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

Andrew Sutton (MSFC)
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 \( L_x \sim 10^{39} - 10^{41} \text{ erg s}^{-1} \)
    - ULXs exceed the Eddington limit for stellar remnant black holes \( \sim 1.3 \times 10^{38} \text{ erg s}^{-1} M_\odot^{-1} \)
      - 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

Soft ultraluminous

Hard ultraluminous

Broadened discs below $\sim 3 \times 10^{39}$ erg s$^{-1}$

$f(1-10$ keV)/$f(0.3-1$ keV)

Sutton et al. 2013
The most luminous ULXs

- Hard ultraluminous
- Soft ultraluminous
- Variable soft ultraluminous

Key feature: super-Eddington outflow

Inclination and mass accretion rate determine properties

Modified from Middleton et al. 2011
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

Ultra-Soft State
Thermal Dominant State
Very High State
Low/Hard 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 \( L_X < 3 \times 10^{39} \) 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 $\sim$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 \( \sim 0.1 \, L_{\text{Edd}} \)
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 $\sim 0.3 L_{\text{Edd}}$
  - Radiation pressure is not expected to support a slim disc at these Eddington ratios
  - Magnetic pressure has been suggested
ULXs below $L_X \sim 3 \times 10^{39} \text{ erg s}^{-1}$ 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 $\sim 0.1-0.3 \ L_{\text{Edd}}$
  - But this implies $\sim 40-90 \ M_\odot$ black holes with maximal spin
  - Or, accretion discs can remain 'slim' from $\sim 0.1-1 \ L_{\text{Edd}}$
    - Radiation pressure smoothly takes over from some other effect (magnetic pressure)