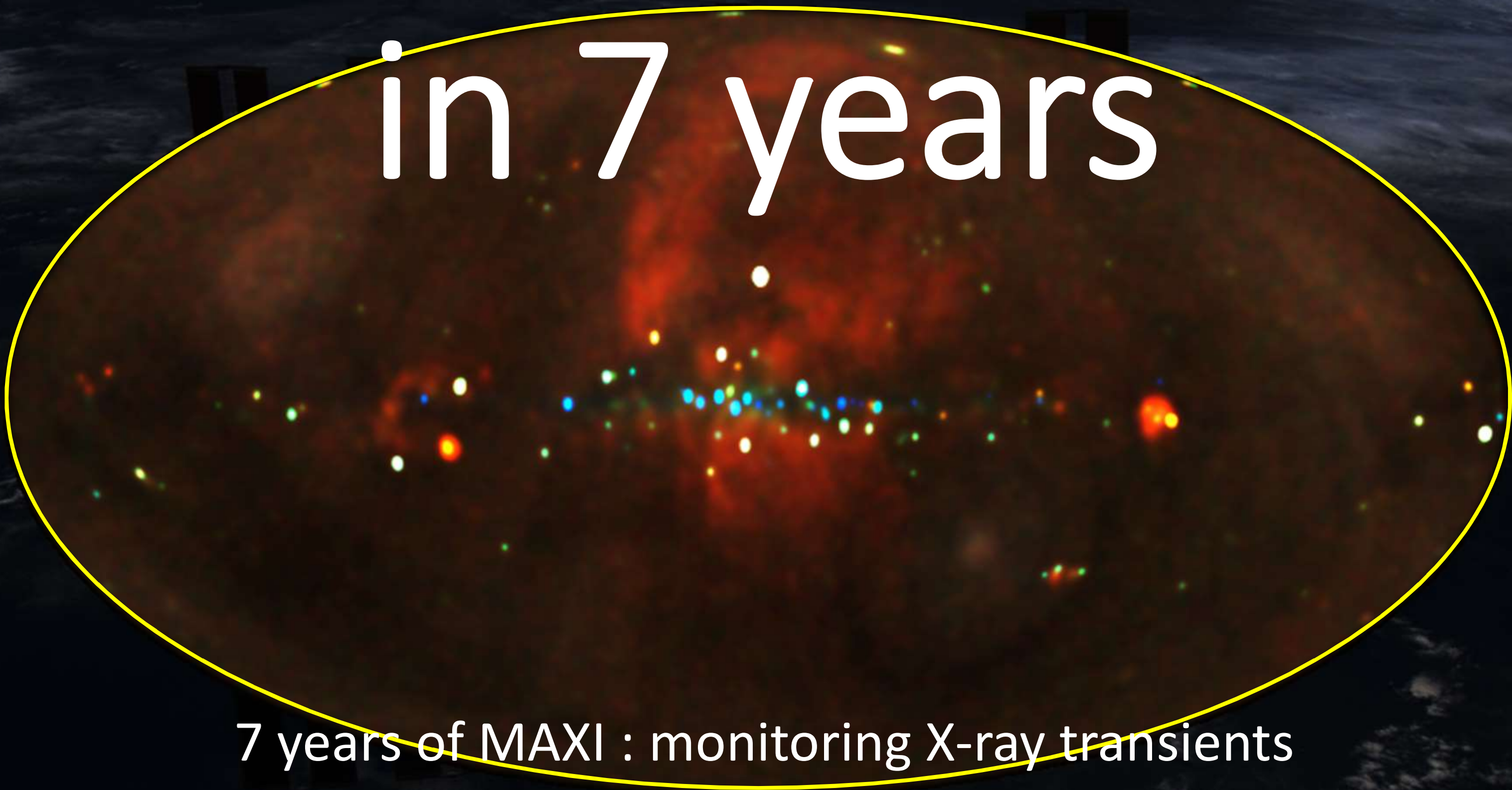
MAXI-SSC results in 7 years



7 years of MAXI : monitoring X-ray transients

05-07 December 2016, Suzuki Umetaro Hall, RIKEN

by H. Tsunemi (Osaka university, JAPAN) and SSC team

Talk plan

- Performance of the SSC
  - Hardware, Observation efficiency, CCD degradation
- SSC catalog
- SSC results
  - GRB
  - WD Nova
  - Cygnus Super Bubble
  - NPS and its extended structure
- Summary

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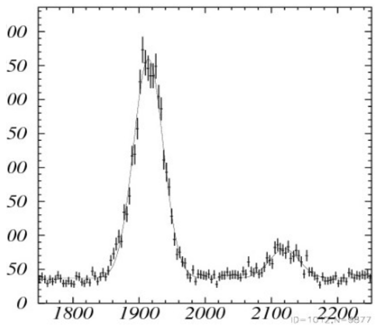
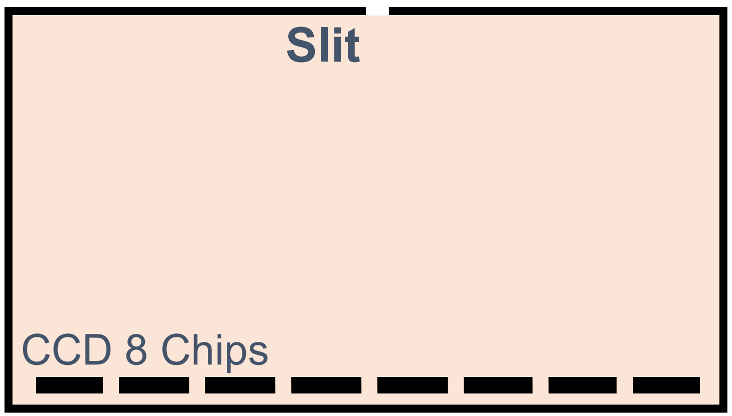
SSC structure

Each CCD camera has 8x2 CCDs (below photo). It is a pin-hole (slit) camera. Effective area of the slit is 1.5cm^2. 1-D collimator made of Cu is placed above the CCD array. In this way, each CCD receives Cu-K line generated by cosmic rays, which shows the performance in detail.

Cu-K line

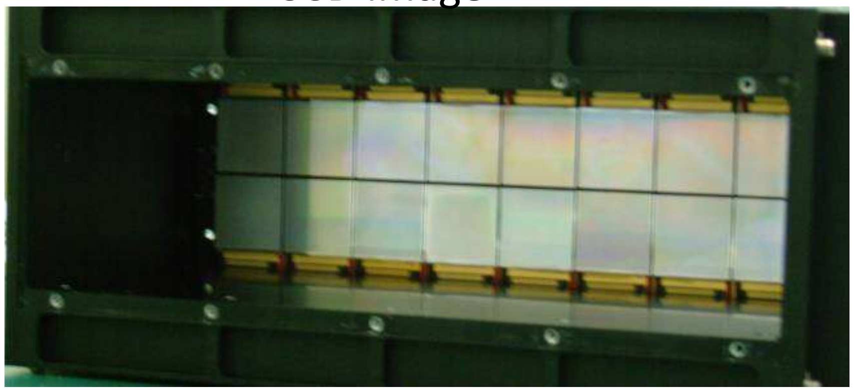


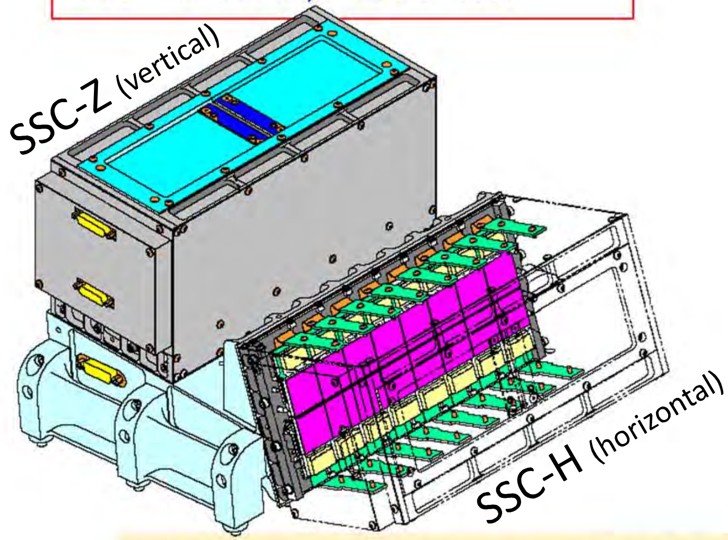
Cross-section of the SSC



X-ray CCD Camera
Solid-state Slit Cameras (SSC)
32 CCD Chips with a Peltier cooler on each
0.6 - 7 keV; 200 cm^2

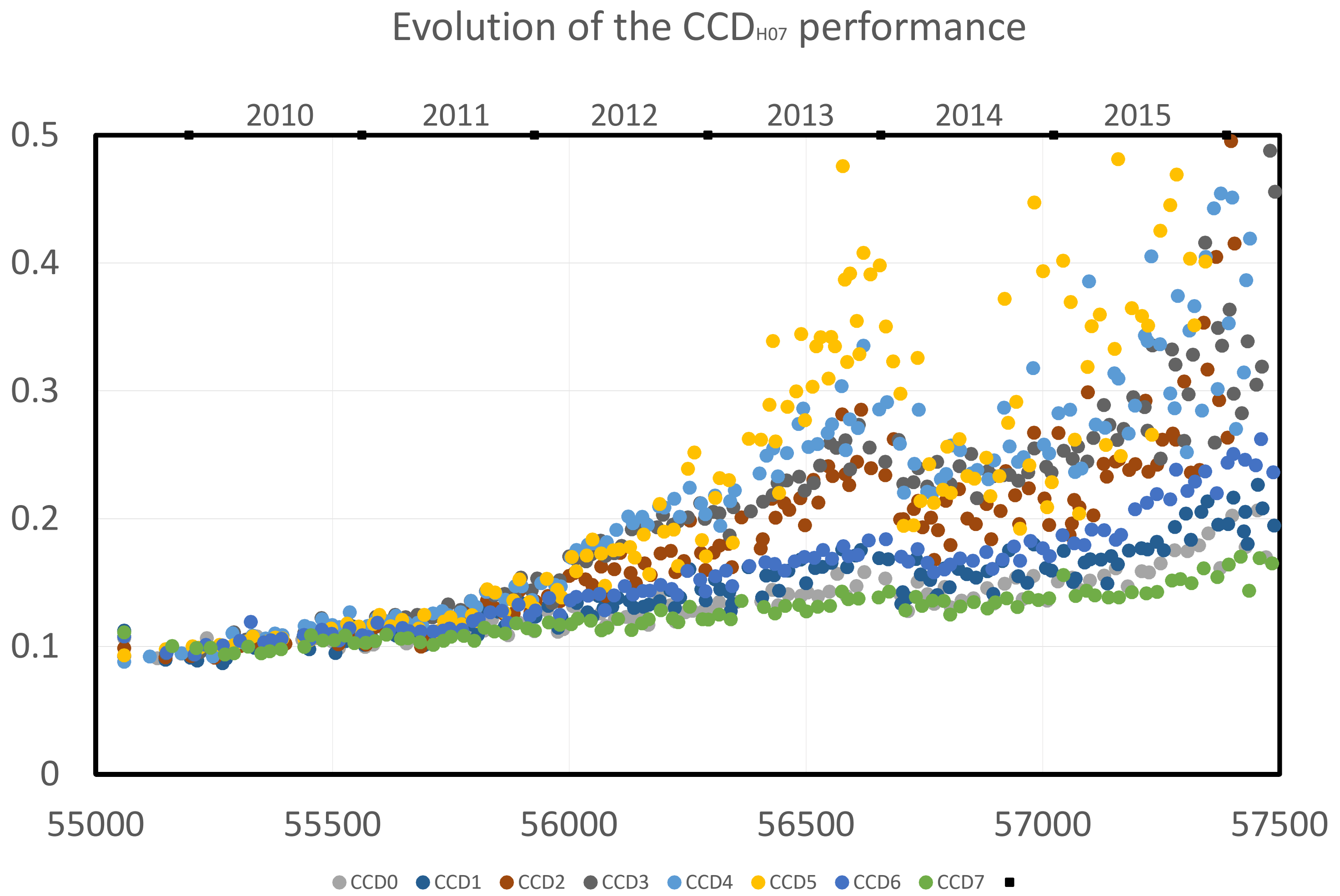
CCD image

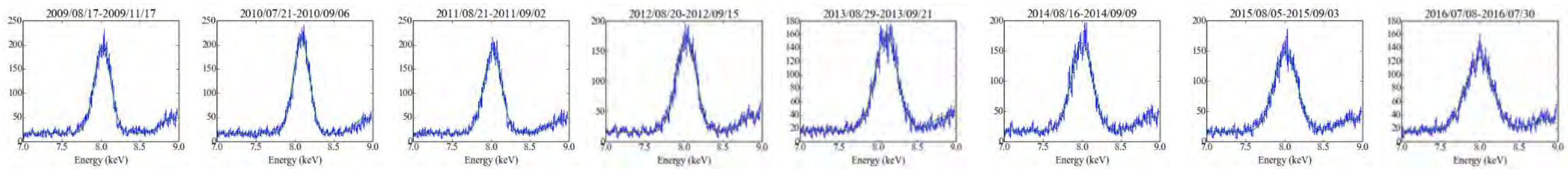




⇒ see P-42 TOMIDA, Hiroshi

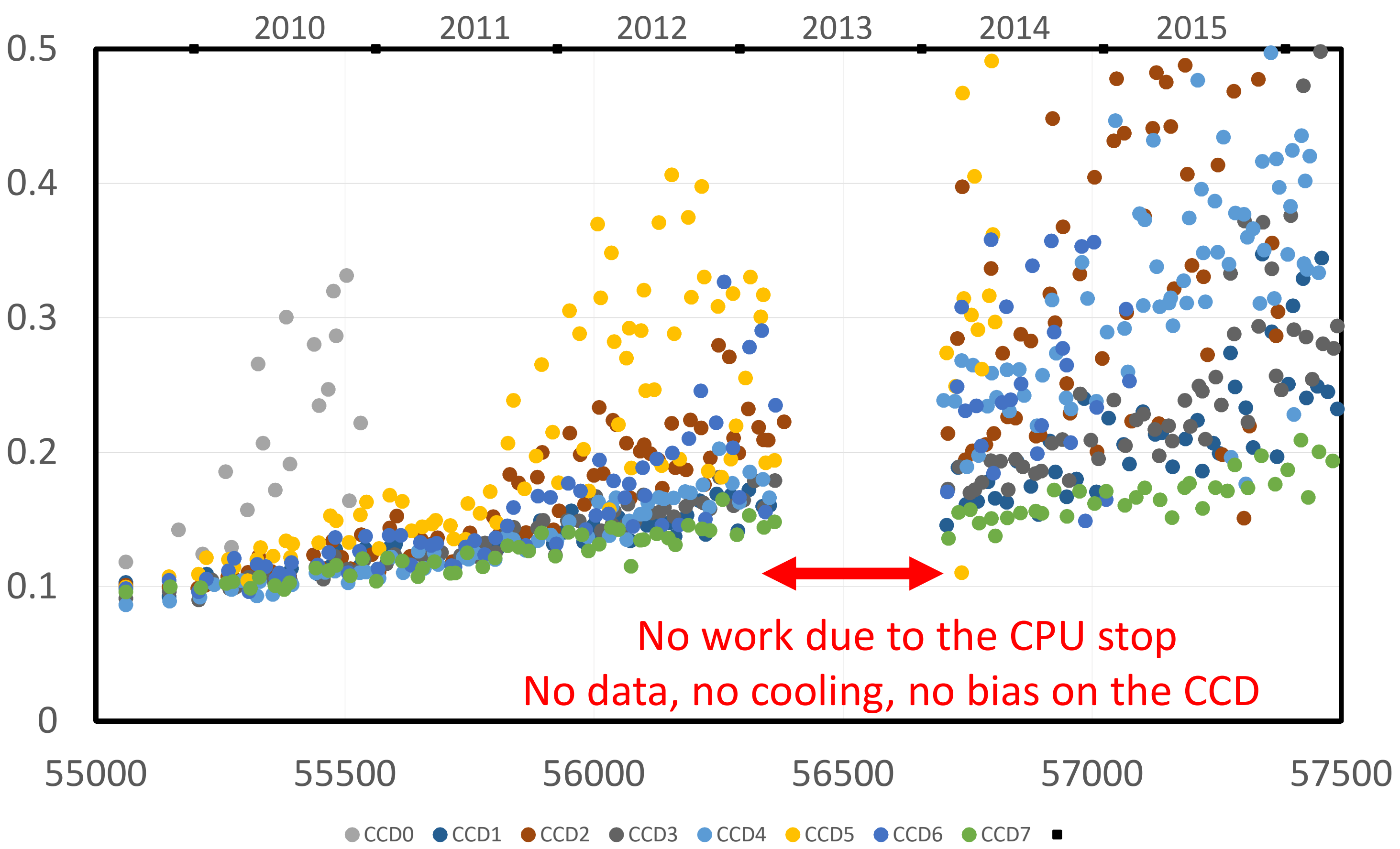
SSC (Horizontal direction) performance
Cu-K line

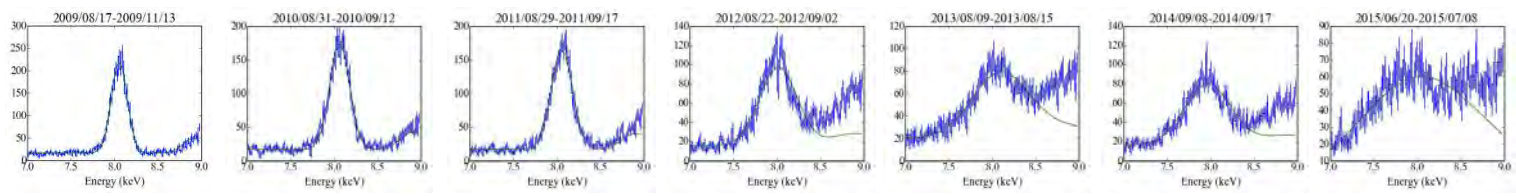




SSC (Zenith direction) performance
Cu-K line

Evolution of the CCD$_{Z07}$ performance





Performance of the SSC

SSC consists of a pair of CCD camera (SSC-H and SSC-Z)

- Each camera contains 8x2 CCDs; 32CCDs in total. CCD is 1K x 1K, 25mm square, Front illumination type. Working temperature is about -60^{o}C
- FOV is a fan beam, 1.5^{o} x 90^{o}. Slit area is about 1.5cm^{2}.
- Practical energy range in orbit is 0.6-7 keV (thermal noise and Cu-K line).

CCD is gradually degrading by charged particles.

- Degradation of the CCD depends on the location inside the camera body. The CCD just below the slit is damaged 4 times worse than that of far from the slit.
- The ISS orbit is in high inclination (52^{o}), much higher that other X-ray satellites.
- Observation efficiency is about 30%, mainly due to the IR contamination during the daytime.

Cooling system functions properly for more than 7 years.

- CCD is cooled by a combination of Peltier cooler and radiator panels/loop heat pipe. Cooling performance looks stable, suggesting no degradation.
- When one camera stopped working for a year (no heat load), the other camera temperature became hot a little rather than cold. This is probably due to the characteristic of the loop heat pipe.

⇒ see P-42 TOMIDA, Hiroshi

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Table 3. Source category of the SSC catalog.*

Category	Number of sources
Galaxies/AGNs	22
Clusters of galaxies	29
SNRs	21
X-ray binaries	75
Stars	8
Isolated pulsar	5
Unknown/no identification	11

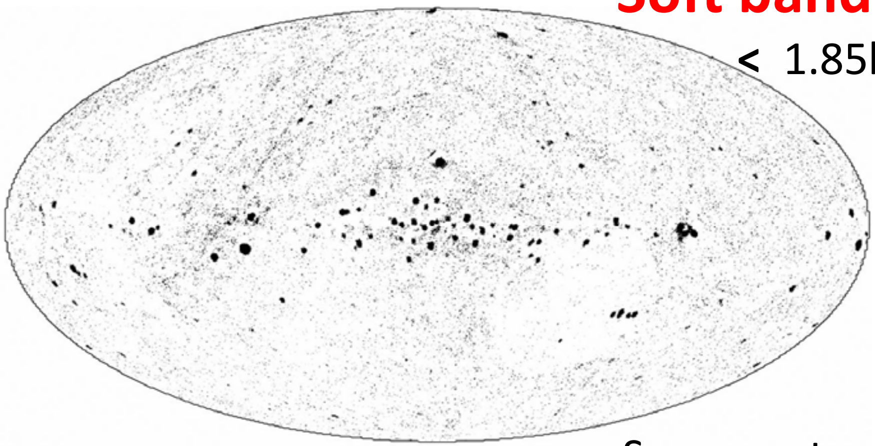
*The number of sources in table 5 is 170, while the sum of the numbers in this list is 171. This is because source ID = 43 in table 5 consists of two sources: Vela pulsar and SNR.

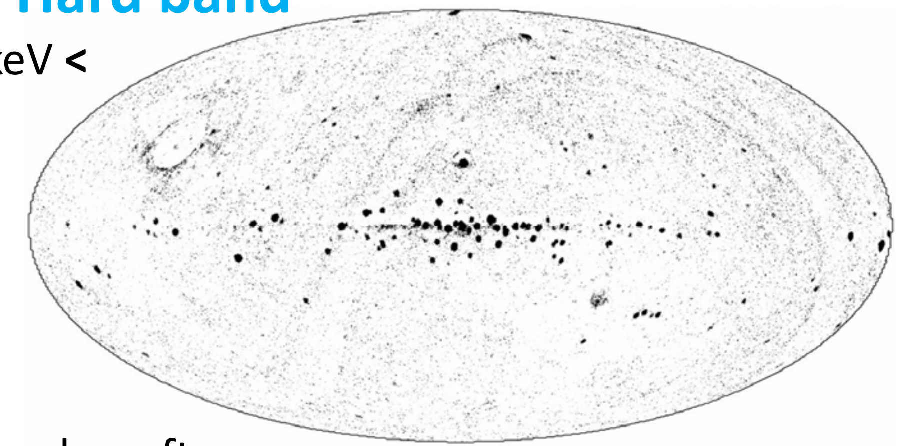
Point source search by SSC

We employed ***SExtractor*** to the data accumulated by SSC. The detection limit is a few mCrab unit.

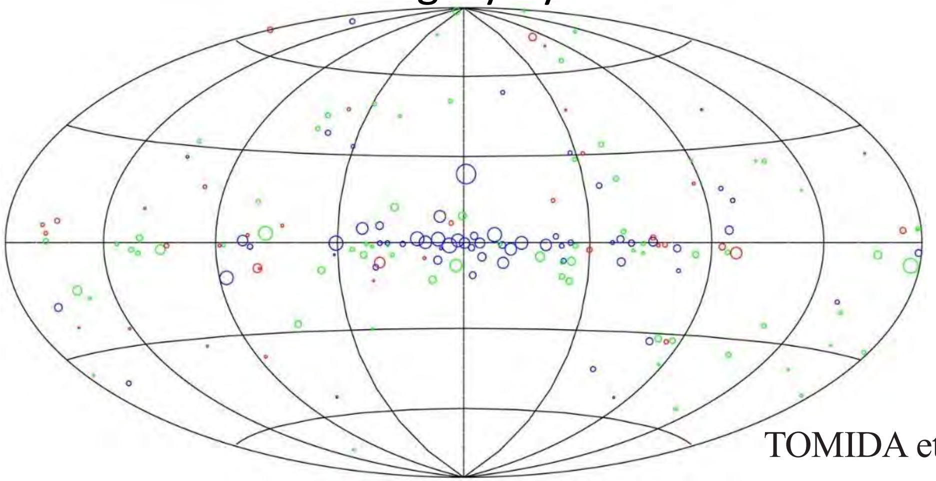
Soft band **Hard band**

< 1.85keV <



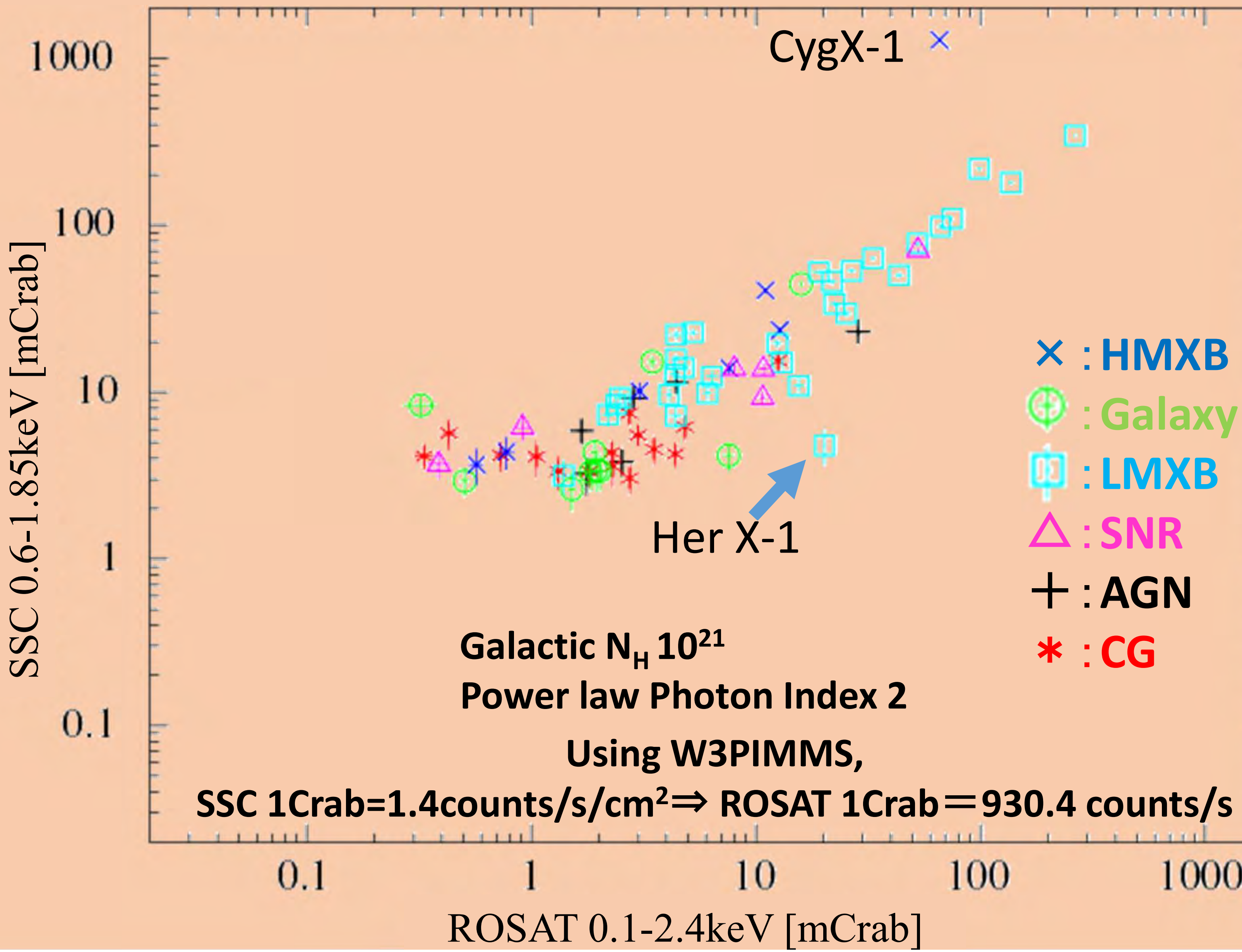


Source category by softness

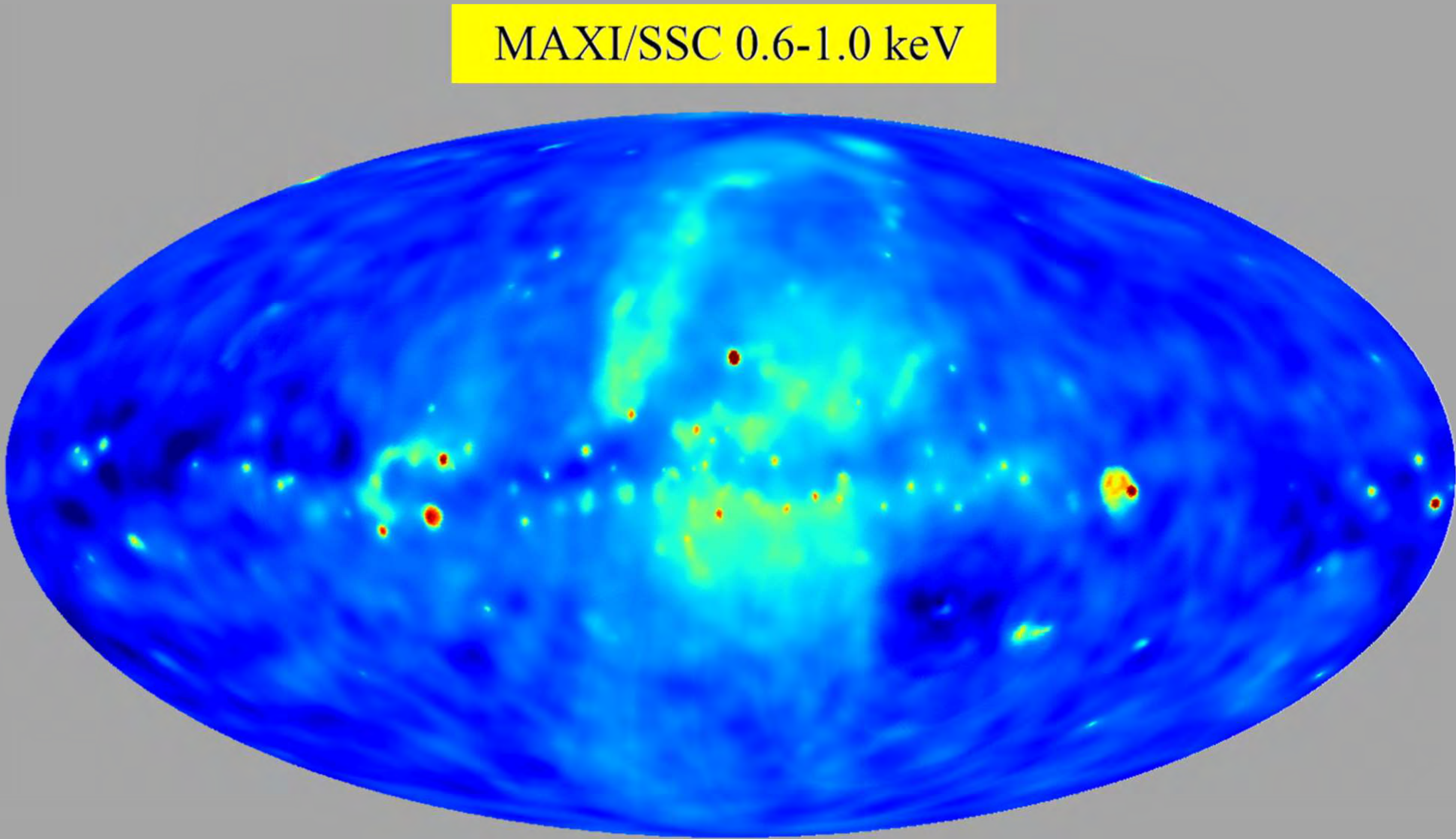


TOMIDA et al., PASJ 68, S32, 1-14 (2016)

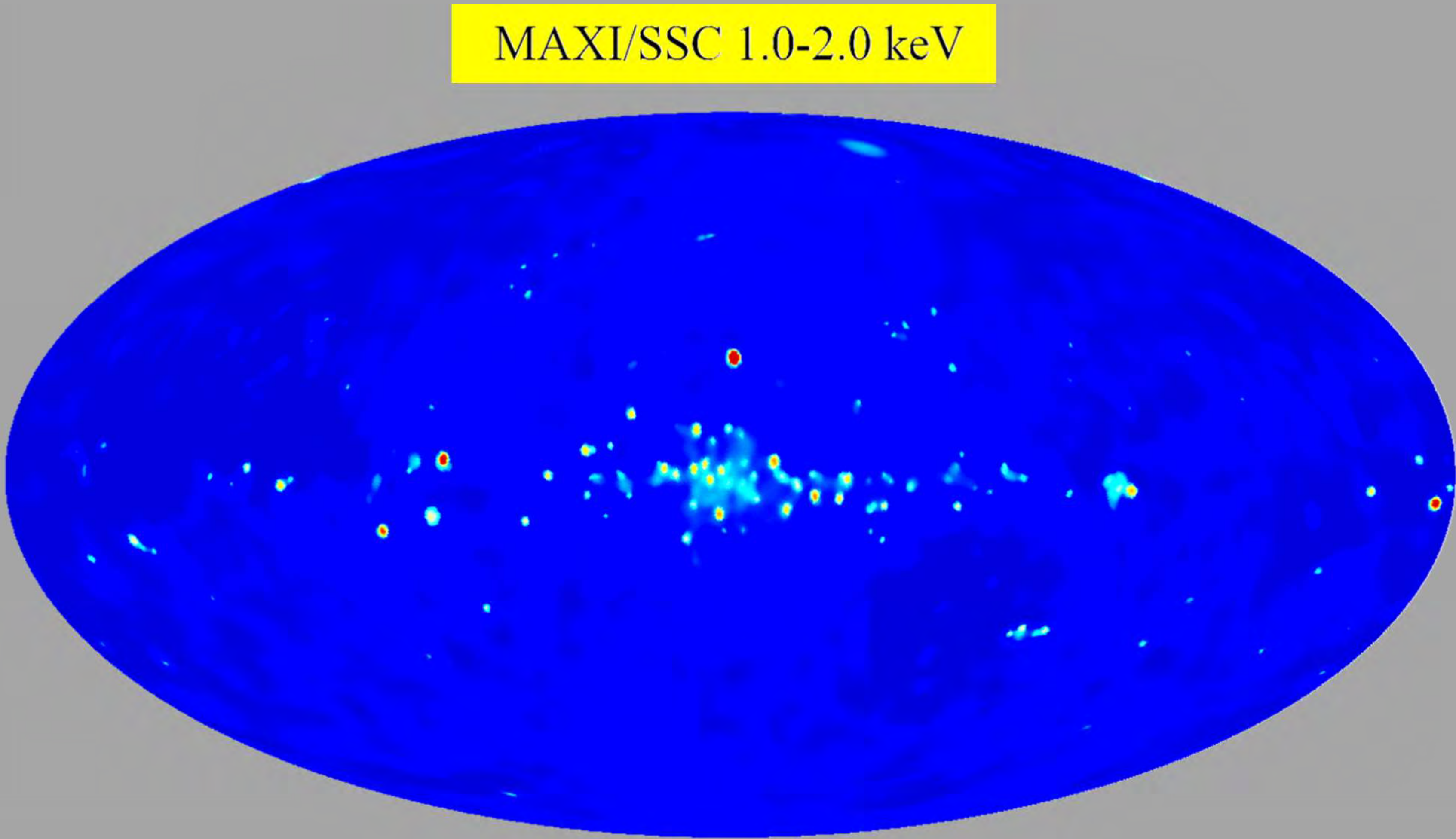
ROSAT VS SSC (point sources)



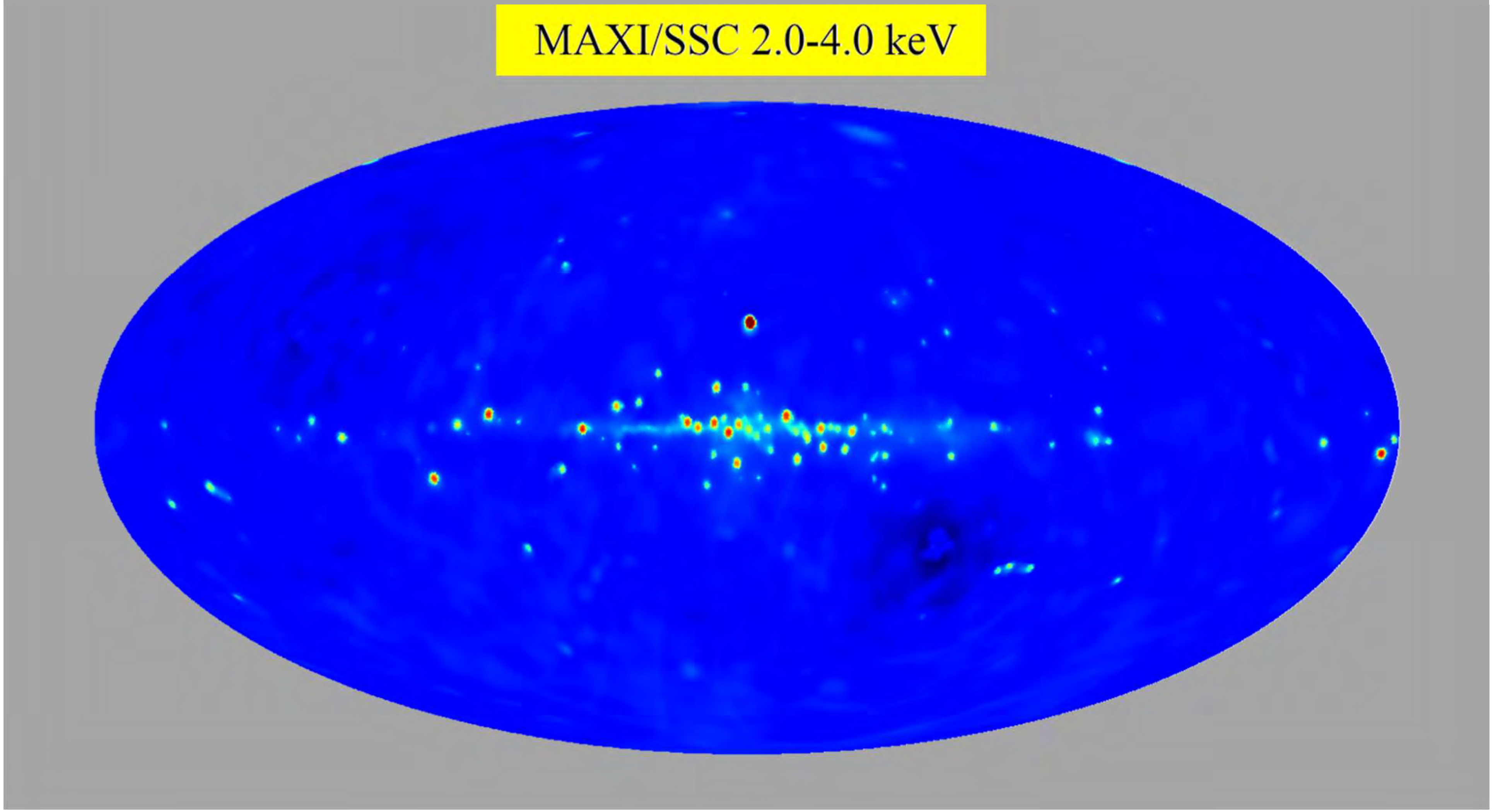
All sky map by MAXI SSC



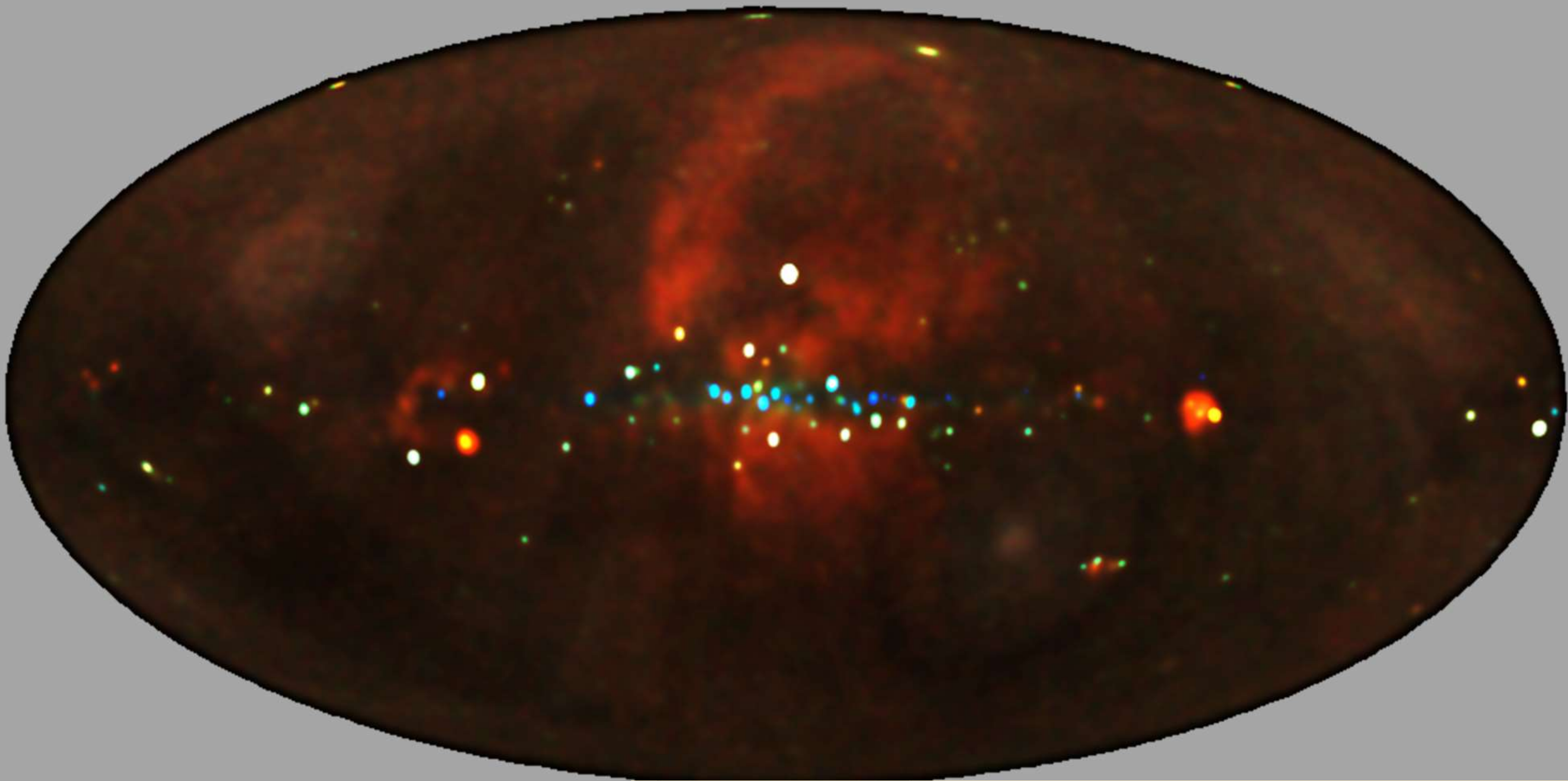
All sky map by MAXI SSC



All sky map by MAXI SSC



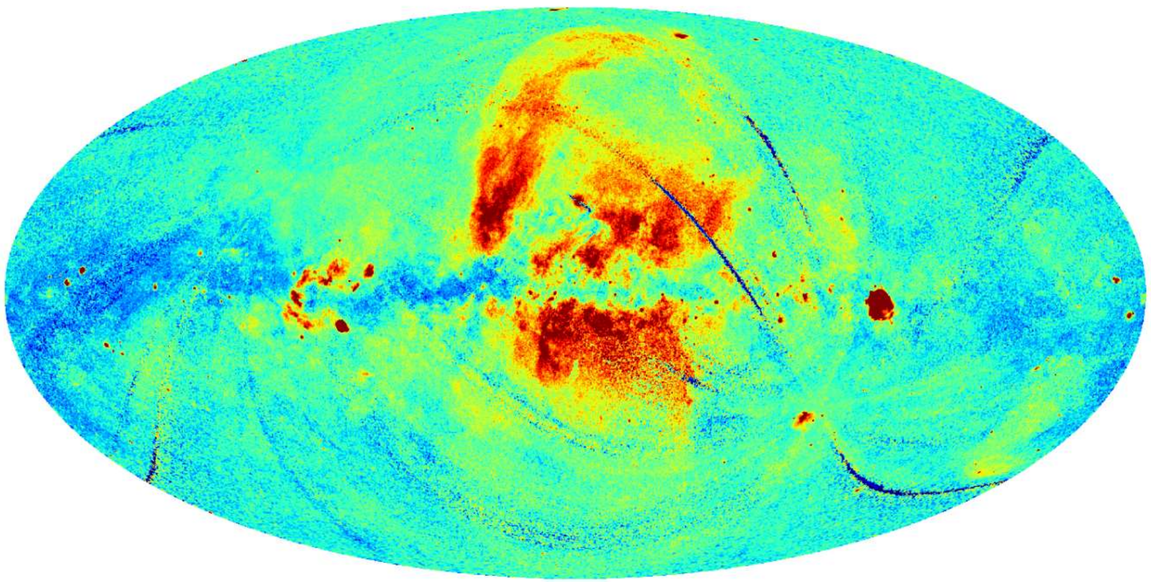
All sky map by MAXI SSC



⇒ **see P-40 SHIDATSU, Megumi (GSC map and diffuse)**

Comparison of SSC with ROSAT

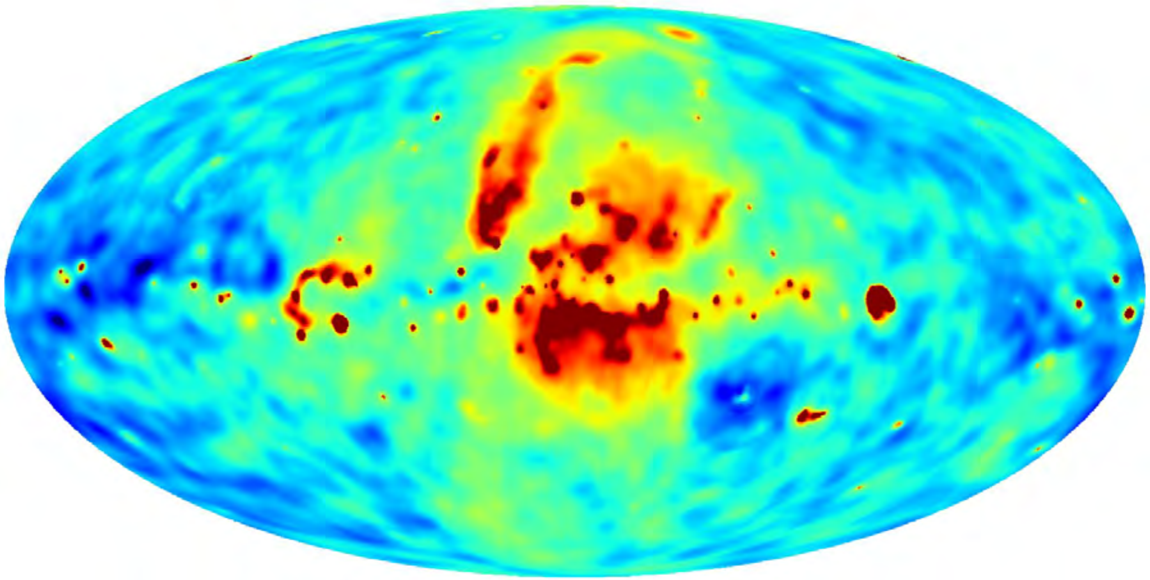
ROSAT R4(0.44-1.01 keV)+R5(0.56-1.21 keV)



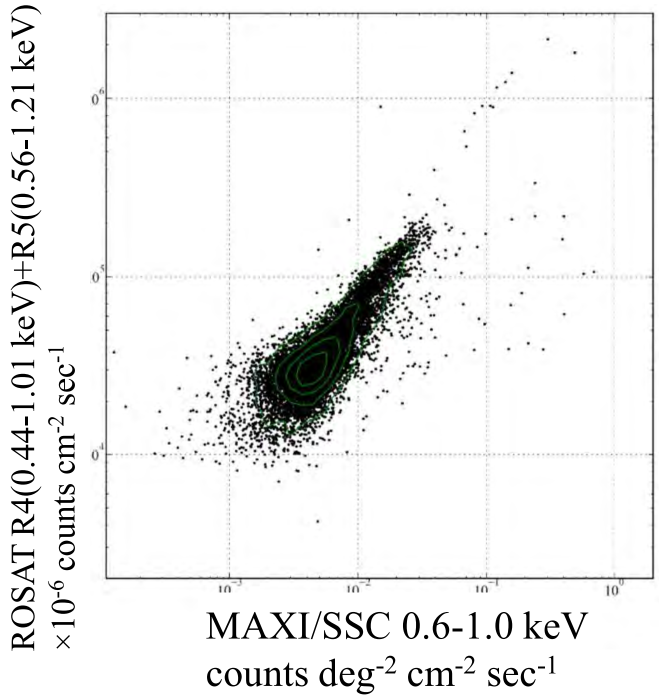
We confirmed that the diffuse map of ROSAT (R4+R5) is quite similar to that by SSC (0.6-1.0 keV) with the exception of the PSF.

The below figure is the intensity correlation of the heal-pix elements (12288) between ROSAT and SSC.

MAXI/SSC 0.6-1.0 keV



Correlation between ROSAT and SSC



X-ray source catalog by SSC

Source catalog by using SSC in good performance

- Due to the degradation of the CCD, we used the 45-month data from 2010 August to 2014 April in the 0.6–7.0 keV bands. The low energy end is limited by the thermal noise. The high energy end is practically limited by the Cu-K lines above which the SSC receives few photons due to the source flux and the detection efficiency.
- We divide the data into two energy bands, 0.6–1.85 keV (soft) and 1.85–7.0 keV (hard), divided at the Si-K edge. The limiting sensitivities of 3 and 4 mCrab are achieved, and 140 and 138 sources are detected in the soft and hard energy bands, respectively. Combining them, we listed 170 sources in the MAXI/SSC catalog.
- They are 22 galaxies including AGNs, 29 cluster of galaxies, 21 supernova remnants, 75 X-ray binaries, 8 stars, 5 isolated pulsars, and 9 non-categorized objects. Comparing the soft-band fluxes at the brightest end in our catalog with the ROSAT survey, which was performed about 20 years ago, 10% of the cataloged sources are found to have changed its flux since the ROSAT era.

⇒ see P-39 HORI, Takafumi : for GSC

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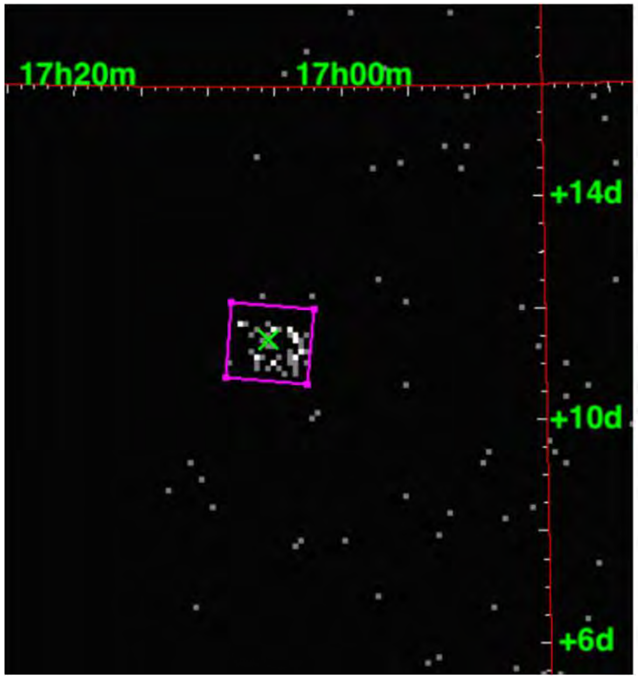
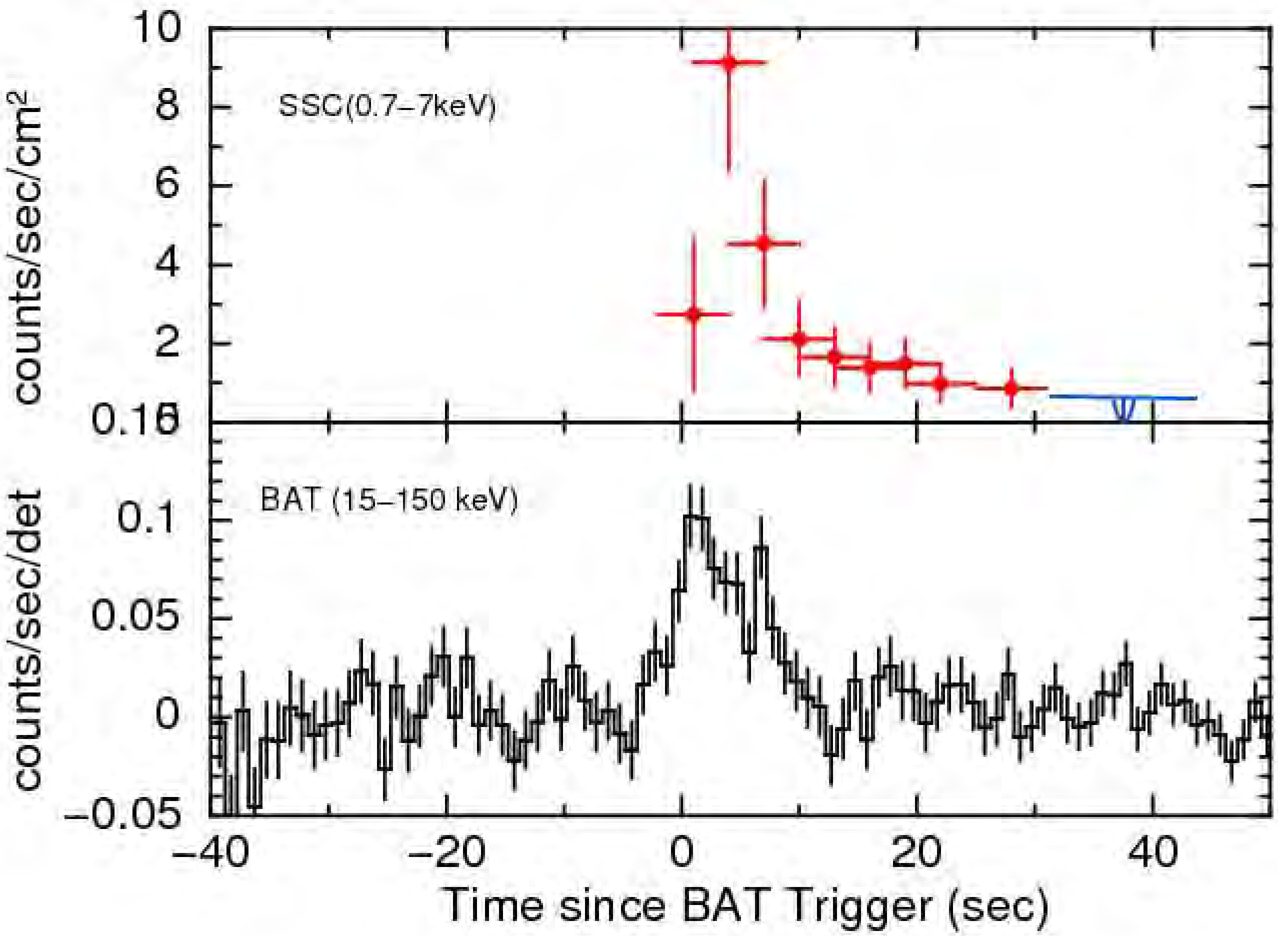
SSC detects the prompt emission of GRB 100418A

The BAT trigger time of GRB 100418A was 2010/04/18,21:10:08 (UT) that was 2sec after the source got into the FOV of the SSC-Z. The source was in the FOV for about 50sec.

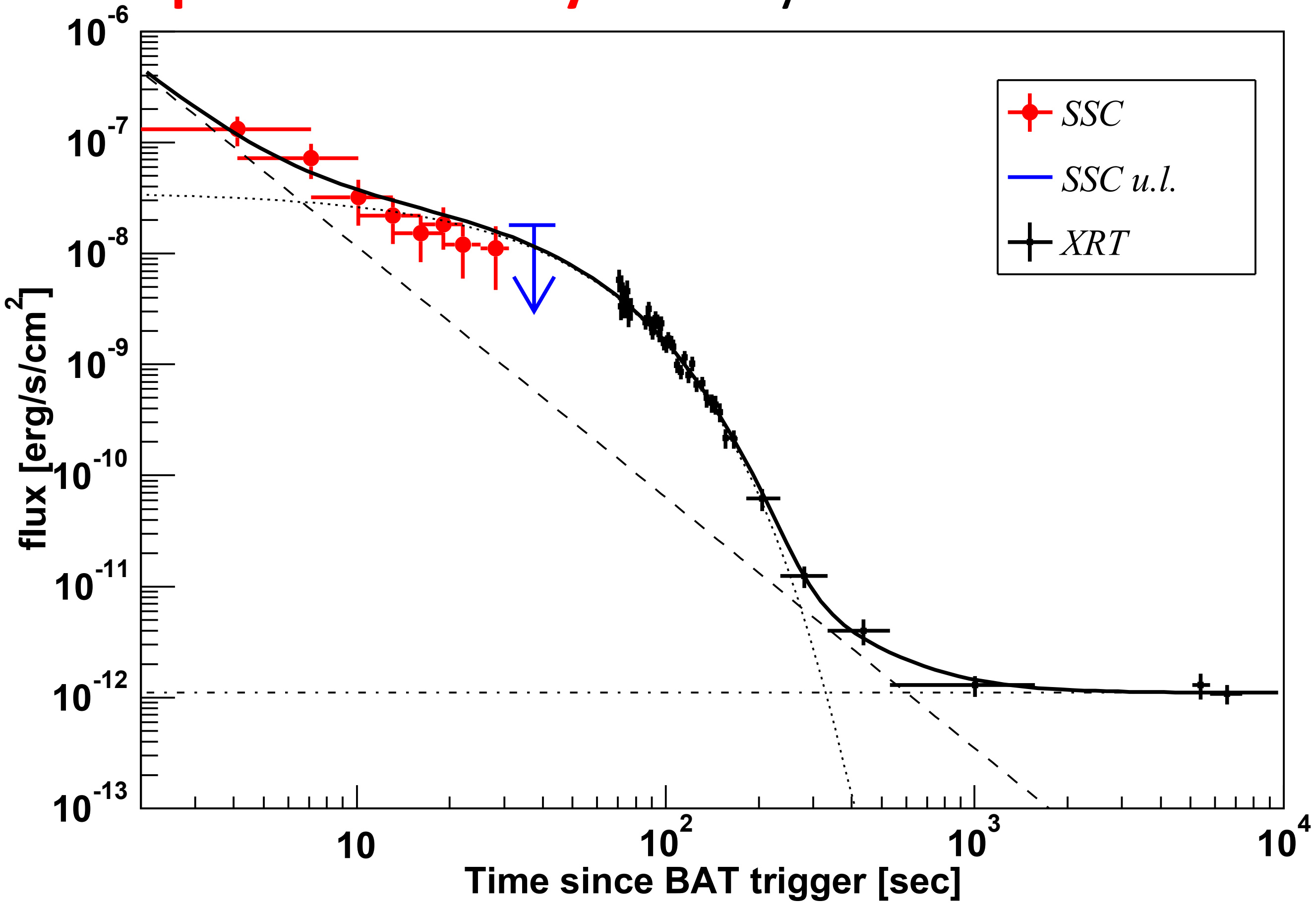




IMATANI et al., PASJ 68, S29 (2016)

Light Curve of the prompt emission of GRB 100418A

It's rare case we obtained light curve from the beginning of the burst in soft X-ray band. We confirmed that the light curve of the prompt emission could be expressed by a **combination of a power law with an exponential decay**. Decay time scale is 31.6±1.6 sec.



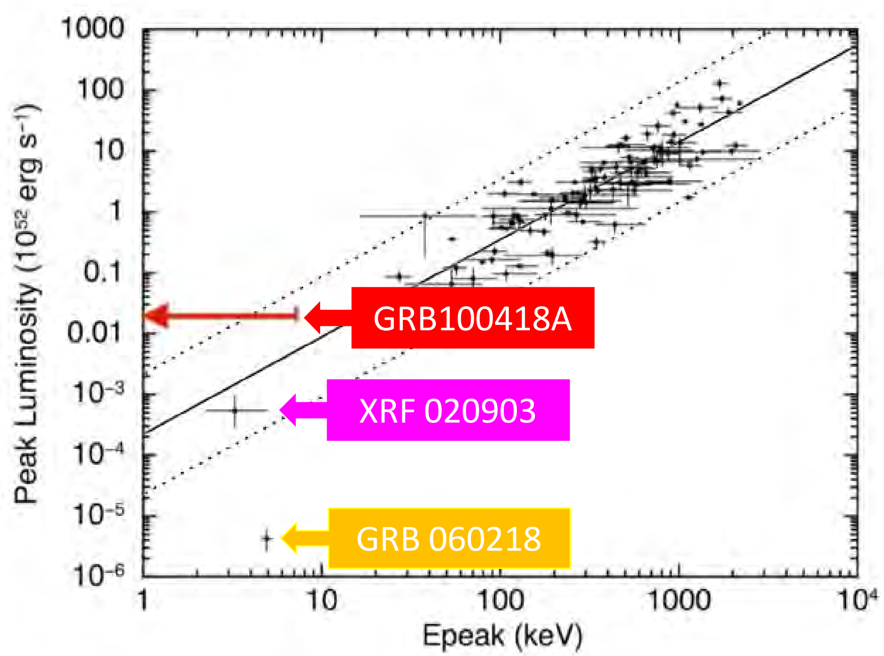
Two well-know relations

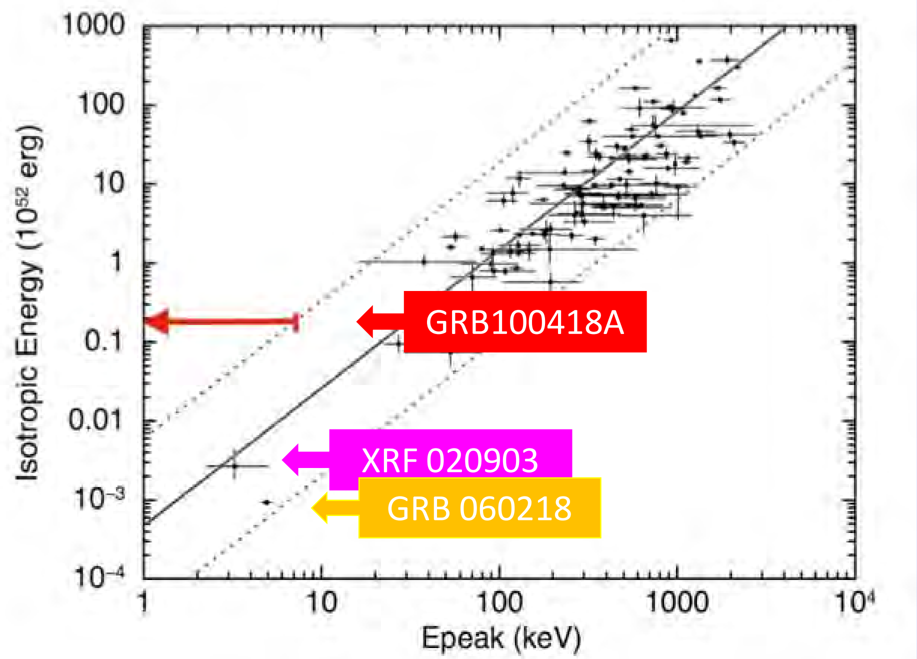
The upper limit of GRB100418A lies in the acceptable range of Yonetoku-relation(left:E_p-L_p) while it is quite marginal in the Amati-relation(right:E_p-E_{iso}).

Other two GRBs showing low values of Ep.

XRF 020903 (Ep=$3.3^{+1.8}_{-1.0}$keV) no photon above 10 keV, X-ray-rich GRB (Sakamoto + 2004)

GRB 060218 (Ep=5.1±0.3keV), Low Luminosity GRB showing a long T_{90} of 2.1ks, dominated by a shock breakout. LLGRB may show a different feature. (Campana + 2006)





(Yonetoku et al., 2010)

GRB detected by SSC

SSC detected GRB100418A from its very beginning.

- We observed the prompt emission of GRB100418A in the SSC energy range (0.6-7 keV) from the very beginning of the BAT trigger time.

Light curve is not a power law but an exponential decay.

- The light curve was expressed not in a simple power law decay but in a combination of a power law and an exponential decay with a decay constant of 31.6 ±1.6 sec.

Detection of very low value of E_p, a very rare GRB.

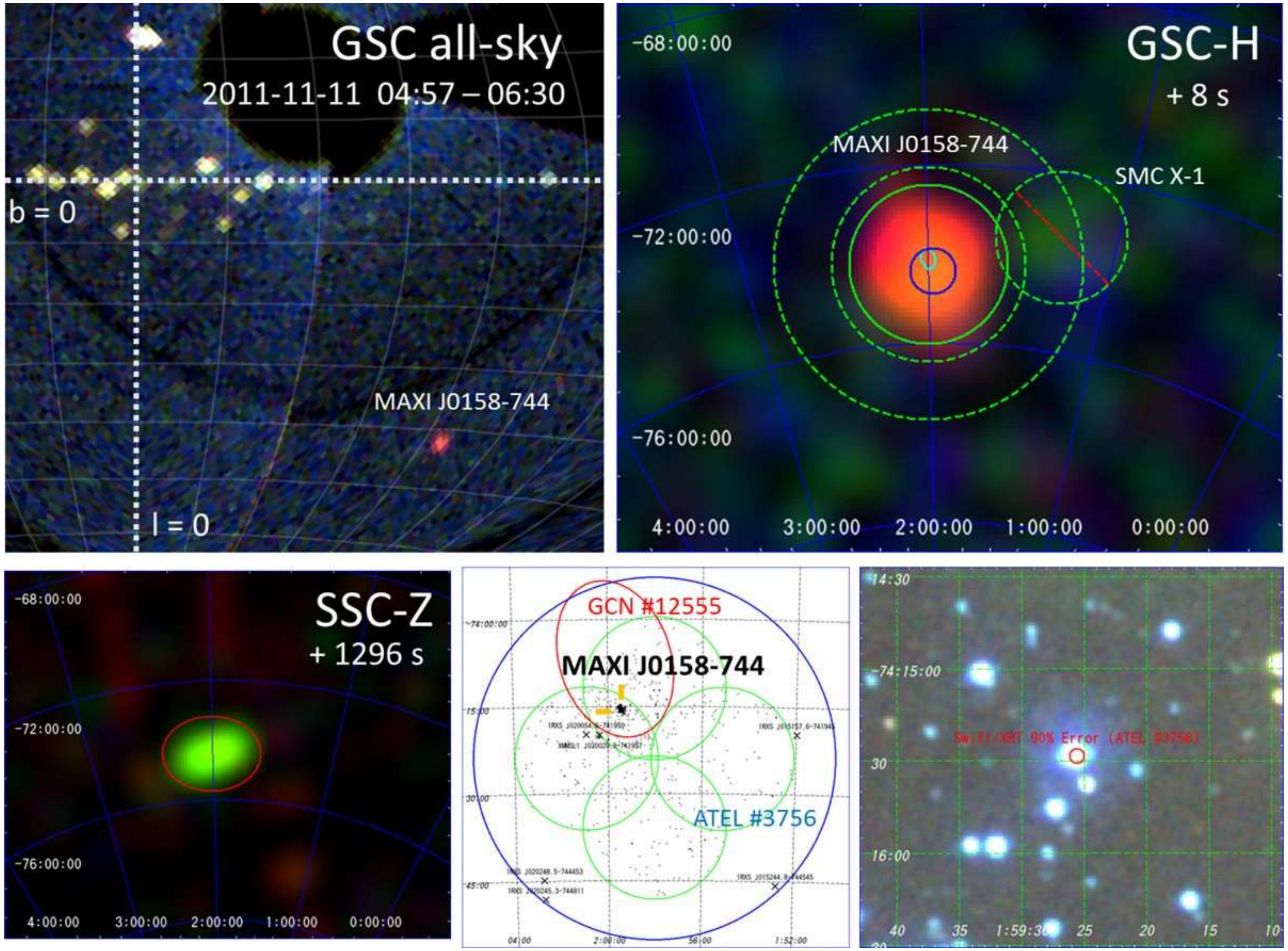
- GRB100418A is a typical long GRB having a very low value of E_p(<8.3 keV) reported that is a very rare GRB.

Comparison with Yonetoku-relation and Amati-relation.

- The X-ray spectrum can be expressed by a power law. Using Band function, we obtained E_p < 8.3 keV. It is also consistent with the Yonetoku-relation while it is 2.5σ level with the Amati-relation.

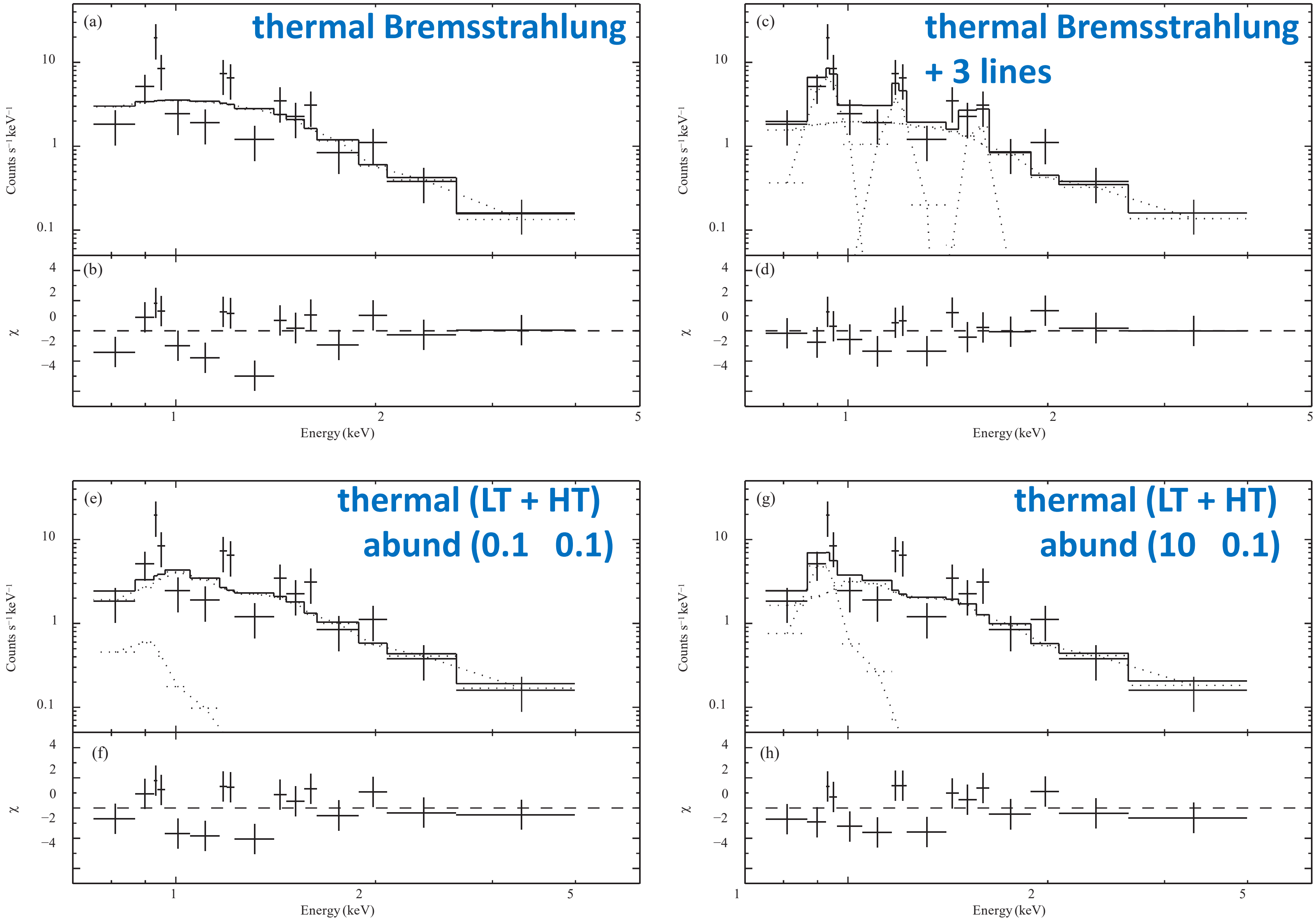
⇒ today's talk in the afternoon NAKAHIRA Satoshi
Also see P-10 SAKAMOTO, Takanori : for GSC GRB

EXTRAORDINARY LUMINOUS SOFT X-RAY TRANSIENT MAXI J0158−744 AS AN IGNITION OF A NOVA ON A VERY MASSIVE O–Ne WHITE DWARF

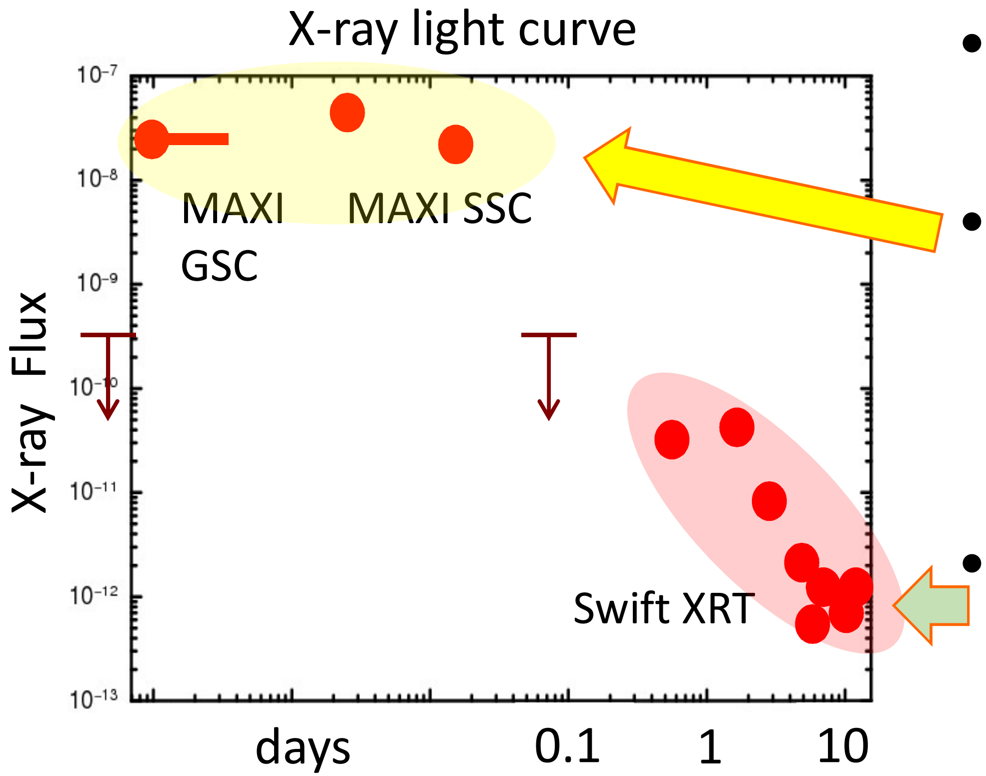


M. Morii et al., ApJ 779, 118 (2013)

MAXI SSC-Z spectrum of MAXI J0158−744 at +1296 s. Model fit results



MAXI J0158-744



Morii et al. 2013

- Duration ≈ hour
  - (1.3×10^3 s <ΔT< 1.1×10^4 s)
- Extremely luminous
  - 10^{40} erg / s
  - x100 solar mass Eddington luminosity
- Super-soft 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)

MAXI J0158−744: IGNITION OF A NOVA, WD

This is characterized by a soft X-ray spectrum as below.

- a short duration (1.3×10^3 s < ΔTd < 1.10×10^4 s)
- a rapid rise (< 5.5×10^3 s)
- a huge peak luminosity of 2×10^{40} erg s^{-1} in 0.7–7.0 keV band

We detect 0.92 keV neon emission line.

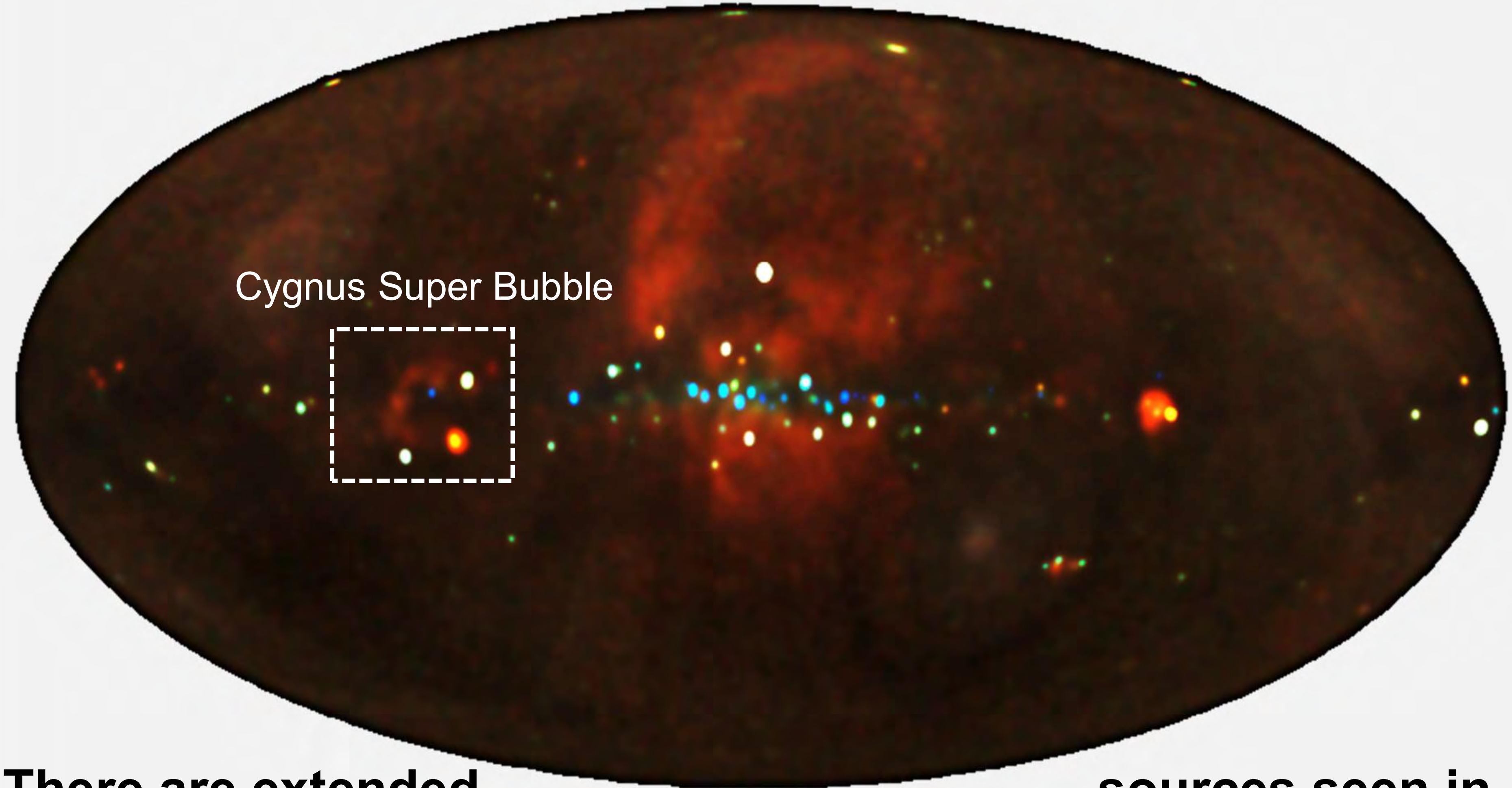
- We confirmed that MAXI J0158−744 is a nova explosion, on a white dwarf in a Be binary near the Small Magellanic Cloud.
- Early turn-on of the super-soft X-ray source (SSS) phase (< 0.44 days)
- Short SSS phase duration of about one month
- 0.92 keV neon emission line, 1296 s after the first detection

We propose a thermonuclear runaway process in a nova.

- Explosion involves a small amount of ejecta and is produced on an unusually massive O–Ne white dwarf close to, or possibly over, the Chandrasekhar limit.

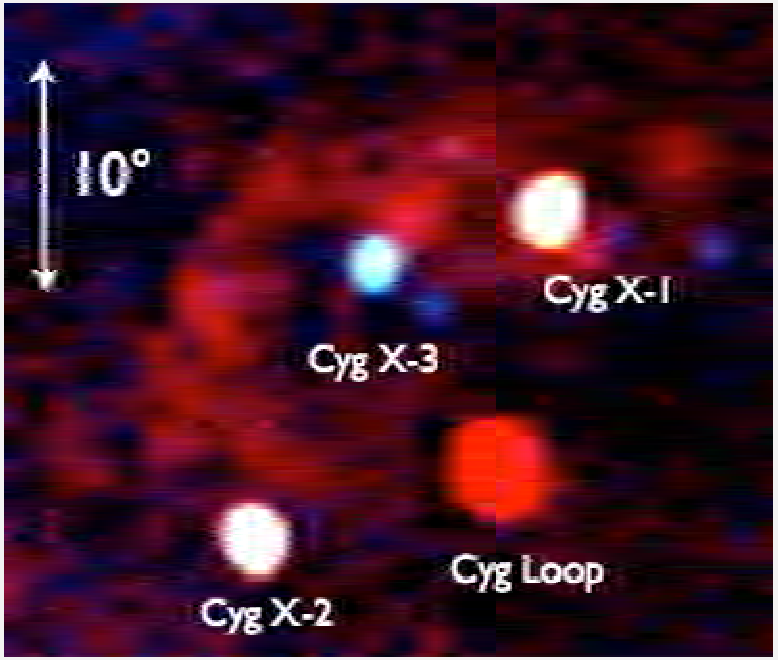
⇒ see Shigeyama-san talk, tomorrow morning

Cygnus Super Bubble



There are extended sources seen in the SSC map. Cygnus Loop and Vela SNR are bigger than the SSC PSF. The next bigger structure is the Cygnus Super Bubble that was detected by the HEAO-1 observation.

Cygnus Super Bubble

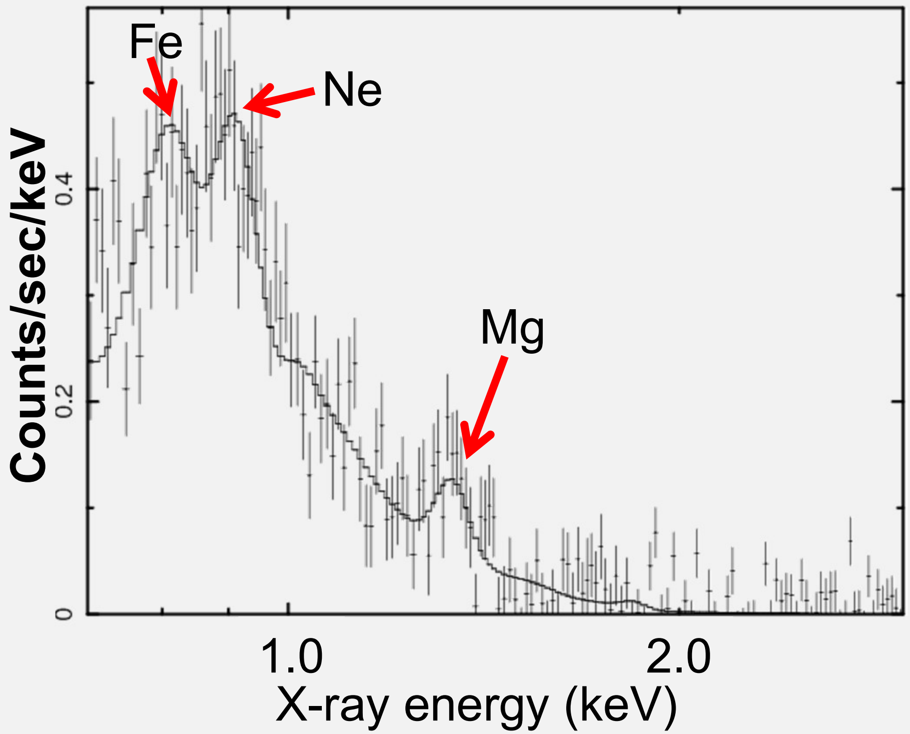


Expansion of the Cygnus region of the SSC map. Colors correspond to the X-ray photon energy.

- Cygnus SB shows a horseshoe shape, extending ~20^{o}.
- The first detection was done by HEAO-1. ROSAT also revealed the fine structure. Due to the limited energy resolution, they could not find its origin.
- MAXI/SSC detected the Cygnus SB and studied it using CCD.

KIMURA et al., PASJ 65, 14K (2013)

X-ray spectrum



X-ray spectrum from the Cygnus SB.

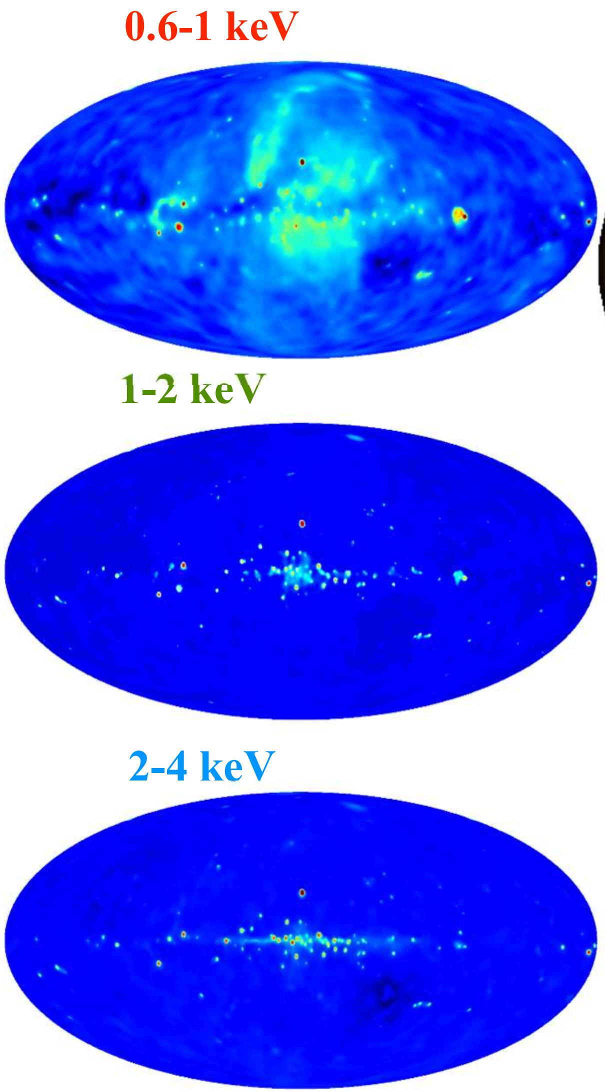
- X-ray spectrum shows line features, confirming the thin hot plasma origin.
- Spectrum shows the abundance of 0.26 ± 0.1 solar, temperature of 0.23 ± 0.01 keV. We divide it into four regions. All show similar results. Combining them with ROSAT data, we determined N_H. It indicates that the Cygnus SB is a single unity.
- Using the present thermal energy, we estimate the explosion energy to be a few orders of magnitude larger than that of a supernova. It strongly suggests the hypernova origin.

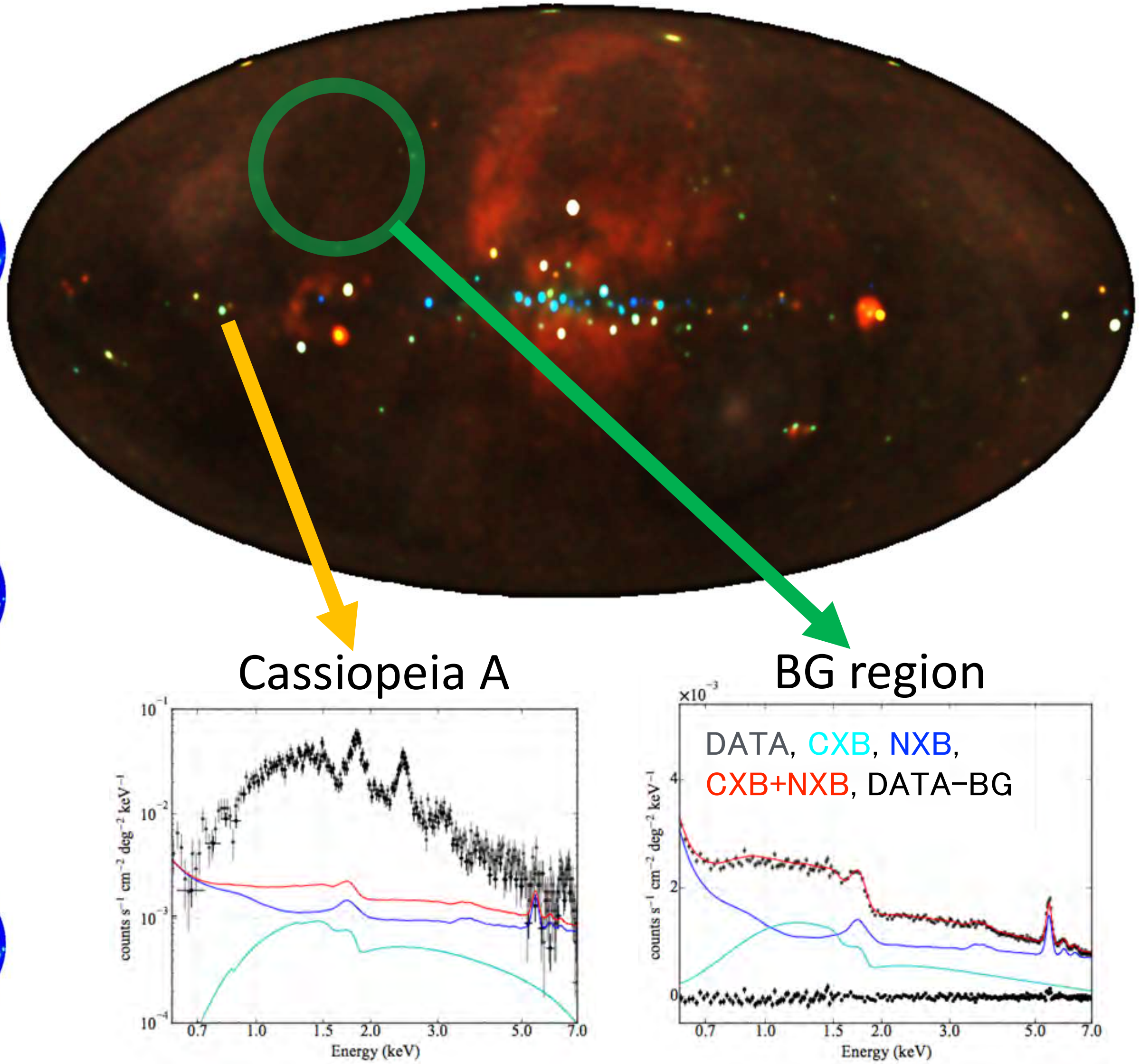
Is the Cygnus SB a Hypernova Remnant?

Cygnus Super Bubble shows a thin thermal emission.

- Cygnus Super Bubble was discovered by HEAO-1 A2 (Cash + 1980). ROSAT also confirmed it. These observations were done by using gas counters.
- We detected Fe, Ne, Mg emission lines from the CSB for the first time, showing that it originated from a thin hot plasma.
- $kT \approx 0.23$ keV, abundance of 0.26 ± 0.1 solar
- Joint spectrum fittings of the ROSAT/PSPC data and MAXI/SSC data enabled us to measure precise values of N_H and the temperature inside the CSB.
- Since N_H is constant through the CSB within a statistical uncertainty, we conclude that it is a single unity.
- Since the Cyg OB2 is in off-center of the CSB, it is difficult to be an energy source of the CSB. The origin of the CSB is most likely to be a Hypernova.

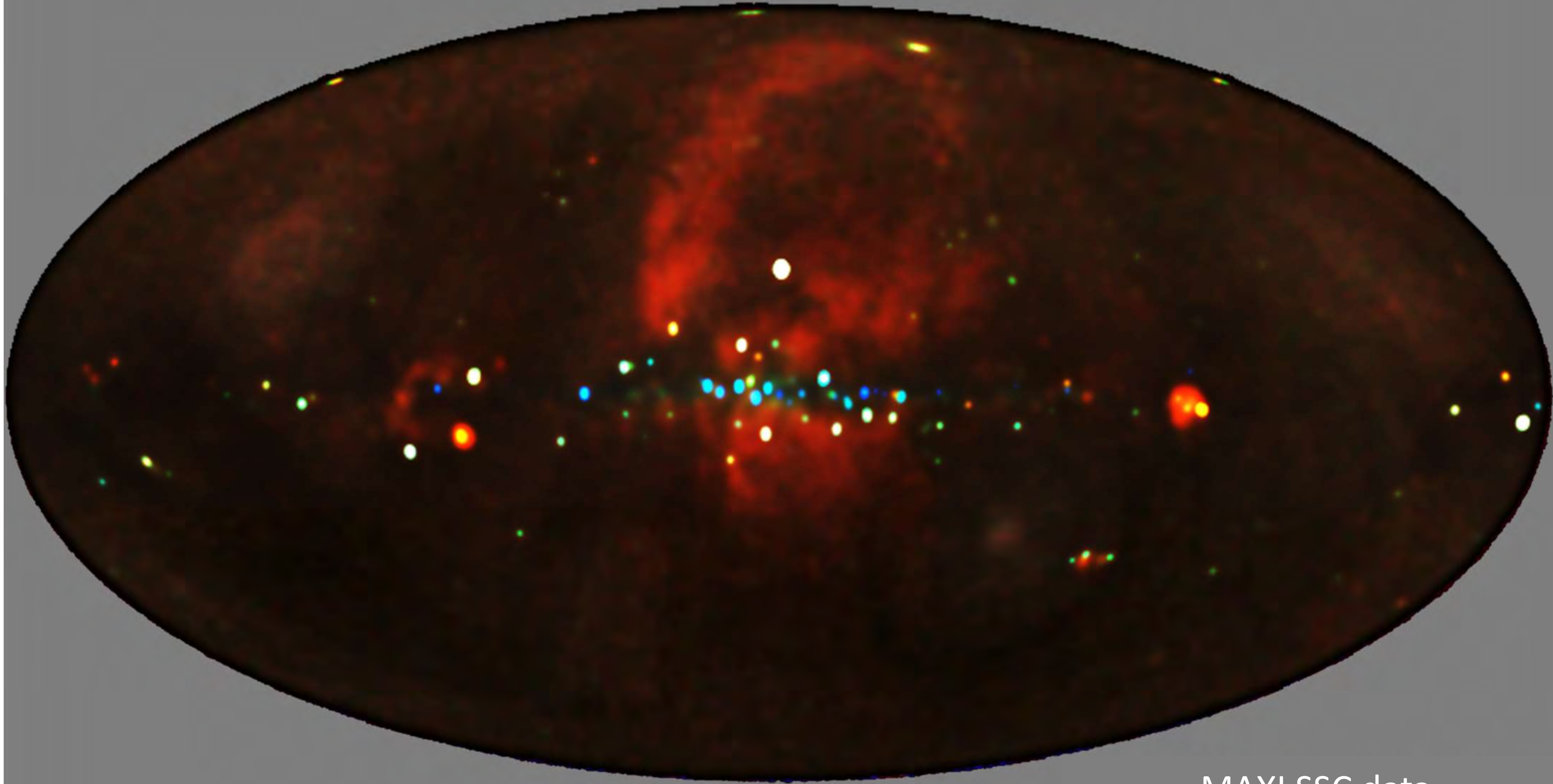
A large scale structure, remind people the Fermi Bubble





⇒ **see P-40 SHIDATSU, Megumi : map for GSC**

Fermi data reveal giant gamma-ray bubbles



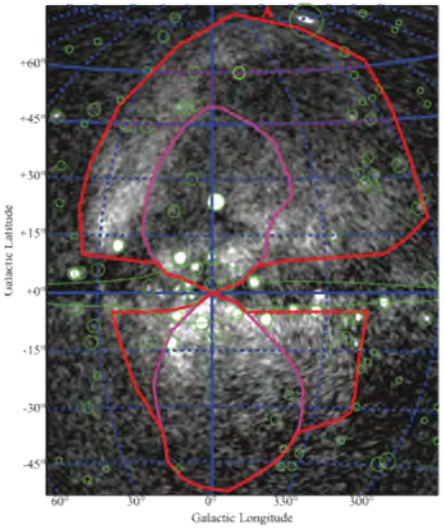
MAXI SSC data

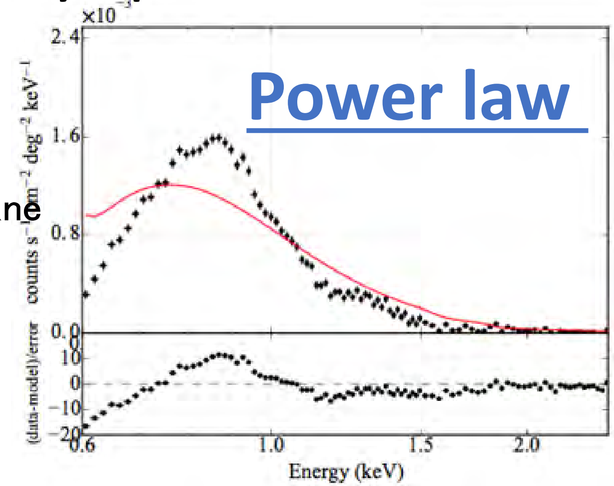
X-ray spectrum in the north

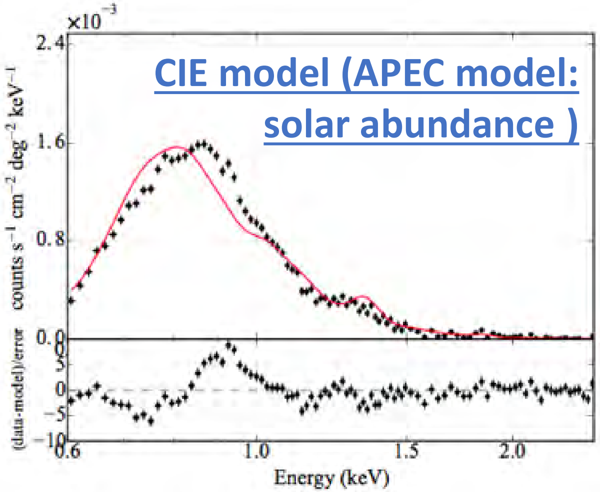
Out side the Fermi Bubble

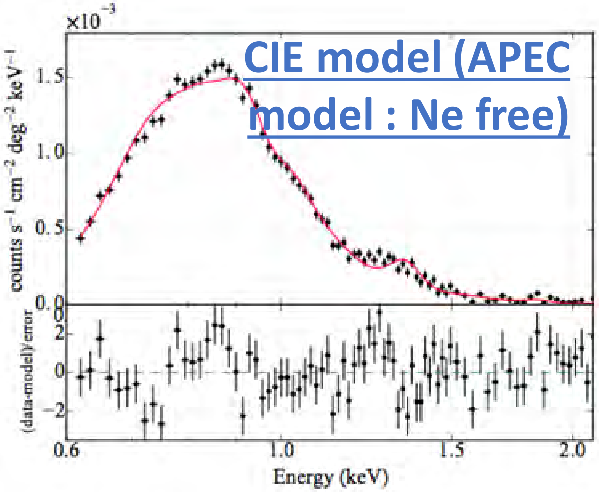
Fermi Bubble

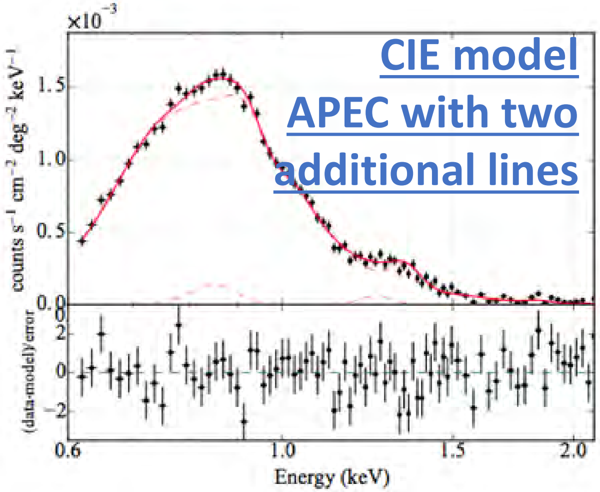
Masking bright sources and G-plane











Similar results are obtained in the south

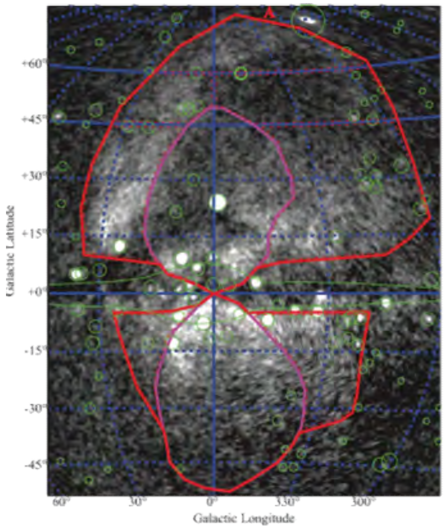
Fix the absorption feature to the galactic absorption

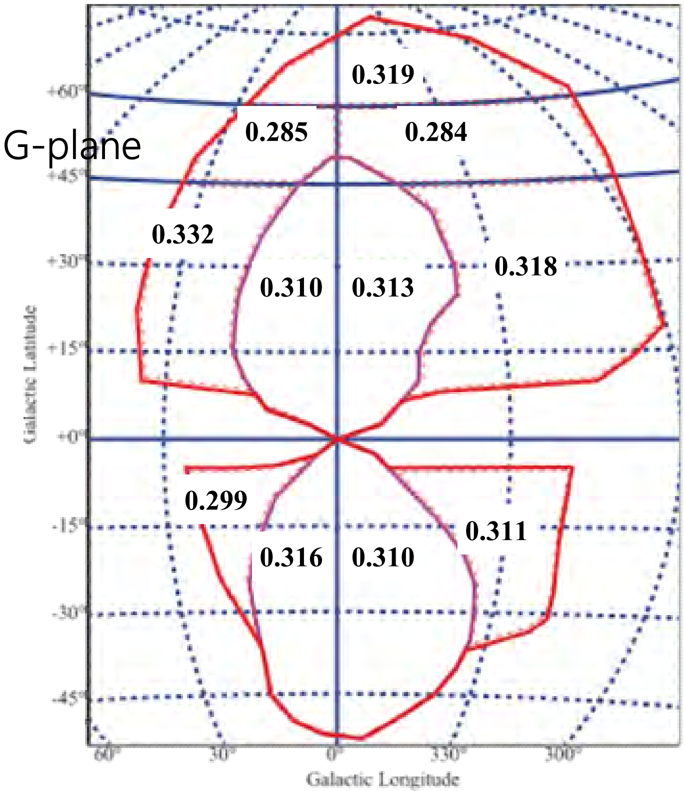
Temperature distribution

Out side the Fermi Bubble

Fermi Bubble

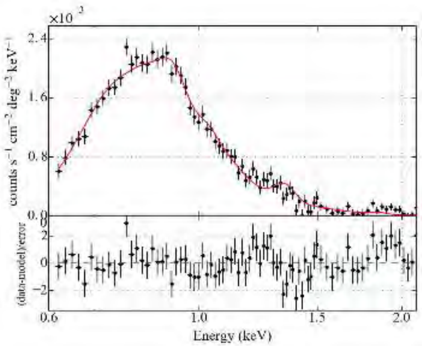
Masking bright sources and G-plane



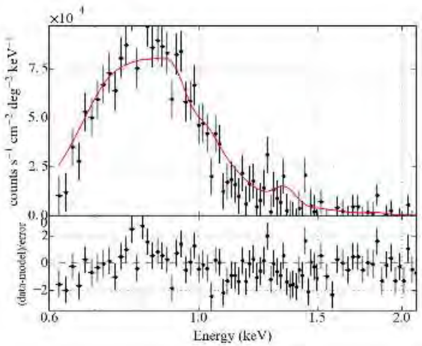


- We divide the bright region into several segments. Temperature is shown in each segment.
- Fermi bubble segments show similar temperature to those of surrounding segments.

Within the FB

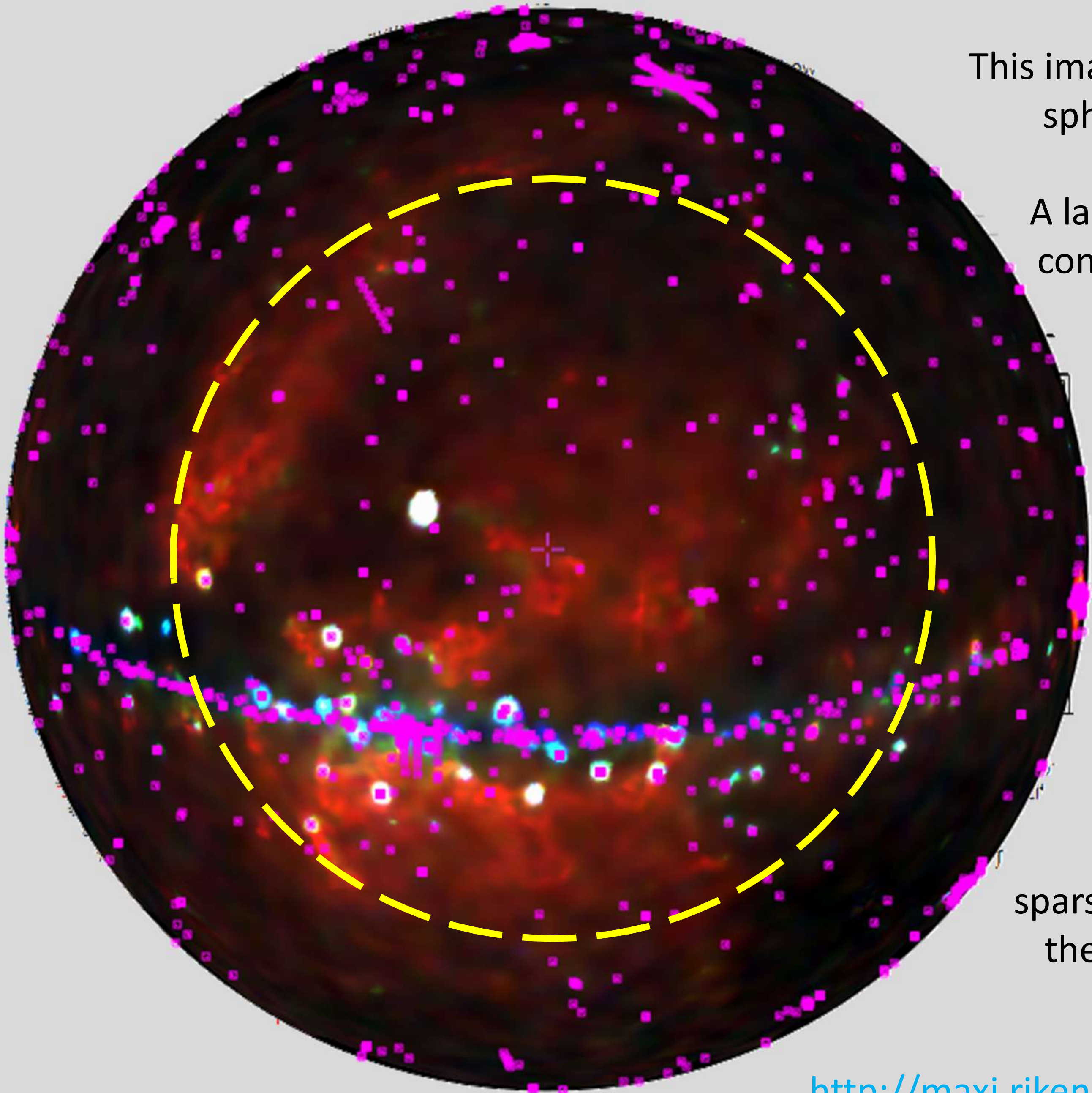


North end



Large scale structure shows uniform temperature (~0.3keV) while its intensity varies by a factor of 4-6. This is also suggested by Suzaku observation (Kataoka et al.2013,2015, Tahara et al.2015).

A large scale structure in the direction of the Galactic center



This image shows a celestial sphere centered on the arbitrary point.
A large scale structure is confined in a circle with a radius of 40°.
Diffuse emission is obscured by the Galactic Plane and point sources.

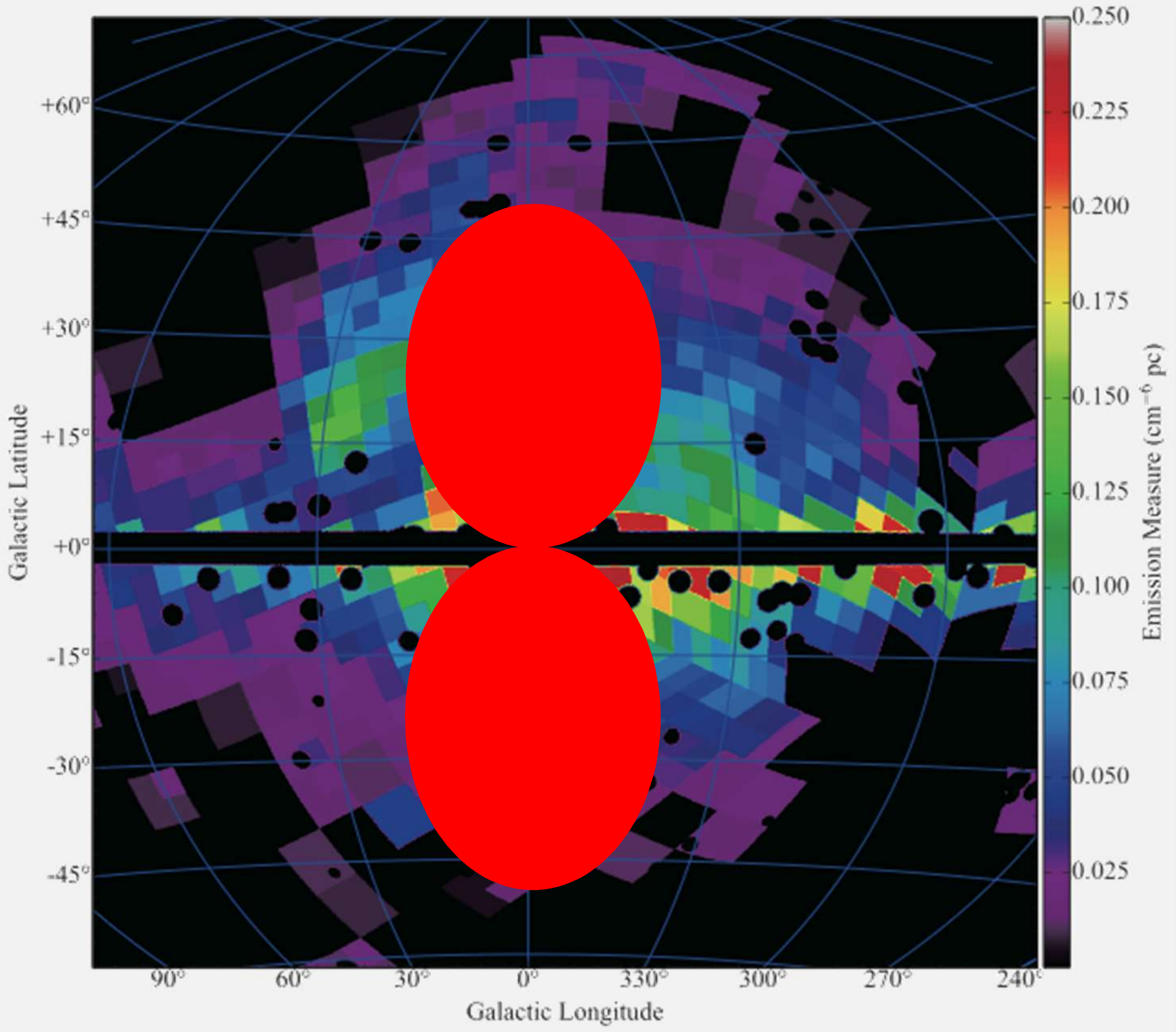
Pink-color small squares indicate the Suzaku observation. Most of them are on the known sources. Very few pointings sparsely scattered are for the study of the diffuse emission so far.

http://maxi.riken.jp/astro/judo2/

Since the plasma is thin thermal, we can estimate the mass and thermal energy.

$$M \sim 6.31 \times 10^{6} \left(\frac{\theta}{30^\circ}\right)^{5/2} \left(\frac{D}{8000\,\mathrm{pc}}\right)^{5/2} \left(\frac{EI}{0.05\,\mathrm{cm}^{-6}\mathrm{pc}}\right)^{1/2} [\mathrm{M}_\odot]$$

$$E \sim 3.94 \times 10^{54} \left(\frac{\theta}{30^\circ}\right)^{5/2} \left(\frac{D}{8000\,\mathrm{pc}}\right)^{5/2} \left(\frac{EI}{0.05\,cm^{-6}\mathrm{pc}}\right)^{1/2} \left(\frac{kT}{0.31\,\mathrm{keV}}\right) [\mathrm{erg}]$$



Large scale structures : NPS and Fermi Bubble

North Polar Super (NPS) shows a thin thermal emission.

- kT ≈ 0.31 keV, abundance of 0.1 ~ 0.2 solar
- Distance to the NPS is not well determined so far.

Fermi Bubble.

- A giant gamma-ray structure was discovered by Fermi all-sky data.
- The dumbbell-shaped feature (center) emerges from the galactic center and extends 50^{o} north and south from the plane of the Milky Way.

Suzaku observation.

- Very small FOV and several pointing observations have been done. This is not enough to cover the entire structure.

SSC observation

- North South asymmetry.
- Due to the sources along the galactic plane, it is difficult to extract the diffuse structure. Apart from the galactic plane, the extended source looks like a single unity, a circular structure with a radius about 40^{o}.

Talk plan

- Performance of the SSC
  - Hardware, Observation efficiency, CCD degradation
- SSC catalog
- SSC results
  - GRB
  - WD Nova
  - Cygnus Super Bubble
  - NPS and its extended structure
- **Summary**

Summary

The SSC consists of 32 CCDs (25mm square each) functioned properly. Due to the cosmic ray bombardment, each CCD degrades depending on its location inside the SSC. The heavily damaged CCD just below the slit degrades almost 4 times faster than those in the far end CCD. Each CCD has its own single stage Peltier cooler, achieving a temperature difference about 40^{O}C. A loop-heat-pipe and two radiator panels are also working well. Since we have an IR contamination problem at daytime, the observation efficiency is limited around 30%.

SSC has an effective energy range from 0.6keV to 7keV that is below that of the GSC. The SSC source catalog is compiled by using data obtained for the first 4 years. The detection limit is a few mCrab. The diffuse map by SSC is basically identical to that obtained by ROSAT.

We have detected several GRBs. Among them, we observed GRB100418A from its emergence for 50sec which connected to the observation by Swift XRT. It is a typical long GRB having a very low value of Ep(<8.3 keV) that is a very rare GRB.

A very soft transient, MAXI J0158-744 was discovered by MAXI. The SSC detected emission lines in its initial phase, suggesting that the explosion involved a small amount of ejecta and produced on an unusually massive O-Ne white dwarf possibly far over the Chandrasekhar limit.

The Cygnus Super Bubble extending more than 10^{O} was observed by SSC. We detected Fe, Ne, Mg emission lines, establishing the thermal origin of kT~0.23keV. Joint spectrum fittings of the ROSAT/PSPC data and MAXI/SSC data indicates that the CSB is a single unity. An energy budget and the geometrical structure suggest a Hypernova origin.

We confirmed a large scale structure below 1 keV that was detected by ROSAT. The spectrum shows a thermal origin of kT~0.31keV. This structure extends from the North-Polar-Spur to the region below the galactic plane, forming a circle with a diameter about 90^{O} whose center is off-set from the galactic center. It is quite difficult to find a connection to the Fermi Bubble in TeV.