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Probing Accretion Flow Dynamics in X-ray Binaries
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Summary

Astronomy is the scientific study of objects such as planets, stars and galaxies in the universe. These objects can be studied by observing the light (electromagnetic radiation) they emit. The electromagnetic radiation can be of different types characterized by different frequencies. The Earth's atmosphere allows only part of this radiation to reach the surface, as shown in Figure A. Various detectors sensitive to the different types of radiation are used to observe the celestial objects; some detectors are sent on board satellites to observe the radiation that cannot penetrate the atmosphere.

The celestial objects that can be seen with the naked eye are stars and planets. A star is a globe of hot and dense gas producing its own light from nuclear fusion (a nuclear reaction where atomic nuclei combine to form new atomic nucleus) of the gas. When the star eventually runs out of 'fuel' for nuclear fusion (it cannot combine nuclei any more), it reaches the end of its life cycle. It can take up to billions of years for a star to reach this stage. At this stage, the inward pull of gravity (which was earlier supported by gas pressure) collapses the star into a very dense object. These extremely dense and compact objects can be of two types: neutron stars and black holes. Neutron stars, as the name suggests, consist mostly of neutrons and are small in size: imagine the sun (which is a sphere with a diameter of 1.4 million km and 3.3 $\times 10^{5}$ times the mass of the Earth) packed in a sphere with diameter of only few km! The gravity on these objects is extreme: compared to Earth, you would weigh more than a billion times as much on a neutron star. Black holes are even more exotic as they are not only more massive, but also smaller than the neutron stars. Their gravity is so strong that even light cannot escape from them (and hence their name)! These objects are interesting to study as they provide extreme environments, which cannot be generated in the laboratories on Earth.

If a sun-like star is in orbit with a compact object, the compact object can strip the

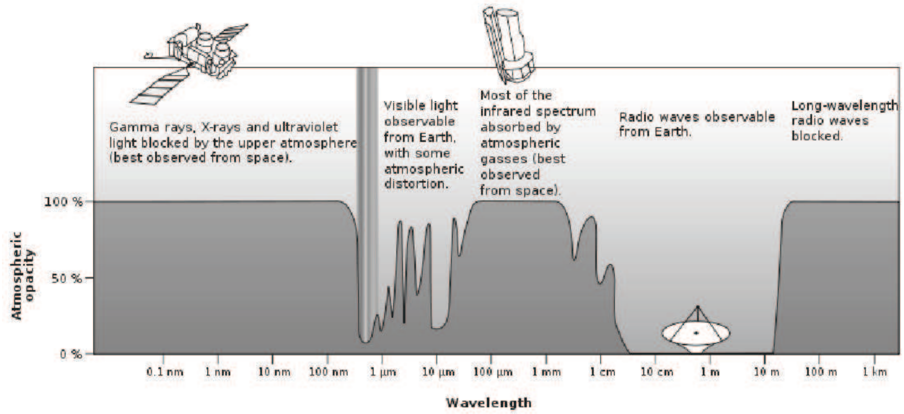

Figure A: The degree of opacity of Earth's atmosphere to electromagnetic radiation shown as a function of wavelength. The different types of radiation are the radio (e.g., from the radio station), microwave (which cooks the food), infrared (which we associate with heat), visible (which we can see with our eyes, e.g., colours of the rainbow), ultraviolet (the harmful radiation from sun that is blocked by the ozone layer), X-rays (e.g., the X-ray that shows the bones in our body) and gamma rays. Image credit: NASA/IPAC

star of its outer layers. This stripped matter spirals inwards, forming a disc around the compact object (called accretion disc) and eventually falls on to the neutron star or in the black hole. During this process, the accreting matter becomes extremely hot (few million degrees) and emits radiation which is mostly in the X-ray region, and hence these systems are called X-ray binaries. Figure B shows an artistic impression of an X-ray binary. In this thesis, I study the accretion phenomena in X-ray binaries which were observed using the X-ray satellites called Rossi X-ray Timing Explorer (RXTE, which can observe in the 0.6-0.02 nanometre wavelength range) and *Swift* (which can observe in the 4-0.12 nanometre wavelength range). The detectors on board these satellites provide information on the 'energy' and the arrival times of the X-ray photons.

The study of radiation from the accreting matter is an active area of research. The amount of radiation received by a detector is generally expressed in terms of intensity (brightness) and it changes on various time scales. This *variability* can be measured in terms of different frequencies at which the intensity changes and the strength at each frequency. The time scale of the motion of the in-falling matter very close to the compact object is extremely short: it takes less than a millisecond to complete one orbit around the compact object. Study of fast variability provides an excellent probe to investigate the behaviour of matter under extreme conditions in the vicinity of a

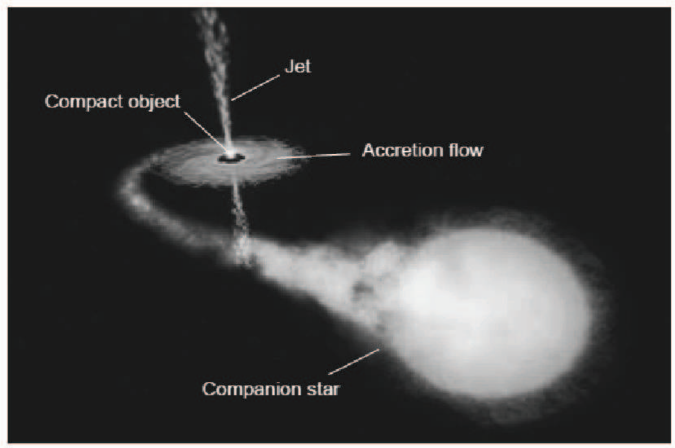

Figure B: Graphic illustration of an X-ray binary (Image courtesy- R. Hynes).

compact object.

X-ray variability is ubiquitously observed in X-ray binaries, but the mechanism that causes this variability is incompletely understood. There are also many challenges in understanding the structure and geometry of the accretion flow: it is more complex than a simple accretion disc. Studies suggest that the accreting matter forms a hot inner gas flow (size and structure of which is unclear), along with the accretion disc. The aim of this thesis is to investigate these unsolved issues.

In Chapter 1, I study the X-ray variability in a neutron star system with observations from the RXTE satellite. In this system, variability on time scales of the order of seconds to milliseconds is observed. I investigate how the results of this study fit in the current ideas, called models, proposed to understand the origin of fast (millisecond) variability. In the second chapter, I study the variability of an X-ray binary with data from the RXTE satellite over period of a few weeks. Based on the variability evolution of the source, the binary system is suggested to host a black hole.

The third chapter forms a transition in the thesis, as I use data from the *Swift* satellite. Compared to RXTE, *Swift* can observe an additional range of emission (the 4-0.6 nanometre wavelength range) allowing us to see more emission from the accretion disc. This is the first time that such a detailed variability study was performed using *Swift*. I provide an optimal solution to take the instrumental effects into account, in order to study variability with the detectors on board *Swift*. The results strongly support the idea that the variability also originates in the accretion disc, in addition to the hot gas flow (as was mostly believed to be the case earlier). After successfully demonstrating the utility of the detector on board *Swift* for variability study, I apply the same methodology to the source studied in chapter 2 (with RXTE), arriving at the same conclusion that part of the variability originates in the accretion disc. I investigate different models proposed to explain the origin of variability.

To get the complete picture, it is necessary to study not only the variability of the emission, but also the energy distribution of the emission (energy spectrum). The 'spectral' studies can give us information on the characteristics of the accretion flow e.g., how hot the disc is, etc. In the fifth chapter, I performed a study of both the spectral and variability properties in three sources (incorporating sources studied in chapters 3 and 4). The spectral properties such as the temperature of the disk and the variability properties such as the frequency and strength of variability mostly evolve in a correlated fashion. The correlations depend on which is the dominant emission component: the accretion disc/hot gas flow, providing a tool to study the structure of the accretion flow.