Power Density Spectra in Accreting Black Holes (BH) & Detection the Mass of BH

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Overview

- Introduction
- XTE J1752-223
- GX339-4
- Scaling Method & Determination the mass of GX339-4
- Conclusion
- Plan for next year

Introduction

What kind of object do we study?

- Oppenheimer & Snyder (1939) made the first rigorous calculation describing the formation of a BH. The first strong evidence for such an object came from X-ray and optical observations of the X-ray binary Cygnus X–1. Today, more than 20 similar X-ray binary systems are known that contain a compact object believed to be too massive to be a neutron star or a degenerate star of any kind (i.e., $M > 3\ M_{\odot}$) (Ronald A. Remillard, 2006). We call these system as black-hole binaries (BHBs). In this presentation, I focus on GX339-4, which considered as a famous BHB. And I also analyzed a new source XTE J1752-223, which showed us very similar behaviors like the BHB.

Ronald A. Remillard, et. al., 2006, Annu. Rev. A&A, 44, 49

Why are they so interesting for us? & How do we deal with them?

- The principal motivation for studying accreting BHs is that these objects provide a unique window on the physics of strong gravity and dense matter. One of the most important resource for examining the nearby of a BH is the variations in X-ray intensity. The analysis tool commonly used for probing the variability is the Power Density Spectrum (PDS, the Fourier transform of the autocorrelation function of the light curve of a source) (M. van der Klis, 2000). In this presentation I show a full analysis for investigate the timing behavior of XTE J1752-223 and GX339-4 during their 2009-2010 outburst.

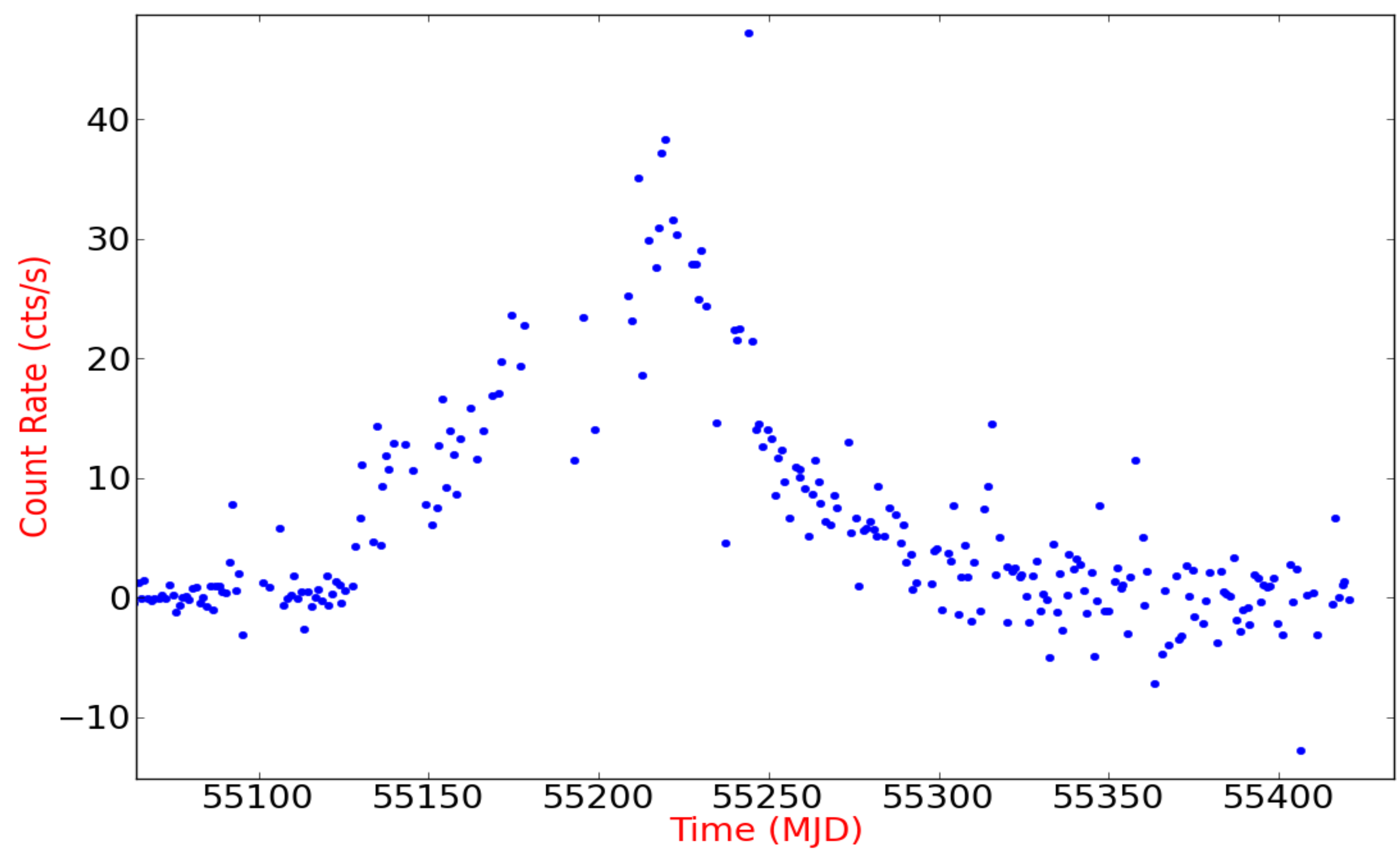
M. van der Kils, 2000, Annu. Rev. A&A 2000, 38, 717

How could we testify them?

- Determination the mass of BH is also a very important task in modern astronomy, since it can constrain the maximum mass of a neutron star and the minimum mass of a BH. The knowledge of the BH mass distribution of the Galaxy can also provide important clues on stellar evolution. In this presentation, I will show a method, which can easily estimate the mass of BH by the correlation between timing and spectral properties.

XTE J1752-223

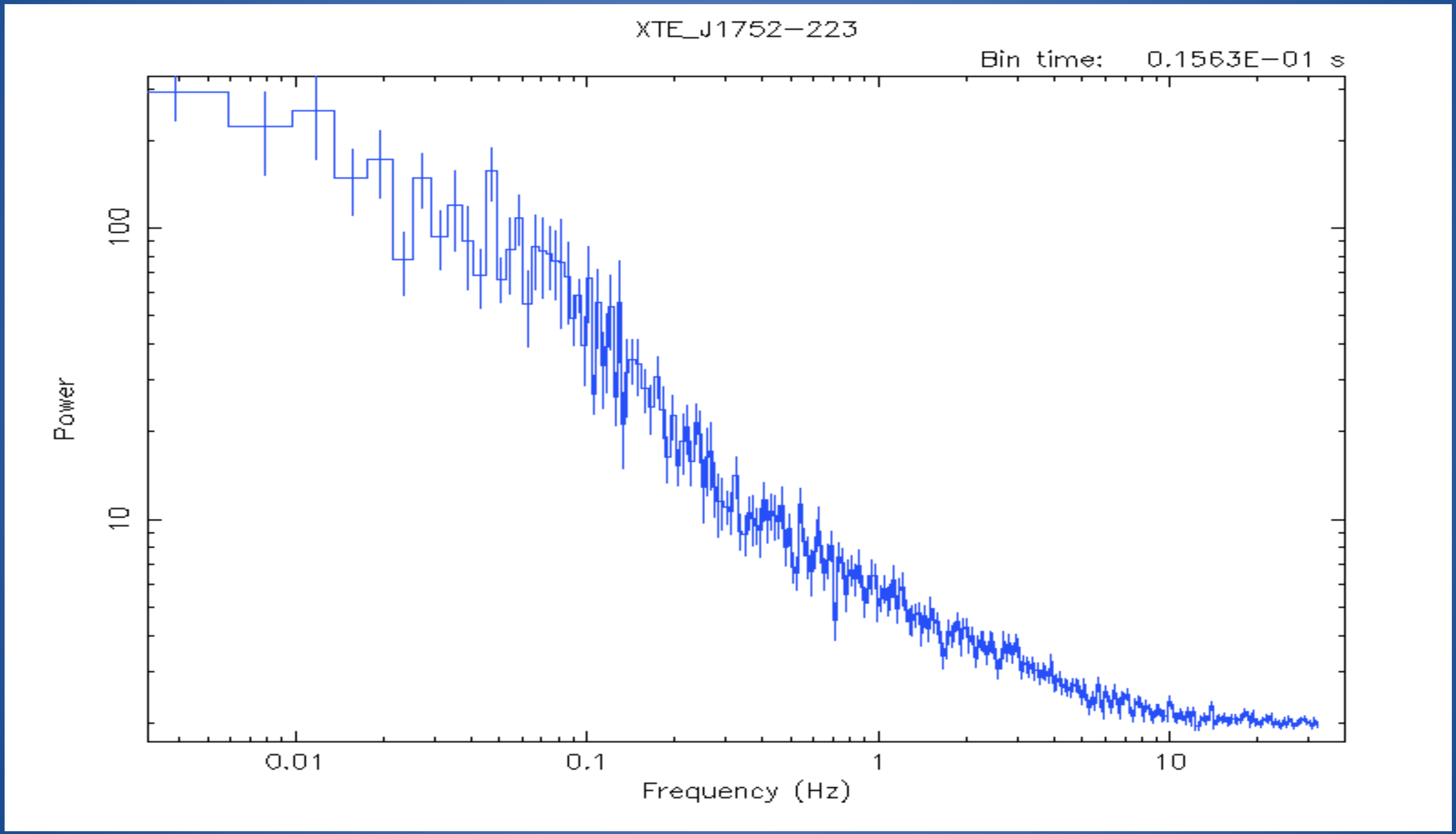
On 2009-10-23 at 19:55 UT, RXTE discovered a new source, which named XTE J1752-223 (C. B. Markwardt, 2009)
MJD 55132-55383 (Sun constraint 55156-55217)



C. B. Markwardt, et. al., 2009, Atel #2258

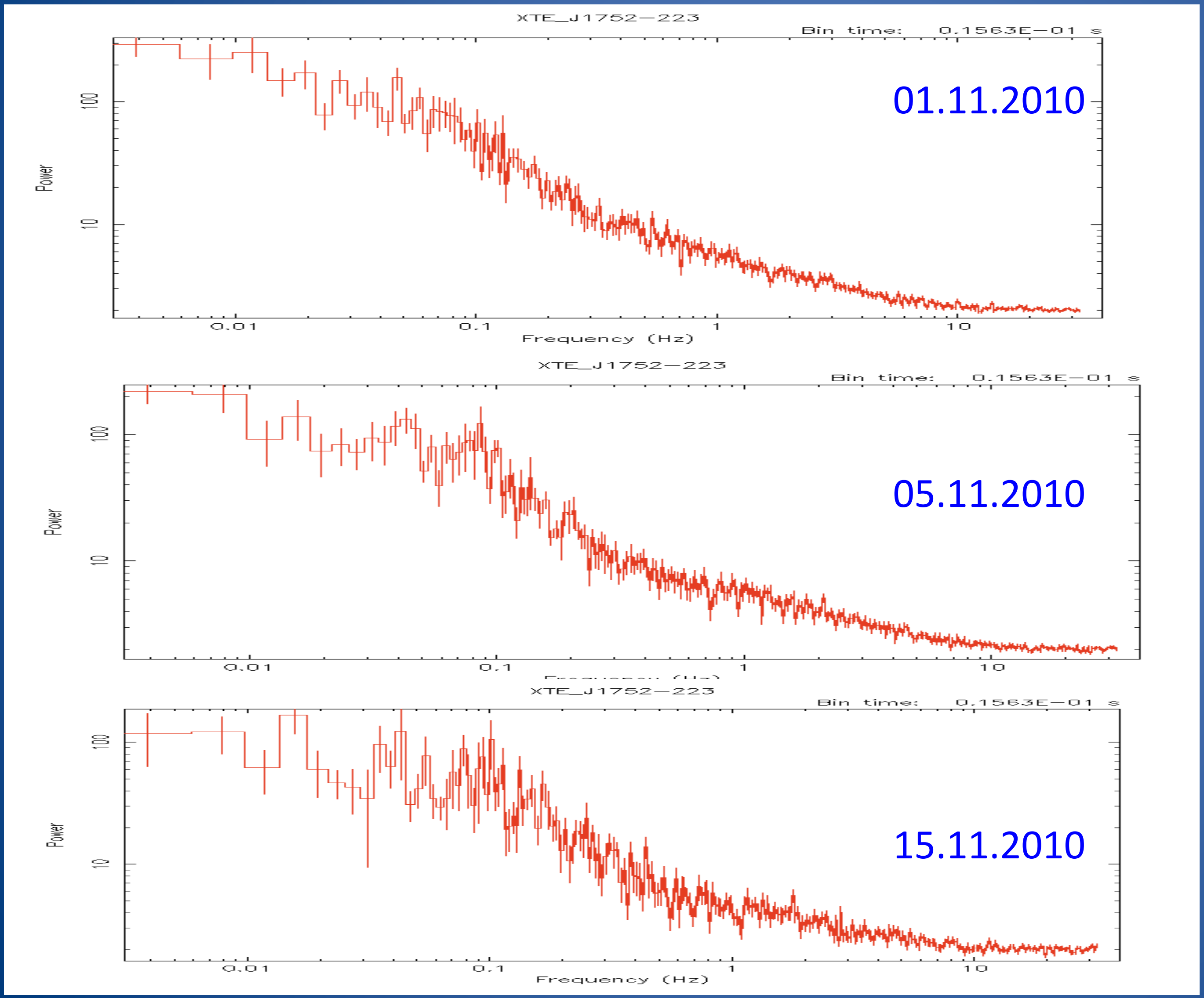
Timing properties of XTE J1752-223

The Continuum on PDS



In the beginning of the outburst of XTE J1752-223 the PDS are like this – there isn't any clear peak (QPO), the line relatively smooth.

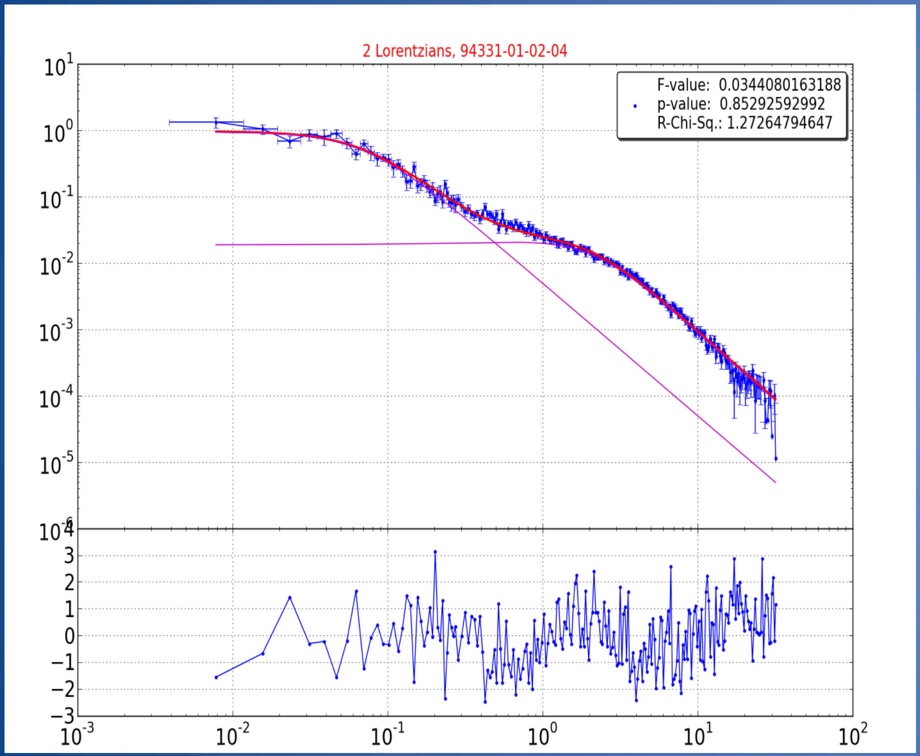
Change of Continuum



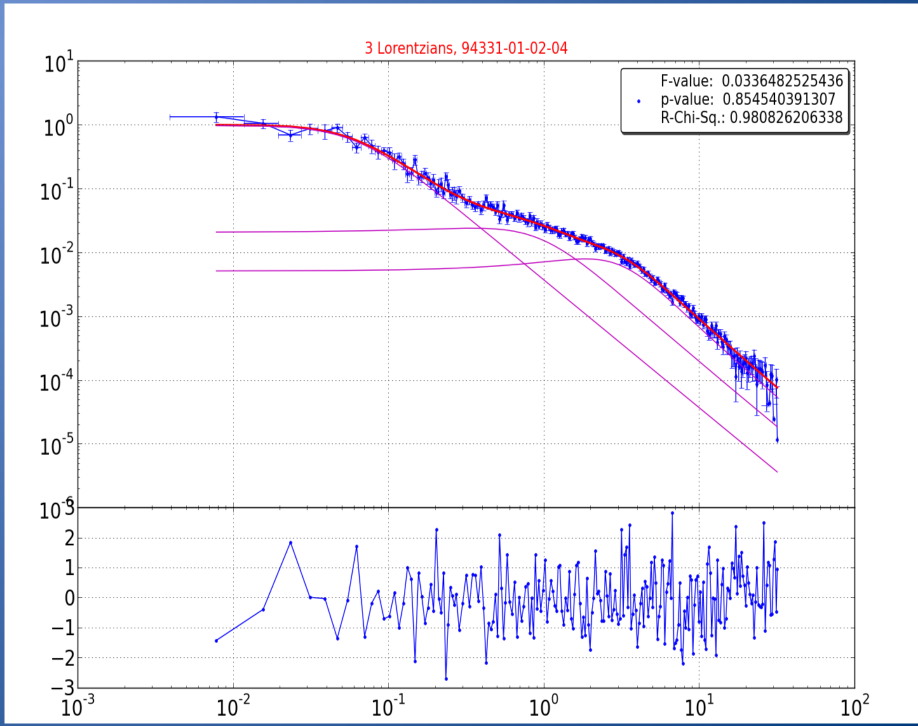
It seems something is changing slightly, but by these plots is no clear, so …

Fitting of the Continuum

(For Hard State (HS) 28.10.2010-23.01.2010)

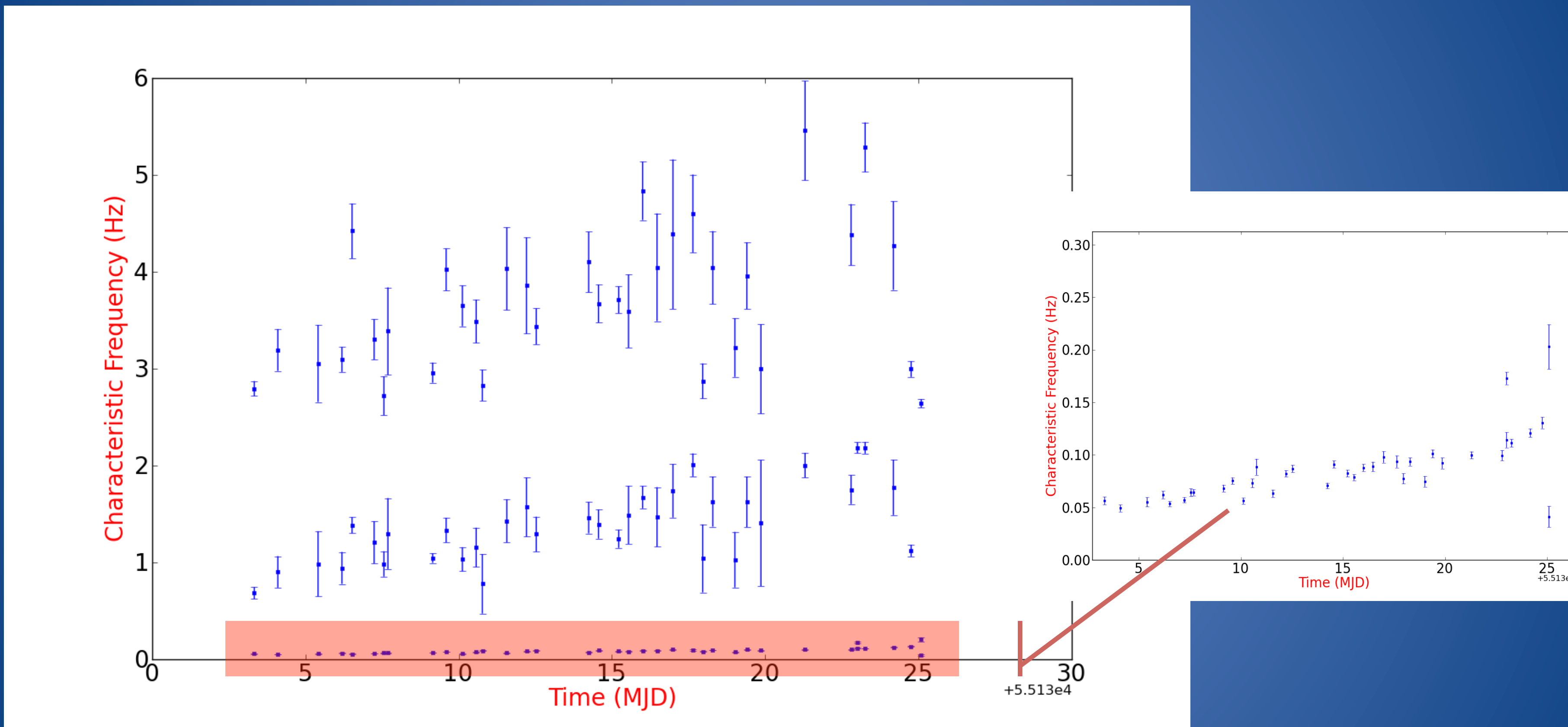


So we decide to fit the continuum, to check how the fitting parameters change.



Comparing the two figures, we can see that 3 lorentzians can well fit the continuum.

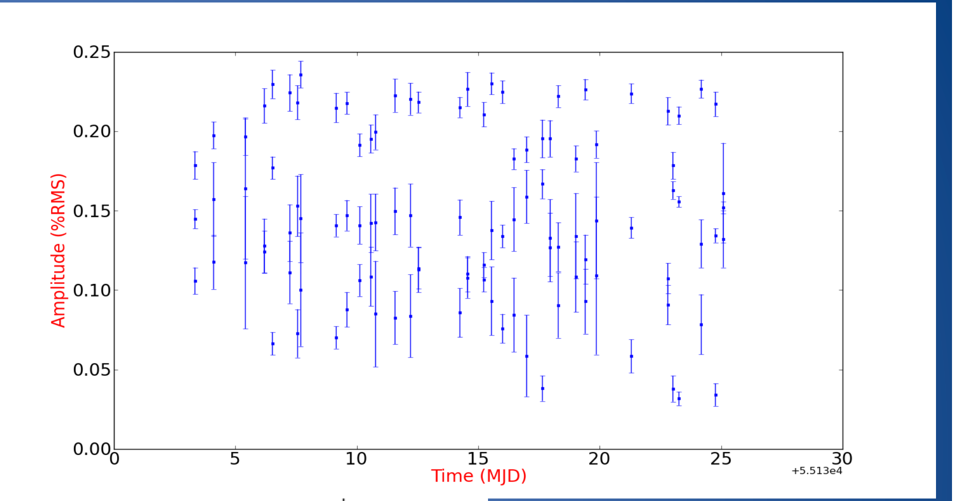
The change of Characteristic Frequency

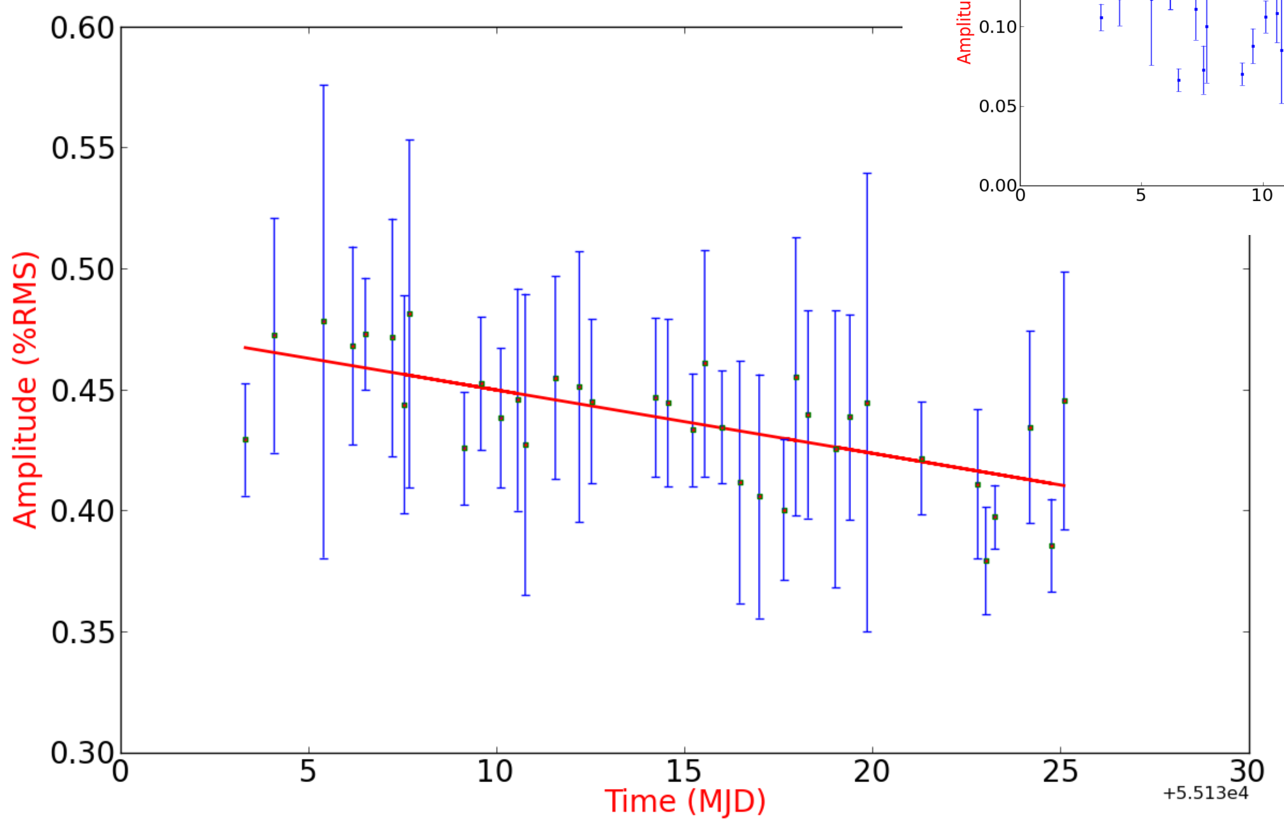


The char. freq. were increasing by time (similar phenomena has been found on GX339-4, Belloni, 2005)

T. Belloni, et. al., 2005 A&A, 440, 207

The change of Root Mean Square



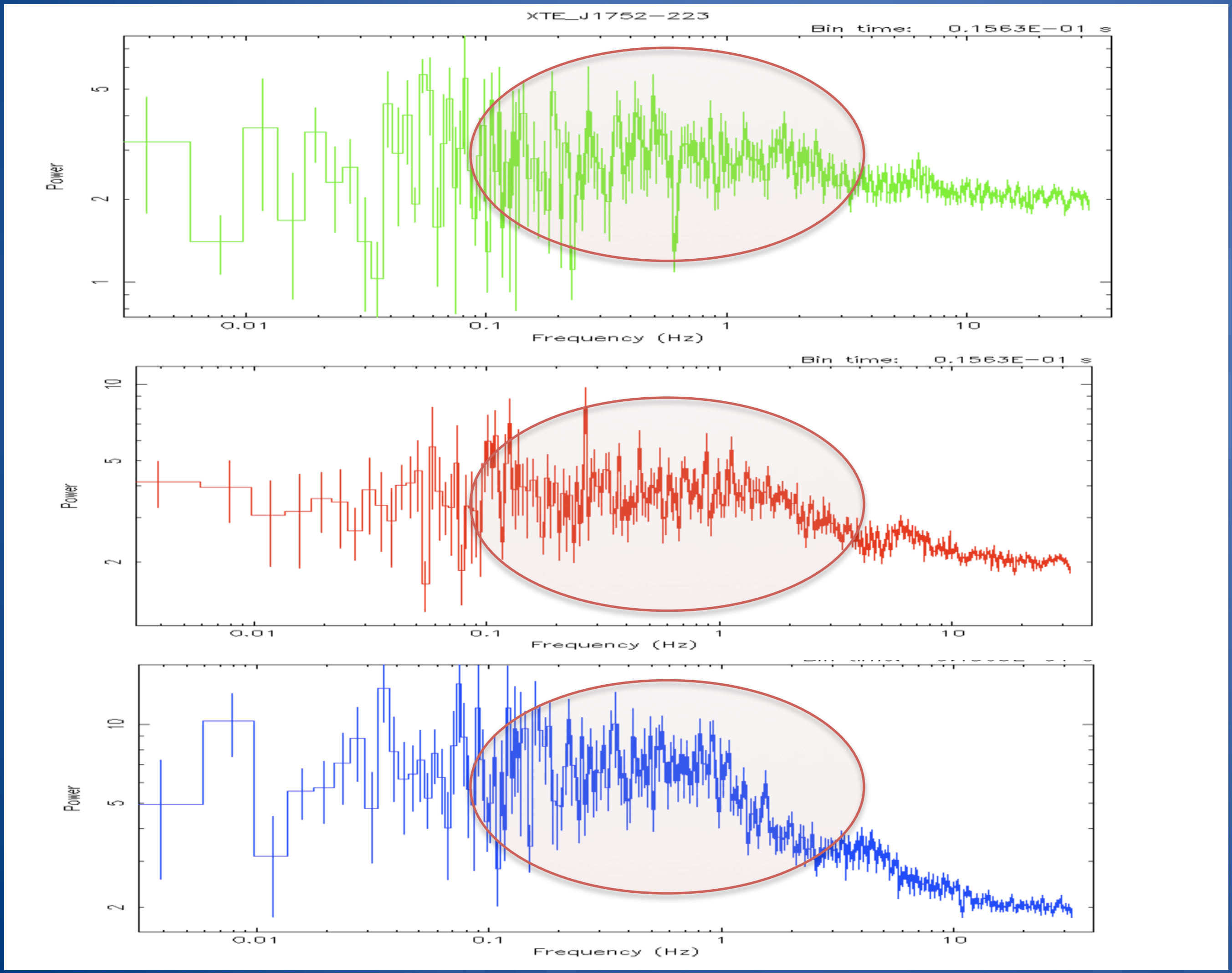


RMS ≈ 45%!

(For neutron star the RMS lower than 20%).

State Transition on PDS

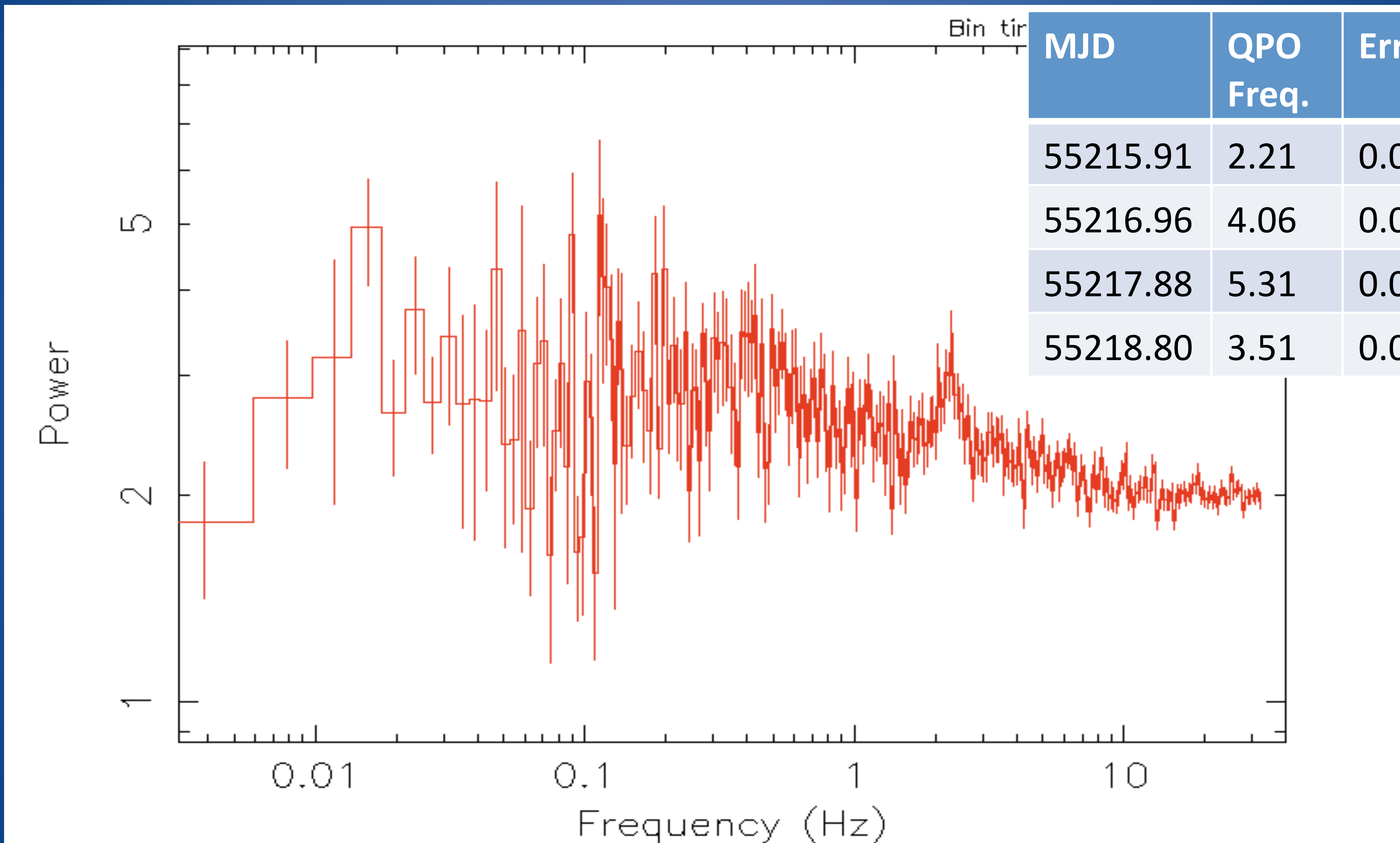
(from Intermediate State to Hard State)



Green line: 01.04.2010
Red line: 02.04.2010
Blue line: 03.04.2010

During the State Transition from IS to HS, the amplitude low frequency parts increased.

Quasi Periodic Oscillation (QPO)

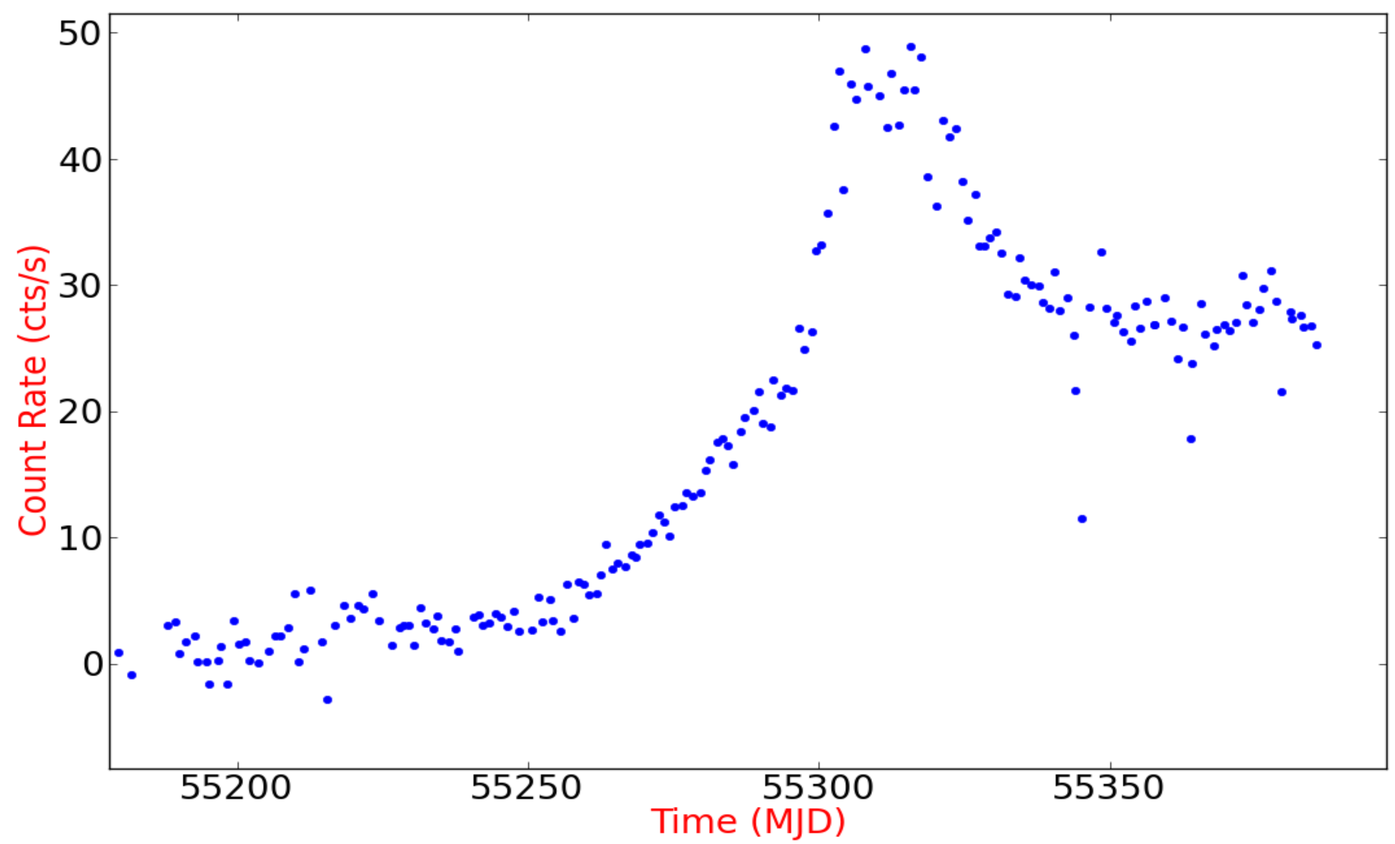


MJD	QPO Freq.	Error
55215.91	2.21	0.03
55216.96	4.06	0.04
55217.88	5.31	0.04
55218.80	3.51	0.02

The QPOs of XTE J1752-223 show a low amplitude and narrow width behavior on PDS. Due to the Sun constraint there is not so much QPO has been found on this source.

GX339-4

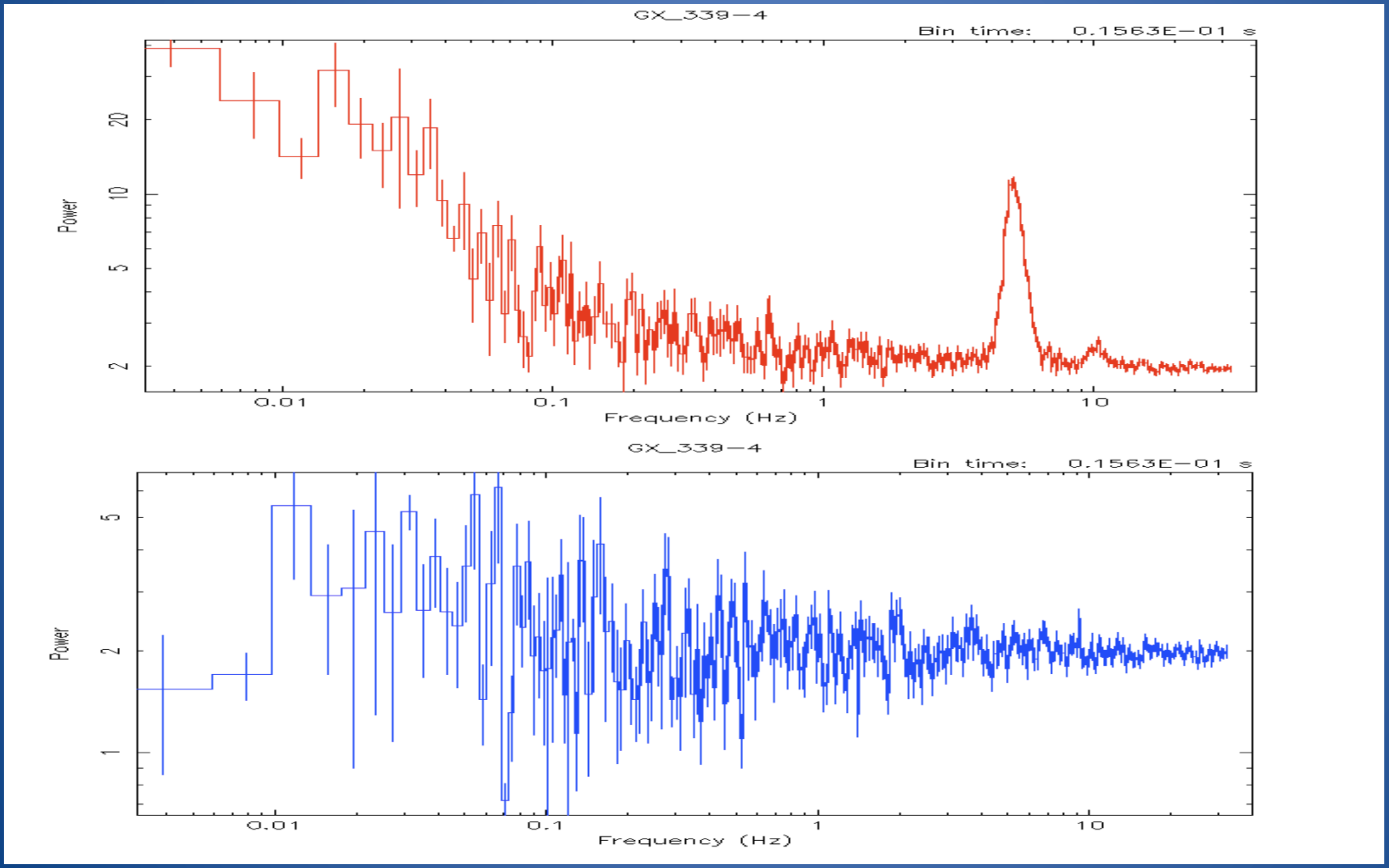
On the beginning of January of 2010, GX339-4 was detected a new outburst by MAXI/GSC (K. Yamaoka, 2010)
MJD 55256-55357



K. Yamaoka, ea. al., 2010, Atel #2380

State Transition on PDS

(From HS to IS)

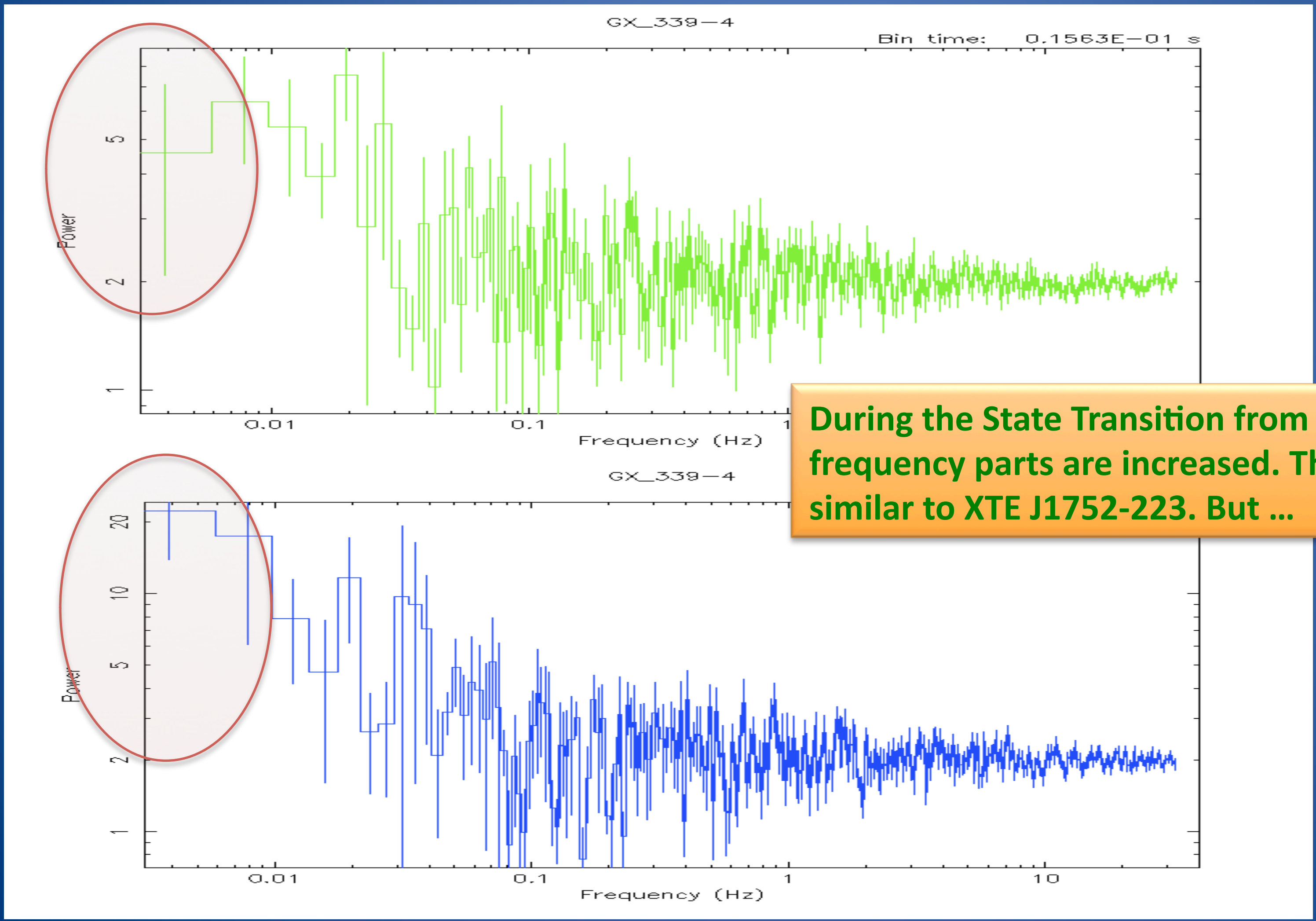


Red line: 08.05.2010
Blue line: 09.05.2010

This transition for XTE J1752-223 -> Yoon Young's talk

State Transition on PDS

(From IS to HS)

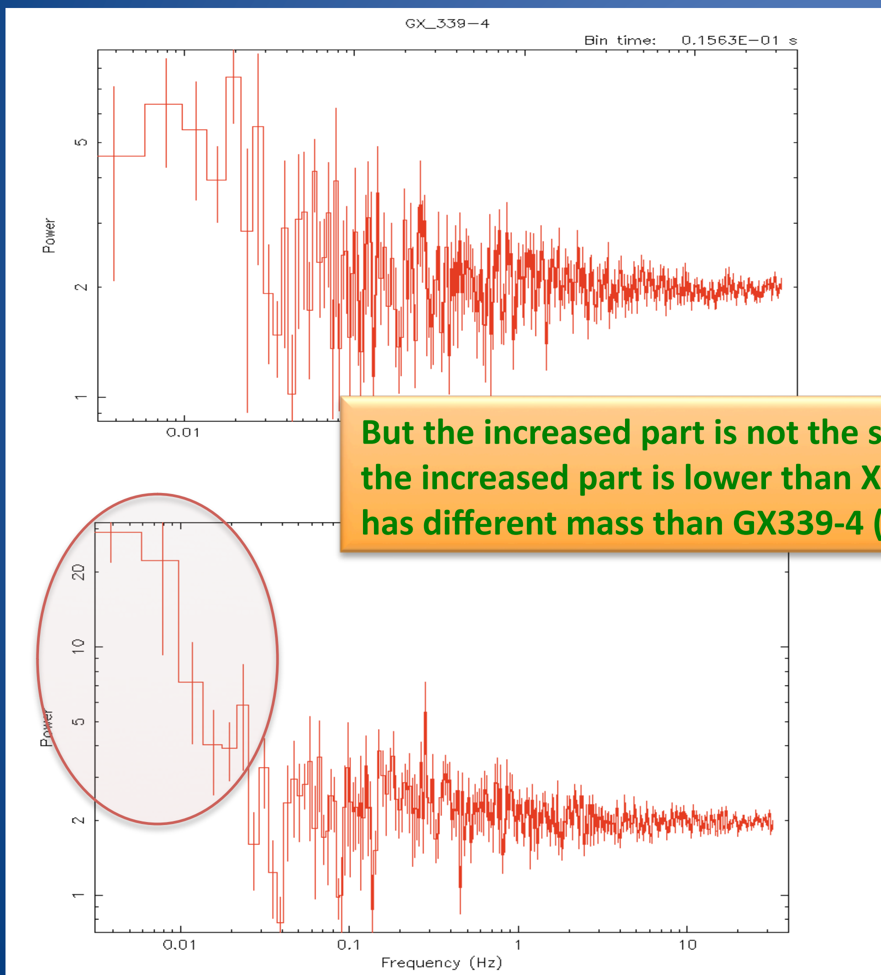


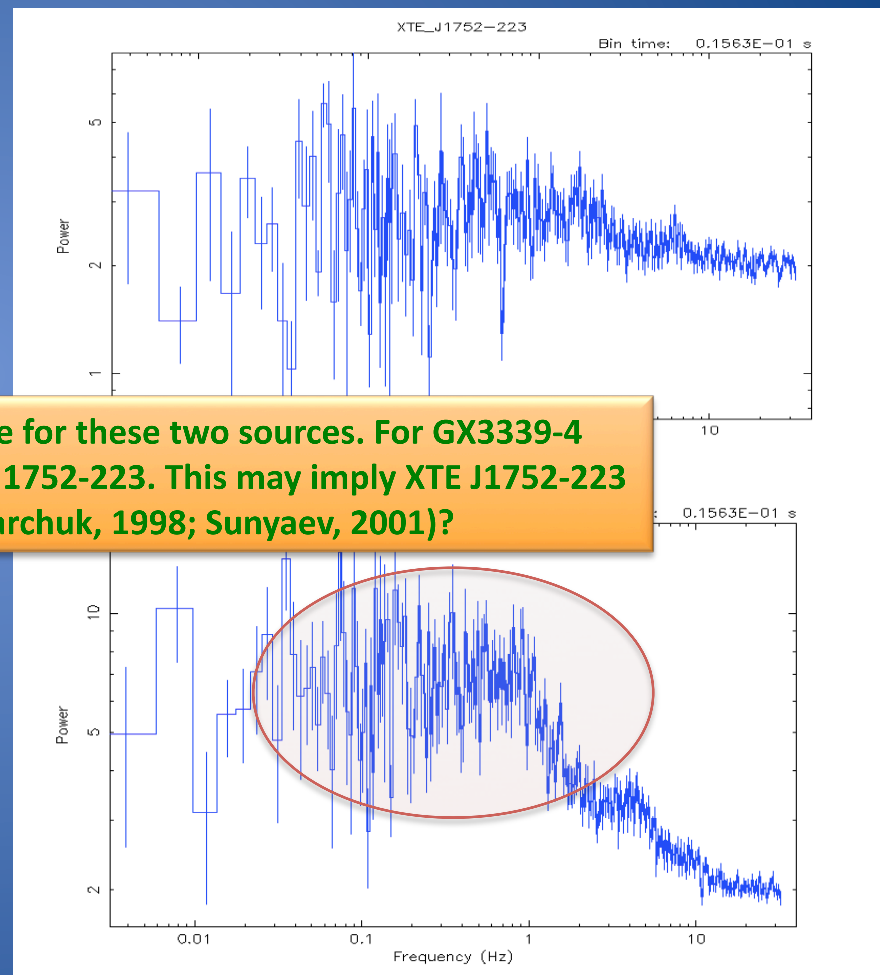
Green line: 07.06.2010
Blue line: 09.06.2010

During the State Transition from IS to HS, the low frequency parts are increased. This behavior is quite similar to XTE J1752-223. But …

Comparison the State Transition between GX339-4 and XTE J1752-223

Red line: GX339-4 Blue line: XTE J1752-223

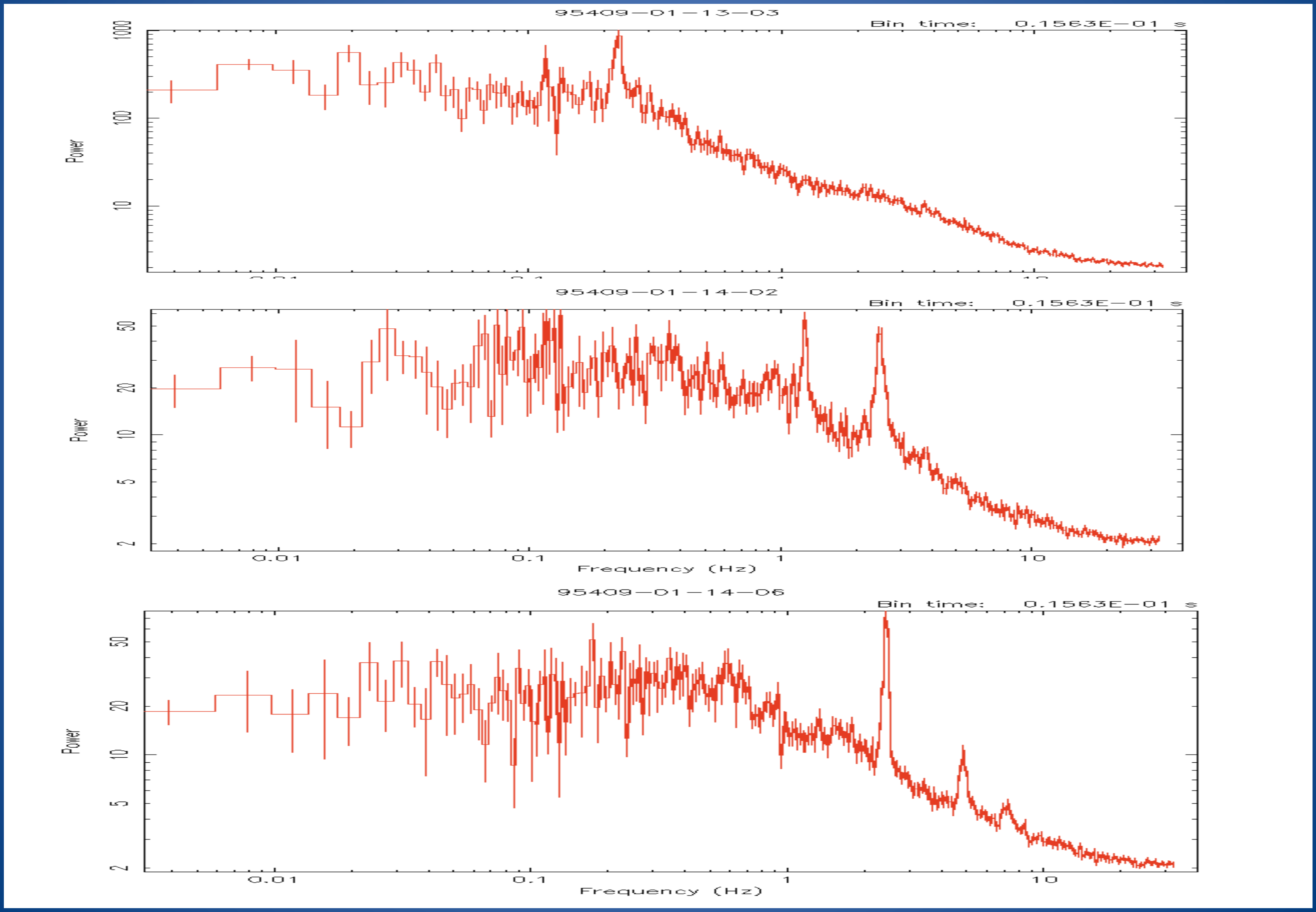




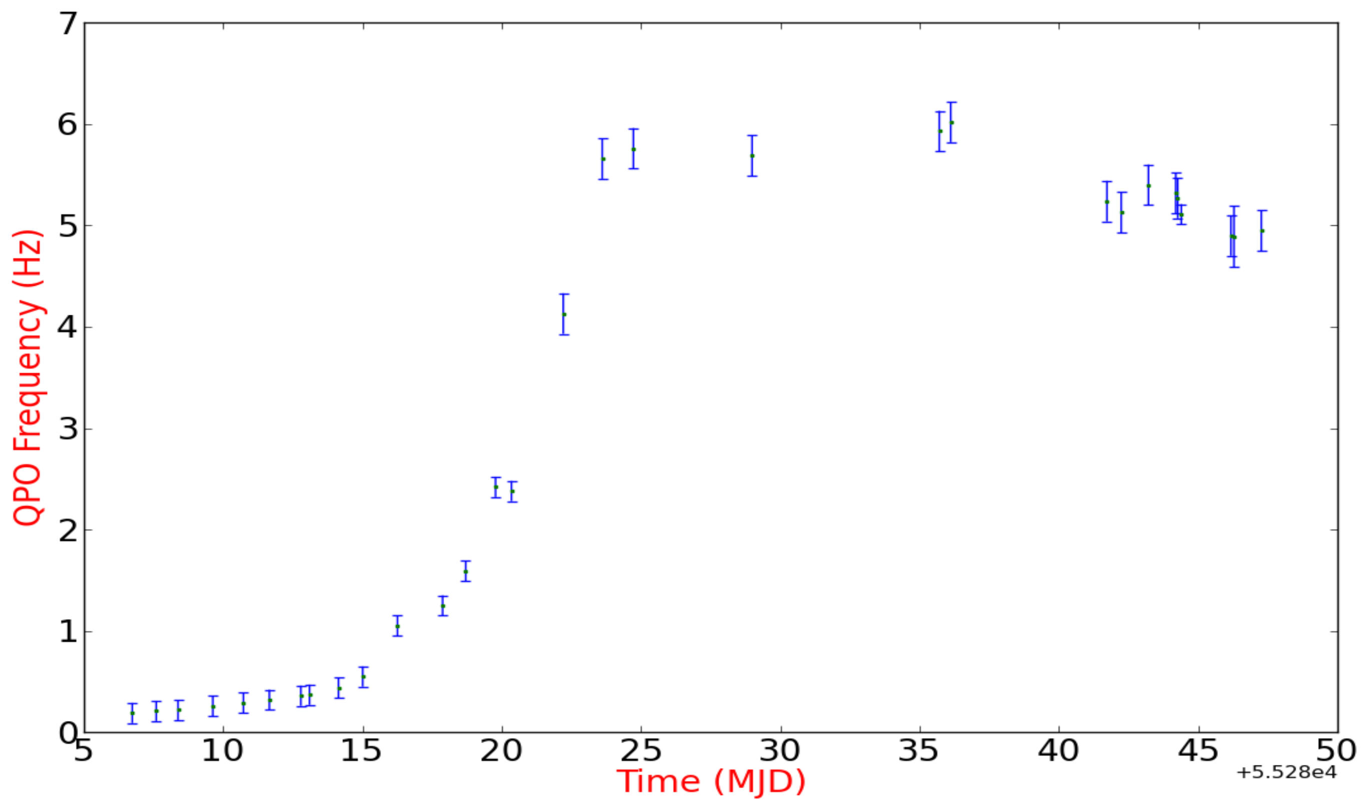
But the increased part is not the same for these two sources. For GX3339-4 the increased part is lower than XTE J1752-223. This may imply XTE J1752-223 has different mass than GX339-4 (Titarchuk, 1998; Sunyaev, 2001)?

L. Titarchuk, 1998, ApJ 499, 315
R. Sunyaev, 2001, ESO Astr. Sym. DOI: 10.1007/b75143

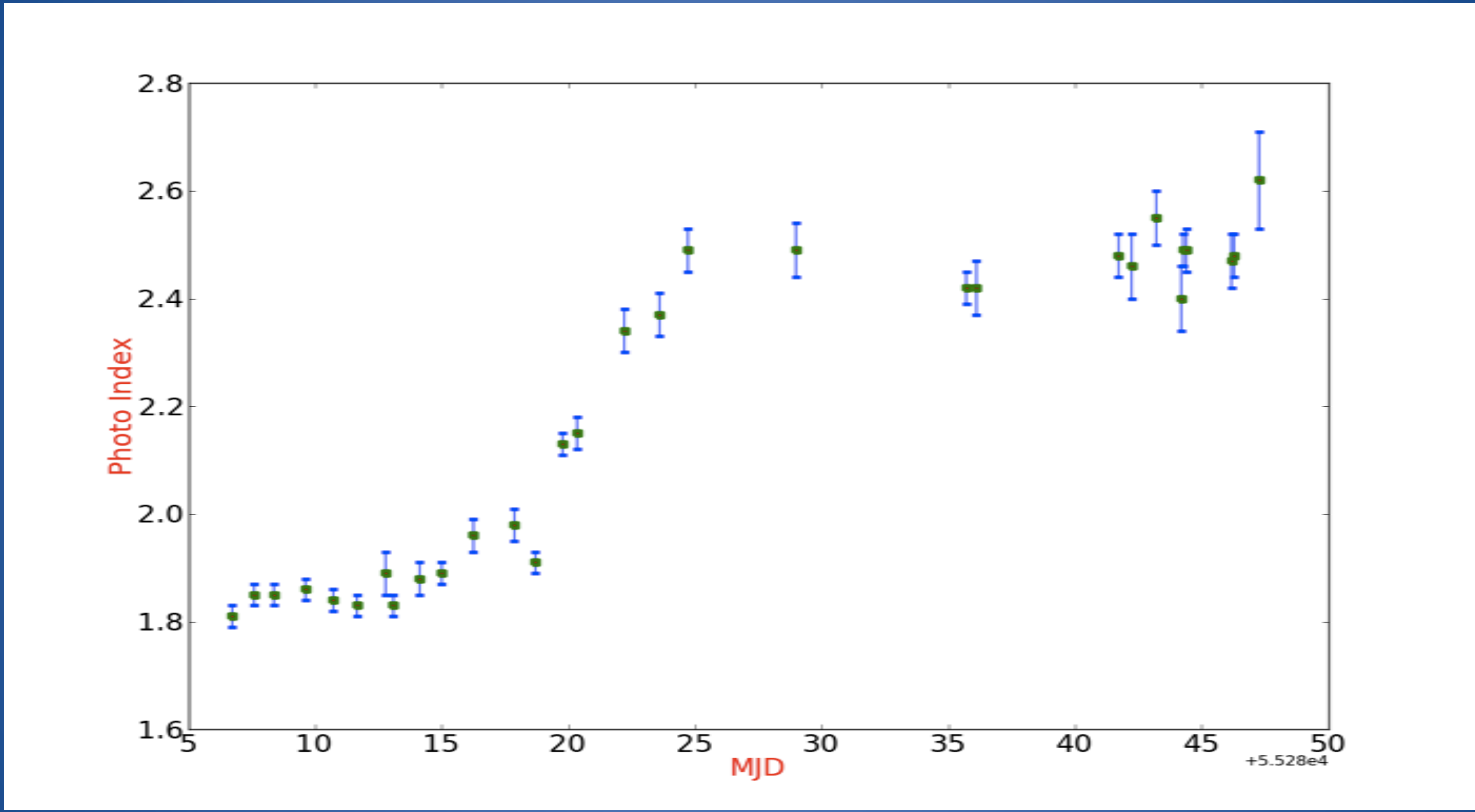
Quasi-Periodic Oscillations (QPO) on GX339-4



The change of QPO frequency

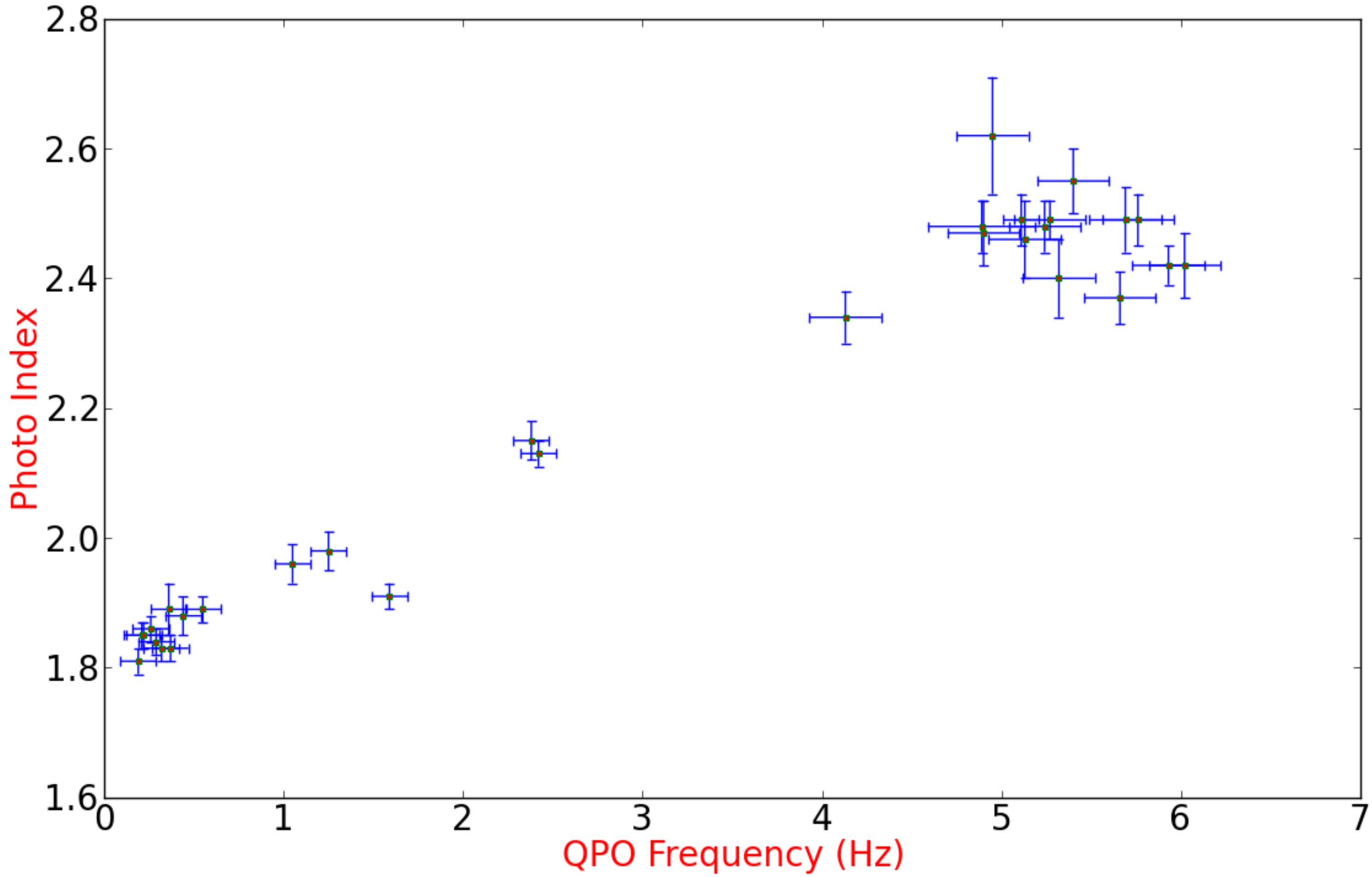


Spectral Analysis



For the low-hard state, the spectra are fitted by the model of Exponentially cut-off power law reflected from ionized matter (pexriv) and a Simple Gaussian line profile; for intermediate state we use a simple photon power law, a blackbody disk and a Gaussian. For both case the Photon-electric absorption is frozen to $0.53 \times 10^{22} cm^{-2}$

Correlation Between Photon Index & QPO Frequency



Determination of The Mass of Black Hole

Shaposhnikov & Titarchuk (2006) have shown that correlations during state transitions can be used to estimate BH mass. This method is named scaling method. The scaling method relies on the theoretically motivated and observationally tested assumption that the QPO frequency for a particular accretion state of BHB system is set by the BH mass.

Shaposhnikov N., & Titarchuk L., 2006, ApJ, 699, 453

Scaling Method

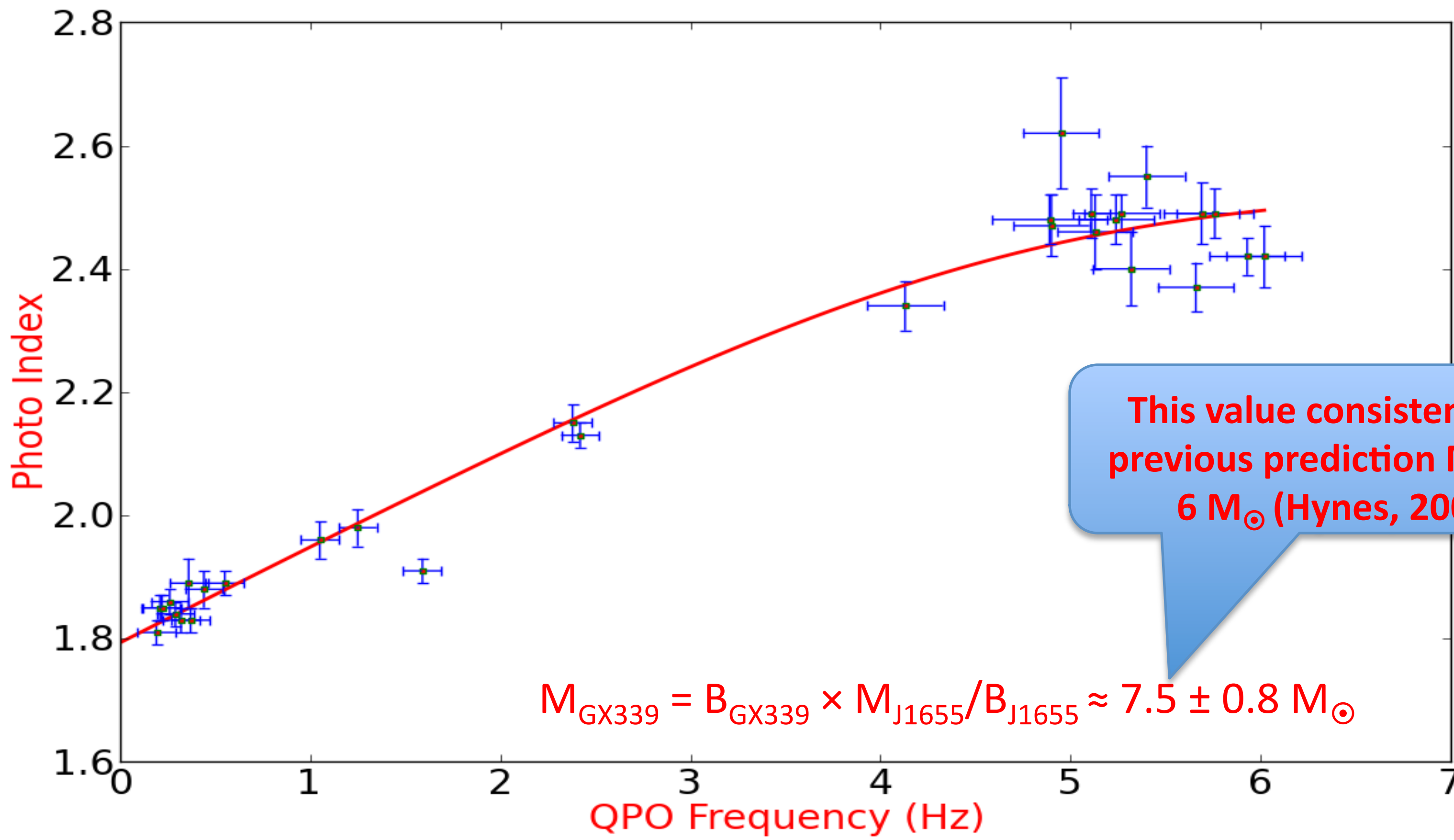
The correlation between photon index and QPO frequency can be well fit by a analytical function:

$$f(\nu) = A - DB\ln[\exp(\frac{\nu_{tr} - \nu}{D}) + 1]$$

For determination of the BH's mass M_{BH}, the parameter B_{BH} should be knew. It can be obtained by fitting of correlation between photon index and QPO frequency with above function. Next step is to compare this value with a standard source, which has a well-known mass. GRO J1655-40 (which commonly used for this method. Its mass was known by optical method) was used for this purpose. Finally, the mass of the BH can be estimated by a simply equation:

$$M_{BH} = B_{BH}\frac{M_{J1655}}{B_{J1655}}$$

The mass of GX339-4



This value consistent with previous prediction $M_{GX339} \geq 6\ M_{\odot}$ (Hynes, 2003).

Hynes R.I. et. al., 2003, ApJ, 583, L95

Conclusion

- A full analysis of XTE J1752-223 and GX339-4 has been done.
- Some interesting timing behavior has been found on the new source XTE J1752-223 (increase of char. freq., the high value of RMS) , which also be seen on the other BHBs (GX339-4).
- The state transition has been found on XTE J1752-223. By comparing the state transition (between IS and HS) between XTE J1752-223 and GX339-4 we see a similar PDS change during the transition, but the change is not completely the same, we assume that if XTE J1752-223 source is a BHB, then it should have a different mass than GX339-4 (recently, Shaposhnikov (2010) determined the mass of XTE J1752-223 equal $9.6 \pm 0.9\ M_{\odot}$).
- The Scaling Method has been introduced, which can be easily used to estimate the mass of BH.
- The mass of GX339-4 has been estimated by Scaling Method ($7.5 \pm 0.8\ M_{\odot}$) based on its 2010's outburst, which well consist with the previous prediction.

Plan for next year

- To estimate the masses of BH candidates, which have not known yet its mass, for proving if they are real BH or not.
- To estimate the masses of BH candidates, which have already known, for improving the method.
- To study all the features shown on PDS, and correlations with the spectral parameters. This give us a way to understand the origin of variability (timing properties) and their connection with the different X-ray emitting media and the jet.
- To investigate the energy dependence of PDS.