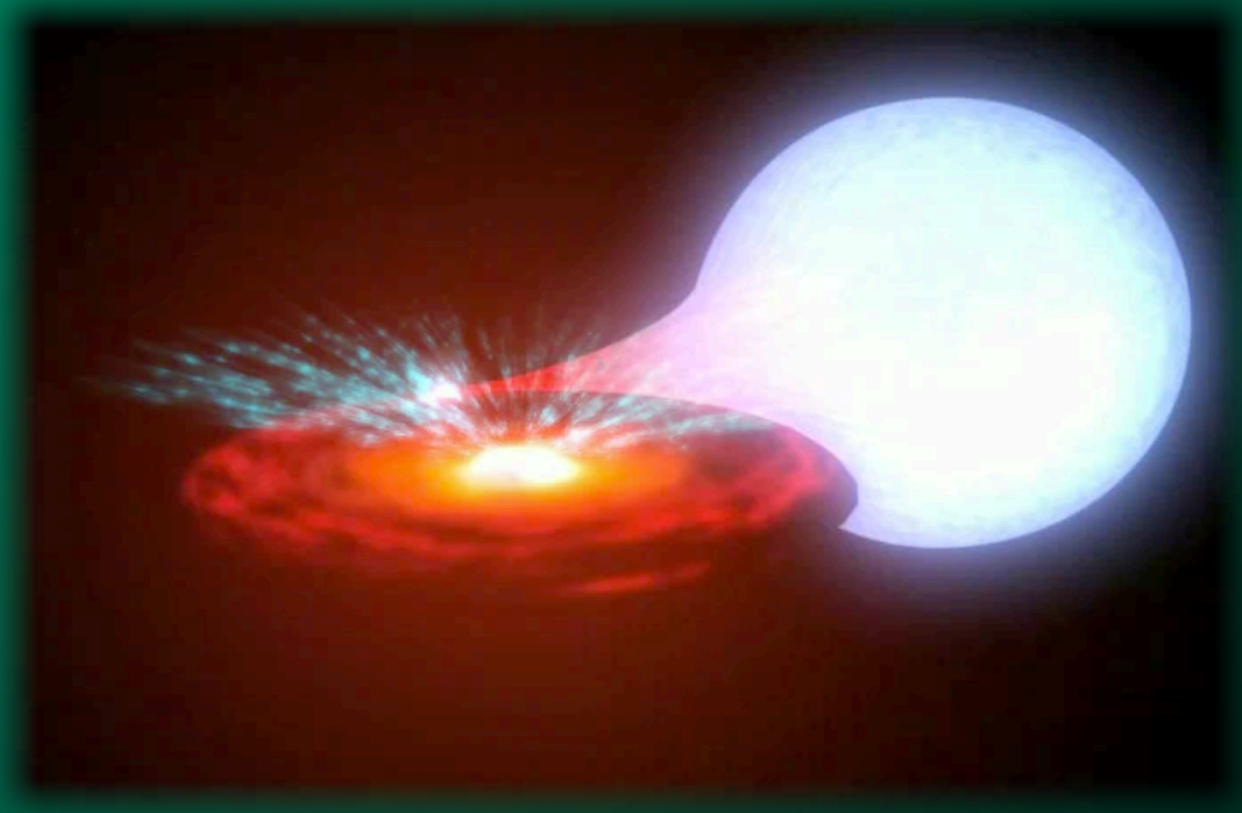


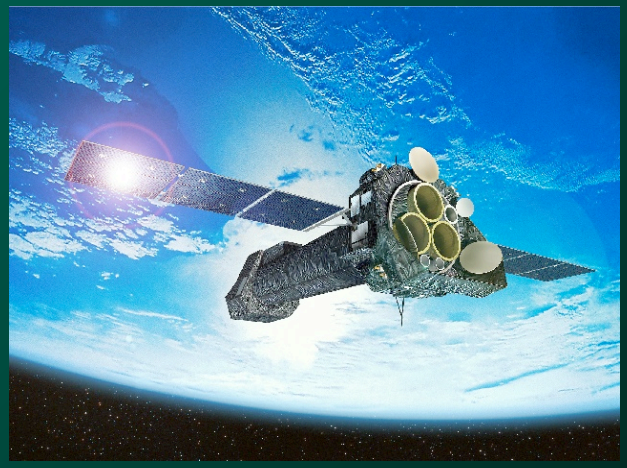
Ultraluminous X-ray sources

Jeanette Gladstone

UNIVERSITY OF ALBERTA

… to modern day …

Chandra



XMM-Newton

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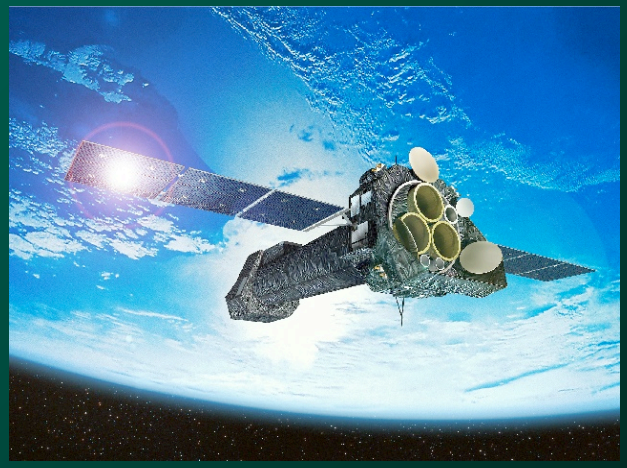
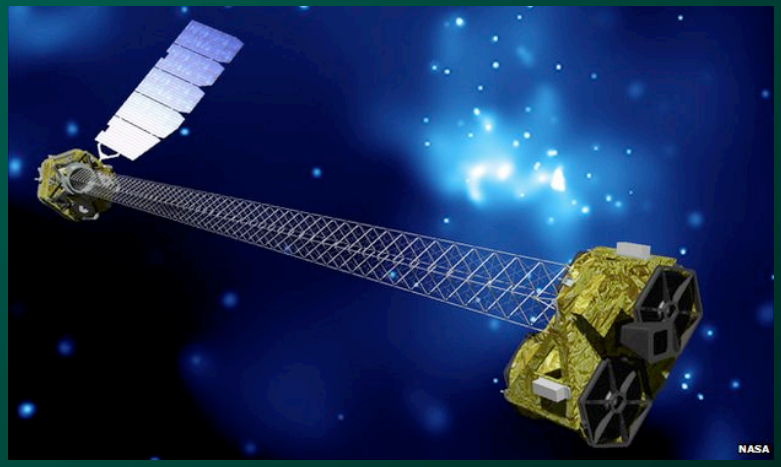


XMM-Newton

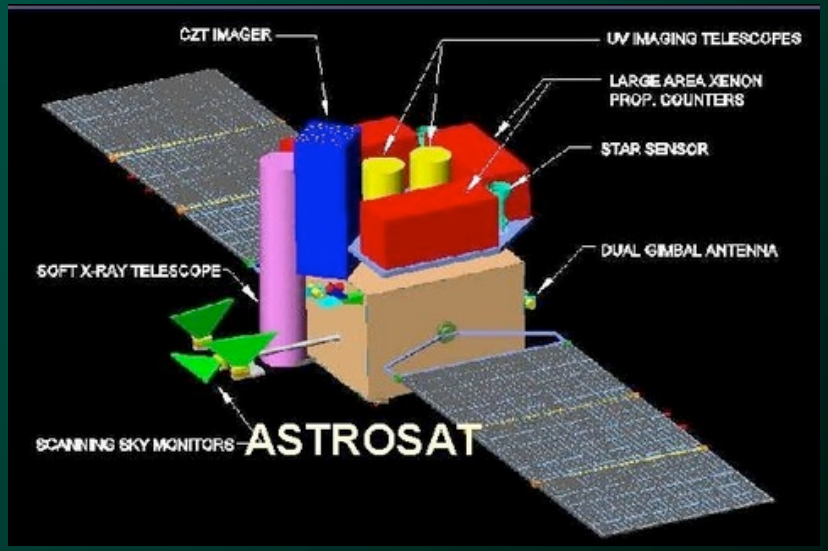


NuSTAR

the next steps …

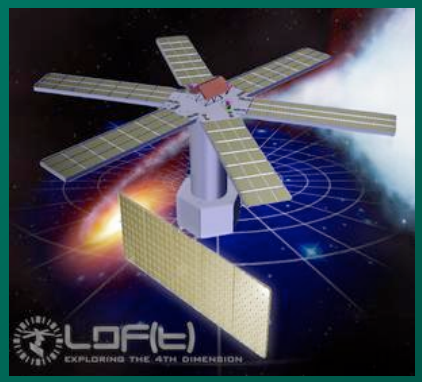
Astro-H; 2014

AstroSat; Soon



… what does that mean for the furture 50 years?

LOFT



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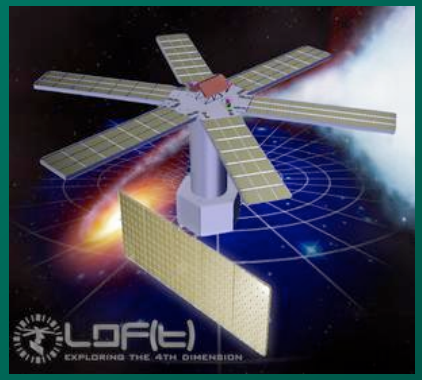

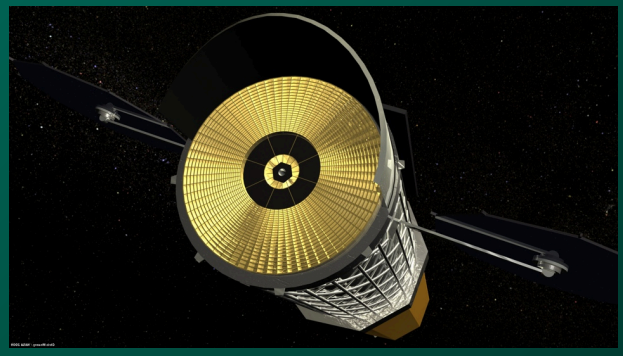

Athena

(image is IXO)

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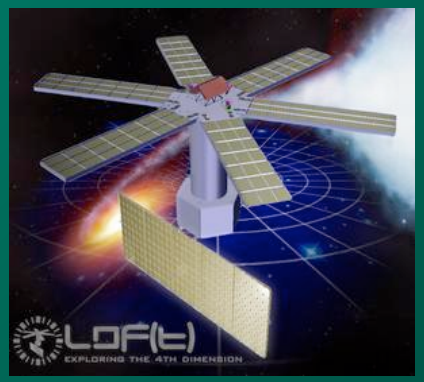
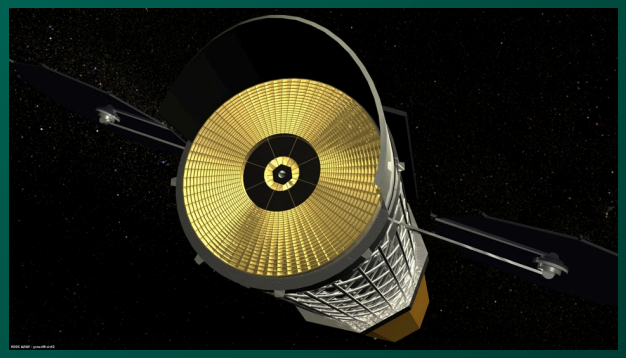
LOFT





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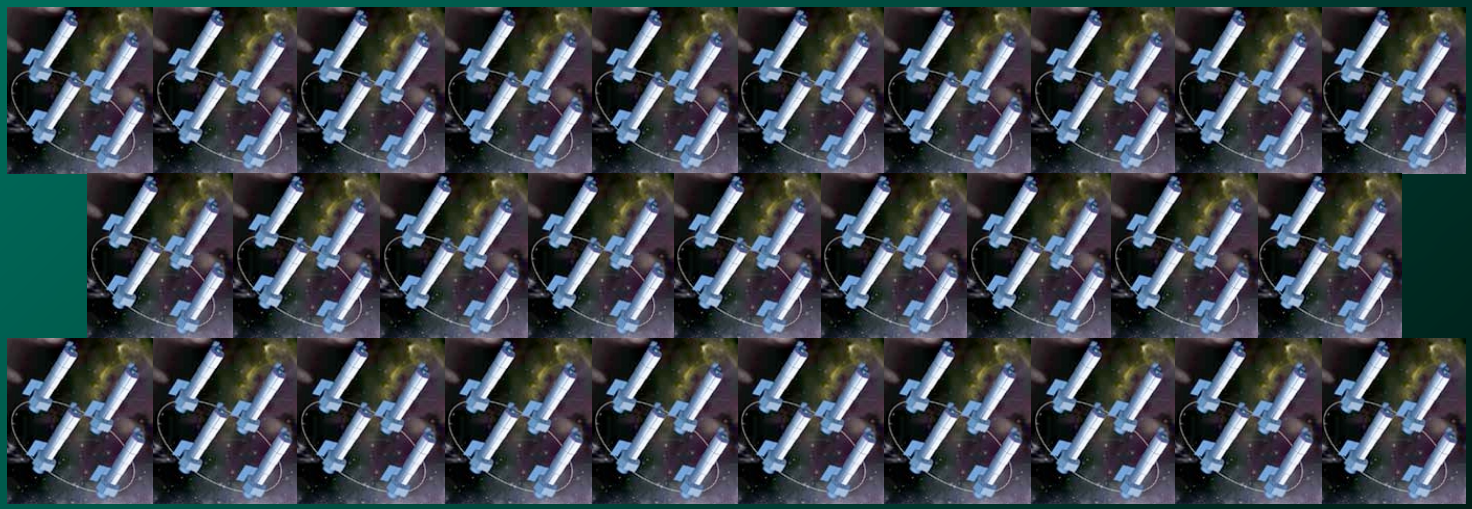

X-ray Square Kilometre Array?

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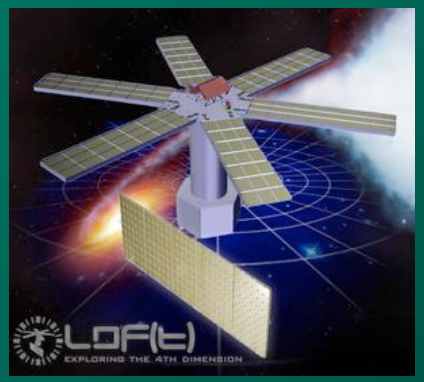
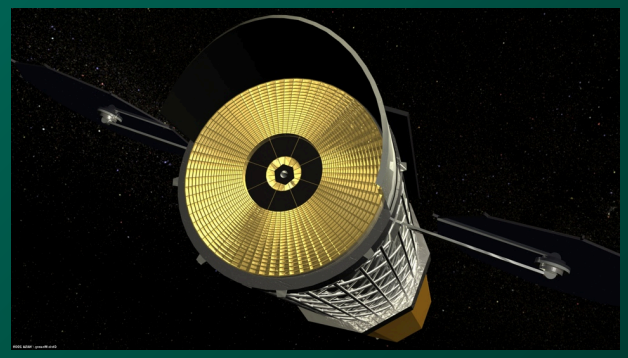




Athena

(image is IXO)

X-ray Square Kilometre Array?

What are Ultraluminous X-ray sources?

- ★ Original definition
  - ★ X-ray point source residing outside the nucleus of the galaxy
  - ★ $L_X > 10^{39}$ erg s^{-1}
    (above Eddington limit for ~10 solar mass black hole)

composite X-ray (red)/optical (blue & white) image of the spiral galaxy M74 (NASA/ CXC/U. Michigan/J. Liu et al.)

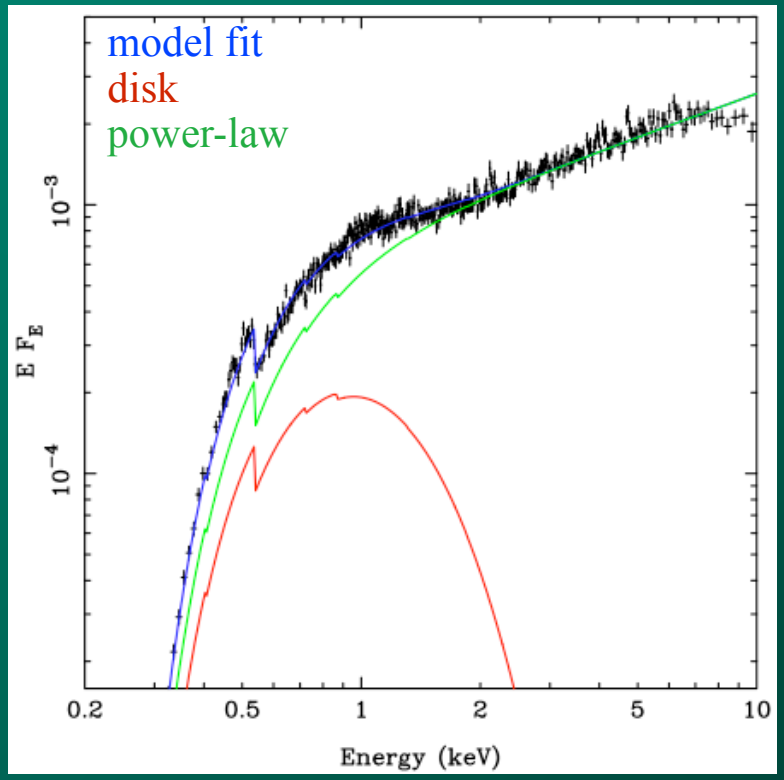
Ultraluminous X-ray sources

- Now can be split into three subclasses
  - standard ULXs
    - $\sim 10^{39}$ erg s^{-1} < L_X < ~ 2 * 10^{40} erg s^{-1}
  - extreme ULXs
    - ~2 * 10^{40} erg s^{-1} < L_X < ~ 10^{41} erg s^{-1}
  - Hyperluminous X-ray sources (HLXs)
    - $L_X > 10^{41}$ erg s^{-1}
- Divisions based on potential arguments over nature of systems, and observational analysis

Options for ULXs

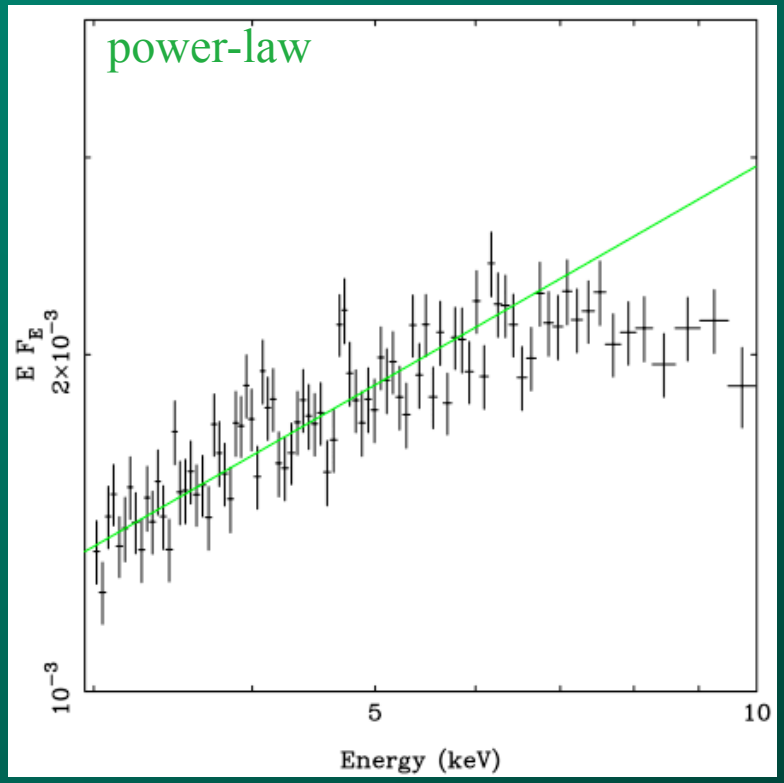
- ★ Intermediate mass black holes (IMBHs)
  - ★ Intermediate in Luminosity between stellar mass & super-massive black holes
  - ★ The missing link in the mass scale?
  - ★ Isotropically, sub-Eddington accretion in a standard accretion state
- ★ Stellar remnant black hole (<~100 M_{sun})?
  - ★ Beamed emission (relativistic jets)? (*e.g.* Körding et al. 2002)
  - ★ Anisotropic system? (King et al. 2001)
  - ★ True super-Eddington accretion?

The 'standard' ULXs - X-ray Spectra



- X-ray spectral studies show that the shape is fundamentally different for that of standard states

The 'standard' ULXs - X-ray Spectra

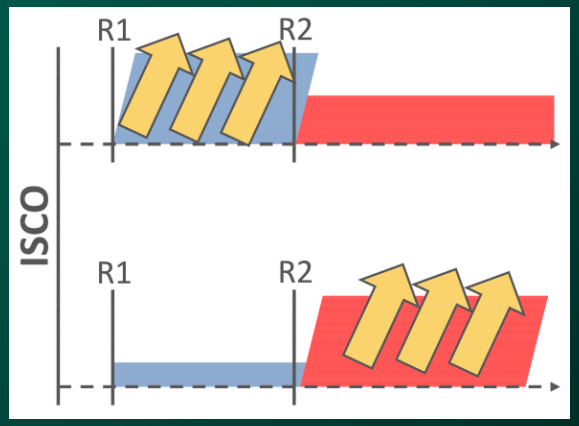


- ★ X-ray spectral studies show that the shape is fundamentally different for that of standard states
- ★ show presence of
  - ★ soft excess
  - ★ break above ~3keV

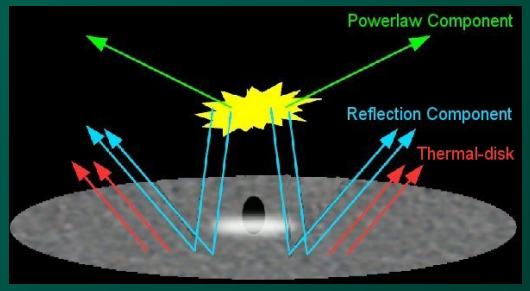
The 'standard' ULXs

- Explanations for this vary and have developed over the last few years (See Tim's Talk for more details)

Gladstone et al. (2009)

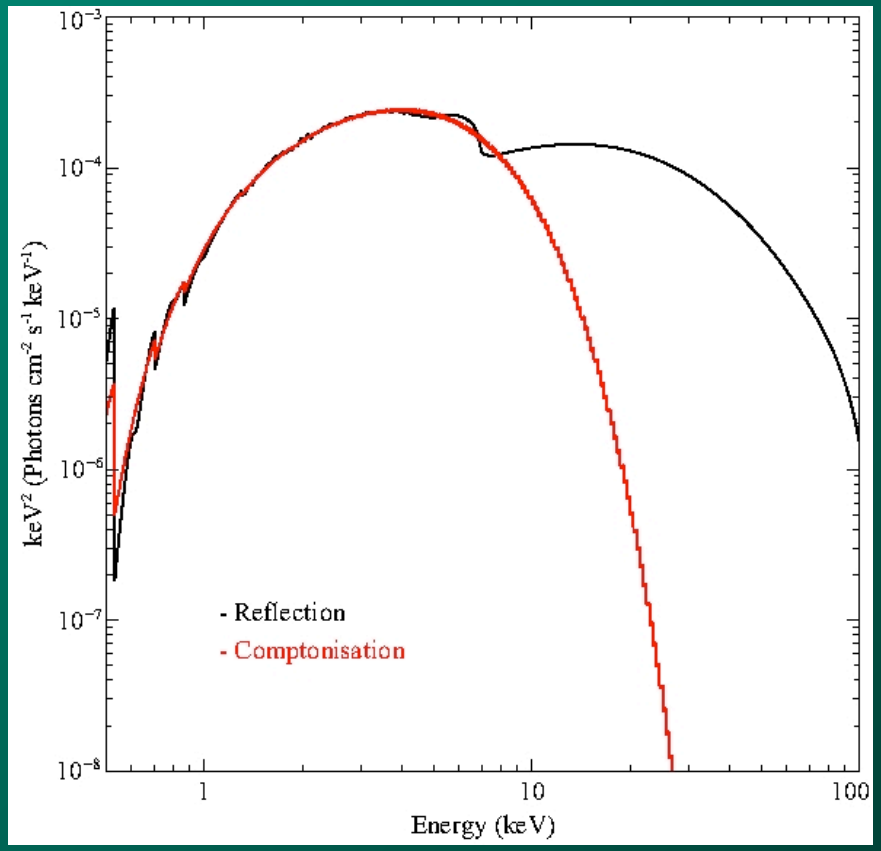


Middleton et al. (2011)



Caballero-Garcia & Fabian 2010

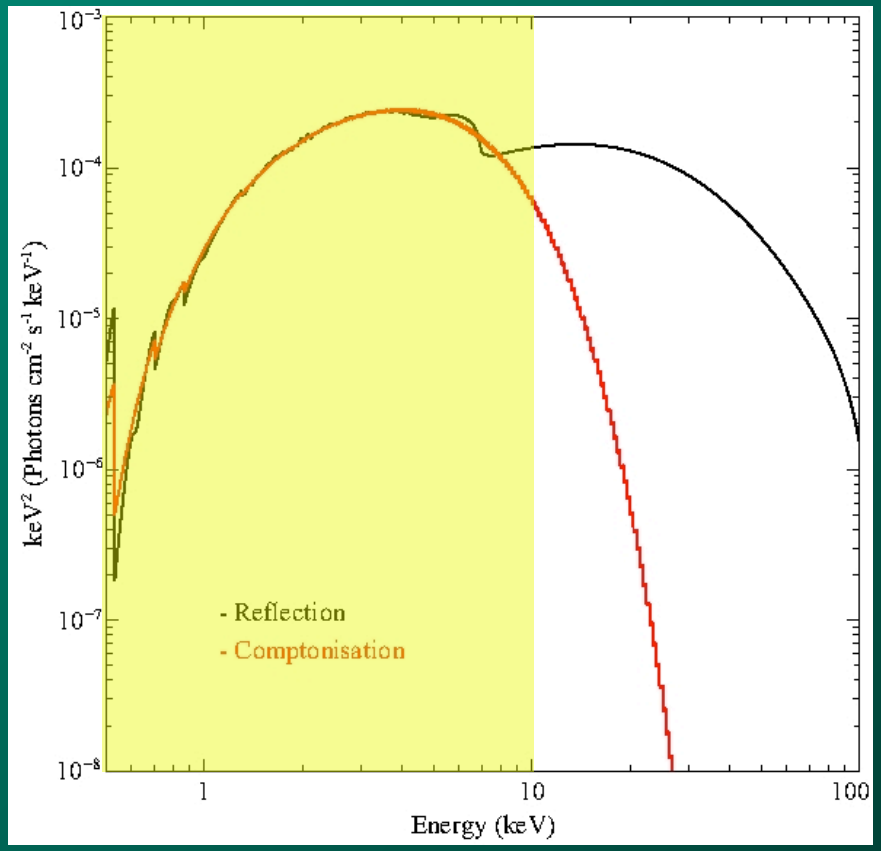
The 'standard' ULXs - comparing models



Comparison of models for NGC 4517 ULX1; Walton et al. 2011

- Comparing the models gives us this

The 'standard' ULXs - comparing models



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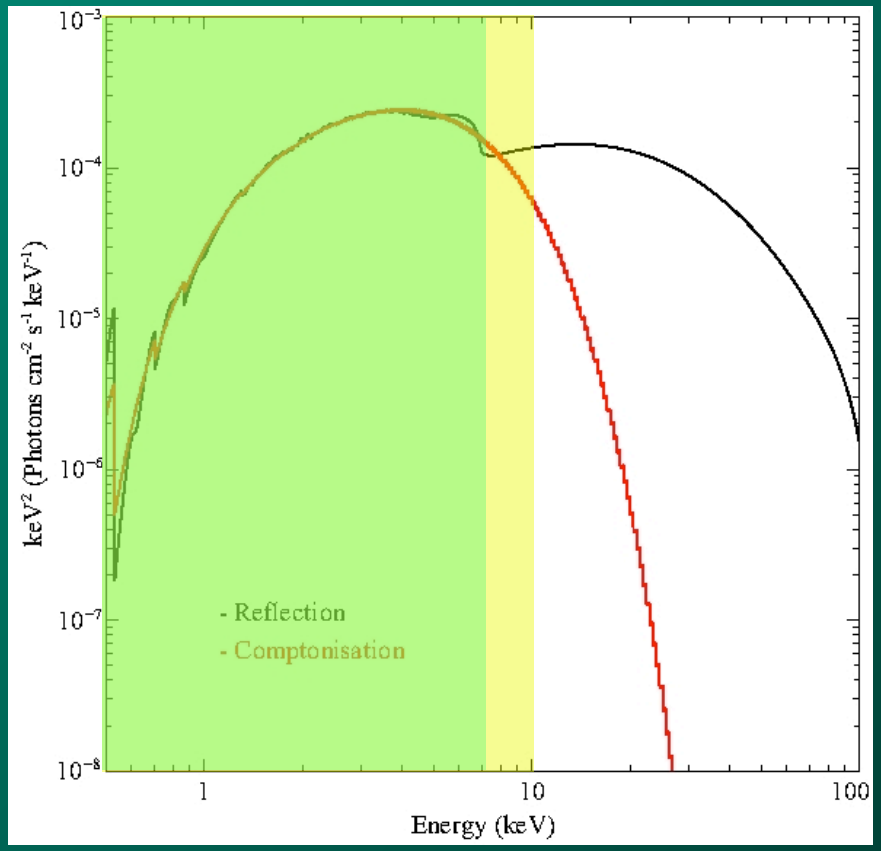
- ★ Comparing the models gives us this
- ★ Comparing within our band-pass is a different matter

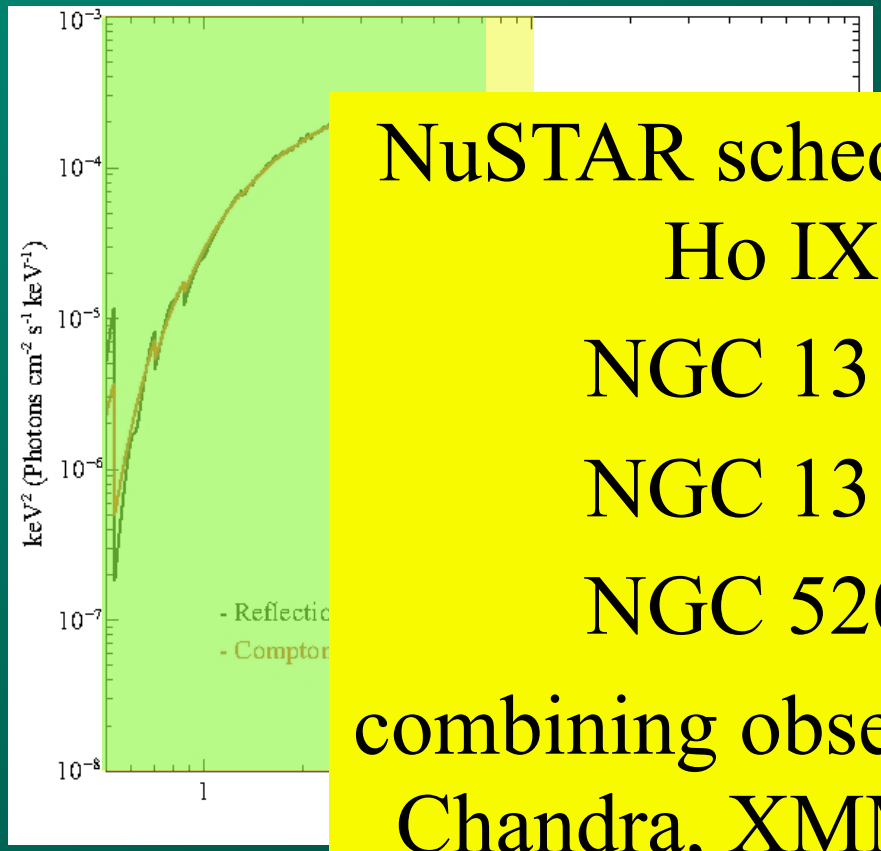
The 'standard' ULXs - comparing models



Comparison of models for NGC 4517 ULX1; Walton et al. 2011

- ★ Comparing the models gives us this
- ★ Comparing within our band-pass is a different matter
- ★ Fold in sensitivity issues
- ★ Get statistically similar fits - need next generation of telescopes to detect this (e.g. Astro-H, NuSTAR)

The 'standard' ULXs - comparing models

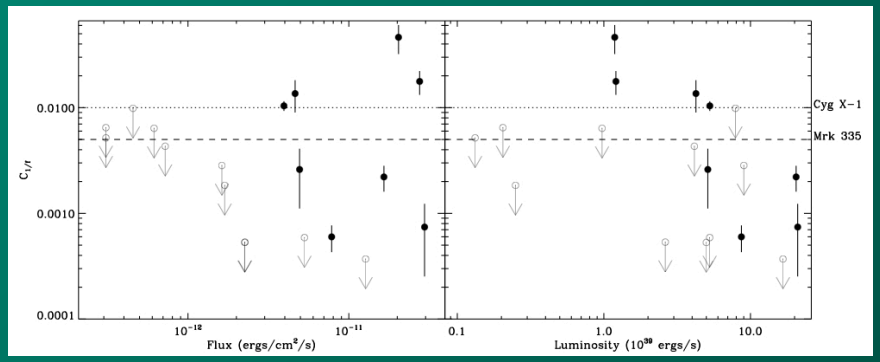


Comparison of models for NGC 4517 ULX1; Walton et al. 2011

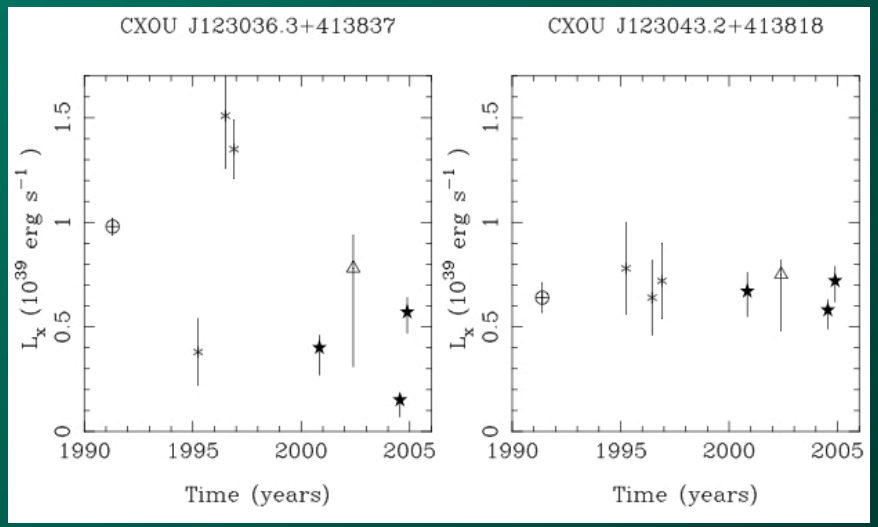
- ★ Comparing the models
- ithin our
- different
- ivity
- ly similar
- xt
- telescopes
- (e.g. Astro-H, NuSTAR)

NuSTAR schedule includes
Ho IX X-1
NGC 1313 X-1
NGC 1313 X-2
NGC 5204 X-1
combining observations with Chandra, XMM & Suzaku

The 'standard' ULXs -X-ray variability



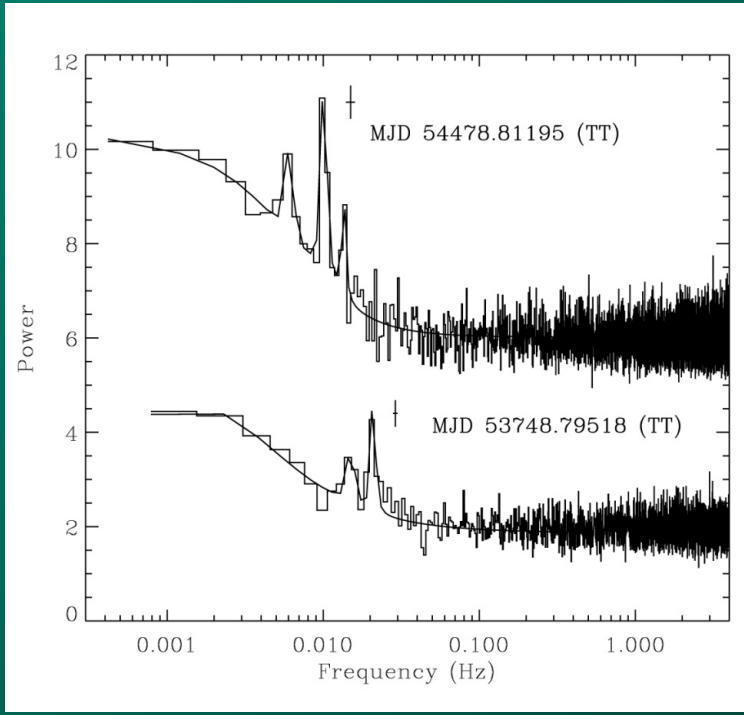
Heil et al. (2009)



Gladstone & Roberts (2009)

- ★ short-term variability appears suppressed in may of these sources
- ★ long-term variability
  - ★ can show up to order of magnitude variations on timescales of days to years

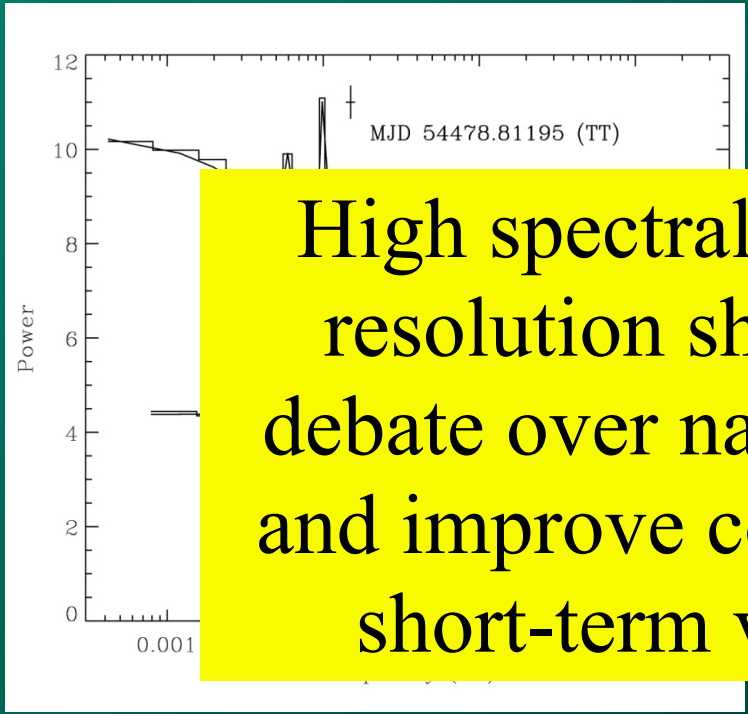
The 'standard' ULXs - QPOs



NGC 5408 X-1
Strohmayer & Mushotzky (2009)
Middleton et al. (2011)

- ★ few show QPOs
- ★ analysis again shows different outcomes
  - ★ IMBH via mass scaling relations for QPO observed in hard state (Strohmayer & Mushotzky 2009)
  - ★ stellar remnant via mass scaling form QPO observed in GRS 1915

The 'standard' ULXs - QPOs



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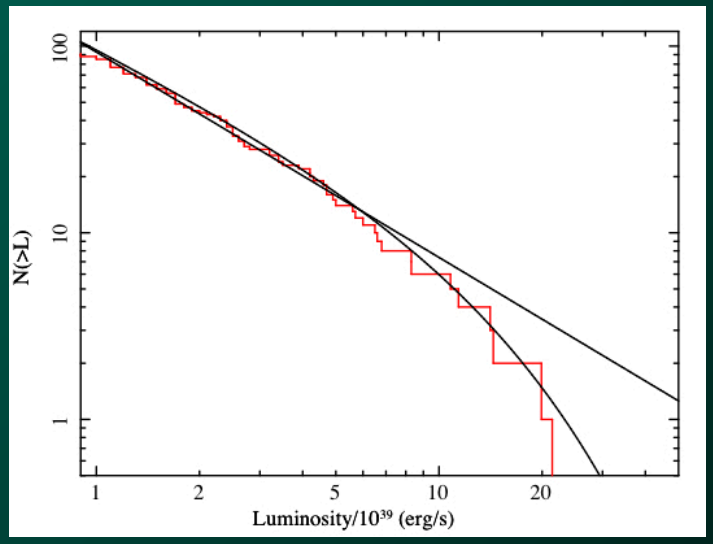
- ★ stellar remnant via mass scaling form QPO observed in GRS 1915

High spectral and timing resolution should settle debate over nature of QPO and improve constraints on short-term variability

The 'standard' ULXs - XLF

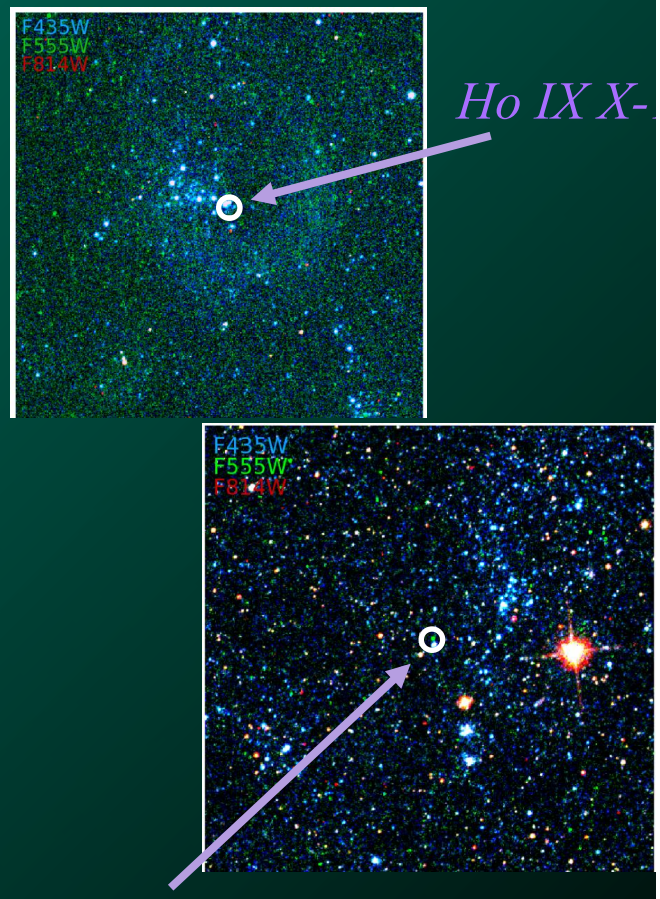
- ★ X-ray luminosity function (XLF) extends as unbroken PL for ~5 decades (Grimm et al 2003)
- ★ Break occurs at ~ 2 * 10^{40} erg s^{-1} (Swartz et al 2011)
- ★ Extension of HMXBs?



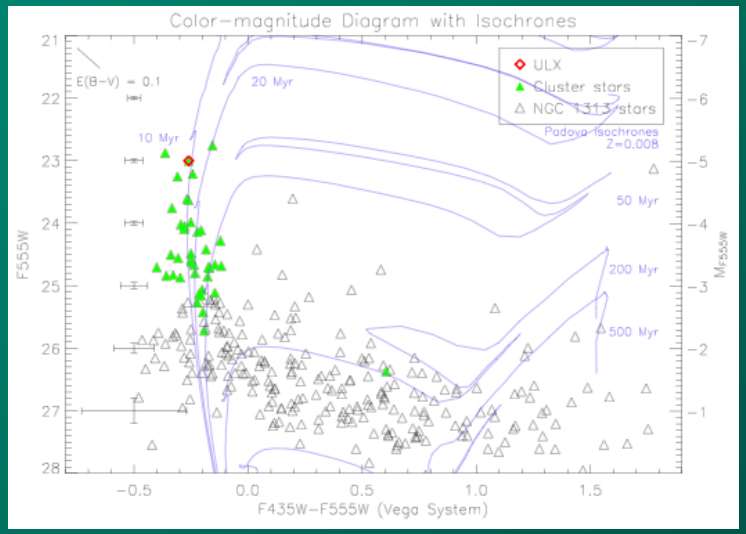
ULX X-ray luminosity function; Swartz et al. (2011)

The 'standard' ULXs - companions?

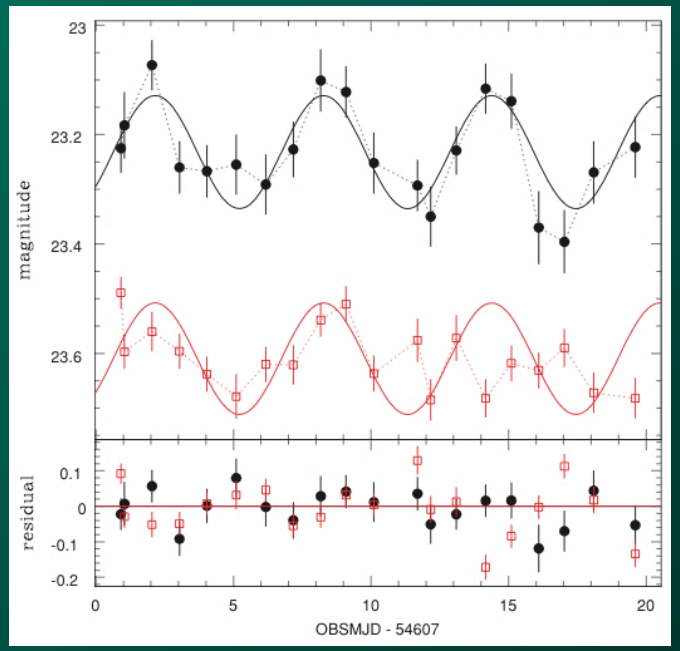
- ★ Search in mainly nearby systems (<10 Mpc)
- ★ $m_V \approx$ 22-26 (e.g Roberts et al. 2008)
- ★ Association with OB stars (e.g. Liu et al. 2007)
  - ★ HMXBs?
  - ★ Blue emission from accretion disc?



The 'standard' ULXs - optical counterparts



NGC 1313 X-2; Grise et al. (2008)

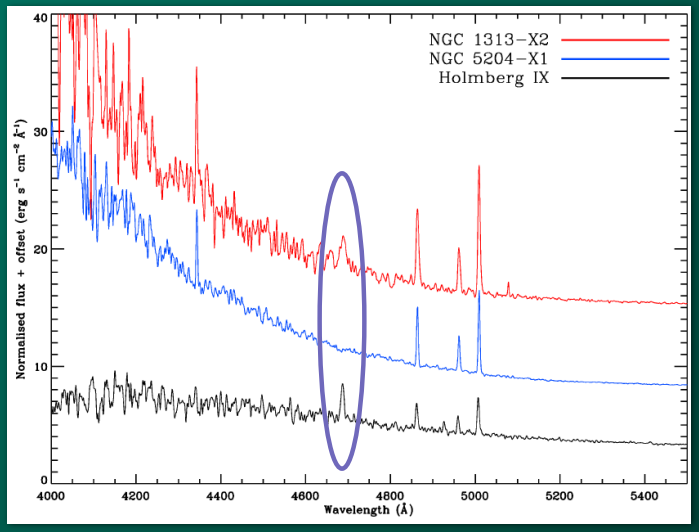


NGC 1313 X-2; Liu et al. (2008)

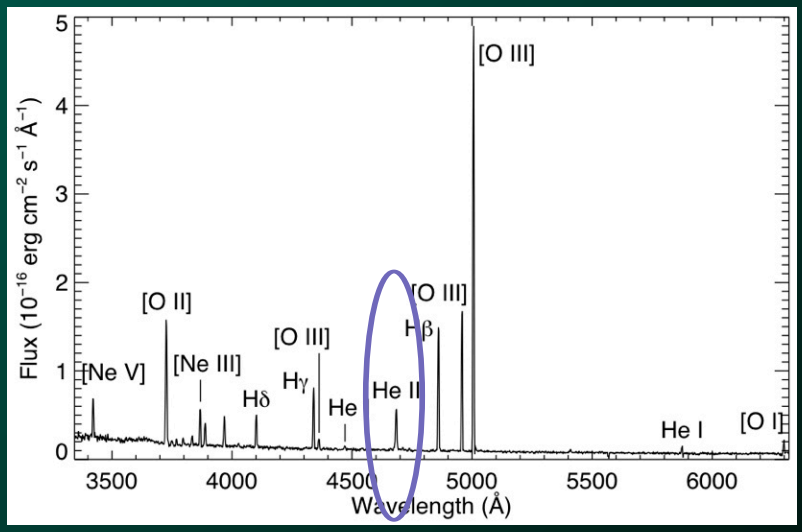
- ★ Photometric studies beginning to place constraints on companions and system
- ★ Work still on-going with both ground and space based applications

The 'standard' ULXs - optical spectra

- ★ Optical spectra have been obtained for a small number of nearby ULXs
- ★ High excitation emission feature present (He II; previously associated with accretion discs)

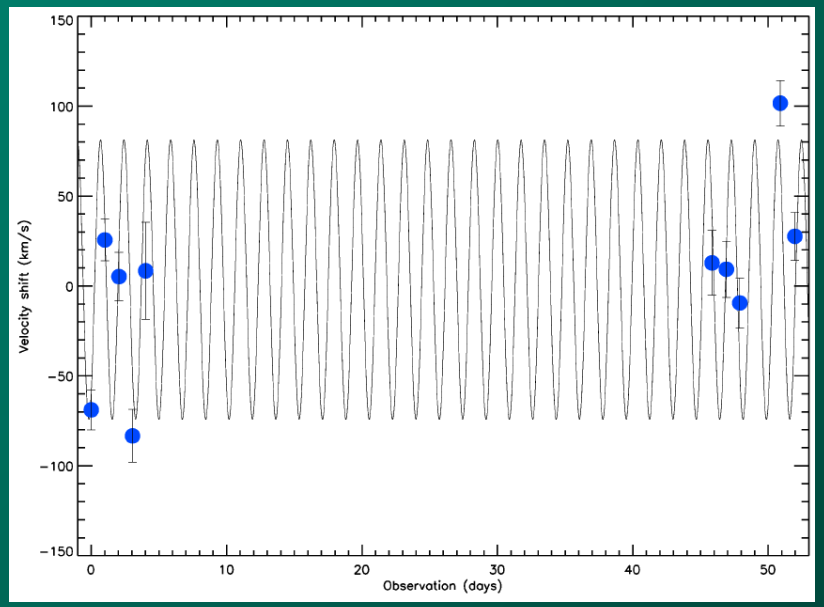


Roberts et al. (2011)



NGC 5408 X-1; Kaaret & Corbel (2009)

The 'standard' ULXs - dynamical mass?



Ho IX X-1; Roberts et al. (2011)

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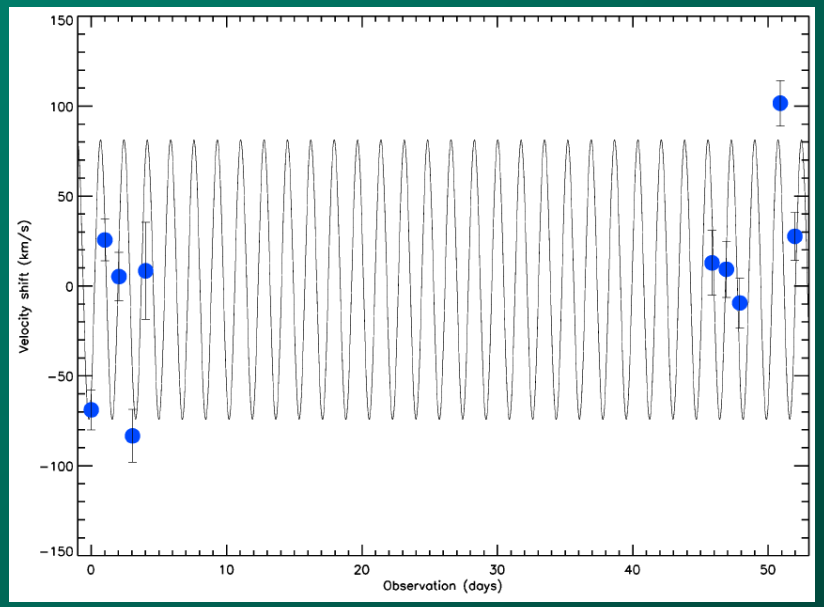

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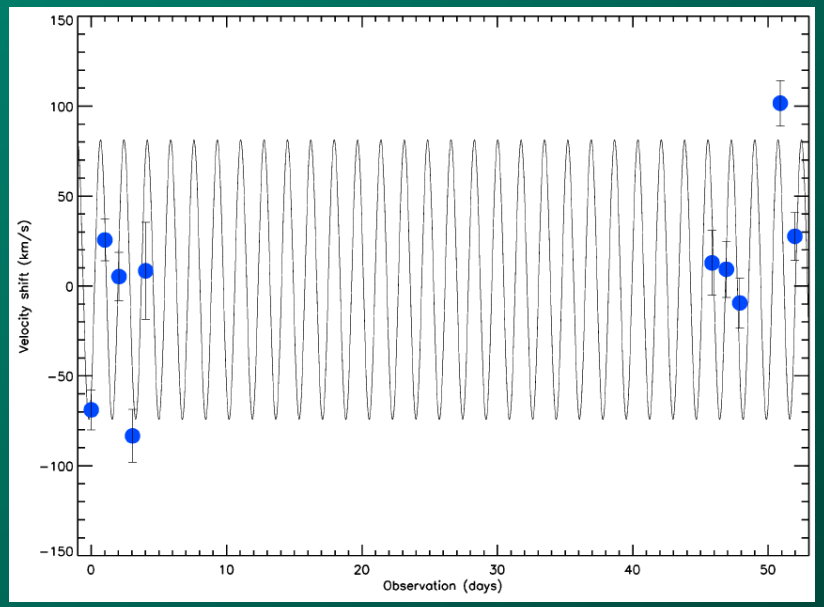

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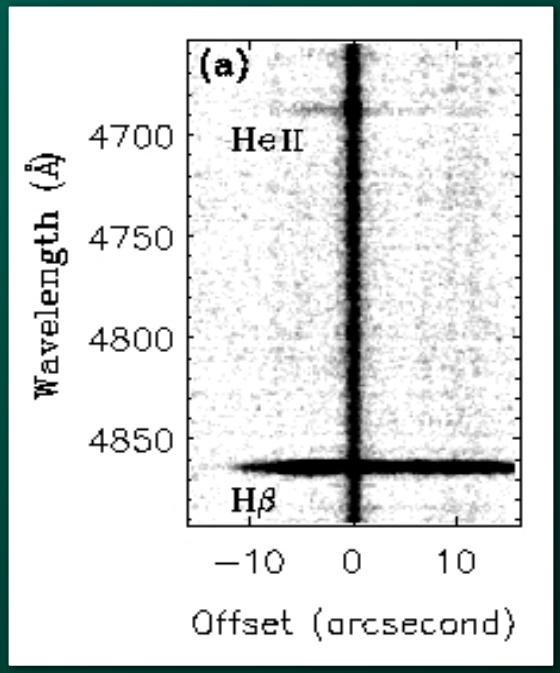

Ho IX X-1 Moon et al. (2011)

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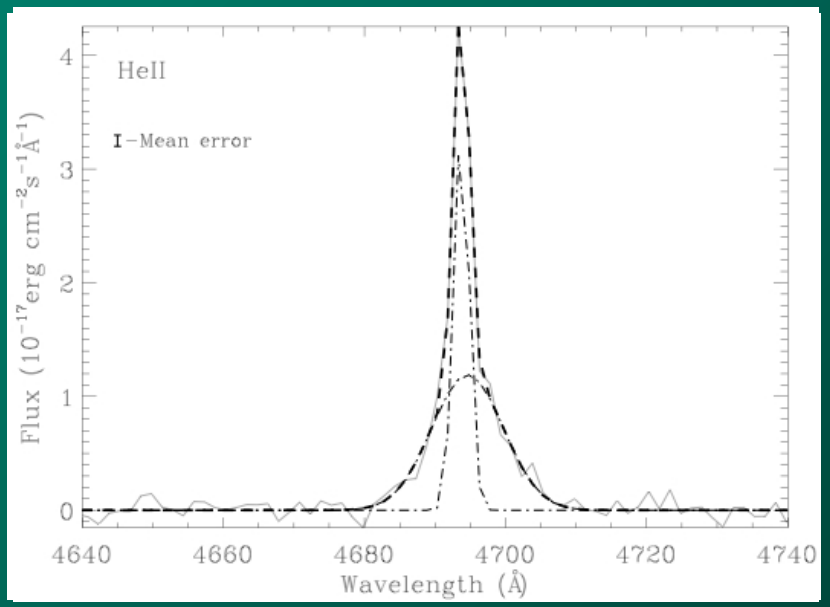
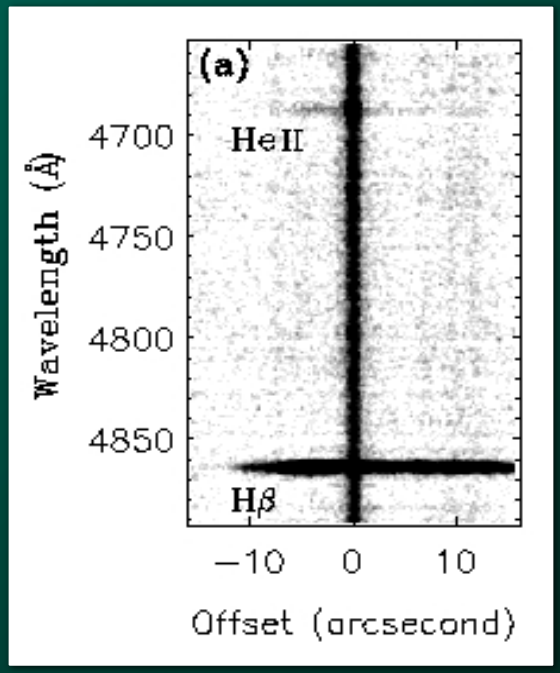


NGC 5408 X-1; Cseh et al. (2011)



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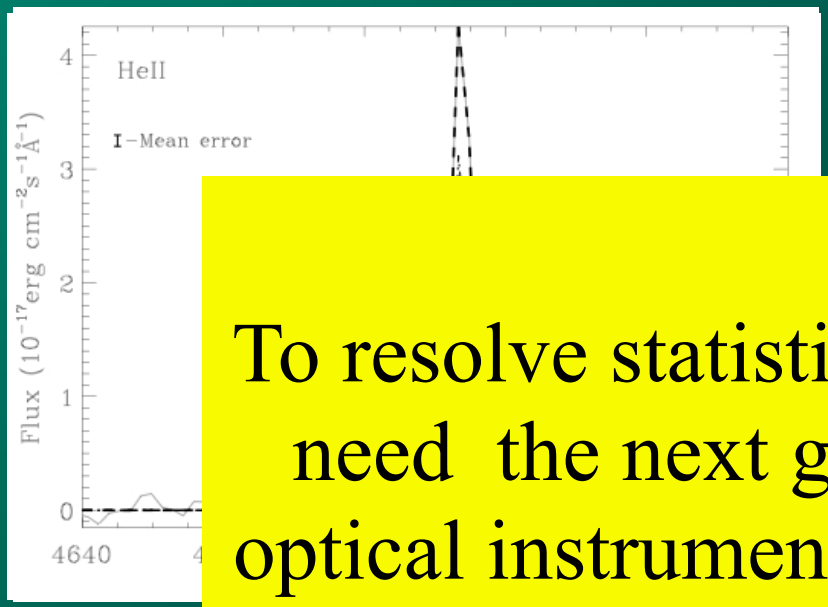
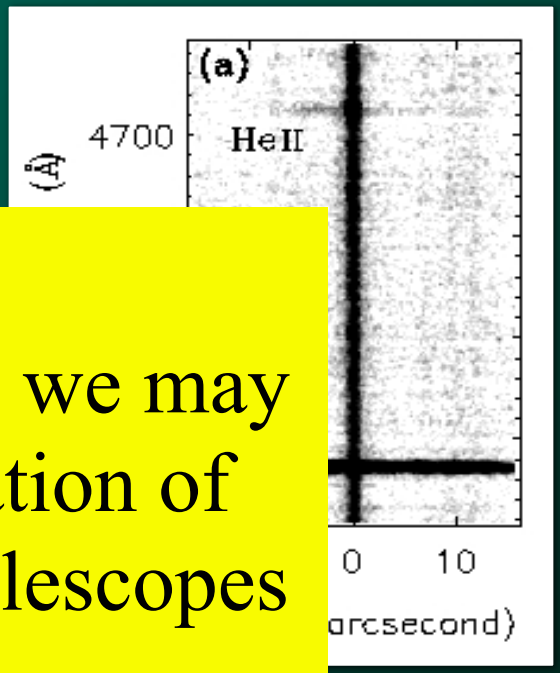




To resolve statistically, we may need the next generation of optical instruments / telescopes

NGC 5 ... bon et al. (2011)

★ No periodicity found as yet, but this could be due to line contamination ...

The 'standard' ULXs

It is thought that the majority of these are stellar remnant black holes accreting from a massive companion star at super-Eddington accretion rates ...

The 'standard' ULXs

It is thought that the majority of these are stellar remnant black holes accreting from a massive companion star at super-Eddington accretion rates ...

... however, more work is needed to

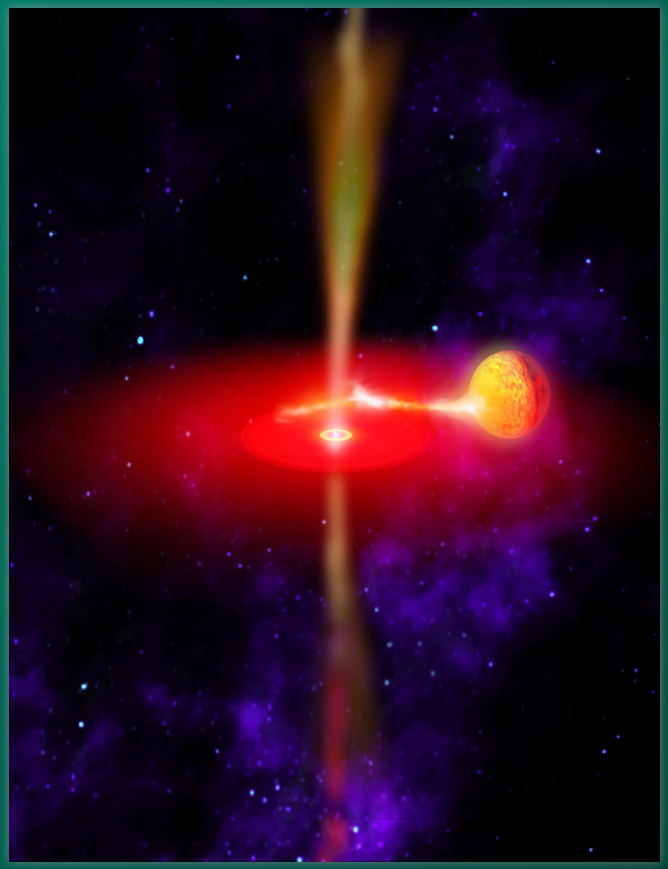
(a) obtain a greater understanding of the accretion geometry

(b) place good constraints on the mass of the black hole

The extreme ULXs

- This is a newly emerging group of objects
- classification came from break in XLF (shown earlier)
- can still be described by stellar remnants ... just
  - requires extreme end of mass range & extreme end of super-Eddington accretion
  - alternative - lower luminosity IMBHs

The extreme ULXs

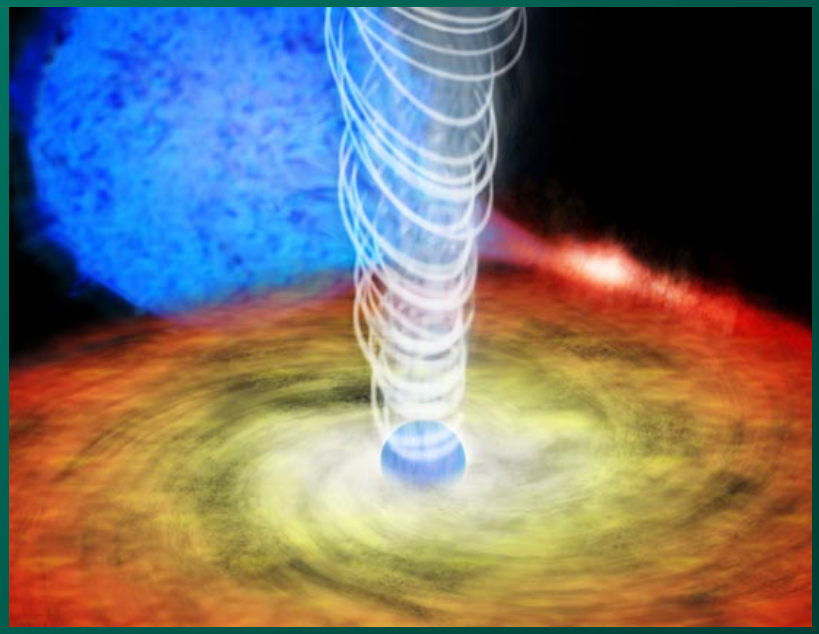


- Studies have only emerged in the last year, and have overlapped with HLX studies ... so discussion will have to overlap here

The HLXs

- These are the brightest end of the ULX scale
- With luminosities above that which can easily be explained by super-Eddington accretion onto a massive stellar remnant black hole
  - $L_X > 10^{41}$ erg s^{-1}

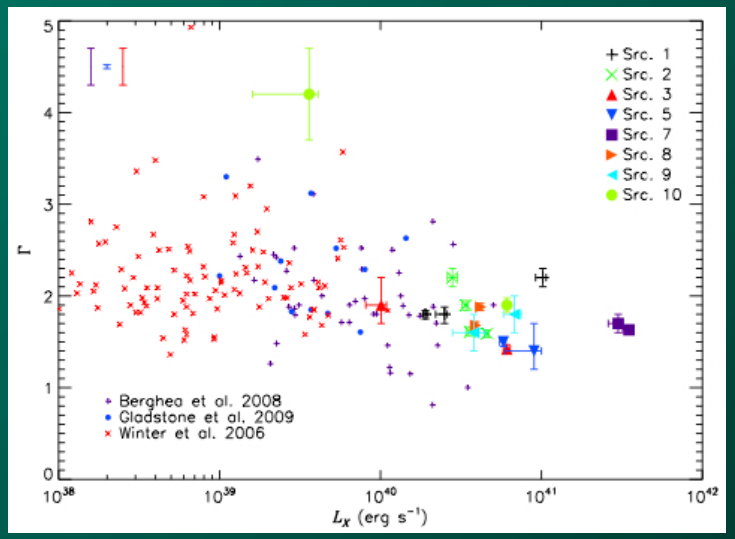
The extreme ULXs & HLXs



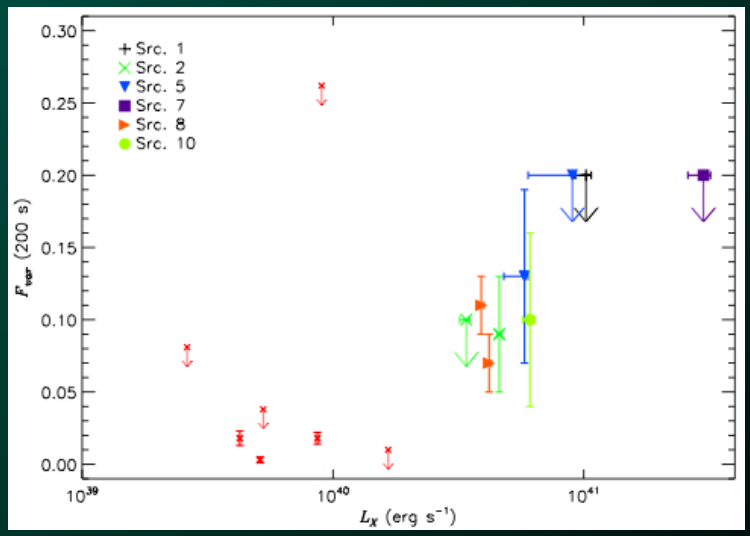
- ★ Only a handful known to date
- ★ Among the strongest IMBH candidates
  - ★ If location, and so luminosity are confirmed

The extreme ULXs & HLXs

- ★ Recent survey compared these to '*standard*' ULXs
  - ★ similarities in spectral shape
  - ★ differences in timing
  - ★ most show greater similarities to hard state

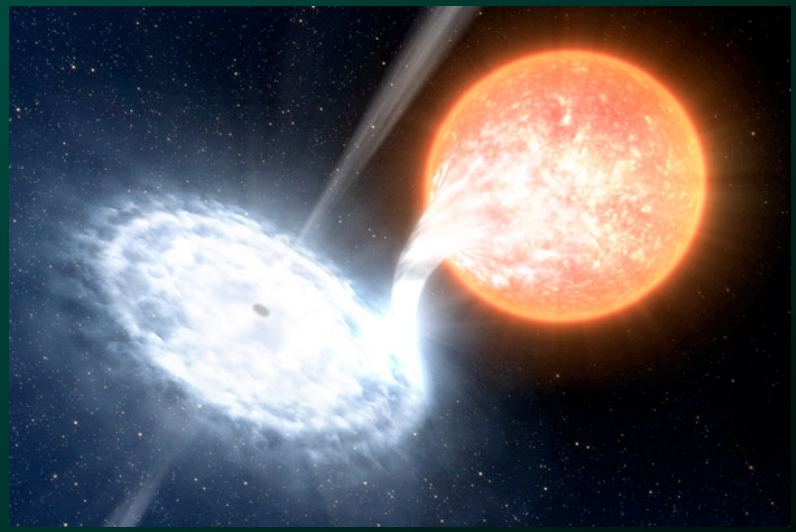


Sutton et al. (2012)

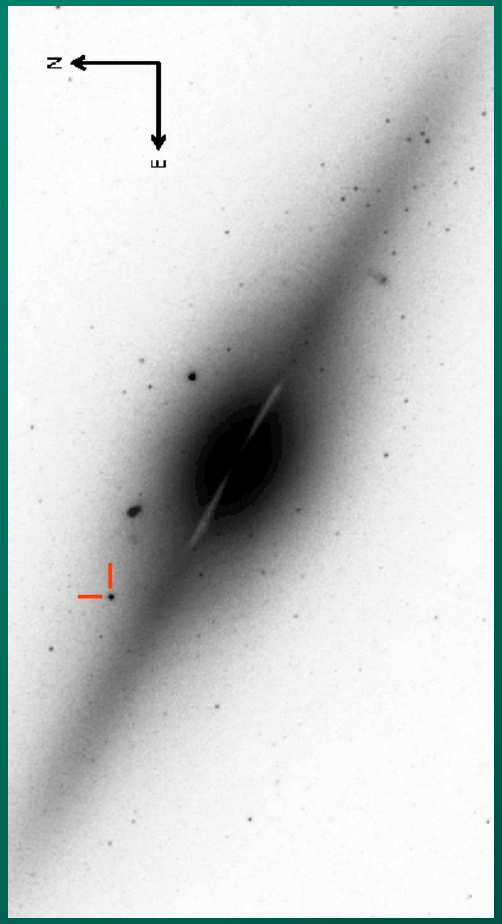


The extreme ULXs & HLXs

- There are a couple of special cases that have been studied in more detail
  - ESO 243-49 HLX-1
  - NGC 5907 ULX



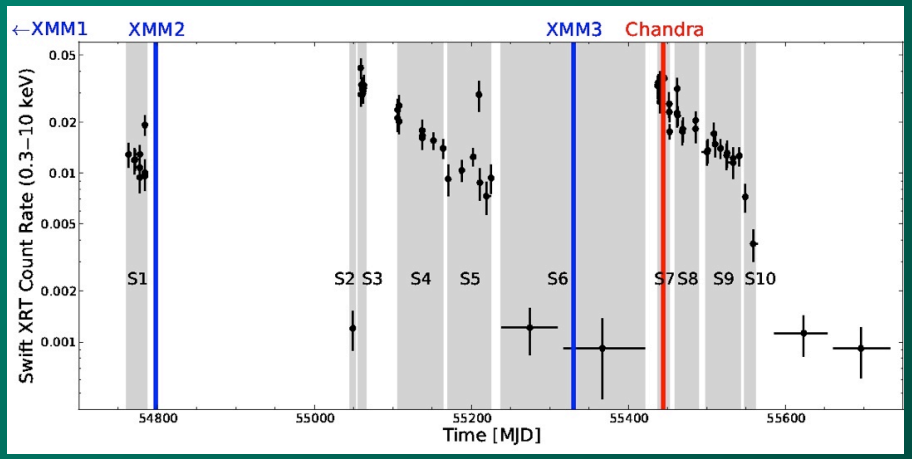
ESO 243-49 HX1



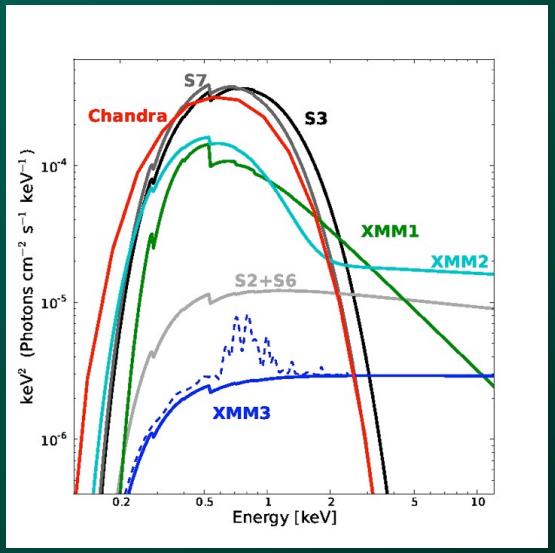
Composite HST image of ESO 243-49 constructed from all UV, optical and near-IR WFC3 data, with position of HLX-1 marked

- ★ First reported by Farrell et al. (2009)
- ★ Residing above plane of galaxy
- ★ Peak $L_X \sim 10^{42}$ erg/s
- ★ Distance confirmed as ~95 Mpc
- ★ multi-wavelength studies underway
- ★ see Sean's talk for more details on that but ...

ESO-243-49 HLX

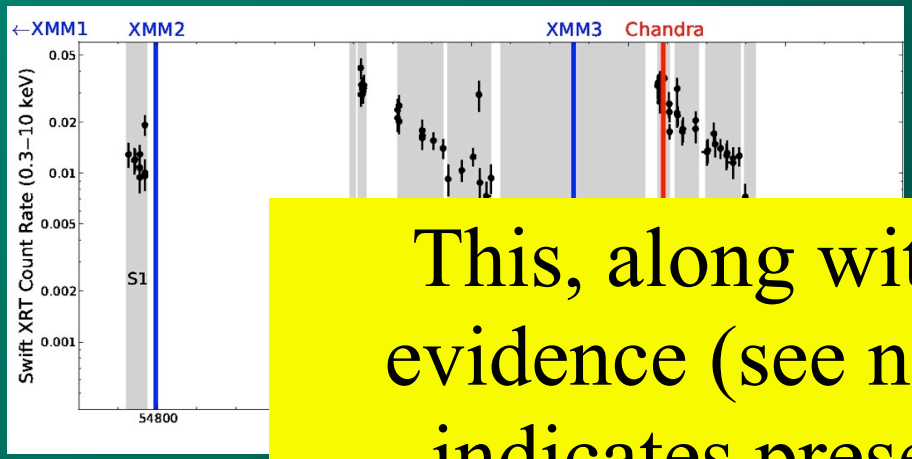


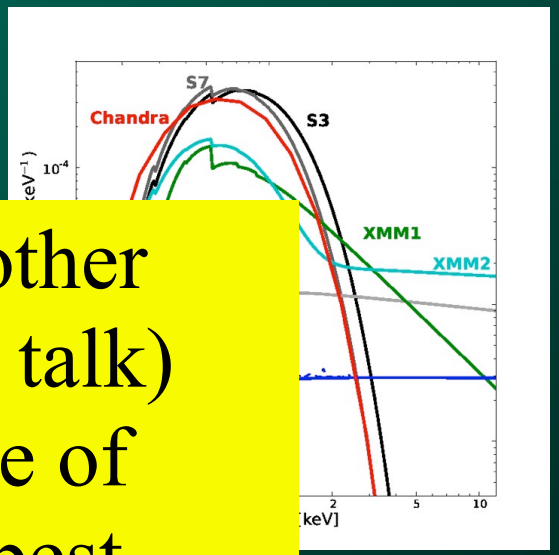
Servillat et al. (2011)



- ★ Swift monitoring shows possible periodic variations (e.g. Godet et al. 2009)
- ★ Peak looks similar to TDS/soft state & low flux looks like hard state (Servillat et al. 2011)
- ★ Scaling based on mass accretion rate in each state suggests ~ 10,000 M_{sun}

ESO-243-49 HLX





This, along with other evidence (see next talk) indicates presence of IMBH ... one of best candidates at present

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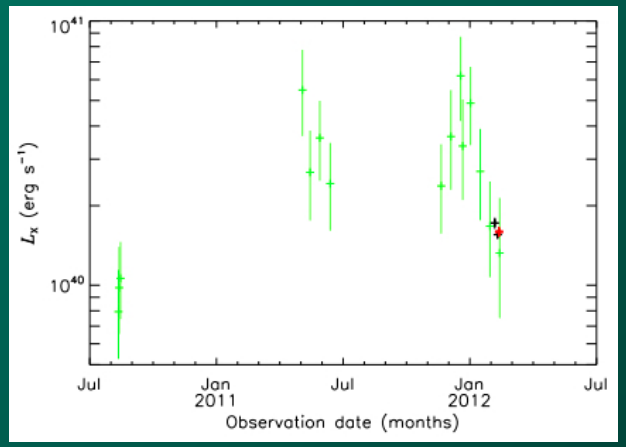
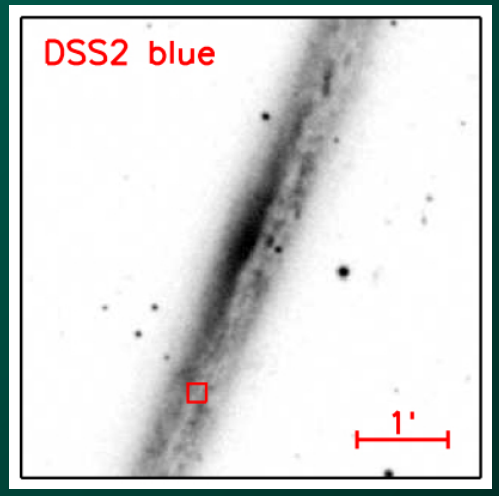
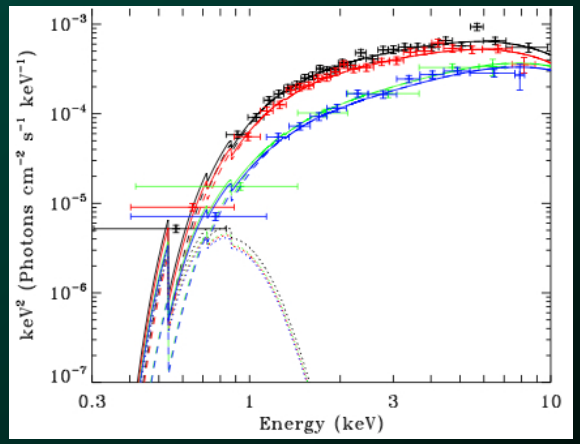
- ★ Peak looks similar to TDS/soft state & low flux looks like hard state (Servillat et al. 2011)
- ★ Scaling based on mass accretion rate in each state suggests ~ 10,000 M_{sun}

NGC 5907 ULX - from Sutton et al. (in prep)

- ★ an '*extreme*' ULX, first catalogued in Walton et al. (2011)
- ★ shows break above 3 keV, little short-term variability up to order of mag long-term
- ★ shows more similarities to *standard* ULXs
- ★ could be extreme end of *standard* ULXs







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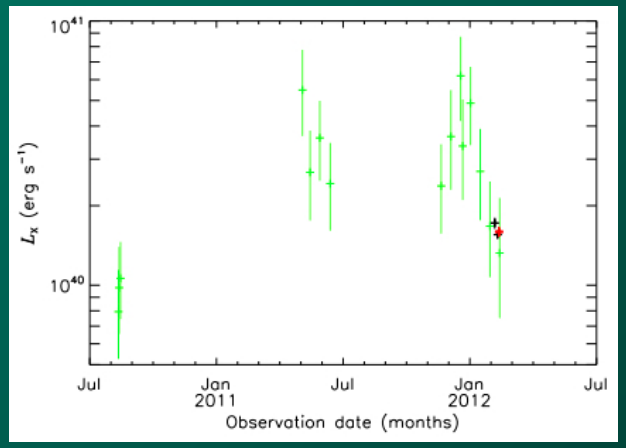

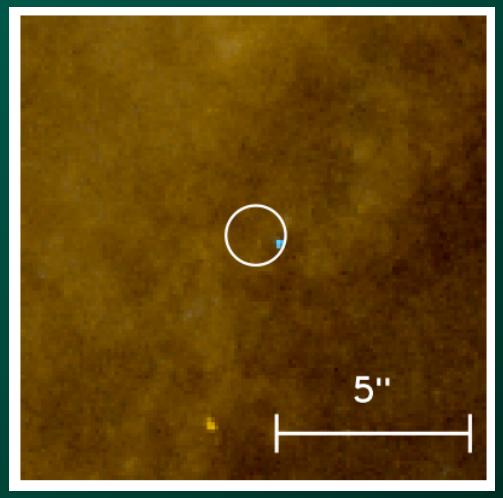

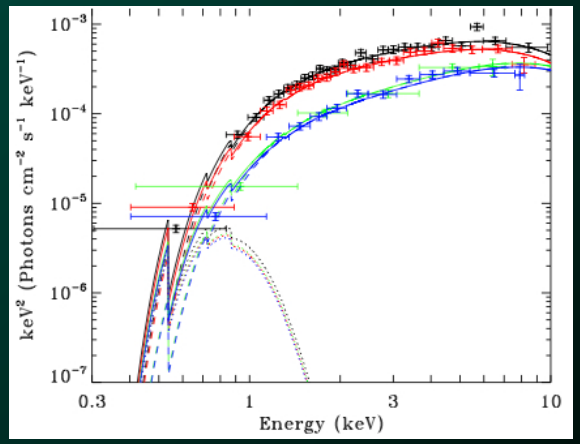

NGC 5907 ULX - from Sutton et al. (in prep)

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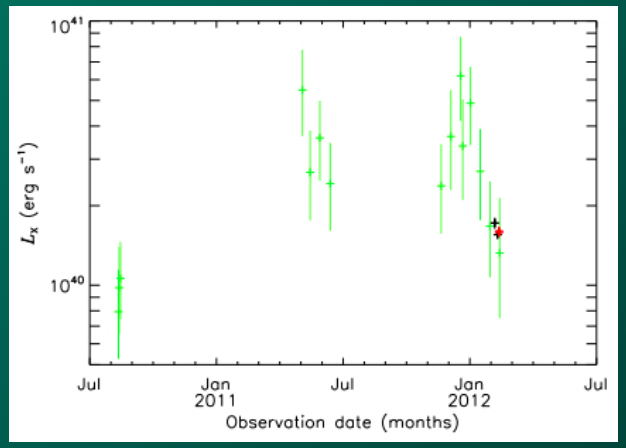
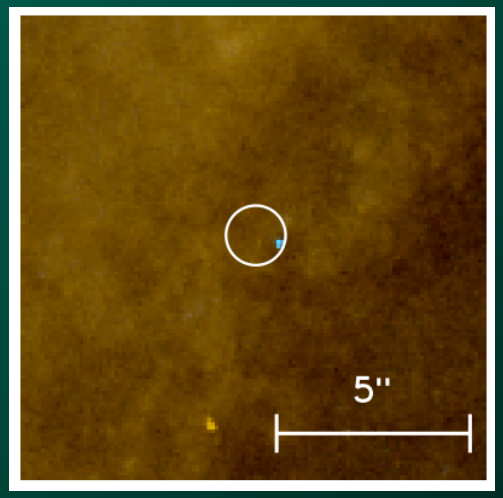
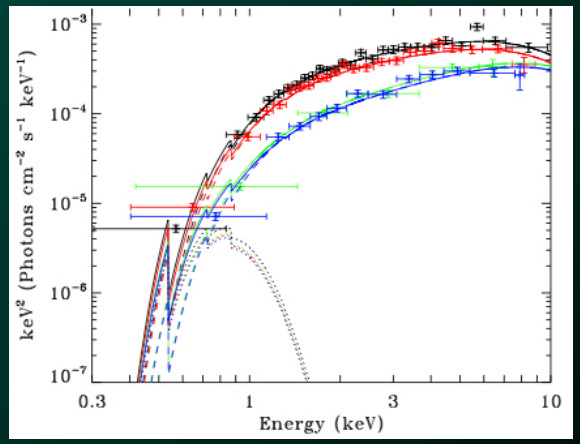
Need to perform multi-wavelength analysis to confirm distance and constrain nature of counterpart







The extreme ULXs & HLXs

- So few of these objects known to date
- To gain more knowledge we must
  - support surveys to find more objects
  - find more to improve statistics
  - tap into wealth of multi-wavelength surveys coming on line to help study these at other ULXs
    - e.g. eROSITA, ASKAP

Ultraluminous X-ray sources

- Can now be split into 3 sub categories
  - '*standard*' ULXs (~10^{39} erg s^{-1} < L_X < ~ 2 * 10^{40} erg s^{-1})
    - stellar remnant black holes (<~100 M_{sun}) accreting at or above the Eddington limit
  - *extreme* ULXs (~2 * 10^{40} erg s^{-1} < L_X < ~ 10^{41} erg s^{-1})
    - probably a combination of IMBH and extreme end of stellar remnant/mass accretion rate scale
  - HLXs (L_X > 10^{41} erg s^{-1})
    - probably best IMBH candidates

Ultraluminous X-ray sources

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Although we think we are starting to classify these, there is much work still to be done using both current and future instruments & telescopes!

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