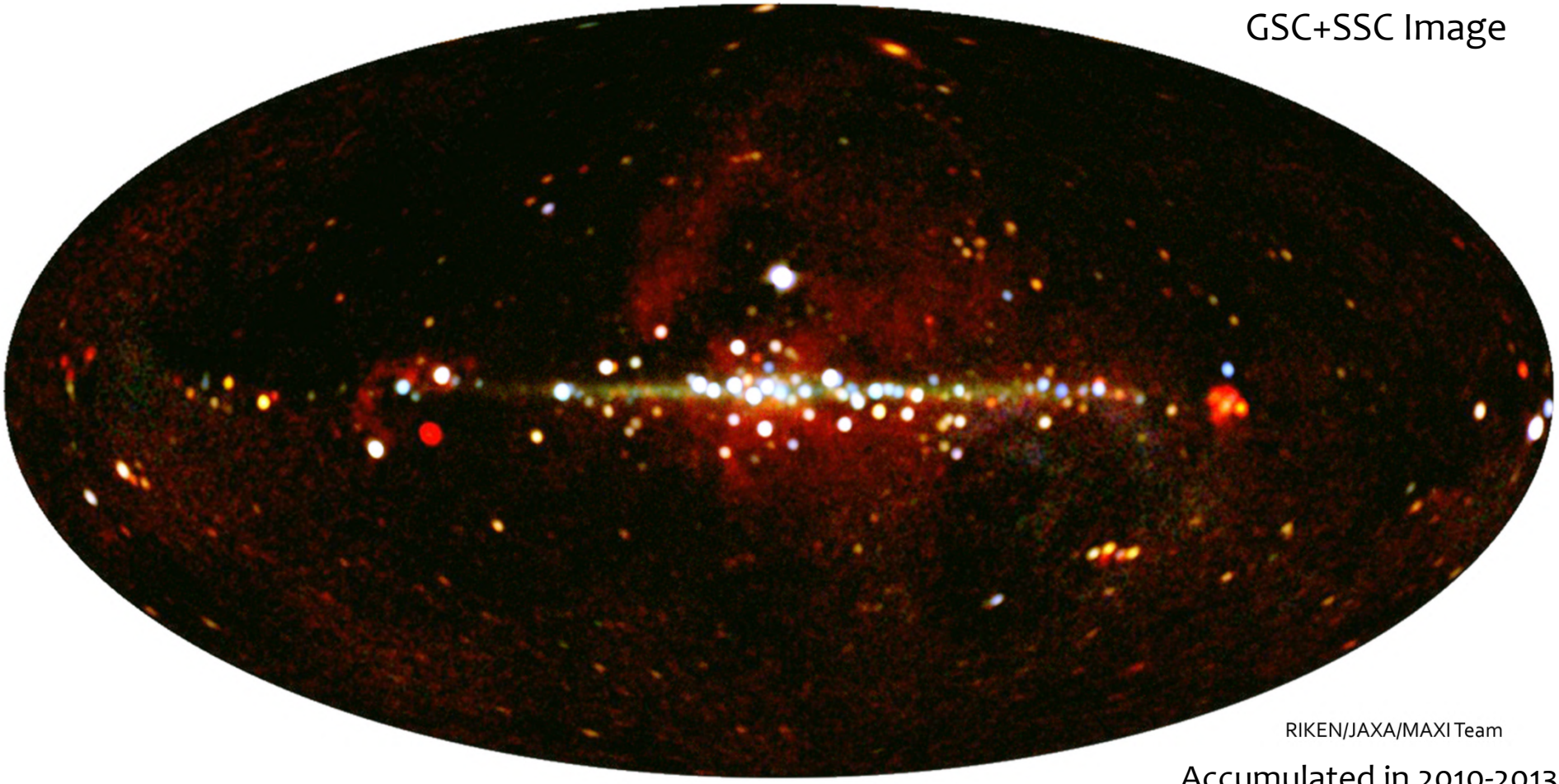
MAXI 7 Years Highlights

Tatehiro Mihara (RIKEN) and the MAXI team

GSC+SSC Image



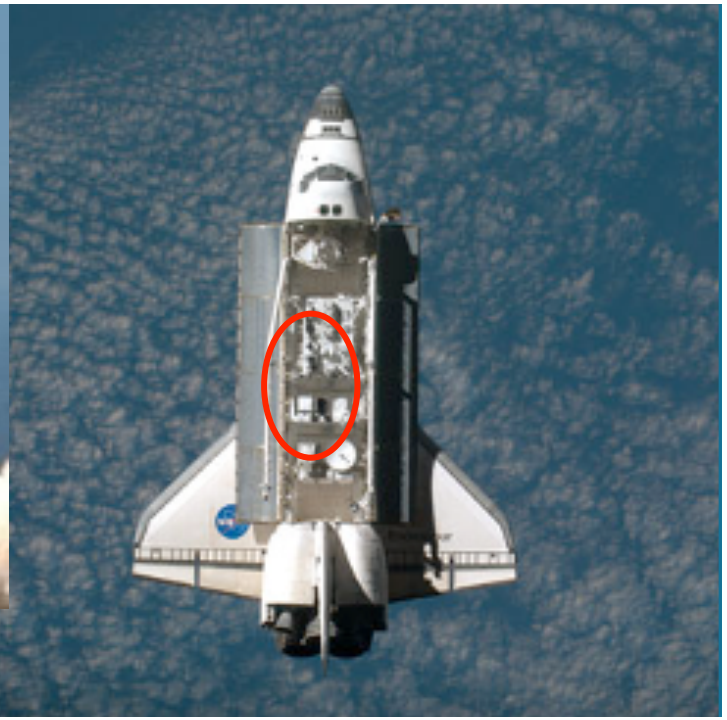
RIKEN/JAXA/MAXI Team

Accumulated in 2010-2013

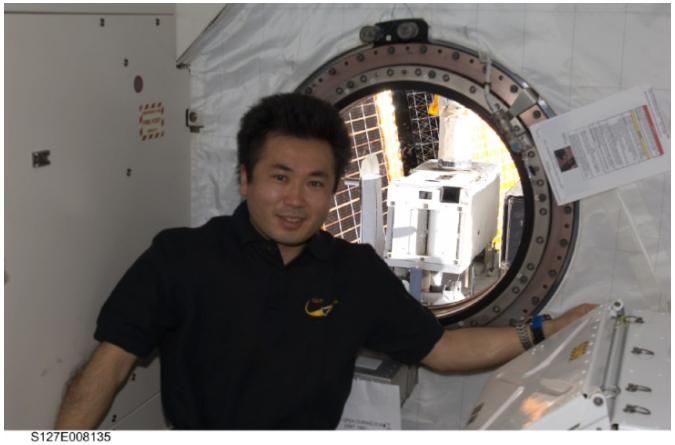
Outline

1. **MAXI instruments**
2. Results
   1. All-sky map
   2. MAXI Catalog
   3. MAXI sources
   4. Massive Nova ignition
   5. Huge stellar flares
   6. Recurrent transients BeXRB、NS-LMXB
   7. Cir X-1 Dust echo
   8. Pulsar Lx P monitoring
   9. AGN monitoring
   10. Tidal disruption
   11. GW 150914
   12. MUSST
3. MAXI future

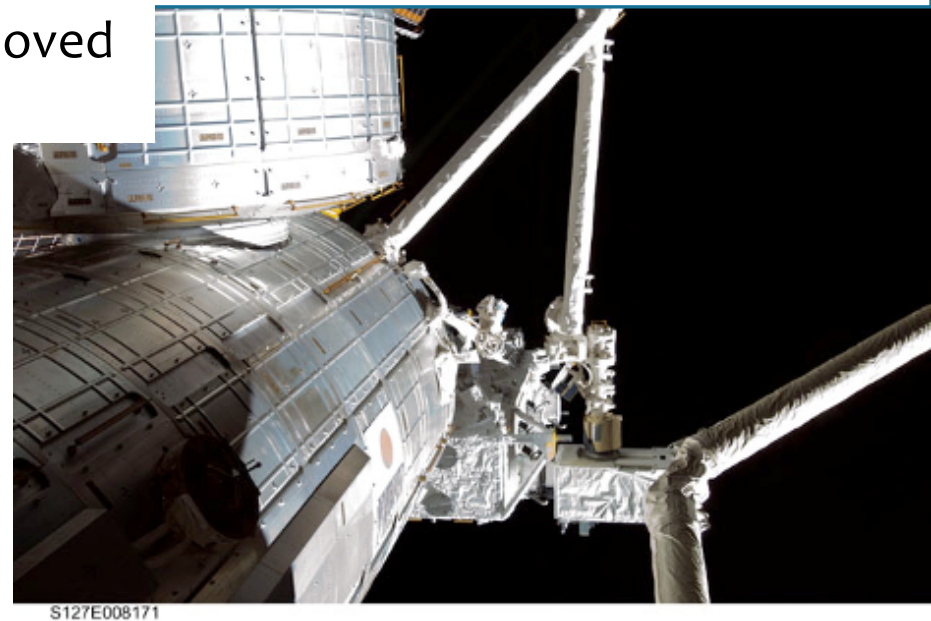
2009/7/16, MAXI was launched by space shuttle Endevour.



2009/7/23 Astronaut Wakata-san at ISS moved robot-arm to mount MAXI at JEM-EF port.



S127E008135



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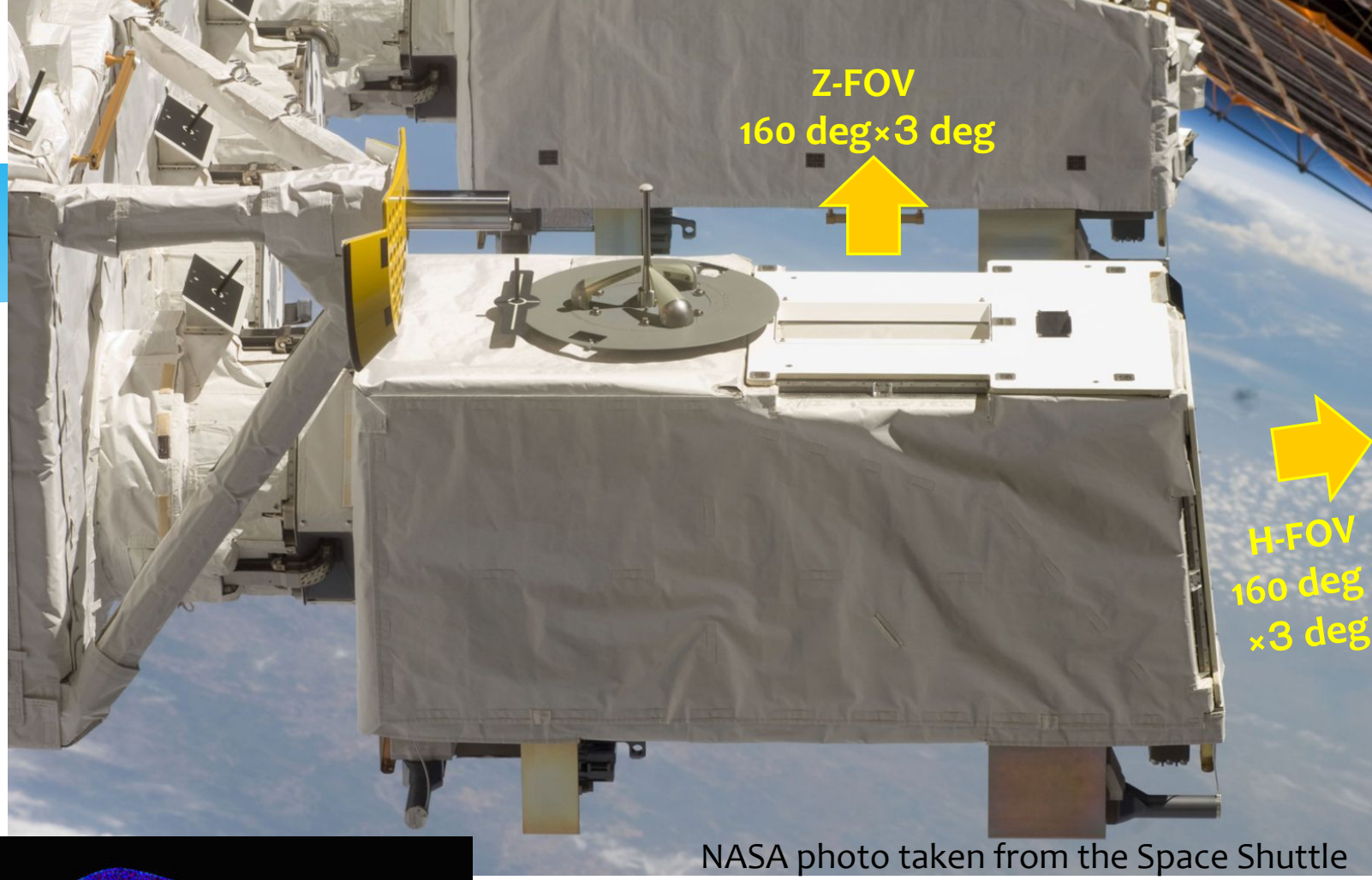
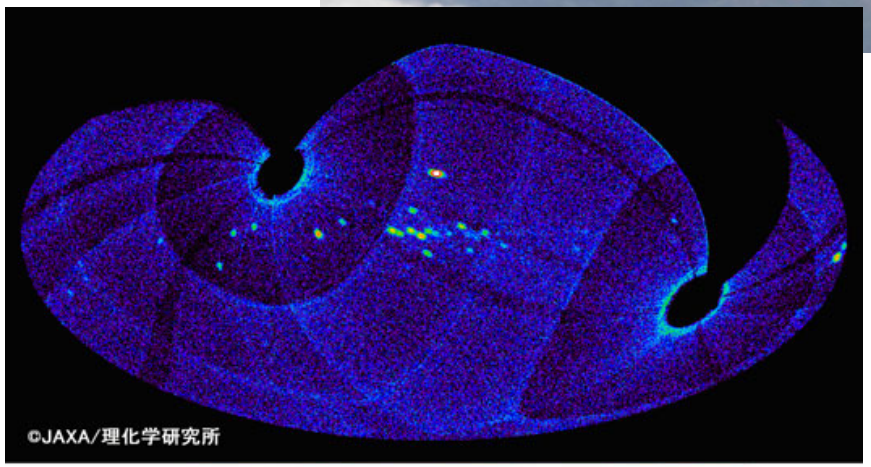
Photos in NASA web page

Real MAXI in space



NASA photo taken from the Space Shuttle



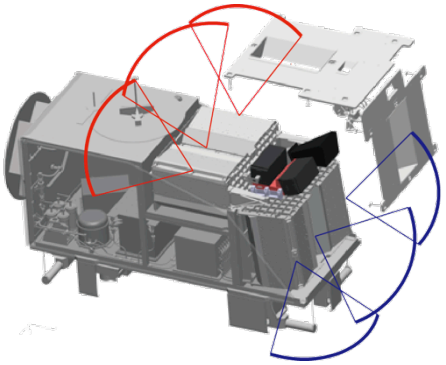
2009/8/15 First light

Scans dwell time ~60 s
Sensitivity (~5σ)

1scan	**100 mCrab**
1day	**30 mCrab**
1month	**5 mCrab**
1year	**1 mCrab**

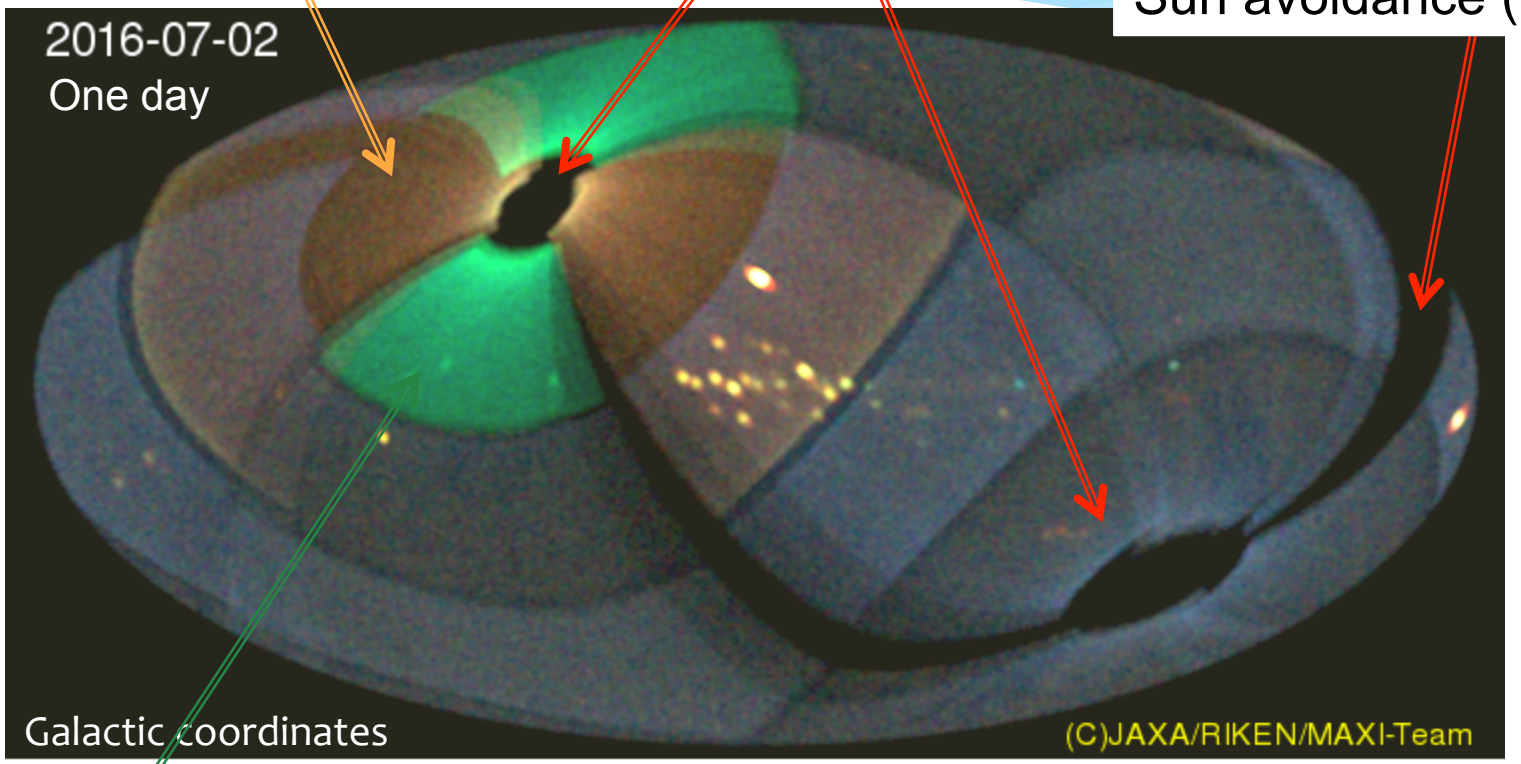
All-Sky Coverage (GSC)

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



GSC 0 (slow gas leak. Now P~0.1atm)

Sun avoidance (5 deg.)



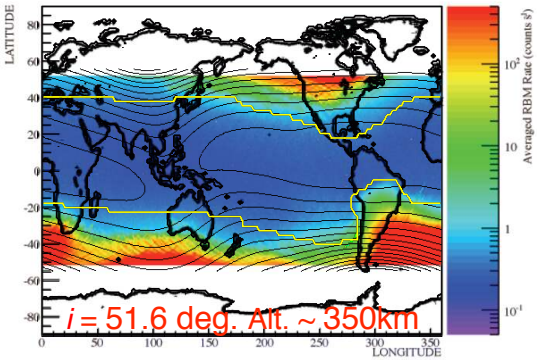
GSC 3 (degraded sensitivity without veto)

http://maxi.riken.jp/

The GSC covers ~90% of the sky every 92 minutes of ISS orbit.

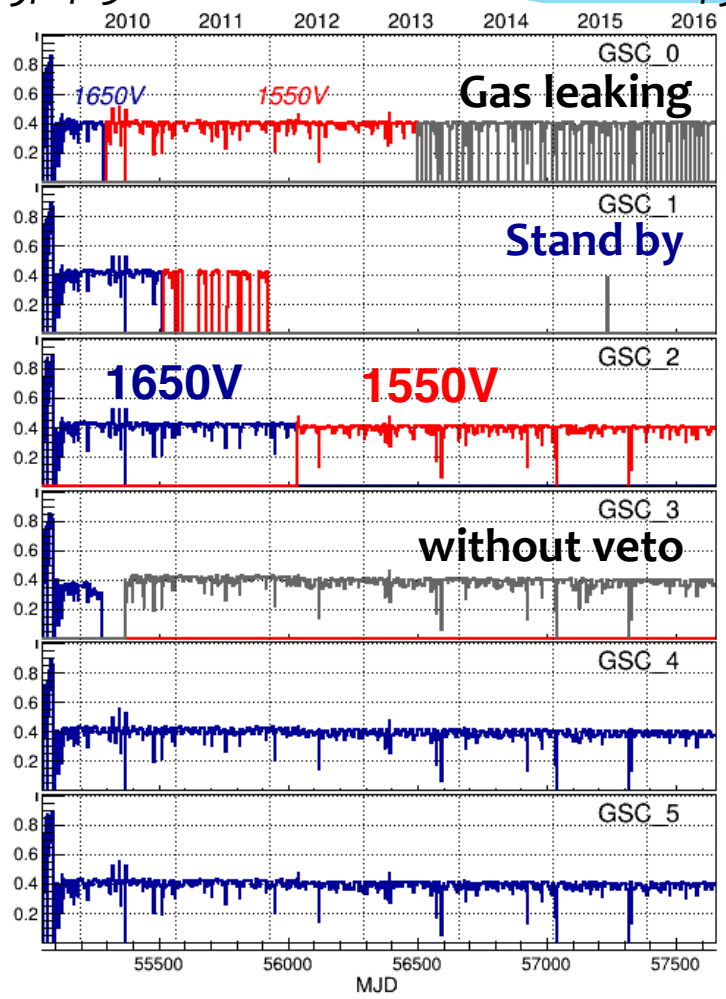
Daily duty cycle of 12 cameras

- Daily average duty cycle ~ 40 % (stopped in SAA and at high latitude)
- GSC_3, GSC_6, GSC_9: veto counters are disabled. GSC_0: gas leak
- GSC_3, GSC_6: under test operation with the veto disabled

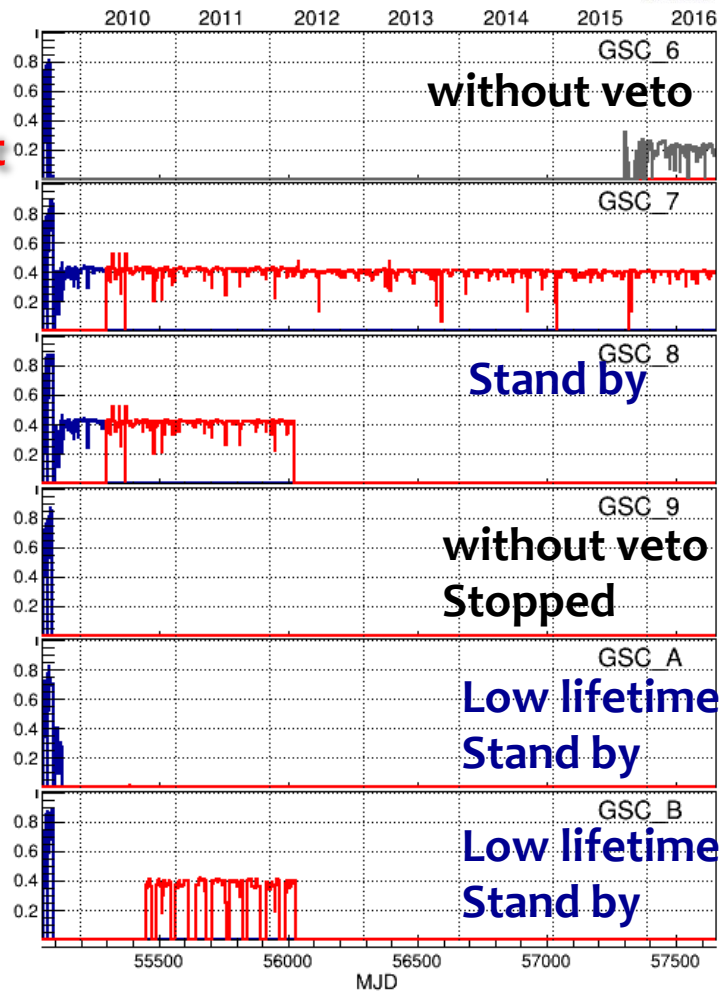


2009/8/15

2016/9/23



Redundant pair



Sugizaki IEEE 2016

Press releases of MAXI

Slow-eating Blackhole

草食系(?) ブラックホールの発見
～ブラックホール新星 XTE J1752-223 の出現から消失まで～

ブラックホールに「草食系」

あらゆる物質をのみ込むブラックホールの中で、吸い込むスピードが極端に遅いタイプが存在することを、理化学研究所などの研究グループが初めて確認した。ブラックホールは周囲の天体のガスを吸収する際に光るが、数日～10日間で吸収と光がピークに達する通常のブラックホールを「肉食系」とすれば、こちらは3カ月かけてゆっくり吸収する、食の細い「草食系」だ。金沢市で22日始まった日本天文学会で同日午後、発表する。【近藤希実】

ブラックホールは太陽の3倍以上の質量を持つ恒星が爆発後、重力崩壊を起こし、中心部に収縮したもの。複数の恒星からなる「連星系」の中で生まれた場合、周囲の天体のガスを吸い込む際に生じる爆発現象「アウトバースト」の光が観測できる。

研究グループは昨年10月、国際宇宙ステーションの日本実験棟「きぼう」に設置したX線監視装置を使い、いて座（射手）座にアウトバーストを確認。継続観測し、ブラックホールの存在が分かった。ゆっくり明るさが増し、変化のない時期を2回経て、最高光度に到達したのは今年1月だった。

ガスを吸収し光が増すペースが従来のものより遅く、同研究所の三原建弘先任研究員は「従来の理論で説明できない新種。こんなマイペースなブラックホールは初めて」と話している。

ガスを少しずつ吸収

3カ月かけて明るさが増すことが確認されたブラックホール＝理化学研究所提供

2010. 9. 21.

Hyper nova remnant in Milkyway

「極超新星爆発」痕跡を天の川で初の発見

ツイート 104　おすすめ 157　おすすめ　チェック

宇宙航空研究開発機構（ＪＡＸＡ）などは、国際宇宙ステーションの日本実験棟「きぼう」に設置したＸ線観測装置を使って、天の川銀河の中では初めて、太陽よりはるかに巨大な恒星の最期の姿である「極超新星爆発」の痕跡を見つけたと発表した。

銀河の進化を探る手がかりになるという。

地球から約５５００光年離れた場所で、約３００万度の高温のガスが、長さ２０００光年の範囲にわたって広がっていた。ガスの温度や分布などから、太陽の数十倍の質量の星が、約３００万年前に大爆発を起こした名残と判断した。

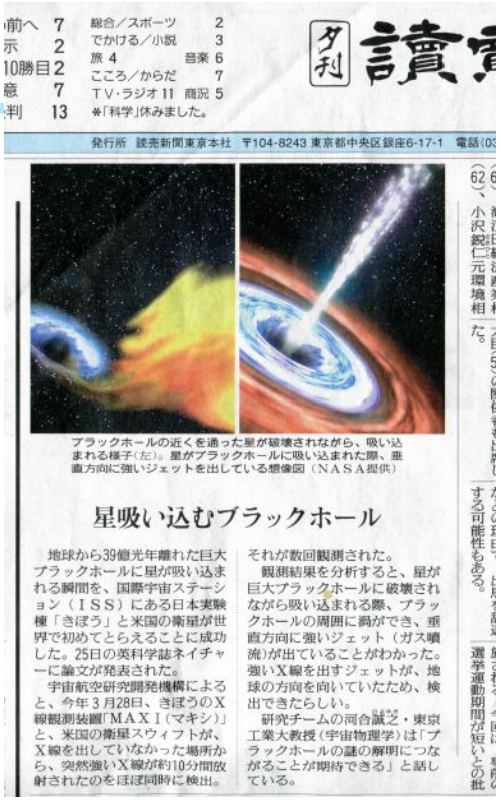
太陽のように光り輝く恒星は、そのエネルギーを失うにつれて、自らの重さに耐えられなくなり、超新星爆発と呼ばれる現象を起こすことがある。しかし、今回見つけたものは、通常の超新星爆発の１００倍の規模で、銀河の中で１０万～１００万年に１回程度しか起きない珍しい現象だという。

（2013年2月23日14時41分 読売新聞）

Ｘ線の観測データに基づく極超新星爆発の痕跡の想像図。赤い部分が高温ガスの広がる痕跡（ＪＡＸＡ、理化学研究所提供）

2013. 2. 22.

Blackhole swallowing a star



夕刊 讀賣

発行所 読売新聞東京本社 〒104-8243 東京都中央区銀座6-17-1 電話(03

ブラックホールの近くを通った星が破壊されながら、吸い込まれる様子（左）。星がブラックホールに吸い込まれた際、垂直方向に強いジェットを出している想像図（ＮＡＳＡ提供）

星吸い込むブラックホール

地球から39億光年離れた巨大ブラックホールに星が吸い込まれる瞬間を、国際宇宙ステーション（ＩＳＳ）にある日本実験棟「きぼう」と米国の衛星が世界で初めてとらえることに成功した。25日の英科学誌ネイチャーに論文が発表された。

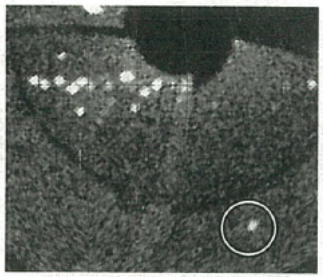
宇宙航空研究開発機構によると、今年３月28日、きぼうのＸ線観測装置「ＭＡＸＩ（マキシ）」と、米国の衛星スウィフトが、Ｘ線を出していなかった場所から、突然強いＸ線が約10分間放射されたのをほぼ同時に検出。それが数回観測された。

観測結果を分析すると、星が巨大ブラックホールに破壊されながら吸い込まれる際、ブラックホールの周囲に渦ができ、垂直方向に強いジェット（ガス噴流）が出ていることがわかった。強いＸ線を出すジェットが、地球の方向を向いていたため、検出できたらしい。

研究チームの河合誠之・東京工業大教授（宇宙物理学）は「ブラックホールの謎の解明につながることが期待できる」と話している。

2011. 8. 25.

Ignition of nova explosion



きぼうの装置が捉えた新星爆発の火の玉（円内）＝理化学研究所・宇宙航空研究開発機構提供

■新星爆発の瞬間を初観測

星が急激に明るさを増す現象「新星爆発」が起きた瞬間に発生する火の玉を捉えることに、世界で初めて成功したと理化学研究所などのチームが発表した。

二つの星が互いを回る連星で、片方の星からもう片方の星に水素ガスが流れ込むと激しい核融合反応が起き、火の玉となる。続いて明るく輝くのが新星爆発と考えられている。

チームは、国際宇宙ステーションの日本実験棟きぼうに設置した「全天エックス線監視装置」で2011年11月11日、地球から22万光年離れた小マゼラン星雲で非常に明るいエックス線の光を見つけた。少なくとも約20分間続いた。その後の分析で火の玉から出ていたと判明した。通常の新星爆発より100倍明るく、従来の理論で上限とされるより重い星が起こした可能性があるという。

2013. 11. 14.

Taken from Japanese newspapers

CBSNEWS Video | US | World | Politics | Entertainment | Health | MoneyWa

By MICHAEL CASEY / CBS NEWS / June 25, 2015, 4:25 PM

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.

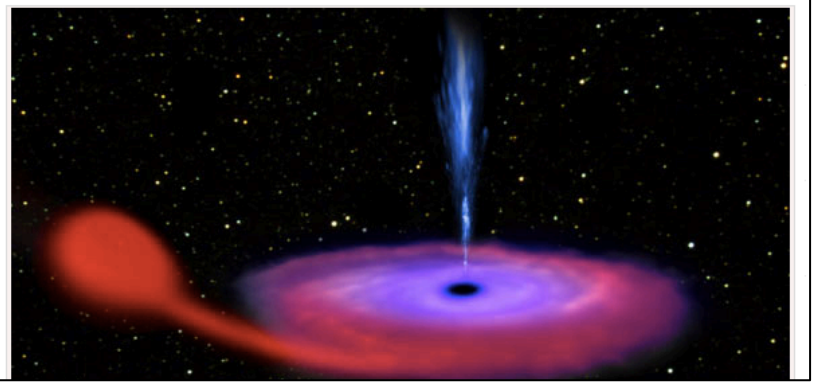
Part of the Milky Way galaxy, the system had been silent for a quarter century. But that all changed earlier this month, when a number of telescopes and the European Space Agency's (ESA) Integral satellite observed a burst of high energy light coming from almost 8,000 light-years away in the constellation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

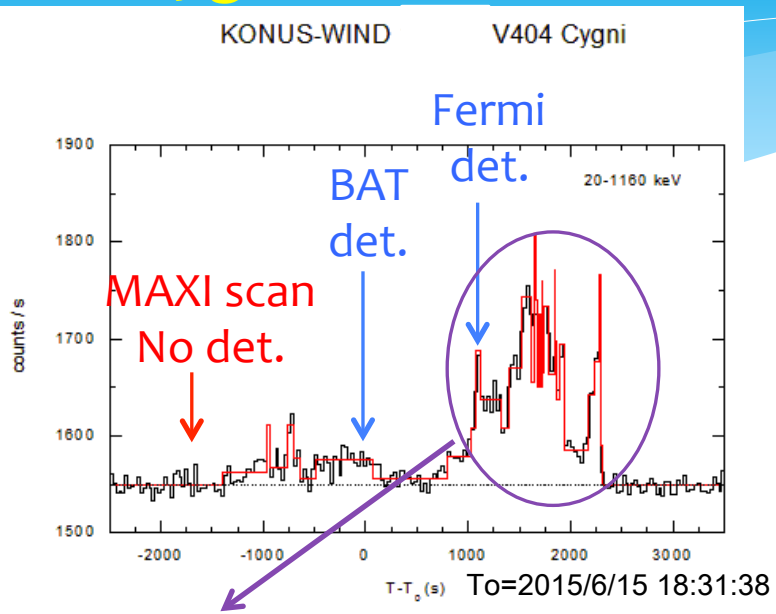
Published in
Astronomy

Tagged as
Binary star
Black hole
ESA
Gamma rays
Integral
MAXI
NASA
Swift spacecraft
V404 Cygni
X-rays

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.



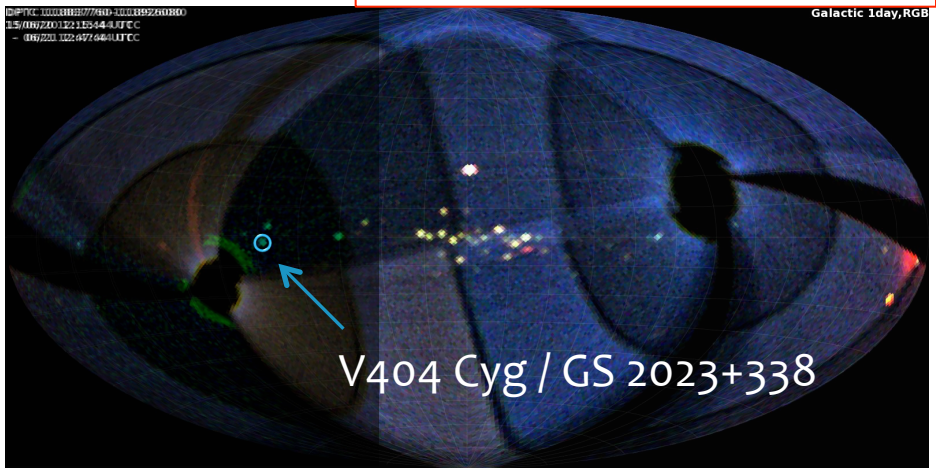
V404 Cyg on 2015.6.15.



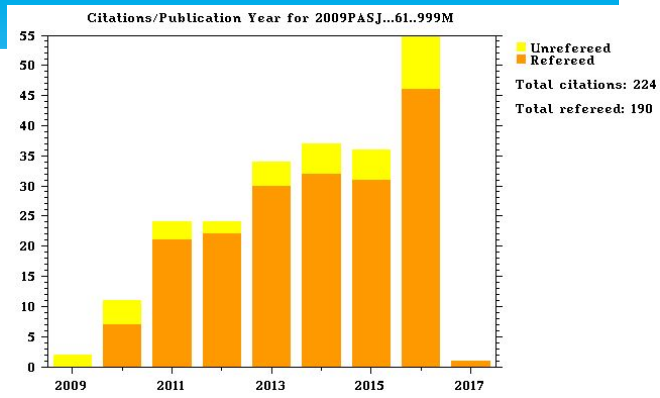
To=2015/6/15 18:31:38

Quick follow-up optical observation
Discovery of rapid variability (Kimura et al. Nature 2016)

⇒ Kimura-san's talk



Papers and Awards



* Refereed paper using MAXI data 190
* Refereed papers (by MAXI team) 62
* Invited talks in Intern. Conf. 11
* Press releases
* 2013 Paper Award by Publ. Astron. Soc. Japan
* MAXI conferences 3
* Riken Symposium 4


授賞式の様子（2014年3月20日）

* ISS award on innovation in earth and space science,

  CASIS (Center for the Advance. of Sci. In Space),

  American Astronautical Soc., NASA

  Time domain astronomy
  Multi-messenger astronomy

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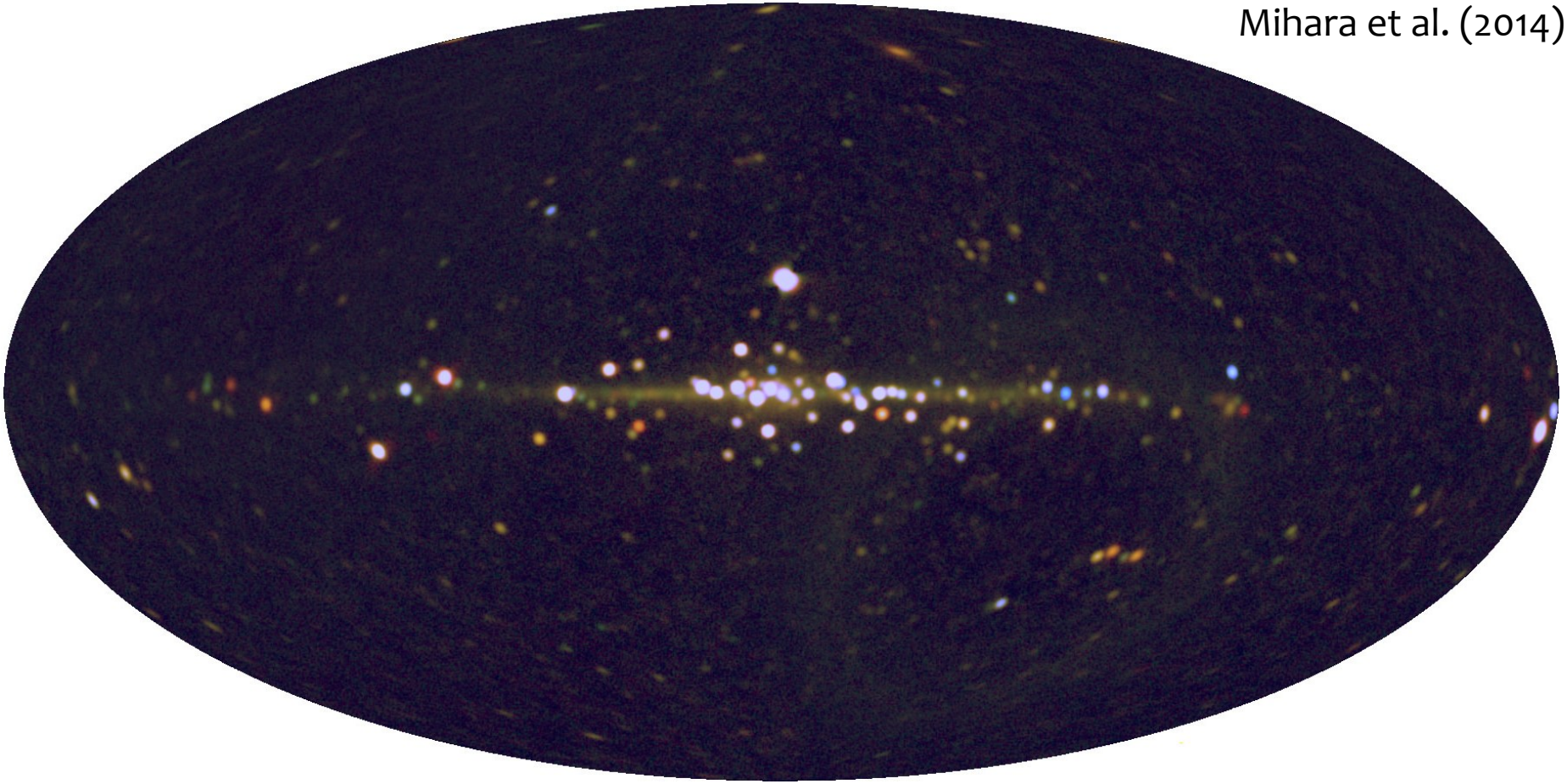
GSC all-sky map (4.1 years)

Mihara et al. (2014)

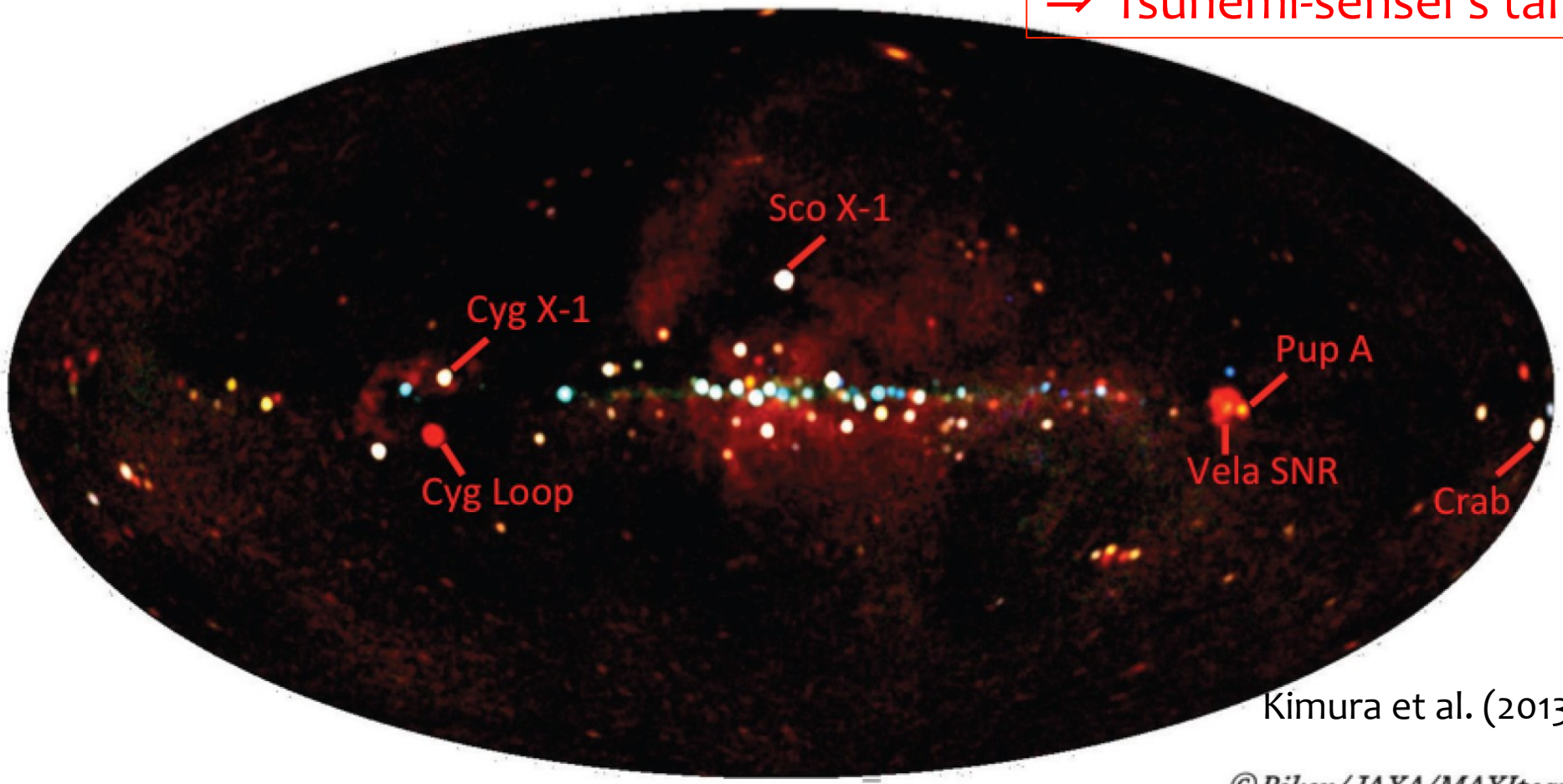


Red: **2-4** keV, Green: **4-10** keV, and Blue: 10-20 keV.
X-ray binary pulsars appear in blue, supernova remnants appear in red, low-mass X-ray binaries appear in yellow.
More than 500 sources are detected. Members of bright AGN have changed in 30 years. A new catalog in the early 21st century.

Hiroi et al. (2013)

GSC+SSC all-sky map

⇒ Tsunemi-sensei's talk



Kimura et al. (2013)

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.

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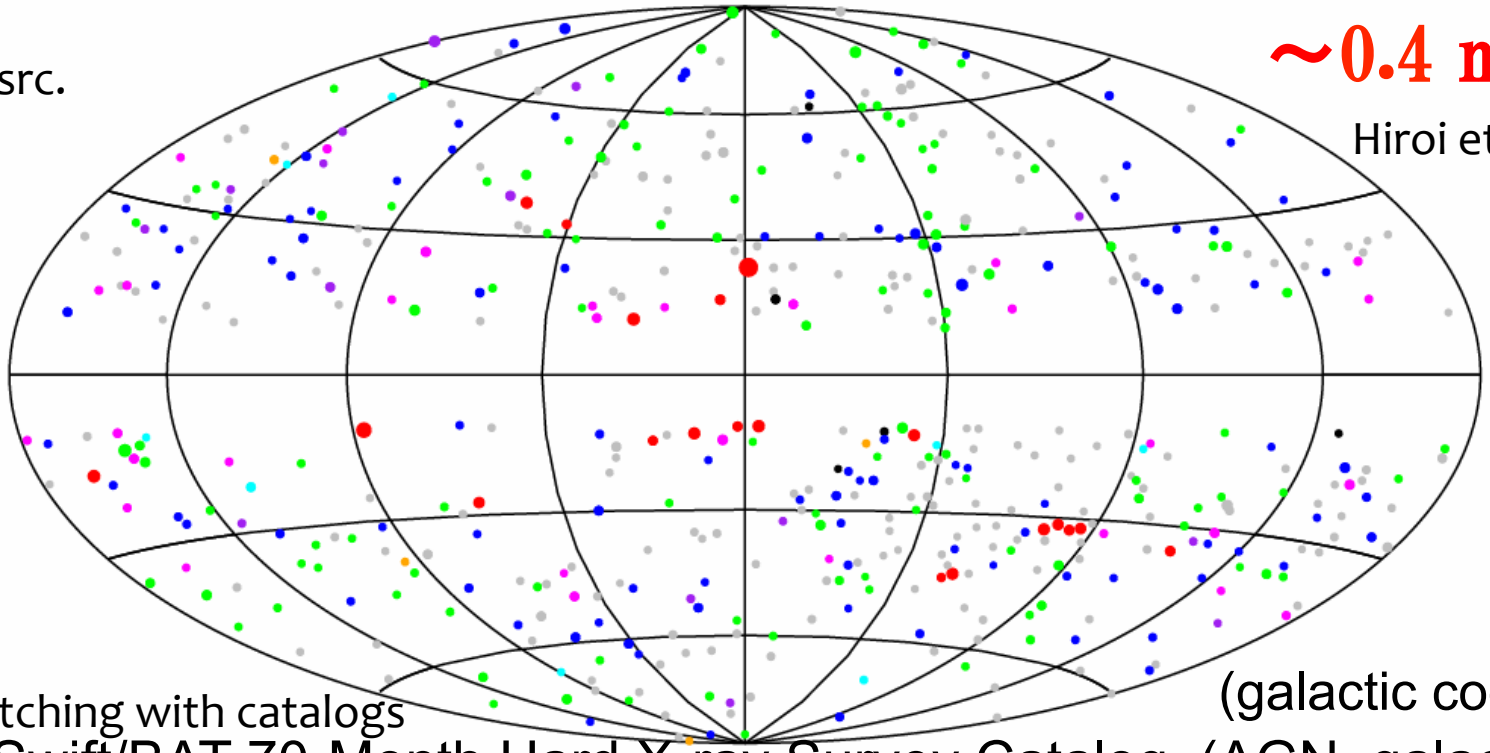
2nd MAXI / GSC 37 months catalog

500 sources are detected ($|b|>10^\circ$, $>7\sigma$) Detection limit

1st 143 src.

~0.4 mCrab

Hiroi et al. (2013)



(galactic coordinate)

Cross-matching with catalogs

Swift/BAT 70-Month Hard X-ray Survey Catalog (AGN, galactic)

Meta-Catalog of X-Ray Detected Clusters of Galaxies (clusters)

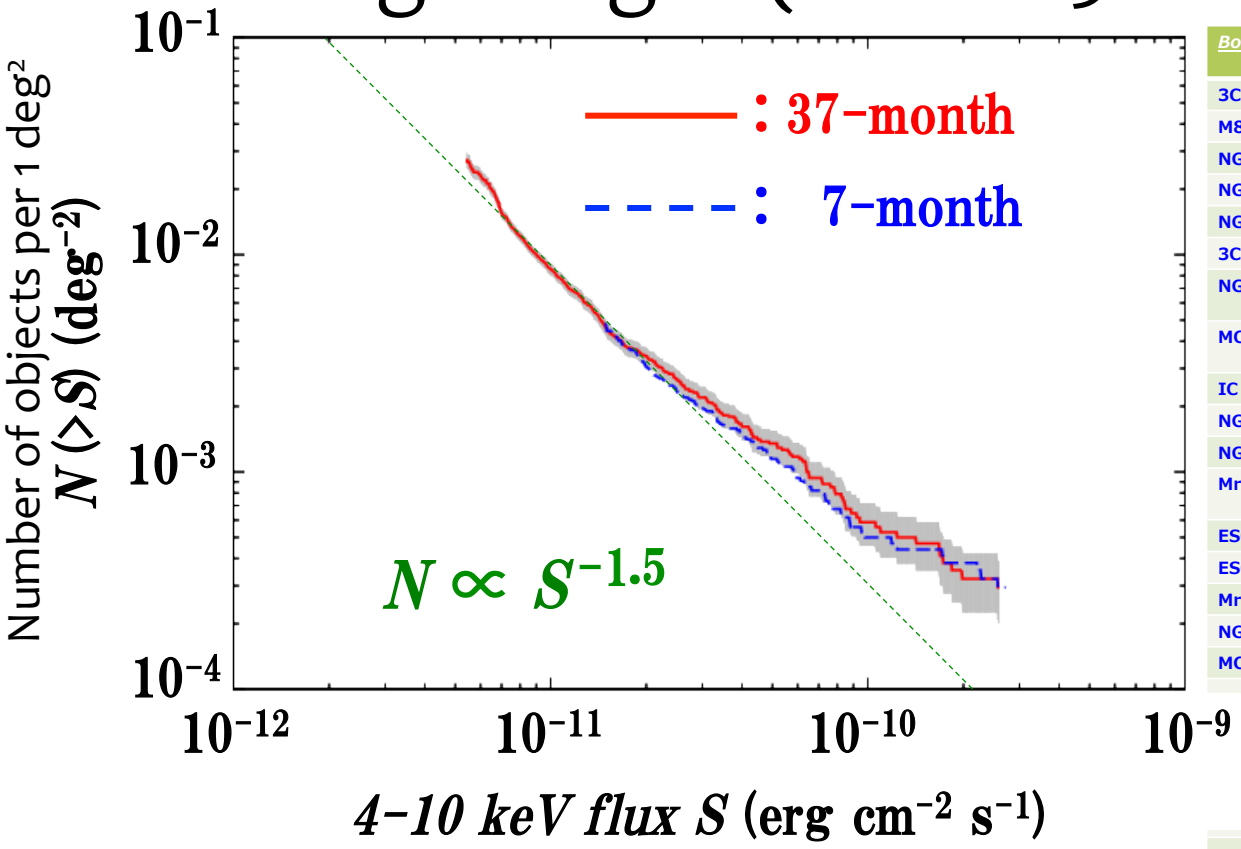
X-ray binary : 20	CV/Star : 30	Galaxy cluster : 114
Seyfert galaxy: 100	Blazar : 15	Galaxy : 8
Confused : 4	X-ray source : 5	Unmatched : 204

→ About **60%** were identified. Careful and precise localization is needed.

Surface density of X-ray sources

log *N*-log *S* (MAXI's 500 objects)

Hiroi et al. (2013)



Both by MAXI and by HEAO-1	Only by HEAO-1	Only by MAXI
3C 120	III ZW 2	Mrk 348
M82	Fairall 9	NGC 931
NGC 3227	NGC 526A	NGC 1365
NGC 3783	Mrk 590	1RXS J042601.6-571202
NGC 4151	H0557-385	Ark 120
3C 273	NGC 2992	NGC 3516
NGC 4593	H1219+305	2MASX J11454045-1827149
MCG -6-30-15	PKS 2155-304	ESO 509-66
IC 4329A	NGC 7213	NGC 5252
NGC 5506	3C 445	4C +18.51
NGC 5548	NGC 7469	3C 390.3
Mrk 501	NGC 7582	2MASX J18470283-7831494
ESO 103-G35		NGC 6860
ESO 141-G55		1RXS J213623.1-622400
Mrk 509		NGC 7172
NGC 7314		MR 2251-178
MCG -2-58-22		1ES 0120+340
		PKS 0548-322
		QSO B0706+591
		1ES 1101-232
		Mrk 421
		RGB J1136+676
		1ES 1426+428
		3C 454.3

- Consistent with HEAO-1's result (fluxes >10^{-11} erg cm^{-2} s^{-1})
- But, 40% of objects were changed.
- $N \propto S^{-1.5}$ (in low flux of f < 10^{-11} cgs)

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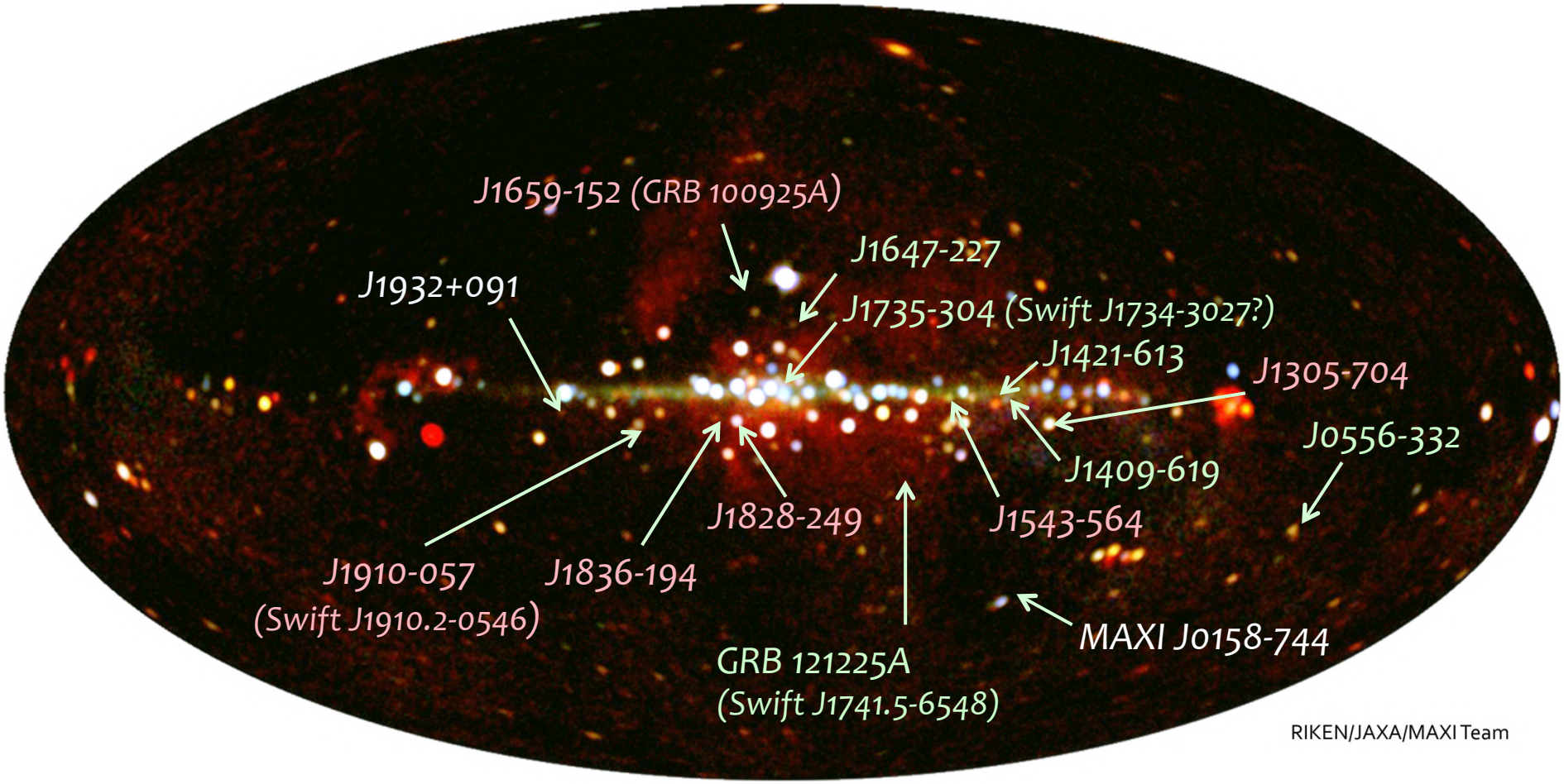
MAXI discovered 17 X-ray Transients in 7 years

⇒ Negoro-san's talk



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

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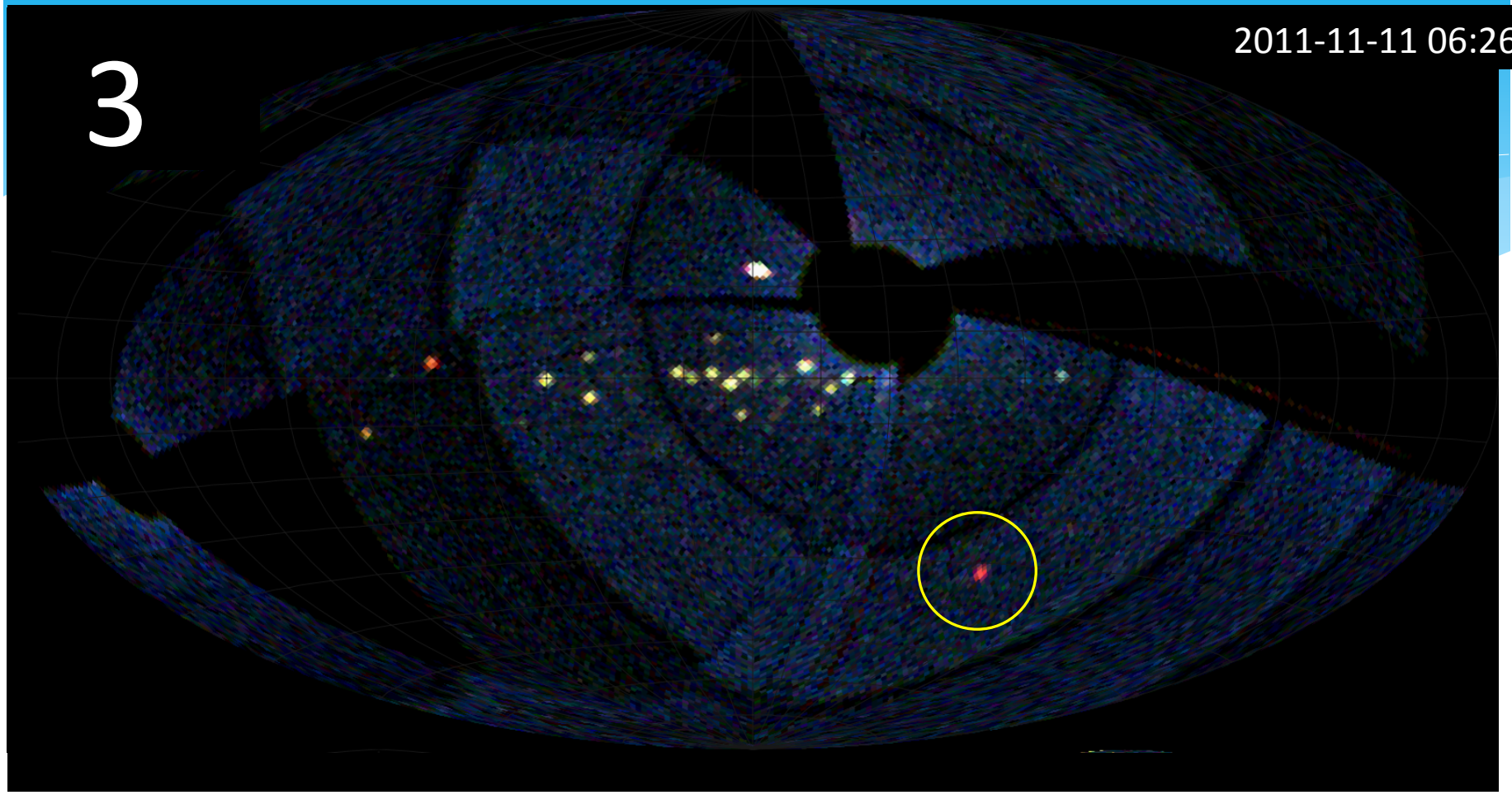
Discovery of MAXI J0158-744

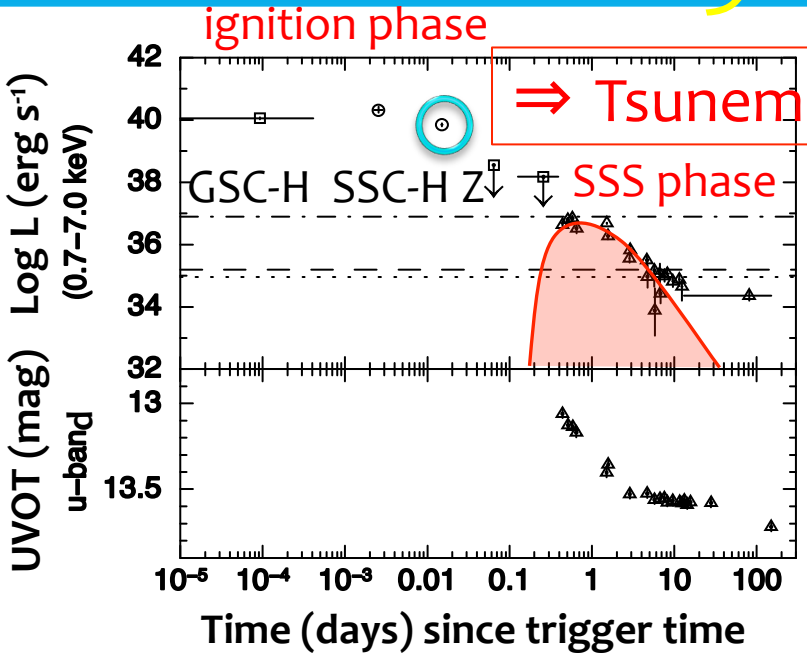


- MAXI GSC 1 orbit image

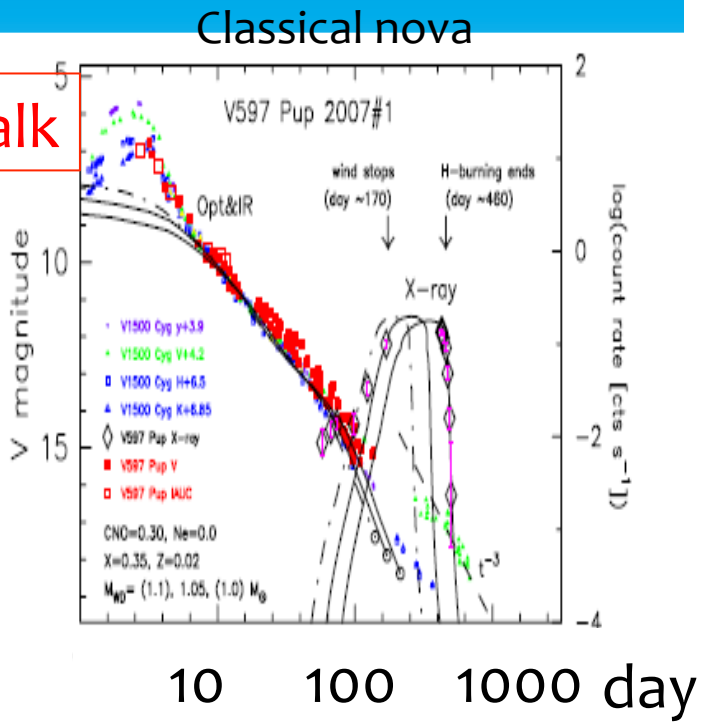
- Soft X-ray short Transient (< 5 keV)

None of GRBs, X-ray burst on neutron stars, Flare of magnetars, Super-giant Fast X-ray Transient, and supernova shock breakout

MAXI J0158-744



⇒ Tsunemi-sensei's talk

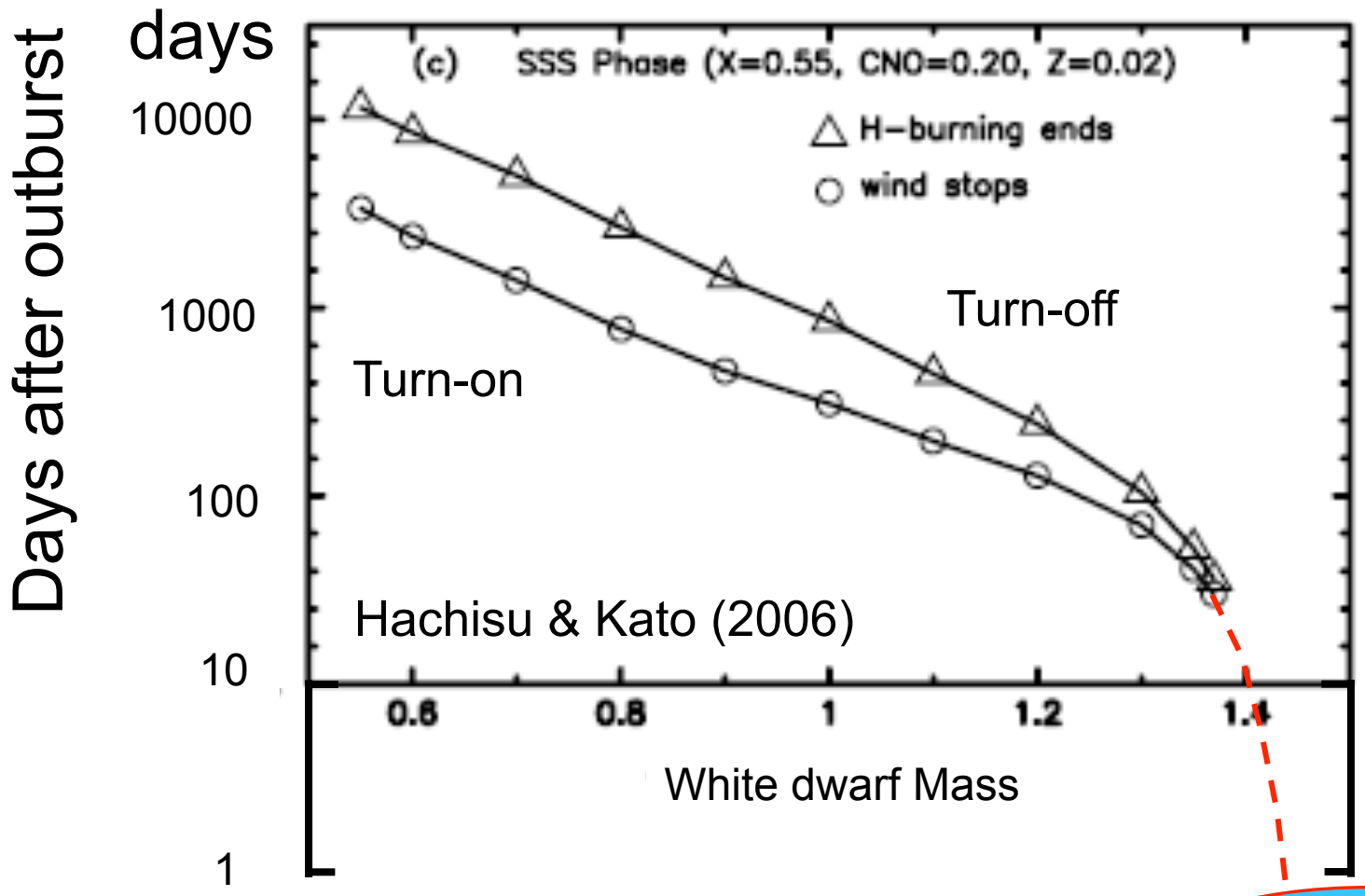


* Near the edge of Small Magellanic Clouds (SMC)
  - Optical spectrum: Be star at SMC distance (= 60 kpc) (B1-2 IIIe)
  - Luminosity = 10^{40} erg/s (Ignition phase)
  - Ionized Ne line was detected.
* Latter phase (0.5 ~ 30 days) :
  * Blackbody (radius = 10^4 → 10^2 km, Temperature= 60 → 110 eV)
  * Similar to soft X-ray emission after nova explosions.
  * Super Soft X-ray Source phase (SSS phase)

Very rapid
Very luminous
Less total Energy

SSS phase: very early (started before 0.5 days)

very short duration (about 10 days)



WD mass is close to the Chandrasekhar limit (1.4 Mo)

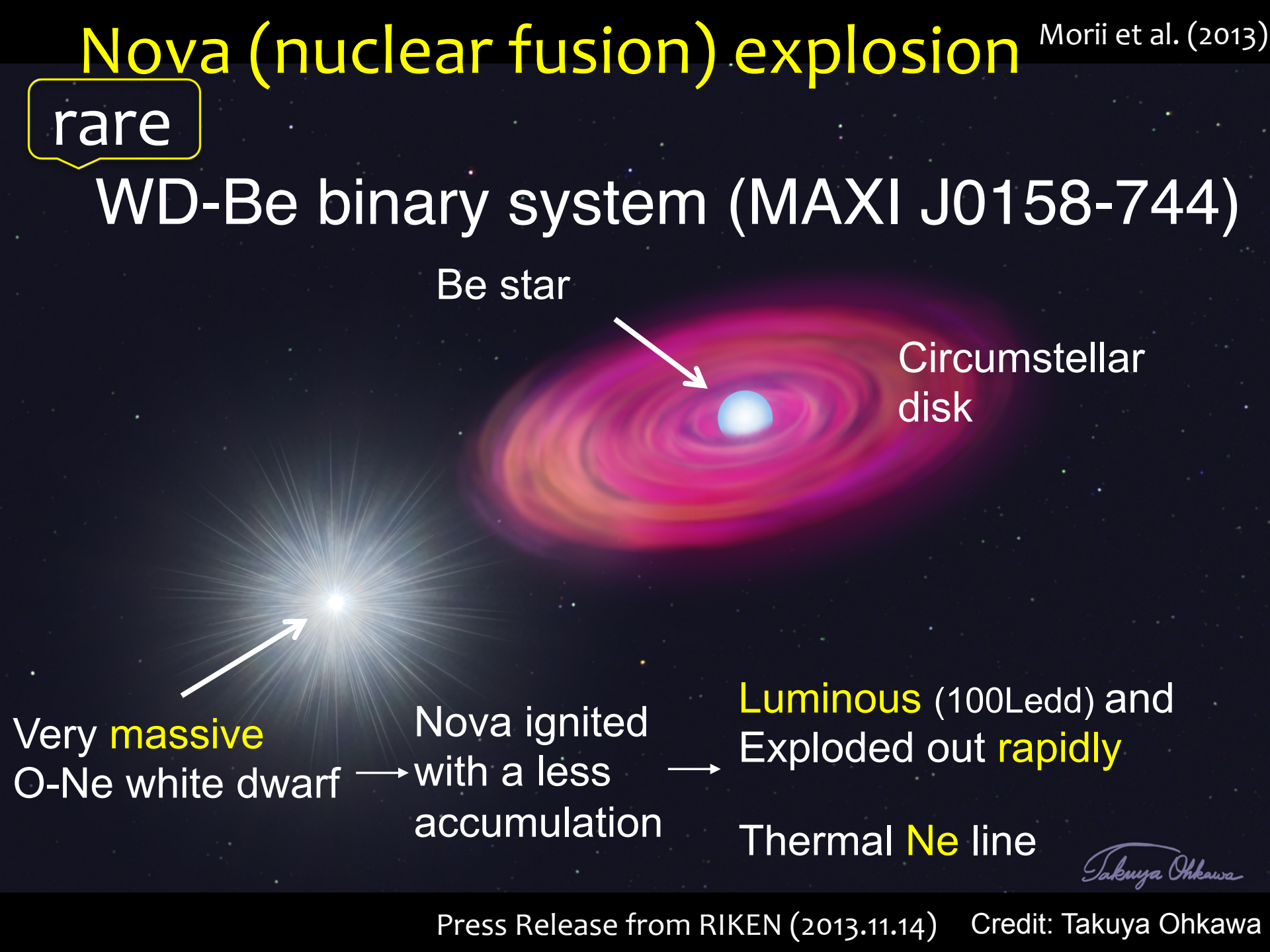
MAXI J0158-744

Nova (nuclear fusion) explosion

Morii et al. (2013)

rare

WD-Be binary system (MAXI J0158-744)



Press Release from RIKEN (2013.11.14) Credit: Takuya Ohkawa

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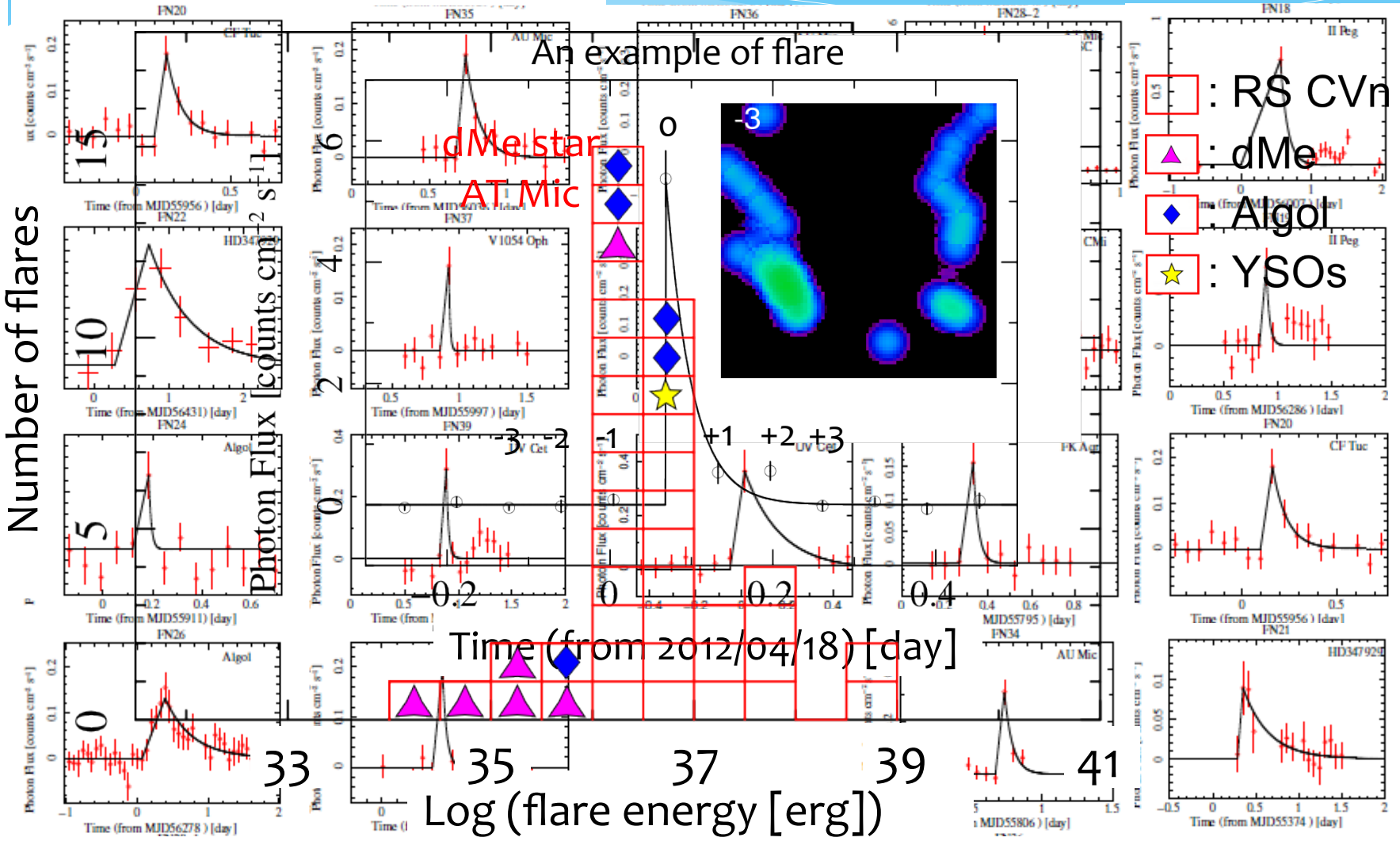
MAXI detected large stellar flares

⇒ Tsuboi-san's talk

64 large flares from 21 stars in 4 years.

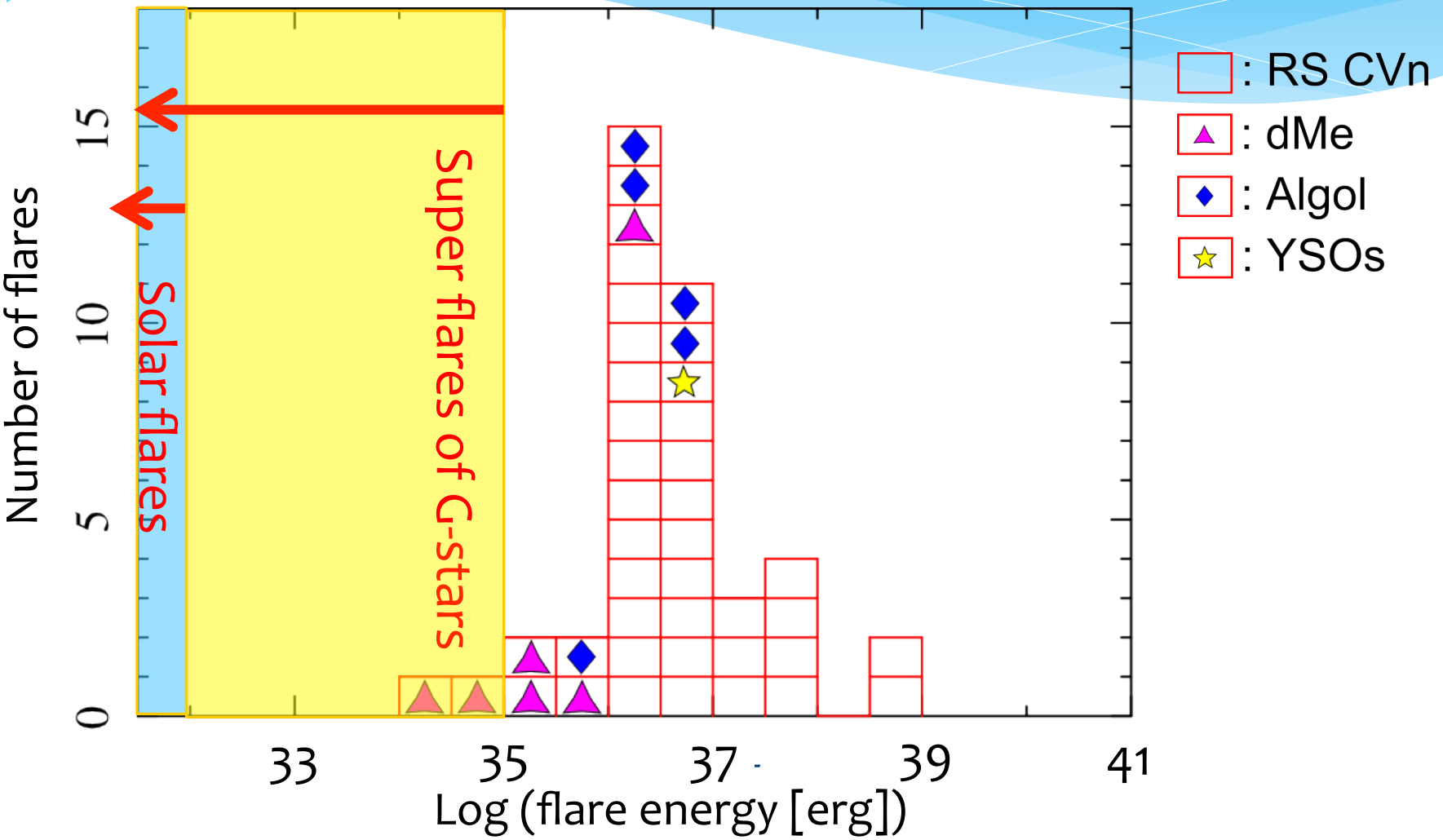
Tsuboi et al. (2014)



Luminosity distribution : MAXI detected large flares

⇒ Tsuboi-san's talk

64 large flares from 21 stars in 4 years.



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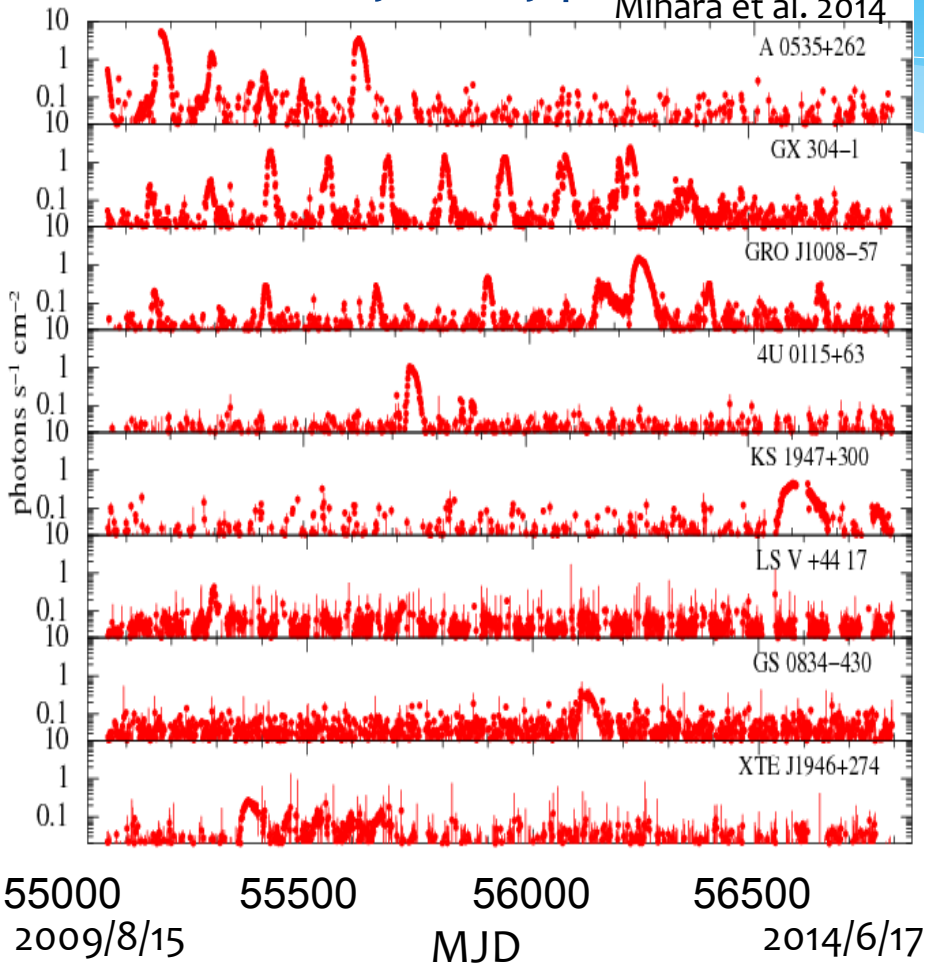
X-ray sources are variable

⇒ Nakajima-san's talk

⇒ Asai-san's talk

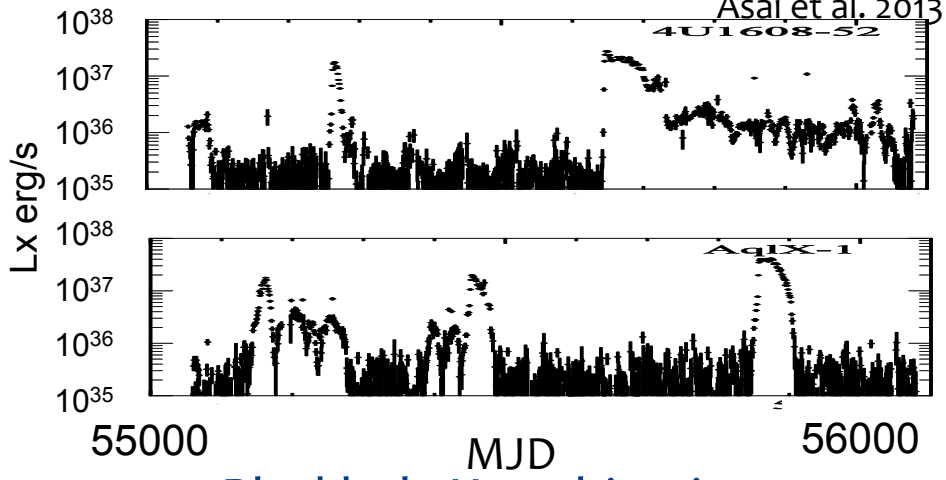
Be X-ray binary pulsars

Mihara et al. 2014

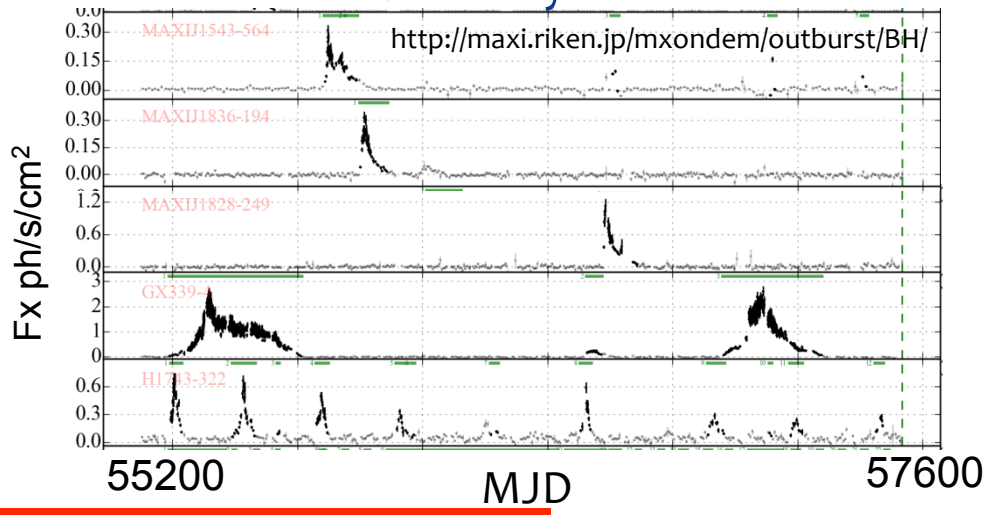


Neutron star Low-mass X-ray binaries

Asai et al. 2013



Blackhole X-ray binaries



We need to watch every day and every second.

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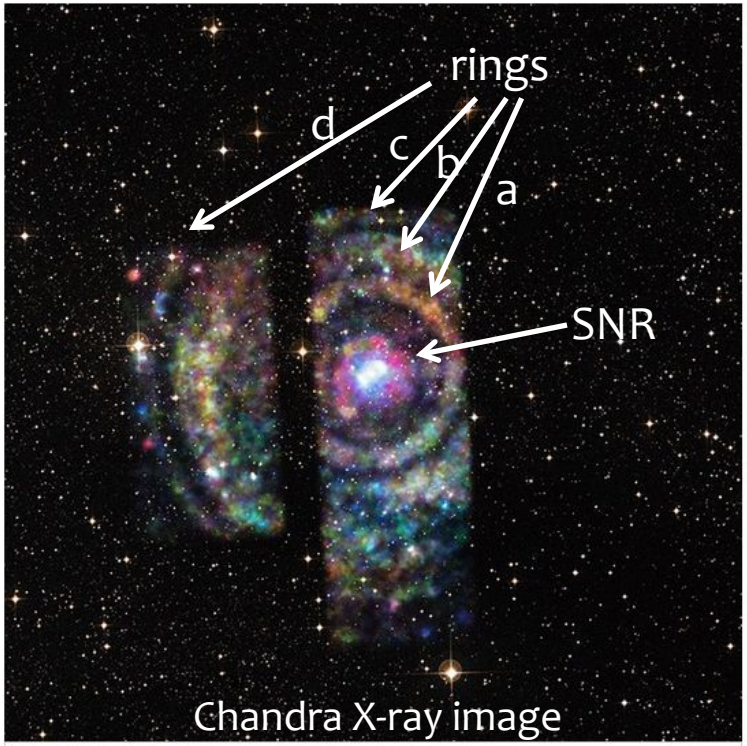
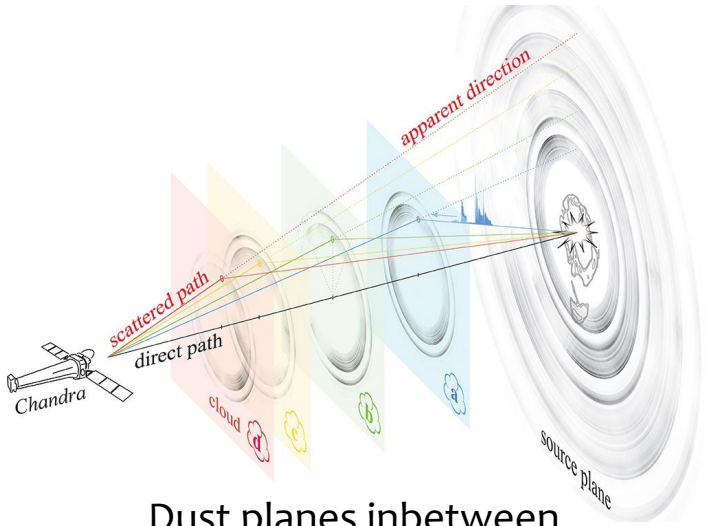
Cir X-1 dust echo



NASA's Chandra X-ray Observatory captured four rings of X-ray emissions, pointing to the precise location of a powerful neutron star at their center. The X-ray observations are overlaid on an optical view of the star, Circinus X-1, and its neighborhood.

Credit: NASA/CXC/U. Wisconsin/S. Heinz View full size image



Dust planes inbetween

LORD OF THE RINGS: A KIN

Heinz et al. 2015

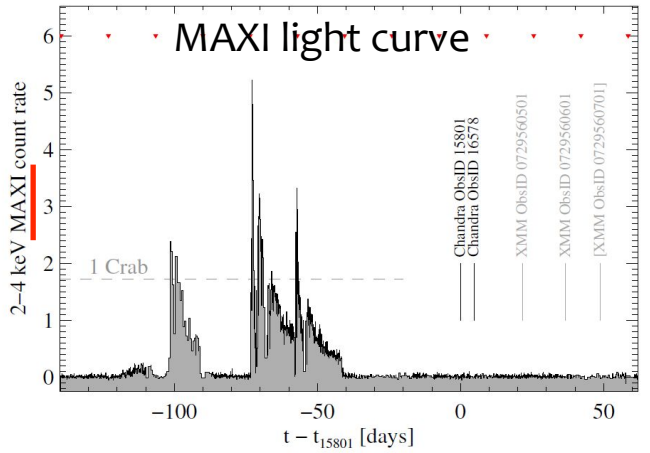


FIG. 3.— MAXI 2-4 keV lightcurve of Circinus X-1 at the time of the 2013 flare. Also shown are the median-times of our two *Chandra* and three *XMM* observations (*XMM* ObsID 0729560701 was not used in this paper). T_0 was chosen to correspond to the time of our first Chandra observation at (T_0 =MJD$_{15801}$=56683). Red diamond symbols indicate periastron at orbital phase zero

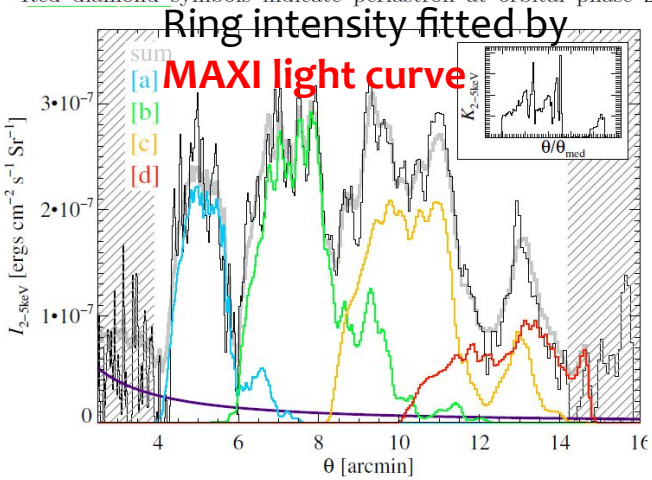


FIG. 10.— Radial X-ray intensity profile of *Chandra* ObsID 15801 in the 2-5keV band (chosen to roughly match the MAXI 2-4 keV

- A snap shot by Chandra contains sum of the activities in one-year.
- Historical light curve of MAXI was necessary to solve the echo rings.

Taken from space.com 2015 June 24.

http://www.space.com/29755-neutron-star-lord-of-rings-chandra.html

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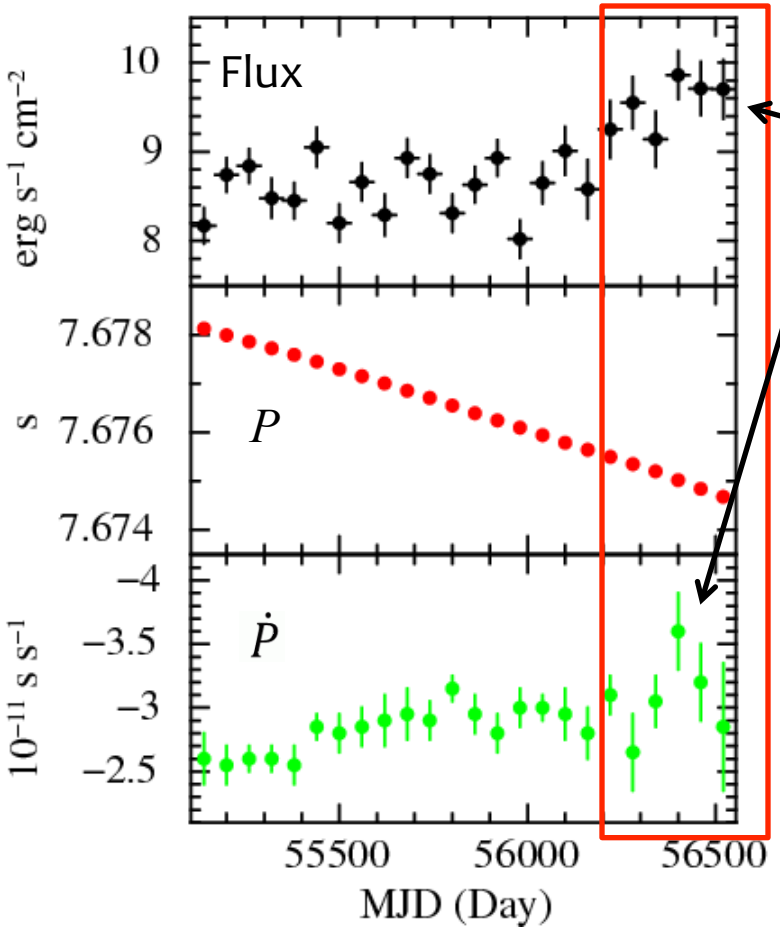
P and Pdot of 4U 1626-67

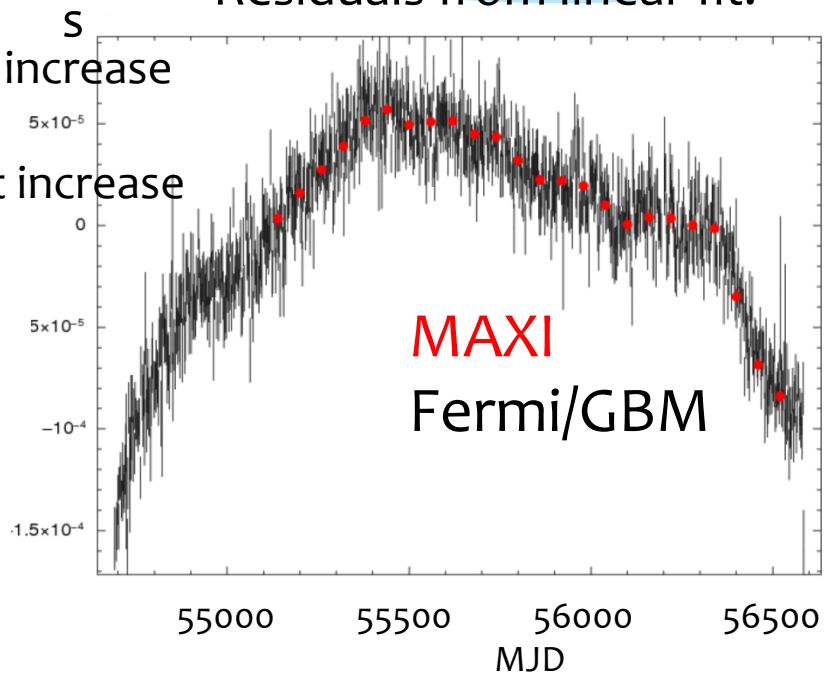
were monitored with MAXI in each 60-day.

Takagi + 2016



Flux increase and Pdot increase

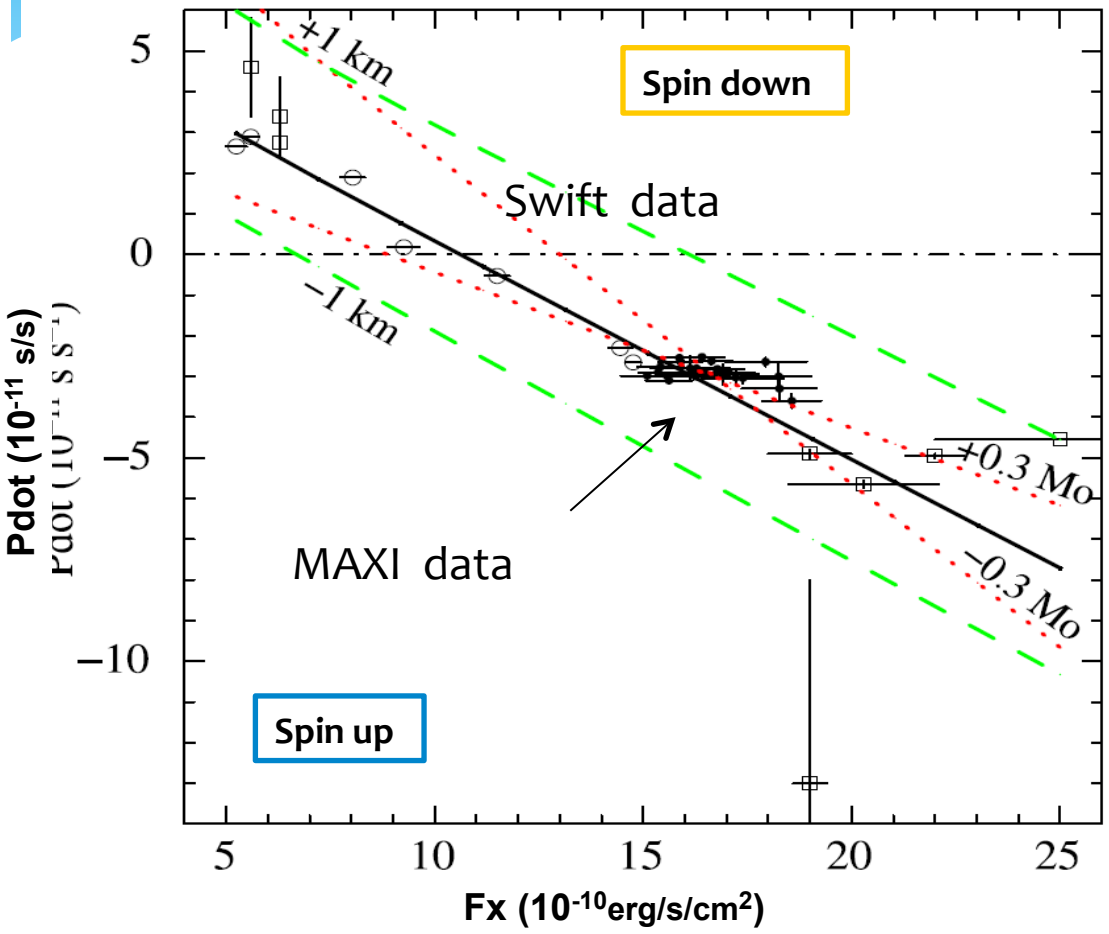
Residuals from linear fit.



MAXI and GBM results agree well.

Apply G&L eq. to MAXI and past data, obtain best-fit M and R.

Takagi + 2016



Best-fit model for D=10kpc
M = 1.74±0.05 Mo,
R = 13.5±0.1 km
Very accurate.

χ^2_ν=0.99

Flux error 5.5% is added.

Ghosh and Lamb (1979)

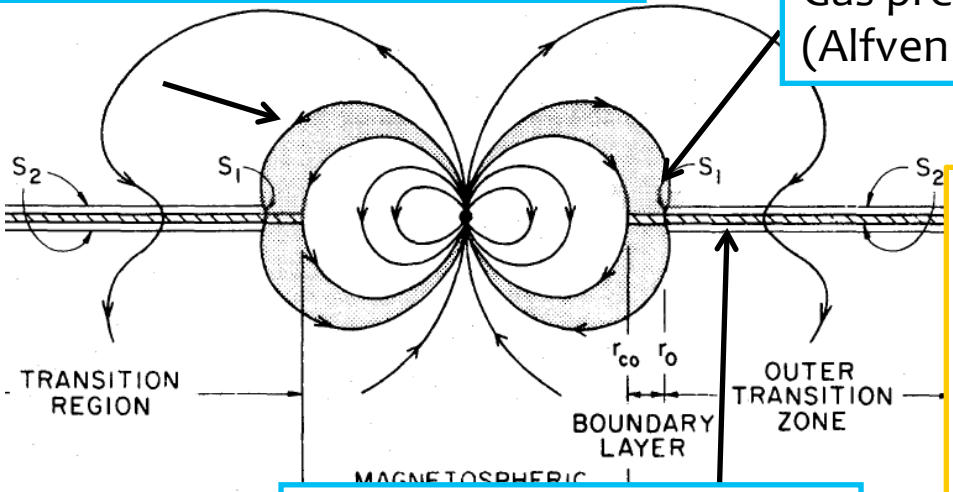
Relation between Pdot and Lx.
Parameters are μ, I ⇒ B, R, M

$$-\dot{P} = 5.0 \times 10^{-5} \mu_{30}^{\frac{2}{7}} n(\omega_S)\, S_1(M)\, P^2\, L_{37}^{\frac{6}{7}} \text{ s yr}^{-1}$$

$$n(\omega_S) \approx 1.39[1 - \omega_S\{4.03(1-\omega_S)^{0.173} - 0.878\}](1-\omega_S)^{-1}, \omega_S \approx 1.35\, \mu_{30}\, S_2(M)\, (PL_{37}^{\frac{3}{7}})^{-1}$$

Mag. Fields rotates rigidly with pulsar

Gas pressure = mag. pressure (Alfven radius)

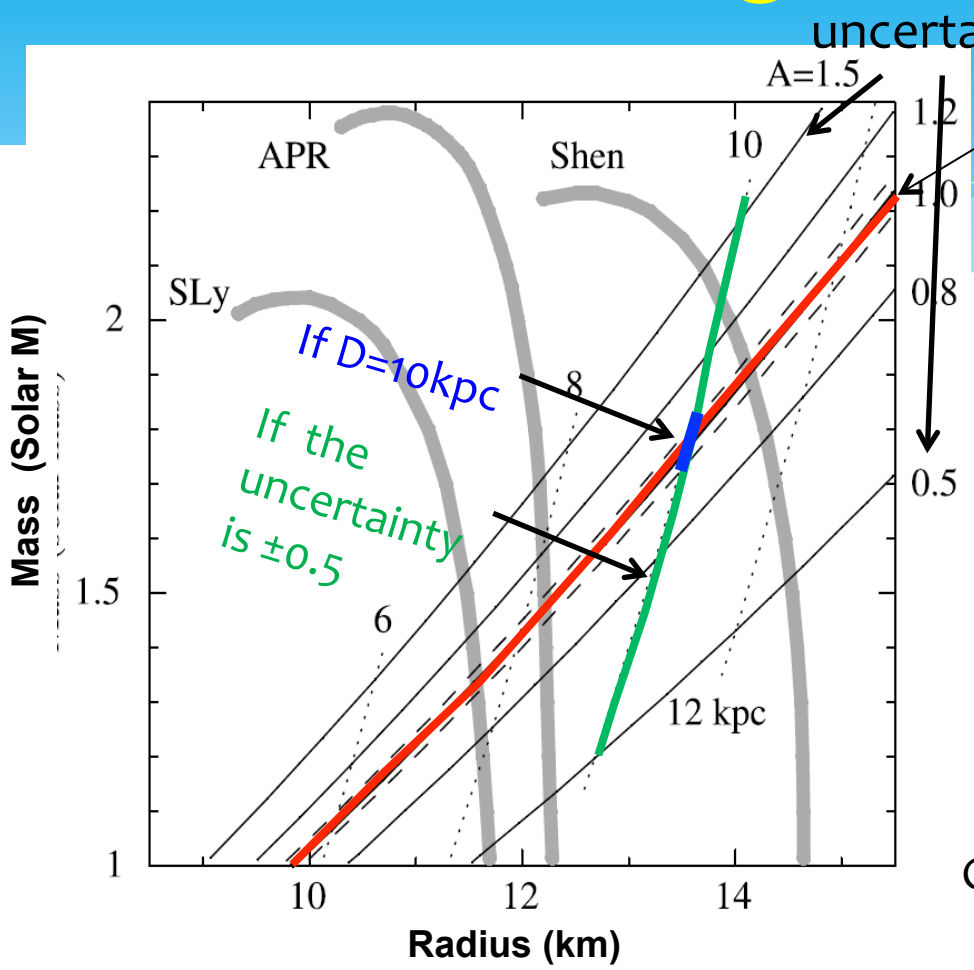


Gas transfers from Kepler rotation to rigid rotation at Alfven radius. The angular momentum is transferred from the gas to the pulsar.

Acc. Disk : Kepler rotation

Allowed M - R region of NS in 4U1626-67

⇒ Sugizaki-san's talk



Takagi + 2016

Uncertainty includes
- distance
- Uniformity of X-ray radiation
- Accuracy of GL equation

Lines by a factor of (1,±0.2, 1±0.5).

Gray lines are EoS of a NS (SLy, APR, Shen)

If the distance can be available by other method as GAIA, we can put limits on M and R.

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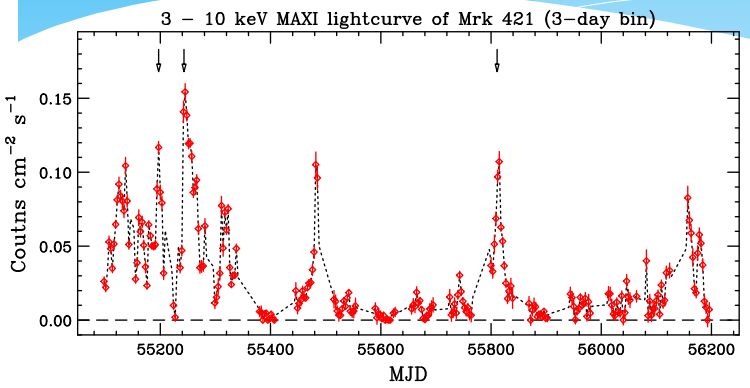
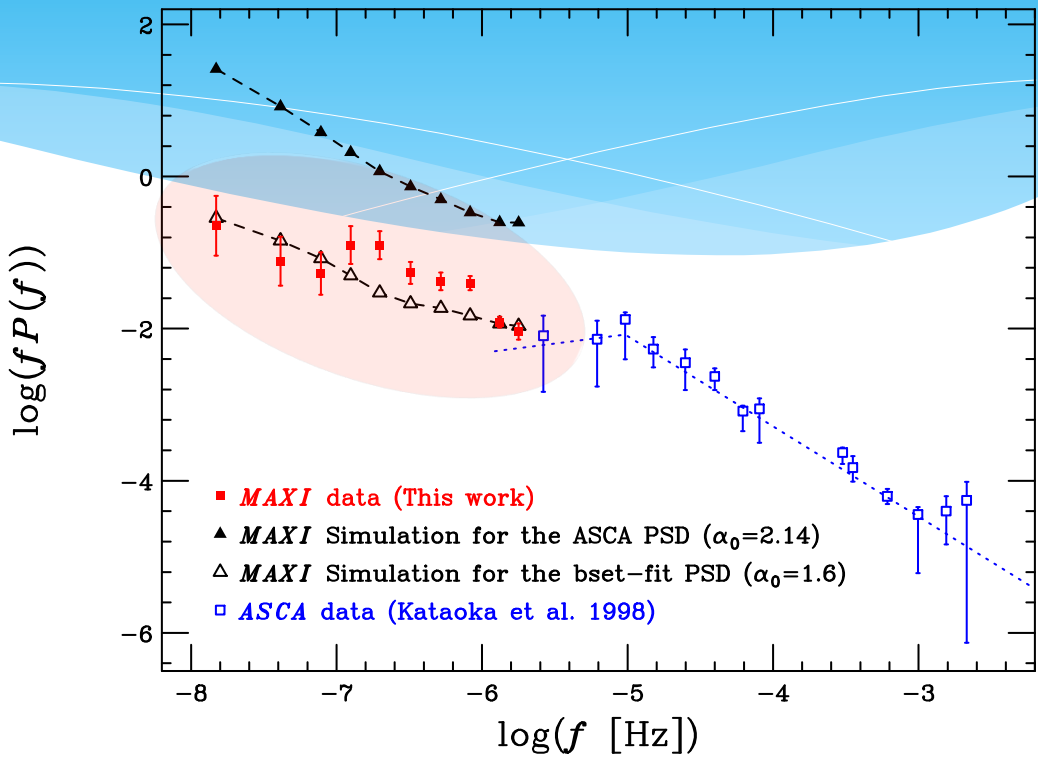
Long-term monitoring of AGN



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)

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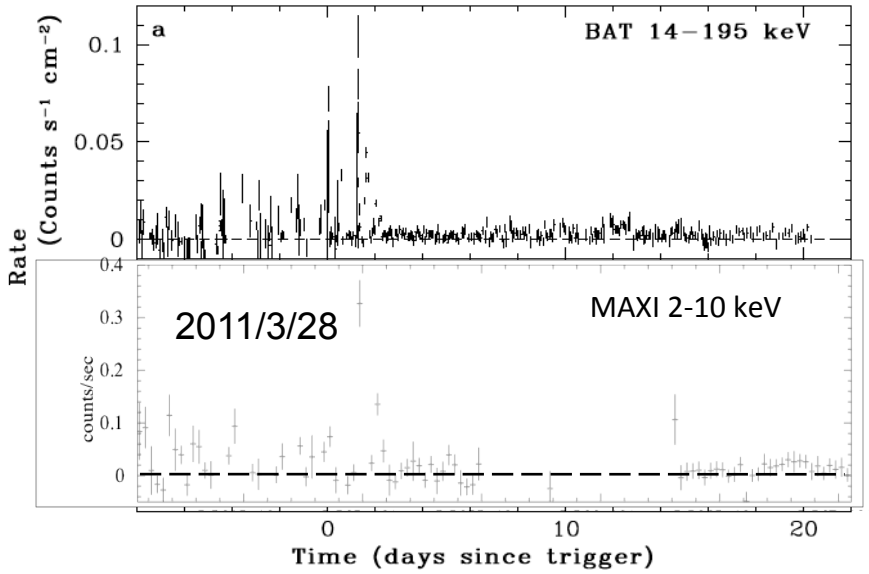
⇒ Kawamuro-san's talk

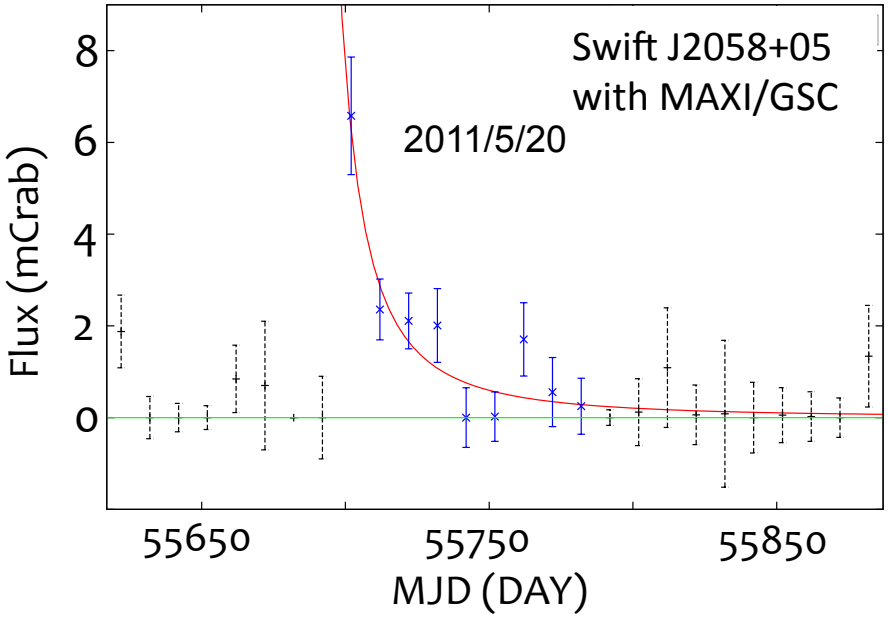
Tidal Disruption Event with MAXI

- 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.

Burrows et al. Nature 2011

Swift J1644+57 with Swift/BAT and MAXI/GSC





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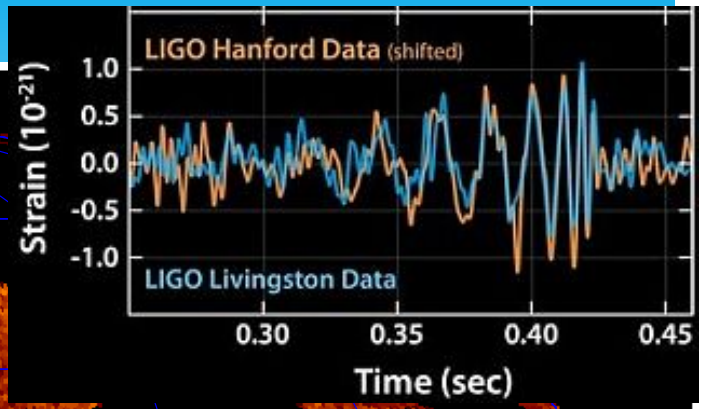
GW 150914

1 orbit (~92 min)

⇒ Kawai-san's talk



Abbott et al. 2016

Sun

Kawai et al. in prep.

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

3 σ upper limit (2-20 keV) : 0.1 c/s/cm^2 ~ 30 mCrab ~ 10^{-9} erg/s/cm^2 (Serino et al. 2015)

MAXI put upper limit in flux in just after the event, long before and after the event.

GW 151226 : upper limit (Serino in prep.)

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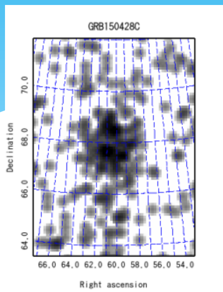
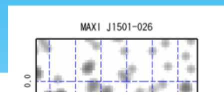
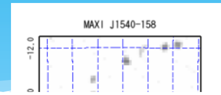
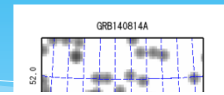
7 MUSST (MAXI UnID Short Soft Transient)

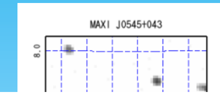
GRB 150428C	MAXI J1501-026	MAXI J1540-158	GRB 140814A	MAXI J0545+043	GRB 130407A	MAXI J1631-639
(l, b) = (139.1, +11.3)	(354.6, +46.8)	(351.6, +30.6)	(139.9, +66.4)	(201.1, -12.6)	(26.4, +35.6)	(324.4 -10.8)

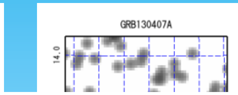


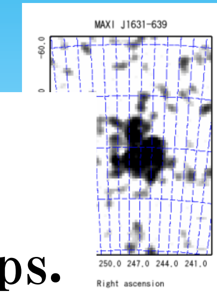






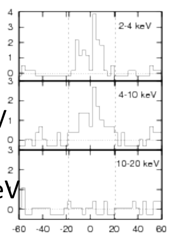


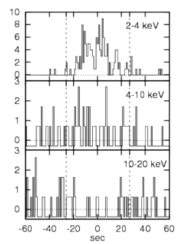




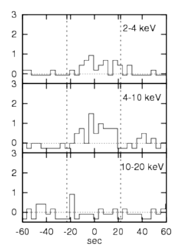
Soft: only detected in soft X-ray (**MAXI** 2-10 keV).
Short transient: Undetection in the next scan of MAXI.
Undetection in the Swift/XRT follow-ups.

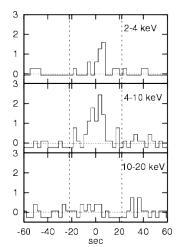
2-4 keV
2-4 keV
4-10 keV
10-20 keV

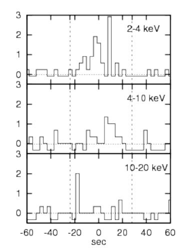


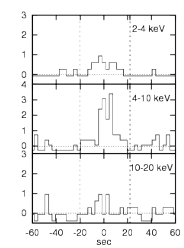


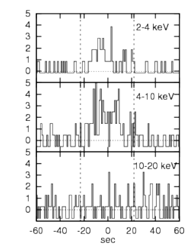
No flux in high energy band



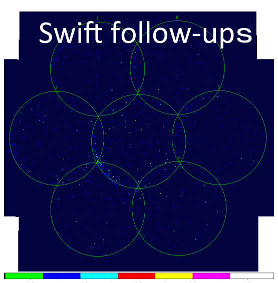


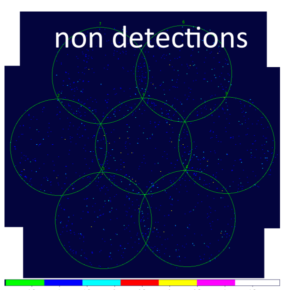


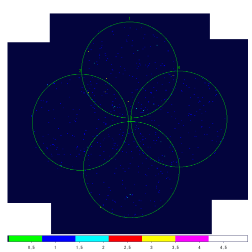
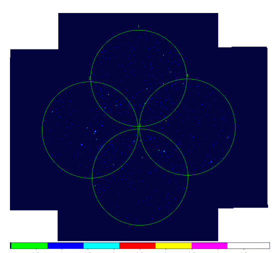
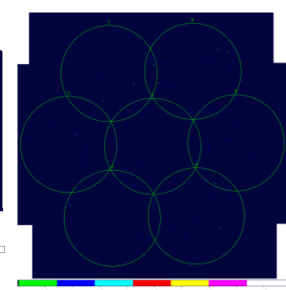
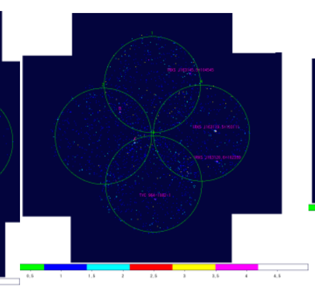
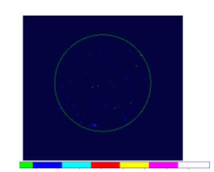




flux	0.16 Crab	0.44 Crab	0.1 Crab	0.23 Crab	0.2 Crab	0.17Crab	0.12 Crab
	2015-04-28	2015-08-26	2015-03-11	2014-08-14	2014-04-12	2013-04-07	2011-04-29
	GCN #17772	Atel #7954	GCN #17568	GCN #16686	ATel #6066	GCN #14359	ATel #3316





11' FOV

We put GRB name and reported to GCN. But they might not be GRBs in fact.
Higher performance of novasearch and 7-tiled follow-up of Swift/XRT increased the number of MUSST after 2014.

Scan profile is not corrected in light curves.

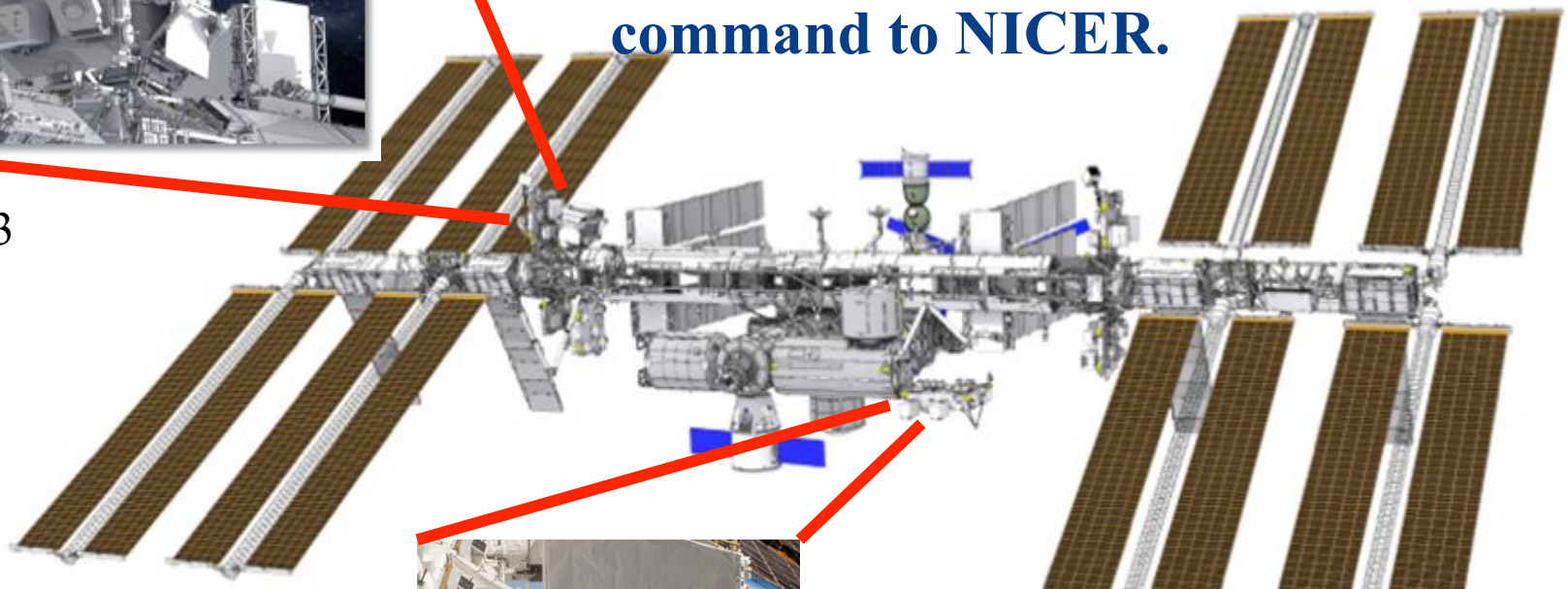
OHMAN (Onorbit Hookup of MAXI And NICER)

NICER: Launch in March 2017

Keith Gendreau (NASA/GSFC)

- **Prompt follow up**
- **Watch the transient in X-ray while still X-ray bright.**
- **Nova search on ISS and command to NICER.**

ISS ELC3



GSFC: MIDX MOO
Riken ISAS 小規模

MAXI: Already on orbit

Outline

1. MAXI instruments
2. Results
   1. All-sky map
   2. MAXI Catalog
   3. MAXI sources
   4. Massive Nova ignition
   5. Huge stellar flares
   6. Recurrent transients BeXRB、NS-LMXB
   7. Cir X-1 Dust echo
   8. Pulsar Lx P monitoring
   9. AGN monitoring
   10. Tidal disruption
   11. GW 150914
   12. MUSST
3. **MAXI future**

MAXI future

* MAXI is operated till 2018. 3. We will apply for a further operation.
* JAXA continues ISS program till 2024 (op-3).
* **Global cooperation with new instruments**
  * CALET: 2015 – simultaneous obs. of GRB
  * Advanced LIGO: 2015 – GW sources. O2 is going.
  * NICER: 2017 – pointing X-ray observation from ISS
* **Coordinated obs. of transients** (Japan, International)
  * New blackhole binaries : 1-2/yr
  * Low-mass X-ray binary : Super Bursts
  * Tidal disruption events
  * Giant stellar flares
  * Gamma-ray bursts
  * X-ray binary transients
- **Catalog (3rd), Low galactic (|b|<10°)**
  * More statistics → reaches confusion limit (~0.5 mCrab) ～1000 objects
  * With Light curves and variability index. (info. in time-dimension)
* **Permanent MAXI archive at ISAS** ⇒ Ebisawa-san's talk

Summary

- 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.

End