Spectral Evolution of an Ultraluminous Compact X-Ray Source in NGC 253

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We report an observational result for a ULX in NGC253. We find that the spectral evolution is well consistent with the standard behavior. That is, the source satisfies the relation $L_{\rm disk} \propto {T_{\rm in}}^4$ as established for black hole binaries. By comparing with black hole binaries, we estimate black hole mass of this ULX as $7M_\odot$.

§1. Introduction

Ultraluminous compact X-ray sources (ULXs[1]) are point-like sources often seen in off-center regions of nearby galaxies.[2] Assuming the Eddington limit, their high luminosity requires them to be accreting black holes (BHs) as massive as $\sim 10 - 100M_\odot$. The spectra of the majority of ULXs are fit well with the multi-color disk (MCD) blackbody model,[3] which approximates the optically thick standard accretion disk.

In order to understand the nature of ULXs, it is important to study spectral evolution, as is done for BH binaries (BHBs). The spectral evolution is often studied on a $T_{\rm in}$-$L_{\rm disk}$ diagram, where $T_{\rm in}$ is the inner disk temperature, and $L_{\rm disk}$ is the disk bolometric luminosity. Many BHBs evolve as $L_{\rm disk} \propto {T_{\rm in}}^4$ in this diagram, called the "standard regime". This behavior gives strong evidence that the inner disk radius, $R_{\rm in}$, remains constant at a value consistent with the last stable orbit for a central BH. On the other hand, the brightest ULXs have been found to evolve as $L_{\rm disk} \propto {T_{\rm in}}^2$, which is consistent with the slim disk solution. Some features predicted by the slim disk solution have been observed also in BHBs, called the "apparently-standard regime".[4] This regime is realized when the accretion rate becomes as high as the Eddington accretion rate, and $L_{\rm disk}$ has been found to evolve in proportion to $T_{\rm in}^2$, as observed in ULXs. Owing to the nature of this spectral evolution of ULXs, they have been identified with high mass accreting BHs, and this encourages us to obtain the spectral evolution in much wider range of $L_{\rm disk}$. The standard regime is expected to appear in a luminosity range lower than that of many other ULXs which evolve as in the apparently-standard regime. With this perspective, we have analyzed less luminous ULX, NGC 253 Source 1 ($D = 2.58$ Mpc).

§2. Analyses and results

The archival data of *XMM-Newton* and *Chandra* data were analyzed. The net observation time of *XMM-Newton* data was 37 ksec and that of *Chandra* data was

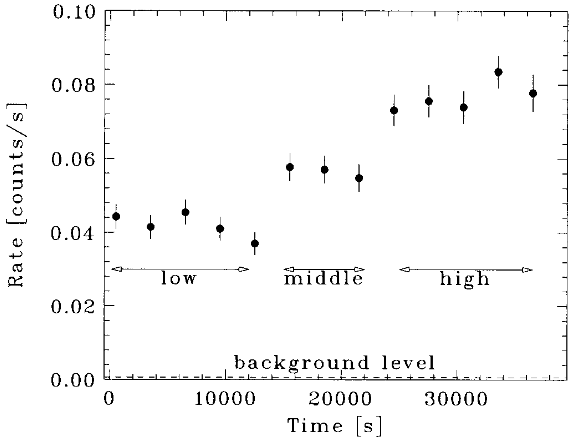

Fig. 1. The 0.5–10 keV lightcurve of Source 1 (in counts per second), obtained with *XMM-Newton*.

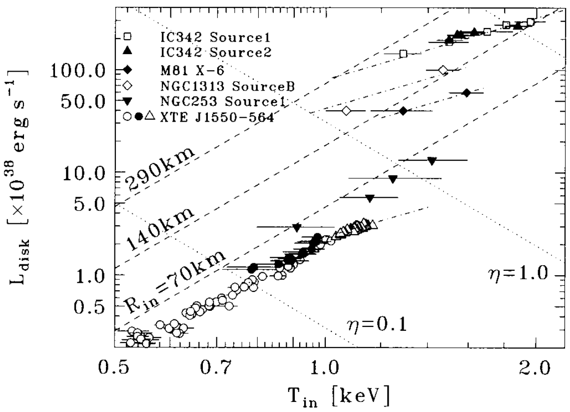

Fig. 2. Relation between $L_{\rm disk}$ and $T_{\rm in}$ obtained from the MCD-model fit. All data points for NGC253 Source 1 were obtained with this analysis (three periods of the *XMM-Newton* data, and the *Chandra* data), and those of other ULXs, IC 342 Source 1, M81 X-6 and NGC1313 Source B are with *ASCA*.[5] The data for the BHB, XTE J1550–564 were obtained with *RXTE*.[4] The inclination is assumed to be 60° for all ULX data. The dashed lines represent $L_{\rm disk} \propto T_{\rm in}^4$, and thus that correspond to a constant value of $R_{\rm in}$.

14 ksec. During the *XMM-Newton* observation, the count rate of Source 1 varied by a factor of 2 (Fig. 1). Following the previous works on ULXs, the MCD model and the single power law model were applied to reproduce the time-averaged spectra of Source 1 obtained with *XMM-Newton* and *Chandra*. As a result, the MCD model successfully reproduced the both spectra with $\chi^2/\nu = 149.5/152$ and $\chi^2/\nu = 23.8/30$ for the *XMM-Newton* data and the *Chandra* data, respectively.

In order to examine the spectral evolution in more detail, the *XMM-Newton* data were split into three periods, covering low-flux, middle-flux and high-flux periods, as denoted with the three arrows in Fig. 1. The spectrum was constructed for each period and was investigated within the framework of the MCD model. The MCD model reproduced each spectrum very well.

The values of $L_{\rm disk}$ were calculated on the basis of the best-fit parameters of the MCD model, and are plotted as functions of $T_{\rm in}$ in Fig. 2. In contrast to other ULXs, NGC 253 Source 1 evolves as $L_{\rm disk} \propto {T_{\rm in}}^4$ like BHBs in the standard regime. The value of $R_{\rm in}$ remains almost constant at 63 km. By assuming that $R_{\rm in}$ coincides with the last stable orbit, $3R_{\rm s}$, where $R_{\rm s}$ is the Schwarzschild radius, the mass of the black hole is estimated to be $\sim 7M_\odot$. This is consistent with stellar mass black hole. As shown in Fig. 2, this ULX exhibited an intensity variation of $L_{\rm disk}$ of 3–13 $\times 10^{38}$ erg s^{-1}, which corresponds to 30–120 % of $L_{\rm E}$ of a black hole of mass $7M_\odot$.

References

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