Spectral-timing studies of ultraluminous X-ray sources

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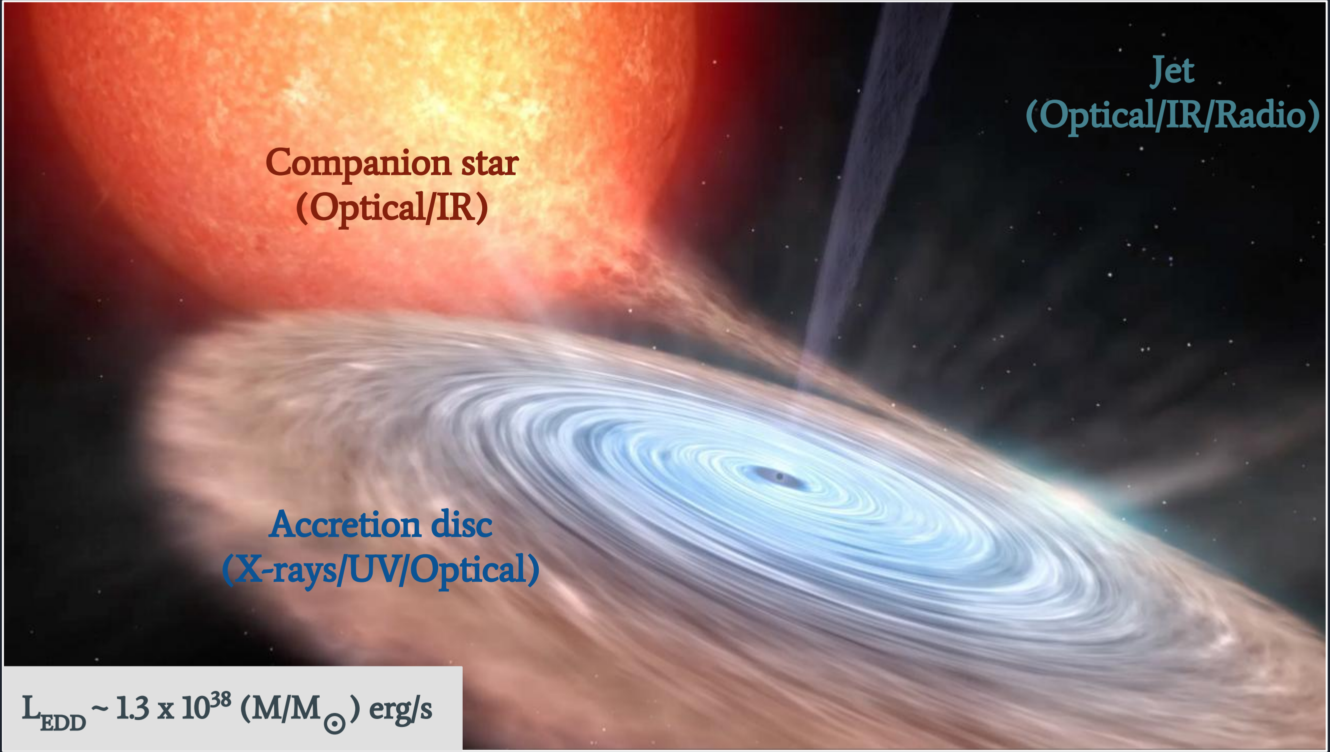
PhD student

Ciro Pinto, Dominic Walton, Roberto Soria,
Fabio Pintore, Peter Kosec ...

Accretion: the standard picture

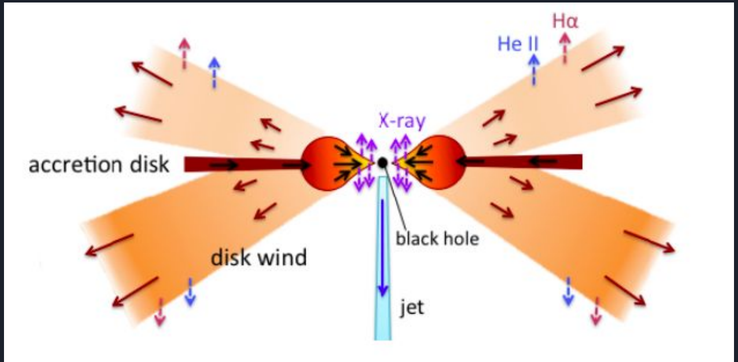


← increasing temperature

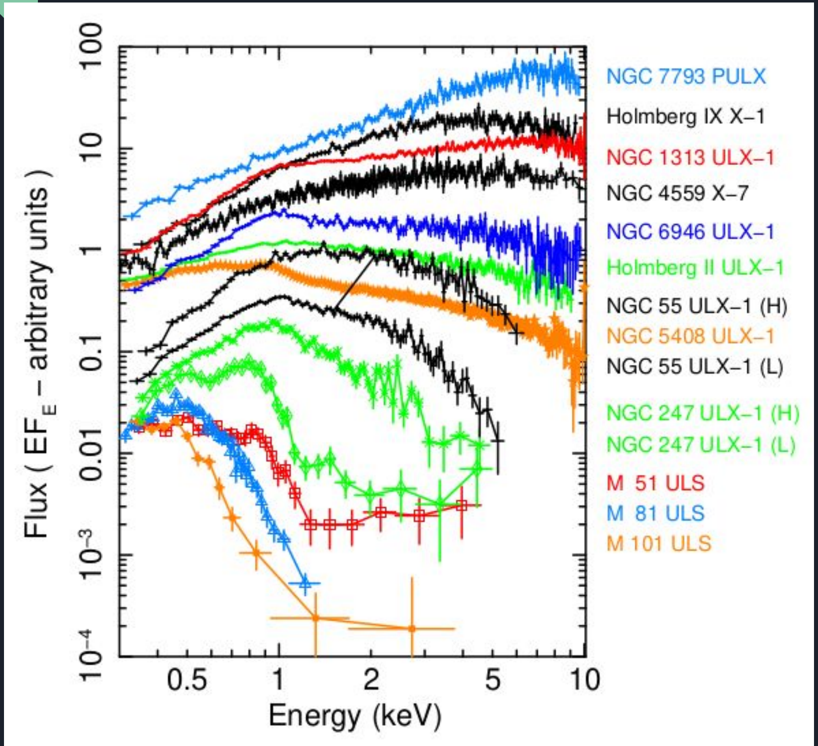
Ultraluminous X-ray sources

→ Bachetti's talk
→ Pinto's talk ...

- **X-ray luminosities** that exceed the isotropic Eddington luminosity for a standard black hole (BH) of 10 $M_\odot$
- ULXs are among the **brightest** (10^{39}-10^{41} erg s^{-1}), off-nuclear, X-ray sources in the Universe
- At high mass accretion rates the radiation inflates the disc and launches **winds**

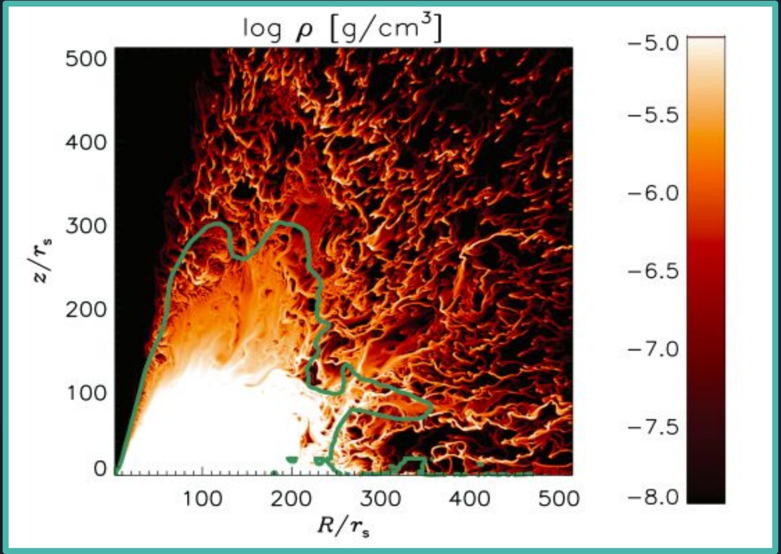


1) The X-ray spectral variability



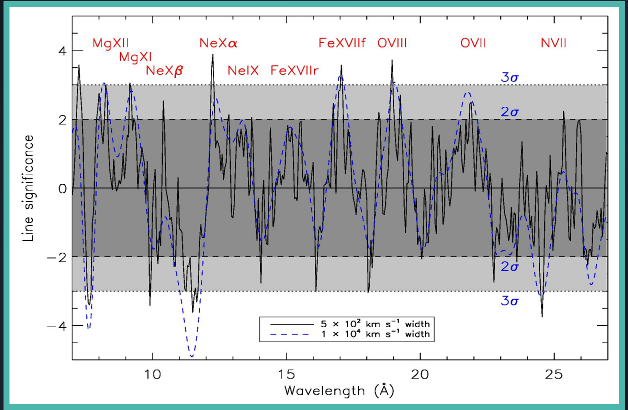
- **Strong curvature** between 2–10 keV
- Often a **soft excess** below 2 keV
- ULXs classified by Sutton+13 as SUL, HUL and BD
- Sub-class of ULXs: **ultraluminous supersoft sources** (ULSs)

2) Powerful outflows



Takeuchi +13

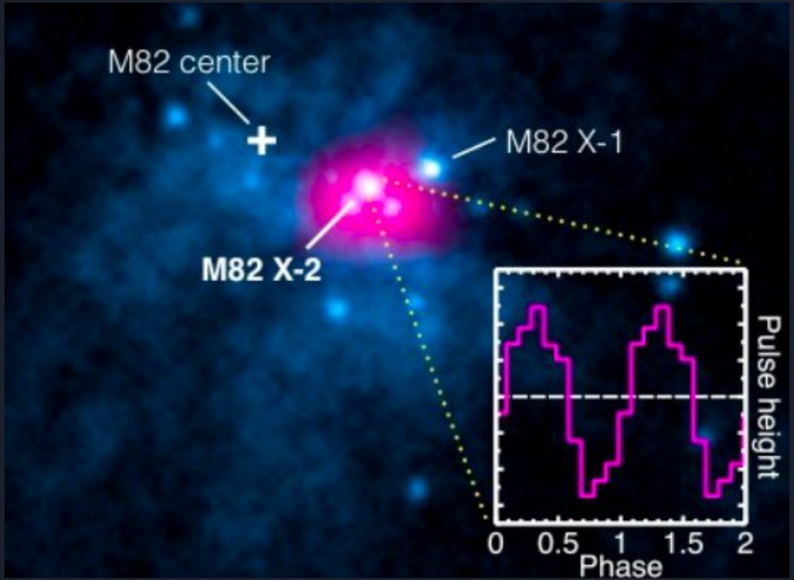
Blueshifted absorption lines and emission lines at laboratory wavelength have been discovered



Pinto +16

Theory predicts powerful winds at super-Eddington accretion rates

3) Discovery of ULX Pulsars



M 82 X-2 (Bachetti+2014)

Around **7 known NS-ULXs**

From all ULXs with sufficient statistics ~25% NSs (Rodriguez-Castillo+20)

- NGC 7793 P13 (Israel+16,Fuerst+16)
- NGC 5907 ULX (Israel+17)
- NGC 300 ULX 1 (Carpano+18)
- NGC 1313 X-2 (Sathyaprakash+19)
- M51 ULX-7 (Rodriguez Castillo+20)
- NGC 7793 ULX-4 (Quintin+21)

Open questions

- **Spectral transitions** in ULXs: changes in the wind or variations in the accretion rate / geometry
- **%** of matter lost into the wind / **net accretion rate** onto the compact object?
- What is the **fraction of BH-NS** powered ULXs?

ULXs → strong spectral variability

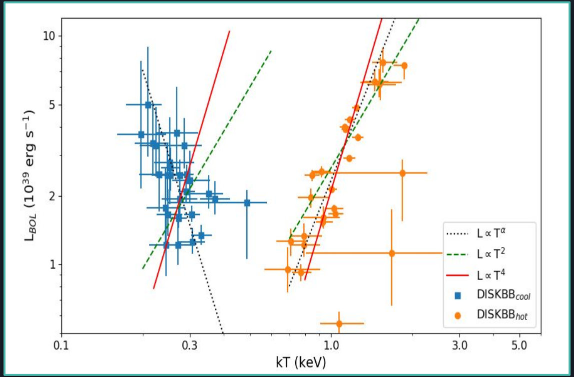
Sample studied

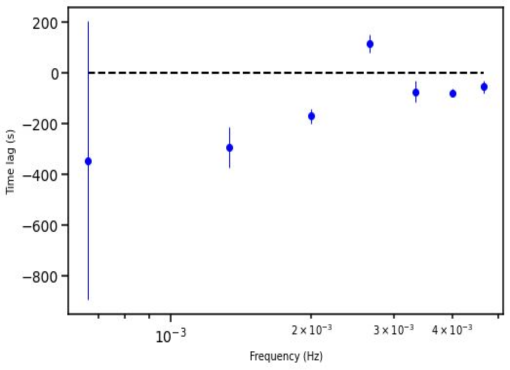
Study the structure of the accretion disc in super Eddington regime

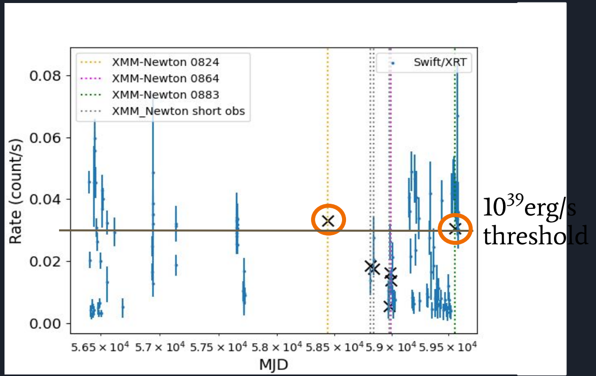
Luminosity/Temperature trend | **Time Lags** | **New ULX**

NGC 1313 ULX-2

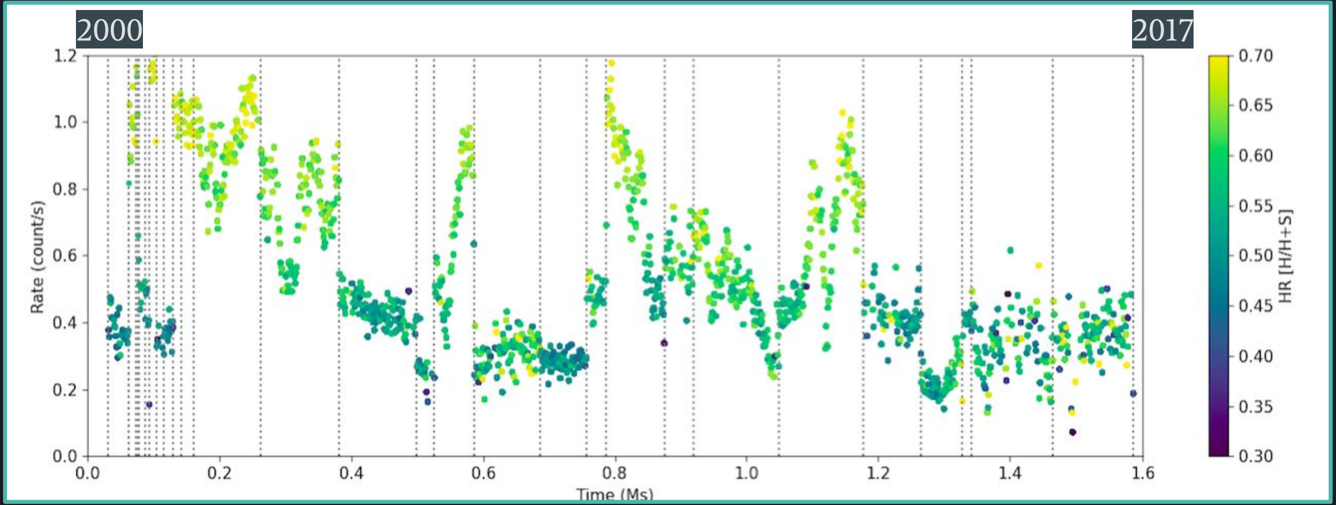
NGC 55 ULX-2







Study of accretion disc structure: NGC 1313 X-2

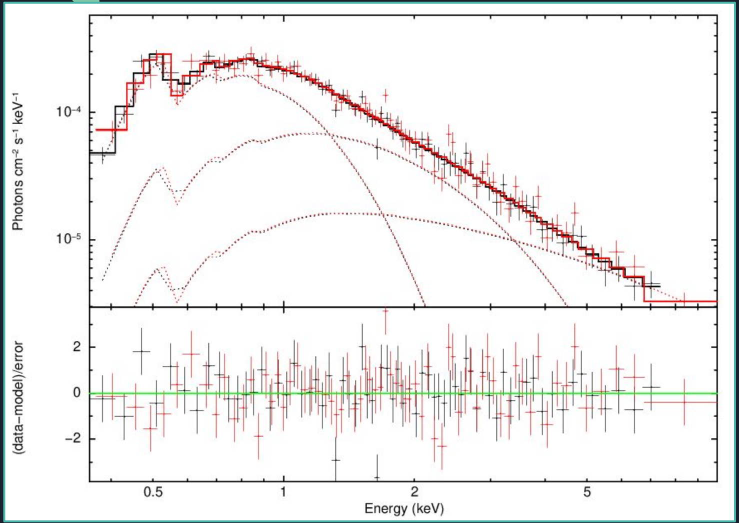


The source becomes harder when brighter

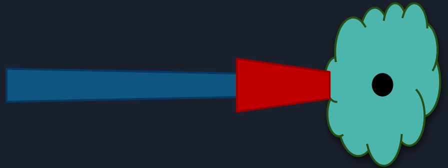
Hardness Ratio (HR) = 1.2 - 10 keV / 0.3 - 10 keV

Robba et al, 2021, A&A. vol 652, pages A118

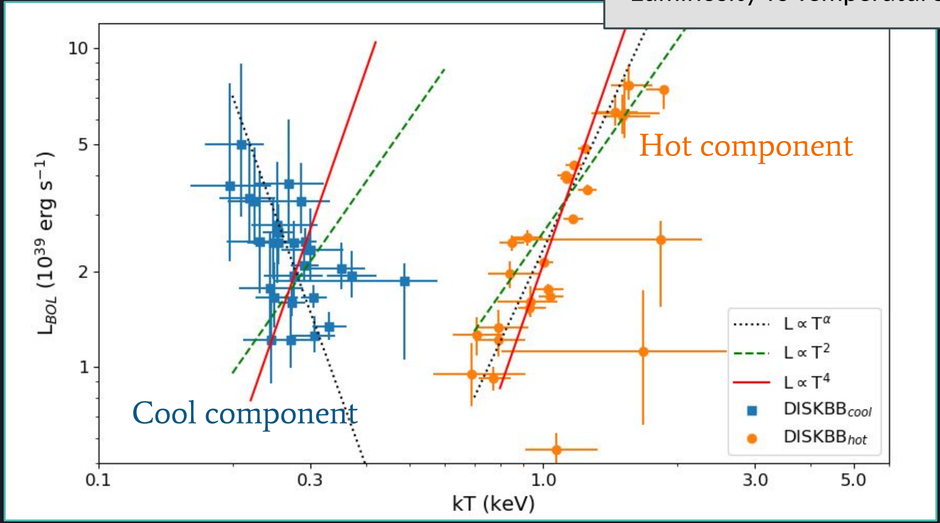
Study of accretion disc structure: NGC 1313 X-2



model: TBabs * (dbb + dbb + cutoffpl)



Luminosity vs Temperature



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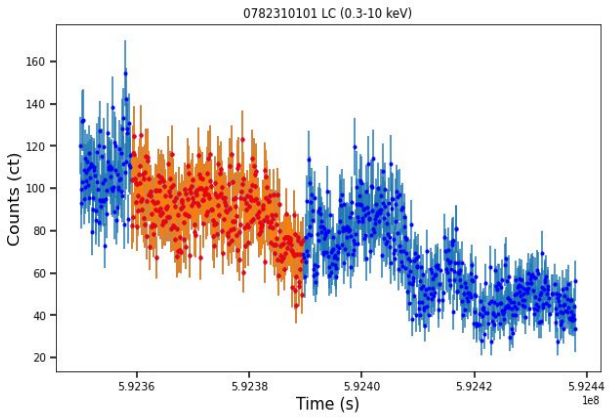
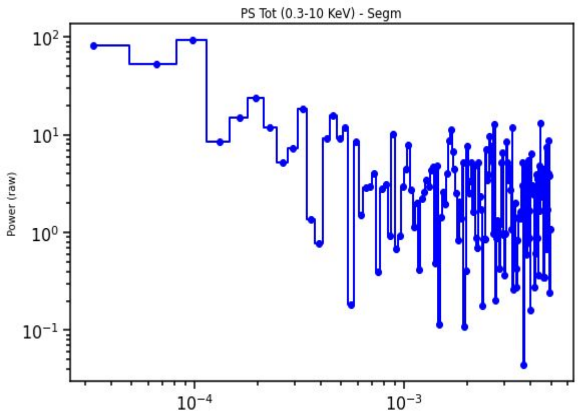
Timing analysis: NGC 1313 X-2

Lightcurve

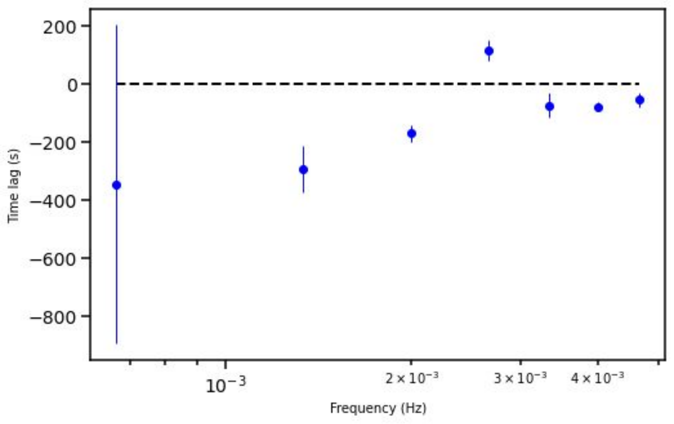


Powerspectrum



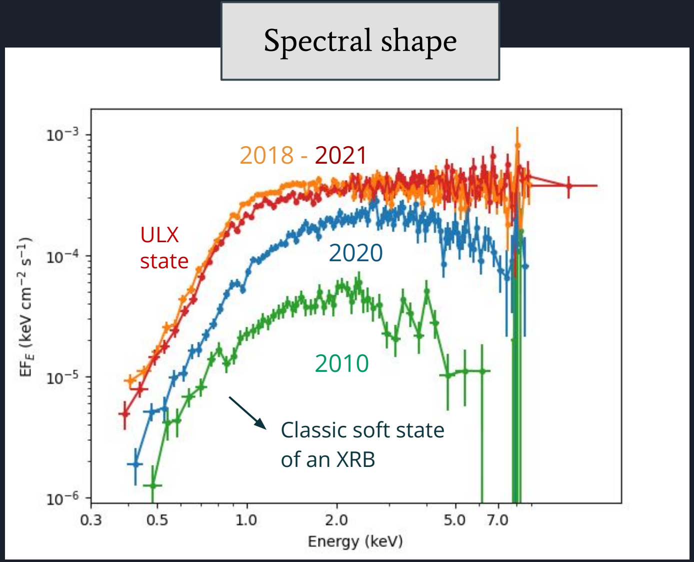
Timing analysis: NGC 1313 X-2

Time - Lags

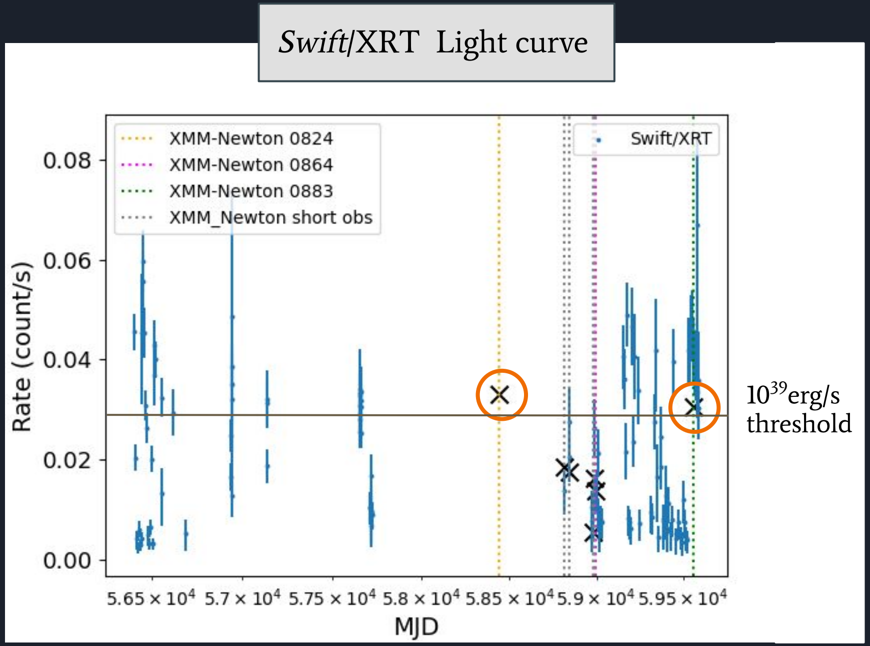


- **Presence of soft-lags** → the wind could be scatter a fraction of the inner disc photons which become softer than the fraction of the inner disc (hard) photons.
- All ULXs that show soft lags, also show evidence for relativistic outflows

NGC 55 ULX-2: spectral variability



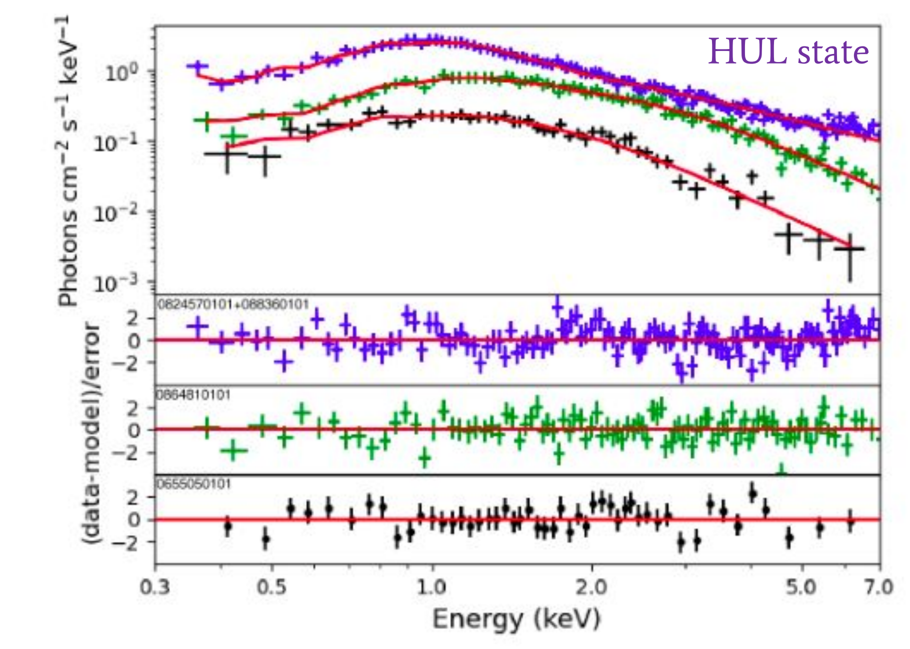
no detection in obs 00280101 - 201 (November 2001)



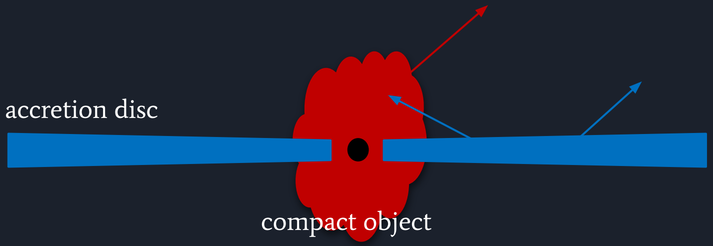
April 2013 → January 2022

Robba et al, 2022, MNRAS vol 515, pp. 4669

NGC 55 ULX-2: spectral analysis



model: hot * (dbb + comt)



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Summary

- **NGC 1313 X-2**

  spectral evolution of the cool component agrees with the prediction of super-Eddington accretion

  presence of soft lags → hotter inner disc photons could be scattered by the outflow

- **NGC 55 ULX-2**

  identification of a new ULX candidate

- **Timing & Spectral evolution** of ULXs is a tool to understand the super-Eddington accretion mechanism

Summary

- **NGC 1313 X-2** — spectral evolution of the cool component agrees with the prediction of super-Eddington accretion

  presence of soft lags → hotter inner disc photons could be scattered by the outflow

- **NGC 55 ULX-2** — identification of a new ULX candidate

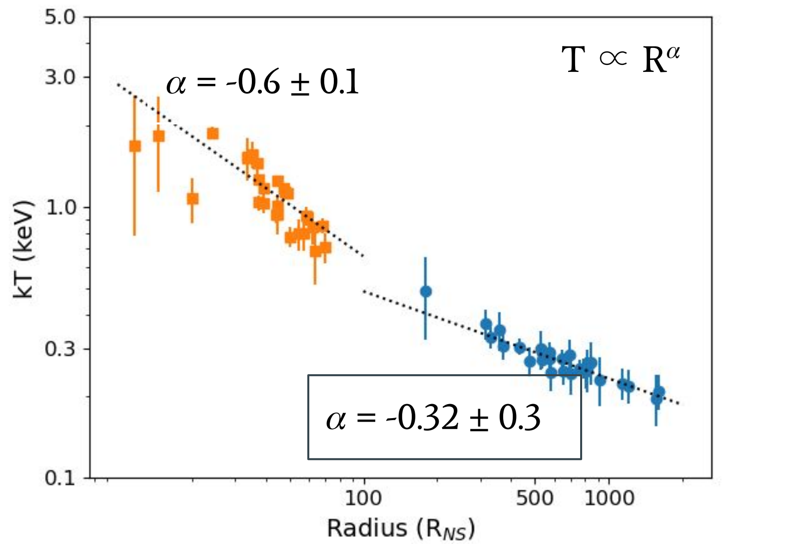
- **Timing & Spectral evolution** of ULXs is a tool to understand the super-Eddington accretion mechanism

Thank you for your attention!

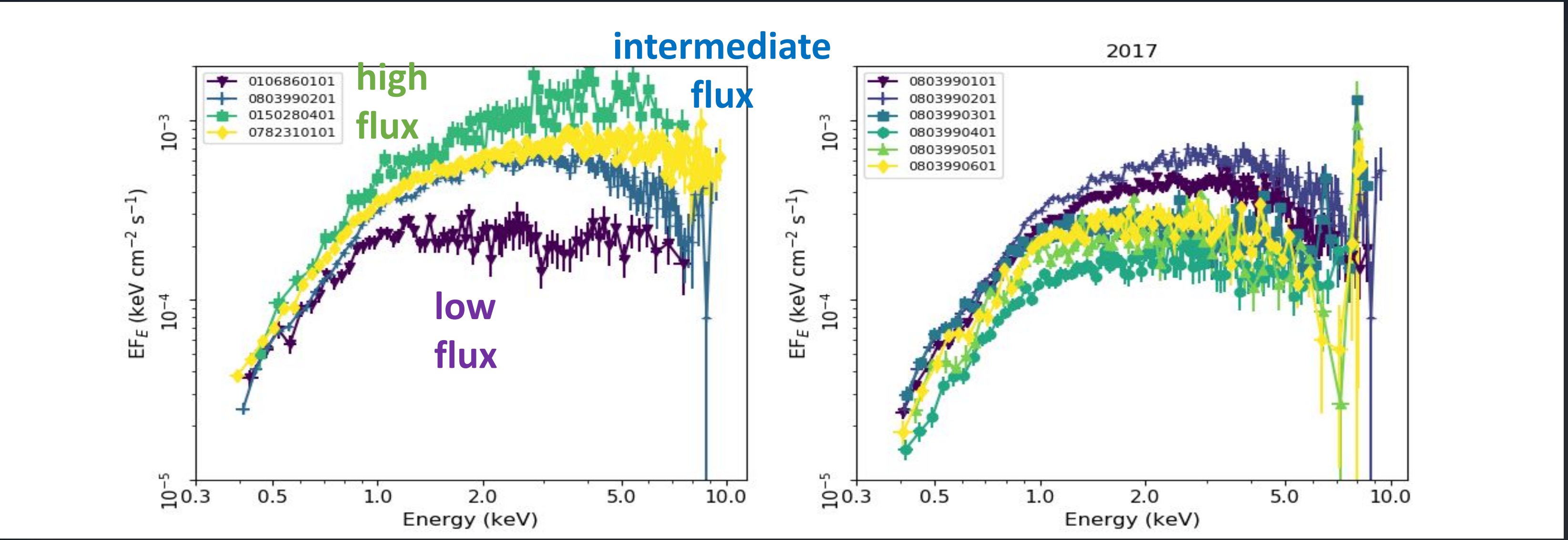
Bonus Slides

NGC 1313 X-2 - Temperature/Radius

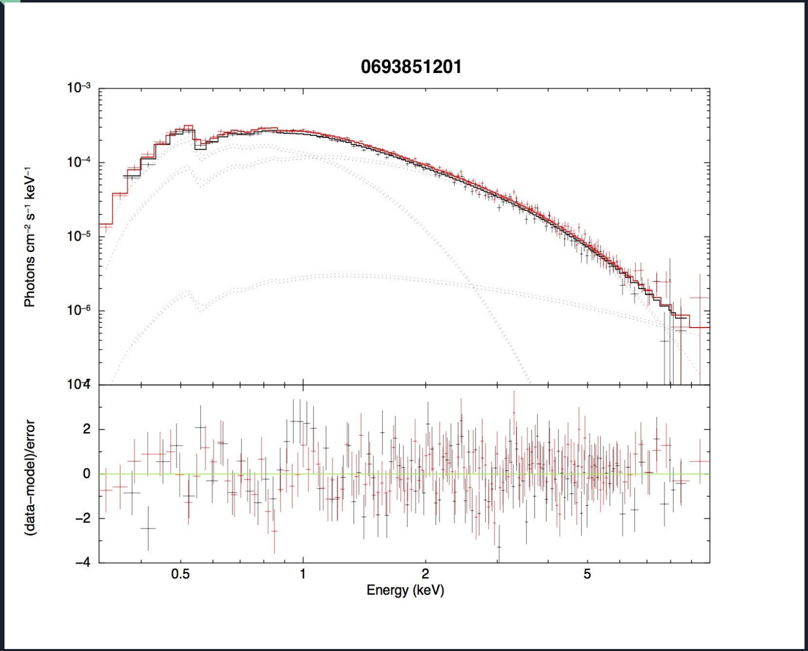
Temperature vs Radius



NGC 1313 X-2: spectral variability



NGC 1313 X-2: example fit



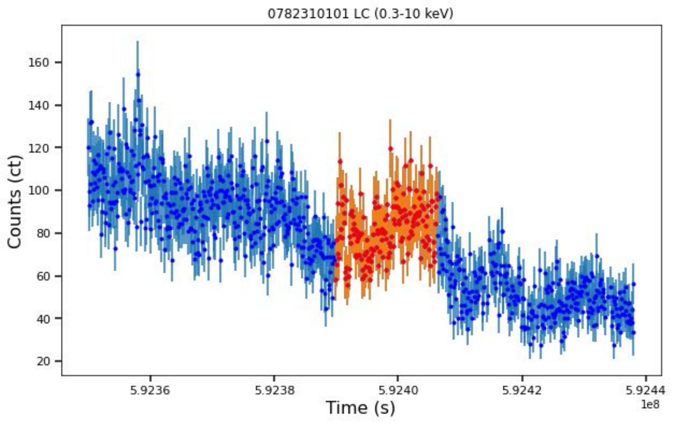
TBABS*(DISKBB+DISKBB+CUTOFFPL)			
Model component	Parameter	Unit	
TBABS	N_H	$[10^{22}\text{cm}^{-2}]$	0.218 ± 0.013
DISKBB	T_{in}	[keV]	0.31 ± 0.02
	norm		$0.046^{+0.009}_{-0.008}$
DISKBB	T_{in}	[keV]	$1.01^{+0.05}_{-0.04}$
	norm		$4.3^{+1.8}_{-1.2}$
CUTOFFPL	PhoIndex		0.59 (fixed)
	HighECut	[keV]	7.9 (fixed)
	norm		$0.00005^{+0.000002}_{-0.000003}$
χ^2/dof			1.1311 (235)

Photoindex = 0.59 keV (fixed)
HighECut = 7.9 keV (fixed)

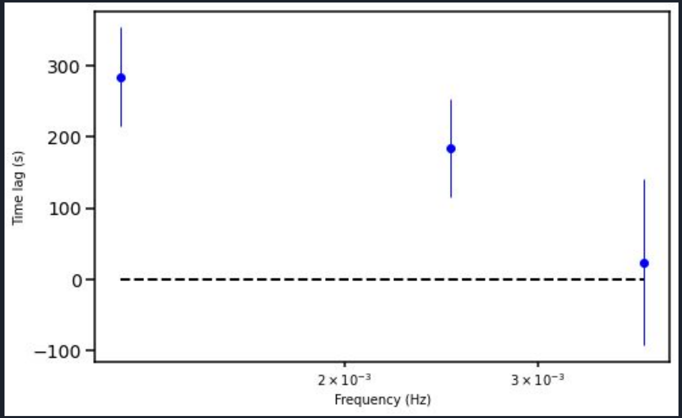
Brightman +16
Walton +18

Timing analysis: NGC 1313 X-2

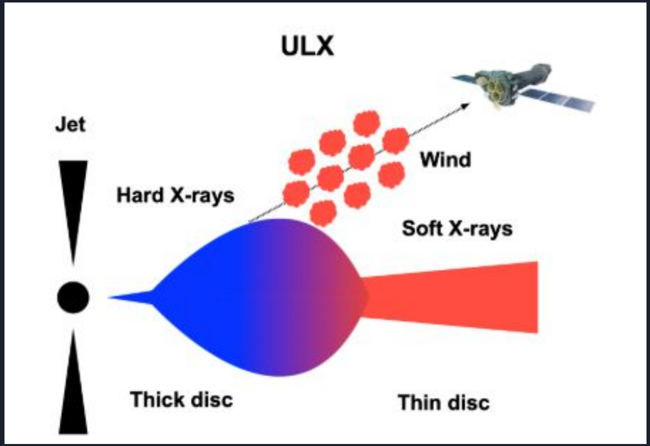
Lightcurve



Time - Lags

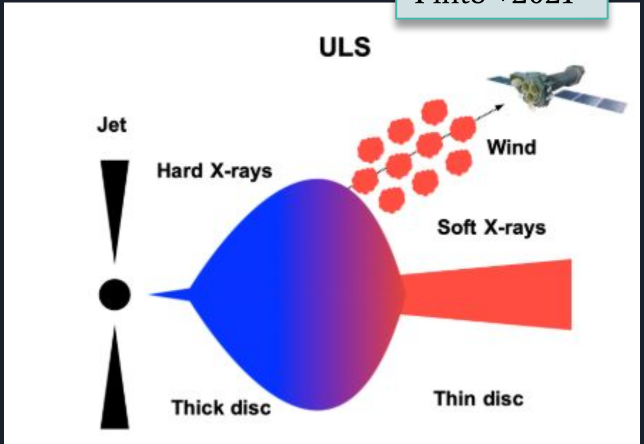


Possible scenario for dips: ULX-ULS transitions



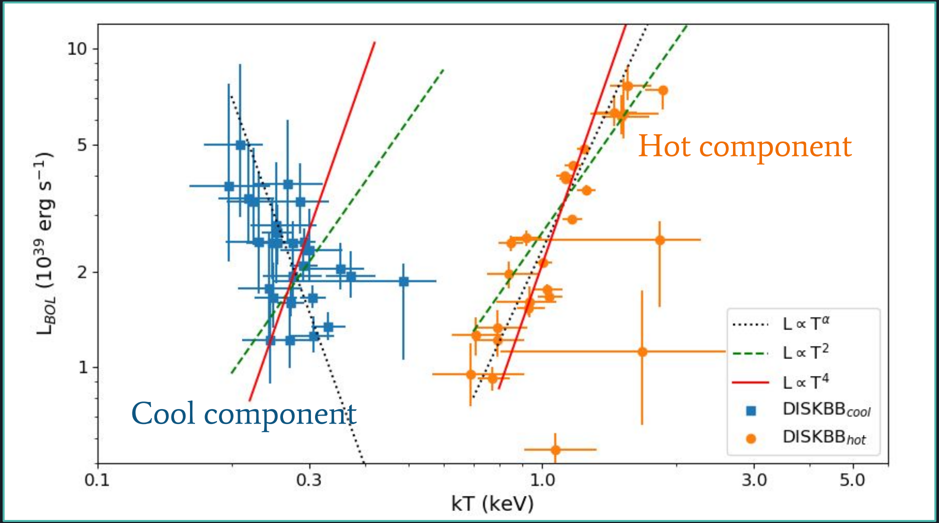
The source is observed at a viewing angle that is high enough that the inner disc is already partly obscured by the wind (soft ULXs)

Pinto +2021



High accretion rate → Increase of the scale-height of the disc and the optically-thick base of the wind → near-total obscuration of the inner regions (ultraluminous supersoft source, ULS)

L/T trend: NGC 1313 X-2



$\alpha_{cool} = -3.9 \pm 1.0$

$\alpha_{hot} = 3.0 \pm 0.35$