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 \( \sim 10^{41} \text{ erg s}^{-1} \) (Farrell et al. 2009, Sutton et al. 2012)

- How does super-Eddington accretion work?
ULX spectral sequence

- 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 $L_{\text{Edd}}$ & 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 $L_{\text{Edd}}$?
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)

L-T plot for soft component, Roberts et al. (in prep.)
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

UL & extreme UL found at similar $L_X$

Higher $L_X$ discs – massive BHs?

Below $\sim 3 \times 10^{39}$ erg s$^{-1}$ modified discs dominate
Hardness-variability diagrams

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

- Mainly observed at ~ $1 - 3 \times 10^{39}$ 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)
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.

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

- ‘Photon-tired’ wind in inner regions falls back – hard thermal X-rays
- Disc becomes radiation-pressure dominated
- Optically-thick wind launched from loosely bound top layers
- ‘Standard’ disc