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Topic: Broad Band Study of Spectral and Timing Properties of Compact Object Systems

Findings

My thesis has been dedicated to investigating the spectral and temporal properties of black hole X-ray binaries using data from the X-ray instruments; *AstroSat*, *NICER*, *NuSTAR* and *Swift*. Apart from spectral evolution, the X-ray lightcurve shows broad range of variability which is manifested as Quasi-periodic Oscillations (QPOs) in the power spectra, superimposed on the broadband noise continuum. Despite substantial research there are some questions related to their temporal and spectral nature which still persist, like the understanding of the origin and energy-dependent behavior of QPOs remains incomplete. There are also reports of deviation of spectra from standard disk model at high luminosities, which is also not well understood.

This thesis aims to better our understanding of these phenomena, particularly by investigating the spectral and temporal nature of different black hole binaries in different states, from faint hard state to the brightest soft state. To better understand the X-ray variability, we model the PDS and explore the broadband noise continuum. We also explore the energy-dependent behaviour of the QPOs and model it with a general propagation scheme. Additionally, we test geometric and dynamic origin for the variability. We also model the energy spectra in different spectral states, implementing relativistic and non-relativistic models to understand the geometry and properties of the accretion flow. Lastly, we highlight a peculiar case involving deviations from the standard disk model at high luminosities.

In Chapter 1, we begin by exploring various compact objects and their characteristics. The discussion extends to accretion dynamics and the diverse types of disks involved. Moving forward, we explore the spectral evolution of black hole binaries, explaining the different spectral components. This leads us to the timing properties and rapid variability observed in the power spectra. We then discuss the properties of broadband noise and Quasi-periodic oscillation, including their energy-dependent characteristics. In Chapter 2, we explore methods for studying black hole binary systems. We start with spectral analysis, which involves understanding the energy spectrum in terms of an X-ray detector and using a goodness of fit statistic. The chapter then moves on to constructing Power Density Spectra from a time series, explaining concepts like fractional RMS and Fourier time-lag spectra which are to be modelled later in this study. We also introduce various X-ray observatories used in this work, like AstroSat, SWIFT/XRT, NuSTAR, and NICER to perform spectro-temporal analysis and their data reduction techniques.

In Chapter 3, we dealt with broadband noise variability in the PDS of faint *AstroSat* observations of the famous BHXB GX 339-4. We identified a mHz break in the broadband noise continuum, whose detection was confirmed independently with *LAXPC* and *SXT*. We found the disk to be highly truncated at $> 90\ \mathbf{R_g}$ in line with truncated disk geometry of low-flux hard state. In Chapter 4, we focused on BHXB H 1743-322, which exhibited Type-C QPO (<1Hz) in *AstroSat* data, with the aim of identifying the radiative components whose oscillation is responsible for the observed quasi-periodic variability. To do this, we employed a general stochastic fluctuation model given by Garg et al. (2020) This also allowed us to explain the soft and hard lags as variability propagating from corona to the disk and vice versa.

In our Chapter 5, we test two theories for QPO origin: the dynamic origin, where the QPO frequency is associated with the sound crossing time-scale; geometric origin, which relates the QPO frequency to the Lense-Thirring precession frequency. We conducted spectro-temporal analysis of long term observations of two BHXB systems MAXI J1535-571 and H 1743-322 with Type-C QPOs. We find that the dynamic origin favours the QPO evolution better than the geometric origin. In Chapter 6, we followed the outburst decay of one such BHXB, 4U 1543-47. The most prominent feature was the truncation of inner disk during its high/soft state, which we confirmed with both non-relativistic and relativistic disk models. Another notable feature was one of a kind absorption edge in 6-11 keV, suggesting a possible origin due to the disk wind.

Lastly, in Chapter 7, we discuss the implication of our work and conclude. This thesis has contributed to better understanding of spectral and temporal behaviour of four black hole binaries, in different spectral states. Our work has mainly focused on the rapid variability observed in the X-ray lightcurve, and we ex, this could not be modelled with any reflection models and necessitated the inclusion of partial covering modelplore the broadband noise and QPOs. The modelling of energy-dependent properties of the QPO with the general propagation model, allows to identify the origin of the QPO, by identifying the radiative components.