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PROBING THE IRRADIATION PATTERN OF AGN ACCRETION DISKS WITH FUTURE SATELLITE MISSIONS

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Abstract. The X-ray reflection features of irradiated accretion disks around black holes enable to probe the effects of strong gravity. We investigate, to which precision the reflection signs, i.e. the iron K-line complex and the Comptonized hump, can be observed by future X-ray satellites, in particular by the upcoming Simbol-X and the planned XEUS observatories. The simulations presented include accurate computations of local X-ray reflection spectra and the modifications due to general relativistic effects in the vicinity of the black hole. We discuss the impact of global black hole parameters and of the irradiation pattern of the disk on the resulting spectra.

1 Introduction

The broad iron line complex observed in the X-ray spectra of many active galactic nuclei (AGN) is commonly assumed to be a reprocessing feature, which is distorted by relativistic effects acting in the innermost region of the accretion disk (e.g. Tanaka et al. 1995; Fabian et al. 2002; Guainazzi et al. 2006). The line emitting region lies at distances of only a few gravitational radii $R_{\rm g} = \frac{GM}{c^2}$ from the disk center. In some cases the observed spectral variability of the line can be interpreted as the signature of orbiting hot spots on the accretion disk (Iwasawa et al. 2004; Turner et al. 2006; Tombesi et al. 2007). An attractive scenario for the origin of the X-ray irradiation envisions the reconnection of magnetic loops above the disk surface (see e.g. Galeev, Rosner & Vayana 1979; Haardt et al. 1994; Collin et al. 2003). The resulting compact sources then co-rotate at some height above the disk giving rise to the reprocessing hot spot underneath. In Goosmann et al. (2007), we study in detail the Compton reflection/reprocessed component coming from a single orbiting spot. We include the variations of the irradiation pattern across the spot, the vertical structure of the disk, and the dependence of the reprocessed spectra on the local emission angle. We then combine these results with a relativistic ray-tracing method to model the time-dependent spectra seen by a distant observer.

In this proceedings note, we investigate the detectability of orbiting spots in nearby Seyfert galaxies with current and future X-ray observatories. Using the same modeling suite as in Goosmann et al. (2007) we compute simulated X-ray spectra of the Seyfert galaxy NGC 3516 as observed with the upcoming Simbol-X and the planned XEUS missions. We investigate different arrangements for the orbiting spot and discuss the observational consequences.

2 Model

The details of our computational method are given in Goosmann et al. (2007): we first compute the vertical density structure of the disk at a given radius, R, assuming that the disk is in hydrostatic equilibrium without any external irradiation. The density, flux, and temperature profiles are computed using an advanced version of the code described in Różańska & Czerny (1996). Using the density structure of the disk's surface layers we then conduct detailed radiative transfer computations with the codes Titan and Noar (Dumont, Abrassart, & Collin 2000; Dumont et al. 2003) for the disk irradiated by a localized flare. The computations of the local reprocessed spectrum take the details and angular dependencies of the flare/spot geometry into account. The

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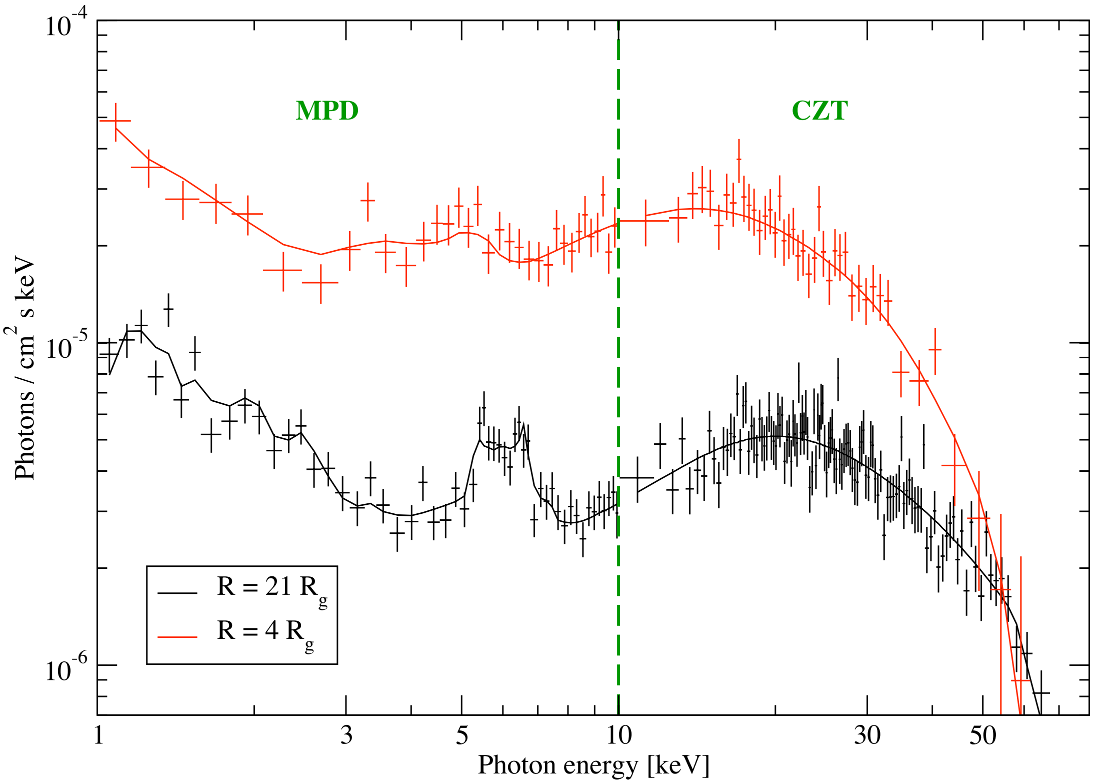

Fig. 1. Simulated MPD and CZD spectra of an orbiting flare spot at $R = 4\,R_{\rm g}$ (top) and $R = 21\,R_{\rm g}$ (bottom). The underlying XSPEC models are shown as solid lines. The data sets contain a vertical offset for clarity.

relativistic modifications of the local spectra and the Doppler shifts due to the Keplerian motion of the accretion disk are then added by applying the ray-tracing code KY (Dovčiak et al. 2004).

With this method it is further possible to obtain simulated "observed spectra" using a version of KY that is implemented in XSPEC. Applying a modified version of the KYL1CR model (Dovčiak et al. 2004) in XSPEC V.11.3.2 we simulate the observation of an orbiting hot spot using the local spectra we obtained with TITAN/NOAR. Since the KYL1CR model does not include a time-dependence of the emitting spot, we imagine the spot's intrinsic luminosity as smeared out over a belt at the disk radius R. The extension of the belt in the radial direction is given by the spot diameter, set to $2R_{\rm g}$, and for the azimuthal direction by $\Omega(R)T$, where $\Omega(R) = \left[\frac{GM}{c^3}\left(\left[\frac{R}{R_{\rm g}}\right]^{3/2} + a\right)\right]^{-1}$, M is the black hole mass, a the dimensionless black hole spin, and T the observation time. The fake data of the spot emission is obtained using the currently available response matrices of the future SIMBOL-X and the planned XEUS satellites. In the following computations we assume a black hole with $M = 3 \times 10^7\, M_\odot$ that is maximally spinning. The accretion disk is seen at the inclination $i = 30°$ measured from the disk normal. This is a likely scenario for the Seyfert galaxy NGC 3516 that has been investigated in the X-ray range with several X-ray satellites (Guainazzi et al. 2001; Iwasawa et al. 2004; Markowitz et al. 2006). In our simulated observations we normalize the obtained count rate in the red wing of the iron K-line to the value that was observed with XMM-NEWTON by Iwasawa et al. (2004).

3 Observing the radial disk structure with Simbol-X

The SIMBOL-X mission (Ferrando et al. 2006) is going to be a broad band X-ray observatory (0.5 keV – 80 keV) supported by France, Italy, and Germany. The current launch frame is 2014/15 and theoretical response matrices are already available for a low-energy detector MPD and a high-energy instrument CZT. Due to its simultaneous coverage of the iron K-line band and the spectral range of the Comptonized hump around 30 keV,

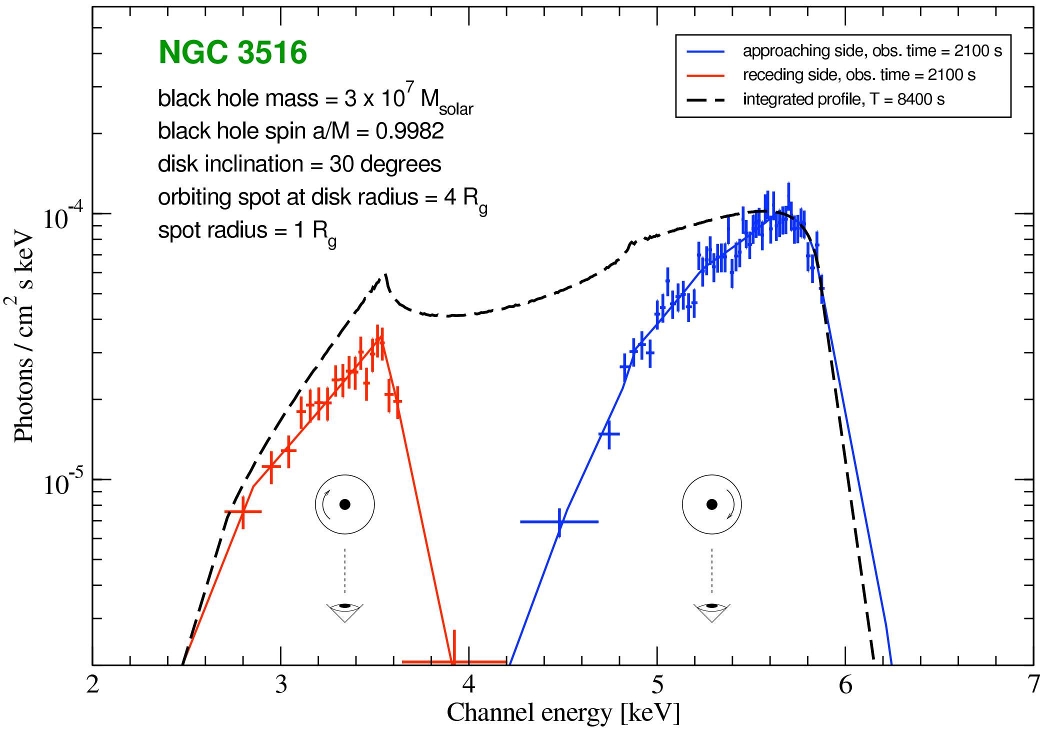

Fig. 2. Simulated XEUS observations (TES detector) of a relativistically broadened iron Kα line emitted by localized X-ray sources that orbit at $4\,R_{\rm g}$ around the black hole of NGC 3516.

Simbol-X is particularly well-suited to observe the reprocessed X-ray radiation we model and investigate here.

In our model, we consider orbiting spots at the disk radii $R = 4\,R_{\rm g}$ and $R = 21\,R_{\rm g}$. Simulated data are obtained for the "observed" spot emission at both radii with an observation time set to one Keplerian orbit in both cases. In Fig. 1 the time-integrated spectra for both orbiting flares are plotted over the spectral range covered by the two detectors. While the overall spectral shape is similar for spots at both disk radii, the position and the shape of the reflection features differ significantly. At $R = 4\,R_{\rm g}$ the impact of the gravitational redshift pushes the maximum of the Comptonized hump below 15 keV and the strong projected velocity gradient along the orbit almost entirely flattens the profile of the iron line complex. At $R = 21\,R_{\rm g}$, on the other hand, the Compton hump is centered on 20 keV and the iron line profile is clearly visible showing a double horn. The data further suggests the appearance of separate soft X-ray emission lines below 3 keV.

For rapidly spinning black holes, it might thus be impossible to detect reprocessed emission from the innermost accretion disk (below $R = 6\,R_{\rm g}$) in the iron line band, but the position of the Comptonized hump can give an alternative handle on the location of the reprocessing site. For larger disk radii, the fact that Simbol-X observes both reflection features simultaneously puts important constraints on the emission disk radius and also on the applied reprocessing models.

4 Observing the azimuthal disk structure with XEUS

For the Seyfert galaxy NGC 3516 Iwasawa et al. (2004) reported time-dependent spectral data from XMM-Newton that are in agreement with the modeling of an orbiting hot spot between 7 $R_{\rm g}$ and 16 $R_{\rm g}$. The data suggest a periodic signal in the iron line flux, which can be interpreted as a long-term flare completing several orbits. Nevertheless, the sensitivity of XMM-Newton is not sufficient to clearly resolve sub-orbital features in the spectral evolution of NGC 3516. Such investigations, which allow to map out the azimuthal irradiation structure of the inner accretion disk, will become possible with the much higher effective collecting areas of future satellite observatories like XEUS and CONSTELLATION-X.

The planned XEUS mission (Hasinger et al. 2006) is a powerful X-ray satellite offering a much higher effective collecting area as is possible with current X-ray observatories. It is designed as a follow-up mission to XMM-NEWTON. As such, it is going to be a particularly powerful tool for observations in the iron K-line band. We show that due to the expected count rates the XEUS observatory will spectroscopically resolve the detailed X-ray emission structure at distances $< 5\,R_{\mathrm{g}}$ from the central black hole of NGC 3516 and similar Seyfert galaxies. The orbital phase of emission sites existing for only a few kiloseconds will be determined from spectroscopy in the iron K-line band. We simulate such observations assuming an observation time $T = 2100$ s, which corresponds to a quarter of a full orbit with radius $= 4\,R_{\mathrm{g}}$ (Fig. 2).

Temporary hot spots on the approaching and on the receding side of the accretion disk can be clearly distinguished from each other. A theoretical line profile for a spot completing a whole orbit is shown for comparison. In these simulations the intrinsic luminosity of the emission site was assumed to be constant and the resulting spectral dependence on the orbital phase is only due to the orbital motion and the relativistic modifications. The high precision of XEUS will allow to disentangle these effects from the intrinsic variability of the local emission.

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