Latest constraints on the epoch of reionisation from CMB data

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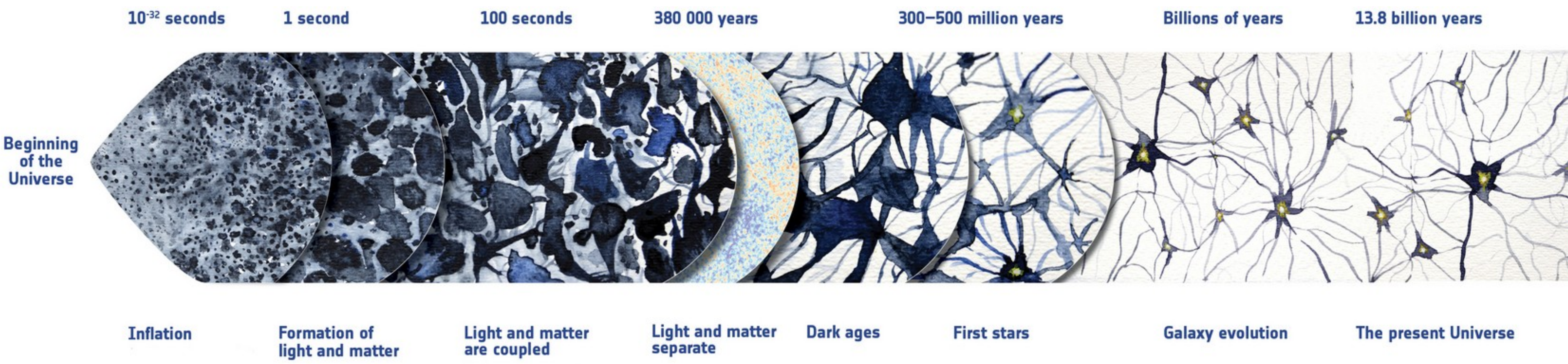
L'Univers du pôle A2C: épisode 7, 13/12/2024

The standard model of cosmology

- The ΛCDM paradigm: a (relatively) simple model, with many successes…



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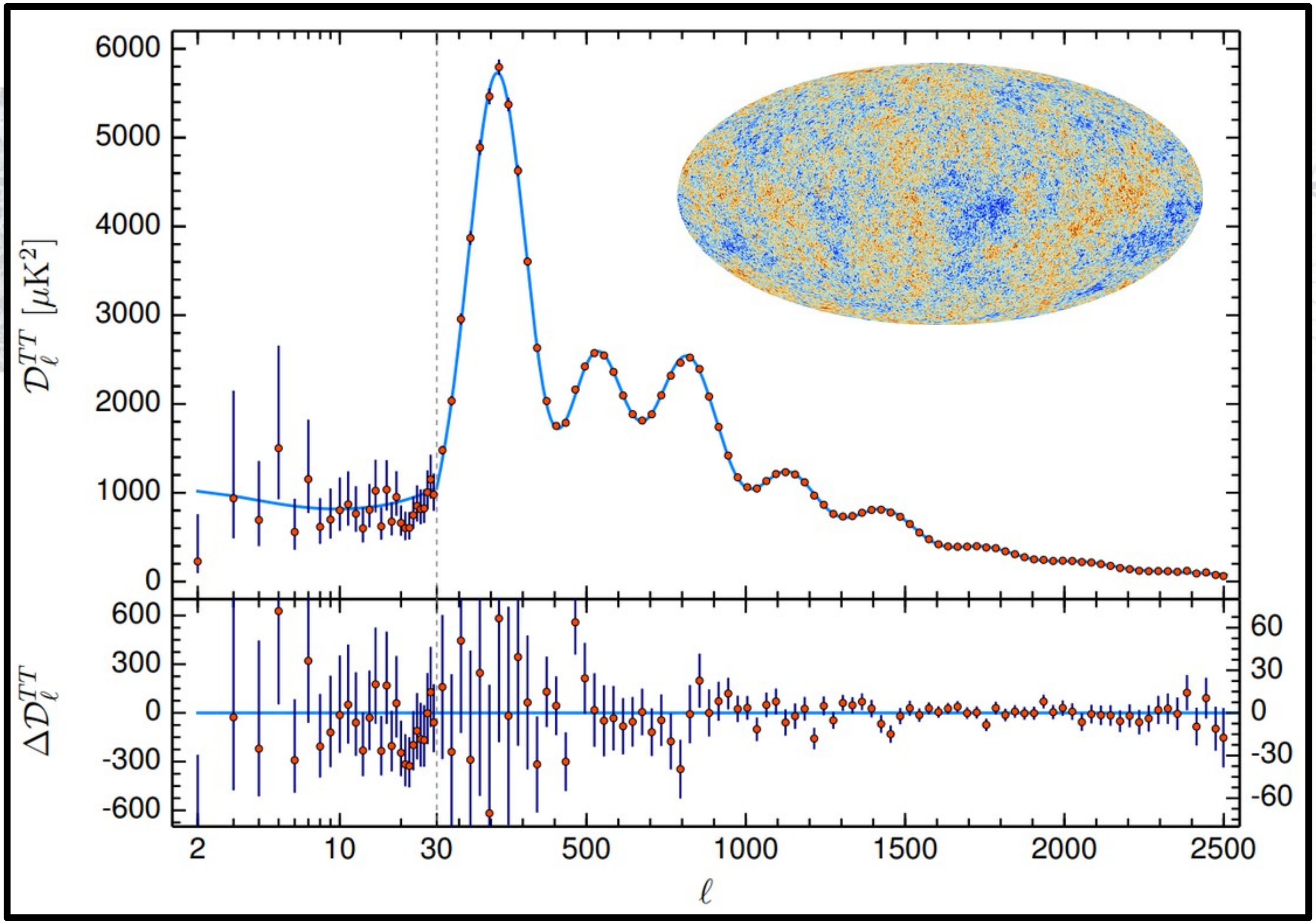

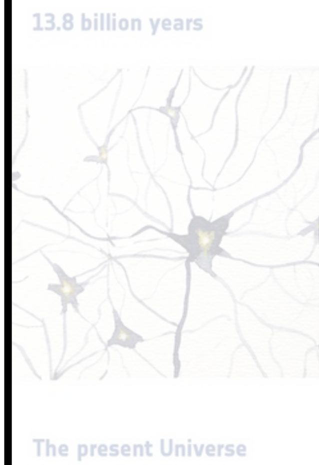

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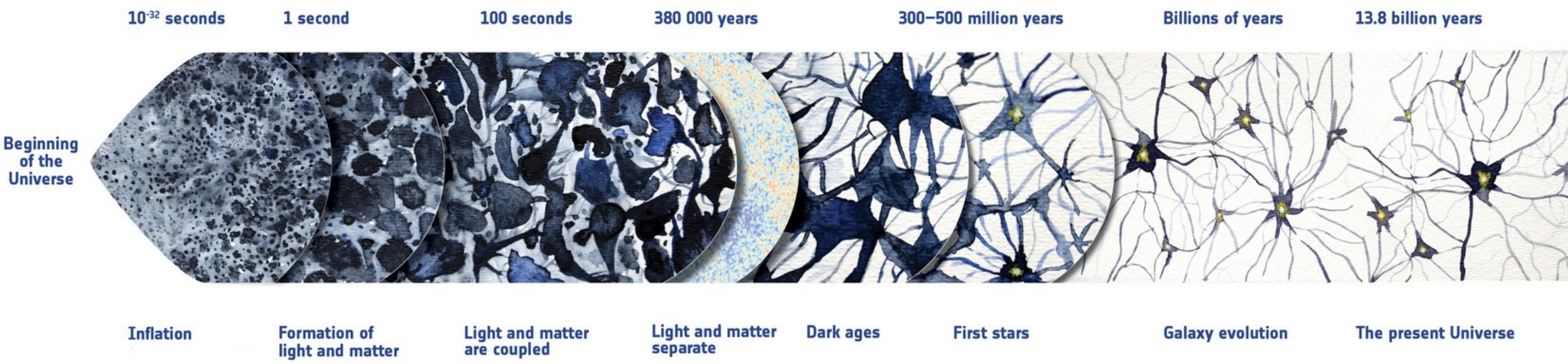

- ... but rests on some pillars that are "shrouded in darkness":
  - Primordial Universe, inflation
  - Dark ages & reionisation
  - Dark matter (''CDM'')
  - Dark energy (''Λ'')

- ... and is shaken by some persistent tensions :
  - H_0 discrepancies
  - σ_8 tensions
  - ISW excesses
  - CMB "anomalies"

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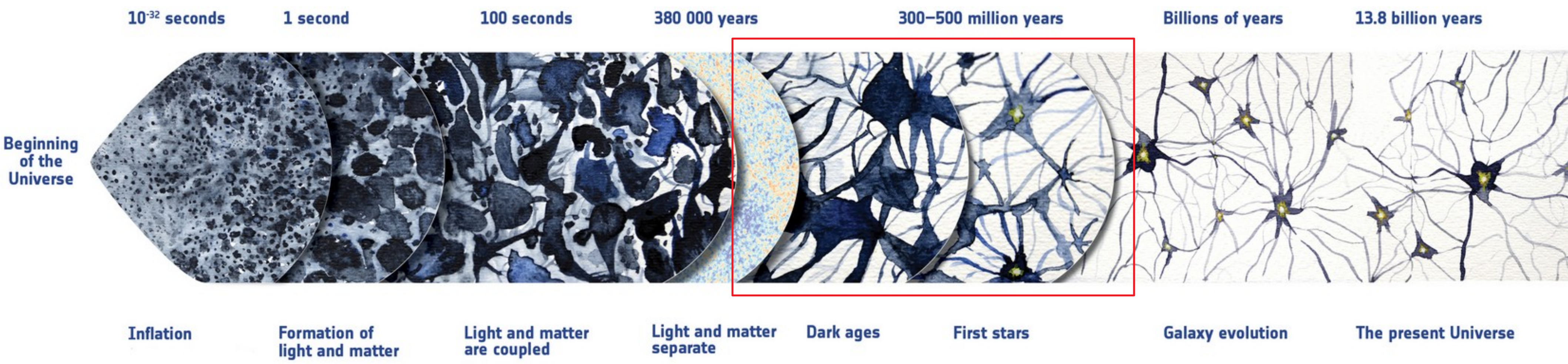

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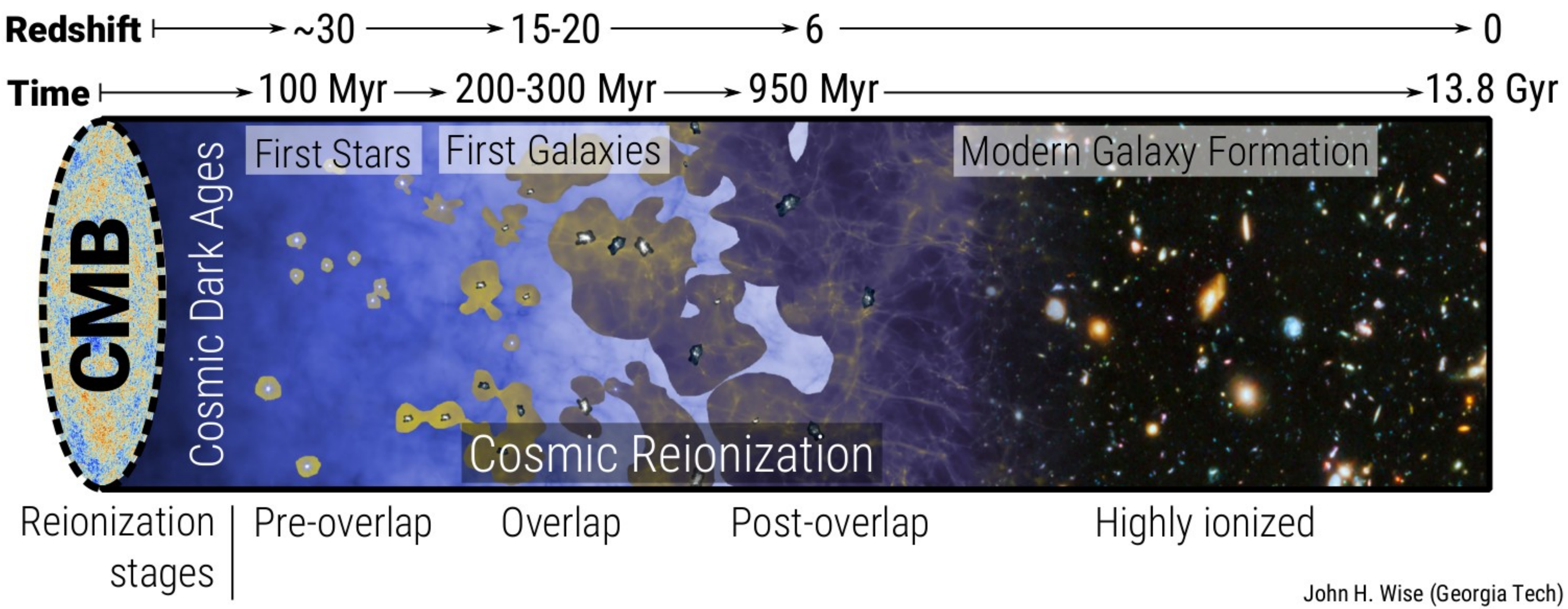
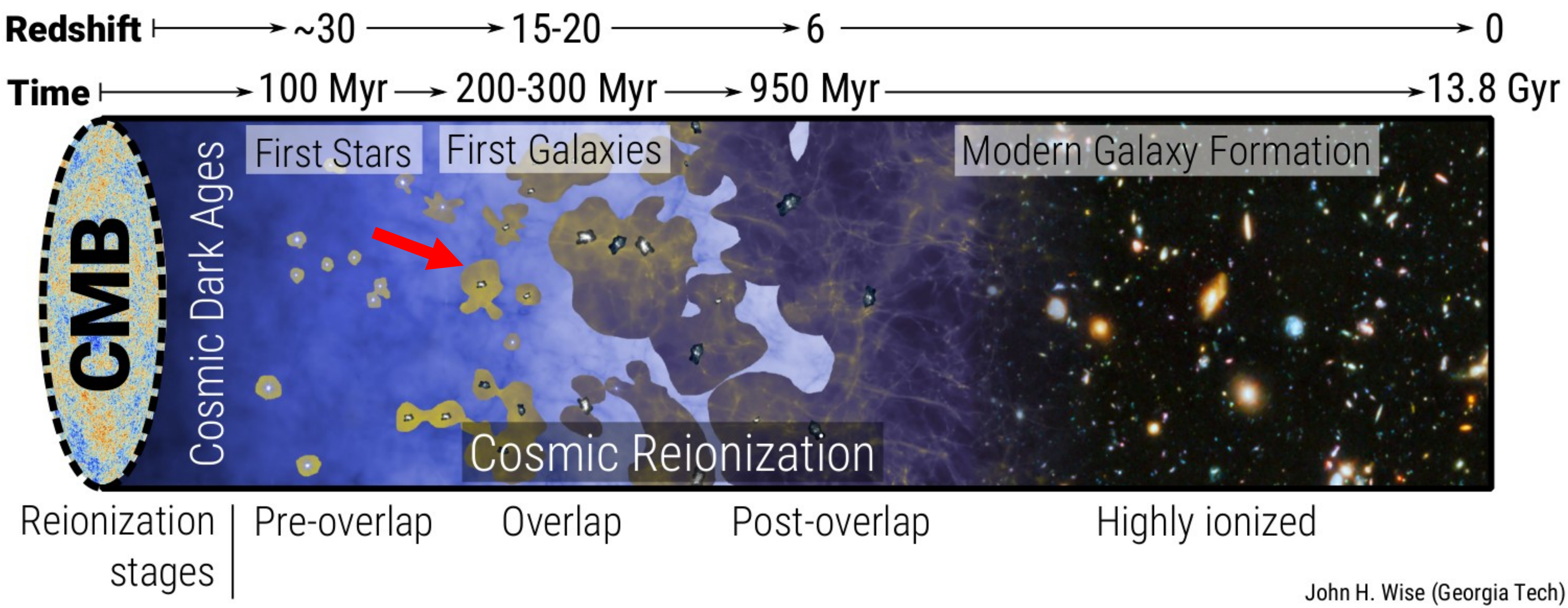
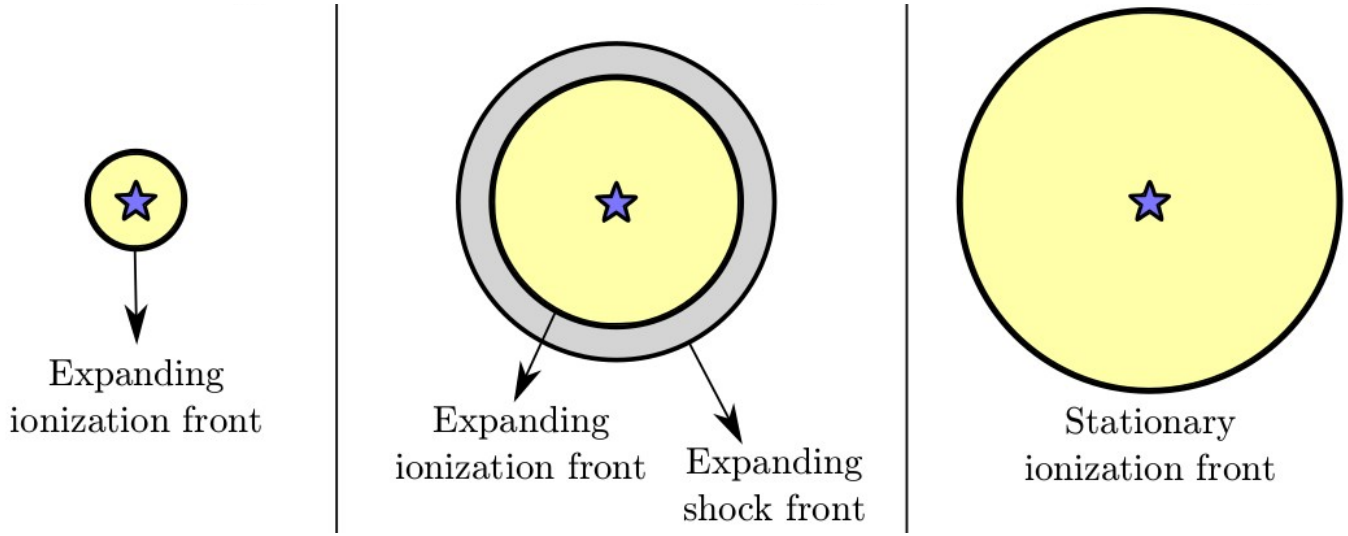
The epoch of reionisation



John H. Wise (Georgia Tech)

The epoch of reionisation





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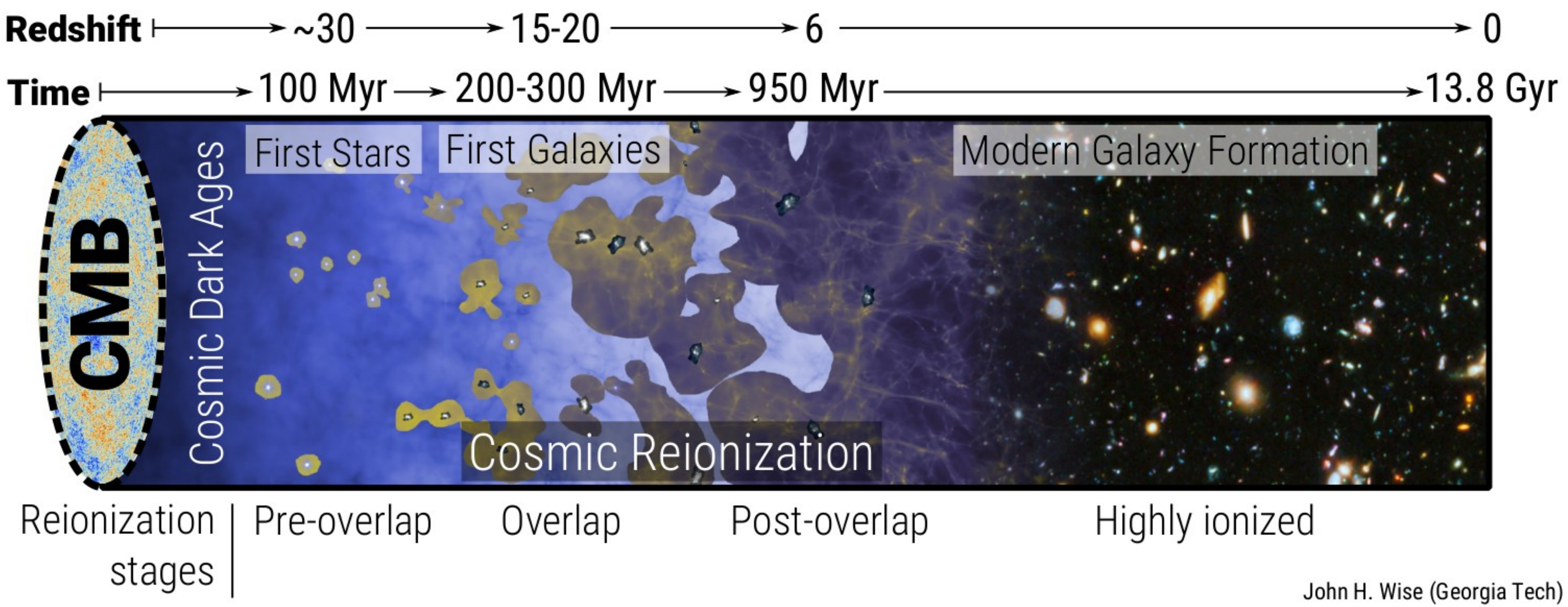
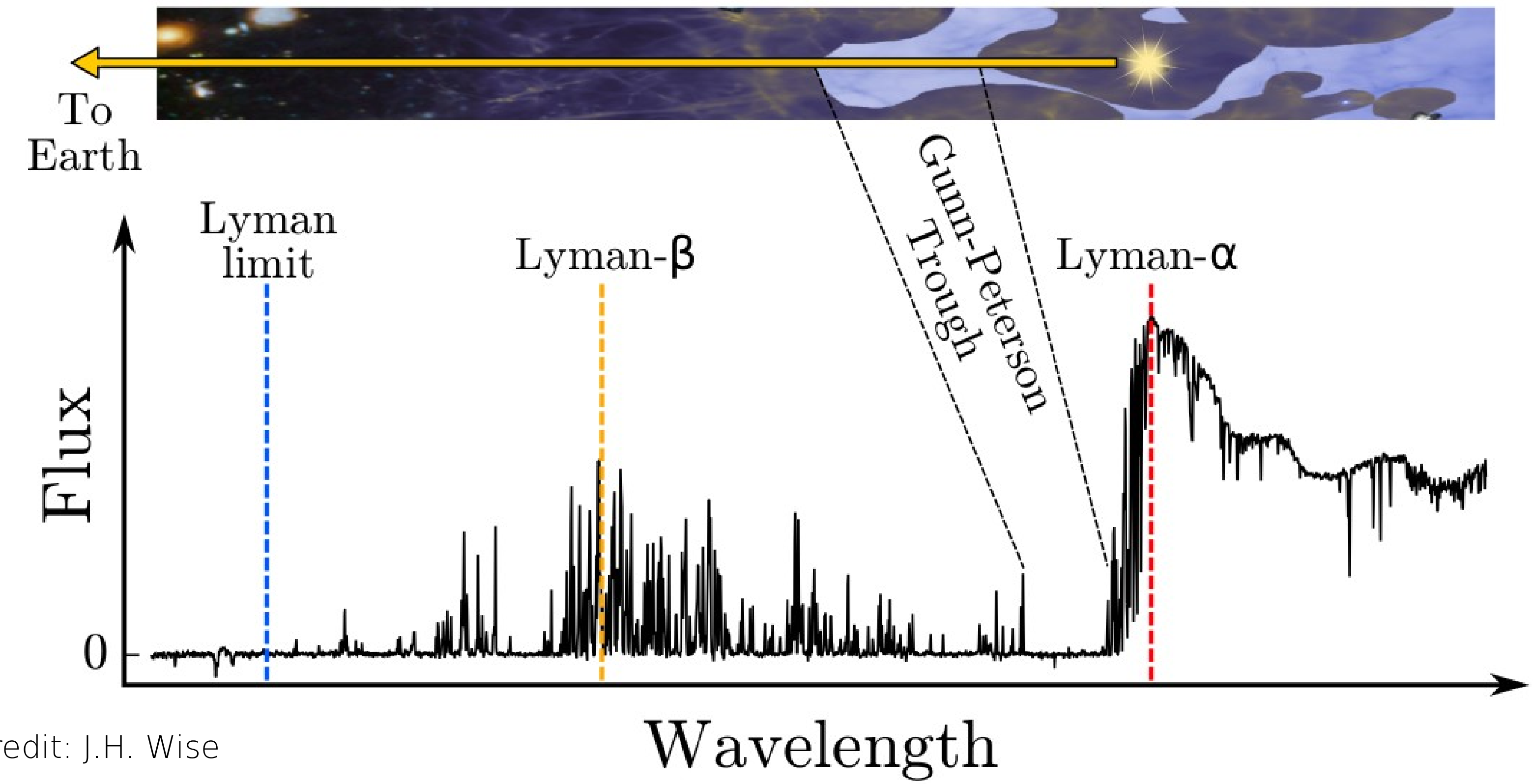


The transition from the neutral intergalactic medium (IGM = H + He) left after the Universe recombined at z~1100 to the fully ionised IGM observed today

The epoch of reionisation

First evidence from distant quasars (Gunn & Peterson 1965)



Credit: J.H. Wise

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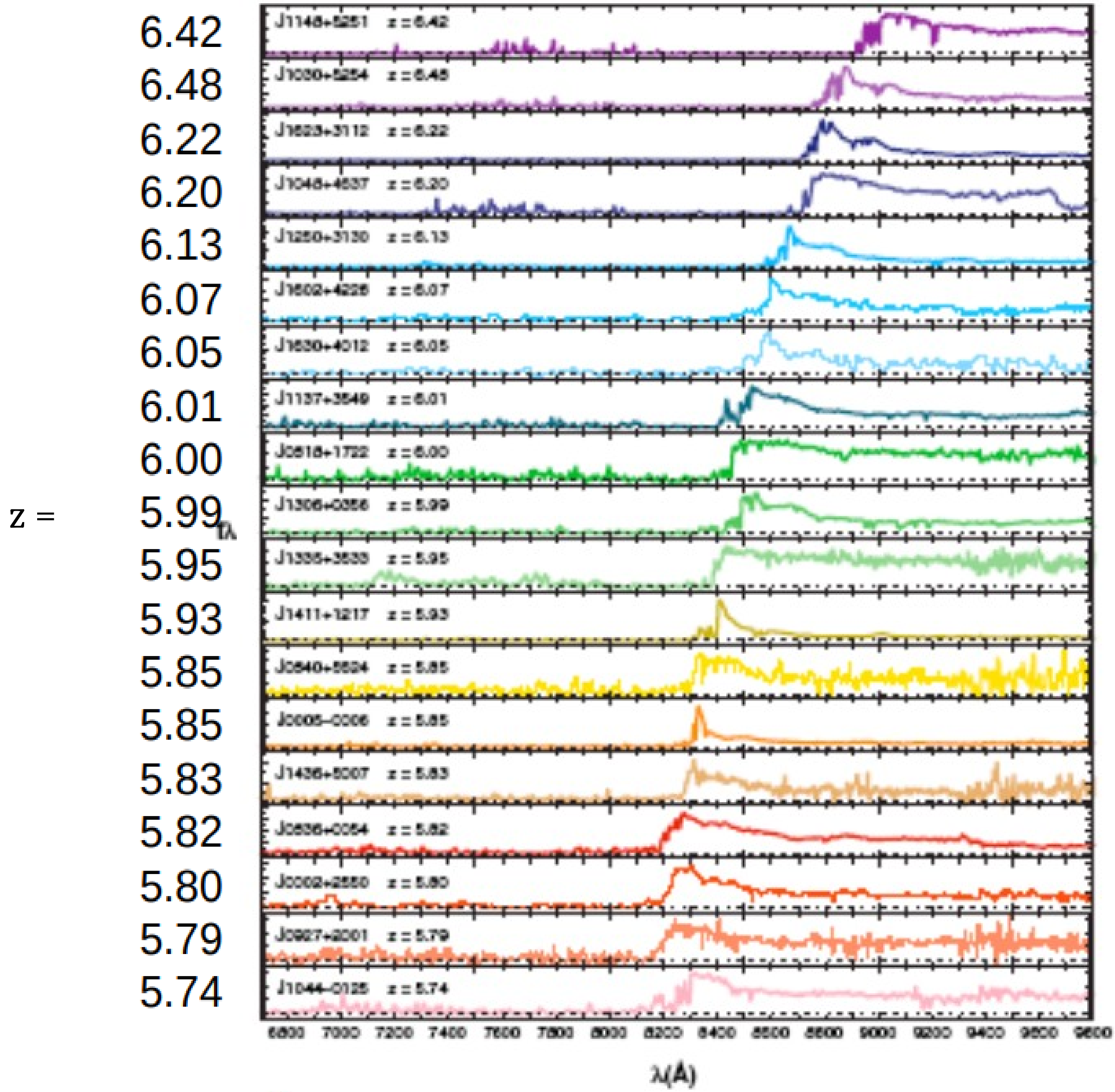

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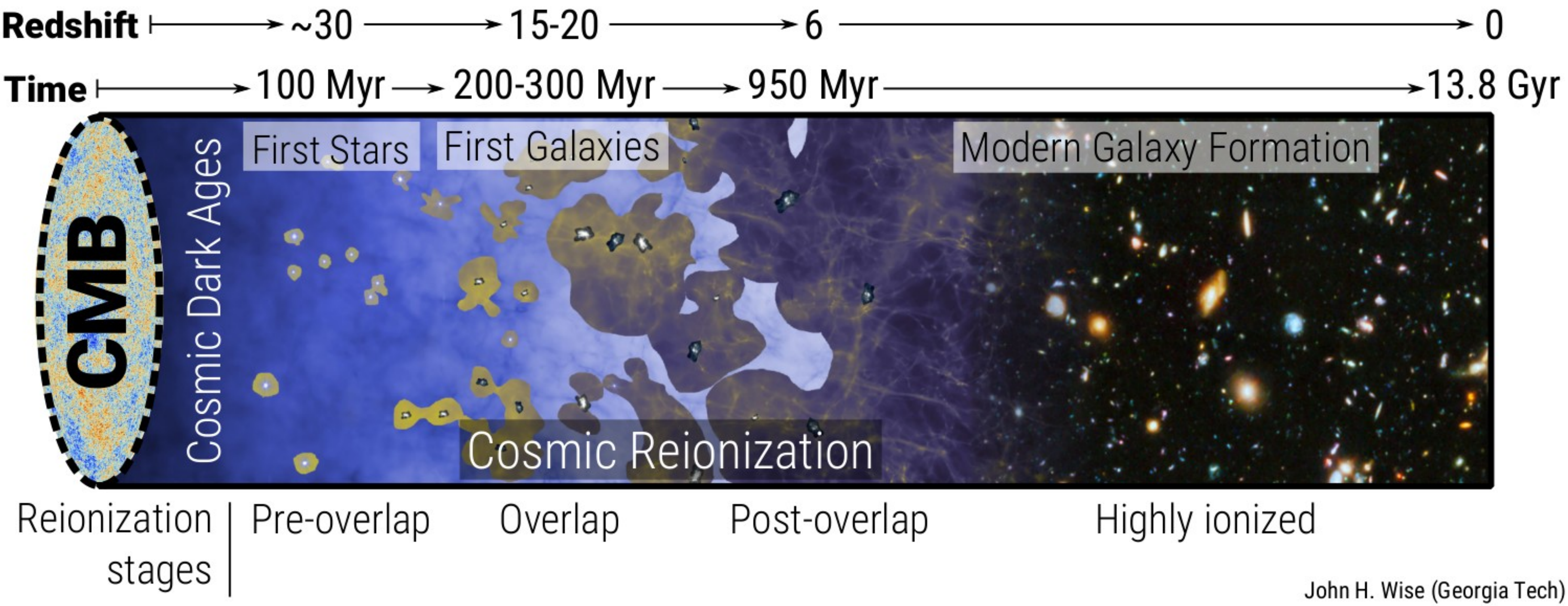
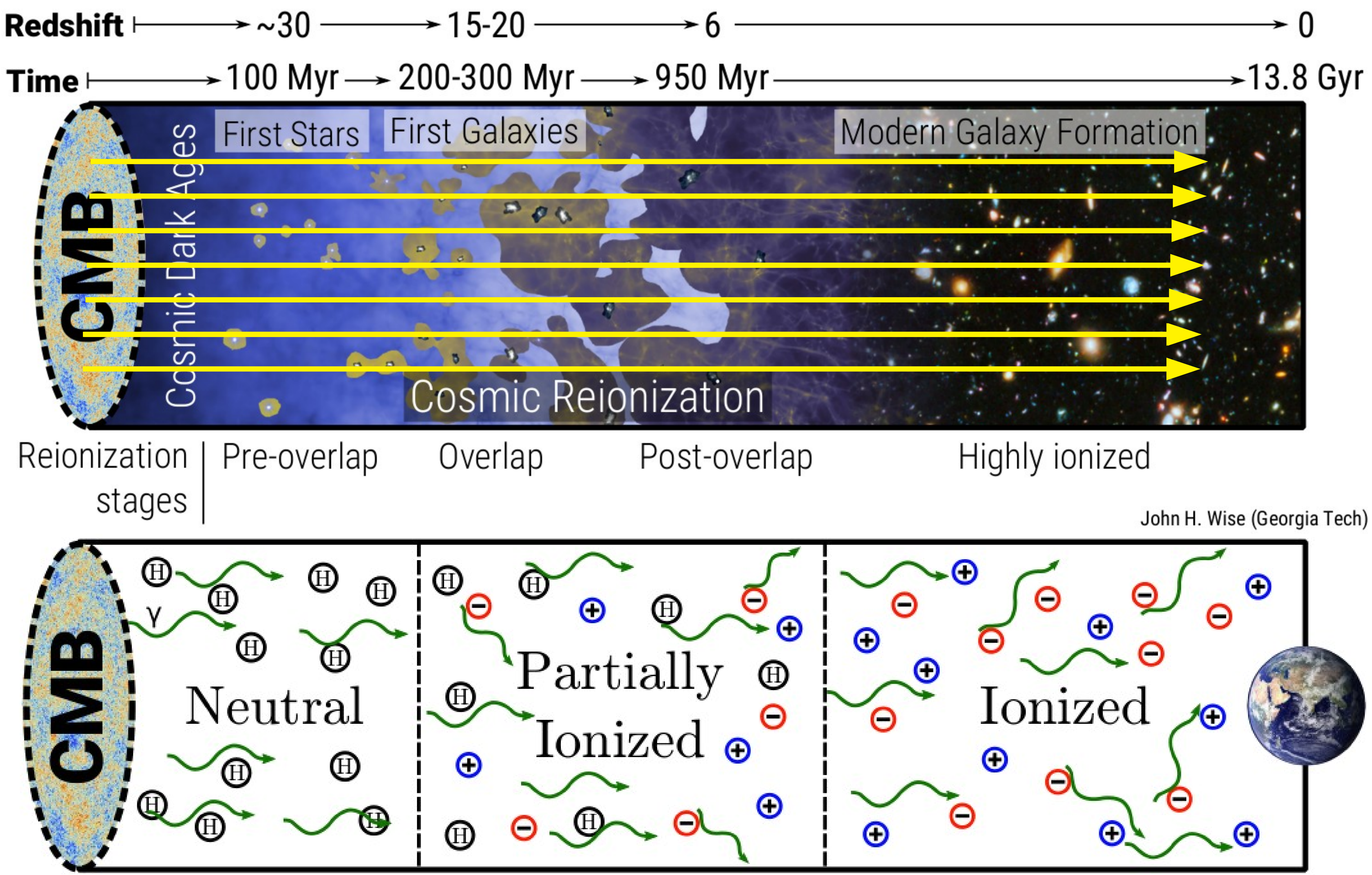


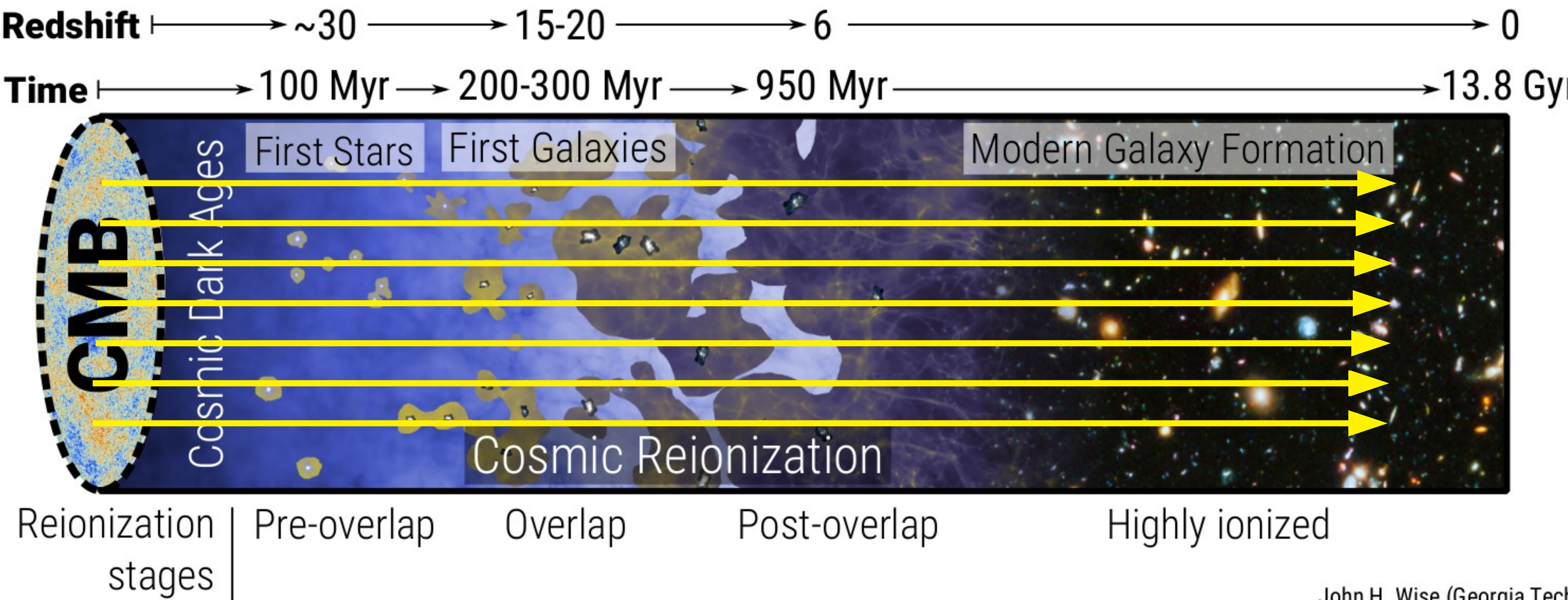
<u>Decades later, still many open questions:</u>

- WHEN: When did it happen? How long did it last?
- WHO: What were the sources responsible?
- HOW: How did it proceed? Was it gradual or sudden? What was its topology? Was it homogeneous or patchy?

Reionisation & the CMB



Reionisation & the CMB



John H. Wise (Georgia Tech)

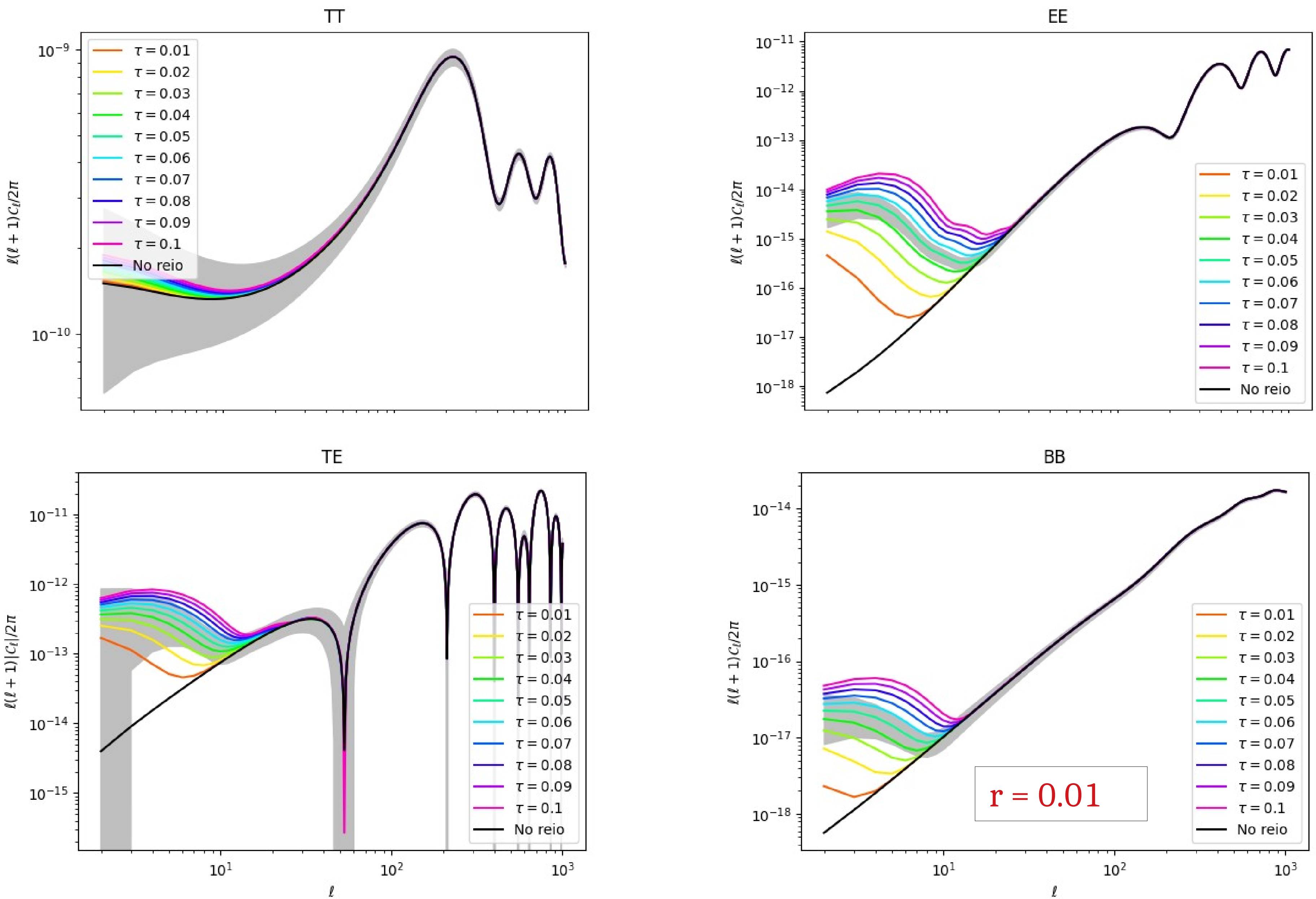
$$\tau = \int_0^{\eta_0} a n_e \sigma_T d\eta$$

Density of free electrons

Probability for a CMB photon to be scattered = 1- exp(-τ)

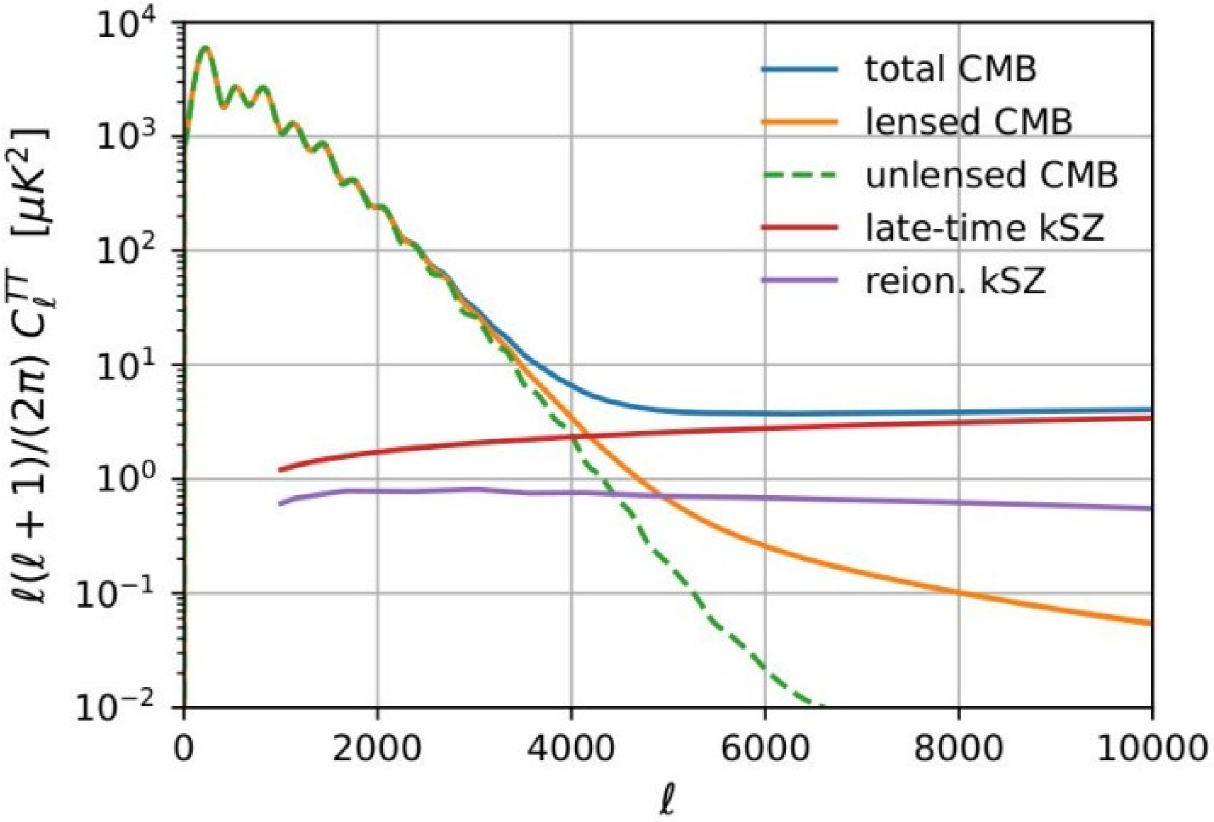
Effects of reionisation on the CMB

Impact on all CMB angular power spectra:



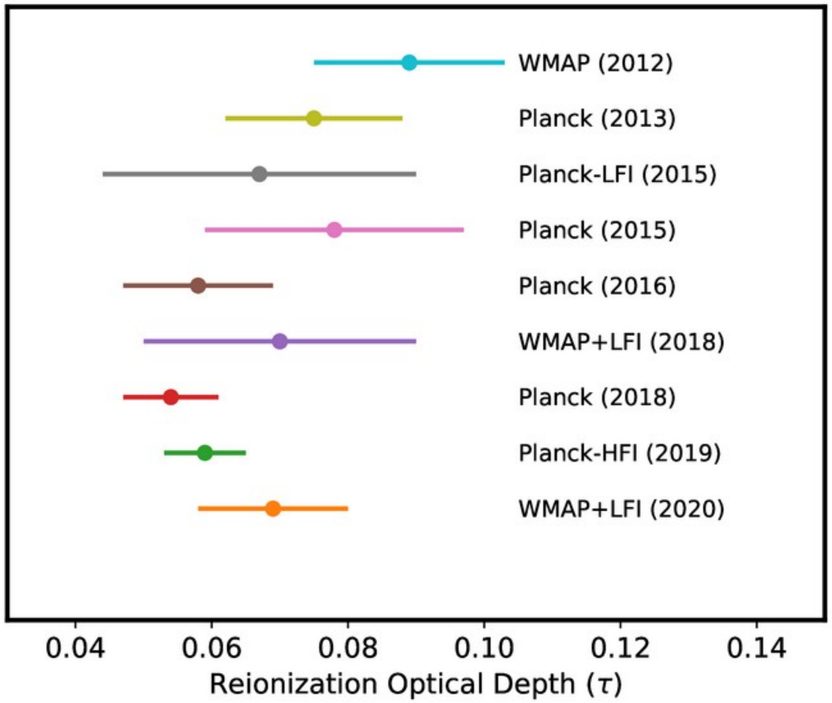
Reionisation & the CMB

Kinetic Sunyaev-Zel'dovich (kSZ) effect

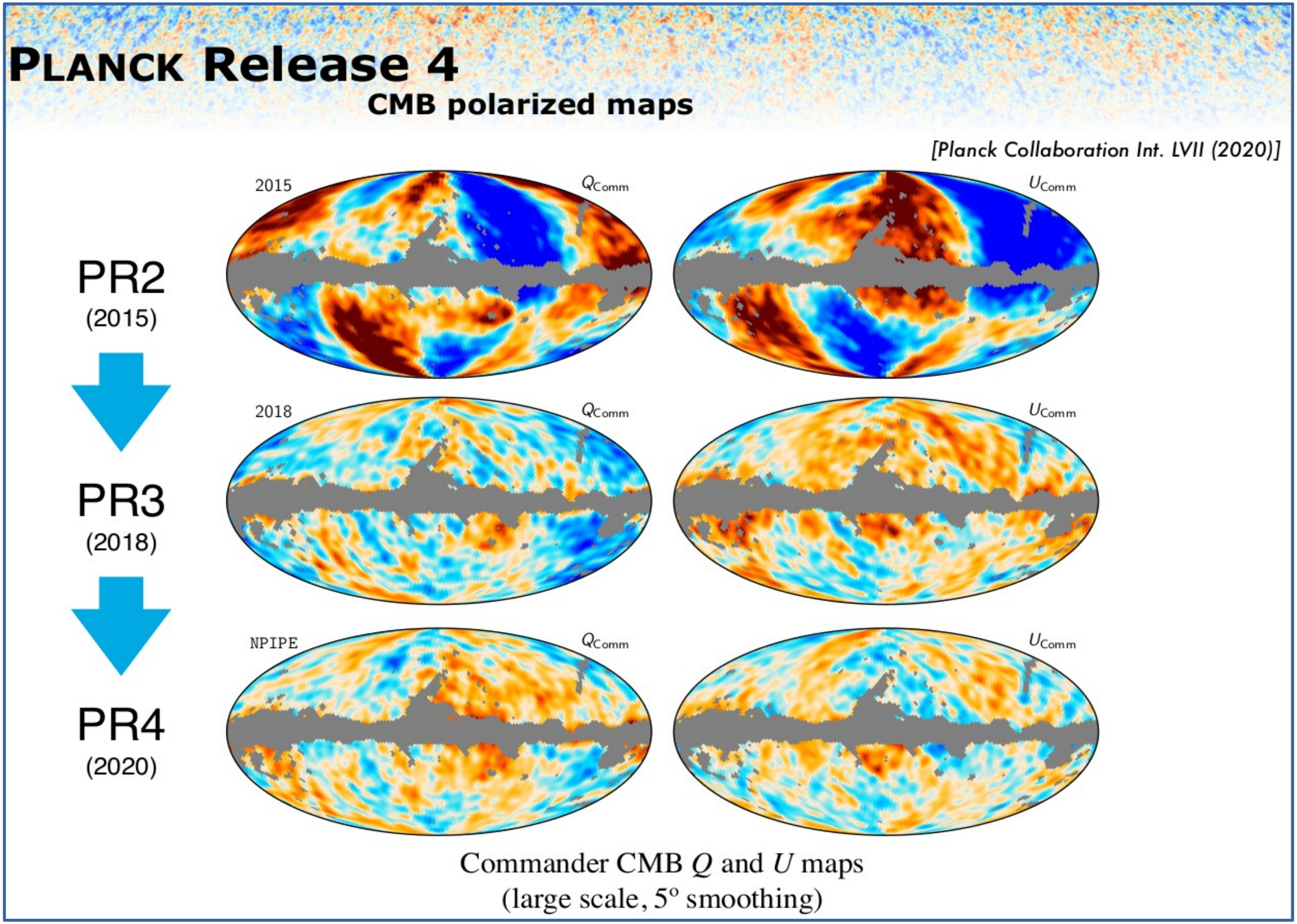


Current reionisation constraints

$$\tau = \int_0^{\eta_0} a n_e \sigma_T d\eta$$



Revisiting large-scale CMB constraints



Courtesy of M. Tristram

Why studying reionisation with large-scale CMB?

- Amplitude of matter fluctuations (A_s/σ_8) strongly degenerate with reionisation optical depth

- Neutrinos mass and hierarchy: impact of neutrinos hard to estimate without a good handle on the matter power spectrum

- Reionisation can potentially complicate the detection of inflationnary signatures in the CMB

Objectives

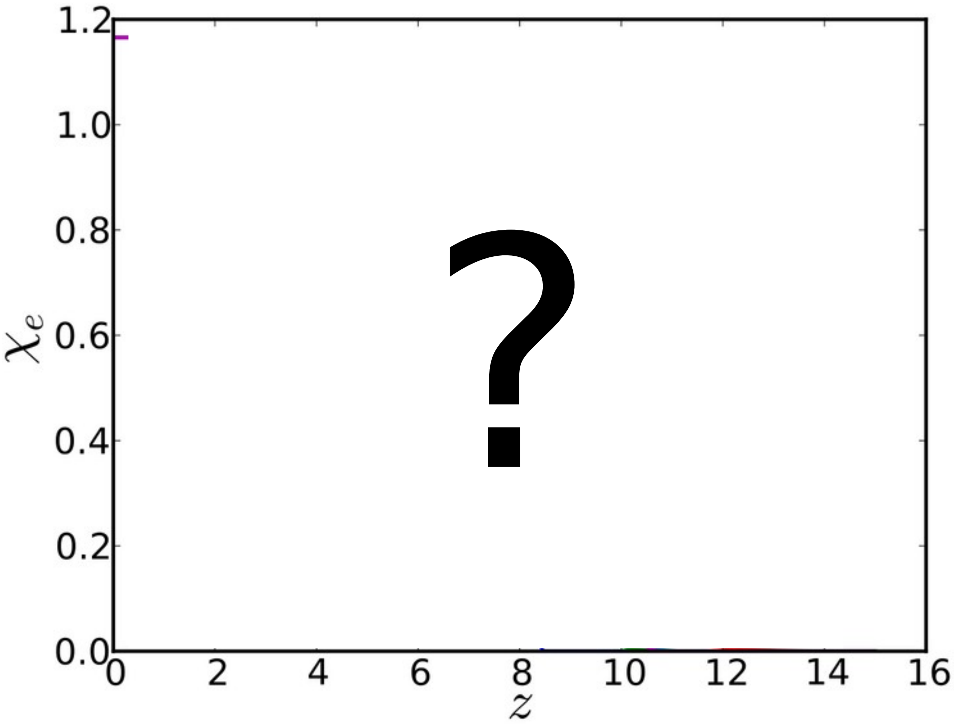
<u>Ilic et al. in prep:</u> PR4 constraints on reionisation

- Reassess in depth sensitivity of Planck on optical depth
- Explore constraints beyond instantaneous reionisation
- Determine the impact of the choice of model

Modelling reionisation

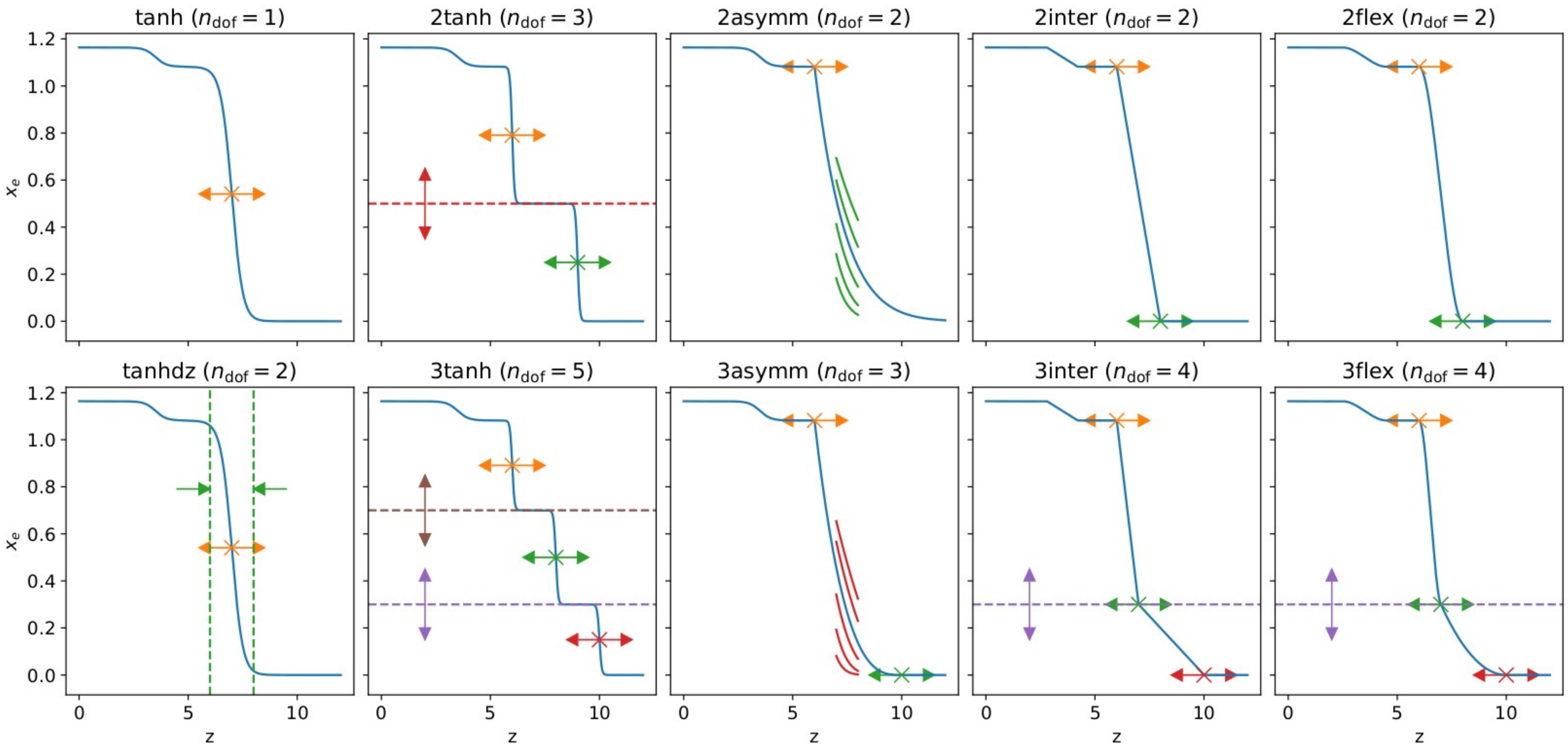
$$\tau = \int_0^{\eta_0} a n_e \sigma_T d\eta$$

Free electron density



χ_e = ionisation fraction as a function of the redshift

Modeling reionisation



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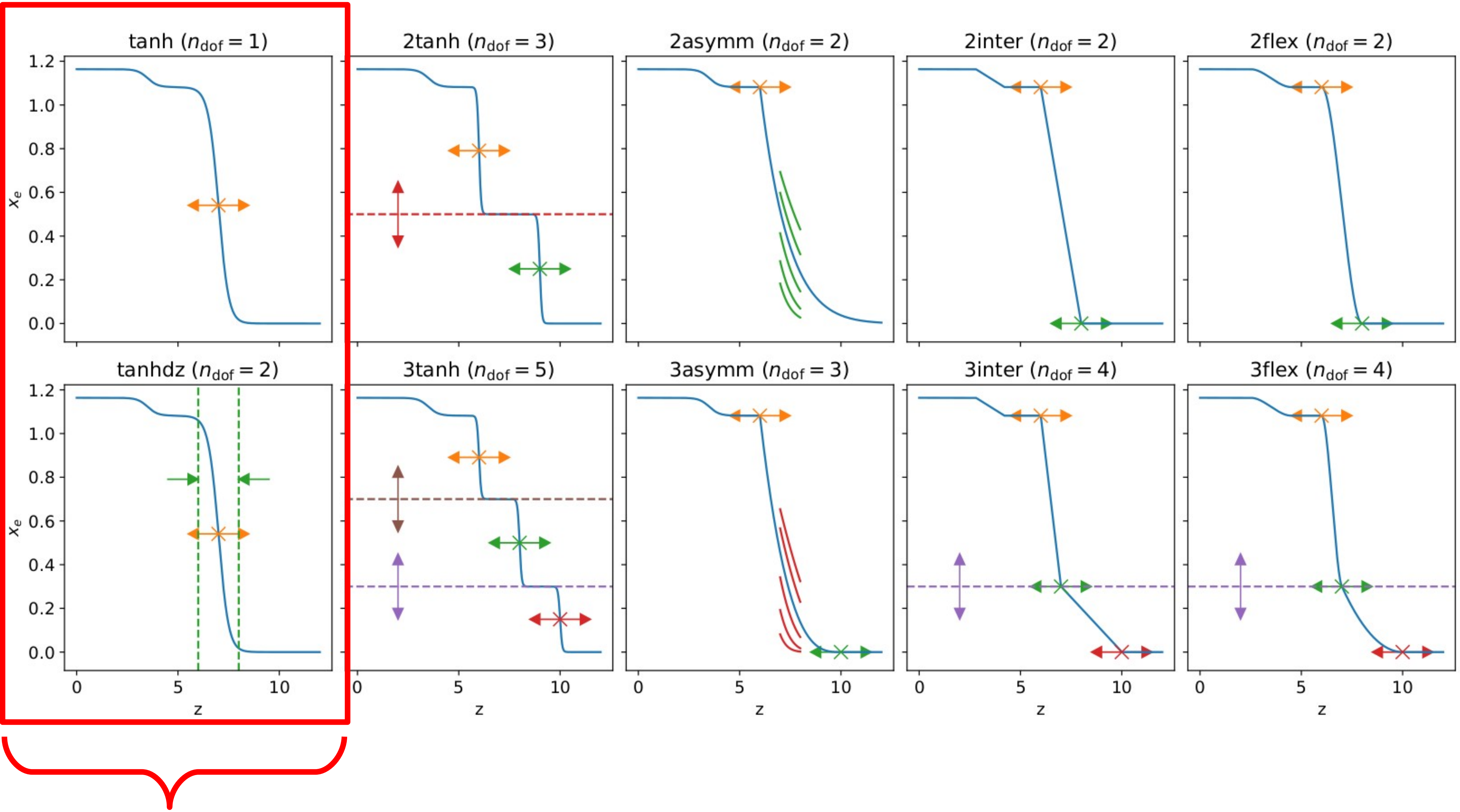
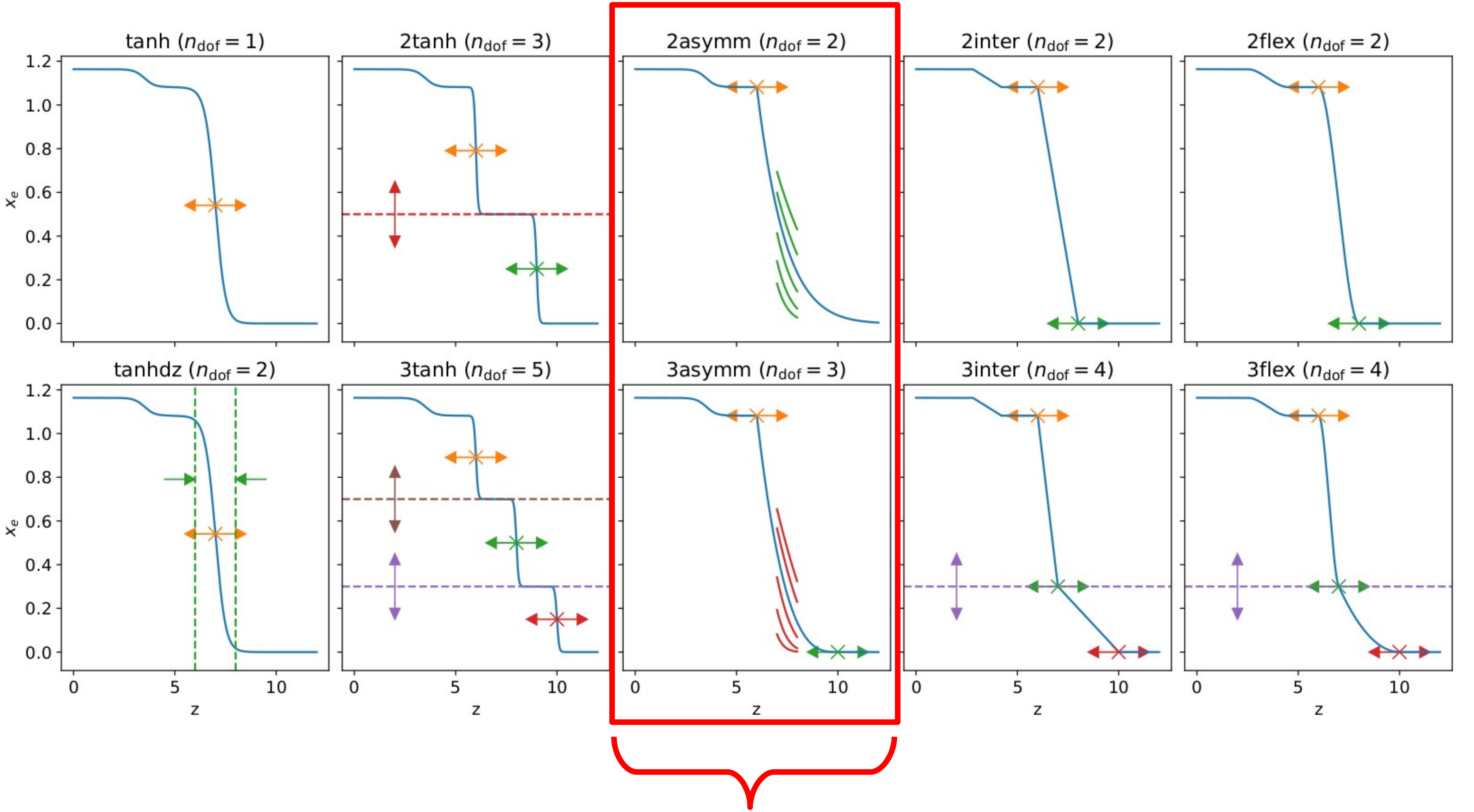


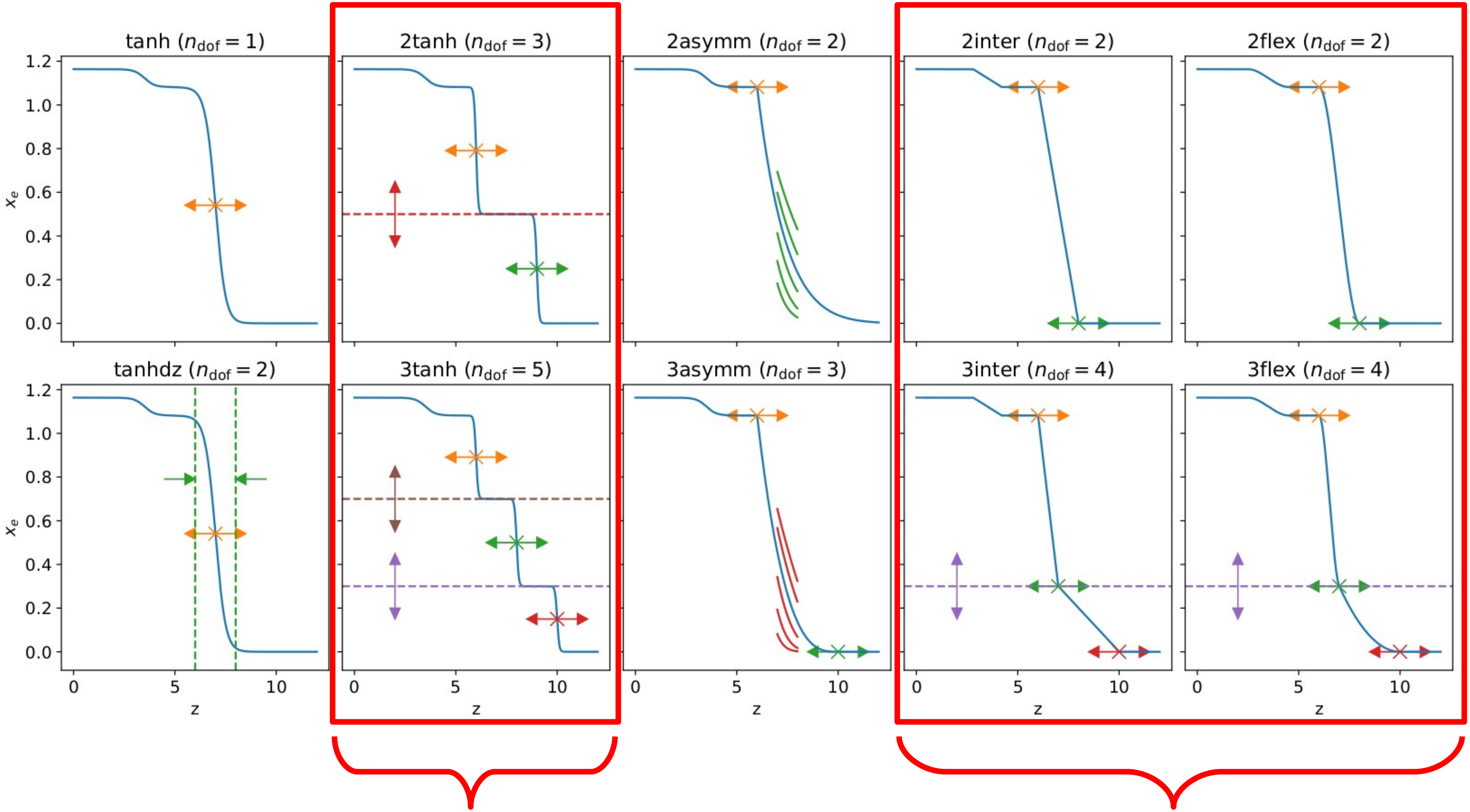
(Standard) symmetric models, tanh-based

Modeling reionisation



Asymmetric models, phenomenological,
emulating e.g. 2 populations of ionising sources

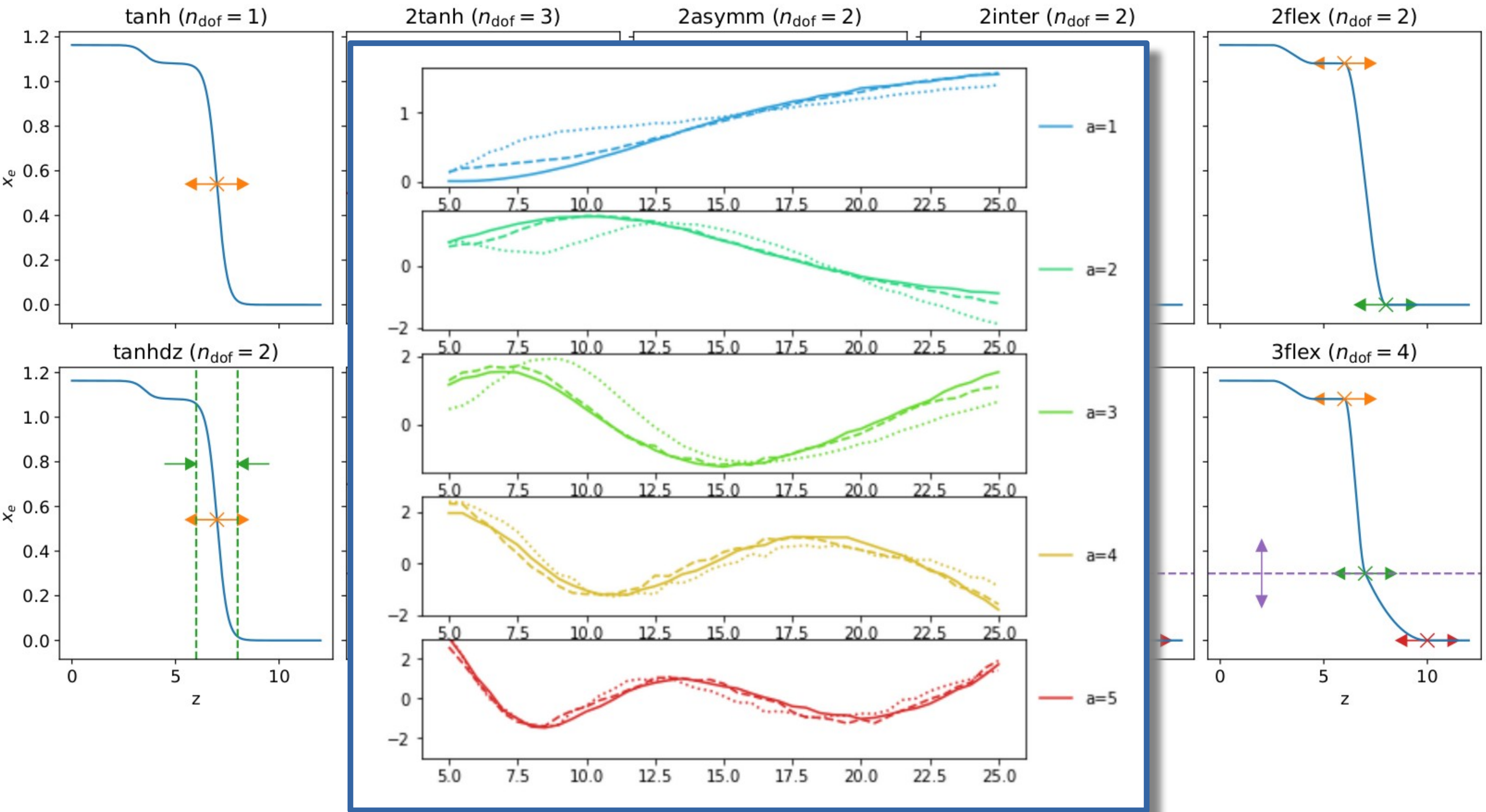
Modeling reionisation



Model-independent approaches :

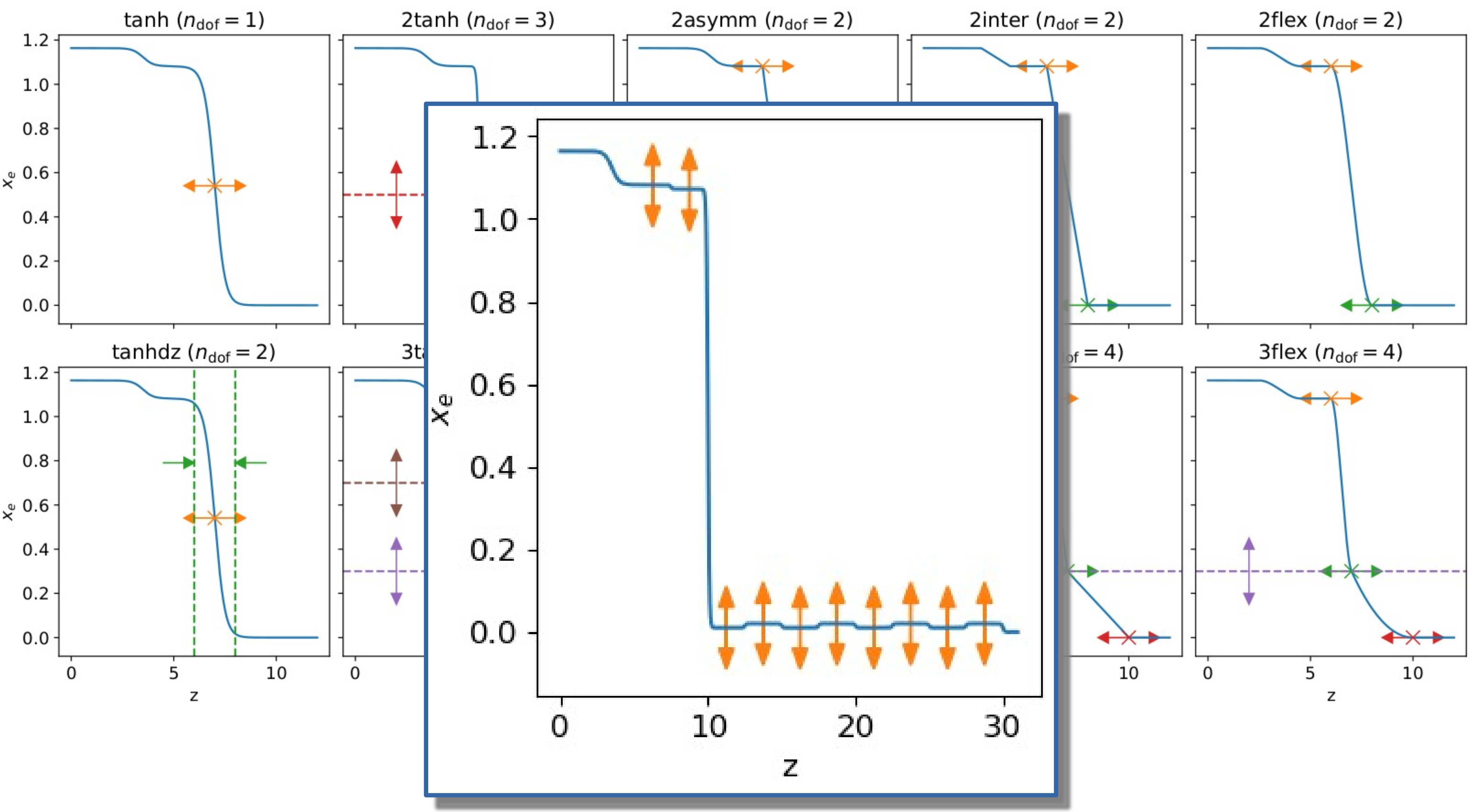
binned $x_e(z)$, interpolating polynomials (linear & PCHIP)

Modeling reionisation



+ Principal Component Analysis

Modeling reionisation



+ Reference 10 bins model

Datasets & Methodology

Data:

Planck Public Release 4, lollipop & hillipop

- low-ell polarization data only
- low-ell & high-ell temperature and polarization data

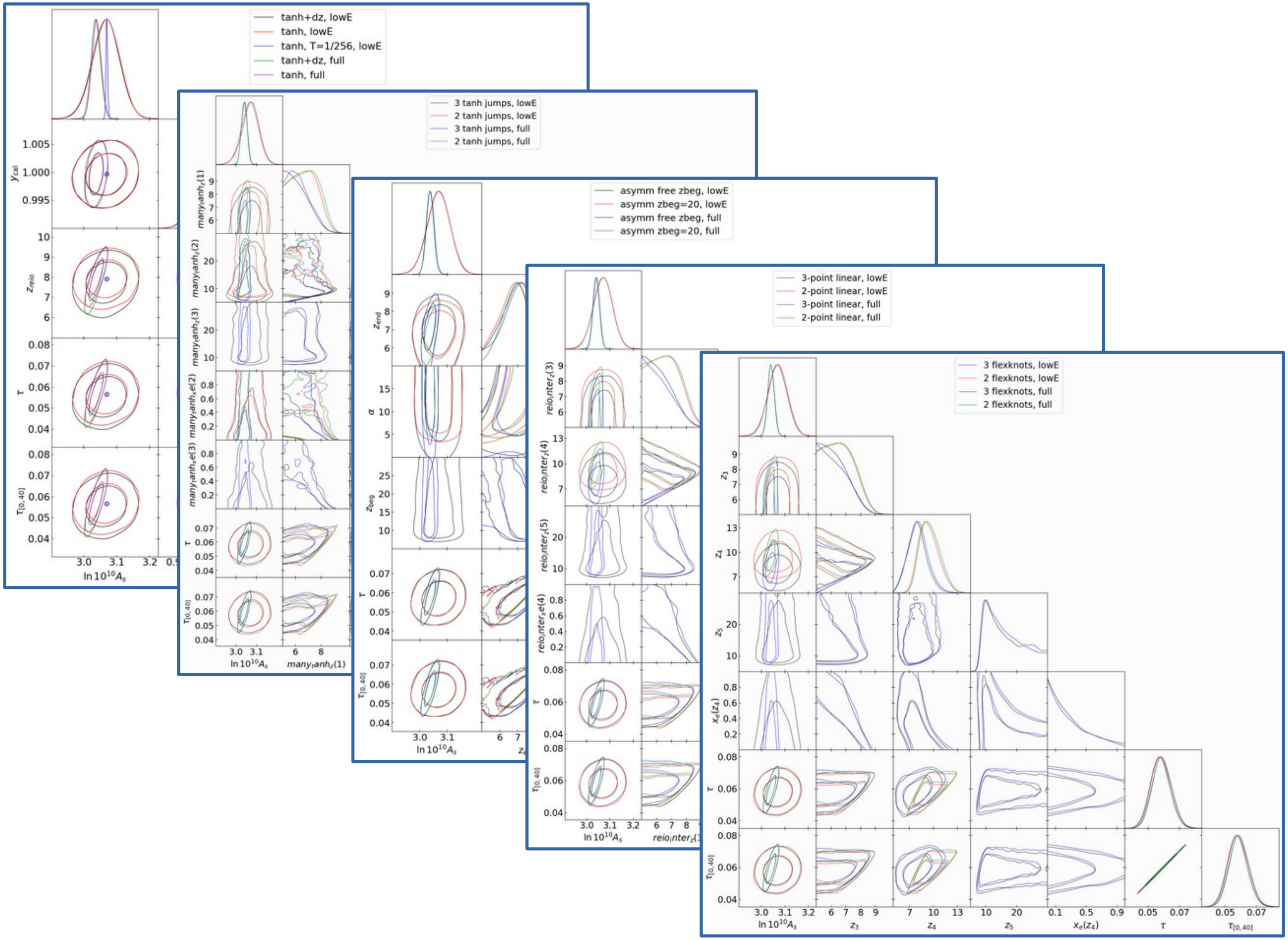
Theory:

Custom version of Boltzmann code CLASS
(github.com/s-ilic/class_reio)

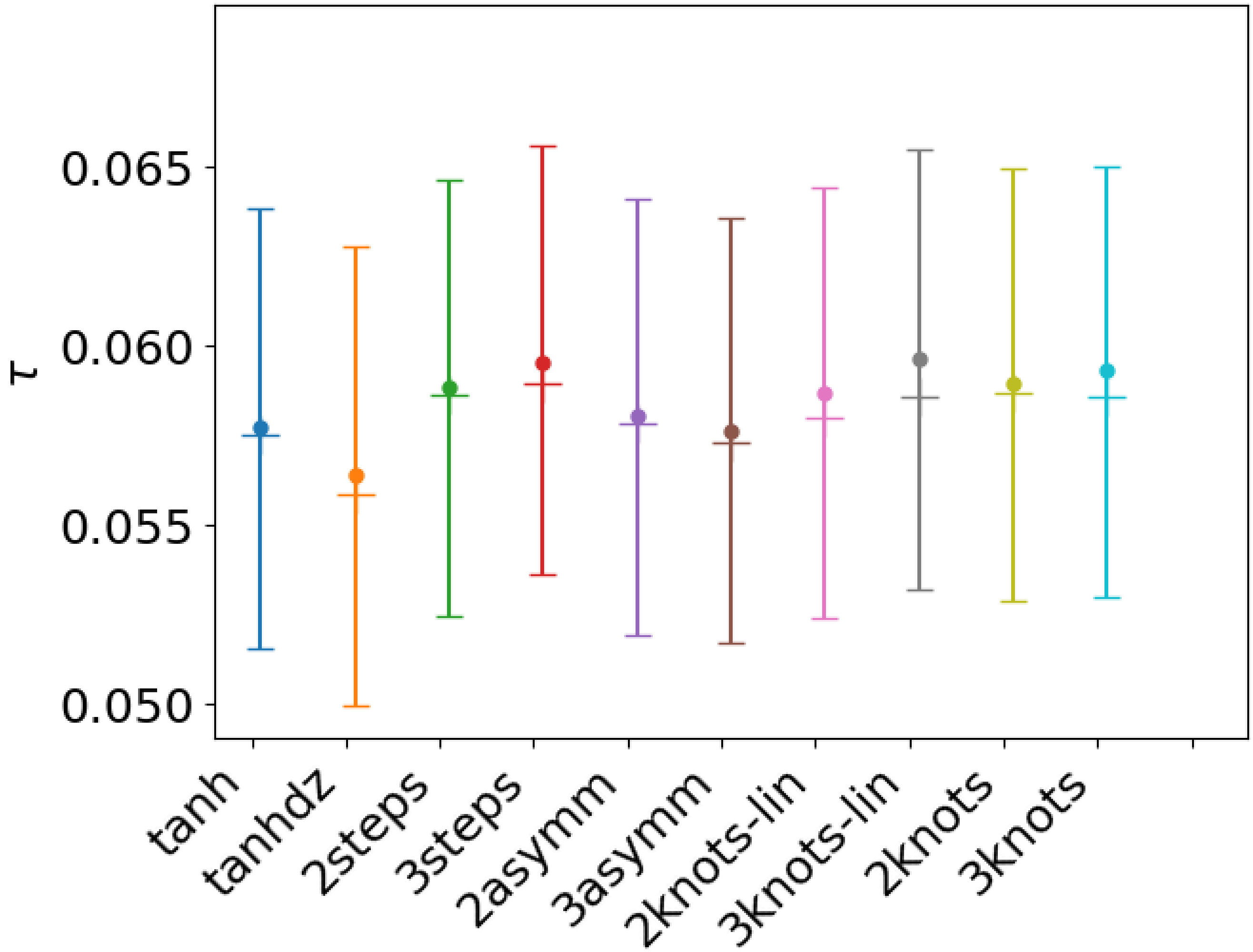
Sampler/pipeline:

Ensemble sampling Markov Chains Monte Carlo via ECLAIR (github.com/s-ilic/ECLAIR) (soon-to-be GPU compatible/accelerated)

Constraints on reionisation parameters



Constraints on τ



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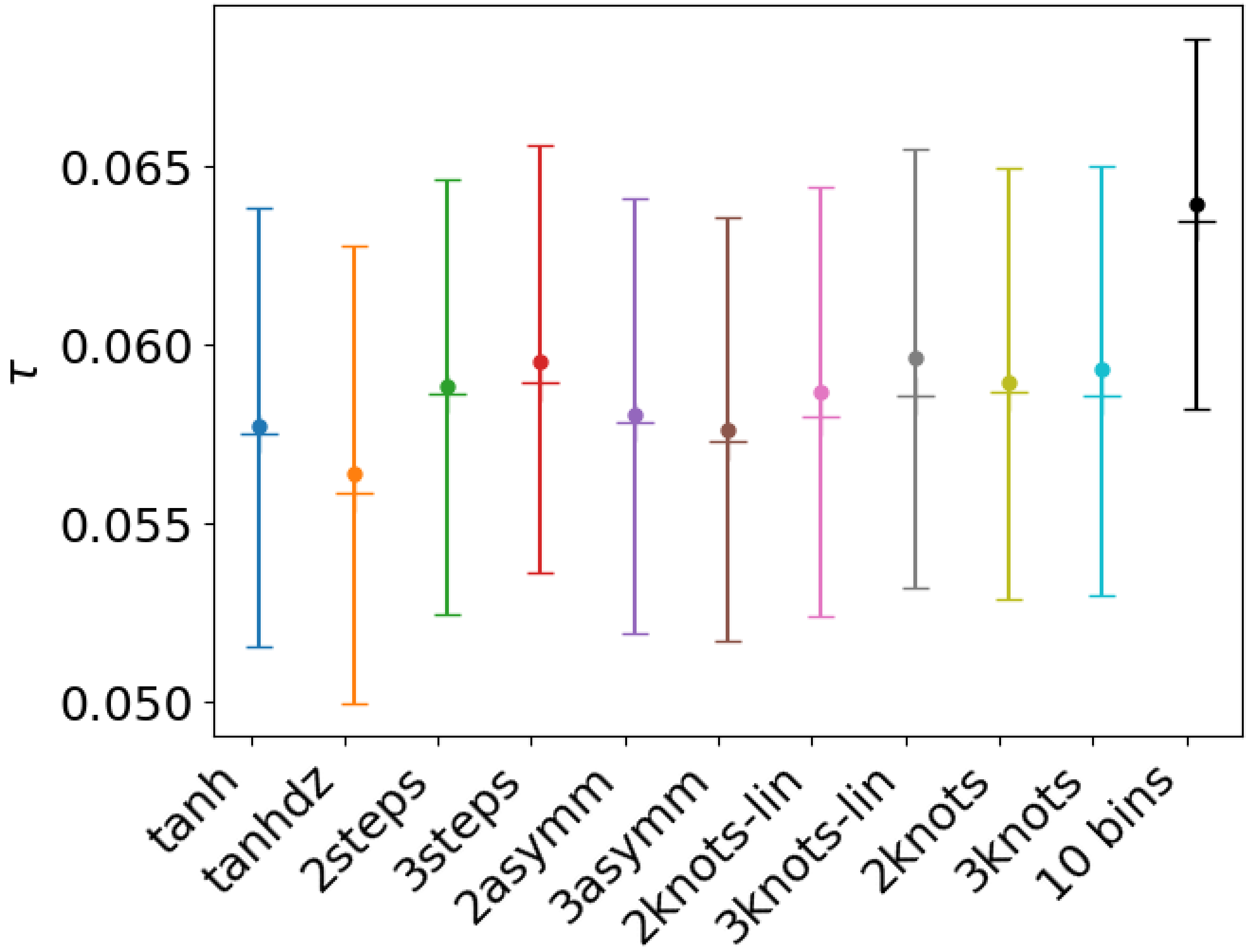
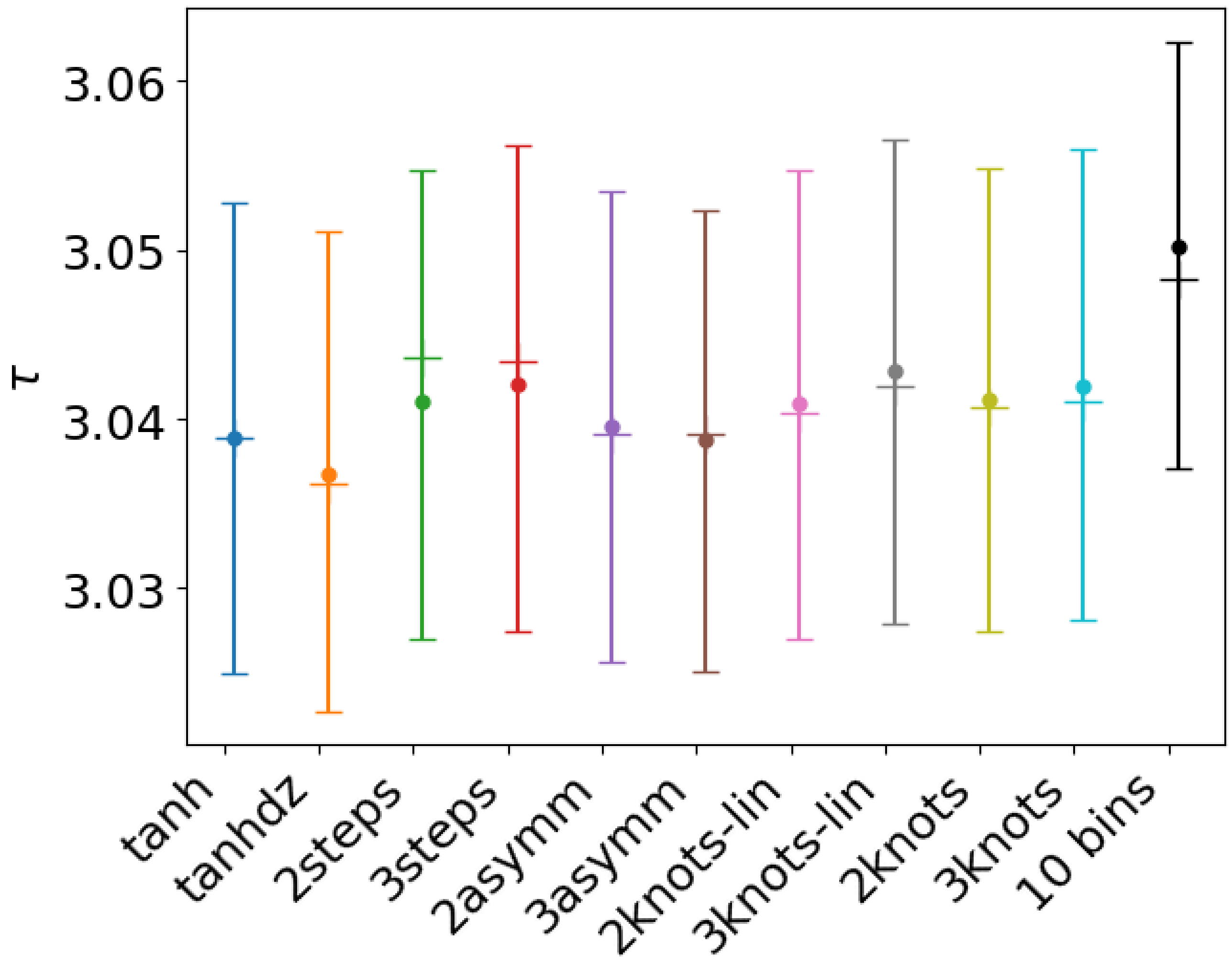


Constraints on A_s



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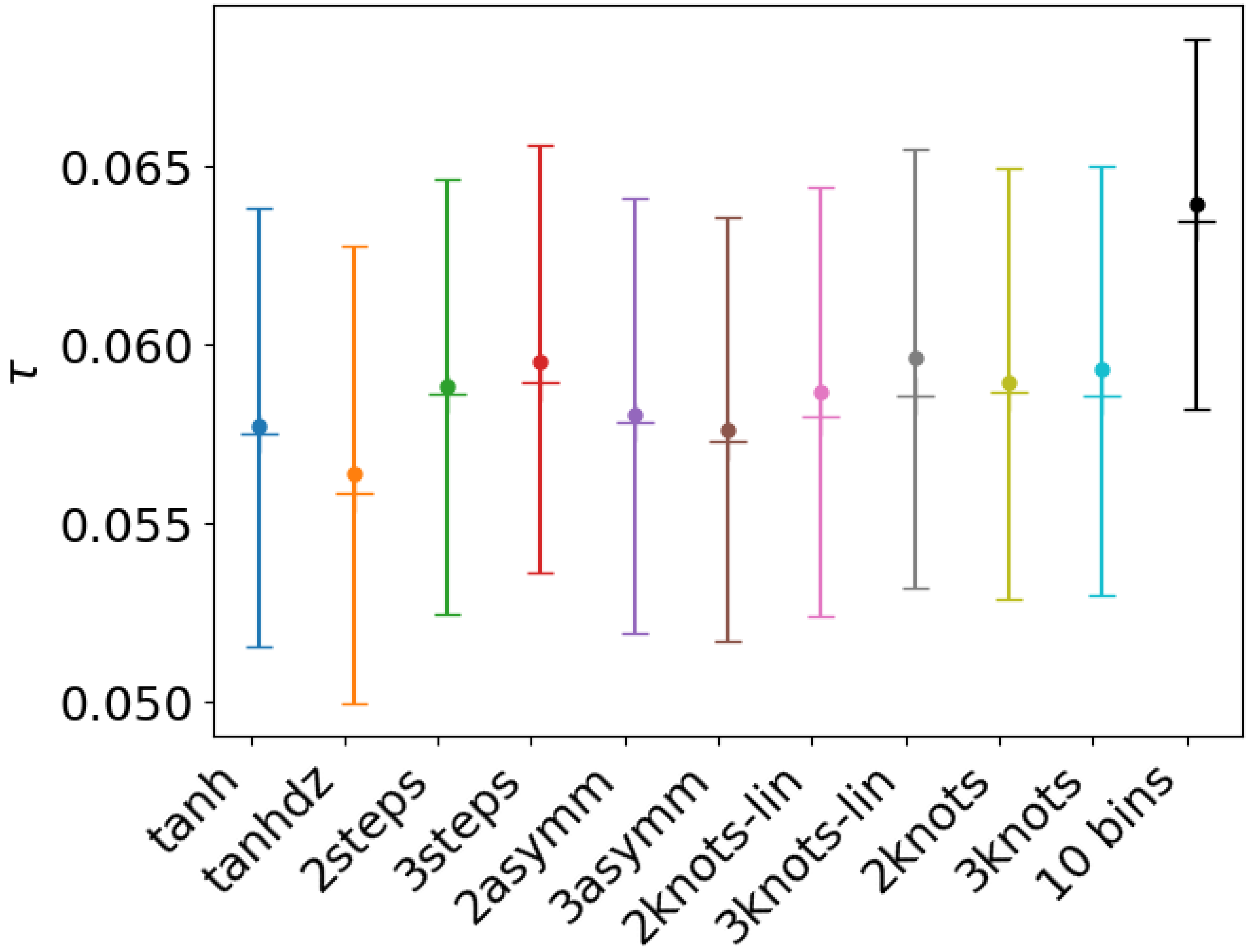
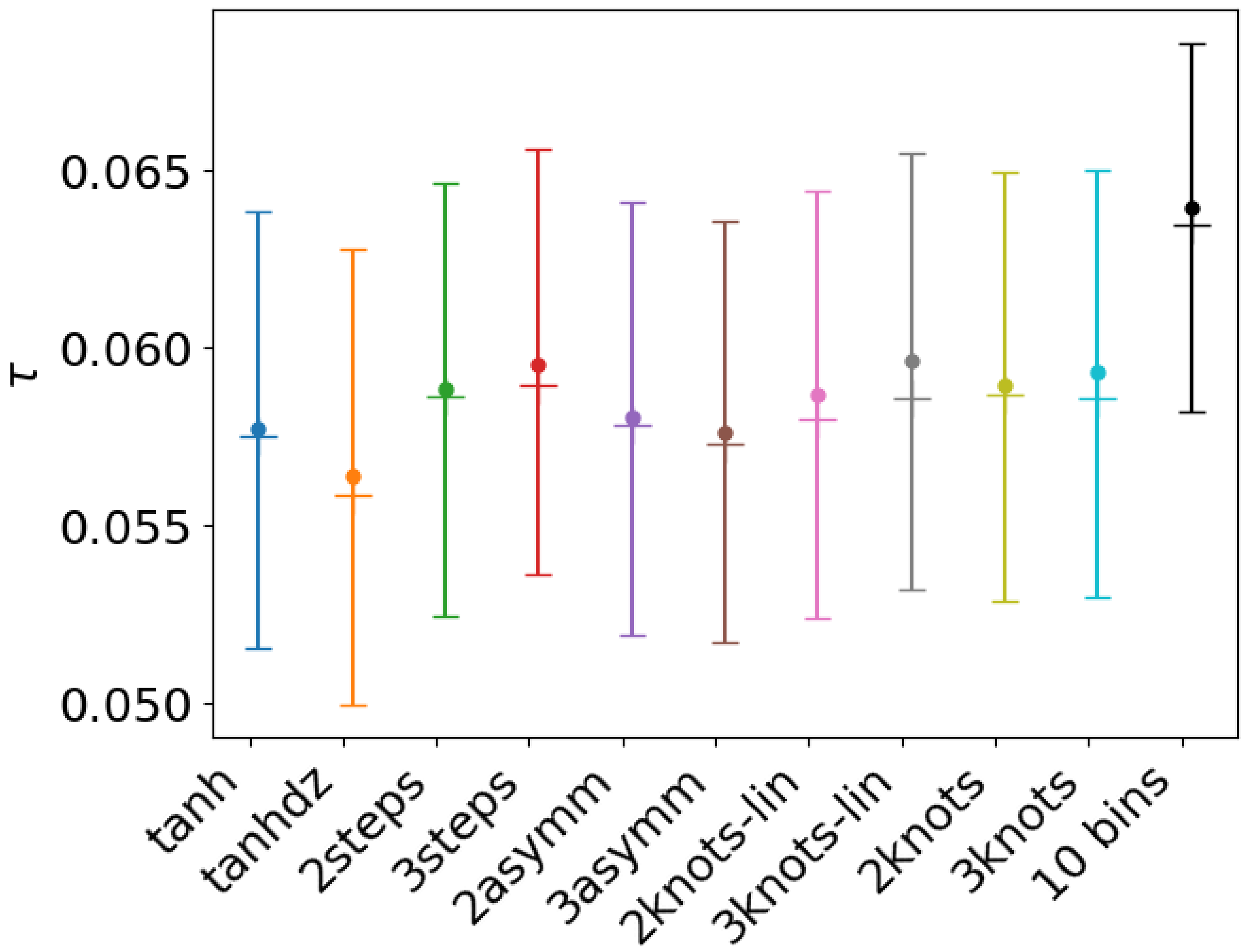
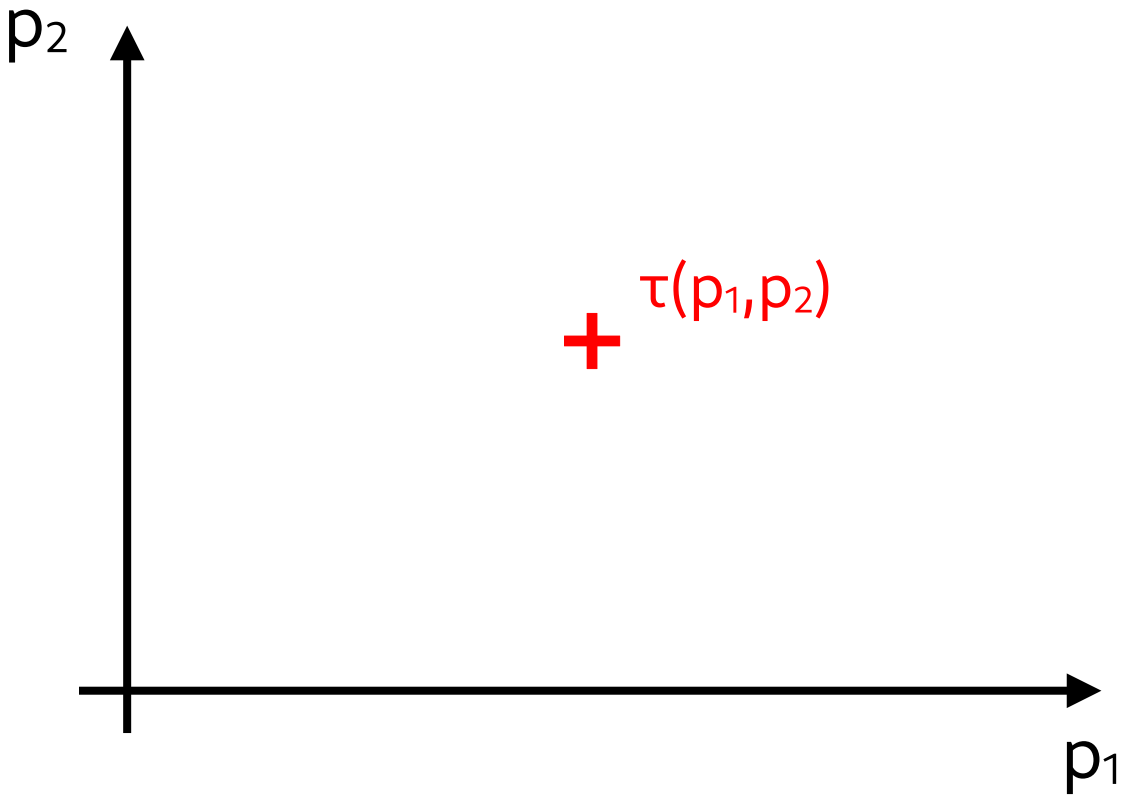


Constraints on τ

Effects of an implicit prior on τ



Influence of model choice on τ prior



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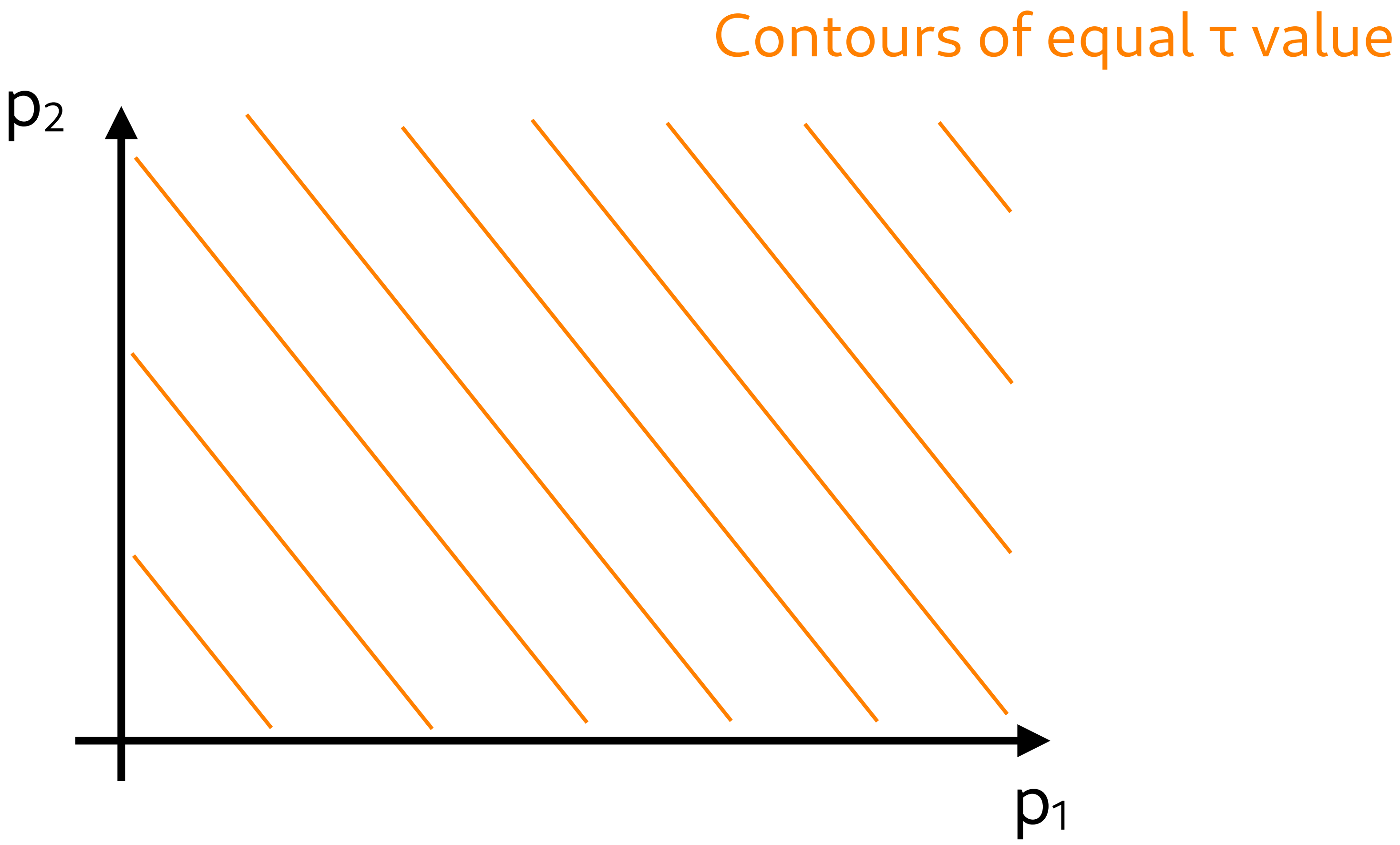

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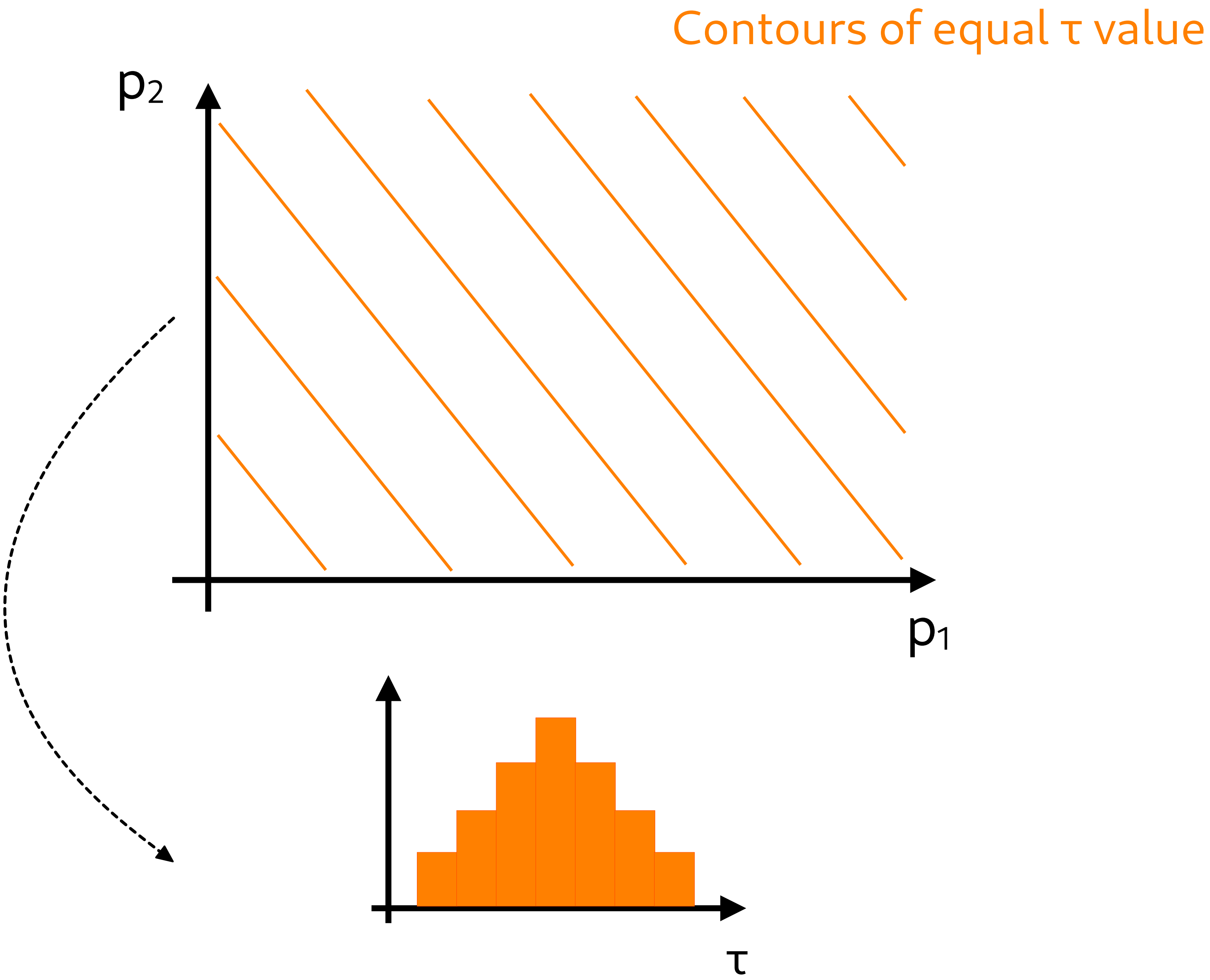

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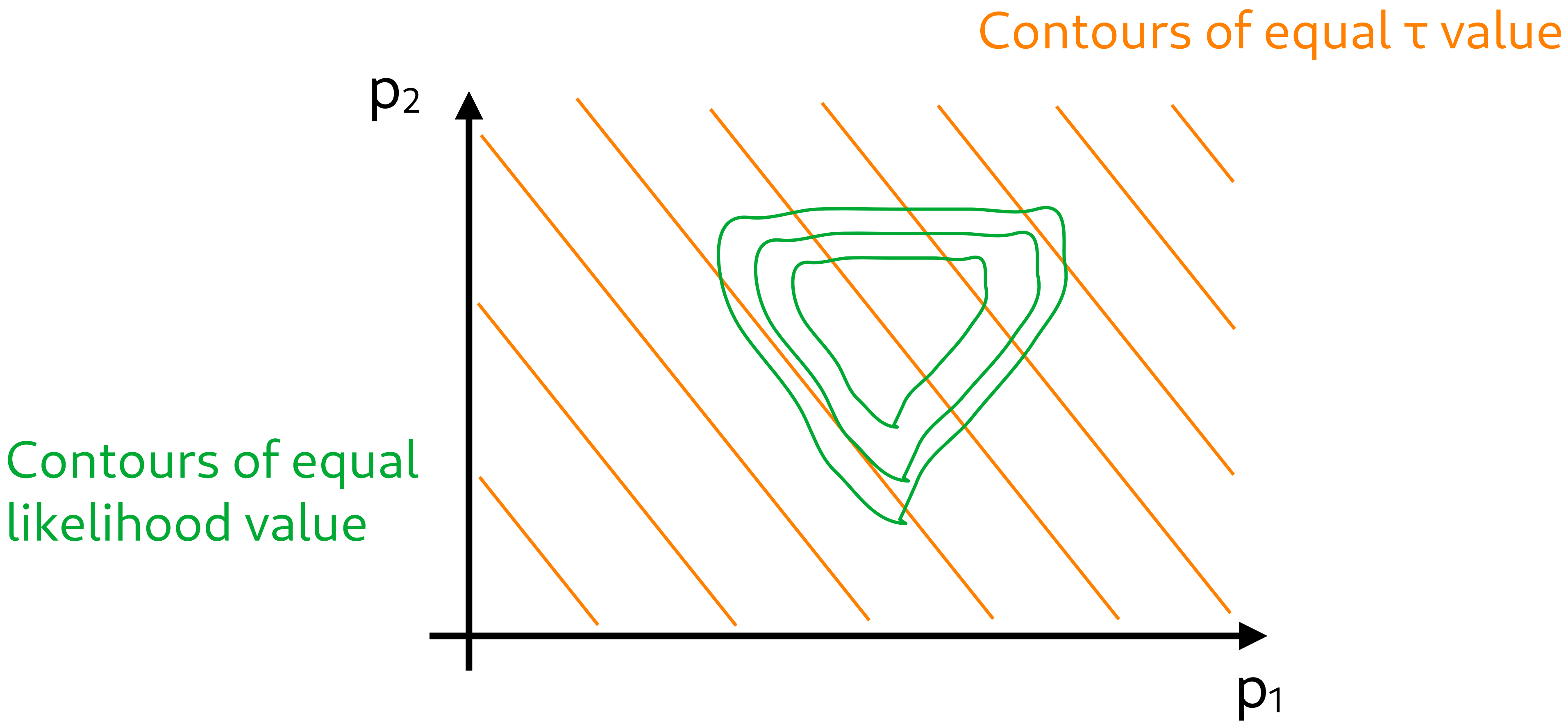
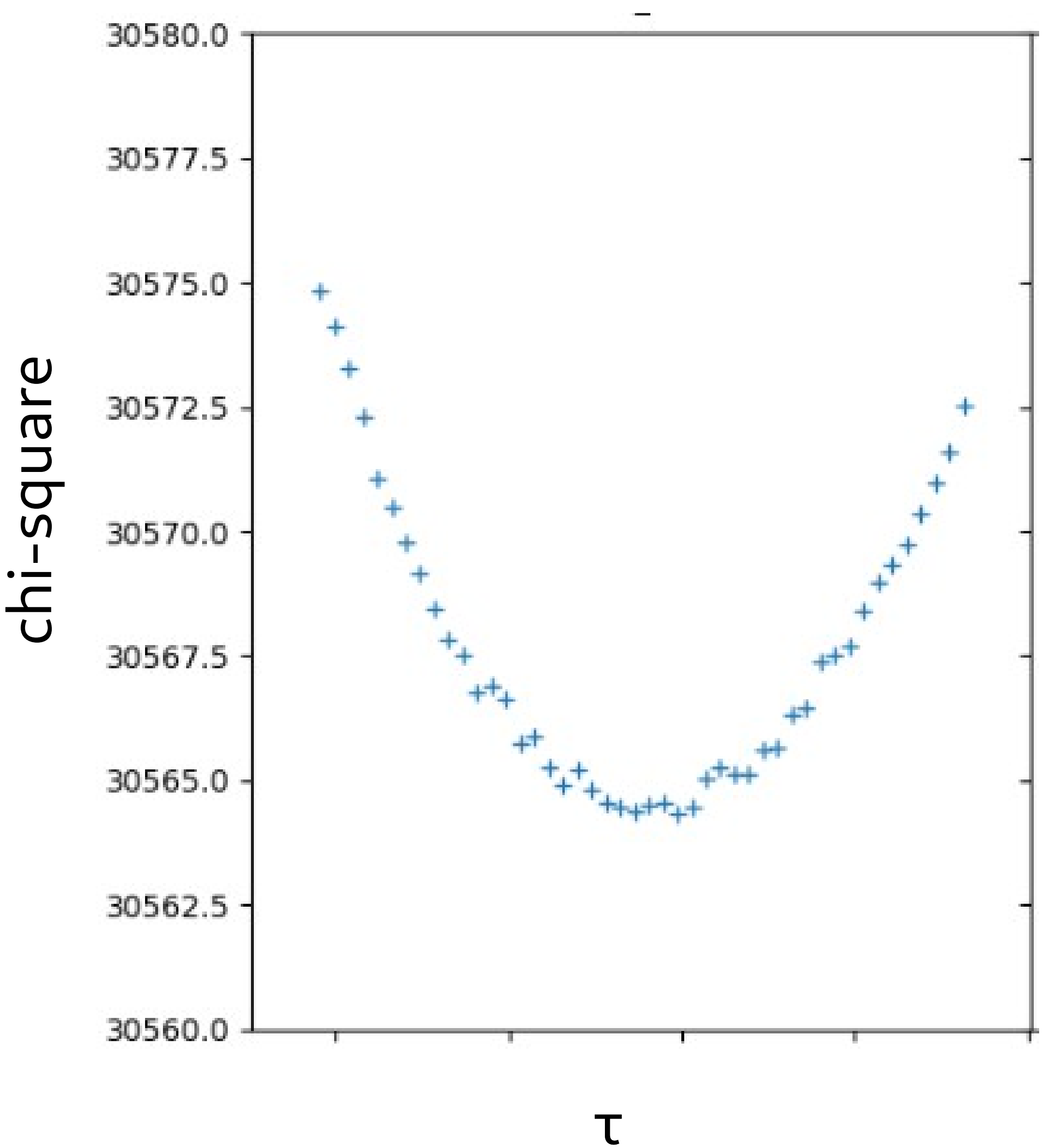


Profile likelihood method



Given a fixed grid of τ values, find for each of them the best possible model by minimizing the chi-square across all other free parameters

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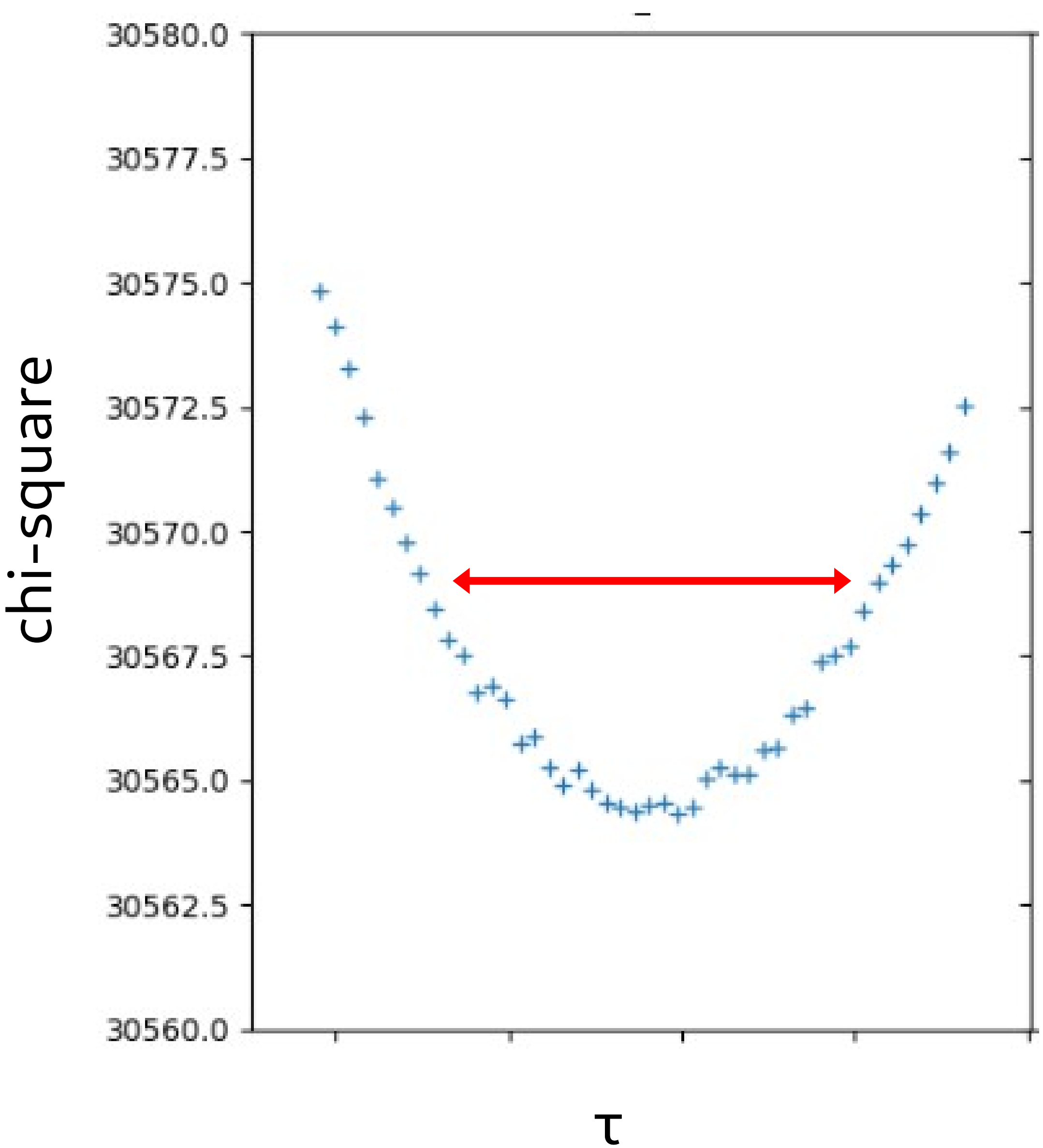

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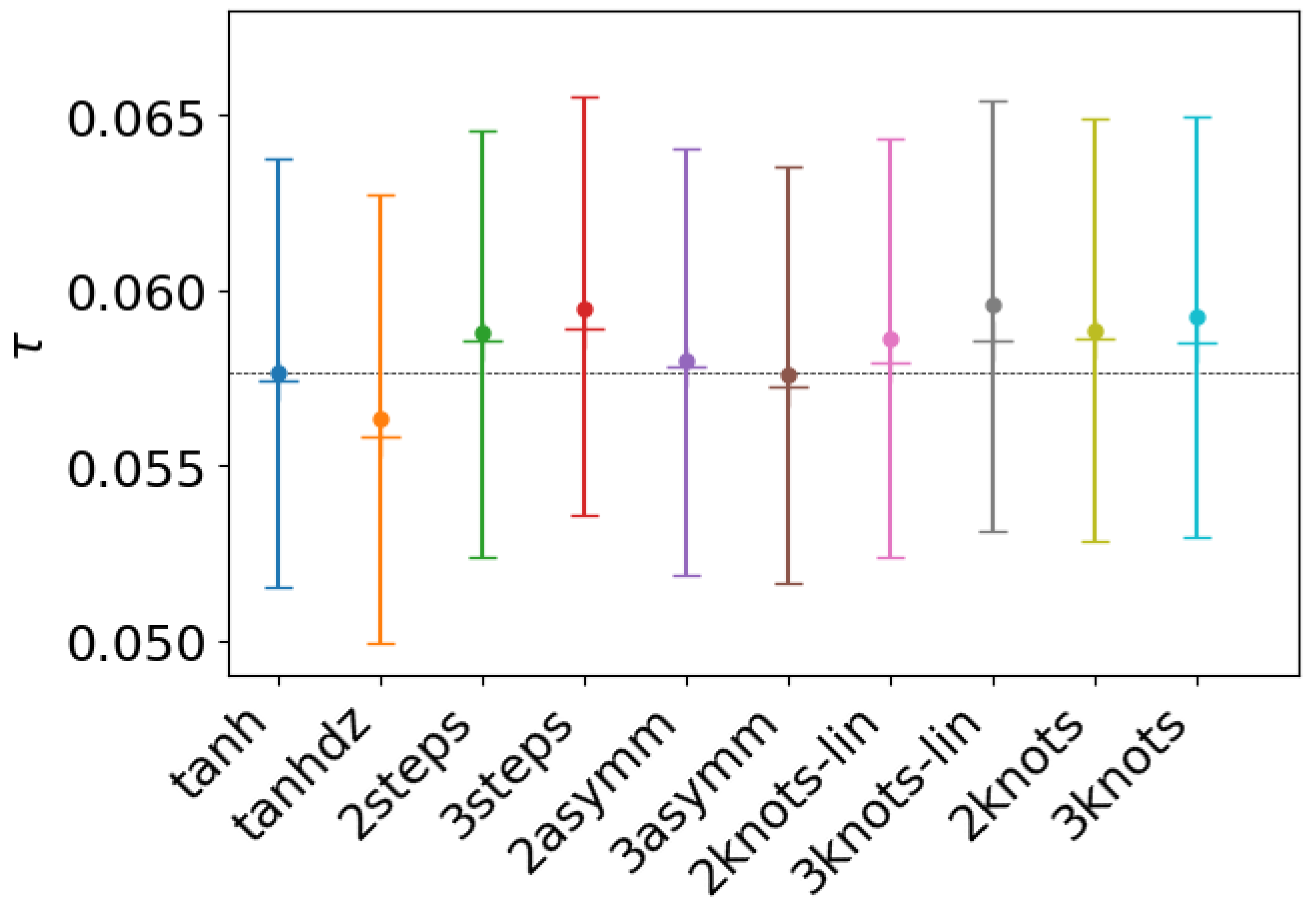
Comparison of approaches on τ constraints



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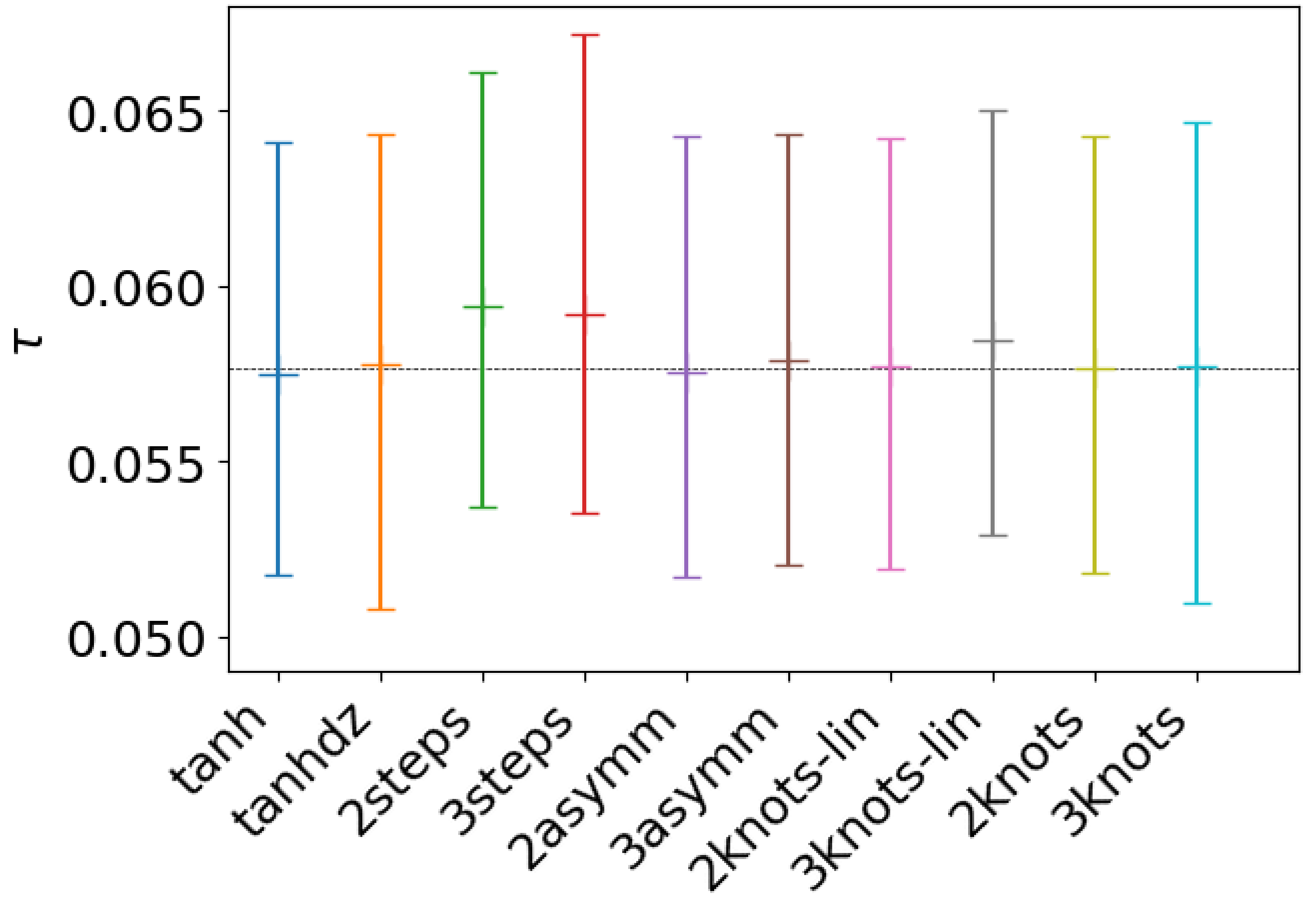

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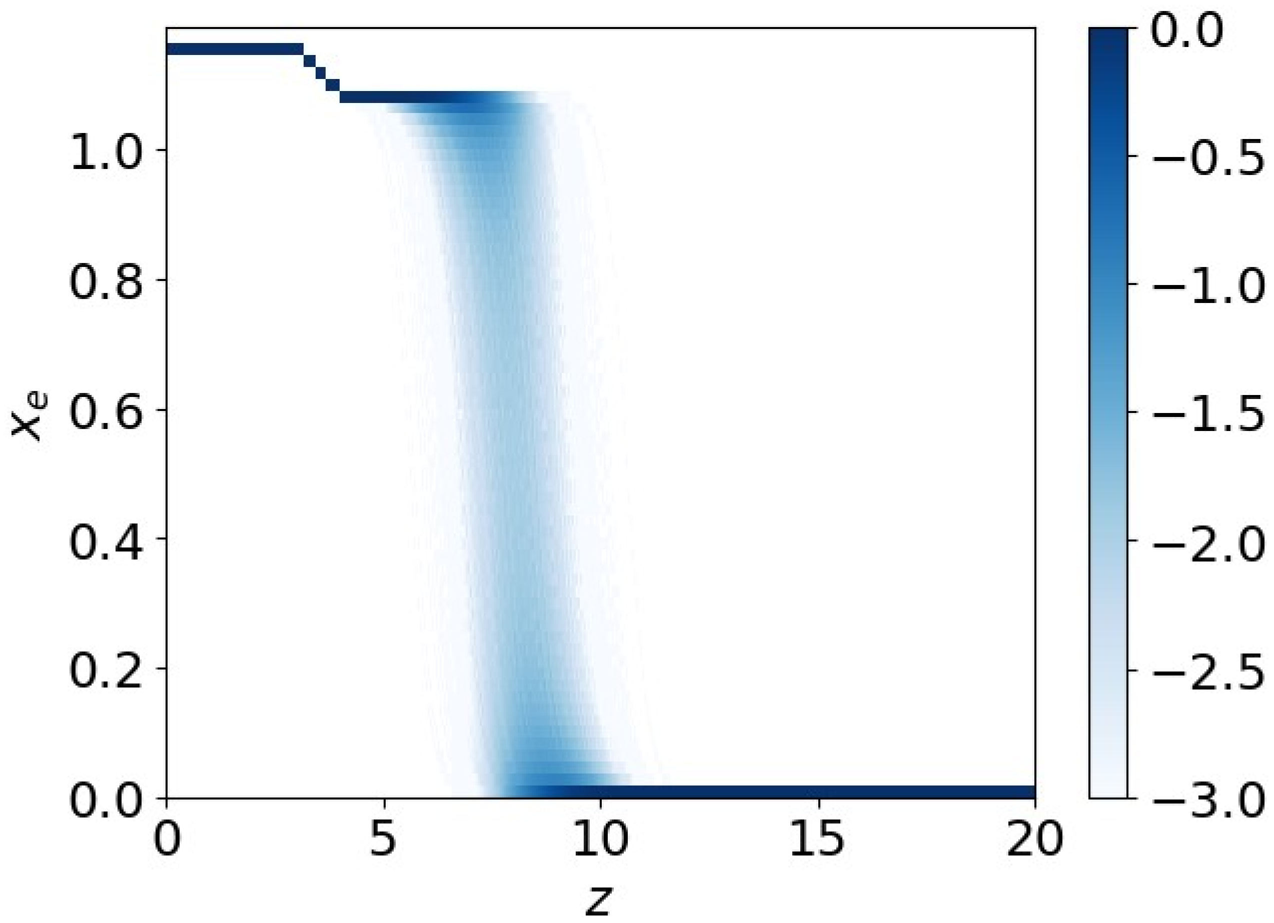

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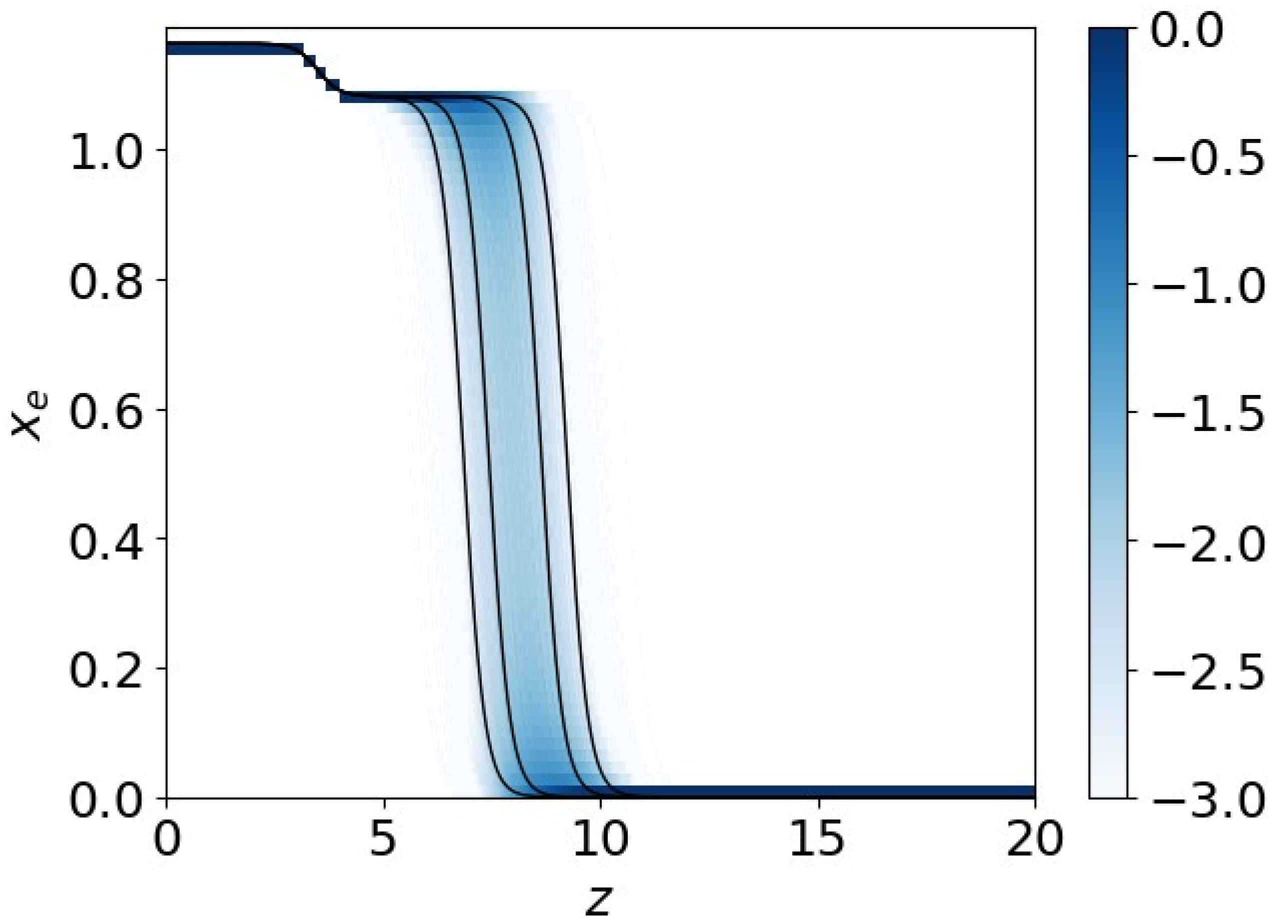

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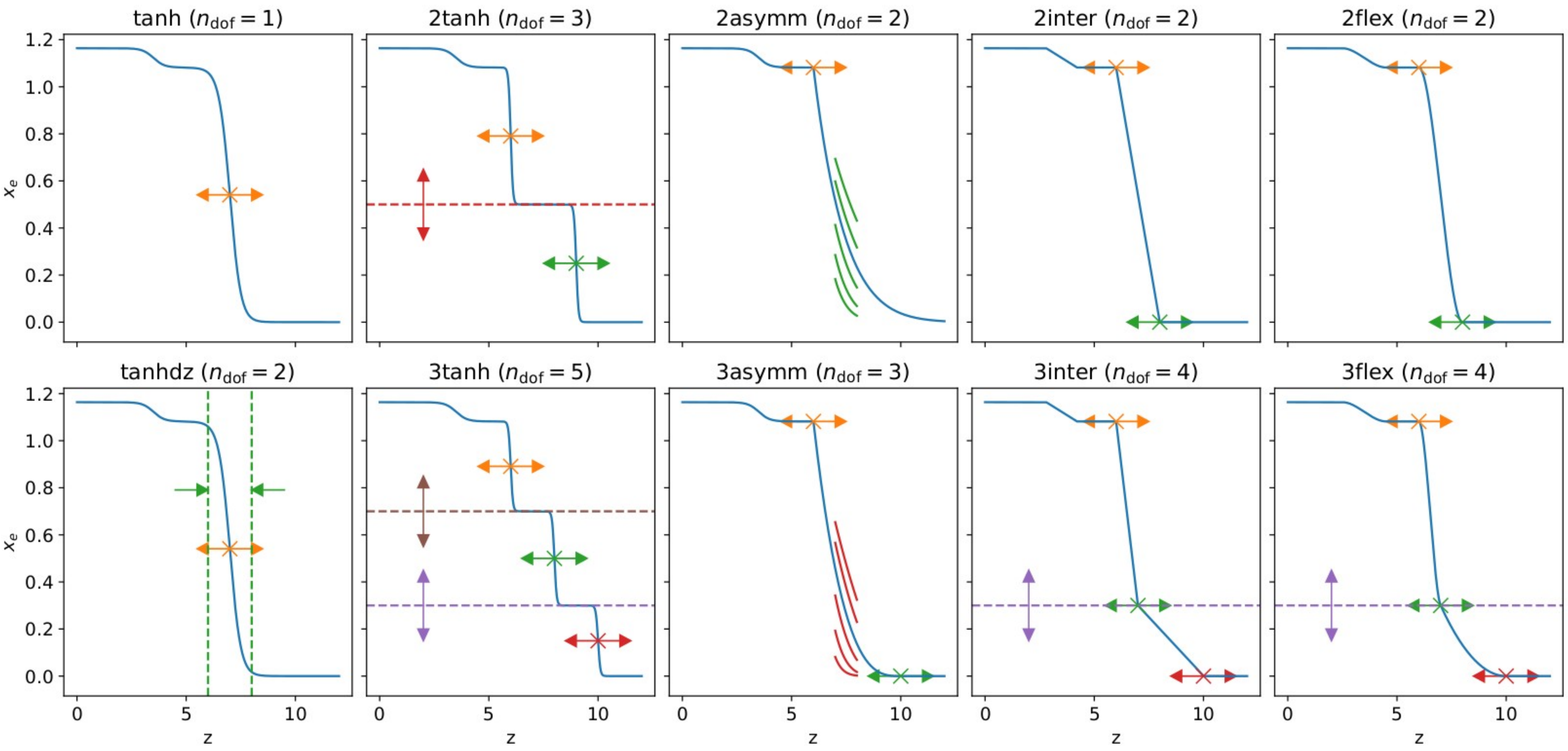

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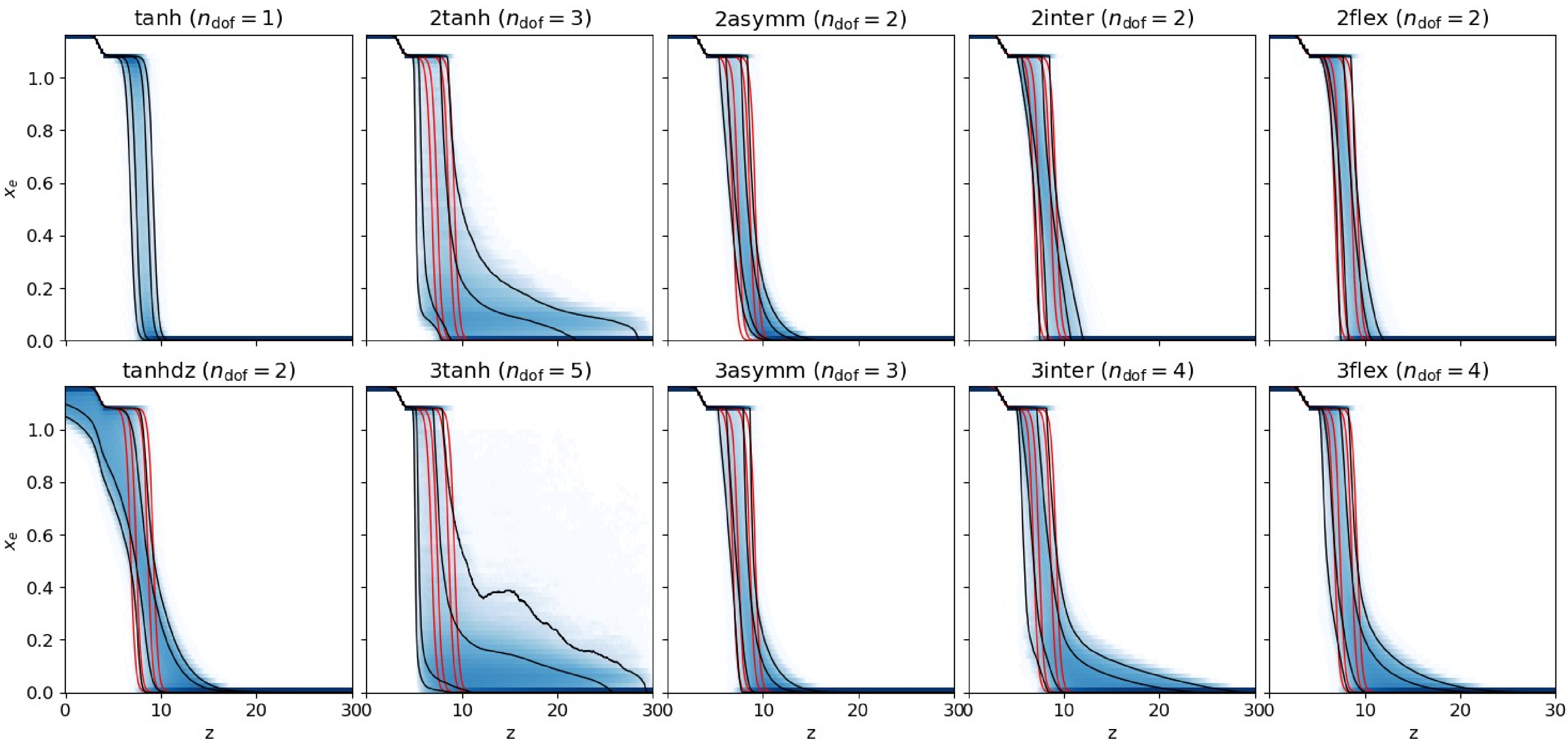

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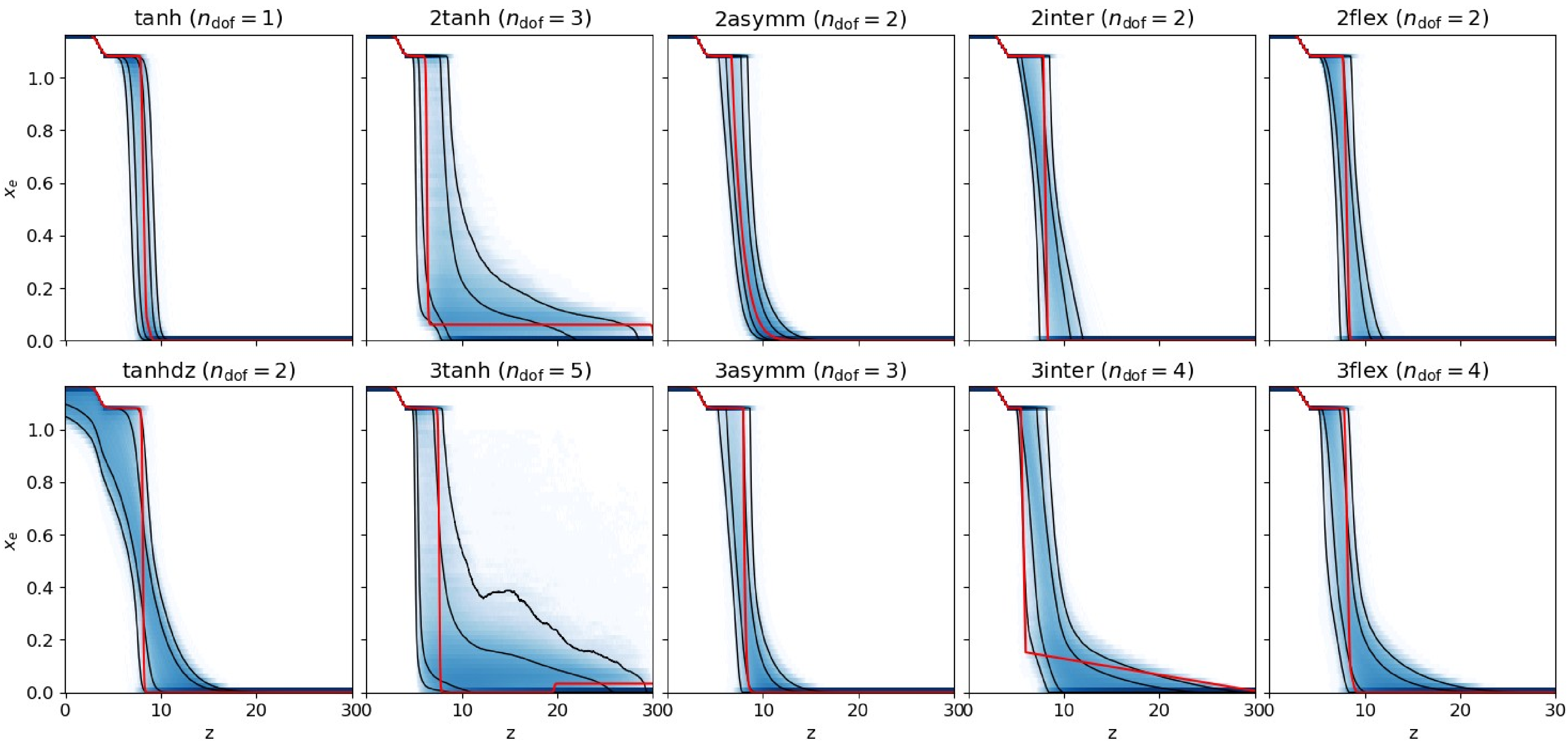

Final word and perspectives

- Finishing touches to be applied to Ilic et al. (mostly 10 bins and PCA)

- Some future perspectives:

  - Interplay with neutrinos constraints/models

  - Combination with external datasets:
    → ground-based CMB e.g SPT & ACT
    → background measurements e.g. BAO
    → LSS measurements
    → astrophysical measurements

Stay tuned !

The end

Thank you very much
for your attention!

Constraints on τ(z, 30)

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z

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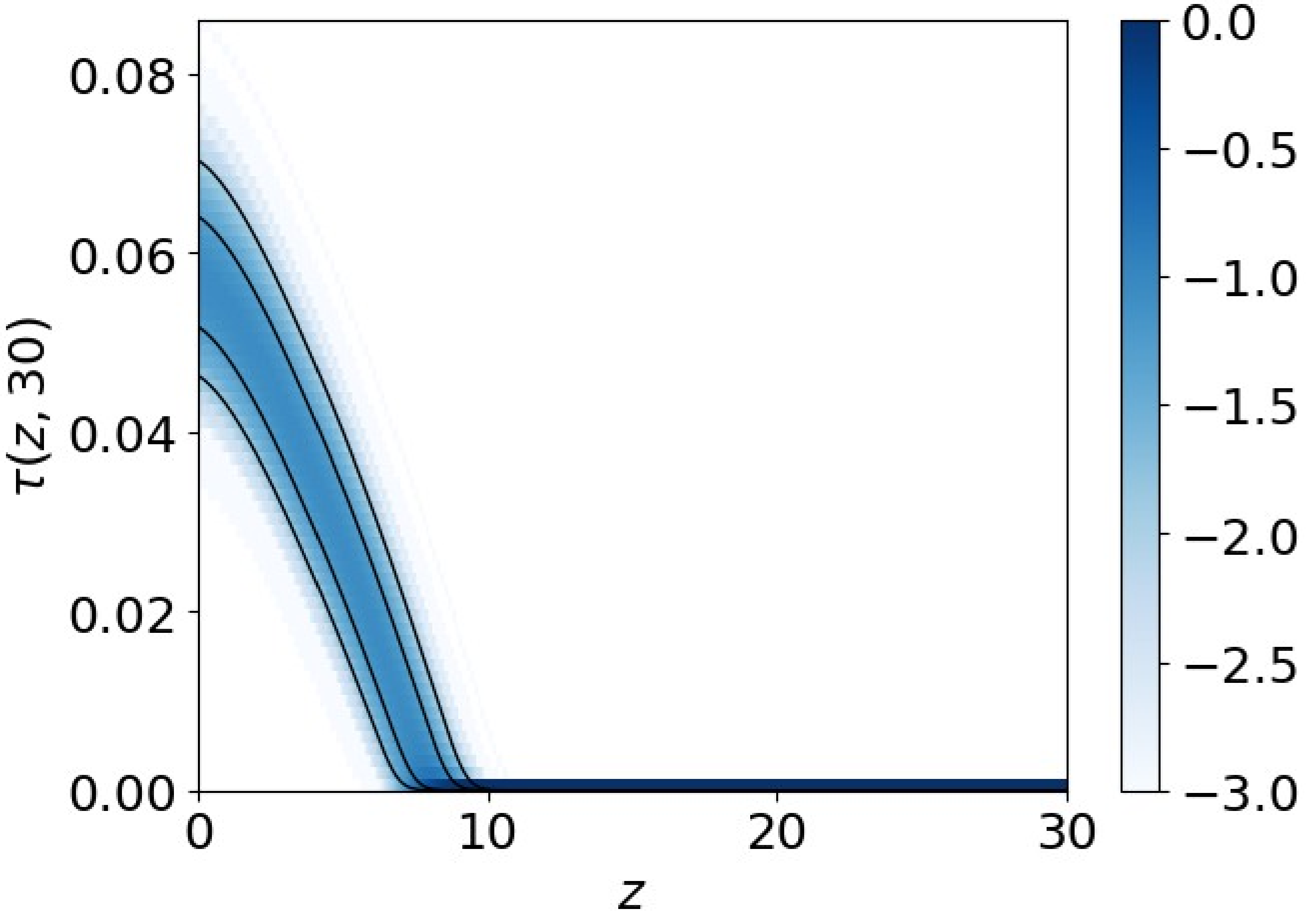
z



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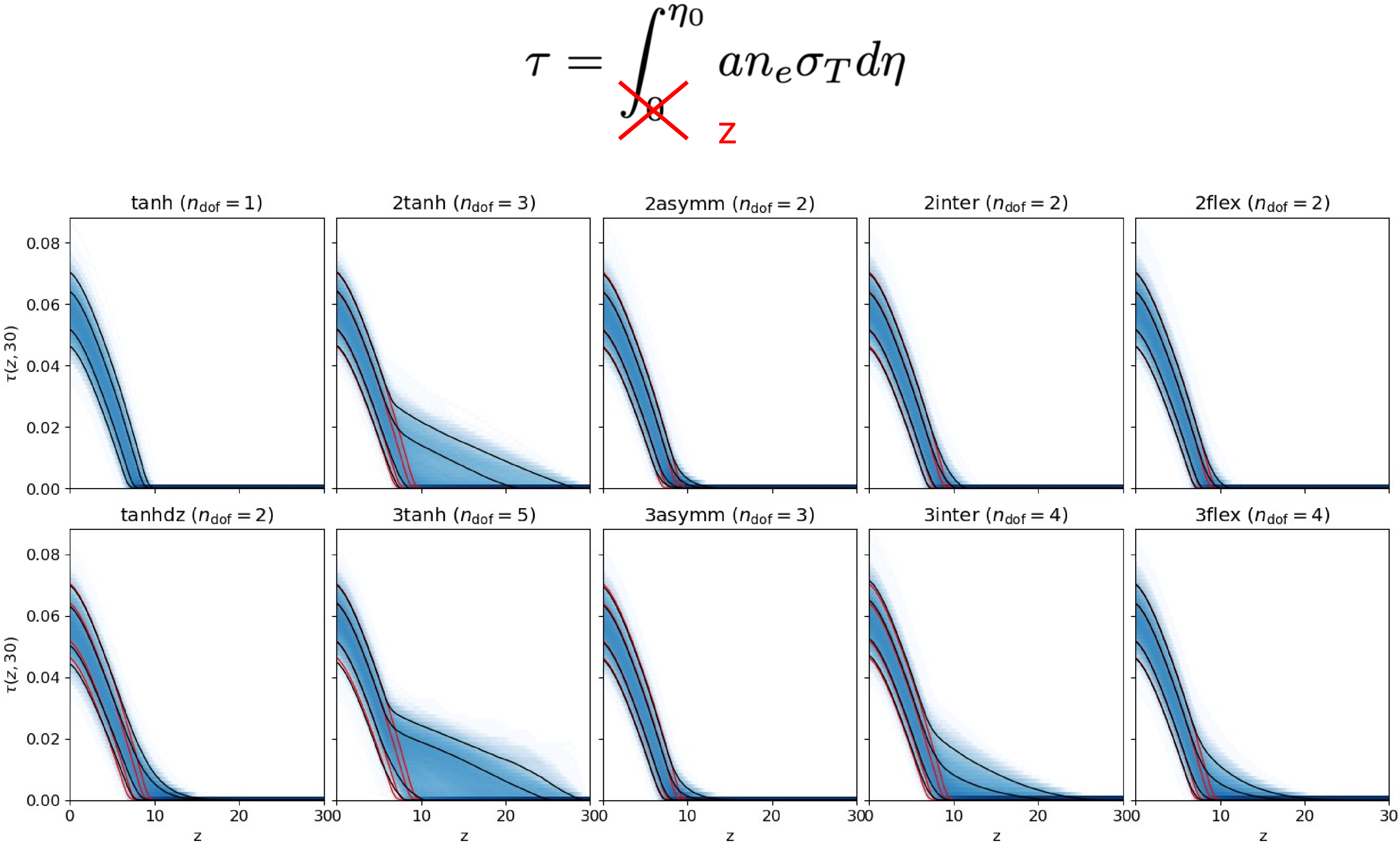

V) Further observations

- QSO spectra
- Lyman-alpha forests
- IGM temperature measurements
- ...
- Neutral hydrogen (21cm) absorption/emission