Suzaku Observations of Iron Lines and Reflection in AGN

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Establish ‘reality’ of broad Fe K lines -
  - NGC3516, MCG-5-23-16, MCG-6-30-15, NGC2992….

Determine accurate reflection parameters and comparison of Fe K line to reflection -
  - NGC2110 (no reflection)
  - MCG-5-23-16, MCG-6-30-15, NGC3516

Precision measurements of Fe line parameters

Time variability of different spectral components and their connection
Work is started preliminary results
NGC 4051, MCG-5-23-16, MCG-6-30-15

Does the reflection (+Fe line) vary with the continuum?

High energy cutoffs - and connection to x-ray background

NGC4388, NGC4945, MCG-5-23-16, Cen-A, NGC2110
Important Suzaku Properties for AGN research

- High signal to noise from 0.3- 50(200) keV
- Well calibrated
- Good energy resolution (better than XMM and Chandra CCDs)

Suzaku data for Cyg X-1

Cutoff (Te=110keV)

soft excess

narrow Fe (6.4keV)

Kα-Kβ line energies in NGC2110
Suzaku XIS: Excellent Spectral Resolution especially at $E < 1$ keV

Suzaku Chandra ACIS-S

E0102-SNR
Suzaku Observation of Mrk 3 (Awaki et al.)

Soft X-ray emission lines

Fe K band

![Graph showing soft X-ray emission lines and Fe K band spectra with labeled elements and energy levels.](image-url)
Comparison of Suzaku, XMM and Chandra Background/Areas

For point sources Suzaku is flux limited - with similar counting rates for hard sources to XMM EPIC. Hard x-ray detector is more sensitive than SAX in 10-40 keV band.
Sample AGN Spectra
Watanabe et al.
NGC4388 Direct Comparison of Suzaku and BeppoSax

- One XIS (Suzaku)- 2 MECS (SAX)
- Flux state very similar
- Same Model fit to data (Suzaku 0.1 steeper PL slope)
- Swift BAT catalog has ~250 AGN above the flux level limits of the PIN and >100 galactic sources

BAT high latitude Log N-Log S (Markward et al 2006)
NGC4945 Direct Comparison of Suzaku and BeppoSax

- **Complex spectrum of Compton-thick Seyfert 2, with reflection, and transmission, requires broad band to deconvolve.**
Non-Simultaneous Suzaku and XMM Observation - notice the variation of the Fe K line shape

Iron line Profile of 3C120 (Kataoka et al.)

Comparison with XMM: revisited

XMM (130ksec)


Suzaku (150ksec)

(1) red-wing in 6.4 keV
(2) much better statistics
(3) clear 6.9 keV bump
(4) extremely low BGD
Simultaneous Suzaku and XMM-Newton Observation of MCG -5-23-16 - notice the excellent agreement on Fe K line shape

- Ratio to $\Gamma=1.8$ PL
- EPIC-PN
- Suzaku XIS
- Fe K$\alpha$ Core (peak energy at 6.397 keV - within 10eV for PN and XIS)
- Fe K$\beta$ (at 7.05 keV)
- Fe K edge (at 7.1 keV)
- Red-wing
**Broad-band Suzaku Spectrum of MCG -5-23-16**

Observed Flux $9 \times 10^{-11}$ cgs (2-10 keV) and $2 \times 10^{-10}$ cgs (15-100 keV).

Fe K line present between 6-7 keV and reflection hump clearly detected above 12 keV in HXD.

The reflection component is well constrained with $R=1.2\pm0.2$, with an Fe abundance of $0.6 \times$ solar and a cut-off of 200 keV.

The edge at 7.1 keV and the Compton hump allows us to determine both parameters.
MCG-5-23-16: Parameters are well determined

- Fe abundance of reflector, cutoff energy and reflection fraction are all well determined and are not highly correlated with each other.

Accurate measurement of the Fe abundance of material near the black hole.
Iron K line Models
(MCG -5-23-16)

Narrow Fe Kα line at 6.40 keV resolved by Chandra/HETG (σ=35 eV or 1600 km/s). EW of 70 eV.

Fe Kβ line of 10 eV EW.

Weak, but v. significant broad Fe component, resolved by XIS (σ =400 eV or 20000 km/s). EW of 70 eV. Modeled by a diskline, 45 deg inclination, Rin=50Rg.

Reflection component with R=1.2. Fe abundance determined (by ratio of Compton hump to Fe K edge) to be x0.6 solar.

Iron line parameters are no longer degenerate with simultaneous measure of reflection component and high energy continuum.
Variations in the iron K line and Reflection Component (MCG -5-23-16)

**High flux = Red; Low flux = Blue; Reflection: Black**

Observation split into high and low flux states

Iron K line and reflection component do not appear to vary during observation.

Spectra can be fit with a superposition of a variable power-law and constant Fe line + reflection hump.

Weak variations in broad Fe line cannot be statistically excluded though.
High - Low Difference Spectrum (MCG -5-23-16)

Source continuum varies by about 40% over Suzaku observation (220ks duration).

High - low spectrum shows that the variable component is just a power-law ($\Gamma = 1.9$), modified by absorption.

Line and reflection hump appear constant.
Suzaku Observation of MCG -6-30-15 (Jan 06, 300ks, Fabian et al.)

Ratio of XIS + PIN data to a power-law, note broad iron line and reflection hump

Broad iron line
Note He-like and H-like Fe absorption lines in blue wing
Variability of Iron line and Reflection in MCG-6-30-15

Strong iron K line and disk reflection from around a Kerr (spinning) black hole

No variations in Fe line/reflection - gravitational light bending around a Kerr BH? (Miniutti & Fabian 2004)
MCG -6-30-15 High-Low Difference spectrum

Ratio to a Gamma=2.2 power-law. This clearly indicates that the main variable component is an absorbed power-law. The reflection component varies little.
NGC3516 (see Alex Markowitz talk next)

- Both broad (redshifted) and narrow components of the Fe line are required and reflection is seen in HXD,

- several soft X-ray lines are also detected.

A new feature is also observed, due to an absorption edge near 7.3 keV in the rest frame, which is detected in XIS. This could be due to an ionized reflector.
NGC 4051  Light curve (Terashima et al.)

86 ksec XIS+HXD simultaneous exposure
Average flux in 2-10 keV
9x10^{-12} erg/s/cm^2
NGC 4051- Spectral Variability

NGC4051 (Terashima et al) - spectral variability breaks into two components (constant + variable power law); E > 10 keV spectrum varies very little.

Very little if any change in hard band
Suzaku Fe K band “Absorption” Features - PG 1211+143, 1H 0707-495 (but also NGC 4388, MCG -6-30-15)

PG 1211+143; Reeves et al.

1H0707-495; Hayashida et al.
Line width of emission lines: $\sigma=29\, (+6,-22)\, \text{eV}$, $v=3100\, (+600,-2500)\, \text{km/s}$, suggesting $R_{Fe}>6600\, R_{Sch}$.

for a $1.8\times10^8\, M_{\odot}$ black hole, this is $\sim$120 light-days from the nucleus.

The absorbing material is consistent with also being the origin for the Fe K $\alpha$ line, consistent with an origin in uniform-density gas.

No Compton hump seen: *Fe K line originates in Compton-thin absorbing material*

Edge at 7.15 $\pm$ 0.01 keV corresponds to optical depth $\tau = 0.20 \pm 0.01$
NGC2110-Okajima et al

- Detection to E>150 keV
- Best fit puts strong upper limit on reflection (R<0.1), yet Fe line is 70-80 eV.
- Compton-thin matter (BLR?)
NGC2110- narrow line resolved

- Suzaku data have allowed the resolution of several of the ‘narrow’ Fe K lines with errors similar to that of the Chandra HETG.

- Fe55 calibration source on XIS allows for very accurate constraints on Fe line width and energy.

- The ionization state of the Fe can be determined from the ratio of Ka/Kb and the energy of the Fe K line.
By combining the energy and line ratio information from K-alpha and K-beta, one can get a tight constraint on the ionization state of Fe.
Conclusions

• The broad bandpass of Suzaku enables us to break the degeneracies in modeling the broad iron line. Uncertainties in the modeling of continuum shape, absorption and reflection component are removed.
• Broad Fe lines are confirmed in a number of sources - MCG -6-30-15, MCG -5-23-16, NGC 3516 (possibly NGC 4051).
• Narrow line origin not ubiquitous. Some (e.g. MCG -5-23-16) originate from Compton-thick matter (torus?). In others (Cen A, NGC 2110), no reflection is present (Fe line from BLR?). Line widths can be constrained (e.g. NGC 2110).
• A constant hard component appears to be present in a number of spectra (MCG -6-30-15, NGC 4051, MCG -5-23-16). Fe line and reflection component do not respond to continuum.
• In the future, a large sample of AGN (>200 from Swift/BAT survey) can be studied with XIS+HXD.