On steep radial emissivity in the disc-reflection spectra of accreting black holes

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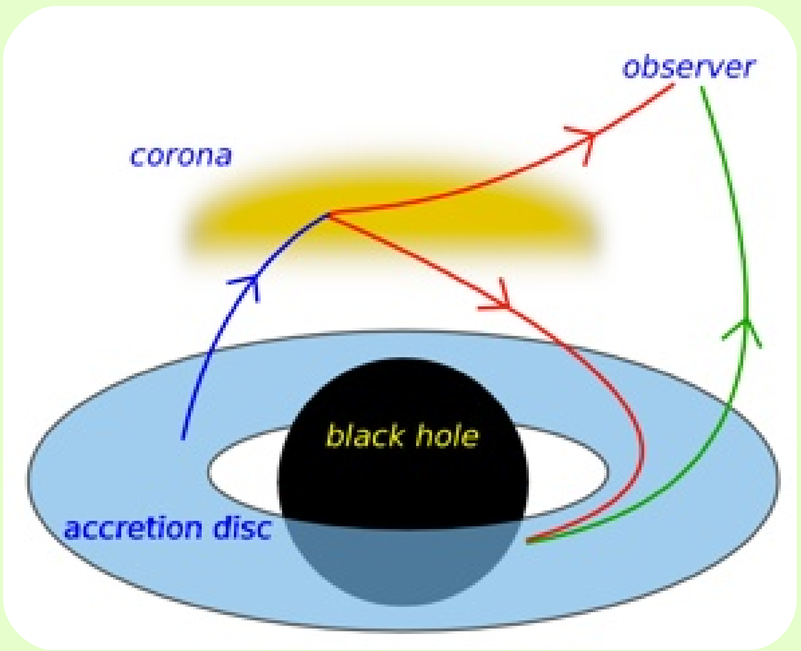
Abstract: X-ray spectroscopy of accreting black holes in active galactic nuclei (AGN) and X-ray binaries (XRB) provides an opportunity to study accretion processes in strong gravitational field. Some of the recent measurements revealed a very steep radial decrease of the disc reflection emissivity, especially in the central region. We show here that this can be caused by a compact and very centrally localised corona, by radially stratified ionisation and/or by using of an improper prescription for angular emissivity.

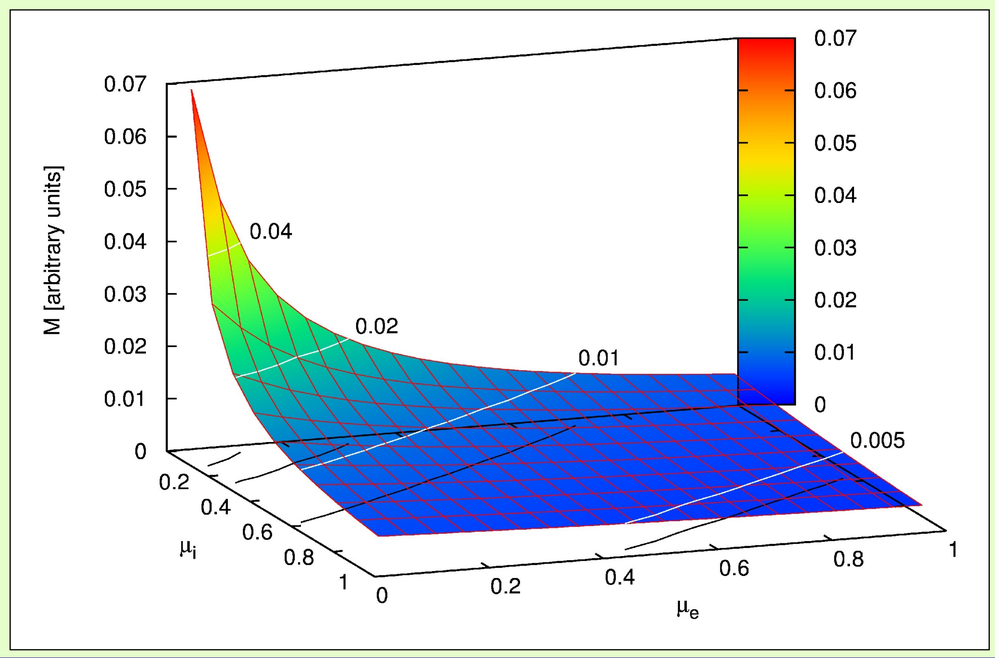
Lamp-post geometry

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). Such a configuration is illustrated in the figure below. The disc irradiation far from the ``lamp-post'' source decreases as r^{-3}. However, the relativistic effects such as light bending and aberration significantly affect the profile in the innermost region (Matt et al., 1991; Martocchia et al., 2000). The closer the corona is to a black hole the steeper disc-reflection emissivity is expected (see e.g. Svoboda et al., 2012a; Wilkins et al., 2012).



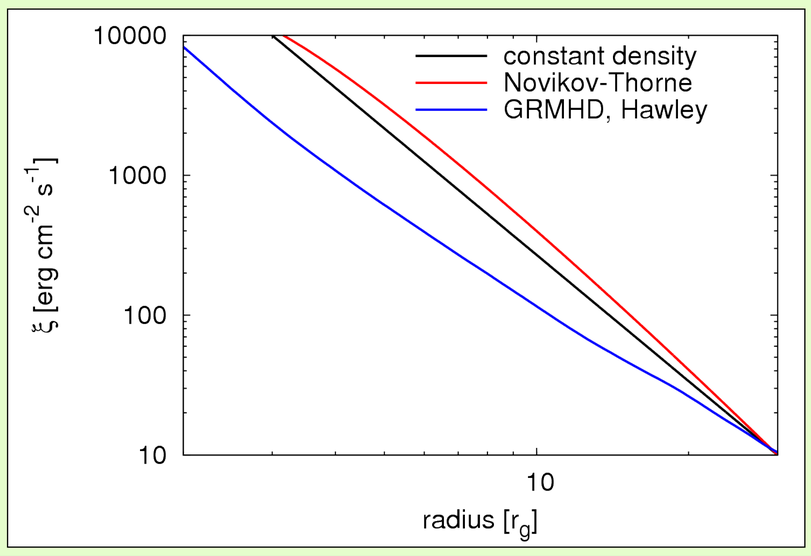
Emission directionality

Light bending and aberration cause that the incident and emission angles (measured with respect to the disc normal) are always high in the innermost region (Beckwith & Done, 2004; Svoboda et al., 2009). Figure below shows the angular dependence of the emissivity calculated from the numerical calculations using the NOAR code (Dumont et al., 2000). Strong limb-brightening effect is present when the incident angle is very high, i.e. in the innermost region.



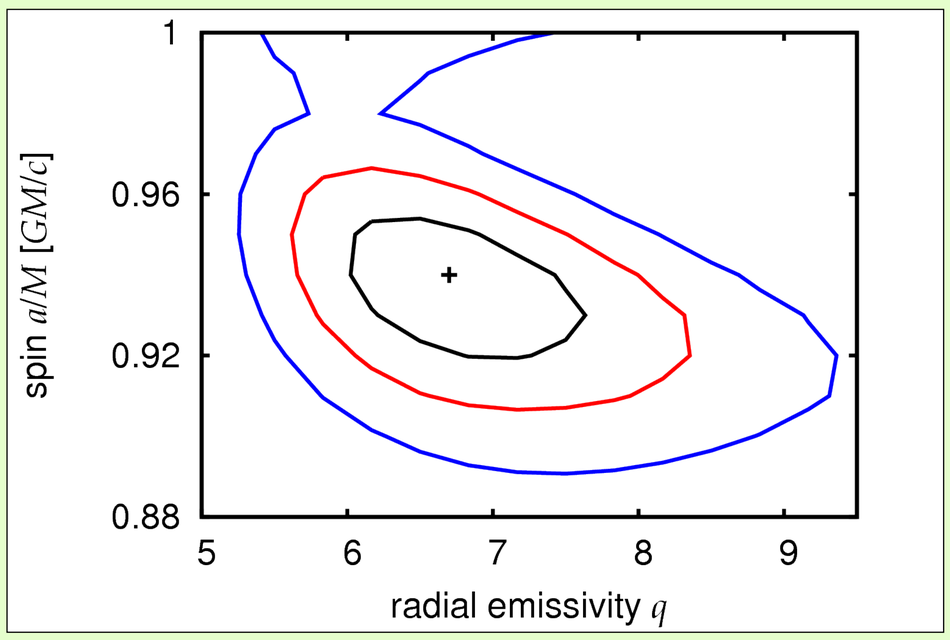
Ionisation profile of the disc

If the photoionisation is the dominating factor determining the state of the plasma the ionisation parameter is proportional to the incident flux and inversely proportional to the volume density. The disc illuminating flux decreases at least as $F_{inc} \sim r^{-3}$ and even more in the central region if the corona is compact. In the figure below, the disc radial ionisation profile is shown for different density prescriptions. The illumination of the disc is much stronger function of radius than the density implying very steep radial decrease of the disc ionisation in all studied cases. The ionised reflection occurs in the central region. When the corona is bright enough the innermost parts of the disc might be too over-ionised to produce a fluorescent iron line (see e.g. Ross & Fabian, 1993). In such case, the inner radius inferred from the relativistic line profile does not correspond to the innermost disc radius. This could explain some "truncated disc" observations (see e.g. Svoboda et al., 2010, 2012b; Bhayani & Nandra, 2011).



Steep radial emissivity

A compact corona, radially stratified ionisation and emission directionality may all account for a steep radial emissivity profile (Svoboda et al., 2012a). They are not completely independent and most likely they all take part together. We simulated the data by considering a lamp-post scenario with a very low height ($h = 1.5\ r_g$), the corresponding radial ionisation profile (assuming constant density) and for simplicity, we assumed an isotropic directionality. The simulated data were then fitted by a single-ionisation reflection model with the radial emissivity profile defined as a broken power-law and limb-darkening law for angular emissivity. The figure below shows a resulting contour plot between the radial-emissivity index and the spin. The obtained radial emissivity is very steep with $q \sim 7$ while the spin is found to be close to its default value ($a=0.94$).



Conclusions: Very steep radial emissivity profiles with $q \sim 7$ have been previously claimed from the analysis of the disc reflection component in the X-ray spectra of some active galaxies and black hole binaries. We have shown that these profiles can be a natural consequence of i) a compact centrally concentrated X-ray corona located ~1-2 gravitational radii away from the central black hole, and ii) the radial dependence of the disc ionisation state. We have also demonstrated that an additional steepening can be simply an artifact of improper usage of the emission directionality in the relativistic models.

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