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Unveiling the Temporal Properties of MAXI J1820+070 through *AstroSat* Observations

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Abstract

We present here the results of the first broadband simultaneous spectral and temporal studies of the newly detected black hole binary MAXI J1820+070 as seen by Soft X-ray Telescope and Large Area X-ray Proportional Counter (LAXPC) on board *AstroSat*. The observed combined spectra in the energy range 0.7–80 keV were well modeled using disk blackbody emission, thermal Comptonization, and a reflection component. The spectral analysis revealed that the source was in its hard spectral state ($\Gamma = 1.61$) with a cool disk ($kT_{\rm in} = 0.22$ keV). We report the energy dependent time-lag and root mean squared (rms) variability at different frequencies in the energy range 3–80 keV using LAXPC data. We also modeled the flux variability using a single-zone stochastic propagation model to quantify the observed energy dependence of time lag and fractional rms variability, and then compared the results with that of Cygnus X-1. Additionally, we confirm the detection of a quasi-periodic oscillation with the centroid frequency at 47.7 mHz.

Unified Astronomy Thesaurus concepts: Black hole physics (159); Stellar accretion disks (1579); Low-mass X-ray binary stars (939); X-ray transient sources (1852); Stellar accretion (1578); X-ray astronomy (1810); Stellar mass black holes (1611); Black holes (162)

1. Introduction

Accreting black hole X-ray binaries (BHXBs) in outburst exhibit random short-term variability in their flux (van der Klis 1989), which may arise due to the perturbations occurring at different radii of the accretion disk propagating inward (Lyubarskii 1997). These perturbations cause variations to mass accretion rate at the inner regions of the accretion disk on different timescales (Spruit et al. 1987; Narayan & Yi 1994; Abramowicz et al. 1995; Chen 1995). The X-ray variability in BHXBs is well represented by their power density spectra (PDS), which exhibit systematic changes throughout the course of an outburst with remarkable similarities among themselves, thereby suggesting a common underlying physical phenomenon (Belloni 2010, and references therein). The PDS of most BHXBs are characterized by broad-band-continuum-noise-—like features and sometimes narrow peak features called quasi-periodic oscillations (QPOs). The exact mechanism of the origin of QPOs is still an open question but the origin of broadband noise could be due to the inward propagation and coupling of perturbations occurring throughout the accretion disk, resulting in flux variations. This scenario best explains the observed linearity of the root mean square (rms)-flux relationship in galactic black holes (Gleissner et al. 2004) and other type of X-ray sources (Uttley & McHardy 2001; Gaskell 2004). Furthermore, Heil et al. (2012) showed that the rms-flux relationship of broadband noise is an universal feature of all accreting BHXBs, independent of their spectral state.

Over the past two decades, there have been several efforts to develop a unified propagation fluctuation model to explain and predict the energy and frequency dependent fractional rms and time-lag (Ingram & Done 2011, 2012; Ingram & van der Klis 2013; Rapisarda et al. 2016, 2017; Axelsson & Done 2018). The motivation for this is that such efforts could provide the necessary tools to probe the geometry of the system within this regime and possibly explain the exact mechanism of origin of QPOs (Böttcher & Liang 1999; Misra 2000; Kotov et al. 2001).

Maqbool et al. (2019) proposed and validated one such model by comparing its predictions with observed data of Cygnus X-1 from *AstroSat*. The model invokes a simple geometry of standard truncated disk with a hot inner region (Esin et al. 1997) and assumes that hard X-ray component originates from this hot inner region by a single temperature thermal Comptonization process. The model considers the variation of the temperature of the inner radius of the truncated disk and that of the hot inner flow with a frequency dependent time-lag between them. Data from Soft X-ray Telescope (SXT) and Large Area X-ray Proportional Counter (LAXPC) on board *AstroSat* play a crucial role for validating the model as it provides unprecedented spectro-timing information with broad-band coverage (Misra et al. 2017). The model successfully explained the energy dependent rms and time lags in Cygnus X-1. Nonetheless, the results obtained are for a persistent BHXB in its hard state. It is unclear how the results would change for a transient BHXB in the same state, thereby making it necessary to test and validate the model on different types of X-ray binaries.

In view of this, we considered *AstroSat*'s data of the newly discovered transient MAXI J1820+070 to validate the model proposed by Maqbool et al. (2019). MAXI J1820+070, a galactic black hole X-ray transient, is one among the brightest X-ray novae observed to date (Corral-Santana et al. 2016). The source was first discovered in the optical on 2018 March 6 by the *All-Sky Automated Survey for Supernovae* (*ASSAS-SN*) project (Tucker et al. 2018) and later in X-rays on 2018 March 11 by the *Monitor of All-sky X-ray Image* (*MAXI*; Kawamuro et al. 2018). Subsequent multi-wavelength observations revealed that MAXI J1820+070 is a BHXB system (Baglio et al. 2018; Uttley et al. 2018). The outburst cycle, which lasted