Broad emission lines for a negatively spinning black hole

T. Dauser[1], J. Wilms[1], C. S. Reynolds[2], and L. W. Brenneman[3]

[1]Dr. Karl Remeis-Observatory and ECAP, Sternwartstr. 7, 96049 Bamberg, Germany
email: `thomas.dauser@sternwarte.uni-erlangen.de`
[2]Department of Astronomy and Maryland Astronomy Center for Theory and Computation,
University of Maryland, College Park, MD 20742, USA
[3]Harvard-Smithsonian C. for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

Abstract. We present an extended scheme for the calculation of the profiles of emission lines from accretion disks around rotating black holes. The scheme includes disks with angular momenta which are parallel and antiparallel with respect to the black hole's angular momentum, as both configurations are assumed to be stable (King *et al.* 2005). Based on a Green's function approach, an arbitrary radius dependence of the disk emissivity and arbitrary limb darkening laws can be easily taken into account, while the amount of precomputed data is significantly reduced with respect to other available models. We discuss line shapes for such disks and present a code for modelling observational data with this scheme in X-ray data analysis programs. A detailed discussion will soon be presented in a forthcoming paper (Dauser *et al.* 2010).

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1. How does a black hole get negative spin?

Misalignments between the angular momenta of a black hole and its accretion disk are a prediction of stochastic evolution models for AGN (e.g., Volonteri *et al.* 2005). In galactic black holes, misalignments can be produced by the initial supernova kick (Brandt & Podsiadlowski 1995). As shown by King *et al.* (2005), both parallel and antiparallel alignments of the disk and black hole angular momenta are stable configurations; misaligned discs will evolve to one of them. In fact, accretion onto rapidly-spinning retrograde black holes, where the angle between the angular momenta is greater than 90°, may be of some importance for understanding the properties of powerful radio-loud AGN. Garofalo (2009) argues that an accretion disk around a retrograde black hole is a particularly potent configuration for generating powerful jets, which might also explain the lack of radio-loud AGN (Garofalo *et al.* 2010).

2. Line Profiles

Since the shape of the observed emission line (e.g. at $6.4 \, \mathrm{keV}$ for a neutral Fe Kα transition) depends on the spin of the black hole, a, and the emissivity (i.e., the intensity dependence on the radius) and inclination of the surrounding accretion disk, the diagnostic power of relativistic lines is very high, as they provide one of the most direct ways to probe the physics of the region of strong gravity close to the black hole.

In order to allow for a comparison of the pure frame-dragging effects, the inner edge of the accretion disk in the left part of Fig. 1 was set to $9 \, r_{\mathrm{g}}$ for all profiles, which is the smallest inner radius possible for an accretion disk around a maximally negatively rotating black hole. The major difference between the different spins is the relative strength
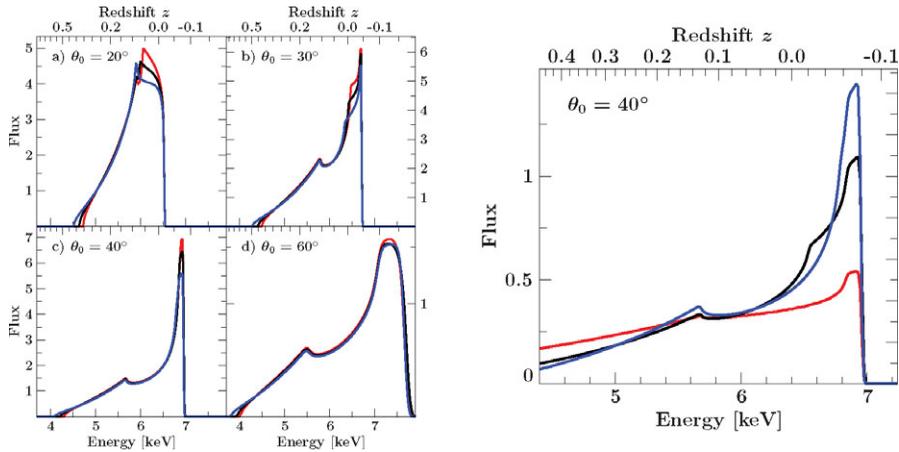
Figure 1. Line profiles for a relativistic iron line at $6.4\,\mathrm{keV}$, an emissivity of r^{-3} and under an inclination angle of θ_o. The maximal spinning black hole ($a = +0.998$) is drawn in red, the non-rotating ($a = 0$) in black and the line for maximal negative spin ($a = -0.998$) in blue. Left: Accretion disk with an inner radius of $9\,r_\mathrm{g}$. Right: Line for a disk extending down to the marginal stable orbit, which varies from $1.23\,r_\mathrm{g}$ ($a = +0.998$) to $9\,r_\mathrm{g}$ ($a = -0.998$).

of the core of the line to the red wing, which decreases with decreasing a. For this case of a large inner radius, the most significant differences in line shape are seen for low values of θ_o while the red tails are virtually indistinguishable.

The more realistic case, where the disk extends down to the marginally stable orbit, is shown in the right part of Fig. 1. Since the inner edge of the disk is closer to the black hole for positively spinning black holes, more strongly redshifted photons emerge and therefore broader lines (especially for emissivities strongly peaked inwards).

3. Data Analysis

As none of the currently available line models like the `kerrdisk` (Brenneman & Reynolds 2006) or the `ky`-family of models (Dovčiak *et al.* 2004) are valid for retrograde accretion disks, we implemented a model function, called `relline`, that can be added to data analysis software such as ISIS or XSPEC for spin $-0.998 \leqslant a \leqslant 0.998$ and inclination $0° \leqslant \theta \leqslant 89°$. Both, an additive and a convolution model are provided at `www.sternwarte.uni-erlangen.de/research/relline/`.

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