Observations of cosmic reionization with the 21 cm line

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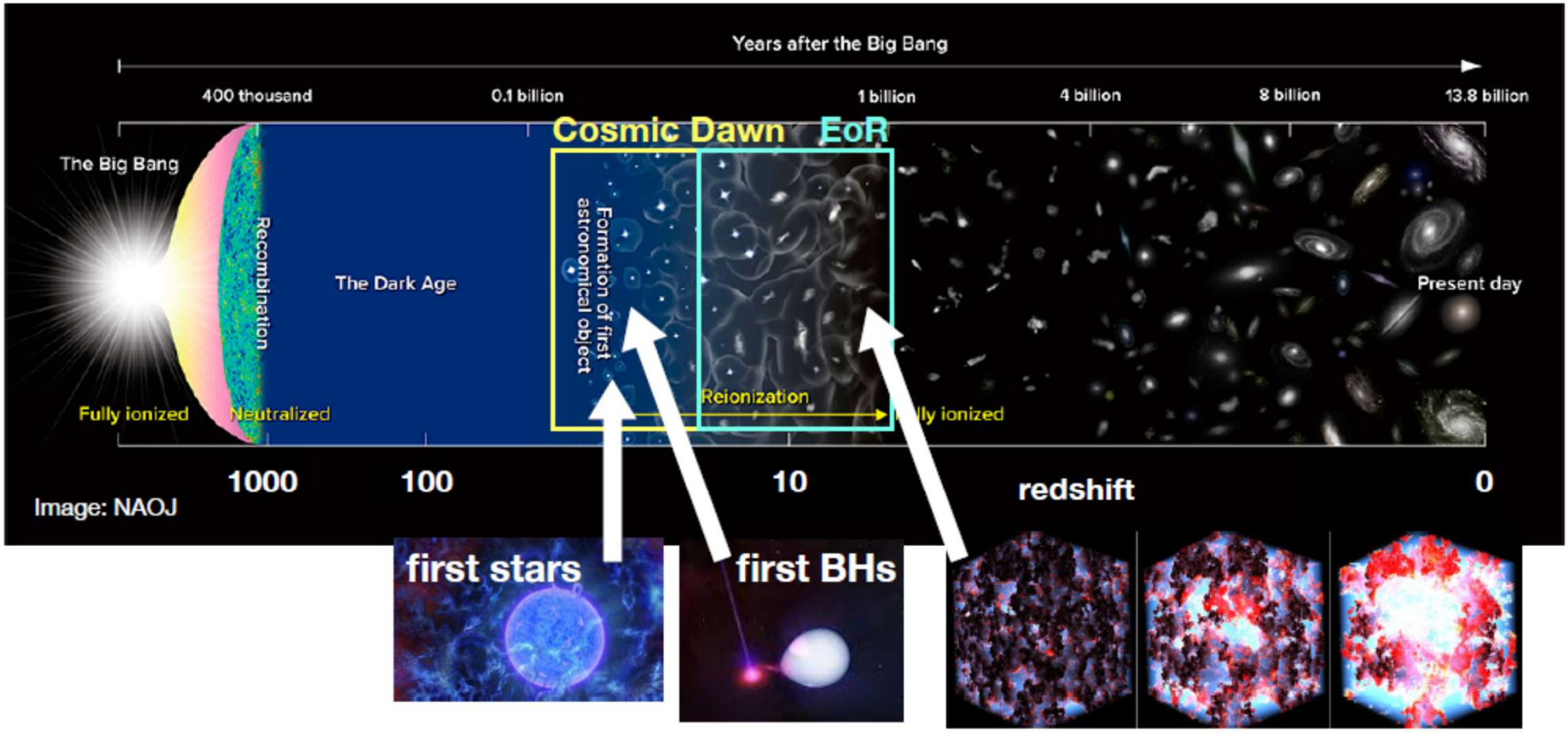
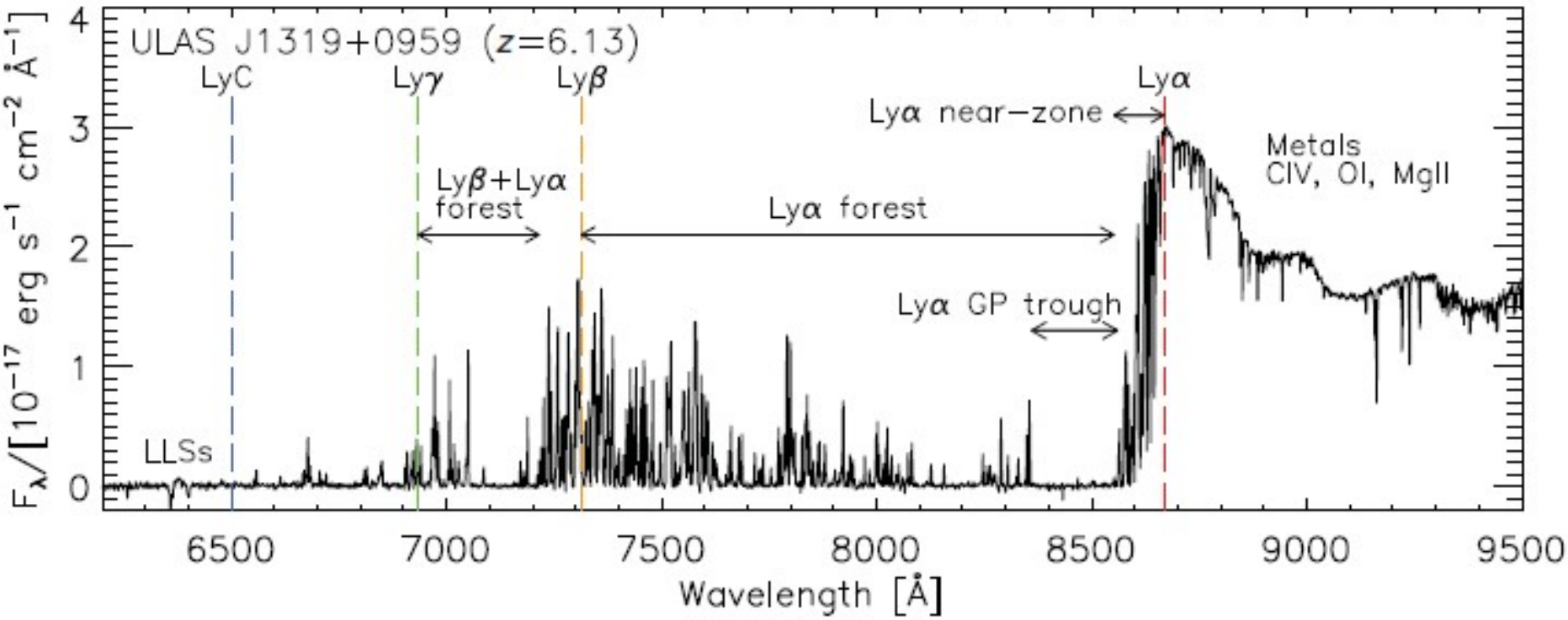
Thanks to N. Charles, E. Ceccotti, C. Konprachaya, the HERA collaboration and O. Smirnov

Cosmic Dawn and the Epoch of Reionization:



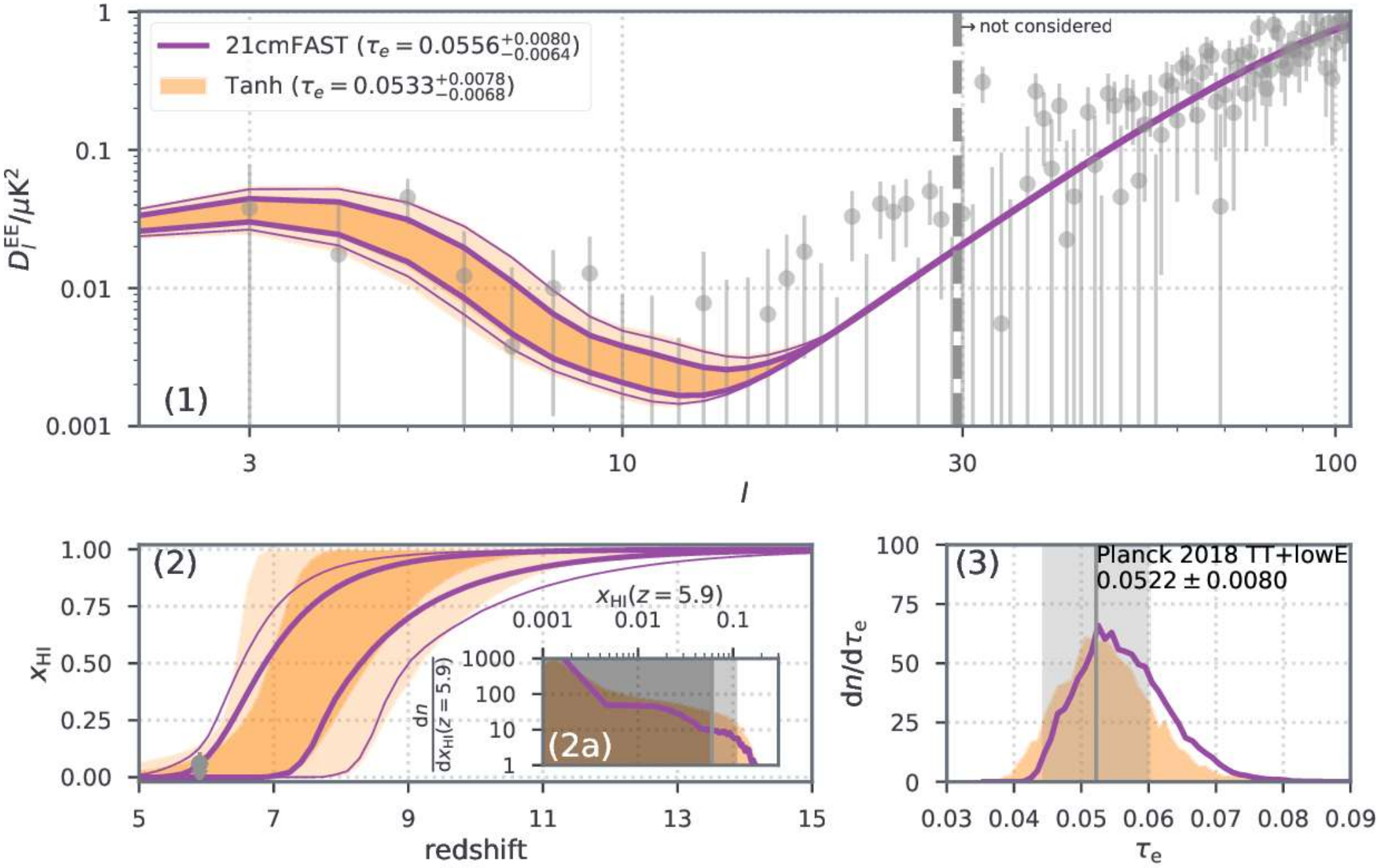
Reionization from quasar absorption spectra



Indicate that reionization was complete at z ~ 5 – 5.5

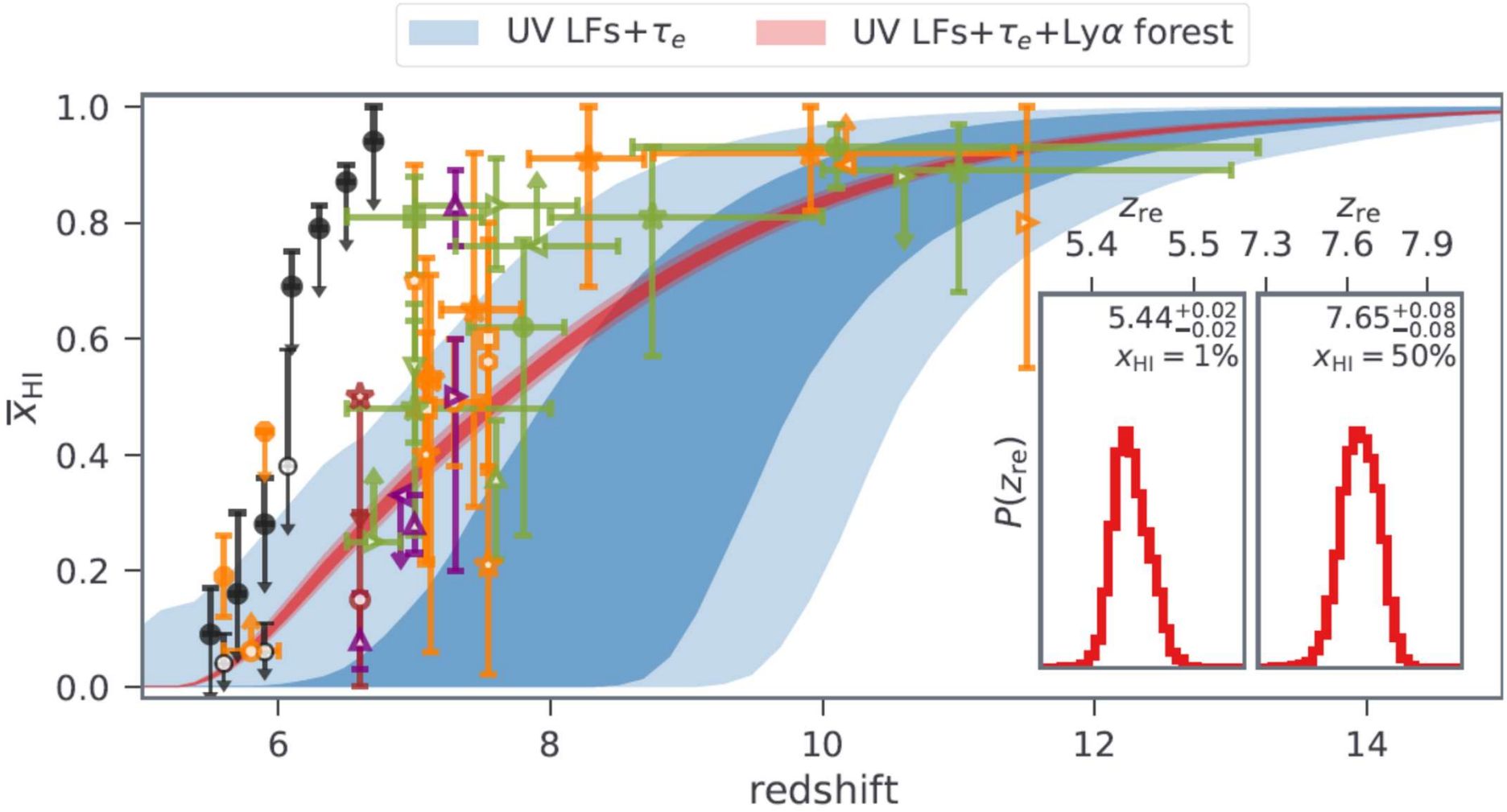
Becker et al. (2015)

Reionization history from CMB observations



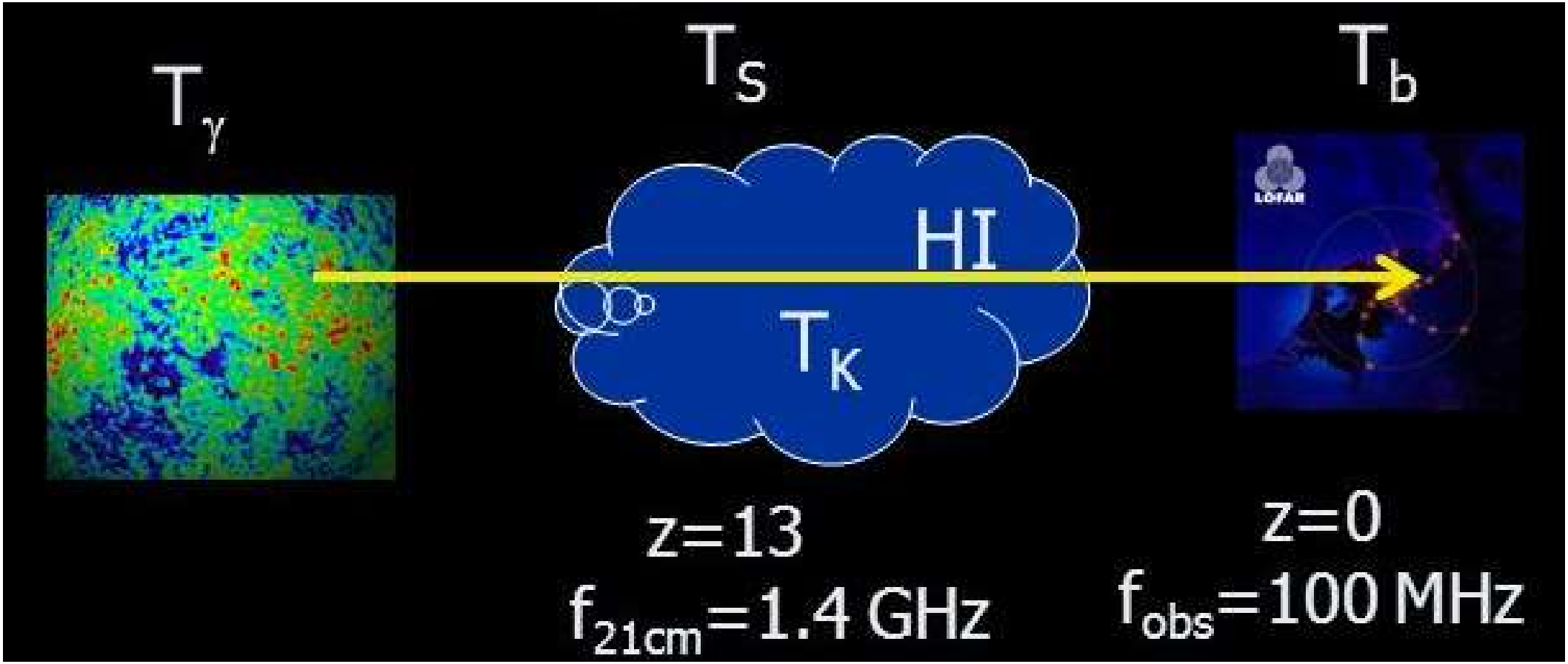
Qin et al. (2020)

Reionization from combined probes



Qin et al. (2025)

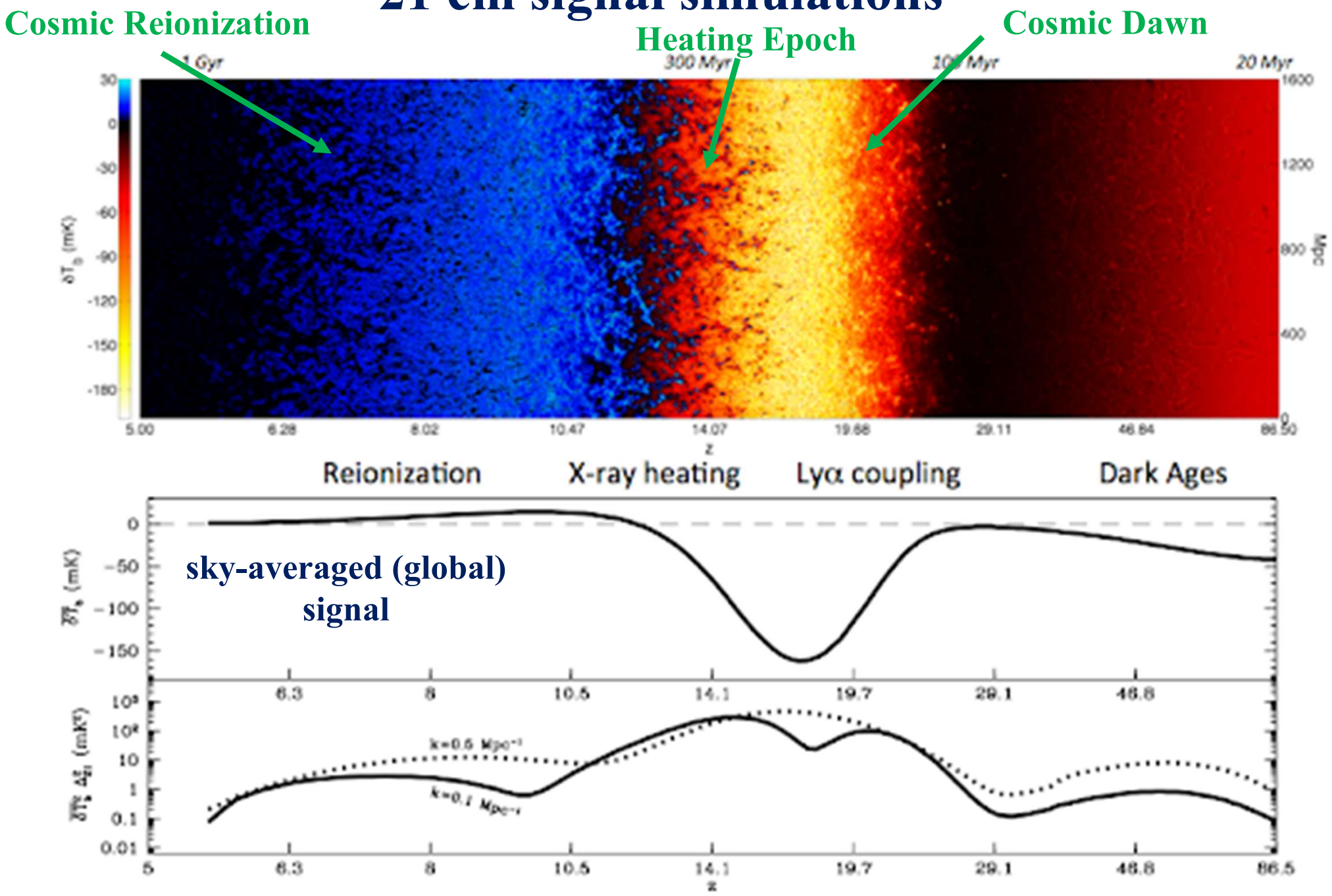
The redshifted 21 cm signal



courtesy J. Pritchard

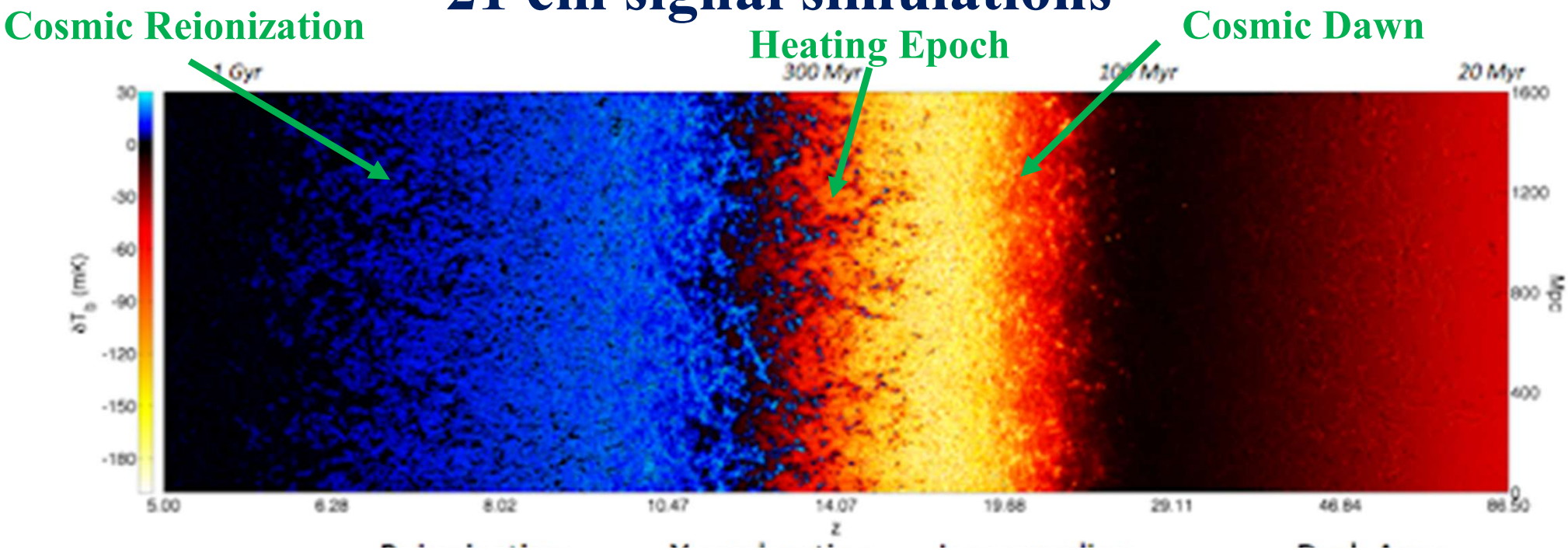
$$T_b(z) \cong 28 x_{HI}(1+\delta)\left(1-\frac{T_\gamma}{T_s}\right)\sqrt{\frac{1+z}{10}\frac{0.15}{\Omega_m}\frac{\Omega_b h}{0.0023}}$$

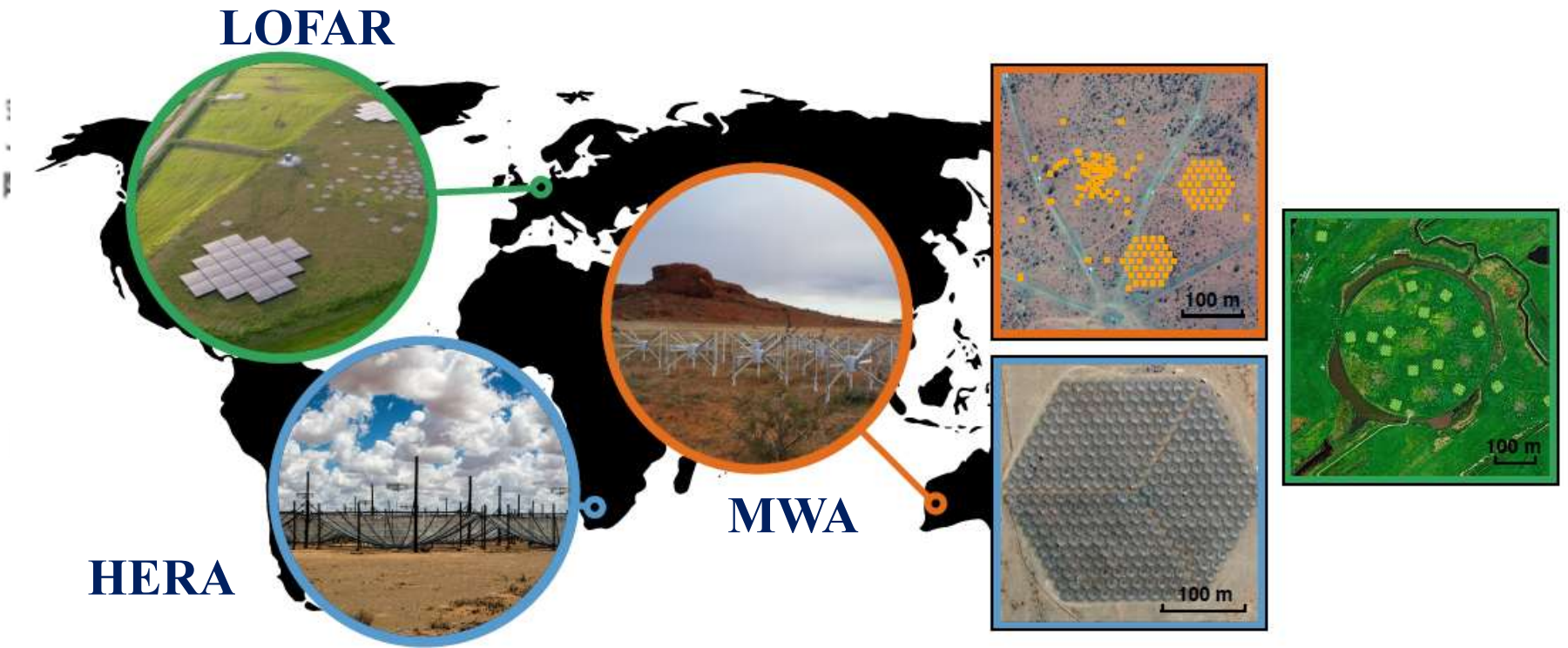
21 cm signal simulations



courtesy A. Mesinger

21 cm signal simulations





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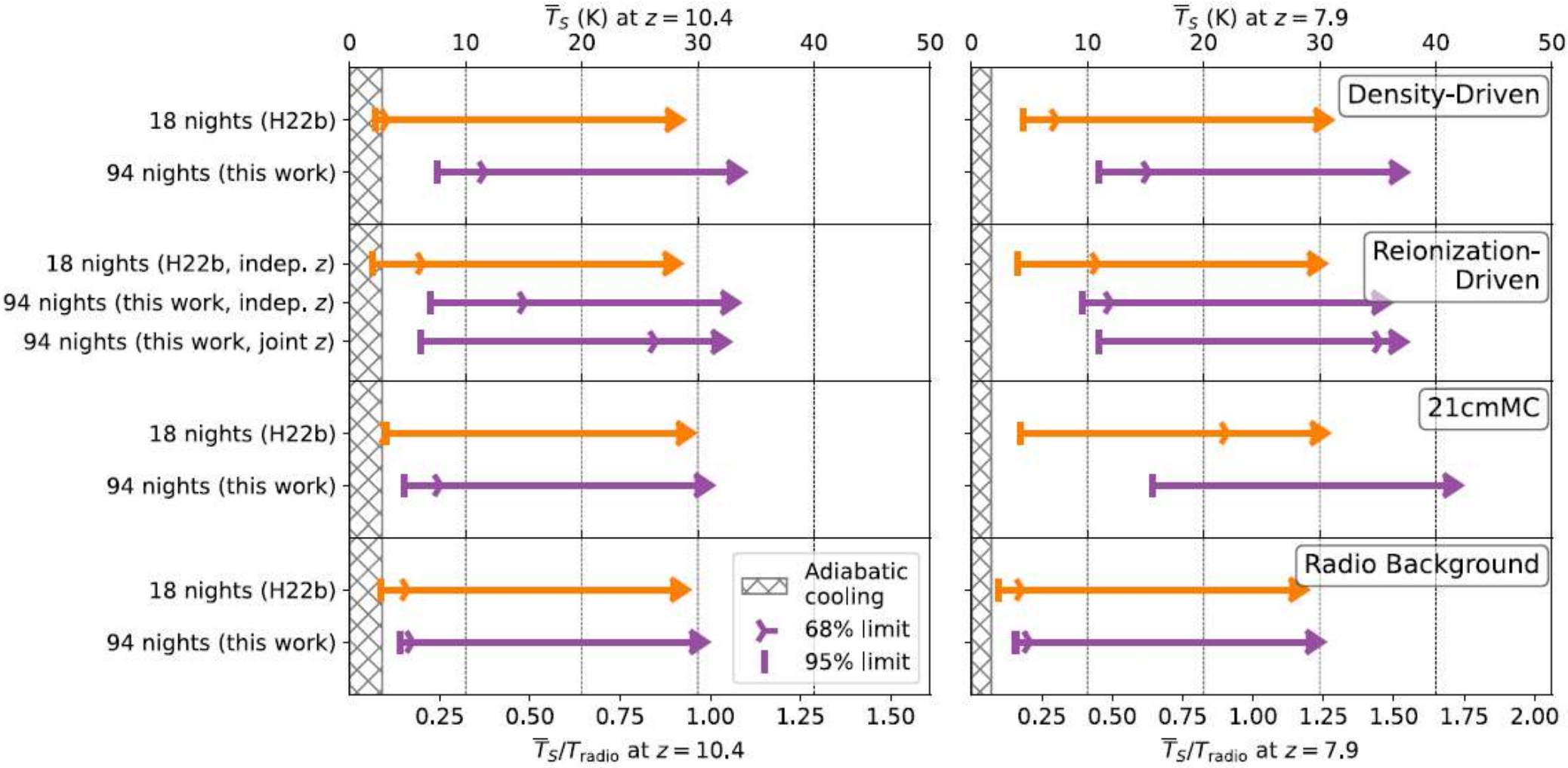
Constraints on the IGM temperature



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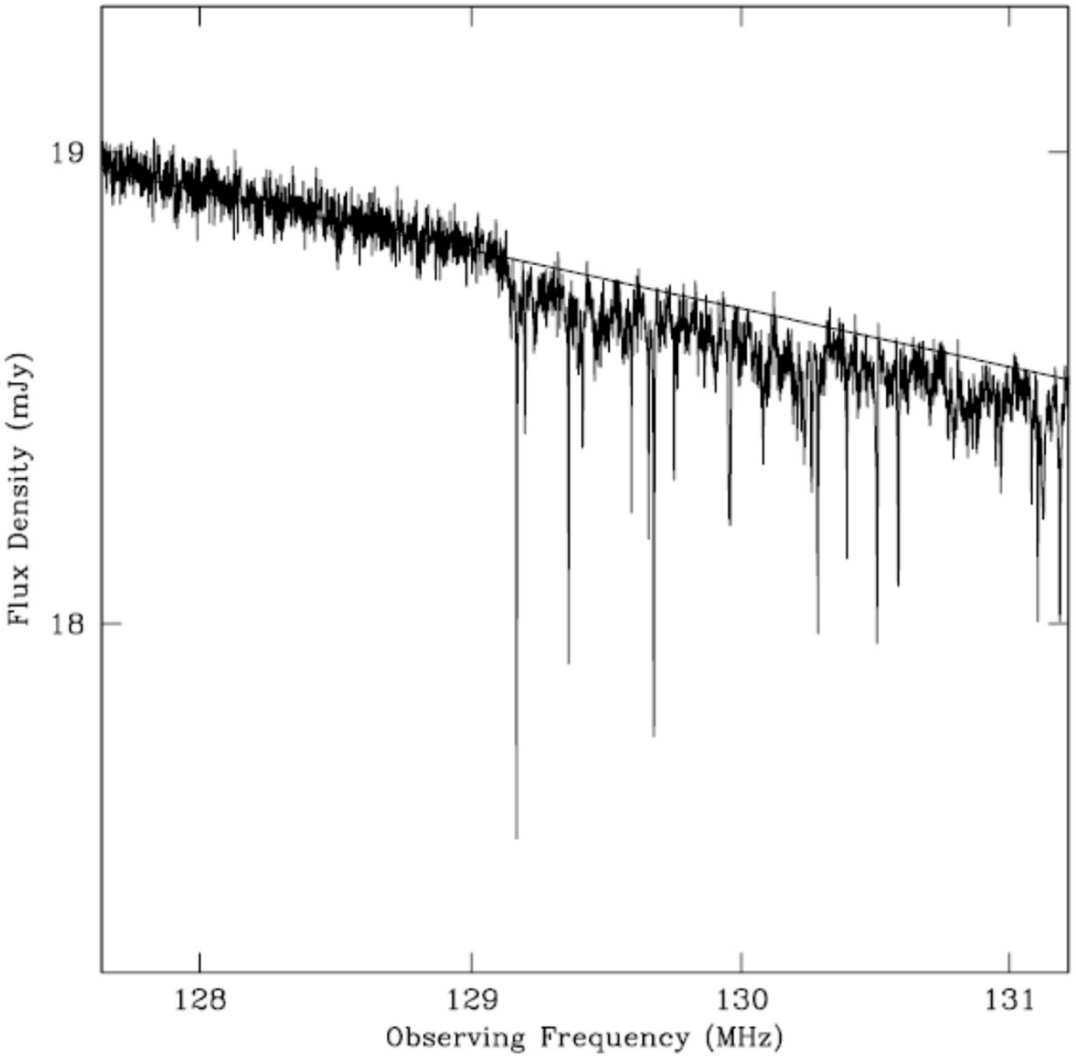
The HERA collaboration 2023 (Mertens et al., 2025; Nunhokee et al., 2025)

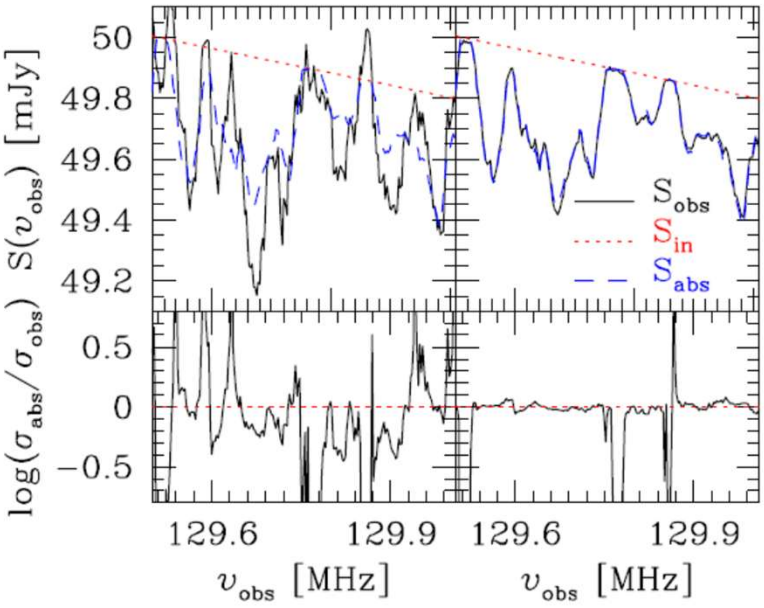
21 cm absorption against high redshift radio sources



Carilli et al. (2002)

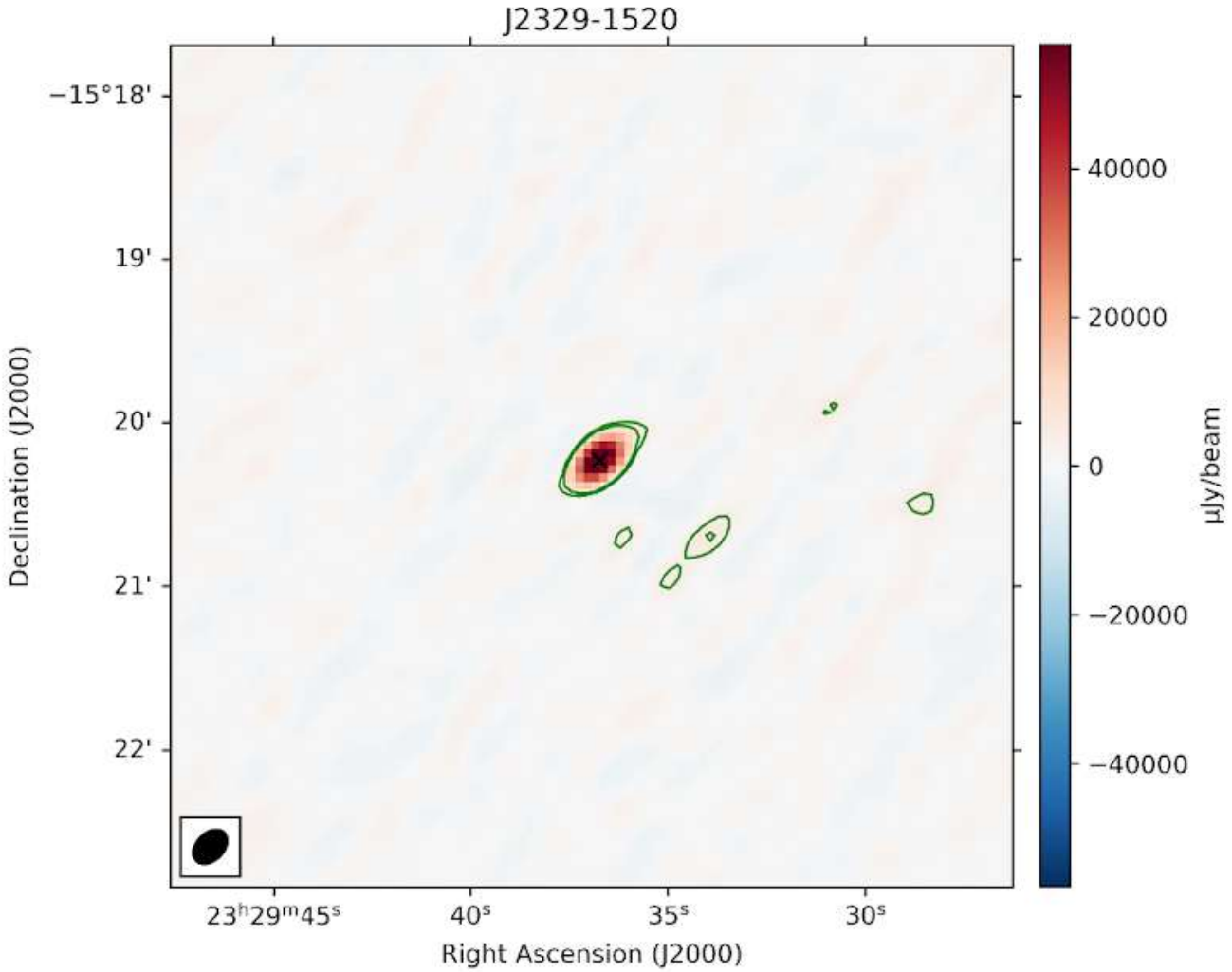
$$S(\nu) = S_0(\nu)\, e^{-\tau(z)}$$

$$\tau(z) \approx 0.092\, x_{HI}(z) \left(\frac{1+\delta(z)}{T_s(z)} \right)$$



Ciardi et al. (2014)

The case of J2329-1520 quasar @ z = 5.84



150 MHz uGMRT data; 1 mJy continuum rms noise; 80 mJy @ 216 MHz

Kongprachaya, GB et al. (submitted)

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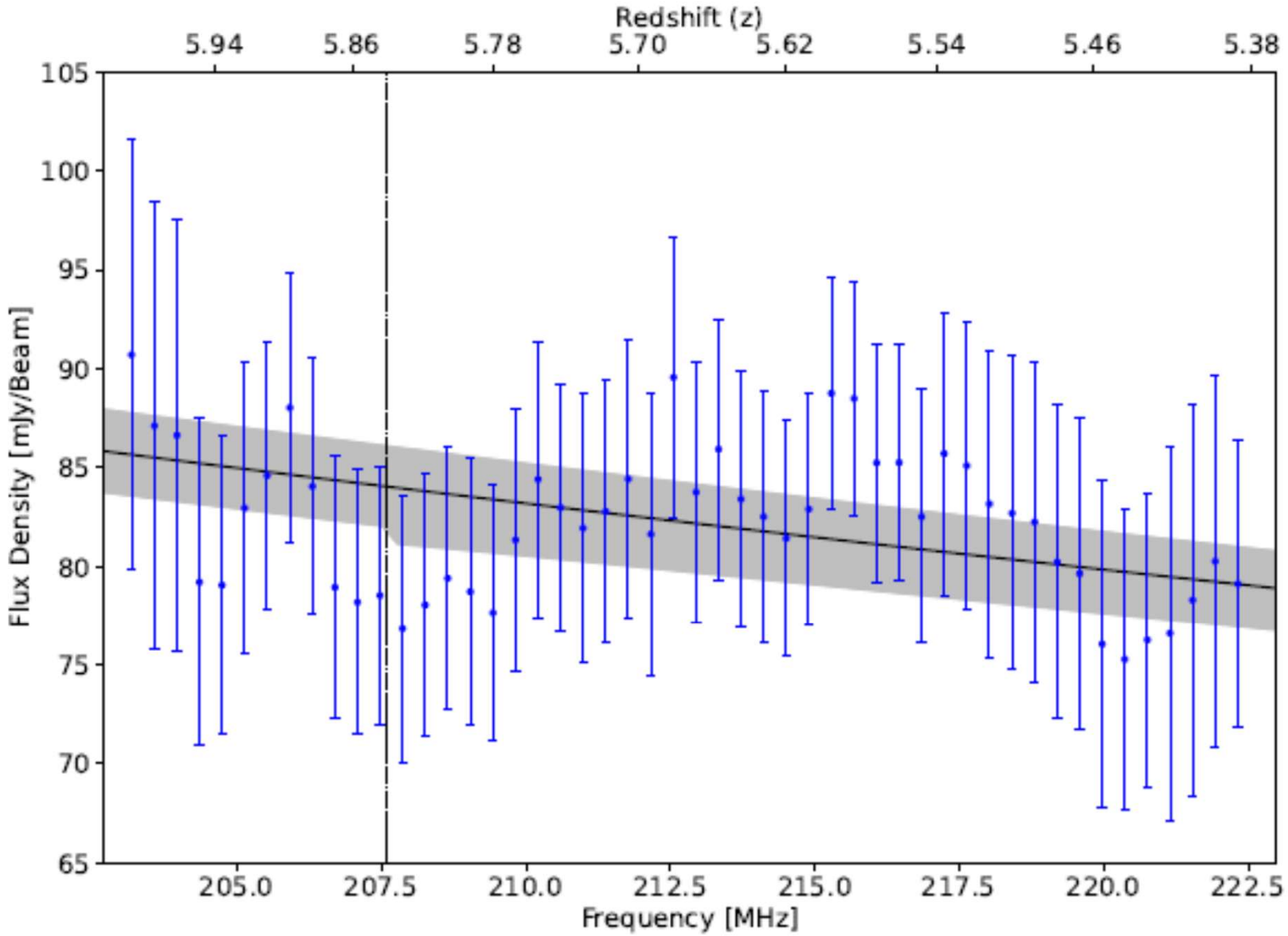
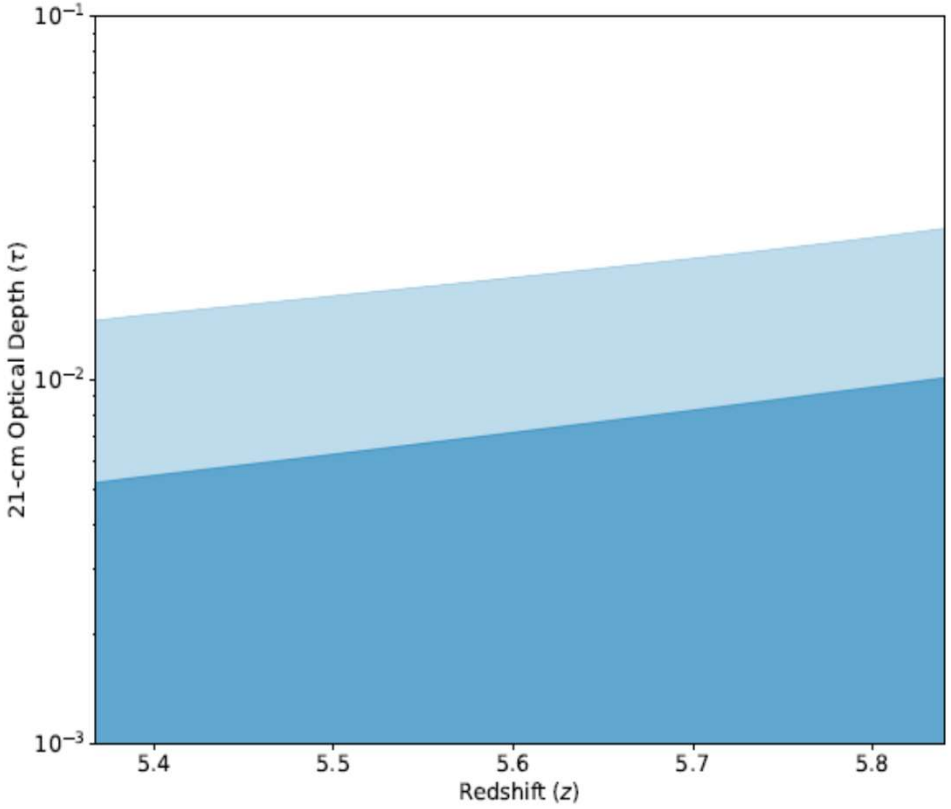
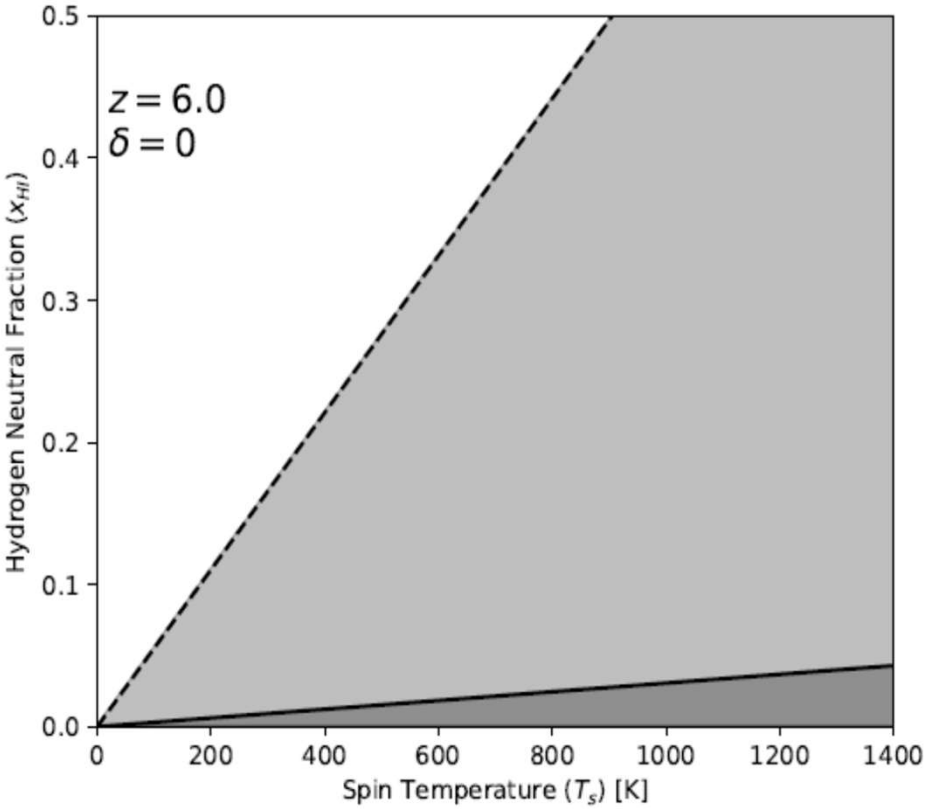


~8 mJy rms noise per (390 kHz) channel

Reionization constraints from 21 cm absorption observations





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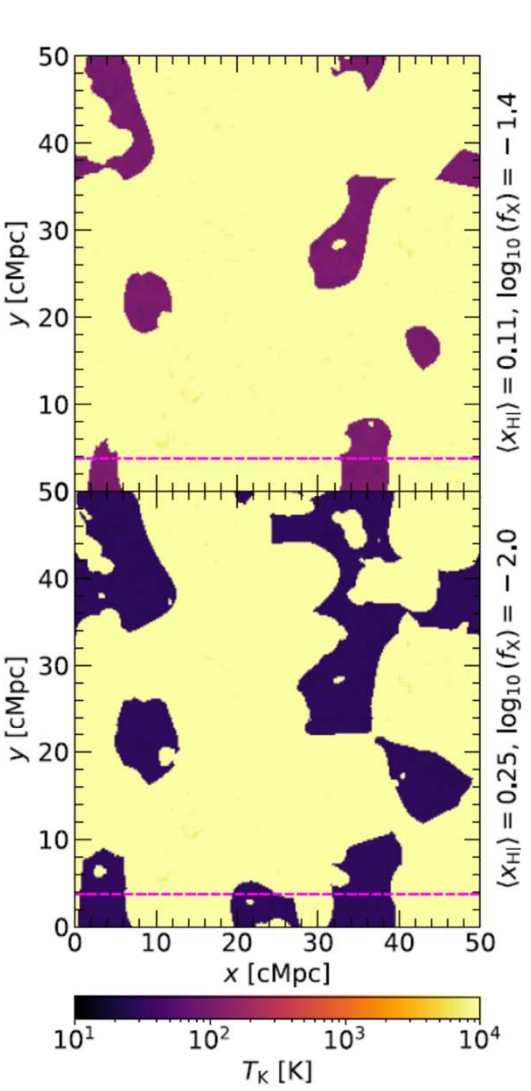
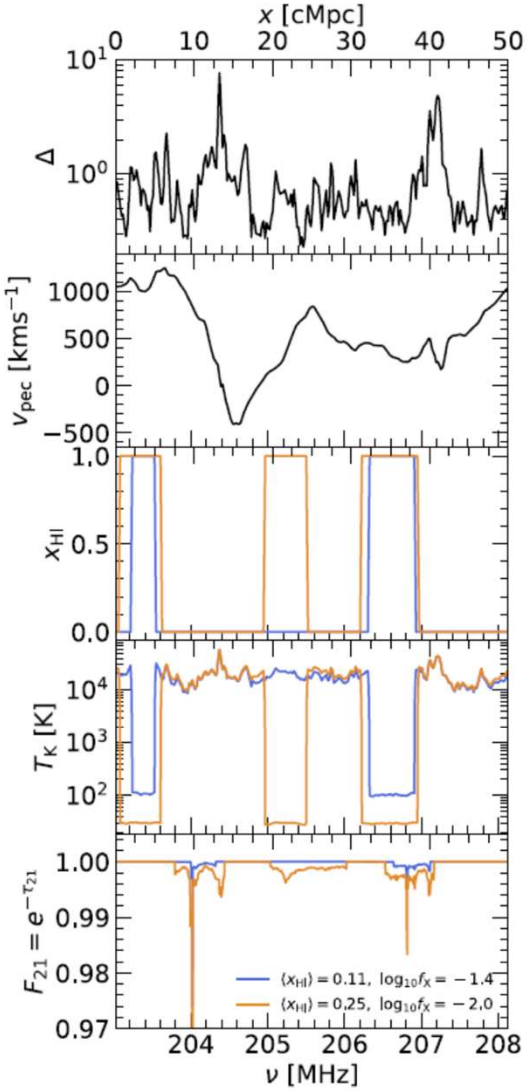
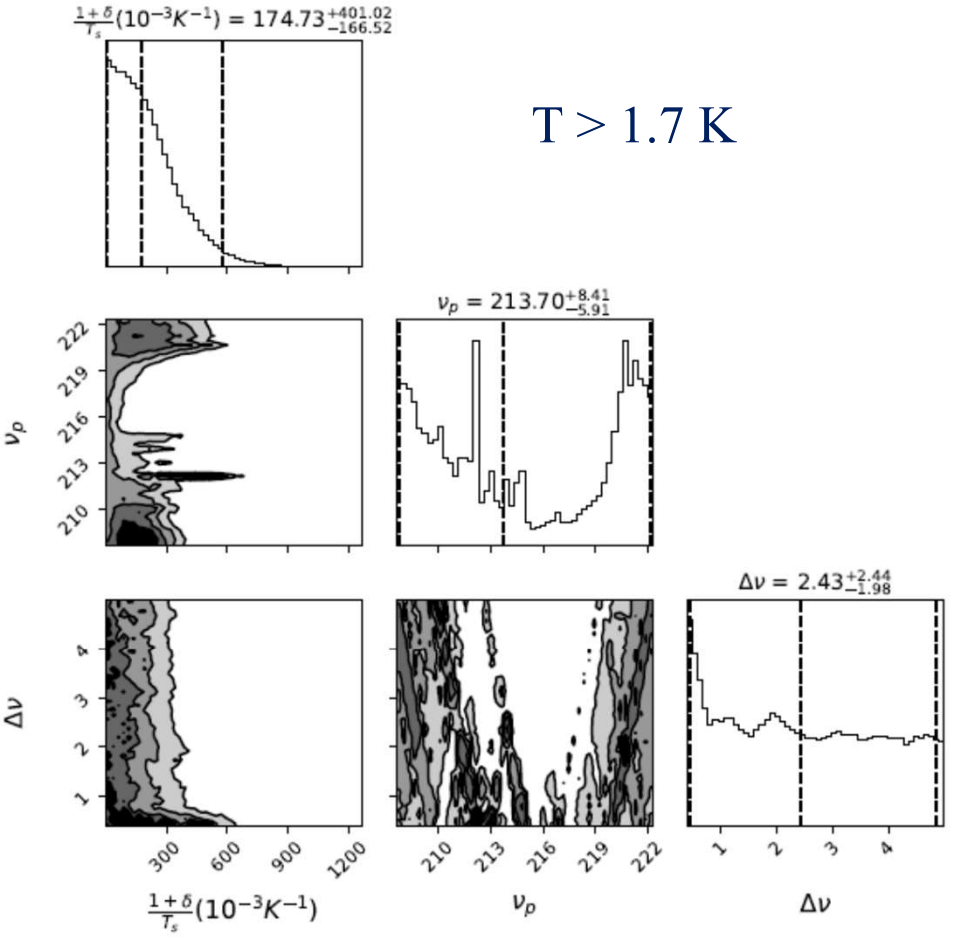




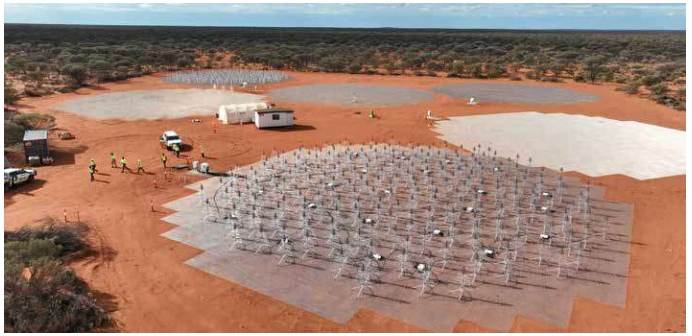


T > 1.7 K

Soltinsky et al. (2024)

Conclusions and future outlooks

- **Observations of the 21 cm are an excellent probe of Cosmic Dawn and Reionization;**
- **Recent observations have started to place constraints on the IGM temperature at $z > 8$ to be warmer than a few Kelvin → heating sources already at $z > 8$, most likely X-ray binaries;**
- **Observations of 21 cm absorption against high redshift radio sources start to become a viable IGM probe**
- **Observations of the PSO J2329-1520 quasar at $z = 5.84$, led to the first constrain on the 21 cm optical depth in the $5.38 < z < 5.84$ range to be smaller than 0.03. If we assume that neutral HI pockets still exist then their temperature should be higher than 1.7 K**
- **Stay tuned for updates from SKA pathfinders, 21 cm absorption towards more sources and first SKA-low observations!**



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THANK YOU