Monitor of All-sky X-ray Image (MAXI): Watching stars in X-Rays from ISS

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GSC+SSC Image

Accumulated in 2010-2013
First astronomical mission on ISS
Infrastructure (power and realtime-link)
First light was on August 15 2009
Scans every 92 min. with ISS rotation
Observing for 7 yrs, till 2018.3. and more
Data available at http://maxi.riken.jp
Scans with Slit + Slats collimator

ISS rotation

Slat Collimator

1-dimensional position sensitive detector

proportional counter

X-ray CCD

Celestial sphere

160 deg

1.5 deg (FWHM)

3.0 deg (at bottom)

Particle background rate

Operating in equatorial region

1. MAXI
Today’s All-Sky Coverage (GSC, one-day)

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

GSC 0 (slow gas leak)

Sun avoidance (5 deg.)

GSC 3 (degraded sensitivity with a damaged anode)

Galactic coordinates

http://maxi.riken.jp/
Outline

1. MAXI instruments
2. Results
   1. All-sky map
   2. Cygnus super bubble
   3. Variable X-ray sources
   4. Nova Alerts
   5. New blackholes
   6. Nova ignition
   7. Tidal disruption
   8. GW 150914
Red: 0.7-2 keV, Green: 2-4 keV, and Blue: 4-7 keV.
Supernova remnants appear in red.
Large structures (North polar spur, Cygnus super bubble) are recognized.
Red: 0.7-2 keV, Green: 2-4 keV, and Blue: 4-7 keV. Supernova remnants appear in red. Large structures (North polar spur, cygnus super bubble) are recognized. MAXI CCD achieved an imaging spectroscopy for diffuse emission for the first time.
2.2 Cyg. super bubble

- Emission lines like SNR.
- Similar $N_H$ and $kT$ in 5 regions.
- Suggesting the same distance and age.
- $E_{\text{total}} = 9 \times 10^{51} \text{ergs}$
  $\sim 1000 \ E_{\text{SuperNova}}$
- $\Rightarrow$ Hyper nova remnant
- First HNR in the Galaxy

Kimura et al. (2013)
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X-ray sources are variable

Be X-ray binary pulsars

- GX 304-1
- GRO J1008-57
- 4U 0115+63
- KS 1947+300
- LS V +44 17
- GS 0834-430
- XTE J1946+274

Neutron star Low-mass X-ray binaries

- 4U 1608-52

Blackhole X-ray binaries

- MAXI J1353-564
- MAXI J1828-064
- MAXI J1638-194
- MAXI J1825-249

We need to watch every day and every seconds.
Transients in various time scales

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

MAXI opened the time-domain astronomy

- 50 sec (50 µs resolution, GSC)
- 92 m
- 4 orbits ~6h
- 1 day
- 50 days
- X-ray burst From 4U 1916-053
- Superburst + Outburst From EXO 1745-248
  Serino+ 2012
- BH Outburst MAXI J1659-152
  Negoro+ 2010, Yamaoka+ 2011

2.3. Variable X-ray sky
Massive black hole wakes up after 26 years

Scientists had all but given up on the system known as V404 Cygni, which includes a monster black hole that was fond of devouring material from its stellar companions.

Part of the Milky Way galaxy, the system had been silent for a quarter century. But that all changed earlier this month, when a number of telescopes and the European Space Agency’s (ESA) Integral satellite observed a burst of high energy light coming from almost 8,000 light-years away in the constellation Cygnus, the Swan.

The first inklings the system may be active came from the Burst Alert Telescope on NASA’s Swift satellite, which detected a sudden burst of gamma rays. 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.

Astronomers using a fleet of orbiting telescopes, including ESA’s Integral satellite, NASA’s Swift satellite and the Japanese MAXI telescope, have observed a strong outburst of gamma rays and X-rays produced by a low-mass black hole in a binary system called V404 Cygni.

Quick follow-up optical observation
Discovery of rapid variability (Kimura et al. Nature 2016)
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Thanks to the real-time connection to ISS, a prompt alert has been realized.

Astronomers all over the world.

228 Atels and 98 GCNs
>150 original papers

Nova Search and Alert System
12 sec (Real) after emergence

Negoro+ 2016
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MAXI discovered 17 X-ray Transients in 6 years

1 White Dwarf, 6 Neutron Stars, 6 Black Hole Candidates, and 1 unknown

2.5 Blackholes
6 Blackholes discovered by MAXI

Since 2009 August, 12 BHCs were discovered. 6 out of them were discovered by MAXI.

Negoro et al. (2014)
MAXI watches through the whole Galaxy.

\[ F = \alpha L_{\text{Edd}} / 4\pi d^2 \]
\[ \alpha = 0.01-0.04 \ (\text{Maccarone 2003}) \]

Soft-to-Hard Transition

J1828 (l, b) = (8.1, -6.5)
\( d > 12 \text{kpc} ?! \)

J1543 (l, b) = (325.1, -1.1)
\( d > 12 \text{kpc}? \ (\text{Stieble+ 2012}) \)

J1305 (l, b) = (304.2, -7.6)

Negoro 2008
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Discovery of MAXI J0158-744

- MAXI GSC All-sky Image
- Every 90 min.
- 2011-11-11 05:05:59 (UT)

- Soft X-ray short Transient (< 5 keV)
  None of GRBs, X-ray burst on neutron stars,
  Flare of magnetars, Super-giant Fast X-ray
  Transient, and supernova shock breakout
Near the edge of Small Magellanic Clouds (SMC)
- Optical spectrum: Be star at SMC distance (\(= 60 \text{ kpc}\)) \(\text{(B1-2 IIle)}\)
- Luminosity = \(10^{40} \text{ erg/s}\) (Ignition phase)
- Ionized Ne line was detected.

Energy spectrum (0.5 \( \rightarrow \) 30 days):
- Blackbody (radius = \(10^4 \rightarrow 10^2 \text{ km}\), Temperature = \(60 \rightarrow 110 \text{ eV}\))
- Similar to soft X-ray emission after nova explosions.
- Super Soft X-ray Source phase (SSS phase)
Nova (nuclear fusion) explosion

rare

WD-Be binary system (MAXI J0158-744)

Be star

Circumstellar disk

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

Press Release from RIKEN (2013.11.14)  Credit: Takuya Ohkawa

Morii et al. (2013)
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Tidal Disruption Event with MAXI

- A star approaching to a giant blackhole in the center of a galaxy is torn into pieces by the tidal force. The debris accretes to the blackhole.
- Long time monitoring of MAXI guarantees a single event, not one of the AGN activities.
- MAXI detected three TDE during 2009-2012.
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GW 150914 Event

MAXI was not operating at the GW time 2015.9.14. 9:50:45 UT.

Credit: LIGO Caltech

Abbott et al. 2016
4-30 min after the detection

Scans on the GW region started in 4 minutes later. About 90% of the error region was observed in less than 30 min.
Although MAXI was off at the GW time, it put upper limit in flux in just after the event, long before and long after the event.
Continuous monitoring of MAXI on ISS provides basic information on variability of X-ray sources, which is distributed freely to the world.

A real-time alert triggers many follow-up observations of ground observatories and satellites in orbit.

New phenomena (as an ignition of a nova) and six blackholes were discovered.

MAXI has opened a new era of time-domain astronomy and of multi-messenger astronomy with the highly-sensitive X-ray all-sky monitor and the real-time alert.

Together with new instruments (gravitational wave detectors, the X-ray detector NICER on ISS), MAXI will be on the cutting edge of the X-ray astronomy.