Spectral and Timing Studies of the X-ray transient MAXI J1348-630 using *NICER* and *AstroSat*

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MNRAS, Accepted on 5 May 2021 (arXiv: 2105.03066)
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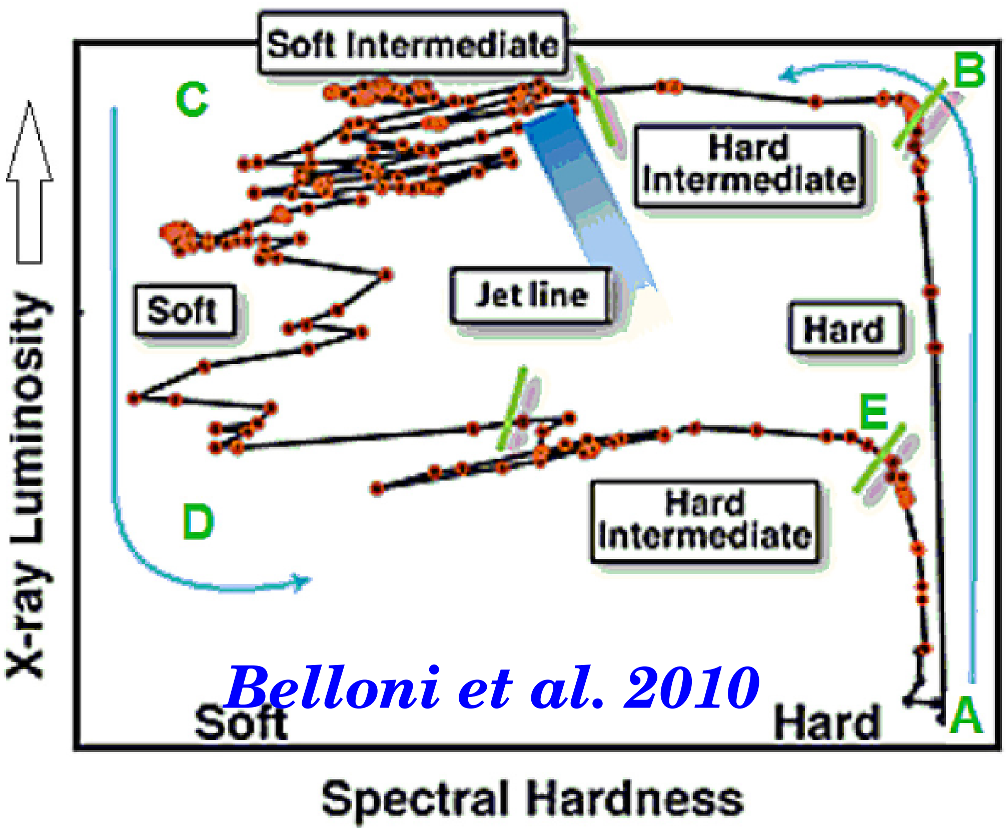
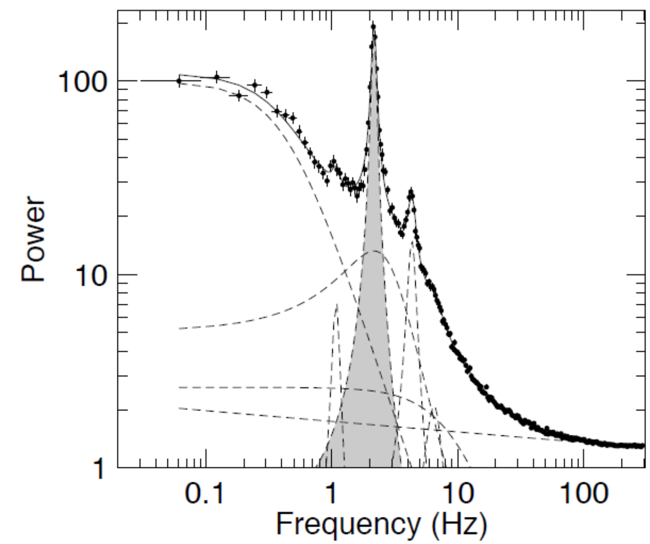
BH Transients & Rapid Variability

HID for BHXRBs



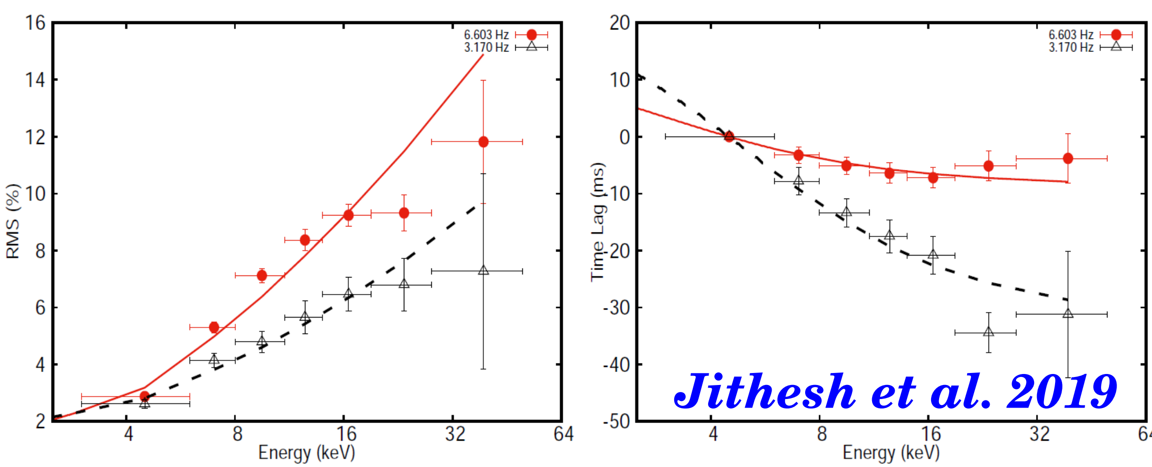
- ***RXTE*** **(1996 -2012): The workhorse in the field of rapid time variability of X-ray binaries.**
- **LAXPC: Contributing to the rapid time variability studies in the hard energy band.**
- ***AstroSat*** **& black hole X-ray binaries:**

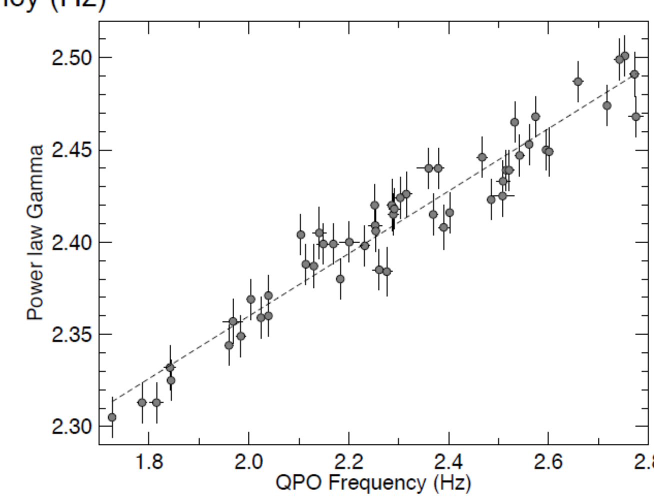


MAXI J1535–571

Bhargava et al. 2019

Swift J1658.2–4242

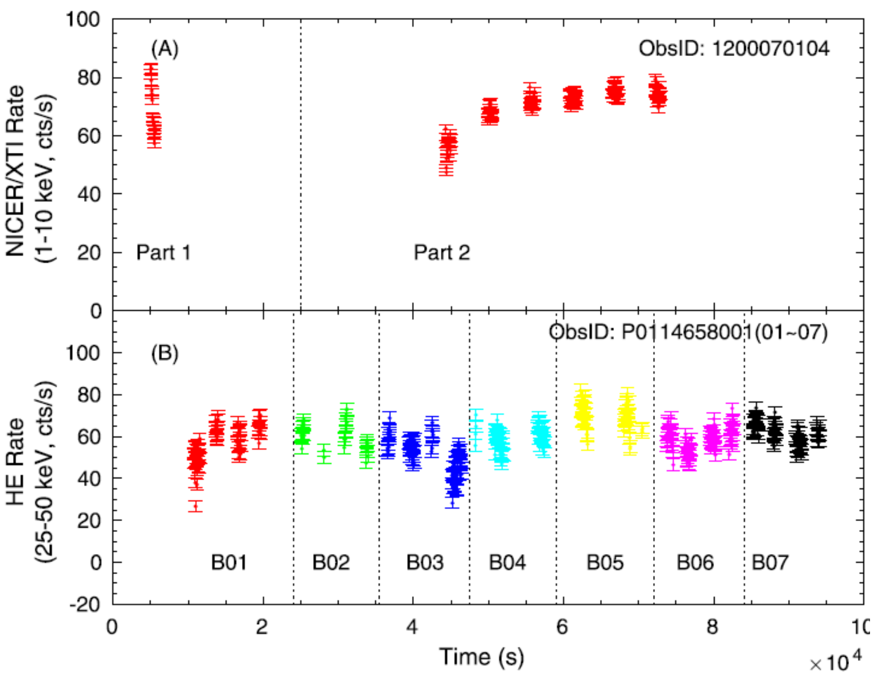




Broadband Rapid Variability

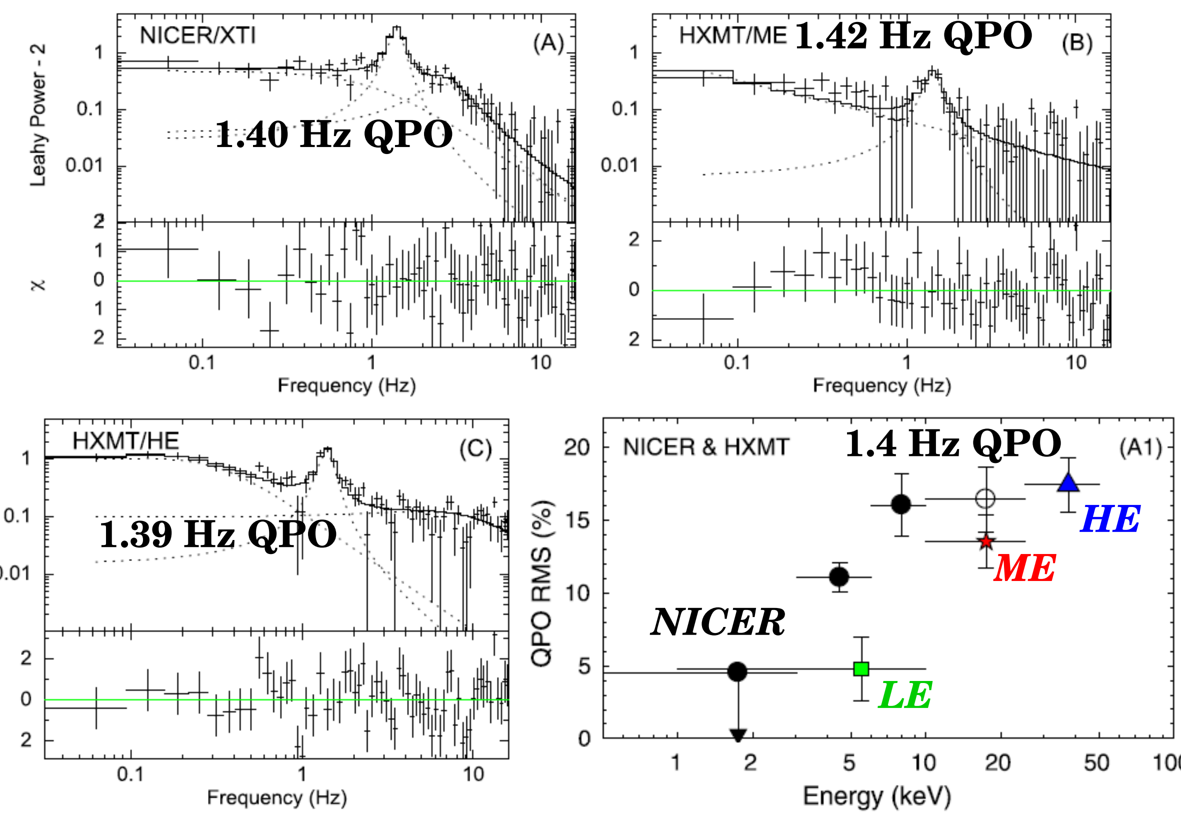
- **The soft X-ray (< 4 keV) rapid timing properties were largely unknown.**
- **Now explored using the X-ray Timing Instrument (XTI) onboard *NICER*.**
- **Broadband (0.3–30 keV) fast timing properties have been relatively less studied.**

Swift J1658: *HXMT & NICER*



Xiao et al 2019

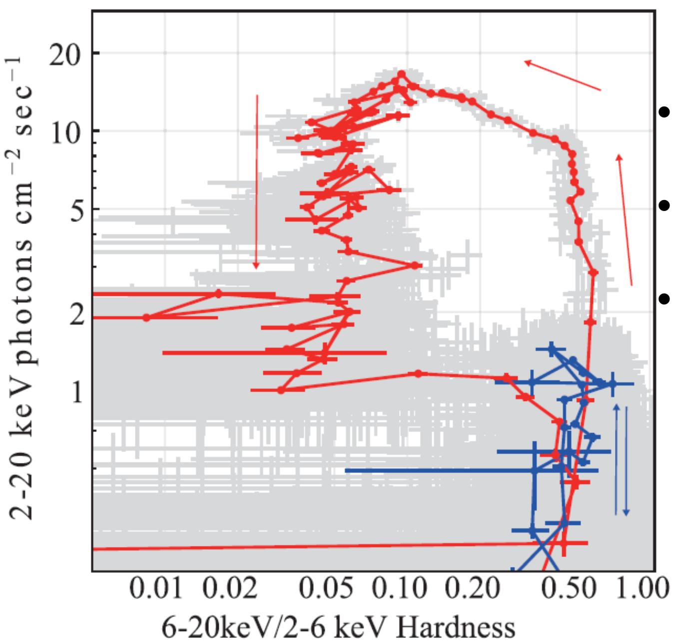
Broadband Rapid Variability



MAXI J1348-630

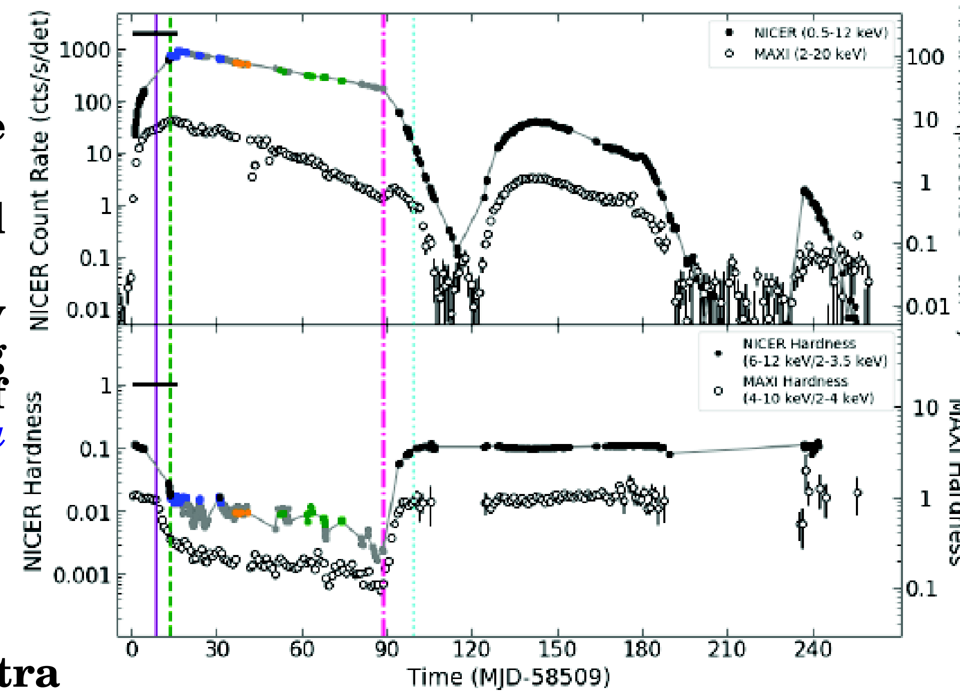
- **New X-ray transient discovered by the *MAXI*/GSC on 2019 January 26 (*Byatabe et al 2019*).**
- ***Swift* XRT position: R.A. = 13:48:12.73, Decl. = -63:16:26.8 (*Kennea & Negoro 2019*).**

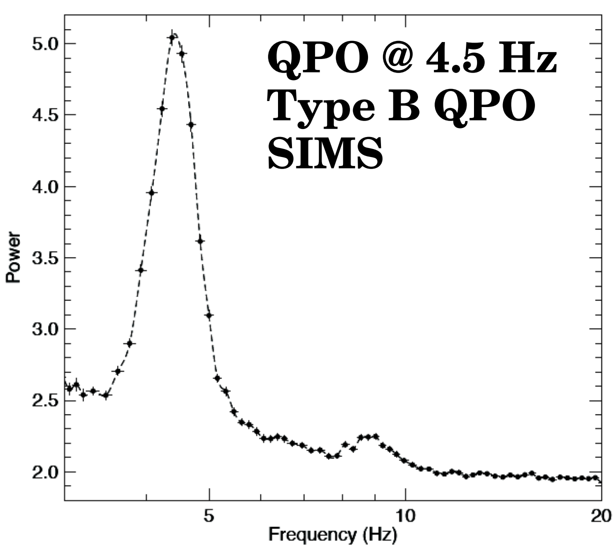
MAXI/GSC HID



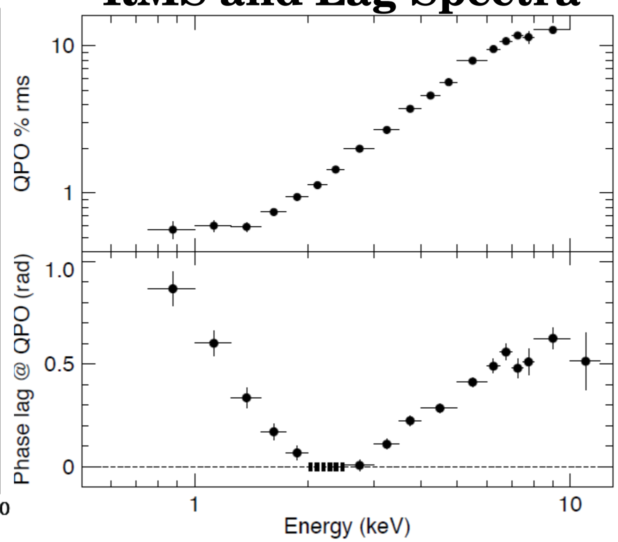
- **A new black hole X-ray binary.**
- **Continuum model fitting**
- **Host a relatively massive spinning BH with a mass of ~ 16$M_\odot$(*Tominaga et al. 2020*).**

NICER Light Curve





RMS and Lag Spectra



Black = Noise, Type-C QPO
Blue = Type B QPO
Orange = Type A QPO
Green = Noise, 18 Hz QPO in SS
Gray = Little power
Purple solid line: hard-to-soft transition
Green dashed line: enters the SIMS
Pink dash-dot line: soft-to-hard transition
Cyan dotted line: goes back to the HS

Belloni et al. 2020, Zhang et al 2020

AstroSat & *NICER* Observations

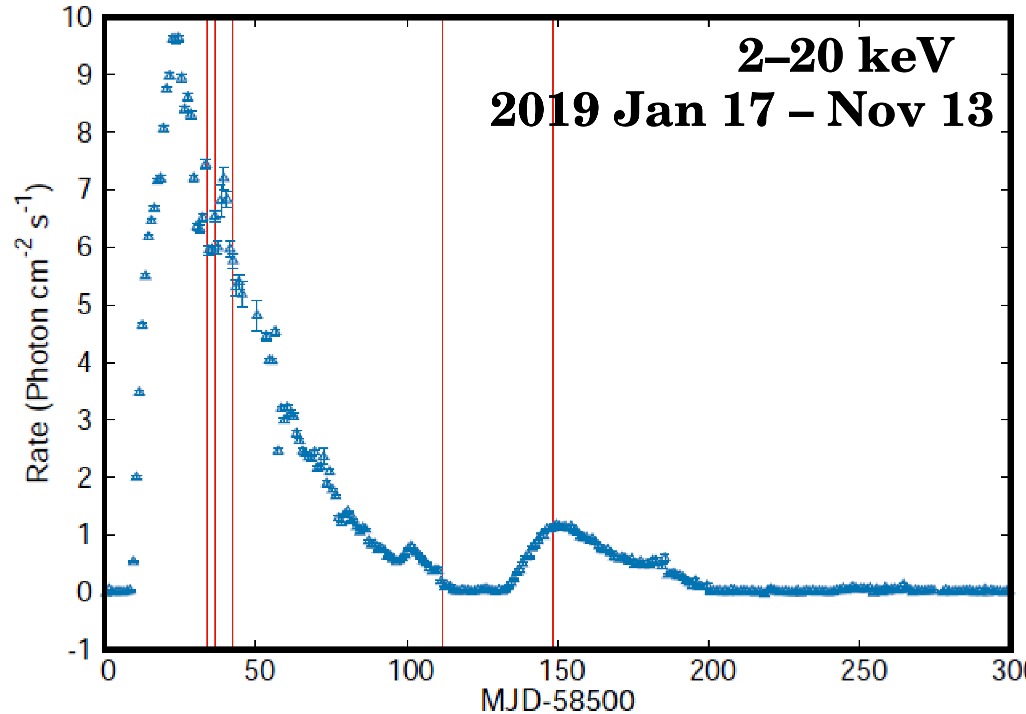
AstroSat

- India's First dedicated astronomy satellite
- LAXPC (3-80 keV): Timing resolution ~ 10 microseconds
- SXT (0.3-8 keV)

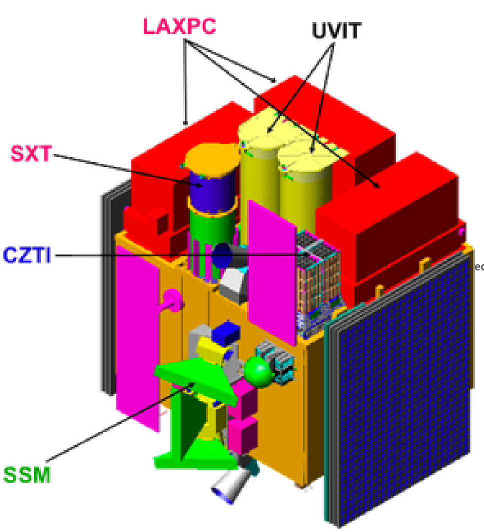
NICER

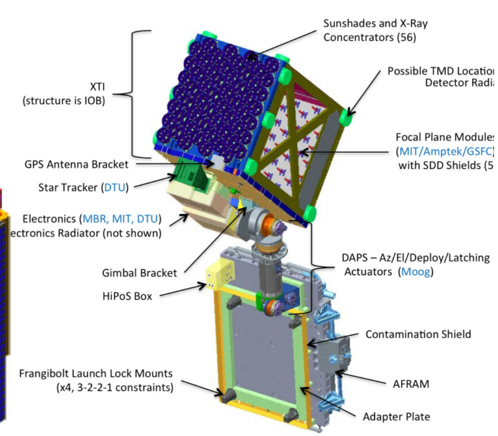
- International Space Station payload installed in 2017.
- X-ray Timing Instrument (XTI): Operate in the soft X-ray band, 0.2-12 keV
- Effective area: 1900 cm^2
- Absolute timing precision of ~100 ns.

MAXI Light Curve of MAXI J1348-630



AstroSat   *NICER*





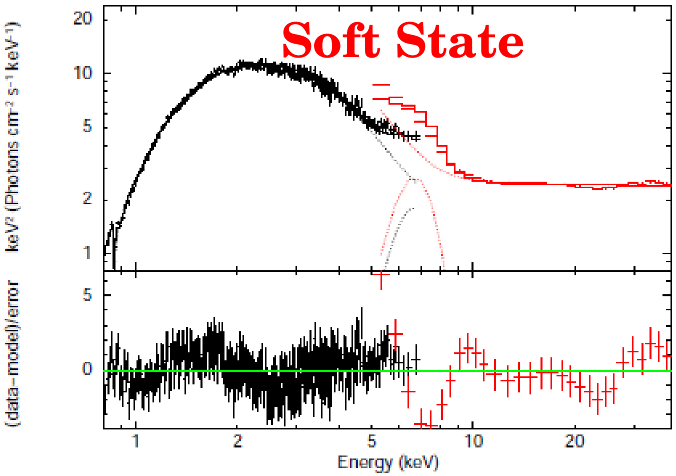
Observation Log

Data	ObsID	Date	Exposure (ks)
AS1	T03_083T01_9000002722	2019 February 19–20	5.5(L)/1.9(S)
N1	1200530118	2019 February 19	5.0
AS2	T03_083T01_9000002728	2019 February 22	20.2(L)/11.1(S)
N2	1200530121	2019 February 22	2.5
AS3	T03_083T01_9000002742	2019 February 28	23.2(L)/12.2(S)
N3	1200530127	2019 February 28	2.8
AS4	T03_112T01_9000002896	2019 May 8–9	13.8(L)/6.8(S)
N4	2200530133	2019 May 9	1.9
AS5	T03_120T01_9000002990	2019 June 14–15	35.0(L)/14.9(S)
N5	2200530154	2019 June 14	1.8
N6	2200530155	2019 June 15	1.6

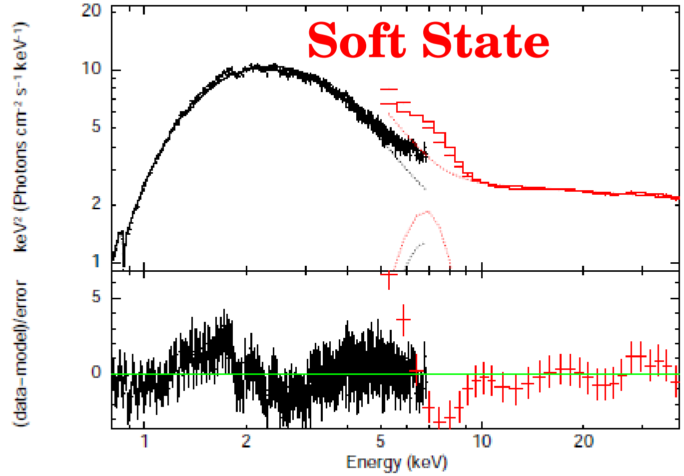
Broadband X-ray Spectral Properties

SXT : 0.8-7 keV, LAXPC: 5-40 keV **Model: Tbabs*(simpl*diskbb+gaussian)**

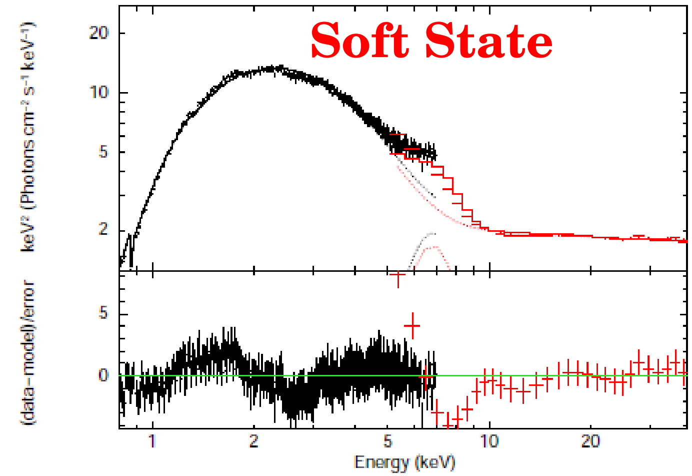
AS1



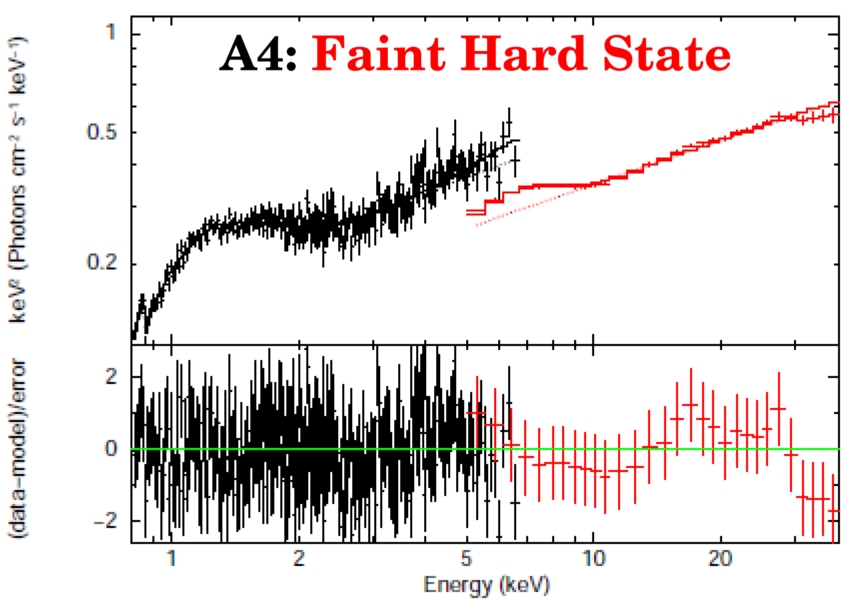
AS2



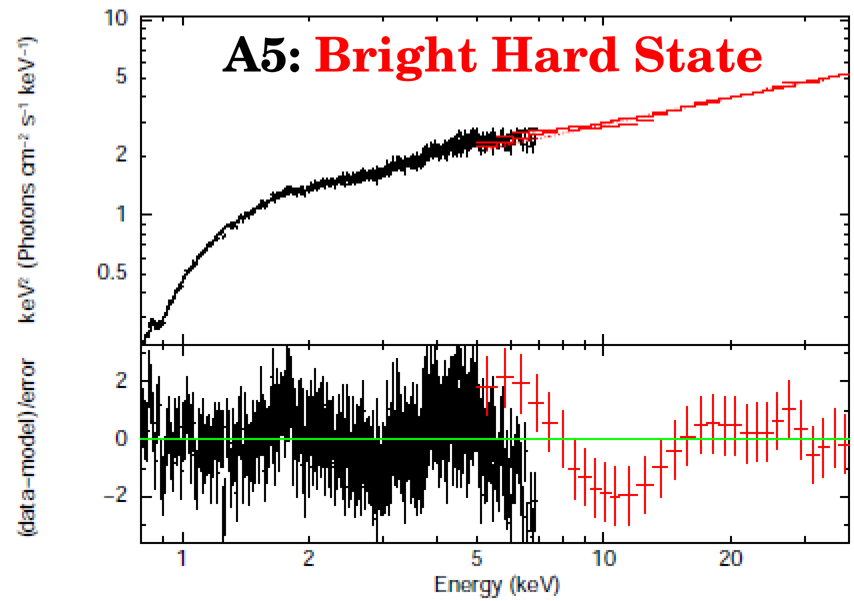
AS3



Soft state: Index ~ 2.1, kTin ~ 0.8 keV, Flux = 36.3 – 47.5*10^{-9} erg/cm²/s, F_D/F_T ~ 0.8



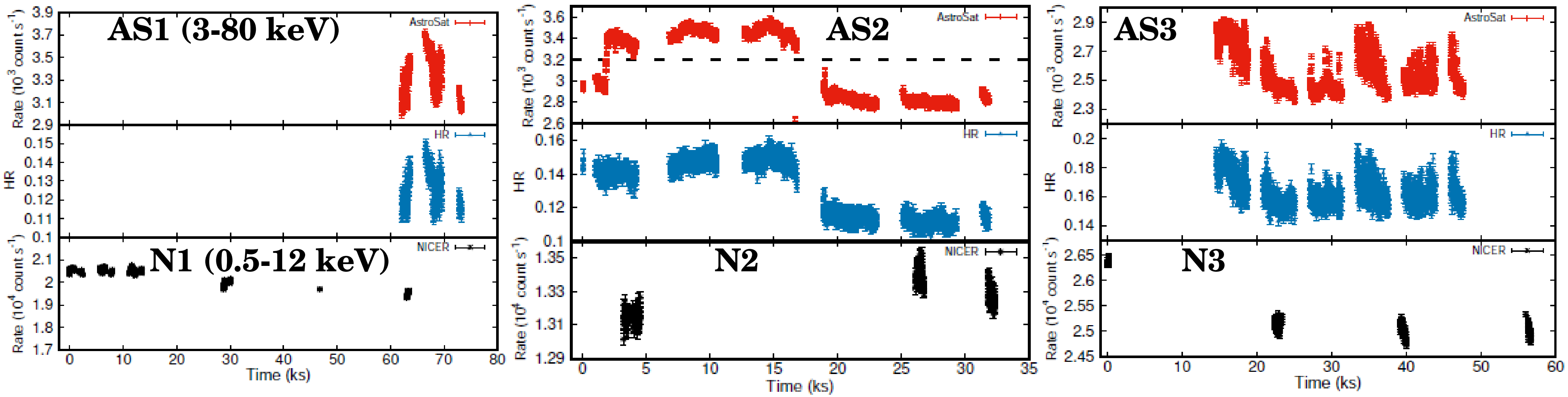
Index = 1.57, kTin = 0.27 keV
Flux = 3.2*10^{-9} erg/cm²/s, F_D/F_T ~ 0.15



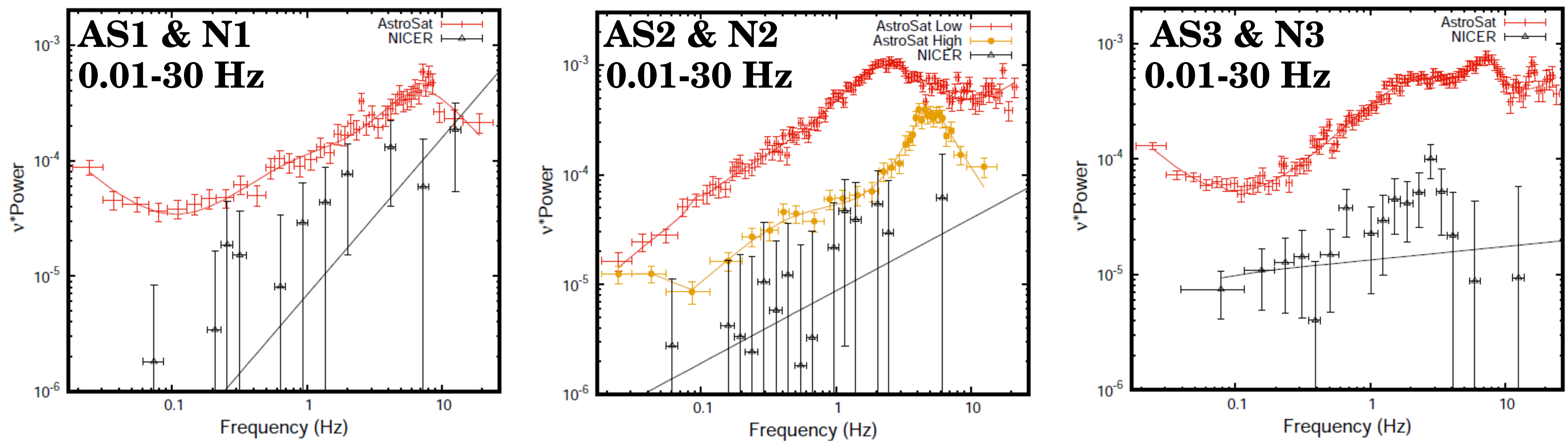
Index = 1.55, kTin = 0.33 keV
Flux = 18.1*10^{-9} erg/cm²/s, F_D/F_T ~ 0.09

Broadband Timing: Soft State

AstroSat LAXPC and *NICER* Light Curves



Power Density Spectrum (PDS)

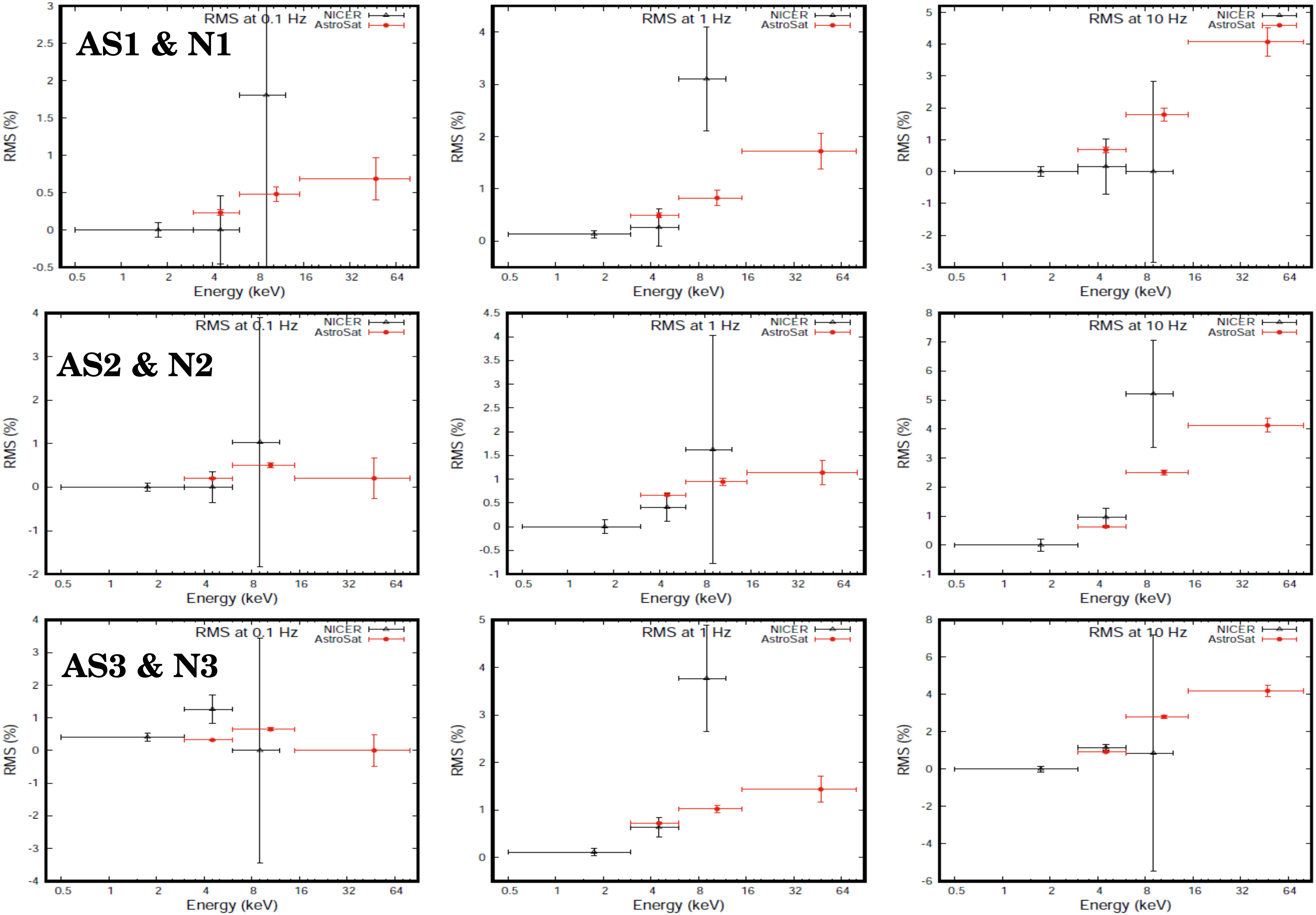


- **LAXPC PDS (3-15 keV).**
- **Fitted with multiple Lorentzians.**
- **NICER PDS (0.5-12 keV).**
- **Fitted with power law.**

The difference in variability suggests a strong energy dependence of the fractional rms.

- **QPO at ~ 6.85 Hz in AS3.**
- **Width ~ 3.80 Hz.**
- **The Q-factor is ~ 1.8.**
- **The rms is < 2%.**

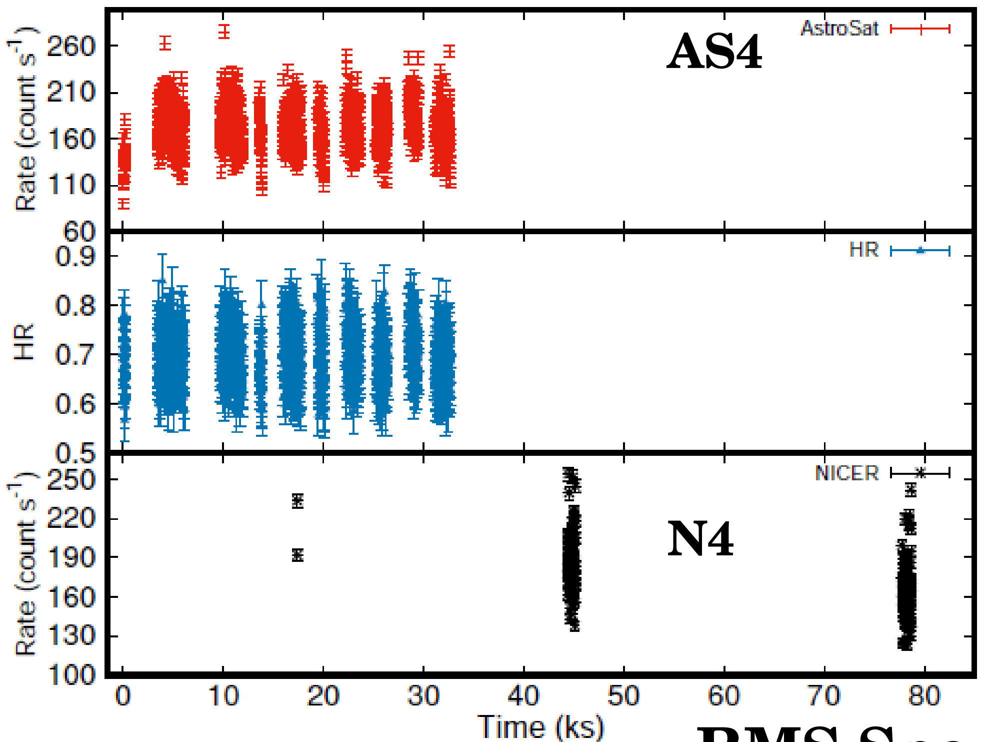
RMS Spectra



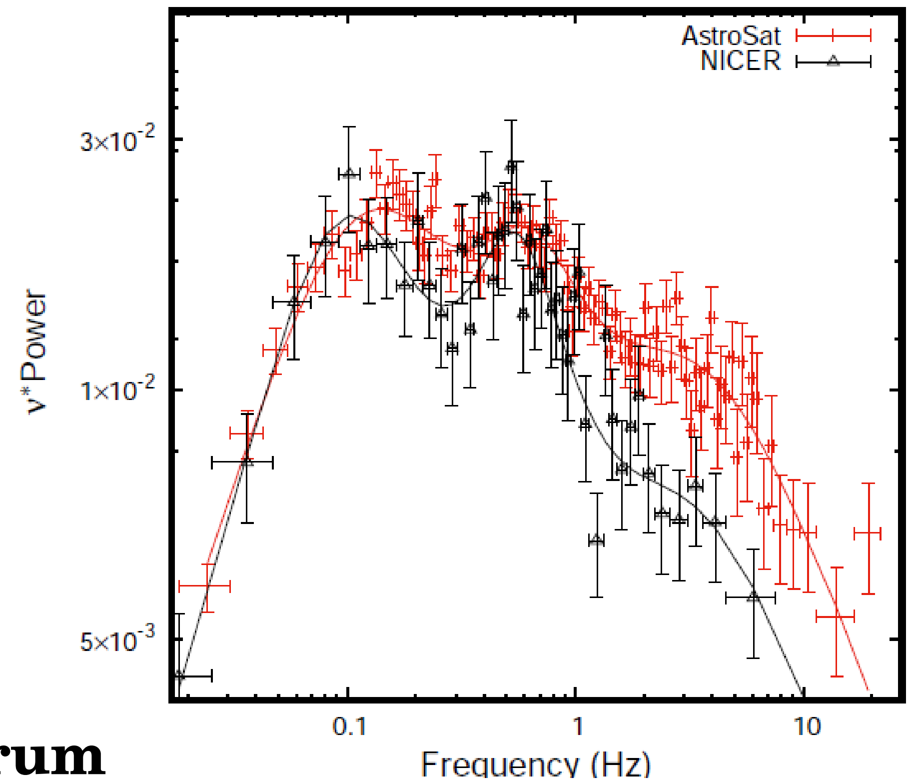
The disk emission is non-variable while the Comptonized component rapidly varies.

Broadband Timing: Faint Hard State

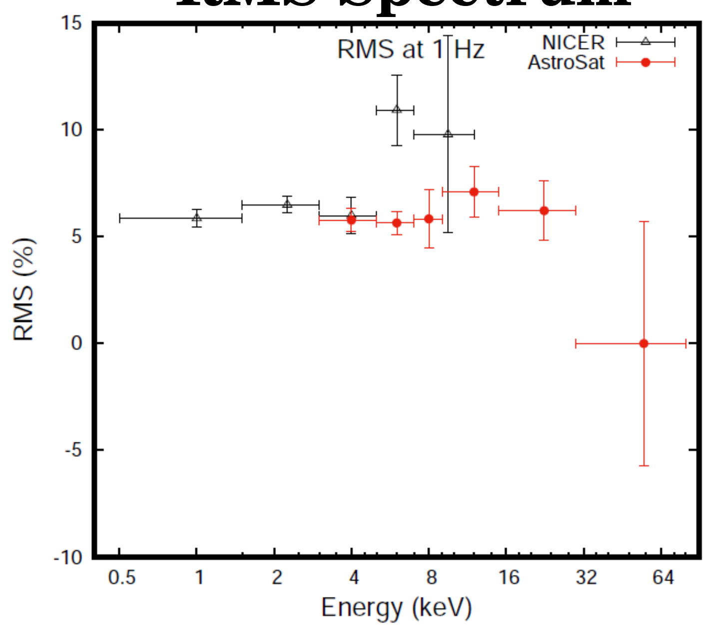
Light Curves



PDS



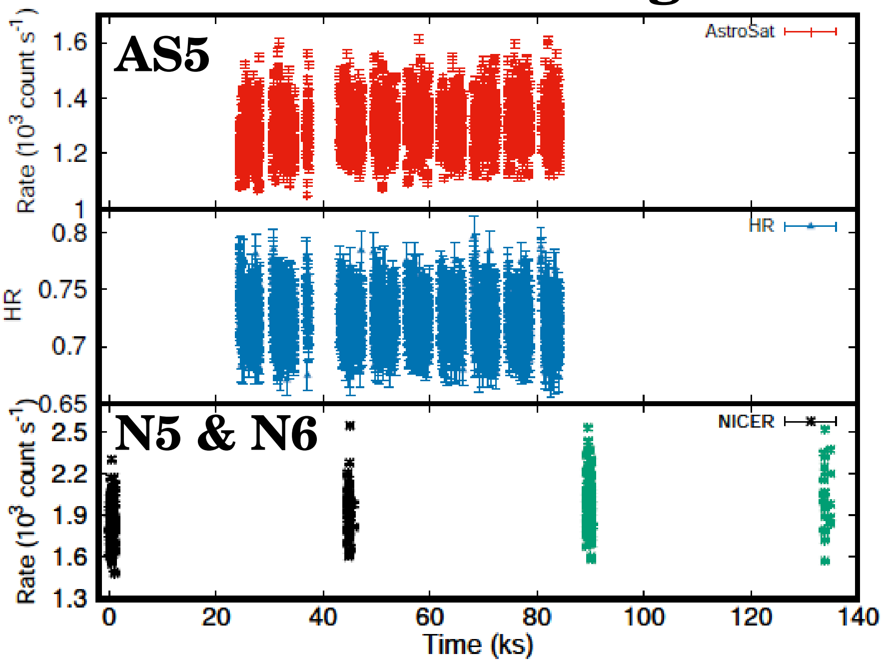
RMS Spectrum



- **Both PDS are similar**
- **Enhanced variability in the higher energy LAXPC band for frequencies > 2 Hz.**
- **The variability is nearly a constant at ~ 7%.**

Broadband Timing: Bright Hard State

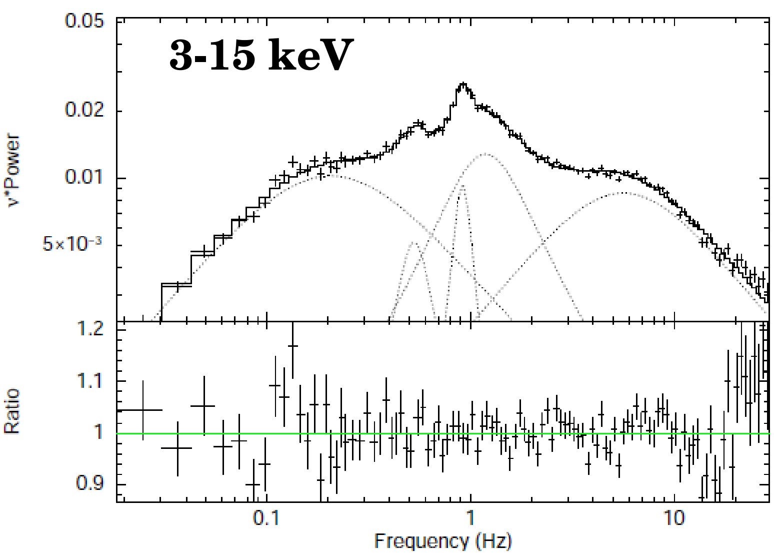
LAXPC and *NICER* Light Curves



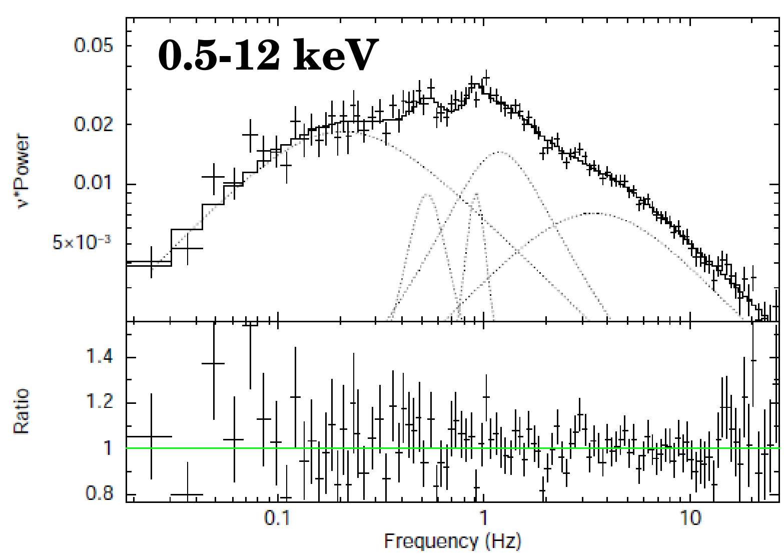
- **The source exhibited a re-flare after main outburst.**
- **Intensity increased from 200 c/s (AS4) to 1300 c/s (AS5).**
- **Bright hard state.**

Power Density Spectrum

AstroSat



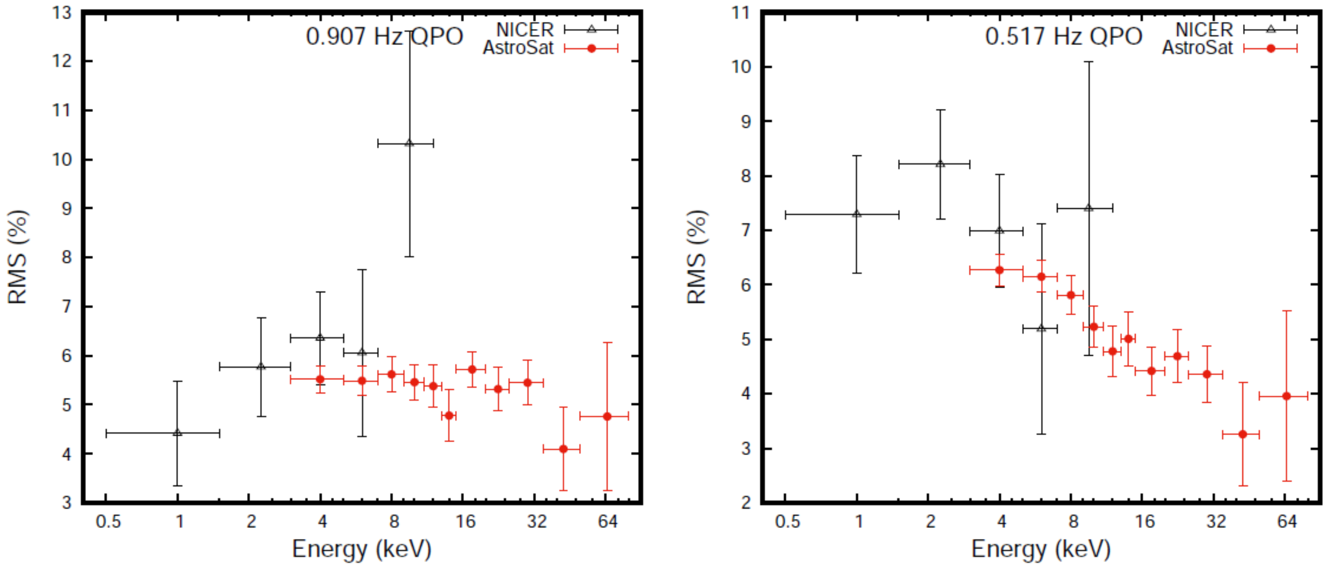
NICER



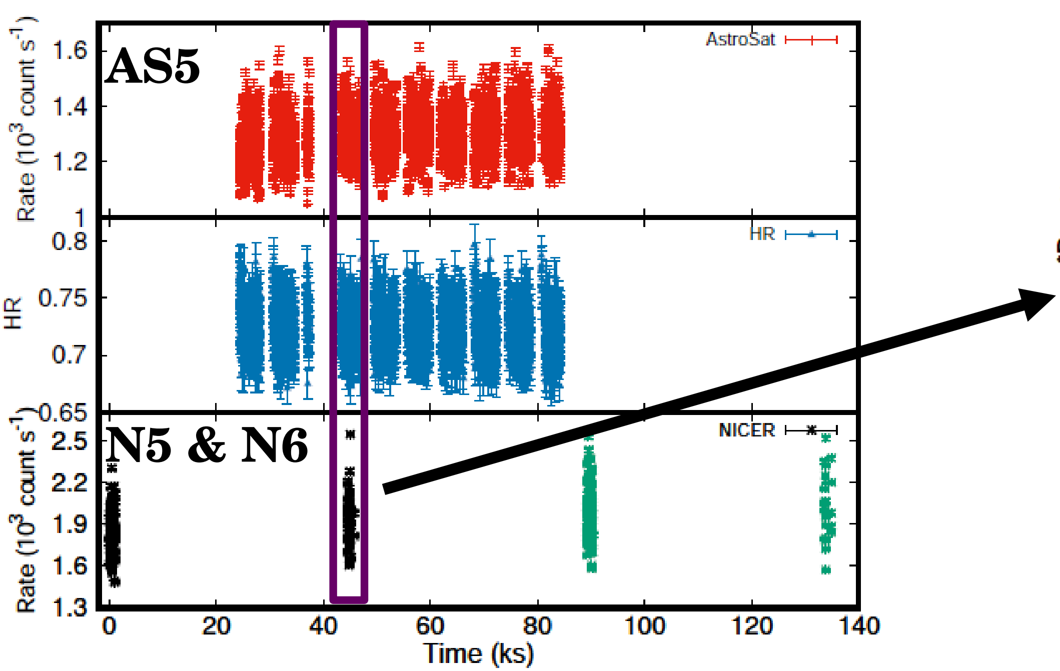
- **The *NICER* PDS shape is similar to that of LAXPC.**
- **But changes in relative strengths of the components.**
- **QPO at ~ 0.9Hz**
- **RMS ~ 6%, Q factor ~ 4.7**
- **Type-C QPO**
- **Sub-harmonic at ~ 0.5 Hz**

Broadband Timing: Bright Hard State

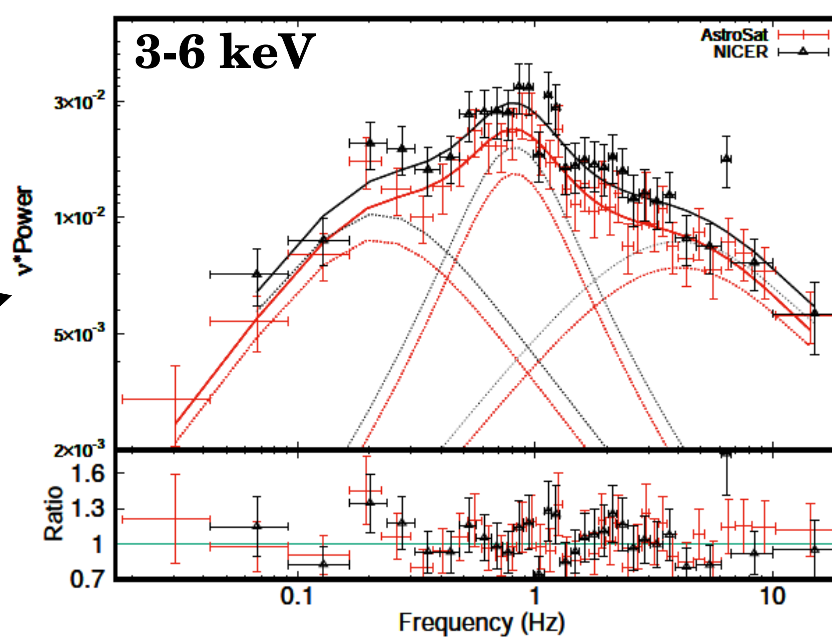
RMS Spectra of QPO and sub-harmonic



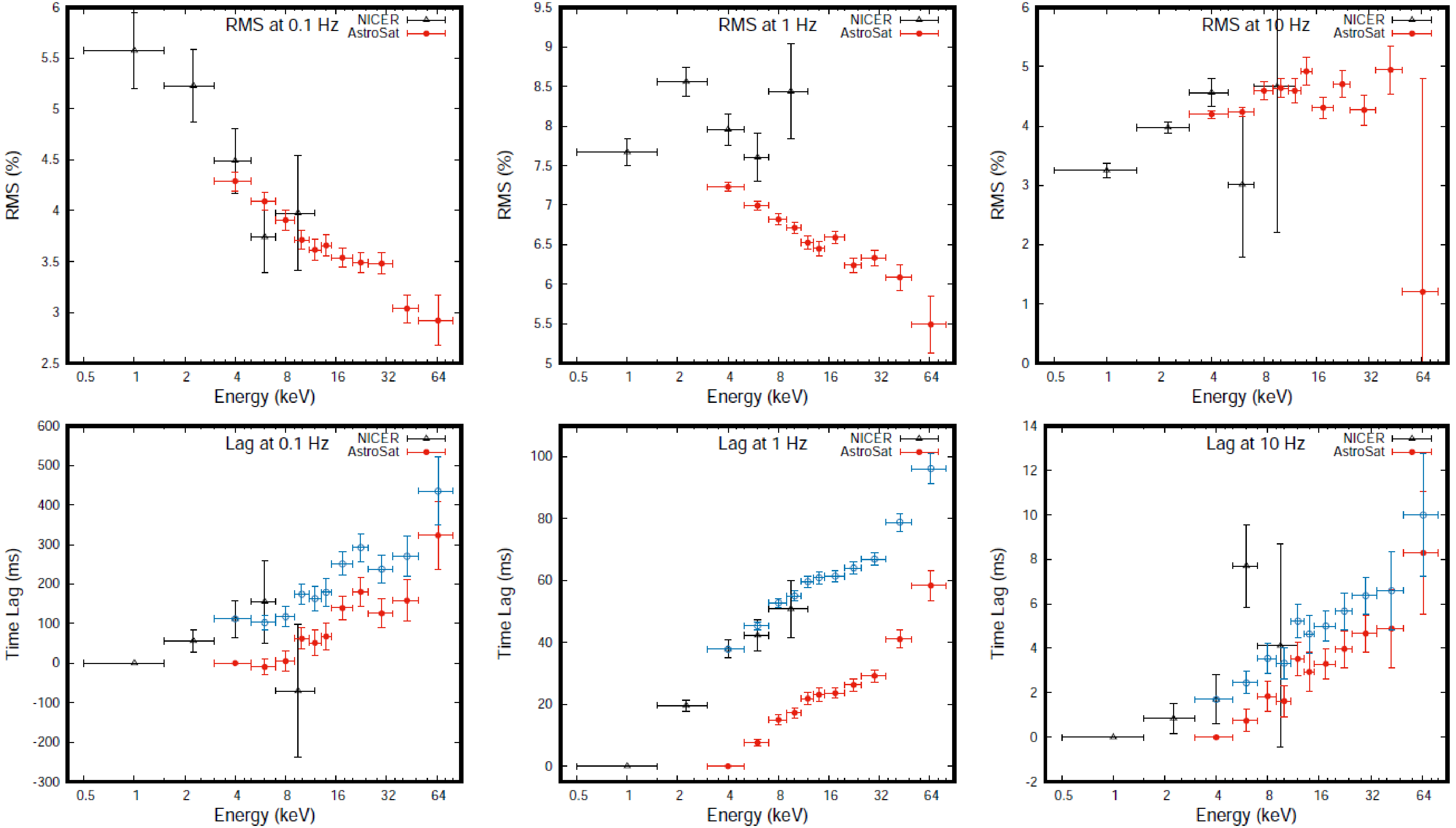
- **Strength of the primary QPO is nearly energy independent.**
- **For the sub-harmonic rms decreases with energy.**
- **The slight difference in the temporal behaviour seen between LAXPC and *NICER*.**



PDS from Strict Simultaneous Data



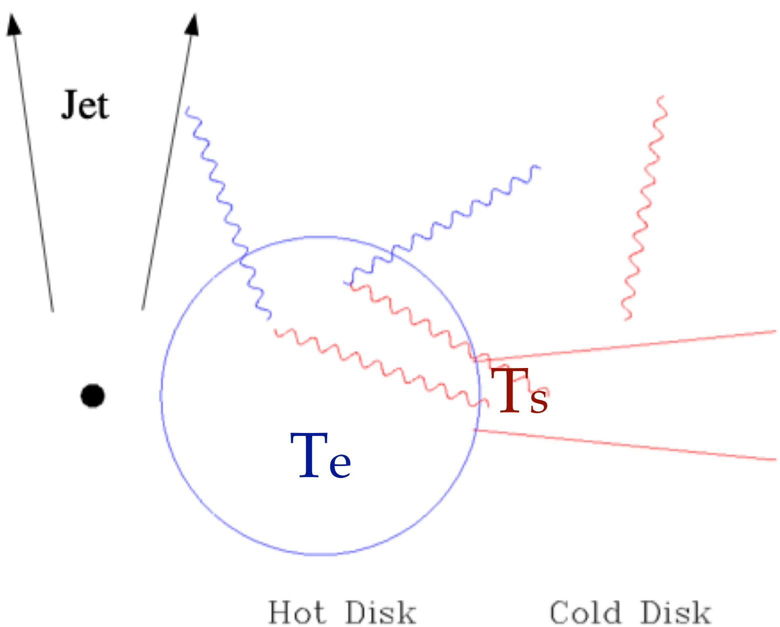
RMS and Lag Spectra



- **The rms is seen to decrease with energy for ~ 0.1 and ~ 1 Hz.**
- **For ~ 10 Hz, rms marginally increases with energy.**
- **Lag increases with energy: Hard time lag.**

Single Zone Stochastic Propagation Model

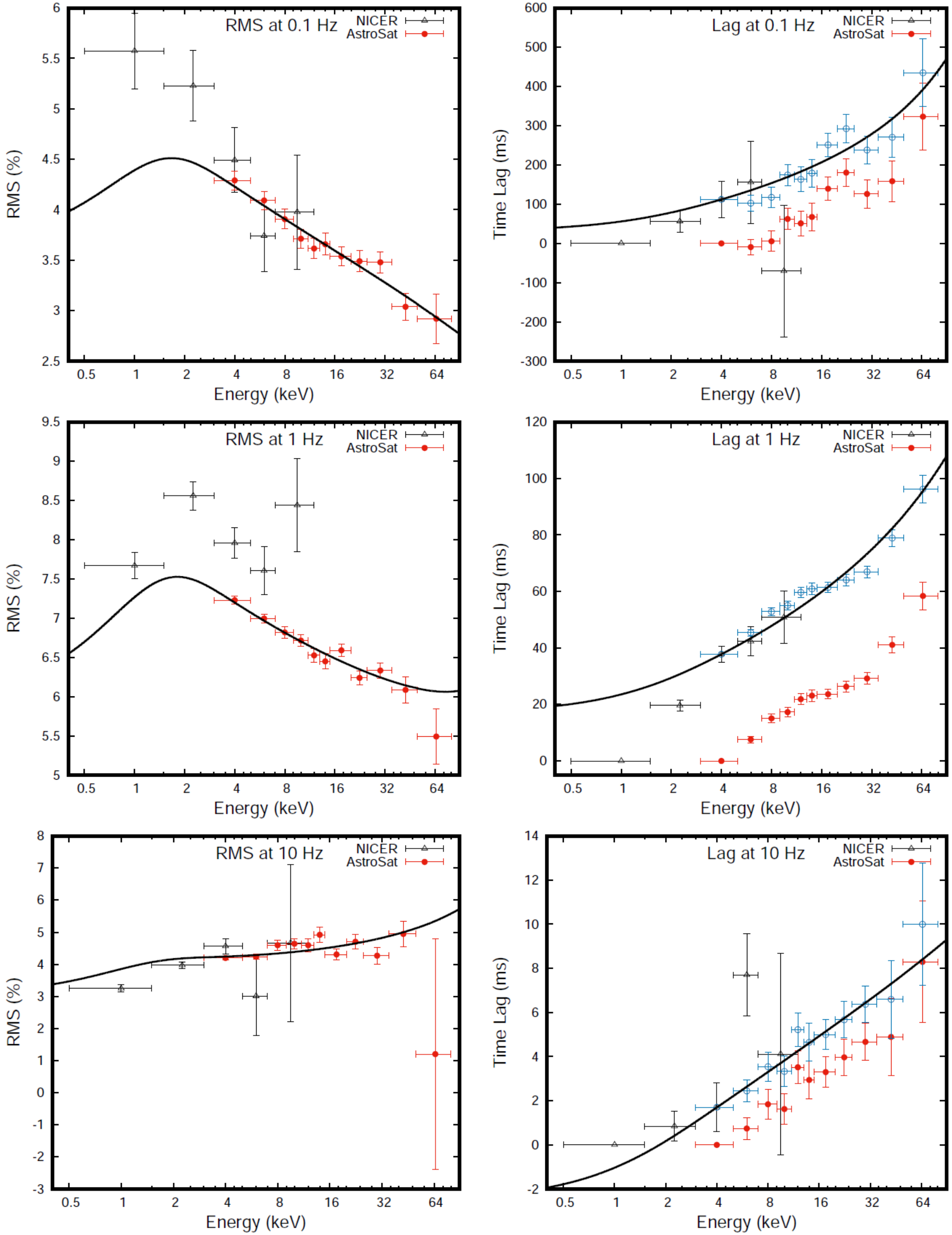
Geometry



Maqbool et al 2019

- **The primary model to explain the energy dependent variability.**
- **Geometry: A truncated standard disk characterised by a inner disk temperature T_s , with a hot inner flow having a single uniform temperature T_e.**
- **The inner flow Compontonizes photons from the truncated disk to produce the observed hard X-ray emission.**
- **An oscillation which originates in the outer regions causes the temperature of the truncation radius to vary causing variations in the Comptonized spectrum.**
- **The perturbation reaches the inner region after a time delay causing a change in the electron temperature of the inner region and hence a variation in the spectrum.**

Modelling RMS & Lag Spectra using Stochastic Propagation Model



- **Quantify the energy dependent fractional rms and time-lags.**
- **Three parameters: The normalised variations of**

a) The Seed Photon Temperature δT_{in}

b) The hot inner flow temperature δT_e

c) The Phase-angle between them $\phi_D = 2\pi f \tau_D$

- **For fitting, we have used the parameters:** δT_e **,** τ_D**,** $\delta T_{\rm in}/\delta T_{\rm e}$

- **Model is applicable only to the thermal Comptonized component.**
- **Formally fit the LAXPC data alone.**
- **Extrapolate the predicted variability to low energies to compare with the *NICER* results.**
- **The predicted rms and time lag are qualitatively similar but quantitatively different from *NICER* results, especially at ~ 1 Hz.**

Freq	$\delta T_{\rm in}/\delta T_{\rm e}$	τ_D	$\delta T_{\rm e}$	$\chi^2_{\rm r}$/d.o.f
0.08-0.12	$1.09^{+0.10}_{-0.09}$	$342.26^{+60.77}_{-60.51}$	$0.011^{+0.001}_{-0.001}$	0.8/17
0.8-1.2	0.86	71.86	0.024	**2.9**/17
8-12	$0.52^{+0.05}_{-0.05}$	$9.07^{+1.21}_{-1.23}$	$0.021^{+0.001}_{-0.001}$	1.2/17

Summary

- **Investigated the broadband spectro-timing properties of the new black hole binary MAXI J1348-630 using *NICER* and *Astrosat*.**
- **The source to be in the soft and hard spectral states.**
- **Detected QPOs at frequencies of ~ 6.9 (type-A) and 0.9 (type-C) Hz in the soft and bright hard states, respectively.**
- **Estimated the energy-dependent fractional rms and time lag in the unprecedented 0.5–80 keV energy band using the *NICER*/XTI and *AstroSat*/LAXPC for a range of frequencies and for the QPOs.**
- **The hard time lags are clearly detected at different frequencies.**
- **Quantified the energy-dependent fractional rms and time lag mainly in the LAXPC band using a single zone stochastic propagation model.**
- **Variation of the temperature of the disk and the corona with a time lag between them can explain the energy-dependent temporal behaviour.**
- **Extending the single-zone stochastic model to lower energies, we find that the predicted rms and time lag are qualitatively similar but quantitatively different from *NICER* results.**
- **This discrepancy could be because the *NICER* and LAXPC data are not strictly simultaneous and/or the model does not take into account disk emission which contributes in the low energy band.**

Thank You!