Ultraluminous X-ray sources

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Definition

Ultraluminous X-ray sources are *off-nuclear, point-like* X-ray sources exceeding the (isotropic) Eddington limit for a stellar-mass Black Hole (StBH)

$L_{ULX} > 3x10^{39}$ erg/s

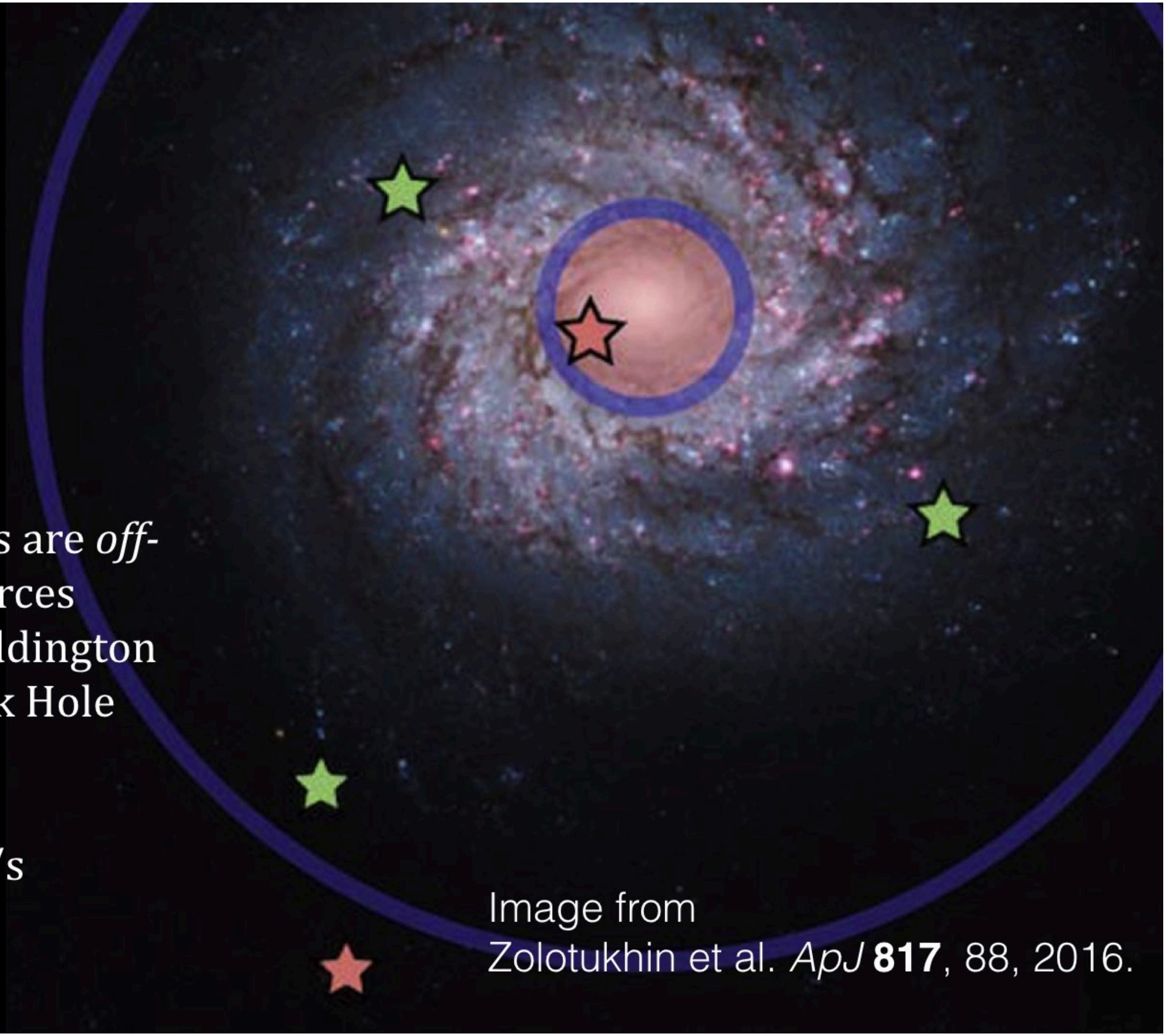

Image from
Zolotukhin et al. *ApJ* **817**, 88, 2016.

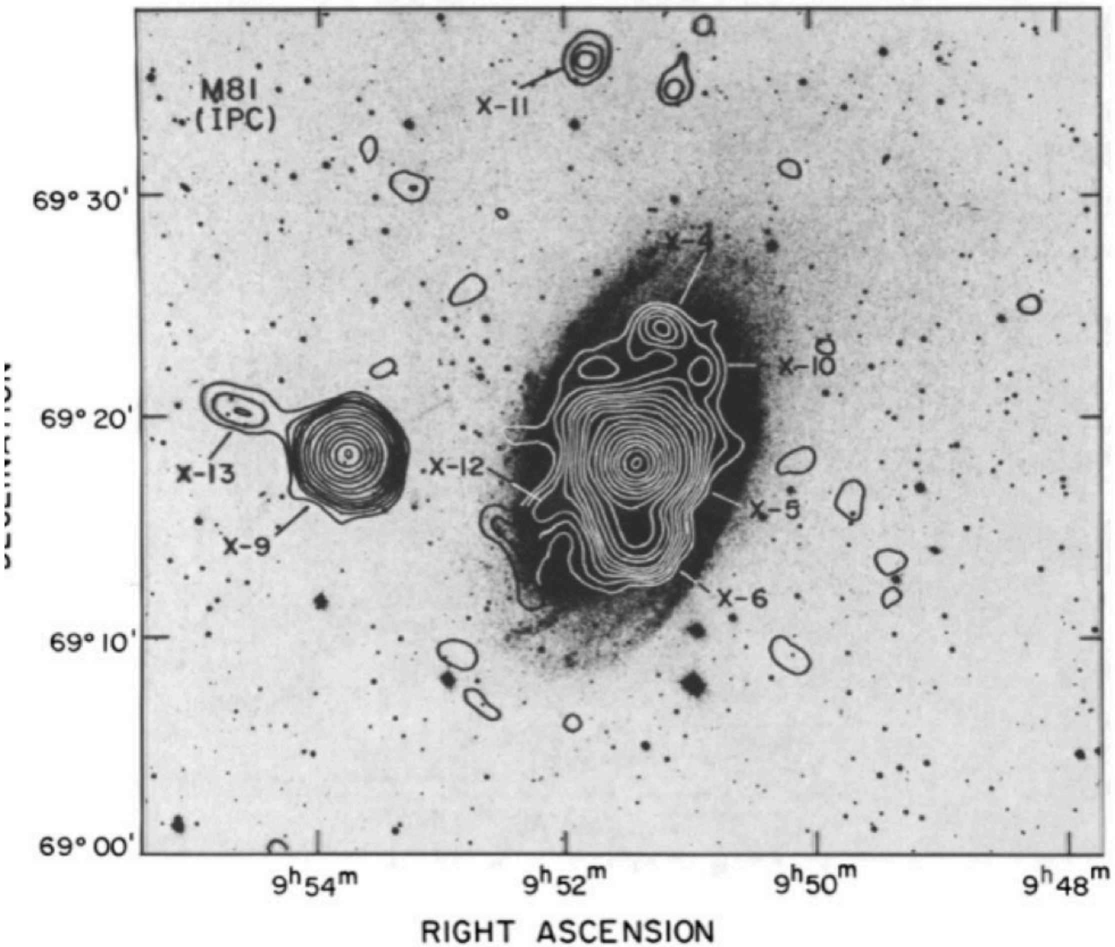

Fig. 2.—IPC contour map of M81 overlaid on the POSS O plate. The first contour is at 2 σ above the field background. Discrete sources detected in the IPC iage are indicated by an X followed by a number. Data were smoothed with a Gaussian with $\sigma_G = 35''$. The equivalent Gaussian sigma of a point source in this map $\sigma_G \sim 57''$.

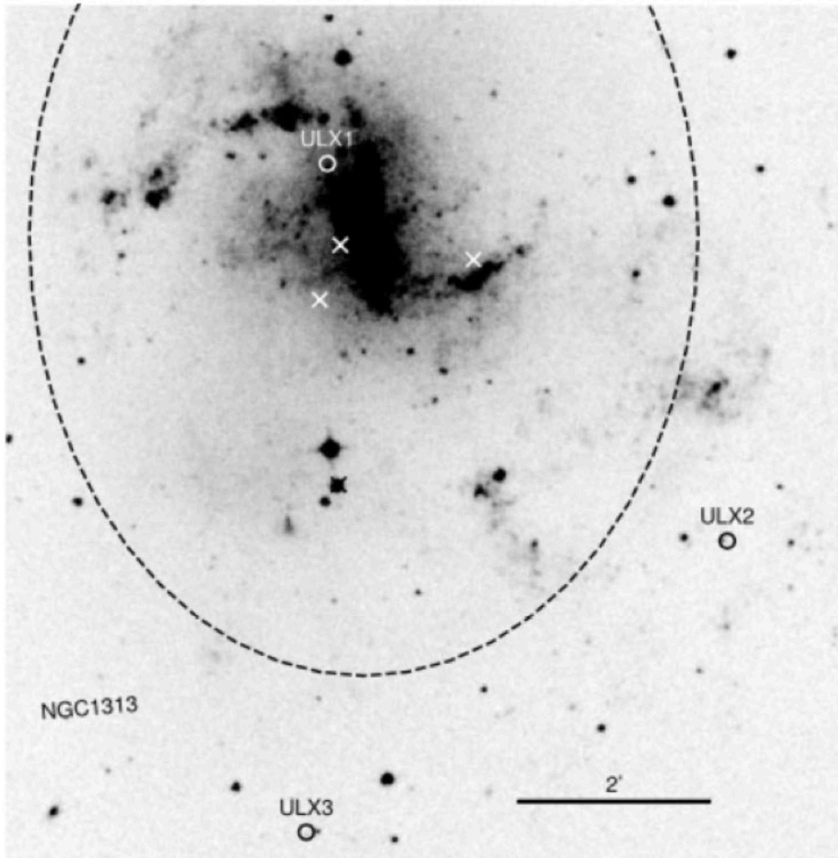

Fig. 23.—Finding chart for the ULXs in NGC 1313.

EINSTEIN - Fabbiano, *ApJ*, **325**, 544–562, 1988. ROSAT - Liu & Bregman, *ApJ*, **642** 171–187, 2006.

ULTRALUMINOUS X-RAY SOURCES IN EXTERNAL GALAXIES

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ABSTRACT

We investigate models for the class of ultraluminous nonnuclear X-ray sources (i.e., ultraluminous compact X-ray sources [ULXs]) seen in a number of galaxies and probably associated with star-forming regions. Models in which the X-ray emission is assumed to be isotropic run into several difficulties. In particular, the formation of sufficient numbers of the required ultramassive black hole X-ray binaries is problematic, and the likely transient behavior of the resulting systems is not in good accord with observation. The assumption of mild X-ray beaming suggests instead that ULXs may represent a short-lived but extremely common stage in the evolution of a wide class of X-ray binaries. The best candidate for this is the phase of thermal-

in many intermediate- and high-mass X-ray binaries. This in turn sugges

The short lifetimes of high-mass X-ray binaries would explain the ass

formation. These considerations still allow the possibility that *individua*

black holes.

[redacted]

Chandra High-Resolution Camera observations of the luminous X-ray source in the starburst galaxy M82

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d 2000 August 30; in original form 2000 August 10

ABSTRACT

We analyse *Chandra* High Resolution Camera observations of the starburst galaxy M82, concentrating on the most luminous X-ray source. We find a position for the source of RA = $09^h55^m50^s.2$, Dec. = $+69°40'46''.7$ (J2000) with a 1σ radial error of 0.7 arcsec. The accurate X-ray position shows that the luminous source is neither at the dynamical centre of M82 nor coincident with any suggested radio AGN candidate. The source is highly variable between observations, which suggests that it is a compact object and not a supernova or remnant. There is no significant short-term variability within the observations. Dynamical friction and the off-centre position place an upper bound of 10^5–$10^6\,M_\odot$ on the mass of the object, depending on its age. The X-ray luminosity suggests a compact object mass of at least $500\,M_\odot$. Thus the luminous source in M82 may represent a new class of compact object with a mass intermediate between those of stellar-mass black hole candidates and supermassive black holes.

SUPER-EDDINGTON FLUXES FROM THIN ACCRETION DISKS?

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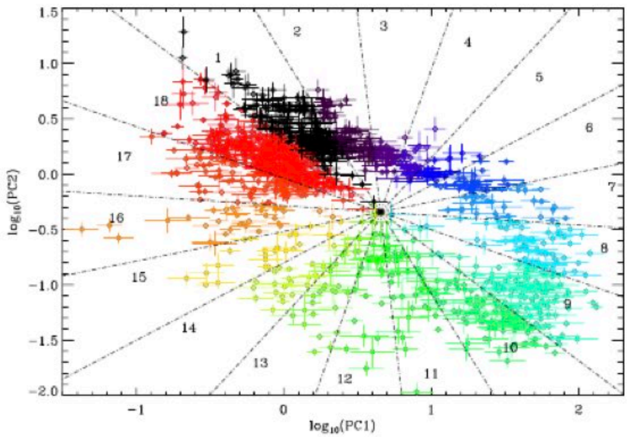
ABSTRACT

Radiation pressure–dominated accretion disks are predicted to exhibit strong density inhomogeneities on scales much smaller than the disk scale height as a result of the nonlinear development of photon-bubble instability. Radiation would escape from such a "leaky" disk at a rate higher than that predicted by standard accretion disk theory. The disk scale height is then smaller than that of a similar disk without small-scale inhomogeneities, and the disk can remain geometrically thin even as the flux approaches and exceeds the Eddington limit. An idealized one-zone model for disks with radiation-driven inhomogeneities suggests that the escaping flux could exceed $L_{\rm Edd}$ by a factor of up to ~10–100, depending on the mass of the central object. Such luminous disks would develop strong mass loss, but the resulting decrease in accretion rate would not necessarily prevent the luminosity from exceeding $L_{\rm Edd}$. We suggest that the observed "ultraluminous X-ray sources" are actually thin, super-

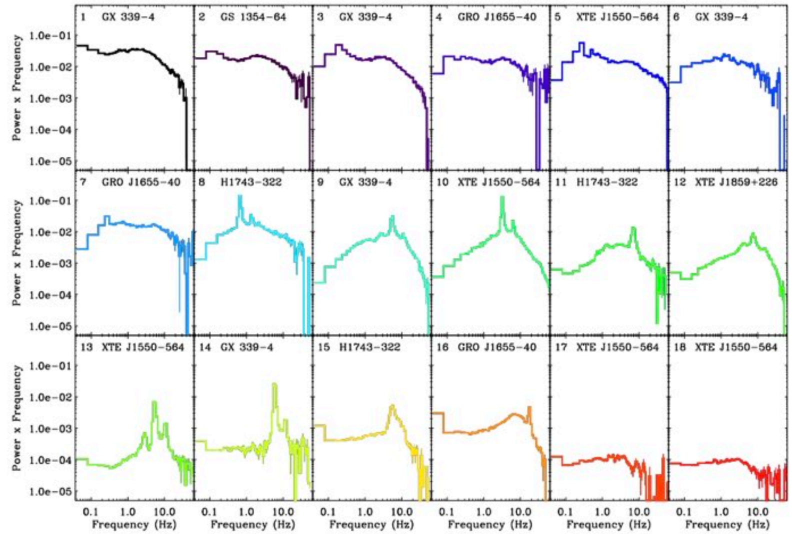
Intermediate mass black holes?

Credits: NASA/JPL

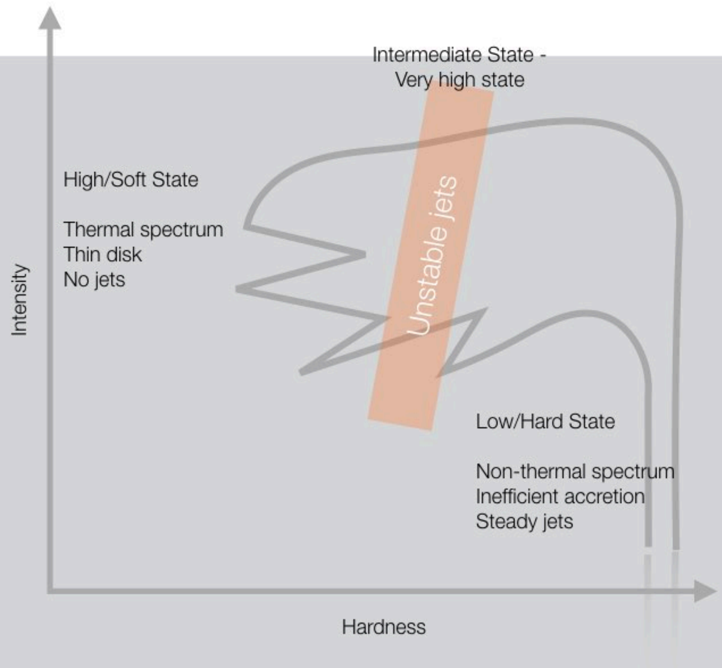
Population III large StBH, seeds for SMBHs: Madau & Rees, *ApJ* **551**, L27–L30 (2001).

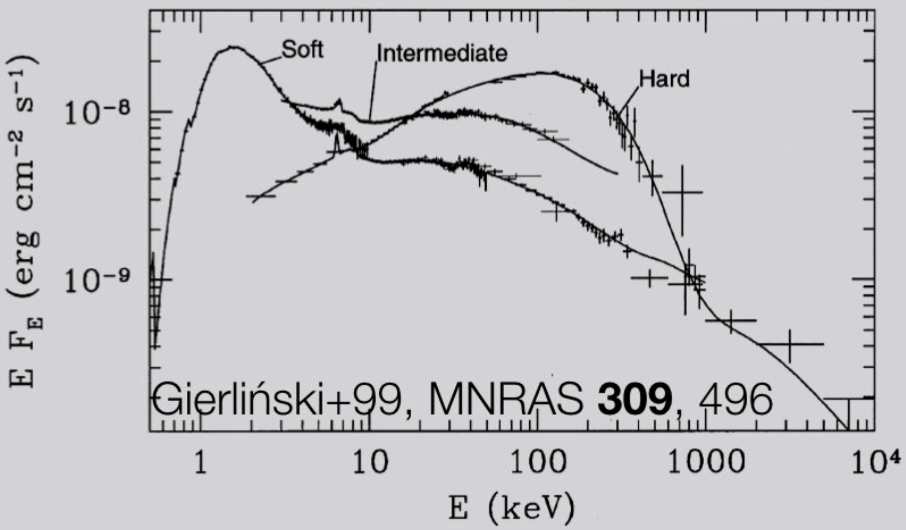


Heil, Uttley, & Klein-Wolt, *MNRAS* **448**, 3339–3347, 2015.



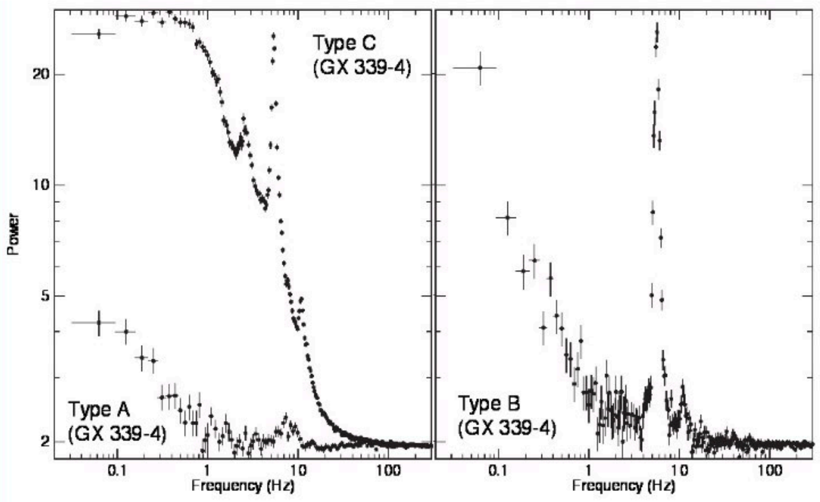
VARIABILITY

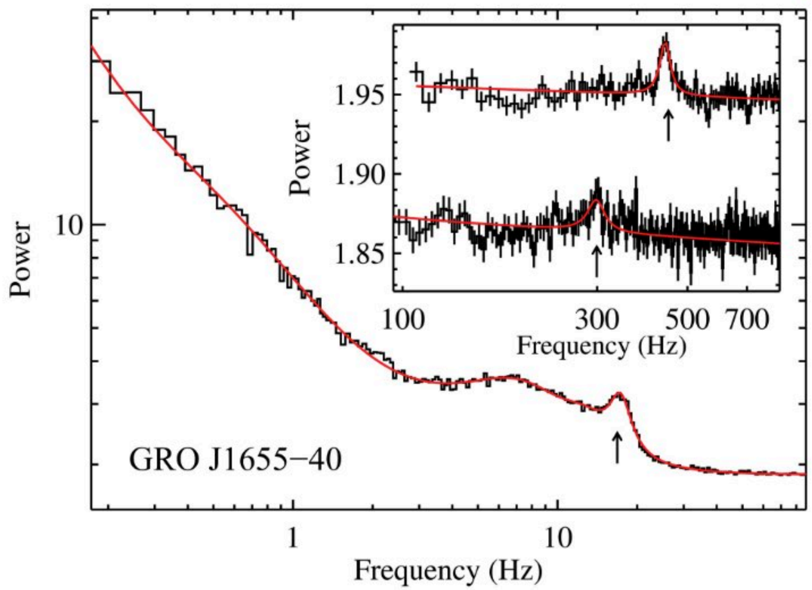


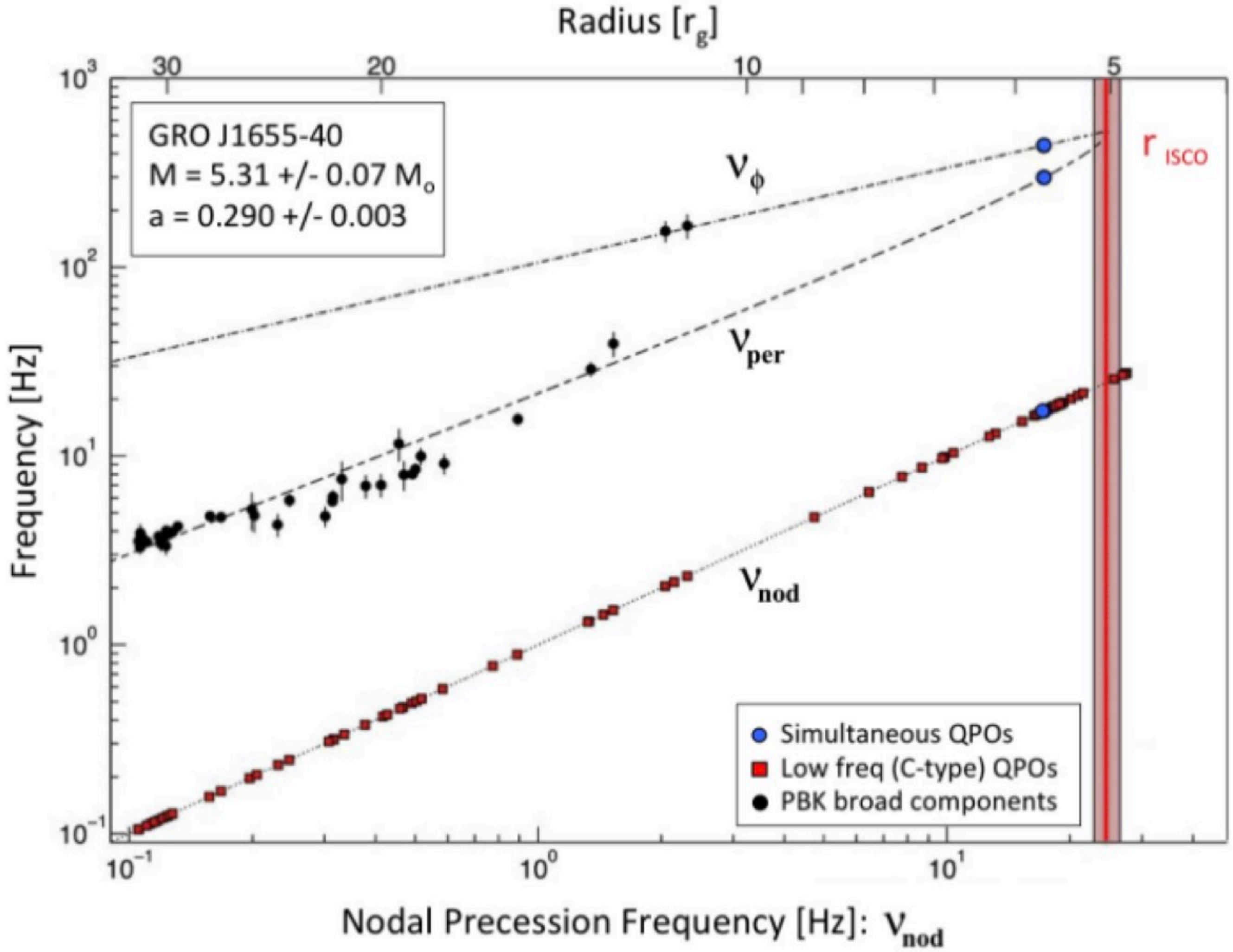


Gierliński+99, MNRAS **309**, 496

SPECTRA



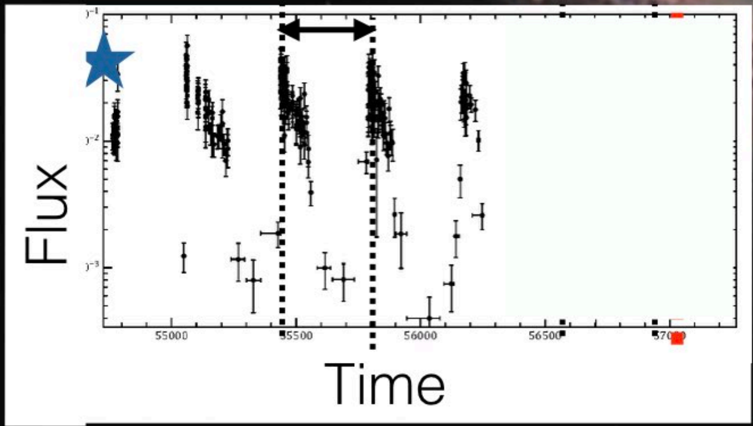




Quasi Periodic Oscillations

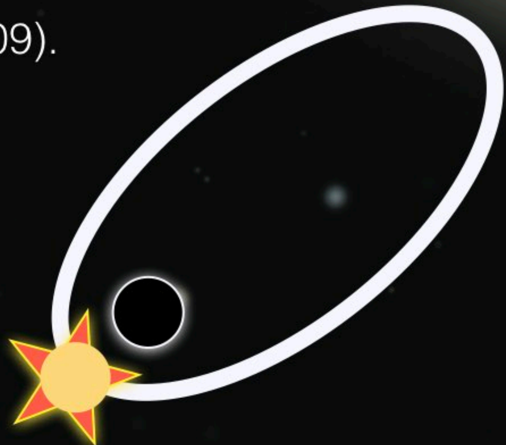
Motta+11,14; review: Belloni+*14,* Space Sci.Rev. **183**, 43-60

ESO 243-49 HLX-1



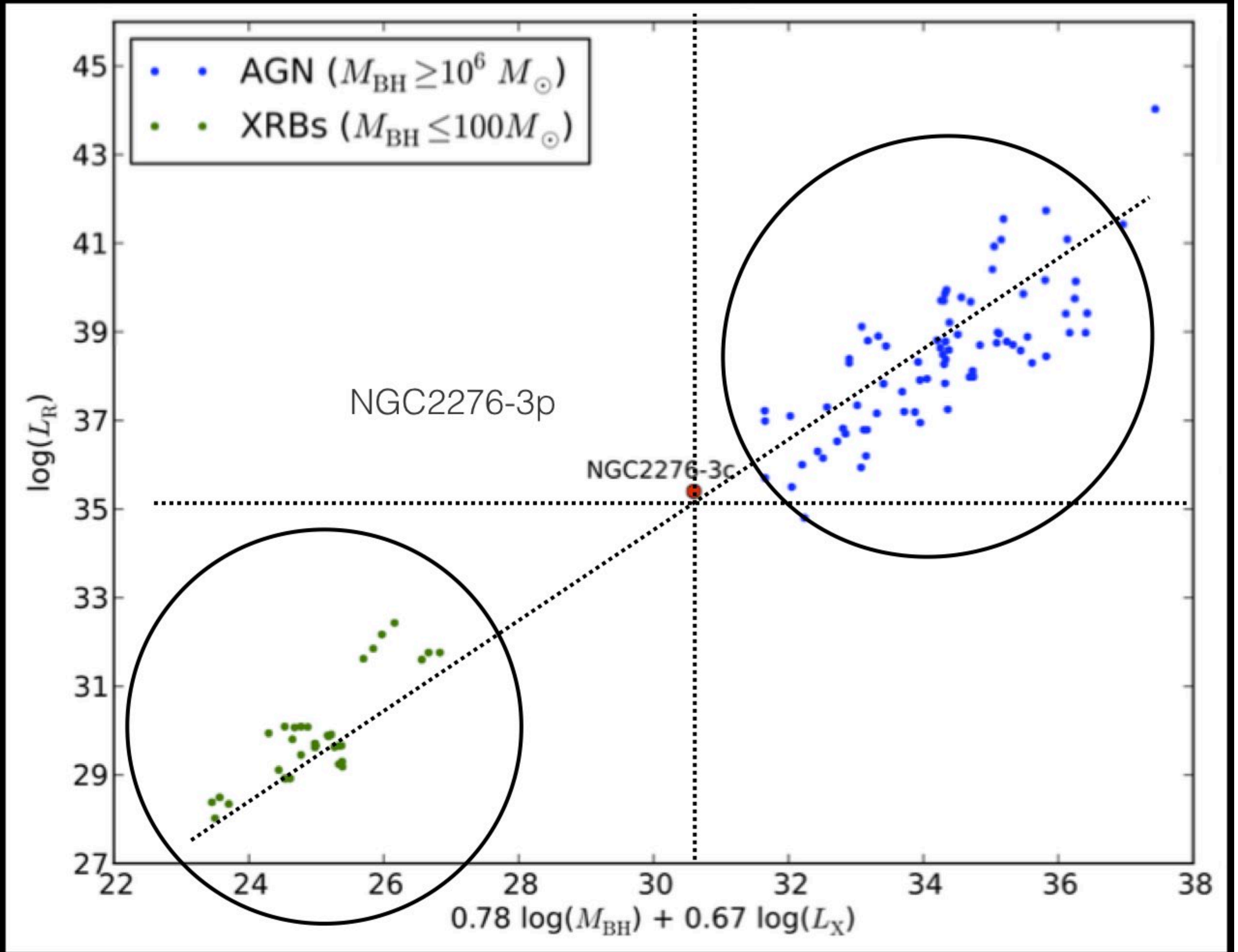
Farrell et al. *Nat.* **460**, 73–75 (2009).
Lasota et al. *ApJ* **735,** 89 (2011).
Servillat et al. *ApJ* **743,** 6 (2011).

Delay?
Godet et al. *ApJ* **793**, 105 (2014).
van der Helm, et al. *MNRAS* **455**, 462, 2016.

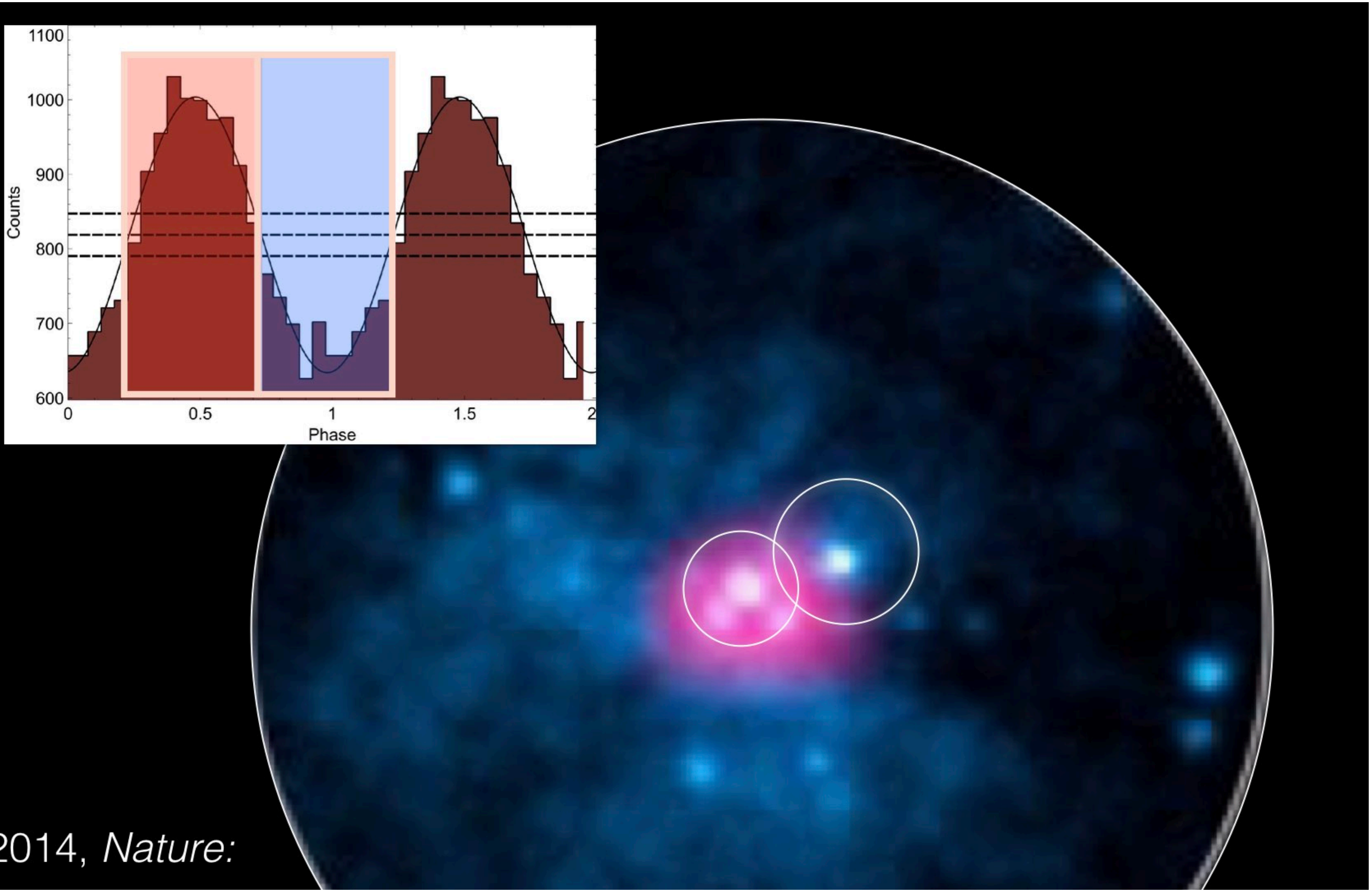


- $L > 10^{42}$ erg/s
- Spectral states comparable to standard BHs
- Best IMBH candidate (alternative interpretation: King & Lasota, *MNRAS Let.* **444,** L30–L33 (2014).)

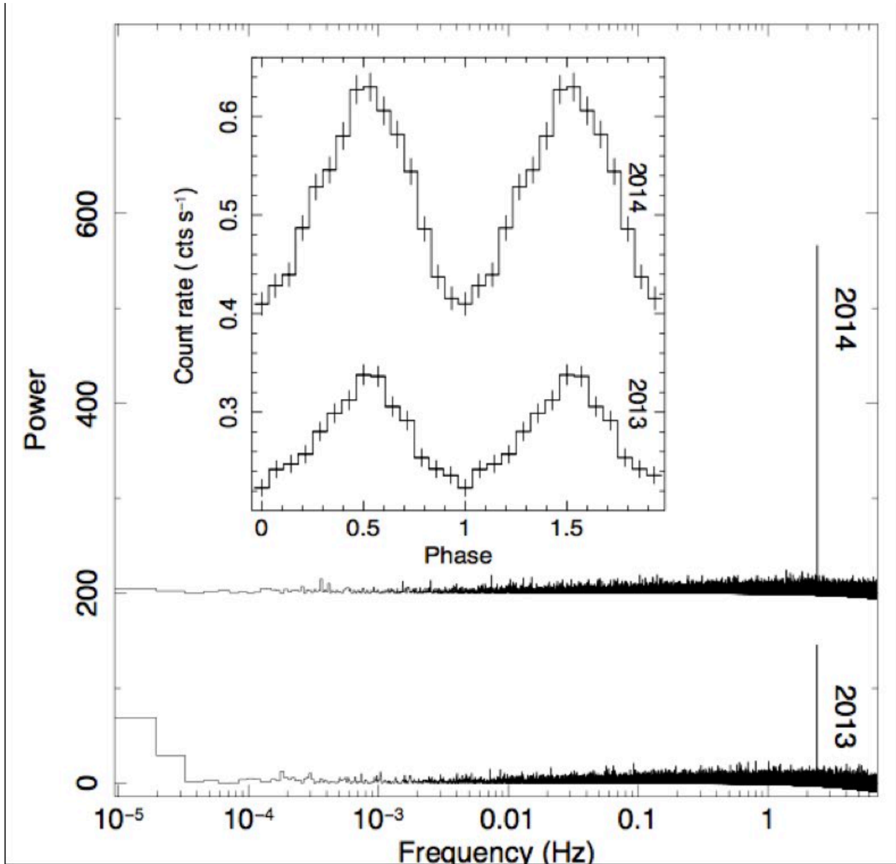
Mezcua+15, *MNRAS* **448**, 1893

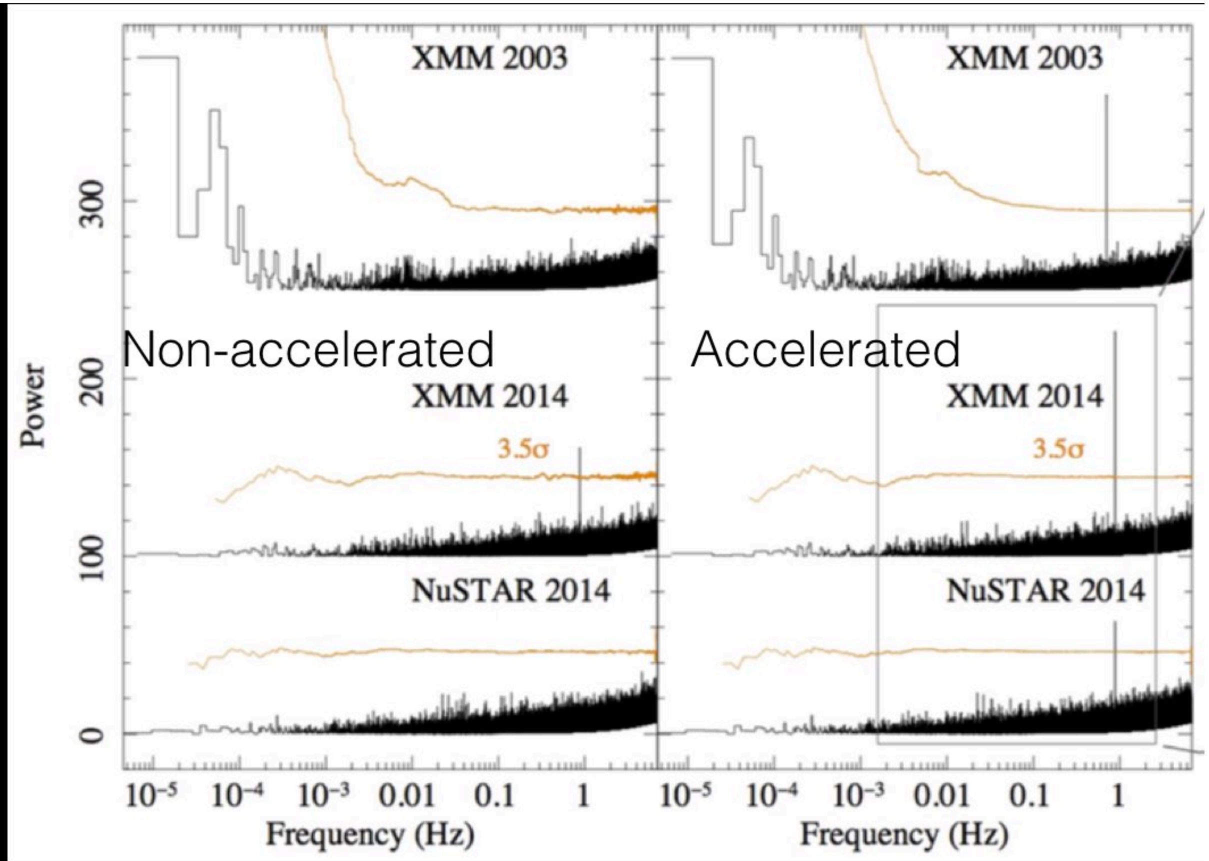


These are certainly super-Eddington ——> click here



MB+2014, *Nature:*



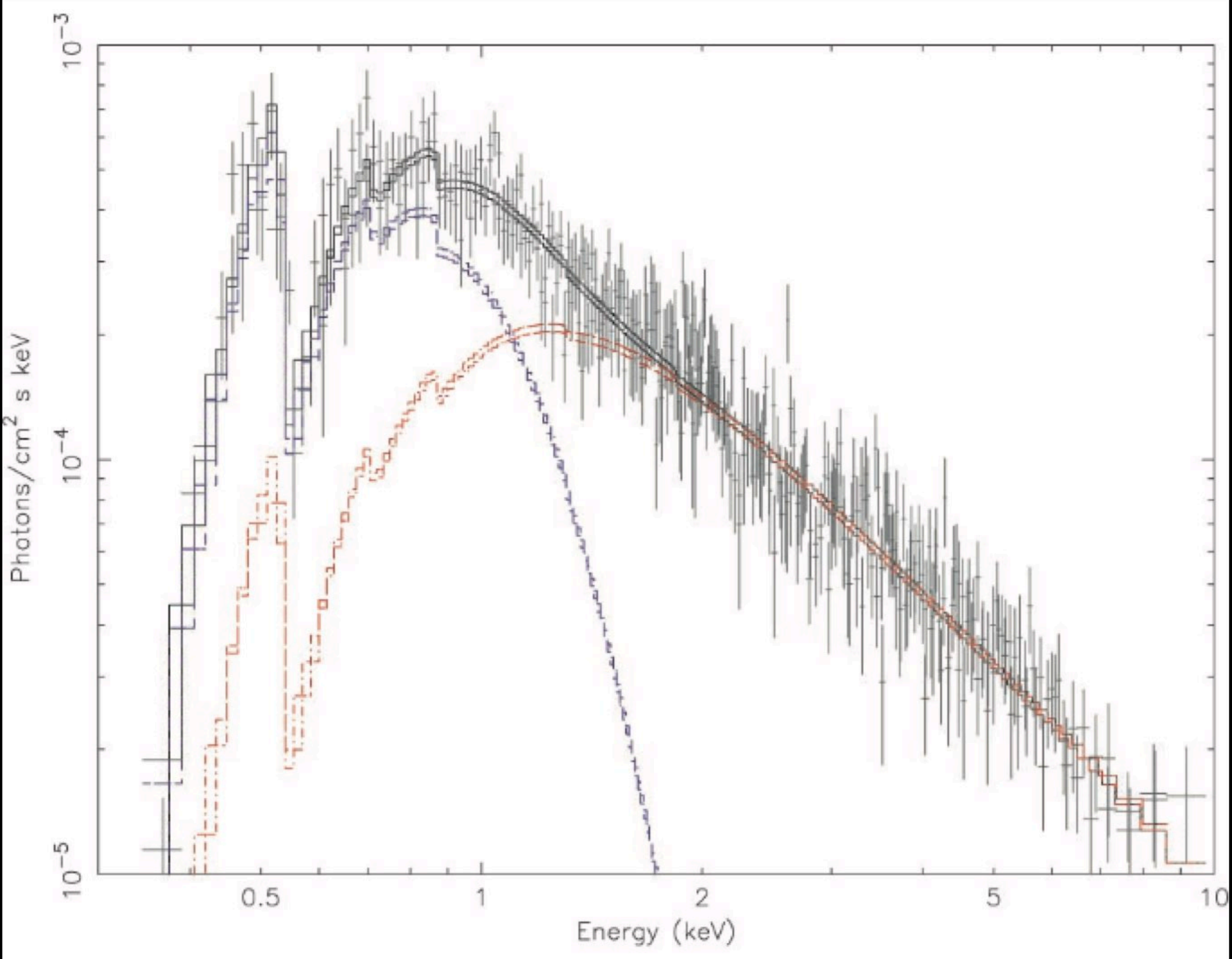


Israel et al.,
Science, 2017
MNRAS 466, 48I 2017

Fürst et al. 2016, *ApJ*

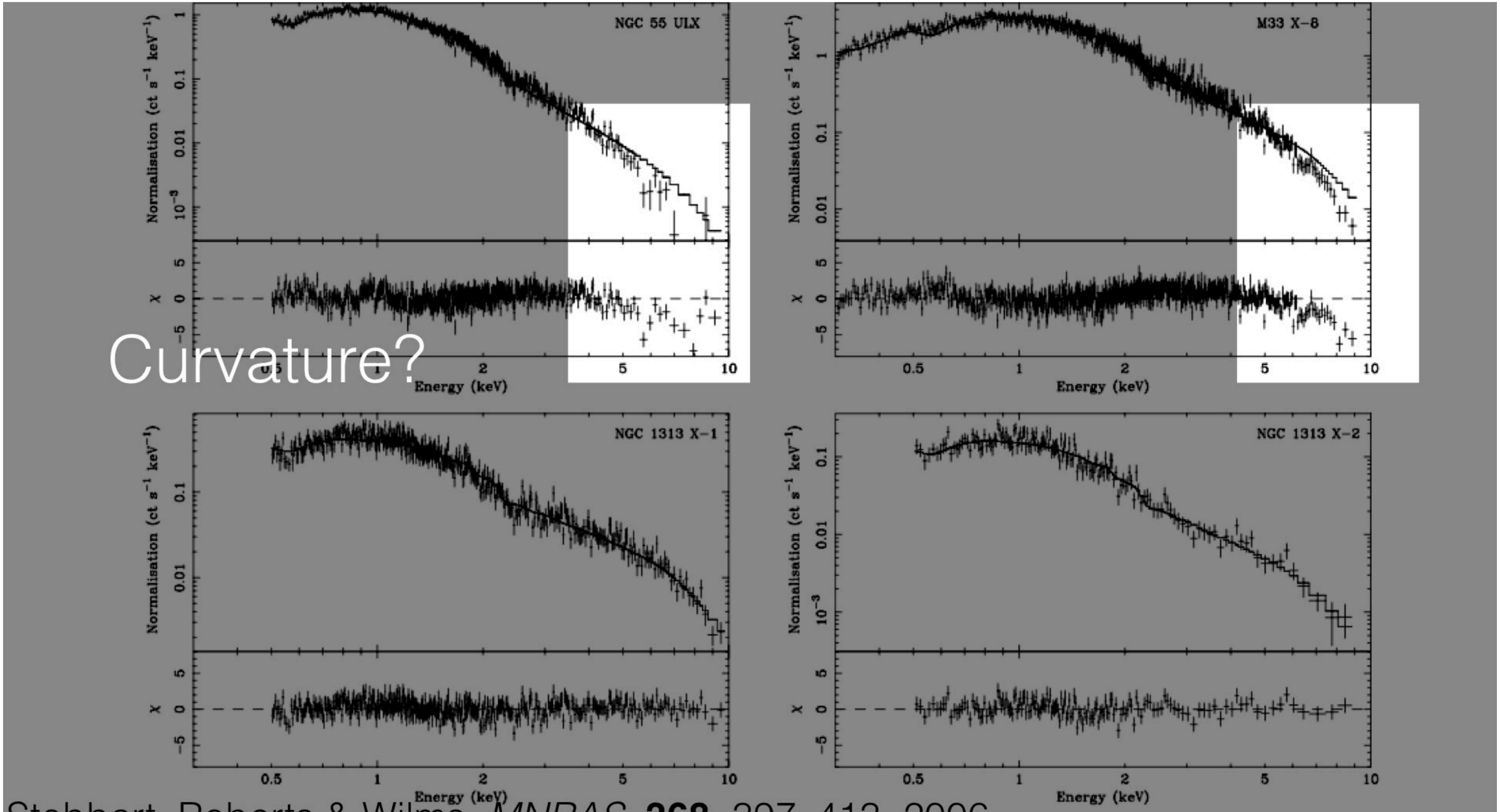
What about the bulk of ULXs?

(Cool) disk + powerlaw?



In Multicolor-disk models,
T ~ $M^{-1/4}$

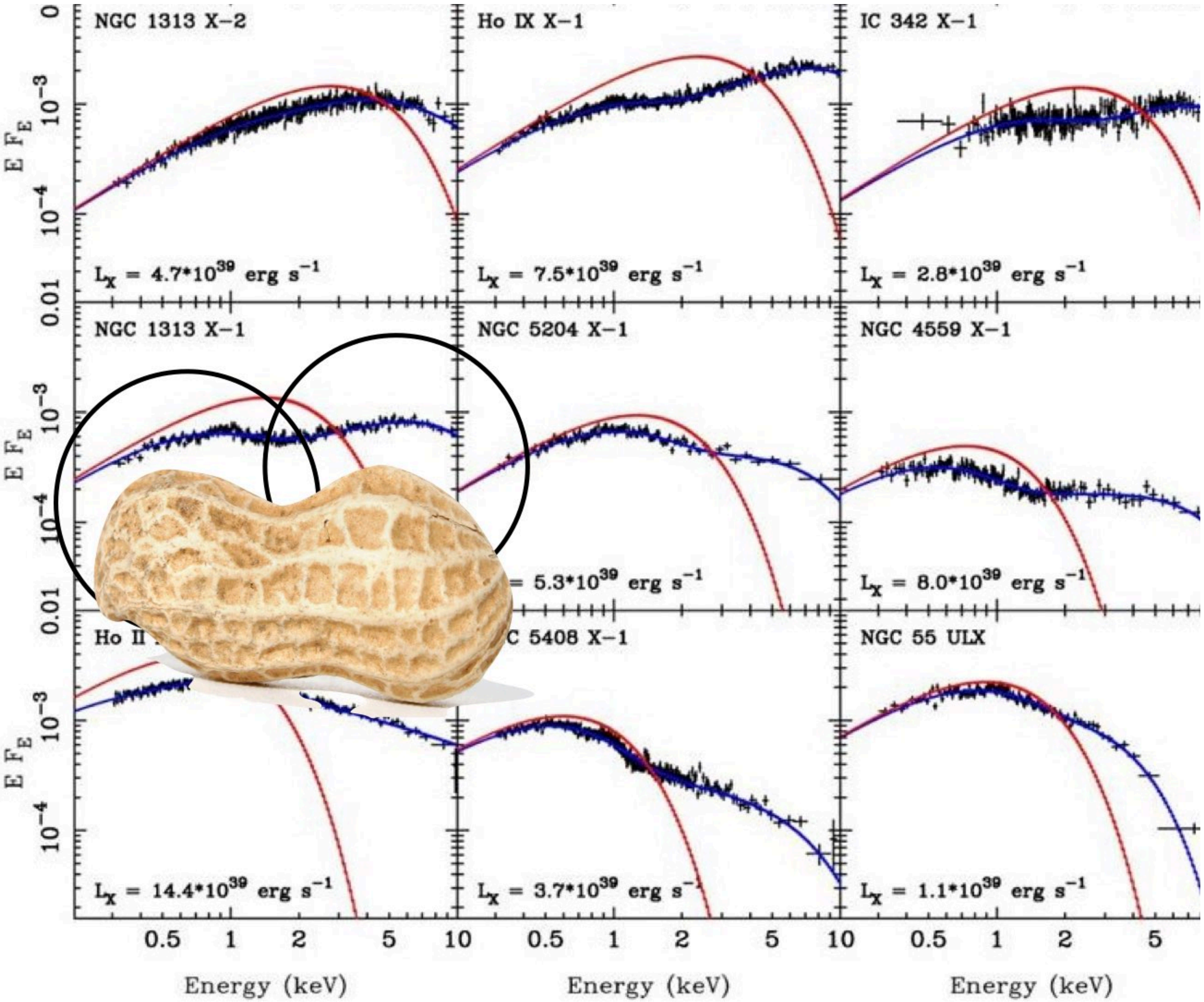
So, 1 keV -> 0.2 keV means a factor 625 in mass!
Miller et al., *ApJ* **585**, L37–L40, 2003.



Stobbart, Roberts & Wilms, *MNRAS*, **368**, 397–413, 2006.

Curvature.

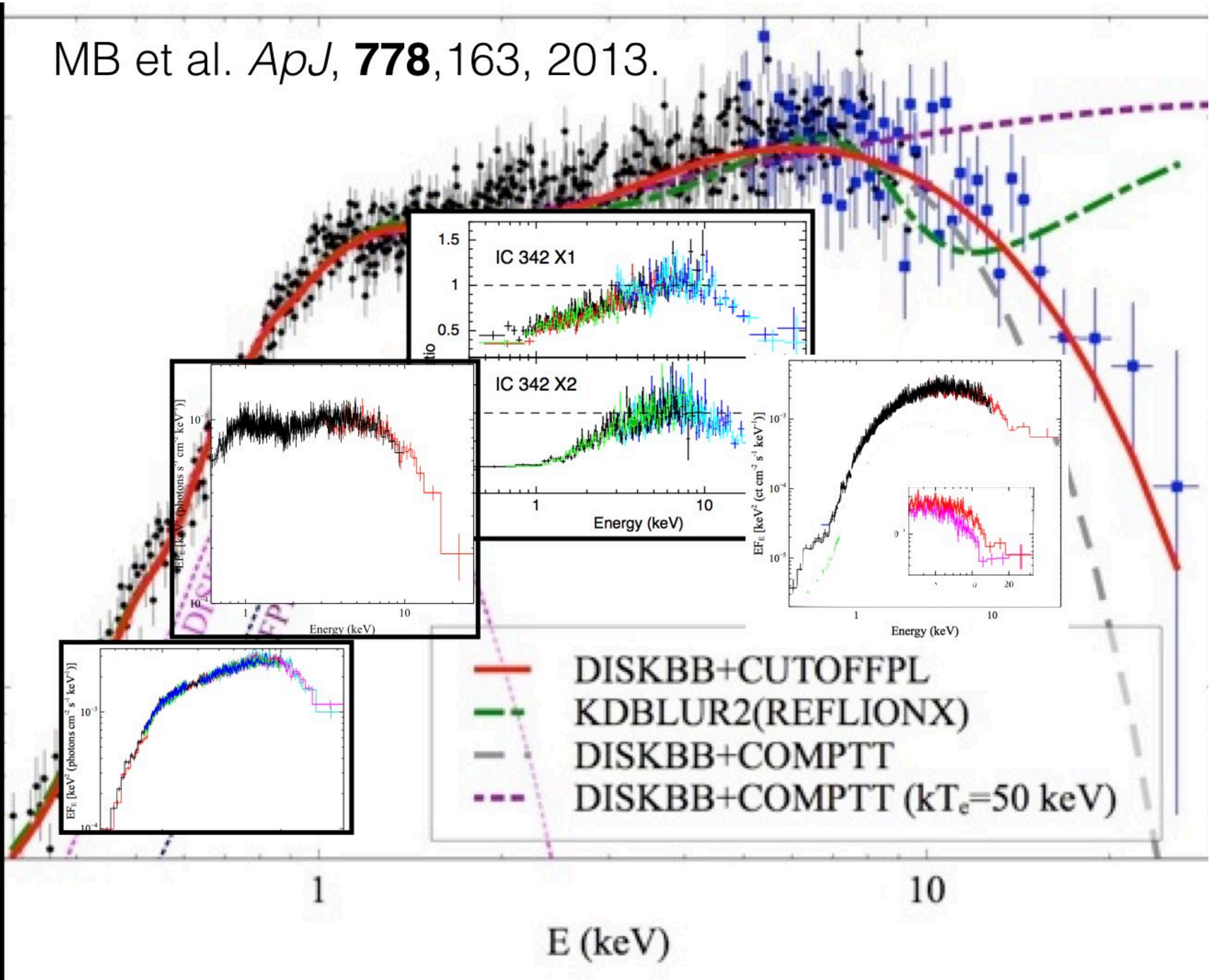
Gladstone et al., *MNRAS*, **397**, 1836–1851, 2009.



Curvature!

NuSTAR: above 10 keV, ULX spectra invariably fall down

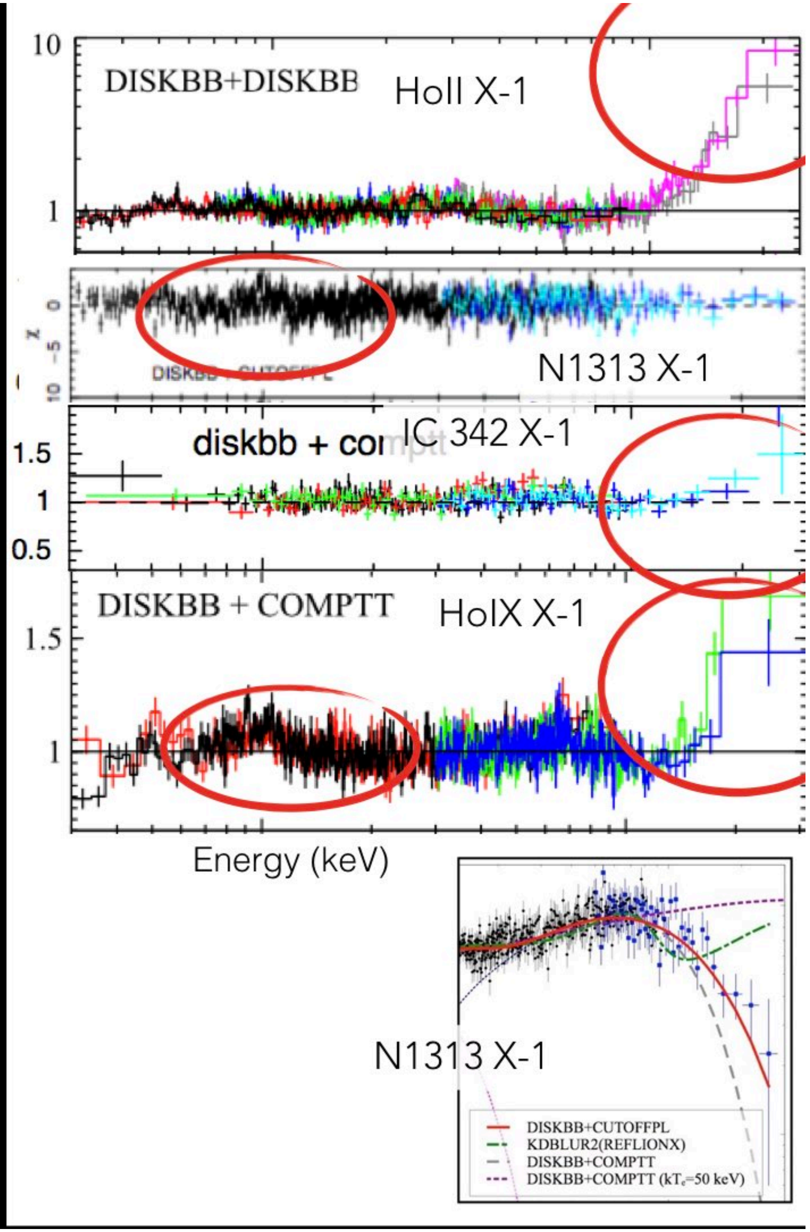
MB+ *ApJ* **778**, 163 (2013).
Walton+ *ApJ* **779**, 148 (2013).
Walton+ *ApJ* **793**, 21 (2014).
Rana+ *ApJ* **799**, 121 (2015).
Walton+ *ApJ* **799**, 122 (2015).
Walton+ *ApJ* **806,** 65 (2015)
(…)



A life of excess

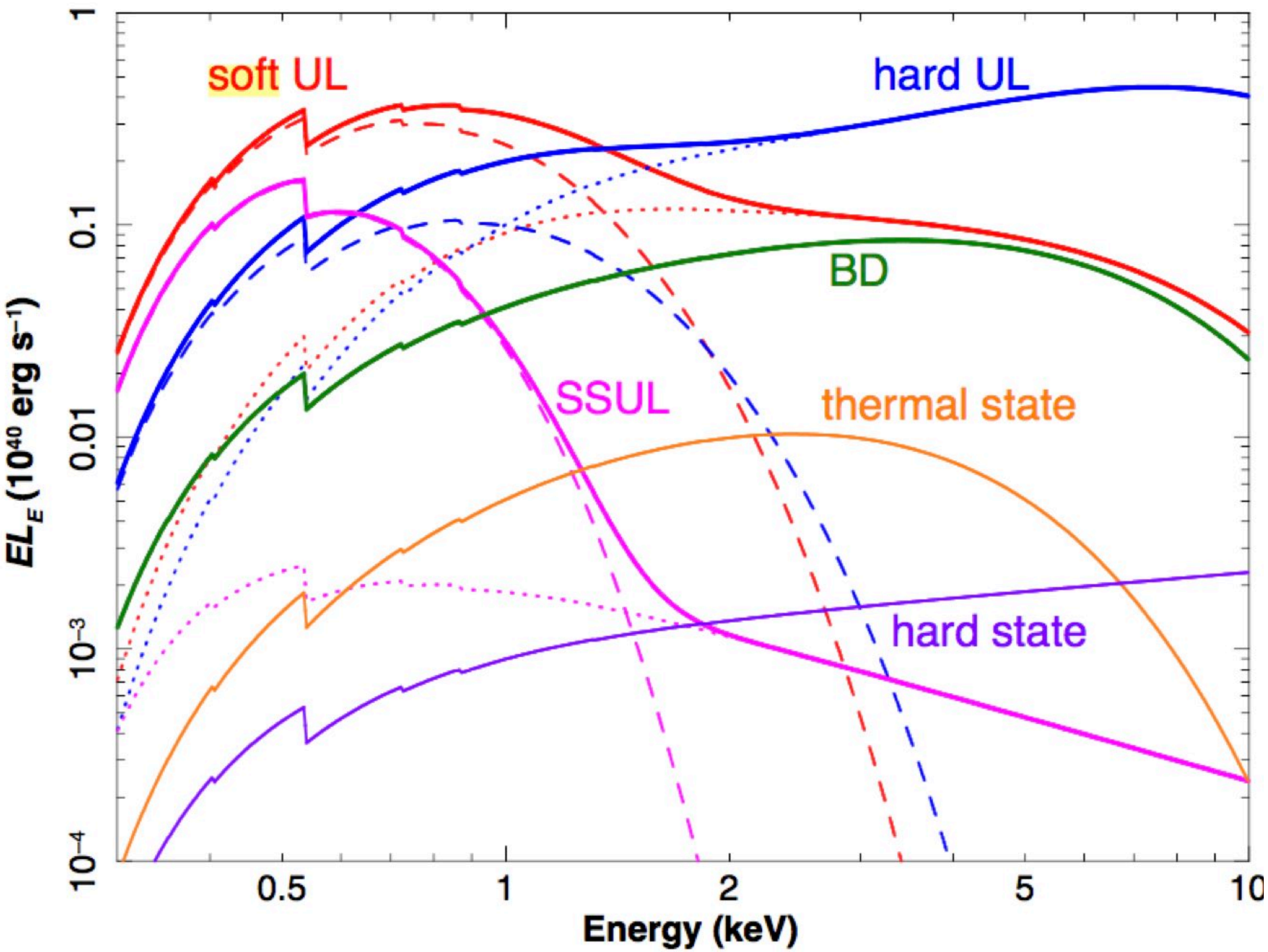
Taking a two-component model as a reference, ULXs show a hard excess (start of a powerlaw?) and a 1-keV excess (discuss later)

MB+ *ApJ* **778**, 163 (2013).
Walton+ *ApJ* **779**, 148 (2013).
Walton+ *ApJ* **793**, 21 (2014).
Rana+ *ApJ* **799**, 121 (2015).
Walton+*ApJ* **799**, 122 (2015).
Walton+ *ApJ* **806,** 65 (2015)
(…)

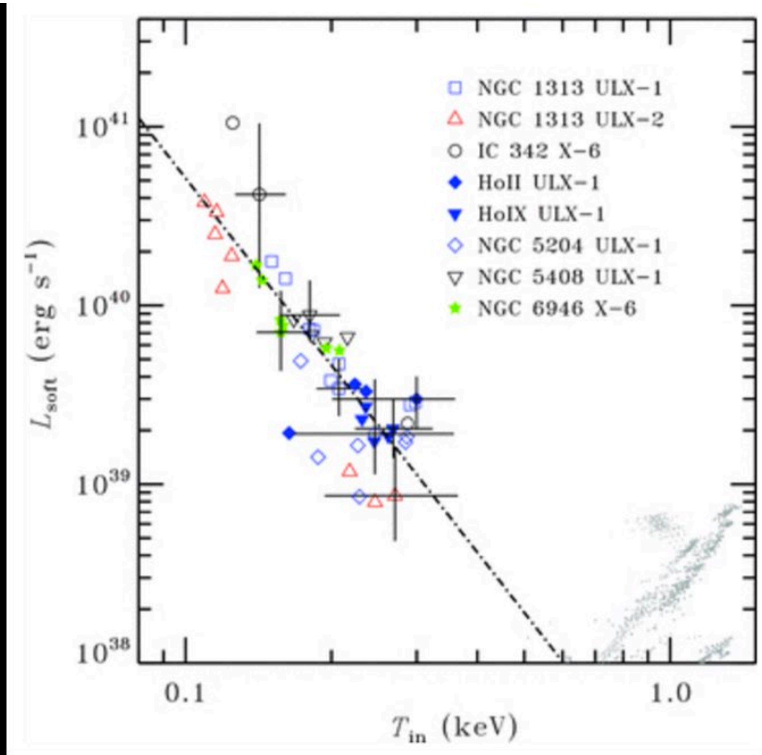


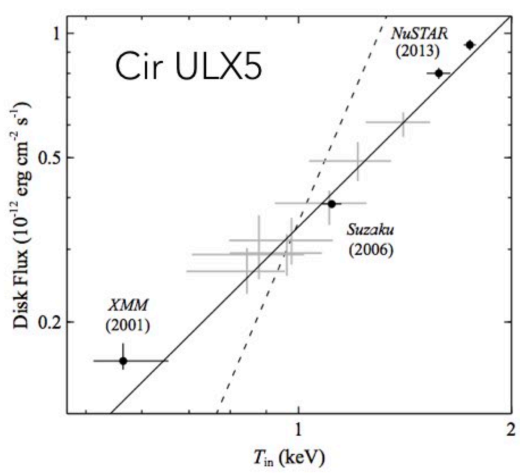
ULX spectra at a glance (compared to BHBs)

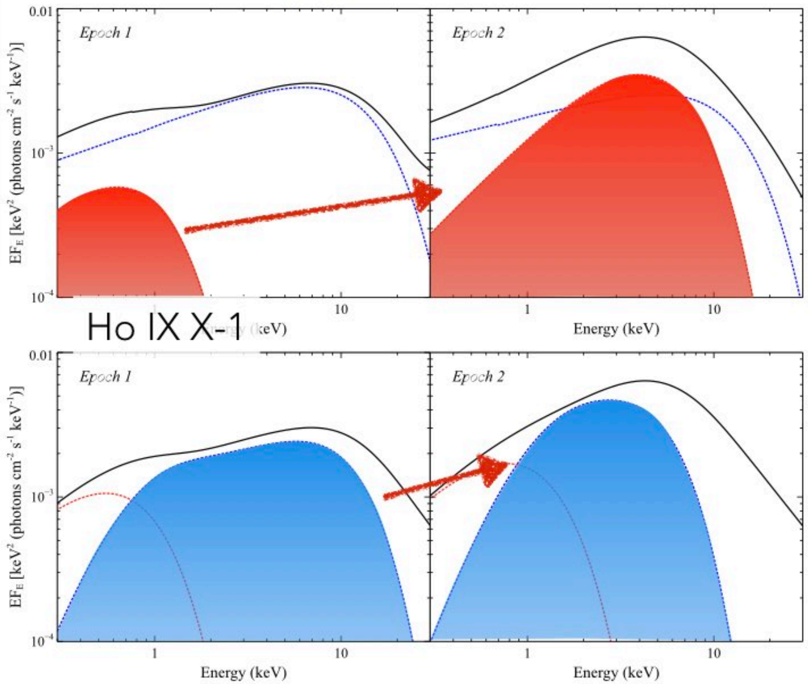
Kaaret, Feng, & Roberts, arXiv:1703.10728



Kajava & Poutanen, *MNRAS*, **398**, 1450–1460 2009.







No standard disks

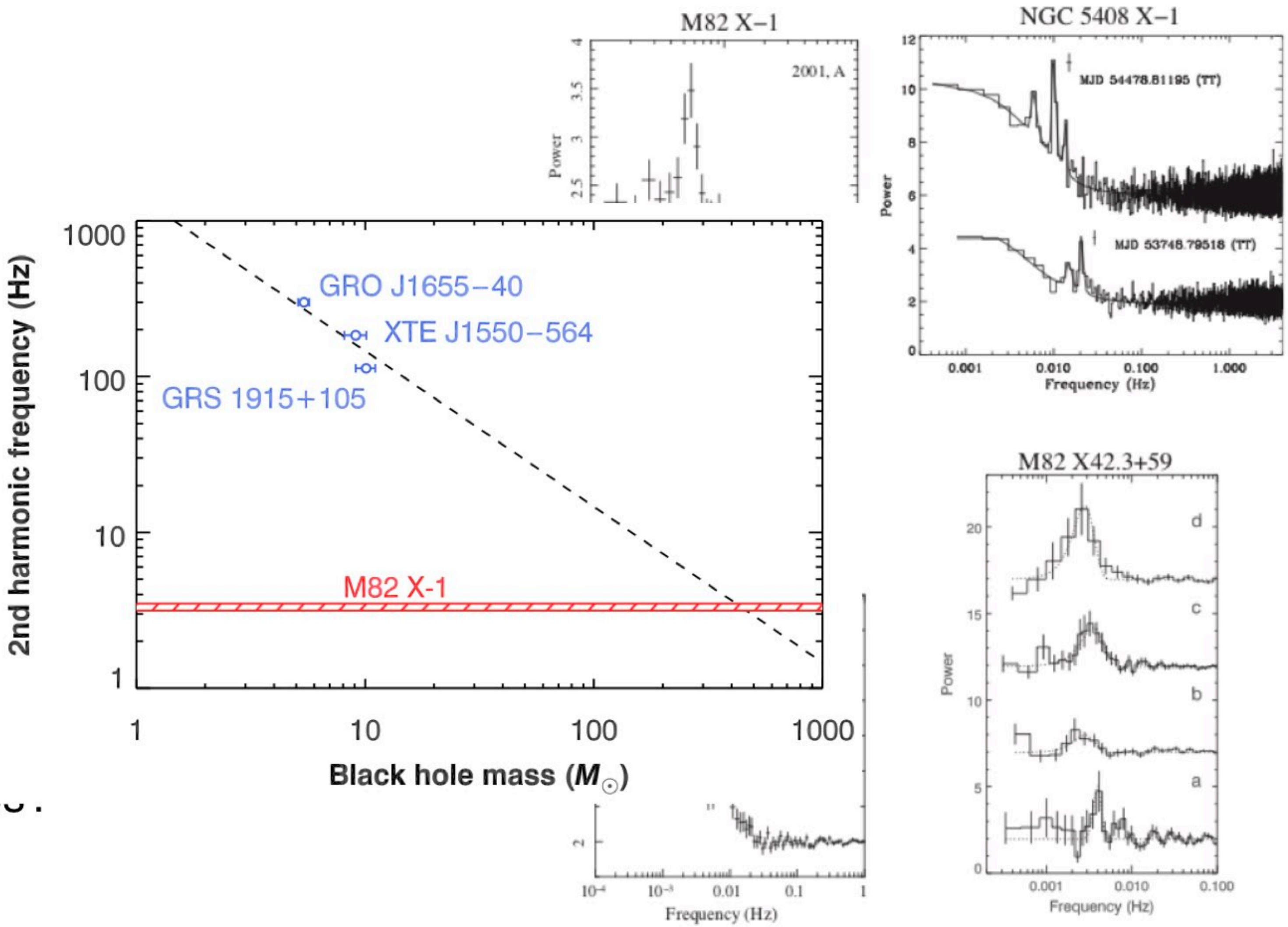
Walton+ *ApJ* **779**, 148 (2013).
Walton+ *ApJ* **793**, 21 (2014).

Variability

Quasi-peri oscillations

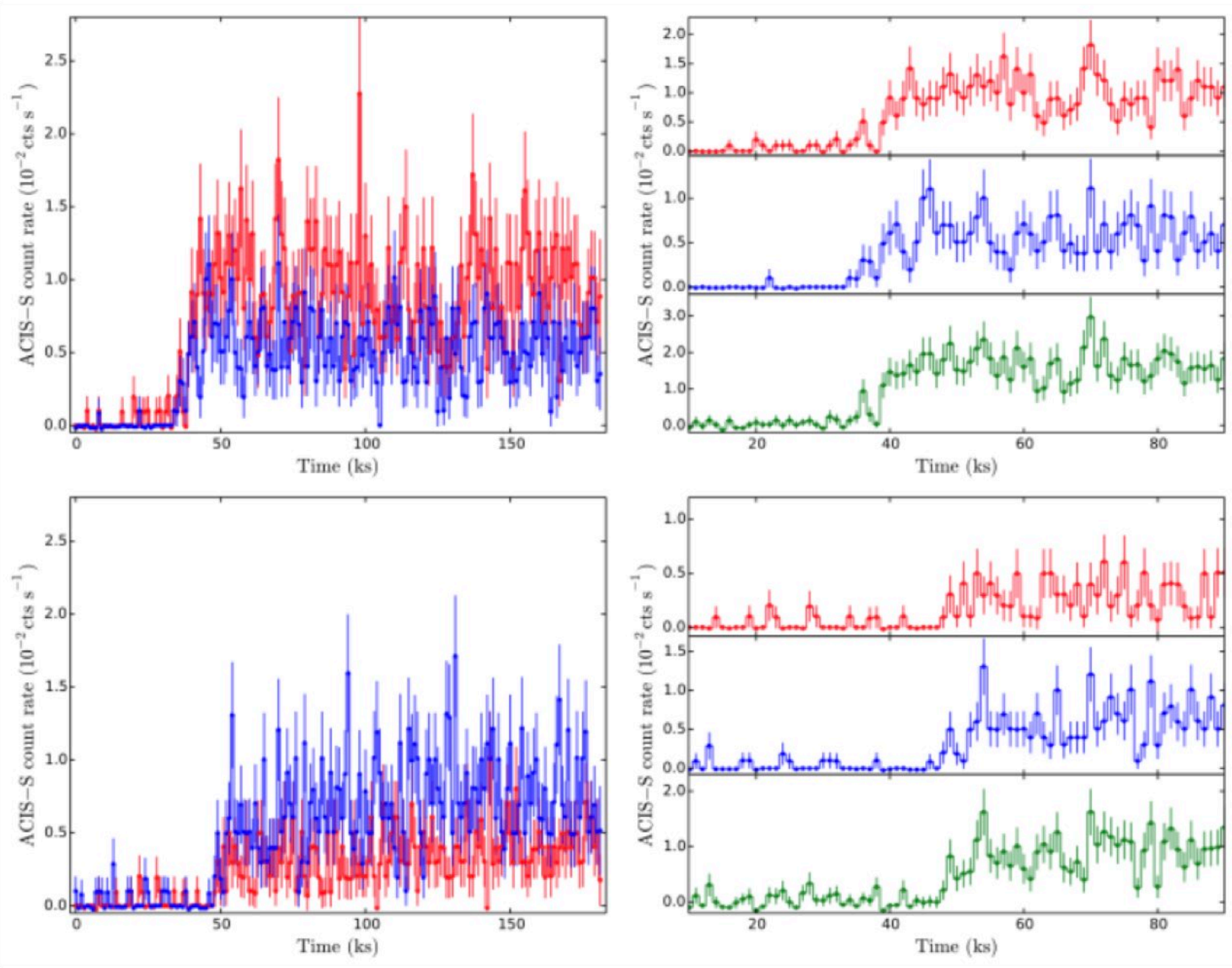
Only a few ULXs sl variability. The two QPOs

Type A, B, C, HF?
Mass scaling studie



Feng & Soria, New Astronomy Reviews, 2011

Eclipses in M51: two birds with a stone



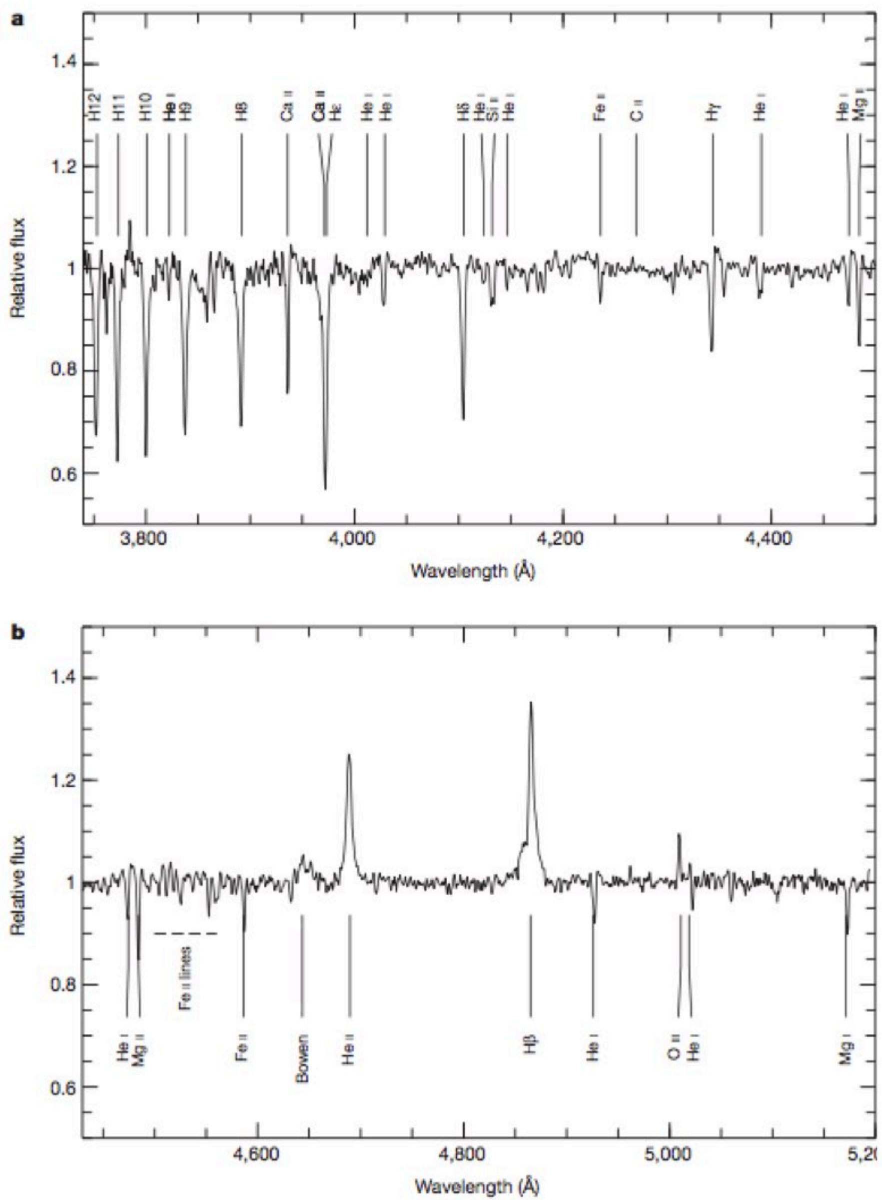
Urquhart & Soria, *ApJ*, **831**, 56, 2016.

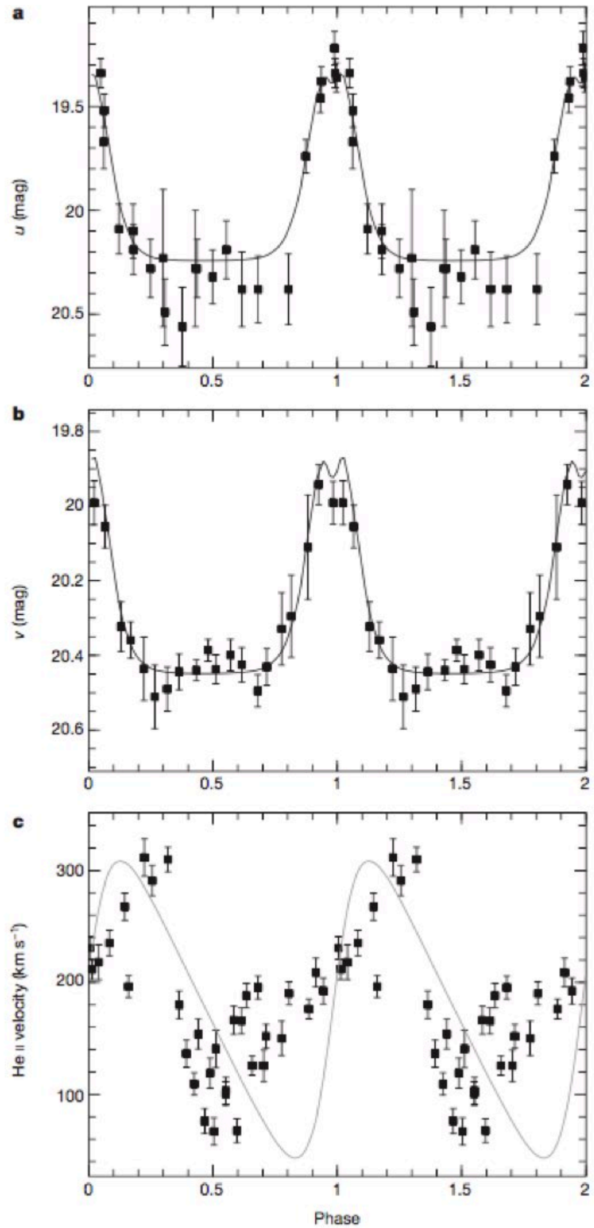
Orbital periods?

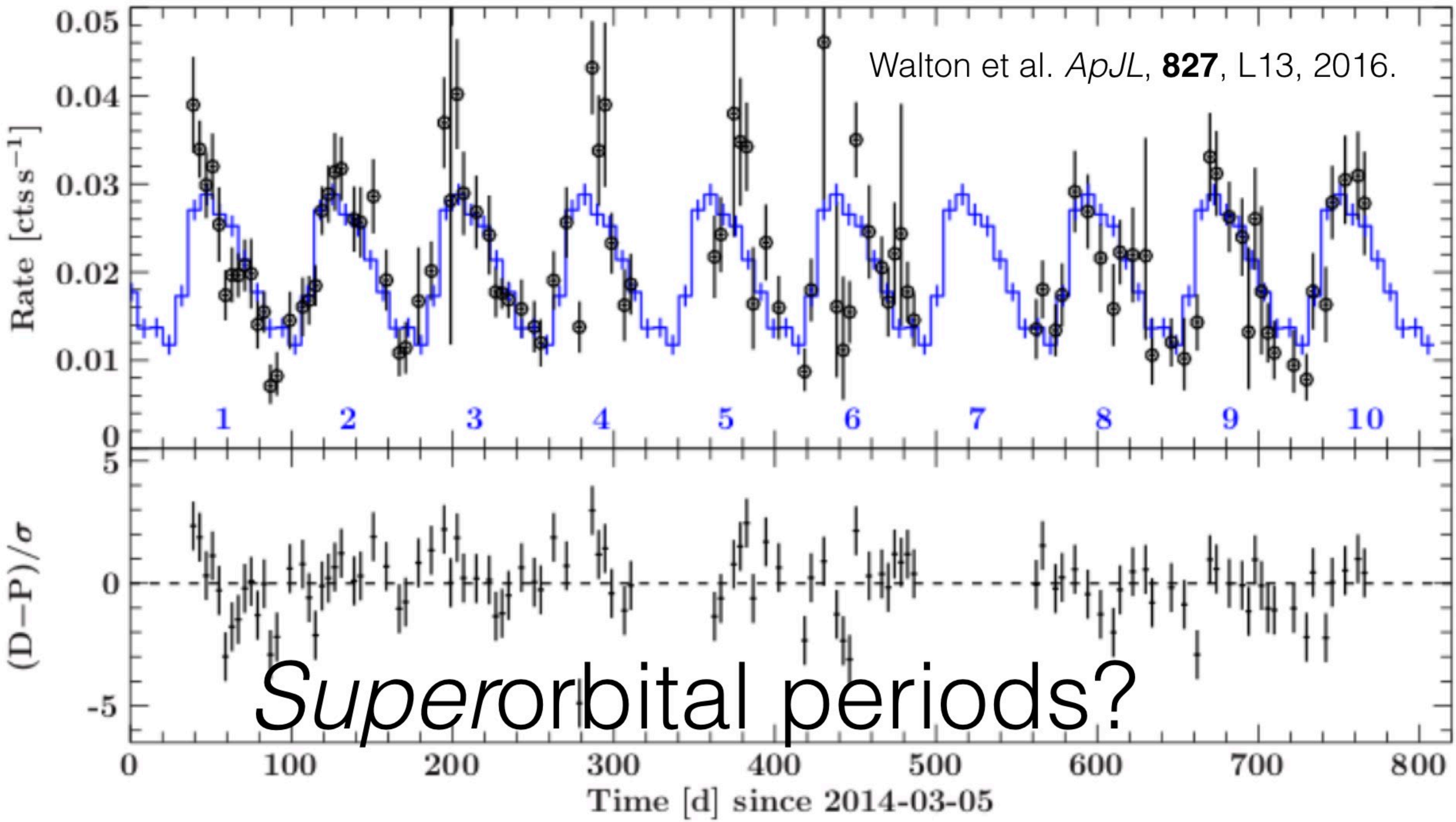
Motch et al. *Nat.*, **514**, 198–201, 2014:

“64-d orbit with B9 supergiant companion”

But see Fabrika et al. *Nature Physics*, **11**, 551–553, 2015.

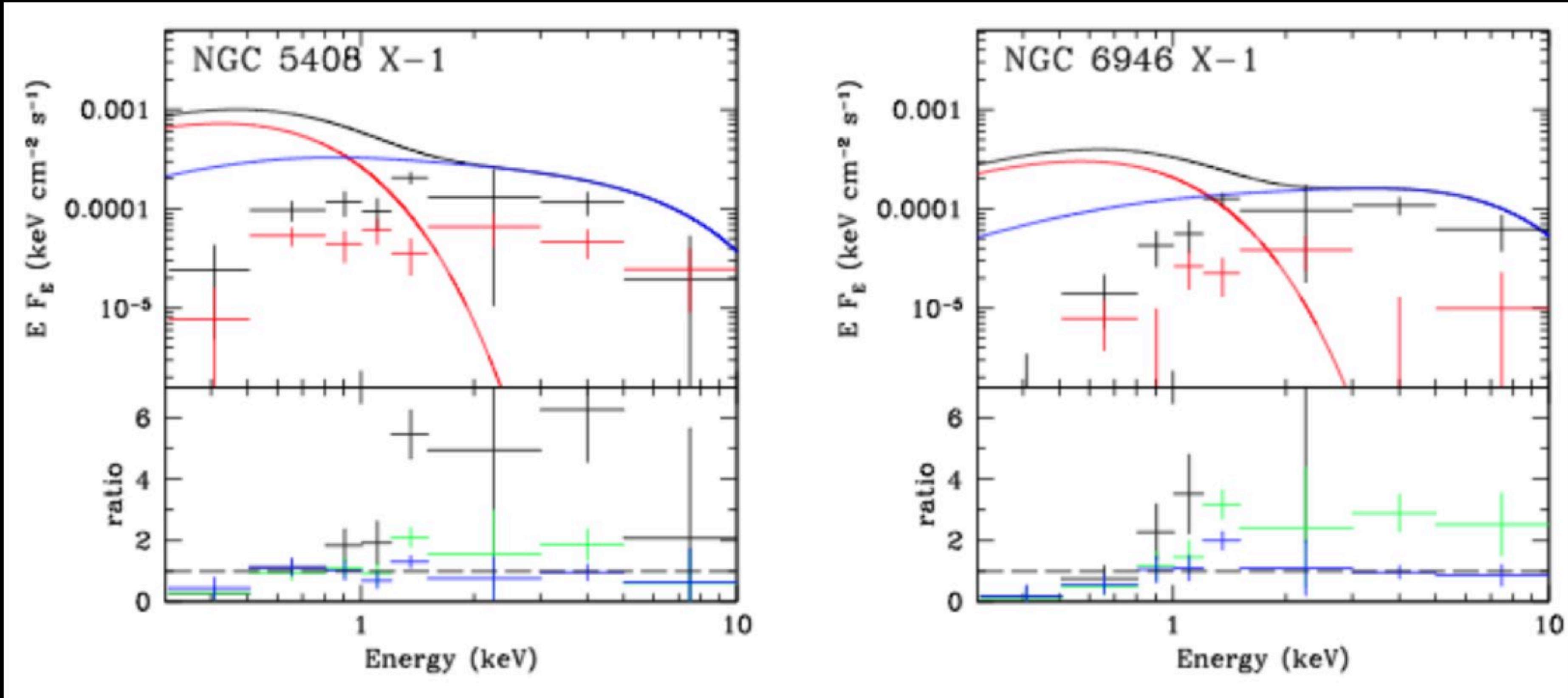






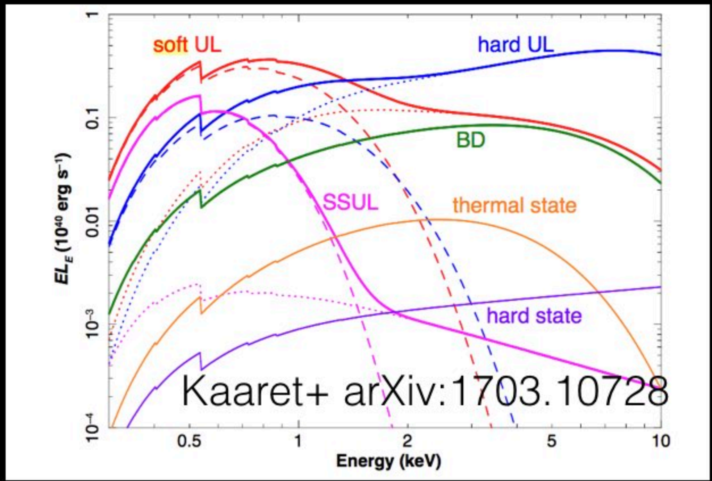
Walton et al. *ApJL*, **827**, L13, 2016.

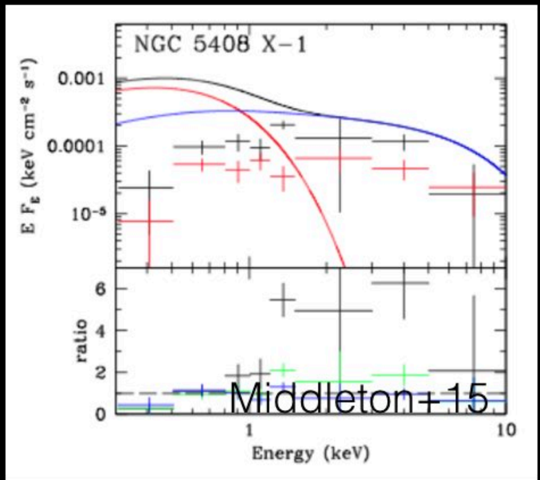
*Super*orbital periods?

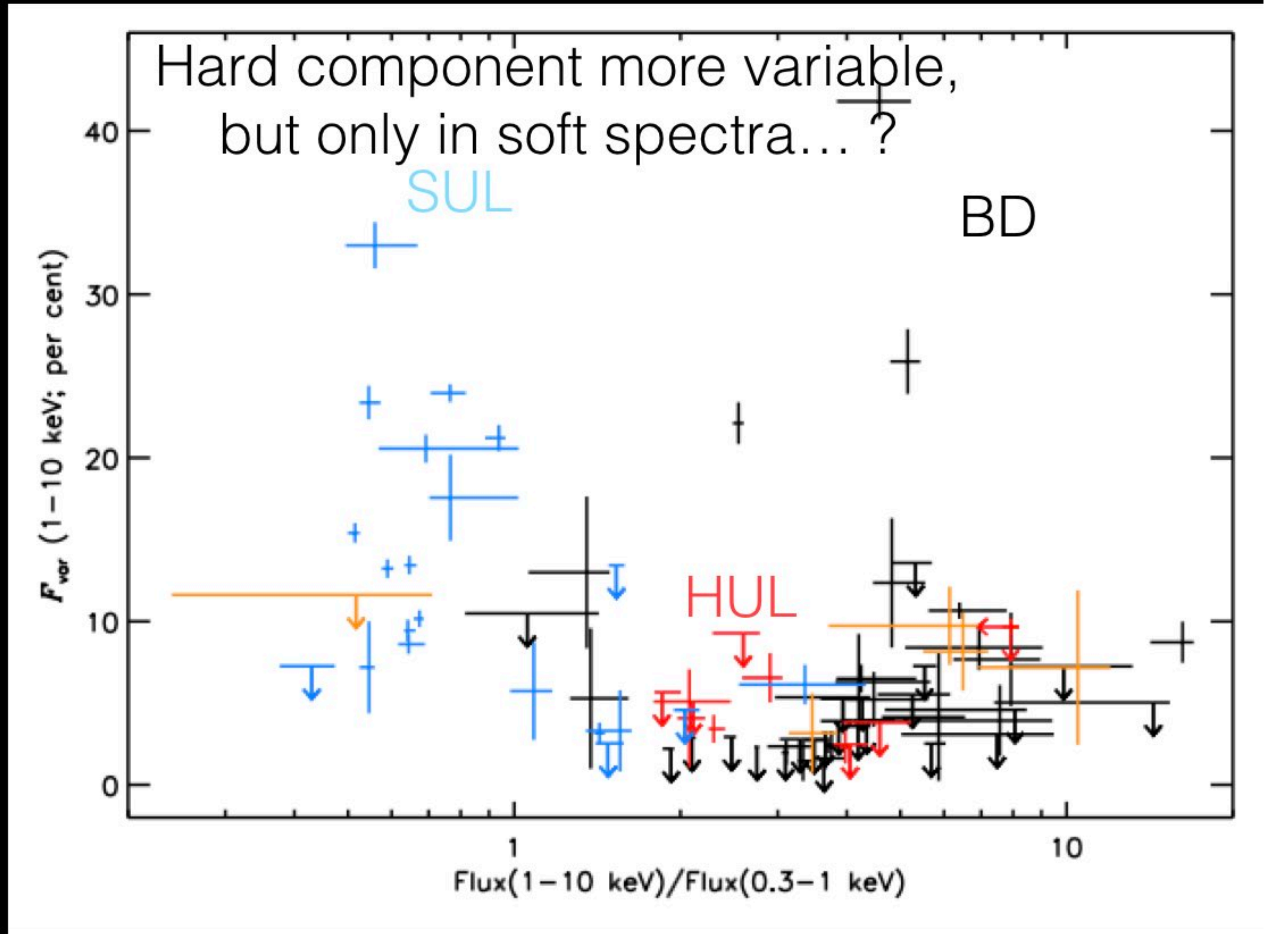


Covariance spectrum:

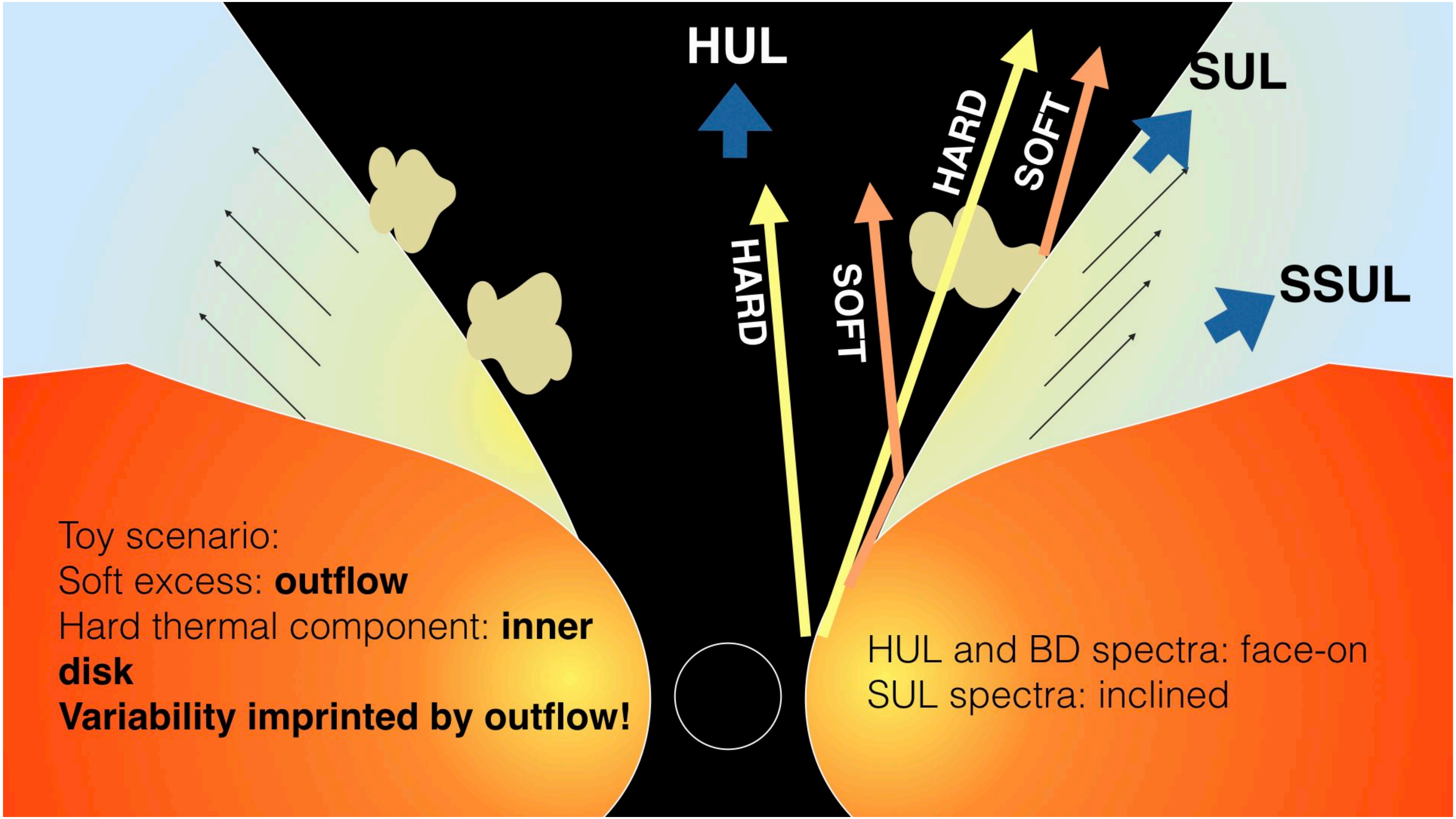
Look what spectral component is dominating the *variability*
Middleton,et al. *MNRAS* **447**, 3243–3263, 2015.

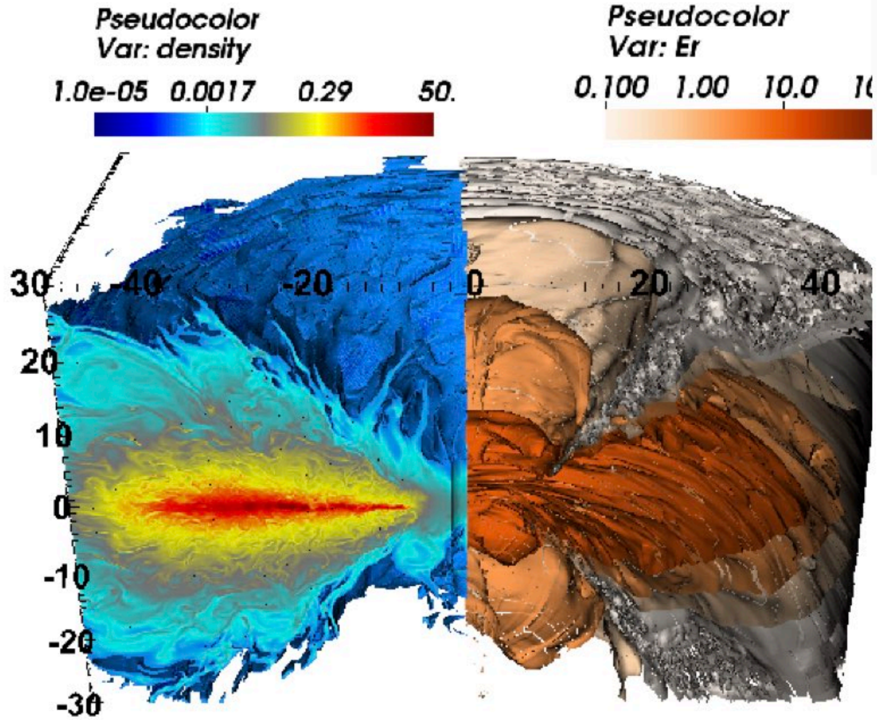


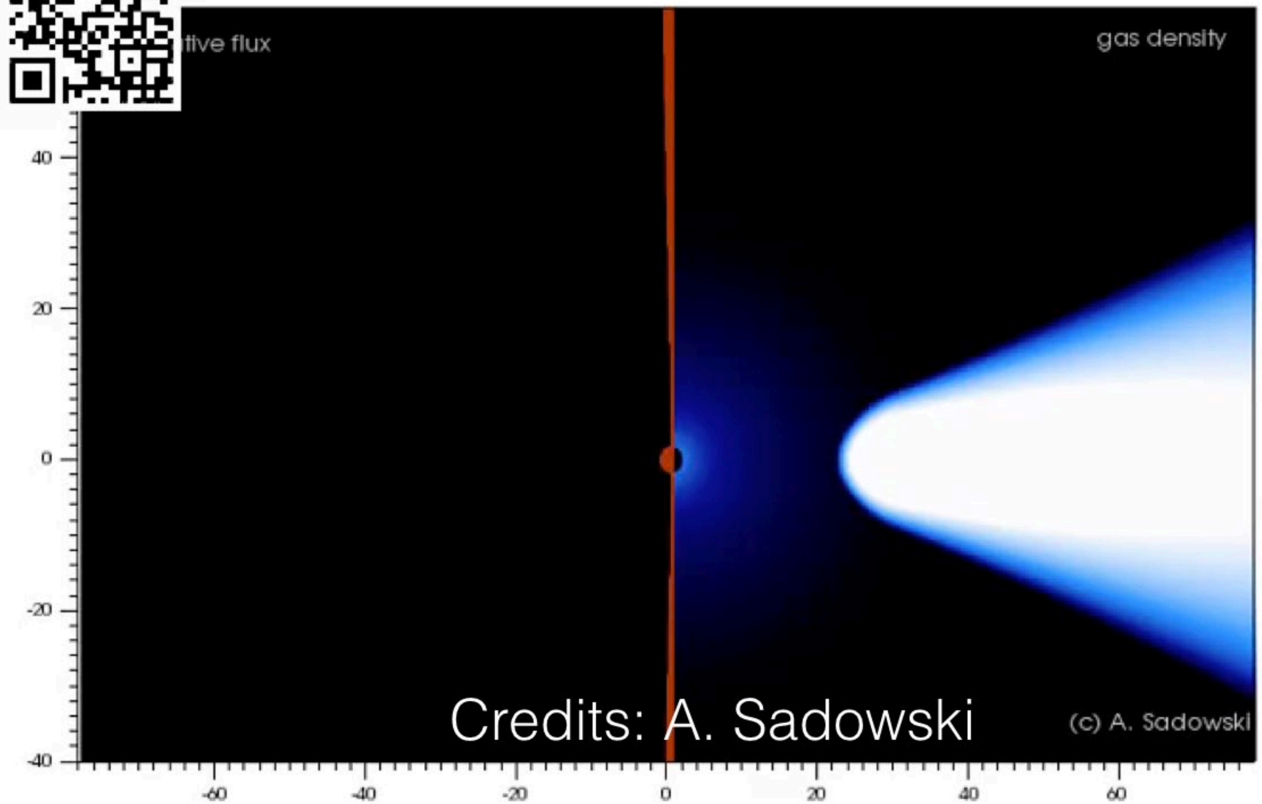




Sutton, Roberts & Middleton, *MNRAS* **435**, 1758, 2013.


HUL
SUL
SSUL
HARD
SOFT
HARD
SOFT
Toy scenario:
Soft excess: **outflow**
Hard thermal component: **inner disk**
Variability imprinted by outflow!
HUL and BD spectra: face-on
SUL spectra: inclined



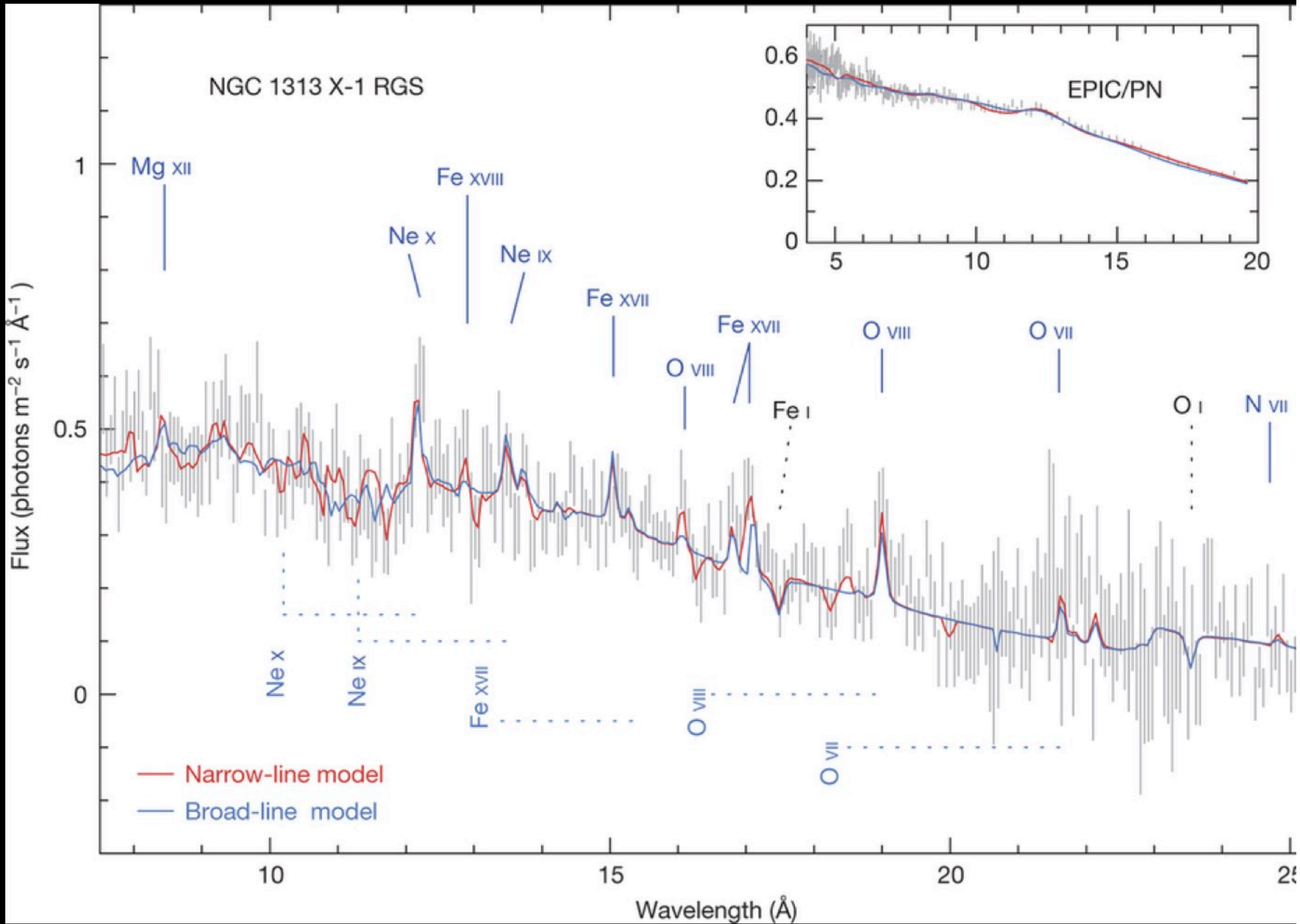


Jiang et al. ApJ **796** (2014) 106

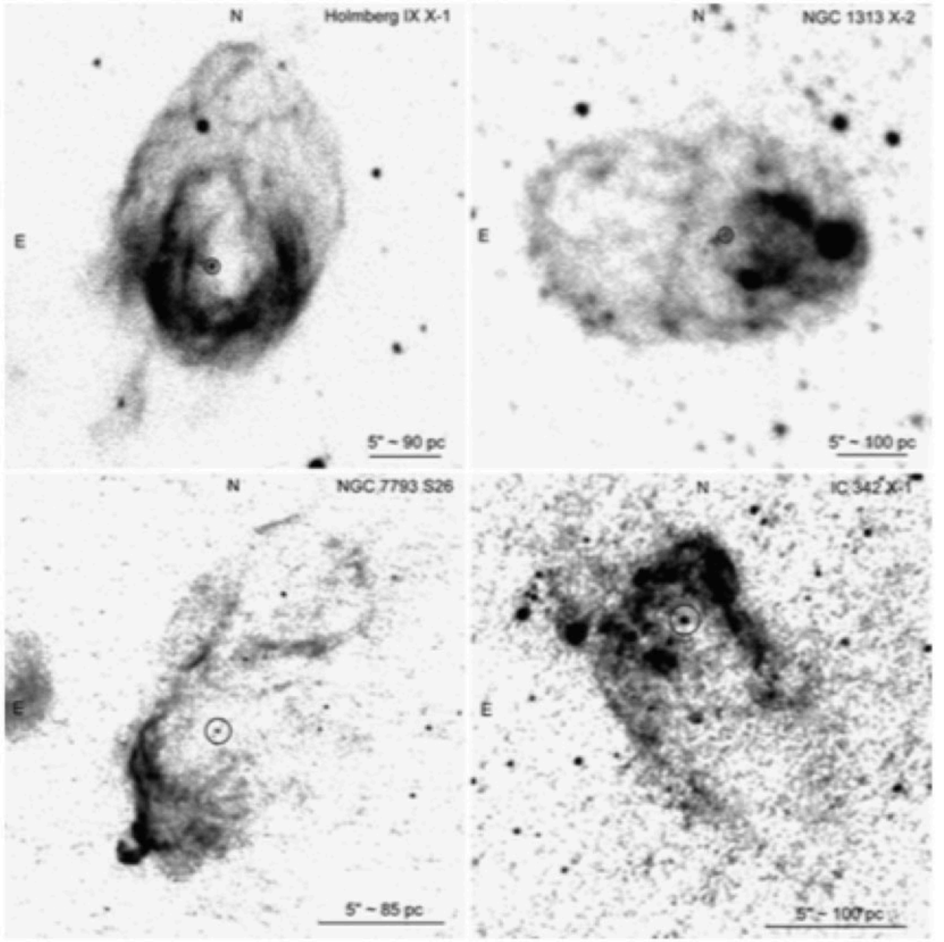
Outflows!

Pinto, Middleton, & Fabian, *Nat.* **533**, 64–67 2016.

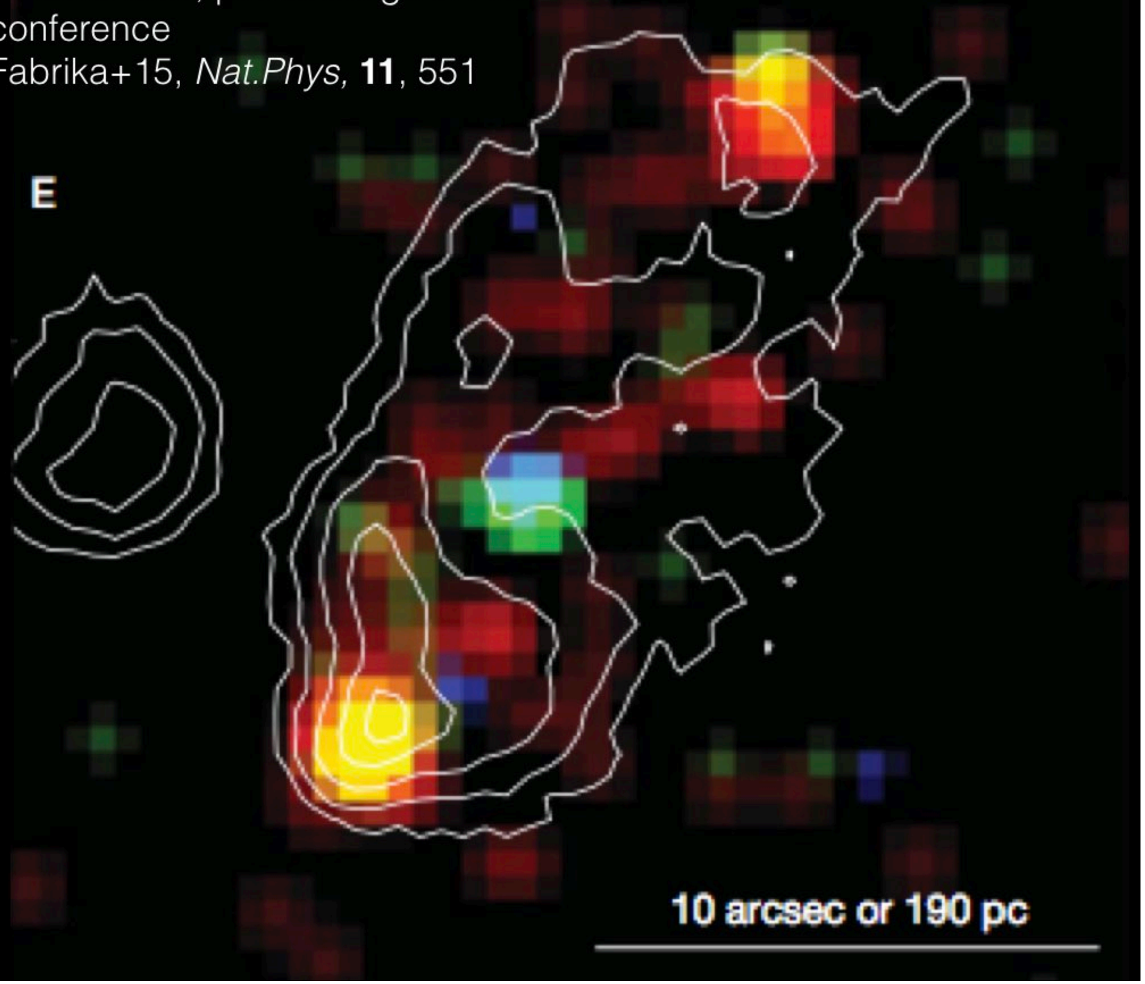
Outflows: lines blueshifted at 0.2 c



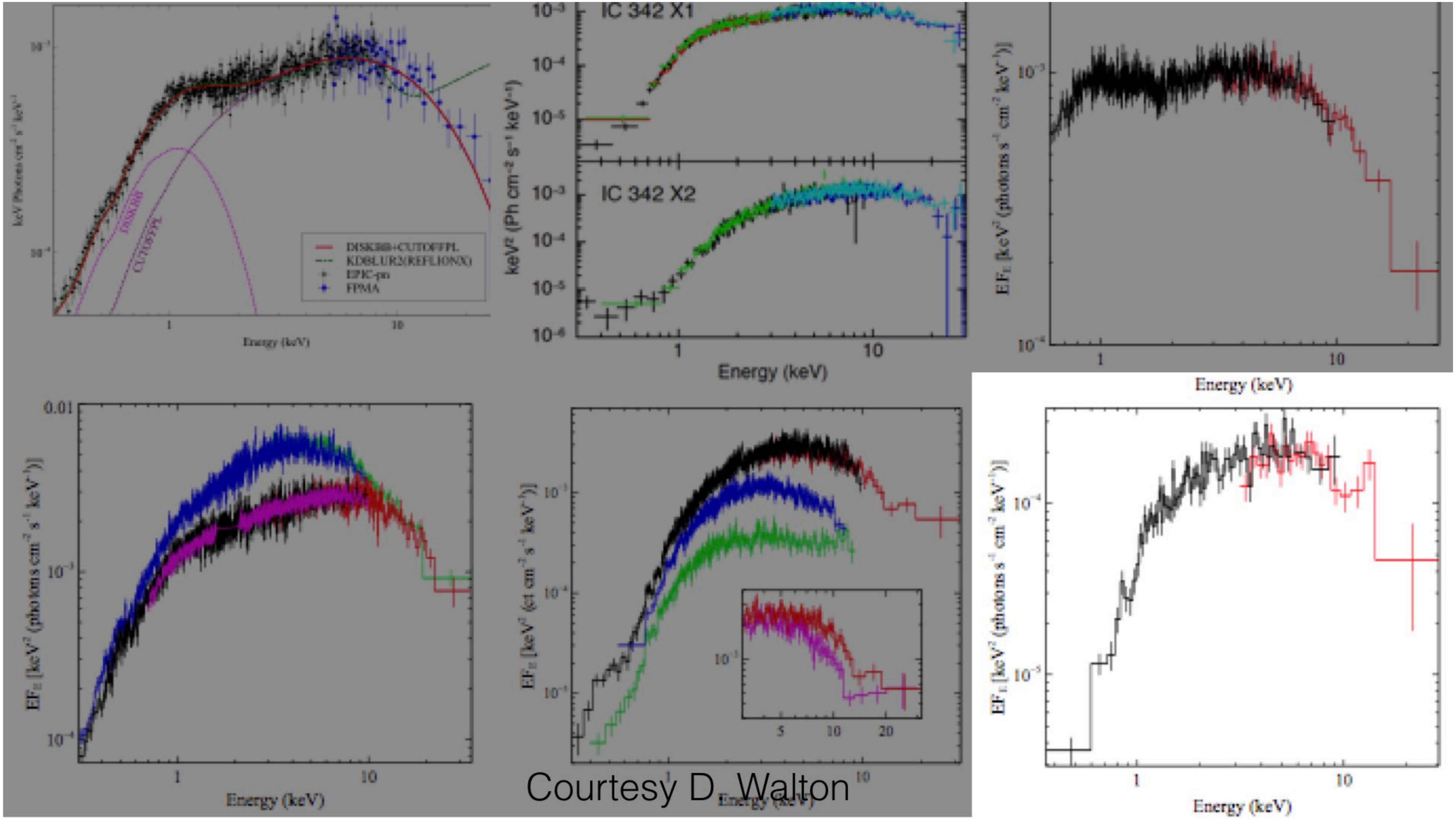
Pakull,& Mirioni, *Winds* **15**, 197 (2003).
Mezcua, et al. *MNRAS* **436,** 3128–3134 (2013).
Cseh, D. et al. *MNRAS Let.* **439**, L1–L5 (2014).
Pakull, Soria & Motch, *Nat.* **466**, 209–212 (2010).
Roberts et al, proceedings of Extreme BH conference
Fabrika+15, *Nat.Phys,* **11**, 551



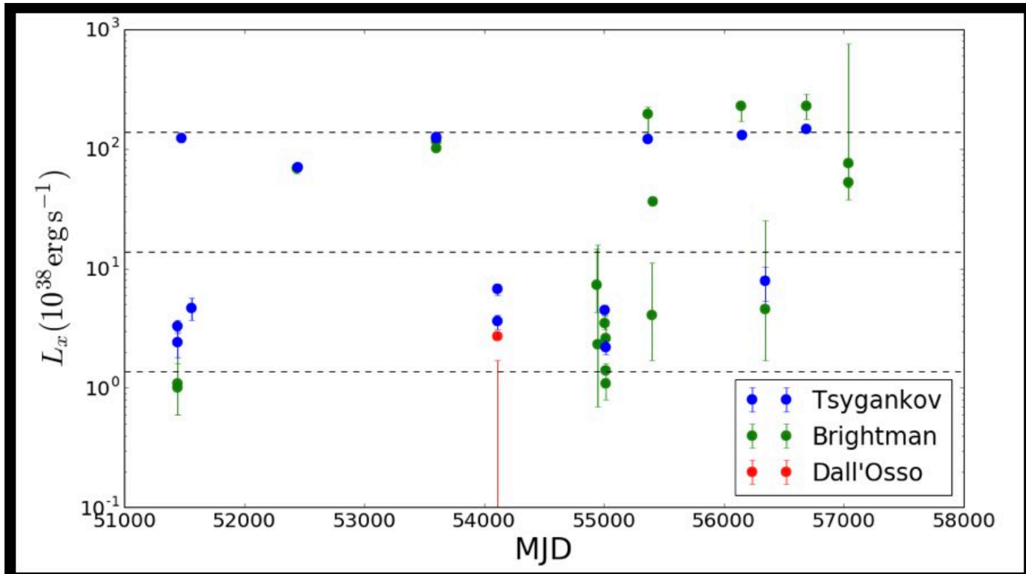
Hα bubbles
(credit: F. Grisé, in Feng & Soria *NAR* **55**, 166–183 (2011).)

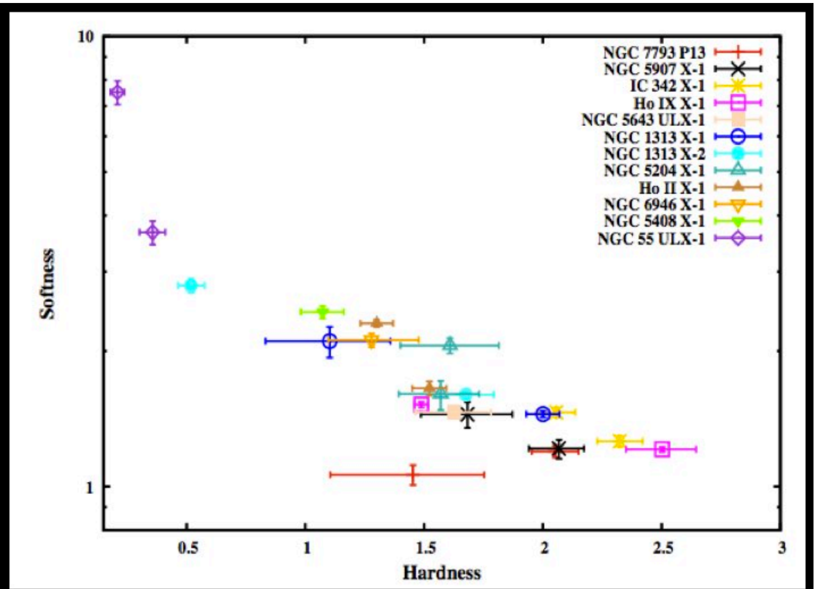


Are ULX pulsars really different?

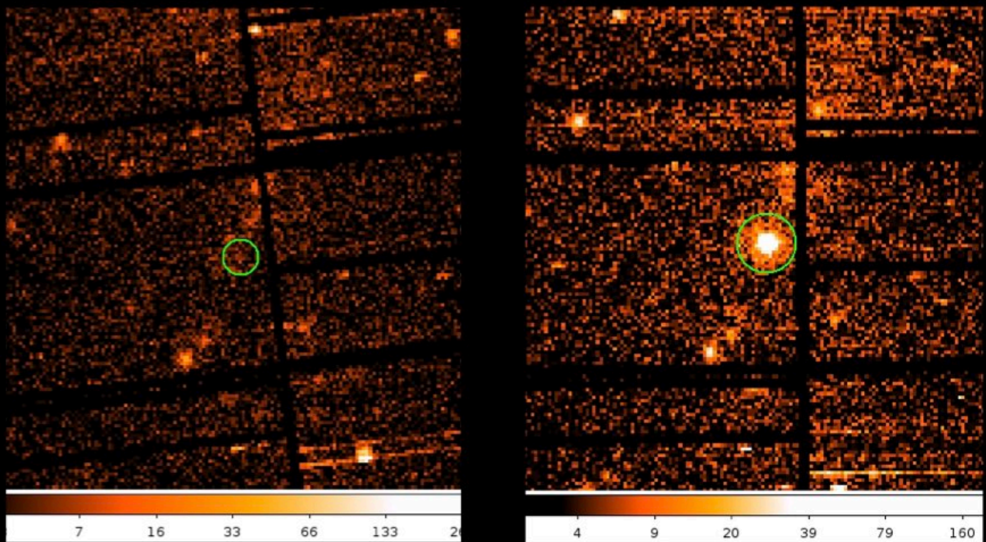


Courtesy D. Walton



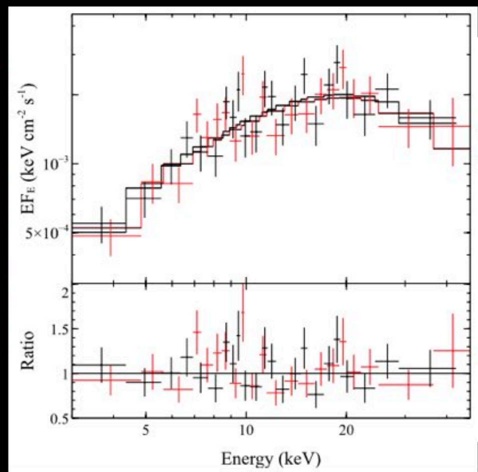


Pintore et al. *ApJ*, **836**,113, 2017.

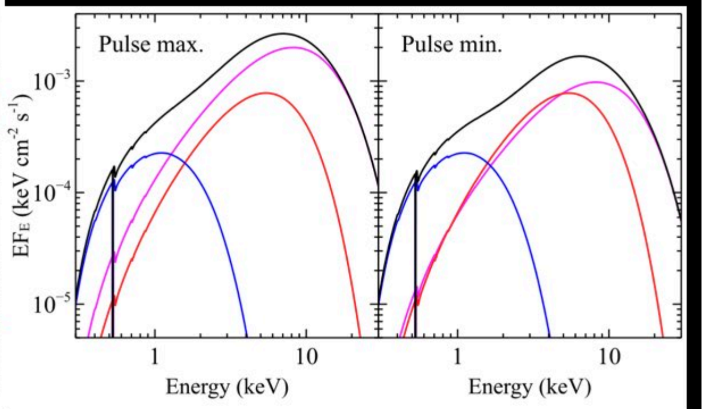


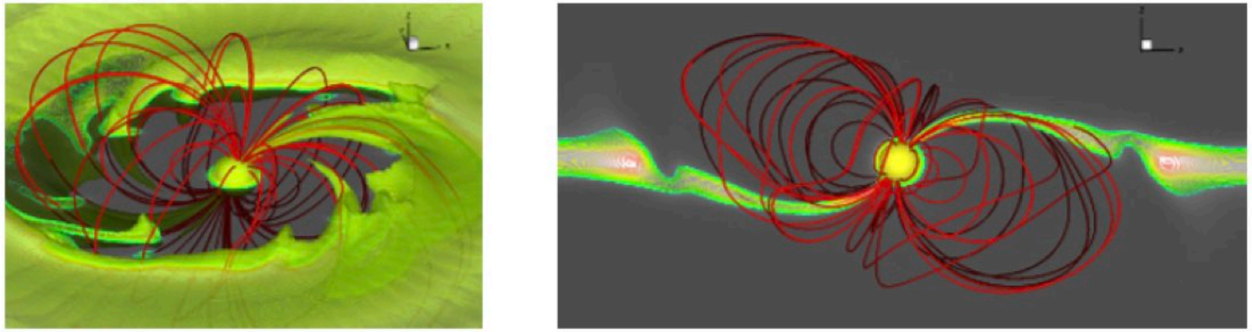
NGC 5907 X-1: Walton+arXiv:151705.10297

M82 X-2: Brightman+16

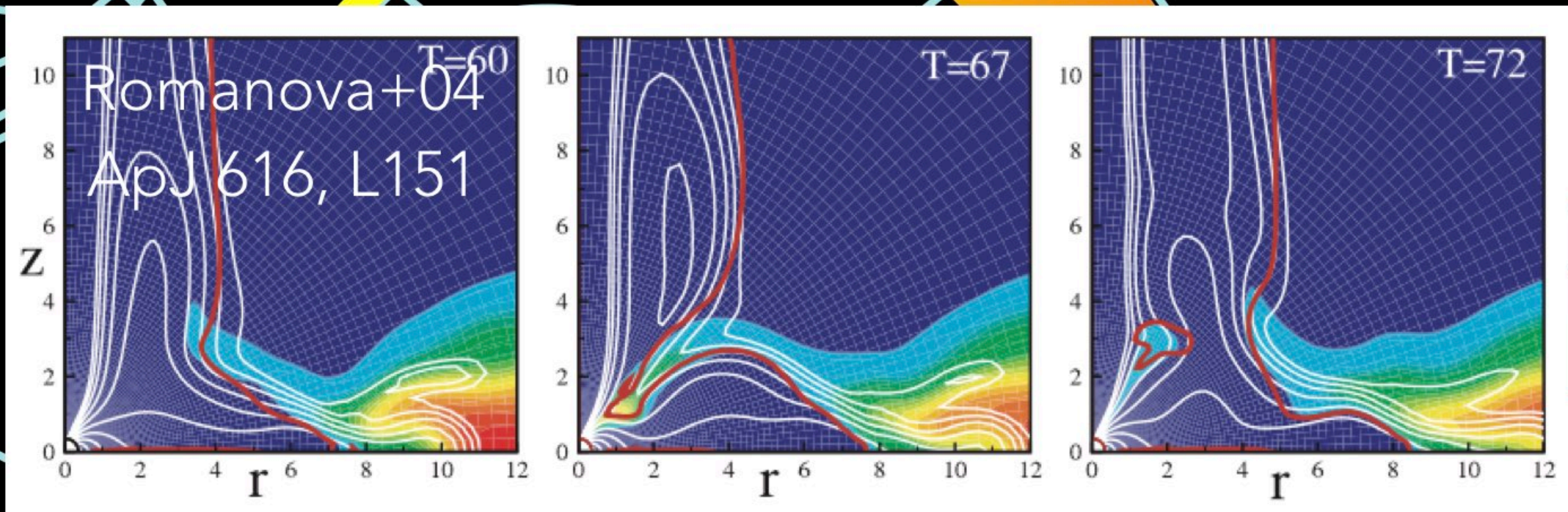


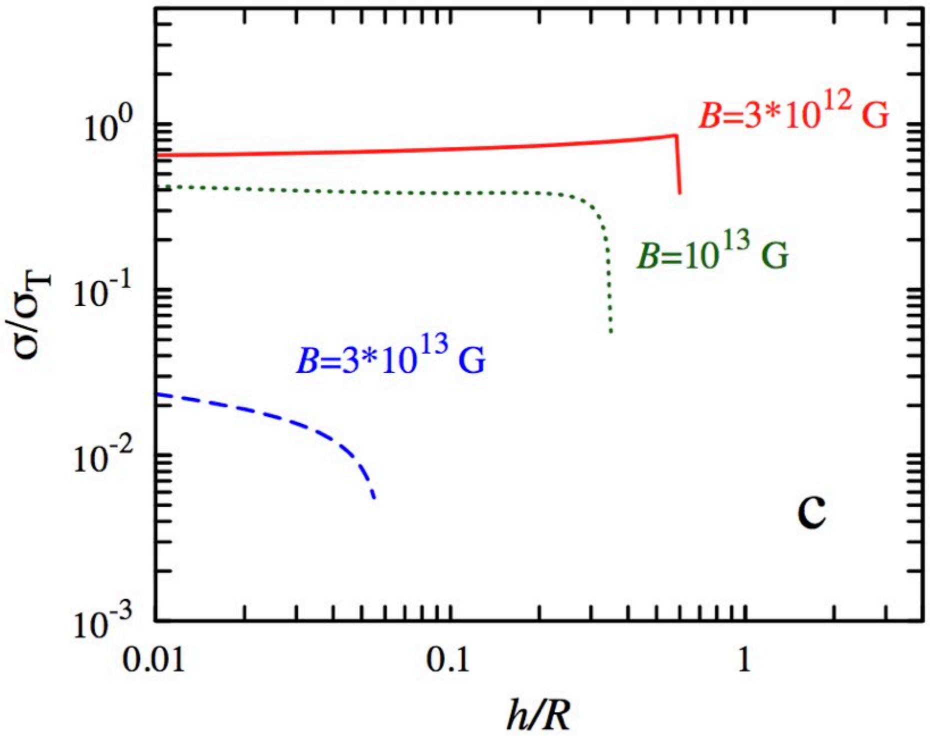
P13: Walton+





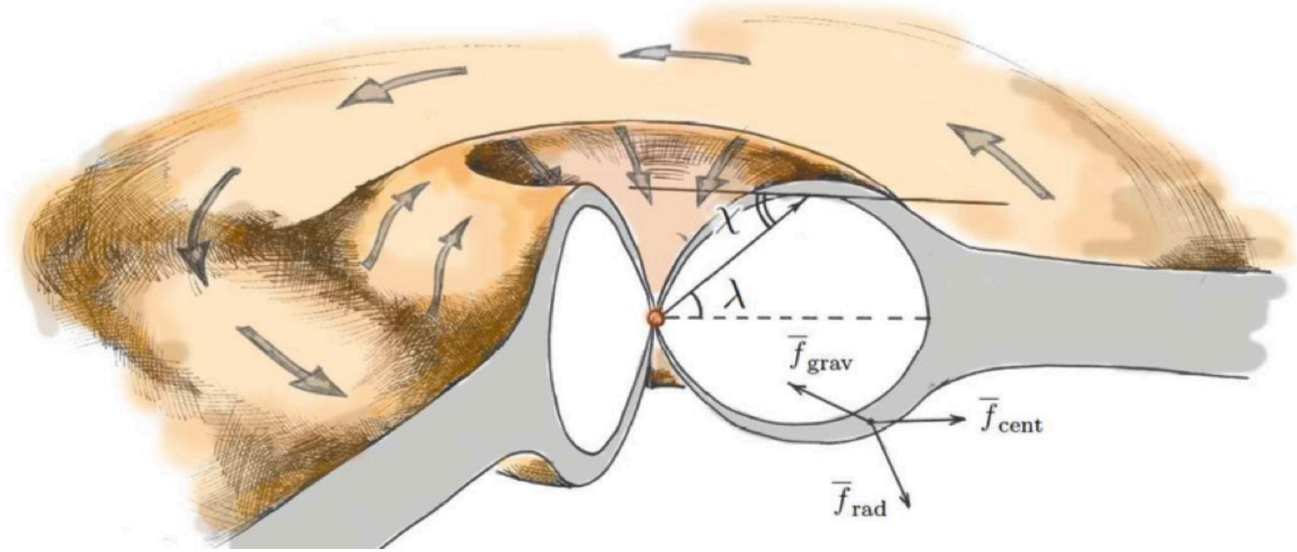
Romanova+14, EPJ WoC **64,** 05001





Mushtukov+15,16

(See talk by Koliopanos)



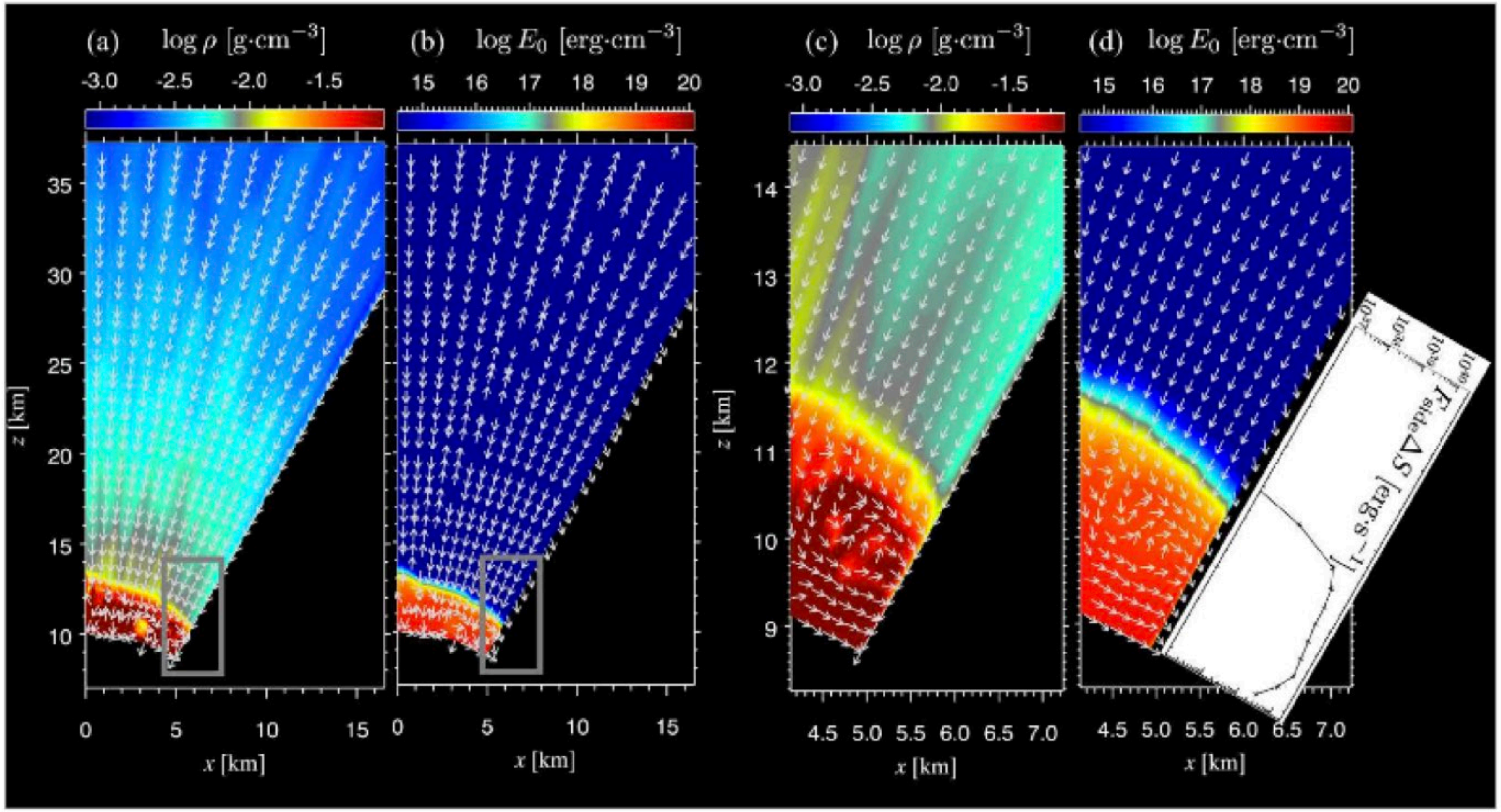


Fig. 1. Two-dimensional diagrams displaying mass and energy flow of super-critical column accretion at the elapsed time of 0.0335 sec. The left two panels show the structure of a column within $r = 37\mathrm{km}$, whereas the right two are magnified views of the innermost region enclosed by the gray squares in the left ones. In each pair of panels, the left panels show matter density color contours overlaid with matter velocity, while the right ones show color contours of radiation energy density overlaid with radiation flux in the laboratory frame (i.e., $\boldsymbol{F}_0 + \boldsymbol{v}E_0$), respectively. Radial profile of the radiation luminosity leaked from the side of accreting column with an area of $\Delta S \equiv 2\pi r \sin\theta \Delta r$ is shown in the inserted figure, where $\Delta r \sim 0.2$ km is the mesh spacing.

Kawashima+16 *PASJ*


HERE HE COMES TO
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Open questions

- What's the real accretion rate?
- How do we model spectra? What's the hard excess?
- How many pulsars?
- How many IMBHs?
- …. see next talks!

THE MORE YOU
KNOW
THE MORE YOU REALIZE YOU DON'T
KNOW