Accretion flows in black holes AGN and binaries!

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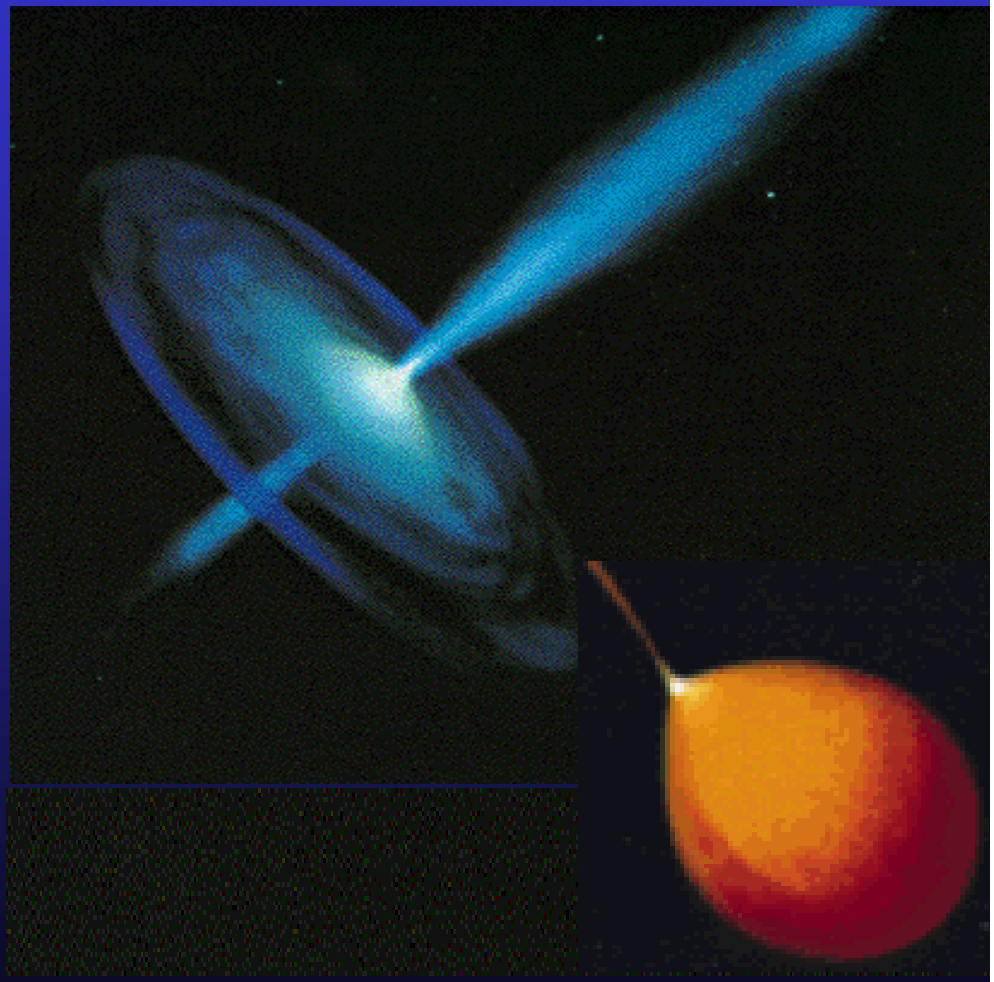
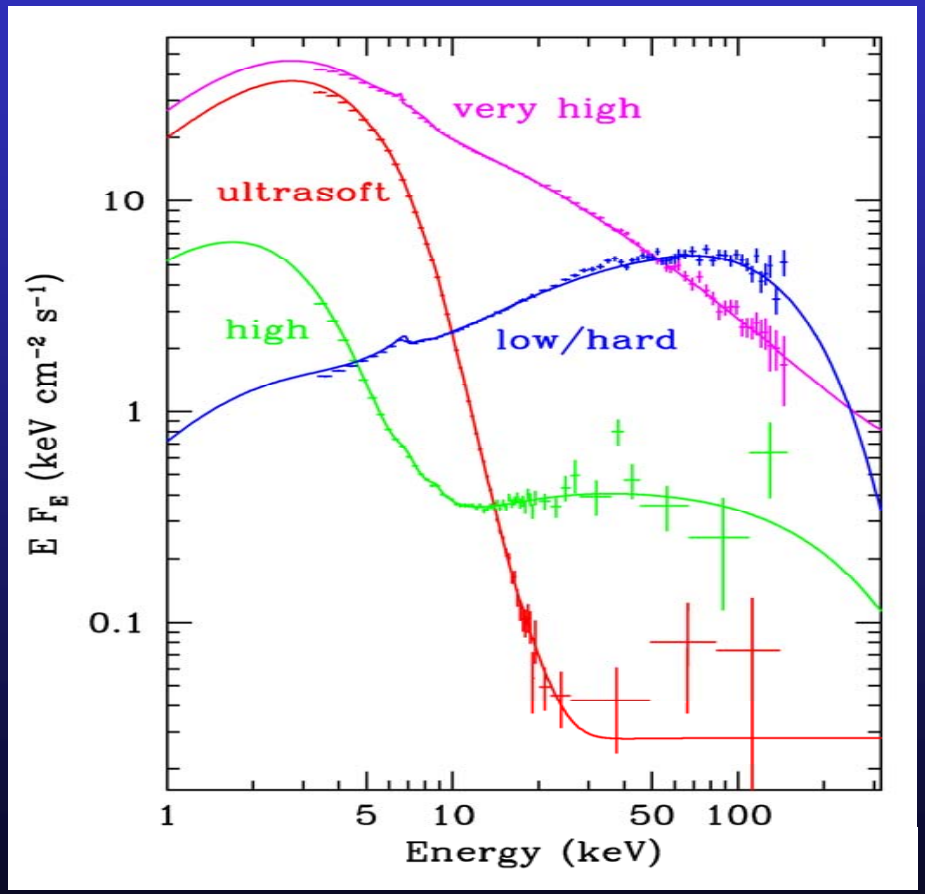
Accreting black holes

- Appearance of BH depends only on mass and spin (black holes have no hair!)
- Black hole binaries (BHB)
- M~3-20 $M_\odot$ (stellar evolution) - very homogeneous
- Form observational template of variation of flow with L/L_{Edd}
- Active Galactic Nuclei (AGN)
- M~10^5-10^{10} $M_\odot$ (build through accretion and mergers) very inhomogeneous



But rest are not simple…

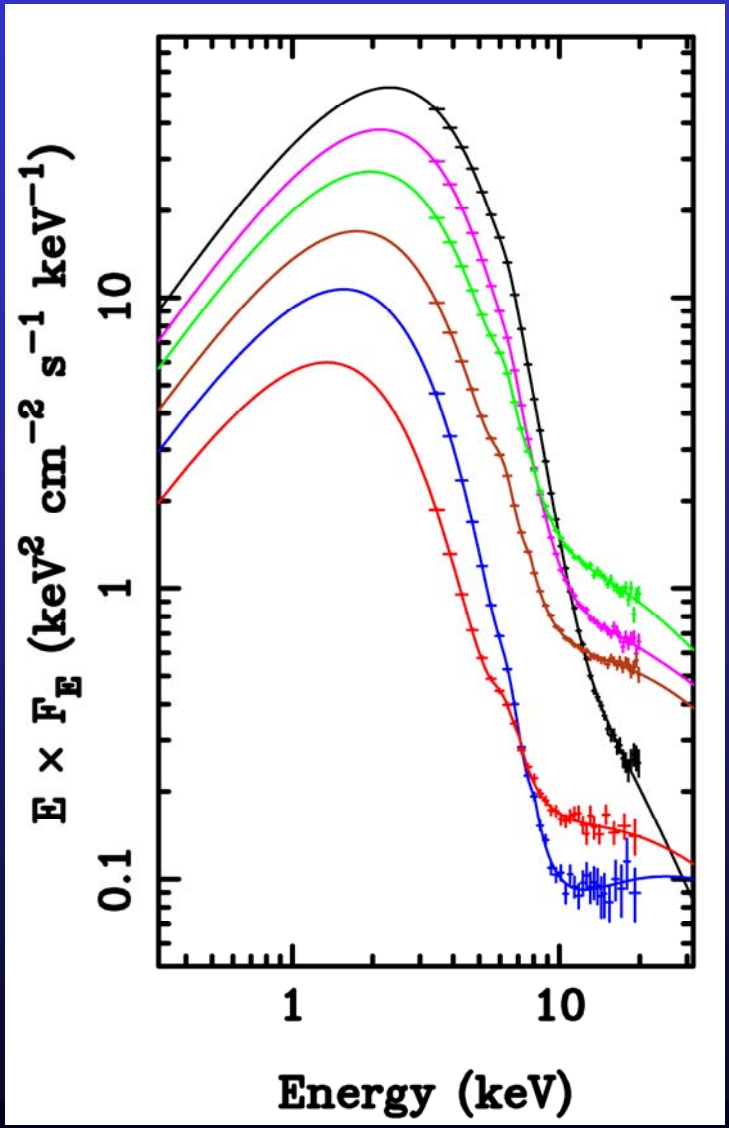
- Bewildering variety of spectra from single object
- Underlying pattern
- High L/L_{Edd}: soft spectrum, peaks at kT_{max} often disc-like, plus tail
- Lower L/L_{Edd}: hard spectrum, peaks at high energies, not like a disc



Gierlinski & Done 2003

Observed disc spectra

- Pick only ones that look like disc
- $L/L_{Edd} \propto T^4_{max}$ (Ebisawa et al 1993; Kubota et al 1999; 2001)
- Constant size scale – last stable orbit!!
- Proportionality constant gives a measure R_{lso} i.e. spin
- Consistent with low to moderate spin **not** extreme spin **nor** extreme versions of higher dimensional gravity - braneworlds (Gregory, Whisker, Beckwith & Done 2004)



Disc spectra: last stable orbit

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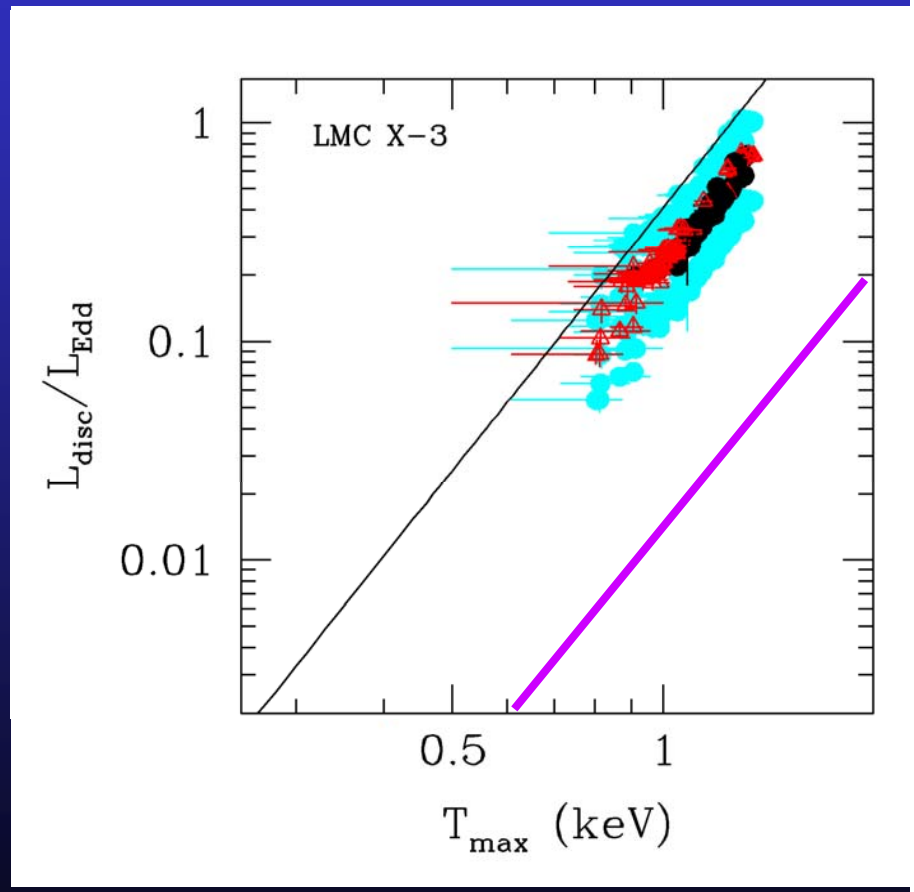

Gierlinski & Done 2003

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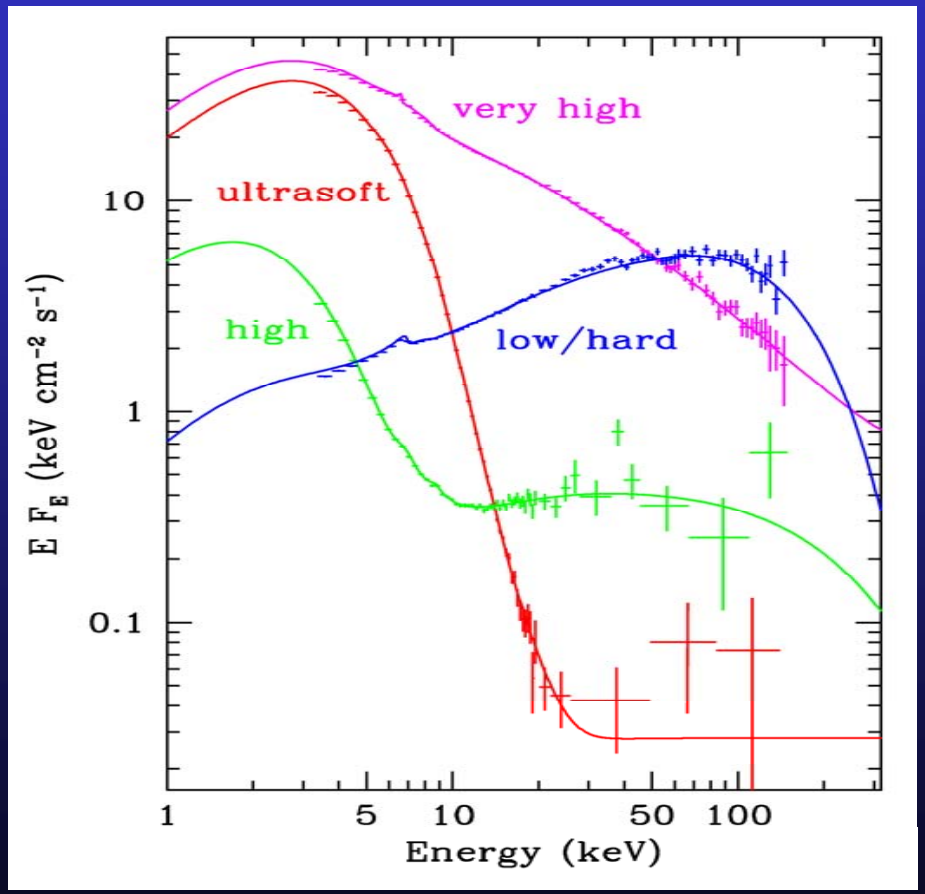
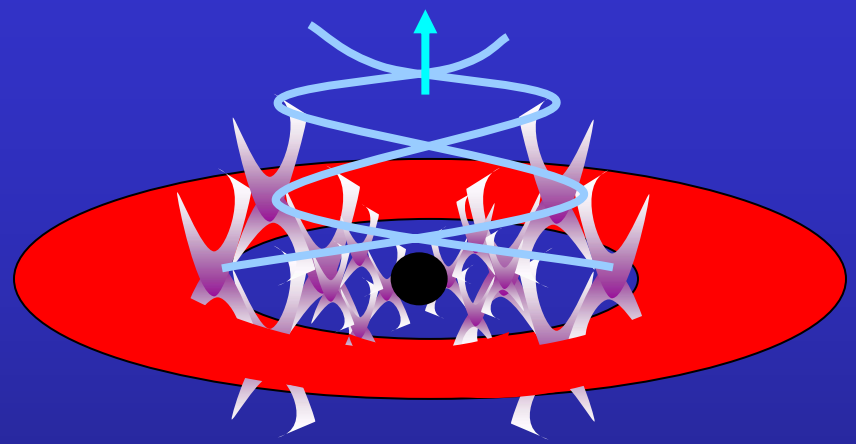
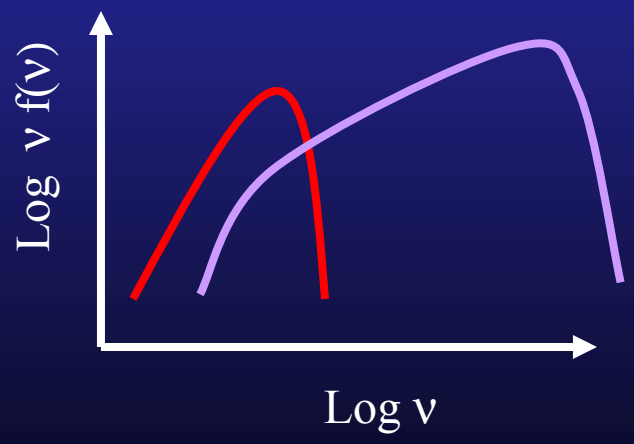


Gierlinski & Done 2003

Accretion flows without discs

- Disc models assumed thermal plasma – not true at low L/L_{Edd}
- Instead: hot, optically thin, geometrically thick inner flow replacing the inner disc (Shapiro et al. 1976; Narayan & Yi 1995)
- Hot electrons Compton upscatter photons from outer cool disc
- Few seed photons, so spectrum is hard
- MRI: large scale height flow lauches jet!

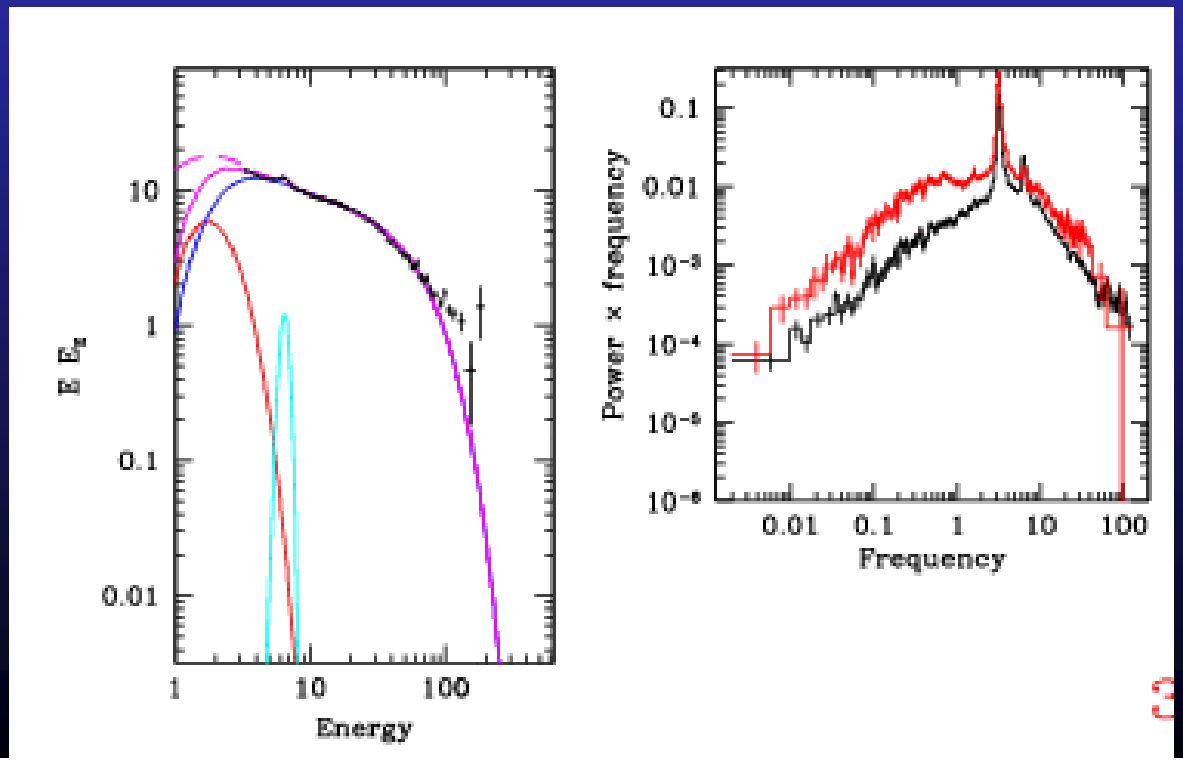


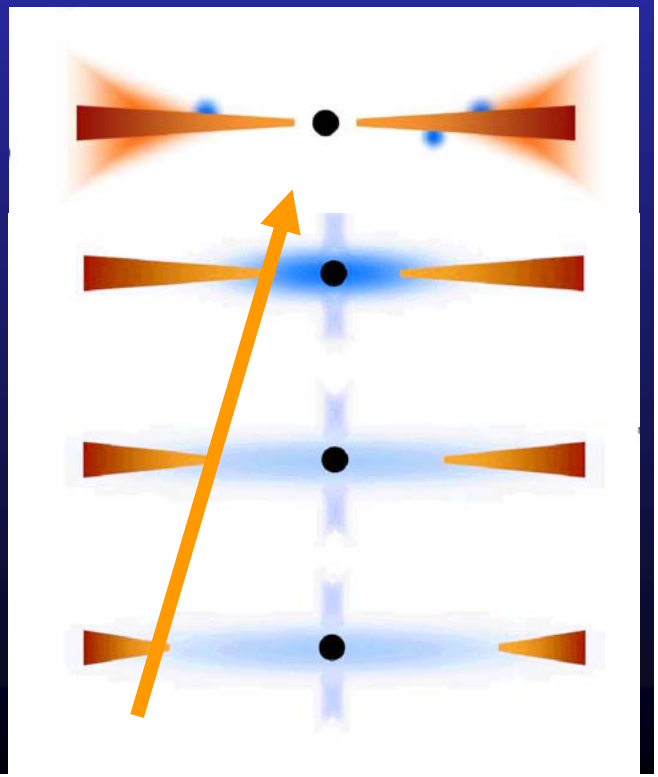


Moving disc – moving QPO

- Low frequency QPO – very strong feature at softest low/hard and intermediate and very high states (disc+tail)
- Moves in frequency: correlated with spectrum
- Moving inner disc makes sense of this. Disc closer in, higher f QPO. More soft photons from disc so softer spectra (di Matteo et al 1999)

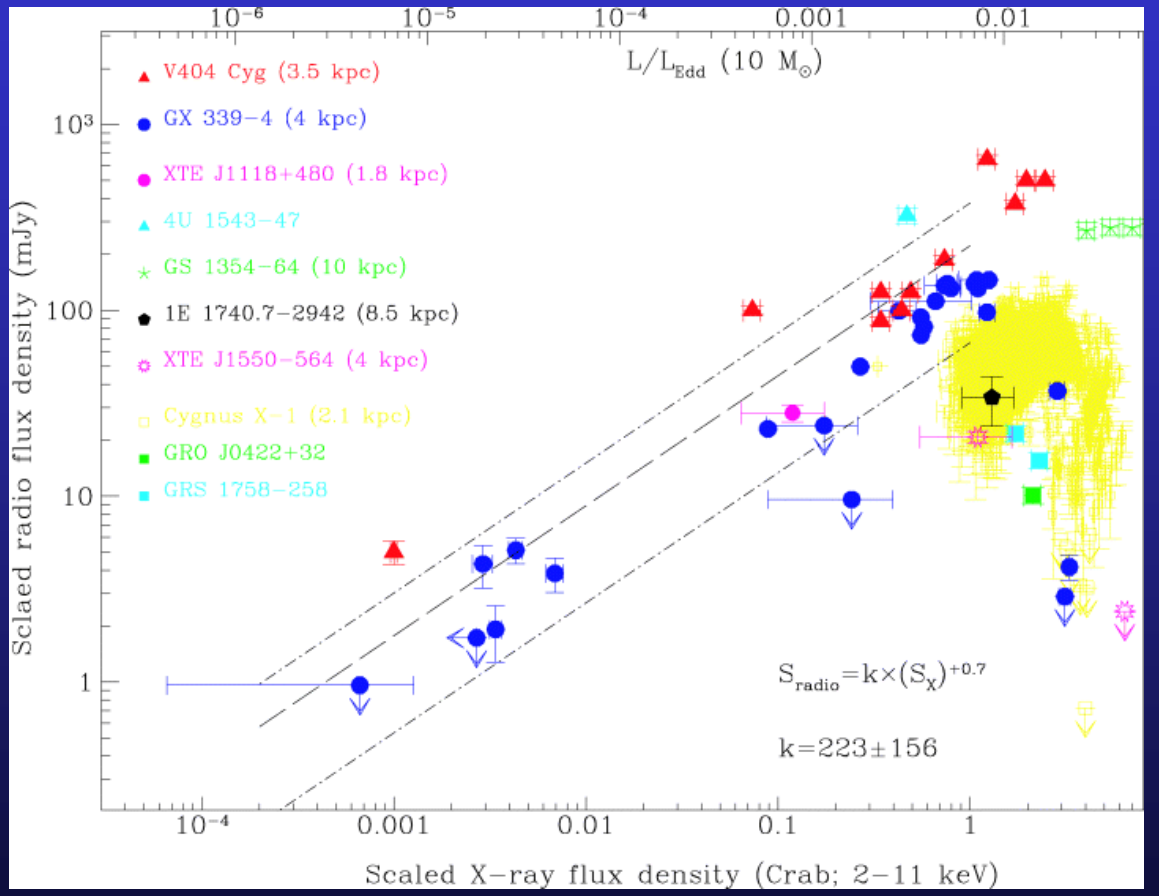
DGK07





And the radio jet…

- No special μQSO class – they ALL produce jets, consistent with same radio/X ray evolution
- Jet links to spectral state
- Steady jet in low/hard state, power depends on accretion rate! i.e. L/L_{Edd} (Merloni et al 2003; Falke et al 2004)
- Bright radio flares in rapid low/hard to high/soft transition (Fender et al 2004)
- No jet in disc dominated state



Gallo et al 2003

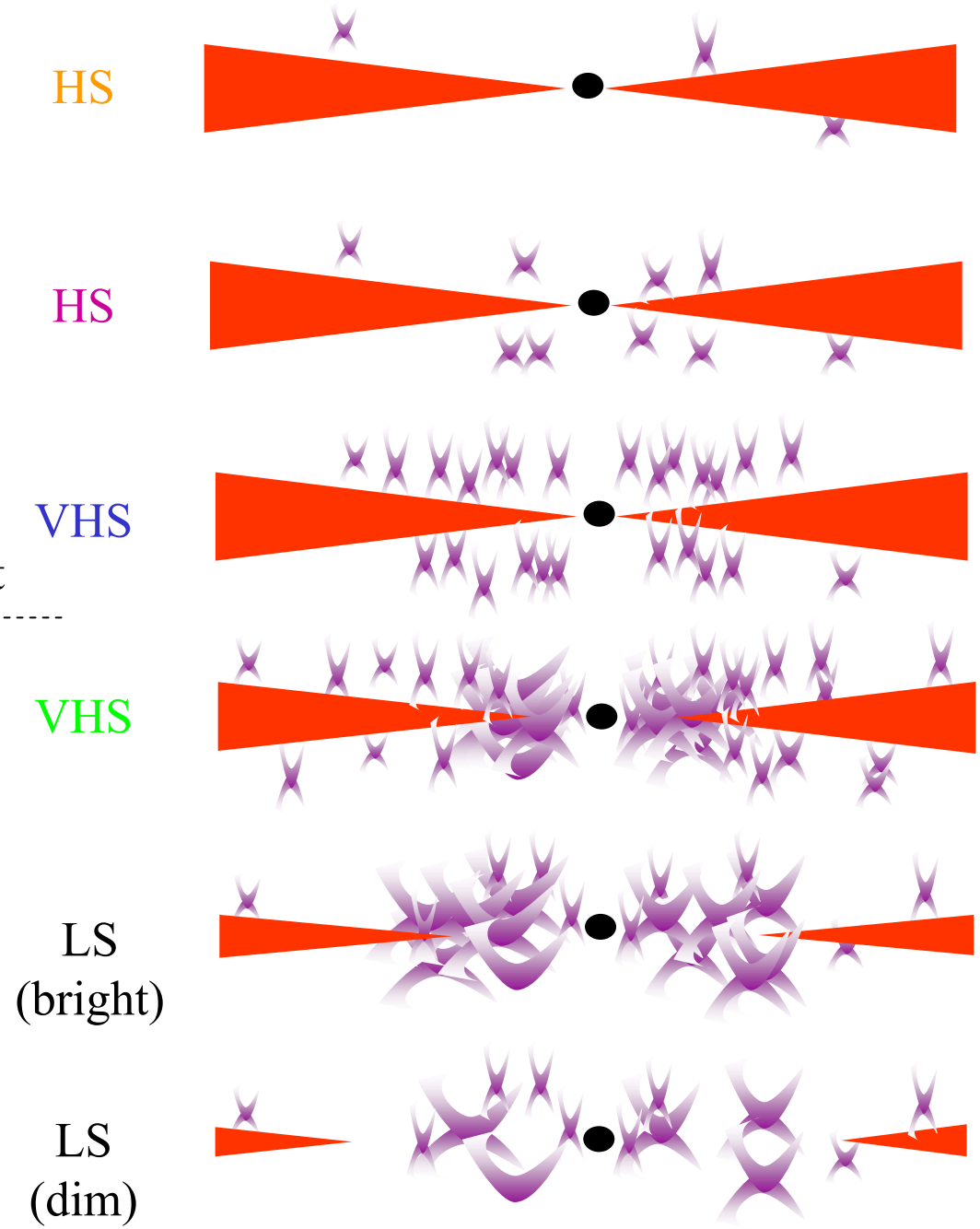
No jet

Decrease fraction of power in nonthermal reconnection above disc

Disc to minimum stable orbit

Decrease inner disc radius, and maybe radial extent of corona giving increasing LF QPO frequency

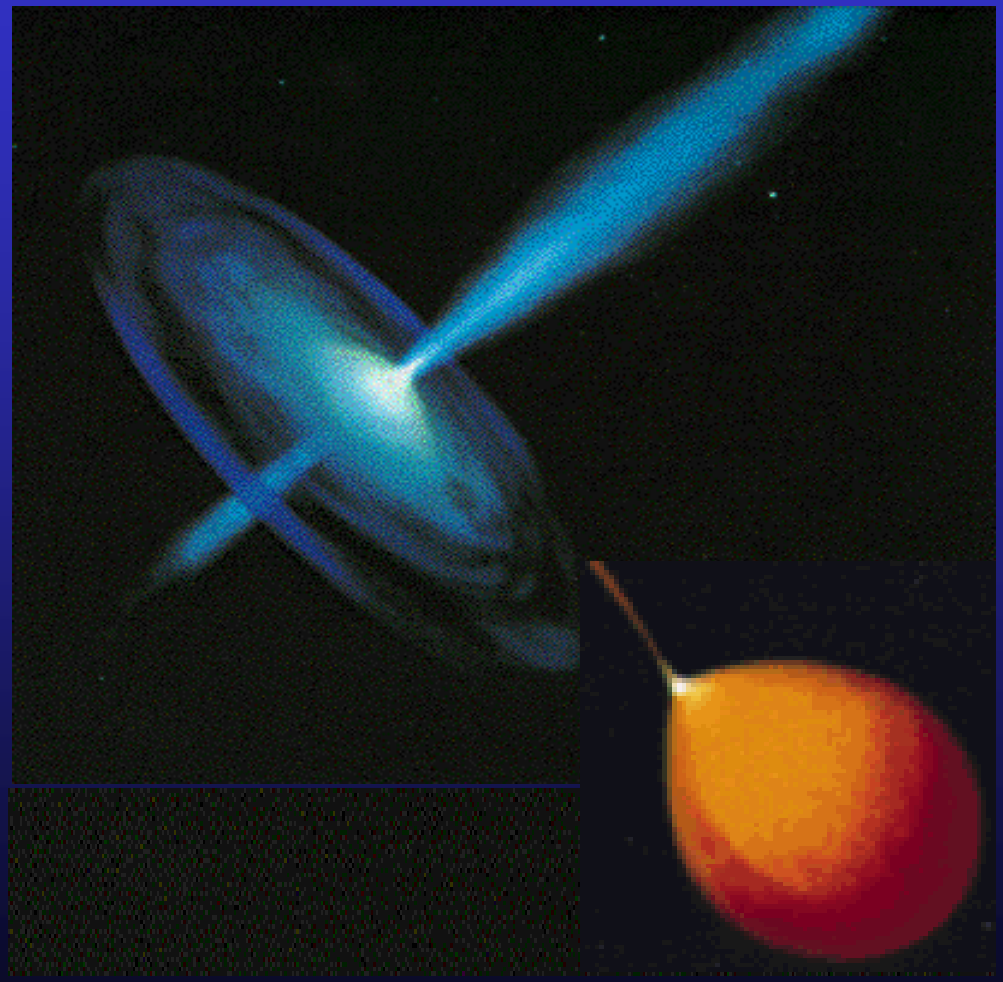
Jet gets faster, catches up with slower outflow, get flares of radio emission from internal shocks Fender (2004)



Done Gierlinski & Kubota 2007

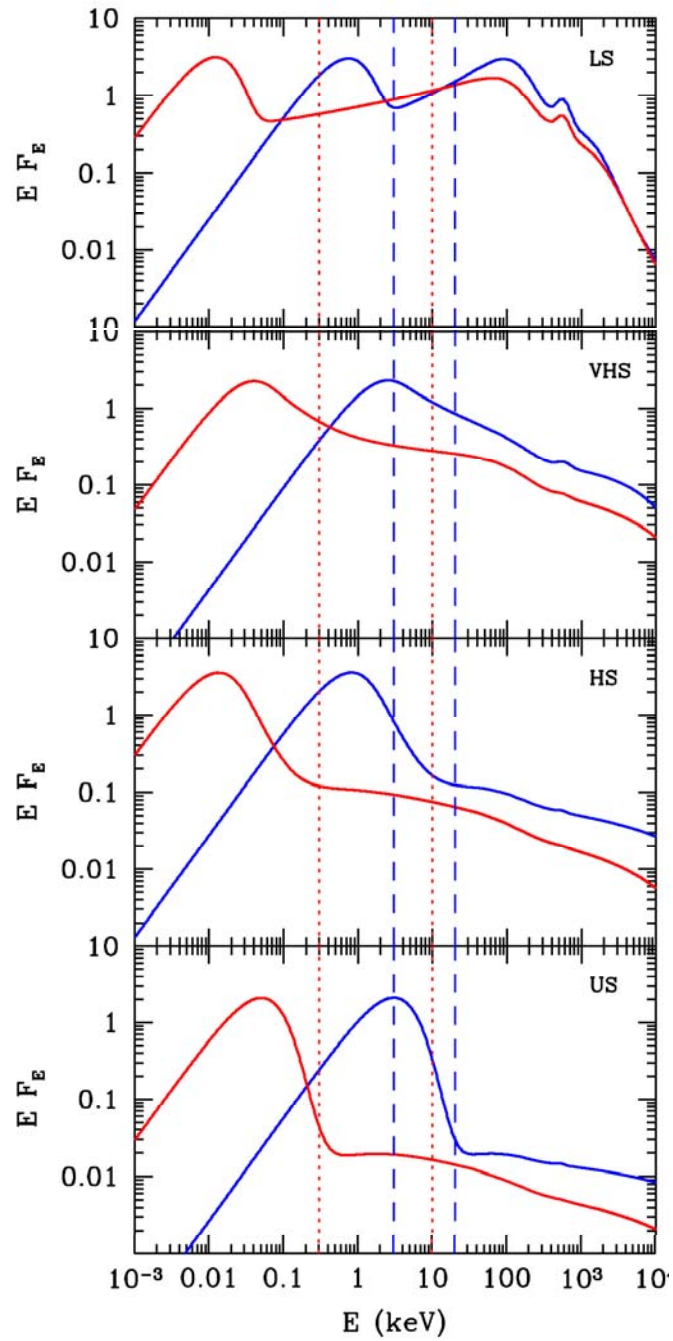
Scale up to AGN

- Disc temperature $M^{-1/4}$ for same L/L_{Edd}
- 10 eV from 1 keV for factor 10^8 change in BH mass
- UV/EUV hidden by ISM so can't easily see peak of disc



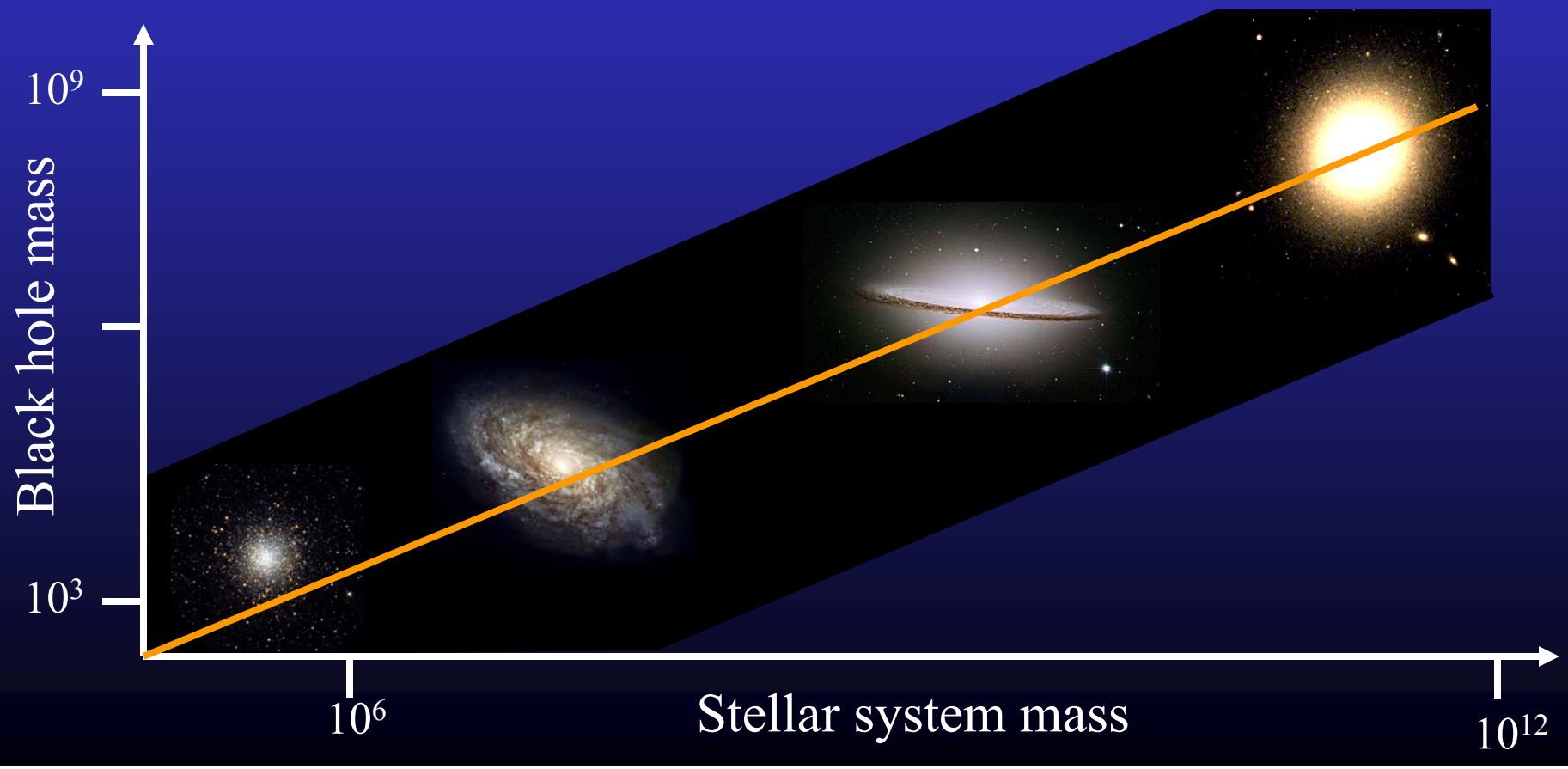
AGN spectral states

- Stretched out by lower disc temperature so states not so obvious as in BHB but still….
- …AGN NOT all the same underneath absorption as in simplest unified models!! Their SED should depend intrinsically on L/L_{Edd} in same way as BHB
- So need to know AGN mass in order to calculate L_{Edd}

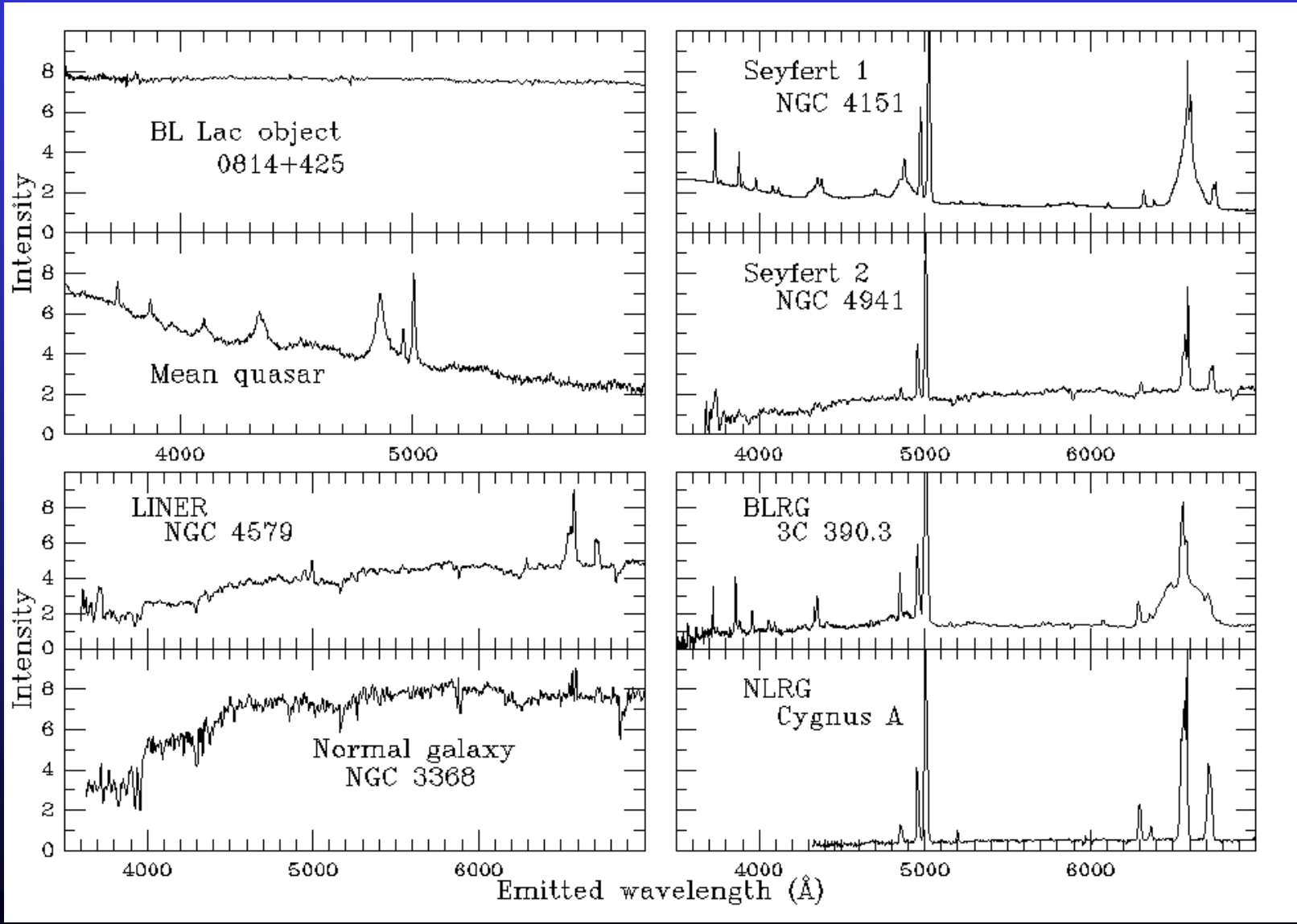


Mass of AGN??

- Magorrian-Gebhardt relation gives BH mass!! Big black holes live in host galaxies with big bulges! Either measured by bulge luminosity or bulge mass (stellar velocity dispersion)
- Plus scaling relations for BLR in AGN (Kaspi et al 2000)



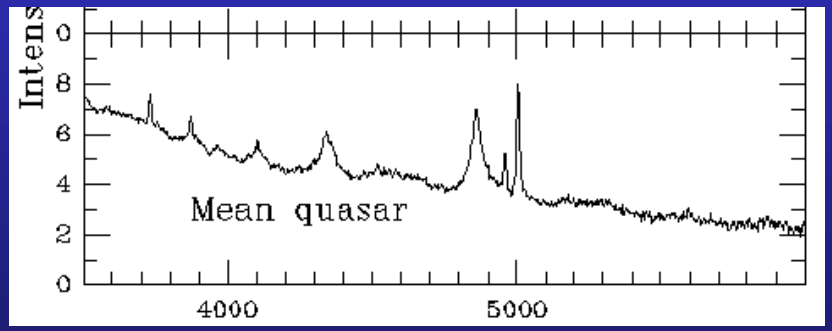
AGN/QSO Zoo!!! Optical

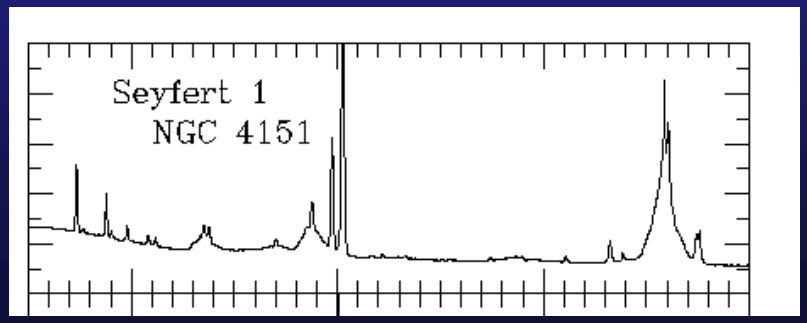


Seyfert 1 - Quasars

Similar spectra and line ratios,
strong UV flux to excite lines,
probably similar $L/L_{Edd} \sim 0.1\text{-}0.3$

Increasing L

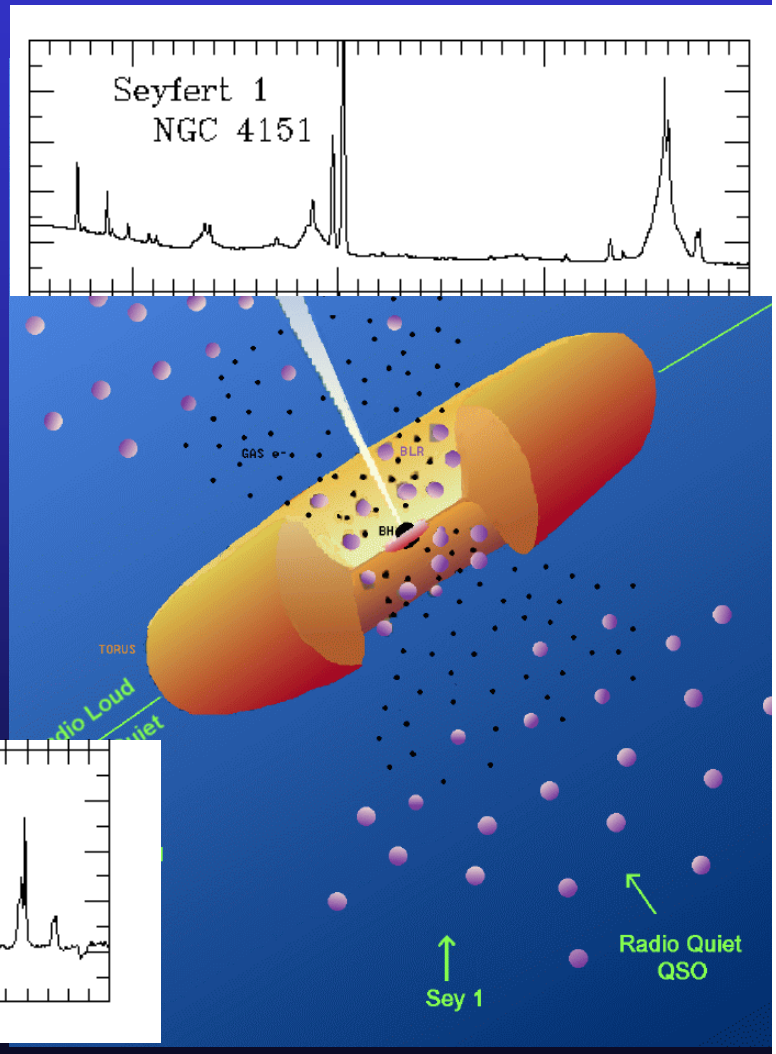


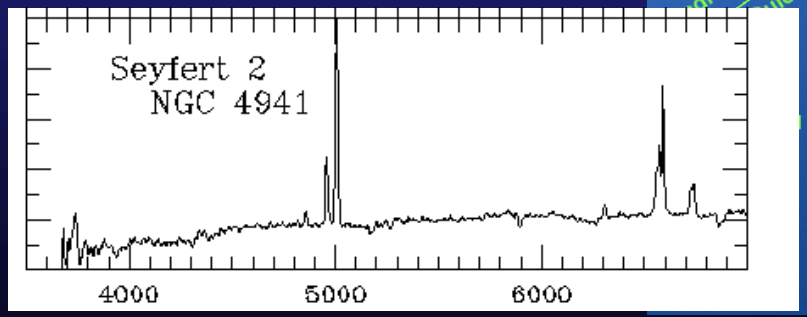


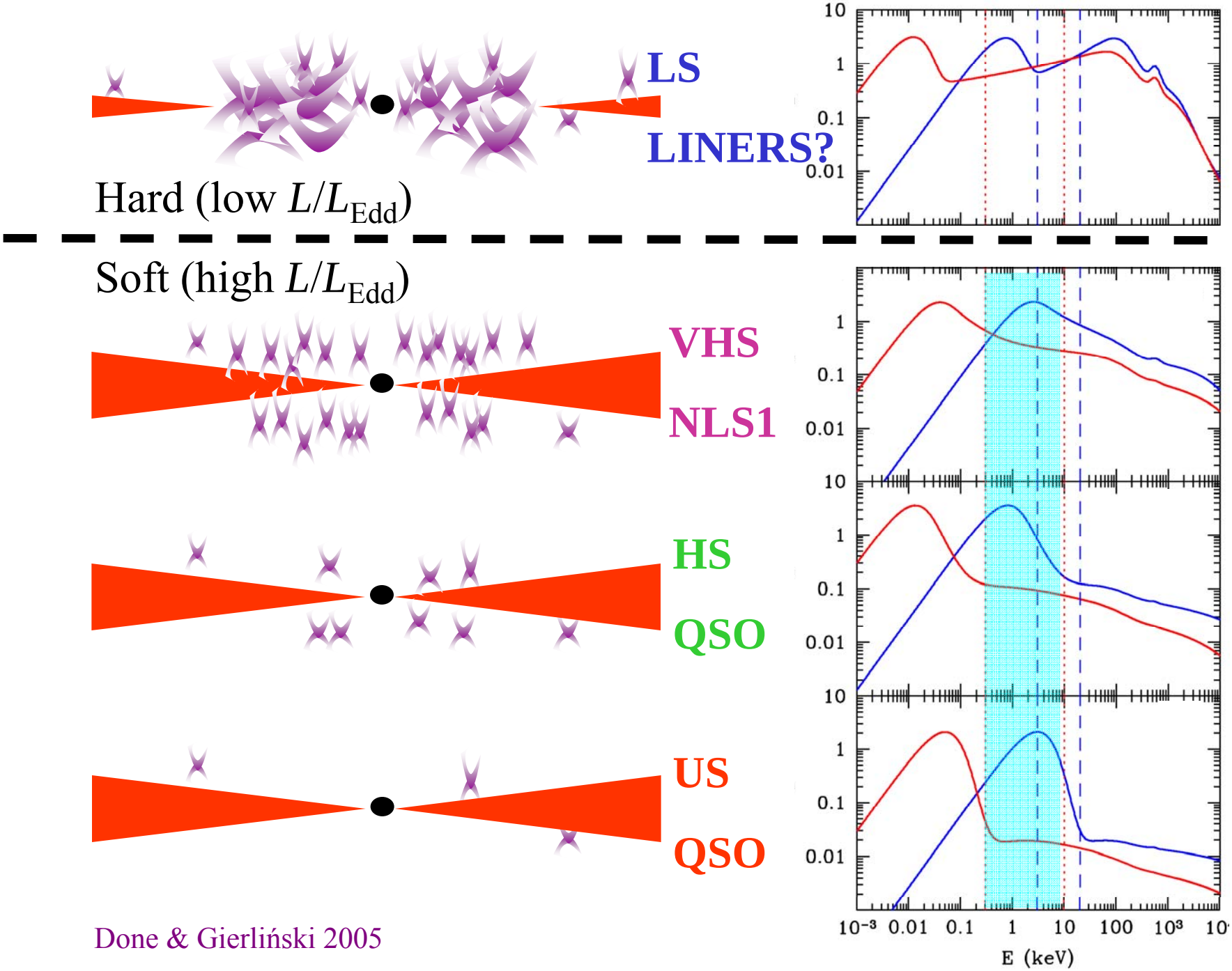
Increasing M

Seyfert 1 – Seyfert 2

- Intrinsically same except for obscuration
- But differences in HIGH energy spectra (20-200 keV). S1's softer than S2's – but also have higher $<L/L_{Edd}>$ than S2 sample so same correlation as in BHB - softer when higher L/L_{Edd} in LHS (Middleton, Done & Schurch 2008; Winter et al 2009)



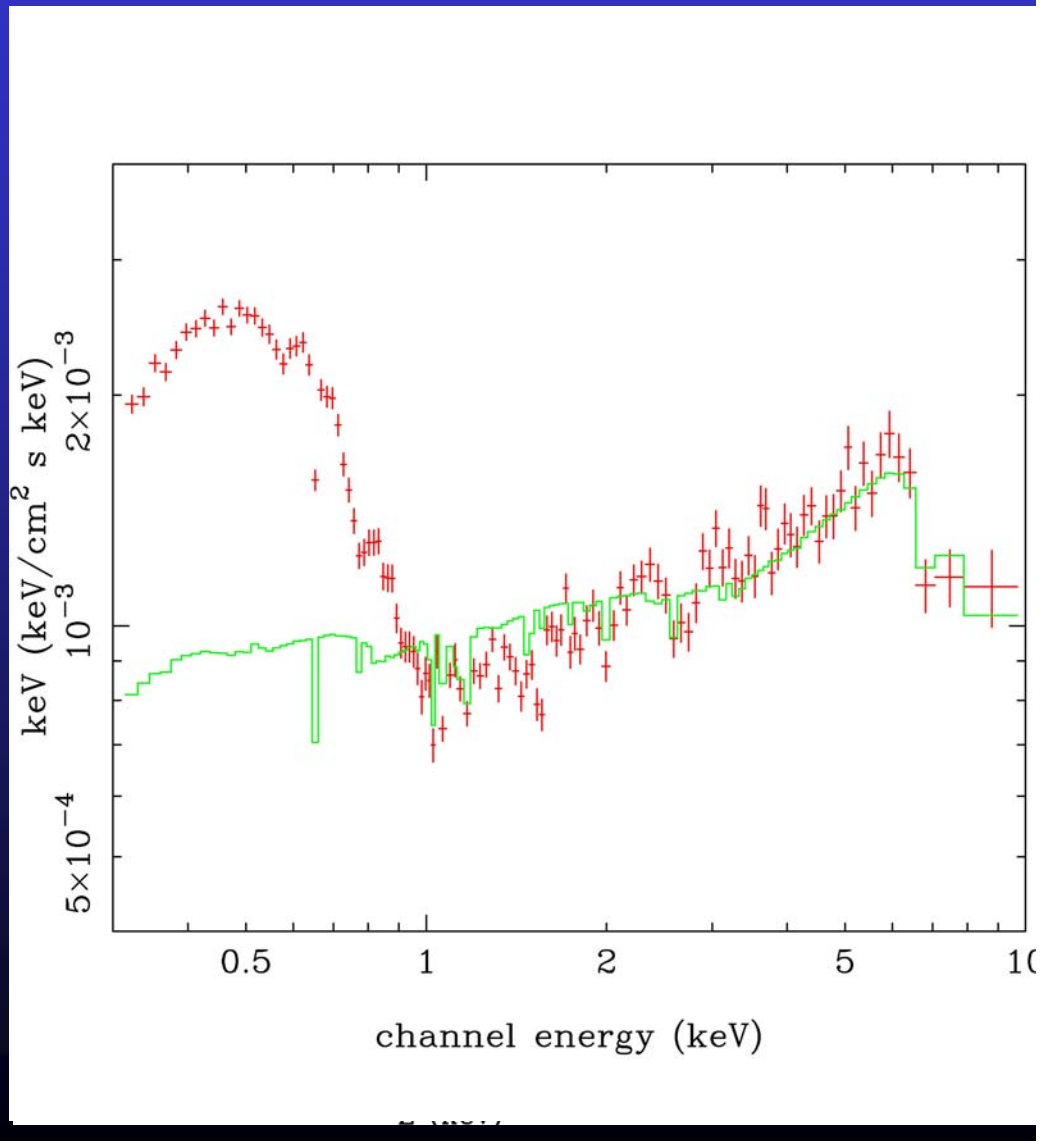




Done & Gierliński 2005

Implications for high L/L_{Edd}

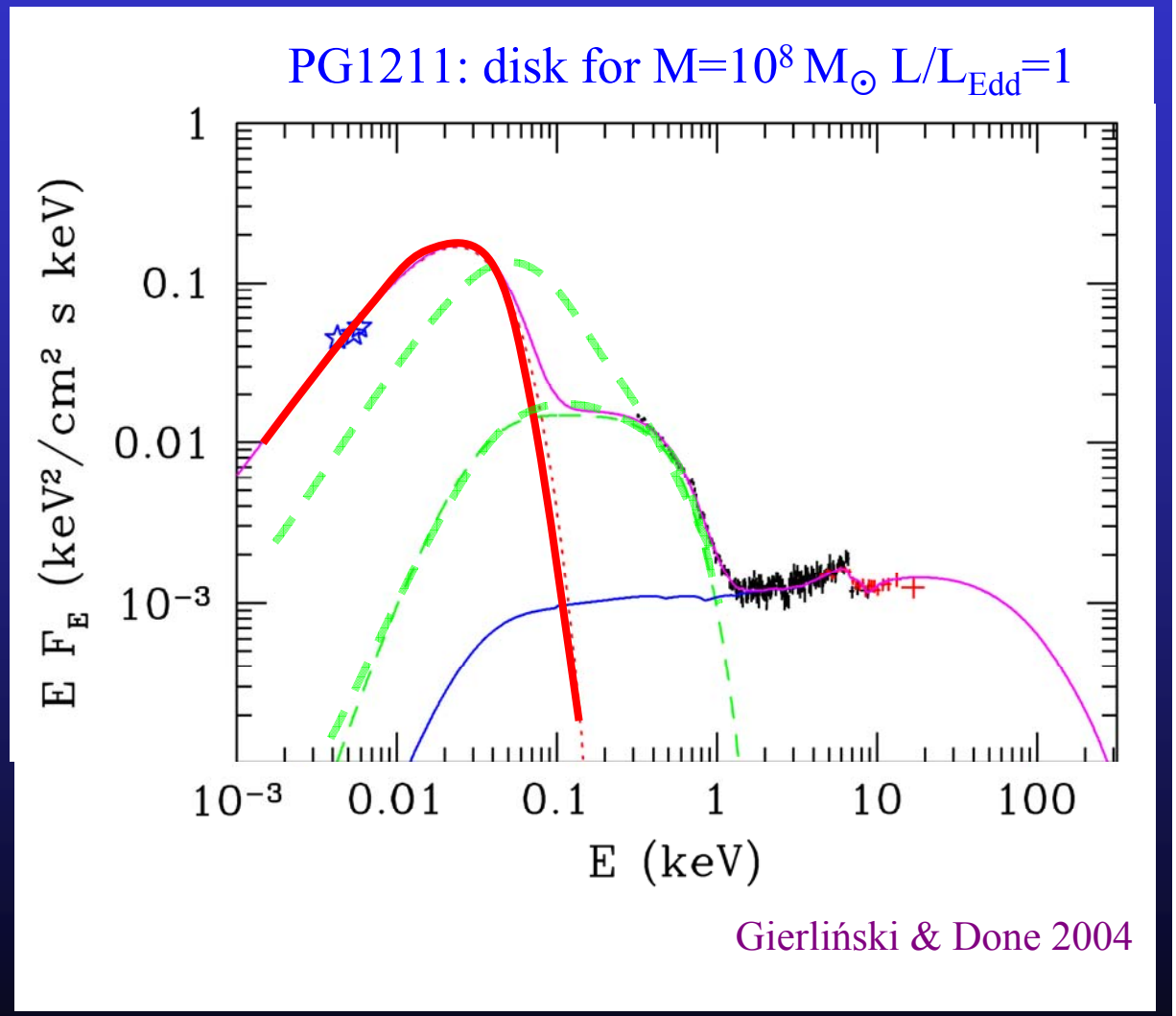
- High L/L_{Edd} objects easy to find. Typically most PG QSO's have $L>0.05\ L_{Edd}$
- For these, soft excesses should be very rare in XMM bandpass. When seen they should be very steep, and low temperature
- Power law at high energies should be steep, Γ=2-2.5
- PG1211- what not to see! Strong soft excess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



Soft excess? NOT from the disc!

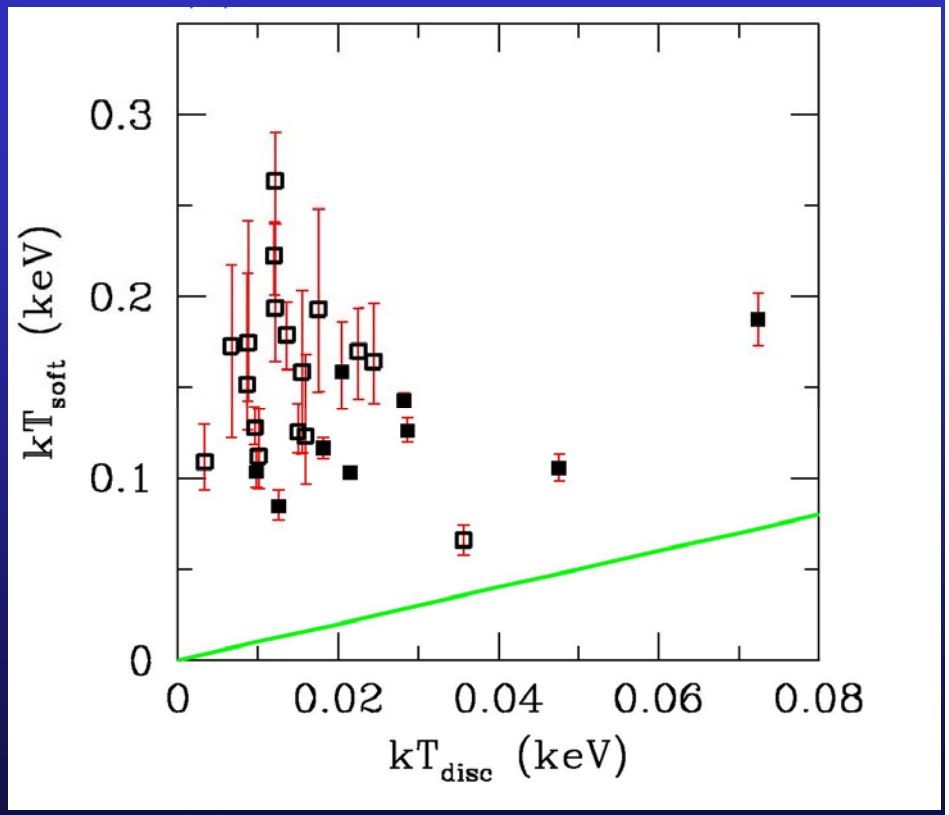
- NOT THE DISC - doesn't get close to rise in data at 1keV
- unless extreme spin and/or modified by advection – but disc tail very steep while SX gradual
- Compton scattering of disc by low T_e, high τ material?

Magdziarz et al 1998, Czerny et al 2003



NOT from Comptonisation

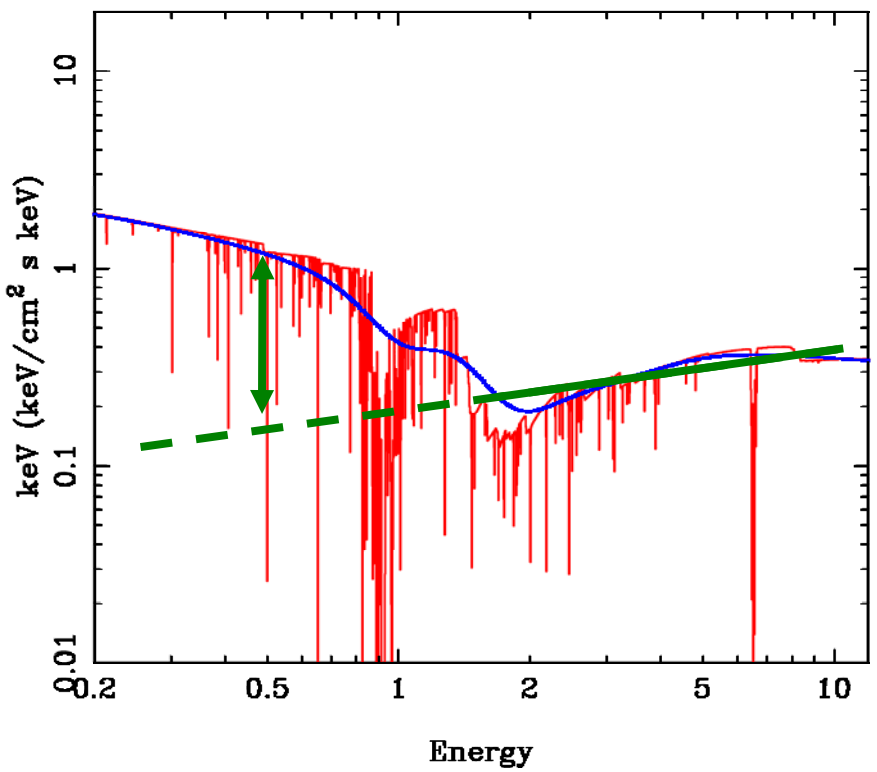
Gierlinski & Done 2004



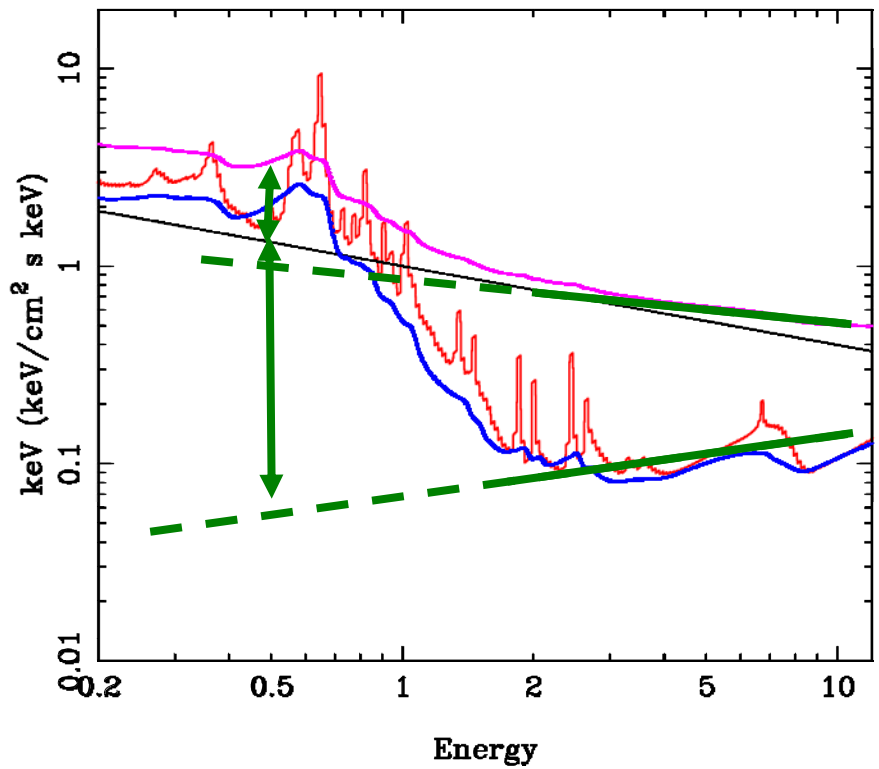
- ALL need soft excess
- Fit with comptonisation...
- ALL have same kT_e for soft excess!! Yet big range in expected disc kT (mainly M)
  Walter & Fink 1993, Czerny et al 2003, Gierlinski & Done 2004, Crummy et al 2006
- Expect electron temperature to change if seed photons from disc change – different efficiency of Compton cooling
- NOT COMPTON SCATTERING

Partially ionised, relativistic material

- Opacity jump at OVII/VIII at 0.7 keV: fixed energy
- Atomic features not seen so relativistic smearing sometimes extreme
- Reflection: needs intrinsic power law suppressed for large SX
- Absorption: larger SX by larger column, curvature gives red wing



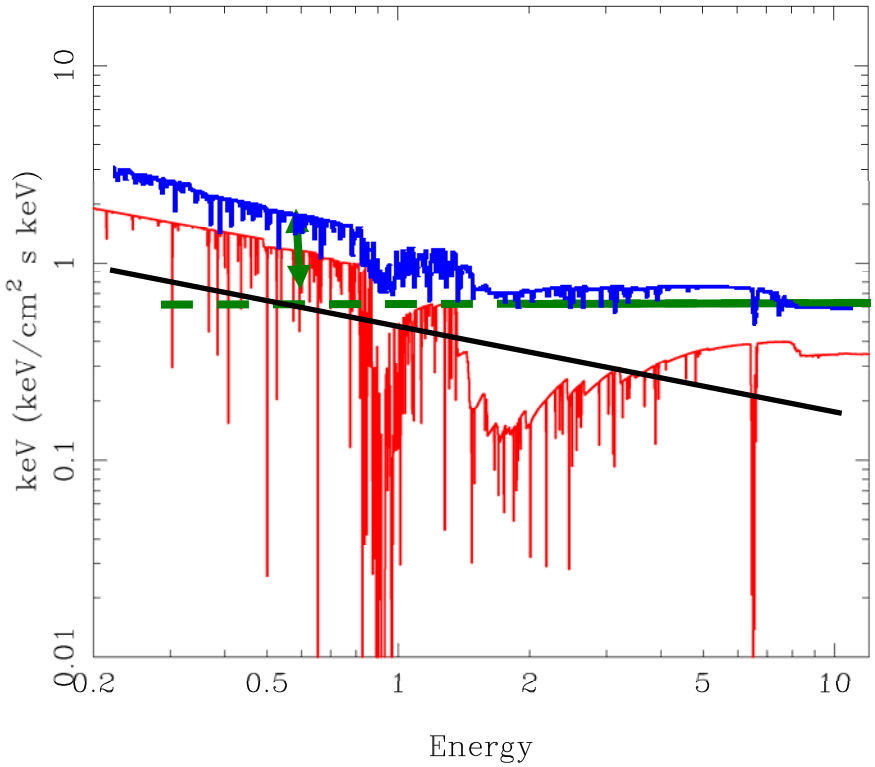
Gierliński & Done 2004, Chevallier et al 2006



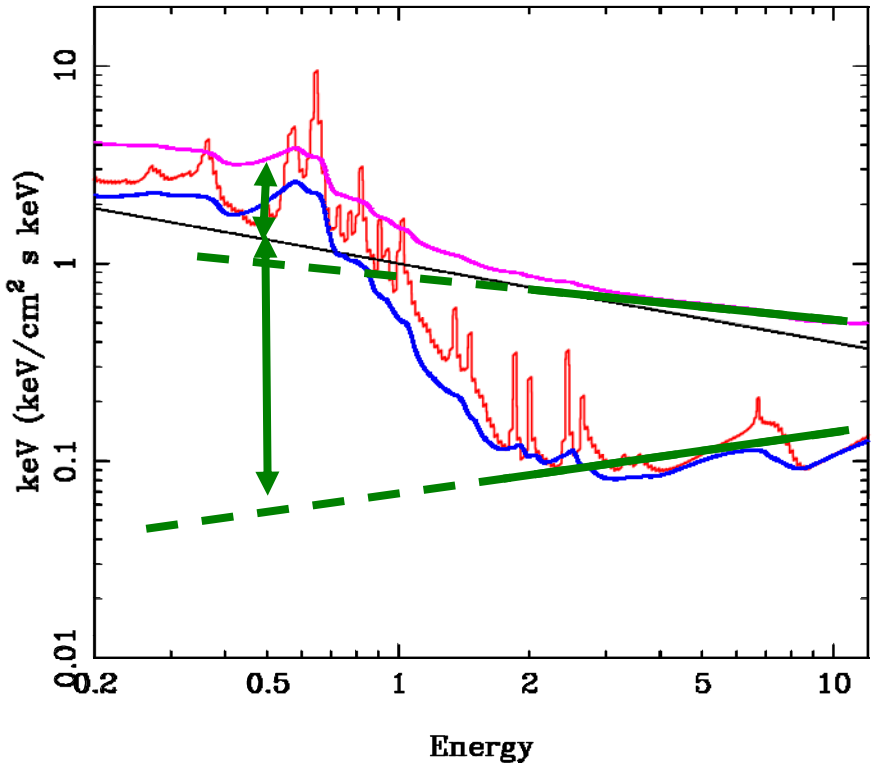
Fabian et al 2002; 2004 Miniutti & Fabian 2004

Partially ionised, partial covering

- Opacity jump at OVII/VIII at 0.7 keV: fixed energy
- Atomic features not seen due to dilution by unabsorbed flux
- Absorption: curvature gives red wing



Inoue 2002; Miller et al 2007; 2008; Turner et al 2007



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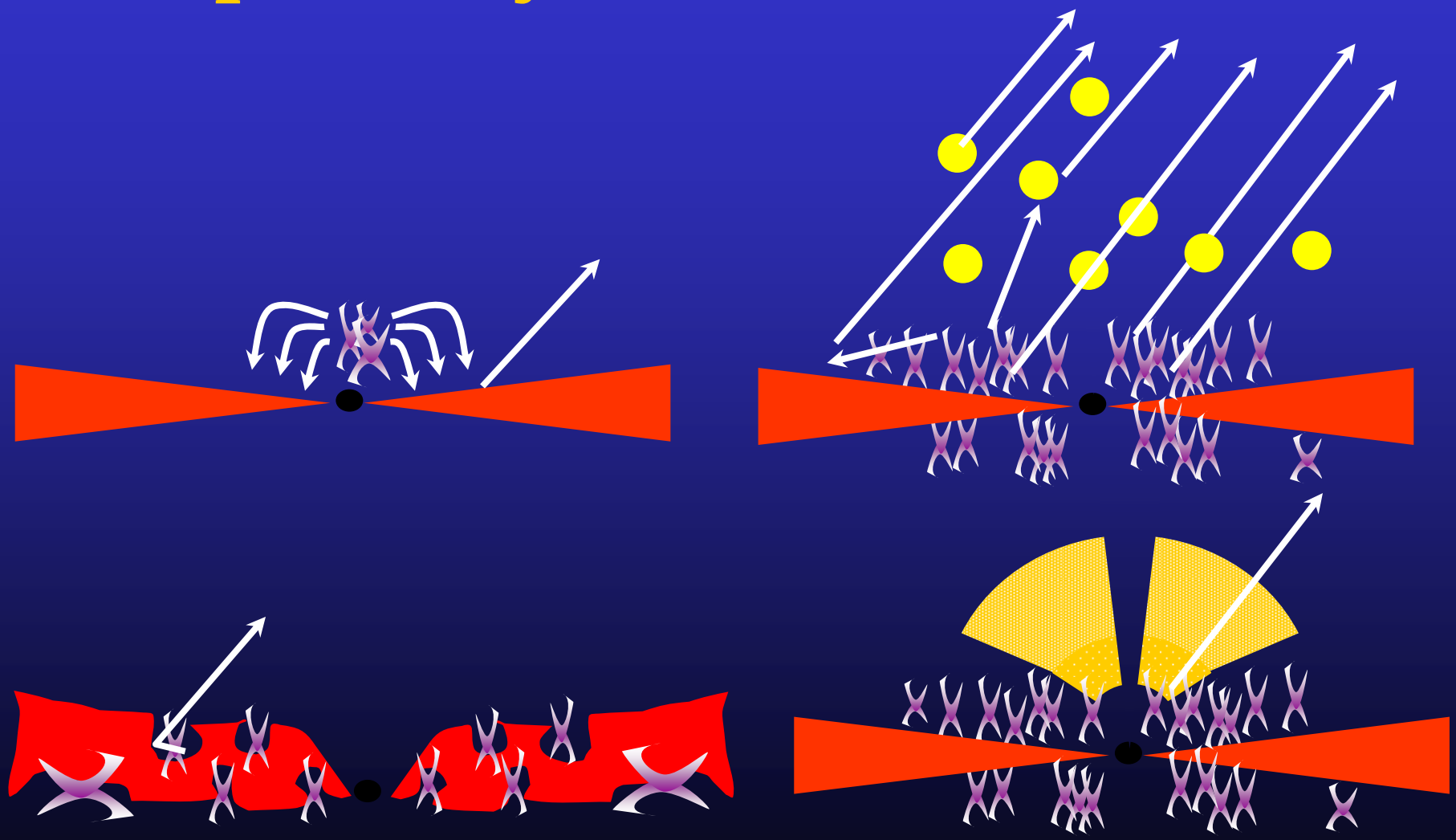
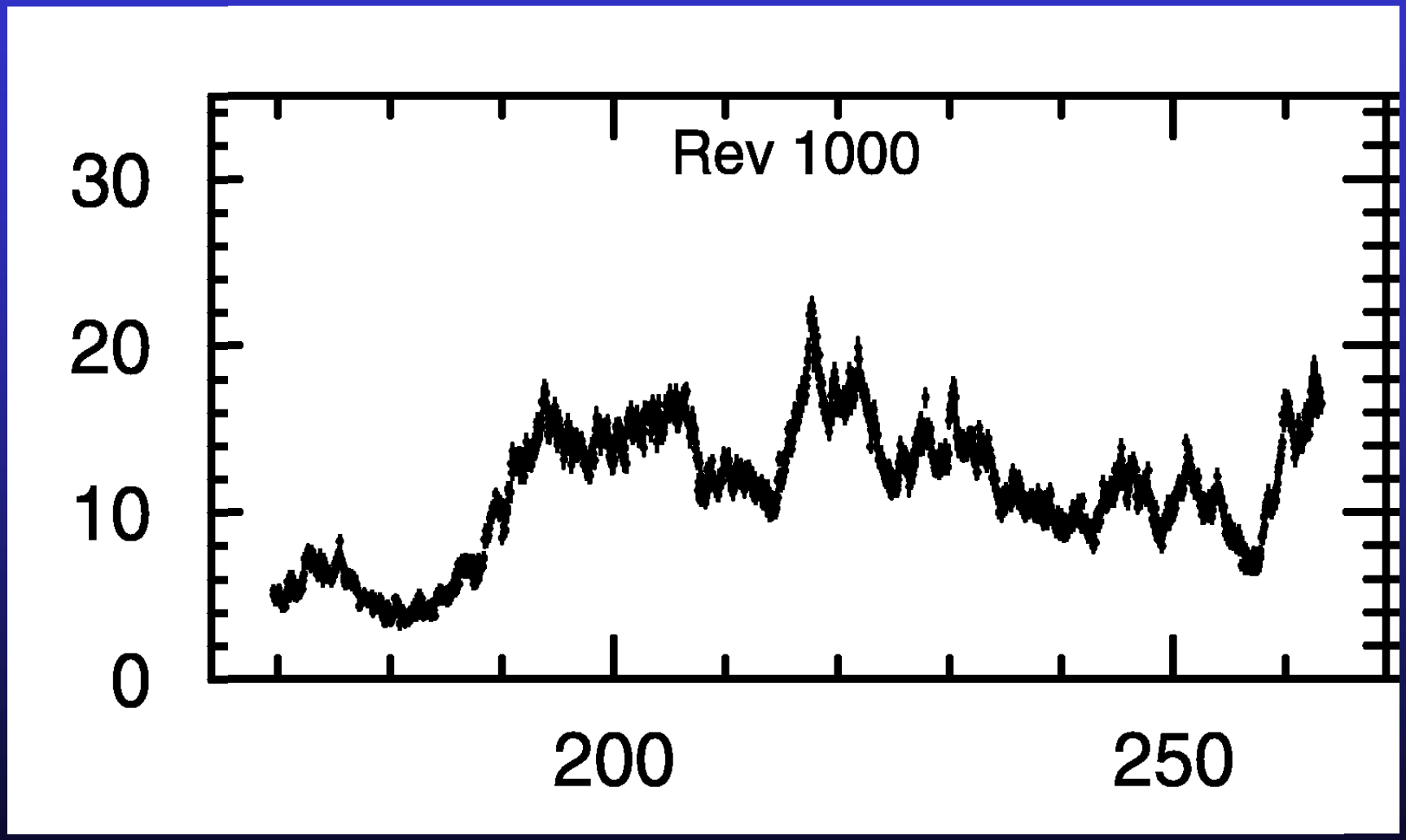
Alternative geometries for soft excess from partially ionised material



Reflection

Absorption

More soft excesses in AGN



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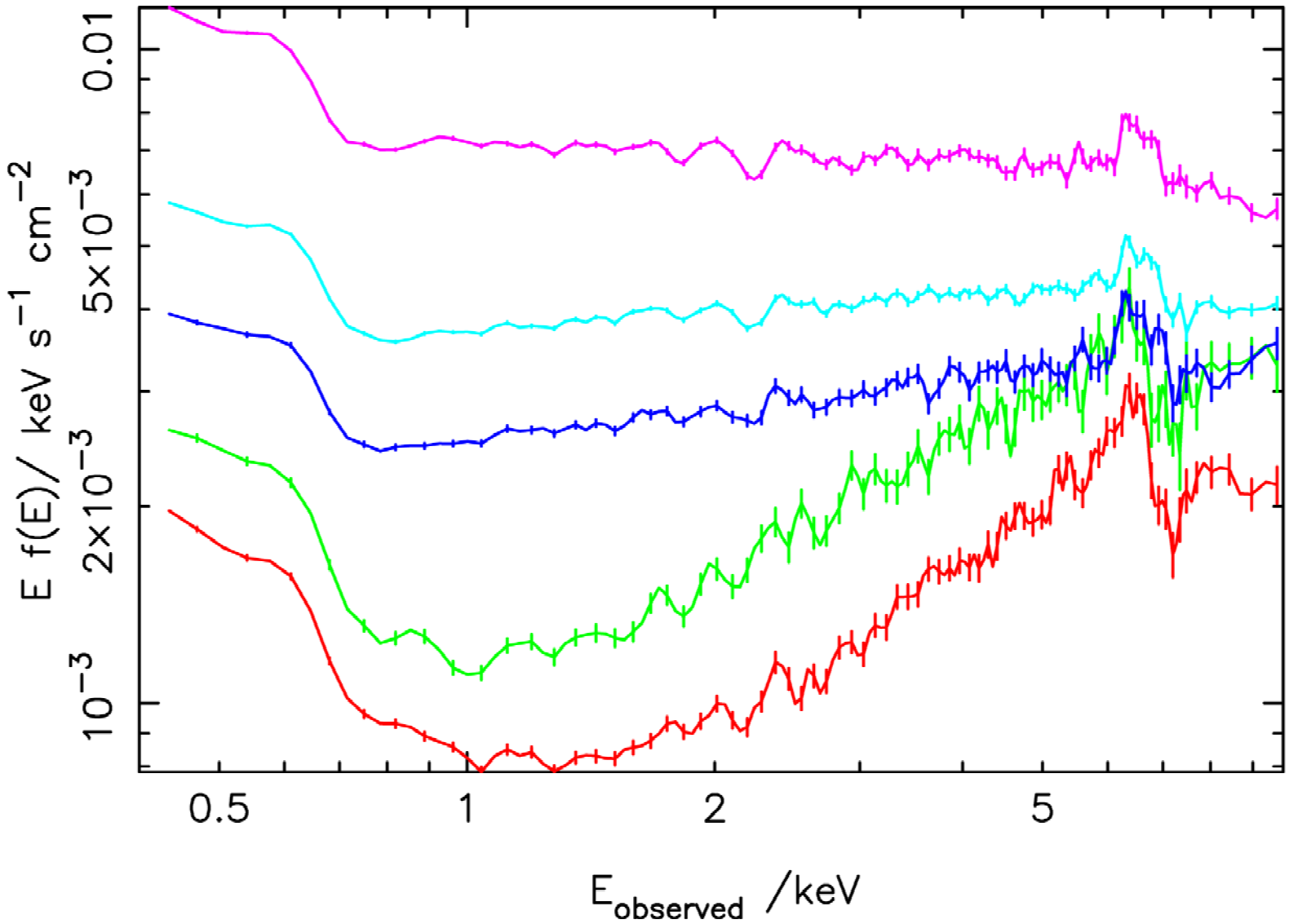

Miller et al 2007, Miller et al 2008

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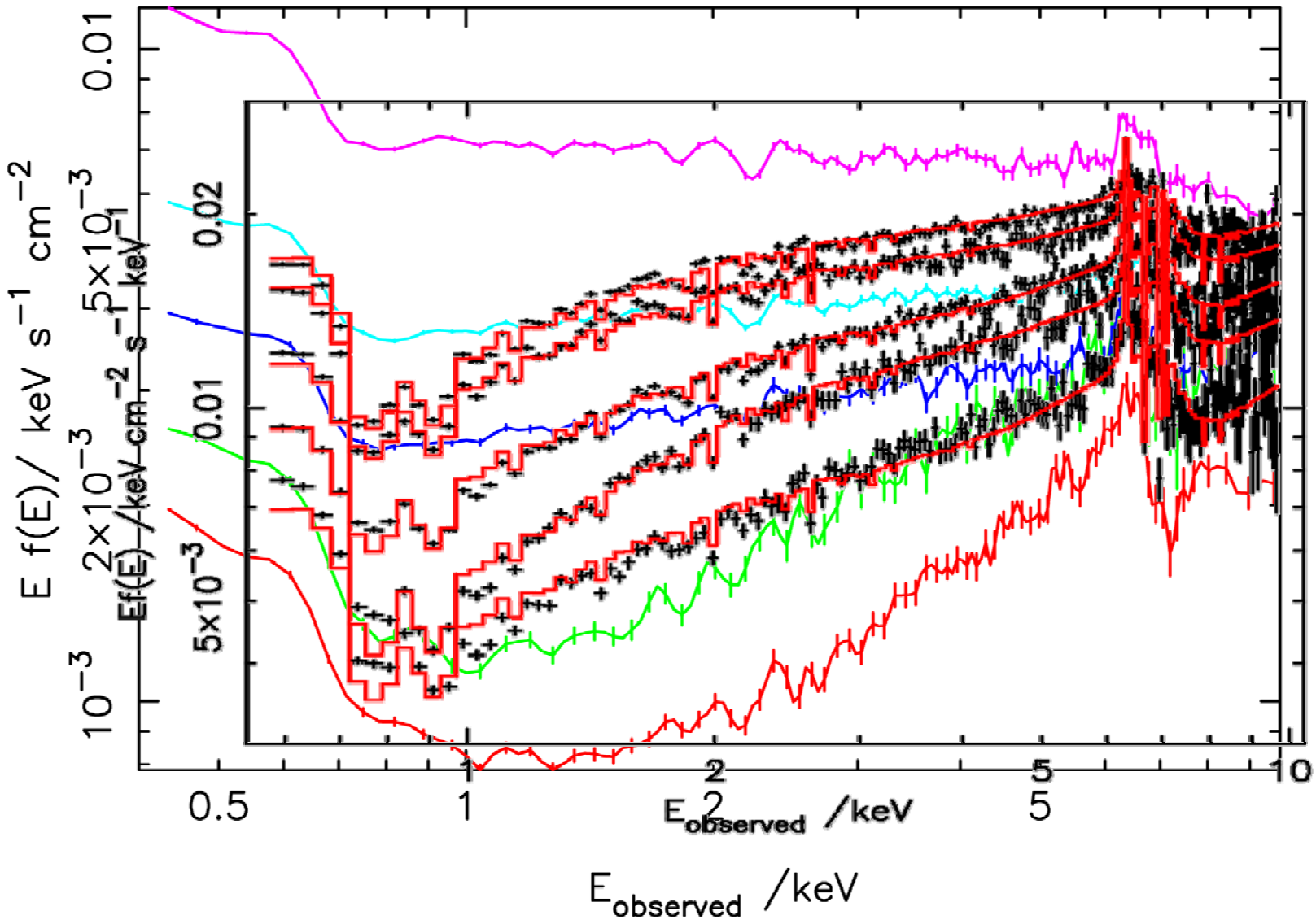

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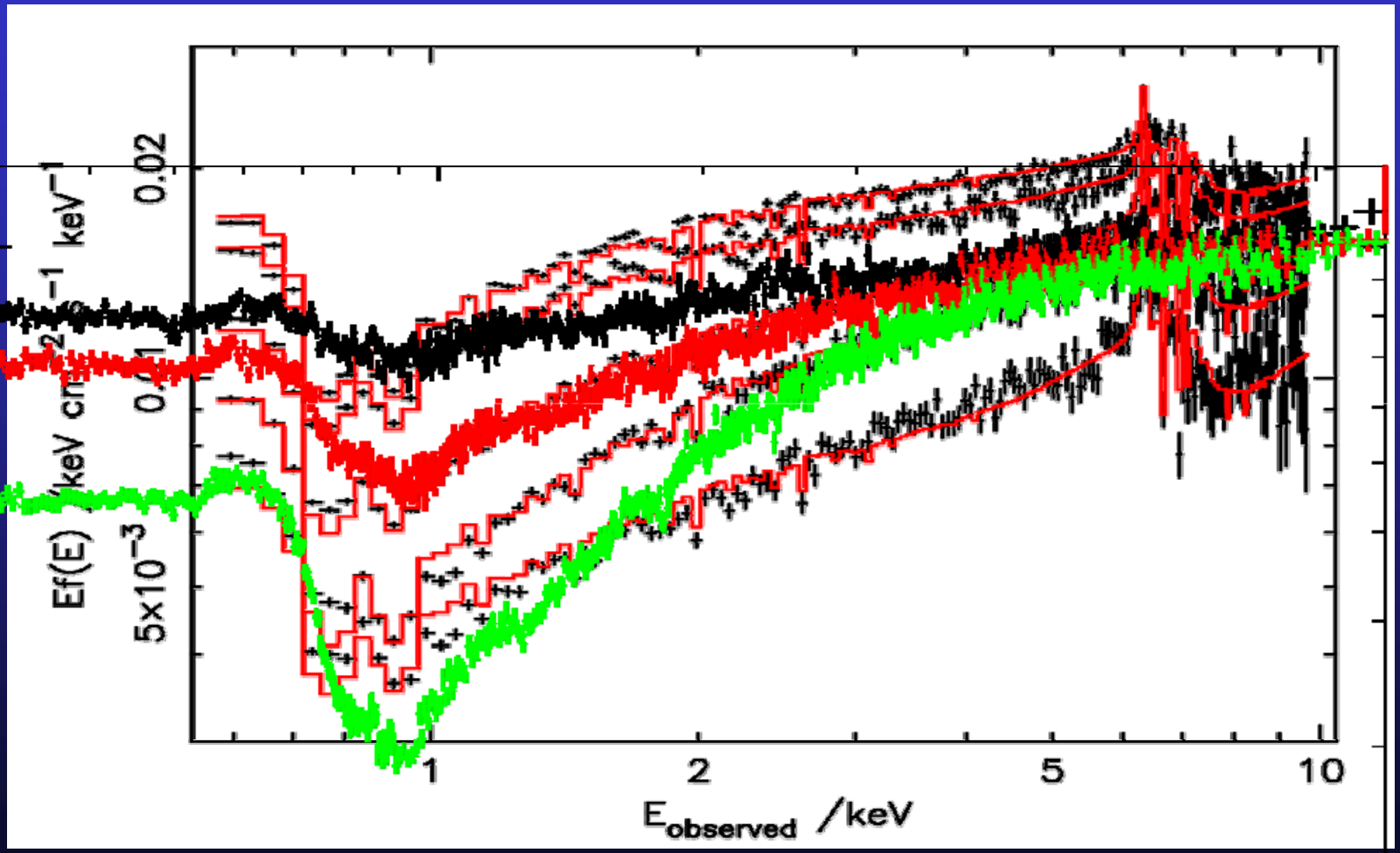
More soft excesses in AGN



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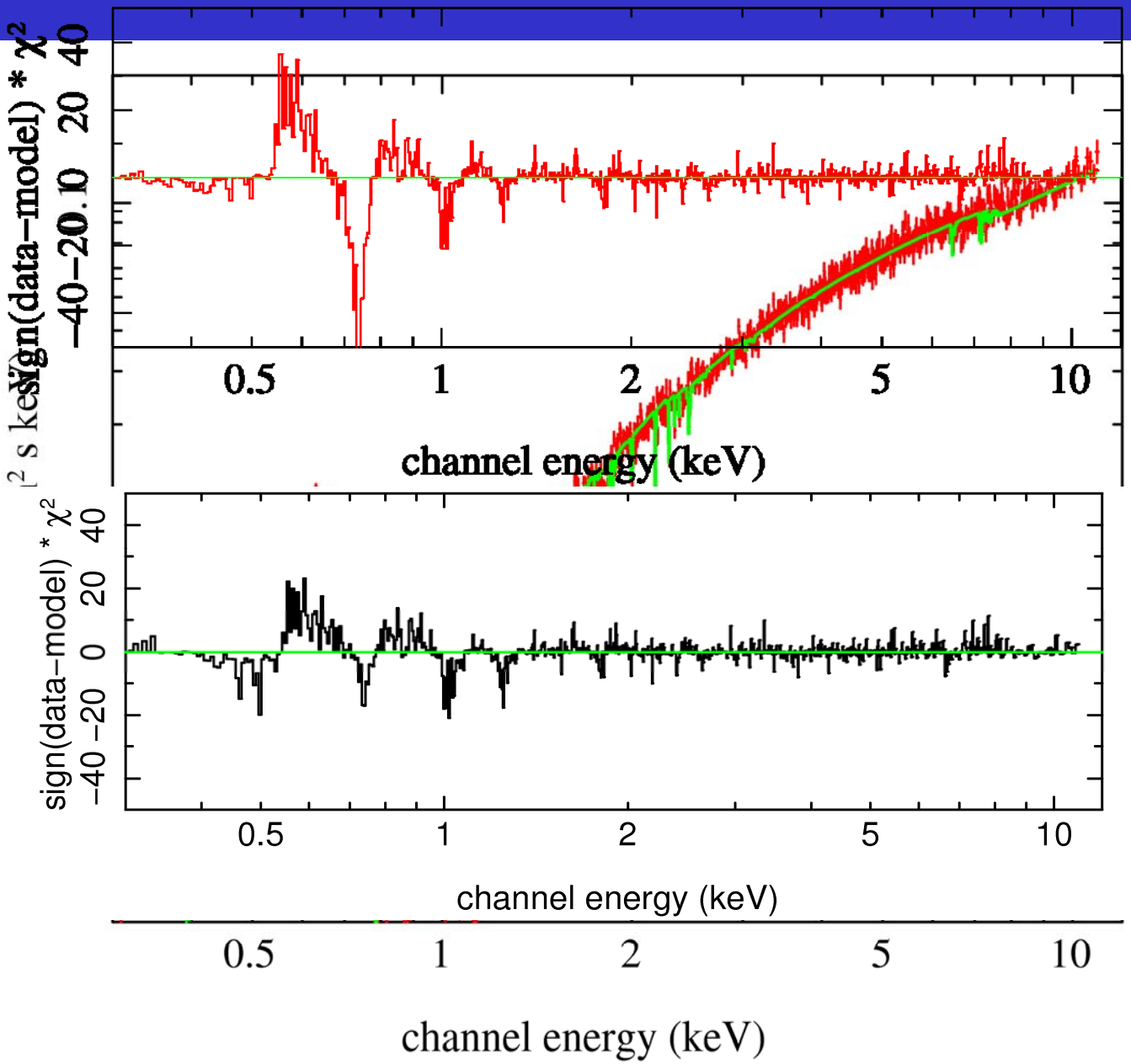
sign(data−model) * χ²
40
20
0
−20
−40
0.5
1
2
5
10
channel energy (keV)
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40
20
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10
channel energy (keV)
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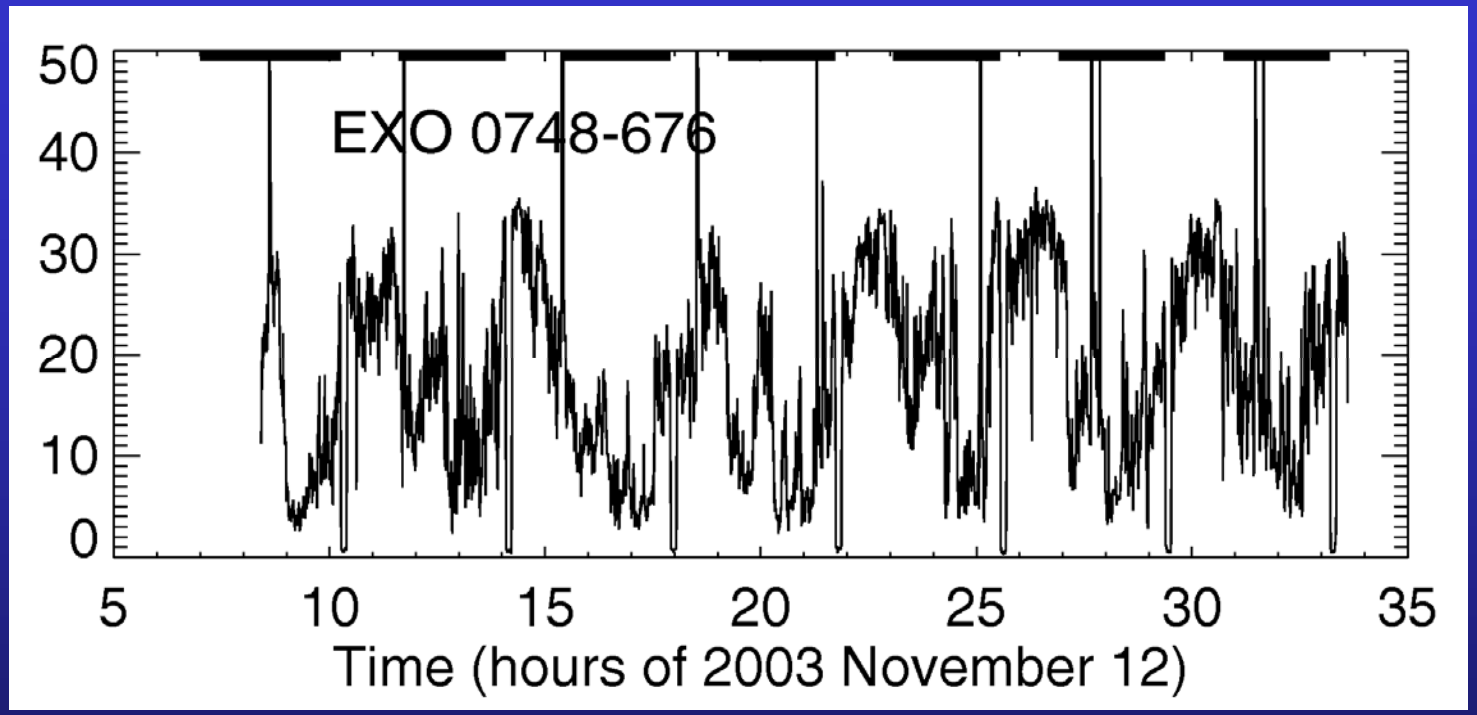
But this was a dipper!!!

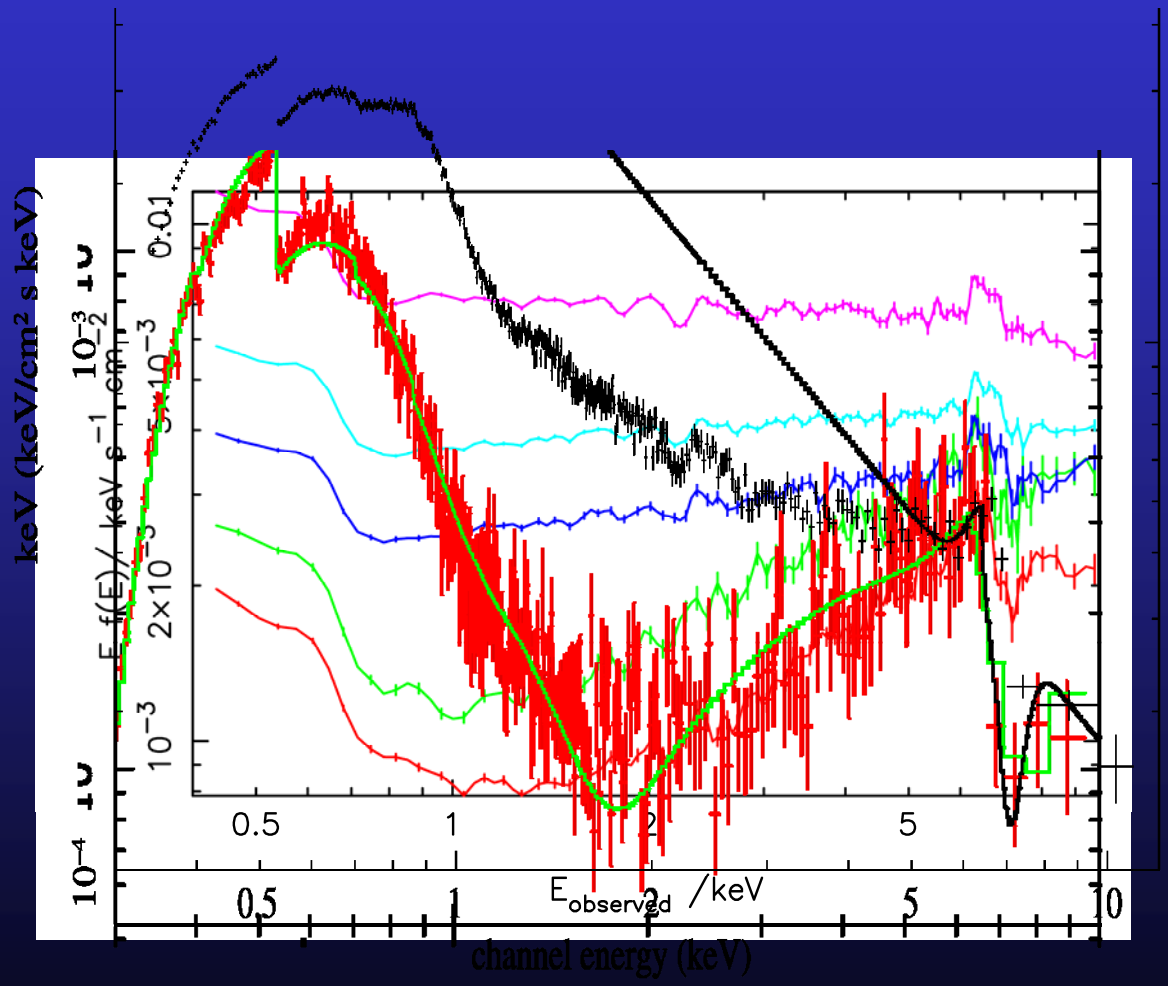


Diaz-Trigo et al 2006

- Neutron star binary at high inclination
- Phase dependent complex (photo and collisional ionsation) absorption needed for RGS data! Van Peet et al 2009
- Complexity (multiple pcf) doesn't rule it out!!!

1H0707-495: iron

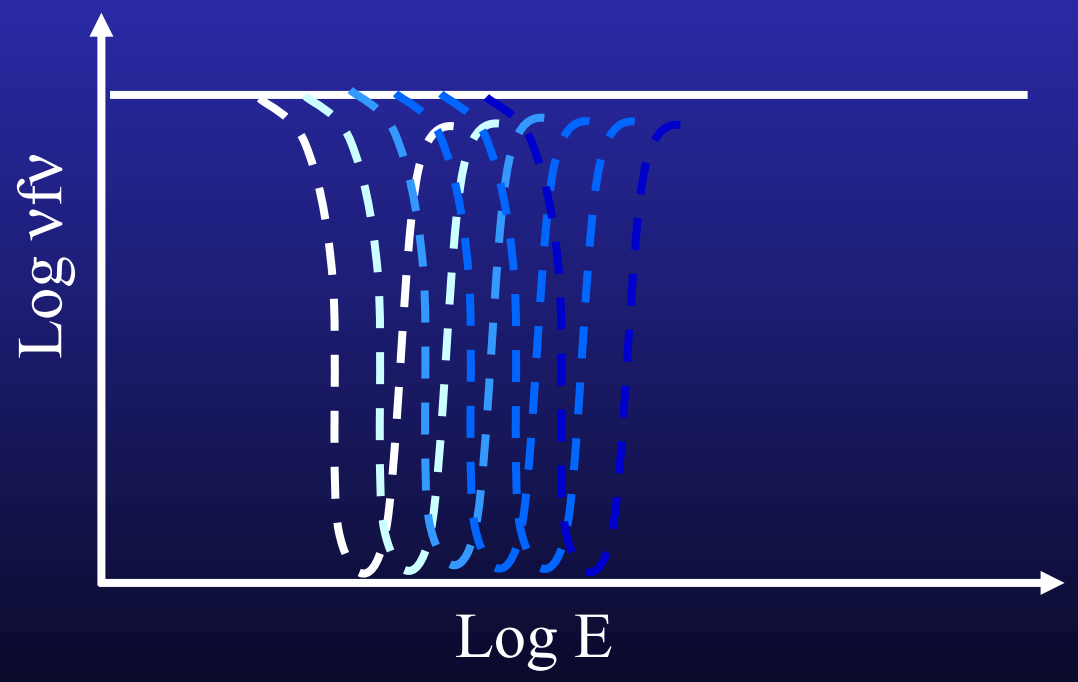
- Huge drop at iron K (plus huge SX)
- If absorption then should come out as line and if its not relativistic then it is narrow and easy to see! Reynolds et al 2009 But if it's a wind then its easy! P Cygni line profile is broad Sim 2005; Sim et al 2008; Done et al 2008
- Big feature at iron L in the data though !!!



Miller et al 2007, Done st al 2008

Winds

- Most opacity in resonance lines
- Accelerating wind shifts energy of absorption so make notch…



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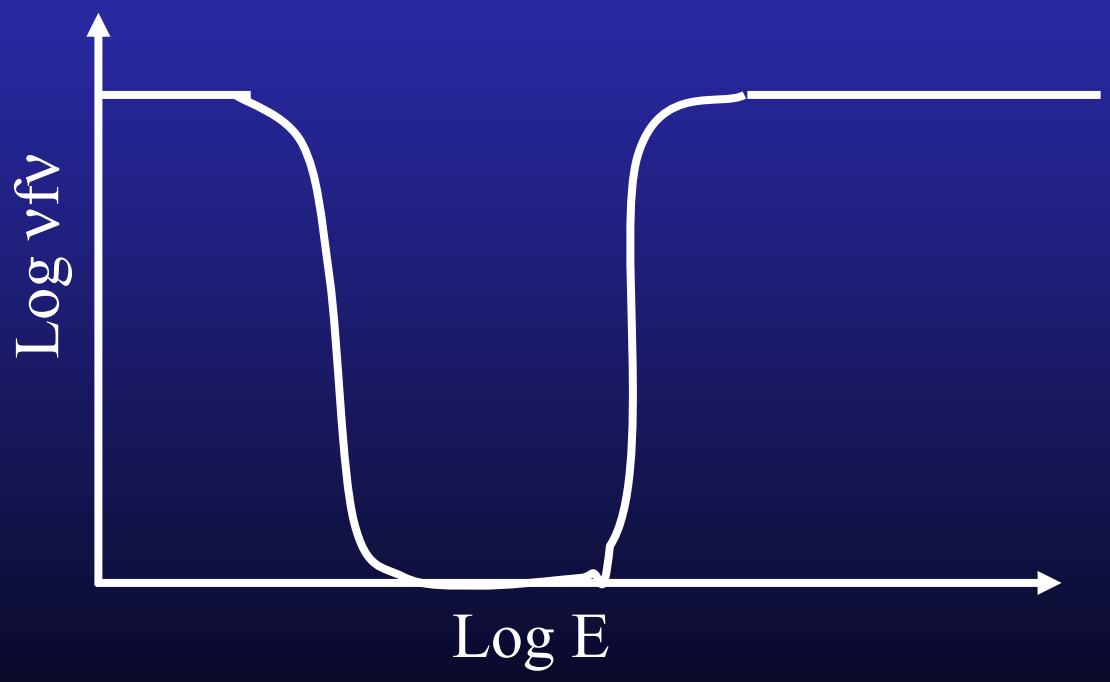
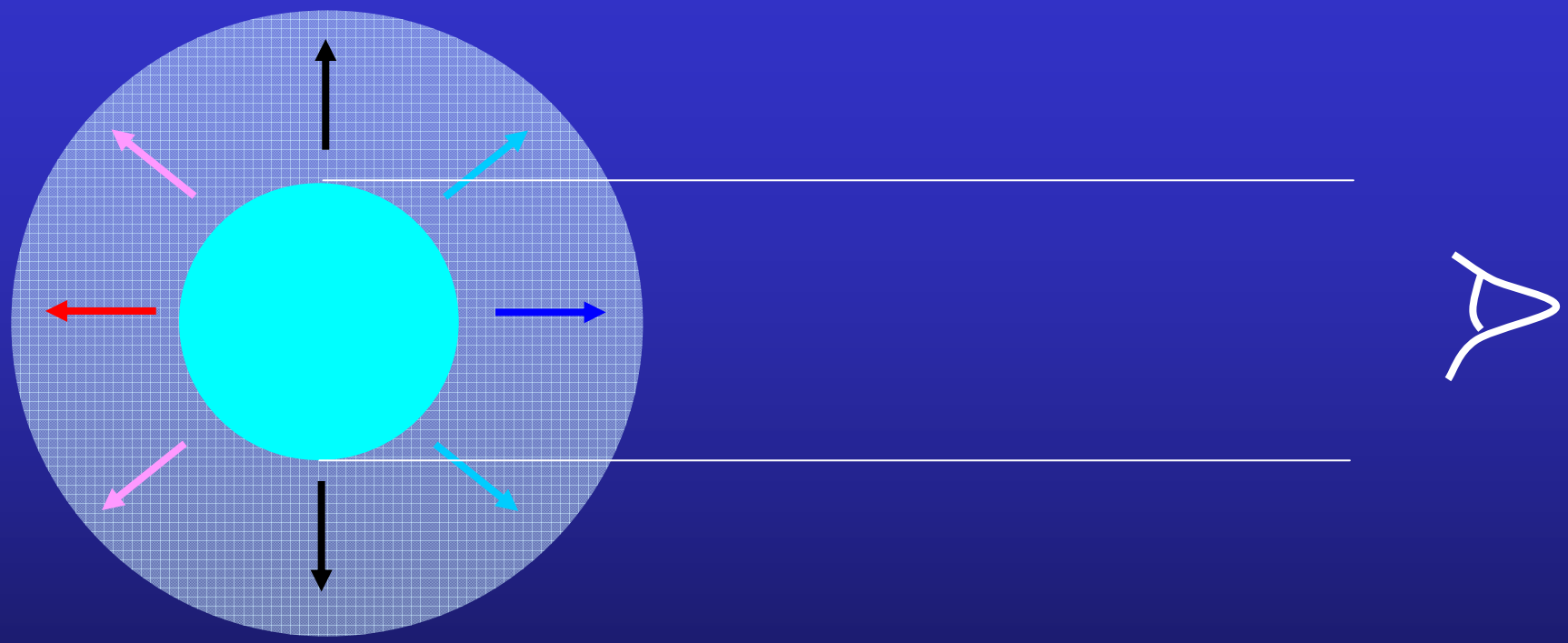


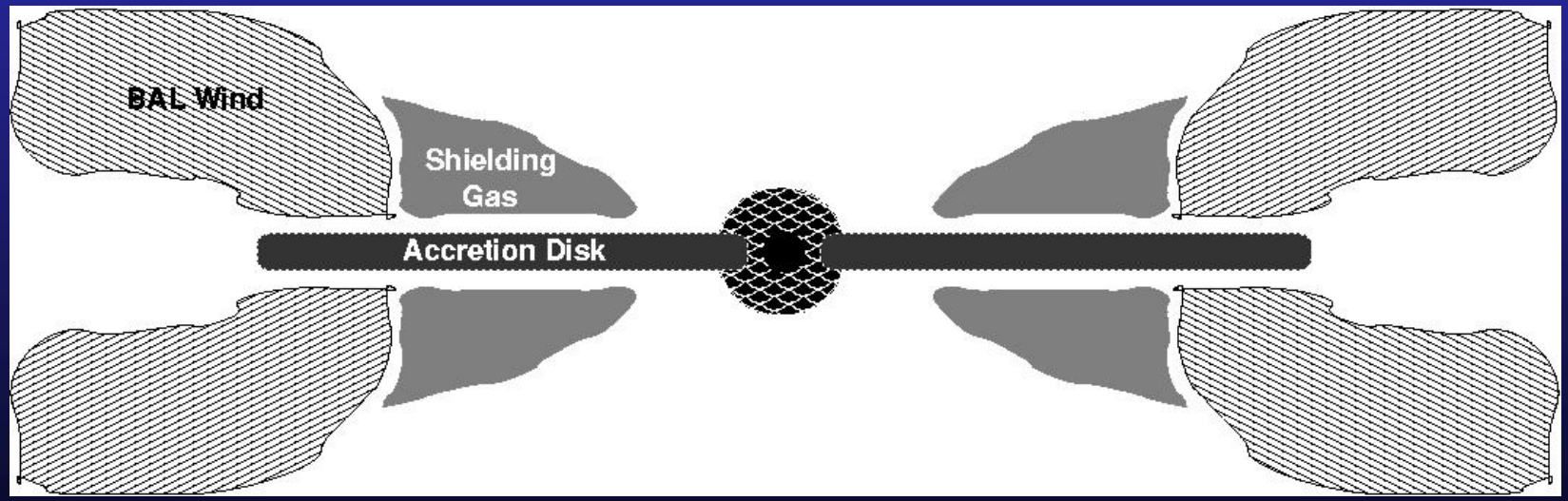
P Cygni line profiles



symmetric emission + blueshifted absorption = P Cygni profile

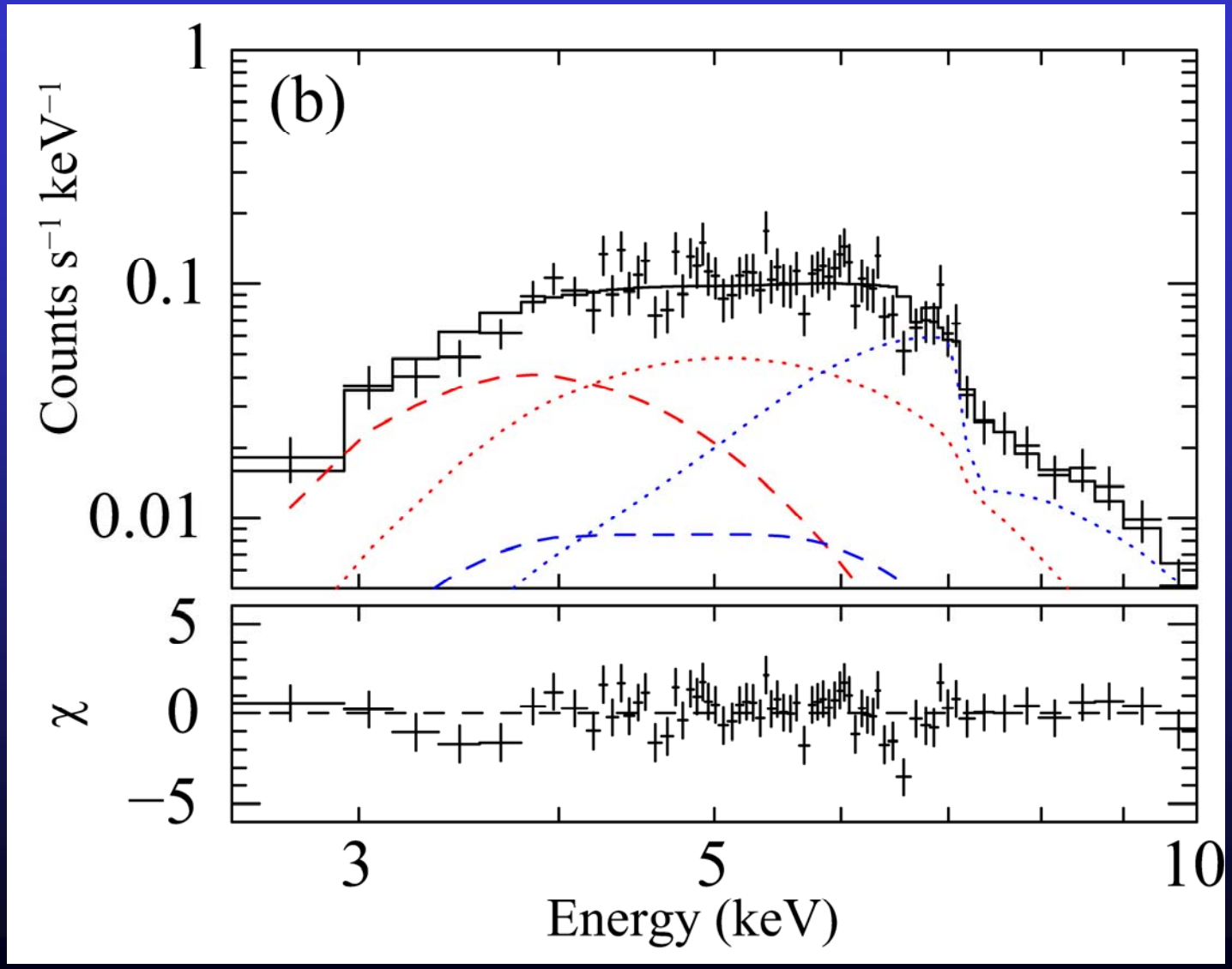
UV line driven Winds ?

- UV bright disc launches vertical wind. Rises up but then illuminated by central X-ray source which overionises it so that no UV transitions! Only X-ray lines and these don't absorb as much momentum $L_x << L_{UV}$
- BAL QSO need shielding gas Murray & Chiang 1996



Murray & Chiang 1996

Similar drop in deepest dips!!



Hyodo et al 2009

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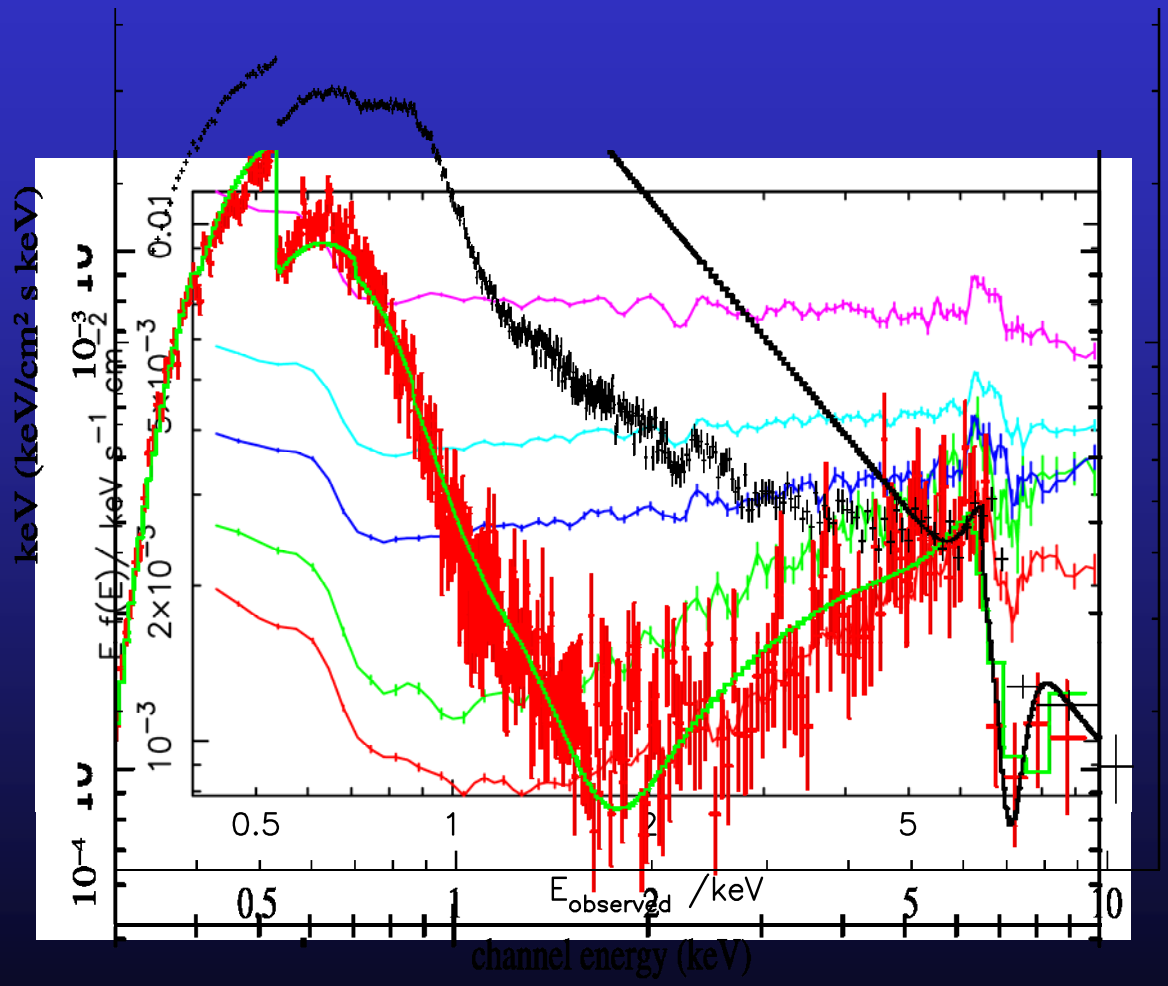
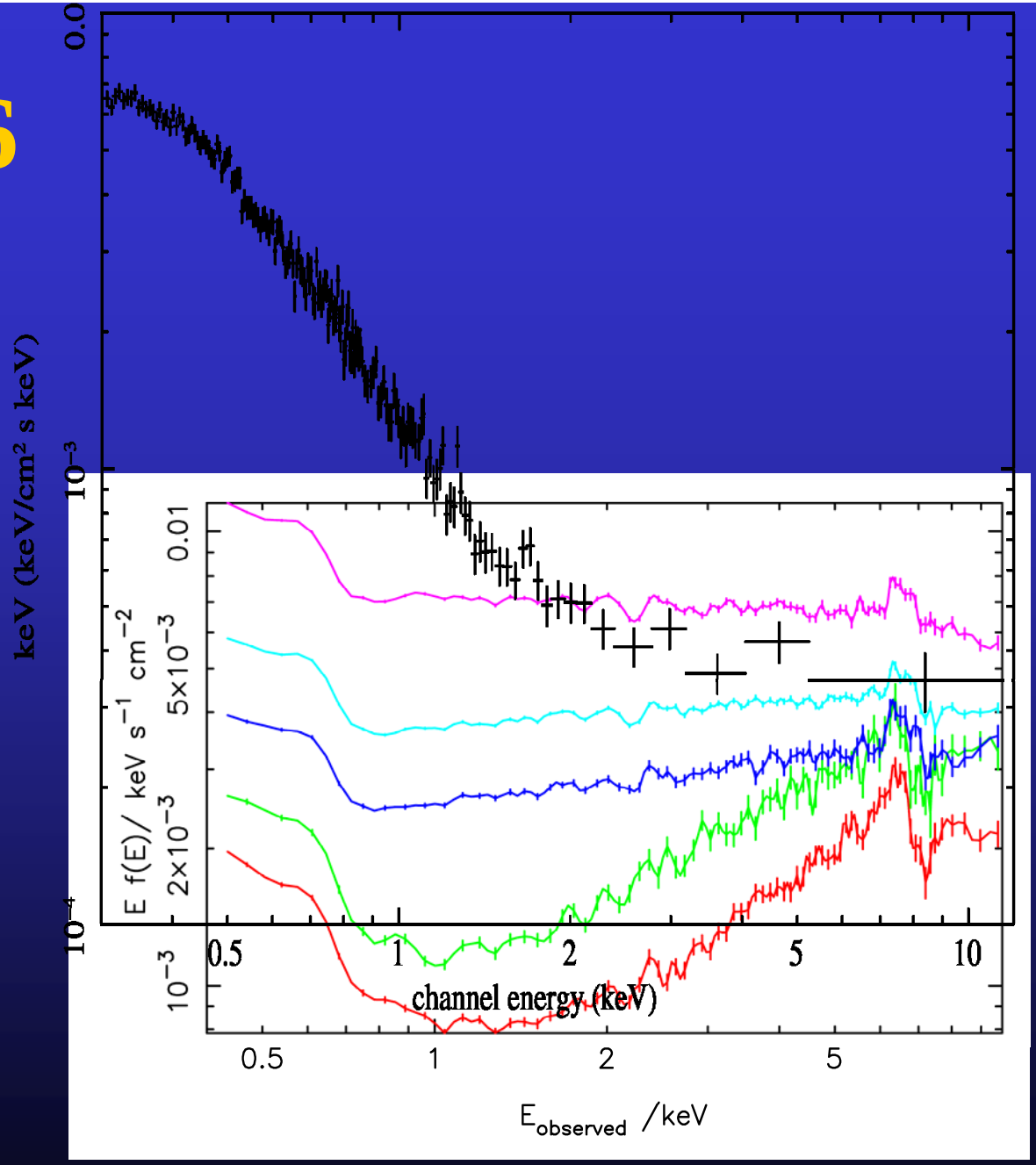


Miller et al 2007, Done st al 2008

RE1034+396

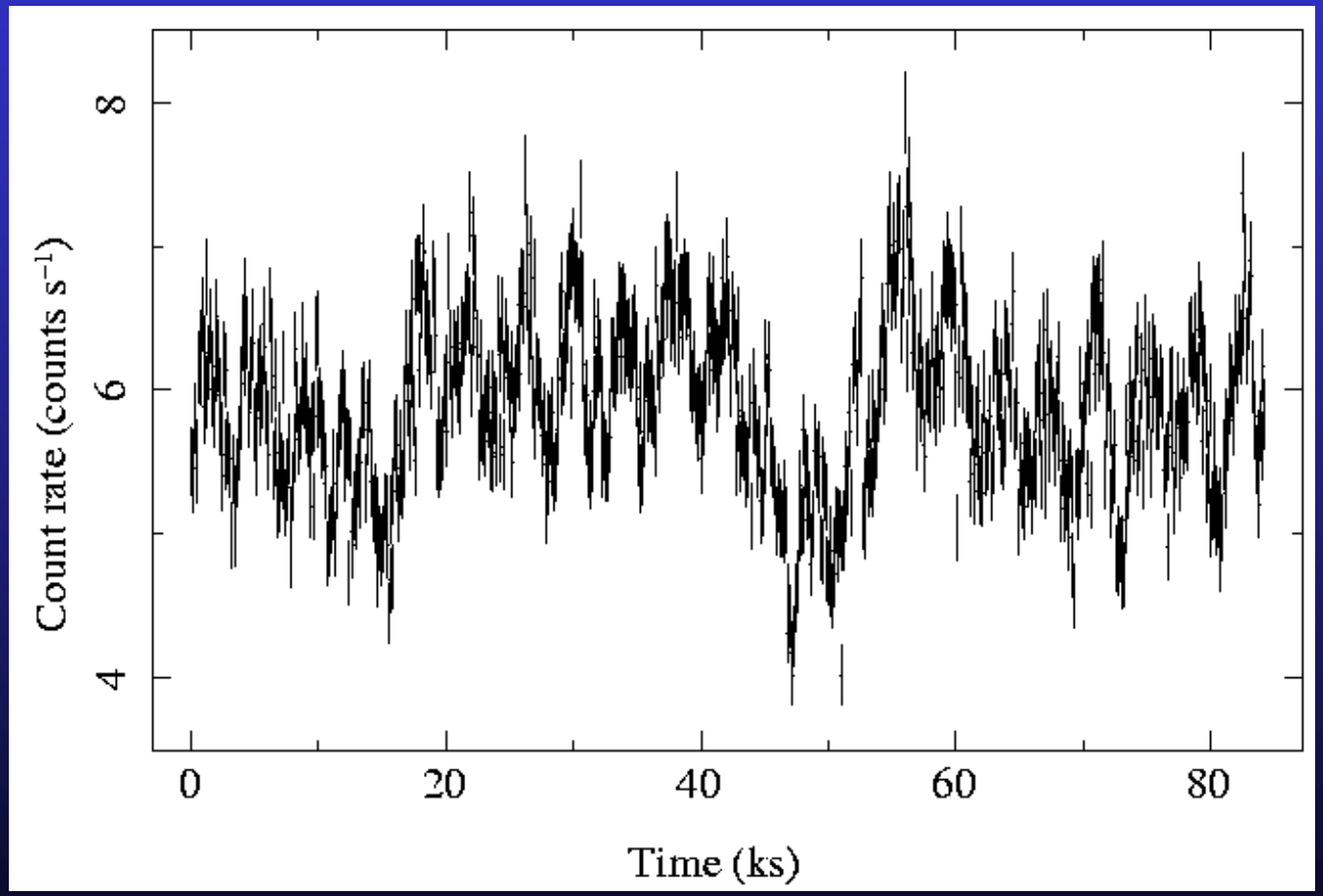
- Huge SX (similar size to softest 1H0707 spectra) and no clear drop at Fe…



Miller et al 2007 Middleton et al 2008

RE J1034+396: spot that period!!

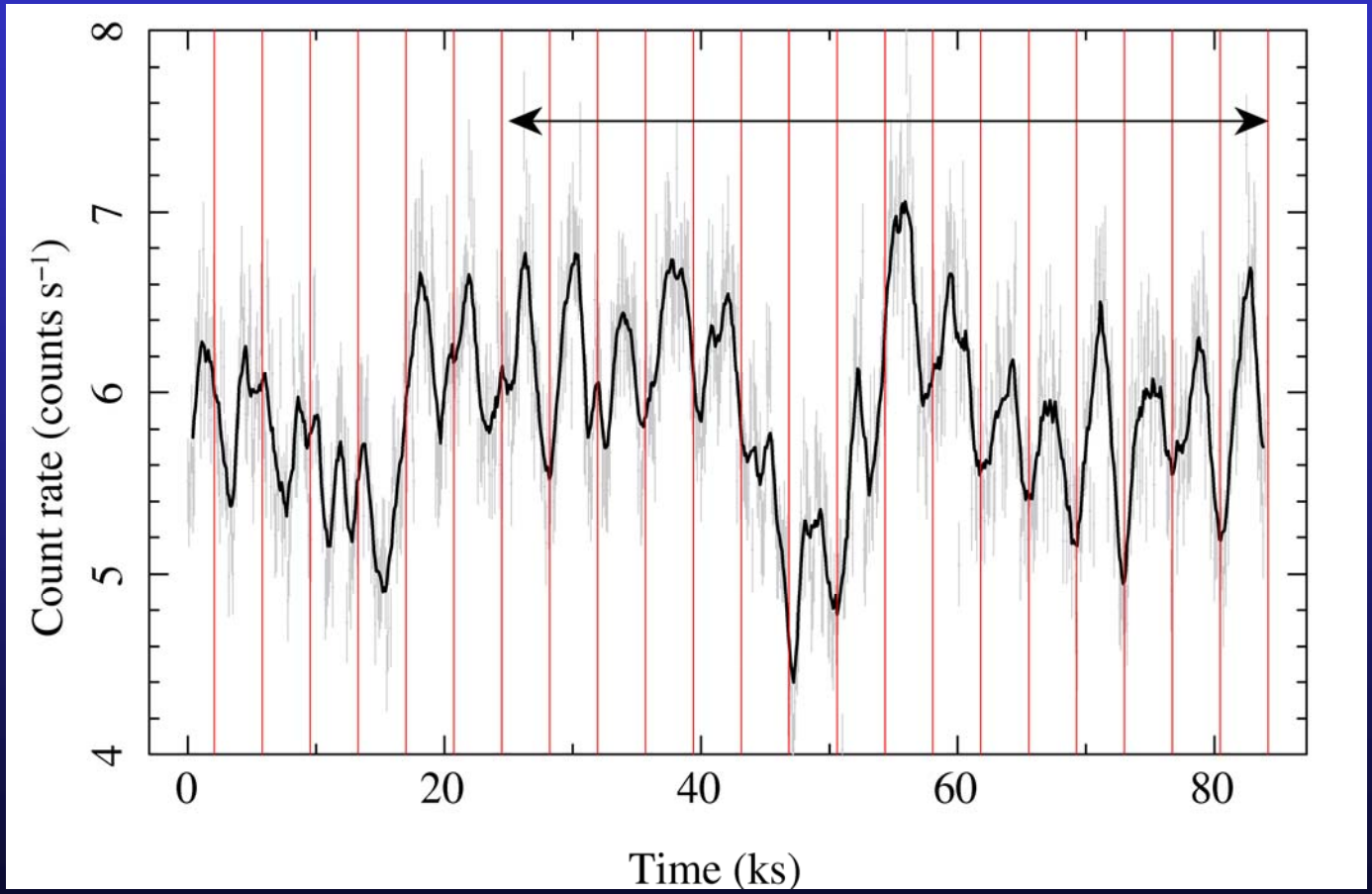
100ks of XMM-Newton data, co-adding MOS1, 2 and PN data



Gierlinski, Middleton, Ward & Done 2008

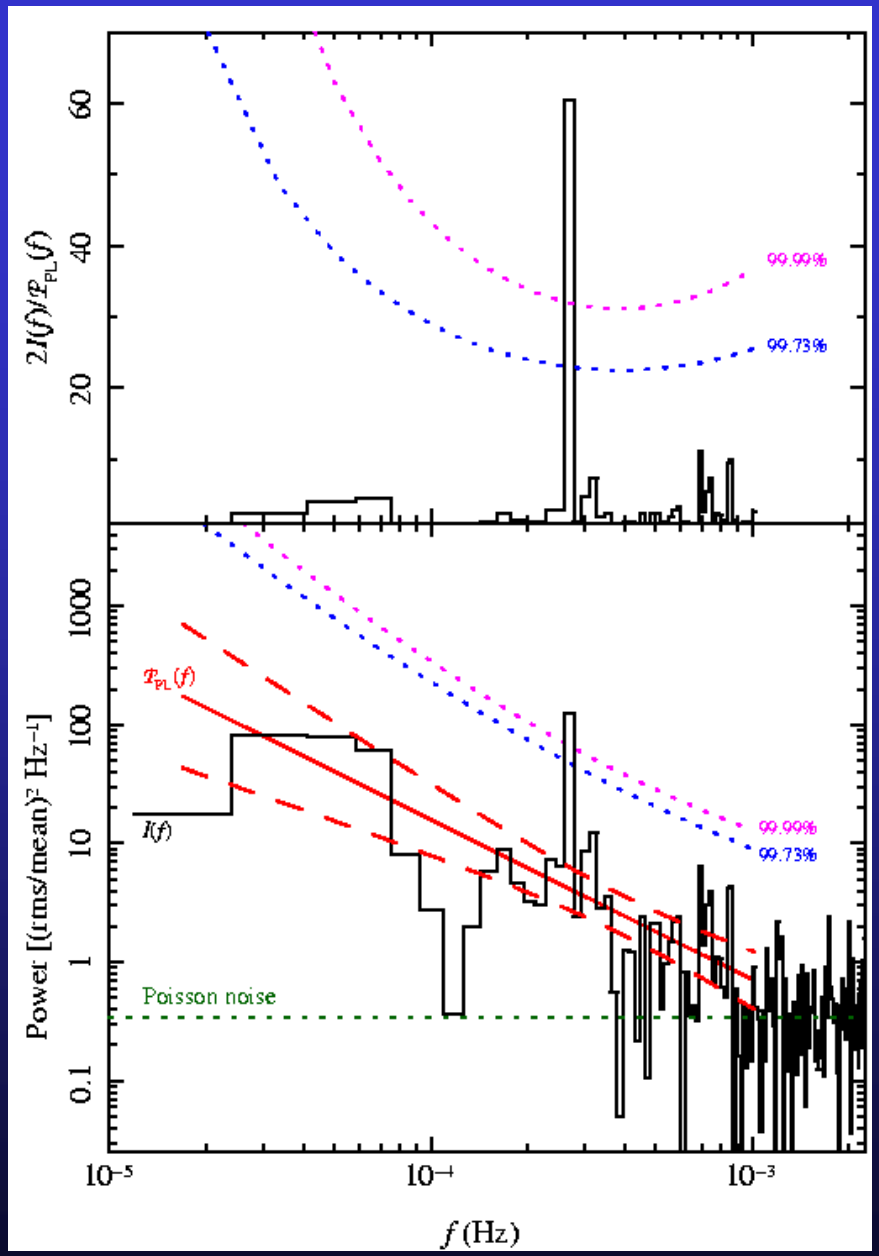
Smoothed lightcurve

Period much clearer in last ~60ks – almost periodic $Q = \upsilon/\Delta\upsilon > 16$



Gierlinski, Middleton, Done & Ward 2008

Power spectrum



Gierlinski, Middleton, Ward & Done 2008

Even sampling so analytic

Power law $P_{PL} \propto f^{-\alpha}$

$\alpha = 1.35 \pm 0.18$

$f_{QPO} = 2.7 \times 10^{-4}$ Hz (=3700 s)

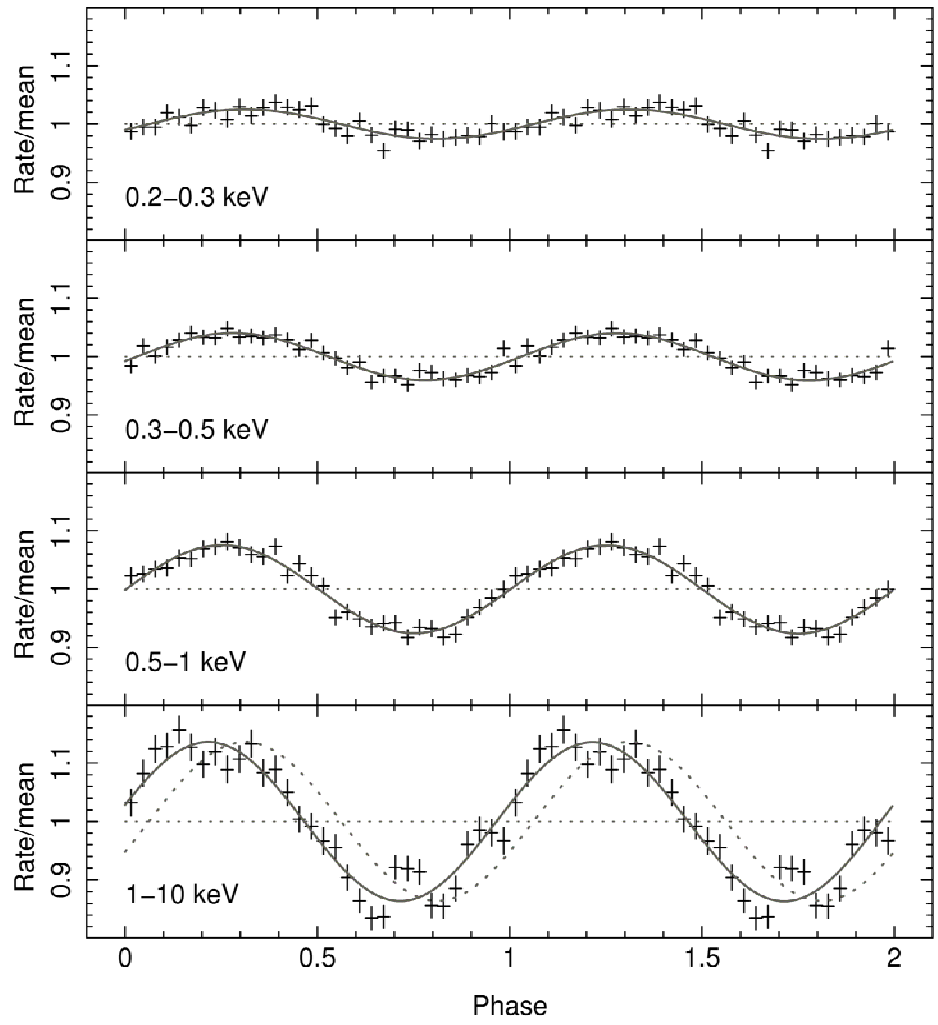
Much bigger than 99.99% significance (chance probability is 10^{-7})

Derived from same methods used to reduce significance of previous claims *Vaughan et al. 2006*

REJ1034: rms variability

Middleton et al 2008

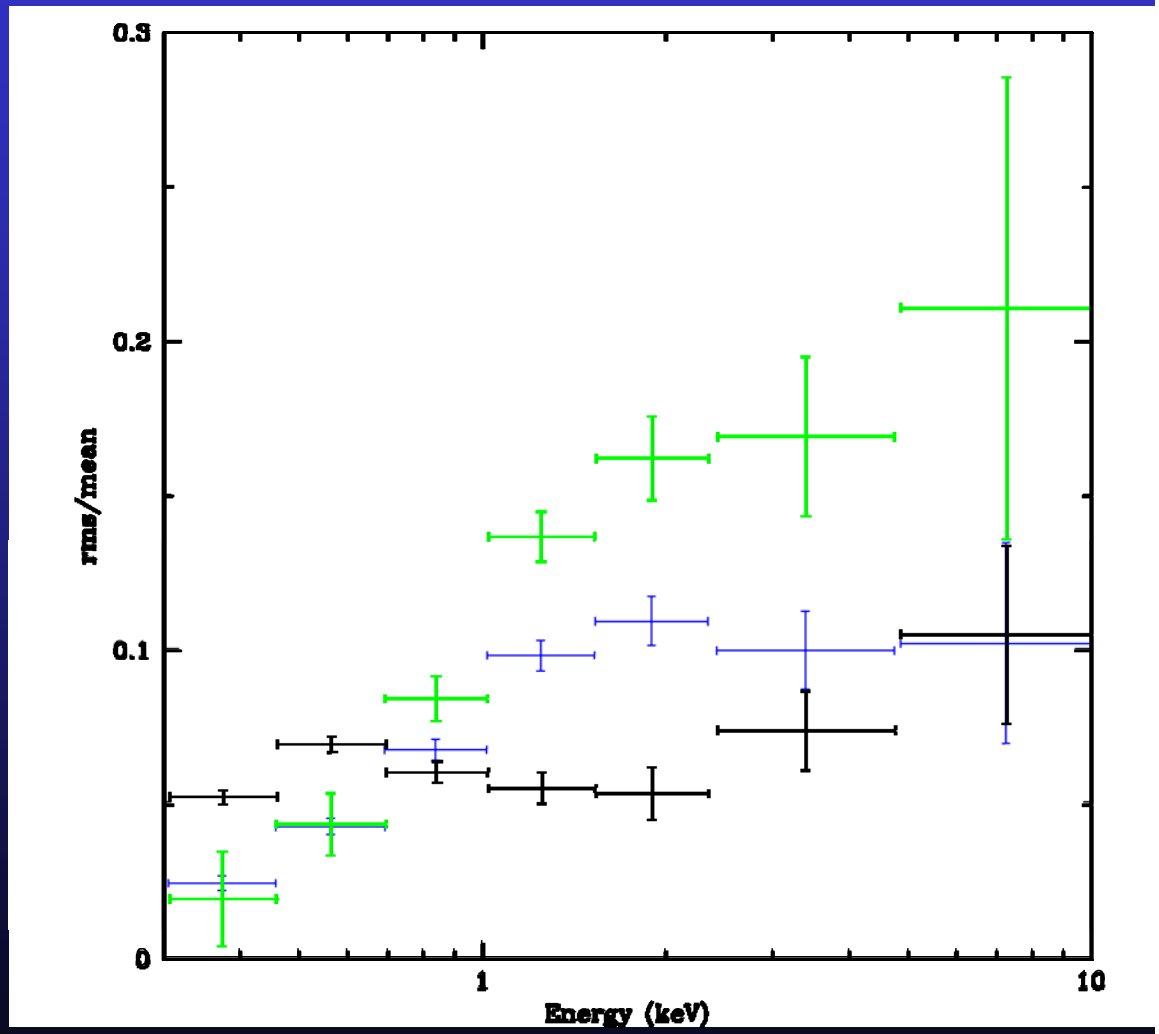
- Not as expected if have same modulation at all energies!
- Obvious energy dependance of QPO
- Much higher amplitude at higher energies



REJ1034: rms variability

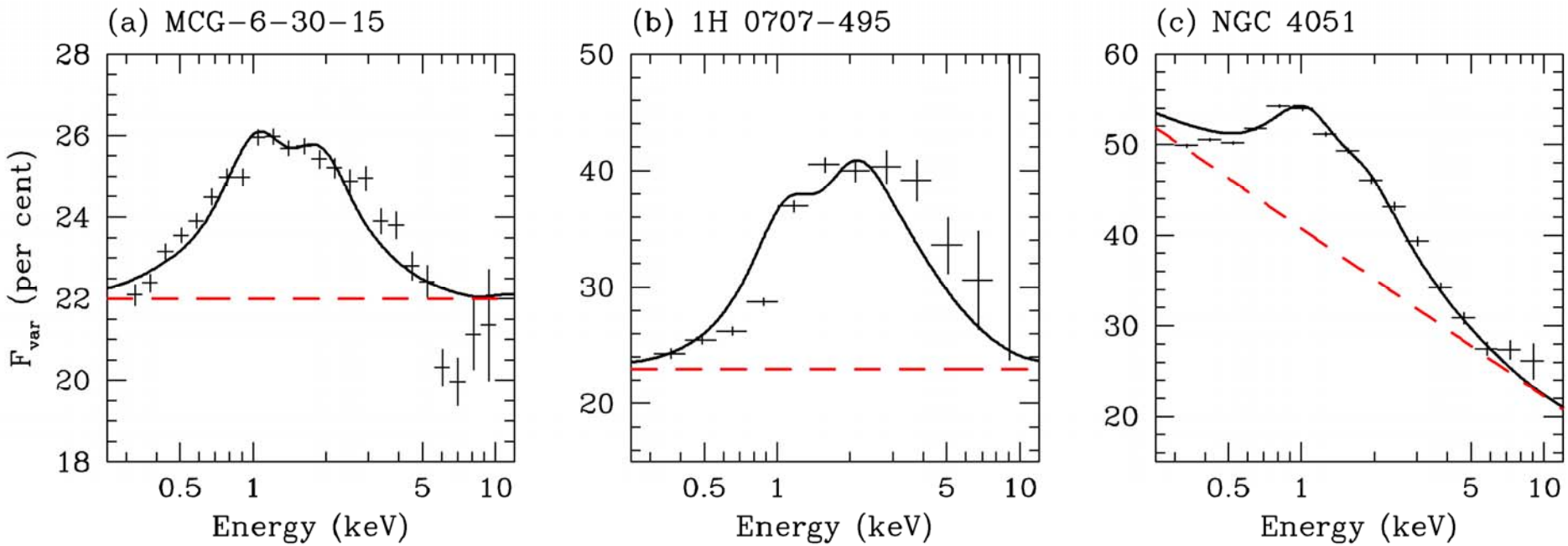
Middleton et al 2008

- Not as expected if have same modulation at all energies!
- Obvious energy dependance of QPO
- Much higher amplitude at higher energies
- Sharp change in properties at ~2keV
- Similar to all rapid variability
- But not to long timescale!



cf other NLS1's …

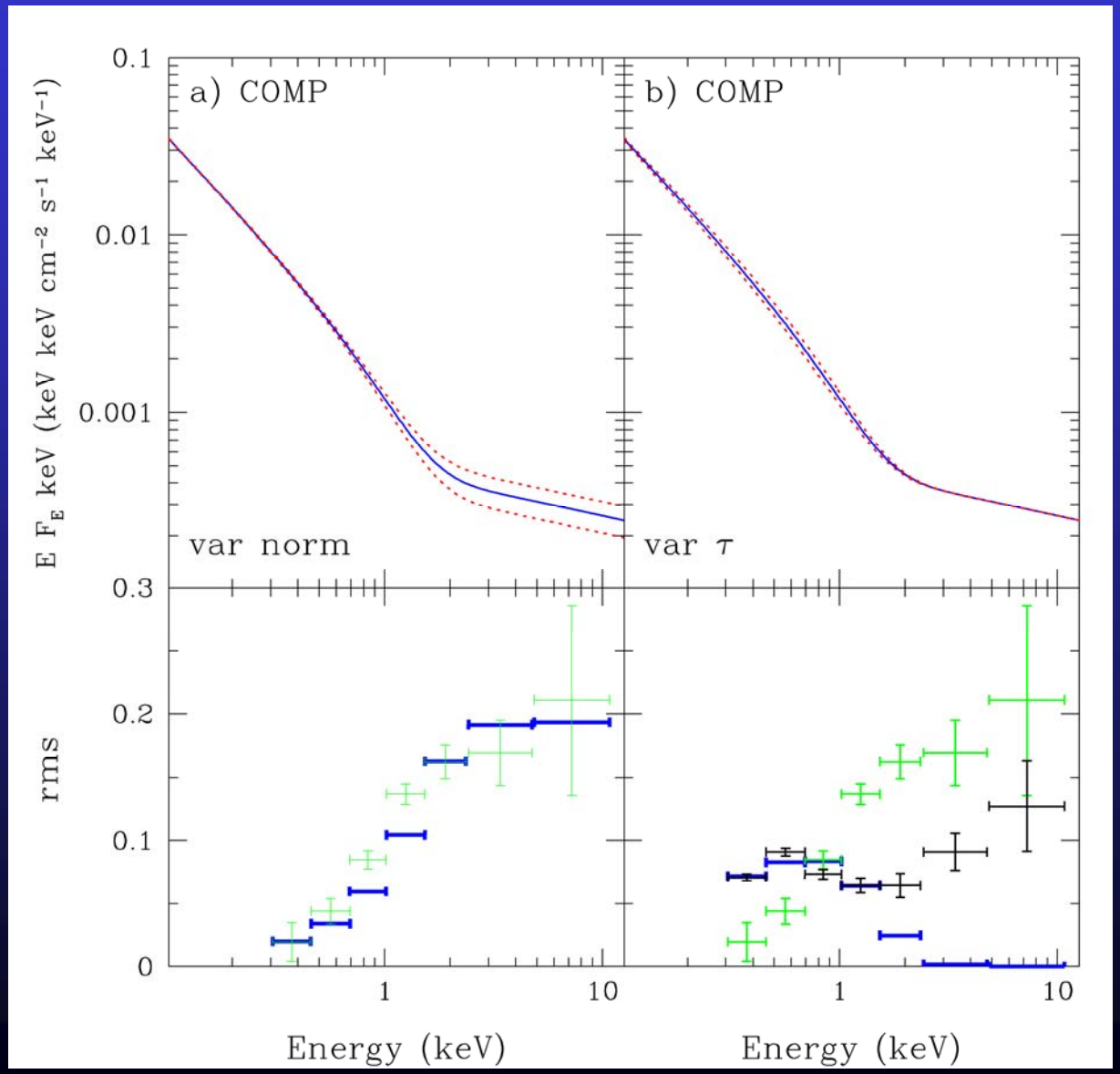
- Nothing like!!
- Often (not always) peaks between 0.7-3 keV – smoking gun for atomic processes (but also warm absorber in these systems)



Gierliński & Done 2006

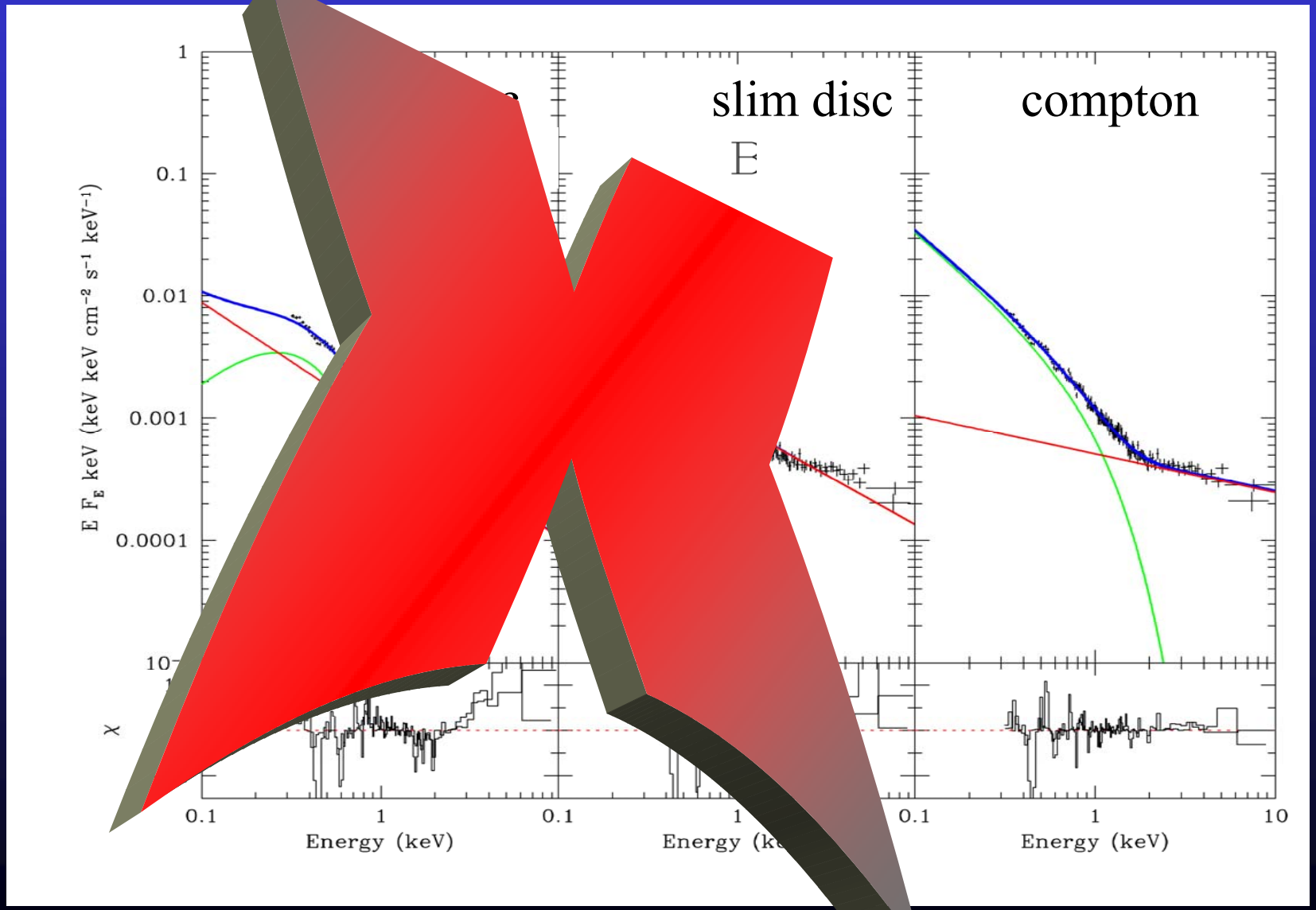
REJ1034: separate soft component

- Vary power law norm, keep comptonised disc constant!!
- Like in BHB, QPO is in tail, not disc!
- Can make longer timescale by slow variability of comptonised disc BUT lightcurve complex!!



Middleton et al 2008

REJ1034: separate soft component

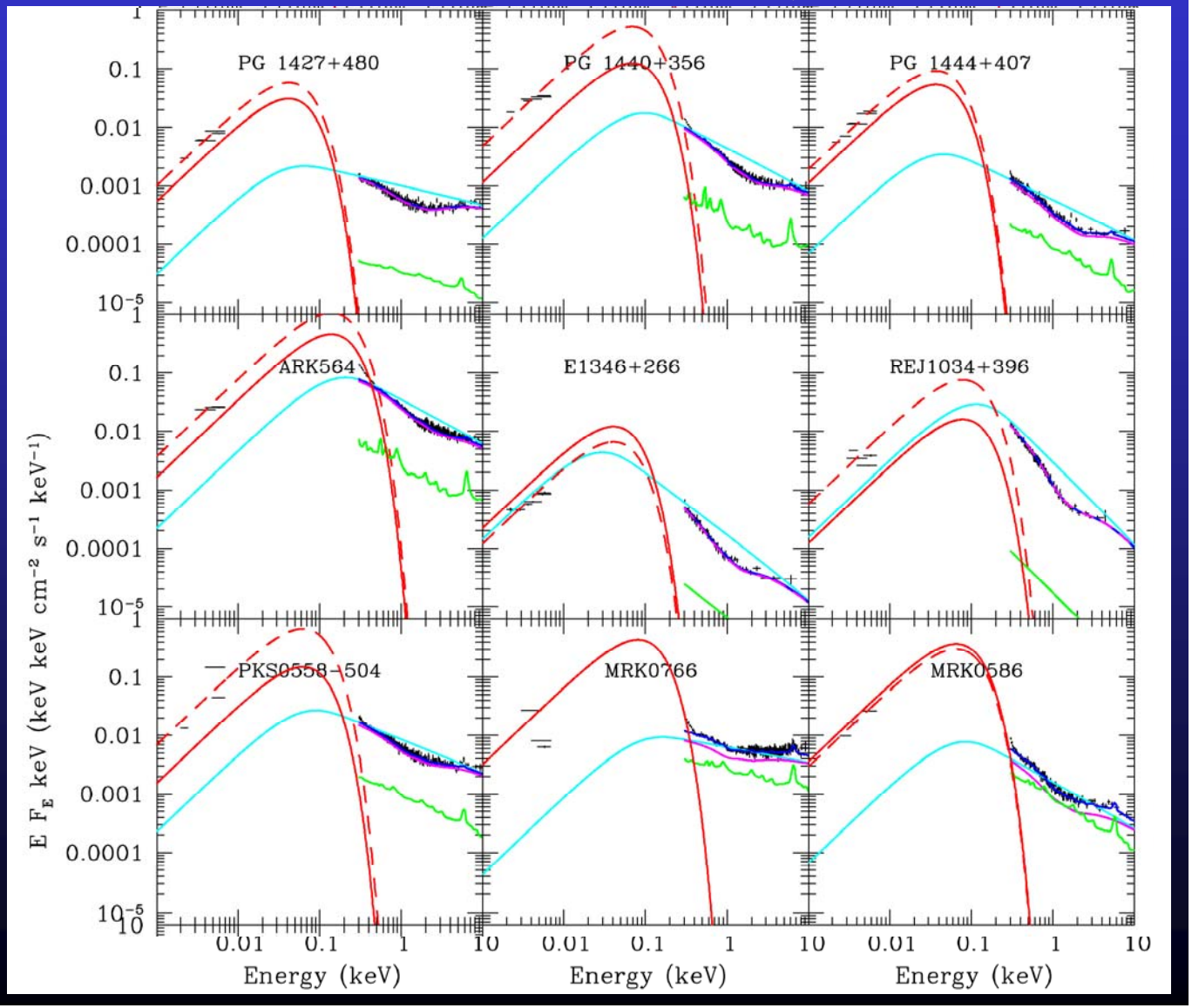


Middleton et al 2008

Range of local high L/L_{Edd} AGN

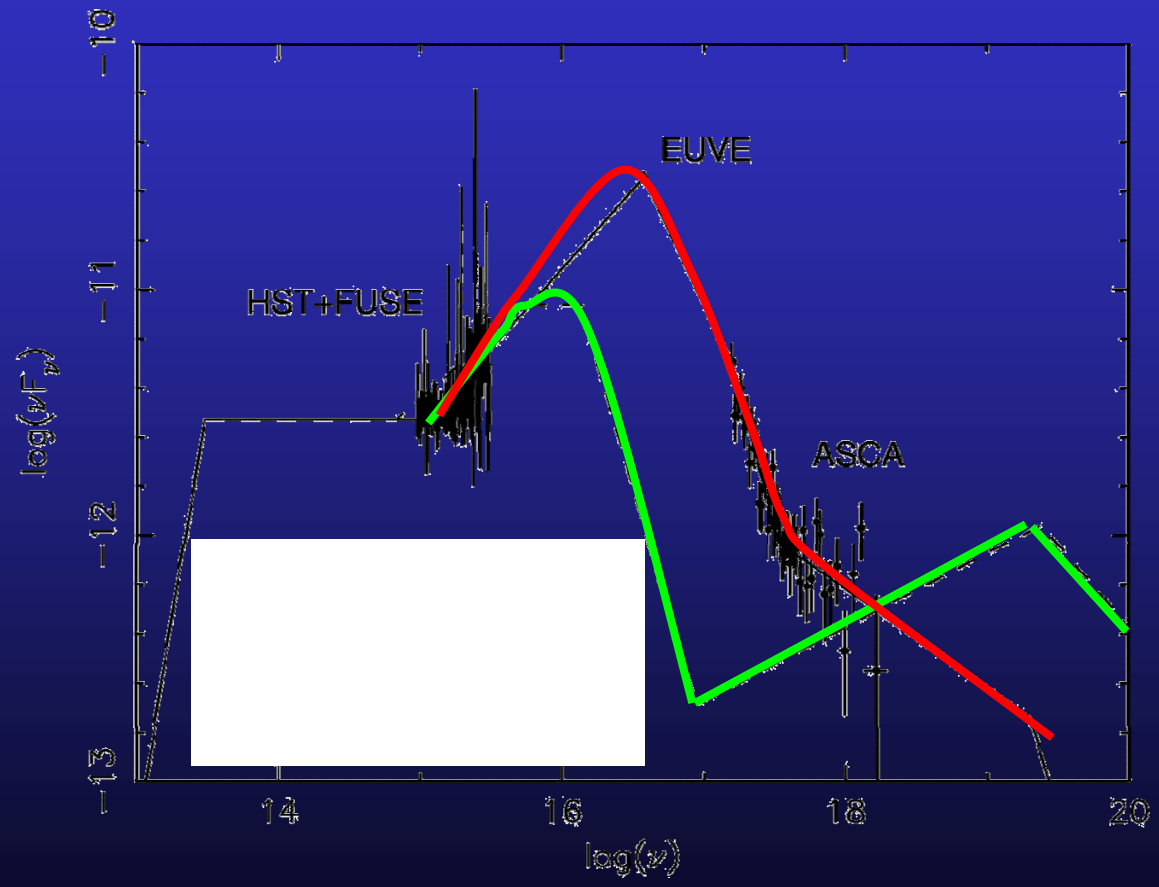
Middleton, Done & Gierlinski 2007

- Soft excess: factor ~2 at 0.5 keV but can be much larger
- Lsx/Lbol <<1 in *MOST* AGN but REJ1034…
- Standard disc is far too cool and its Wien tail is too steep
- Always at same energy!



What else is special about REJ1034?

Casebeer et al 2006



Extreme SED compared to normal even for NLS1

Highest temperature disc/largest soft excess

Small mass and high L/L_{Edd}?

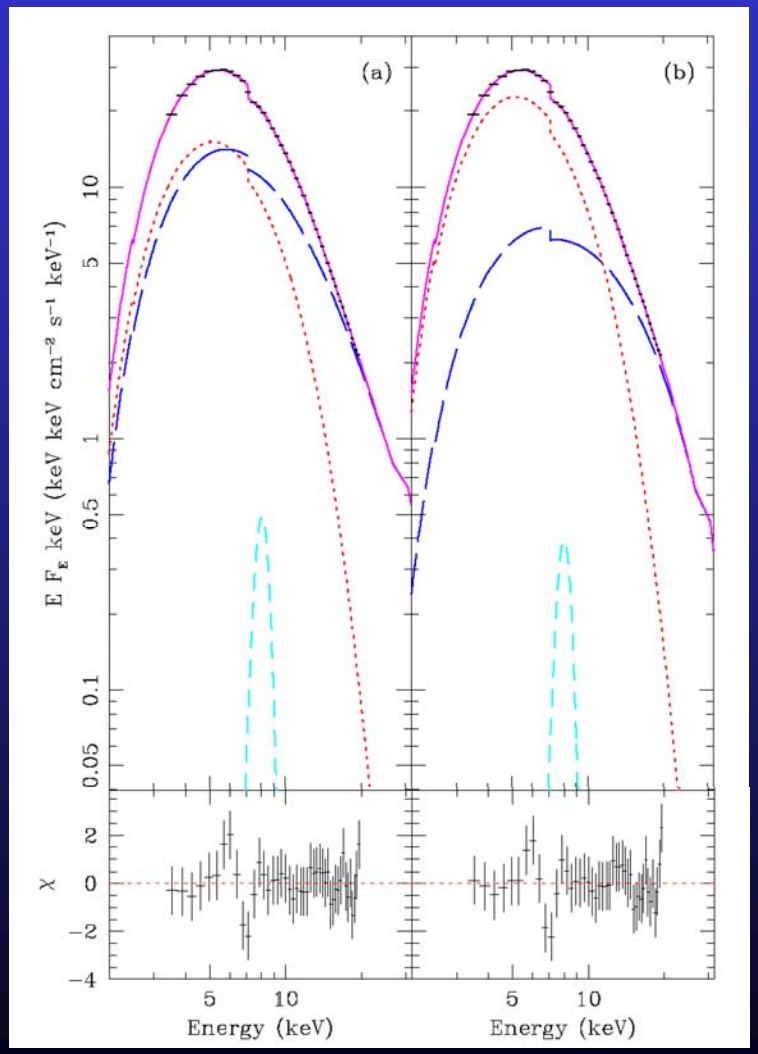
$L_{bol} \sim 5\text{x}10^{44}$ ergs s^{-1}

Extreme accretion rate? $M<3\text{x}10^{6}M_{\odot}$ for $L>L_{Edd}$

GRS1915+105

- See a lot low kTe spectra spectra in the superEddington BHB GRS1915+105
- Can't assume electrons always high temperature kT_e = 50 keV – gives completely different spectral decomposition (and black hole spin!) and doesn't fit so well
- Obvious wind features even at RXTE resolution!

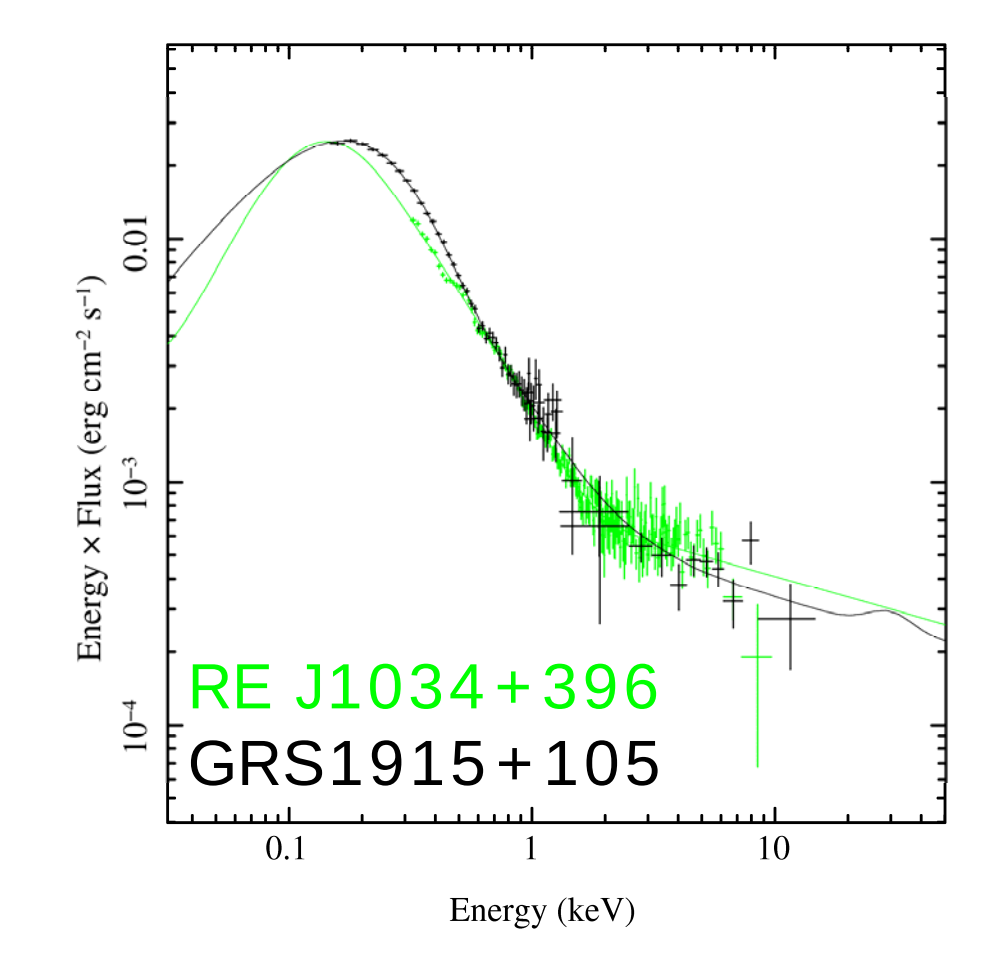
kT_e free kT_e=50 keV



Middleton, Davis, Done & Gierlinski 2005

REJ1034+396: Comptonised disc

Middleton et al 2008



Looks very similar to some spectra seen in GRS1915+105 if shift energy scale by ~20

=> mass of ~2×10^6 $M_\odot$

Conclusions

- BHB give template for sub-Eddington accretion flow
- Simple disc L-T^4 in high/soft state
- NOT always simple disc – low/hard and very high states are dominated by Comptonisation
- Scale up to AGN – LINERs are dim low/hard, some Seyferts (esp S2) are bright low/hard, some (esp S1) are high/soft as are radio quiet QSO's
- NLS1 as very high state? But SX. And sometimes hard 2-10 keV spectra. Many (most?) of these are a distortion from atomic processes (reflection/absorption)
- But some SX REAL! Optically thick, low temperature, optically thick Comptonised disc!! see also in uniquely luminous BHB GRS1915+105 and in AGN with X-ray QPO (and ULX!)