zELDA : fitting Lyman – alpha line profiles using deep learning .

redshift Estimator using Line profiles
of Distant Lyman-Alpha emitters

S . Gurung – Lopez, C . Byrohl and M . Gronke

Lyα as an astrophysical tool

◎Detect Galaxies at high redshift (LAEs)

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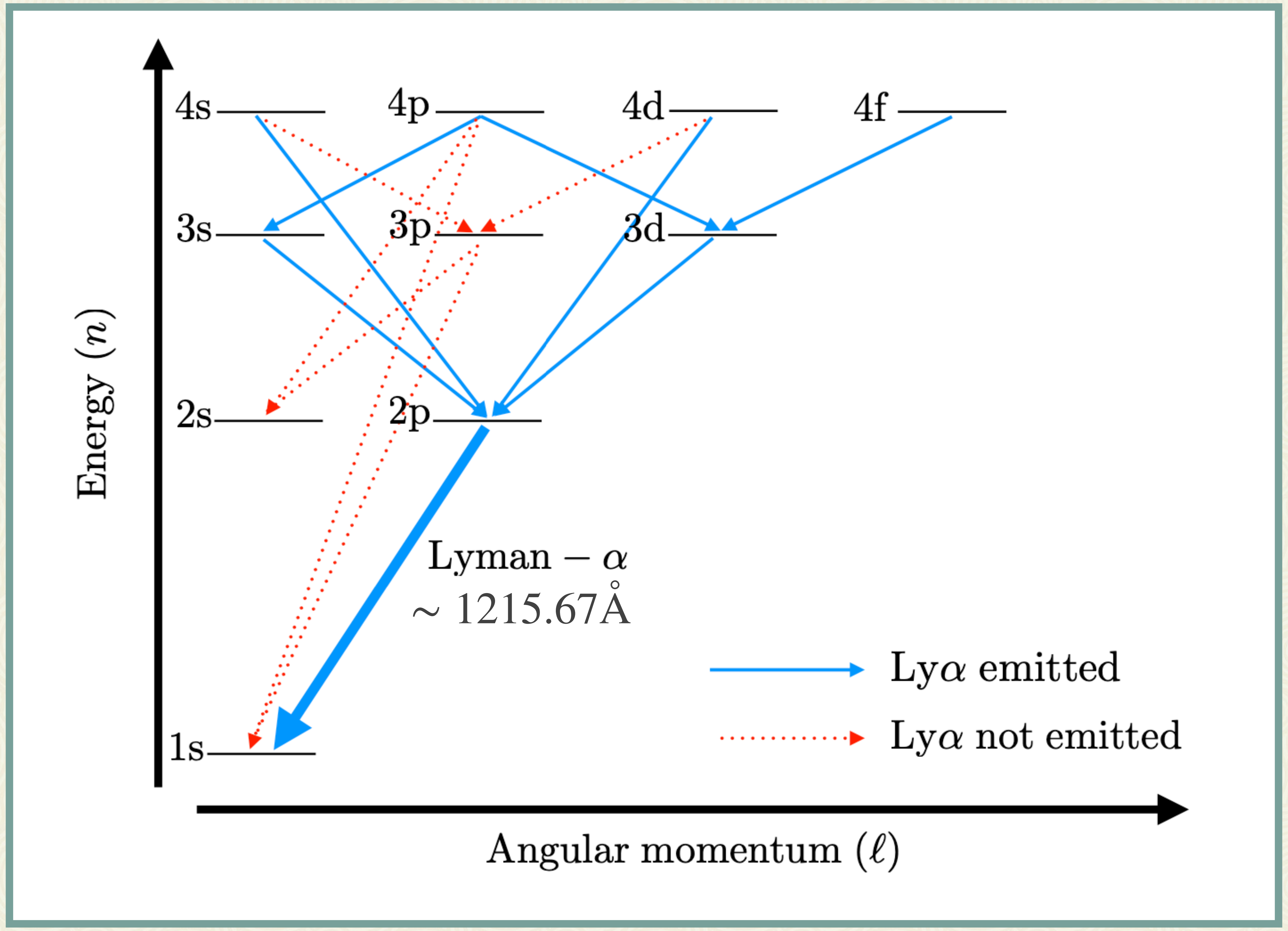

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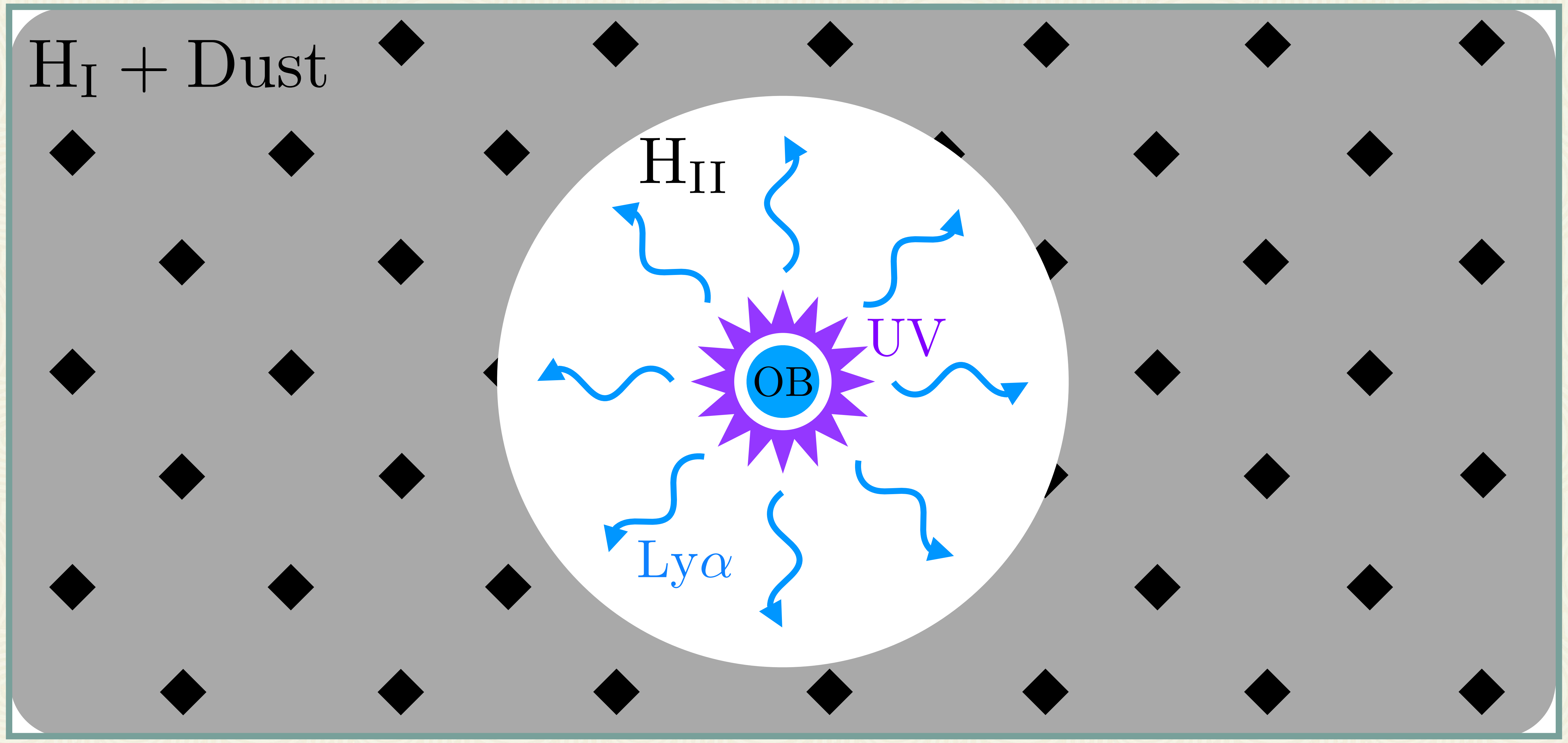

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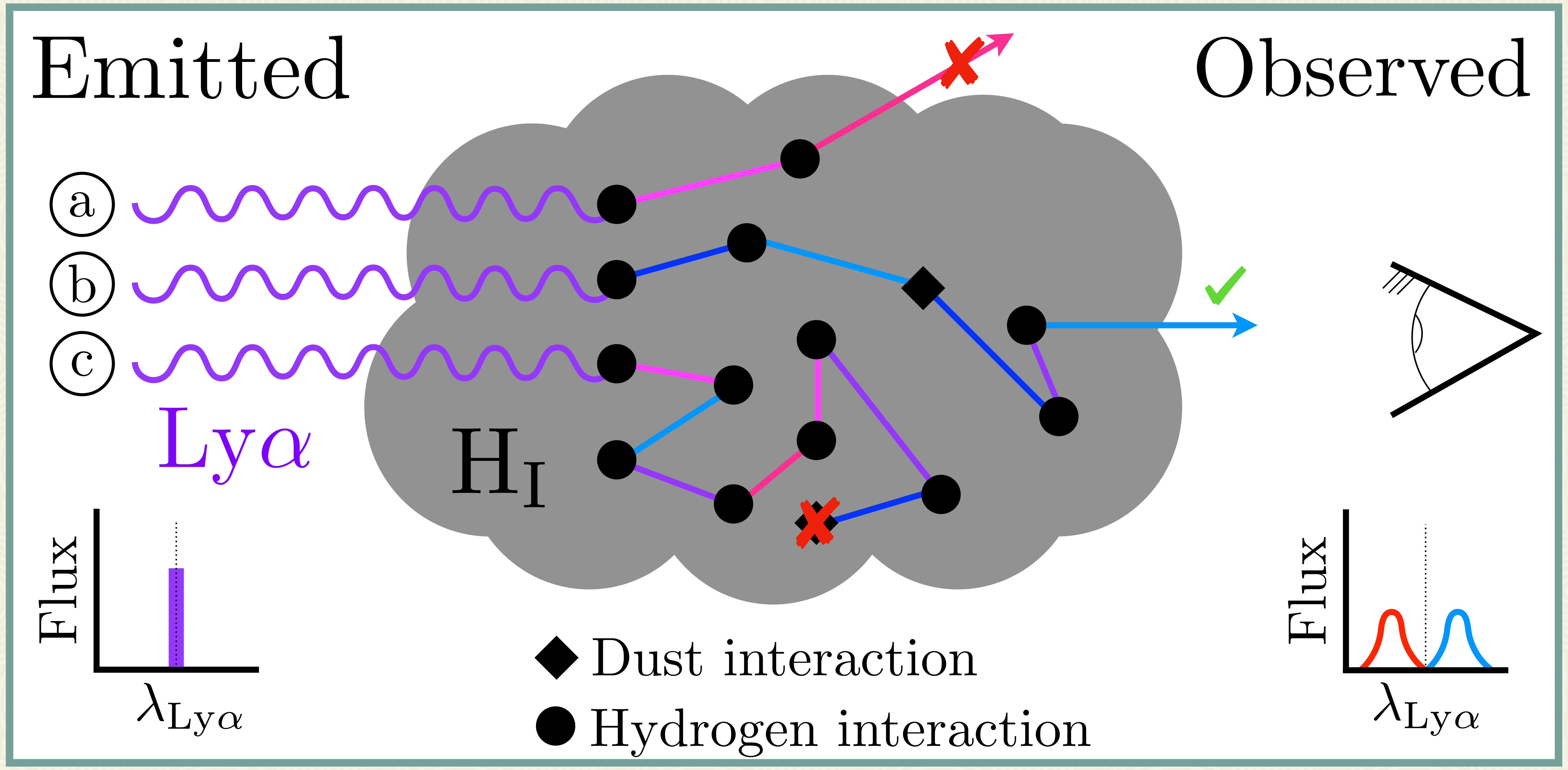

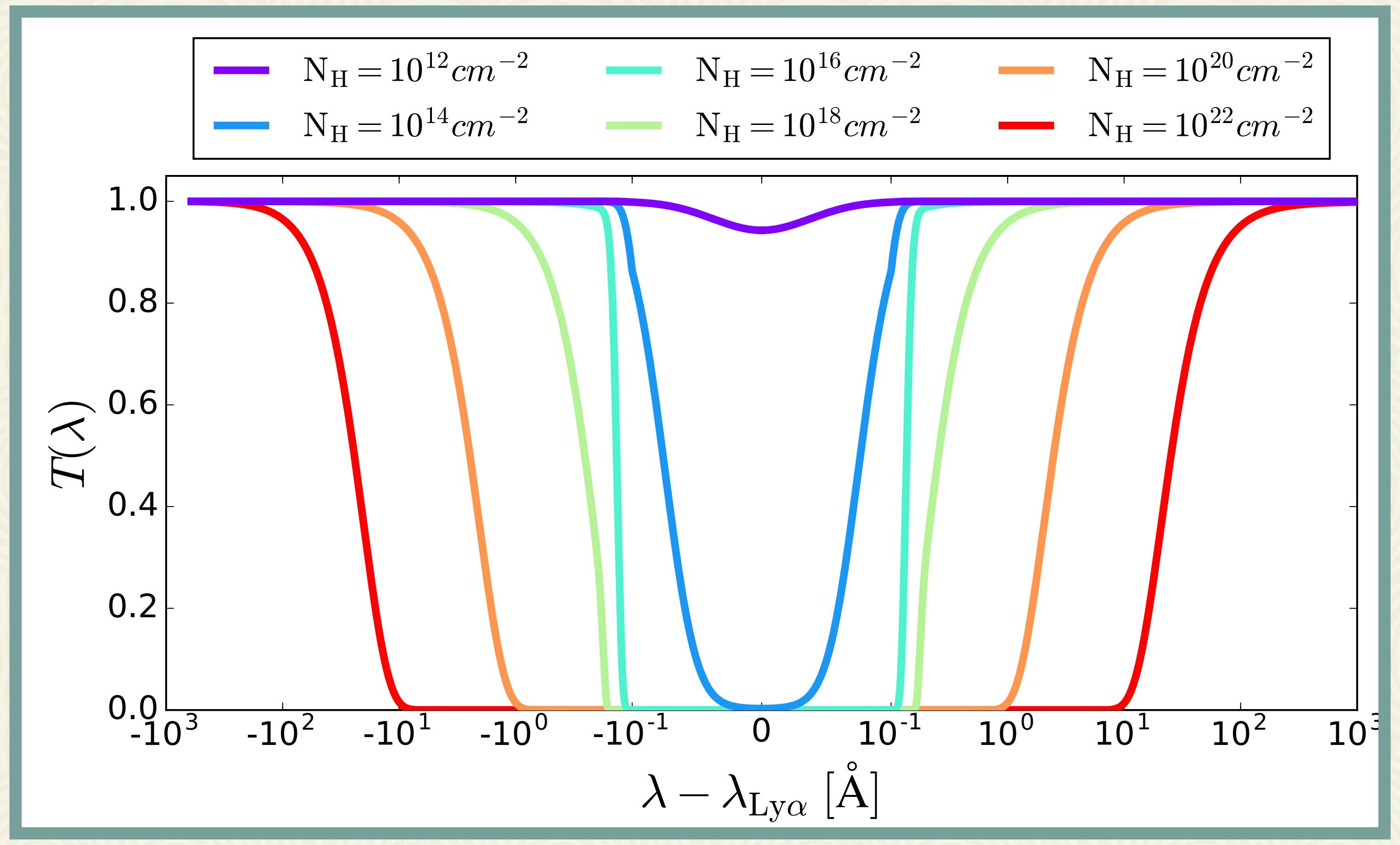

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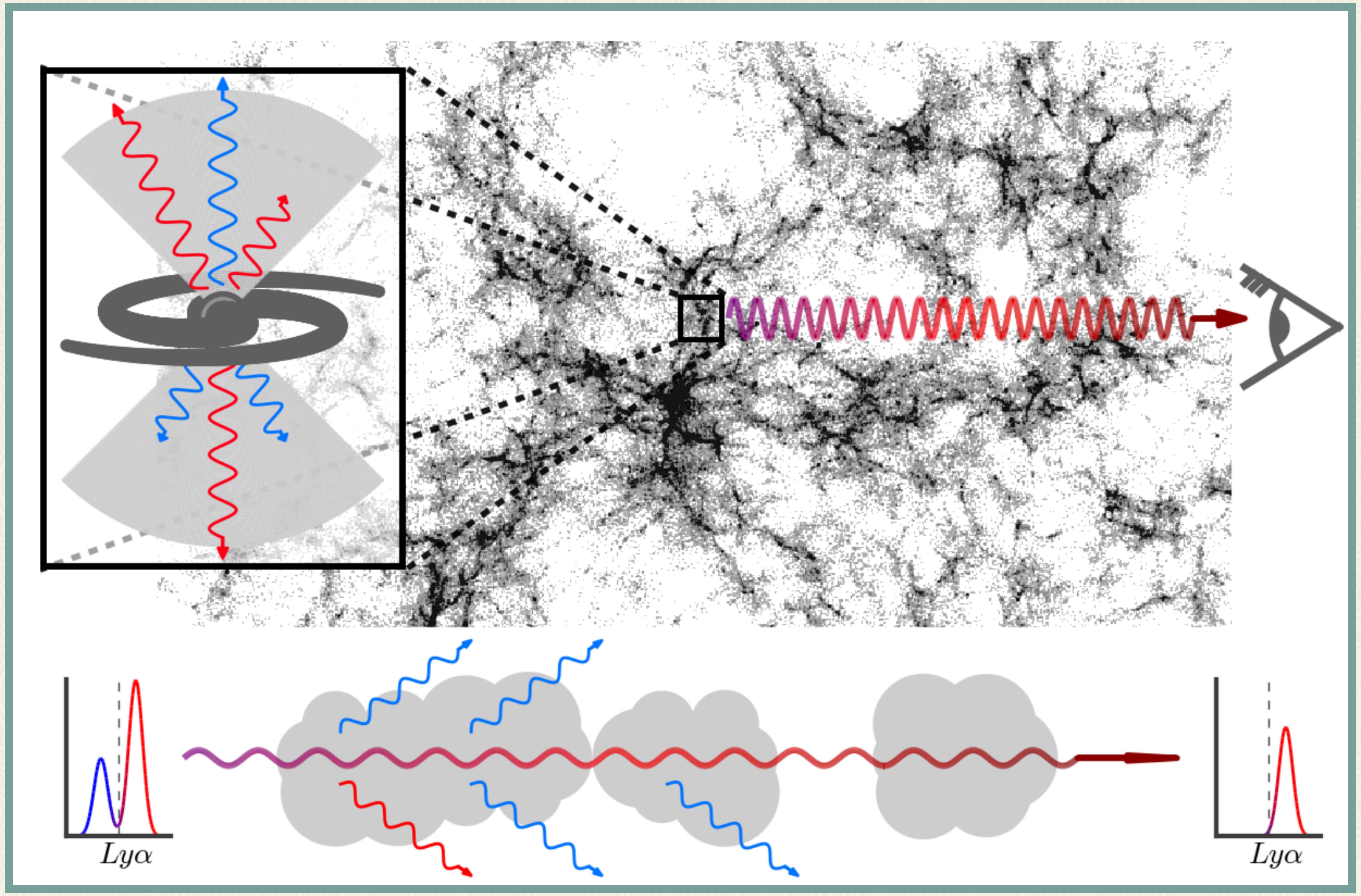
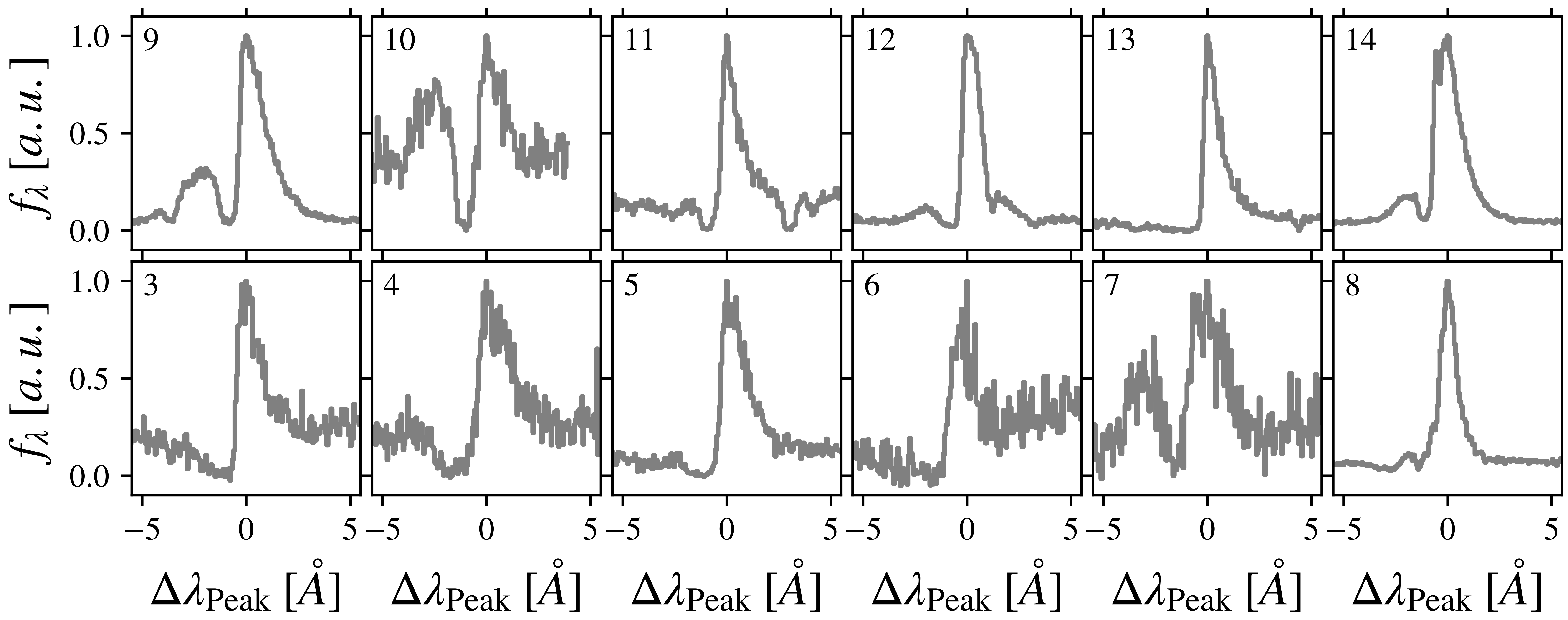


LYMAN ALPHA SPECTRAL DATABASE

http://lasd.lyman-alpha.com

Runnholm et al.+20



97 Lyα line profiles obtained by the
Cosmic Origins Spectrograph on HST
GO 11522 and 12027 (PI: Green, Salzer et al. 2001)
GO 11727 and 13017 (PI: Heckman et al. 2011,2015)
GO 12269 (PI: Scarlata, Songaila et al. 2018)
GO 12583 (PI:Hayes, Hayes et al. 2014)
GO 12928 (PI:Henry, Henry et al. 2015),
GO 13293 and 14080 (PI: Jaskot, Jaskot &Oey 2014)
GO 14201 (PI: Malhotra, Yang et al.2017)
GO 13744 (PI: Thuan Izotov et al. 2016, 2018)

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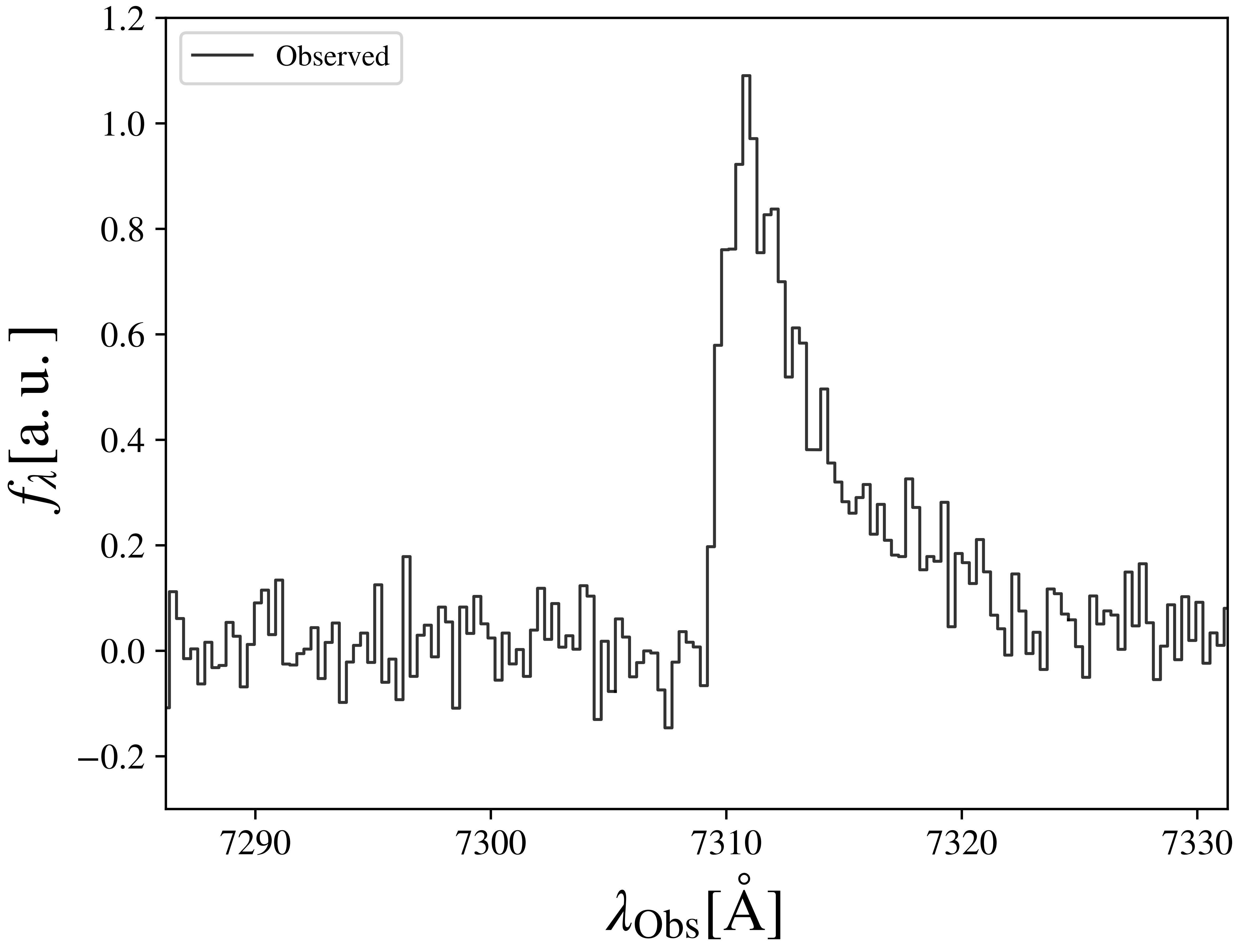

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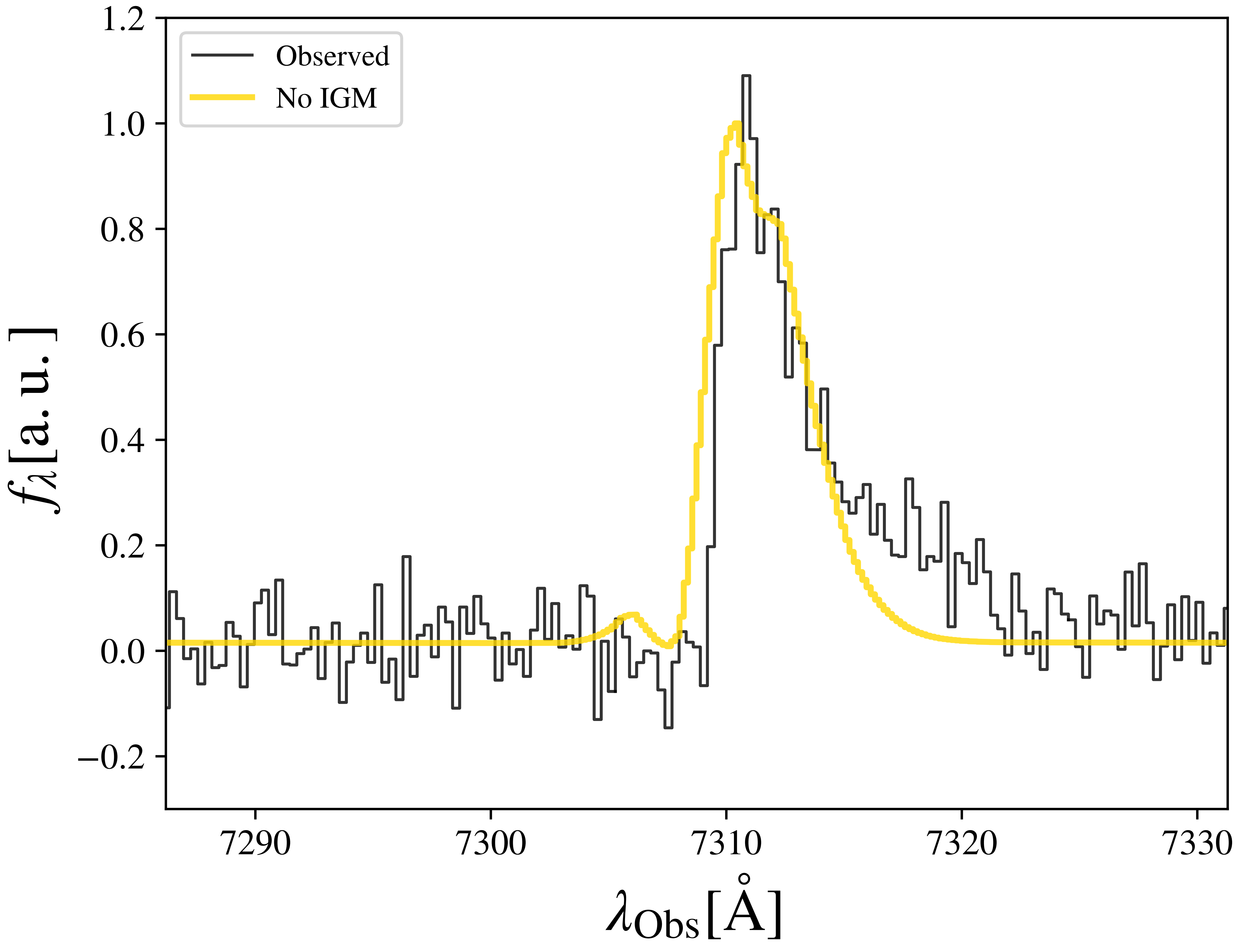

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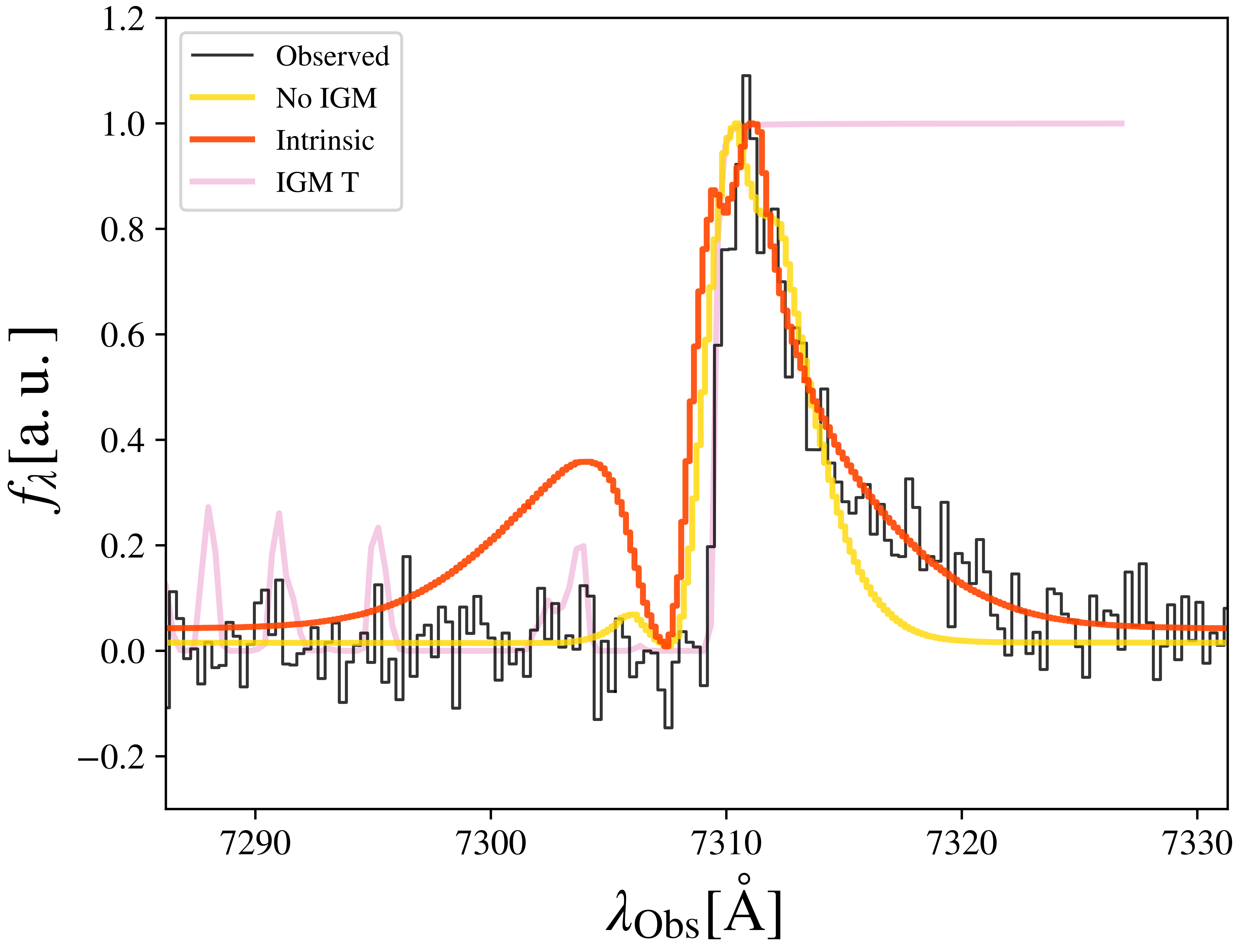

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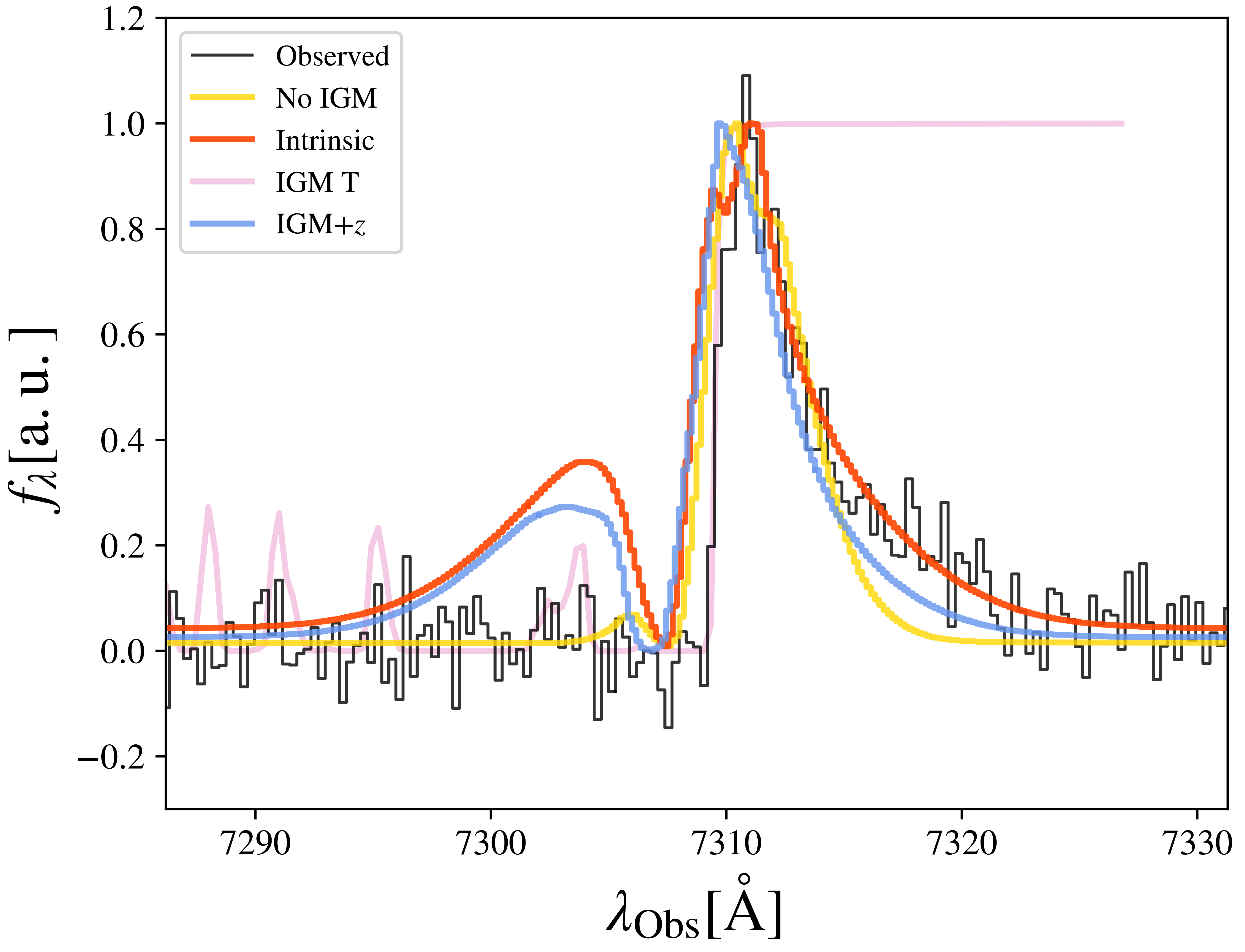
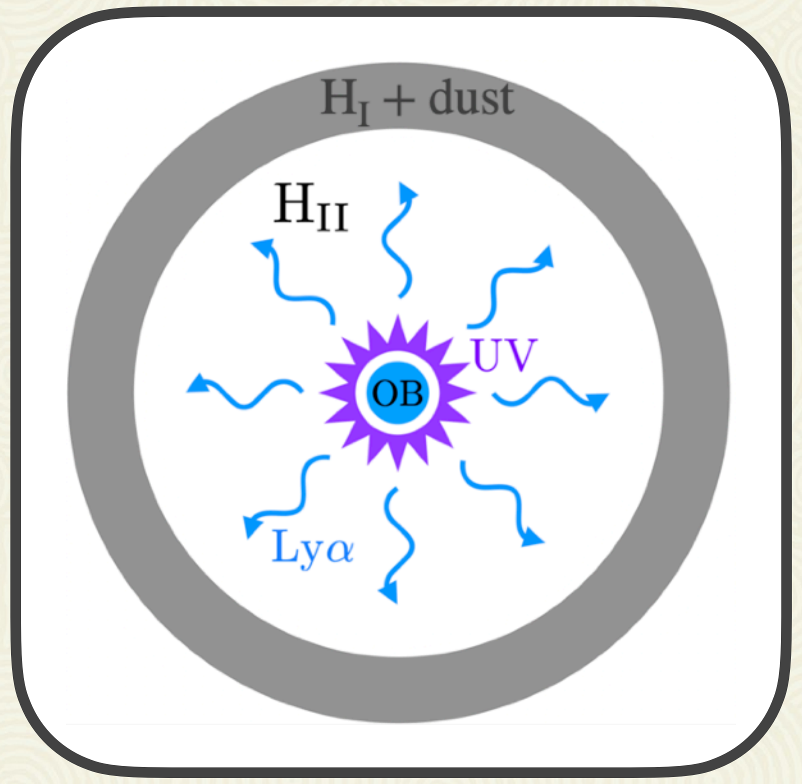


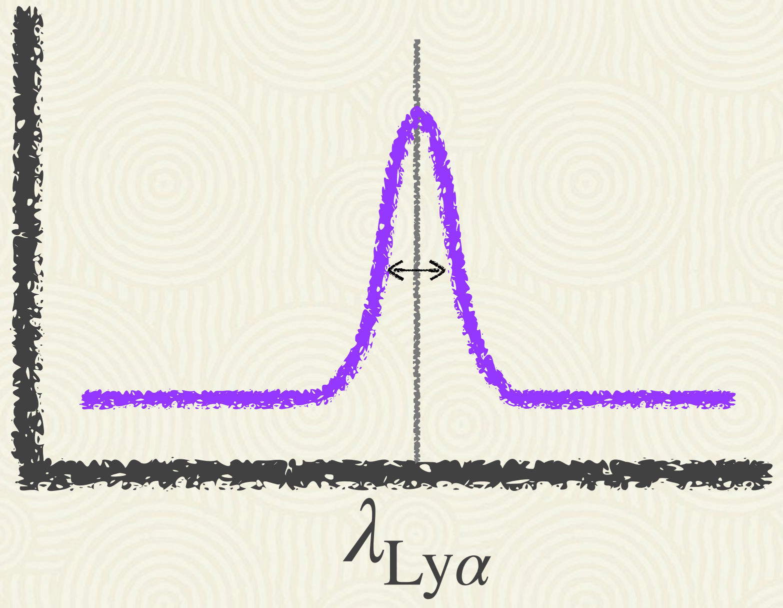
Modeling Interestelar medium radiative transfer

◎Gas properties



- ◎Gas Geometry
- ◎Column Density
- ◎Expansion Velocity
- ◎Dust content

◎Injected Spectrum



- ◎Line width
- ◎Equivalent width

N_H

V_{exp}

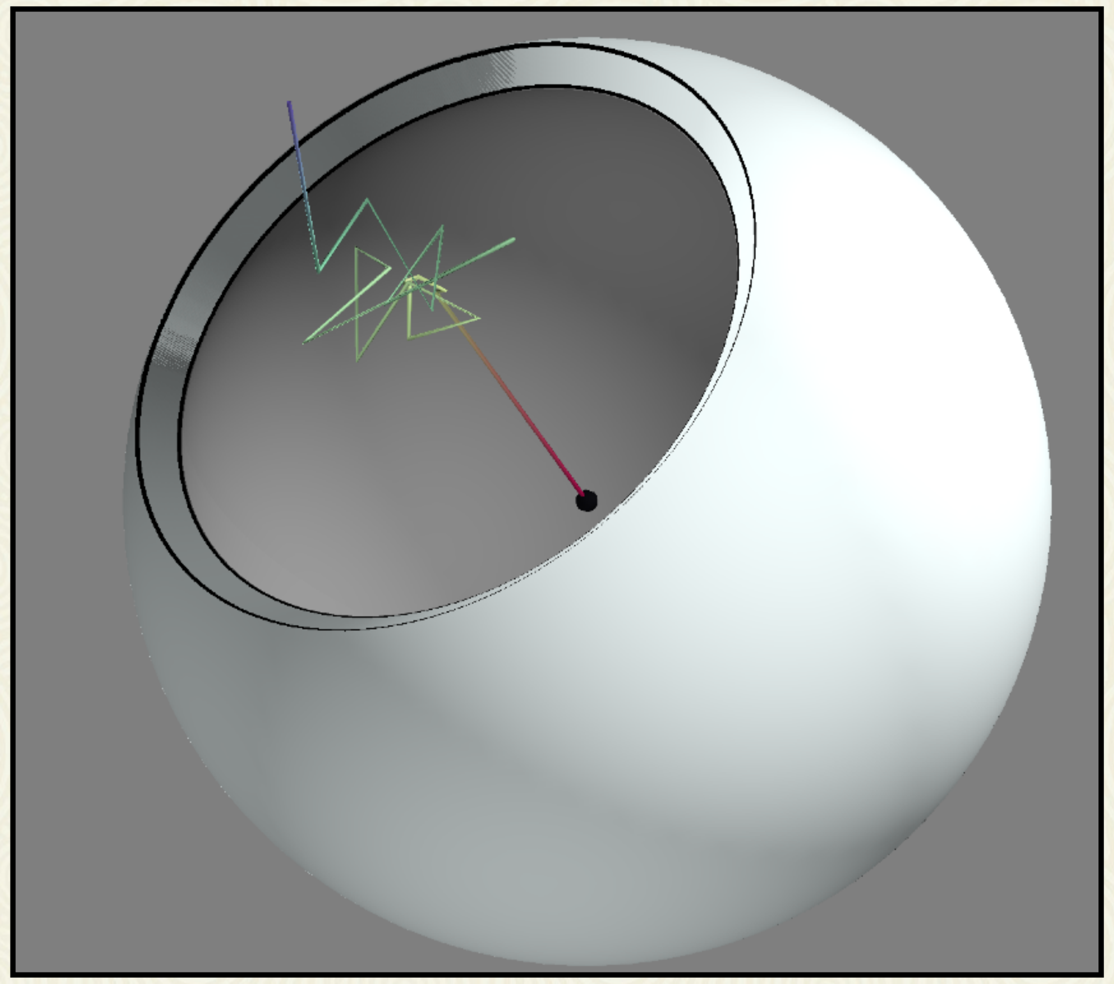
τ_a

W_{in}

EW_{in}

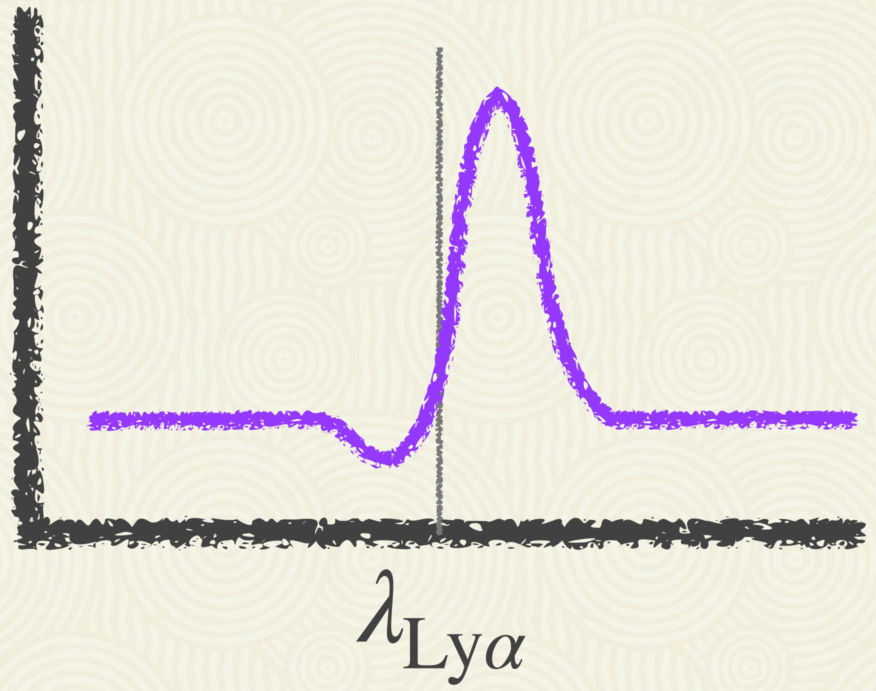
Model parameters

Monte Carlo Radiative Transfer Code



LyaRT
Orsi et al. +12

◎Lyα line profile



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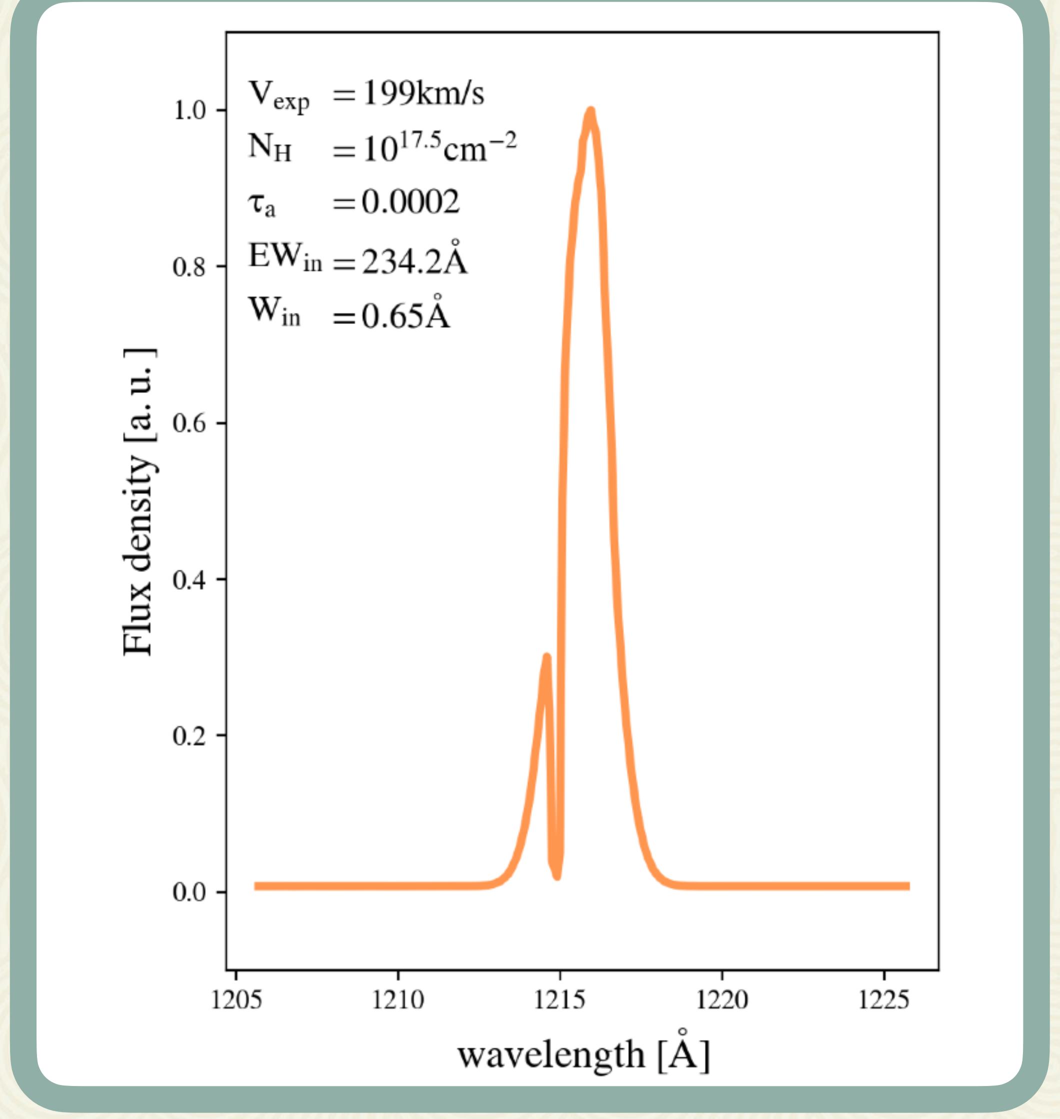
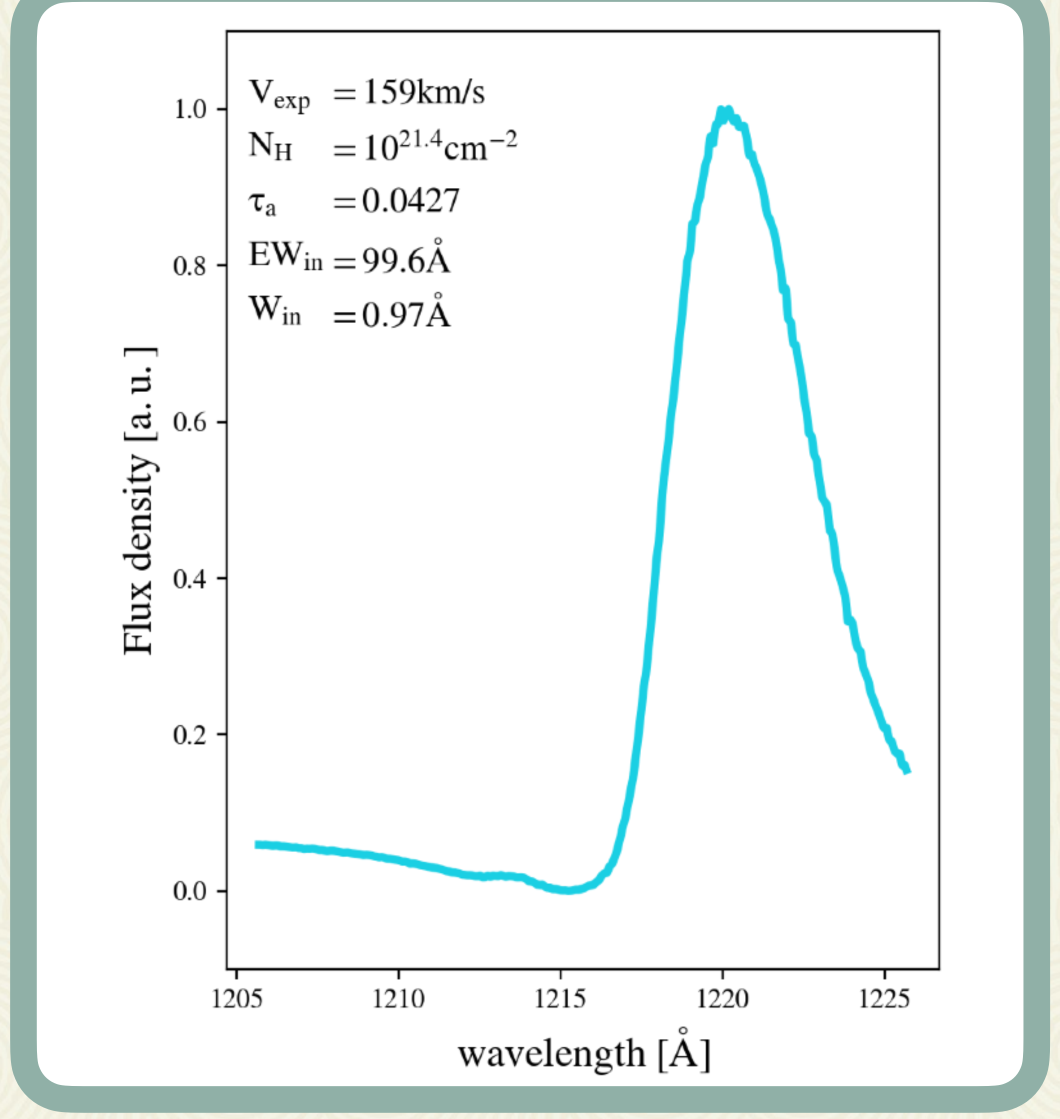
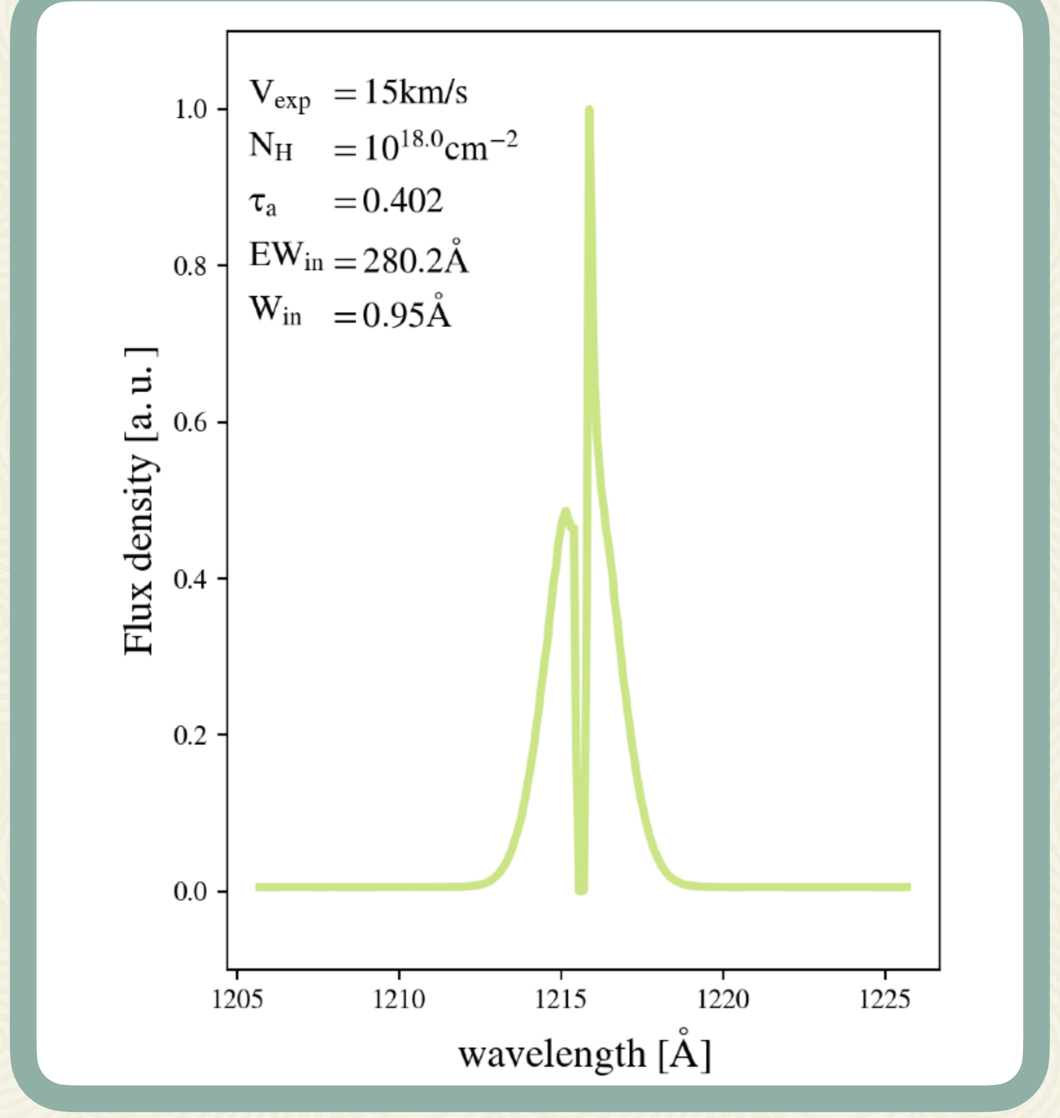
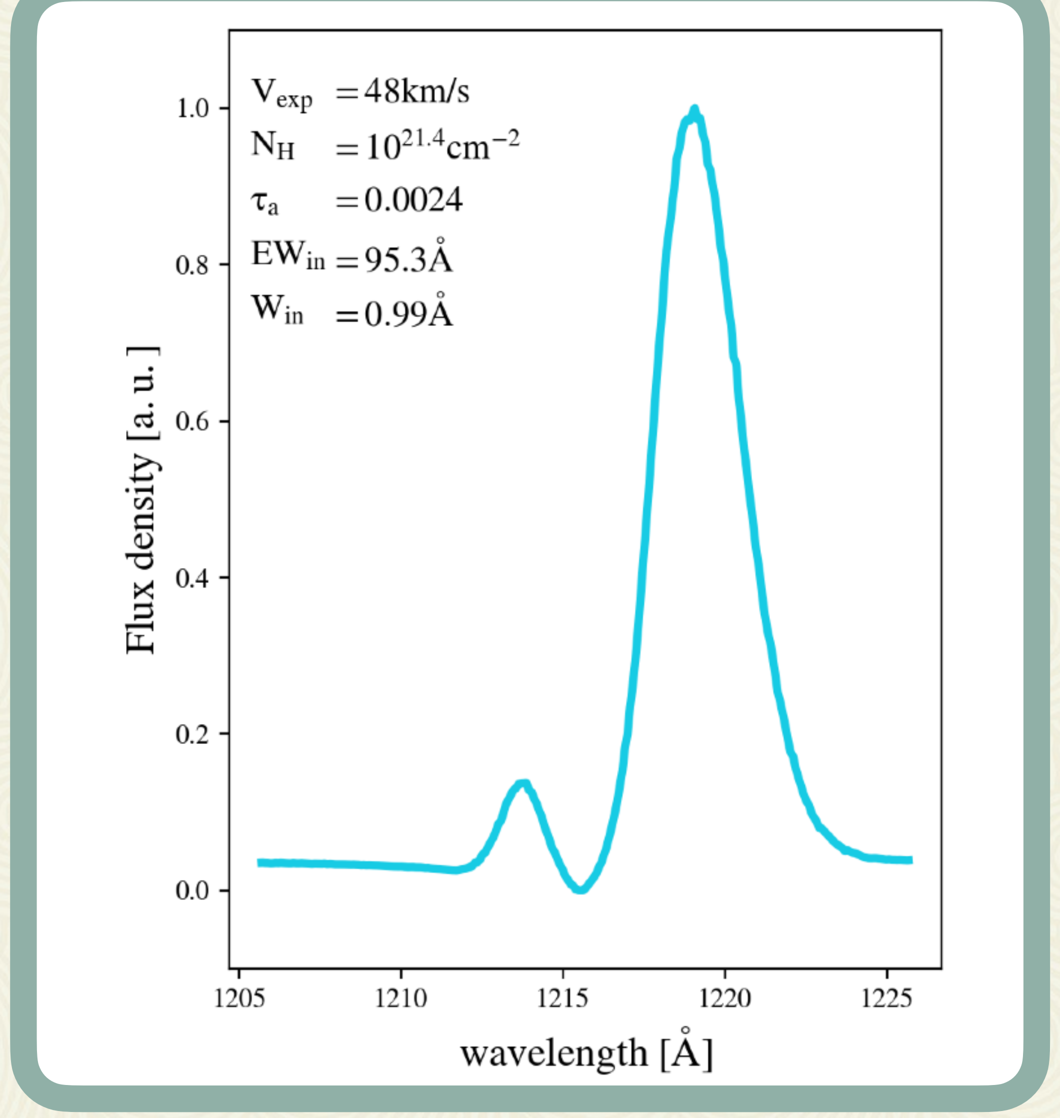
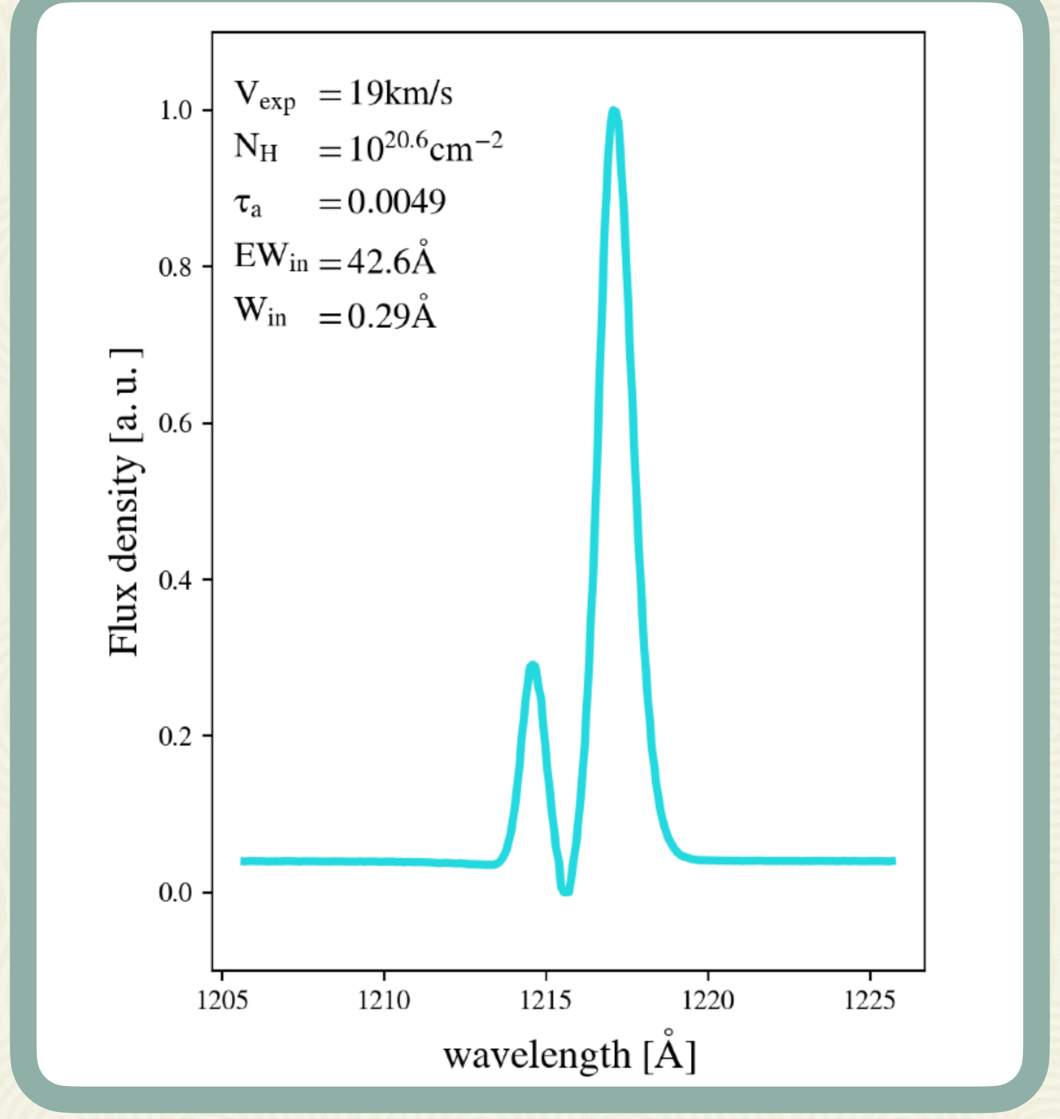
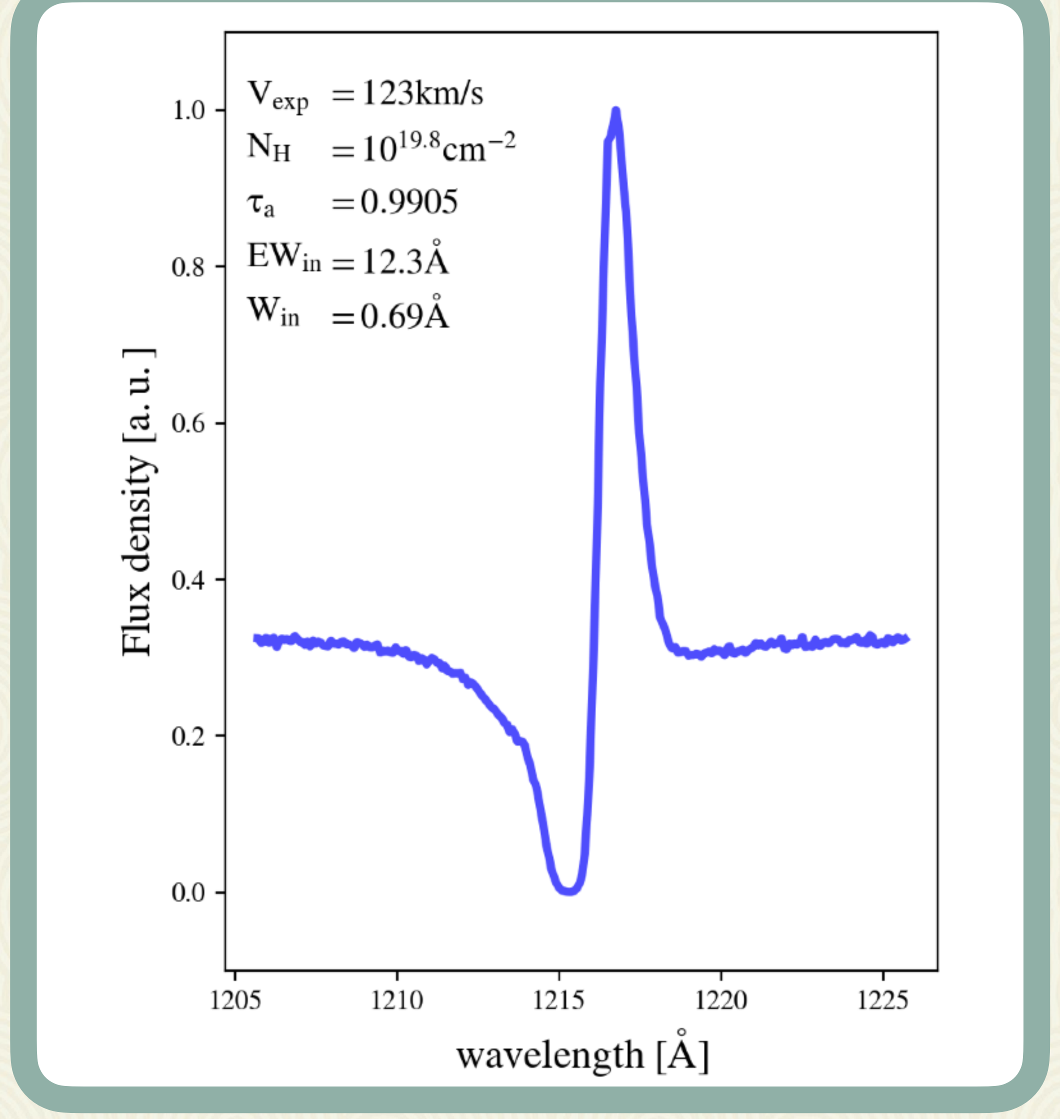


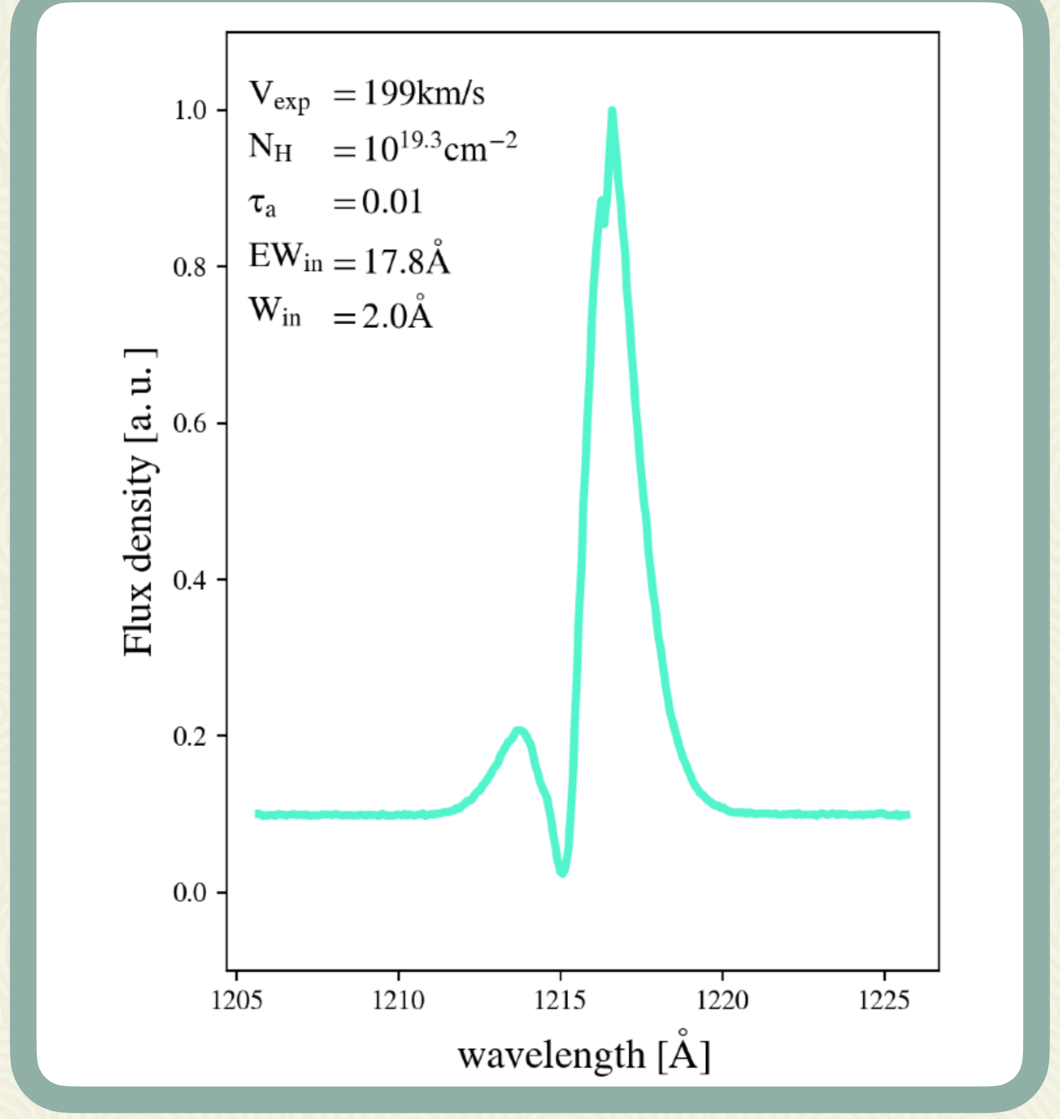


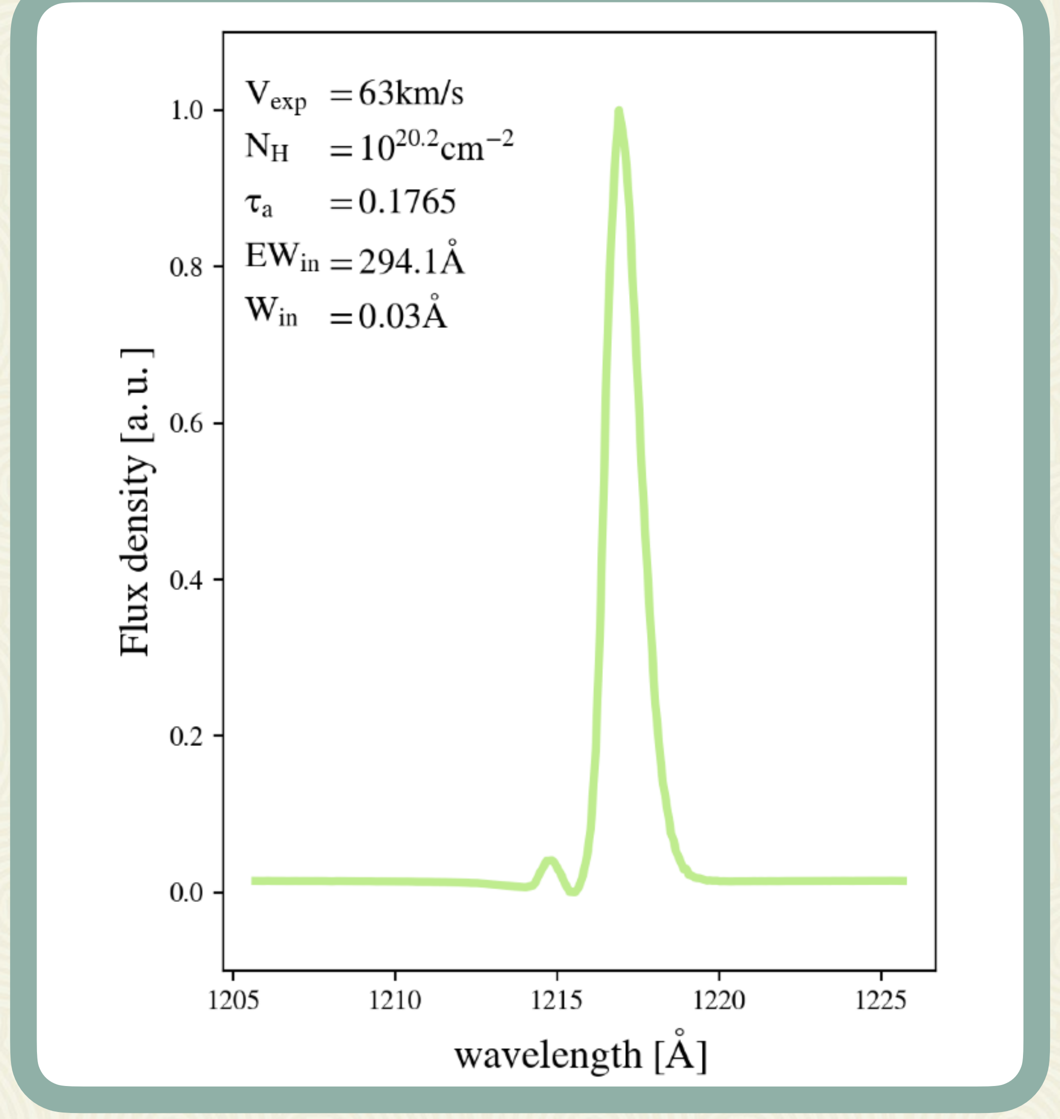










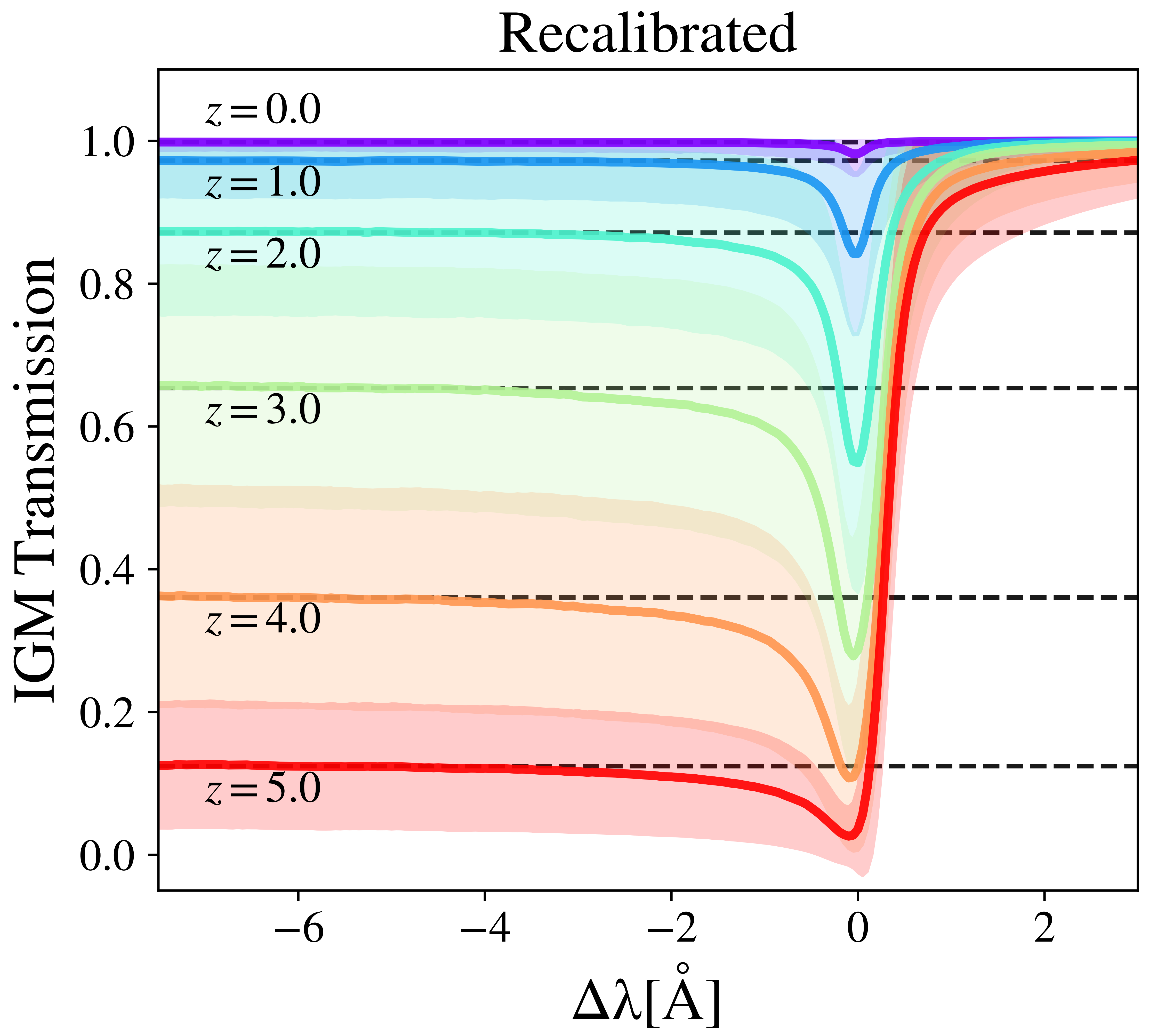


Modeling Intergalactic medium radiative transfer

IGM transmission curves from C.Byrohl & M. Gronke 2020 (arXiv:2006.10041):

IllustrisTNG100 simulation : tracing the optical depth in the IGM between the Lyα emitting galaxies and the observer for chosen lines of sight.

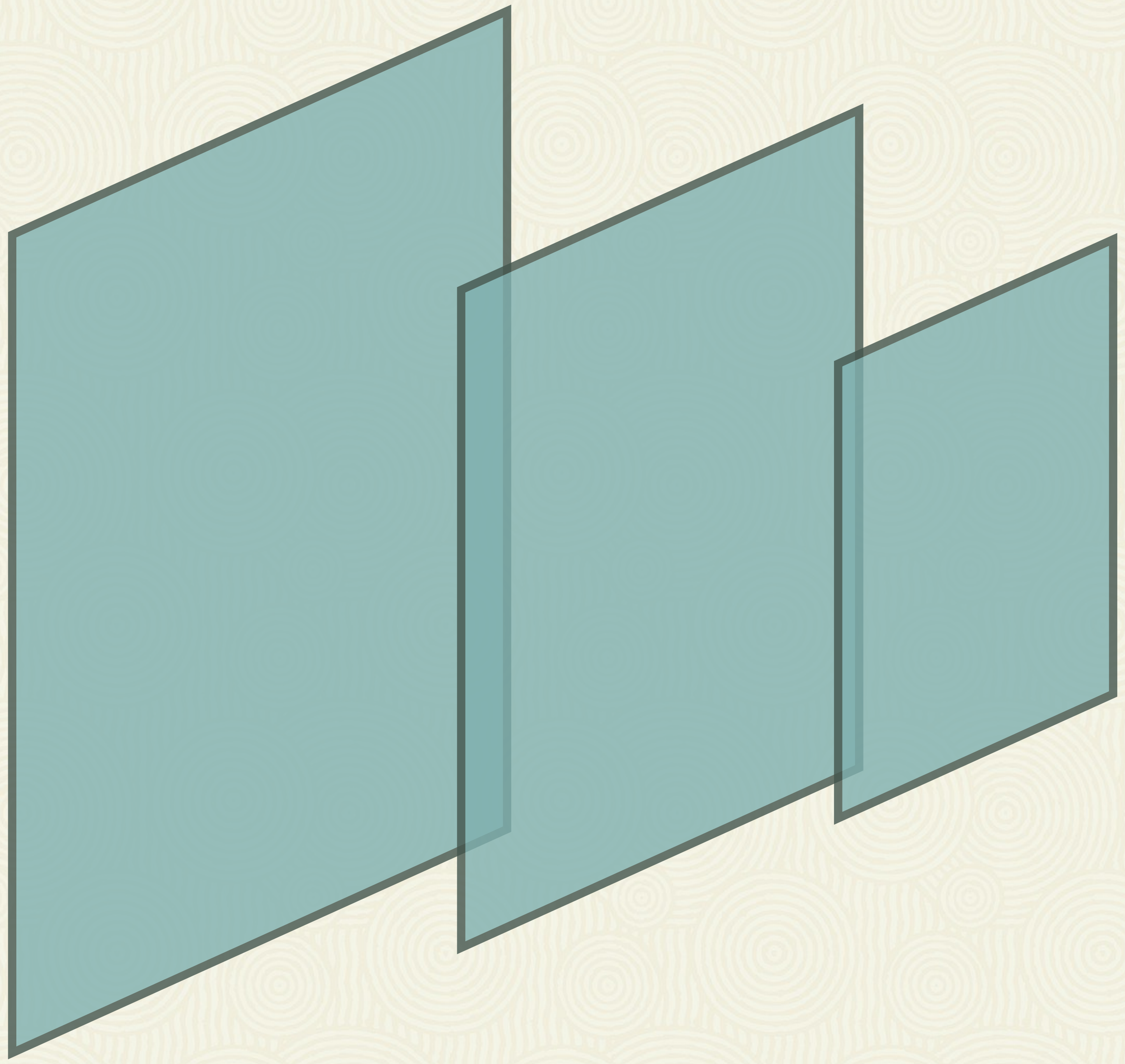
doi:10.5281/zenodo.3832098, https://doi.org/10.5281/zenodo.3832098



Artificial neural network architecture

Input — **Hidden layers** — **Output**

$$\begin{bmatrix} \vdots \\ \text{100 PCA} \\ \vdots \\ z_{\max} \\ W_g \\ \Delta\lambda_{\text{pix}} \end{bmatrix} \times$$



$153 \times 53 \times 25$

$$= \begin{bmatrix} \Delta\lambda_{\text{True}} \\ V_{\text{exp}} \\ N_H \\ \tau_a \\ W_{\text{in}} \\ EW_{\text{in}} \\ f_{\text{esc}}^{4\text{Å}} \end{bmatrix}$$

Artificial neural network architecture

Input

$$\begin{bmatrix} \vdots \\ 100\ \text{PCA} \\ \vdots \\ z_{max} \\ W_g \\ \Delta\lambda_{pix} \end{bmatrix}$$

Hidden layers

Training

10^7 Mock line profiles

- $\log\ |V_{exp}|[\mathrm{km\,s^{-1}}] \in [1.0, 3.0]$,
- $\log N_H[\mathrm{cm^{-2}}] \in [17.0, 21.5]$,
- $\log \tau_a \in [-4.0, 0.0]$,
- $\log EW_{in}[\text{Å}] \in [0.7, 2.3]$,
- $\log W_{in}[\text{Å}] \in [-2.0, 0.7]$,

$0.0001 < z < 6.5$

Output

$$\begin{bmatrix} \Delta\lambda_{True} \\ V_{exp} \\ N_H \\ \tau_a \\ W_{in} \\ EW_{in} \\ f_{esc}^{4\text{Å}} \end{bmatrix}$$

Artificial neural network architecture

3 NN models

IGM+z:

- Input includes redshift.
- Trained with redshift accurate IGM transmission curves.

IGM-z:

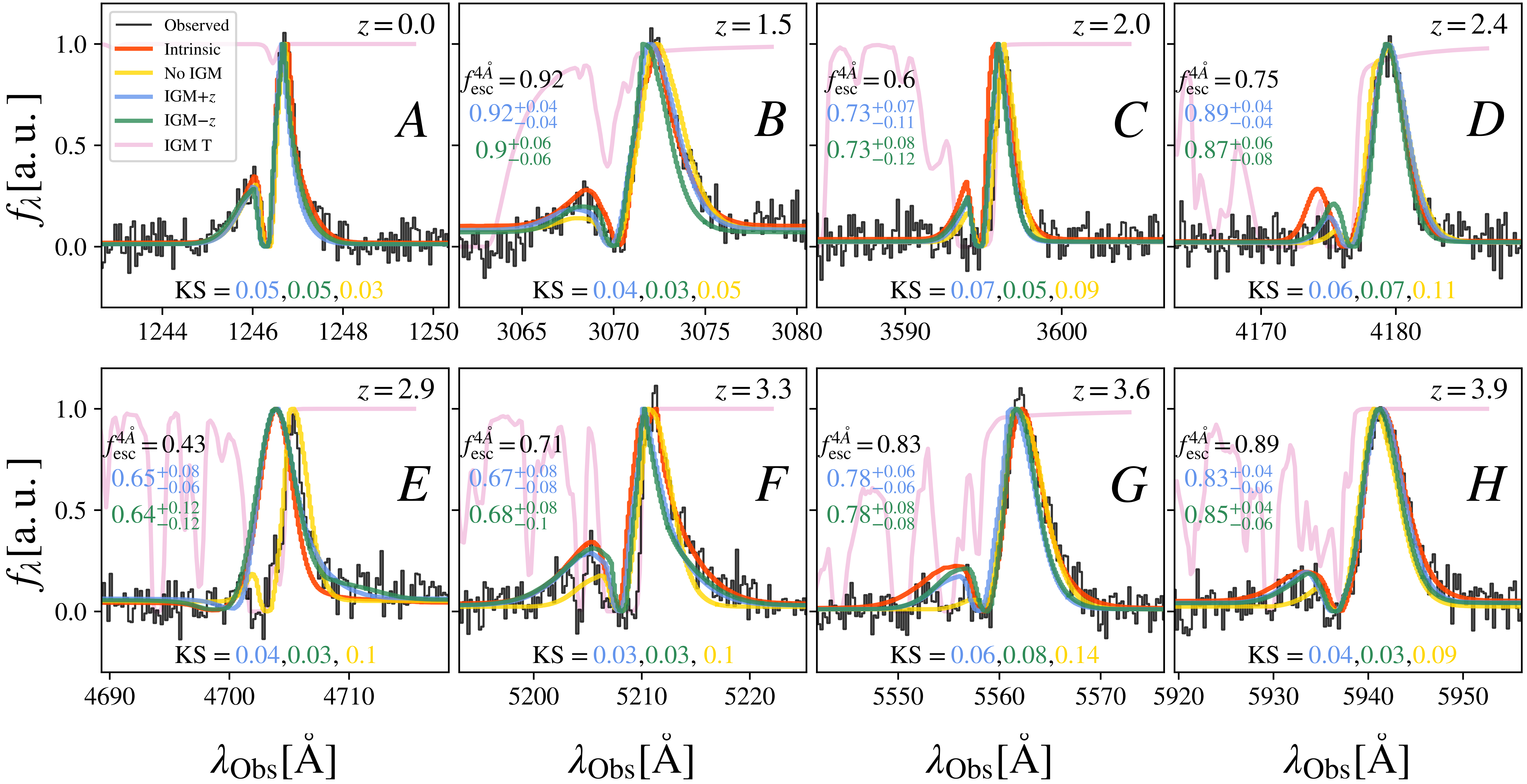
- Input does not include redshift.
- Trained with redshift shuffled IGM transmission curves.

NoIGM:

- Input includes redshift.
- Trained without IGM transmission curves.

NN results in mock Lyman-alpha lines

Successful reconstruction



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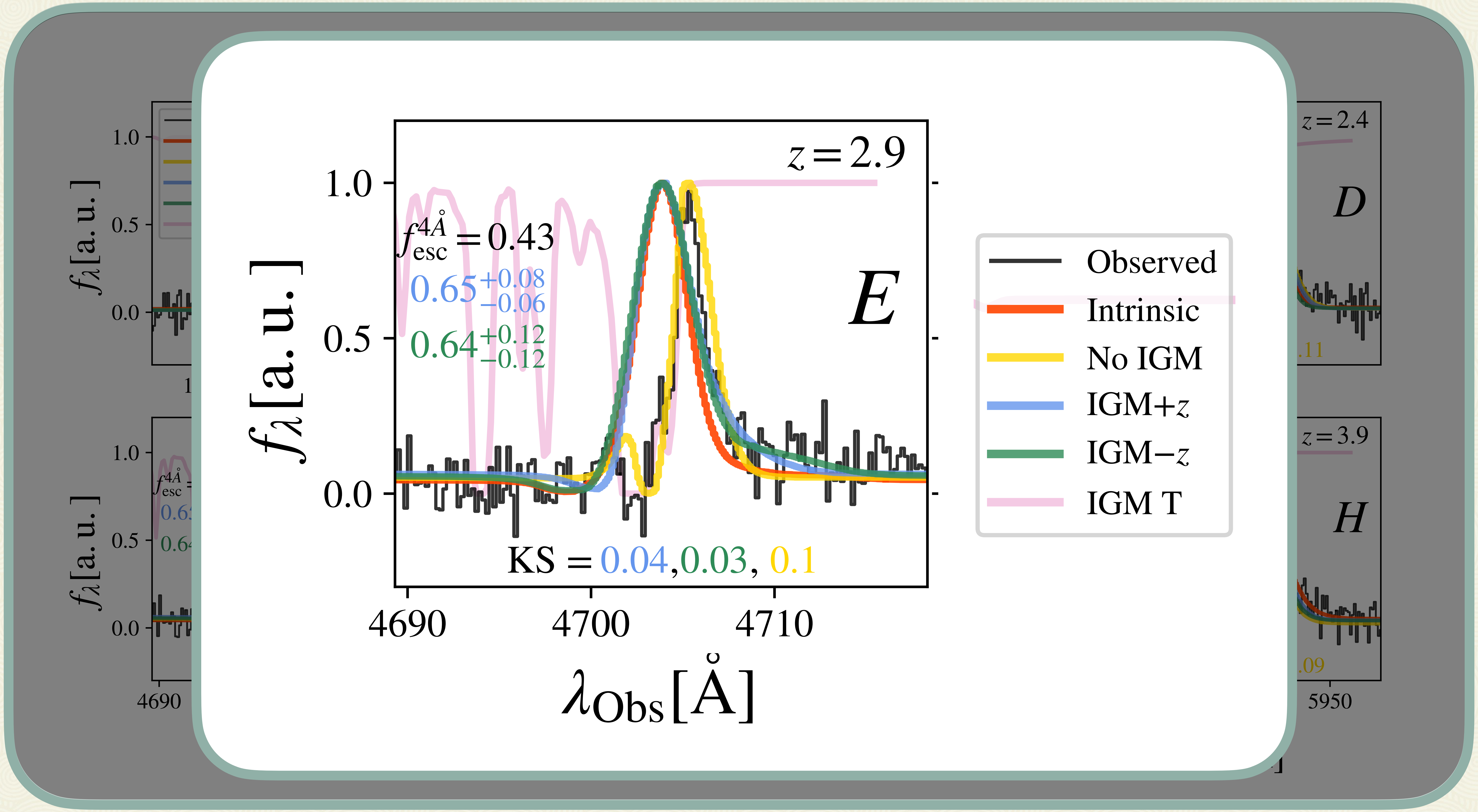

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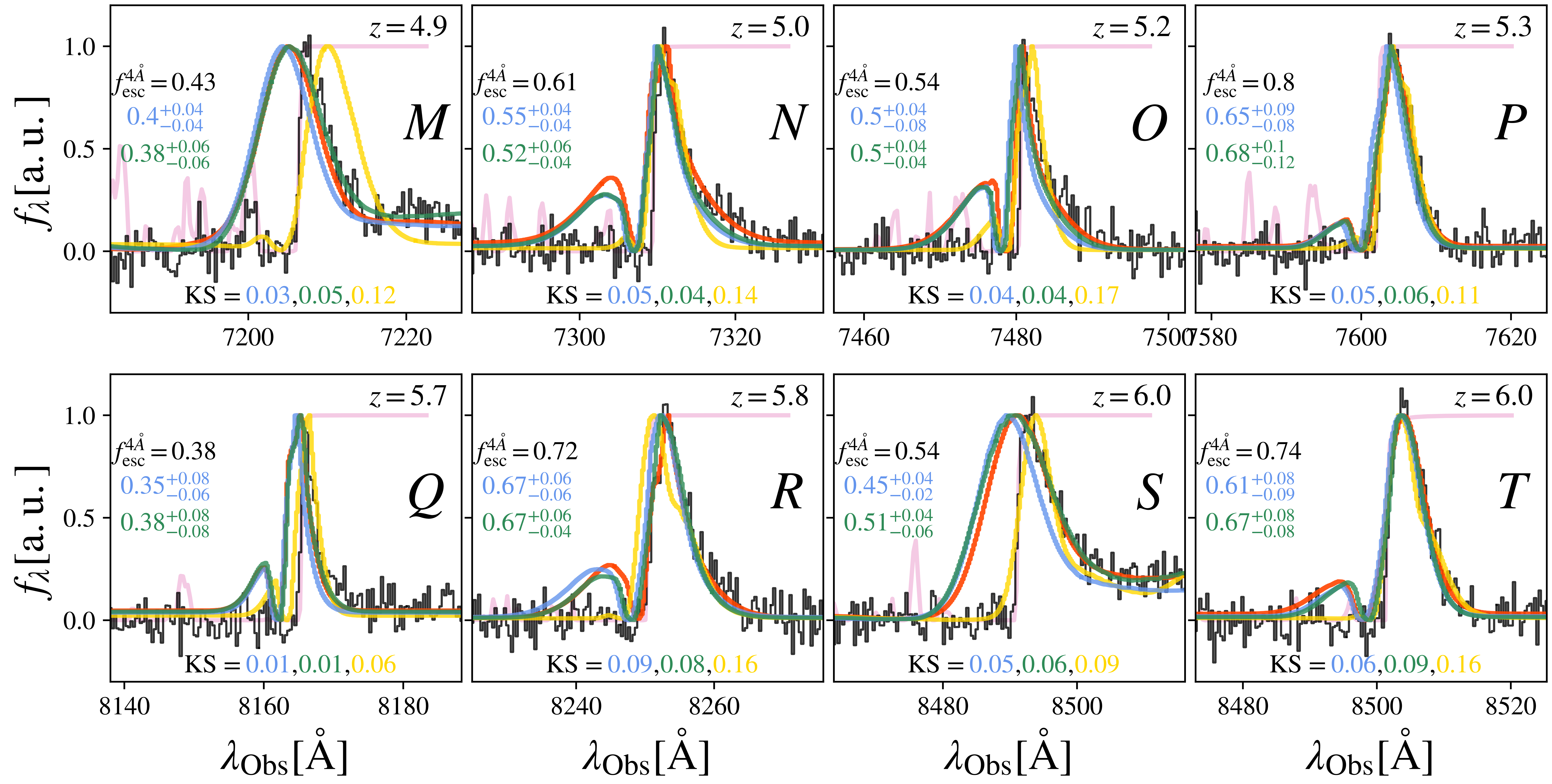

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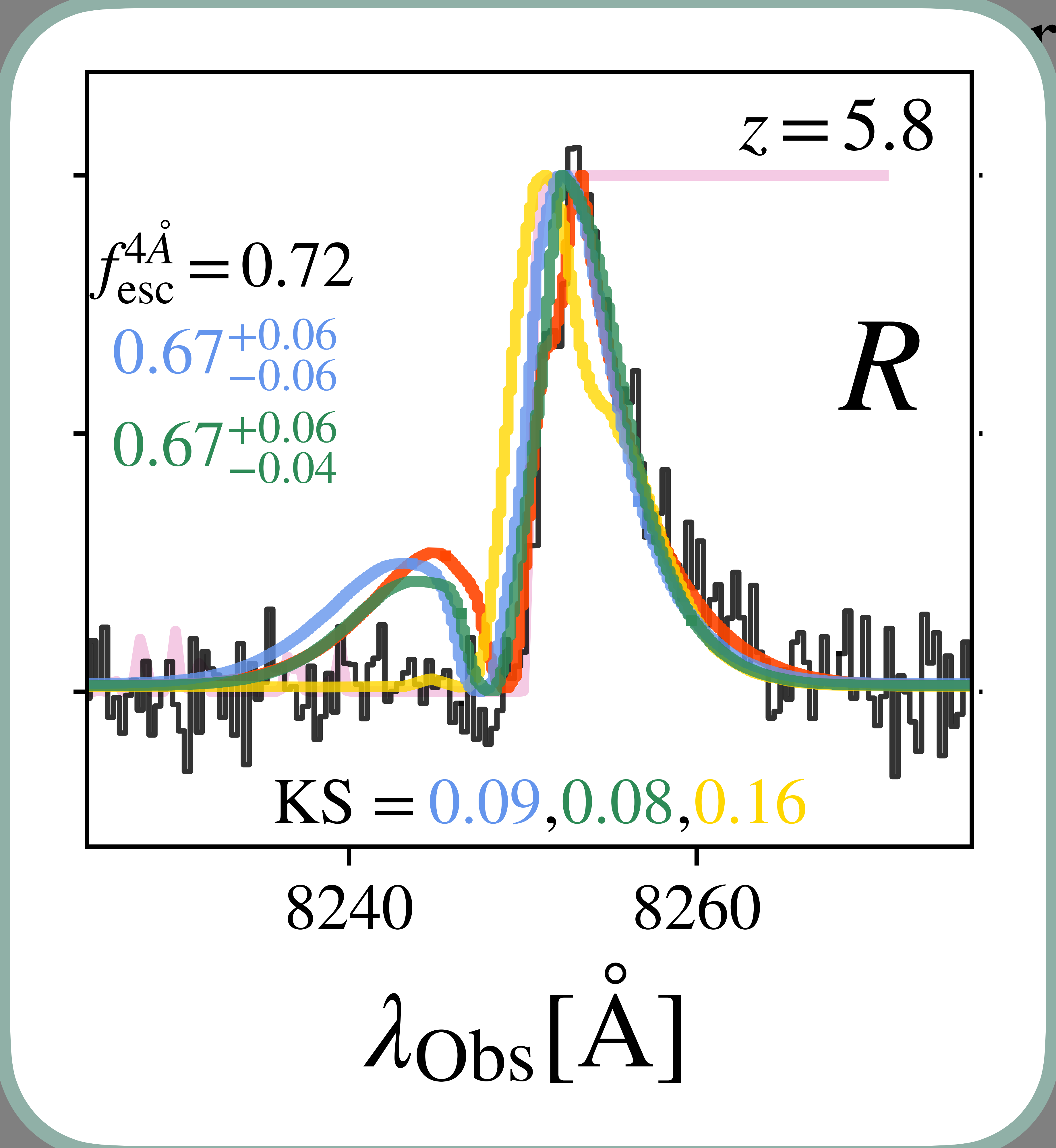
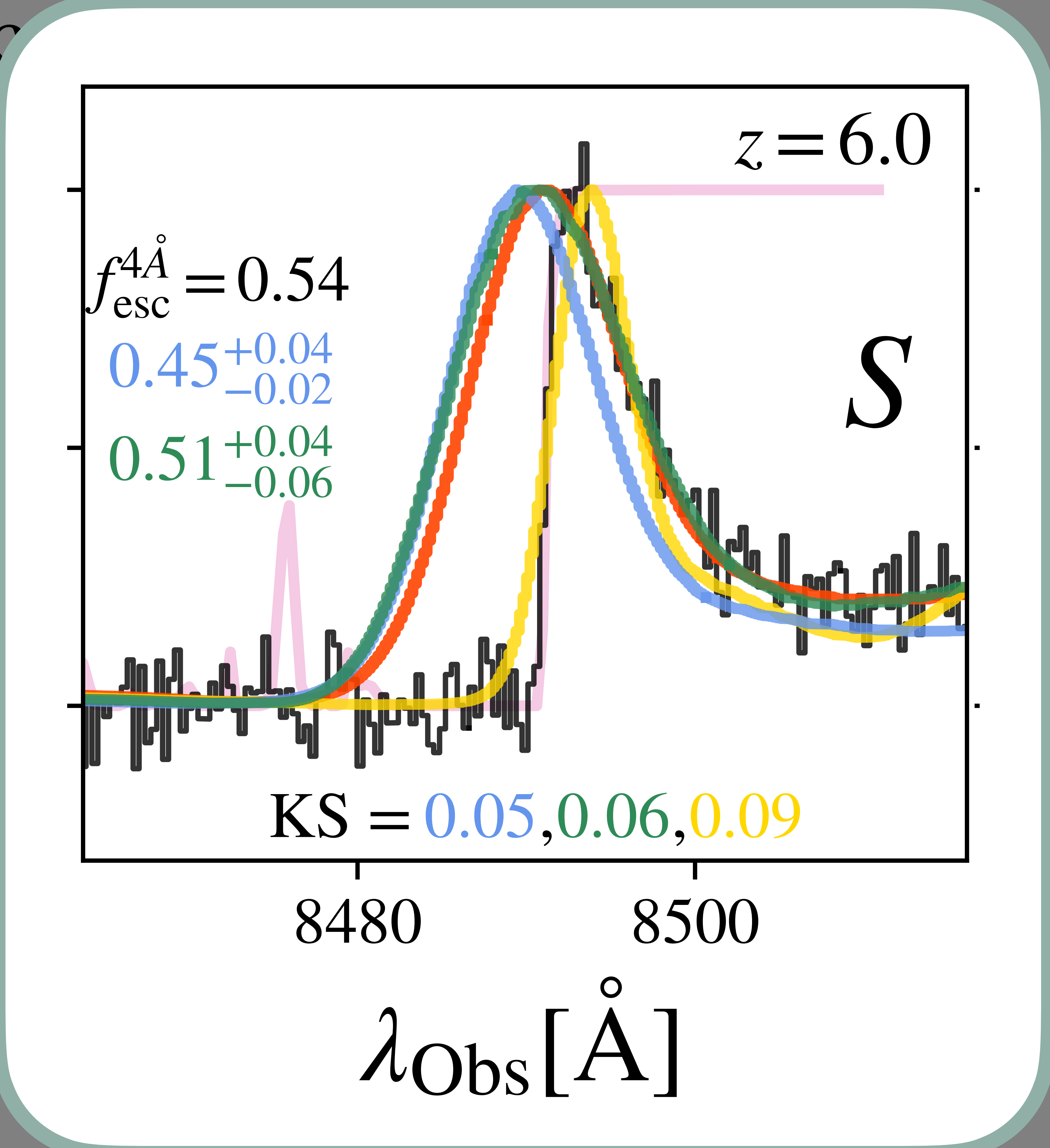
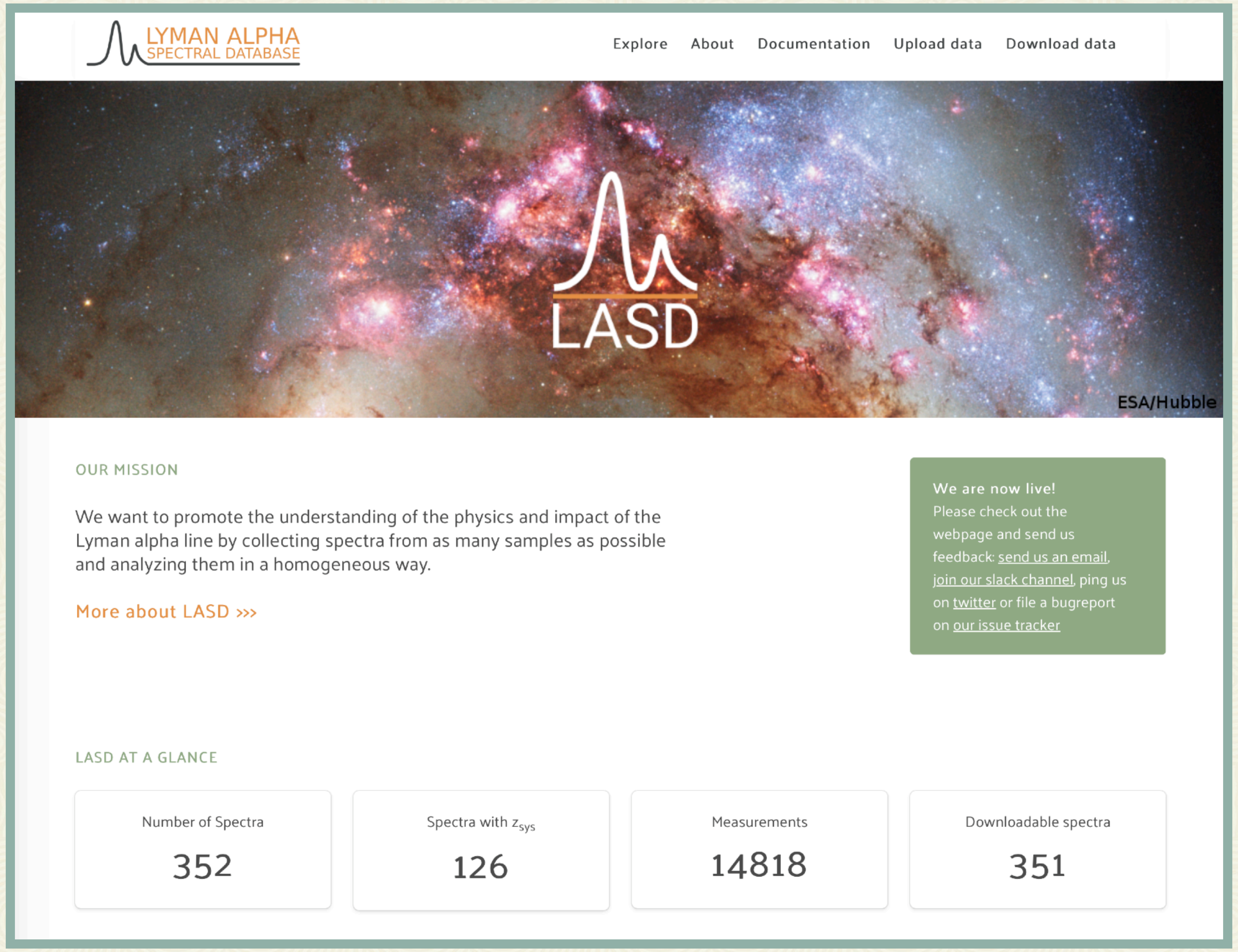
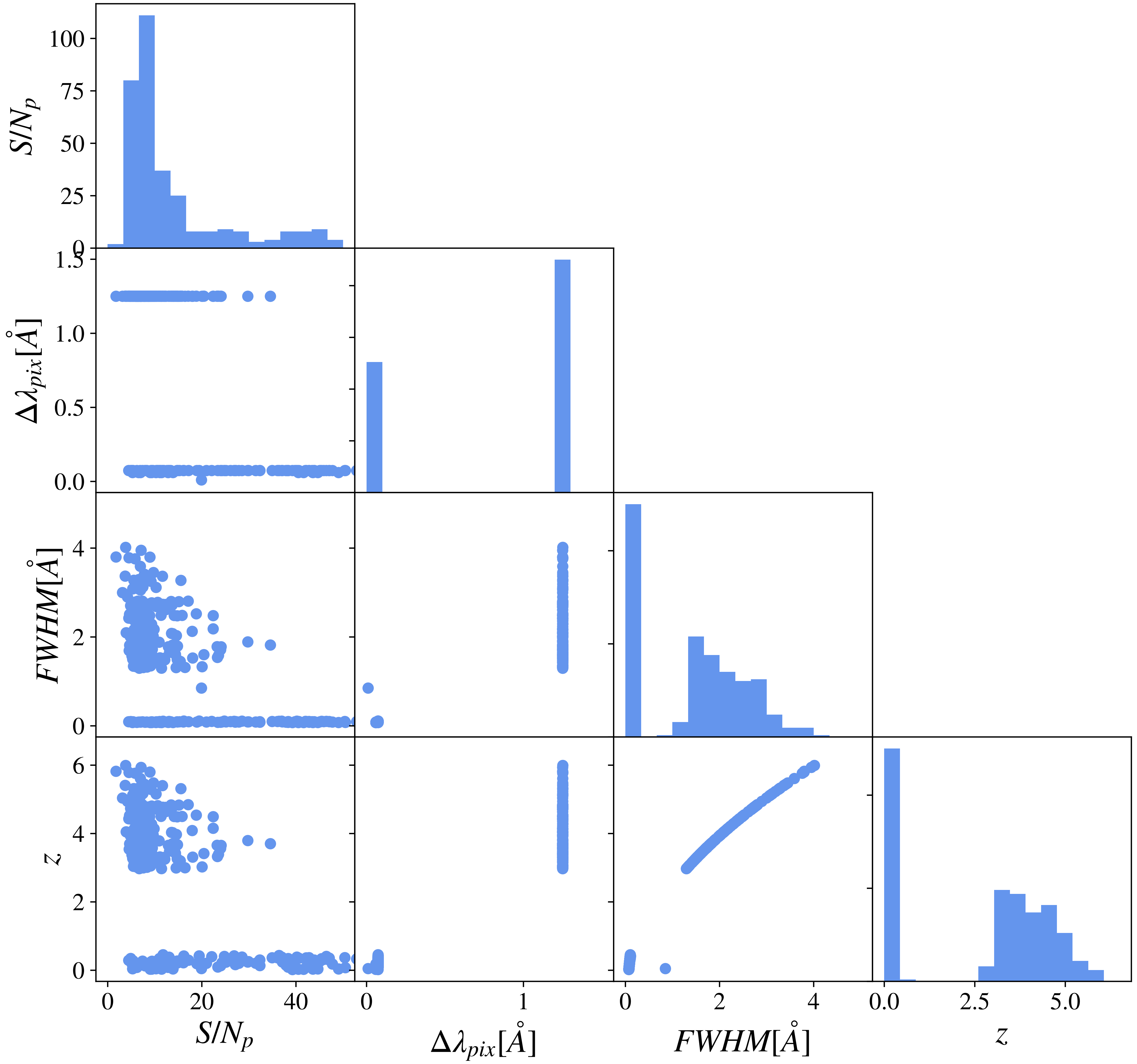




LASD: a data base of Lyman-alpha line profiles

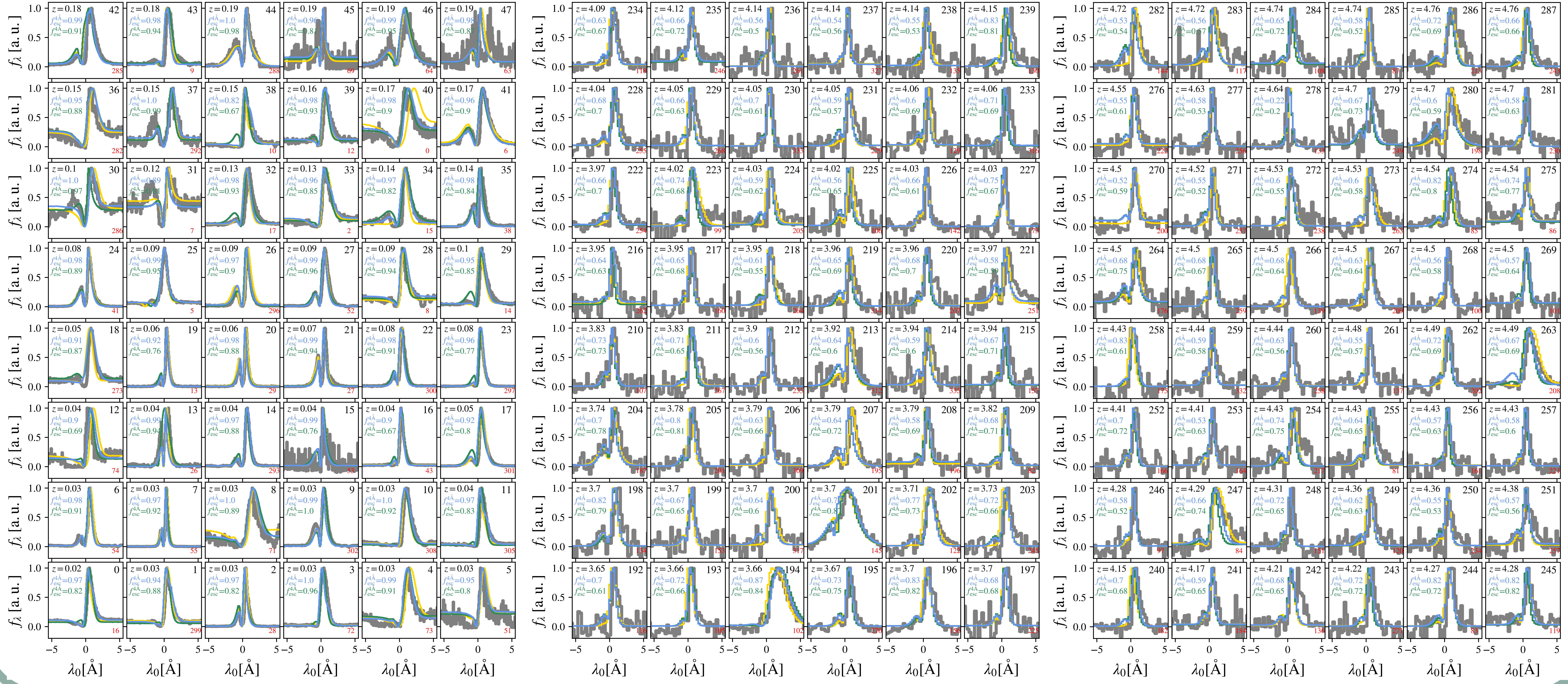




Github: github.com/sidgurun/Lya_zelda

Docs: zelda.readthedocs.io/en/latest/

NN results in observed Lyman-alpha lines



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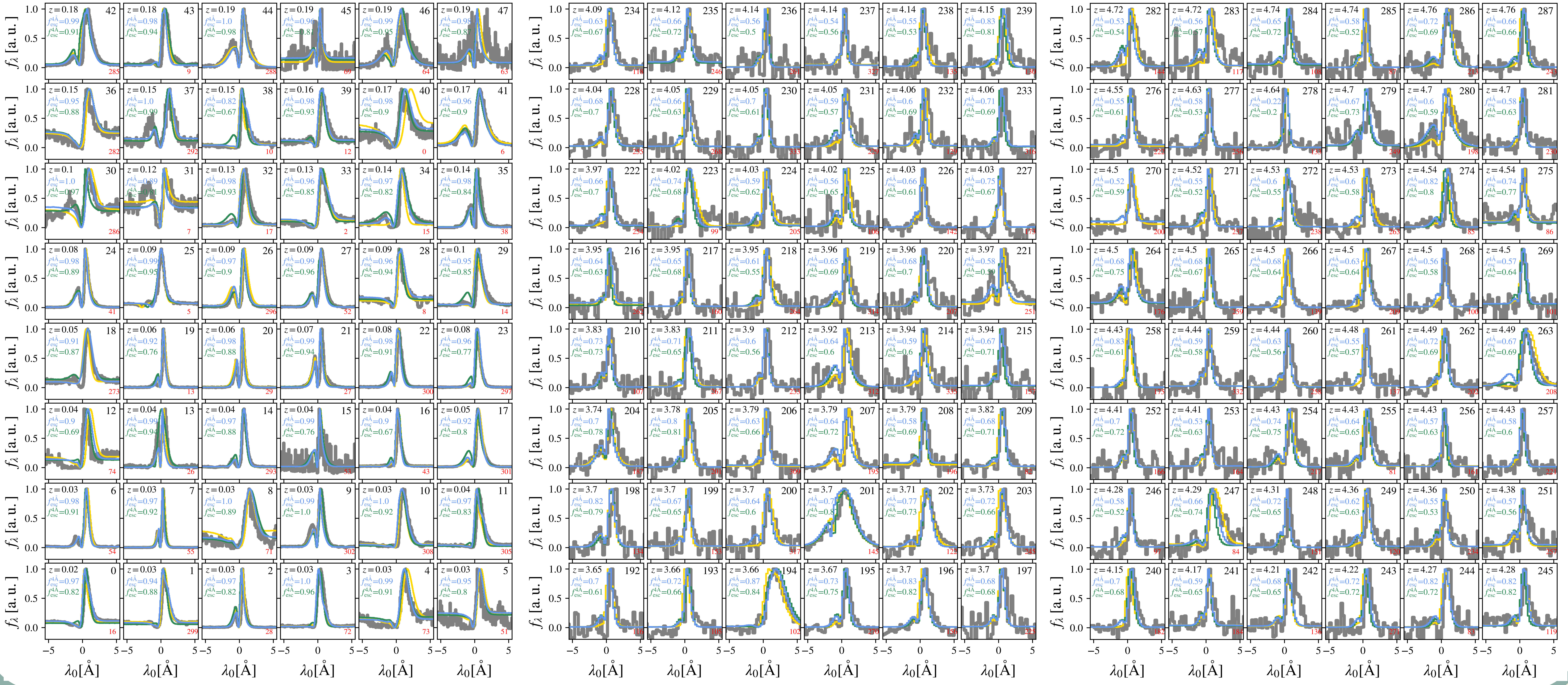
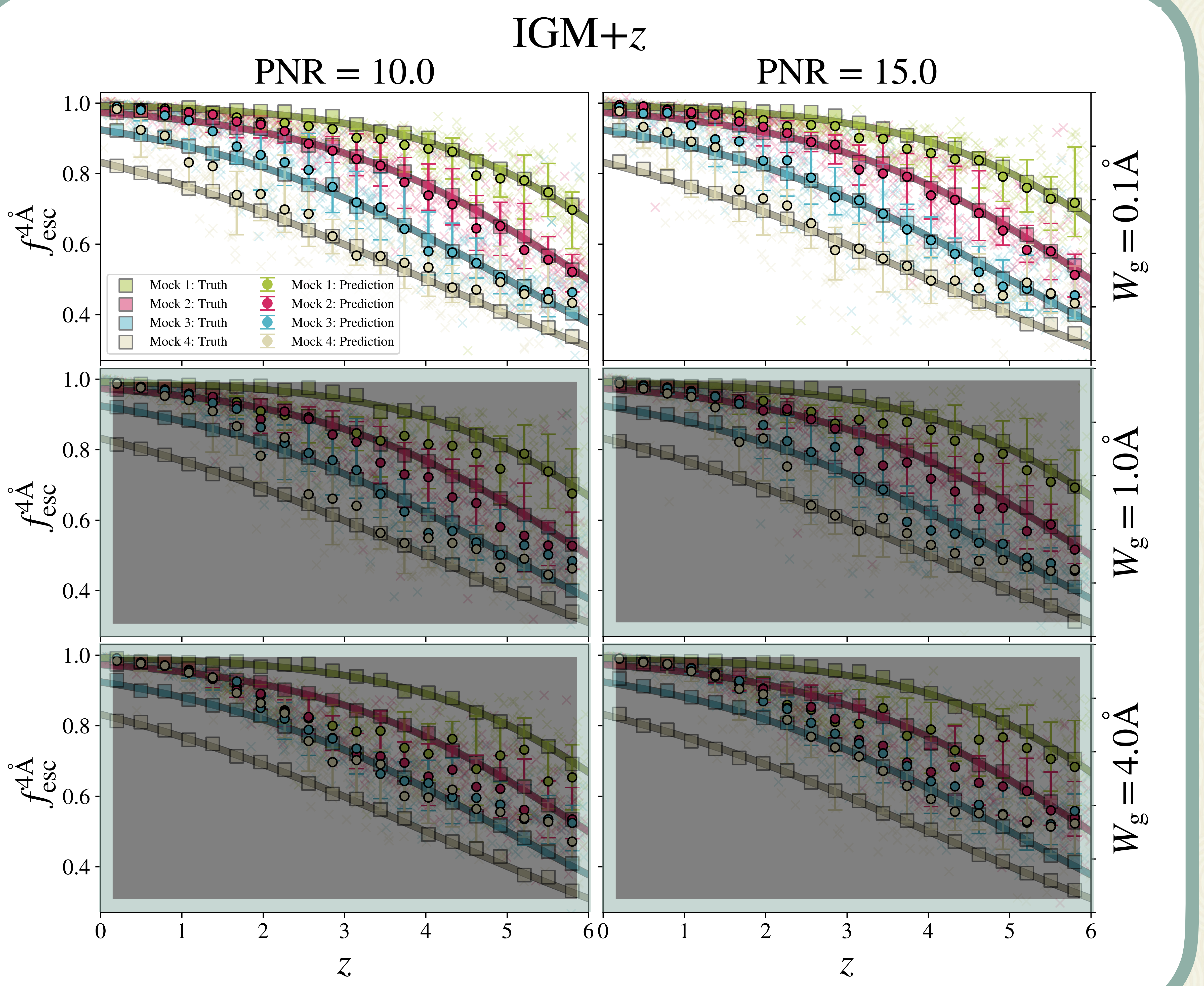


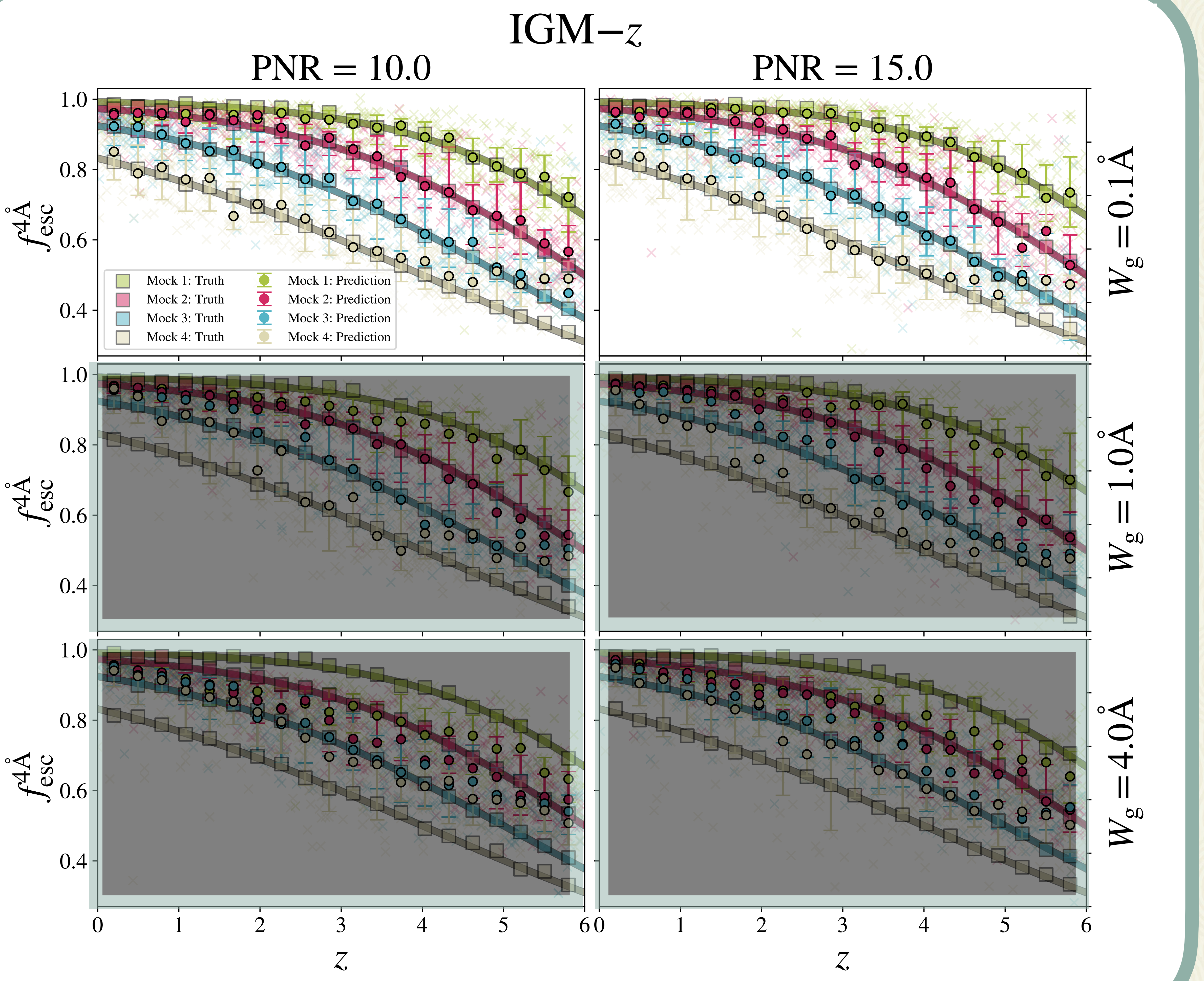
NN results in observed Lyman-alpha lines

$z \in [0.0, 7.0]$

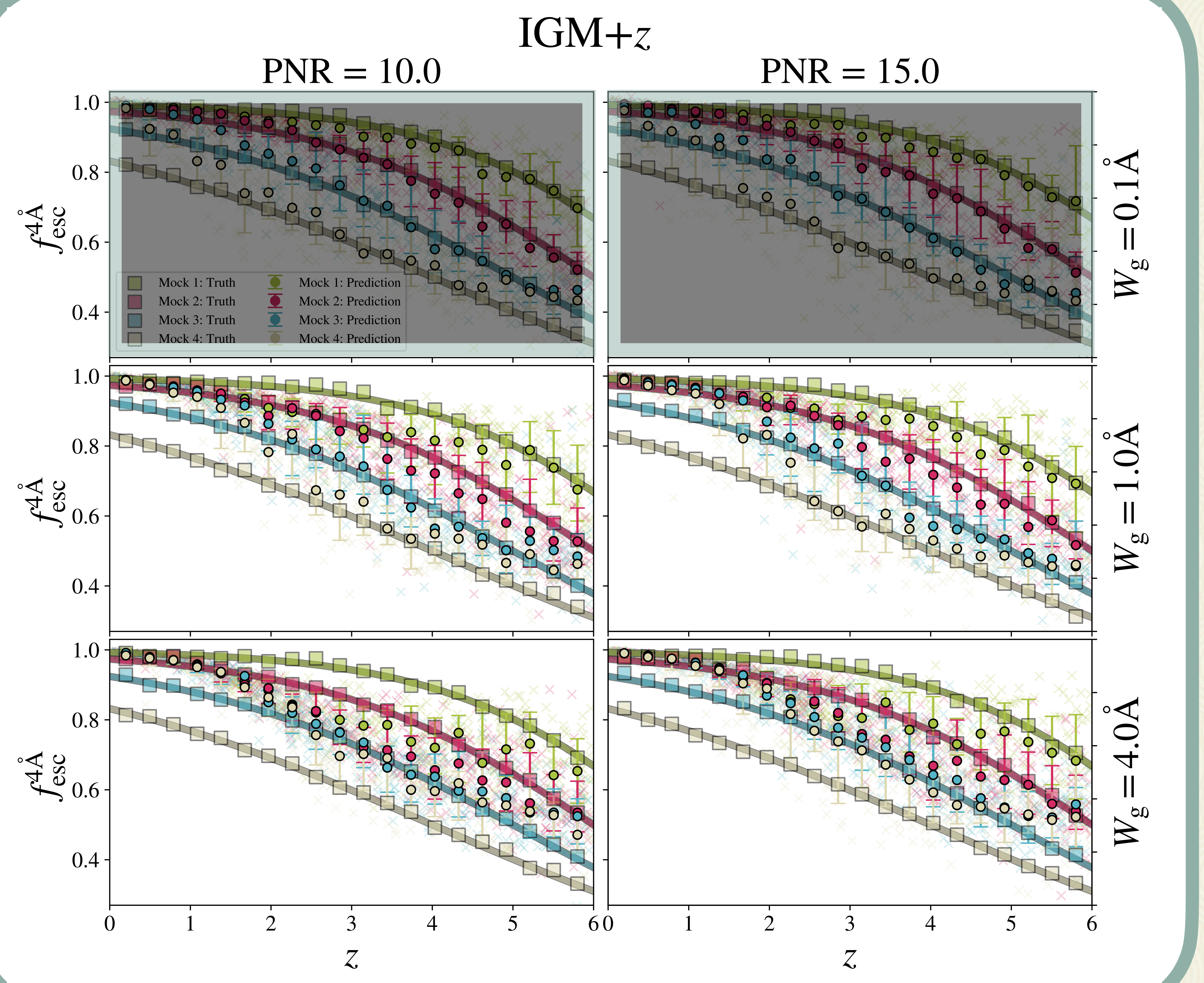
	$\log V_{\rm exp}$	$\log N_{\rm H}$	$\log \tau_{\rm a}$	$\log EW_{\rm in}$	$\log W_{\rm in}$	z	$f_{\rm esc}^{4\AA}$
$\log V_{\rm exp}$		$0.07^{+0.01}_{-0.03}$	$0.13^{+0.04}_{-0.04}$	$0.01^{+0.03}_{-0.06}$	$0.15^{+0.03}_{-0.03}$	$-0.2^{+0.03}_{-0.02}$	$0.11^{+0.03}_{-0.0}$
$\log N_{\rm H}$	$0.2^{+0.03}_{-0.02}$		$-0.07^{+0.02}_{-0.04}$	$-0.0^{+0.05}_{-0.03}$	$0.23^{+0.03}_{-0.05}$	$-0.19^{+0.01}_{-0.02}$	$0.32^{+0.02}_{-0.02}$
$\log \tau_{\rm a}$	$0.12^{+0.03}_{-0.03}$	$-0.02^{+0.03}_{-0.03}$		$-0.28^{+0.03}_{-0.02}$	$-0.01^{+0.05}_{-0.03}$	$-0.22^{+0.03}_{-0.02}$	$0.03^{+0.02}_{-0.02}$
$\log EW_{\rm in}$	$0.01^{+0.01}_{-0.04}$	$-0.05^{+0.04}_{-0.01}$	$-0.4^{+0.03}_{-0.05}$		$0.18^{+0.02}_{-0.02}$	$0.14^{+0.03}_{-0.02}$	$-0.03^{+0.03}_{-0.02}$
$\log W_{\rm in}$	$-0.06^{+0.01}_{-0.06}$	$0.15^{+0.01}_{-0.03}$	$-0.16^{+0.01}_{-0.02}$	$0.23^{+0.04}_{-0.03}$		$-0.26^{+0.02}_{-0.01}$	$0.18^{+0.03}_{-0.03}$
z	$-0.1^{+0.01}_{-0.02}$	$-0.15^{+0.03}_{-0.01}$	$-0.35^{+0.04}_{-0.03}$	$0.13^{+0.02}_{-0.01}$	$-0.02^{+0.01}_{-0.03}$		$-0.66^{+0.02}_{-0.01}$
$f_{\rm esc}^{4\AA}$	$0.16^{+0.02}_{-0.03}$	$0.24^{+0.04}_{-0.02}$	$0.14^{+0.03}_{-0.02}$	$0.07^{+0.02}_{-0.03}$	$0.14^{+0.03}_{-0.02}$	$-0.8^{+0.02}_{-0.02}$	

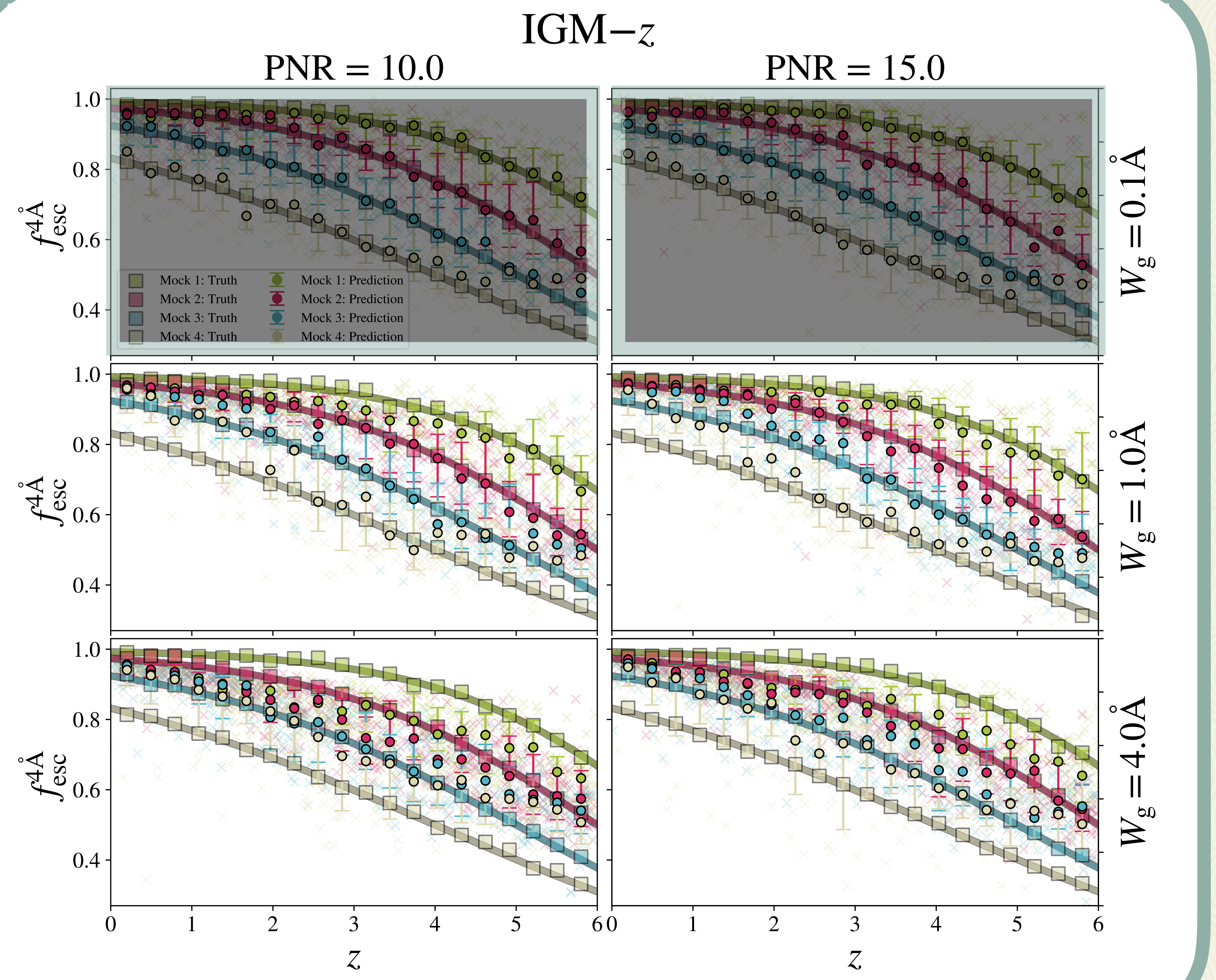
Measuring the escape fraction z evolution: Mocks



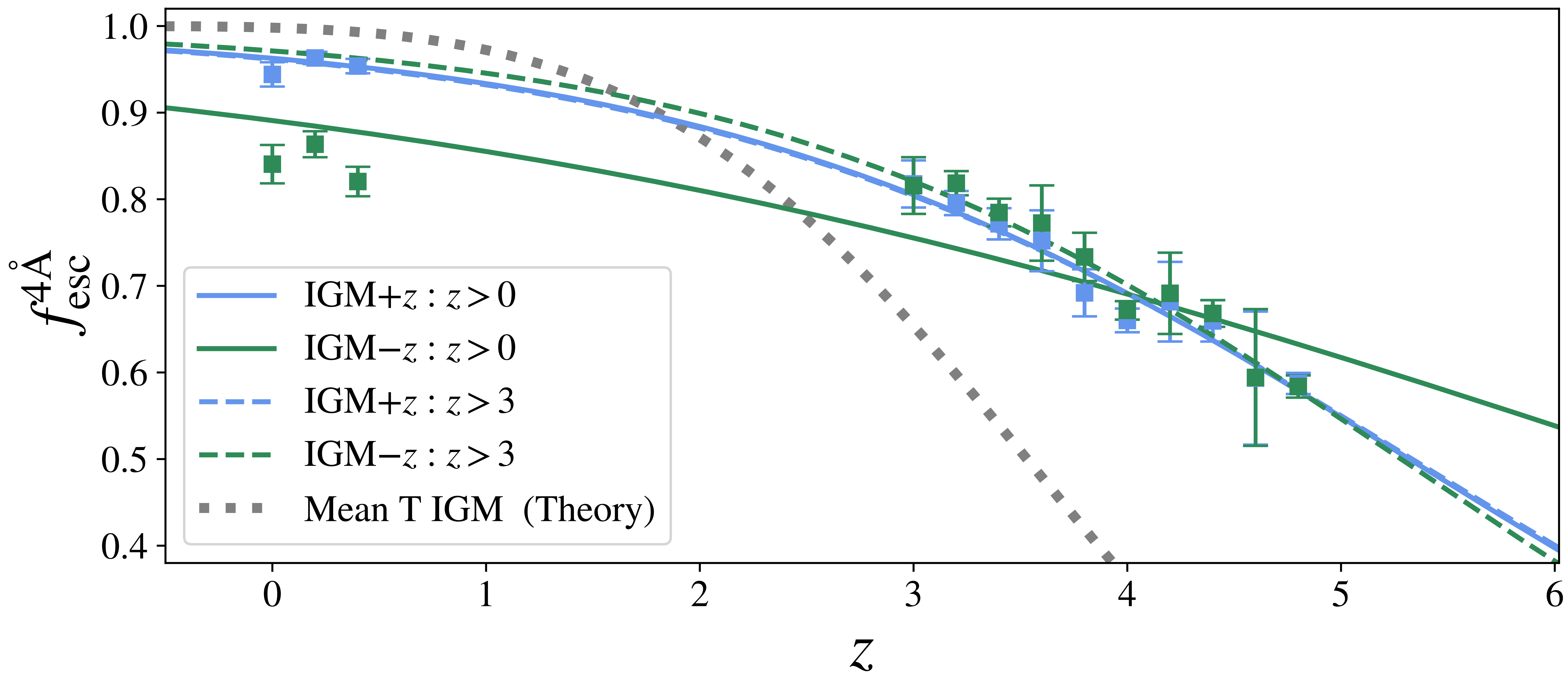


Measuring the escape fraction z evolution: Mocks

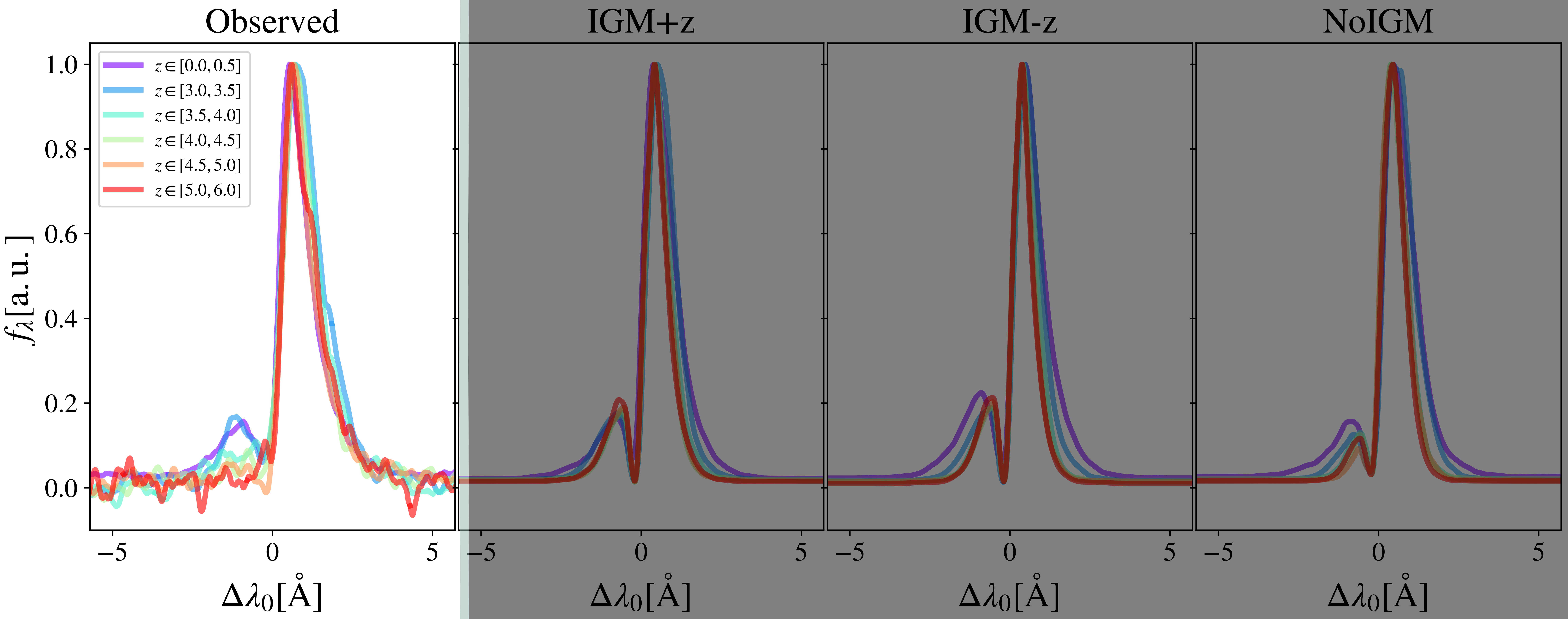




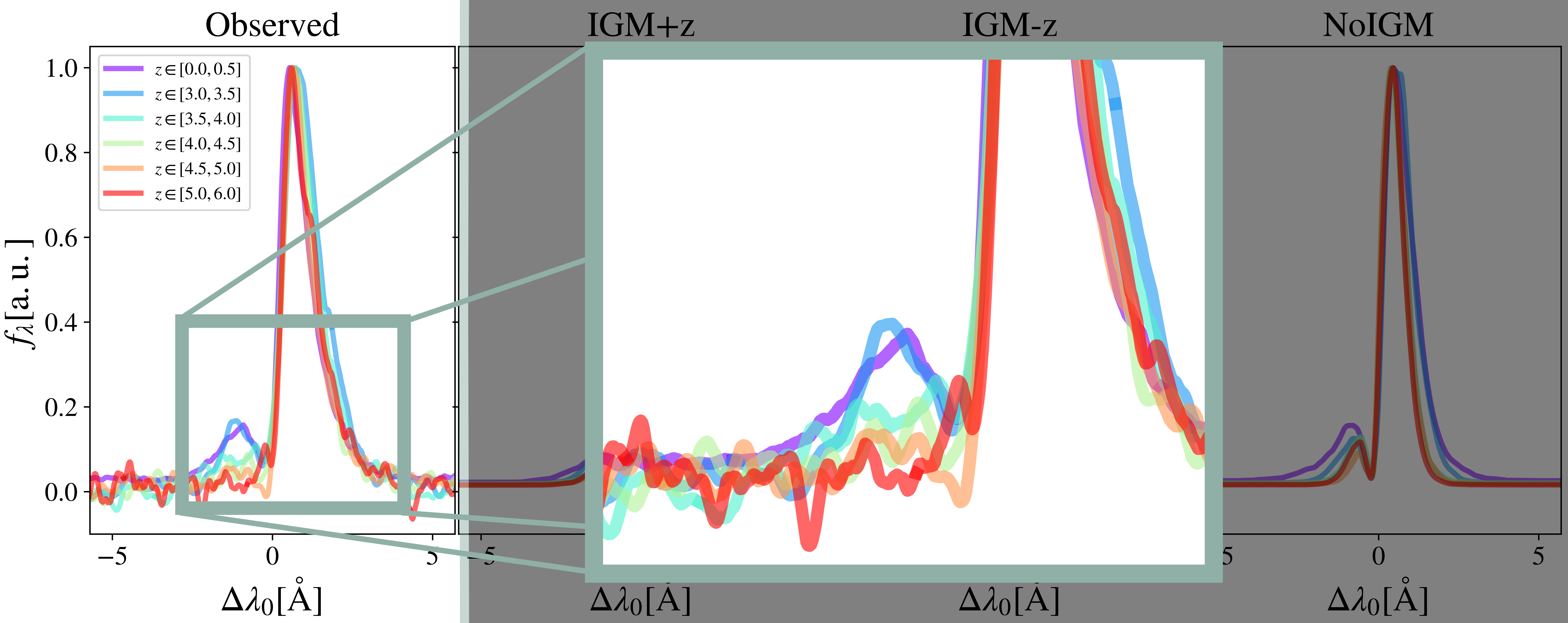
Measuring the escape fraction z evolution: Observations



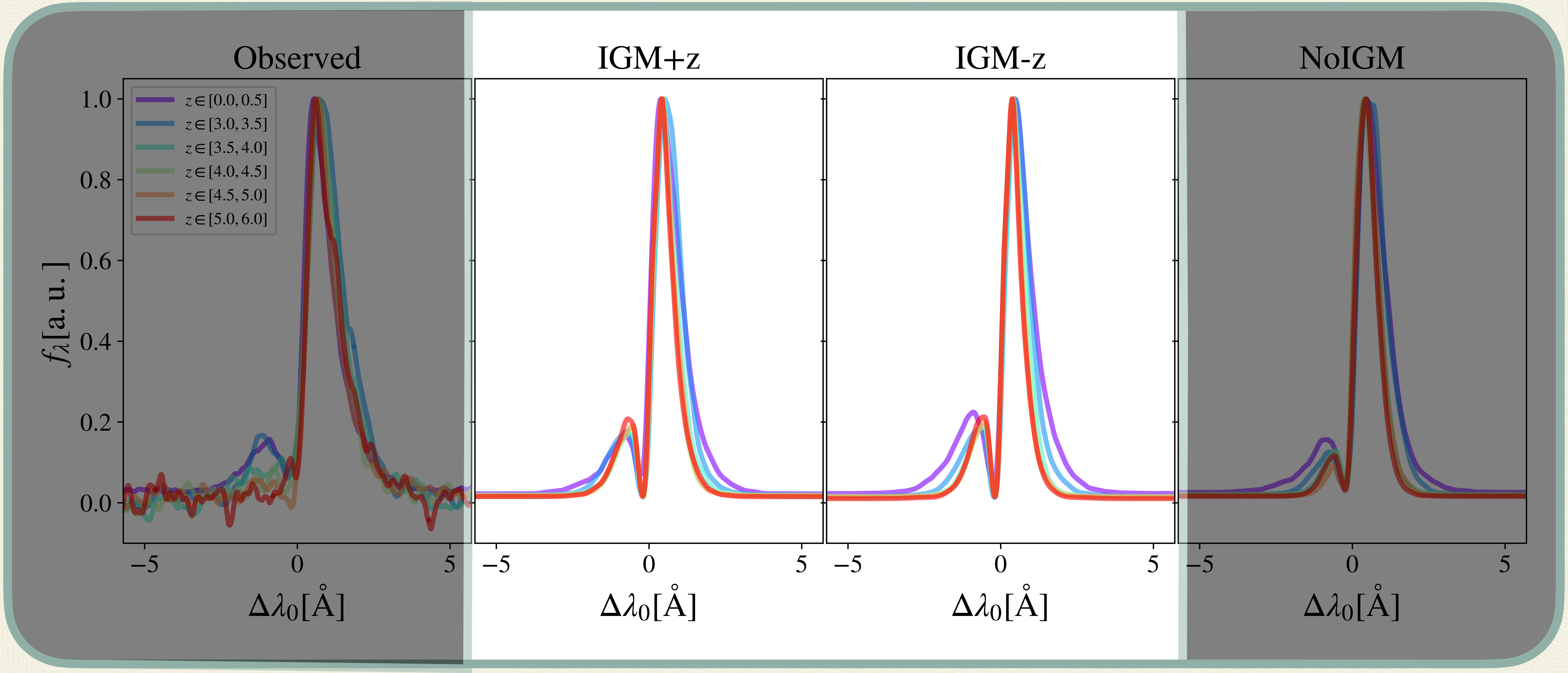
Reconstructing the stack line profile: Observations



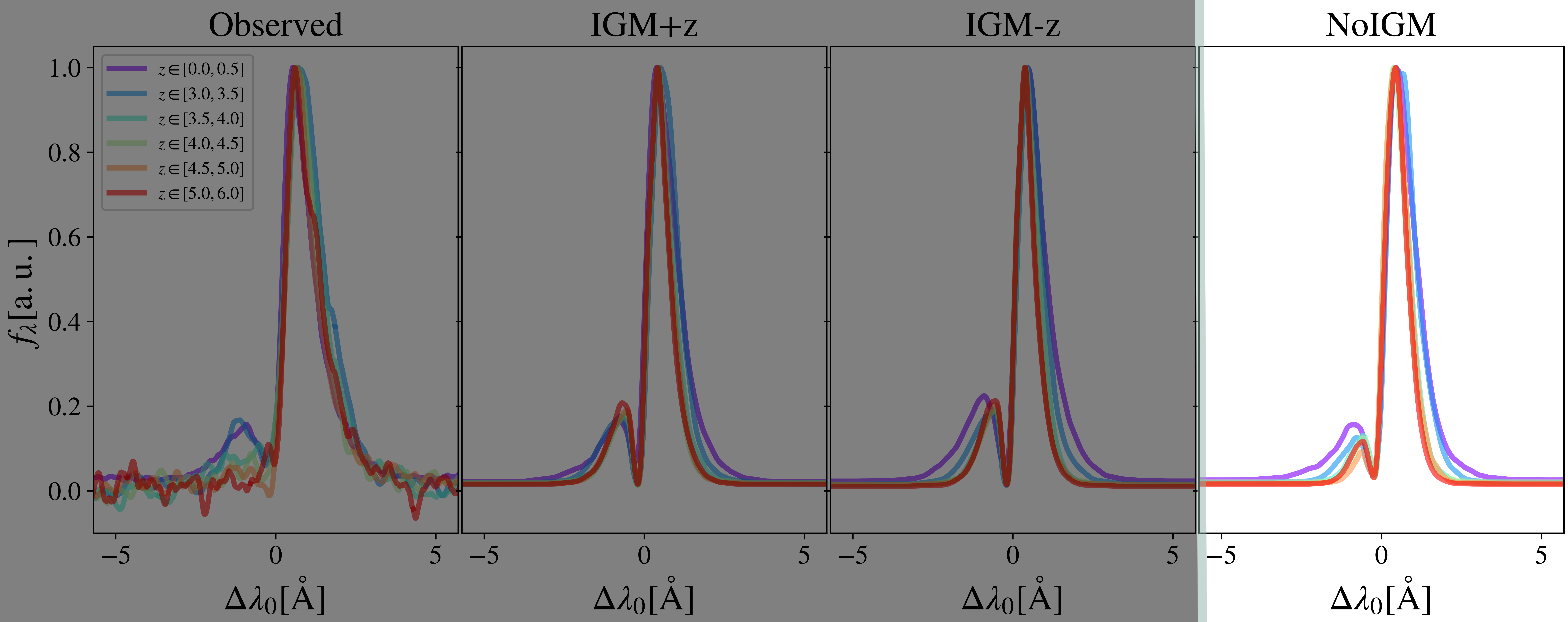
Reconstructing the stack line profile: Observations



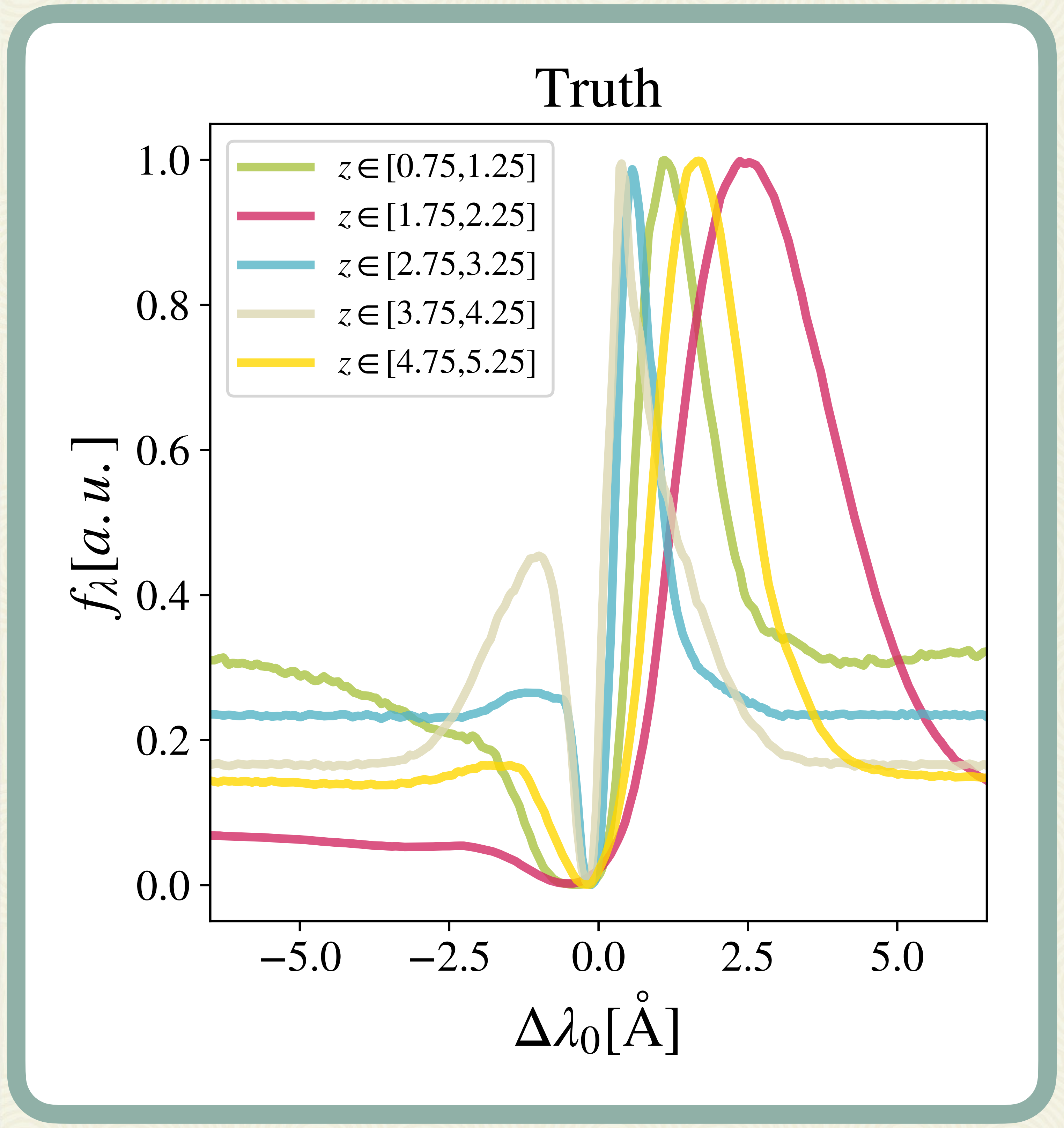
Reconstructing the stack line profile: Observations



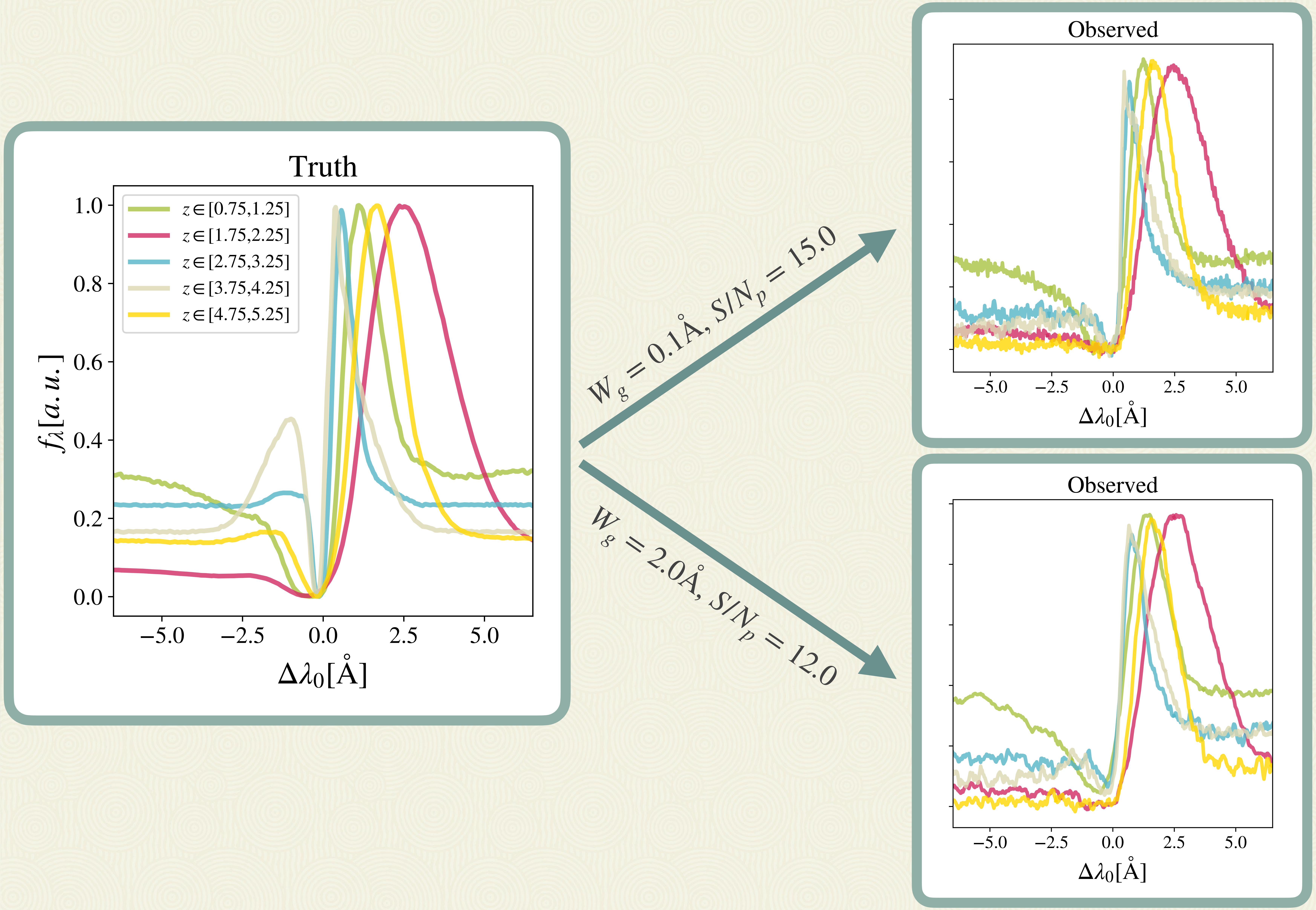
Reconstructing the stack line profile: Observations



Reconstructing the stack line profile: Mocks : z evolution



Reconstructing the stack line profile: Mocks : z evolution

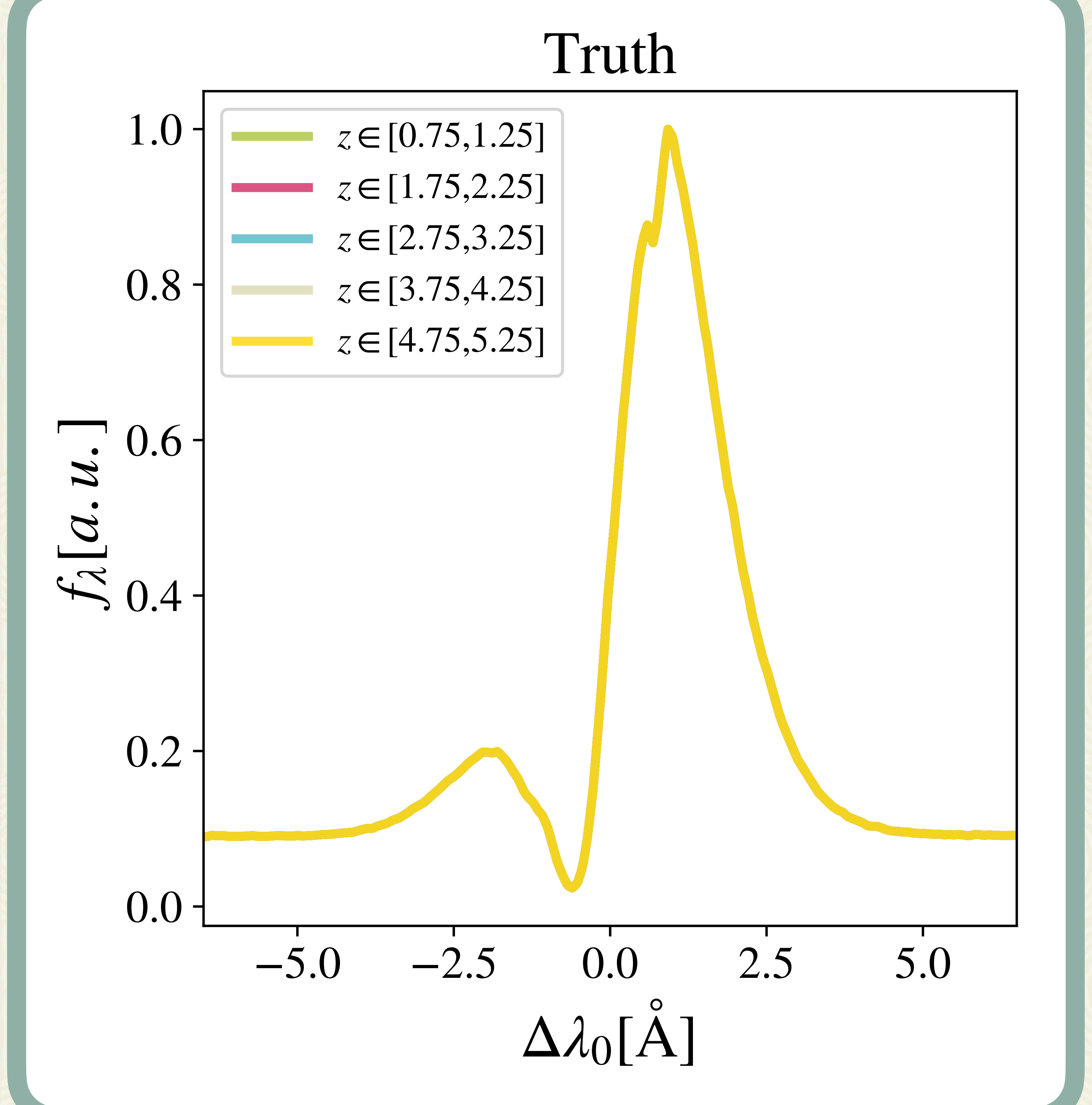


Reconstructing the stack line profile: Mocks : z evolution

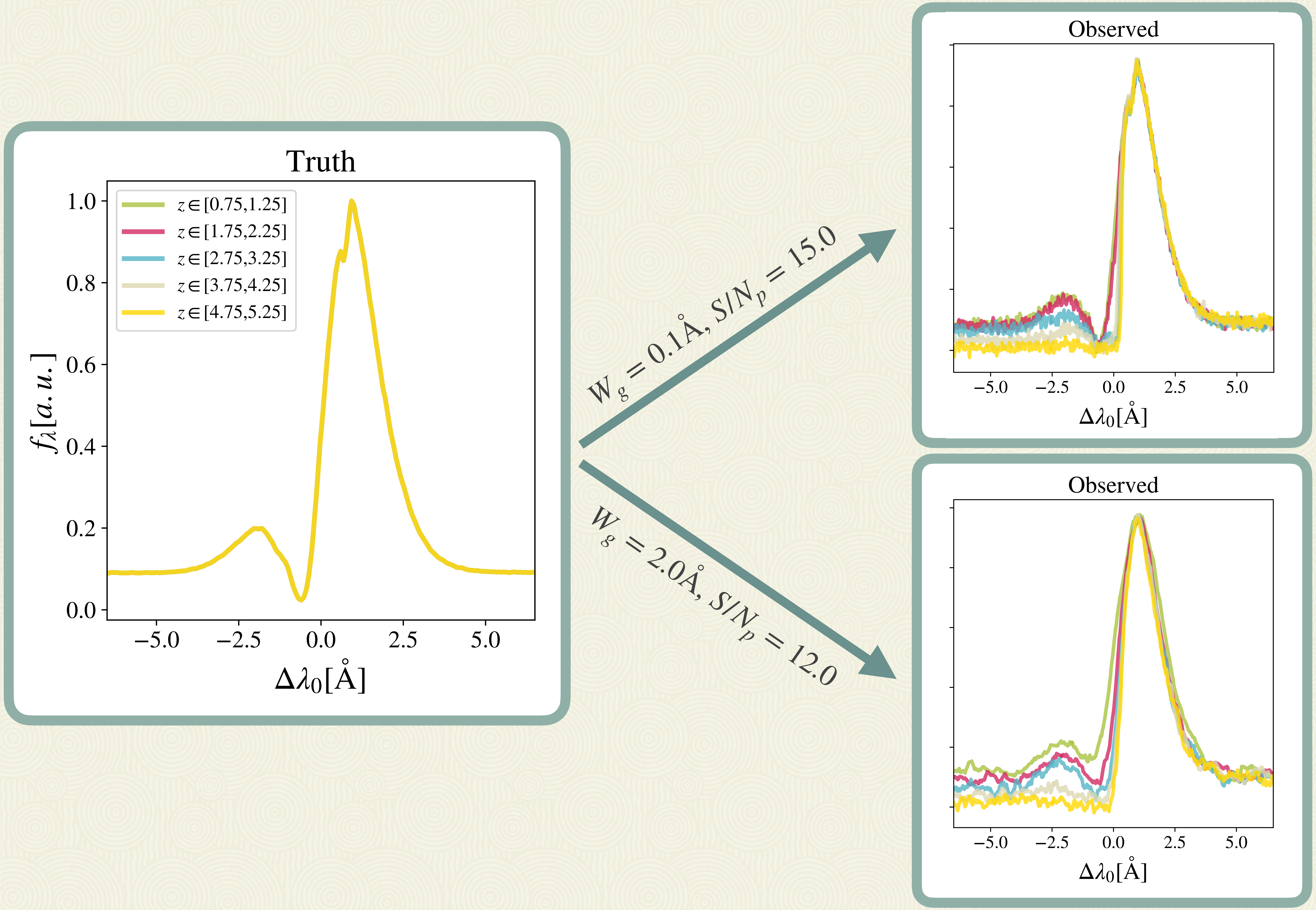
Github: github.com/sidgurun/Lya_zelda

Docs: zelda.readthedocs.io/en/latest/

Reconstructing the stack line profile: Mocks : No z evolution

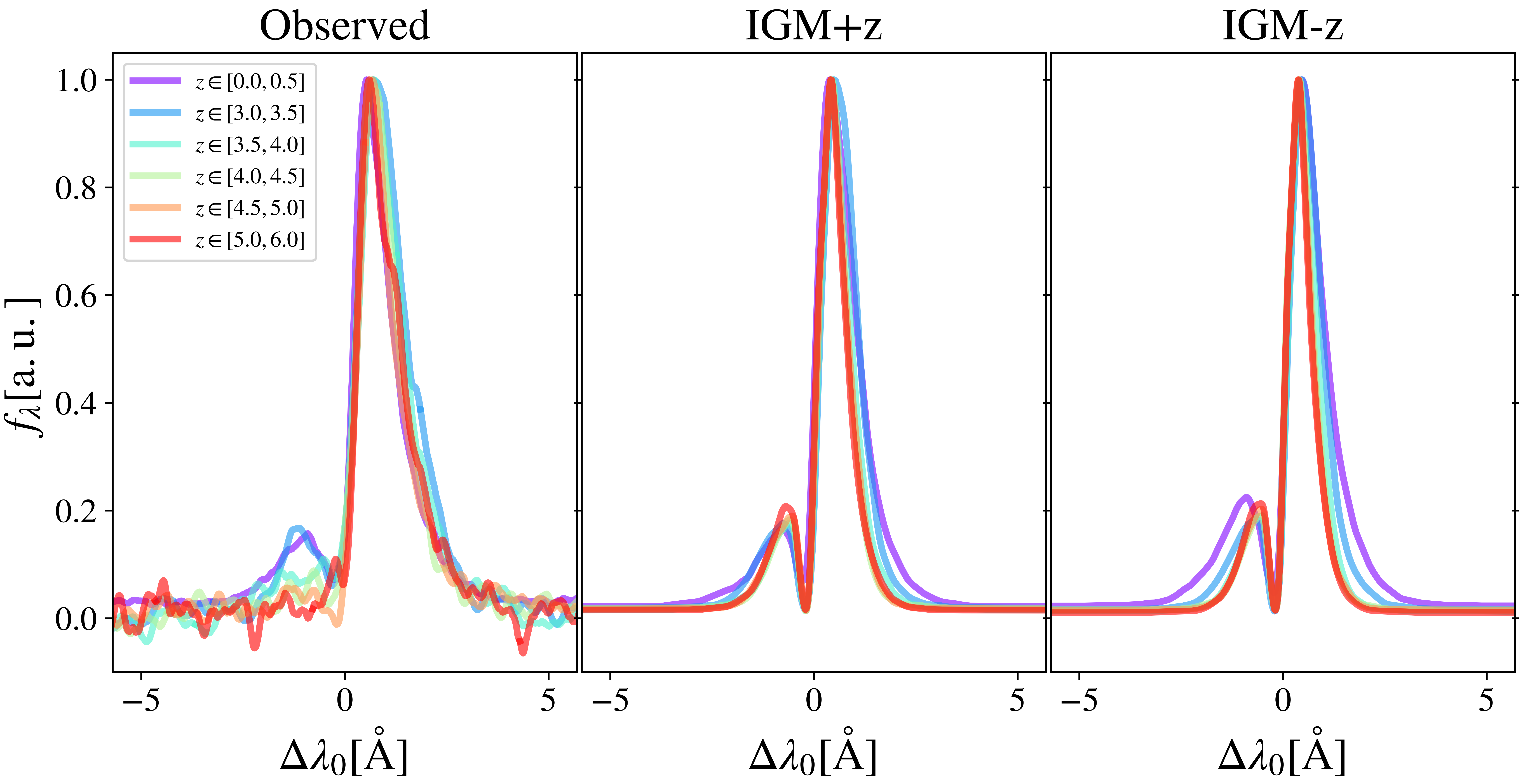


Reconstructing the stack line profile: Mocks : No z evolution

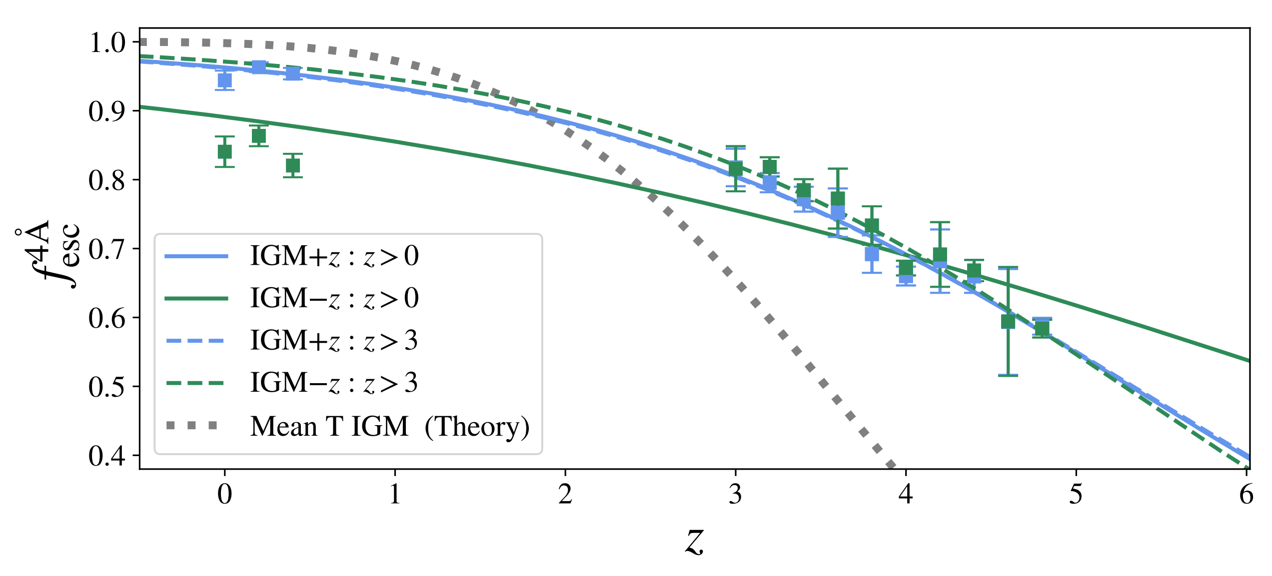


Reconstructing the stack line profile: Mocks : No z evolution

Reconstructing the stack line profile: Observations



Summary



Lyman-alpha spectrum exhibits a large variety of features.

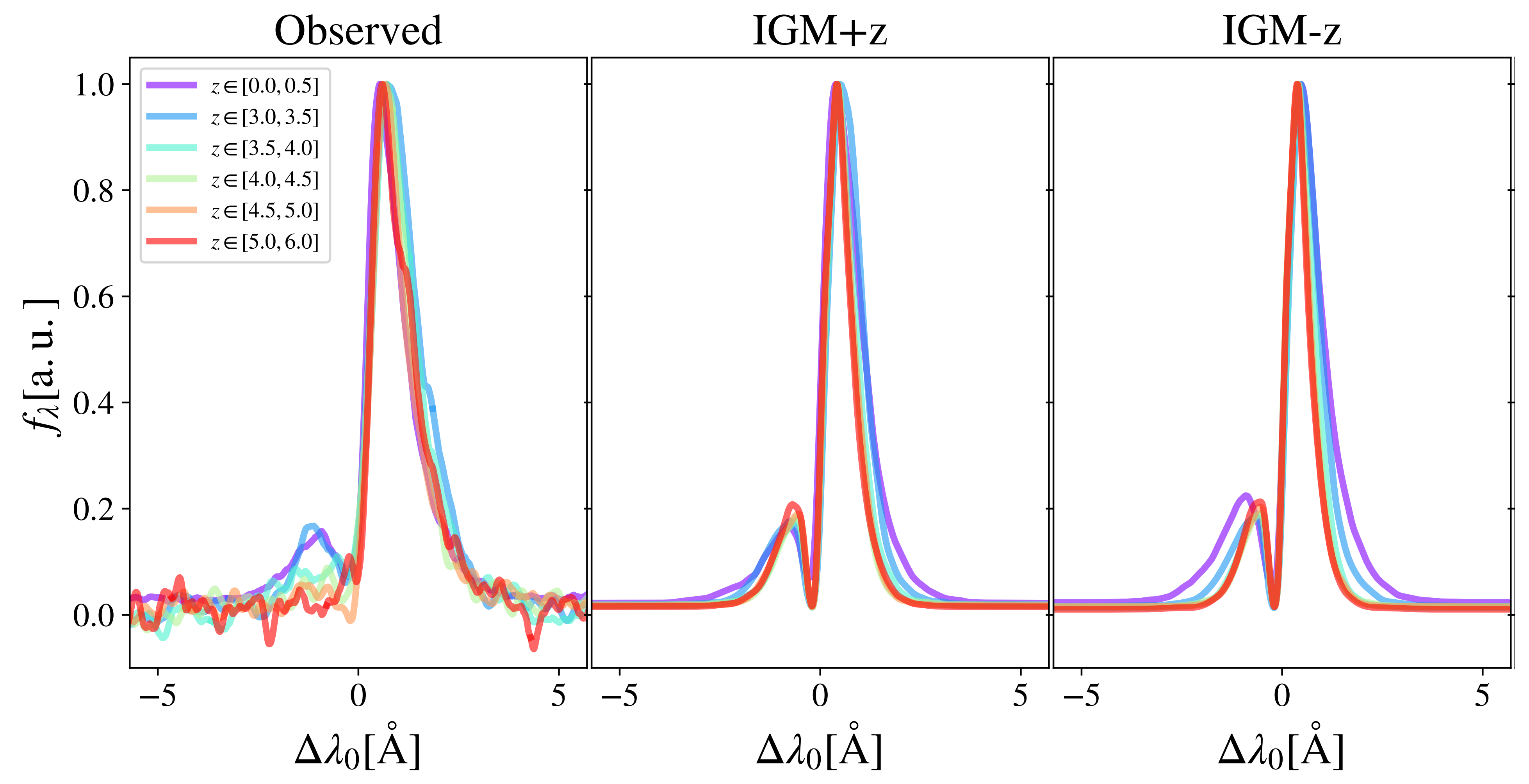
Lyman-alpha lines are shaped by the interestelar, the circumgalactic and intergalactic medium.

zELDA is an open source code to mock and fit Lyman-alpha spectrum.

zELDA is able to disentangle between the IGM / CGM and ISM contributions to the spectral features.

zELDA is able to compute IGM escape fractions for individual line profiles

The new zELDA version will be available soon



Thanks!

Lyα as an astrophysical tool

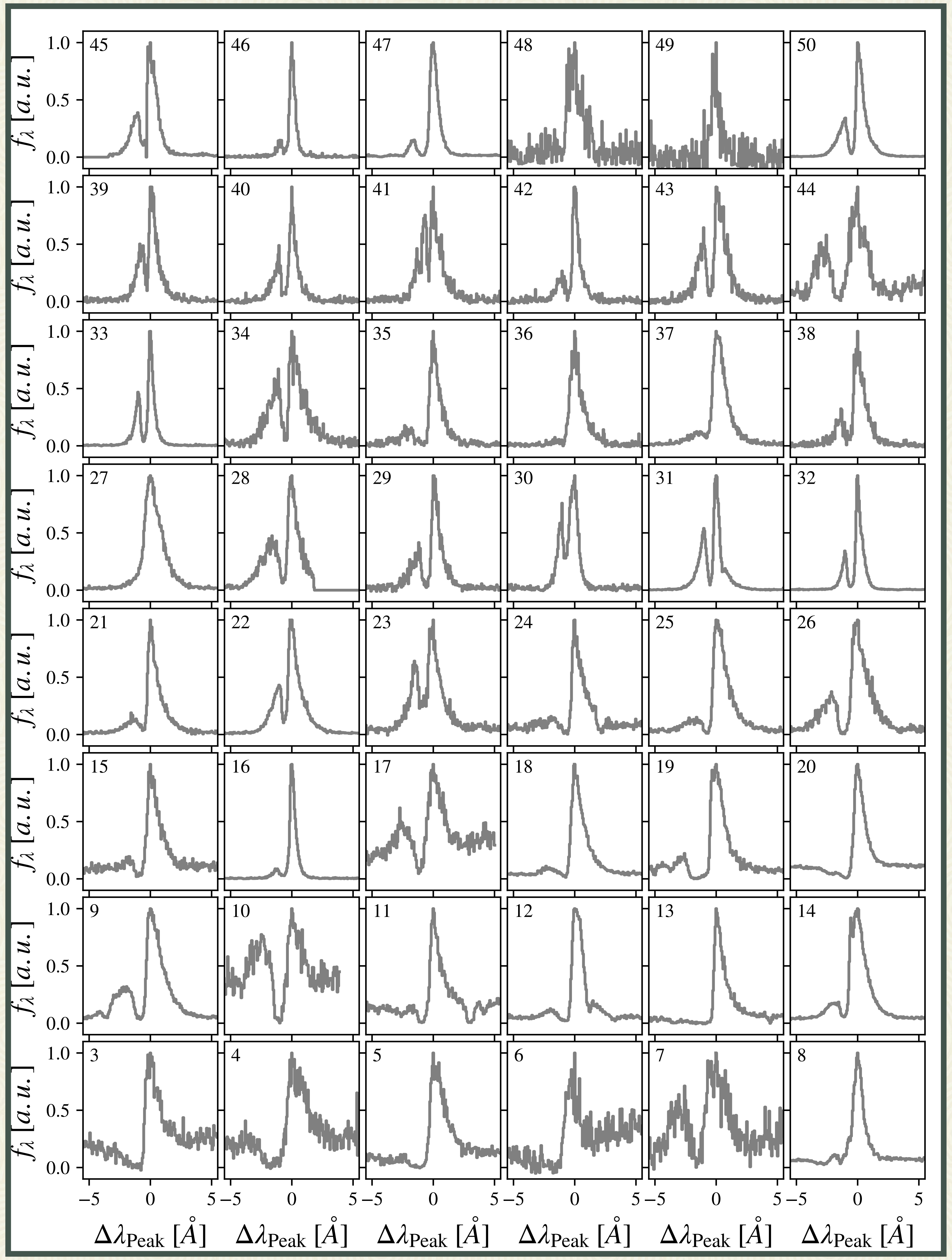
Lyα as an astrophysical tool

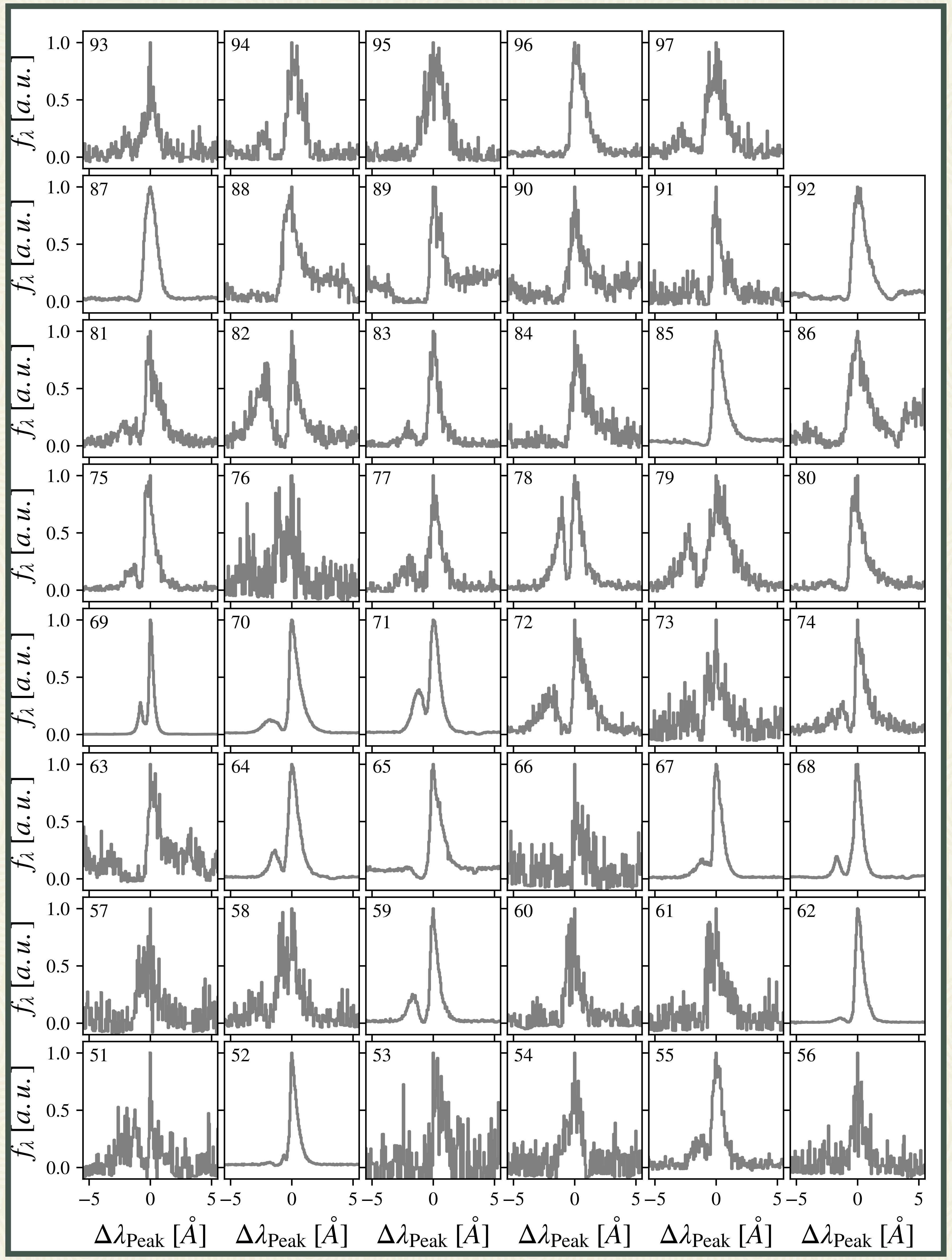
LYMAN ALPHA SPECTRAL DATABASE

http://lasd.lyman-alpha.com

Runnholm et al.+20

97 Lyα line profiles obtained by the
Cosmic Origins Spectrograph on HST
GO 11522 and 12027 (PI: Green, Salzer et al. 2001)
GO 11727 and 13017 (PI: Heckman et al. 2011,2015)
GO 12269 (PI: Scarlata, Songaila et al. 2018)
GO 12583 (PI:Hayes, Hayes et al. 2014)
GO 12928 (PI:Henry, Henry et al. 2015),
GO 13293 and 14080 (PI: Jaskot, Jaskot &Oey 2014)
GO 14201 (PI: Malhotra, Yang et al.2017)
GO 13744 (PI: Thuan Izotov et al. 2016, 2018)





Lyα as an astrophysical tool

$Q(KS=0.1)$, $z\in[0.0,6.0]$

f_{esc}	S/N$_p$	W_g 0.1Å	W_g 0.25Å	W_g 0.5Å	W_g 1.0Å	W_g 2.0Å	W_g 4.0Å
[0.95, 1.0]	15.0	94	94	93	93	88	78
	10.0	94	94	91	88	82	69
	7.5	94	92	89	84	75	63
	5.0	90	85	77	66	57	53
[0.8, 0.95]	15.0	93	94	92	90	86	80
	10.0	94	91	91	88	83	71
	7.5	93	91	88	84	76	64
	5.0	88	86	77	68	59	54
[0.65, 0.8]	15.0	90	89	90	86	82	77
	10.0	90	88	87	84	81	76
	7.5	88	85	84	81	76	68
	5.0	86	84	78	73	65	63
[0.5, 0.65]	15.0	88	89	87	82	78	79
	10.0	88	86	84	80	77	76
	7.5	87	85	83	81	76	72
	5.0	85	80	78	73	70	64
[0.35, 0.5]	15.0	84	83	83	78	73	73
	10.0	85	81	79	78	70	69
	7.5	81	81	79	75	69	68
	5.0	81	74	73	68	65	61
[0.2, 0.35]	15.0	71	68	67	61	65	60
	10.0	67	67	62	64	61	56
	7.5	72	63	65	58	57	58
	5.0	64	60	58	62	51	55

$Q(KS=0.1)$, $z\in[0.0,6.0]$

f_{esc}	S/N$_p$	W_g 0.1Å	W_g 0.25Å	W_g 0.5Å	W_g 1.0Å	W_g 2.0Å	W_g 4.0Å
[0.95, 1.0]	15.0	96	95	96	95	90	78
	10.0	94	95	94	92	83	69
	7.5	95	94	92	88	77	62
	5.0	93	88	80	70	57	49
[0.8, 0.95]	15.0	97	97	96	95	90	80
	10.0	96	95	95	92	85	73
	7.5	96	94	93	89	79	65
	5.0	92	88	81	72	60	52
[0.65, 0.8]	15.0	95	95	95	90	86	80
	10.0	94	94	93	88	84	77
	7.5	93	92	90	86	81	70
	5.0	89	87	82	77	68	61
[0.5, 0.65]	15.0	94	95	92	87	83	80
	10.0	94	93	91	85	81	78
	7.5	93	91	89	84	80	72
	5.0	90	86	83	79	73	65
[0.35, 0.5]	15.0	90	92	86	81	76	77
	10.0	90	87	82	79	72	72
	7.5	84	86	82	77	73	70
	5.0	80	78	79	75	72	67
[0.2, 0.35]	15.0	72	68	66	60	62	62
	10.0	68	65	65	61	64	59
	7.5	70	63	65	60	62	59
	5.0	61	62	60	65	57	59

$Q(KS=0.1)$, $z\in[0.0,6.0]$

f_{esc}	S/N$_p$	W_g 0.1Å	W_g 0.25Å	W_g 0.5Å	W_g 1.0Å	W_g 2.0Å	W_g 4.0Å
[0.95, 1.0]	15.0	98	98	98	97	95	92
	10.0	98	98	97	96	93	86
	7.5	98	96	96	93	87	81
	5.0	94	93	86	80	73	67
[0.8, 0.95]	15.0	85	86	84	83	80	79
	10.0	85	84	83	81	79	75
	7.5	83	85	82	79	76	70
	5.0	82	81	77	71	68	65
[0.65, 0.8]	15.0	62	66	62	62	58	54
	10.0	61	65	63	60	55	57
	7.5	62	63	64	61	59	55
	5.0	62	63	65	63	59	56
[0.5, 0.65]	15.0	50	51	48	41	38	38
	10.0	49	48	48	43	39	39
	7.5	50	49	47	46	39	42
	5.0	50	52	51	50	50	48
[0.35, 0.5]	15.0	32	36	32	26	24	23
	10.0	34	34	33	28	23	26
	7.5	35	38	36	33	30	33
	5.0	41	41	45	39	41	41
[0.2, 0.35]	15.0	29	26	24	14	20	18
	10.0	28	23	24	23	20	19
	7.5	32	30	25	26	22	25
	5.0	33	32	30	35	31	38