MNRAS **000**, 1–8 (2022) Preprint 3 February 2023 Compiled using MNRAS LATEX style file v3.0

Low Frequency Quasi-periodic Oscillation in MAXI J1820+070: Revealing distinct Compton and Reflection Contributions

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Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

X-ray low frequency quasi-periodic oscillations (LFQPOs) of black hole X-ray binaries, especially those type-C LFQPOs, are representative timing signal of black hole low/hard state and intermediate state, which has been suspected as to originate due to Lense-Thirring precession of the accretion flow. Here we report an analysis of one of the *Insight*-HXMT observations of the black hole transient MAXI J1820+070 taken near the flux peak of its hard spectral state during which strong type-C LFQPOs were detected in all three instruments up to photon energies above 150 keV. We obtained and analyzed the short-timescale X-ray spectra corresponding to high- and low-intensity phases of the observed LFQPO waveform with a spectral model composed of Comptonization and disk reflection components. We found that the normalization of the spectral model is the primary parameter that varied between the low and high-intensity phases. The variation in the LFQPO flux at the hard X-ray band ($\gtrsim$ 100 keV) is from the Compton component alone, while the energy dependent variation in the LFQPO flux at lower energies ($\lesssim$ 30 keV) is mainly caused by the reflection component with a large reflection fraction in response to the incident Compton component. The observed X-ray LFQPOs thus should be understood as manifesting the original timing signals or beats in the hard Compton component, which gives rise to additional variability in softer energies due to disk reflection.

Key words: accretion, accretion discs – stars: black holes – X-rays: binaries – X-rays: individual: MAXI J1820+070

1 INTRODUCTION

Most of black hole X-ray binaries (BH XRBs) in our galaxy are transient sources. They occasionally experienced an outburst and spent most of their time in quiescence. During an outburst, the X-ray spectral and timing properties usually changes dramatically on a timescale of days to months (Miyamoto et al. 1995; Remillard & McClintock 2006; Done et al. 2007; Belloni & Motta 2016). So different spectral states are classified based on the X-ray spectral and timing properties. The two main spectral states are hard and soft states. The accretion flow in the soft state is thought to be the geometrically thin disk (Shakura & Sunyaev 1973), which is characterised by the multi-temperature black body X-ray spectrum and very low level short term X-ray variability. The X-ray spectra of the hard state are dominated by the inverse Comptonization scattering of the hot corona. A part of the hard X-ray illuminates the accretion disk and then produces a reflection component, which is characterised by the fluorescent iron Kα line and the reflection hump at $\sim$ 30 keV (e.g. Fabian & Ross 2010, , for a review). During the hard state, the X-ray variability amplitude is very high, and low-frequency quasi-periodic oscillations (LFQPOs) are usually detected.

One of the most common type low-frequency QPO for BH XRBs is called type-C QPO, the central frequency of which may evolve in the tens of mHz to 30 Hz range, depending on its spectral state(Psaltis et al. 1999; Casella et al. 2004; Van der Klis 2006). The type-C QPO generally appears as very strong and narrow peaks in the power spectrum. The origin of type-C QPO is still under debate, and a popular model is the Lense-Thirring precession of the hot flow(see reviews by Ingram & Motta 2019).

Besides conventional timing and spectral analysis of the QPO properties, phase-resolved timing and spectral analysis can provide timing and spectral information of the QPO at different phases, revealing the origin of QPOs (Yu et al. 2001; Yu & van der Klis 2002). Specifically for the LFQPOs in black hole binaries,Miller & Homan (2004) detected variation of the Fe Kα line with QPO phase which suggests that the QPOs originate in the inner disk. Ingram & van der Klis (2015) observed modulation of the Fe Kα line width and reflection component by reconstructing the GRS 1915+105 energy spectrum at different phases, providing evidence for a geometric origin of the X-ray QPO. Later on, more comprehensive analysis of the LFQPOs has been performed with the observations of H1743-322 (Ingram et al. 2016, 2017). Both the iron line energy and the reflection fraction are found modulated with the QPO phase. This is taken as strong evidence supporting the Lense-Thirring precession model.In recent analysis about QPO phase-resolved spectroscopy, Nathan et al. (2022) detected a significant modulation of the reflection fraction in GRS 1915+105, which indicates that the inner accretion disk geometry changes with QPO phase.

MAXI J1820+070 is one of the brightest transient black hole X-ray binaries, which is discovered in X-ray on 2018 March 11 by Monitor of All-sky X-ray Image (MAXI; Kawamuro et al. 2018; Tucker et al. 2018). The X-ray intensity of the source increased rapidly and

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