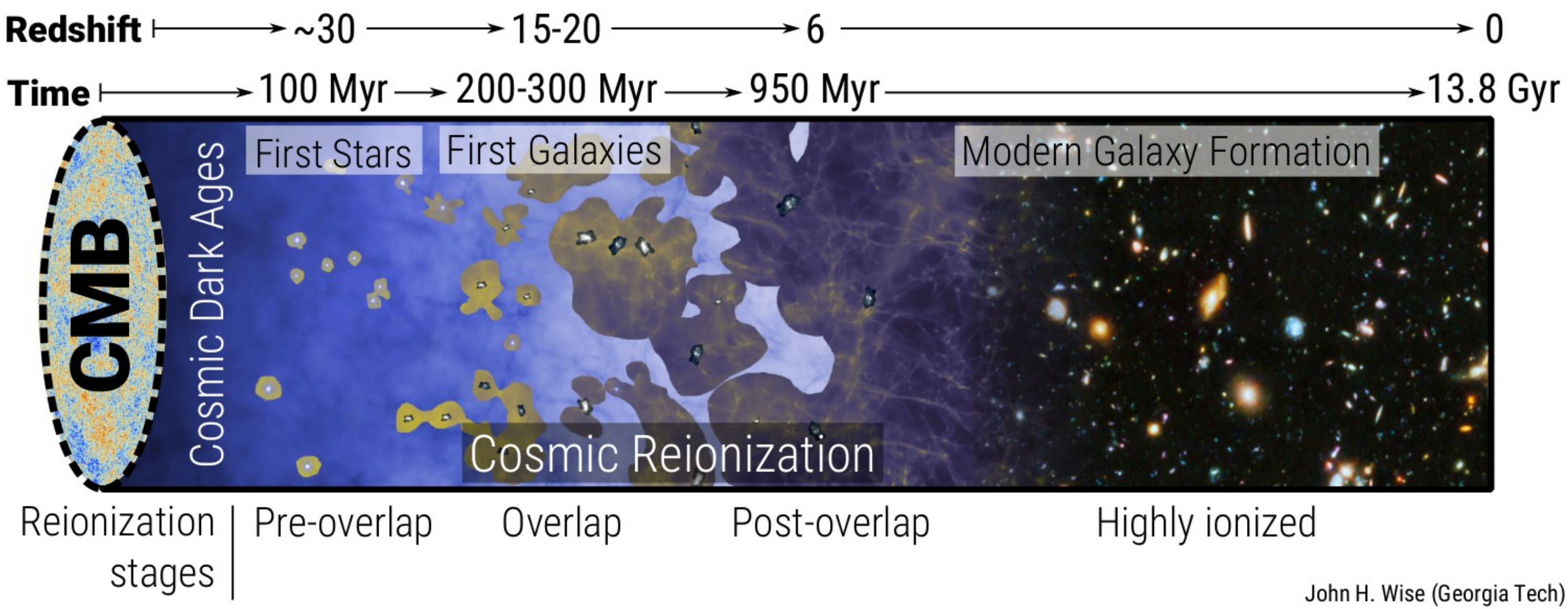
Optical Depth,
Reionization of the Universe and
Neutrino Masses with LiteBIRD

Stéphane Ilić
(IJCLab)

on behalf of the Working Group

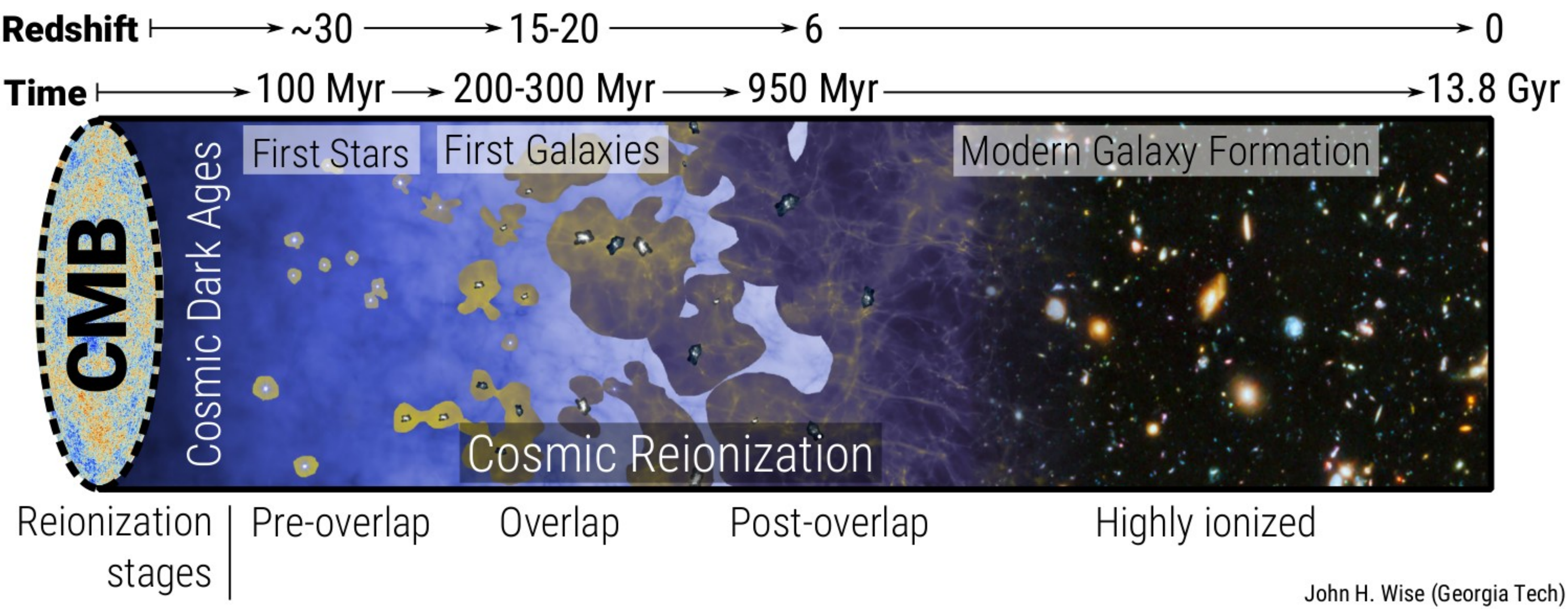
LiteBIRD France Day @ APC, 13/04/2024

The epoch of reionization



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

The epoch of reionization

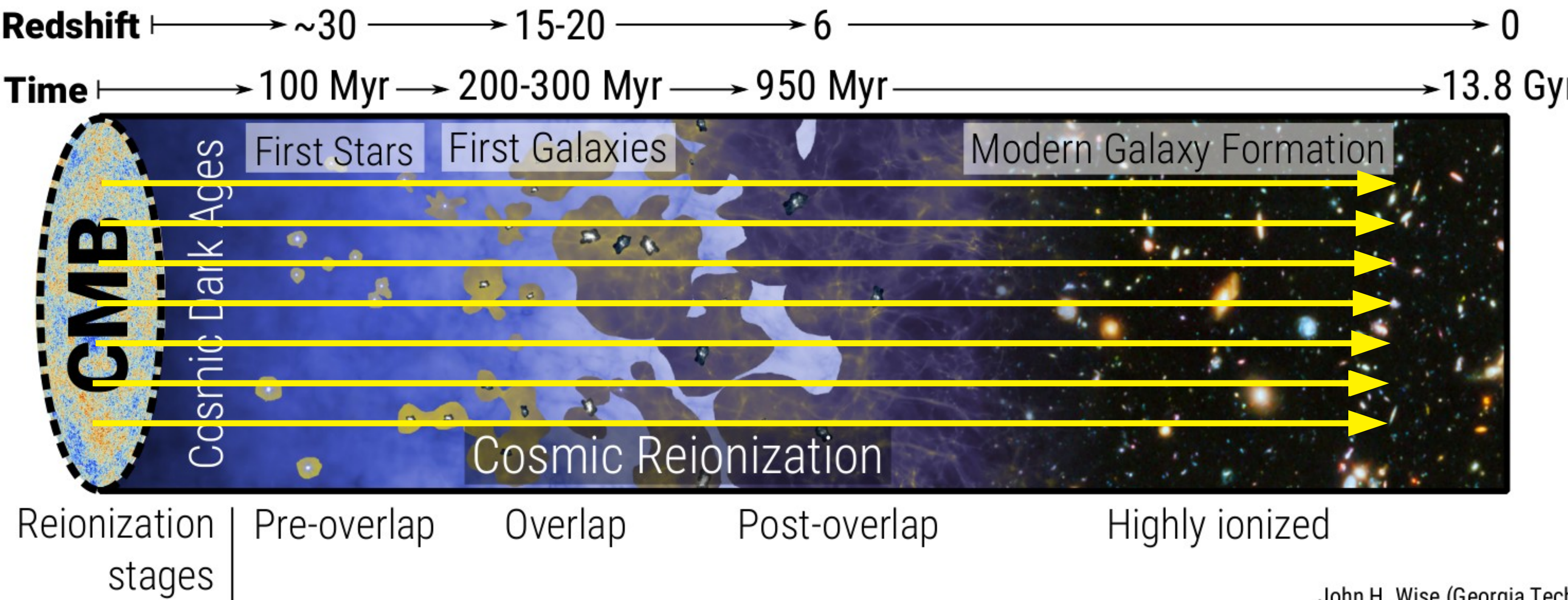


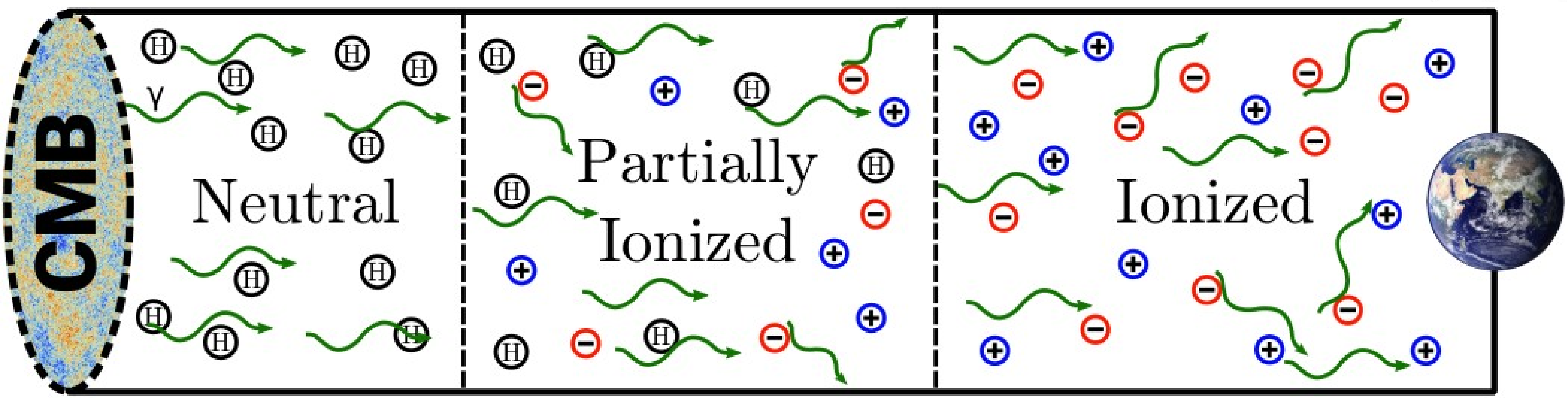
<u>Still many open questions:</u>

- WHEN: When did it happen exactly? 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?

The epoch of reionization





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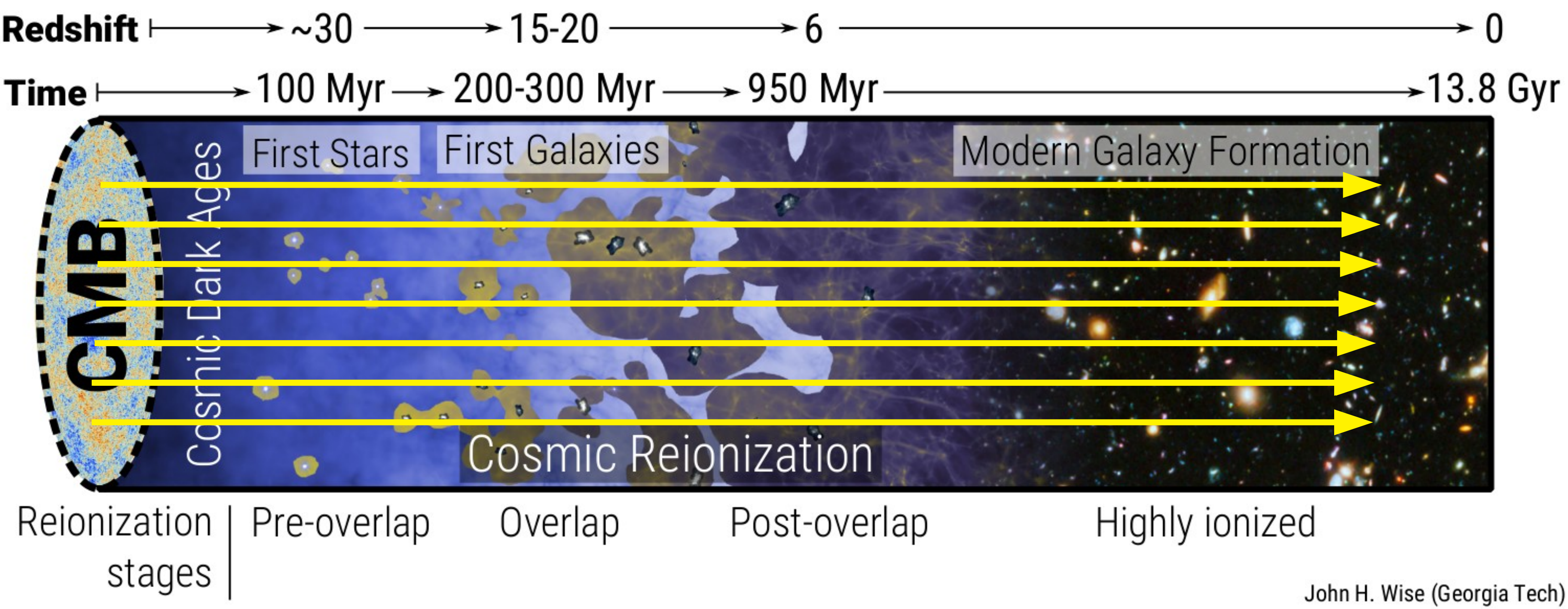


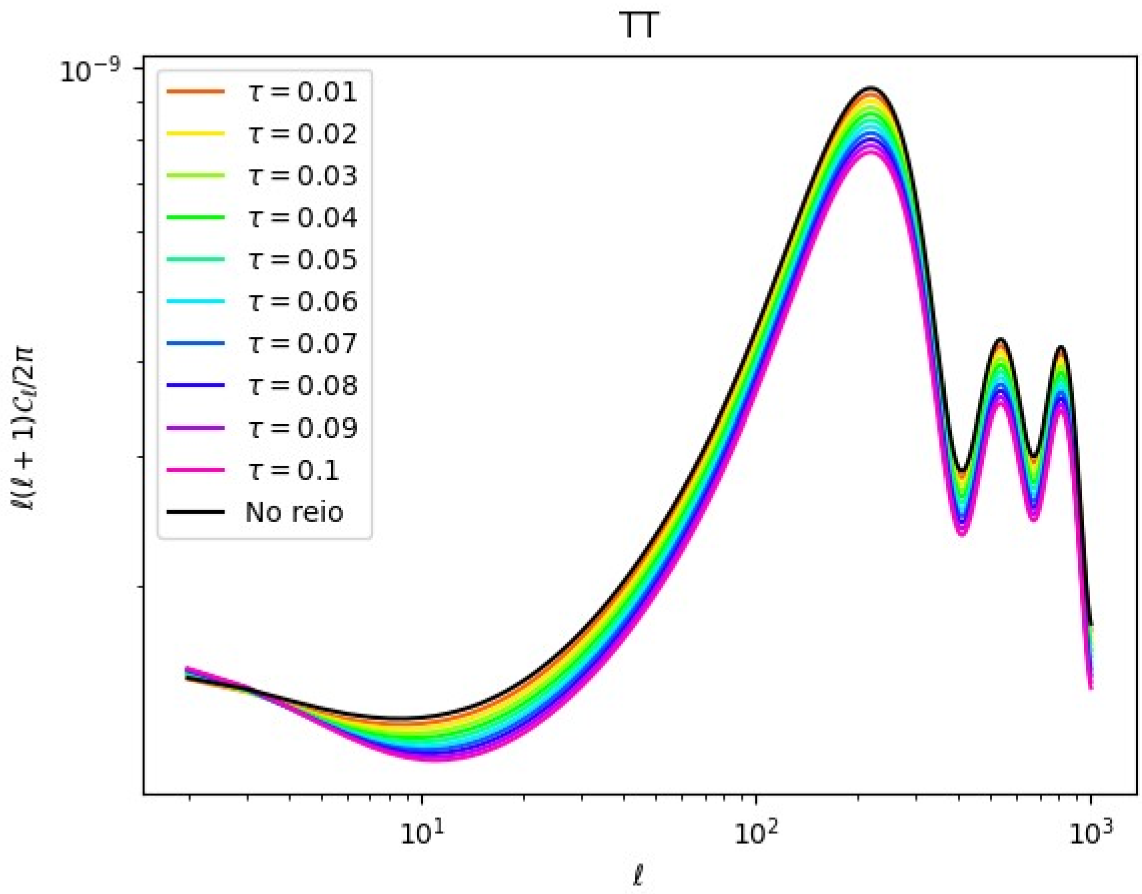
$$\tau = \int_0^{\eta_0} a n_e \sigma_T d\eta$$

Density of free electrons

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

Effects of reionization on the CMB

Impact on CMB temperature angular power spectrum:



Effect (almost) degenerate with a change in A_s

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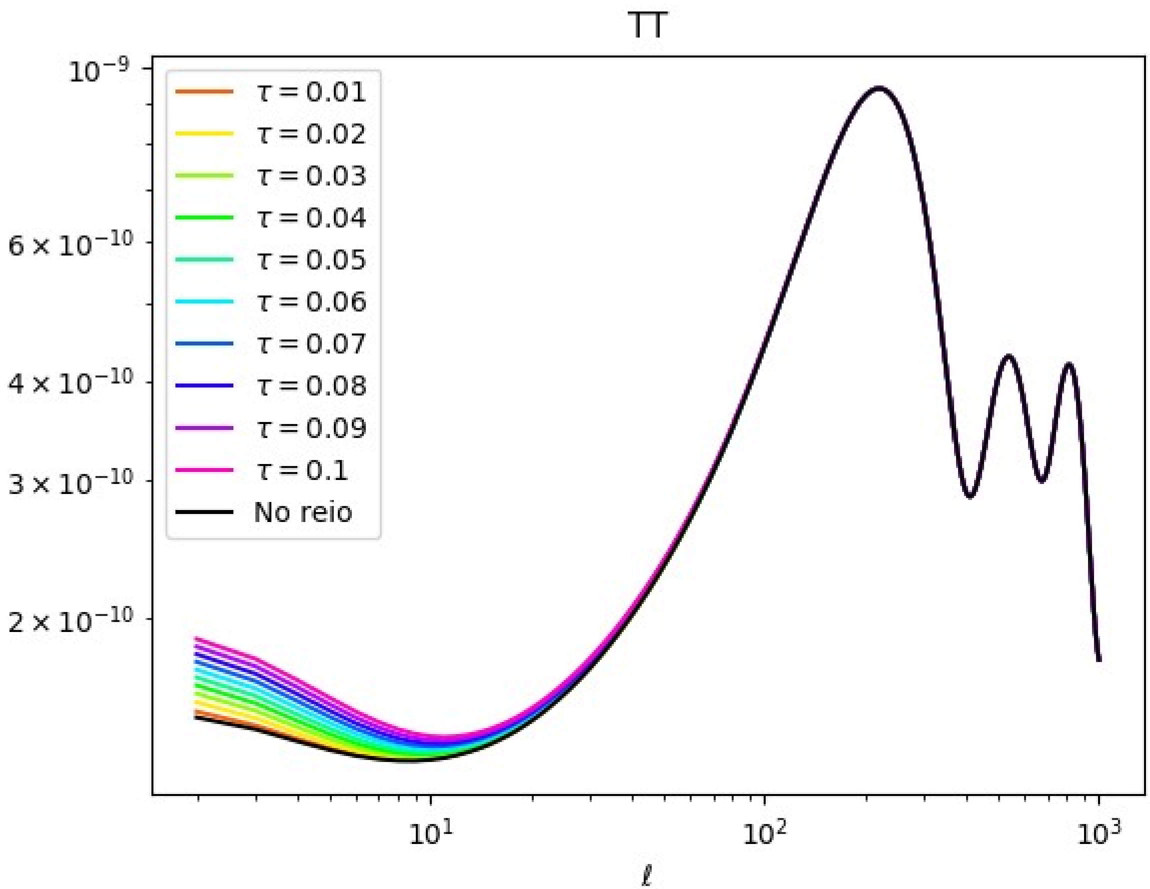
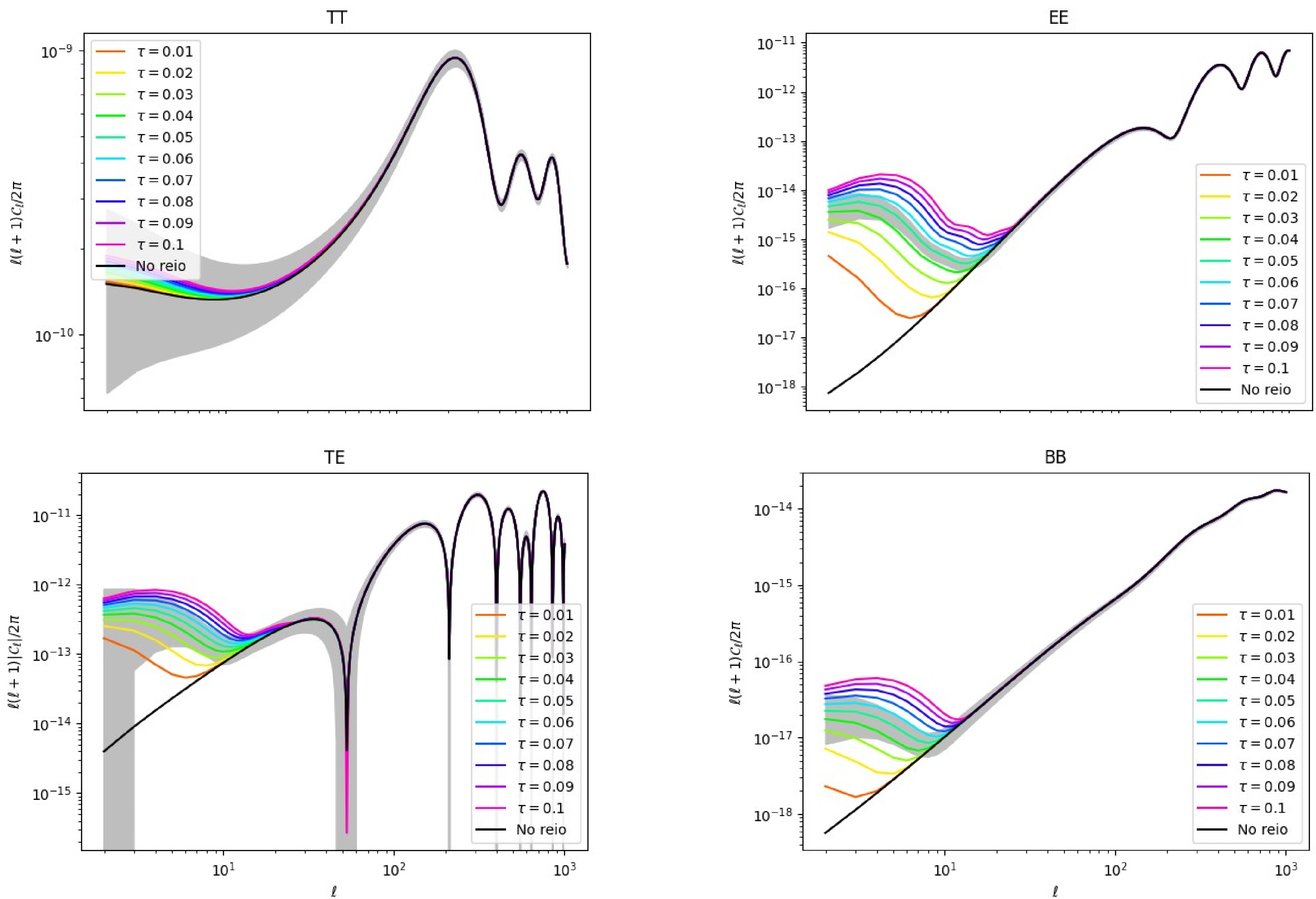


After rescaling A_s by exp(-2τ)

Effects of reionization on the CMB

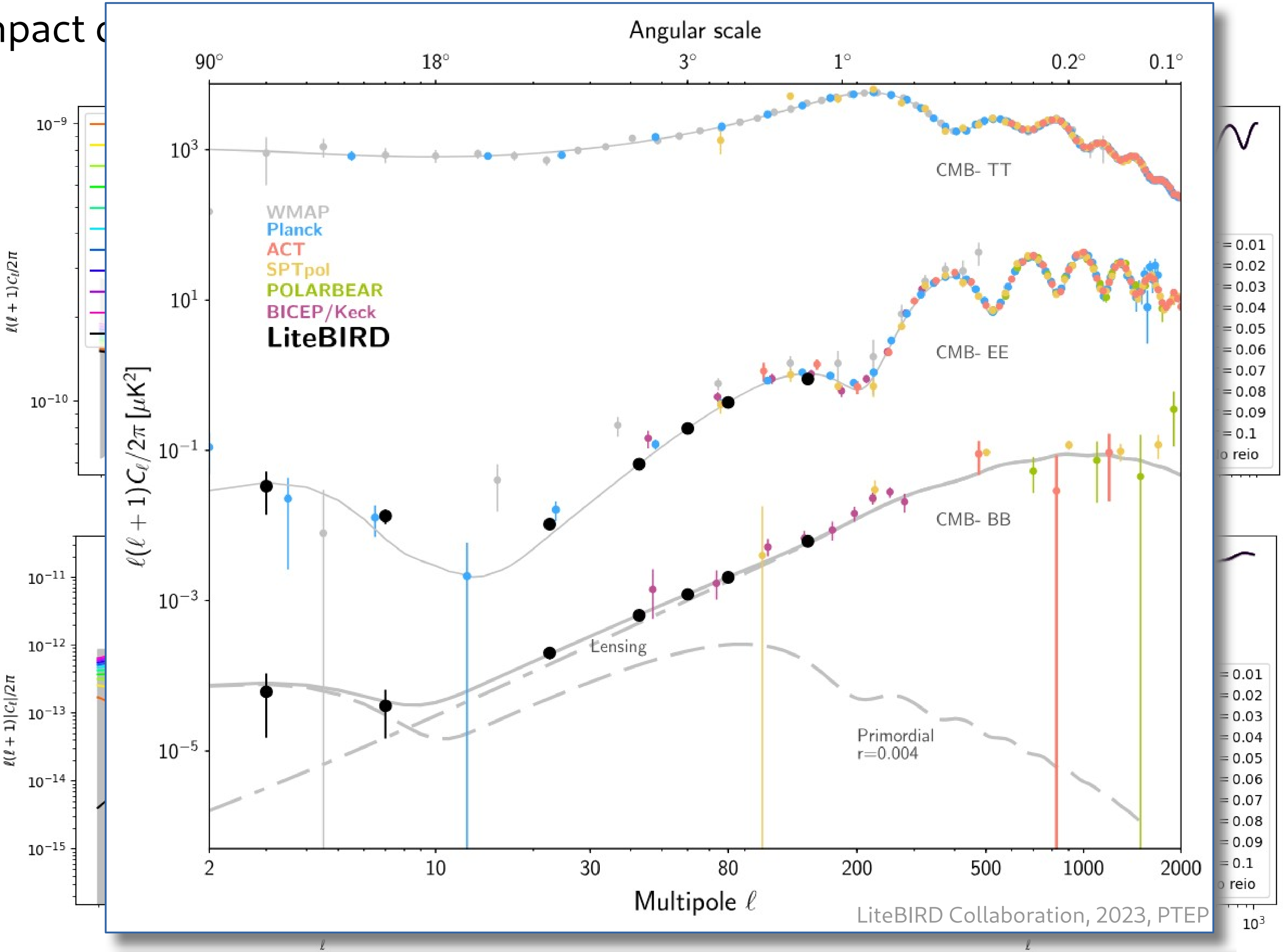
Impact on all CMB angular power spectra:



r=0.01

Effects of reionization on the CMB

Impact o



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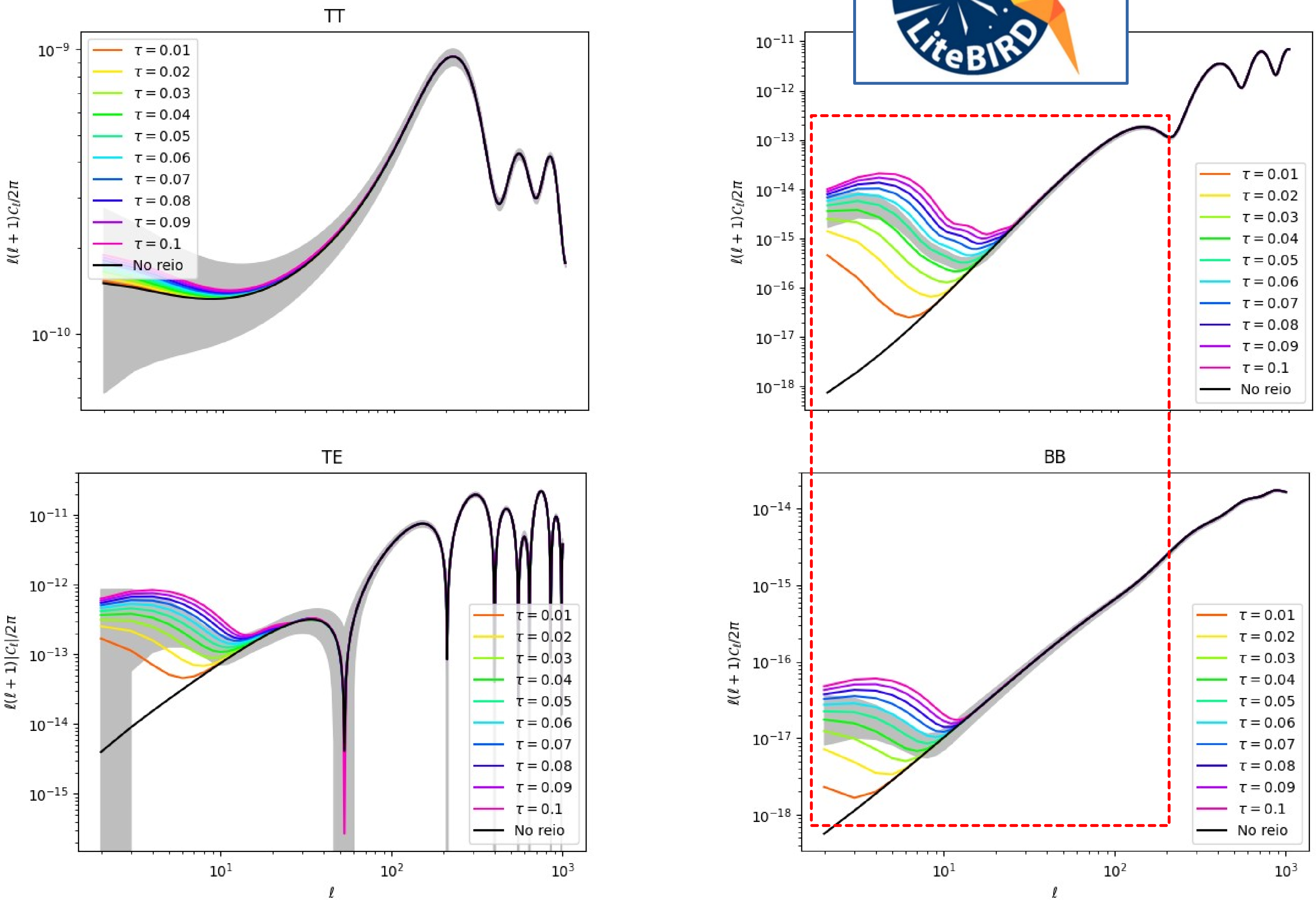

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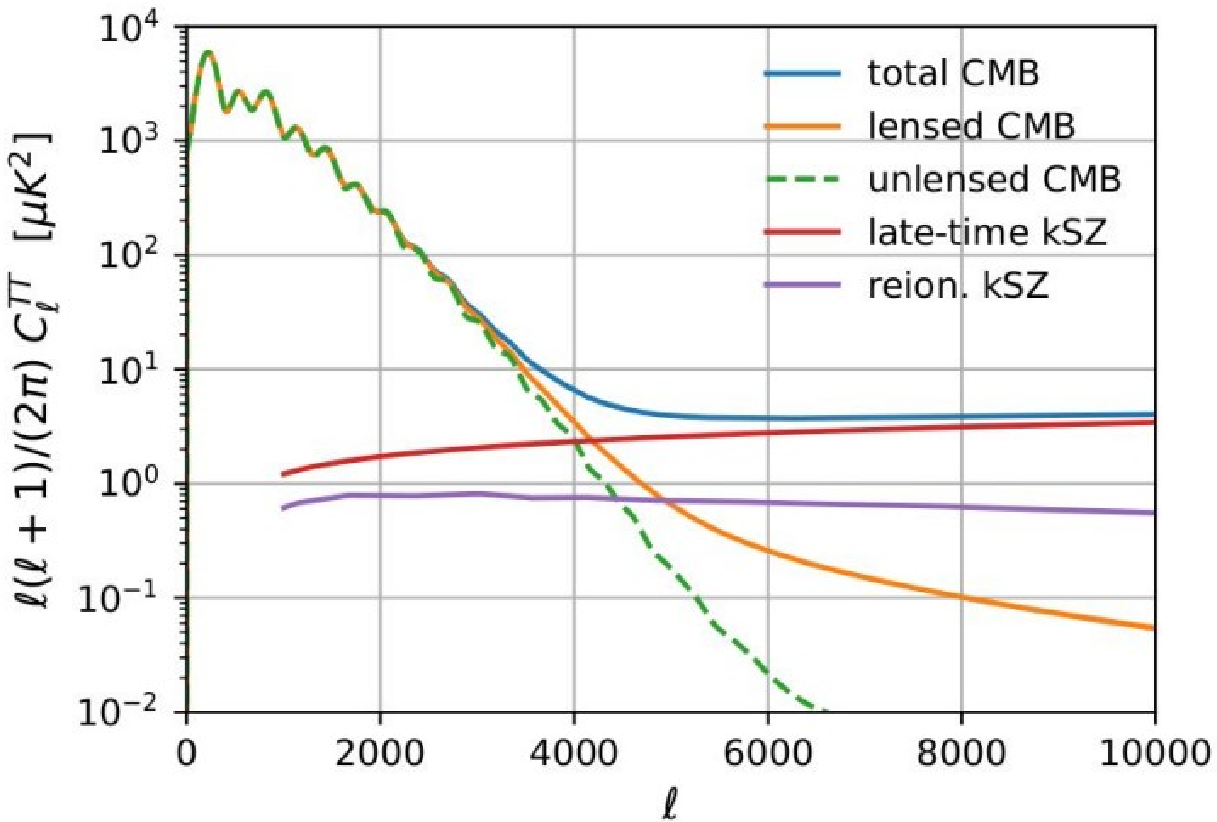

Kinetic Sunyaev-Zel'dovich (kSZ) effect

Purpose of the Working Group

Optical Depth, Reionization of the Universe and Neutrino Masses Working group

Goals:

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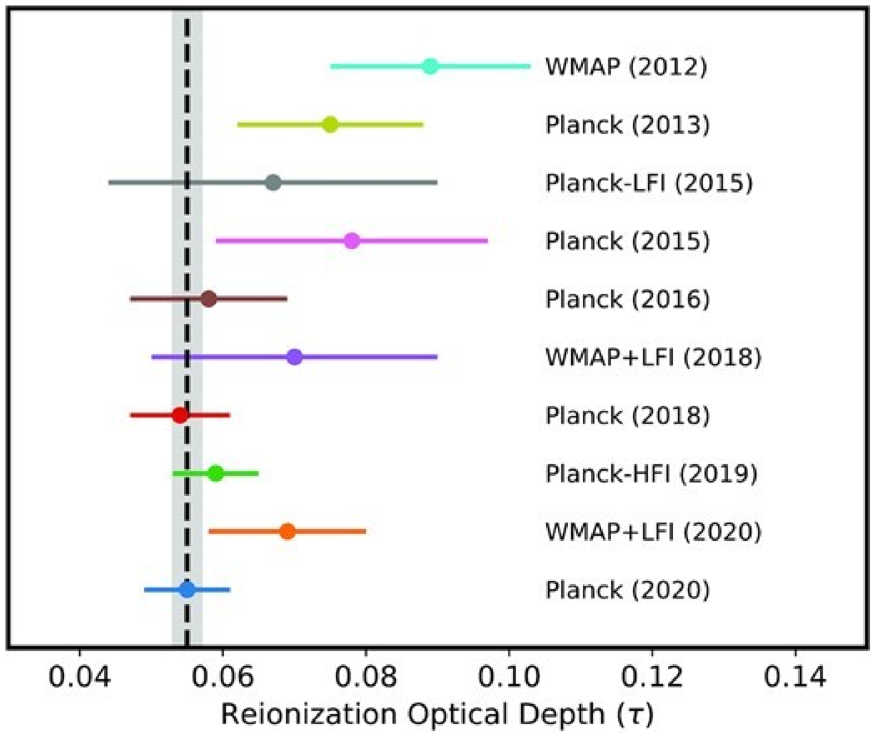
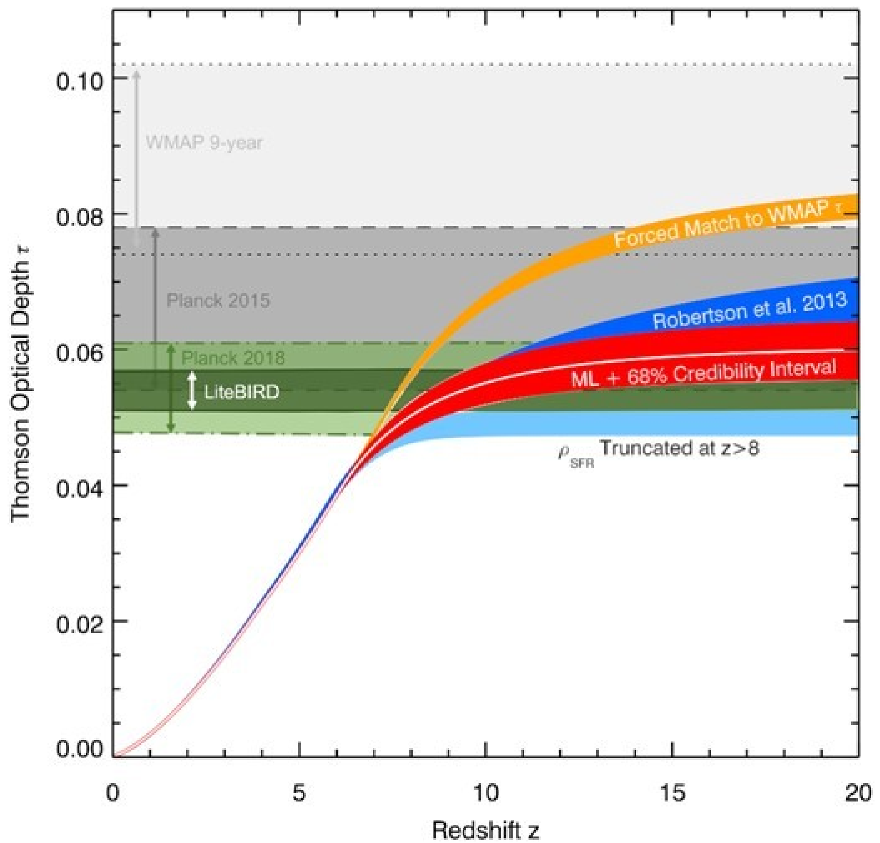
- Assess sensitivity on optical depth expected from LiteBIRD

Current and future constraints on reionization

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





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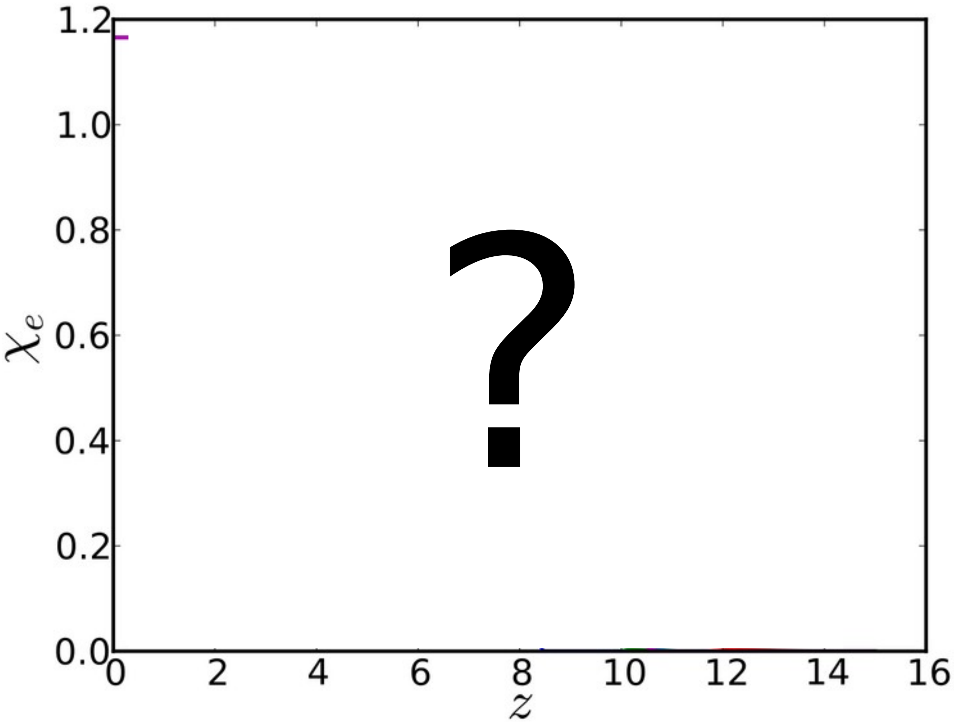
How to model reionization

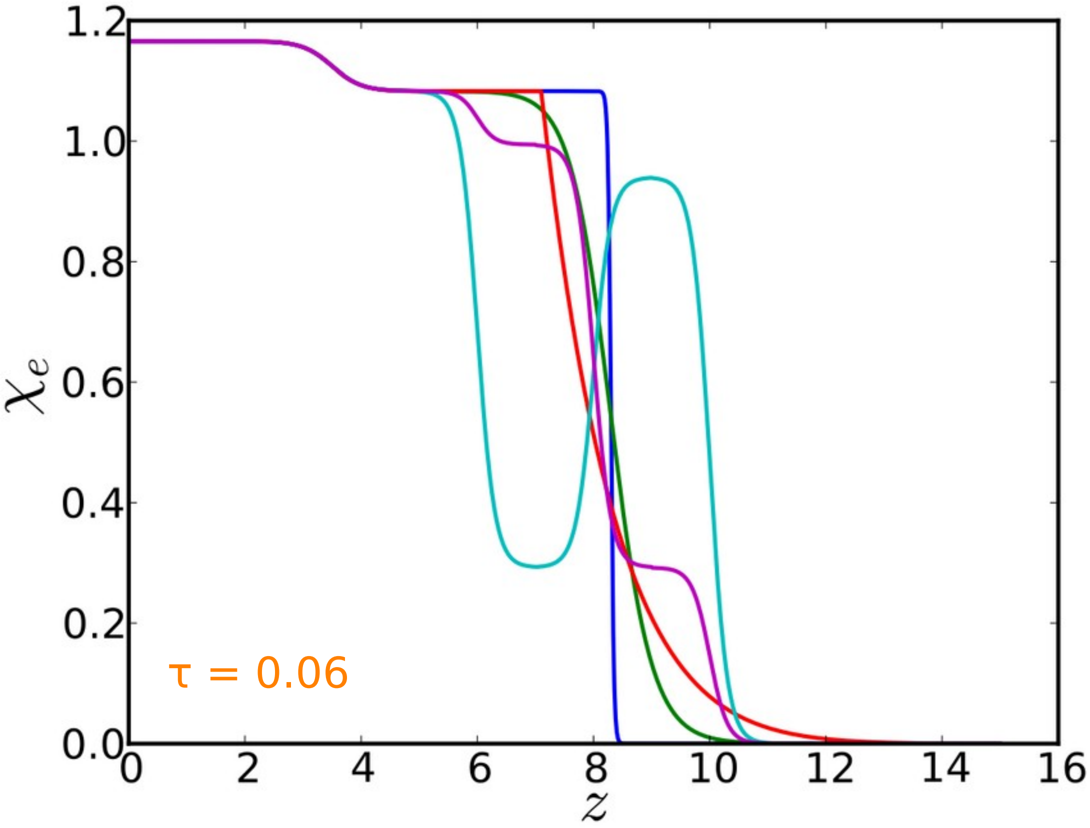
$$\tau = \int_0^{\eta_0} a n_e \sigma_T \, d\eta$$

Free electron density



χ_e = ionization fraction as a function of the redshift

How to model reionization



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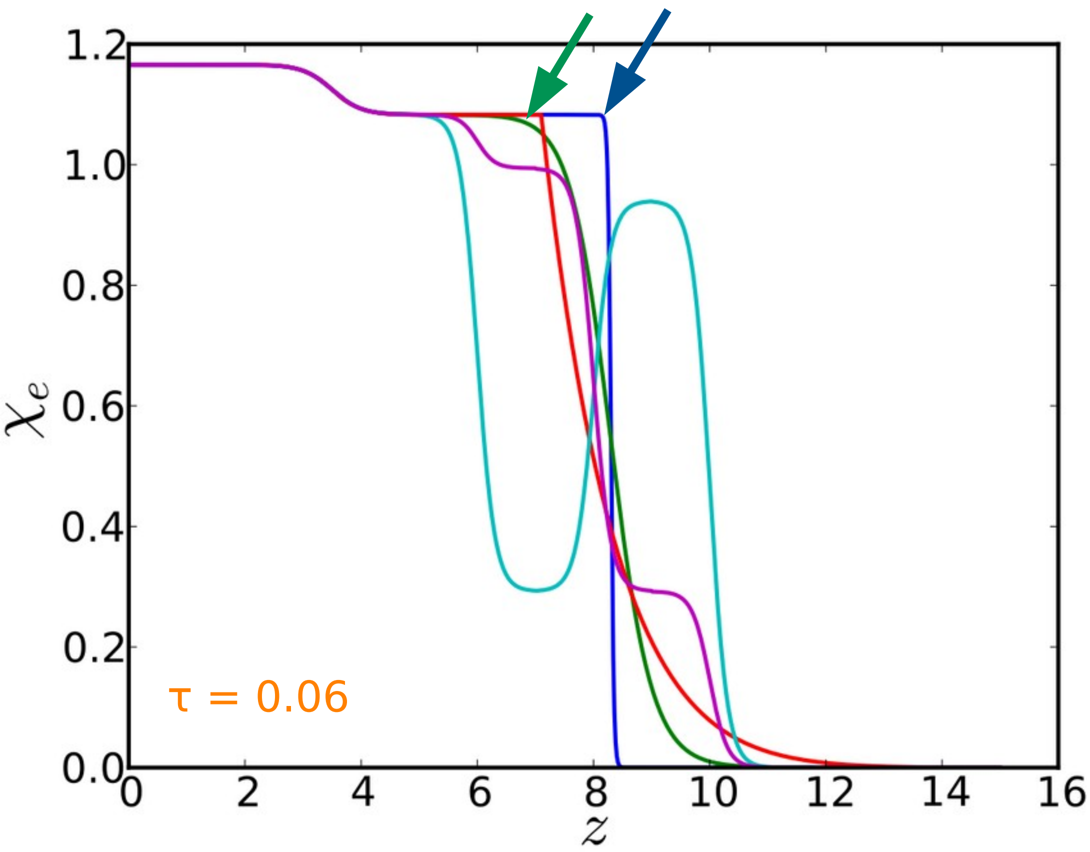
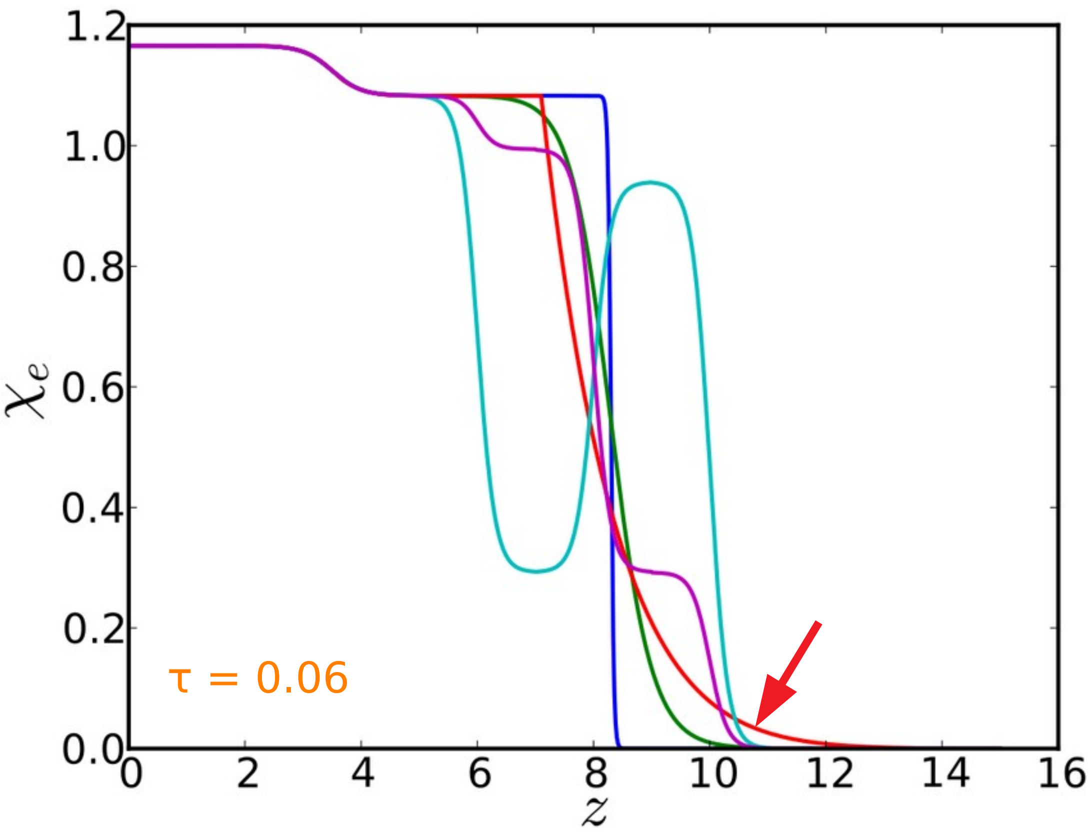


- symmetric (standard tanh)
  - 1 or 2 parameter(s): z_{re}, Δz, τ (pick 2 at most)

How to model reionization



- symmetric (standard tanh)
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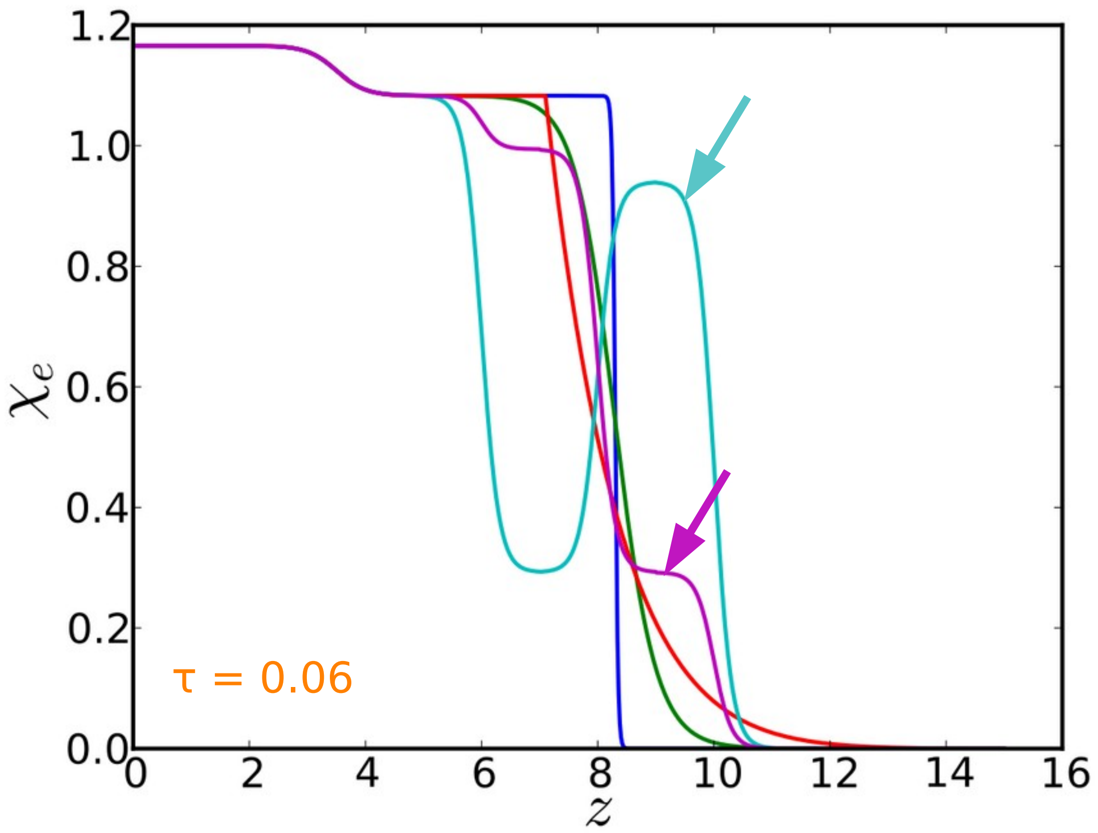
- asymmetric
  - emulates 2 populations of sources :
    1. "gentle" : stars & DGs
    2. "abrupt" : QSOs finish
  - phenomenological description : z_{start}, z_{end}, z_{trans} $\leftrightarrow$ z_{re}, Δz_{begin}, Δz_{end}

How to model reionization



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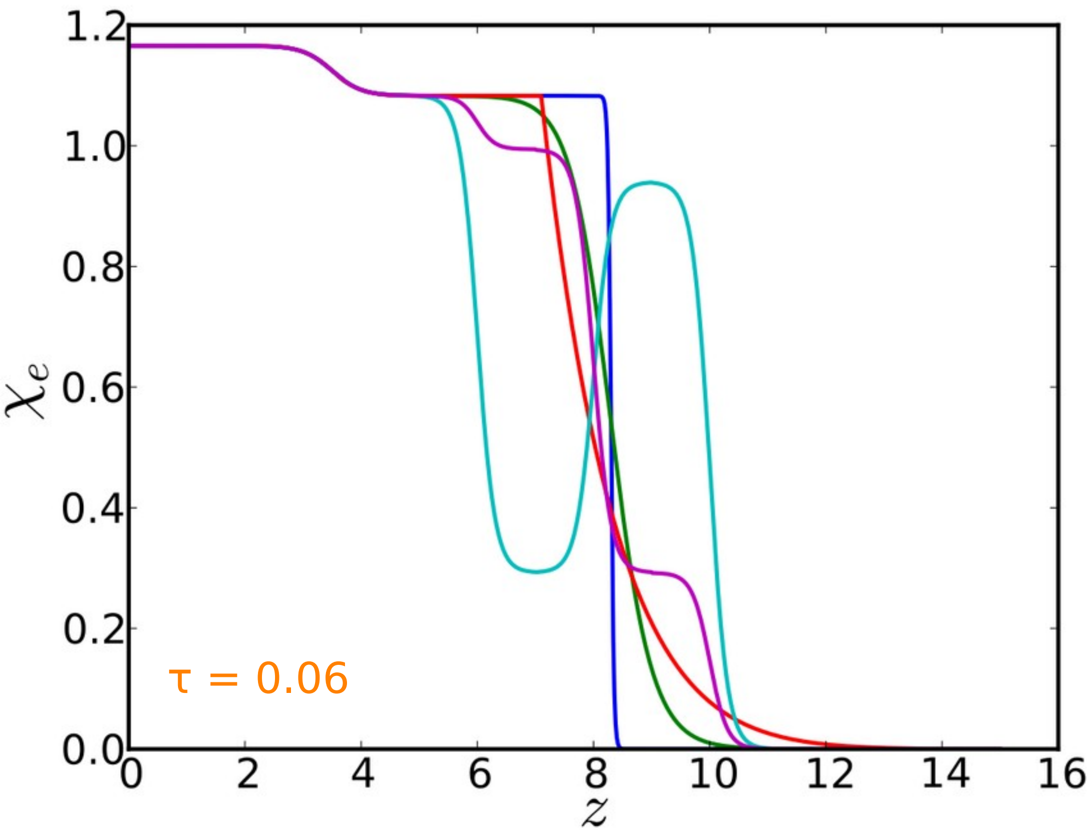
- model-independent
  - $x_e(z)$ in redshift bins
  - Principal Component Analysis
  - Piecewise Cubic Hermite Interpolating Polynomials (PCHIP)
  - FlexKnot (Milea & Bouchet 2018)
  - ...

How to model reionization



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+ physical models (sometimes in combination with other astro data)

Reionization & inflation

Phys. Rev. D. 2009

CMB polarization features from inflation versus reionization

Michael J. Mortonson,[1,2,*] Cora Dvorkin,[1,2,†] Hiranya V. Peiris,[3,‡] and Wayne Hu[4,2,§]

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[2]*Kavli Institute for Cosmological Physics and Enrico Fermi Institute, University of Chicago, Chicago IL 60637, U.S.A.*
[3]*Institute of Astronomy, University of Cambridge, Cambridge CB3 0HA, U.K.*
[4]*Department of Astronomy & Astrophysics, University of Chicago, Chicago IL 60637*

(Dated: November 5, 2018)

The angular power spectrum of the cosmic microwave background temperature anisotropy observed by WMAP has an anomalous dip at $\ell \sim 20$ and bump at $\ell \sim 40$. One explanation for this structure is the presence of features in the primordial curvature power spectrum, possibly caused by a step in the inflationary potential. The detection of these features is only marginally significant from temperature data alone. However, the inflationary feature hypothesis predicts a specific shape for the E-mode polarization power spectrum with a structure similar to that observed in temperature at $\ell \sim 20-40$. Measurement of the CMB polarization on few-degree scales can therefore be used as a consistency check of the hypothesis. The Planck satellite has the statistical sensitivity to confirm or rule out the model that best fits the temperature features with 3 σ significance, assuming all other parameters are known. With a cosmic variance limited experiment, this significance improves to 8 σ. For tests of inflationary models that can explain both the dip and bump in temperature, the primary source of uncertainty is confusion with polarization features created by a complex reionization history, which at most reduces the significance to 2.5 σ for Planck and $5-6$ σ for an ideal experiment. Smoothing of the polarization spectrum by a large tensor component only slightly reduces the ability of polarization to test for inflationary features, as does requiring that polarization is consistent with the observed temperature spectrum given the expected low level of TE correlation on few-degree scales. If polarized foregrounds can be adequately subtracted, Planck will supply valuable evidence for or against features in the primordial power spectrum. A future high-sensitivity polarization satellite would enable a decisive test of the feature hypothesis and provide complementary information about the shape of a possible step in the inflationary potential.

Effects of reionization on the CMB

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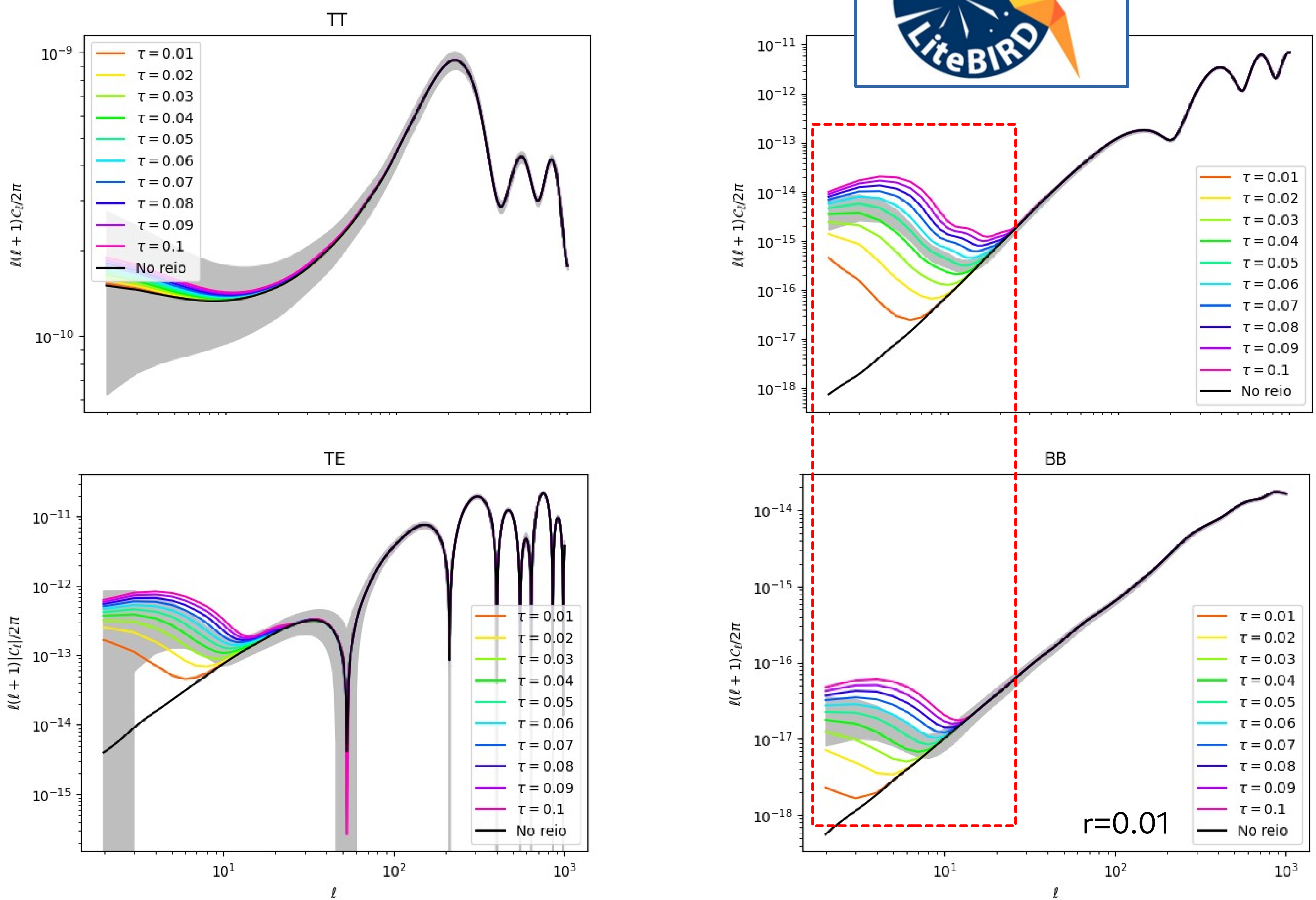

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Impact of massive neutrinos

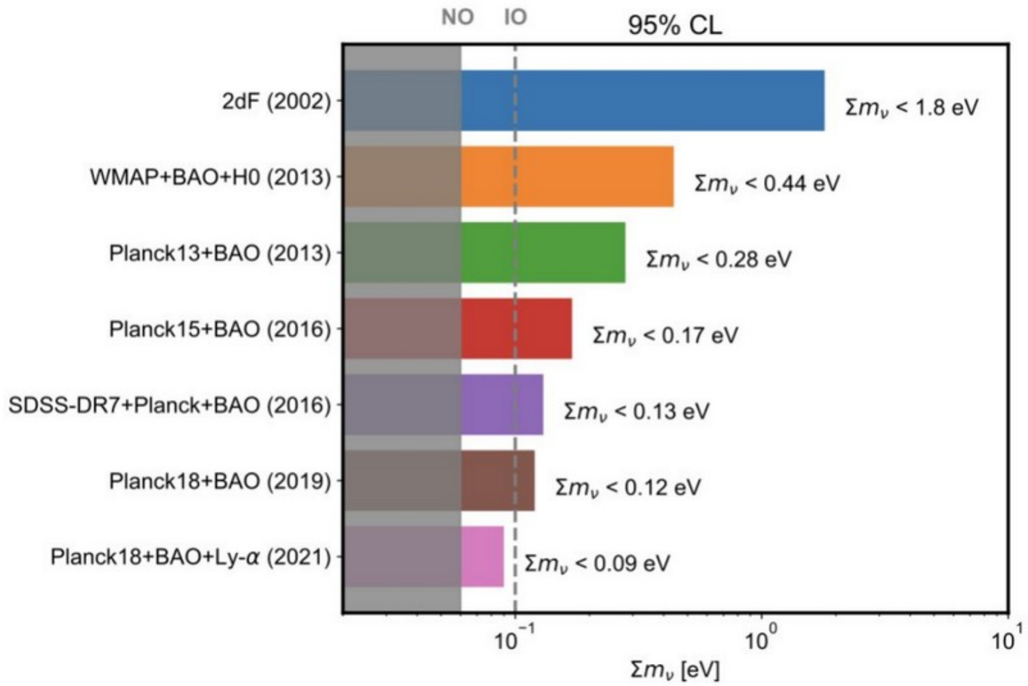
Massive neutrinos suppress structure formation:

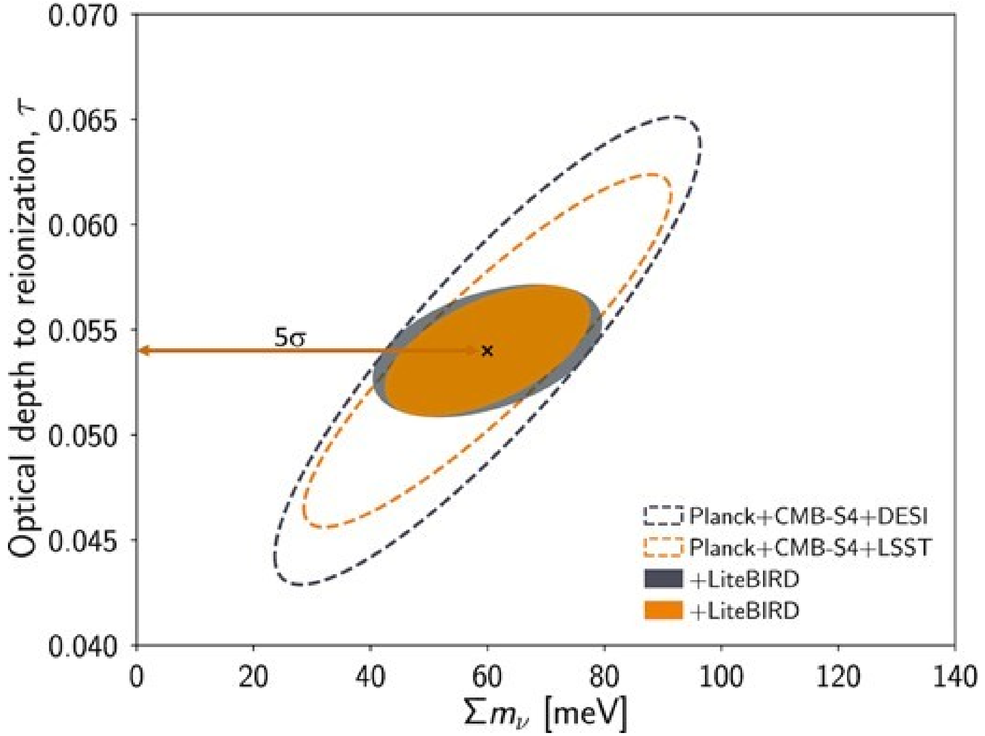
- alter matter power spectrum, decreasing power at small scales
- in CMB, affect (among other things) lensing at higher multipoles

→ impact of neutrinos hard to estimate without a good handle on the primordial power spectrum (A_s)

→ if A_s is incorrectly inferred due to inaccurate τ: interferes with accurate measure of neutrinos power suppression

Impact of massive neutrinos





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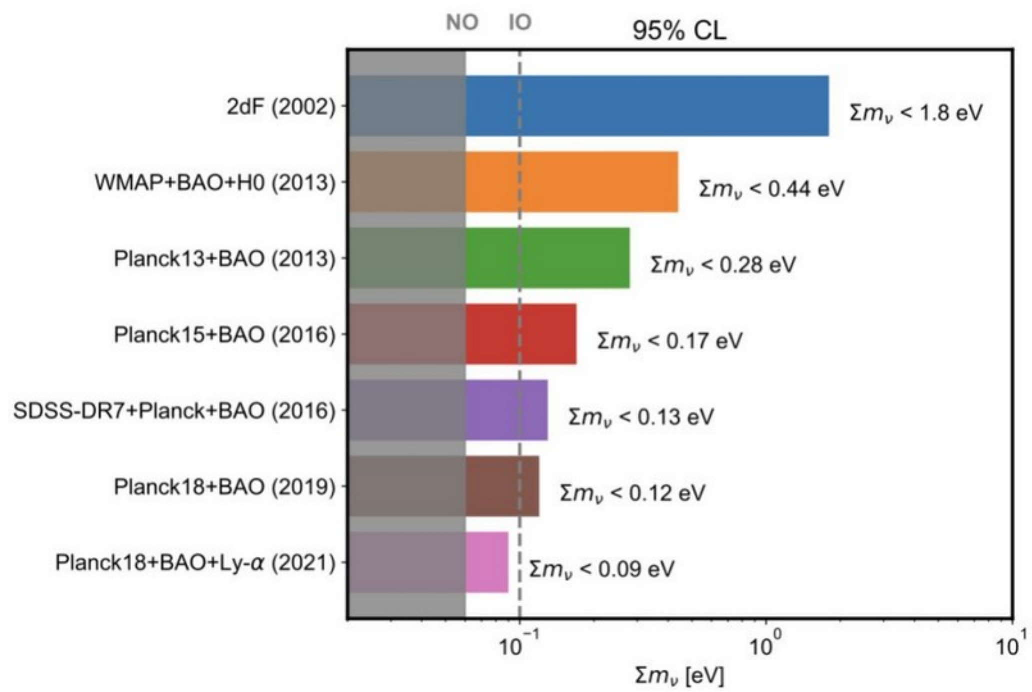

arXiv:2405.00836v1 [astro-ph.CO] 1 May 2024

No νs is Good News

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[3] *Department of Physics, University of California, San Diego, La Jolla, CA 92093, USA*
[4] *Department of Physics, Southern Methodist University, Dallas, TX 75275, USA*
[5] *Department of Physics & Astronomy, The Johns Hopkins University, Baltimore, MD 21218, USA*

Abstract

The baryon acoustic oscillation (BAO) analysis from the first year of data from the Dark Energy Spectroscopic Instrument (DESI), when combined with data from the cosmic microwave background (CMB), has placed an upper-limit on the sum of neutrino masses, $\sum m_\nu < 70$ meV (95%). In addition to excluding the minimum sum associated with the inverted hierarchy, the posterior is peaked at $\sum m_\nu = 0$ and is close to excluding even the minumum sum, 58 meV at 2σ. In this paper, we explore the implications of this data for cosmology and particle physics. The sum of neutrino mass is determined in cosmology from the suppression of clustering in the late universe. Allowing the clustering to be enhanced, we extended the DESI analysis to $\sum m_\nu < 0$ and find $\sum m_\nu = -160 \pm 90$ meV (68%), and that the suppression of power from the minimum sum of neutrino masses is excluded at 99% confidence. We show this preference for negative masses makes it challenging to explain the result by a shift of cosmic parameters, such as the optical depth or matter density. We then show how a result of $\sum m_\nu = 0$ could arise from new physics in the neutrino sector, including decay, cooling, and/or time-dependent masses. These models are consistent with current observations but imply new physics that is accessible in a wide range of experiments. In addition, we discuss how an apparent signal with $\sum m_\nu < 0$ can arise from new long range forces in the dark sector or from a primordial trispectrum that resembles the signal of CMB lensing.

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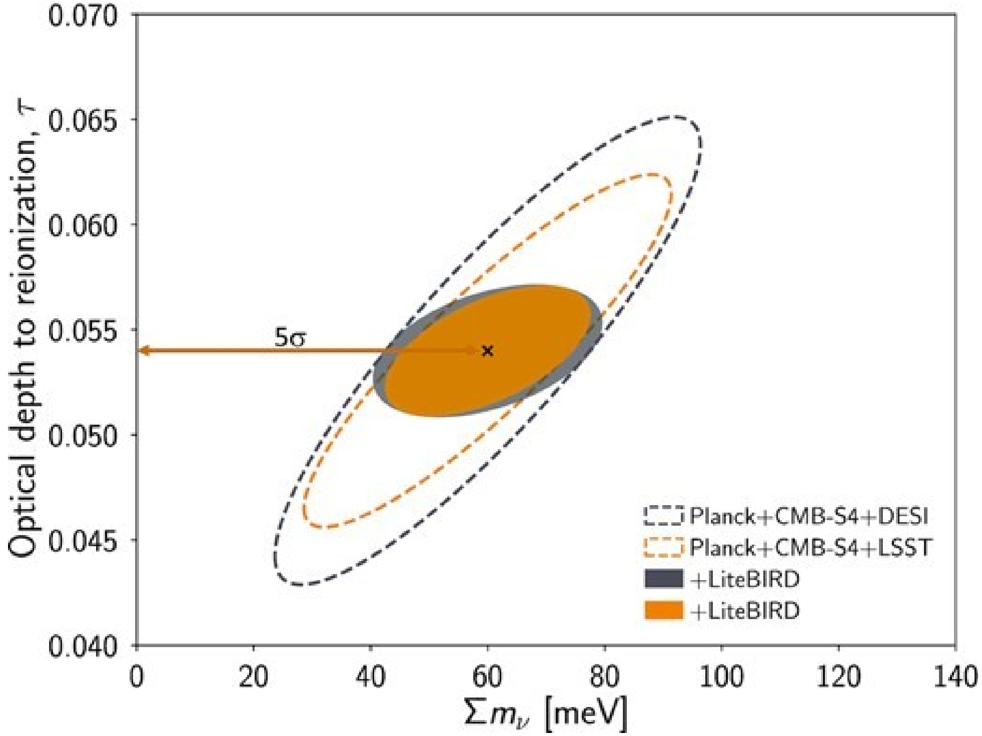

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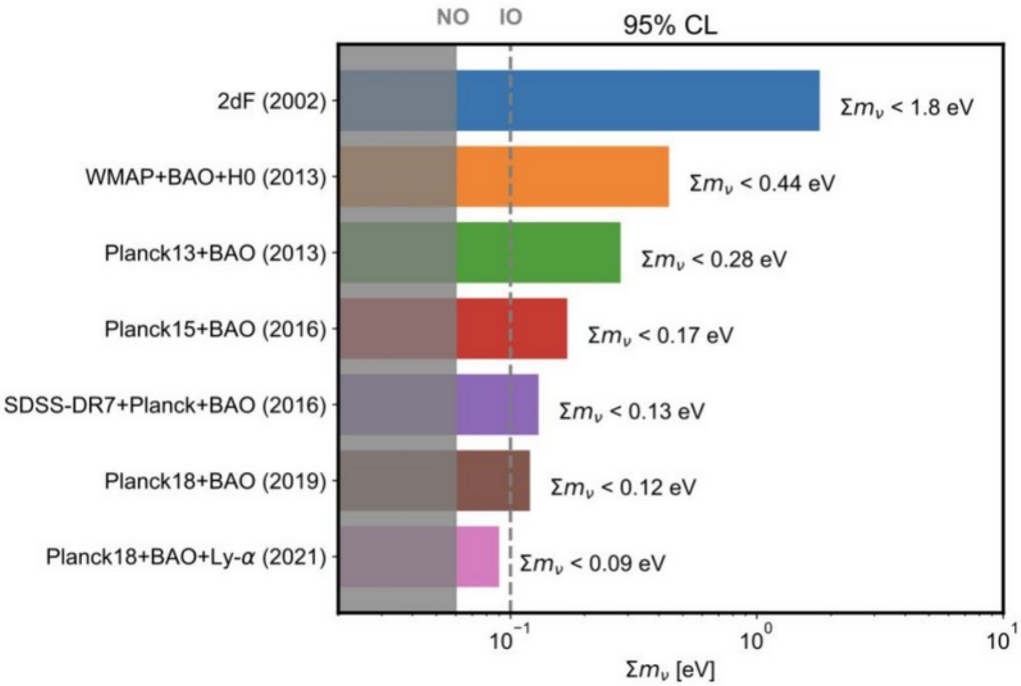
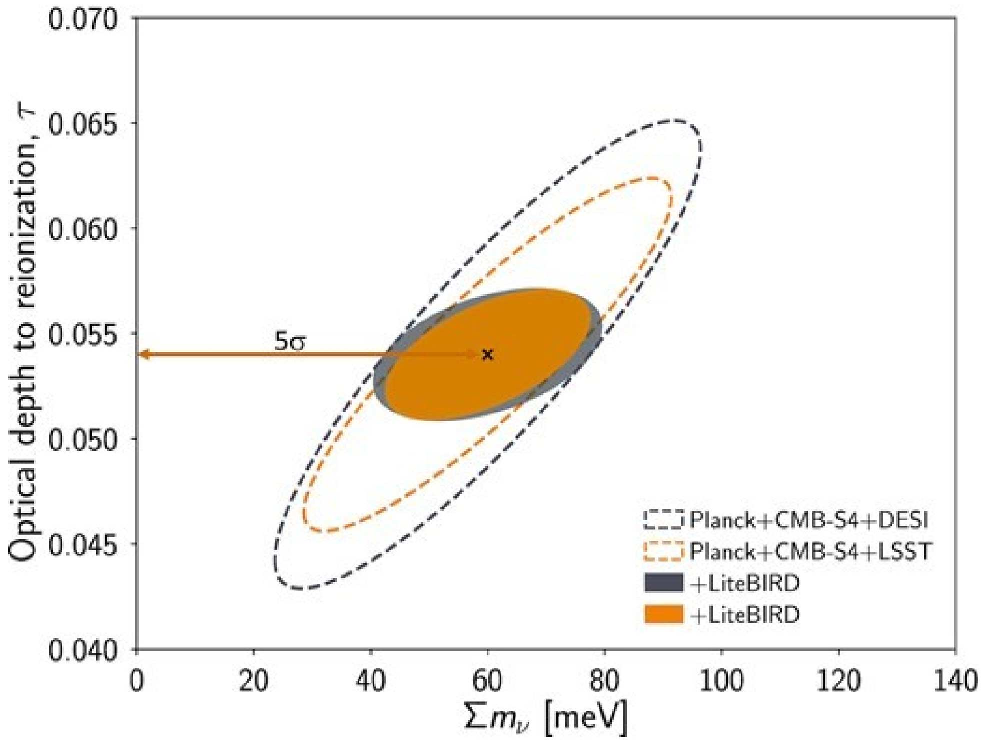
Impact of massive neutrinos





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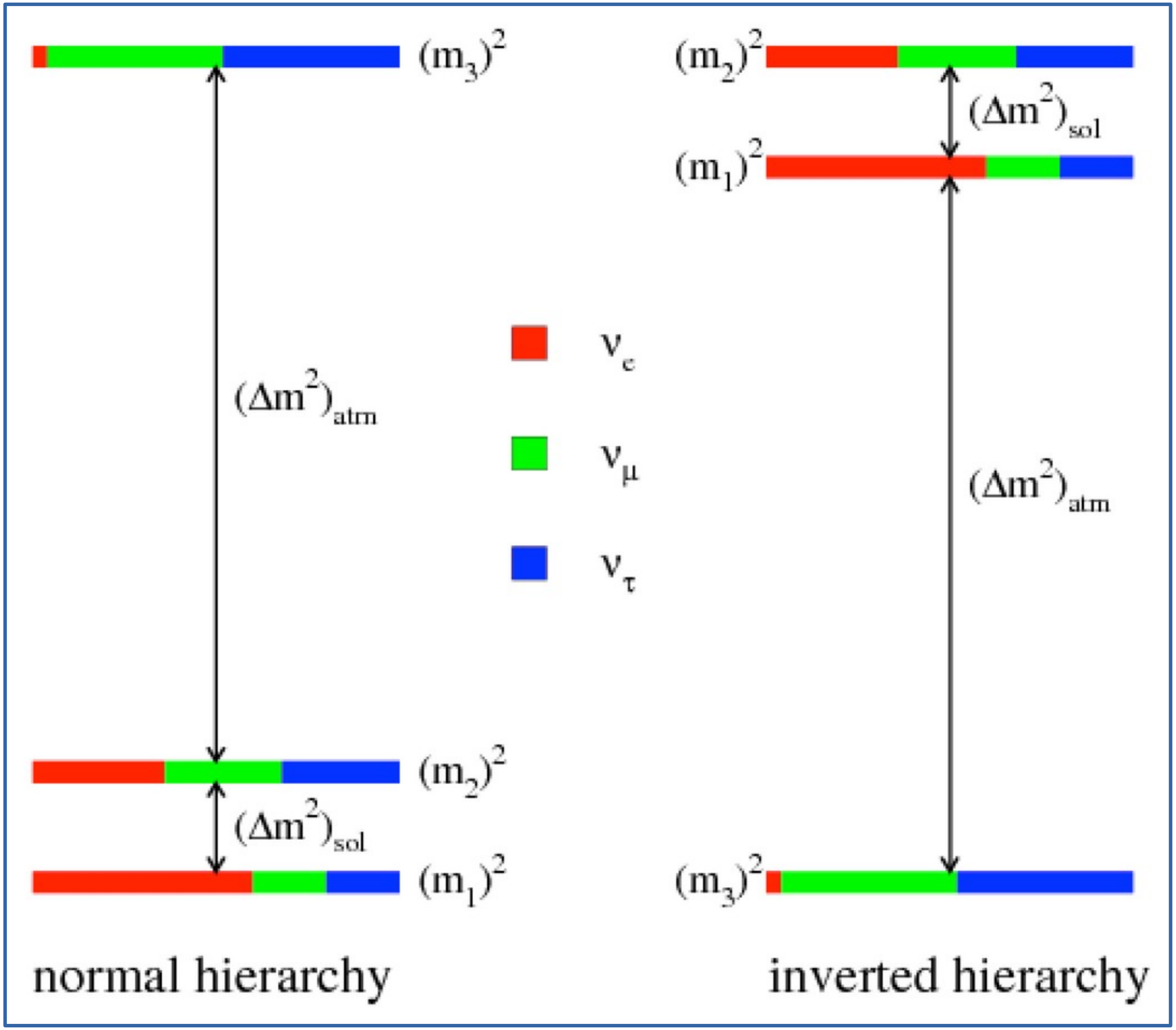

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The team

- Leads: Matthieu Tristram & Massimiliano Lattanzi

- Members: Carlo Baccigalupi, Anthony Banday, Thejs Ehlert Brinckmann, Alessandro Carones, Marian Douspis, Josquin Errard, Samuel Farrens, Silvia Galli, Ricardo Tanausú Génova Santos, Martina Gerbino, Serena Giardiello, Tommaso Ghigna, Alessandro Gruppuso, Lukas Hergt, Stéphane Ilic, Clément Leloup, Julien Lesgourgues, Juan Francisco Macias-Perez, Tomotake Matsumura, Marina Migliaccio, Mishra Satvik, Paolo Natoli, Luca Pagano, Guillaume Patanchon, Valeria Pettorino, Gianluca Polenta, NicolÒ Elia Raffuzzi, Mathieu Remazeilles, Laura Salvati, Douglas Scott, Blake D. Sherwin, Giovanni Signorelli, Jean-Luc Starck, Wang Wang, Sabarish Venkataramani

Plans and additional perspectives

- Fisher and MCMC-based forecasts, focusing on the benefits brought by LiteBIRD
- Explore large range of reionization histories, with careful treatment of potential prior effects
- Explore extended datasets:
  - ground-based CMB e.g SO, S4, TBD
  - background measurements e.g. BAO
  - LSS measurements
  - astrophysical measurements
- Check dependency of neutrinos constraints on reionization history

The end

Thank you very much
for your attention!