The relativistic iron line in the lamp-post scheme of the illuminated black-hole accretion disc

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Abstract: One of the interpretations of the broad feature in the spectra of several AGNs and black hole binaries in the energy range 2 − 10 keV is a relativistically smeared iron line. This line can arise when the accretion disc is illuminated by a hot corona above. We revisit the lamp-post setup in which the corona is positioned on the axis above the rotating black hole and show the importance of the local reprocessing for the expected shape of the broad iron line in the observed spectra. We compare our results with the relativistic line where broken-power law for radial emissivity is assumed. We use preliminary Athena response matrix in our simulations.

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The sketch of the model

Black hole: rotating Kerr metric for the central gravitating body with the mass M and spin a. In this poster we use $a = 0.94\,GM/c$.

Accretion disc: co-rotating, Keplerian, geometrically thin, optically thick, cold neutral disc extending from the marginally stable orbit $r_{in} = r_{ms}$.

Corona: non-moving hot point-like patch of plasma located on the rotation axis at the height h above the centre and emitting isotropic power-law radiation, $f = E^{-\Gamma}$, with the power-law index $\Gamma = 1.9$ for the specific photon number density flux.

Light rays: fully relativistic ray-tracing code in vacuum is used for photon paths from the corona to the disc and from the disc to the observer.

Reflection: Monte Carlo multi-scattering code (NOAR) is used for computing the fluorescent Kα iron line from a cold neutral disc; the flux in line depends on the incident and emission angles, δ_i and δ_e.

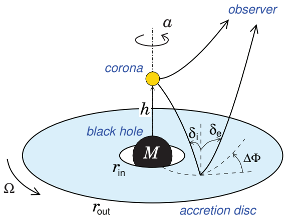

Figure 1: The sketch of the lamp-post geometry.

The intrinsic line flux

The flux of the intrinsically narrow line in the local frame co-moving with the disc has several components:

$F(r, \varphi, E) = R(r) \times M(\mu_i, \mu_e) \times \delta(E - E_{rest})$.

The radial emissivity is given by the incident flux from the primary source above the black hole, $R(r) = N_{inc}(r)$, see Fig. 2.

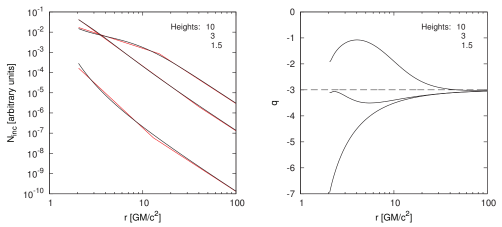

Figure 2: The dependence of the incident flux (left panel) and the radial power-law index q (right panel) on the radius for the primary source at heights $h = 1.5$, 3 and $10\,GM/c^2$. The radial power-law index in the right panel is defined as the slope of the radial dependence of the incident flux N_{inc} on the left panel (in logarithmic scale), i.e. $q(r) \equiv \frac{\mathrm{d}\log N_{inc}(r)}{\mathrm{d}\log r}$. The broken power-law functions approximating the incident flux is shown in red colour on the left panel with the outer radial power-law index $q_{out} = -3$. The estimated inner radial power-law index and break radius are shown in Tab. 1.

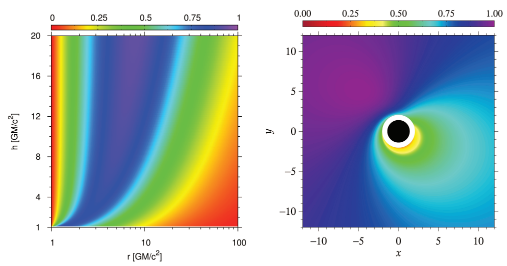

Figure 3: The radial dependence of the cosine of the incident angle (left panel), μ_i, for different heights of the primary source. The dependence of the cosine of the emission angle (right panel), μ_e, on the position on the disc from which the photon is emitted.

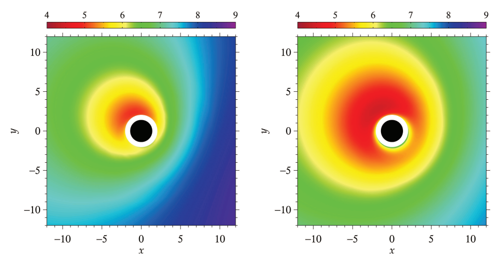

Figure 4: The dependence of the emission directionality, $M(\mu_i(r), \mu_e(r, \varphi))$, on the position on the disc from which the photon is emitted. Here, the height of the source is $h = 1.5\,GM/c^2$ (left panel) and $h = 3\,GM/c^2$ (right panel) and inclination of the observer is 30°. One can figure out that the contribution of this dependence to the overall shape of the line will be important, as opposed to e.g. isotropic emission which is constant everywhere.

The reprocessing in the disc, the fluorescence and the following Compton scattering, is given by the directionality function $M(\mu_i, \mu_e)$. The local line flux depends on the cosines of the incident and emission angles, $\mu_i(r)$ and $\mu_e(r, \varphi)$, through this function. Thus the flux varies with the position on the disc. The emission is enhanced at the places with high incident and high emission angles, see Figs. 3-4.

Athena simulations

- Simulated data were created with the preliminary Athena response matrix for the lamp-post model `power-law+kyrline` for heights $h = 1.5\,GM/c^2$ and $h = 3\,GM/c^2$ with the observer inclination $\theta_o = 30°$, spin of the black hole $a = 0.94\,GM/c$ and the photon index of the primary emission $\Gamma = 1.9$.
- Then a fit with the radial broken-power-law emissivity was obtained with the isotropic directionality.
- We were interested in the parameter values describing the radial dependence of the local emission, i.e. the inner radial power-law index q_{in} and break radius r_b, and the spin of the black hole. The outer radial power-law index was fixed to the fiducial value $q_{out} = -3$. The results are summarized in Figs. 5-7 and Tab. 1 below.

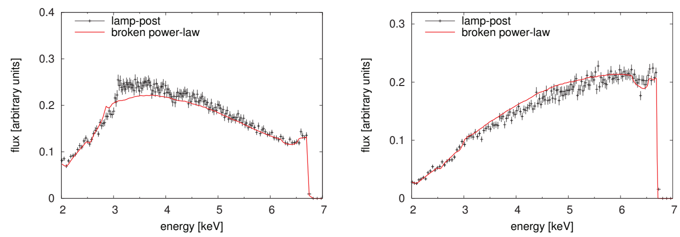

Figure 5: The simulated data for the Athena X-ray satellite (in black) for a lamp-post geometry with the primary source at heights $h = 1.5\,GM/c^2$ (left panel) and $h = 3\,GM/c^2$ (right panel). Only the flux in neutral Kα line is shown convolved with the preliminary Athena response matrix. The fit with the broken-power-law emissivity is depicted by red colour (see the text and Tab. 1 for the parameters of the fit).

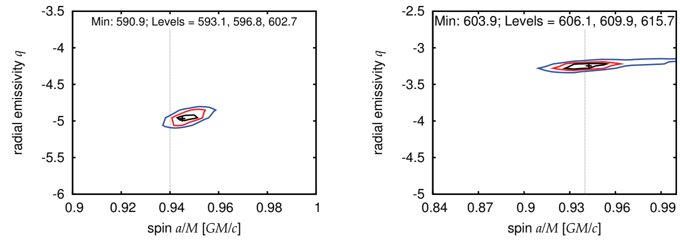

Figure 6: The χ^2 contours of the inner radial emissivity index, q_{in}, versus the spin of the black hole, a, for the lamp-post heights $h = 1.5\,GM/c^2$ (left panel) and $h = 3\,GM/c^2$ (right panel).

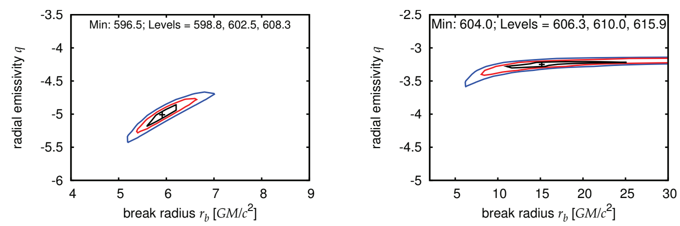

Figure 7: The χ^2 contours of the inner radial emissivity index, q_{in}, versus the break radius, r_b, for the lamp-post heights $h = 1.5\,GM/c^2$ (left panel) and $h = 3\,GM/c^2$ (right panel).

	estimated values		fitted values	
$h[GM/c^2]$	q_{in}	$r_b[GM/c^2]$	q_{in}	$r_b[GM/c^2]$
1.5	−4.3	13	$-5.0^{+0.4}_{-0.1}$	$6.0^{+0.3}_{-0.2}$
3.0	−3.35	40	$-3.2^{+0.1}_{-0.1}$	15^{+10}_{-3}
10	−1.5	15	$-2.3^{+0.2}_{-0.1}$	48^{+5}_{-7}

Table 1: The inner radial emissivity and break radius in column 2 and 3 are estimated from the radial dependence of the incident flux (see Fig. 2) while the values in column 4 and 5 are the results of the fit to the simulated data with the preliminary Athena response matrix.

Conclusions

- Line models with radial broken power-law emissivity fit the lamp-post geometry very well even for low heights of the primary source.
- The inner radial power-law index q_{in} drops to very low values only for very low lamp-post heights.
- On the other hand, the inner radial power-law index q_{in} rises quickly to quite large values already for lamp-post height $h = 10\,GM/c^2$.
- The local emission directionality changes the shape of the broad line significantly.

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