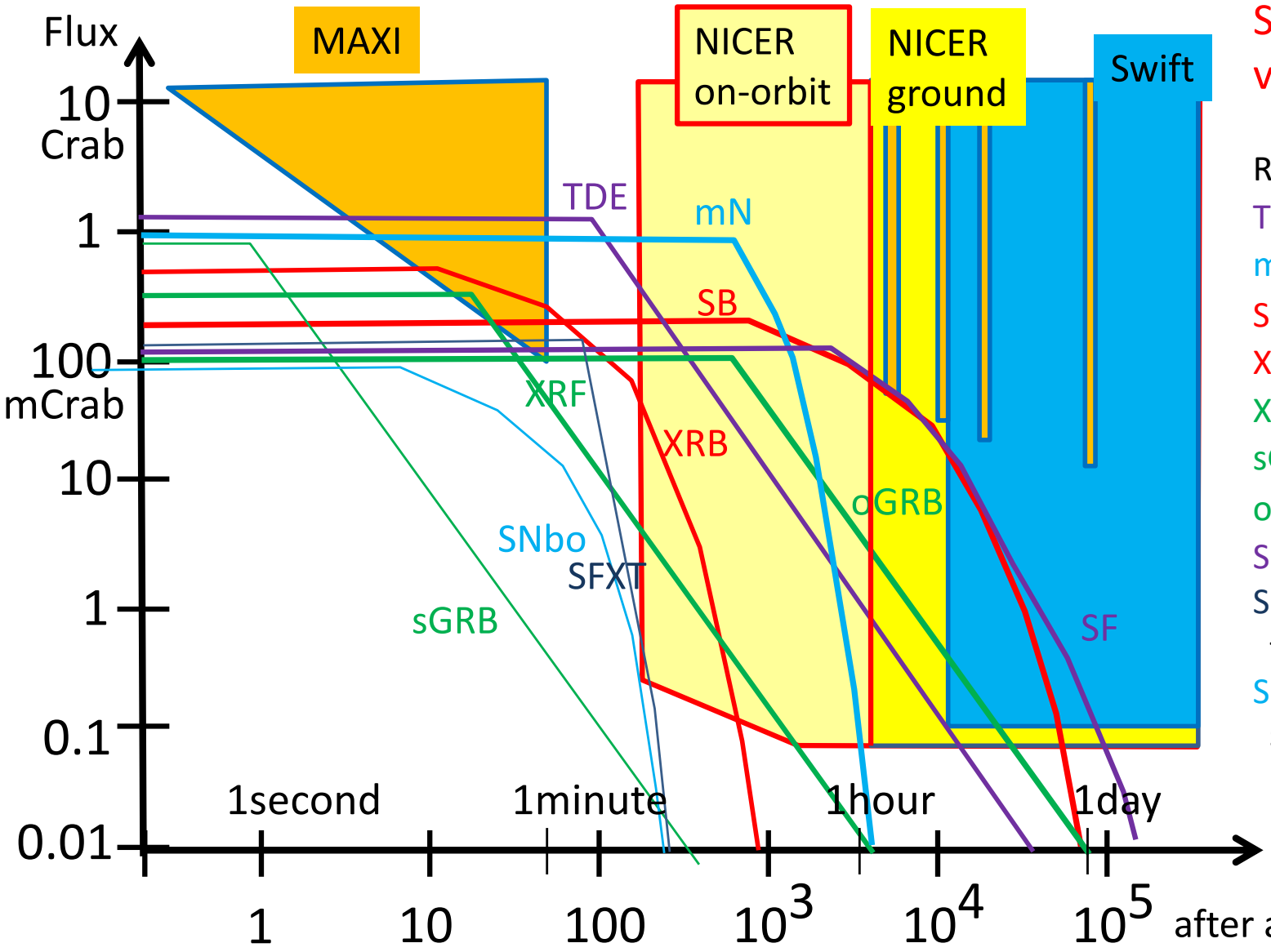
Rapid decaying objects.

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

MAXI: Already on orbit

Future: Time-domain astronomy of Rapidly decaying objects

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