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Photon Spectra of Supercritical Accretion Flows with Comptonizing Outflows around Stellar-Mass Black Holes

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Ultraluminous X-ray sources (ULXs) have recently been found in the off-center region of nearby external galaxies. The typical photon luminosities of ULXs range 10^{39-41}[erg/s], which exceeds the Eddington luminosity for neutron stars and stellar-mass black holes. There are two possible models considered to account for such large photon luminosities: subcritical accretion (i.e., accretion below the Eddington accretion rate) onto an intermediate-mass black hole and supercritical accretion (i.e., accretion exceeding the Eddington accretion rate) onto a stellar-mass black hole. Since the black hole masses of ULXs are poorly known at present, we cannot discriminate between these two models. The study of radiation spectra of supercritical accretion flows may give a clue to resolve this issue.

We calculated X-ray spectra of supercritical accretion flows with mildly hot outflows by Monte-Carlo techniques using two-dimensional radiation hydrodynamic simulation data of Kawashima et al. (2009). Our method is based on Pazdnyakov et al. (1976), and we incorporated radiative processes such as the modified blackbody radiation with special relativistic effects (i.e., the Doppler shift and the aberration) at the photosphere, the free-free absorption, the photon trapping effect, the thermal Comptonization, and the bulk Comptonization.

We found that the thermal inverse Compton scattering by electrons of the outflow affects the spectral energy distribution (SED) of the supercritical accretion flow. The fraction of the hard emission increases as the mass accretion rate increases (i.e., the photon luminosity increases). When the isotropic X-ray luminosity is below about 10 Eddington luminosity, the SED is similar to that of the slim disk state (i.e., one-dimensional model of the supercritical accretion flow). By contrast, when the isotropic X-ray luminosity is larger than about 10 Eddington luminosity, the SED becomes harder at high energy region and deviates from the slim disk state. This spectral property is consistent with that of some ultraluminous X-ray sources.

Keywords: accretion disk, black hole, radiative transfer, hydrodynamics