Using *NuSTAR* to probe X-ray pulsars with warped disks and flares

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1. Light curve variability from warped disks

X-ray binaries consisting of a pulsar and a stellar companion offer a unique laboratory for studying physics onto magnetized objects. The high magnetic field of a neutron star can result in the magnetic forces truncating the accretion disk and dominating the inner accretion flow in a process that has yet to be well studied observationally.

X-ray binaries with warped, precessing inner disks such as LMC X-4, SMC X-1, and Her X-1 show variable light curves (far right). **By observing within a single superorbital period, we can constrain the geometry of the inner magnetized accretion flow in warped disk binaries with pulse phase spectroscopy and tomography.**

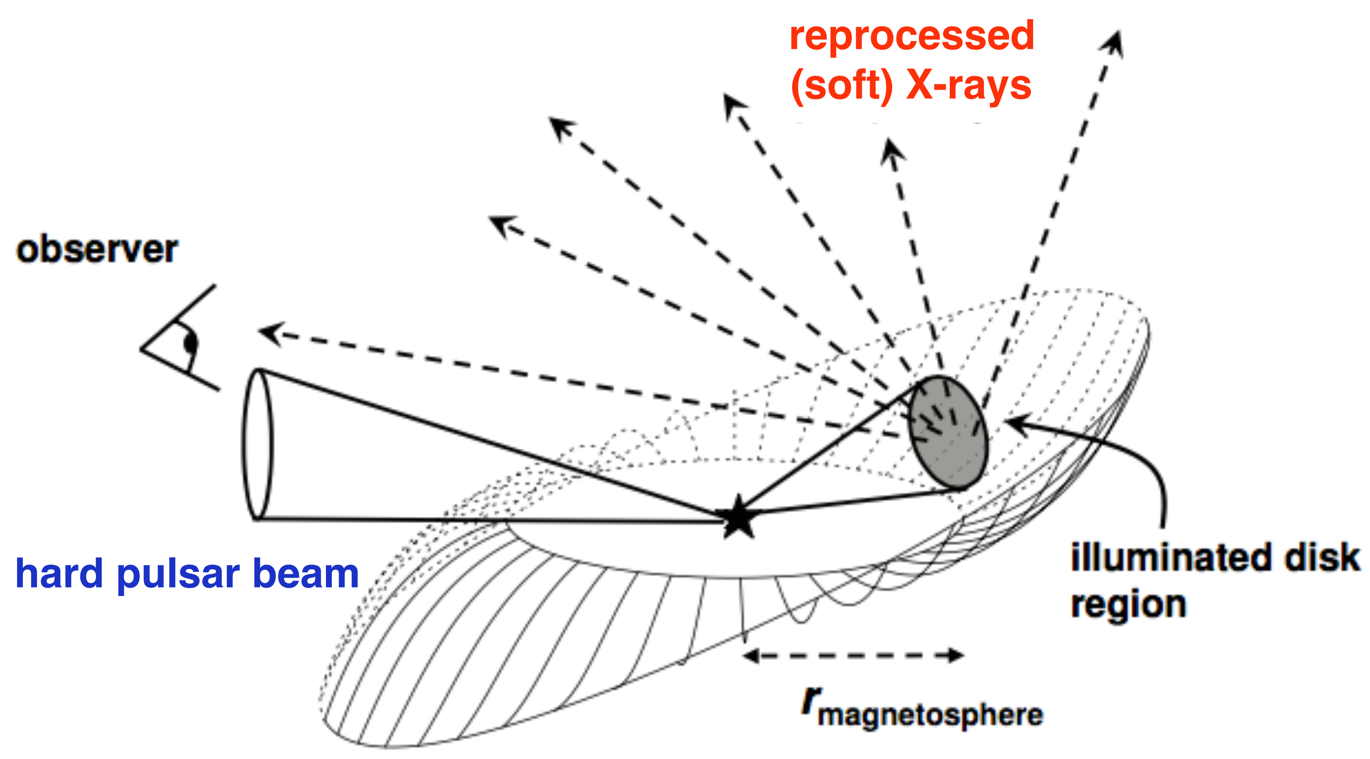
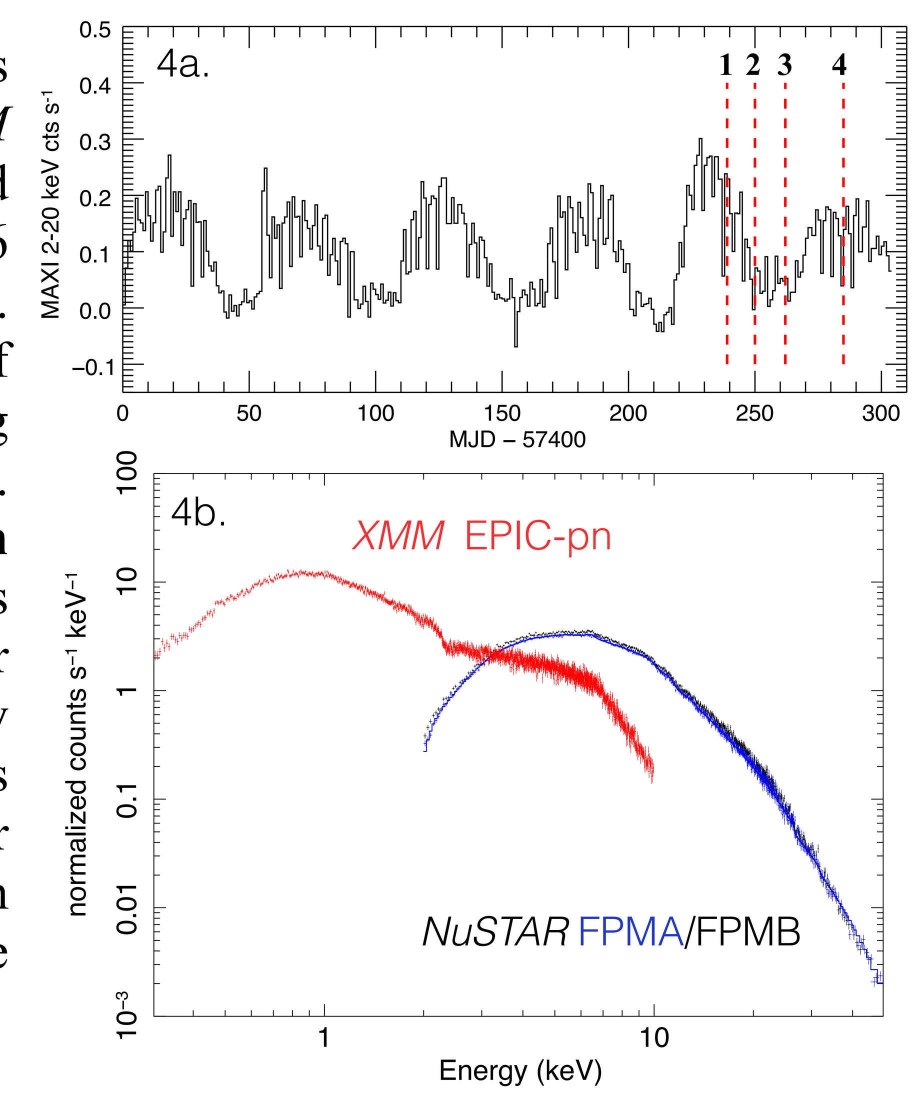


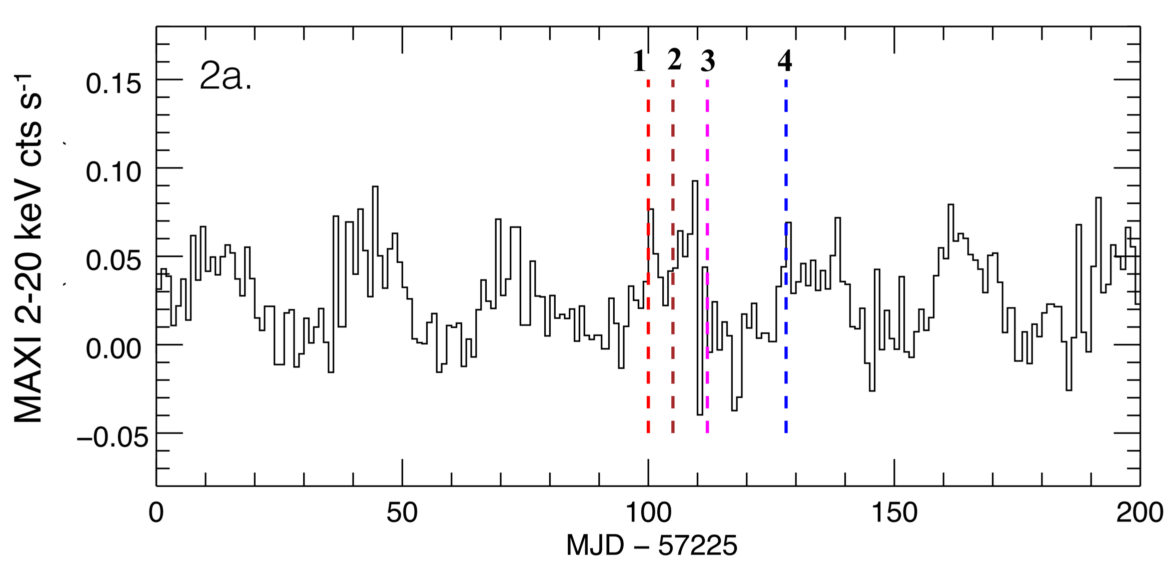
Figure 1: Model of a warped inner accretion disk, where the observer sees both hard emission from the pulsar beam and reprocessed photons from the disk. Model from Hickox & Vrtilek (2005).

4. SMC X-1:New data and future work

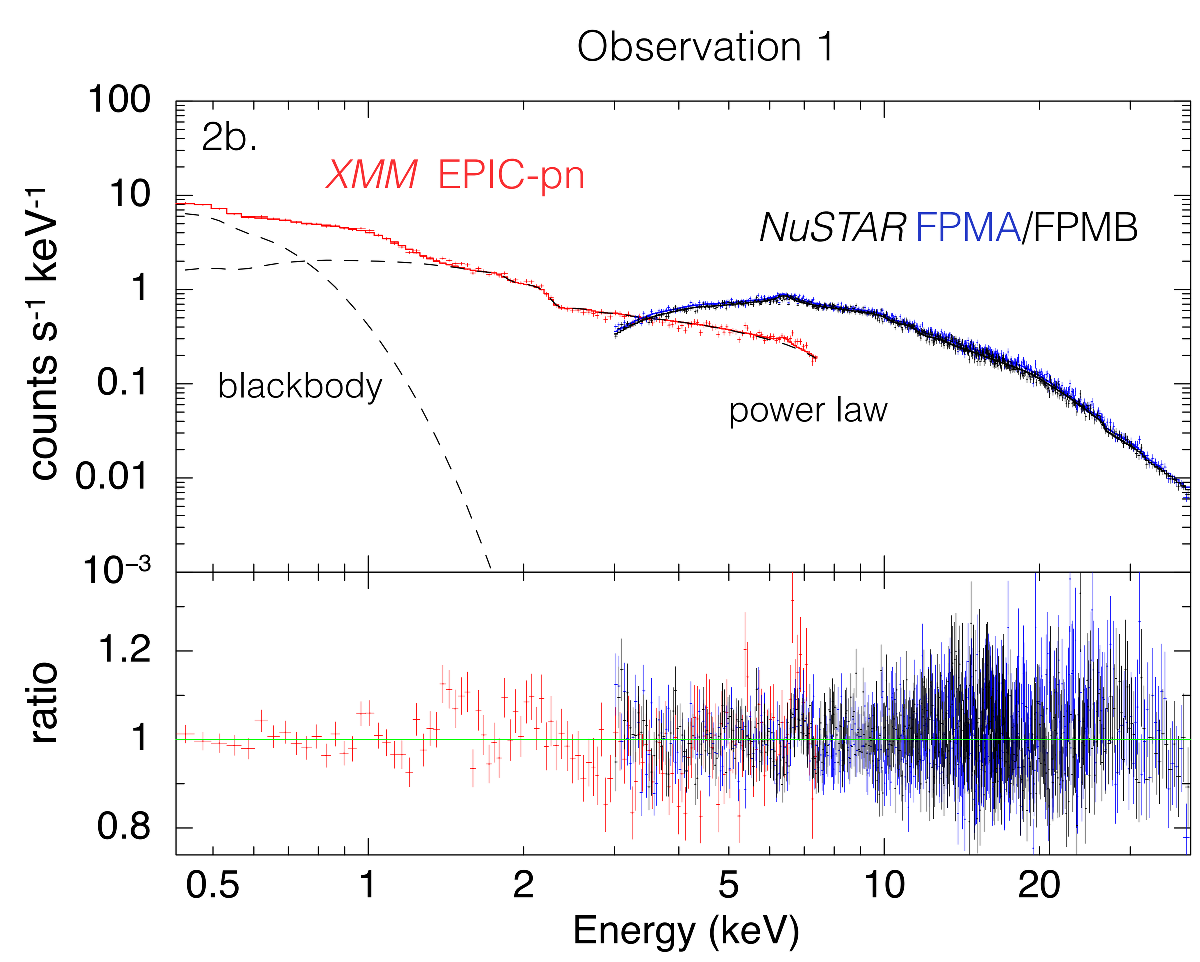
Four joint observations of SMC X-1 with *XMM* and *NuSTAR* occurred between 08 Sept. 2016 and 24 Oct. 2016 (Fig. 4a). Spectral analysis of these data are ongoing (Obs 1 spectrum in Fig. 4b). **Future work on this data set** includes performing a similar pulse-phase spectroscopy and tomography analysis as the one in progress for LMC X-4 (see box 2) in order to better model the accretion flow.

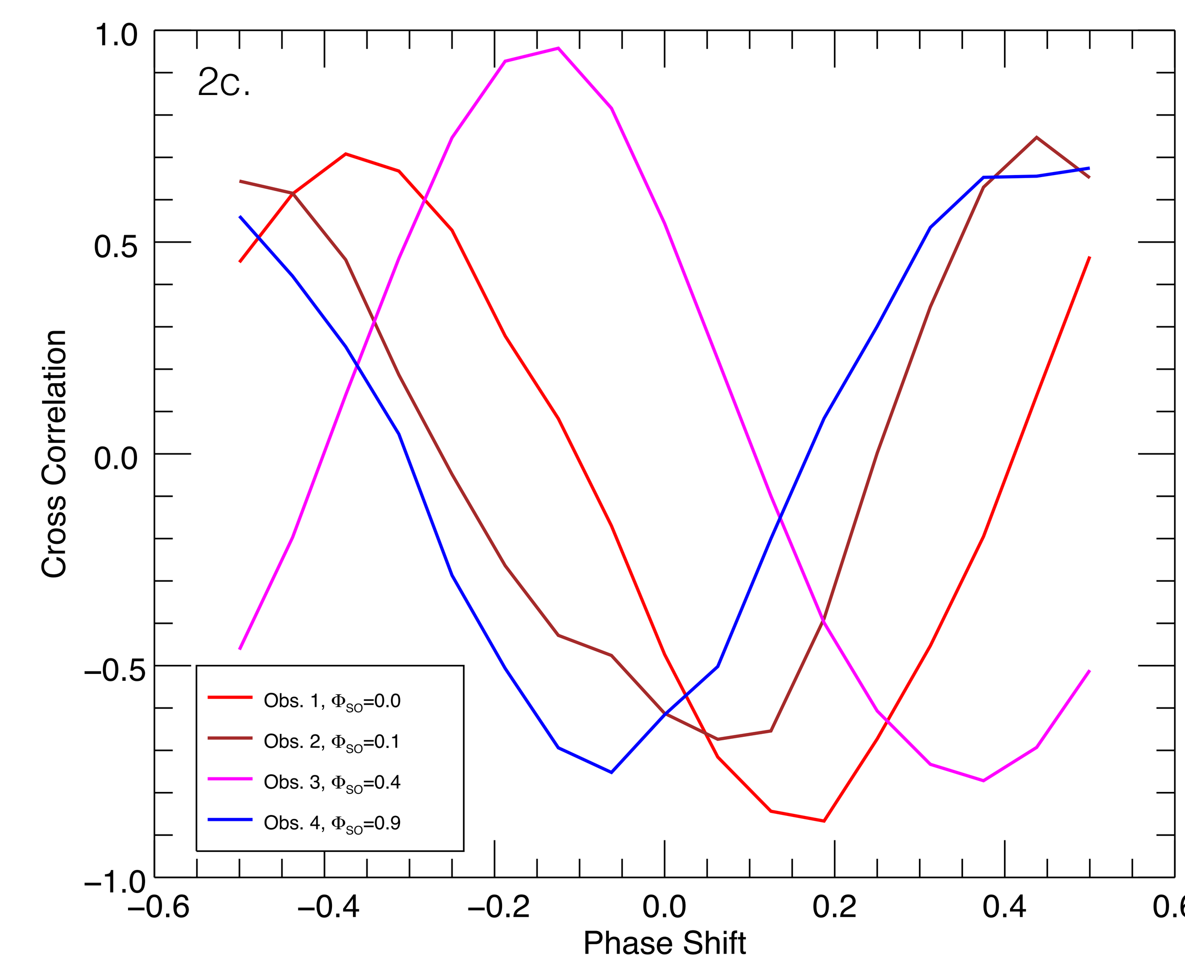


2. LMC X-4: *NuSTAR* and *XMM* observe disk precession



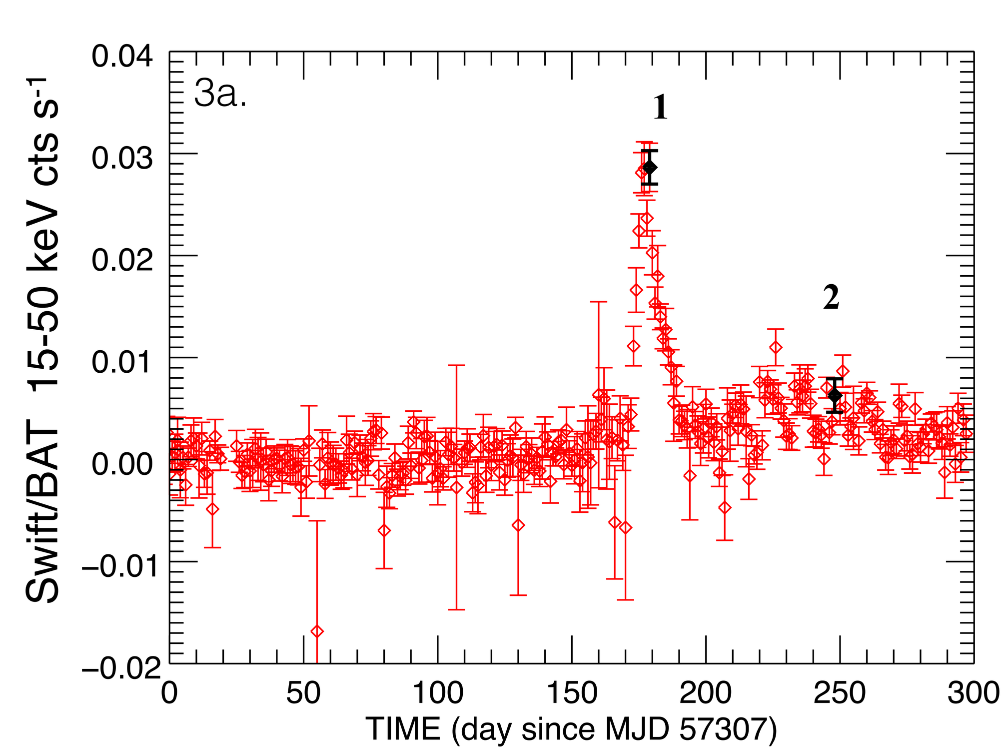
For four joint observations of LMC X-4 taken between 30 October and 27 November of 2015 (Fig. 2a), we extract phase averaged spectra (Fig. 2b) and fit with a power law and blackbody model. We cross correlate pulse profiles taken from high (8-40 keV) and low (0.5-1 keV) energy bands in each observation (Fig. 2c). The shift in relative phase, **corresponding to a complete precession of the disk**, is visible.

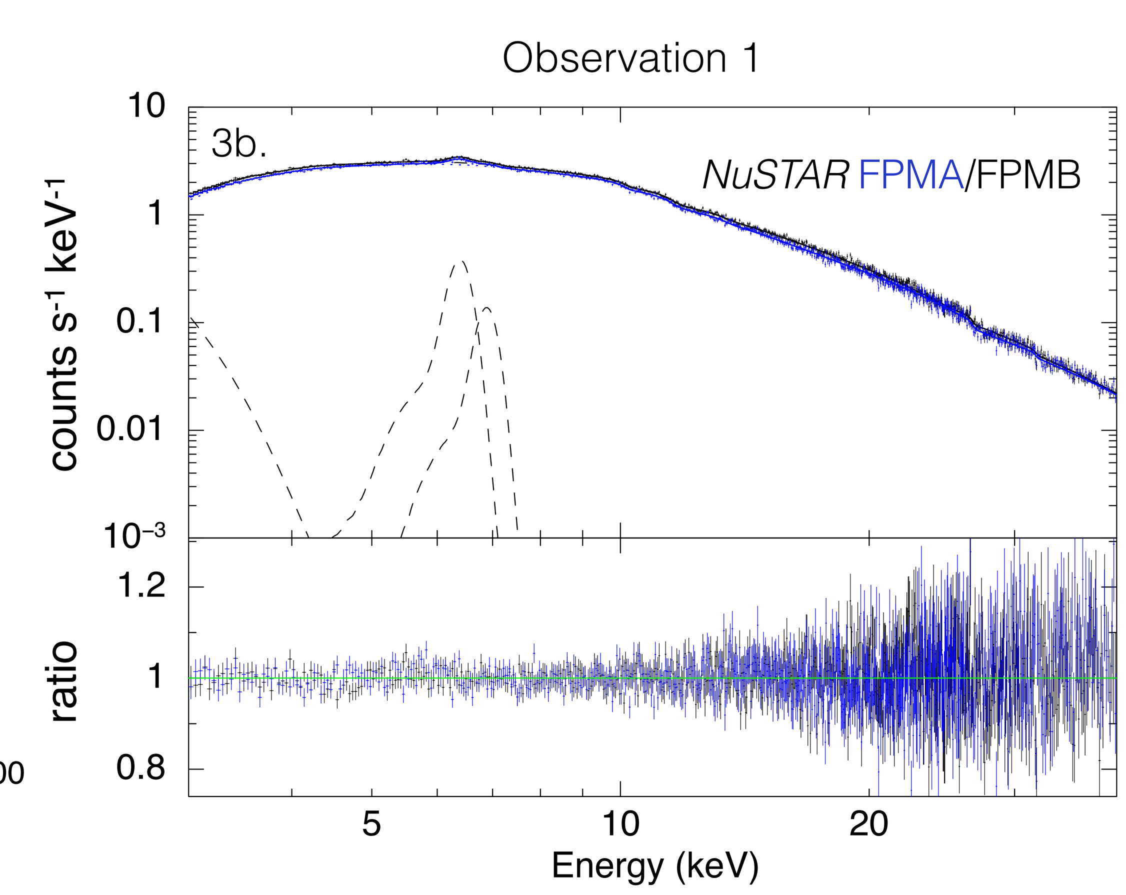


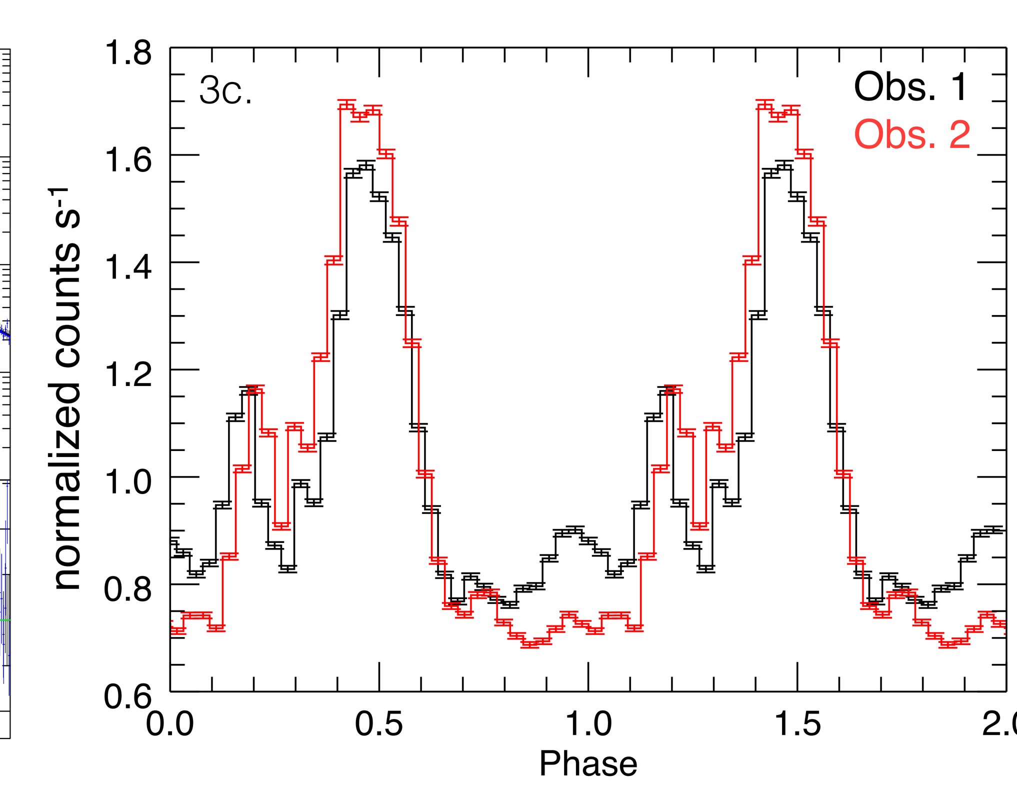


3. SAX J2103.5: Flux state comparison

We observed the Be X-ray binary SAX J2103.5+4545, with *NuSTAR* on 8 April and 16 June 2016 (Fig. 3a). These ToOs captured the source during its bright precursor flare, at the brightest state since *NuSTAR*'s launch, and again later in outburst during periastron passage. We fit the spectrum with an NPEX model with a thermal component. We observe a highly ionized iron line, but no evidence of a cyclotron feature (Figure 3b). We also note changes in the pulse profile shape (Figure 3c). Ongoing pulse phase spectroscopy can illustrate changes in spectral parameters with pulse phase.







References and Acknowledgements

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