ON THE ORIGIN OF THE BROAD RELATIVISTIC IRON LINE OF MCG–6-30-15 OBSERVED BY XMM-NEWTON

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Abstract

The relativistic iron line profile recently observed by XMM-Newton in the spectrum of the Seyfert 1 galaxy MCG–6-30-15 (Wilms et al., 2001) is discussed in the framework of a simple lamp-post model. It is shown that the steep disc emissivity, the large line equivalent width and the amount of Compton reflection can be self-consistently reproduced in this scenario.

Introduction

Wilms et al. (2001) recently presented and discussed an extremely broad and red-shifted iron Kα line, detected in the June 11-12, 2000, 100 ksec XMM-Newton observation of MCG-6-30-15. The line profile is extremely broad and redshifted, indicating that a large fraction of the emission comes from $r < 6r_g$, and that the disc emissivity law is very steep. If a simple powerlaw is used for the emissivity, the best-fit powerlaw index is β ~4, i.e. the dependence on radius is much steeper than usual in Seyfert galaxies (Nandra et al., 1997). In this contribution we show that this emissivity, as well as the observed strong line Equivalent Width (EW~300 eV) and the amount of Compton reflection ($R \gtrsim 1$), may be reproduced by a model in which the primary X-ray source - located on the BH symmetry axis at a height h ~a few r_g (the gravitational radius) - illuminates the disc. This is the so called lamp-post picture (cp. Martocchia & Matt, 1996, Petrucci & Henry, 1997, Bao et al., 1998, Reynolds et al., 1999, Dabrowsky & Lasenby, 2001). It can be considered a phenomenological scheme appropriate for models like those by Henry & Petrucci (1997) or Agol & Krolik (2001).

Further details can be found in: Martocchia, Matt & Karas (2001).

An X-ray illuminated disc in Kerr metric

If the primary source, assumed to be isotropic in its own reference frame, is very close to the BH (i.e. h is small), the illuminating photons' trajectories are strongly bended by the spacetime curvature. The illuminating flux is thus very anisotropic, and the emission is concentrated in the innermost part of the disc. With decreasing h, the effect of light bending, i.e. the anisotropy, increases (see Figure 1). This causes a substantial increase of the fluorescent and Compton-reflected components, and a decrease of the primary continuum.

The emissivity is derived by means of fully relativistic calculations of the primary flux impinging onto the disc (Martocchia & Matt 1996, 1997; Martocchia, Karas & Matt, 2000). Results on the iron line profiles and underlying Compton-reflected continuum have been presented by Martocchia, Karas & Matt (2000).

Predictions of the model

1. Emissivity laws

The radial dependence of the emissivity accounts for the local illuminating flux and incident angle; it depends on h (it steepens when h decreases because of the enhanced anisotropy of the primary emission) and can be approximated through functions of the form $\epsilon(r) = Ar^{-B} + Cr^{-D}$. Plots of the computed emissivity vs radius, and best-fit coefficients for the approximating formula, have been presented in Martocchia, Karas & Matt (2000). It is easy to recognize (see Figure 2) that an emissivity law with β ~4, i.e. the one derived by Wilms et al. (2001), may be reproduced in our model with a small height of the primary source:

$$h \sim 3r_g$$

For an emissivity law of this kind, the line profile results to be very broad and red-shifted (see Figure 3, and Martocchia, Karas & Matt, 2000, for details).

2. Line intensity and Compton reflection

Due to the high (relativistic) speeds of the disc matter at very low radii, the impinging photons as seen in the matter's frame arrive with high incident angles, and their energy is substantially blue-shifted. These effects further increase the amount of fluorescence and reflection.

For $h \sim 3r_g$ our model predicts:

EW $\sim$ 250-300 eV

$$R \sim 4$$

which are consistent with the values found by Wilms et al. (2001).

References

Agol E. & Krolik J.H. (2000), ApJ 528, 161

Bao G., Wiita P.J. & Hadrava P. (1998), ApJ 504, 58

Dabrowski Y. & Lasenby A.N. (2001), MNRAS 321, 605

Henri G. & Petrucci P.O. (1997), A&A 326, 87

Martocchia A. (2000), "X-ray Spectral Signatures of Accreting Black Holes", PhD Thesis, SISSA-ISAS, Trieste

Martocchia A., Karas V. & Matt G. (2000), MNRAS 312, 817

Martocchia A. & Matt G. (1996), MNRAS 282, L53

Martocchia A. & Matt G. (1997), in: Proc. of the 12th Italian Conference on Gen. Rel. & Grav. Phys., World Scient. Pub. Co., Singapore

Martocchia A., Matt G. & Karas V. (2001), A&A, to be submitted

Petrucci P.O. & Henry G. (1997), A&A 326, 99

Reynolds C.S. et al. (1999), ApJ 514, 164

Wilms J., Reynolds C.S., Begelman M.C., Reeves J., Molendi S., Staubert R., Kendziorra E. (2001), MNRAS 328, L27

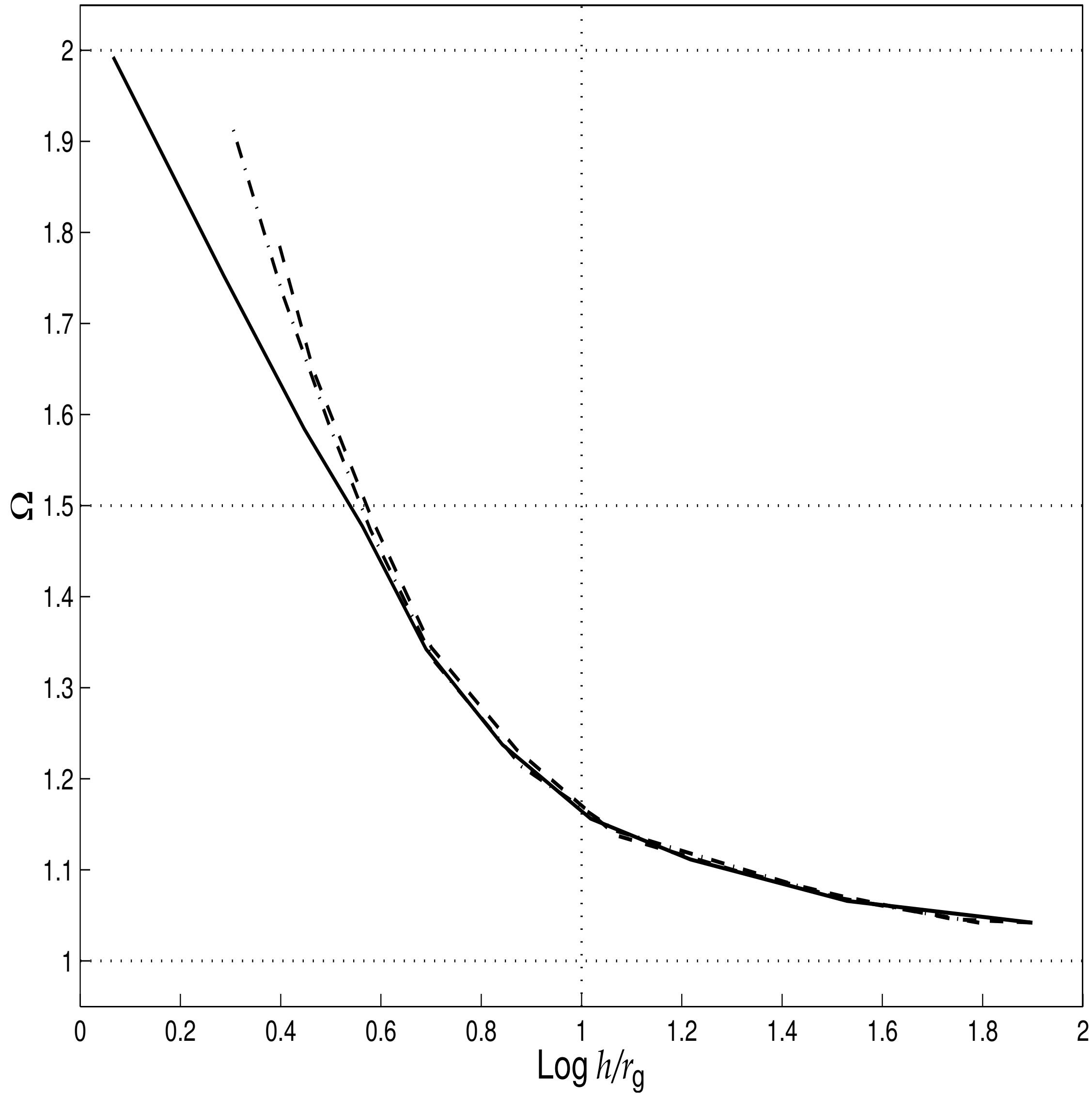

Figure 1: Variation with h of the ratio between the solid angle of the radiation which reaches the equatorial plane and the same solid angle as it would come out in a flat spacetime, in the assumption that the disc extends up to 1000 r_g and for three values of the BH spin (solid line: $a{=}m$; dotted line: $a{=}0.5m$; dashed line: static BH).

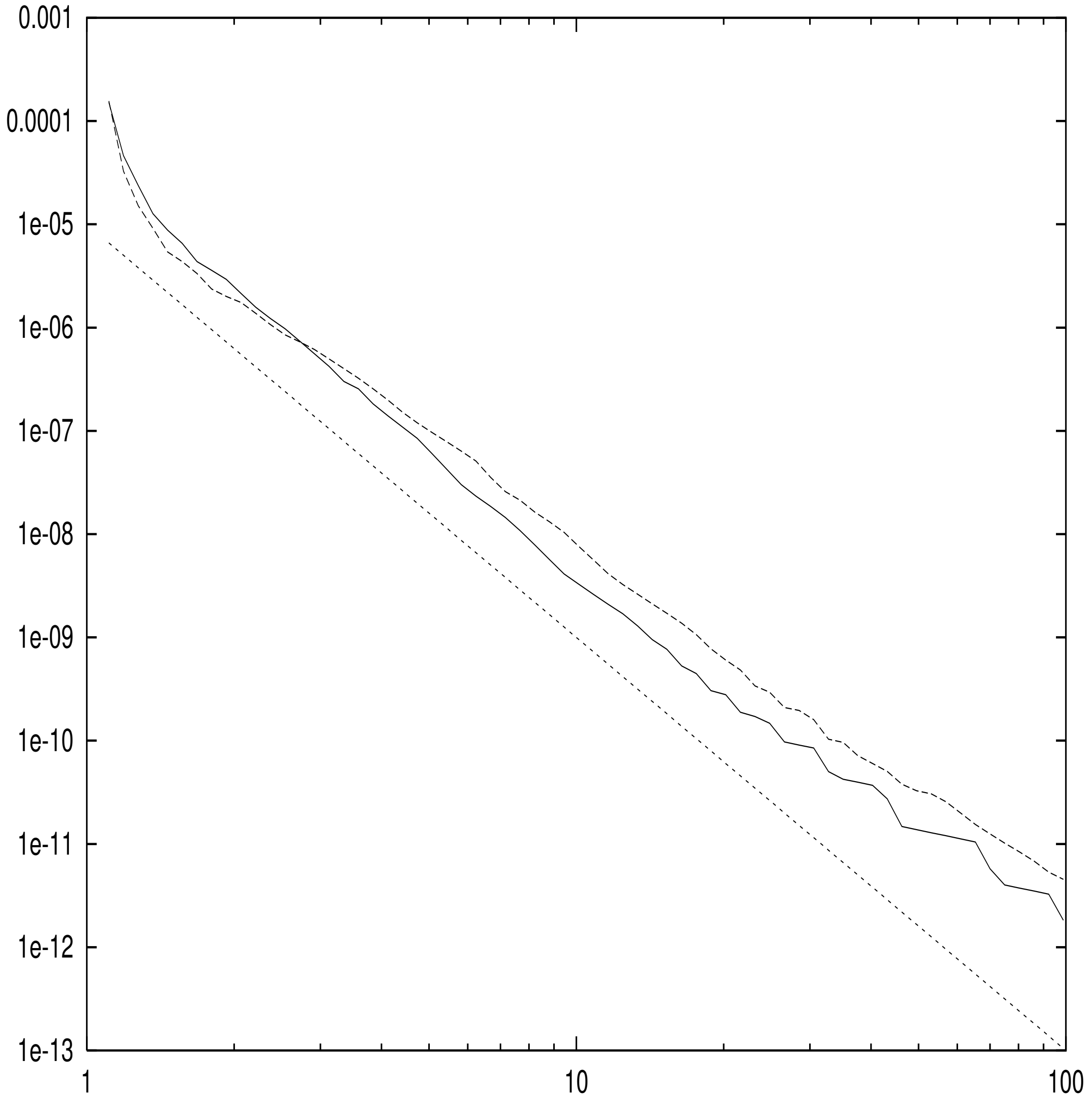

Figure 2: Disc emissivity (in arbitrary units) vs. radius (in units of r_g) for a source located at $h = 3r_g$ (solid line) and $h = 4r_g$ (dashed line) in a maximally spinning BH metric. The lower, straight dotted line corresponds to a power law with $\beta \sim 4$.

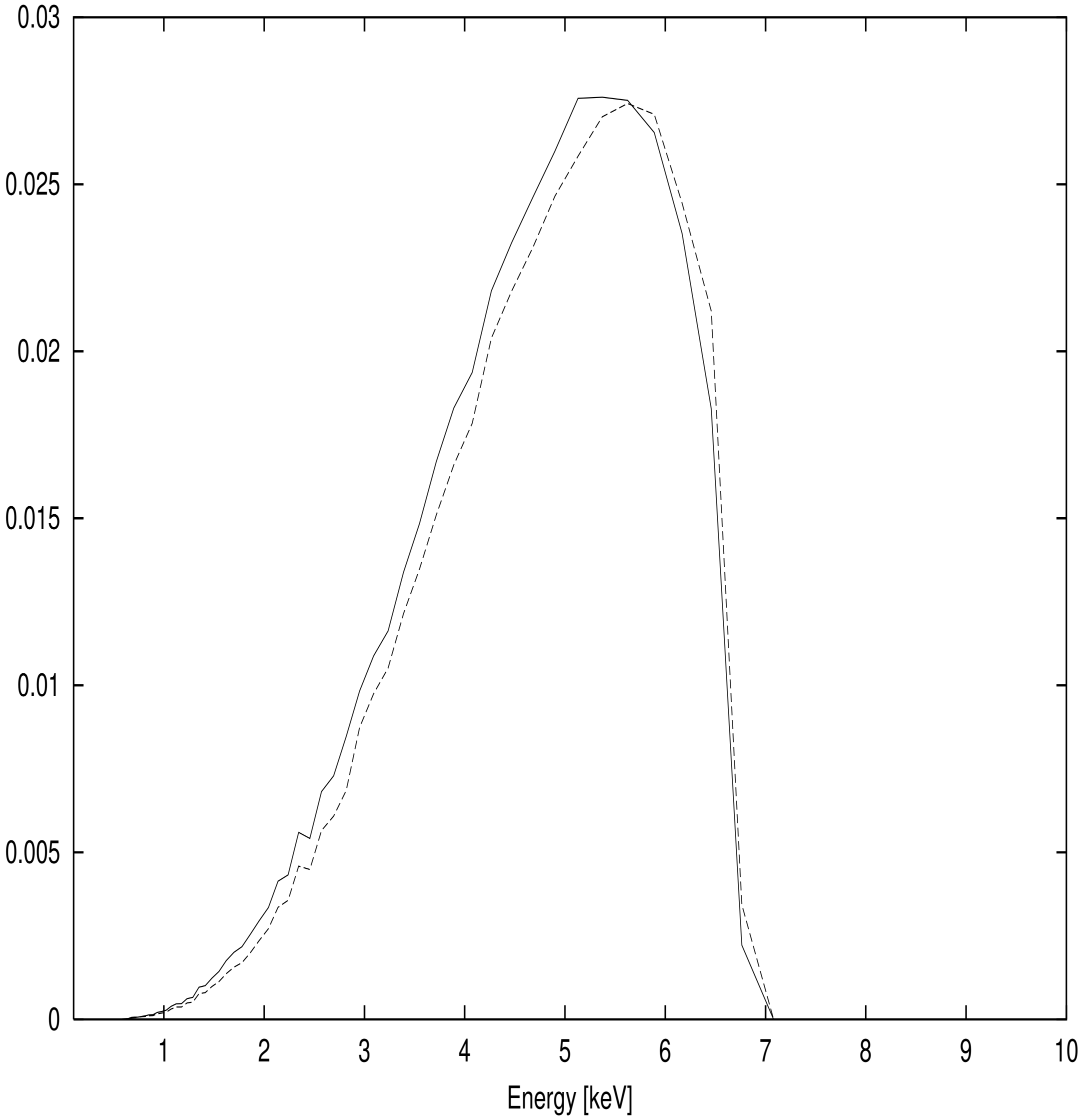

Figure 3: Fe Kα line profiles computed with the XSPEC routine KERRSPEC (Martocchia 2000), using respectively a power-law emissivity with $\beta = 4$ (solid line) and a lamp-post emissivity with $h = 3r_g$ (dashed line). All other parameters have been fixed to the best-fit values found by Wilms et al. (2001). Differences between the two plotted models are clearly too small to be detectable by XMM.