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%

Matsuoka et al. 2009
Scans with Slit + Slats collimator

ISS rotation

Slit + Slats collimator

1-dimensional position sensitive detector

proportional counter

X-ray CCD

Operating in equatorial region

Celestial sphere

160 deg

1.5 deg (FWHM)

3.0 deg (at bottom)

1. MAXI

Particle background rate
Nova Alert System

< 10 sec (Real)
~ 1.5 h (Stored)

RIKEN & MAXI MLs (& ATel/GCN)

Negoro+ 2016, PASJ
Various Timescales to Investigate

- X, γ-ray bursts
- Superburst
- SFXT
- Star Flares
- X-ray novae
- AGN Flares

**X-ray burst**
- From 4U 1916-053
  - tbin = 1 s, 3 s, 10 s, 30 s
  - ~ 200 sec (50 µs resolution, GSC)

**Superburst + Outburst**
- From EXO 1745-248
  - Serino+ 2012
  - 5 days

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

- 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 16+....
- 4U 0728-25

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

Edge-on View

4 kpc distance is assumed for J1619, J1932, J1957

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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 7\textsuperscript{th} brightest in history. In fact it was the brightest X-ray nova since 1999, that is, in the 21\textsuperscript{st} 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 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
  - $(1300 \text{ s} < \Delta T < 1.1 \times 10^4 \text{ s})$

- 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 x$10^4$ more luminous than known nova X-ray emission
    - (shocked ISM? Li et al. 2012)

Morii et al. 2013
Nova (nuclear fusion) explosion

WD-Be binary system (MAXI J0158-744)

Be star

Circumstellar disk

Very massive O-Ne white dwarf → Nova ignited with a less accumulation → Luminous (100L_⊙) and Exploded out quickly → Thermal Ne line

Morii et al. (2013)

Credit: Takuya Ohkawa
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/
1/2 of MAXI GRBs are "Only MAXI" events

Only MAXI GRBs tend to Soft and Dim

many of them are XRFs?
### 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**

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

A MUSST, GRB Reported as 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 (?)
- ...

15
MAXI for GW event

(a) before merger
Neutron star binary

(b) ≈2 seconds
GW

(c) ≈100 seconds

(d) 1–10 days

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

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

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

- 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
Triggers 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”

• 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

Nova-search
◇ 1-orbit trigger event
□ 4-orbits trigger
“X-ray upper limits of GW151226 with MAXI”

PASJ in press (Serino et al.)

Short excess in the GW error region

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

GW 170817

Sugita+ 2017
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)
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 blazar 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
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

Pulsar closest approach
Dec. 15, 2010

Jan./Feb. 2011 disk passage
Fermi sees intense gamma-ray emission

Pulsar orbit
Period: 3.4 years

Pulsar B1259 – 63
Mass: About twice the sun's
Diameter: 12 miles (20 km)

Nov./Dec. 2010 disk passage
Fermi observes faint gamma-ray emission

LS 2883
Type: Be star
Mass: 24 solar masses
Diameter: 9 suns

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

Hirayama et al. 1996
PSR B1259–63
gamma-ray and X-ray emission near periastron

Days from Periastron

M. Chernyakova et al. (2014)
PSR B1259-63
X-ray light curve
### MAXI flare source positions

<table>
<thead>
<tr>
<th>Flare ID</th>
<th>Orbital phase $\phi$</th>
<th>Flux (1-20 keV) $\times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$</th>
<th>$L_{1-20\text{keV}} \times 10^{35}$ [erg cm$^{-2}$ s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flare 2</td>
<td>0.085</td>
<td>$2.81^{+0.51}_{-0.60}$</td>
<td>$1.77^{+0.32}_{-0.37}$</td>
</tr>
<tr>
<td>Flare 3</td>
<td>0.641</td>
<td>$4.76^{+0.50}_{-0.71}$</td>
<td>$3.00^{+0.32}_{-0.45}$</td>
</tr>
<tr>
<td>Flare 4</td>
<td>0.962</td>
<td>$7.41^{+0.50}_{-2.31}$</td>
<td>$4.67^{+0.32}_{-1.46}$</td>
</tr>
<tr>
<td>Flare 5</td>
<td>0.148</td>
<td>$3.89^{+0.21}_{-0.73}$</td>
<td>$2.42^{+0.13}_{-0.46}$</td>
</tr>
</tbody>
</table>

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

extended source moving at 0.07c

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

Pavlov et al, 2015
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/

Image and spectrum by ondemand

BeXRB monitor @ ESA

Maxi 1535 monitor

Power spectrum

MAXI-BAT Hardness ratio

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
  
  5 yr ( /yr )
  
  (a) 41 ( 8.2 )
  
  (b) 68 (13.6 )
  
  (c) 106 (21.2 )

- This extended period
  
  2014.12～2017.11
  
  3 yr ( /yr )
  
  (a) 25 ( 8.3 )
  
  (b) 76 (25.3 )
  
  (c) 126 (42.0 )

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.

![Graph showing citations per year from 2008 to 2017]
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

Flux

- MAXI
- NICER on-orbit
- NICER ground
- Swift

Crab

- 10

SB

- 1

XRF

- 100

mCrab

- 10

TDE

- 1

XRB

- 1

sGRB

- 0.1

SNbo

- 0.01

SFXT

- 1second

Time (s) after appearance

- 1

- 10

- 100

- 10^3

- 10^4

- 10^5

- 1hour

- 1day

Swift