Abstract

Ultraluminous X-ray sources (ULXs) are enigmatic sources that defy the Eddington limit for accretion. Due to their high observed apparent X-ray luminosity, ULXs were thought to be the potential candidate of an intermediate-mass black hole (IMBH: 10^{2-4} $M_{\odot}$). However, a breakthrough discovery was made by *NuSTAR* satellite detecting a coherent pulsation from the ULX M82 X-2 suggesting that ULXs can host neutron stars (NSs) with the prospect of stellar-mass black holes (BHs) existing in many other ULXs. Now it is commonly believed that most ULXs harbor stellar-mass compact objects accreting at a super-Eddington rate and their apparent high luminosity results from geometrical beaming by the optically thick wind.

In Paper I and Paper II, I performed the broad-band multi-epoch spectral studies of two ULXs: NGC 5055 X-1 and Circinus ULX5, respectively. NGC 5055 X-1 is an extremely luminous X-ray source with 0.3-10 keV unabsorbed luminosity up to 2.32×10^{40} erg s^{-1}. I was able to derive various conclusions from correlations between the spectral fitting parameters. The negative correlation between the inner disk temperature and the source luminosity suggests that the source is accreting at a high Eddington ratio and the presence of geometrical beaming. The positive correlation between the photon index and the flux indicates that the accretion geometry is disk+corona. Circinus ULX5 shows both flux and spectral variability. Spectral and timing analysis performed by me revealed at least two distinctive spectral states of the source. The power-law dominated state is found in the low flux level and the thermal disk dominated state is found in the high flux level. Furthermore, there is an intermediate state in which the source flux is low but the spectrum is dominated by the thermal disk component. The inner disk radii obtained from the fitting of the disk component suggest that the mass of the central compact object is < 10 $M_{\odot}$. Even though I do not see the pulsation in the light curves, the compact object in Circinus ULX5 can also be a NS.

In Paper III, I performed a Fourier timing analysis of NGC 7456 ULX-1. The time-averaged spectrum is broadly described by a two-component model with soft (accretion disk) and hard (thermal Comptonization) components, dominating mostly below and above 1 keV, receptively. I found the Fe K_{α} line with an equivalent width of 300 eV, which indicates that the line must be originated at a distance of $\geq 85 R_{\rm g}$. The source displays an extreme level of flux variability with 0.5–10 keV fractional variability up to $44.25 \pm 1.46\%$ within the time scale of 1000 s–40 ks. Form the timing analysis, I found that the soft X-ray flux lags behind the hard X-ray flux with nearly 1300 s delay. The covariance spectrum indicates that the harder component is responsible for the observed time delay. The reverberation is highly unlikely for the origin of this delay, however, it can be explained by multiple scattering of the X-ray photons inside the outflowing medium.

In Paper IV, with the use of `StarTrack` population synthesis code, I found the evolutionary connection between ULXs and merging double compact objects (DCOs: BH-BH, BH-NS, NS-NS) detected by advance LIGO/Virgo. The optical observation of a few ULXs identified massive supergiant donors, therefore these ULXs are potential progenitors of merging DCOs. Various evolutionary scenarios have been put forward to explain the origin of DCOs: isolated binary evolution, dynamical evolution inside a dense cluster, and chemically homogeneous evolution of field binaries. Hence, finding connections between ULXs and DCOs can point to the origin of the DCOs. Our merger rate calculation shows that nearly 50% of the merging BH-BH have evolved through a ULX phase.