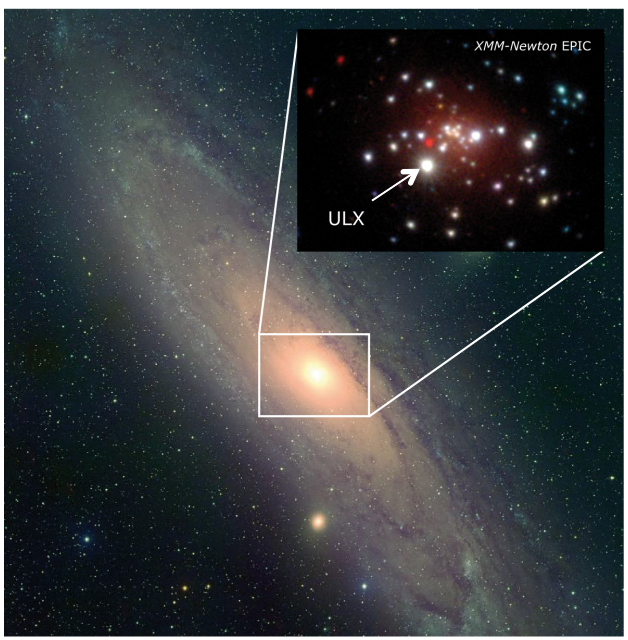
# ULXs and accretion physics beyond the Eddington limit





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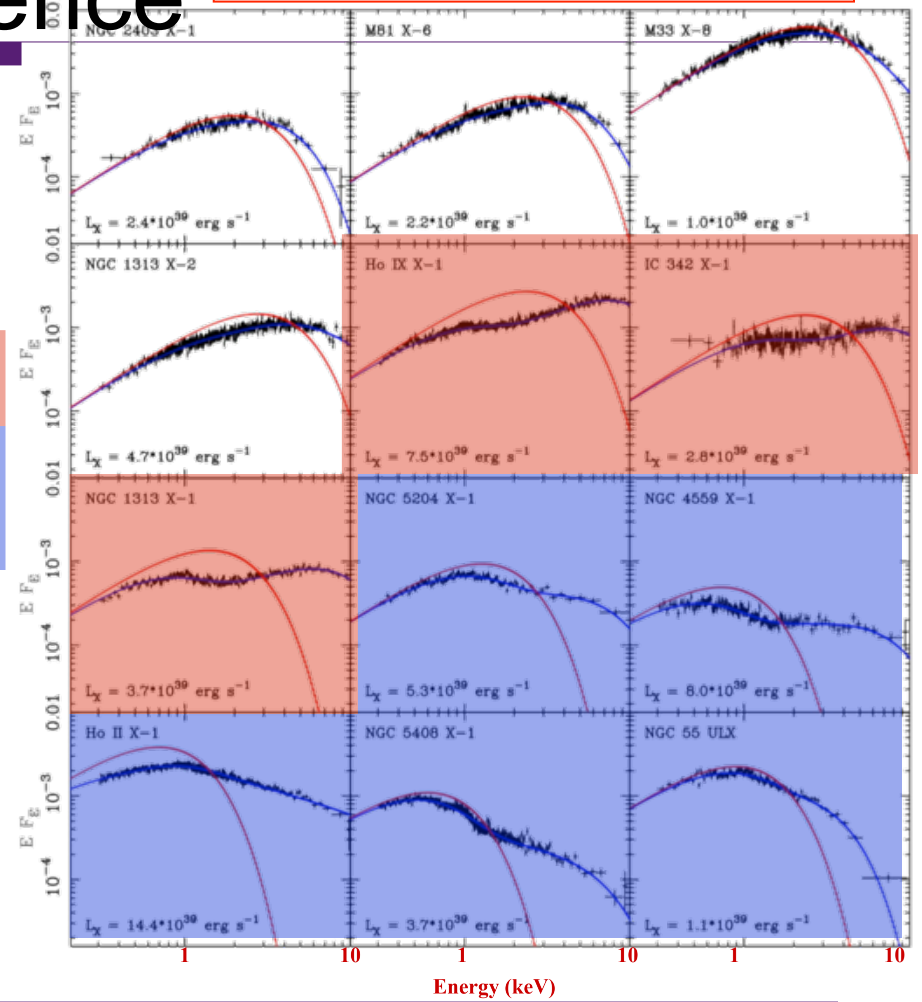
# ULXs and super-Eddington accretion

- Now commonly accepted most ULXs harbour stellar remnant BHs accreting at or above Eddington limit (Feng & Soria 2011)
  - Evidence: *ultraluminous state* X-ray spectra (Gladstone et al. 2009); X-ray luminosity functions (Swartz et al. 2011; Mineo et al. 2011); relation to star formation (King 2004) etc…
  - Exception: most luminous ULXs, at ~ $10^{41}$ erg $s^{-1}$ (Farrell et al. 2009, Sutton et al. 2012)
- How does super-Eddington accretion work?

# ULX spectral sequence

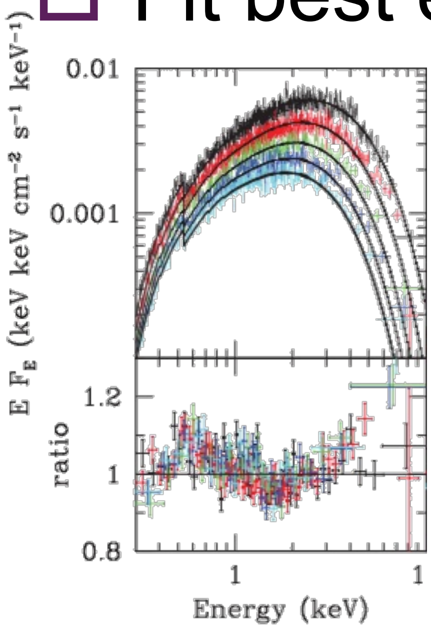
*Gladstone, Roberts & Done 2009*

- Spectral sequence: rise in accretion rate?
  - Modified disc regime
  - Ultraluminous regime
  - Extreme ultraluminous regime
- Outstanding questions:
  - How do the disc spectra evolve to ultraluminous?
  - Is this sequence solely a function of accretion rate?



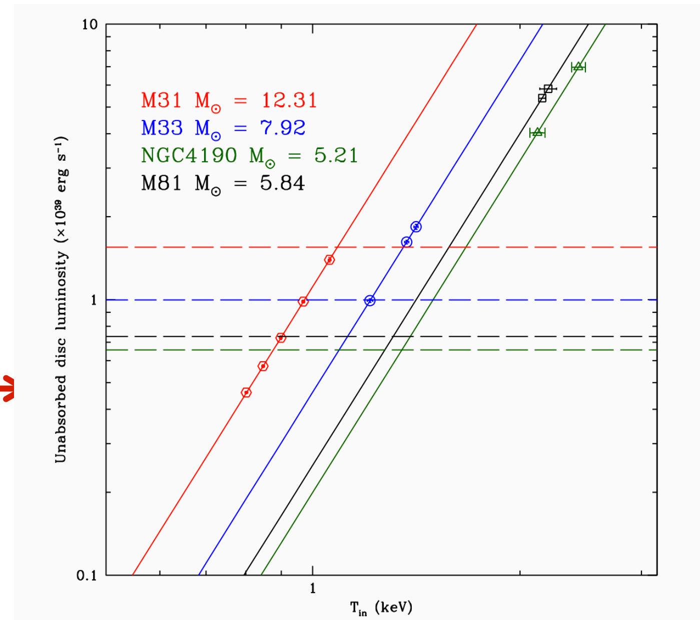
# Are the disc spectra really disc-like?

- Fit best examples with best disc models




*XMM data for M31 ULX, fit with BHSPEC model (Middleton et al. 2012)*

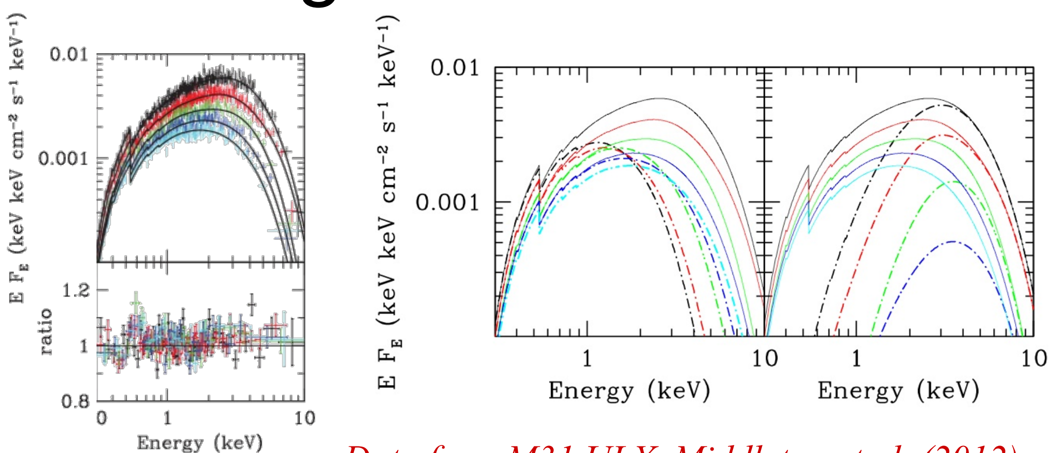
*KERRBB results for 4 brightest modified disc ULXs. Horizontal lines show $L_{Edd}$ & diagonal show L-T track for BH mass; best fit spin is maximal (Roberts et al. in prep.)*



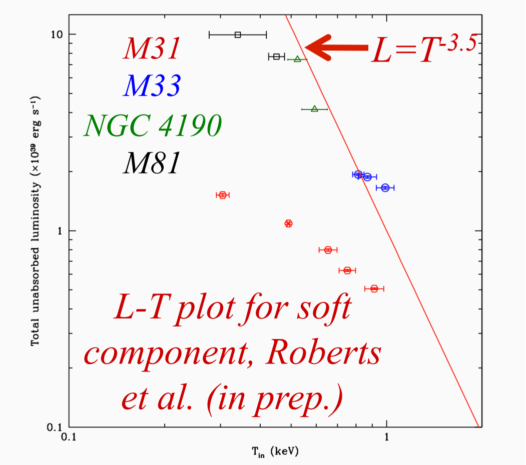

- Recover $L \sim T^4$; but fits poor
- Do we understand accretion discs at $L_{Edd}$?

# Discs as 2-component models

- Try 2-components as per brighter ULXs
- Better fits with advective disc + corona
- Physically – wind launched as ULX crosses Eddington threshold



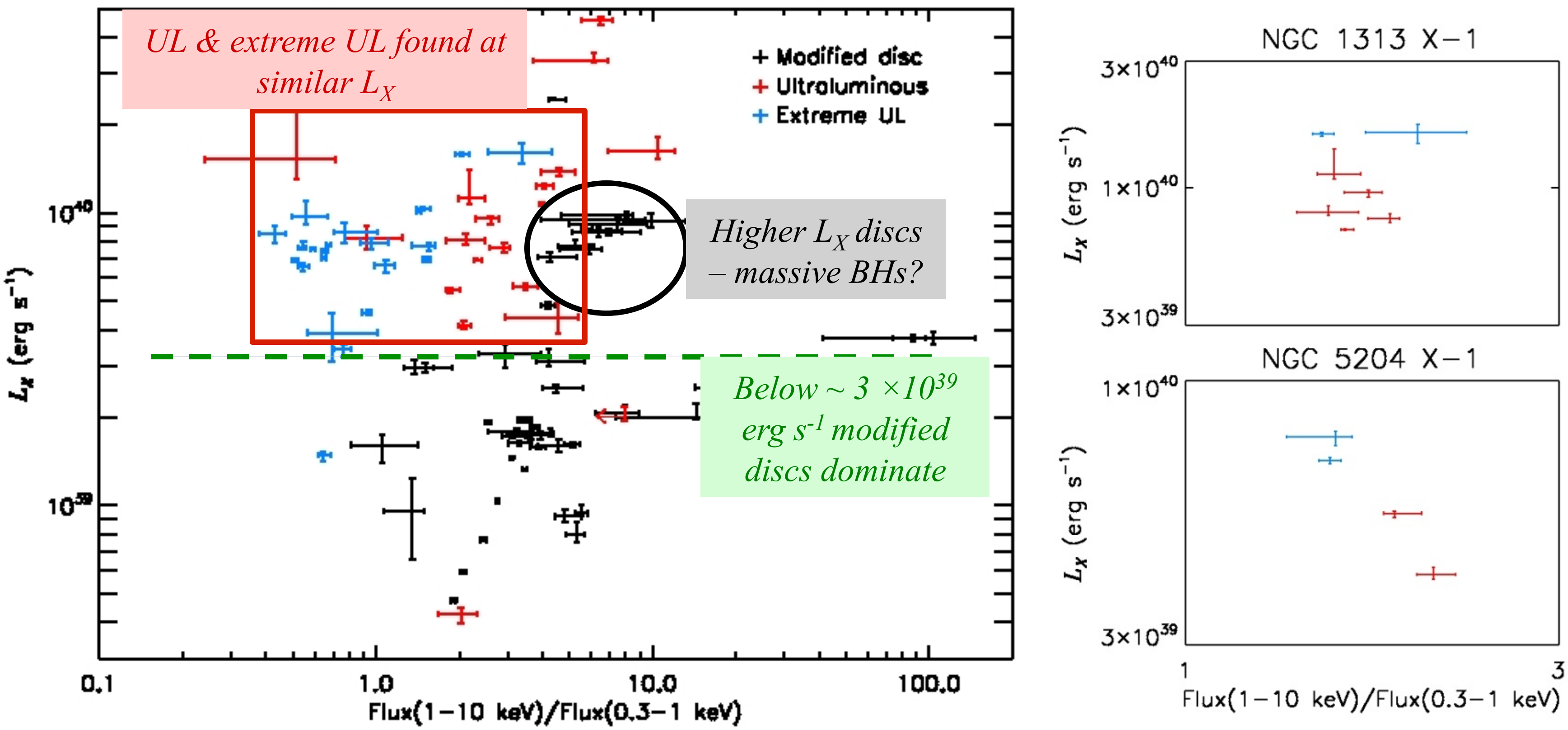

Data from M31 ULX, Middleton et al. (2012)



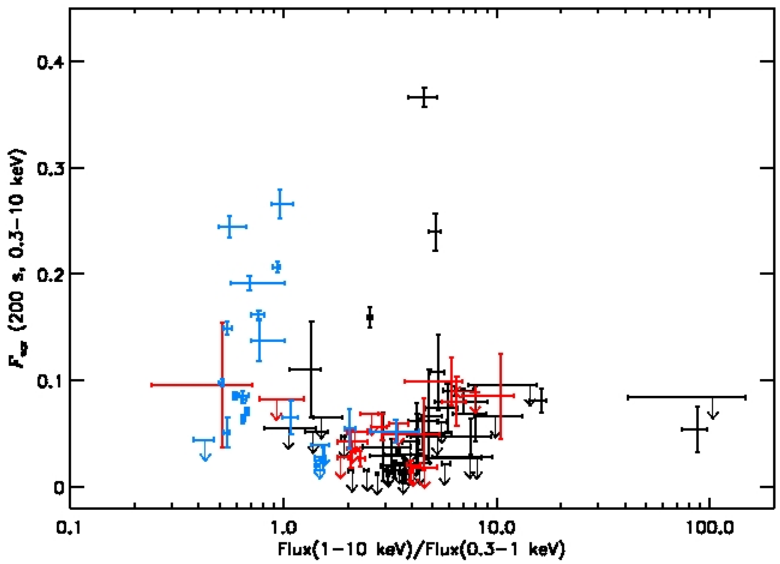
# Can we say more about ULX physics?

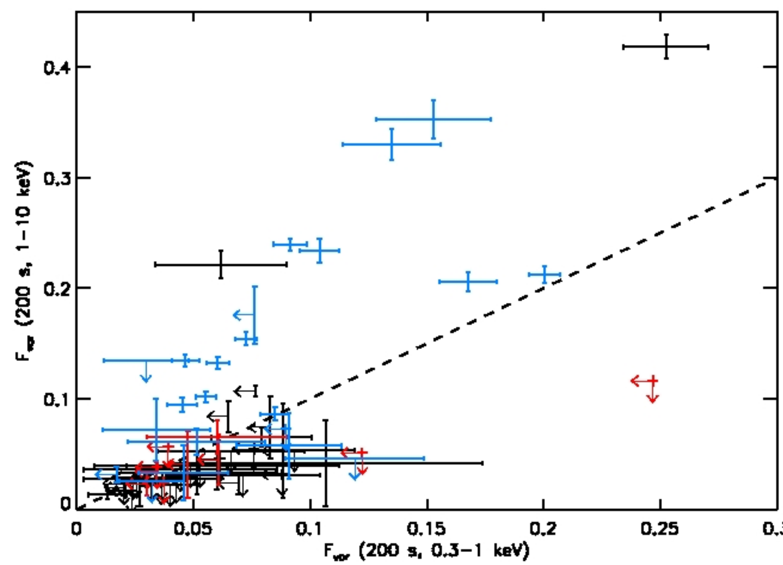
- Broadened disc spectra show emergence of two components in bright ULX spectra
- What are these components?
- New study (Sutton poster)
  - Separate 89 obs from 20 ULXs into 3 distinct regimes based on empirical spectral model
  - Recover deabsorbed fluxes, hardness
  - Calculate fractional variability on 200 s timescale in broad, soft & hard bands

# Hardness-intensity diagram



# Hardness-variability diagrams




- Low $F_{var}$ (< 10%) in most disc & all UL
- High $F_{var}$ mainly seen in some extreme UL; stronger above 1 keV; not persistent

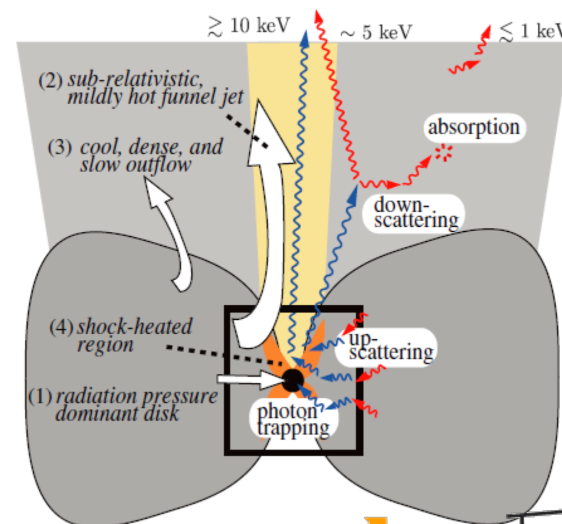
# Implications (1): modified discs

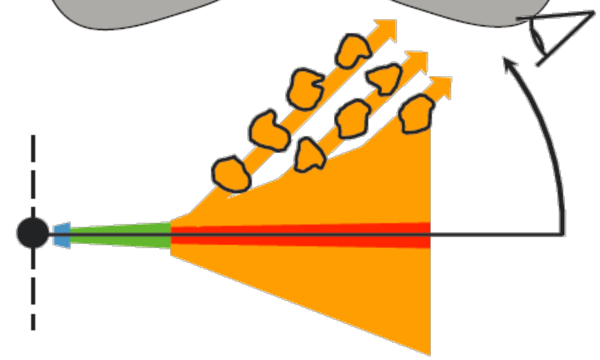
- Mainly observed at ~ 1 – 3 × $10^{39}$ erg $s^{-1}$: transition between sub- and super-Eddington for stellar-mass BHs
- Some at higher $L_X$ – massive stellar remnant BHs ($20M_\odot < M_{BH} < 100M_\odot$)
- Detection of strong, hard variability inconsistent with classic disc – supports 2-component model with emergent ULX spectrum

# Implications (2): super-Eddington ULXs

- Inclination important in perceived spectrum (cf. Poutanen et al. 2007)
  - On-axis: ultraluminous
  - Off-axis: extreme UL
- Supported by variability
  - Extrinsic, caused by clumpy wind crossing line of sight
- State changes in ULXs due to narrowing of funnel opening angle (cf. King 2009)

*Kawashima et al. (2012)*

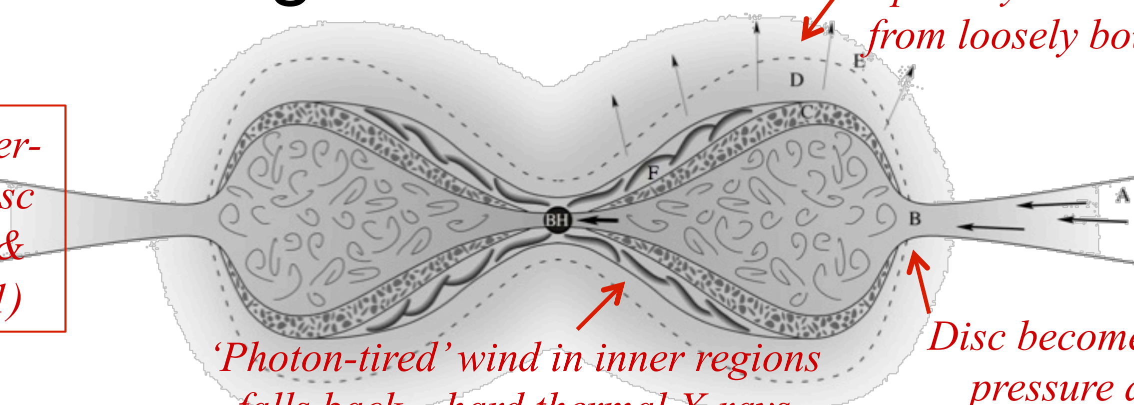


*Middleton et al. (2011)*

# Conclusions

- We can now qualitatively explain the range of ULX spectra in terms of 3 properties: BH mass, accretion rate and inclination
- Main characteristics agree with models of super-Eddington accretion




*Model of super-Eddington disc from Dotan & Shaviv (2011)*