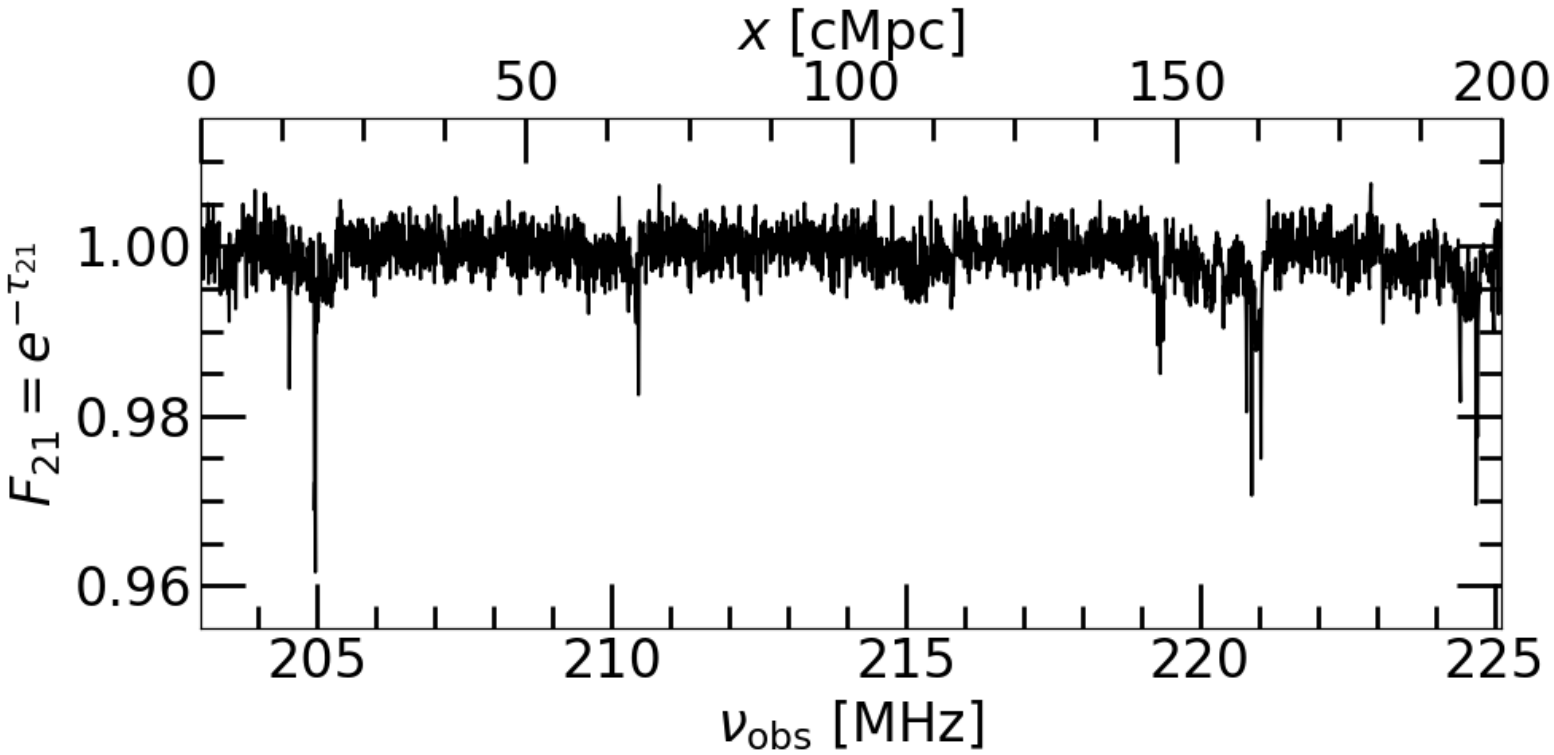


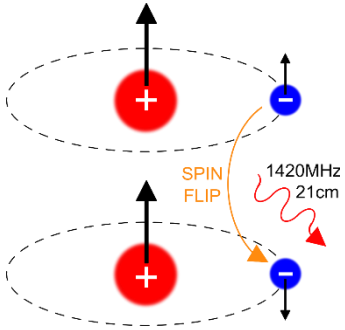
https://arxiv.org/abs/2412.06879

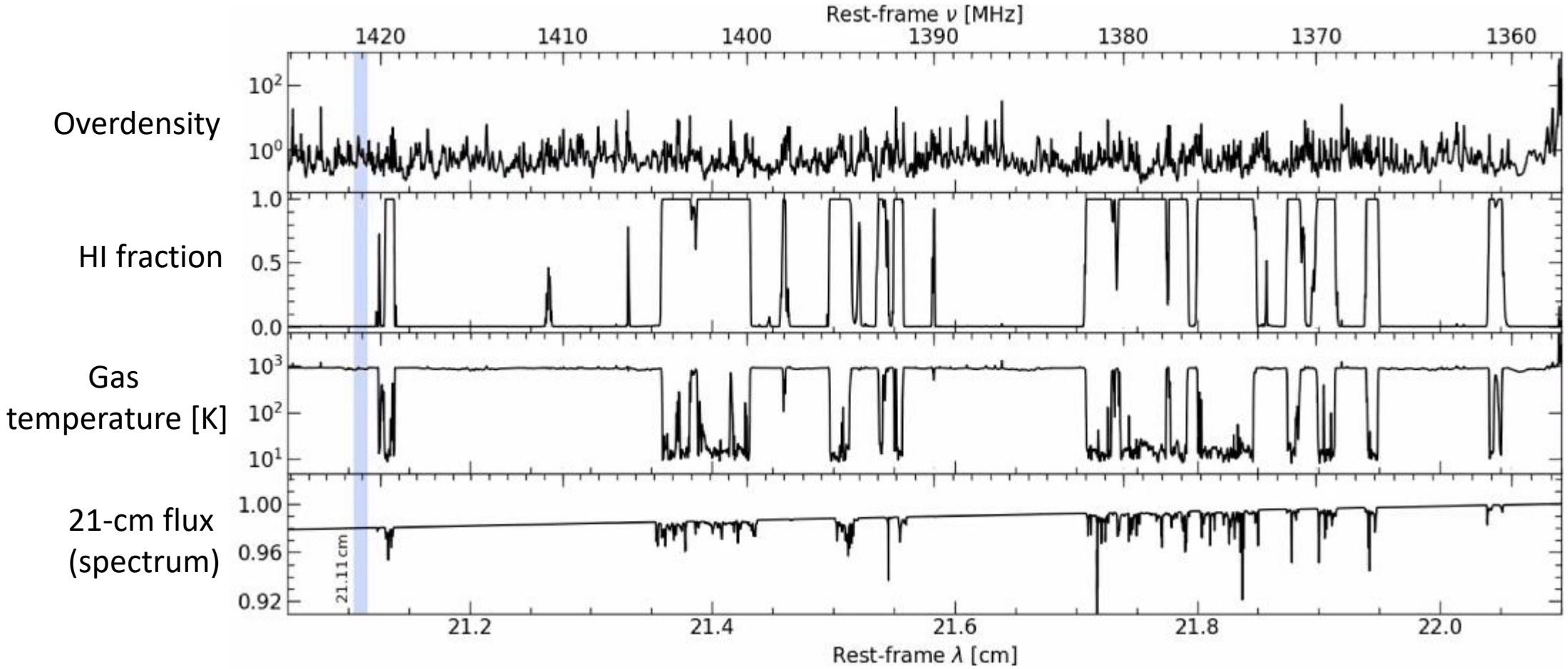
Prospects of a statistical detection of the 21-cm forest and its potential to constrain the cosmic heating and reionization history

TOMÁŠ ŠOLTINSKÝ, GIRISH KULKARNI, SHRIHARSH TENDULKAR, JAMES BOLTON, SAMEER PATIL, SOUMAK MAITRA

What is 21-cm forest?

21-cm forest


SPIN
FLIP
1420MHz
21cm


Rest-frame ν [MHz]
1420
1410
1400
1390
1380
1370
1360
Overdensity
HI fraction
Gas temperature [K]
21-cm flux (spectrum)
21.11 cm
21.2
21.4
21.6
21.8
22.0
Rest-frame λ [cm]

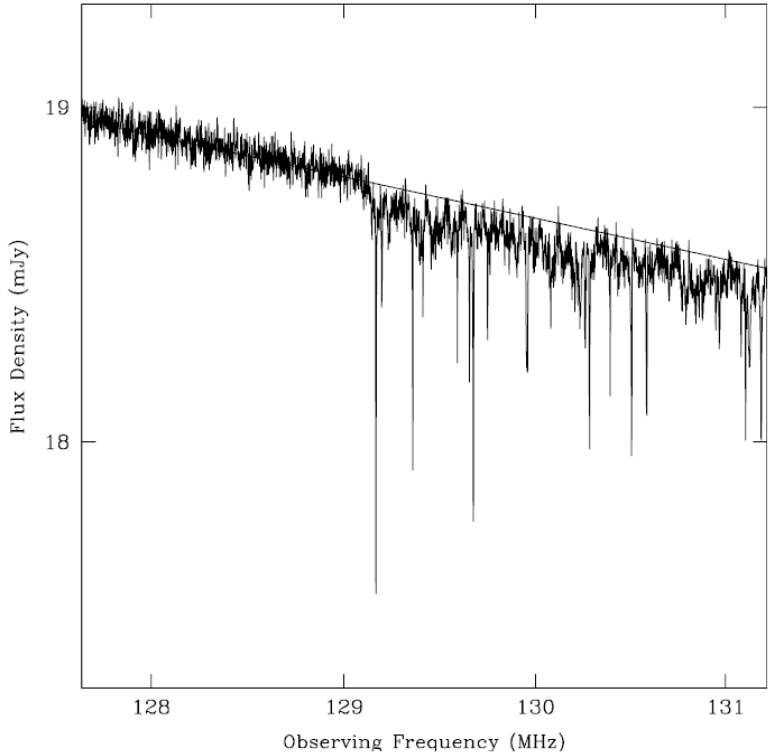
21-cm forest - complementary

To other 21-cm line observables:

- only requirement is a high signal-to-noise spectrum
- in principle less complicated to detect
- challenge is the abundance of radio-bright sources

To the Lyα forest:

- unique probe of cold and neutral hydrogen at z>6
- nature of dark matter (Shimabukuro et al. 2014, 2020, Shao et al. 2023)
- supermassive black hole growth models (Šoltinský et al. 2023)



Carilli et al. 2002
(Simulated spectrum)

Why now?

https://www.nottingham.ac.uk/astronomy/sherwood-relics/
Puchwein et al. 2023

Reionization ends late

Motivated by Lyα observations

(Becker et al. 2015, Eilers et al. 2018)

↓

Seem to require reionization completed by z<5.6

(Kulkarni et al. 2019, Keating et al. 2020, Bosman et al. 2022, Zhu et al. 2023)

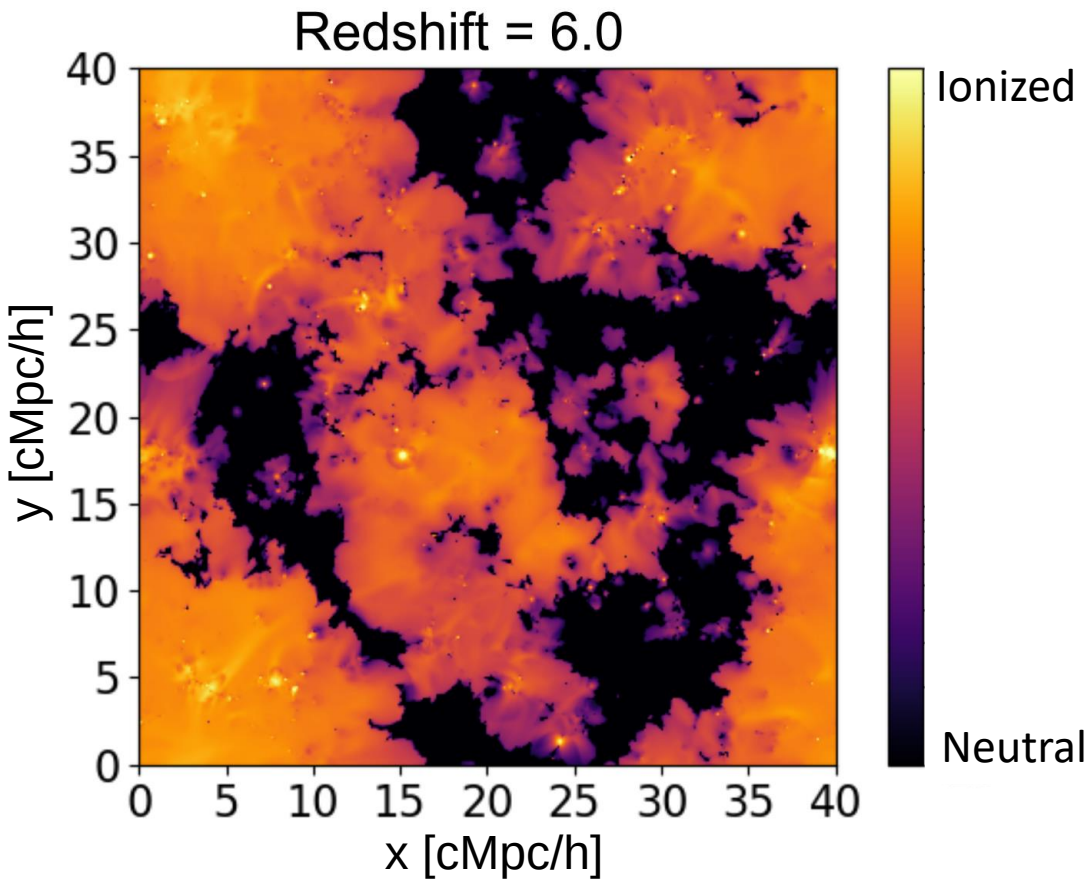
↓

Large islands of HI persist until z≈6

↓

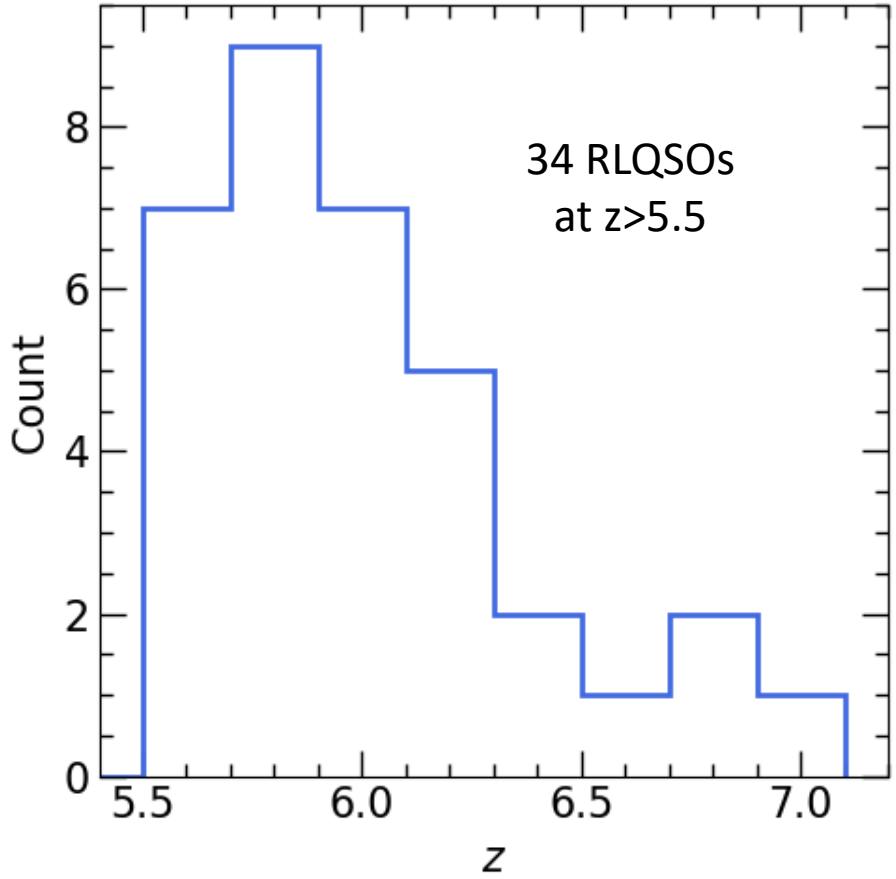
Possibility of detecting 21-cm forest

(Šoltinský et al. 2021)



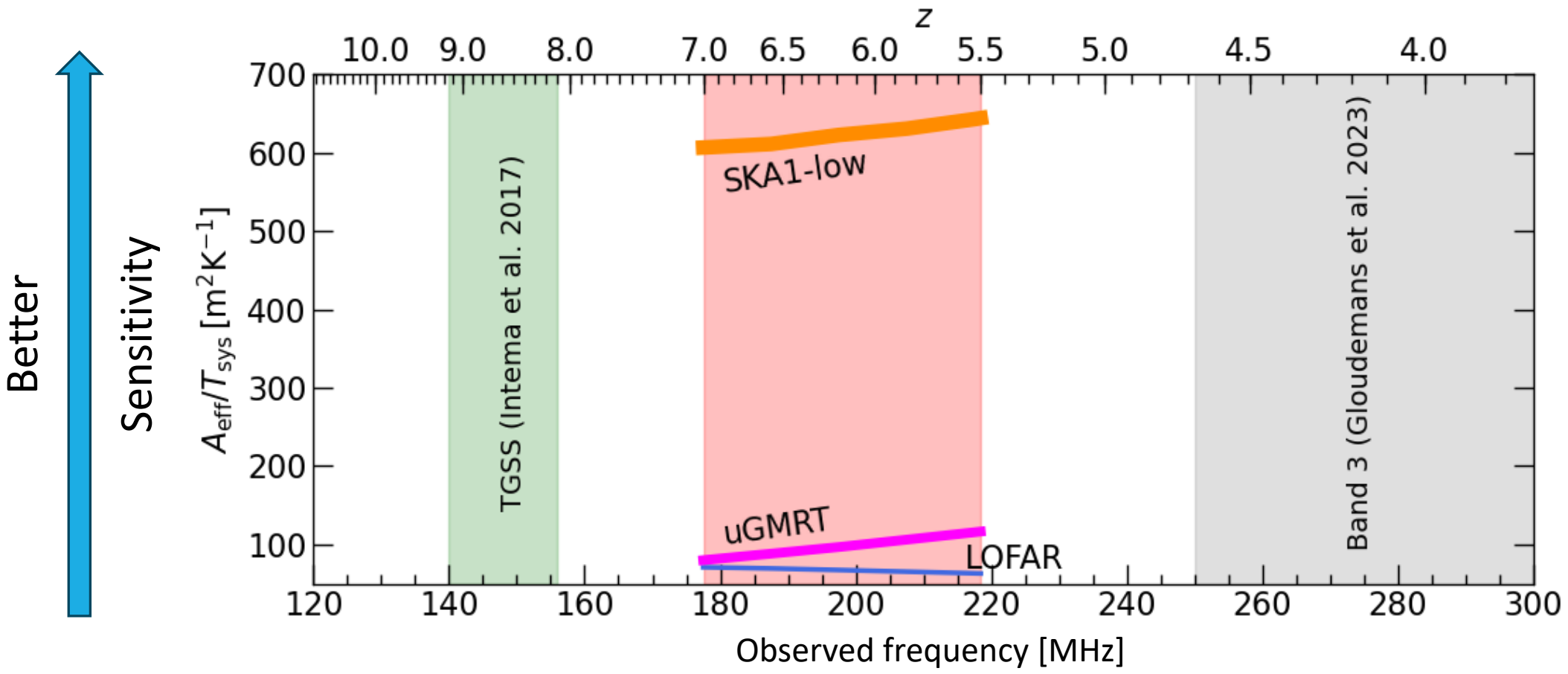
New high-z radio-loud quasars detected

Šoltinský et al. 2025



Wolf et al. 2024
Bañados et al. 2015,2018,2021,2023,2024
Ighina et al. 2021,2023,2024
Endsley et al. 2023
Gloudemans et al. 2022,2023
Shao et al. 2022
Connor et al. 2021
Liu et al. 2021
Belladitta et al. 2020
Frey et al. 2011
Zeimann et al. 2011
Willot et al. 2010
Jiang et al. 2009
McGreer et al. 2006
Fan et al. 2001

Instrumentation improving and looking forward to SKA



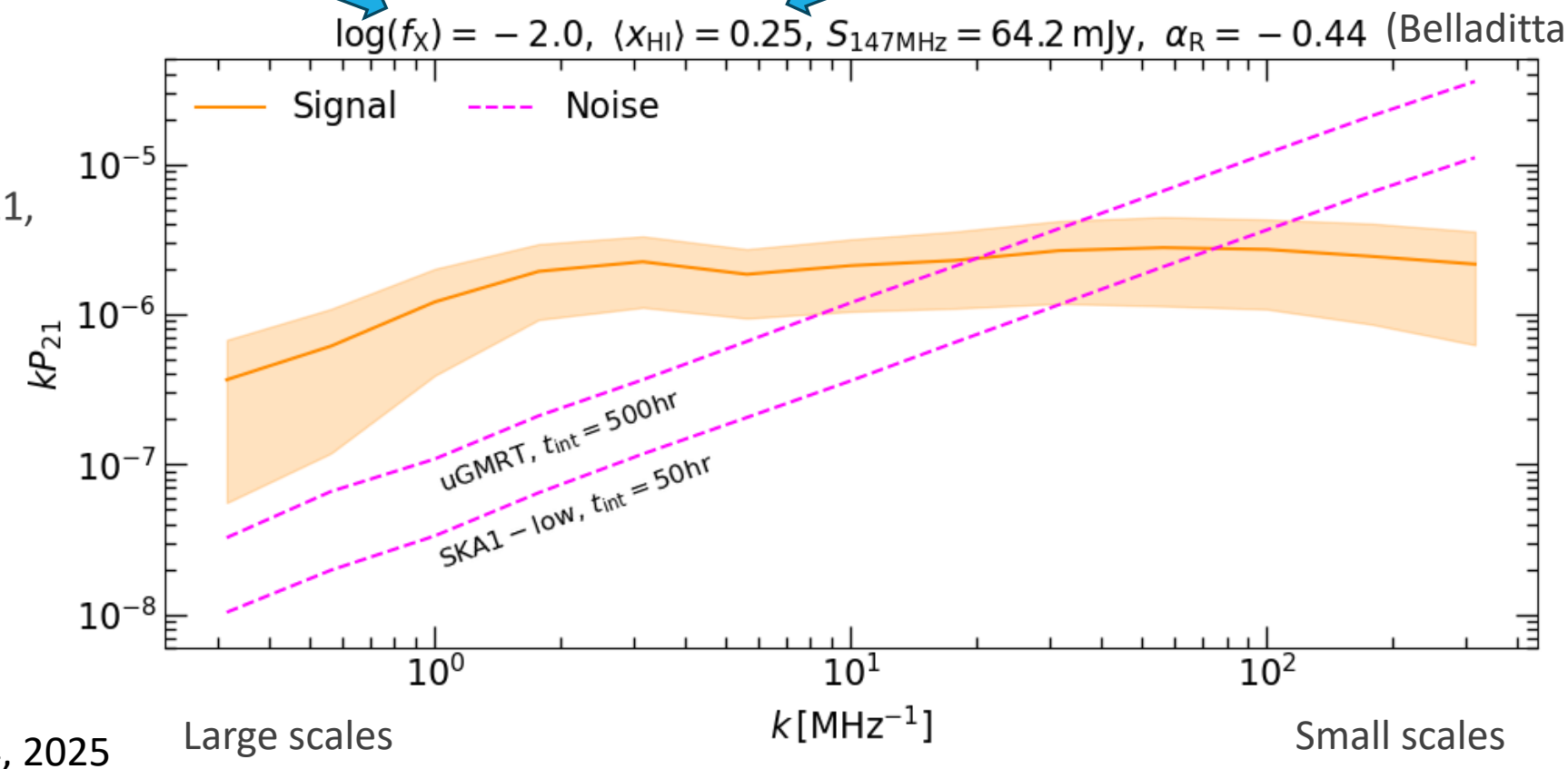
Braun et al. 2019

How?

21-cm forest power spectrum

Thermal state of the IGM

Ionization state of the IGM



(Belladitta et al. 2020)

Šoltinský et al. 2025

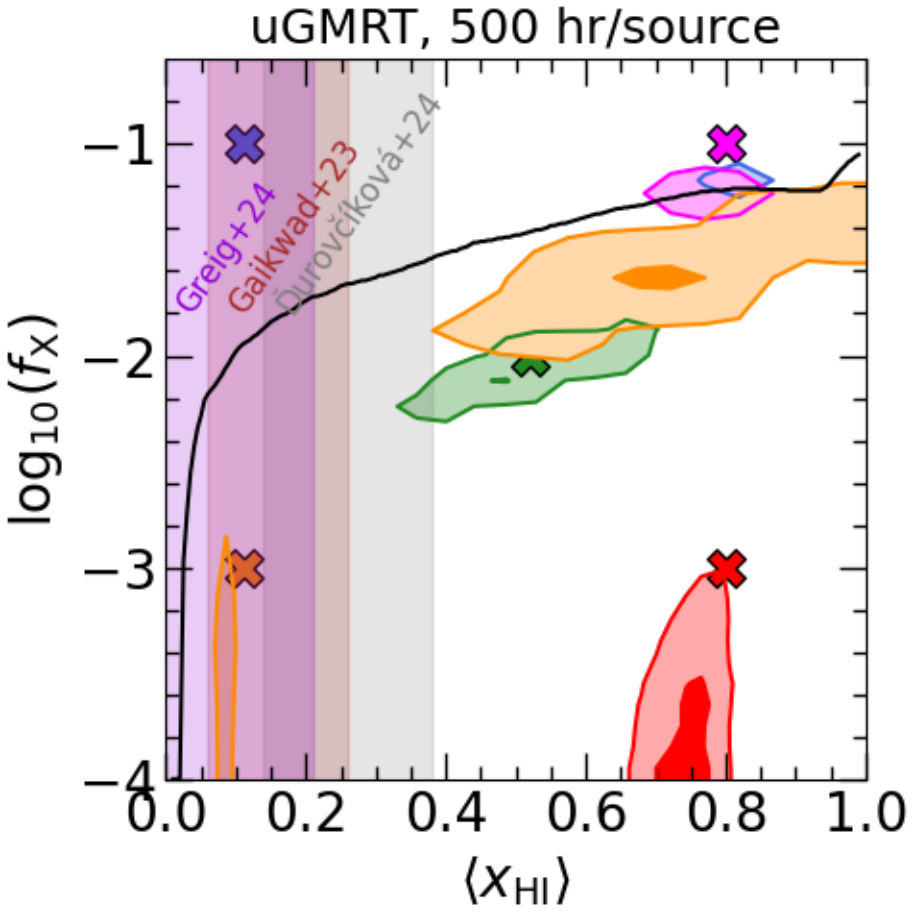
$z = 6$
21cmFAST
(Mesinger et al. 2011,
Murray et al. 2020)

Large scales

Small scales

See also
Thyagarajan 2020,
Shao et al. 2023, 2024, 2025

Constrain thermal and ionization state of the IGM at the same time



Observation of
10 spectra
of 200cMpc at z=6
Δν=22.1MHz

A null-detection disfavouring
these regions in parameter space

Šoltinský et al. 2025

Proposed observations by the uGMRT

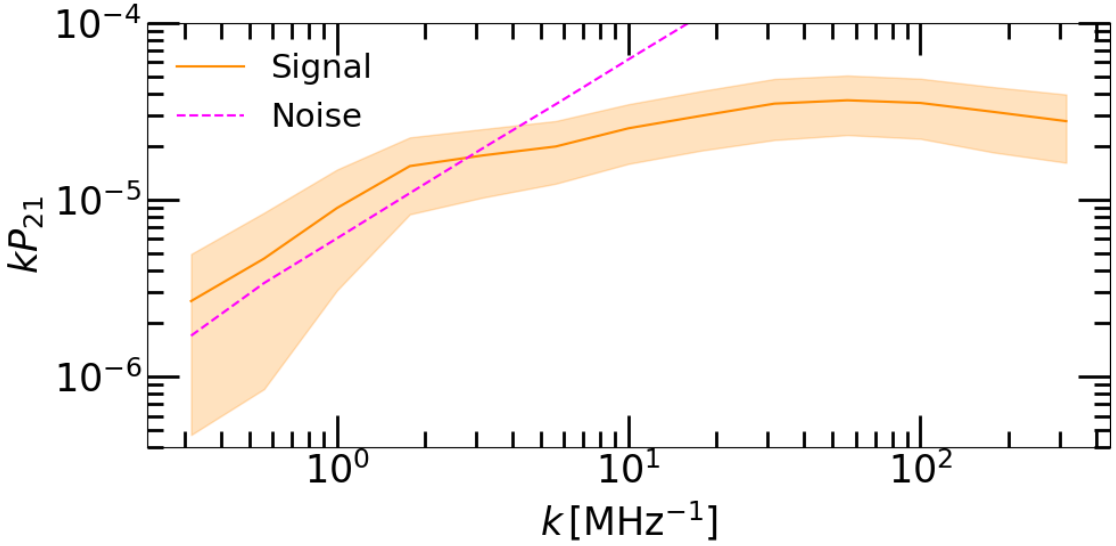
Asked for 147hr to observe the PSO J0309+27 and PSO J352-15 at z≈6

+archival data on PSO J352-15 ➡ Noise rms of ~1.5mJy/Bm and ~2.2mJy/Bm

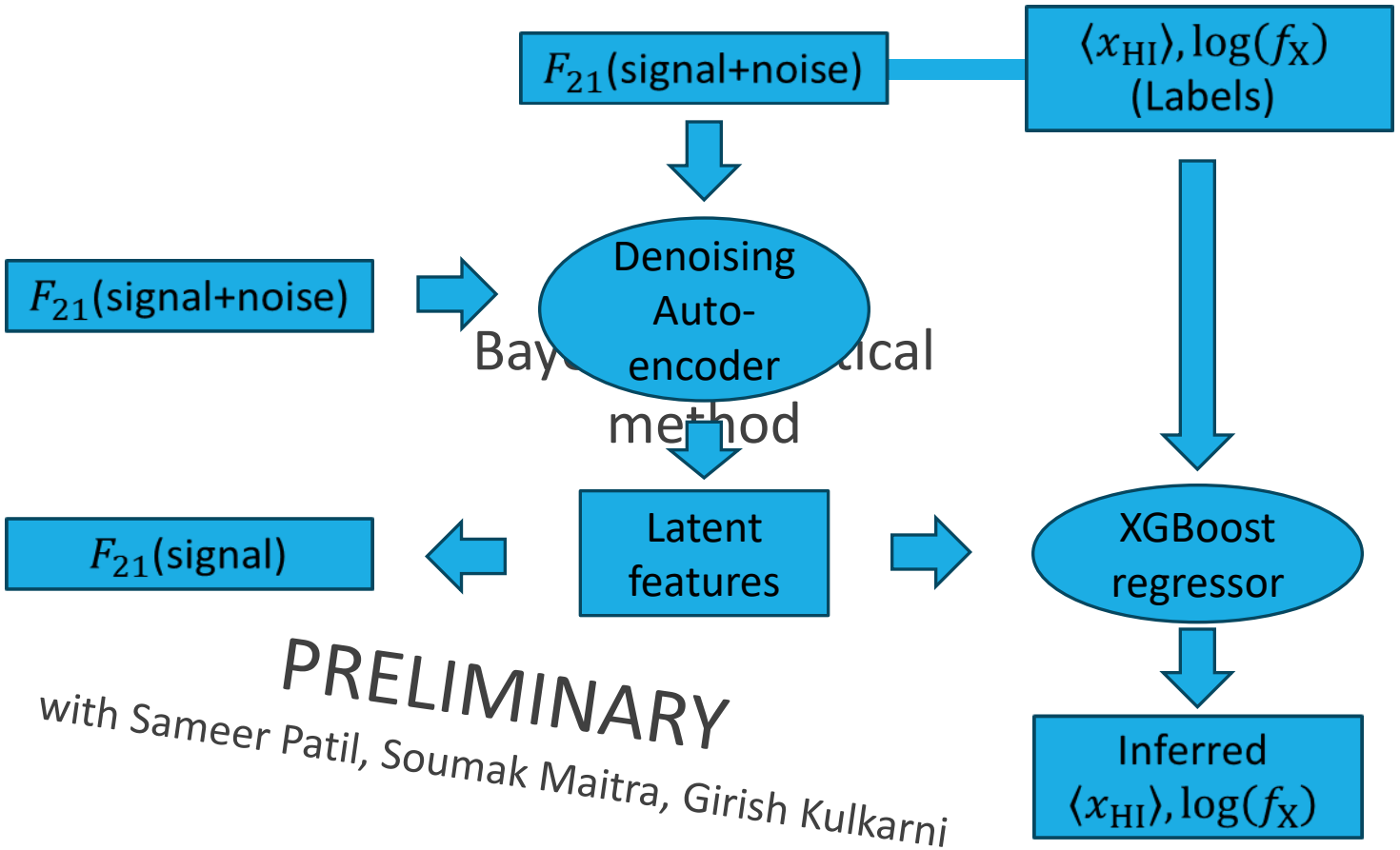
➡ Proposal rejected Normalized ~0.0265

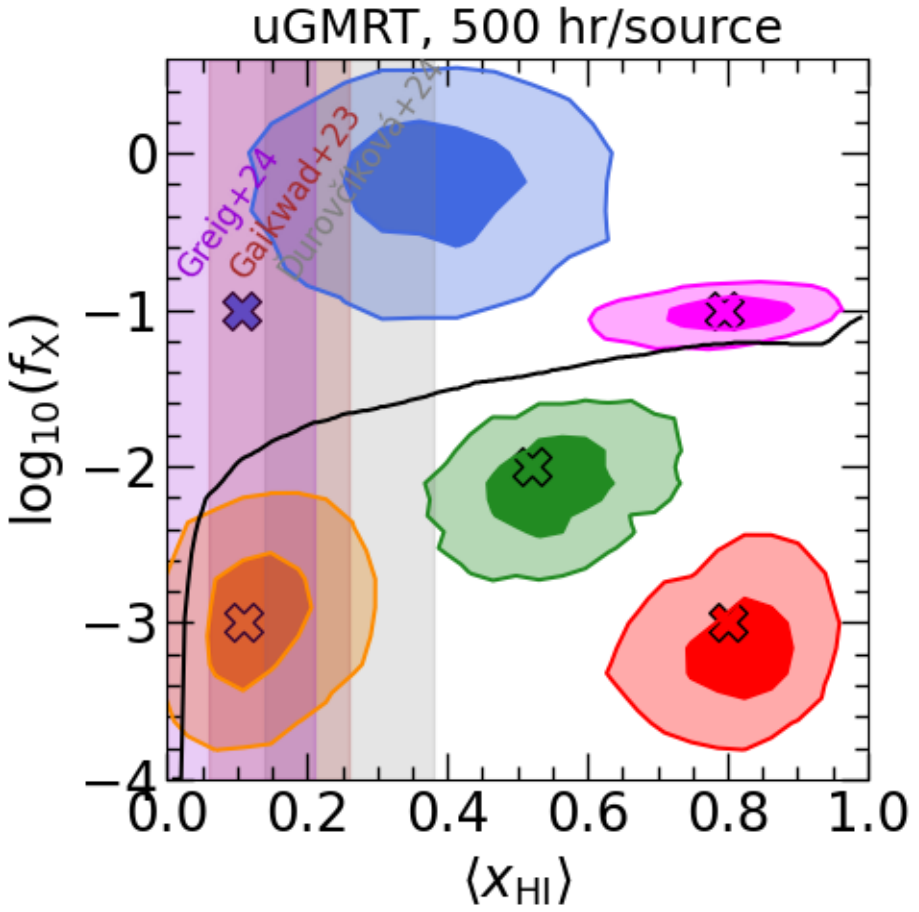
Currently analysing the archival data of the PSO J352-12

A null-detection is still very valuable



Improving our analysis (using ML)





Summary

Prospects of detecting the 21-cm forest are improving

21-cm forest is a unique probe

- Possibility of constraining
  the thermal and ionization state of the IGM
  even in the case of a null-detection

Šoltinský et al. 2025
https://arxiv.org/abs/2412.06879

Improving our analysis

- Utilizing the archival data
- ML techniques

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Acknowledgements

TŠ is supported by the Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Trieste (INAF-OATs) under the Theory grant ‘Cosmological Investigation of the Cosmic Web’ (C93C23006820005).