X-ray reflection from black-hole accretion discs with a radially-stratified ionisation

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Abstract: Recent X-ray observations have suggested a very high compactness of coronae in Active Galactic Nuclei, as well as in X-ray Binaries. The compactness of the source implies a strong radial dependence in the illumination of the accretion disc. We present here how the X-ray spectra are modified assuming the radially-stratified ionisation according to the illumination by a point-like source on the black-hole rotational axis. We discuss how this assumption affects the measurements of the radial-emissivity index. We also show the application of our model to the recent simultaneous XMM-Newton and NuSTAR data of an active galaxy MCG-6-30-15.

X-ray reflection from black-hole accretion discs

Accreting black holes produce high-energetic thermal radiation (UV in AGN, X-ray in XRB). The disc photons are inversely Comptonised in a plasma of hot electrons (corona). Some of the scattered photons reflect off the disc surface before reaching an observer. The exact geometry of the corona is still unknown although recent X-ray observations suggest it to be very compact and centrally localised (see e.g. Wilkins & Fabian, 2011; Chen et al., 2012; Parker et al., 2014). Such a configuration is illustrated in Figure 1 (left).

Disc irradiation and the ionisation profile

The disc irradiation is often approximated by a power law, $I \sim r^{-q}$. A standard value of the radial-emissivity index is q=3, which corresponds to the thermal dissipation from the disc and also to a distant irradiation by a lamp-post source. However, the relativistic light bending and aberration significantly affect the profile in the innermost region. The closer the source is to a black hole the steeper disc-reflection emissivity is expected (Martocchia et al., 2000; Svoboda et al., 2012; Wilkins et al., 2012; Dauser et al., 2013). A rapid decrease of the illumination may imply a strong radial dependence of the disc ionisation (Svoboda et al., 2012), see Figure 1 (middle, right).

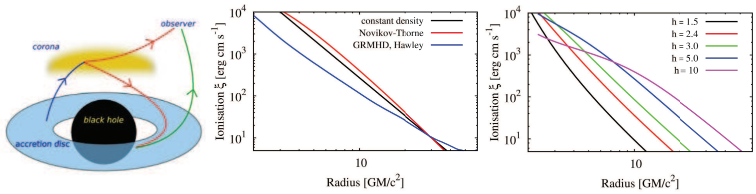

Fig. 1 Left: Illustration of the lamp-post geometry. **Middle:** Radial ionisation profile for illumination given by $I \sim r^{-3}$ for different assumptions about the density. **Right:** Radial ionisation profile for constant density and lamp-post illumination for different heights of the source.

Effects of the disc ionisation on measured radial-emissivity

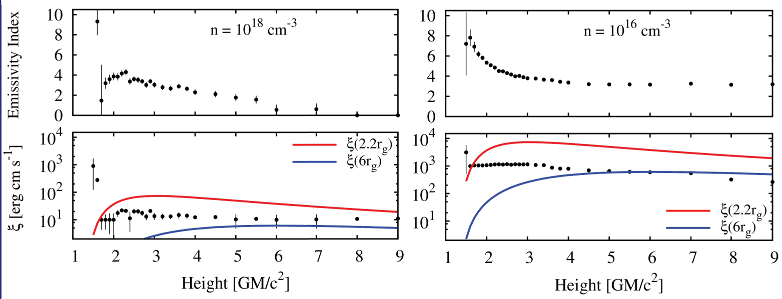

Fig. 2 Dependence of the inner emissivity index and ionisation on the height. The data were created by a lamp-post model with the radially-stratified ionisation and fitted by a single-ionisation reflection model with a broken power-law radial emissivity. The red and blue curves indicate the ionisation of the seed model at 2.2 r_g and 6 r_g, respectively. **Left:** cold disc with only little ionisation at the innermost radii. **Right:** disc with a significant ionisation in the innermost region.

The radially-stratified ionisation can be roughly approximated by a single-ionisation model only at the cost of artificial changes of some model parameters, such as the radial-emissivity index (Svoboda et al., 2012). To study these effects, we generated fake data using the KYREFLIONX model with different heights and densities. Then, we fitted the simulated data by a simple model (POWERLAW + KYCONV*REFLIONX) with a single value of the ionisation. We assumed a break radius at 6 r_g ($r_g = GM/c^2$), after which the emissivity is given by r^{-3}. The results are shown in Figure 2 for two different values of the density. The first case corresponds to a relatively cold disc, where only innermost radii are a little ionised. The second case corresponds to a disc that is significantly ionised in the inner region. We also plot the ionisation of the seed model at radii 2.2 and 6 r_g, respectively. The measured single ionisation is usually between these two values suggesting that the most emission is coming from this innermost region. It is closer to the ionisation at the smaller radius for lower heights, and vice versa. The obtained results indicate that the radially-stratified ionisation enhances the measured steepness of the radial emissivity.

Model KYREFLIONX

KYREFLIONX model combines the relativistic smearing (Dovčiak et al., 2004) and X-ray ionised reflection model REFLIONX (Ross & Fabian, 2005) or XILLVER (García et al., 2013). The model assumes the disc illumination by a lamp-post source. The ionisation of the disc is given at each radius as a ratio between the irradiation strength and the density. Similar functionality is also provided by models developed by Dauser et al. (2013).

Application to MCG -6-30-15

We have re-analysed recent XMM-Newton and NuSTAR simultaneous observations of an active galaxy MCG -6-30-15. Marinucci et al. (2014) showed that the complex spectrum and flux variations can be described by a relativistic light-bending model. However, they fixed the emissivity index (q=2.95) and used a single ionisation (variable between observations). We relaxed these conditions by i) allowing the emissivity index to vary, and ii) employing the reflection model with the radially-stratified ionisation calculated from the illumination by a lamp-post source with a variable height.

In Figure 3, we show the dependence of the emissivity index (black circles) and height (red triangles) on the measured reflection fraction. The model with the radially-stratified ionisation provides rather satisfactory relation, while the small values of the emissivity index are not expected for larger reflection fractions (Dauser et al., 2014; Dovčiak et al., 2014).

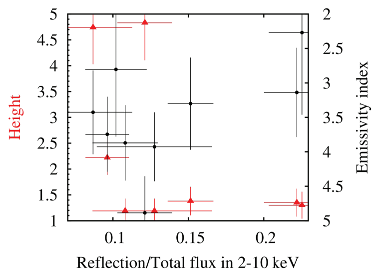

Fig. 3 Dependence of the measured height and emissivity index on the reflection fraction.

In Figure 4, we show that the measured ionisation (by RELCONV*XILLVER model) is proportional to the flux and follows a trend rather similar to a variable luminosity (green line), but it is not consistent with the variable height (red triangles), resulting from the simulations for $h < 5r_g$.

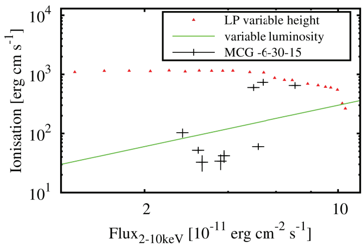

Fig. 4 Measurements and theoretical predictions of the disc ionisation and observed X-ray flux.

Conclusions:

- strong radial dependence of the disc illumination may imply radial stratification of the disc ionisation
- radially-stratified ionisation can explain measurements of steep indices of the radial emissivity
- the disc ionisation and the observed flux are not linearly correlated in the lamp-post scenario
- more elaborated X-ray reflection models can be applied to the current data (work in progress...)

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