High Resolution X-ray Spectroscopy of Seyfert Galaxies: Why Key Science is in the Details

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What are we hoping to get from AGN studies?

Ultimately we hope to understand something fundamental:

- black hole accretion/fueling (hence growth, evolution, structure formation) *Warm Absorbers & “Hot Absorbers”*

- physics in the strong gravity regime *Fe Kα*

Study of narrow features breaks key ambiguities
To understand Fe K profiles, X-ray absorption needs to be accounted for …

Column of moderate-\(\zeta\) gas \(\rightarrow\) curvature from Fe L edge (0.7 keV) up to Fe K-band, difficult to distinguish from red wing of diskline (Kinkhabwala thesis 2003)
Example - NGC 3783

NGC 3783 - abs$^n$ line from ionized Fe
$N_H \sim 5 \times 10^{22}$ cm$^{-2}$, log $\xi \sim 2.9$

(Reeves et al 2004)
Example - NGC 3516

New high-column/$\xi$ zones found (Turner et al 2005)

$N_{\text{H}} \sim 2 \times 10^{22} \text{ cm}^{-2}$
$log \xi \sim 4.7$

$N_{\text{H}} \sim 3 \times 10^{23} \text{ cm}^{-2}$
$log \xi > 4.2$
covering $\sim 50%$

absorbers respond to continuum flux - explains spectral variability
Warm Absorbers - not just AGN “weather”

Inclusion of high-$\xi$/high-column absorption reduces implied broad red wing .....but how much?

Reeves et al 2004

Turner et al 2002

NGC 3516

broad residual explained by reflection & complex absorption

Room for a diskline but no compelling evidence...!

NGC 3783 - broad base consistent w/ Compton shoulder from absorber

No need for diskline here!
... may not “work” for all sources...

*MCG-6-30-15 500 ks HETG, Young et al 2005*

Strong features ~6.5 keV, not always observed - e.g. *MCG-6-30-15* - if abs^n “hidden” in line flux then there must be broad line there anyway
Another absorption ambiguity

NGC 5506 & Mkn 766 show absorption features at 7.3, 7.6 keV - hard to identify

H-like & He-like Fe absorption lines at \( v \sim 0.1 \) c, disk wind?

But same in NGC 5506 - seems unlikely both AGN have wind of same \( v \)
Con-X Improvement over HETG for narrow features

Con-X $\times \sim 300$ area improvement over HEG (summed 1st-order) Spectral resolution improves $\sim$ order of magnitude at Fe-K (40 eV $\rightarrow$ 4 eV)!

Goals:
Identify absorption lines $\rightarrow$ separate layers of absorption $\rightarrow$ track response to continuum flux thus get broad diskline right

Track wind acceleration/deceleration
- launch radii
- mass outflow etc
NGC 5506 Con-X simulations

$F_{2-10} \sim 7 \times 10^{-11}$ erg cm$^{-2}$s$^{-1}$

$V_{\text{turb}} = 200$ km/s 1 ks Con-X

$V_{\text{turb}} = 1000$ km/s 2 ks Con-X

Track lines on $\sim$ksec timescales for brightest AGN

Model has $N_H = 4 \times 10^{22}$ log $\xi = 3.4$ vel $\sim 0.1c$
Continuum & Broad Line Emission & Variability

Once we separate absorption components from emission - can understand spectral variability

Mkn766: lowest flux dominated by ‘cold’ reflection with strong absorption

High flux dominated by PL & ionized Fe line emission while absorber obviously more ionized

He-like Fe emission correlated with continuum down to 10 ks (at least)

Line goes to zero before continuum - continuum from cold reflector
He-like Fe emission correlated with continuum.

Neutral Fe line not correlated with continuum.

Line/flux correlation in Mkn 766.

He-like Fe emission originates in disk $\sim 150 r_g$. 

Mkn 766 - Miller et al 2006
In Mkn 766, can diagnose disk from line variations seen when source flux is high ie during 2001 and part of 2005 dataset.
Con-X improvement over EPIC for broad Fe K features

~ x10 gain in effective area over pn in Fe-K band

For targets as faint as Mkn 766 ($F_{2-10} \sim 1 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$)
Con-X will allow us to probe diskline/continuum down to 2-3 ks (probing 1-1.5 $\times 10^7$ cm, $t_{\text{orb}}$ at 6-8 $R_g$)

For brighter sources like 5506 probe down to ~ 1 ks, $t_{\text{orb}}$ at 6 $R_g$

Con-X probes critical scales, may allow direct distinction between Schwarzschild / Kerr metrics!
Other probes of inner disk

Narrow Fe lines, shifted from rest-energy (Doppler/GR)

Rapid (tens of ks) flux/energy variability - must be diagnostics of gas very close to BH

First found NGC 3516 (Turner et al 2002) simult. XMM /Chandra - suggested to be emission from disk hotspots integrated over partial orbits at tens-hundreds of $r_g$
Narrow ‘shifted’ lines a common phenomenon!

> dozen reported, inferred origins few tens - hundreds of \( r_g \) strengthening link to disk

Large EWS a problem ??
Selection effect - currently only sensitive to large EW lines
**Time to rethink the uniformity of the disk!!**

However, the fact EWs **can be** so large likely telling us we need to review idea that the disk has simple emissivity profile

Possible uneven illumination - X-rays can be produced in intense localized flares on disk, leading to a high EW from spots

Or lines may arise in
- areas of enhanced density in disk
- regions of warped geometry

Con-X will allow us to track rapid energy changes of narrow disk lines
- derive emitting radii
- BH mass limits
- reverberation mapping from line/continuum lags /disk tomography
Summary

Absorber/reflectors *details* give working model for Seyfert spectral variability featuring:
- changes in relative levels of cold reflection / PL / ionized disk
  combined with the flux-linked absorption effects

- *diagnose* disk from ionized line variations

Need Con-X to get to the fundamental physics
Disk interpretations supported by possible periodicity in these lines

Periodicity in flux suggested Iwasawa et al (2004) for April data from NGC 3516

Line energy varies as expected from orbital Doppler shifts in Mkn 766 (Turner et al 2006)