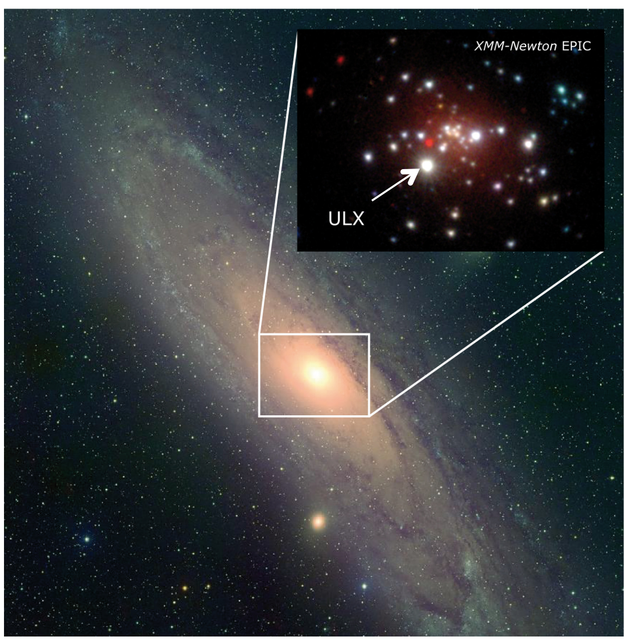
ULX behaviour: the ultraluminous state, winds and interesting anomalies



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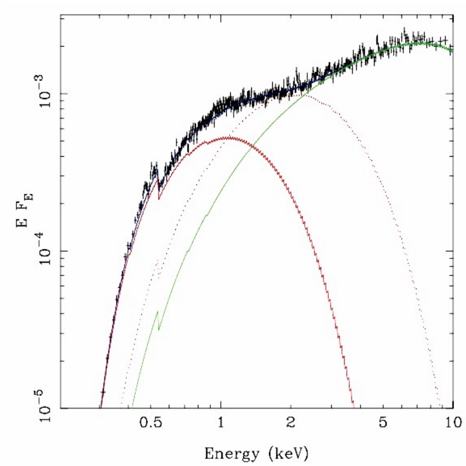
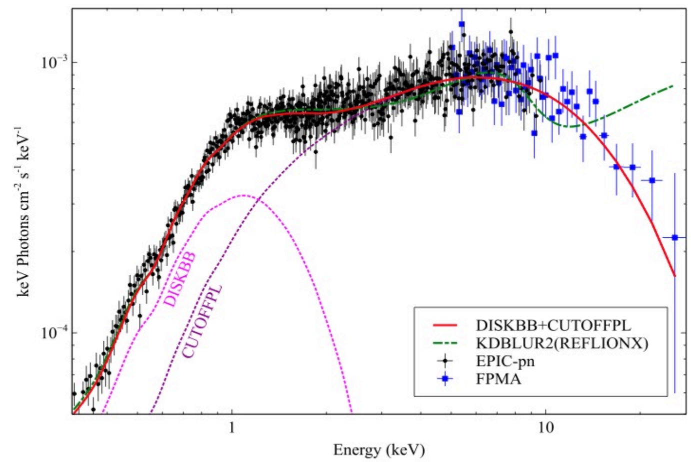
Lucy Heil (Amsterdam)

The ultraluminous state



Left: XMM-Newton pn spectrum of Ho IX X-1 (Gladstone et al. 2009)

Right: XMM + NuSTAR spectrum of NGC 1313 X-1 (Bachetti et al. 2013)



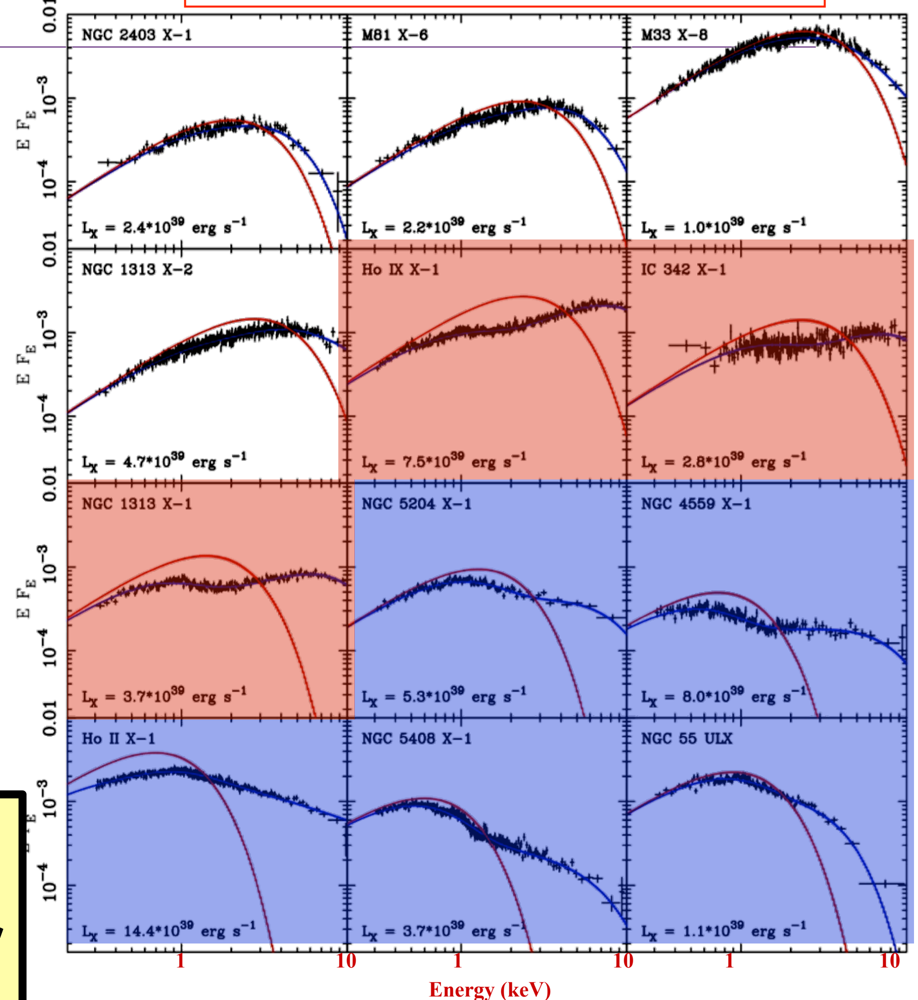
- ULX X-ray spectra **different** to sub-Eddington BHs (Stobbart et al. 2006; Gladstone et al. 2009; Bachetti et al. 2013 etc…): new ***ultraluminous state***
- Confirmed as super-Eddington accretion onto stellar-mass BH by Motch et al. (2014)
- **Key question now: how does this work?**

ULX X-ray spectra

- Gladstone et al. (2009): ULX spectral sequence
- Sutton et al. (2013) refined this into 3 separate shapes of ULX spectrum
  - Broadened disc regime
  - Hard ultraluminous regime
  - Soft ultraluminous regime

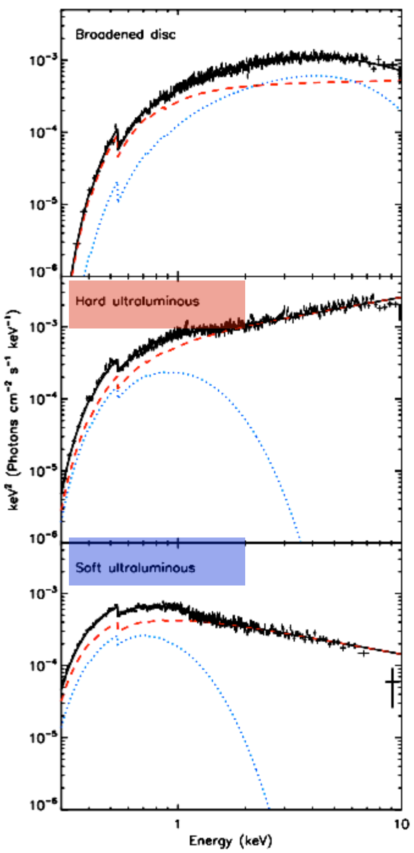
Key to understanding ULX physics: behaviour in these regimes

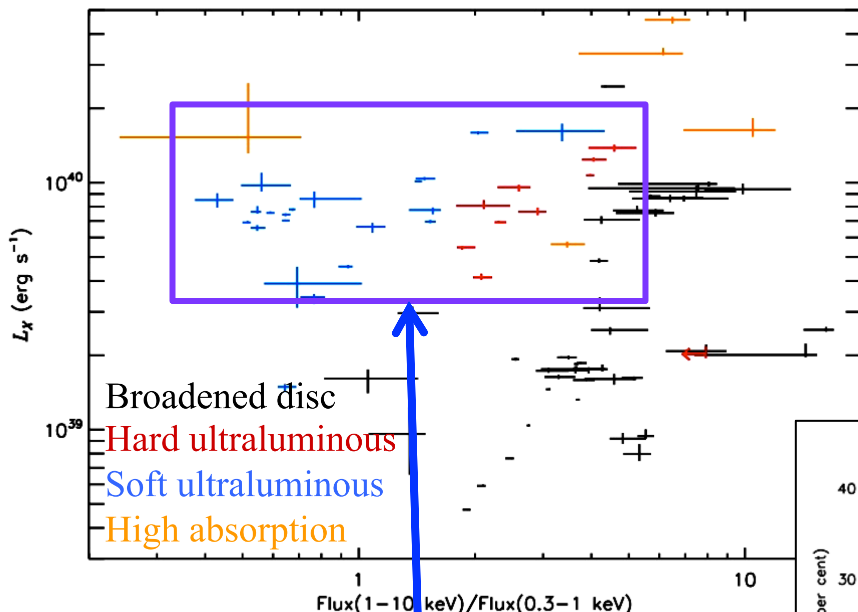
Gladstone, Roberts & Done (2009)



Key behaviours

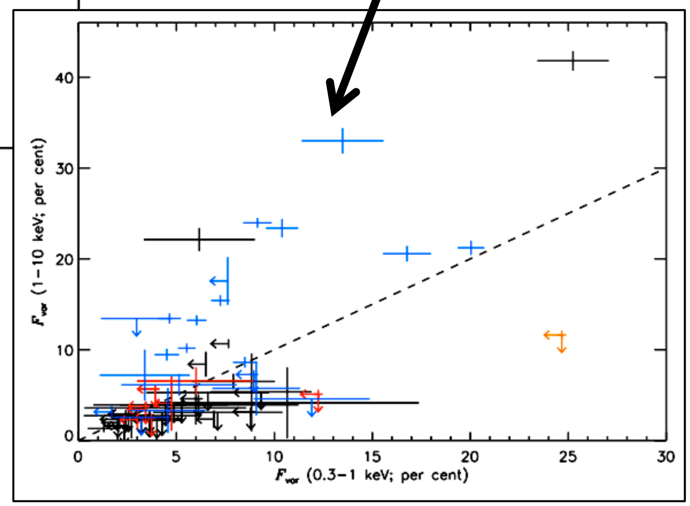
Sutton, Roberts & Middleton (2013)





Soft & hard ultraluminous (SUL/HUL) found at similar L_X

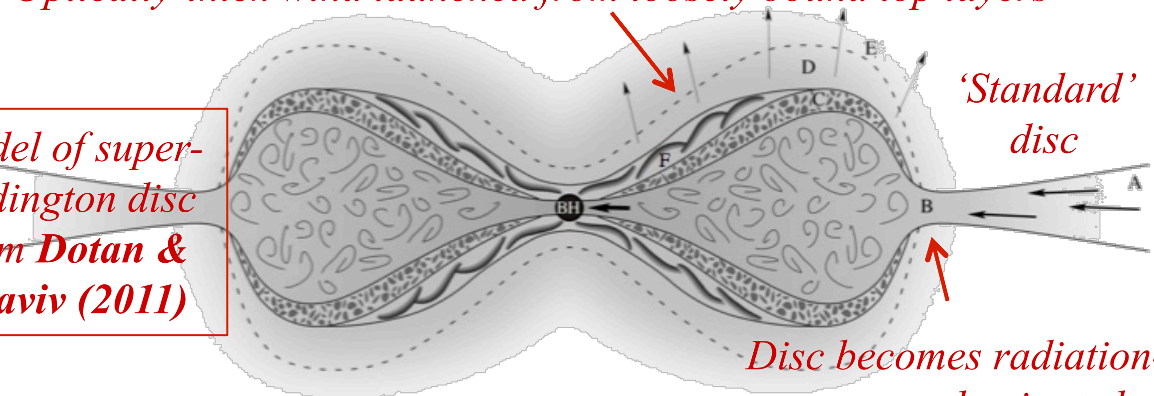
Variability predominantly found in SUL regime; and much stronger above 1 keV than below



Super-Eddington models

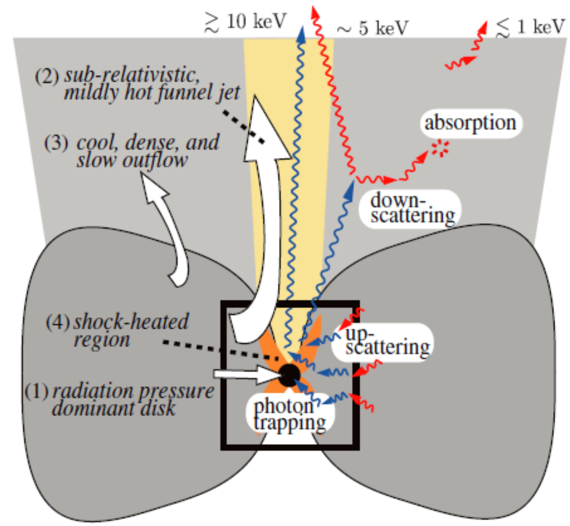
Optically-thick wind launched from loosely bound top layers

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



'Standard' disc

Disc becomes radiation pressure dominated



Kawashima et al. (2012)

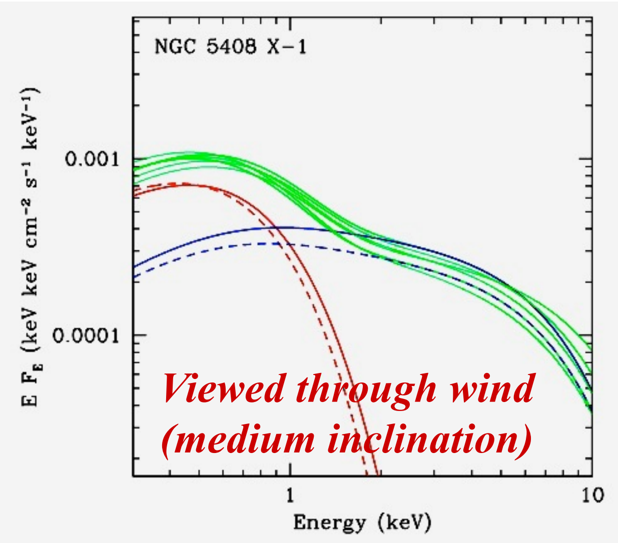
- Super-Edd models naturally explain 2-component spectra as optically thick wind + inner disc
- Poutanen et al. (2007) – inclination critical for observed spectrum: so on-axis HUL, off-axis SUL
  - ***Soft X-rays prop. to mdot, hard depend on viewing angle***

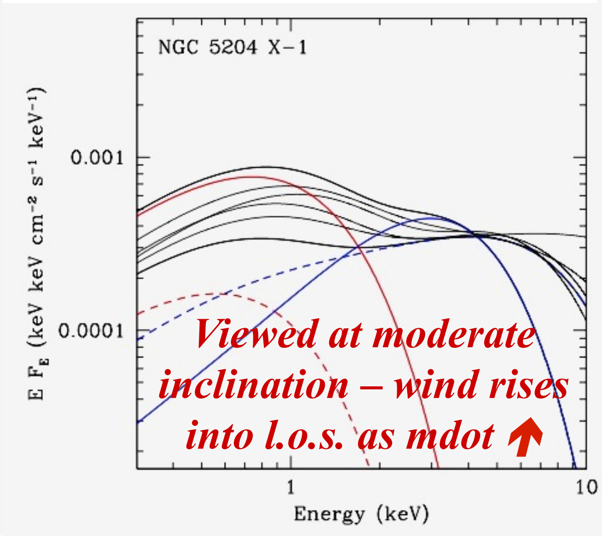
Evolution of behaviour

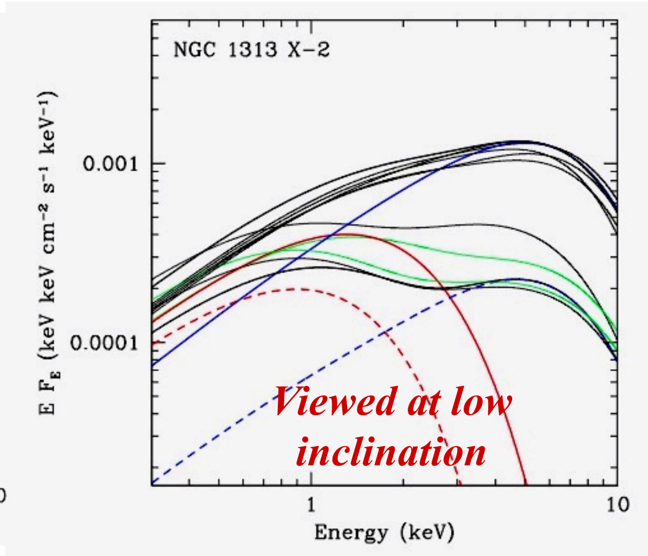
Middleton et al. (2015)

- Data consistent with wind model

Best fitting models for multiple epochs of XMM data – green spectra when also variable. Red/blue are soft/hard components for least (dotted) and most (solid) luminous epochs

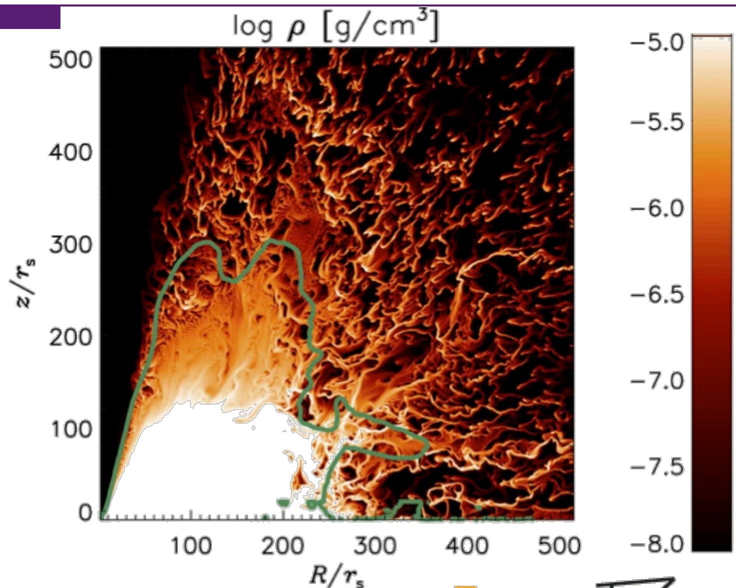




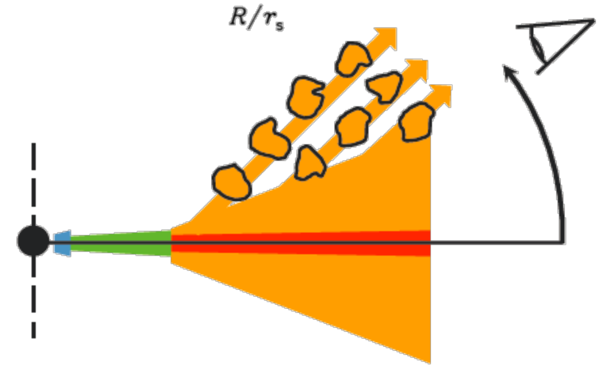


Origin of variability

- Variability seen predominantly in wind-dominated ULXs
- Face-on systems show little variability
- Explanation: extrinsic hard variability imprinted by edge of clumpy wind passing through line of sight



Takeuchi et al. (2013)

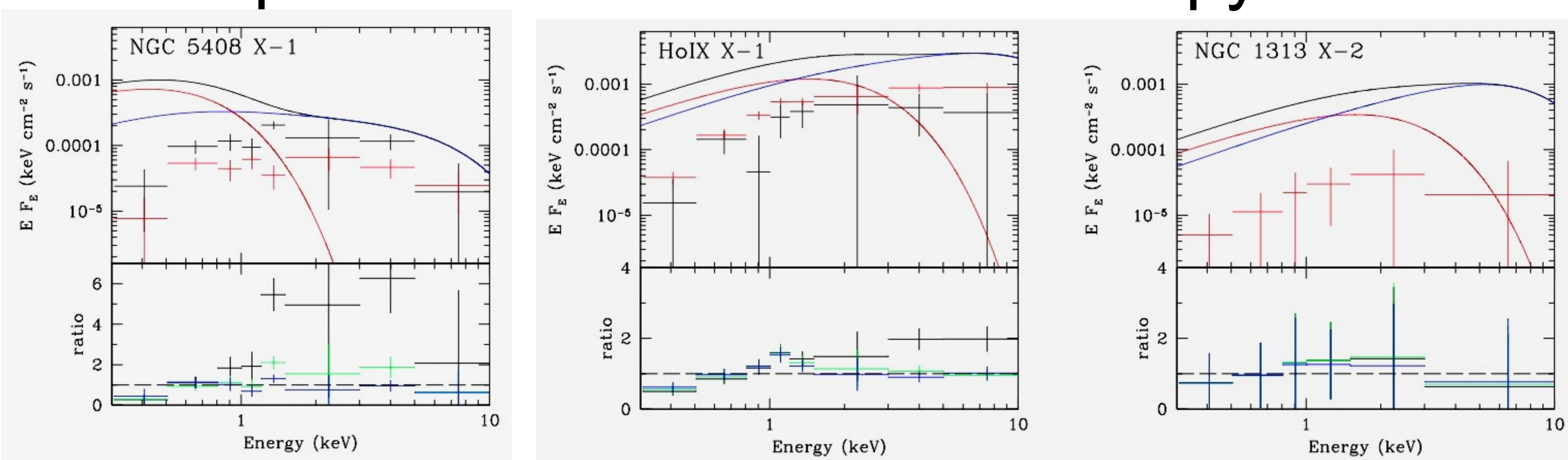


Middleton et al. (2011)

Covariance spectra

Middleton et al. (2015)

- Variability is constrained solely in the hard component – consistent with clumpy wind!

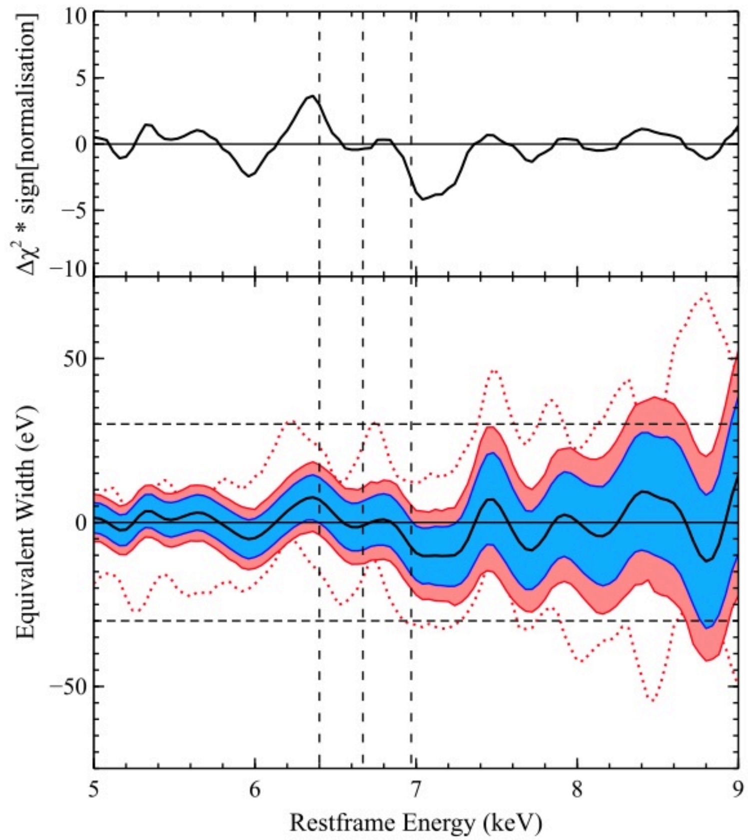


From Middleton et al. (submitted). Top panels: model plus decomposition, red data points:0.9 – 3 mHz, black: 3 – 200 mHz, both taken as covariance spectra against reference 1.5 – 3 keV band. Bottom panels: fits to covariance data. Black – diskbb+nthcomp with ratio fixed as per full model; green – diskbb+nthcomp with ratio free; blue – pure nthcomp

Winds

Walton et al. (2013)

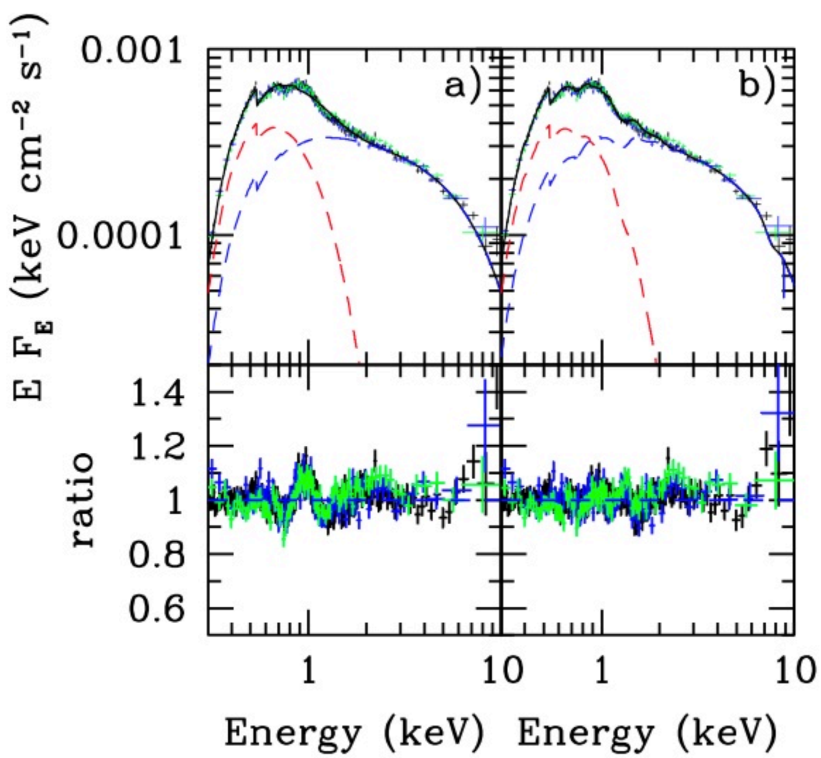
- Interpretation predicated on presence of wind
- Any direct evidence for presence of wind material?
- No narrow emission lines around Fe K in deep *Suzaku* observation of a HUL object, Ho IX X-1
- But HUL – so not viewed through wind!



Top: change in χ^2 statistic for addition of narrow Gaussian feature; bottom: limits on line equivalent width

Evidence for winds?

Middleton et al. (2014).



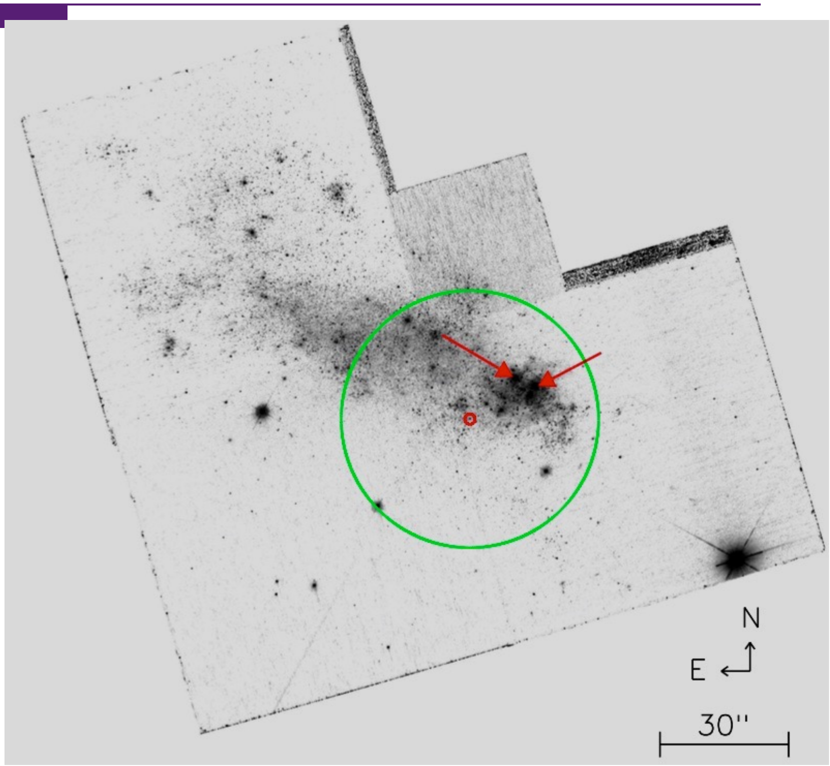
Combined NGC 5408 data – left: continuum model; right: continuum model plus broad, partially ionised absorber

- Long known that soft ULXs can have extensive fit residuals
- Can be fitted by thermal plasma
- But also explained by absorption from broadened, partially ionised and blueshifted ($v \approx 0.1c$) material – outflowing wind!

It's not SF-related plasma

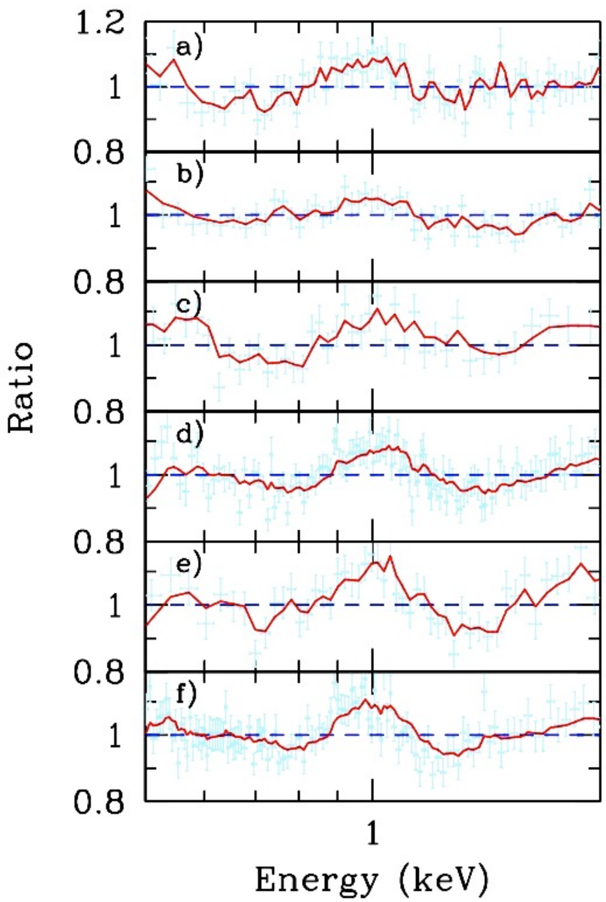
Sutton et al. in prep.

- Expected $L_{x,SFR}$ (e.g. Mineo et al. 2012) << observed $L_{x,plasma}$
- In NGC 5408 – SFRs located within *XMM* footprint – but resolved by *Chandra* (left)
- > 2/3 of 'plasma' remains spatially unresolved



HST WFPC2 F336W image of NGC 5408, with the XMM footprint in green and Chandra in red. The two main SF clusters are indicated by red arrows.

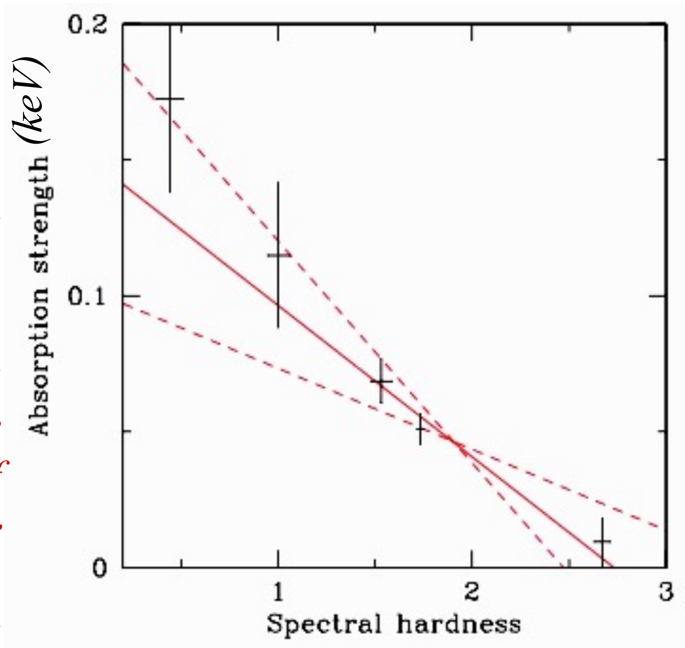
Evidence for a wind from behaviour



Left: similar residuals seen across 6 high quality ULX XMM spectra, including both HUL and SUL objects

Right: variation of hardness in NGC 1313 X-1 allows us to see that absorption line depth anti-correlates with hardness – again consistent with the optically-thin outer regions of a ULX wind. Note a similar anti-correlation in an emission line fit argues against reflection producing the residuals

Middleton et al. submitted.



f_X(1-10 keV)/f_X(0.3-1 keV)

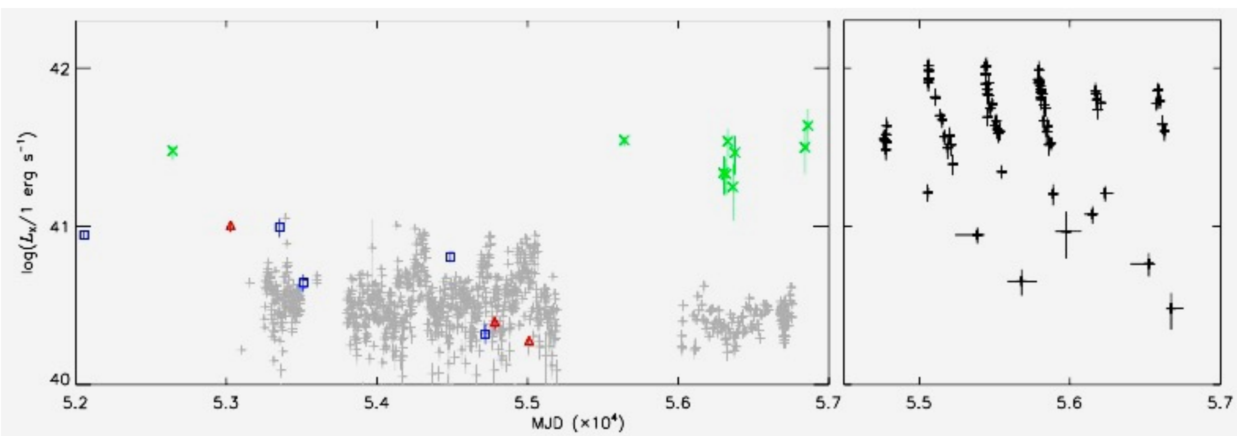
A corollary to super-Eddington ULXs

- Ultraluminous state & associated behaviour provides a template for stellar mass BH ULXs
- But different (e.g. classic sub-Eddington state) behaviours could reveal different underlying objects (e.g. ESO 243-49 HLX-1, Servillat et al. 2011)
- For example – spectrally hard but highly variable ULX in M51 (Earnshaw talk)
- Also – extreme ULXs ($L_X > 5 \times 10^{40}$ erg s^{-1}) show sub-Eddington behaviour (Sutton et al. 2012)

Extreme ULXs as IMBHs?

Sutton et al. 2015

- NGC 5907 ULX not IMBH – spectral turnover (Sutton et al. 2013b, Walton et al. 2015)
- IC 4320 HLX revealed as z ~ 2.8 QSO; other eULXs peak at ~ 10^{41} erg s^{-1} so 100 $M_{\odot}$ BHs at 10 × Eddington?



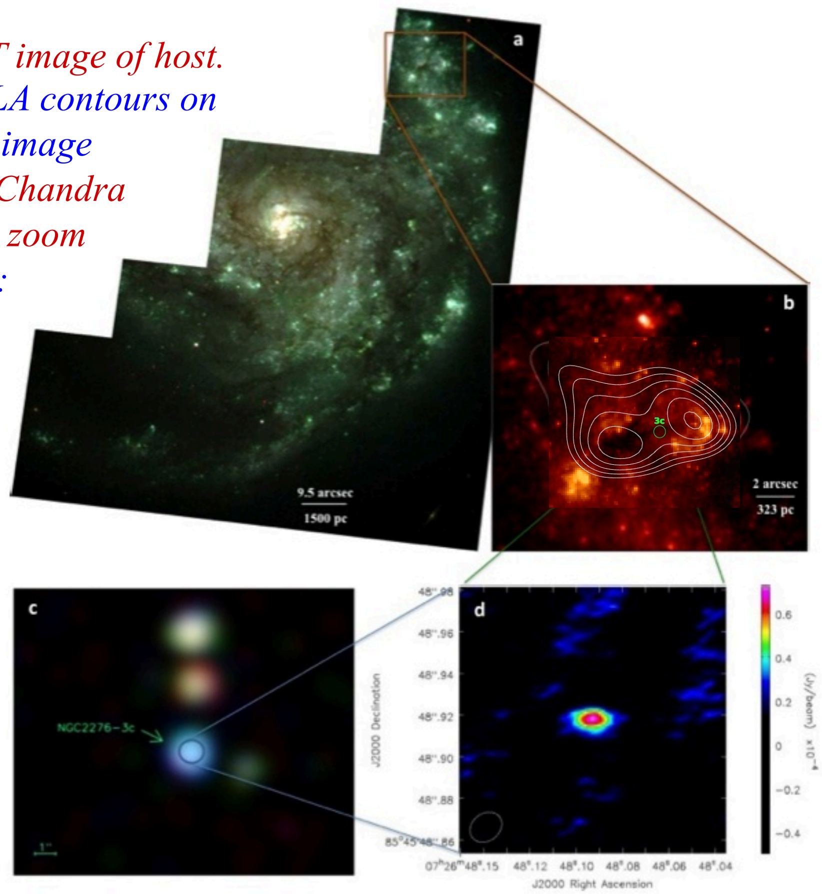
Left panel: green – IC 4320 HLX (before QSO ID); grey - M82 X-1; blue – Cartwheel N10; red – NGC 470 ULX.

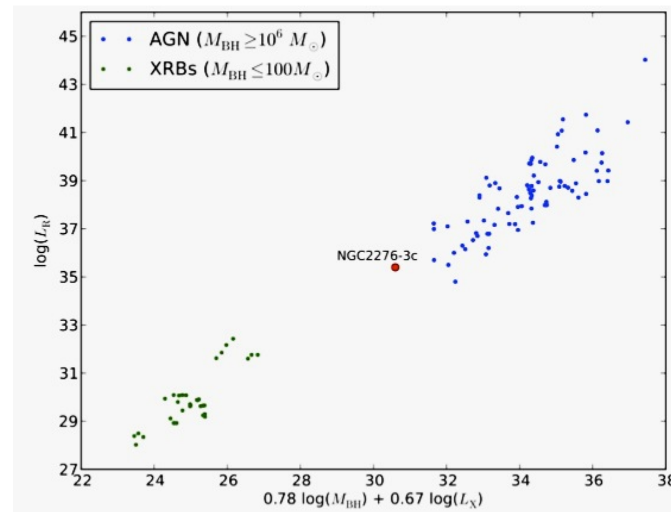
Right panel: ESO 243-49 HLX-1

A new IMBH candidate in a hard state

Mezcua et al. (2015)

Top left: HST image of host.
Top right: VLA contours on HST F814W image
Bottom left: Chandra X-ray colour zoom
Bottom right: VLBI image of radio core





Above: Gültekin et al. (2009) X-ray/radio fundamental plane for hard state objects. ***Our quasi-simultaneous X-ray/radio data point is shown, approximating the BH mass as ~ 5 × 10^4^ M$_\odot$***

Conclusions

- The coarse behaviour of many nearby ULXs can be understood in the context of super-Eddington accretion, including a massive wind
  - Direct evidence for wind now emerging
  - But will this model survive further, more detailed data & techniques, e.g. lags, calorimeter spectra?
- Some minority ULX populations could be revealed by differing behaviour – IMBHs may still be identified via sub-Eddington states