X-RAY PROPERTIES OF MAGNETIC FLARES ORBITING ABOVE THE ACCRETION DISK IN ACTIVE GALACTIC NUCLEI

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ABSTRACT

We present radiative transfer modeling of the X-ray emission from magnetic compact flares in Active Galactic Nuclei (AGN). In this model the hard X-ray primary radiation coming directly from the flare source illuminates the accretion disk, which is supposed to stay in hydrostatic equilibrium. A Compton reflection/reprocessed component coming from the disk surface is computed for several flare locations and for different emission directions. This modeling takes into account the variations of the incident radiation across the hot-spot underneath the flare source. Time-dependent spectra and light curves for orbiting flares at various distances from the black hole are computed using a full general relativity ray-tracing technique. The computations are carried out for black holes of different masses and accretion rates. Rms-variability spectra for large flare distributions across the disk are also computed and compared to observed X-ray data of the Seyfert-1 galaxy MCG-6-30-15.

Key words: active galactic nuclei; flares; X-rays.

1. INTRODUCTION

X-ray spectra of Active Galactic Nuclei (AGN) exhibit a Compton reflection/reprocessed component due to hard X-ray radiation illuminating an optically thick medium at a temperature of $T = 10^5$ K —10^6 K. This medium is commonly identified with the accretion disk (e.g. Collin, 2001). One way to explain the incident hard X-rays is by assuming the existence of magnetic flares similar to solar flares. Due to reconnecting magnetic fields above the disk, compact regions of optically thin plasma are created. These plasma blobs emit the primary X-ray component partly reaching the observer directly, and partly shining toward the disk to form a hot-spot, which emits the Compton reflection/reprocessed component.

We investigate time-dependent properties of the reprocessed spectrum of a hot-spot orbiting around the black hole in Keplerian motion. We take into account the varying ionization profile across the spot and include relativistic effects. Then we perform Monte-Carlo simulations of spot distributions to model the variability spectra of the Seyfert-1 galaxy MCG -6-30-15.

2. LOCAL REPROCESSED SPECTRA

We perform detailed radiative transfer simulations using the codes TITAN and NOAR (Dumont et al., 2000; 2003) to obtain the locally emitted Compton reflection/reprocessed spectra across the hot-spot. We assume a plane-parallel atmosphere with the initial density structure of a non-irradiated disk in hydrostatic equilibrium (Różańska et al., 1999). The incident flux spectrum is modeled as a power-law with a photon index of 1.9 over 0.1 keV —100 keV. We limit the size of the hot-spot to a flare half-opening angle of $60°$. The main parameters of the model are the Schwarzschild black hole mass M, the Eddington accretion rate $(dm/dt)_{\rm disk}$, the distance r of the spot to the disk center (in $R_{\rm g} = GM/c^2$), and the ratio between incident flux $F_{\rm inc}$ and disk flux $F_{\rm disk}$.
The reflection spectra contain typical features of Compton reflection and reprocessing, like an iron K_α-line and a Compton hump. Seen face-on and at high energies, they are similar for all rings. At low energies the spectrum from the spot center is softer than from the limb. For higher inclinations, significant changes in the hard X-rays are observed, with the Compton hump being stronger in the outer parts of the spot than closer-in.

3. SPECTRUM DURING THE ENTIRE ORBIT OF A SPOT

We investigate the time evolution for a hot-spot completing a whole Keplerian orbit using the relativistic

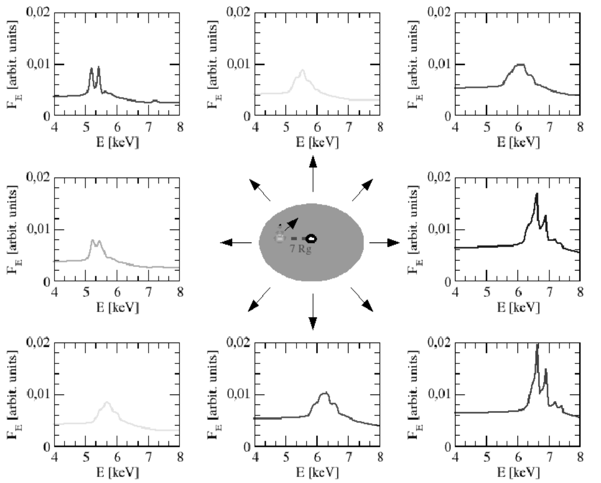

Figure 1. Profile of the iron line complex as a function of the orbital phase; disk at $i = 30°$; other parameters: $M = 10^8\ M_\odot$, $(dm/dt)_{\rm disk} = 0.001$, $r = 7R_{\rm g}$.

ray-tracing program KY (Dovčiak et al., 2004). Although, the accretion disk atmosphere does not remain at the same hydrostatic equilibrium during such a long time scale, the case is instructive to understand the influence of the relativistic effects at various orbital phases.

In Fig. 1 we show the evolution of the iron K_α-line complex during one orbit in a disk seen at the viewing angle $i = 30°$. The relativistic effects have a strong impact on the line profile, changing its strength by a factor of 2 and shifting the centroid in a range of 1.5 keV. The different line components can only be resolved at specific orbital phases, and the relative fluxes of these components change with phase, indicating a predominance of highly ionized iron when the spot is moving away from the observer. The model assuming the Schwarzschild metric cannot reproduce a broad red line wing as observed in MCG -6-30-15. This would require a Kerr black hole.

4. LIGHT CURVES AND SPECTRAL EVOLUTION OF SHORT-LASTING FLARES

We also consider short lasting flares, having a duration comparable to the light-crossing time of the hot-spot. In this case, the varying ionization and temperature structure across the spot becomes more important for the variability. We investigate the resulting spectra and light curves at two inclinations, a face-on view at $i = 0°$ and an intermediate viewing angle at $i = 60°$. In addition to the previous model with $M = 10^8\ {\rm M}_\odot$ and $(dm/dt)_{\rm disk} = 0.001$, we investigate a model with a smaller black hole mass $M = 10^7 {\rm M}_\odot$, a higher accretion rate $(dm/dt)_{\rm disk} = 0.02$, and a lower ratio $F_{\rm inc}/F_{\rm disk}$. In Fig. 2, we show X-ray light curves, obtained over the energy range of 1.3 keV —82.0 keV, for a short-lasting hot-spot located at the distance $r = 18R_{\rm g}$ and moving toward the observer. The light curves of the two models differ mainly in normalization. Their shape depends on the inclination - no symmetric shape of the light curve can be obtained for a face-on viewing angle. The components of the iron-line indicate a different ionization state of the medium for the two models.

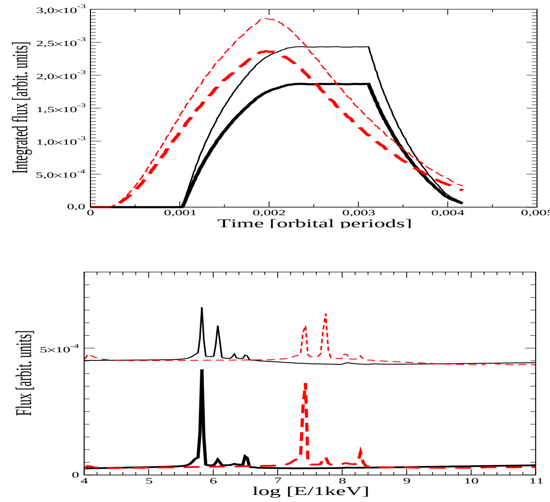

Figure 2. Light curves (top) and spectra (bottom) at the maximum of the light curves for a short lasting hot-spot at $r = 18R_{\rm g}$ moving toward the observer; disk inclination $i = 0°$ (solid lines), and $i = 60°$ (dashed lines); models: $M = 10^8\ M_\odot$, $(dm/dt)_{\rm disk} = 0.001$ (thin lines, offset), and $M = 10^7 M_\odot$, $(dm/dt)_{\rm disk} = 0.02$ (thick lines).

We attempt to model the variability of MCG -6-30-15 sampling random flare distributions across the disk and including relativistic line tracing of the reflected photons. The method is given by Czerny et al. (2004). A good fit of the fast (point-to-point) variability around the iron line can be obtained for 750 flares and a fast-rotating black hole. The observed dip of the rms-spectrum around the K_α-line is well reproduced (see Goosmann et al., 2005).

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