# Across the Eddington boundary: Examining disc spectra at high accretion rates

Andrew Sutton (MSFC)

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# Introduction

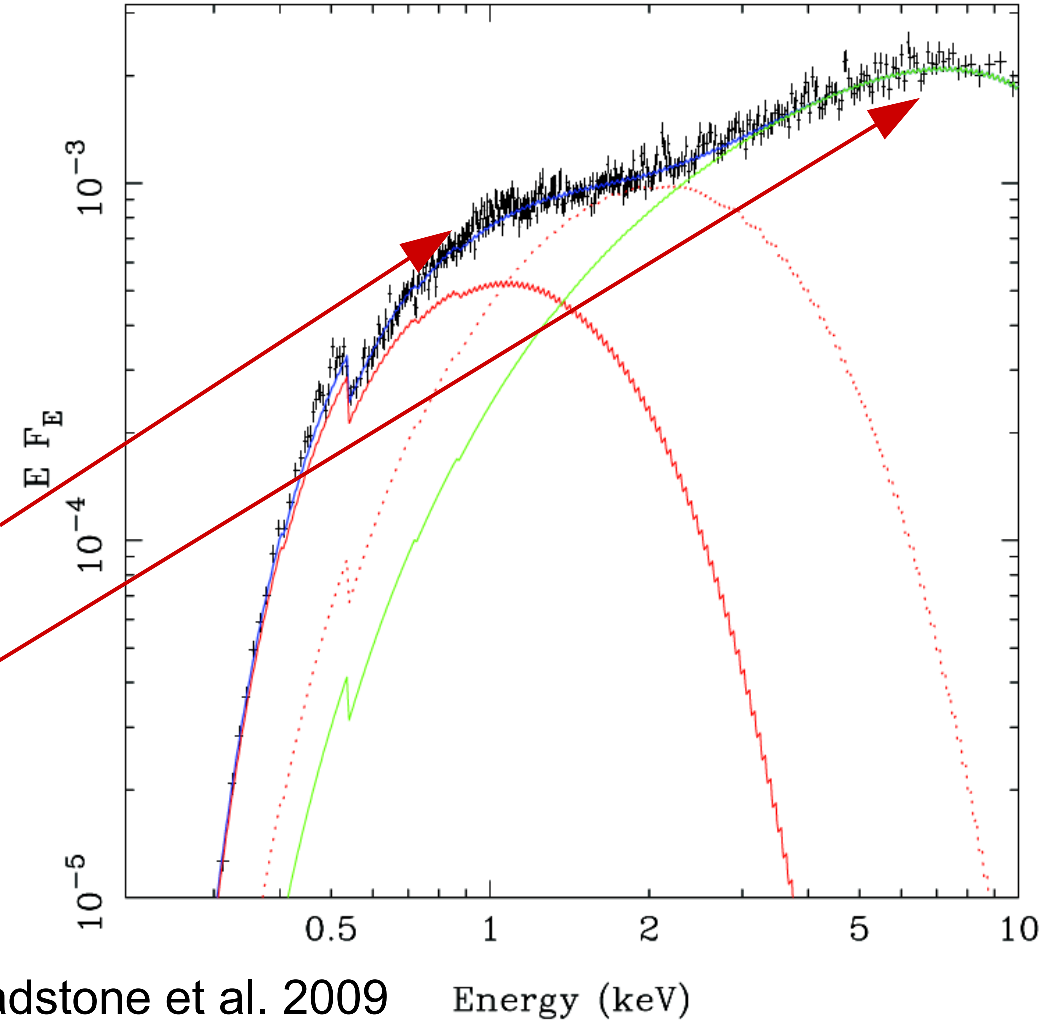
- Super-Eddington accretion states in ultraluminous X-ray sources (ULXs)
- Broadened disc ULXs: ~Eddington rate accretion?
- A new study comparing bright sub-Eddington accretion discs with broadened disc ULXs
  - Motivation
  - Results
  - Implications

# Super-Eddington accretion

- Key class of sources: the ultraluminous X-ray sources (ULXs)
  - Extra-Galactic (distances of ~ 5 – 100 Mpc)
  - Non-nuclear - they are not supermassive black holes
  - Bright X-ray point sources ($L_X \sim 10^{39} - 10^{41}$ erg s$^{-1}$)
    - ULXs exceed the Eddington limit for stellar remnant black holes ($\sim 1.3 \times 10^{38}$ erg s$^{-1}$ $M_\odot^{-1}$)
      - Super-Eddington accretion
      - Or more massive black holes

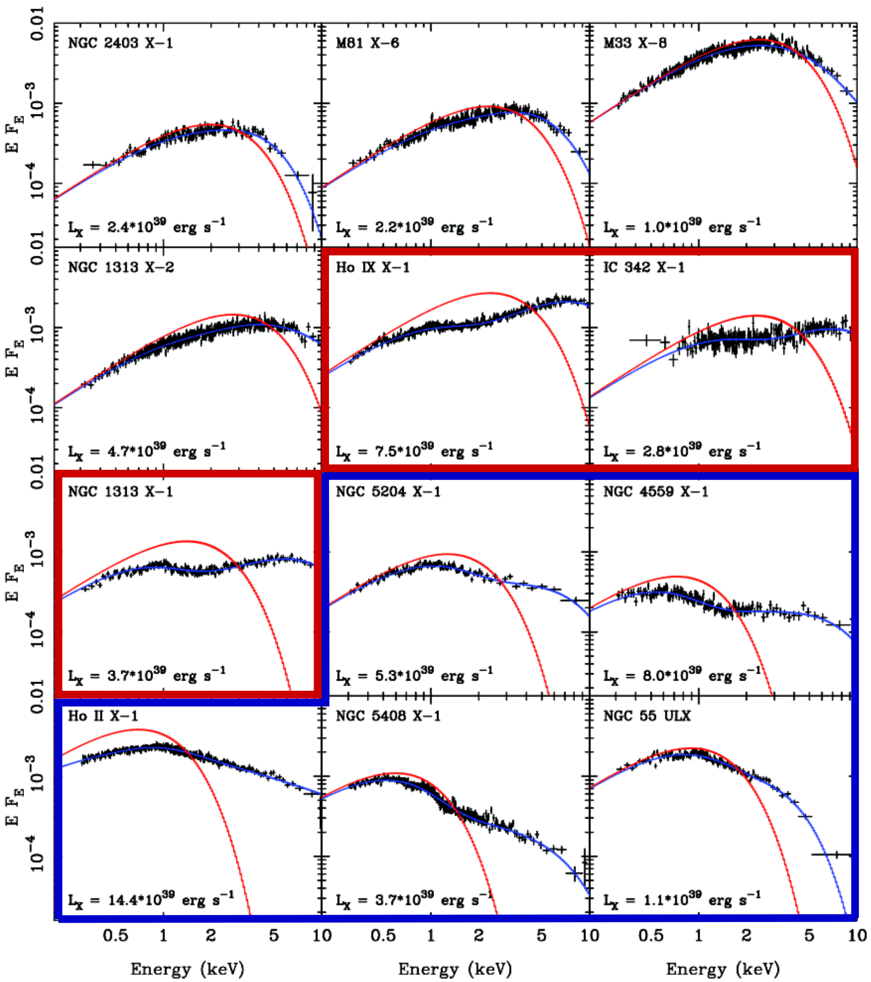
# ULX spectra

- The highest quality *XMM-Newton* ULX spectra differ from sub-Eddington states
- Rules out sub-Eddington massive black holes
- Most ULXs are in a new accretion state
  - Characterised by a soft excess
  - And a high energy break

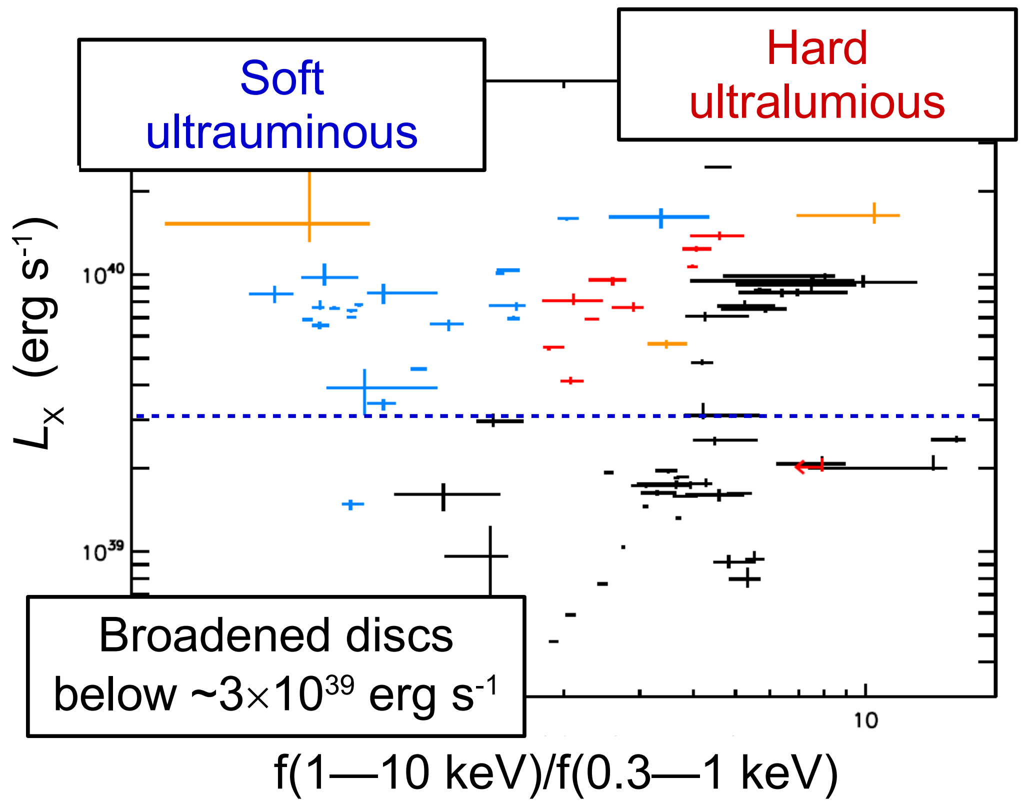



Gladstone et al. 2009

# The ultraluminous state

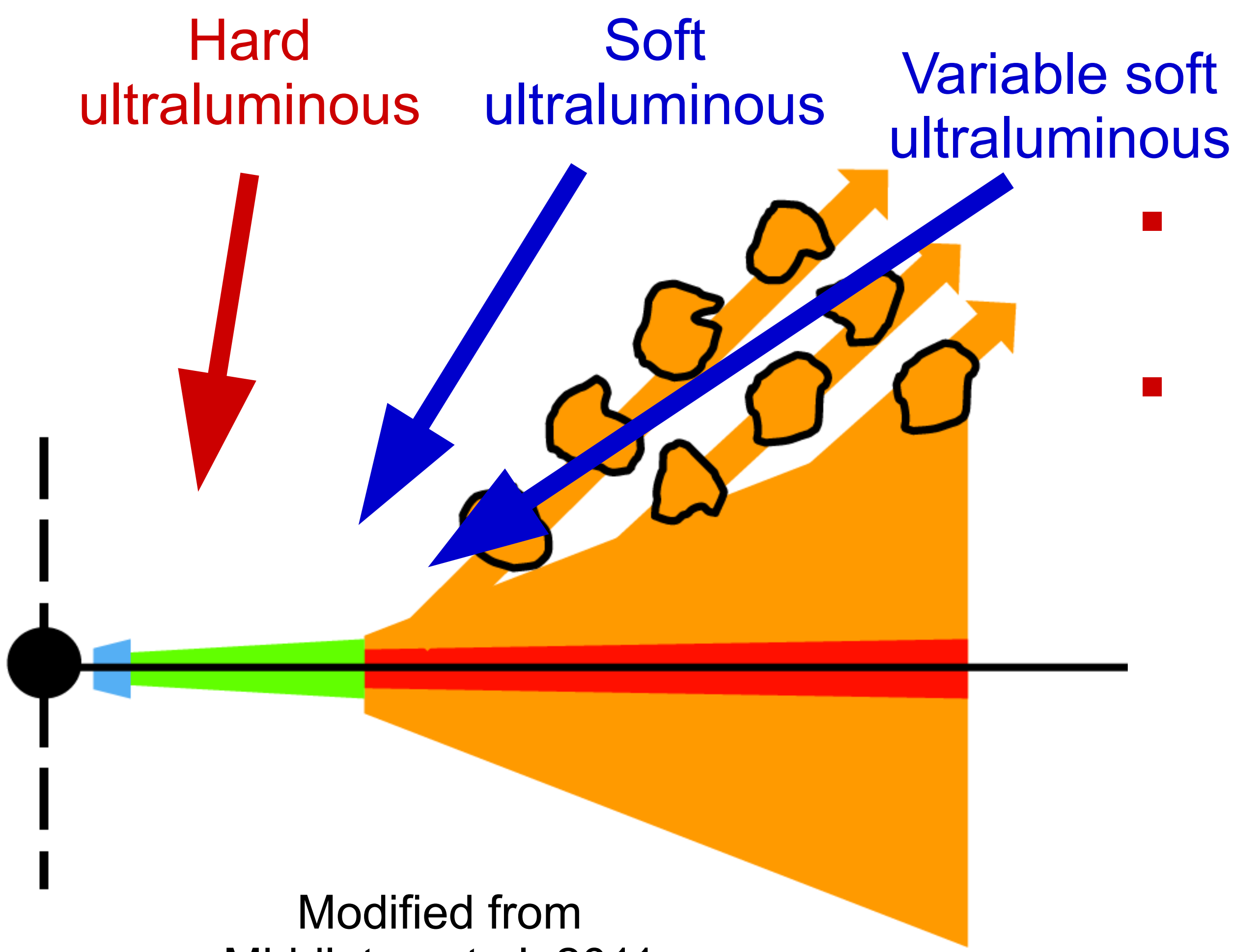



Gladstone et al. 2009




Sutton et al. 2013

# The most luminous ULXs

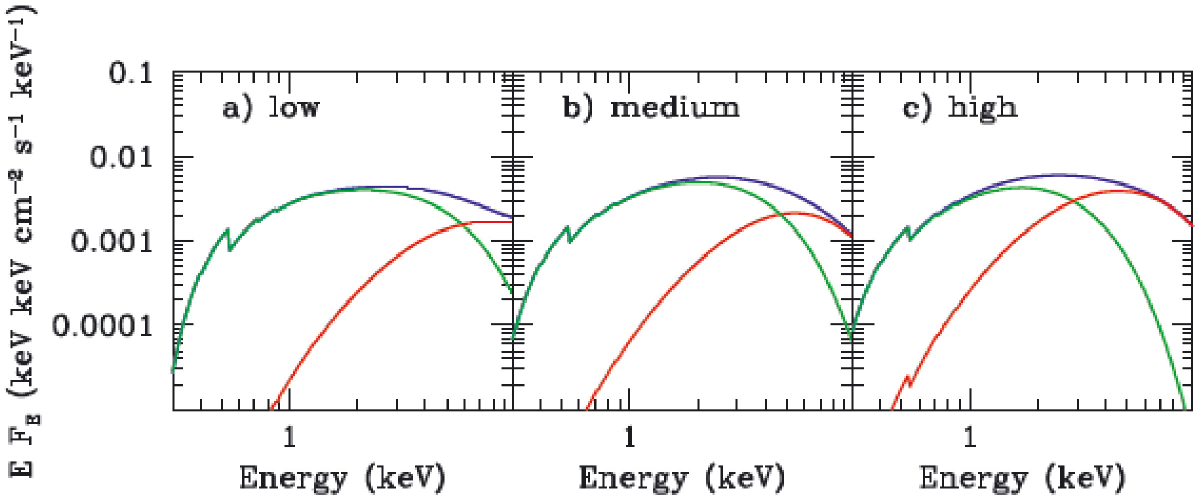



Modified from
Middleton et al. 2011

- Key feature: super-Eddington outflow
- Inclination and mass accretion rate determine properties

# Broadened disc spectra

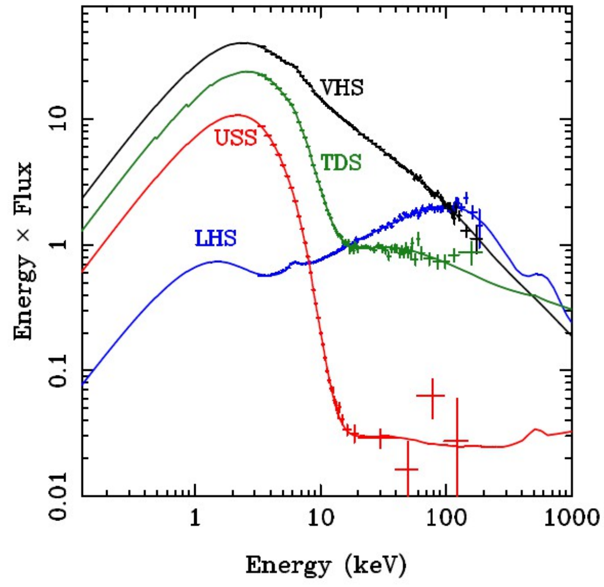
- From a comparison with the hard/soft ultraluminous sources
  - Broadened disc ULXs may have subtle, emerging 2-component spectra

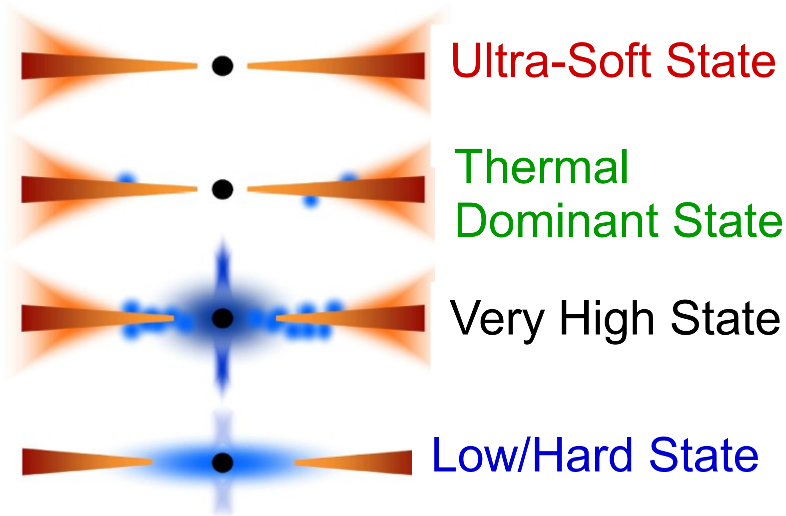



M33 X-8, Middleton et al. 2011

# Sub-Eddington accretion discs

- Differentiated by mass accretion rate, to first-order
- 2-components: accretion disc and 'power-law'
- Thin accretion disc component dominates at high accretion rates in the thermal dominant state

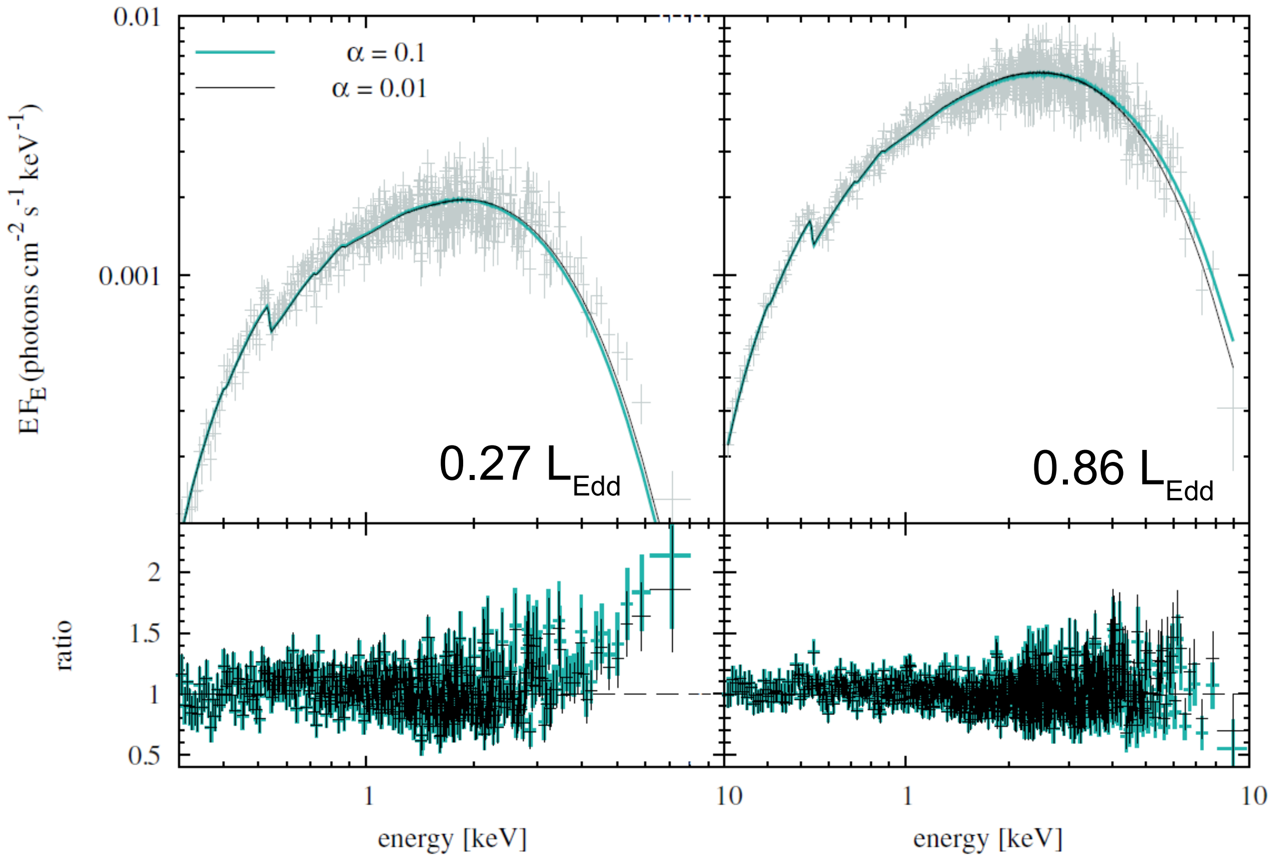



Done et al. 2007

# Broadened disc spectra

- Broadened disc ULXs may be an extension of the thermal dominant state
- With geometrically slim, advection dominated discs



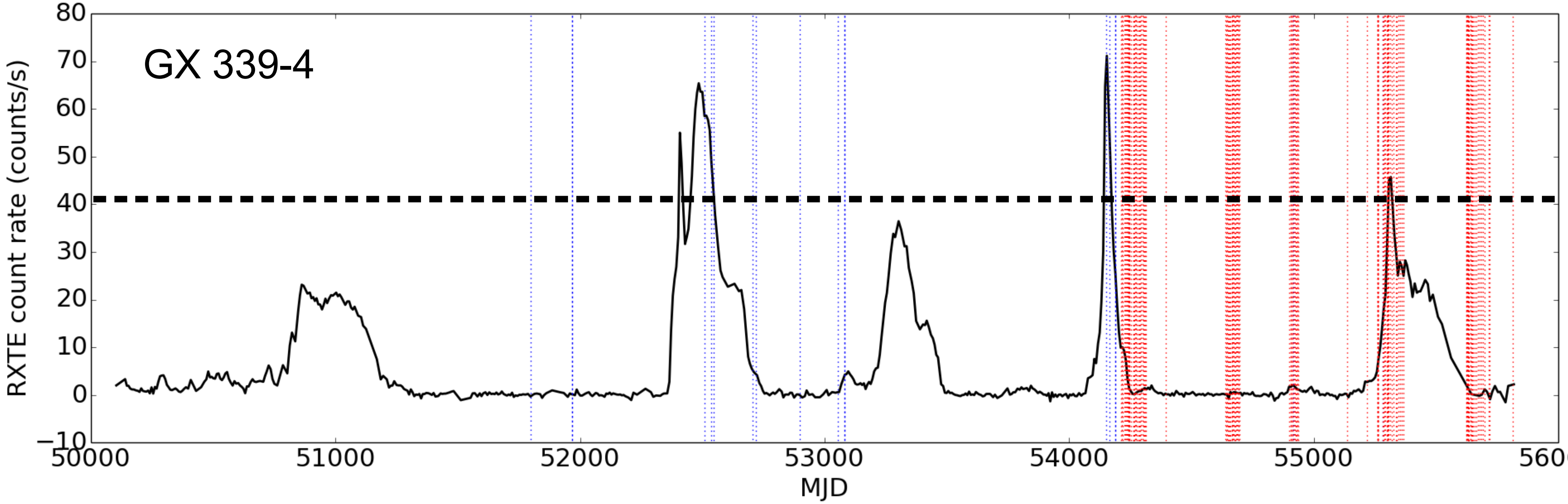

CXOM31 J004253.1+411422
Straub et al. 2013

# A new study: motivation

- To test whether thermal dominant spectra can really be approximated by thin disc models in soft X-rays
- Carry out a comparison of the most luminous thermal dominant spectra and broadened disc ULX spectra
  - What is the accretion physics in broadened disks?
  - What are their Eddington ratios?

# BHB Sample selection

- Obtained *RXTE* light curves for 21 BHBs out to LMC (Zhang 2013)
- Searched for *XMM-Newton* and *Swift* observations during periods where *RXTE* data exceeded $10^{38}$ erg $s^{-1}$
- Eliminated obvious non-thermal dominant spectra and GRS 1915+104
- 8 observations of 3 sources: GX 339-4, LMC X-3 and LMC X-1

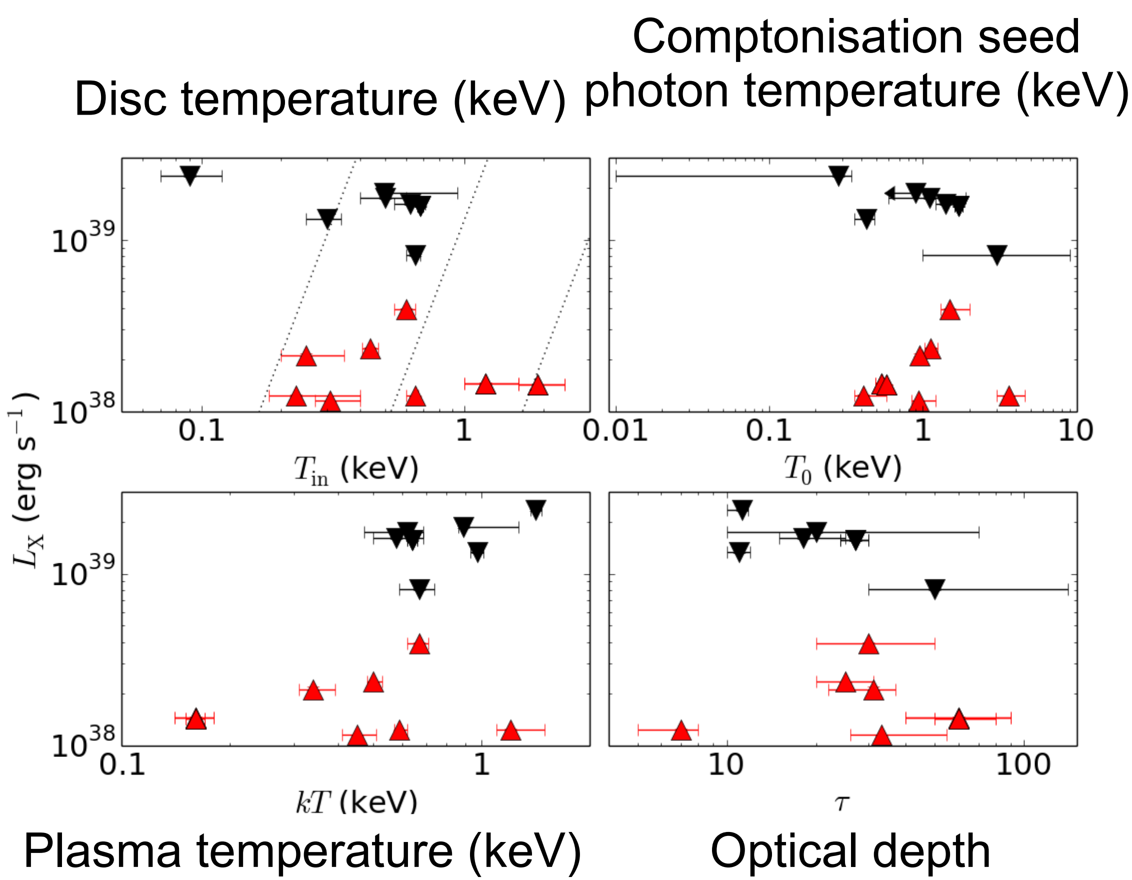


# Methods

- Extract BHB spectra
- Degrade BHB spectra such that they are of comparable quality to the ULX sample (~25000 counts)
- Extract broadened disc spectra from ULXs with $L_X < 3\times10^{39}$ erg $s^{-1}$ from Sutton et al. (2013) plus a transient in M31
- Fit all 3 sets of spectra with various models appropriate for thin discs, slim discs and bright ULXs
- Extract covariance spectra from the ULXs to test for multiple spectral components

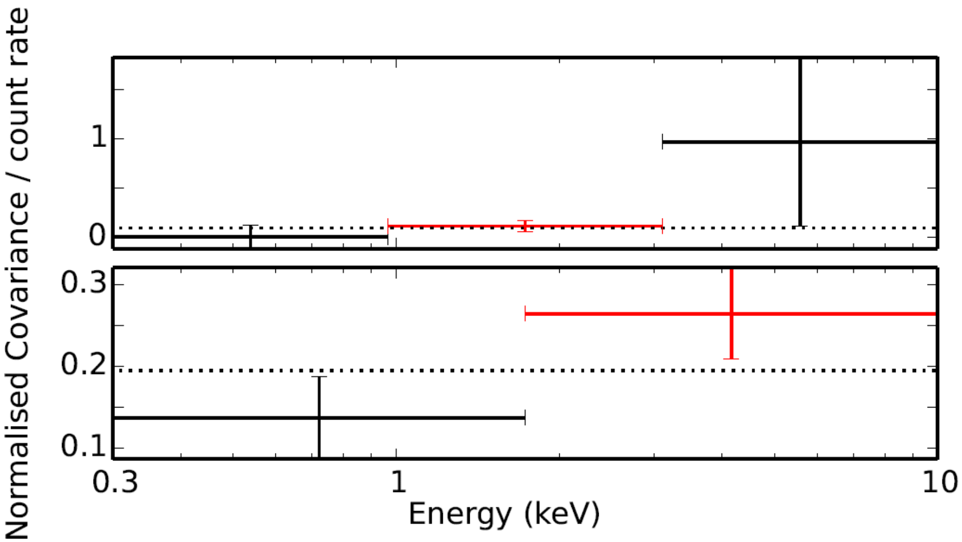
# Results: 2-component ULX model

- Multi-colour disc + Comptonisation
  - Fits most broadened disk spectra
  - And most (ULX quality) thermal dominant spectra
- Similar parameters in both
- Clearly phenomenological in the thermal dominant sources



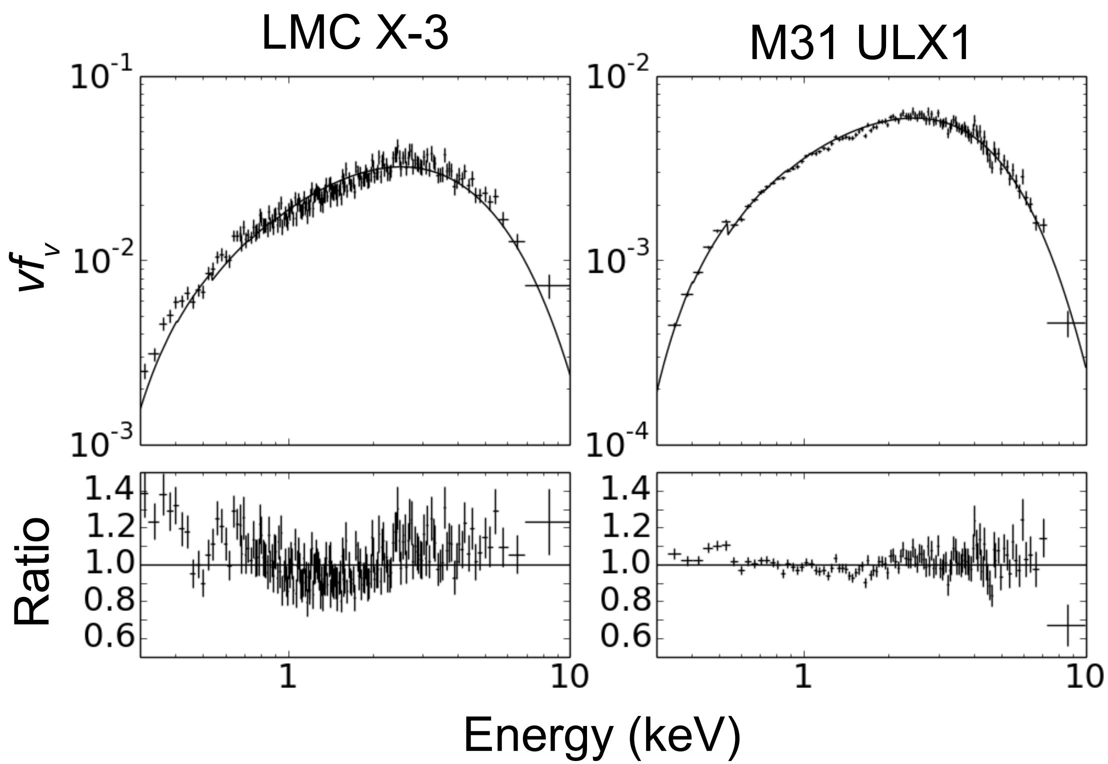
# Results: timing

- Able to extract rudimentary fractional normalised covariance spectra in 2 broadened disc ULXs
- Consistent with constants
  - i.e. single component energy spectra
- 2-component energy spectra are not required in this sample of broadened disc ULX spectra



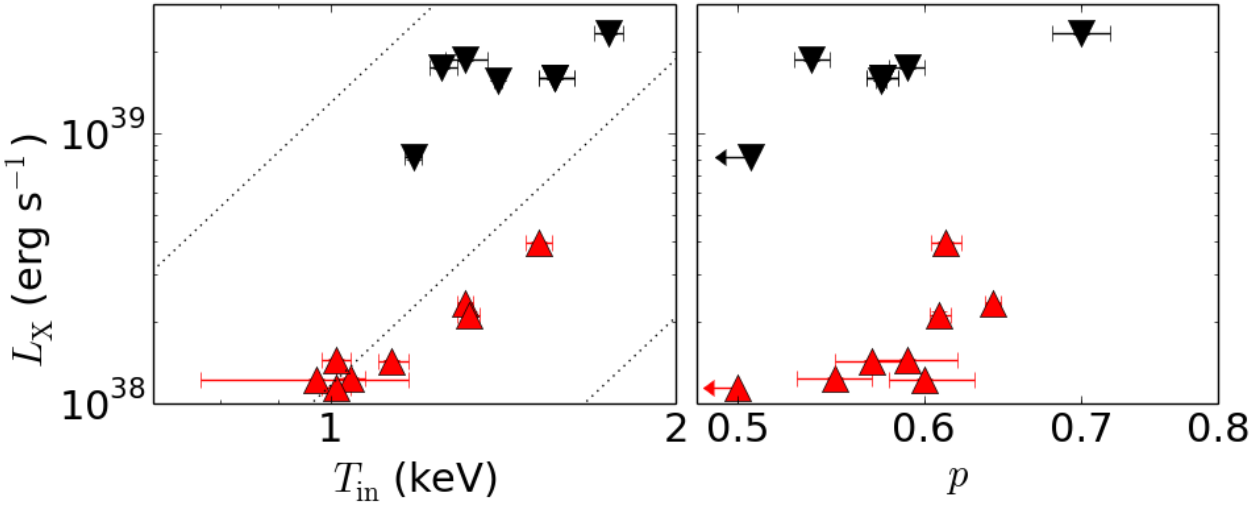
# Results: thin disc model

- Kerr thin disc model:
  - Broadened disc ULXs have ~40-90 $M_\odot$ black holes
  - In sub-Eddington states
  - But ubiquitous near maximal spin
- Fits rejected in both samples



# Results: slim disc model

- *p*-free disc approximation of slim disc
  - *p* significantly less than 0.75 in both thermal dominant and broadened disc sources
  - Not standard thin accretion discs, even at ~0.1 $L_{Edd}$



# Implications

- Either broadened disc ULXs are sub-Eddington massive stellar black holes (~40-90 $M_{\odot}$)
    - But poor fit statistics and requires ubiquitous near maximal spin
- Or, accretion discs become geometrically slim and have broad X-ray spectra even below ~0.3 $L_{\mathrm{Edd}}$
    - Radiation pressure is not expected to support a slim disc at these Eddington ratios
    - Magnetic pressure has been suggested

# Summary

- ULXs below $L_X \sim 3\times10^{39}$ erg s$^{-1}$ have broadened disc spectra and may represent ~Eddington accretion
  - Emerging 2-component spectra have been suggested, but are not required by this sample
  - Instead, they appear to be dominated by a single broad, disc-like component
- Some bright thermal dominant BHBs are similar in shape to the broadened disc ULXs
  - Either broadened disc ULXs may have thin disc spectra at ~0.1-0.3 $L_{Edd}$
    - But this implies ~40-90 $M_\odot$ black holes with maximal spin
  - Or, accretion discs can remain 'slim' from ~0.1-1 $L_{Edd}$
    - Radiation pressure smoothly takes over from some other effect (magnetic pressure)