Precision Fe Kalpha and Fe Kbeta Line Spectroscopy of the Seyfert 1.9 Galaxy NGC 2992 with Suzaku

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We present detailed time-averaged X-ray spectroscopy of the Seyfert 1.9 galaxy NGC 2992 with the XIS. The XIS spectrum of NGC 2992 can be described by several components. There is a primary continuum that is obscured by a Compton-thin absorber with a column density of \(N_\text{H} = 8.0^{+0.6}_{-0.5} \times 10^{21} \text{ cm}^{-2}\). There is another, weaker, unabsorbed power-law component that is likely to be due to the primary continuum being electron-scattered into our line-of-sight by a region extended on a scale of hundreds of parsecs. We measure the Thomson depth of the scattering zone to be \(\tau_{\text{es}} = 0.072^{+0.021}_{-0.021}\). There is also optically-thin thermal emission with a temperature of \(kT = 0.656^{+0.088}_{-0.061} \text{ keV}\). We detect an Fe K emission complex which we model with broad and narrow lines and we show that the intensities of the two components are decoupled at a confidence level \(> 3\sigma\). We also detect the Fe-K\(\beta\) line (corresponding to the narrow Fe-K\(\alpha\) line) with a high signal-to-noise ratio and describe a new robust method to constrain the ionization state of Fe responsible for the Fe-K\(\alpha\) and Fe-K\(\beta\) lines that rules out states higher than Fe \(\text{vii}\).

§1. Introduction

Fe-K lines observed in active galactic nuclei (AGN) are very powerful diagnostics of the nuclear region. A narrow 6.4 keV line (with FWHM < 10000 km s\(^{-1}\)) is found in nearly all nearby AGN\(^6\)–\(^8\),\(^16\) and a broad line is often also detected.\(^7\)–\(^9\),\(^13\),\(^15\) Clearly, it is critical to decompose narrow and broad Fe-K line emission in order to properly assess their properties, however often the signal-to-noise of X-ray spectra is not high enough to apply dual-line models.\(^16\) The narrow line core most likely originates from gas distant from the black hole (\(r > 100r_\text{g}\)) however the precise location remains unknown. The issue is further complicated in obscured AGN since this increases the complexity of modeling the spectra.\(^3\),\(^14\),\(^15\)

Here we present the results of a Suzaku observation of the nearby (\(z=0.00771\)) Seyfert 1.9 galaxy NGC 2992. From the Suzaku CCD spectra we show that the broad and narrow line intensities are decoupled for the first time (i.e., statistically both the broad and narrow line normalizations are required to be \(> 0\)). The Fe-K\(\beta\) line is also detected, and we discuss a new method that utilizes the Fe-K\(\beta\) line to place tight limits on the ionization state of Fe in the line-emitting material. These results are also discussed in Yaqoob et al. (2007).\(^17\)
§2. Data reduction

NGC 2992 was observed by Suzaku on three occasions, with a total exposure time of $\sim 100$ ks. No significant variability or spectral variability was detected within the observations, and only a $\sim 30\%$ variation in net count rate was observed between the observations (likewise with no spectral variability detected). At the time of the analysis XIS2 and XIS3 were the best calibrated so we present these data and defer XIS0 and XIS1 for future work. Therefore here we present the combined XIS2 and XIS3 spectrum integrated over the three exposures. While a preliminary analysis of the PIN data resulted in a detection of a Compton reflection component, the significance of this detection was sensitive to the relative PIN/XIS normalization and background systematics. Therefore we also defer detailed analysis of the HXD data pending improved calibration.

§3. Results

We fit the spectra with a simple power-law, which was a poor fit due to a soft excess, narrow and break Fe-K$\alpha$ emission, and Fe-K$\beta$ emission. The soft excess was fit well with an optical-thin plasma model (APEC) with $kT = 0.66^{+0.09}_{-0.06}$ keV and luminosity $1.2 \times 10^{40}$ ergs s$^{-1}$, similar to values observed in starburst galaxies.$^{1),2),11),12)}$

3.1. Fe-K Emission

The residuals in the Fe-K band when fit with a power-law are shown in Fig. 1. For the first time in NGC 2992 broad and narrow Fe-K emission are both required in a dual line fit. The confidence intervals for the normalizations of the broad and narrow line components in the dual-line model (with the broad component fit with a disk-line model and the narrow component fit with a Gaussian model) are shown in Fig. 2, which shows that the normalizations of both components must be $> 0$ at better than $3\sigma$ confidence.

![Fig. 1](https://example.com/fig1.png)

Fig. 1. a) Ratio of data to model when a simple power-law is fit to the Fe-K region. b) Ratio of data to model when the narrow Fe-K core is fitted to the spectrum (with a Gaussian component). In both plots the vertical lines show the expected energies of neutral Fe-K$\alpha$ and Fe-K$\beta$ lines.
3.2. \( \text{Fe-K}\alpha / \text{Fe-K}\beta \) constraints on ionization state

\( \text{Fe-K}\beta \) emission is also clearly detected in the spectrum (see Fig. 1). Since the energies of both the \( \text{Fe-K}\alpha \) and \( \text{Fe-K}\beta \) lines are a function of the ionization state,\(^4,10\) the offset between the \( \text{Fe-K}\alpha \) and \( \text{Fe-K}\beta \) lines can be used to constrain the ionization state of the narrow-line emitting gas. Specifically, the observed energies are related to the “true” energies of the lines (assuming a linear gain correction) by

\[
E_{\text{i,Fe K}\alpha}^{\text{observed}} = A + B \times E_{\text{i,Fe K}\alpha}^{\text{true}},
\]

(3.1)

\[
E_{\text{i,Fe K}\beta}^{\text{observed}} = A + B \times E_{\text{i,Fe K}\beta}^{\text{true}}.
\]

(3.2)

These equations can be used to convert confidence contours for the observed line energies into contours for the gain intercept and slope \( A \) and \( B \). This is shown in Fig. 3. Also plotted are vertical lines showing ±50 eV offsets in the gain, which is conservative since the energy scale of the XIS CCDS is known to within \( \sim 13 \) eV.\(^5\) We fitted the Mn K\( \alpha \) calibration line spectrum (also integrated over all three observations as was done with the NGC 2992 spectrum) and found an offset from the expected energy of 11 ± 3 eV. This shows that the ionization state of the gas producing the \( \text{Fe-K} \) emission must be in the range \( \text{Fe i} - \text{Fe vii} \).

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Fig. 3. Confidence contours for the gain intercept ($A$) and slope ($B$) derived from the offset between the Fe-Kα and Fe-Kβ lines. The vertical lines show a ±50 eV gain offset, which is conservative since the energy scale of the XIS is accurate to within ∼13 eV.

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