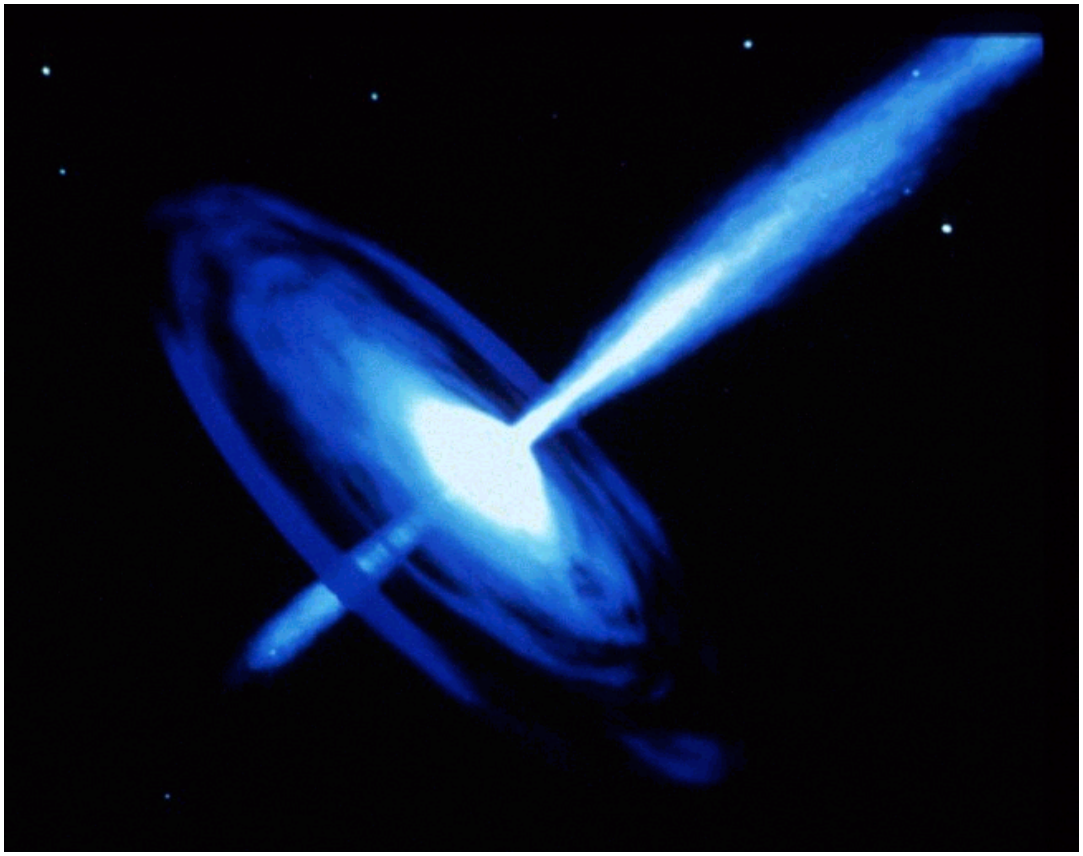
Outflows in AGN and implications for the broad iron line.



James Reeves,
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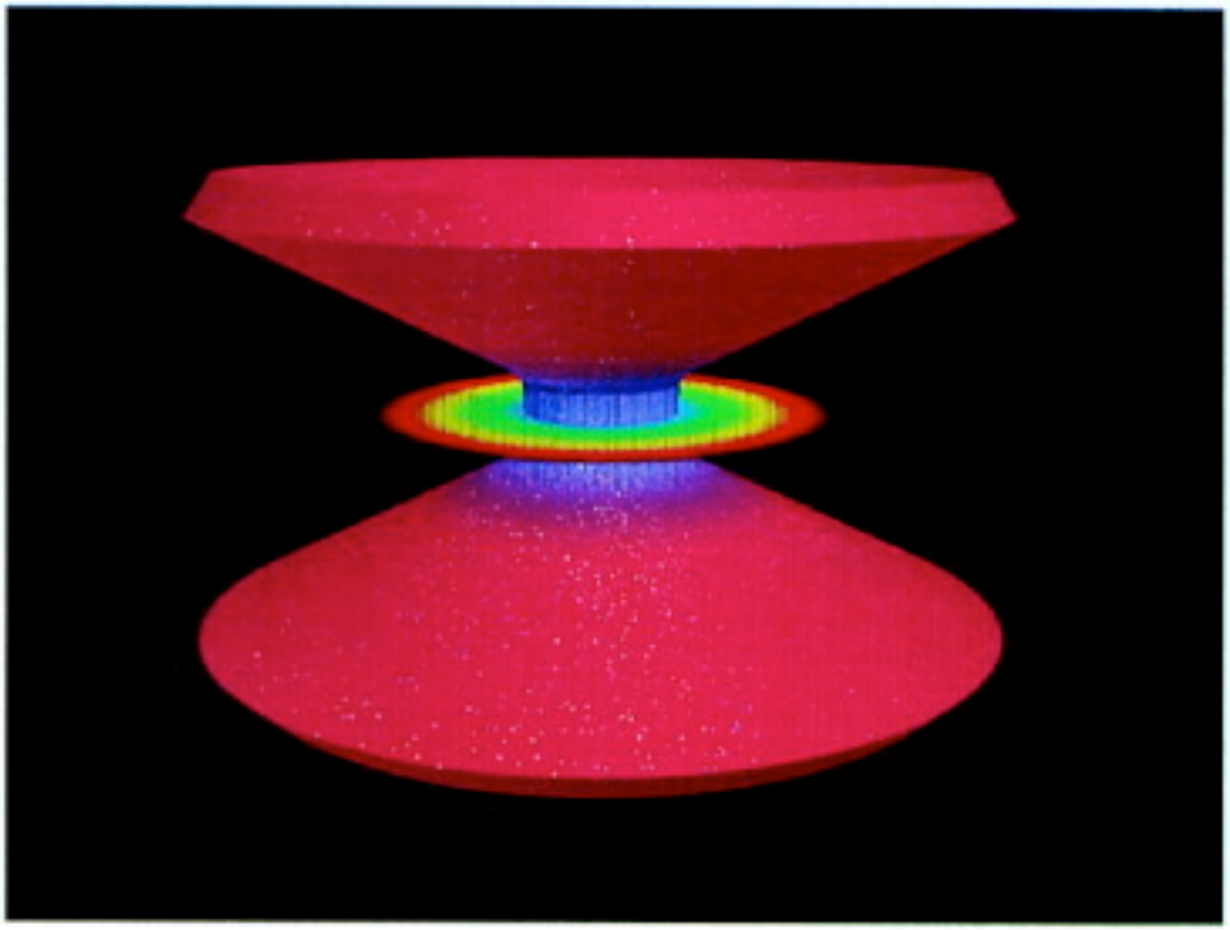
Collaborators:-

Ken Pounds (Leicester), Jane Turner, Ian George (UMBC/GSFC), Valentina Braito (JHU/GSFC), Delphine Porquet (MPE), Tahir Yaqoob (JHU/GSFC), Paul Nandra (ICL).

Outflows in AGN - how do they effect the iron line?



(Outflow Schematic; Elvis 2000)

Outflows (in the form of warm absorbers) are seen in the majority of AGN.

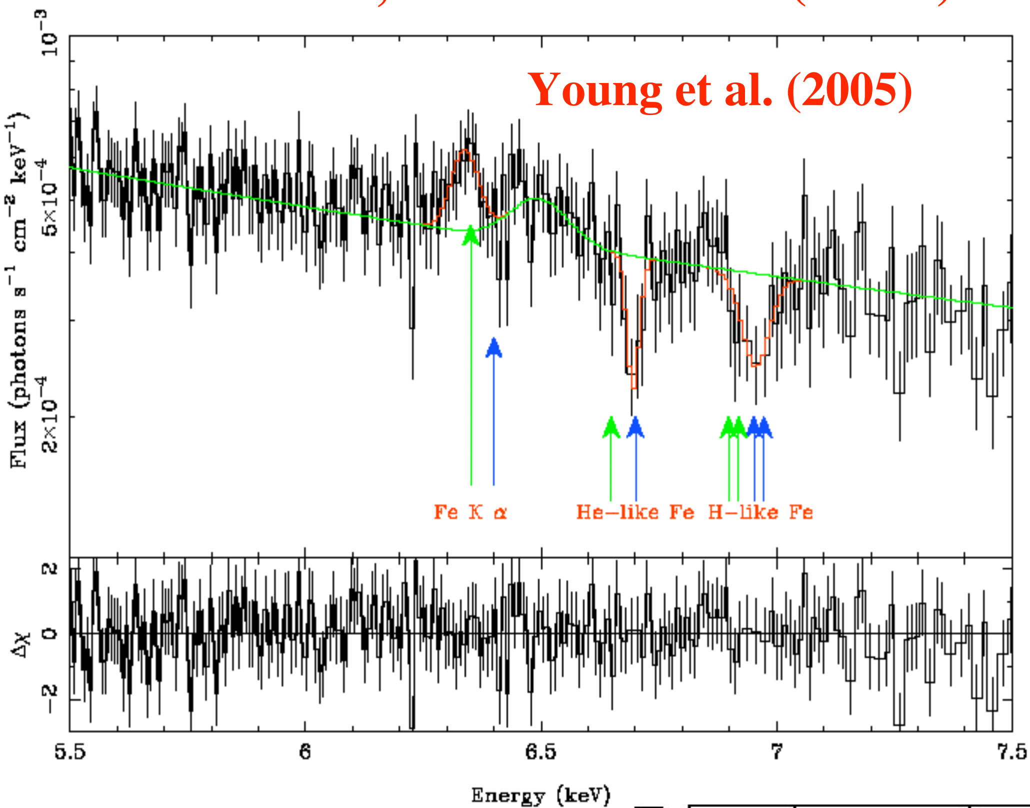
Typically velocities (in the UV and X-ray) from a few 100 km/s to a 1000 km/s, which could carry a few solar masses per year (out to pc scales).

Significant opacity from absorbers in X-ray band could effect broad line modeling.

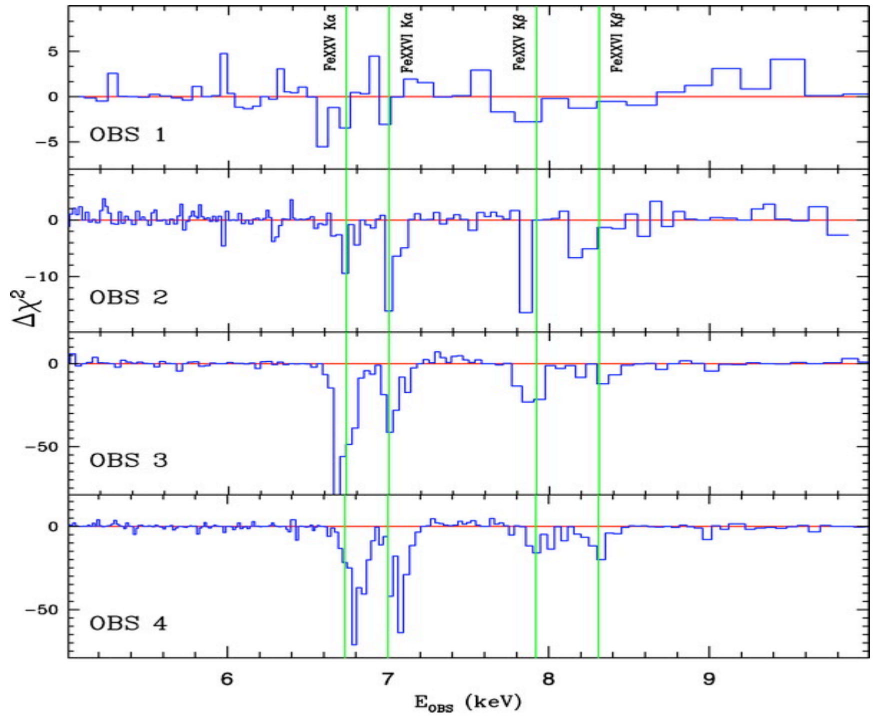
In some higher luminosity AGN (NLS1s, QSOs) strong Fe K absorption features are seen above 7 keV (high v outflows?)

Iron K-shell Absorption in Seyfert 1s.

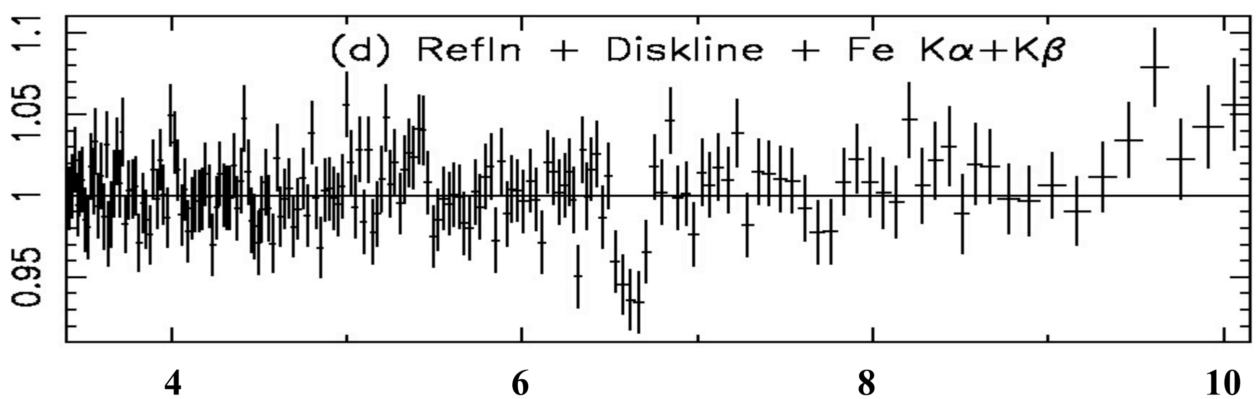
MCG-6-30-15, Chandra/HETG (500ks)



NGC 1365, XMM-Newton (Risaliti et al. 2005)

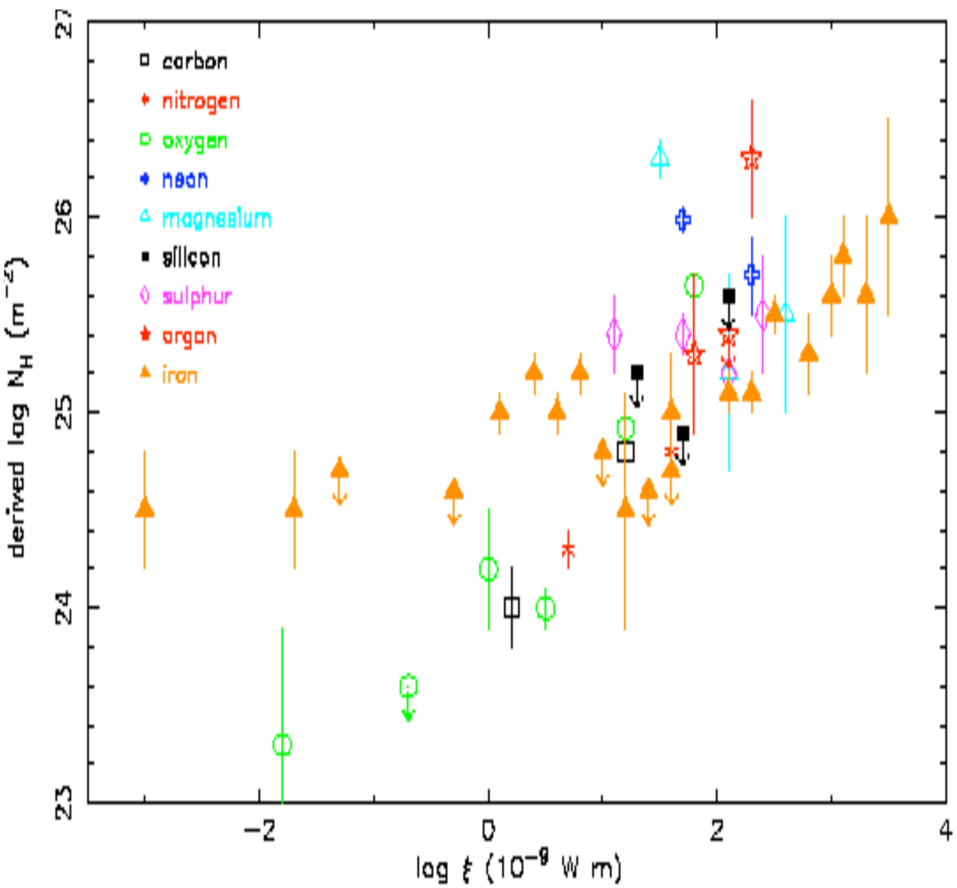


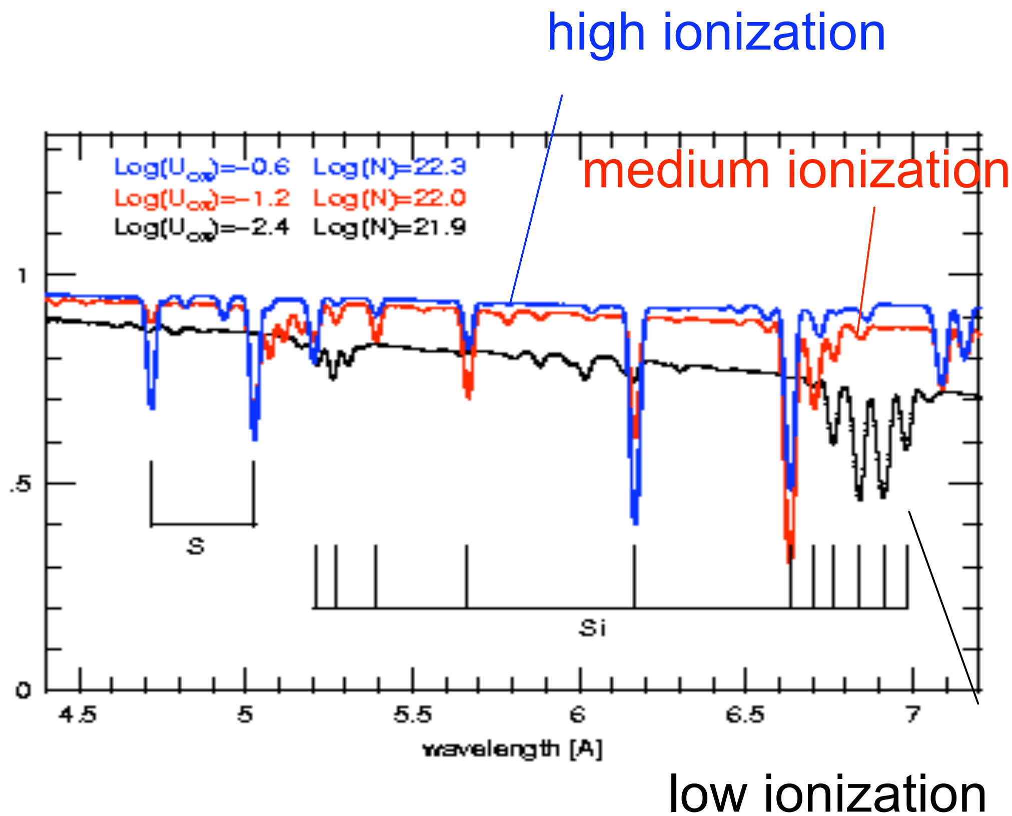
NGC 3783, XMM-Newton, Reeves et al. (2004)



Multiple zones of the Warm absorber

NGC 5548 (Steenbrugge et al 2003); NGC 3783 (Kaspi et al 2001; Netzer et al 2003)

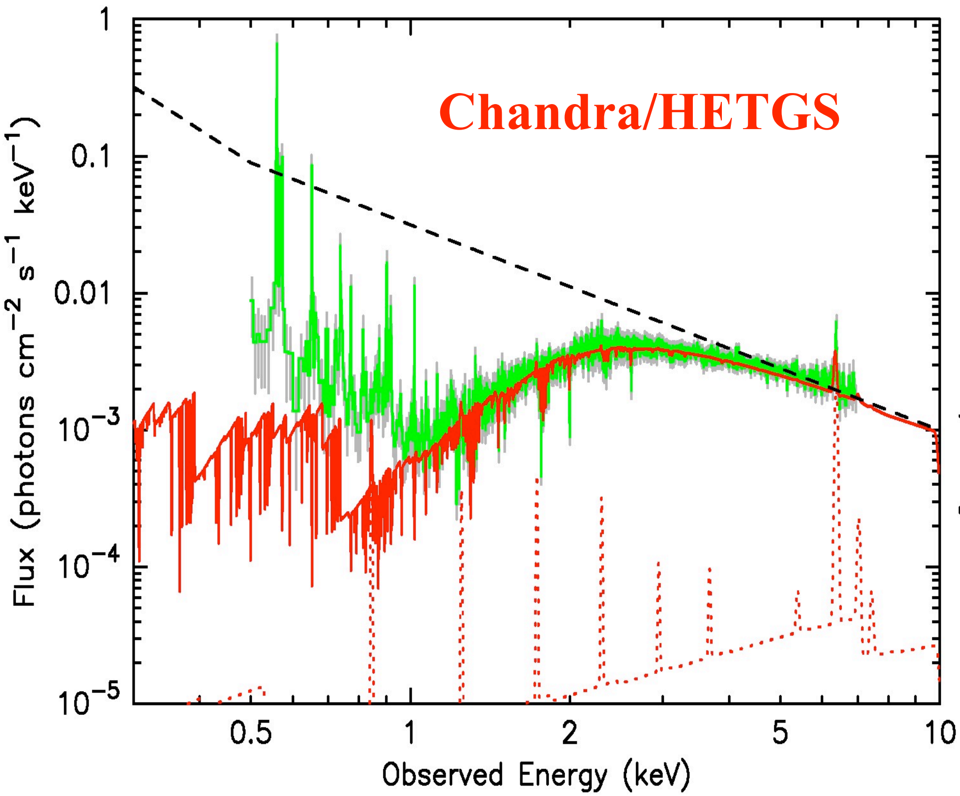




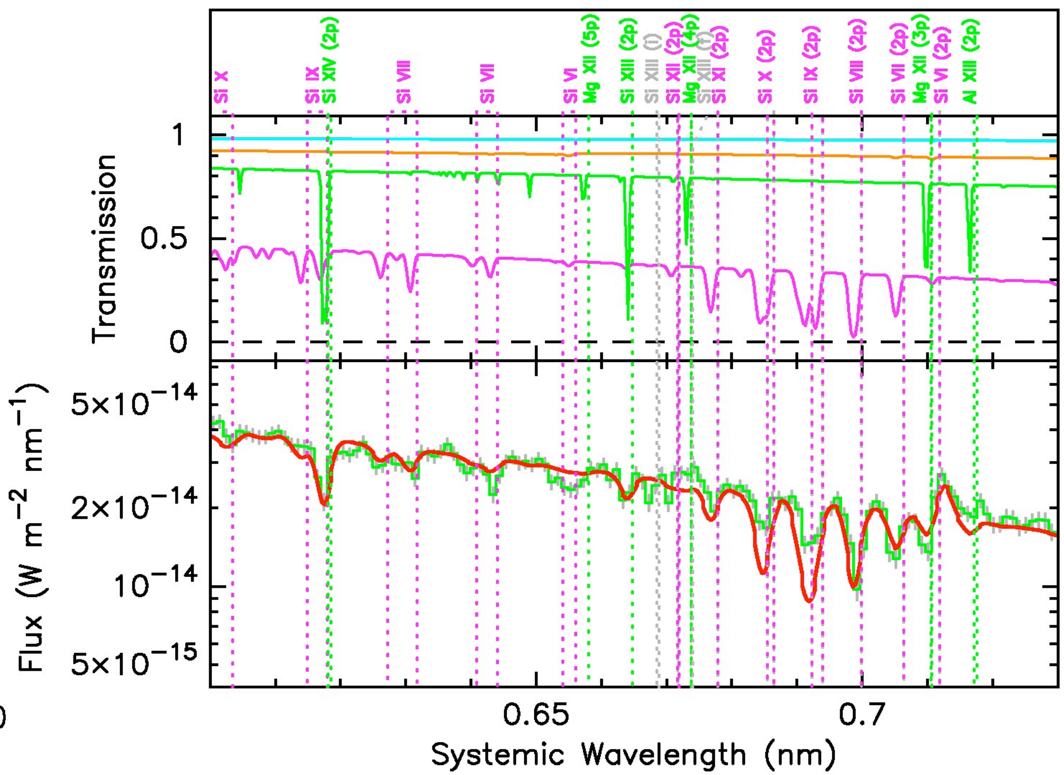
•Broad band high resolution spectroscopy shows that one zone models often do not describe the data

•For $\tau_{compton}$~0.1 at high ionization - predict high optical depth Fe XXIV-XXVI resonance absorption lines

Multiple Zones of photoionized gas in NGC 4151 (Kraemer, George et al. 2005)

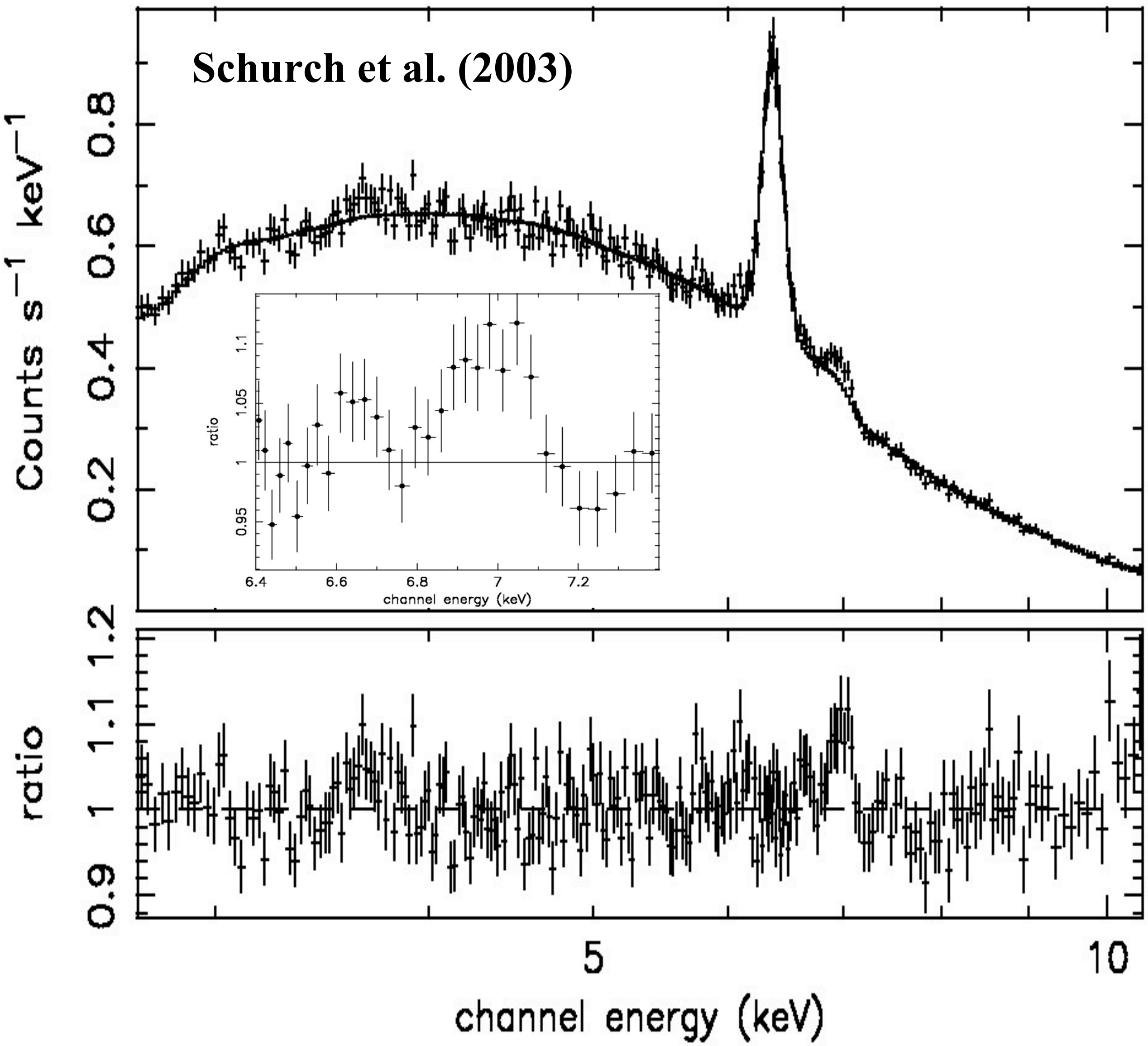


Broad band HETG spectrum of NGC 4151. Green is data, red is warm absorber model. Note the strong curvature of the continuum due to the absorber.



HETG data in the Si band (1.7-2.1 keV). Two components are needed to fit the data; green=high ionization (e.g. Si XIII/XIV, He/H-like), purple=low ionization (Si VI-XII, F-Li like).

No Broad Iron K Line in NGC 4151?



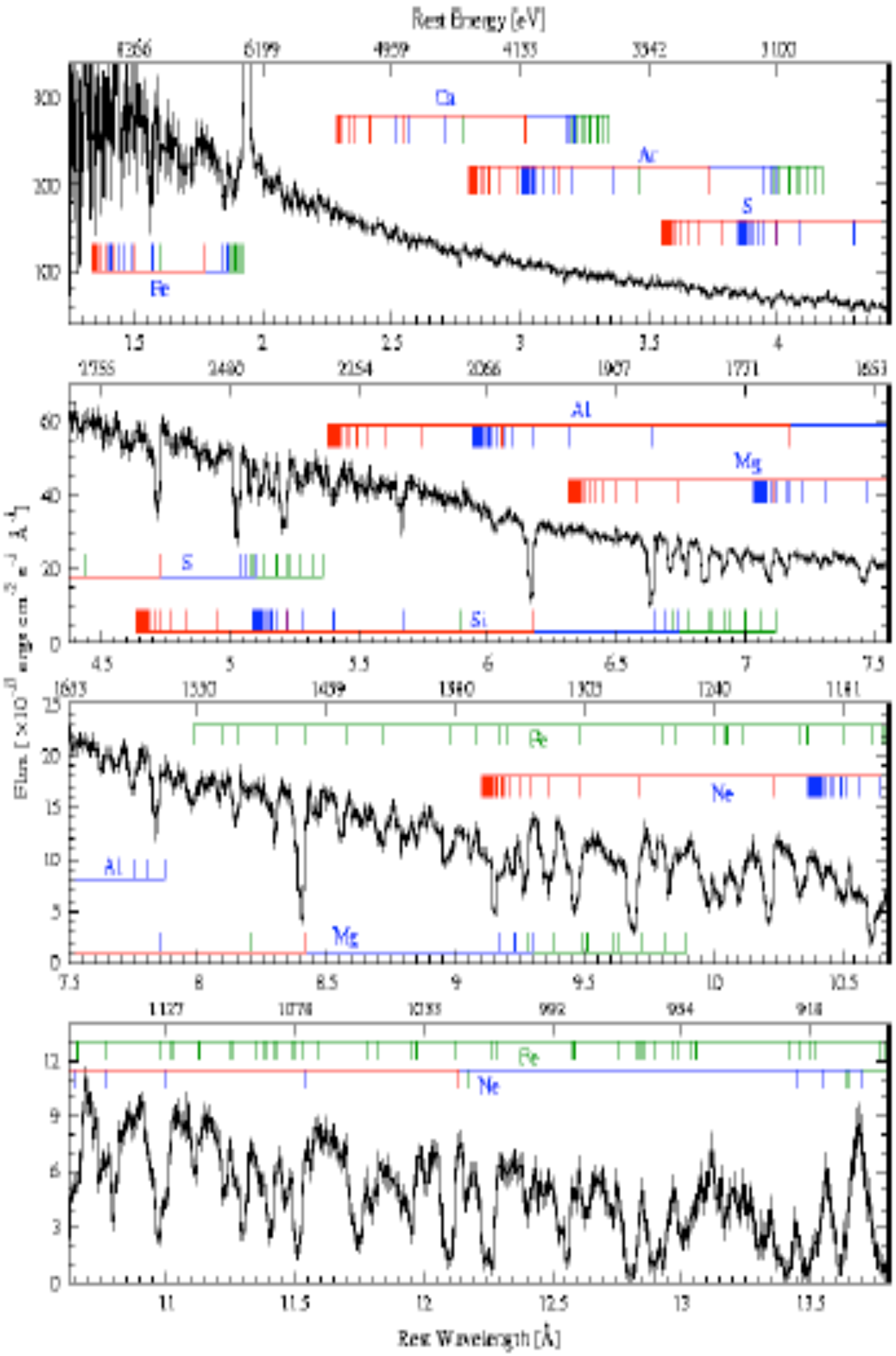
NGC 4151 still in low flux state during the *XMM-Newton* observations. (F$_{2-10}$ = 4.25x10^{-11} ergs cm^{-2} s^{-1})

Iron Kα emission is *narrow* during the *XMM-Newton* observation:

E= 6.40 keV, σ~30 eV (FWHM ~3000 km/s)

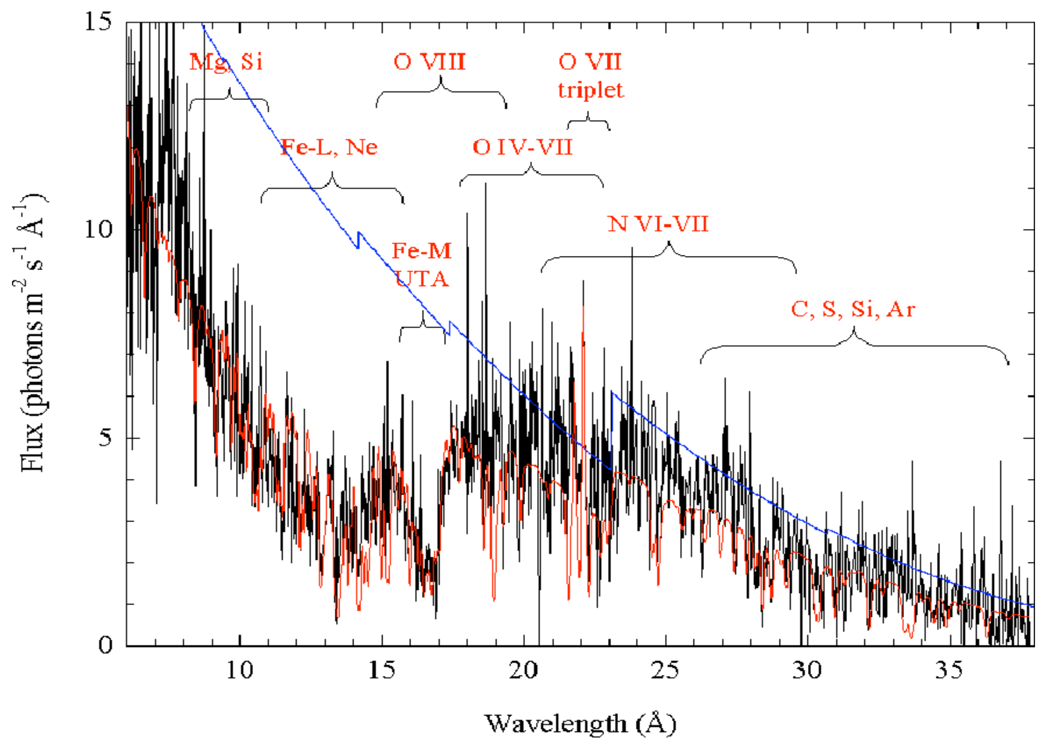
No Broad iron K line is required.

Reflection (from distant matter) is needed.



NGC 3783: 900ks Chandra-HETG and 250ks XMM-Newton RGS

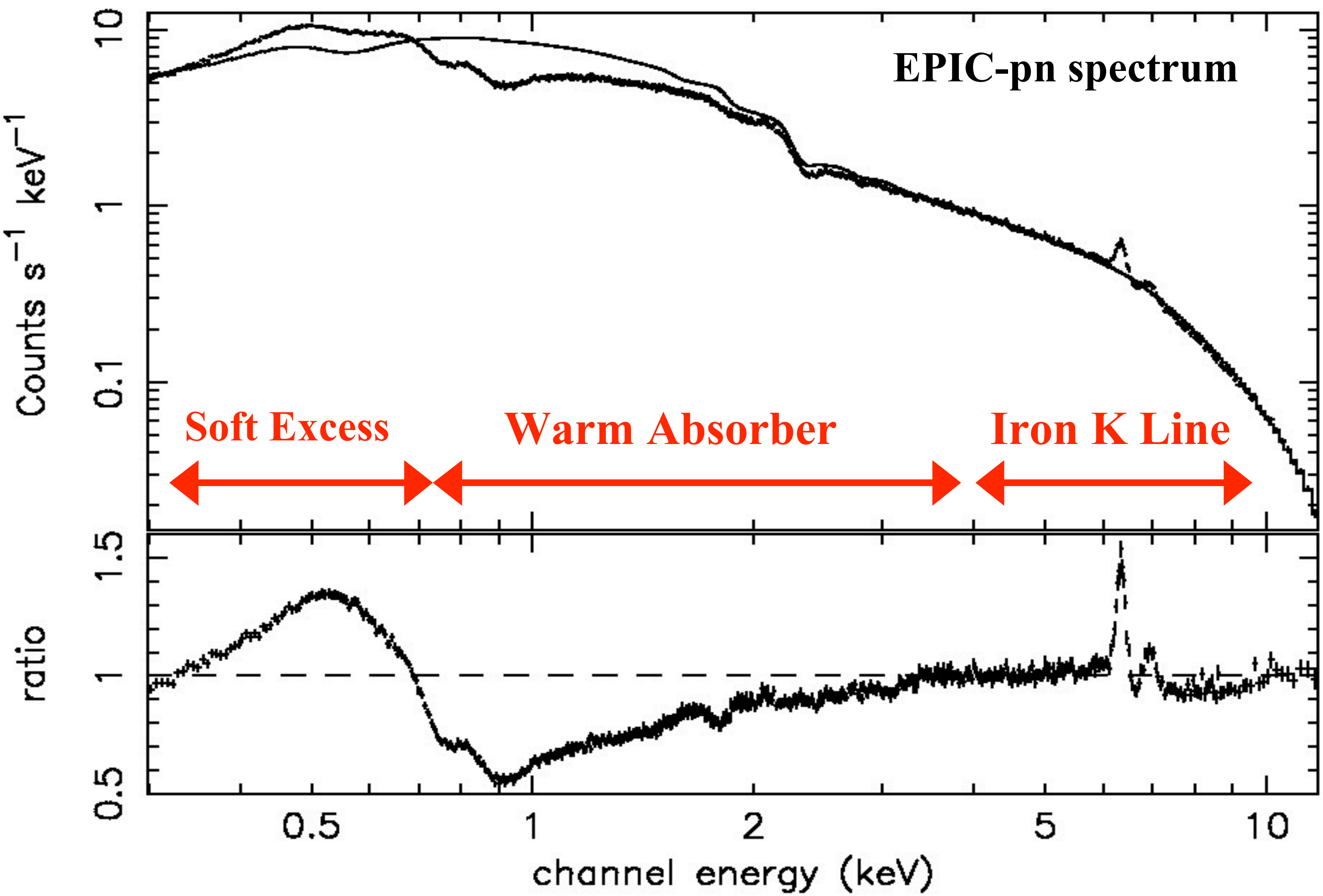
(Kaspi et al 2002, Netzer et al. 2003, Blustin et al. 2002)



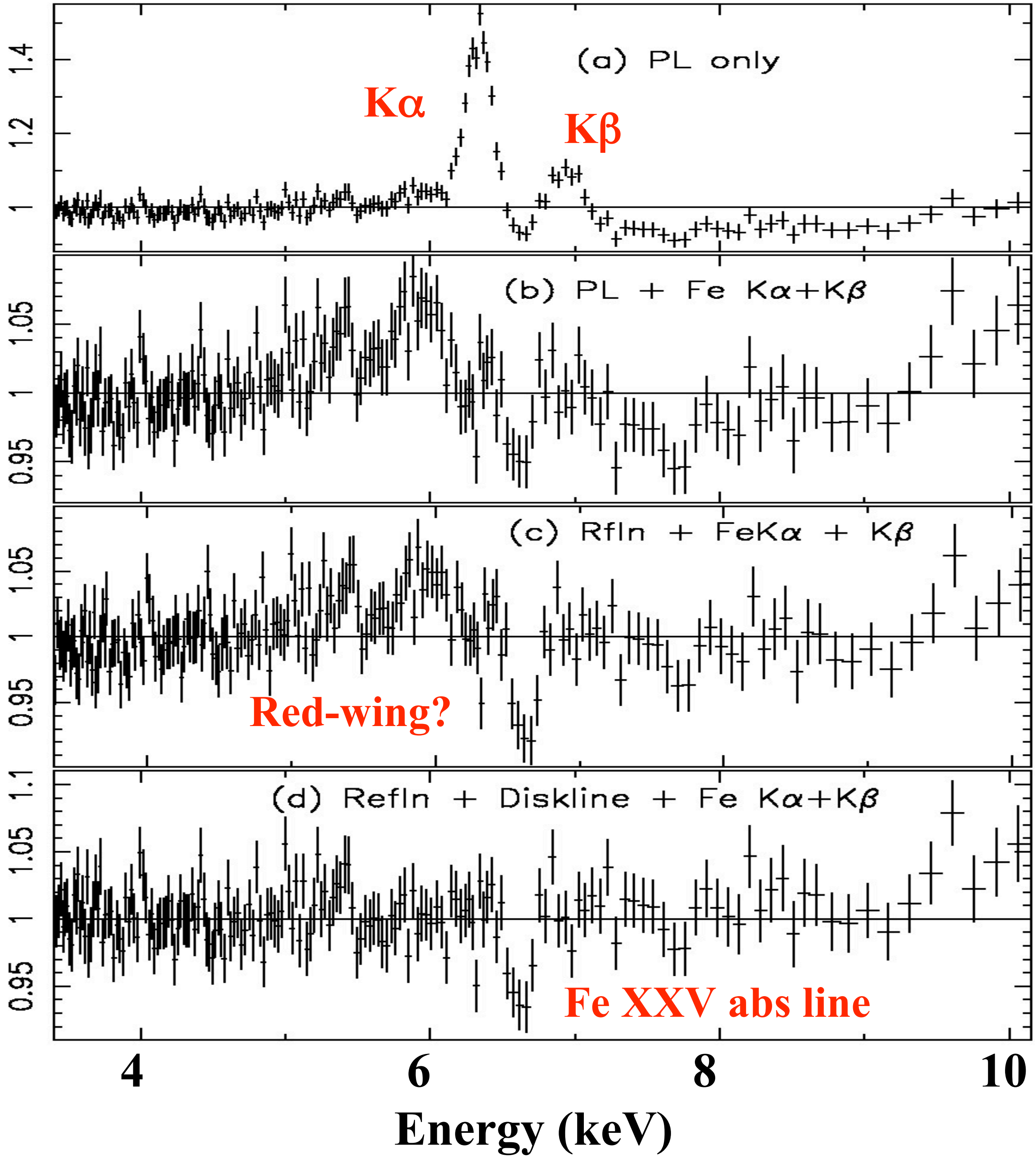
Multi-component warm absorber present in soft X-rays. Significant opacity below 3 keV.

The Seyfert 1 NGC 3783 - 250 ks XMM-Newton Observation

(Reeves et al. 2004, ApJ, 602, 648)



XMM Iron Line Profile of NGC 3783



2 "narrow" Iron K lines

Kα (6.4 keV) and

Kβ/Lyα (7.0 keV)

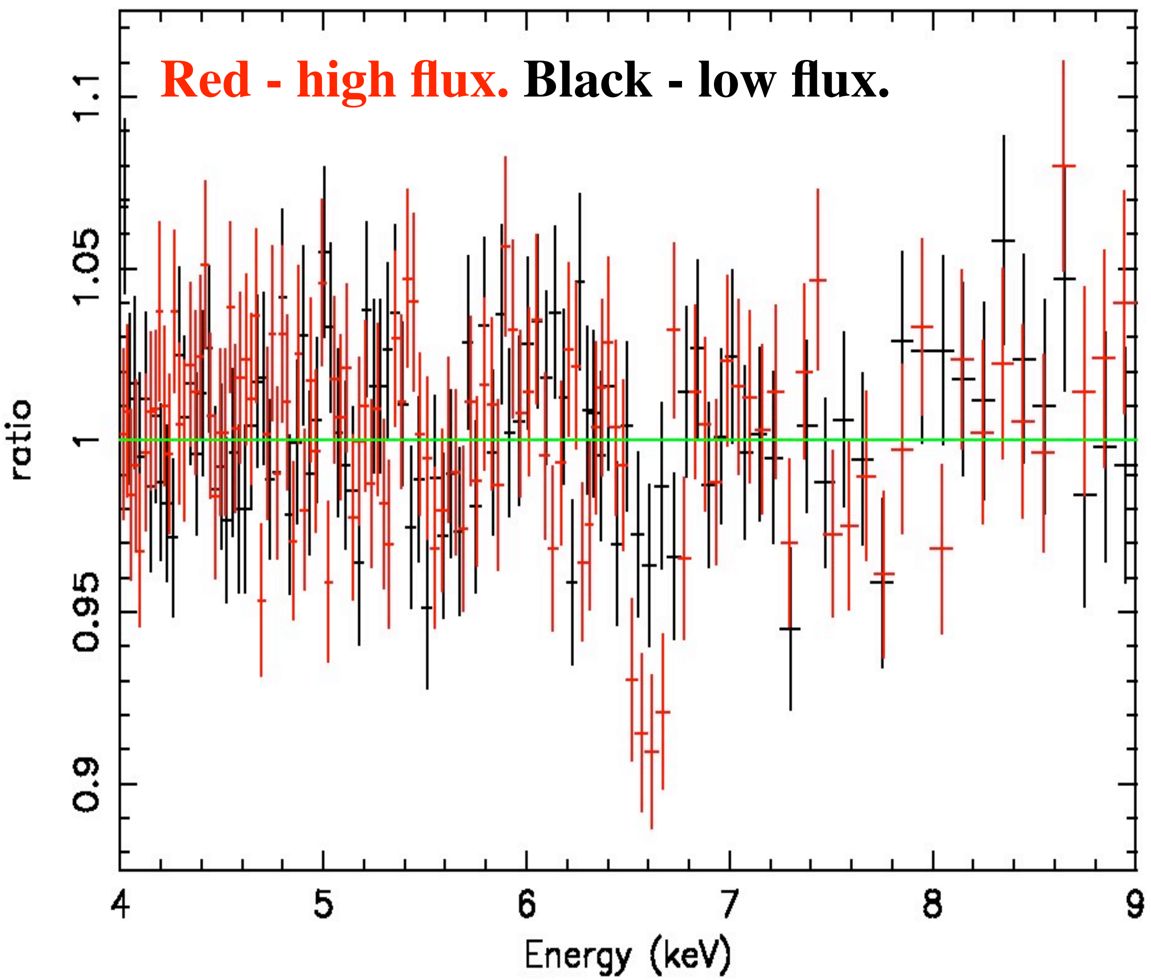
Compton reflection - torus?

Weak red-shifted line?

<u>NEW - absorption line</u>

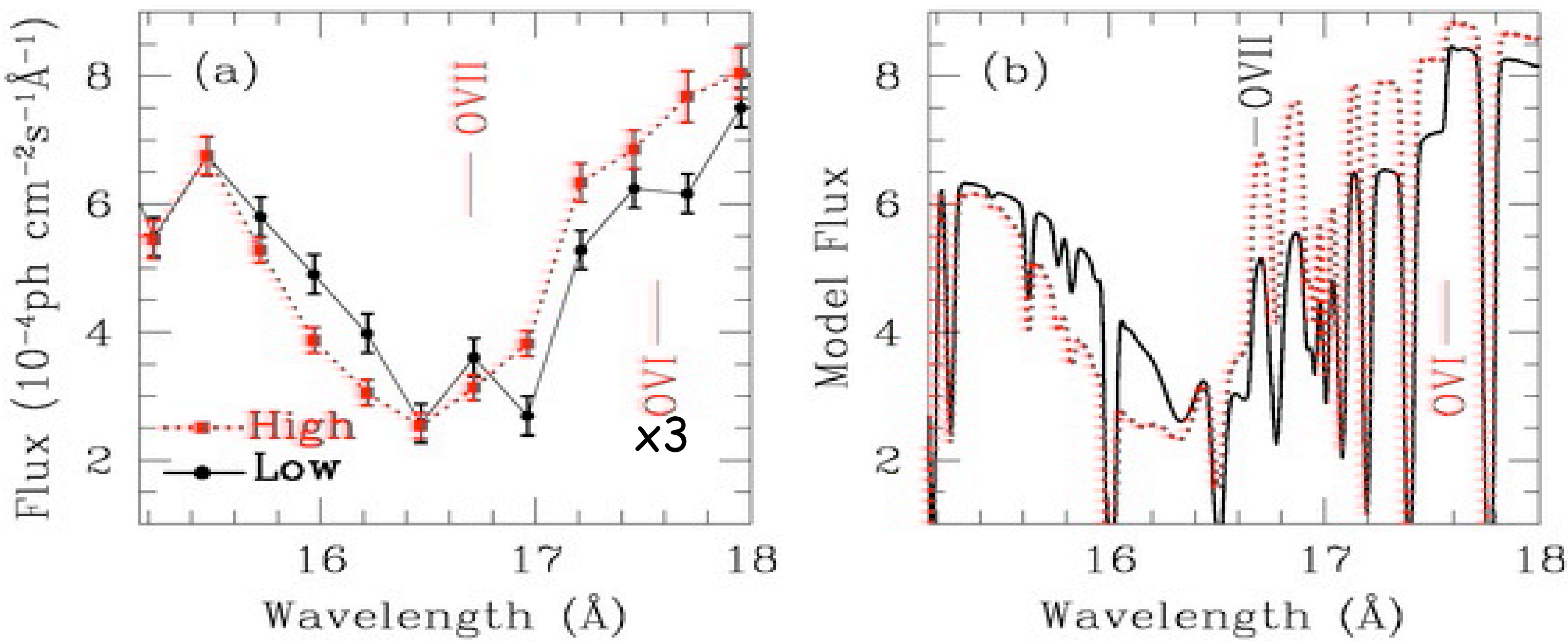
<u>(6.7 keV) due to He-like Fe</u>

Variability of the absorption line in NGC 3783



- **Highest Ionization ($\log\xi=10^3$, $N_H \sim 10^{22} cm^{-2}$) component of the warm absorber.**
- **Surprise! - Absorption line appears variable on the timescale of $t=10^5$ s. Not previously known to be variable**
- **Iron K emission lines are not variable**
- **Absorber deepest when continuum flux is higher**
- **Absorber is located closer ($R<10^{16}\ cm^{-2}$) to black hole.**

NGC 3783 UTA Variability



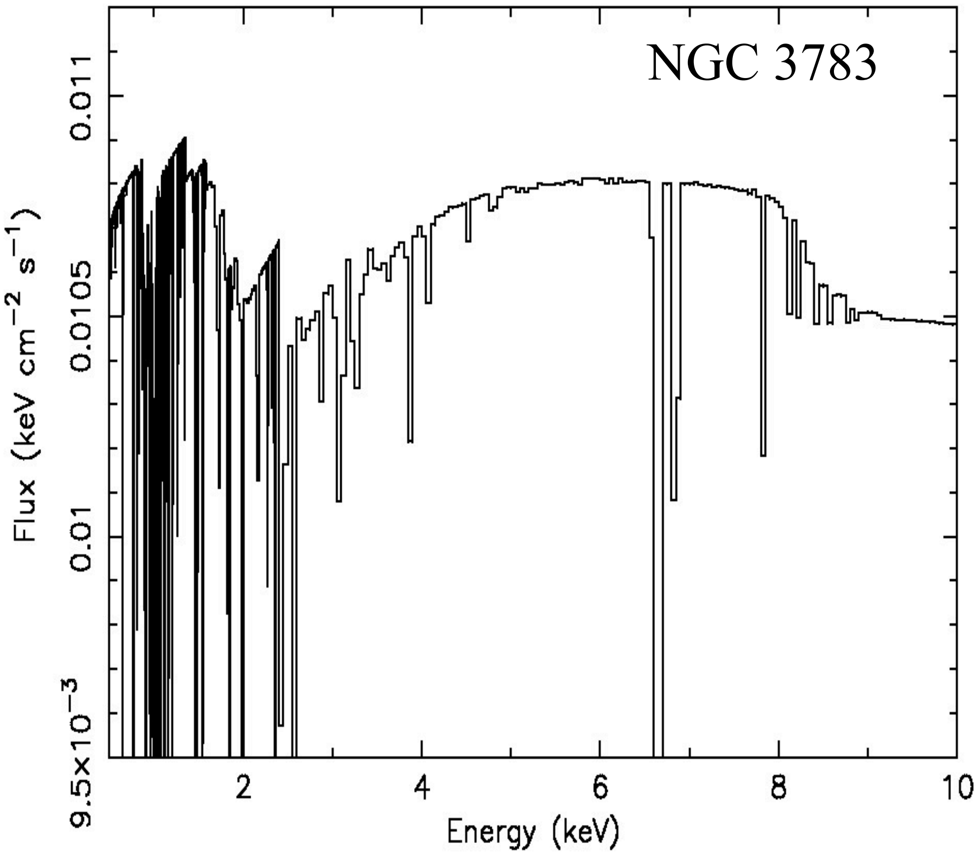
HETGS/NGC 3783 - Krongold et al 2005

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

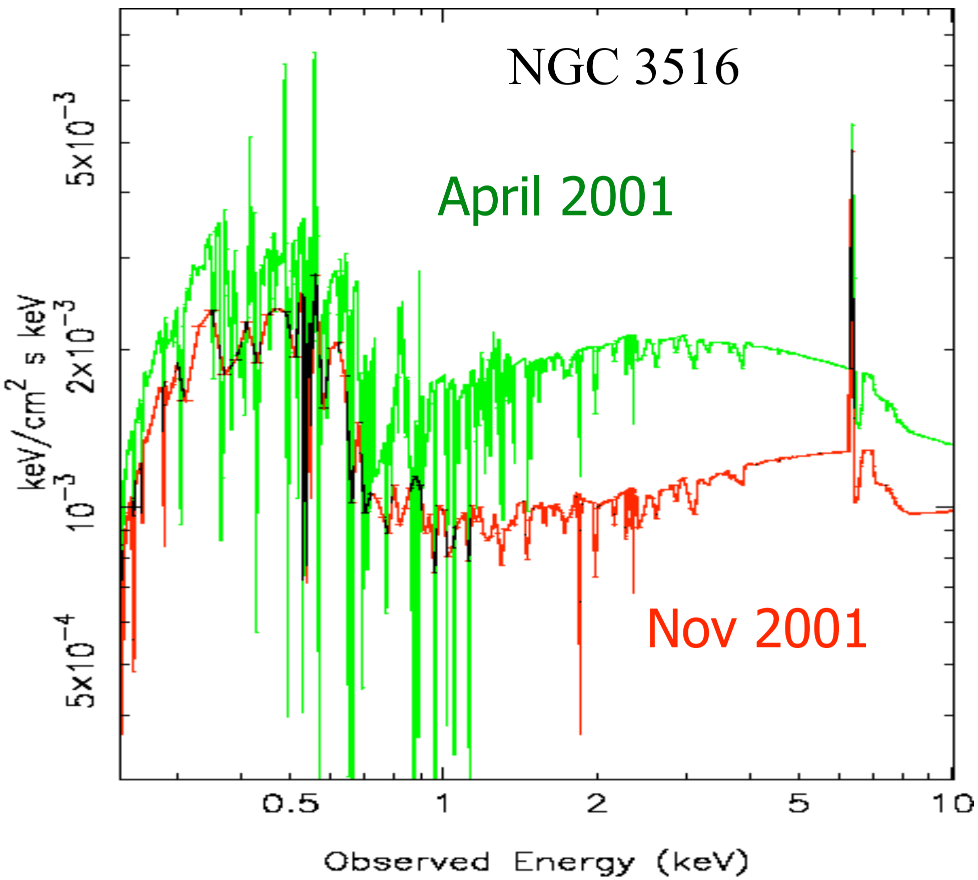
WA is **not** the Kpc-scale cones observed in Sy 2 (e.g. Kinkhabwala 2002)

In studying broad Fe K line, the effects of X-ray absorption need to be accounted for

Reeves et al. 2004



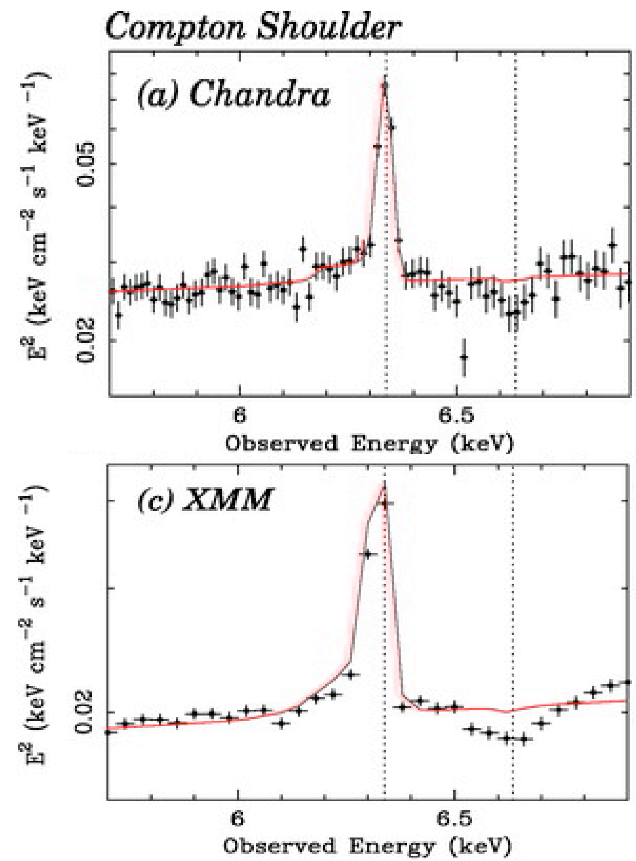
Turner et al. 2005



Absorption can explain the spectral curvature below 6 keV - in some cases accounting for part of the broad iron line.

NGC 3783

Reeves et al 2004, Yaqoob et al 2005

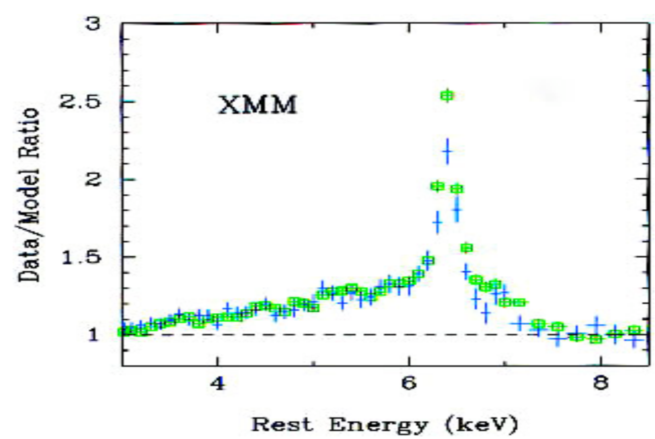


Fe Ka core FWHM ~1700 km/s originating between BLR-NLR (Kaspi et al 2002)

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

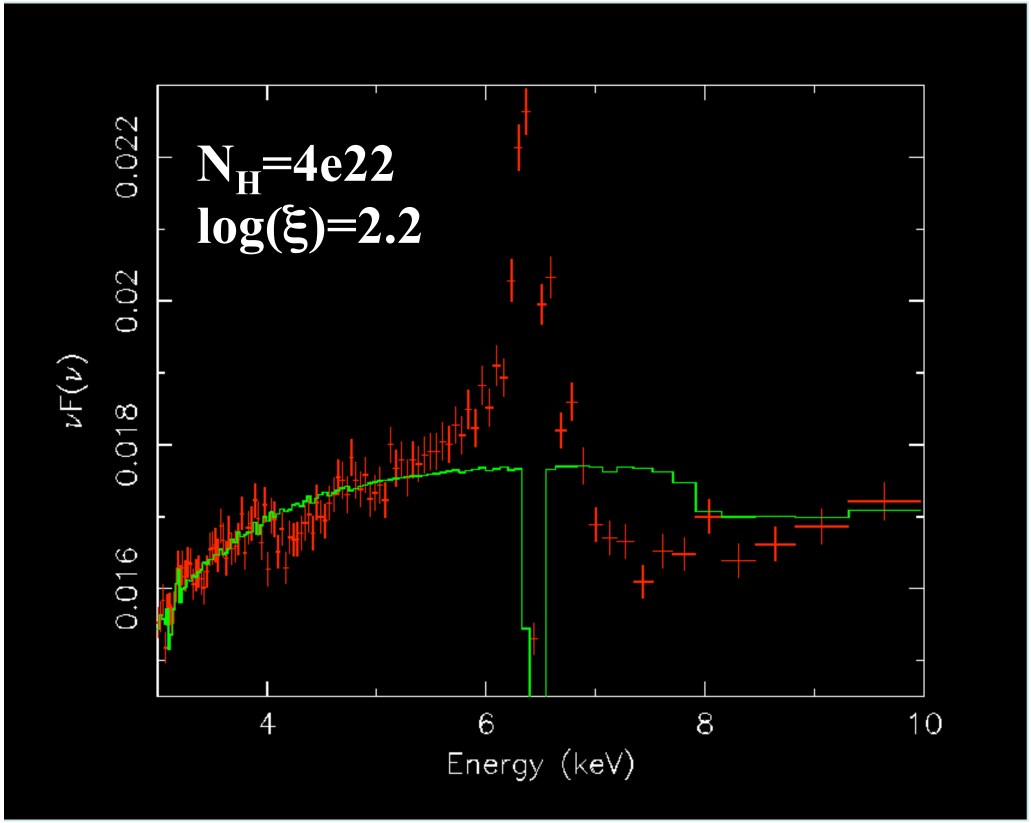
NGC 3516

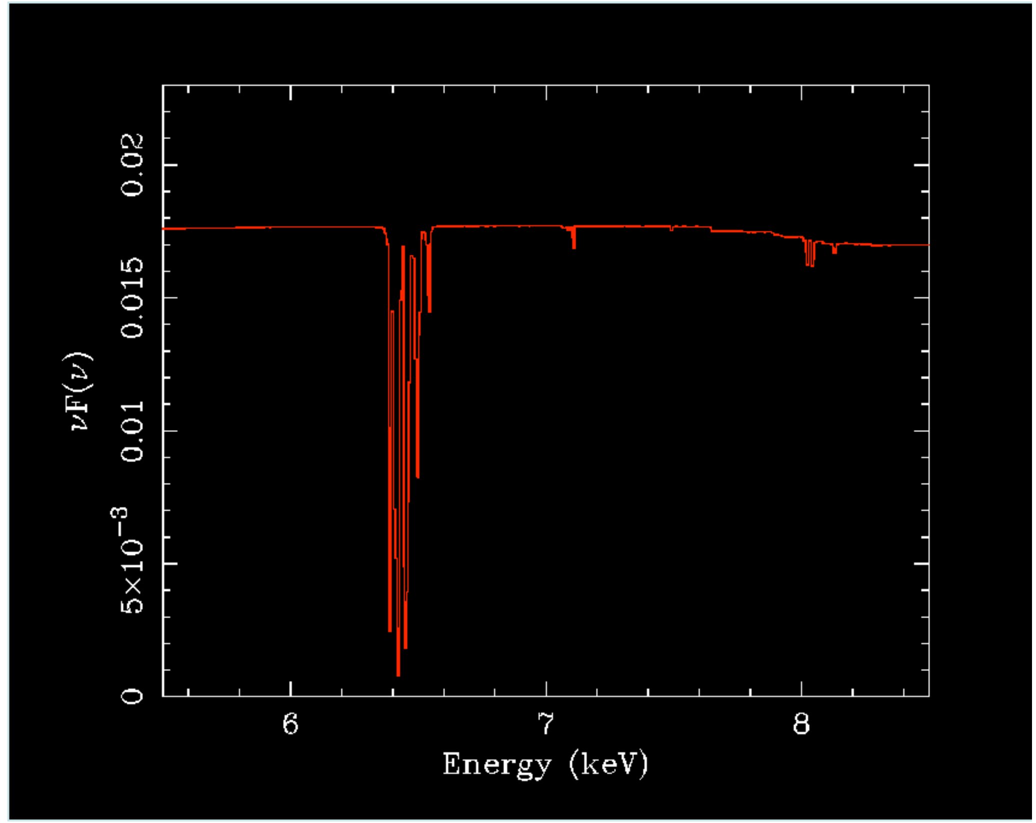
Turner et al 2002, 2005



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

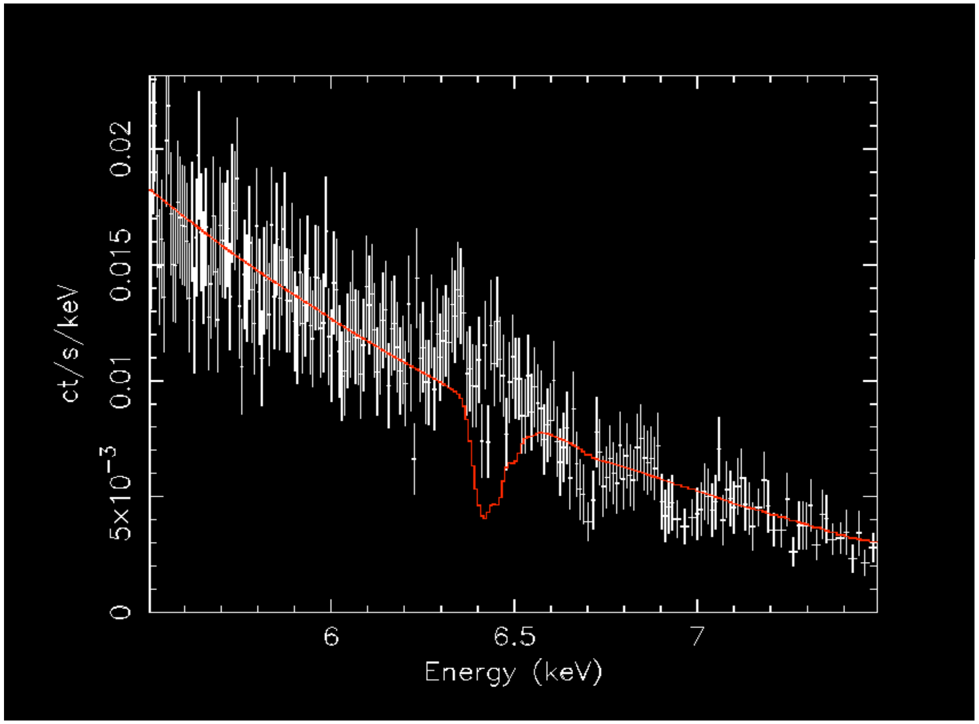
Can the Relativistic Fe line in MCG-6-30-15 be explained by absorption?



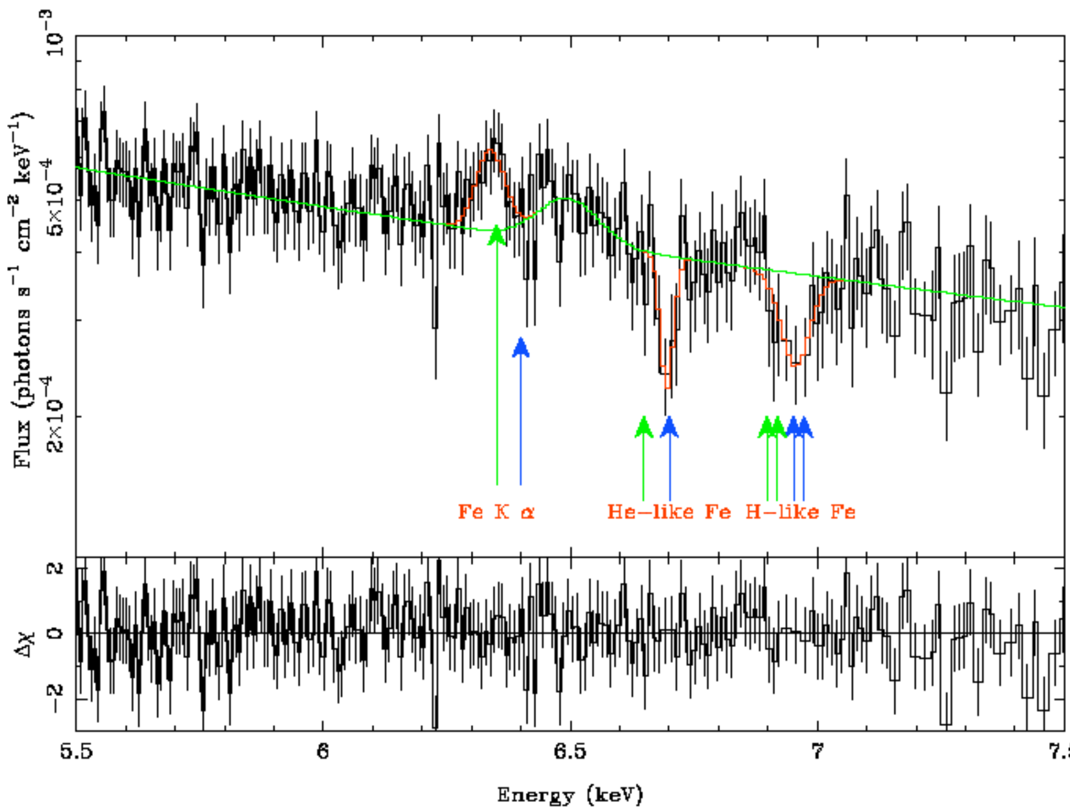


- **Fitting 3-6keV and 8-10keV band, can reproduce “red-wing”curvature from iron-L absorption (Kinkhabwala 2003; PhD thesis)**

Can the broad line in MCG-6-30-15 be explained by absorption? - 500ks Chandra-HETG observation:



Clearly detect narrow cold FeK line and blueshifted FeXXV and FeXXVI abs lines



Clearly do not see the FeXVII-FeXXIII abs lines that accompany a “broad-line mimicking” WA

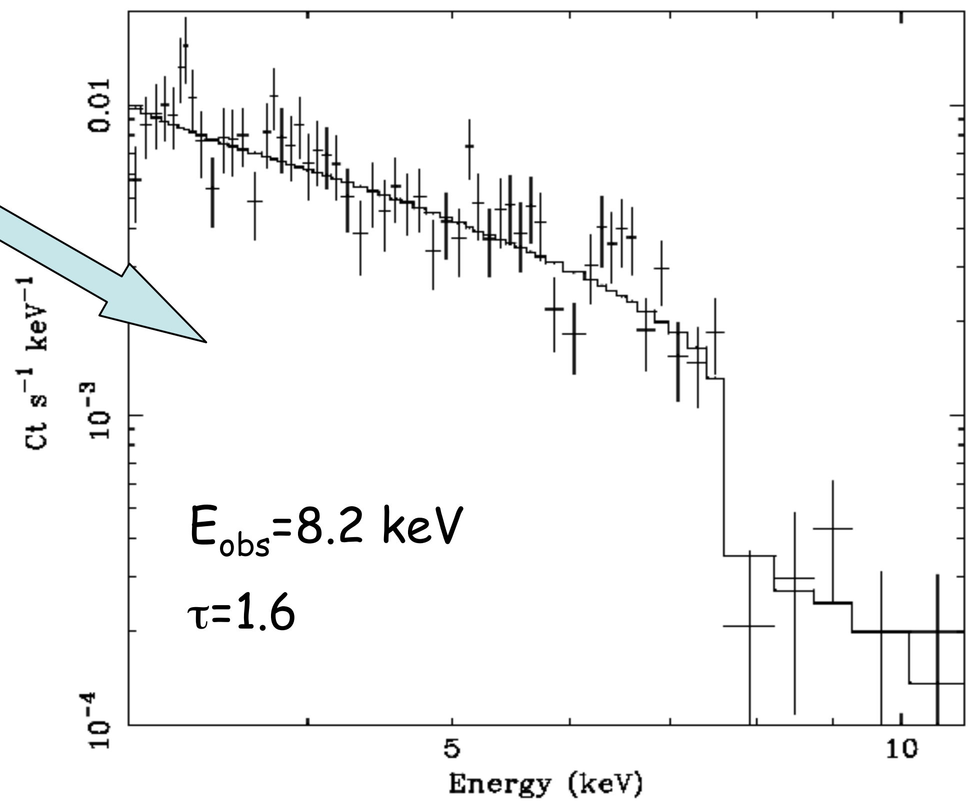
[Young, Lee, Fabian, Reynolds et al., 2005, ApJ,]

Evidence for highly-ionized Fe K Absorption Features

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

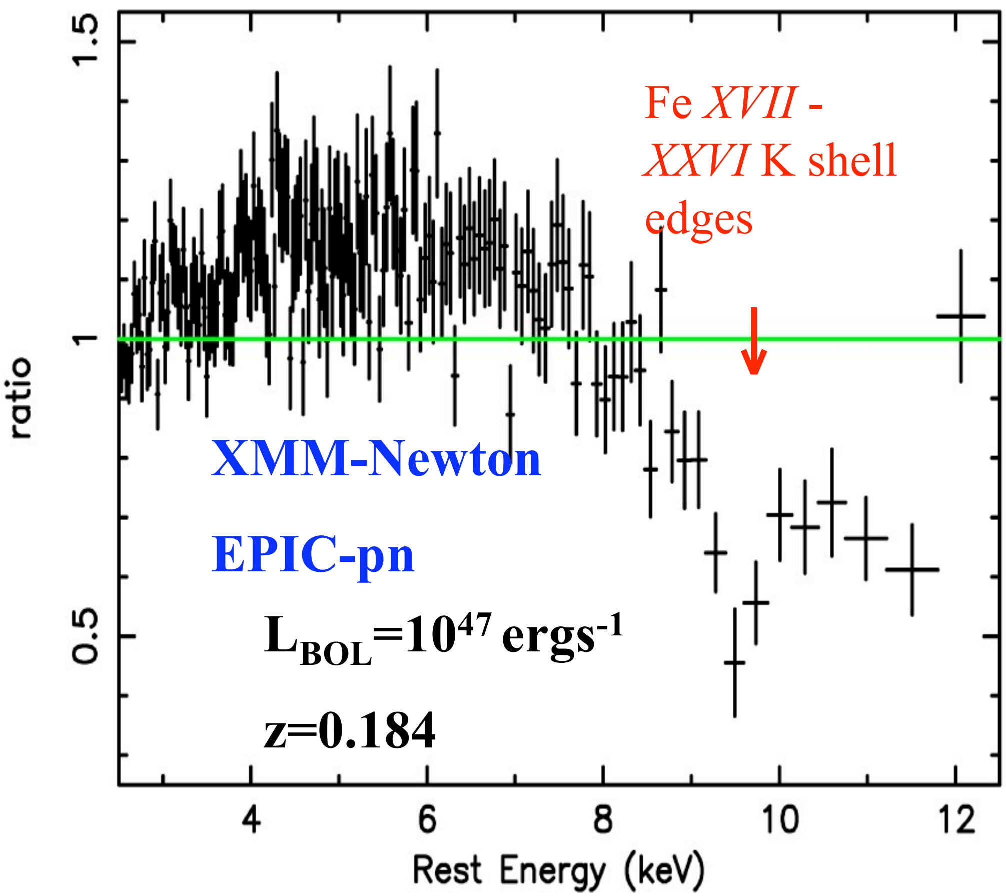
An alternative explanation could be a strongly reflection dominated spectrum.

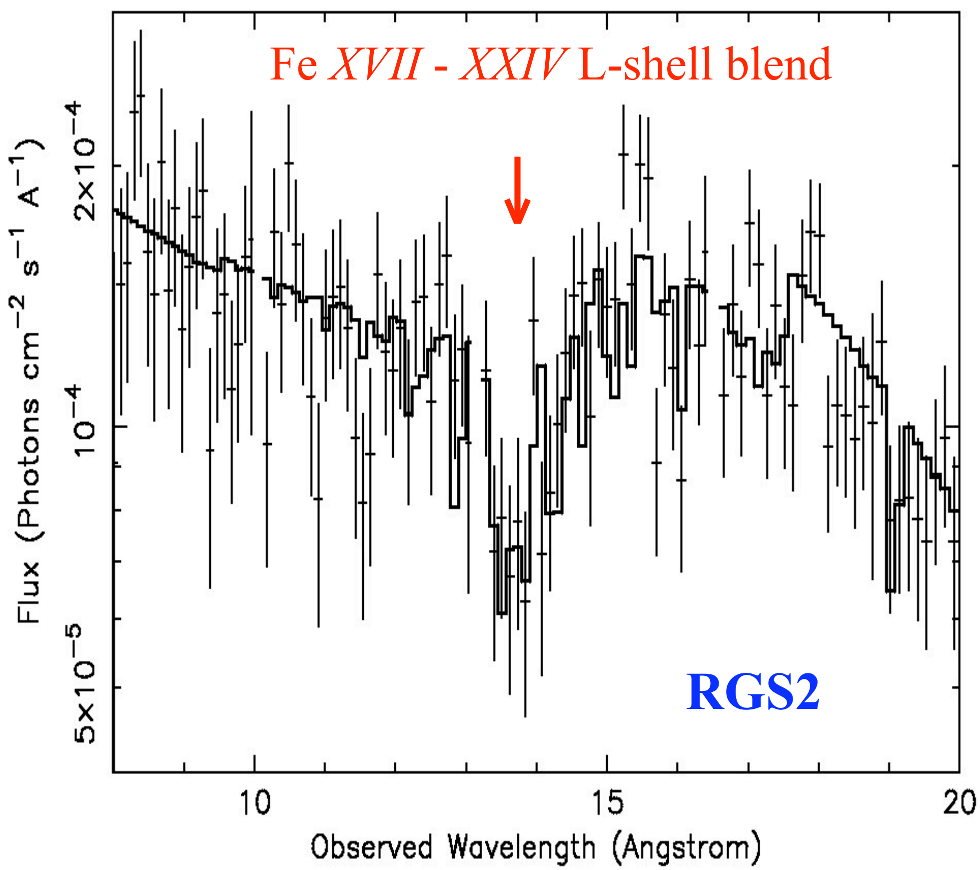


A Massive outflow in the Quasar PDS 456? (Reeves et al. 2003)

PDS 456 is the most luminosity nearby quasar ($z=0.184$ $L_{BOL} \sim 10^{47}$ erg s^{-1}). Deep Fe K-shell absorption seen in XMM-Newton spectrum.

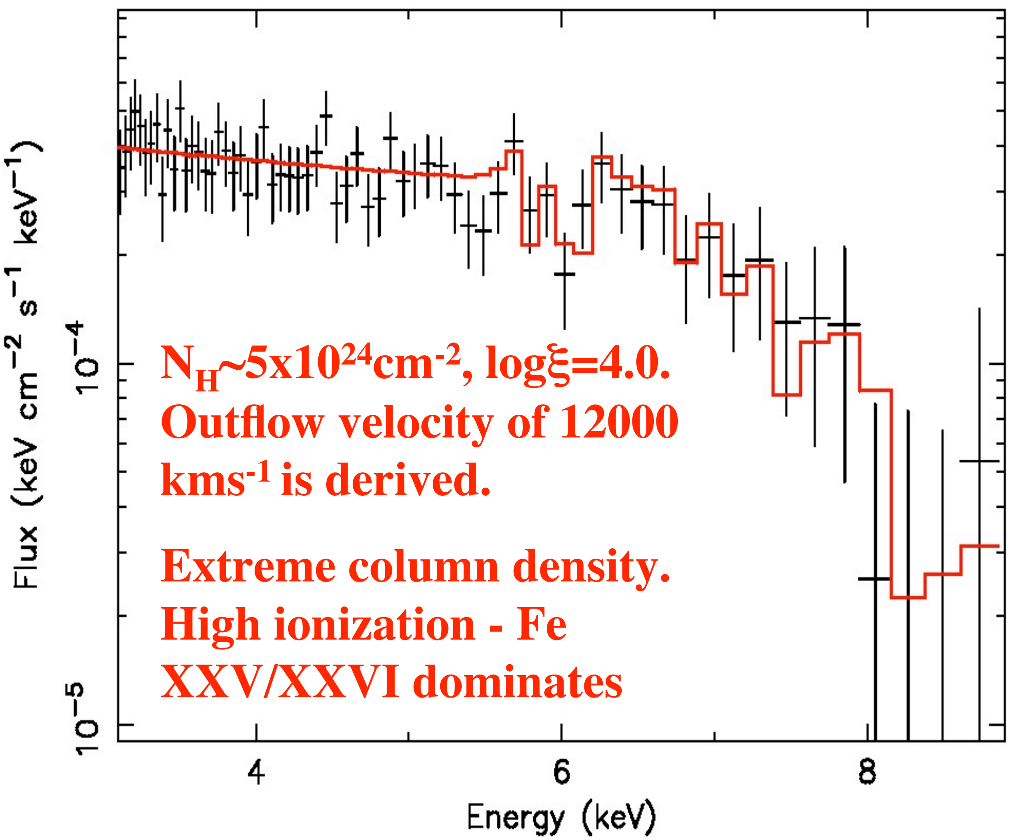
X-ray column density 5×10^{23} cm^{-2} and outflow vel ~50000 km s^{-1}. Mass outflow rate huge (10 solar/yr, similar to M_{EDD}). UV BAL absorption features seen (HST-STIS) in Lyα and CIV. Velocity 12000-22000 km/s (O'Brien et al. 05)



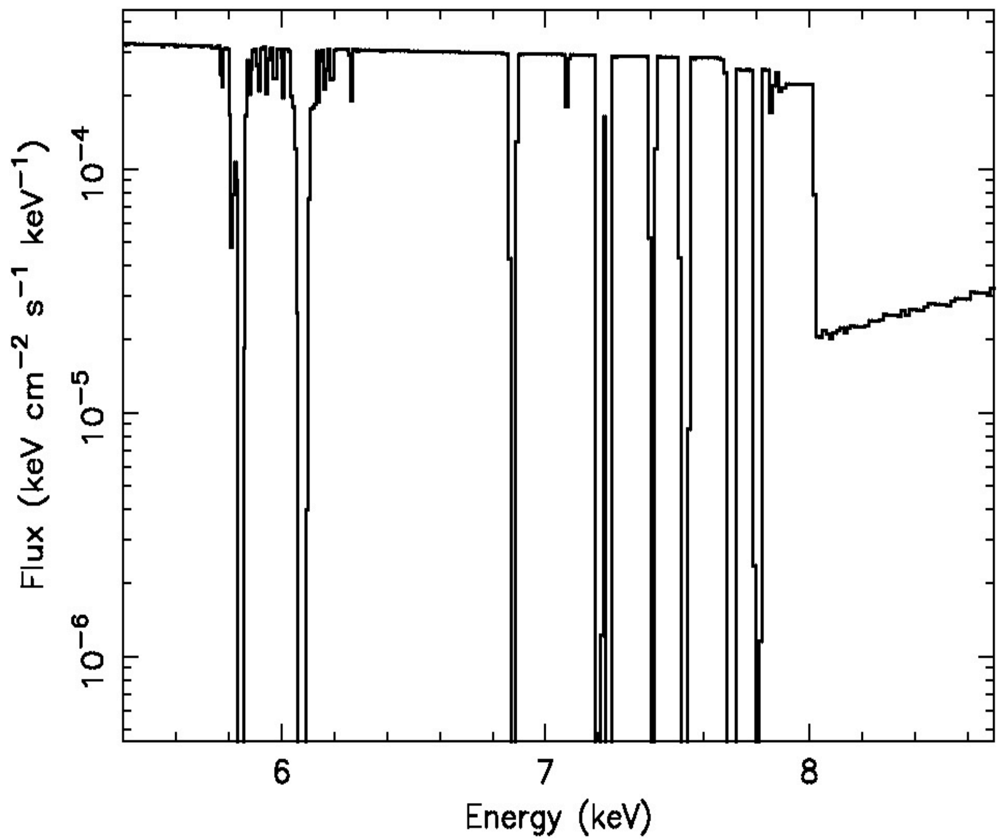


The Fe K Edge at High Resolution

HEG Data, Fe K region

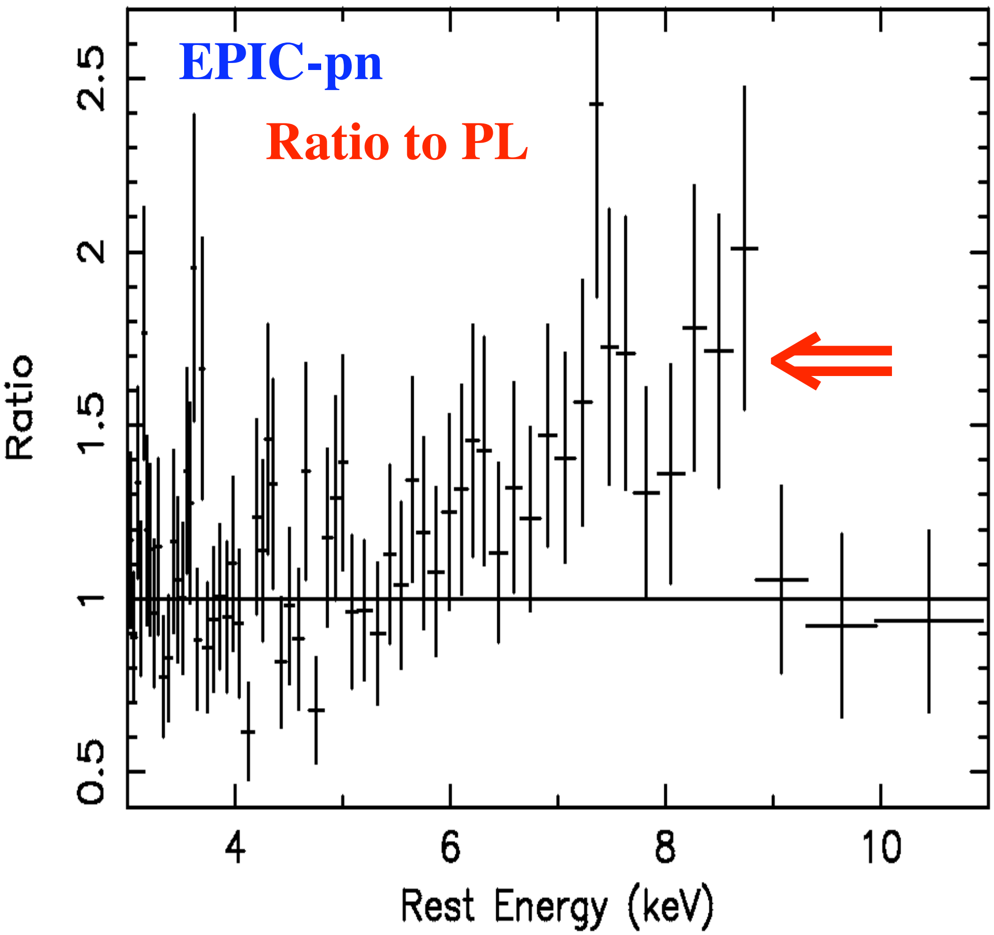


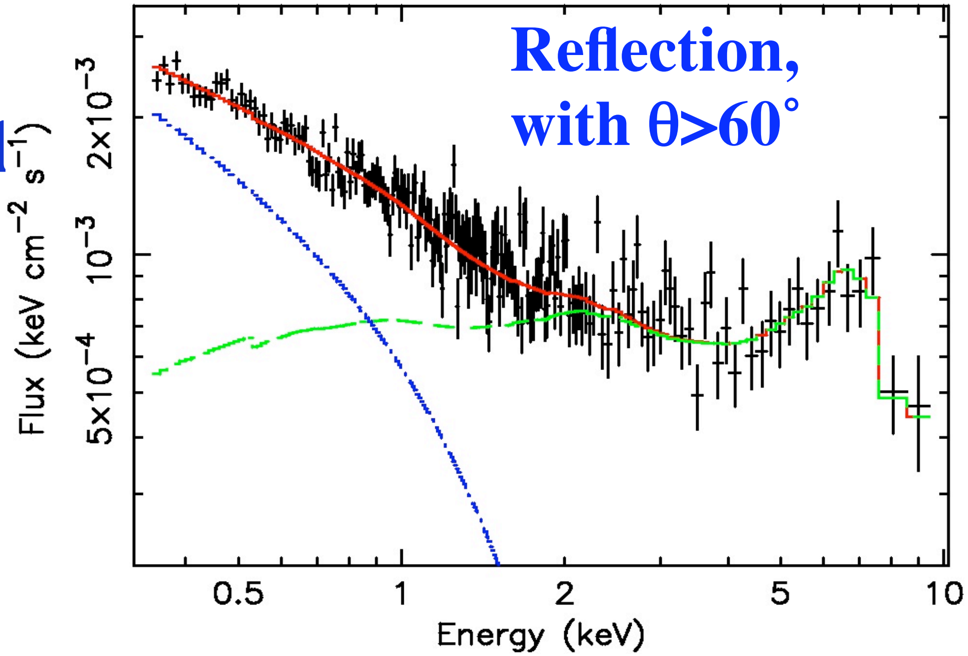
Xstar Model)

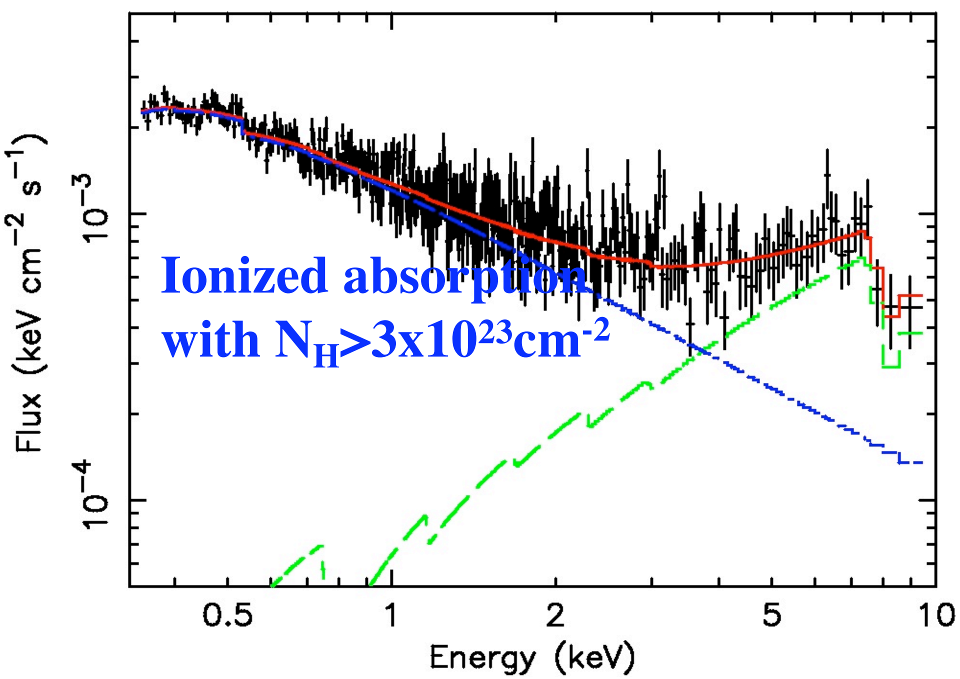


HEG spectrum shows Fe K edge is ***broadened***. Resonance lines below the Fe K threshold smear the edge.

An edge-on disk or highly-ionized absorption in the NLS1 PG1402+261 (z=0.164, Reeves et al. 2004).

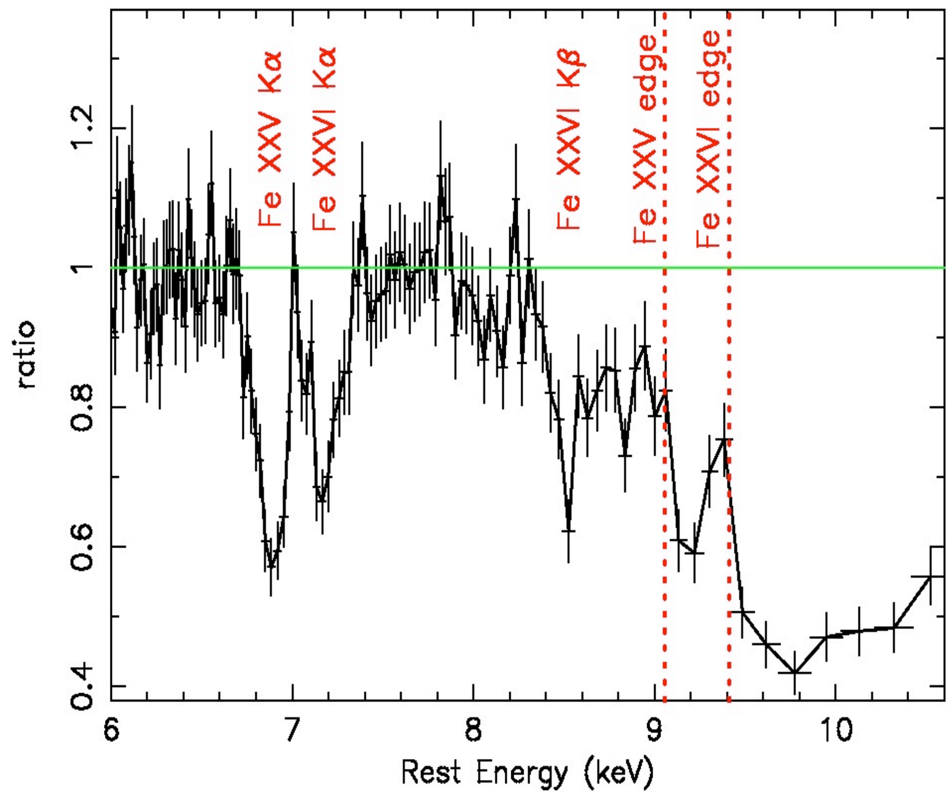




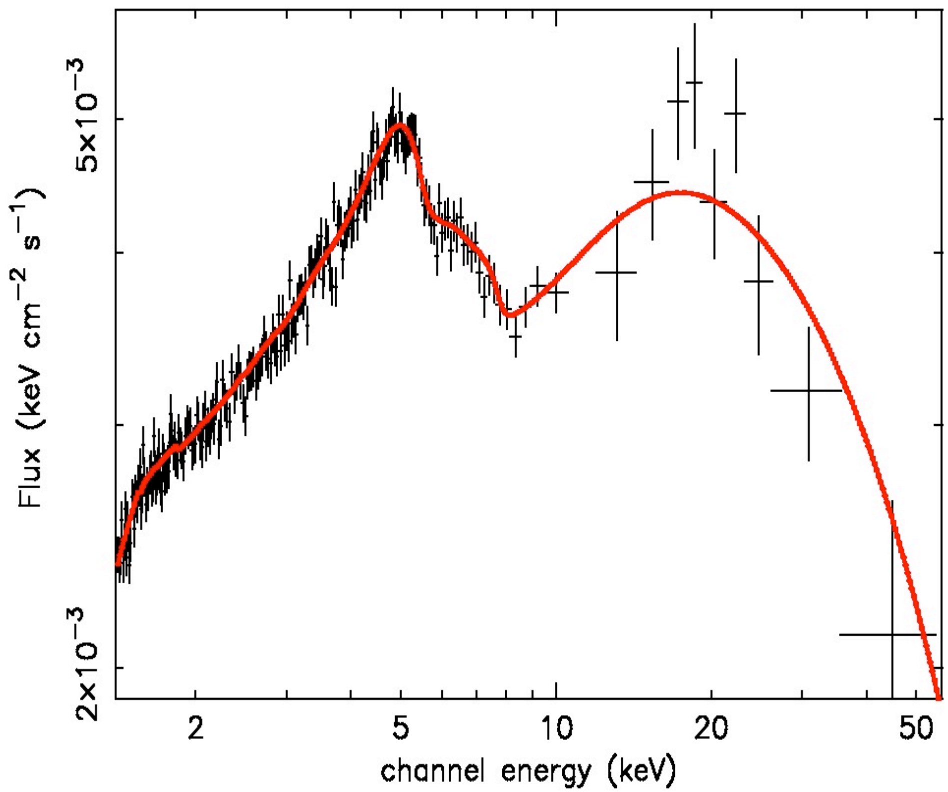


How to distinguish between a highly ionized Fe K absorber and a disk reflector

PDS 456, 150ks Suzaku simulation



In ionized outflow model, discrete lines and energies should be present, unless absorber is relativistically smeared.



With bandpass above 10 keV, the reflection component can be detected.

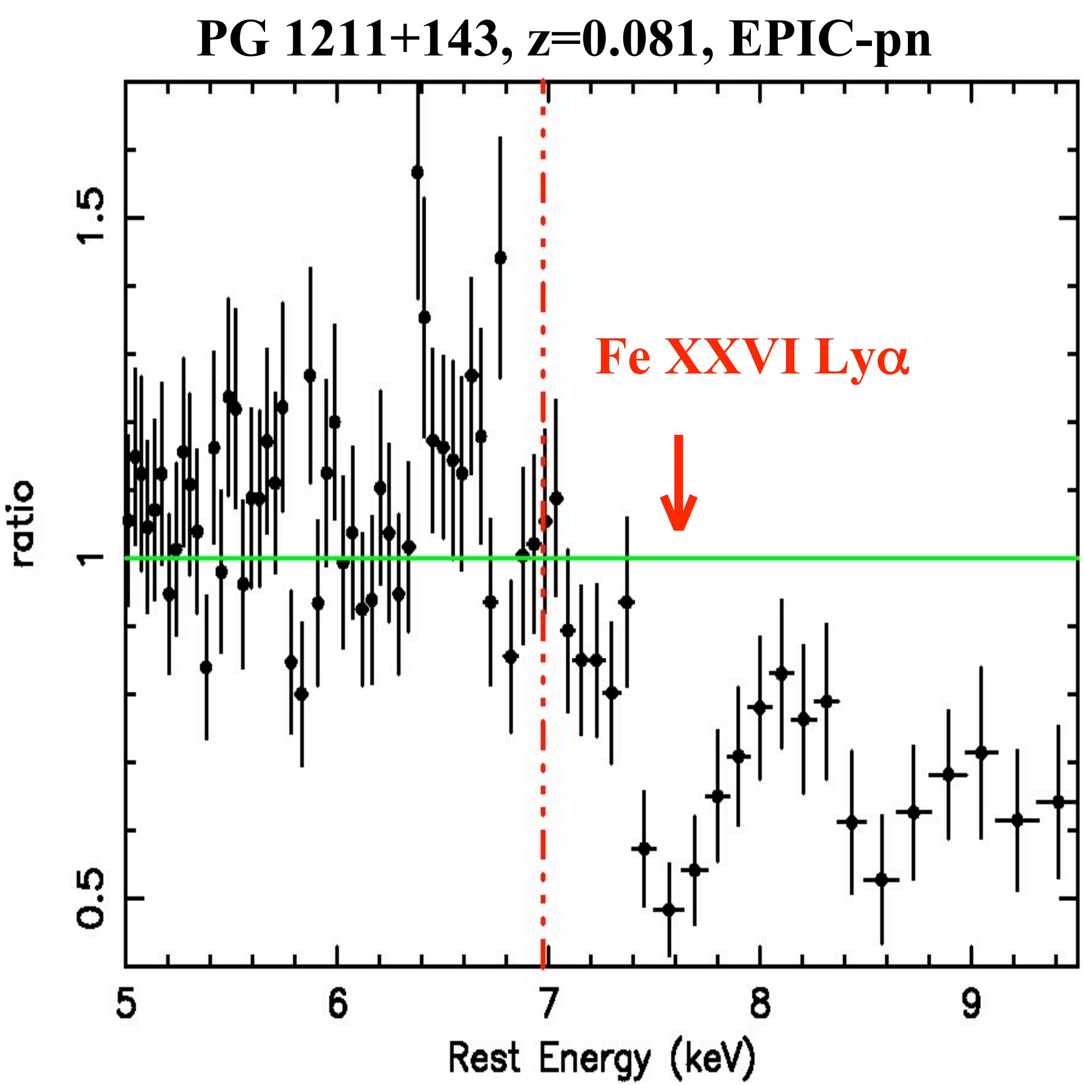
X-ray evidence for high velocity outflows in AGN

Outflows of ~0.1-0.4c have been claimed from X-ray spectra of several AGN, mainly via absorption features in the Fe K band. Detection of absorption in the Fe K band requires a large column density - together with a high velocity that implies the outflow is both massive and energetic (unless highly collimated)

APM 08279+5255 v~0.2-0.4c (Chartas et al, ApJ, 2002, 579, 169) PG1211+143[1] v~0.08-0.1c (Pounds et al, MNRAS, 2003, 345, 705) PG1115+080 v~0.1/0.34c (Chartas et al, ApJ, 2003, 595, 85) PG0844+349[2] v~0.2c (Pounds et al, MNRAS, 2003, 346, 1025) PDS 456 v~0.17c (Reeves et al, ApJ, 2003, 593, 65) IRAS13197-1627 v~0.11c (Dadina and Cappi, A&A, 2004, 413, 921) RXJ0136.9-3510 v~0.1/0.14c (Ghosh et al, ApJ, 2004, 607, L111) Mrk509[3] v~0.2c (Dadina et al., 2005, A&A, 442, 461) IC 4329a v~0.09c (Markowitz et al. 2006, ApJ, in press) MCG -5-23-16 v~0.1c (Braito et al, 2006, this workshop).

NB 1. Disputed by Kaspi et al., who claim the outflow may arise from a lower velocity, depending on the specific identification of lines in the spectrum. 2. Disputed on the basis of background subtraction in the EPIC/pn spectrum (Brinkman et al. 2005). 3. Shows red and blue-shifted iron absorption lines.

A Highly Ionized, Relativistic Outflow in PG 1211+143 (Pounds et al. 2003)



XMM-Newton data reveal a highly ionised outflow

Fe XXVI, Mg XII, S XVI lines (EPIC), Ne X/IX, O VIII/OVII, NVII, CVI in RGS

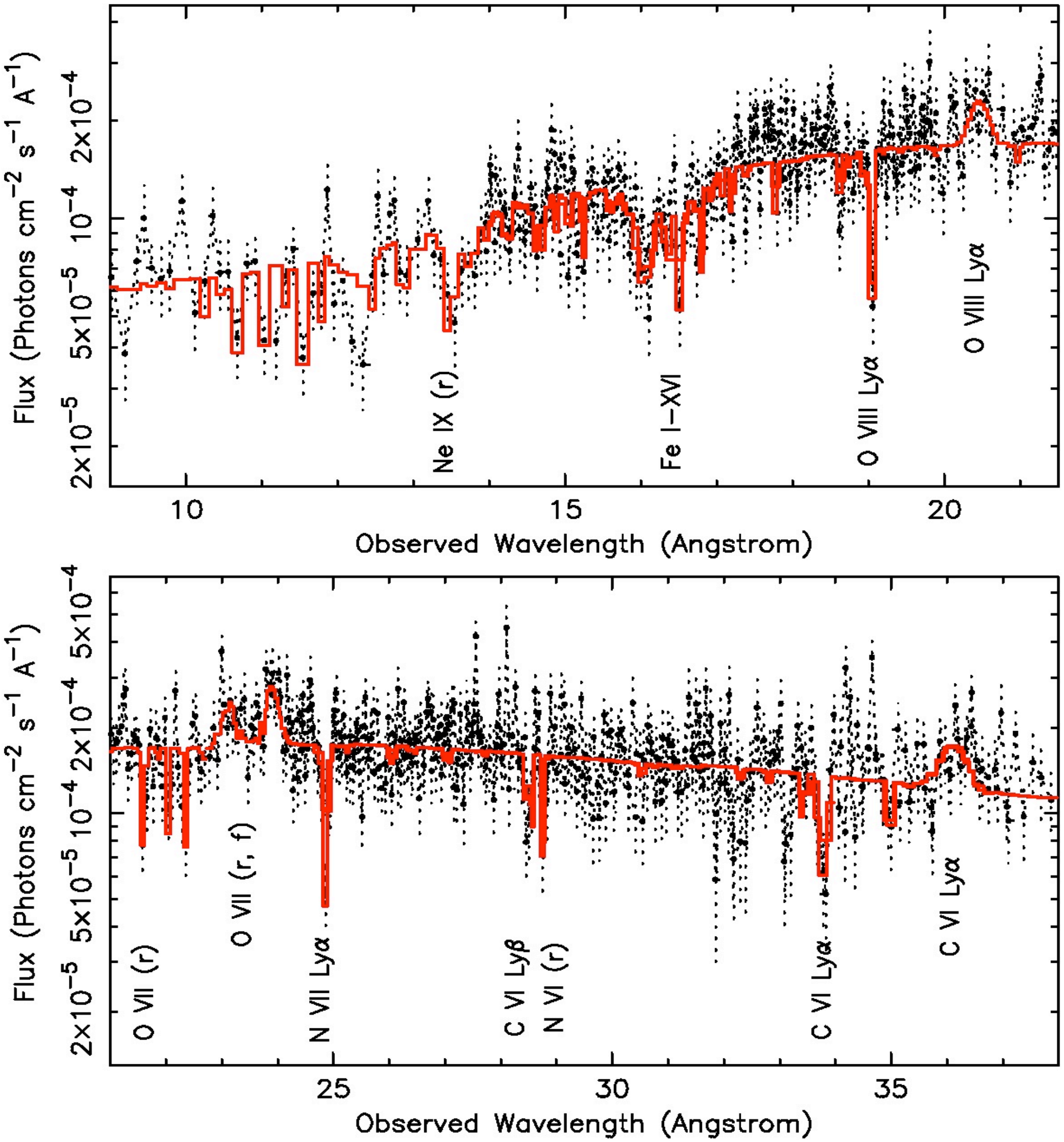
Highest ionization absorber has $\xi \sim 10^{3.4}$ and $N_H \sim 5\times10^{23}$ cm^{-2} outflowing at 0.08c (24000 km/s)

Outflow launched from inner disc at <130Rs ($\tau \sim 1$)

Mass-loss rate ~ 3 $M_\odot$ yr^{-1} K.E. ~ 10^{45} erg s^{-1} (~L_{BOL})

Kaspi et al. (2004) suggest *lower* velocity for RGS line (3000 km/s), but does not explain Mg/Si/Fe blueshifts.

PG 1211+143 RGS spectra show multiple high v lines.



Re-analysis of RGS spectra published by Pounds et al. (2003).

Multiple absorption lines are present in RGS data identified with CVI, N VI, O VII, OVIII, Ne IX at systematically high outflow velocities (20000-28000 km/s).

Sensible identifications are not possible for most lines at lower velocity.

Uncertainty in identification near 12A/1keV - iron L lines could be fitted with lower velocity (Kaspi et al.)

Two zones of ionized matter (logξ=3.0 and 0.5 with N_H~5x10^{22} cm^{-2} and 10^{21} cm^{-2}) requiring 0.1c outflow.

<u>NOTE UTA feature observed at 16A.</u>

A Physical Model For the Fast Outflow in PG 1211+143

considering the outflow observed in PG1211+143 in terms of a simple 'Black Hole Wind' model (King and Pounds, 2003) provides several physical consistency checks:

(1) assuming a radial outflow, the optical depth (from infinity) reaches unity at a distance $r_{\mathbf{ph}}$ from the black hole of Schwarzschild radius $r_{\mathbf{s}}$. For PG1211+143: $r_{\mathbf{ph}} \sim c/v$. $M_{\mathbf{dot.out}} / M_{\mathbf{dot.acc}} \sim 140\ r_{\mathbf{s}}$

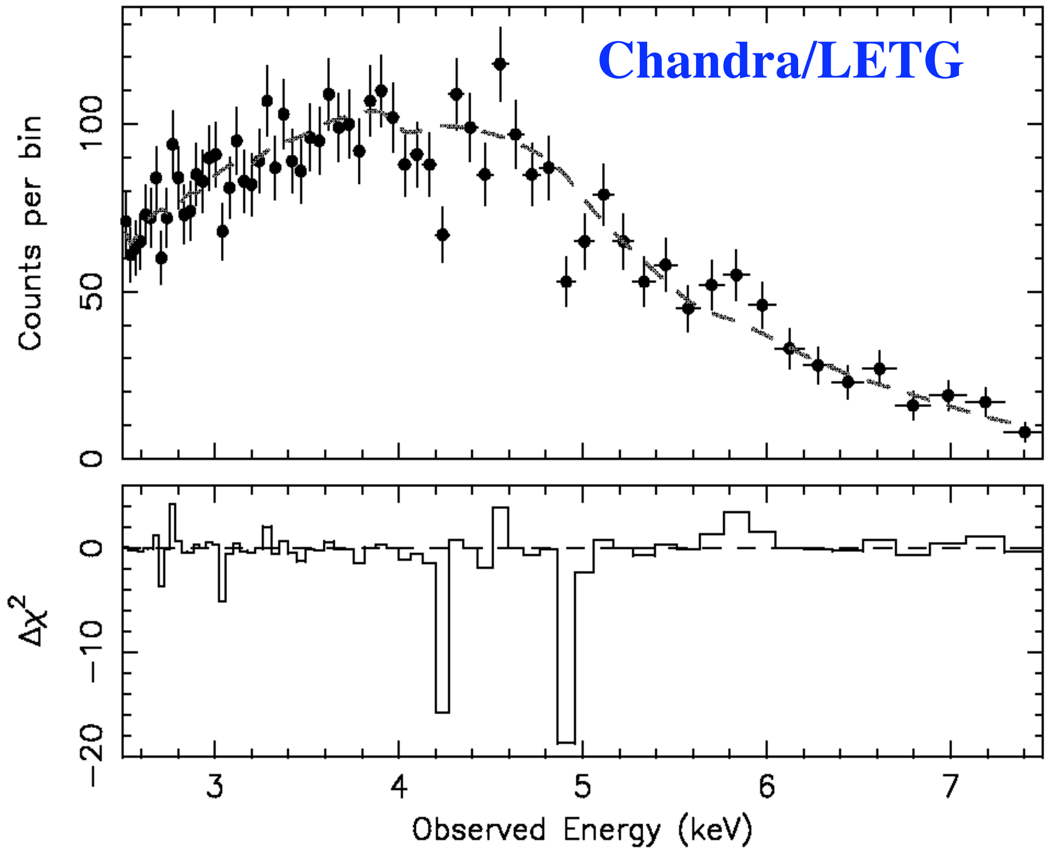
(2) then, for $v_{\mathbf{out}} \sim$ escape velocity at $r_{\mathbf{ph}}$ vout ~ 0.085c (**check 1**)

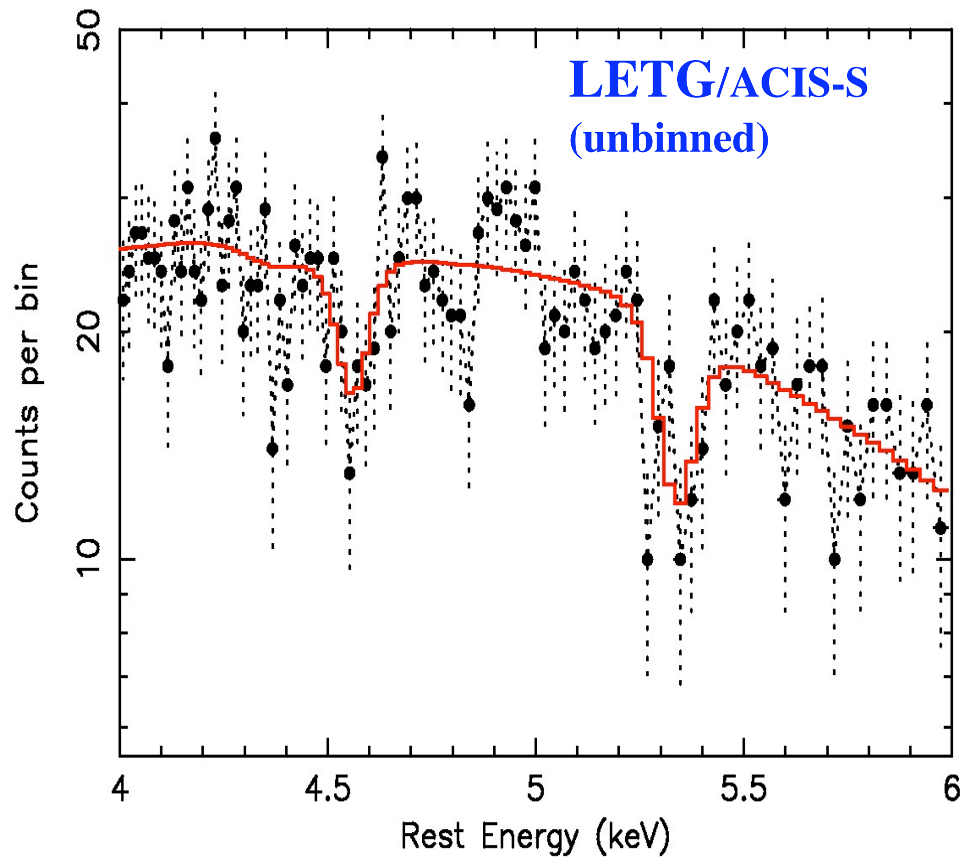
(3) outflow momentum rate $M_{\mathbf{dot.out}}.v \sim 7 \times 10^{25} \times 2.7 \times 10^{9} = 1.9 \times 10^{35}$ cgs - for a radiation-driven wind this should be of order the radiation momentum rate $L_{\mathbf{Edd}}/c \sim 5 \times 10^{45}/c \sim 1.7 \times 10^{35}$ cgs **(check 2)**

(4) Mechanical luminosity of wind $M_{\mathbf{dot.out}}.v^{2} \sim 5 \times 10^{44}$ ergs/s is then of order v/c times L_{Edd}.. **(check 3)**

Evidence of Gravitational Infall in PG 1211+143?

(Reeves et al. 2005)



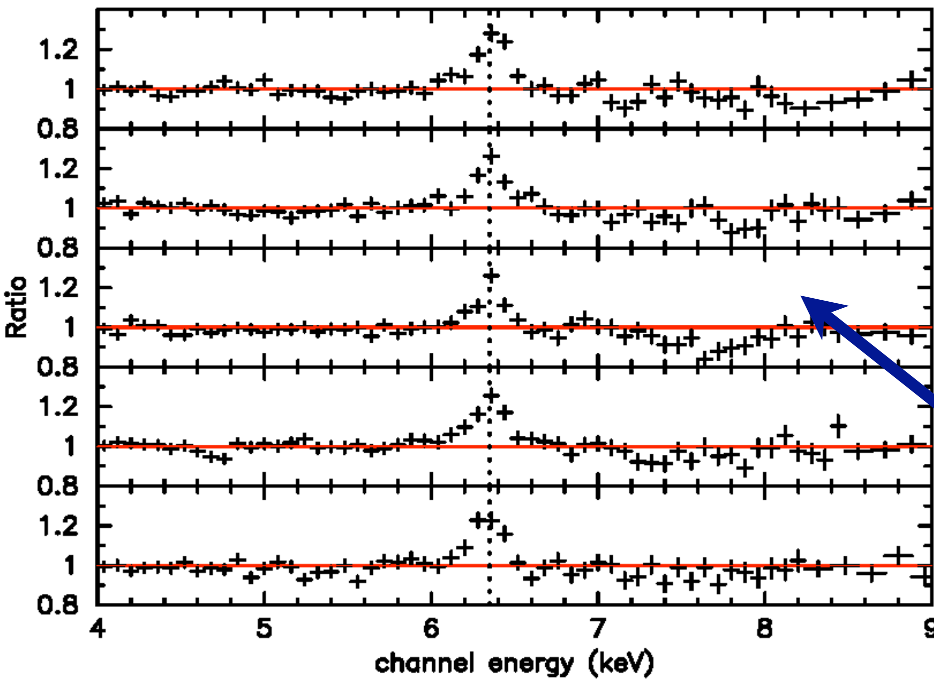


Redshifted absorption lines at 4.56 keV and 5.33 keV (rest frame). Closest known lines are from Sc XXI (4.53 keV) and V XXIII (5.43 keV) , but very low abundance.

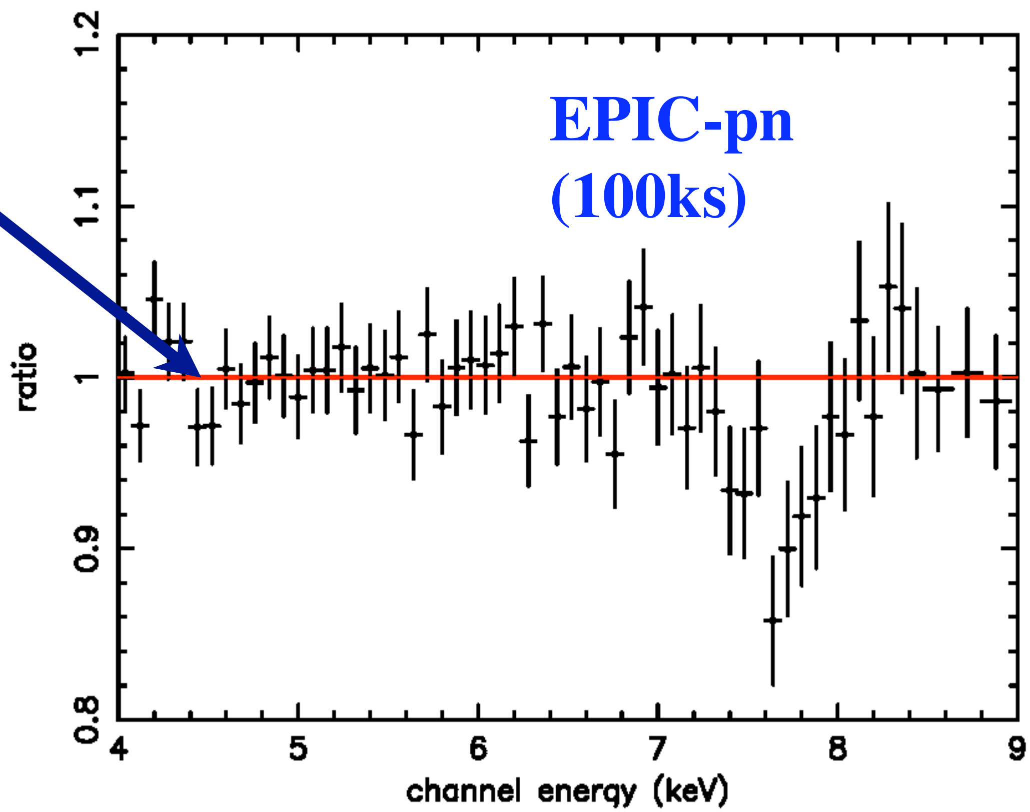
Most likely identification is with Fe XXV (6.7 keV) or Fe XXVI (4.97 keV), with velocities 0.26/0.4c. <u>Requires gravitational redshift either within <6Rg or direct infall of matter onto the black hole.</u>

A transient blue-shifted Fe K absorption line in MCG -5-23-16 (Braito et al., next session).

Fit with baseline continuum model

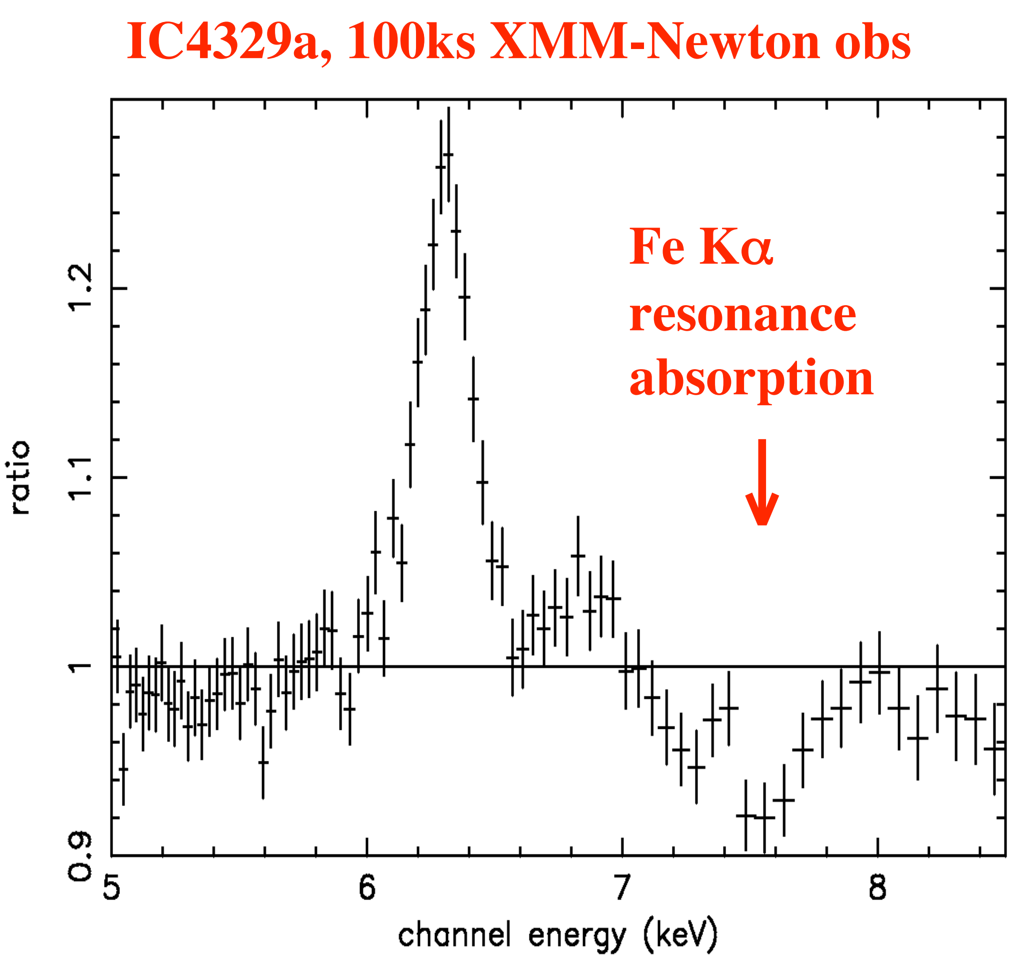


MODEL: diskline+narrow Kα+Kβ + reflection



In the 3rd spectrum a possible absorption feature is present at ~7.8 keV (Rest Frame). |EW|~50 eV ($\Delta\chi^2$~35).

A high velocity outflow in IC4329a (Markowitz et al. 2006)



Absorption line in IC 4329a spectrum at 7.68 keV (rest-frame). If associated with Fe XXVI, then outflow velocity is 27000 km s^{-1}

Feature is significant at >99.9% (Monte-Carlo). Not due to bgd (40x lower)

Well modeled by absorption from Fe XXVI Kα (6.97 keV rf) with a velocity shift of 27000 km/s.

Can rule out absorption from Fe XXII or XXIII Kβ near 7.6-7.7 keV with no velocity shift - model predicts Kα absorption at 6.6 keV (not observed)

Absorption from low ionization Kβ (Fe <XVII at 7.1-7.2 keV) with v=0.07c ruled out - requires too much bound-free abs below 6 keV.

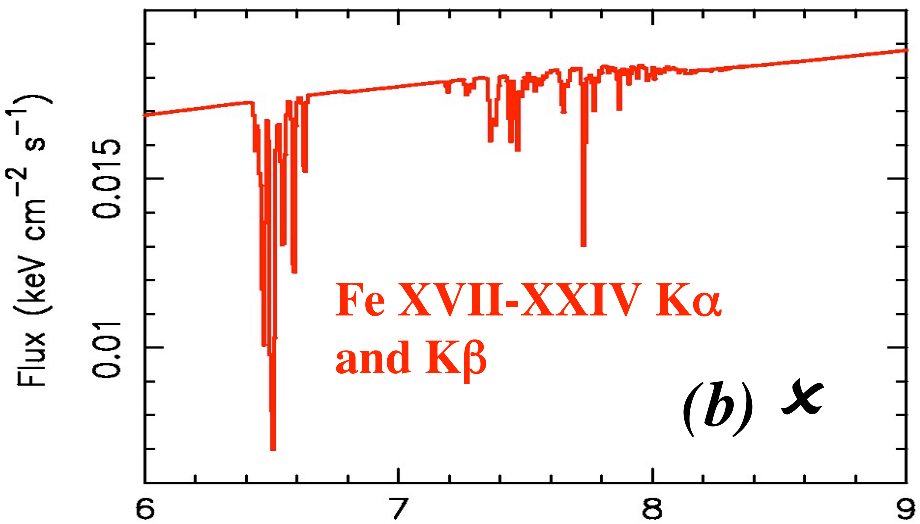
Do the iron K outflows have to be fast?

(a) High ionization fast outflow. Models the 7.6 keV feature well with an outflow of 0.1c.

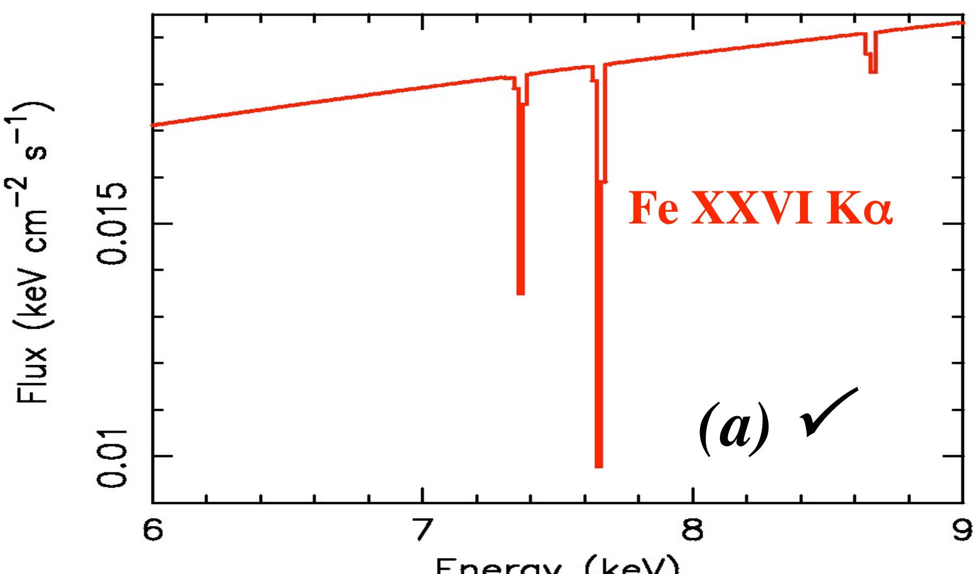
(b) Low vel, moderate ionization outflow. Absorption due to Fe XVII - XXIV Kβ near 7.6 keV. Overpredicts Kα at 6.6 keV.

(c) Low ionization outflow. Fe Kβ absorption at 7.2 keV. Also requires fast outflow (0.06c). Overpredicts abs below 6 keV.

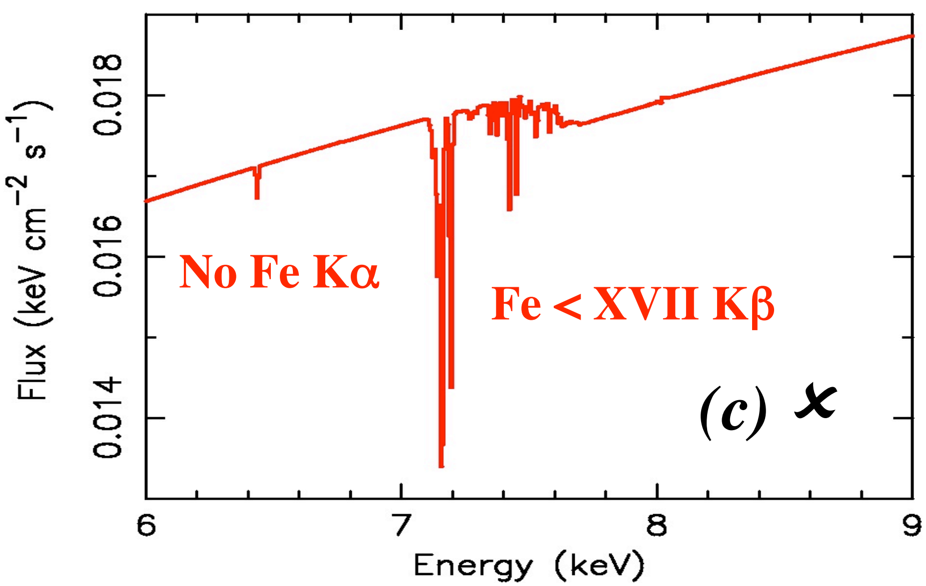
logxi=2.5, $N_H=1.5\times10^{22} cm^{-2}$, v=0



logxi=3.5, $N_H=1.5\times10^{22} cm^{-2}$, v=0.1c

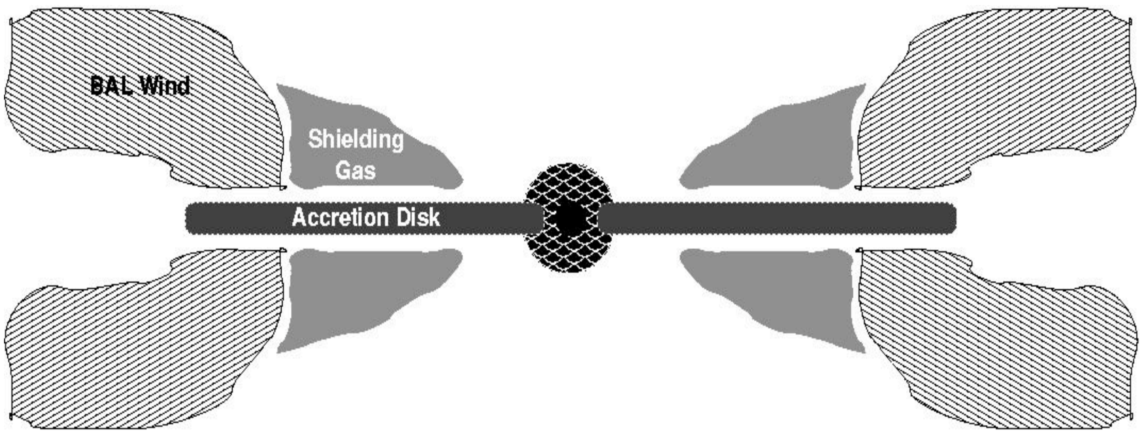


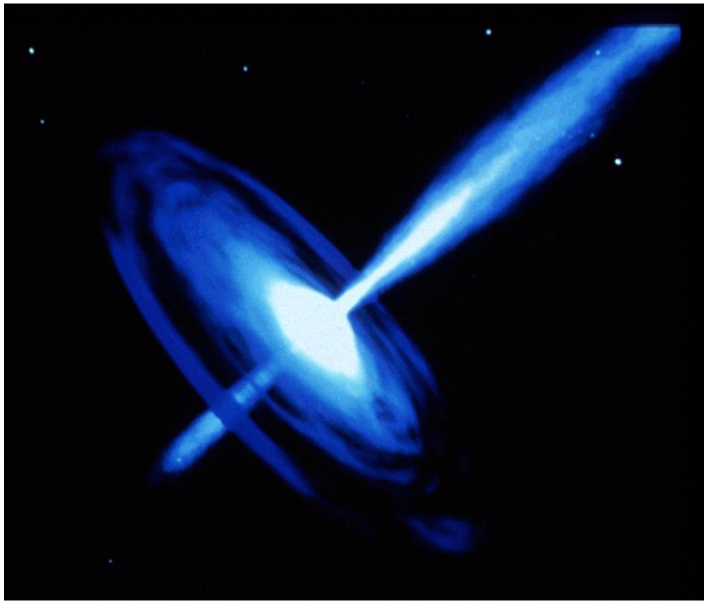
logxi=1.5, $N_H=1.5\times10^{22} cm^{-2}$, v=0



Outflow geometry and driving mechanism

Flow along disk plane (BAL) ? **Flow along BH axis?**





Black holes accreting at Eddington or above can produce optically thick winds, driven by continuum radiation presssure (King & Pounds 2003). Optically thick within ~100Rs. Mass outflow rate similar to Eddington ($M_{out} \sim M_{edd}$).

Alternative is magnetic field driving. Significant energy in magnetic field in PDS456 from rapid X-ray variability, e.g. factor x2 within 10ks with $E_{flare}=10^{51}$ erg (Reeves et al. 2002).

Conclusions -X-ray Outflows

- Highly ionized Fe K-shell absorber discovered in several Seyfert galaxies (NGC 3783, MCG -6-30-15, NGC 1365 etc). In NGC 3783 and NGC 1365, the ***Fe XXV line is variable on 10^5s timescale*** and absorber is located $<10^{16}$ cm of the black hole (BLR and within).

- High ionization absorber produces significant opacity in iron K band, which can effect modeling of the broad iron K line (although is still present in some AGN nonetheless). Wide bandpass of Suzaku will help break degeneracy between absorber and broad iron line.

- High velocity outflow discovered in a number of objects (e.g. **PG 1211+143** and **PDS 456)**, via high ionization lines/edges of iron in K-shell band.

- Mass outflow rates are VERY high - ***several solar masses per year***. Outflow rates close to Eddington rates for quasars.

- High mass outflow may be common in high accretion rate quasars. Carries a significant proportion of bolometric output. Outflow may be optically thick at ~100Rs.