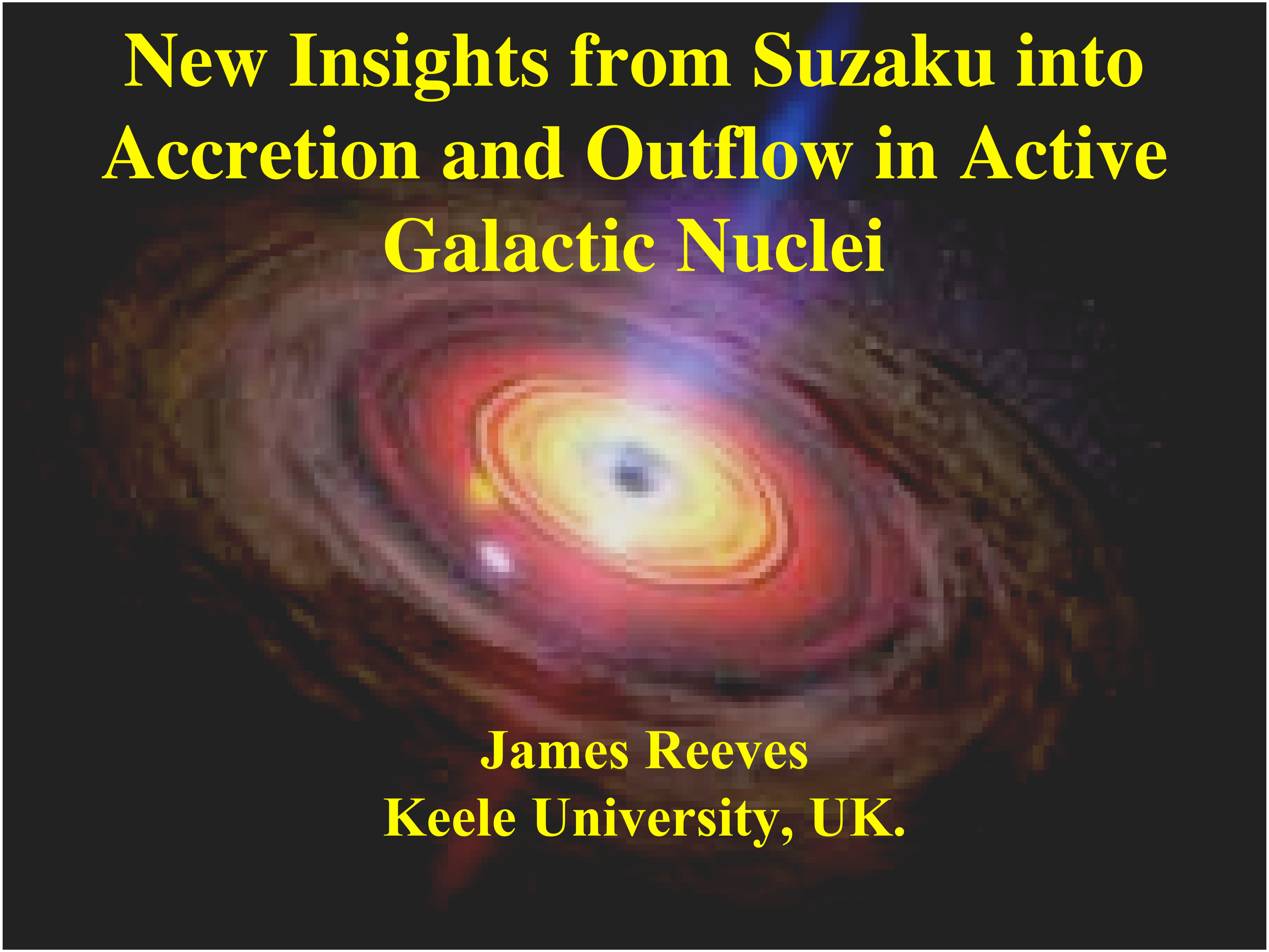
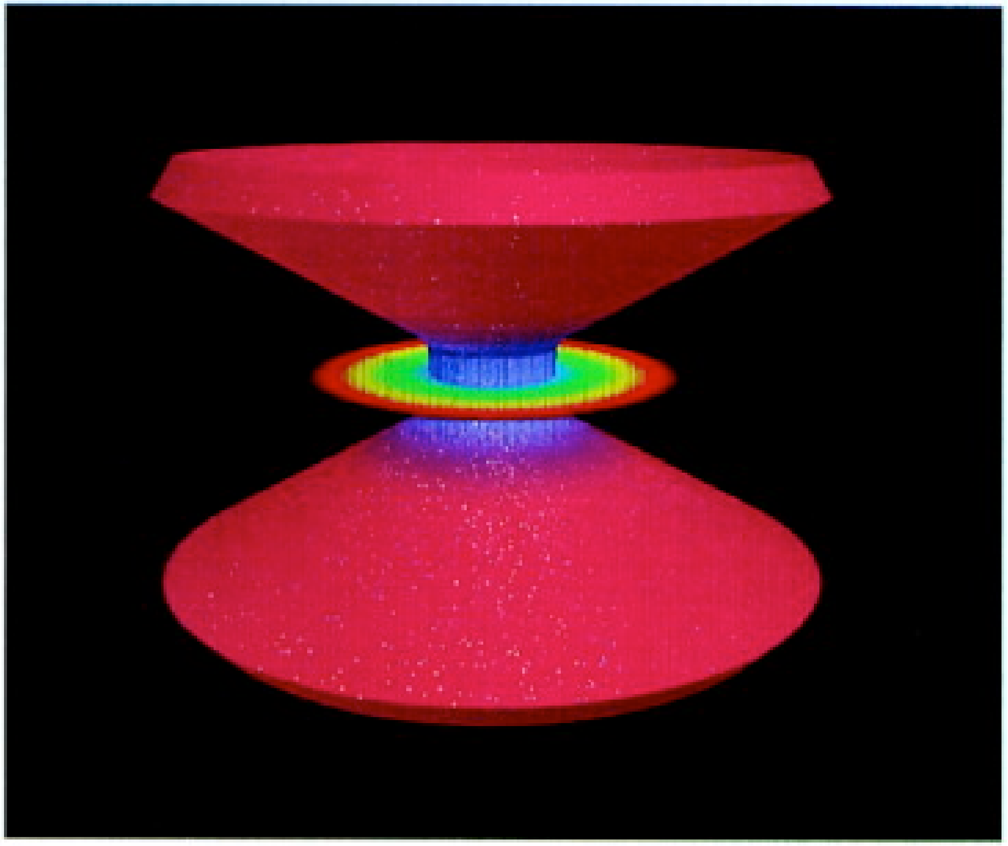
New Insights from Suzaku into Accretion and Outflow in Active Galactic Nuclei



James Reeves
Keele University, UK.

Outflows in AGN



(Outflow Schematic; Elvis 2000)

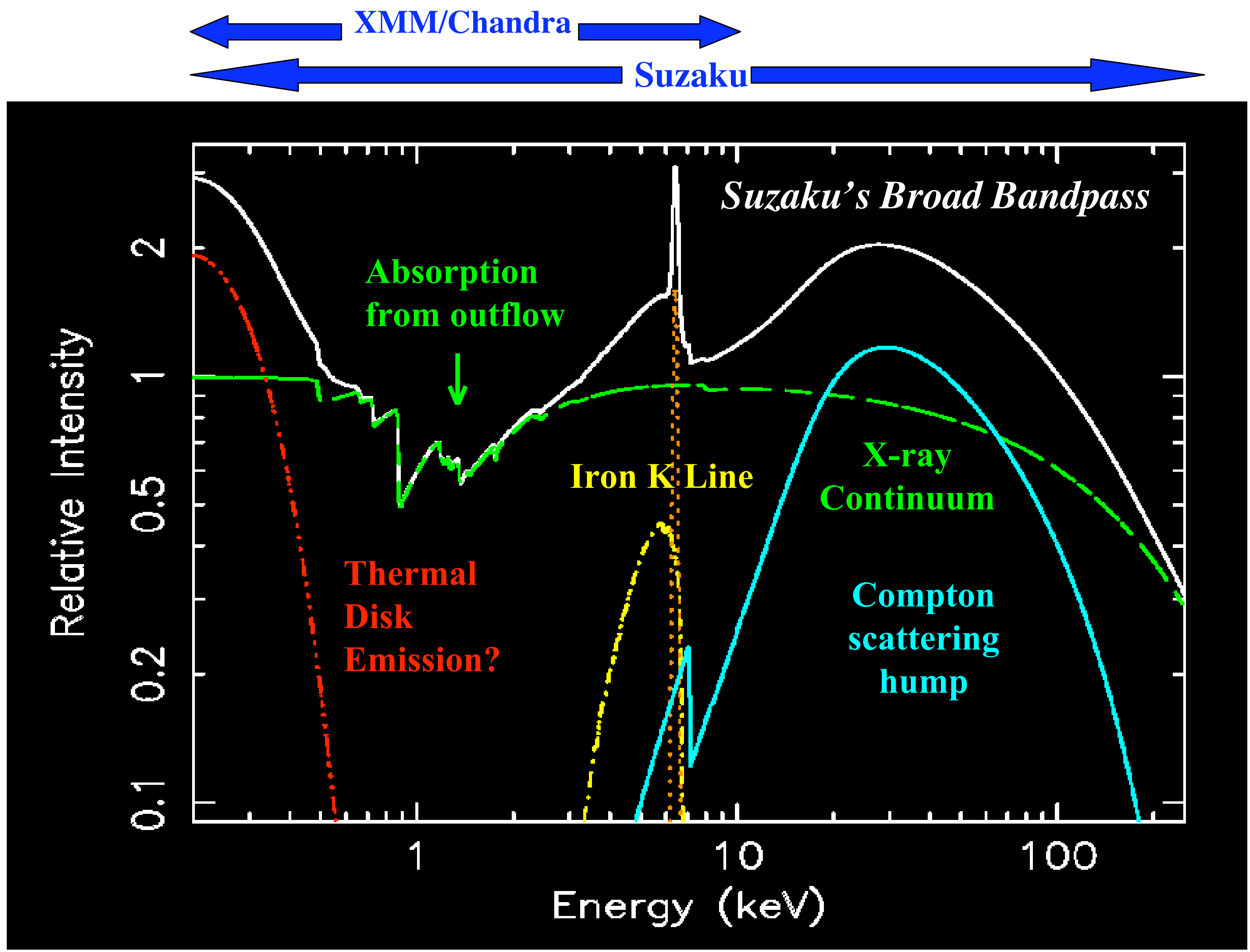
Outflows seen in the majority of nearby AGN.

Typically velocities100s km/s to 1000s km/s.

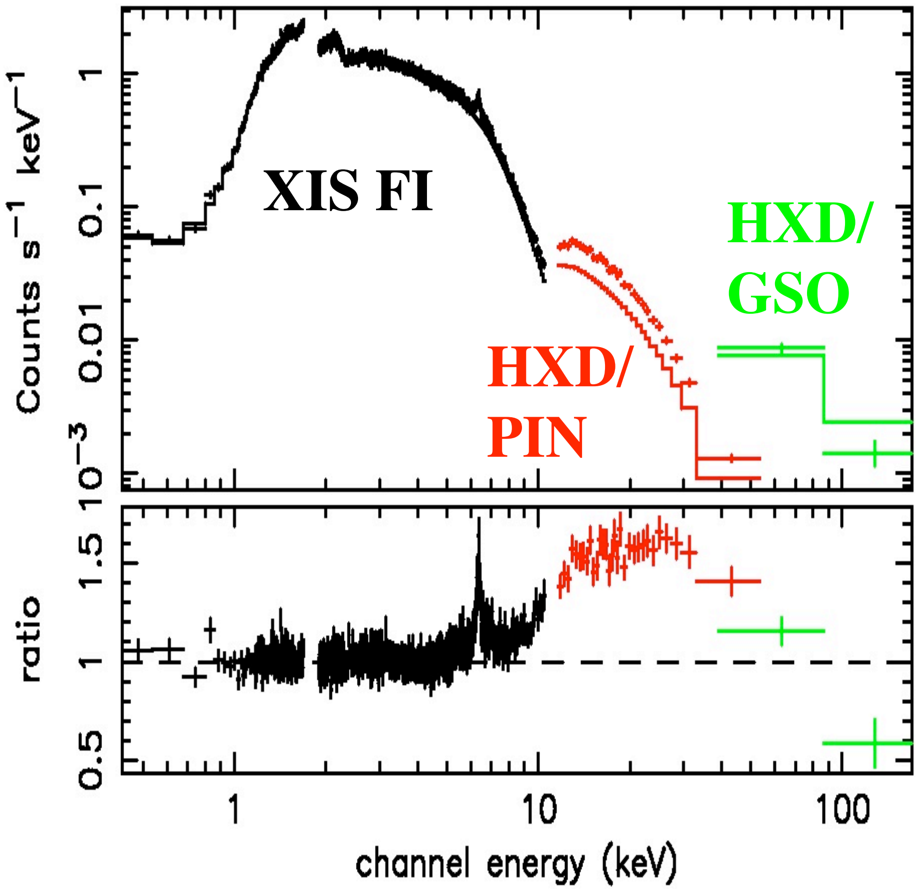
In some higher mdot AGN strong blue-shifted Fe K absorption features are seen above 7 keV - possible high v outflows at v~0.1-0.3c

Such outflows can carry significant kinetic power - equivalent to the bolometric output - feedback between BH/bulge mass in galaxy.

In order to measure the **Fe line profile** accurately we need to understand the form of the **underlying continuum** AND the properties of **outflowing matter** $\Rightarrow$***broad bandpass and good spectral resolution required.***

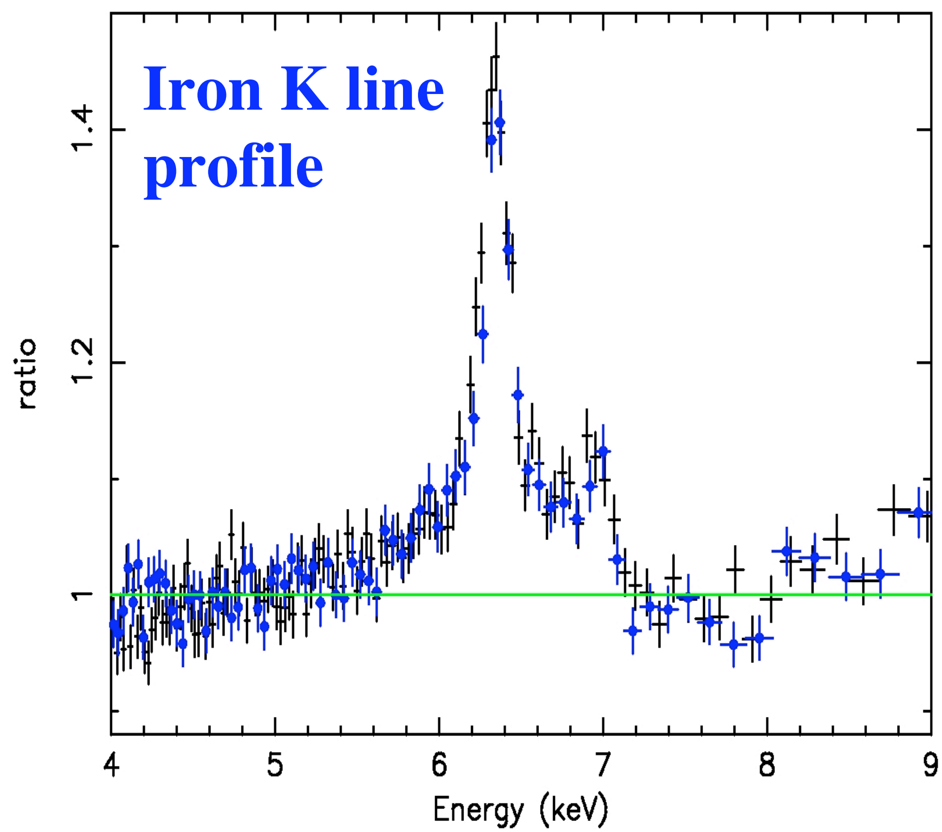

XMM/Chandra
Suzaku
Suzaku's Broad Bandpass
Absorption
from outflow
Iron K Line
X-ray
Continuum
Thermal
Disk
Emission?
Compton
scattering
hump
Relative Intensity
0.1
0.2
0.5
1
2
1
10
100
Energy (keV)

Suzaku Measurement of Iron Line Profile and Reflection in MCG -5-23-16 (Reeves et al. 2007)

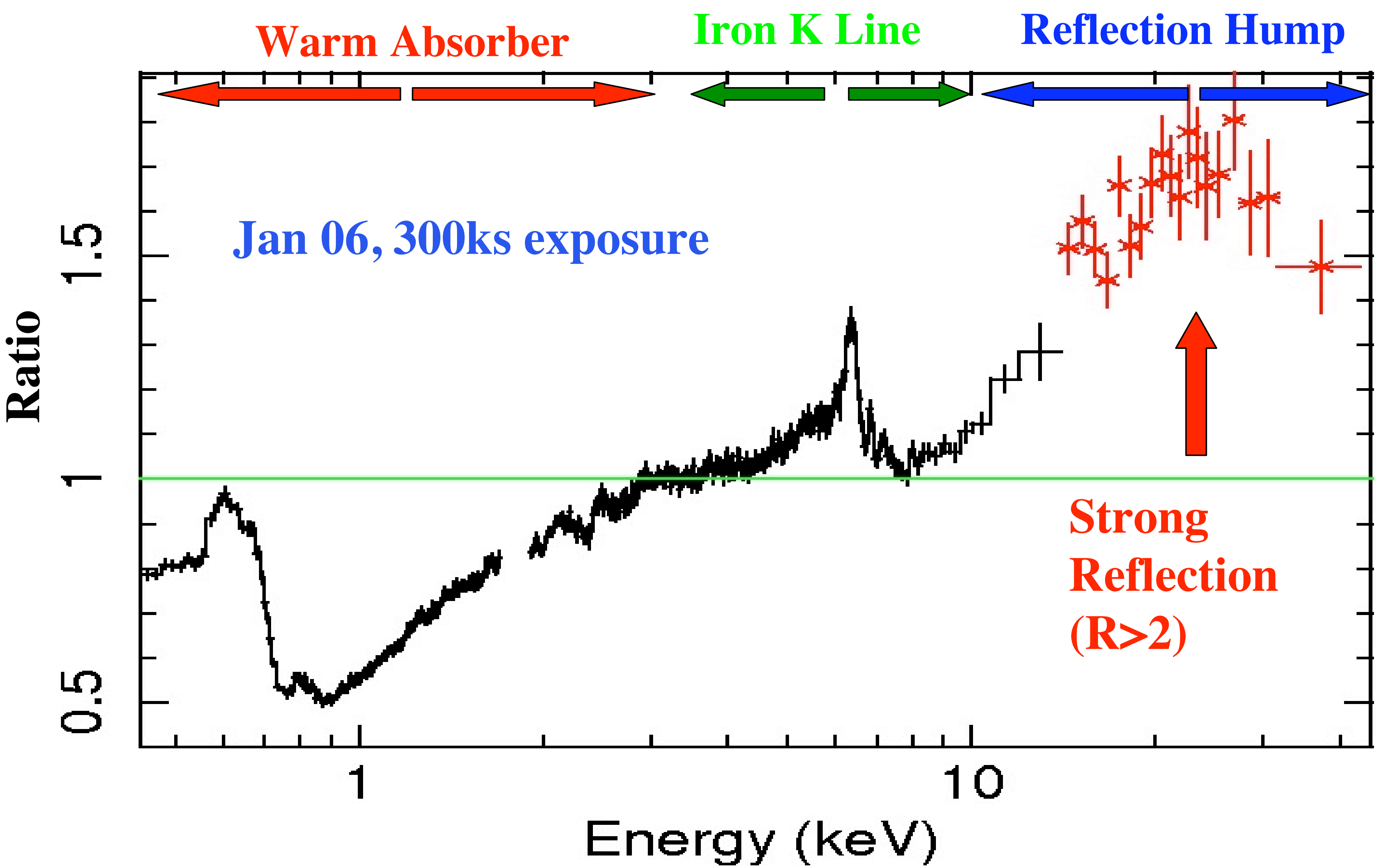


Broad-band Suzaku observation allows us to deconstruct the absorption, reflection and iron line emission from the intrinsic continuum.

Iron line profile deconvolved into broad and narrow components. Reflection hump measured with accuracy ($R=1.2\pm0.2$, $A_{Fe}=0.5\pm0.1$)



Broad-band Suzaku Observations reveal the relativistic line/disk reflection in MCG -6-30-15 (Miniutti et al. 2007, PASJ)



The Evidence for Relativistic Iron Lines in AGN from Suzaku

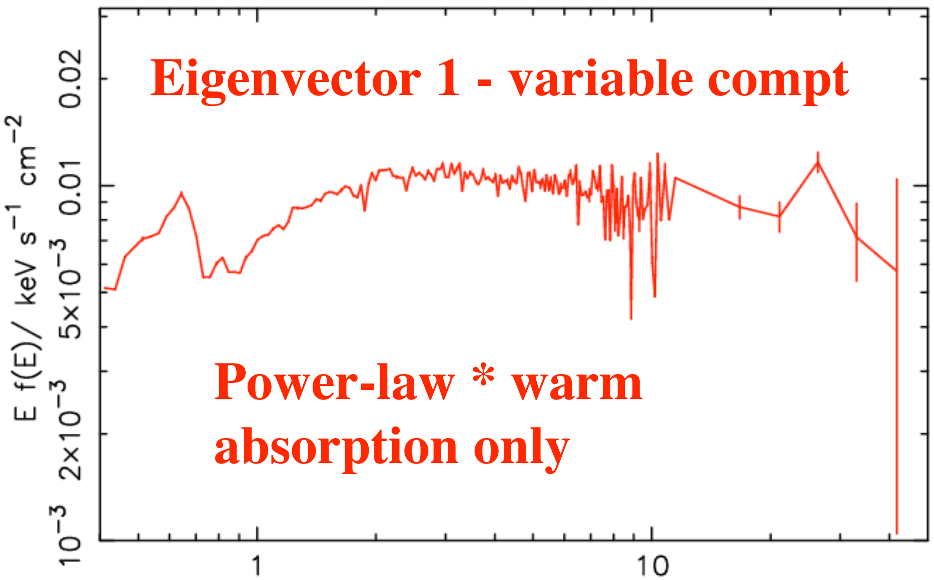
Broad Lines /reflection

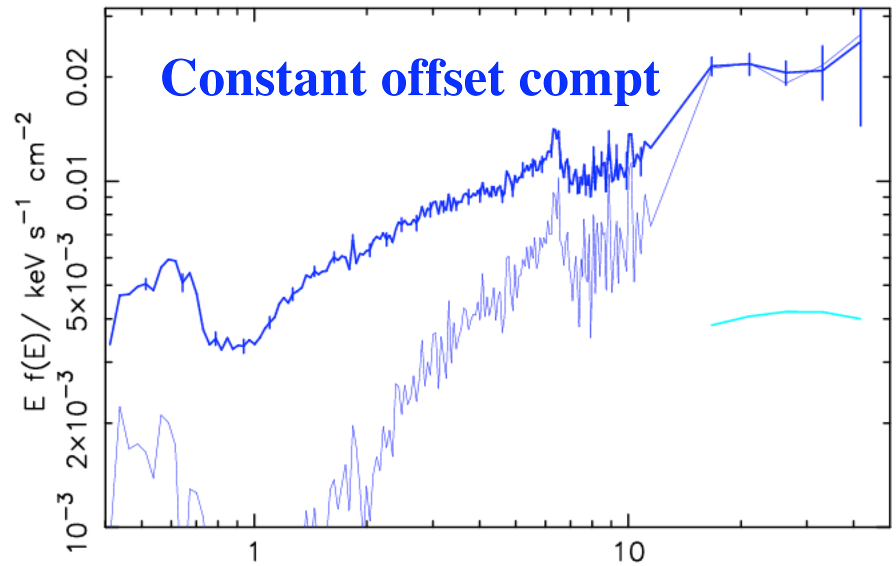
- **MCG -6-30-15.** V.strong reflection (Miniutti et al. 07, but see Miller et al.)
- **MCG -5-23-16**. Rin=20-30Rg. Moderate reflection (R=1.2)
- **NGC 2992**. Narrow+broad deconvolved (Yaqoob et al. 07)
- **3C 120**. Broad line from face-on disk. Rin=10Rg. Weak reflection (R=0.6) - Kataoka et al. 07
- **NGC 3516**. Broad line + reflection robust to complex absorber. (Markowitz et al. 07)
- **3C 382.-** broad and narrow lines + reflection (R Sambruna talk)

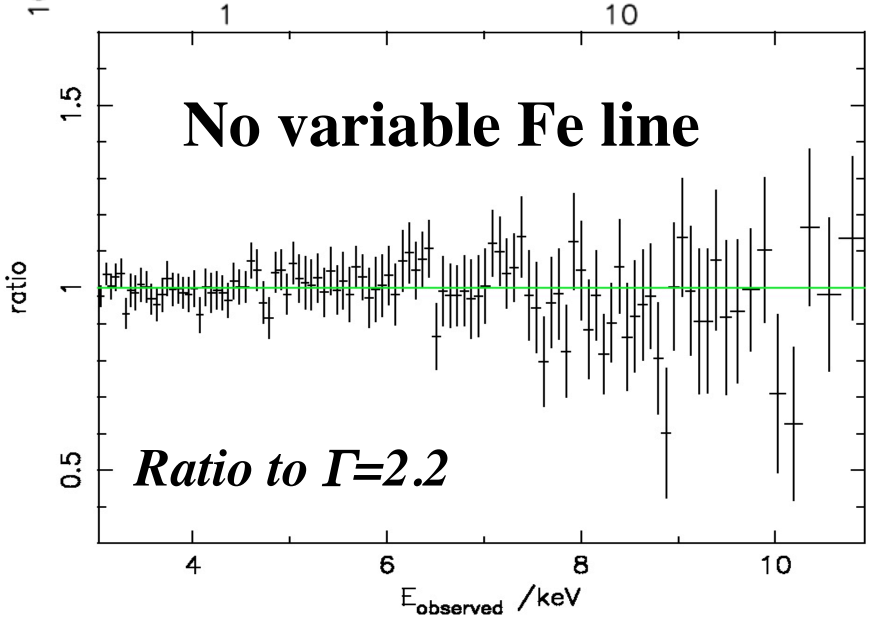
No Broad Lines

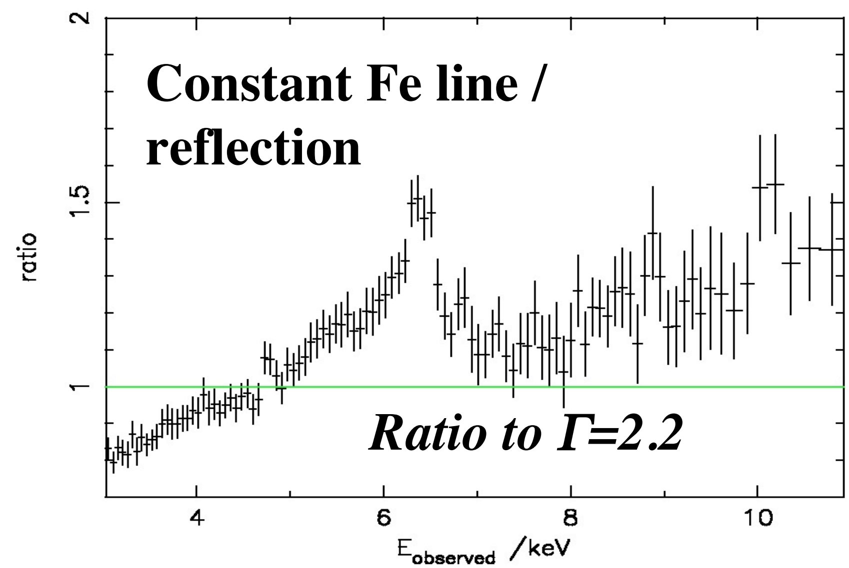
- **NGC 2110**. no broad line and no reflection (Okajima et al. 08)
- **NGC 7213**. No broad line + weak reflection (AO2, in prep)
- **NGC 5548** - narrow iron line only (Elvis et al.). Doesn't respond to continuum.
- **Cen A**. no broad line nor reflection (Markowitz et al. 2007)
- **NGC 3783**. Ambiguous broad line, but weak reflection (R=0.5) and line dependent on absorption (A Markowitz poster)

PCA deconstruction of MCG -6-30-15 with Suzaku
(see L. Miller poster)

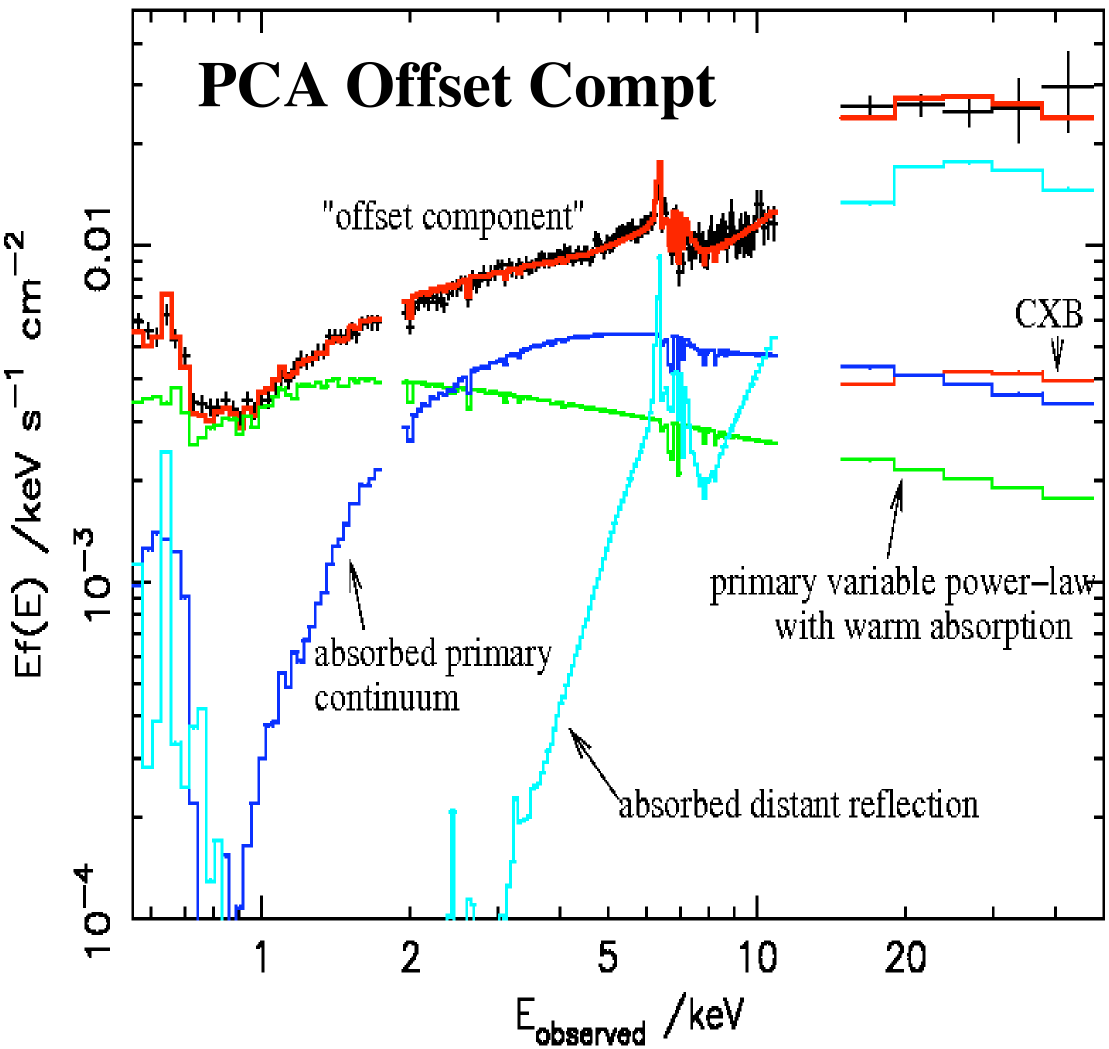








An Alternative to Light-Bending in MCG -6-30-15? (L. Miller poster)



Model consists of:-

“distant” absorbed reflector (R=1-1.5)

intrinsically variable power-law (with warm absorber).

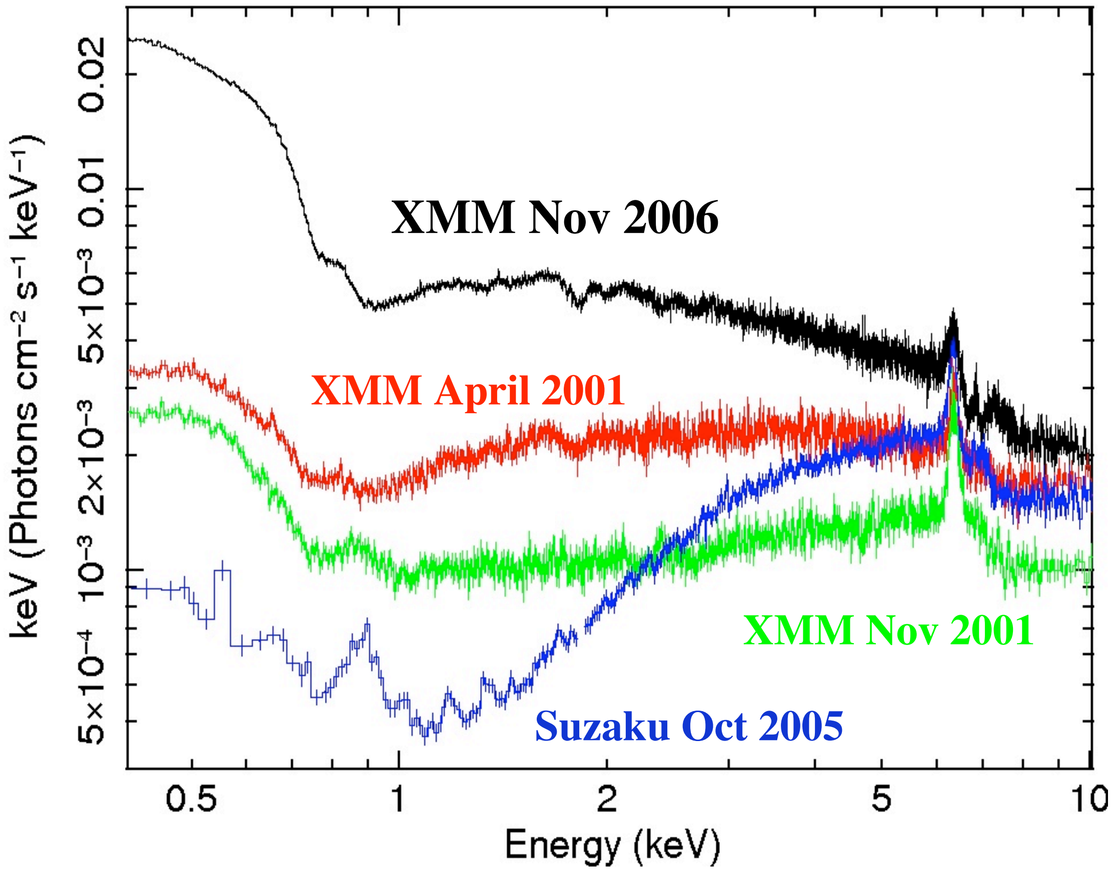
Partially covered absorbed power-law.

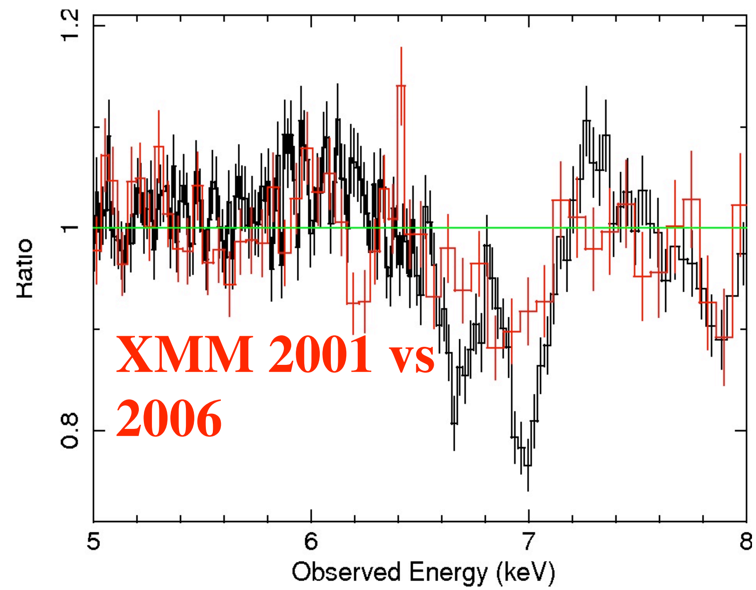
Excellent fit statistic in broad-band Suzaku/XMM datasets.

Reproduces absorption in Chandra/HETG, XMM/RGS

Absorption Variability in NGC 3516
(Markowitz et al. 2007, Turner et al. 2008)

Strong changes in source flux driven by changes in covering fraction of "heavy absorber".

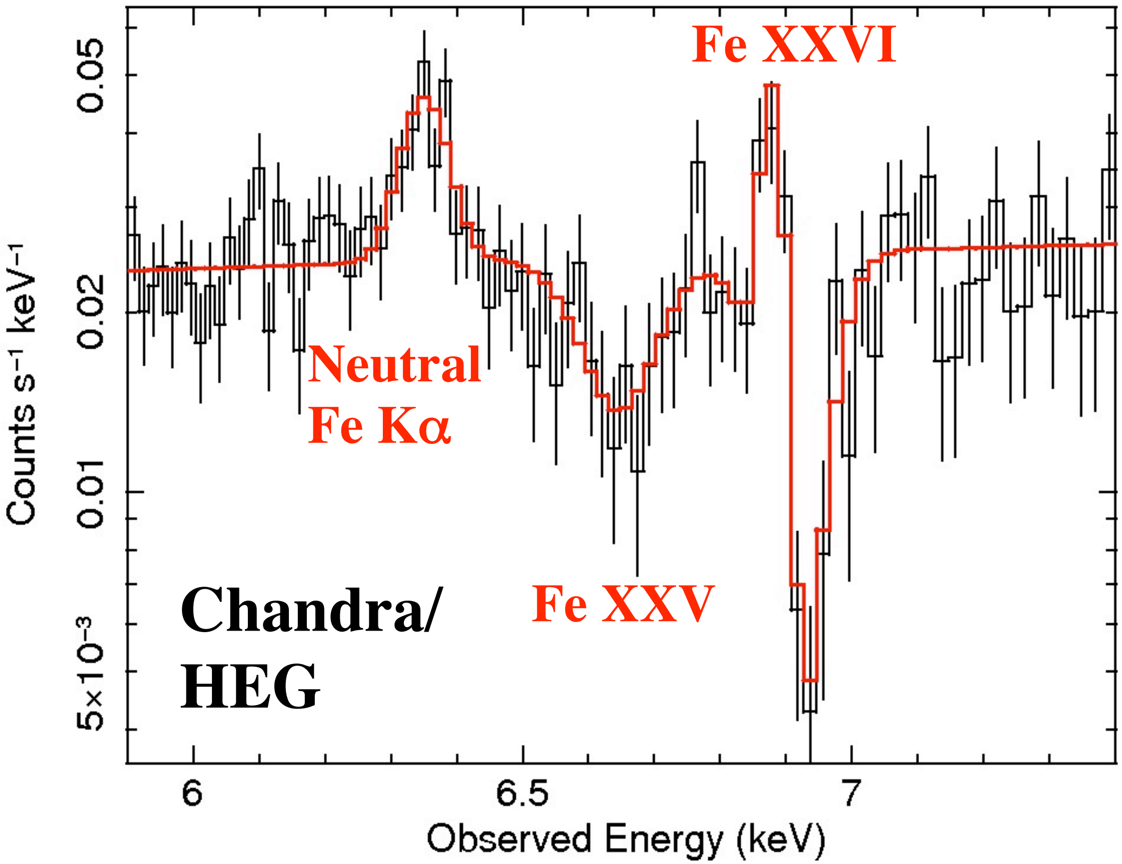




Increase in column of highest ionized absorber, with strong Fe XXV/XXVI absorption lines emerging in 2006 obs campaign.

A highly ionized outflow in NGC 3516

(Turner et al. 2008)



Observed frame and energies at 6.64, 6.92 (±0.02 keV) rules out local (z=0) origin, e.g. WHIM.

NGC 3516 observed for 200ks with XMM/Newton and Chandra/HETG in 2006.

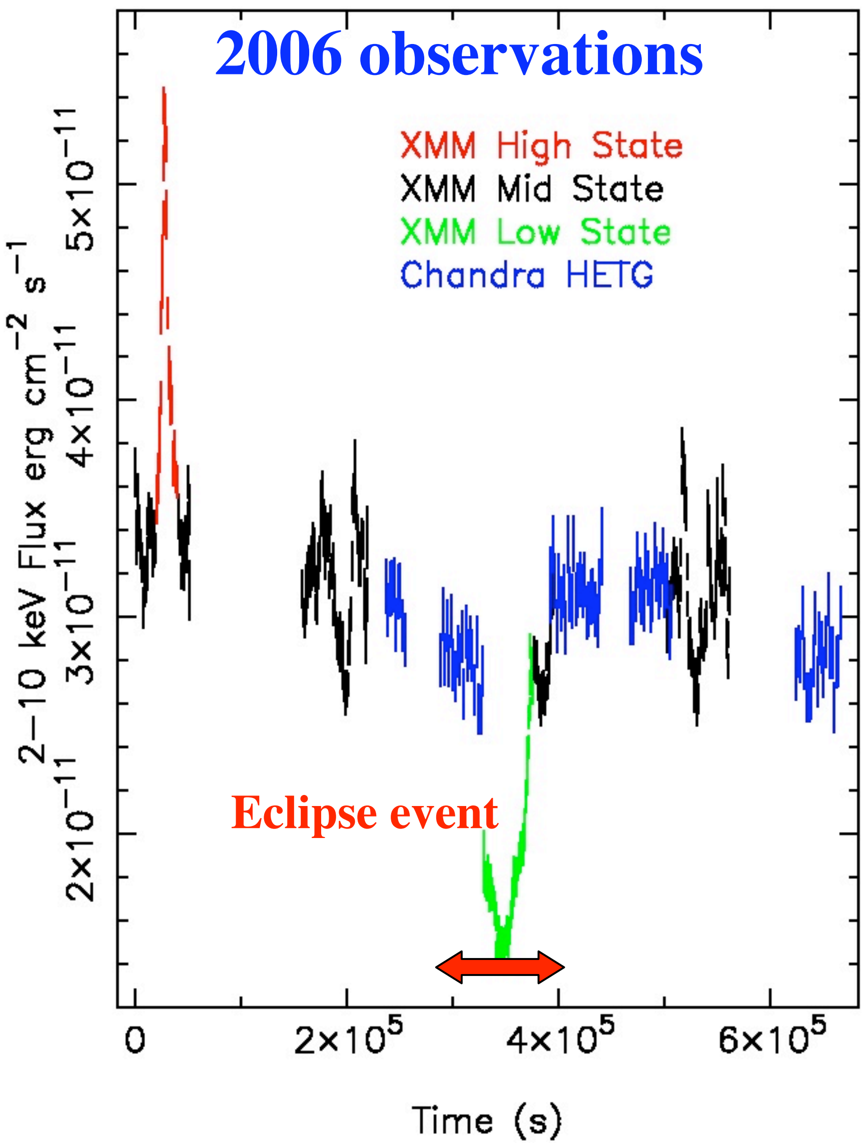
Source returned to former bright state ($5e^{-11}$ cgs, 2-10 keV)

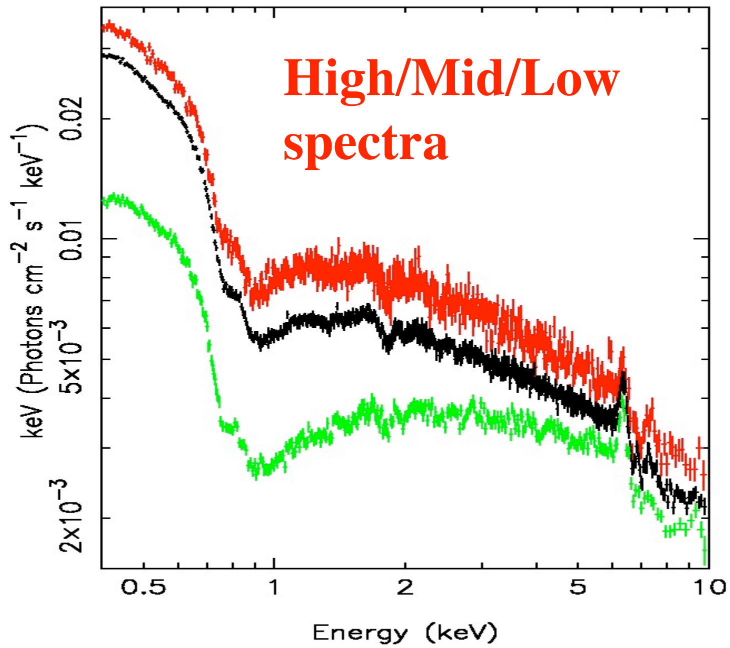
Strong (100 eV, EW) absorption lines near 6.7, 6.97 keV rest frame, due to Fe XXV, XXVI 1s-2p. $N_H > 10^{23}$ cm^{-2}.

Evidence of P-Cygni profile from outflow to Fe XXVI. Velocity shift ~2000 km/s

Similar profile seen in Mg/Si/S lines.

An eclipse event in NGC 3516 (Turner et al. 2008)





Changing covering of absorber accounts for spectral variability

Short timescale (0.5 day) 'eclipse" implies emission region only a few Rg in size (clouds similar size), as v=2000 km/s (HETG)

Absorbing matter in clumpy disk wind, at distances of <0.1pc.

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)

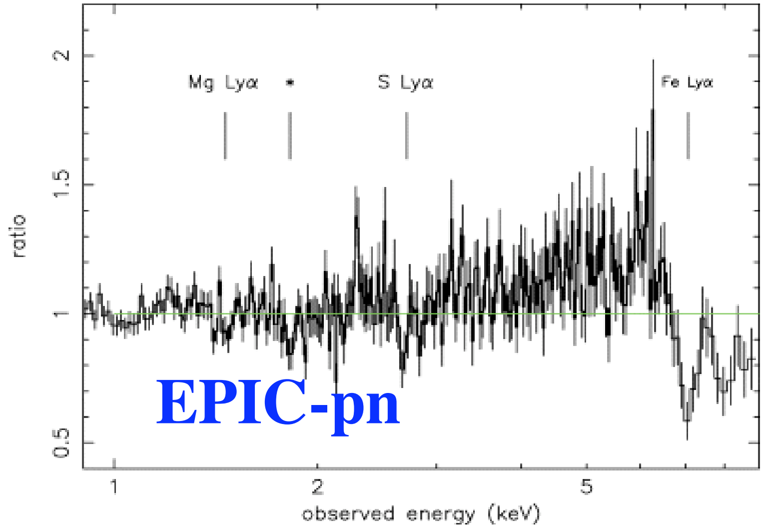
APM 08279+5255	v~0.2-0.4c	(Chartas et al, ApJ, 2002, 579, 169)
PG1211+143[1, 2]	**v~0.08-0.14c**	**(Pounds et al, MNRAS, 2003, 345, 705)**
PG1115+080	v~0.1/0.34c	(Chartas et al, ApJ, 2003, 595, 85)
PG0844+349	v~0.2c	(Pounds et al, MNRAS, 2003, 346, 1025)
PDS 456[2]	**v~0.12-0.27c**	**(Reeves et al, ApJ, 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	v~0.2c	(Dadina et al., 2005, A&A, 442, 461)
IC 4329a	v~0.09c	(Markowitz et al. 2006, ApJ, 646, 783)
MCG -5-23-16	v~0.1c	(Braito et al, 2007, ApJ, in press).

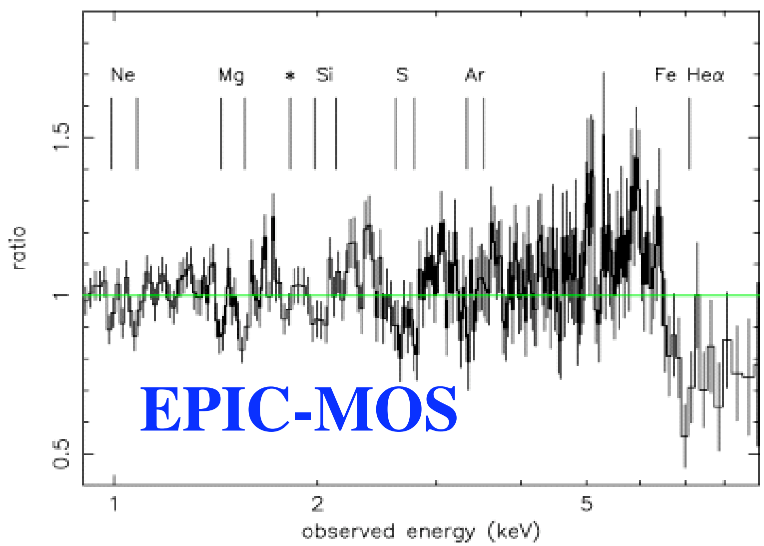
NB

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. McKernan et al. 04,05 have claimed the lines may arise from local (z=0) hot gas with no outflow velocity.

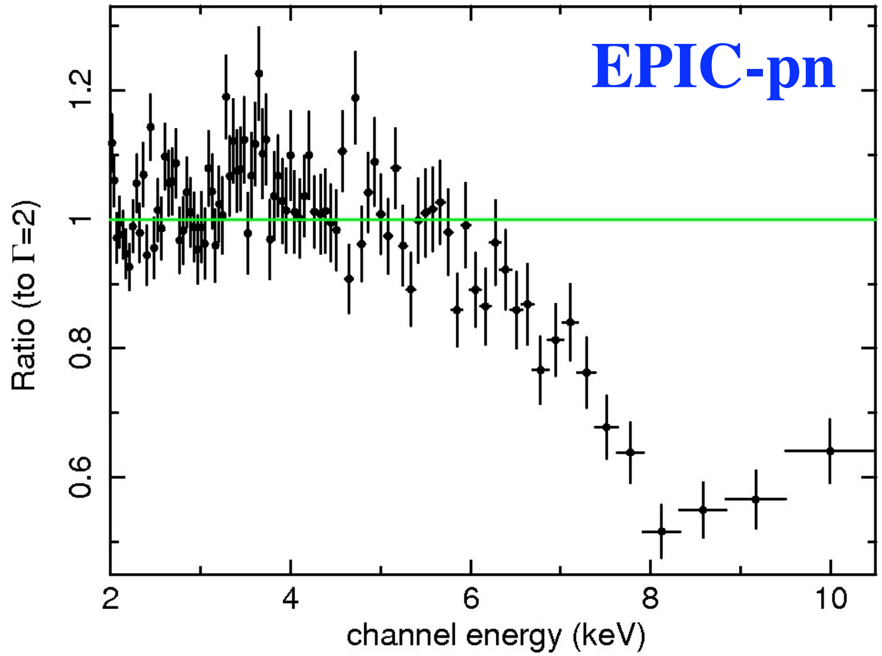
Discovery of Highly Ionized / High Velocity Outflows

PG 1211+143, z=0.081 (Pounds et al. 03, 06, 07)





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

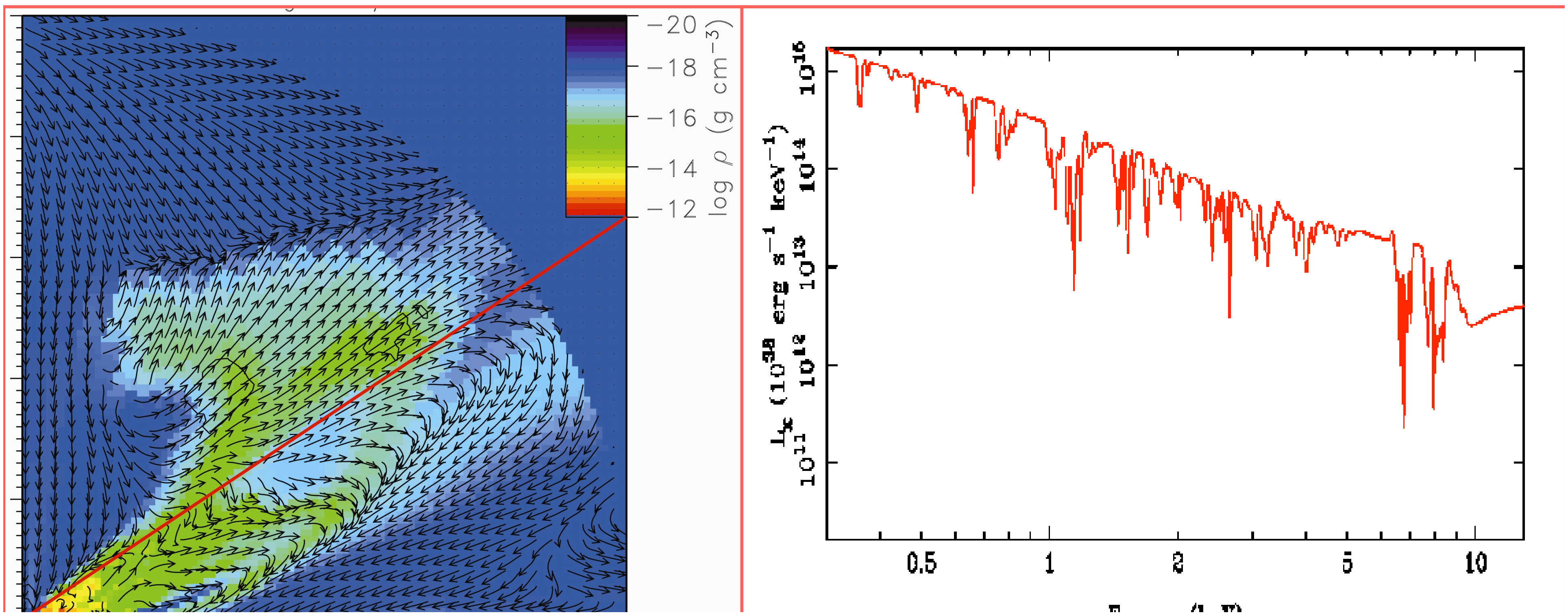


Blue-shifted absorption due to highly ionized iron (e.g. Fe XXV) as well as Mg/Si/S.

Velocities implied are 0.1-0.2c, launched from < 100Rg, with columns >10^{23} cm^{-2}. Suggests kinetic power ~ L_{bol}.

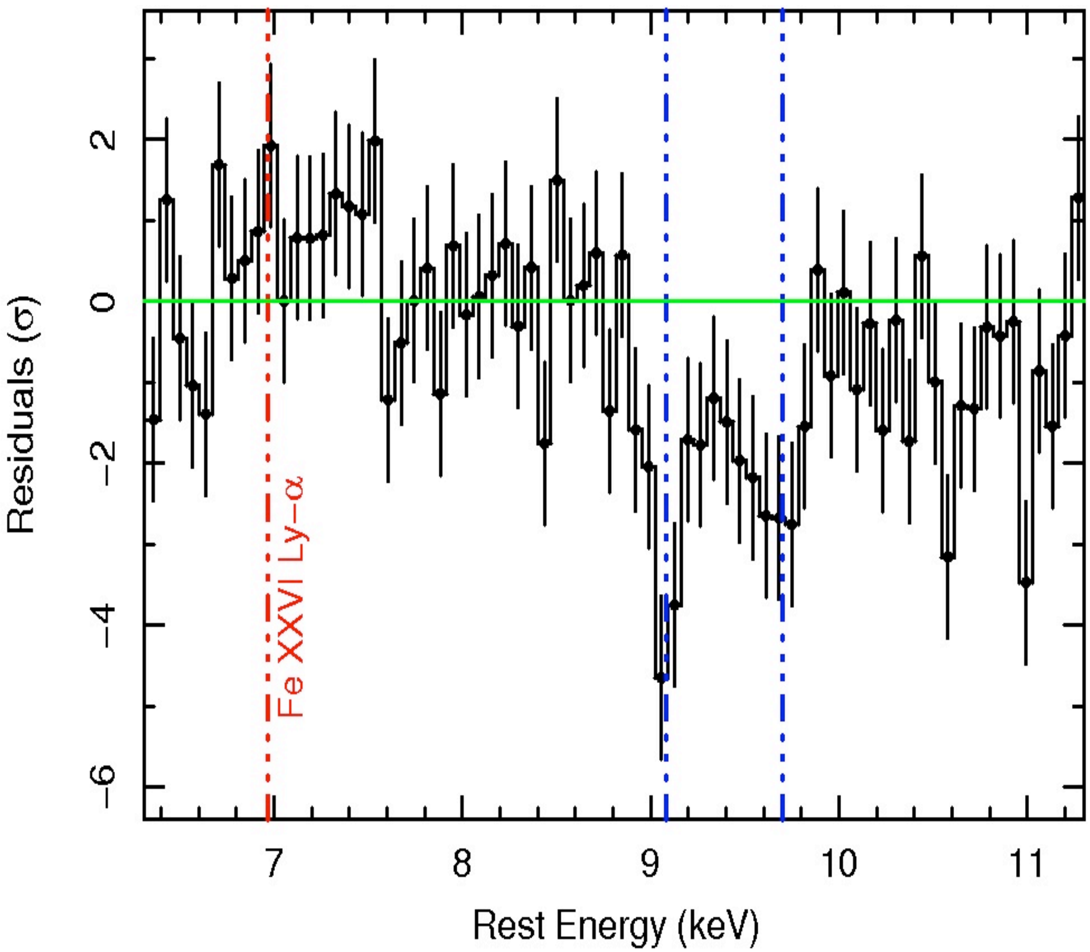
Fast, Line driven Winds ?

- Disk winds simulations of Proga (2004; 2007)
- looks a lot like the high ionization absorption lines at Fe Kα! (e.g. PDS 456, PG 1211+143).
- Terminal velocities ~ 0.2-0.3c, densities (10^8-10^{10} atoms cm^{-3}) and columns (10^{22} - 10^{24} cm^{-2}) consistent with observed systems.



Relativistic Outflow in PDS 456

(Deep Suzaku Observation, 190ks, Feb 07)



High luminosity QSO z=0.184
L_{BOL}~10^{47} erg s^{-1}

High v outflow originally claimed in 2001 XMM observation (Reeves et al. 2003) and in UV via HST/STIS (O'Brien et al. 2006).

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

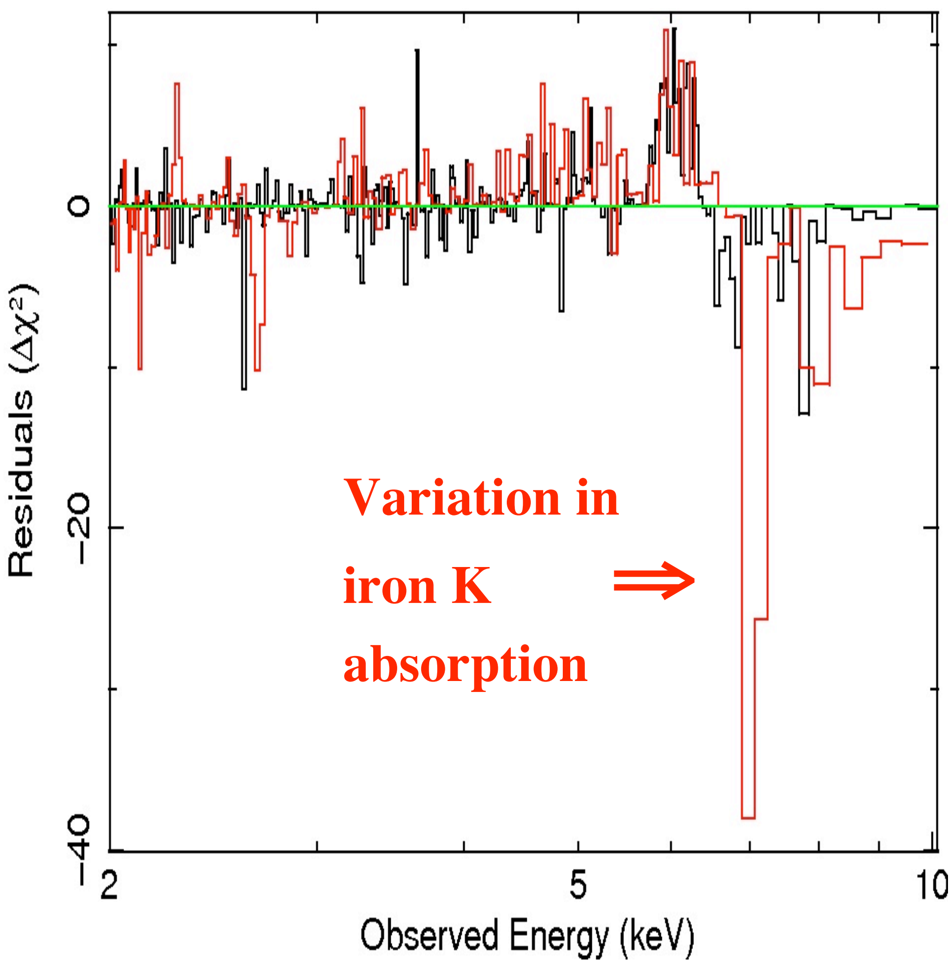
NOT associated with obvious transition at z=0 frame, ruling out WHIM or local bubble.

Outflow velocity of 0.26/0.32c, if associated with Fe XXVI 1s-2p.

In PDS 456, outflow rate is ~25M_{solar}/yr assuming only 10% covering.
At 1/3c, the KP of outflow is 10^{47} ergs^{-1}, similar to bolometric output.

Fe K Absorption line variability in PG 1211+143
(Reeves/Done et al. 2008)

XMM (2001) vs Suzaku (2005)



XMM revealed a highly ionised outflow (Pounds et al. 2003), with strong 7.6 keV Fe K absorption (7.0 keV observed), likely from Fe XXV (0.14c) or Fe XXVI (0.08c).

Kaspi & Behar (06) suggested lower vel for RGS lines (3000 km/s). But does not account for Fe K.

McKernan et al. (04,05) suggested that 7.0 keV arises from local hot gas, i.e. coincident with Fe XXVI (6.97 keV). But from variability:-

T_{recomb}<4 yr ⇒ n>4x10^{3} cm^{-2}

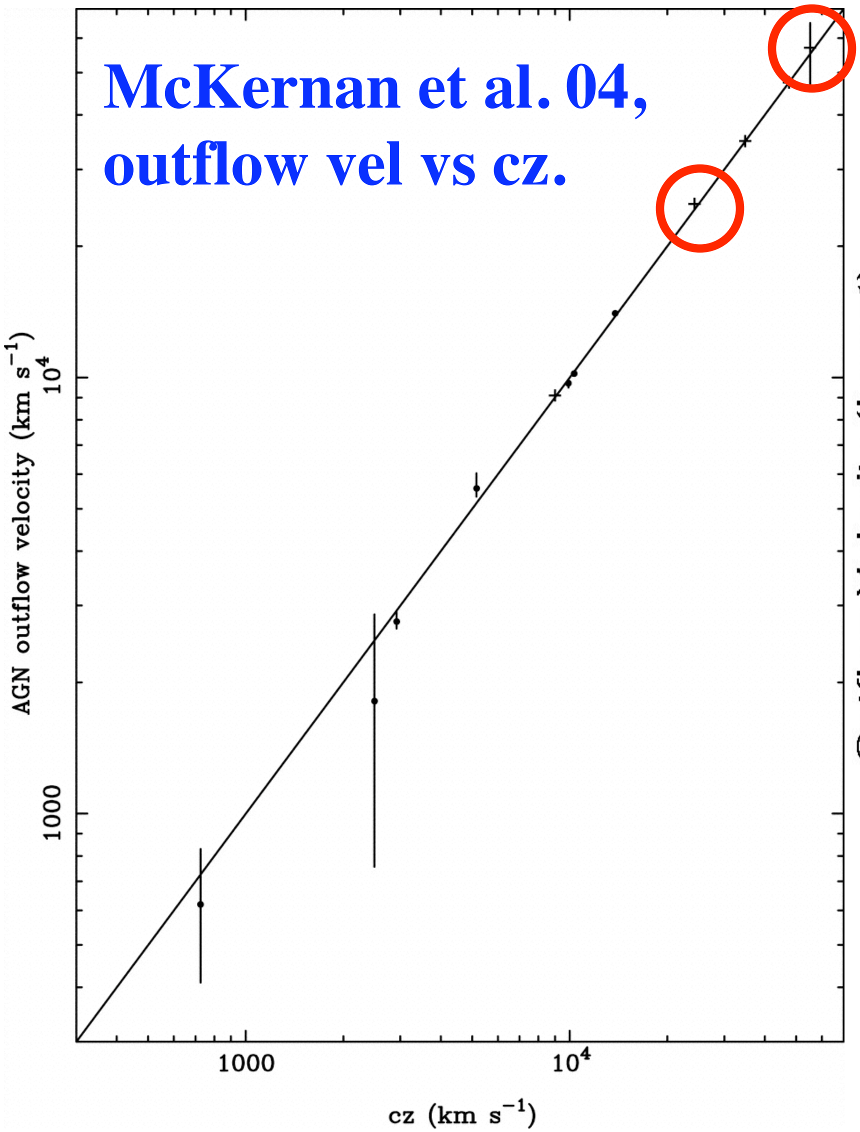
2x10^{22} cm^{-2} < N_H < 1x10^{24} cm^{-2}

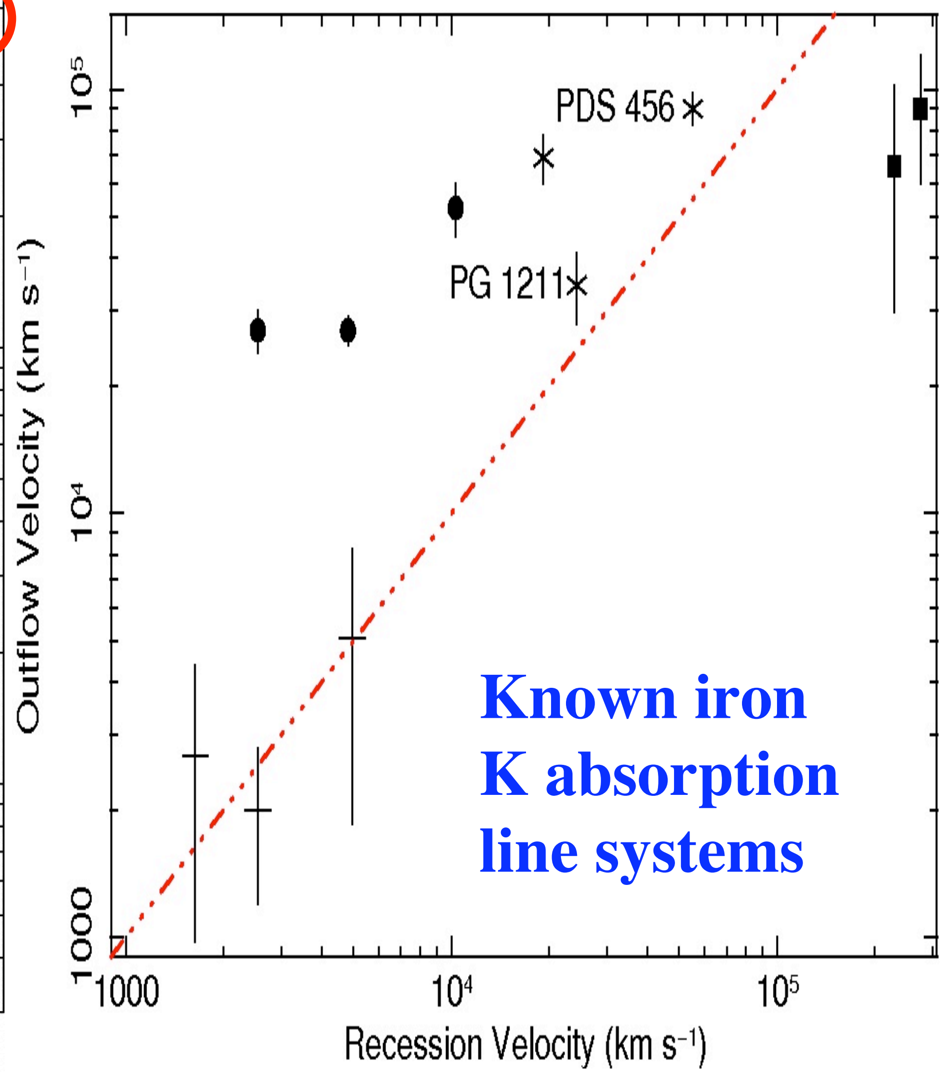
Delta R < 2x10^{20} cm^{-2} (<100 pc)

Surface brightness > 10^{-6} ergs cm^{-2} s^{-1} arcmin^{-2}. **Brighter than the Crab in every direction if local to our galaxy!!**

Iron K absorption MUST BE intrinsic to AGN outflow.

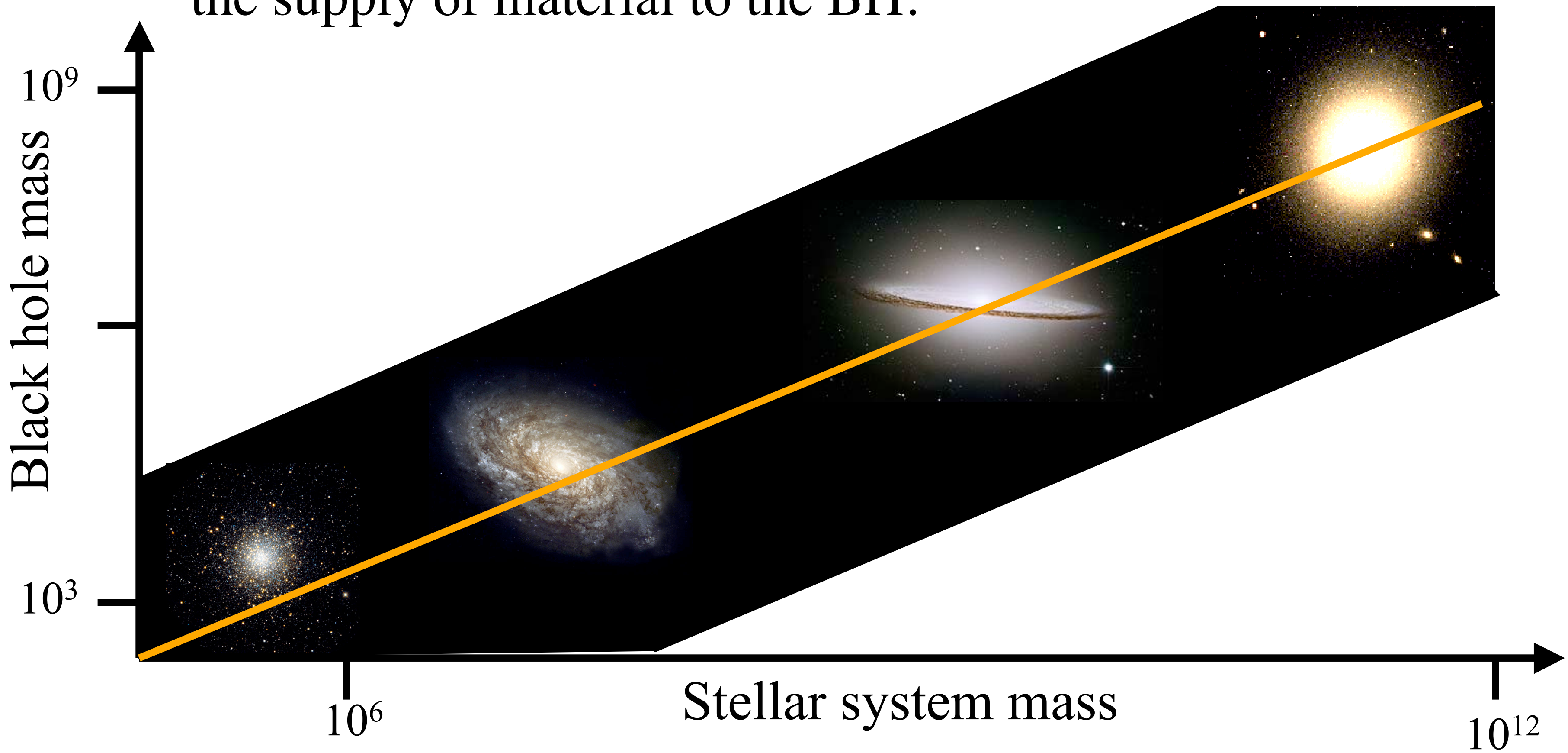
Fe K Absorption lines are not from local line of sight (z=0) gas (Reeves/Done et al. 2008)



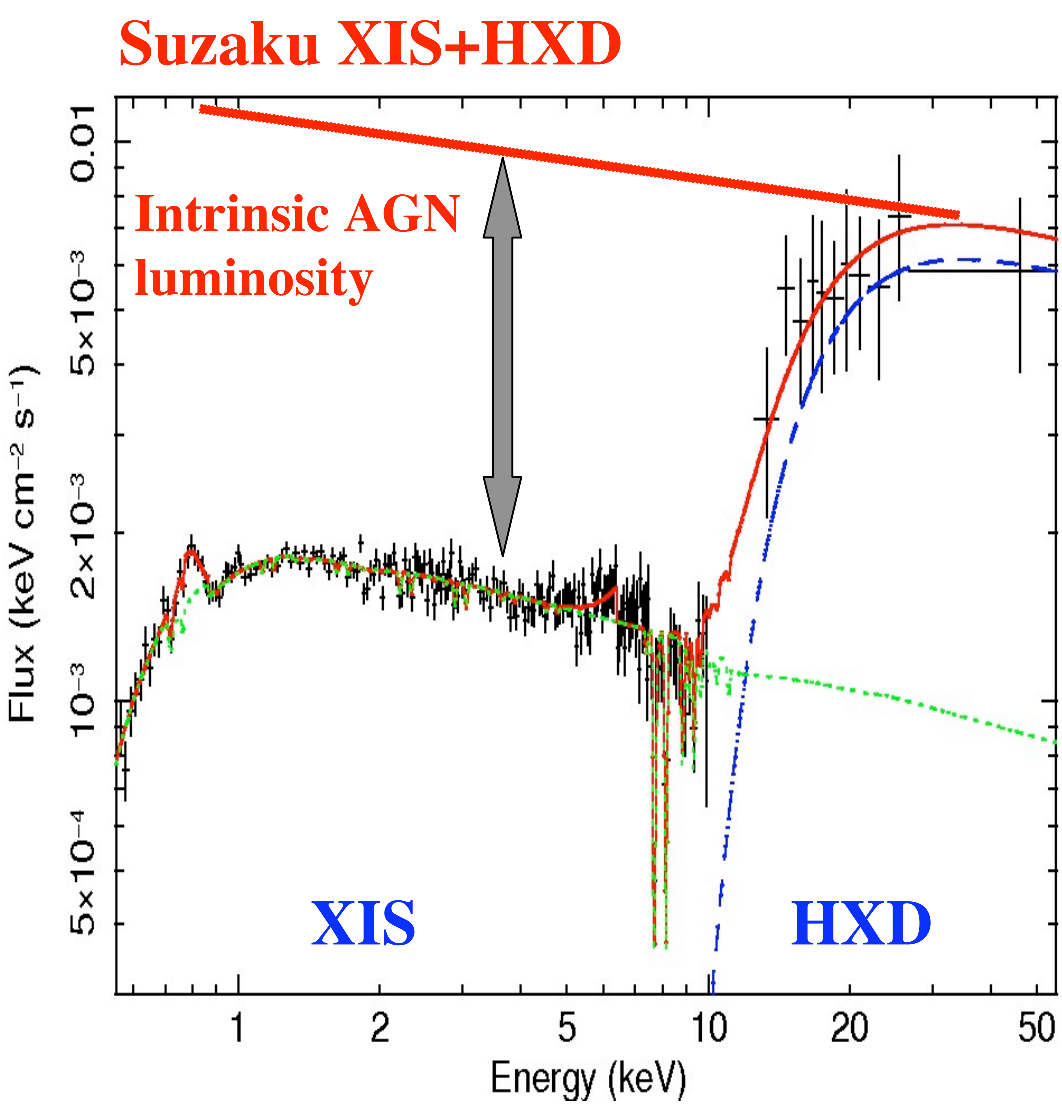


Outflows can regulate growth of black holes

- Direct correlation between the bulge/galaxy mass and black hole mass (i.e. M-Sigma relation).
- Massive black holes grow by accretion. Powerful outflows can provide the feedback for this process, by shutting off the supply of material to the BH.



A Surprise from PDS 456 (preliminary!)



Optical type I AGN - but looks like a type II AGN in X-rays!

The hard X-ray data (above 10 keV) show a large x8 excess of flux.

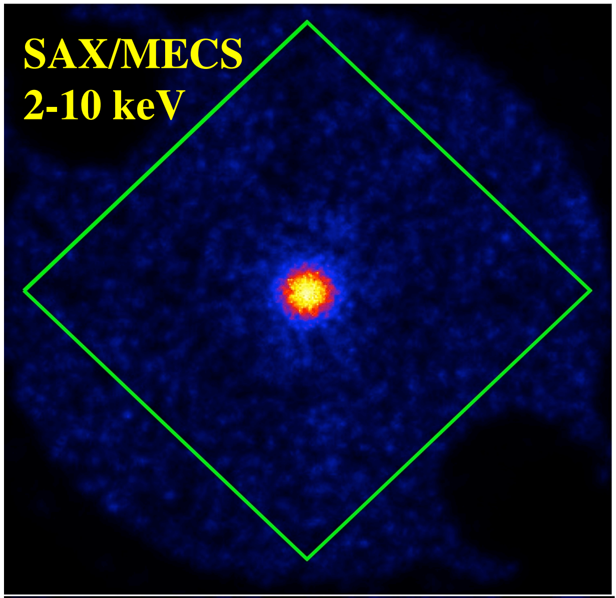
Strongly absorbed (N_H>$10^{24}$$cm^{-2}$) emission emerges above 10 keV.

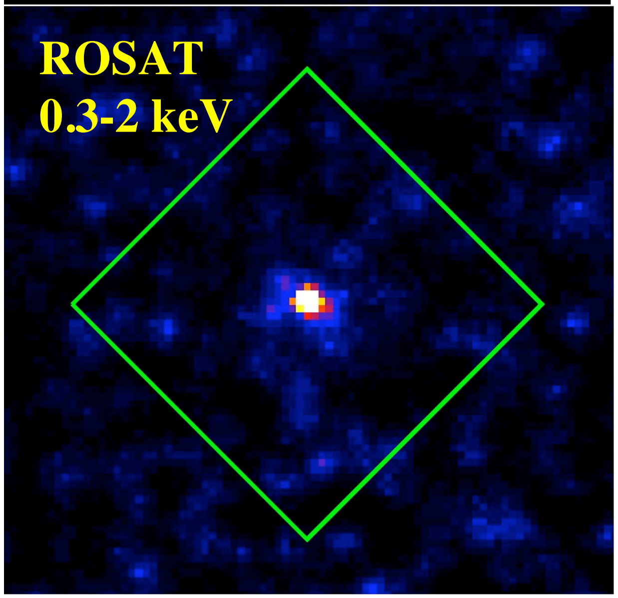
Absorber must be located ***close to black hole*** (well within BLR) to ***partially cover*** X-ray source

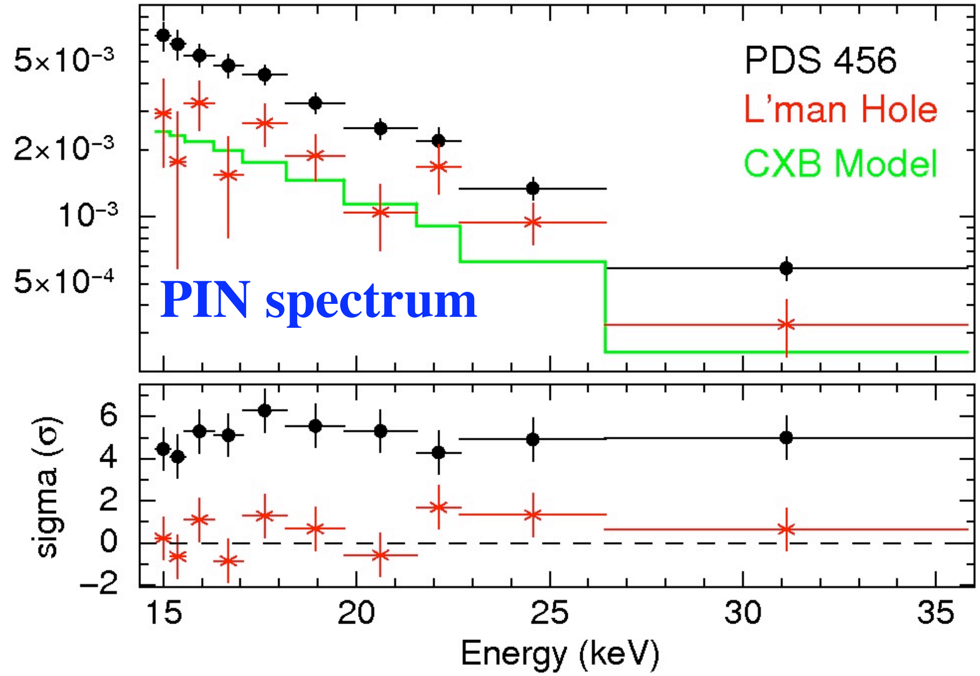
Or more exotic - a binary black hole (e.g. NGC 6240)?

Intrinsic X-ray luminosity much higher than is apparent(L_{2-10}=10^{46} erg s^{-1}, cf L_{bol}=10^{47} erg s^{-1})

HXD detection of PDS 456 is robust





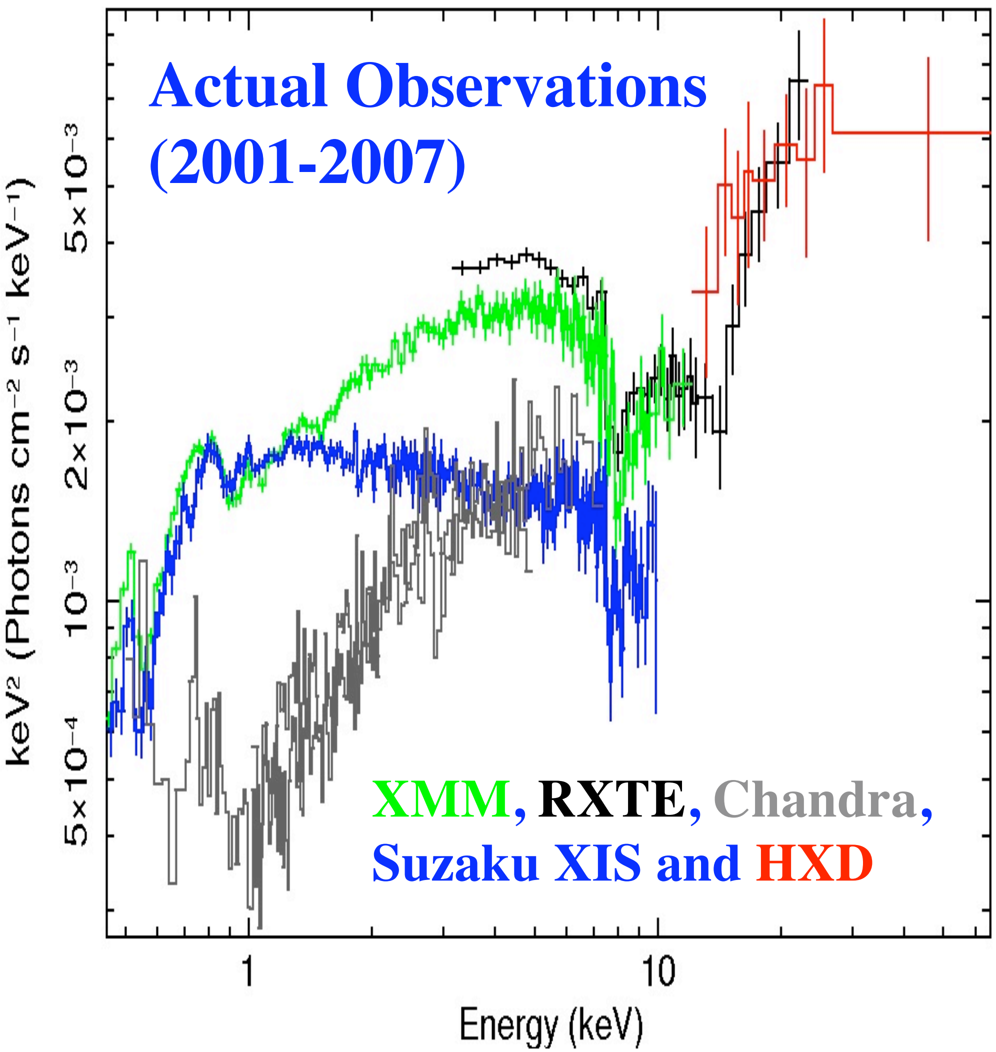


Strong detection in HXD/PIN **(>8σ, 4% sys. $F_{15\text{-}50}$ 2×10^{-11} cgs, vs 8×10^{-12} cgs CXB)**

No known strong X-ray sources in HXD field.
Galactic diffuse (ridge) emission negligable.
Probability of a 1mCrab src in HXD field is $<10^{-3}$
(e.g. Tueller et al. 07, BAT survey).

Has to be absorbed, with $N_H>10^{24}$ cm^{-2} (<10% prob)

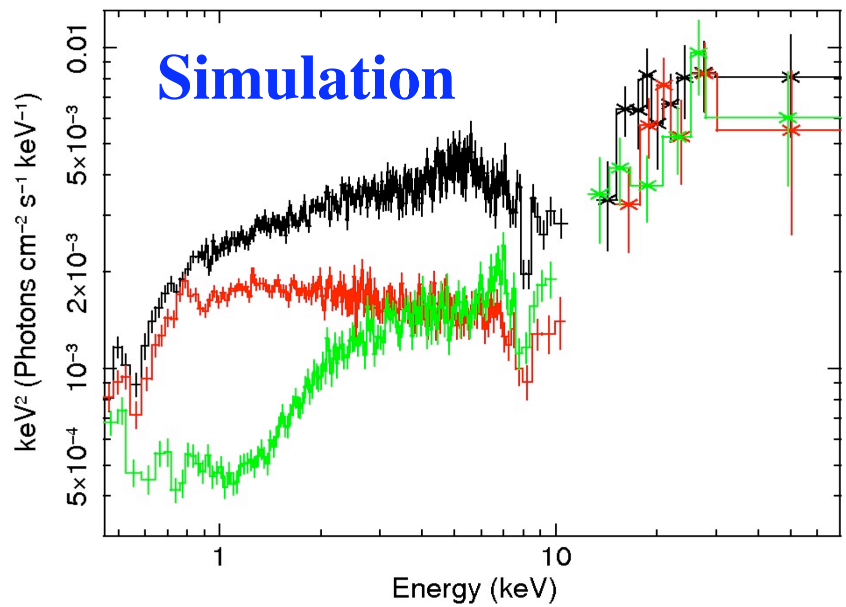
Can the spectral variability in PDS 456 be explained by variable absorption?



Can rapid variations in the large (10^{24} cm^{-2}) absorbing column (e.g. covering fraction) account for the spectral var in PDS 456?

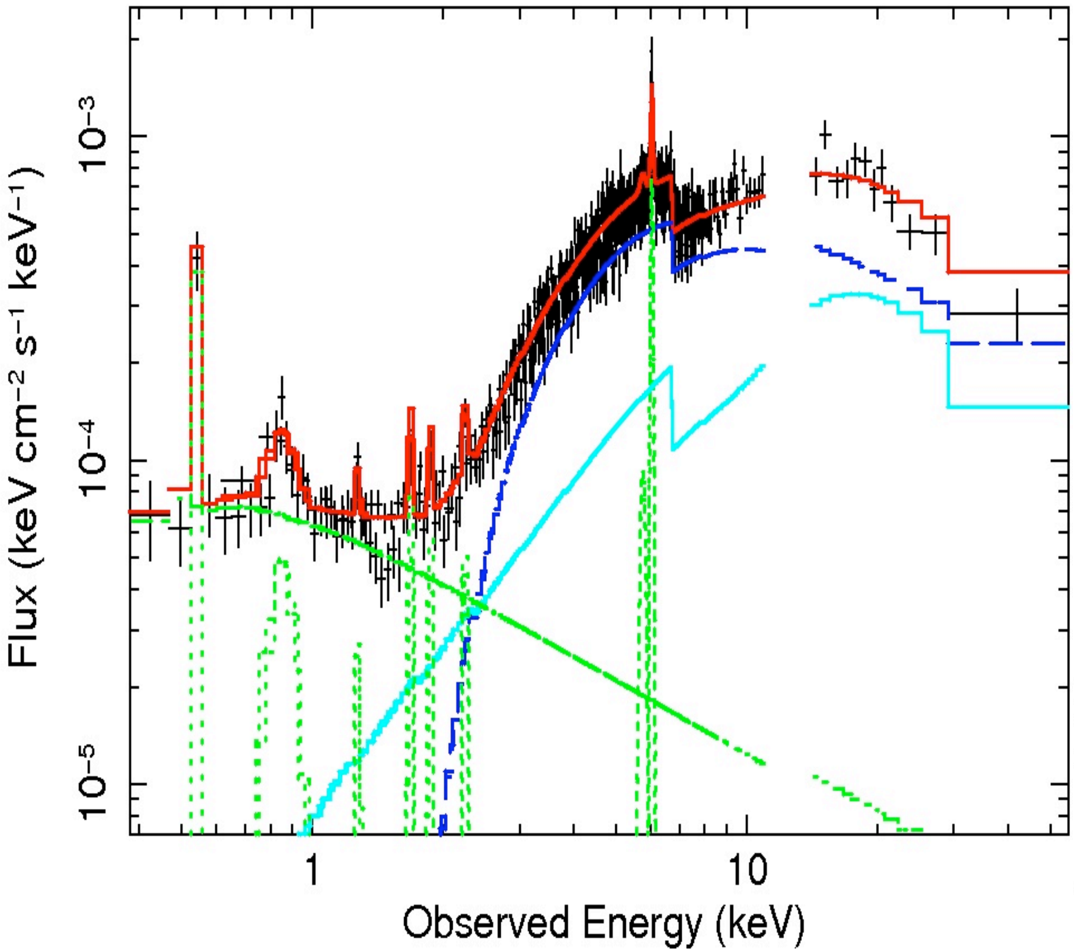
Prediction is for ***least variability*** in the hard X-ray band (i.e. 10 keV).

Absorbing clouds must be compact (few Rg) and close to source (e.g. bricks or a clumpy outflow?)



Optical - X-ray mismatch in the BLRG 3C 445 (Braito, Sambruna, Reeves, in prep)

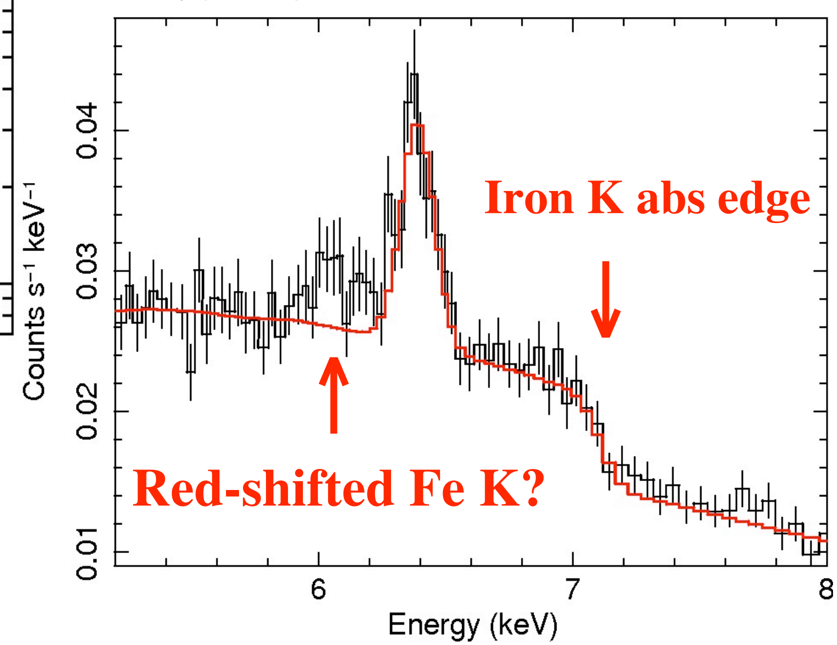
100ks Suzaku observation



Absorbed PL (Γ=1.8) + modest reflection (R=1-1.5) + strong scattered/photoionized emission.

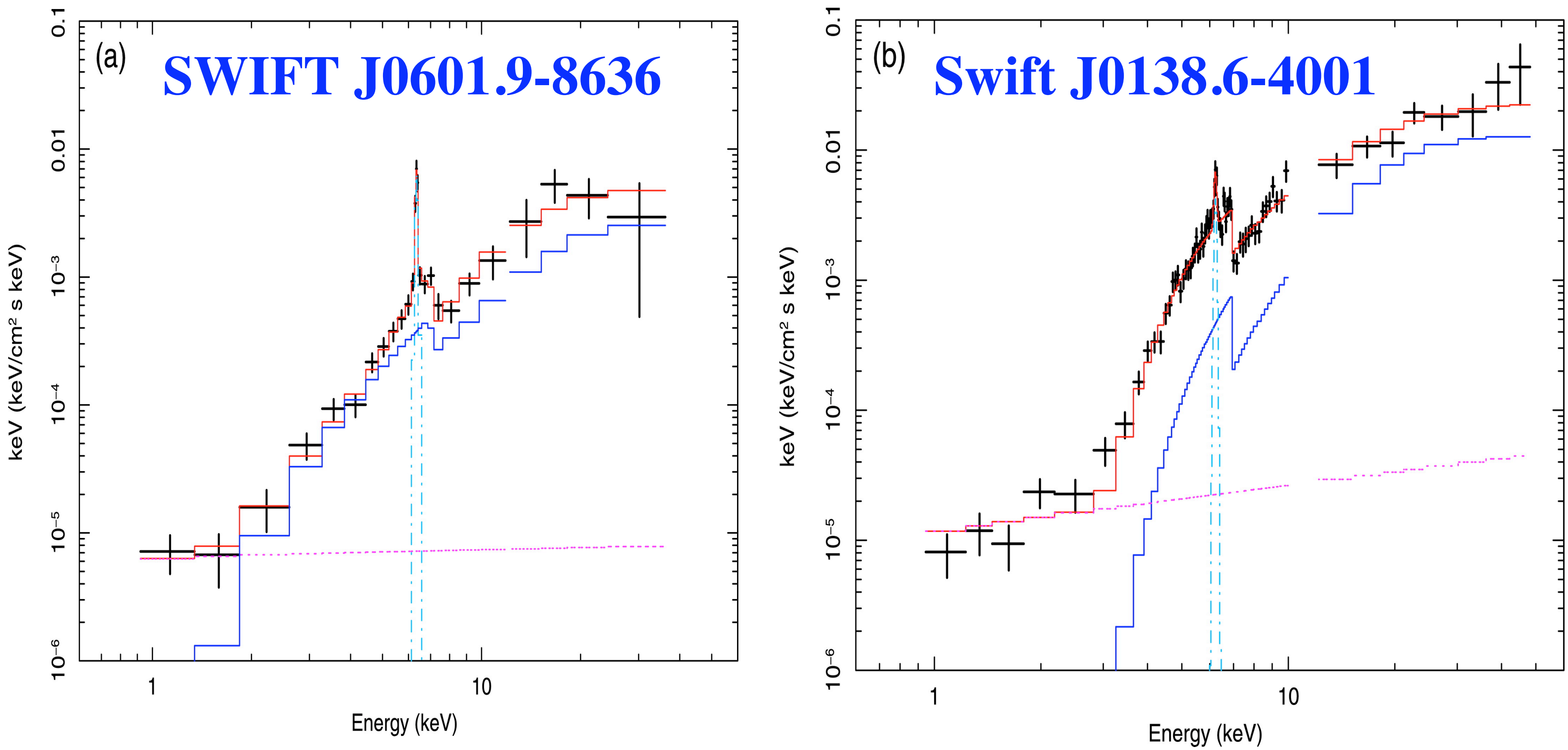
X-ray spectrum requires heavy absorber (**>10^{23} cm^{-2}**) - either partial covering or mildly (log xi~1) ionized.

At odds with modest optical reddening (Av~1) - however 3C 445 is viewed at high inclination (>60 deg) - viewed along disk/outflow?

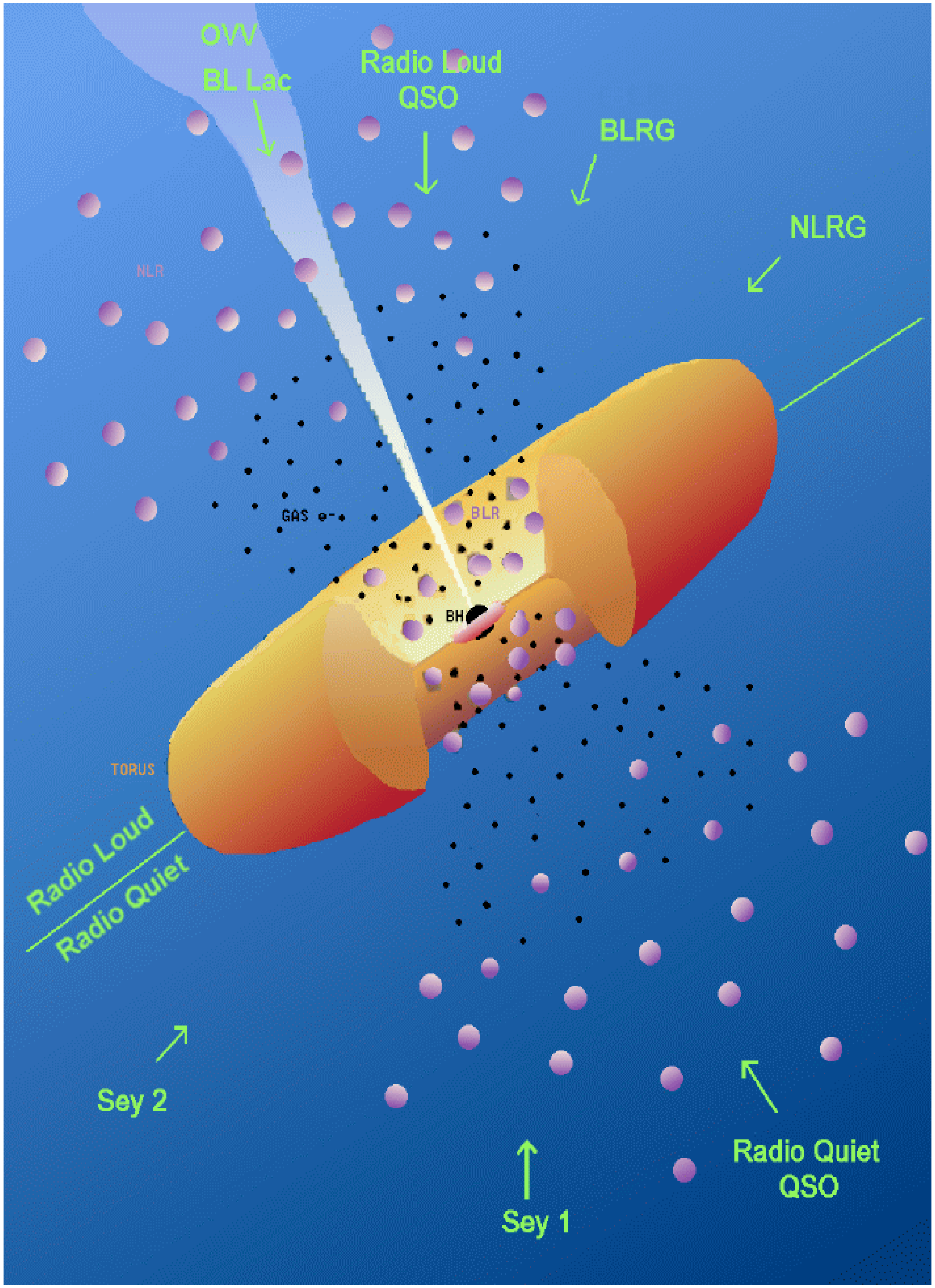


A different view of Seyfert 2s (Ueda et al. 2007)

Suzaku XIS + HXD



Swift-BAT selected Seyfert 2s with high reflection fraction (R~2, geometrically thick torus) and very weak scattered emission (< 0.5%). J0601.9 no previous known AGN activity (e.g. no OIII optical emission)



The Standard Unification Scheme of AGN

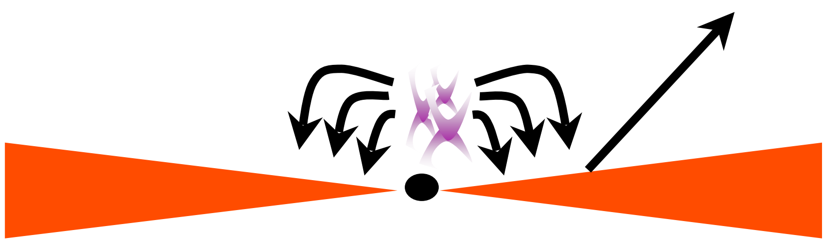
How well does this hold up with current observations?

e.g. type I AGN with large amount of X-ray obscuring matter on compact (sub pc) scales - e.g. within the torus or BLR and most likely associated with a high column disk wind.

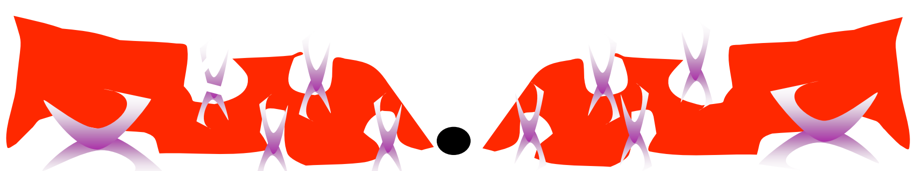
Type 2 AGN with non-standard X-ray properties (e.g. Ueda et al. 2007, Winter et al. 2007)

Geometries for AGN inner regions?

Reflection dominated

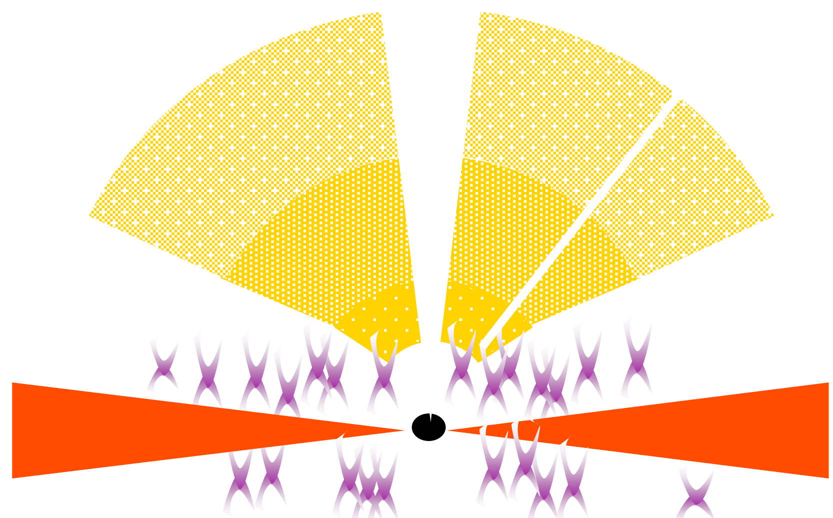


Light Bending (GR)



Inhomogeneous disk

Absorption dominated



Outflow

Conclusions

- **New Suzaku, XMM, Chandra observations are revealing that the AGN accretion flow is less simple than expected in standard thin accretion disk model.**

- **Outflows are a common property of many AGN. Disk-winds observed in many Type 1 AGN.**

- **Some type I AGN may have column densities greater than predicted by unified models, while variable heavy obscuring columns may even account for spectral variability. Absorbing gas on much more compact scales than, e.g. torus.**

- **In some cases outflows may reach near-relativistic velocities, transmitting a substantial fraction of the energy output.**

- **Future calorimeter resolution (<6 eV) spectra will provide a wealth of data at Fe K on high column density outflows. Hard X-ray imaging will reveal new types of obscured black holes.**