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Topic Of Research: Probing energy dependent timing behavior of the X-ray binaries

Findings

In the passing decades, improved multi-wavelength telescopes have made it possible to peek at the most luminous objects in the Universe and ascertain the underlying physical phenomena. One such class of objects is the Galactic X-ray binaries, where a compact object such as a black hole, neutron star, or a white dwarf owing to its strong gravity, accretes the material from a companion star and thereby emits profusely in the X-ray and other parts of the electromagnetic spectrum. Numerous timing studies in the past have shown that Black hole X-ray binaries possess rapid X-ray variability on time scales of msec to sec during their outburst period. In Fourier space, the power density spectrum presents a broadband noise and peaked features known as Quasi-periodic oscillations (QPOs). However, there are currently few models developed that can translate the observed variability to physical interpretations. There have been attempts to explain observed features either by geometric origin or by identifying radiative components that can give rise to them. We have taken the latter approach in this thesis and have developed a generic and physically motivated technique to probe QPO and its energy-dependent properties such as fractional rms and time lags. Further, we tested the technique using the remarkable observations of the QPOs made by the Indian multi-wavelength satellite AstroSat in different black hole systems. We present the results of our studies and highlight their implications for understanding the dynamical accretion geometry. The whole thesis comprises six Chapters.

In Chapter 1, we have briefly introduced the astrophysical objects relevant to this thesis. We begin by briefly reviewing the onset of X-ray astronomy and the discovery of X-ray sources. Afterward, we define compact objects and explain their formation during stellar evolution. Such compact objects in a binary relationship with normal stars constitute the X-ray systems. We have described how these X-ray binaries can transfer matter through Roche lobe overflow or stellar wind accretion. Then in Chapter 2, we addressed the long-time variations in the accretion geometry during the outbursts of the black hole X-ray binaries. Typically in an outburst, the source passes through states which differ in terms of flux intensity, variability, and the shape of the time-dependent energy spectrum. Throughout the Chapter, we have discussed the known origins of the soft and hard components in the observed energy spectrum. Essentially, we first review the optically thick and geometrically thin disc model proposed by Shakura and Sunyaev, generally used to fit the soft black body component. After that, we give details of the thermal Comptonization process, which occurs in the hot, optically thin, and geometrically thick region and produces the hard power-law component. Both these geometries can be combined to get a truncated disc model where the thermal disc gets truncated at some distance from the black hole, and a hot coronal cloud occupies the inner region. We conclude this Chapter with a few details about this model and other alternative geometries.

In Chapter 3, we have focussed on the core issue of the thesis- the rapid X-ray variability. We have first defined the QPOs and their properties. A brief description of the energy-dependent features such as fractional rms and time lags central to the technique is given. After laying out the details of the classification of QPOs, we have listed the predominant theoretical models that attempt to explain the nature of QPOs. However, we point out that these models are complicated and may not quantitatively explain the observed features in the power spectra. Further, we argue for another possible approach which is primarily based on the spectro-temporal correlation as identified in multiple works. Some studies worked in this direction using the RXTE (Rossi X-ray Timing Explorer) satellite data, but the results are insufficient due to the limited energy range of RXTE. We mention the need for high-time resolution data in a wide energy band to carry out the studies, which is fulfilled by the AstroSat. Following this, a concise introduction to the AstroSat and its payloads is given at the end of the Chapter.

In Chapter 4, we have put forward a generic technique where one models the observed time-dependent energy spectra using known radiative processes, converts associated spectral parameters into physical ones, and determines which variations of these physical parameters reproduce the observed energy-dependent fractional rms and time-lags. For instance, we applied the technique to the AstroSat/LAXPC observations of the low-frequency QPOs in the black hole system GRS 1915+105, where the energy spectrum is characterized by blackbody photons from a truncated disc and power-law emission from an inner hot thermal Comptonizing coronae. We found that the correlated variations in the accretion rate, inner disc radius, coronal heating rate, and optical depth with time lags between them can explain the QPOs and their harmonics. Although the analysis was carried out using only a small set of observations, we have stressed that the Chapter aims to illustrate the scheme and qualitatively check the scheme's efficiency.

Since the early results were successful, it called for a thorough investigation using a large set of observations for a different black hole system. Thereby, in Chapter 5, we employed the technique for MAXI J1535-571, observed extensively by payloads LAXPC and SXT onboard AstroSat. Initially, during the spectro-temporal study, the QPO frequency is found to correlate with the scattering fraction (i.e., the fraction of the soft photons Comptonized), and its dependence on the accretion rate and inner disc radii are consistent with it being dynamical frequency. Further, we discovered that the rms and lag spectrum could be explained using a model where accretion rate and inner disc radius vary coherently with no time lag and coronal heating rate varies with a time lag compared to the other two. The lag is seen to flip sign at a QPO frequency of $\sim$ 2 Hz, showing that the QPO possibly originates from the truncated disc for frequencies lesser than 2 Hz and the corona for higher frequencies. However, there could be another explanation where QPO arises simultaneously from disc and corona regions.

The employed technique is a potential step towards unraveling the radiative process responsible for variability using high-quality spectral and temporal data from AstroSat. But definitely, there is a scope for improvement. In Chapter 6, we have summarised the whole work, discussed the issues related to the techniques, and listed the important extensions of the work.