X-ray spectra of AGN: obscuring material and disk winds

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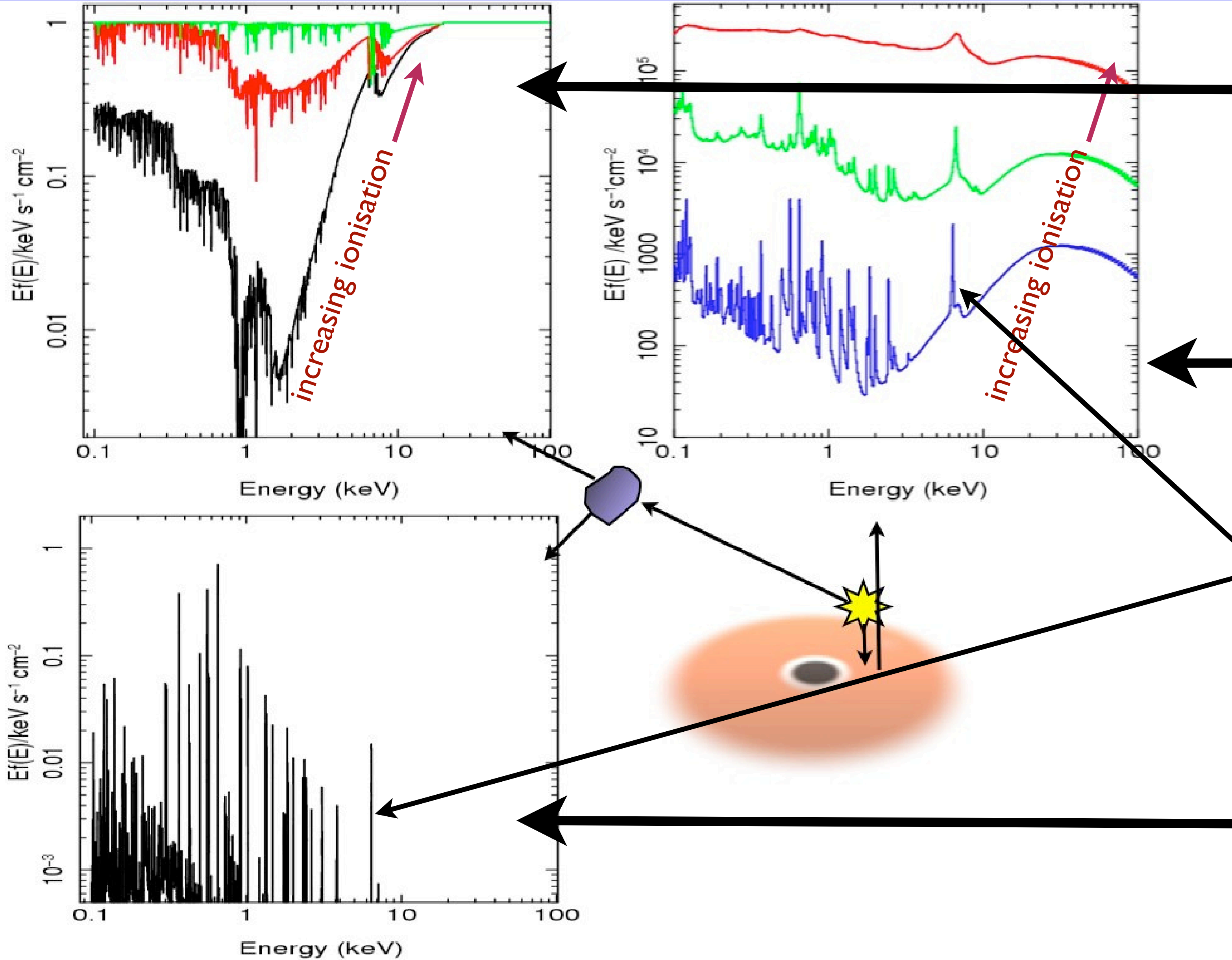
Accretion disk winds, why do we care?

- At high Eddington ratio, Compton radiation pressure equals gravitational force, so we expect accretion to be complex mix of inflow and outflow (in partially ionised material line opacity likely makes radiation force substantially larger). We want to understand BH growth through the accretion process.
- The BH - galaxy mass relation is extremely tight and likely requires feedback to self-regulate the growth (see King 2003 and this session)
- High-velocity outflows are common in the UV spectra of QSOs. Higher-ionisation outflows should be detectable in X-ray observations of type 1 AGN.

Theme of this talk - can we detect and measure accretion disk winds at X-ray energies?

X-ray broad-band spectral signatures



effect of absorption through optically-thin material
(*xstar* - Kallman et al 2001)

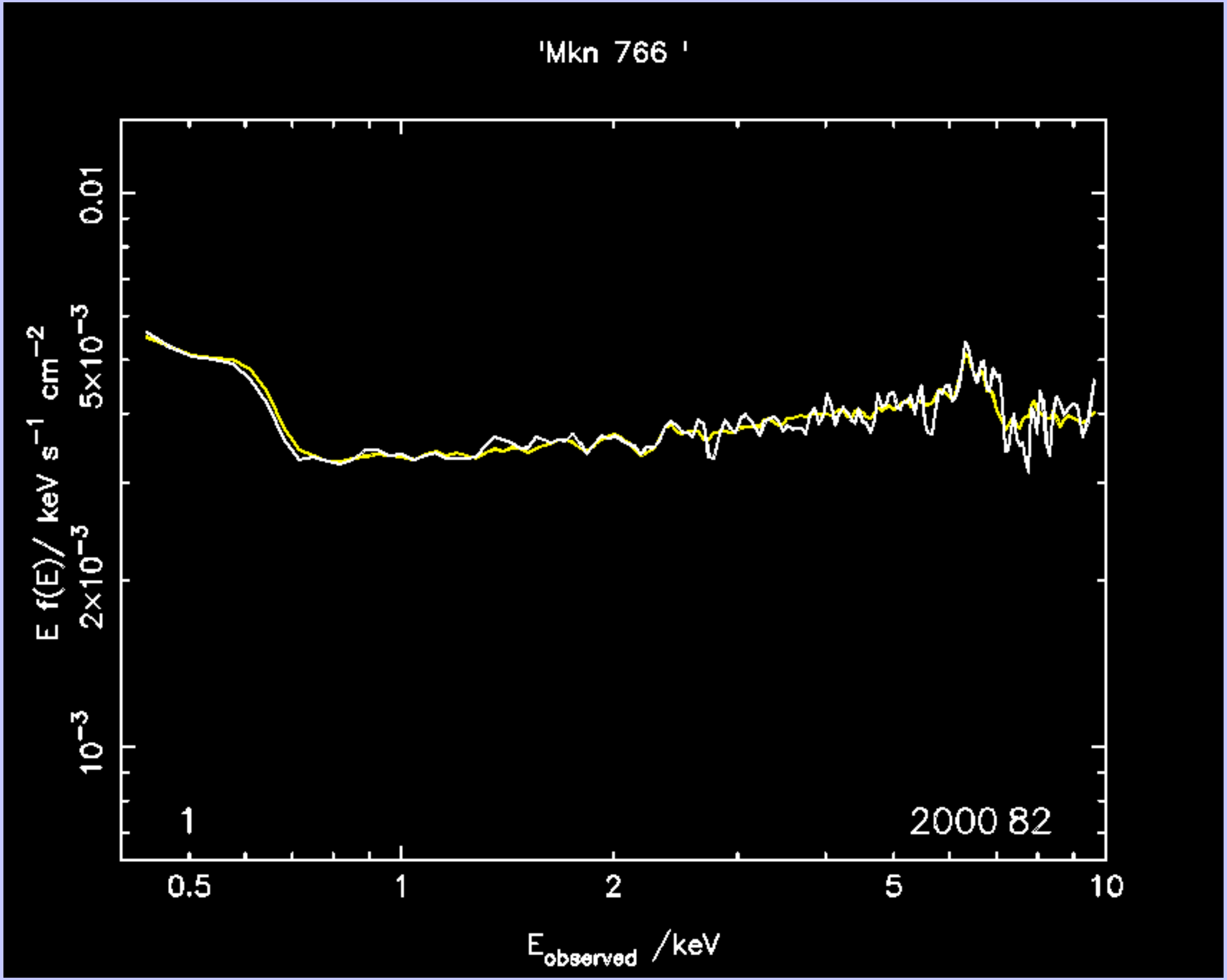
effect of atomic opacity due to reflection from optically-thick material
(*reflion* - Ross & Fabian 2005)

Fe Kα emission

line emission from absorbing gas
(*xstar* - Kallman et al 2001)

from Turner & Miller 2009 review

AGN X-ray spectral variability



Miller et al 2007

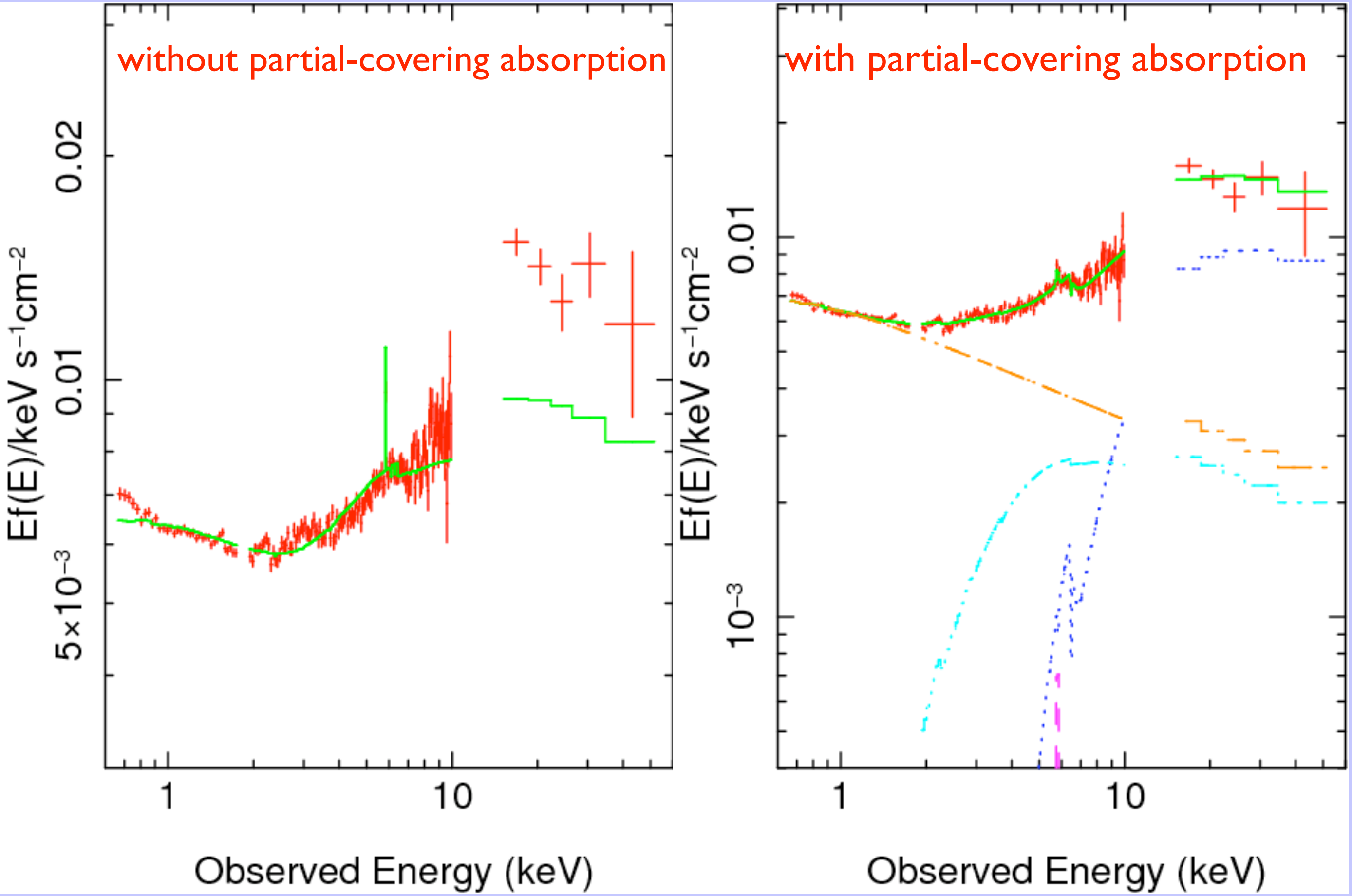
Absorption or reflection (or both)?

- low flux states of AGN are characterised by high opacity
  - If due to absorption, the most natural inference is that low flux states are *caused* by absorption
  - If due to reflection, a mechanism must exist that allows reflected light to remain visible when the primary illuminating continuum disappears
    - (e.g. GR "light-bending" around the black hole in tandem with a vertically-moving source near the BH can be tuned to produce a low-state in which a distant observer's view is dominated by reflection and a high-state dominated by primary emission - Miniutti & Fabian 2004)
- both reflected emission and highly absorbed emission can produce "hard" X-ray spectra - but observations (>20 keV) may be able to discriminate
  - high-column absorbers can show arbitrarily steep rises into the hard X-ray band

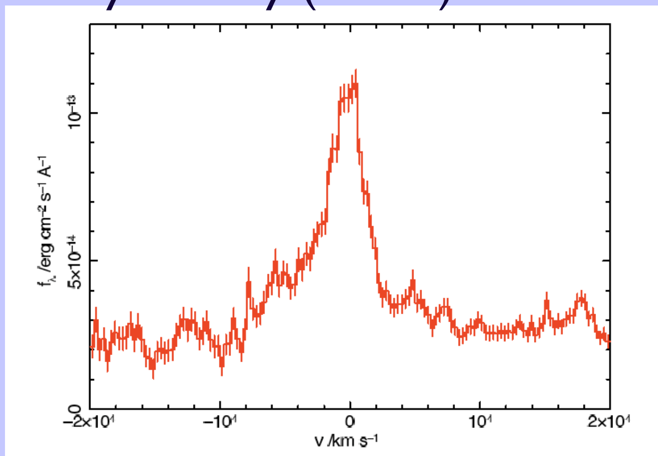
Examples of high-column clumpy absorption in type 1 AGN :

1H 0419-577 (Turner et al. 2009)

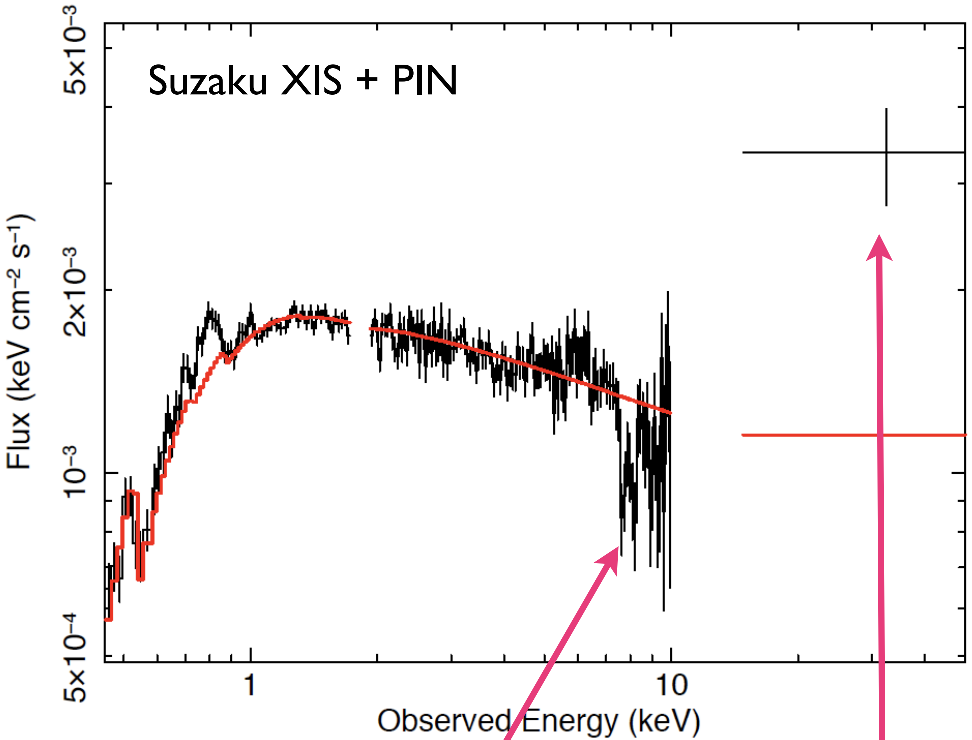
Requires nearly optically-thick partial covering absorption to explain excess observed at E>20 keV in Suzaku HXD PIN data

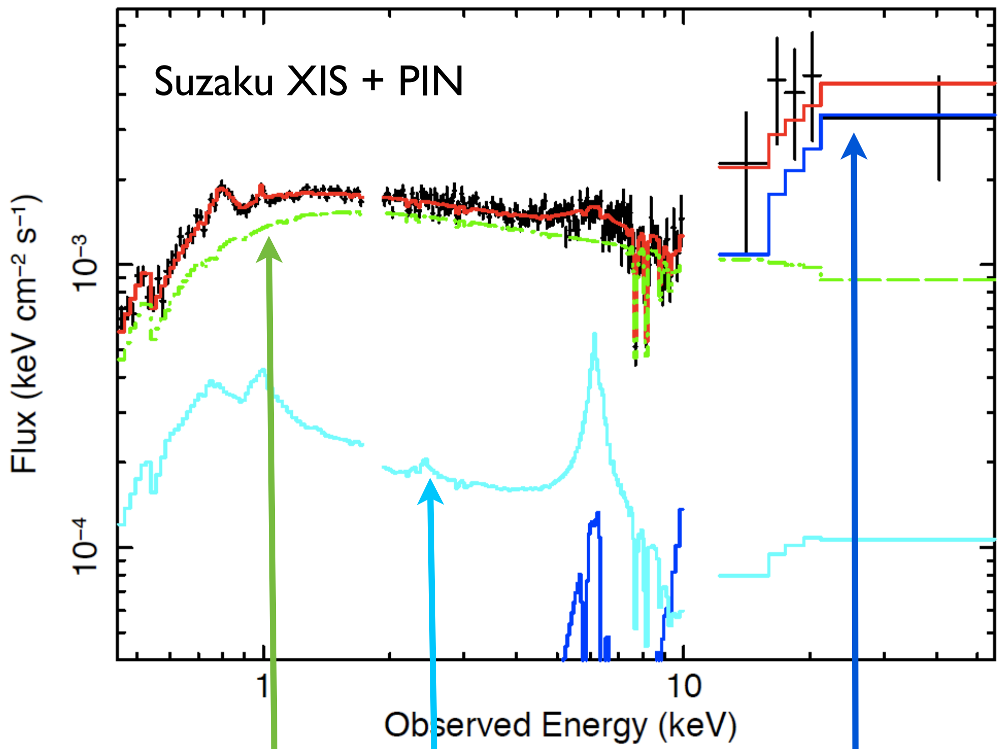


- Very strong hard excess in HXD, cannot be fit by reflection
- observer sees $N_H > 10^{24}$ cm^{-2} covering >70%
- emission-line luminosity implies wind subtends ~12% at source
- $L_{bol} \sim 10^{47}$ erg/s
- Located close to black hole (e.g. within BLR)
- Signature of a thick disk wind? CIV emission shows "disk wind" blue asymmetry (below)



PDS 456 - a clumpily-absorbed type I AGN with a high-velocity (0.3c) outflow (Reeves et al 2009)





blue-shifted Fe Kα absorption @ 0.26-0.31c

hard excess

primary absorbed continuum

reflected continuum

source 20% covered by τ≳1 absorber

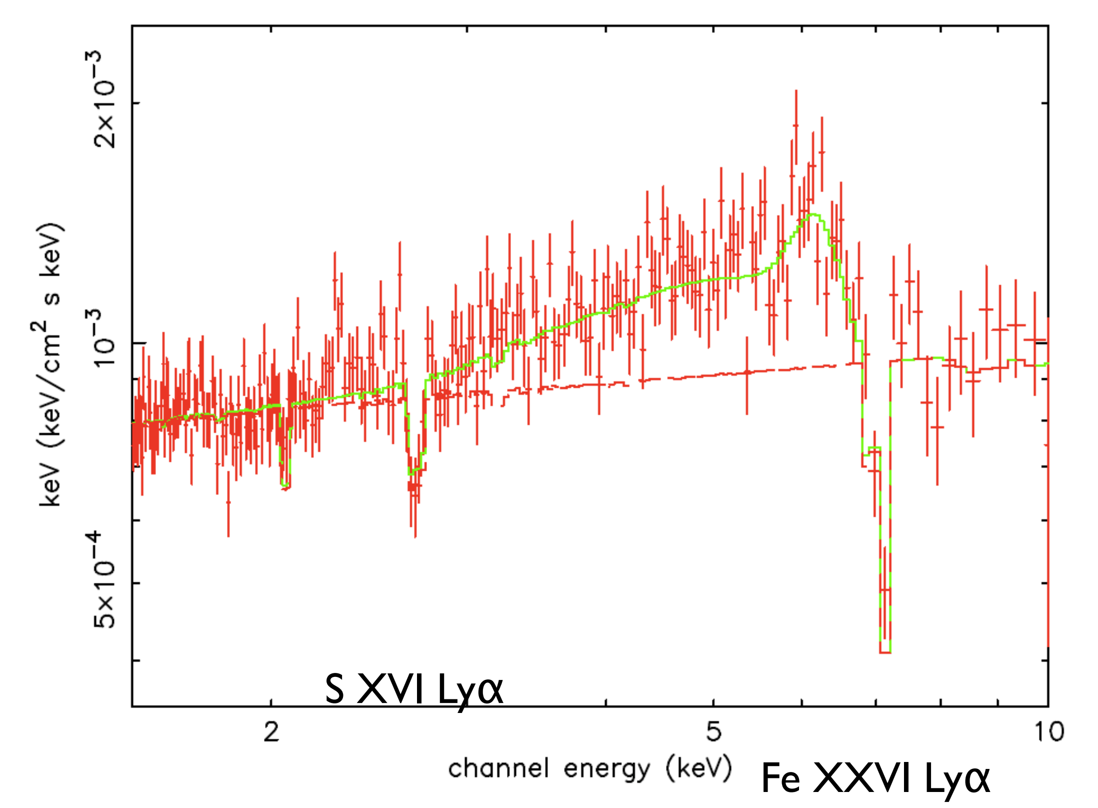
left: Suzaku data (black) shown with a simple absorbed power-law (red).

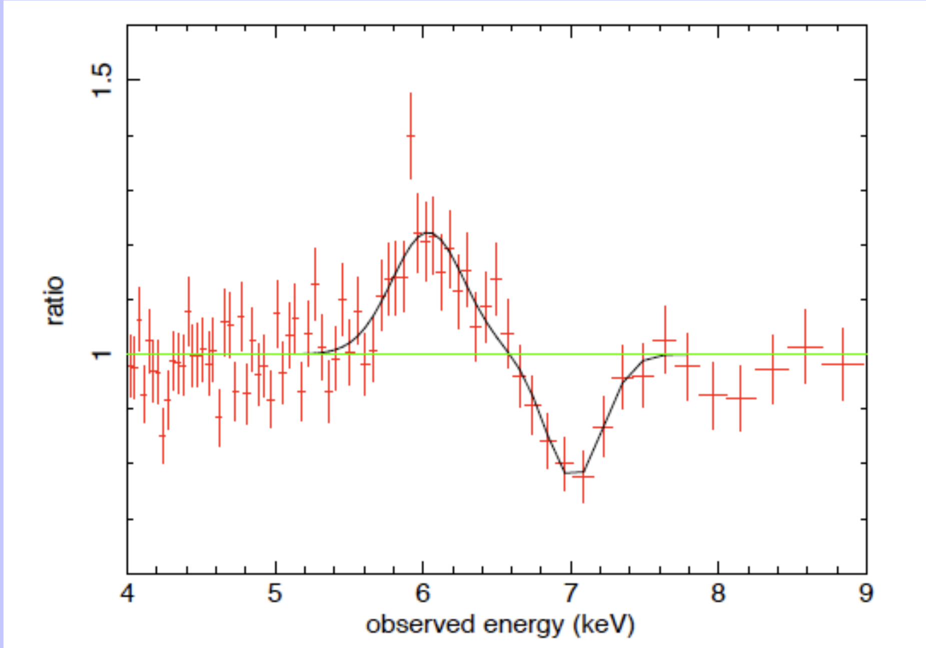
right: model fit

PDS 456 - a clumpily-absorbed type I AGN with a high-velocity (0.3c) outflow (Reeves et al 2009)

- $L_{bol} \simeq 2.10^{47}$ erg s^{-1}
- $M_{BH} \simeq 3.10^{9}$ $M_{\odot}$ (estimated from Kaspi relations) $\Rightarrow$ $L_{Edd} \simeq 2.10^{47}$ erg s^{-1}
- $\dot{M}_{outflow} \simeq 100$ C $M_{\odot}$ $year^{-1}$ (covering fraction C, assuming smooth wind, see e.g. Blustin this session)
- $\dot{E}_{outflow} \simeq 2.10^{46}$ erg s^{-1} (assuming C=0.1)
- total feedback energy comparable to binding energy of galaxy bulge, 5.10^{59} erg, after 10^{7} years
- launch radius $\simeq GM/v^2 \simeq 20\ r_g$

Outflows are common: PG1211+143



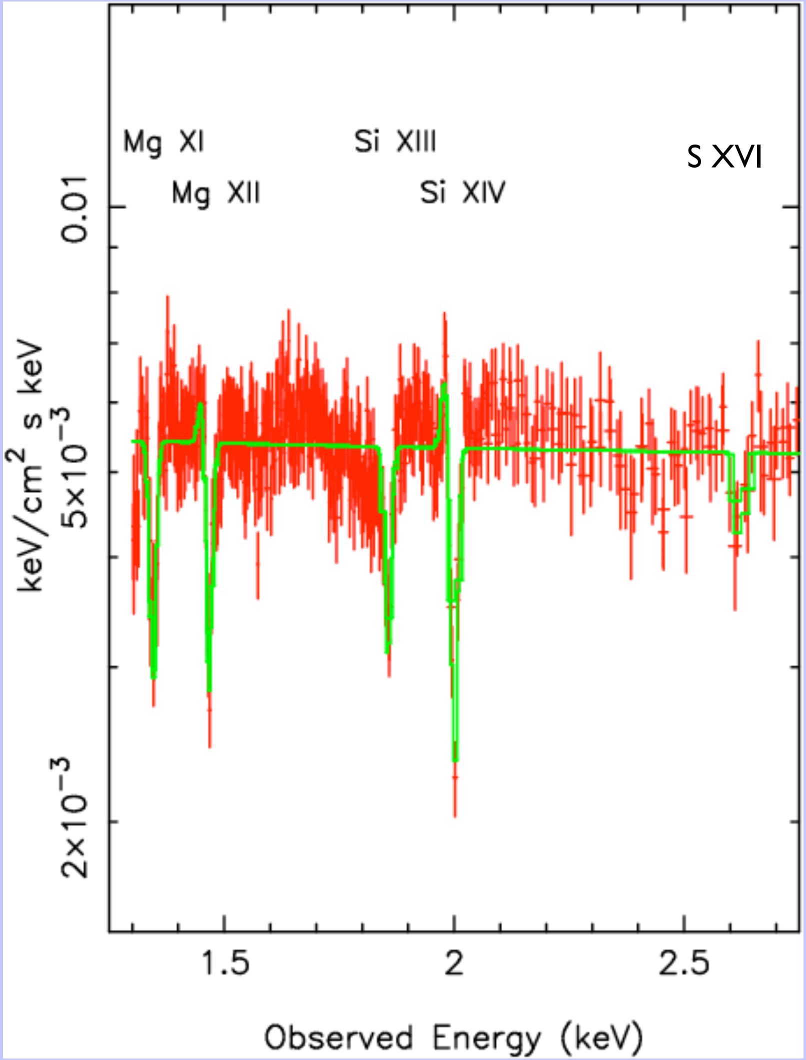


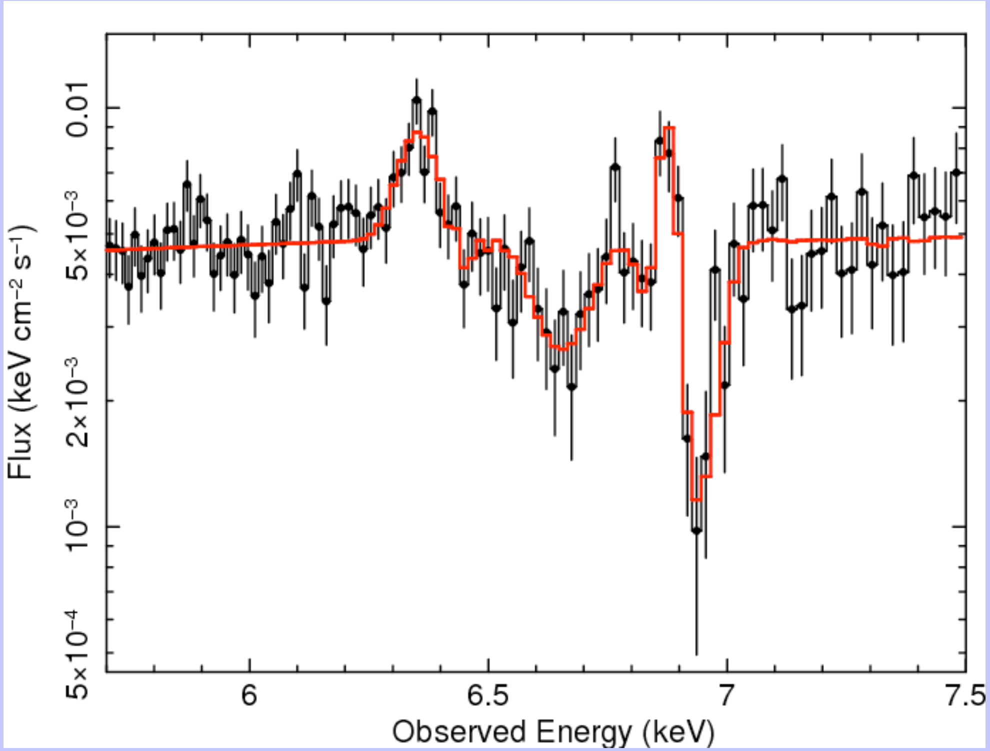
new data, Pounds et al 2008
Fe Kα line P Cygni profile

Pounds et al 2003 - outflow velocity 25,000 km/s

- see also Sim et al 2005 and this JENAM session
- outflow velocities in AGN range over 10^2 - 10^5 km/s
- high outflow velocities tend to be associated with highest ionisations - consistent with winds with $v \approx \sqrt{GM/r}$

Outflows are common (but most are not high velocity): NGC 3516 (Turner et al 2008)





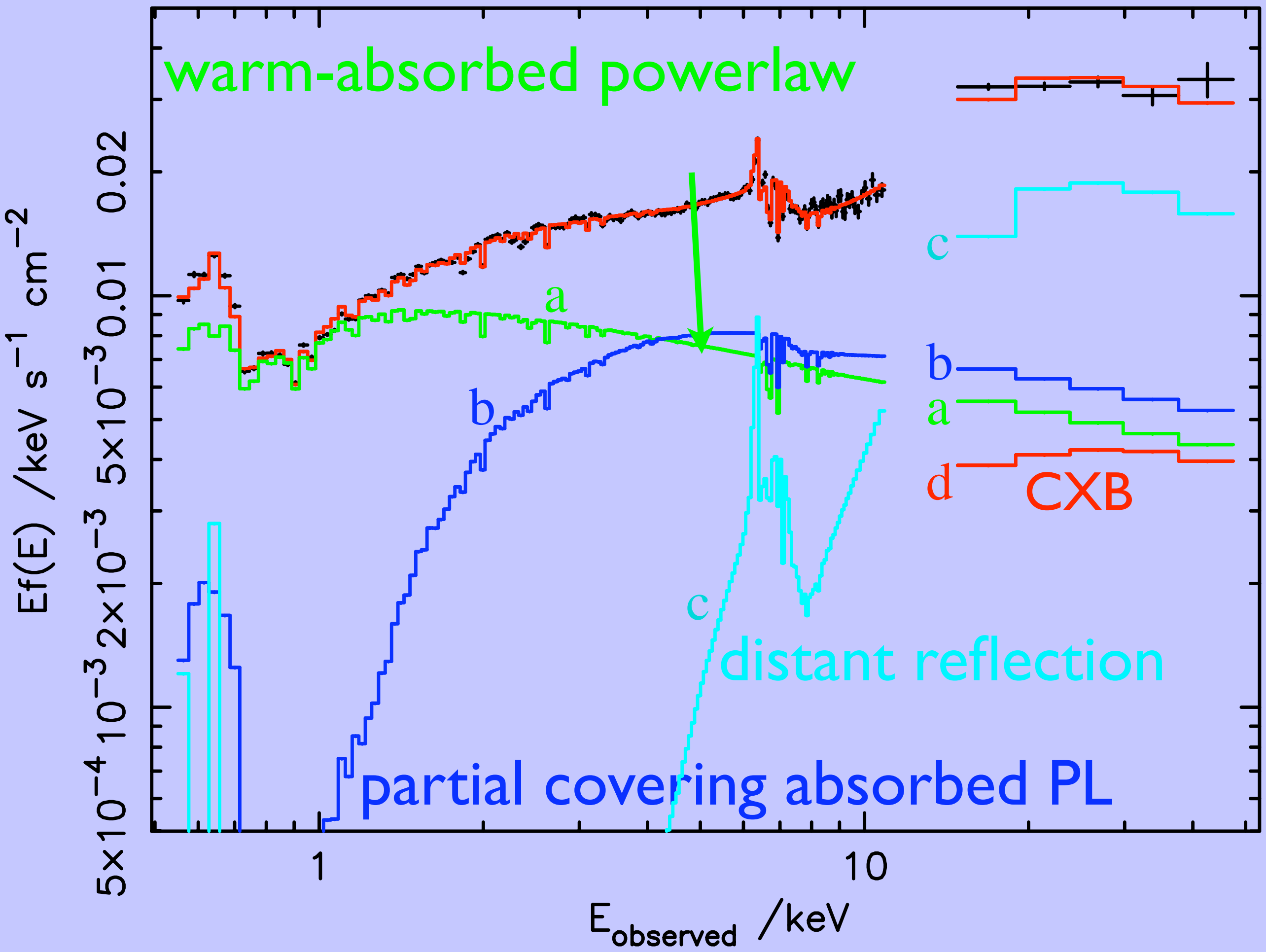
above Chandra HEG data showing P Cygni-like Fe Kα profile

left Chandra MEG+HEG data showing zones both at systemic redshift and outflowing at 2000 km/s

Turner et al 2008

partial-covering absorption may also be common: the case of MCG-6-30-15

a type 1 AGN with a complex variable spectrum including a broad "red wing" below Fe Kα

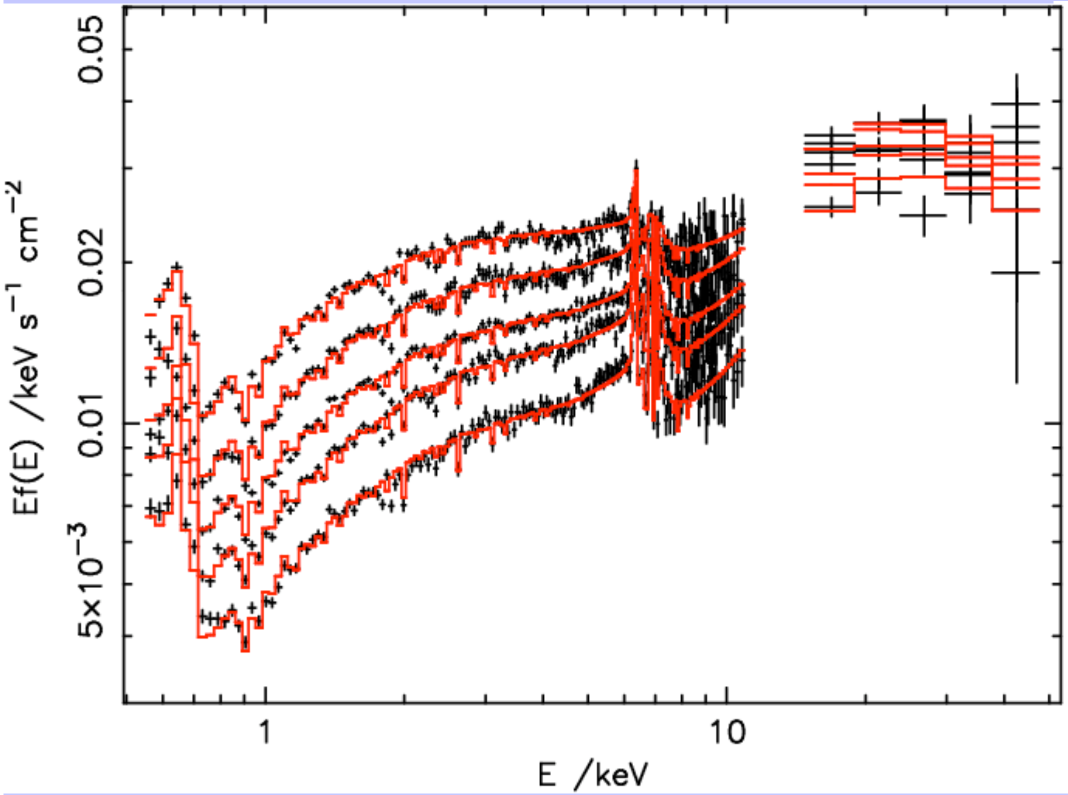


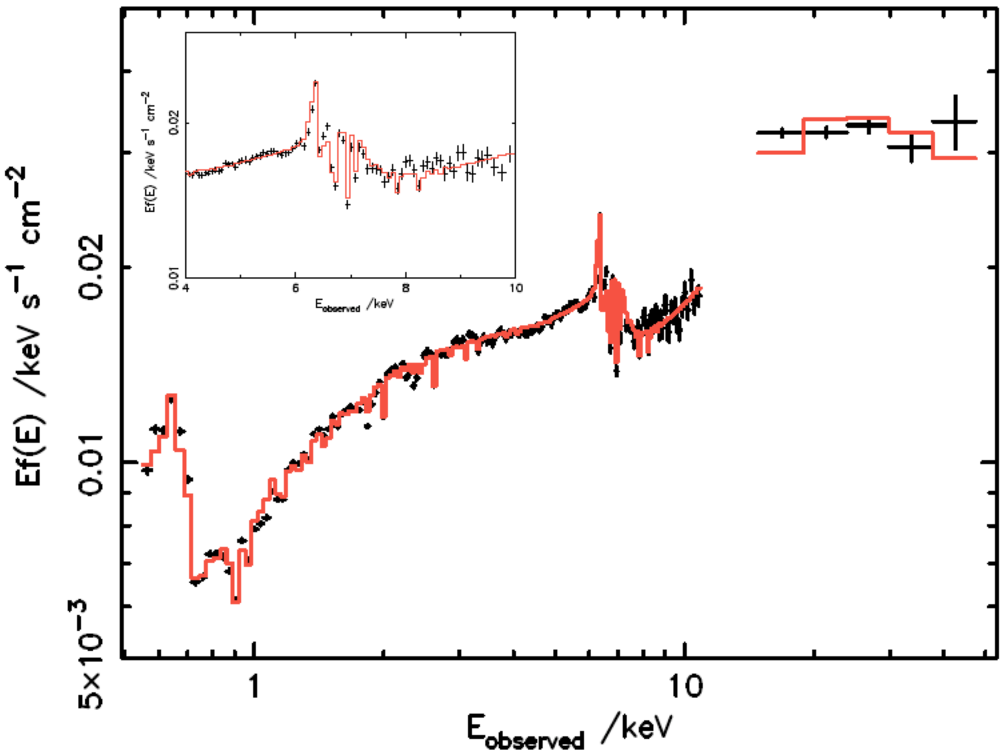
baseline model: changes in covering fraction of the absorber plus correlated changes in total brightness explain full range of spectral shape

(caution - such model-fitting does not yield a unique model)

Miller et al 2008 A&A 483, 437

model fits to multiple flux states MCG-6-30-15
Suzaku xis & pin simultaneous fit



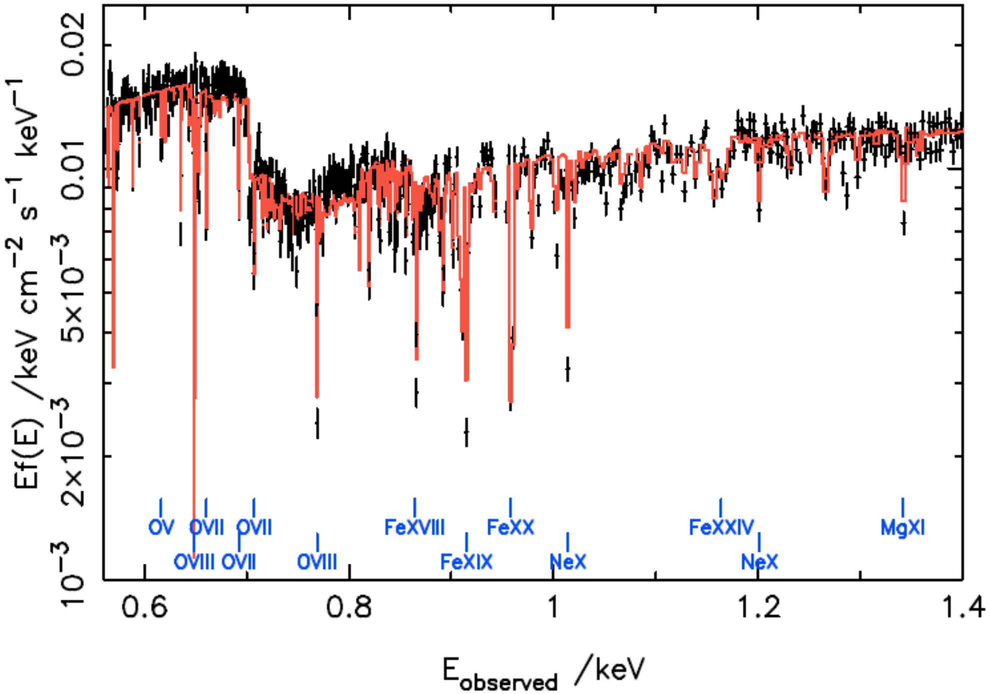


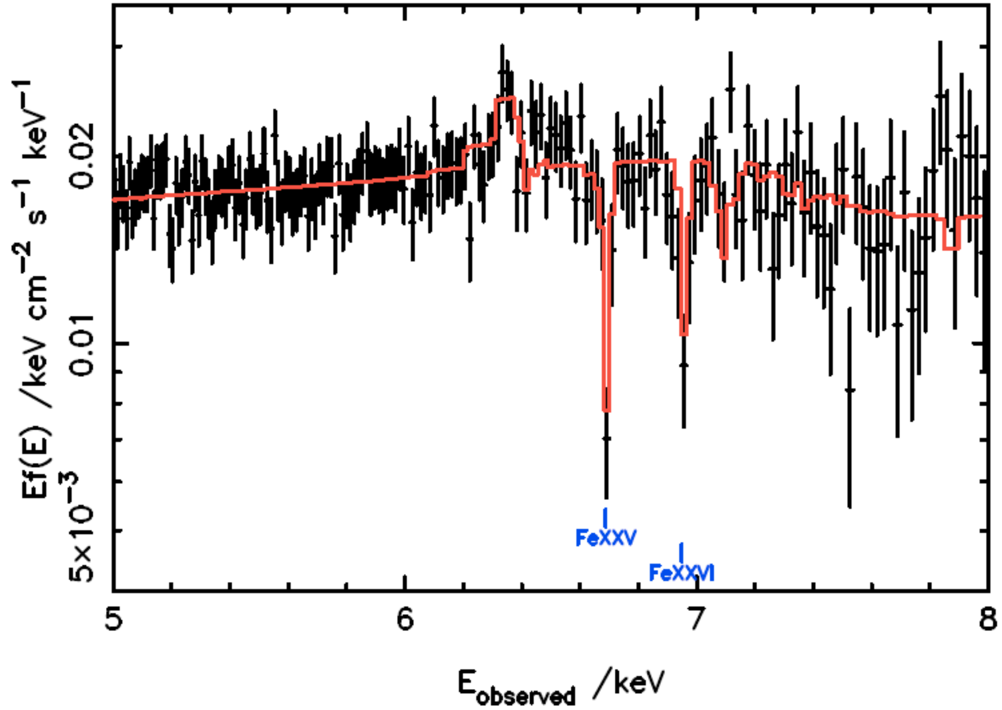
multiple flux states

mean spectrum

Miller et al 2008 A&A 483, 437

MCG-6-30-15: fit to higher resolution grating data



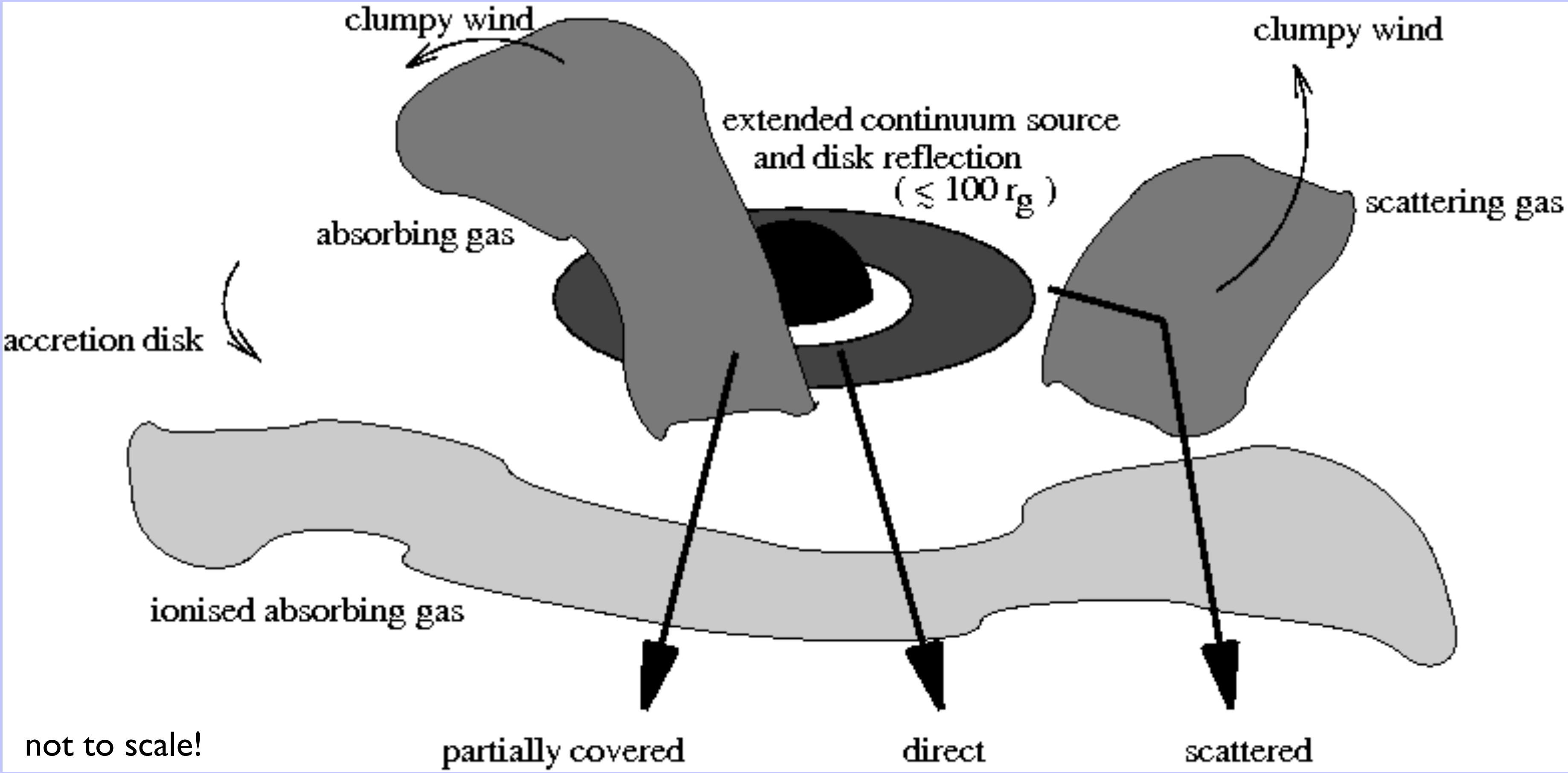


XMM-Newton RGS & Chandra HEG grating data, showing zones covering a wide range of ionisation, the highest ionisation outflowing at 1800 km/s

Miller et al 2008 A&A 483, 437

towards a better future: wind models

- partial covering implies absorber and source are likely of comparable size
- coupled with 20ksec variability implies a (likely clumpy) accretion disc origin for the absorber(s)
- we should expect composite absorption and reflection from a clumpy wind
- winds are expected from high Eddington-ratio AGN (e.g. King & Pounds 2003)

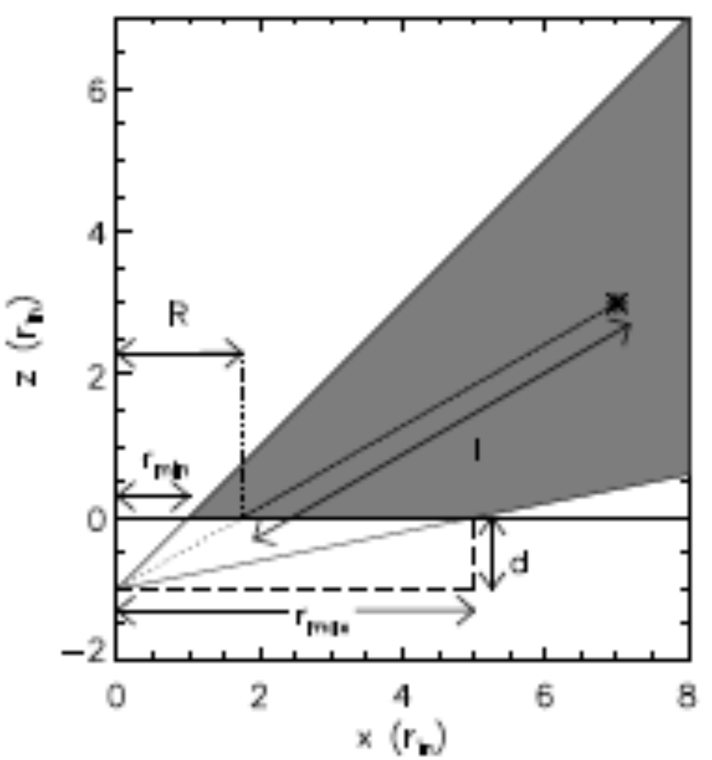


X-ray radiative transfer through disk winds (see Stuart Sim, this session)

Multi-dimensional modelling of X-ray spectra for AGN accretion-disk outflows

MNRAS 388, 611 (2008)

S. A. Sim[1], K. S. Long[2], L. Miller[3], T. J. Turner[4,5]



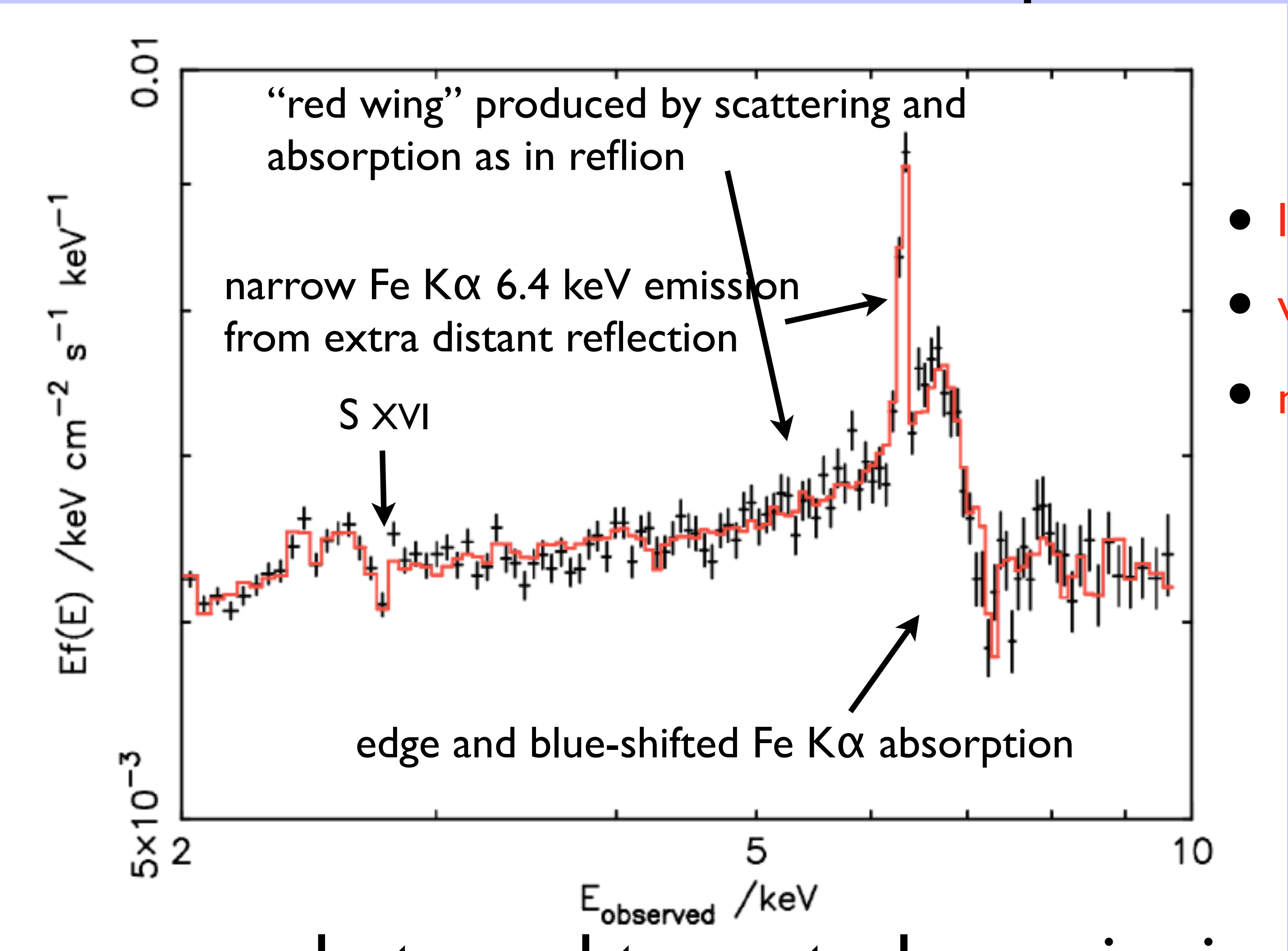
simplified parameterised wind geometry, but full 3D Monte-Carlo radiative transfer

NB significant improvement over widely-used *reflion* "slab" model - assumes a constant density slab with no atmosphere - accretion disc photospheres are not expected to look like that (e.g. Nayakshin et al. 2000)

Sim et al. 2008

try it against some data...

2-10 keV XMM-Newton mean spectrum of Mrk 766



- launch radius 385 r_g
- wind opening angle 58°
- mass-loss rate 0.4 $M_\odot$ year^{-1}

....but need to go to lower ionisation to fit entire spectral variability (see Stuart Sim's talk)

Summary

- We expect winds to be driven off accretion disks, especially at high Eddington ratio
- X-ray spectroscopy yields evidence for clumpy, ionised absorbing material that significantly affects 2-10 keV X-ray spectra even in type 1 AGN
- X-ray grating spectroscopy also reveals multiple absorbing zones covering a wide range of ionisation and outflow dynamics
- The feedback effect of accretion disk outflows and how common they are is not yet firmly established, but is a key aim for future work.
    - The most extreme case so far, PDS 456, could easily supply enough mechanical energy to halt galaxy bulge growth (but how common are these cases, what are the selection effects and line-of-sight effects? Kinetic power output depends on v_{out}^3 so we need to know the distribution of outflow velocities: c.f. statistics of UV BAL QSOs, around 18 percent "observed").