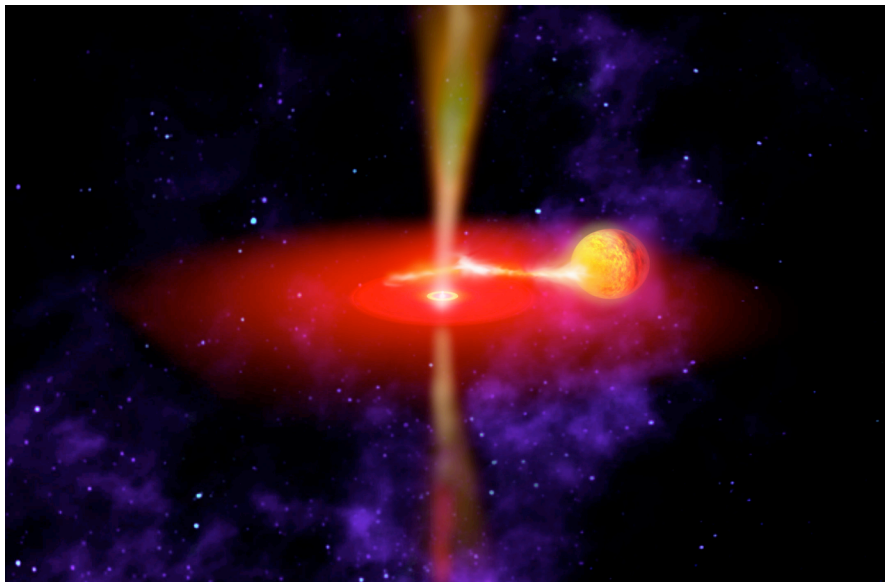
Durham University

The Ultraluminous State

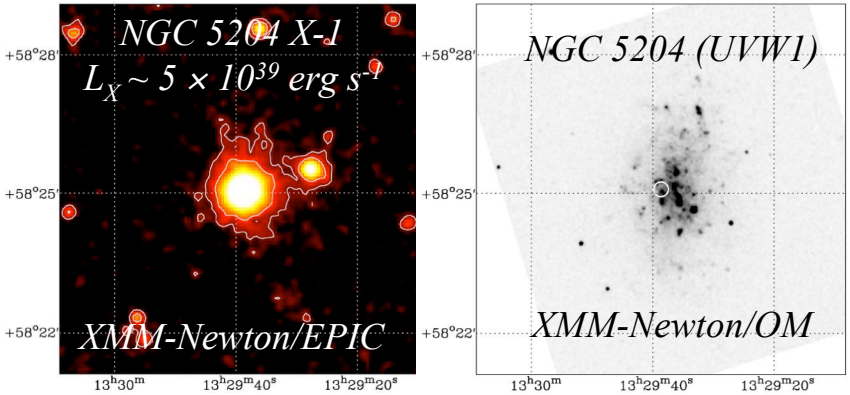


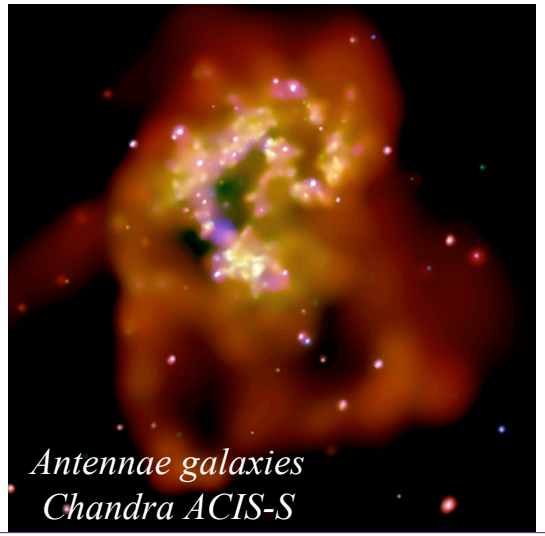
Tim Roberts

Jeanette Gladstone, Chris Done (Durham)
Lucy Heil, Simon Vaughan (Leicester)
Kiki Vierdayanti (Kyoto)

Ultraluminous X-ray sources (ULXs)

- Brightest extra-nuclear X-ray sources, with $L_X > 10^{39}$ erg s^{-1}
- **What are they?**
  - Intermediate-mass black holes (IMBHs) - origin is primeval or merging BHs - sub-Eddington accretion: familiar behaviour
  - Stellar remnant BHs (see Zampieri talk) - super-Eddington accretion: poorly understood

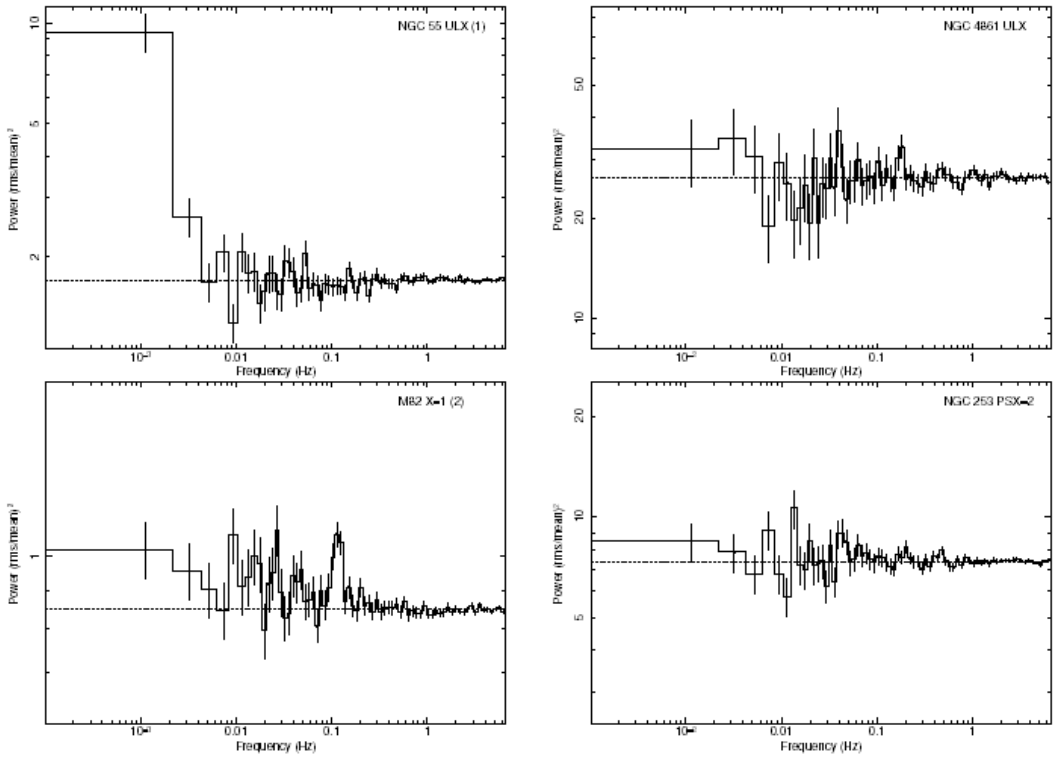




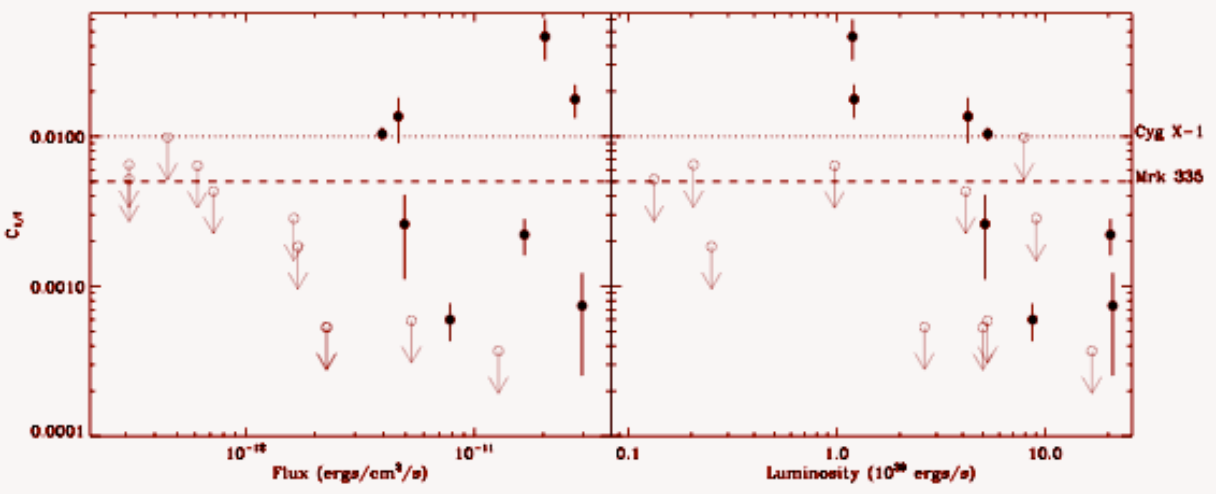
A systematic study of ULX PSDs

Heil, Vaughan & Roberts 2009

- 19 observations of 16 ULXs with sufficient quality to derive PSDs
- 8 observations of 6 ULXs show detectable variability power
  - Confirm QPOs, PSD breaks seen before (e.g. Strohmayer et al. 2003, 2007)
- But other ULXs show remarkable lack of variability



Lack of fast variability in ULXs



- Constrain variability power using simple models
- Comparison to red power spectrum shows suppressed variability of ULXs compared to Galactic BHs and AGN
  - Disc-domination or similarity to χ-state of GRS1915+105 possible; both imply small BHs, super-Eddington rates
- Predicted for super-Eddington accretion (Ohsuga 2007)

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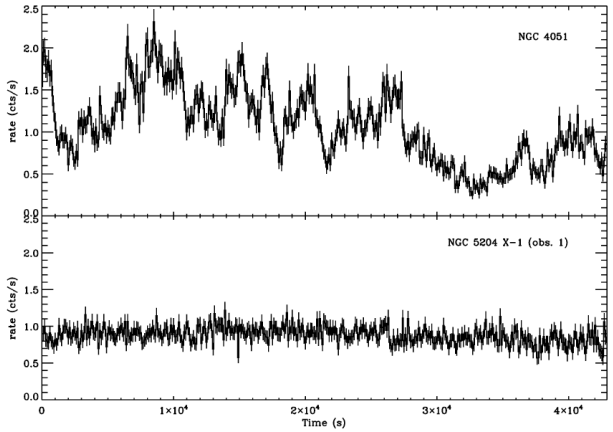

Variability of NGC 5204 X-1 compared to the AGN, NGC 4051. The count rate of NGC 4051 is scaled to that of NGC 5204 X-1

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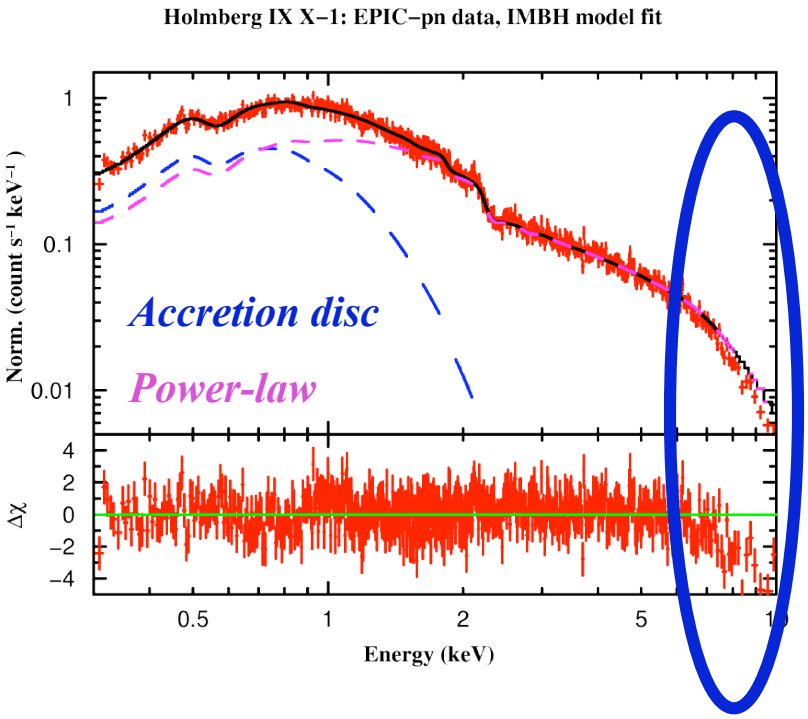
ULX spectra

Stobbart, Roberts & Wilms 2006

- Previously: Miller et al. (2003,4) - cool disc + power-law fits as evidence for ~1000$M_\odot$ IMBHs
- Stobbart et al. (2006) demonstrate that 2-10 keV spectrum fitted by a broken power-law in all of the highest quality data
- Invalidates IMBH model - disc not dominant, hard component is not a simple power-law



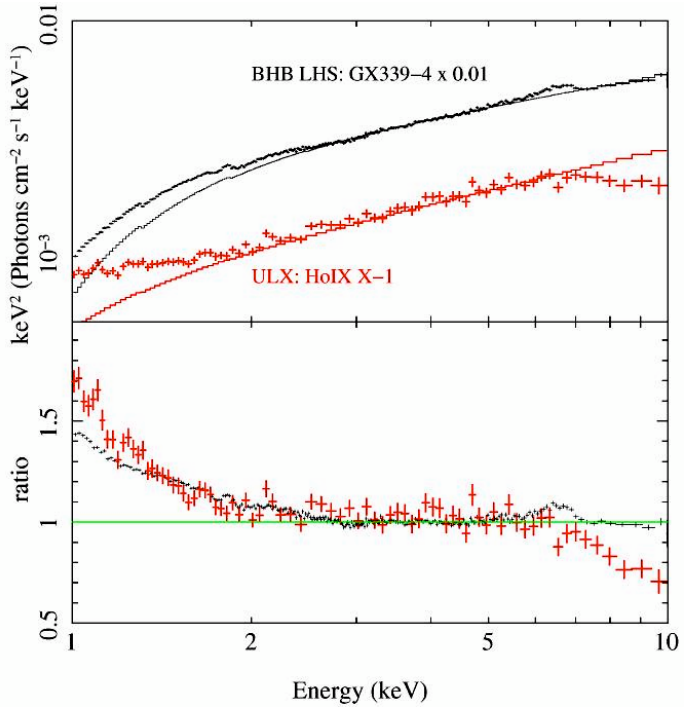
Explanations for spectral break

- Stobbart et al. (2006) - fit accretion disc plus Comptonised corona models - find fits with cool disc and cool, optically thick corona
  - Extreme version of very high state, inner disc hidden by thick corona so only see cool outer disc
- Kerr disc models (Makishima et al. 2000)
- "Slim" accretion discs (e.g. Watarai et al. 2000)
  - Slim-disc-like accretion disc profiles for ULXs (e.g. Tsuneda et al. 2006, Vierdayanti et al. 2006, Mizuno et al. 2007).
- Fully comptonised VHS with spectrum modified by ionised fast outflow (Goncalves & Soria 2006).
- Common thread: **high accretion rate, small black holes ($M_{BH} < 100\ M_{\odot}$).**

ULX spectra II

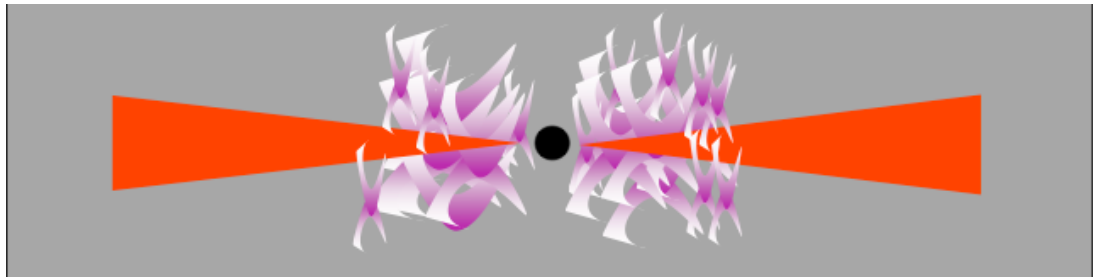
Gladstone, Roberts & Done 2009

- Revisit best quality spectra with simple empirical models
  - 11/12 show strong improvement to fit ($\Delta\chi^2 > 30$) with addition of soft excess
  - 11/12 show > 98% statistical improvement to fit using broken power-law (over power-law) above 2 keV
- Unlike any known spectral state
- **A new, ultraluminous accretion state?** (Roberts 2007)



Low hard state in GX339-4 vs a classic ULX, Ho IX X-1

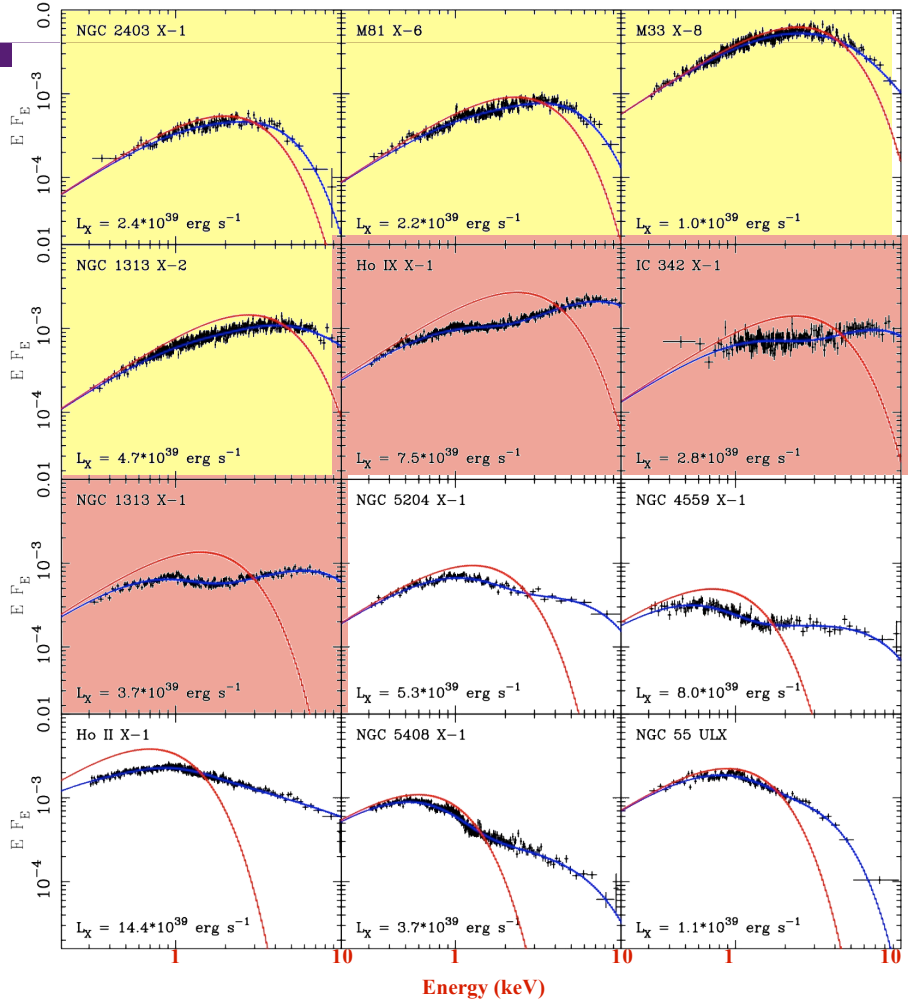
Physical models



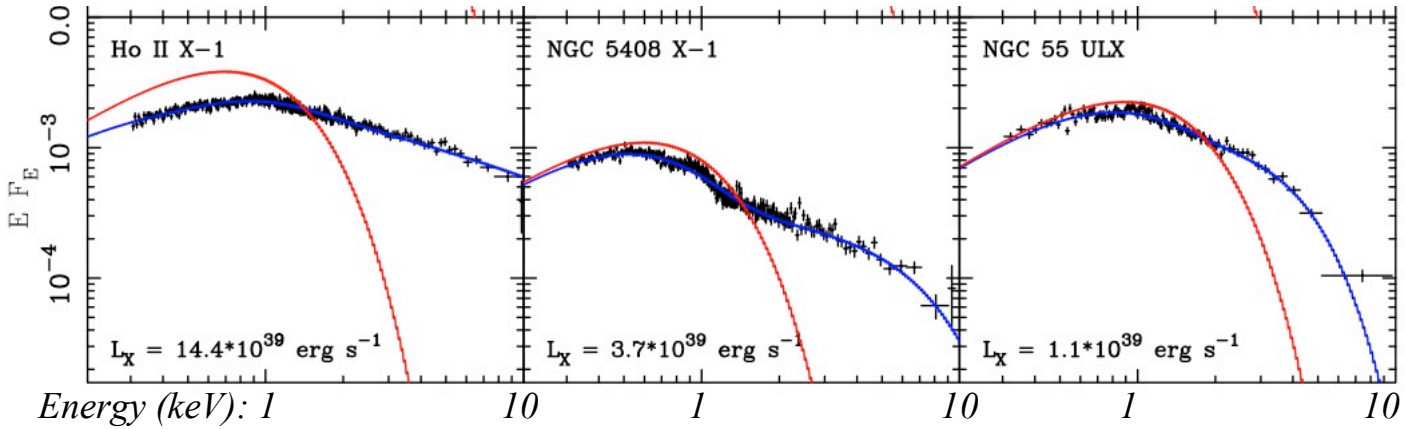
- Slim disc models (p-free) - in some ULXs provide poor physical parameterisation - kT_{in} too high (1 - 13 keV)
- Revisit disc plus corona models (illustrated above) - fits give cool discs (0.2 - 0.8 keV), optically thick coronae ($6 < \tau < 80$) in *all* cases
- But assumptions made - inner disc visible, unaffected by optically thick corona

Coupled disc-corona

- Can correct for energy used to launch corona, obscuration of inner disc (Done & Kubota 2006)
- Recover disc temps ~ 0.6 - 1 keV for 8/12 ULXs
  - Modified disc spectra - ~Eddington-rate: big stellar BHs or beamed?
  - Truly super-Eddington - optically thick coronae



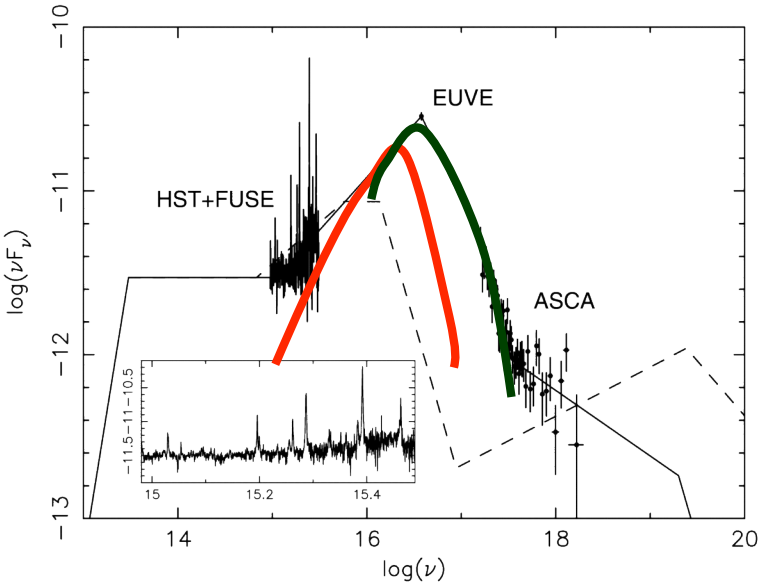
Low temperature discs?



- Four sources still possess low temp discs (~0.3 keV) - evidence for IMBHs?
- But theory predicts key characteristic of super-Eddington accretion is a wind (e.g. Poutanen et al. 2007, King 2008)
- If sufficient material present - cool photosphere formed at base of wind - greater effect for higher accretion rate
- **ULXs are most extreme accretion environments, not IMBHs**

The ultraluminous state at large

- High L_X observations of GRS 1915+105, GRO J1655-40 show optically-thick Comptonisation spectra (e.g. Ueda et al. 2009)
- Highest Eddington fraction AGN show similar spectra (Middleton et al. 2009, Jin et al. 2009)
- *ULXs as super-Eddington template, applications from growth of stars to growth of QSOs and galaxies…*



Optical-UV-X-ray spectrum of RE J1034+396 (Casebeer et al. 2008)

Work remains to be done…

- Confirm spectra are different to sub- and near-Eddington BHBs in 0.3 - 10 keV regime
- Outstanding challenge for ultraluminous state: consolidate spectral properties with short-term variability (i.e. PSDs) and long-term spectral variability
  - Heil et al. (2009) - ULXs with apparently similar spectra may show very different PSDs
  - Variety of spectral behaviours (Feng & Kaaret 2009, Kajava & Poutanen 2009)
- **New data required**

The final word

- The hypothesis that many ULXs contain ~1000 $M_\odot$ IMBHs is increasingly discredited - although some examples may exist (e.g. in HLXs)
- X-ray spectral, timing properties unlike Galactic black holes - suggesting ULXs are in a higher accretion rate state - an "ultraluminous state"
  - Black holes may still be up to ~100 $M_\odot$
- **Controversy cannot finally be resolved without dynamical mass measurements for the BHs underlying ULXs - *coming soon?***