

天文学会 秋季年会 2025

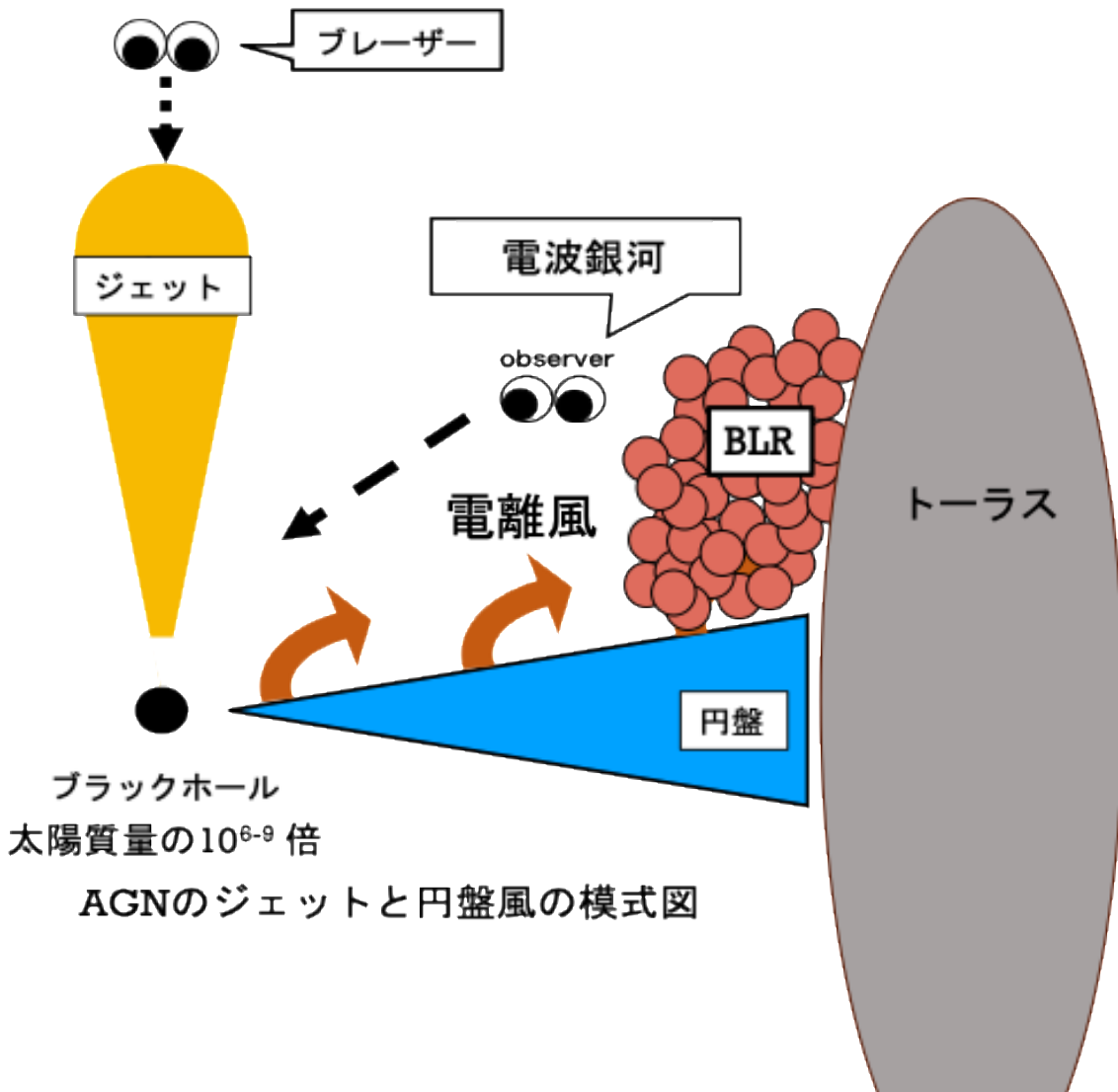
XRISM観測による Centaurus Aの電離風解析

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on behalf of XRISM Cen A team

1: 広島大学, 2: Tsinghua University, 3: The University of Michigan

AGN アウトフロー：ジェット、電離風 (UFOやWarm absorberなど)



宇宙物理の大問題：

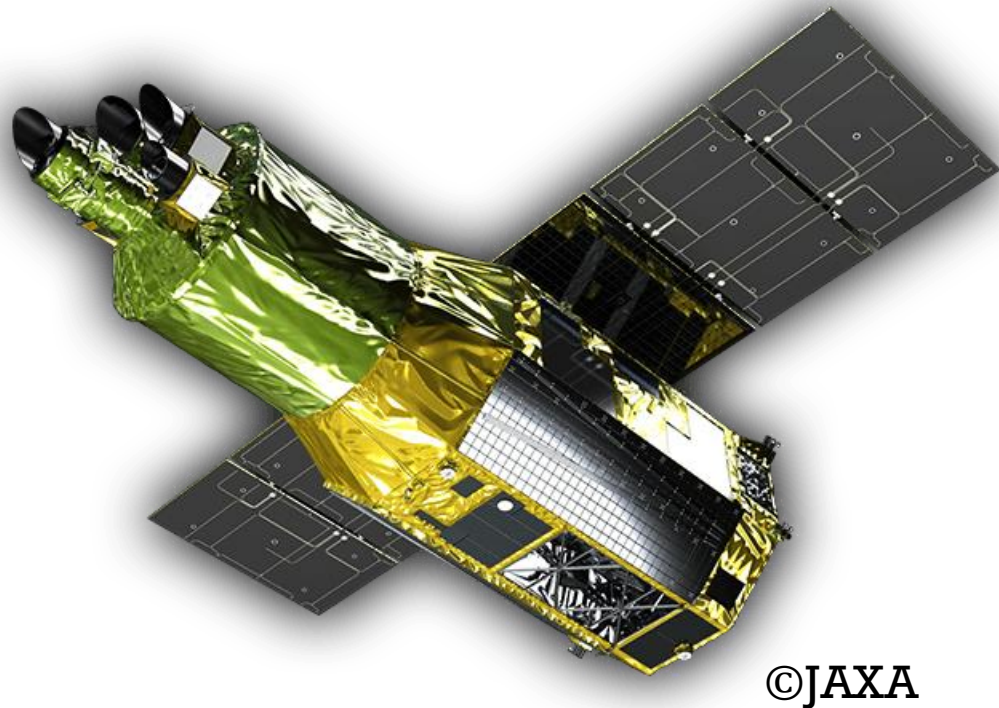
- 電離風は母銀河へのFeedbackに影響を与えることができるのか？
- 電離風がジェットの生成、コリメーションにどのように影響を与えるか？

BH近傍の電離物質の物理状態を理解することが問題解決の鍵

しかし従来のCCDカメラでは、BHごく近傍の電離物質の議論は困難

Resolve: マイクロカロリメータ。エネルギー分解能に優れる ($\Delta E \lesssim 5 \text{ eV}$)。

Xtend: 広視野 CCD カメラ



	Resolve	Xtend
Pixels	6×6	1280×1280
FOV	3.05'×3.05'	38'×38'
ΔE @6keV	$\lesssim 5 \text{ eV}$	$\sim 180 \text{ eV}$
Energy band	1.7-12 keV	0.4-13 keV

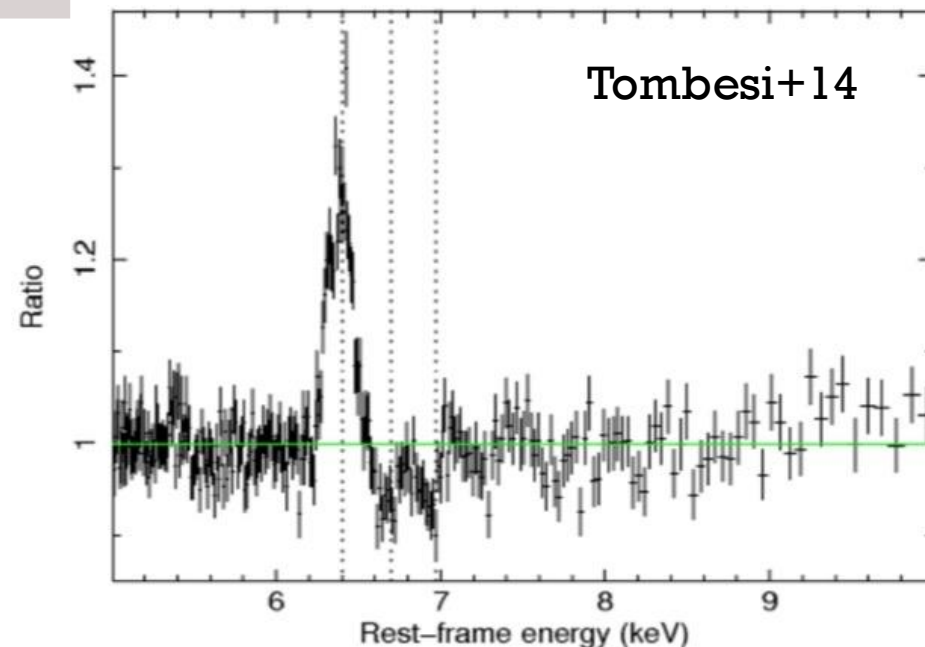
ターゲット; Centaurus A

Centaurus A (Cen A) は最近傍の電波銀河で、XRISM衛星のPVターゲットの一つ

赤方偏移	ブラックホール質量	Galactic N_{H} (cm^{-2})
0.00187695	$5.5 \times 10^7 M_{\odot}$	2.36×10^{20}

Cen AはFe-Kバンドに吸収線があることが示唆されてきた (e.g., Tombesi+14)。

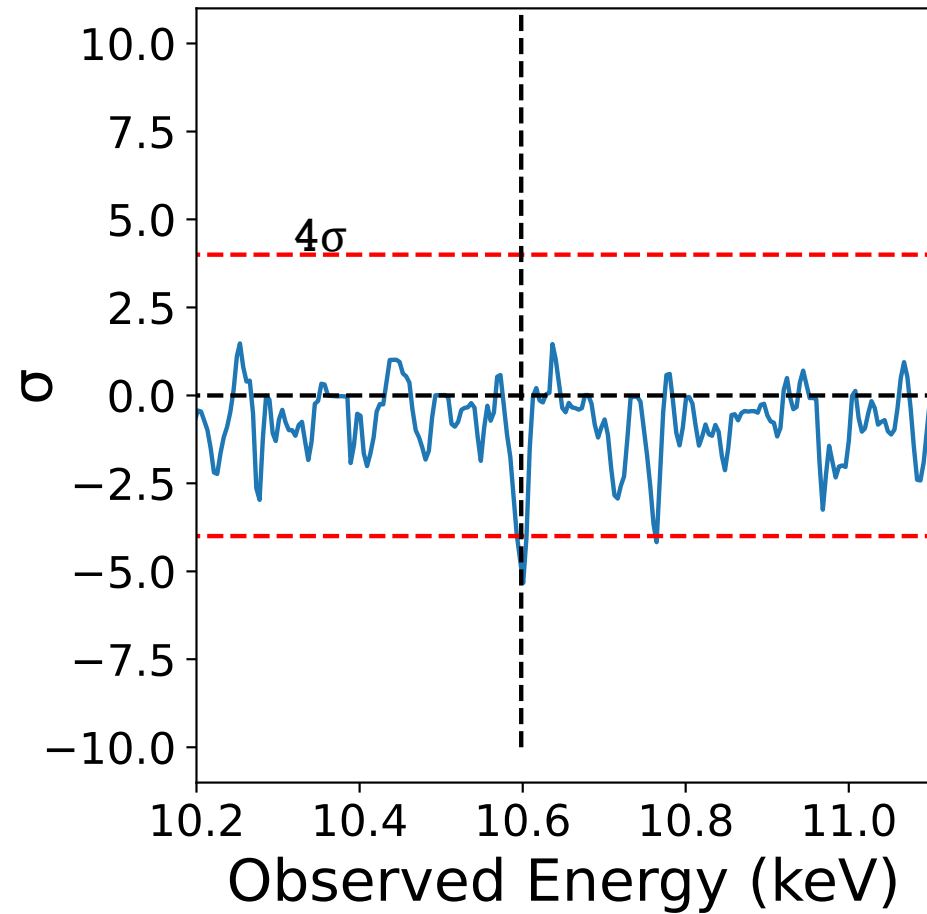
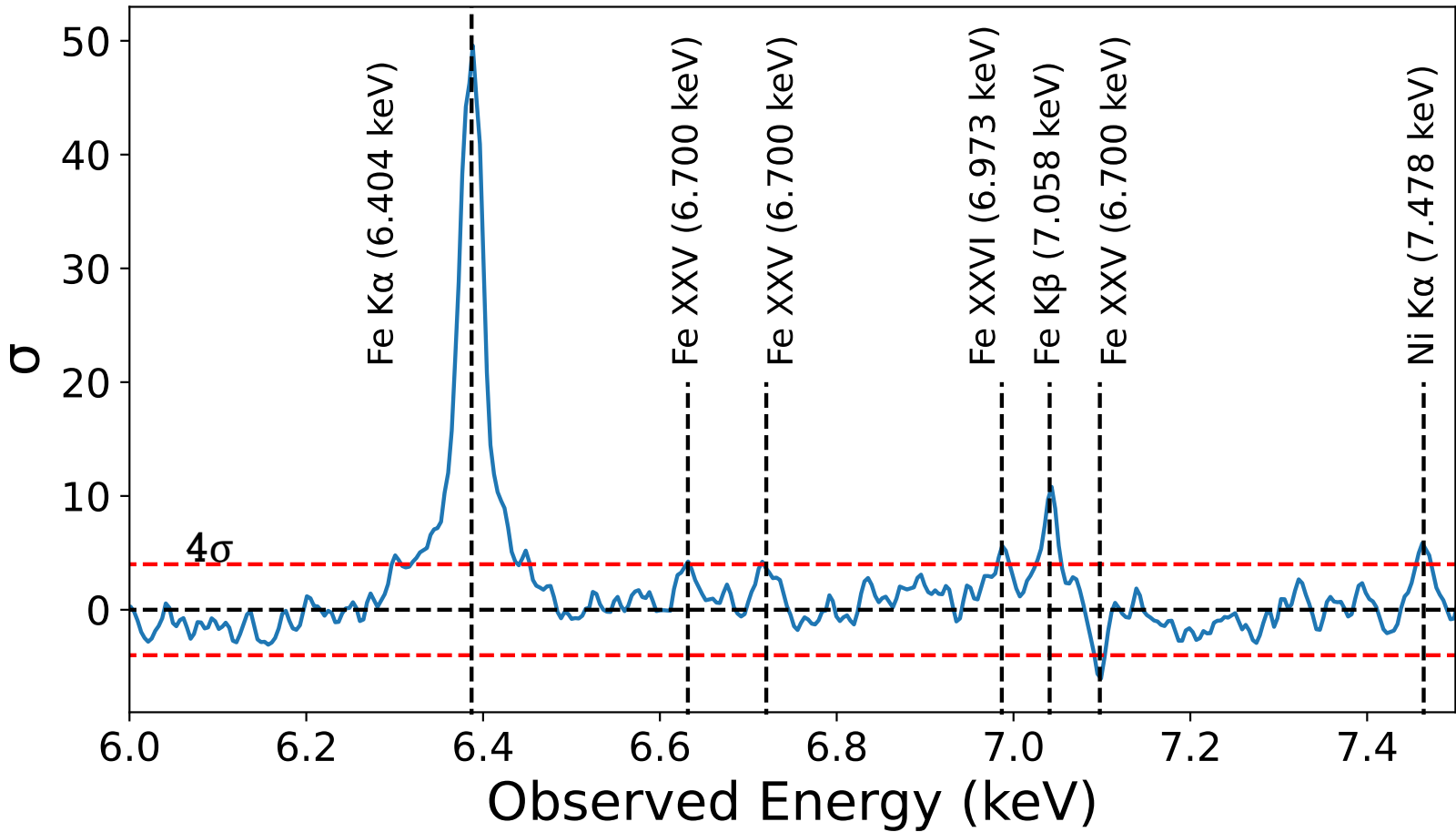
しかしCCDのエネルギー分解能により、物理パラメータの不定性が大きい。

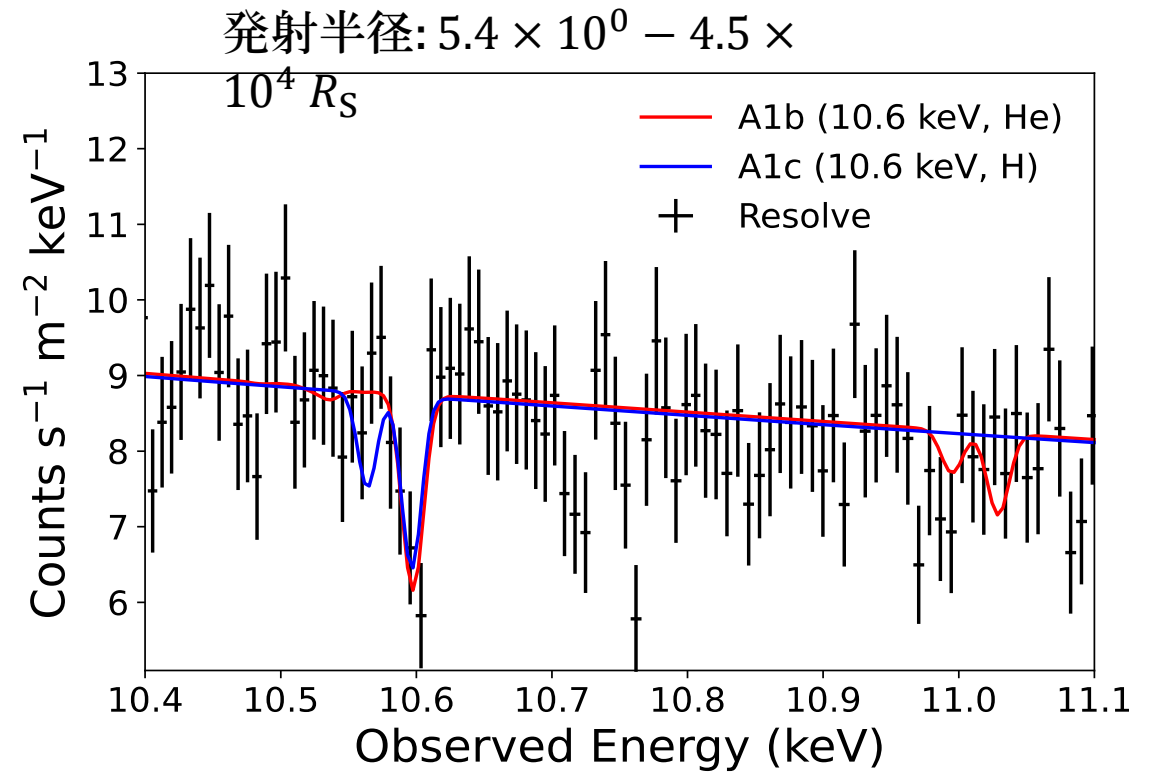
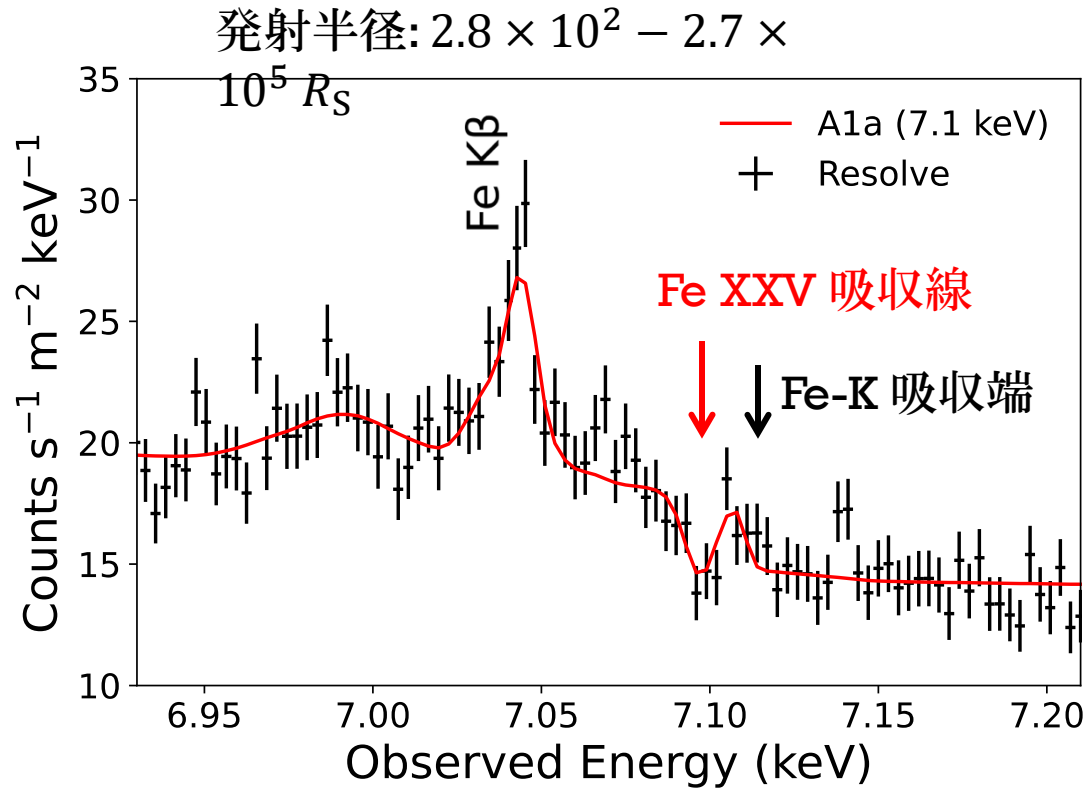


輝線/吸収線 (Scanning Gaussian)

吸収を受けた べき関数+ガウシアン

Step = 4 eV, FWHM = 8 eV



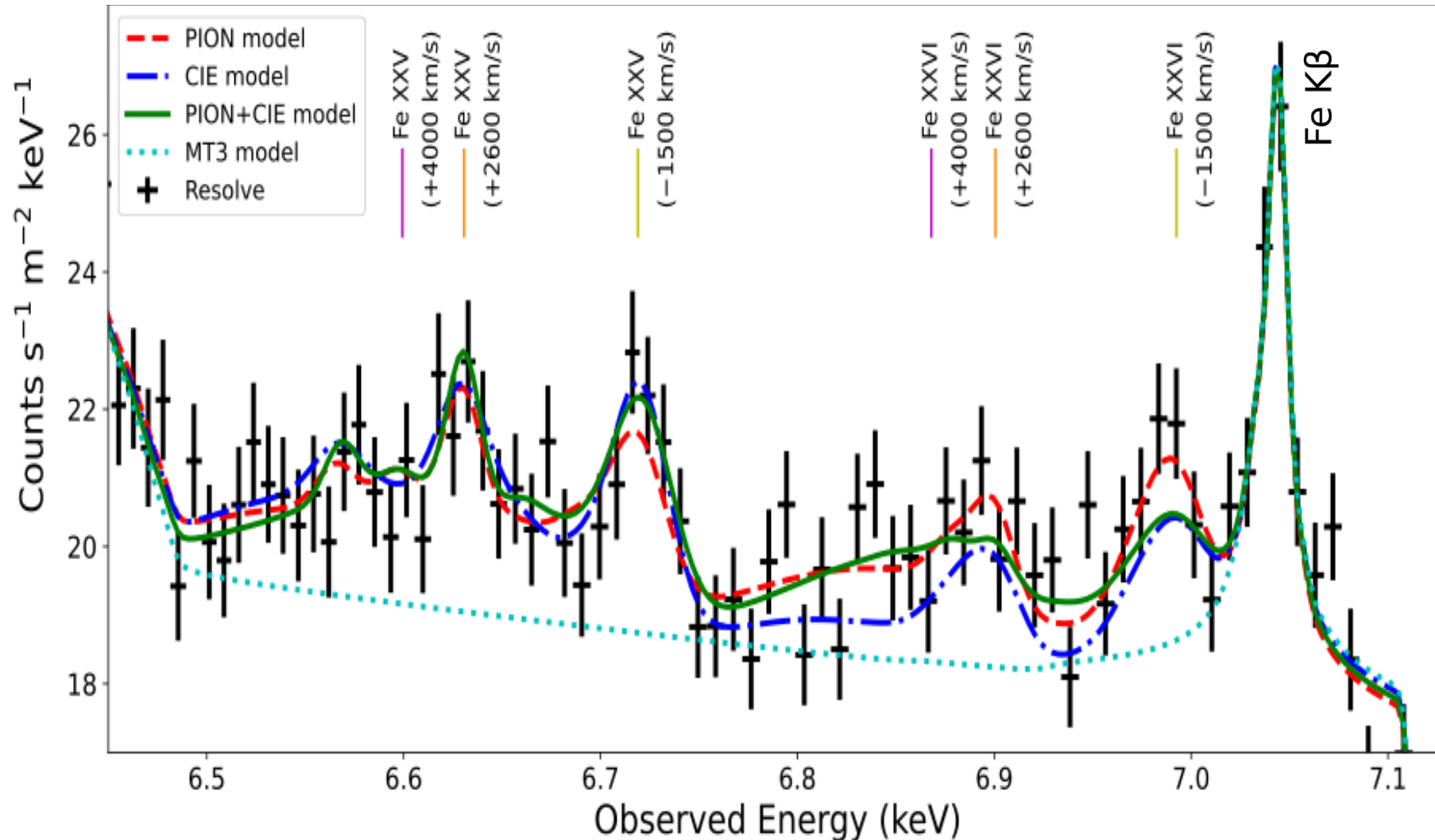


Model	Comp.	N_H ($10^{21} cm^{-2}$)	$\log \xi$ ($erg cm s^{-1}$)	v_{out} ($km s^{-1}$)	v_{turb} ($km s^{-1}$)	C-stat	d.o.f.	AIC
A1a	7.1 keV	1.5 ± 0.4	$2.90^{+0.09}_{-0.08}$	-17790^{+80}_{-60}	150^{+90}_{-70}	3622.7	3346	3671.1
A1b	10.6 keV (He)	4^{+2}_{-1}	3.3 ± 0.1	-129010^{+50}_{-60}	190^{+60}_{-50}	3618.9	3346	3667.3
A1c	10.6 keV (H)	$(2.0 \pm 0.2) \times 10^3$	5.8 ± 0.1	-119080^{+60}_{-70}	150 ± 70	3577.7	3346	3626.1

fcov = 1.0 (fixed)

1つのBroadな輝線成分と2つのNarrowな輝線成分が必要

PION: 光電離
CIE: 衝突電離



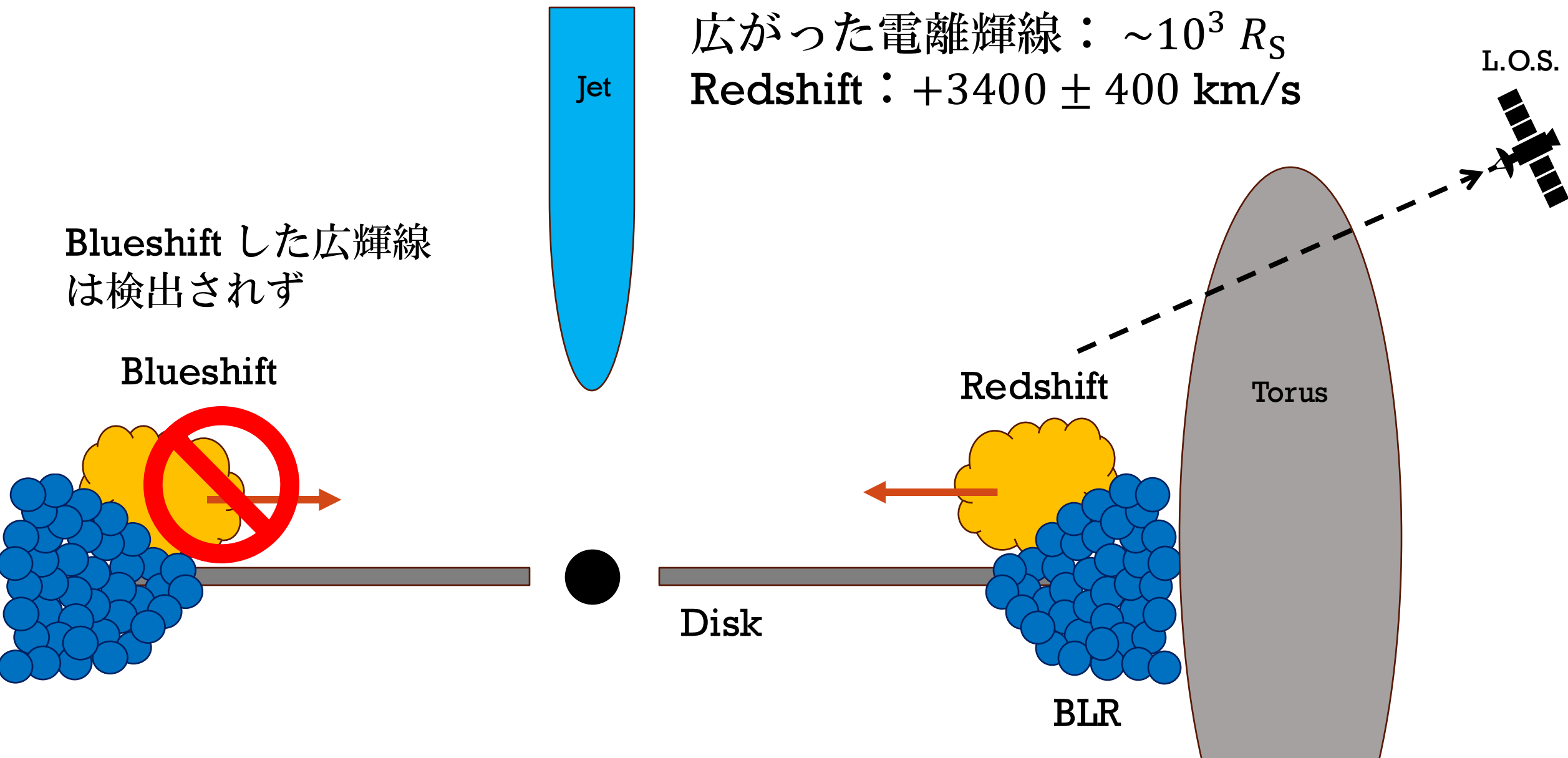
- ① **PION × 3**
- ② **CIE × 3**
- ③ ~~CIE + PION × 2~~
- ④ **PION + CIE × 2**

Broad: PION
Narrow: PION or CIE

$L_{\text{bol}} = (1 - 4) \times 10^{43} \text{ erg/s}$	Broad	Narrow × 2成分	(M81*)
電離メカニズム	光電離	衝突電離 or 光電離	衝突電離 or 光電離
Broadening (km/s)	3000 ± 400	$500 \pm 100 / 400 \pm 100$	800 & 210
Redshift (km/s)	3400 ± 400	$-1500 \pm 100 / 2600 \pm 100$	170 & 1500
電離物質の位置 (R_s)	4×10^3	$1 \times 10^5 / 3 \times 10^5$	←ケプラー回転を仮定

電離輝線物質は(低光度)AGNの一般的な特徴であるかもしれない。
しかし、M81*とは特徴が異なる。

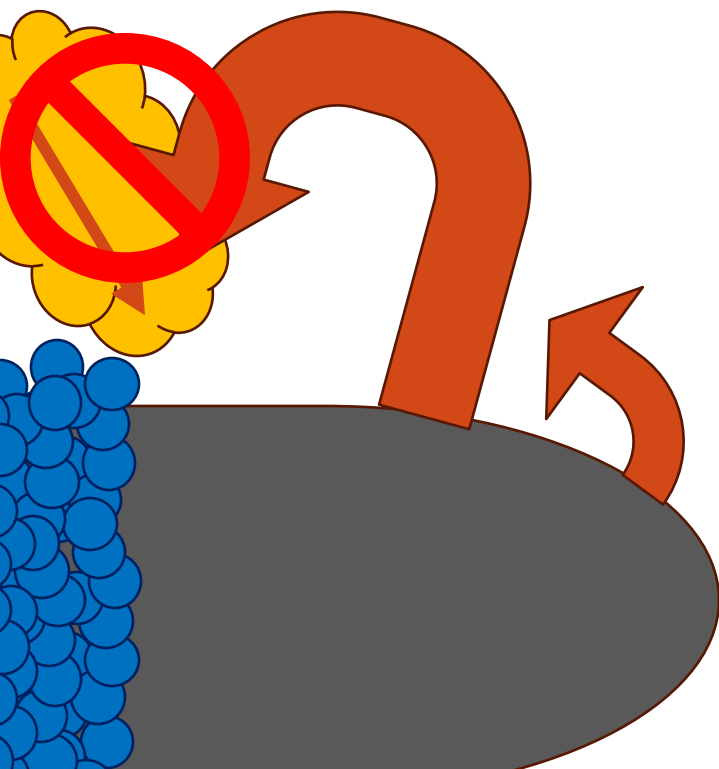
電離鉄輝線 (Broad emission)



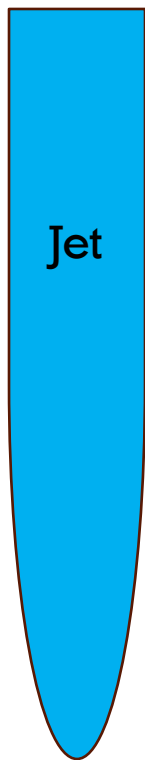
電離鉄輝線 (Broad emission)

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BLR/Torusに
落ちていく?

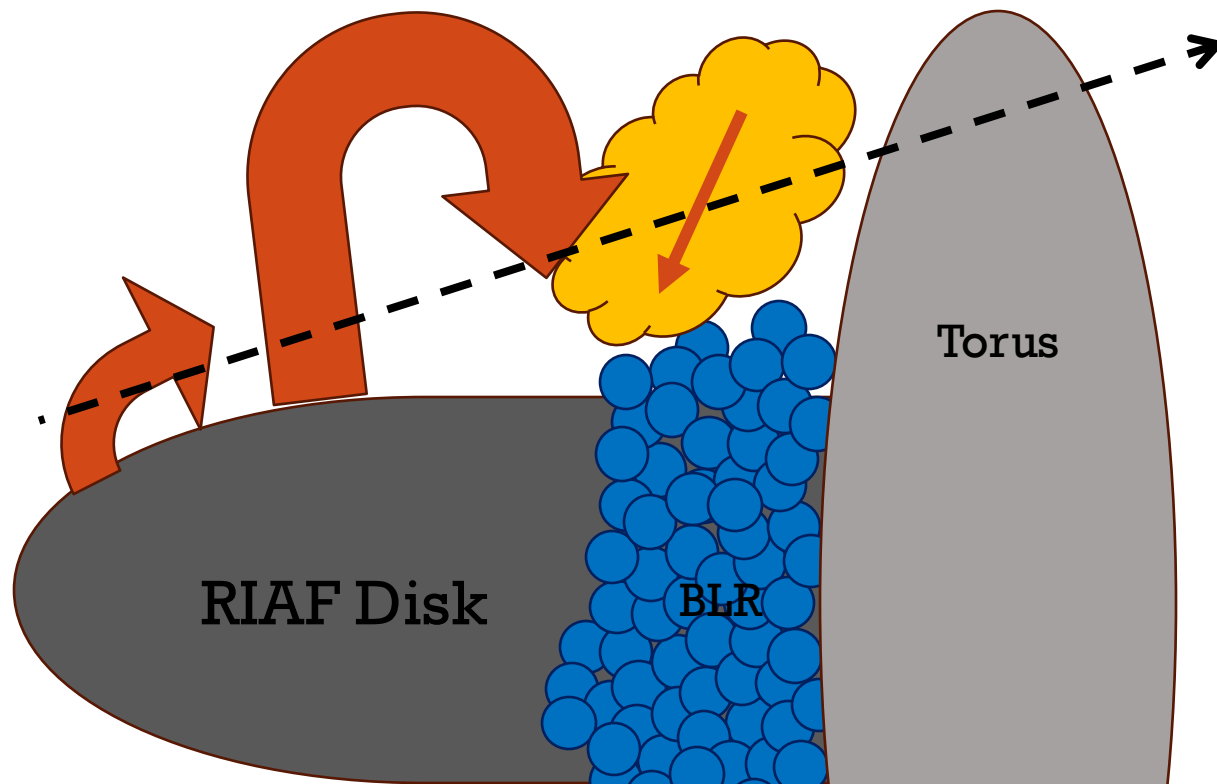


Jet

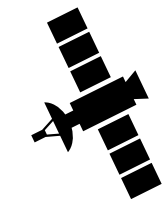


7.1 keV 吸収線 : $2.8 \times 10^2 - 2.7 \times 10^5 R_S$

広がった電離輝線成分は視線方向
の近くでインフロー?



L.O.S.

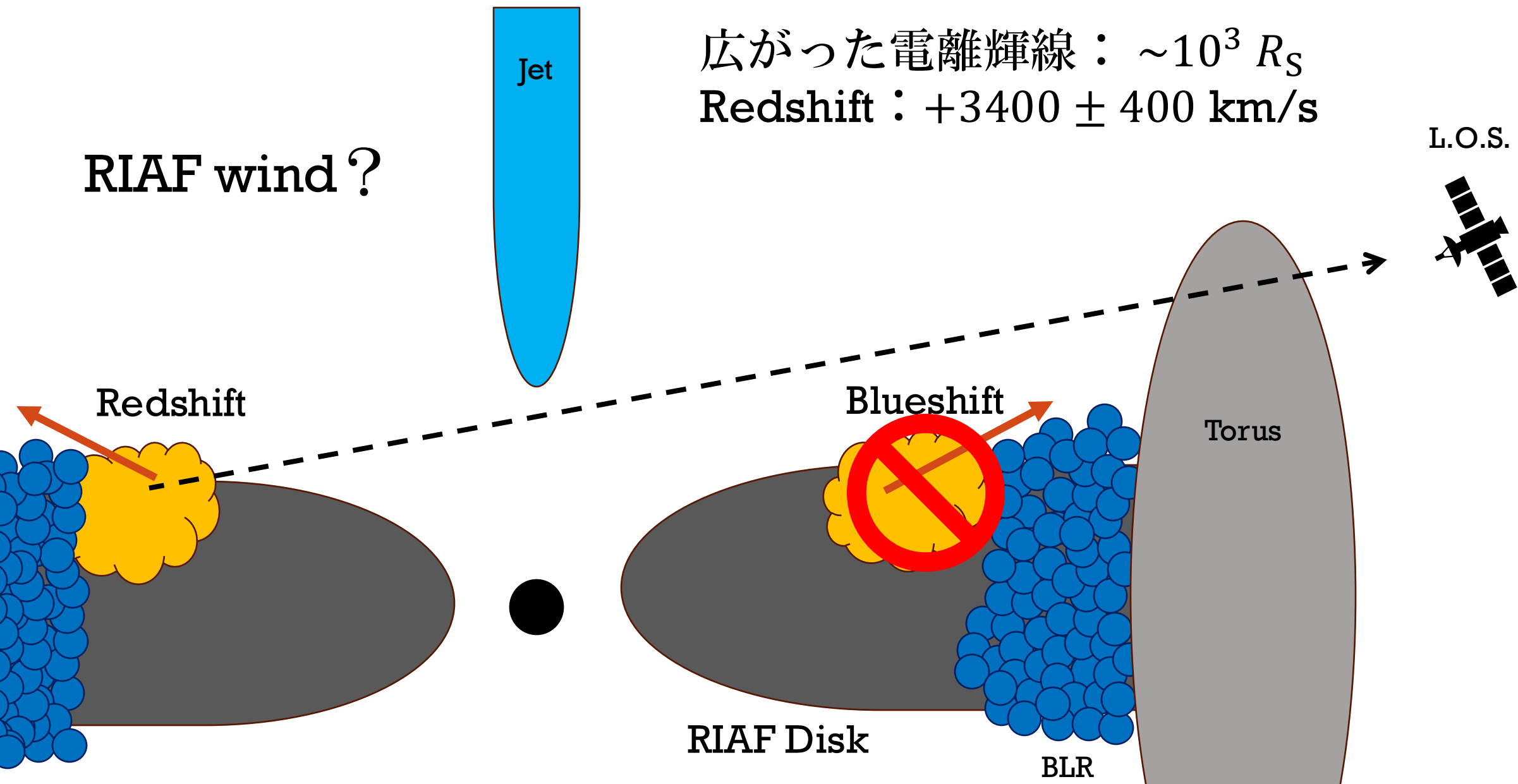


Torus

RIAF Disk

BLR

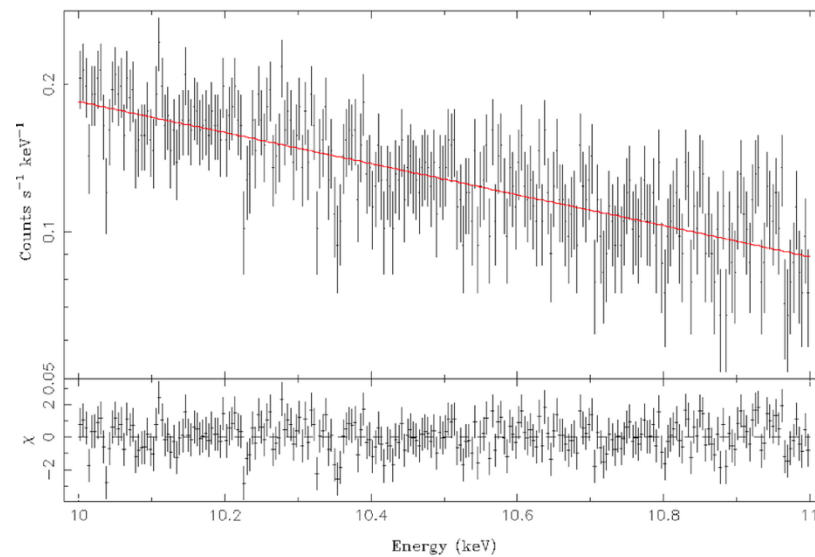
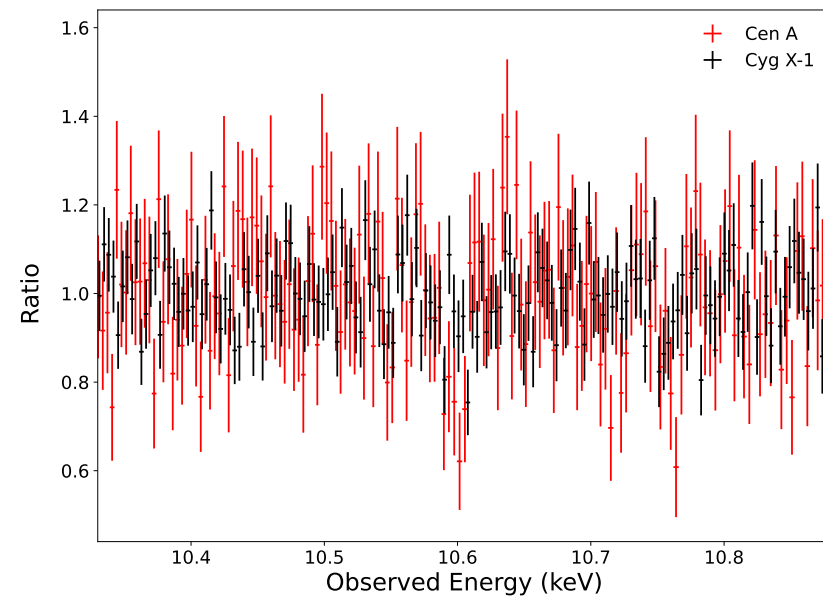
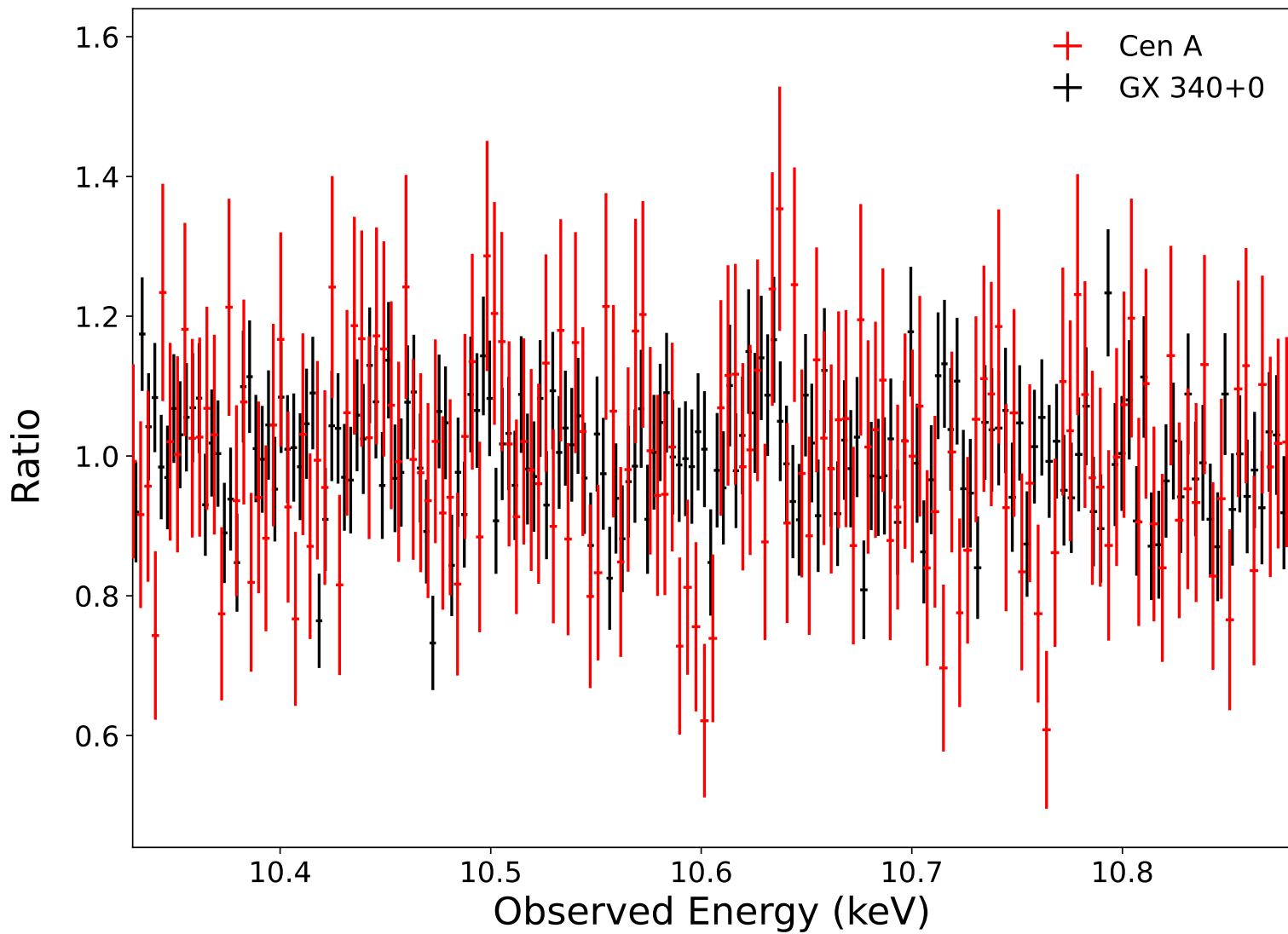
電離鉄輝線 (Broad emission)



- XRISMで最近傍電波銀河のCentaurus Aを観測した
- 複数の吸収線と輝線が検出された
- 吸収線
 - ✓ 10.6 keV: He-like? H-like?
 - ✓ 7.1 keV: UFO
- 電離鉄輝線
 - ✓ Broad -redshifted emission: 光電離
 - ✓ Narrow -redshifted/blueshifted: 衝突電離 or 光電離

How about other observation?

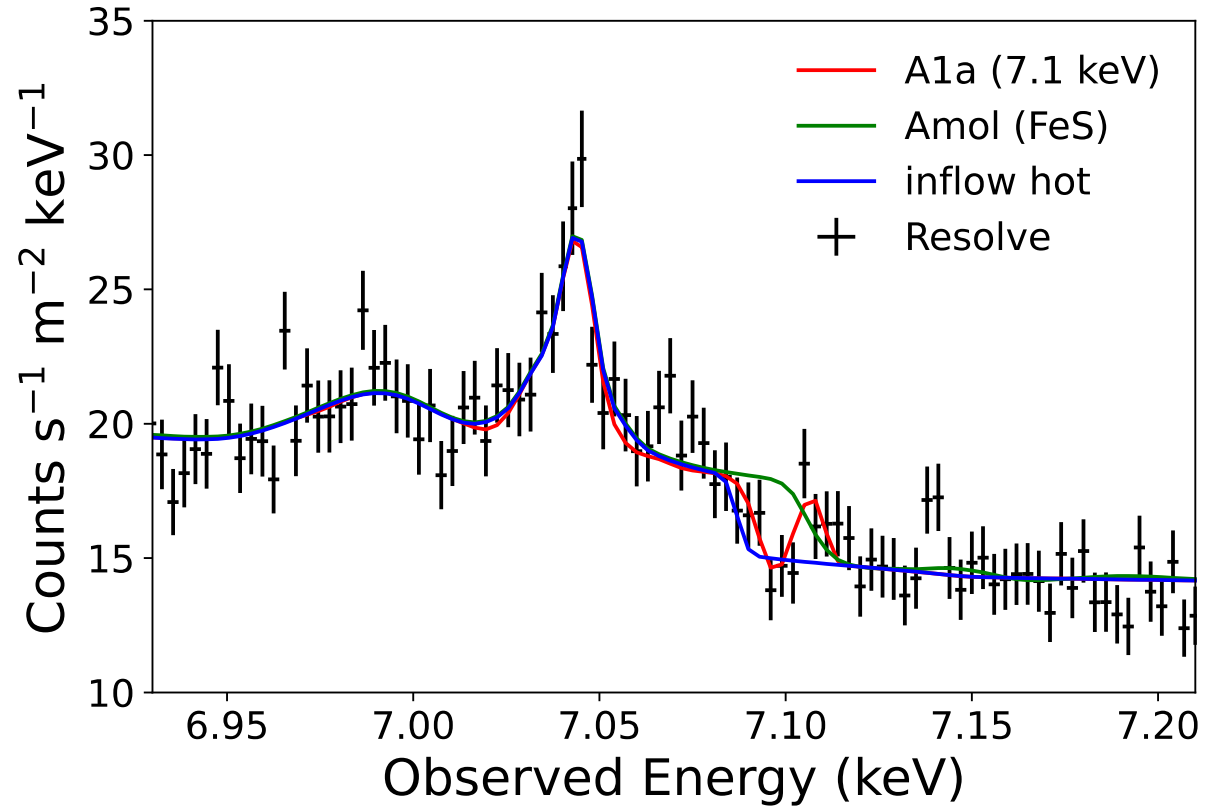
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7.1 keVの吸収線はFe-K吸収端構造の上に位置している。したがって、Fe-K吸収端が適切にモデル化されないと、偽の構造として現れる可能性がある。

そこで、3つの可能性を調査

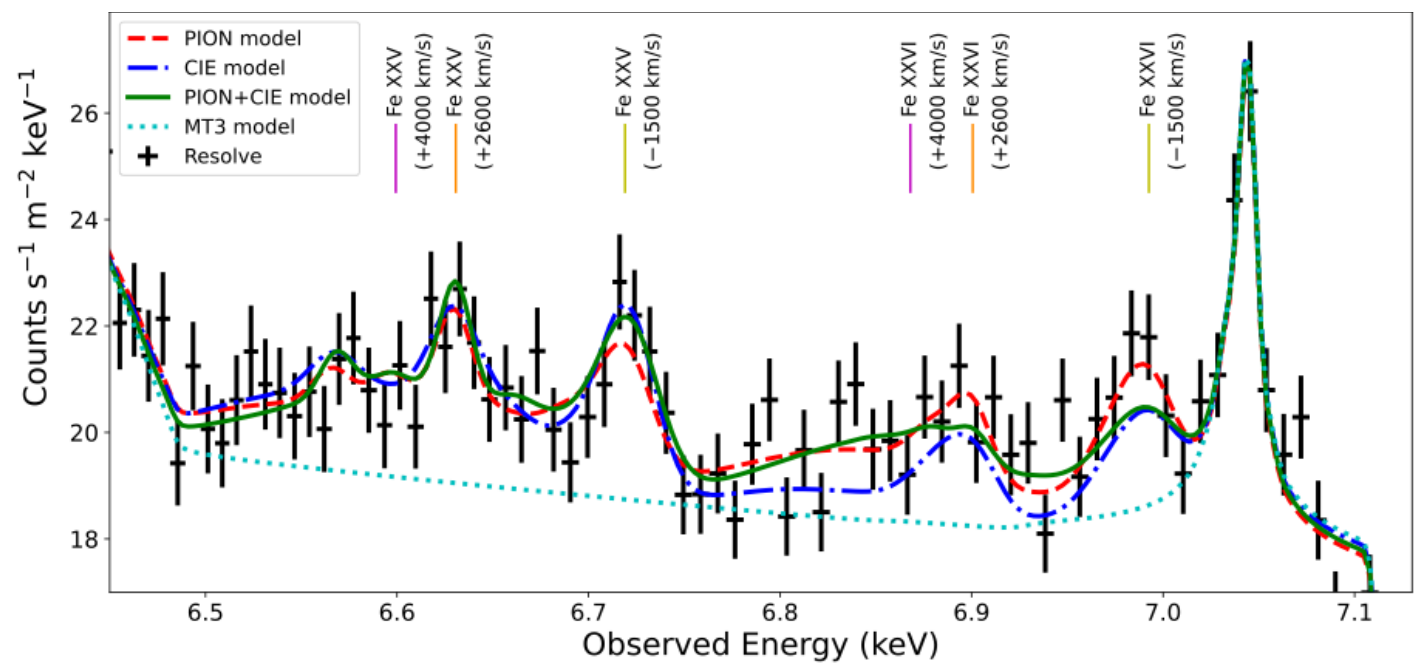
- 通常の吸収端+ 吸収線 ← 最も良く表現
- 分子吸収による吸収端
- インフローする吸収端



	pion (A1a)	amol (FeS)	Inflow hot
N_H ($\times 10^{22}$ cm $^{-2}$)	0.15 ± 0.04	$(4.60 \pm 0.01) \times 10^{-4}$	15.59 ± 0.05
v_{flow} (km s $^{-1}$)	-17790^{+80}_{-60}	-	$+810^{+170}_{-90}$
C-stat	3622.7	3629.9	3630.5

Ionized emission lines

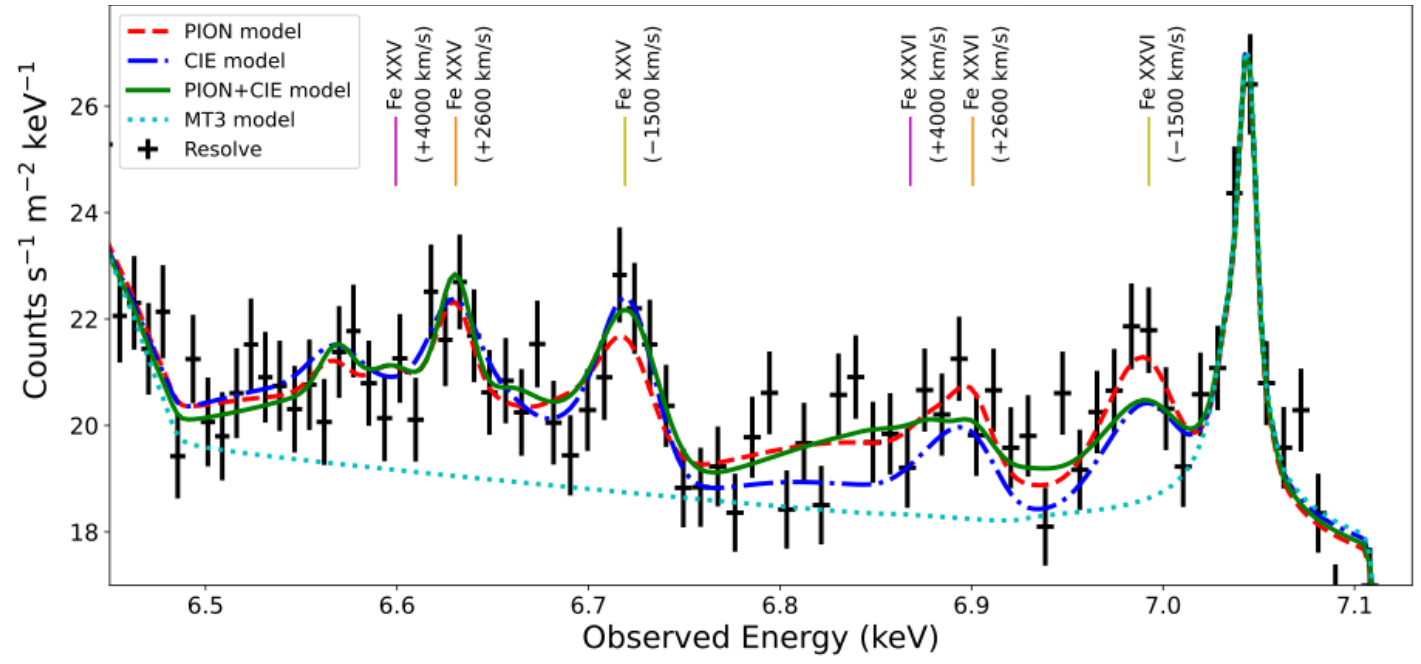
① PION × 3



Parameter	Unit	PION model
Component Em1		
<code>pion</code> N_H ⁽¹⁾	10^{22} cm^{-2}	$2.8^{+1.0}_{-0.9}$
<code>pion</code> $\log \xi$ ⁽²⁾	erg cm s^{-1}	$3.10^{+0.07}_{-0.08}$
<code>pion</code> v_{shift} ⁽³⁾	km s^{-1}	2600 ± 100
<code>vgau</code> v_{broad} ⁽⁴⁾	km s^{-1}	400^{+200}_{-100}
Component Em2		
<code>pion</code> N_H ⁽¹⁾	10^{22} cm^{-2}	6 ± 1
<code>pion</code> $\log \xi$ ⁽²⁾	erg cm s^{-1}	3.14 ± 0.04
<code>pion</code> v_{shift} ⁽³⁾	km s^{-1}	-1400 ± 100
<code>vgau</code> v_{broad} ⁽⁴⁾	km s^{-1}	600^{+200}_{-100}
Component Em3		
<code>pion</code> N_H ⁽¹⁾	10^{23} cm^{-2}	$1.7^{+0.6}_{-0.4}$
<code>pion</code> $\log \xi$ ⁽²⁾	erg cm s^{-1}	$3.20^{+0.05}_{-0.04}$
<code>pion</code> v_{shift} ⁽³⁾	km s^{-1}	4600^{+700}_{-800}
<code>vgau</code> v_{broad} ⁽⁴⁾	km s^{-1}	3300^{+700}_{-500}
<i>C</i> -stat / d.o.f.		3627.3 / 3346
AICs		3675.7

Ionized emission lines

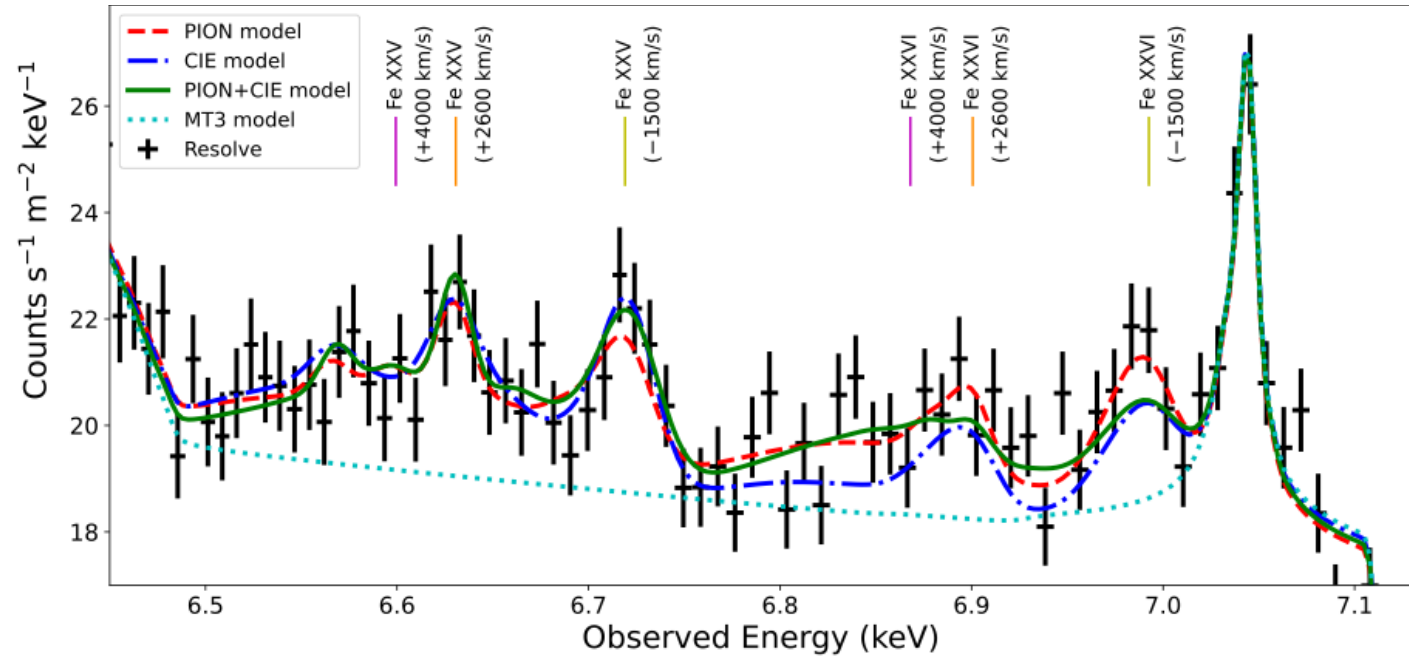
② CIE × 3



Parameter	Unit	CIE model
Component Em1		
cie kT ⁽¹⁾	keV	8 ± 1
cie $n_H n_e V$ ⁽²⁾	10^{63} cm^{-3}	$1.7^{+1.0}_{-0.5}$
reds v_{shift} ⁽³⁾	km s^{-1}	2600 ± 100
vgau v_{broad} ⁽⁴⁾	km s^{-1}	400^{+200}_{-100}
Component Em2		
cie kT ⁽¹⁾	keV	$7.5^{+0.7}_{-0.6}$
cie $n_H n_e V$ ⁽²⁾	10^{63} cm^{-3}	$3.0^{+0.4}_{-0.5}$
reds v_{shift} ⁽³⁾	km s^{-1}	-1500 ± 100
vgau v_{broad} ⁽⁴⁾	km s^{-1}	590^{+110}_{-90}
Component Em3		
cie kT ⁽¹⁾	keV	$7.3^{+0.8}_{-0.9}$
cie $n_H n_e V$ ⁽²⁾	10^{63} cm^{-3}	$3.3^{+0.9}_{-1.3}$
reds v_{shift} ⁽³⁾	km s^{-1}	4800^{+1400}_{-800}
vgau v_{broad} ⁽⁴⁾	km s^{-1}	2500^{+800}_{-900}
C-stat / d.o.f.		$3653.1 / 3346$
AICs		3701.5

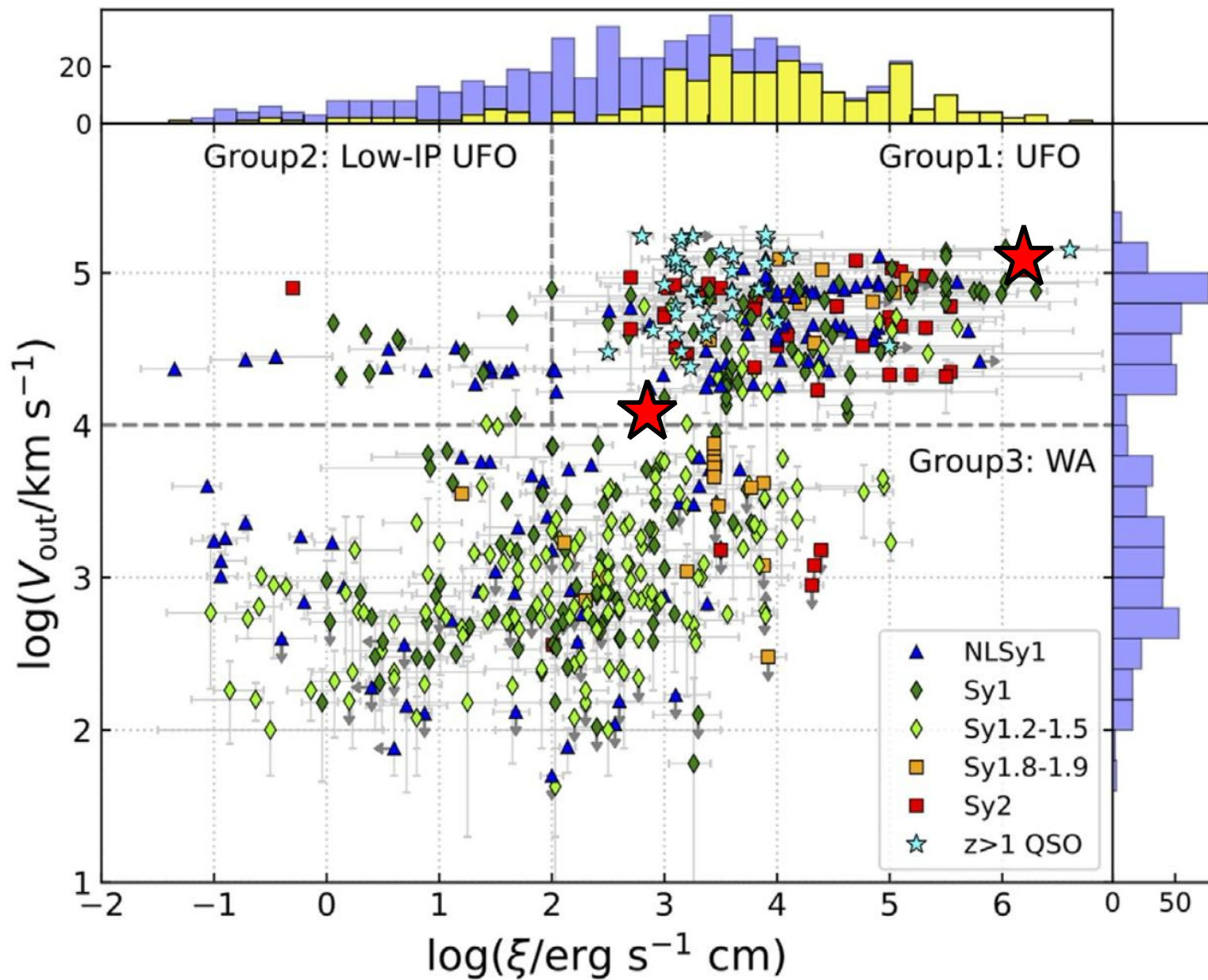
Ionized emission lines

④ Broad PION + Narrow CIE × 2



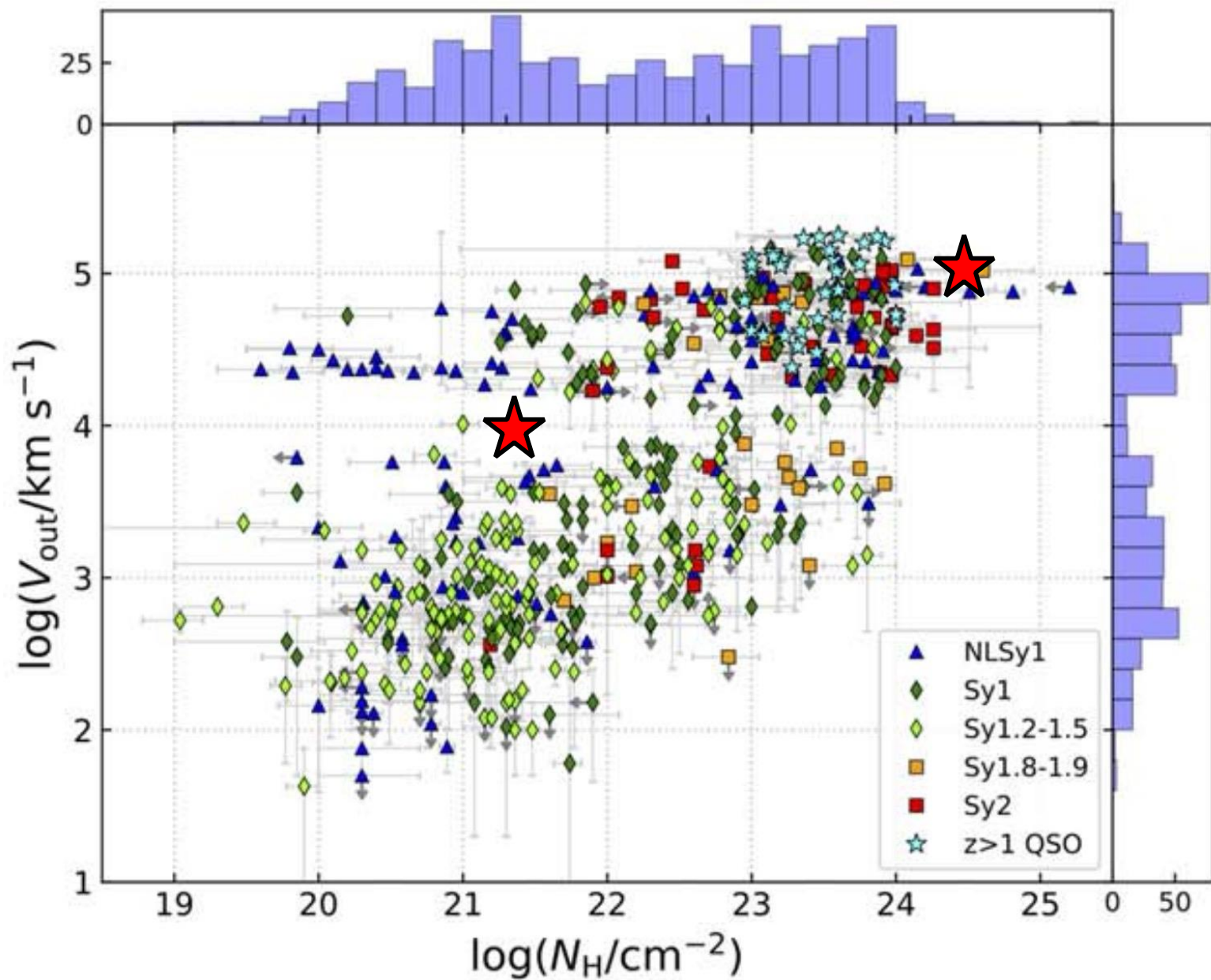
Parameter	Unit	PION+CIE model
Component Em1		
cie kT ⁽¹⁾	keV	5_{-2}^{+1}
cie $n_H n_e V$ ⁽²⁾	10^{63} cm^{-3}	$1.3_{-0.3}^{+0.4}$
reds v_{shift} ⁽³⁾	km s^{-1}	2600 ± 100
vgau v_{broad} ⁽⁴⁾	km s^{-1}	400 ± 100
Component Em2		
cie kT ⁽¹⁾	keV	$7.5_{-0.7}^{+0.8}$
cie $n_H n_e V$ ⁽²⁾	10^{63} cm^{-3}	$2.8_{-0.4}^{+0.5}$
reds v_{shift} ⁽³⁾	km s^{-1}	-1500 ± 100
vgau v_{broad} ⁽⁴⁾	km s^{-1}	550_{-80}^{+110}
Component Em3		
pion N_H ⁽⁵⁾	10^{23} cm^{-2}	$1.8_{-0.4}^{+0.5}$
pion $\log \xi$ ⁽⁶⁾	erg cm s^{-1}	$3.23_{-0.04}^{+0.05}$
pion v_{shift} ⁽⁷⁾	km s^{-1}	4000 ± 500
vgau v_{broad} ⁽⁸⁾	km s^{-1}	3100 ± 500
$C\text{-stat} / \text{d.o.f.}$		$3665.97 / 3346$
AICs		3675.7

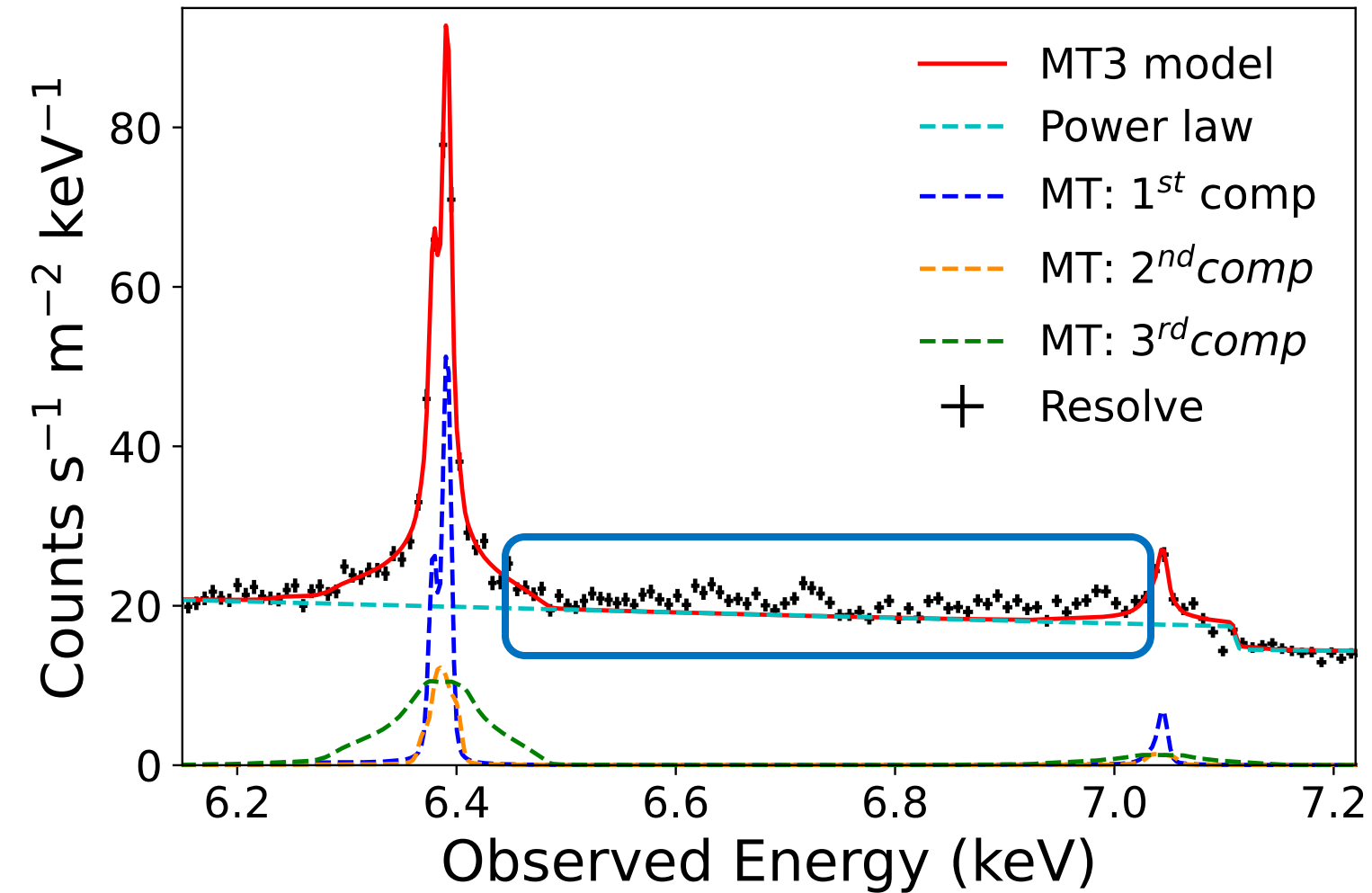
PION absorption ($\log \xi$ v.s. v_{out})



PION absorption (N_H v.s. V_{out})

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Resolve: 3-12 keV, NuSTAR: 11.2-60 keV

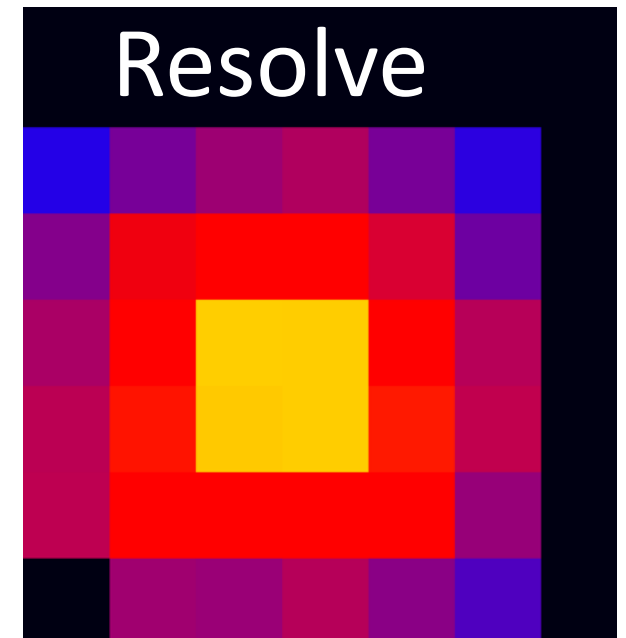
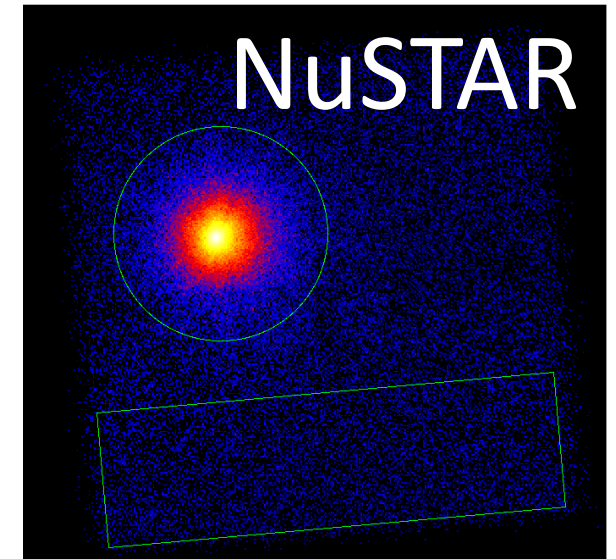
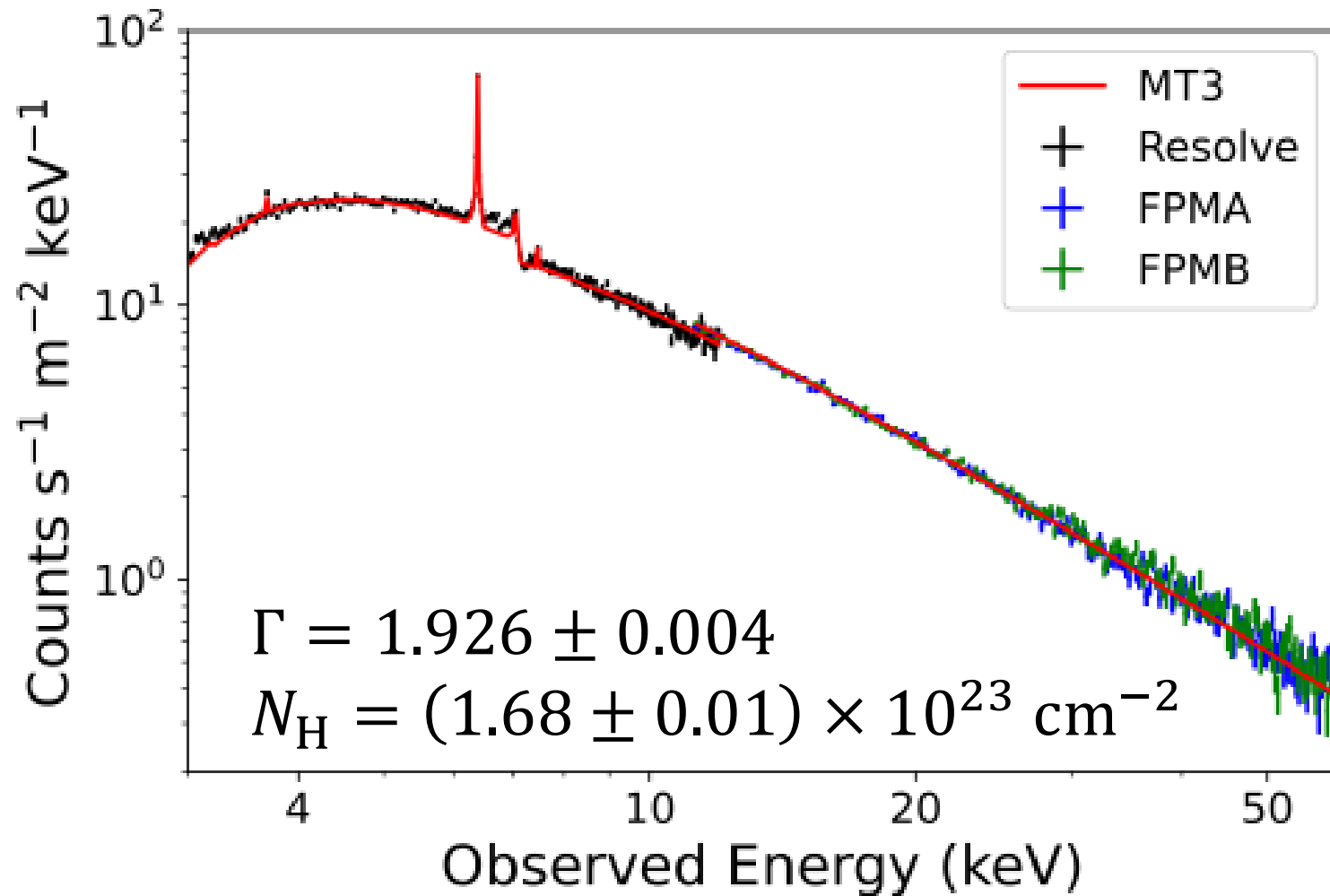
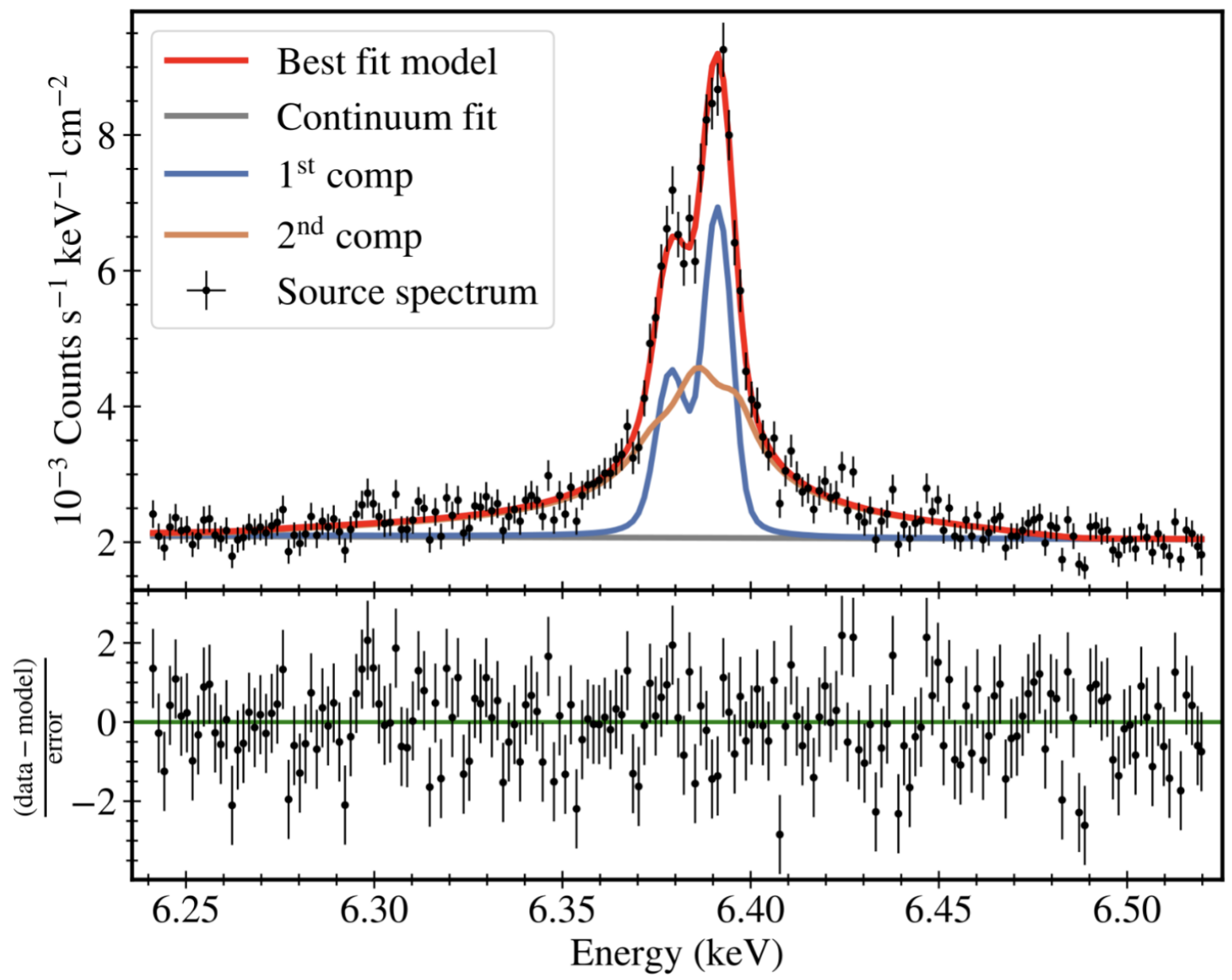


Table 2: Lines above the 4σ confidence level

$E_{\text{obs}}^{\text{a}}$ (keV)	ID	$E_{\text{rest}}^{\text{b}}$ (keV)	σ^{c}	FWHM (eV)	$v_{\text{shift}}^{\text{d}}$ (km/s)	Emit/Abs ^e
$6.3989^{+0.0002}_{-0.0003}$	Fe $K\alpha$	6.4038	59.7	29.7 ± 0.7	220 ± 10	E
$6.644^{+0.003}_{-0.004}$	Fe XXV	6.700	5.9	30 (fix)	2500^{+100}_{-200}	E
6.733 ± 0.003	Fe XXV	6.700	5.2	30^{+7}_{-6}	-1400 ± 100	E
7.000 ± 0.003	Fe XXVI	6.973	7.2	30 (fix)	-1100 ± 100	E
$7.054^{+0.001}_{-0.002}$	Fe $K\beta$	7.058	12.7	30 (fix)	170^{+40}_{-80}	E
7.111 ± 0.001	Fe XXV	6.700	4.4	9^{+4}_{-3}	-12810 ± 40	A
7.478 ± 0.002	Ni $K\alpha$	7.478	5.8	21^{+5}_{-4}	0 ± 80	E
10.618 ± 0.002	Fe XXVI	6.973	5.5	16 ± 5	-119120 ± 50	A

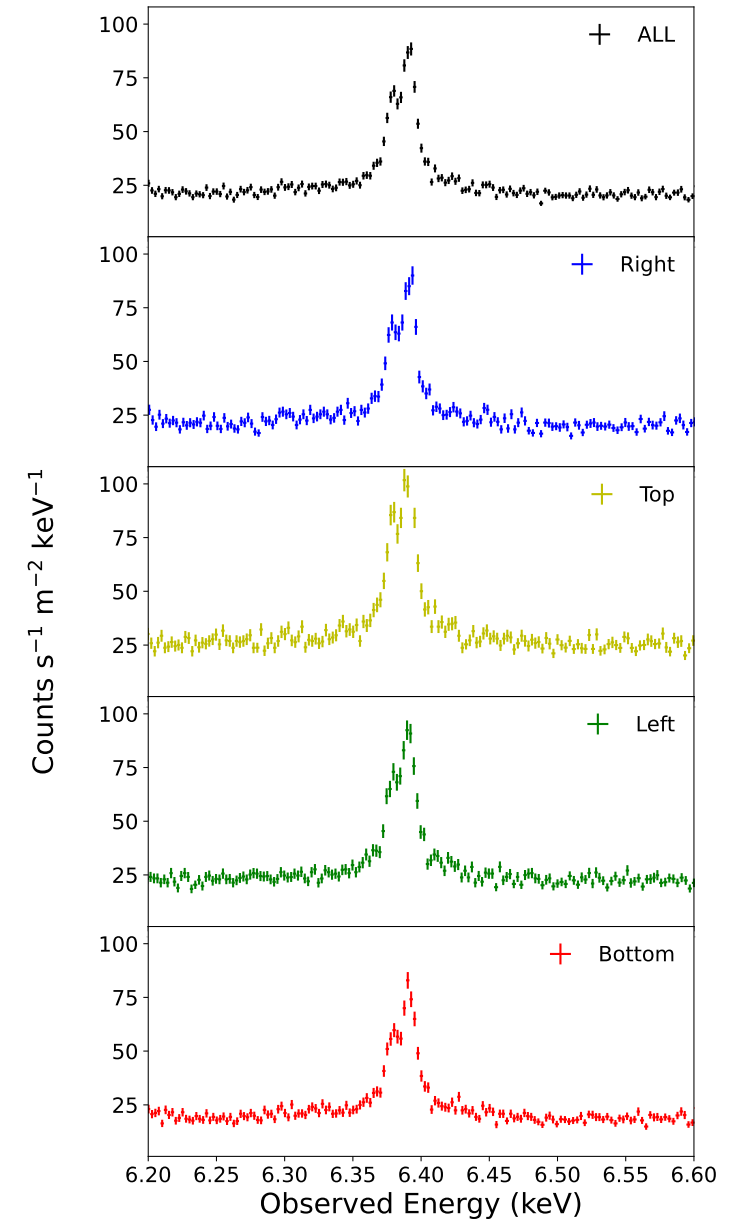
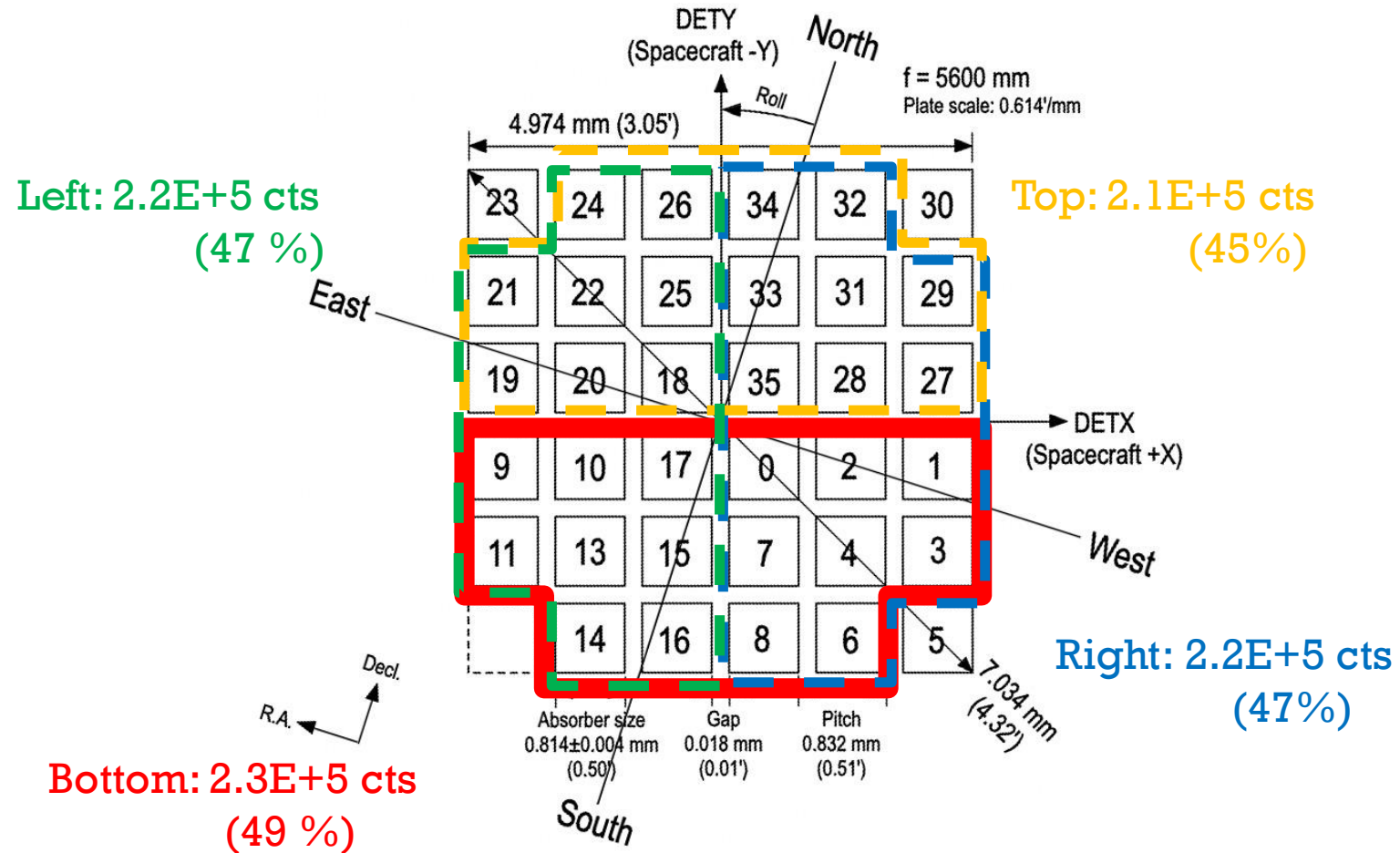
a: Observed Energy (source frame). b: Theoretical Energy (rest-frame). The line identifications are derived from the AtomDB database 3.0.9. c: Significance of the line. d: velocity shift. e: "E" means an emission line and "A" means an absorption line.

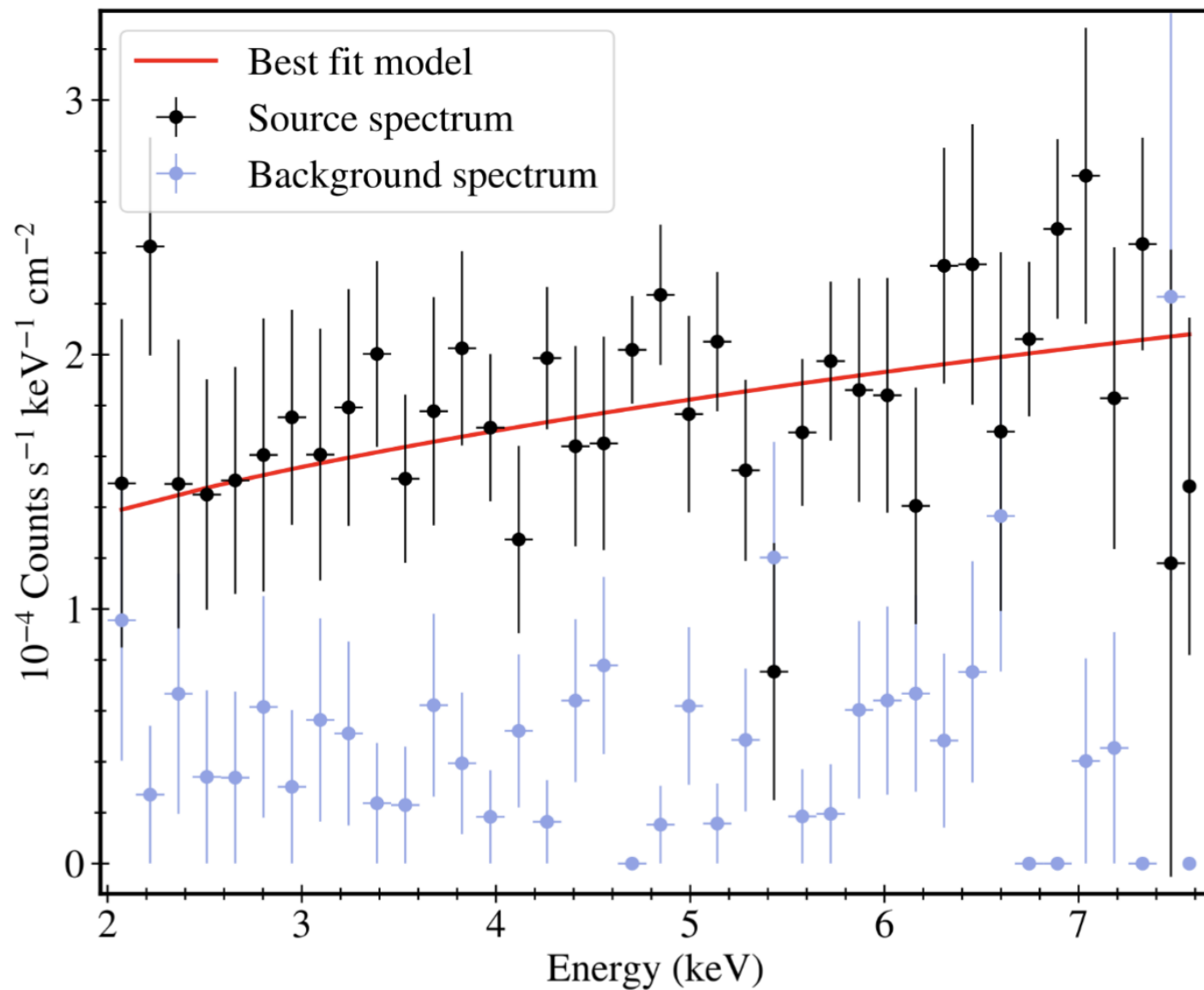


Check the Resolve Data; Time frame

Counts (2-10 keV): Total 4.7E+5 cts

The ratio of Total counts to the counts of each regions (Average 47 %)



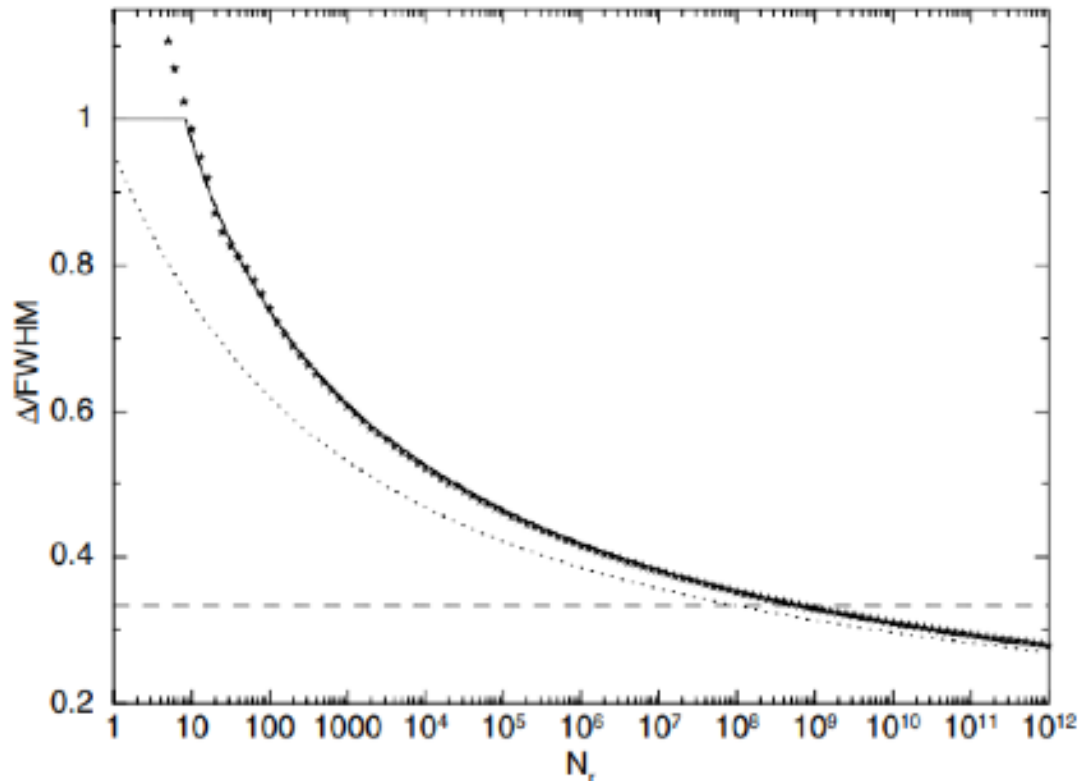


Too large bin size;

- The narrow emission/absorption line will be disappeared from the spectrum
- The error of the peak energy and line width will get larger

Too small bin size;

- Fewer counts per bin and larger statistical errors
- Fitting takes a huge CPU power and an enormous amount of time



$$\frac{\Delta}{\text{FWHM}} = \begin{cases} 1 & (x \leq 2.119) \\ \frac{0.08 + 7.0/x + 1.8/x^2}{1 + 5.9/x} & (x > 2.119) \end{cases}$$

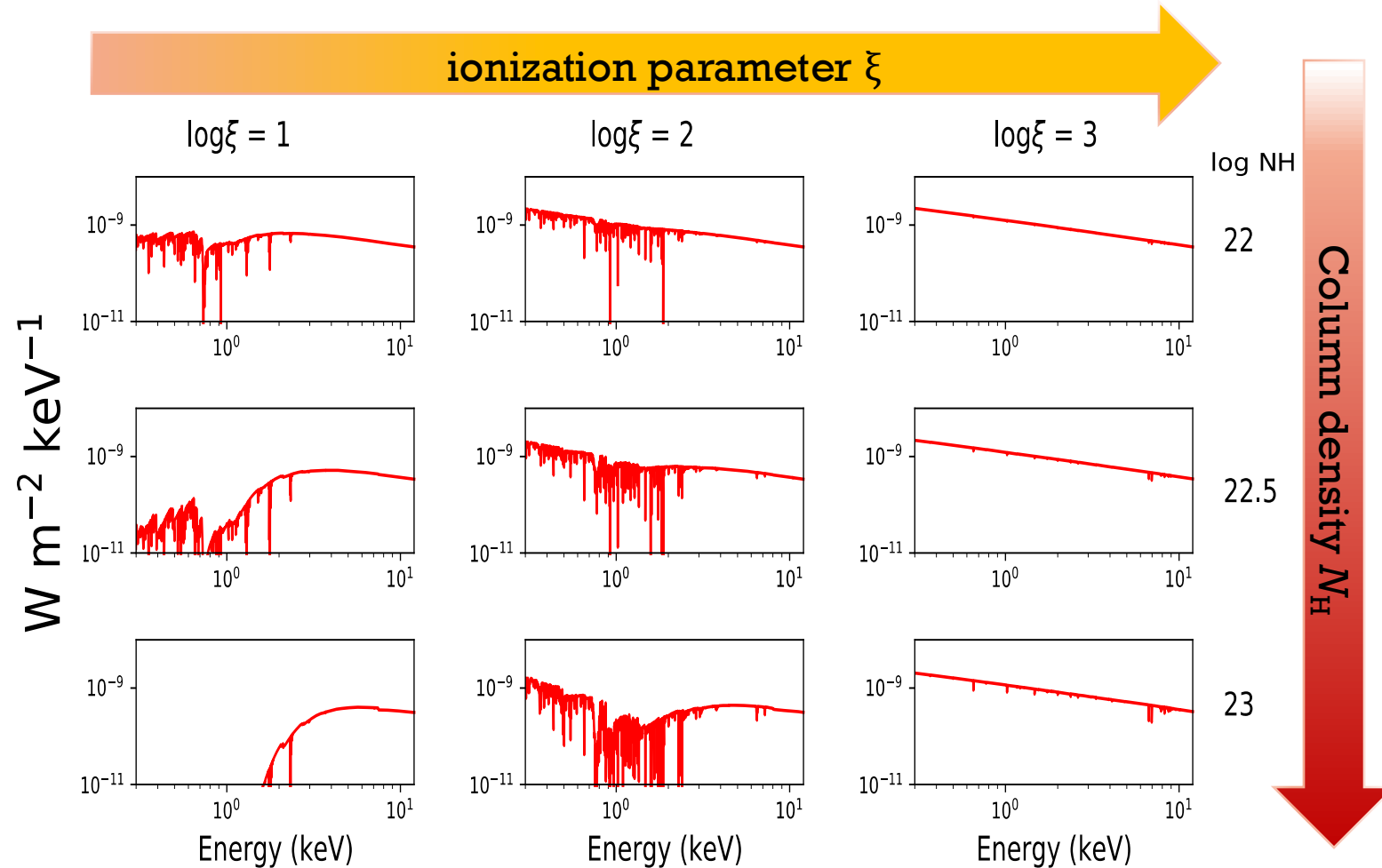
$$x \equiv \ln[N_r(1 + 0.20 \ln R)]$$

R : Number of resolution elements

N_r : Counts per resolution element

To obtain the parameters (ξ , N_{H} , v_{out}) of the disk wind, we use the **photoionized plasma model**

Photoionized plasma model (PION model):
Calculate the transmission and emission of photo-ionized plasma



Outflow velocity should be faster than the escape velocity

→ Lower limit of the distance: r_{\min}

$$r_{\min} = \frac{2GM_{\text{BH}}}{v_{\text{out}}^2} \quad G: \text{gravitational constant}$$

Assuming that the disk wind thickness Δr does not exceed the distance r to the BH, the upper limit r_{\max} for the disk wind distance is:

$$r_{\max} = \frac{L_{\text{ion}} C_v}{\xi N_{\text{H}}} \quad \text{Wang et al. 2022}$$

We assumed $C_v=1$

Resolve

Parameter	Expected
Lifetime	Goal: 5 years
Energy range	1.7-12 keV
Effective area	$\sim 180 \text{ cm}^2 @6\text{keV}$
Angular resolution	1.3' HPD
Energy resolution	5 eV (FWHM)
Energy-scale accuracy	0.5 eV
Line-spread function accuracy	Goal: 1 eV
Pixel size	30" \times 30" 818 μm \times 818 μm
Field of View	3.1' \times 3.1'
Array format	6 \times 6 35 science pixels 1 calibration pixel
Relative timing accuracy	80 μs for high- and mid-res events
Operating temperature	50 mK
Maximum X-ray count rate	200 counts s^{-1} array $^{-1}$
Residual background	0.8×10^{-3} counts s^{-1} keV $^{-1}$

Xtend

Field of View	38' \times 38' (Full window)
Sensitive band	0.4 – 13 keV
Effective area	356 $\text{cm}^2 @1.5 \text{ keV}$, 307 $\text{cm}^2 @6 \text{ keV}$
On-axis XMA PSF at 6.4 keV [†]	1.47' (HPD), 7.2" (FWHM)
Pixel size	1.74" (48 μm , logical)
Time resolution	4 sec (Full window), 0.5 sec (1/8 window)
Energy resolution (FWHM)	$\sim 180 \text{ eV @ } 6 \text{ keV}$
Pileup tolerance	2.5 mCrab (Full window)
Total (NXB + Sky) X-ray background [‡]	$\leq 10^{-6}$ counts keV $^{-1}$ s $^{-1}$ arcmin $^{-2}$ cm $^{-2}$

Absorption line (1)



	He-like	H-like
$\log \xi$	3.4 (+/- 0.1)	6.3 (+/- 0.1)
NH (cm ⁻²)	5.0 (+0.2/-0.1)e21	4.0 (+/- 0.1)e24
V_{out} (km/s)	-129040 (+30/-50)	-119060 (+30/-70)
r_{min} (pc)	2.8e-5	3.3e-5
r_{max} (pc)	0.15	5.9e-6

inconsistent

Fixed the ionization parameter of inner UFO

