Ionized Iron Lines in X-ray Reflection Spectra

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Abstract. We present results from new calculations of the X-ray reflection spectrum from ionized accretion discs. These computations improve on our previous models by including the condition of hydrostatic balance in the vertical direction, following the work of Nayakshin, Kazanas & Kallman. We find that an ionized Fe Kα line is prominent in the reflection spectra for a wide variety of physical conditions. The results hold for both gas and radiation pressure dominated discs and when the metal abundances have been varied.

1. Introduction

The iron Kα line is arguably the most important feature in the hard X-ray spectrum of Active Galactic Nuclei (AGN) and Galactic Black Hole Candidates (GBHCs). Sensitive measurements of the shape and energy of the line could provide information on the velocity and ionization state of the accretion flow, as well as constraining the properties of the central black hole (see the recent review by Fabian et al. (2000) and references therein). The line is thought to arise from the fluorescence of irradiated optically-thick material, most likely the accretion disc itself. With the launch of the high-throughput telescope XMM-Newton, high signal-to-noise detections of the Fe Kα line will soon be common. It is therefore important that the models of X-ray reflection are suitably advanced to take advantage of this high-quality data.

In this contribution, we present new calculations of X-ray reflection from an ionized accretion disc, and concentrate on the properties of the Fe Kα line. It will be shown that emission from ionized Fe is quite common over a wide range of physical conditions.

2. Computations

The calculations were performed using the code described in detail by Ross & Fabian (1993) and Ballantyne, Ross, & Fabian (2001). The program computes the reflection spectrum from an optically thick layer of gas over the energy range 0.001 to 100 keV. The incident radiation is in the form of a power-law with
photon index $\Gamma$ which strikes the gas with a flux $F_x$ and at an incidence angle of $i$ degrees to the normal. The atmosphere then relaxes into thermal, ionization and pressure equilibrium before the reflection spectrum is computed. The transfer of the illuminating radiation is treated analytically in a one-stream approximation. The diffuse radiation (that from the disc, the gas, and the scattered component of the illuminating radiation) is treated using the Fokker-Planck/diffusion method (Ross, Weaver, & McCray 1978). The calculations are one-dimensional and occur at a radius $r$ along the accretion disc ($r = 9$ Schwarzschild radii for all the models presented below). We include levels from C v–vii, O v–ix, Mg ix–xiii, Si xi–xv, and Fe xvi–xxvii with the abundances of Morrison & McCammon (1983). The radiation pressure from both the impinging and diffuse radiation is included in determining hydrostatic balance. Calculations were performed using both the gas and radiation pressure dominated boundary conditions with no energy dissipation in the corona as described by Merloni, Fabian, & Ross (2000).

3. Results

Figure 1 presents results from the models run with the assumption of a gas pressure dominated accretion disc. In these cases, the illuminating radiation was incident on a disc that was accreting at 0.001 of the Eddington rate for a $10^8 \text{ M}_\odot$ black hole ($\dot{m} = 0.001$). The incident flux was $10^{15} \text{ erg cm}^{-2} \text{ s}^{-1}$, the

![Figure 1](image-url)
incidence angle was set so that $\cos i = 1/\sqrt{3}$, and $\Gamma$ was varied from 1.6 to 2.2. The left hand panel shows that ionized Fe lines at 6.7 and 6.97 keV were found to be prominent for larger values of $\Gamma$. The reason for this is illustrated in the right hand panel of Figure 1. Here, we plot the temperature of the gas versus the Thomson depth of the gas in the illuminated atmosphere. The gas temperature decreases rapidly, but not discontinuously (cf. Nayakshin, Kazanas, & Kallman 2000). There is a zone at $\sim 2 \times 10^6$ K which is kept thermally stable by a balance of photoelectric heating and a combination of line and bremsstrahlung cooling. This zone of stability allows sufficient quantities of helium-like and hydrogenic iron to exist and imprint their features on the reflection spectrum. For harder illuminating spectra (smaller $\Gamma$), iron is fully ionized to greater depth until the Fe lines disappear almost entirely. Ballantyne et al. (2001) also find ionized Fe lines when the other model parameters, such as $F_x$, have been varied.

Figure 2 presents Fe lines that were calculated for two other physical situations. The left-hand panel presents results for when radiation pressure dominated boundary conditions were assumed, allowing calculations at higher accretion rates. In these models, the accretion rate around a $10^8 \, M_\odot$ black hole was varied, and the illuminating parameters were held fixed at the following values: $\Gamma = 1.9, F_x = 10^{15} \, \text{erg cm}^{-2} \, \text{s}^{-1}$, and $\cos i = 1/\sqrt{3}$. As before, a line

Figure 2. (Left) X-ray reflection spectra, plotted between 1 and 10 keV to emphasize the Fe K$\alpha$ line, for differing values of the dimensionless accretion rate $\dot{m}$. The spectra have been offset vertically for clarity. These models were calculated assuming a radiation pressure dominated accretion disc around a black hole of mass $10^8 \, M_\odot$. The incident power-law had the following parameters: $\Gamma = 1.9, F_x = 10^{15} \, \text{erg cm}^{-2} \, \text{s}^{-1}$, and $\cos i = 1/\sqrt{3}$. As in Fig. 1, the dotted lines denote the position of the three different Fe lines. (Right). A comparison of models with one-fifth (solid line) and solar (dashed) abundance of oxygen. The straight dashed line denotes the continuum: $\Gamma = 1.9, F_x = 10^{15} \, \text{erg cm}^{-2} \, \text{s}^{-1}$, and $\cos i = 1/\sqrt{3}$. The accretion rate was $\dot{m} = 0.25$ for both these models and radiation pressure dominated boundary conditions were assumed.
at 6.7 keV from helium-like Fe was found for every value of the accretion rate that was considered. The right-hand panel of Figure 2 compares two different calculations of the $\dot{m} = 0.25$ model from the left-hand panel. The solid line denotes a model that was calculated with an oxygen abundance one-fifth of solar, while the dashed line denotes the solar abundance model from the other panel. Changing the abundance of oxygen could potentially impact the stability of the small plateau in the temperature structure of the atmosphere, and therefore affect which Fe Kα line dominates the reflection spectrum. However, as Fig. 2 illustrates, changing the oxygen abundance does not have an impact on the ionization state of the predicted Fe Kα line.

These results show that ionized Fe lines are expected from AGN reflection spectra over a wide range of physical conditions. This could have important implications on determining the structure of accretion discs and how they are illuminated. However, disentangling ionization effects from instrumental and/or relativistic ones will be a challenge with current instruments.

Acknowledgments. DRB is grateful for financial support from the Commonwealth Scholarship and Fellowship Plan and the Natural Sciences and Engineering Research Council of Canada. RRR and ACF acknowledge financial support from the College of the Holy Cross and the Royal Society, respectively.

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