Black hole accretion states and AGN activity

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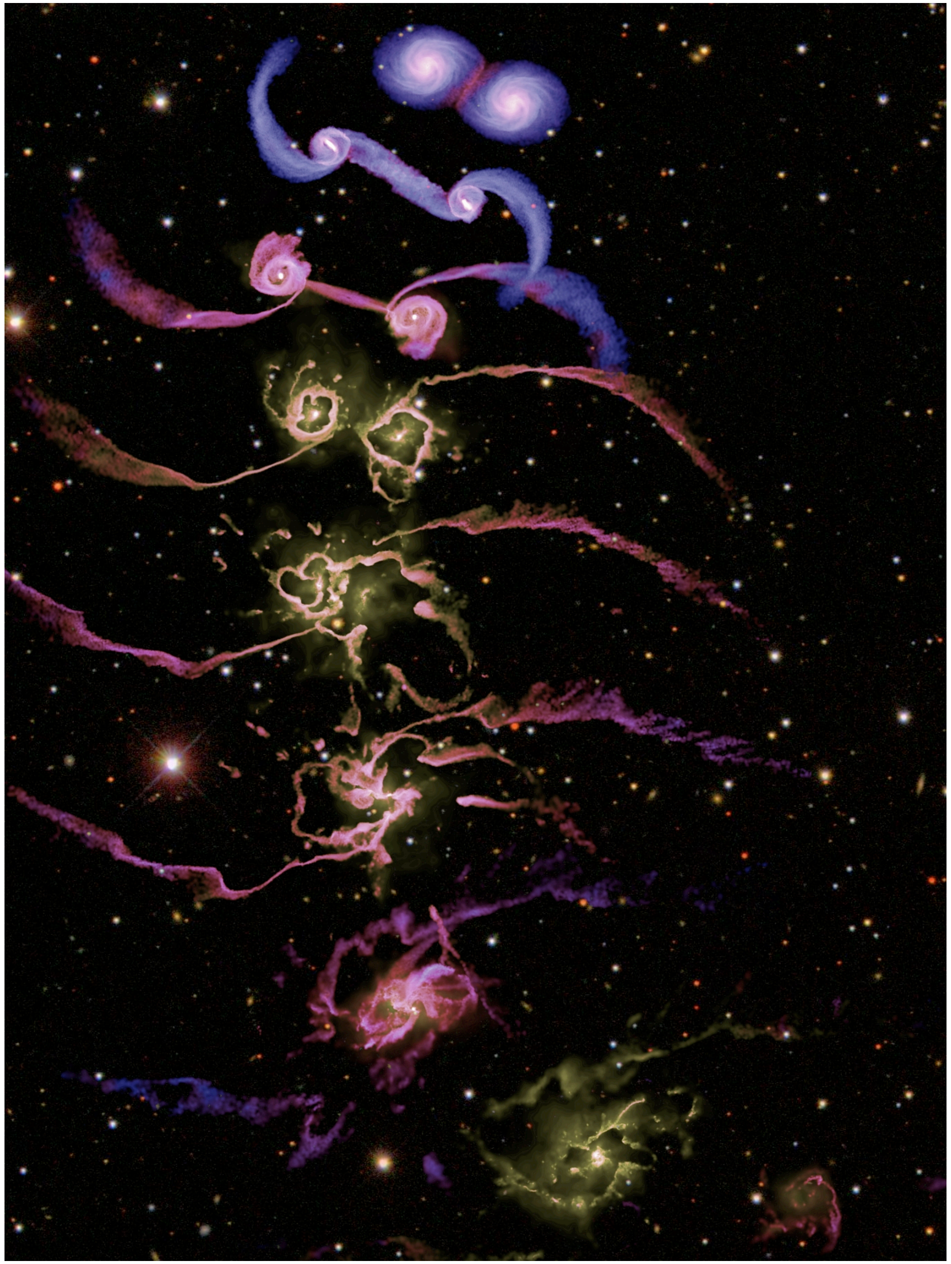
Black holes grow by accretion

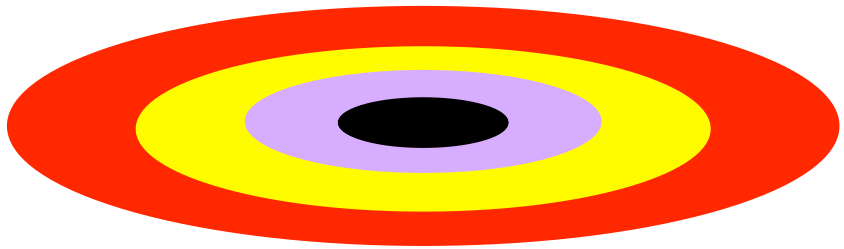
- Gas supply to nucleus
  - Galaxy disc instabilities
  - Major mergers
  - Minor mergers
  - Cooling flow of hot gas from halo
- Regulated by feedback – supernovae, radio mode, quasar mode (both radiation and winds)

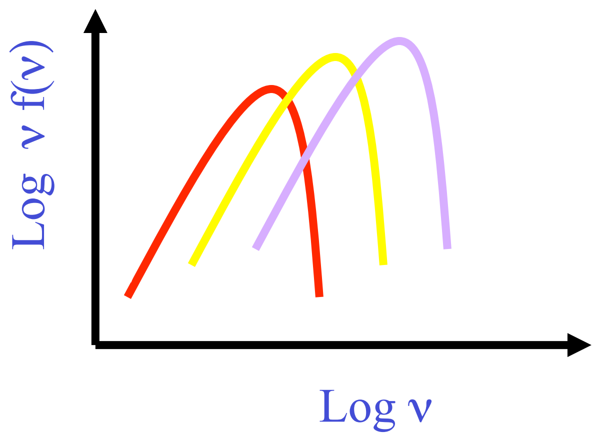


Di Matteo et al 2005

Spectra of accretion flow: disc

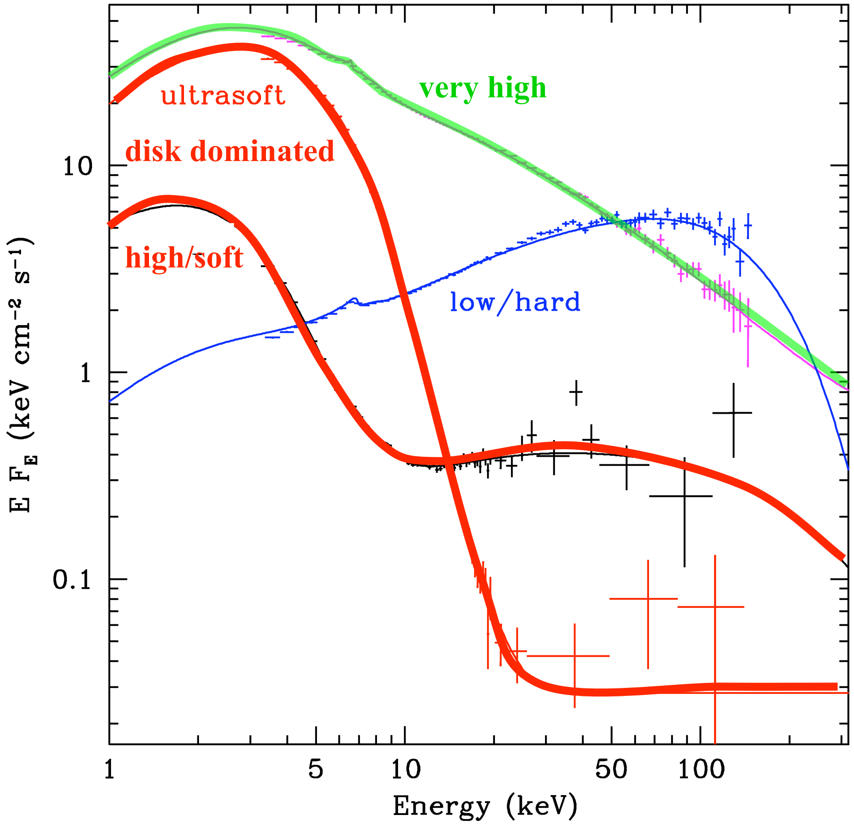
- Differential Keplerian rotation
- Viscosity B: gravity → heat
- Thermal emission: $L = A\sigma T^4$
- Temperature increases inwards until minimum radius $R_{lso}(a_*)$
  For $a_*=0$ and $L \sim L_{Edd}$ T_{max} is
  - 1 keV (10^7 K) for 10 $M_\odot$
  - 10 eV (10^5 K) for 10^8 $M_\odot$
  - big black holes luminosity scales with mass but area scales with $mass^2$ so T goes down with mass!





Spectral states in stellar mass BH

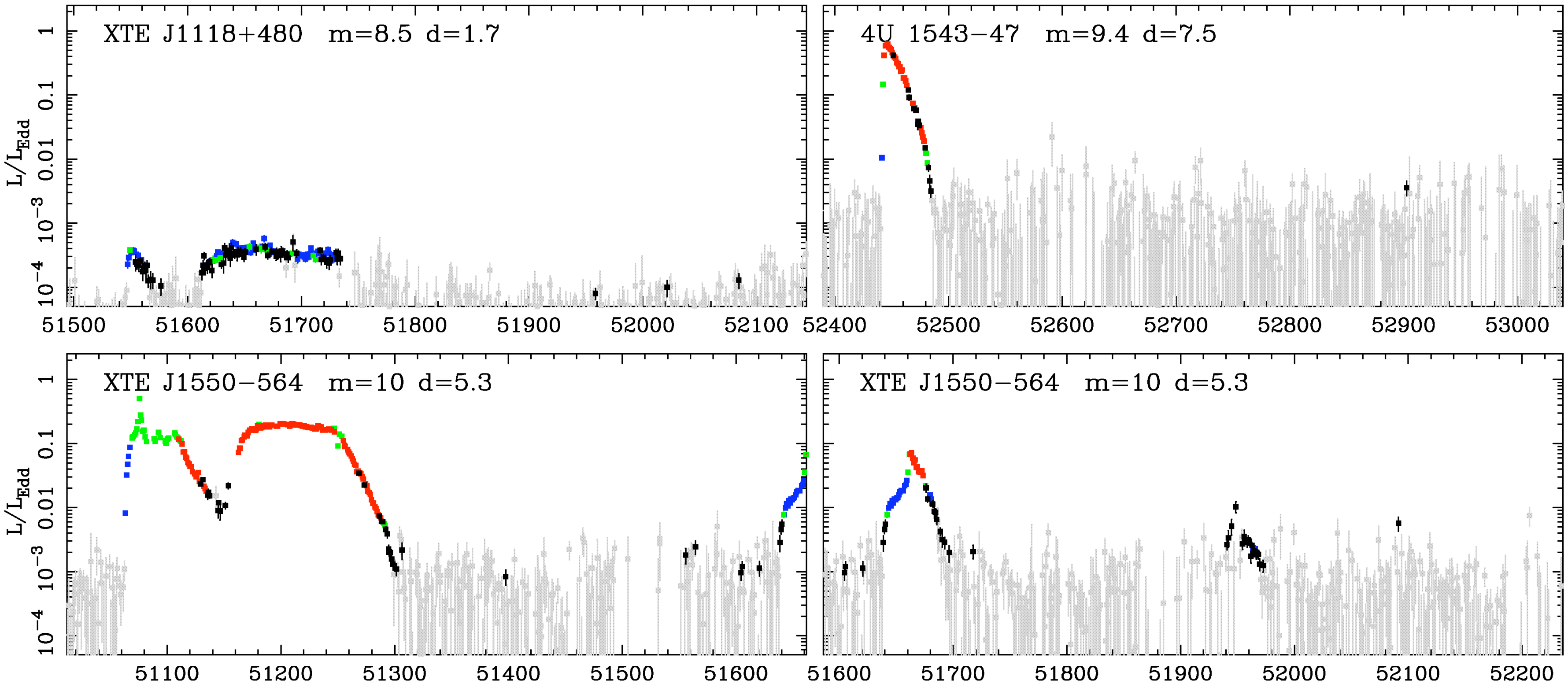
- Dramatic changes in continuum – single object, different days (Nowak 1995)



Gierlinski & Done 2003

Transients

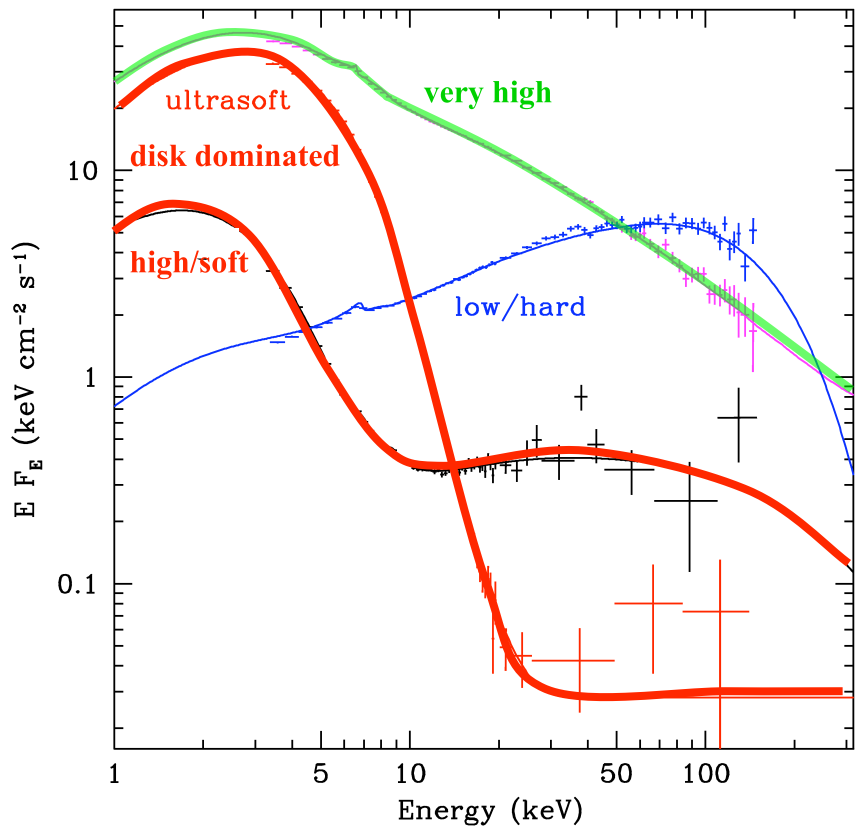
- Huge amounts of data, long term variability (days –years) in mass accretion rate (due to H ionisation instability in disc)
- Observational template of accretion flow as a function of L/L_{Edd} onto ~10 $M_\odot$ BH



DGK07

Spectral states

- Dramatic changes in continuum – single object, different days
- Underlying pattern in all systems
- 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 (McClintock & Remillard 2006)



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
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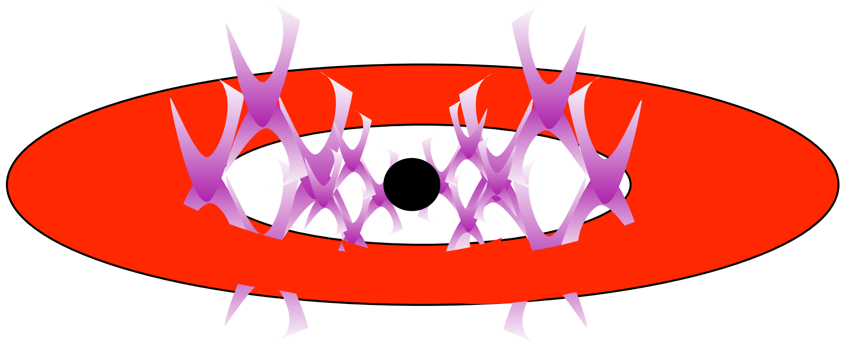
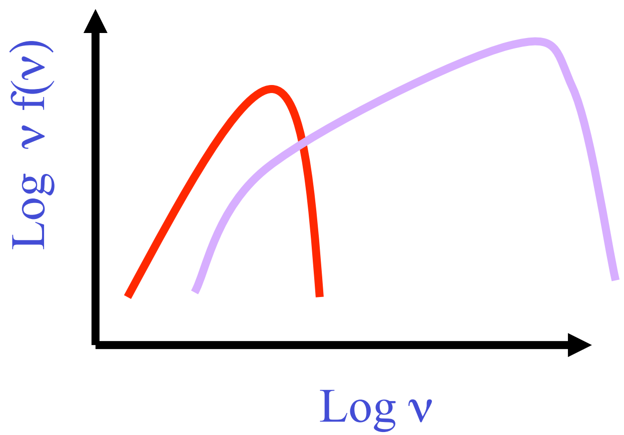
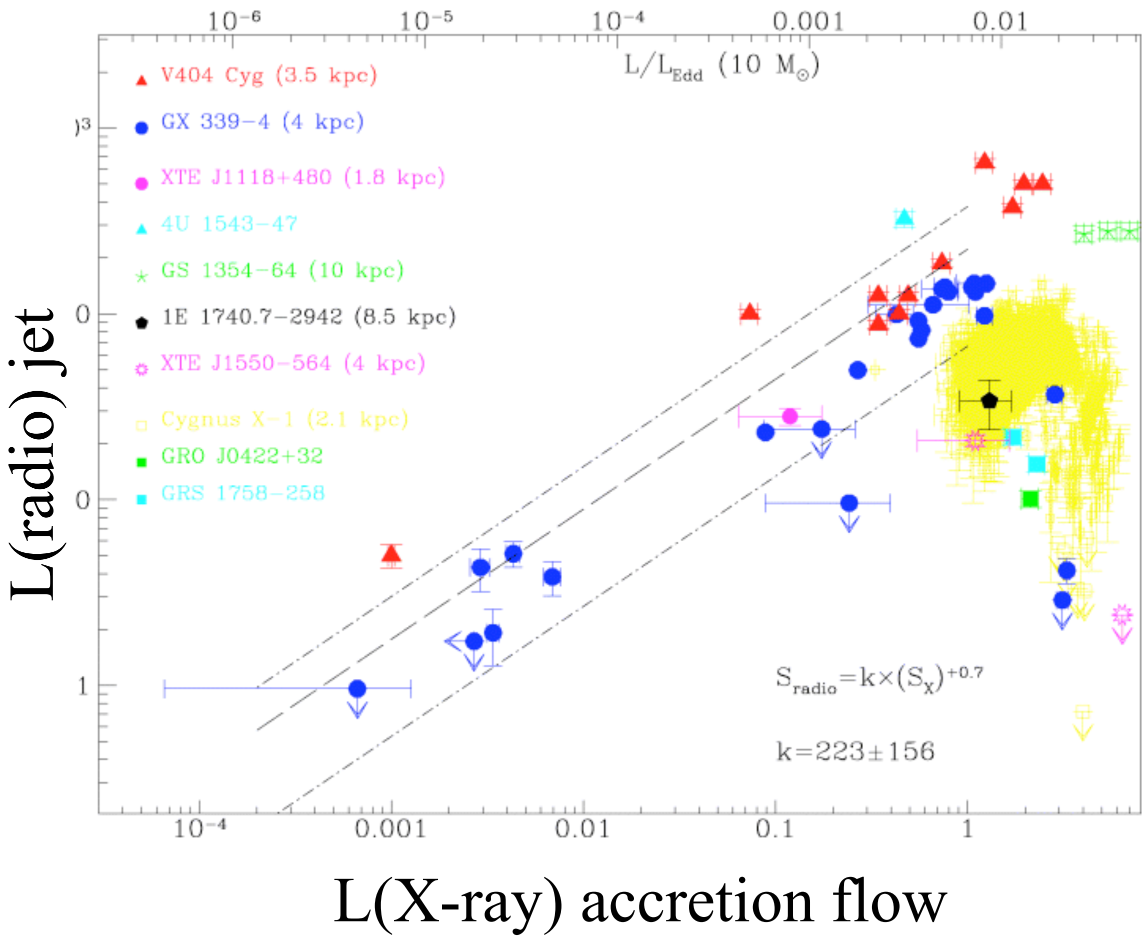




And the radio jet…

- No special μQSO class – they ALL produce jets, consistent with same radio/X ray evolution
- Jet links to spectral state – hard state has steady radio jet which gets brighter as the hard X-rays get brighter
- Then collapses as make transition to disc
- (Fender et al 2004)



Gallo et al 2003

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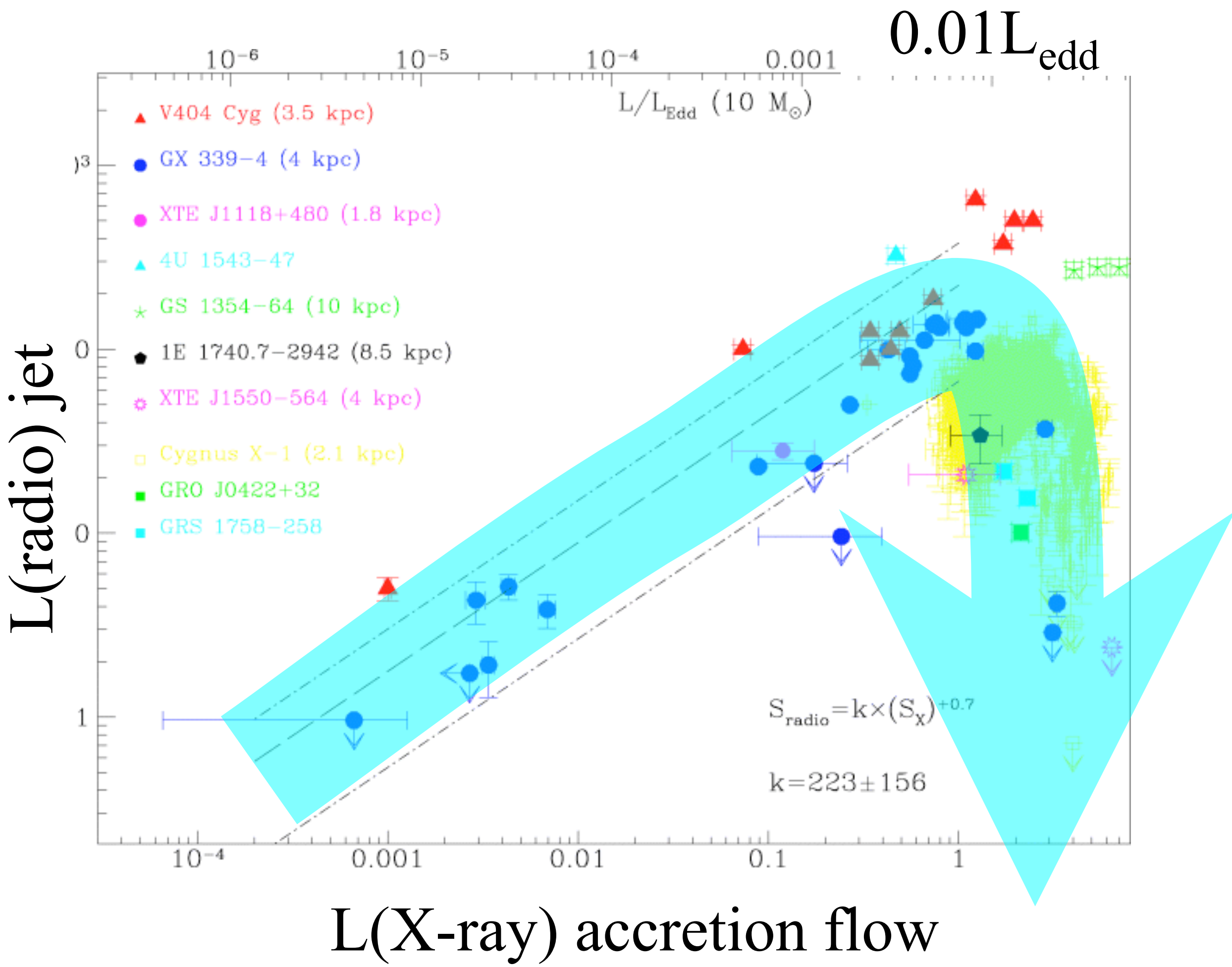

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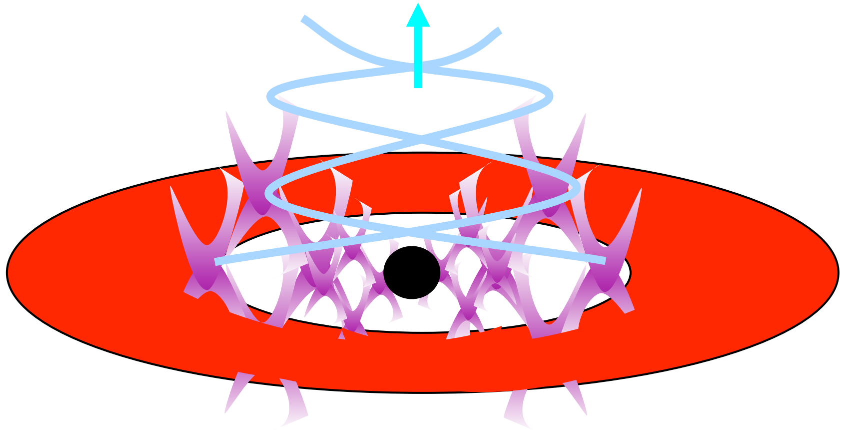
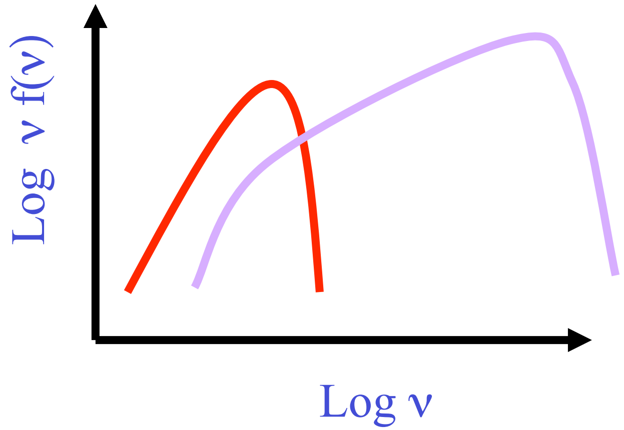
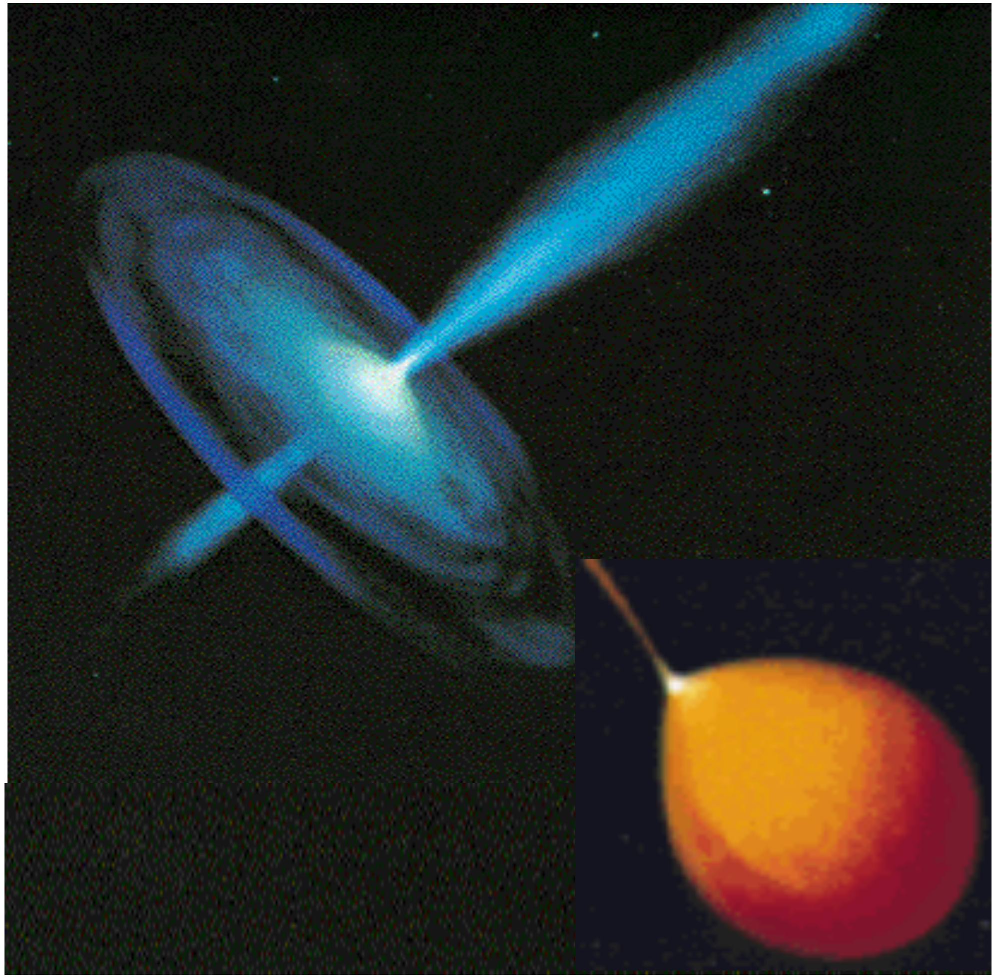


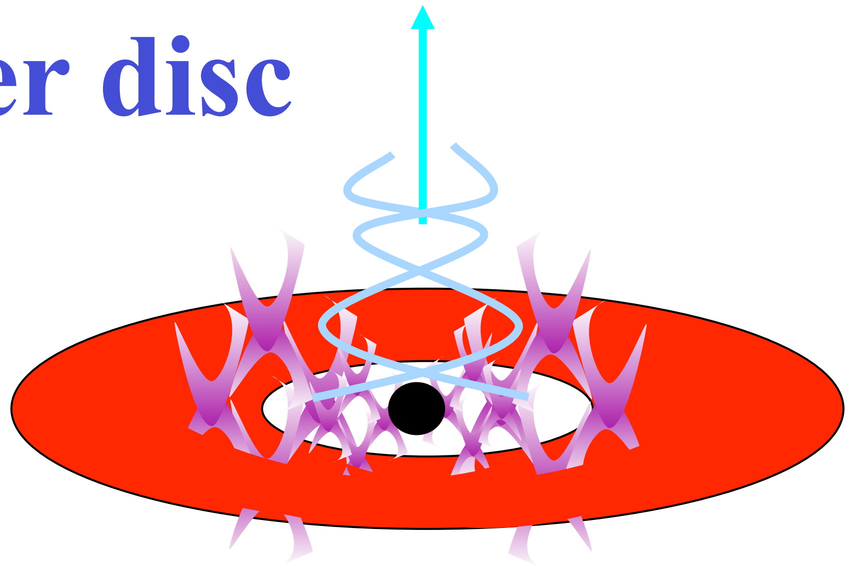


Accreting black holes

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



No inner disc



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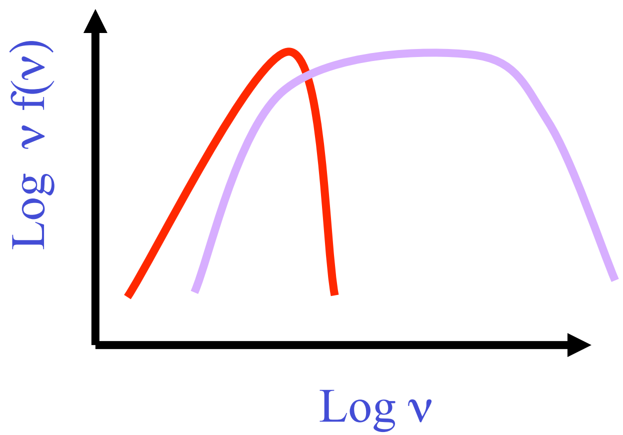

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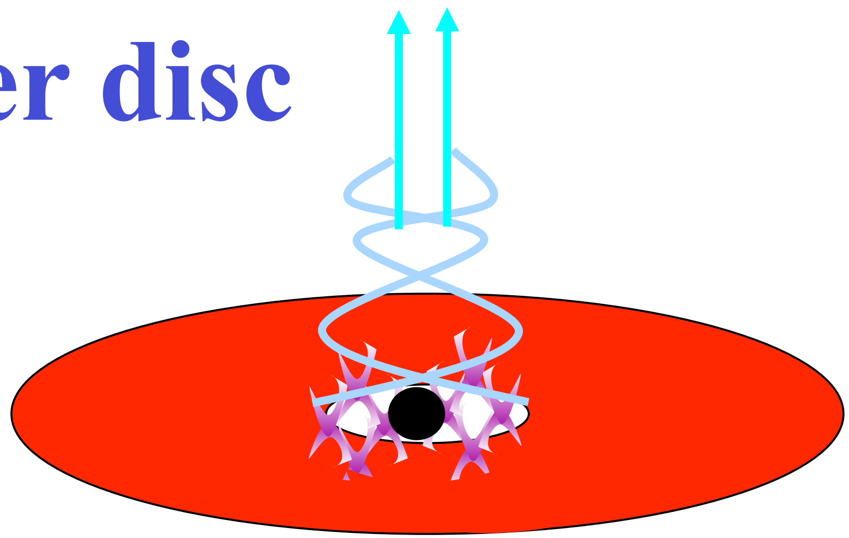

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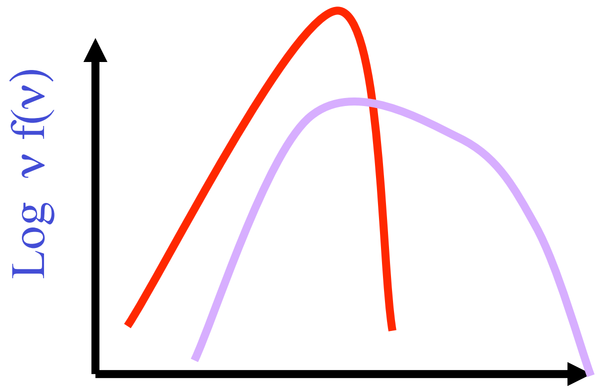

Collapse of hot inner flow

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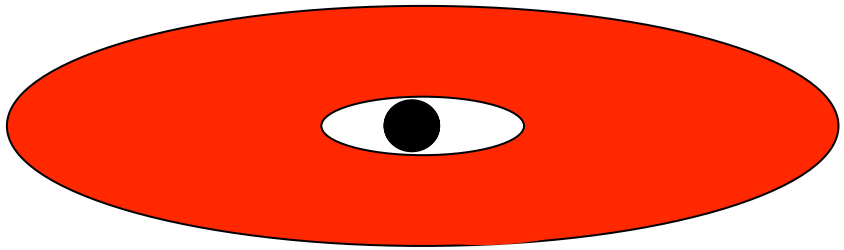
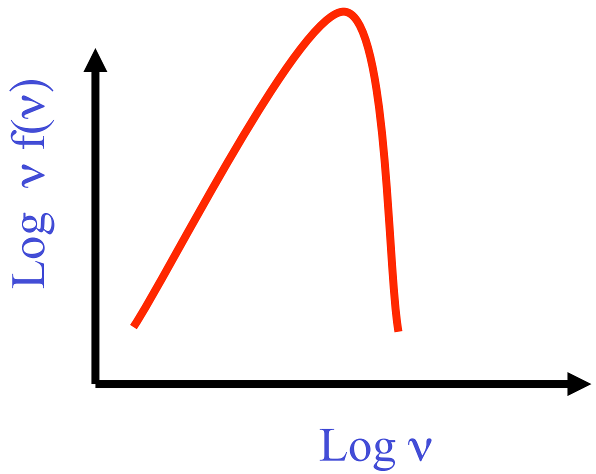
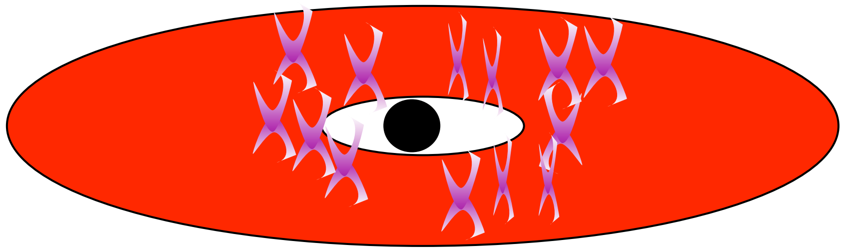
- Jet from large scale height flow collapse of flow=collapse of jet

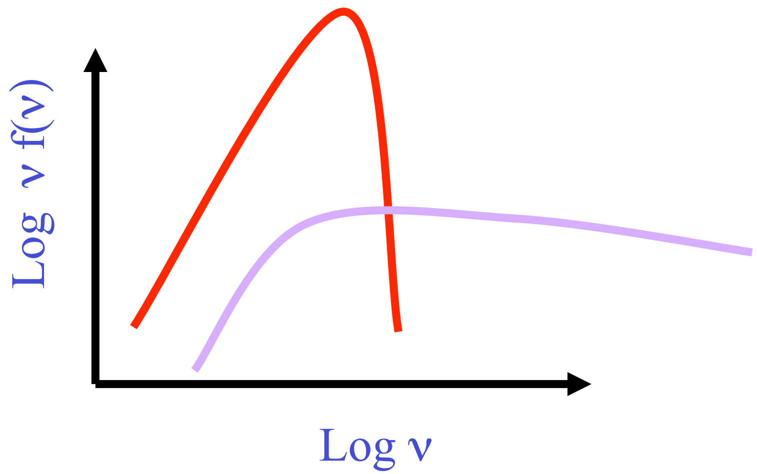




remnant hot flow over disc

- But always see some tail to high energies
- Magnetic reconnection over disc? Comptonising some of disc flux out into tail
- But see disc spectrum clearly so only small fraction of disc upscattered. So either localised or optically thin (or both)





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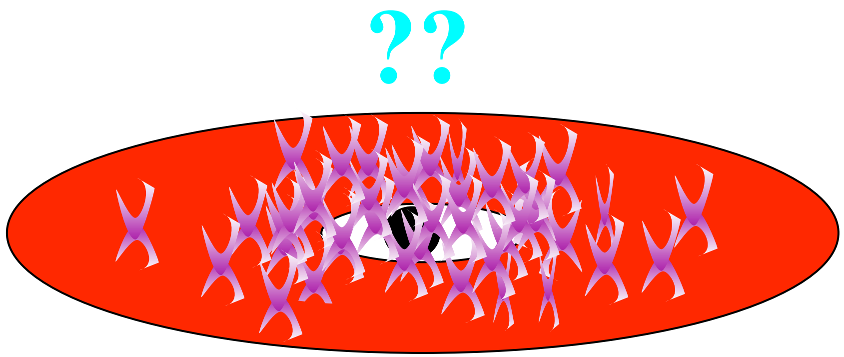
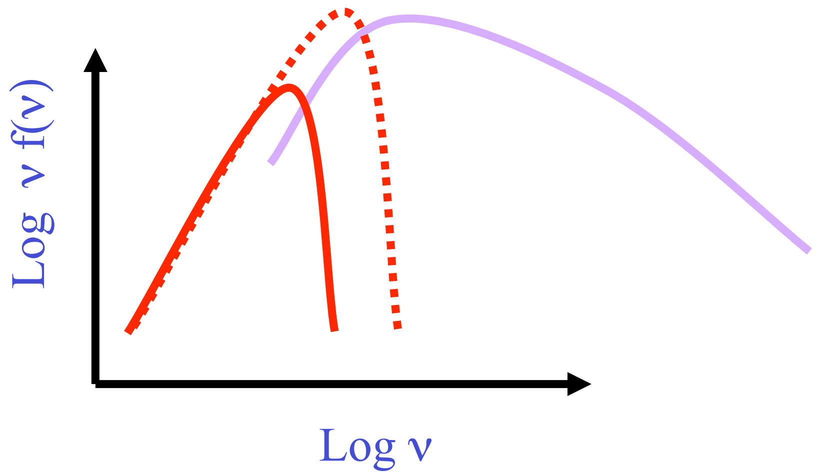
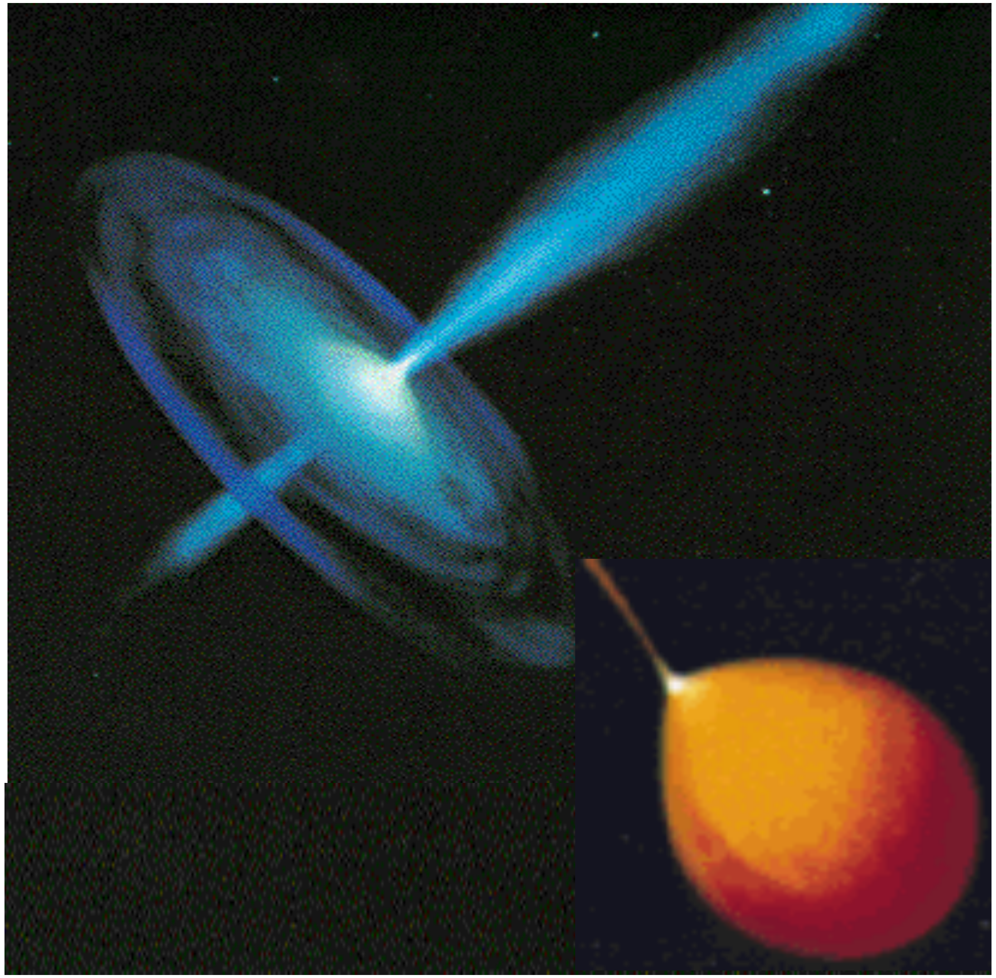
- So when DON'T see disc spectrum clearly then need most photons from inner disc to be compton scattered





Scale up to AGN

- AGN – much more massive so disc in UV



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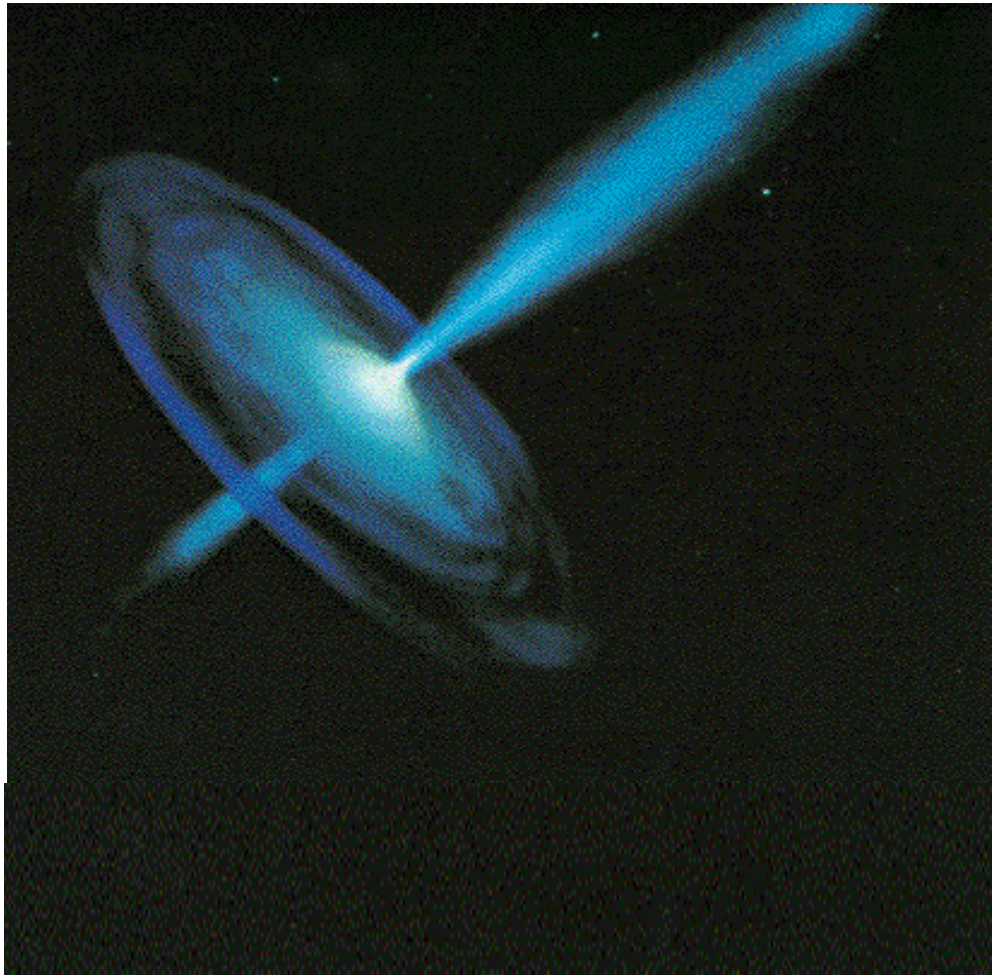

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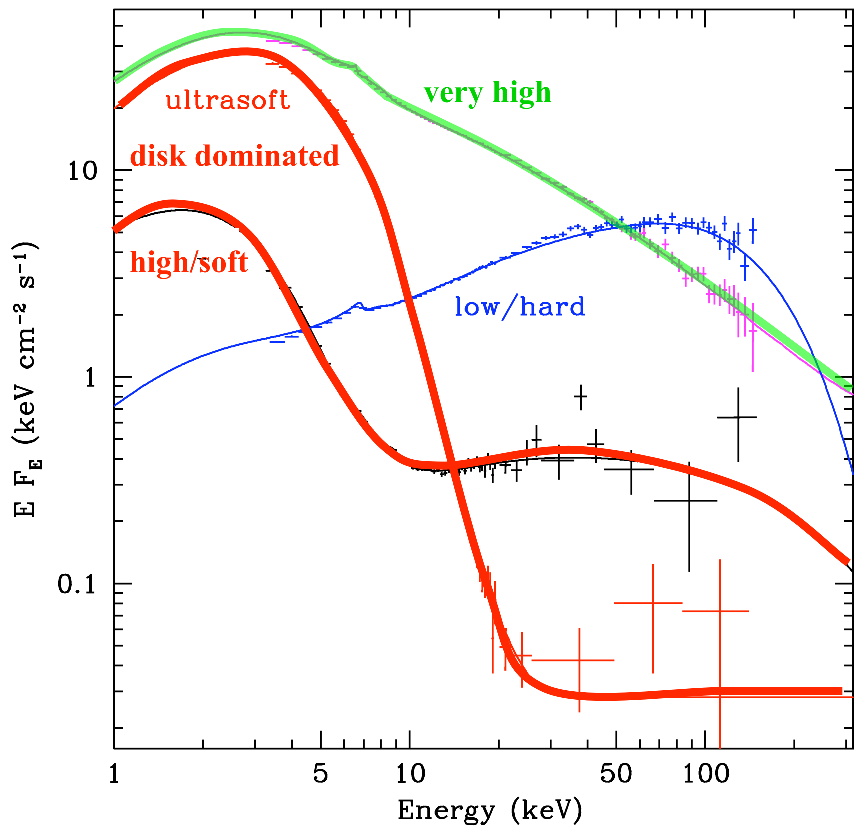
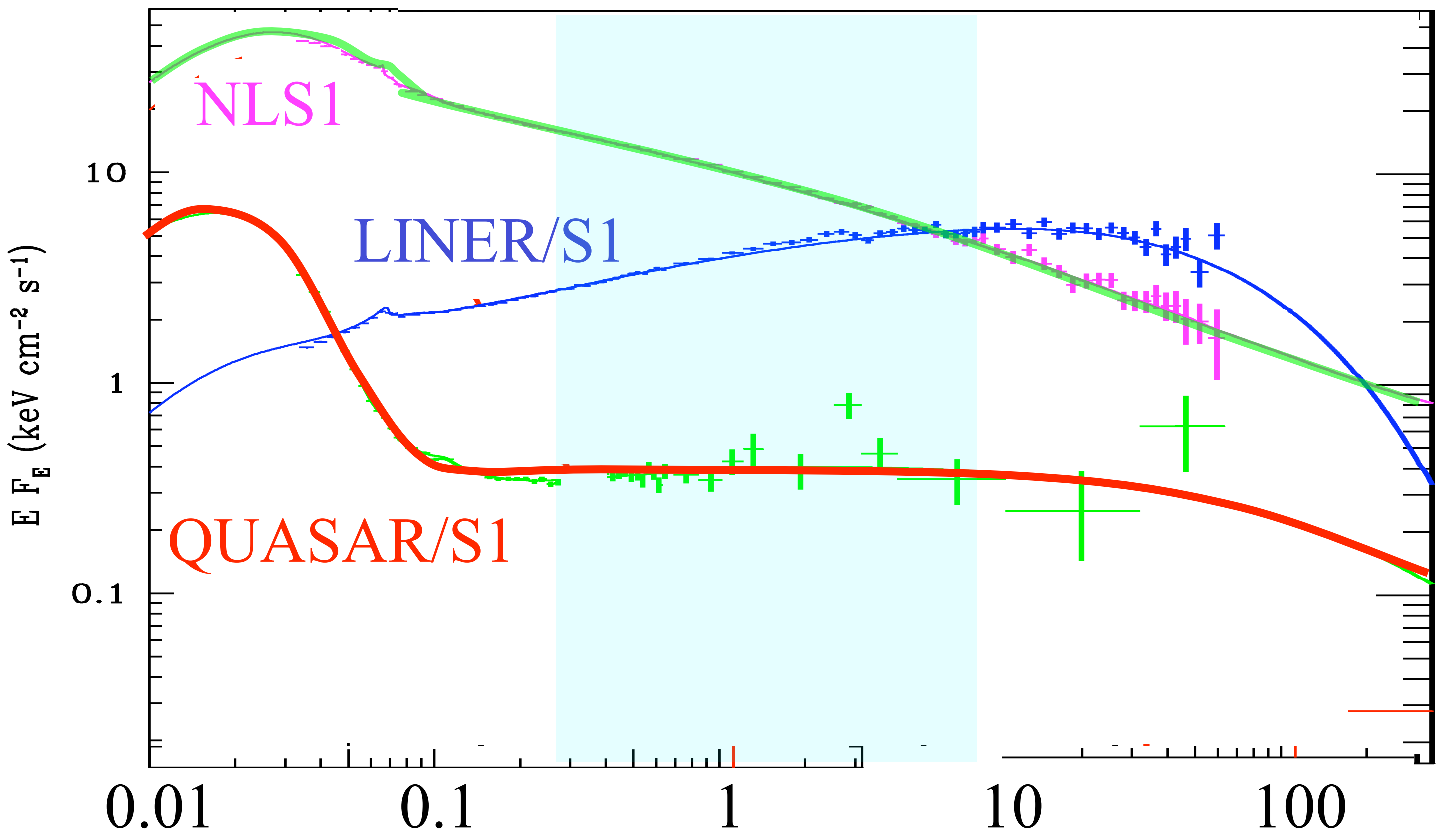


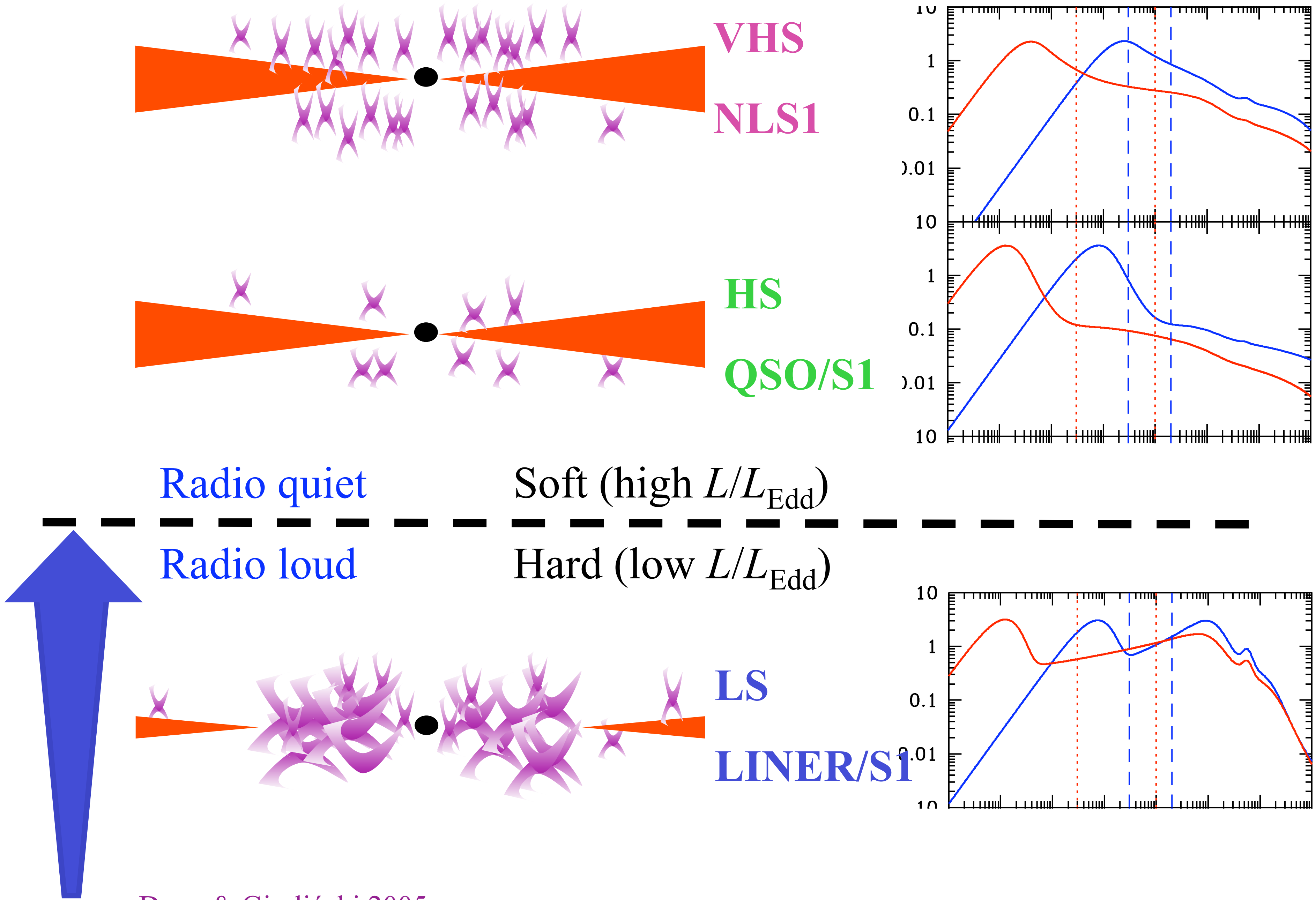
Gierlinski & Done 2003

‘Spectral states in AGN’

Disc BELOW X-ray bandpass. Only see tail



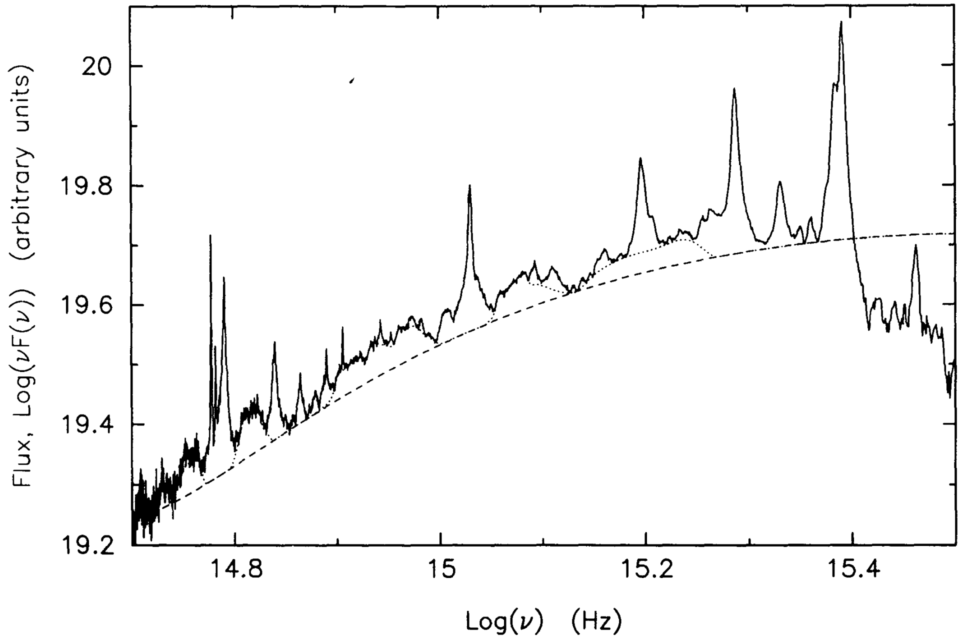
Intrinsic differences in ionising spectrum (same M, different L/LEdd)



Done & Gierliński 2005

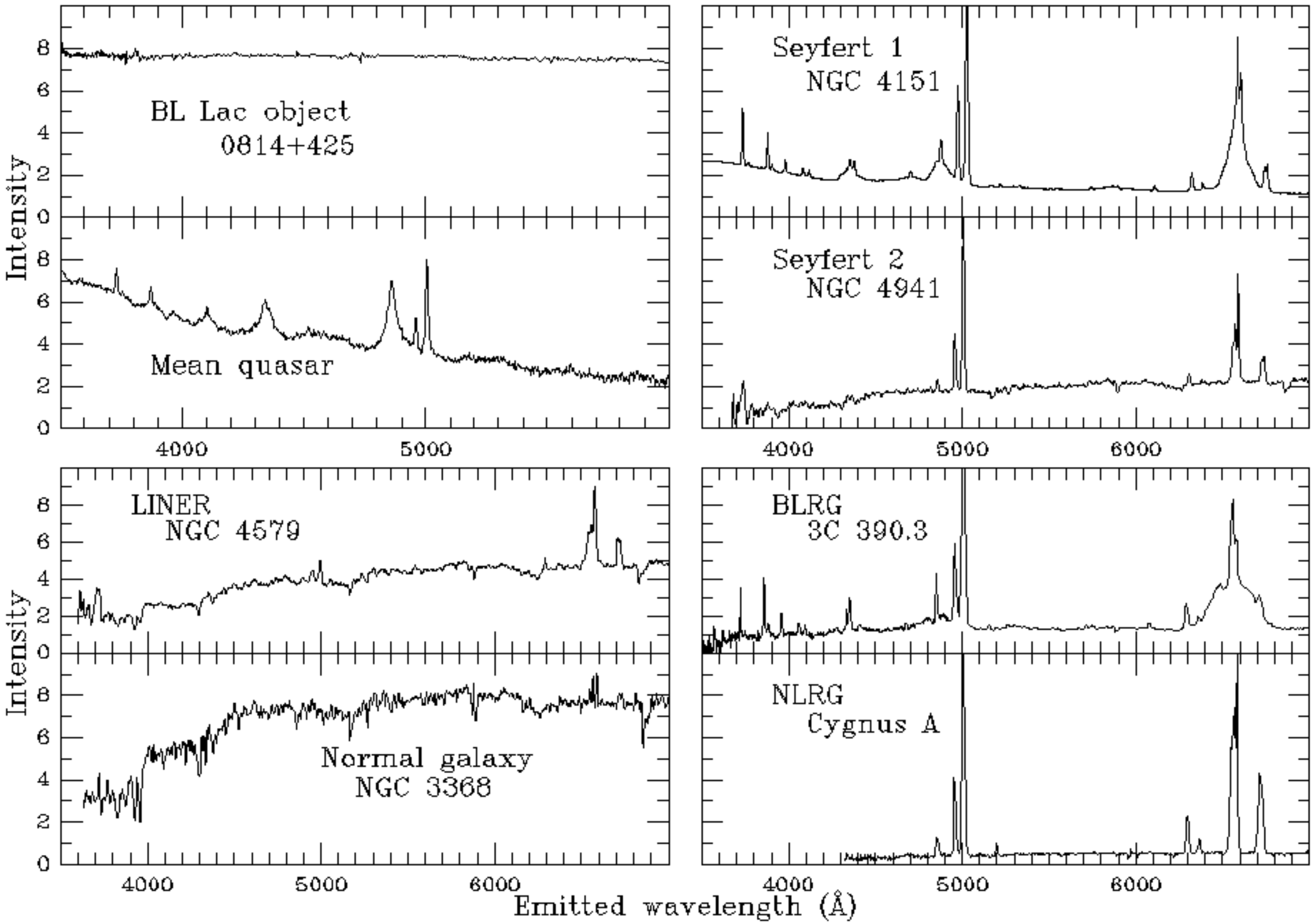
UV disc seen in Quasars!

- Bright, blue/UV continuum from accretion disc.
- Gas close to nucleus irradiated and photo-ionised – lines!



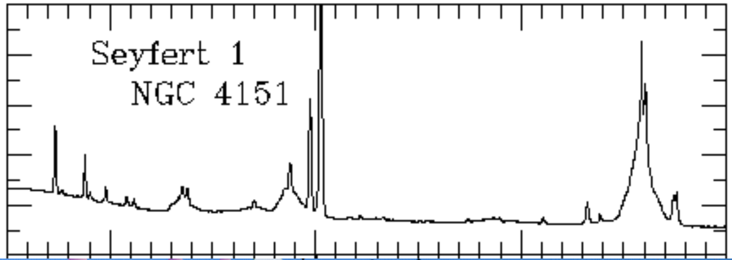
Francis et al 1991

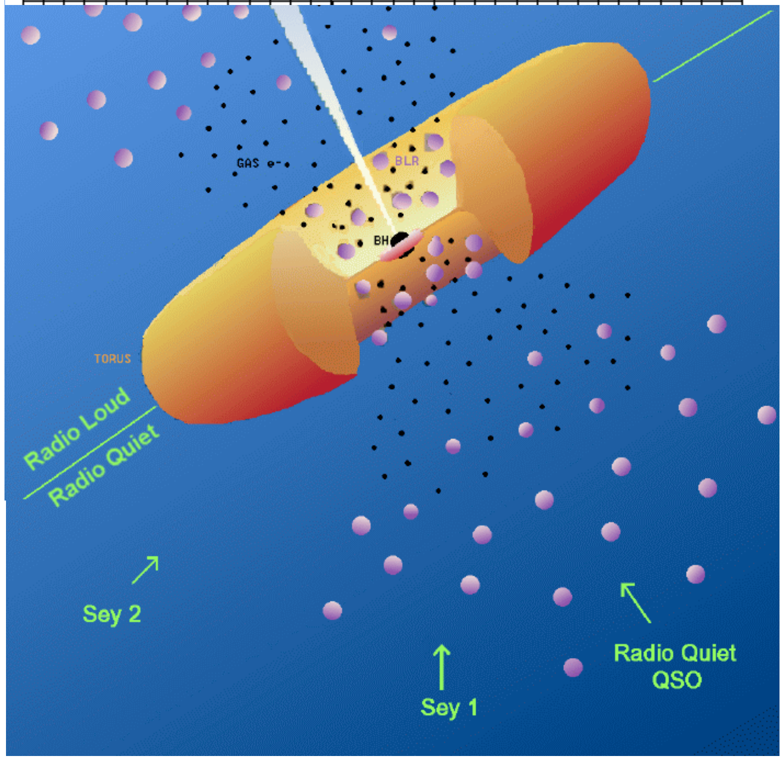
UV also means LINES: ionises!

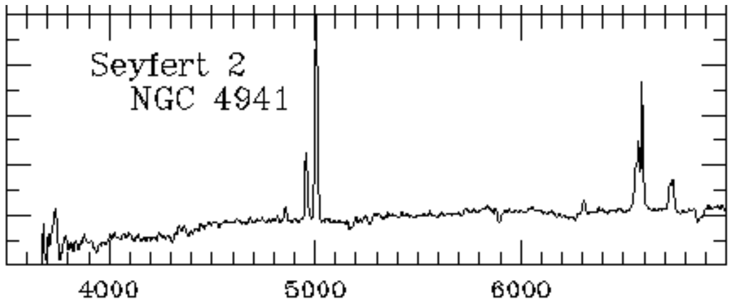


Orientation unification scheme

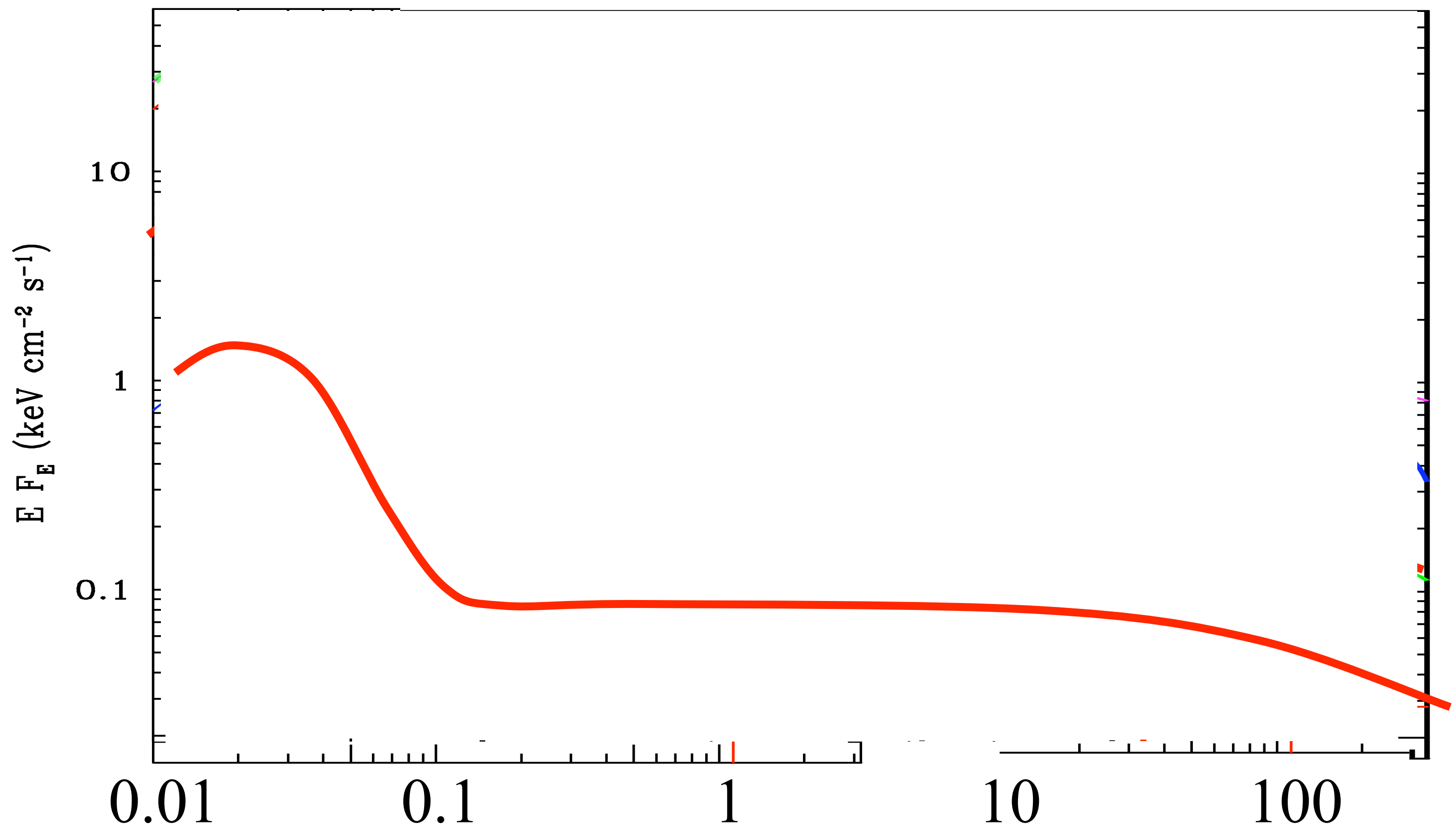
- Intrinsically same except for obscuration ?
- same mass and mass accretion rate, but different obscuration can transform S1 into S2
- But much wider spread in mass! BHB ~ $10 M_\odot$ AGN $10^{5-9}\ M_\odot$







Same state, different mass



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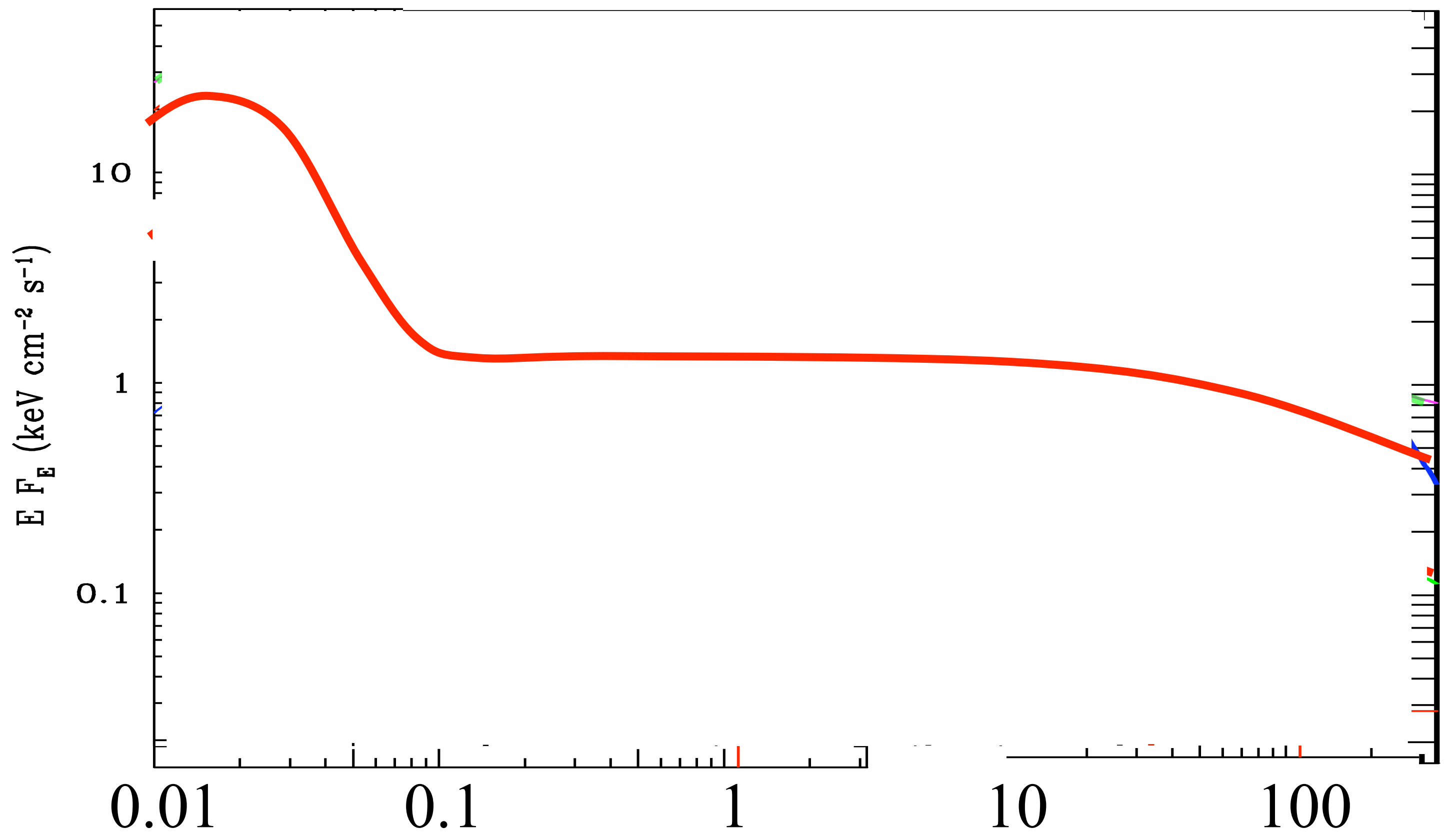
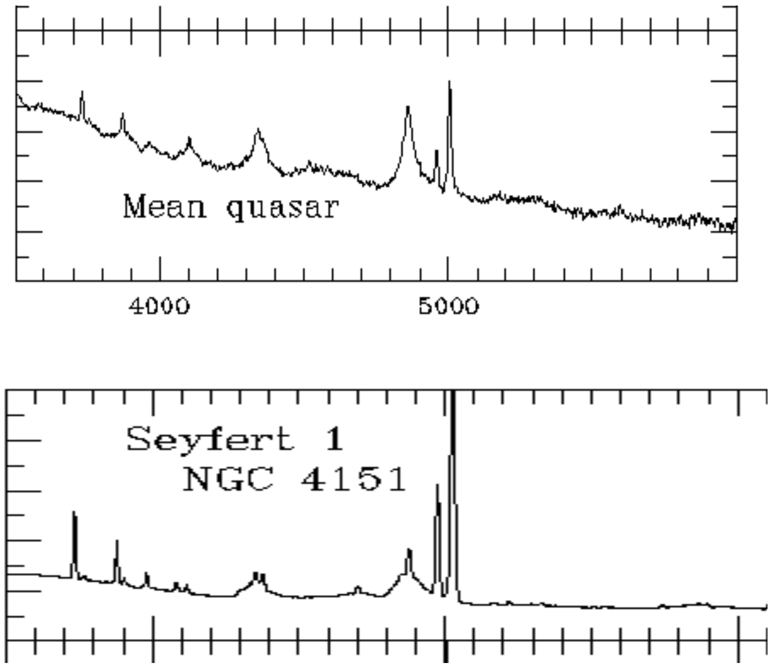


Seyfert 1 - Quasars

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

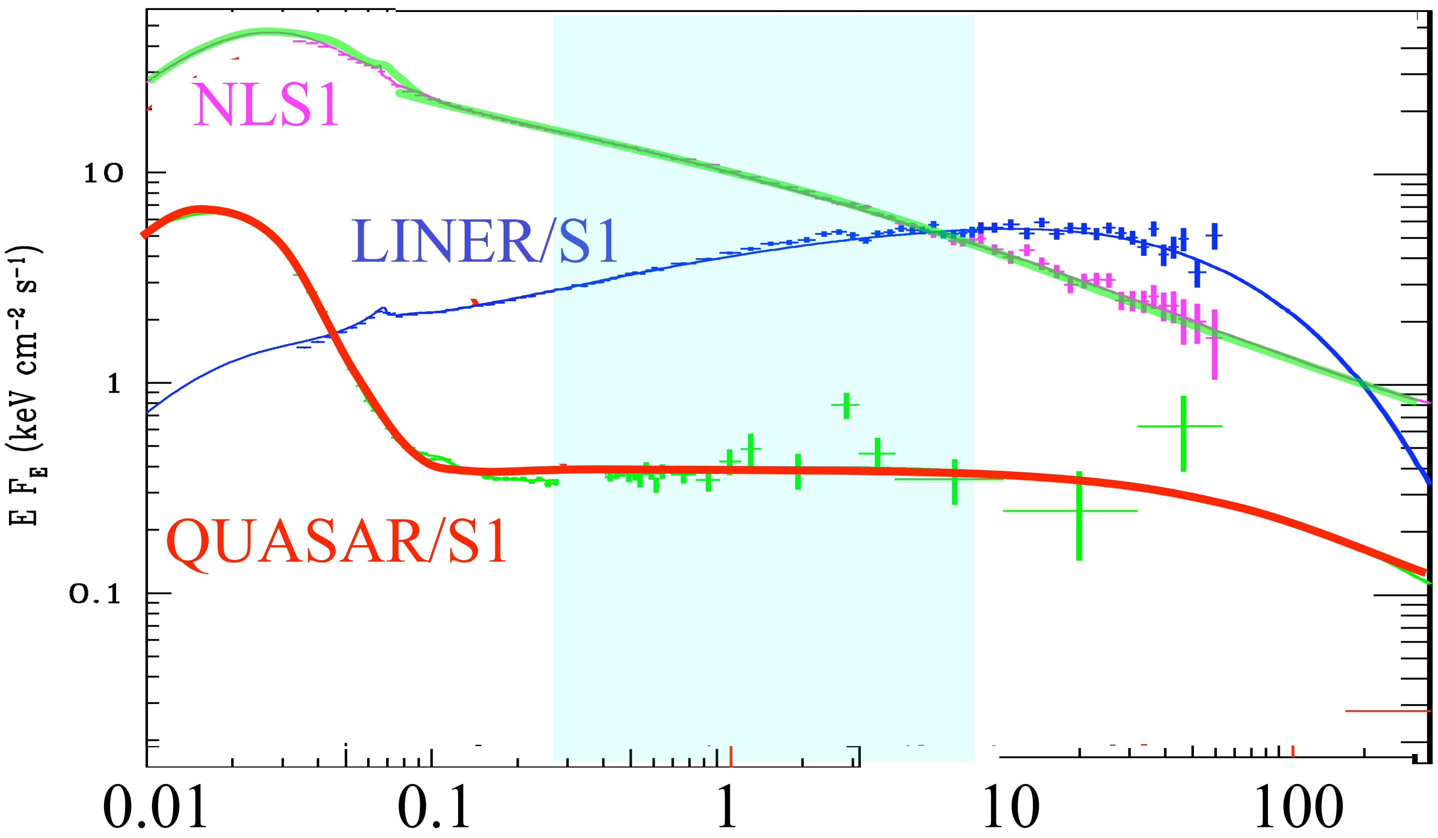
Increasing L



Increasing M

Same mass, different state

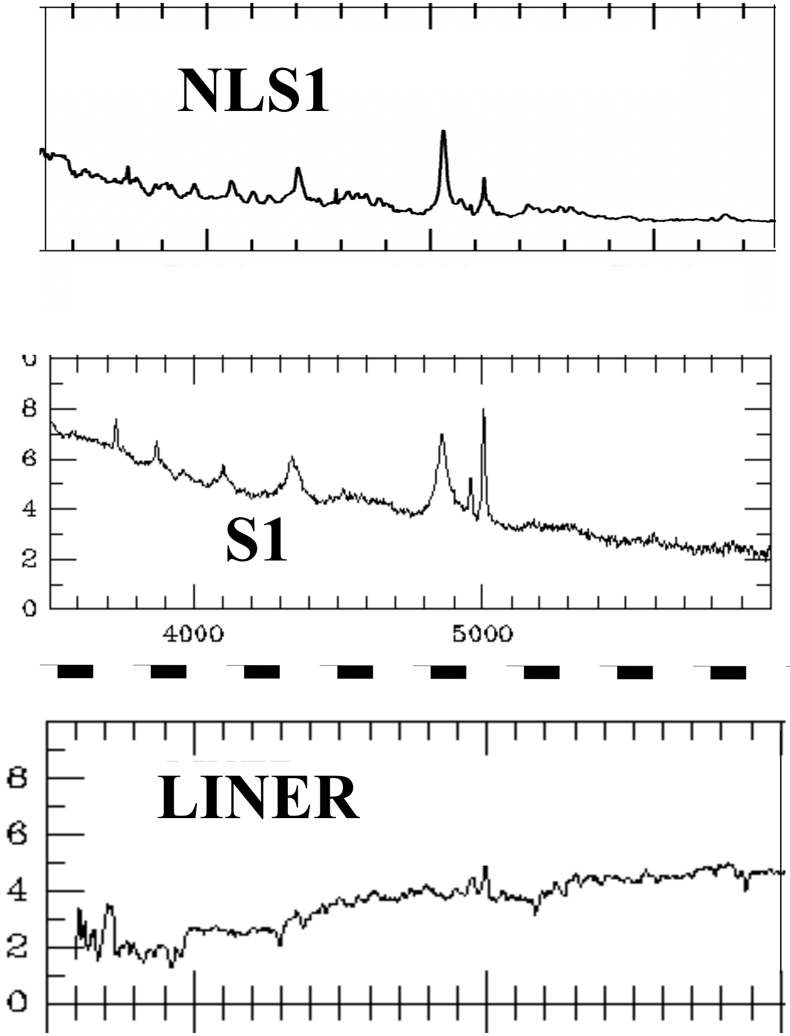
Very different ionising spectra, so different line ratios



LINERS-S1-NLS1

Similar mass.
Different L/L_{Edd}
Different ionisation

Increasing L/L_{Edd}



????

disc

Radio quiet

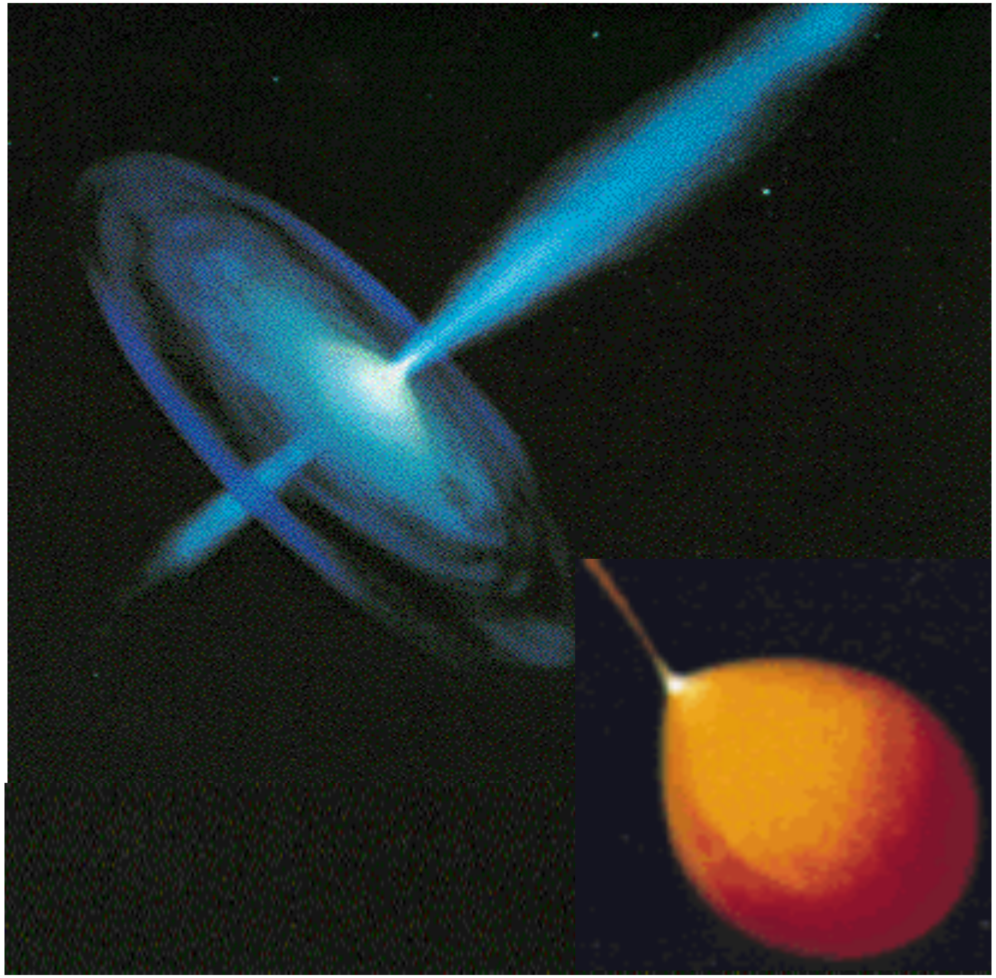
Hot inner flow, no UV bright disc

Radio loudness

Jester 2005; Leighy 2005; kording et al 2007

Fuelling mechanism

- BHB companion star – low mass x-ray binaries need to fill roche lobe!
- Maximum mass accretion rate $10^{-6} < L/L_{Edd} < 0.5$
- Higher L/L_{Edd} only for very evolved low mass star (GRS1915+105) or for high mass stars (Tim Roberts)
- Different fuelling of AGN means not limited in same way – can reach $L/L_{Edd} \geq 1$?



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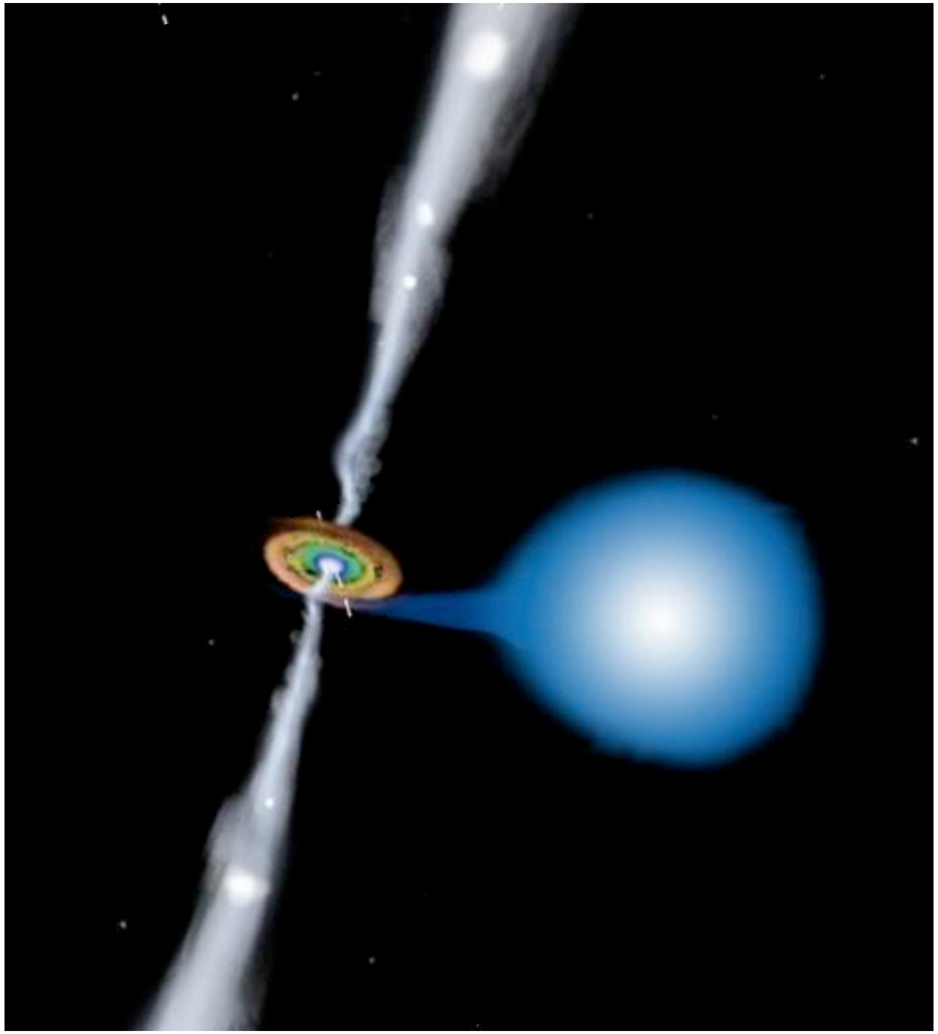

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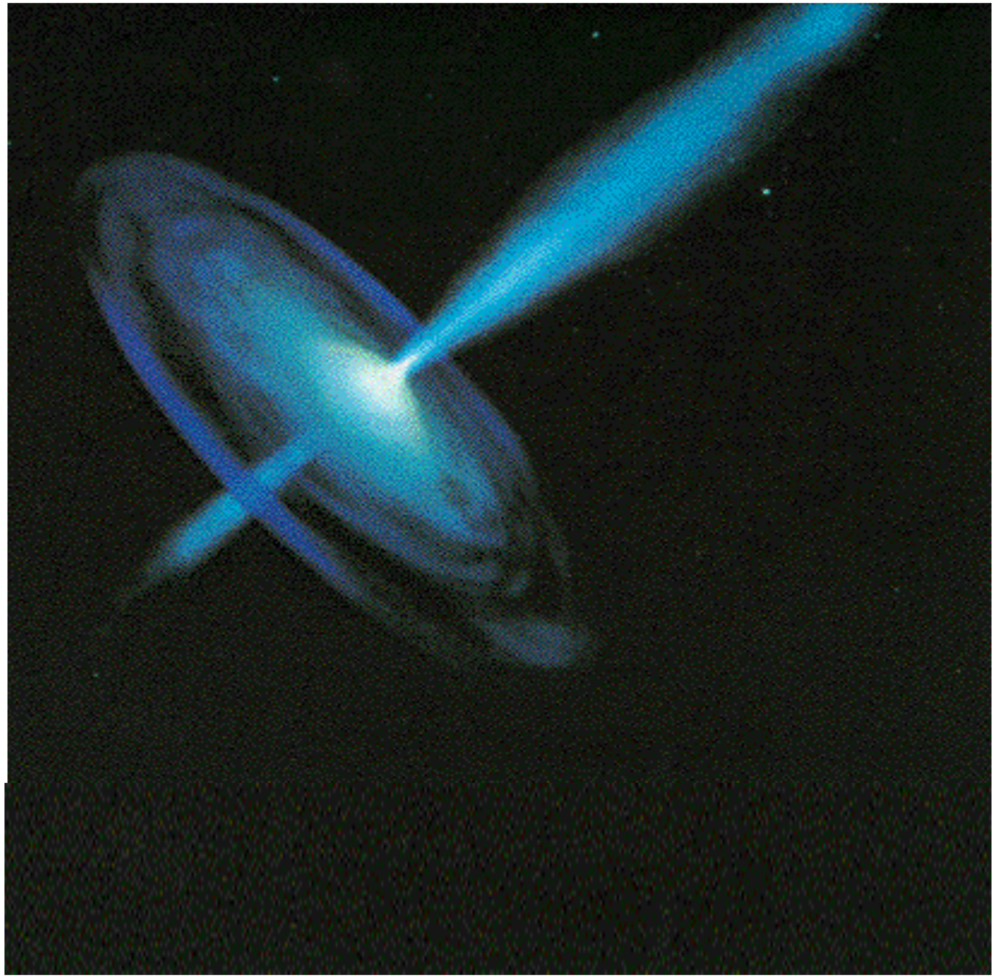
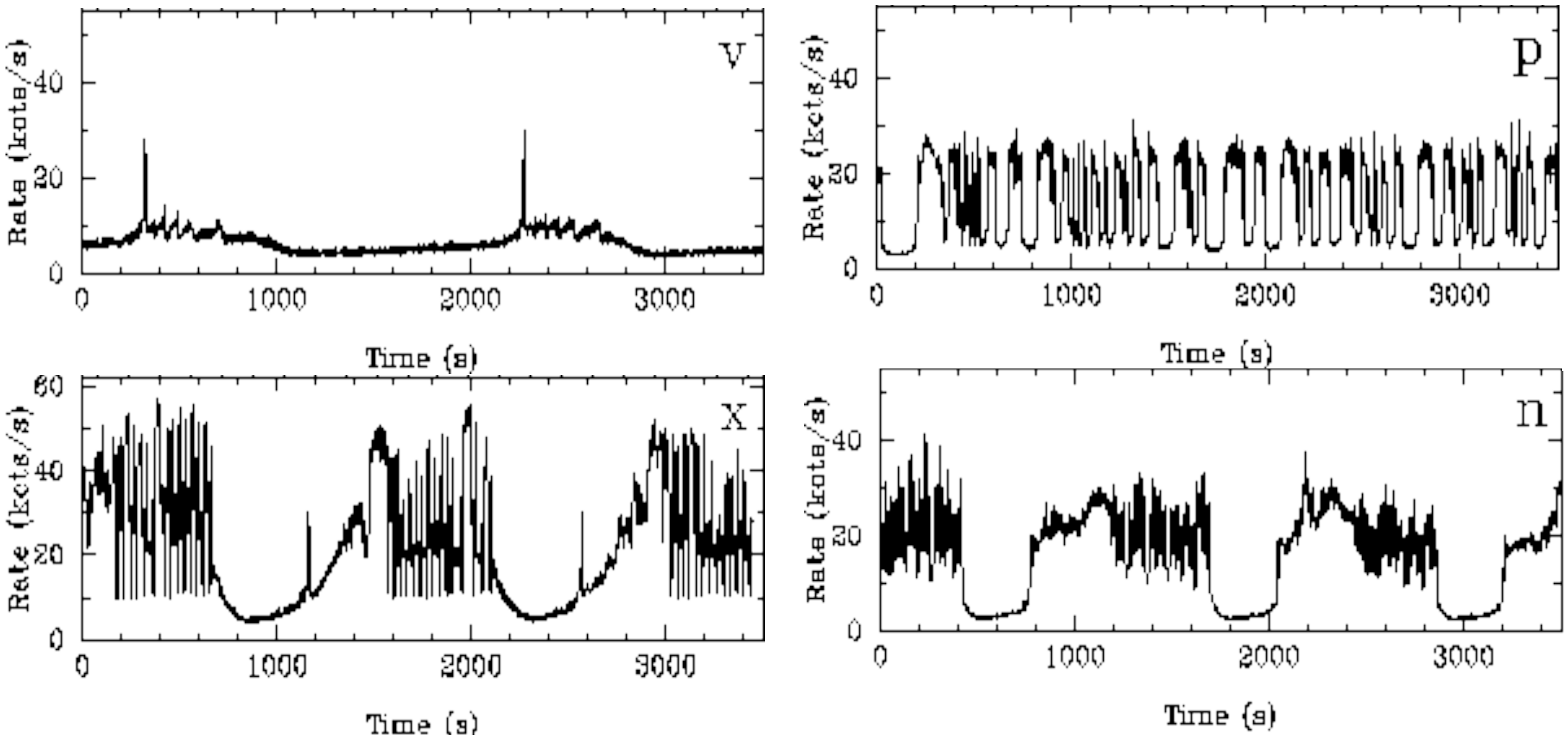


GRS 1915+105

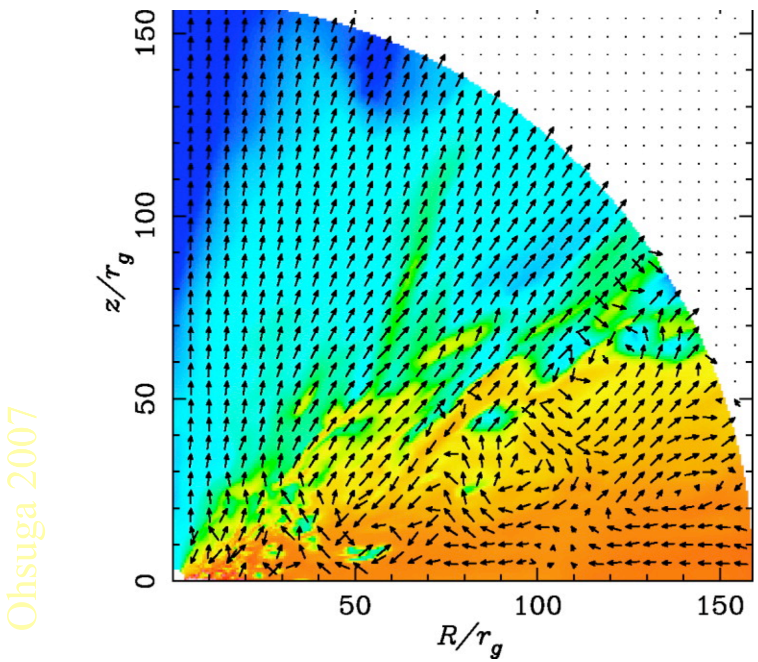
- Microquasar, relativistic jet, UNIQUE limit cycle variability in 50% of data - most likely because it goes to uniquely high L (Done Wardzinski & Gierlinski 2004)

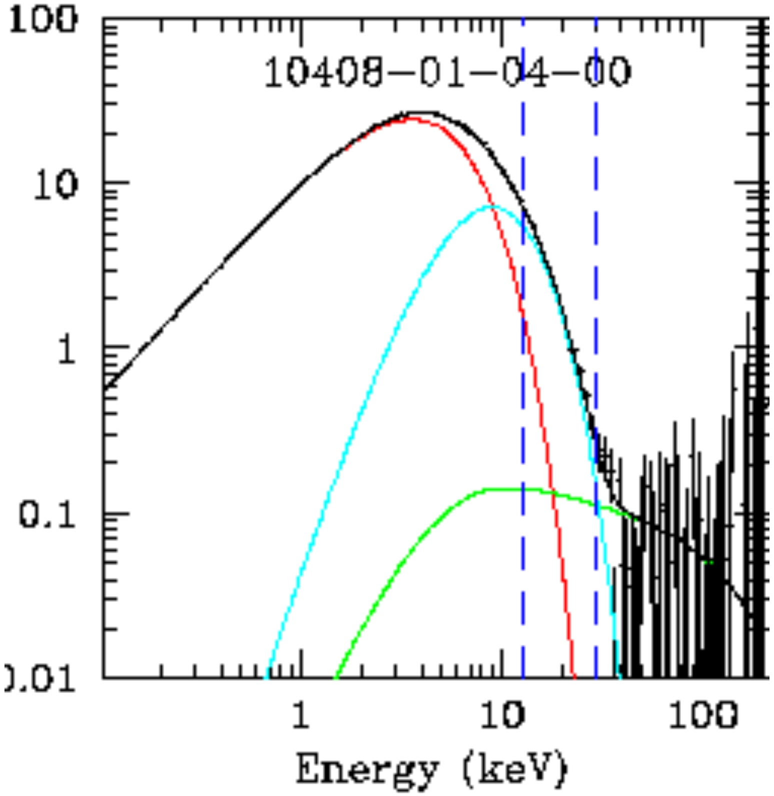
Belloni et al 2000



And different spectra…?

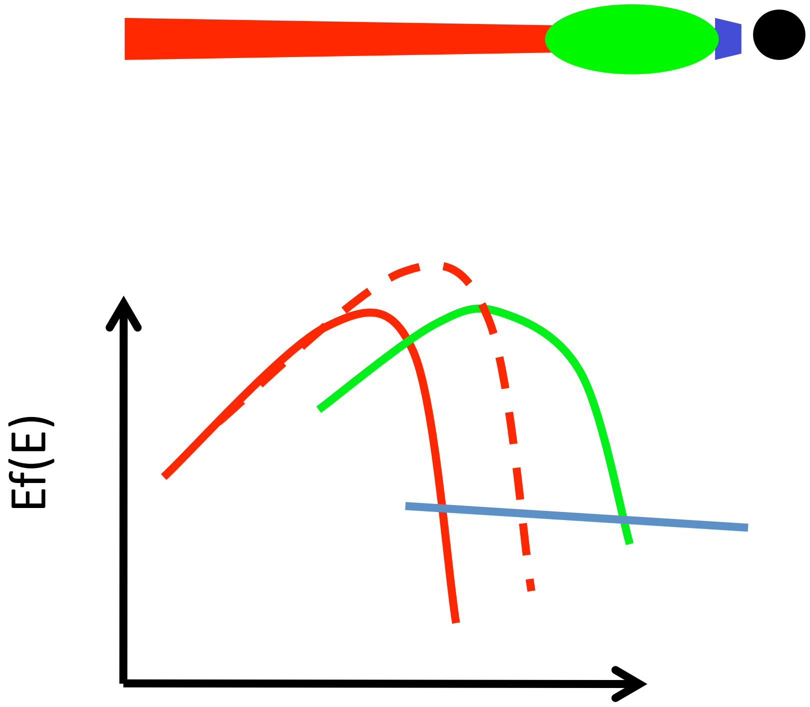
- 'Disc' goes odd. Low temperature, optically thick Comptonisation
- Expect advection to be important (Abramovicz et al 1989) but also expect strong wind. Disc has extended atmosphere so doesn't thermalise

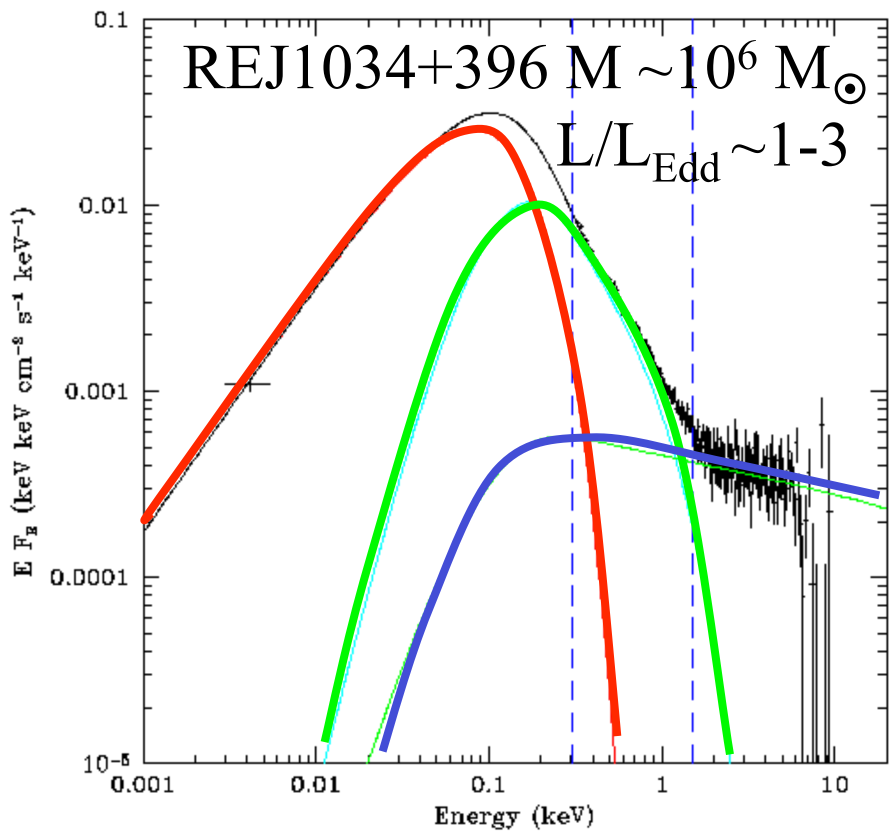




Middleton et al 2009; Ueda et al 2009; Zdziarrski et al 2001

And AGN ?? Extreme NLS1





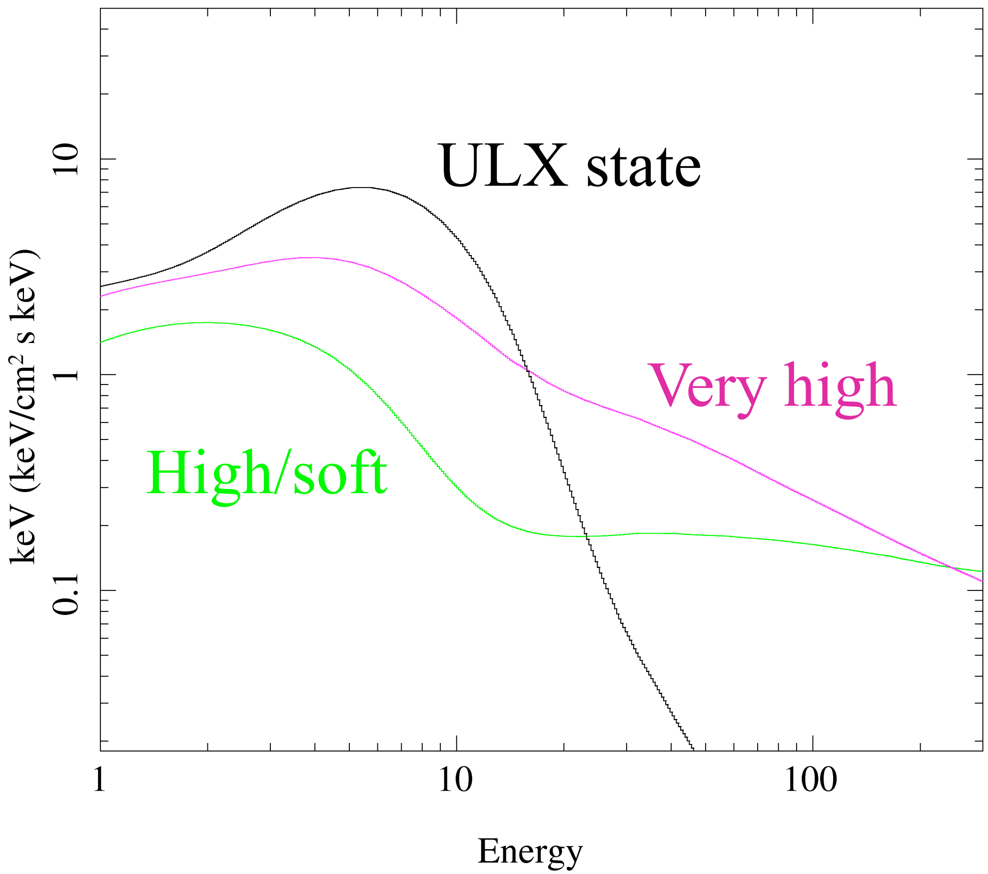
Gladstone, Roberts & Done 2009;

Middleton et al 2009; 2010;

see also Martin Wards talk

How it all fits…..

- Super Eddington state (ULX state)



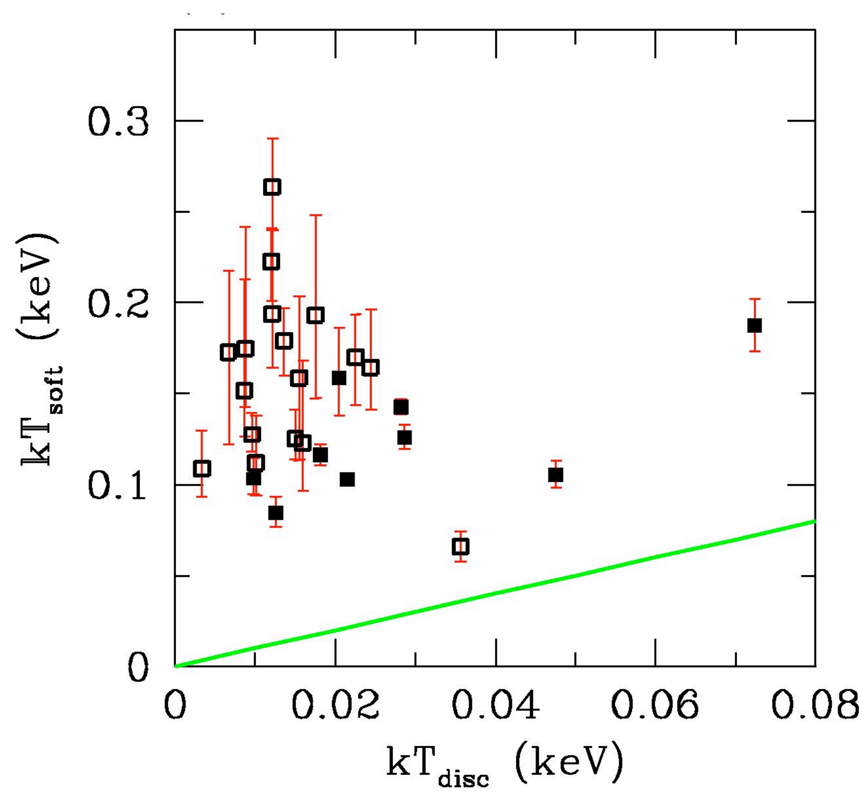
Conclusions: BHB-AGN

- Accretion flow – disc $T \propto M^{-1/4} (L/L_{Edd})^{1/4}$ so AGN disc in UV rather than soft X-rays for same L/L_{Edd}
- But disc always accompanied by tail in BHB. Ratio of disc to tail and steepness of tail also varies as L/L_{Edd} (and other parameters) – spectral states hard - soft - very high
- Scale to AGN and should have different ionising spectra for same M at different L/L_{Edd} – LINERS - S1 - NLS1
- Should also link to radio jet properties! radio loudest just before collapse of hot flow
- Also differences in mass (S1-QSO) and orientation
- Super Eddington flows?? Wind?? inner disc no longer quite thermalises?
- spin???

NOT from Comptonisation

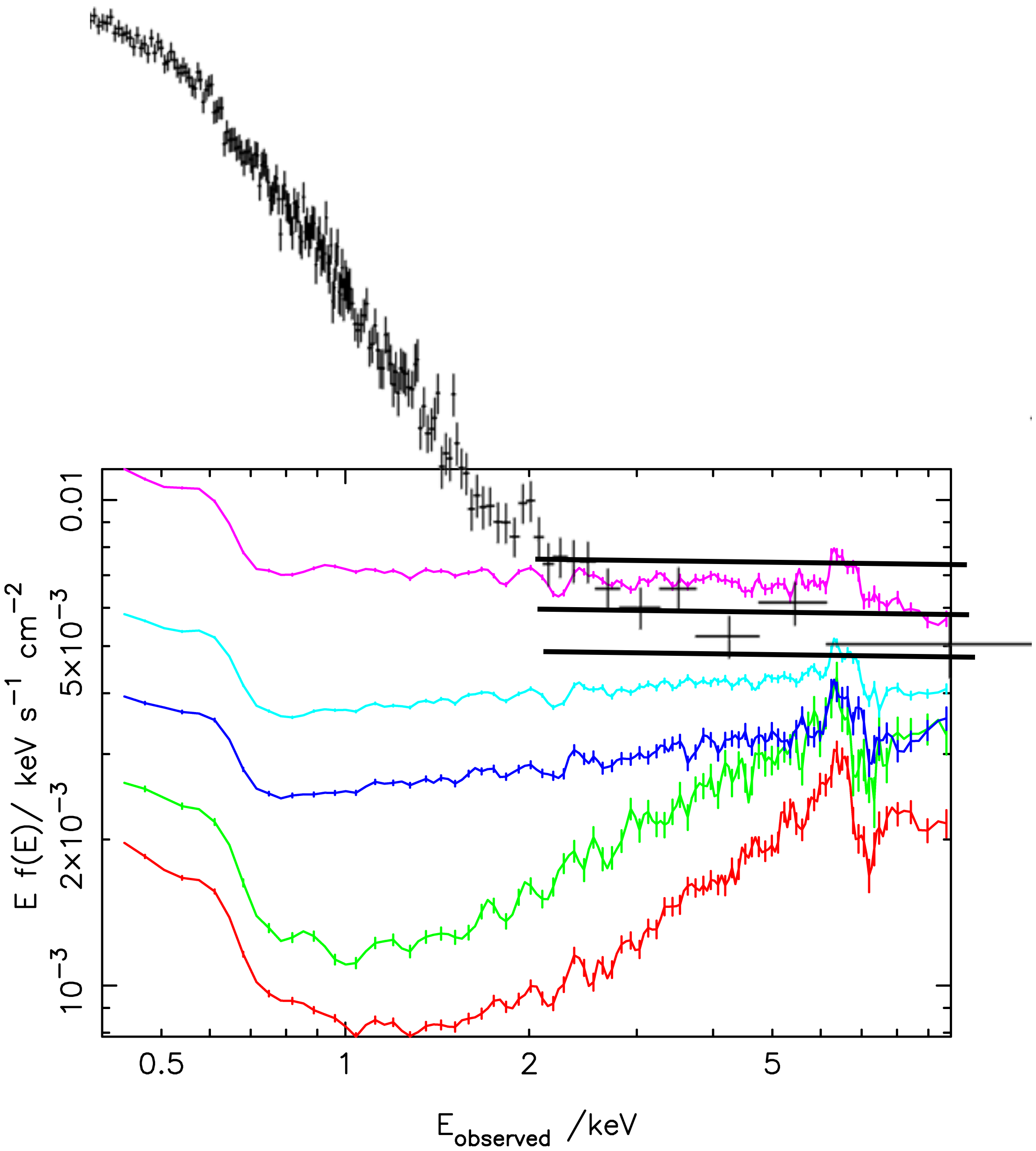
Gierlinski & Done 2004

- 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



RE1034
Mkn766

- REJ1034 has huge SX and not much variability below 2keV
- Mkn766 looks less like true excess and varies tremendously below 2keV



Miller et al 2007 Middleton et al 2008

Observed rms variability

- 2 types of soft excess?
- ‘true’ soft excess doesn’t vary much on rapid timescales
- ‘fake’ soft excess from atomic processes (reflection, absorption in partially ionised material) peaks at 2keV