LyAl-Net: A high-efficiency Lyman-α forest simulation with neural network

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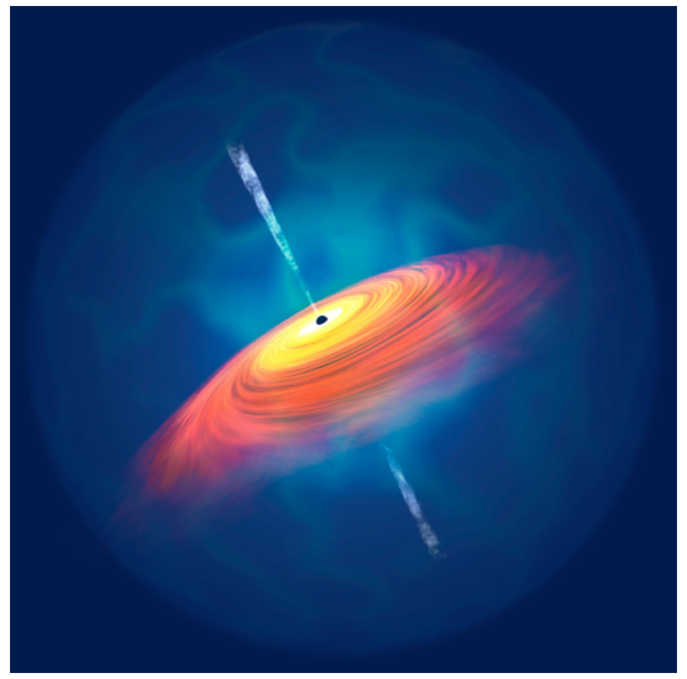
Boonkongkird et al. 2022 (work is still in progress)

What is Lyman-Alpha Forest?

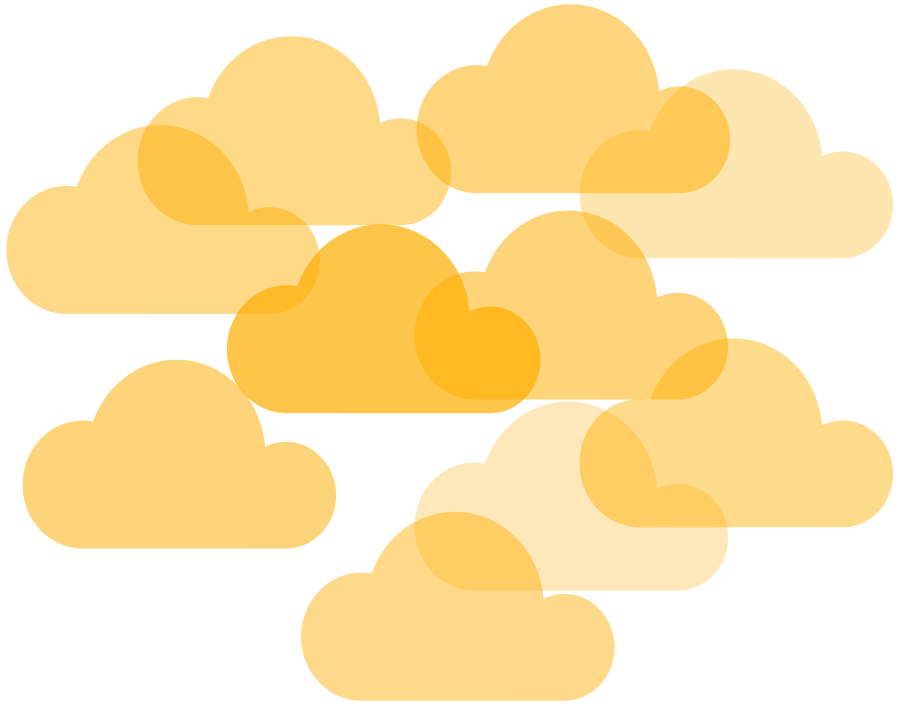


QSO

UV Photons

Redshifted

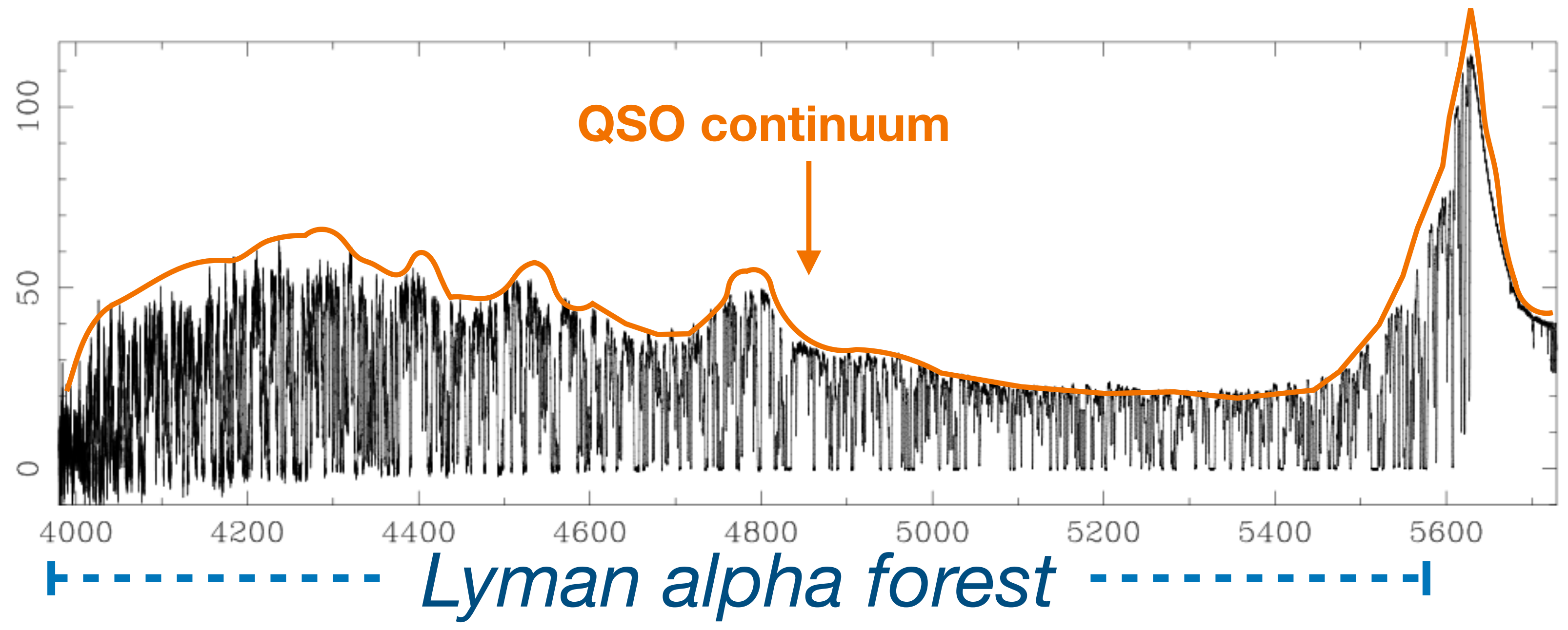
Lyman Alpha Absorption



Neutral Hydrogen clouds

Absorption Features

Redshifted



Observed QSO Spectra

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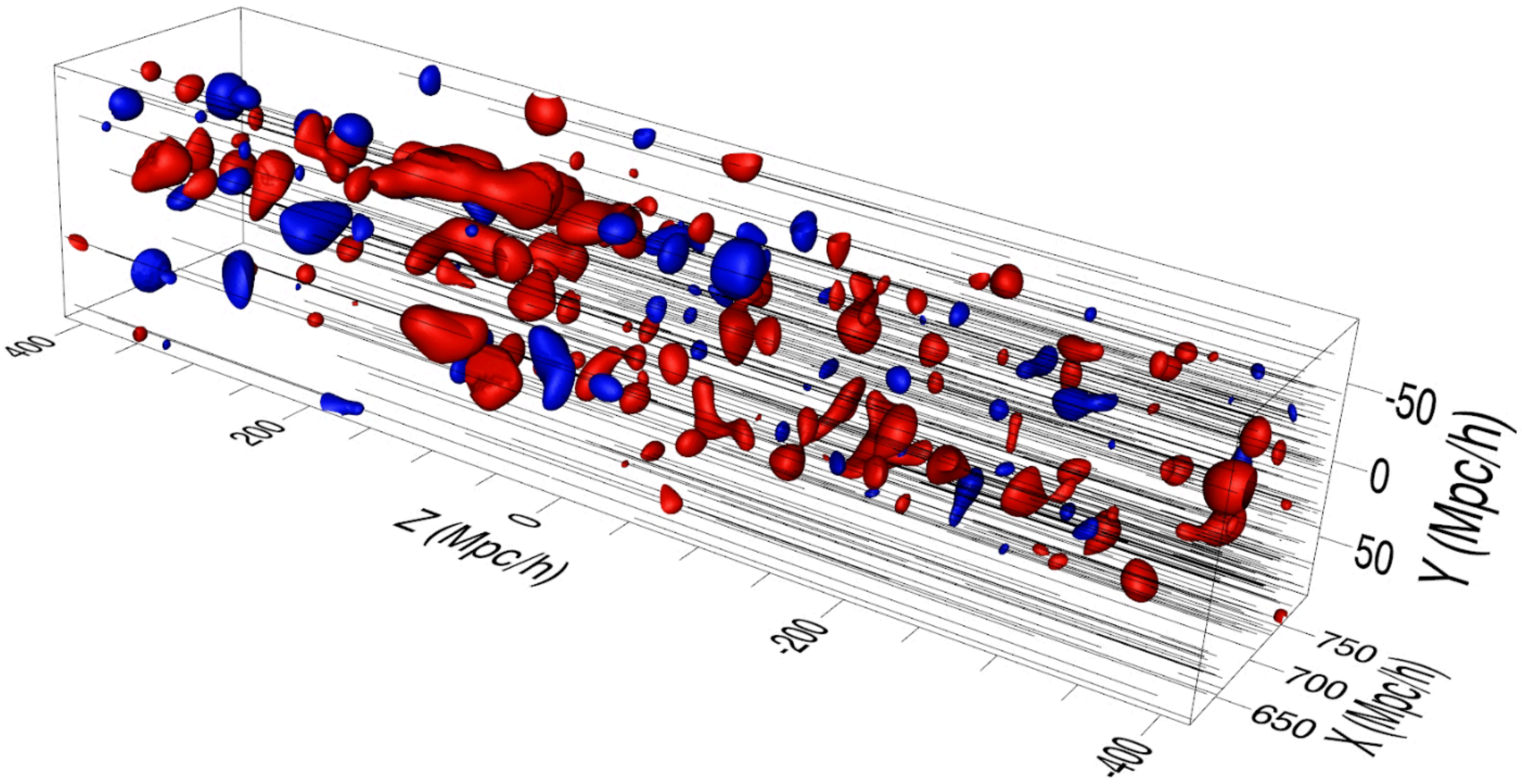
Overview

Motivations

- Matter overdensities map
  (Ravoux et al. 2020)
- Neutrino masses
  (Palanque-Delabrouille et al. 2019)
- Forward Modelling
  (Porqueres et al. 2020)



Matter overdensities from eBOSS

A tomographic map of the large-scale matter distribution using the eBOSS Stripe 82 Ly-α forest (Ravoux et al. 2020)

Boonkongkird et al. 2022 (work is still in progress)

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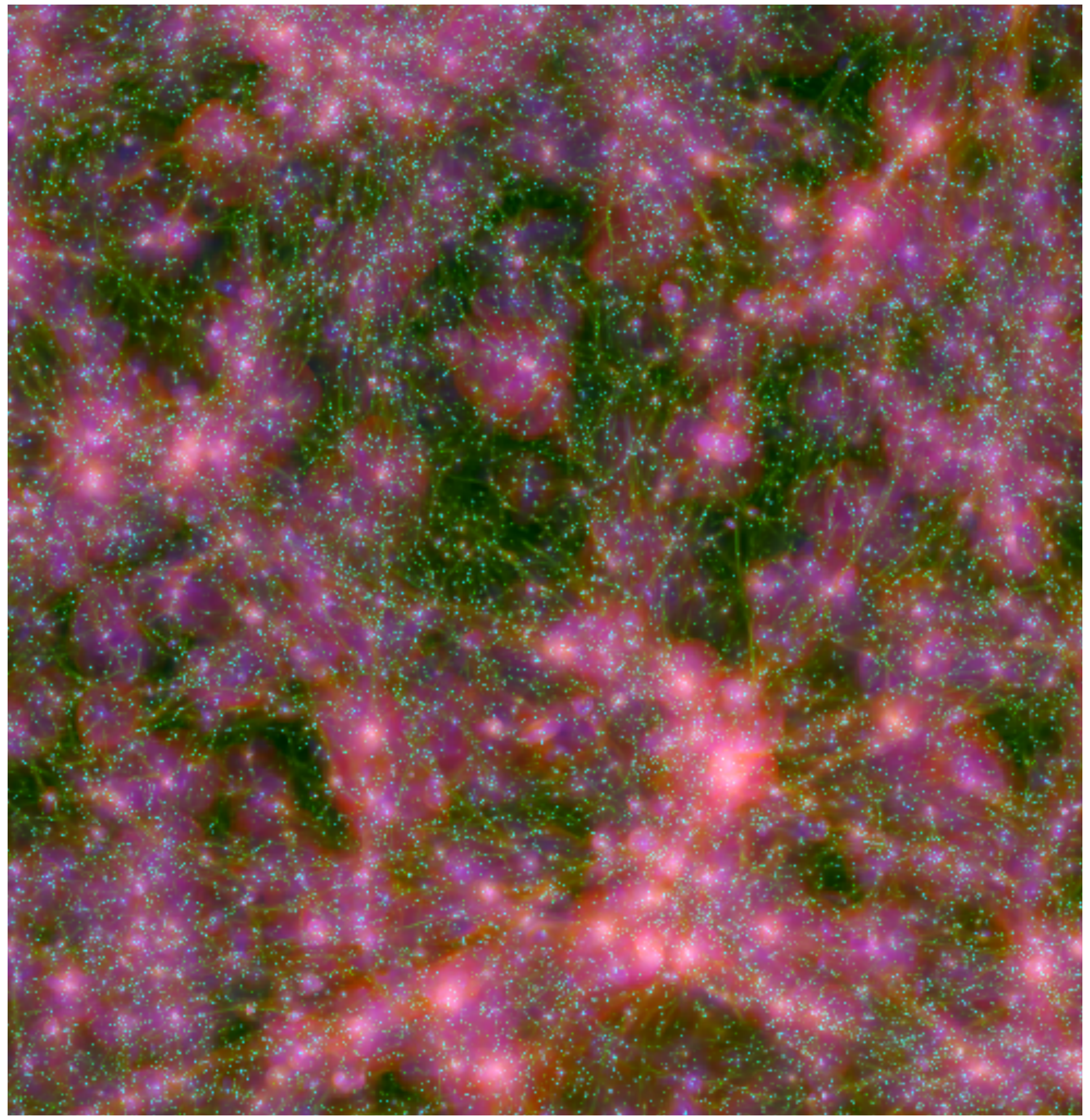
Problems

- Extremely expensive N-body simulation
- The volume of Hydrodynamic simulations limited by the computational costs
- Horizon simulation takes *millions of CPU hours*
- *Tons of mocks needed*



Horizon AGN Simulation

Dancing in the dark: galactic properties trace spin swings along the cosmic web *(Dubois et al. 2014)*

Boonkongkird et al. 2022 (work is still in progress)

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Possible Solution

- Using a *Neural Network* as an emulator
- Cheaper, faster, can be run on a small machine

Challenges

- Architecture choice, *U-net*
- Feature engineering
- Physical Interpretability
- Model generalisation for other gas physics

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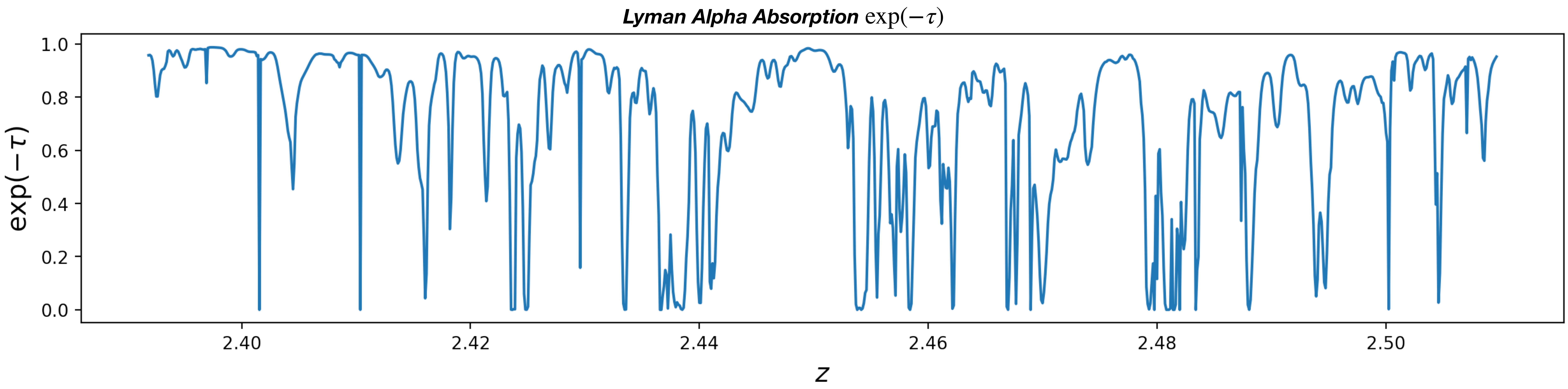
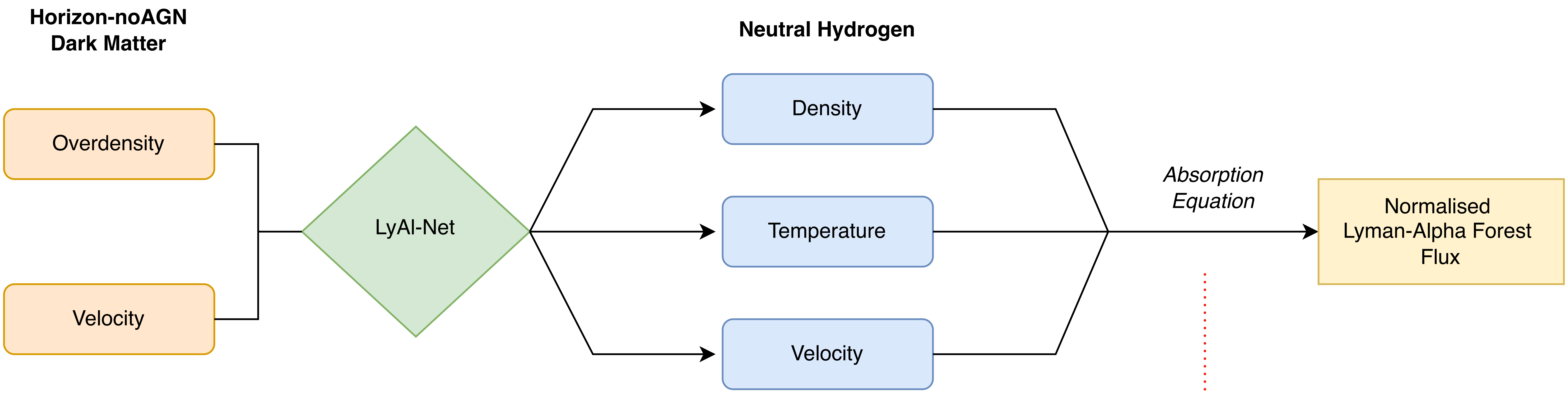
Objective

Simulate the Lyman Alpha Absorption from **Dark Matter density & velocity**



LyAl-Net

Methodology Overview



$$\tau(\nu_{obs}) = \int_0^l n_{HI}\sigma(\nu_{obs})dl$$

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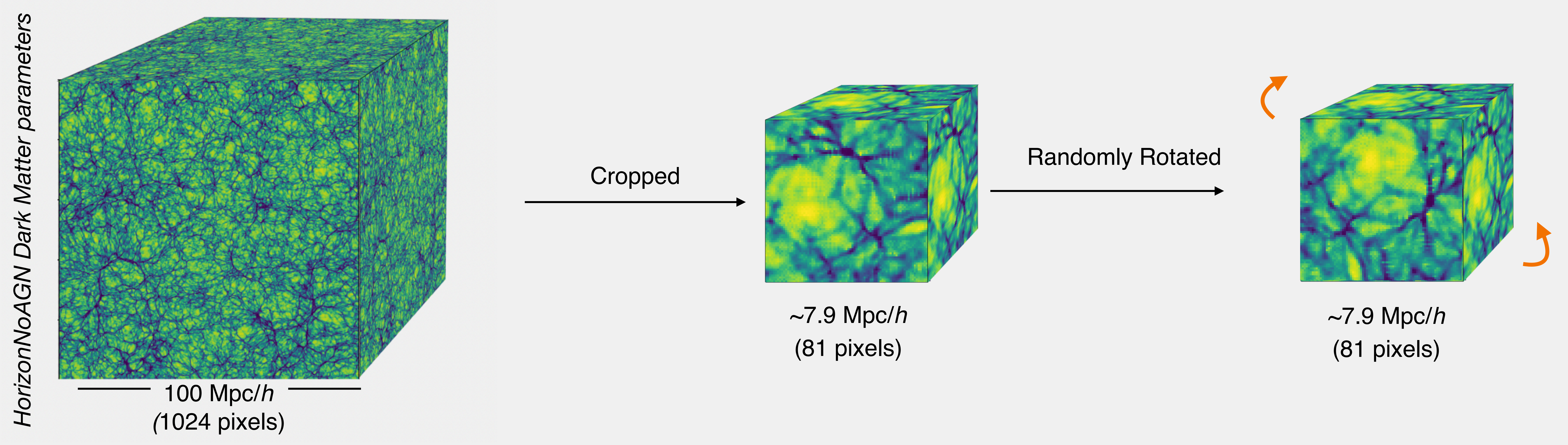
LyAI-Net
Data Pre-Processing



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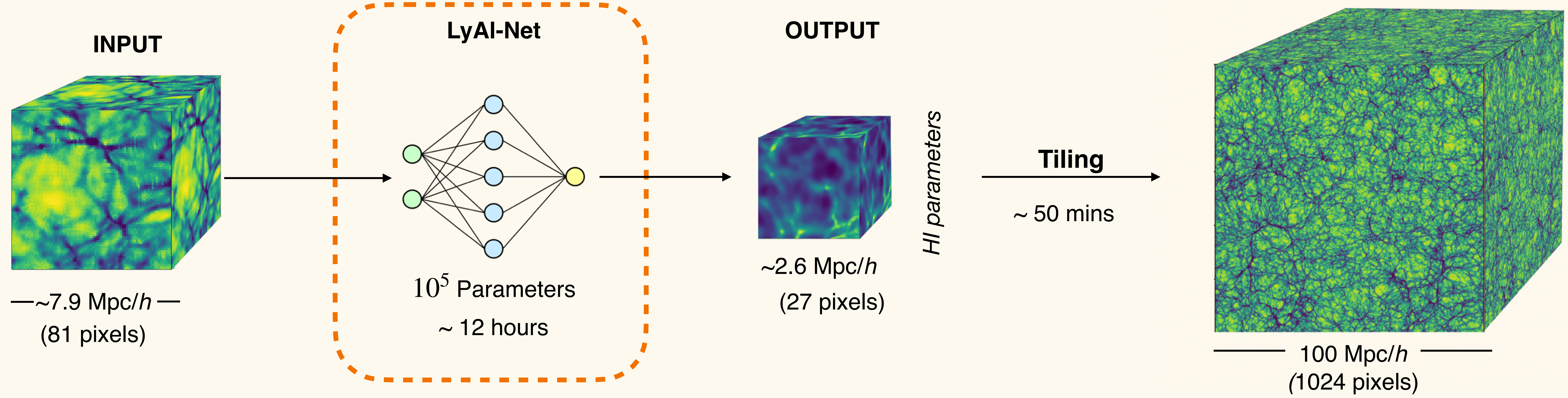
LyAl-Net
Training Process



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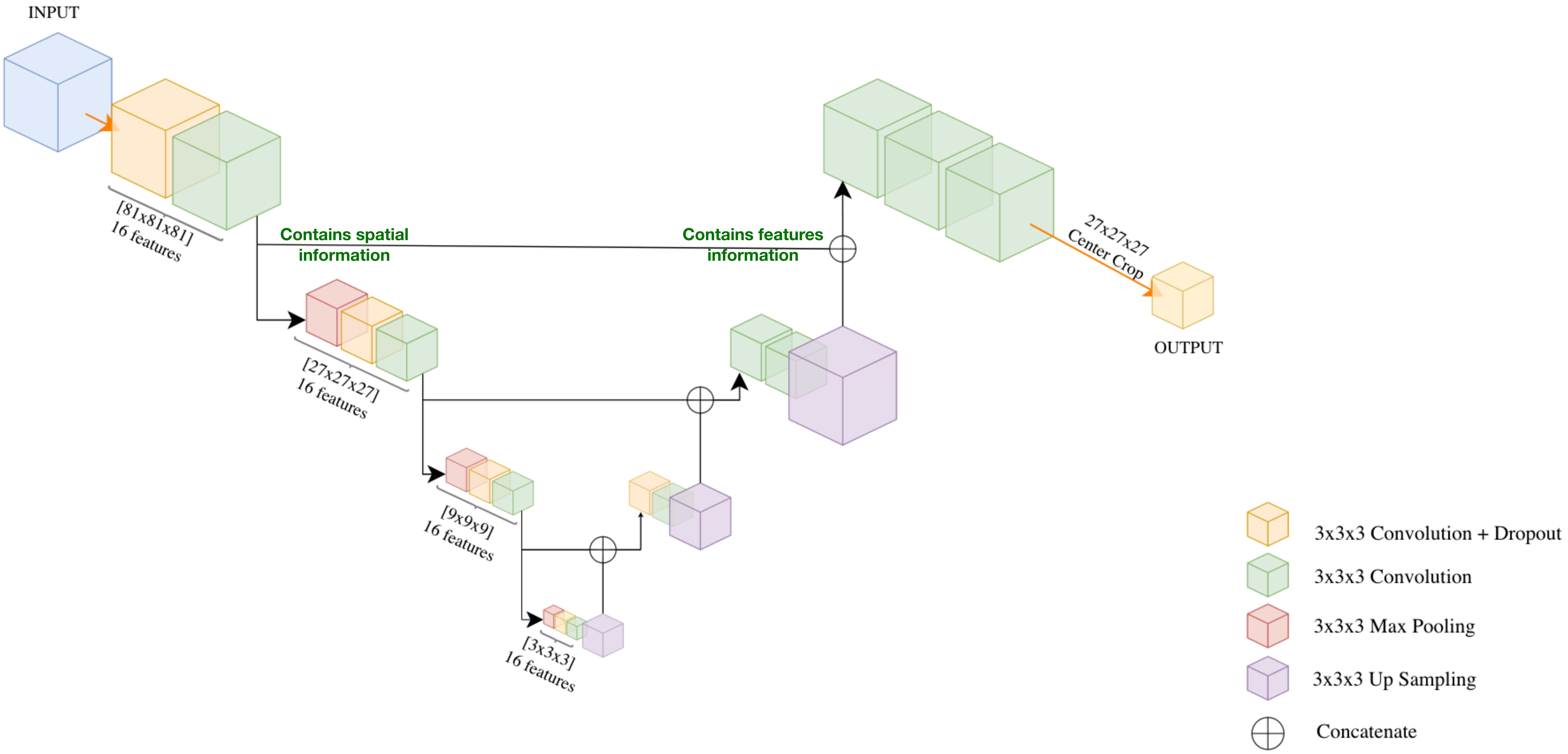
LyAI-Net

The Schematic of the LyAI-Net



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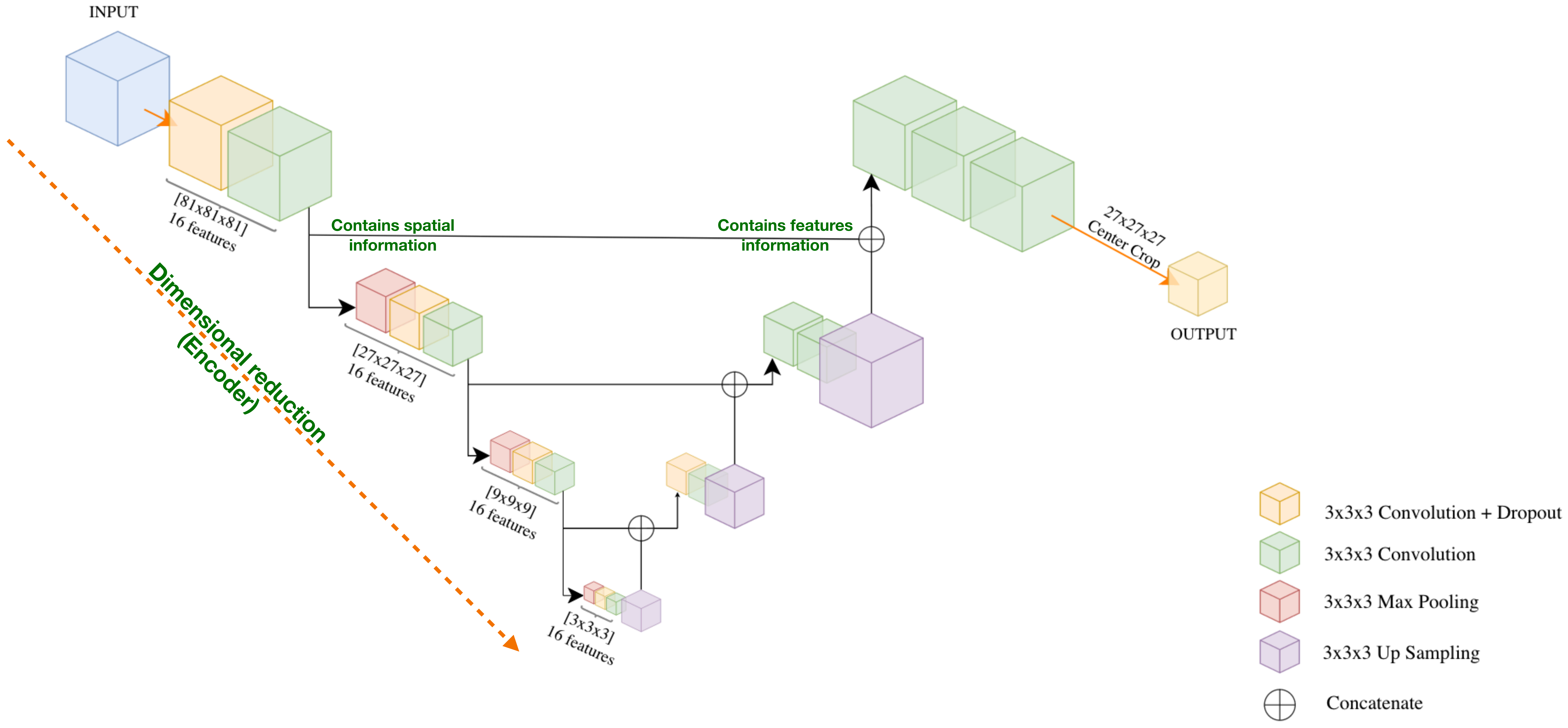

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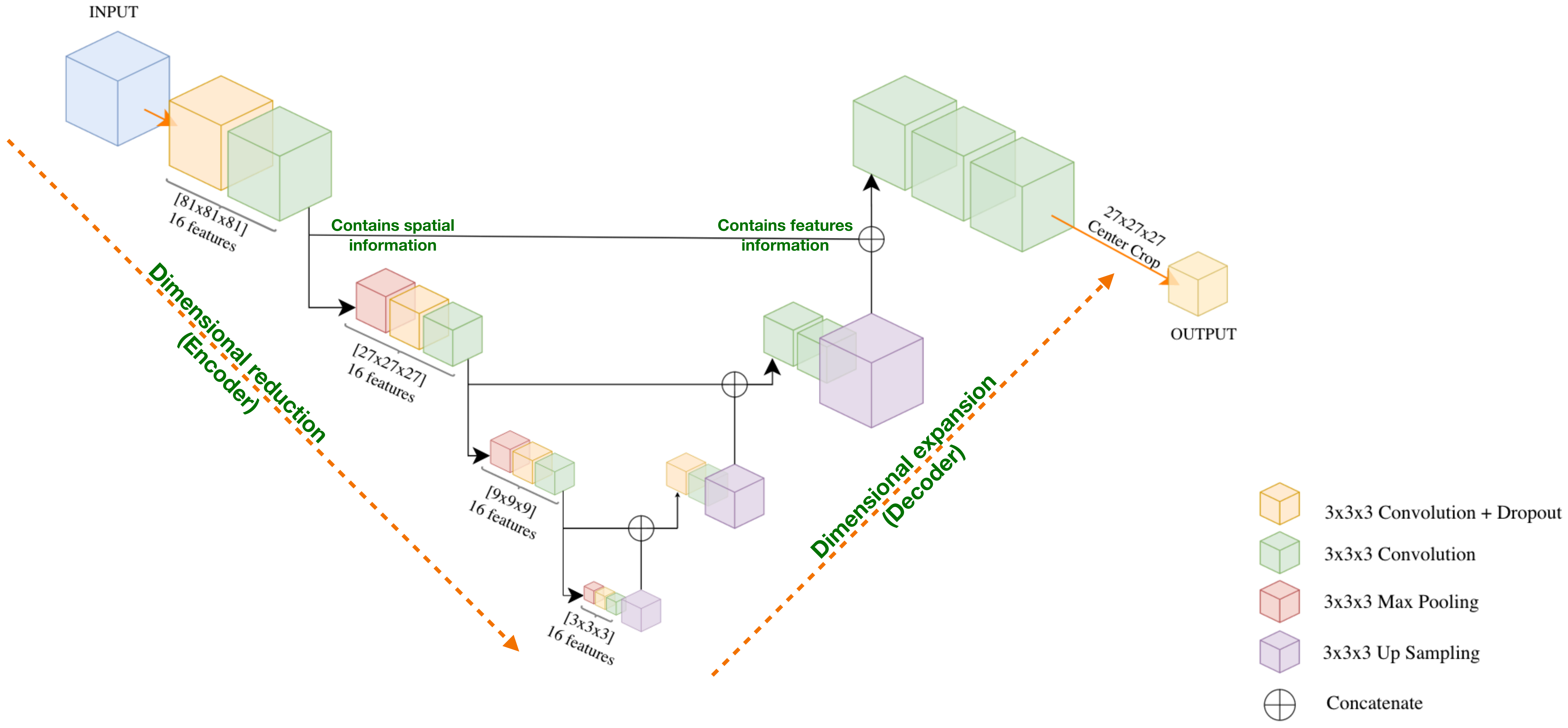

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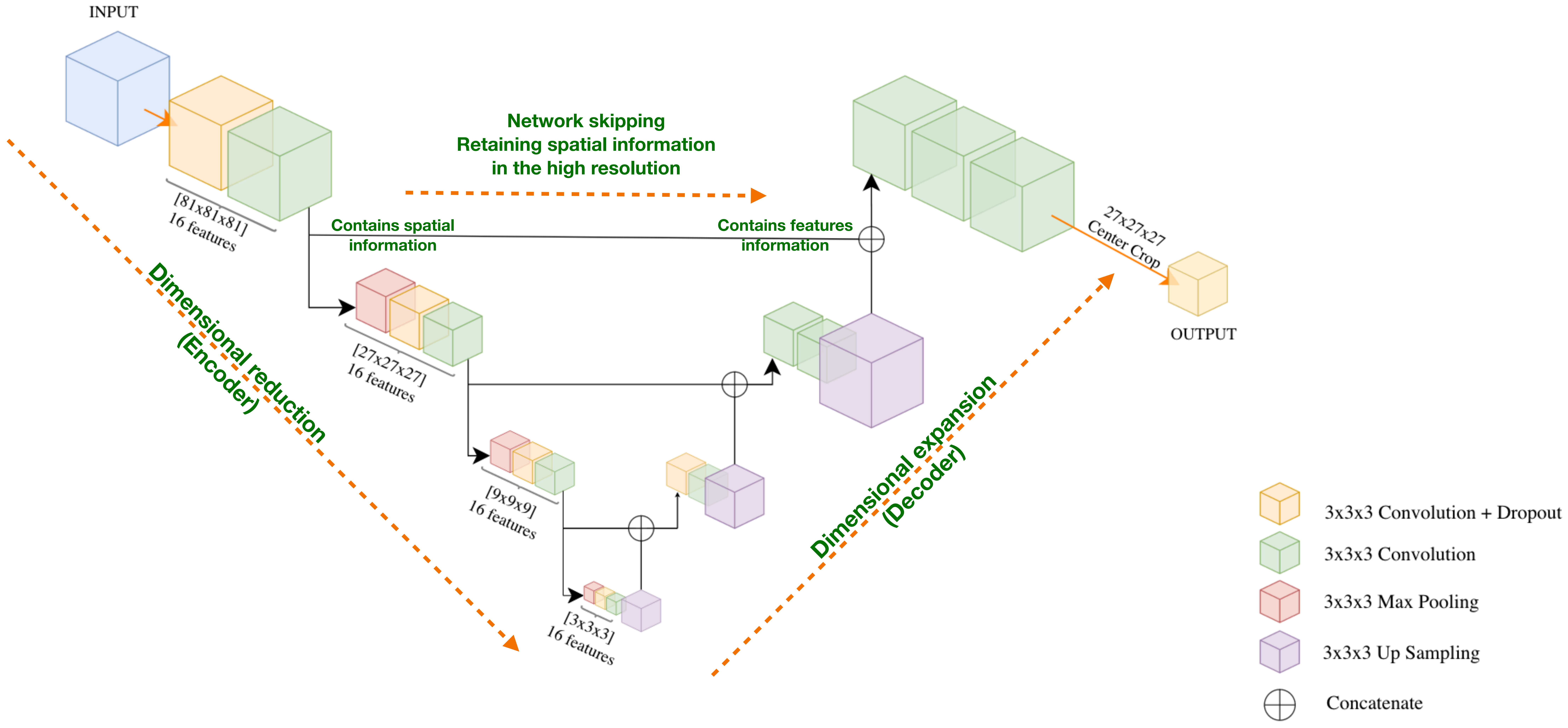

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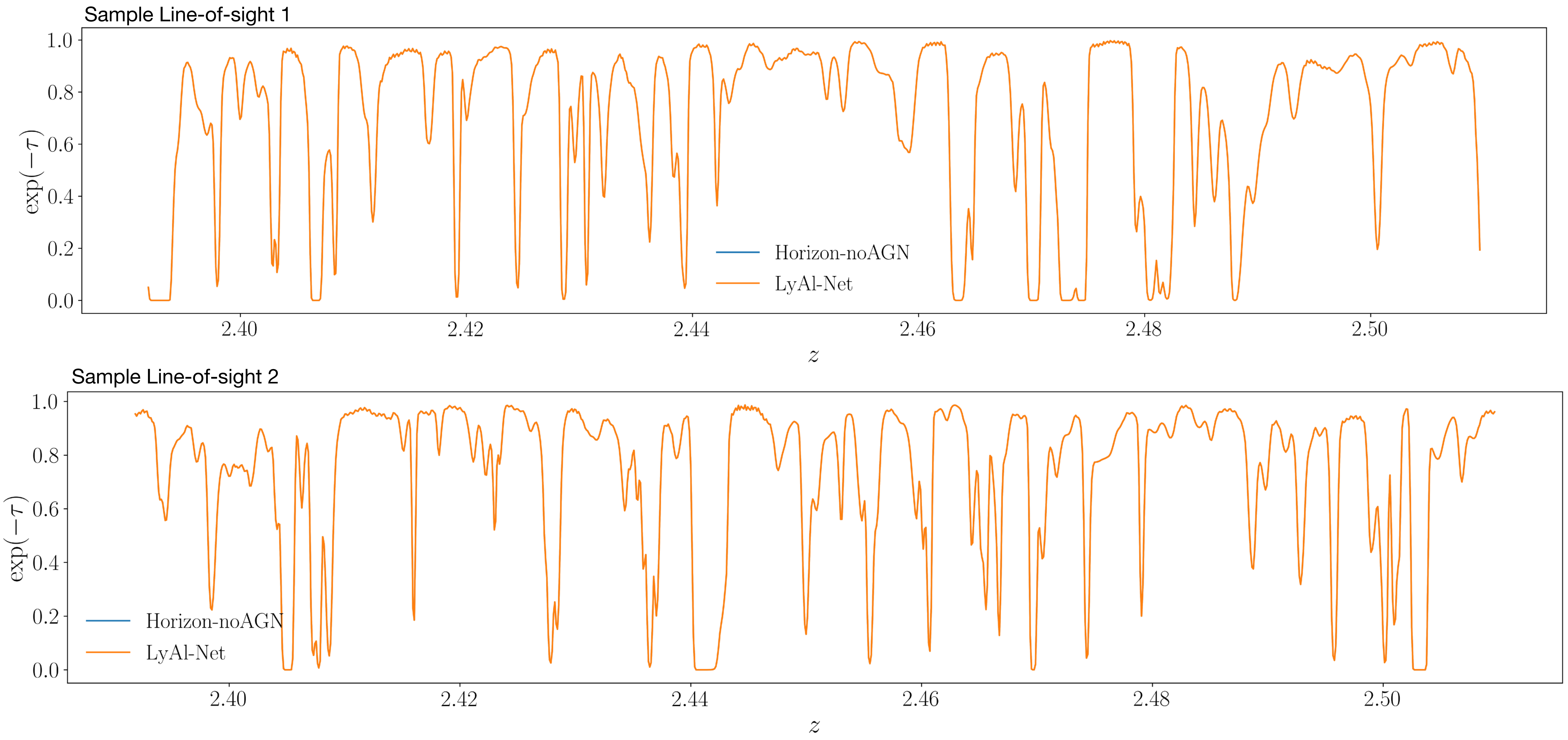
Lyman-alpha Absorption: Quality Assessment



Samples of comparison Lyman-alpha absorption of Horizon-noAGN using LyAl-Net vs ground truth

Lyman-alpha Absorption: Quality Assessment

Two-point correlation function

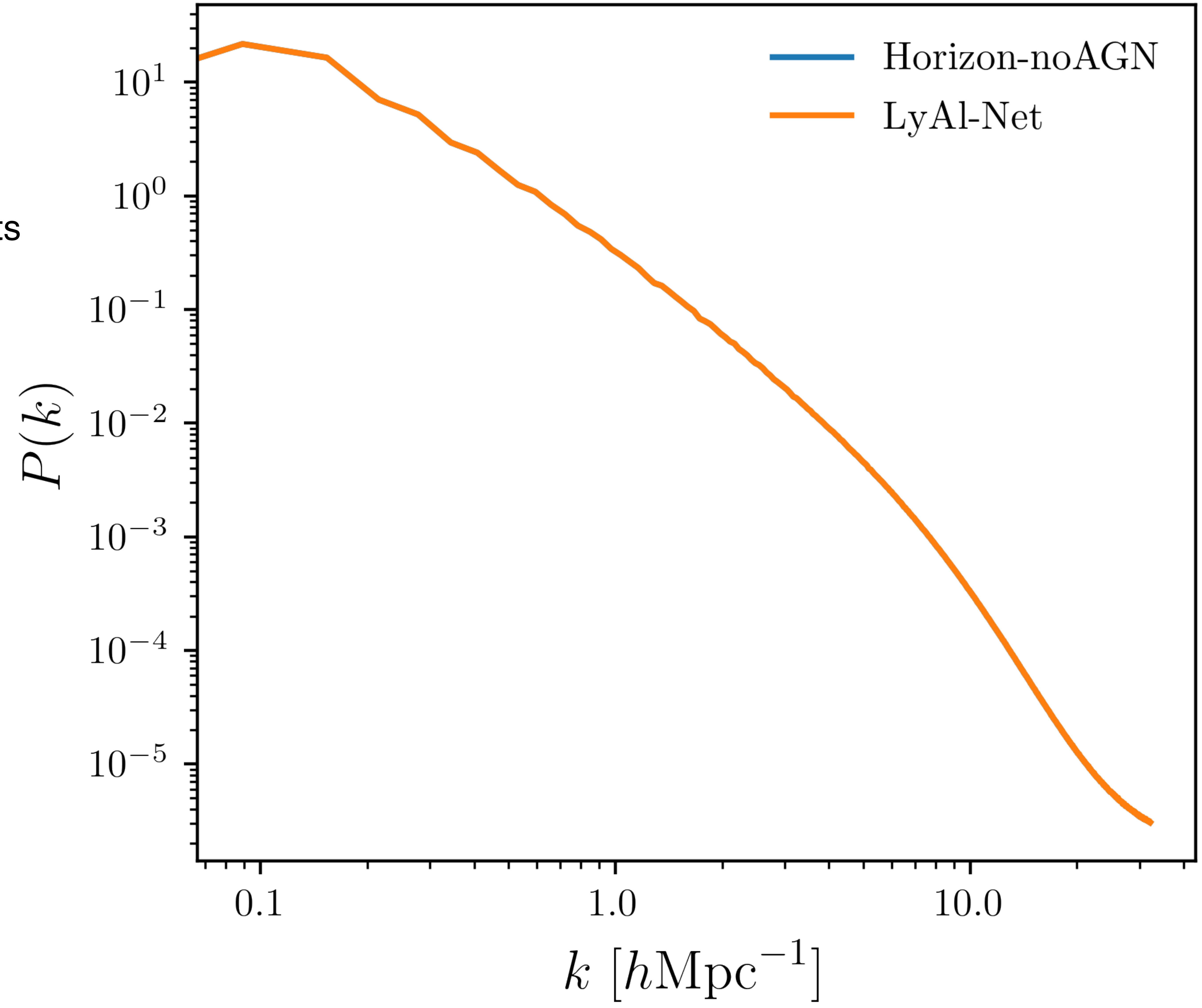
Measure the excess probability to find two point objects

$$\xi(|\mathrm{r}|) = \langle \delta_A(\mathrm{r}')\delta_B(\mathrm{r}' + \mathrm{r})\rangle$$

Power Spectrum

Two-point correlation in Fourier space

$$P(|\mathrm{k}|) = \int d^3\mathrm{r}\,\xi(r)e^{i\mathrm{k}\cdot\mathrm{r}}$$



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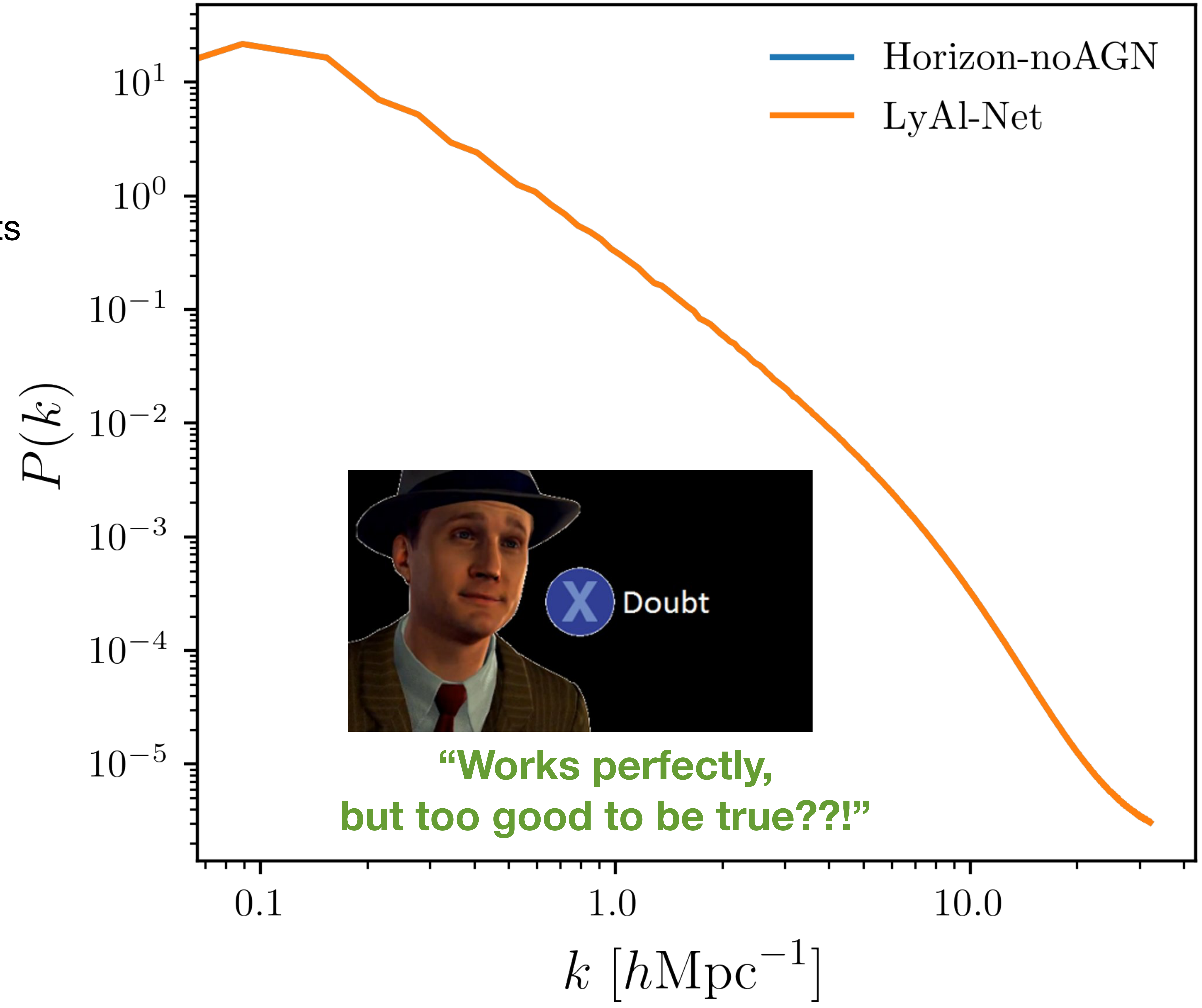

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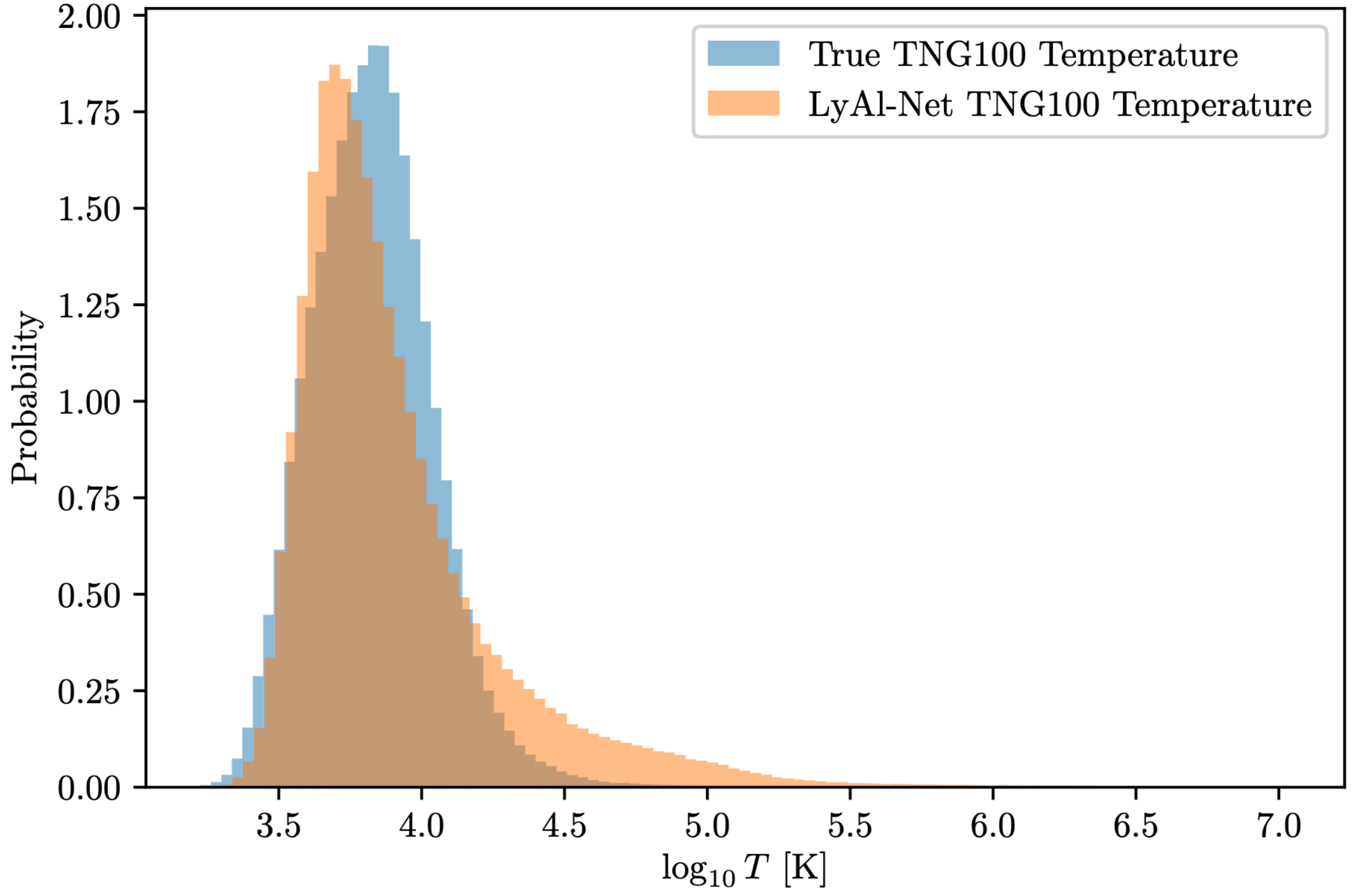
What about other simulations with different cosmology and AGN physics?

LyAl-Net with TNG100 - Naïve Application

- Agrees well in the main region of the distribution
- struggles with the high temperature
- Bias due to a different Baryonic physics; e.g.background UV, AGN feedbacks



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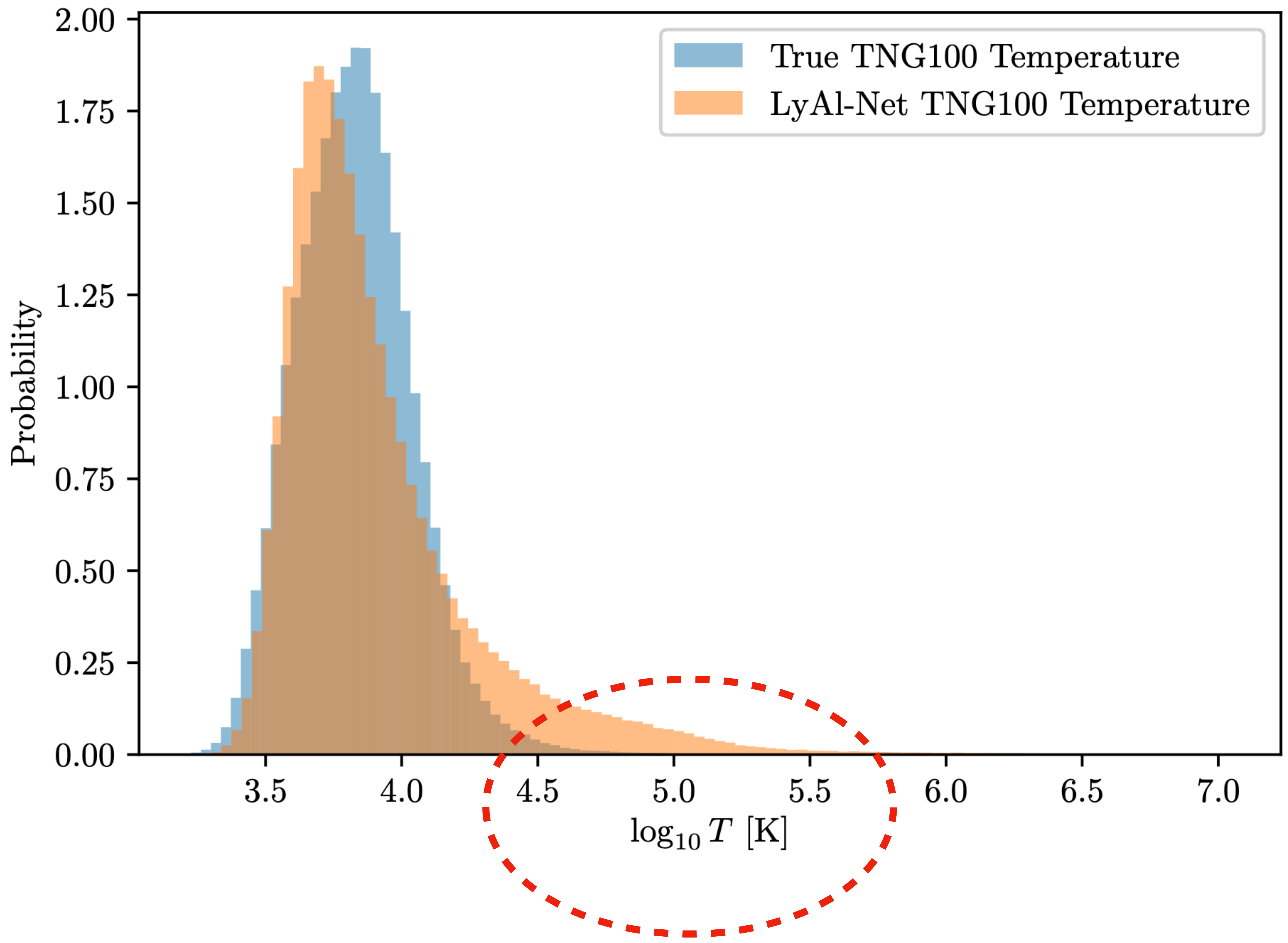

Lack of high temperature predictions

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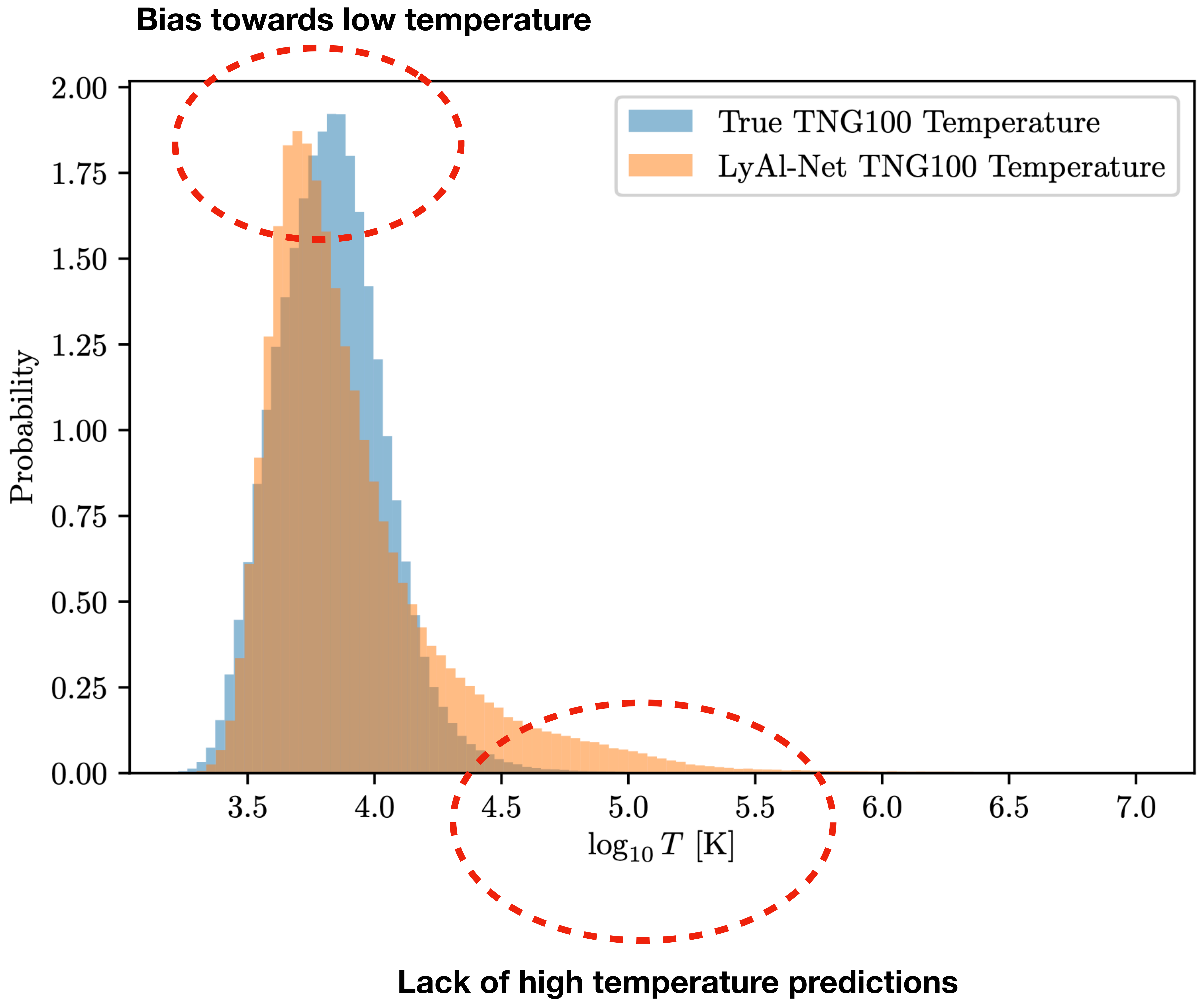

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LyAl-Net with TNG100 - Lyman-alpha Absorption

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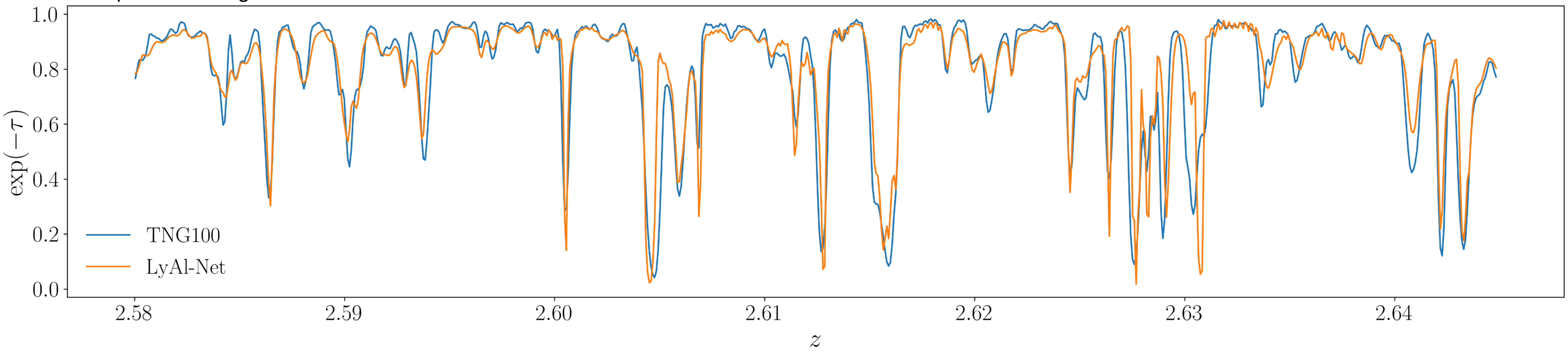
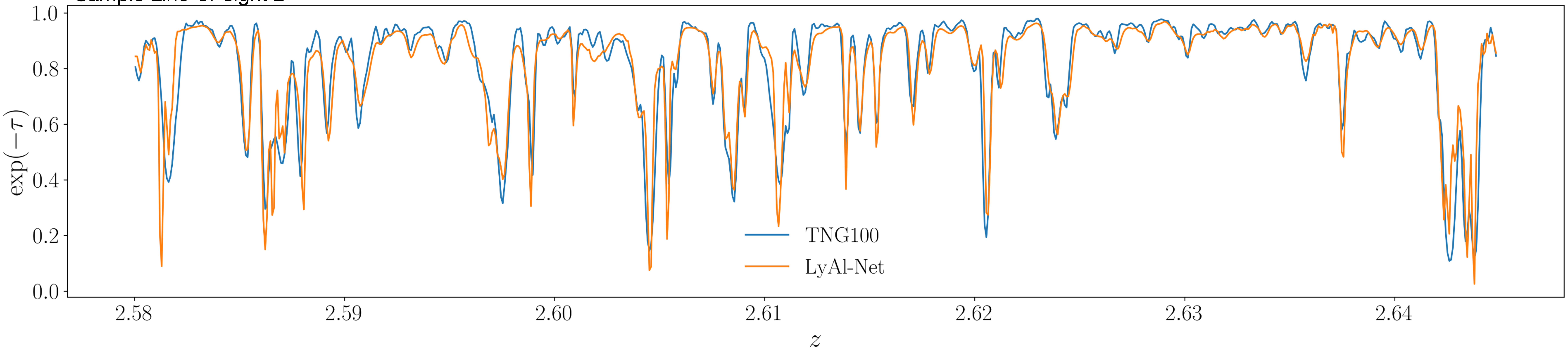
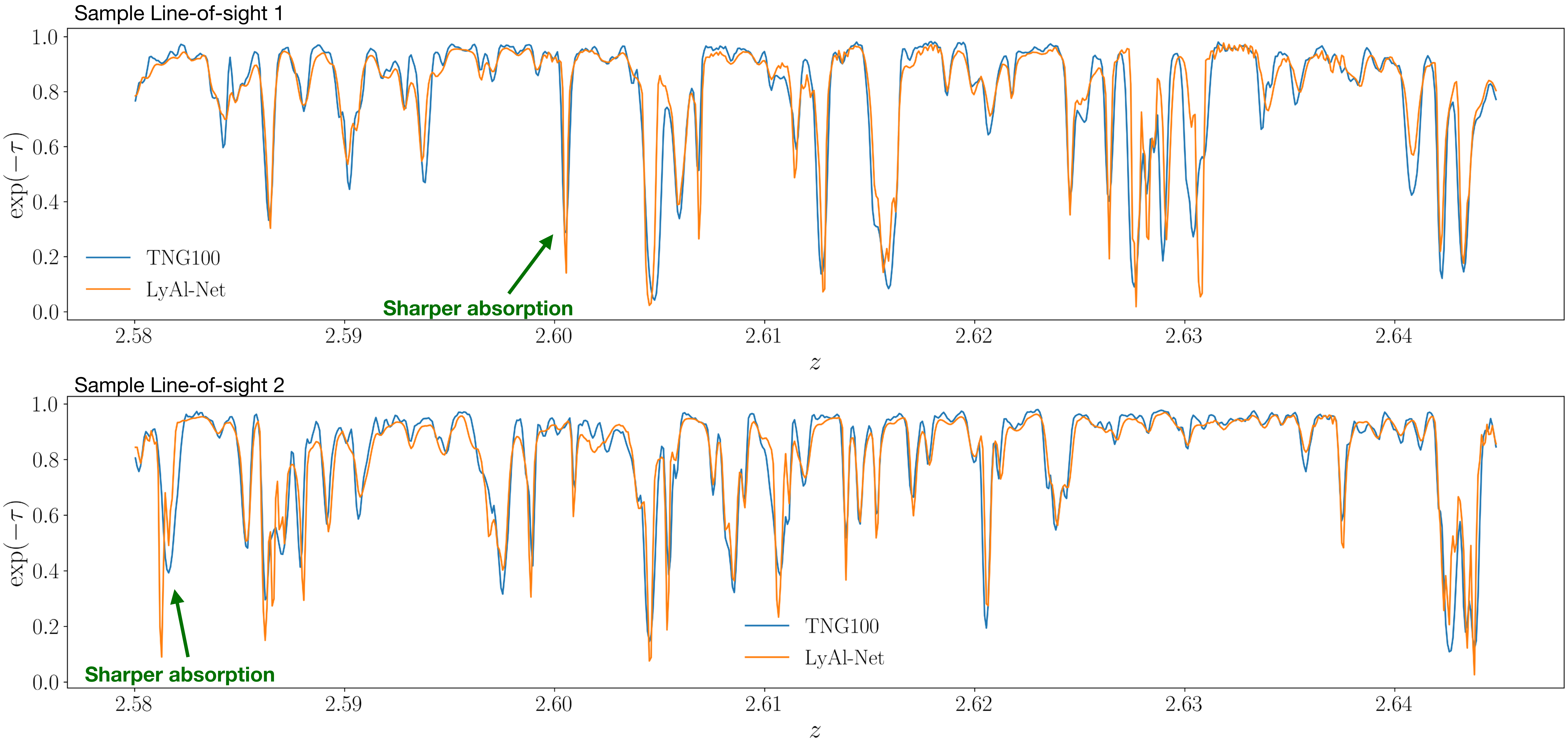


Sample Line-of-sight 2



Samples of comparison Lyman-alpha absorption of TNG100 using LyAl-Net vs ground truth

LyAl-Net with TNG100 - Lyman-alpha Absorption



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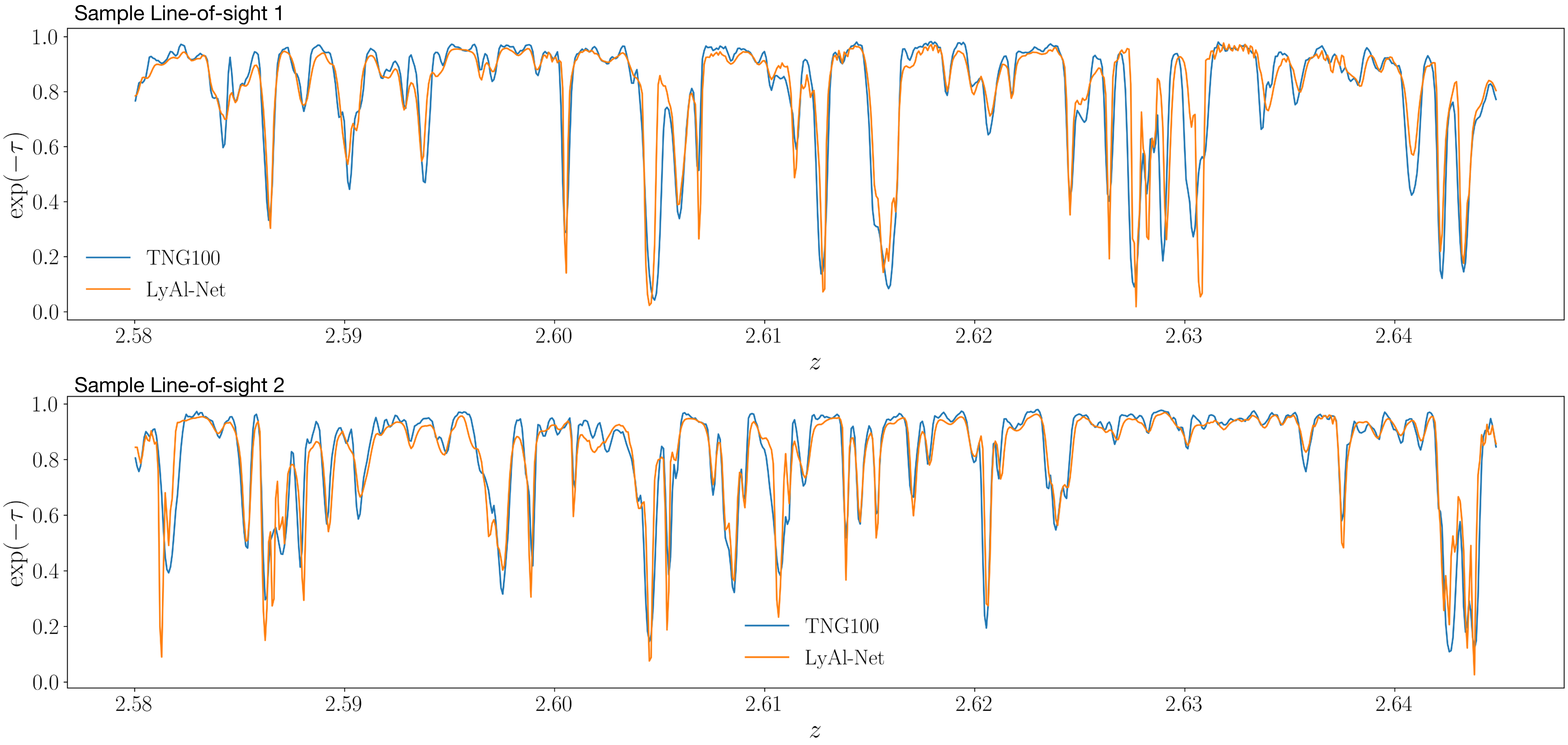

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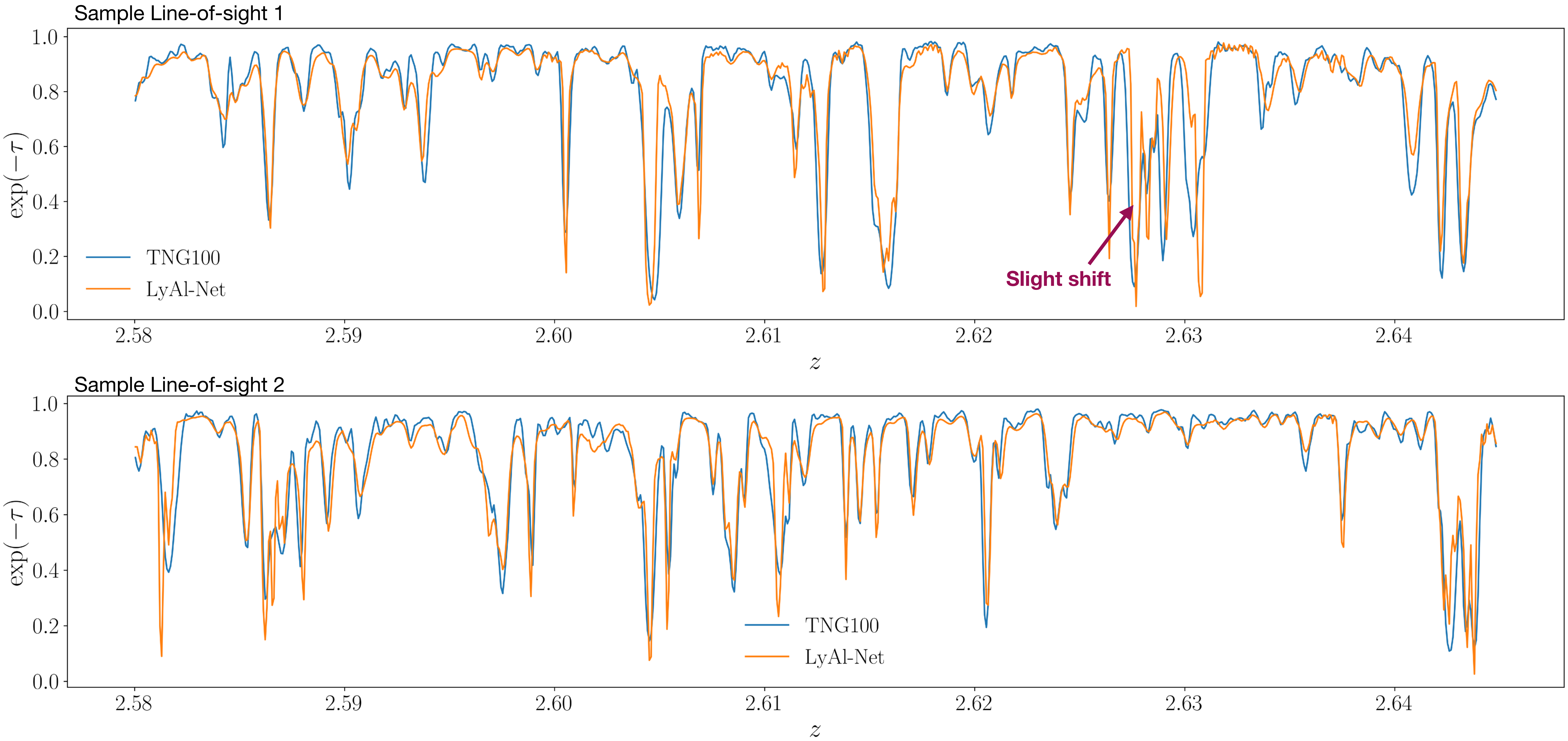

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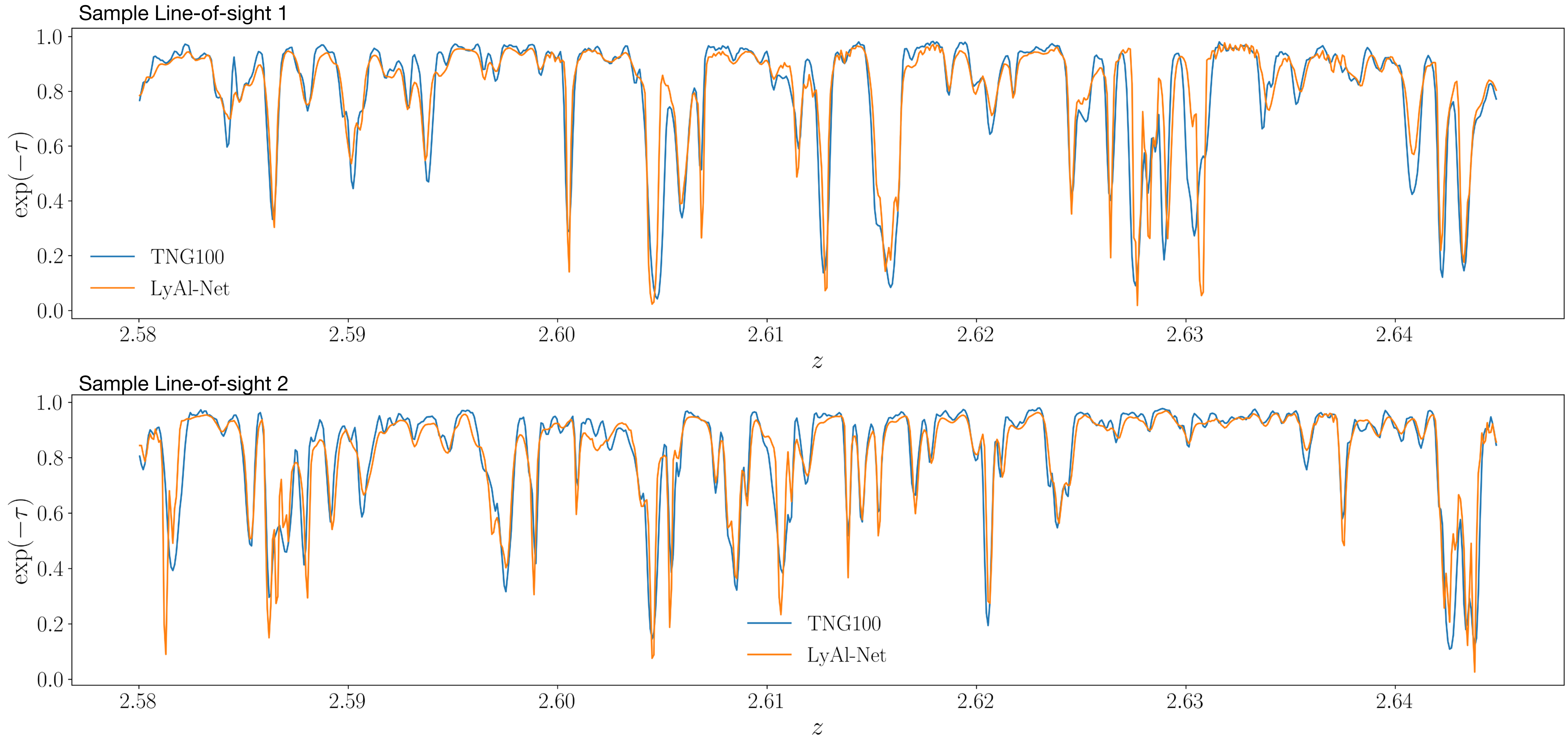

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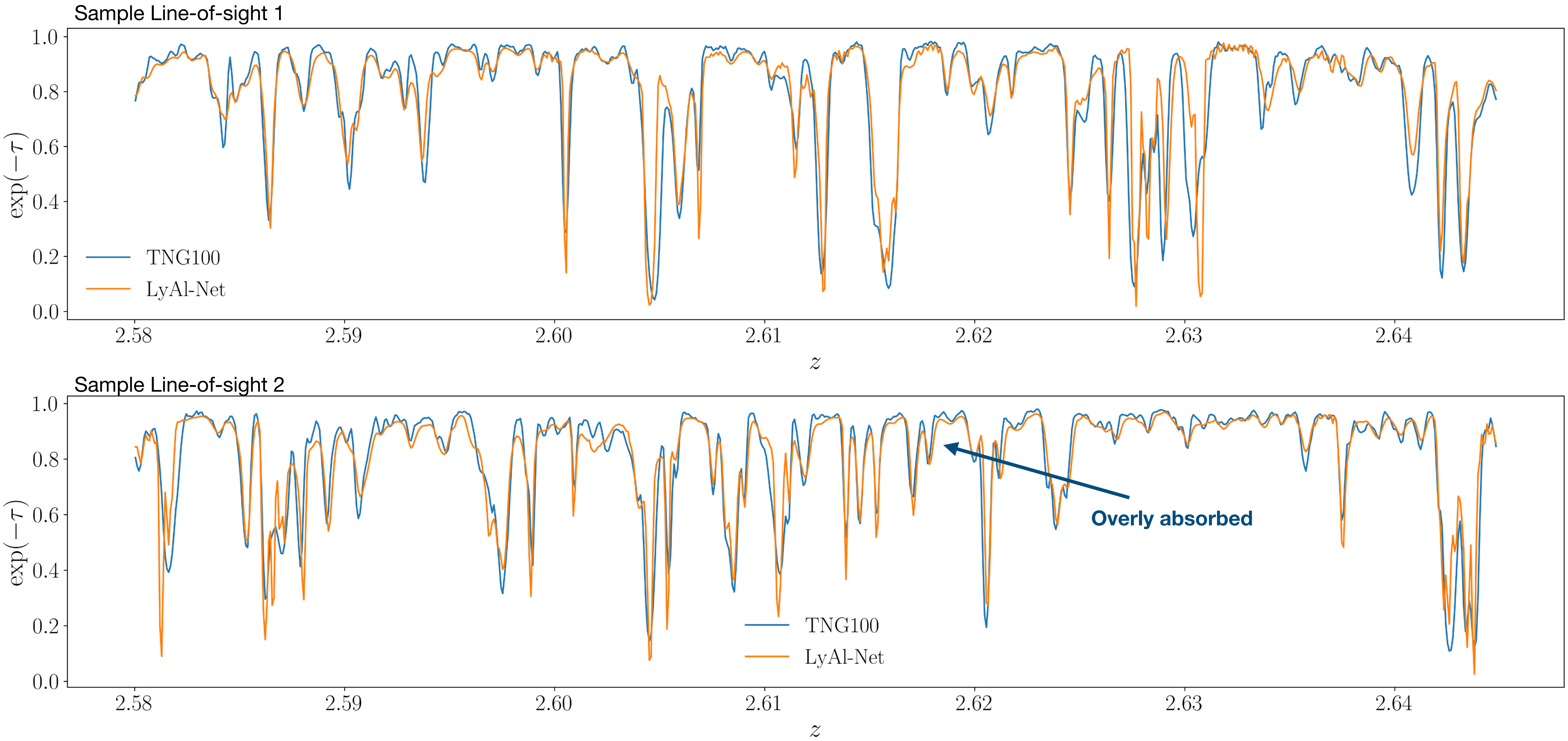

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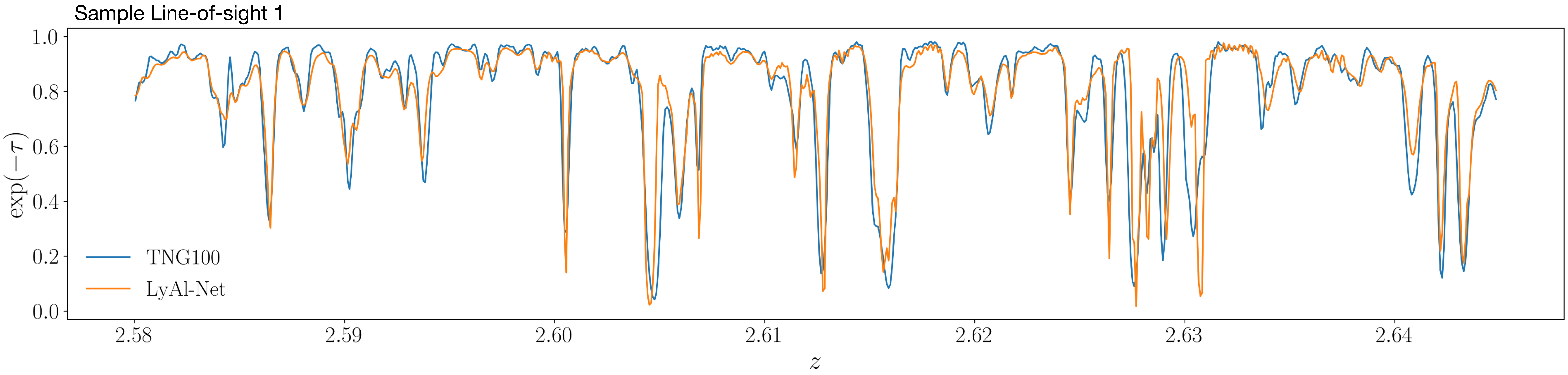

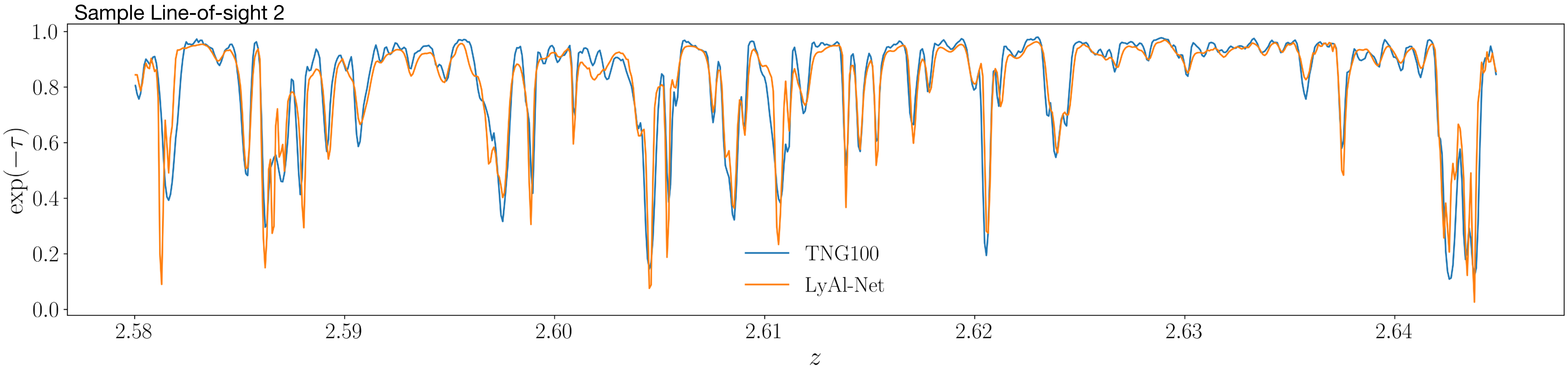

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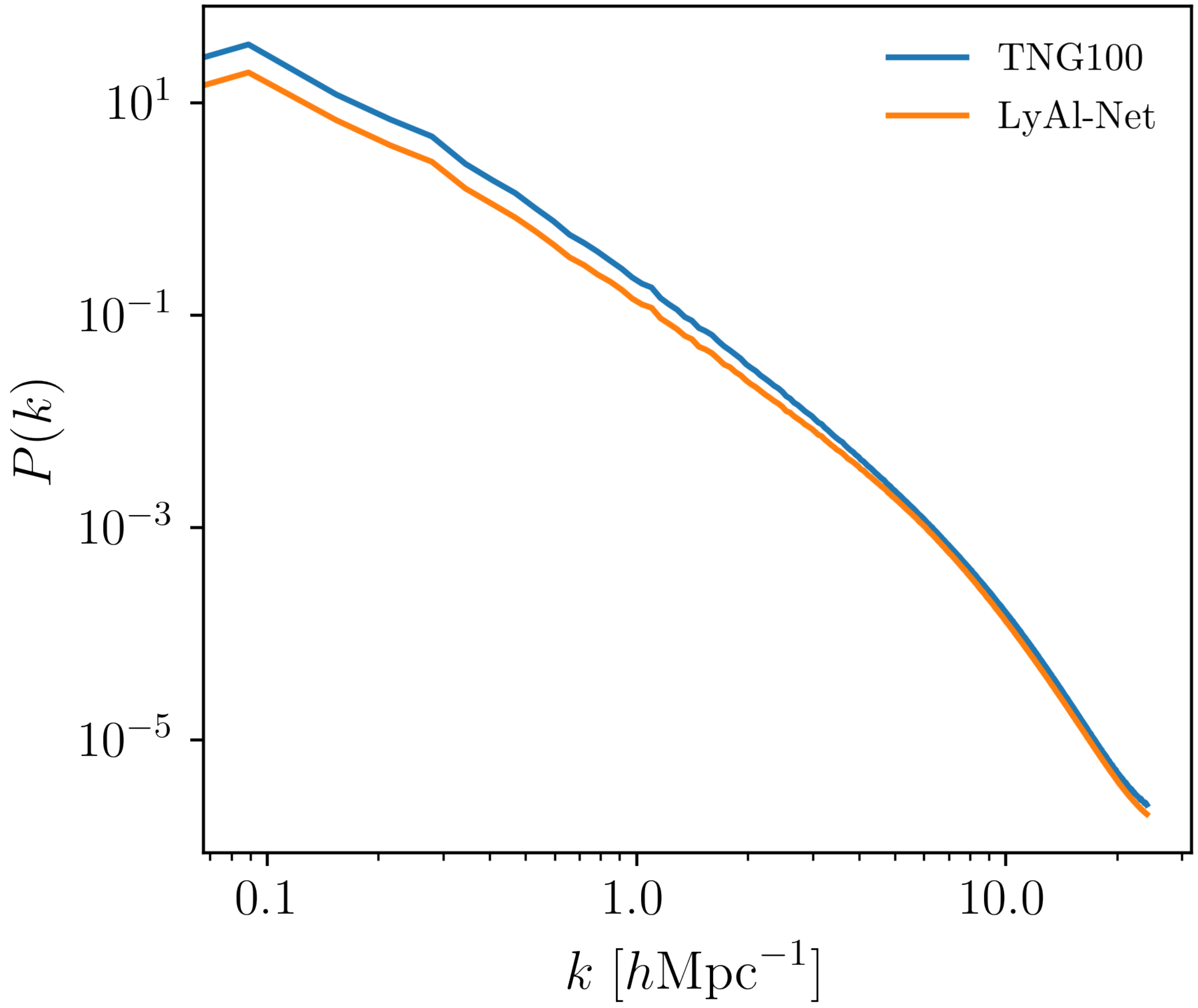

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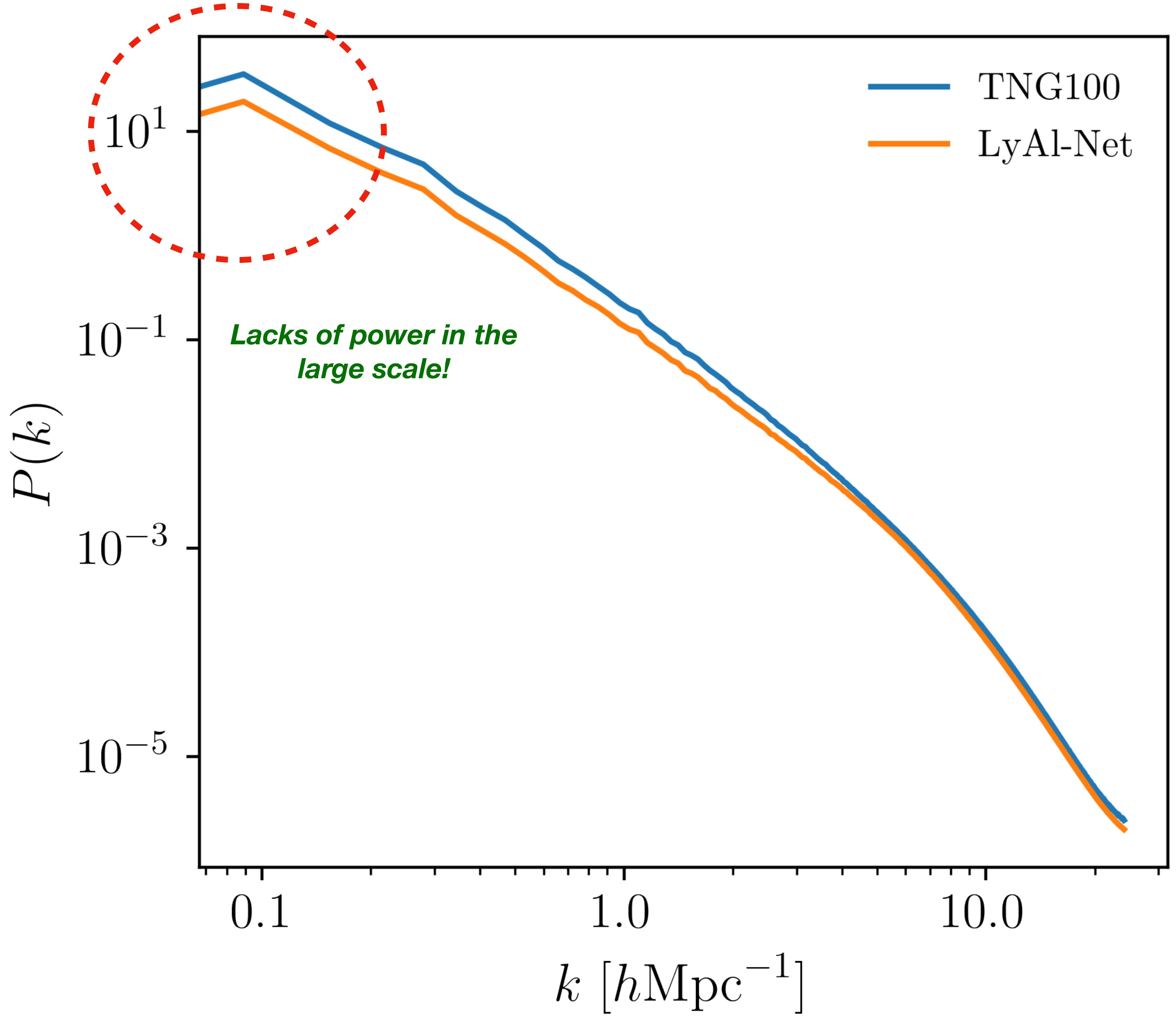

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LyAl-Net with TNG100 - Lyman-alpha Absorption

Transfer Function

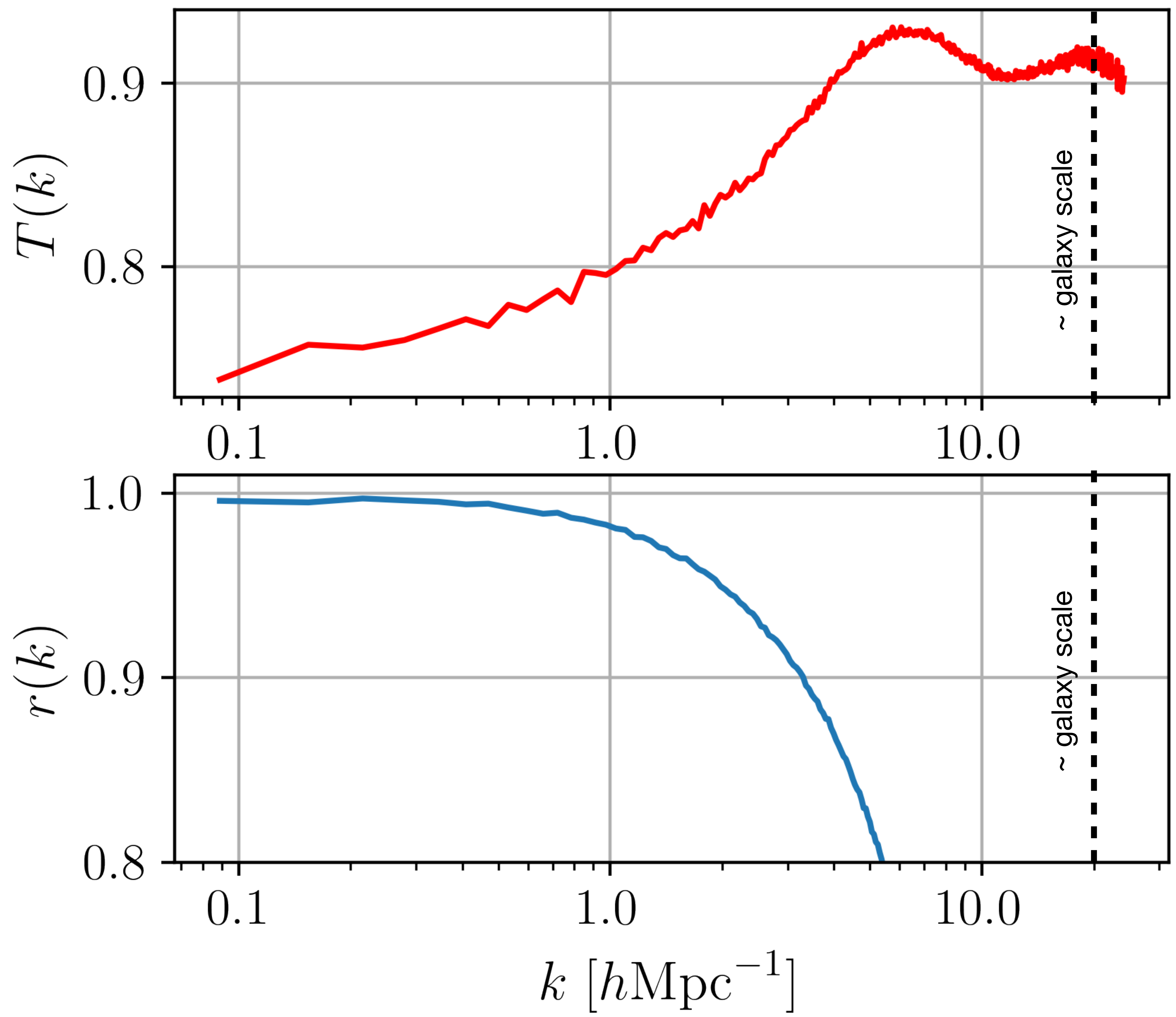
Measure the magnitude information

$$T(k) = \sqrt{\frac{P_k^{\text{Pred}}}{P_k^{\text{True}}}}$$

Cross Correlation Function

Measure the spatial information

$$r = \sqrt{\frac{P_k^{\text{True}\times\text{Pred}}}{P_k^{\text{True}} P_k^{\text{Pred}}}}$$



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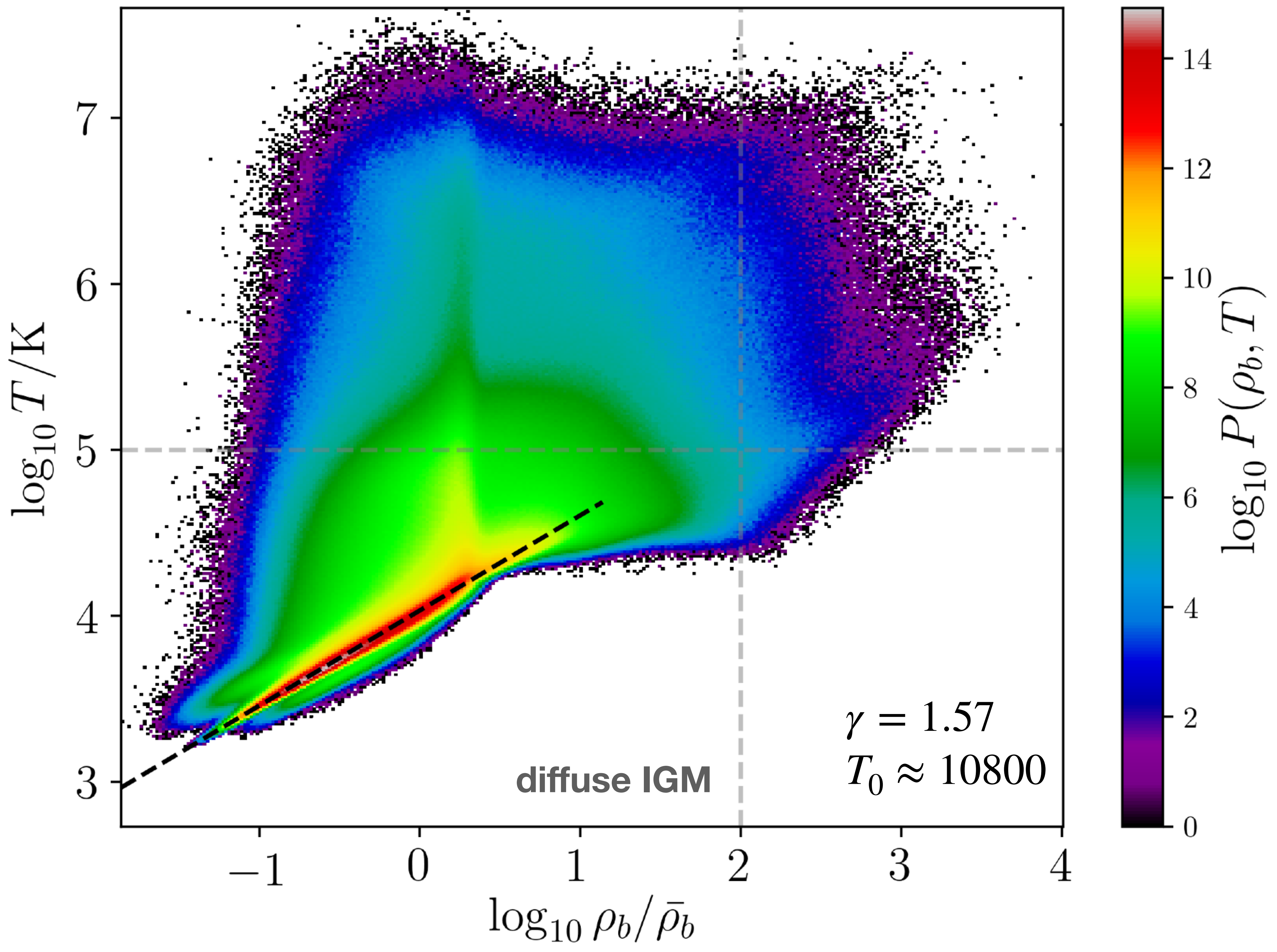
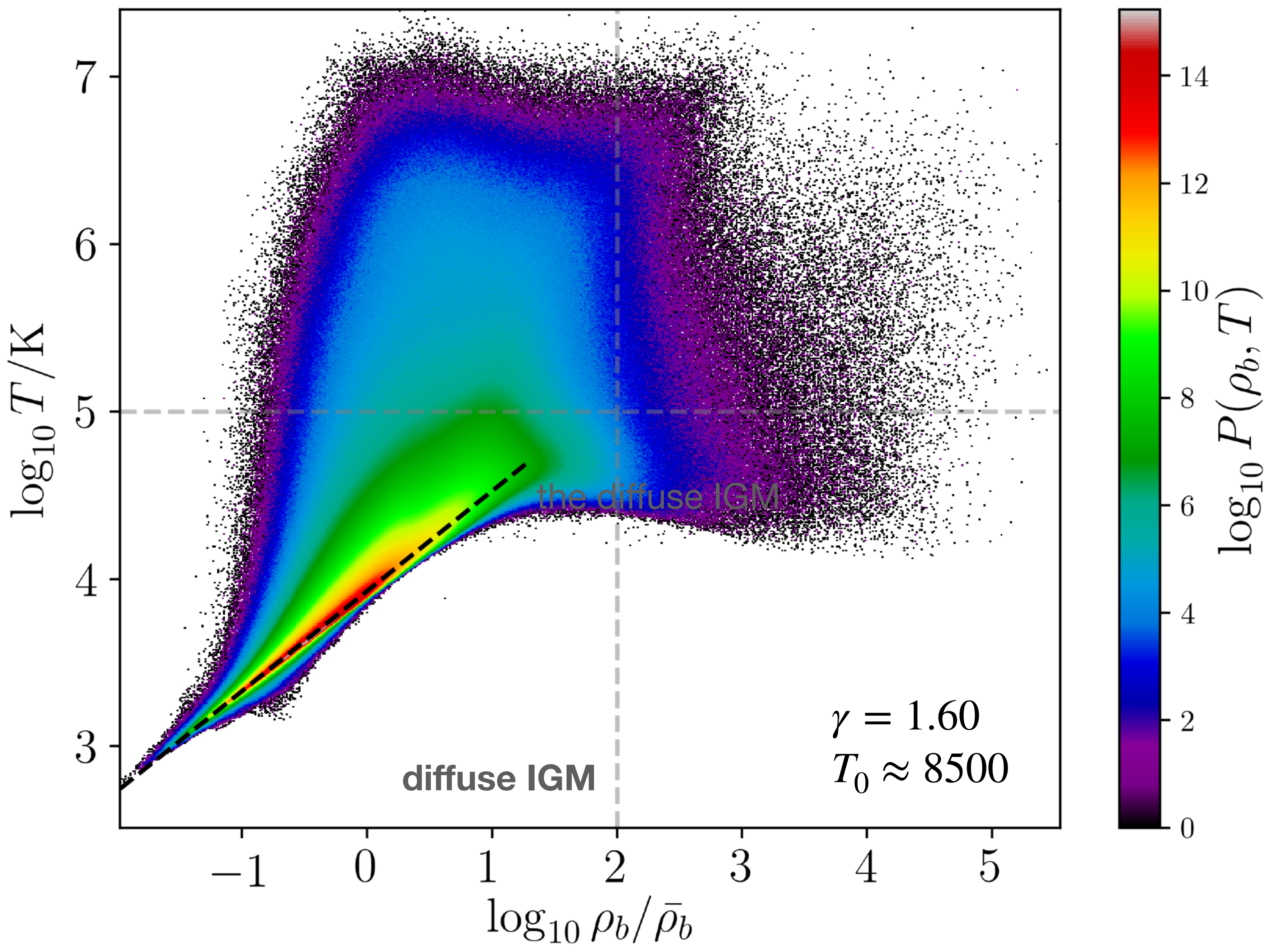
LyAl-Net -TNG100 vs Horizon-noAGN

$$T = T_0 \left(\frac{\rho_b}{\bar{\rho}_b} \right)^{\gamma - 1} \longrightarrow \log_{10} T = \log_{10} T_0 + (\gamma - 1) \log_{10} \left(\frac{\rho_b}{\bar{\rho}_b} \right)$$



The density-temperature distribution of gas of TNG100 at z=2.50



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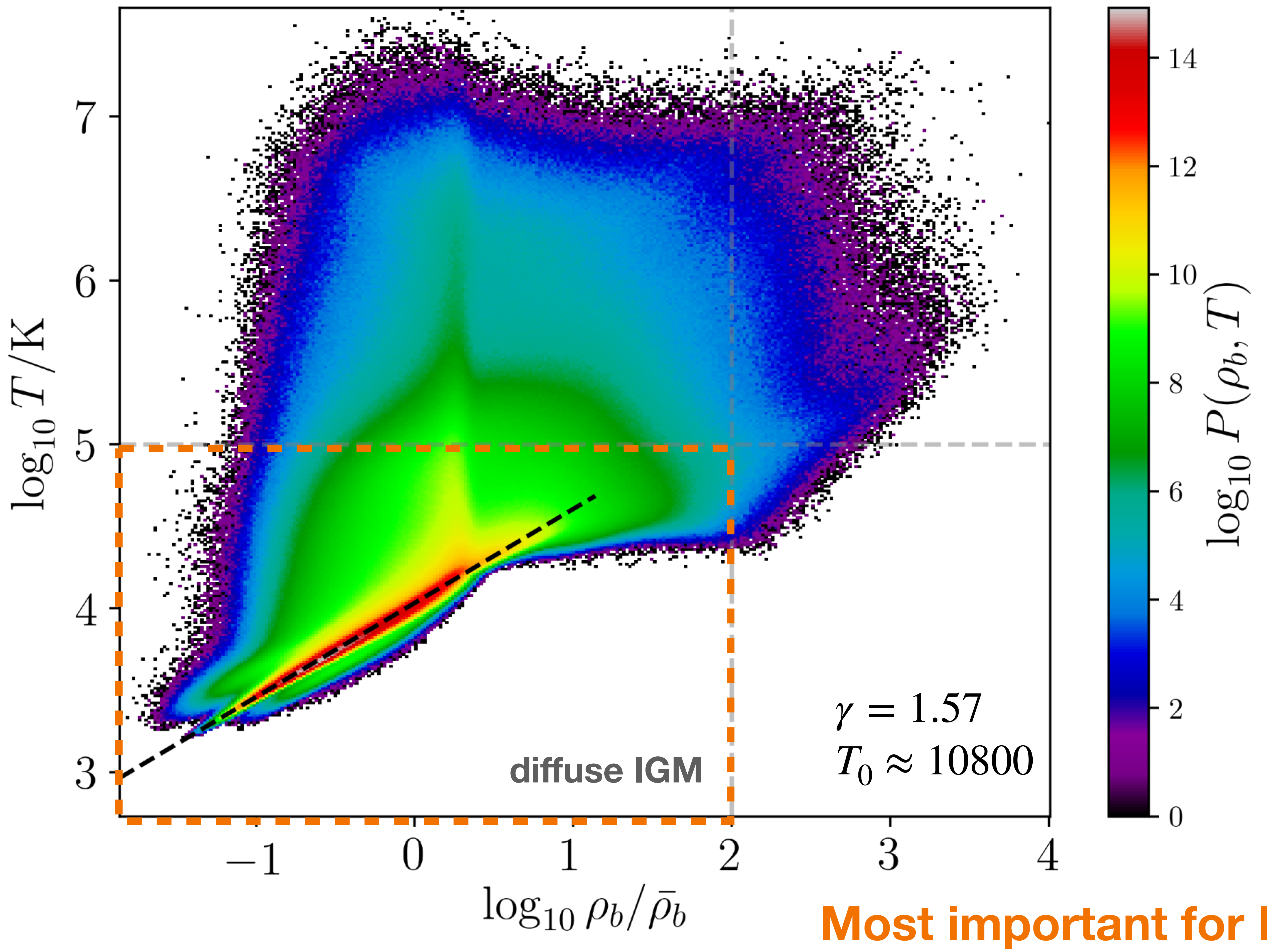

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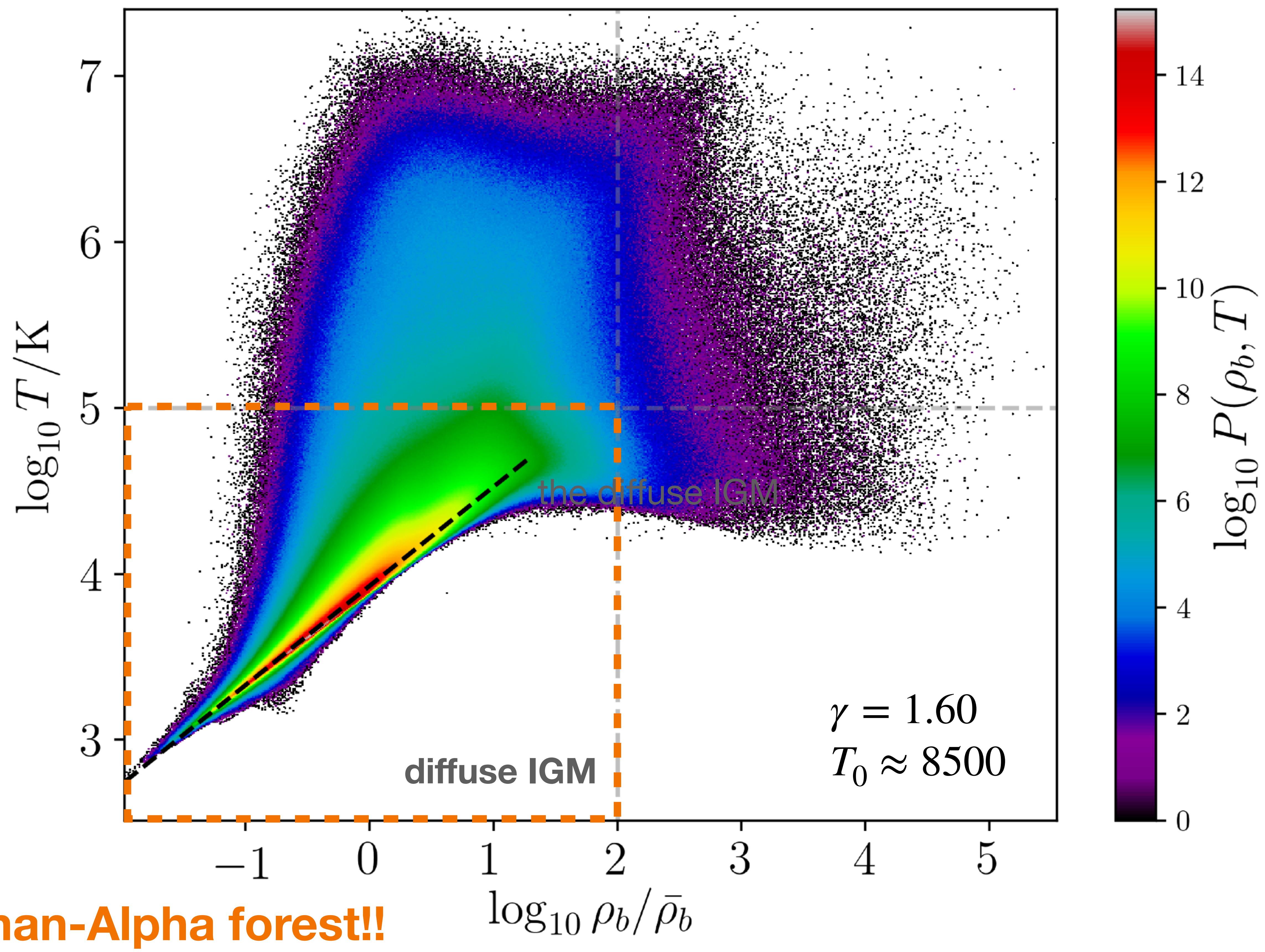

The density-temperature distribution of gas
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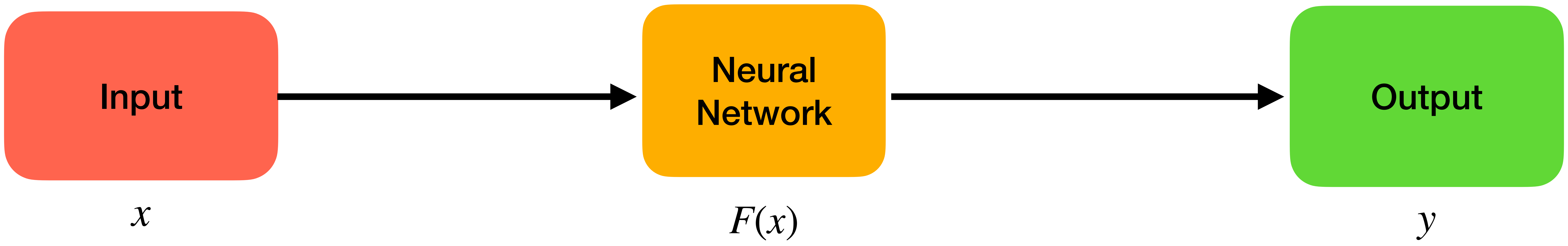
Most important for Lyman-Alpha forest!!

Transfer Learning with TNG100 - Overview



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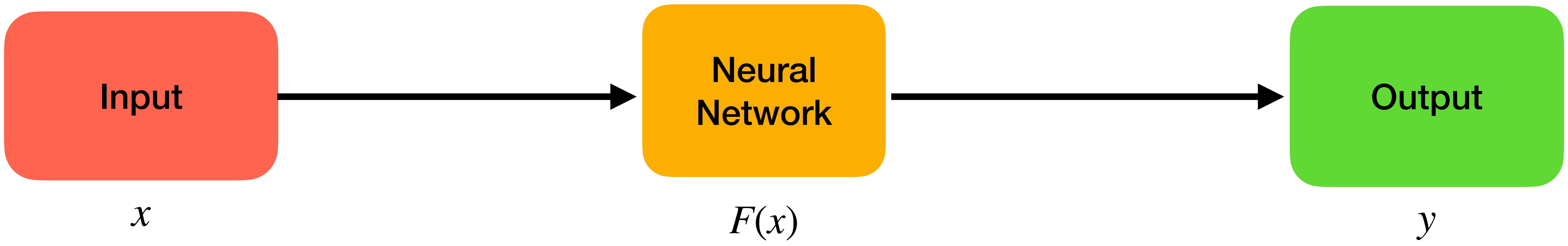

If x changes, then y changes!

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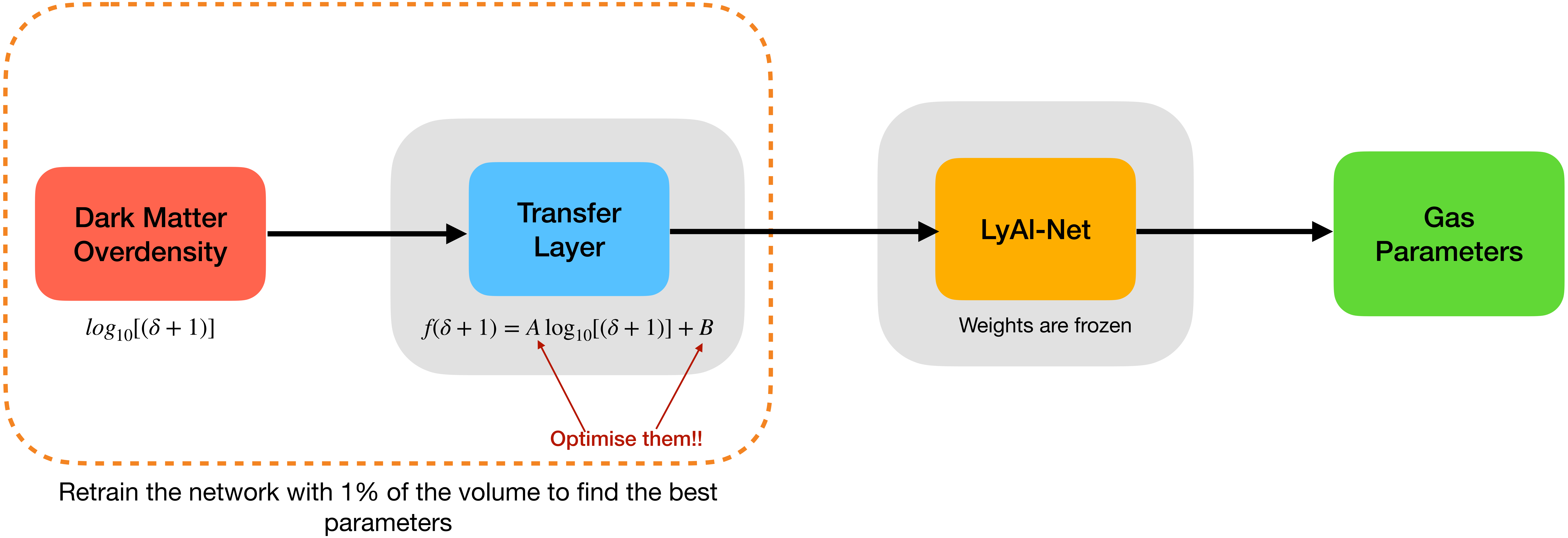

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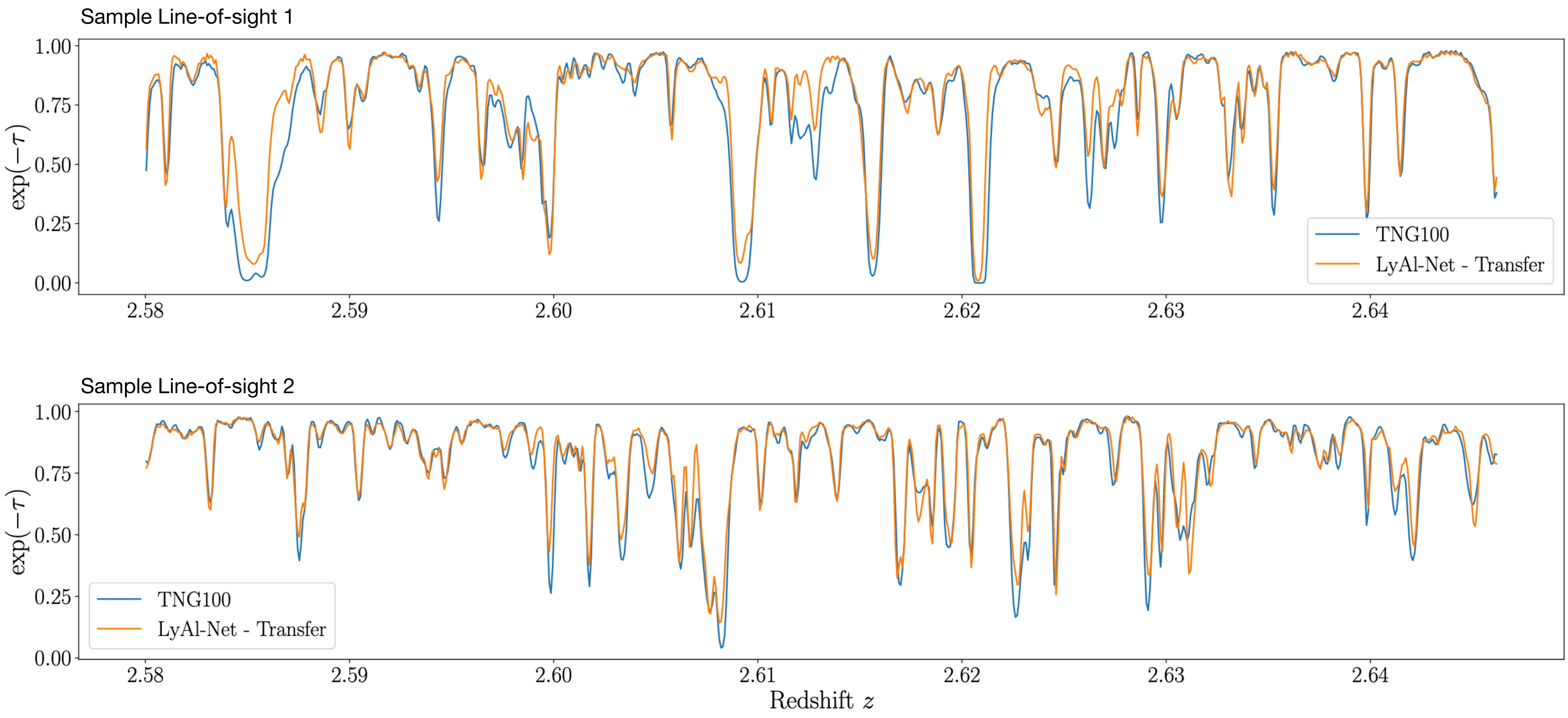
Transfer Learning with TNG100 - Lyman-alpha Absorption



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Transfer Learning with TNG100 - Lyman-alpha Absorption

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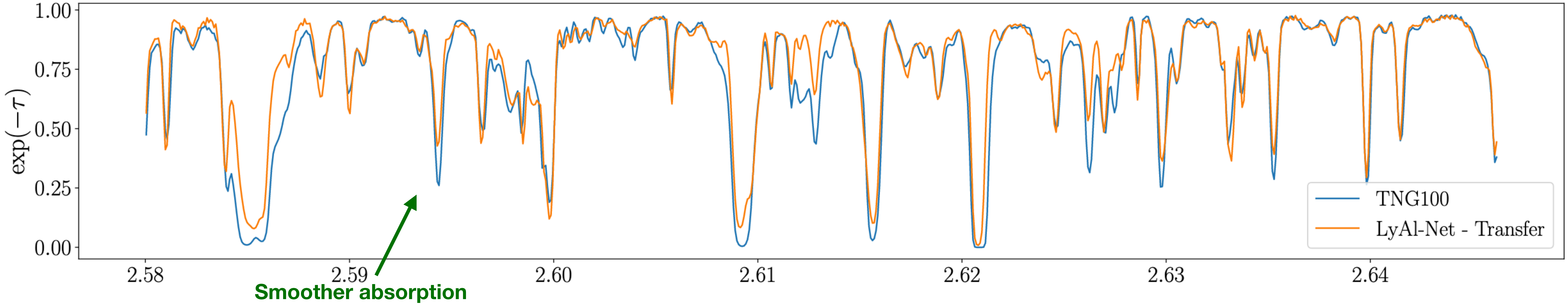
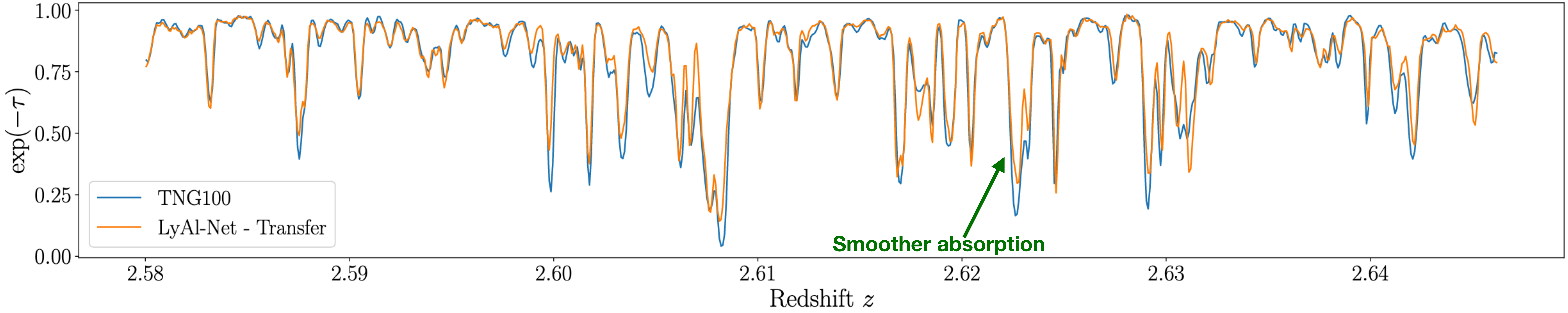


Sample Line-of-sight 2



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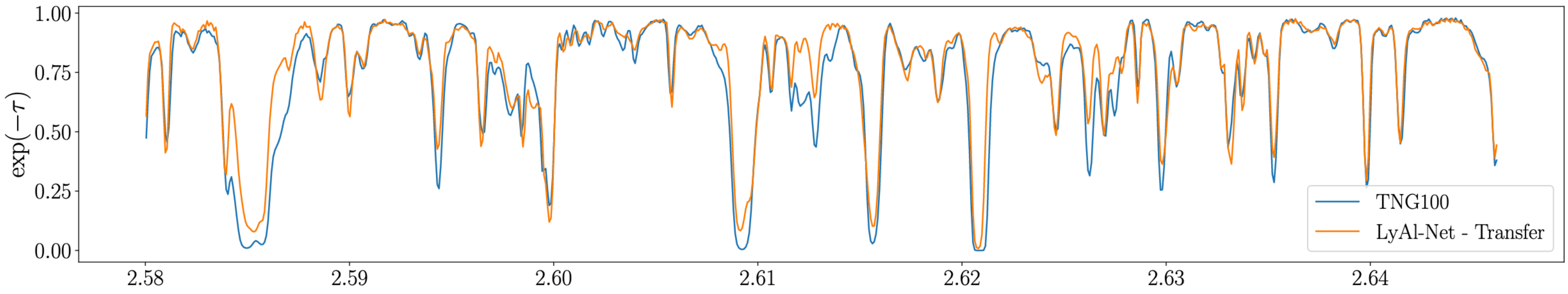

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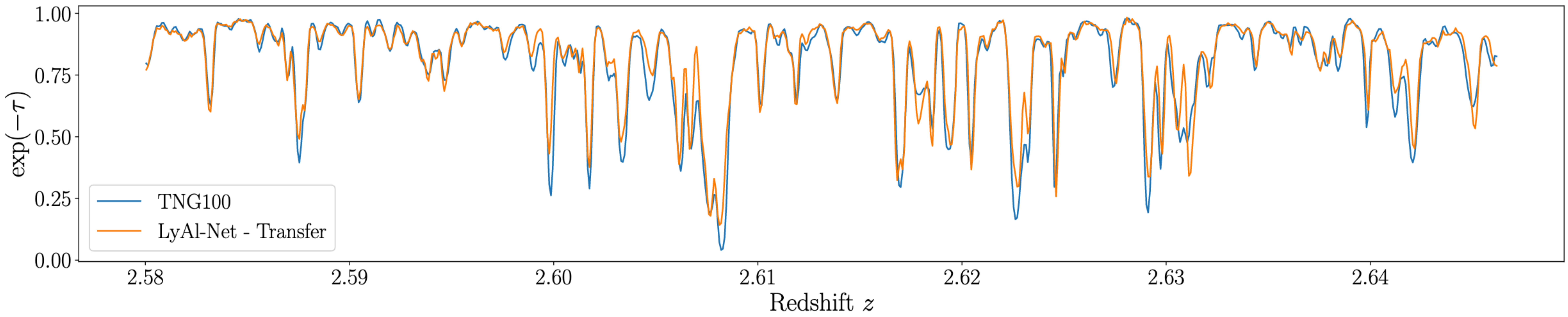

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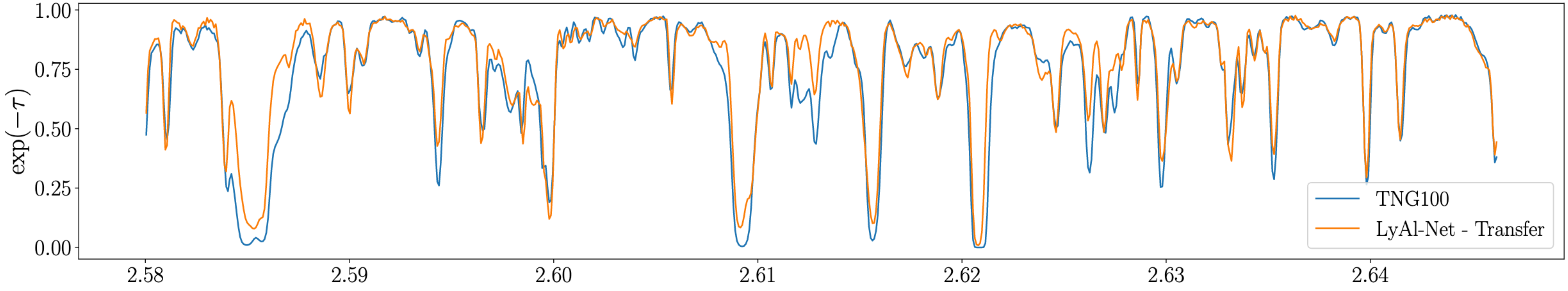
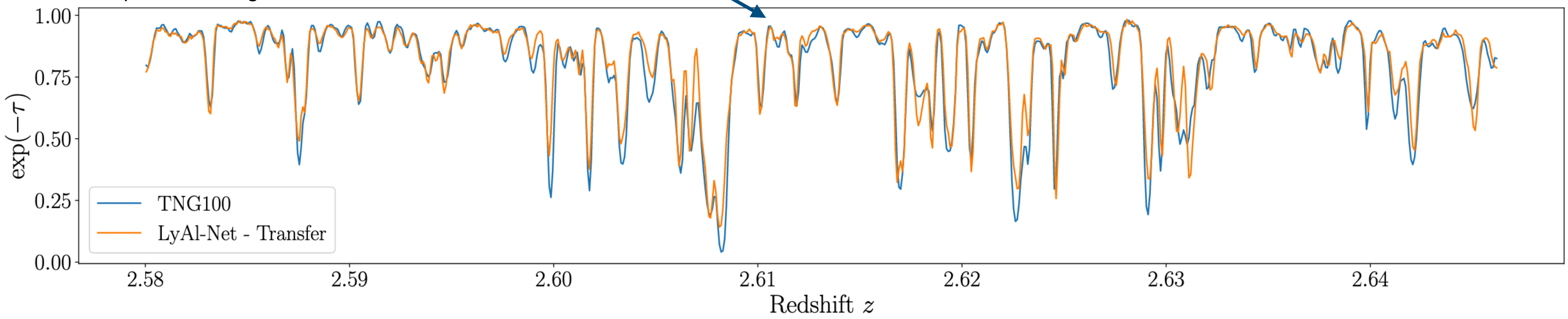


Sample Line-of-sight 2

Tracks better on the small scale



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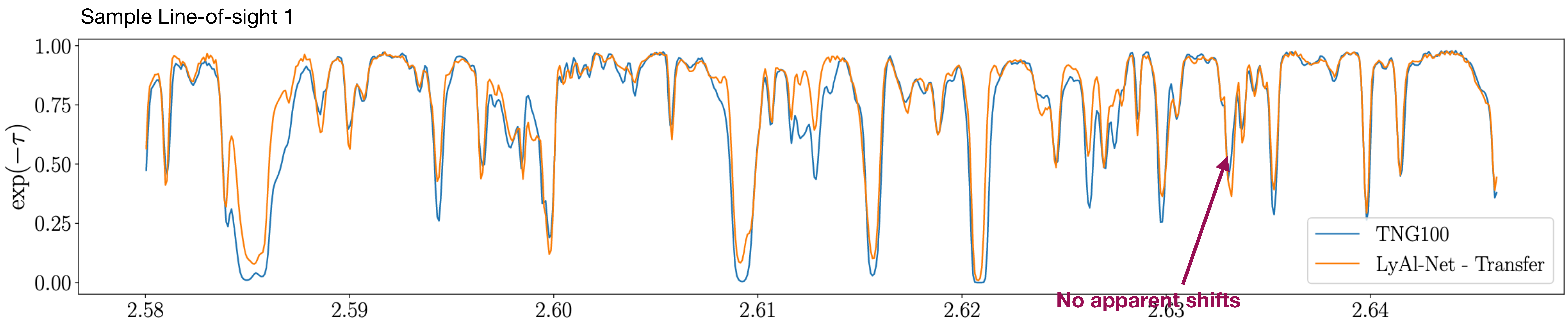

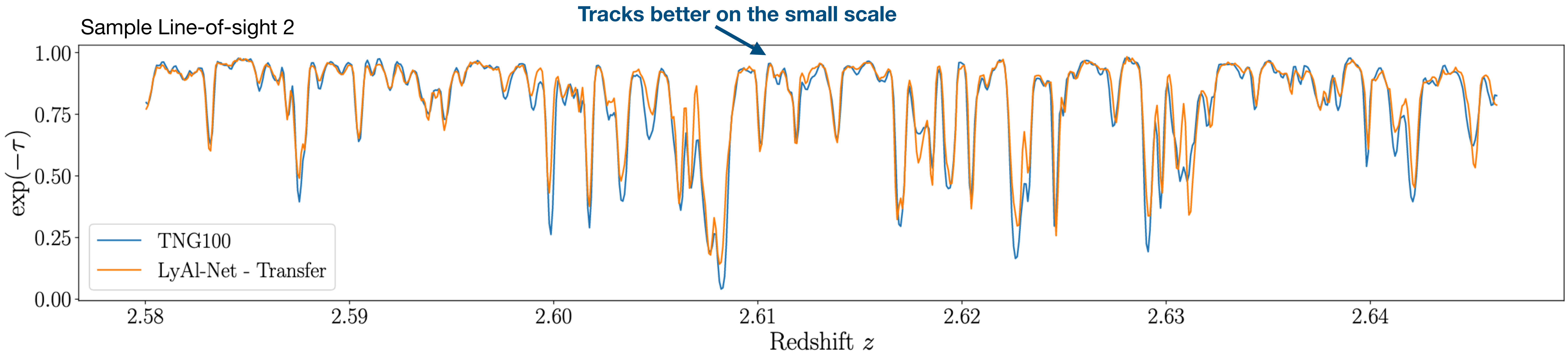

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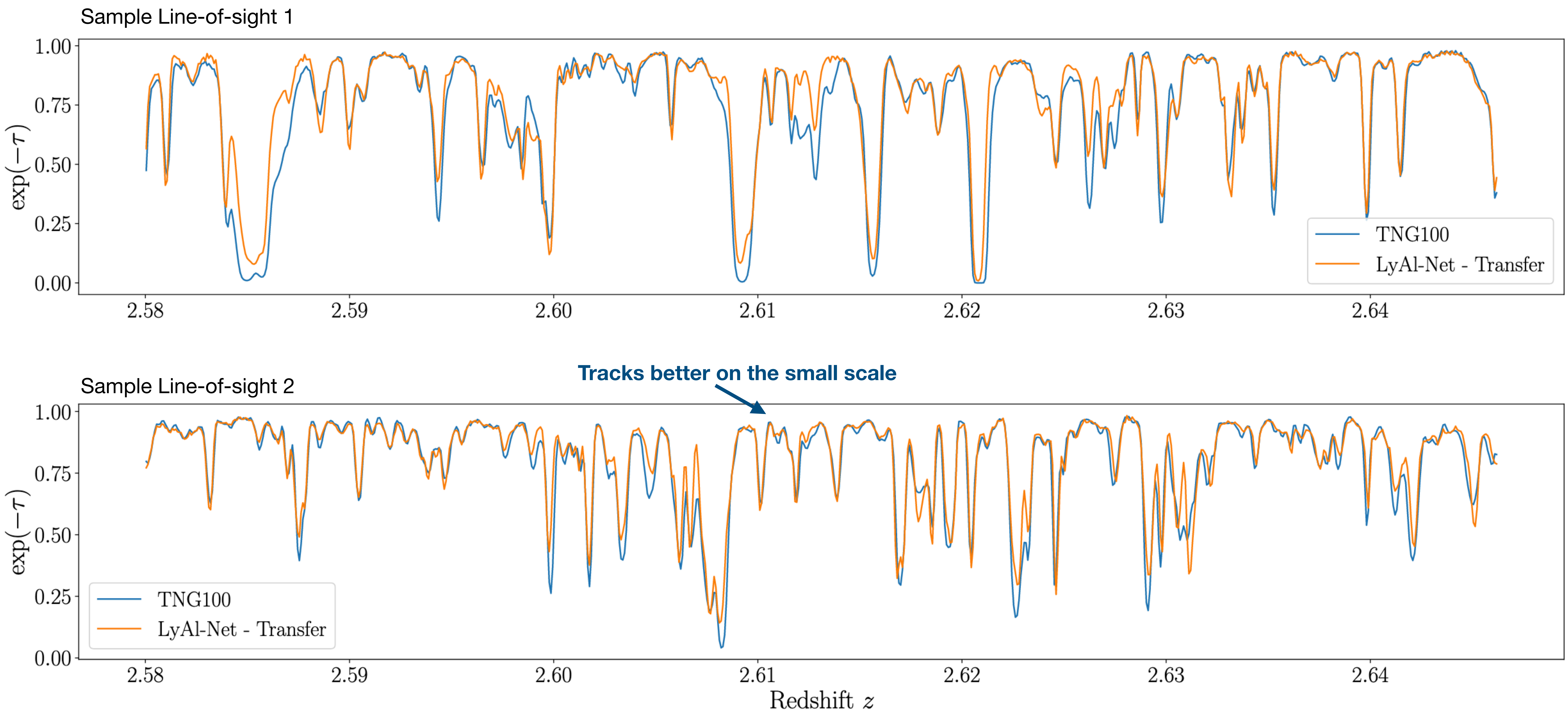

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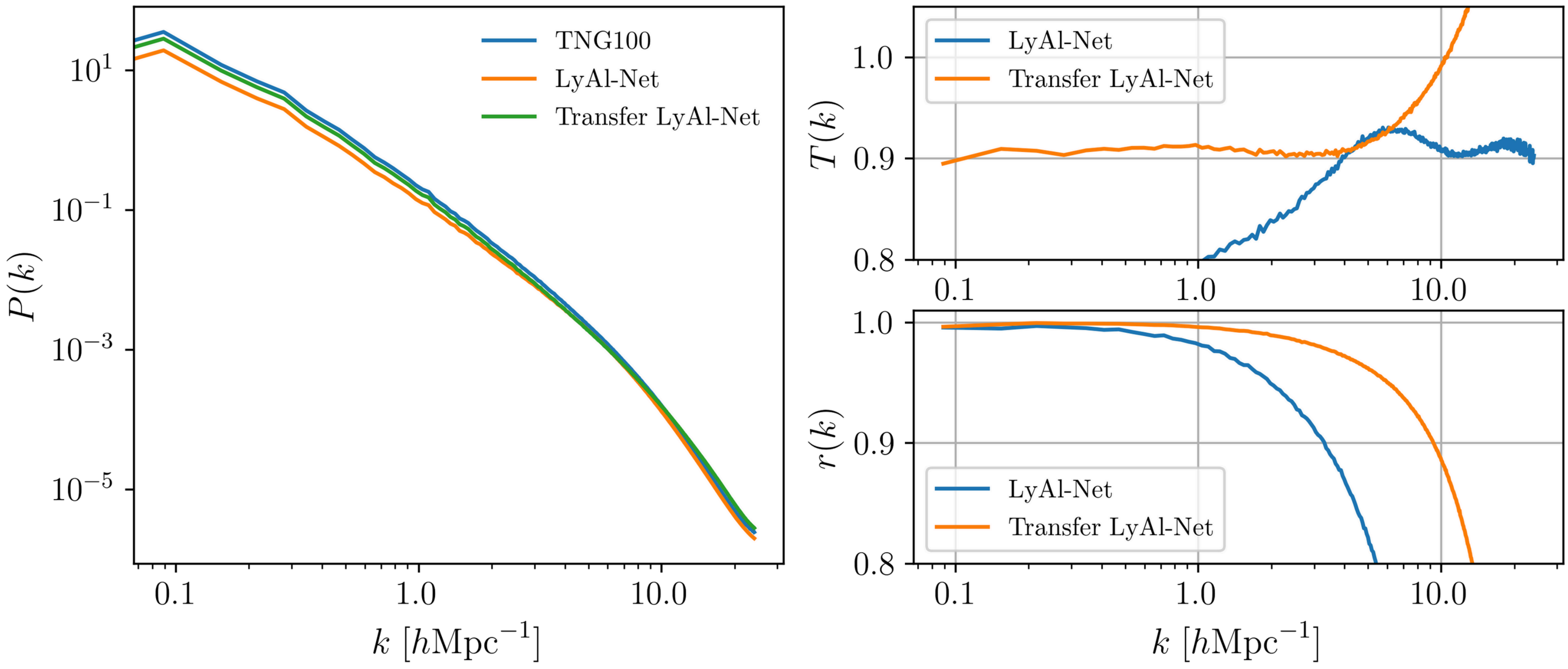

Boonkongkird et al. 2022 (work is still in progress)

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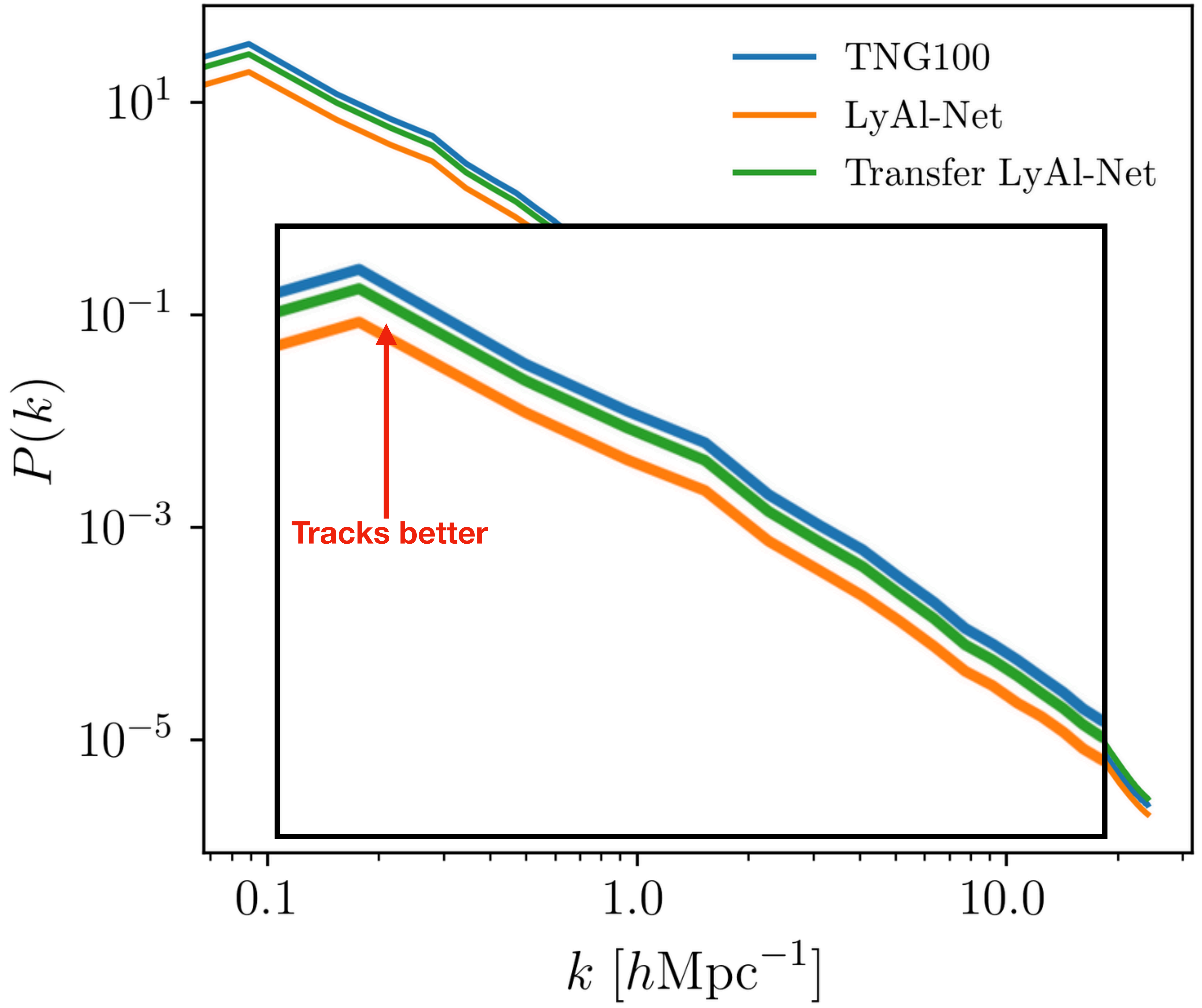

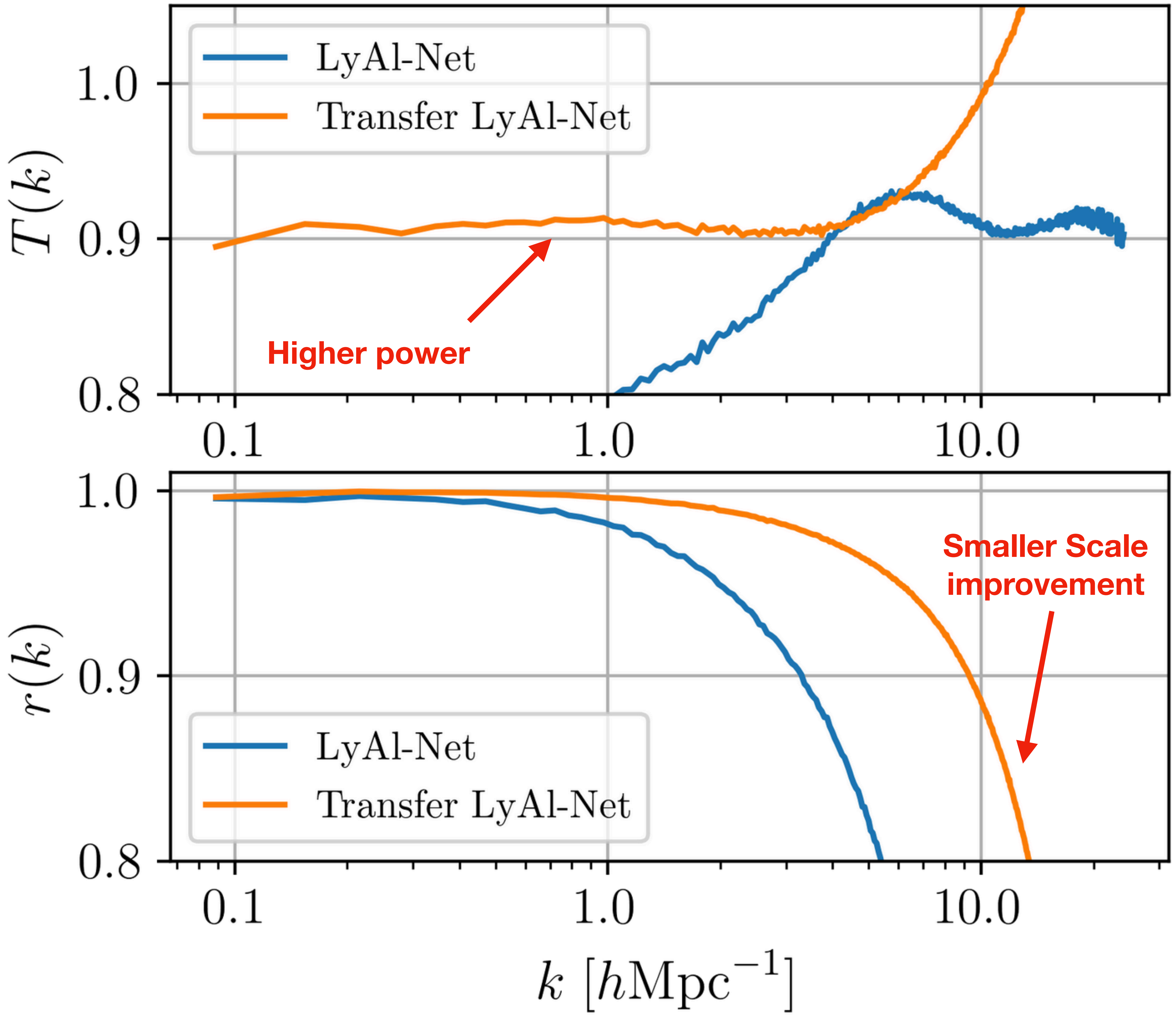

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Conclusions

Short Term Goal

- In-depth study the sensitivities of the absorption model to be within an observational errors
- Emulate different configurations of the physics

Long Term Goal

- Applying to Lyman alpha forest observation/data
- Likelihood free inference model, such as SELFI

Boonkongkird et al. 2022 (work is still in progress)

Appendix

TNG100 - Dark Matter vs Gas Velocities