Reionization and neutrino Masses

Massimiliano Lattanzi

(on behalf of the Reionization and Neutrino Masses Project Study Paper group)

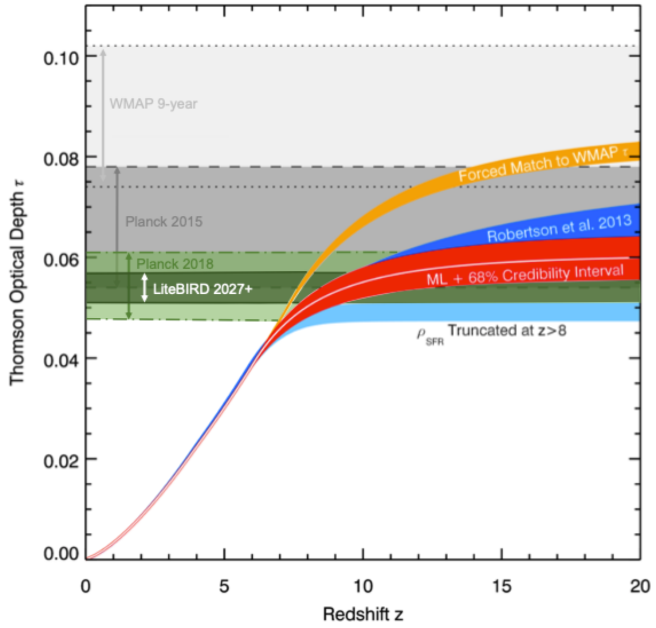
INFN, sezione di Ferrara

Meeting LiteBIRD-Italia

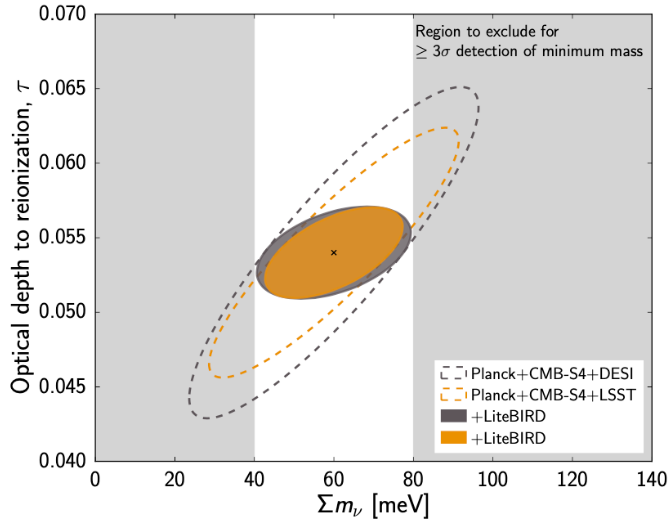
LNF, May 22nd, 2023

LiteBIRD other science outcomes

- The mission specifications are driven by the required sensitivity on r
- Meeting those sensitivity requirements would allow to address other important scientific topics, such as:
  1. Characterize the B-mode power spectrum and search for source source fields (e.g. scale-invariance, non-Gaussianity, parity violation, …)
  2. Power spectrum features in polarization
     - Large-scale ***E*-modes**
     - **Reionization** (improve $\sigma(\tau)$ by a factor of 3)
     - **Neutrino mass** ($\sigma(\sum m_\nu) = 15$ meV)
  3. Constraints on **cosmic birefringence**
  4. **SZ effect** (thermal, diffuse, relativistic corrections)
  5. Elucidating **anomalies**
  6. Galactic science
     - Characterizing the foreground SED
     - Large-scale Galactic magnetic field
     - Models of dust polarization



adapted from Robertson+2015



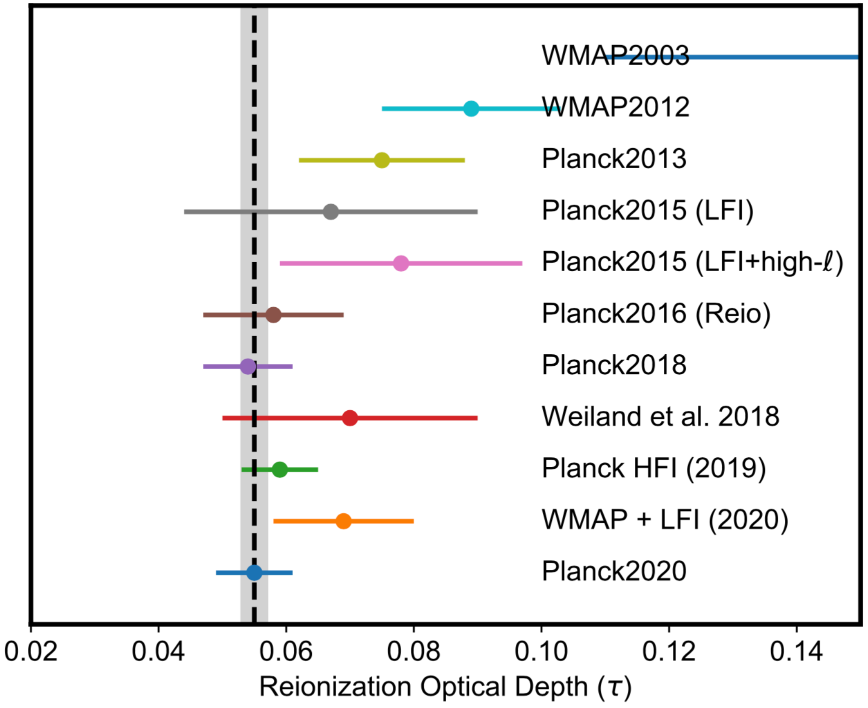
adapted from Calabrese+2017

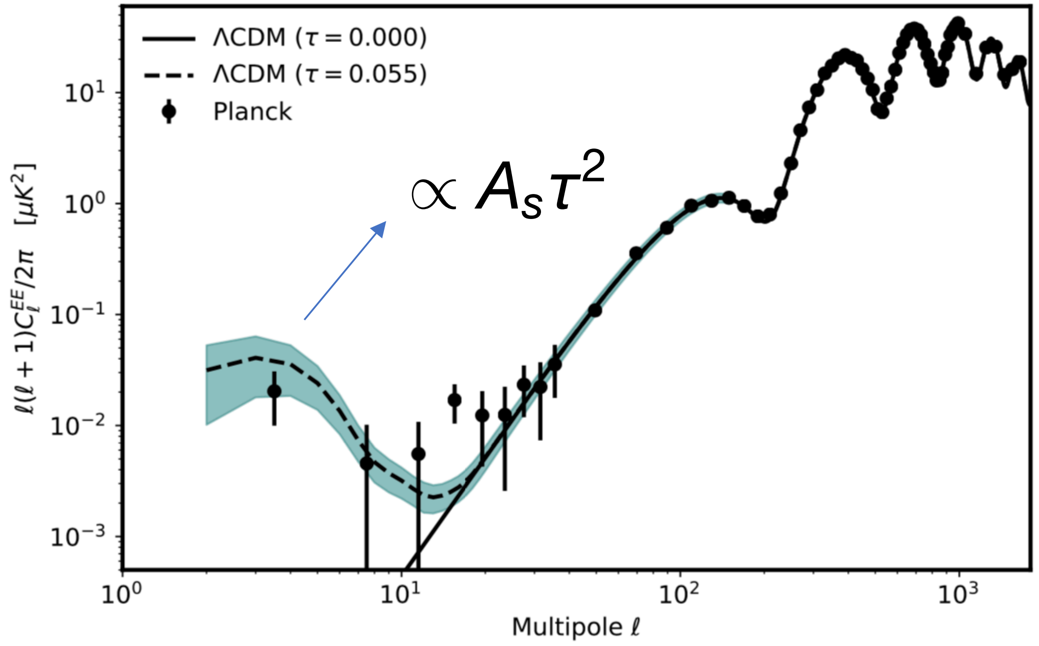
Reionization optical depth

$$\tau \equiv c\sigma_T \int n_e dt$$

Planck 2020: $\tau = 0.051 \pm 0.006$

CV limit: $\sigma_\tau = 0.002$





Estimates of tau are very sensitive to large-scale systematics in polarization (FG residuals, instrumental…)

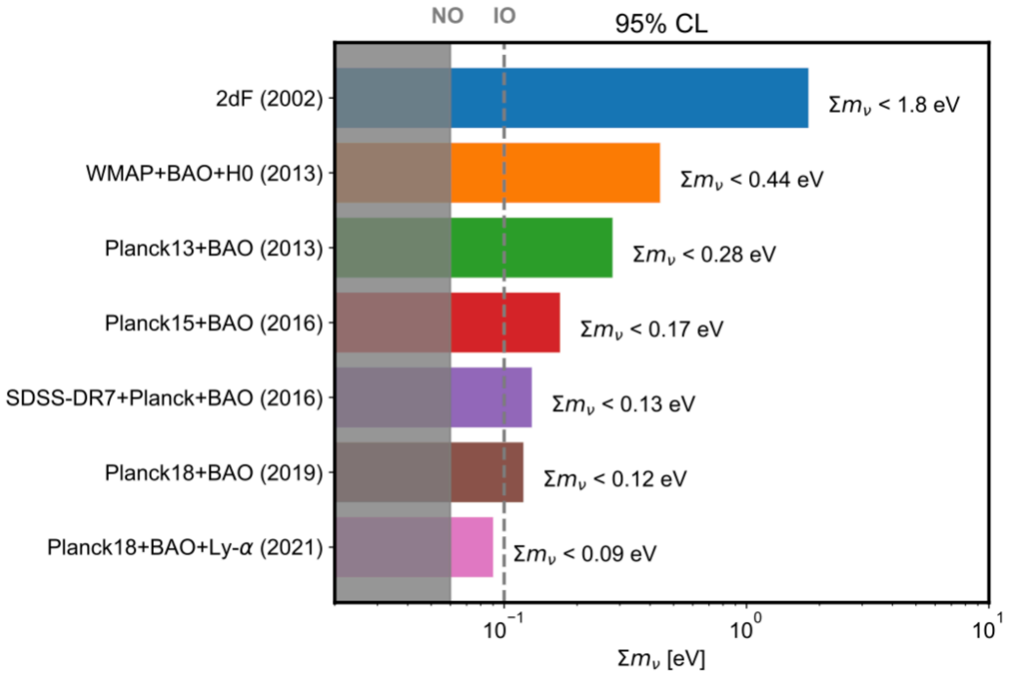
Neutrino masses from cosmology

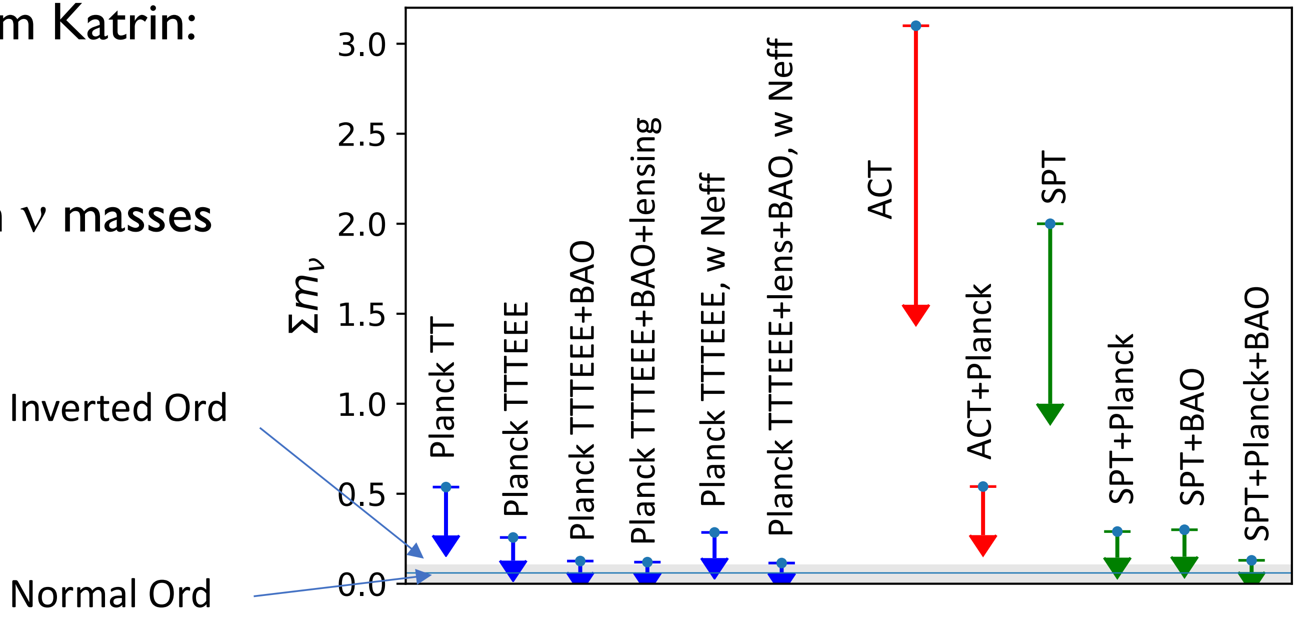
Planck 2020: $\Sigma m_\nu < 0.12\,\mathrm{eV} \quad (95\%\text{C.I.})$

Compare with current laboratory constraints from Katrin:

$\Sigma m_\nu < 2.4\,\mathrm{eV} \quad (90\%\text{C.I.})$

Cosmology provides the strongest constraints on ν masses



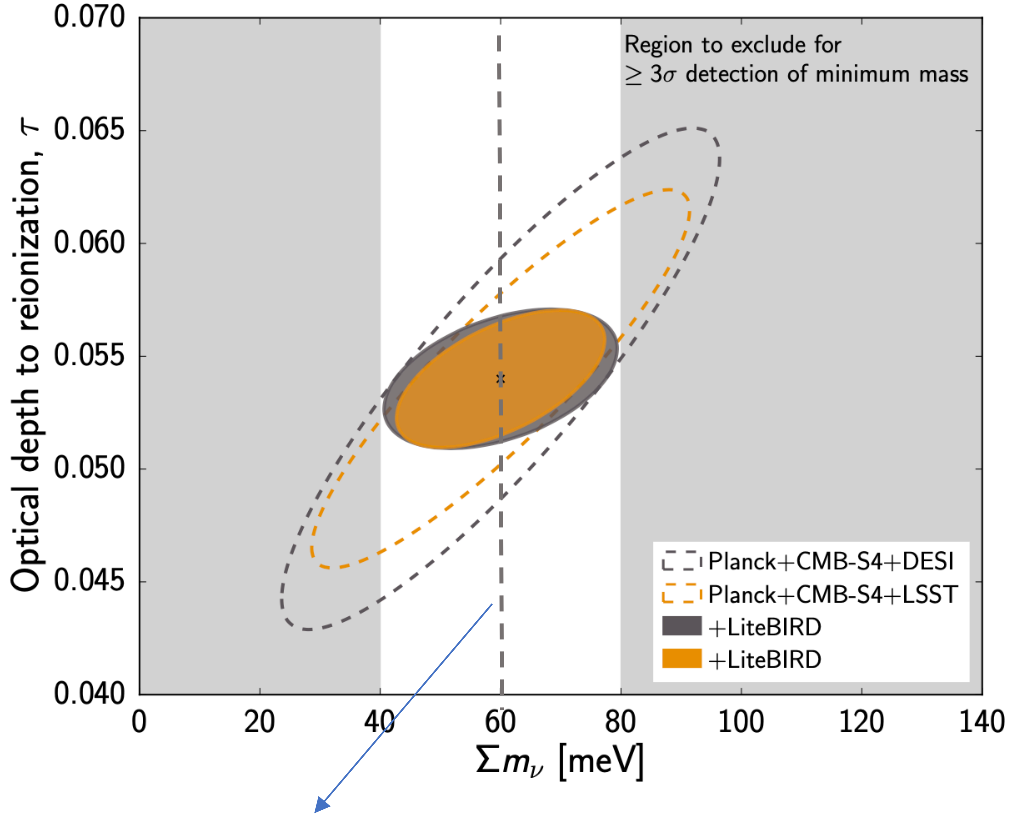


The CMB constraining power mostly comes from suppression of structure formation at small scales, as seen in lensing at high ells

Neutrino masses from cosmology

Next-generation observations of the small-scale CMB polarization can potentially measure the minimum value of Σm_ν allowed by oscillation experiments at (at least) the 3-sigma level.

However, assessing the effect of neutrinos on structure formation requires knowledge of the initial conditions!



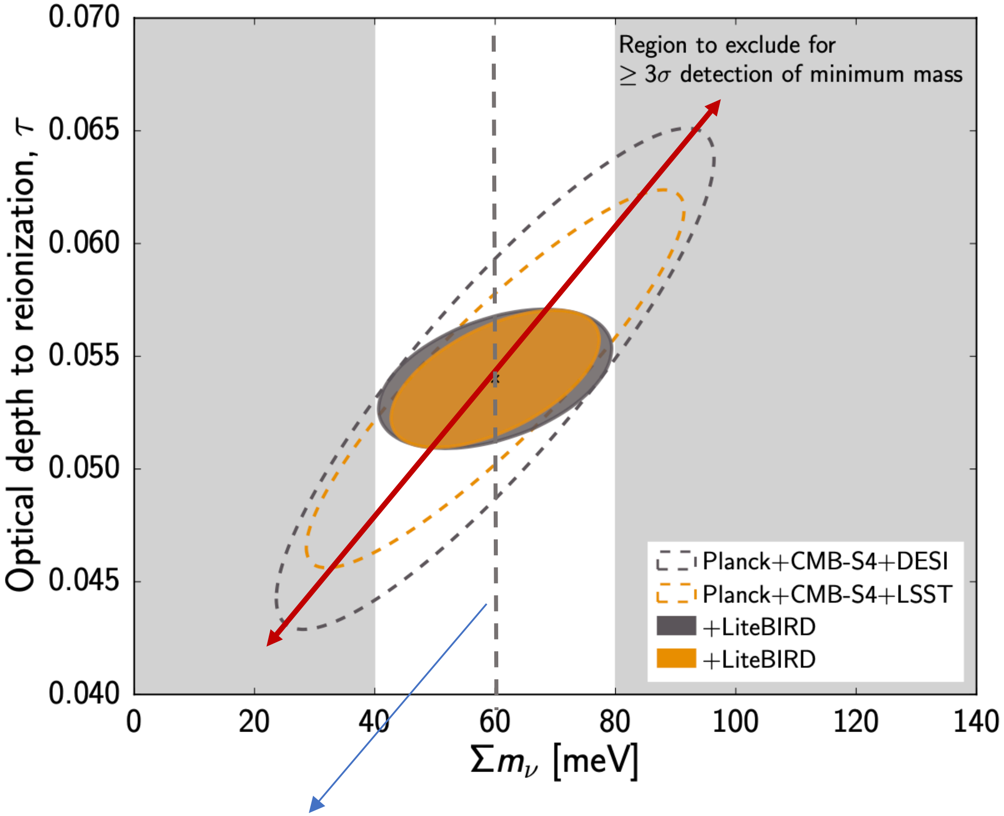
Minimum value for the normal mass ordering

Neutrino cosmology

Next-generation observations of the small-scale CMB polarization can potentially measure the minimum value of Σm_ν allowed by oscillation experiments at (at least) the 3-sigma level.

However, assessing the effect of neutrinos on structure formation requires knowledge of the initial conditions!
This introduces a degeneracy between τ and Σm_ν

A CV-limited measurement of the optical depth is required for a precise cosmological estimate of neutrino masses



Minimum value for the normal mass ordering

LiteBIRD Project Paper on Optical Depth, Reionization of the Universe and Neutrino Masses

Coordinators: M. Lattanzi & M. Tristram

https://wiki.kek.jp/display/cmb/Project+Paper:+Optical+Depth,+Reionization+of+the+Universe+and+Neutrino+Masses

•Goals:

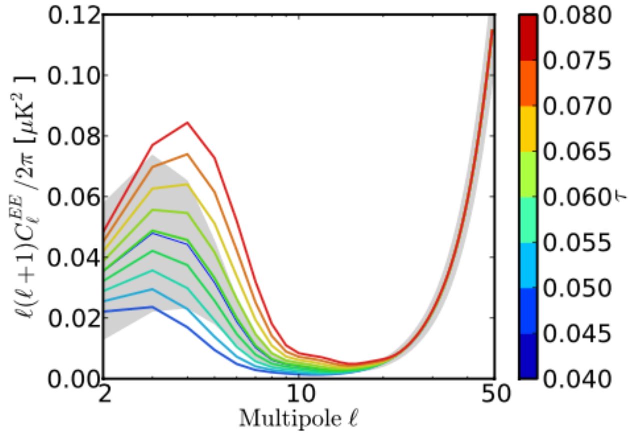
1. derive the **expected sensitivity on the optical depth τ**. Then we plan to discuss the capability of LiteBIRD to c**onstrain the reionization history, beyond the instantaneous reionization approximation**. We will consider both "model-independent" parametrizations of the reionization history (e.g. principal component analysis) as well as astrophysically-motivated models of reionization. We will also consider external measurements such as kSZ or the radio survey which will bring complementary constraints on reionization history.
2. how the LiteBIRD determination of the parameters describing reionization history (simple instantaneous and more complicated processes), combined with external measurements coming from high-resolution CMB experiments or from galaxy surveys, will allow measuring the **masses of neutrinos and other light relics**.
   We will also discuss the prospects for the determination of the neutrino mass ordering.

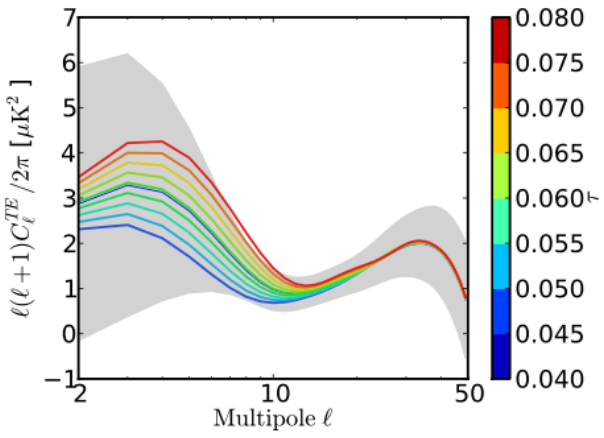
•Inputs

1. LiteBIRD noise and residuals spectra
2. external constraints from CMB high-ℓ, BAO, lensing

•Outputs

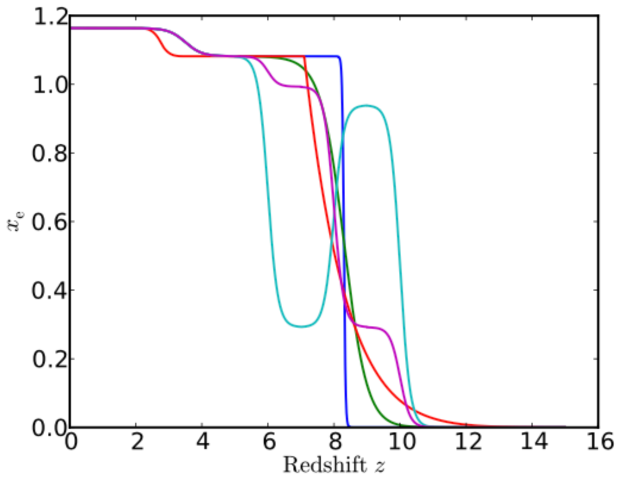
assess the scientific outcome from LiteBIRD for the history of reionization and the constraints on the neutrino masses and hierarchy

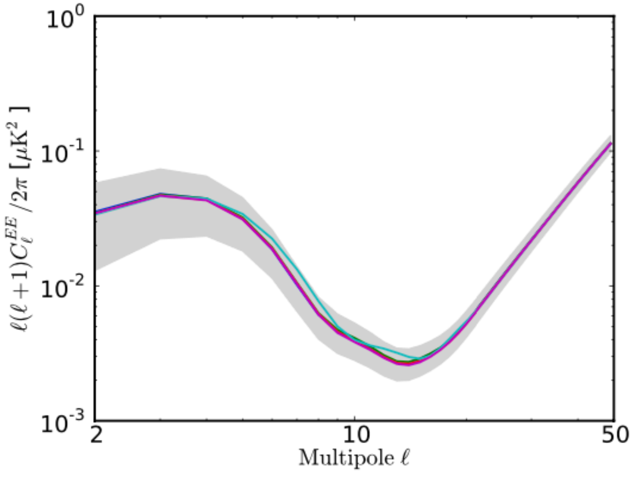




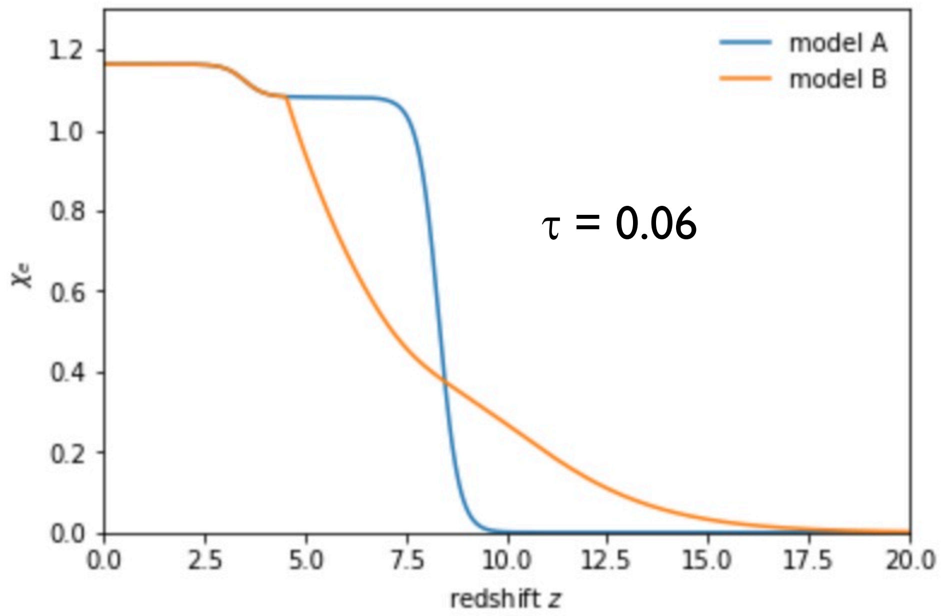
Large scales in polarisation (low-ℓ EE) are sensitive to the reionization optical depth…

…however, different reionization histories can lead to the same EE spectrum:





Preliminary analysis



Three teams working on two likelihoods for forecasting (exact v.s. Hamimeche-Lewis)

Inputs in spectra domain:

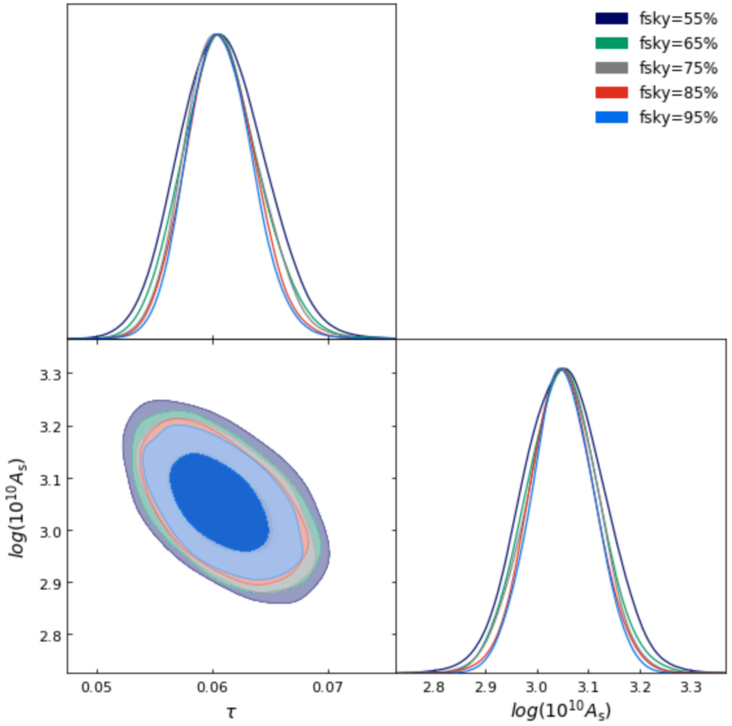
- signal: two different histories of ionization $\chi_e(z)$ with the same optical depth (τ = 0.06) as mock data
- noise: based on the component separation residuals with two beam size (30' and 50')

Allow to study different sky fraction

Noise can be updated with post-PTEP simulations when available

Preliminary analysis

- Dataset: LiteBIRD EE only, fsky = 0.65, beam = 30, 50 arcmin
- Sample the relevant reionisation parameters and As, while the other ΛCDM parameters fixed
- Use different parametrization for reionization history with various number of free parameters (TANH, FlexKnots, HS17, …)

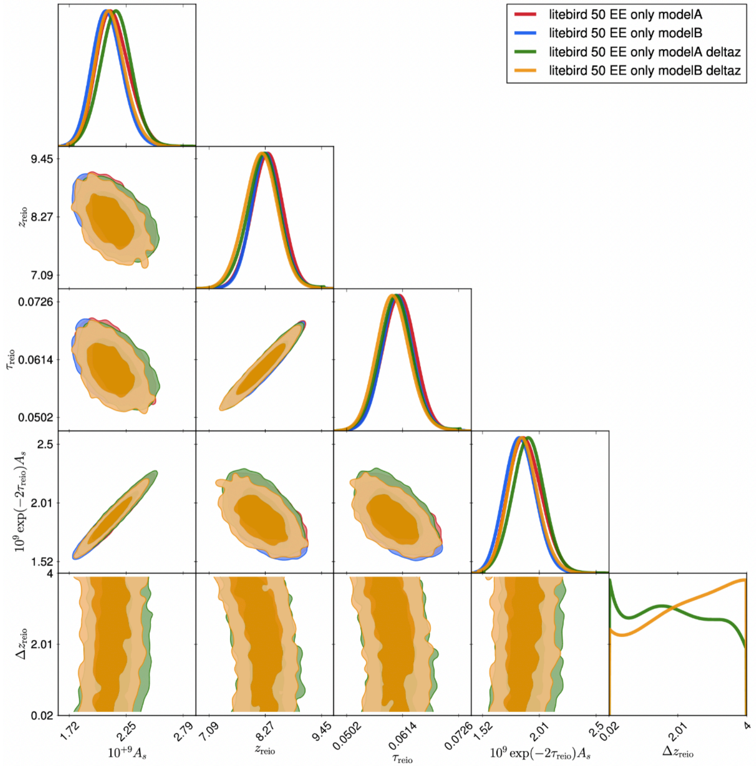


- variations with fsky compatible with Fisher estimates
- effect of the beam size is negligible

```
fsky=55%,  τ=0.06080 +/- 0.00367
fsky=65%,  τ=0.06072 +/- 0.00334
fsky=75%,  τ=0.06073 +/- 0.00315
fsky=85%,  τ=0.06069 +/- 0.00292
fsky=95%,  τ=0.06065 +/- 0.00277
```

Preliminary analysis

- Dataset: LiteBIRD EE only, fsky = 0.65, beam = 30, 50 arcmin
- Sample the relevant reionisation parameters and As, while the other ΛCDM parameters fixed
- Use different parametrization for reionization history with various number of free parameters (TANH, FlexKnots, HS17, …)

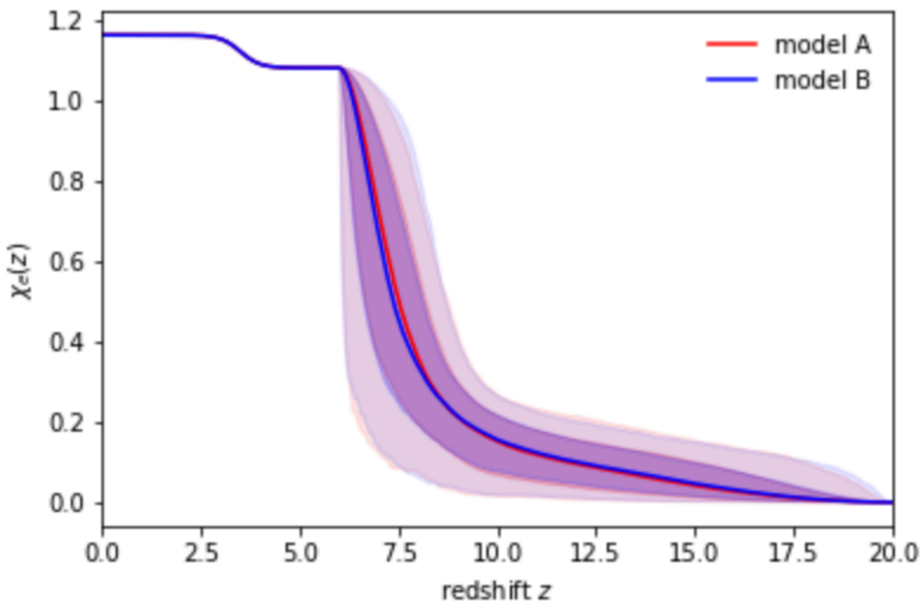


- LB **not able to differentiate** the two reionization models using E-mode only

- constraints on τ are of the order of $\sigma(\tau)$ ~ 0.0032-0.0035 (for fsky = 0.65) depending on the models

Preliminary analysis

- Dataset: LiteBIRD EE only, fsky = 0.65, beam = 30, 50 arcmin
- Sample the relevant reionisation parameters and As, while the other ΛCDM parameters fixed
- Use different parametrization for reionization history with various number of free parameters (TANH, FlexKnots, HS17, …)



- LB **not able to differentiate** the two reionization models using E-mode only
- constraints on τ are of the order of $\sigma(\tau)$ ~ 0.0032-0.0035 (for fsky = 0.65) depending on the models

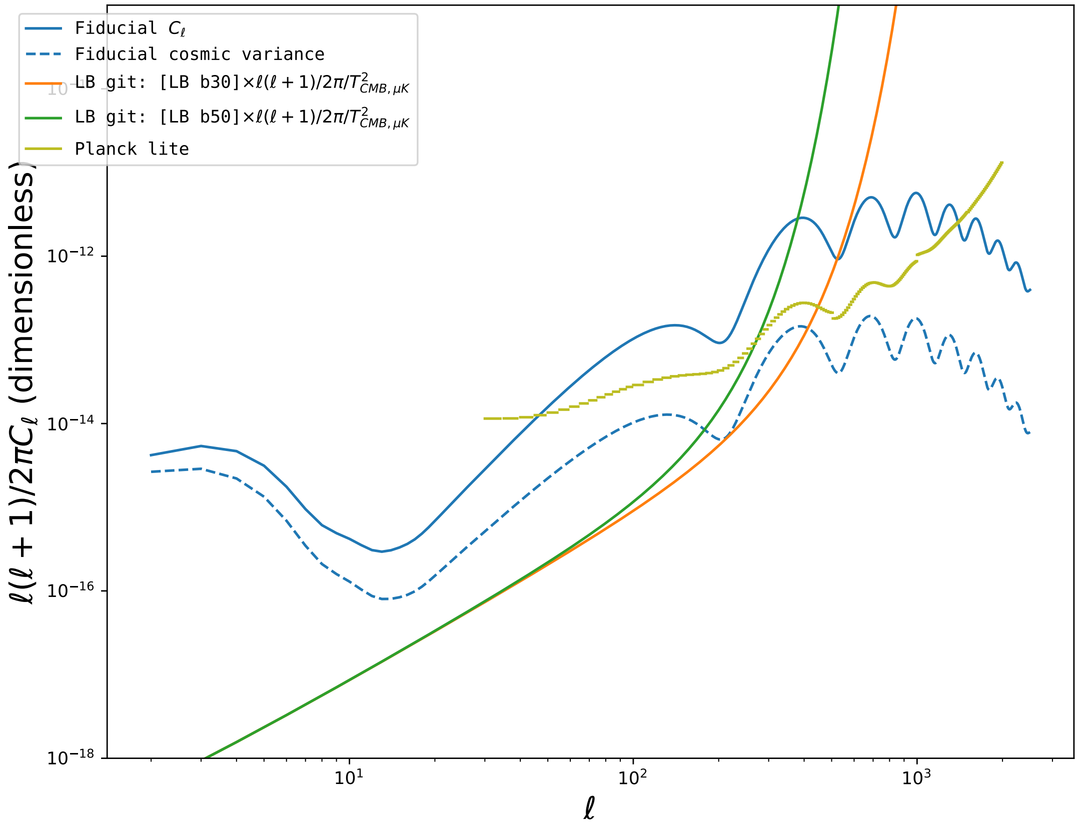
Ongoing analysis

- Extend the CMB dataset: LiteBIRD**+Planck**, **TT+TE**+EE (**+lensing**)
- MC sampling ΛCDM parameters + the relevant reionisation parameters
- Explore different parameterizations: TANH (both with fixed and varying Δz), Model-independent reionization history (using FlexKnot)
- Consider two fiducials: TANH reio and a more realistic history
- Vary instrumental/analysis settings: fsky, noise spectra (see below), beam

Ongoing analysis

Noise model

- LB: white noise level deconvolved with the beam
- Planck: PlanckLite noise
- The noise curves are patched together at some lcut
- lensing TBD



Summary

- LiteBIRD aims to provide a sample variance-limited measurement of the reionization optical depth (also necessary for a cosmological determination of neutrino masses)
- Control of foregrounds (large fsky) and large-scale systematics is fundamental
- LiteBIRD alone does not seem to be sensitive to the details of the reionization history
- Currently investigating the constraining power of the combined LiteBIRD – Planck dataset
- Next steps:
  - more realistic noise model
  - Inclusion of lensing
  - Neutrino masses