**Chandra Grating Observations of AGN**

Tahir Yaqoob $^{1,2}$ & Urmila Padmanabhan $^1$

$^1$ Johns Hopkins University, 3400 N. Charles St., Baltimore, MD21218.
$^2$ NASA/GSFC, Code 662, Greenbelt Rd., Greenbelt, MD20771.

**Abstract.** The highest spectral resolution data for the Fe-K lines in type I AGN, as observed with the Chandra High Energy Grating (HEG), reveal a variety of line shapes. However, the energies of the most prominent peak are all clustered tightly around 6.4 keV (weighted mean $6.403 \pm 0.062$ keV). If all the peaks were part of single, relativistically broadened disk line, this would require unrealistically fine tuning. Thus, some of the cores must originate in distant matter (e.g. BLR, NLR, torus). On the other hand, in at least two AGN, the emission at 6.4 keV has been seen to vanish on short timescales, indicating an origin close to the central engine. For one of these (Mrk 509) this is puzzling because the HEG and simultaneous RXTE time-averaged spectra indicate only a narrow line was present at that time. Simultaneous HEG/RXTE observations for NGC 4593 indicate a broad and narrow Fe-K complex, all originating in neutral Fe, and for F9 show a narrow, neutral Fe-K component plus a broad, He-like component. The latter signature has been observed in three other AGN by XMM and may be quite common.

1. **Introduction**

We discuss here results on the Fe-K emission lines in type I AGN using Chandra HEG and RXTE. The HEG currently provides the best spectral resolution available in the Fe-K region ($\sim 1860$ km s$^{-1}$ FWHM at 6.4 keV). We do not discuss the soft X-ray spectra (see McKernan & Yaqoob 2003, for a recent review, and references therein). Padmanabhan & Yaqoob (2003; hereafter PY03) present the most precise measurements of the centroid energy, width, and equivalent width of the cores of the Fe-K lines in a sample of type I AGN using the HEG. In this paper we extend some of those results using RXTE.

2. **The Fe-K Lines: Origin of the Core Emission**

At least part of the Fe-K emission line in some AGN is believed to originate in a relativistic accretion disk around the black hole (e.g. see review by Fabian et al. 2000). However the Fe-K line profile is in general complex (e.g. Yaqoob et al. 2001). The total line emission may contain a component originating in matter located far from the black hole, such as the BLR, a putative obscuring torus, or the NLR.
Preliminary results from studying the Fe-K lines with the Chandra HEG in a sample of type I AGN have been given in Yaqoob et al. (2001) and PY03. Studies of additional, individual objects have been presented by Fang et al. (2002), Kaspi et al. (2002), Lee et al. (2002), and Turner et al. (2002). The equivalent widths (EW) of the HEG Fe-K line cores, as measured with a single Gaussian, are typically in the range $\sim 50 - 200$ eV. For the sample of nine type I AGN in PY03 (i.e. excluding the type 1.5–1.9 AGNs, NGC 4151 and MCG $-5-23-16$), the weighted mean centroid energy is $6.403 \pm 0.062$ keV. Only in the cases of MCG $-6-30-15$ (Lee et al. 2002) and NGC 3783 (Kaspi et al. 2002), and F9 (Figure 2) is the line core resolved at $> 99\%$ confidence by the HEG (in addition to the intermediate Seyferts, NGC 4151 and MCG $-5-23-16$). For the remaining AGN, the upper limits on the FWHM are all different. In fact, for data with this kind of spectral resolution, the actual shapes of the line intensity versus centroid energy, and EW versus FWHM contours carry information about the shape of the Fe-K line away from the peak (see PY03). Note that just because the line core may be resolved by the HEG, it does not necessarily mean that the core is from distant matter.

In some cases a broad base to the Fe-K line is clearly detected in the Chandra data (e.g. NGC 4051, F9, Yaqoob et al. 2001; MCG $-6-30-15$, Lee et al. 2002). However, due to the very small effective area, it is in general difficult to detect. Either way, it is difficult from time-averaged spectra alone, to ascertain whether the core of the Fe-K line is from distant matter or really part of a single broad line which has contributions from a disk extending to large radii. Certainly, the main peak of the line in every type I AGN so far is at $\sim 6.4$ keV with a very small dispersion (62 eV). This, along with simulations, shows that much fine tuning is required (especially of the inclination angle) if the line is only from a disk (see PY03). Thus, line cores measured by Chandra cannot all be due to the peak of a disk line. In one case (MCG $-6-30-15$, Lee et al. 2002), it has been possible to deduce, from variability, that the core of the Fe-K line is not from distant matter. However, most AGN do not vary as rapidly as MCG $-6-30-15$ in a single observation so we must await further monitoring data to establish origin of the Fe-K line core in more AGN.

3. The Broad Fe-K Line Components

Now we discuss some of the Chandra observations which were simultaneous with RXTE (Mrk 509, NGC 4593, F9). The RXTE PCA has more than 100 times the effective area of the HEG in the Fe-K band. Although the velocity resolution is $\sim 55,000$ km s$^{-1}$ FWHM, the PCA is excellent for studying the broad component of the Fe-K lines. If we use a simple Gaussian (with intrinsic width free) to model the line in separate instruments, the PCA will ‘pick-up’ more line emission than the HEG (with possibly a different centroid energy), if the line is complex.

Details of the HEG Gaussian fitting are described in (PY03). For the PCA data, in addition to a power-law continuum and Gaussian line, we included a Compton reflection continuum (from neutral, optically-thick matter) with the ‘reflection fraction’ ($R$) free, utilizing data out to $\sim 14-15$ keV. Fig. 1 shows the 68%, 90%, and 99% confidence contours of line intensity versus centroid energy.
Figure 1. HEG and PCA confidence contours (68%, 90%, 99%) of Fe-K line intensity vs. center energy (top) and EW vs. FWHM (bottom).

and EW versus FWHM respectively. We see that for Mrk 509 the HEG and PCA give consistent results, both giving peaks at $\sim 6.4$ keV, with PCA giving only a marginally larger EW than the HEG. Therefore, during this observation of Mrk 509, the Fe-K line was dominated by a narrow, unresolved (by HEG) component with only a weak broad component. However, ASCA monitoring data of Mrk 509 showed that the peak at 6.4 keV can disappear and move to lower or higher energy, on a timescale of days. This is puzzling and would suggest that the peak of the Fe-K line is not from distant matter (i.e. it is from well inside the BLR).

Next, the contours for NGC 4593 show that the HEG and PCA line intensities and EWs do not overlap at 99% confidence (Fig. 1). Therefore the Fe-K line is definitely complex, with the HEG only picking up the core, which is about half of the intensity of the total line emission. The centroids of the HEG core and the total are both consistent with 6.4 keV, indicative of an origin in cold Fe for the whole line. Variability information is required to determine whether there are two separate line components or a single broad line.
The contours for F9 show that the HEG and PCA measure lines with different centroid energies (Fig. 1). We know from Mrk 509 and NGC 4593 that this is not a cross-calibration issue. In F9 the HEG line peaks at \( \sim 6.4 \) keV and the PCA line peaks at \( \sim 6.66 \) keV. So again, the line is definitely complex. The PCA line likely includes a contribution from He-like Fe in addition to the 6.4 keV component measured by the HEG. This time there is not a clear distinction between the HEG and PCA EW versus FWHM contours, because, as is evident from the line profile (see Yaqoob et al. 2001), the core of the line is not as ‘peaky’ as that in some of the other AGN (such as Mrk 509 and NGC 4593). In fact, Fig. 1 shows that the HEG contours from single-Gaussian fits pick up the whole broad line, and indeed F9 is one of the objects in which the broad profile is detected with the HEG. Note that a neutral, narrow Fe-K line plus a broad He-like line has been observed in XMM observations in at least three other AGN (Mrk 509, Mrk 205, Reeves, these proceedings; NGC 5506, Matt et al. 2001) and may be a common signature.

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References

Fabian, A. C., Iwasawa, K., Reynolds, C. S., & Young, A. J. 2000, PASP, 112, 1145
Fang, T., Davis, D. S., Lee, J. C., Marshall, H. M., Bryan, G. L., & Canizares, C. R. 2002, ApJ, 565, 86
Kaspi, S., et al. 2002, ApJ, 574, 643
Lee, J. C., Iwasawa, K., Houck, J. C., Fabian, A. C., Marshall, H. M., & Canizares, C. R. 2002, ApJ, 570, L47
Matt, G., Guainazzi, M., Perola, G. C., Fiore, F., Nicastro, F., Cappi, M., & Piro, L. 2001, A&A, 377, L31
McKernan, B., & Yaqoob, T. 2003, in ASP Conf. Ser., IAU Symp. 214, High Energy Processes and Phenomena in Astrophysics, ed. X.-D. Li, Z.-R. Wang, & V. Trimble (San Francisco: ASP), in press
Padmanabhan, U., & Yaqoob, T. 2003, in ASP Conf. Ser., IAU Symp. 214, High Energy Processes and Phenomena in Astrophysics, ed. X.-D. Li, Z.-R. Wang, & V. Trimble (San Francisco: ASP), in press (PY03)
Turner, T. J., et al. 2002, ApJ, 574, L123
Weaver, K. A., Gelbord, J., & Yaqoob, T. 2001, ApJ, 550, 261
Yaqoob, T., Padmanabhan, U., Dotani, T., George, I. M., Nandra, K., Tanaka, Y., Turner, T. J., & Weaver, K. A. 2001, in Conf. Proc., X-ray Emission from Accretion onto Black Holes, Proceedings, ed. T. Yaqoob, & J. H. Kroll (published electronically on ADS), E79 [astro-ph/0111419]