Maxime Parra, Pierre-Olivier Petrucci, Stefano Bianchi, Vittoria Elvezia Gianolli, Francesco Ursini, Gabriele Ponti

The current state of disk wind observations in galactic Black Hole LMXBs through X-ray absorption lines

https://arxiv.org/abs/2308.00691

Université Grenoble Alpes

High Resolution X-ray Spectroscopy 2023| 03-08-23

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The current context

The current context

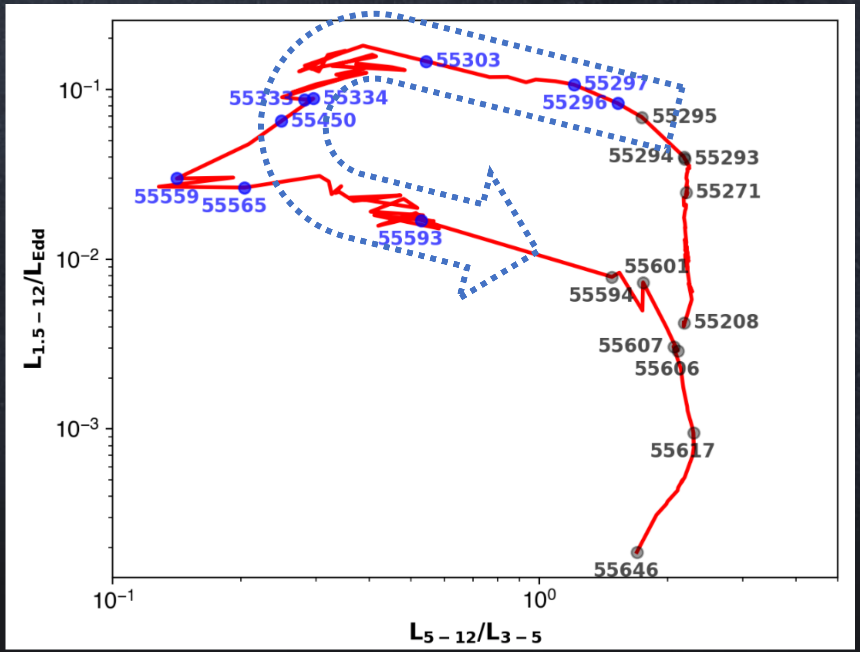
- Accretion in Black Hole X-ray Binaries

❑ Low-Mass X-ray Binaries

- Accretion through Roche-Lobe overflow → Accretion disk

Switch between two standard states

Soft State



Hard State

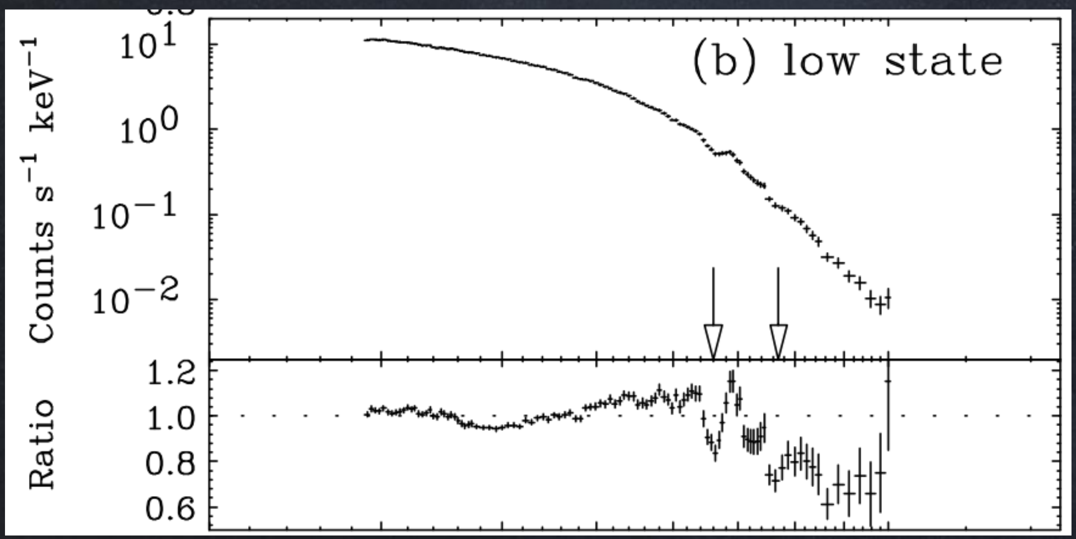
Petrucci et al. 2021

The current context

- Wind detection in Black Hole X-ray Binaries

❑First detections of blueshifted narrow absorption lines before 2000 (Ueda et al. 1998, Kotani et al. 2000)

- material + low speed = not jet



The current context

- Wind detection in Black Hole X-ray Binaries

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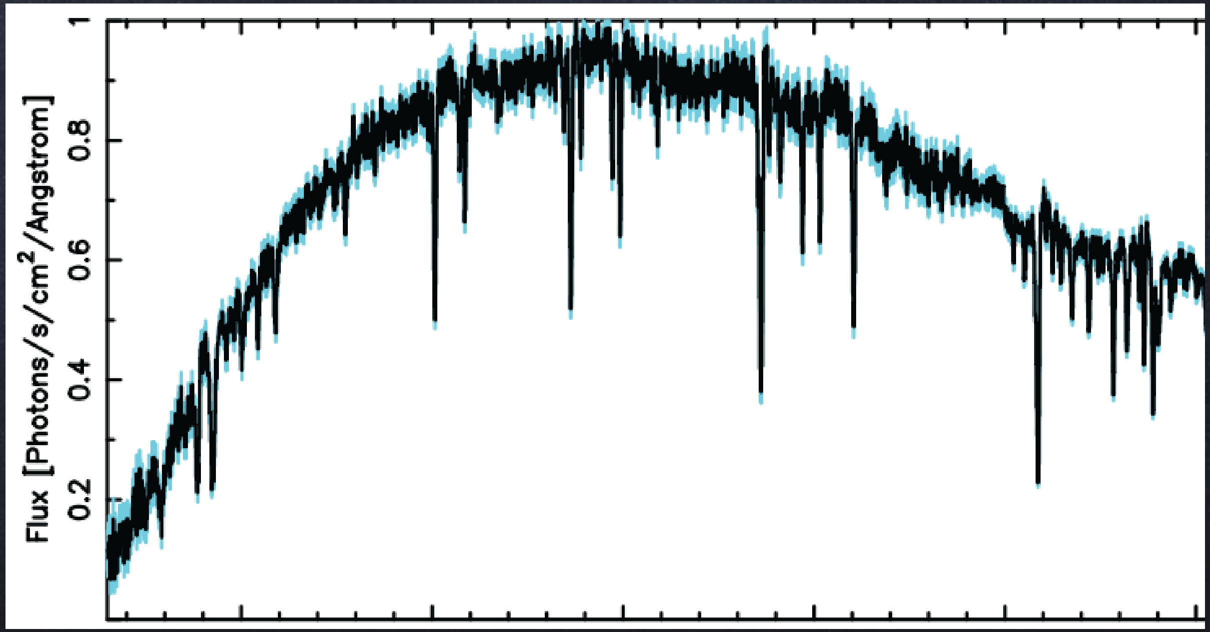
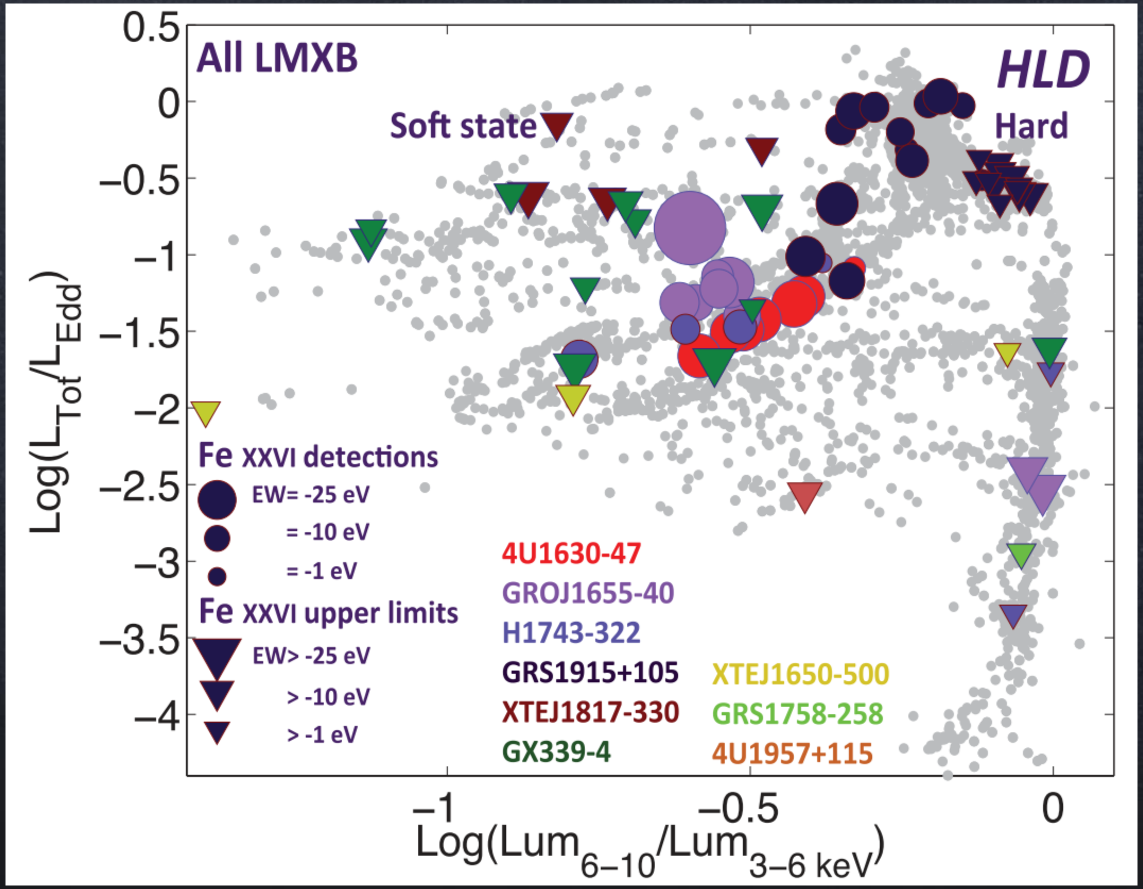


Miller et al. 2008

The current context

- Wind detection in Black Hole X-ray Binaries

❑ First global analysis by Ponti et al. in 2012



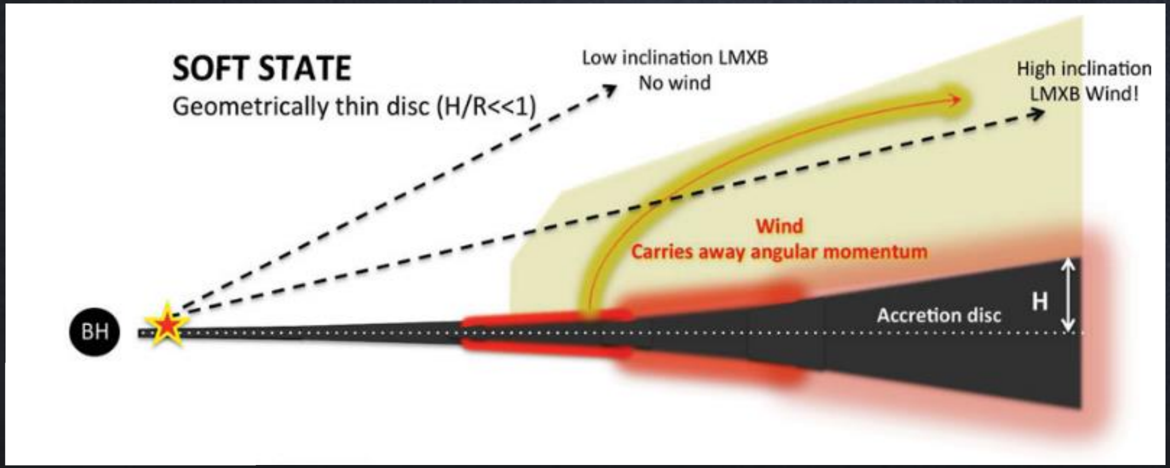
The current context

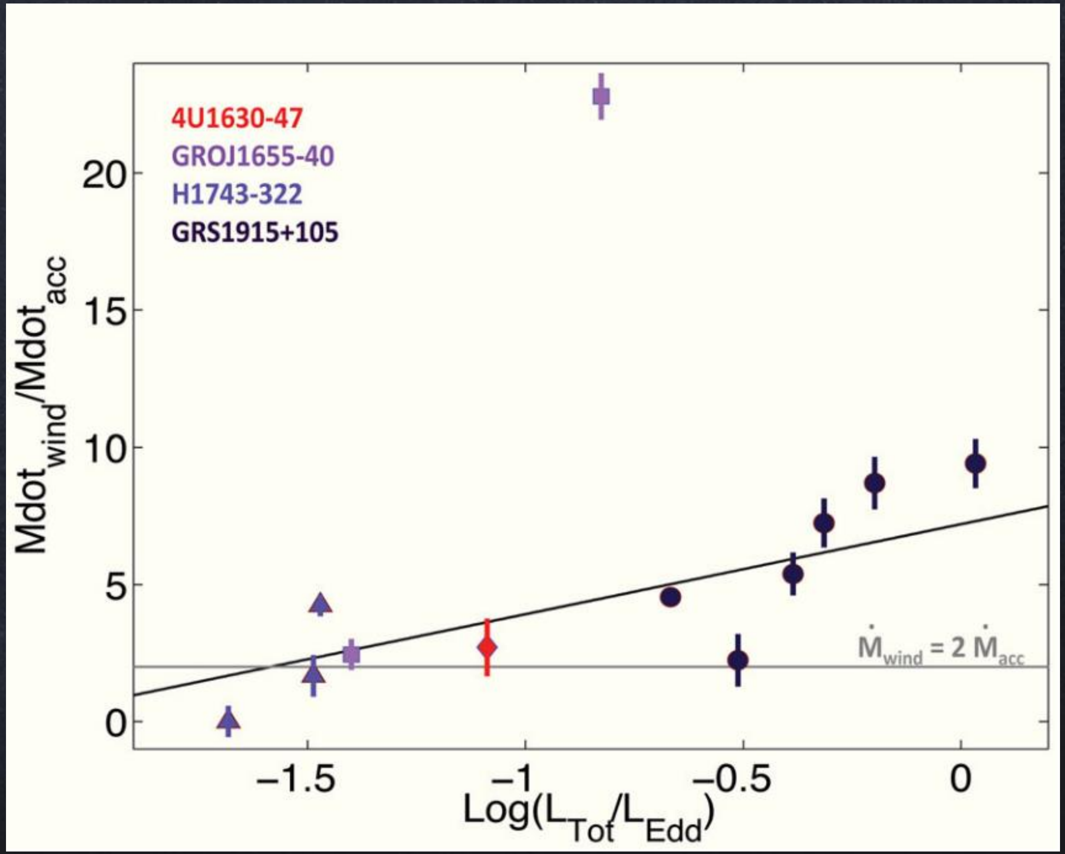
- Wind detection in Black Hole X-ray Binaries

❑First global analysis by Ponti et al. in 2012

❑Winds → soft state

→ high inclination





The current context

- Wind detection in Black Hole X-ray Binaries

The picture is much more complex now:

- ❑Explain more exotic detections ?
- ❑Thermal and/or MHD driving to launch the gas ?
- ❑Build a coherent picture combining all wavelengths ?

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Methodology

Methodology

- Main elements

❑Sample of sources

- All the BHLMXB candidates from BlackCAT[1] + WATCHDOG[2]

  68 sources + 13 more

❑Available spectra where we can detect lines of EW<75eV

- For XMM EPIC PN exposures -> 137 "good" spectra
- For *Chandra* HETG exposures -> 102 "good" spectra
- 42 sources have at least one 'high-quality' spectrum

❑A line detection procedure

[1] Corral-Santana et al. 2016 [2] Tetarenko et al. 2016

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Methodology

- Line detection

❑Methodology

Data reduction

↓

Continuum Fit

↓

Blind Line Search

↓

Line fit / Upper limit computation

❑Line significance assessment

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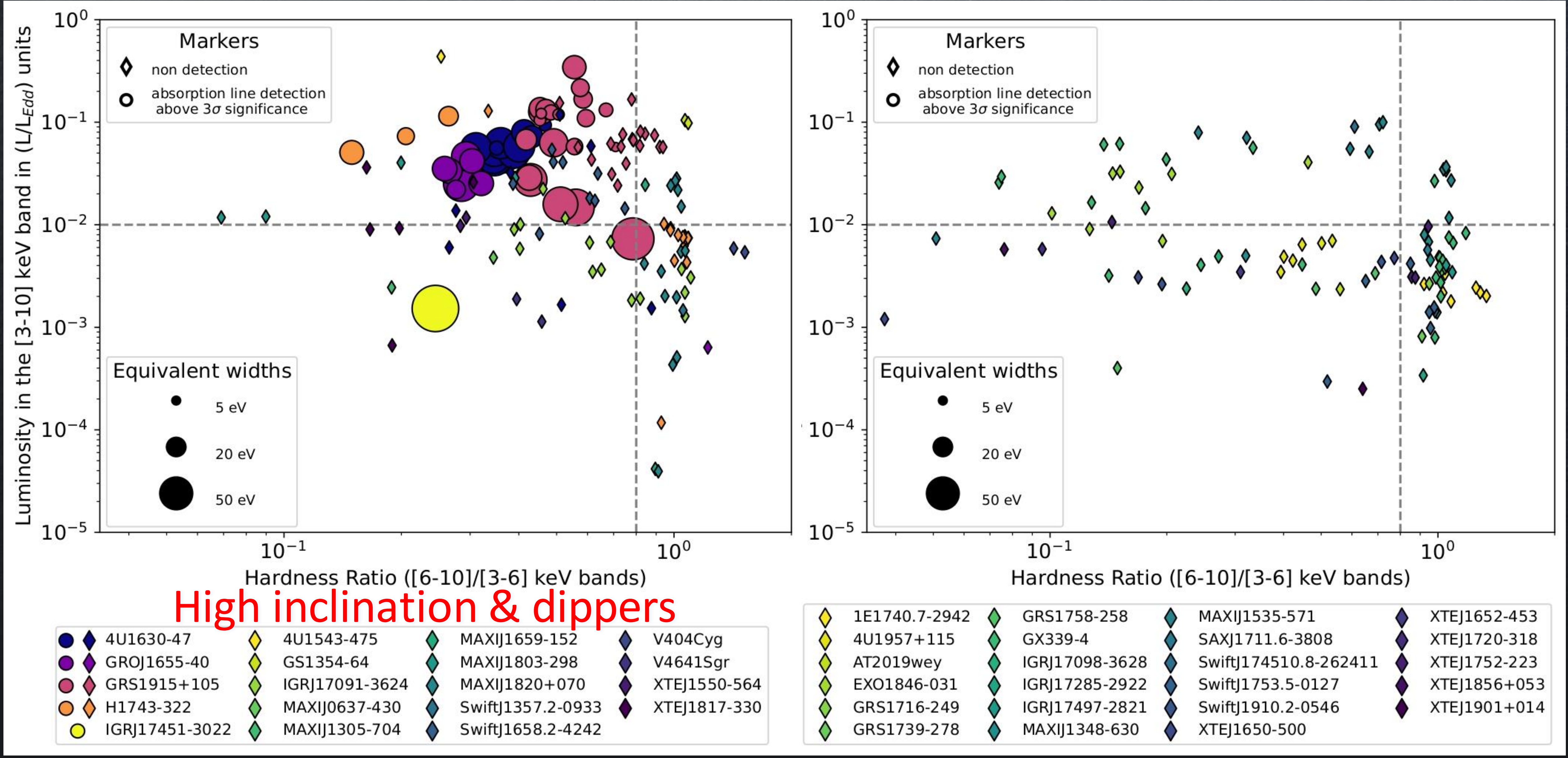
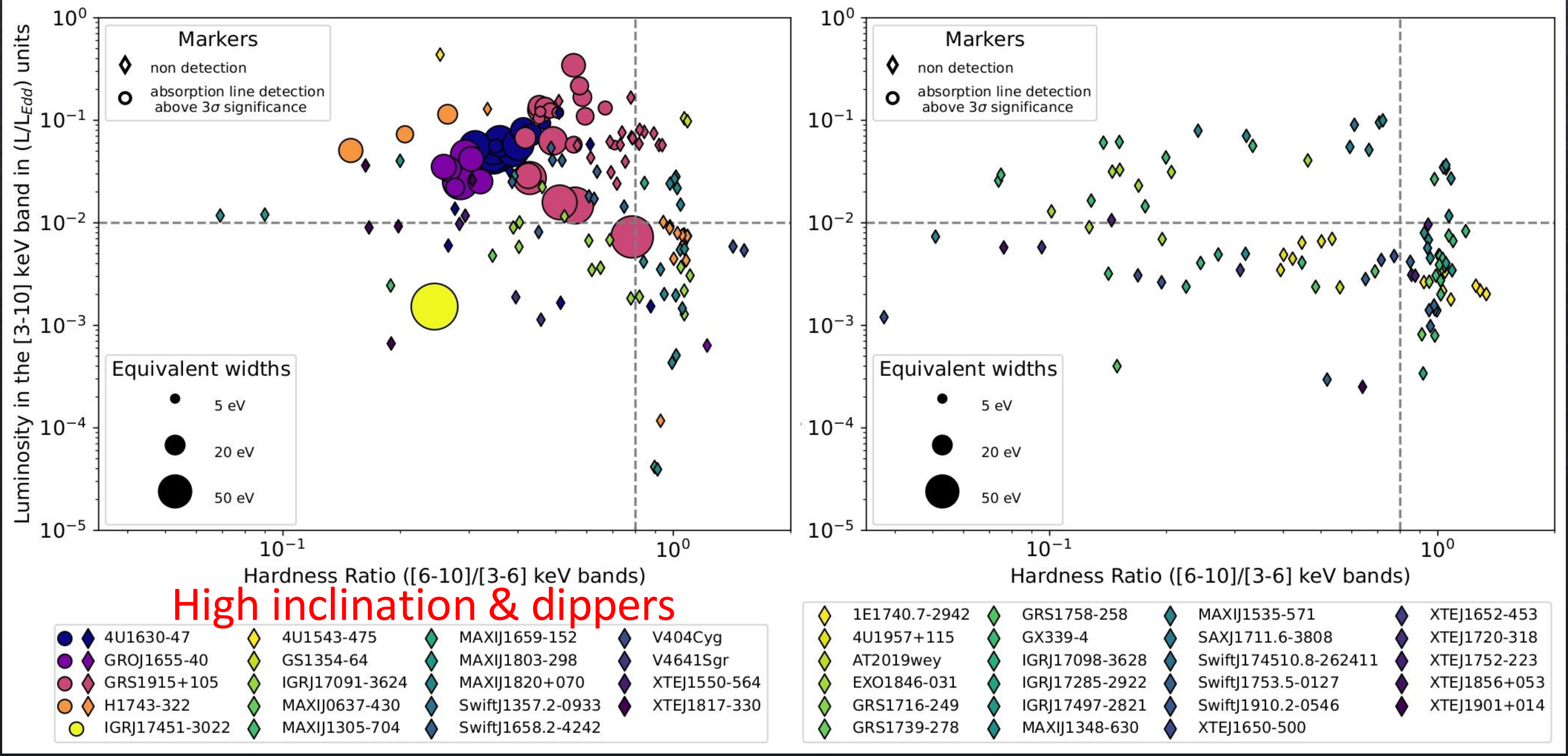
Results

Results

- Global HLD behavior



- No detection above HR=0.8
- No standard detection below L_x/L_{Edd}=0.01
- No detection at low inclination



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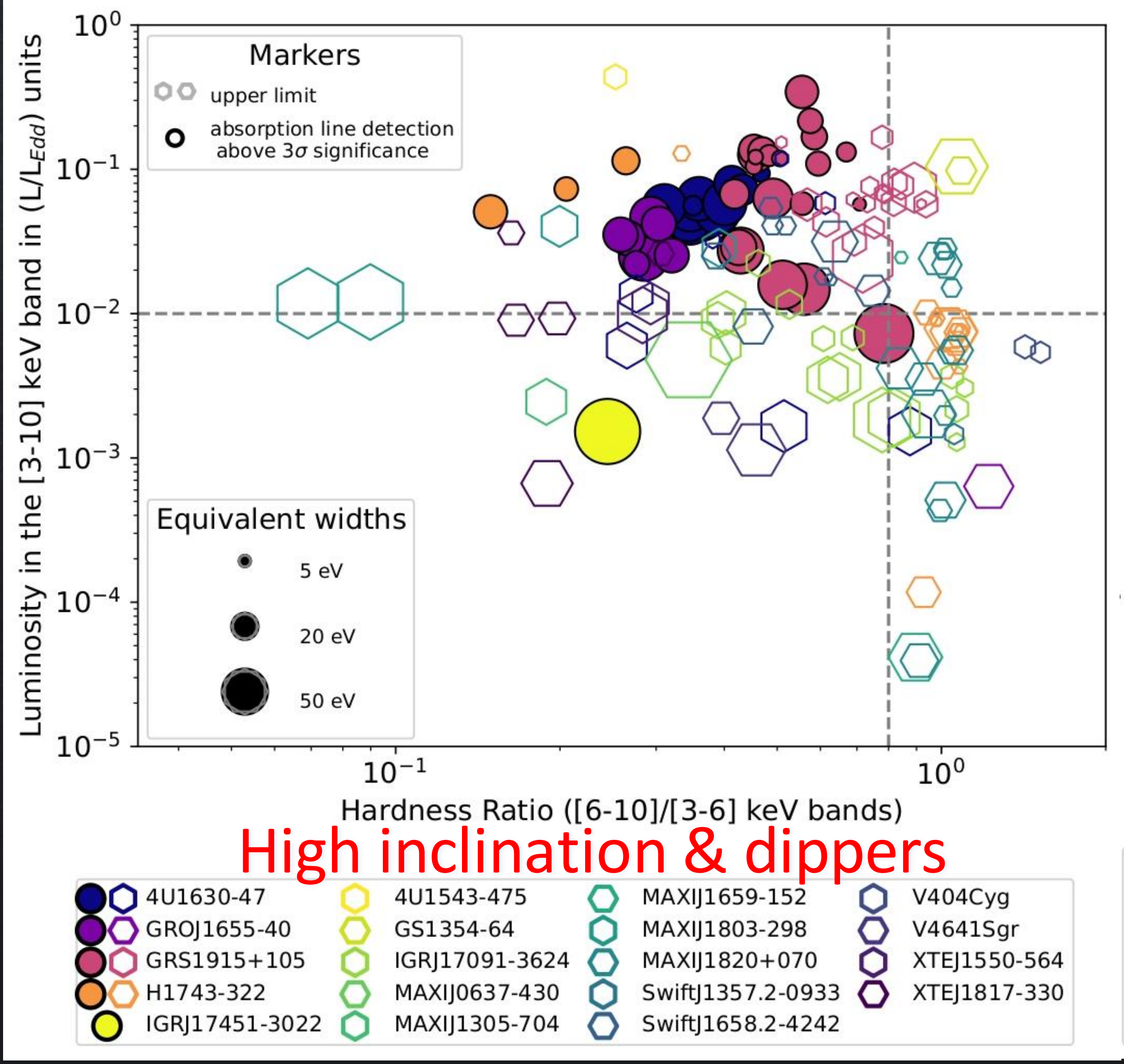
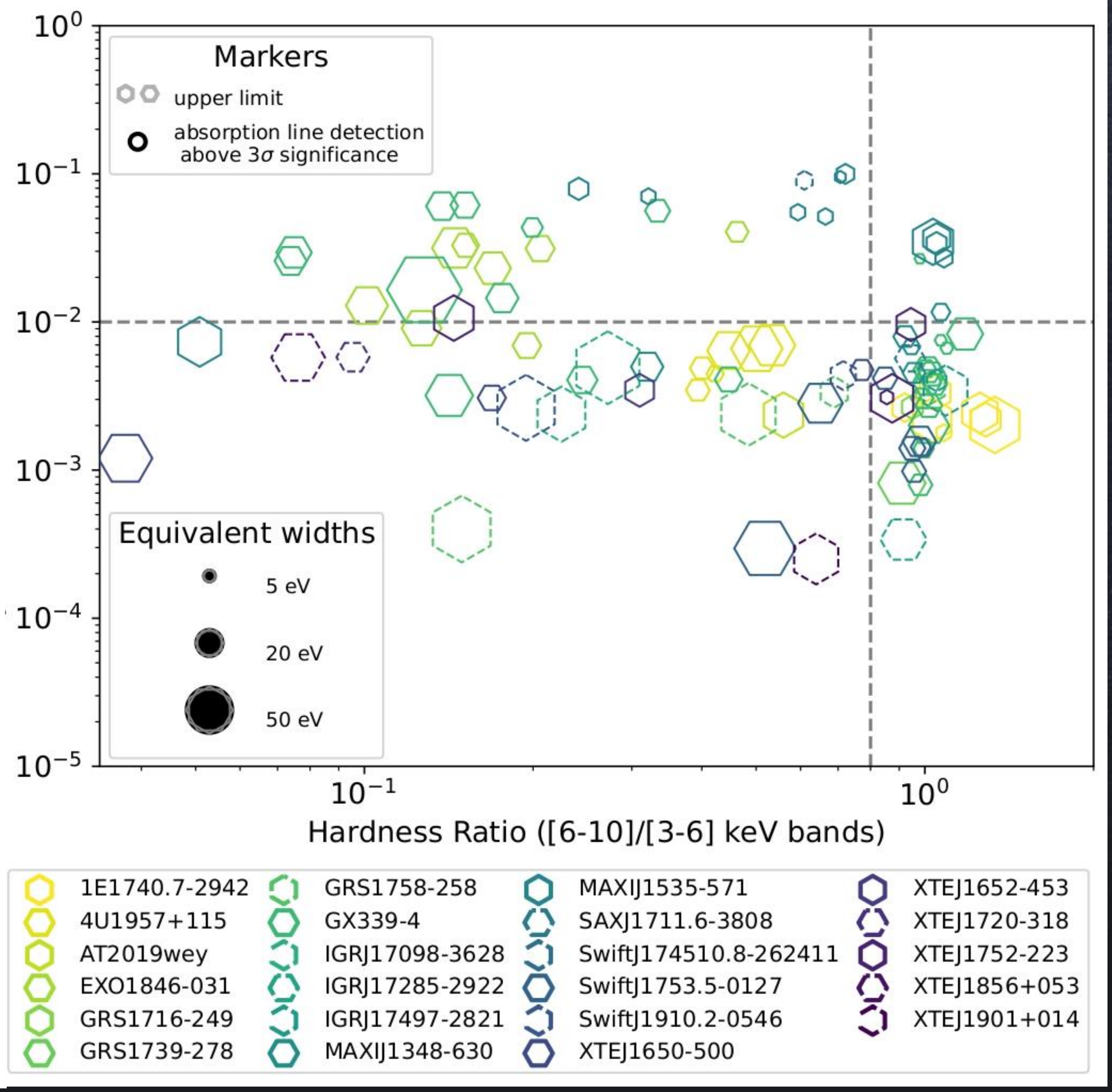
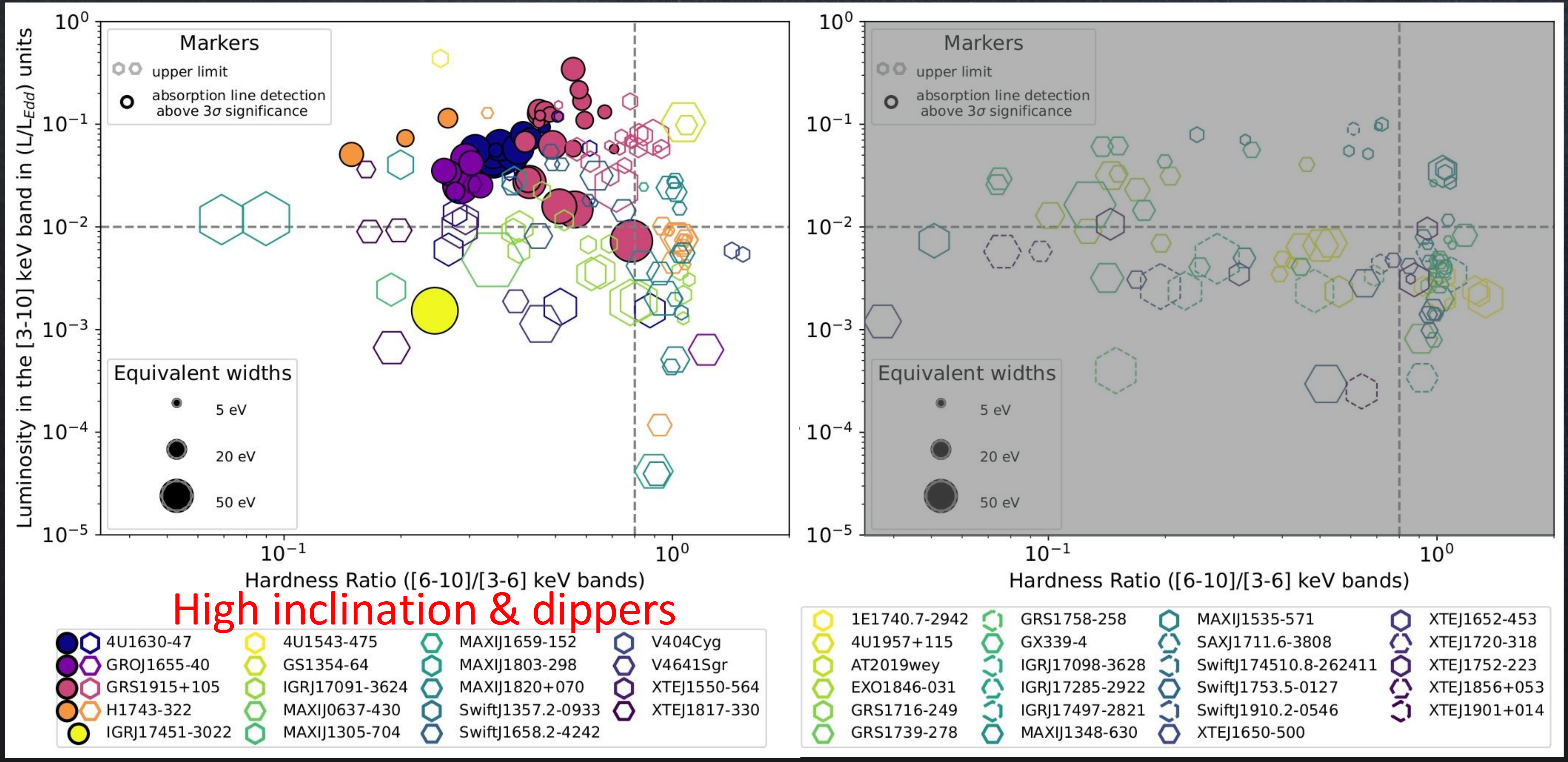




- No detection at low inclination ?



- No detection above HR=0.8 ?
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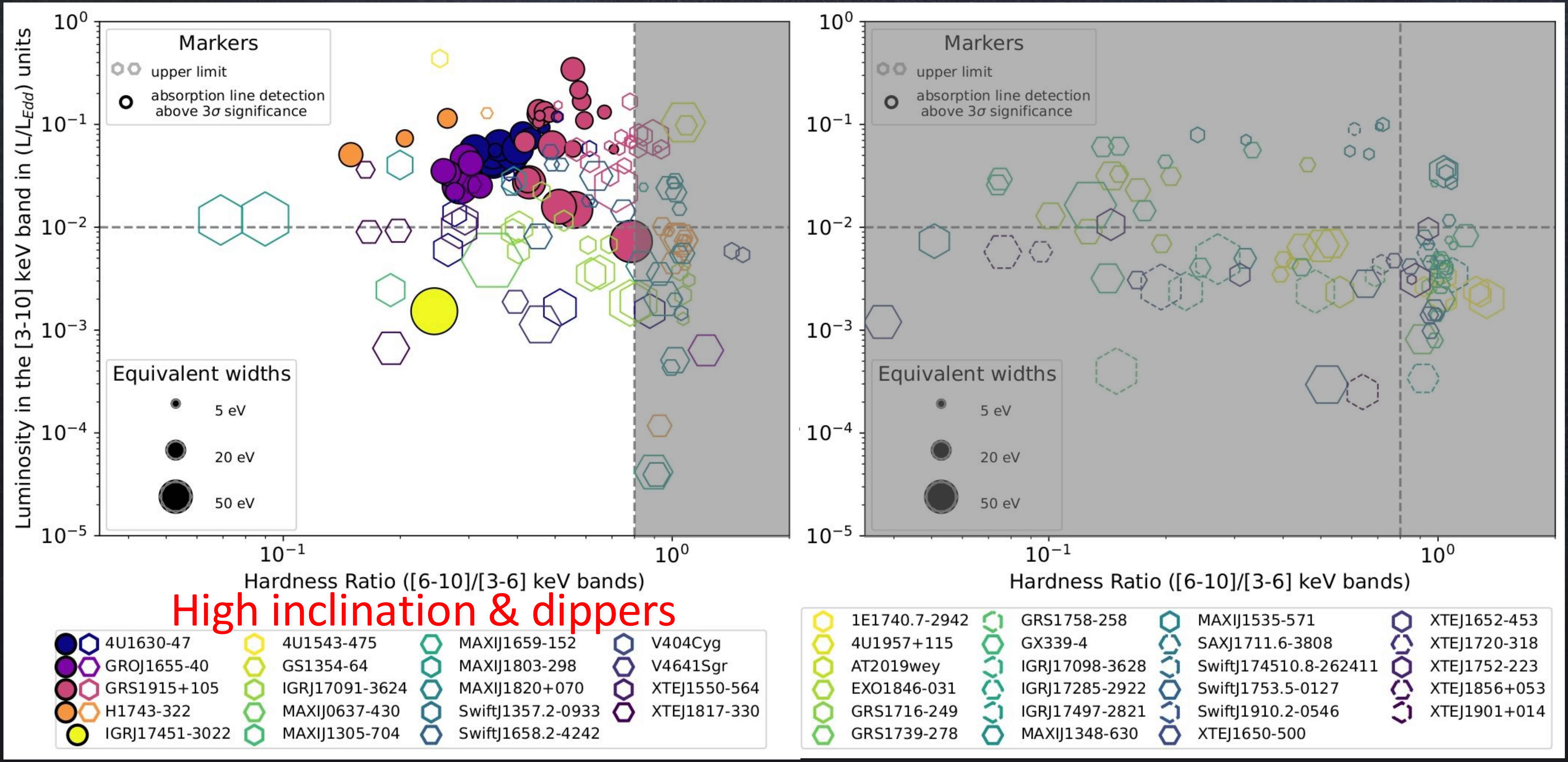

- No detection above HR=0.8 ? ✓
- No detection at low inclination ? ✓
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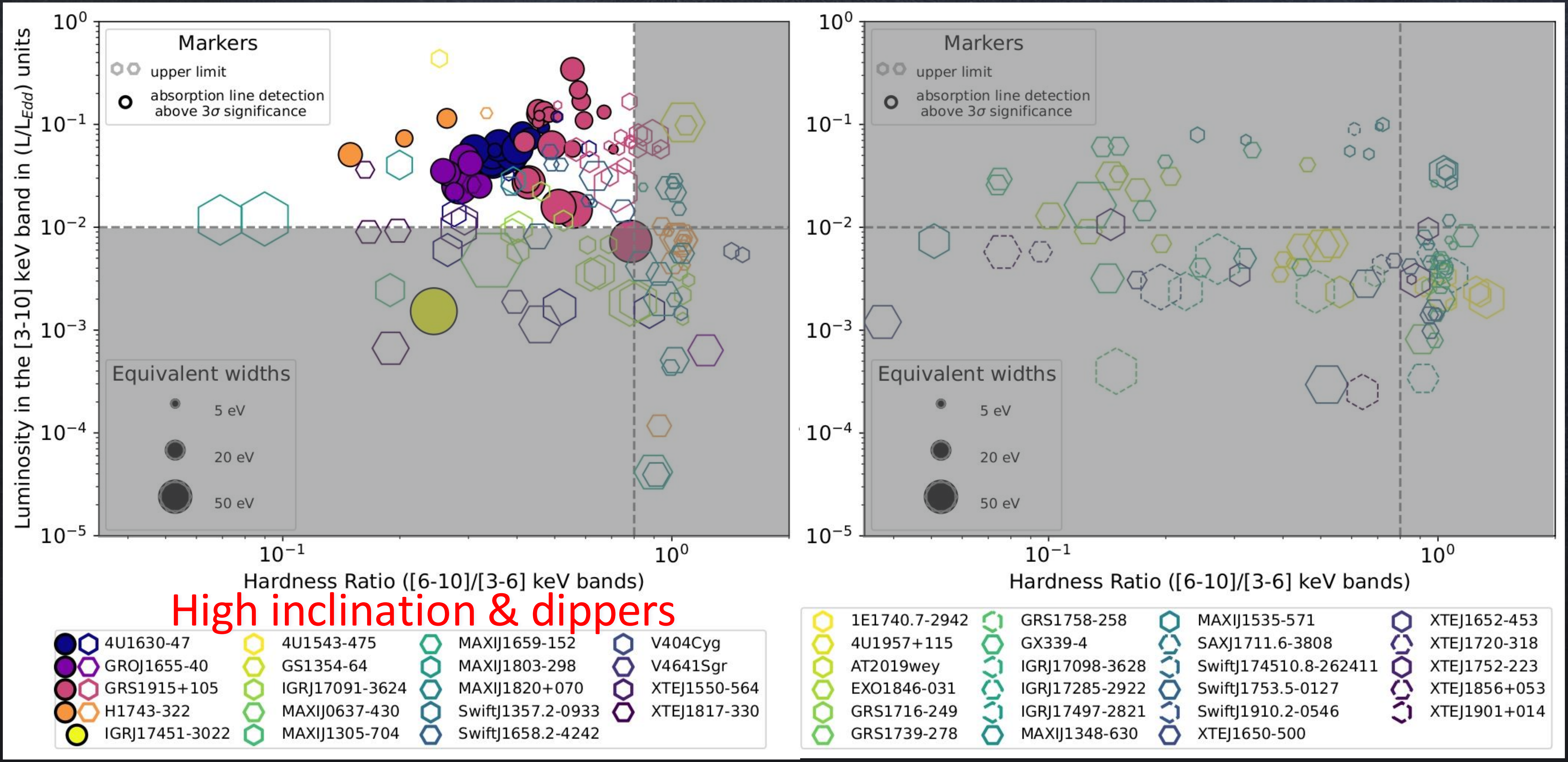
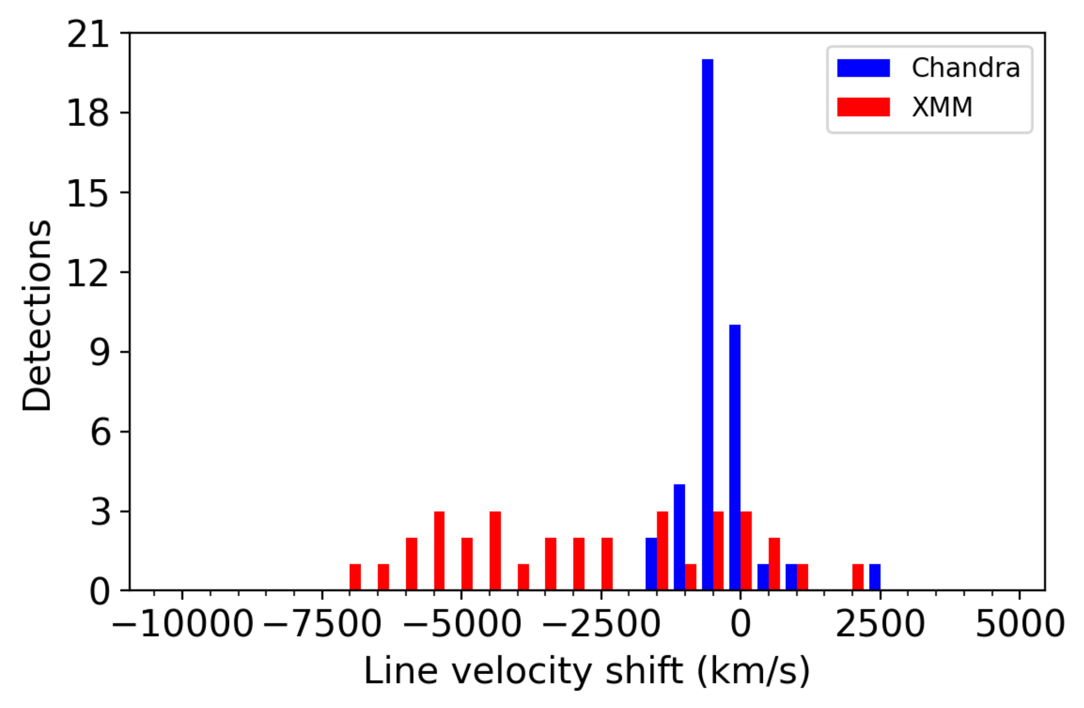


Results

- Distributions of line parameters



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Results

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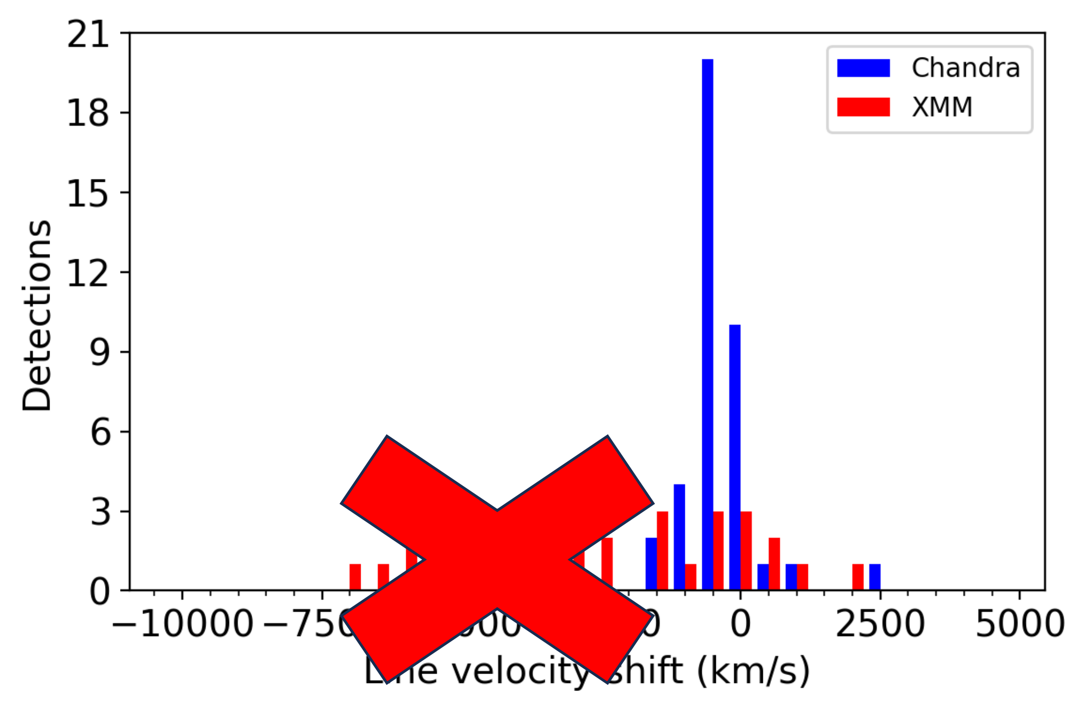

Results

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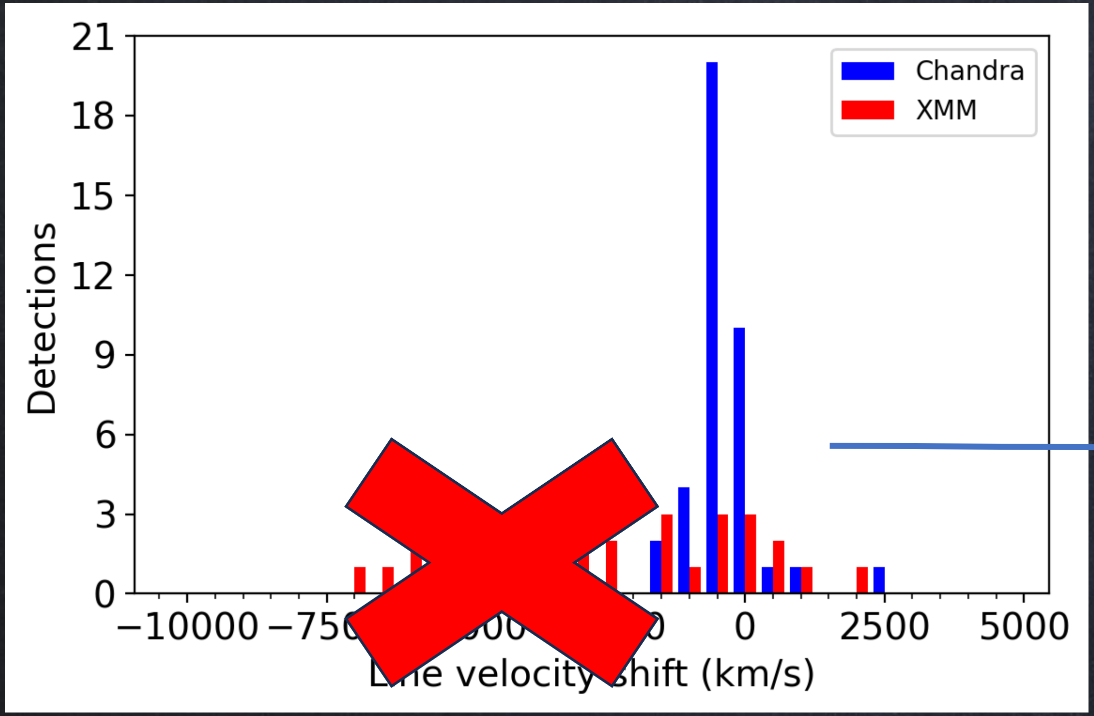
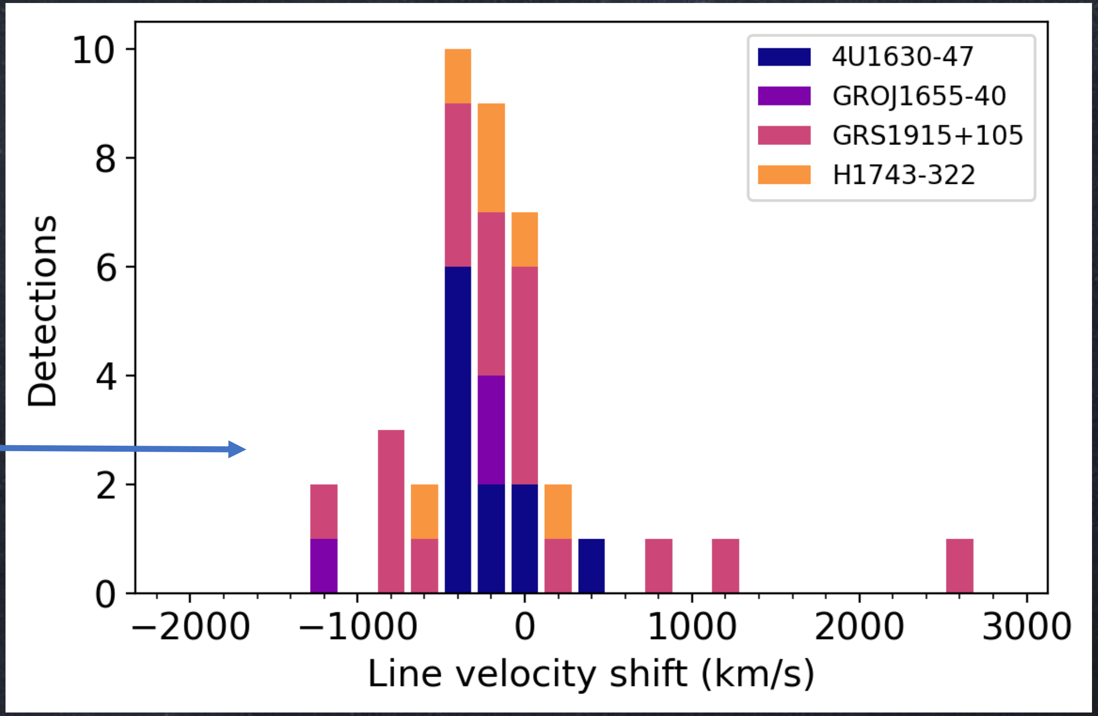


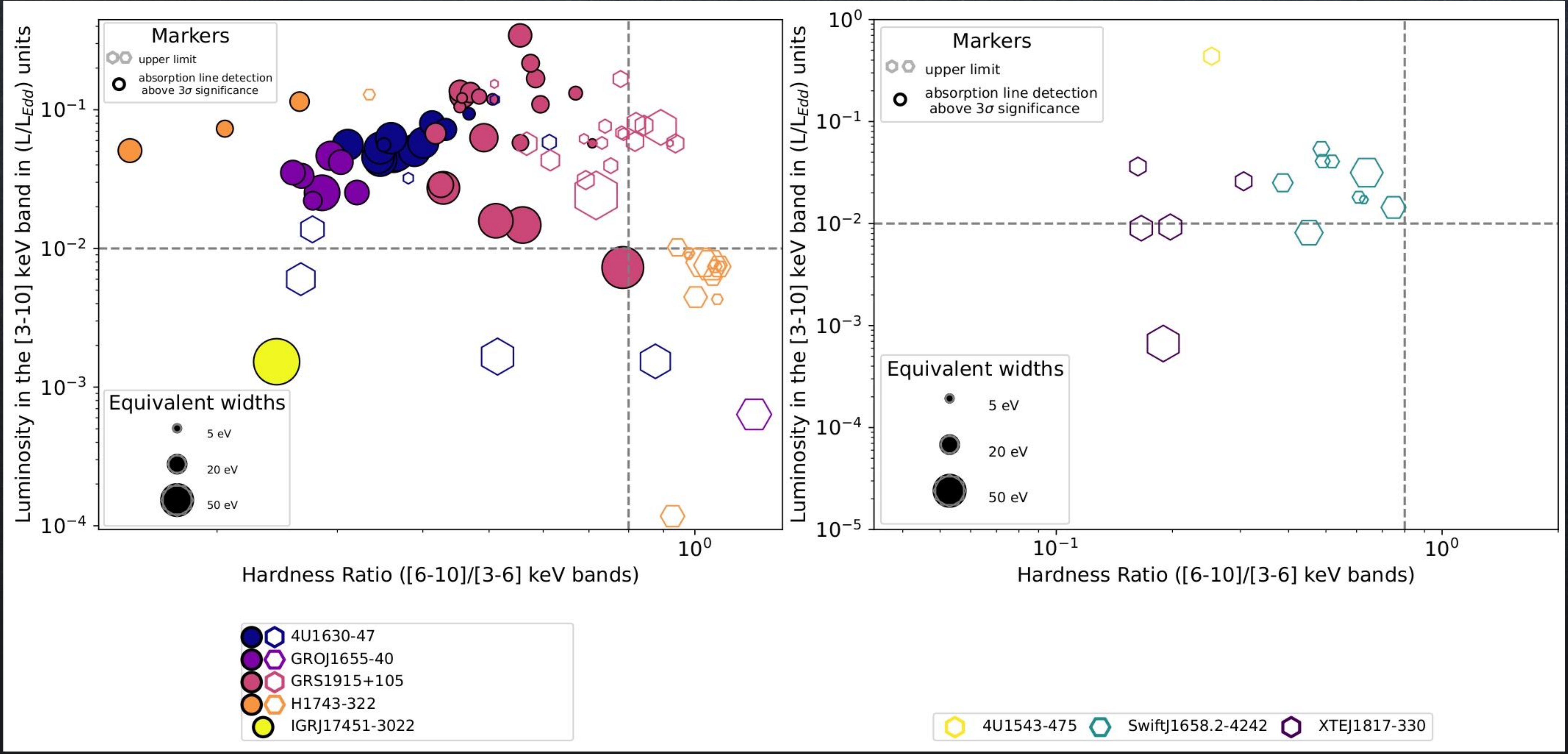


μ = −200 +/- 60 km/s

σ = 360 km/s

Results

- Non detections in the favorable zone



Comparisons & Conclusion

Comparisons & Conclusion

- The bigger picture

❑Current Sample

- 5 sources with detections, all dippers
- Almost all soft states
- Blueshifts of few 100km/s

Comparisons & Conclusion

- The bigger picture

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❑ Literature in the X-rays

- Few other sources with detections, almost all high inclination
- Multiple detections in the hard state BUT vast majority embedded in strong reflection components
- Mostly low blueshifts except for secondary components and when mixed with reflection

Comparisons & Conclusion

- The bigger picture

Current Sample

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Literature in Visible & Infrared

- Other sources, almost all high inclination
- Visible only in hard state, IR everywhere
- Higher blueshifts (few 1000km/s)

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Comparisons & Conclusion

- The bigger picture

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❑ Literature in Visible & Infrared

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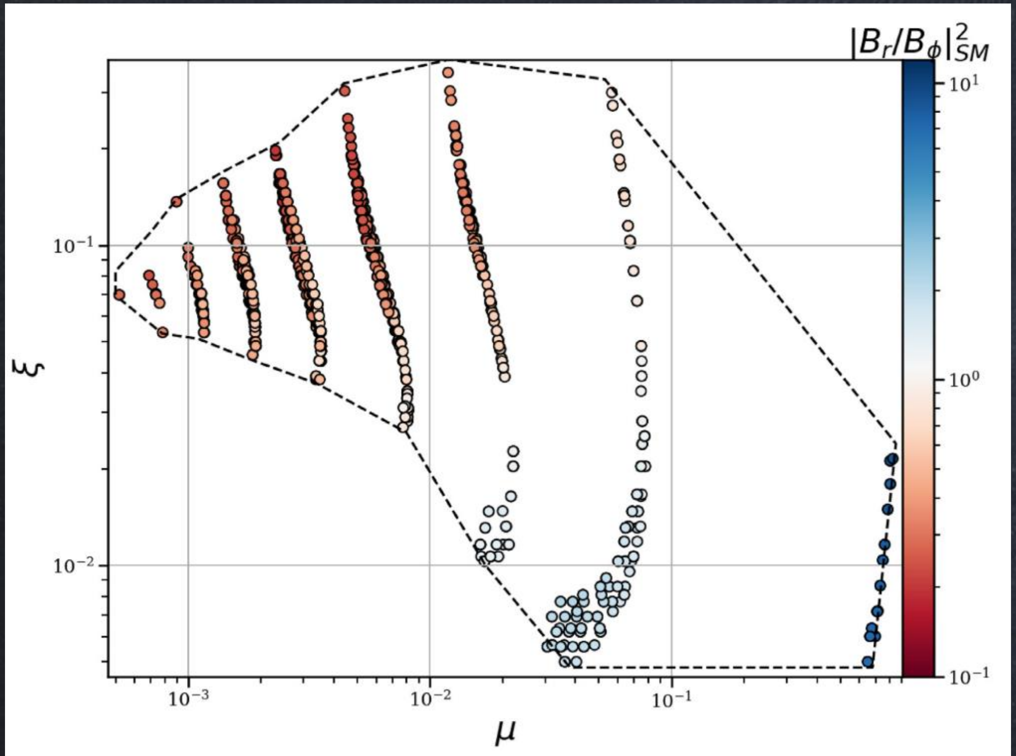
Comparisons & Conclusion

- Current work

Self similar modeling

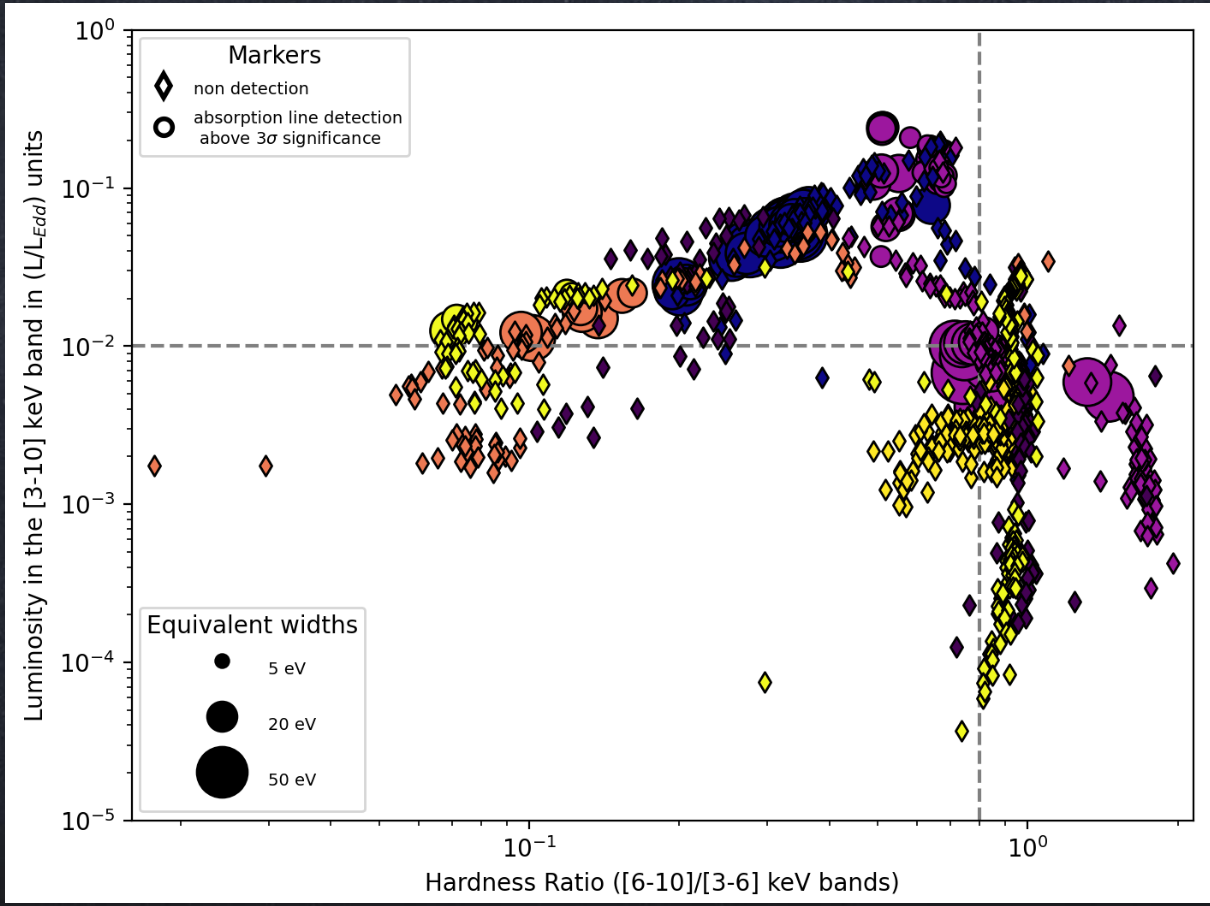


VS

-high resolution detections
-high resolution non-detections

-evolutions during single outbursts

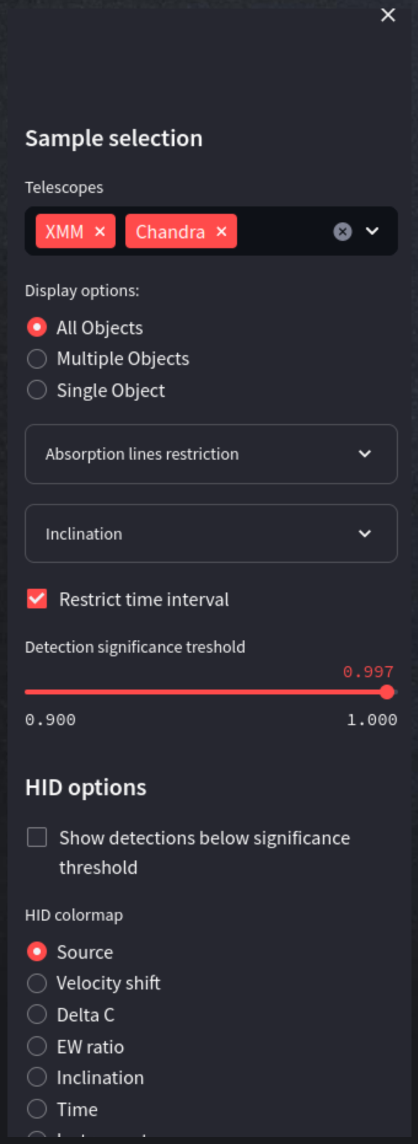
NICER archive



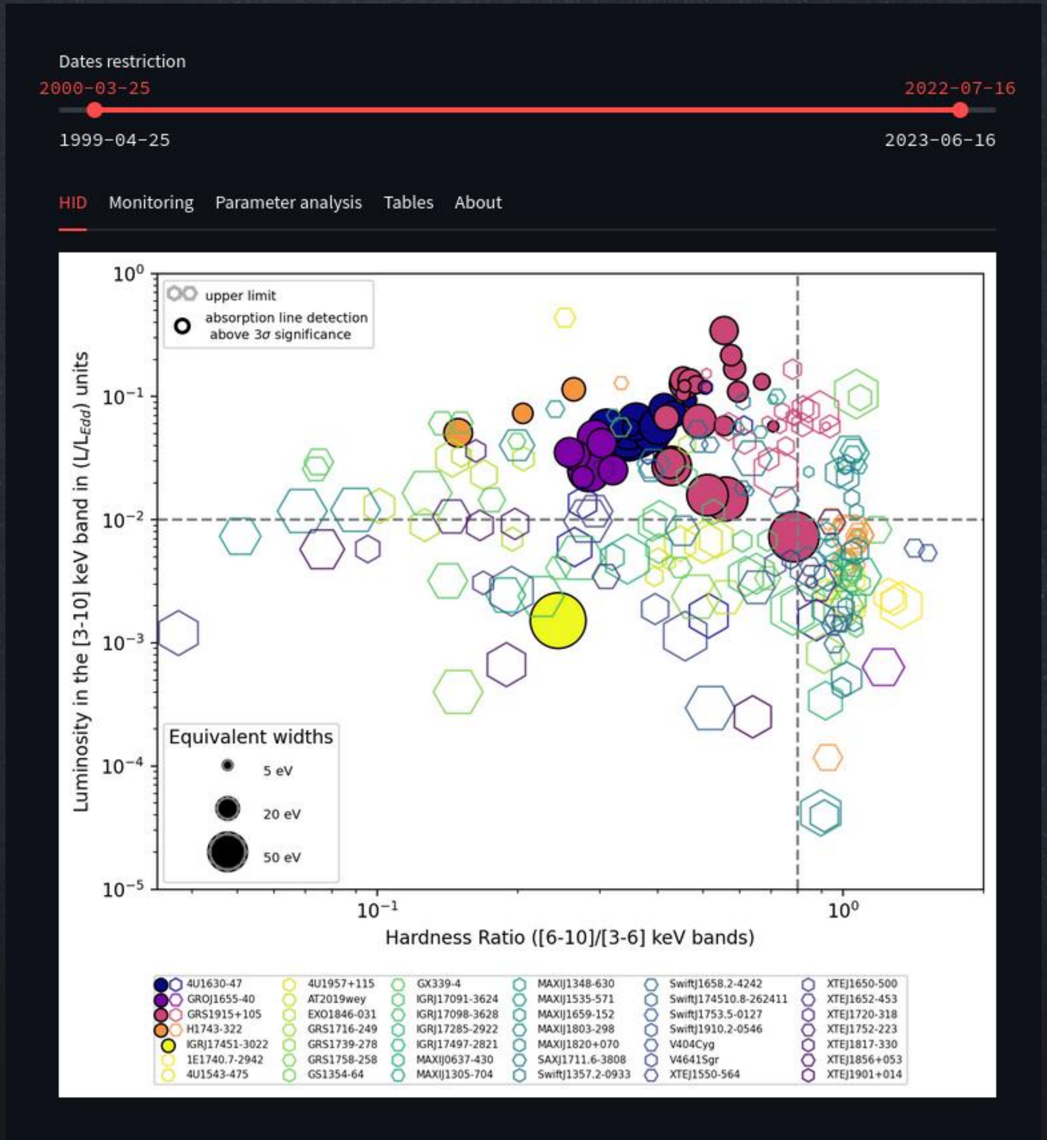
Thanks for your attention !

Bonus

https://visual-line.streamlit.app/



+



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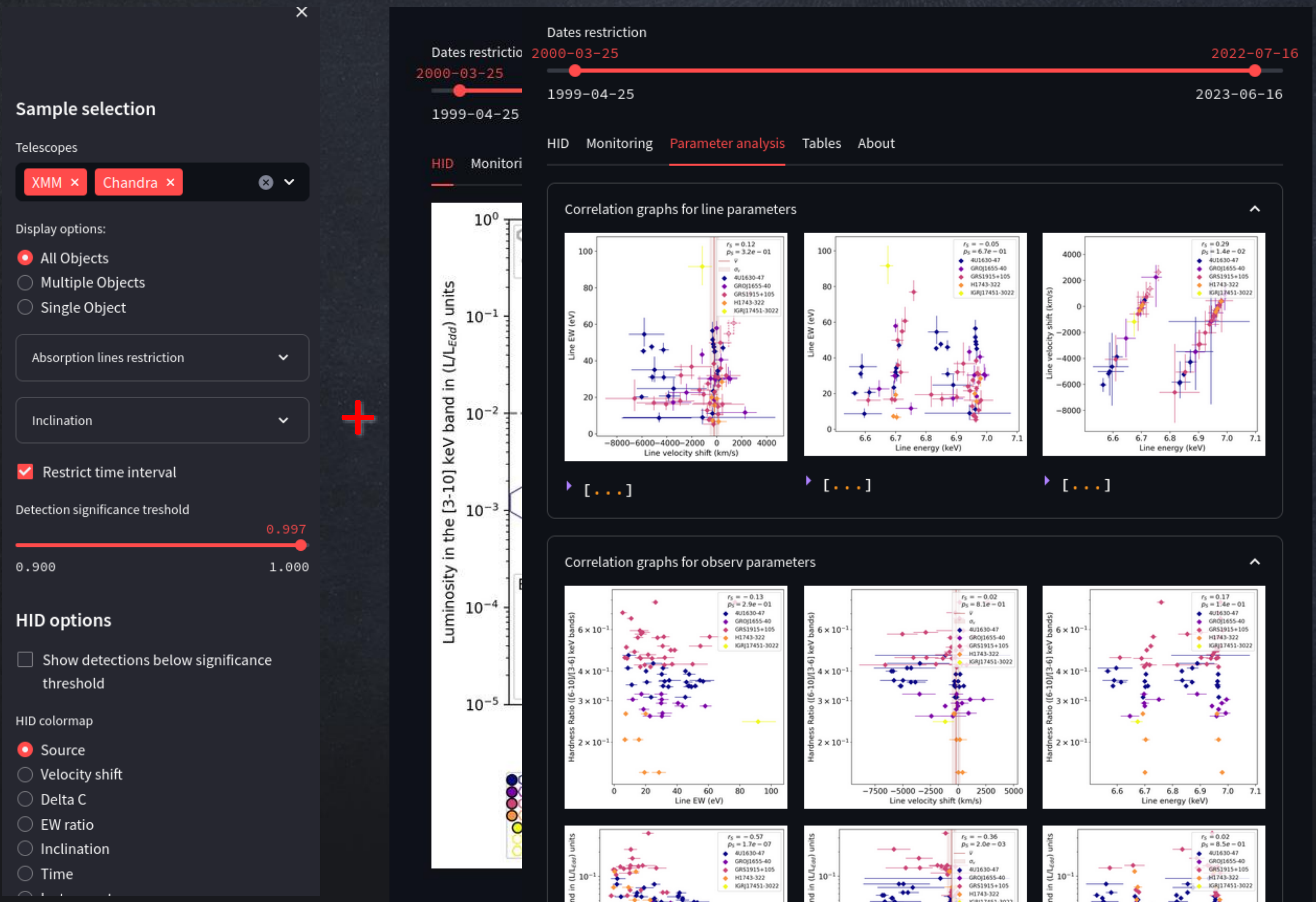

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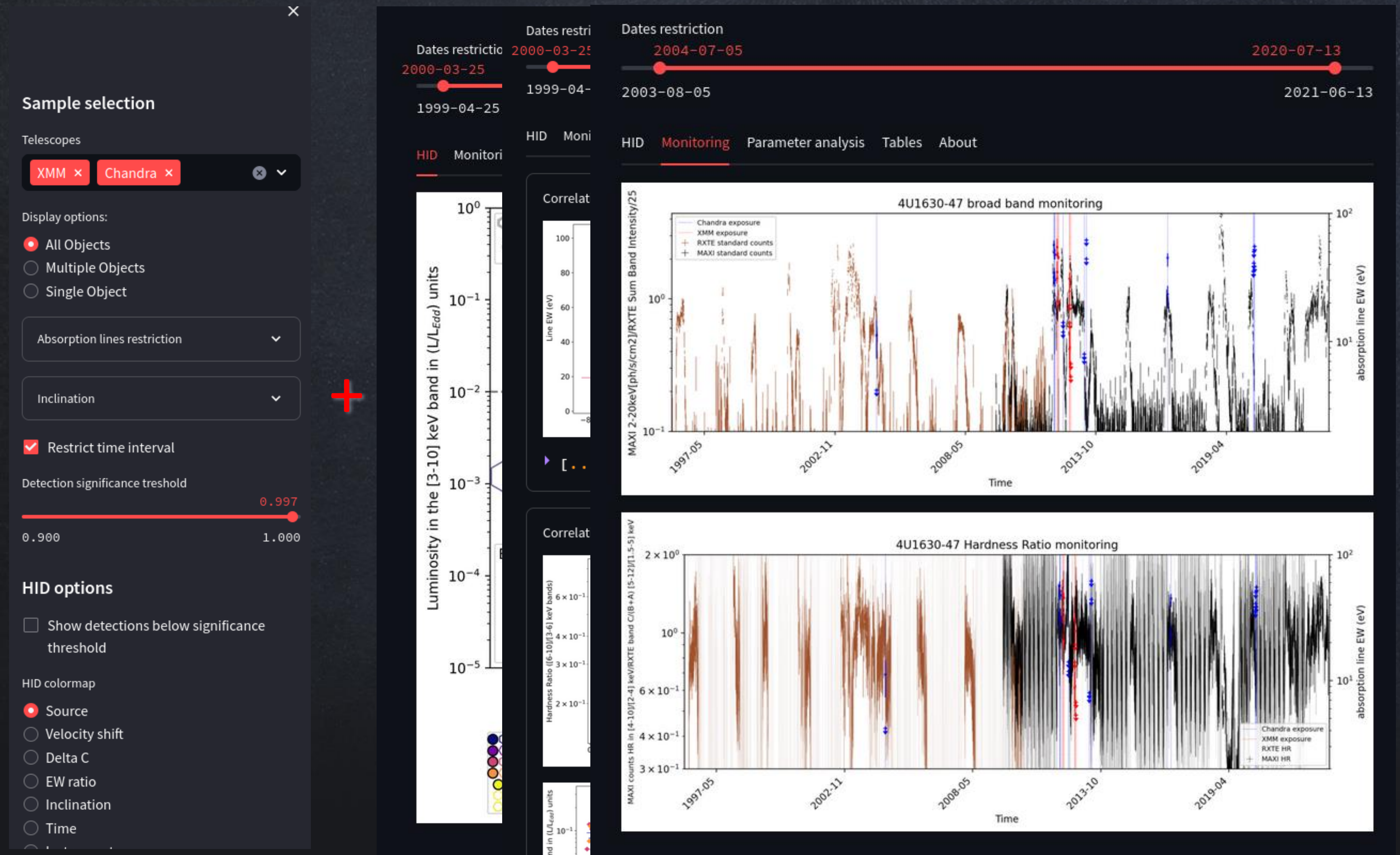

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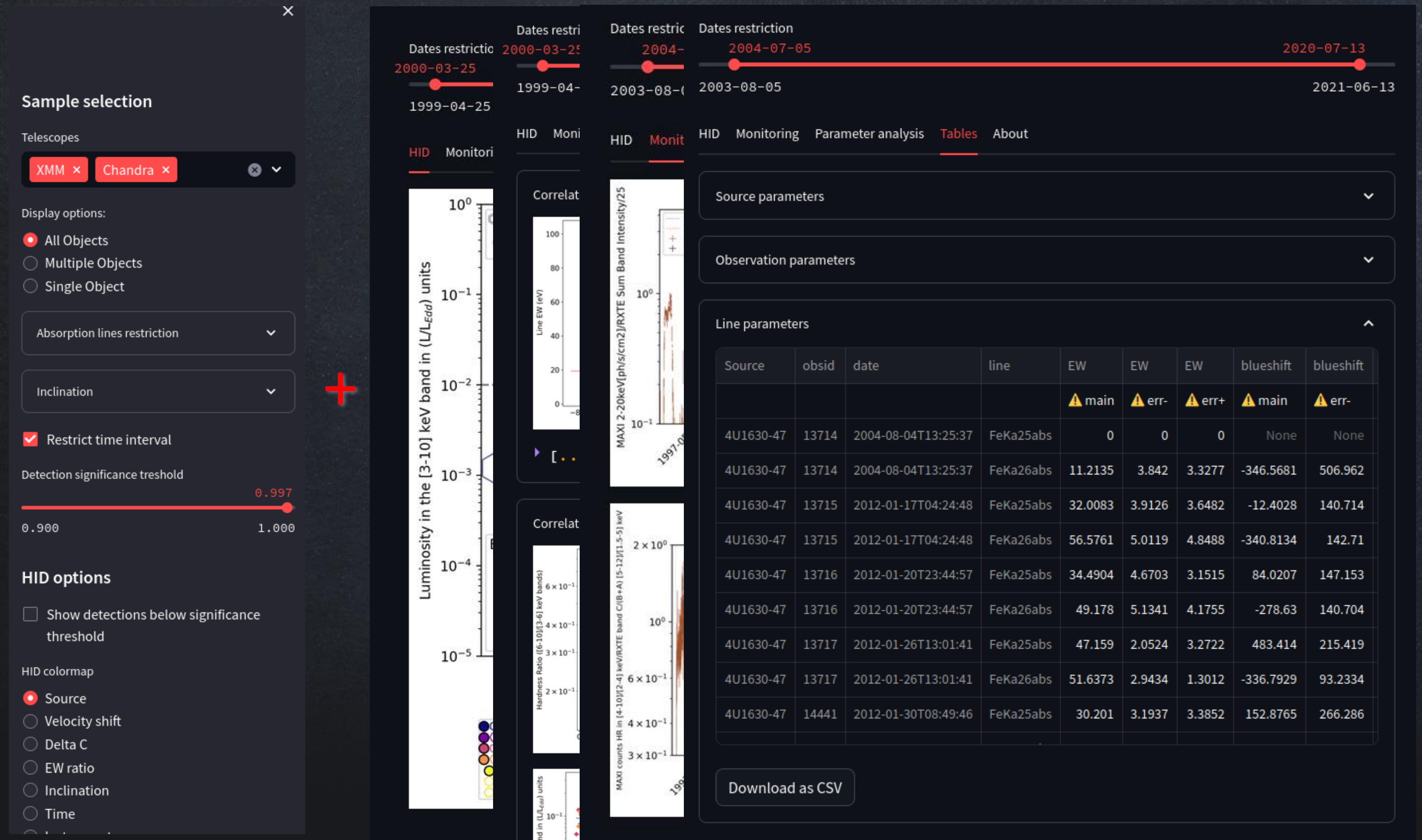

Source	obsid	date	line	EW main	EW err-	EW err+	blueshift main	blueshift err-
4U1630-47	13714	2004-08-04T13:25:37	FeKa25abs	0	0	0	None	None
4U1630-47	13714	2004-08-04T13:25:37	FeKa26abs	11.2135	3.842	3.3277	-346.5681	506.962
4U1630-47	13715	2012-01-17T04:24:48	FeKa25abs	32.0083	3.9126	3.6482	-12.4028	140.714
4U1630-47	13715	2012-01-17T04:24:48	FeKa26abs	56.5761	5.0119	4.8488	-340.8134	142.71
4U1630-47	13716	2012-01-20T23:44:57	FeKa25abs	34.4904	4.6703	3.1515	84.0207	147.153
4U1630-47	13716	2012-01-20T23:44:57	FeKa26abs	49.178	5.1341	4.1755	-278.63	140.704
4U1630-47	13717	2012-01-26T13:01:41	FeKa25abs	47.159	2.0524	3.2722	483.414	215.419
4U1630-47	13717	2012-01-26T13:01:41	FeKa26abs	51.6373	2.9434	1.3012	-336.7929	93.2334
4U1630-47	14441	2012-01-30T08:49:46	FeKa25abs	30.201	3.1937	3.3852	152.8765	266.286

Bonus

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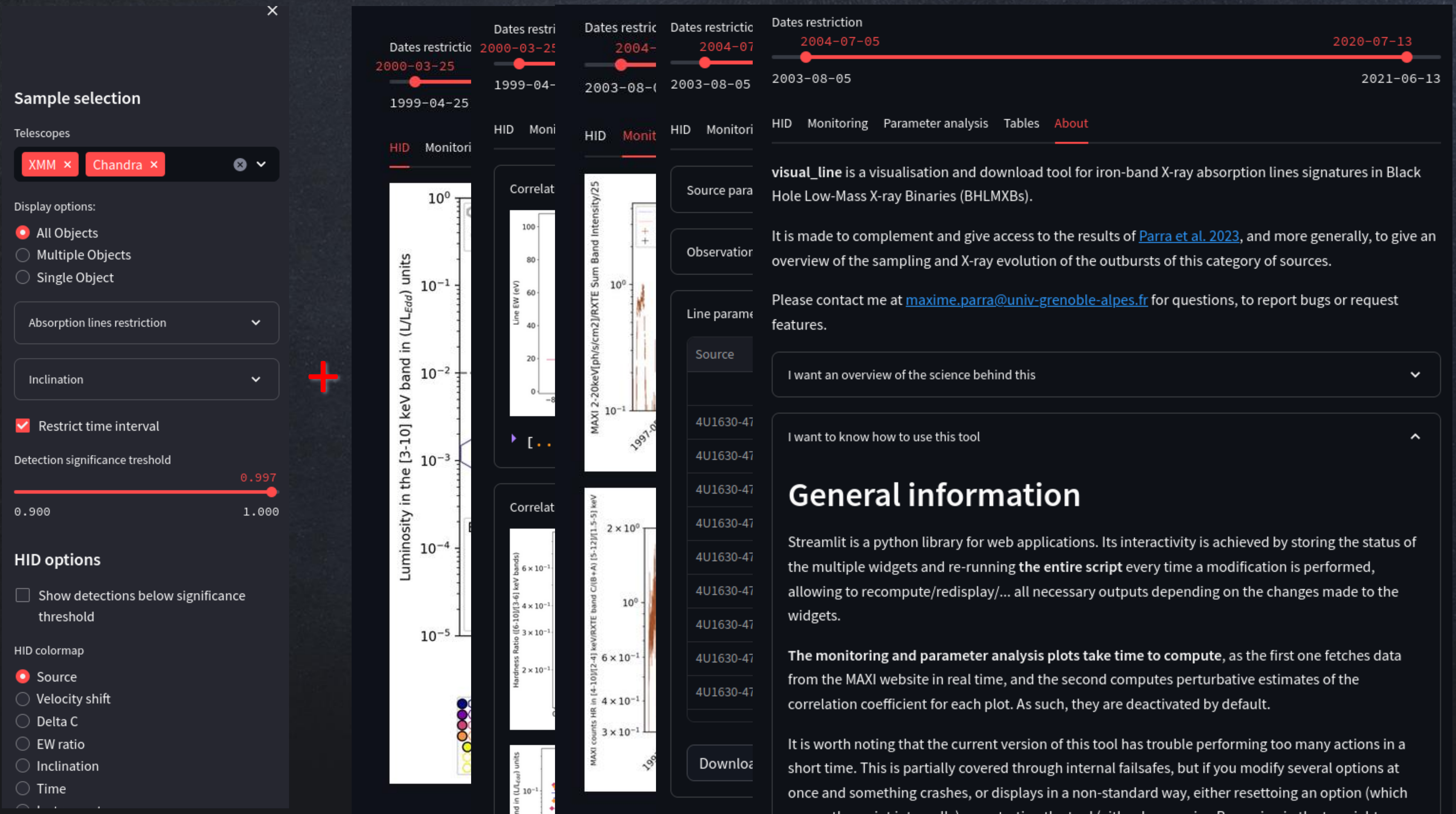
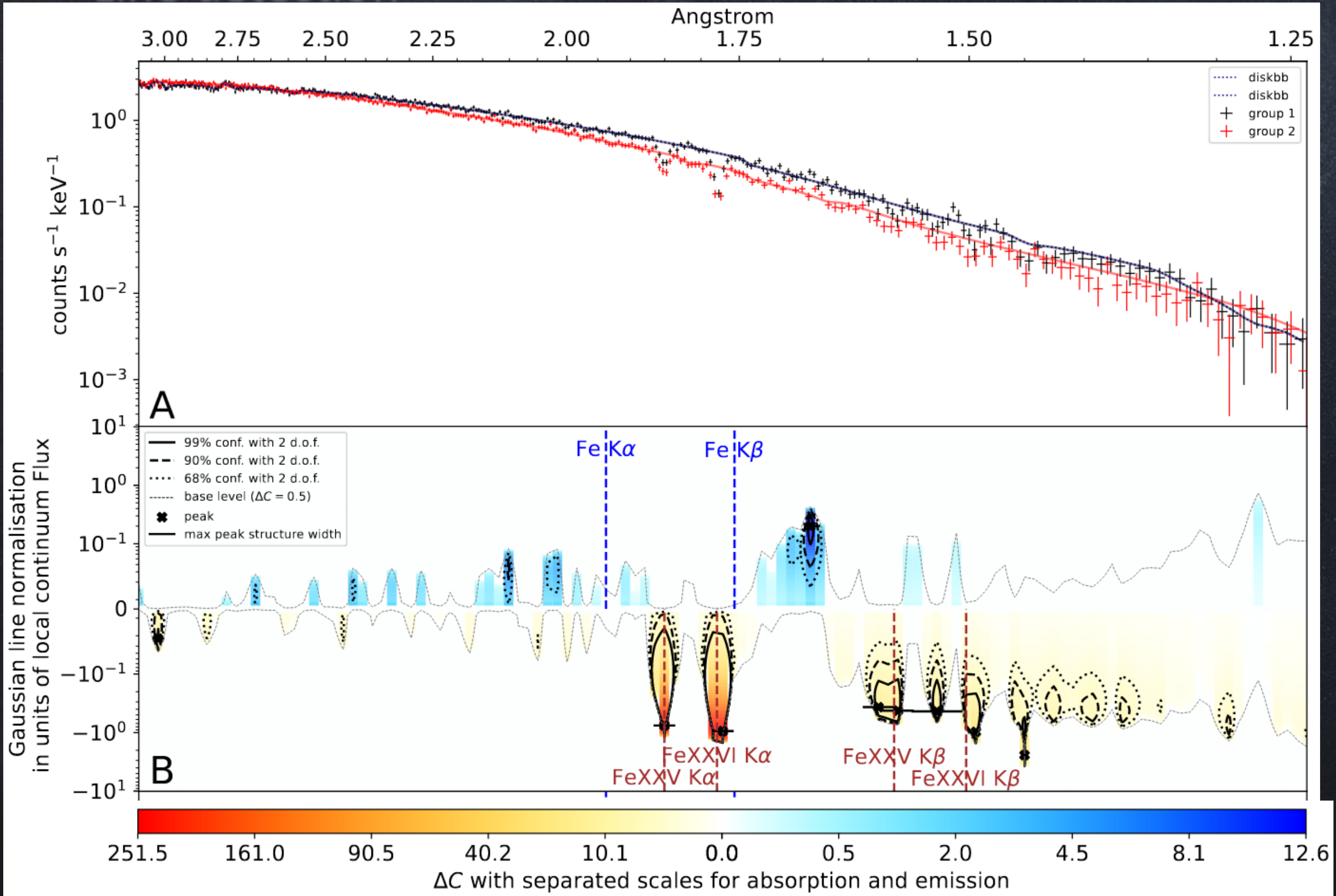


Appendices

Methodology

- Line detection



The current context

- Winds detection in Black Hole X-ray Binaries

The picture is much more complex now:

❑What about intermediate states ?

- Due time for a new global analysis of the observations

❑Thermal and/or MHD driving to launch the material ?

- Difficult to assess with current observations

(Díaz-Trigo & Boirin 2016, Tetarenko et al. 2018,…)

❑Impact of the spectral shape on the thermal stability

- The wind could be a permanent component

(Sánchez-Sierras & Muñoz-Darias 2020)

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The current context

- Modeling and stability of absorption lines

The picture is much more complex now

❑What about intermediate states ?
- Many observations but unclear global behavior

↓

❑Thermal and/or MHD driving[5][6] to launch the material ?
- $T_{wind} \ll T_{acc}$

↓

❑The spectral shape affects the thermal stability and ξ
- Wind always here[7] but only detectable in the right conditions ?

[5] Díaz-Trigo & Boirin 2016 [6] Tetarenko et al. 2018 [7] Sánchez-Sierras & Muñoz-Darias 2020

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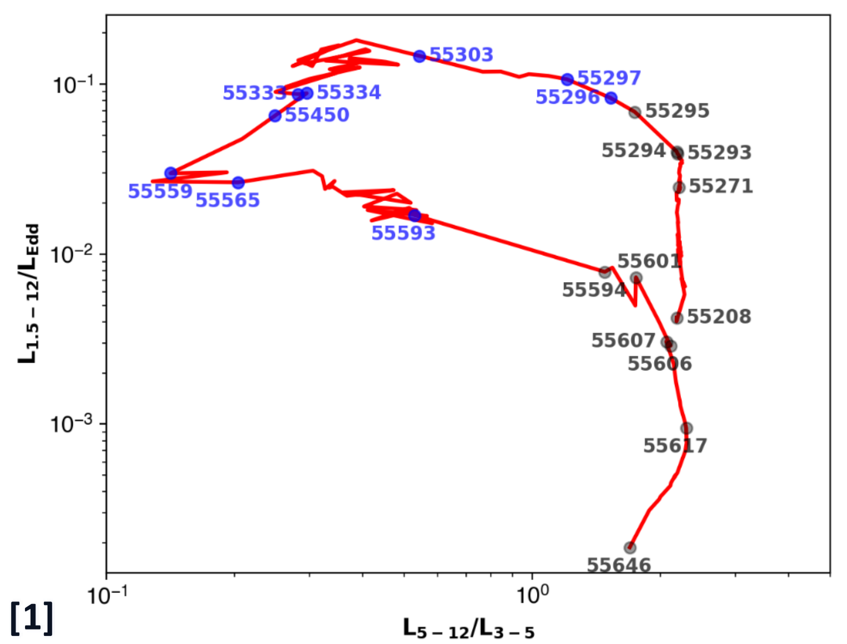
The current context

- Modeling and stability of absorption lines

❑The wind thermal stability curves can be computed

- Very sensitive to the SED → requires broad band data that doesn't exist

❑With a bit of physically motivated[8] extrapolation…[9]



[1]

[8] Marcel et al. 2018 [9] Marcel et al. 2019

[1] Petrucci et al. 2021

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The current context

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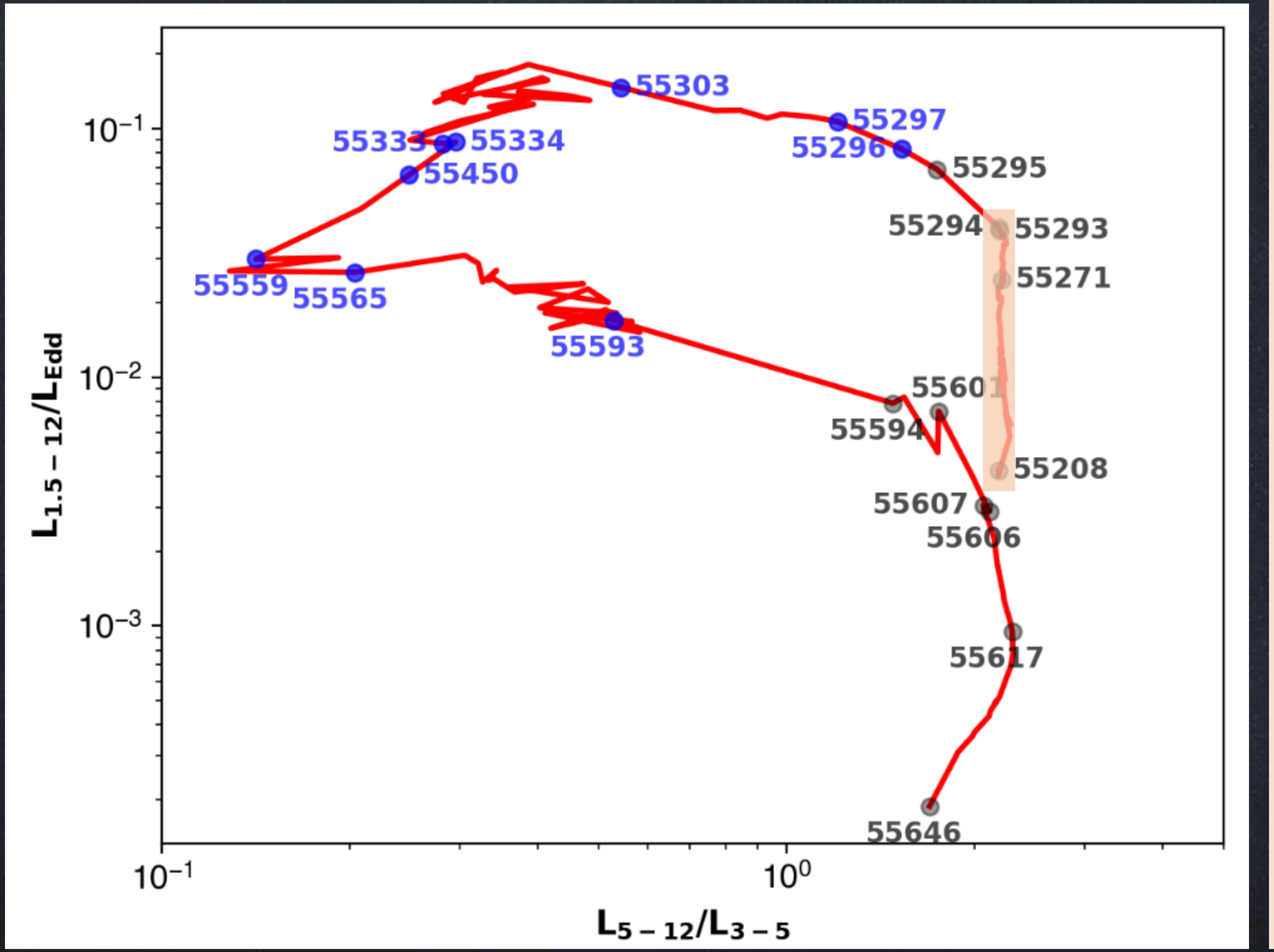
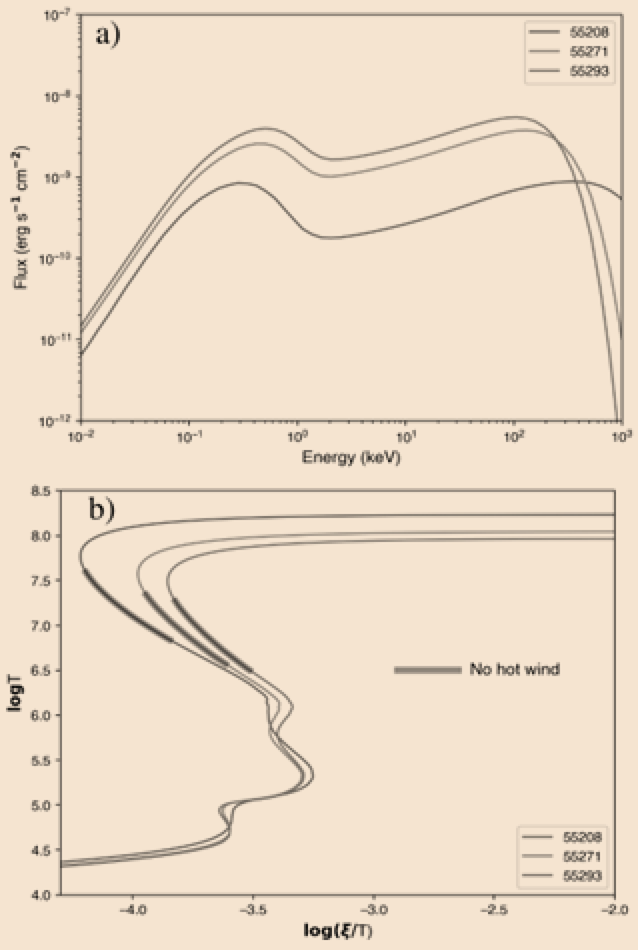
- Modeling and stability of absorption lines

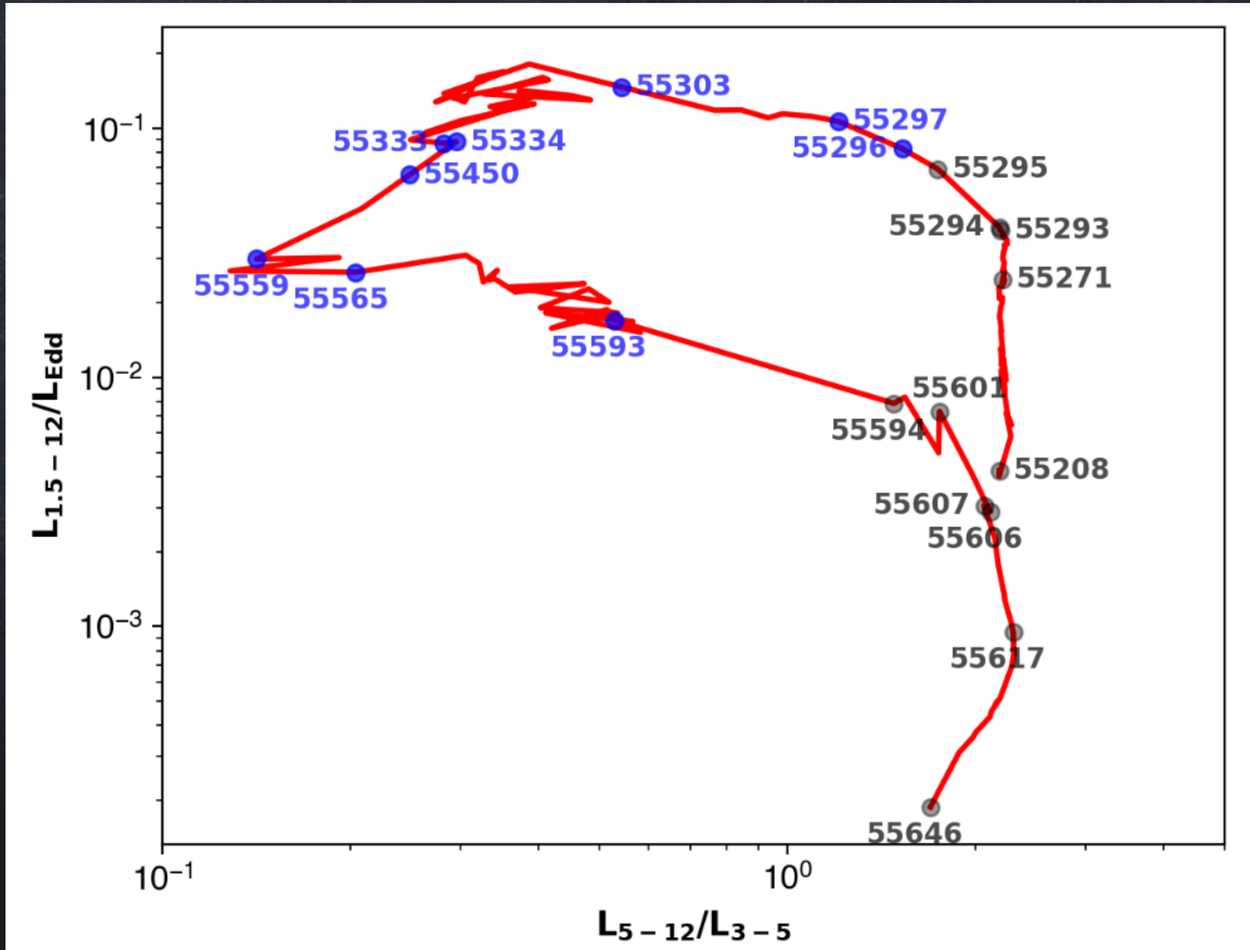


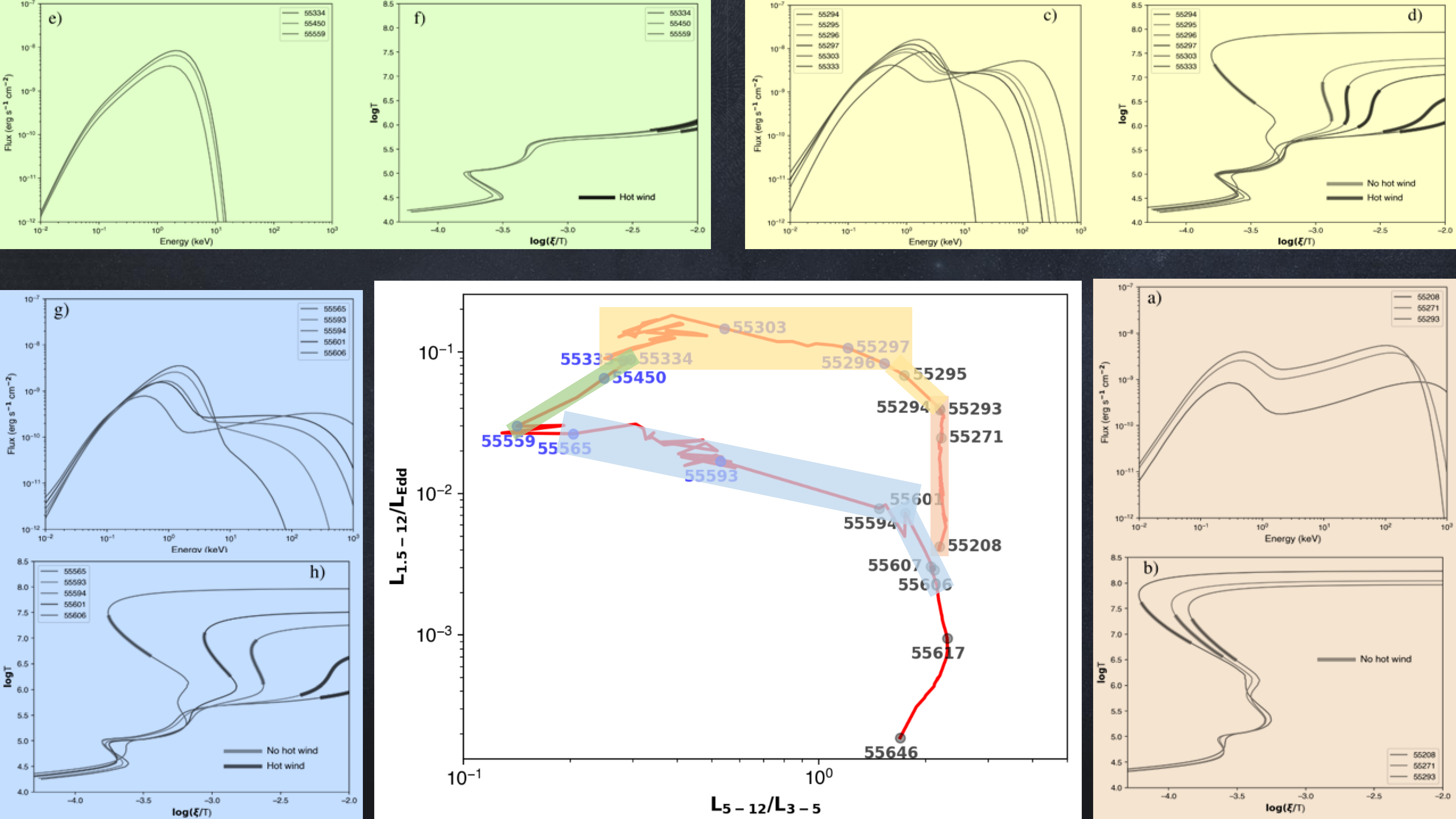


❑Now to be compared with observations for objects with detections

The current context

- Modeling and stability of absorption lines

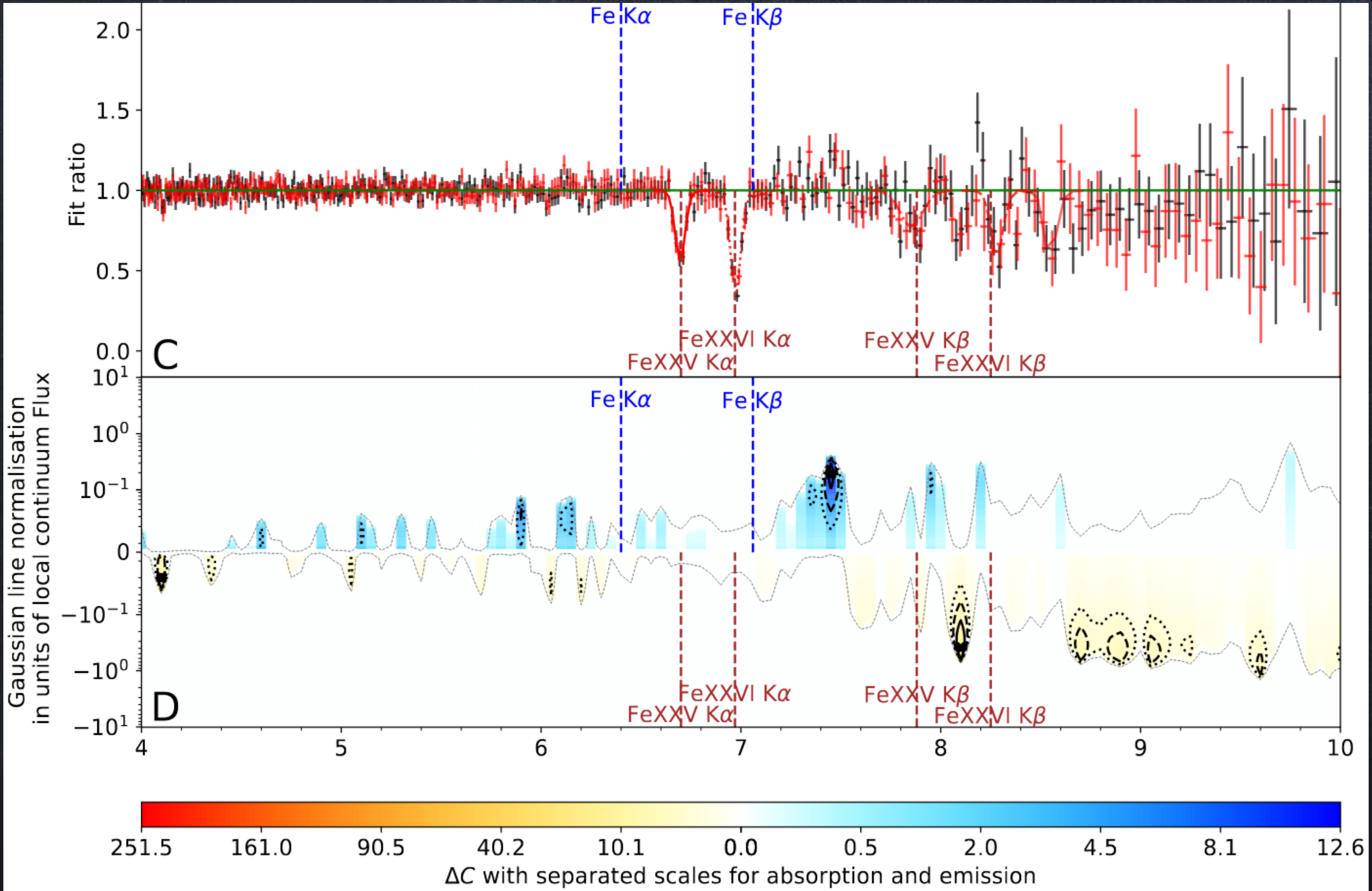




e)
f)
c)
d)
g)
h)
a)
b)
Flux (erg s⁻¹ cm⁻²)
Energy (keV)
logT
log(ξ/T)
Hot wind
No hot wind
55334
55450
55559
55294
55295
55296
55297
55303
55333
55565
55593
55594
55601
55606
55208
55271
55293
55607
55617
55646
$L_{1.5-12}/L_{Edd}$
L_{5-12}/L_{3-5}

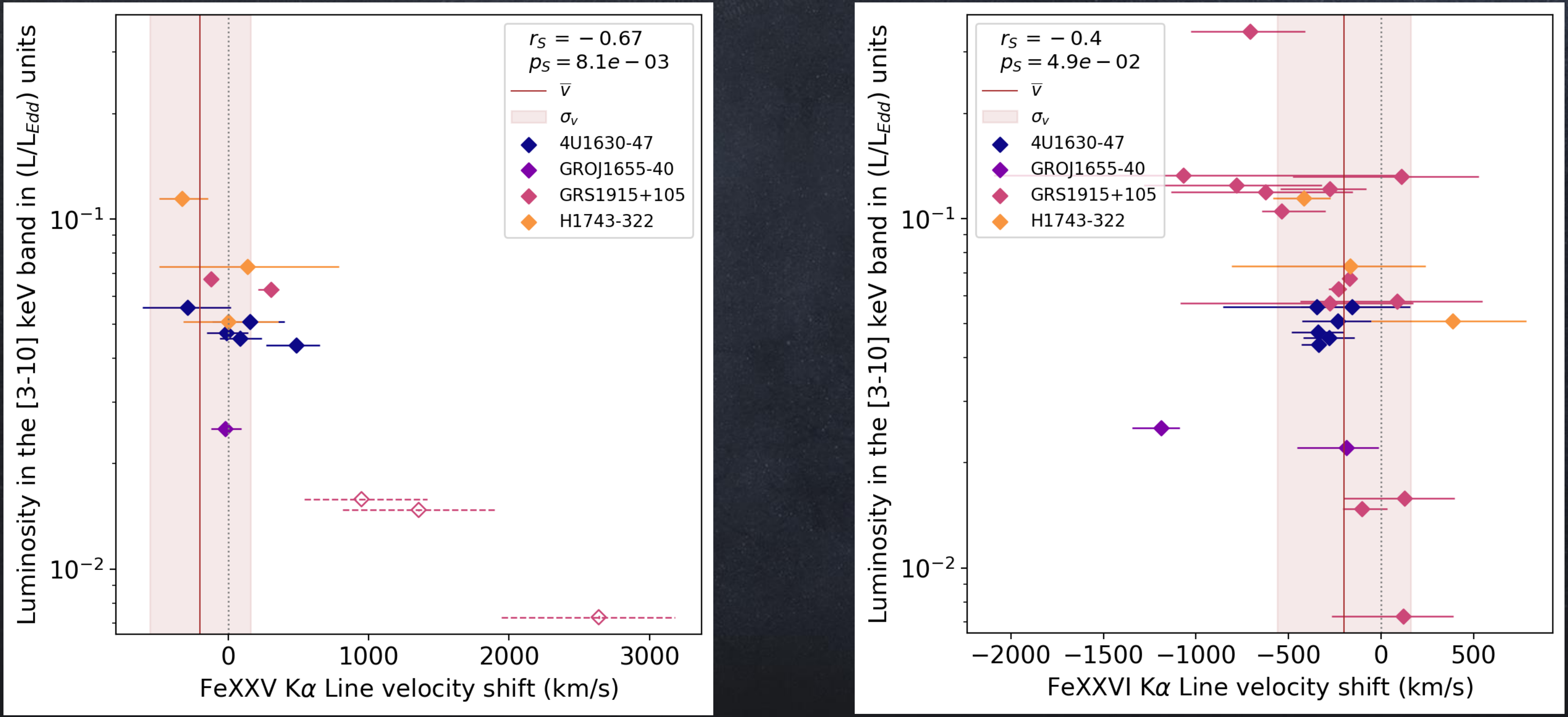
Methodology

- Line detection



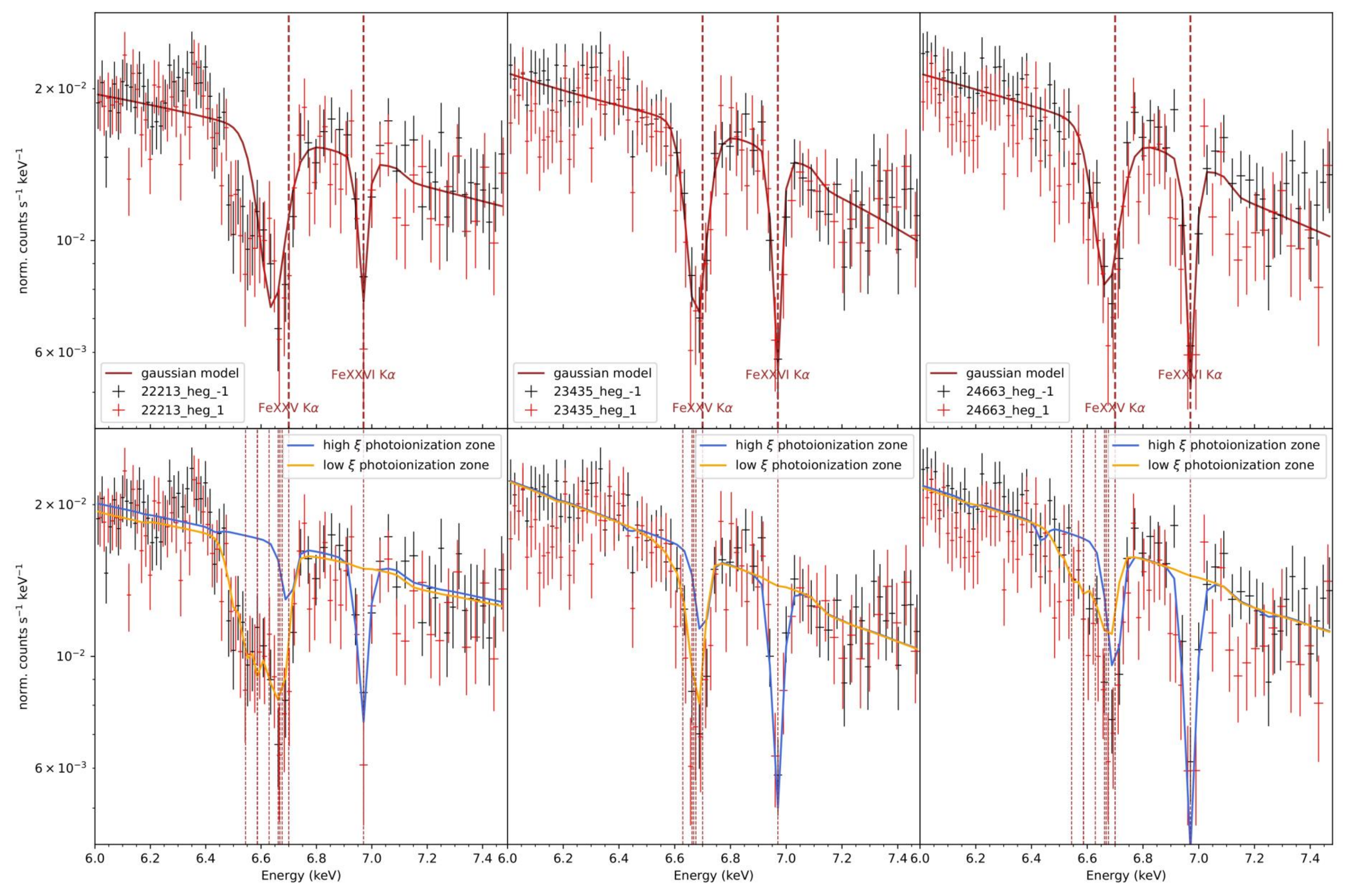
Results

- Distributions



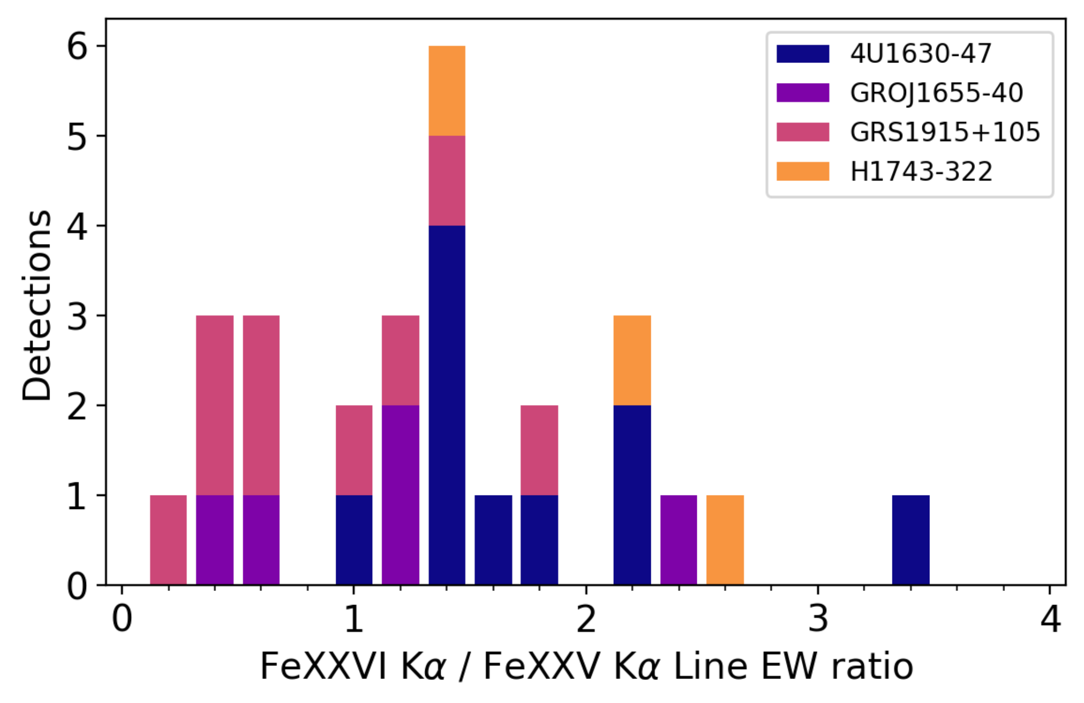
Results

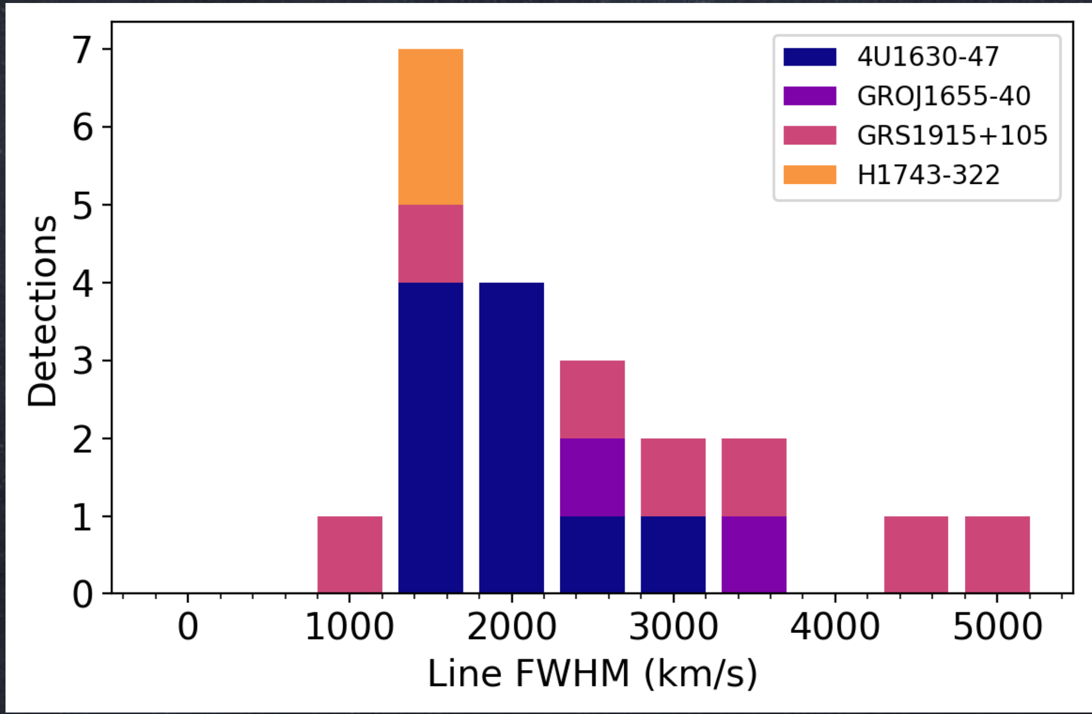
- Distributions



Results

- Distributions of line parameters





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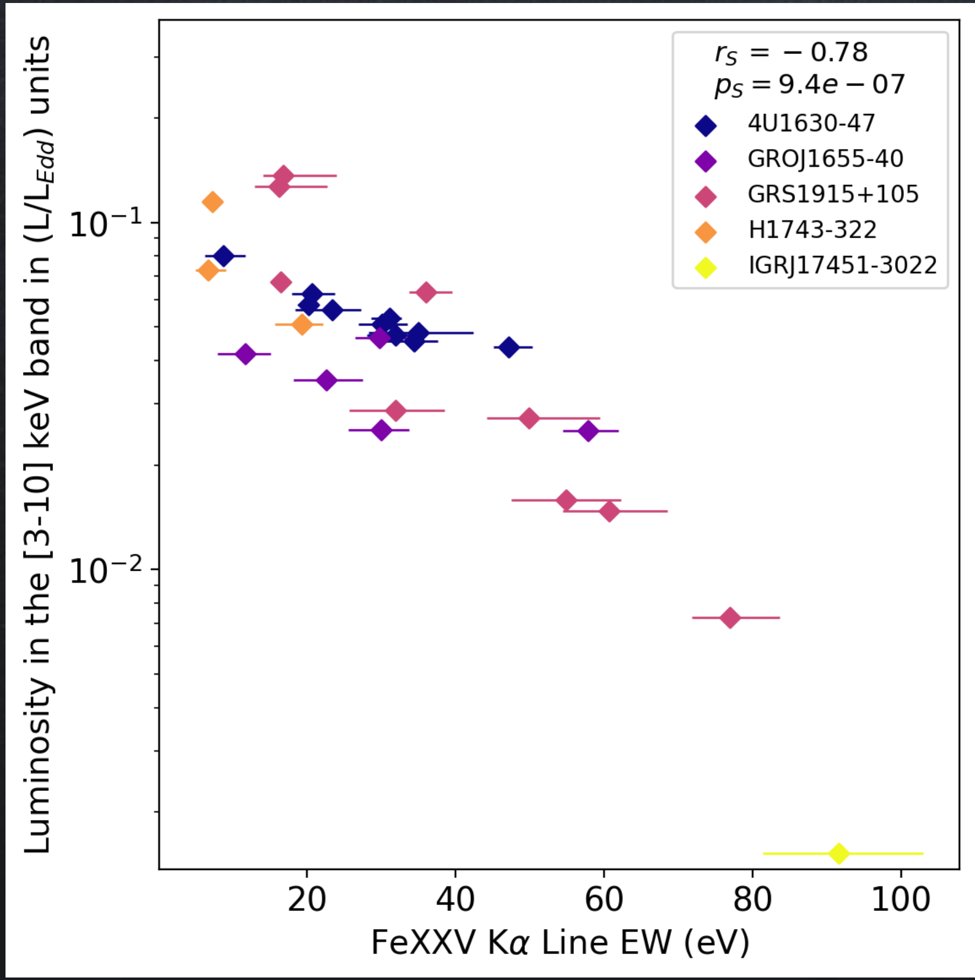
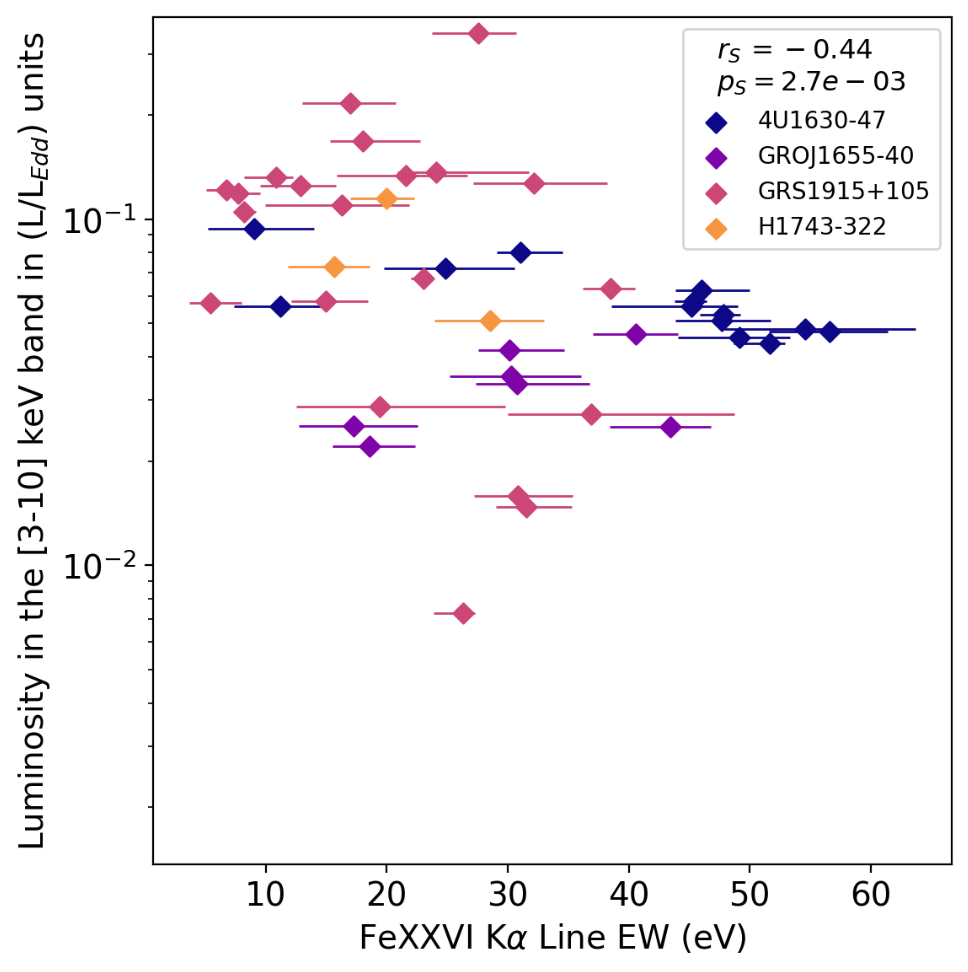
Results

- Comparing line behaviors

❑The FeKa25 EW correlates significantly with luminosity



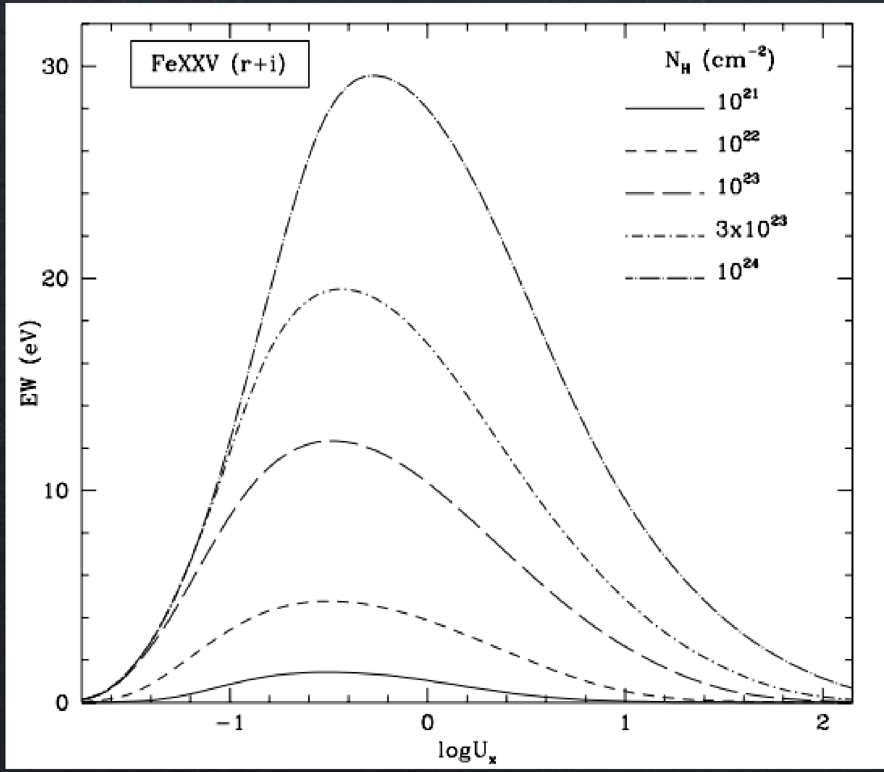


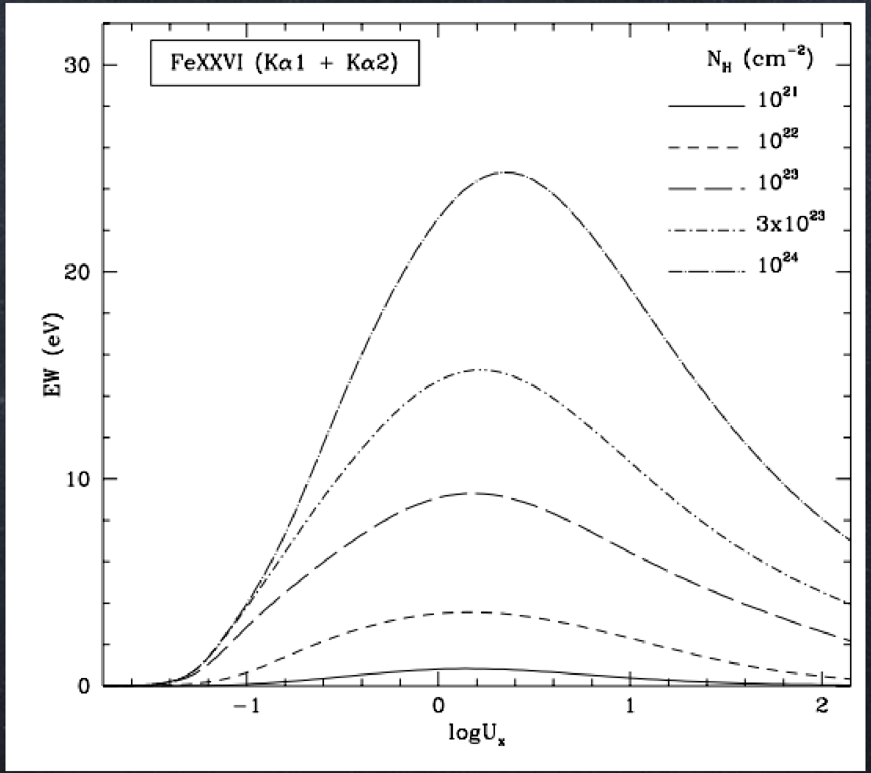
FeKa26 EW behaves completely differently

Results

- Parameter distribution and correlation

❑ This can be explained if the range of ionisation parameter we probe has two different behaviors for FeKa26/FeKa25.





Example of the effect of Ux (modified ionisation parameter) on the line EW for a single spectral shape in AGNs [13]

[13] Bianchi et al. 2005

Results

- Parameter distribution and correlation

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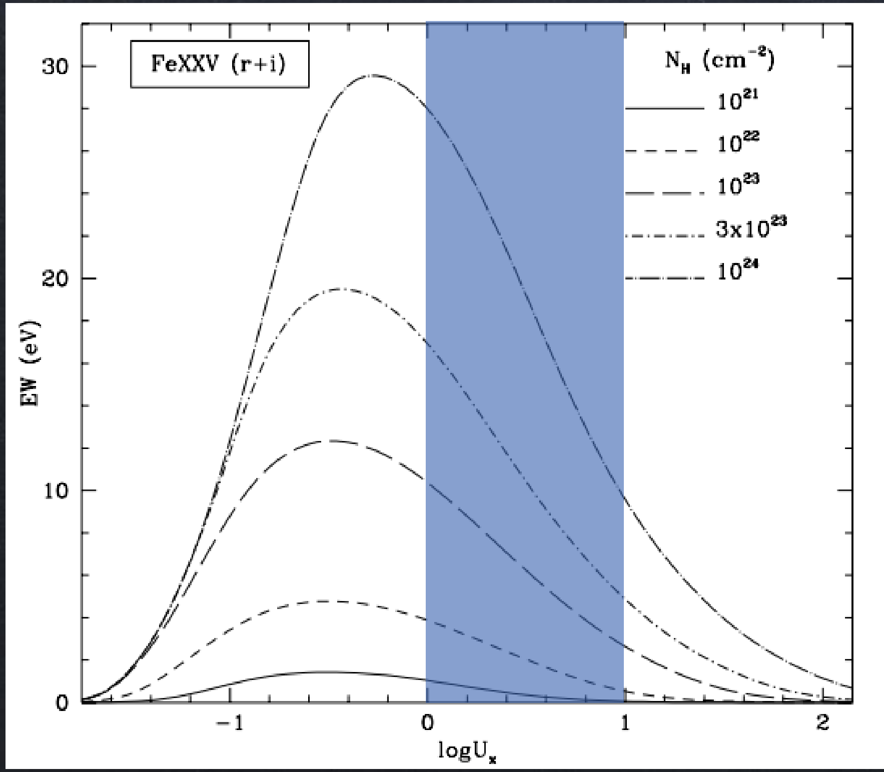

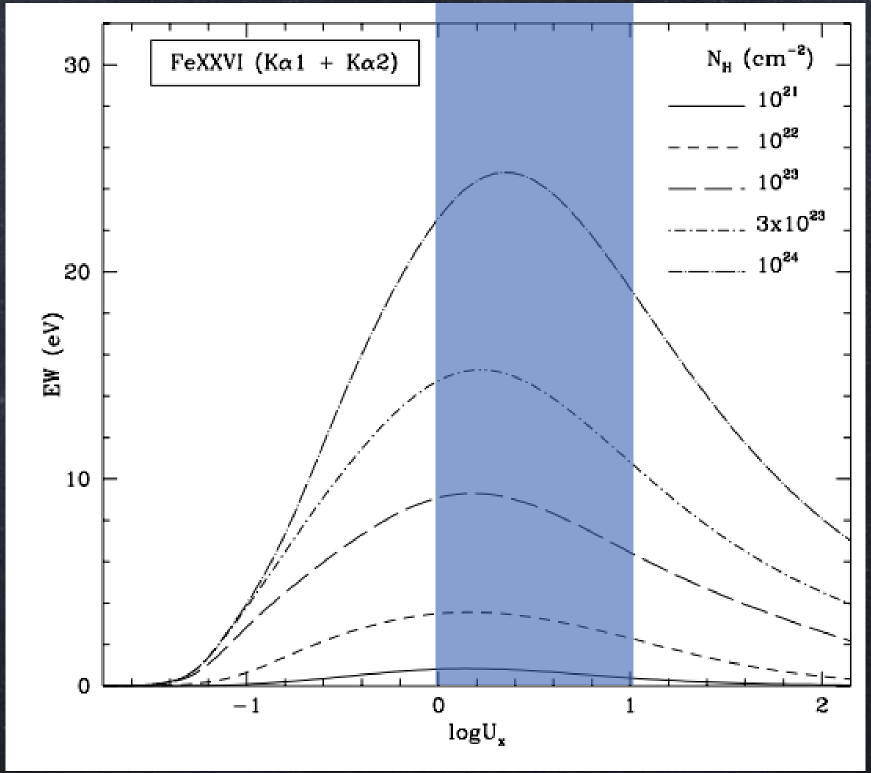

Example of the effect of Ux (modified ionisation parameter) on the line EW for a single spectral shape in AGNs [13]

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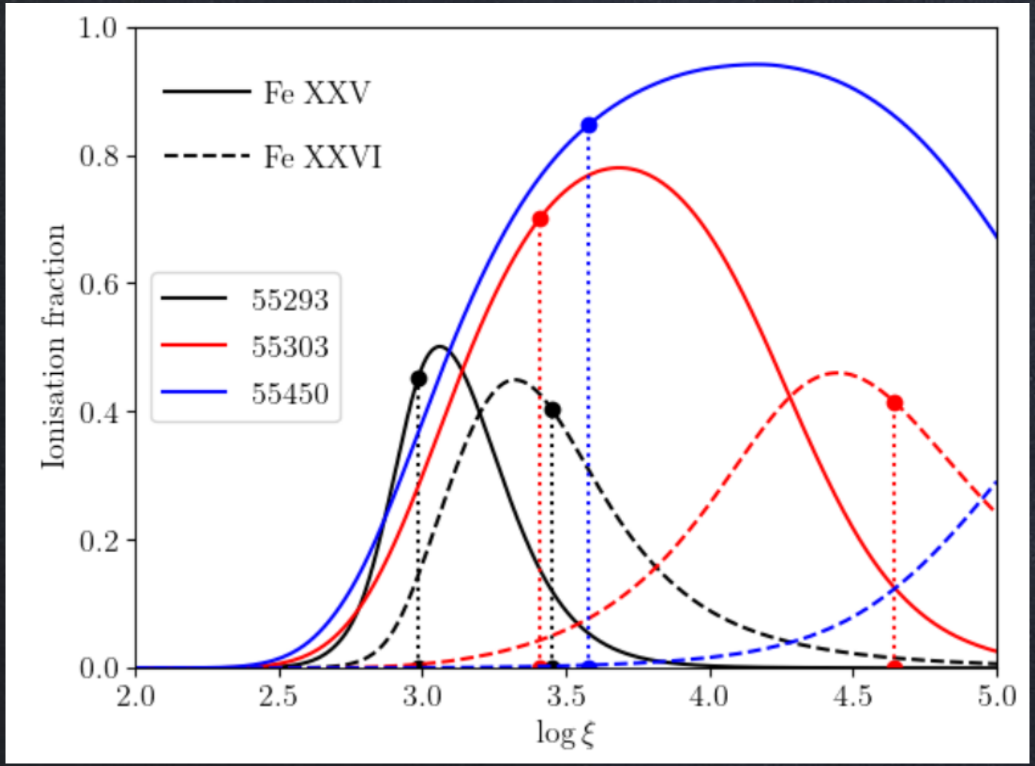
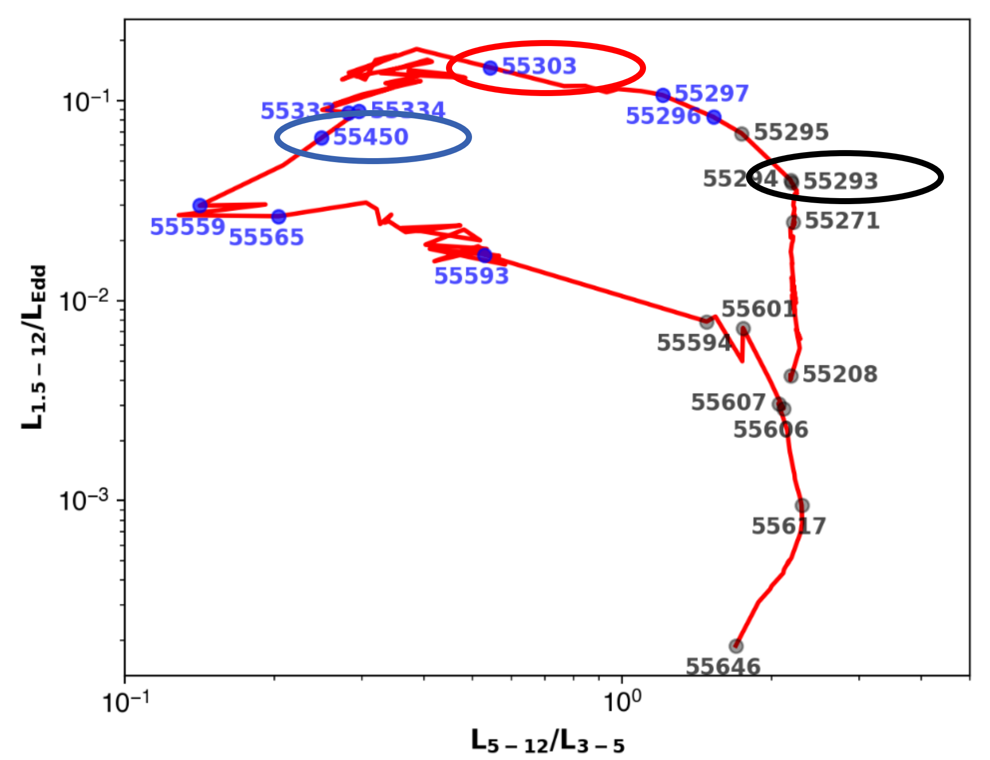
Results

- Parameter distribution and correlation

❑ This can be amplified by the changes in spectral state (even in the soft state) of BHLMXBs





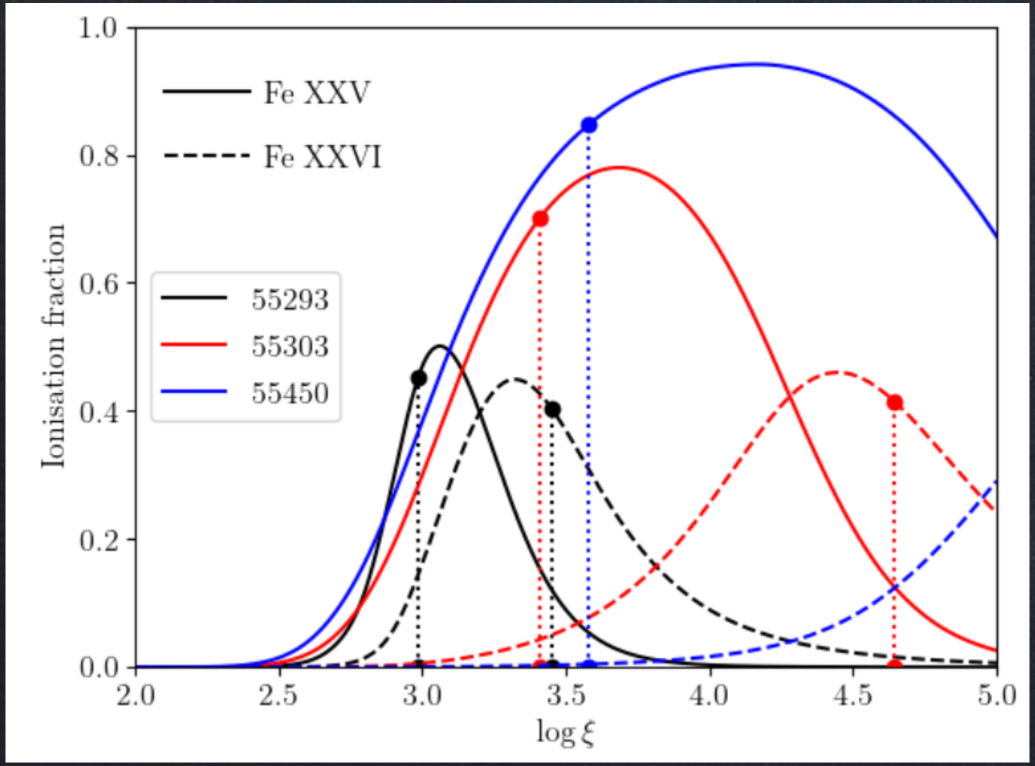
Effect of different SEDs on the ionic fractions of Fe XXVI and Fe XXV in GX339-4 from [1]

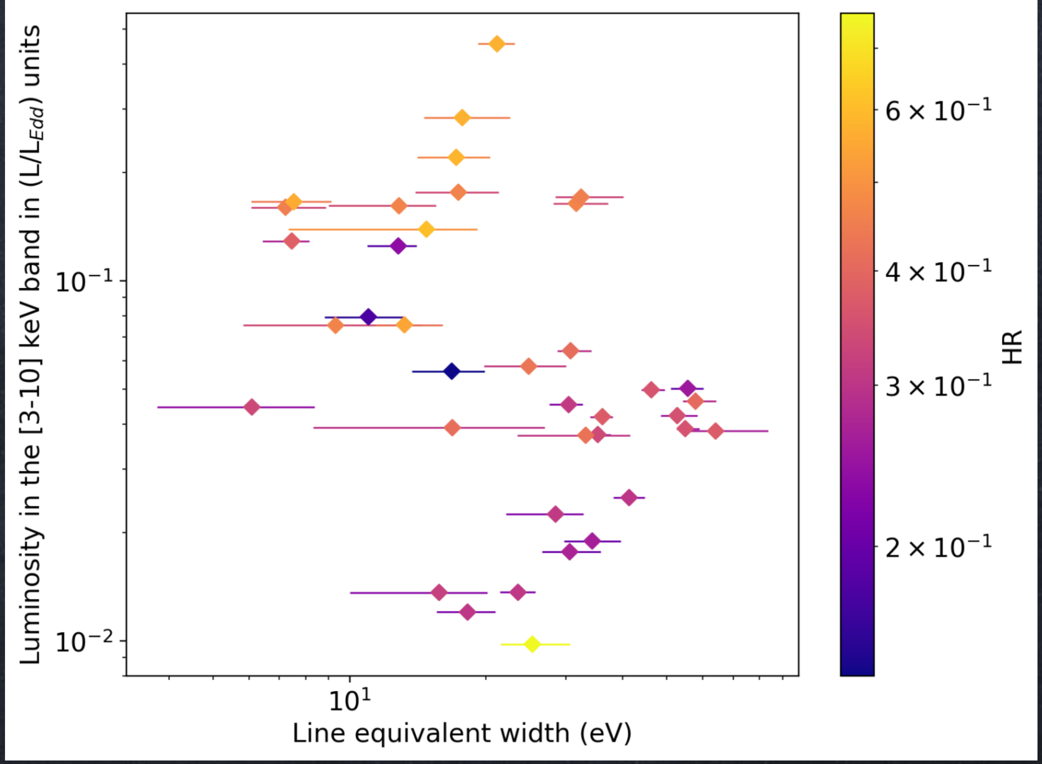
[1] Petrucci et al. 2021

Results

- Parameter distribution and correlation

❑This can be amplified by the changes in spectral state (even in the soft state) of BHLMXBs





FeKa26 Scatter color-coded with the HR ratio

Comparisons & Conclusion

- The bigger picture

Source	accretion states with absorption lines reported		
	this work	other works	
	iron band	iron band	other energies
4U 1543-47	X	soft [1]	X
4U 1630-47	soft	soft [2]	soft^X [3]
EXO 1846-031	X	*hard*[4]	X
GRO J1655-40	soft	soft[5]	soft^X [6]
GRS 1716-249	X	X	hard^V [7]
GRS 1758-258	X	hard[8]	X
GRS 1915+105	soft,hard	soft:$\phi, \gamma, \rho, \beta$[9],$\theta$[10],$\kappa$[11],$\lambda$[12],hard:$\chi$[13],obscured*[15]	soft^X:ϕ[14]
GX 339-4	X	X	soft^V[16],hard^V[16]
H 1743-322	soft	soft[17]	X
IGR J17091-3624	X	soft [18],*hard*[19]†	hard^X [20]
IGR J17451-3022	soft	soft[21]	soft^X[21]
MAXI J1305-704	X	*soft*[22][23],*hard* [23]	soft^X[22][23],hard^X[23]
MAXI J1348-630	X	*soft*[24], *hard*[24]	hard^X[25],soft^{IR}[26],hard^{V,IR}[26]
MAXI J1803-298	X	soft[27][28]	hard^V[29]
MAXI J1820+070	X	soft[30]	soft^{IR}[31],hard^{V,IR}[31]
Swift J1357.2-0933	X	X	hard^V[32][33]
Swift J1658.2-4242	X	*hard*[34]	X
V404 Cyg	X	hard [35]	obscured*: hard^X [36],hard^V[37]
V4641 Sgr	X	X	obscured*: hard^V[38]
XTE J1652-453	X	*hard*†[39]	X

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GRO J1655-40	soft	soft [5]	soft^{X} [6]
GRS 1716-249	X	X	hard^{V} [7]
GRS 1758-258	X	hard [8]	X
GRS 1915+105	soft,hard	soft:ϕ,γ,ρ,β [9],θ [10],κ [11],λ [12],hard:χ [13],obscured* [15]	soft^{X}:ϕ [14] IR?
GX 339-4	X	X	soft^{V} [16],hard^{V} [16]
H 1743-322	soft	soft [17]	X
IGR J17091-3624	X	soft [18],*hard* [19] †	hard^{X} [20]
IGR J17451-3022	soft	soft [21]	soft^{X} [21]
MAXI J1305-704	X	*soft* [22] [23],*hard* [23]	soft^{X} [22] [23],hard^{X} [23]
MAXI J1348-630	X	*soft* [24], *hard* [24]	hard^{X} [25],soft^{IR} [26],hard^{V,IR} [26]
MAXI J1803-298	X	soft [27] [28]	hard^{V} [29]
MAXI J1820+070	X	soft [30]	soft^{IR} [31],hard^{V,IR} [31]
Swift J1357.2-0933	X	X	hard^{V} [32] [33]
Swift J1658.2-4242	X	*hard* [34]	X
V404 Cyg	X	hard [35]	obscured*: hard^{X} [36],hard^{V} [37]
V4641 Sgr	X	X	obscured* hard^{V} [38]
XTE J1652-453	X	*hard*† [39]	X

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Comparisons & Conclusion

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Dipper

Dynamical high inclination

No conclusive info

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GRS 1758-258	X	hard [8]	X
GRS 1915+105	soft,hard	soft:ϕ,γ,ρ,β [9],θ [10],κ [11],λ [12],hard:χ [13],obscured* [15]	soft^X:ϕ [14] IR?
GX 339-4	X	X	soft^V [16],hard^V [16]
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MAXI J1305-704	X	*soft* [22] [23],*hard* [23]	soft^X [22] [23],hard^X [23]
MAXI J1348-630	X	*soft* [24], *hard* [24]	hard^X [25],soft^{IR} [26],hard^{V,IR} [26]
MAXI J1803-298	X	soft [27] [28]	hard^V [29]
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V404 Cyg	X	hard [35]	obscured*: hard^X [36],hard^V [37]
V4641 Sgr	X	X	obscured* hard^V [38]
XTE J1652-453	X	*hard*† [39]	X

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GRS 1716-249	X	X	hard^V [7]
GRS 1758-258	X	~~hard [8]~~	X
GRS 1915+105	soft,hard	soft:ϕ,γ,ρ,β [9],θ [10],κ [11],λ [12],hard:χ [13],obscured* [15]	soft^X:ϕ [14] IR?
GX 339-4	X	X	soft^V [16],hard^V [16]
H 1743-322	soft	soft [17]	X
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IGR J17451-3022	soft	soft [21]	soft^X [21]
MAXI J1305-704	X	~~*soft* [22] [23], *hard* [23]~~	soft^X [22] [23],hard^X [23]
MAXI J1348-630	X	~~*soft* [24], *hard* [24]~~	hard^X [25],soft^{IR} [26],hard^{V,IR} [26]
MAXI J1803-298	X	soft [27] [28]	hard^V [29]
MAXI J1820+070	X	~~soft [30]~~	soft^{IR} [31],hard^{V,IR} [31]
Swift J1357.2-0933	X	X	hard^V [32] [33]
Swift J1658.2-4242	X	~~*hard* [34]~~	X
V404 Cyg	X	hard [35]	obscured*: hard^X [36],hard^V [37]
V4641 Sgr	X	X	obscured* hard^V [38]
XTE J1652-453	X	~~*hard** [39]~~	X

Dipper

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4U 1543-47	X	~~soft(1)~~	X
4U 1630-47	soft	soft (2)	soft^X (3)
EXO 1846-031	X	~~hard(4)~~	X
GRO J1655-40	soft	soft(5)	soft^X(6)
GRS 1716-249	X	X	hard^V(7)
GRS 1758-258	X	~~hard(8)~~	X
GRS 1915+105	soft,hard	soft:ϕ,γ,ρ,β(9),θ(10),κ(11),λ(12),hard:χ(13),obscured*(15)	soft^X:ϕ(14) IR?
GX 339-4	X	X	soft^V(16),hard^V(16)
H 1743-322	soft	soft(17)	X
IGR J17091-3624	X	soft (18),~~hard(19)*~~	hard^X(20)
IGR J17451-3022	soft	soft(21)	soft^X(21)
MAXI J1305-704	X	~~soft(22)(23),hard(23)~~	soft^X(22)(23),hard^X(23)
MAXI J1348-630	X	~~soft(24), hard(24)~~	hard^X(25),soft^{IR}(26),hard^{V,IR}(26)
MAXI J1803-298	X	soft(27)(28)	hard^V(29)
MAXI J1820+070	X	~~soft(30)~~	soft^{IR}(31),hard^{V,IR}(31)
Swift J1357.2-0933	X	X	hard^V(32)(33)
Swift J1658.2-4242	X	~~hard(34)~~	X
V404 Cyg	X	hard (35)	obscured*: hard^X(36),hard^V(37)
V4641 Sgr	X	X	obscured* hard^V(38)
XTE J1652-453	X	~~hard*(39)~~	X

ongoing

missing?

Dipper

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EXO 1846-031	X	~~hard [4]~~	X
GRO J1655-40	soft	soft [5]	soft^X [6]
GRS 1716-249	X	X	hard^V [7]
GRS 1758-258	X	~~hard [8]~~	X
GRS 1915+105	soft,hard	soft:ϕ,γ,ρ,β [9],θ [10],κ [11],λ [12],hard:χ [13],obscured* [15]	soft^X:ϕ [14] IR?
GX 339-4	X	X	soft^V [16],hard^V [16]
H 1743-322	soft	soft [17]	X
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IGR J17451-3022	soft	soft [21]	soft^X [21]
MAXI J1305-704	X	~~soft [22][23],hard [23]~~	soft^X [22][23],hard^X [23]
MAXI J1348-630	X	~~soft [24],hard [24]~~	hard^X [25],soft^{IR} [26],hard^{V,IR} [26]
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Swift J1357.2-0933	X	X	hard^V [32][33]
Swift J1658.2-4242	X	~~hard [34]~~	X
V404 Cyg	X	hard [35]	obscured*: hard^X [36],hard^V [37]
V4641 Sgr	X	X	obscured* hard^V [38]
XTE J1652-453	X	~~hard* [39]~~	X

ongoing

compatibility

missing?

Dipper

Dynamical high inclination

No conclusive info