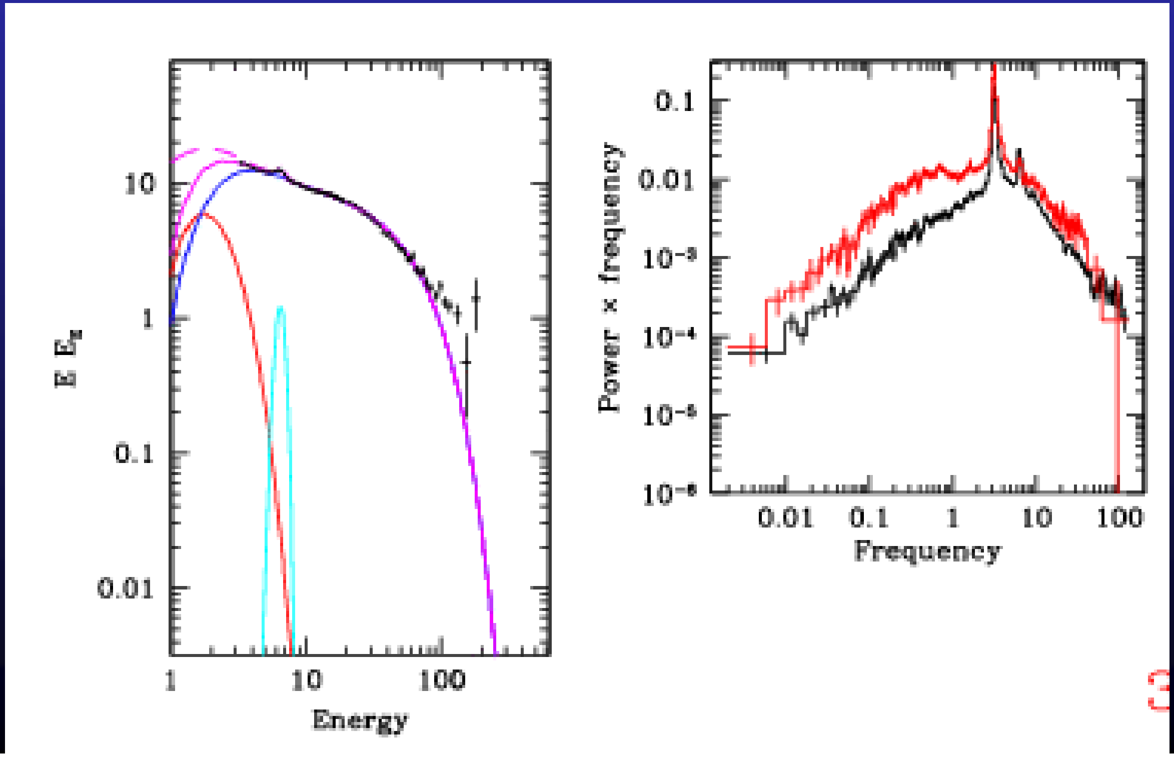
Accretion flows onto black holes: Controversy!

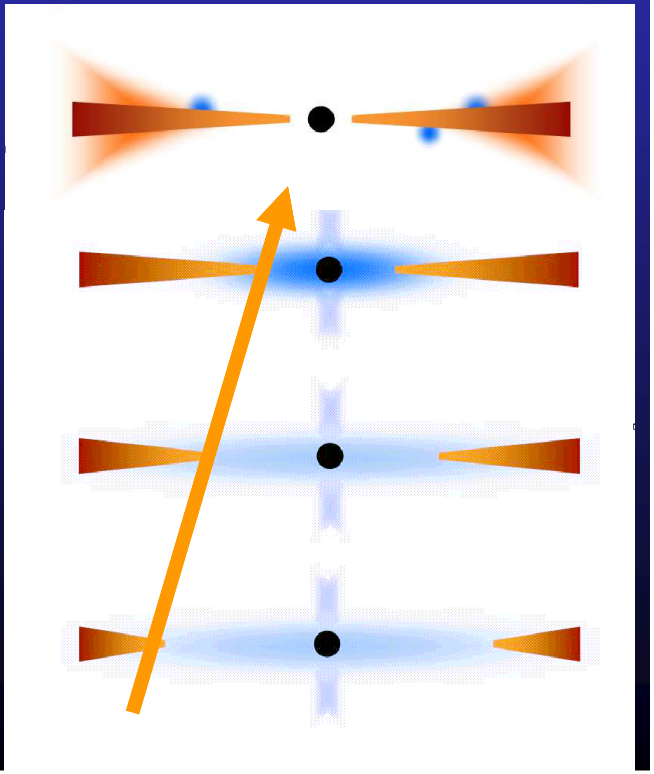
Chris Done
University of Durham

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

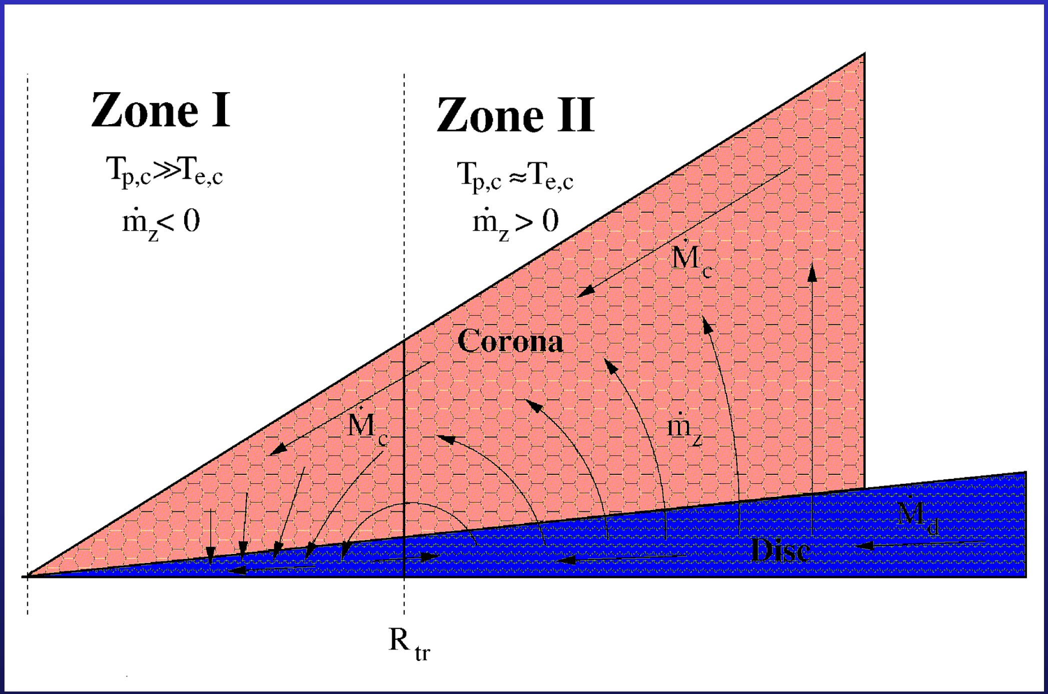
DGK07





Accretion flows without discs

- Can form such configuration by thermal conduction from hot corona evaporates inner disc at low L/L_{Edd} Meyer & Meyer Hofmeister 1994; Lui et al 1999; 2002 Rozanska & Czerny 2000
- Time dependent disc calculations show this! Mayer & Pringle 2007



- Mayer & Pringle 2007

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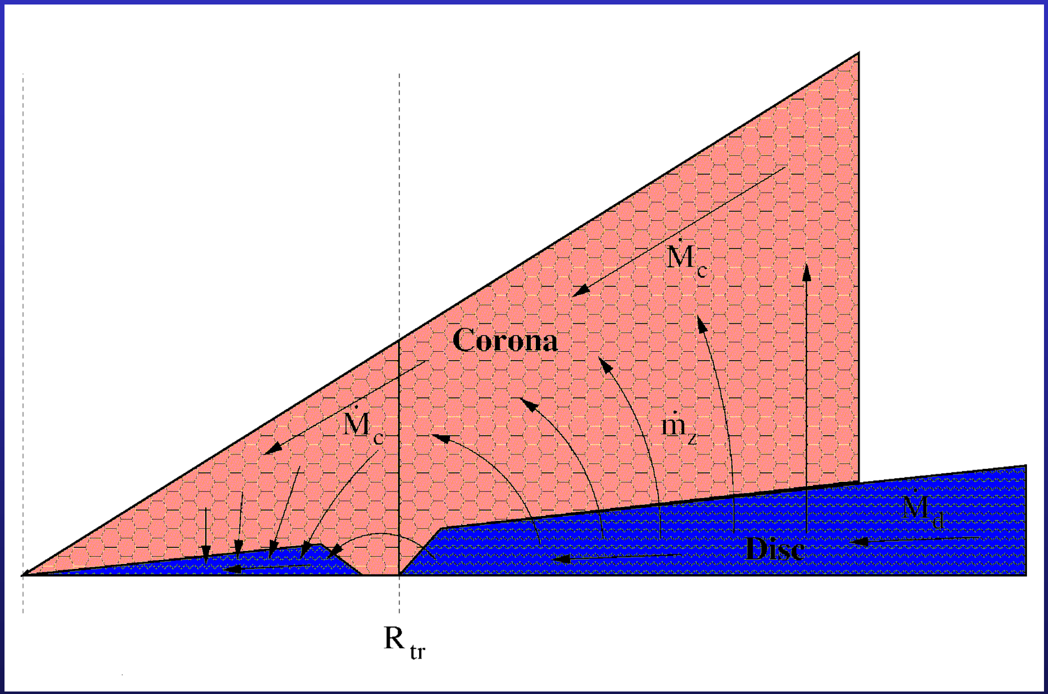

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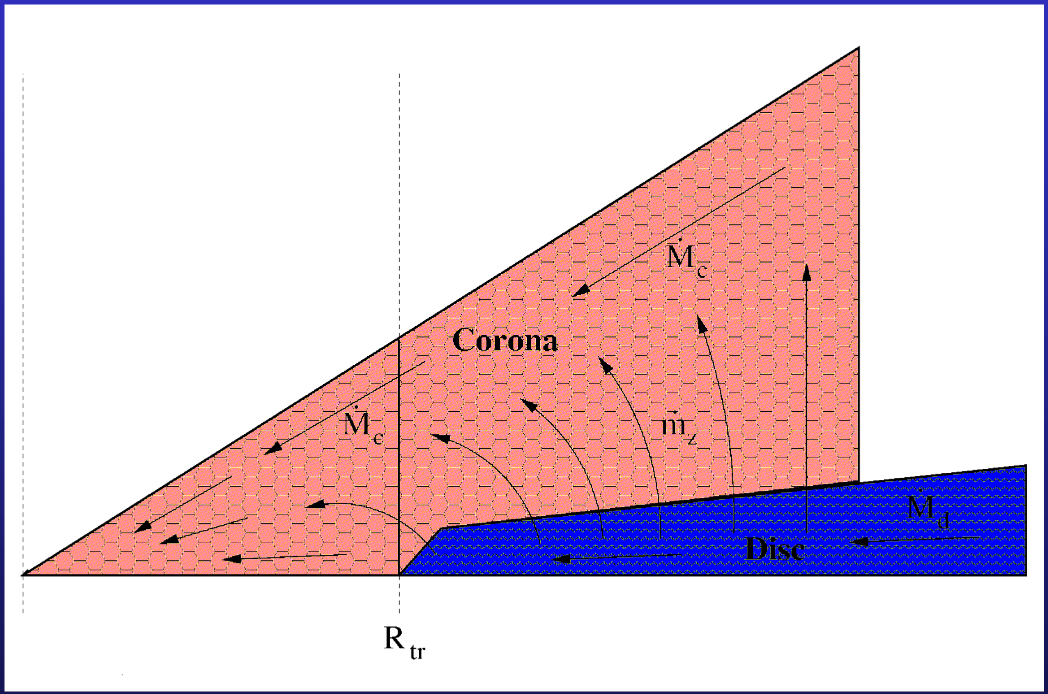
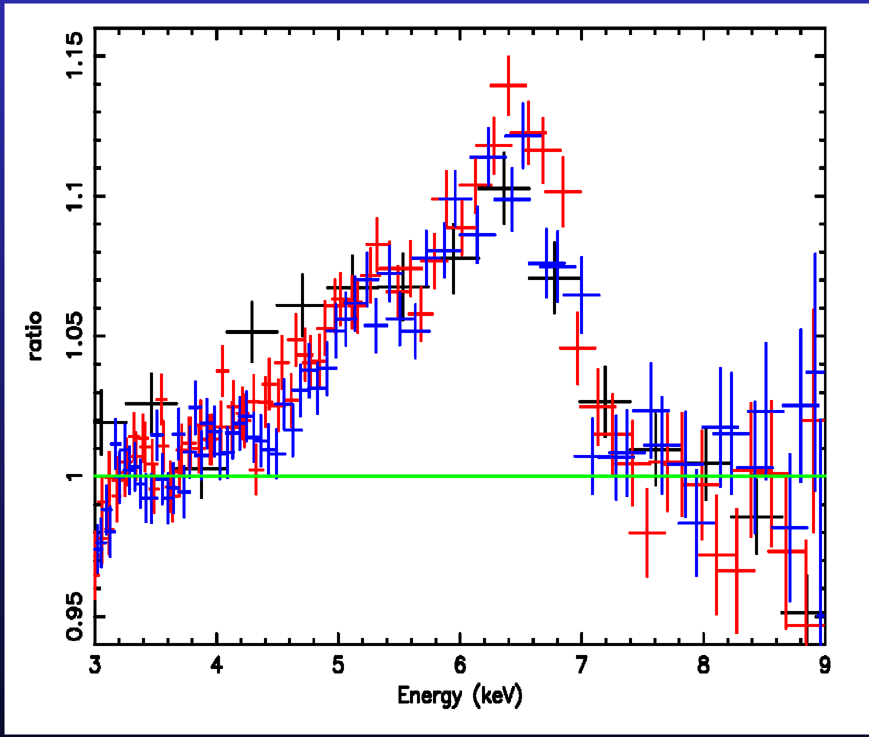


- Mayer & Pringle 2007

But is there really a hole in hard state?

challenge 1

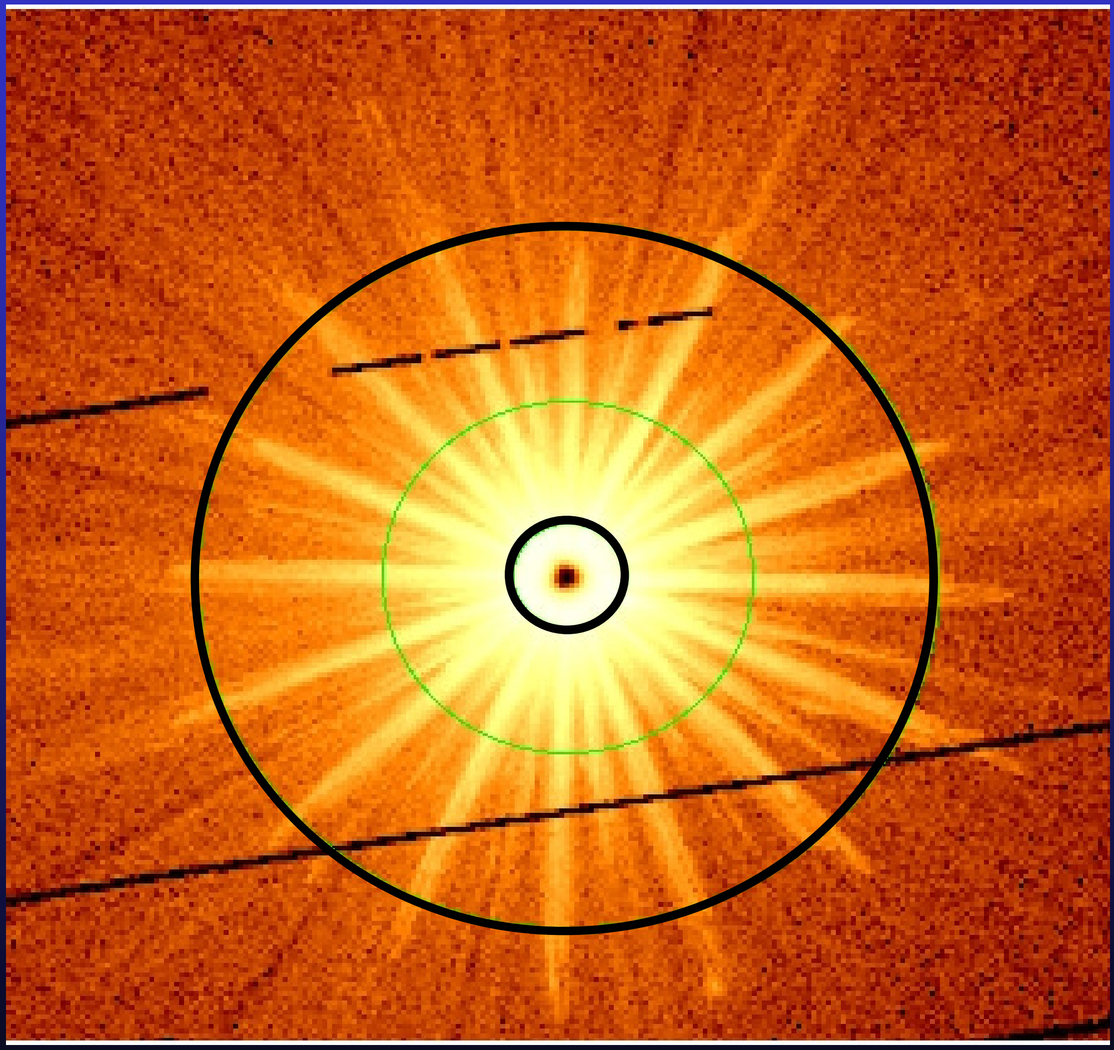
- Extreme broad iron lines in the low/hard state:
- GX339-4: Miller et al 2006; Reis et al 2008: Rin~2-5Rg with ionised reflection



Miller et al 2006

GX339-4 XMM data

- Flux gives MOS count rate 200x > than pileup limit
- Exclude core. 18-120” singles Miller et al 2006
- But data are still piled up Done & Diaz-Trigo 2009
- PN in timing mode so not (much) affected by pileup so use them instead (Wilkinson & Uttley 2009; Done & Diaz-Trigo 2009)



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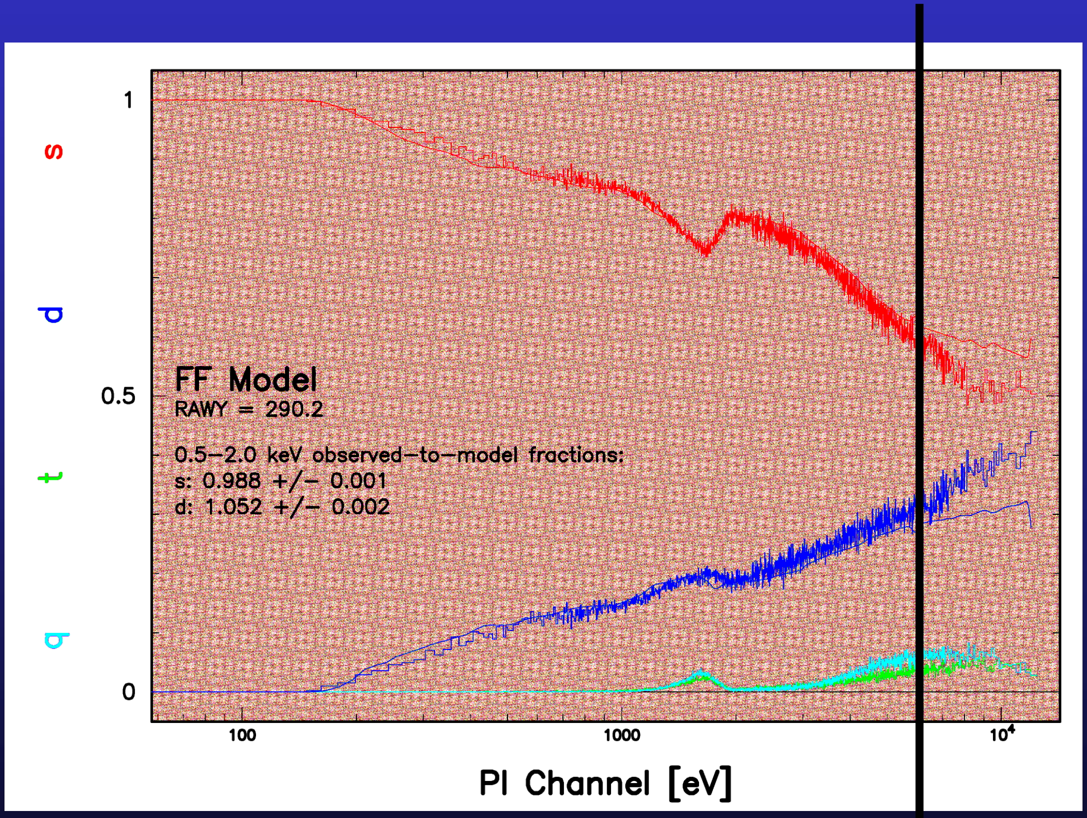
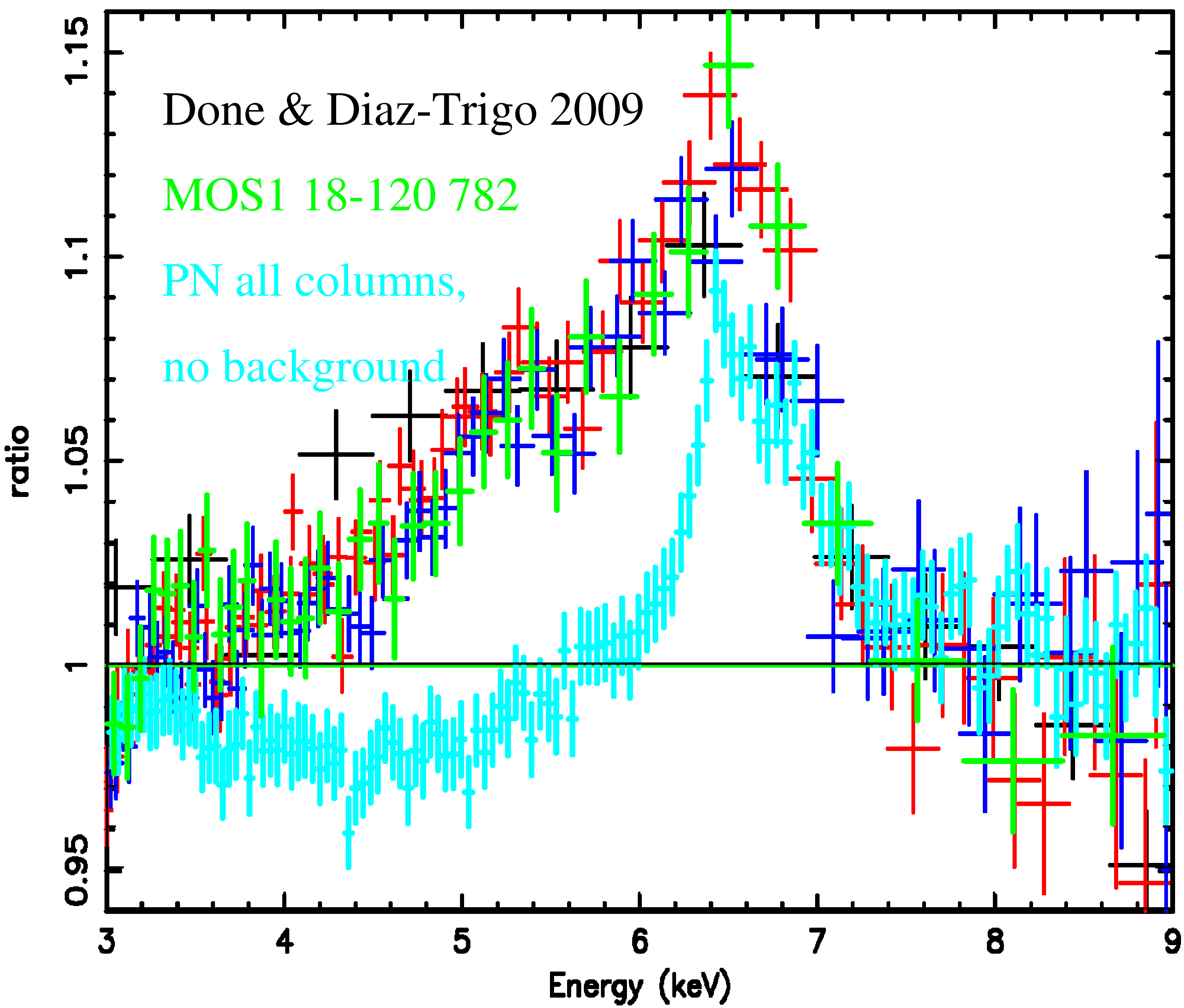


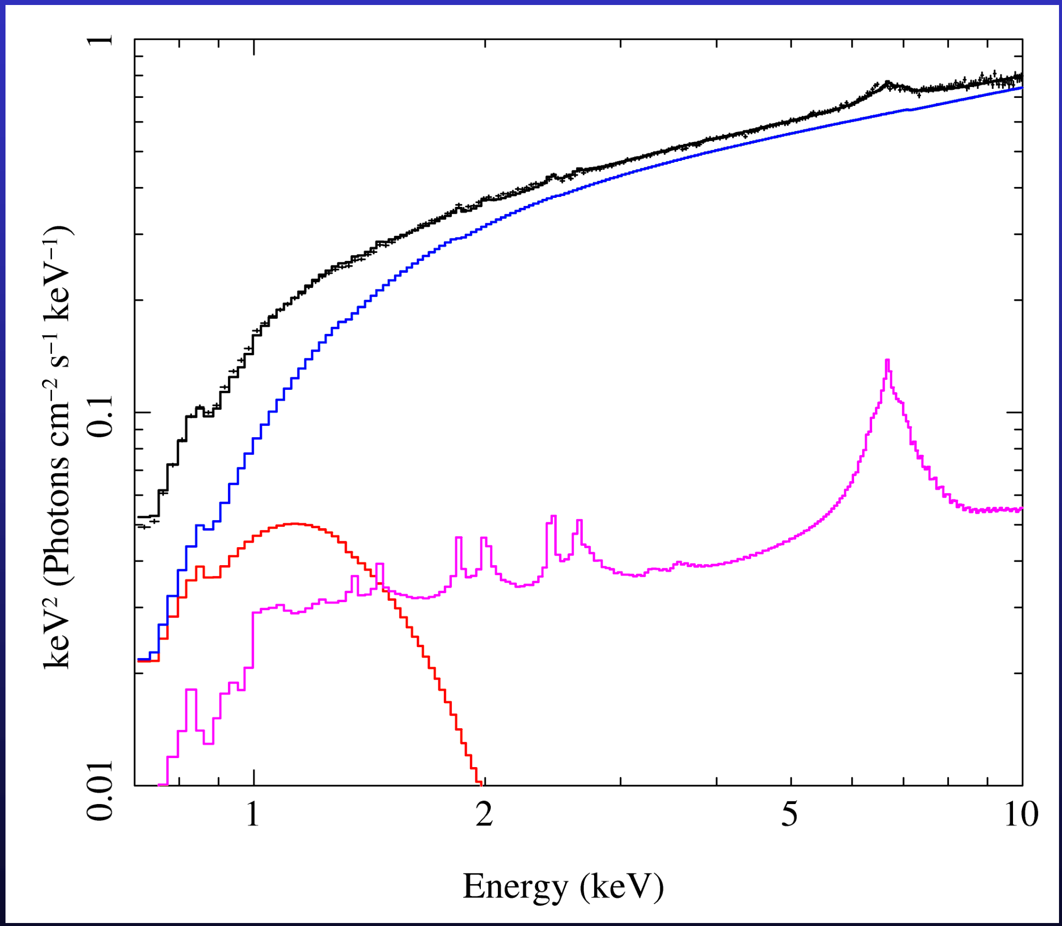
data deviates from model E > 6keV



Done & Diaz-Trigo 2009
MOS1 18-120 782
PN all columns,
no background
ratio
0.95
1
1.05
1.1
1.15
3
4
5
6
7
8
9
Energy (keV)

GX339-4 XMM data

- Unsmeared, moderately ionised reflection
- Single laor line gives much poorer fit but Rin = 33 Rg Done & Diaz-Trigo 2009)

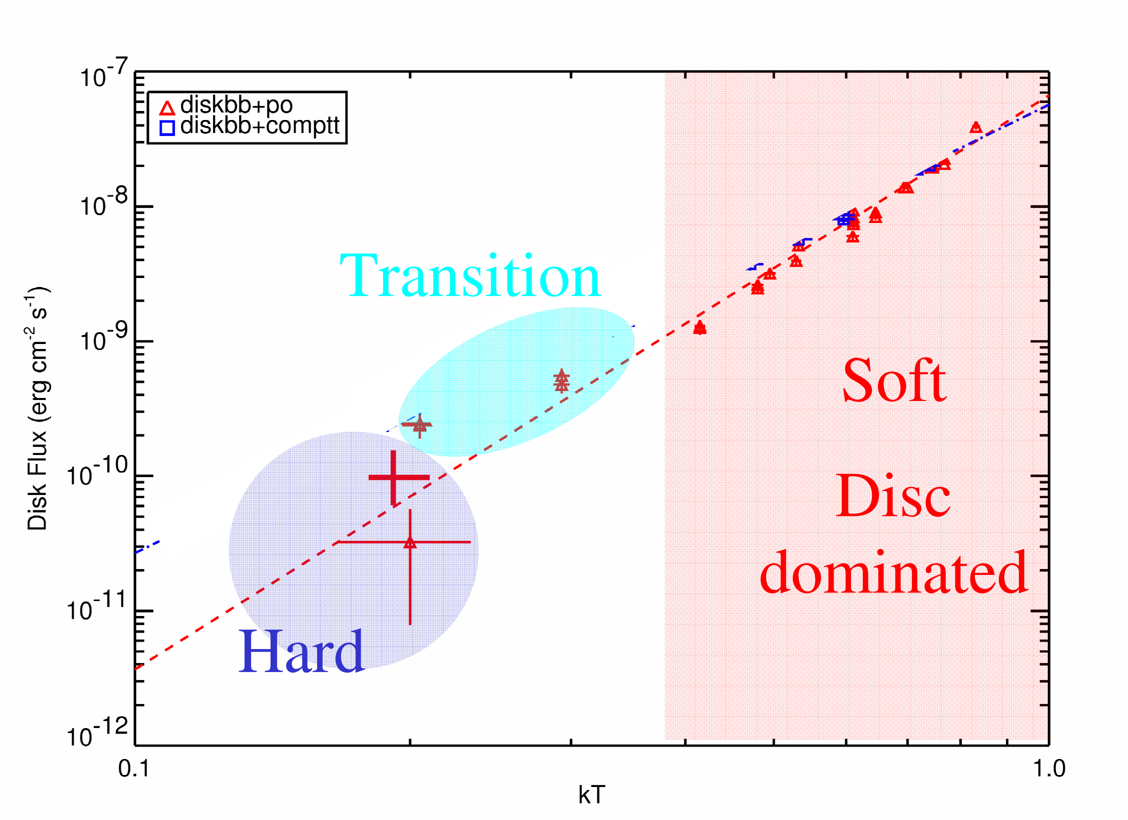


But is there really a hole?

challenge 2

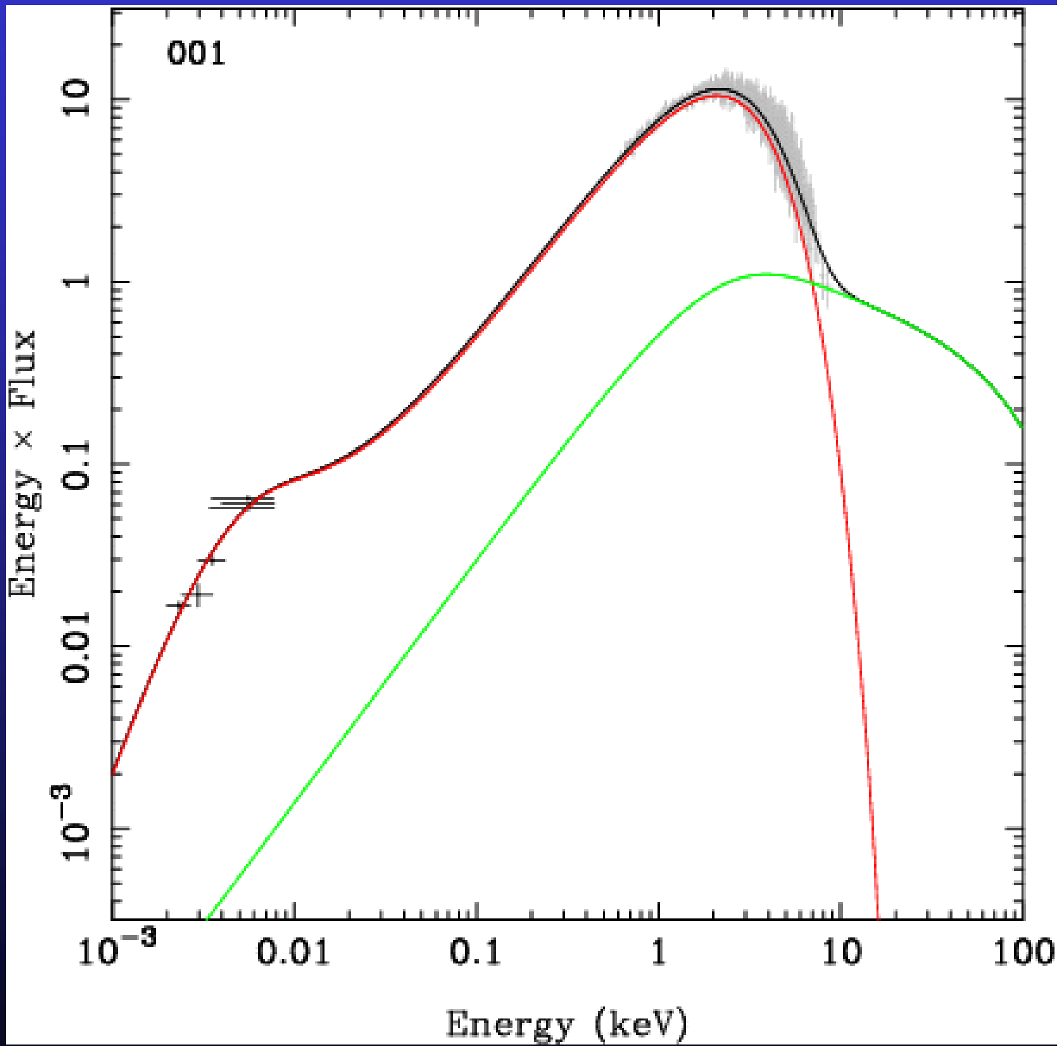
Rykoff et al 2007

- See disc with constant inner radius in soft state $L = A\sigma T^4$ ie constant radius - Rlso
- Same in low/hard state just after transition $L_{bol} \sim 0.01 L_{Edd}$
- GX339-4 Miller et al 2006
- XTE J1817-330 Rykoff et al 2007



Modifies optical continuum

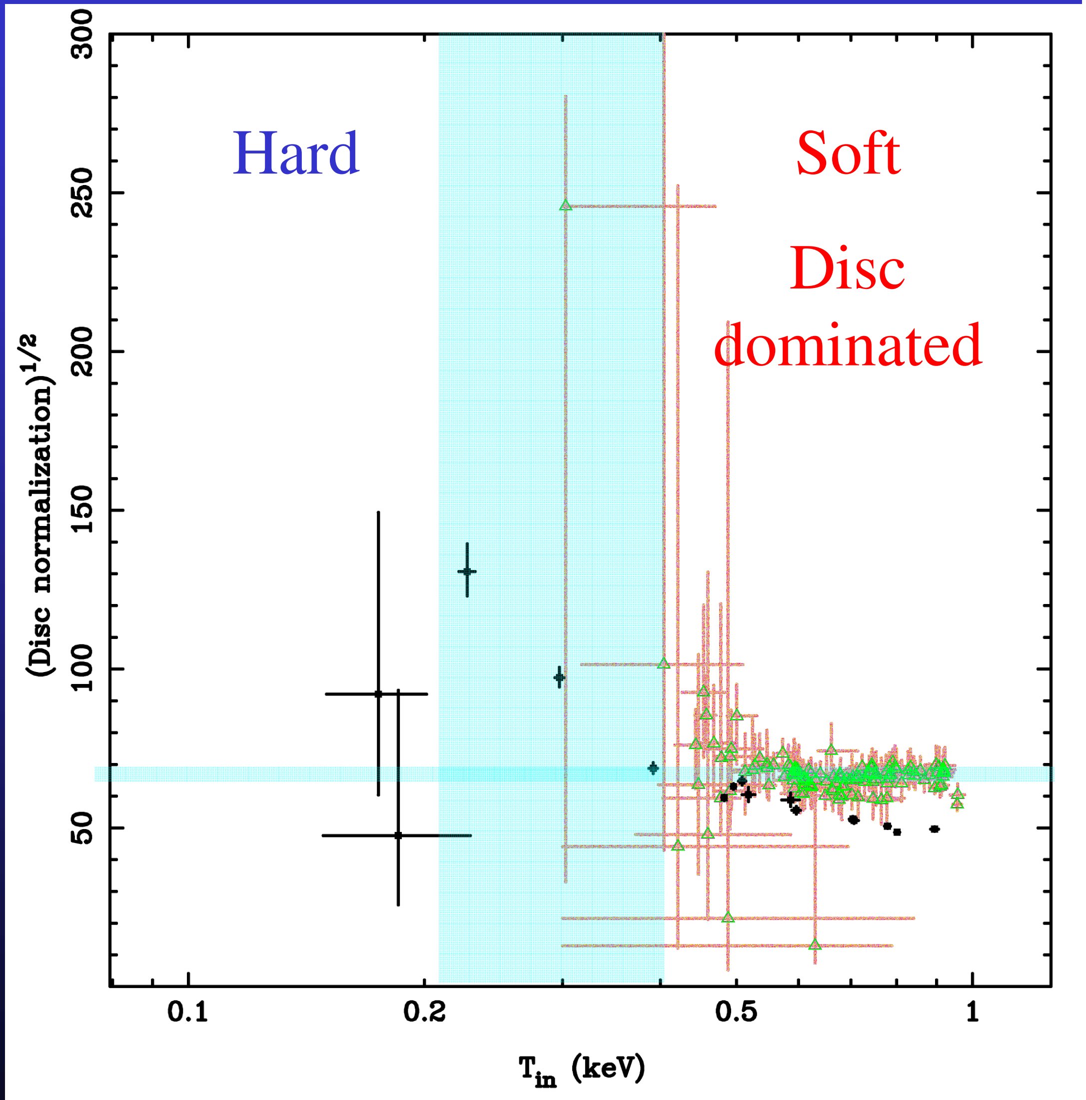
- X-rays illuminate outer disc where intrinsic flux is low so reprocessed can dominate (van Paradijs 1996)
- SWIFT/XMM X-opt simultaneously
- XTE J1817-330 - trace scattered fraction through outburst SWIFT+RXTE
- $L_{opt} \sim 0.002\ L_{disc}$ in high/soft state.
- Big changes at transition to low/hard state….



Gierlinski Done & Page 2007

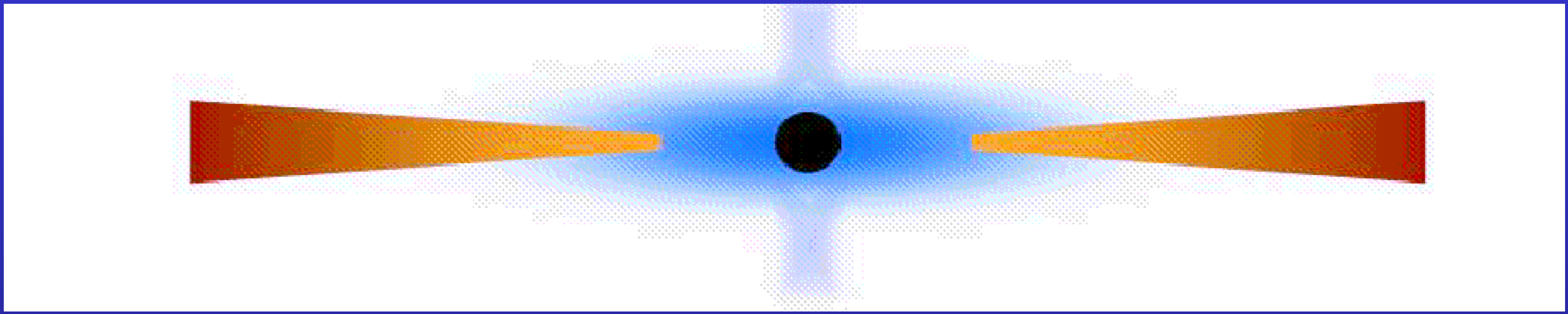
Radius from SWIFT-RXTE

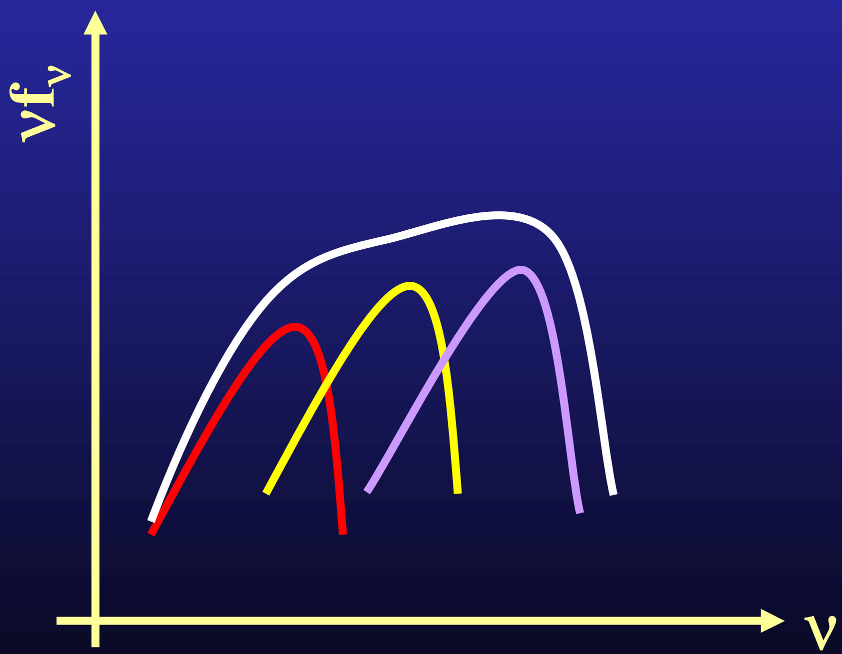
- Clear that SWIFT radius does increase in transition
- Can actually see in Rykoff et al plot as well but much clearer with RXTE data to define radius in disk dominated state
- And their main point is about the disc in the hard state where it does seem small again – but with large errors.

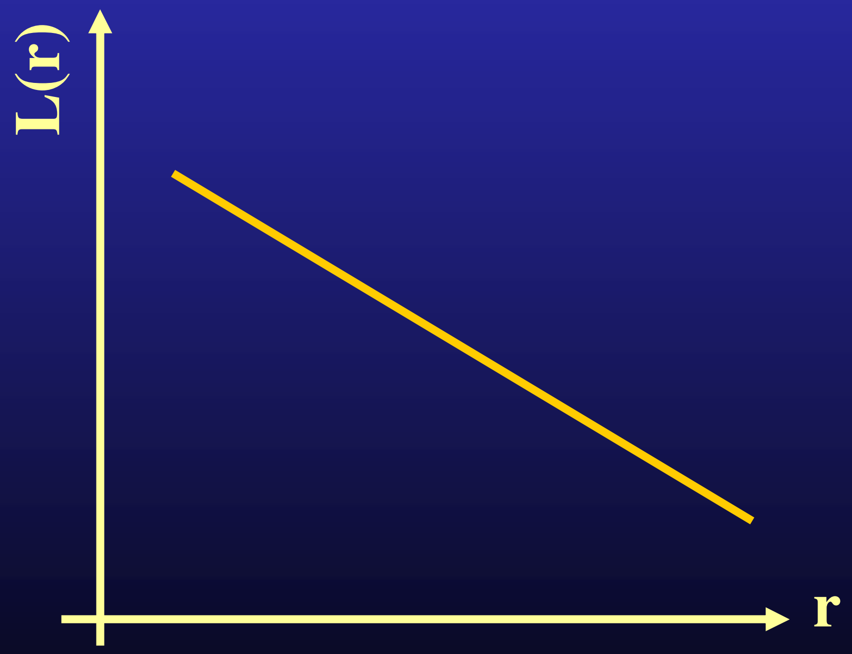


Gierlinski Done & Page 2007

But not simple just after transition







Gierlinski Done & Page 2007

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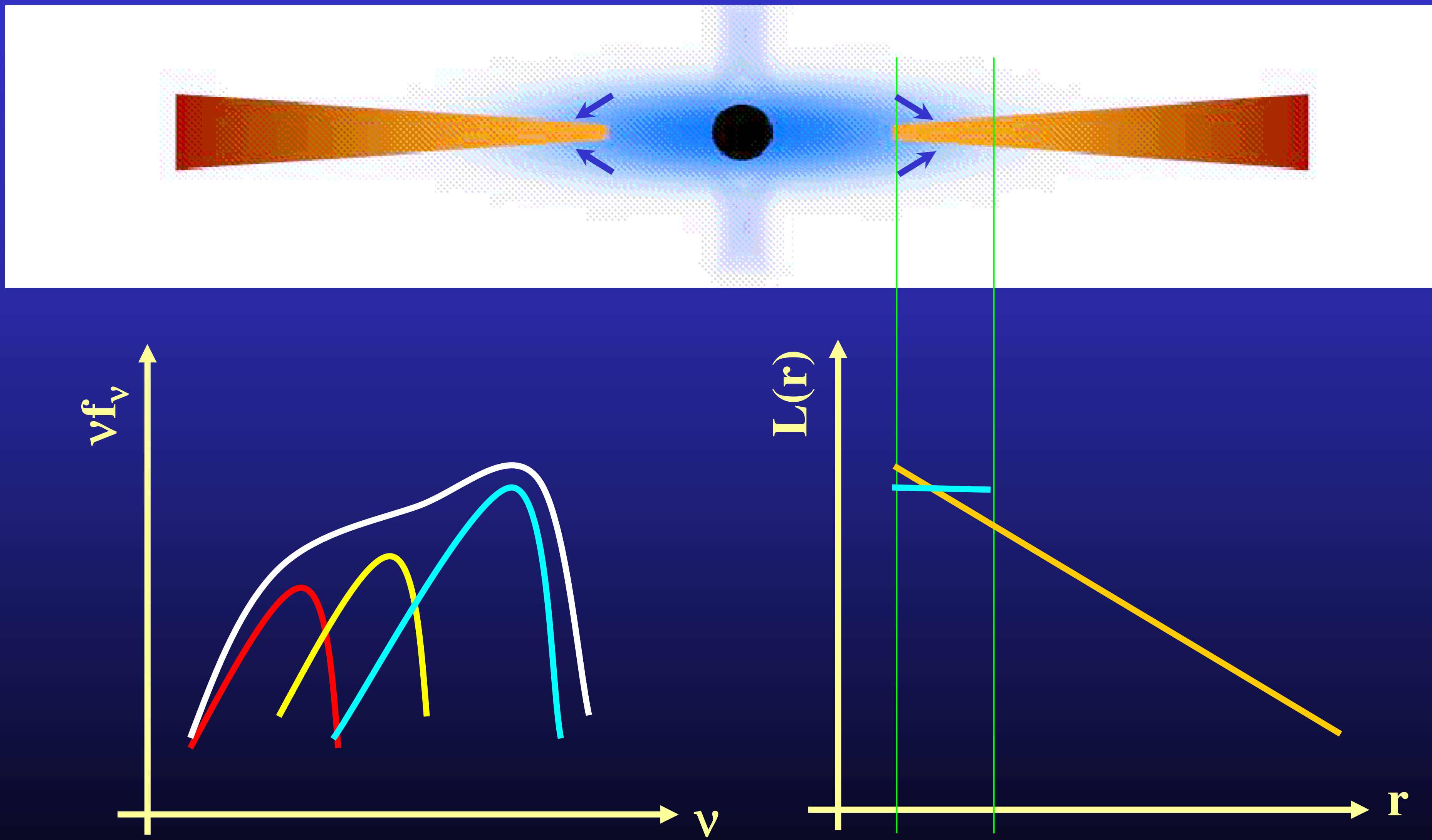
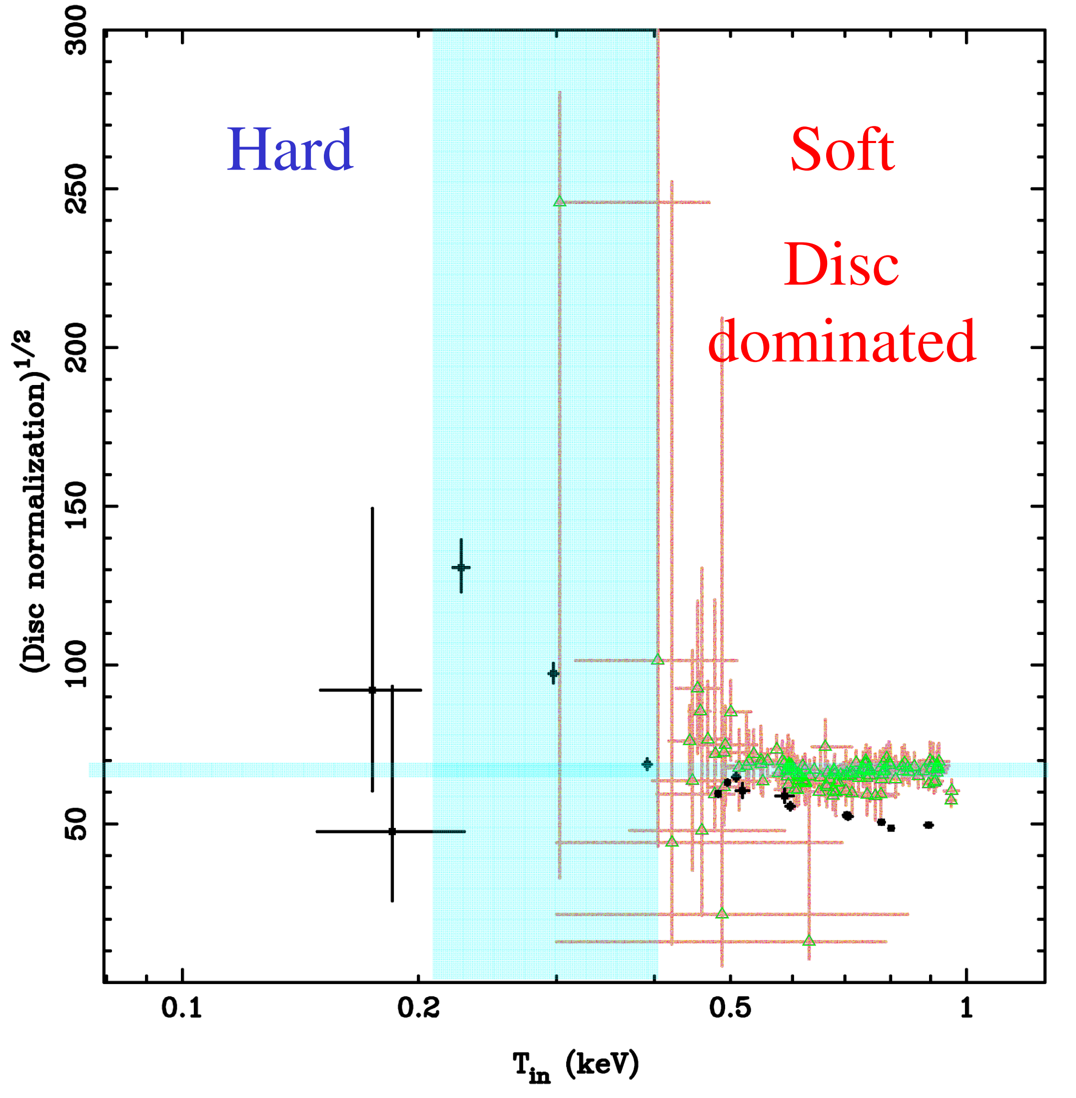


Gierlinski Done & Page 2007

Direct illumination

- Inferred disc radius moves larger with irradiation
- Different stress on inner boundary
- Still assuming same colour temperature correction, radiation thermalises and not correcting for Compton scattering
  Makishima et al 2008



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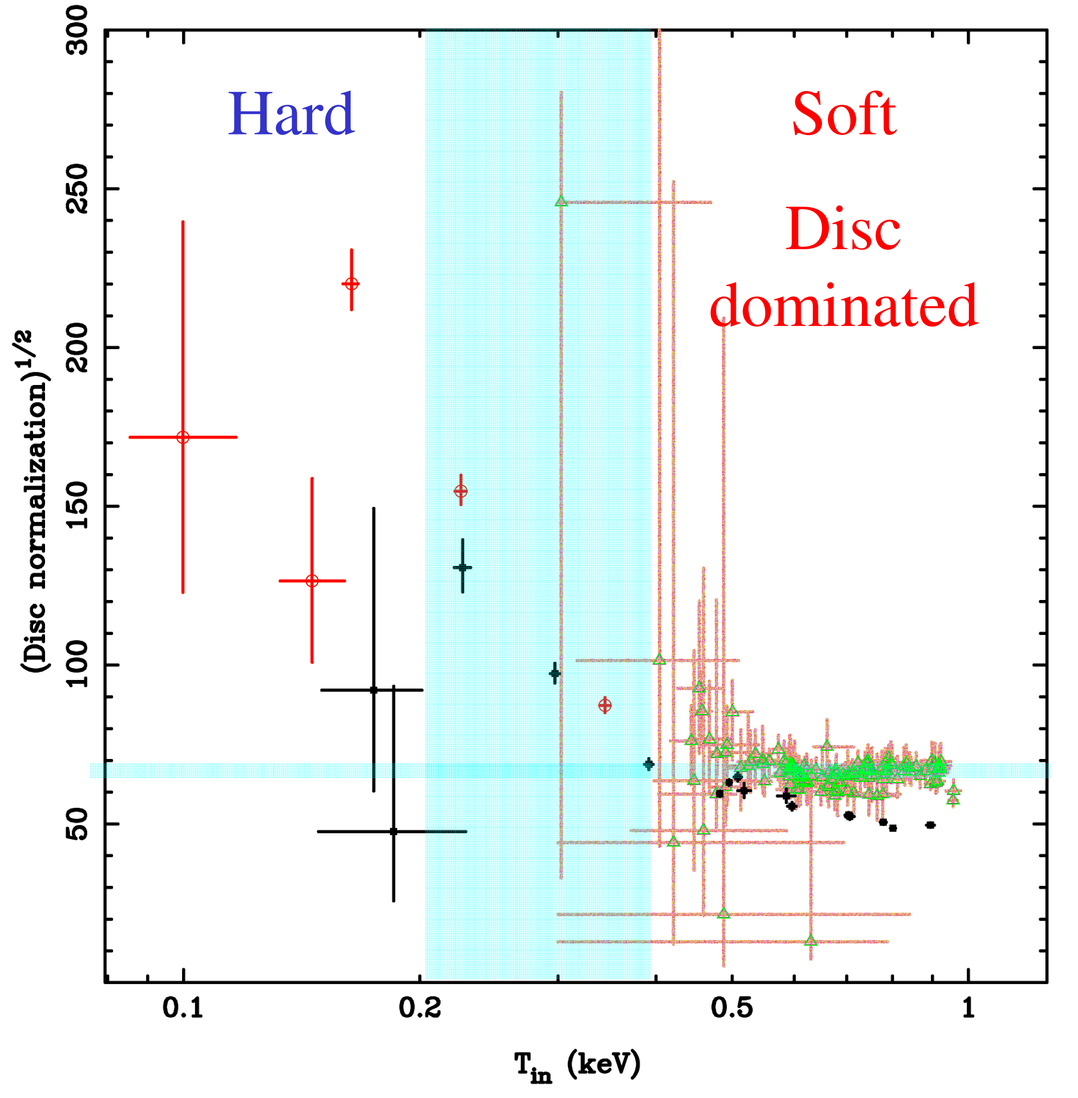

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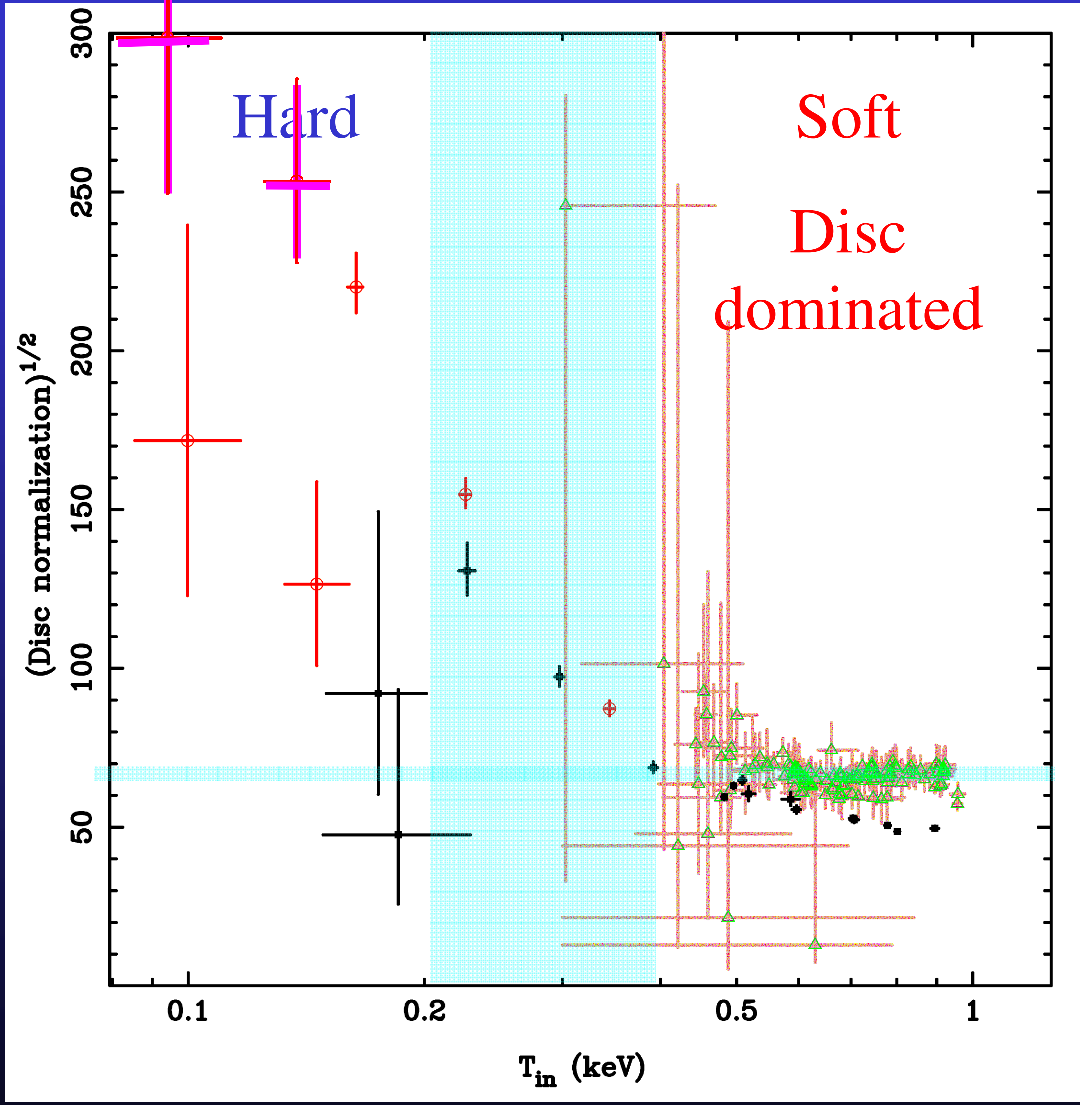

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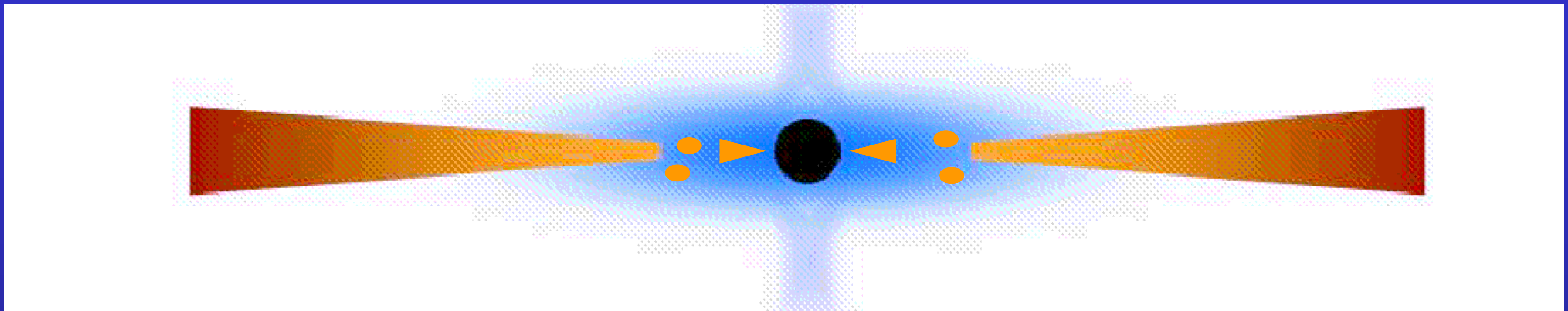
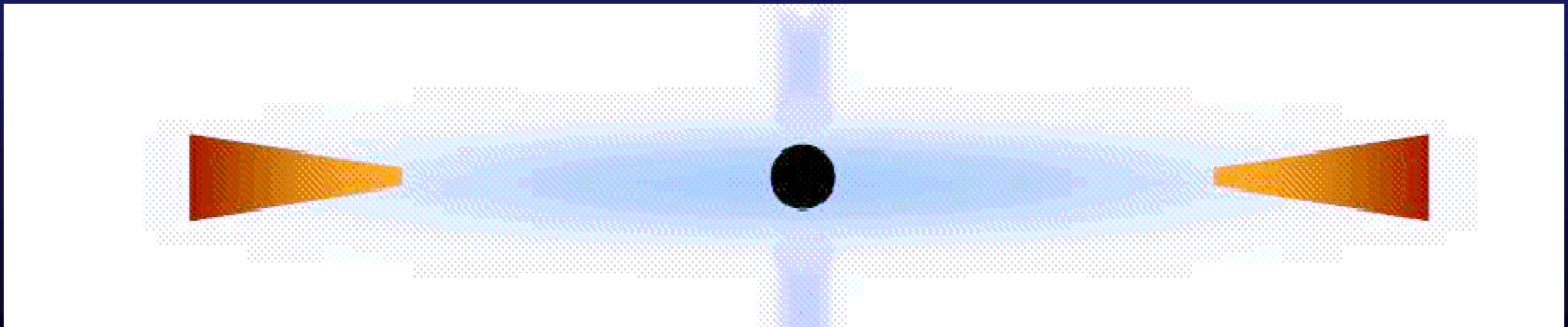


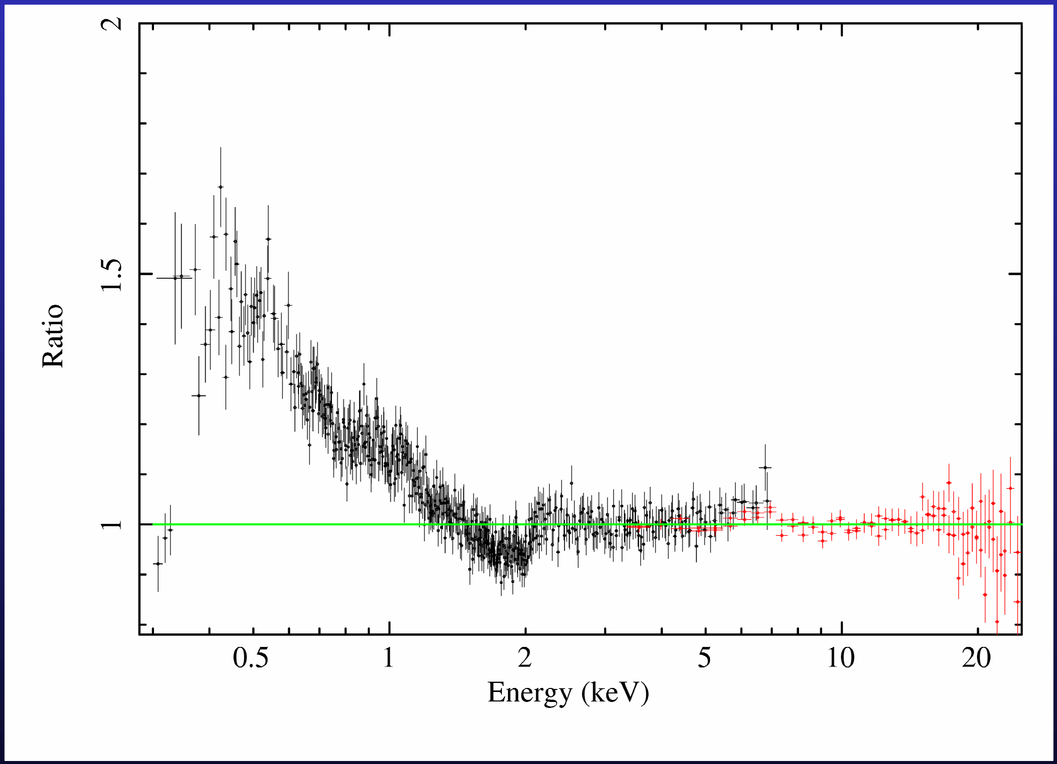
- Expect transition to be messy! Clumpy?
- Disc evaporation gives residual disc close to transition Liu et al 2006; 2008
- Cleaner to look at lower luminosity low/hard state



But is there really a hole?

challenge 3

Reis et al 2009



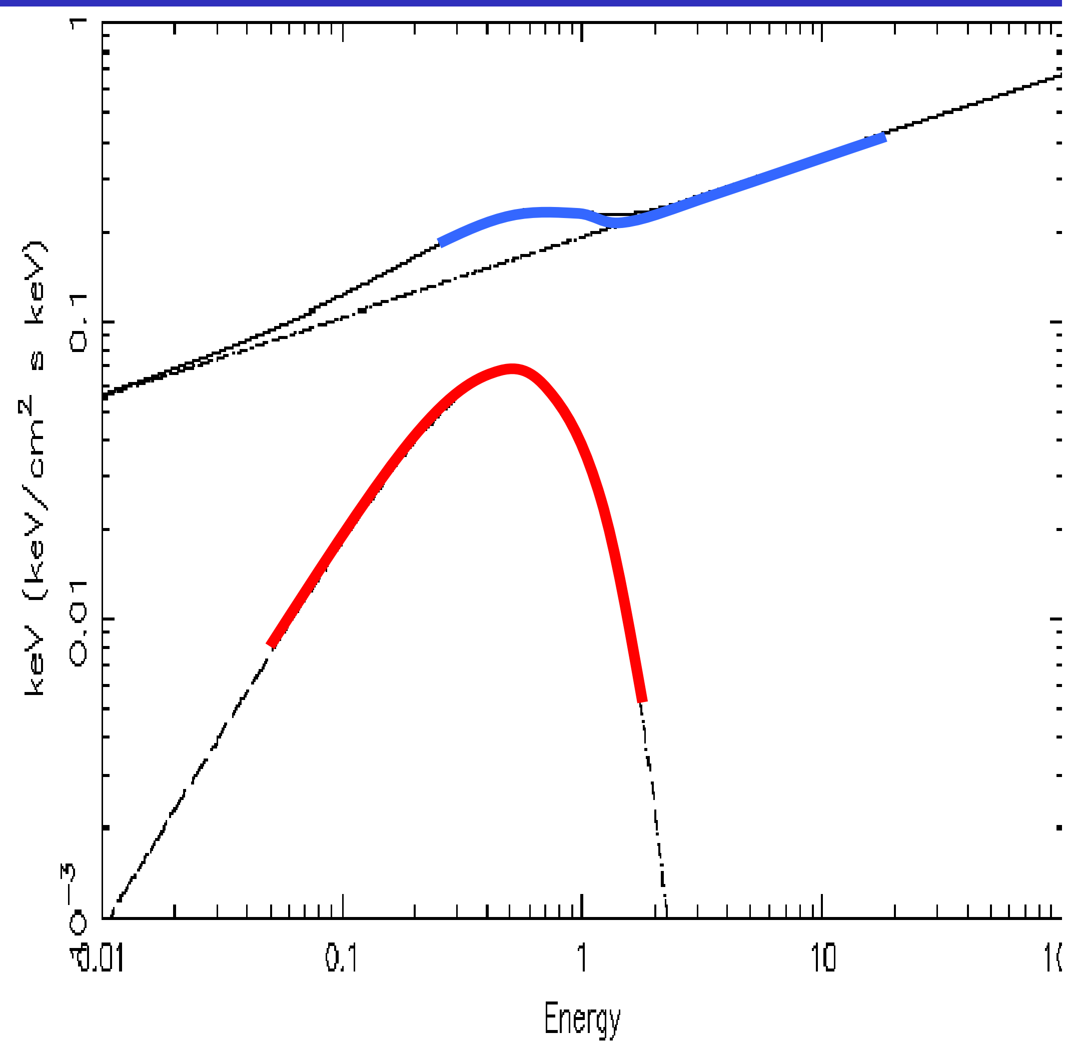
- Soft X-ray component in deep quiescence
- $L_{bol} \sim 0.001 L_{Edd}$

  XTE J1118 Reis, Miller & Fabian 2009
- kT ~ 0.2 keV plus luminosity give radius. Most likely small (Reis et al 2009)

And we do SEE a cool disc

McClintock et al 2001; Reis et al 2009

- McClintock et al 2001 & Esin et al 2001 said no soft x-ray disc from same data
- But LETGS calibration was preliminary – Reis et al 2009 reanalysis shows soft X-ray rise
- Lc~20 Ld



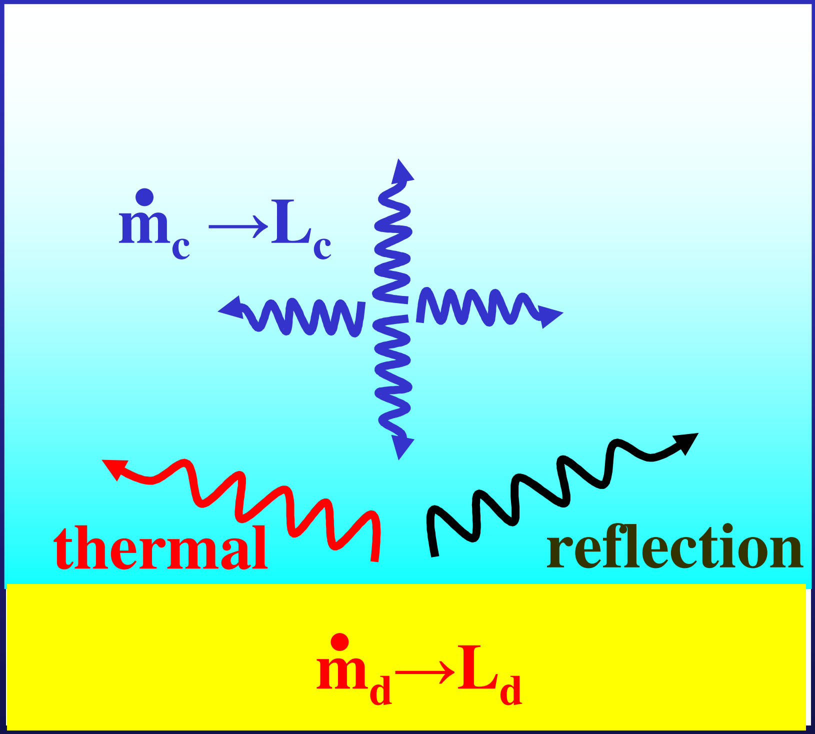
Hot inner flow in low/hard state ?

- But corona also must come from small radii as that's where gravity power is so cospatial
- Lc/Ld > 20!!! So mass accretion rate through corona > 20x mass accretion rate through disc!!
- But illumination - more thermal emission from reprocessing

  Ld > ½(1-a) Lc ie Lc/Ld < 3

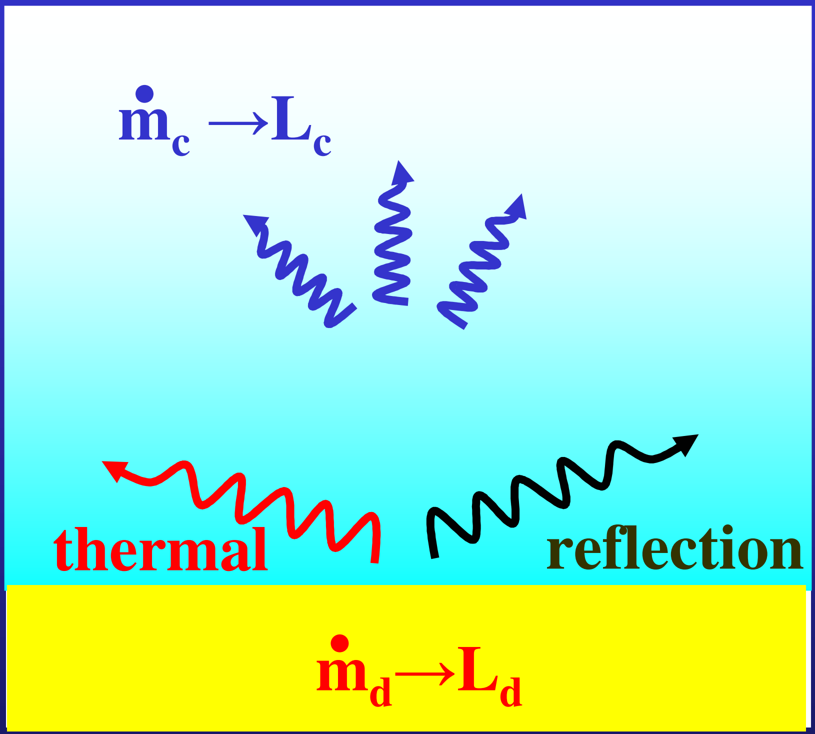
  (Haardt & Maraschi 1993) as a < 0.3 for hard spectrum
- So this weak soft X-ray emission can't come from this geometry!

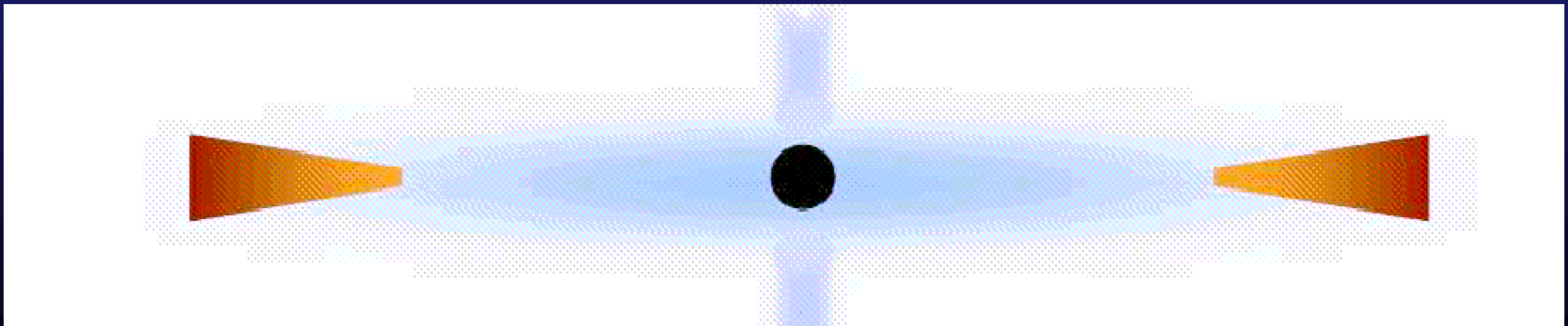
Chiang & Done 2009



Hot inner flow in low/hard state ?

- So maybe the hard x-ray source is beamed away from the disc ? Part of jet?
- But can't simultaneously explain very broad line as that need focussing TOWARDS disc – but the 'line' is from pileup so its OK





And we do SEE a cool disc

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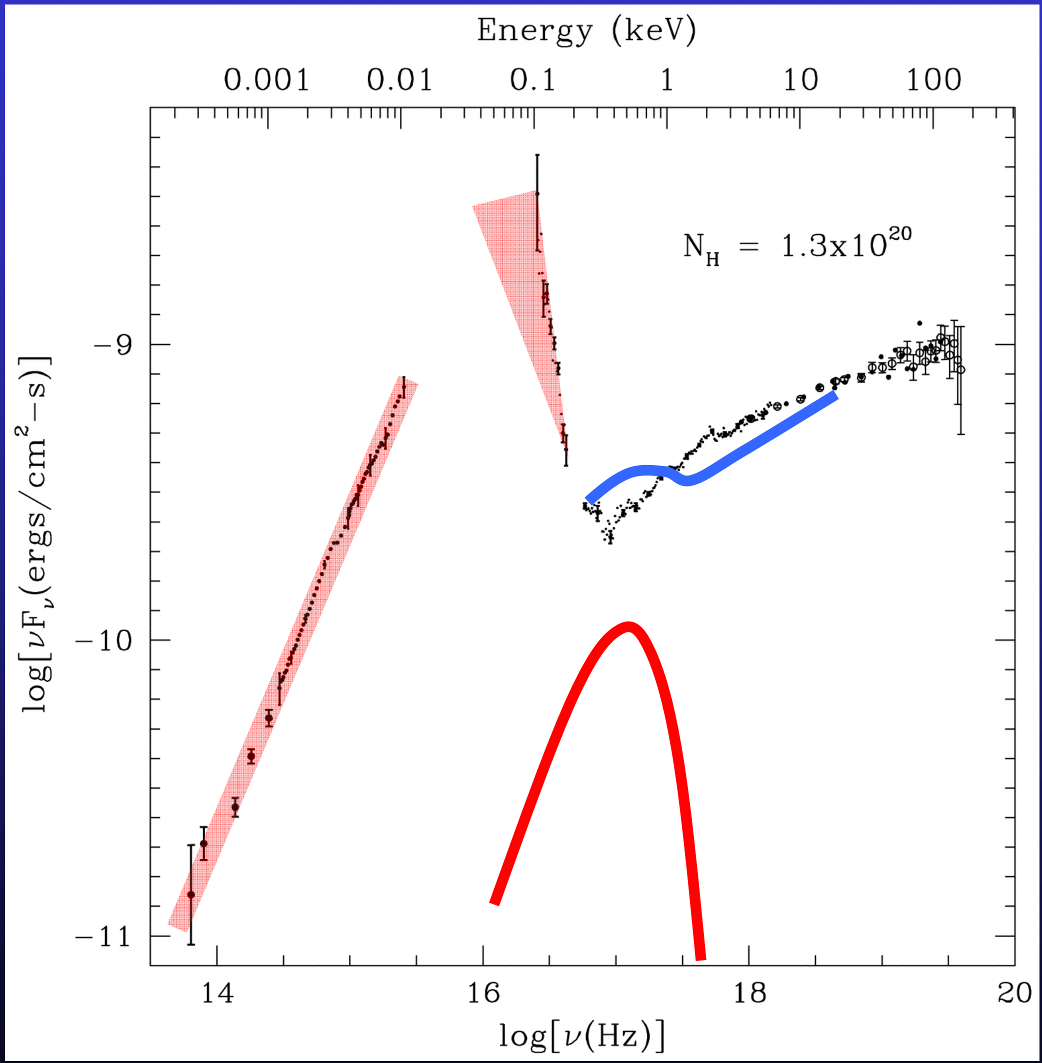
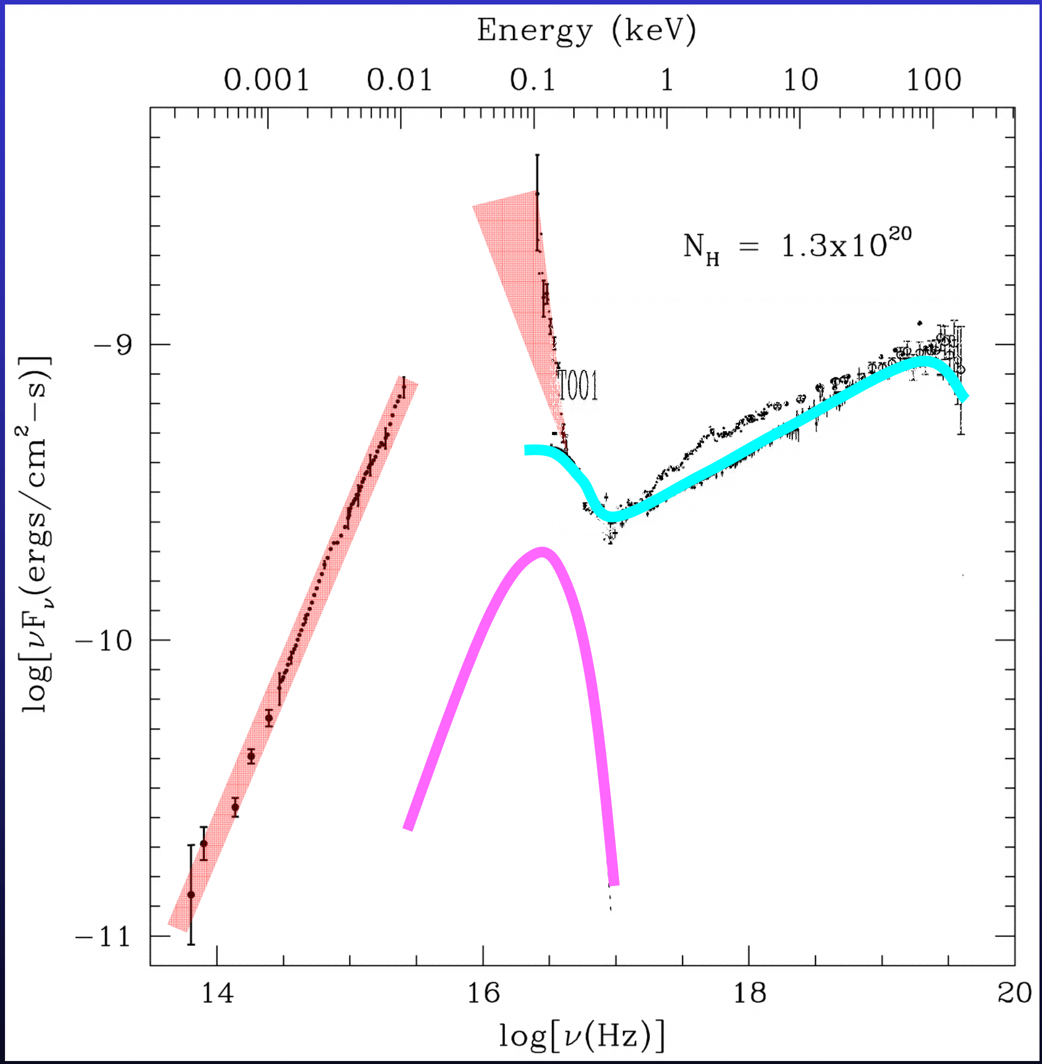


McClintock et al 2001; Reis et al 2009

And we do SEE a cool disc

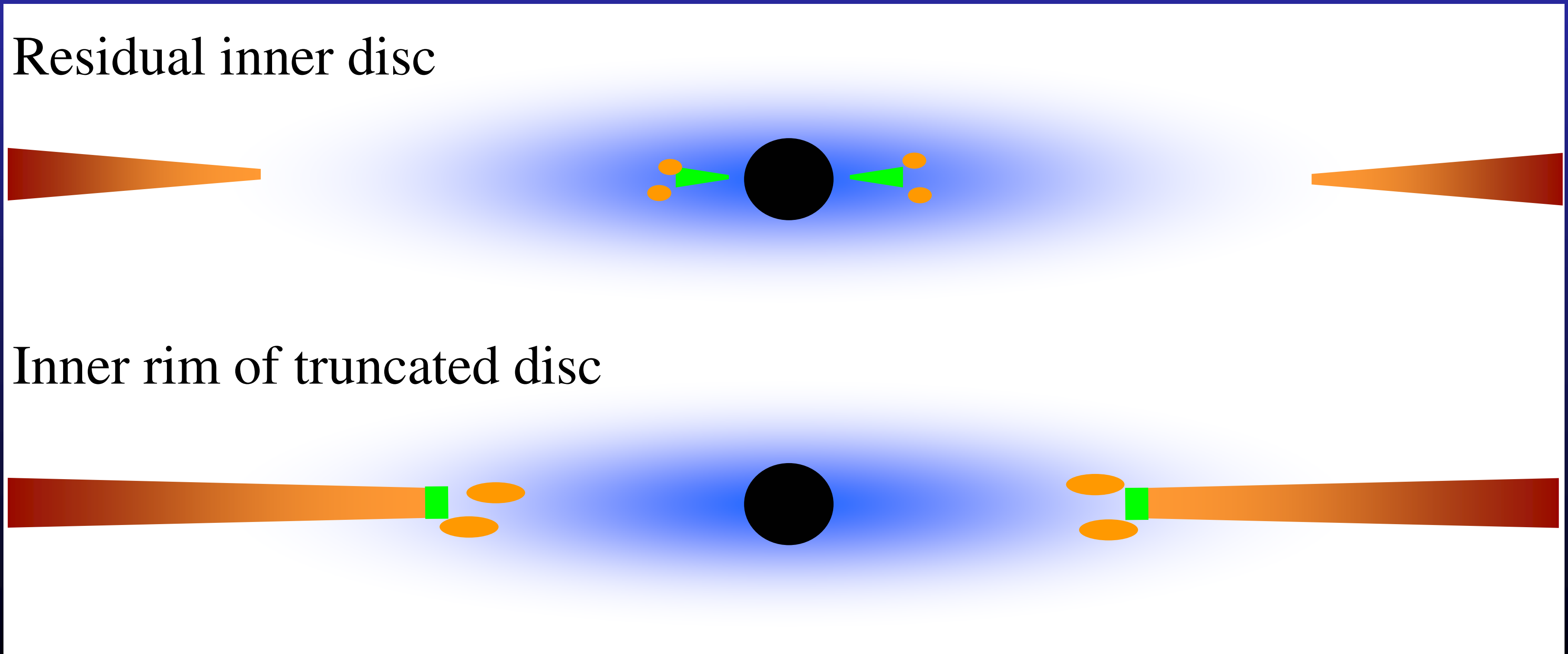
- Similar to beppoSAX Frontera et al 2001; 2003 from few days earlier
- Soft X-ray component in deep quiescence
- But simultaneous UV/EUV data show much bigger and cooler - truncated disc!
- So if that's the disc, what is the soft X-ray component??



McClintock et al 2001; Frontera et al 2003

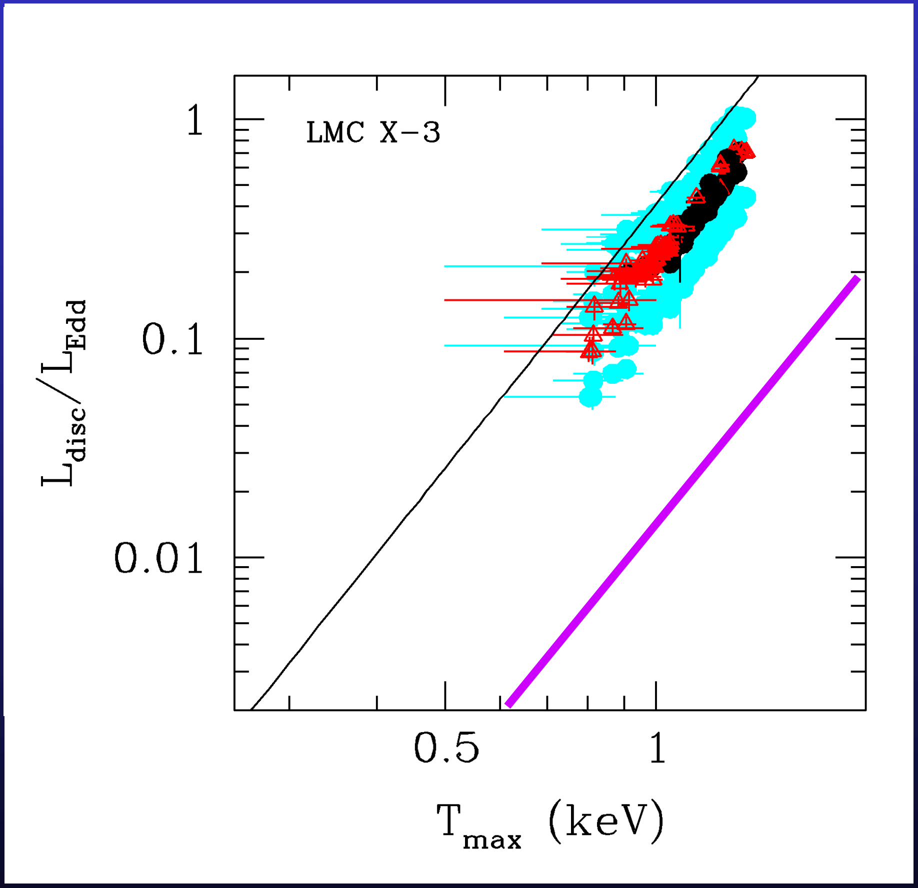
Two components?

- Truncated cool disc for UV component
- Relatively high kT, small luminosity implies small area
- Either residual inner disc
- Or inner rim of truncated disc Chiang & Done 2009



Soft state: Disc spectra: last stable orbit

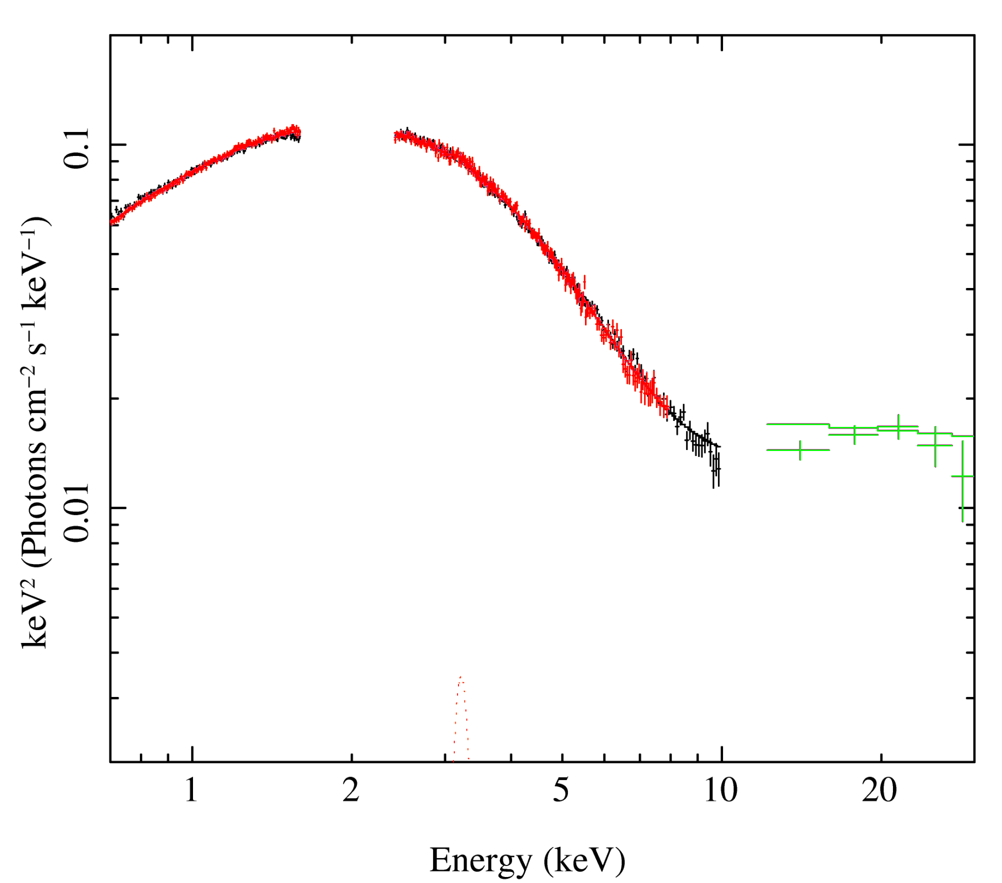
- Bewildering variety
- Pick ONLY ones that look like a disc!
- $L/L_{Edd} \propto T^4_{max}$ (Ebisawa et al 1993; Kubota et al 1999; 2001)
- Constant size scale – last stable orbit!!
- Proportionality constant gives a measure R_{lso} i.e. spin
- Consistent with low to moderate spin **not** extreme spin
- But how moderate?



Gierlinski & Done 2003

Observed disc spectra

- Fit excellent disc models but mass 7-9M and i=67-50
- $R_{in} \propto D^2/(M^2 \cos i)$ can change by factor 2.7
- Only factor 2 in Rin from 6-3Rg changes derived spin a=0-0.7!!
- LMC X-3 is the BEST determined system parameters (certainly best distance!) so CAN'T get Rin to better than factor of 2 for any BHB using this method

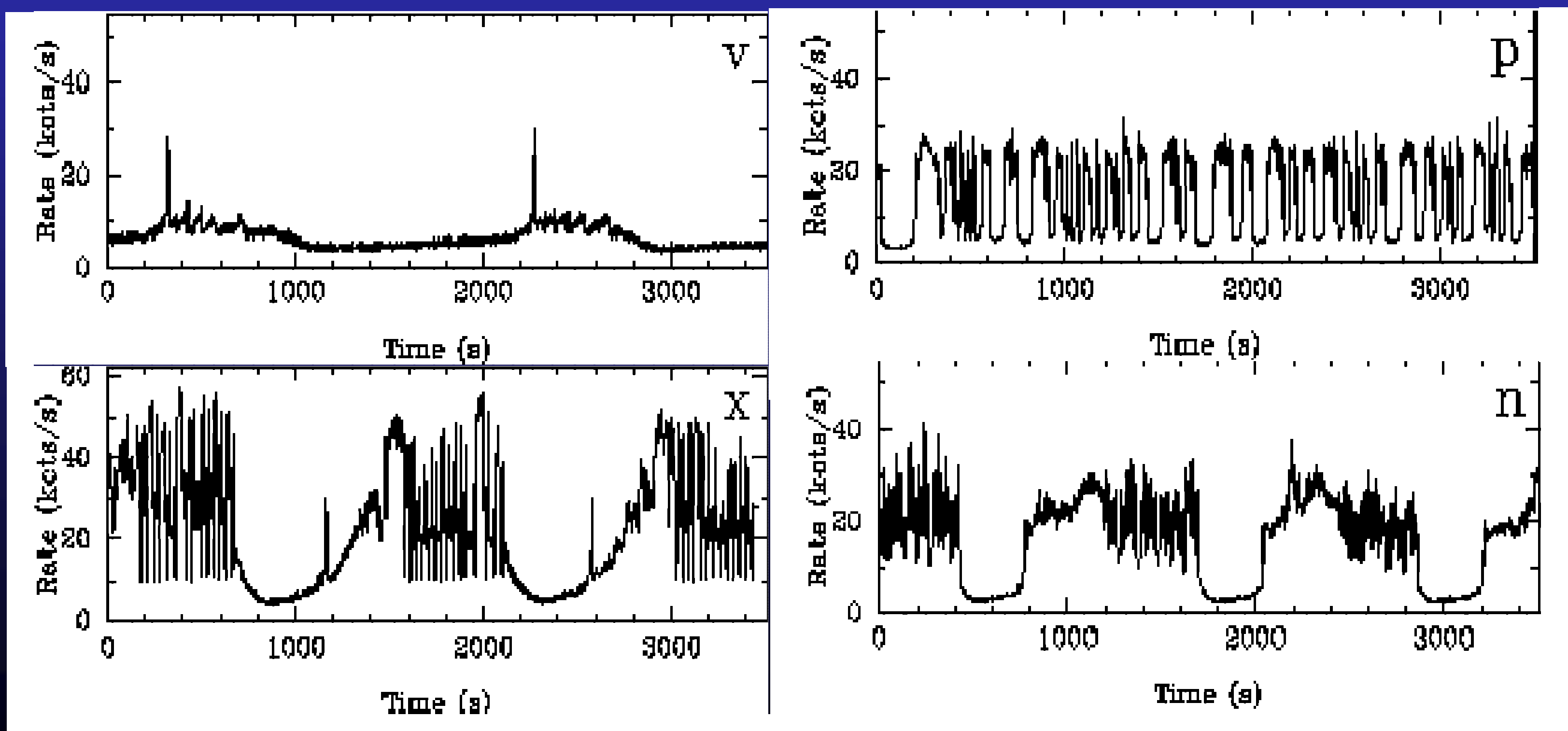


Kubota et al 2009

GRS 1915+105

- Microquasar, relativistic jet, UNIQUE limit cycle variability in 50% of data - most likely because it goes to uniquely high L (Done Wardzinski & Gierlinski 2004)

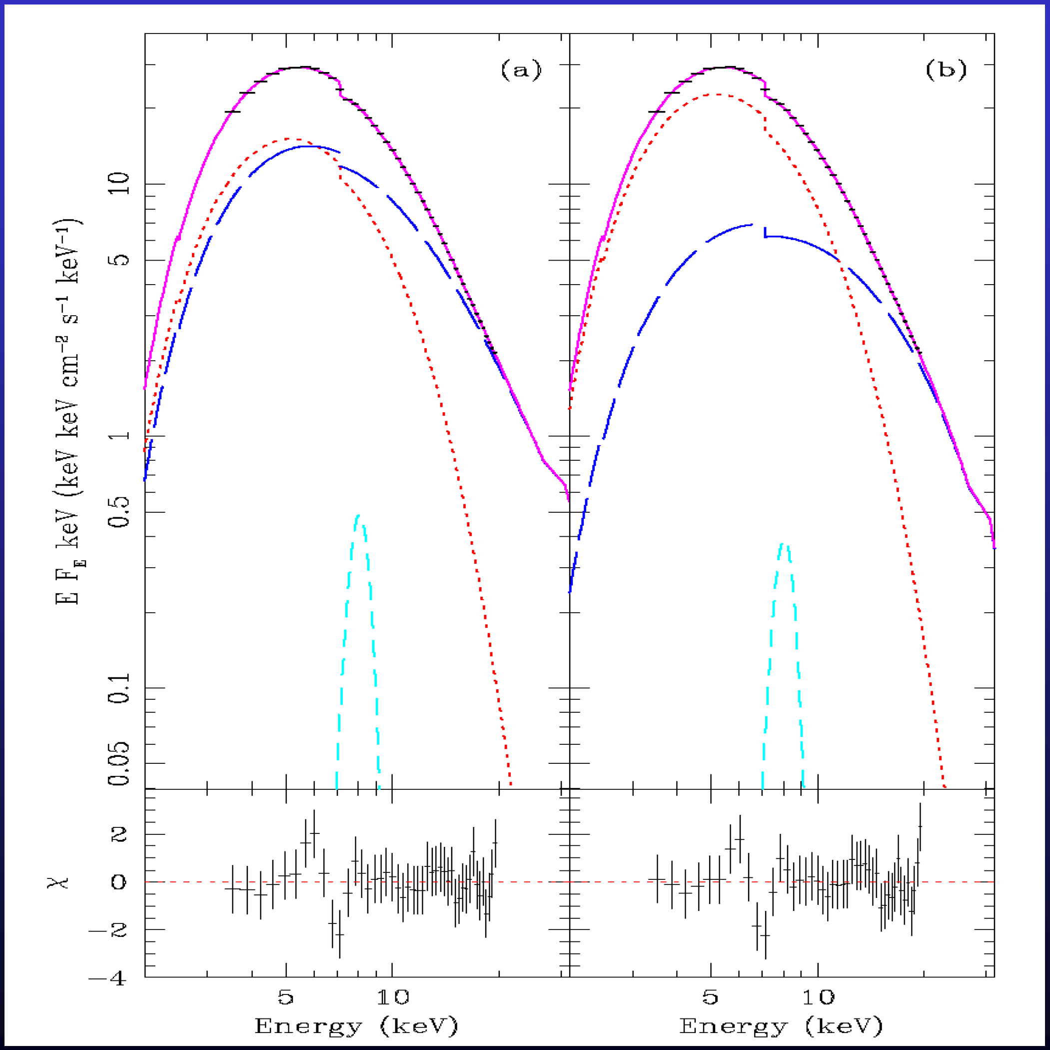
Belloni et al 2000



GRS1915+105

- See a lot of low kTe spectra in the superEddington BHB GRS1915+105
- High Nh so difficult!
- Can't assume electrons always high temperature! Fits better with kT_e~3 keV
- Obvious wind features even at RXTE resolution!

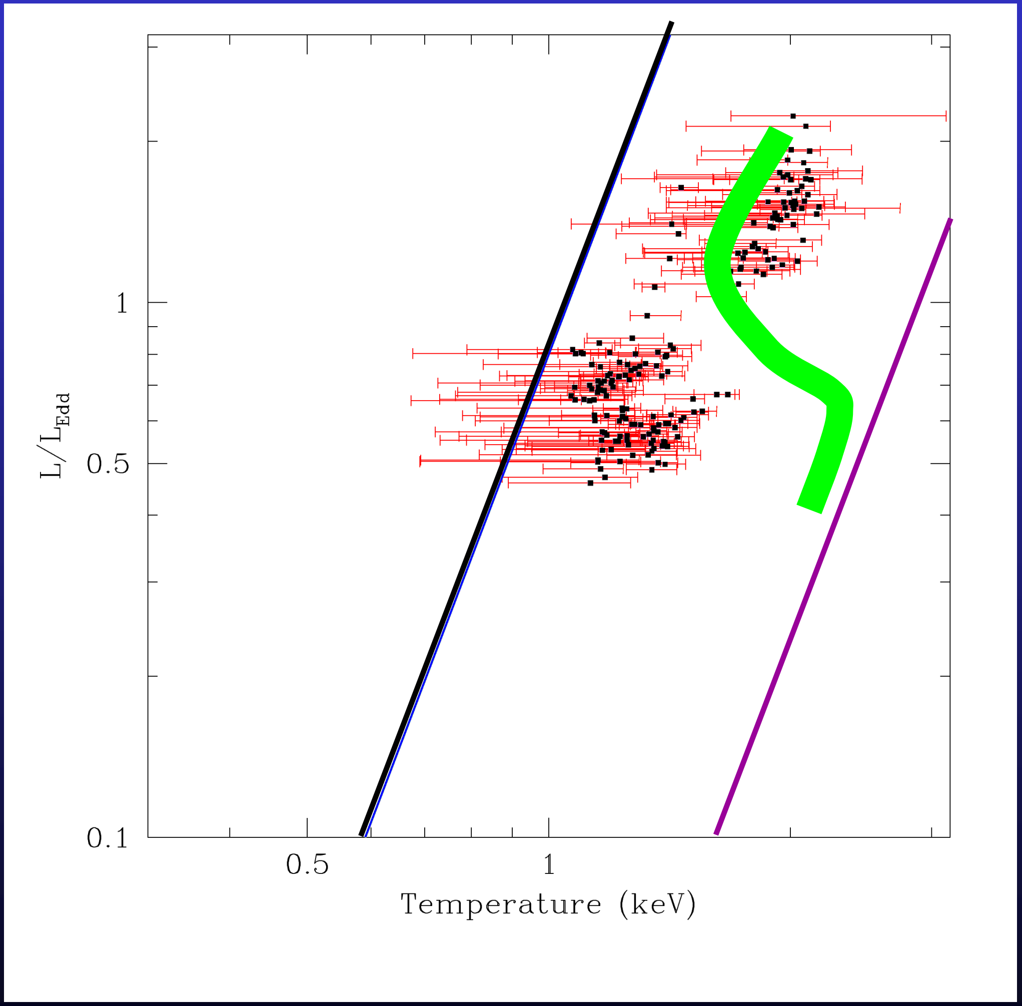
kT_e free $\quad$ kT_e=50 keV



Middleton, Davis, Done & Gierlinski 2005

Last stable orbit in GRS1915

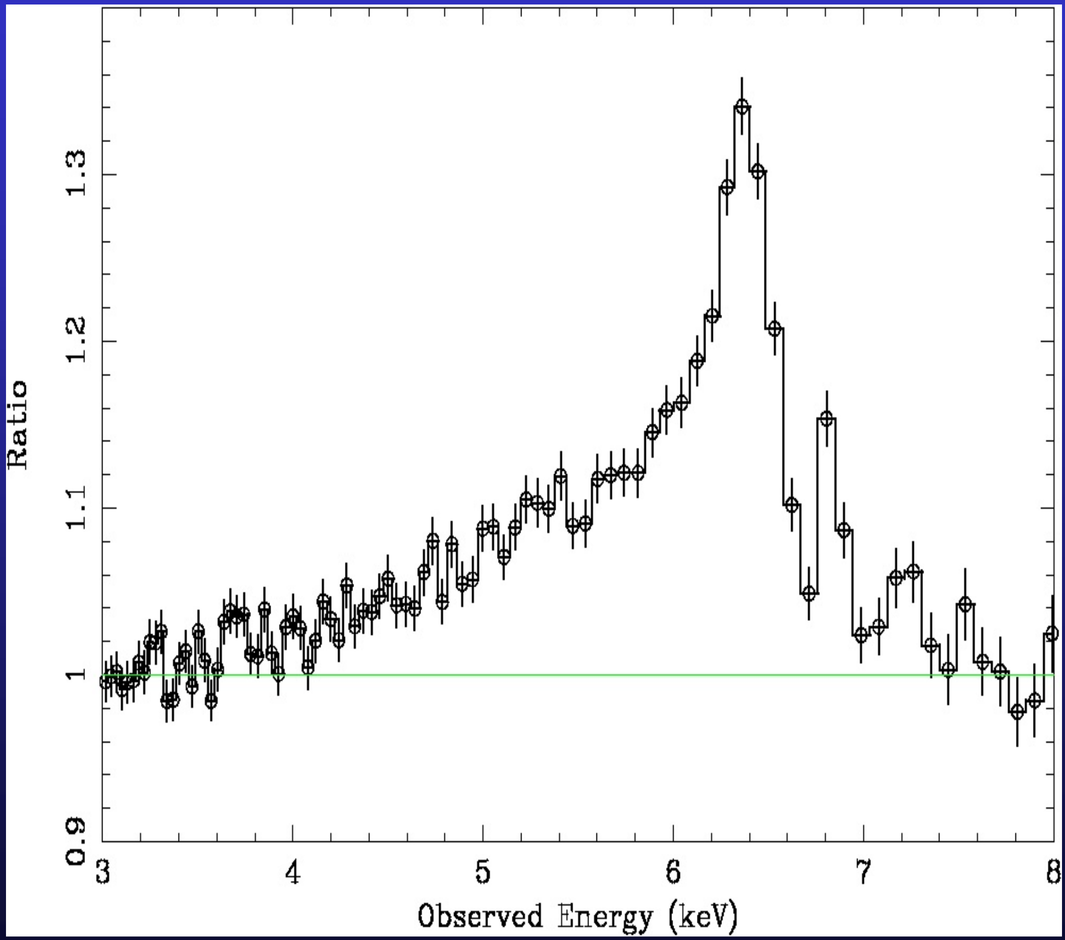
- Moderate spin (a_*~0.7) if kTe free (Middleton et al 2006) as expected in supernovae collapse (Gammie et al 2004)
- Extreme spin at L<L_{Edd} if kT_e fixed at 50 keV Shaffee et al 2007
- Moderate spin seems more likely! But obviously not robust.



Middleton, Davis, Done & Gierlinski 2006

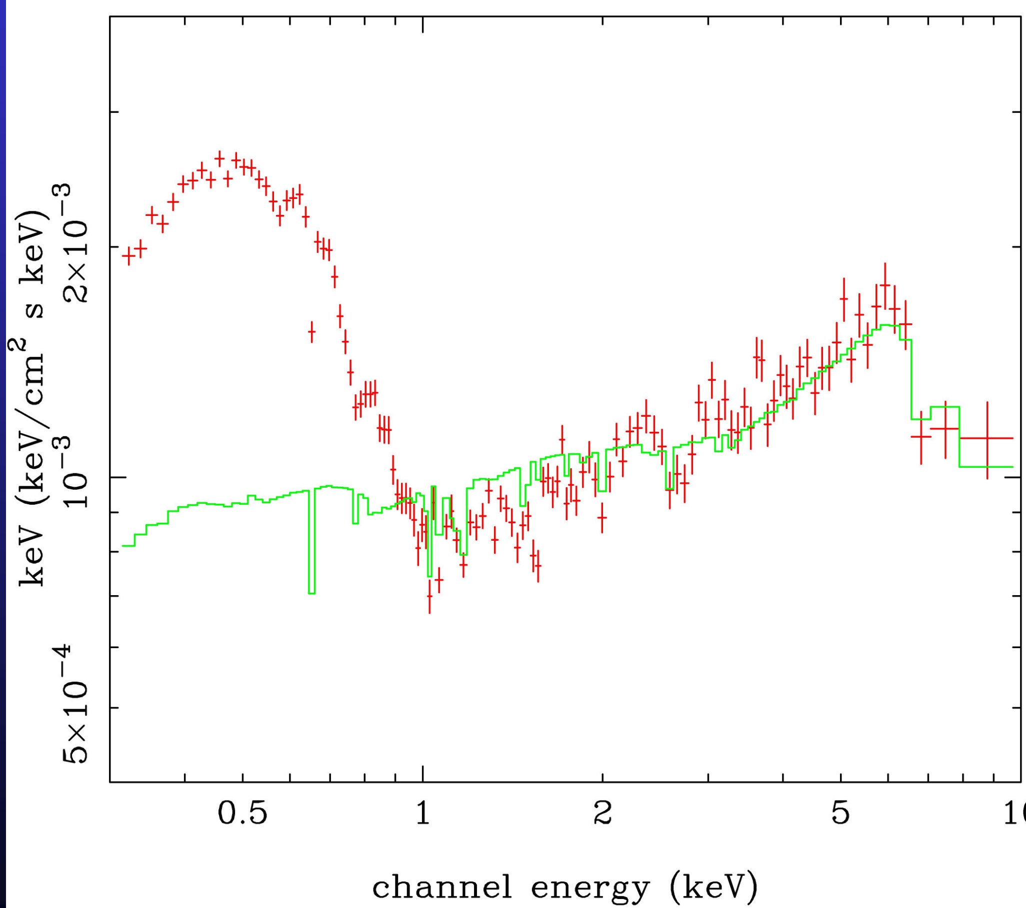
Soft Excesses/broad iron lines in AGN

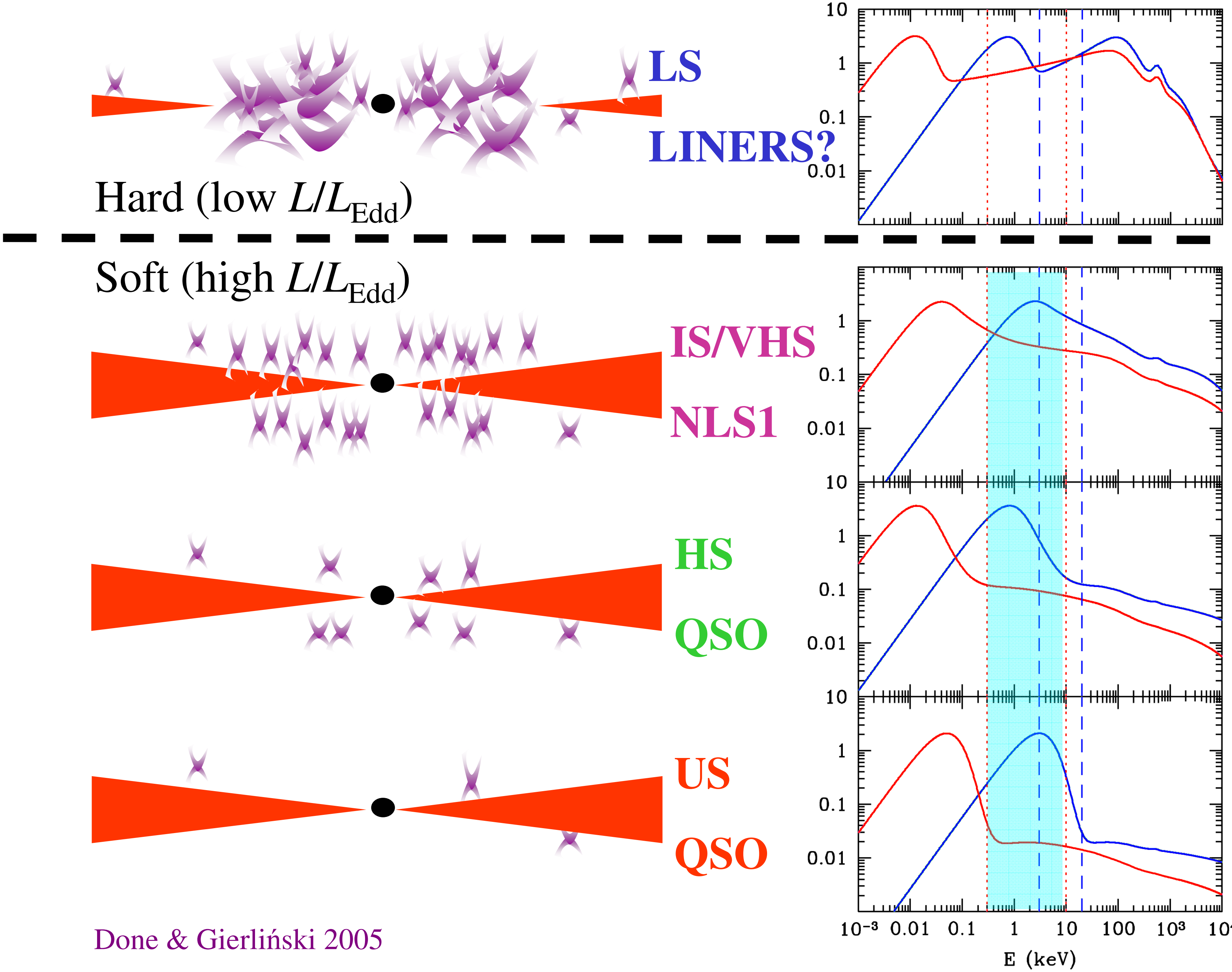
- Broad wing to red side of iron line
- Extreme relativistic smearing ? But need very centrally concentrated illumination, and large reflection fractions
- Are there any alternative models?



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

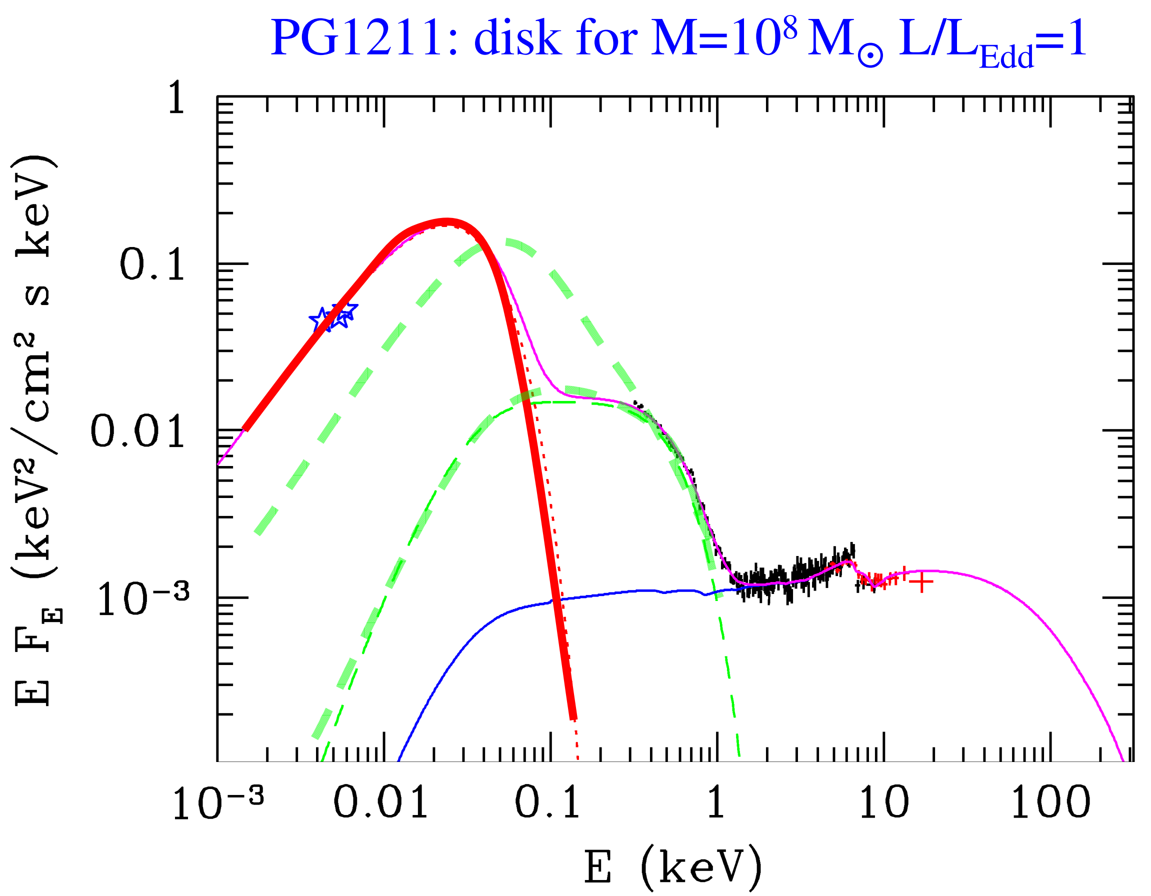



LS
LINERS?
Hard (low L/L_{Edd})
Soft (high L/L_{Edd})
IS/VHS
NLS1
HS
QSO
US
QSO
Done & Gierliński 2005
E (keV)

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

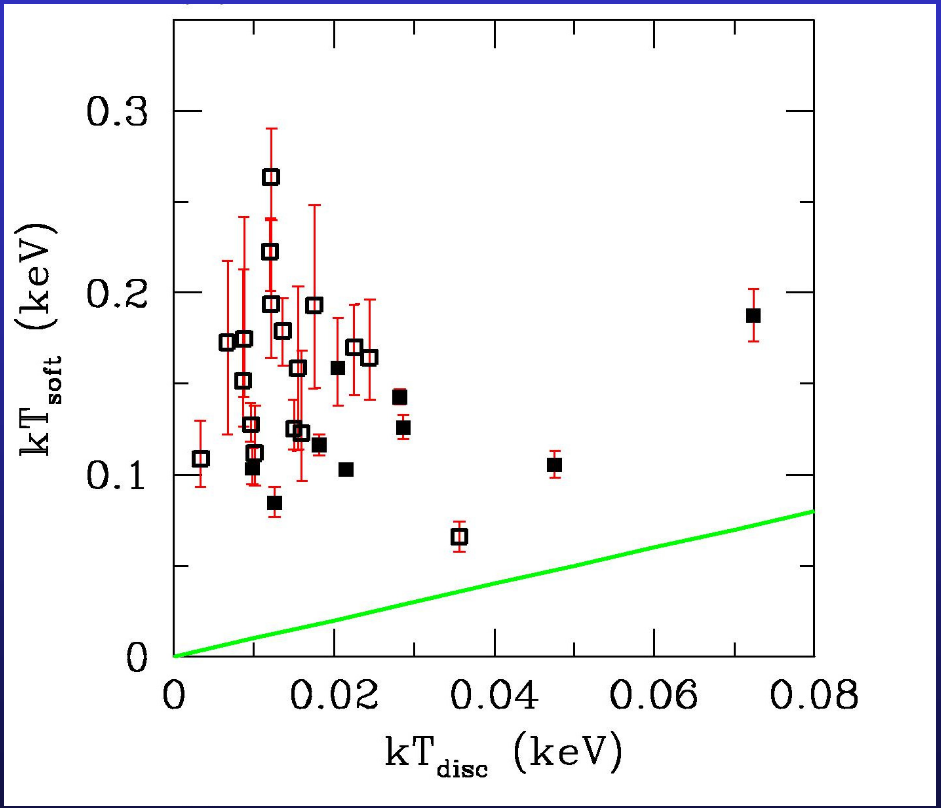


Gierliński & Done 2004

Comptonisation?

- $10^6 < M/M_\odot < 10^9$
  $0.1 < L/L_{Edd} < 3$
- ALL have approx. same kT_e for soft excess!! Walter & Fink 1993, Czerny et al 2003, Gierlinski & Done 2004, Crummy et al 2006
- Yet this should depend on ratio of electron heating to cooling, and number of electrons to share energy
- Some sort of thermostat?

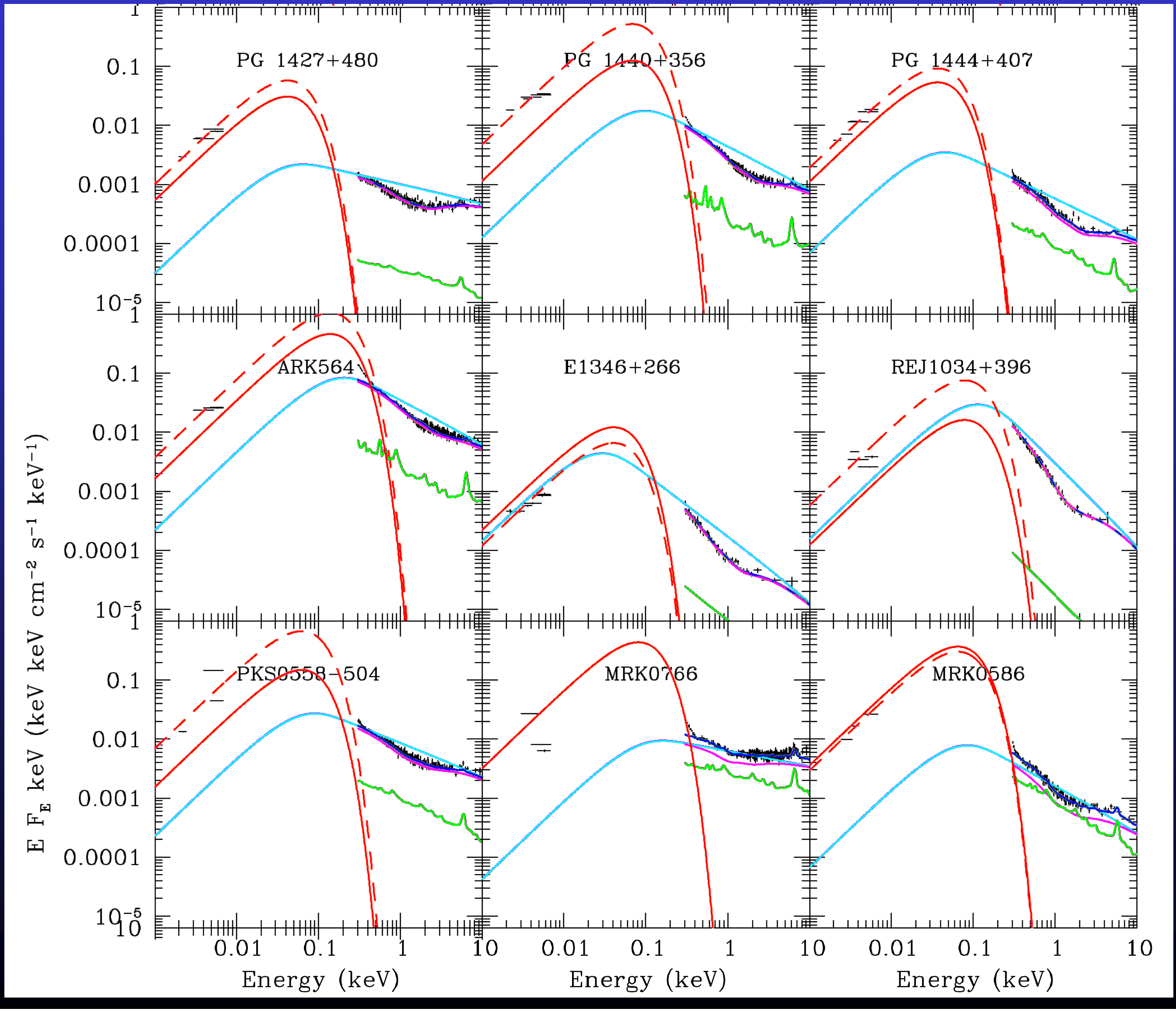
Gierlinski & Done 2004



Range of local high L/L_{Edd} AGN

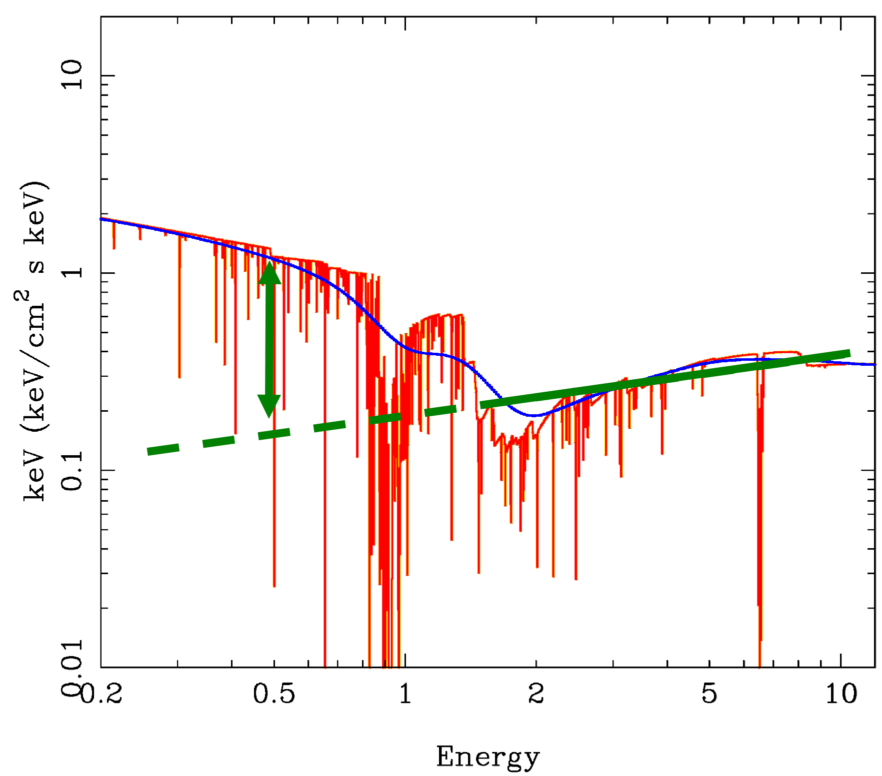
Middleton, Done & Gierlinski 2007

- 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!

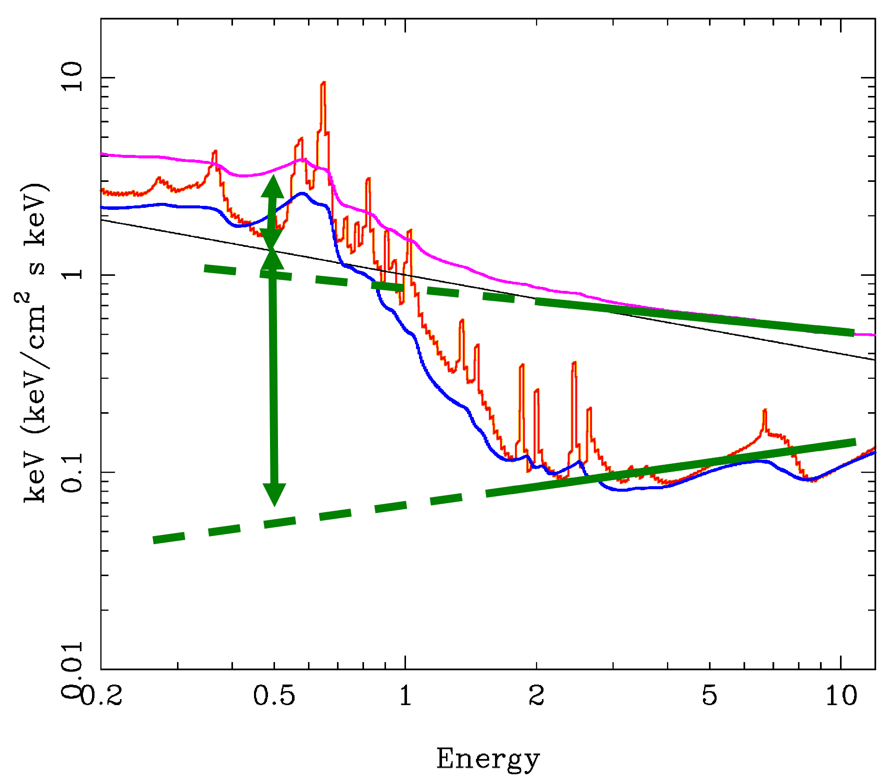


Partially ionised, relativistic material

- 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



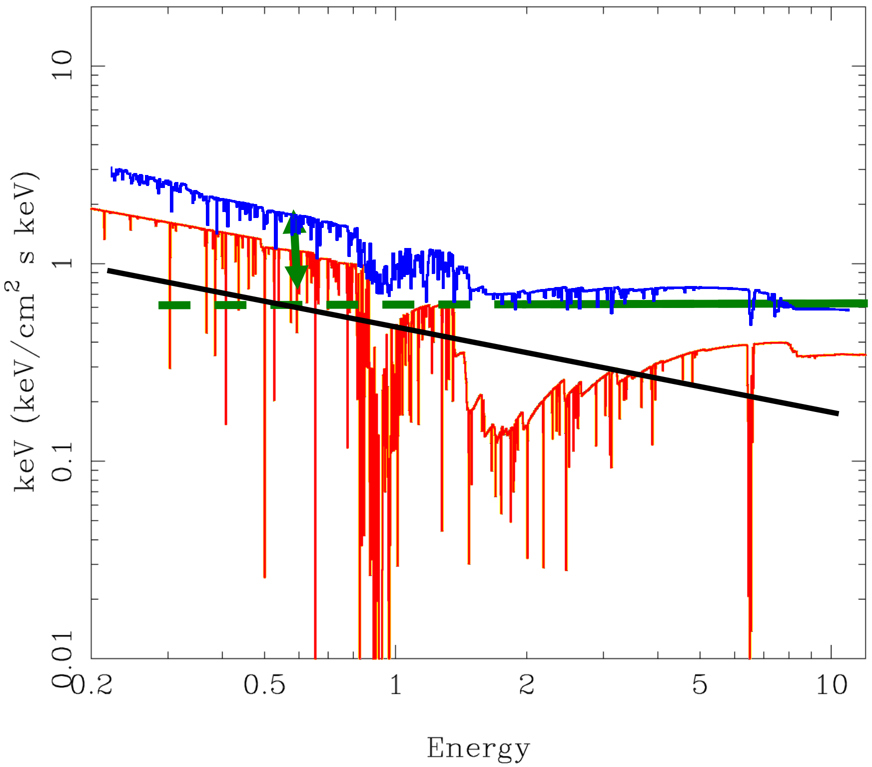
Gierliński & Done 2004, Chevallier et al 2006



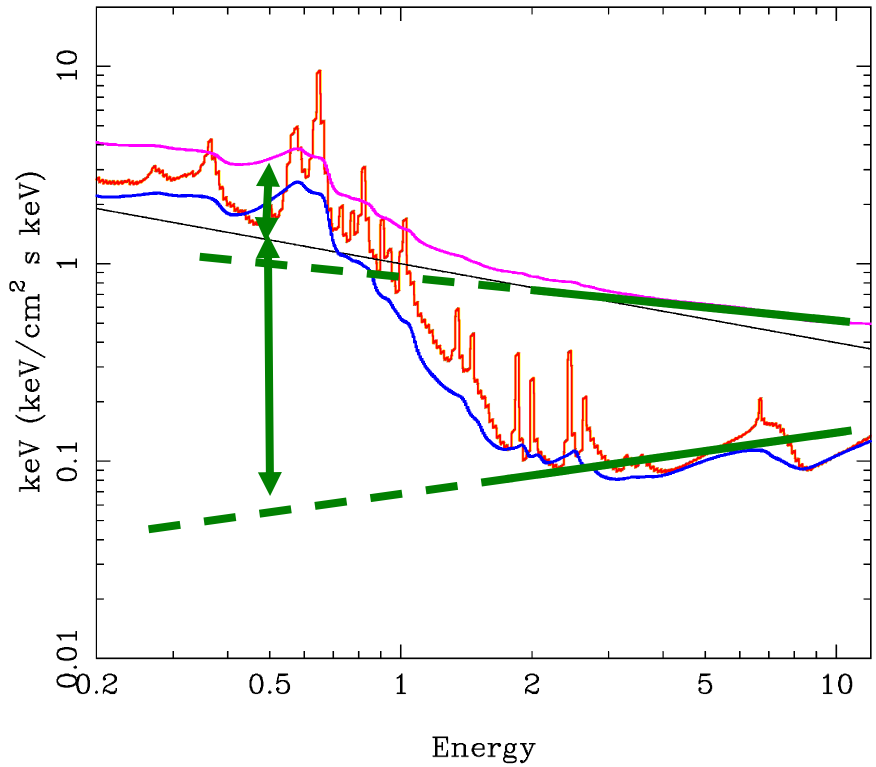
Fabian et al 2002; 2004 Miniutti & Fabian 2004

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



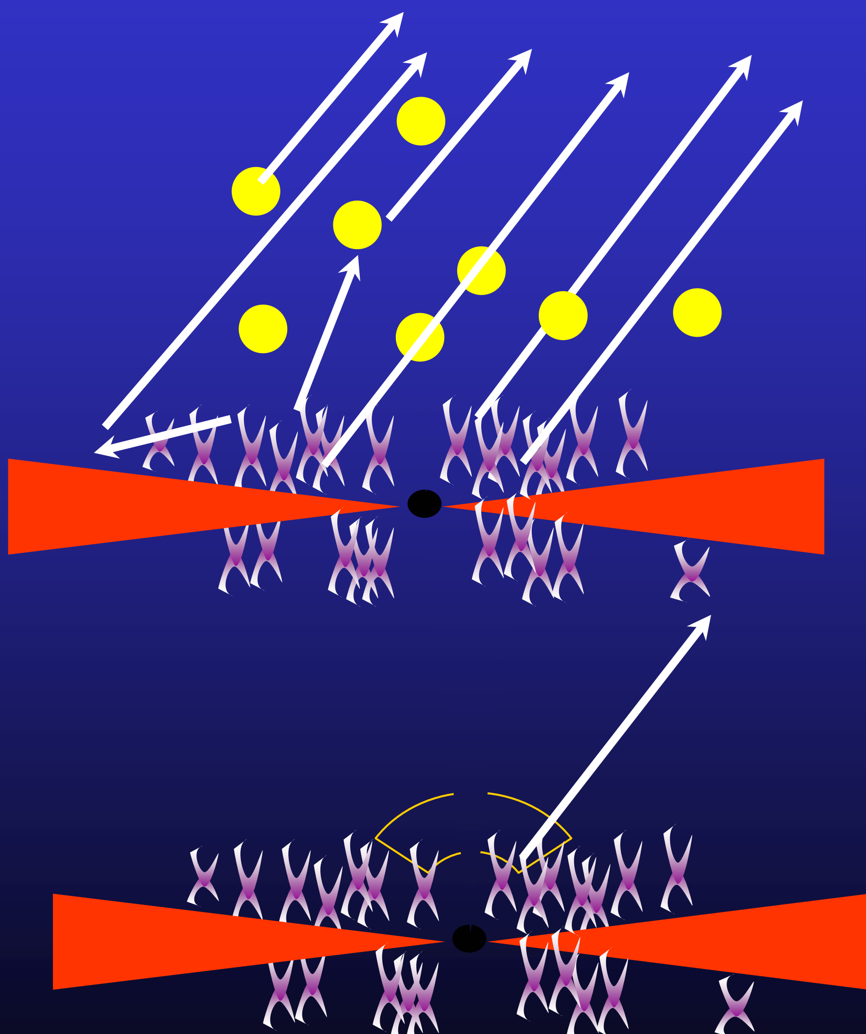
Inoue 2002; Miller et al 2007; 2008; Turner et al 2007



Fabian et al 2002; 2004 Miniutti & Fabian 2004

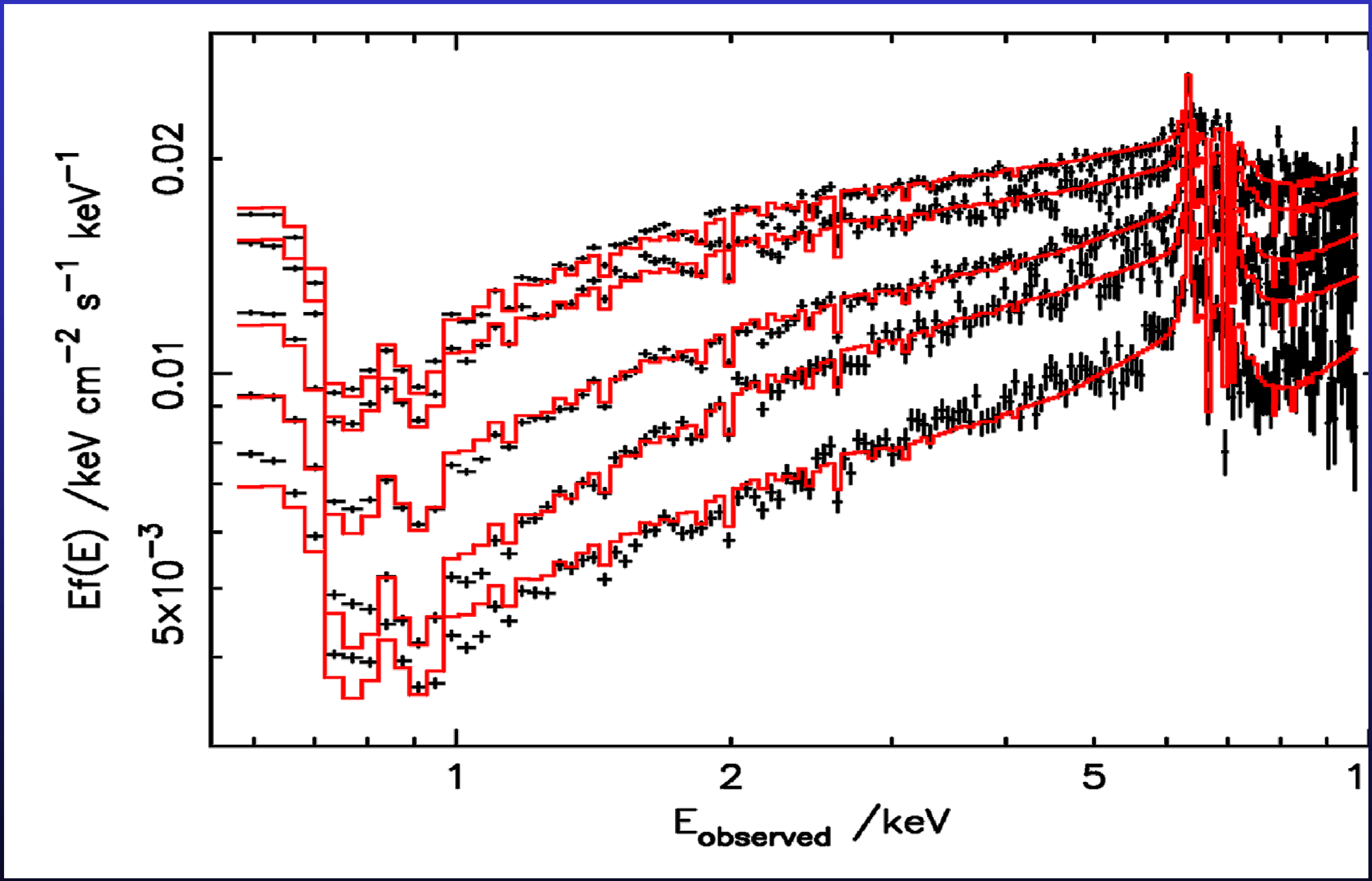
Alternative geometries for soft excess from partially ionised material

Reflection



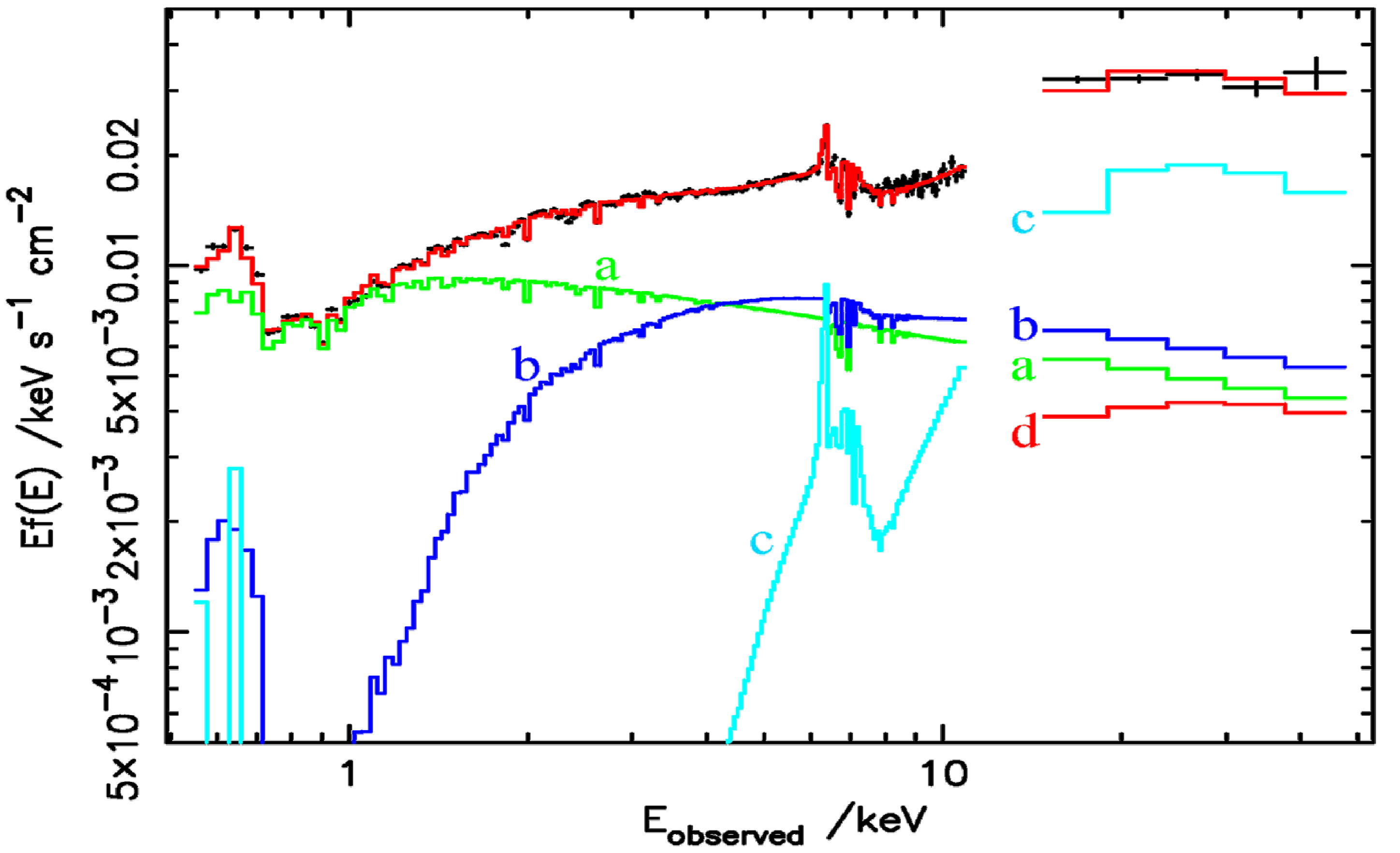
Absorption

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

Conclusions

- Low/hard state – everyone agrees disc truncates below $0.001L_{Edd}$
- But see all spectral and timing change at TRANSITION
- If the disc comes in below this, why don't we see it
- If it does come in below this, what causes what we do see!
- But no real problems either theoretical or observational
  - Evaporation gives inner hole in disc
  - Broad line in GX339-4 low/hard from instrumental pileup
  - Inner disc surface can be irradiated close to transition
  - Inner disc inner rim can be irradiated further out to get soft X-ray as well as truncated disc in UV
- Extreme lines in AGN could be from complex partially ionised absorption as well as reflection – might expect very strong outflows in these UV bright disc systems at $L \sim L_{Edd}$