

The Evaluation of the relation between Quasi-Periodic Oscillation and mass of the black hole candidates

(ブラックホール候補天体における
準周期的振動-質量の関係性の評価)

Naoki Kita

May 9, 2018 @Ando Lab

About this talk

- I talk about my graduation thesis in Tokyo University of Science.
- I explain the overall view of my theme and don't mention everything.
- The theme is “QPO (Quasi-Periodic Oscillation)”, which is seen in compact objects.

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1. Introduction

- Matsushita Lab

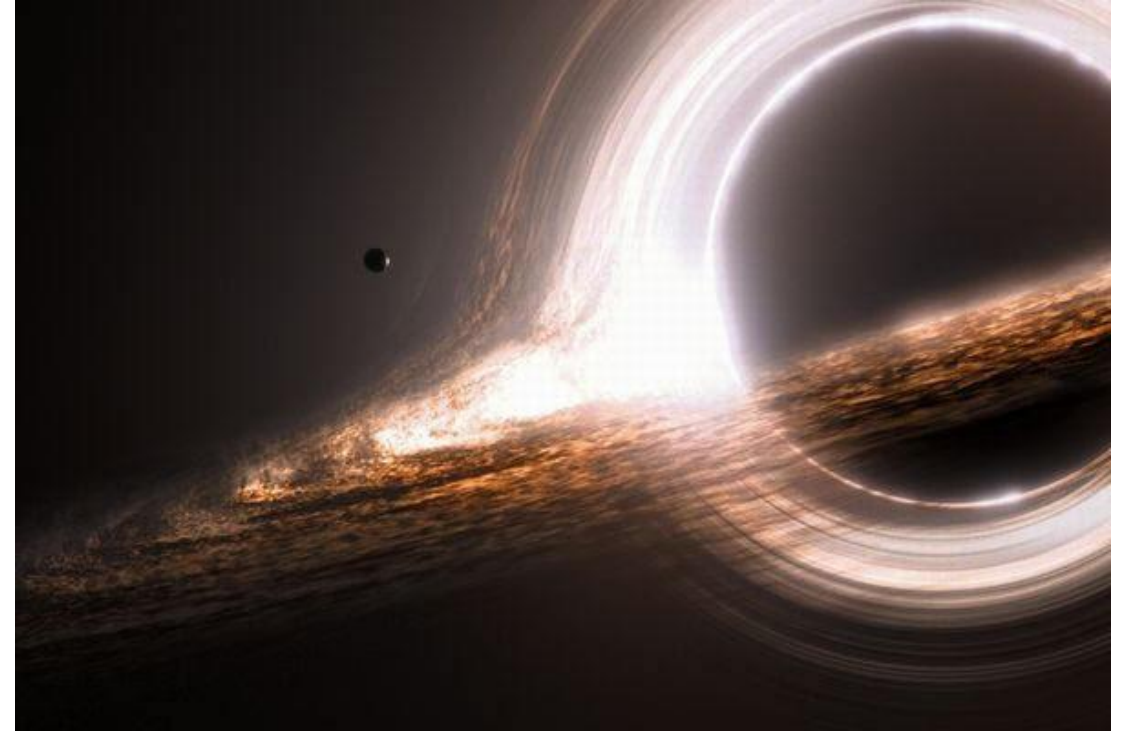
2. Principles

- QPO(Quasi-Periodic Oscillation)

3. Analysis

- Power Spectrum

4. Conclusion



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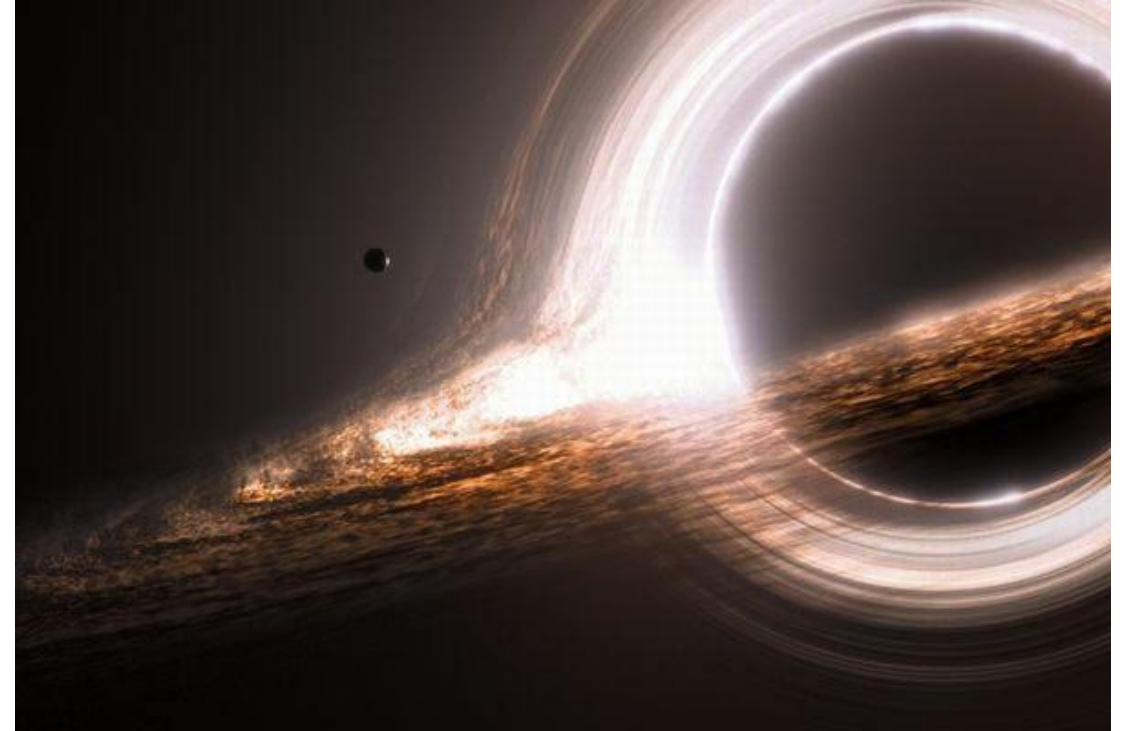
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Introduction

~My life~
I was born



Skip !

18 years old



5 years old



2014 Enroll in the Tokyo University of Science
2018 Graduate from the Tokyo University of Science
Enrole in the University of Tokyo

22 years old



Matsushita Lab

- X-ray Astronomy Lab



Why X-ray?

⇒ There are many kinds of electromagnetic waves.

Especially X-ray and γ -ray are suitable for **high-energy objects**.

How to research?

⇒ Analysis the data from the X-ray observatories.

What main target?

⇒ Galaxy, Cluster of Garaxies, **Black Hole**, AGN, NS and so on...

How to get data

The screenshot shows the NASA's HEASARC website. At the top is the NASA logo and the text "National Aeronautics and Space Administration, Goddard Space Flight Center, Sciences and Exploration". A search bar with "GO" and "Search HEASARC website" is present, along with a link to "[Advanced Search]". Below this is a "HEASARC Quick Links" dropdown menu. A navigation bar contains links: "HEASARC Home", "Observatories", "Archive", "Calibration", "Software", "Tools", and "Students/Teachers/Public". The main banner features the text "NASA's HEASARC High Energy Astrophysics Science Archive Research Center" and a background image of a satellite. Below the banner is another navigation bar with links: "About the HEASARC", "Resources for Scientists", "Feedback, FAQ & Help Desk", "Site Map", and "Other Archives". The main content area is divided into several sections. On the left, "Active Guest Observer Facilities/Science Centers" lists AGILE (AstroSat), Chandra (Fermi), Hitomi (INTEGRAL), MAXI (NICER), NuSTAR (SRG/eROSITA), Swift (TESS), and XARM (XMM-Newton). Below this is "Historic Guest Observer Facilities/Science Centers" listing ASCA (BeppoSAX), CGRO (COBE), EUVE (GALEX), HETE-2 (LPF DRS), ROSAT (RXTE), and Suzaku (WMAP). The central text block describes HEASARC as the primary archive for NASA's high-energy astronomy missions and mentions its merger with the Legacy Archive for Microwave Background Data Analysis (LAMBDA) in 2008. It also states that HEASARC is a member of the NASA Astronomical Virtual Observatories (NAVO). To the right, the "Latest News" section includes two items: "SkyView V3.3.4: GLEAM Survey and new features" (dated 02 May 2018) and "RXTE has Re-entered!" (dated 01 May 2018). At the bottom, there are two image galleries: "HEASARC Picture of the Week" showing a satellite and "APOD: Astronomy Picture of the Day" showing a galaxy.

NASA's HEASARC High Energy Astrophysics Science Archive Research Center

Active Guest Observer Facilities/Science Centers

AGILE	AstroSat
Chandra	Fermi
Hitomi	INTEGRAL
MAXI	NICER
NuSTAR	SRG/eROSITA
Swift	TESS
XARM	XMM-Newton

Historic Guest Observer Facilities/Science Centers

ASCA	BeppoSAX
CGRO	COBE
EUVE	GALEX
HETE-2	LPF DRS
ROSAT	RXTE
Suzaku	WMAP

HEASARC Picture of the Week

APOD: Astronomy Picture of the Day

Latest News

- [SkyView V3.3.4: GLEAM Survey and new features](#) (02 May 2018)
SkyView V3.3.4 has just been released. The new version includes a set of maps from the GaLactic and Extragalactic All-sky MWA Survey (GLEAM). The GLEAM survey was taken at the Murchison Widefield Array (MWA) and covers most of the sky ... [Continue reading →](#)
- [RXTE has Re-entered!](#) (01 May 2018)
NASA's Rossi X-ray Timing Explorer (RXTE), launched on December 30, 1995, operated for more than 16 years observing the fast-moving, high-energy worlds of black holes, neutron stars and X-ray pulsars before it was decommissioned on January 5, 2012. Yesterday (April 30) at 10:45 am EDT, RXTE re-entered the earth's atmosphere (probably in the ocean north of Venezuela) and was destroyed, bringing to an end a [remarkably productive career](#).
- [Catalog of All-Sky Automatic](#)

1. Retrieval object name
2. Choose observatory
3. Choose date

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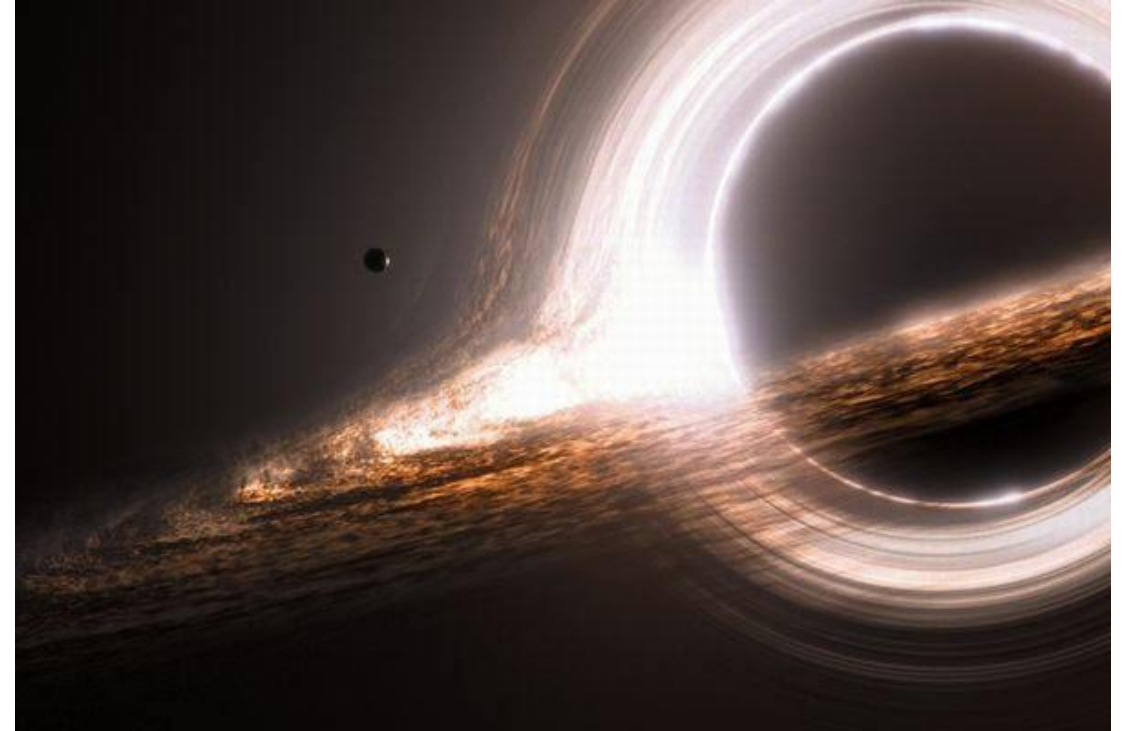
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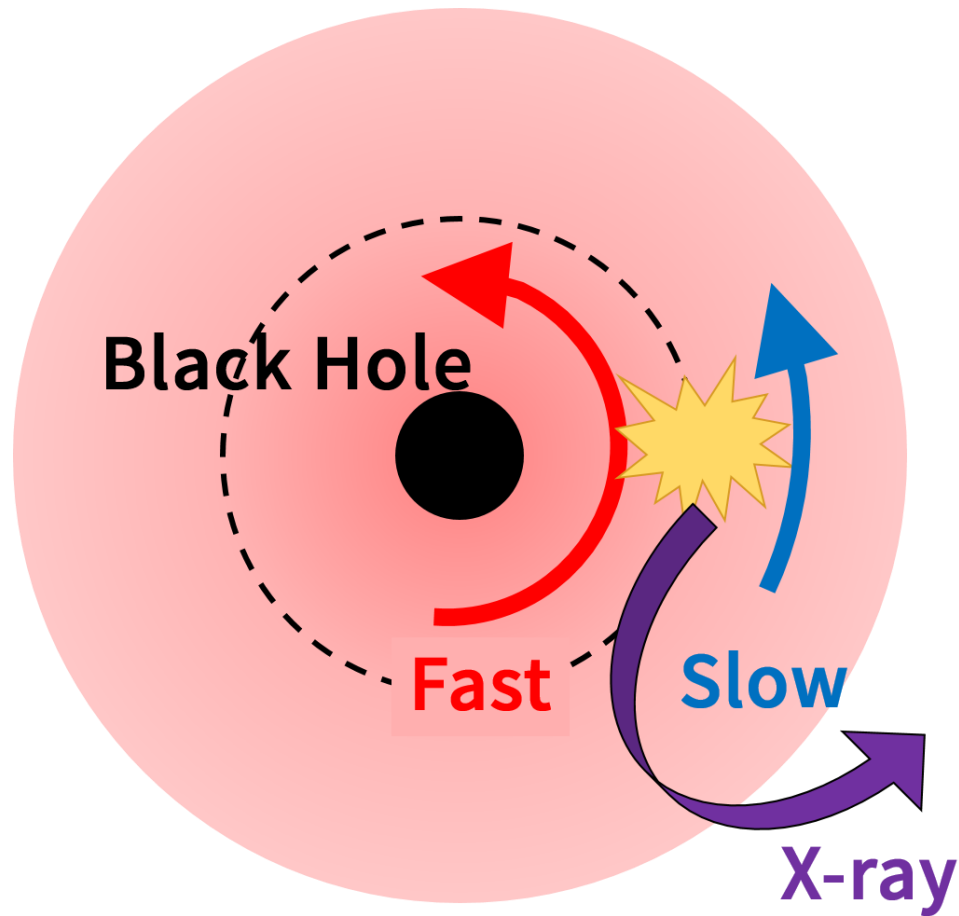
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Accretion Disk



【Angular velocity】

As go **inside** : **Fast**

As go **outside** : **Slow**



Causing friction
at boundaries between
“Fast region” and “Slow region”

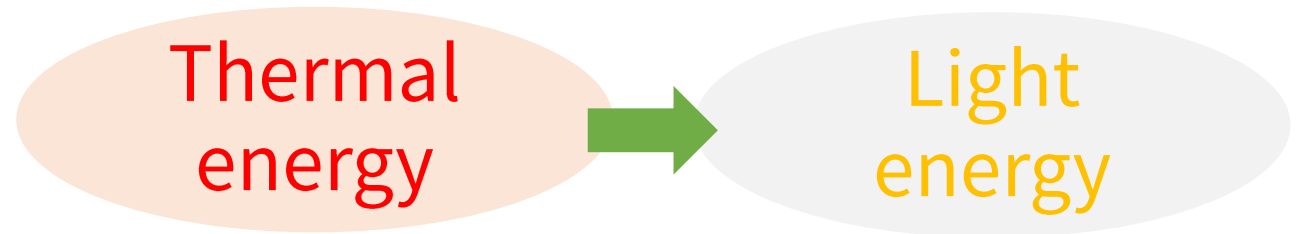


Fig1. X-ray emission mechanism of black hole

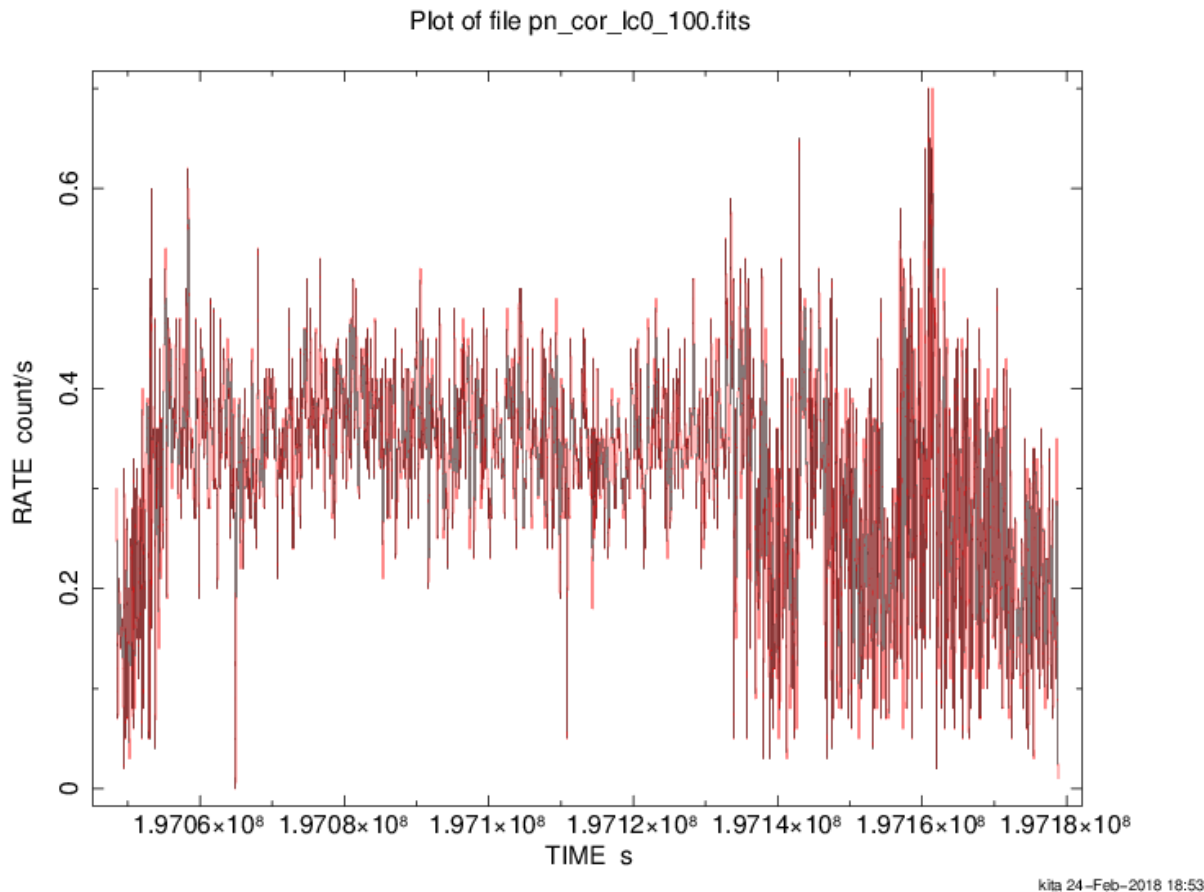
Types of black hole

Stellar-mass BH	Intermediate-mass BH	Massive BH
mass: $5 - 15 M_{\odot}$	mass: $10^2 M_{\odot} \sim$	mass: $10^6 - 10^9 M_{\odot}$
This type is generated from supernova of fixed stars.	This type is generated from the union of two Stellar-mass BHs. The candidates is called “ULX”, Ultra-Luminous X-ray source.	This type is generated from mass accretion around intermediate-mass BHs. But this is one of hypotheses and the existence is almost unknown.

States of stellar-mass black hole

state	features
very high state	Very bright and high energy by Inverse Compton scattering
high/soft state	Rate of accretion and radiation efficiency is high
intermediate state	The state in transition between high and low states
low/hard state	Rate of accretion and radiation efficiency is low
quiescent state	Low state features + lower luminosity

Light Curve



Light Curve is...

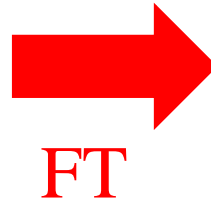
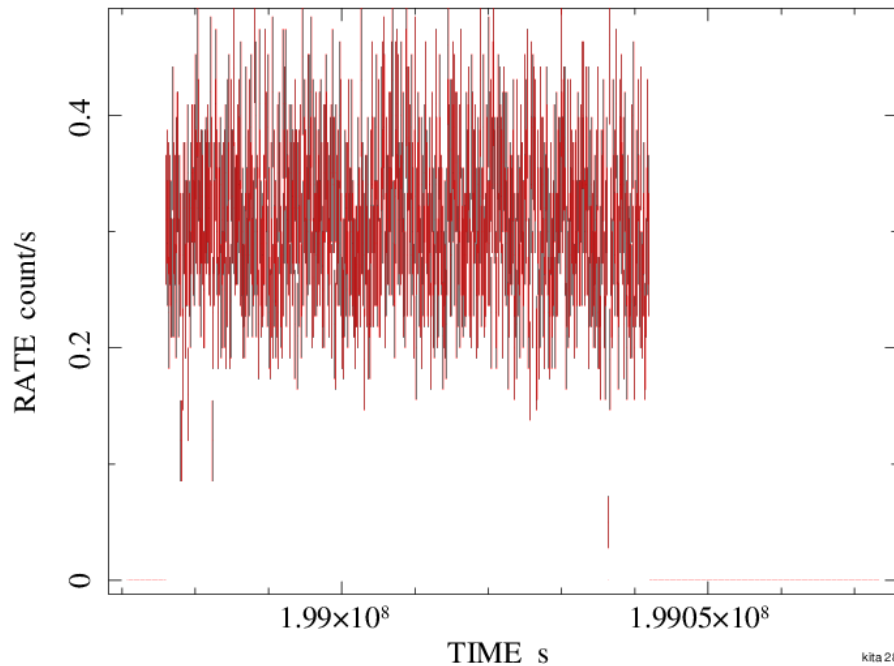
the plot which shows
the relation between
Time[s] and **Count Rate[count/s]**

Count Rate shows
the number of incident photons
per second

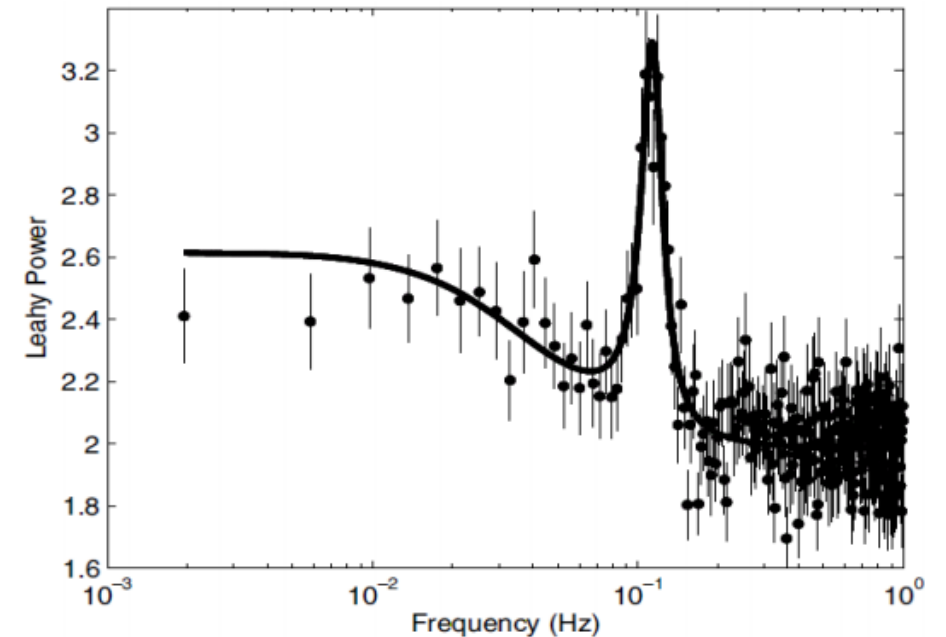
Timing Analysis

We apply Fourier Transform to Light Curve and get Power Spectrum.

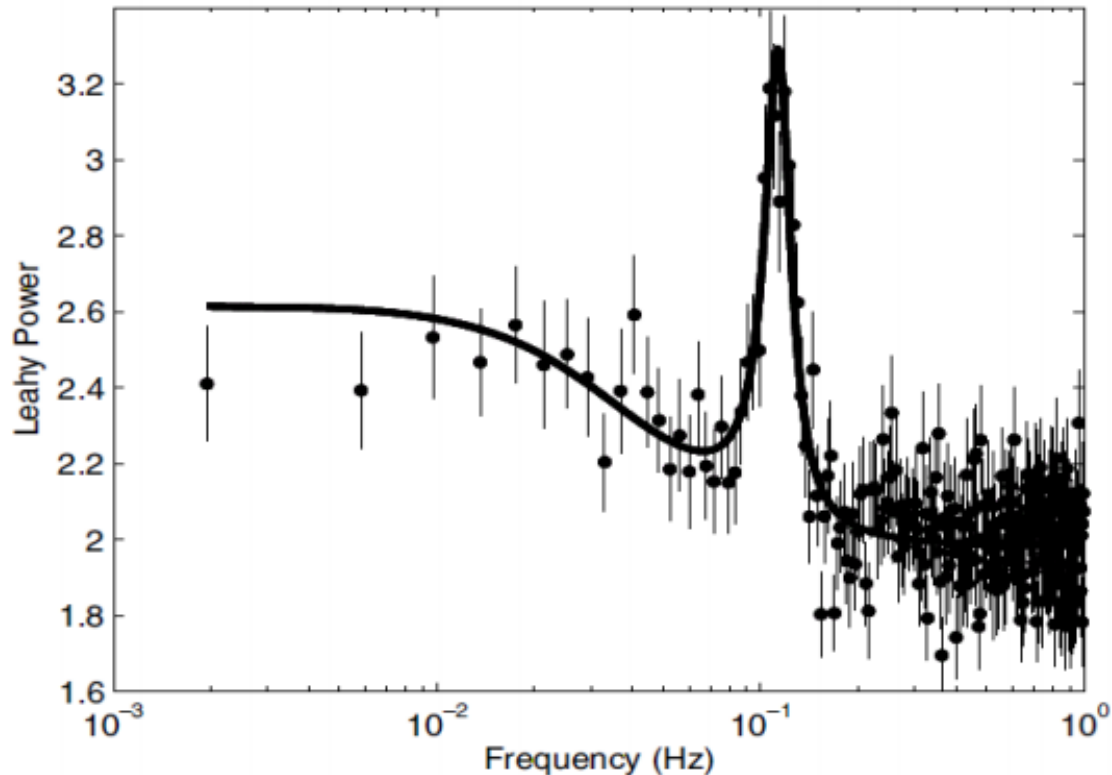
Light Curve



Power Spectrum



QPO(Quasi-Periodic Oscillation)

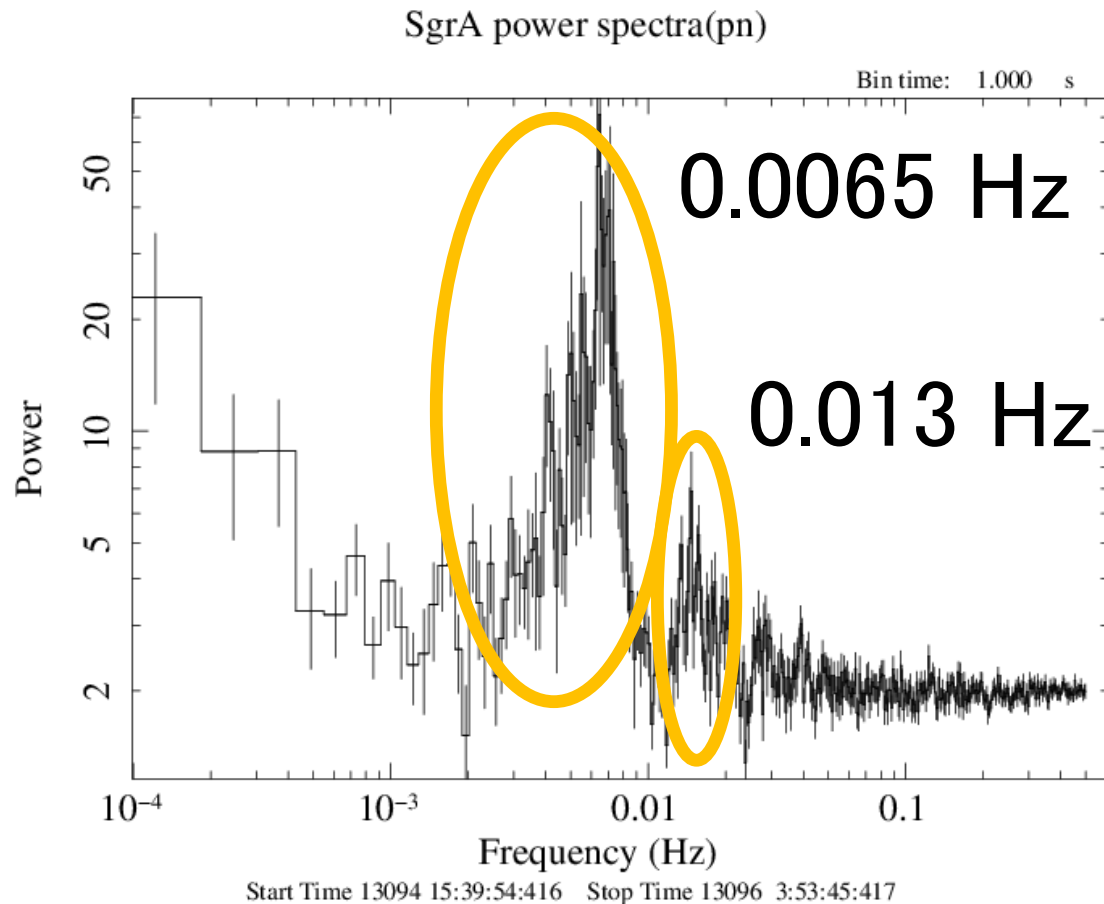


QPO is a phenomenon which have one or some peak(s) with width in power spectrum.

In respect to stellar-mass BH, it is considered that

1. Variability of accretion disk itself
2. Instability of gas in the disk cause QPO.

Twin-peak QPO



It is considered that
Twin-peak QPO is strongly
related to mass of objects.

Vibration period of blightness



Size of radiation area



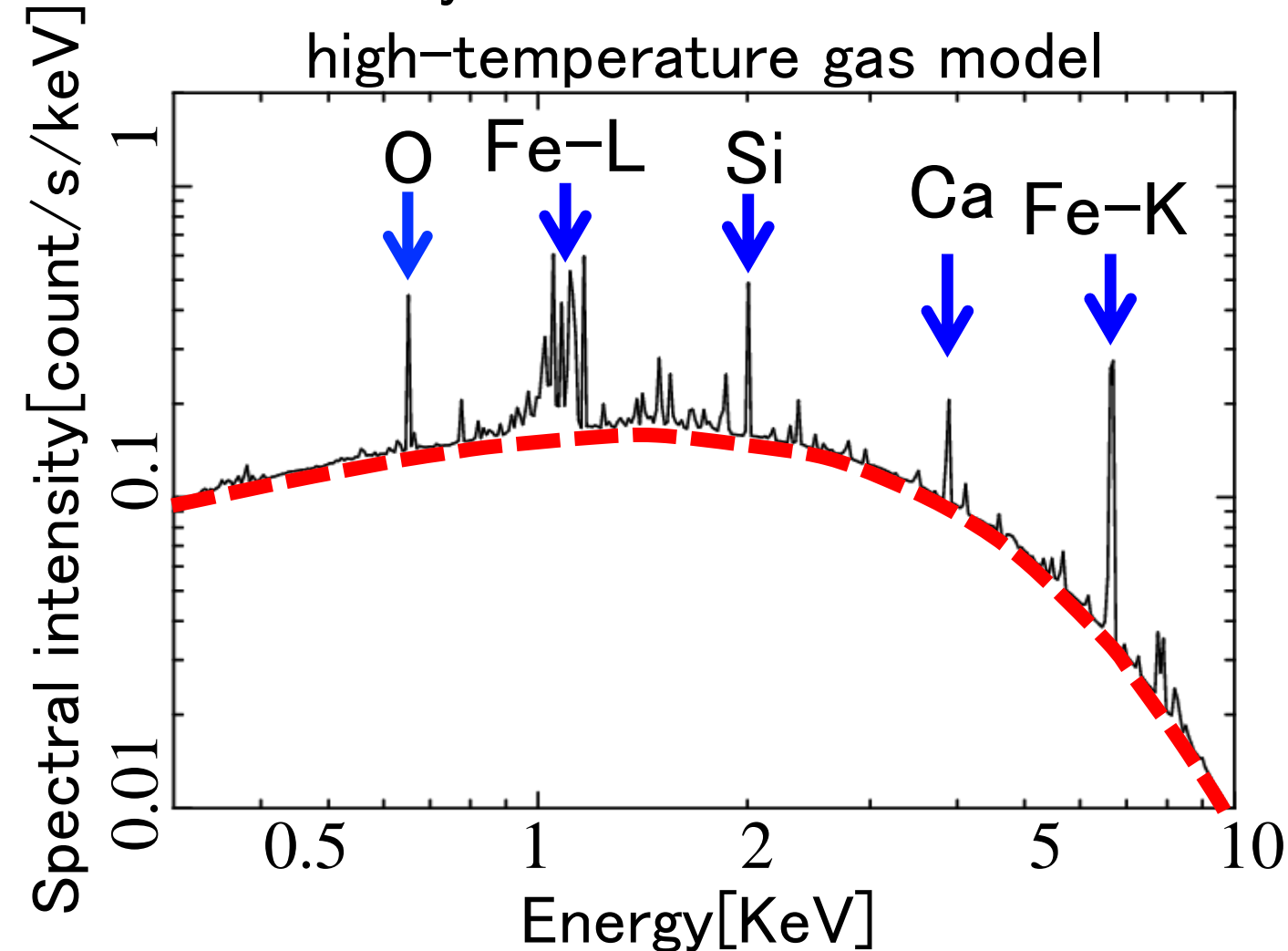
Schwarzschild radius



Mass of BH

Energy Spectrum

X-ray radiation from dilute
high-temperature gas model



Fitting energy spectrum needs
Many models.

e.g)thermal bremsstrahlung,
synchrotron radiation,
black body radiation,
each blight line spectrum

• • •

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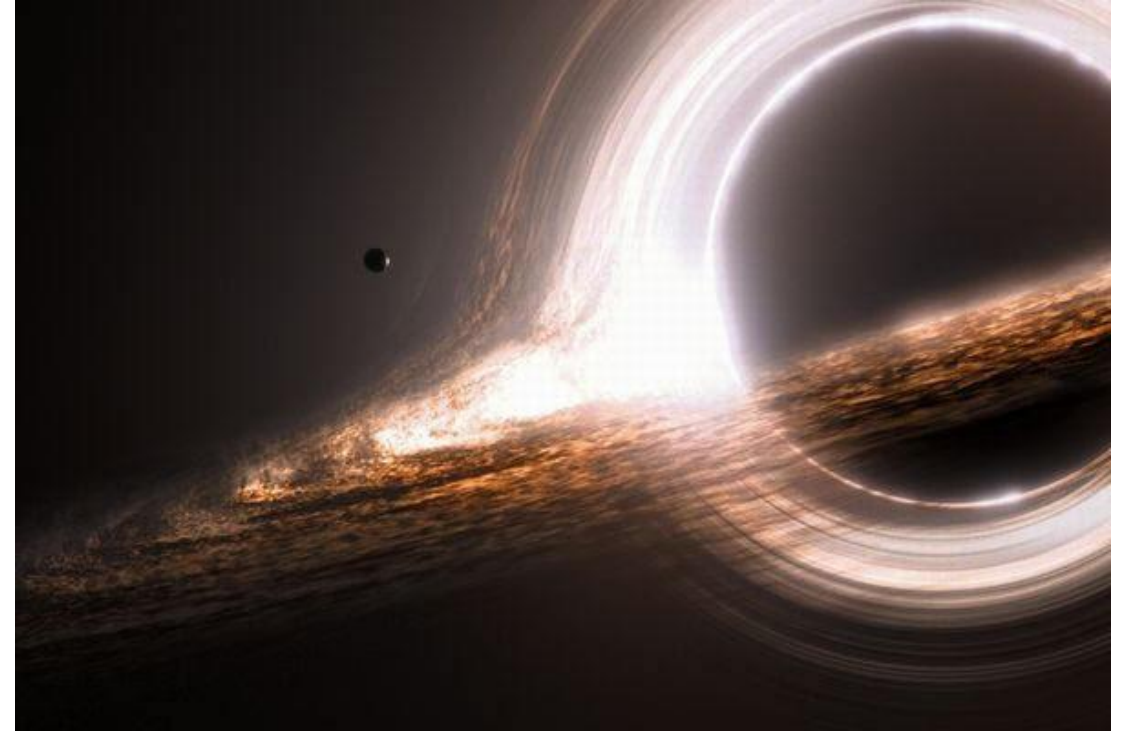
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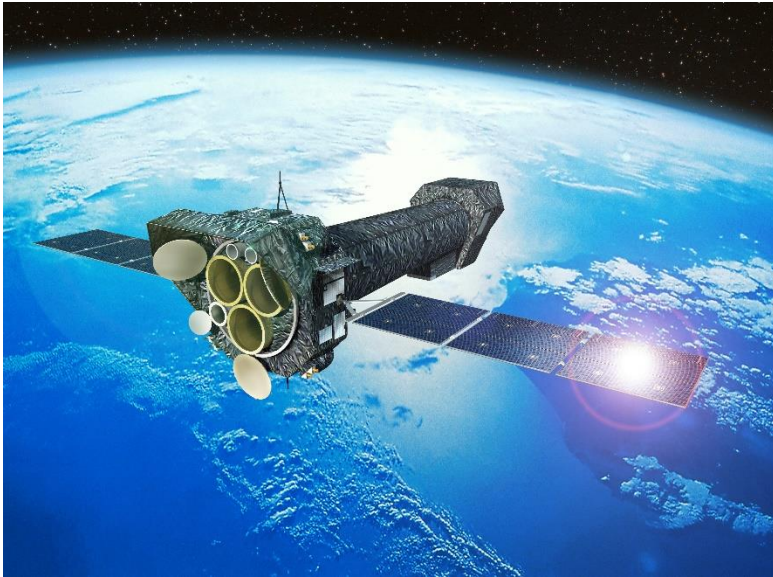
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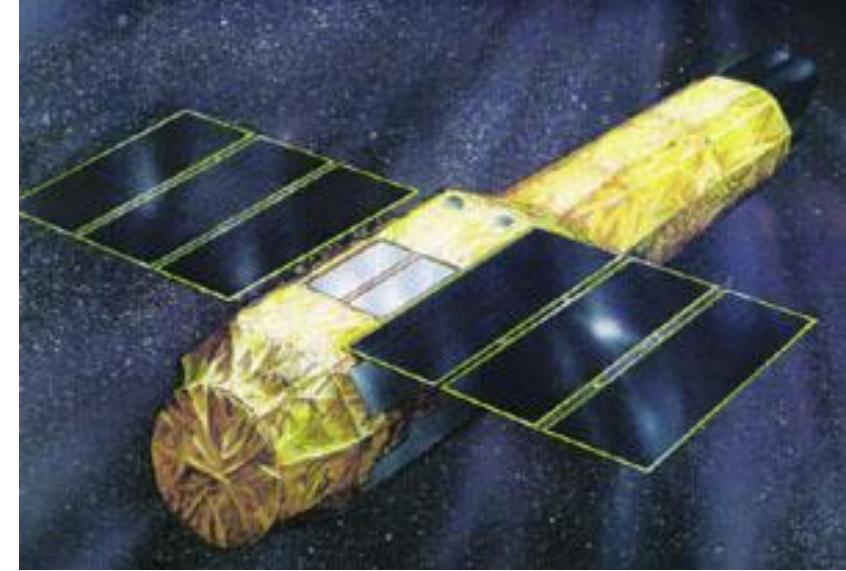
X-ray observatory part1



XMM-Newton



Chandra



Suzaku

X-ray observatory part2



RXTE



ASTRO-H ひとみ

X-ray observatory part2



RXTE

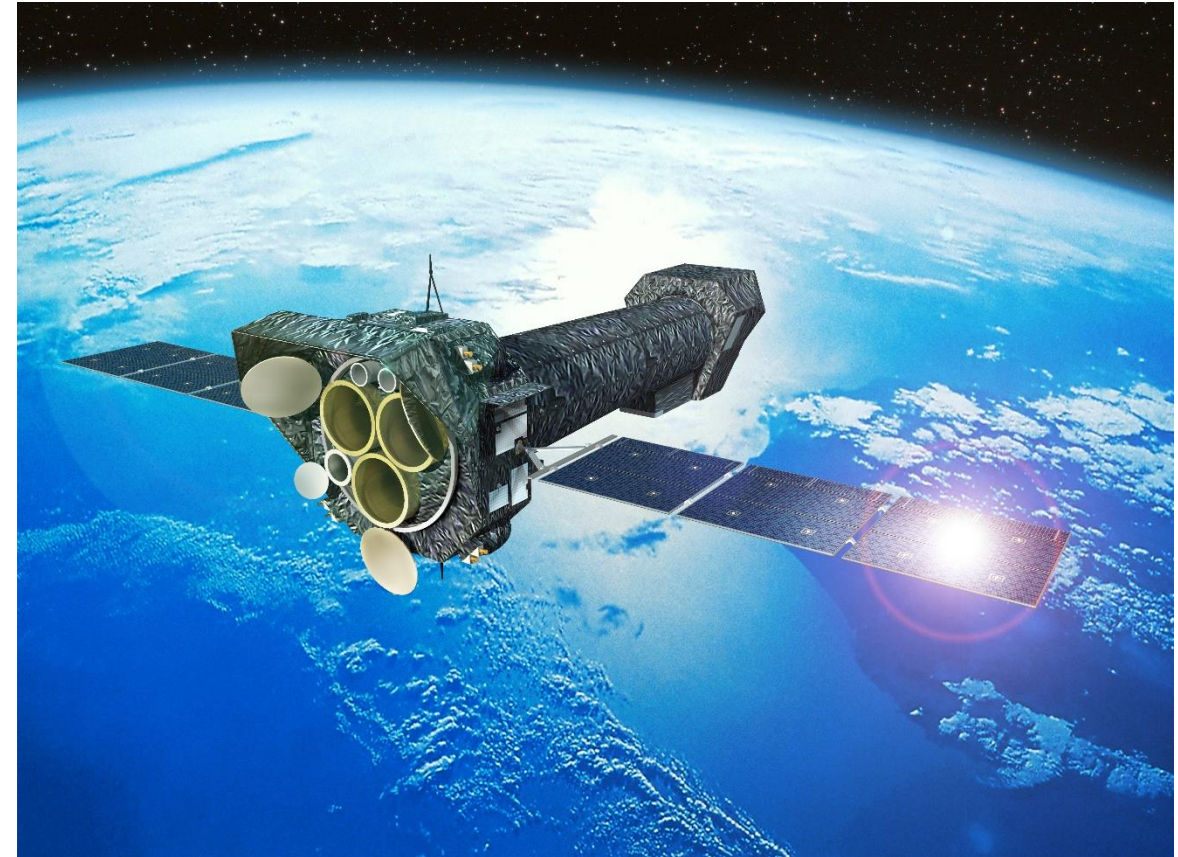


ASTRO-H ひとみ

XMM-Newton

XMM-Newton was launched by ESA
on December 10th 1999.

Time resolution: 12 arcseconda
Effective area: 3000cm^2 to 6keV
Grating: reflective
Hight of perigee: 7000km
Orbital period: 47.8h



Detectors of XMM-Newton

MOS[1 pixel = 1.1"]	Time Resolution [s]	Live Time[%]	Max count rate diffuse(total) [s ⁻¹]	Max count rate (flux) point source [mCrab ⁴ s ⁻¹]
Full frame(600 × 600)	2.6	100.0	150	0.50(0.17)
Large window(300 × 300)	0.9	99.5	110	1.5(0.49)
Small window(100 × 100)	0.3	97.5	37	4.5(1.53)
Timing uncompressedd (100 × 600)	0.00175	100.0	N/A	100(35)

XMM-Newton has 3 detectors, MOS1 • MOS2 and PN.

Time resolution of PN is very high.

So I adopt

1. MOS1+MOS2

2. PN only

as data set .

PN [1 pixel = 4.1"]	Time Resolution [s]	Live Time[%]	Max count rate diffuse(total) [s ⁻¹]	Max count rate (flux) point source [mCrab ⁴ s ⁻¹]
Full frame(376 × 384)	73.4	99.9	1000	2(0.23)
Extended Full frame(376 × 384)	199.1	100.0	370	0.3(0.04)
Large window(198 × 384)	47.7	94.9	1500	3(0.35)
Small window(63 × 64)	5.7	71.0	12000	25(3.25)
Timing(64 × 200)	0.03	99.5	N/A	800(85)
Burst(64 × 180)	0.007	3.0	N/A	60000(6300)

Objects

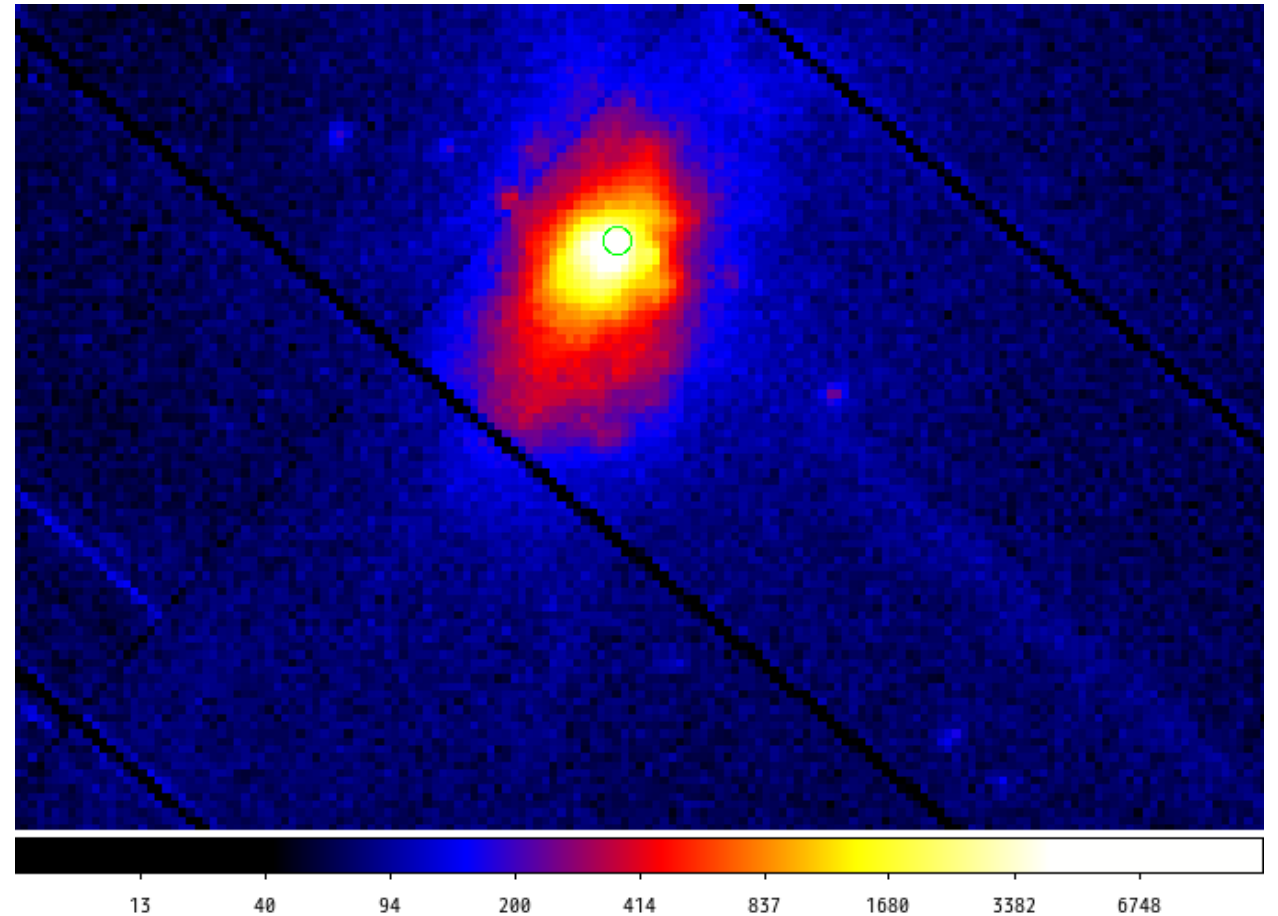
object	obs ID	time
GROJ1655-40	0112460201	2001-08-30 02:37:53
	0112921301	2005-02-27 07:46:53
	0400890201	2007-03-26 15:18:27
XTEJ1550-564	0204270101	2004-08-11 06:24:43
	0400890101	2007-02-25 10:03:06
GRS1915+105	0112990501	2003-10-17 00:10:08
	0144090101	2004-04-17 14:18:56
	0506161201	2007-09-29 23:55:48
H1743-322	0724401901	2014-09-23 19:15:51
	0783540201	2016-03-13 03:25:57
M82 X-1	0206080101	2004-04-21 21:36:32

NGC5408 X-1	0302900101	2006-01-13 18:41:00
	0500750101	2009-01-13 19:05:27
	0723130401	2014-02-13 00:23:35
NGC6946 X-1	0200670401	2006-06-25 16:28:06
	0500730201	2007-11-02 21:53:24
	0691570101	2012-10-21 17:50:58
Swift J1644+57	0678380201	2011-04-30 07:31:07
	0700381601	2012-10-05 19:06:15
	0784790101	2016-10-18 14:20:23
Sgr A*	0202670601	2004-03-30 14:46:36
	0202670701	2004-08-31 03:12:01
	0762250301	2015-09-27 15:48:39
REJ1034+396	0506440101	2007-05-31 19:47:14
	0561580201	2009-05-31 01:44:37
	0655310201	2010-05-11 05:32:56

Region File

Make region files for
each objects.

e.g.) M82 X-1



Software

- Ciao command
⇒ program for analysis of CHANDRA e.g.) deflare
- Sas command
⇒ program for analysis of XMM-Newton e.g.) evselect
- ds9
⇒ make region files
- XRONOS(ver 5.22)
⇒ TF program for Timing Analysis

Fitting model

Different from energy fitting, we mainly use 3 models for Timing Analysis.

【Lorentzian】

$$L(x) = \frac{LN}{1 + \left(\frac{2(x - x_0)}{\Delta x} \right)^2}$$

【Power-law】

$$A(E) = KE^{-\alpha}$$

Exponential model

【Constant】

$$C=C$$

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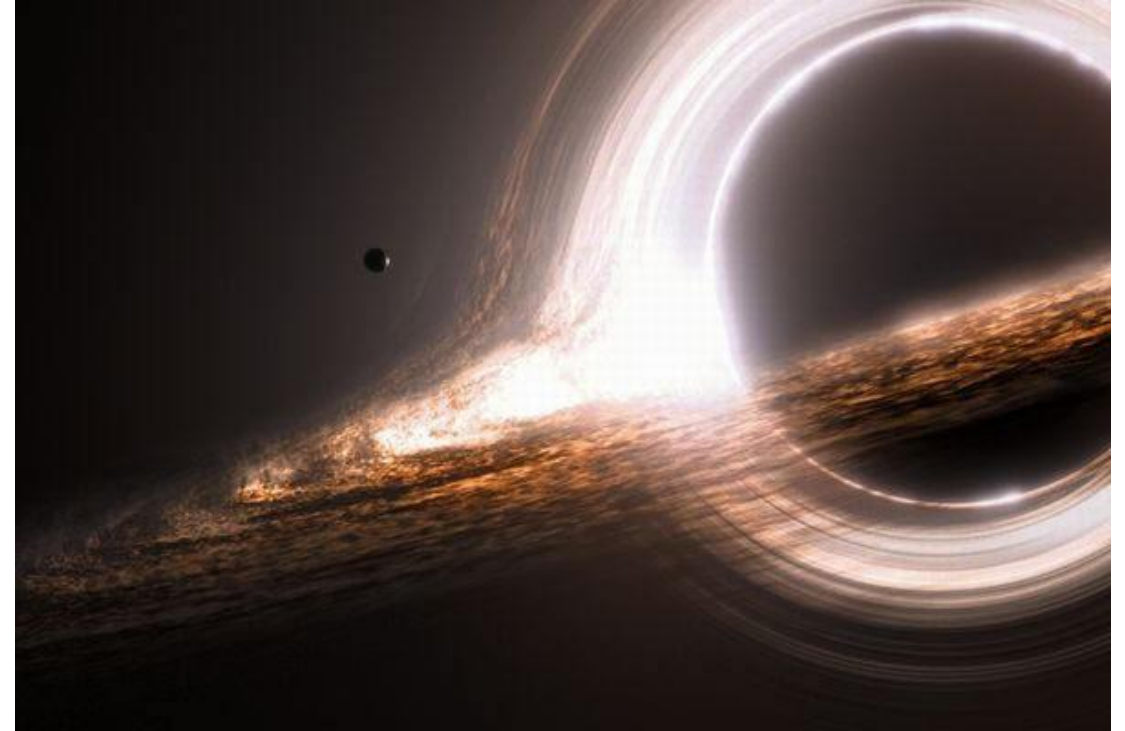
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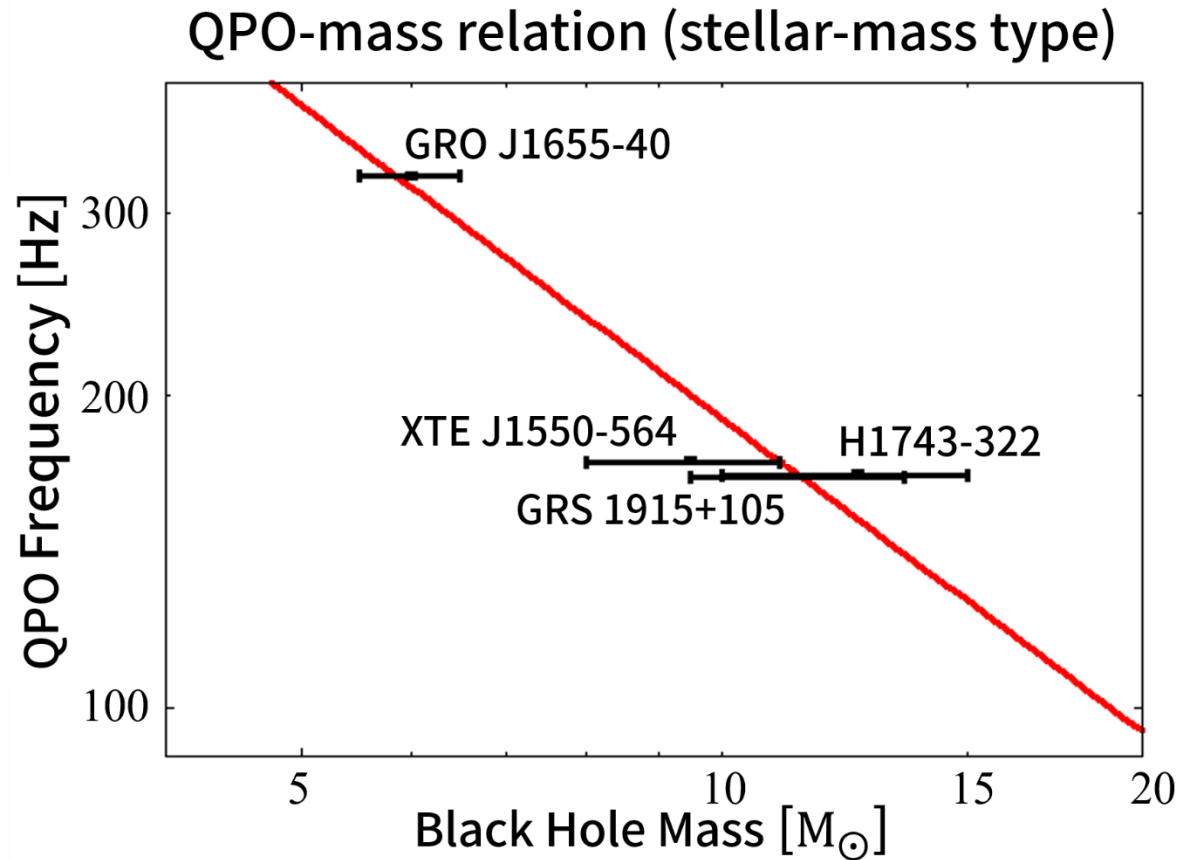
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Conclusion



$$f \text{ [Hz]} = 1903.28 \left(\frac{M}{M_{\odot}} \right)^{-1}$$

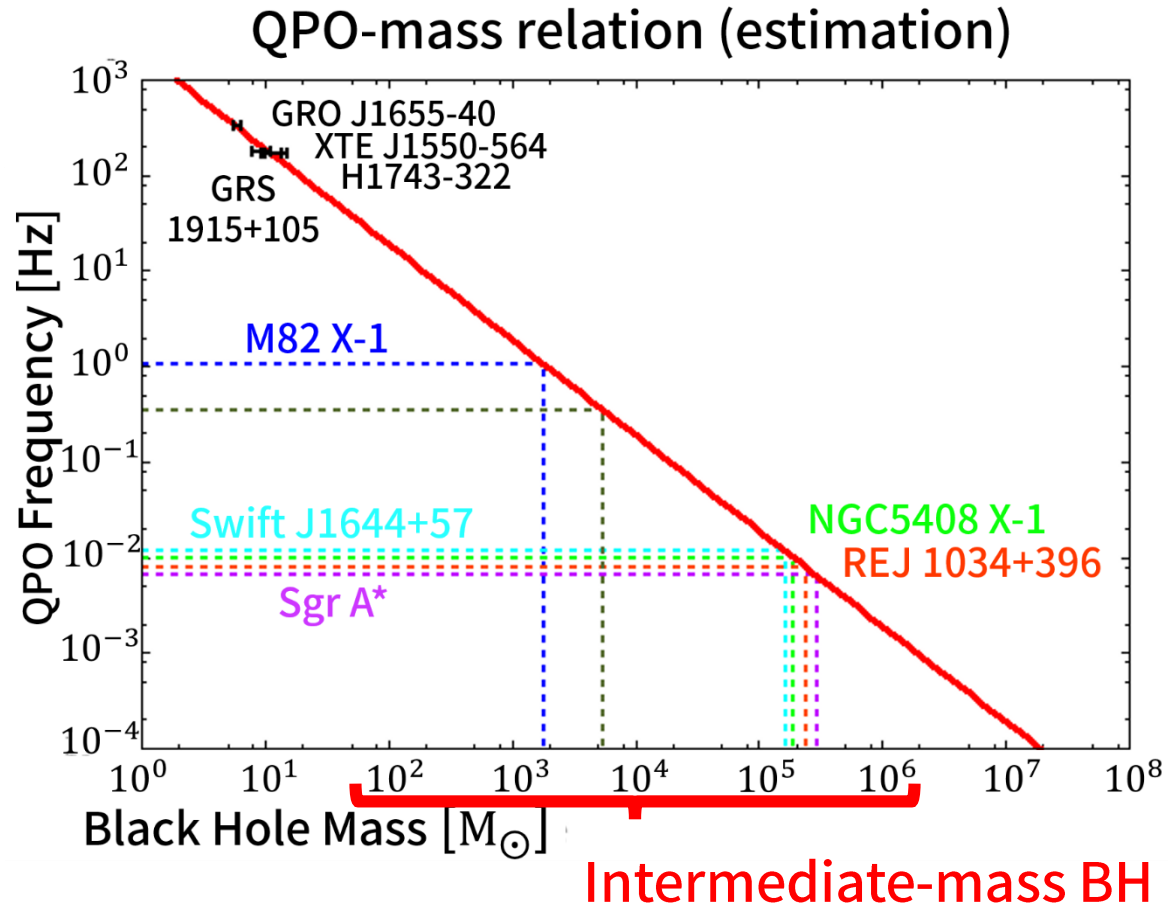
inverse proportionality



If we can adopt the relation to other type BH candidates, Their QPO frequency should be much smaller...?

Fig1. The relation between QPO-mass of the stellar-mass black holes

Conclusion



Analysis QPO of 6 candidates and
Adopt the relation

$$f \text{ [Hz]} = 1903.28 \left(\frac{M}{M_{\odot}} \right)^{-1}$$

Then...

The mass of all objects are included in
Intermediate-mass BH region!!

Fig2. Estimation of the mass of the black hole candidates
from QPO-mass of the stellar-mass black holes

Summary

- I applied the relation between QPO and mass of the stellar-mass black holes to intermediate-mass or massive black hole candidates.
- As a result, it is suggested that the candidates
M82 X-1 , Swift J1644+57 , NGC5408 X-1
NGC6946 , REJ1034+396 , Sgr A*
are intermediate-mass black holes
with respect to QPO.



Thank you for listening !