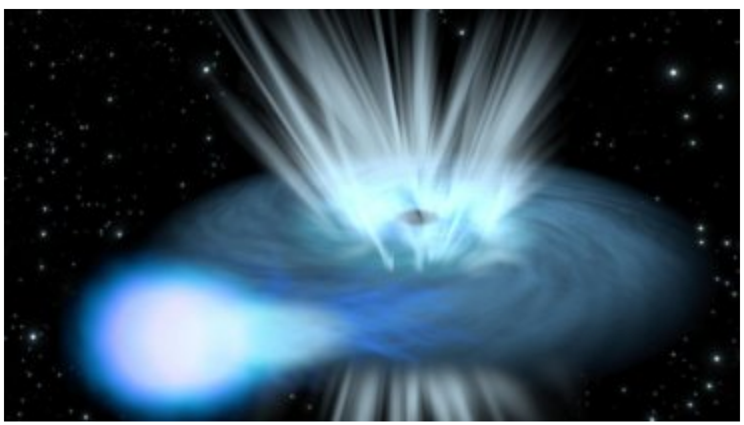
At the extremes of super-Eddington accretion



Tim Roberts

Wasutep Luangtip (Bangkok)

Chris Done (Durham)

Rachel Dudik, Ciprian Berghea (USNO)

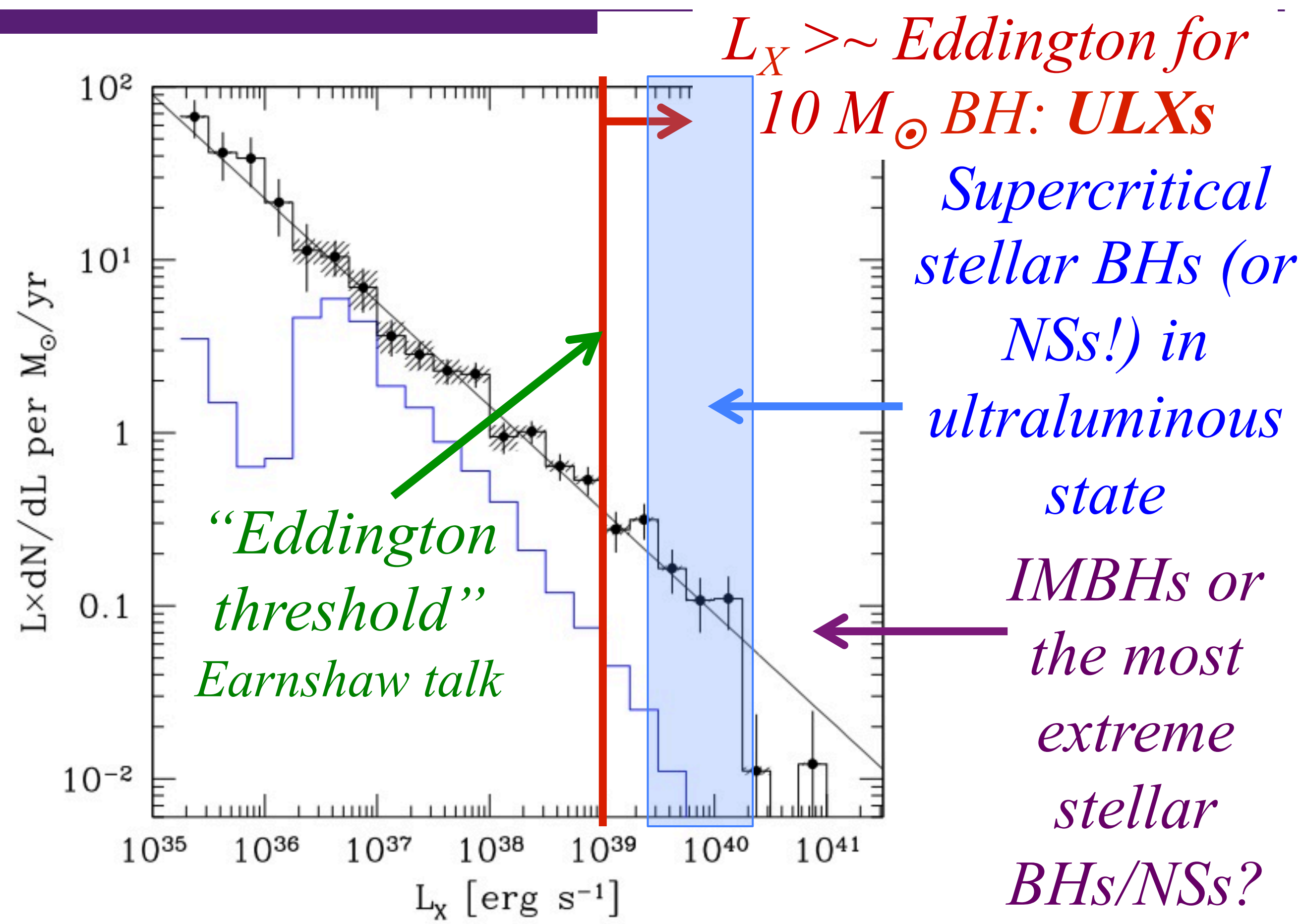
Andy Sutton (MSFC)

Dom Walton (Caltech)

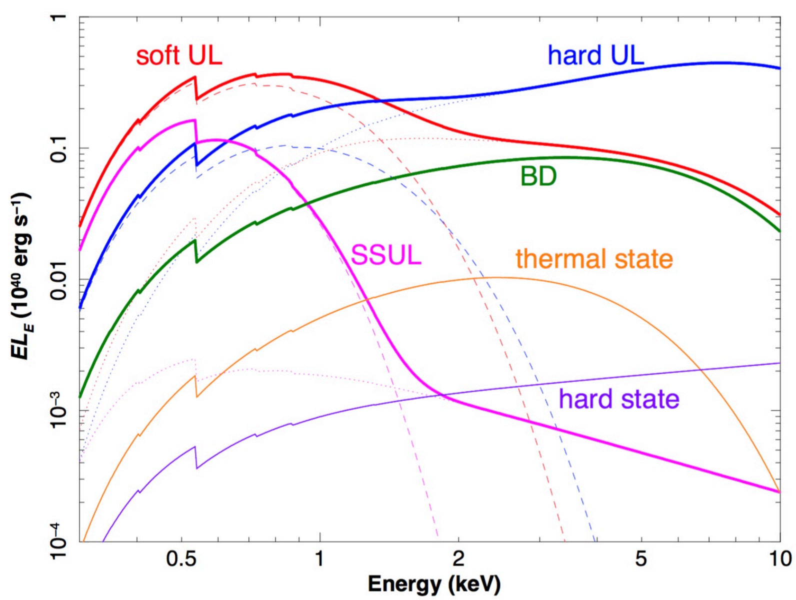
Matt Middleton (Cambridge) et al.

The most and least luminous ULXs

X-ray luminosity function of point sources in galaxies, normalised by star formation rate (Mineo et al. 2012)



The top end of the UL regime



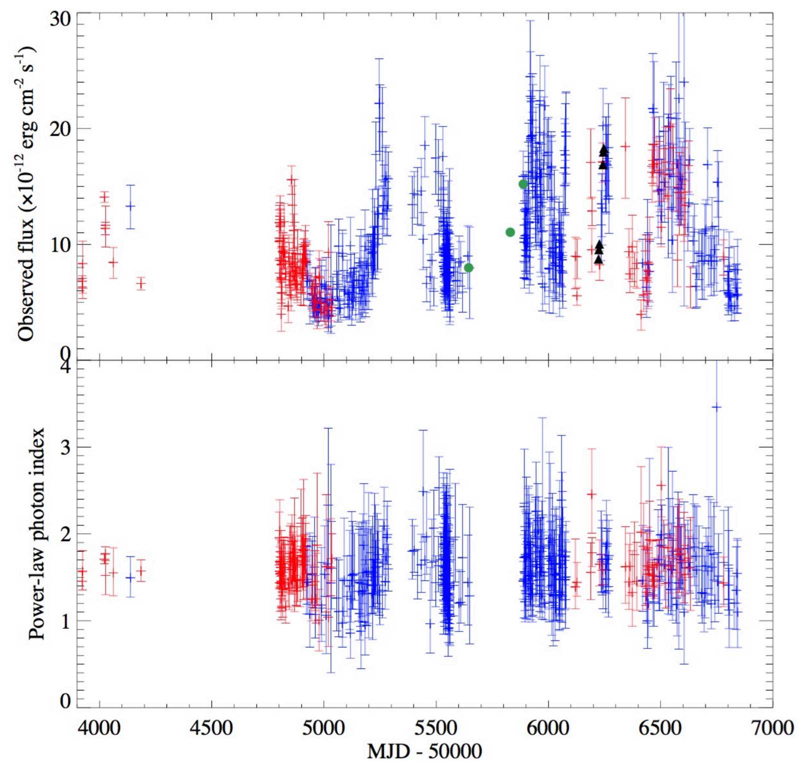
Model spectra comparing UL regimes to classic sub-Eddington states (from Kaaret, Feng & Roberts, ARA&A, submitted)

- The brightest 'normal' ULXs straddle the XLF break
- How do they behave there? Does this tell us anything about more luminous objects?

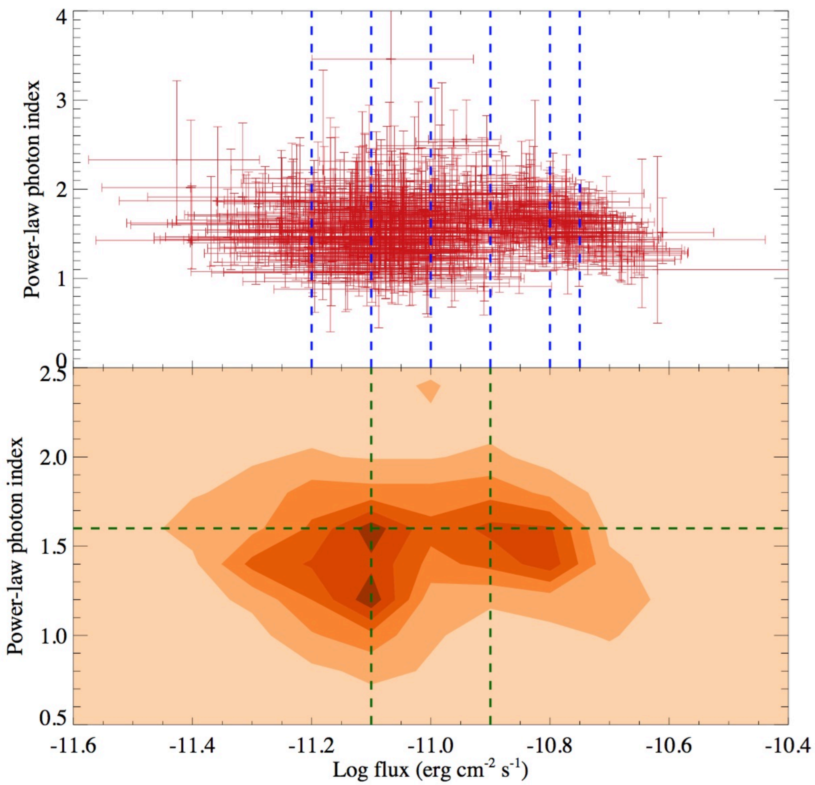
A case study: Ho IX X-1

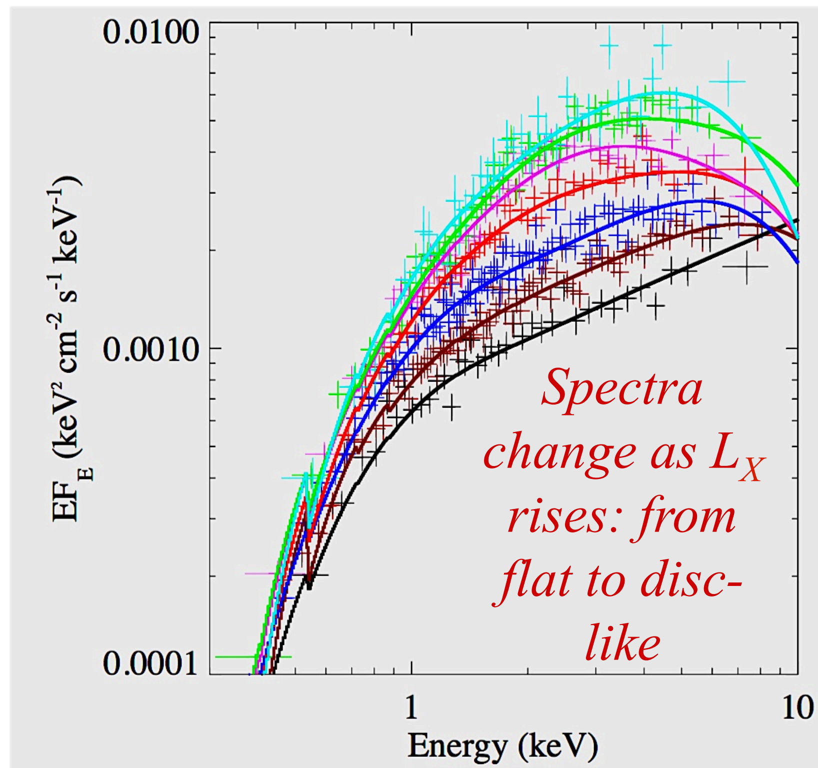
Luangtip, Roberts & Done (2016)

- Luminous ULX: archetypal hard UL object
- Well observed by *Swift*, 132 on-axis (red) & 382 off-axis observations with >~ 10 counts
- Also look at *XMM-Newton*, *NuSTAR*

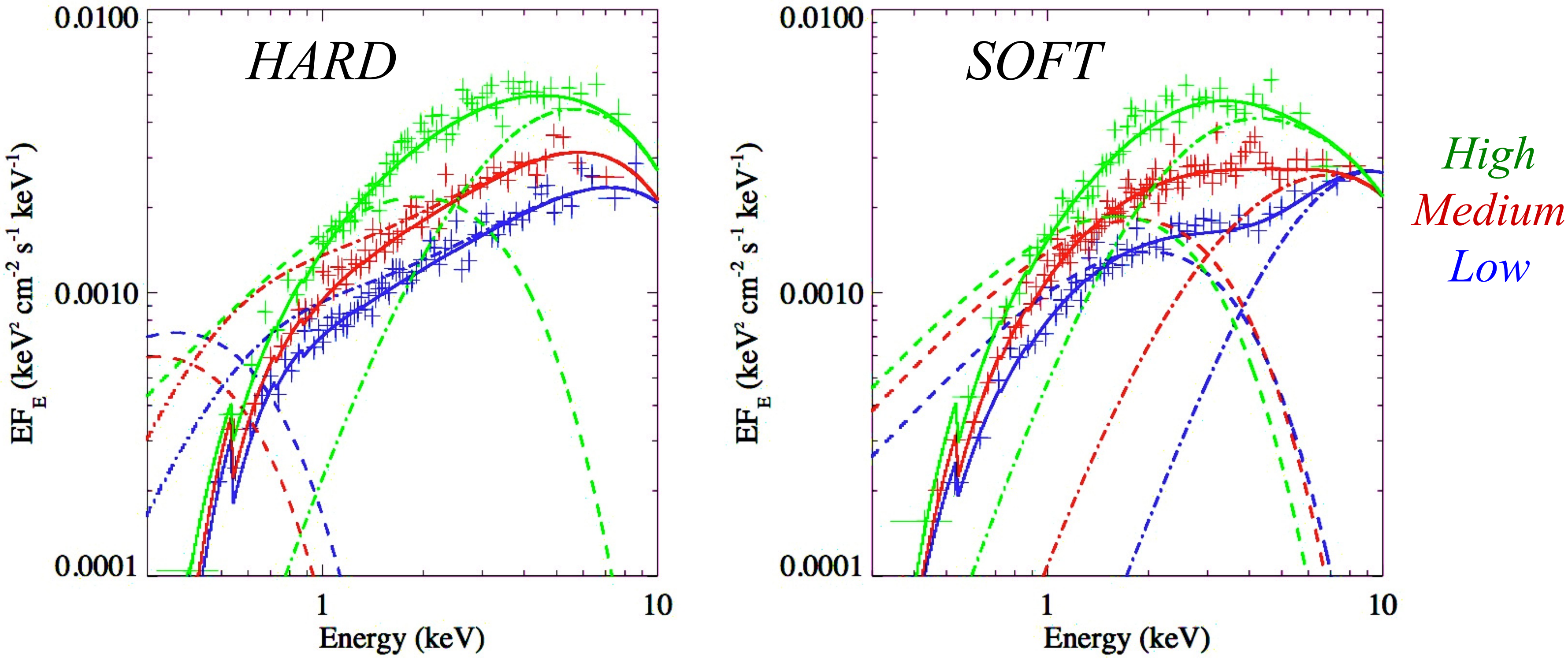


Stacking *Swift* data



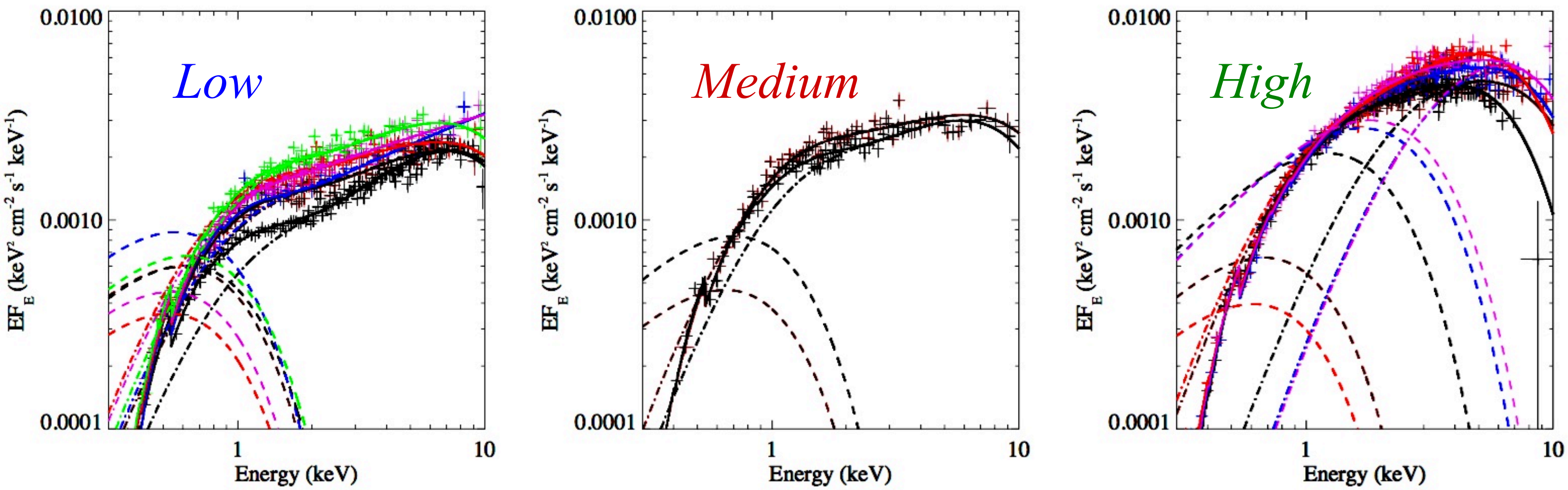


Stacking hard and soft separately



Spectra degenerate with luminosity!

XMM-Newton spectra, same flux bands



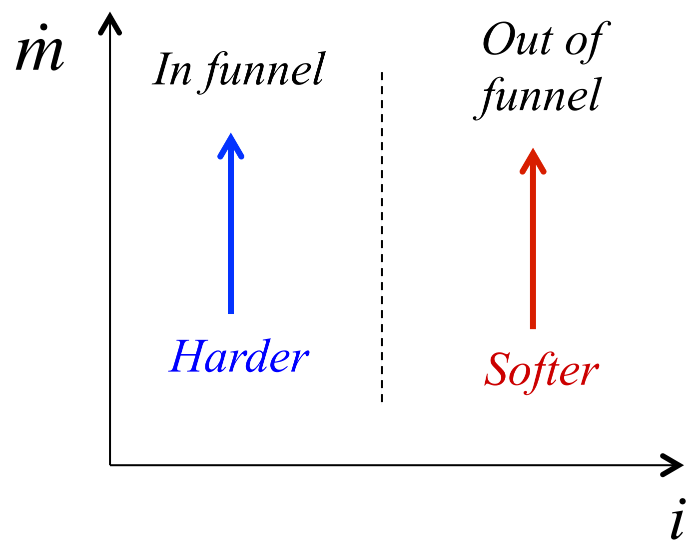
- Same general progression: flat or 2-component to disc-like
- But degeneracy seen too

What's going on?

- In supercritical model: for a beamed component we have beaming factor *b*, where $b \propto \dot{m}^{-2}$ and $L \propto b^{-1} \Rightarrow L \propto \dot{m}^{2}$ (King 2009)
- We see larger spectral changes at 4 keV (~ factor 4) than 0.75 keV (~ 2); hard component beamed, soft component not
  - Soft component increases as $\dot{m}$ - so accretion rate very stable
- Hard component increases faster – so dominates spectral changes

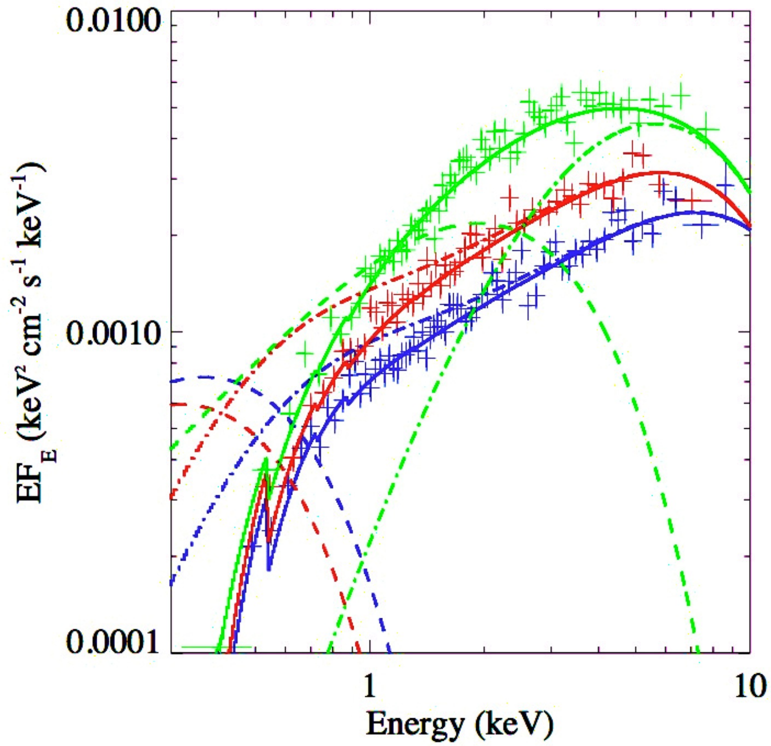
What about the degeneracy?

- Soft component more prominent in soft spectra – that's increased, but hard hasn't?
- Can happen if source precesses



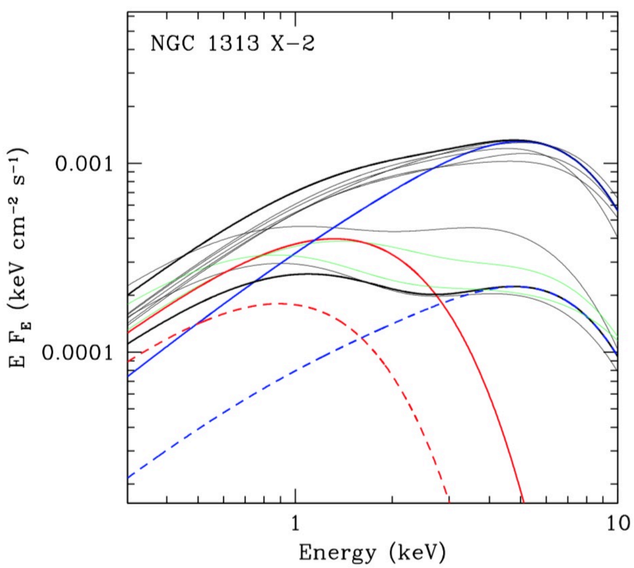
Further evidence for beaming?

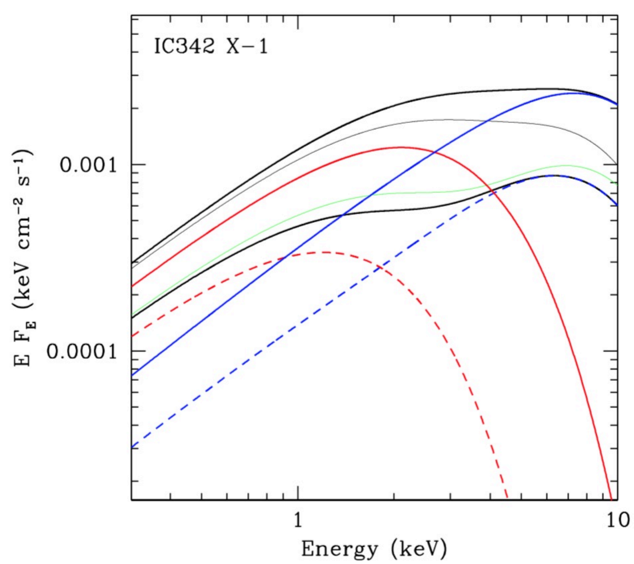
- We also found that the hard component softened as its flux increased
- Not classic disc behaviour!
- Commensurate with more scattering in tighter beam – energy lost in each scattering



Common behaviour?

- Ho IX X-1 appears disc-like at highest L_X – is this seen in other ULXs?
- Yes! E.g. NGC 1313 X-2, IC 342 X-1

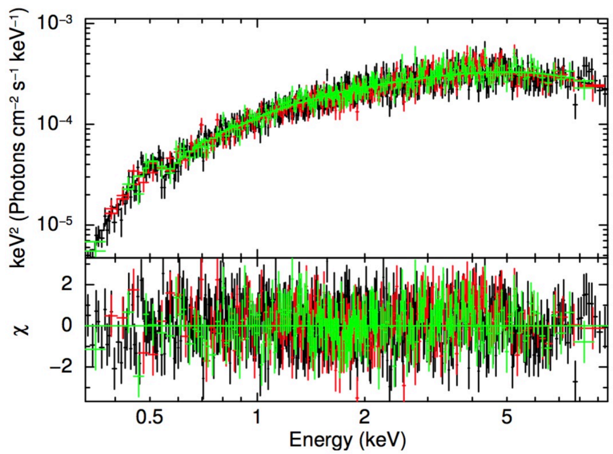




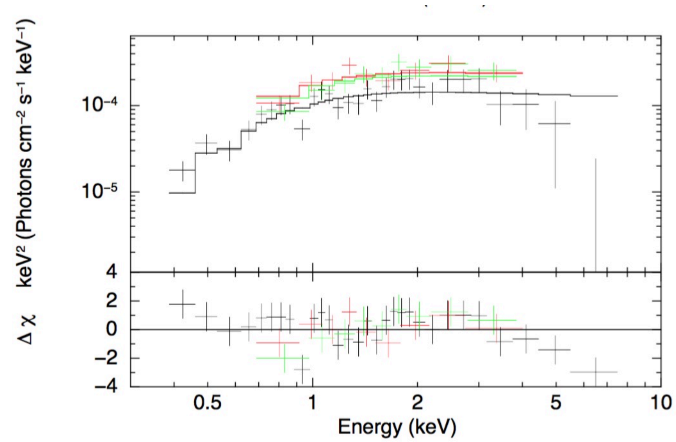
Both from Middleton et al. (2015)

What about objects above XLF break?

- Few objects above 2×10^{40} erg s^{-1}, most are distant – so data poor (Sutton et al. 2012)
- But where spectra not poor – look like discs

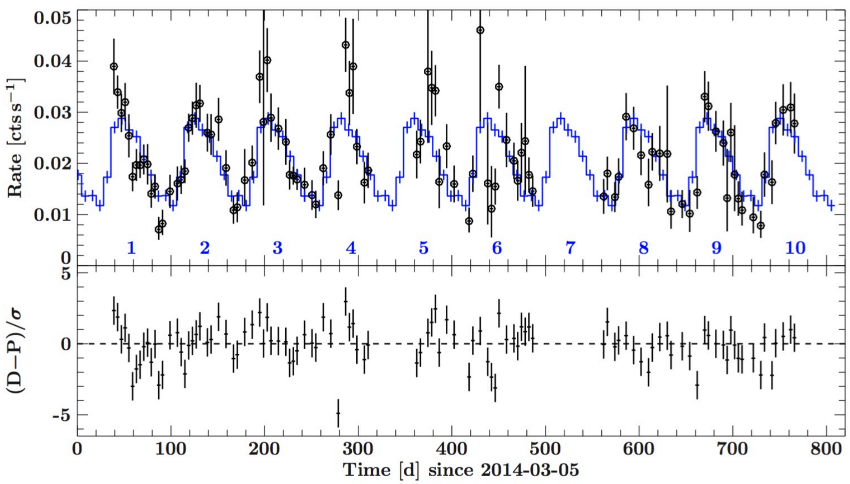


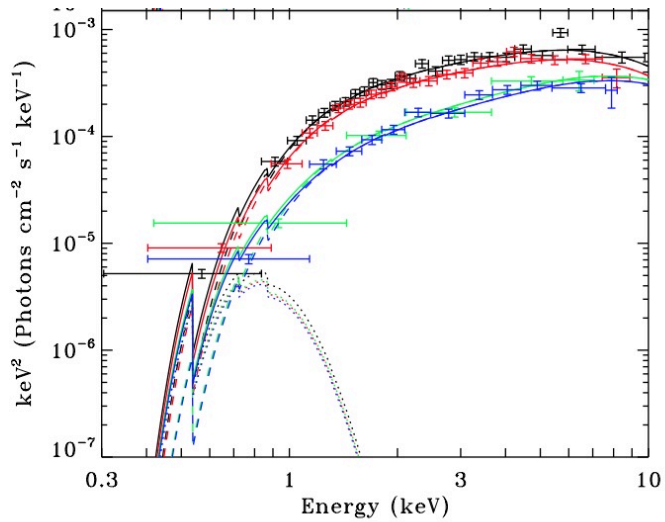
NGC 5643 ULX, $L_X \sim 4 \times 10^{40}$ erg s^{-1}, Pintore et al. (2016)



NGC 470 HLX, $L_X \sim 1 \times 10^{41}$ erg s^{-1}, Sutton et al. (2012)

Also the remarkable NGC 5907 ULX

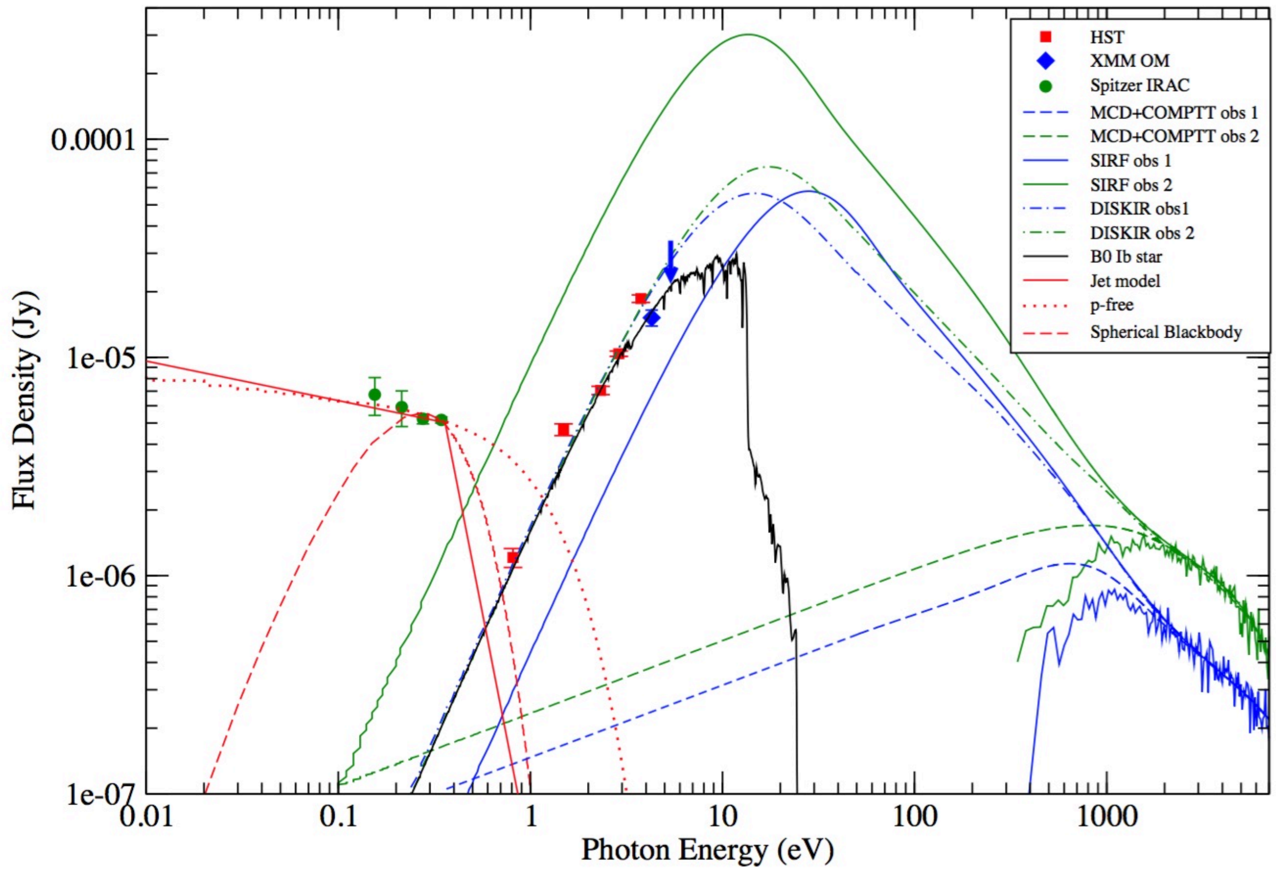




- L_X ~ 1 – 5 × 10^{40} erg s^{-1}; disc-like spectrum; ~ 78 day period (Sutton et al. 2013, Walton et al. 2015, 2016)
- Reported yesterday: pulsations ➔ NS!

Back to Ho IX X-1

Dudik, Berghea, Roberts et al. (2016)



Far IR to X-ray SED of Ho IX X-1

Clear IR excess

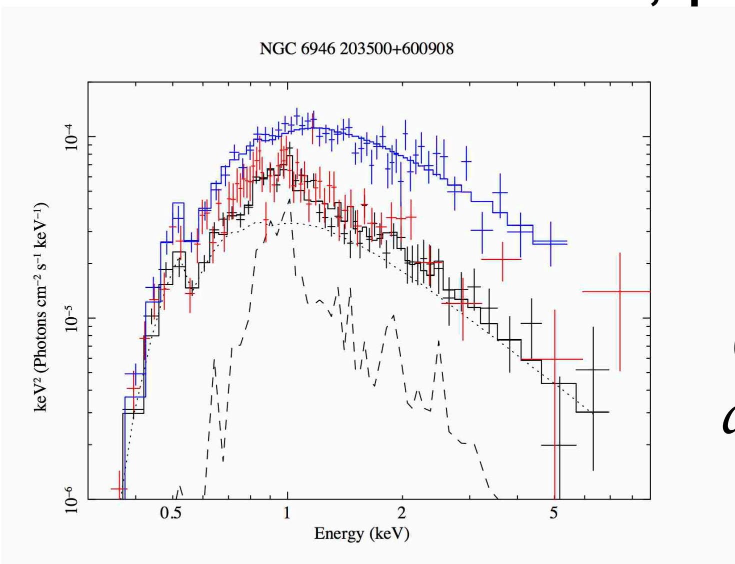
Variable radio jet, or circumbinary disc?

The Eddington Threshold

- Star-forming galaxy XLFs flat – so emit most (>80%) of energy (radiative & mechanical) in objects with luminosities above 10^{38} erg s^{-1}.
- Bulk of output in 1 – 30 × 10^{38} erg s^{-1} regime (*Eddington Threshold*)
- (Far) more binaries created in early Universe
- Feedback impacts on young galaxies
- Cosmologically important regime!

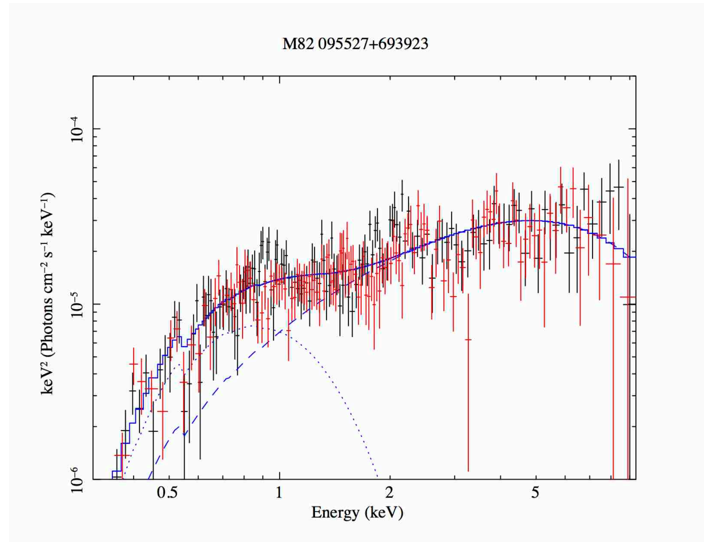
Important – but poorly understood

- Observational constraints on Eddington threshold HMXBs poor
- *Athena* science; pilot studies with *XMM-Newton*



ULS, $L_X \sim 4 - 10 \times 10^{38}$ erg s^{-1}

Stacked spectra (Roberts et al. in prep.)



Hard object, $L_X \sim 1.8 \times 10^{38}$ erg s^{-1}

Conclusions

- At the highest ULX luminosities, objects have broad, disc-like spectra
  - Beamed emission from inner accretion flow?
  - Highly super-Eddington objects – not IMBHs (maybe not even BHs?)
- Lowest ULX luminosities important too
  - ~Eddington accretion not well understood
  - Cosmologically important!