Key Results in X-ray Spectroscopy of AGN

Jane Turner

UMBC
AN HONORS UNIVERSITY IN MARYLAND

What are we hoping to get from AGN studies?

Ultimately we hope to understand something fundamental:

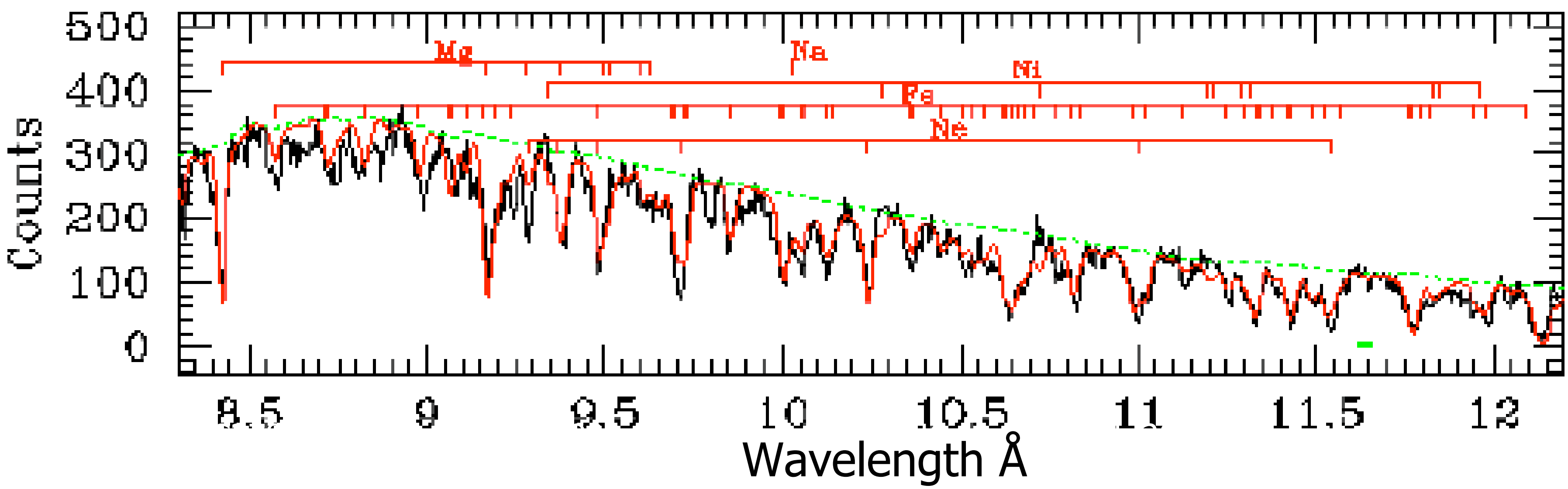
- black hole accretion/fueling (and hence growth, evolution, structure formation) *WA*

- physics in the strong gravity regime *Fe Kα*

Strengths of Chandra/XMM for AGN studies

LETG ~ 240 km/s at 0.2 keV
MEG ~ 280 km/s at 0.5 keV
HEG ~ 1850 km/s at 6.5 keV
RGS ~ 290 km/s at 0.3 keV

} Determine kinematics & physical state of circumnuclear gas

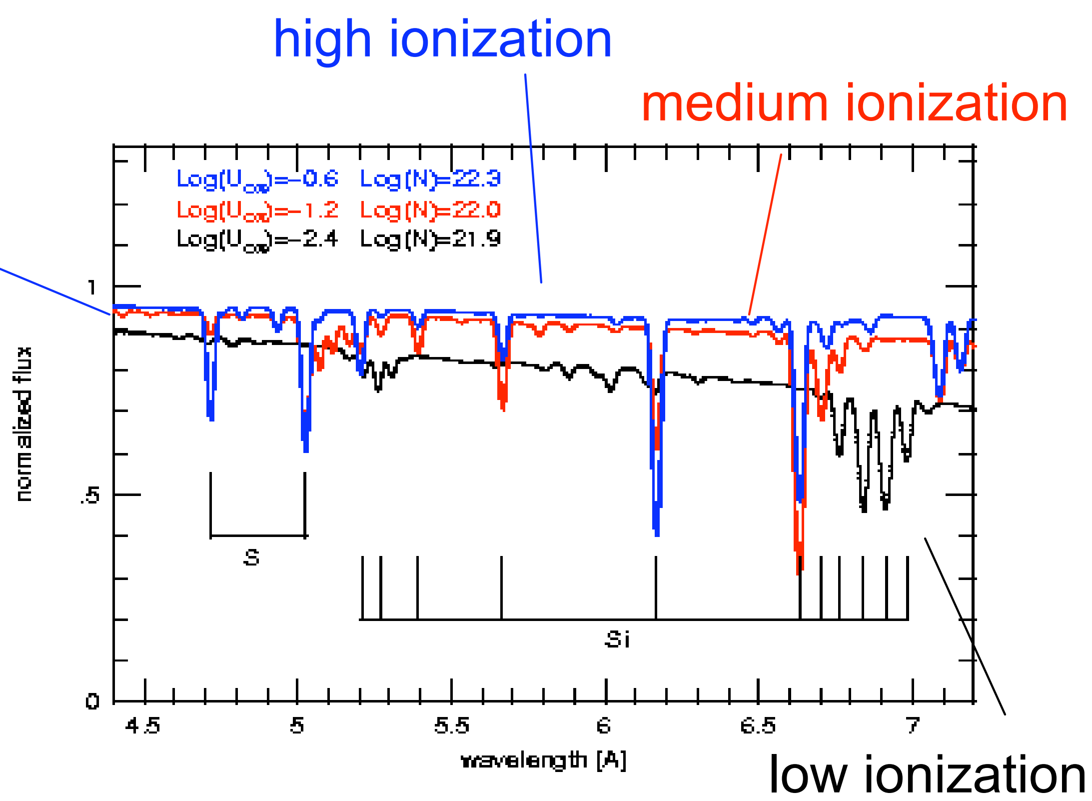


NGC3783 Chandra HETGS 900 ks, Krongold et al. 2003

Multiple Zones of Ionized Gas in Seyferts

e.g. NGC 3783
~100 absn lines detected
(Kaspi et al 2001, 2002; Netzer et al 2003)

NGC 5548 (Steenbrugge et al 2003) 3 layers cover 3 orders of magnitude in ξ



Signatures range from UTA of M-shell Fe ~ 16 Å (e.g. Sako et al 2001; Behar et al 2001) to absorption by H-like Fe (e.g. Reeves et al 2004)

X-ray "Warm" Absorbers

Blustin et al (2005) - collate results from 23 grating observations:

WA in ~90% of sample
global covering fraction for X-ray absorbers

Mostly evident as He-like & H-like absorption lines
unresolved
bulk velocity typically hundreds km/s outflow w.r.t. systemic

WA volume filling factors~ 10%
rest of volume could be gas phases not evident in soft X-ray band

No consensus on acceleration mechanism
e.g. radiative accel^{n} predicts more highly ionized gas would have higher velocity -- but no clear vel/ξ correl^{n} found

X-ray Absorbers

Blustin et al (2005) argue (assuming $vel_{outflow}$ > escape vel) WAs are mostly outflows from the torus
--(but results based only on soft-band abs^n & also subject to assumptions- see Yaqoob, McKernan & Reynolds 2006)

Need n_e estimate (from He-like triplets) or detection of photoionization variability to reliably estimate location of emitting/ absorbing gas

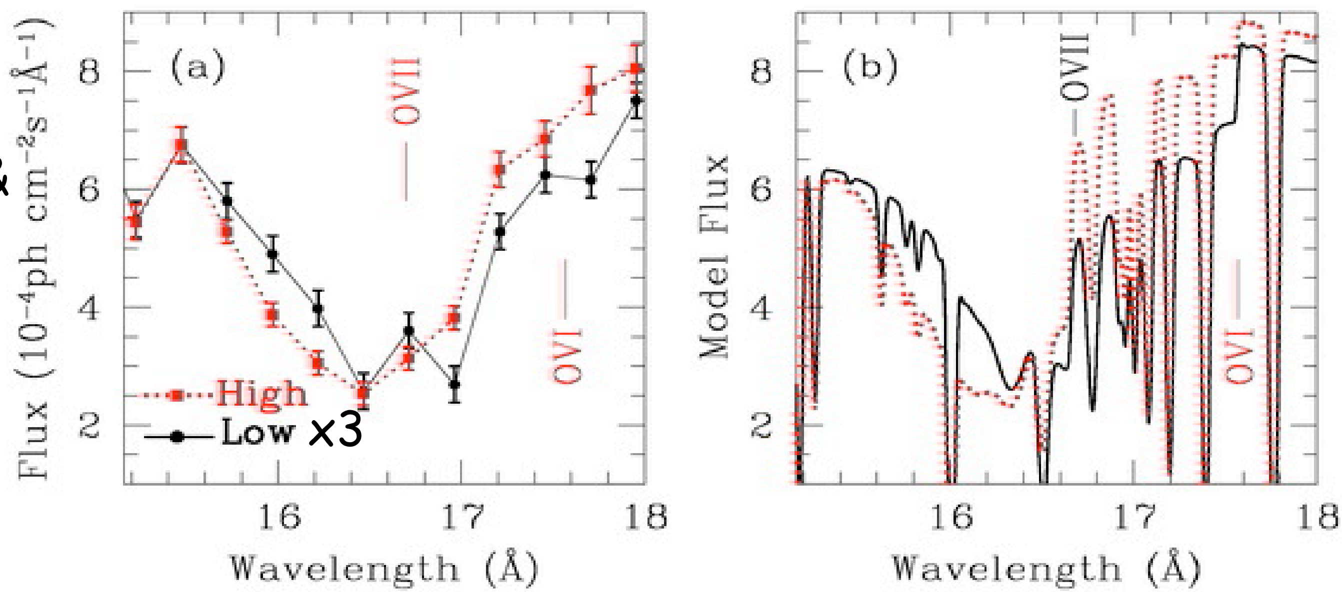
$$\xi = \frac{L}{nR^2}$$

Var -> 'ionization time' & 'recombination time' - yield n_e indep of ξ , thus give R
e.g. Nicastro et al 1999, found for NGC 4051 $n_e = 10^8$ cm^{-3} R = 7.4×10^{15} cm
(few lt-days, ie lies within torus)

Really need long grating observations like that of NGC 3783 to get temporal baseline & S/N for this type of determination…

NGC 3783 UTA Variability

Var^n in UTA opacity & change in O VI K edge in 31 days
-> n ~ 1×10^4 cm^{-3}
R < 6 pc



HETGS/NGC 3783 - Krongold et al 2005

If gas structure had continuous radial range of ionization parameters, variability effects would be washed out by average abs^n in flow (equal amounts of material change from i → i+1 as from i-1 → i) thus Krongold et al conclude the absorber in NGC 3783 has heavily clumped gas

WA is **not** the Kpc-scale cones observed in Sy 2 (e.g. Kinkhabwala 2002)

X-ray Absorbers

More overall conclusions from (Blustin et al 2005) -

Mass loss (assuming spherical outflow) = $\Omega n R^2 m_p v$ ~ accretion rate
- AGN may return up to 10^8 solar masses to host

Typically ~1% of spheroid mass returned to host

-Spiral galaxies have hot gas component ~ 10^{-4} of the bulge mass (e.g. Page et al 2003)
-AGN outflow is a significant (likely dominant) contribution to hot ISM in galaxy spheroids
-Especially since it seems unlikely to escape to IGM, e.g. Crenshaw et al 2000

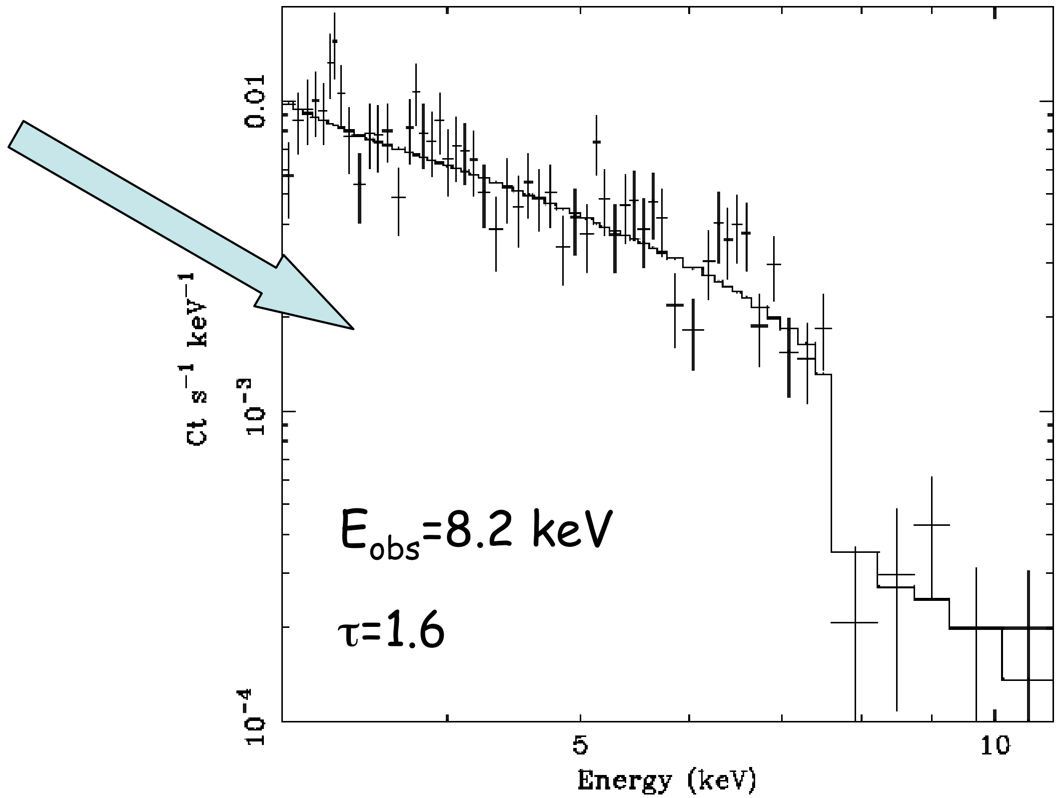
Perhaps related to why AGN tend to show recent burst of star formation (Kauffman et al 2003)

A nice illustration of how WAs can be used to probe key questions in galaxy/BH evolution

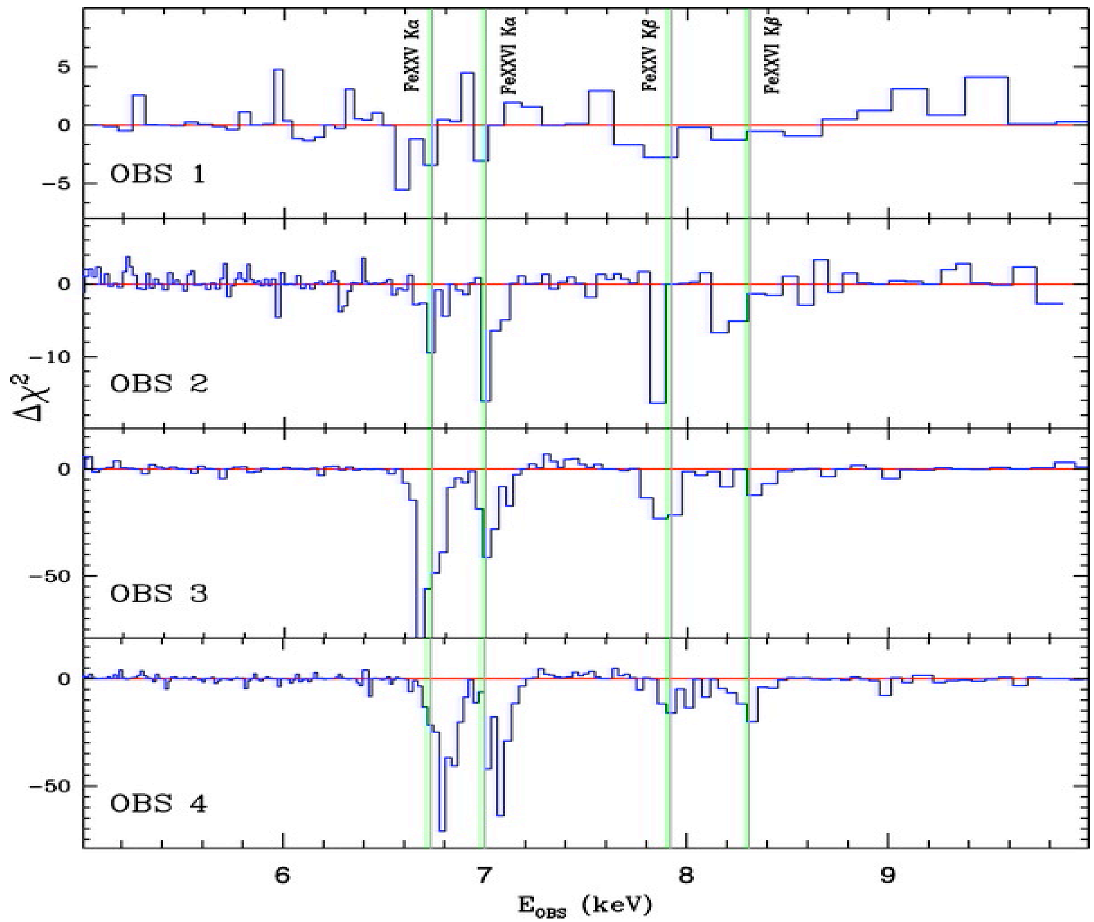
Evidence for highly-ionized zones…

Some sources also show hard-band abs^n from ionized Fe, $N_H > 10^{23}$ cm^{-2} (first noted by Nandra & Pounds 1994, det^n of K edges from ionized Fe in *Ginga* spectra)

Recent examples: IRAS13224,
Boller et al 2003;
1H 0707-495 Fabian et al 2004



Some of these respond quickly to ionizing continuum - must be closer to BH than torus!!!



NGC 1365 shows Fe Kα, Kβ abs^n lines from Fe XXV & Fe XXVI in N_H~ 5 x 10^{23} cm^{-2}

Variable velocity across ~yr 1000-5000 km/s

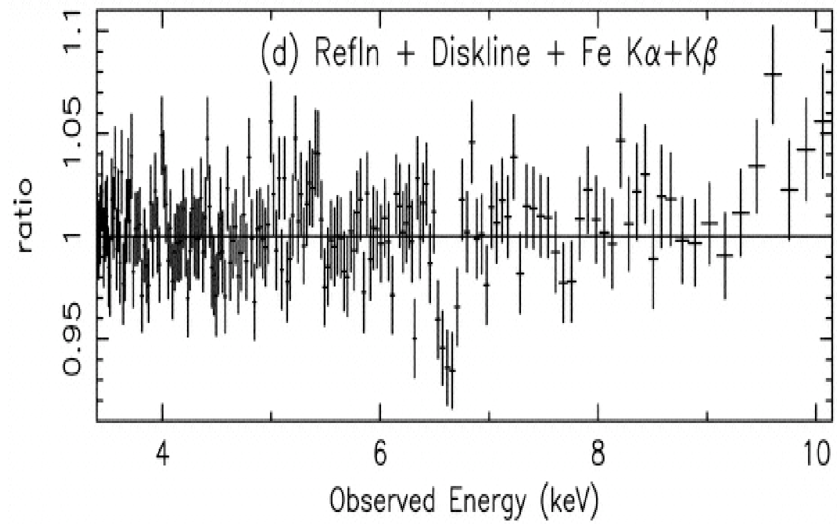
R ~50-100 R_s

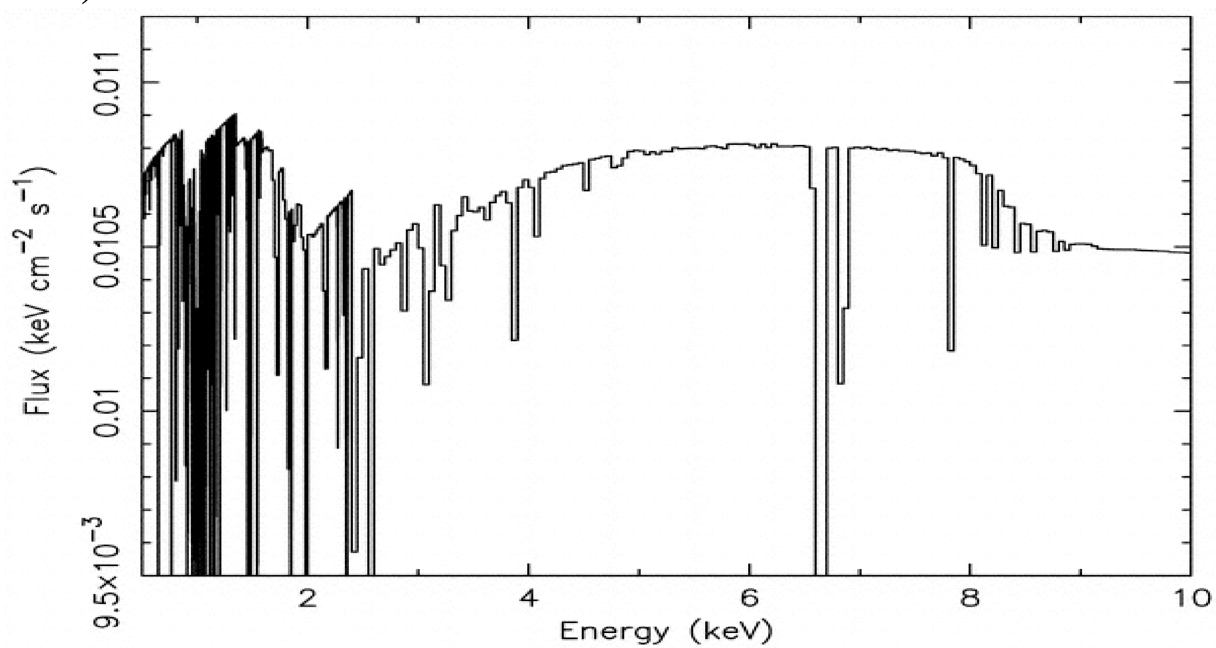
NGC 1365 - Risaliti et al 2005, also poster by Elvis et al

NGC 3783

NGC 3783 - abs^n line from ionized Fe, depth varies within 100,000 s

$R < 2 \times 10^{17}$ cm (0.1 pc, lt-month)





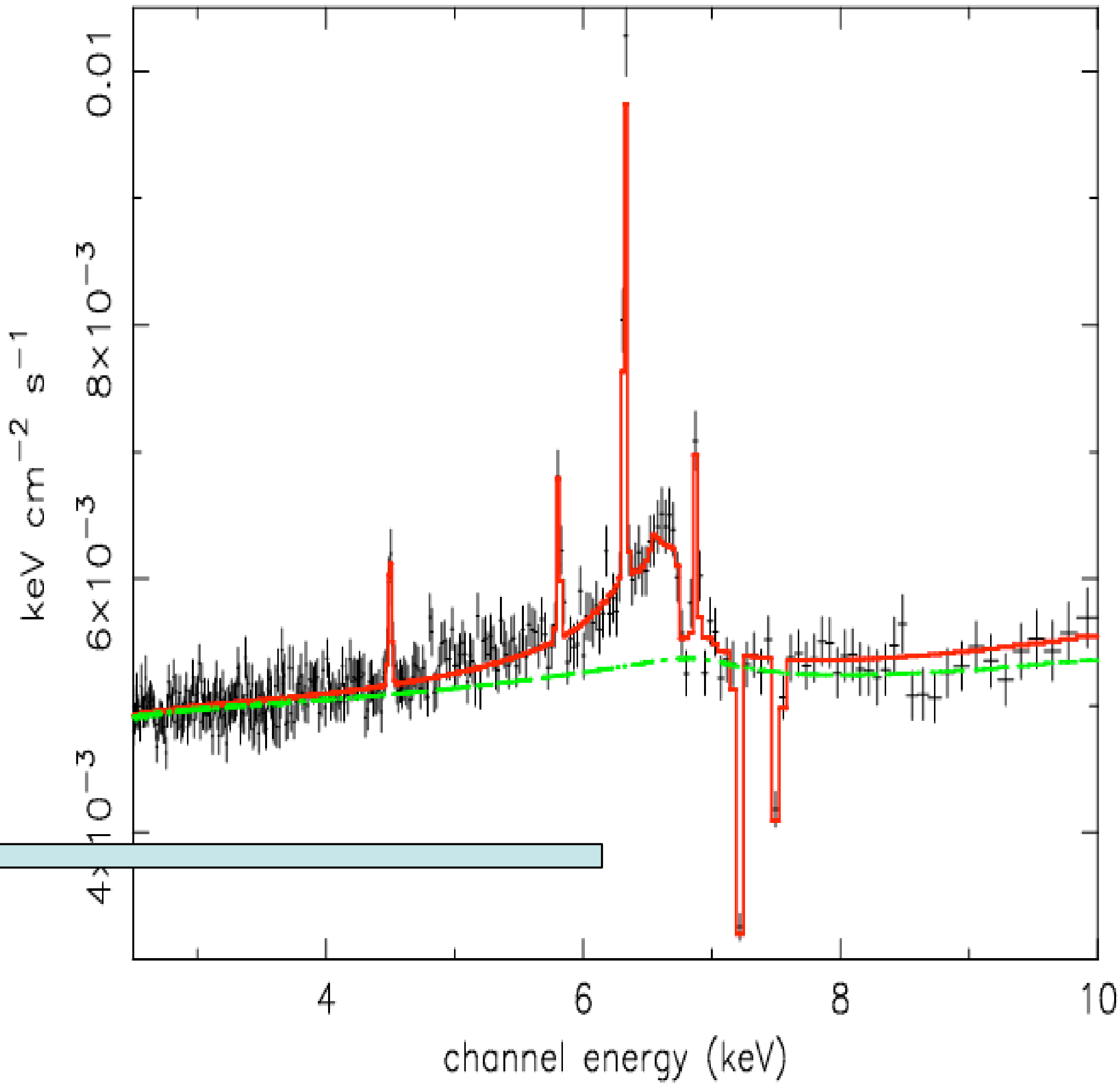
(Reeves et al 2004)

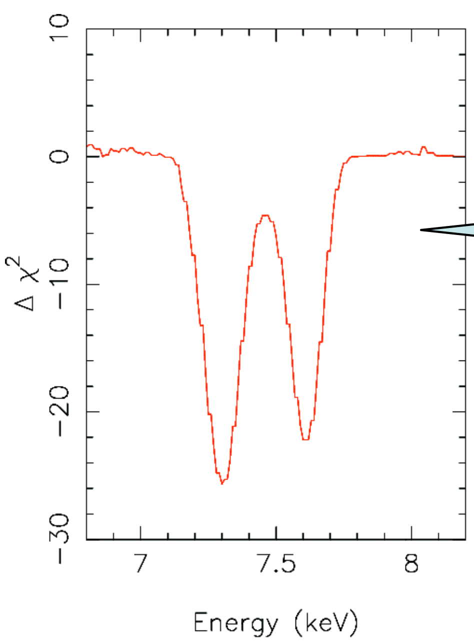
Also see poster by Markowictz on IC 4329A

Some abs^{n} appears in gas with relativistic velocities -

New high velocity absorber - Mkn 766

H-like & He-like Fe abs^{n} lines at v ~0.1 c , **disk wind?**





…see talks by Reeves and Gallagher later today

More highly-ionized zones…..NGC 3516

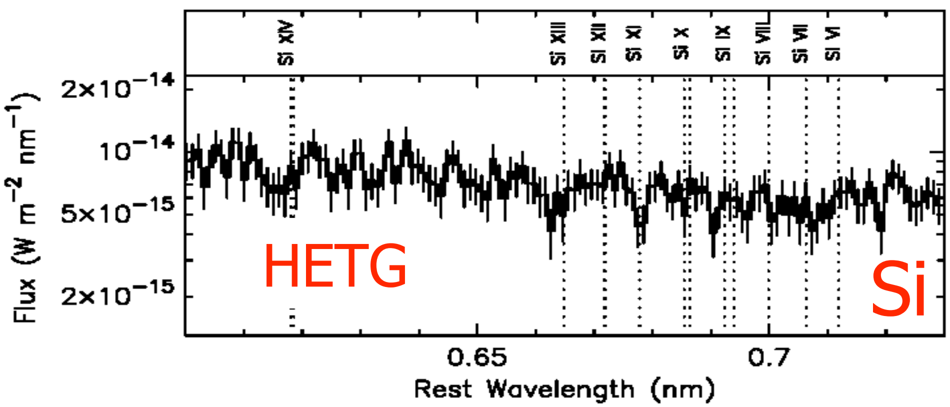
Two additional zones found (Turner et al 2005)

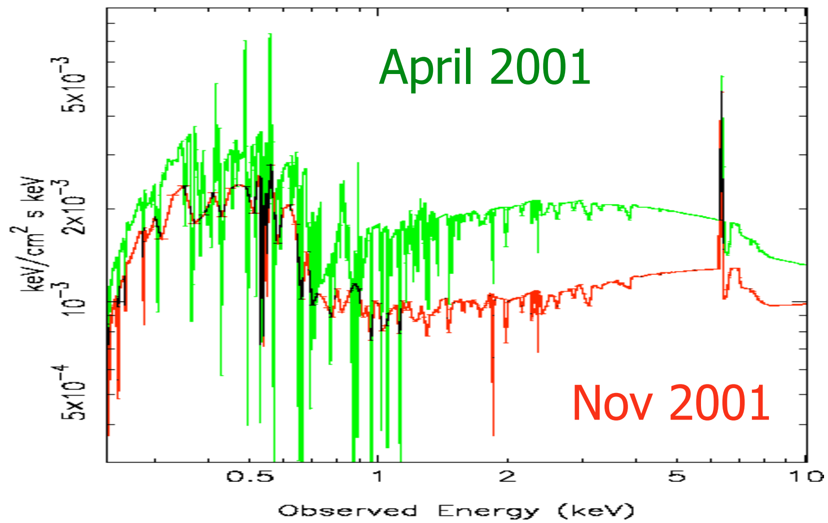
$N_{H\text{-}hi} \sim 1.6 \times 10^{22}\ cm^{-2}$, U=50
vel=-1100 km/s

$N_{H\text{-}UV} \sim 8 \times 10^{21}\ cm^{-2}$, U=0.2

UV-X absorber responds to continuum flux (Netzer 2002)

$N_H \sim 3 \times 10^{23}\ cm^{-2}$, U> 15 cov ~50%

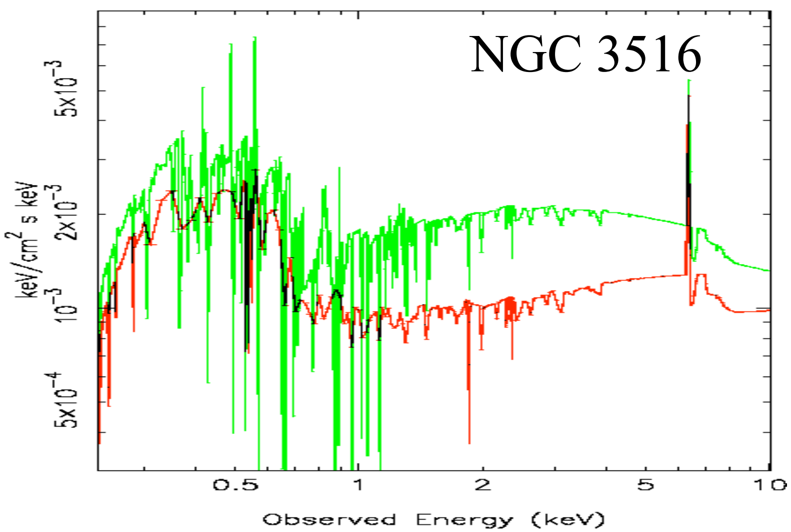




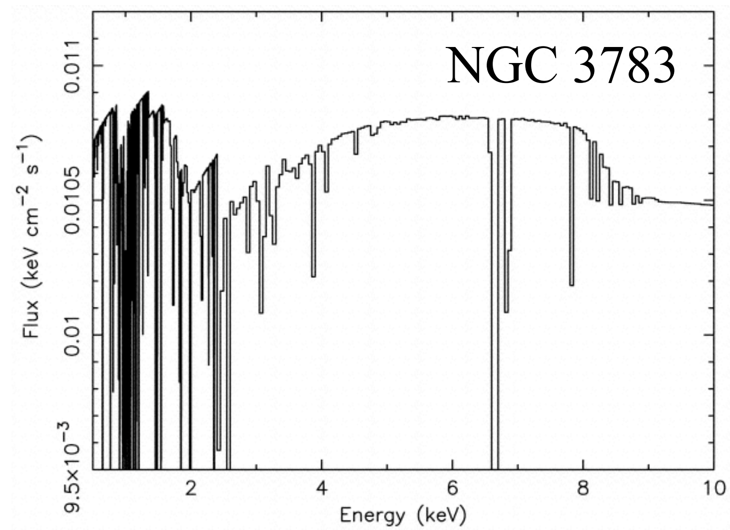
3+ layers, responding to continuum flux - explains much of observed spectral variability

Warm Absorbers - not just AGN "weather"

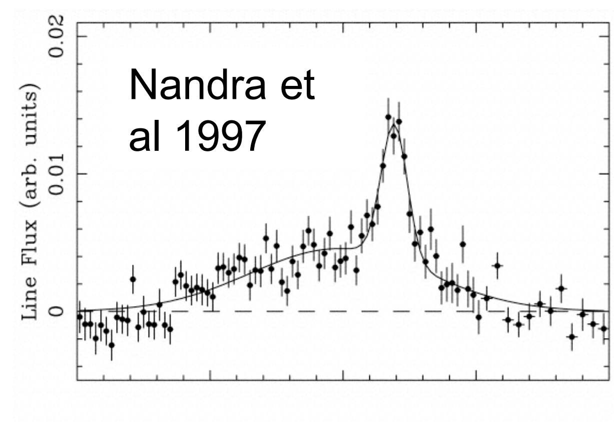
To understand Fe K profiles, X-ray abs^n needs to be accounted for …



Turner et al 2004



Reeves et al 2004



Inclusion of high-ξ/high column absorption reduces implied broad red wing (Kinkhabwala 2003)…..***but how much ?***

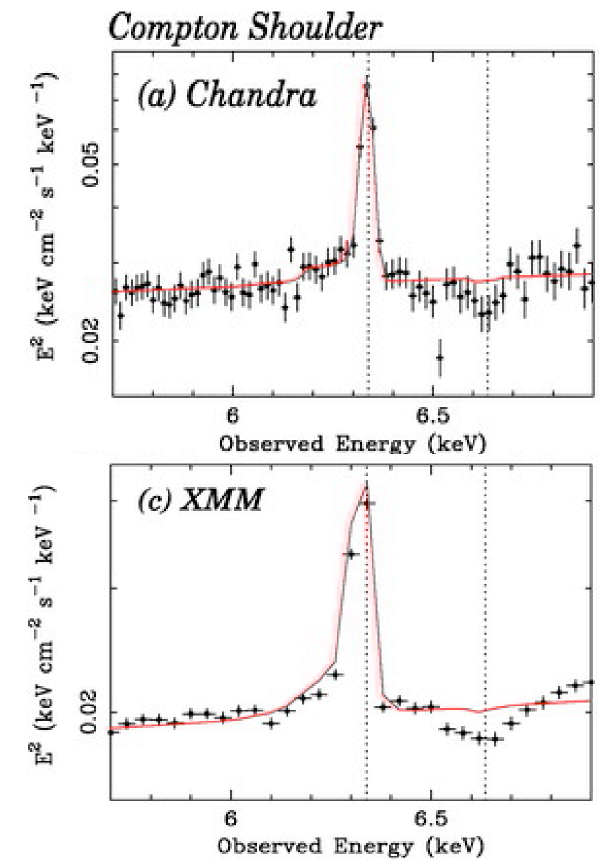
NGC 3783

Reeves et al 2004, Yaqoob et al 2005

Fe Ka core FWHM ~1700 km/s originating between BLR-NLR (Kaspi et al 2002)

Broad base consistent w/ Compton shoulder - scattering medium 7.5×10^{23} cm^{-2}

No need for diskline here!

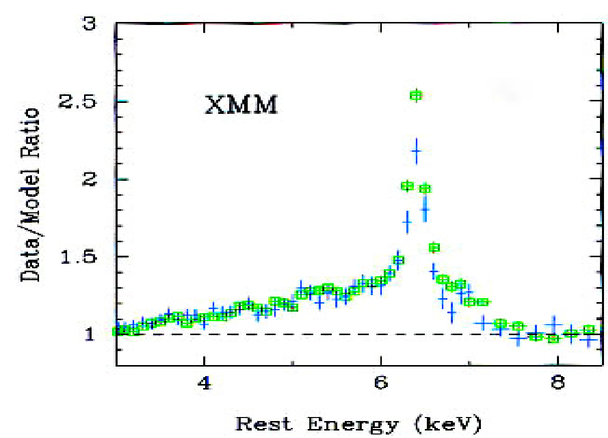


NGC 3516

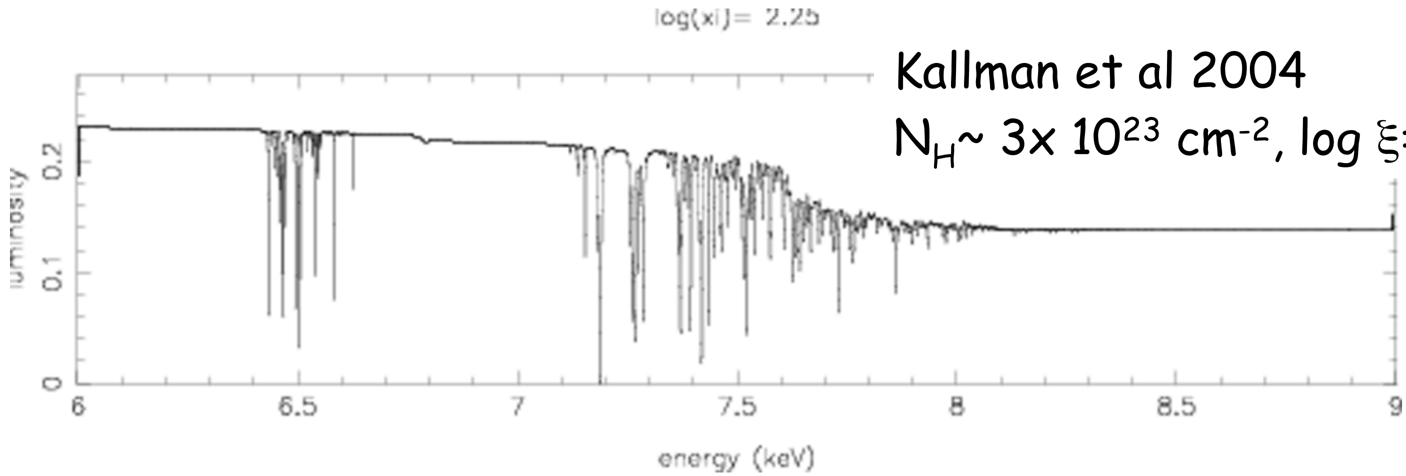
Turner et al 2002

Broad residual relative to PL mostly explained by reflection and complex absorption

Room for a diskline but no compelling evidence…!

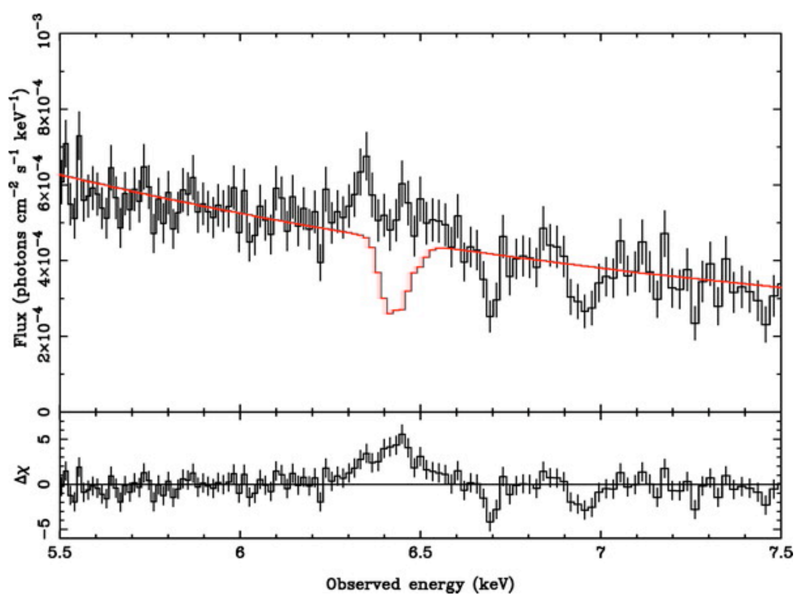


but, this does not “work” for all sources…



Kallman et al 2004

N_H~ 3x 10^{23} cm^{-2}, log ξ=2.25



Sometimes ‘abs^n solution’ predicts strong features ~6.5 keV, not always observed - see talk by Reynolds later for discussion of MCG-6-30-15

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

Other probes of the inner disk

XMM /Chandra revealed narrow Fe emission lines w/ sig. vel shifts & rapidly var flux/energy (e.g. NGC 3516 Turner et al 2002)

Common phenomenon (> dozen reported cases)

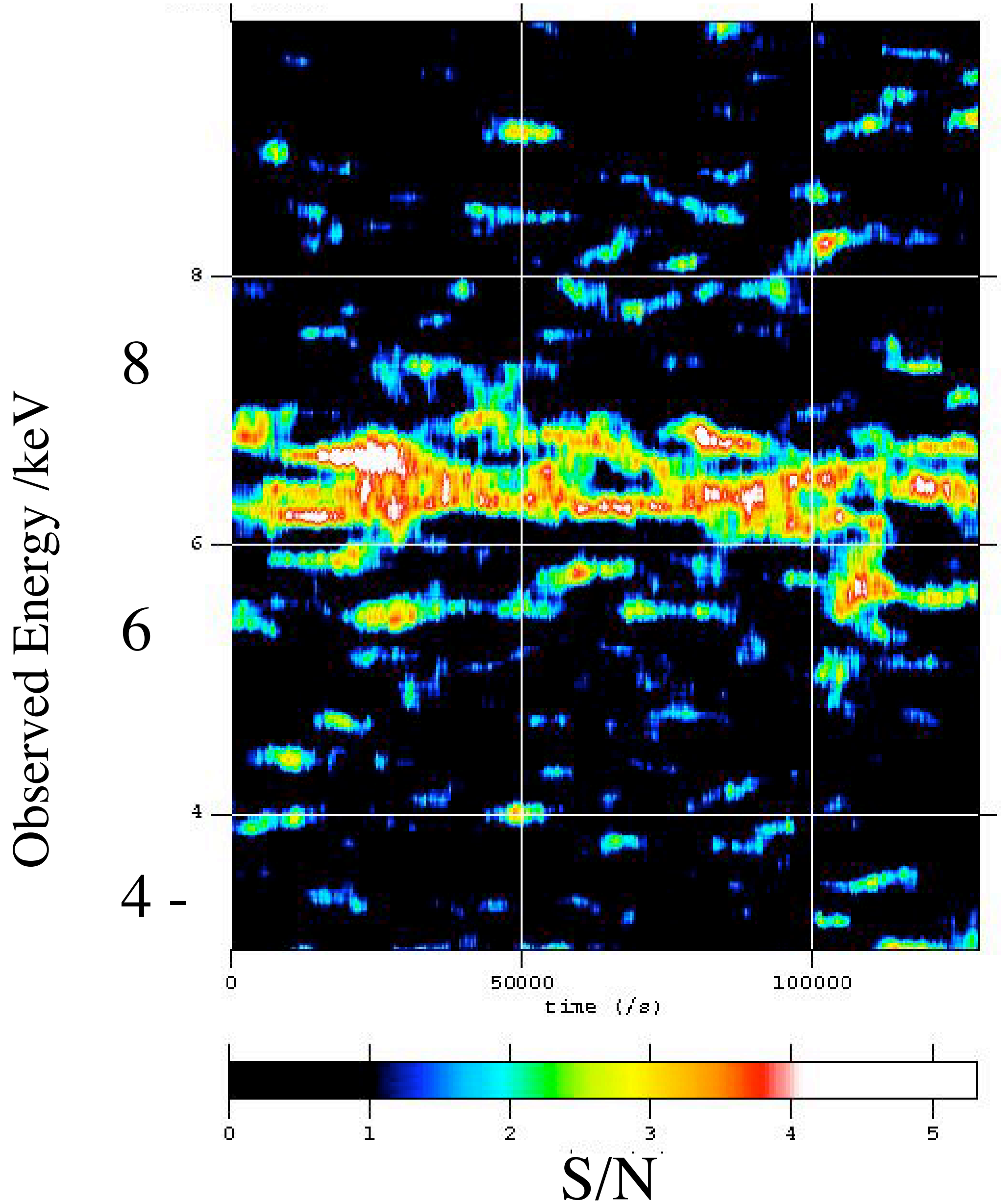
Rapid (tens of ks) flux/energy variability - these must be diagnostics of gas very close to the BH - from disk or wind

Mkn 766, intensity map in the energy-time plane

Exciting disk interpretations suggested based on possible periodicity in these lines

-NGC 3516 (Iwasawa et al 2004)

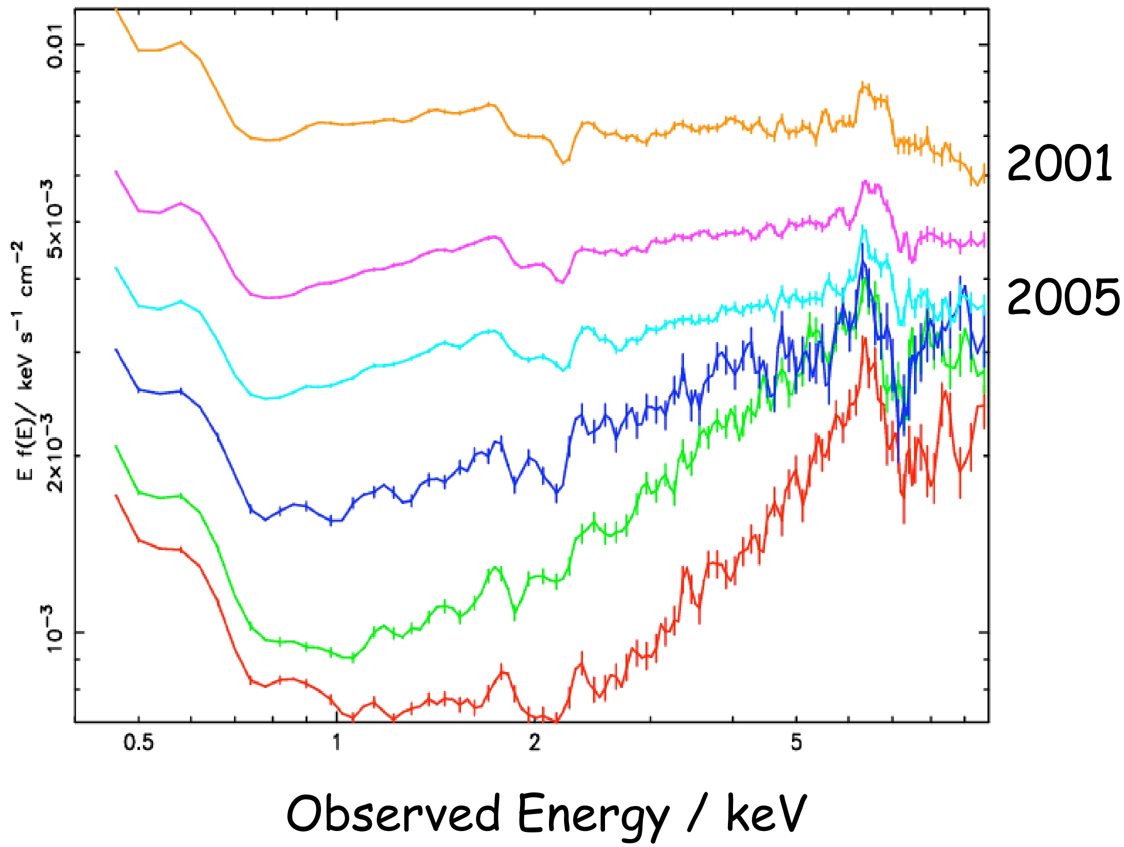
-Mkn 766 (Turner et al 2005)



XMM observed Mkn 766 for 500 ks, ~ June 2005

Flux selected spectra from XMM data 2000-2005, Miller et al 2005

At lowest flux spectrum dominated by 'cold' reflection - highest flux state dominated by PL



Many previous discussions of variable PL, const refl^n to explain spectral variability (e.g. Vaughan & Fabian 2004)

We find *additional complexity* as large column of ionized gas, logξ~4, 10^{23} cm^{-2}, responds to continuum

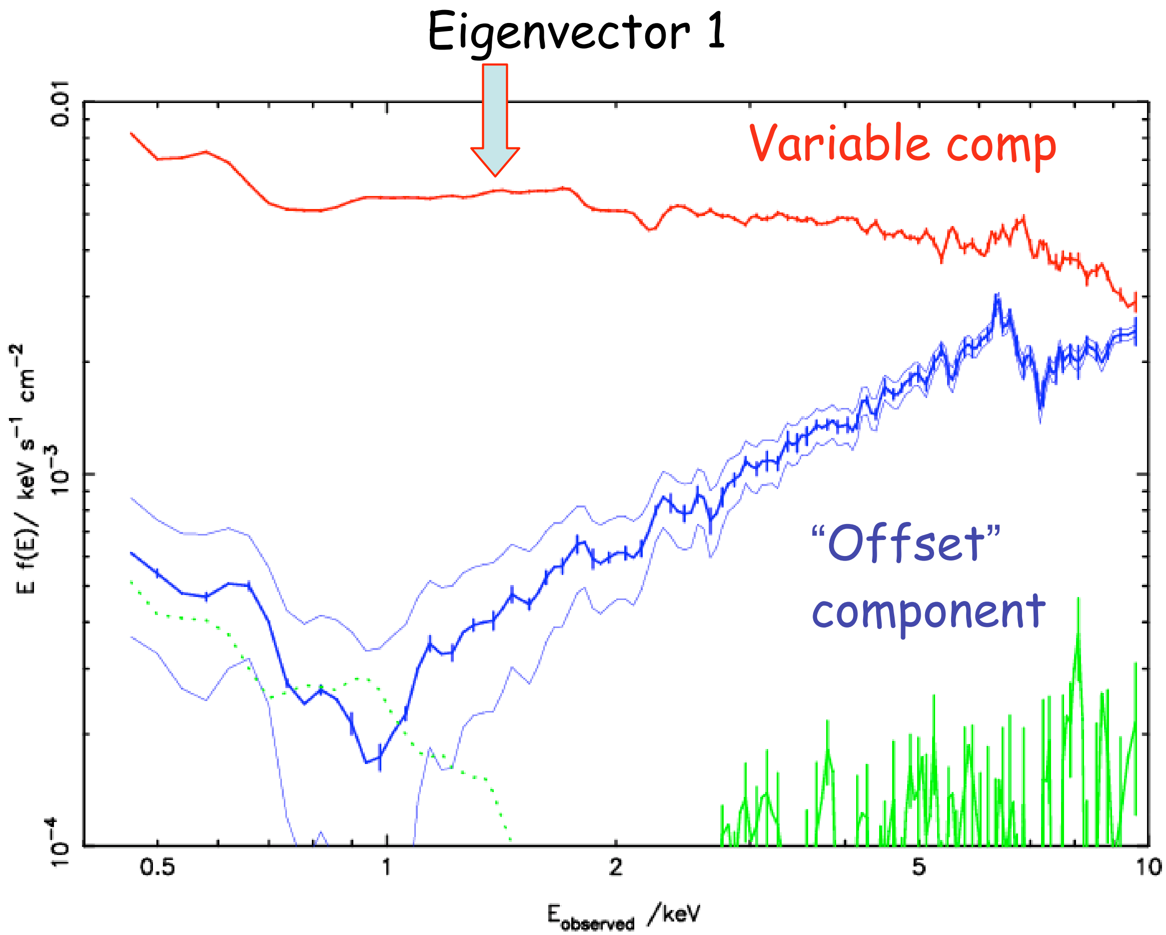
Shape of low spectrum ***combination*** of cold reflector w/ abs^n effects

Principal Component Analysis

PCA - decomposition of data into additive components to describe variance

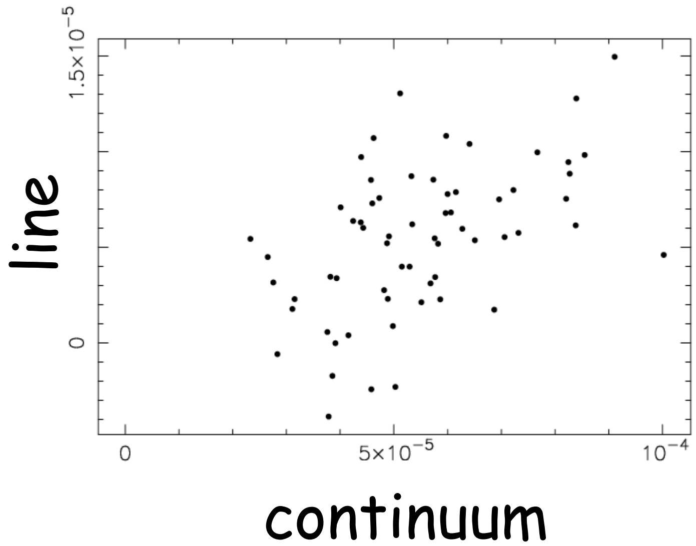
Prev. used on X-ray data by Vaughan & Fabian 2004, Mittaz, Penston & Snijder 1990

Miller et al 2005 achieve PCA with high energy resl^n by using singular value decomposition, this yields results not possible previously



Mkn766 shows cold reflector contribution const over ~week, visible only when PL is very low - *const not necessarily the same as "distant"....but we'll see.....*

Also - ionized Fe line emission ***varying with PL***



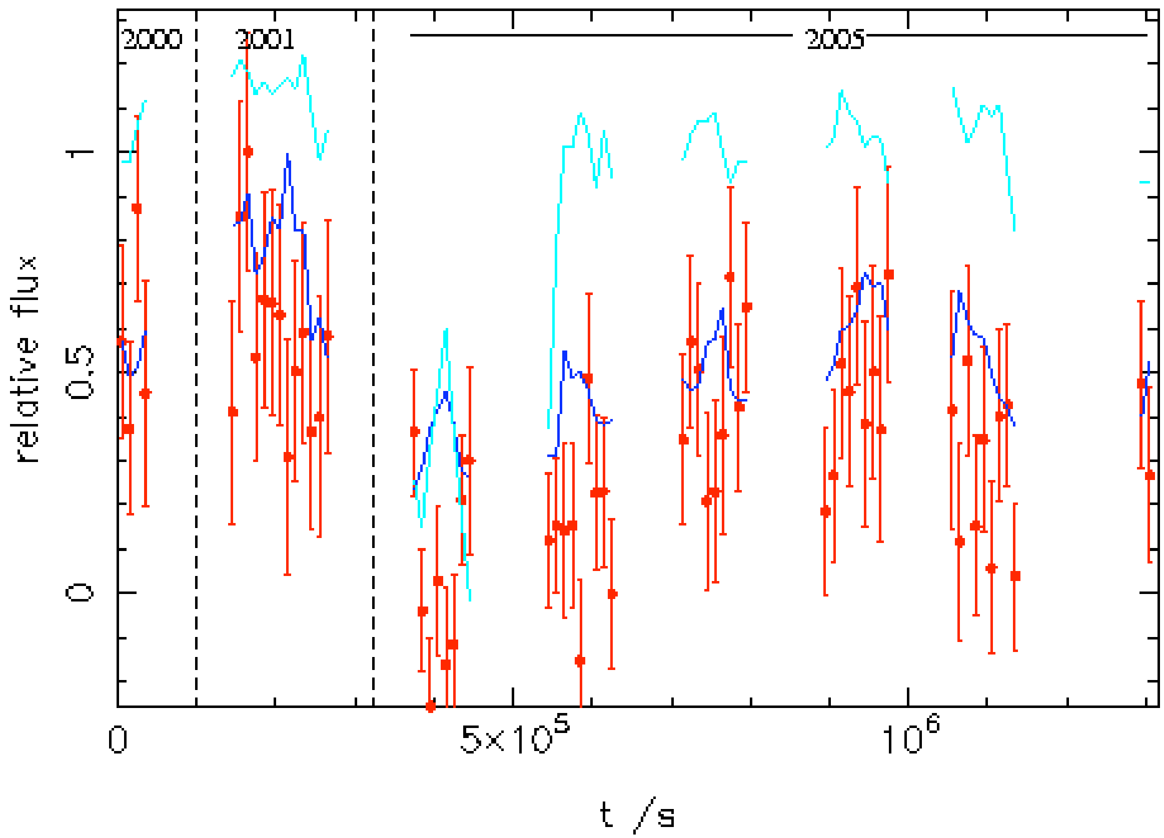
He-like Fe emission correlated w/ continuum down to 10 ks (at least) ***broad profile -> $r\sim150\ r_g$***

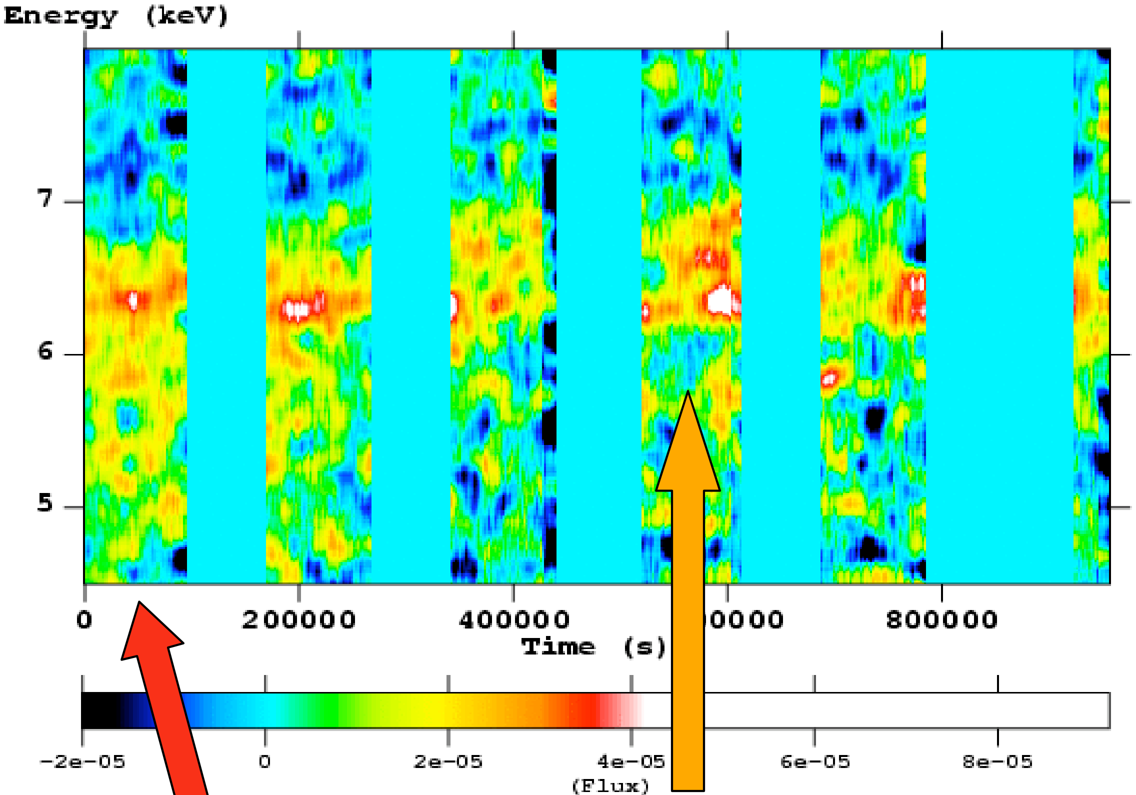
Line goes to zero before continuum

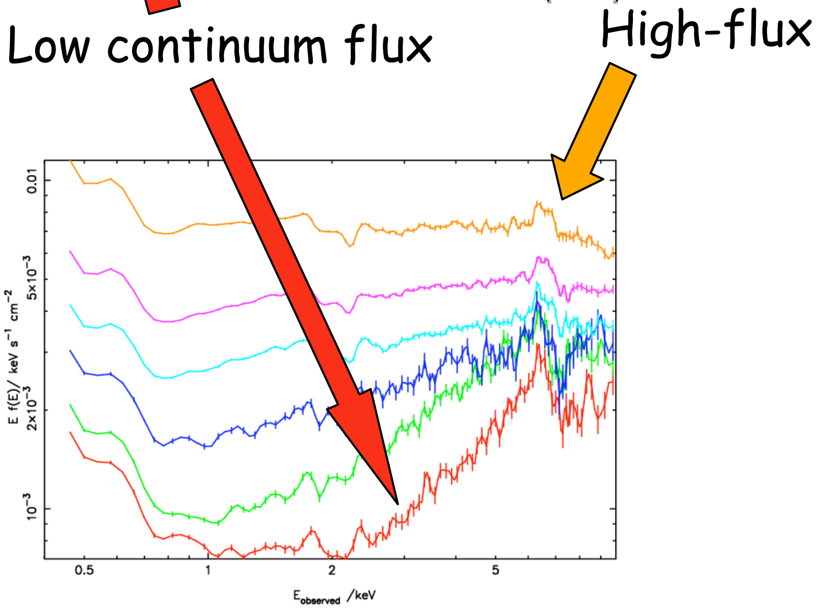
Offset may be due to cont^m contrib from distant cold reflector or abs^n of ionized Fe line in low state

Mkn 766
(Miller et al 2005)

α – energy index
Fe Ka flux
Continuum flux







Line/flux corrl^n ***-in Mkn 766 He-like Fe emission originates in disk***

(previously suggested by Pounds et al 2003)

When Mkn 766 in high-state ionized disk emission dominates

Can diagnose disk from ionized line variations when source flux is high ie during 2001 and part of 2005 dataset

Early indications are this works for some other sources (Miller et al 2005)

Summary

Absorption

Complex ionized layers of abs^n much more important than previously realized
- -absorbers respond to flux changes (across AGN population?)
- -partially responsible for observed spectral variability
- -outflows detected close to BH, some relativistic - disk winds?
- -outflow important in BH/host co-evolution?

Emission

Some ***but not all*** requirements for broad disk lines reduced/removed by inclusion of high-ξ/high-N_H gas

Observed high-steep/low-flat Seyfert spectra explained in many cases by changes in relative levels of cold reflection / PL combined with the flux-linked abs^n effects

PL plus (ionized?) disk features dominate during Seyfert high-states ?
- **- can *diagnose* disk from ionized line variations in this state**
- - underlying cold/distant reflector visible at low continuum flux

Long Chandra/XMM grating observations allow unprecedented insight into the broader AGN phenomenon and thus into fundamental questions in physics and cosmology