Description for the general public (in English)

Black holes are one of the most exotic objects in the Universe, which are the remnants of a star more massive than Sun. The theoretical formalism of a black hole is that of a spacetime singularity from which even light cannot escape. Black holes existing in a binary system with another star can emit electromagnetic radiation due to the process of accretion. Accretion is one of the most energetic processes in the Universe, in which matter from the star falls on to the compact object (like a black hole), releasing its gravitational energy in the form of electromagnetic radiation.

Since the launch of the first X-ray satellite Uhuru in 1970s, these black hole X-ray binaries have been extensively studied for over half a century, by various X-ray satellites. A salient feature of these black hole X-ray binaries is the very high variability in X-ray spectra observed in them, over various timescales. The X-ray spectra observed in these systems is mainly composed of thermal soft component (approximately < 3 keV) and hard power-law component (roughly between 10 keV - 100 keV). The soft component is due to the thermal blackbody like radiation from a relatively cold, optically thick disk which are usually geometrically thin. The power-law spectrum is thought to be emitted due to Compton upscattering from a hot, geometrically thick, radiatively inefficient accretion flow (RIAF) around the black hole. During quiescence, the disk is in low/hard state with the X-ray spectra dominated by the hard component and a weak soft component. As the outburst evolves, the spectrum becomes softer reaching a high state where the X-ray spectra is dominated by the soft component. Theoretical models have been invoked to explain such behaviour attributing to changes in the accretion disk geometry but these models are yet to be confirmed by the numerical simulations.

The primary goal of the proposed research is to perform numerical simulations of accretion disks around black holes to study the changing accretion disk geometry observed during the spectral state transitions. Studying accretion disks close to the black holes requires solving of general relativistic fluid equations that are coupled to magnetic fields and radiation, which can only be solved numerically. With the advancements in computational resources and numerical codes, it is now possible to simulate accretion disk physics close to realistic situations using general relativistic radiation magnetohydrodynamics (GRRMHD) codes. Our research plan is to perform 3D GRRMHD simulations of a RIAF disk fed with an increasing mass accretion rate. It is expected that the additional mass inflow increases the mass density and radiative efficiency of the accretion flow and the gas condenses to form cool disks. With these simulations, we will be able to investigate how the accretion flows with different geometries and different spectral behaviour exist together as observations suggest. We can also study how the flow properties like temperature, density etc evolve as the disk makes transition. Black hole X-ray binaries also exhibit aperiodic variability on very short time scales within a characteristic frequency range known as quasi-periodic oscillations (QPOs). High-frequency QPOs are observed in the intermediate states between the low/hard state and high/soft state but what causes these QPOs is still an open debate. With these simulations, we will also investigate on the possible origin of QPOs owing to the mass accretion rate variability. Additionally, observations report that these X-ray sources are often associated with outflows/disk winds. Presence of any such outflows will be studied as it is important to understand their impact on the disk structure.