Rikkyo University
X-ray Astrophysics Laboratory

RIKEN's Programs for Junior Scientists

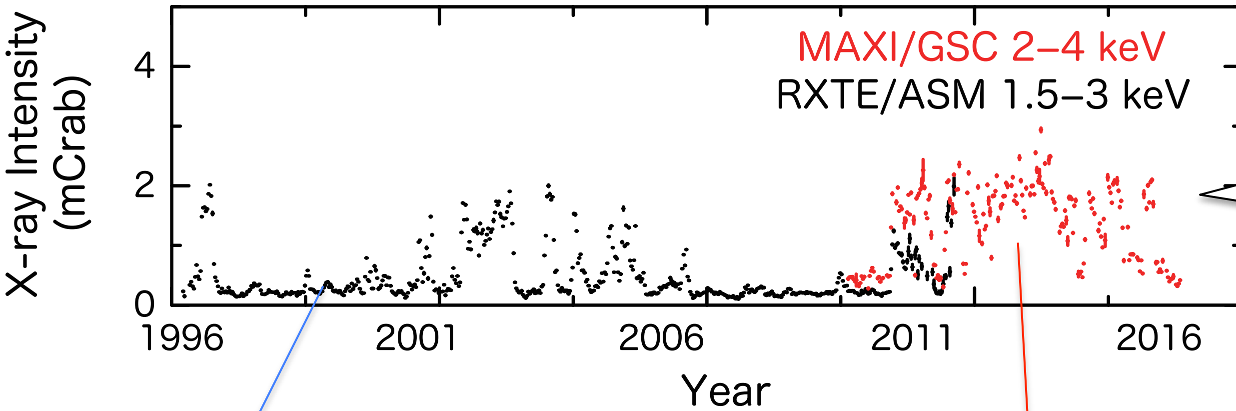
Observation of the long-term variability of Cygnus X-1 with MAXI

Juri Sugimoto (RIKEN/Rikkyo U.)
S.Kitamoto (Rikkyo U.), T.Mihara (RIKEN)
and the MAXI Team

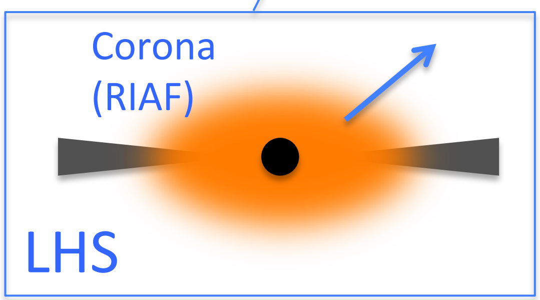
Sugimoto et al. (2016), PASJ. 68, S17

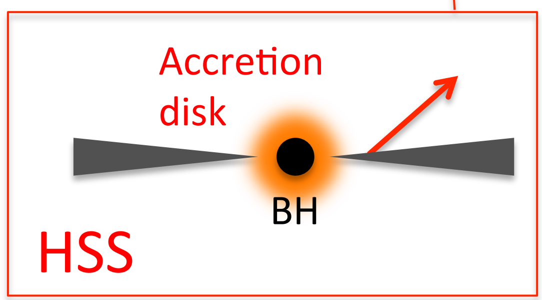
Long-term variability of the black hole binary Cygnus X-1

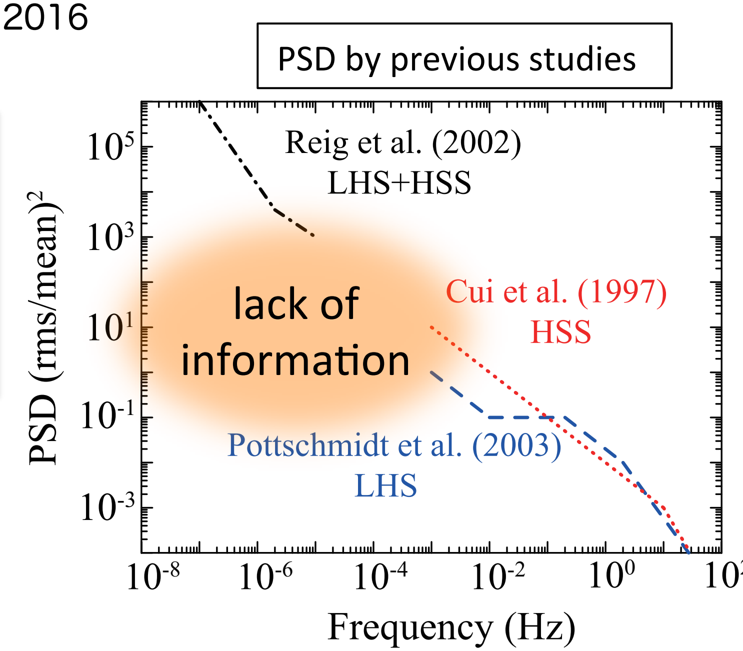
low/hard state (LHS) and high/soft state (HSS)



After the start of the MAXI observation, it stayed in the HSS for most of the time.





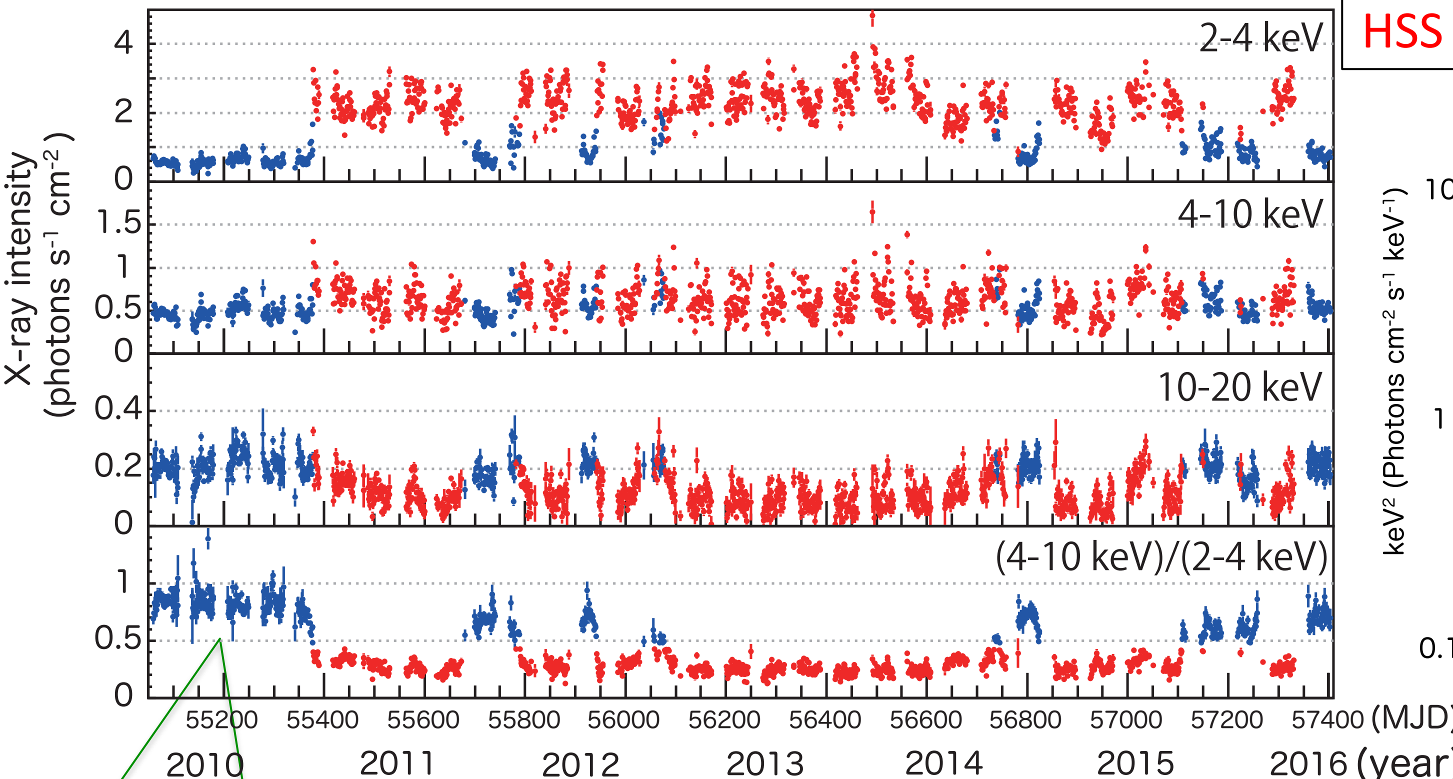


A study of the **long-term variability** is important for understanding the large-scale structure of the accretion disk and of the corona.

- What is the origin of the long-term variability?
- Is there a difference of the long-term variability between the LHS and the HSS?

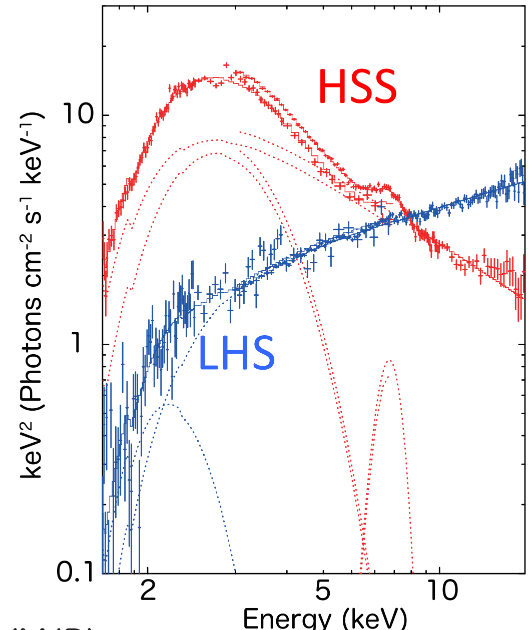
Observation by the MAXI/GSC from Aug 2009 to Jan 2016

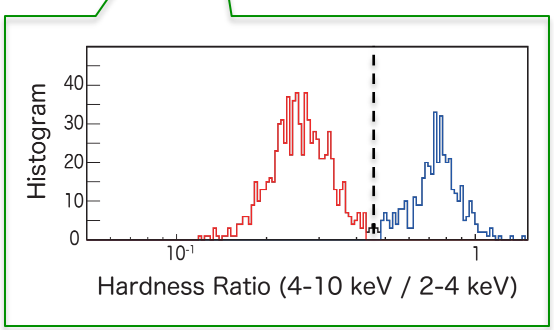
1-day bin light curve with MAXI/GSC



LHS
HSS

Energy spectra
with MAXI/GSC+SSC





The two spectral states can be distinguished by the hardness ratio.

- Cyg X-1 repeats the state transition between the LHS and the HSS.
- It stayed mostly in the HSS in the 6-years of MAXI observations.

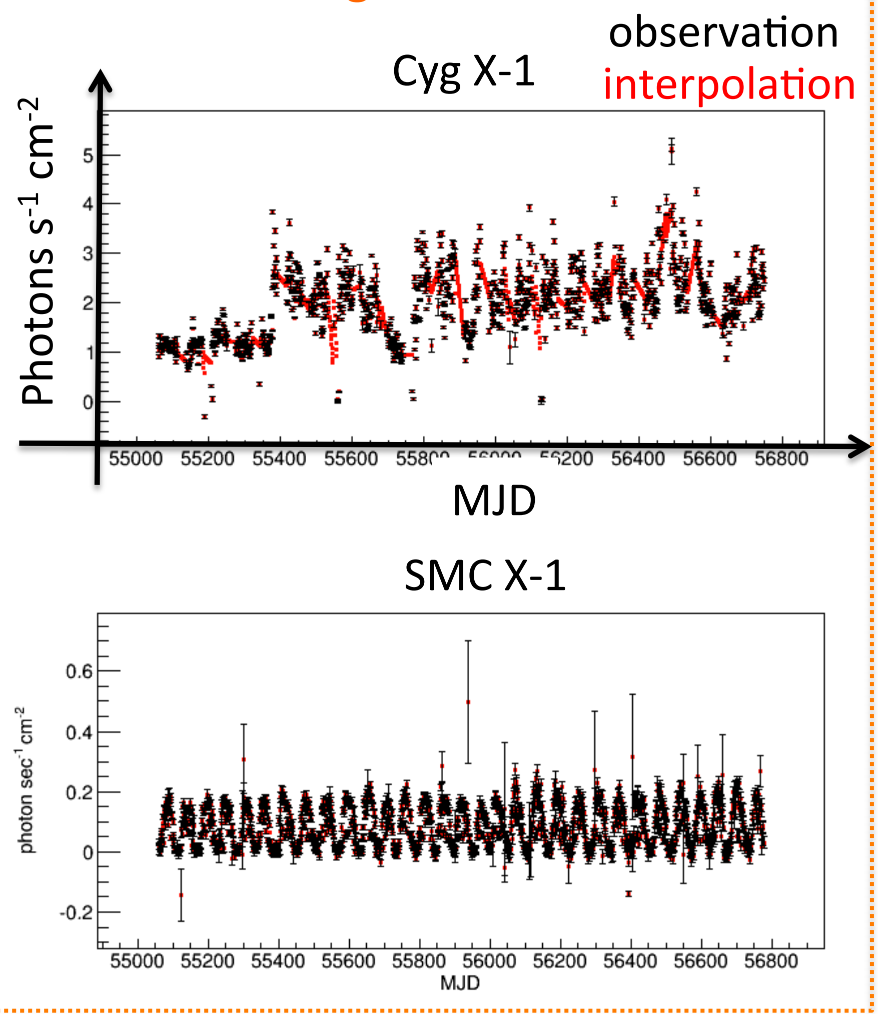
Analysis & Results

Treatment of the data gaps

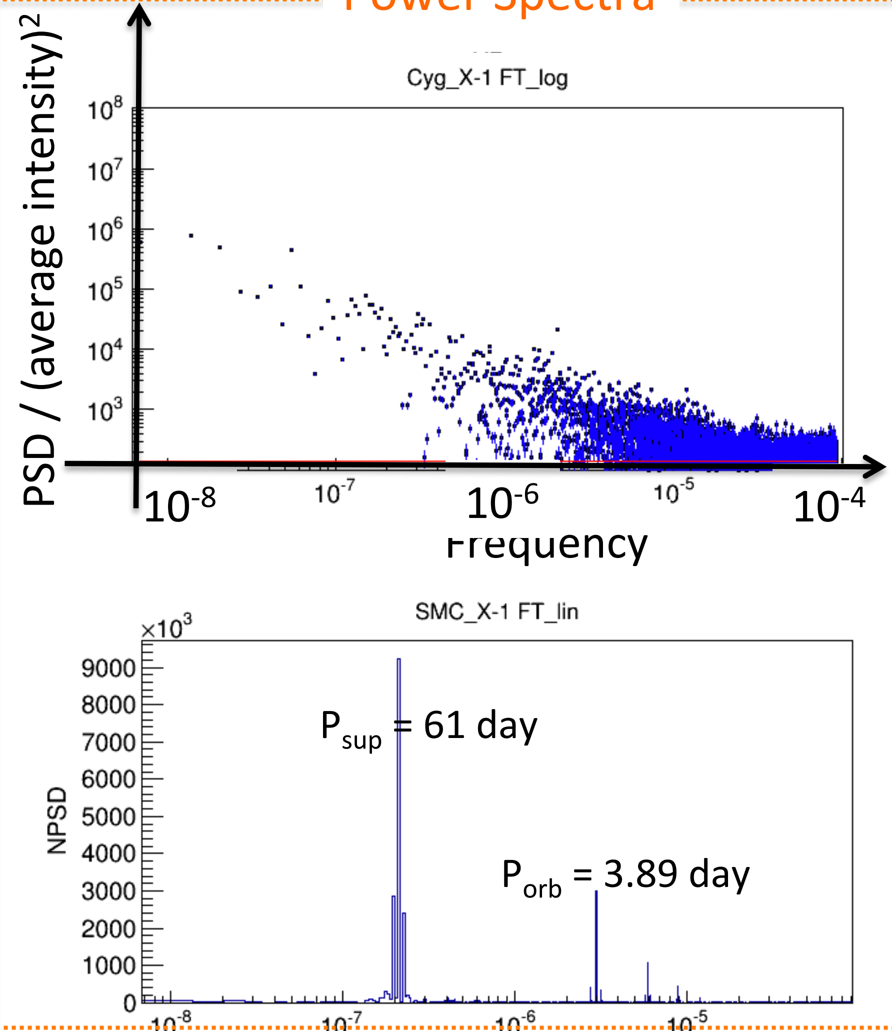
MAXI data includes data gaps
caused by sun avoidance, high particle background regions, etc.
→ We interpolated each gap with a linear function and calculated PSDs.

For example…

Light curves



Power Spectra



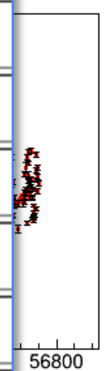
Treatment of the data gaps

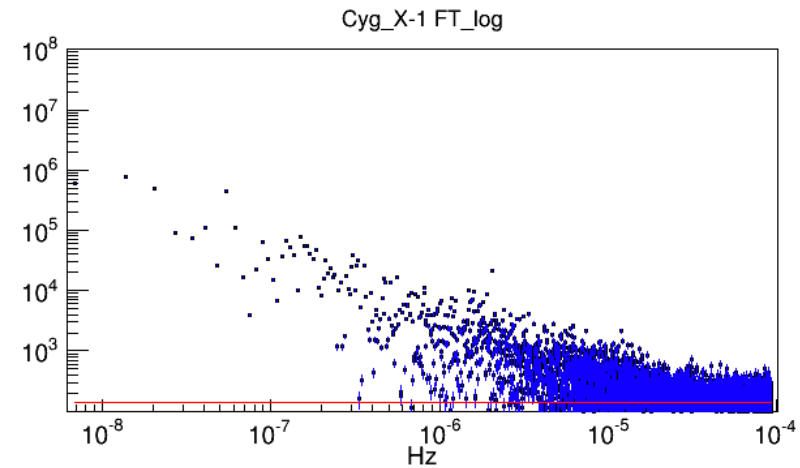
MAXI data includes data gaps

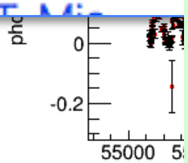
…high particle background regions, etc.

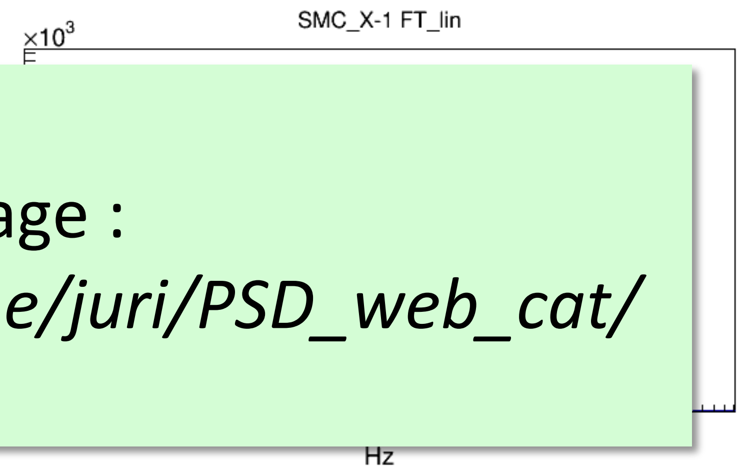
…ap with a linear line and calculated PSDs.

257	XTE J1946+274
258	KS 1947+300
259	4U 1954+319
260	Cyg X-1
261	4U 1957+115
262	Cyg A
263	1ES 1959+650
264	GS 2000+251
265	NGC 6860
266	Abell 3667
267	GS 2023+338
268	EXO 2030…
269	Cyg X-3









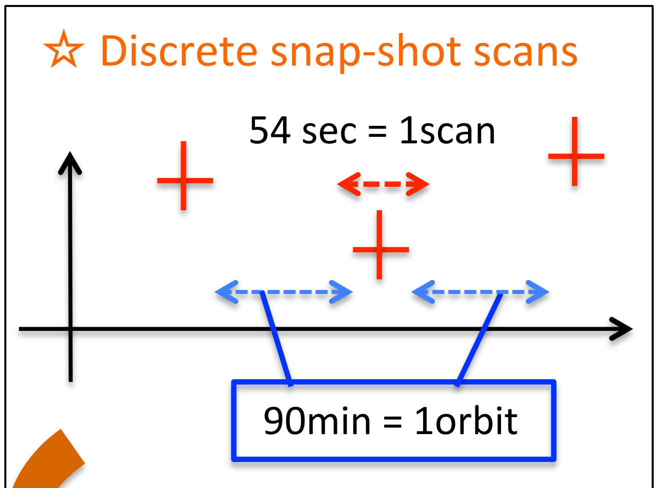
MAXI Power spectrum page :

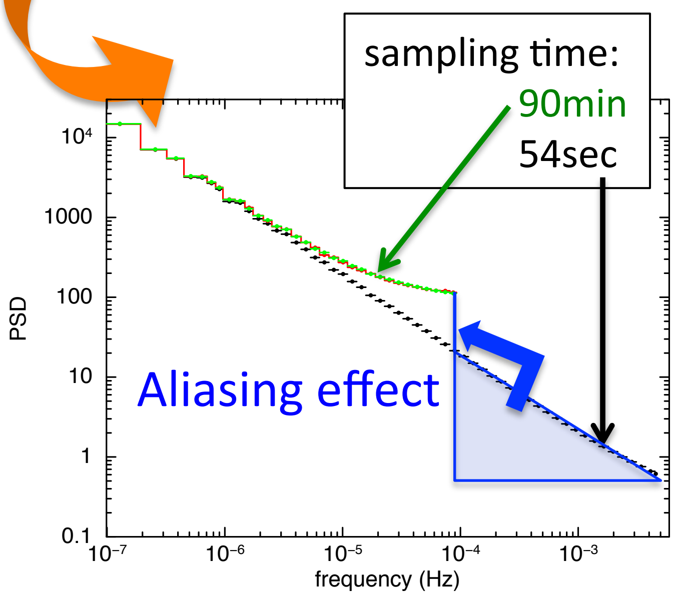
http://maxi.riken.jp/home/juri/PSD_web_cat/

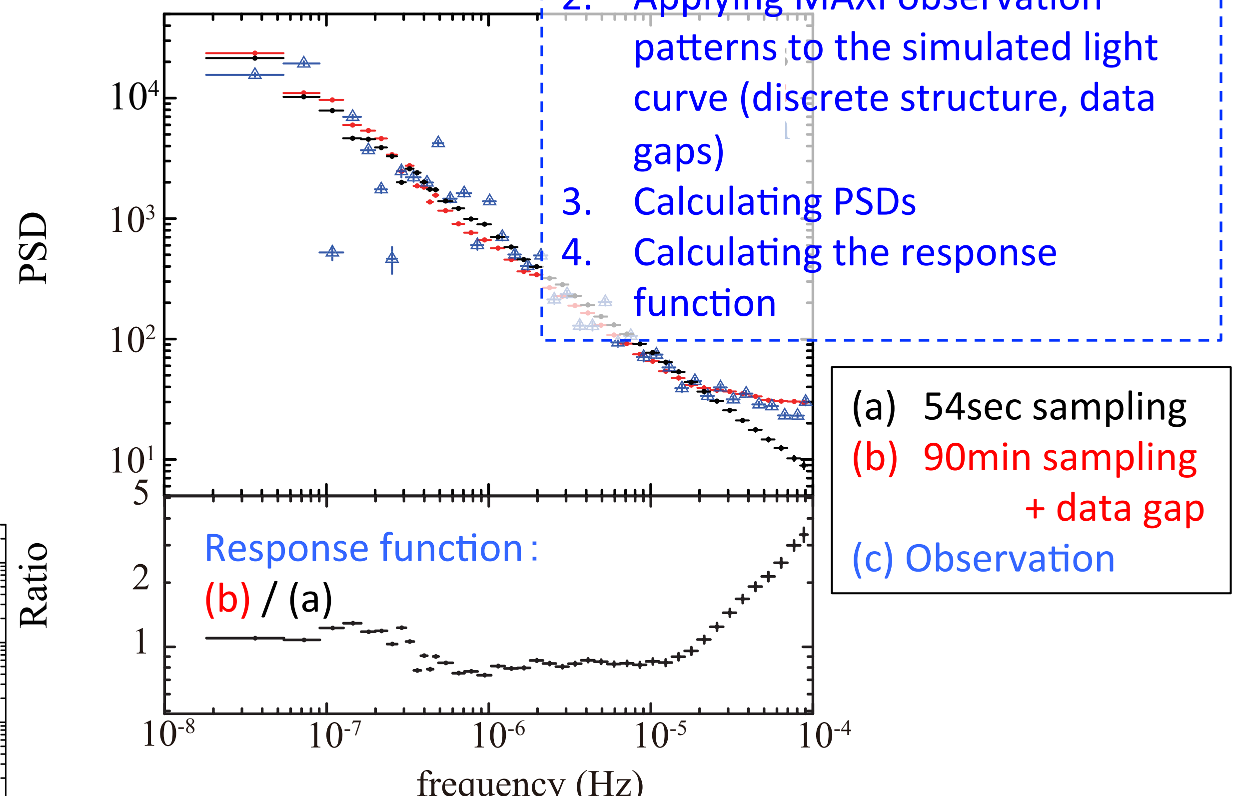
How to correct a PSD with MAXI data

The MAXI light curve consists of discrete snap-shot scans,
because MAXI scans an X-ray source only for 40 ~ 70 s, every 90min-period.

1. Making simulated light curves (54sec sampling, PSD∝f^{-1})
2. Applying MAXI observation patterns to the simulated light curve (discrete structure, data gaps)
3. Calculating PSDs
4. Calculating the response function





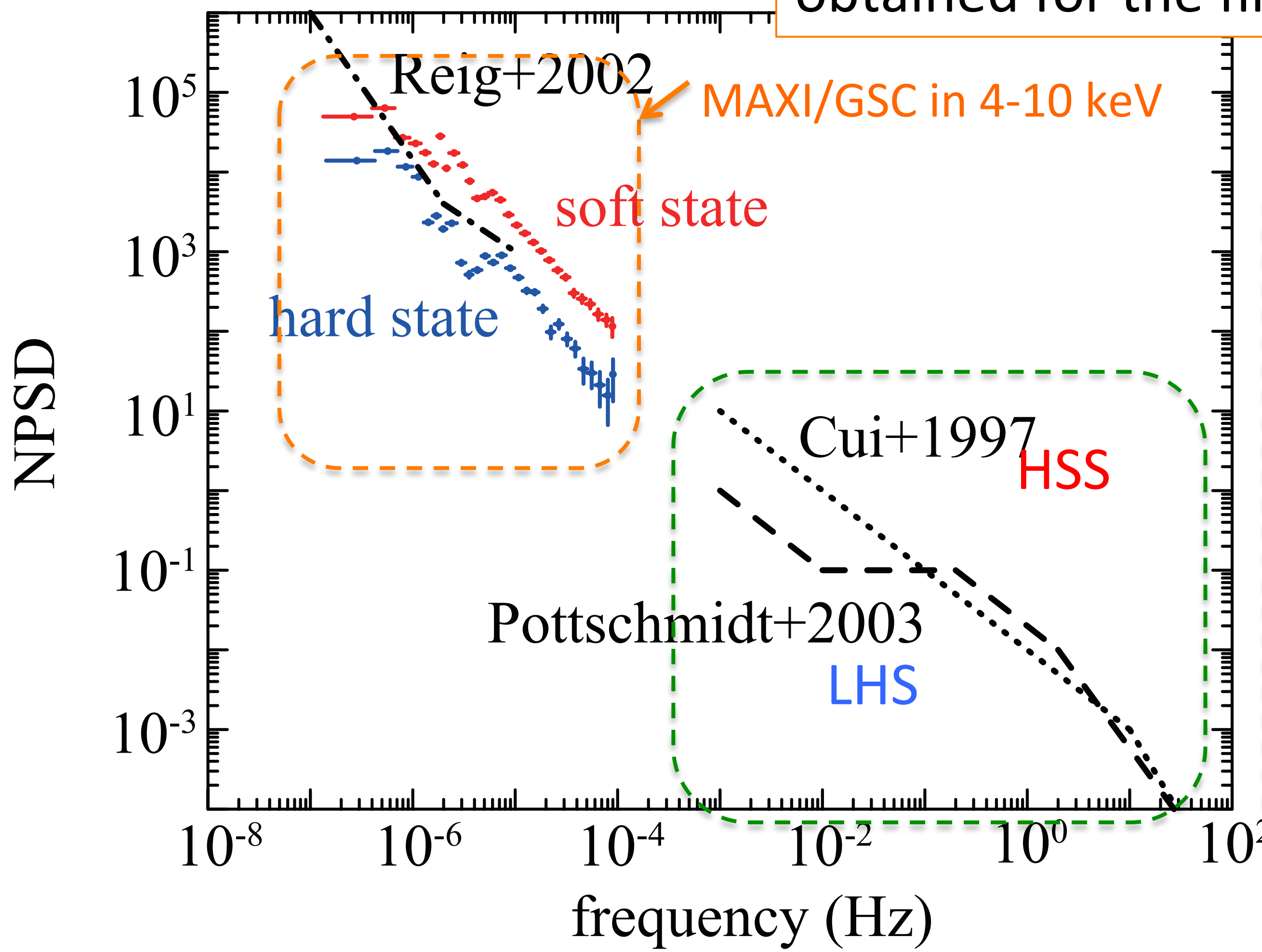


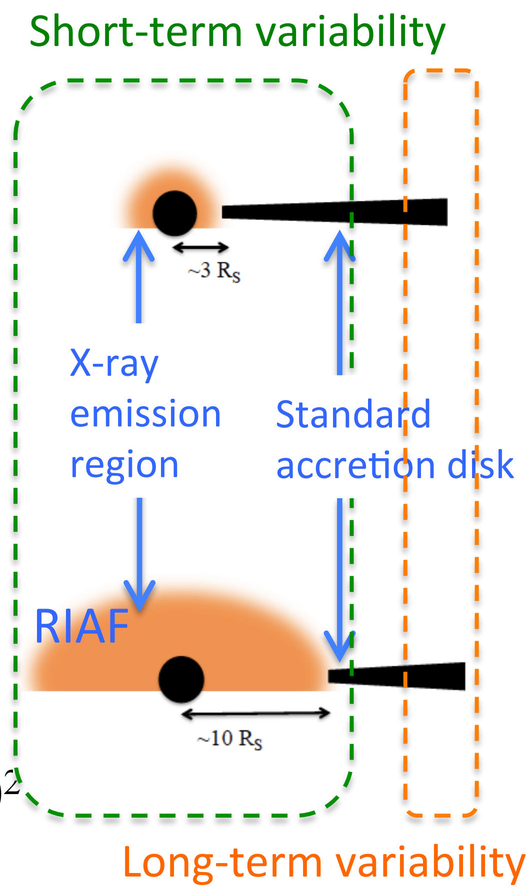
We corrected the sampling and gap effects in the MAXI observation by dividing the PSD calculated from the real data by the response function.

Results: Long-term Power Spectrum Density

NPSD = PSD/(average intensity)^2

The long-term NPSD in the HSS was obtained for the first time !

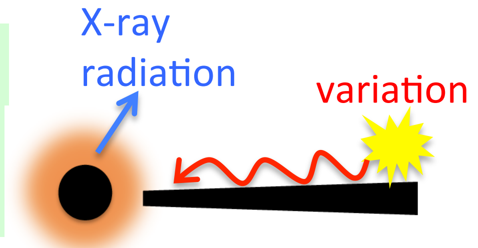




In both states, NPSDs down to 10^{-7} Hz follow **a power law**
and are approximately expressed as **an extrapolation of the NPSD above 0.01 Hz**.

Discussion

We assumed that the long-term variation (10^{-7} Hz) is produced at a large radius and propagates inwards, and that most of the X-rays are radiated from the vicinity of the BH.



→ **How can the long-term variation propagates to the vicinity of the BH?**

Time scales of the variation newly produced in the accretion disk

- Dynamical time scale: $t_d \sim \dfrac{1}{\Omega_K}$
- Thermal time scale: $t_{th} \sim \dfrac{1}{\alpha\Omega_K}$

Time scale for the accretion

Viscous time scale : $t_v = \dfrac{1}{\alpha\Omega_K}\left(\dfrac{H}{R}\right)^{-2}$

H : disk half thickness R : disk radius
α : viscous parameter Ω_K : Keplerian angular velocity

- In an optically-thick and geometrically-thin standard disk :

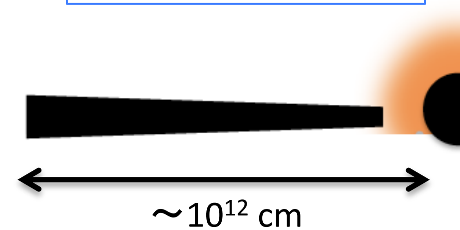
$$H << R,\ \alpha \sim 0.01 \quad \rightarrow \quad t_d < t_{th} < t_{vis}$$

Variations produced at any outer radii would be strongly dissipated and not propagate down to the X-ray emitting region.

Previous picture

- In an optically-thin and geometrically-thick flow (RIAF) :

$$H \sim R,\ \alpha \sim 0.01 \quad \rightarrow \quad t_d < t_{th} \sim t_{vis}$$



The fluctuations can propagate inwards, and cause the X-ray intensity to vary on a wide range of time scales.

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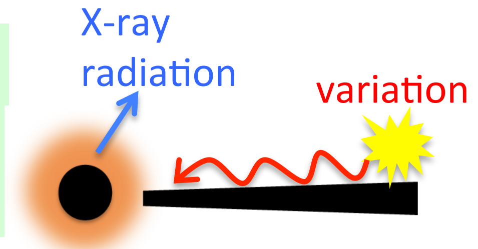

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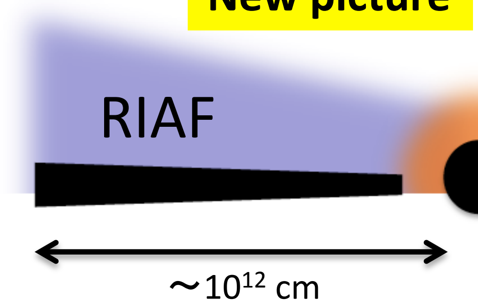
New picture

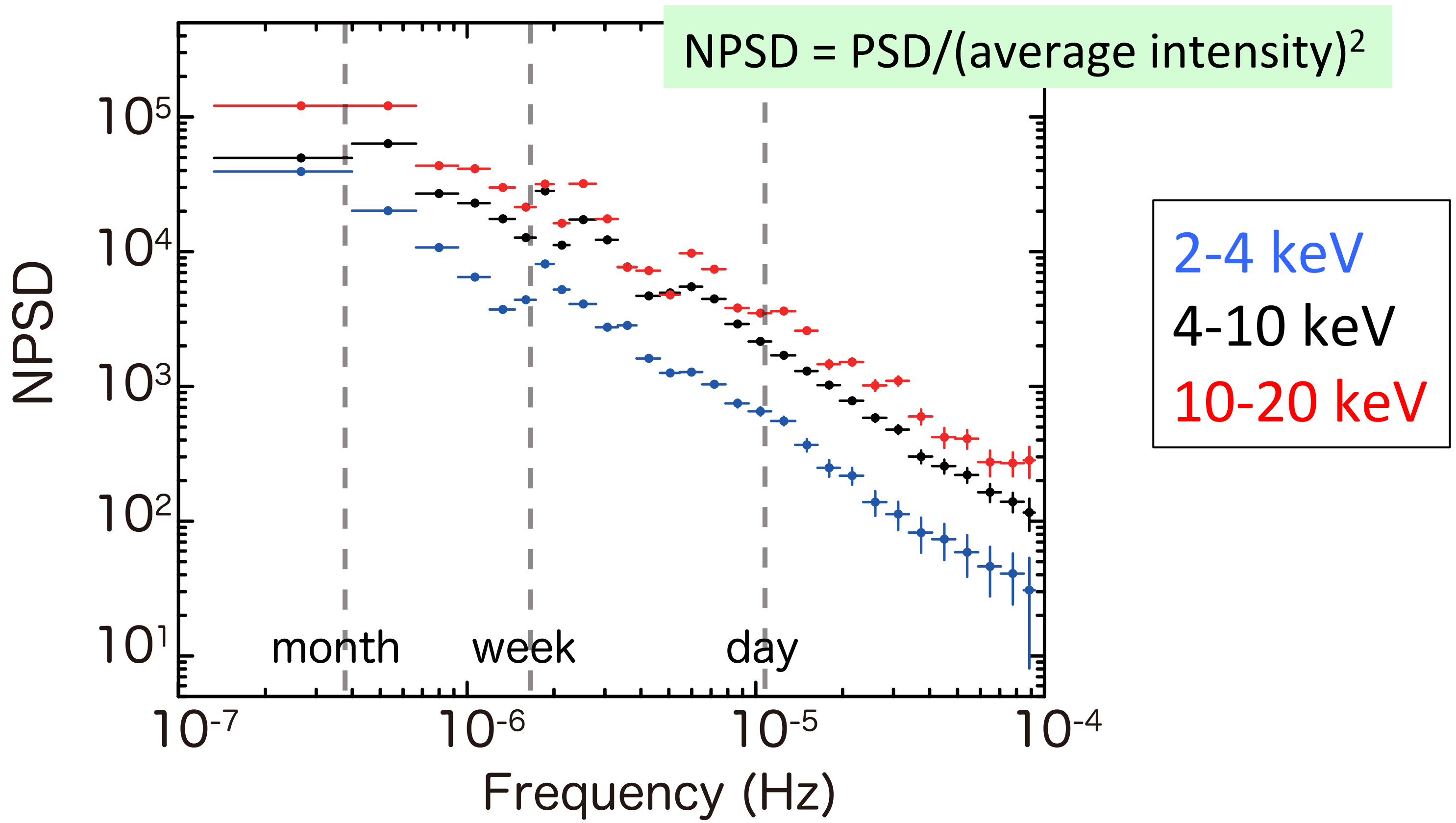


- In an optically-thin and geometrically-thick flow (RIAF) :

$$H \sim R, \alpha \sim 0.01 \quad \rightarrow \quad t_d < t_{th} \sim t_{vis}$$

The fluctuations can propagate inwards, and cause the X-ray intensity to vary on a wide range of time scales.

Result 2: Energy dependence of the long-term NPSD in the high/soft state



- The normalizations are significantly energy dependent.

  2-4 keV (disk component) < 4-10 keV, 10-20 keV (power law component)

The power law component is responsible for the observed long-term intensity variations, while the disk emission is essentially constant.

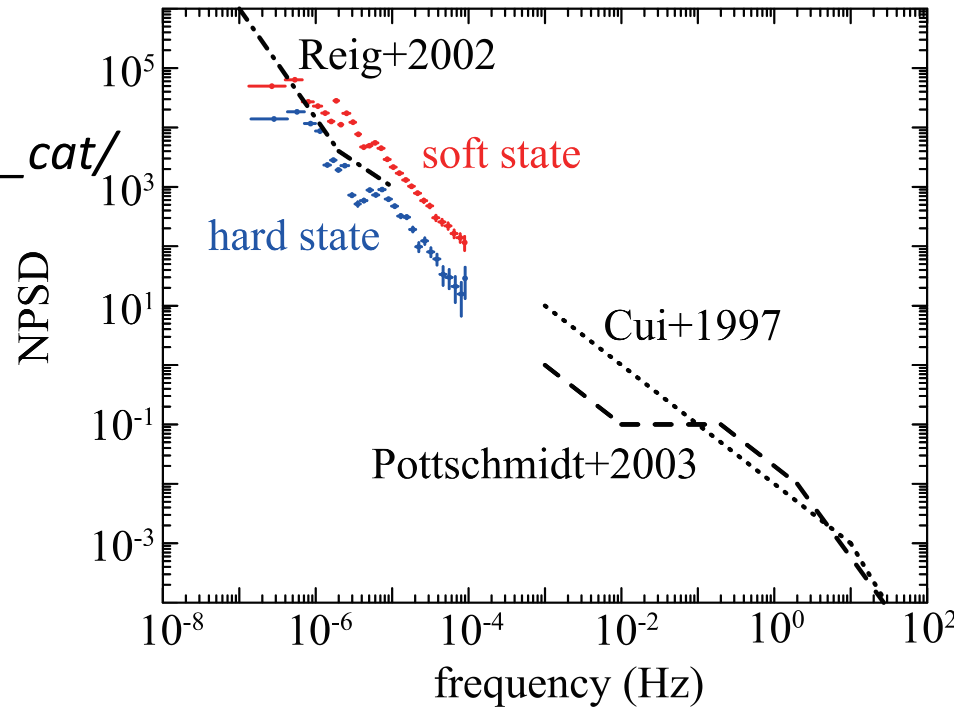
It may provide keys for understanding the origin of the hard component .

Summary

We studied characteristics of the long-term X-ray variation of Cyg X-1 over the frequency range of 10^{-7} – 10^{-4} Hz with 6 years of MAXI data.

☆**NPSD analysis** （Sugimoto et al. (2016), published in PASJ.）

- PSD page
http://maxi.riken.jp/home/juri/PSD_web_cat/
- The long-term NPSD in the HSS was obtained for the first time.
- In both states, our results (< 10^{-4} Hz) connect to the NPSDs above 10^{-3} Hz.
- In the HSS, the disk component is stable while the hard tail varies.



The long-term variation produced at large radii can propagate to the vicinity of the BH through the optically-thin flow (RIAF) extending to 10^{12} cm.