Wind of change

Extreme accretion and feedback in ultraluminous X-ray sources

IASF Istituto di Astrofisica Spaziale e Fisica cosmica Palermo

INAF ISTITUTO NAZIONALE DI ASTROFISICA

Ciro Pinto

esa

UNIVERSITY OF CAMBRIDGE

SRON

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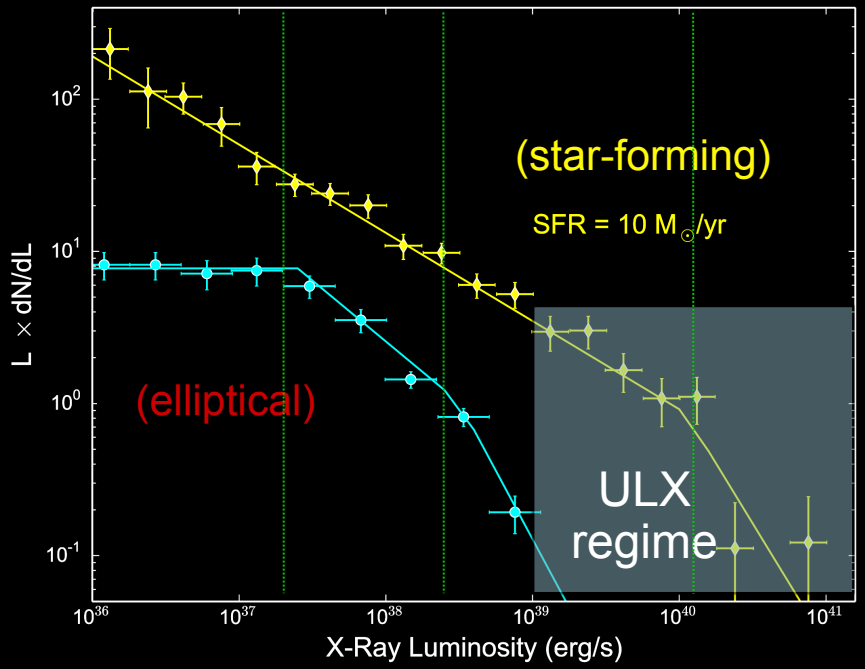
D. Barret (IRAP), R. Soria, (NAO), M. Mehdipour (STScI), H. Earnshaw (Caltech), P. Kosec, E. Kara (MIT)

Ultra-Luminous X-ray source (ULX)

Brighter than a 10 $M_\odot$ black hole accreting @ Eddington limit (10^{39-42} erg/s) & off-nuclear



NS ($Z=Z_\odot$) ~ 10-50x BH

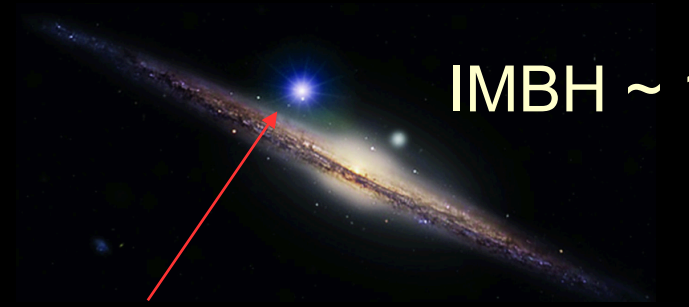
$Z\downarrow$ $M_{BH}\uparrow$ $\%_{BH}\uparrow$ $N_{ULX}\uparrow$

Mineo, Gilfanov & Sunyaev (2012)

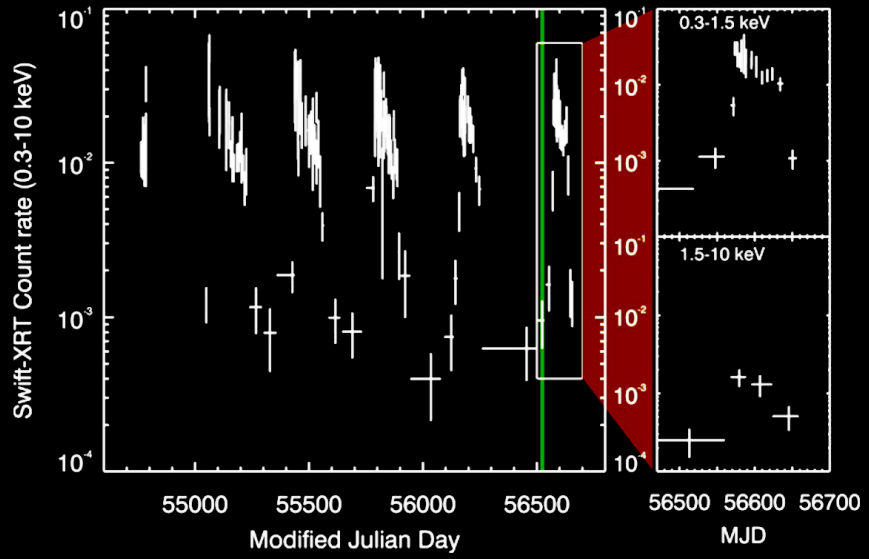
Cartwheel galaxy (X-ray: NASA/CXC; Optical: NASA/STScI)

The Holy Grail?

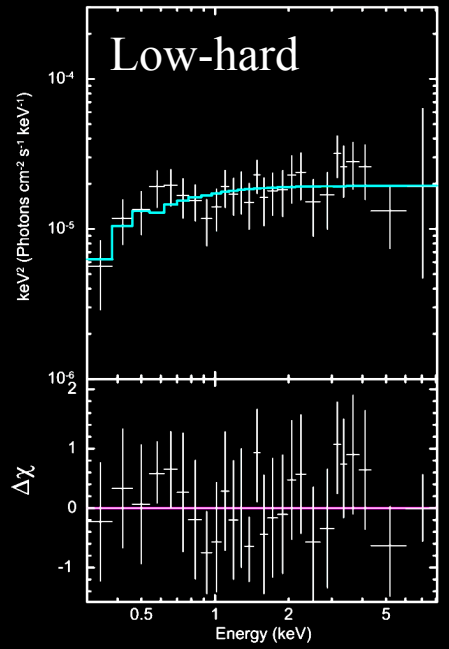
IMBH ~ 10^{2-5} $M_\odot$ ... maybe in some ULXs

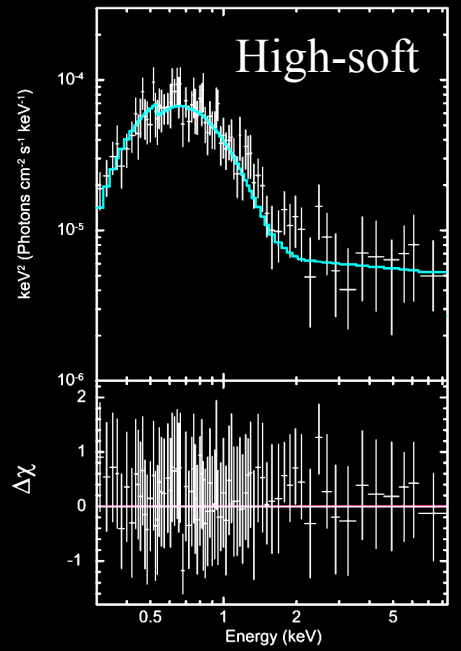


HLX-1 in ESO 243-39



Farrell+09, Webb+12 .. most likely a tidal disruption event



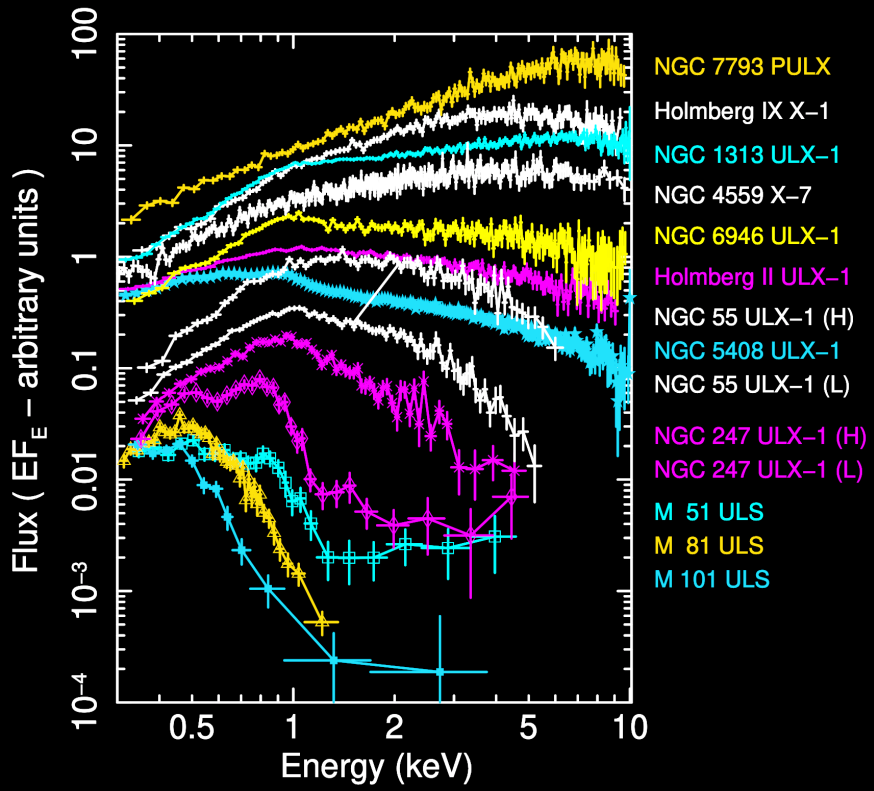


→ ***more on IMBH: Talk by A. Tiengo!***

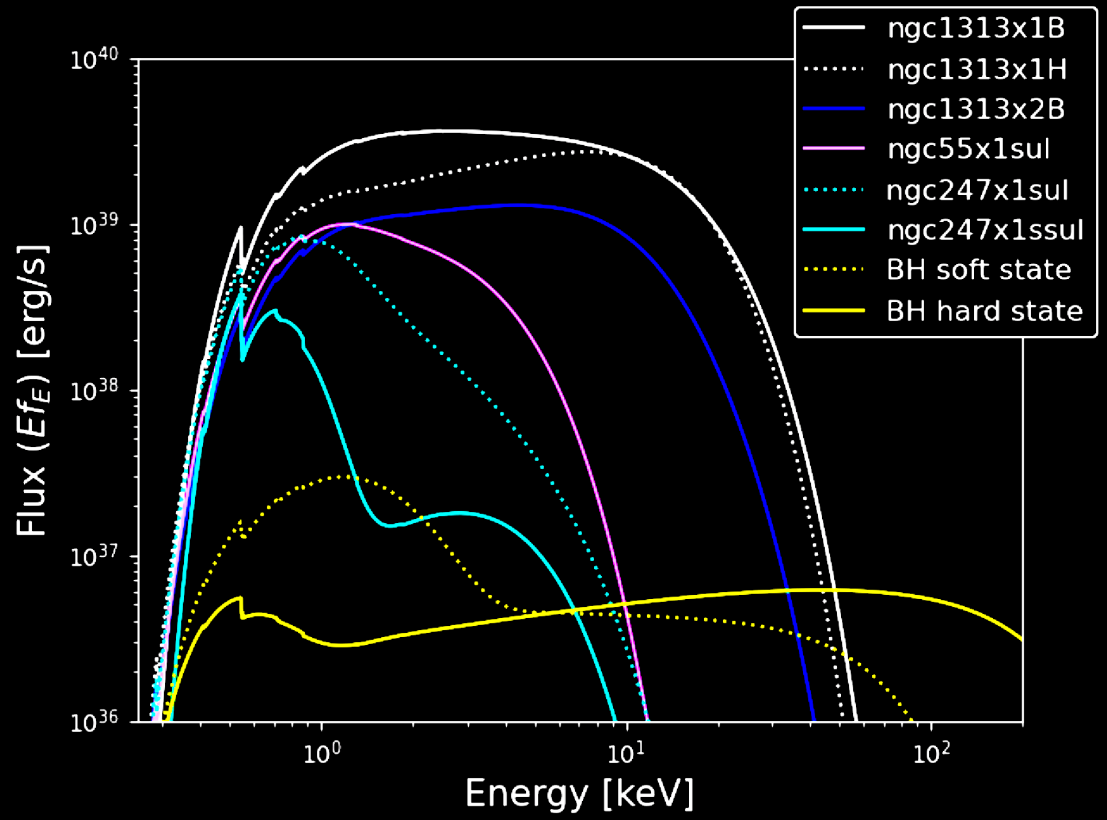
L_X^{peak} ~ 4×10^{42} erg/s

⇒ 10^{5} $M_\odot$ (Titarchuk+16)

ULX vs Galactic XRB states



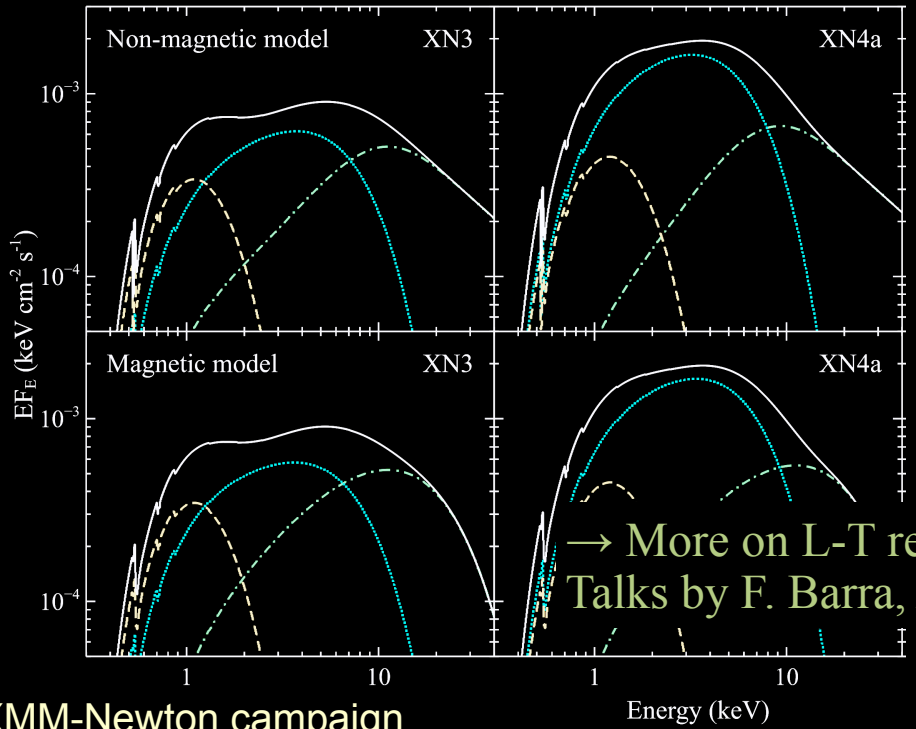
Pinto et al. (review, in prep)



Way much softer than Galactic XRB spectra …

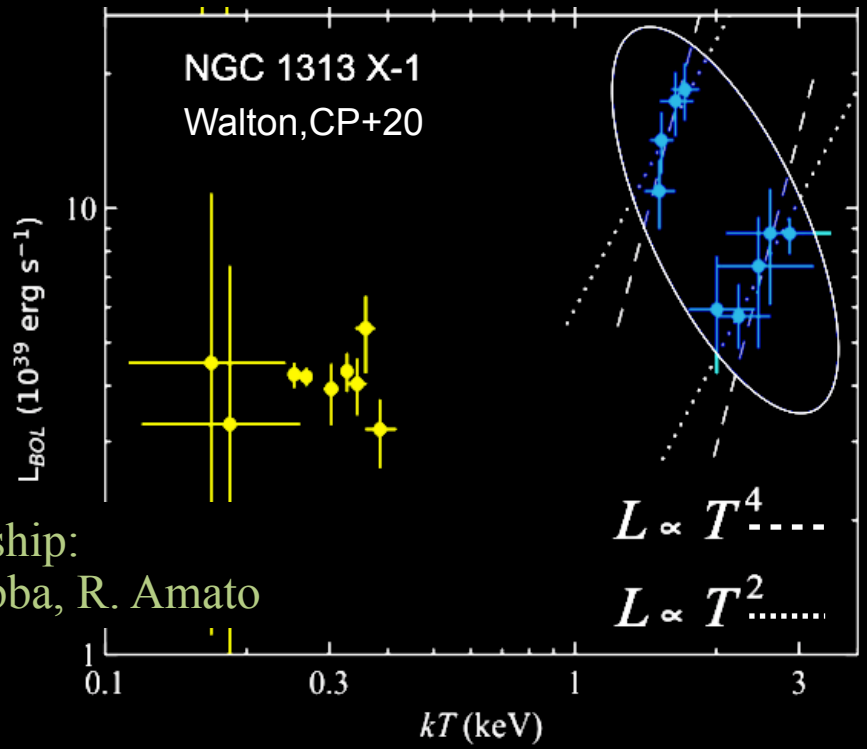
ULX spectral components

1. Cool (0.1-0.5 keV) blackbody
2. Hot (1-5 keV) disc (variable)
3. Hard (> 7 keV) powerlaw tail



XMM-Newton campaign

Luminosity – Temperature deviates from Shakura – Sunyaev thin disc: $L \neq T_{in}^{4}$



→ More on L-T relationship:
Talks by F. Barra, A. Robba, R. Amato

Spectral transitions, dips & flares

HUL ↔ SUL ↔ SSUL

More variable when brighter

Soft Dips of δt ~ 0.1 – 15 ks

Bonus slides:

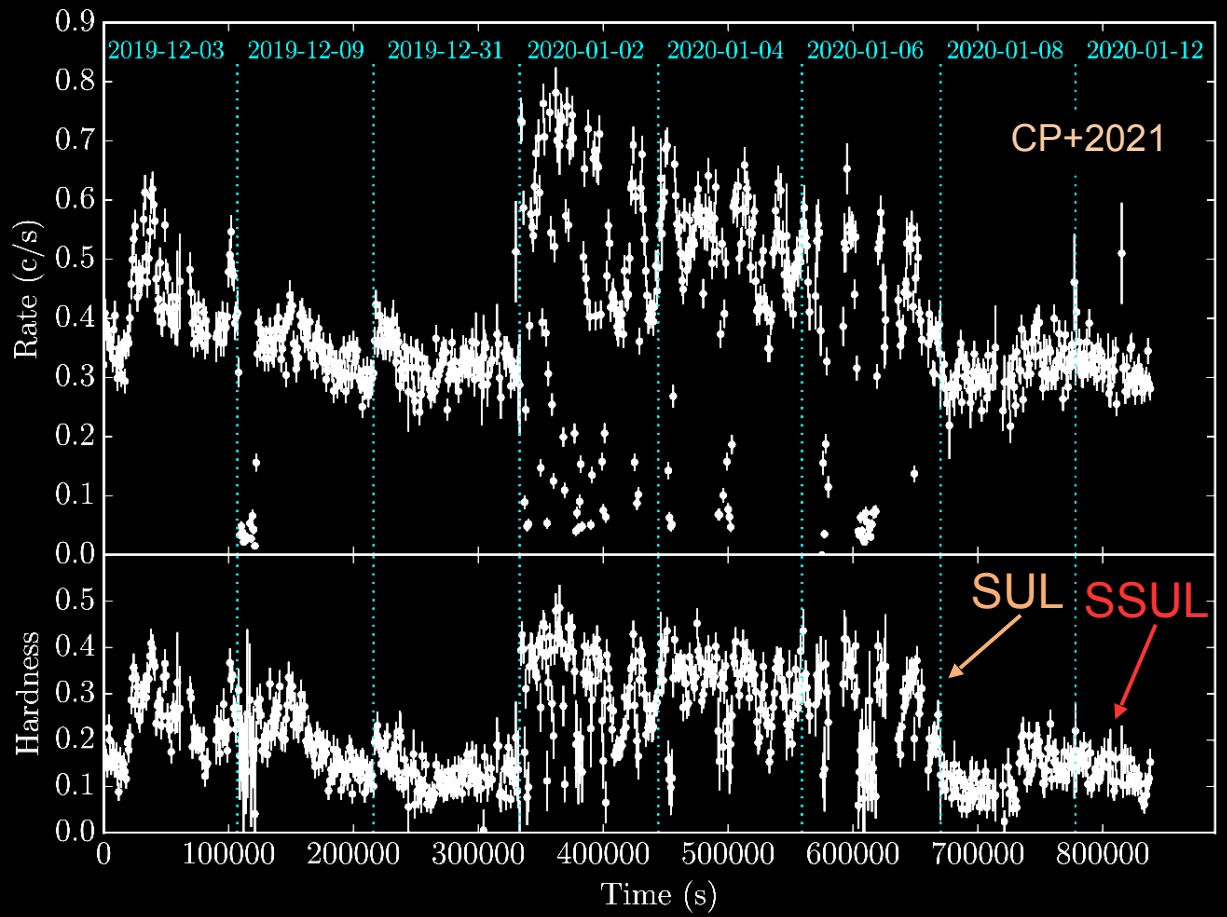
Quasi-period modulations (~ 1 ks)

Associated with dips (Alston, CP+21)

→ HUL flaring see talk by F. Pintore!

→ SUL dipping see talk by A. Robba!

XMM-Newton campaign on NGC 247 X-1



2 branches in the hardness-intensity diagram

Soft ↔ Supersoft transitions

1) **Main branch** shows **R ∝ T^{-2}**

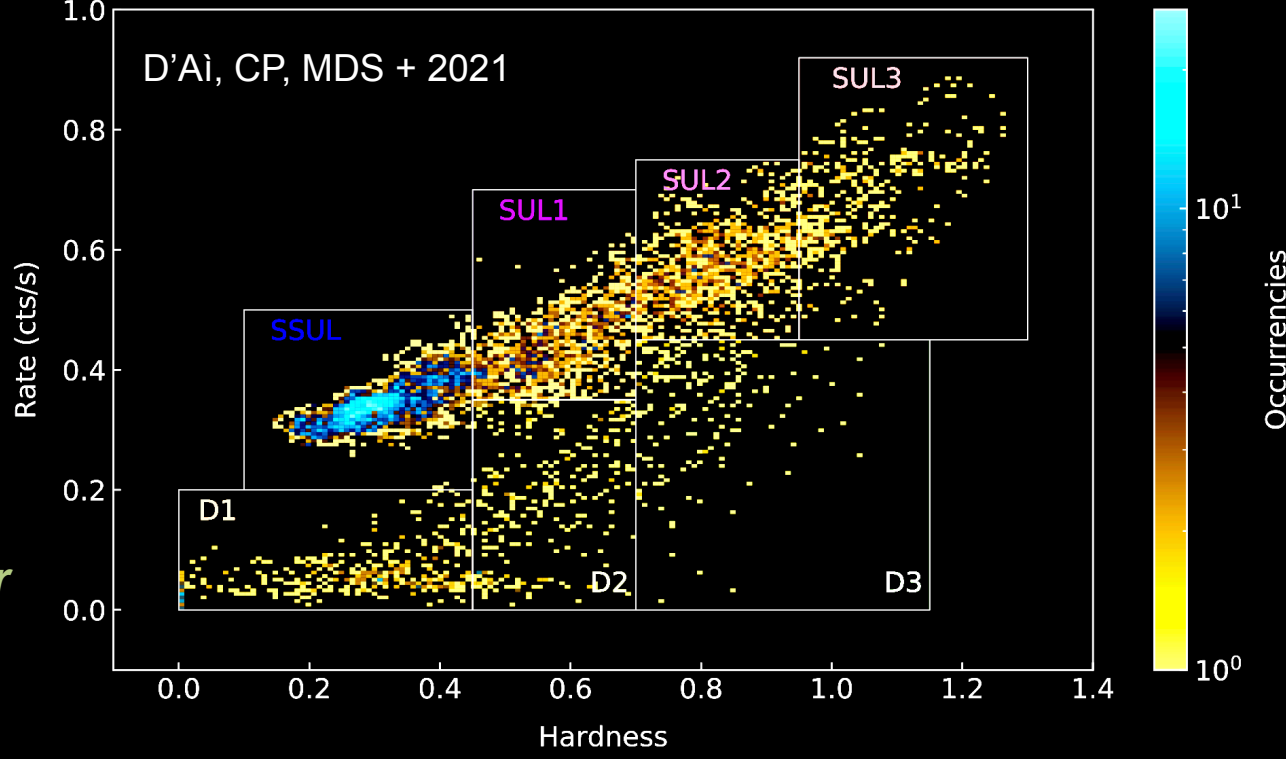
→ *outflowing photosphere*?

2) **Dip branch** L_{max} ~ 5 · 10^{39} erg/s

down to L_{dip} ~ 2 · 10^{38} erg/s

→ propeller? → B ~ 2·10^{11} G

→ ***more on spectroscopy & propeller***
Talks by R. Amato & F. Pintore

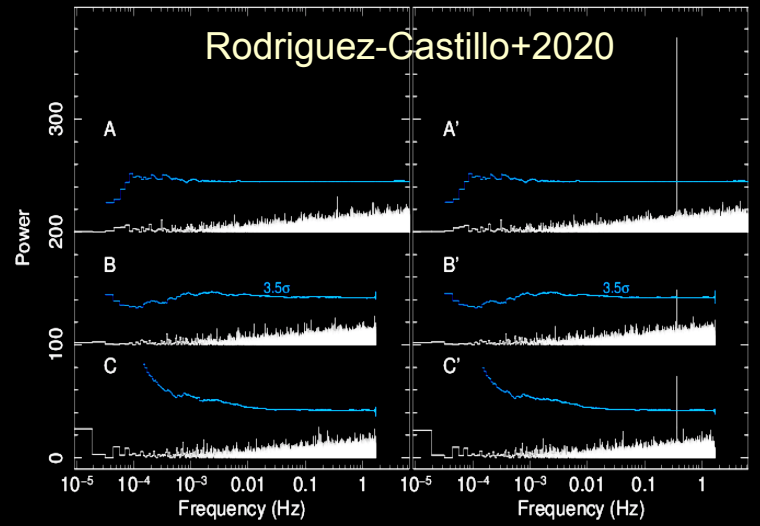


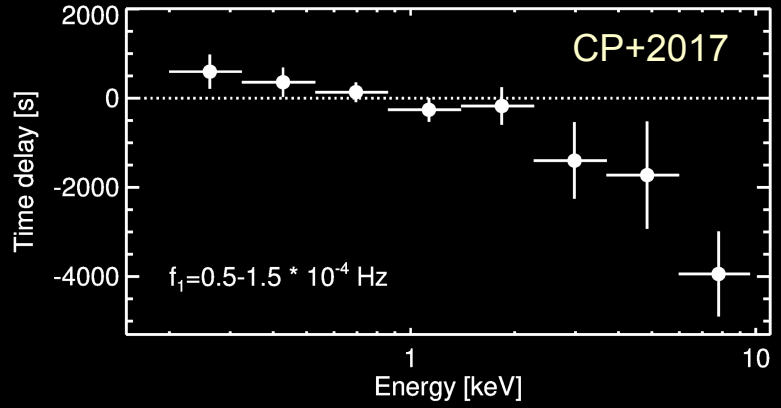
A few highlights on timing

- (Transient) pulsations in *20-25% of high quality data*
- Magnetic fields → $10^{10\text{-}14}$ G, depending on approach
- Quasi-periodic oscillations, difficult to interpret
- HUGE soft-energy time lags (~ 1 ks)

→ ***more on time lags talks by F. Pintore & A. Robba***

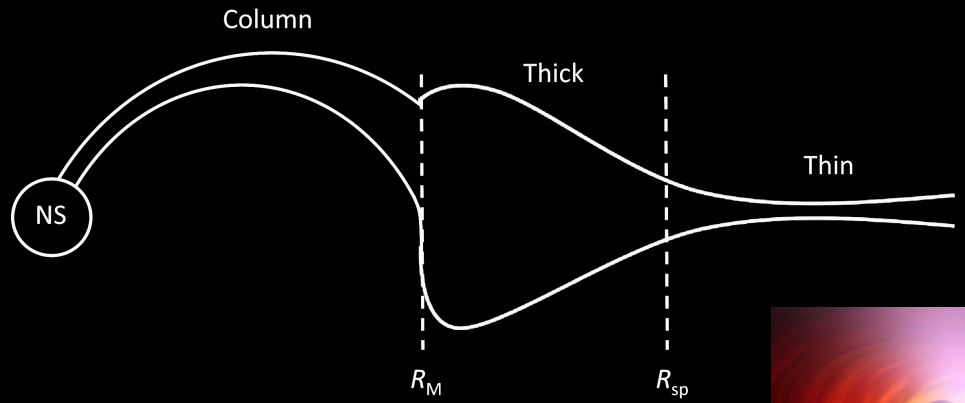
→ ***more on QPO/PDS talks by M. Imbrogno & E. Byad***

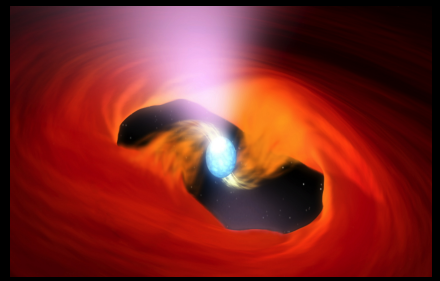




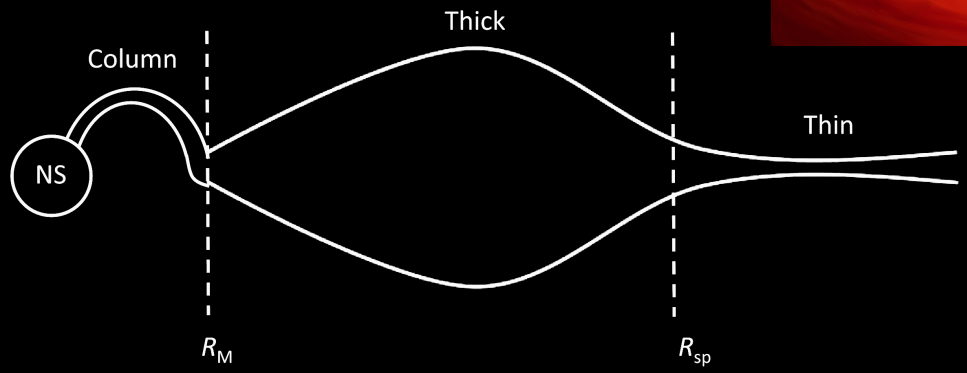
Cyclotron Resonance Scattering Features

Strong magnetic field

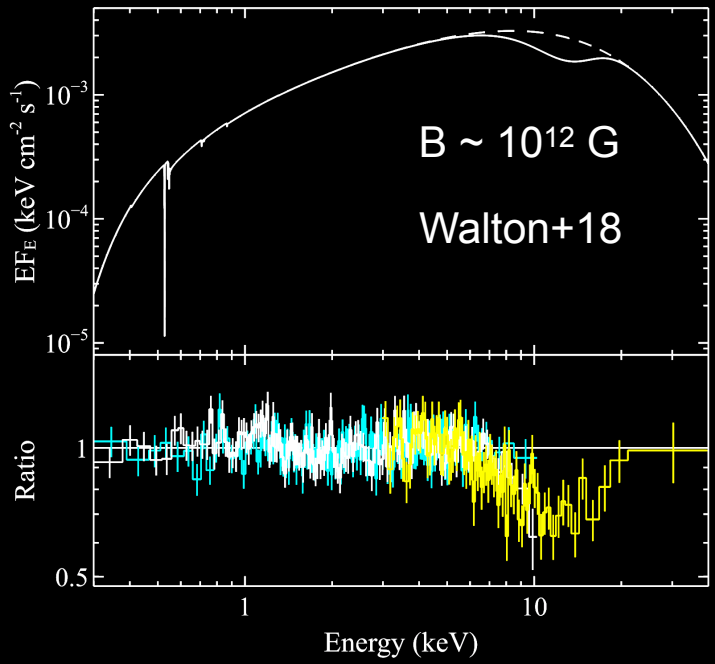




Weak magnetic field



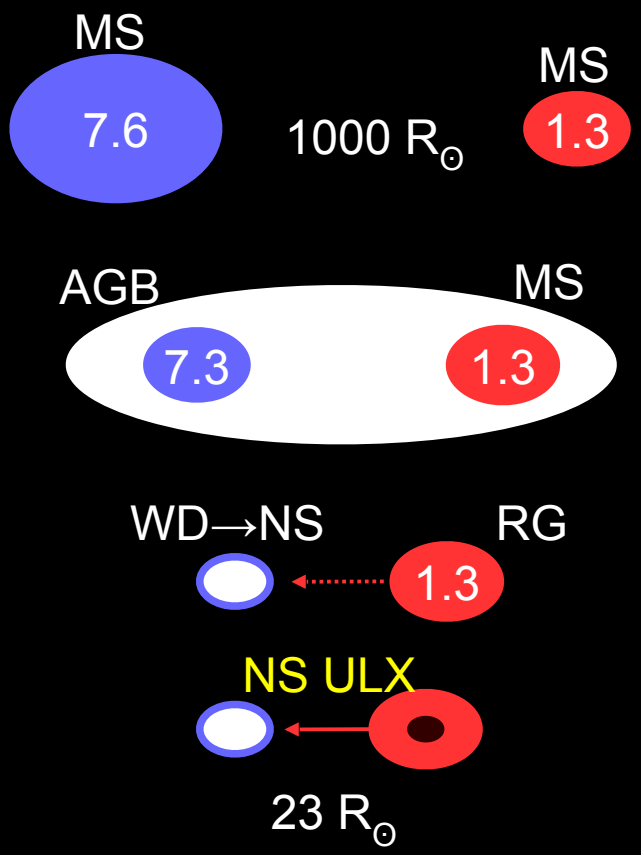
NGC 300 pULX-1



Electrons → $\Delta E_{CRSF} = 11.6\ (B/10^{12}G)\ (1+z_{grav})^{-1}$

Protons → $\Delta E_{CRSF} = 6.3\ (B/10^{15}G)\ (1+z_{grav})^{-1}$

What's the companion star? The accretion rate?



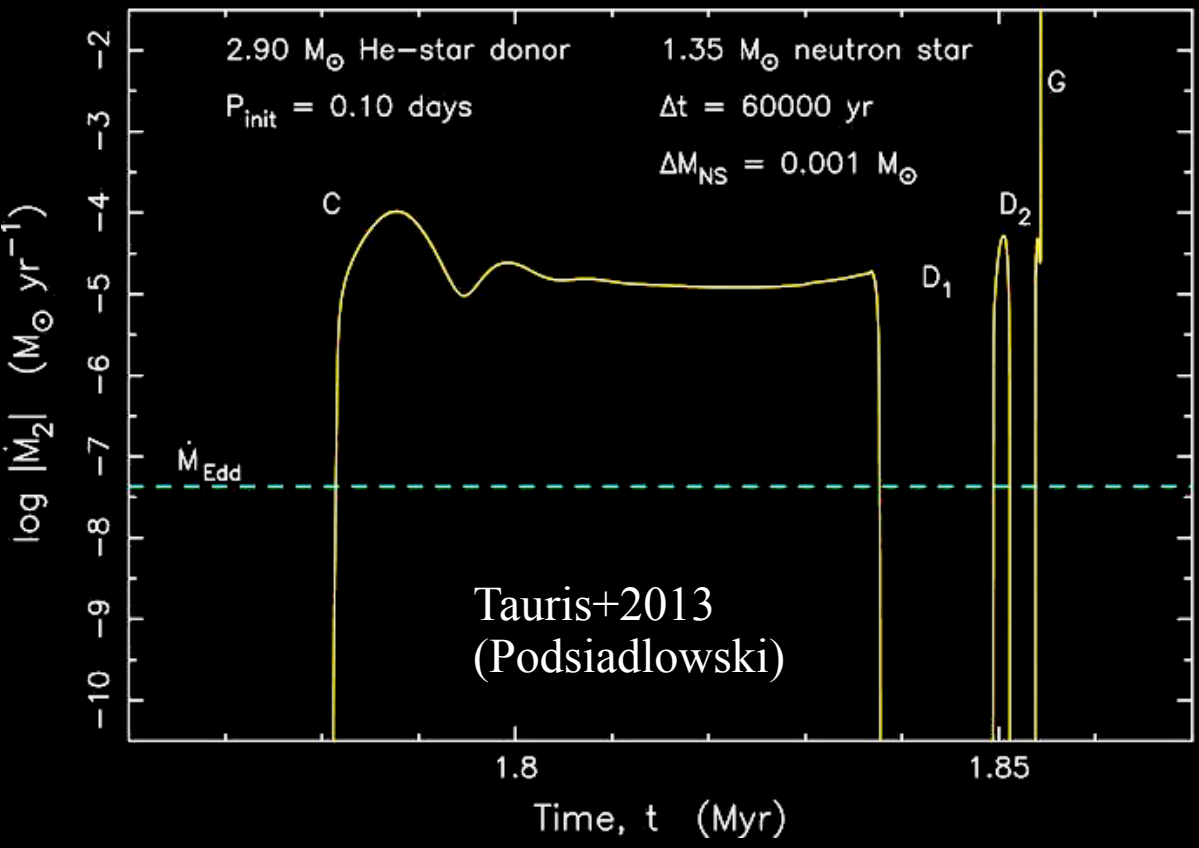
t (Myr)

0

46

4200

4200

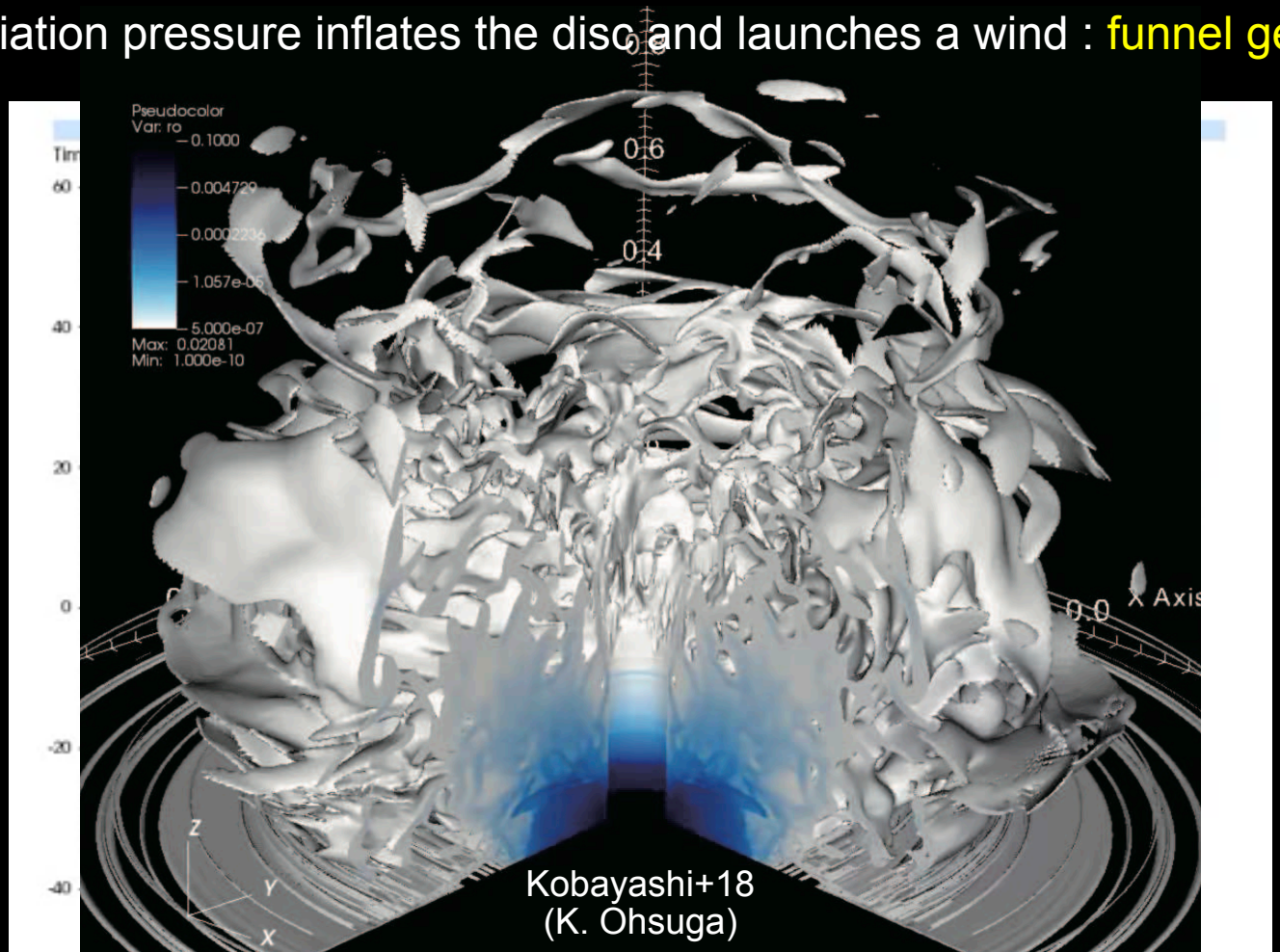


Wiktorowicz+2017, Mondal+2020

Optical counterparts: RSG / BSG
Heida+2015.., Lopez+2017.. (&Jonker)

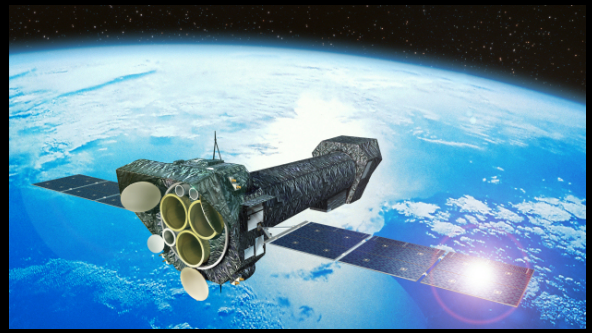
Super-Eddington accretion disc & winds

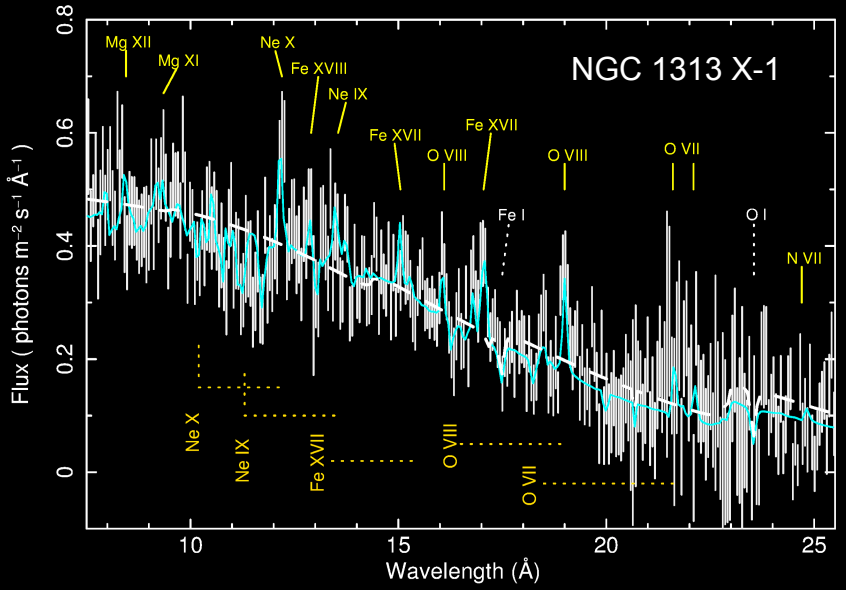
The radiation pressure inflates the disc and launches a wind : funnel geometry

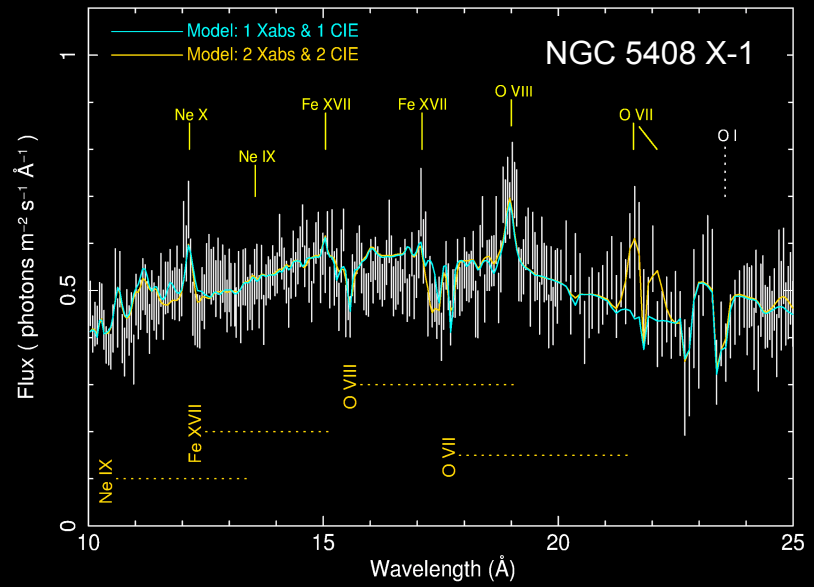


Atomic lines identify mildly-relativistic winds

- Emission lines close to laboratory wavelengths
- Absorption lines blueshifted by ~ 0.2c





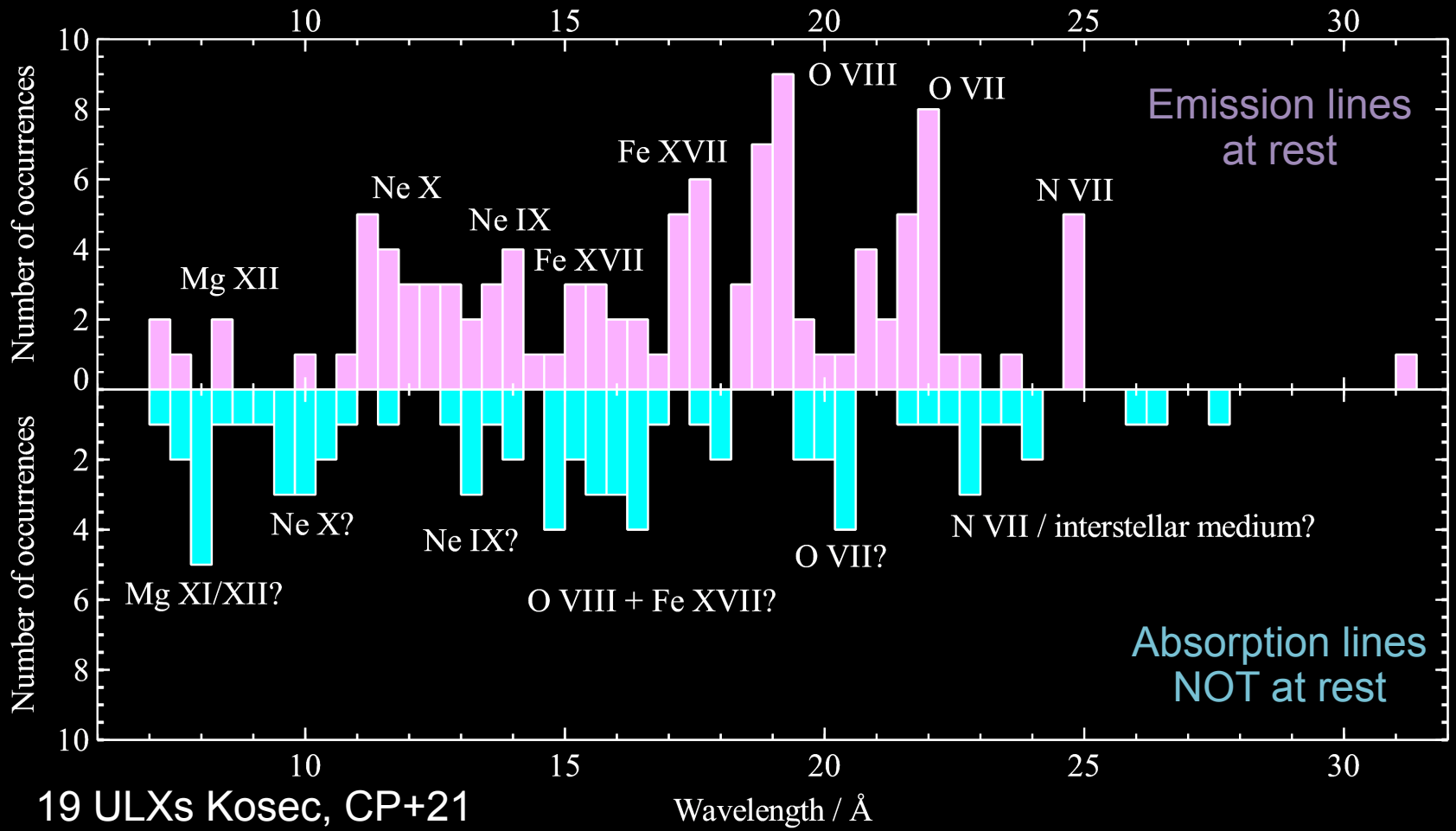


350ks

CP + 2016 *Nature*-21, Walton + 2017
Kosec + 2018-21, Koliopanos + 2018, Wang + 2019

550ks

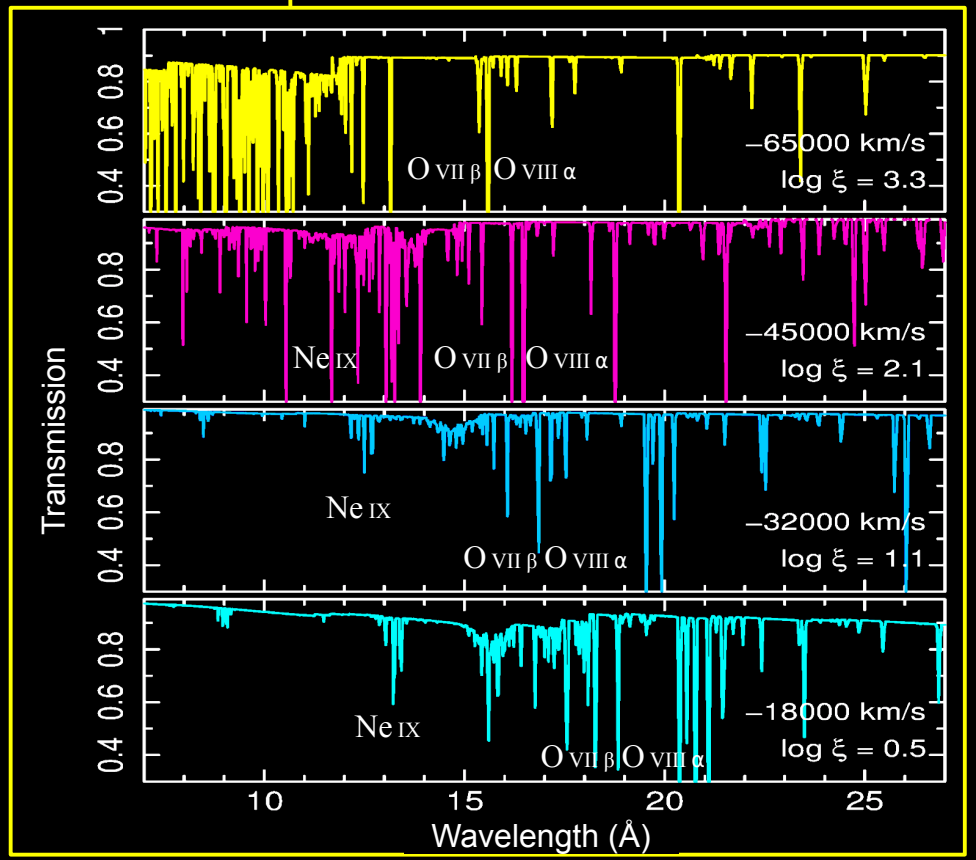
A census of identified spectral lines in ULX

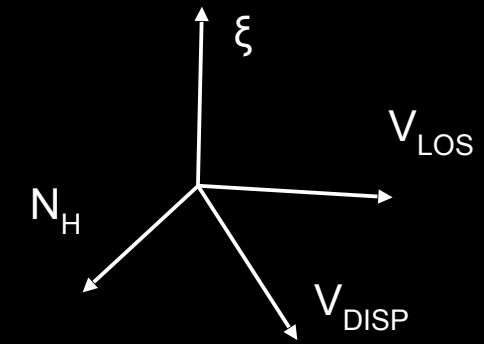


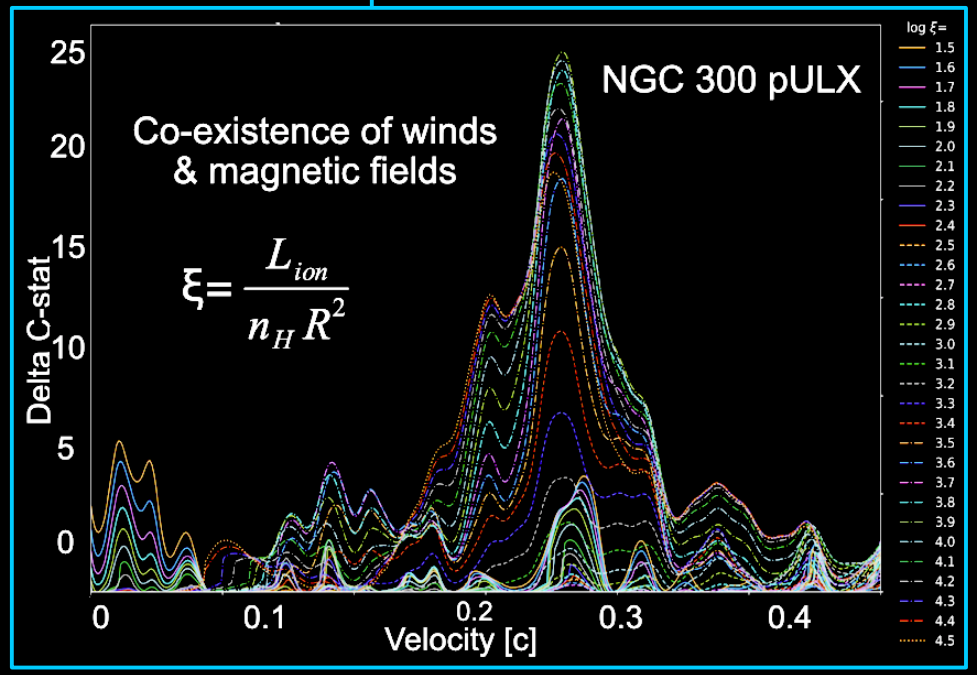
19 ULXs Kosec, CP+21

Multi-dimensional scan

Grid examples / multi-dimension scan

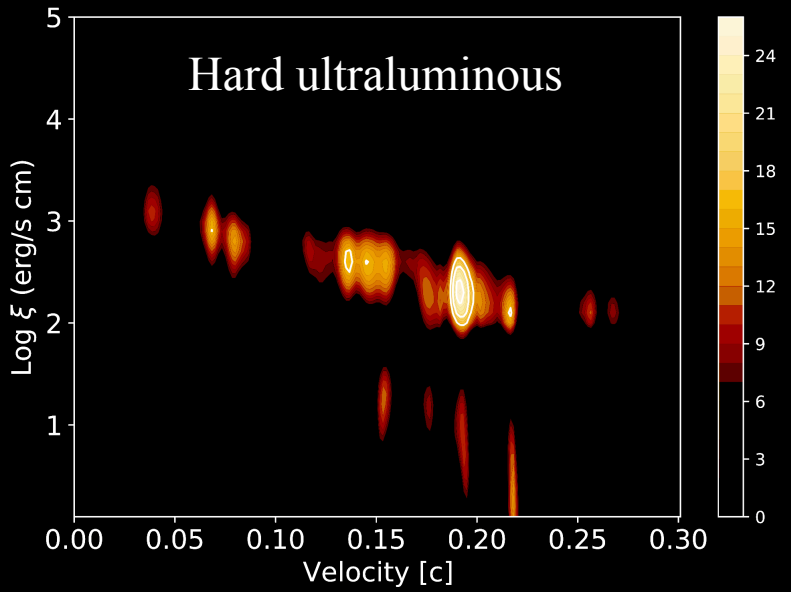




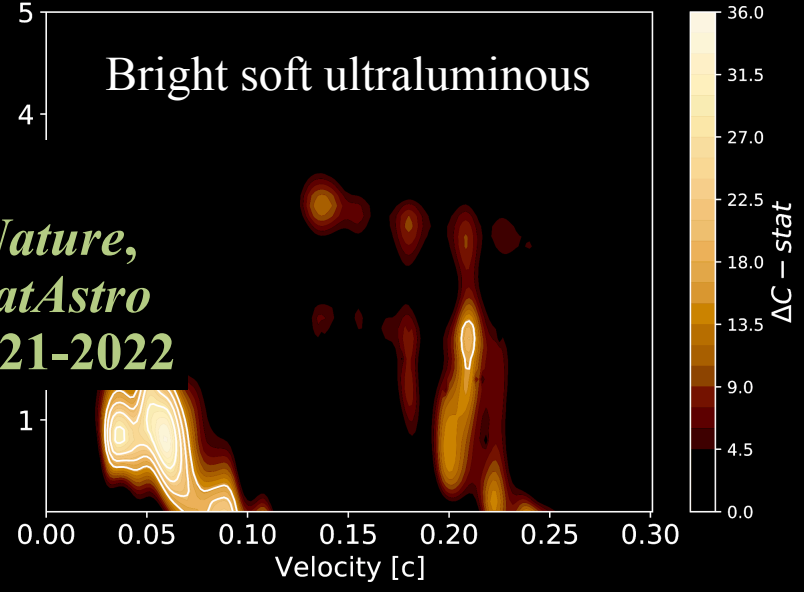


CP + 2016-21, Kosec + 2018-21

Wind vs. Continuum: absorption lines

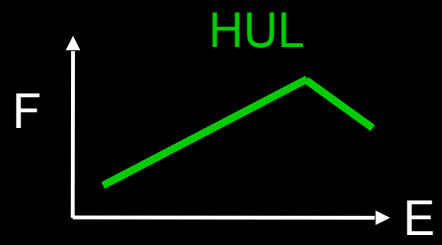


→ Also in AGN!!!
Parker, CP + 2017 *Nature*,
Alston, CP+ 2020 *NatAstro*
CP+20, Xu, CP + 2021-2022

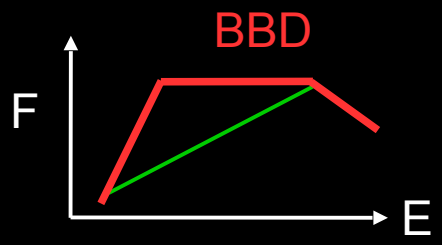


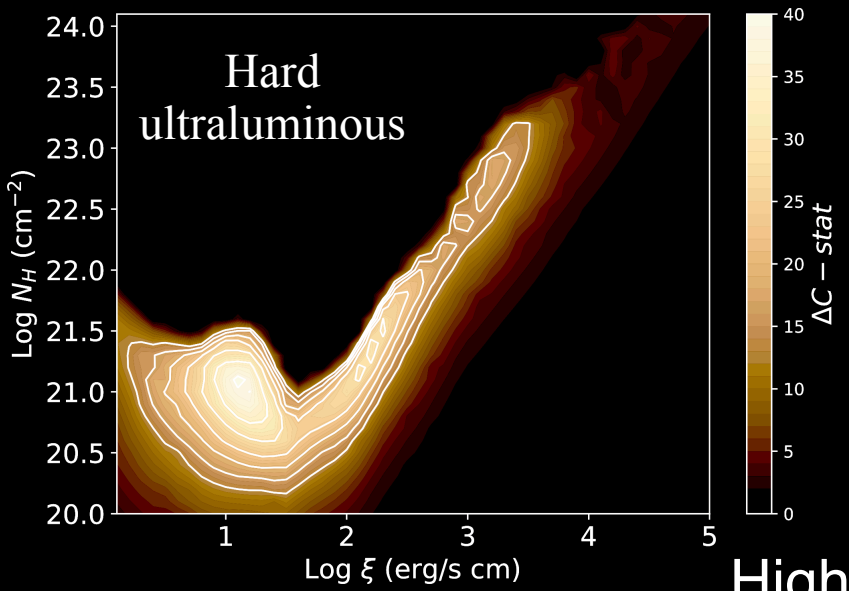
CP + 20b

Wind vs. Continuum: emission lines



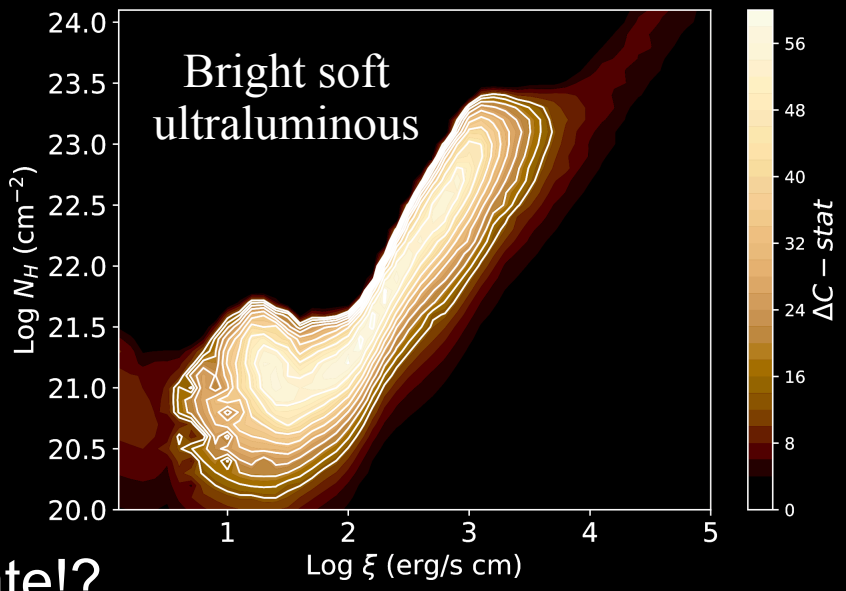
Brightening & Softening





Emitting Component

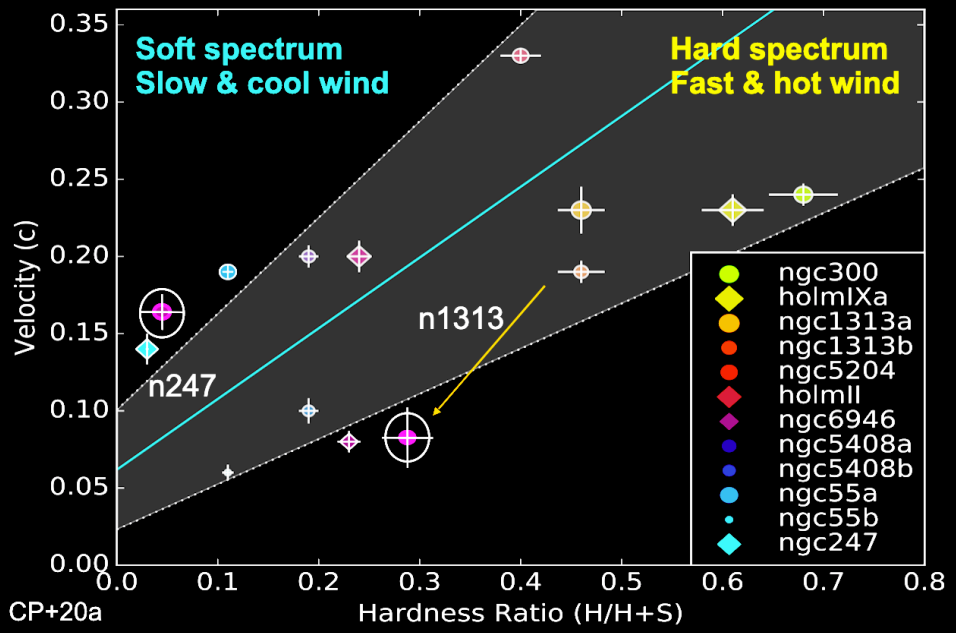
At rest



Higher accretion rate!?

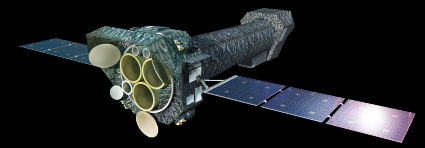
Wind properties to probe inclination & $\dot{M}$

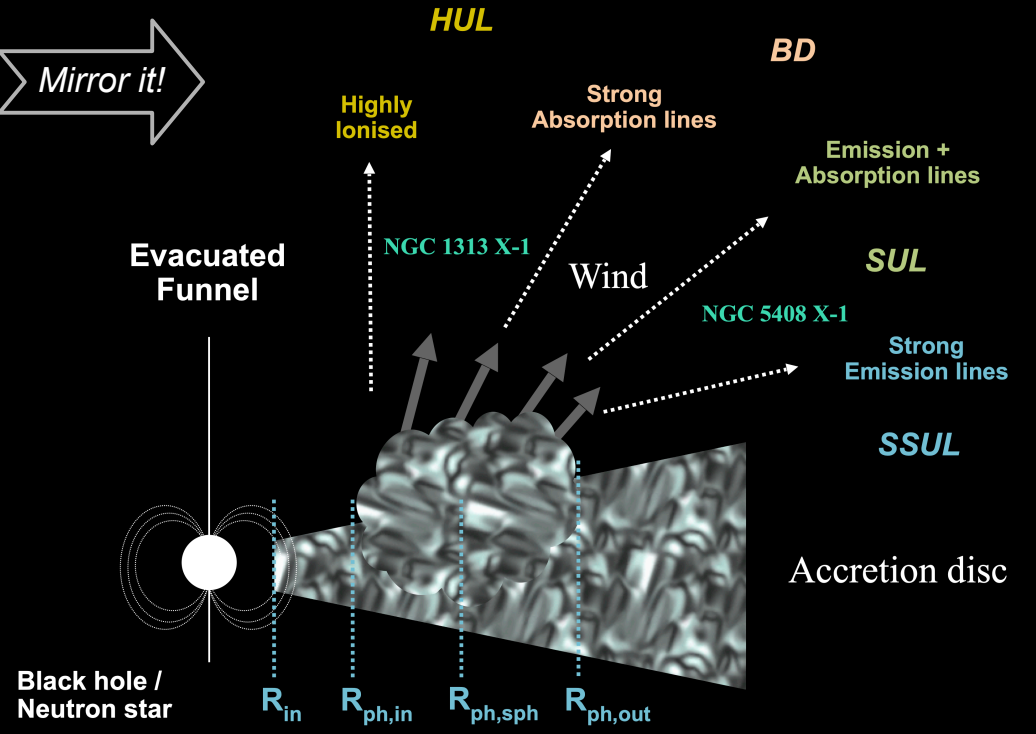
- Harder spectra exhibit faster and hotter outflows
- Different launching radii?



Colour = ionisation parameter

Mirror it!





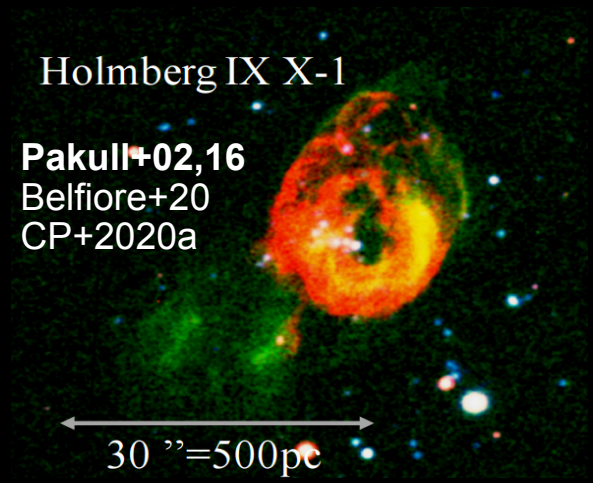
Can the winds *power* ULX bubbles?

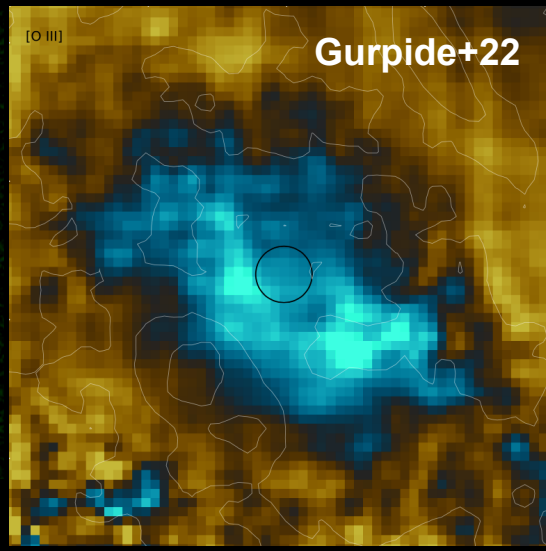
Kinetic power :

$L_{wind} = \frac{1}{2} \dot{M}_{out} v^2$

$= 2 \pi m_p \mu \cdot \Omega C \cdot L_{ion} \frac{v^3}{\xi}$

$\approx 10^{39\text{-}40}$ erg s^{-1}





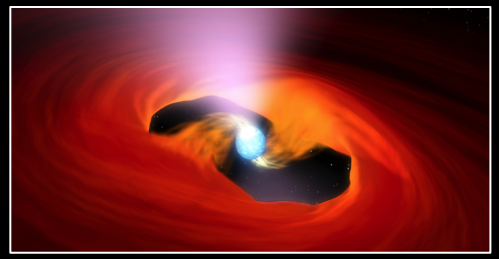
Up to ~ 50% of the total budget!

Required mechanical power :

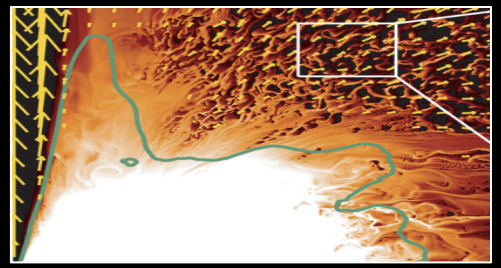
$L_{Mechanical} \geq 10^{39}$ erg/s

Pakull+02,16
Belfiore+20
CP+2020a

($\dot{M}_{out} = 4 \pi R^2 \rho v^2 \Omega C$, $\xi = L_{ion} / n_H R^2$, $\rho = n_H m_p \mu$)



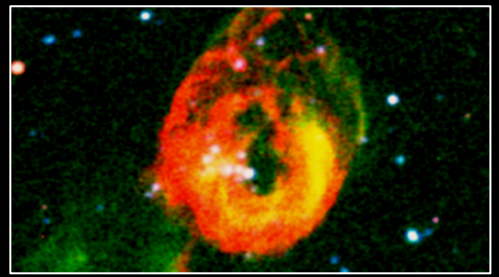
Take away message

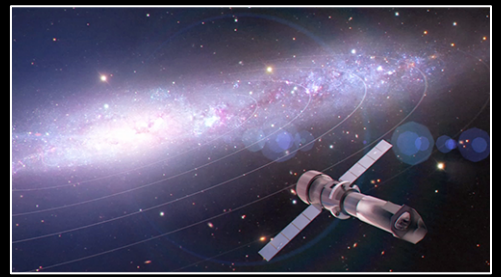


ULXs are ideal probes of **extreme** accretion rates and (stellar) feedback

Past & present facilities (especially XMM) unveiled ULX spectacular **phenomenology**

… and the **future** …

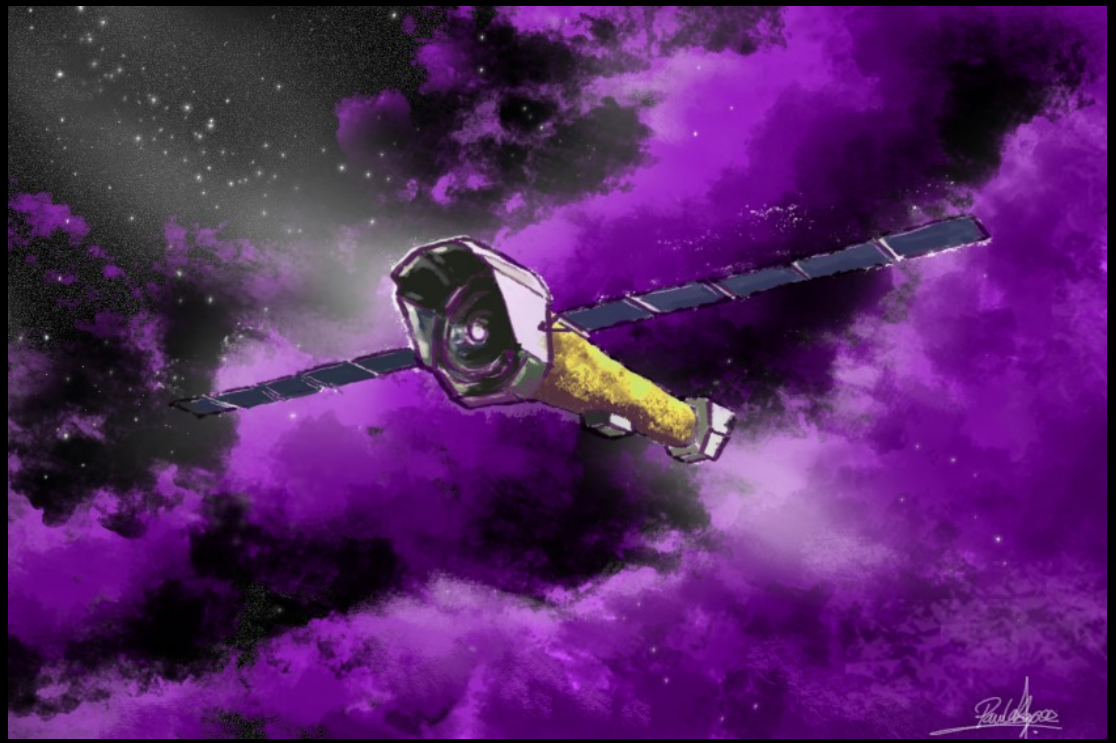




Current limitations & Future advances

- Cyclotron RSFs only a few ULXs
- Time lags only a few ULXs
- What about *non*-pulsating / CRSFs?
- L-T $^{\alpha}$ trends differ → $ULX_{BH} \neq ULX_{NS}$?
- Spectral transitions → $\dot{M}_{in}$, $\dot{M}_{wind}$ or î ?
- Winds are transients → $\dot{M}_{in}$ or î?
- How much is $\dot{M}_{net}$ → $\dot{M}_{wind}$ = ?

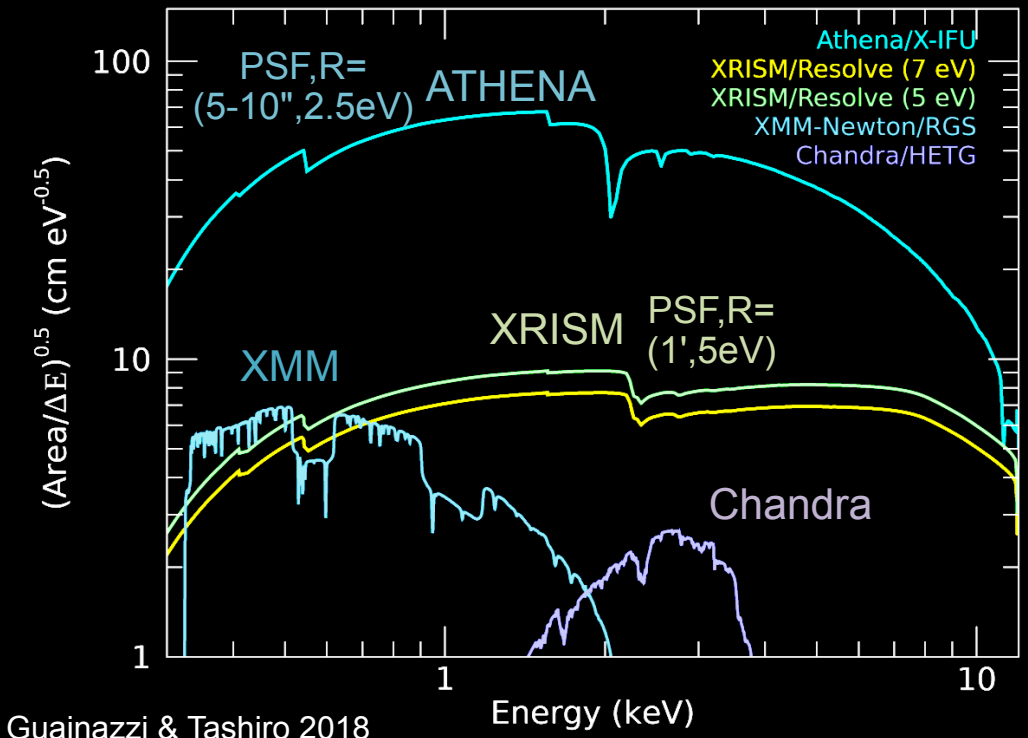
On what timescales and how do the properties of disc, wind & pulsations (inter-)change?



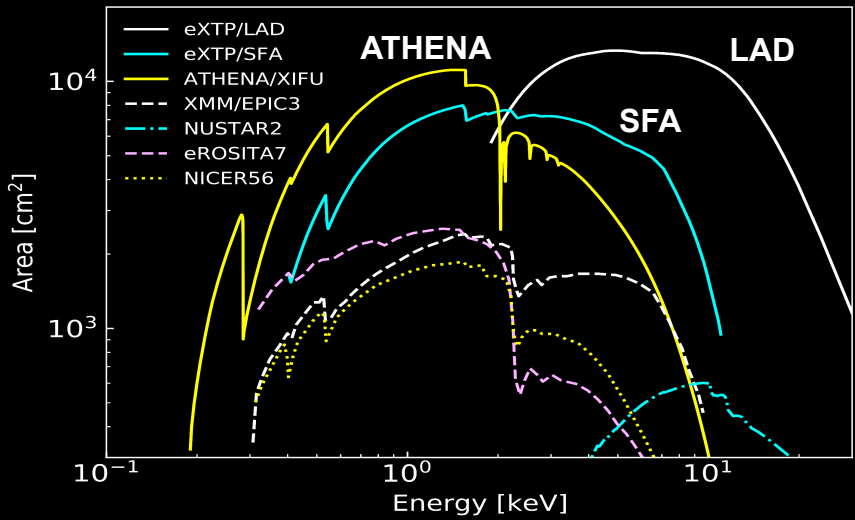
Current & Future X-ray missions

High-res spectroscopy

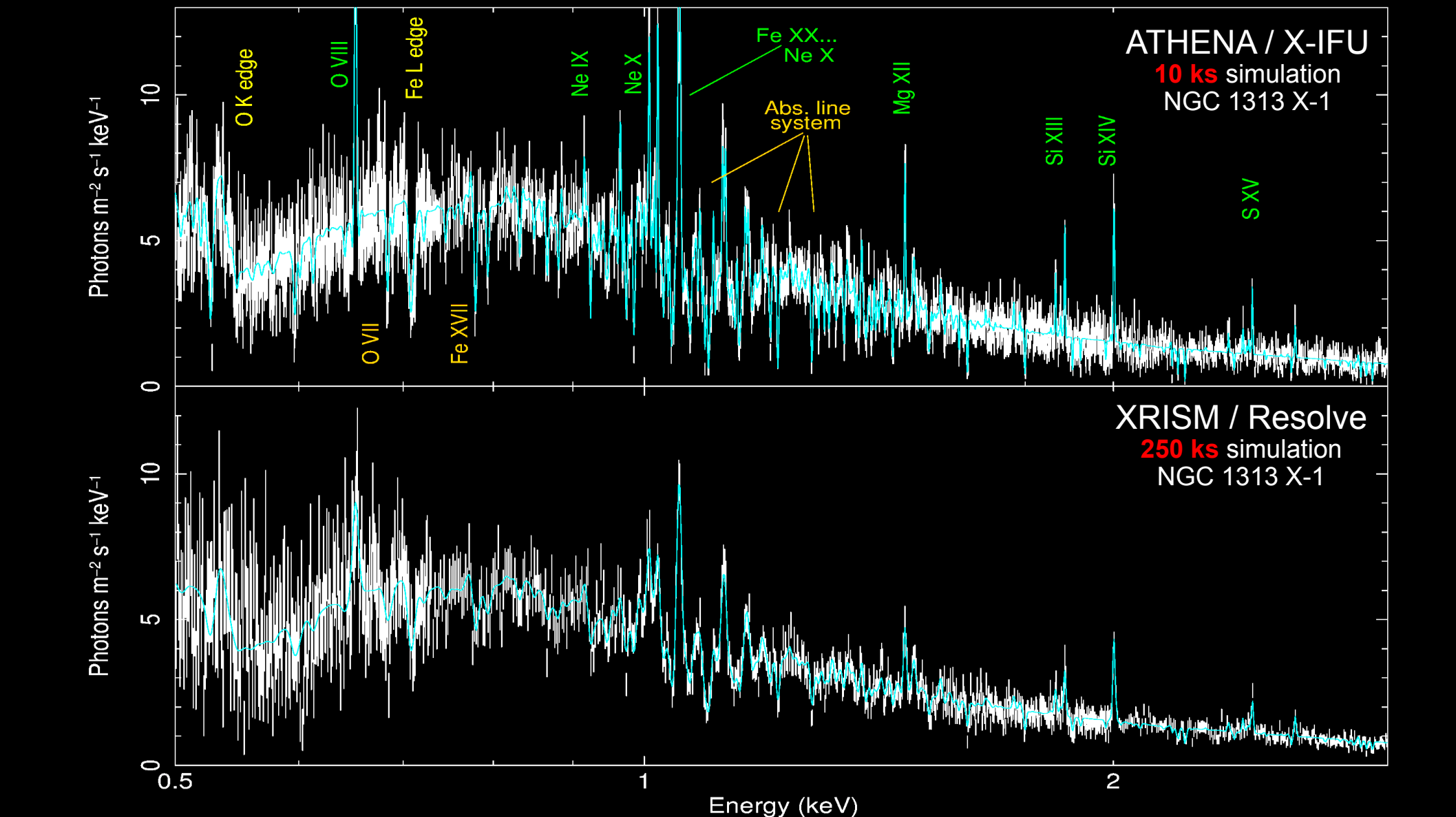
Broad-band spectroscopy



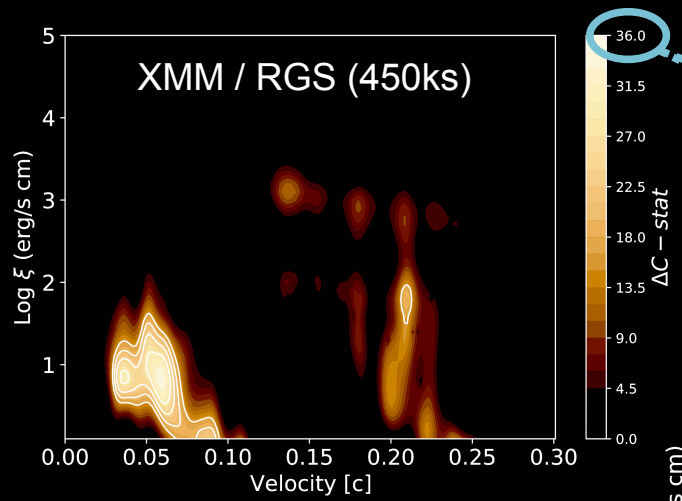
Guainazzi & Tashiro 2018

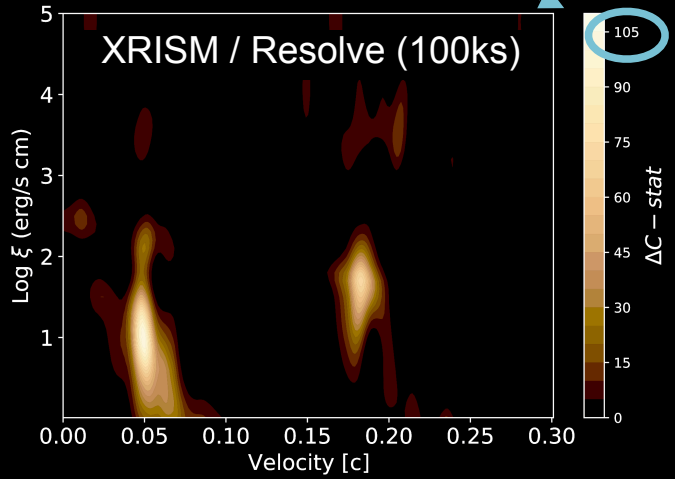


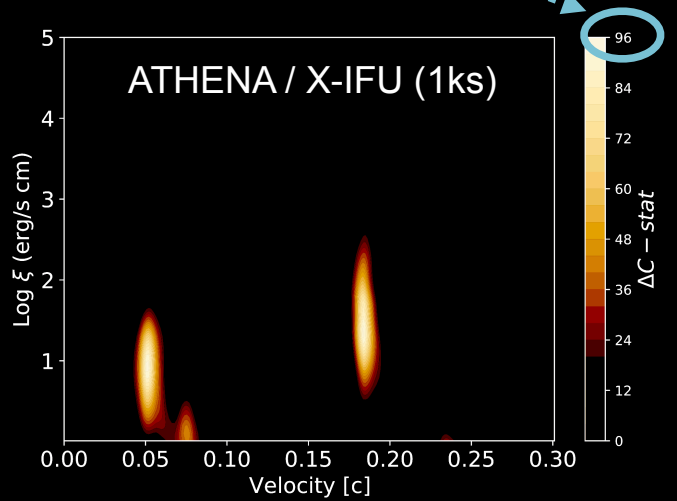
Zhang+2016


ATHENA / X-IFU
10 ks simulation
NGC 1313 X-1
XRISM / Resolve
250 ks simulation
NGC 1313 X-1
O K edge
O VIII
Fe L edge
Ne IX
Ne X
Fe XX...
Ne X
Abs. line system
Mg XII
Si XIII
Si XIV
S XV
O VII
Fe XVII
Photons m⁻² s⁻¹ keV⁻¹
Energy (keV)
0
5
10
0.5
1
2

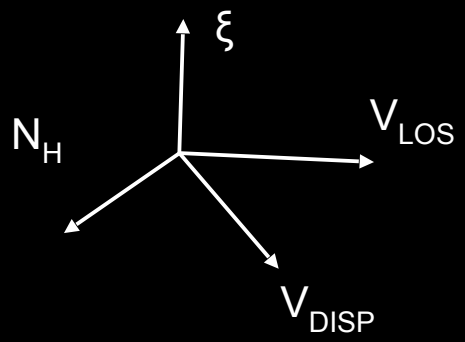
Resolving the wind at smaller time scales







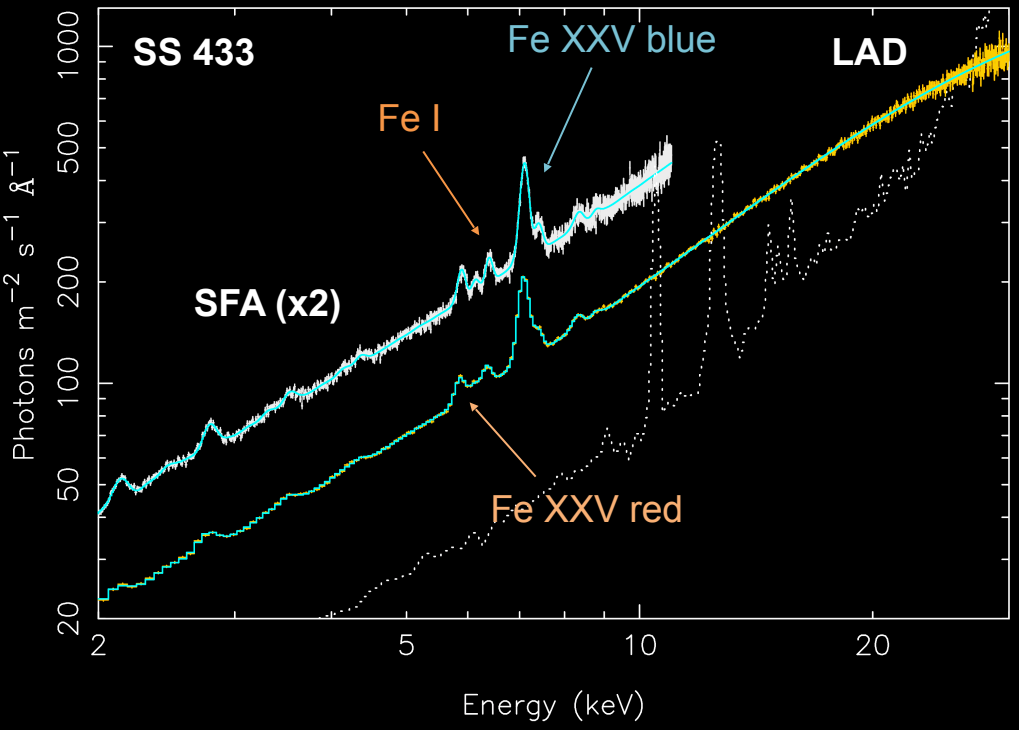
→ Bright soft state ←



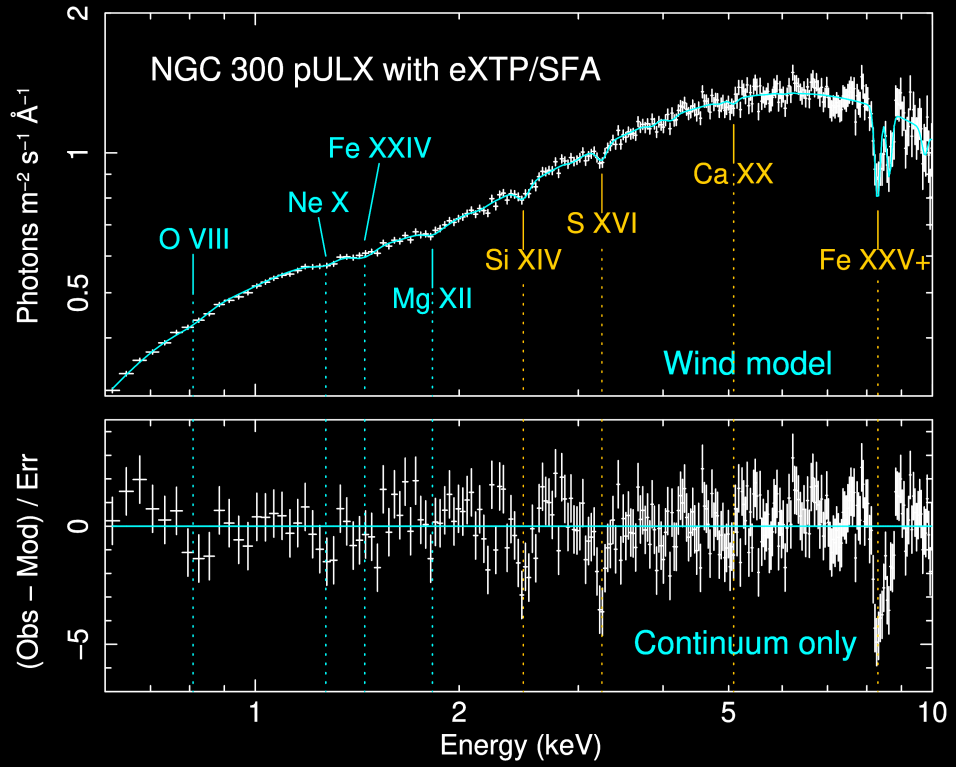
CP+20b

Enhanced X-ray Timing & Polarimetry Mission

Detecting jets in SS 433 (& bright ULXs)



Detecting winds in hard ULXs & pulsars



Thanks!

You can find many of my codes here:

https://github.com/ciropinto1982

You can email me here:

ciro . pinto [at] inaf . it