Fe K Emission & Absorption in the XMM-EPIC Spectrum of the X-ray Bright Seyfert IC 4329a

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ABSTRACT

We present a re-analysis of the XMM EPIC-pn long-look spectrum of the X-ray bright Seyfert 1.2 galaxy IC 4329a. The Fe K bandpass is dominated by two peaks, consistent with emission from neutral Fe Kα and Fe Kβ. A relativistic diskline model whereby both peaks are the result of one doubly-peaked diskline profile is found to be a poor description of the data. Our main result is detection of a narrow absorption line, at a energy of 7.68 keV in the rest frame of the source; its significance has been confirmed using Monte Carlo simulations. This feature is most likely absorption due to Fe Kα XXVI, blueshifted to ~0.1c relative to the systemic velocity. If this interpretation is correct, then IC 4329a is thus added to the list of objects with suspected high-velocity, highly-ionized outflows. We also explore the time-resolved spectral behavior of this source on time scales ranging from minutes to ~2 years, using the XMM data and RXTE monitoring data. We find little variability in the continuum flux or photon index, especially on short time scales. There is no strong evidence for variability of the Fe Kα line on any time scale probed.

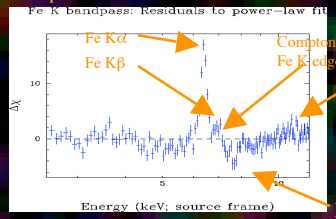
INTRODUCTION

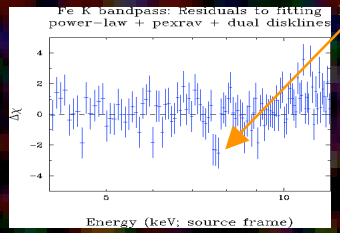
- Narrow 6.4 keV Fe Kα cores are common in Seyferts: (e.g., O'Brien 2001). FWHMs of several thousand km s^{-1} are typical. This component is thought to originate far from the black hole, e.g., in the outer accretion disk, BLR, or torus.
- Ionized absorbing material is common in Seyferts: Grating observations reveal strong evidence for ionized, usually outflowing, material in the inner regions of a large fraction of AGN (e.g., Blustin et al. 2005). Usually, material spanning a range of ionization states is present
- Some AGN show evidence for highly-ionized, sometimes high-velocity, absorbing gas in the Fe K bandpass: An Fe Kα XXV absorption line at 6.7 keV is seen in the EPIC spectrum of the Seyfert 1 NGC 3783, (Reeves et al. 2005). Narrow absorption lines are seen with HEG in MCG-6-30-15, attributed to Fe Kα XXV and Fe Kα XXVI, blueshifted by 2000 km s^{-1} (Young et al. 2005). Absorption features are detected near 7-8 keV in PG and BAL quasars, attributed to strongly-blueshifted, high-ionization Fe K at near-relativistic (~0.2c) velocities; these may be signatures of accretion disk winds.

- **IC 4329a is a well-studied, X-ray bright nearby (z=0.016) Seyfert 1.2, with $L_X = 10^{43.9}$ erg s^{-1}, $L_{BOL} = 10^{45.4}$ erg s^{-1}. It was observed by XMM-Newton for135 ksec in Aug 2003.**
- Steenbrugge et al. (2005)'s analysis concentrated on the soft X-ray, RGS data, which revealed evidence for several absorbing components, including: neutral absorption intrinsic to the host galaxy, a four-component warm absorber spanning a range of ionization states (log ξ spanned -1.4 to +2.7), and absorption due to local (z=0) hot gas. They also noted two emission peaks in the EPIC-pn data near 6.4 and 7.0 keV, identified as the Fe Kα core and a blend of Fe I Kβ and Fe XXVI Kα, respectively.

OUR PRIMARY GOALS

1) Using the pn data from the XMM long-look, quantify IC 4329a's Fe K emission profile in pn spectrum and search for Fe K bandpass absorption using EPIC-pn data, complementary to the analysis of Steenbrugge et al. (2005).
2) Time-resolved spectroscopy of the Fe Kα line on multiple time scales, using RXTE monitoring and the XMM long-look



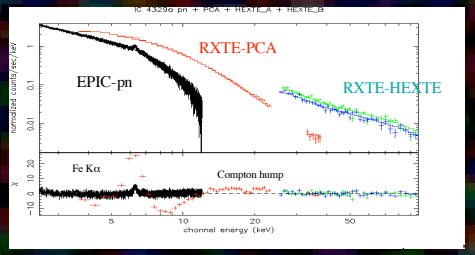


Narrow absorption feature?

EPIC-pn residuals to power-law fit (top) and fit with power-law + pexrav + 2 disklines (bottom). NOTE: The MOS2 spectrum was found to be consistent with the pn, e.g., the 7.68 keV absorption line appears in both data sets, but are not plotted for clarity. MOS1 data were taken in large window mode and suffer from pile-up, and are not presented.

FE K EMISSION IN IC 4329a

- Photon index Γ is 1.73 ± 0.01 (2.5-12 keV band). Reflection strength: based on joint RXTE-PCA/HEXTE fits (from RXTE monitoring, 2003-5), Compton reflection strength is fixed at 0.51 ± 0.04 in the pn fits. Solar abundances assumed
- Emission lines in the pn spectrum at 6.4 and 7.0 keV can each be modeled well using a mildy-relativstic diskline profile with inner radius of $13^{+13}_{-11.5}$ R_g, face-on inclination (1^{+11}_{-1}°), and consistent with Fe Kα and Kβ emission from neutral or near-neutral gas. The EW of the Kα line is 86^{+17}_{-8} eV, consistent with reflection off neutral material (EW(Kα)/150 eV = R; George & Fabian 1991). Fe K profile results are consistent with Steenbrugge et al. (2005).
- The 7.0 keV blue peak is significantly smaller in EW compared to the 6.4 keV red peak, so models wherein a single diskline fit describes both peaks (e.g., McKernan & Yaqoob 2004) are ruled out.
- We find only small upper limits on Fe K XXV and Fe K XXVI Ly α absorption and emission at systemic velocity (all limits < 15 eV in EW)



Simple power law fit (Γ = 1.79) to joint fits of XMM-pn long-look spectrum plus PCA/HEXTE spectrum from long-term RXTE monitoring

THE NARROW ABSORPTION LINE AT 7.68 KEV: A HIGHLY-IONIZED, HIGH-VELOCITY OUTFLOW?

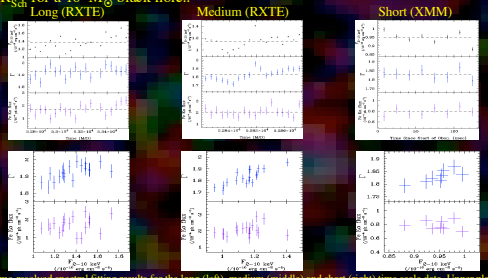
- The absorption feature is modeled well by a narrow Gaussian: EW in absorption = 14 ± 3 eV. Energy centroid: 7.68 ± 0.02 keV
- XSTAR model fits: One absorbing component, with $N_H = 2.7^{+7.4}_{-0.6} * 10^{21}$ cm^{-2}, $\log\xi = 3.46^{+0.18}_{-0.12}$ erg cm s^{-1}, and z = -0.093 relative to systemic, can fit the data well.
- **Consistent with absorption by Fe Kα XXVI, blueshifted by ~0.1c. Disk wind, maybe?**
- Alternate origins: A local (z=0) origin is unlikely, given the unrealistically high column density required. Fe Kβ absorption is unlikely: The ionization state needs to be < XVII or so, otherwise one would see strong Fe Kα absorption and lowly- or mildly-ionized Fe Kβ is unlikely: this requires a very low ionization level, which would introduce strong spectra curvature below ~4 keV (not seen here)
- Estimated mass outflow rate (Blustin et al. 2005) is ~10^{-2}-10^{-3} $M_\odot$ yr^{-1}. Maximum distance estimated at ~10^{16} cm, or about 300 R_{Sch} for a 10^8 $M_\odot$ black hole..

Monte Carlo simulations for the narrow absorption line:
- What's wrong with standard F-test usage: There was no a priori expectation for a line at 7.68 keV. Using the F-test in the "standard" manner can overestimate the detection significance, since the F-test doesn't take into account the possible range of energies where a line might occur or the number of resolution elements over that energy range (see Protassov et al. 2002).
- Monte Carlo simulation method (see Porquet et al. 2004) used to test the null hypothesis that the spectrum doesn't require the absorption line and the feature is due only to photon noise. (talk to AGM or JNR, or contact P. Uttley for details)
- Results for IC4329a EPIC-pn spectrum: The probability that the 7.68 keV feature is due to photon noise is < 1/1000.

TIME-RESOLVED SPECTRAL FITTING

Spectral variability on three time scales probed:
- Long-term (timescales of weeks to years) and medium-term variability (hours to weeks): from RXTE monitoring observations taken between 2003-2005. Short-term (minutes to ~a day) variability: from the XMM long-look
- Procedure (e.g., Markowitz, Edelson & Vaughan 2003): Fit the time-average spectrum, apply that model to the time-resolved slices. Time widths were chosen to ensure adequate S/N in Fe Kα flux.

Results:
- There is little range in 2-10 keV continuum flux: typically the source varies by only a few% on time scales of hours to ~ a day, and only 10-20% on time scales of days to years
- Hard X-ray photon index Γ and F_{2-10} are well correlated. There is little range in Γ: at most, ΔΓ is 0.2-0.3 on time scales of years
- Steenbrugge et al. (2005) first reported a lack of variability in the Fe Kα line in the XMM data, consistent with an origin far from the black hole. We find no strong evidence for the Fe Kα line to vary on any time scale of 2 years or less, consistent with this interpretation -- but, given the minimal continuum variability and the diskline profile fitting above, a likely scenario is that the line originates within ~100 R_g but does not vary strongly because the illuminating continuum varies only weakly.



Time-resolved spectral fitting results for the long (left), medium (middle) and short (right) time scale data. Upper plots show the 2-10 keV continuum flux F_{2-10}, photon index Γ, and Fe Kα flux light curves. Lower plots show Γ and Fe Kα flux plotted against F_{2-10}. Γ is usually well-correlated with F_{2-10} even over the narrow flux range probed, while the Fe Kα flux shows no dependence on F_{2-10}.

CONCLUSIONS

- A dual-diskline model describes the Fe K emission profile well
- A narrow absorption feature is seen at 7.68 keV; Monte Carlo simulations show that the detection is significant.
- The most likely origin: absorption by Fe Kα XXVI, blueshifted by ~0.1c relative to the systemic velocity
- We hereby add IC 4329a to the list of AGN with highly-ionized, high-velocity outflowing components. **It's important to thoroughly identify the features associated with such outflows in order to gauge the frequency of occurrence of this phenomenon in Seyferts and quasars.**
- There is little variability in the continuum flux or photon index, particularly on short time scales.
- There is no strong evidence for variability of the Fe Kα line on time scales less than two years, likely a consequence of the minimal continuum variability.

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Background image: From 2MASS 1.3m