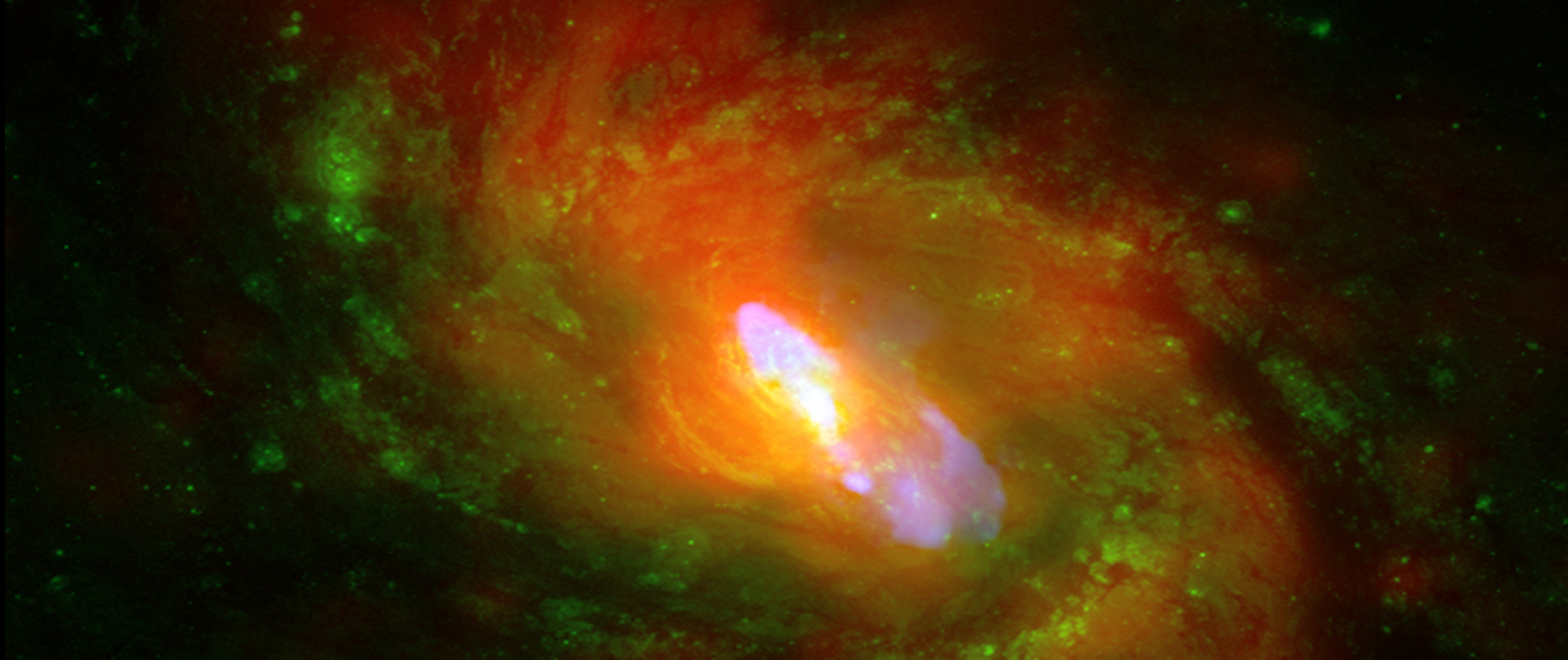
High Velocity Outflows in AGN: – the cases of PDS 456 and PG 1211+143



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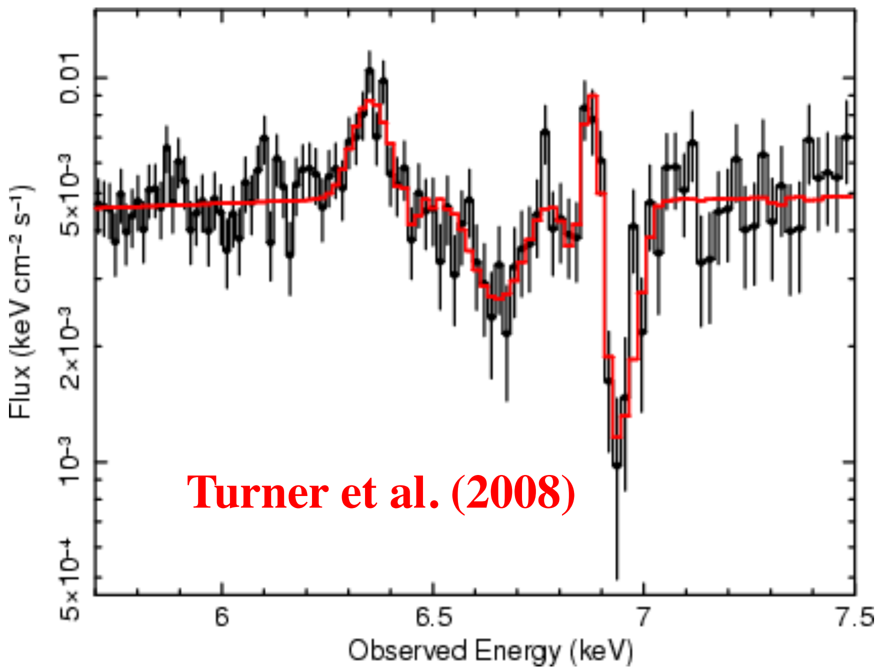
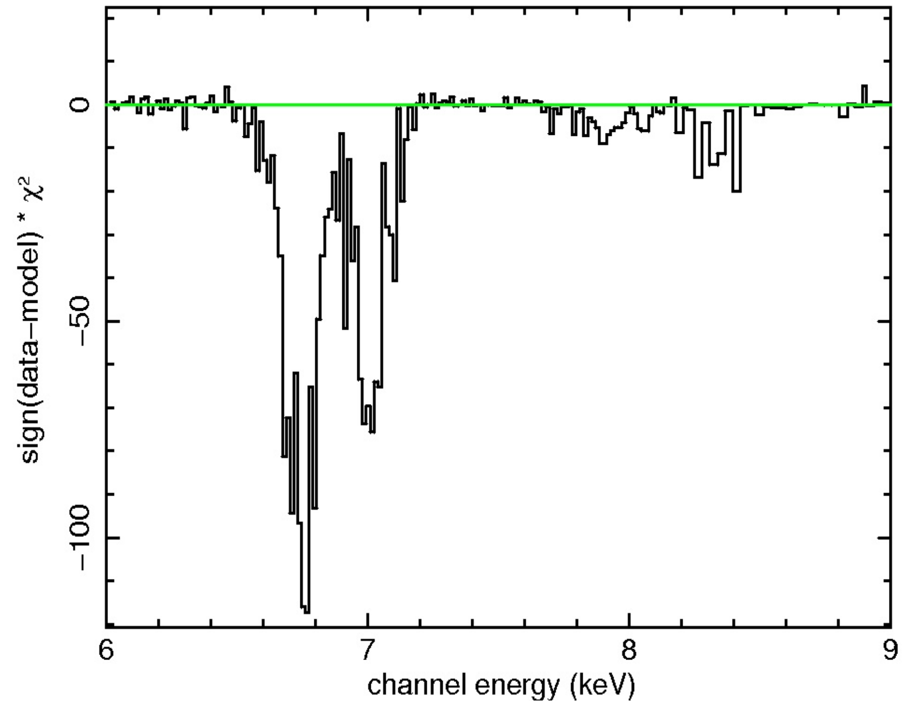
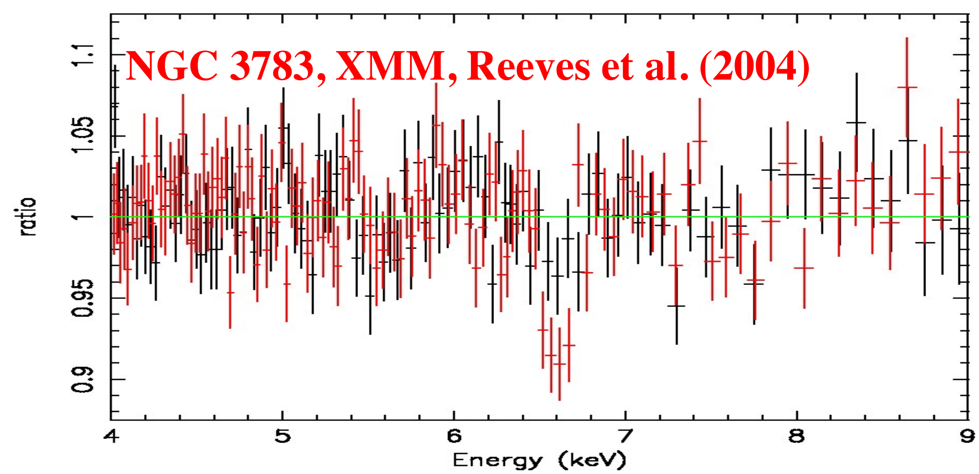
Iron K-shell Absorption in Seyfert 1s

NGC 3516, Chandra/HETG



NGC 1365/XMM, (Risaliti et al. 2010)





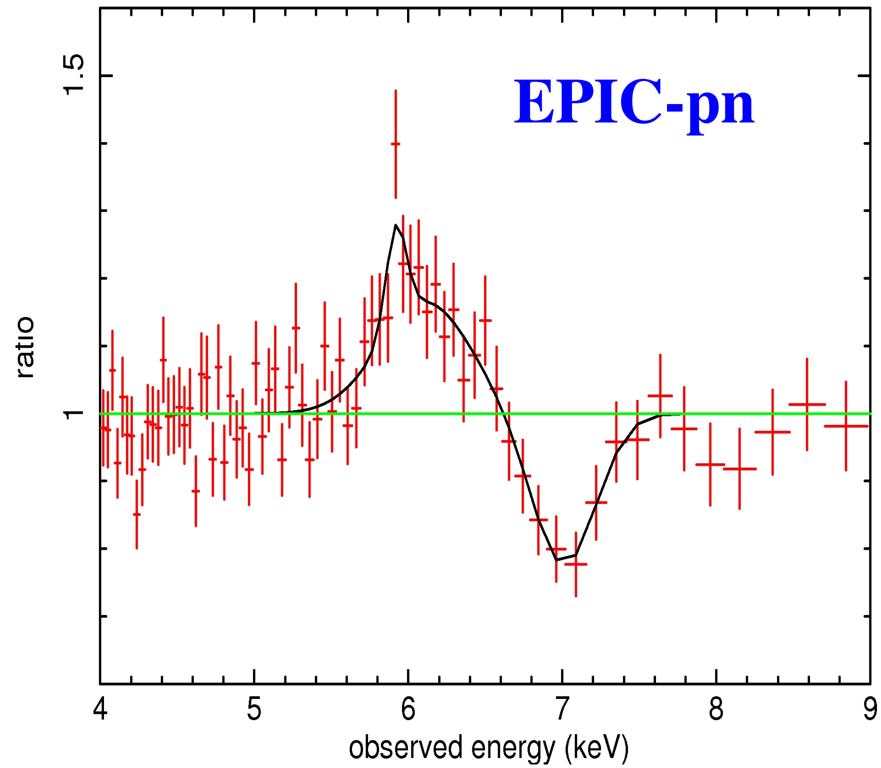
Fe K absorption signatures frequent in AGN X-ray spectra.

Column densities are high, $>10^{23}$ cm^{-2}.

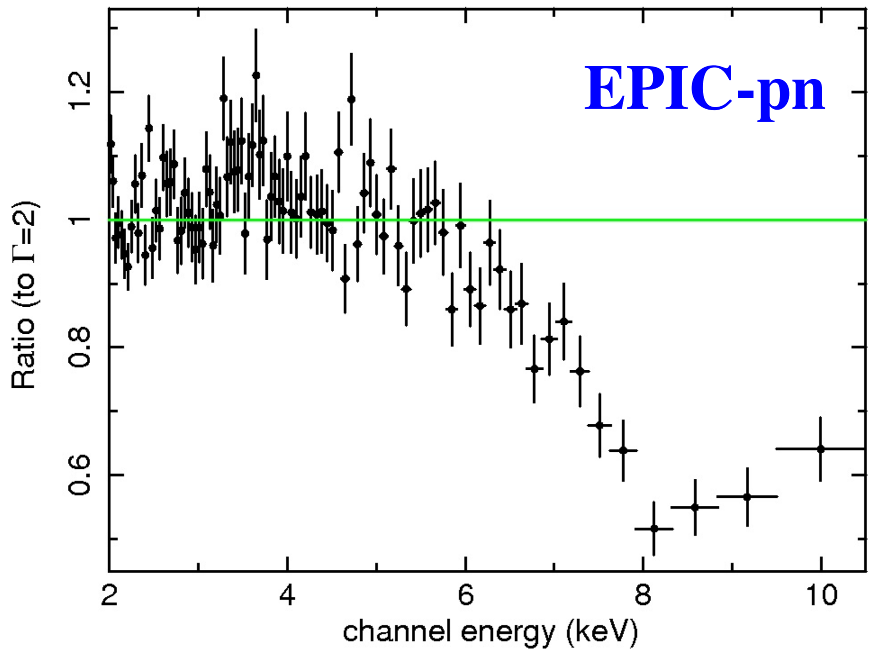
Signature of highest ionization part of outflowing material – the disk wind?

Discovery of Fast Outflows with XMM-Newton

PG 1211+143, z=0.081 (Pounds et al. 03, PR09)



PDS 456, z=0.184, (Reeves et al. 03)



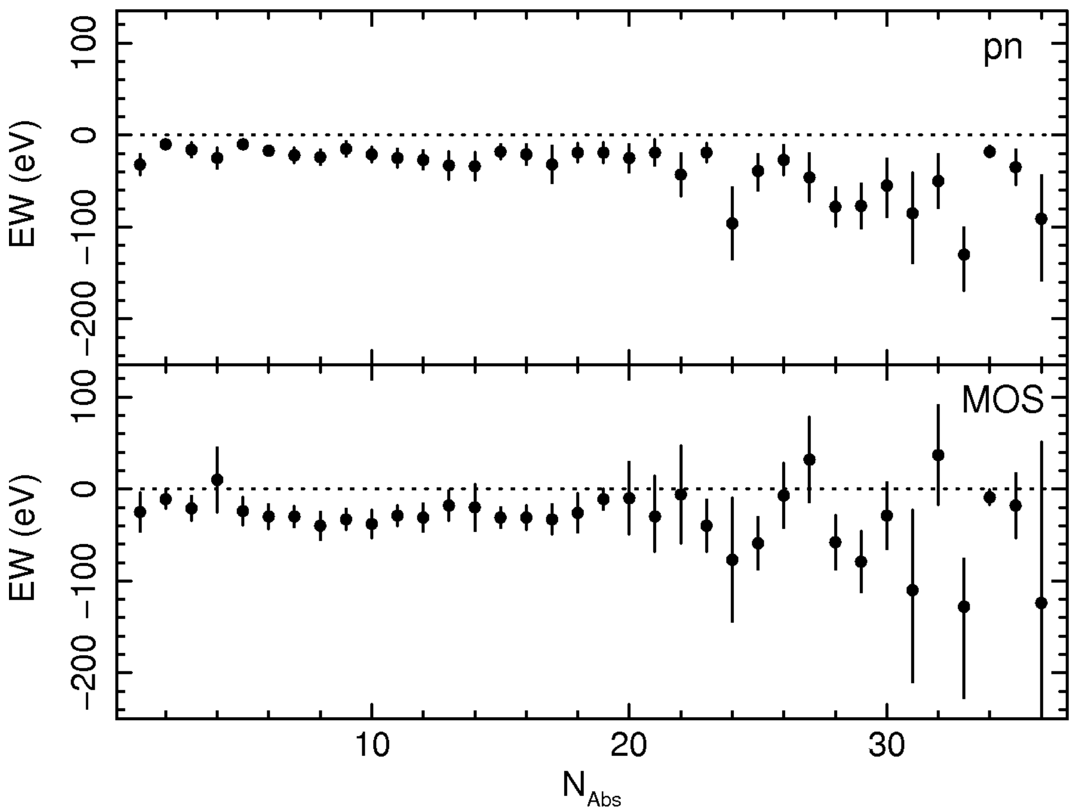
Blue-shifted absorption due to highly ionized iron (e.g. Fe XXV) as well as Mg/Si/S.

Velocities implied are 0.1-0.2c, launched from < 100Rg, with columns up to 10^{24} cm^{-2}. Suggests kinetic power can approach large % of L_{bol}.

Also X-ray BAL QSOs (Chartas et al. and collaborators)

XMM-Newton Sample of Iron K Absorption Lines
"The search for UFOs" (Tombesi et al. 2010)

Tombesi et al. (2010) have systematically analysed a sample of X-ray bright AGN selected from the RXTE slew survey and observed by XMM-Newton to compile a sample of Fe K absorption lines



36/101 observations with Fe K absorption.

35% of AGN have blue-shifted lines at >95% confidence (Monte-Carlo.

Overall null probability of **$P<3x10^{-8}$** (pn only). **11/42 AGN with v>0.1c.**

MOS observation independently confirm detections.

Covering Fractions are high - at least 40% of local AGN likely to contain such outflows.

Ultrafast Outflows in AGN

• How much mass is carried out of the AGN by the outflow - need to know *covering fraction* and location of the outflow.

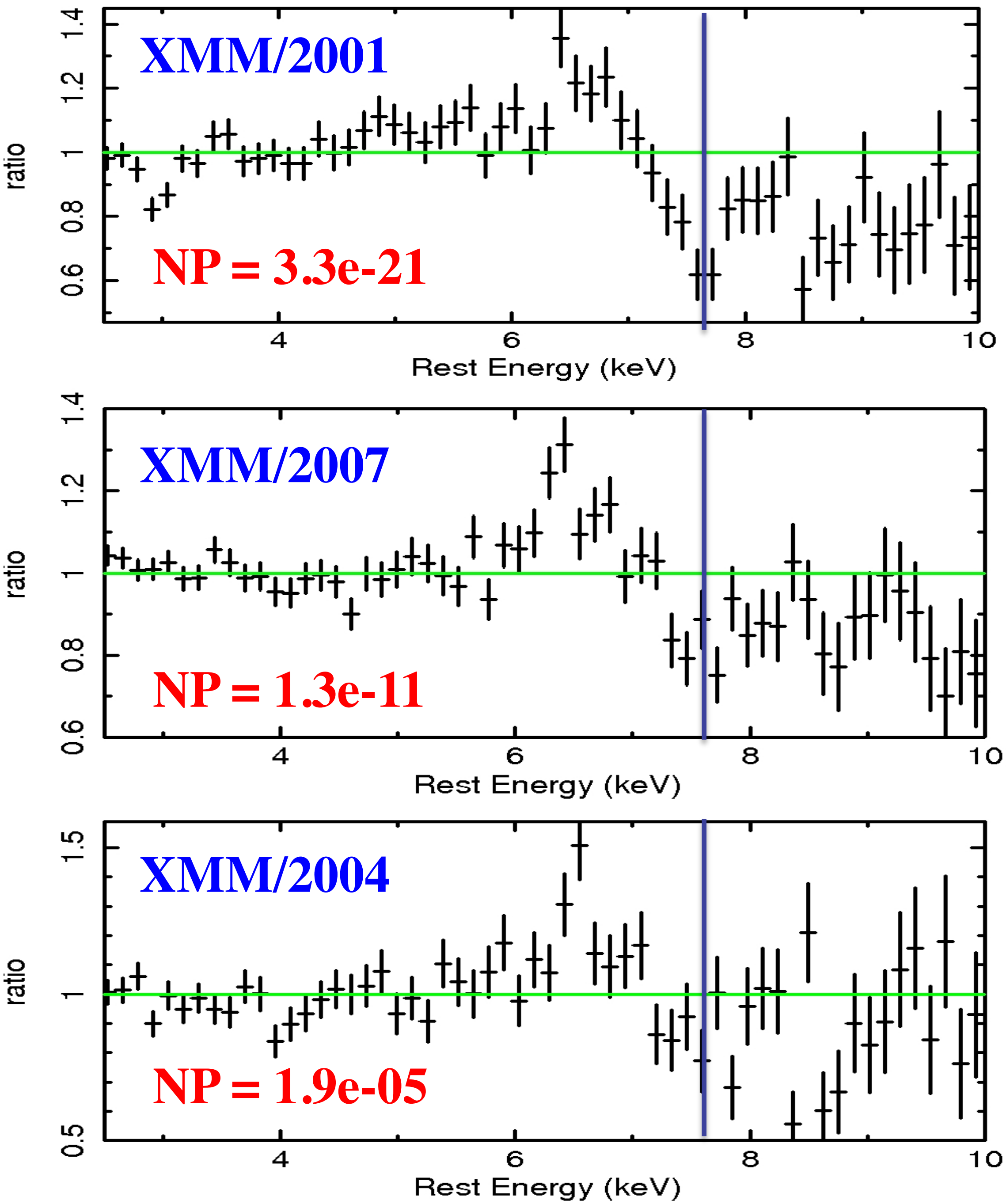
• How does it compare to the amount of matter being accreted?

• Does the ionized outflow carry a significant fraction of the energy output of the AGN? - i.e. prop to ***(outflow velocity)^3***

[c.f. $E=10^{59}$ erg binding energy of a bulge with 10^{11} M_{solar} and σ=300 km/s.]

•Can the outflow regulate the growth of the black hole and the galaxy (bulge) through feedback, i.e. a physical explanation of the M-sigma relation (e.g. King & Pounds 2003; King 2003, 2010)?

High-velocity outflows, with v~0.1c in high accretion rate AGN, are potentially energetically significant.



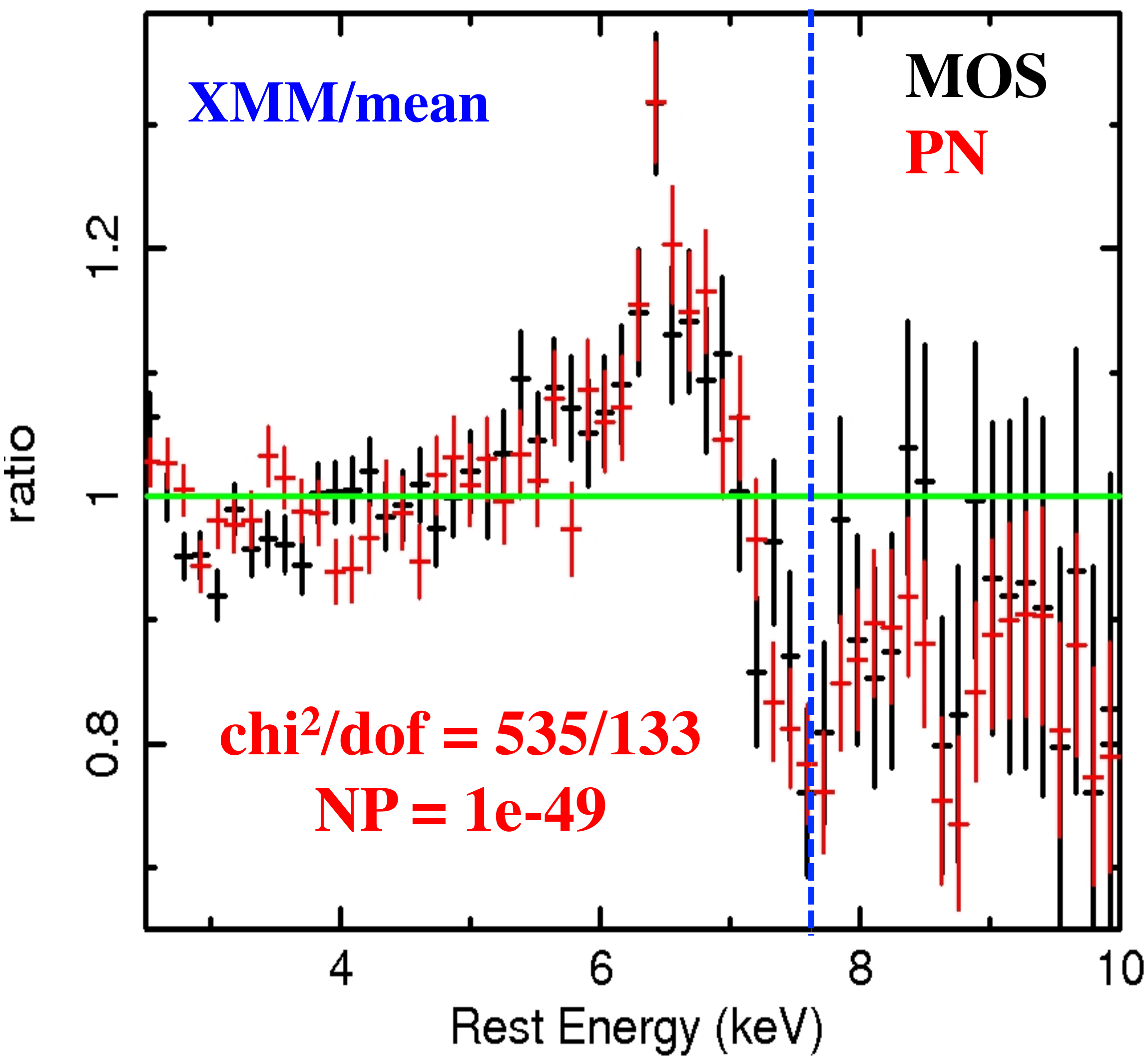
XMM-Newton Observations of PG1211+143

Three observations of PG 1211+143 with XMM:- 2001, 2004, 2007.

Net pn exposures of 49ks (2001), 33ks (2004), 69ks (2007).

7.6 keV (QSO rest-frame) absorption detected both in 2001 and 2007. Short 2004 spectrum noisy, but consistent with 2001/2007 within errors.

PG 1211+143 – the outflow that always was



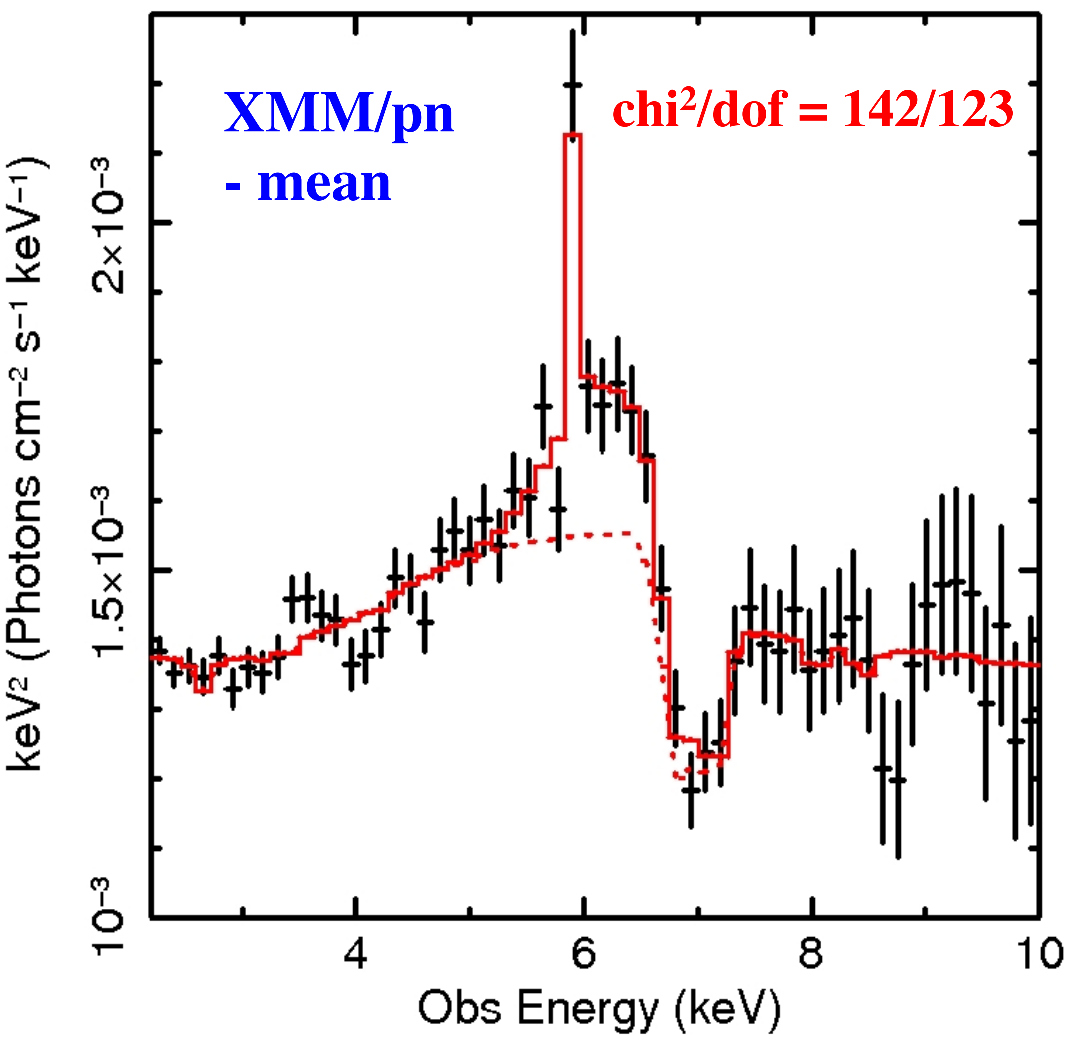
Mean XMM-Newton spectrum of PG1211+143 from 2001-2007.

Total exposure 151 ks (5.5 cts/s pn, 2.4 cts/s MOS).

MOS provides clear confirmation of absorption line profile centered at 7.6 keV (QSO rest frame)

Null probability that simple PL continuum is an acceptable fit is **1e-49**!

PG 1211+143 – modeling of absorption profile



Absorption profile requires both broad ionised Fe K emission (FHWM 30,000 km/s) and a highly ionised absorber (He, H-like Fe).

Xstar absorption parameters:-

N_H = (1.1+/-0.2) x10^{23} cm^{-2}

v_{out} = 0.10+/-0.01c

v_{turb} = 10000 km/s (fixed)

log xi = 4.0+/-0.2

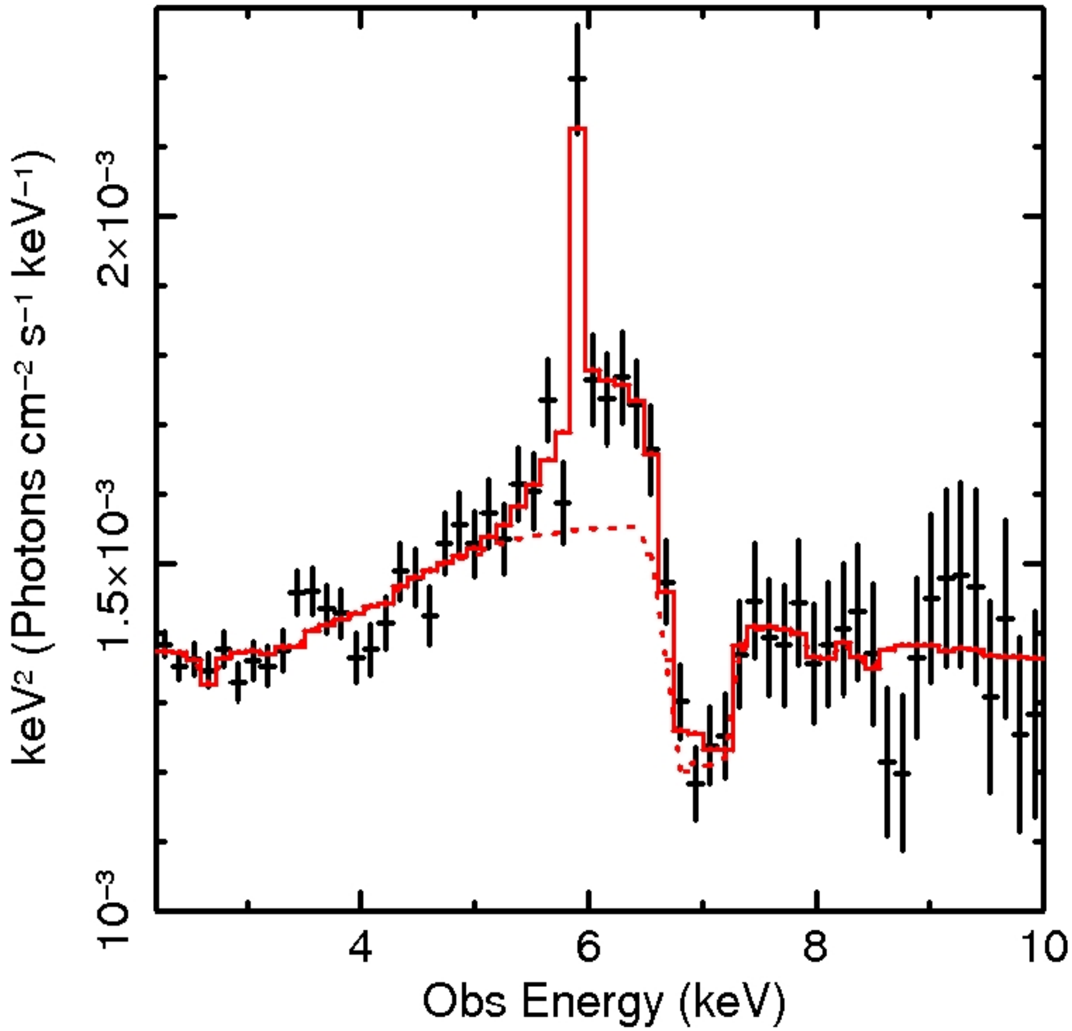
L_{ion} = 2e44 erg/s (1-1000 Ryd)

$L_{(2-10)}$ = 6.5e43 erg/s

Implies wide angle outflow – half angle approx. 50 degrees.

Global covering = 0.33-0.5

PG 1211+143 – wind mechanics



Thus derived numbers for PG 1211+143 implies:-

$nR^2 = L/\xi = 2x10^{40}$ cm^{-1}

M_{out} = $(4\pi b)$ nR^2 m_p v_{out}. So:-

M_{out} = **8 $M_\odot$ yr^{-1}** for b=0.4

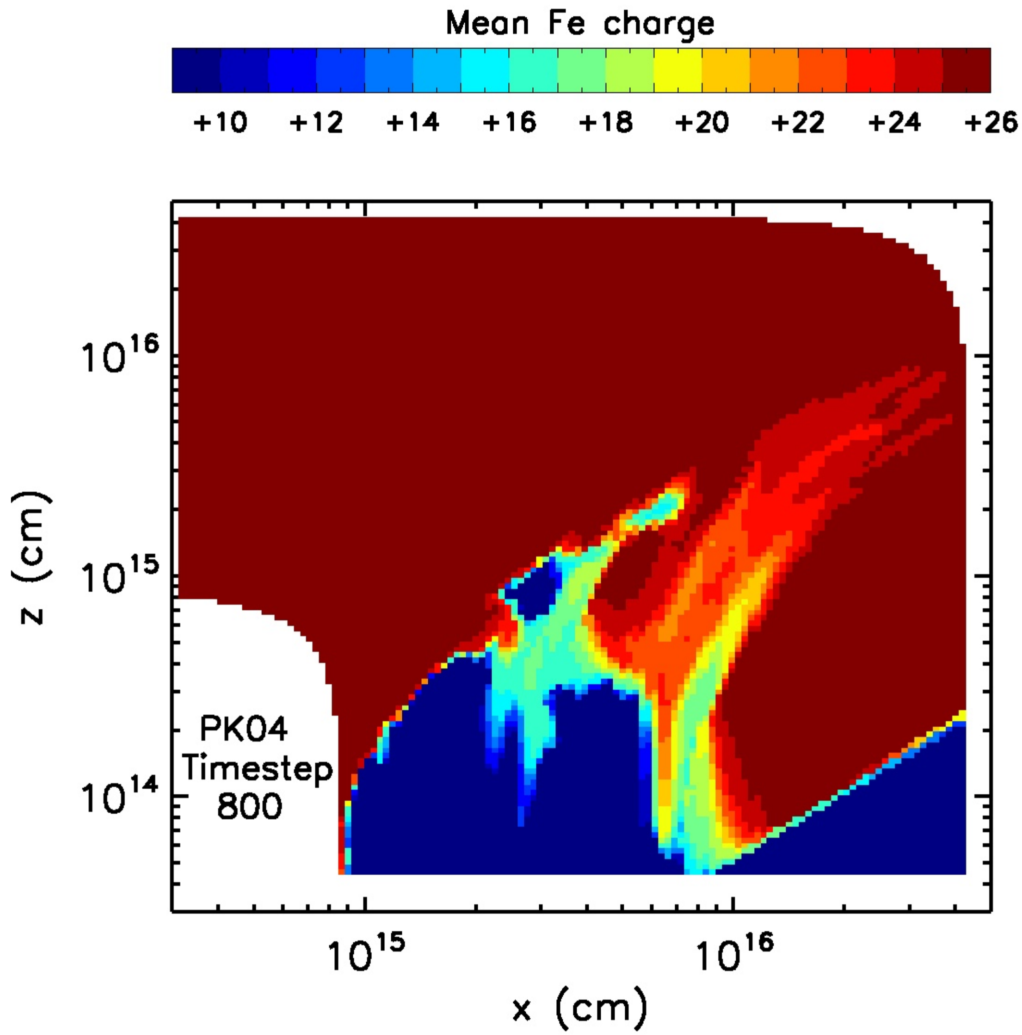
E_{out} = **2x10^{45} erg/s**

For $10^8 M_\odot$ (Peterson 2004):-
M_{Edd} = 4$M_\odot$yr^{-1} (for η=0.05)

Also **M_{out} v_{out} ~ L_{Edd} / c**

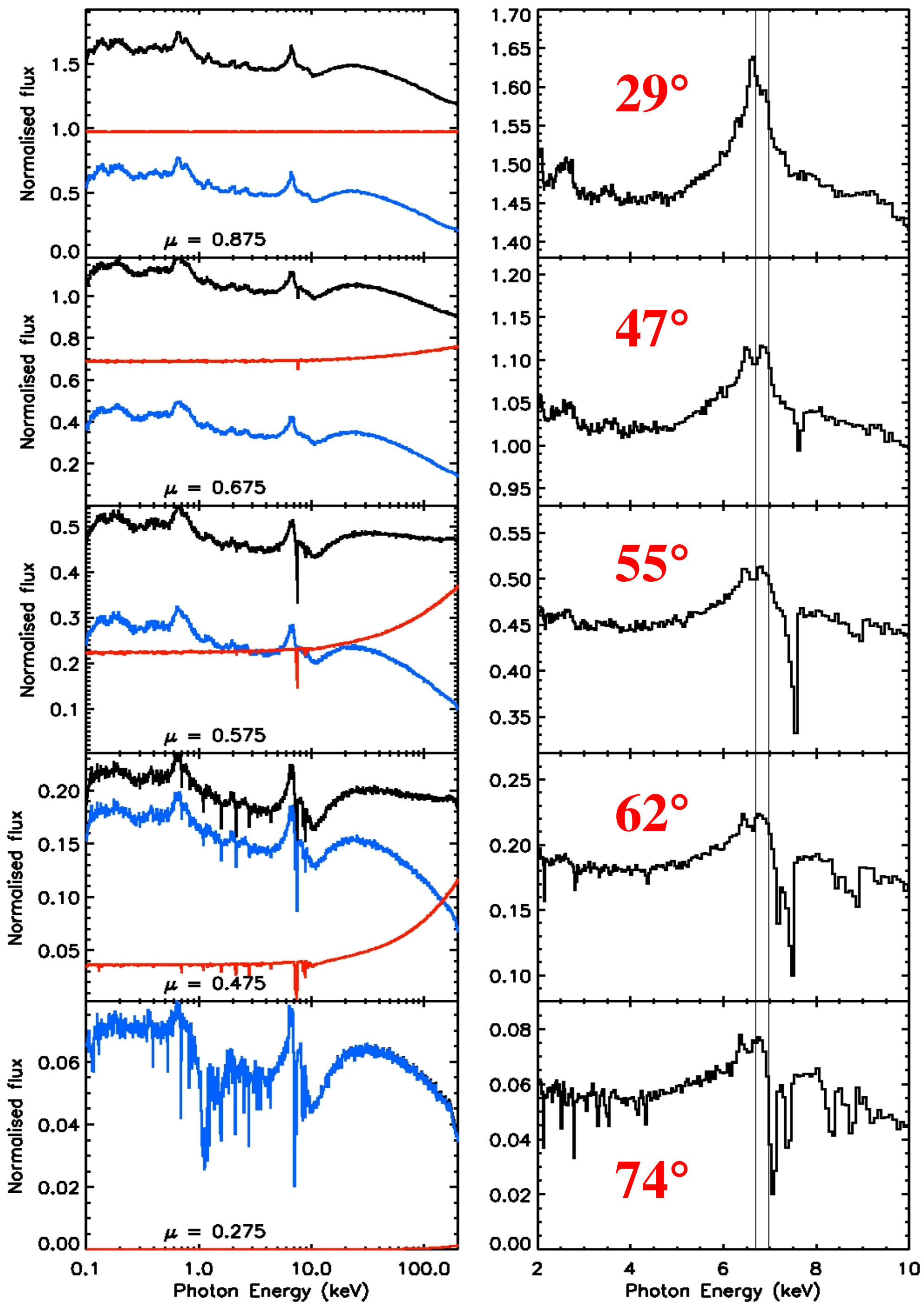
Radiatively Driven Accretion Disk Winds

- Disk winds simulations of Sim et al. (2010), Proga & Kallman (2004)
- Reproduces the blue-shifted absorption lines at Fe K



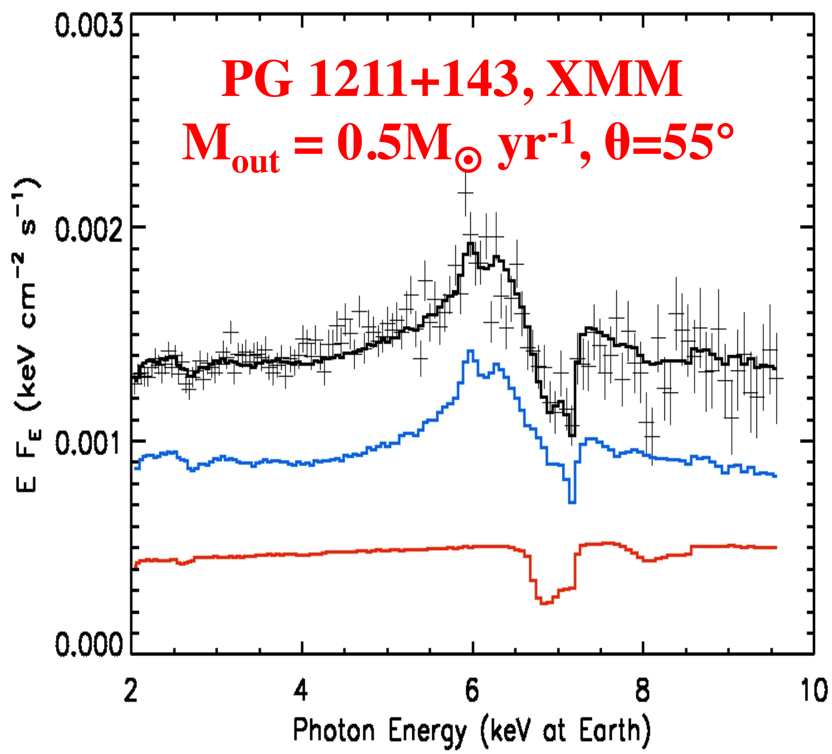
Accretion Disk Winds

(Sim et al. 2010a, b)



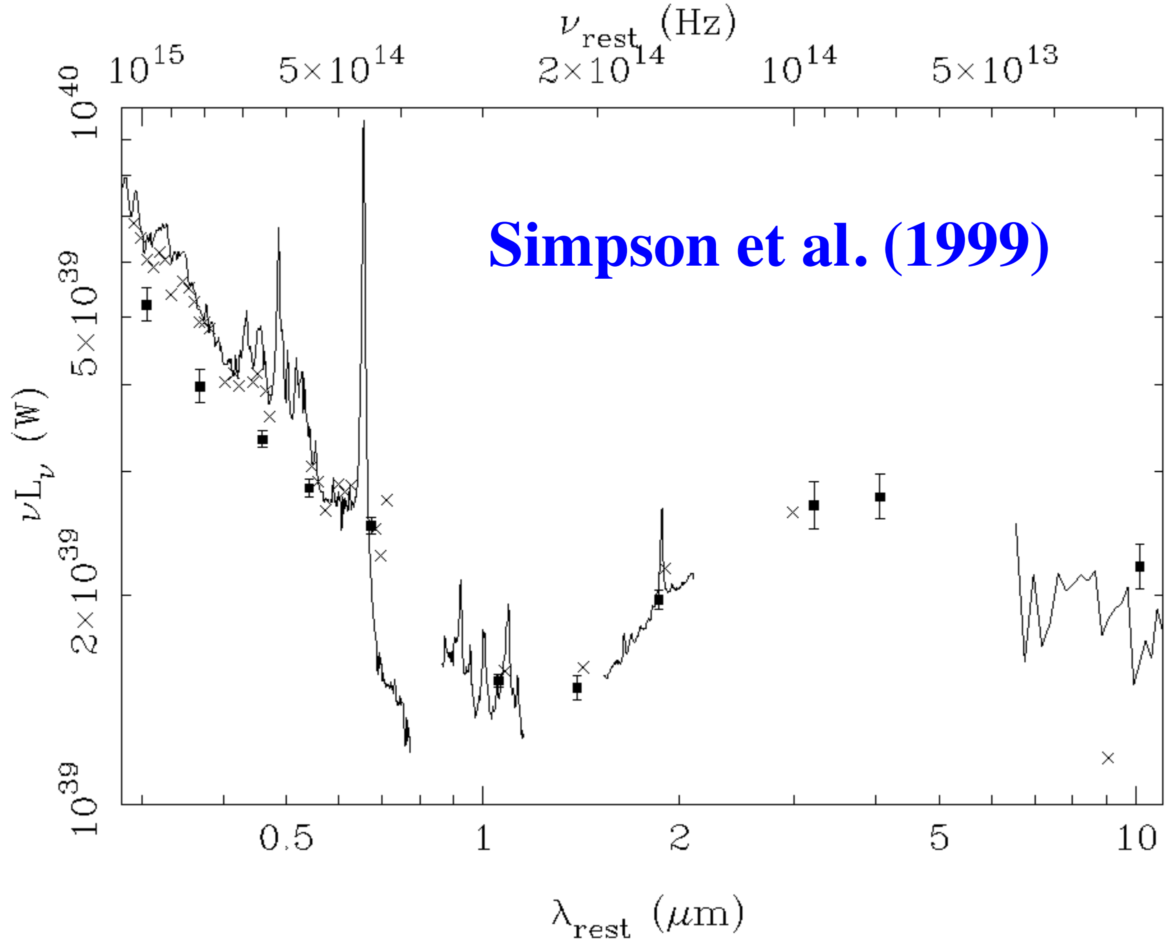
Wind spectra vs inclination

Reproduces P-Cygni like Fe K absorption in PG 1211 (e.g. Pounds & Reeves 2009)

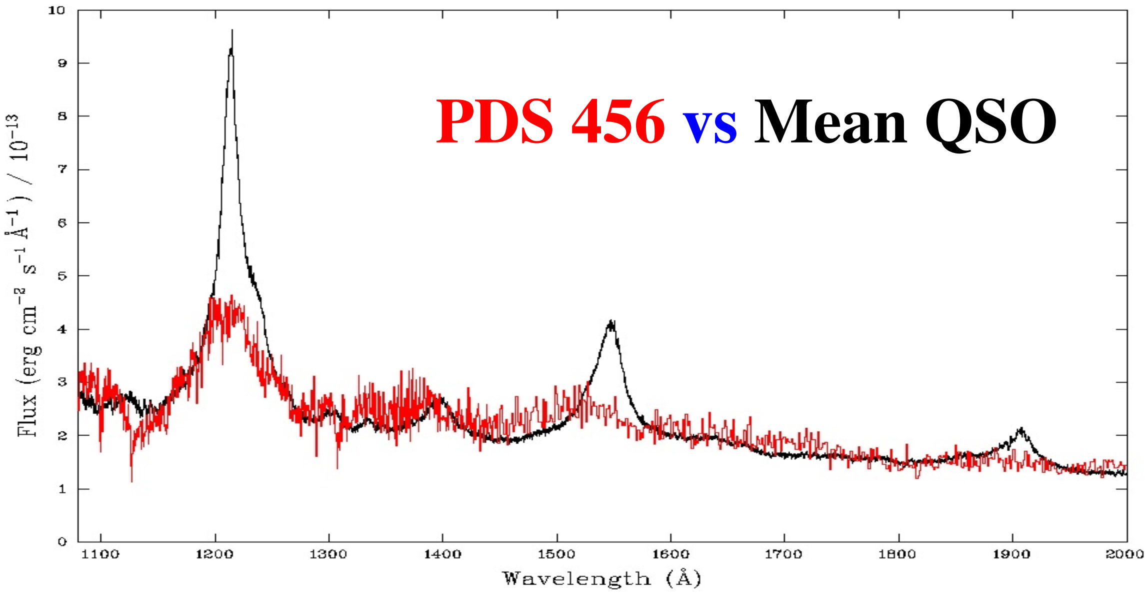


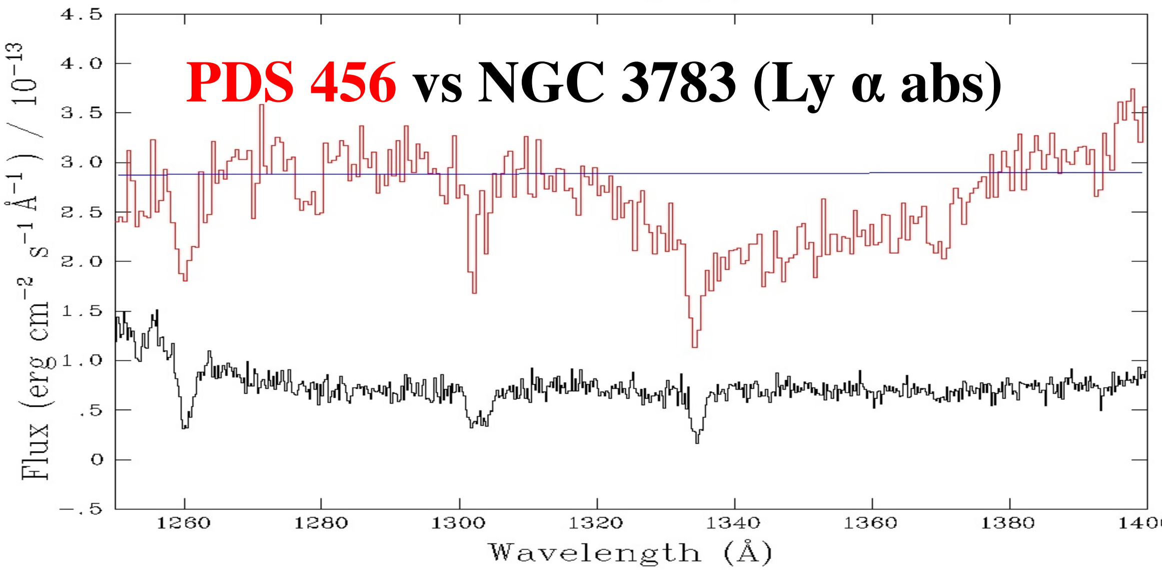
The Most Luminous Nearby Quasar PDS 456

Discovered a decade ago (Torres 1997) - very luminous broad-lined radio-quiet QSO at z=0.184. Most luminous AGN at z<0.3, more typical of z~2 QSOs - *$L_{IR\text{-}UV} \sim 10^{47}$ erg/s (1.7 x 3C 273).*



HST/STIS UV Observations - BAL like features?





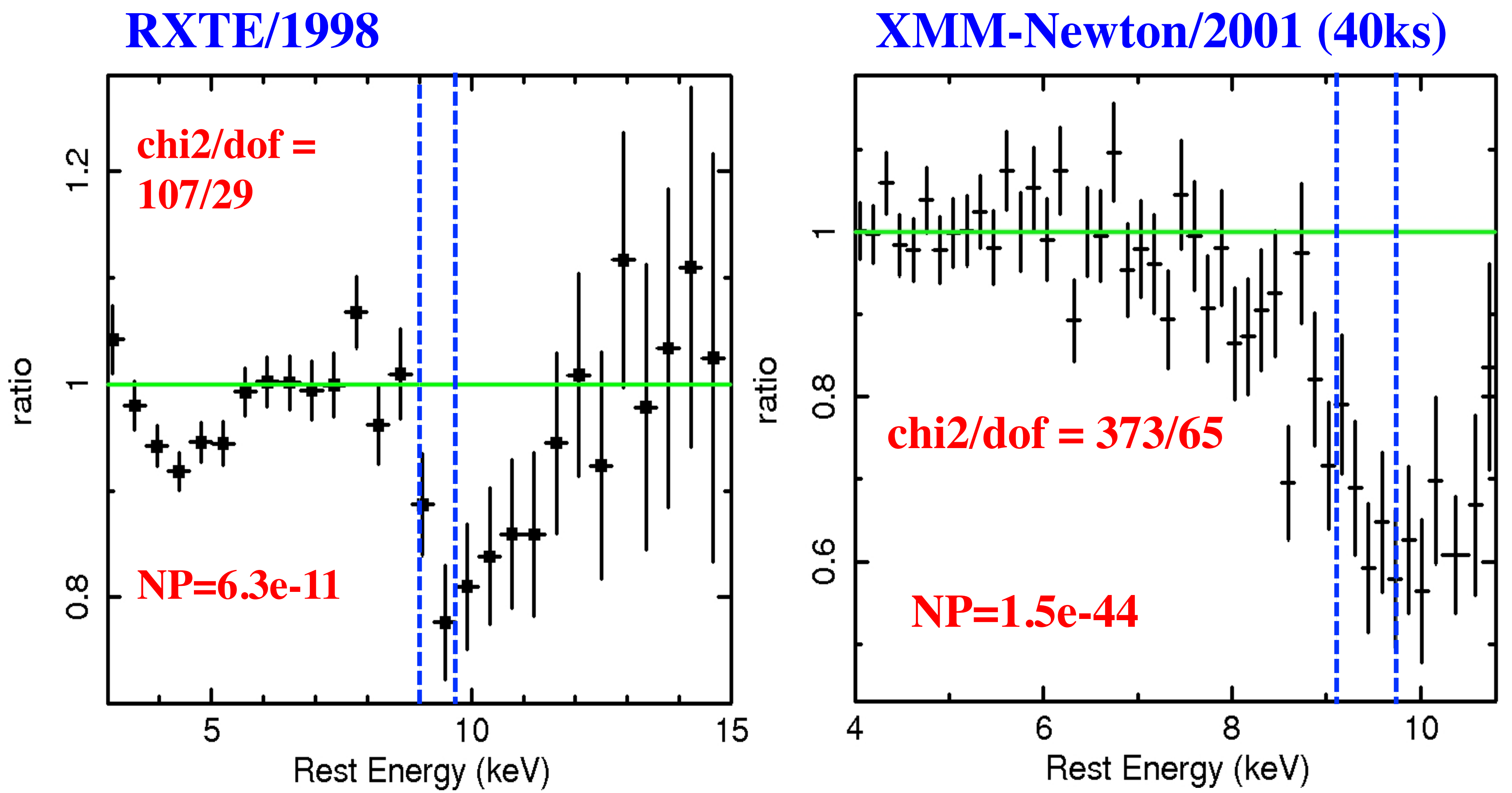
1 orbit STIS spectrum (O' Brien et al. 05)

In the UV, PDS 456 shows very broad emission (e.g. Ly-α and CIV), FWHM of **14000 km/s**.

Lines are blueshifted, - *CIV v=5200+/-500 km/s*.

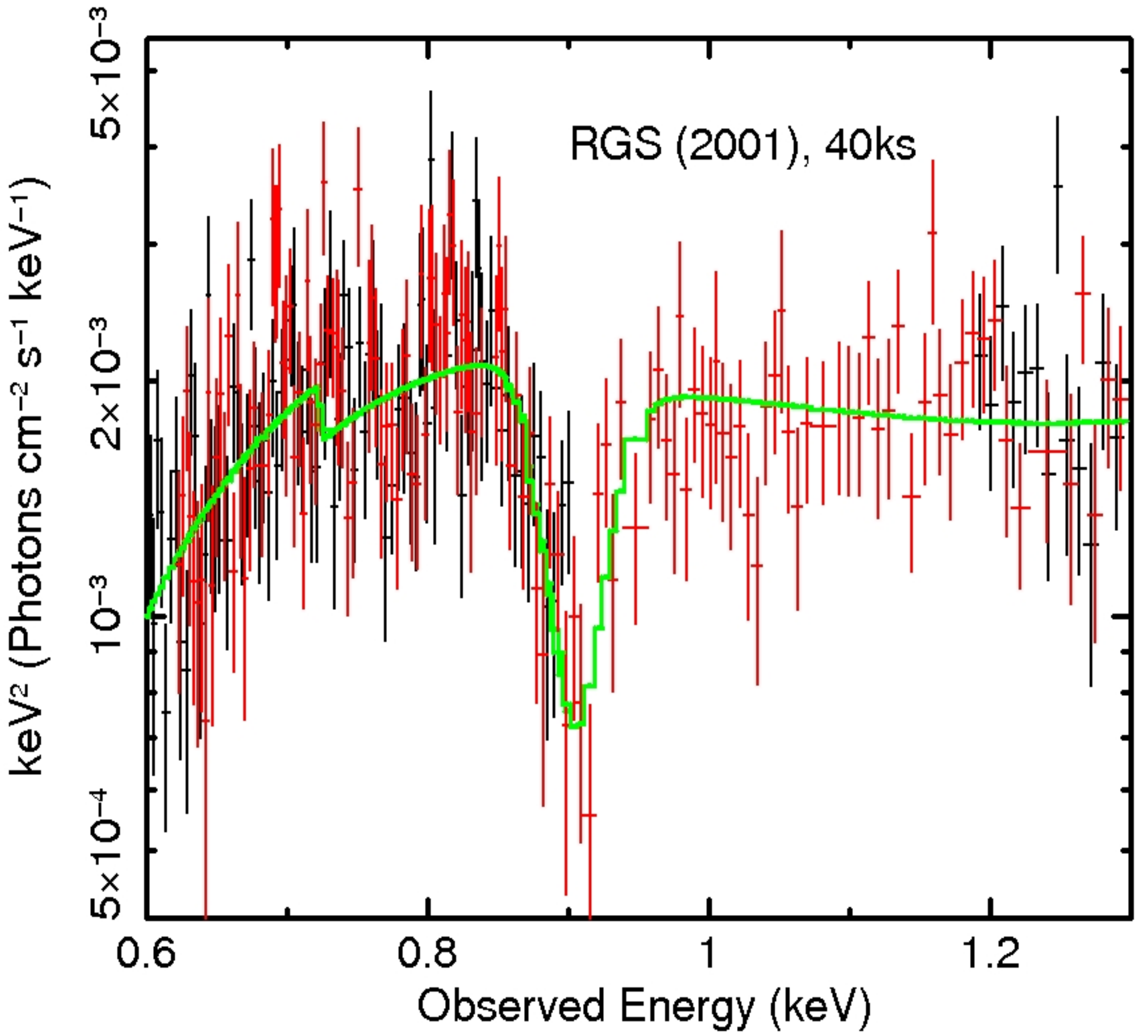
Absorption feature blue-wards of Ly α , if attributed to Ly α than *v_{out}=14000-24000 km/s*

PDS 456 – Previous X-ray Observations



Strong E>9 keV rest frame absorption detected in earlier RXTE (1998) and XMM-Newton (2001) observations of PDS 456 at high confidence.

PDS 456 – 2001 XMM-Newton RGS



Broad absorption profile detected in 2001/XMM-Newton RGS spectrum.

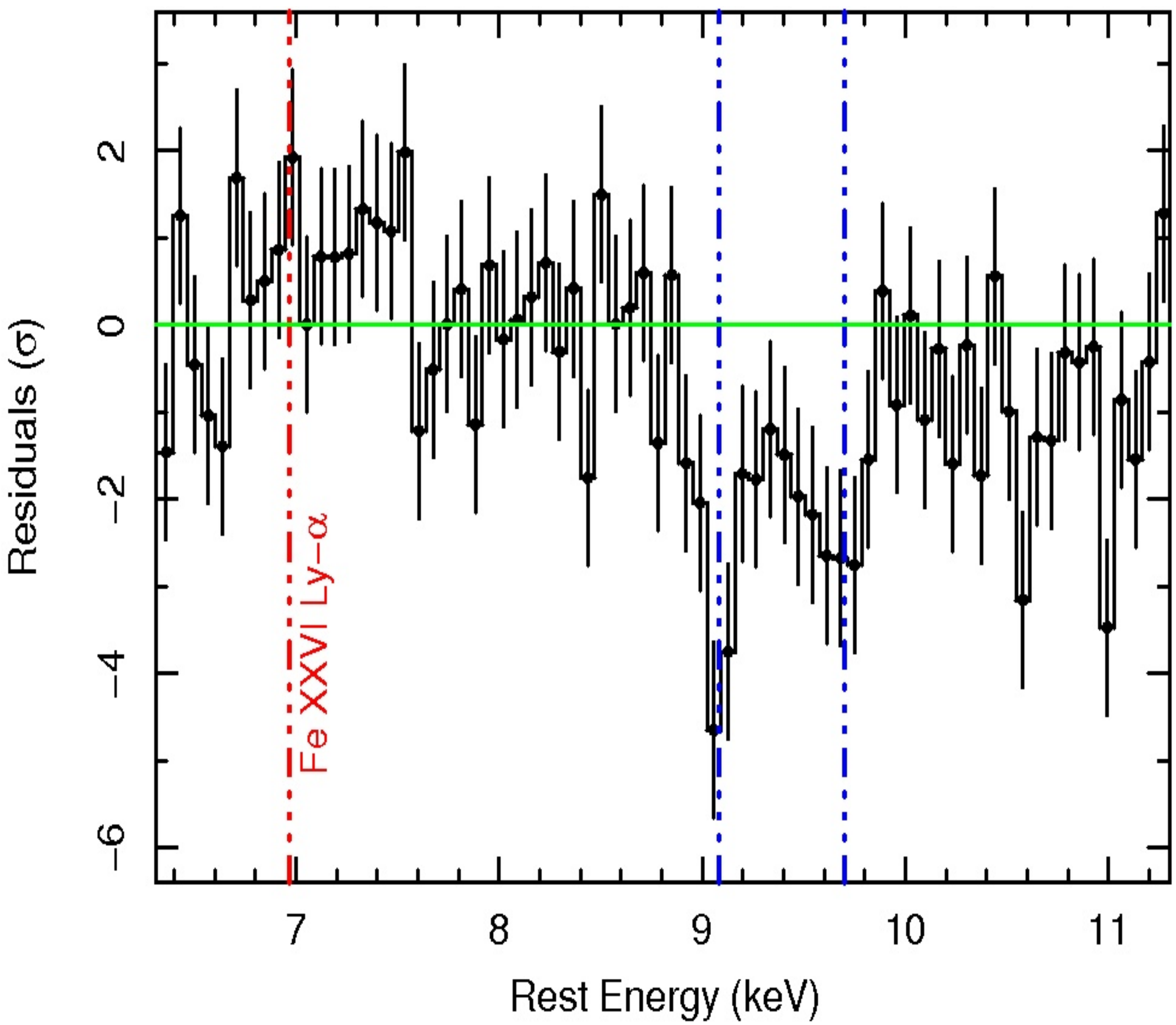
Rest frame energy ~ 1-1.1 keV

Likely associated with iron L-shell absorption, blended also with Ne X Ly-alpha

Recent modeling (Behar et al. 2010) – log xi = 3.1, $N_H \sim 10^{23}$ cm^{-2}, v_{out}=14000 km/s – connection to UV profiles?

Relativistic Outflow in PDS 456 (QSO, z=0.184)

(190 ks Suzaku Observation; Reeves et al. 2009)



Absorption lines resolved with Suzaku at 9.08/9.66 keV (rest frame)

Outflow velocity of 0.25-0.30c, if associated with Fe XXV/XXVI resonance lines (at 6.7-6.97 keV).

Requires $N_H > 10^{23}$ cm^{-2}, with logξ=4.5 to model strong absorption lines.

Detection very robust (MC) >99.99% confidence.

PDS 456 Outflow Energetics

- PDS 456 observables:- $N_H \sim 10^{24}$ cm^{-2}, log $\xi \sim 4.5$ and $v_{out}=0.25c$, $L_{ion}=3\times10^{45}$ erg s^{-1}, $L_{bol}\sim10^{47}$erg s^{-1}. BH mass estimate $M_{BH}=2\times10^9 M_{sun}$.

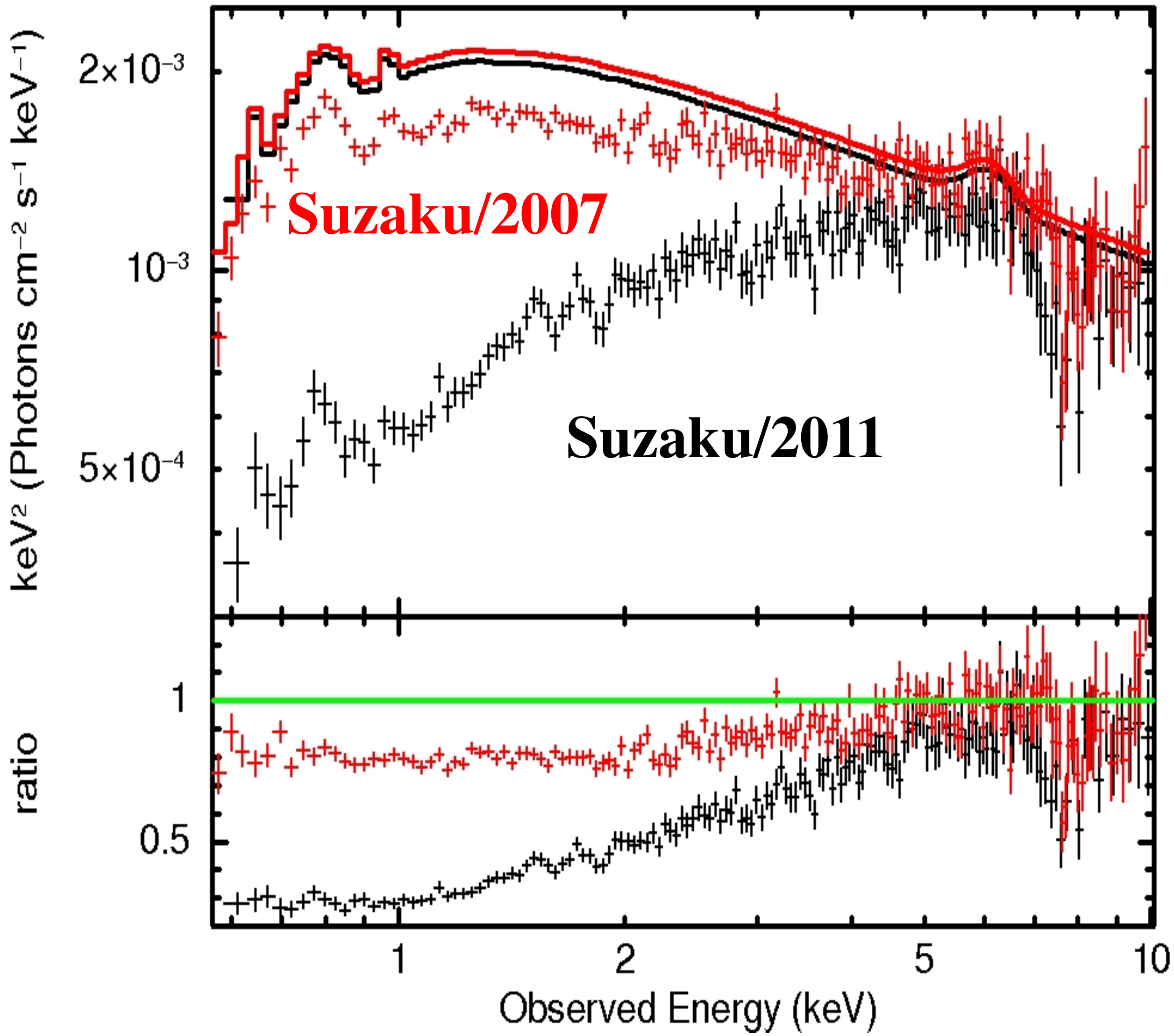
- Outflow Rate $M_{out} = 4\pi\, b m_p v_{out} L_{ion} / \xi \sim 100b\ M_{sun}\ yr^{-1}$

- Kinetic output dE/dt = 1/2 $M_{out} v_{out}^2 \sim 10^{47}$ b erg s^{-1}

- Likely wind radius $R_{in} < L_{ion} / (\xi\ N_H) \sim 100\ R_g$

- If $L_{out} \sim 10^{47}$ erg/s for lifetime of QSO phase ($t > 10^7$ yr) then *$E>10^{61}$ erg* [c.f. $E=10^{59}$ erg binding energy of a bulge with 10^{11} M_{solar} and σ=300 km/s.] **May produce significant feedback**.

PDS 456 – Absorber Variability



Original 2007 Suzaku of PDS 456 at high flux - ratio to steep powerlaw (Γ=2.4)

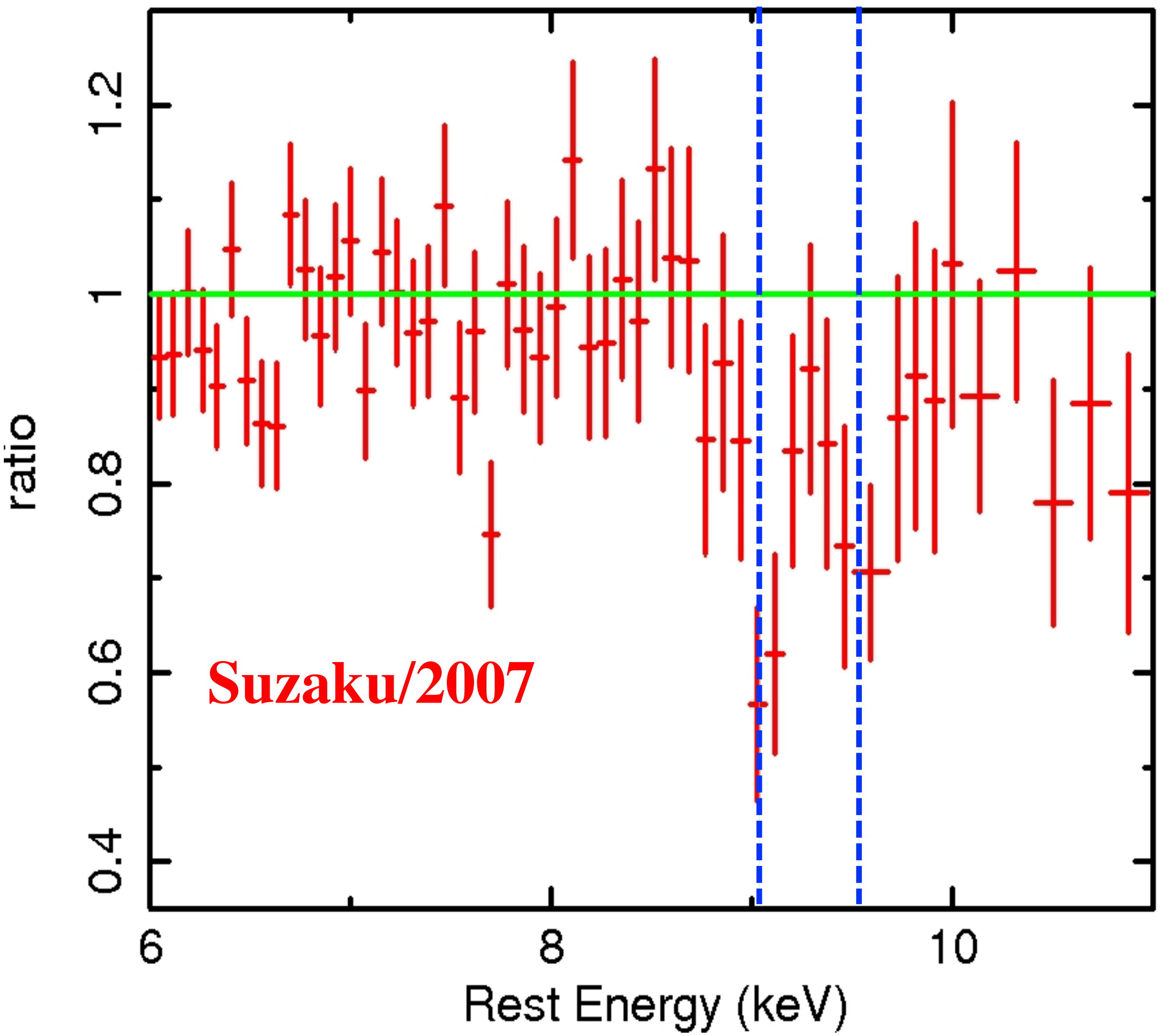
Note iron K absorption above 7 keV (observed).

New 2011 Suzaku data (120ks), at lower flux.

Spectral changes can be accounted for by changing in covering fraction of low xi absorber (<30 to 70%)

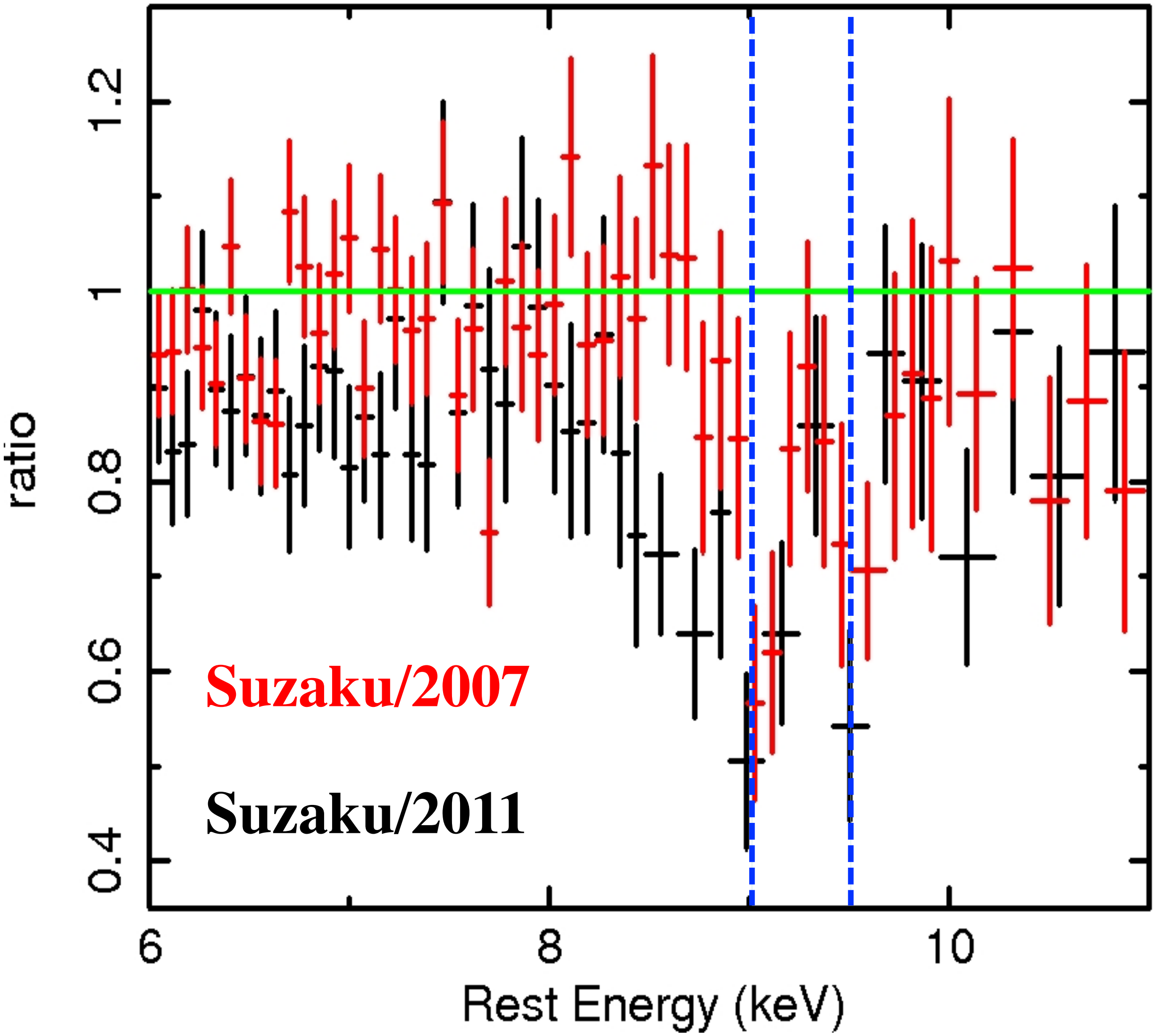
Little change in intrinsic continuum emission.

PDS 456 – Absorber Variability



Suzaku 2007 Fe K band spectrum. Absorption lines present at 9, 9.6 keV (rest). v_{out}=0.27, 0.31±0.01c

PDS 456 – Absorber Variability



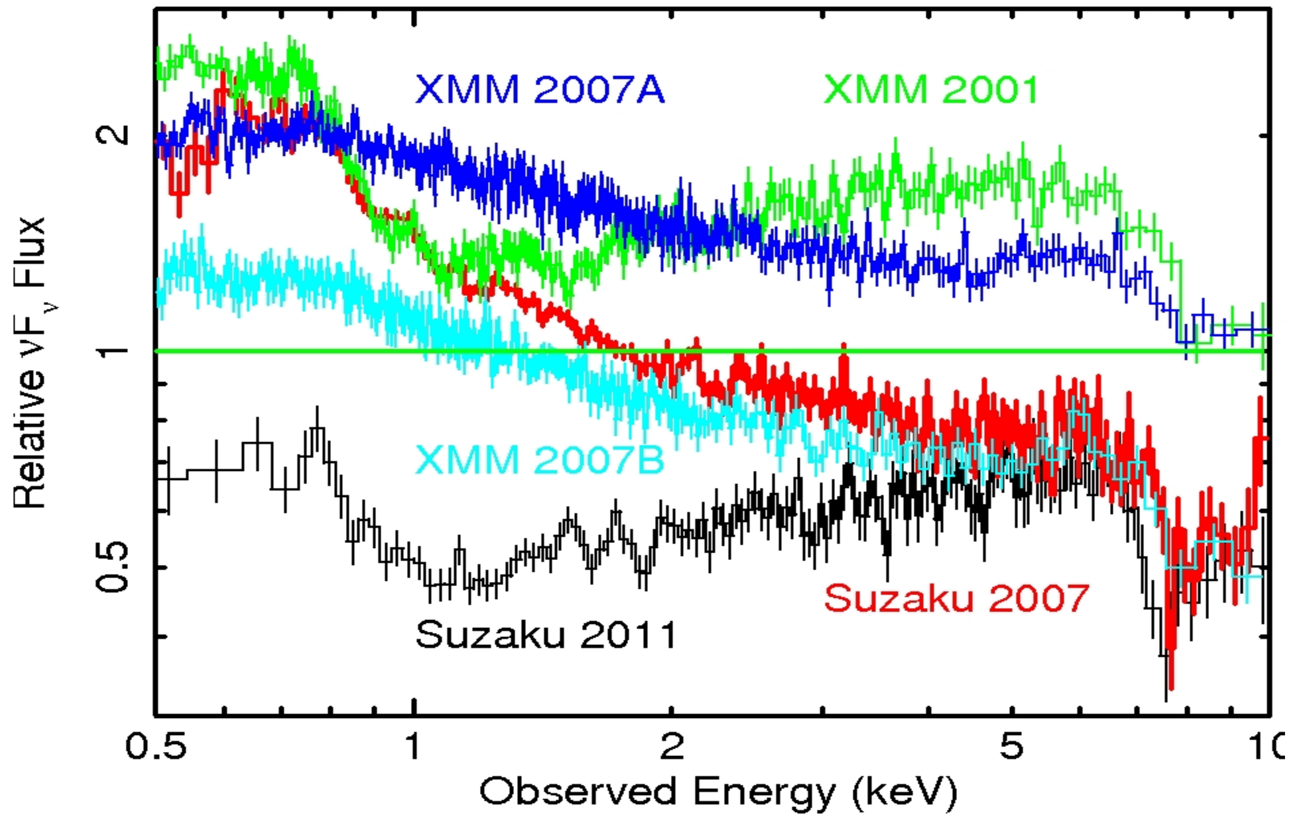
Suzaku 2007 Fe K band spectrum. Absorption lines present at 9, 9.5 keV (rest). v_{out}=0.27, 0.31±0.01c

2011 obs – shows a broad Fe K absorption profile which is appears more redshifted than in 2007.

Can be fitted with a decrease in ionisation with flux – log xi changes from 4.4±0.1 to 3.9±0.1, in response to decrease in overall flux.

PDS 456 Absorber Variability

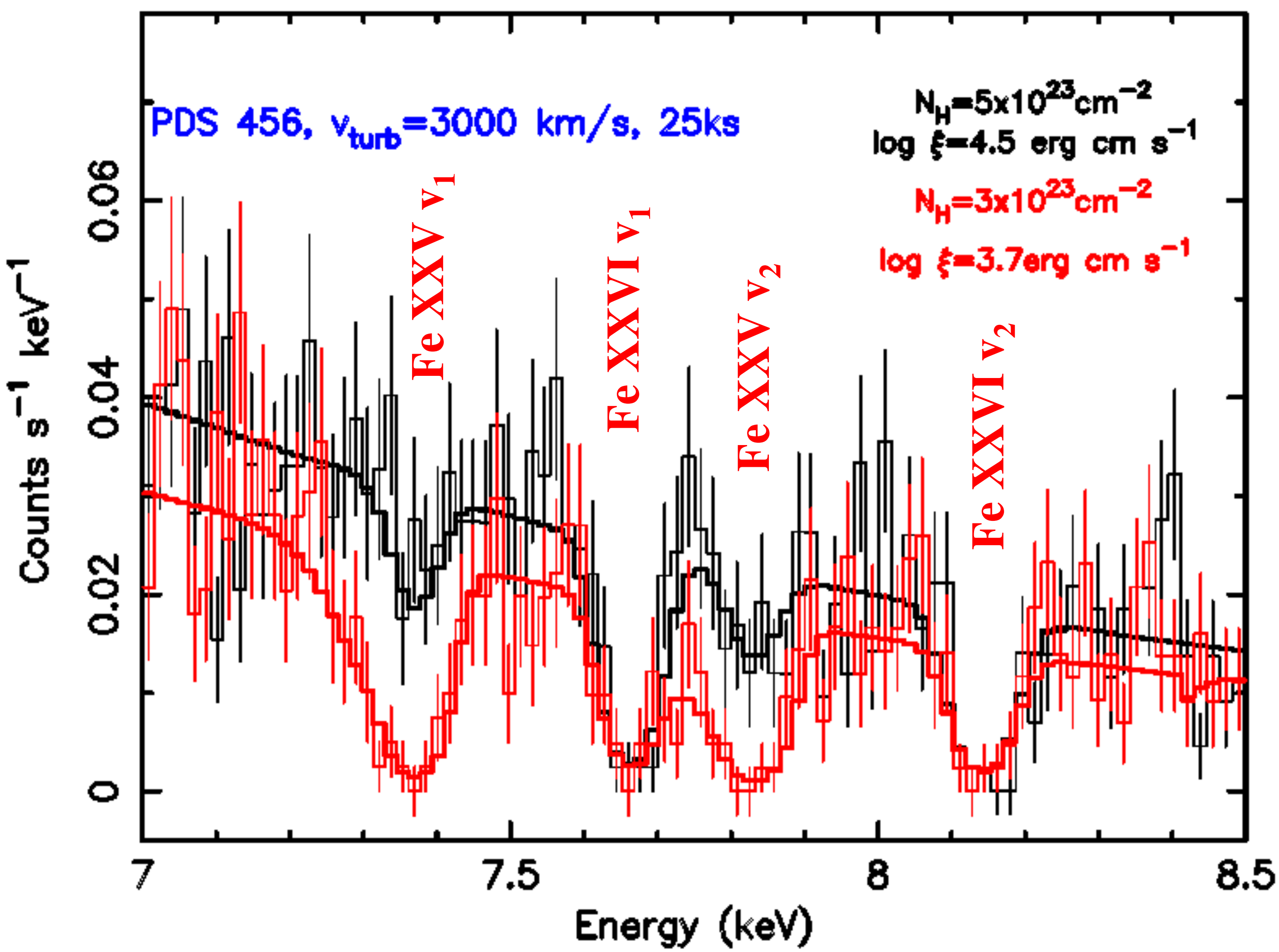
(Reeves et al. 2009, Behar et al. 2010)



PDS 456 shows drastic spectral variability over a decade of observations. ***Variations in the line of sight covering fraction*** (**N_H~2x10^{23} cm^{-2} and p_{cov}=20-80%**) can explain spectra combined with (relatively) constant reflected/scattered component.

Absorbing clouds must be compact and within high ionisation (Fe XXV/XXVI) outflowing gas – clumpy disk wind?

PDS 456 – Athena Simulations



Conclusions

Both PG 1211+143 and PDS 456 show significant evidence for highly ionised iron K absorption.

The absorption profiles are substantially blueshifted wrt to the expect resonance absorption lines of Fe XXV and Fe XXVI (e.g. 6.7 and 6.97 keV).

Both objects show consistent absorption profiles across several observations – ruling out any chance coincidence. For example PDS 456 shows rest frame 9-9.5 keV absorption in 7/8 observations.

The absorption can be modeled self consistently with high velocity outflows, likely originating from a disk wind, with mass outflow rates of several solar masses per year.

Spectral variability in AGN like PDS 456 is likely due to variations in covering fraction and ionisation state of the inner absorber.