A CHANDRA HETGS SPECTRAL STUDY OF THE IRON K BANDPASS IN MCG–6-30-15: A NARROW VIEW OF THE BROAD IRON LINE

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ABSTRACT

We present a 522 ksec Chandra High Energy Transmission Grating Spectrometer (HETGS) observation of the Fe K bandpass of MCG–6-30-15. The Chandra spectrum shows a broad Fe Kα line, consistent with a relativistic disk line. Narrow, blue-shifted H- and He-like Fe absorption lines are detected, with a likely origin in a $\simeq 2000\,\mathrm{km\,s^{-1}}$ outflow. No other narrow absorption lines are detected in the Fe K bandpass. The gas giving rise to the H- and He-like Fe absorption lines is very highly ionized and does not affect the $\sim 2-6\,\mathrm{keV}$ continuum shape. Less highly ionized absorption could alter the $\sim 2-6\,\mathrm{keV}$ continuum shape and reduce the extent of the red wing of the iron line but a generic prediction of such models are narrow absorption lines between $\sim 6.4-6.5\,\mathrm{keV}$ which are inconsistent with the Chandra spectrum. Furthermore, the difference spectrum between the high flux and low flux states shows no deviation from a power law between 2 and 6 keV, contrary to the predictions of simple absorption models. These are compelling arguments that the broad iron Kα line is *not* significantly affected by complex ionized absorption. We conclude that the relativistic disk line interpretation of the broad iron Kα line in MCG–6-30-15 is robust.

Key words: accretion disks — black hole physics — galaxies: active — galaxies: Seyfert — galaxies: individual (MCG–6-30-15) — X-rays: galaxies.

1. INTRODUCTION

Broad iron lines are a potentially powerful probe of the accretion flow and space-time within a few Schwarzschild radii of a black hole (e.g. Fabian et al., 2000; Reynolds & Nowak, 2003). A major discovery of the ASCA observatory was a relativistically broadened Fe Kα fluorescence line from the black hole accretion disk in the Seyfert 1 galaxy MCG–6-30-15 (Tanaka et al., 1995). The broad iron line in MCG–6-30-15 has since been confirmed and extensively studied by many different X-ray observatories.

It has been proposed, however, that ionized absorption can affect the continuum shape in the $\sim 2-6\,\mathrm{keV}$ bandpass and significantly reduce the extent of the broad red wing of the iron line. Ionized absorption models do not require the effects of strong gravity to explain the iron line profile (e.g. Kinkhabwala, A. A., 2003).

One of the science goals of future missions such as Constellation-X or XEUS is to map the accretion flow and space-time in the immediate vicinity of the black hole hole by studying the iron line and its variability. It is, therefore, crucial to test the robustness of the relativistic disk-line interpretation of broad iron K features.

In these proceedings we present the Chandra HETGS observation of MCG–6-30-15 and discuss the implications for broad iron line models. A more general discussion can be found in Young et al. (2005).

2. OBSERVATIONS

MCG–6-30-15 was observed by the Chandra HETGS for 522 ksec. We restrict our attention to the hard X-ray spectrum above 2 keV as our conclusions do not depend on the detailed properties of the warm absorber below 2 keV (i.e. our results are robust to the choice of *any* reasonable warm absorber model). A full analysis of the warm absorber will be presented by Lee et al. (2005).

If the Chandra HETGS spectrum is heavily binned the broad iron Kα line is evident, and consistent with the one seen by XMM-Newton even though these observations were not contemporaneous (Fig. 1).

Looking at the $5.5-7.5\,\mathrm{keV}$ bandpass in more detail, the Chandra High Energy Gratings (HEG) spectrum shows

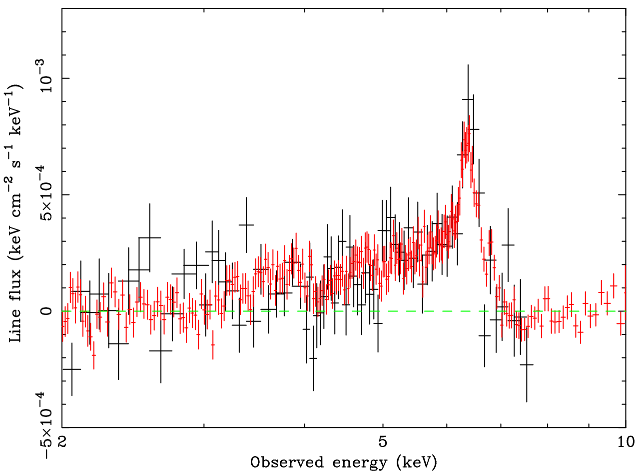

Figure 1. The broad iron line in MCG–6-30-15 observed with the Chandra High Energy Gratings (HEG, black points) and XMM-Newton EPIC-pn (Vaughan & Fabian, 2004, red points). The Chandra spectrum has been heavily binned. There is good agreement between the two line profiles even though these spectra were not contemporaneous.

three narrow lines (Fig. 2). There is a narrow component of the Fe Kα fluorescence line that probably arises in cold material some distance from the nucleus. There are narrow absorption lines from H- and He-like Fe, blueshifted with respect the source frame by approximately $2000\,\mathrm{km\,s^{-1}}$. These probably originate in an outflow.

The continuum light curve of MCG–6-30-15 shows variability by a factor of ~ 2 about the mean. The difference spectrum formed by subtracting low flux states from high flux states is well described by a power law between 2 and 6 keV (Fig. 3).

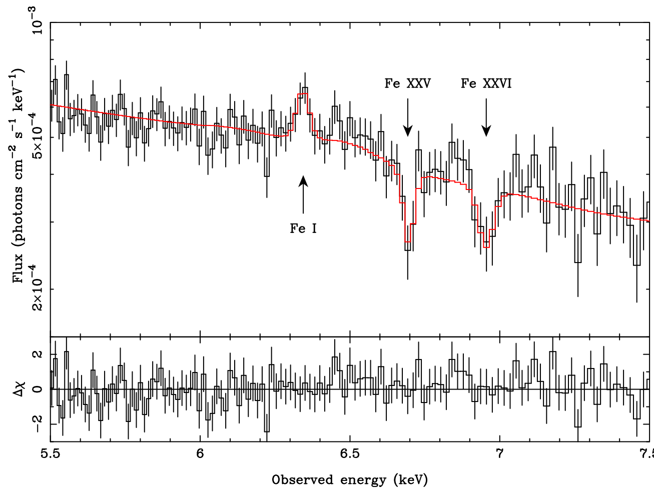

Figure 2. Chandra HEG spectrum of the iron K bandpass in MCG–6-30-15. There is narrow iron Kα emission at 6.34 keV (i.e. at rest in the source frame) and narrow absorption features from He-like iron at 6.69 keV and H-like iron at 6.96 keV. The absorption lines are blueshifted with respect to MCG–6-30-15 by approximately $2000\,\mathrm{km\,s^{-1}}$. No other narrow absorption lines are seen in this band.

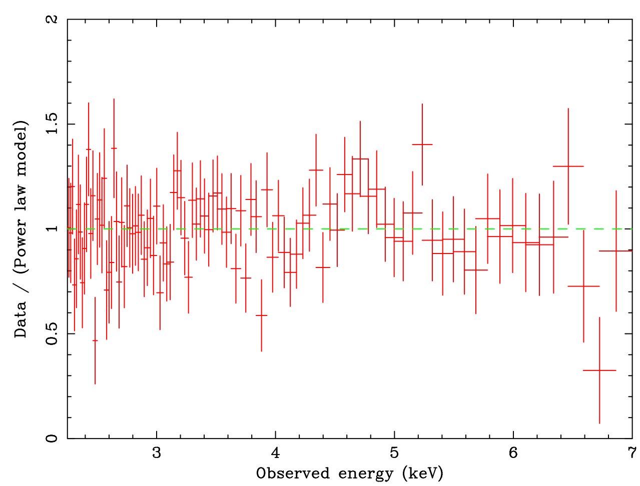

Figure 3. Ratio of the difference spectrum between the high and low flux states of MCG–6-30-15 to a power law model with photon index $\Gamma = 2$. There is no evidence of absorption affecting the continuum shape between 2 and 6 keV, consistent with previous findings (e.g. Fabian et al., 2002). If the red wing of the broad iron line is significantly affected by absorption, that absorption should also be present in the difference spectrum. This implies that the broad, red wing of the iron line is not *significantly affected by absorption.*

3. DISCUSSION

In this section we investigate the robustness of the relativistic disk line interpretation of the broad iron Kα line.

The absorbing gas giving rise to the H- and He-like Fe absorption (§2, Fig. 2) is very highly ionized and does not have a significant affect on the $2-6\,\mathrm{keV}$ continuum. This is because most of the ions that can absorb soft X-ray photons (and hence affect the $2-6\,\mathrm{keV}$ continuum) are completely ionized or, in the case of iron, do not have the necessary L-shell electrons.

Less highly ionized gas can, however, affect the continuum shape between 2 and 6 keV, as illustrated in Fig. 4. The effect of this absorption is to reduce the extent of the red wing of the broad iron line to the point where relativistic effects of strong gravity are not required to explain the line profile. To significantly affect the $2-6\,\mathrm{keV}$ continuum the gas cannot be too highly ionized, and Fe ions must have L-shell electrons. On the other hand, the gas

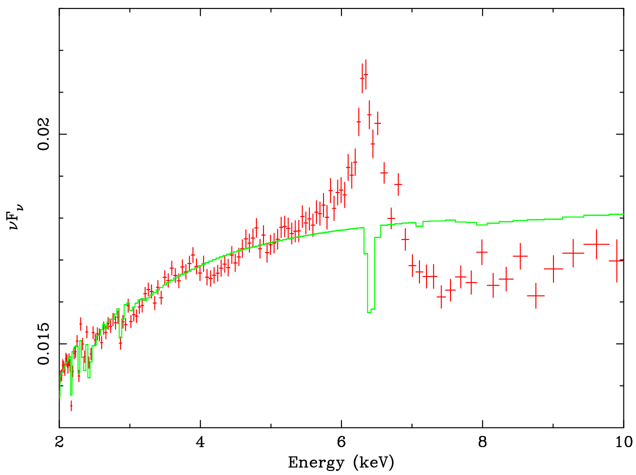

Figure 4. An example of an ionized absorption model fit to the XMM-Newton spectrum. This unfolded spectrum shows how absorption causes curvature of the continuum spectrum below 6 keV that can mimic the broad red wing of the iron line.

cannot be neutral because its spectrum would be inconsistent with the RXTE spectrum above 10 keV (Reynolds et al., 2004). As a result, ionized absorption models of the red wing of the broad iron line predict narrow absorption lines between ~ 6.4 and 6.5 keV. Simple ionized absorption models can therefore be ruled out by the Chandra HEG spectrum (Fig. 5) in which the narrow absorption lines predicted by these models between 6.4 and 6.5 keV are not seen.

4. CONCLUSIONS

1. Narrow H- and He-like Fe absorption lines are detected in the Chandra HETGS spectrum of MCG–6-30-15, with an outflow velocity of $\sim 2000\,\mathrm{km\,s^{-1}}$.
2. No other absorption lines are seen in the Fe K band, ruling out simple ionized absorption models for the red wing of the broad iron Kα line.
3. The difference spectrum between the high and low flux states does not show any deviations from a power law between 2 and 6 keV, further supporting the conclusion that absorption does not significantly affect this band.
4. We conclude that the relativistic disk line interpretation of the broad iron Kα line in MCG–6-30-15 is robust.

ACKNOWLEDGMENTS

We thank the conference organizers for an enjoyable and interesting meeting. Support for this work was provided

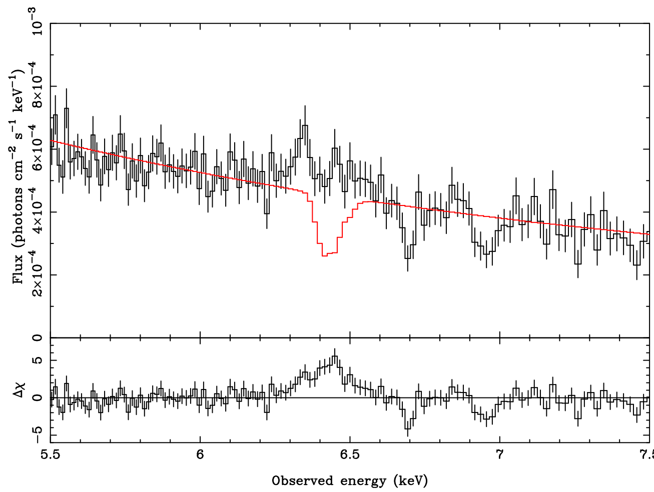

Figure 5. Comparison of an ionized absorption model (red line) with the Chandra HEG spectrum (black points). The ionized absorption model reduces the extent of the red wing of the iron line but predicts strong iron absorption lines around $6.4 - 6.5\,\mathrm{keV}$ that are clearly inconsistent with the Chandra spectrum. We conclude that a simple ionized absorption model cannot *account for the red wing of the broad iron line in MCG–6-30-15.*

by NASA through the Smithsonian Astrophysical Observatory (SAO) contract SV3–73016 to MIT for support of the Chandra X-ray Center which is operated by the SAO for and on behalf of NASA under contract NAS8–03060. JCL thanks and acknowledges support from the Chandra fellowship grant PF2–30023 – this is issued by the Chandra X-ray Observatory Center, which is operated by SAO for an on behalf of NASA under contract NAS8–39073.

REFERENCES

Fabian, A. C., et al., 2000, PASP, 112, 1145

Fabian, A. C., et al., 2002, MNRAS, 335, L1

Kinkhabwala, A. A., 2003, Ph. D. thesis, Columbia Univ.

Lee, J. C., et al., 2005, in prep.

Reynolds, C. S. & Nowak, M. A., 2003, Phys. Rep. 377, 389

Reynolds, C. S., et al., 2004, MNRAS, 349,1153

Tanaka, Y., et al., 1995, Nature, 375, 659

Vaughan S. & Fabian A. C., 2004, MNRAS, 348,1415

Young, A. J., et al., 2005, ApJ, 631, 733