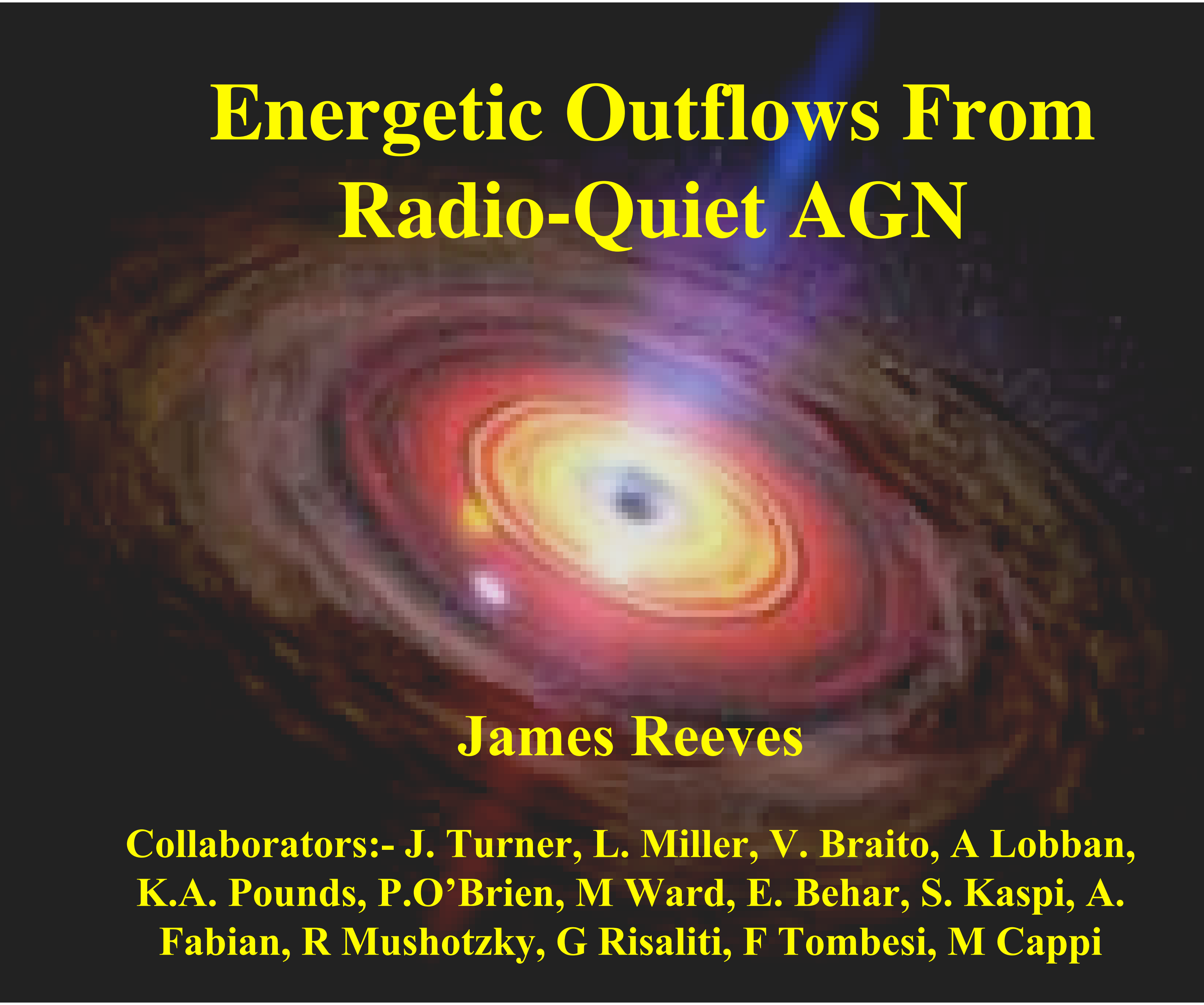


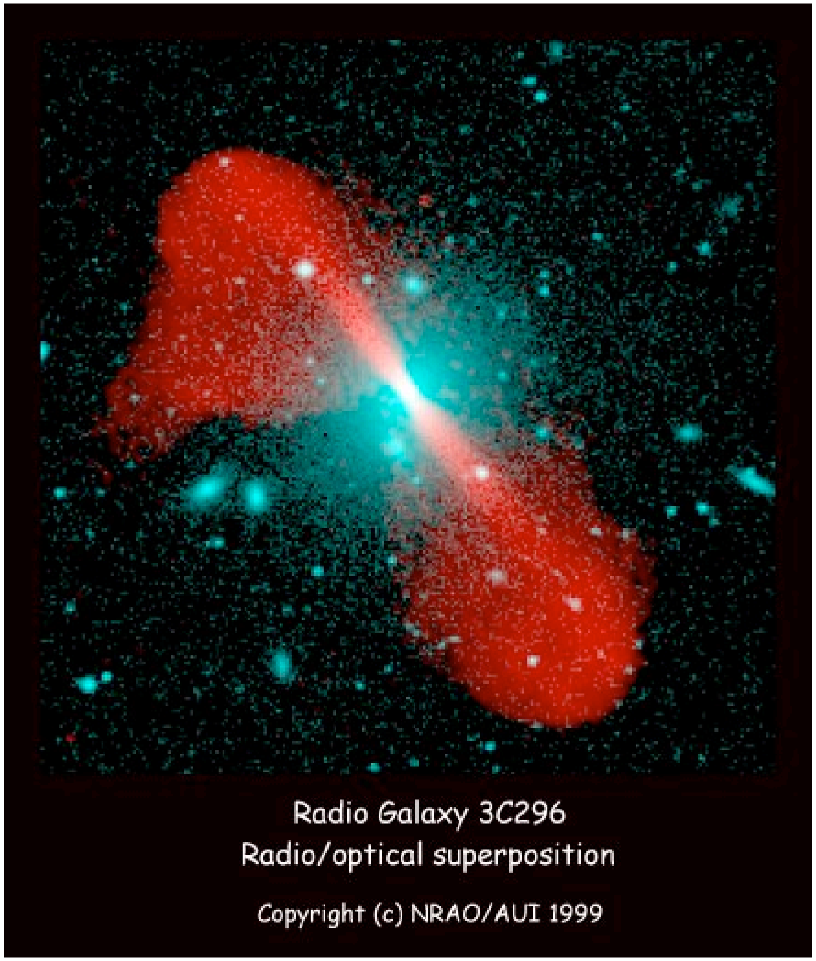
Energetic Outflows From Radio-Quiet AGN

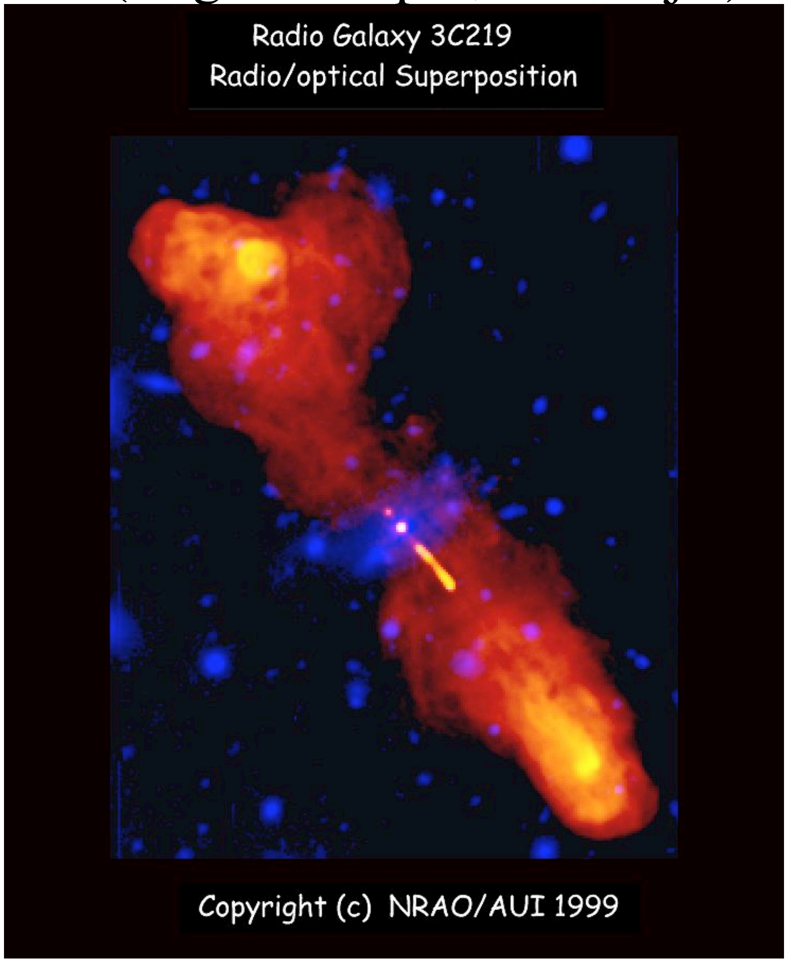
James Reeves

Collaborators:- J. Turner, L. Miller, V. Braito, A Lobban, K.A. Pounds, P.O’Brien, M Ward, E. Behar, S. Kaspi, A. Fabian, R Mushotzky, G Risaliti, F Tombesi, M Cappi

AGN have powerful outflows

- Some have powerful, relativistic jets on Mpc scales
- Radio Loud AGN have jets. Radio-quiet AGN disc winds?
- FRI (fuzzy lobes, 2 sided jet) FRII (bright hot spot, 1sided jet)





High velocity Outflows in AGN

• How much mass is carried out of the AGN by 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?

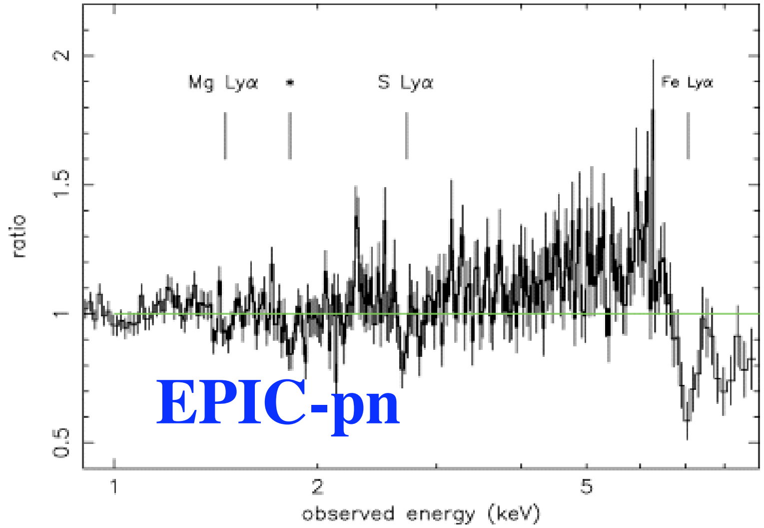
•Can the outflow regulate the growth of the black hole and the galaxy (bulge) through feedback?

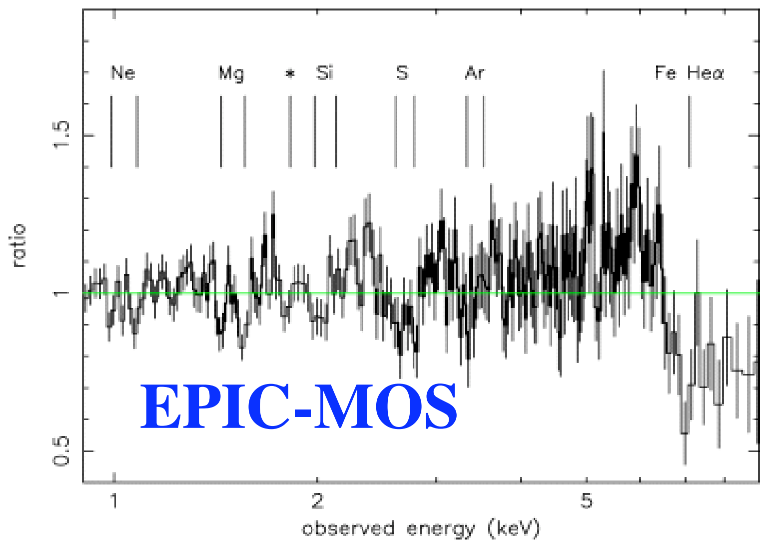
•Could absorption explain some of the X-ray spectral variability in AGN?

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

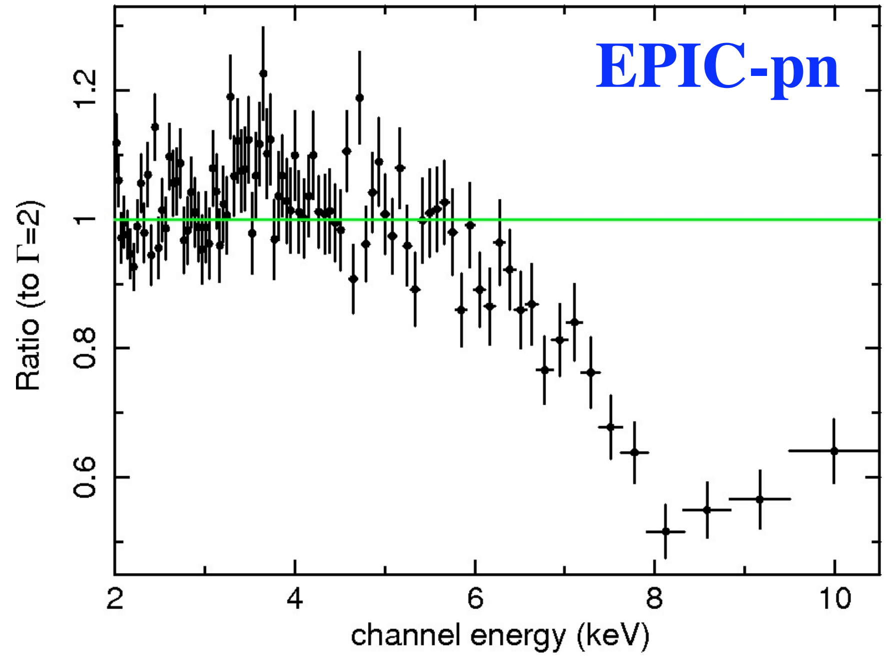
Discovery of Highly Ionized / High Velocity Outflows

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





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 >10^{23} cm^{-2}. Suggests kinetic power ~ L_{bol}.

X-ray evidence for high velocity outflows in AGN

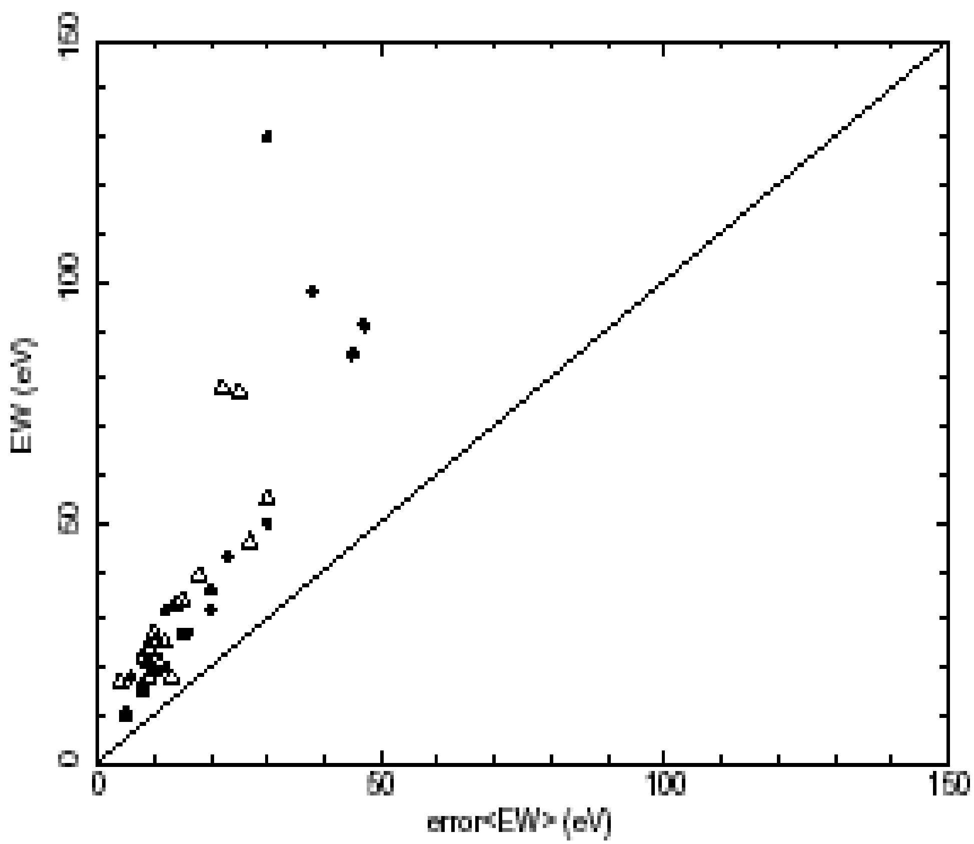
Outflows of ~0.1-0.3c have been claimed from X-ray spectra of several AGN, mainly via absorption features in the Fe K band. Detection of absorption in the Fe K band requires a large column density - together with a high velocity that implies the outflow is both massive and energetic (unless highly collimated)

APM 08279+5255	v~0.2-0.4c	(Chartas et al, ApJ, 2002, 579, 169)
PG1211+143	v~0.08-0.14c	(Pounds et al, MNRAS, 03, 06, 07)
PG1115+080	v~0.1/0.34c	(Chartas et al, ApJ, 2003, 595, 85)
PG0844+349	v~0.2c	(Pounds et al, MNRAS, 2003, 346, 1025)
PDS 456	**v~0.26-0.31c**	**(Reeves et al, ApJ, 2003, 2008)**
Ark564	v~0.17c	(Papadakis et al. A&A, 2007)
Mrk509	v~0.17c	(Dadina et al., 2005, A&A, 442, 461)
IC 4329a	v~0.09c	(Markowitz, Reeves & Braito. 2006, ApJ)
MCG -5-23-16	v~0.1c	(Braito et al, 2007, ApJ).
IRAS13197-1627	v~0.02c	(Miniutti et al. 2007, MNRAS)
Mrk 766	v~0.04c	(Miller et al., 2007, A&A)
MR 2251-178	v~0.04c	(Gibson et al. 2005, ApJ).

Systematic XMM-Newton Sample of Iron K Absorption
(Tombesi et al. 2009, in prep & poster)

Vaughan & Uttley (2008) proposed that the detection of some energy shifted X-ray lines could be an artifact of publication bias. Claim detected lines follow a plot of line EW vs error

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



XMM Sample - 104 observations of 44 type I and II AGN with mean 4-10 keV flux of 2×10^{-11} ergs cm^{-2} s^{-1}

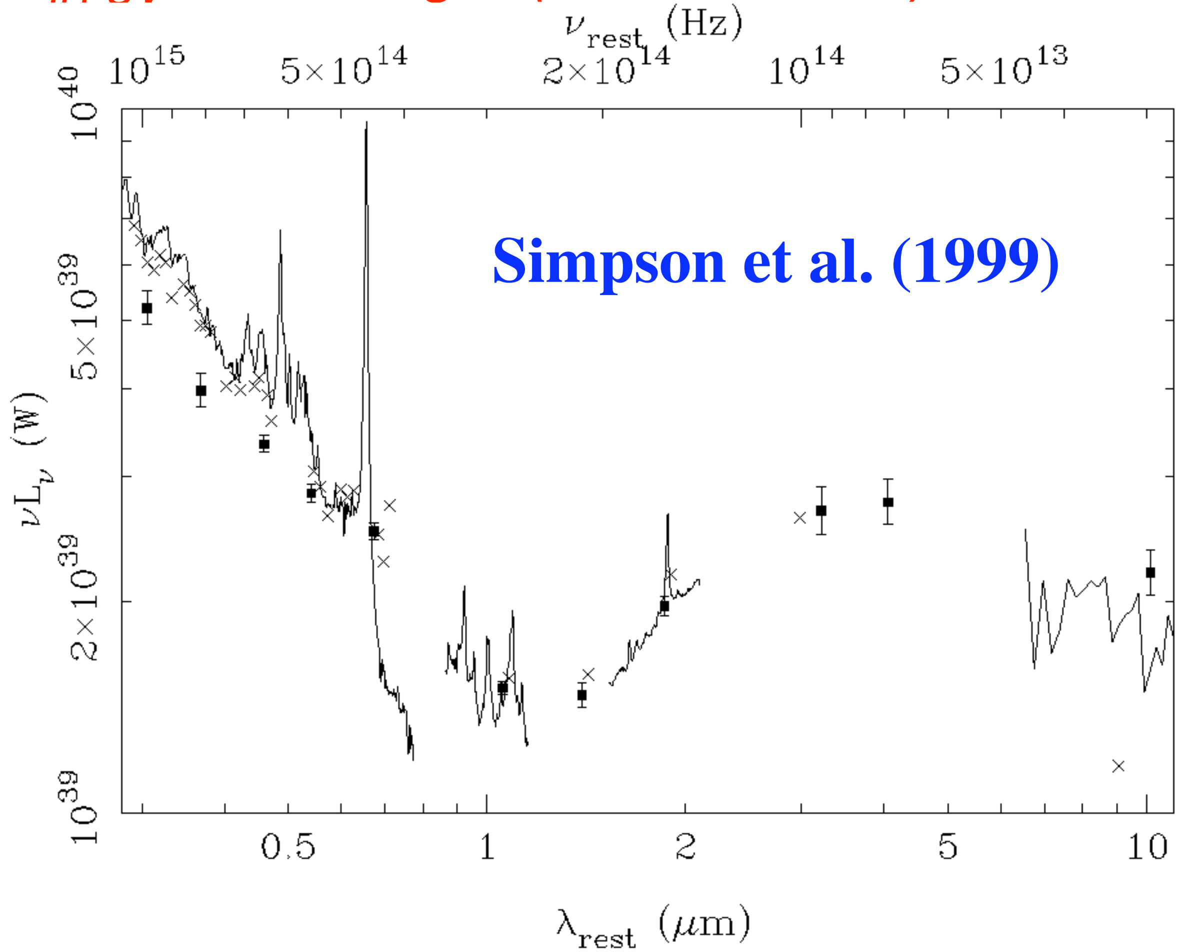
Fe K absorption lines tested by Monte Carlo simulations (blind trial)

22/104 observations have in blue-shifted lines at >95% confidence - overall null probability of **$P<3\times10^{-8}$**.

Blue-shifted lines in 17/44 AGN. **11/44 AGN with v>0.1c.**
Mean blue-shift v_{out}=–0.103 ± 0.004c

The Most Luminous Nearby Quasar PDS456

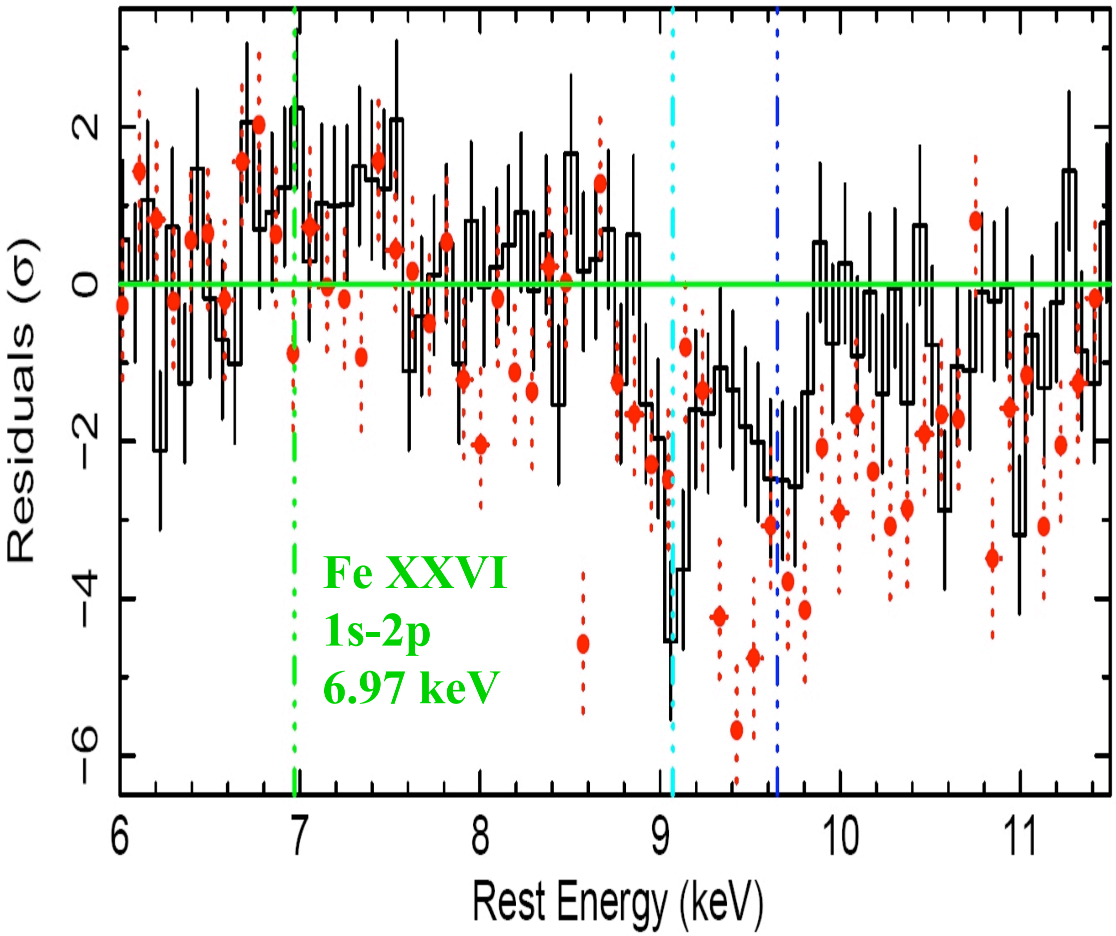
Discovered a decade ago (Torres 1997) - very luminous broad-line radio-quiet QSO at z=0.184. Most luminous AGN at z<0.3 - *$L_{IR\text{-}UV} \sim 10^{47}$ erg/s (1.7 x 3C 273);*



Relativistic Outflow in PDS 456 (Reeves et al. 2009, in press)

(Deep Suzaku Observation, 190ks net)

Black – Suzaku 2007 ; Red – XMM 2001



High v outflow originally claimed in 2001 XMM observation (Reeves et al. 2003) and in UV via HST/STIS (O'Brien et al. 2005).

Pair of blue-shifted absorption lines observed with Suzaku at 9.08/9.66 keV (rest frame) or 7.68/8.15 keV (observed).

NOT associated with obvious transition at z=0 frame, ruling out WHIM or local bubble.

Outflow velocity of 0.25-0.30c, if associated with Fe XXVI 1s-2p.

Requires N_H=5x10^{23} cm^{-2}, with logξ=4.5, for σ>3000 km/s to model strong (EW=125eV) absn lines. Detection very robust (MC) >99.9% confidence.

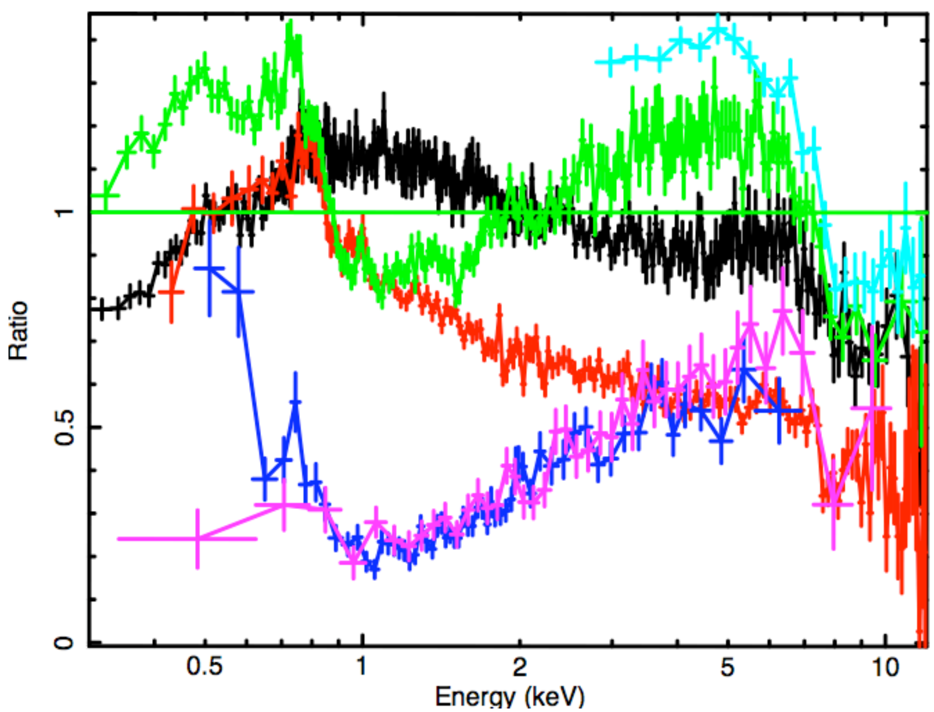
Drastic spectral variability of PDS 456 (Behar et al. 2009)

PDS 456 shows drastic spectral variability over a decade of observations. ***Variations in the line of sight covering fraction*** (**N_H~10^{23} cm^{-2} and p_{cov}=20-80%**) can explain spectra combined with (relatively) constant reflected/scattered component.

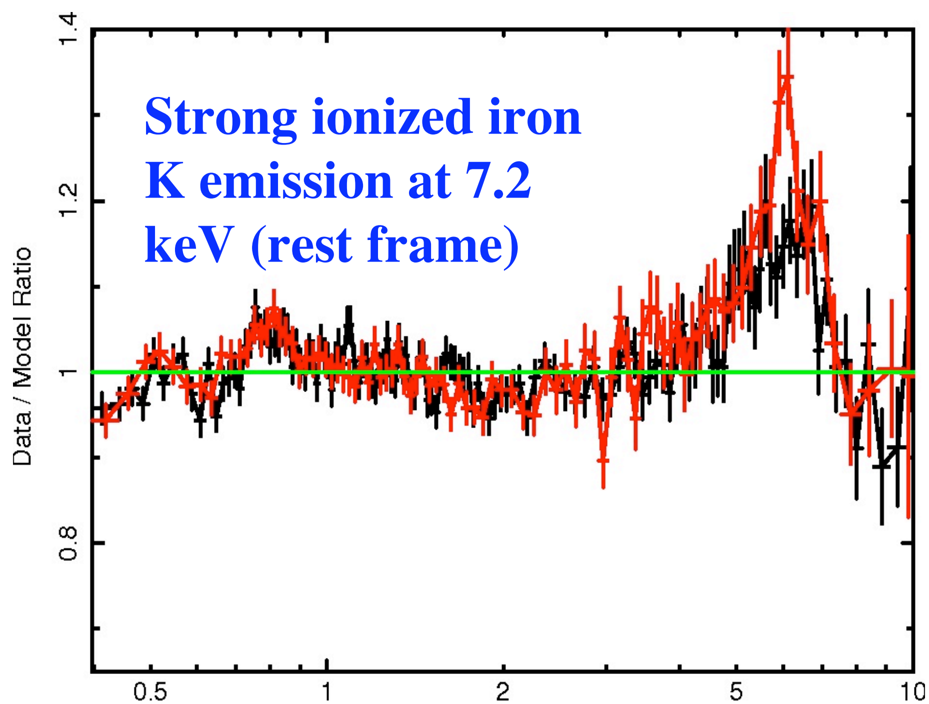
Absorbing clouds must be compact (within BLR) and close to source (clumpy disk wind?)

Highly ionized reflector has a ***global covering factor of 20-25%.*** **Net blueshift –15000km/s.**

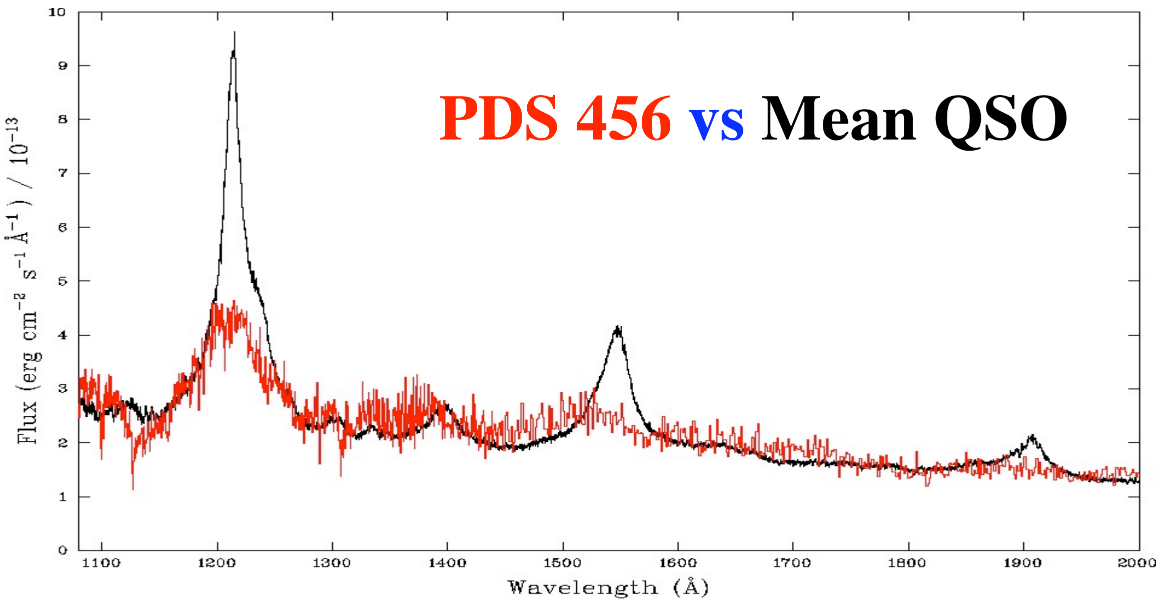
XMM (2001, 2007), Suzaku (2007), RXTE (1998), ASCA (1998) and Chandra (2003).

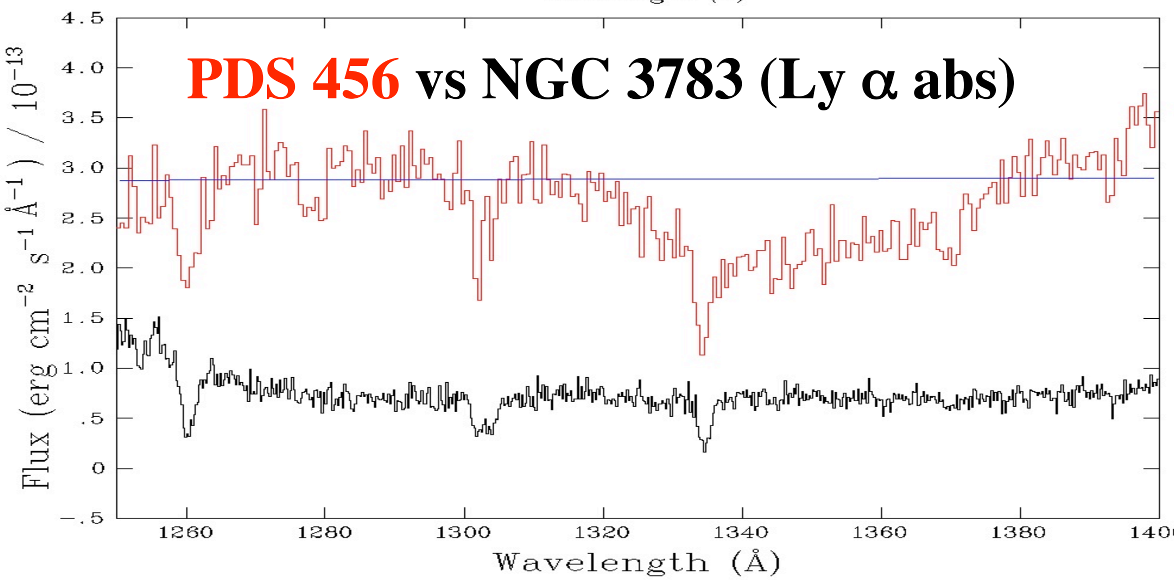


XMM observations in 2007



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*.

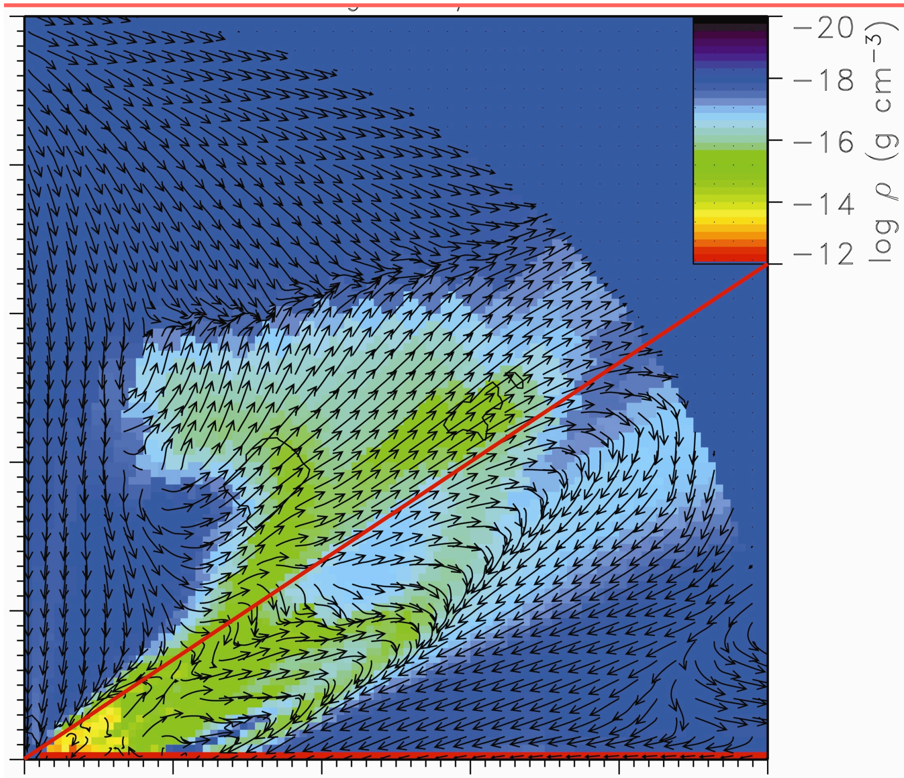
Absorption feature blue-wards of Ly α , if attributed to Ly α than *v_{out}=14000-24000 km/s*

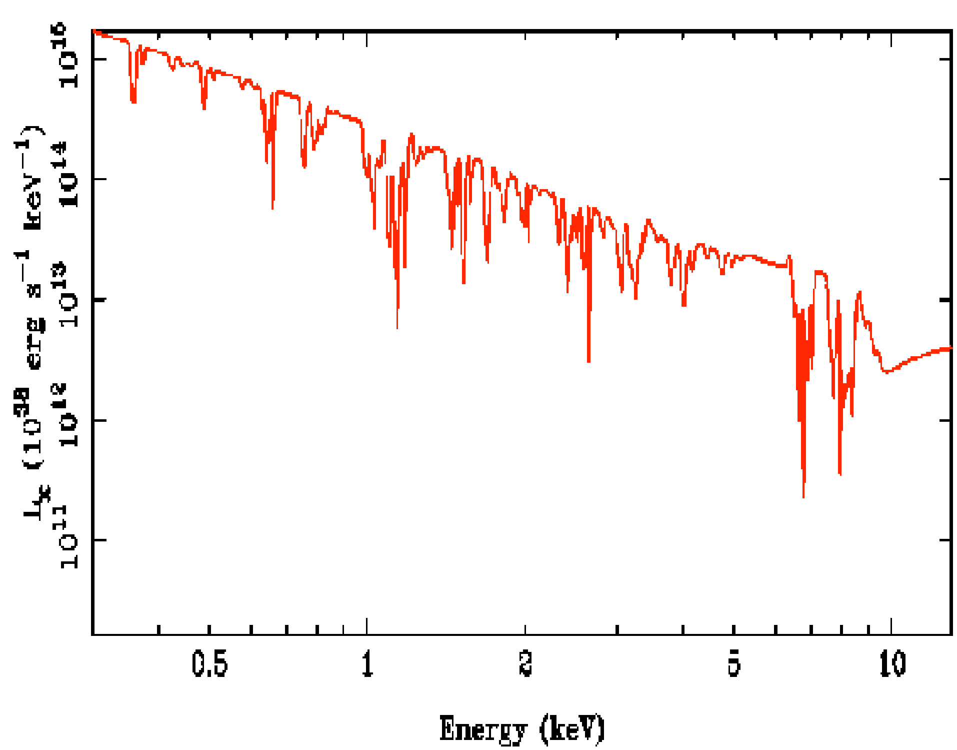
PDS 456 Outflow Energetics

- PDS 456 observables:- $N_H \sim 10^{24}$ cm^{-2}, log $\xi \sim 4.9$ and $v_{out}=0.25c$ (high xi zone), $L_{ion} = 3 \times 10^{45}$ erg s^{-1}, $L_{bol} \sim 10^{47}$erg s^{-1}. BH mass estimate $M_{BH}=2 \times 10^9 M_{sun}$.
- Outflow Rate $M_{out} = 4\pi b n R^2 m_p v_{out} = 4\pi b m_p v_{out} L_{ion}/\xi \sim 100b\ M_{sun}\ yr^{-1}$ (where b=1 corresponds to 4π sr^{-1}.)
- Kinetic output $K = 1/2\ M_{out} v_{out}^2 \sim 10^{47}$ erg s^{-1} (for b=0.2) ~ $L_{bol} \sim L_{Edd}$. Outward momentum flux $p = M_{out} v \sim L_{Edd}/c$ (King & Pounds 03).
- For a *homogeneous* radial flow (i.e. $n \propto R^{-2}$) $R_{out} = L_{ion}/\ \xi N_H = 100\ R_g$ (3×10^{16} cm), c.f. escape radius $R_{esc} > 10^{16}$ cm.
- If $L_{out} \sim 10^{47}$ erg/s for lifetime of QSO phase ($t > 10^7$ yr) then *E=10^61-10^62 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. Duty cycle for outflow??

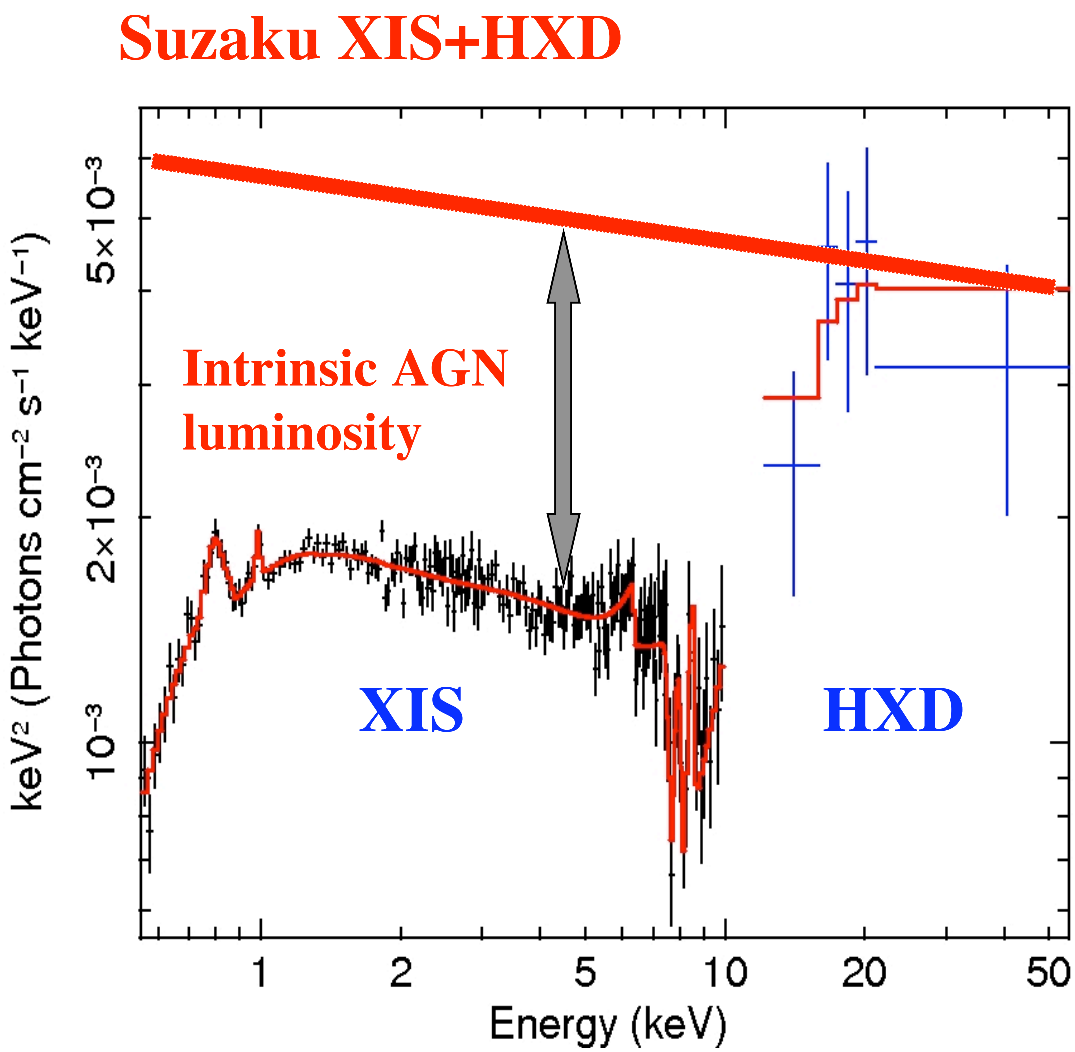
Fast, Radiatively Driven Disk Winds?

- Disk winds simulations of Proga (2004; 2007), recently Sim et al. (08), Schurch et al. (2008)
- looks a lot like the high ionization absorption lines at Fe Kα (e.g. PDS 456, PG 1211+143).
- Terminal velocities ~ 0.1-0.3c, densities (10^{7}-10^{10} atoms cm^{-3}) and columns (10^{22} - 10^{24} cm^{-2}) consistent with observed systems.





Absorbed hard X-ray emission from PDS 456?



Optical type I AGN - but looks like an obscured AGN in X-rays!

The hard X-ray data (above 10 keV) show a large excess of flux.

Strongly absorbed ($N_H > 10^{24} cm^{-2}$) emission emerges above 10 keV.

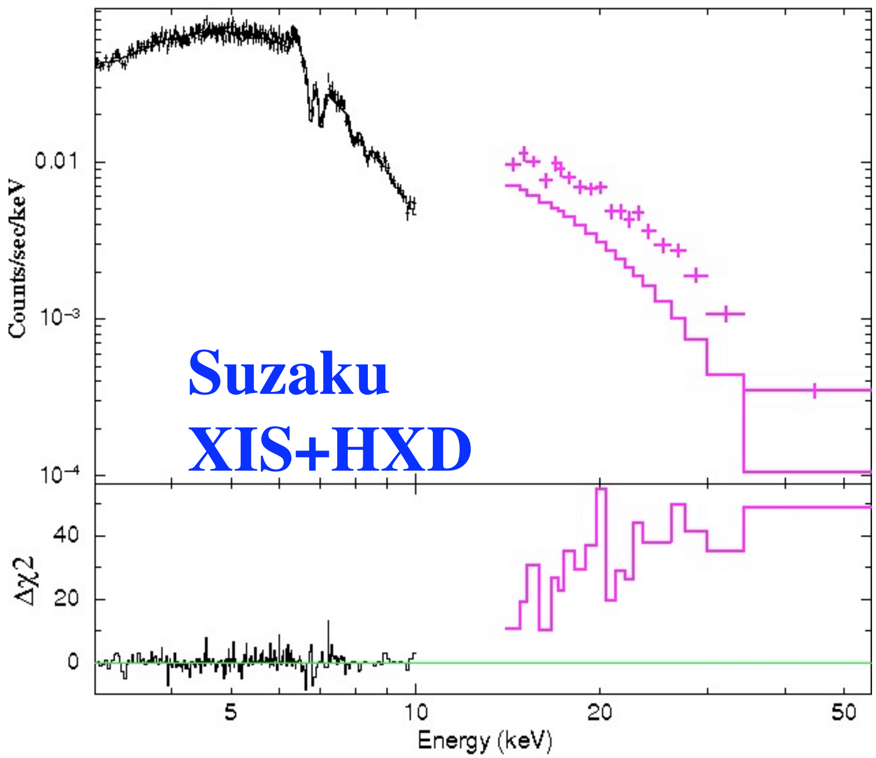
Absorber must be located ***close to black hole*** (well within UV/BLR) to ***partially cover*** X-ray source

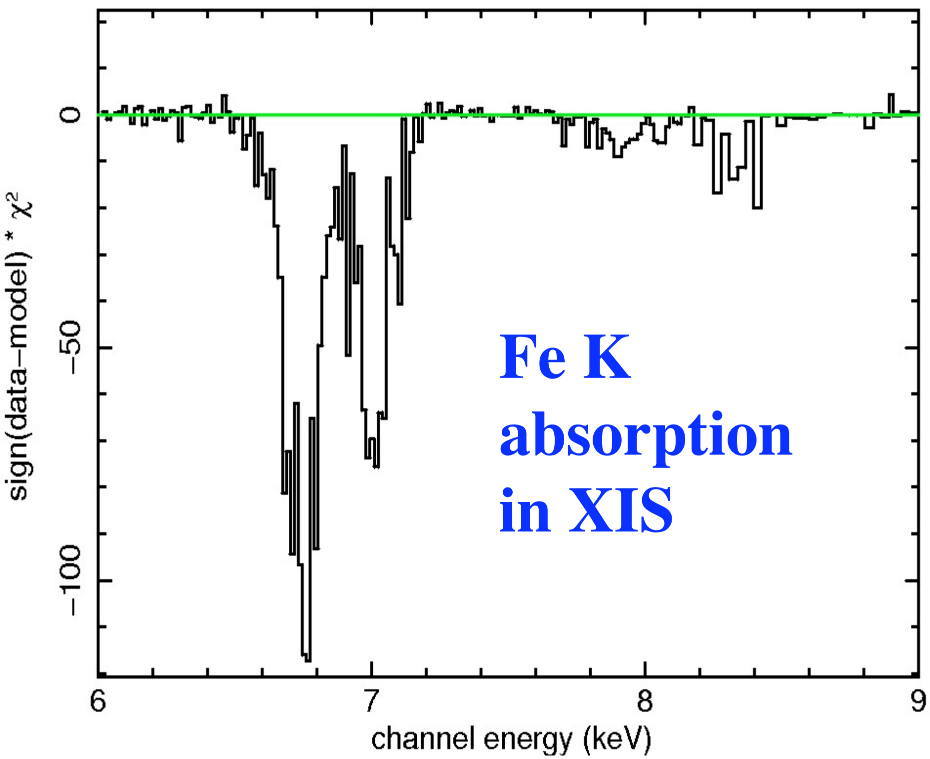
Intrinsic X-ray luminosity much higher than is apparent

($L_{2-10}=5x10^{45}$ erg $s^{-1,}$ cf $L_{bol}=10^{47}$ erg s^{-1})

The Compton-thick Absorber and Wind in NGC 1365

(Risaliti et al. 2009, ApJL, submitted)



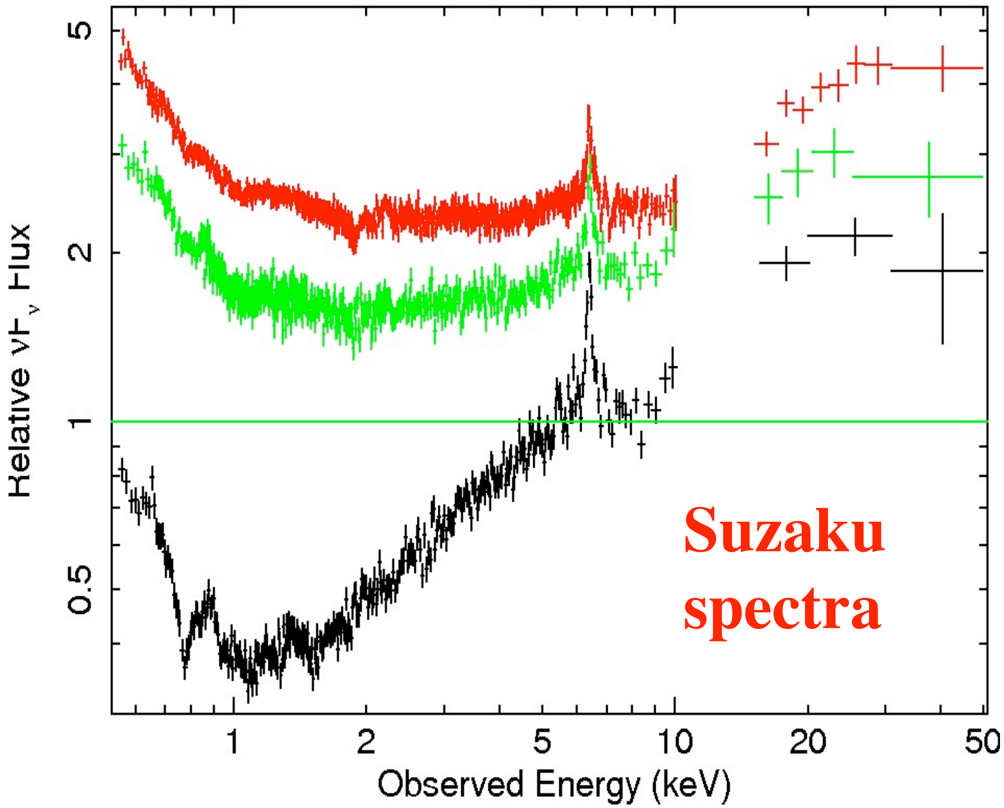


Strong (factor x3) hard X-ray excess seen in Suzaku observation of NGC 1365.

Can only be modelled with a **Compton-thick** absorber (**N_H = 3x10^{24} cm^{-2}**), partially covering the source (**p_{cov}=0.8**).

Highly ionized (**Fe XXV, XXVI**) absorption in XIS, blue-shifted outflow with **v_{out}=5000 km s^{-1}, N_H=10^{24} cm^{-2} and log ξ = 4.**

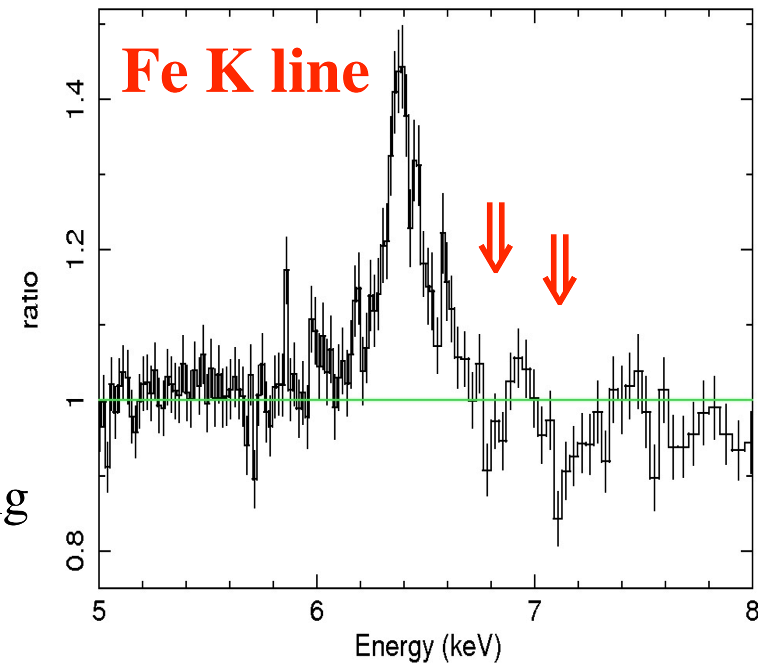
The Hard X-ray Excess in NGC 4051



350+100 ks Suzaku observations of low mass Seyfert 1, NGC 4051.

Rapid variability - spectral changes could be explained by variable absorption

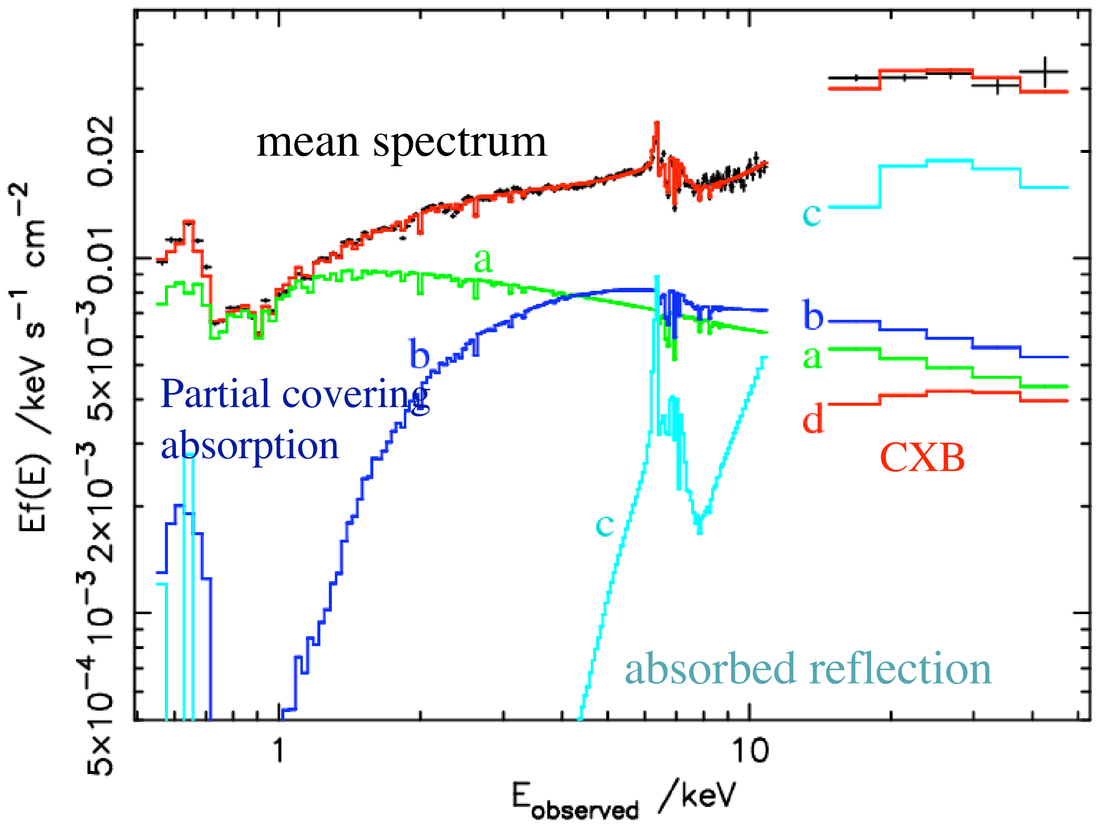
Outflow at Fe K with ~5000 km/s



Fe line profile shows relatively (<8000 km/s) narrow iron line.

Hard X-ray excess in all observations - too strong to be explained just by reflection (with R>>1)? Also see Jane Turner talk (1H 0419-577)

Not relativistic light-bending but absorption in MCG -6-30-15? (Miller, Turner & Reeves 2008)



Model consists of:-

intrinsically variable power-law (with ionized absorber).

Partially covered absorbed power-law, high column 10^{23}cm^{-2}

"distant" absorbed reflection or more high-column absorption

Good fit to full set of time-variable spectra in broad-band Suzaku/XMM datasets.

Reproduces absorption lines in Chandra/HETG, XMM/RGS grating observations

Mass outflow in radio-quiet AGN

- How much mass is carried out of the AGN by the outflow?

In the high v outflows, launched from the inner disk (15-100 Rg) mass outflow rates are <u>at least few x solar.</u>
e.g. PDS 456 $M_{out} = 4\pi b m_p v_{out} L_{ion}/\xi \sim 100b\ M_{sun}\ yr^{-1}$. This is launched from $R_{out} < 100\ R_g$. Global covering at least 20%.

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

For high velocity outflows in high M_{dot}/M_{Edd} AGN, a substantial fraction is driven in the outflow, i.e. $M_{out} \sim M_{Edd}$.

- Does the ionized outflow carry a significant fraction of the energy output of the AGN?

Yes, for some AGN (e.g. PDS 456, $L_{out} \sim 10^{47}$ erg/s), $L_{out} \sim L_{bol} \sim L_{edd}$

Mass outflow in radio-quiet AGN

•Can the outflow regulate the growth of the black hole and the galaxy (bulge) through feedback?

If in the case of PDS 456, if $L_{out} \sim 10^{47}$ erg/s for lifetime of QSO phase (t $>10^{7}$ yr) then E$>10^{61}$ ergs (c.f. E$=10^{59}$ ergs of a bulge with 10^{11} Msolar and σ=300 km/s, also see King 03)

•Could absorption explain some of the X-ray spectral variability?

Outflows with $N_H>10^{23-24}$ cm^{-2} can have a significant effect on the observed flux and shape (Gamma) of spectrum. Less variable in hard X-rays.

Compton-thick absorbers (with variable covering) could replicate constant "reflection" component.