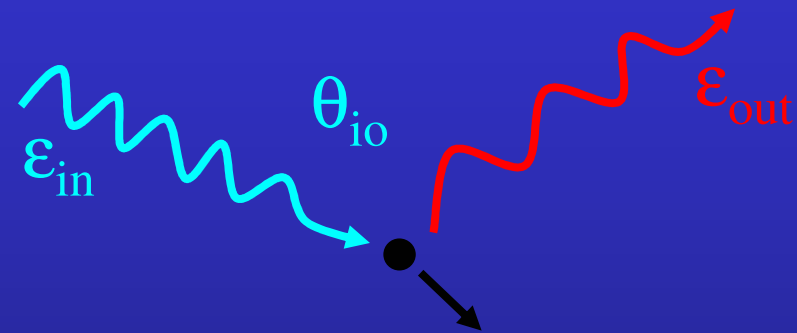


Reflection

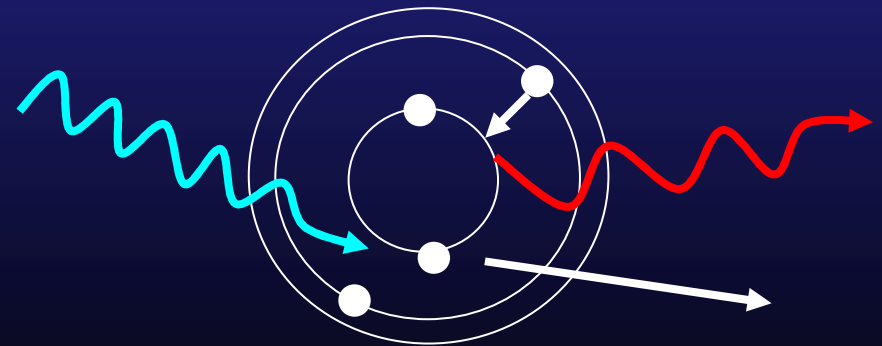
Chris Done
University of Durham

Reflection from a slab

- Reflection by electron scattering where ever X-rays illuminate optically thick material e.g. accretion disk
Lightman & White 1988, George & Fabian 1991, Matt, Perola & Piro 1991, Matt et al 1991,1993,1996, Ross et al 1993,1996, Zycki & Czerny 1994....
- Electrons ~ at rest so mostly downscattering – angles!! Get range of ϵ_{out} (i) for given i, ϵ_{in}
- Not just compton – also got photoelectric absorption (and associated fluorescence lines)

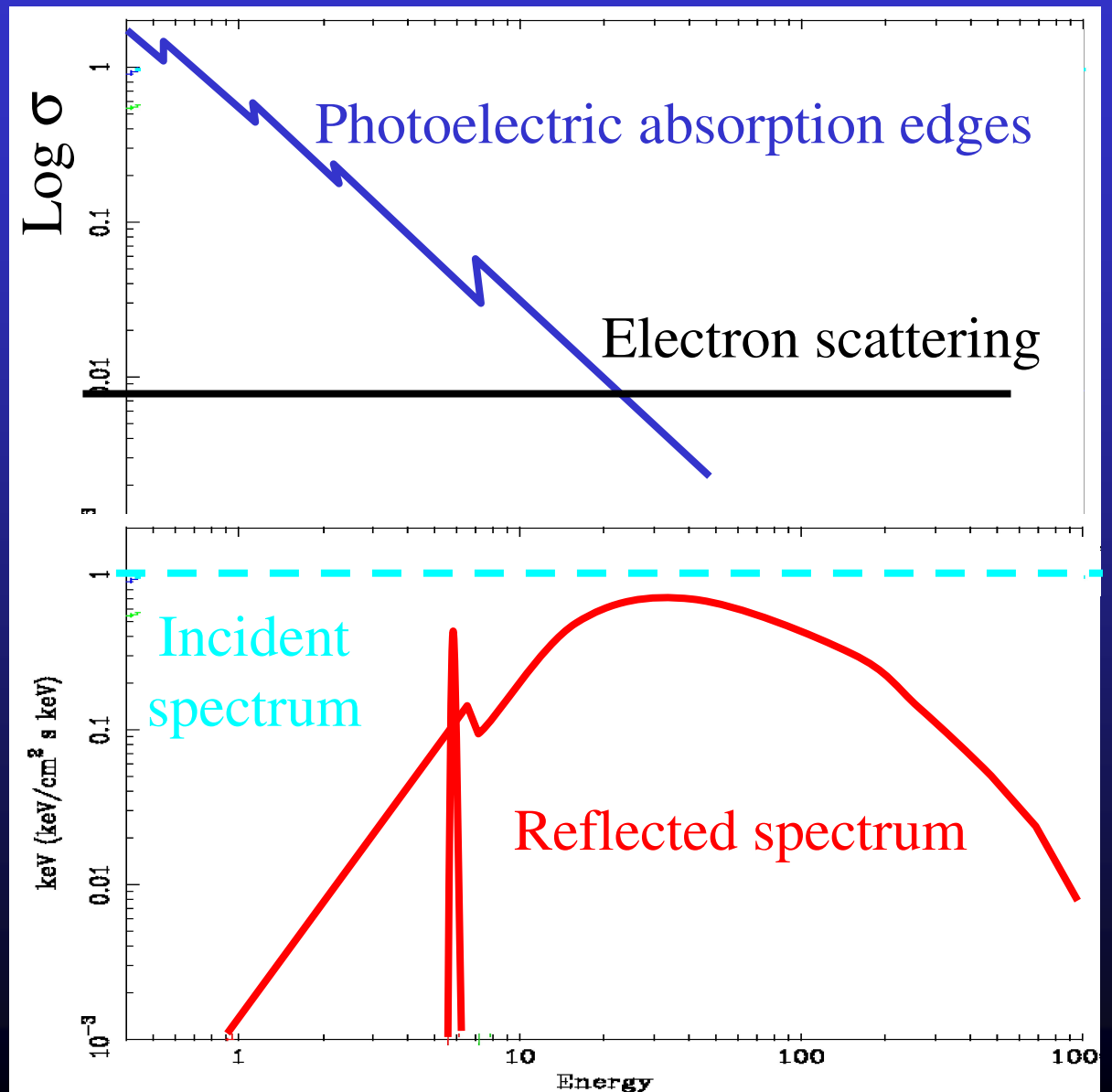


$$\epsilon_{\text{out}} \sim \frac{\epsilon_{\text{in}}}{1 + \epsilon_{\text{in}} (1 - \cos\theta_{\text{io}})}$$



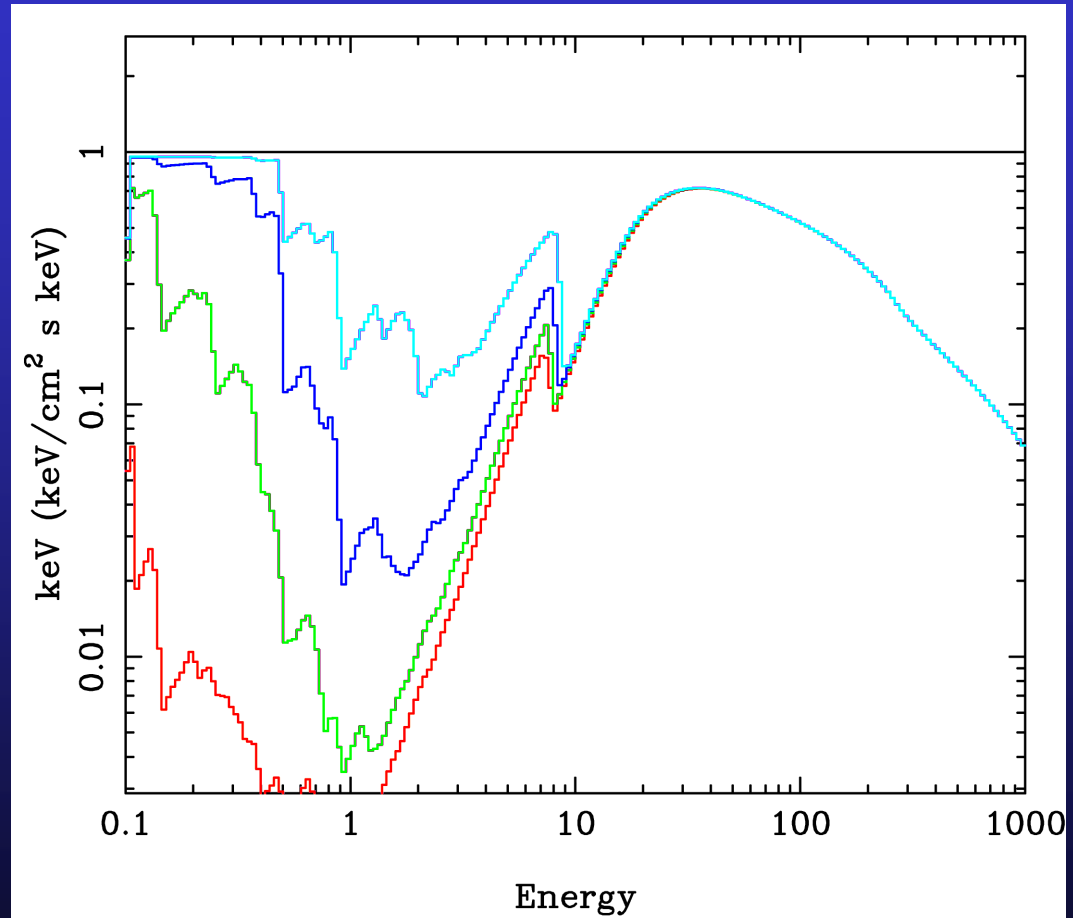
Reflection from a slab: pexriv

- XSPEC: pexrav
- Low E: reflection probability set by relative importance of scattering and photoelectric abs.
- High E: Compton downscattering so depends on spectral shape above bandpass
Magdziarz & Zdziarski 1995
- Makes peak 20-50 keV



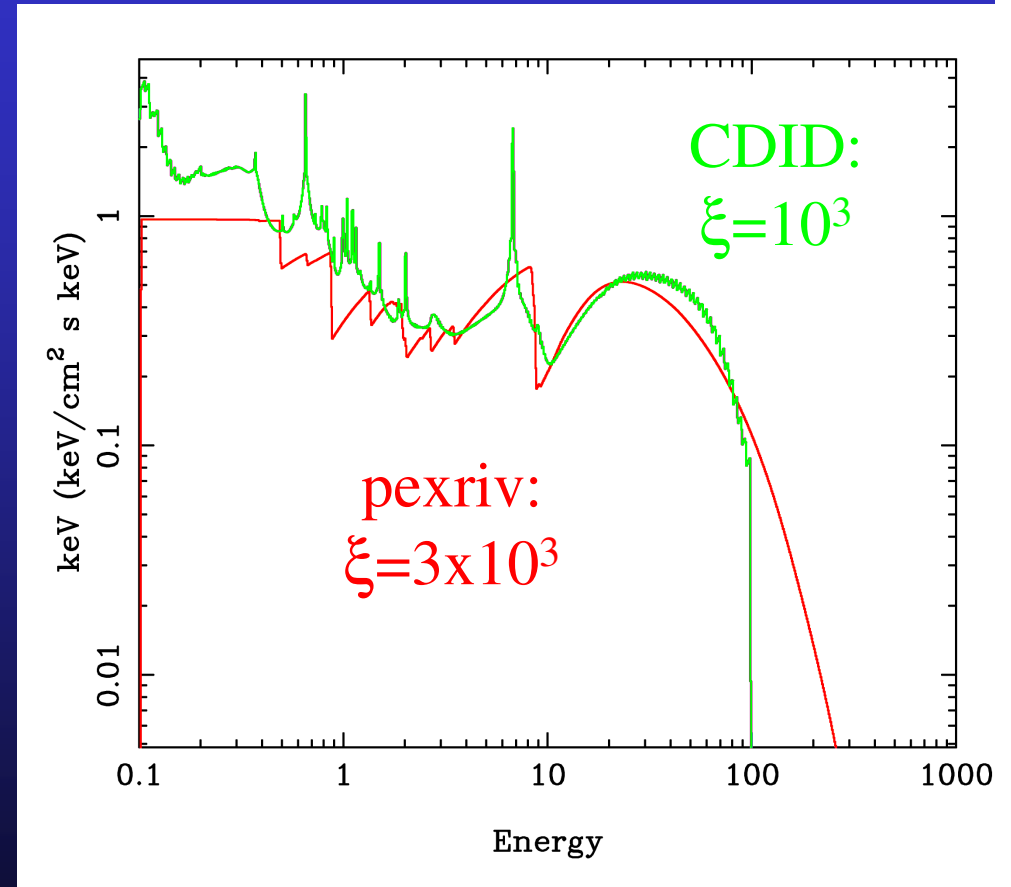
Reflection from a slab: pexriv

- XSPEC: pexriv
- Depends on ionisation $\xi=L/nr^2$. fewer bound electrons so smaller photoabs. So higher reflection Done et al 1992
- High E: Compton downscattering stays constant



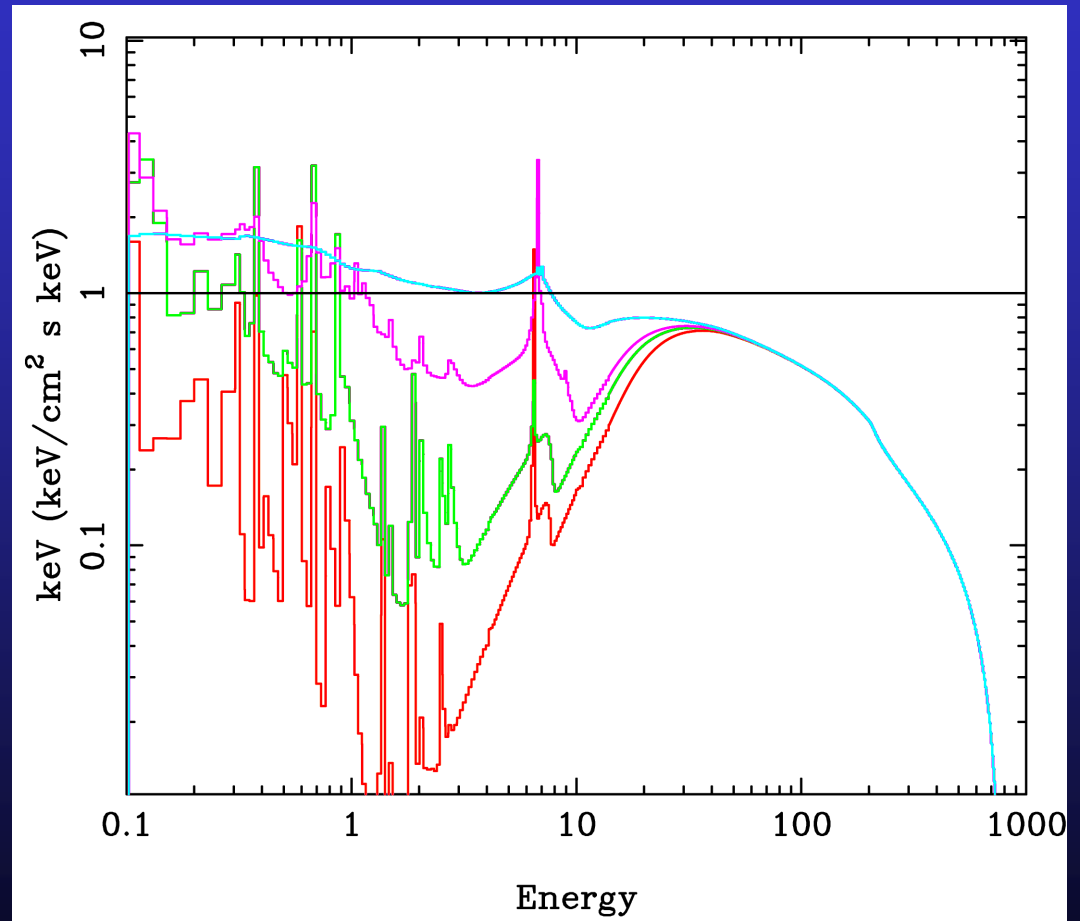
Reflection from a slab: constant n

- Should also do line emission as well as edge absorption
- Constant density ionised disc (CDID/reflion) models of Ballantyne, Iwasawa & Fabian 2001; Ross & Fabian 2005
- Irradiated slab so ξ and temperature drops as go deeper
- Also includes compton UPSCATTERING! SMEARS edge Ross, Fabian & Young 1999



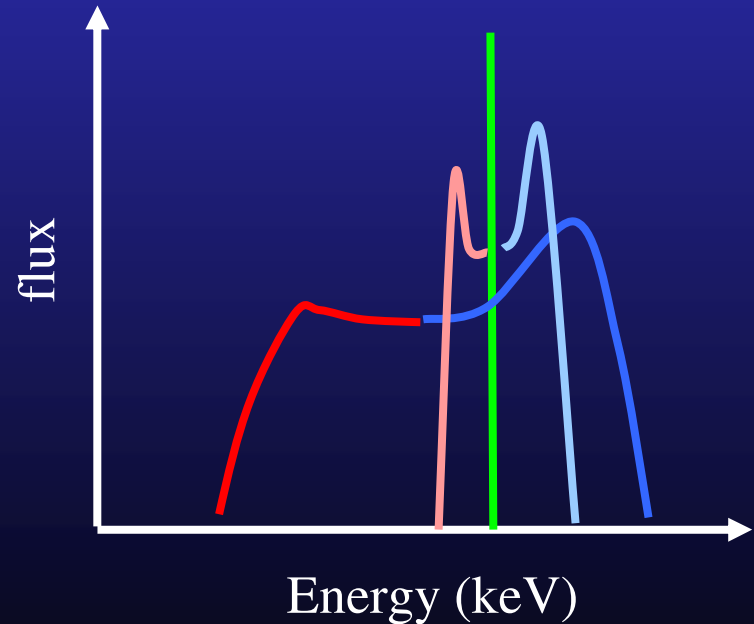
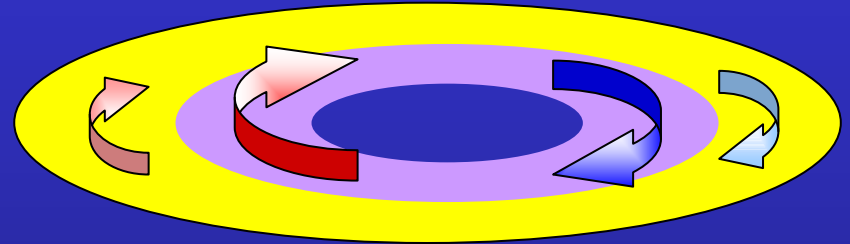
Reflection from a slab

- XSPEC: reflionx
- Depends on ionisation $\xi=L/nr^2$. fewer bound electrons so smaller photoabs. So higher reflection Done et al 1992
- High E: Compton downscattering stays constant

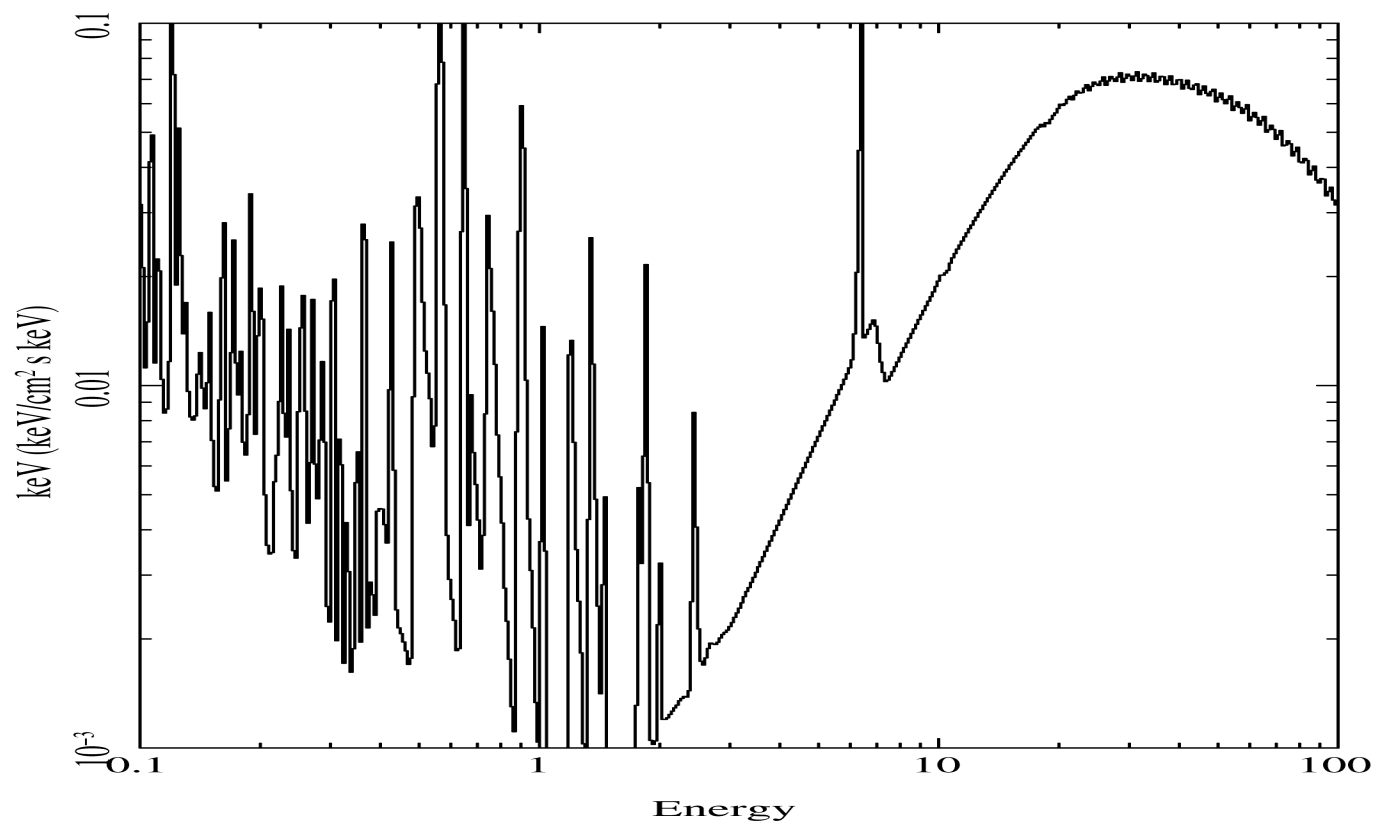


Relativistic smearing: spin

- Relativistic effects (special and general) affect all emission
- Emission from side of disc coming towards us:
 - Doppler blueshifted
 - Beamed from length contraction
 - Time dilation as fast moving (SR)
 - Gravitational redshift (GR)
- Fe $K\alpha$ line from irradiated disc should be broad and skewed, and shape depends on R_{in} (and spin)



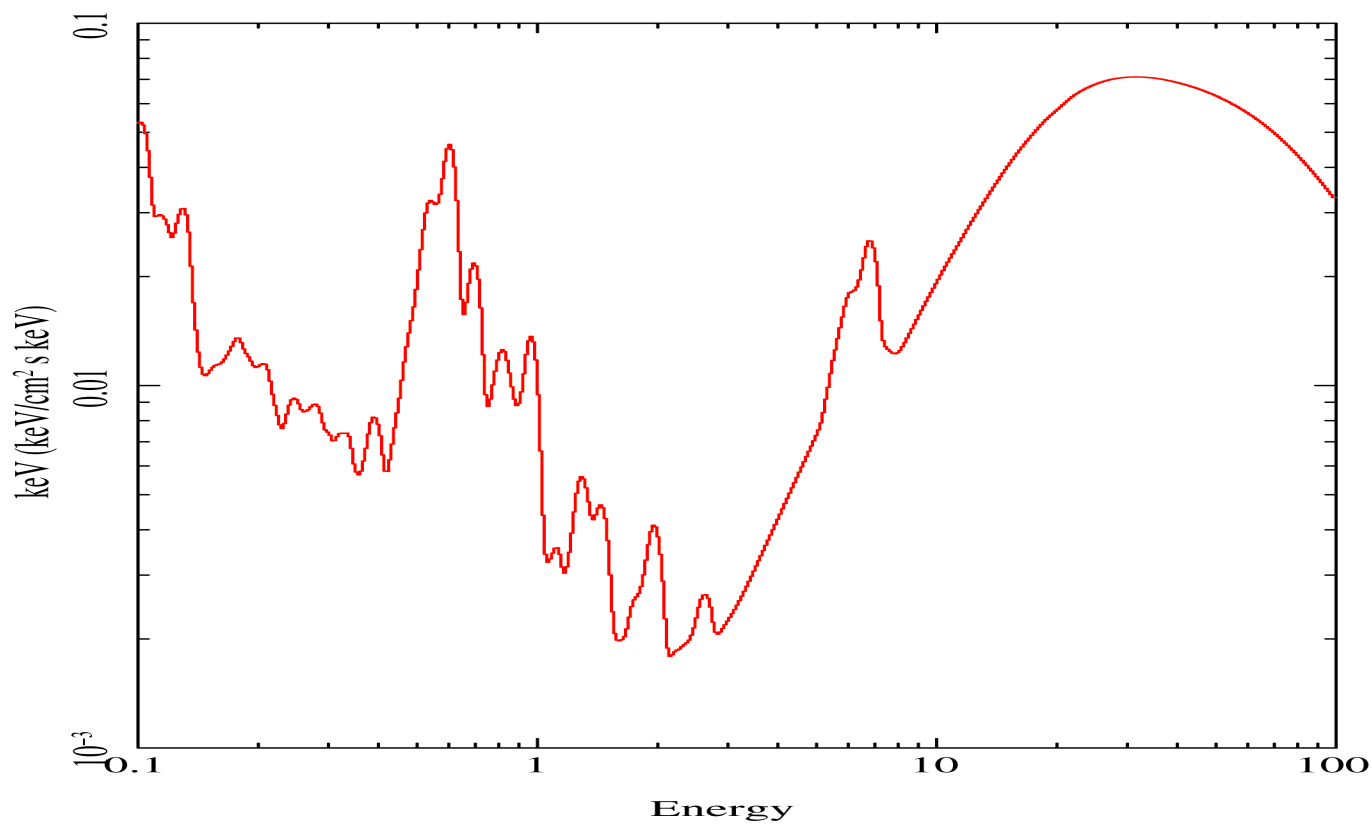
Smear all reflected emission



$i=60, \xi=30$

Fabian et al 2000; 2004

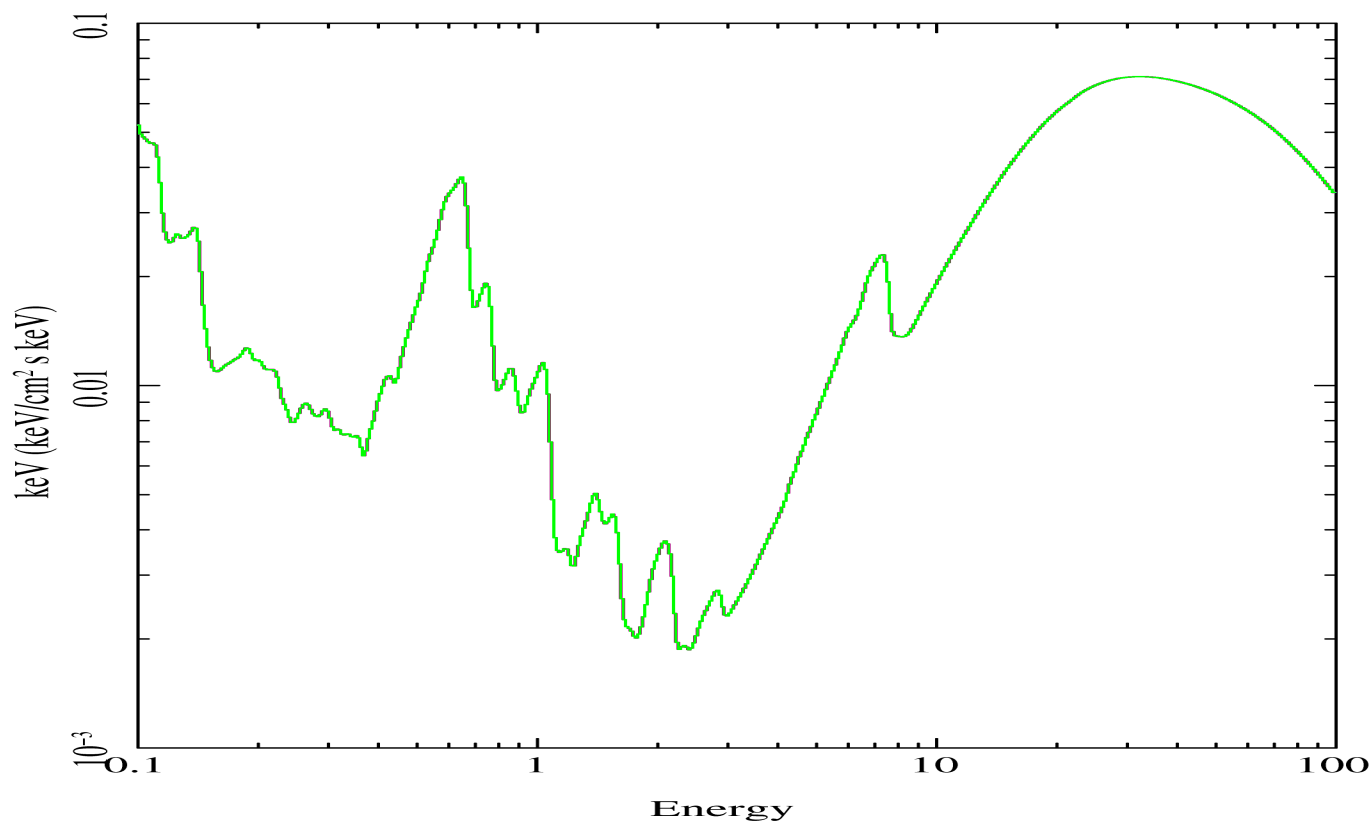
Smear all reflected emission



$i=60$, $\xi=30$, $R=30R_g$

Fabian et al 2000; 2004

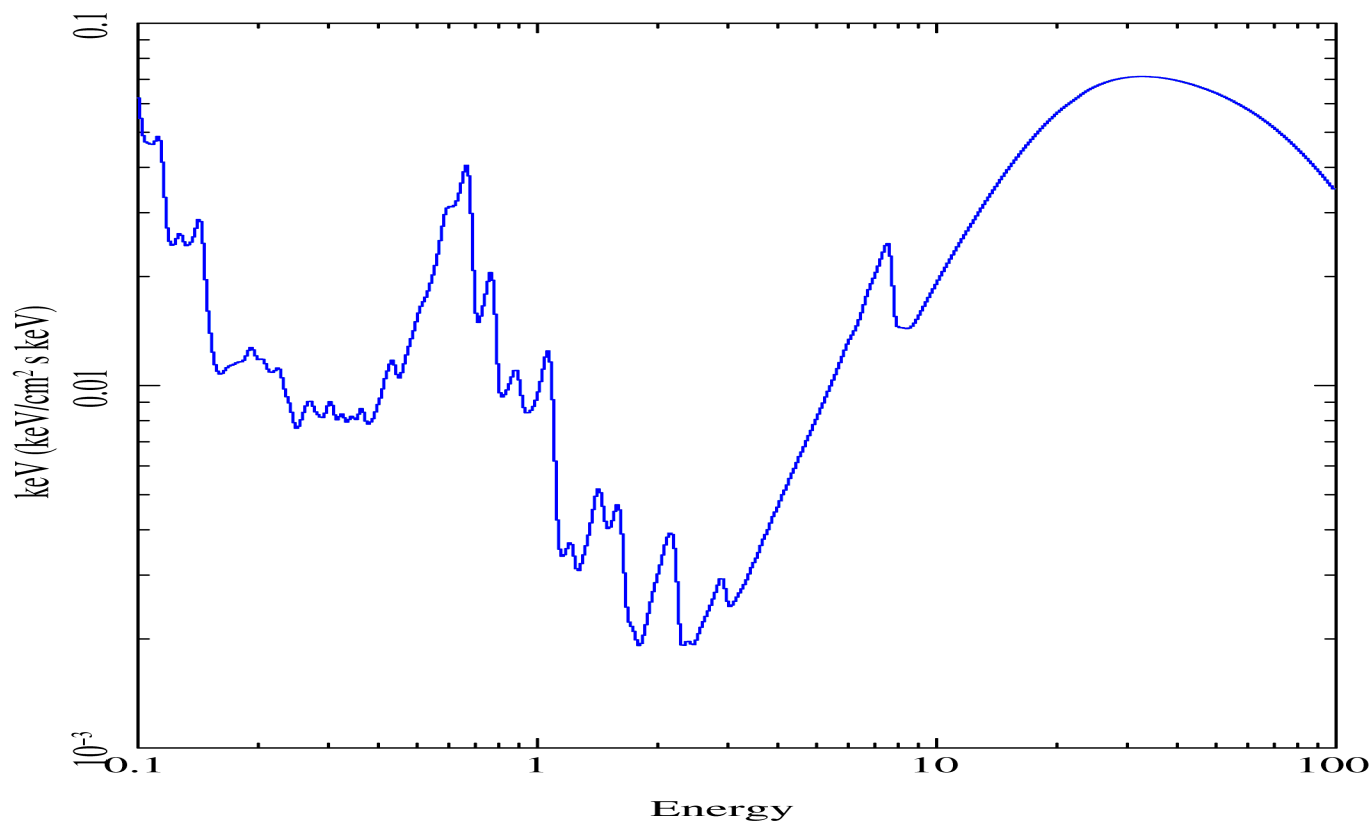
Smear all reflected emission



$i=60$, $\xi=30$, $R=10R_g$

Fabian et al 2000; 2004

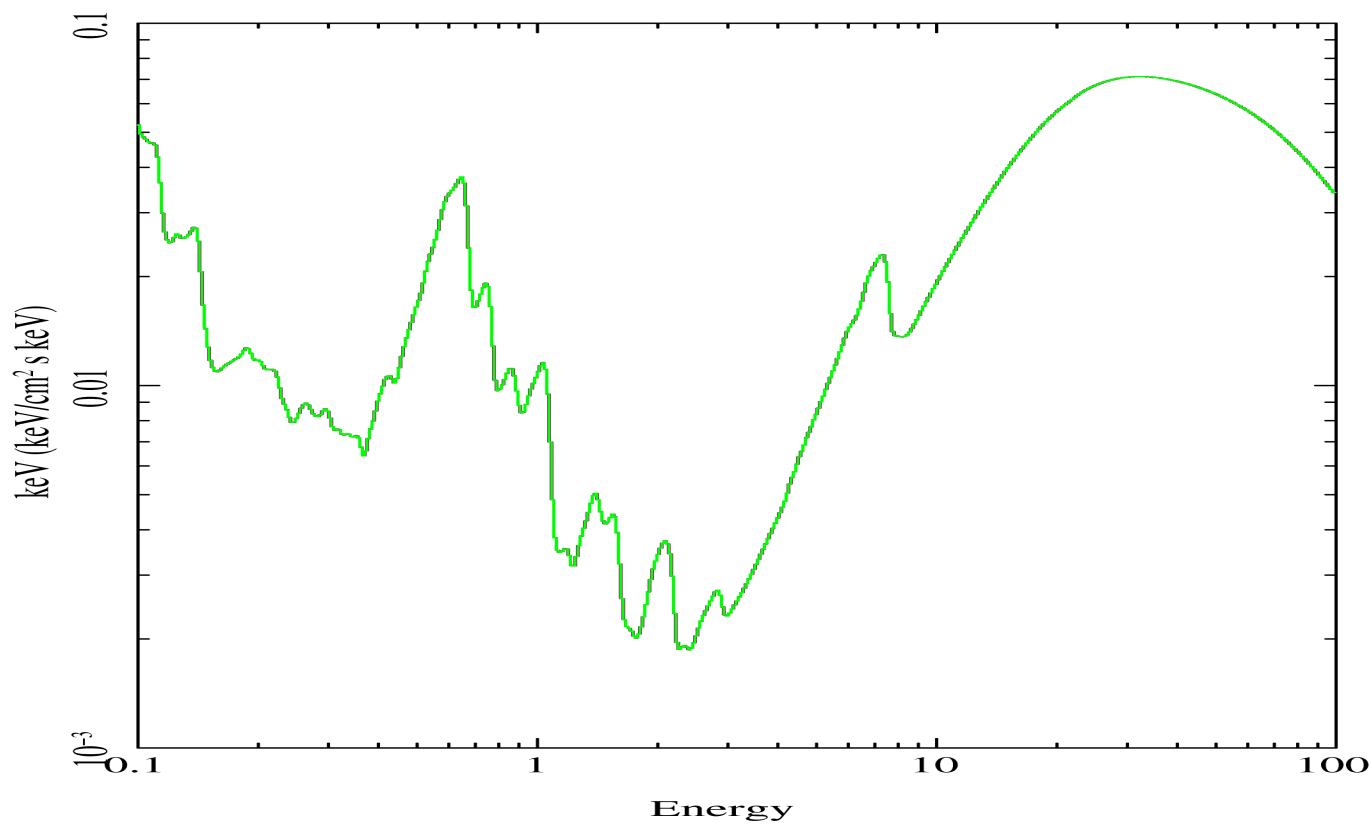
Smear all reflected emission



$i=60$, $\xi=30$, $R=6R_g$

Fabian et al 2000; 2004

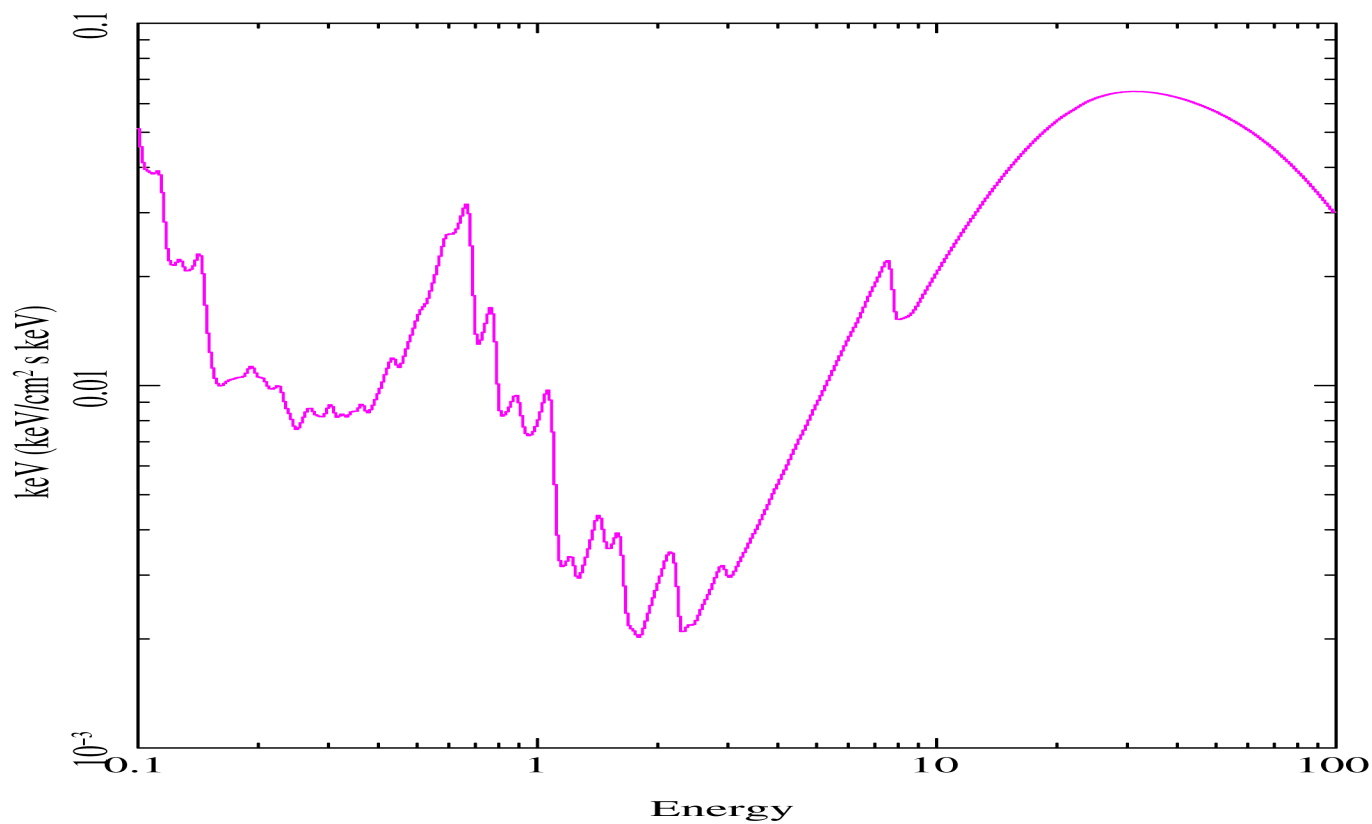
Smear all reflected emission



$i=60$, $\xi=30$, $R=3R_g$

Fabian et al 2000; 2004

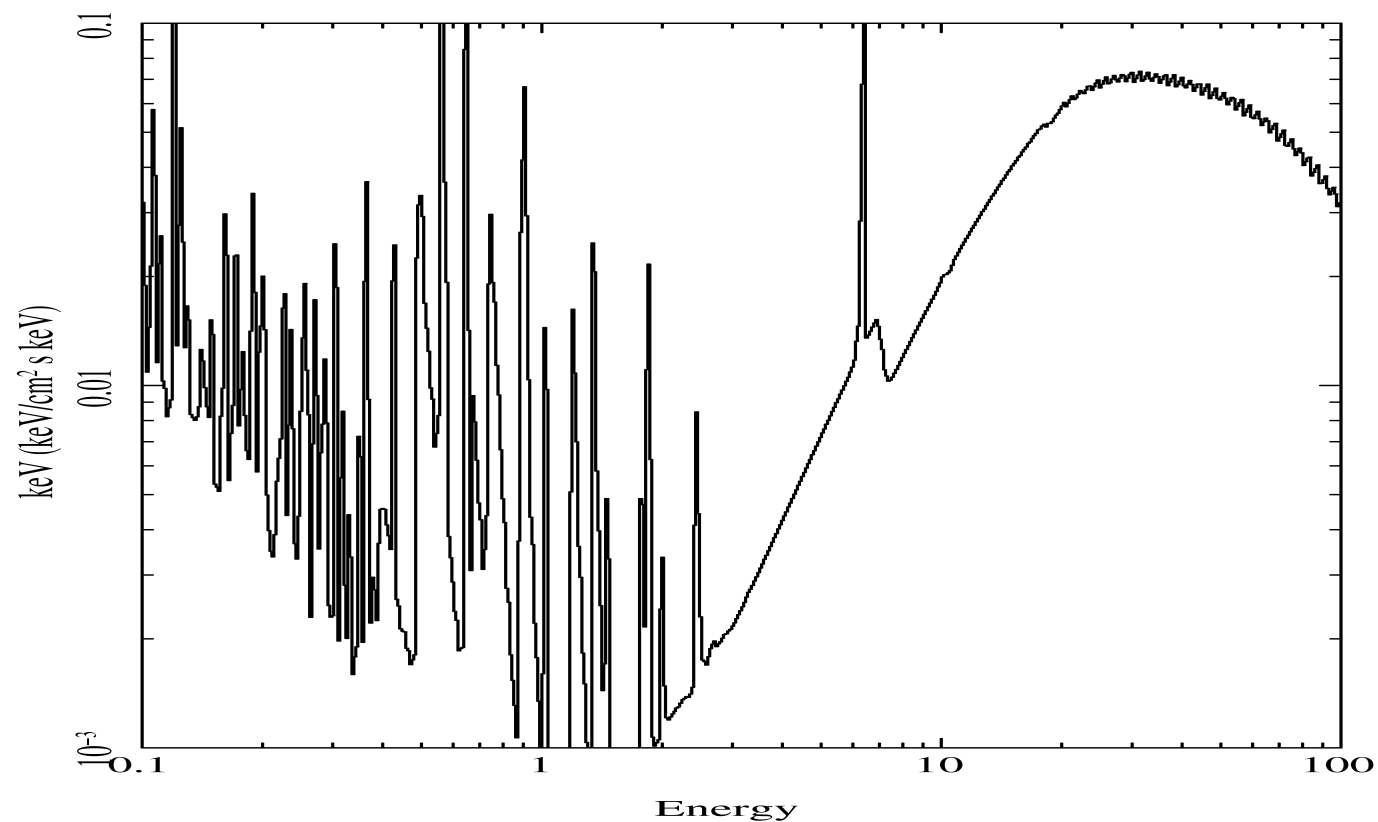
Smear all reflected emission



$i=60$, $\xi=30$, $R=1.23R_g$

Fabian et al 2000; 2004

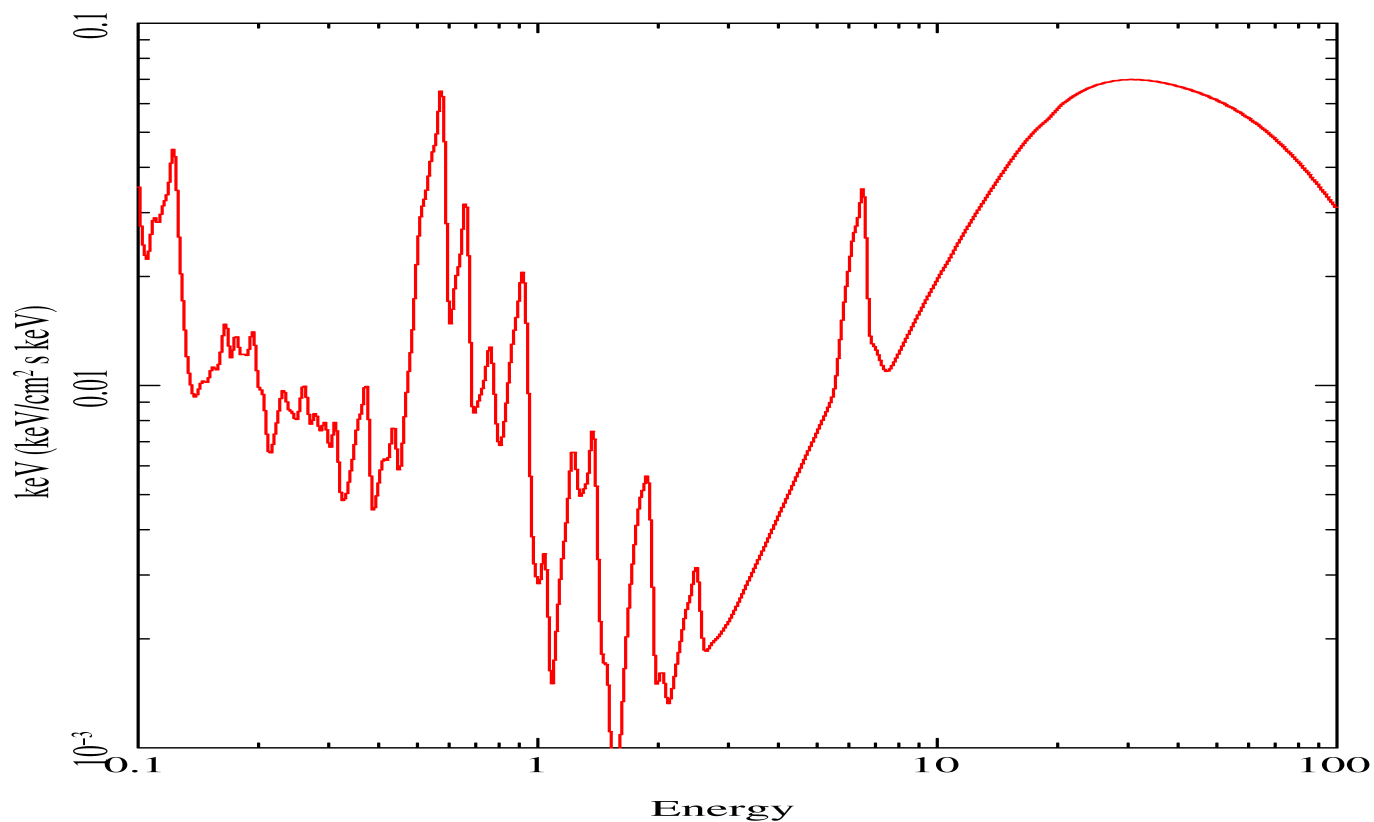
Smear all reflected emission



$i=20, \xi=30$

Fabian et al 2000; 2004

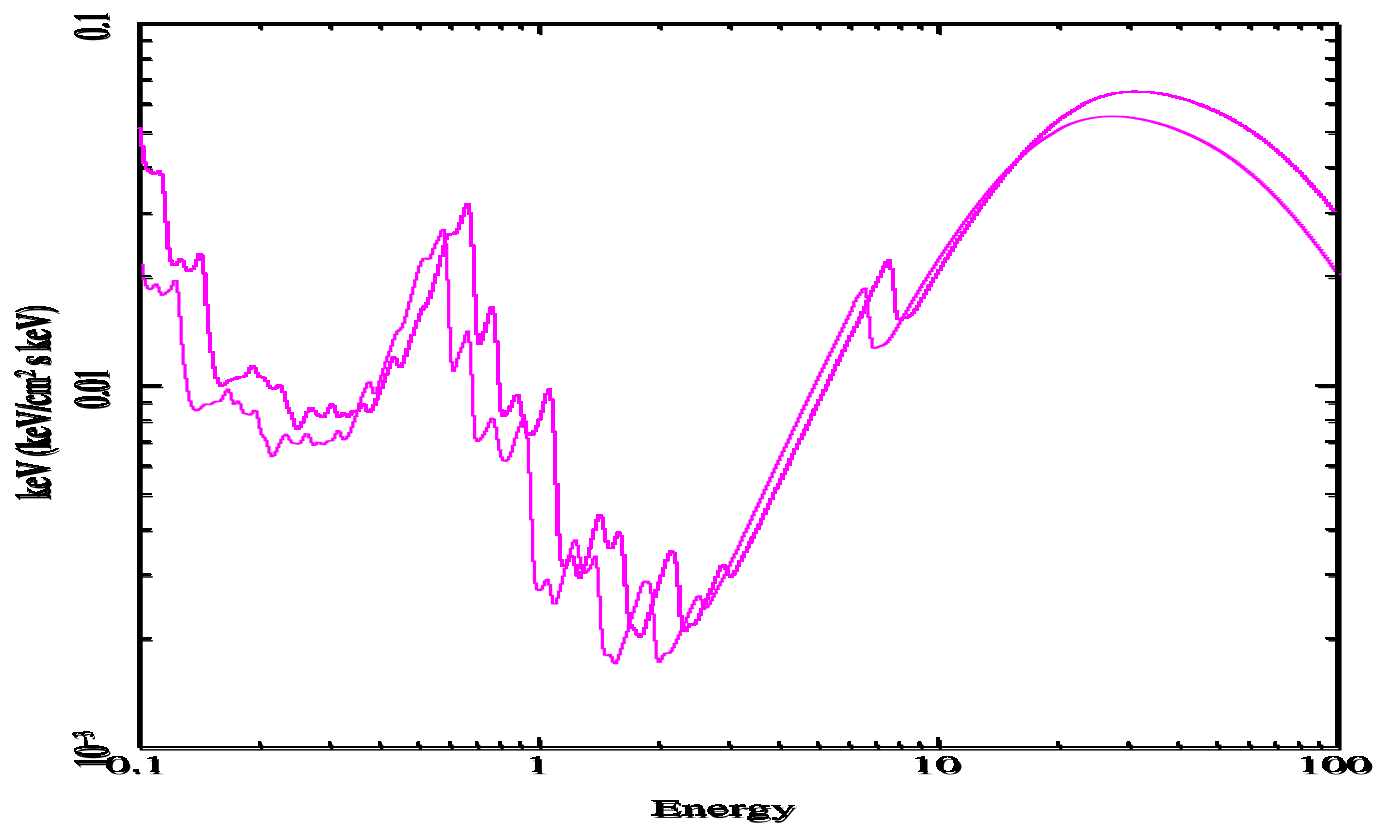
Smear all reflected emission



$i=20$, $\xi=30$, $R=30R_g$

Fabian et al 2000; 2004

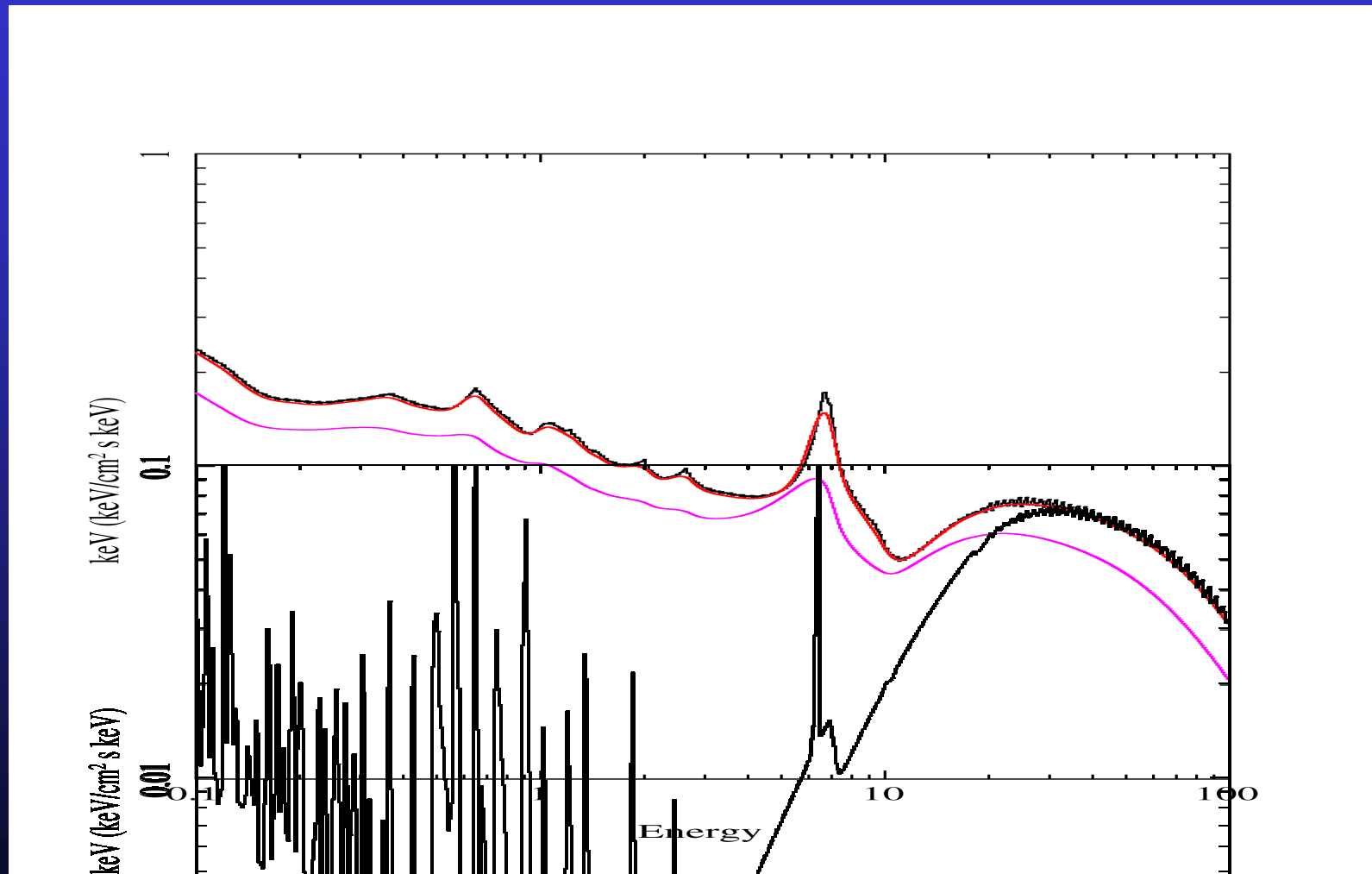
Smear all reflected emission



$i=20$, $\xi=30$, $R=1.23R_g$

Fabian et al 2000; 2004

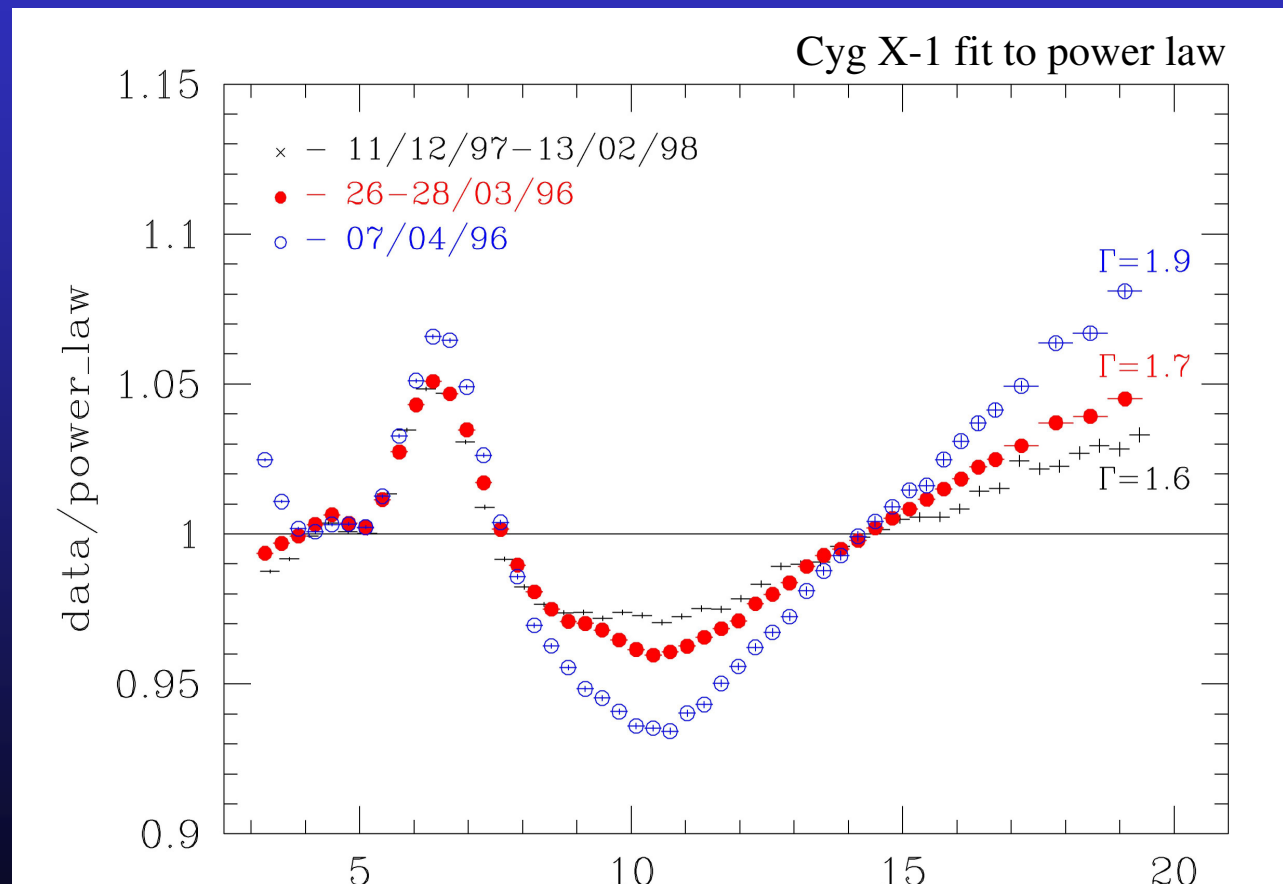
Smear all reflected emission



$i=20$, $\xi=3000$, $\beta=30$, $1.23R_g$

Fabian et al 2000; 2004

Reflected spectra: Cyg X-1

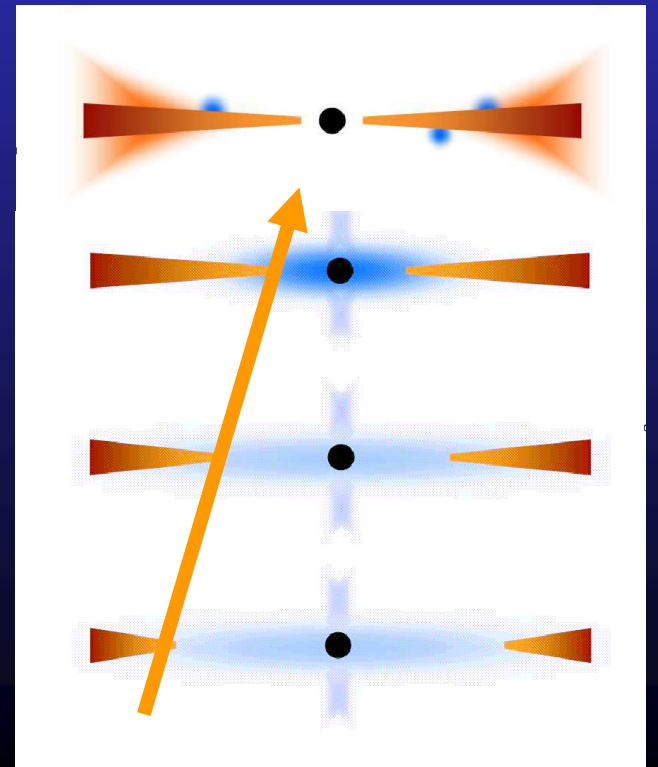
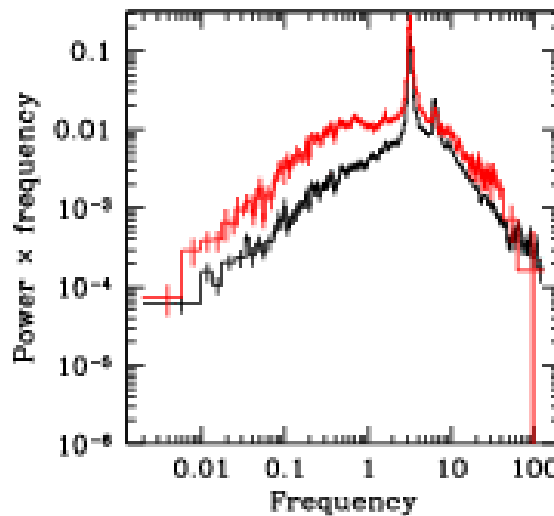
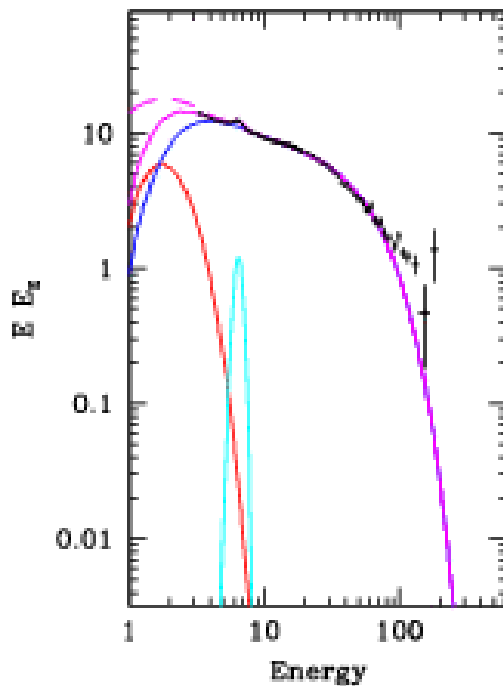


Gilfanov, Churazov & Revnivtsev 2000

Moving disc – moving QPO

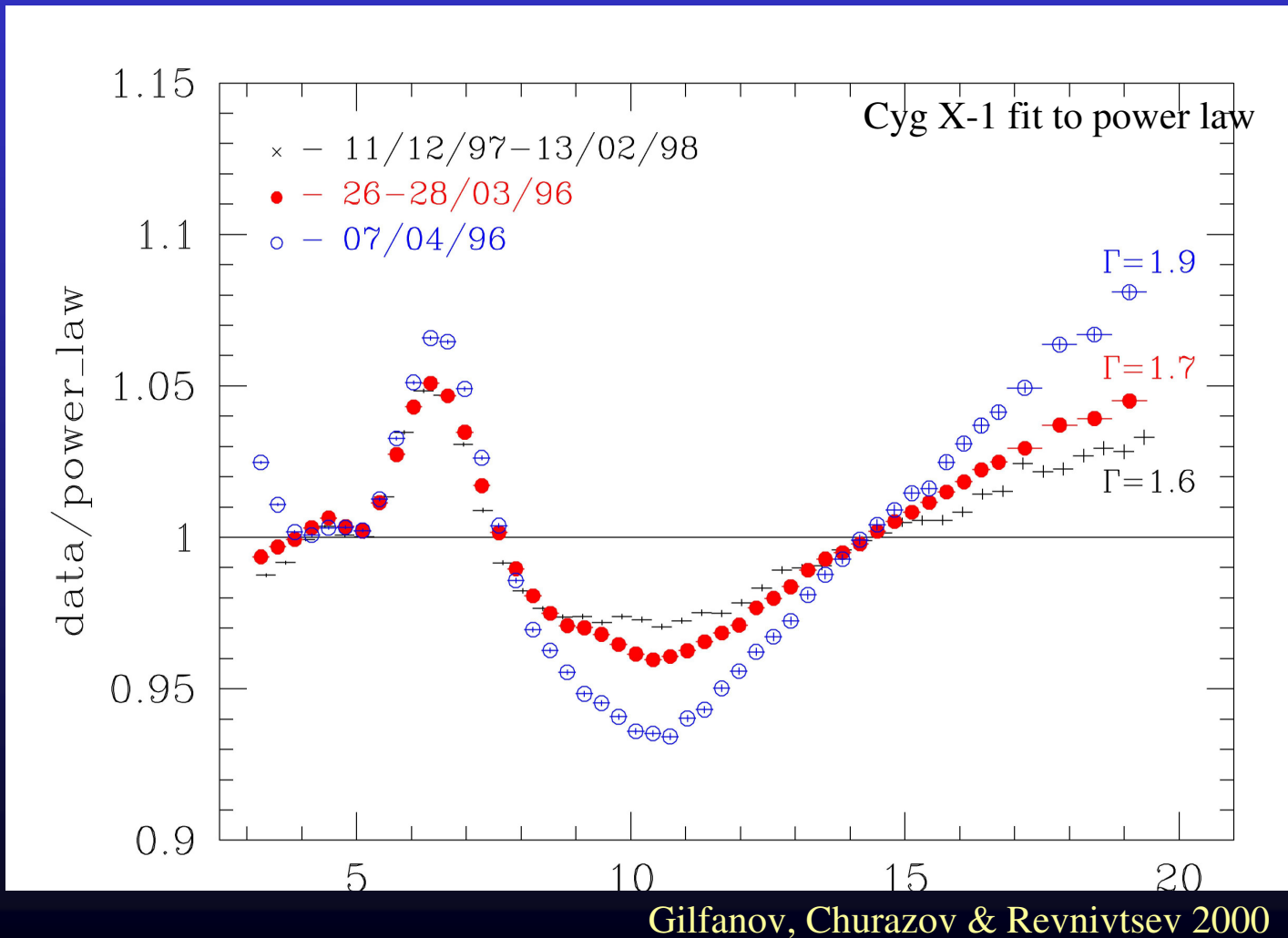
- Spectra need disc to move from 50-6ish Rg as make transition
- Predicts solid angle subtended by disc increases
- Predicts relativistic smearing increases

DGK07



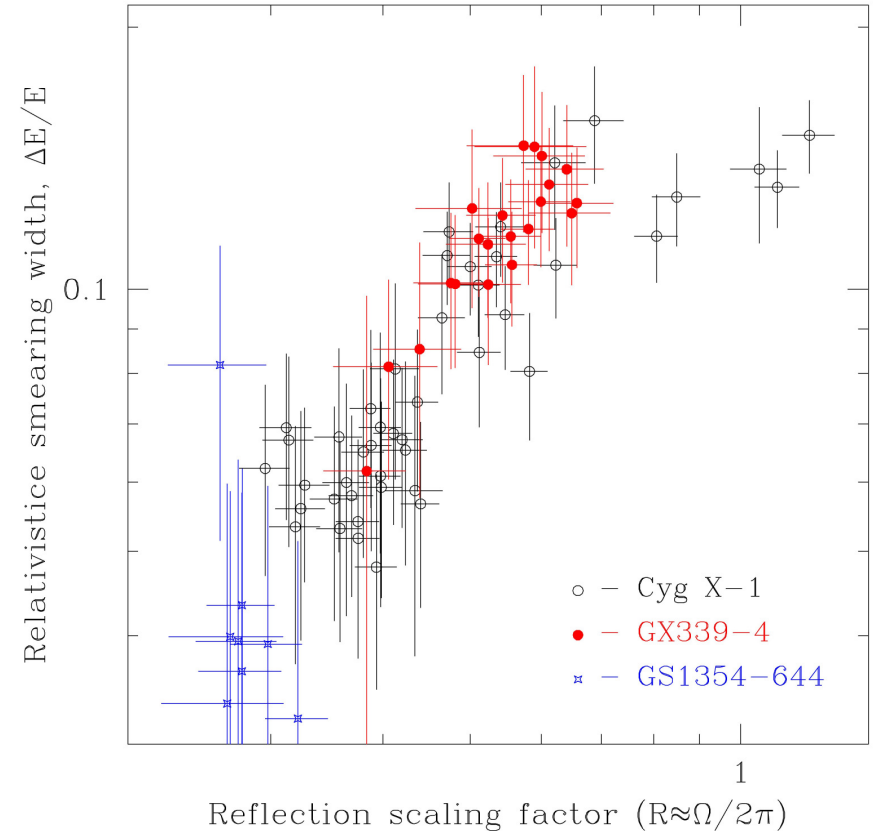
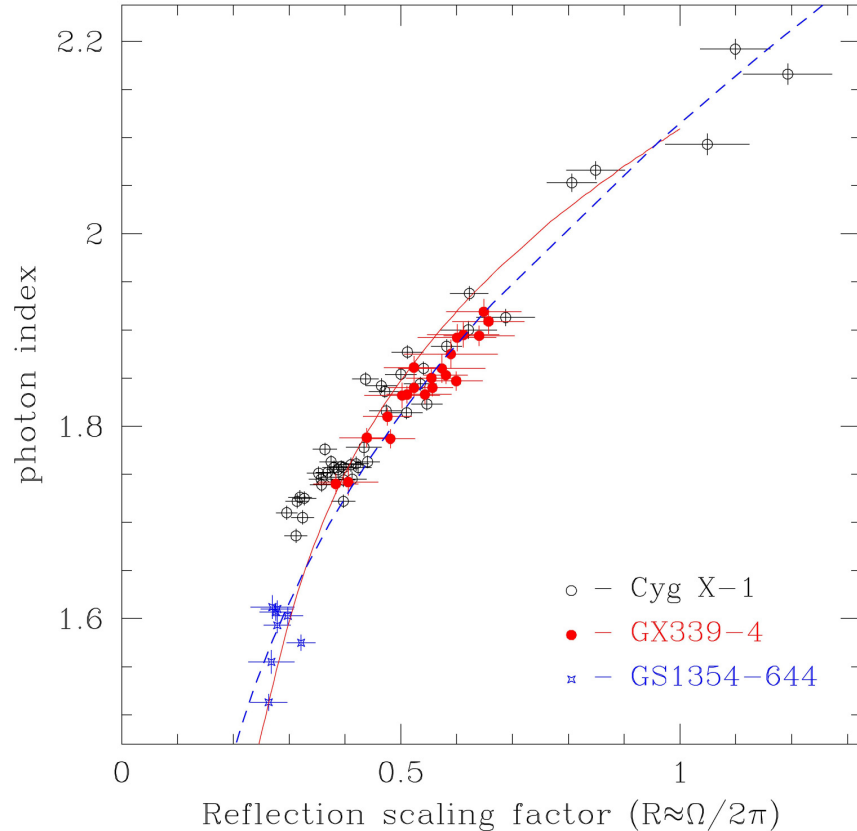
Reflected spectra (1)

- See bigger reflection features as go from hard to soft



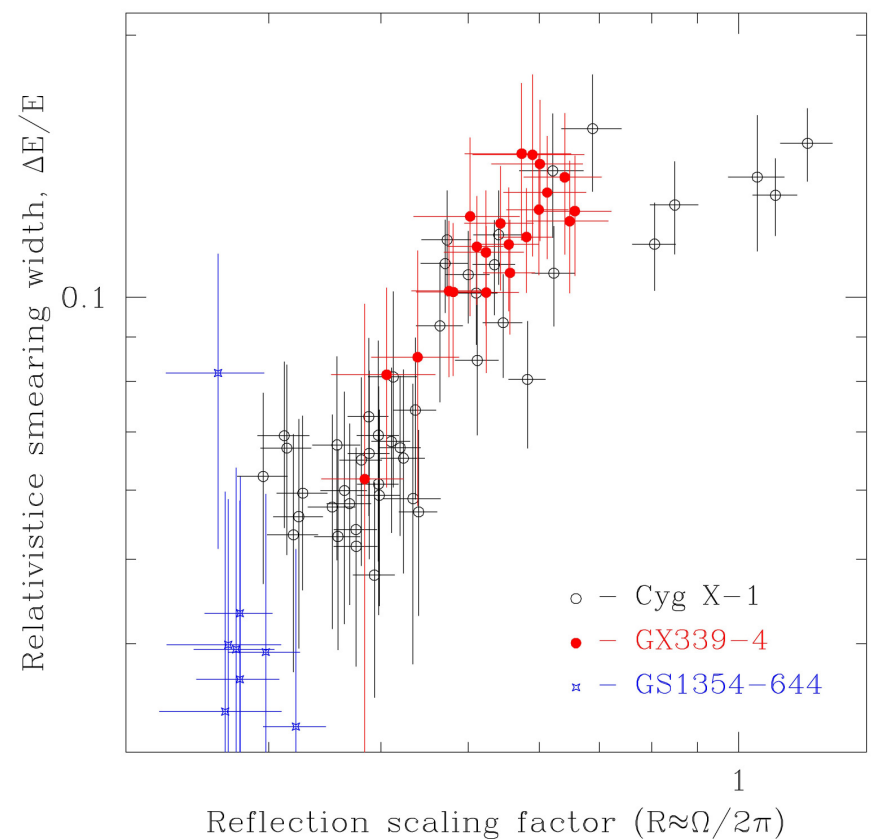
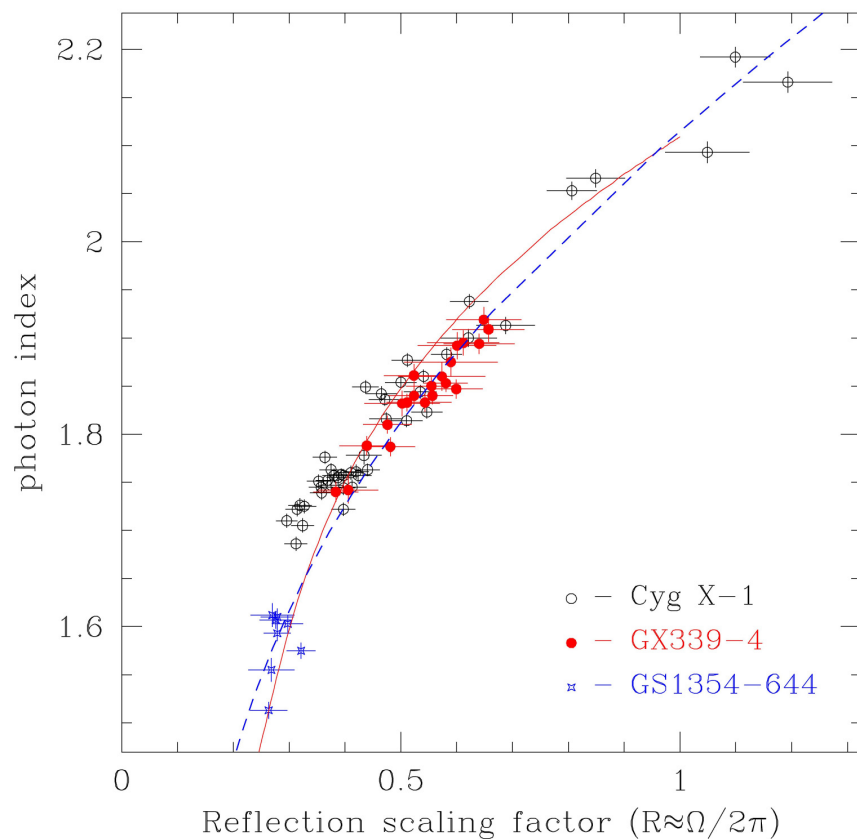
Reflected spectra (2)

- Many objects SAME Γ – $\Omega/2\pi$ correlation and CORRELATED increase in relativistic effects Zdziarski et al., 1999, Gilfanov et al 1999, Zycki et al 1999, Lubinski & Zdziarski 2001, Revnivtsev et al 2001; Abragimov et al 2005



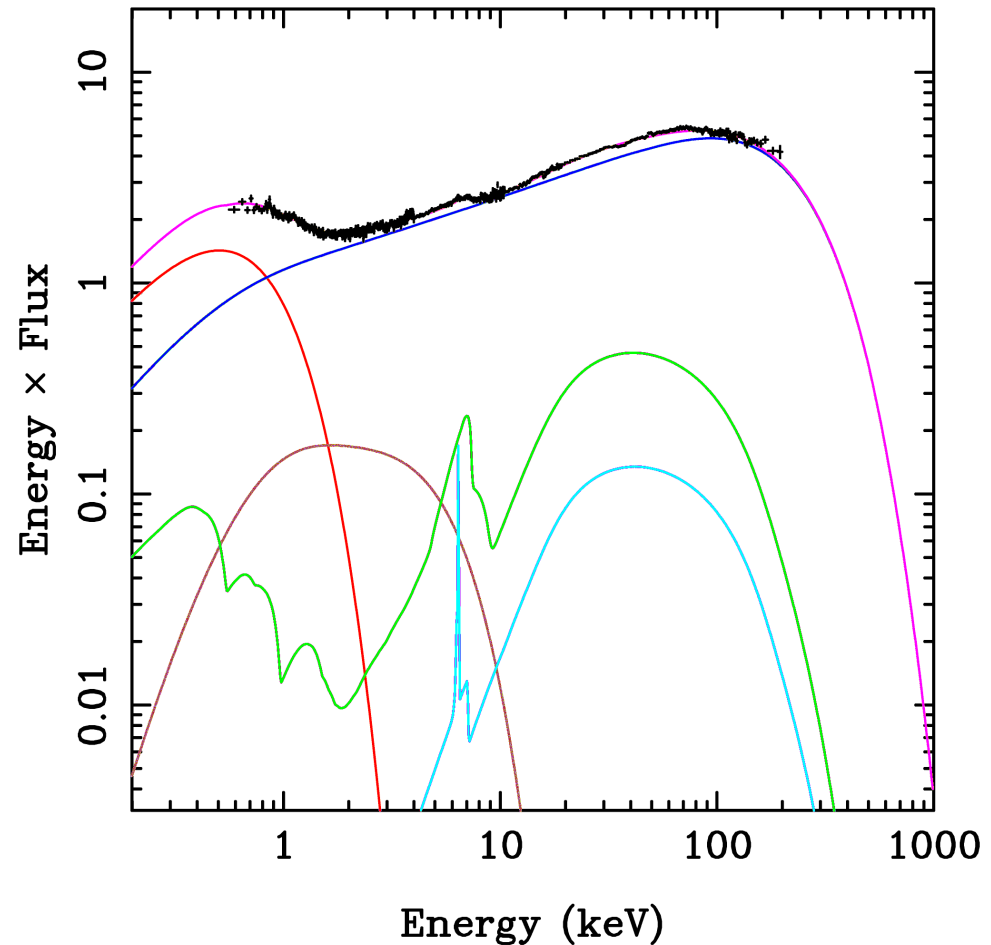
Reflected spectra (2)

- But only neutral reflection models
- RXTE has poor spectral resolution so smearing hard to constrain



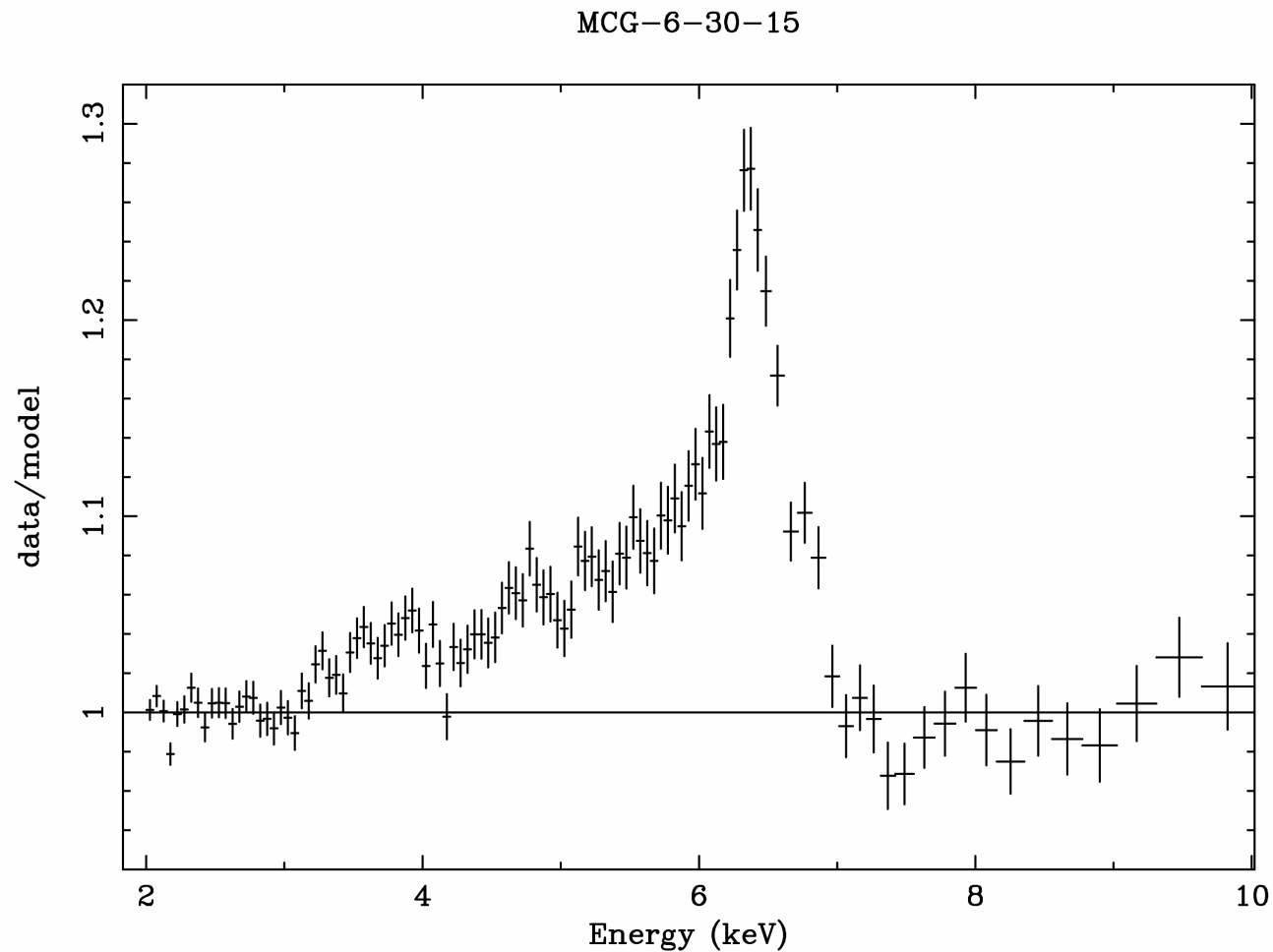
Reflected spectra: Cyg X-1

- Thermal
comptonisation + disc
+ something a bit
complicated in soft X-
rays
- Somewhat ionised
reflection but not good
model (pexriv based)
- Solid angle of
reflecting disc ~ 0.3
- Smeared Rin 6-20 R_g
- Very small neutral
unsmeared (from
companion star/wind)



Di Salvo et al 2000

Reflected spectra: AGN

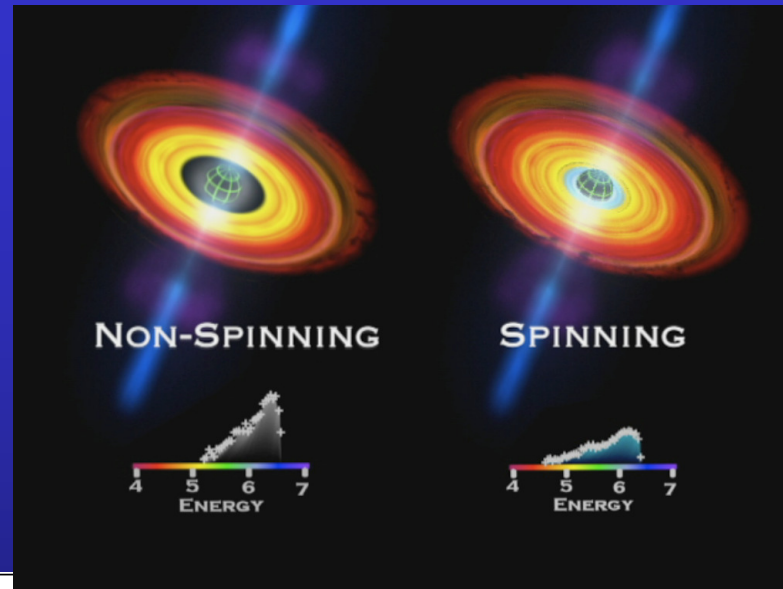
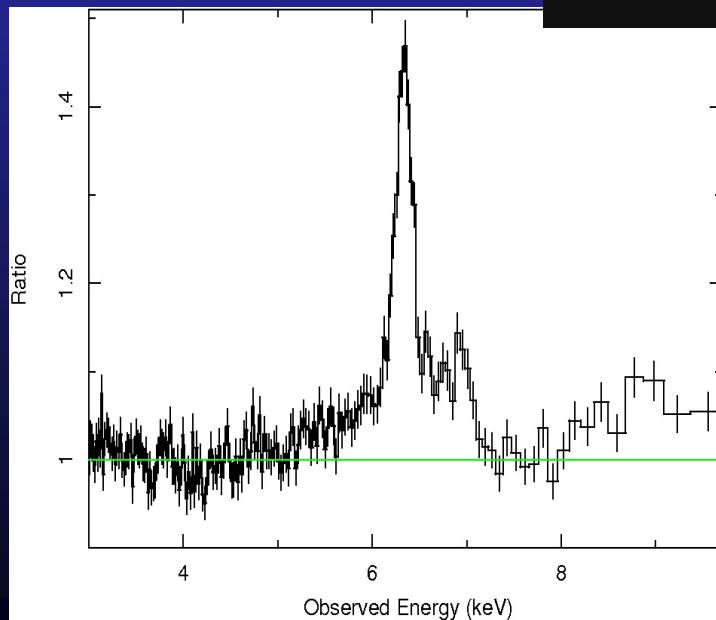


Fabian et al 2002; Vaughan & Fabian 2004

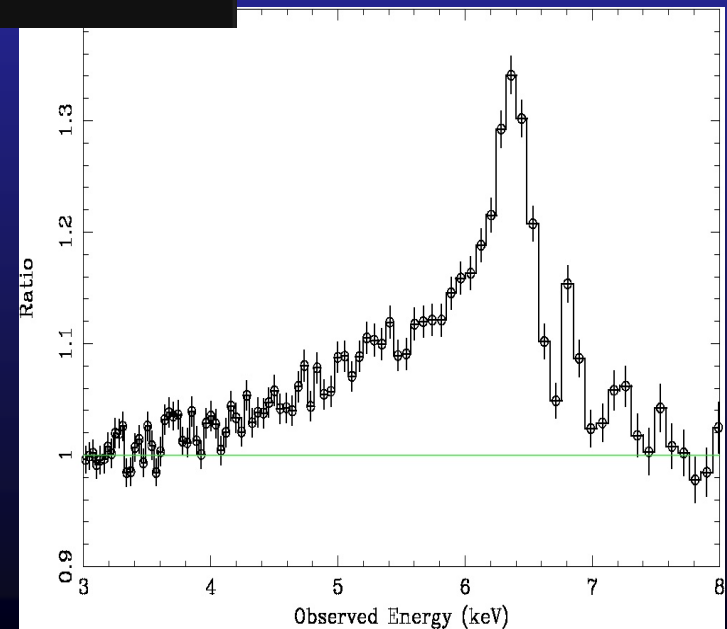
Suzaku Black Hole Spin Measurements

Fabian,
Reeves et al

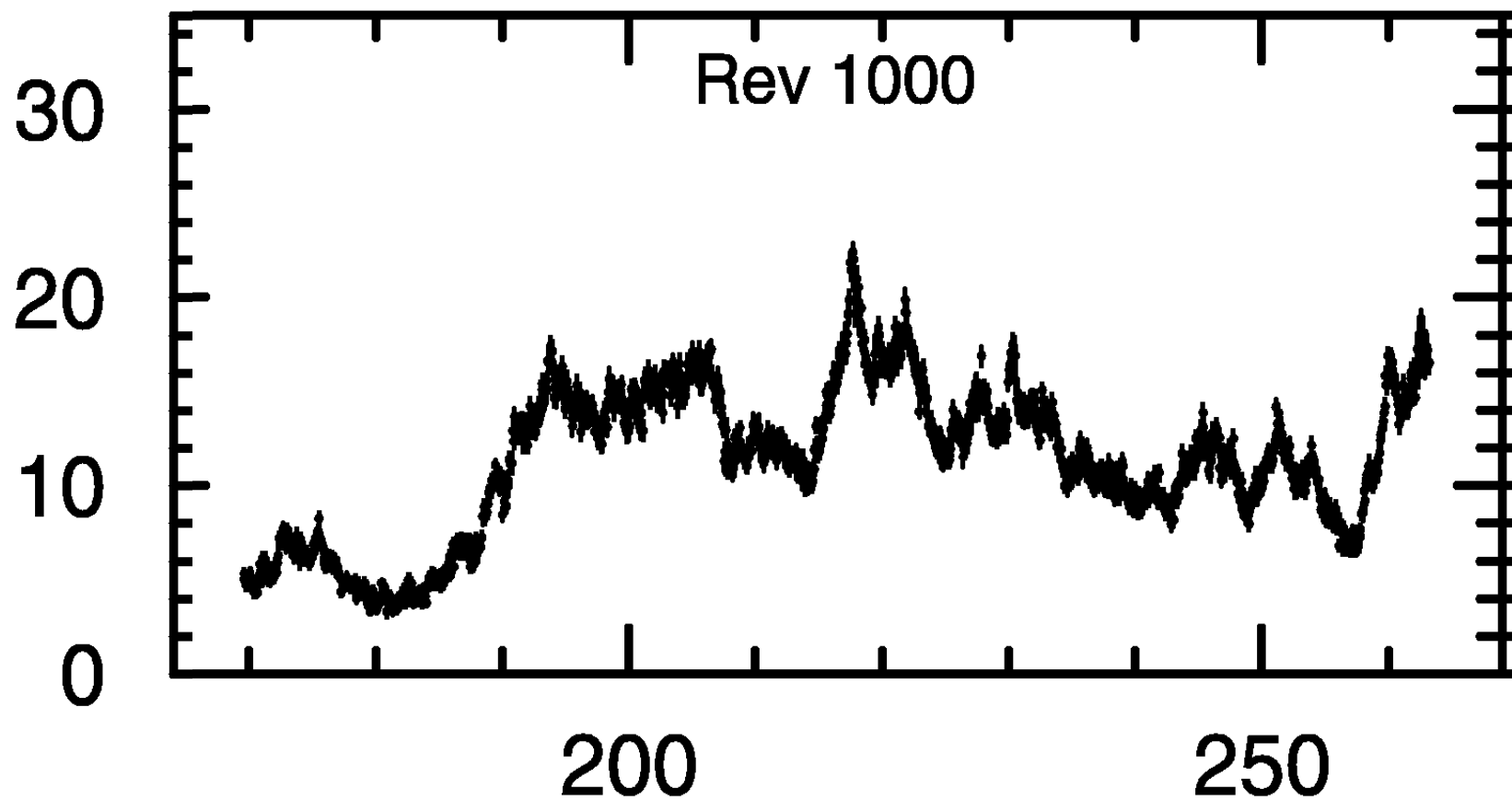
**MCG-5-23-16 (no
evidence for black
hole spin)**



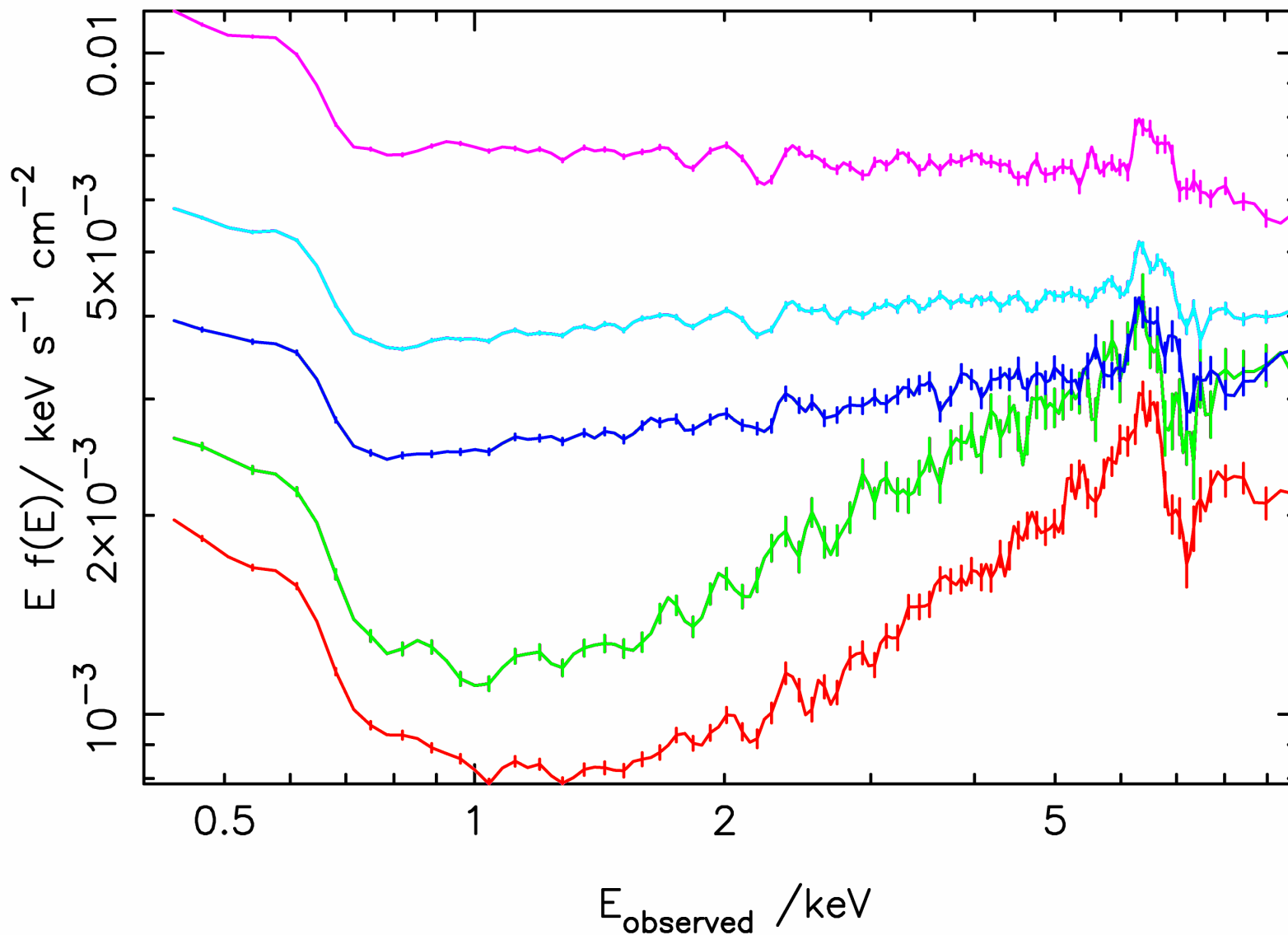
**MCG-6-30-15
(spinning black hole)**



More soft excesses in AGN

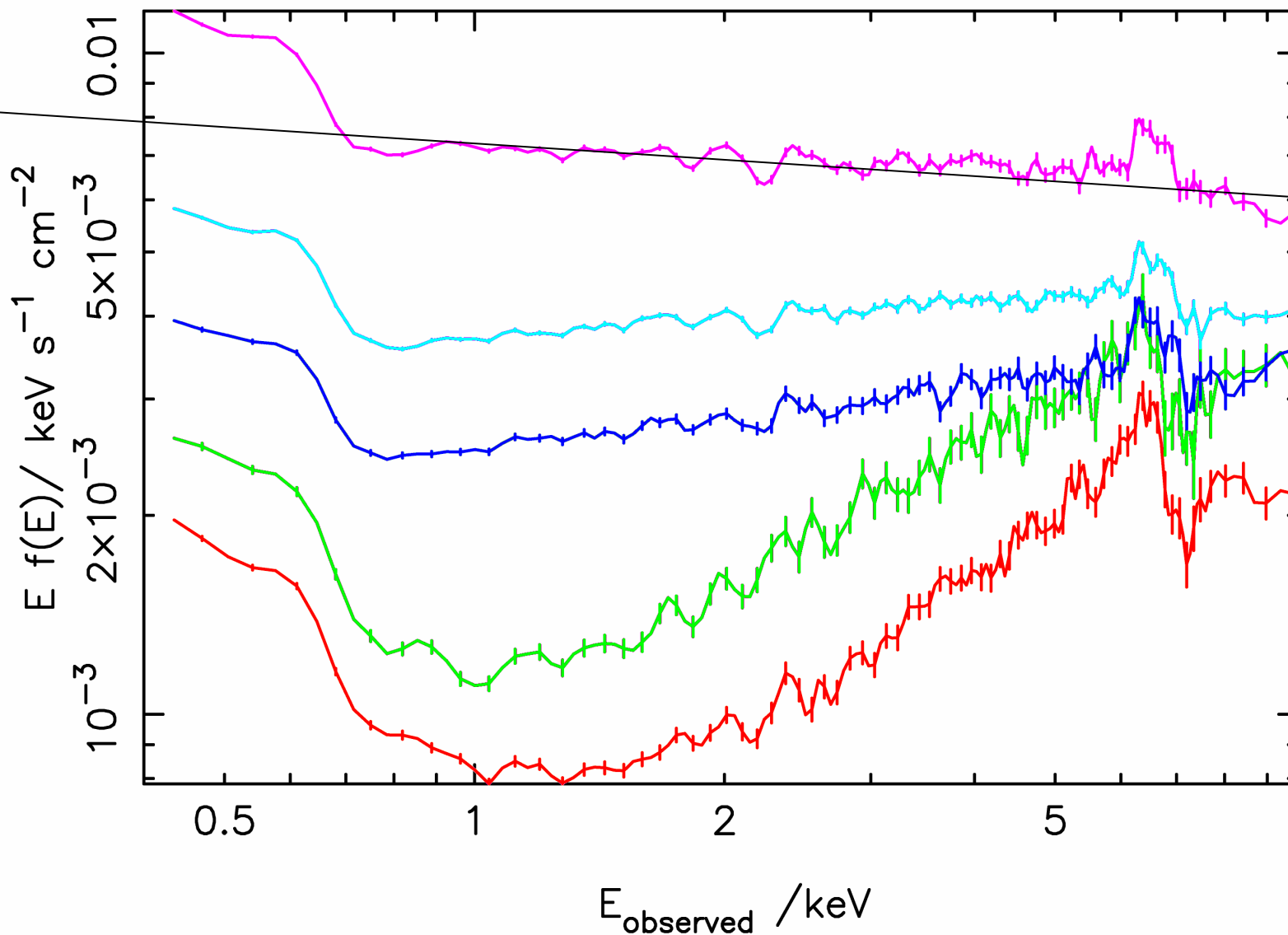


More soft excesses in AGN



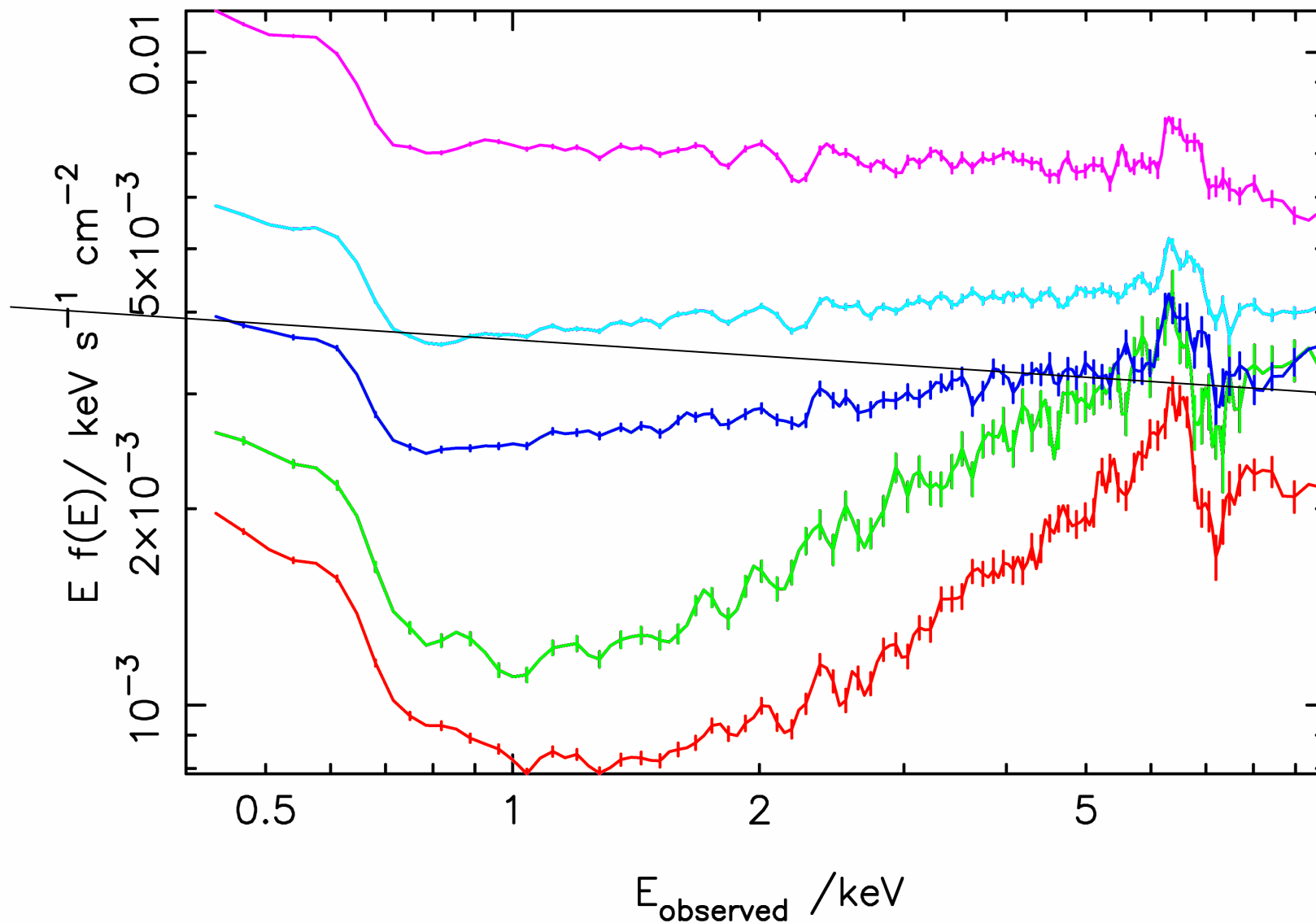
Miller et al 2007, Miller et al 2008

More soft excesses in AGN



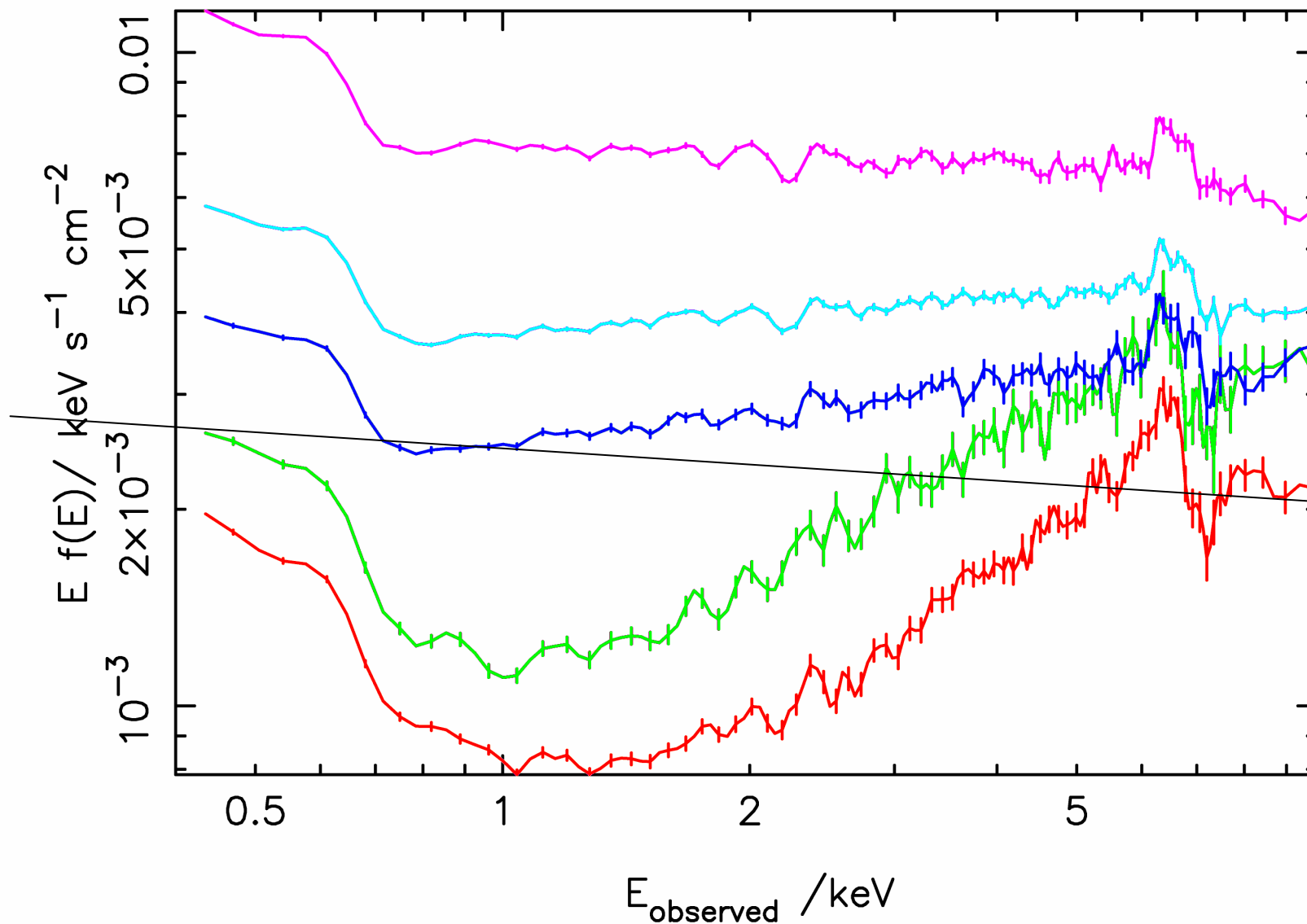
Miller et al 2007, Miller et al 2008

More soft excesses in AGN



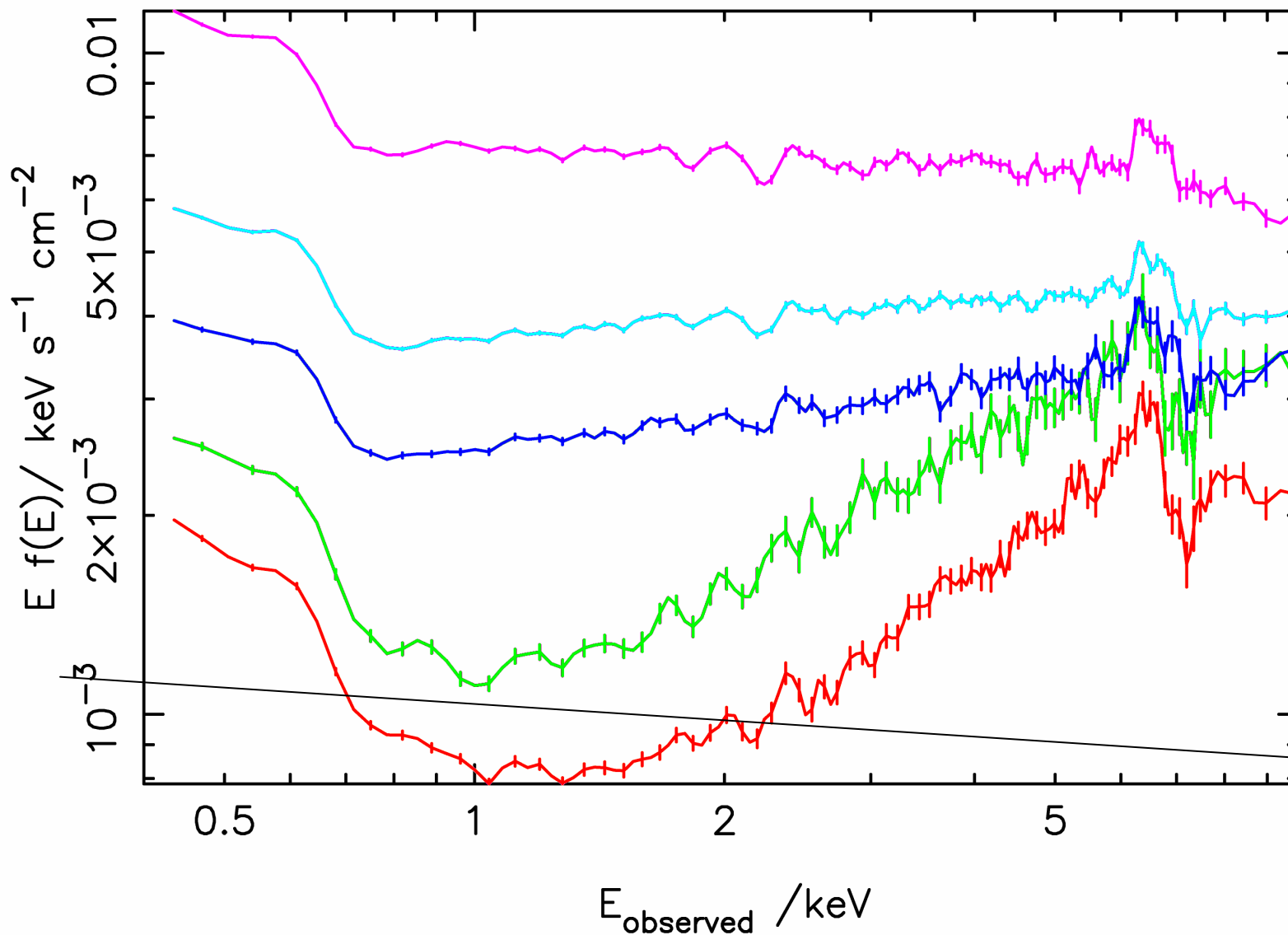
Miller et al 2007, Miller et al 2008

More soft excesses in AGN



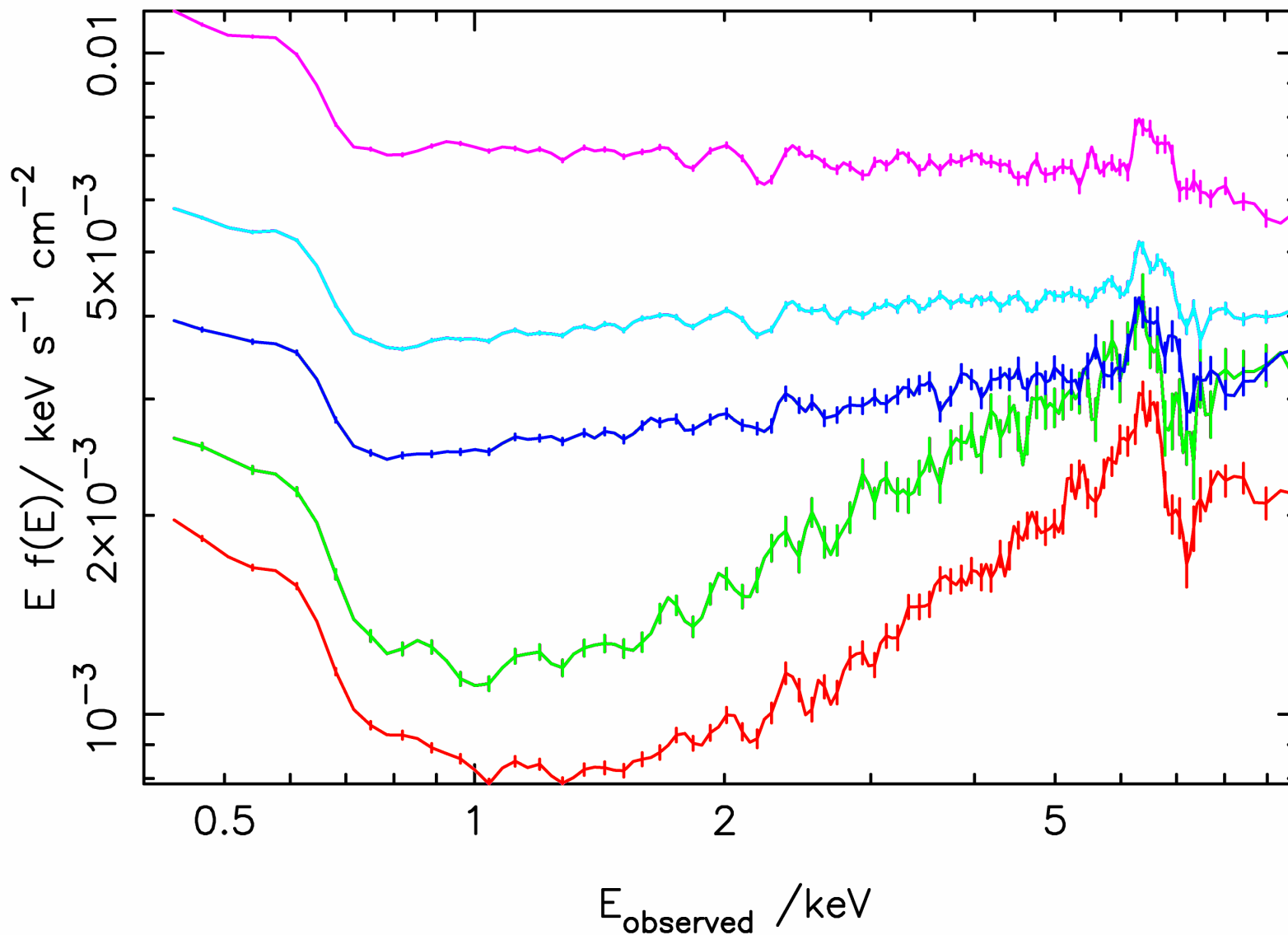
Miller et al 2007, Miller et al 2008

More soft excesses in AGN



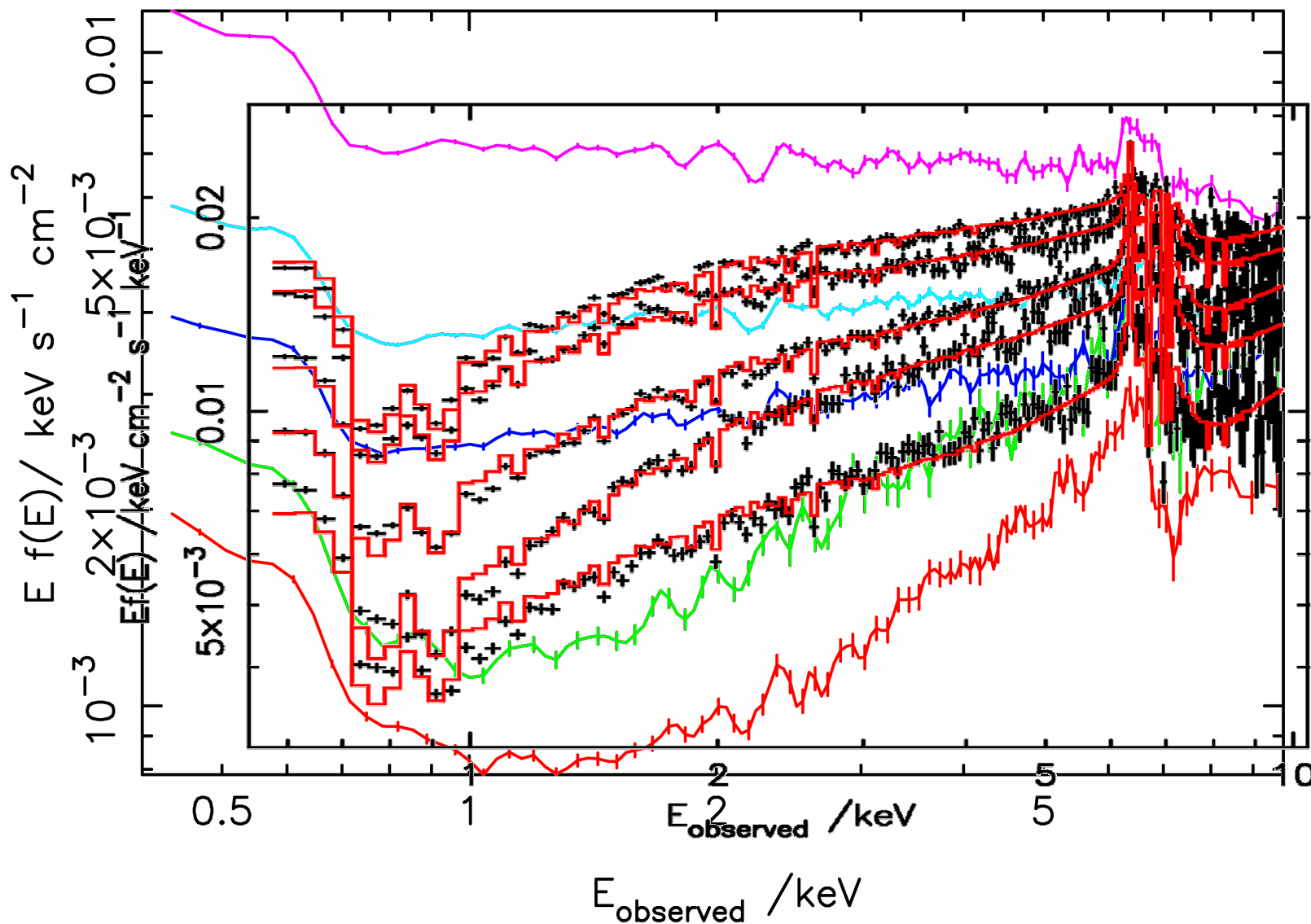
Miller et al 2007, Miller et al 2008

More soft excesses in AGN



Miller et al 2007, Miller et al 2008

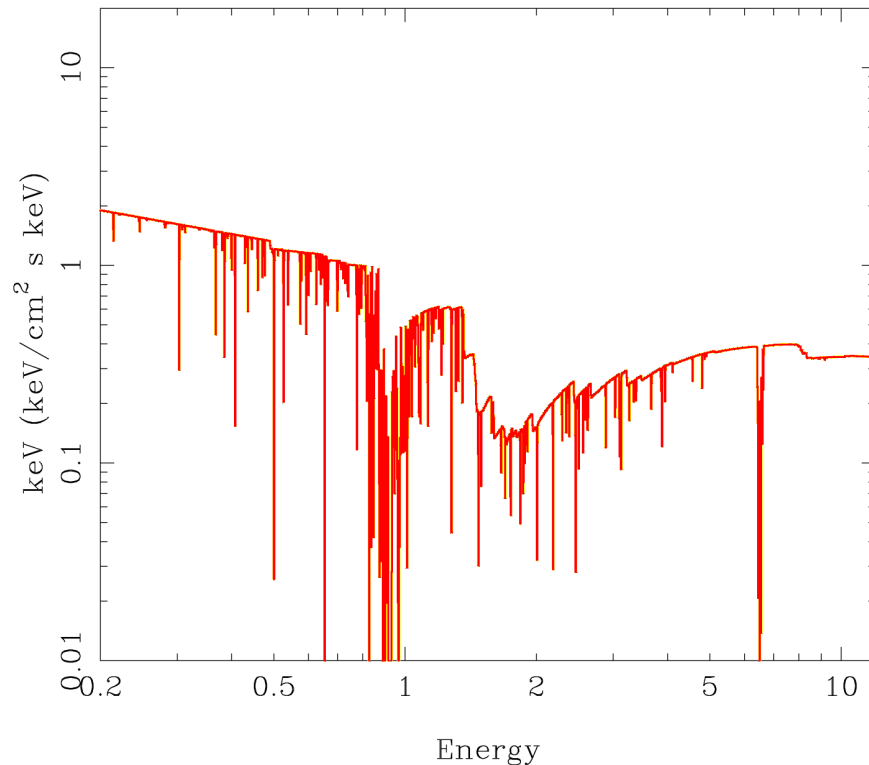
More soft excesses in AGN



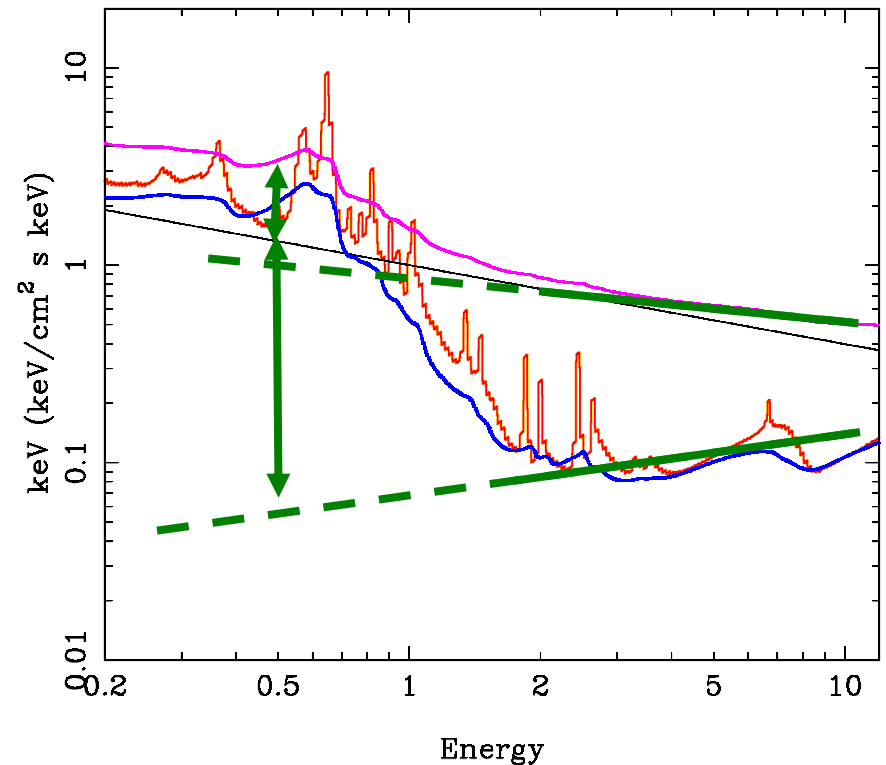
Miller et al 2007, Miller et al 2008

Partially ionised, relativistic material

- Opacity jump at OVII/VIII at 0.7 keV: fixed energy
- Atomic features not seen so relativistic smearing sometimes extreme



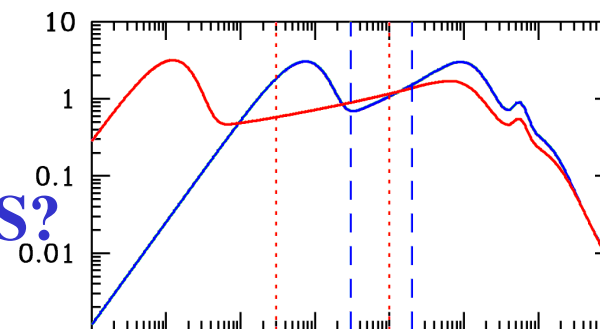
Gierliński & Done 2004, Chevallier et al 2006



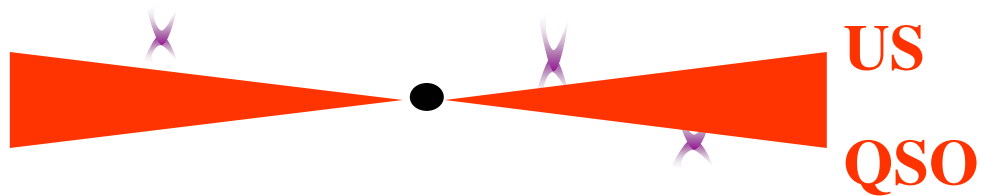
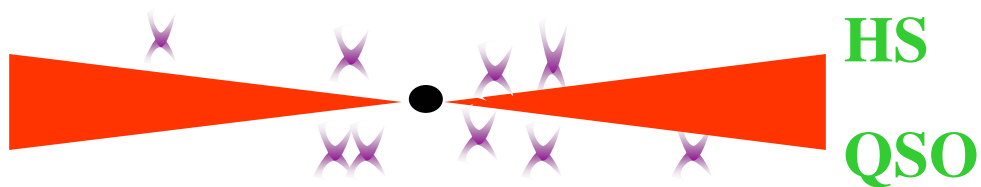
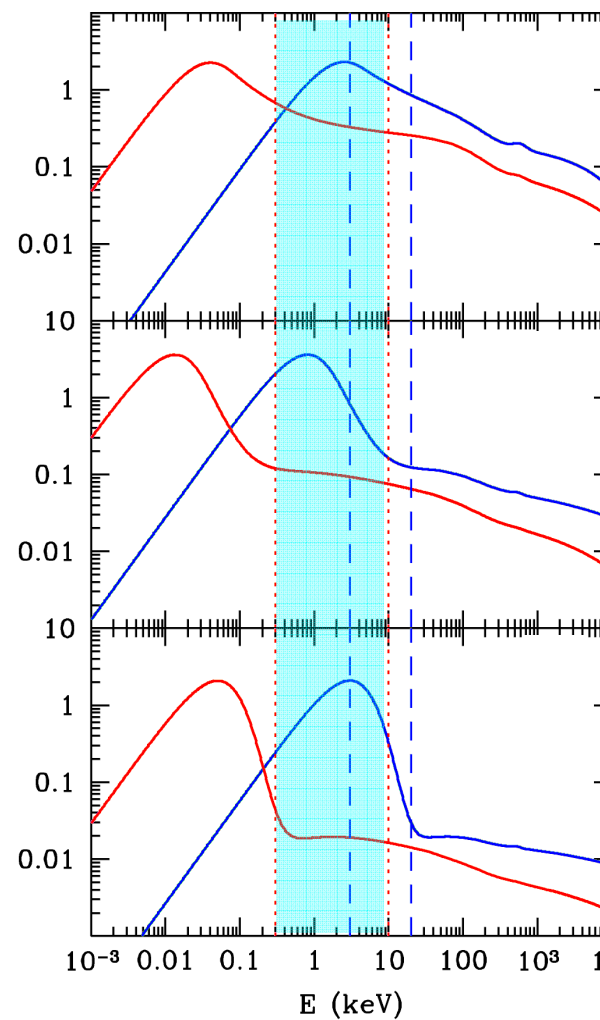
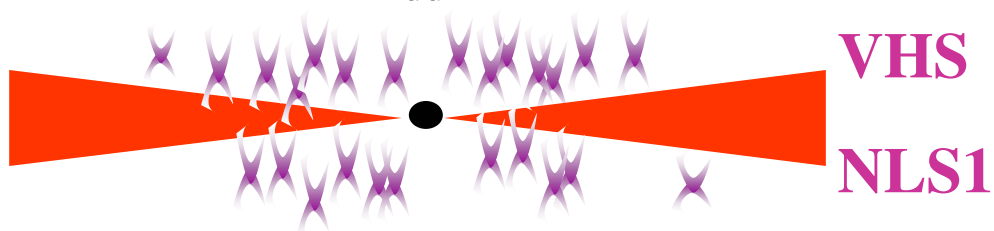
Fabian et al 2002; 2004 Miniutti & Fabian 2004



Hard (low L/L_{Edd})



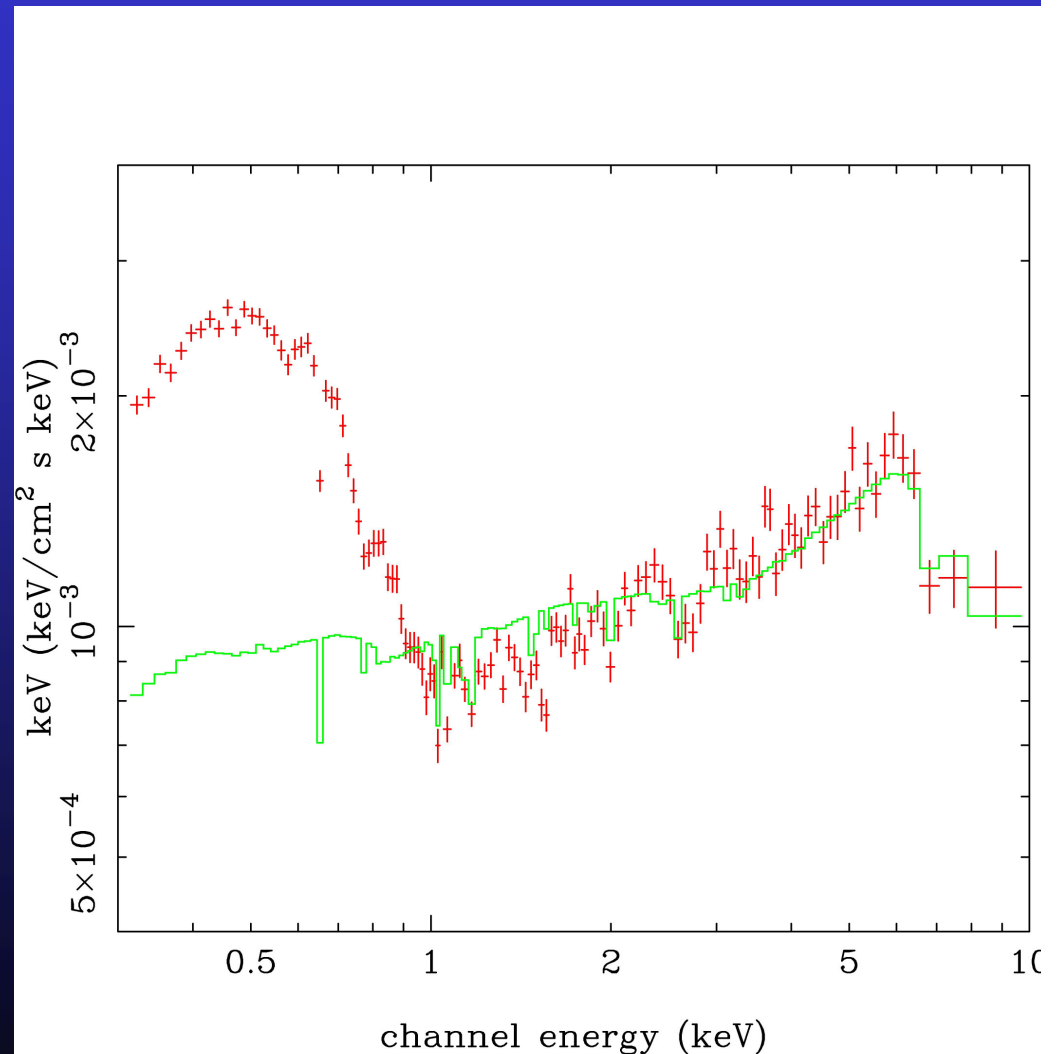
Soft (high L/L_{Edd})



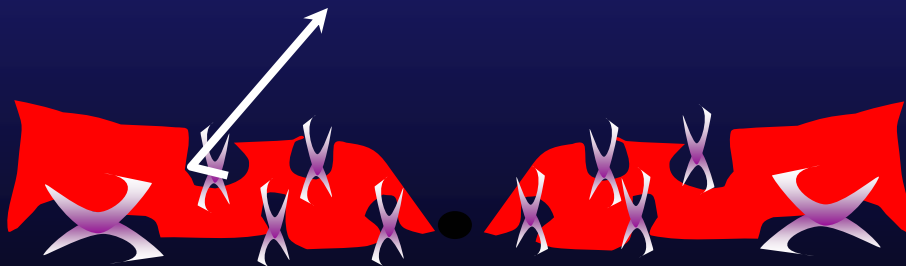
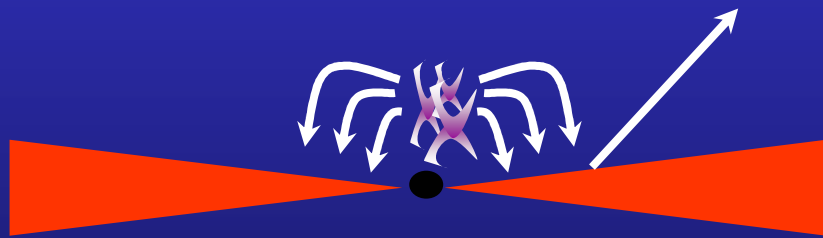
Done & Gierliński 2005

Implications for high L/L_{Edd}

- High L/L_{Edd} objects easy to find. Typically most PG QSO's have $L > 0.05 L_{\text{Edd}}$
- For these, soft excesses should be very rare in XMM bandpass. When seen they should be very steep, and low temperature
- Power law at high energies should be steep, $\Gamma = 2-2.5$
- PG1211- what not to see! Strong soft excess to $\sim 1\text{keV}$, flat power law at high energies



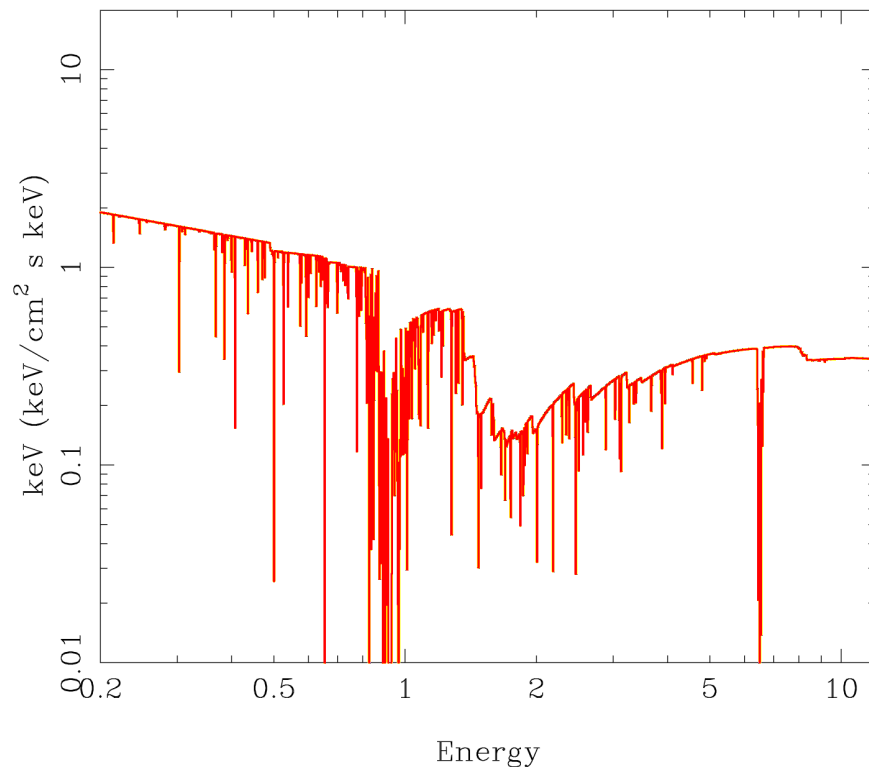
Alternative reflection dominated geometries



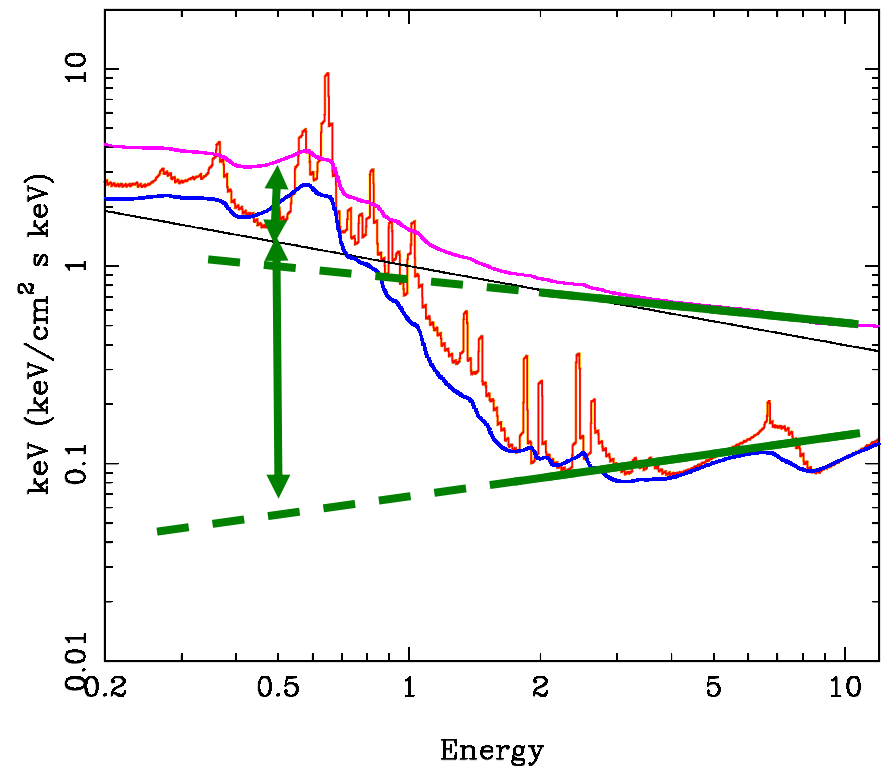
- Lightbending focuses x-rays onto very inner disc so get extreme smearing as well as solid angle > 1
- Fragmented disc gives solid angle > 1 but then all has to be in inner regions to get extreme smearing
- Fabian et al 2002; 2004
Miniutti & Fabian 2004

Partially ionised, relativistic material

- Opacity jump at OVII/VIII at 0.7 keV: fixed energy
- Atomic features not seen so relativistic smearing sometimes extreme
- Need to have particular $\xi \sim 1000$



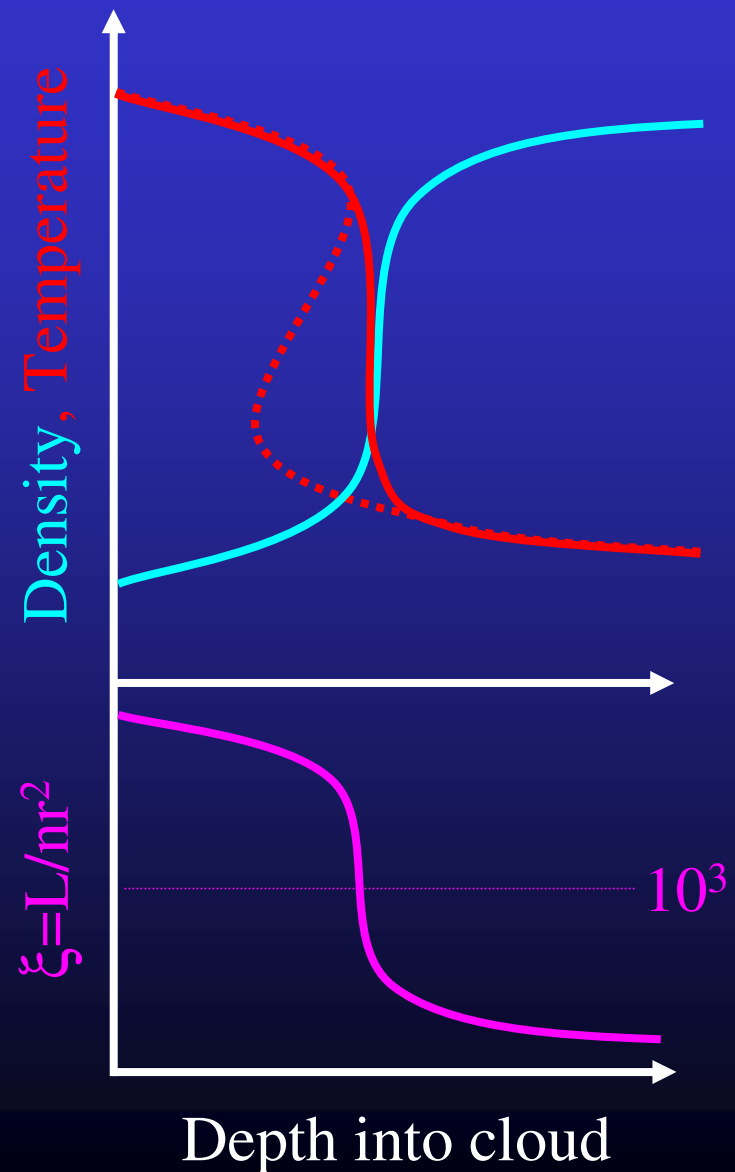
Gierliński & Done 2004, Chevallier et al 2006



Fabian et al 2002; 2004 Miniutti & Fabian 2004

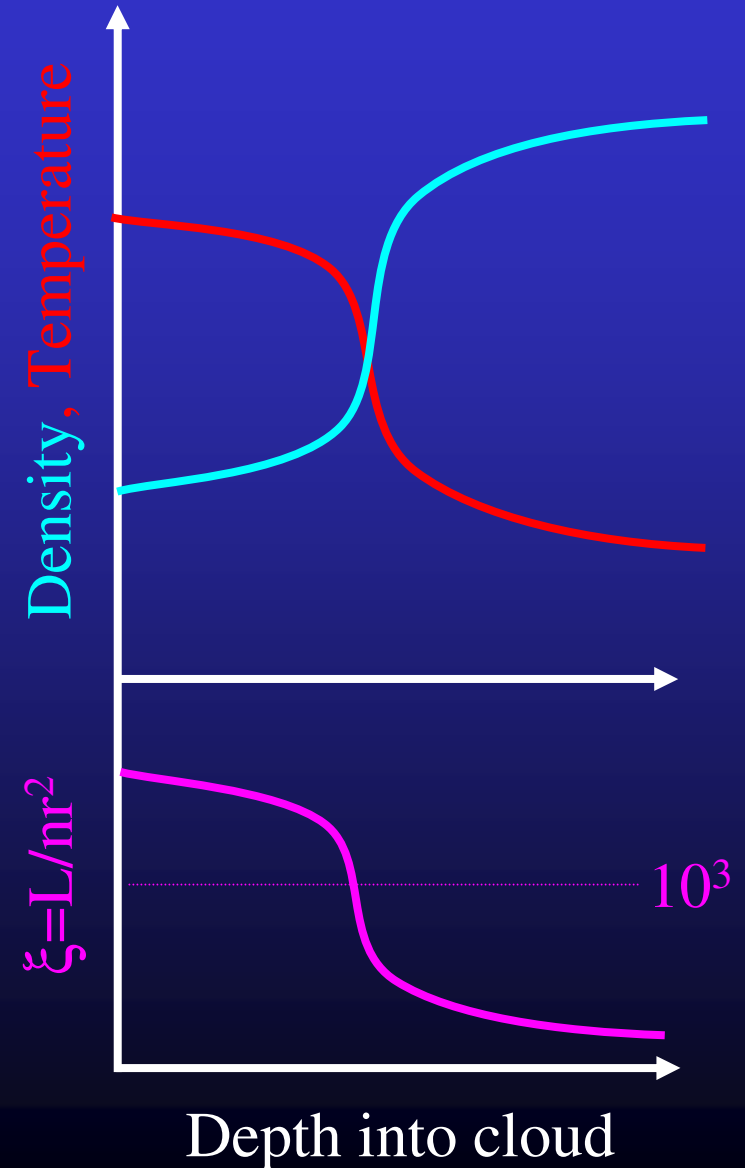
Ionisation instability: hard

- X-ray illuminated constant pressure (Krolik, McKee & Tarter 1984)
- Top T_{IC} : Compton heating versus Compton cooling – set by Γ
- Further in cloud T drops as shielded by upper layers. $P=nkT$ so n higher. Brems $\propto n^2$ so cooling increases fast...
- Lower ionisation $\xi=L/nr^2$ so eventually get to partially ionised ions where get dramatic increase in cooling from lines....
- True instability (double value) smoothed by conduction (?)
- Lines important at OVII/VIII $\xi=10^3$ (Done & Nayakshin 2006)



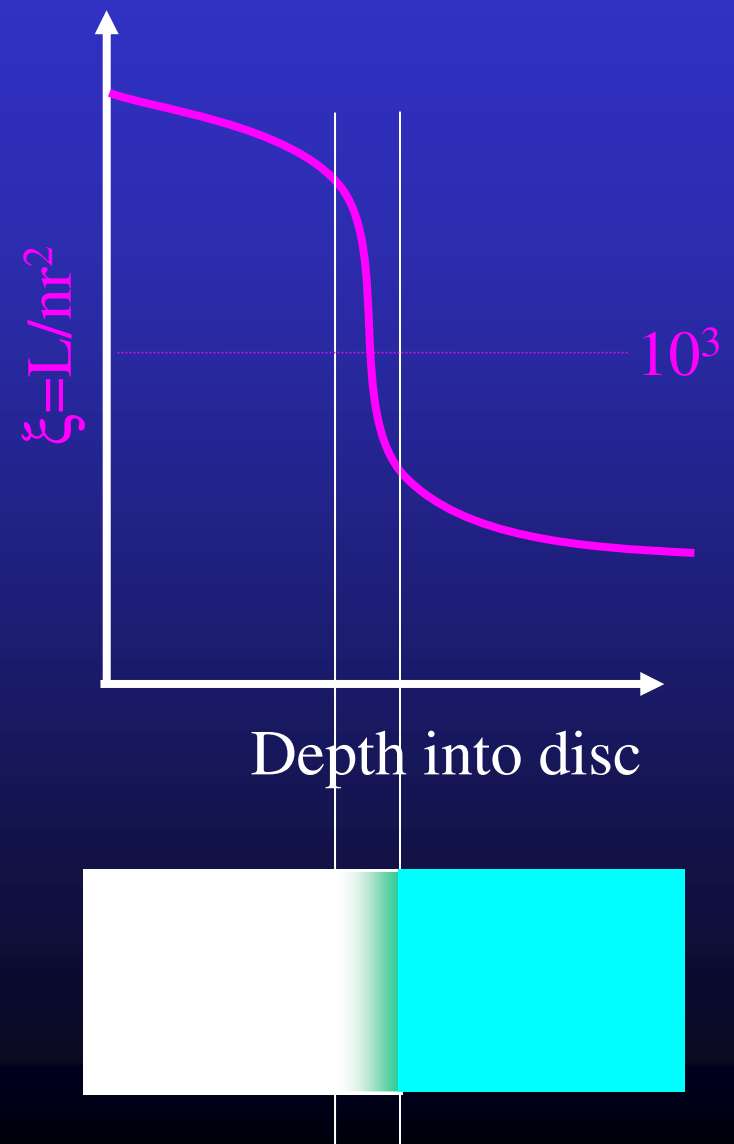
Ionisation ‘instability’: soft

- X-ray illuminated constant pressure (Krolik, McKee & Tarter 1984)
- Top T_{IC} : Compton heating versus Compton cooling – set by Γ
- Further in cloud T drops as shielded by upper layers. $P=nkT$ so n higher. Brems $\propto n^2$ so cooling increases fast...
- Lower ionisation $\xi=L/nr^2$ so eventually get to partially ionised ions where get dramatic increase in cooling from lines....
- True instability (double value) smoothed by conduction (?)
- Lines important at OVII/VIII $\xi=10^3$



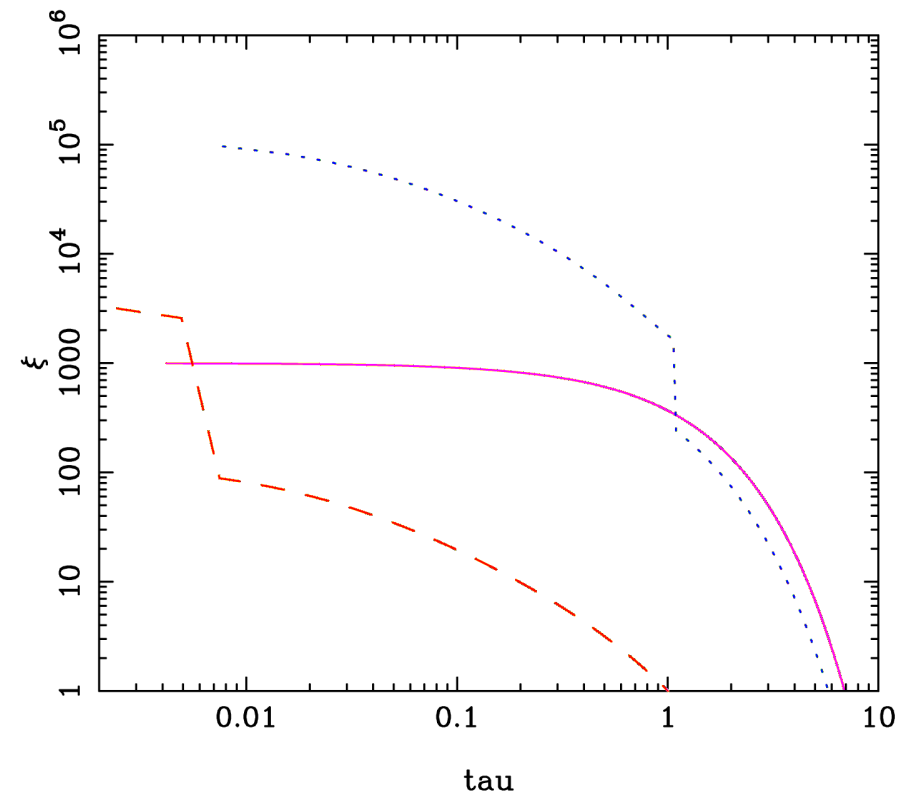
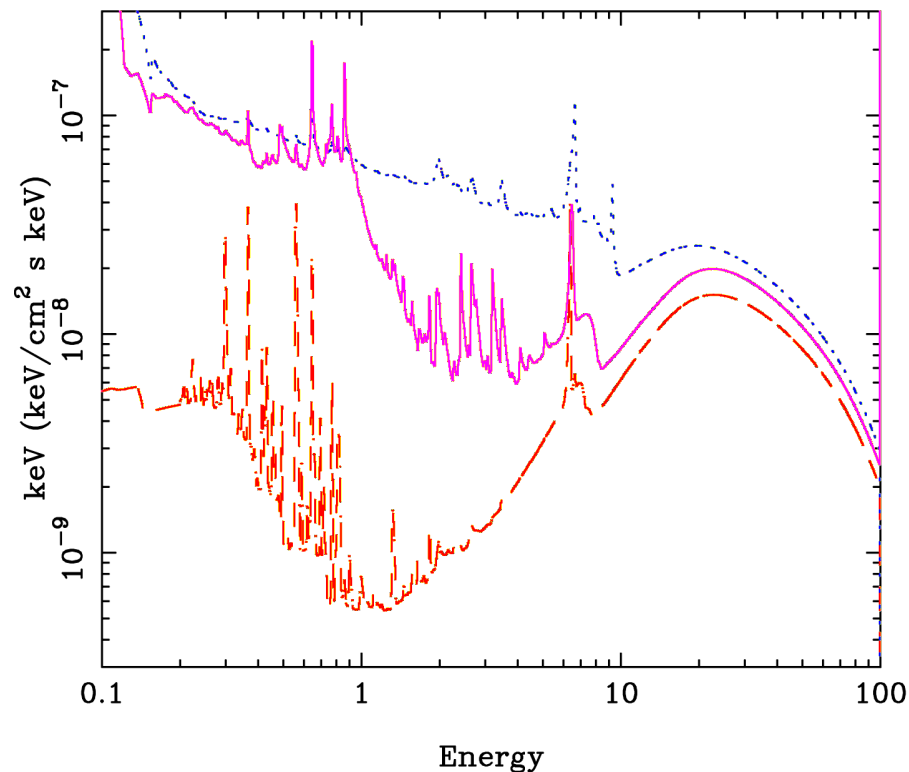
Ionisation ‘instability’: reflection

- Disk in hydrostatic equilibrium so pressure **INCREASES** downwards
- Front face of disc highly ionised, so invisible
- Transition with mean $\xi=10^3$, $\Delta\tau=0.01-0.1$
 $N_H=10^{22}-10^{23} \text{ cm}^{-2}$
- Need whole photosphere $\Delta\tau=1$ to be at $\xi=10^3$!! Done & Nayakshin 2006



Ionisation ‘instability’: reflection

- SX from hydrostatic disc. **Biggest**, **normal**. cf **constant density**
- Either disc is not in hydrostatic equilibrium (B field, wind)?
- Or reflection does NOT make the soft excess Done & Nayakshin 2006



Conclusions

- Reflection – just photon and electrons (sometimes bound)
- Incredible variety and subtle interplay
- Low ionisation – reflection hump, 6.4 keV line
- High ionisation – MUST use Compton scattering below 10 keV. Line/edge are intrinsically broad
- GBH – see reflection amount increase as spectrum softens from low/hard to high/soft but ionisation increases also and ionisation collisional from kT_{disc} as well as ξ
- AGN. See reflection. Sometimes see very smeared lines and big ‘soft excess’. Reflection dominated?
- NOT possible if disc in hydrostatic equilibrium due to ionisation instability