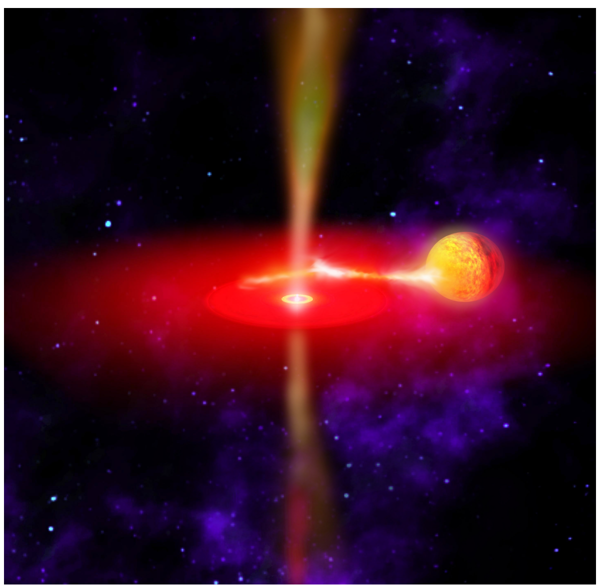
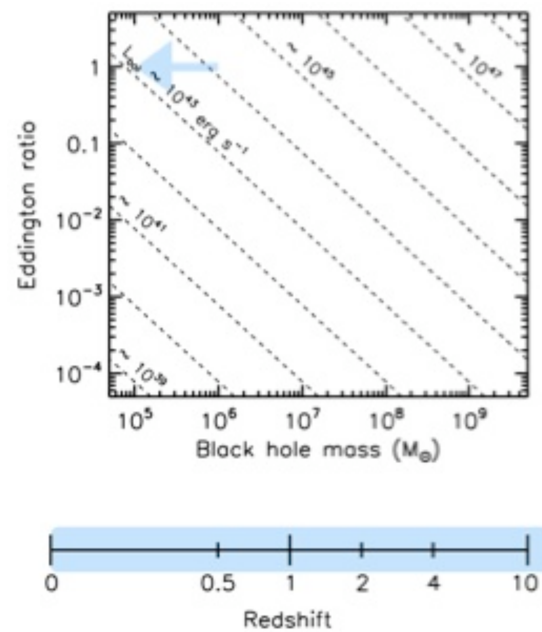
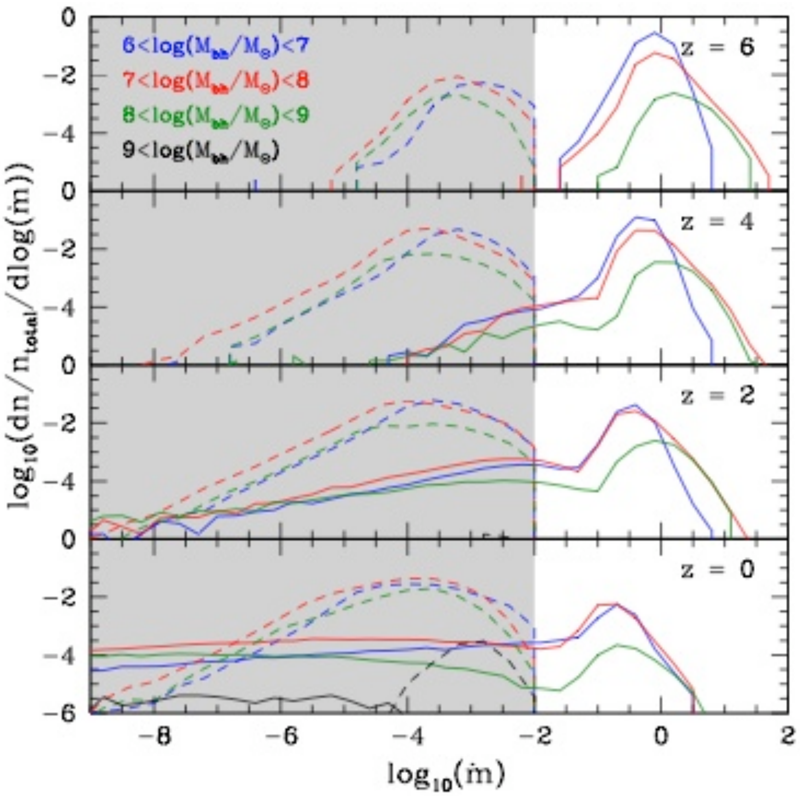
ULXs: a local template for super-Eddington black hole growth



Tim Roberts



Motivation

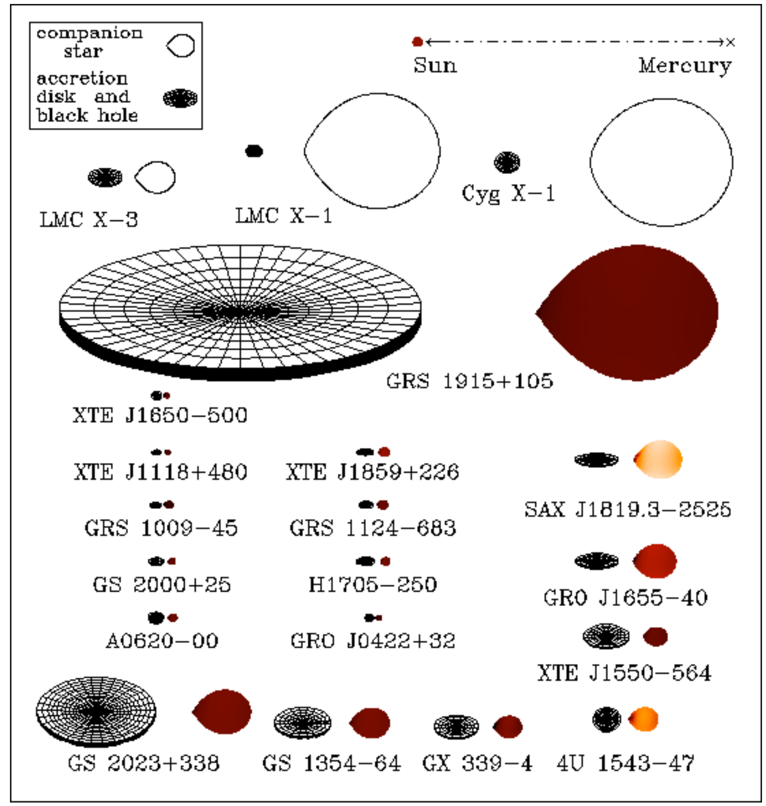


From Fanidakis et al. 2010

- Super-massive black holes mainly grow from accretion processes at or above the Eddington limit (e.g. King 2010)
- But most of this done by $z \sim 2$; difficult to study these accretion processes *in situ*

Where to look?

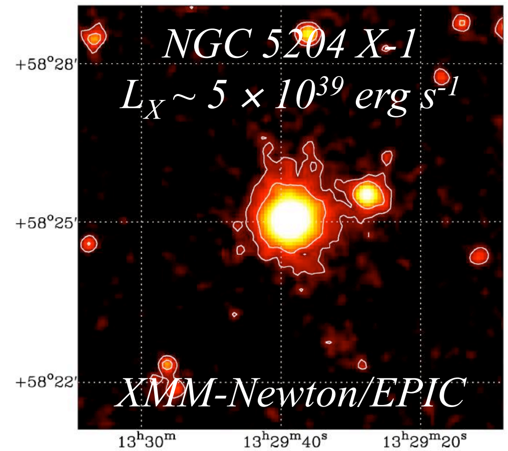
- If we want to study local super-Eddington systems, two options:
  - Study super-Eddington AGNs (e.g. extreme NLS1s?); but few in number
  - Study smaller BHs; but most Galactic stellar BHs sub-Eddington

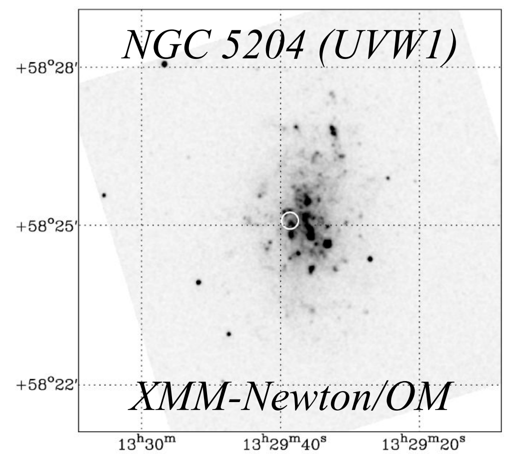


From http://mintaka.sdsu.edu/faculty/orosz/web/

A third way: ULXs

- *Ultraluminous X-ray sources (ULXs)*: brightest extra-nuclear X-ray sources, with $L_X > 10^{39}$ erg s^{-1}
- Although some interlopers at these luminosities (e.g. rare SNe), most ULXs thought to be accreting BHs
- 400+ known candidates





Why are ULXs so interesting?

- Eddington limit for 10 $M_\odot$ BH ~ 10^{39} erg s^{-1}
- So to produce extreme luminosities in ULXs, require one of the following
  - Large BH mass (>> 10 $M_\odot$)

    $10^2 – 10^4$ $M_\odot$ Intermediate-Mass Black Holes (IMBHs; e.g. Colbert & Mushotzky 1999)

    SMBH seeds
  - Radiative anisotropy
  - Super-Eddington emission

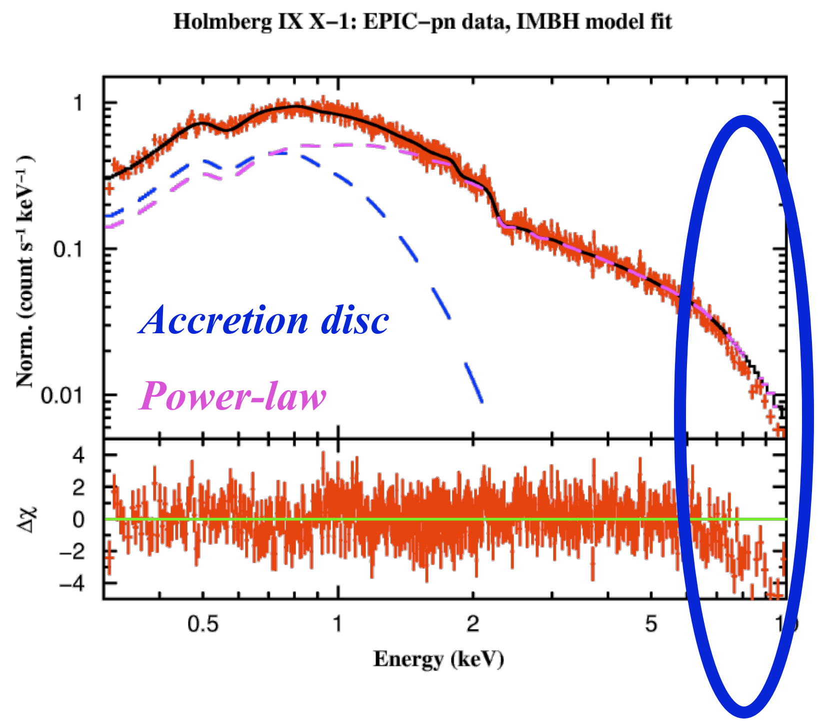
Combined in latest models for stellar-mass BHs as ULXs (e.g. Poutanen et al. 2007, King 2008)

Rapid BH growth; strong radiatively-driven wind

ULX spectral basics

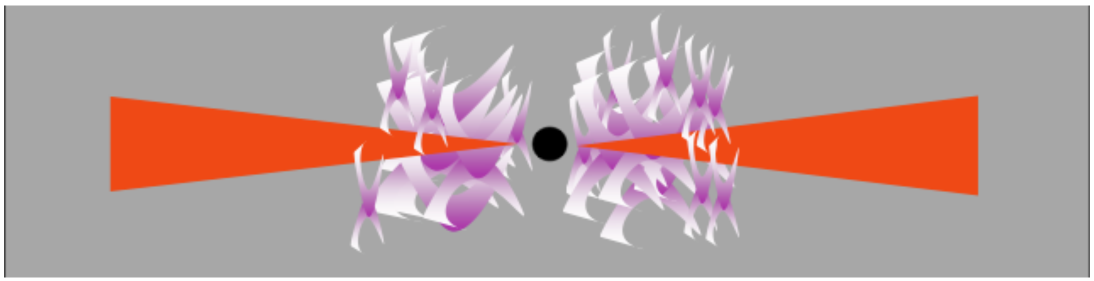
Stobbart, Roberts & Wilms 2006

- Results from *XMM-Newton* data
- ULXs don't fit in with sub-Eddington BH states
- 2-10 keV spectrum fitted by a broken power-law in all of the highest quality data: not seen in sub-Eddington states
- ULXs are in a super-Eddington, *ultraluminous* state (Roberts 2007)
  - **Small black holes!**



Physical models

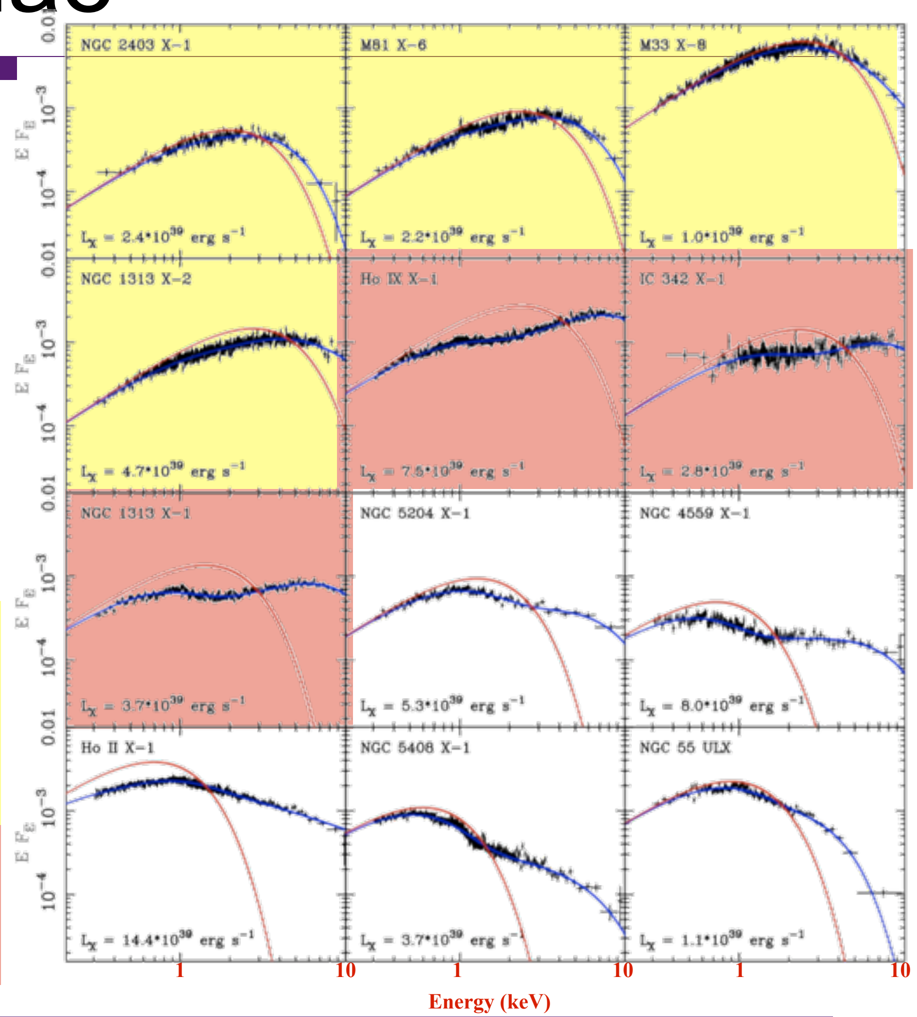
Gladstone, Roberts & Done 2009



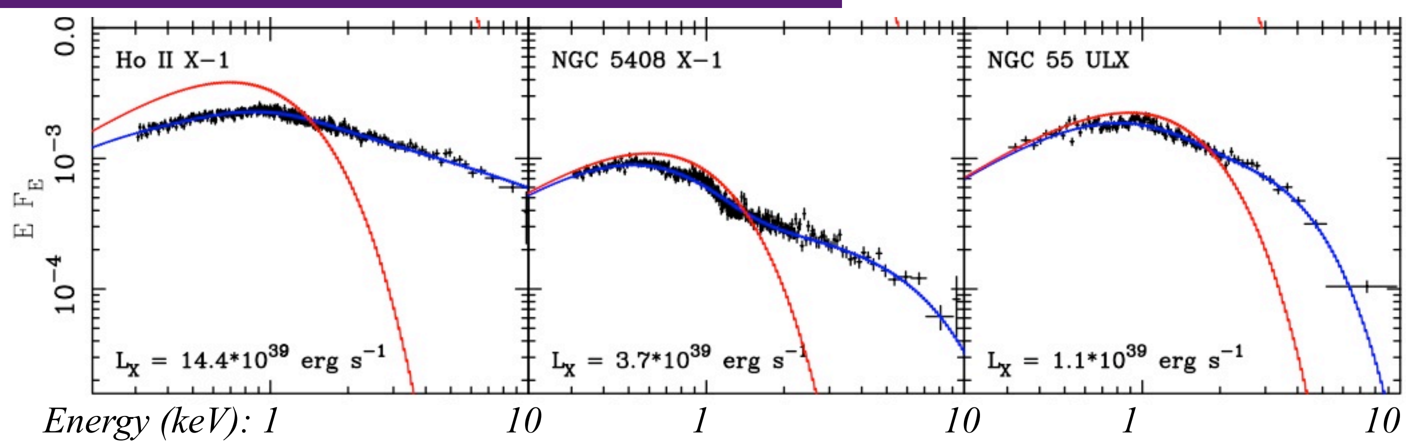
- Revisit results of Stobbart et al. (2006), using superior archival data
- Look at disc plus corona models (illustrated above) - fits give cool discs (0.2 - 0.8 keV), optically thick coronae ($6 < \tau < 80$) in *all* cases
- But assumptions made - inner disc visible, unaffected by optically thick corona

Coupled disc-coronae

- Can correct for energy used to launch corona, obscuration of inner disc (Done & Kubota 2006)
- Recover disc temps ~ 0.6 - 1 keV for 8/12 ULXs
  - Modified disc spectra - ~Eddington-rate: big stellar BHs or beamed?
  - Truly super-Eddington - optically thick coronae



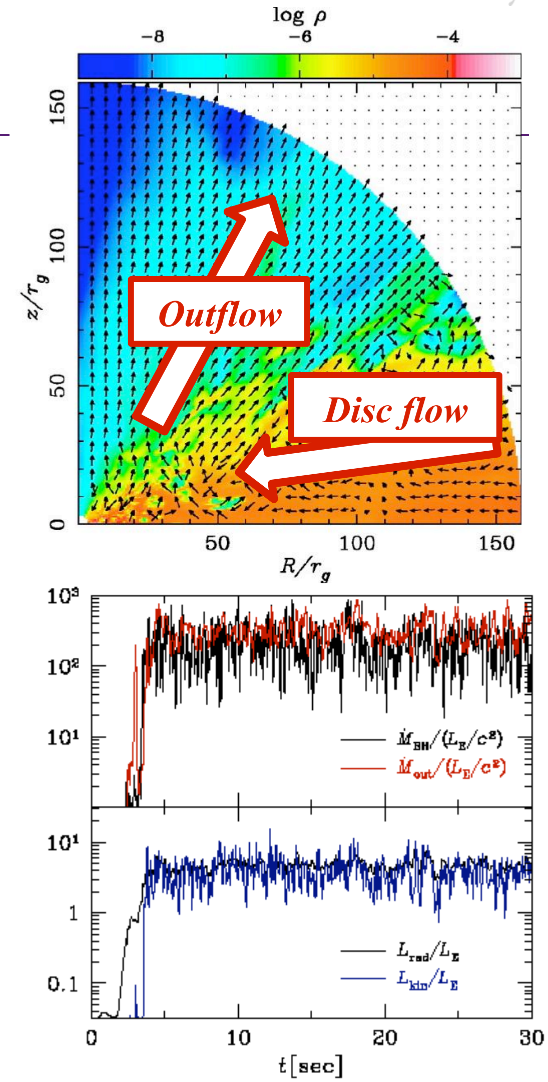
Low temperature discs?



- Four sources still possess low temp discs (~0.3 keV) - IMBHs?
- But theory predicts key characteristic of super-Eddington accretion is a wind (e.g. Poutanen et al. 2007, King 2008)
- If sufficient material present - cool photosphere formed at base of wind - greater effect for higher accretion rate
- **ULX sequence explained by increasingly powerful wind**

The importance of winds

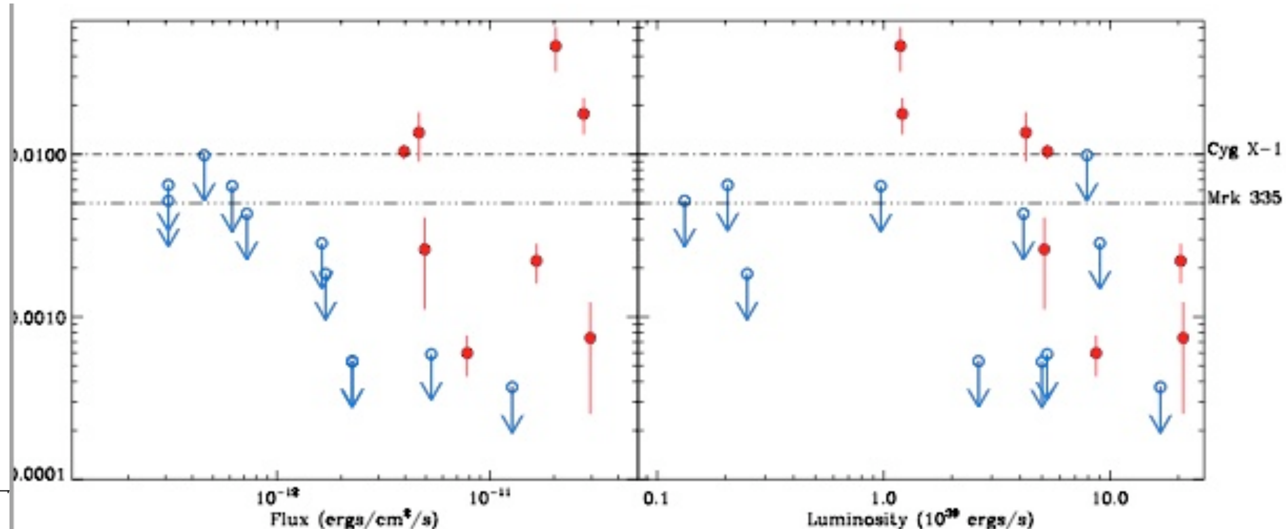
- Hydrodynamical simulations of extreme accretion rates ($\dot{M}$ >> $\dot{M}_{Edd}$) onto stellar-mass black holes - Ohsuga (2006, 2007)
- Extreme wind driven - column ~ 3×10^{24} cm^2 at the poles, much higher elsewhere
- Explains coronae and photospheres, predicts suppressed variability

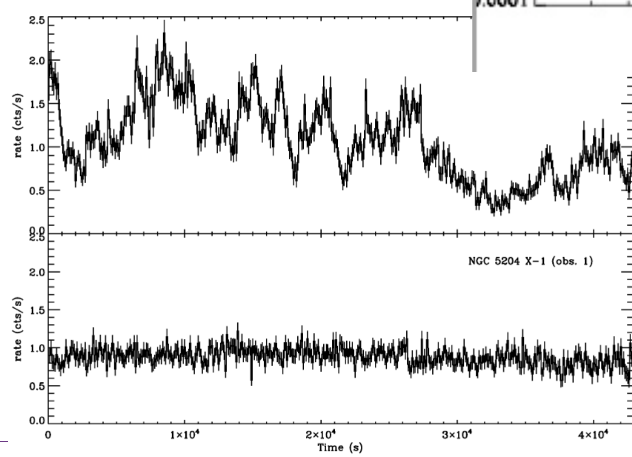


Suppressed variability seen!

Heil, Vaughan & Roberts 2009

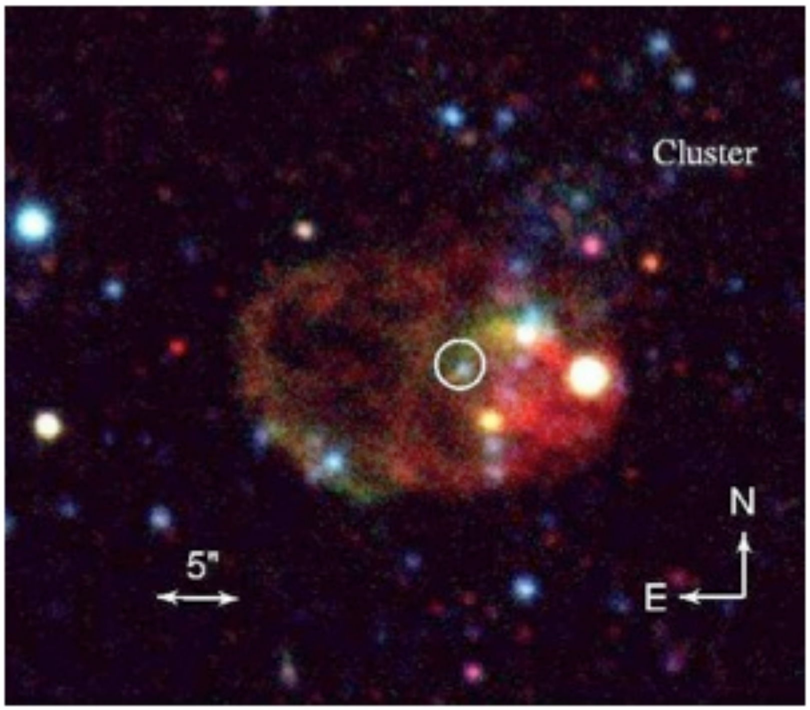
Variability of ULXs, modelled by constraining PSD shape & normalisation



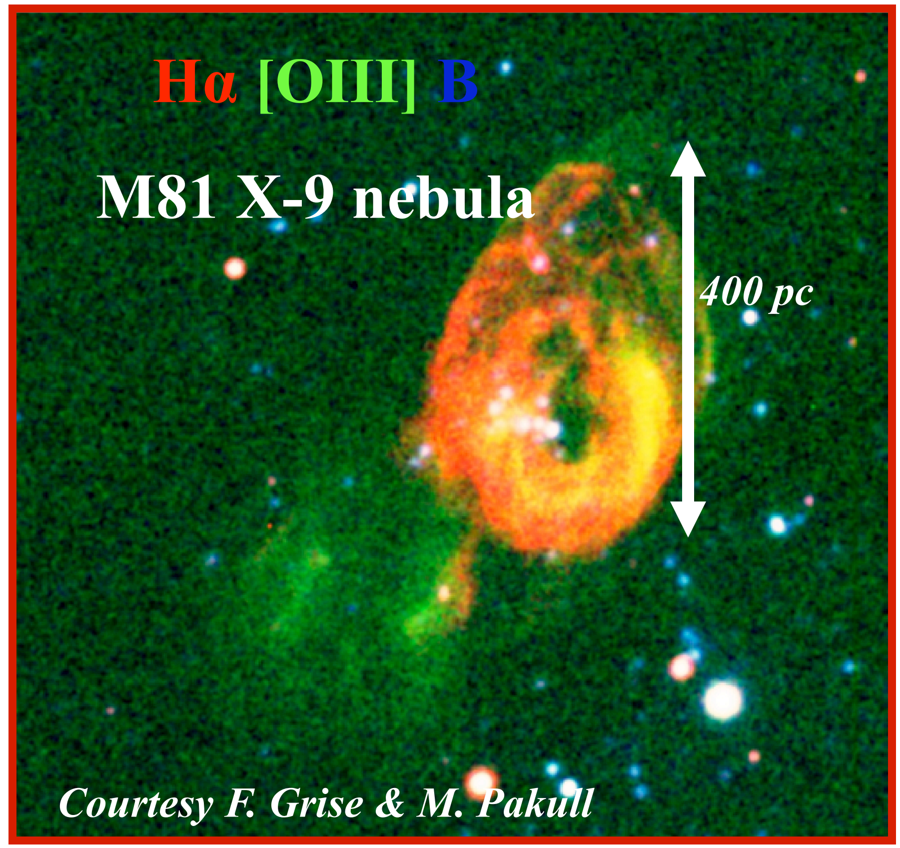


Variability of NGC 5204 X-1 compared to the AGN, NGC 4051. The count rate of NGC 4051 is scaled to that of NGC 5204 X-1

ULX bubble nebulae



NGC 1313 X-2 nebula, with Hα in red (Pakull et al. 2006)

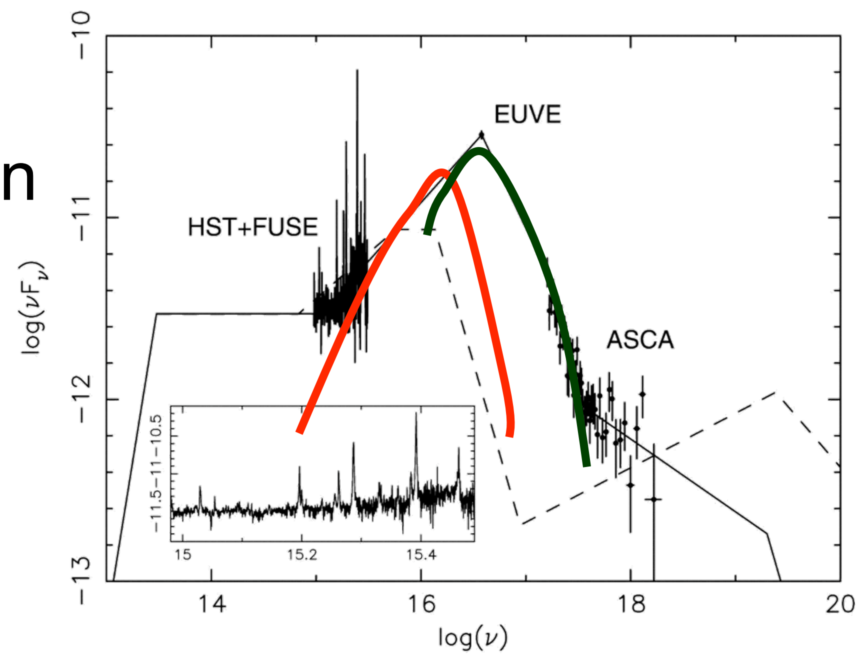


Nebulae energetics

- Only viable explanation for nebulae is that they are inflated by mildly-relativistic wind/jets from ULX
- From various studies by M. Pakull (also Roberts et al. 2003)
  - Age ~10^5 – 10^6 yrs
  - Energy input ~10^{52} – 10^{53} erg
  - Implies $L_{mech} \sim L_{rad}$
  - BH grows by ≥ 1 $M_{\odot}$ in this time (could be much larger, depending on amount of ***advection***)

The ultraluminous state at large

- Highest L_X obs of GRS 1915+105, GRO J1655-40 show optically-thick Comptonisation spectra (e.g. Ueda et al. 2009)
- Highest Eddington fraction AGN show similar spectra, albeit shifted to longer wavelengths (Middleton et al. 2009, Jin et al. 2009)
- If UL state common to > L_{Edd} objects – so are winds etc.

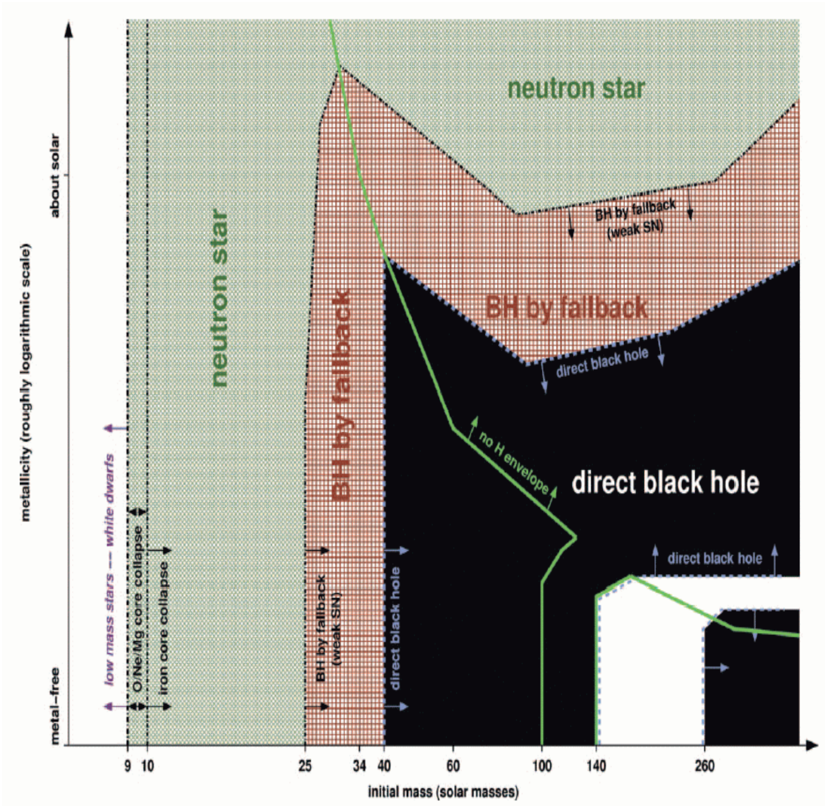


Optical-UV-X-ray spectrum of RE J1034+396 (Casebeer et al. 2008)

How big are ULX black holes?

Zampieri & Roberts 2009

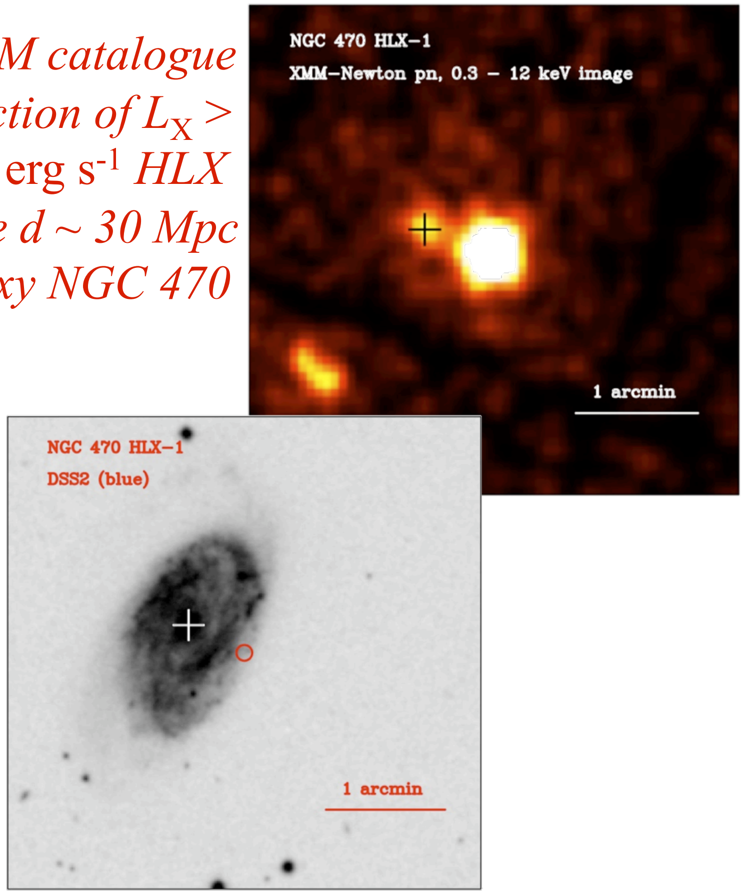
- Evidence from X-ray spectra, timing - pointing towards small BHs, not 1000 $M_\odot$ IMBHs
- But reasonable limits at ~ 100 $M_\odot$ - still larger than seen in Galactic BHs
- Possible if BHs formed in low-metallicity environments!
- Higher rate of ULXs per unit mass already noted for dwarf galaxies (Swartz et al. 2008)
- ~30 $M_\odot$ BH in dwarf starburst IC 10 (Prestwich et al. 2007)



From Heger et al. (2003)

Hyperluminous X-ray sources (HLXs)

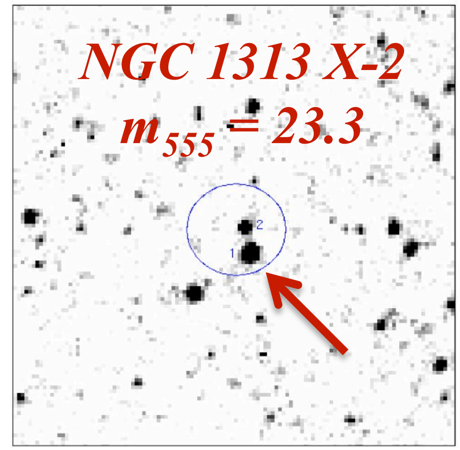
2XMM catalogue detection of $L_X >$ 10^{41} erg s^{-1} HLX in the d ~ 30 Mpc galaxy NGC 470

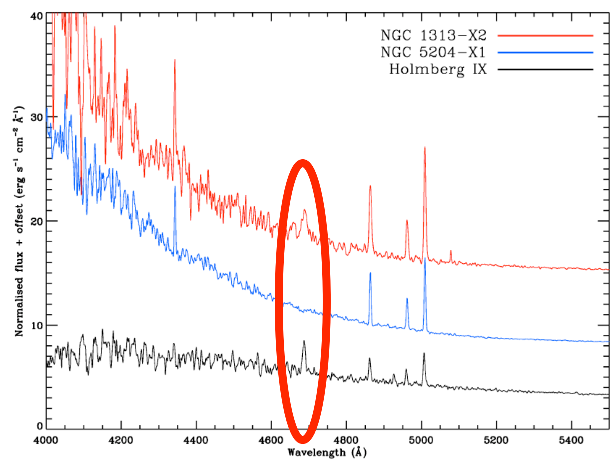


- HLXs best remaining IMBH candidates, $L_X > 10^{41}$ erg s^{-1}
- Only ~ 6 known! ESO 243-49 HLX-1 the highest L_X (Farrell et al. 2009)
- But M82 X-1 has cool, thick corona spectrum (Miyawaki et al. 2009)
- Properties similar to lower L_X ULXs (Sutton, in prep.)

The key observation

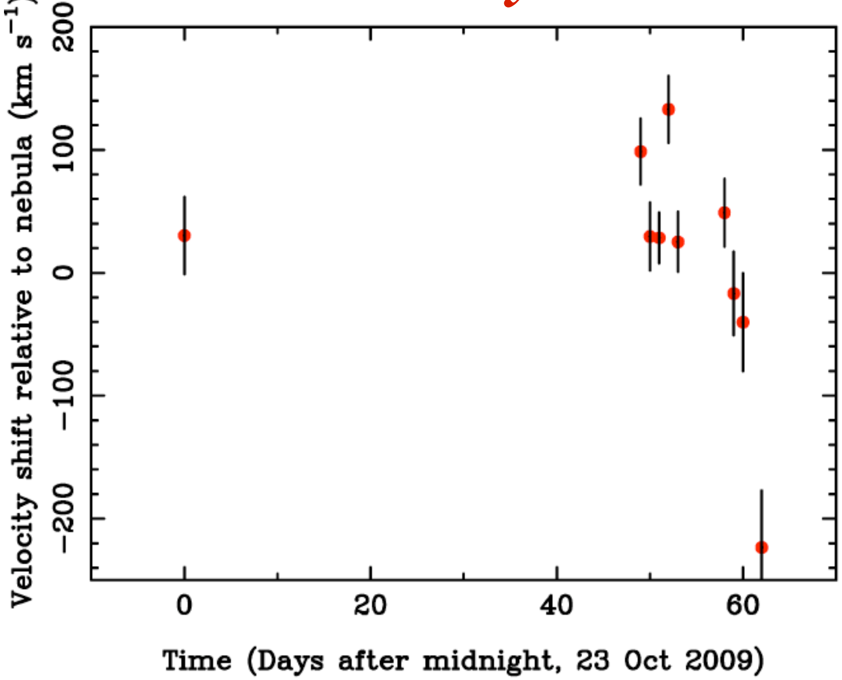
- As with Galactic BHs, the ultimate test of the compact object mass in ULXs must be dynamical studies.
- Pilot observations of *Chandra/ HST* identified counterparts to IMBH-candidate ULXs show broad He II lines
- Obtained ~50 hours of Gemini time to chase radial velocity measurements



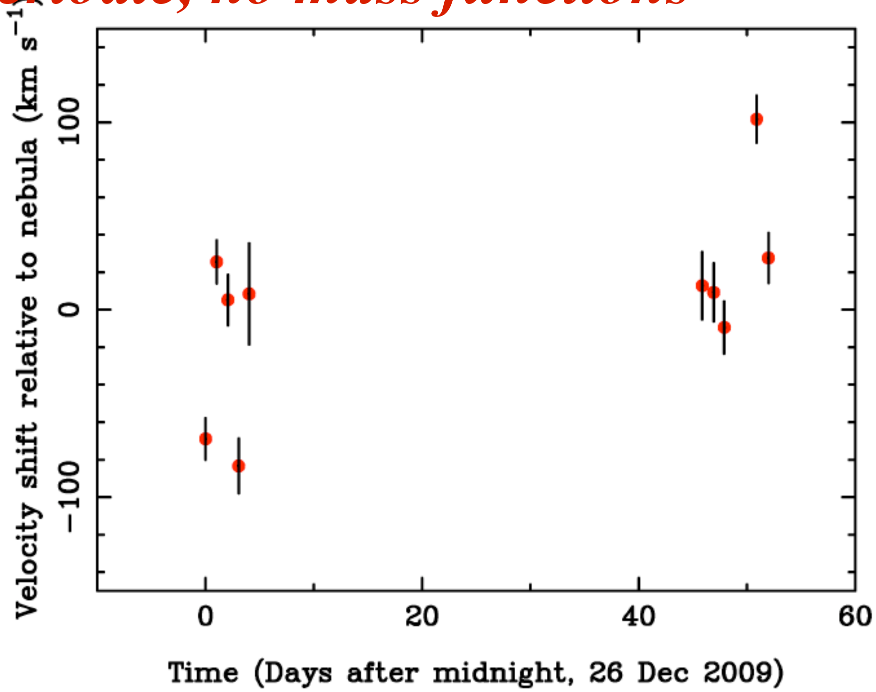


Radial velocity variations

Preliminary result: Not periodic, no mass functions



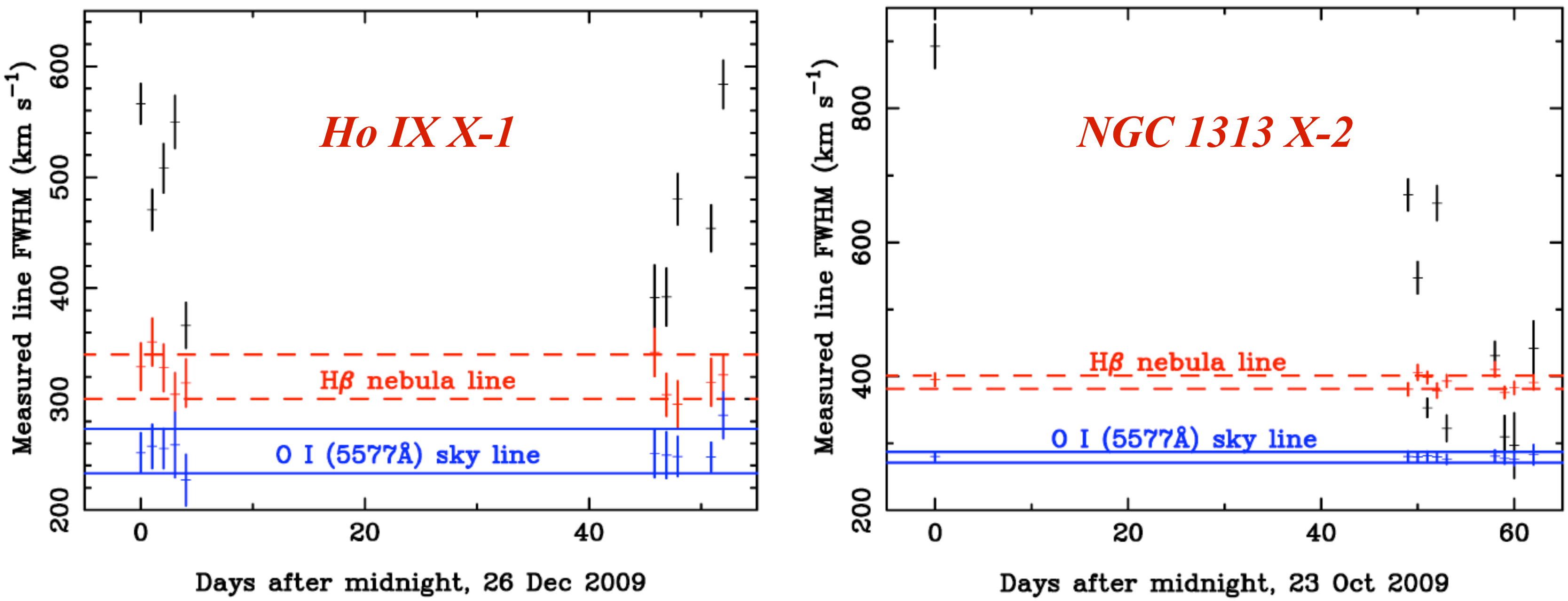
NGC 1313 X-2



Ho IX X-1

But still some science!

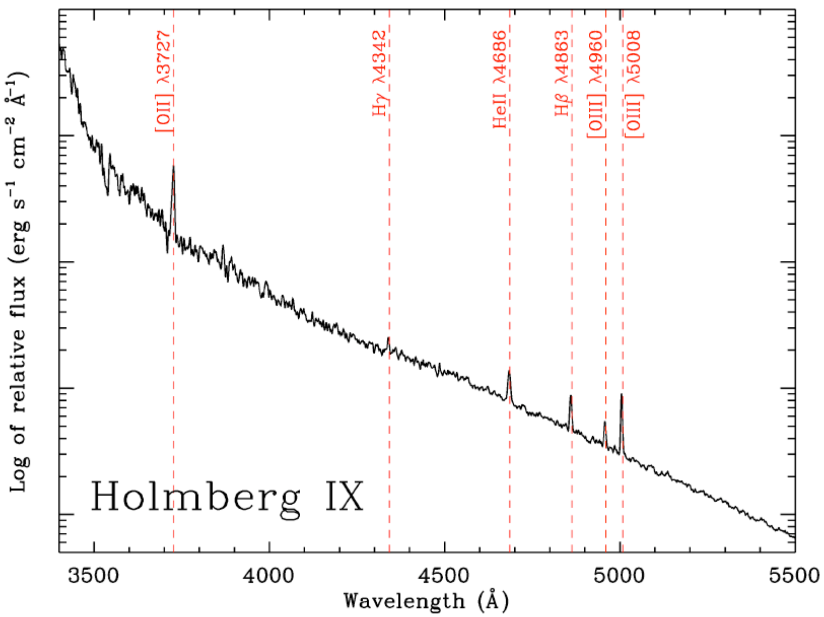
He II 4686Å line very variable on timescales of days

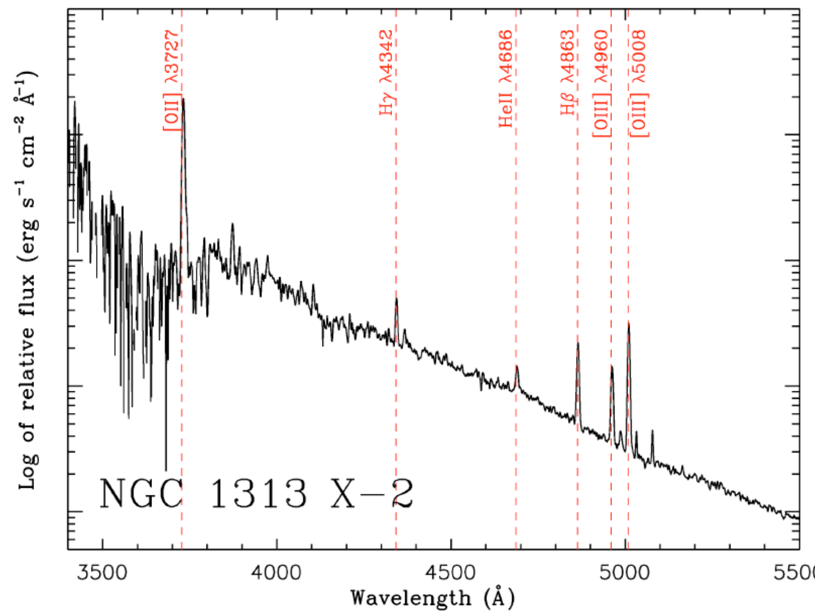


But not broad enough for accretion disc – systems close to face-on? Or other origin (e.g. wind)?

Nature of the counterparts

Stack all 10 spectra per object





Virtually featureless – accretion-disc-dominated?

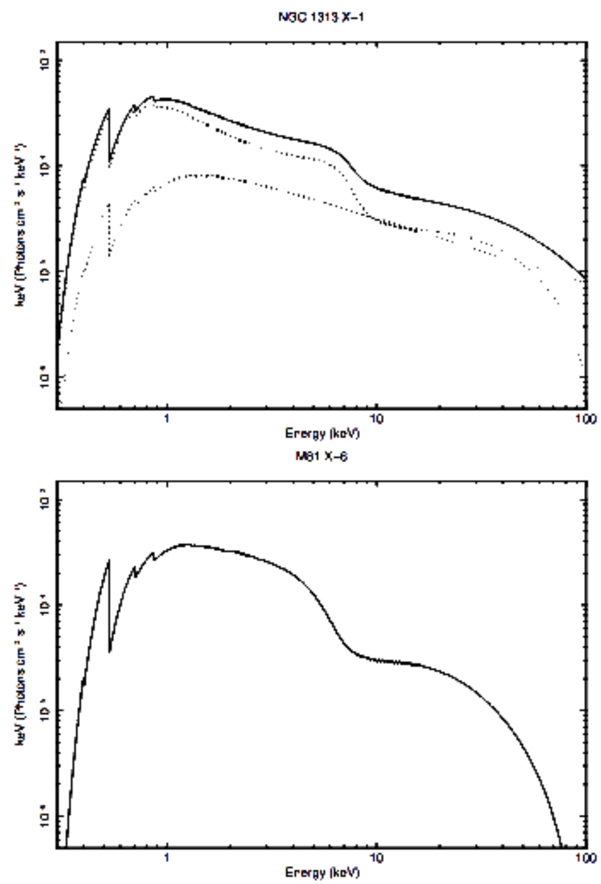
Stellar features at short wavelengths?

Conclusions

- ULXs – local super-Eddington accretors
  - X-ray phenomenology dominated by wind
  - Better understanding ULX physics should give insights into QSO growth and feedback
- But maybe not perfect analogy – scaling issues?
- Some ULXs may contain modern equivalents of initial SMBH seeds

But spectral fitting is degenerate!

- Alternatives include…
- "Slim" accretion discs (e.g. Watarai et al. 2000)
  - Accretion disc structure changes at highest accretion rates
  - Consistent with some ULX spectra (e.g. Vierdayanti et al. 2006, Mizuno et al. 2007).
- Reflection-dominated, highly relativistic emission from inner edge of accretion disc (Caballero-Garcia & Fabian 2010)
- Common thread: **high accretion rate, small black holes ($M_{BH} < 100\ M_{\odot}$).**



From Caballero-Garcia & Fabian 2010