Rapidly alternating flux states of GX 339–4 during its 2021 outburst captured by Insight–HXMT

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Introduction

The corona in black hole X-ray binary (XRB) systems are intrinsically variable. On long timescales (e.g. days or weeks), we see the state transition during which the coronal emission continues to get softer. On short time scales (e.g. < 1s), there are broad band noise and quasi-periodic oscillations in the power spectral density (PSD). In the figure below, we see a different variability pattern in the canonical black hole XRB GX 339-4 during its 2021 outburst. The source was found to alternating between a low and a high-flux states on a timescale less than 1.5 hours. This kind of variability has previously been named as "flip-flop". Understanding the physical mechanism behind this kind of variability may provide more insights into the accretion process.

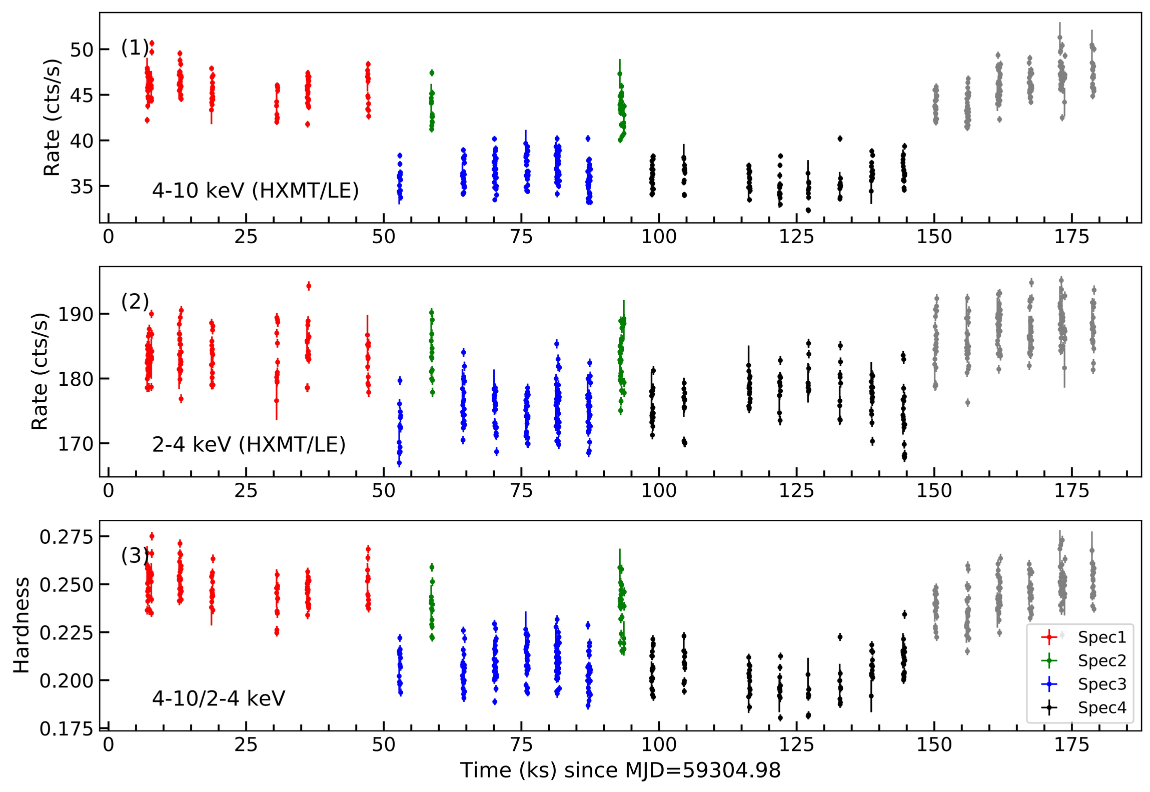

Figure 1. Lightcurves of GX339-4 by Insight-HXMT in 4–10 keV (panel 1) and 2–4 keV (panel 2).The evolution of the hardness ratio is shown in panel 3. The source enters a low flux state at 52 ks that lasts for about 100 ks. Two brief high flux states emerge from the low flux interval on a time-scale less than one orbit. The flux change is more prominent in 4–10 keV. Different colors mark the four spectra extracted from the observation (see Method).

Method

- We first divide the observation into a high-flux interval and a low-flux interval (flux-resolved) and compare their spectra. As shown below, the two spectral are similar in shape in the soft X-ray band (< 4 keV). The flux variability is a result of changes in the hard X-ray band.
- The data show strong reflection features, that is to say, after fitting the spectra with a simple absorbed power-law model, a broad iron line is left in the residuals. This feature is a result of the coronal photons being captured and reprocessed by the optically thick accretion disk. This process produce strong iron Ka emission at 6.4 keV (for neutral disk). Moreover, the reflection component has been widely used as a tool to probe the accretion geometry. Therefore, we apply reflection models to the flux- and time-resolved spectra (as color-coded in Figure. 1) to see what spectral parameters are changing along with the flux.

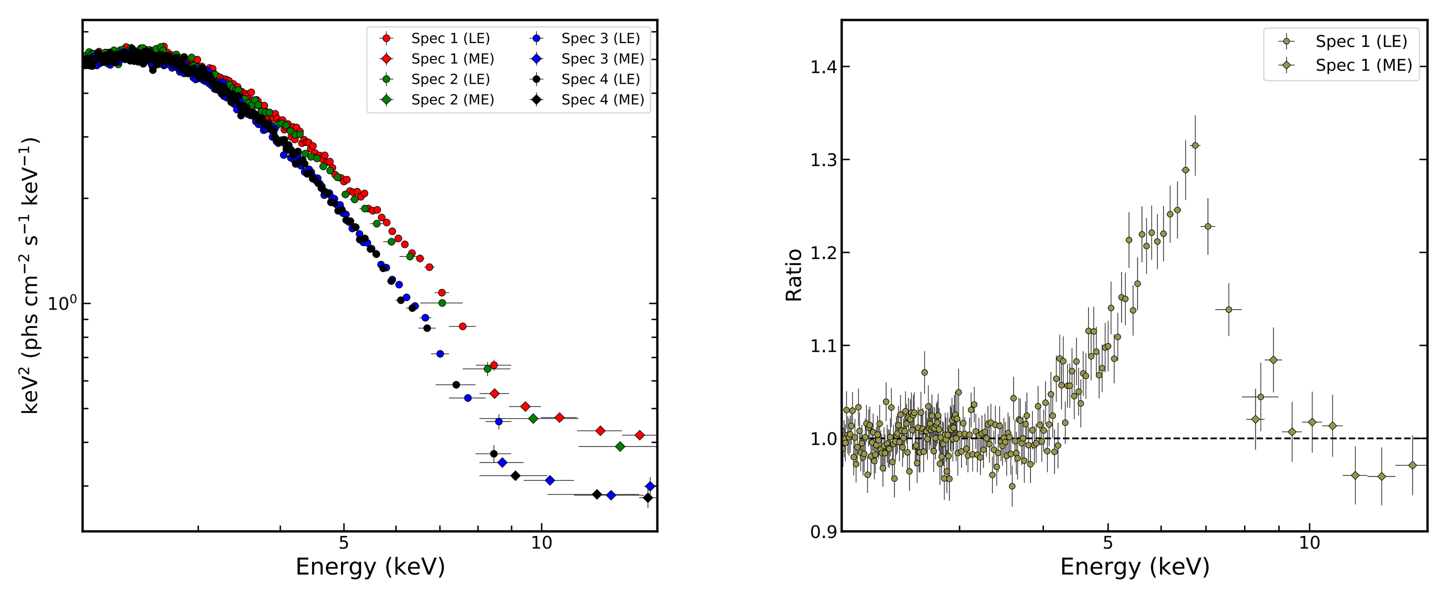

Figure 2. (Left) Spectra of the four intervals as defined in Figure 1. The LE (2–9 keV) and ME (8–15 keV) data are marked with filled circle and diamond, respectively. The spectra are obtained using SETPLOT AREA command in XSPEC and are only shown for demonstration purposes. (Right): Data to model ratio of Spec 1 to a simple absorbed continuum model. Data are binned for visual clarity.

- We also look into the PSD of data of the two flux levels. Previous studies on "flip-flop" have found changes of the band noise and QPOs along with the transition. However, in our case, the variability power is so low and there is not detection of of QPOs or broadband noise.

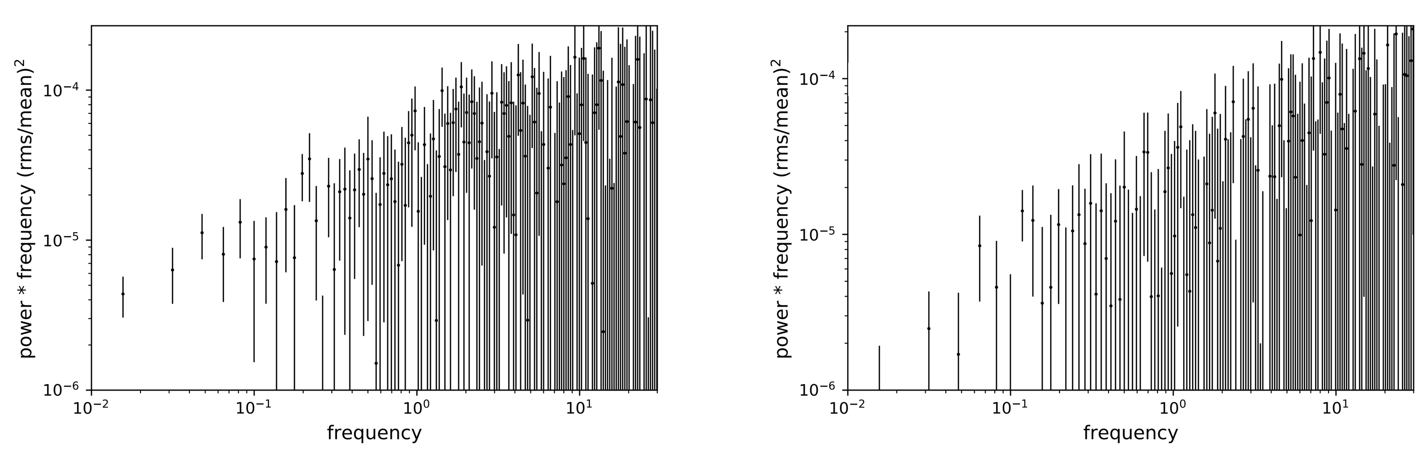

Figure 3. Power spectral density from the low-flux (left) and high-flux (right) intervals.

Result

- The best-fit spectral components show that the strength of the disk thermal emission remains stable during the transition. It is the coronal emission component and the reflection component that are changing.

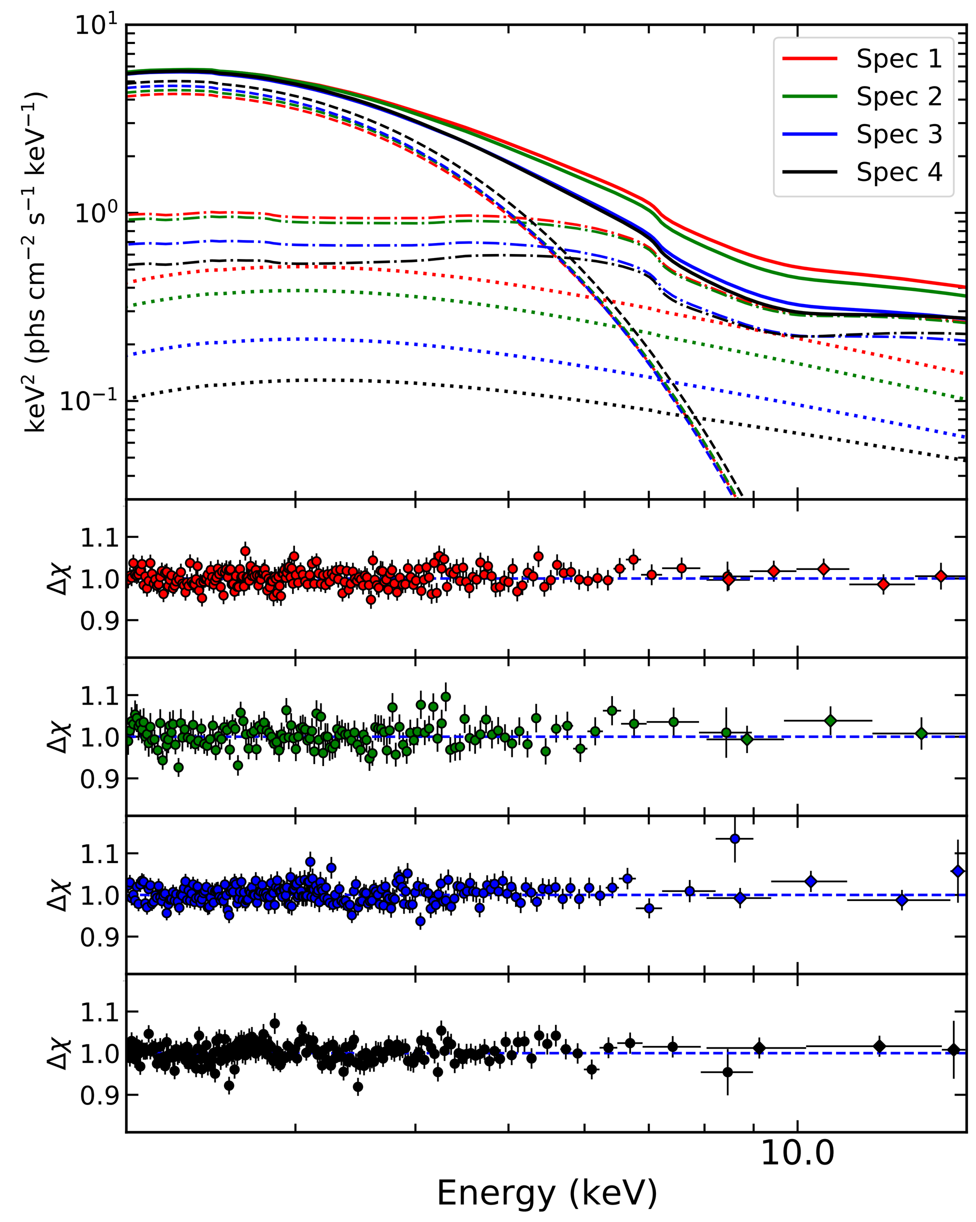

Figure 4. The best-fitting models and the corresponding residuals to the four spectra with model TBABS∗(DISKBB + NTHCOMP + RELCONV ∗ REFLIONX). The full models are plotted in solid lines. The disc, power-law, and reflection components are plotted in dashed, dotted, and dash–dotted lines, respectively

- The results above is confirmed by the evolution of spectral parameters with the source flux (see below). Moreover, we find that the disk inner radius, reflection fraction and the coronal height are also stable. It is the coronal power that is responsible for the variability.

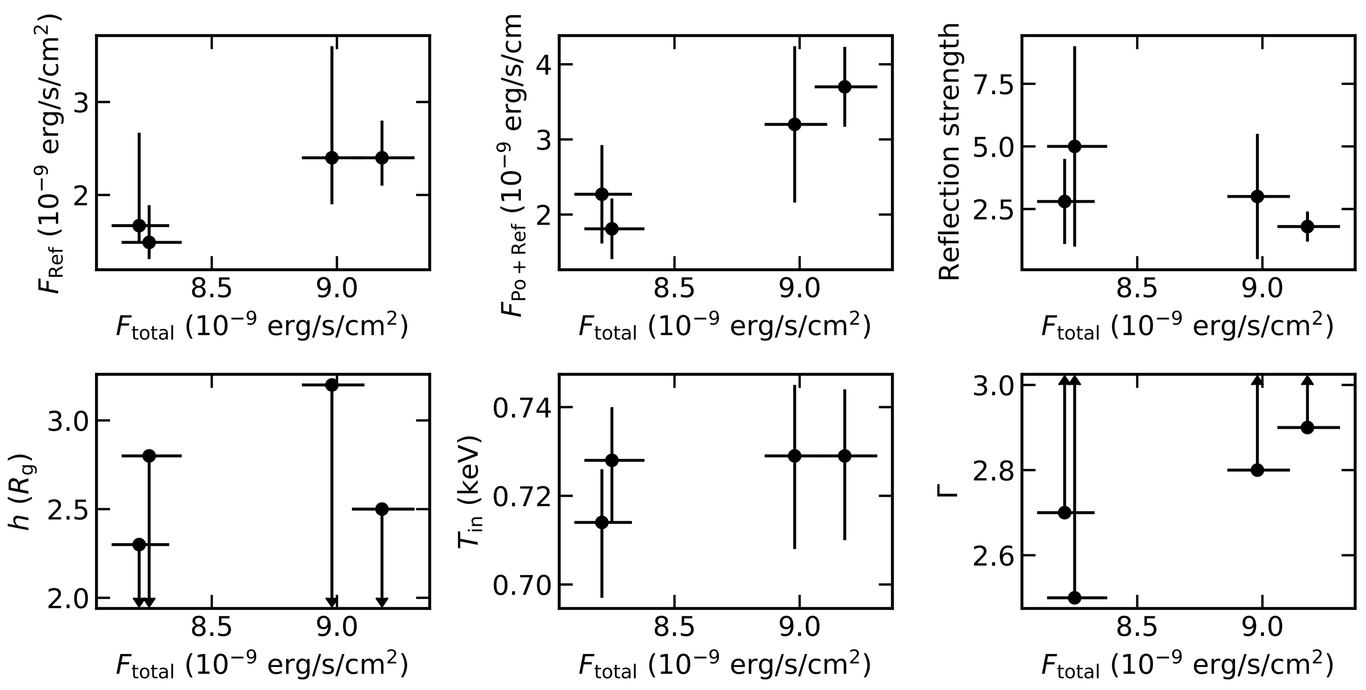

Figure 5. Relations of the some spectral parameters with the total X-ray flux in the energy range 2–15 keV. Lower and upper limits are marked with arrows.

Conclusion

- The flux change is confined in the hard X-ray band (>4 keV) and is regulated by the power-law emission and the reflected emission.
- The strength of the disc thermal emission and the inner radius of the accretion disc do not change with the flux.
- The corona is close to the black hole (3 Rg). There is no evidence for changes in the corona geometry when the flux changes, which suggests the change is in the intrinsic power of the corona.

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