Including a Warm Corona within the Inner Accretion Disk of Active Galactic Nuclei

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Abstract

Warm coronae, Comptonizing regions of warm (temperature ~ 1keV), and optically thick (Thomson depth ~ 10 - 20) gas, at the surfaces of accretion disks in active galactic nuclei (AGNs), have been proposed to explain the origin of the soft X-ray excess commonly observed in the X-ray spectra of AGNs. We calculate the X-ray emission from an irradiated constant density accretion disk atmosphere that includes heating from a warm corona, as well as illumination from an external X-ray power-law, and a blackbody emission from the dissipation in the accretion disk. The model accounts for the radial dependence of disk ionization, including the effects of light-bending on the illuminating X-rays. The final spectra are produced by integrating the local reflection/emission spectrum from approximately 2 to 400 gravitational radii. We demonstrate how the soft excess in AGN X-ray spectra depends on the warm corona heating fraction and optical depth, and the strength of the X-ray illumination. The model will be publicly released in 2022 for use in fitting AGN spectra.

Model Description

A. A radially dependent Warm Corona model with reflection

- We consider the emission/reflection spectrum produced by a constant density disk atmosphere with Thomson depth τ_T at radius R. The disk dissipates a total flux $D(R)$ (Shakura & Sunyaev 1973). A fraction h_f of $D(R)$ is assumed to be uniformly distributed in the warm corona.
- At each R, the density of the warm corona is given by $n_H/1000$, where n_H is calculated from the radiation pressure dominated solution of Svensson & Zdziarski (1994).
- The surface of the warm corona is illuminated by the hot corona, which is located directly above the black hole's rotational axis with a height h. The spectrum from the hot corona is modeled as a cut-off power-law with photon index Γ. A fraction f_X of $D(R)$ within 10 r$_g$ is released in the hot corona and irradiates the disk, where r$_g$ is the gravitational radius of the black hole. The X-ray flux from the hot corona is calculated using the equation in Ballantyne (2017) that accounts for light-bending effects.
- The bottom of the warm corona is heated by the blackbody with the remaining energy of $(1 - f_X - h_f)D(R)$.
- We use the code of Ballantyne et al. (2002) to calculate the reflection and emission spectrum from the surface of the atmosphere at radius R.
- The emission spectrum from R to $R + \Delta R$ is relativistically blurred using the $\mathrm{relconv\_lp}$ model (Dauser et al. 2013)

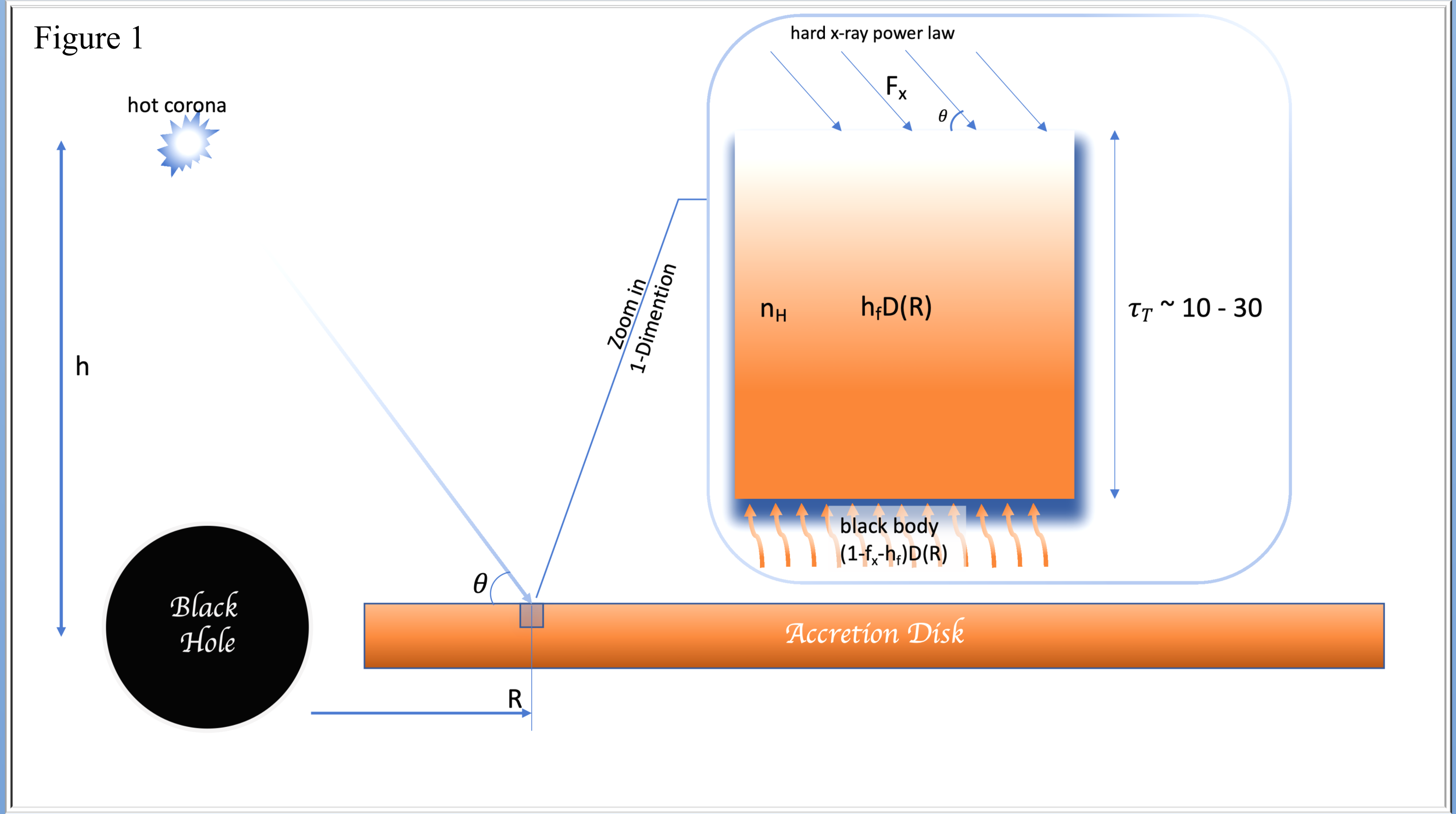

Figure 1

B. The Final Model: 2-D integration

- The final model integrates 20 individual spectrum from $R_{in} = R_{ISCO} + 0.5r_g$ to R_{warm}, the radius at the disk where the ionization parameter $\xi = 5$, plus the extension region which is dominated by neutral reflection from $R_{warm}$to R_{out}~$400r_g$. Each individual spectra in the warm corona region and the extension region has width of ΔR = ($R_{warm} - R_{in}$) / 20 and $\Delta R = 5r_g$ respectively.

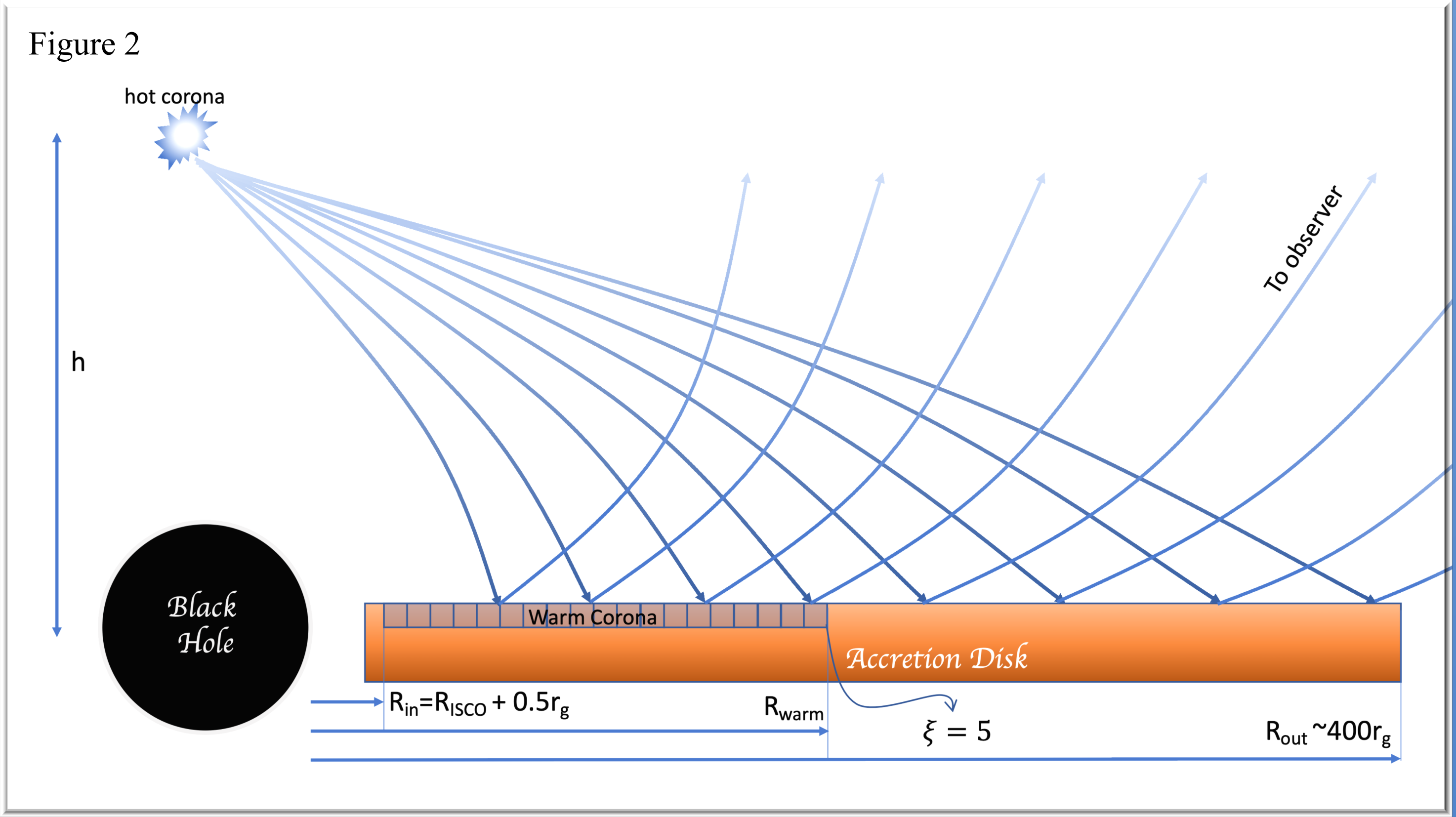

Figure 2

Results

Examples of Spectra and Physical Effects

The solid curves in Figure 3 are the emission and reflection spectra from the 2D warm corona model assuming the black hole mass $\mathrm{M} = 5{\times}10^7 M_{\odot}$, spin $a = 0.99$, and Eddington ratio = 0.01. We focus on the region of 0.3 – 30 keV in the graph.

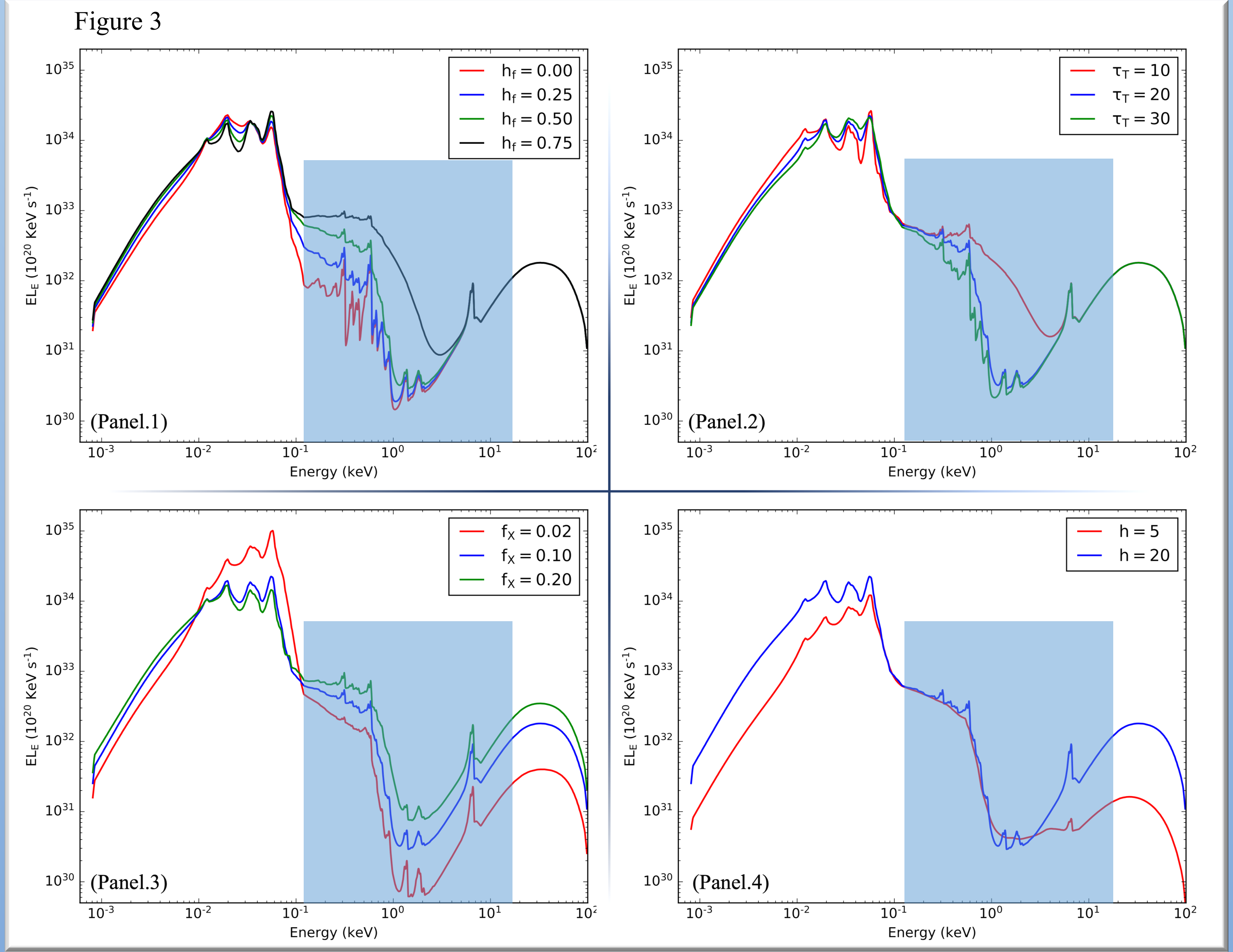

Figure 3

(Panel.1) Varying h_f : The spectrum for the four different values of h_f with $h = 20$, $f_X = 0.1$, and τ_T = 20.

- The increase of h_f enhances the Compton scattering throughout the layer and raises the ionization state of models in the gas. The soft excess is stronger and more ionized.

(Panel.2) Varying τ_T : The spectrum for the three different values of τ_T with $f_X = 0.1$, $h_f = 0.50$, and $h = 20$.

- Smaller τ_T increases the heating rate everywhere throughout the warm corona because the heat is spread into a smaller region. A larger h_f would be needed for a thicker layer (i.e., a bigger τ_T) to increase the Comptonization rates.

(Panel.3) Varying f_X : The spectrum for the three different values of f_X with $h_f = 0.50$, $h = 20$, and τ_T = 20.

- An increasing of f_X heats and ionizes the surface of the disk. But its importance on creating the soft excess is less than h_f and τ_T.

(Panel.4) Varying h : The spectrum for the two different values of h with $h_f = 0.50$, $f_X = 0.1$, and τ_T = 20.

- Higher lamppost height reduces the relativistic blurring effect. More heat from the hot corona illuminates the disk's outer radii, where the gas is less ionized, hence, a stronger $Fe\ K\alpha$ line. Lower lamppost height leads to a more ionized inner disk, but weaker reflection from the outer disk.

References

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