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Unveiling State Transitions and Inner Disk-Corona Dynamics in Black Hole X-ray Binaries Using Power-Color and QPO Analysis

Black hole low-mass X-ray binary (BH-LMXB) systems are exceptional laboratories for studying accretion physics under strong gravity. The variability of these systems, characterised by the power spectra changes systematically in different states. The power color analysis offers a robust way of classifying the spectral states, as an alternative to the traditional HID (Hardness-intensity diagram) method. We consider the ratio of variability amplitude across selected frequency ranges, defined as the hue parameter, to identify the states. We conducted a comprehensive timing analysis of all the archival data of ten BH-LMXB spanning from 2016 to 2021. We investigated the energy dependence of QPO (Quasi-Periodic Oscillations) variability and time lag to probe the physical properties of the QPO emitting region, which are yet to be fully understood. Notably, we detect a sign reversal in the average QPO time lag between hard and soft photons around 2 Hz during the hard to hard-intermediate state transition. We found that the slope of the RMS variability spectra and the time lag spectra also change signs at the same frequency and hue value, highlighting a major change in accretion flow geometry. During the hard lag phase, time lags of 40–50 milliseconds suggest an extended corona modulating the QPOs. In the soft lag phase, much shorter and constrained lags of around 10 milliseconds, indicating a more compact corona surrounding the disk, producing soft lags through reverberation. This study offers critical insights into the transformation of the coronal structure in association with the state evolution of BH-LMXBs.

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