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Damping wings in the Lyman-α forest

A model-independent measurement of the neutral fraction at $5.4 < z < 6.1$

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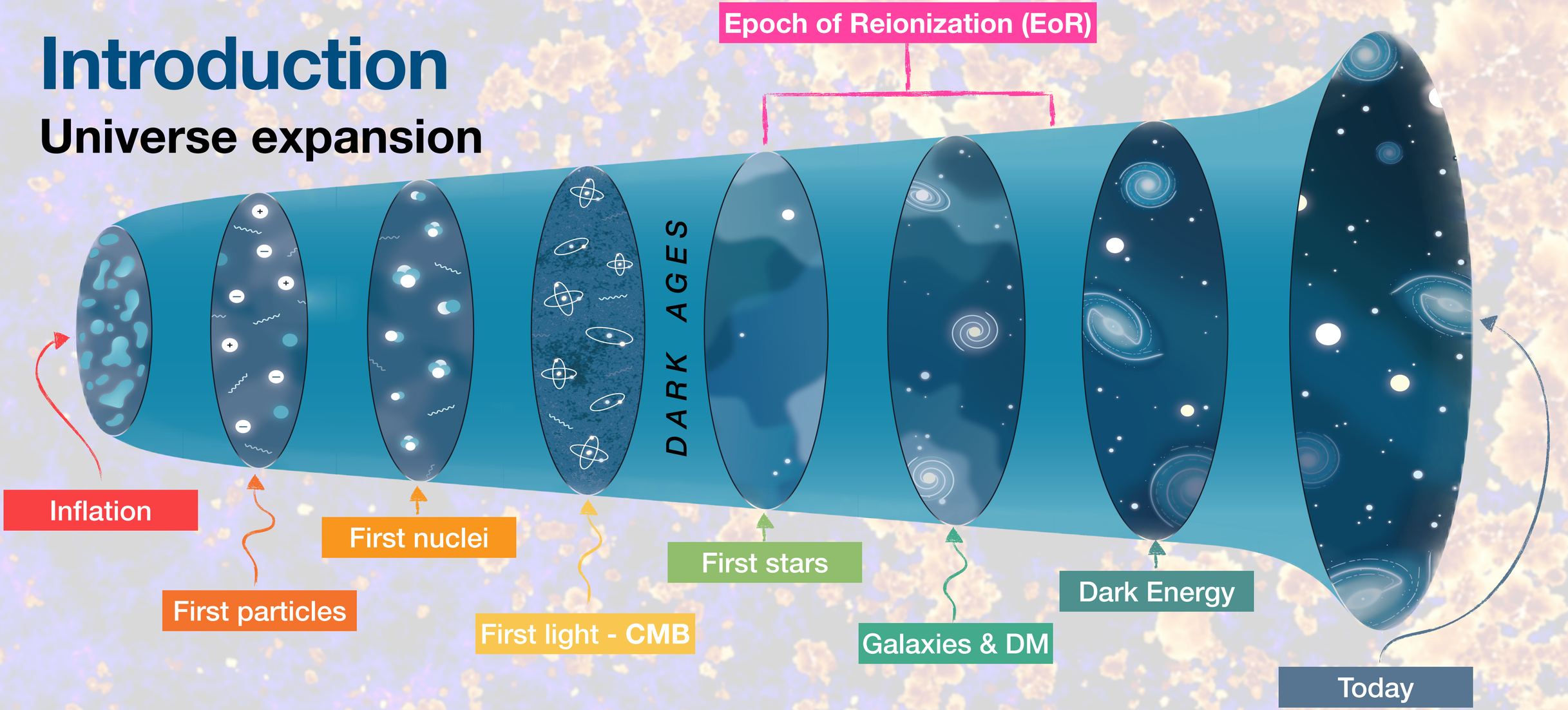
Credit: NASA

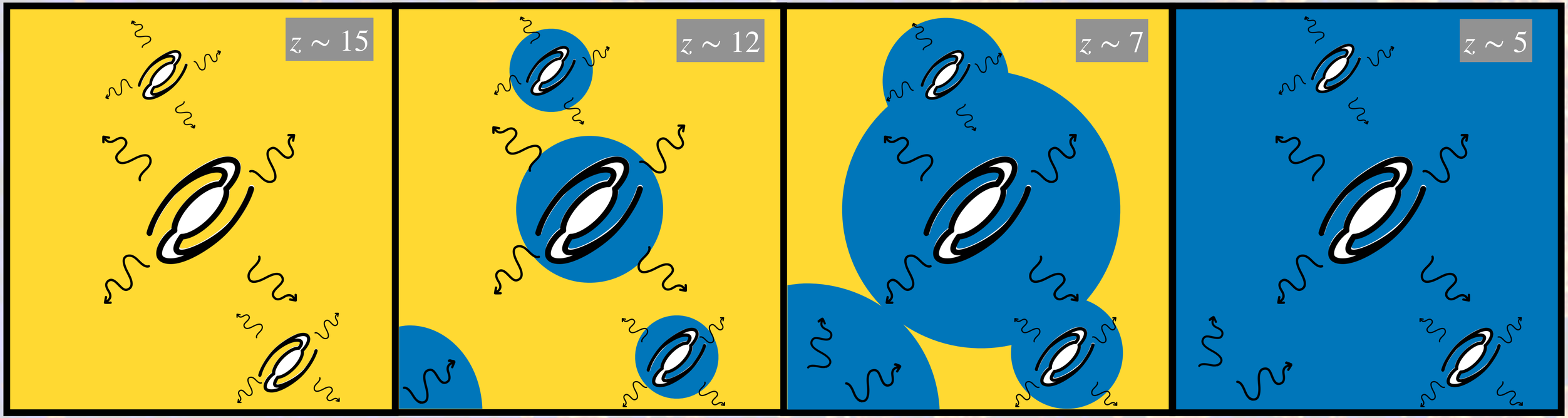
Introduction

Universe expansion



Introduction

Epoch of Reionisation



Stars and galaxies start emitting high-energy radiation.

The UV light strips e^- from p^+ ionizing the IGM (HI, HeI).

The ionized bubbles grow and ionize the IGM.

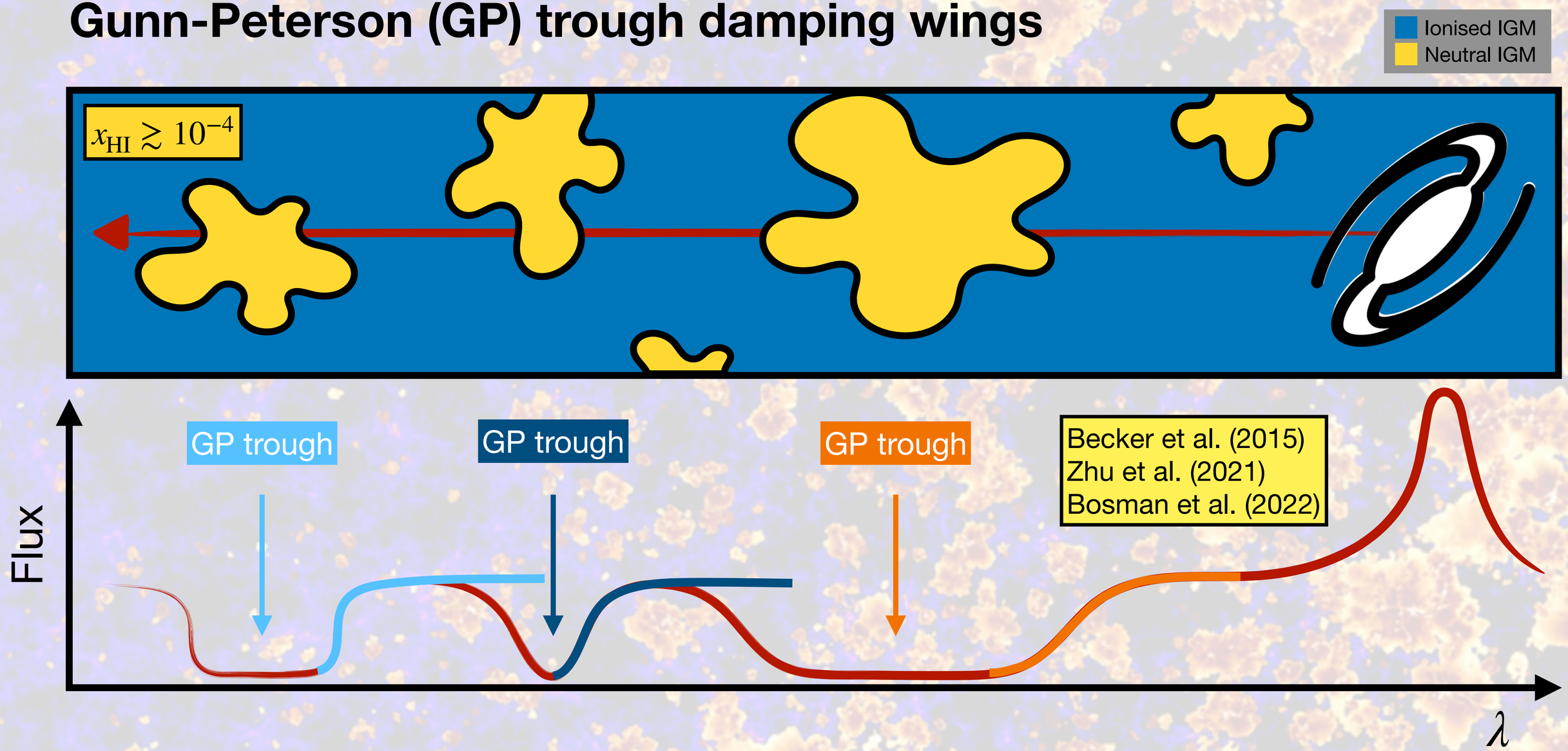
Today the Universe is fully ionized*.

*except within high-density self-shielded regions

Gunn&Peterson (1967)
Miralda-Escudé (1998)

Introduction

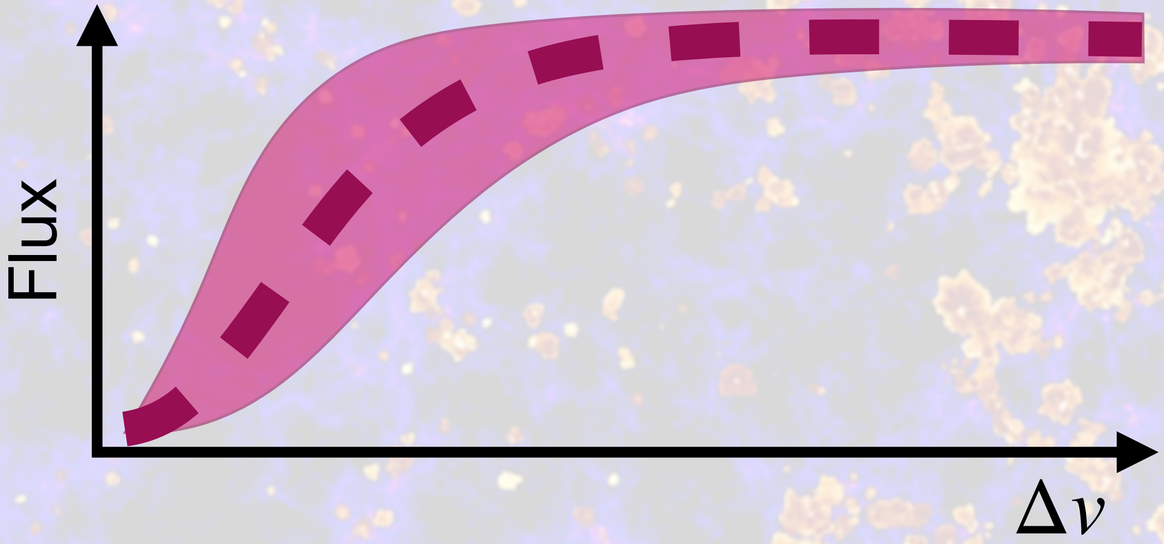
Gunn-Peterson (GP) trough damping wings



Gunn&Peterson (1967)
Miralda-Escudé (1998)

Introduction

Gunn-Peterson (GP) trough damping wings



Damping Wing (DW)

- Optical depth $\tau_{\mathrm{DW}} \propto x_{\mathrm{HI}}, \Delta v$
- Transmission flux $T(\Delta v) = e^{-\tau_{\mathrm{DW}}(x_{\mathrm{HI}}, \Delta v)}$

Stack GP-DWs to constrain the end of the EoR

Work plan

How to measure the HI fraction

Identify GP troughs in **38 XQR-30** QSOs in the z ranges $5.4 - 5.8$, $5.8 - 6.1$

Employ two **toy-models** of the local $x_{\rm HI}\,(L)$, given a gap of length L

Stacking of ***long*** vs. ***short*** gaps, avoiding contamination from HII

Volume average the $x_{\rm HI}\,(L)$ obtained and constrain the **global HI fraction**

Spina et al. (2024)

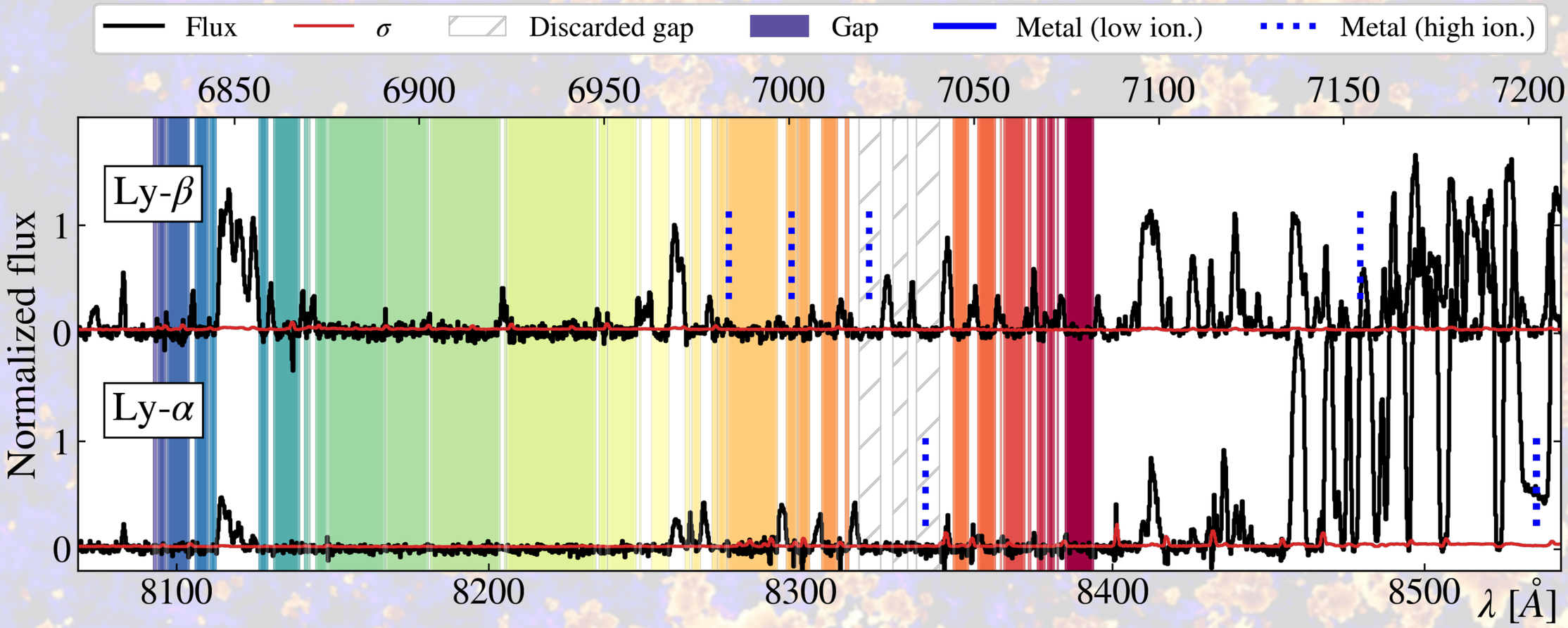
Gaps identification

Lyman-α and Lyman-β

1. Remove **sky-lines** contamination

2. Identify **gaps** in Ly-α and Ly-β

3. Avoid **DLAs** contribution



Spina et al. (2024)

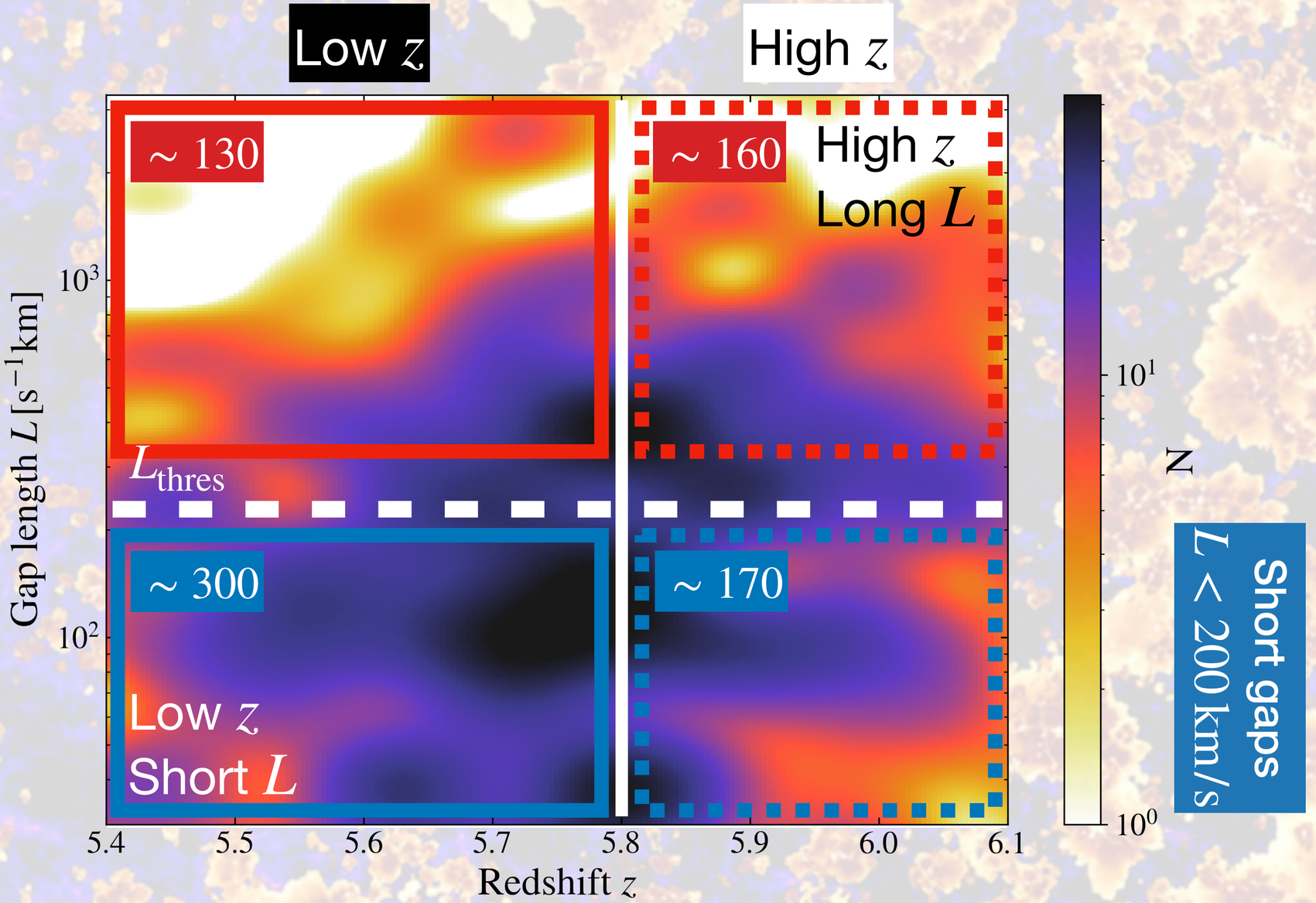
Gaps identification

Distribution

Long gaps
$L > L_{\text{thres}}$

Compromise between
- High number of gaps (≥ 100)
- Contamination from HII (short gaps)

$L_{\text{thres}} = 340\,\text{km/s}$



Spina et al. (2024)

Long vs. Short gaps

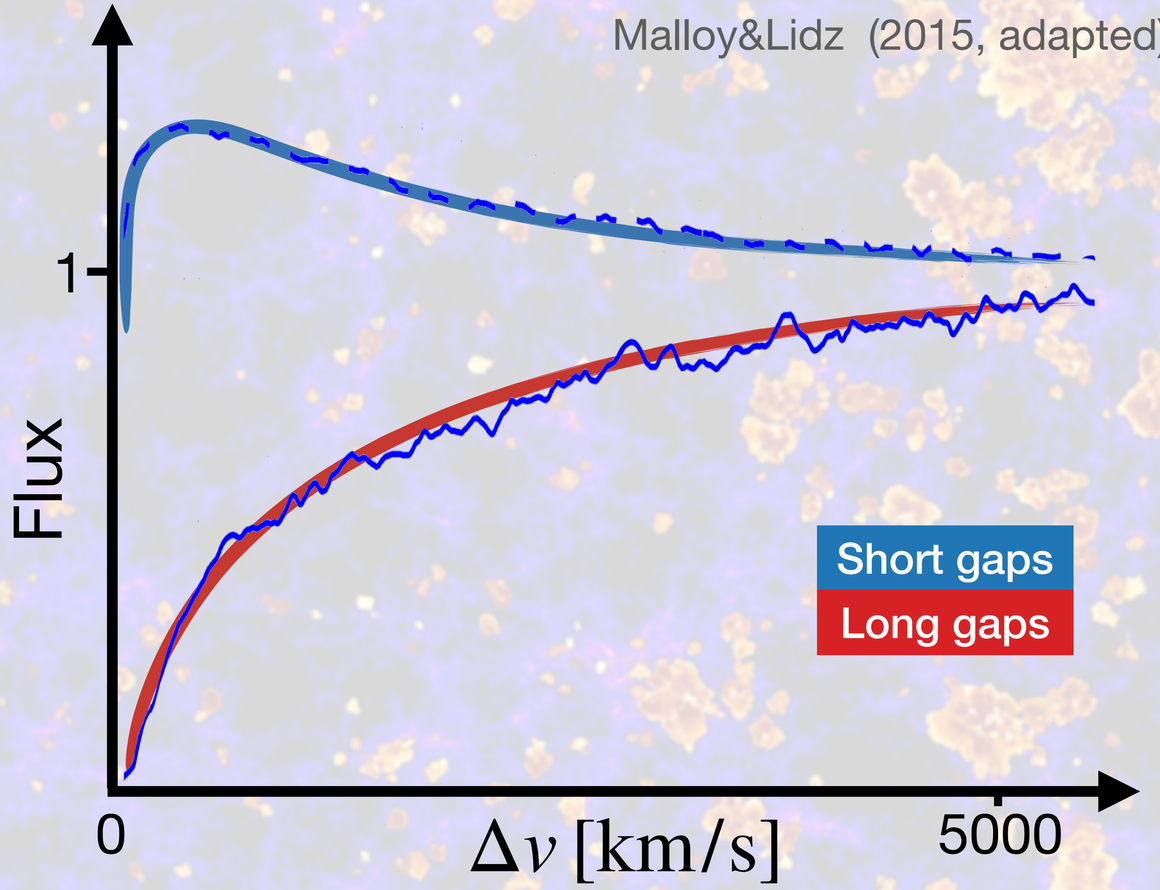
Damping wings: first detection

Short gaps: $L < 200\,\mathrm{km/s}$

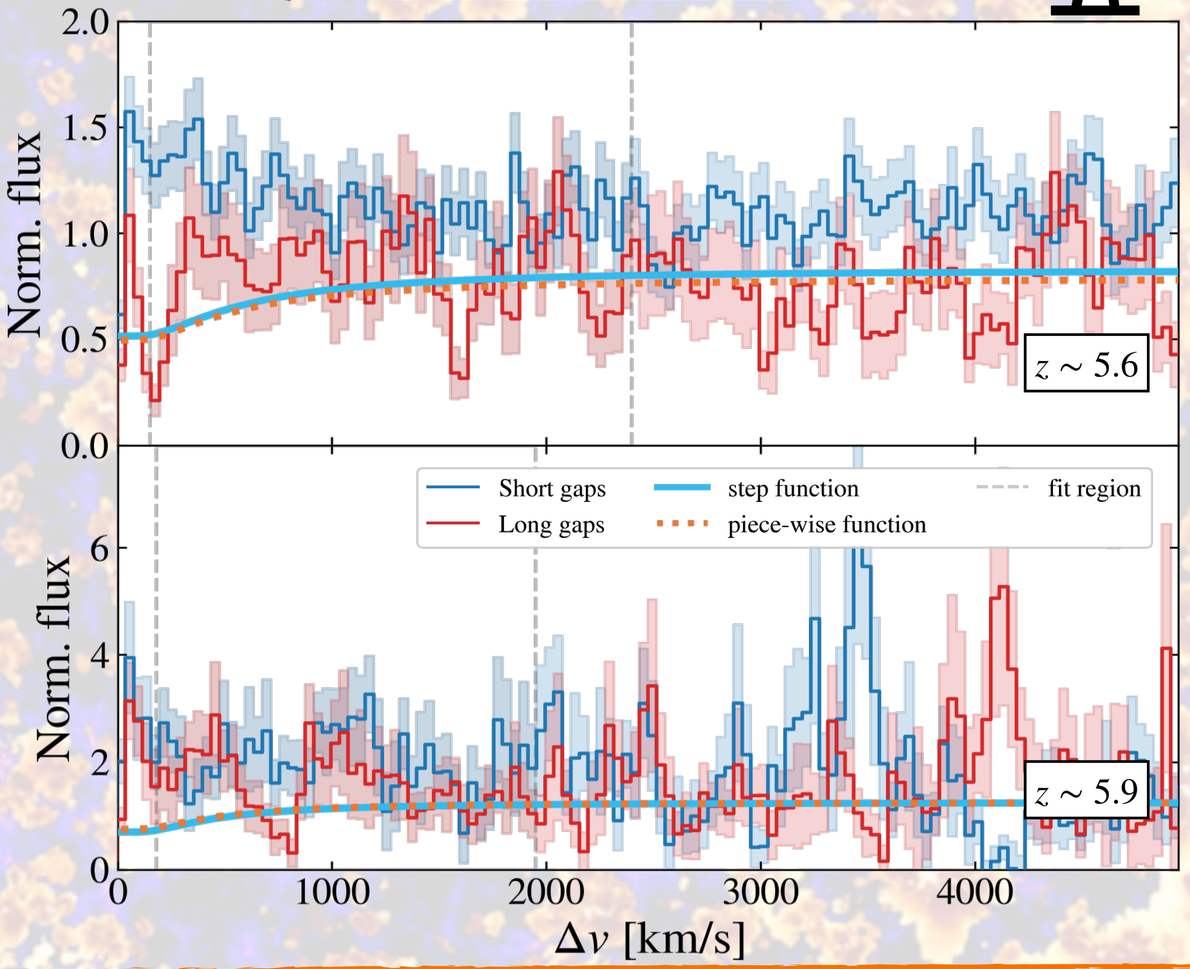
Long gaps: $L > 340\,\mathrm{km/s}$

Malloy&Lidz (2015)

Malloy&Lidz (2015, adapted)

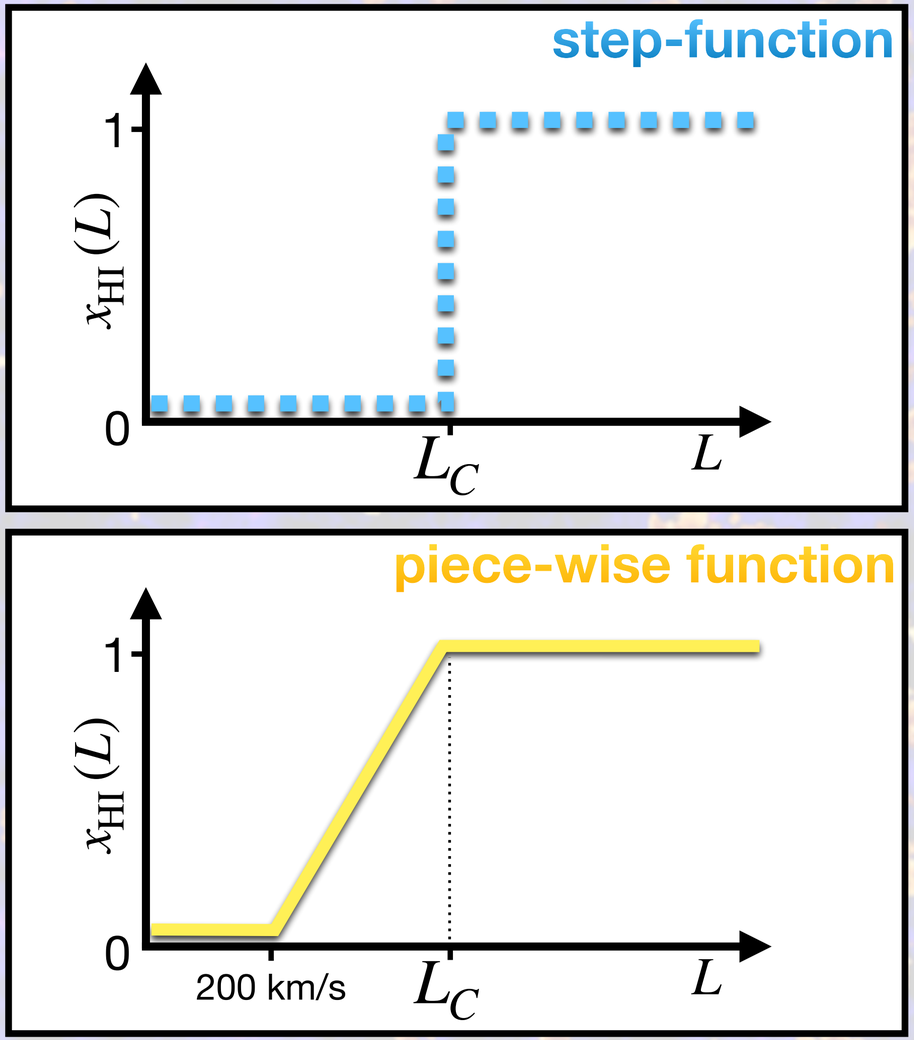


Spina et al. (2024)



Local HI fraction $x_{\rm HI}(L)$

HI fraction in each gap



Employ two **toy-models** to define the local $x_{\rm HI}(L)$, given a gap of length L

Fit the functional shape using χ^2 **minimisation**, constraining L_C

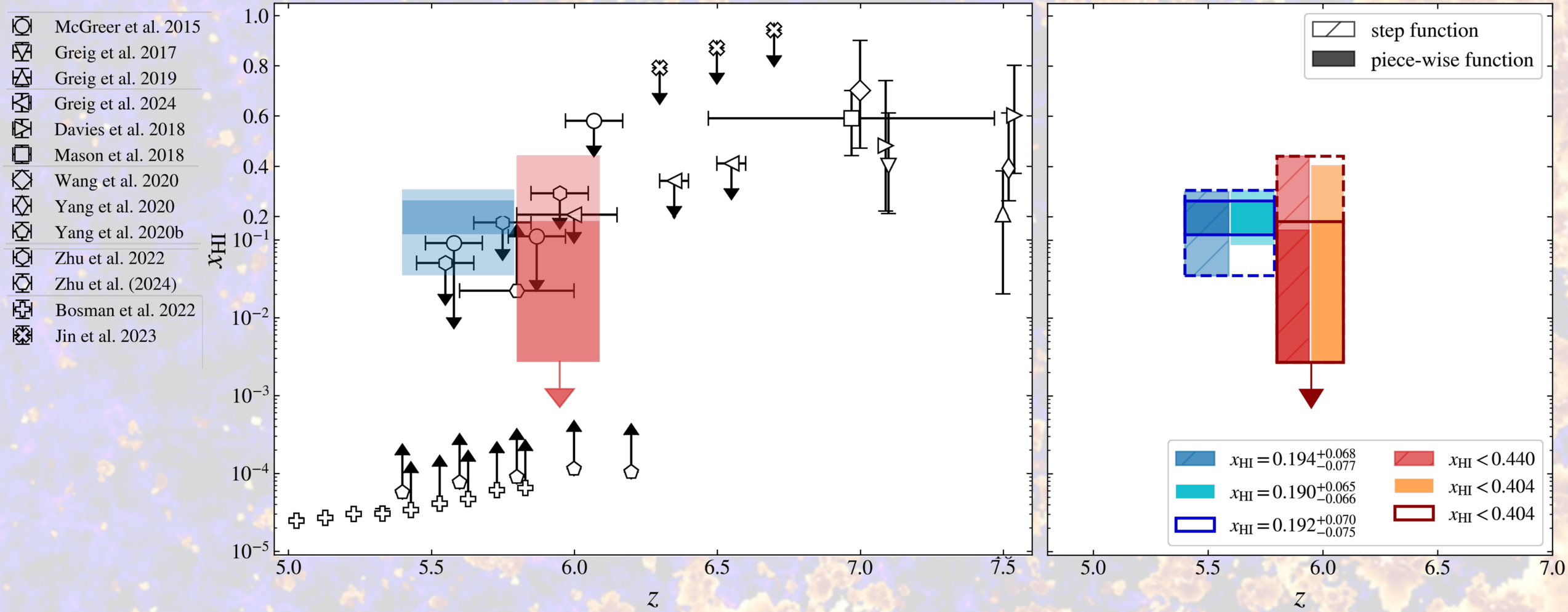
Constraining the **global** $x_{\rm HI}$ using the best-fit for L_C for the two models

Spina et al. (2024)

Results

Global HI fraction

$$x_{\rm HI}\left(z=5.6\right)=0.19\pm0.07\,(^{+0.11}_{-0.16})$$
$$x_{\rm HI}\left(z=5.9\right)<0.44$$



Conclusion

Take-home messages

First identification of **GP damping wings** by stacking **dark gaps** in the **Lyman-α forest**.

Existence of **neutral islands** near the end of the EoR (**late-and-slow** reionization scenario).

Measurement of $x_{\rm HI} = 0.19 \pm 0.07\ (^{+0.11}_{-0.16})$ at $z = 5.6$

Limit of $x_{\rm HI} < 0.44$ at $z = 5.9$.

➡ Explore **Lyman series**,
➡ Compare with **simulations**.

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Thank you for your attention!