Study of Spectral Signatures and Accretion Dynamics of Black Holes During Outbursts

A thesis submitted

in partial fulfillment for the award of the degree of

Doctor of Philosophy

by

Aneesha U

Department of Earth & Space Sciences

Indian Institute of Space Science and Technology

Thiruvananthapuram, India

September 2020

Abstract

Unlike other astrophysical objects, black holes cannot be observed directly using electromagnetic radiation. In a binary system, a black hole can accrete material from the companion star due to its extreme gravity. The accreted matter releases a huge amount of potential energy and a fraction of this is emitted as radiation, mainly in X-ray. Therefore, the study of the nature of X-ray radiation is important to understand the underline accretion process. Black hole X-ray binaries can be persistent showing continuous X-ray activity or transient which exhibits occasional outburst in between long quiescent phases. In this thesis, we attempt to understand the accretion physics around outbursting as well as persistent black hole X-ray binaries through spectral studies utilising various X-ray instruments data.

In Chapter 1, we introduce the astrophysical compact objects and X-ray binaries (XRBs) in general, with particular emphasis on black hole XRBs. We provide an outline on accretion around compact objects via Roche lobe overflow as well as wind accretion. Also, we make an effort to summarize various accretion disc models discussed in the literature. Jet/outflow is an integral part of the accretion process and we have touched upon the jet characteristics to highlight X-ray-radio correlation. It is well accepted that the outburst process may trigger because of instability in the accretion disk. A short description of the disc instability model in presence of irradiation is presented. During the outburst, the source passes through different spectral states which are also mentioned. Finally, we present the motivation behind this thesis and selection of sources.

We have used the two-component accretion flow model extensively for spectral modelling of X-ray data. Therefore, in Chapter 2, we describe the essential insights of the two-component accretion model. We give a brief account of different radiation processes such as bremsstrahlung, Compton scattering and Synchrotron which are required to calculate the radiation spectrum. Few additional model components like, photoelectric absorption, and line emission, which is used for spectral modelling, are also discussed.

In Chapter 3, we highlight the key aspects of different space X-ray observatories (RXTE, XMM-Newton, Swift, AstroSat) whose data have been used in our study. We outline the data reduction techniques for individual X-ray instruments and tasks for extracting useful scientific products.

In Chapter 4, we aim to understand the accretion dynamics of H 1743-322 during outbursts. We analysed all the RXTE/PCA data during 2003-2011. We have performed phe-

nomenological spectral modelling and extract the spectral parameters. Similarly, we have done spectral modelling with two-component accretion model and estimated the accretion parameters. We study the evolution of spectral parameters and understand the spectral state transitions during outbursts. We model the accretion parameters evolution with a toy model and estimate the characteristic time scales that govern the dynamics of the outbursts. We employ the irradiated disc instability model in two-component accretion scenario to understand the evolution of the outburst. We discuss the issues regarding the two-component spectral modelling of 2003 outburst and understand the requirement of additional contribution from the jet. Also, we study the evolution of accretion dynamics with the activity of the jet observed in radio frequency.

In Chapter 5, we study the second outbursting source GX 339-4 having very different outbursts characteristics. We carry out both phenomenological and two-component spectral modelling of RXTE/PCA data over a period 2002-2012. Also, simultaneous broadband (Swift, RXTE, XMM-Newton) spectral studies are performed for better constrain on the spectral parameters. We connect the evolution of the spectral parameters with the accretion parameters. The evolution of the accretion rates is modelled with a logarithmic time variation. We provide a unified view of all the outbursts in the light of the irradiated disc instability picture. Finally, we discuss a possible physical scenario behind outbursts with short and long rise time.

To complement our work on outbursting sources, in Chapter 6 we study the spectral variability and accretion properties of two persistent sources GRS 1758-258 and 1E 1740.7-2942 using AstroSat observations during the period 2016-2018. Both these sources are close to the galactic centre and we discuss the contamination issues in AstroSat observations. We perform broadband spectral modelling of both the sources. The variation in the spectral parameters is discussed in connection with the same of the accretion parameters. We compare the behaviour of the persistent sources in the hardness intensity diagram with that of the outbursting sources studied in the previous chapters and connect the nature of the persistent source with the irradiation phase of the outbursting source.

In Chapter 7, we summarise the thesis work and indicate the future scope of the study.