XMM-Newton and *NuSTAR* Observations of the Redback Millisecond Pulsar PSR J2215+5135

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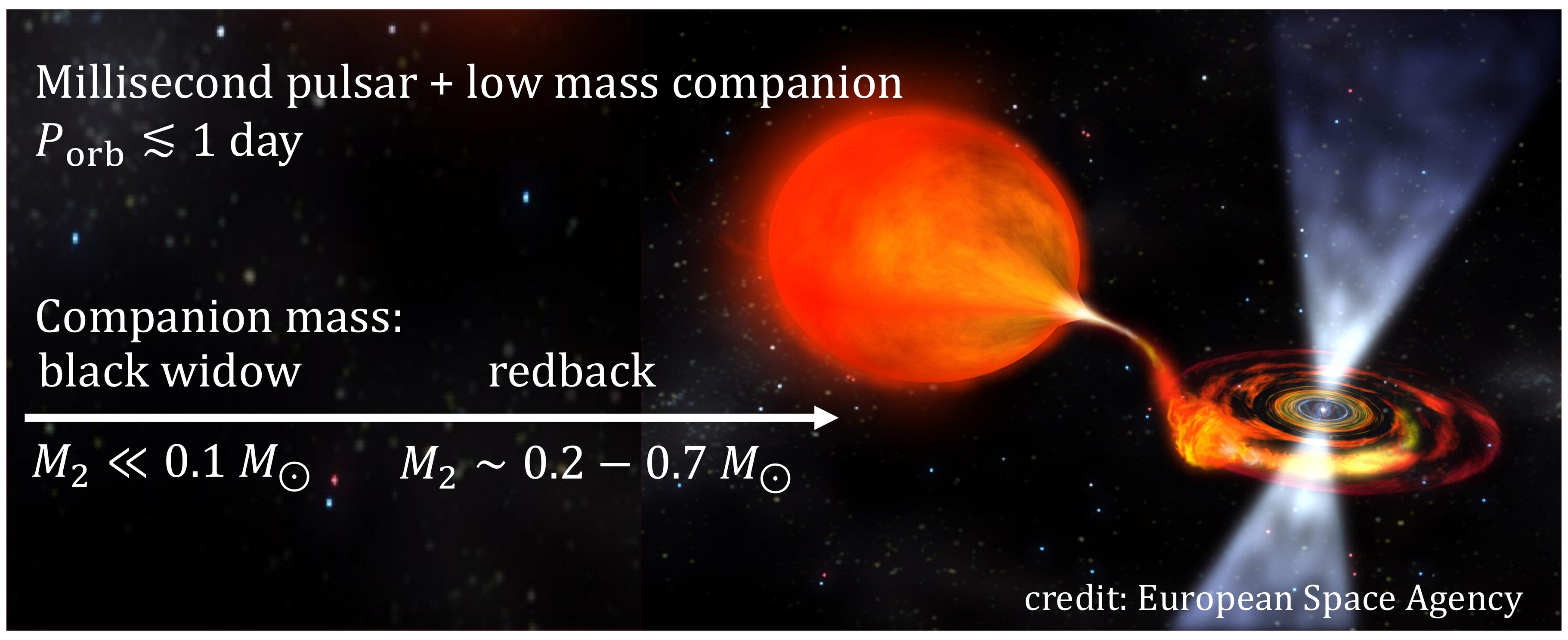
Spider pulsar



- Redback systems occasionally exhibit a double-peaked structure in their X-ray light curves, which could be explained by an intra-binary shock with Doppler boosting [1].
- The intra-binary shock arises from the interaction between the pulsar wind and stellar wind from the companion [2].

Our target

Table 1. Summary of J2215+5135.

Name	M_1 ($M_\odot$)	M_2 ($M_\odot$)	$P_{\rm spin}$ (ms)	$P_{\rm orb}$ (day)	i	d (kpc)
PSR J2215+5135	2.27	0.33	2.61	0.17	63.9°	3

Table 2. Summary of X-ray Observations of J2215+5135.

Instrument	Band (keV)	Date	ObsID	Exposures (ks)
XMM-Newton PN/MOS1/MOS2	0.2-10	2016 Jun 17	0783530301	54.9
XMM-Newton PN/MOS1/MOS2	0.2-10	2022 Jun 08	0900770101	40.8
XMM-Newton PN/MOS1/MOS2	0.2-10	2022 Jun 10	0900770201	41.0
XMM-Newton PN/MOS1/MOS2	0.2-10	2022 Dec 01	0900770301	38.9
NuSTAR FPAM/FPMB	3-79	2024 Mar 04	30901014002	106.0

Timing analysis

- Double-peak structure in both *XMM-Newton* and *NuSTAR* light curves.
- No significant hardness variation through the whole orbital period.

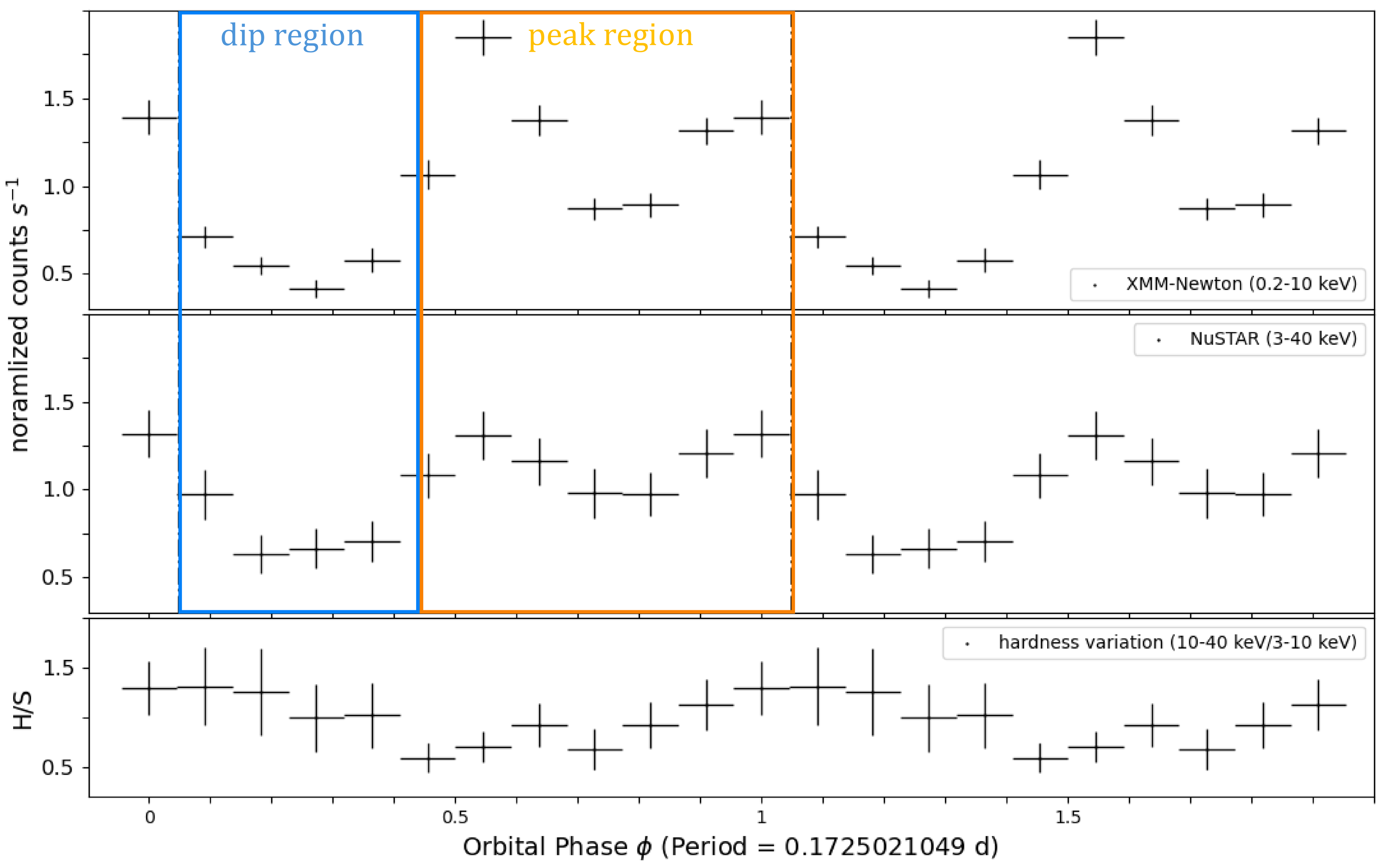
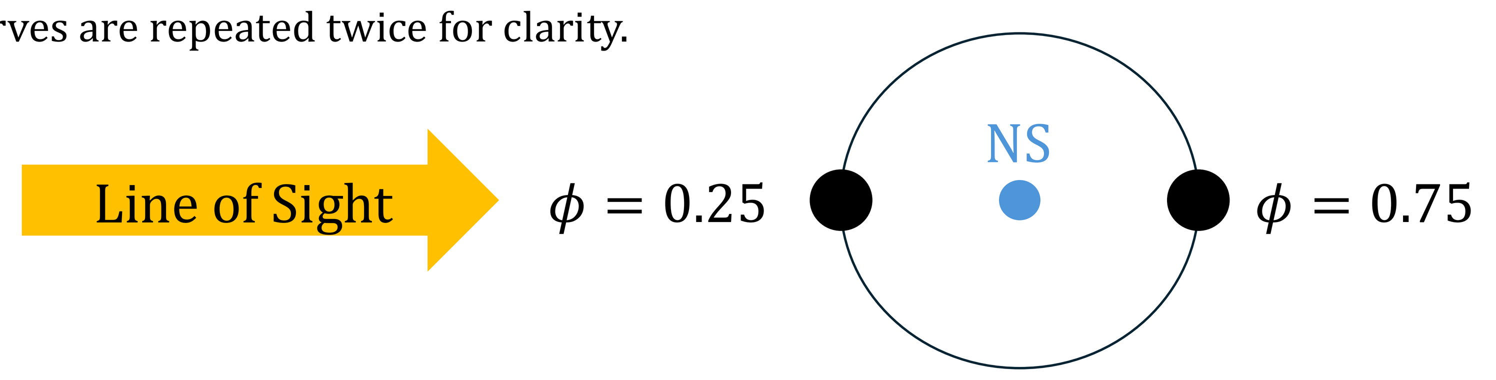


Figure 1. Folded light curves and hardness variation of J2215+5135 taken from *XMM-Newton* and *NuSTAR* observations. All light curves are background subtracted. The light curves are repeated twice for clarity.



Reference

[1] Sullivan, A. G., & Romani, R. W. 2024, APJ, 974, 315
[2] Takata, J., Cheng, K. S., & Taam, R. E. 2012, APJ 745, 100

Spectral analysis

- Phase-averaged and phase-resolved spectral fittings are performed on the combined *XMM-Newton* and *NuSTAR* light curves.

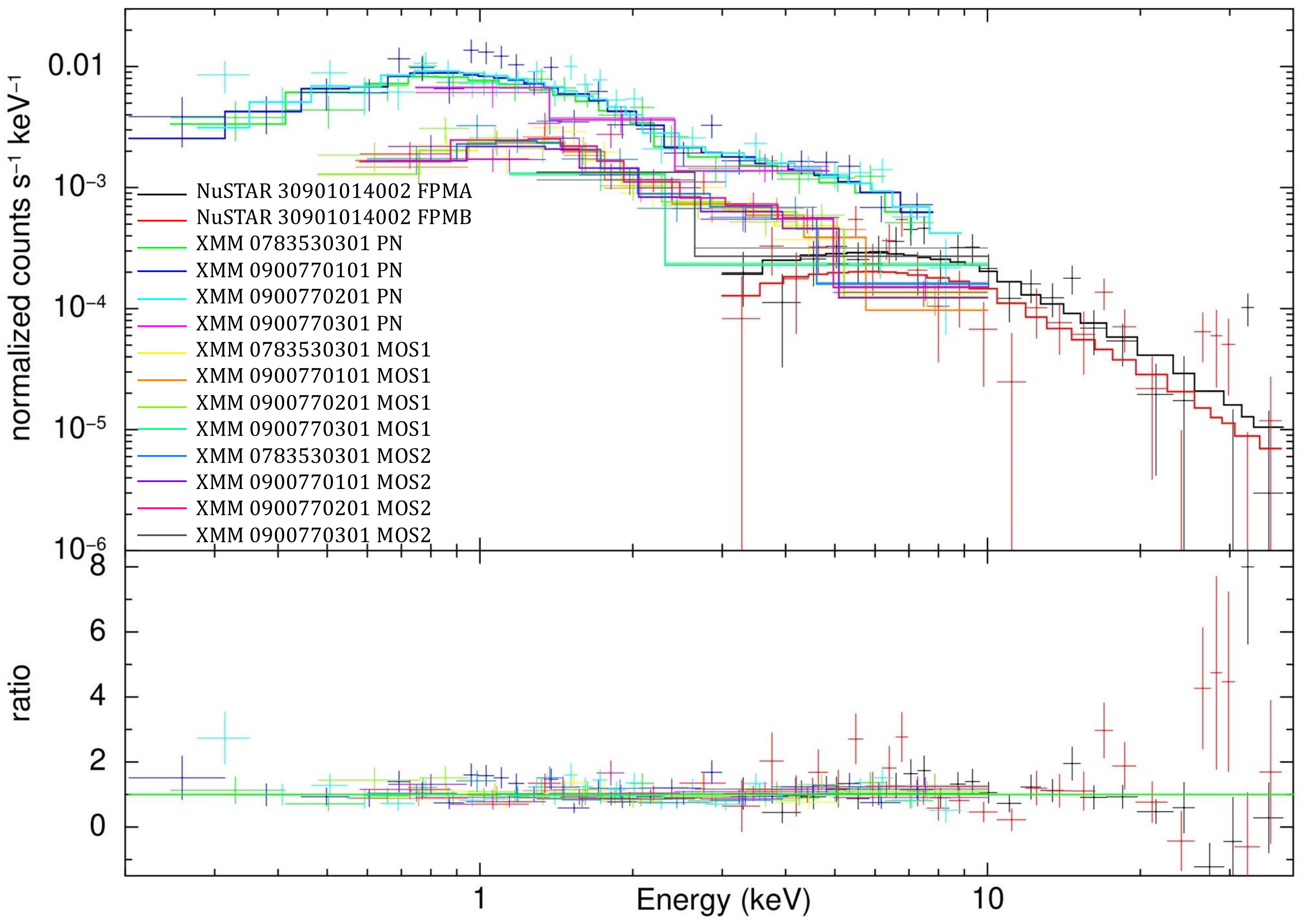


Figure 2. Phase-averaged spectrum of J2215+5135 taken from *XMM-Newton* (0.2 – 10 keV) and *NuSTAR* (3 – 40 keV). The best-fit spectrum (solid lines) is an absorbed power-law plus a neutron star H atmosphere model.

Table 3. Summary of Phase-averaged and Phase-resolved Spectrum Fits for J2215+5135.

Power-law	$\phi = 0.0 - 1.0$	$\phi = 0.05 - 0.44$	$\phi = 0.44 - 1.05$
$N_{\rm H}$ (10^{22} cm^{-2})		0.21 (fixed)	
Γ	$1.34^{+0.06}_{-0.06}$	$2.02^{+0.24}_{-0.24}$	$1.27^{+0.07}_{-0.07}$
$F_{0.2-40}$ (10^{-13} erg cm^{-2})	$3.99^{+1.09}_{-1.22}$	$2.58^{+1.04}_{-1.71}$	$5.58^{+1.50}_{-1.53}$
χ^2_ν/dof	1.55/173	1.07/26	1.39/109
Power-law + H atmosphere	$\phi = 0.0 - 1.0$	$\phi = 0.05 - 0.44$	$\phi = 0.44 - 1.05$
$N_{\rm H}$ (10^{22} cm^{-2})		0.21 (fixed)	
Γ	$1.02^{+0.10}_{-0.10}$	$1.27^{+0.55}_{-0.55}$	$1.03^{+0.11}_{-0.12}$
T (10^6 K)	$1.03^{+0.29}_{-0.23}$	$1.39^{+0.80}_{-0.75}$	$0.96^{+0.41}_{-0.33}$
R (km)	$3.35^{+3.00}_{-1.52}$	$2.13^{+2.45}_{-1.33}$	$3.80^{+7.25}_{-2.17}$
$F_{0.2-40}$ (10^{-13} erg cm^{-2})	$5.22^{+1.64}_{-1.69}$	<4.38	$6.80^{+2.12}_{-2.29}$
χ^2_ν/dof	1.18/171	0.93/24	1.11/107

- Phase-averaged spectrum fits better with a power-law plus a non-magnetic neutron star H atmosphere model than a simple power-law.
- The power-law plus neutron star H atmosphere model gives the unabsorbed 0.2 – 40 keV flux $F_X = 5.22 \times 10^{-13}$ erg cm^{-2} s^{-1}, corresponding to $L_X = 5.44 \times 10^{32}$ erg s^{-1} at a distance of 3 kpc.
- Due to the low photon counts in the flux-dip region, variations in the spectral index across different phases could not be confirmed.

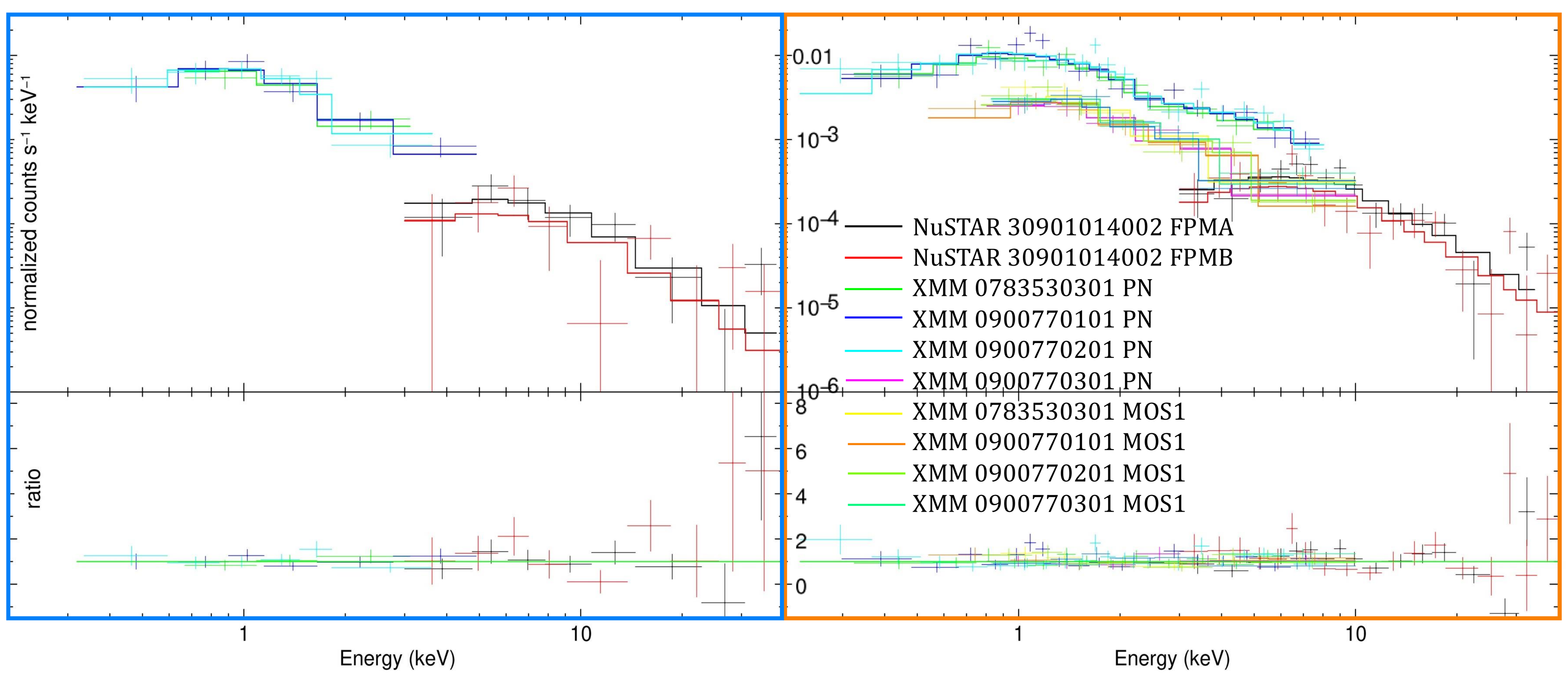


Figure 3. Phase-resolved spectrum of J2215+5135 taken from *XMM-Newton* (0.2 – 10 keV) and *NuSTAR* (3 – 40 keV). The best-fit spectrum (solid lines) is an absorbed power-law pius a neutron star H atmosphere model.

Summary

We present the joint *XMM-Newton* and *NuSTAR* observation of PSR J2215+5135. A double-peaked structure has been confirmed in the light curves from both *XMM-Newton* and *NuSTAR*. The joint X-ray spectrum can be modeled with a power-law plus a neutron star atmosphere model. Statistically, the spectral variation across different phases is not significant.