5 Year Monitoring of Variable X-ray Sources by MAXI

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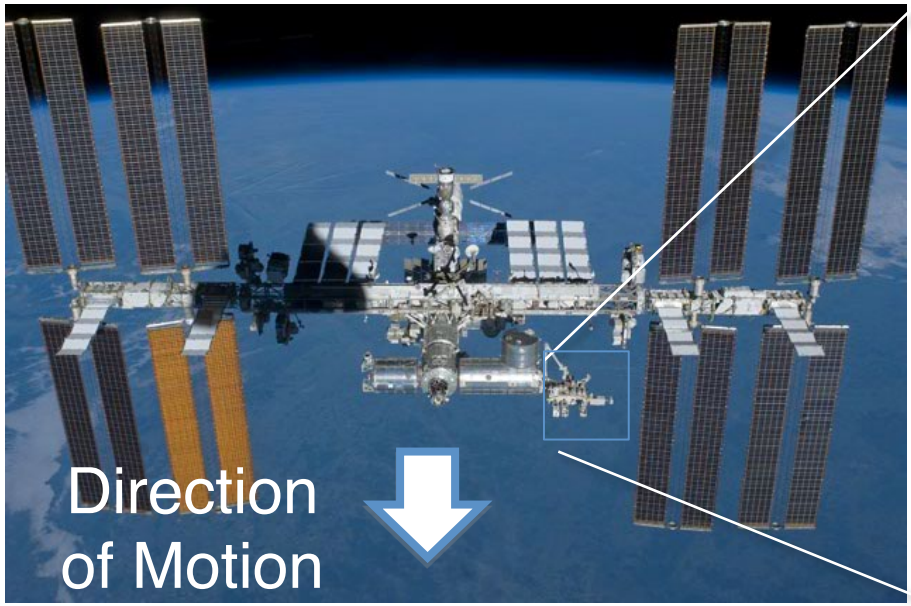
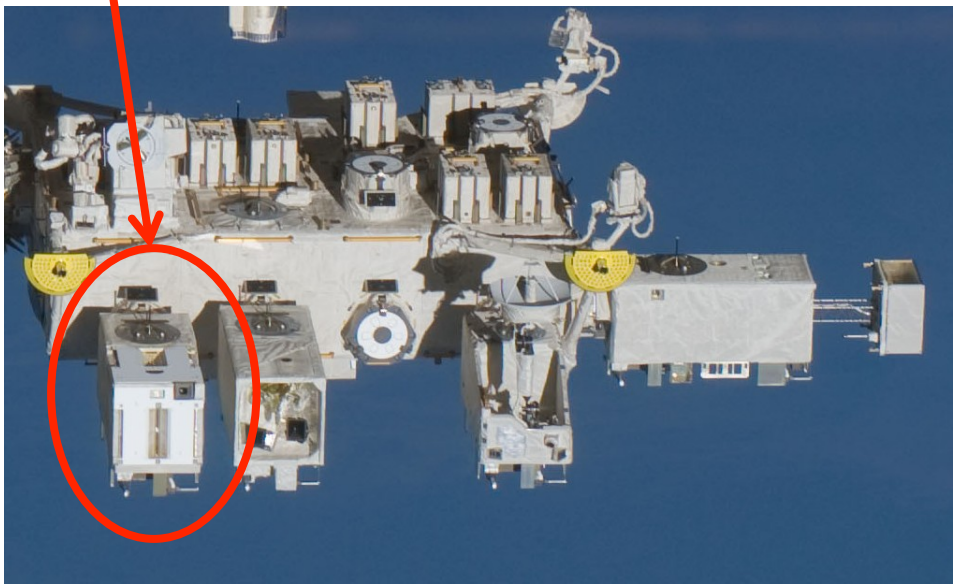
+ graduated students!

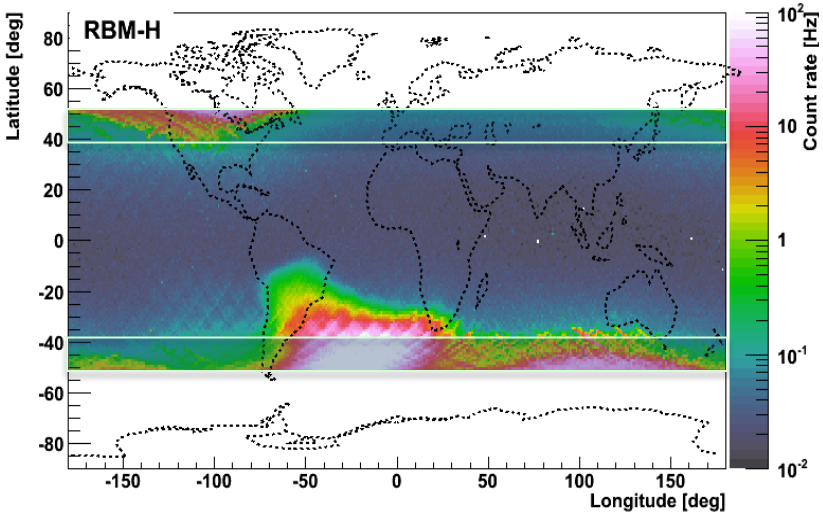
- MAXI overview
- Cygnus superbubble: hypernova remnant?
- Soft X-ray transient of a new rare class
- MAXI/GSC 37 month catalog
- Be-Neutron star binary
- Black hole binary
- AGN

MAXI (Monitor of All-sky X-ray Image) on ISS





- Operational since August 15 2009.
- Operation approved until March 2015.
- 6 working Gas slit cameras (out of 12)
- 2 CCD slit cameras
- Orbit period 92 min, inclination 51.6°, ops at lat.<40° → Obs. efficiencey 40%



MAXI Instruments

6 x 2 GSC (Gas Slit Camera) : 2-20 keV, Time Resolution 50 ms

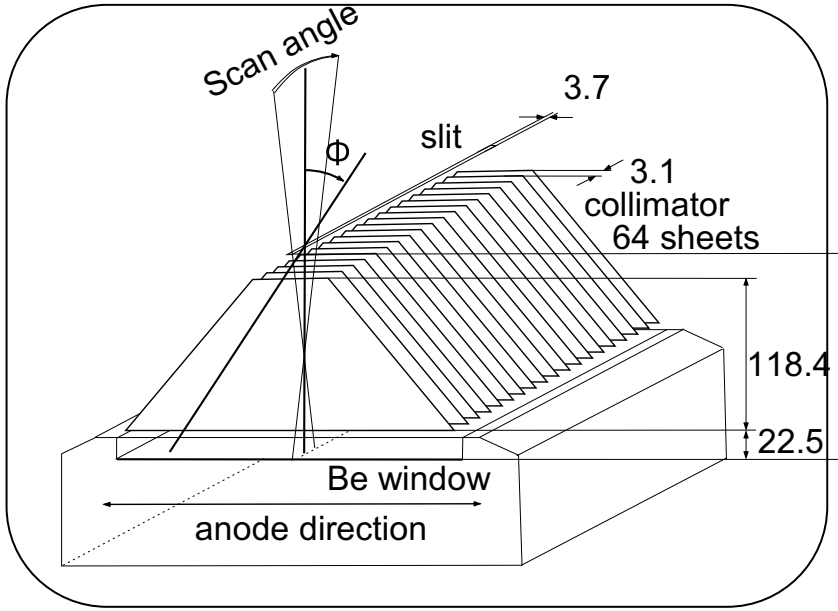
Mihara+ 2011, Sugizaki+ 2011

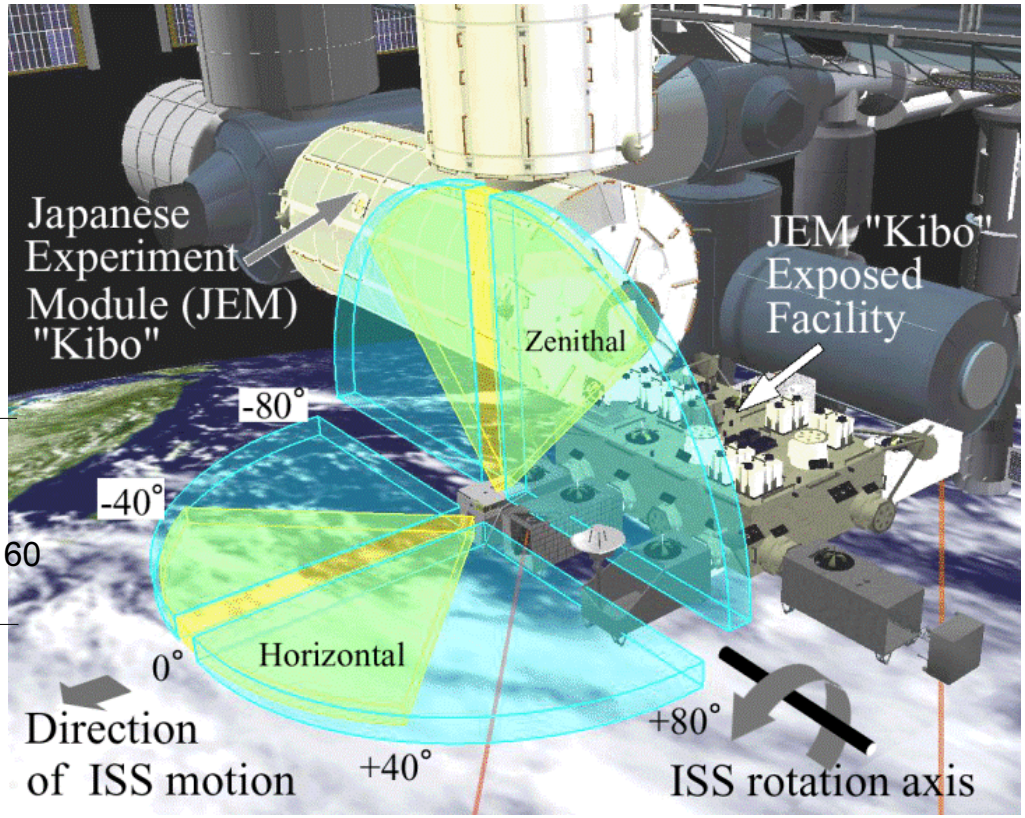
2 x SSC (Solid-state Slit Camera) : 0.7-10 keV, Time Resolution 5.9 s

Tsunemi+ 2010, Tomida+ 2011

PSF ~1.5 deg (FWHM)

Position Determination Accuracy ≤ 0.2 deg

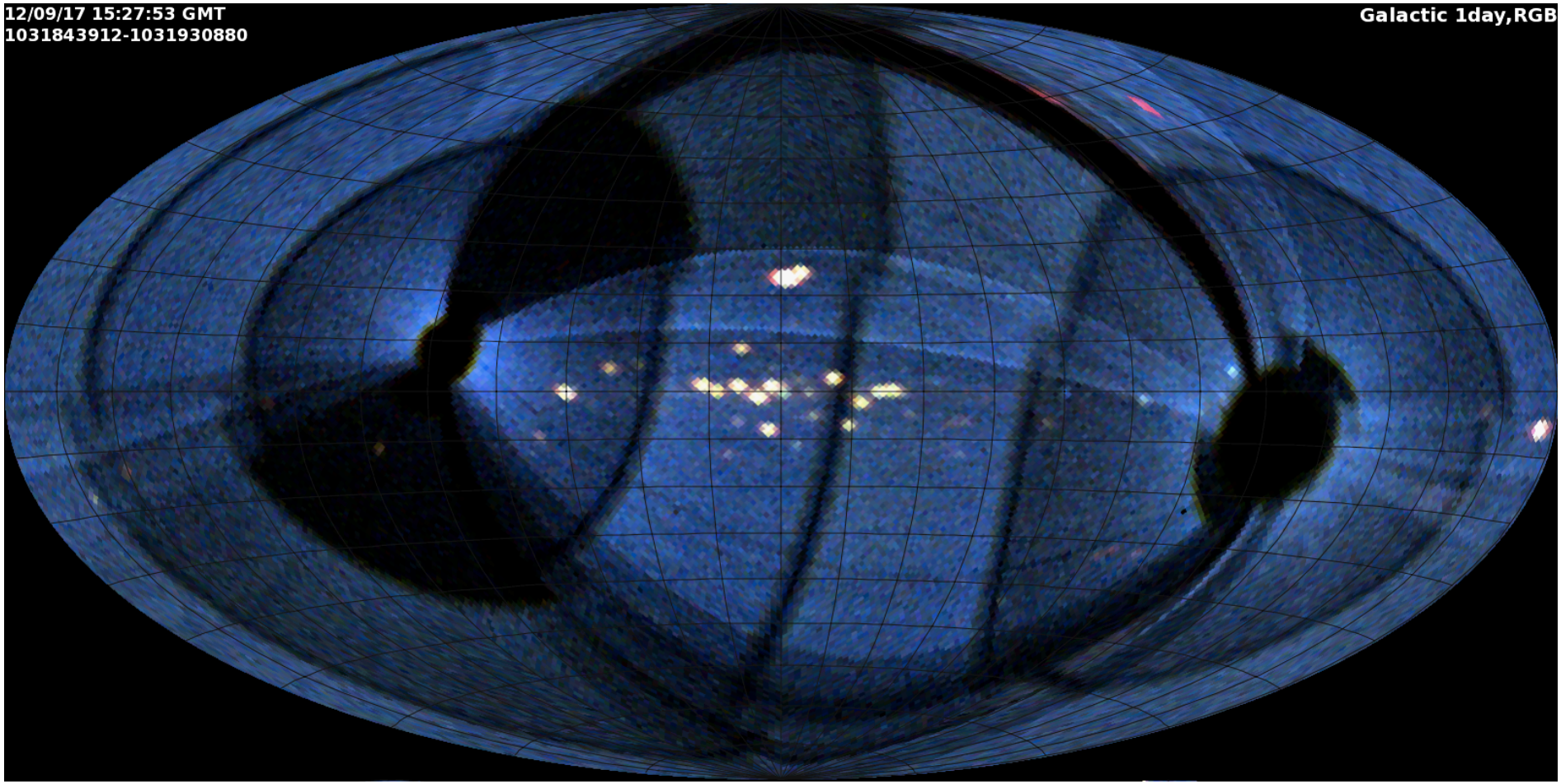




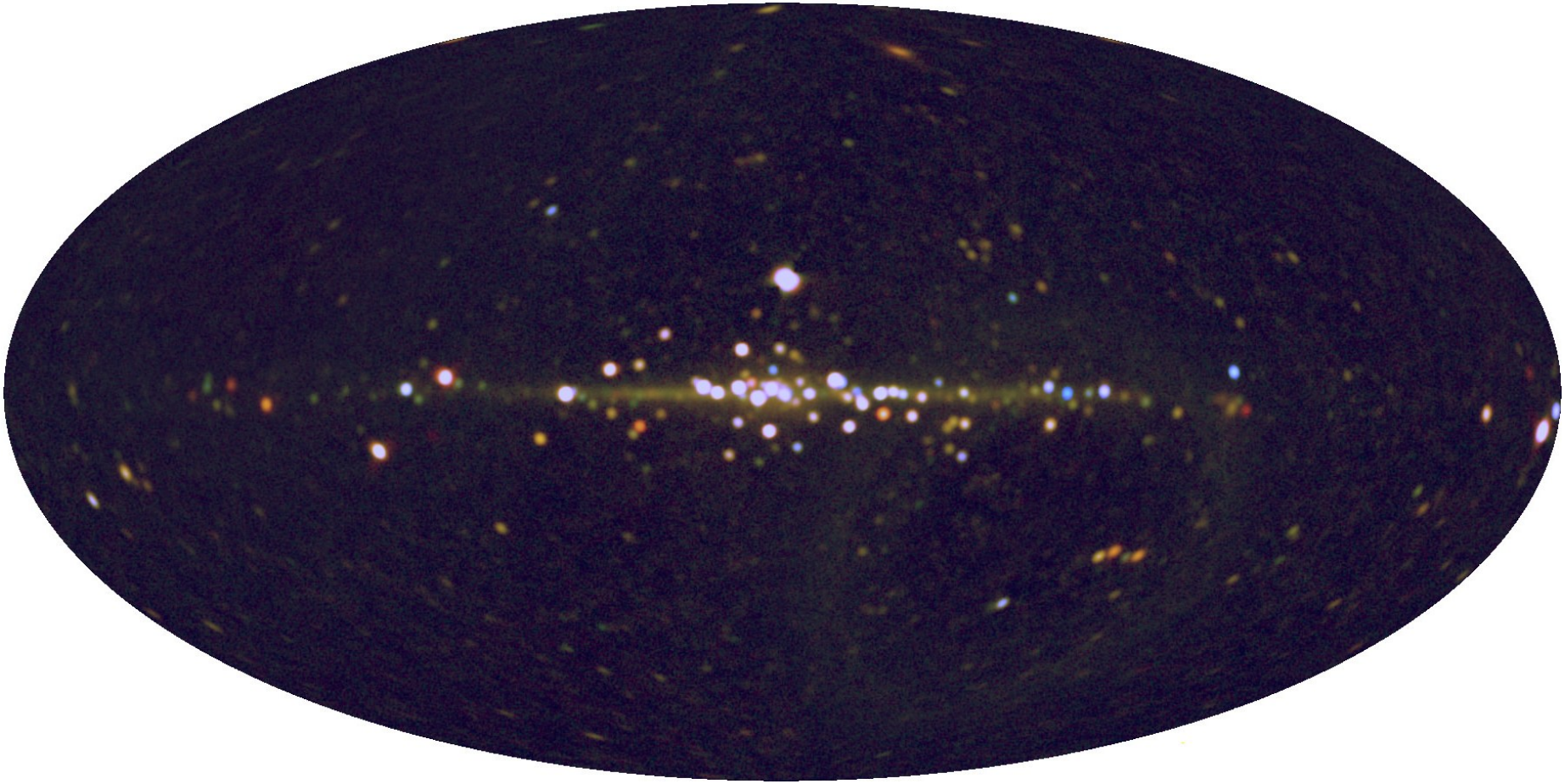
MAXI scans the X-ray sky every 92 min

~ 85 % (1 orbit) Sensitivity (GSC) ~ 100 mCrab

~ 95 % (1 day) ~ 30 mCrab



GSC all-sky map (4.1 years).

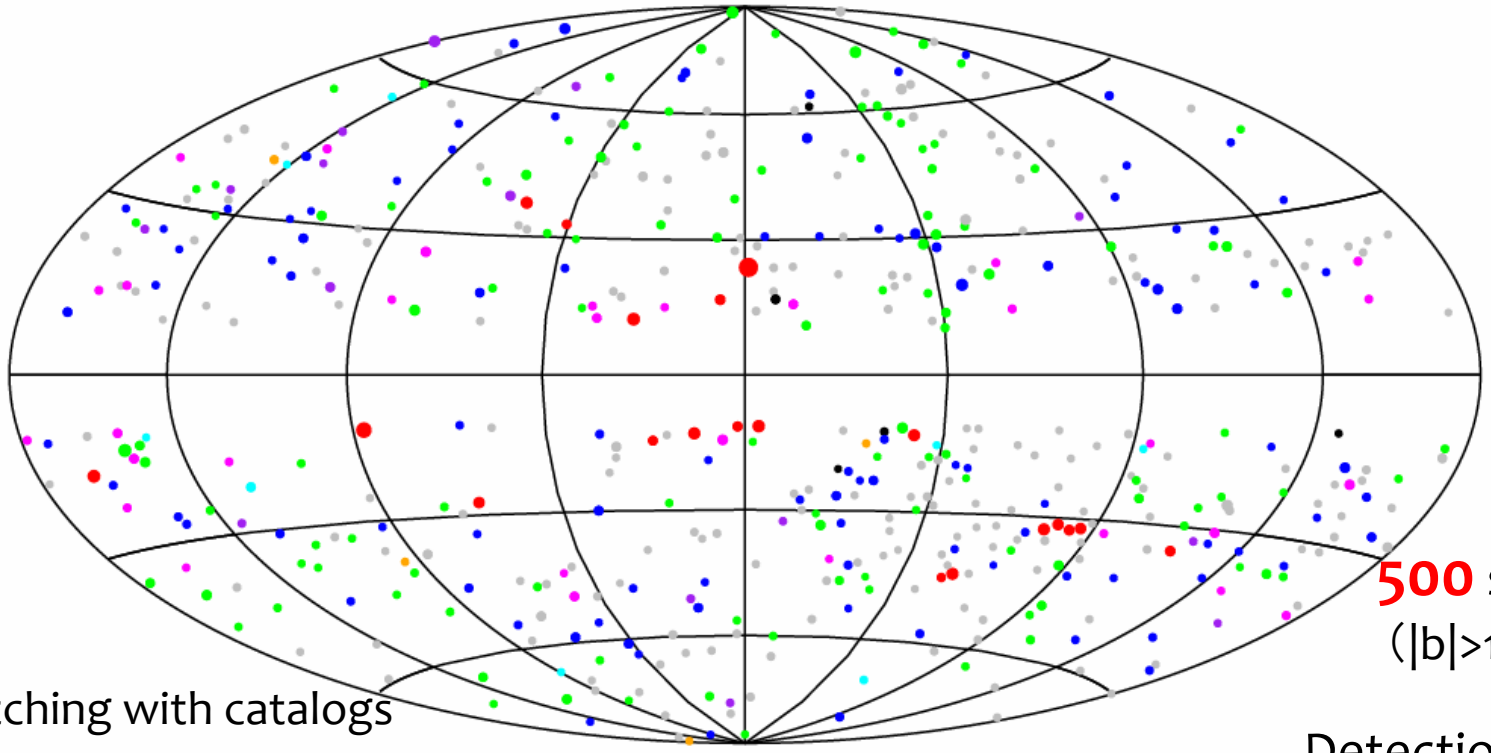


Red: 2-4 keV, Green: 4-10 keV, and Blue: 10-20 keV.

The X-ray binary pulsars appear in **blue**, supernova remnants in **red**.
Yellows are low-mass X-ray binaries.

More than 500 sources are detected.

MAXI / GSC 37 months catalog



500 sources
(|b|>10°, >7σ)

Cross-matching with catalogs

Swift/BAT 70-Month Hard X-ray Survey Catalog (AGN, glactic)
Meta-Catalog of X-Ray Detected Clusters of Galaxies (clusters)

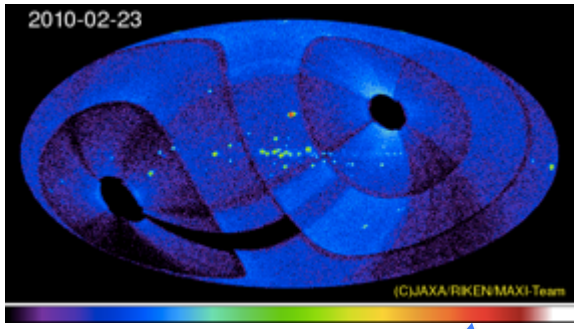
Detection limit :
～0.4 mCrab

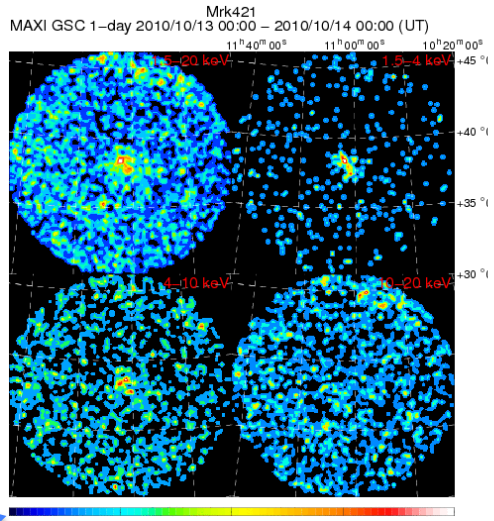
X-ray binary: 20	CV/Star: 30	Galaxy cluster: 114
Seyfert galaxy: 100	Blazar: 15	Galaxy: 8
Confused: 4	X-ray source: 5	Unmatched: 204

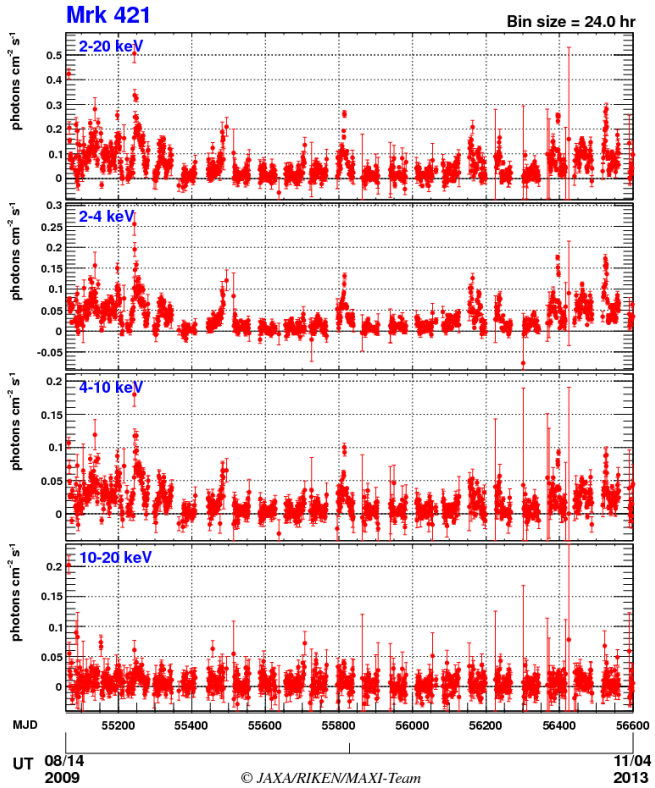
→ **~60%** identified.

Hiroi et al. (2013)

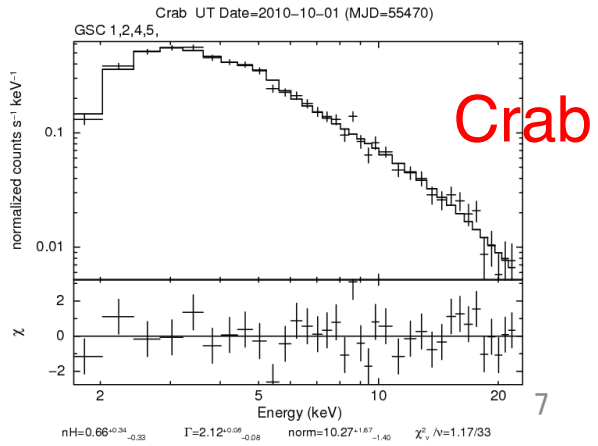
MAXI Public Data (http://maxi.riken.jp)







- Daily all-sky image
- For 324 listed Sources
  - Field image
  - Light curve in three energy bands
  - (updated daily)
- For selected sources
  - Daily energy spectrum with RMF



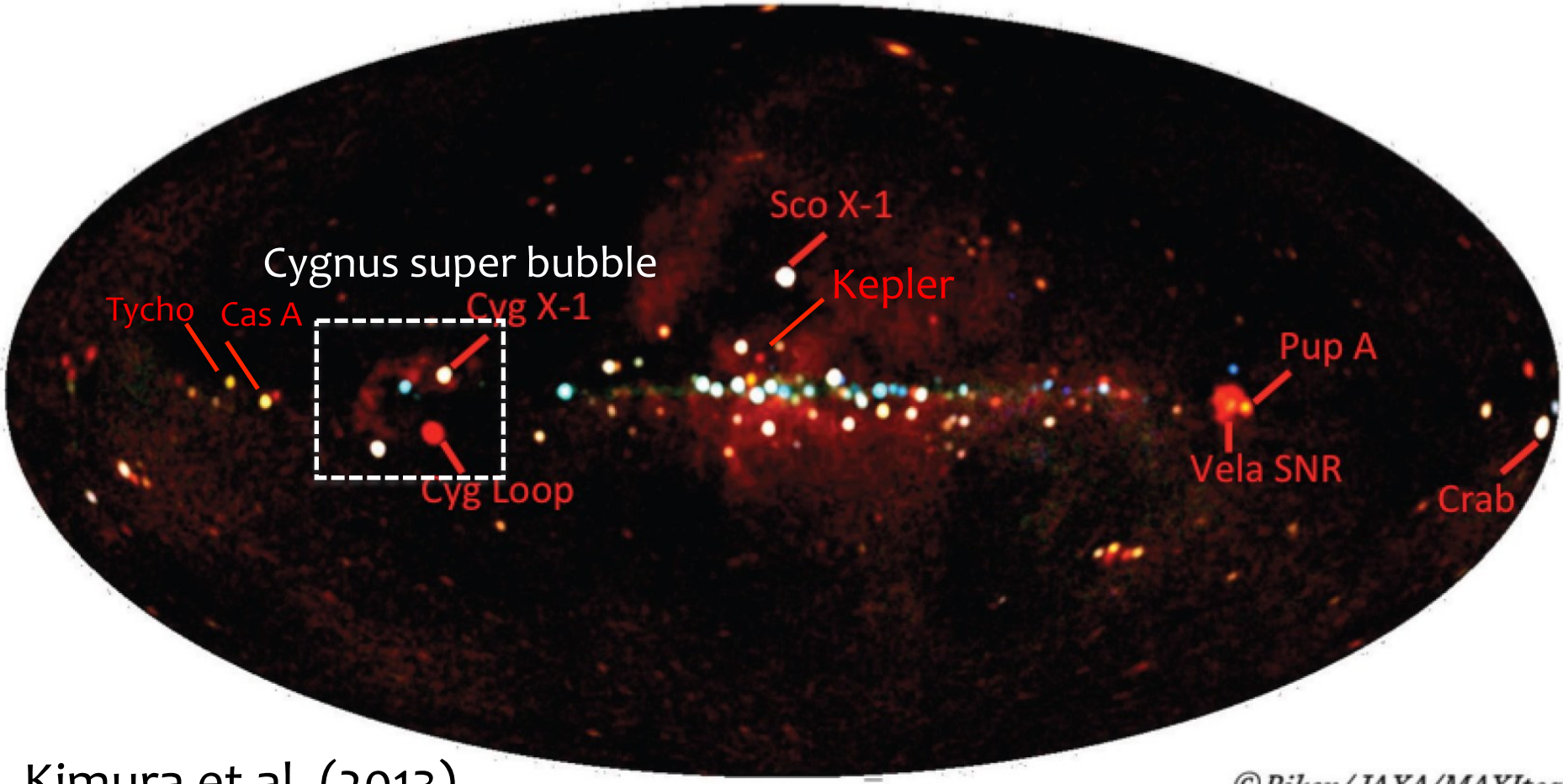
- On-demand analysis on the web
  - Any location of the sky
  - Image, light curve, and spectrum

SSC (CCD slit camera) Results

Cygnus Superbubble
MAXI J0158-744: ignition of a nova

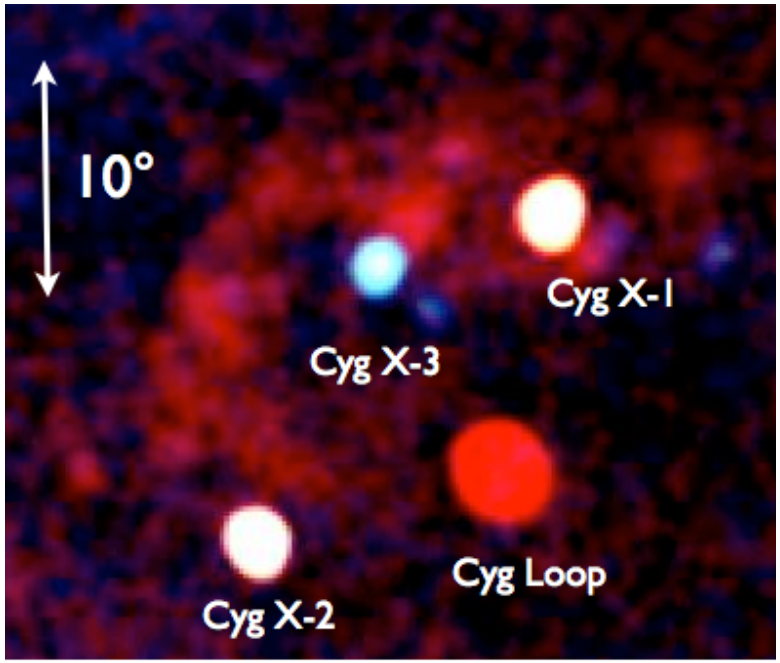
SSC all-sky map

- Operated in the ISS night time to avoid light leak from the Sun.
- Observation duty cycle ~ 40 %
- Cygnus Superbubble is a possible hypernova remnant.

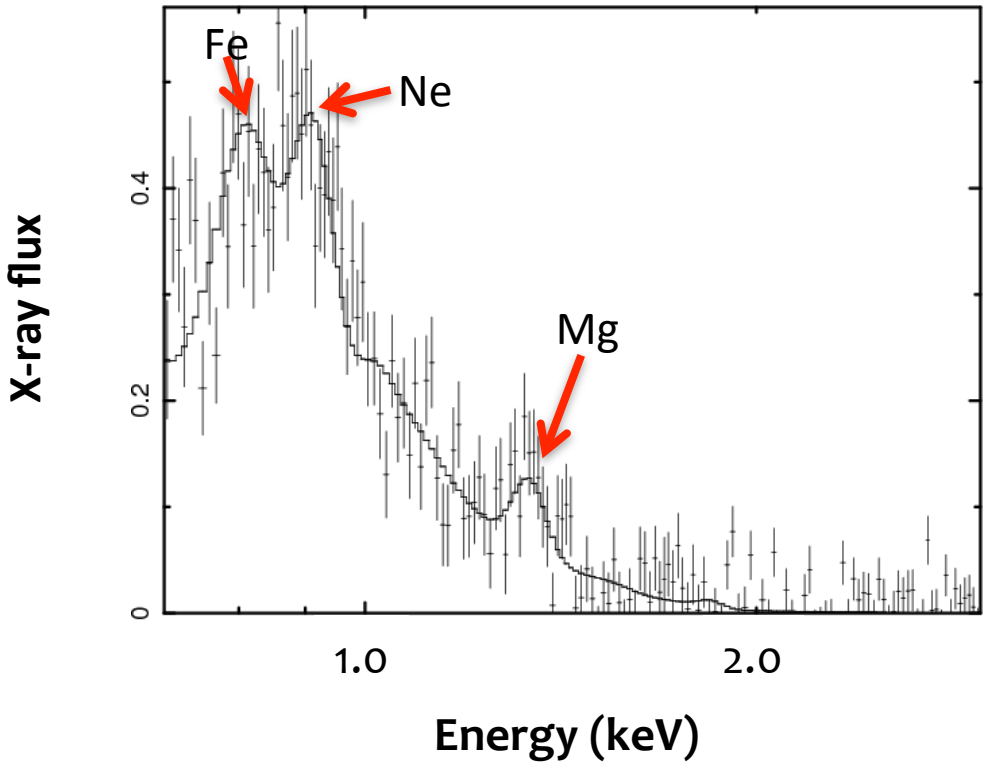


Kimura et al. (2013)

Cygnus Superbubble



Kimura et al. 2013 PASJ

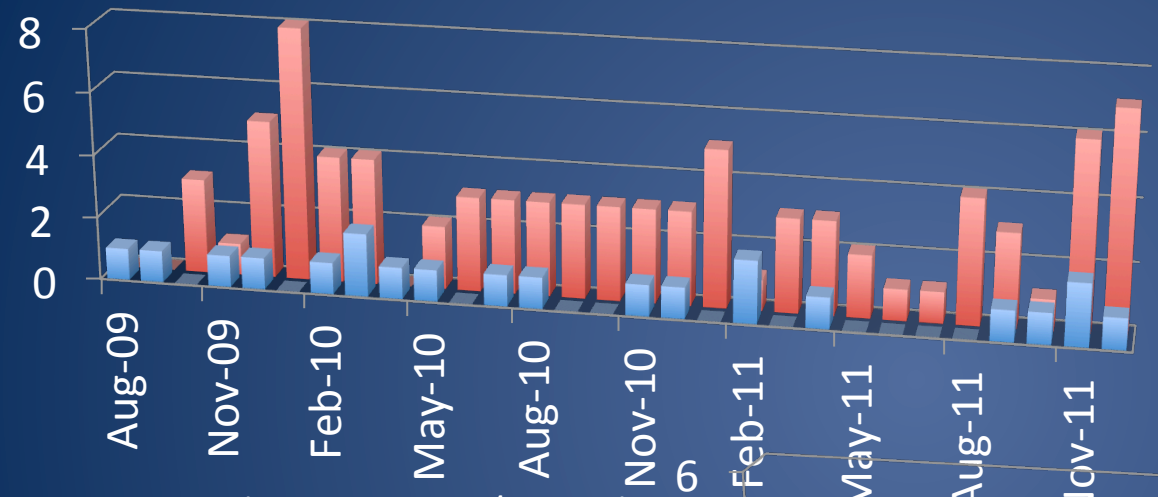


- Uniform temperature ≈ 0.2 keV
- Uniform $N_H \approx 0.3 \times 10^{22}$ cm^{-2}
- Associated with Cyg OB2, but with offset

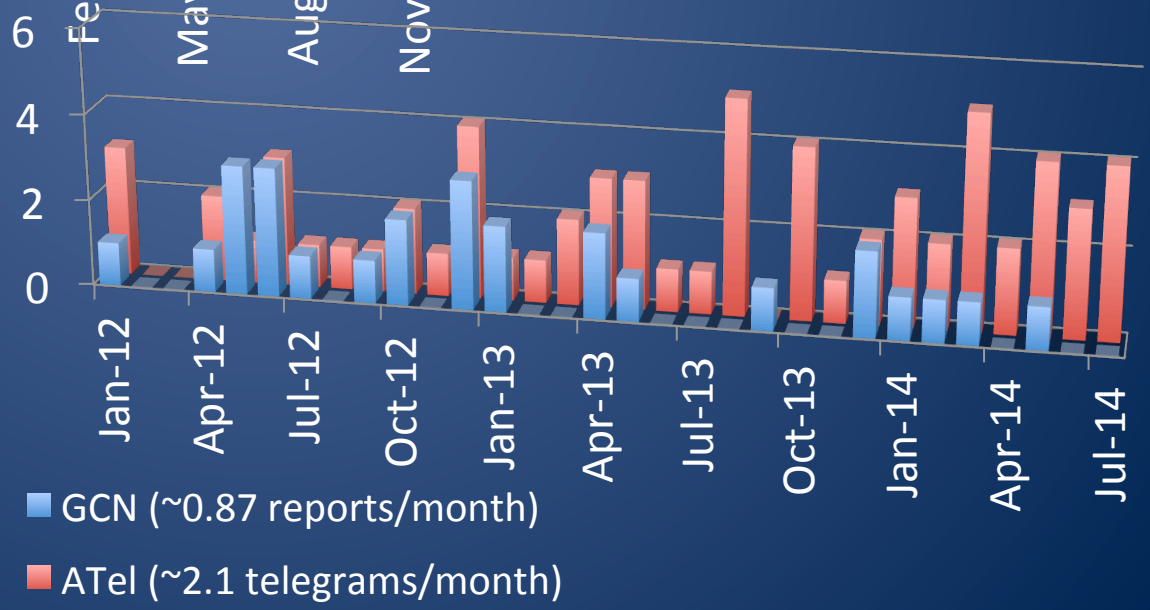
➔ Single SNR

- thermal energy ≈ 10^{52} erg
- explosion energy ≈ 10^{54} erg
  — "Hypernova" (?)

ATels and GCN Circulars



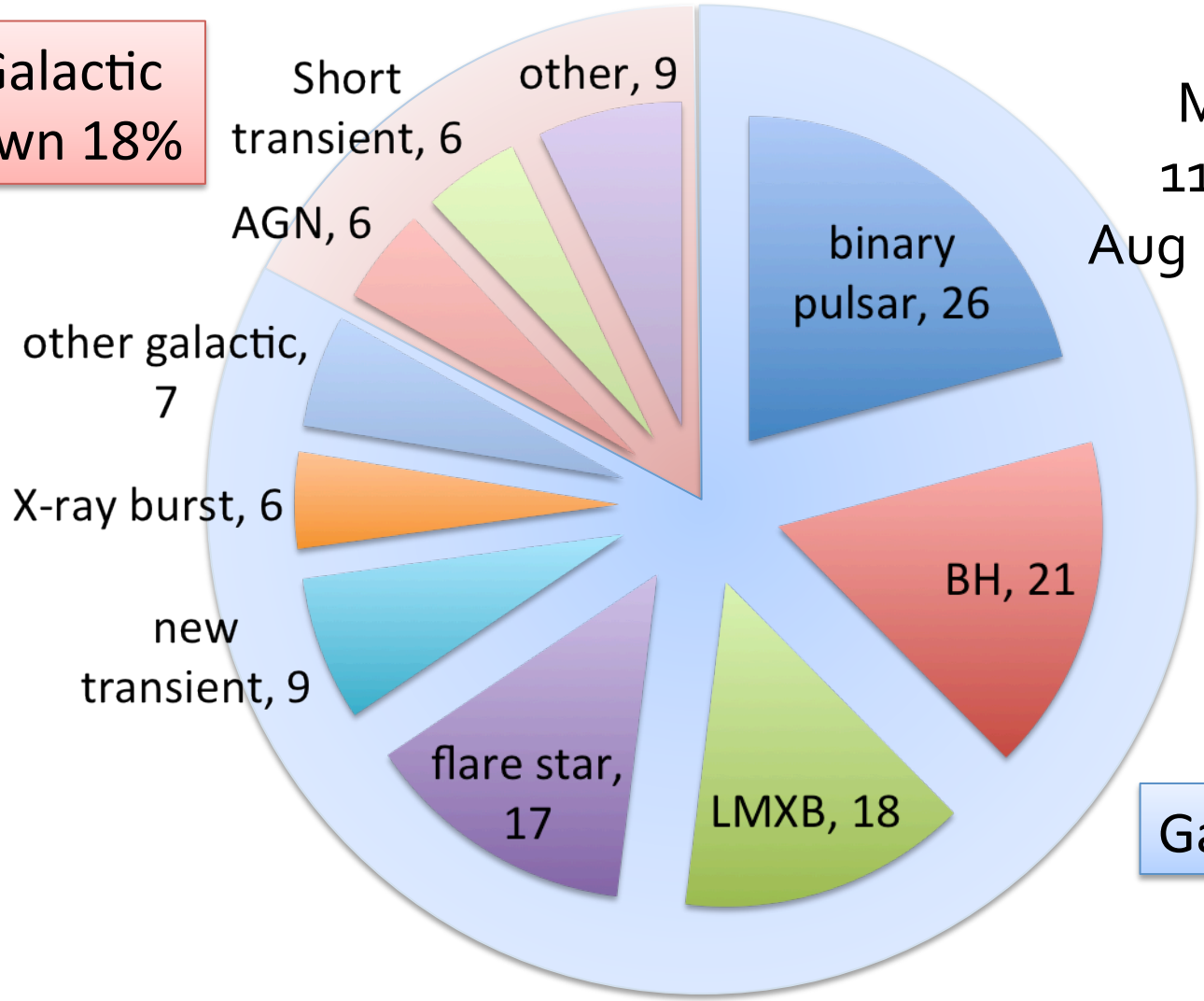
Aug 2008 – Dec 2011



Jan 2012 – Jul 2014

Categories of Transients

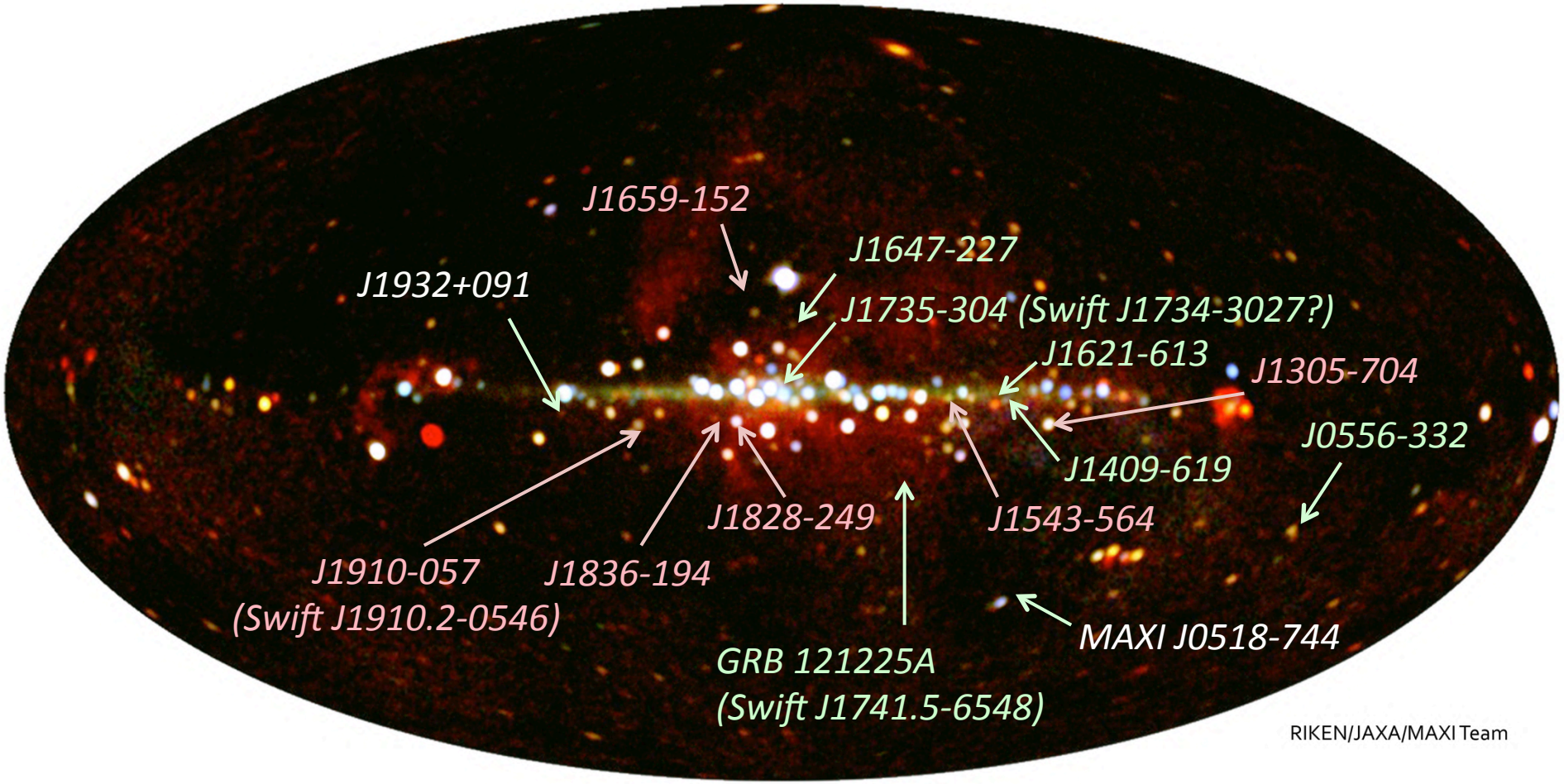
Extra Galactic
Unknown 18%



MAXI ATels
119 issued in
Aug 2009–Jul 2014

Galactic 82%

14 new X-ray Transients discovered by MAXI in 5 years

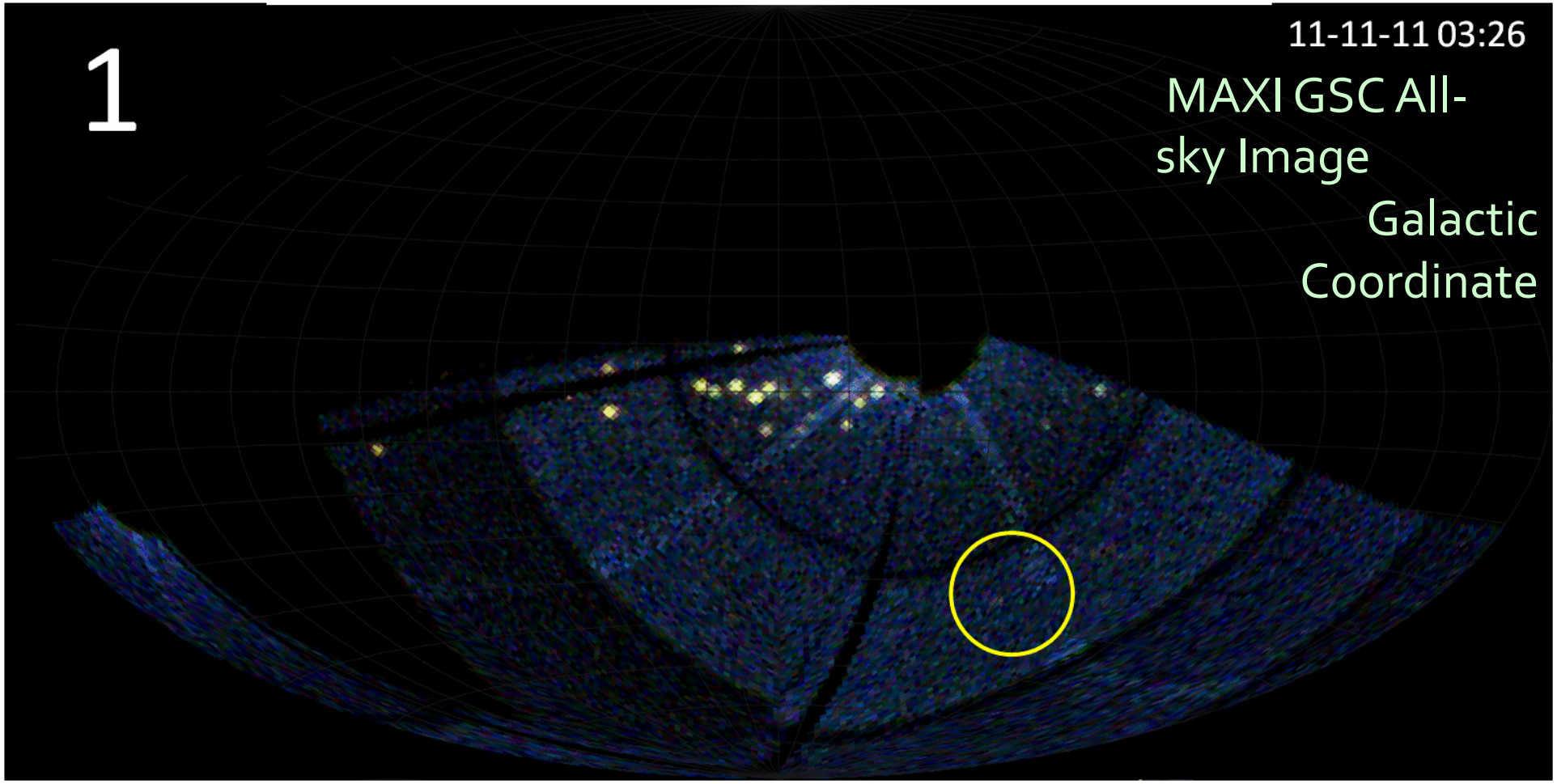


1 White Dwarf, 6 Neutron Stars, 6 Black Hole Candidates, and 1 unknown

A soft X-ray transient of a new rare class

MAXI J0158-744: ignition of a nova

MAXI J0158-744: unique soft X-ray transient

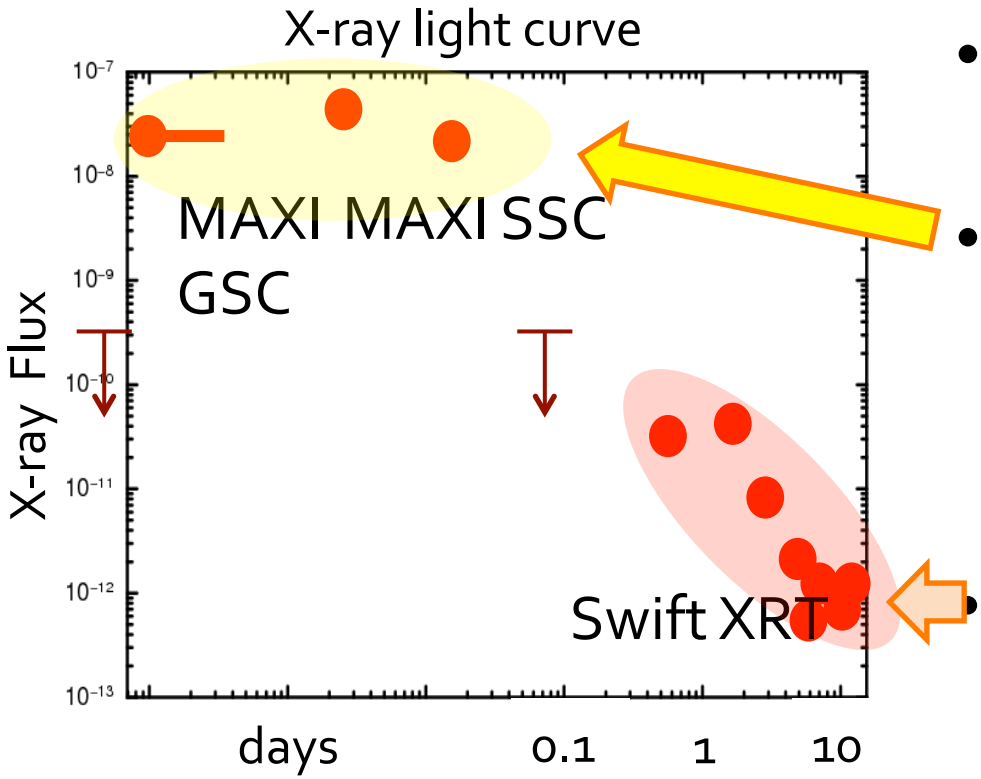


- 2011-11-11 05:05:59 (UT)
- GRB 111111A
- Soft X-ray transient (< 5 keV)

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

Morii et al. 2013

MAXI J0158-744

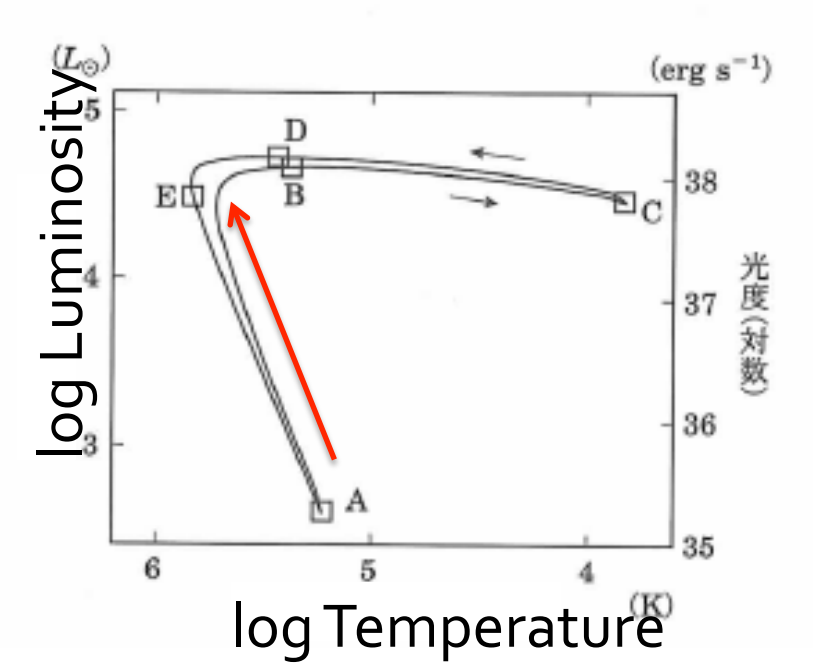


- Duration ≈ hour
  - (1300 s <ΔT< 1.1 x 10^4 s)
- Extremely luminous
  - 10^{40} erg / s
  - x100 solar mass Eddington luminosity
- supersoft X-ray source at late phase
  → white dwarf
  - classical/recurrent nova?
    - but x10^4 more luminous than known nova X-ray emission
      - (shocked ISM? Li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

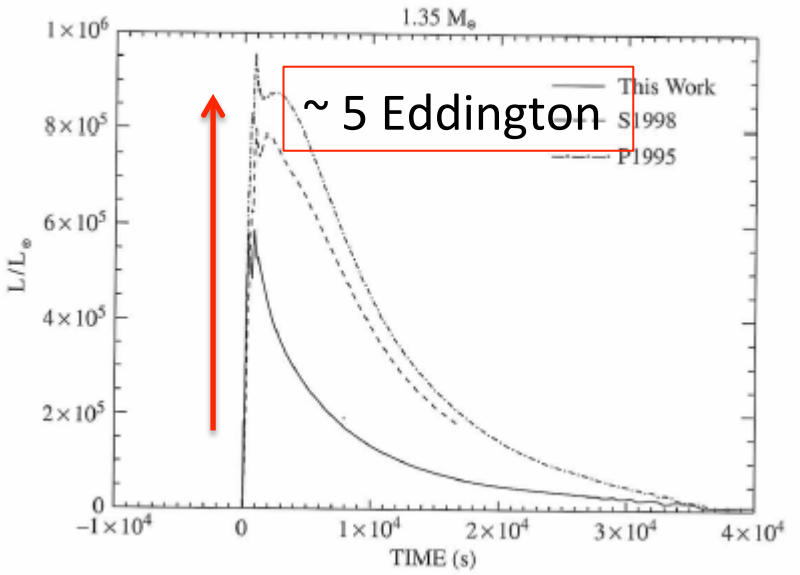
Morii et al. 2013

MAXI J0158-744: interpretation

- Ignition of thermonuclear runaway on a white dwarf
- Transient dynamics allows super-Eddington emission



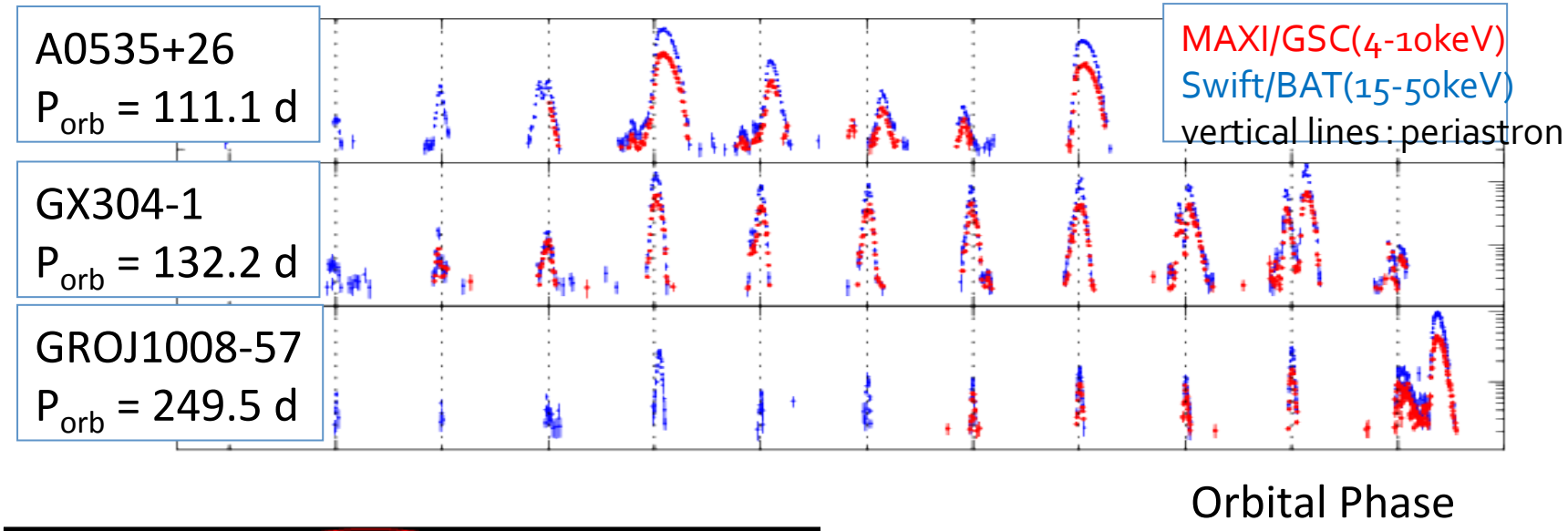
現代の天文学シリーズ「恒星」(Hachisu)

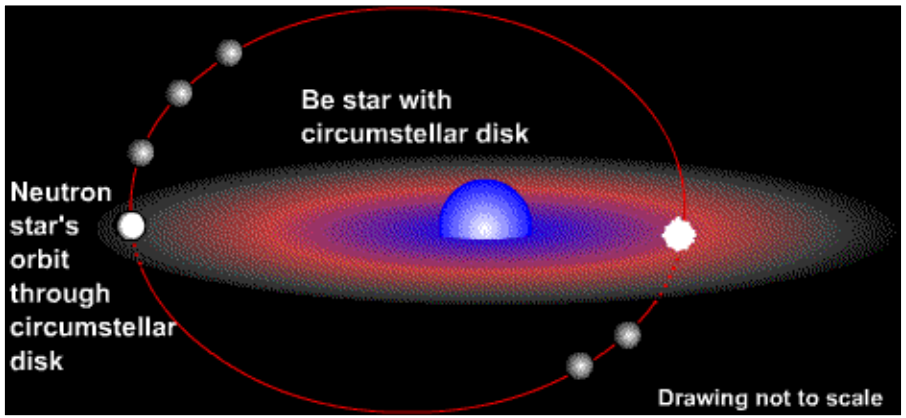


light curve for 1.35 solar mass WD (Starrfield + 2008)

- MAXI J0158-744 : kT = 0.3 – 0.4 keV, L = 100 x Eddington →
- probably the WD is very massive (close to the Chandrasekhar limit)

Be X-ray binary

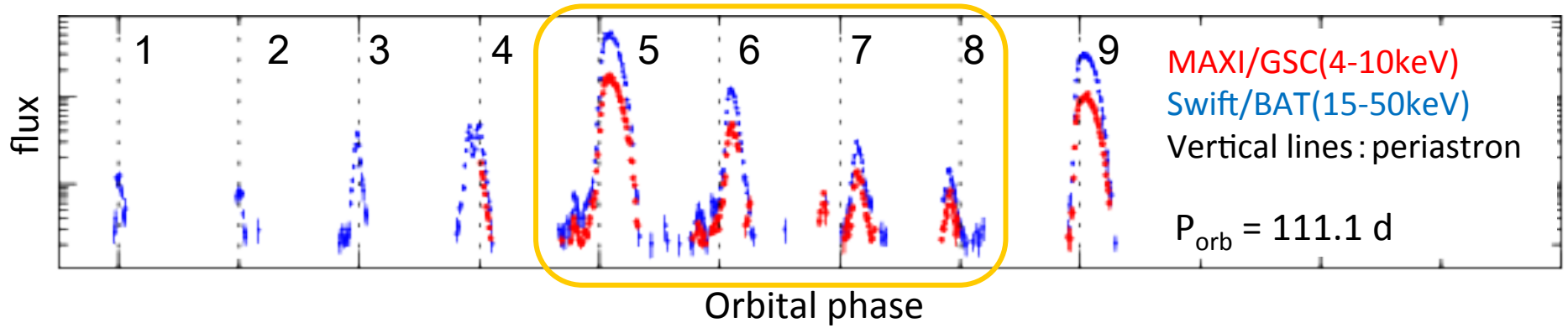


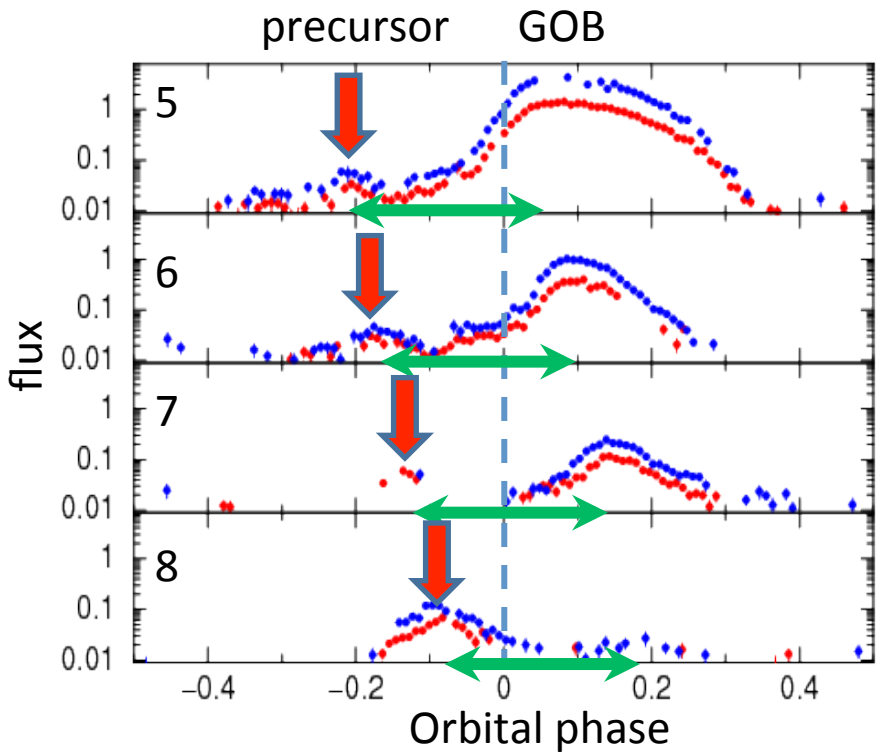


http://science.nasa.gov/science-news/science-at-nasa/1998/ast25mar98_1/

Schematic view of a
Be X-ray binary

Phase drift of Outbursts in Be X-ray binary A0535+26

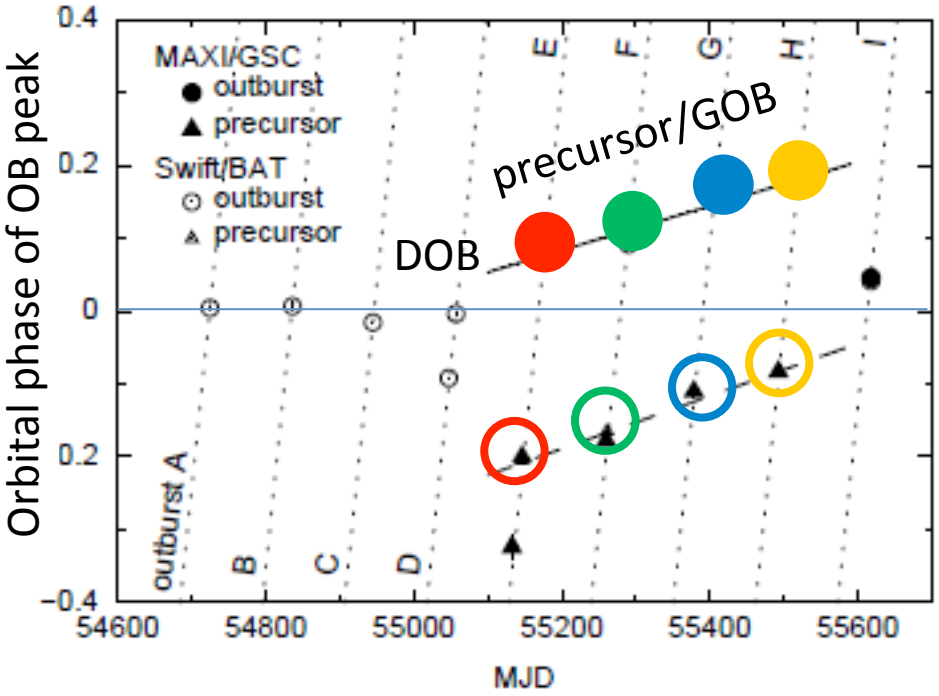




- MAXI detected **precursors** to giant outbursts (GOB)
- Period of precursor/GOB is 115 d, not P_{orb} (=111.1 d)
- Separations between precursor/GOB are constant at about 30 days (0.27 in phase)
- At outburst 8, flux ratio precursor/GOB reversed.

BeXRB

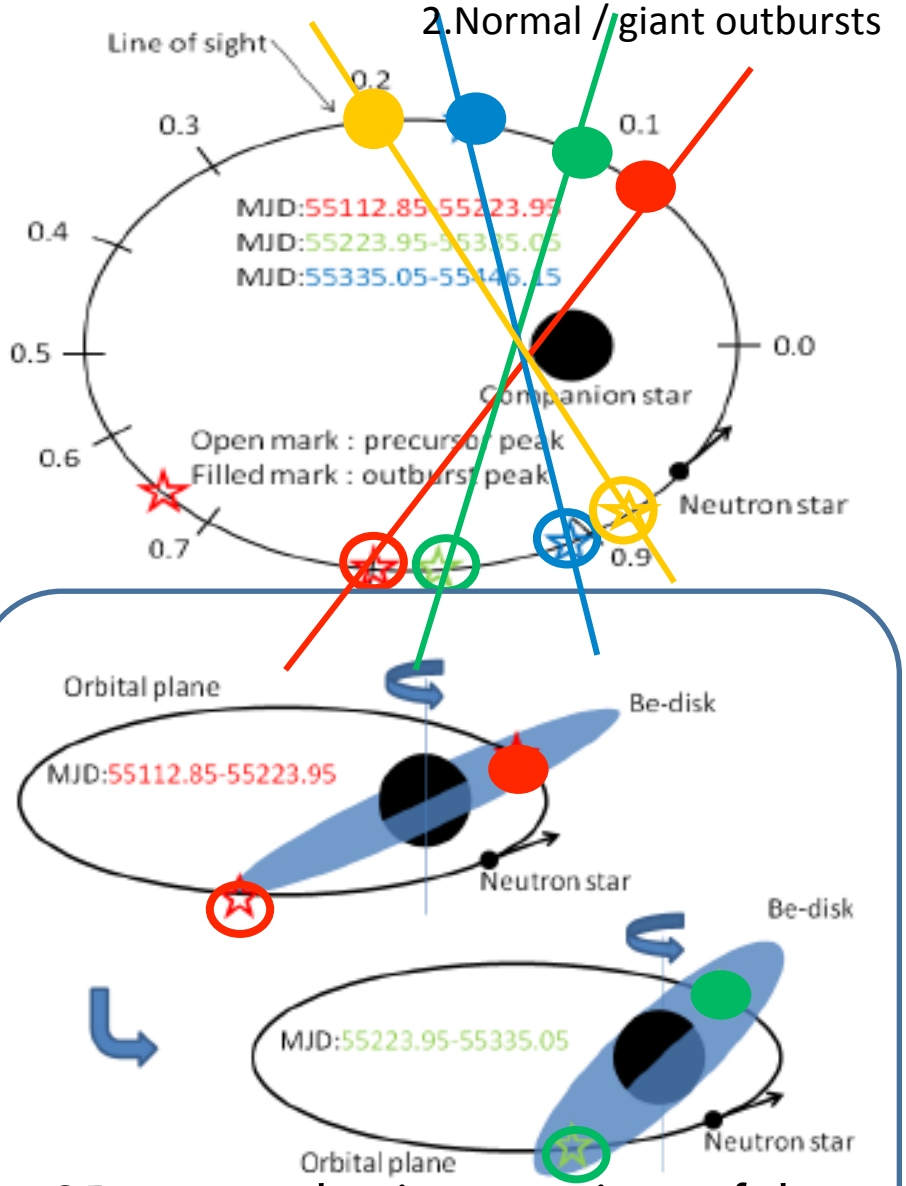
A0535+26 precursor/GOB phase drift



- Outburst location is drifting in orbit
- Lines connecting precursors/GOB cross near the Be star.
- After DOB, EW of Hα line increased. (Moritani+2011)

→ Gas was ejected from the Be star.

2.Normal /giant outbursts



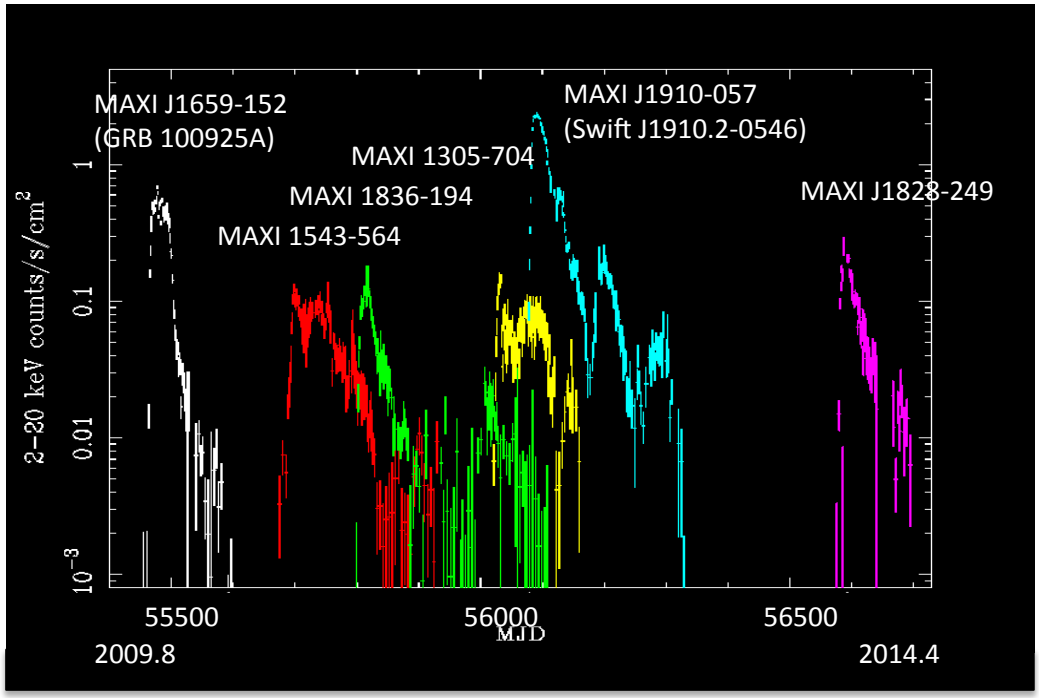
OB occurred at intersections of the NS orbit and the precessional Be-disk ? Precession P is about 8.7 yr.

Nakajima (2014)

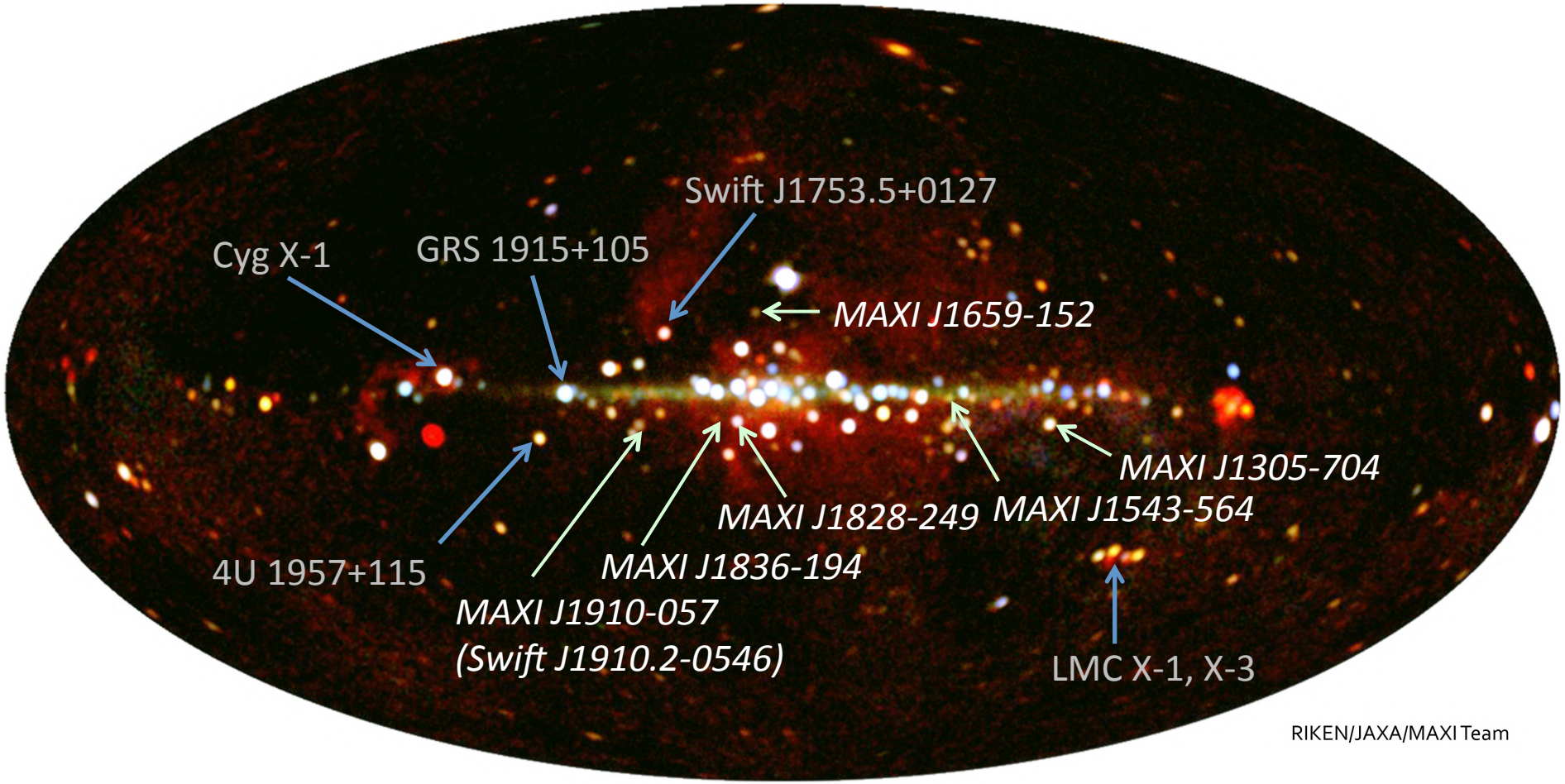
Okazaki (2013)

Black Hole Binaries

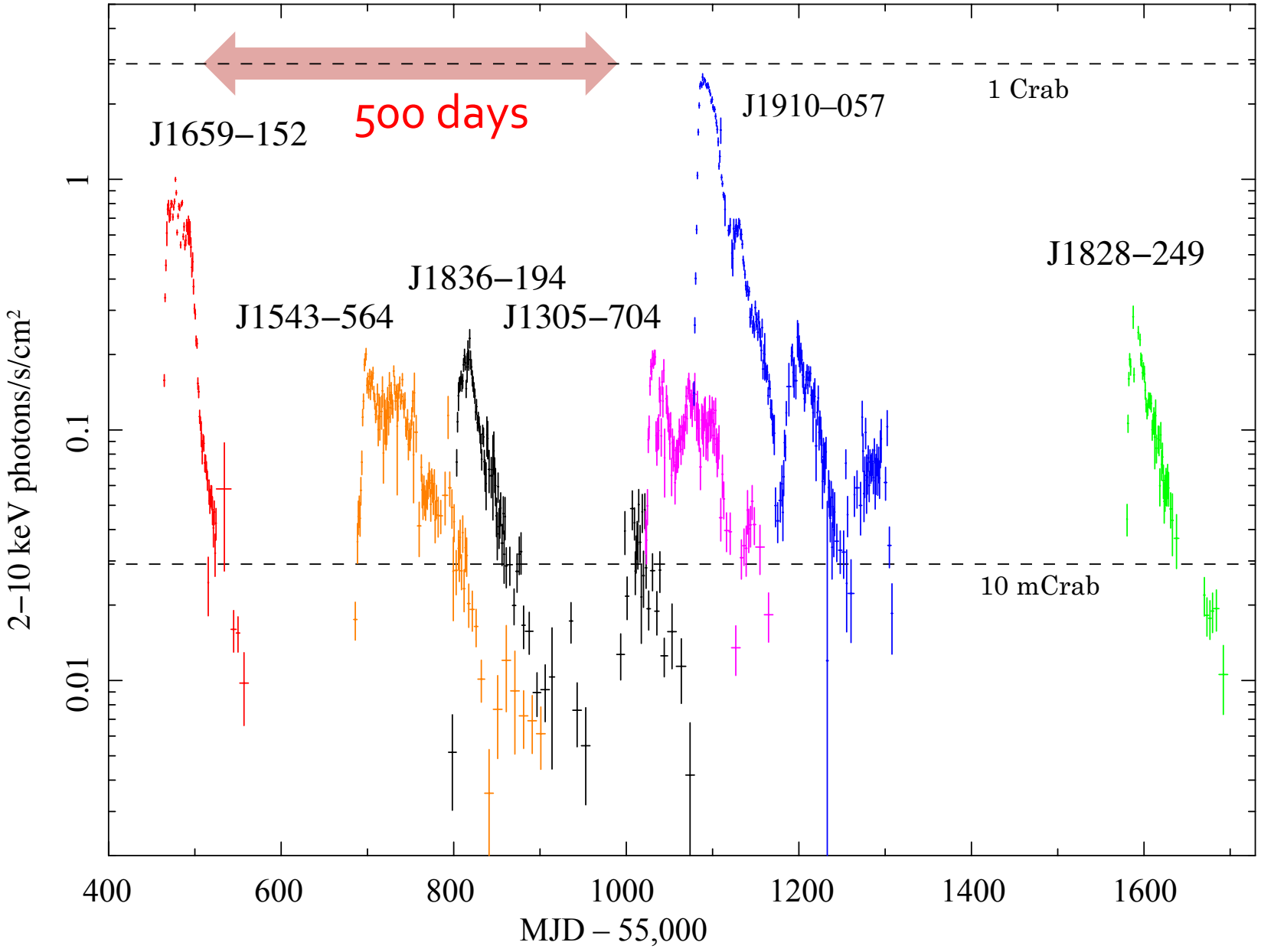
MAXI is finding new black hole binaries

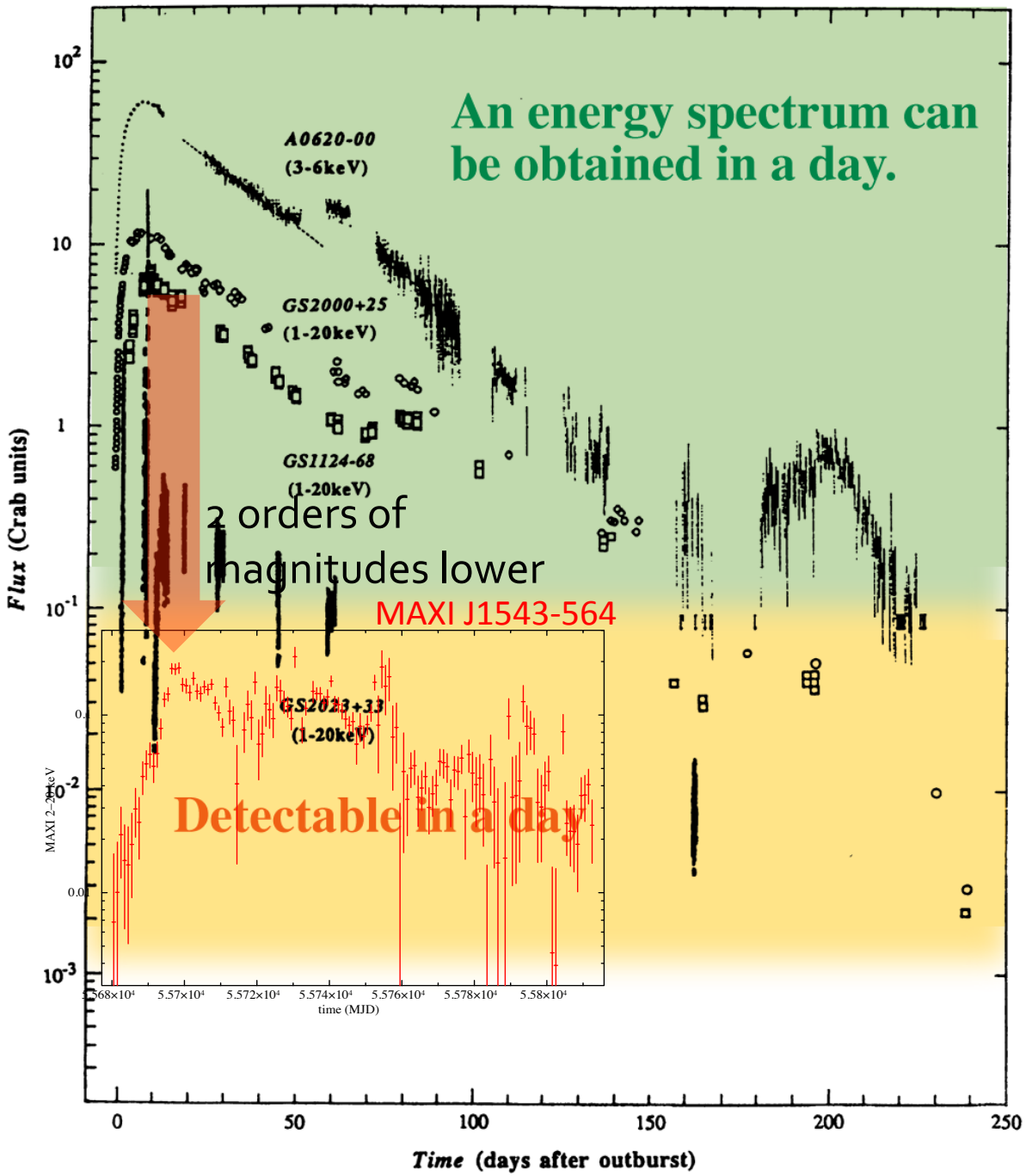


MAXI is finding Black Hole binaries

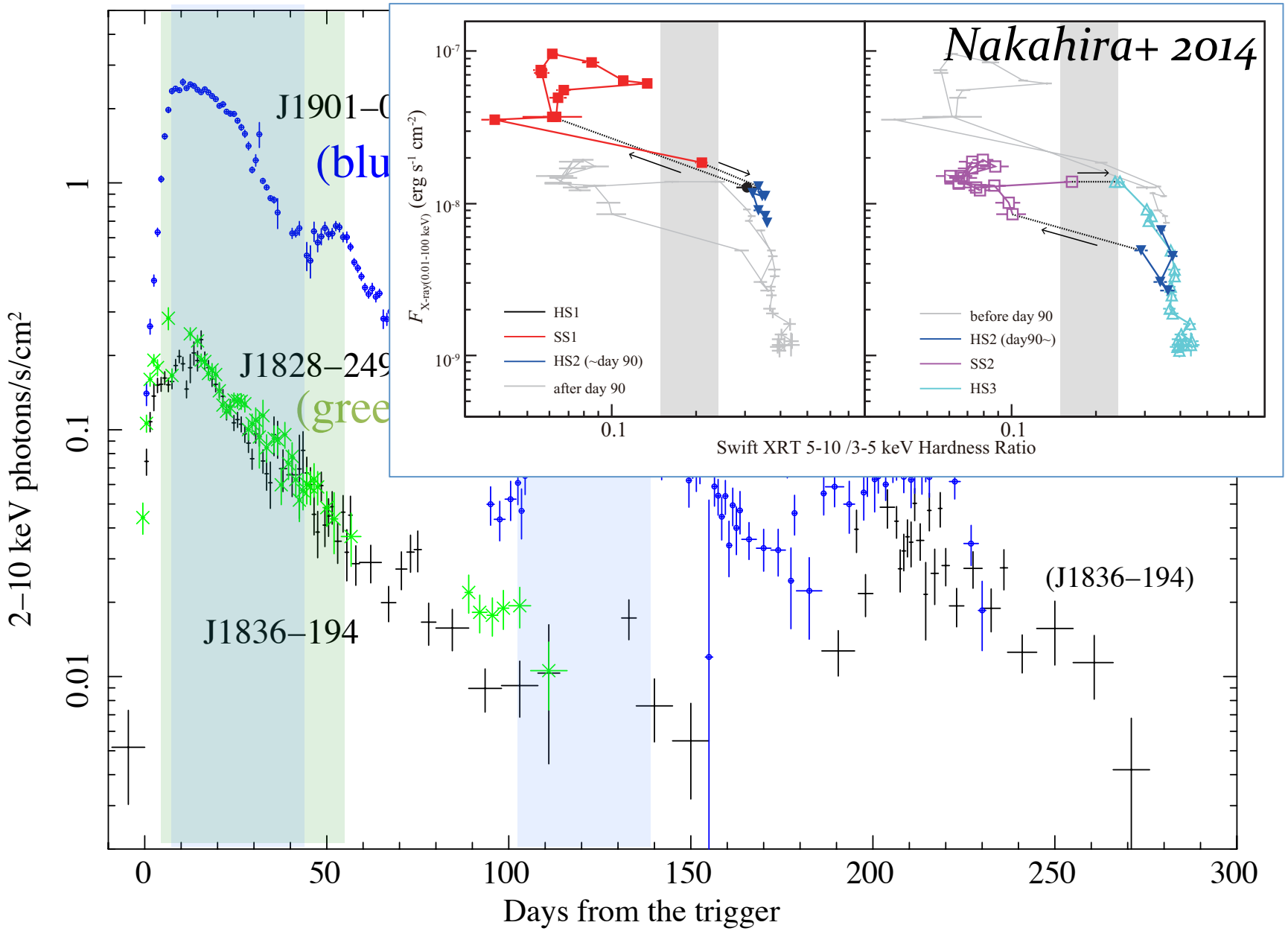


MAXI Black Holes are faint





Tanaka & Shibazaki 1996


J1901–0
(blu
J1828–249
(gree
J1836–194
(J1836–194)
2–10 keV photons/s/cm²
1
0.1
0.01
0
50
100
150
200
250
300
Days from the trigger
Nakahira+ 2014
$F_{X\text{-ray}(0.01\text{-}100\ keV)}$ (erg s^{-1} cm^{-2})
10^{-7}
10^{-8}
10^{-9}
HS1
SS1
HS2 (~day 90)
after day 90
before day 90
HS2 (day90~)
SS2
HS3
0.1
0.1
Swift XRT 5-10 /3-5 keV Hardness Ratio

Transient Objects Observed by MAXI

- Non-degenerate stars
  - Sun, dMe, RSCVn, YSOs, Algol
- White Dwarfs
  - CVs, Super Soft Source
  - MAXI J0158-744
- Neutron Stars
  - LMXB (Burst, Superburst, Outburst), Pulsars, Supergiant Fast X-ray Transients
  - J0556-332, J1409-619, J1647-227, GRB 121225A/Swift J1741.5-6548, J1735-304 (Swift J1734-3027), J1621-613
- Black Holes
  - J1659-152, J1543-564, J1836-194, J1305-704, J1910-057 (Swift J1910.2-0546), J1828-249
- GRB, XRF
  - About 1 GRB or XRF/month (GRB 120528B, 120528C)
- AGN
  - Mrk 421, M82, Cyg A, NGC 4151, Cen A, ..., Swift J1644+57