Draft version June 30, 2020
Typeset using LaTeX **RNAAS** style in AASTeX63

Spectral Variability of a Soft-Intermediate State QPO from MAXI J1820+070

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ABSTRACT

Black hole X-ray binaries are known to exhibit variability in their light curves on timescales as short as milliseconds to as long as months. The short-timescale variability can be in the form of quasi-periodic oscillations (QPOs), which may be produced by general relativistic effects. In this work, we looked at low-frequency QPOs from an exciting recent black hole transient, MAXI J1820+070, which first went into outburst in 2018. This source was observed in a multi-wavelength campaign that included the *NICER* mission, a soft X-ray telescope attached to the International Space Station. In our analysis, we applied X-ray timing and spectral-timing techniques to help place constraints on the QPO emission mechanism in the extreme environment surrounding the black hole. Although the QPO amplitude was too low to carry out phase-resolved spectroscopy, our work indicates that weak QPOs such as this one may be present in the light curves of many sources.

Keywords: High time resolution astrophysics (740), Black holes (162), Low-mass x-ray binary stars (939), MAXI J1820+070

INTRODUCTION

MAXI J1820+070, hereafter J1820, is a low-mass X-ray binary (LMXB) that likely contains a stellar black hole (Torres et al. 2019). Its optical counterpart, ASASSN-18ey was discovered by *ASAS-SN* (Shappee et al. 2014) on 2018 March 06 (Tucker et al. 2018). Six days later on 2018 March 11, a bright X-ray transient was detected by *MAXI* (Matsuoka et al. 2009) at the same location (Kawamuro et al. 2018). During its 2018 outburst, J1820 was observed in a multi-wavelength campaign by telescopes like *NICER*, a soft X-ray telescope with ∼150 eV energy resolution and ∼100 ns timing resolution (Gendreau et al. 2016). *NICER* began observing J1820 on 2018 March 12 and continued for more than 123 days, yielding unprecedented coverage of the outburst of J1820 (Homan et al. 2019).

LMXBs like J1820 are known to exhibit quasi-periodic oscillations (QPOs). A QPO is a rapidly varying signal that appears in the power spectrum as a Lorentzian-shaped component on top of the noise (Ingram & Motta 2020). Low-frequency QPOs (0.1–20 Hz) from black holes can be divided into subcategories based on the noise profile and presence of a harmonic, and the emission mechanism for them is still not fully understood. For discussion on both QPO types and emission theories, see Motta (2016) and Ingram & Motta (2020). This analysis focused on a Type-B QPO found while J1820 was in the soft-intermediate state, aiming to validate or rule out possible QPO emission mechanisms by performing phase-resolved spectroscopy as in Stevens et al. (2018).

DATA

This analysis used *NICER* observation ID 1200120197 taken roughly 116 days after initial outburst. During this observation, the source transitioned to the soft-intermediate spectral state, and a Type-B QPO was identified by Homan et al. (2020). *NICER*/XTI Focal Plane Modules 11, 20, 22, 60 are non-operational, and counts from 10, 14, 34, 40, and 54 were removed from this analysis as in Stevens et al. (2018). We split the *NICER* event list light curves into 16 s segments and bin the light curves with a time step of 7.8 ms. Clear QPOs are seen in the dynamical power spectrum of Figure 1a (lower panel). Our interest was in the Type-B QPO, seen at around 4 Hz in segment

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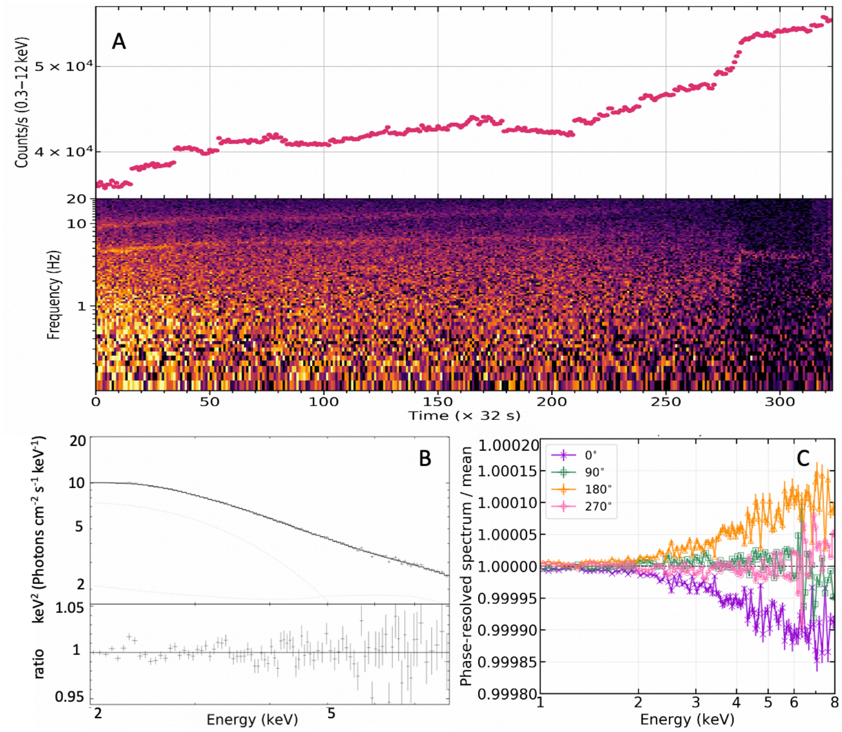

Figure 1. Part A shows the count rate (scaled to 47 FPMs) and dynamical power spectrum, calculated for sequential 32 second segments of the light curve (gaps removed). The Type-C QPO and harmonic are visible at ∼5 Hz and 10 Hz respectively, starting in the beginning of the ObsID. The Type-B of this analysis begins at time bin 280 and lasts until about 310, has a centroid frequency of ∼4 Hz. Part B shows the mean spectrum unfolded with a model. Part C shows the ratio spectra, made by taking spectra from 4 phases in a single QPO cycle and dividing by the mean spectrum.

∼280-310, with a quality factor of $Q = \nu_{\rm centroid}/{\rm FWHM} = 8.9$, and no harmonic. For further analysis, we excluded the broadband noise, Type-C QPO, and harmonic seen in segments 0-270. The average count rate in $0.3-12$ keV for 26 FPMs during the Type-B lifespan was 2.9×10^4 cts s^{-1}, (5.4×10^4 cts s^{-1} scaled to 47 FPMs). The difference between the expected and measured power of the Poisson noise, 2.9%, indicates that detector deadtime does not notably affect the data.

RESULTS AND CONCLUSION

We present the disk-dominated mean spectrum of the data in Figure 1b fitted with the model `phabs × (gaussian + diskbb + nthComp + relxillCp)`. The parameter values and a brief explaination can be found in an accompanying GitHub repository[1]. We see distinct differences in the phase-resolved spectra of this Type-B QPO in the ratio spectra of Figure 1c. This points to the Comptonization component (modelling the corona) appearing to change index and normalization with QPO phase.

While full phase-resolved spectroscopy of this Type-B QPO was not possible due the low signal to noise, it is still notable that we were able to see any differences in the ratio spectra. Our analysis indicates that Type-B QPOs could be present in more sources, but are difficult to detect due to source counts and detector area. This further indicates that the emission mechanism may occur significantly more frequently than what is published in the literature. Future instruments like *STROBE-X* (Ray et al. 2019) or *eXTP* (Zhang et al. 2019) will allow us to phase-resolve faint and transient QPOs such as this one, paving the way for furthering our understanding of QPOs and their emission mechanisms.

[1] www.github.com/davis191/J1820_RNAAS/wiki

Facilities: *NICER*, ADS, HEASARC

Software: Astropy v3.2.1 (Astropy Collaboration et al. 2018), HEASoft v6.26.1, Jupyter notebooks v6.0.0, Matplotlib v3.1.0 (Hunter 2007), NumPy v1.16.4, Python v3.7.3, SciPy v1.3.0 (Virtanen et al. 2020), Stingray v0.1.3 (Huppenkothen et al. 2019), XSPEC v12.10.1 (Arnaud 1996)

ACKNOWLEDGMENTS

M.C.D. and A.L.S. thank J. M. Miller, J. Homan, and J. Strader. We acknowledge support from NASA grant 80NSSC19K1454 and the Packard Foundation. A.L.S. is supported by an NSF Astronomy and Astrophysics Postdoctoral Fellowship under award AST-1801792.

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