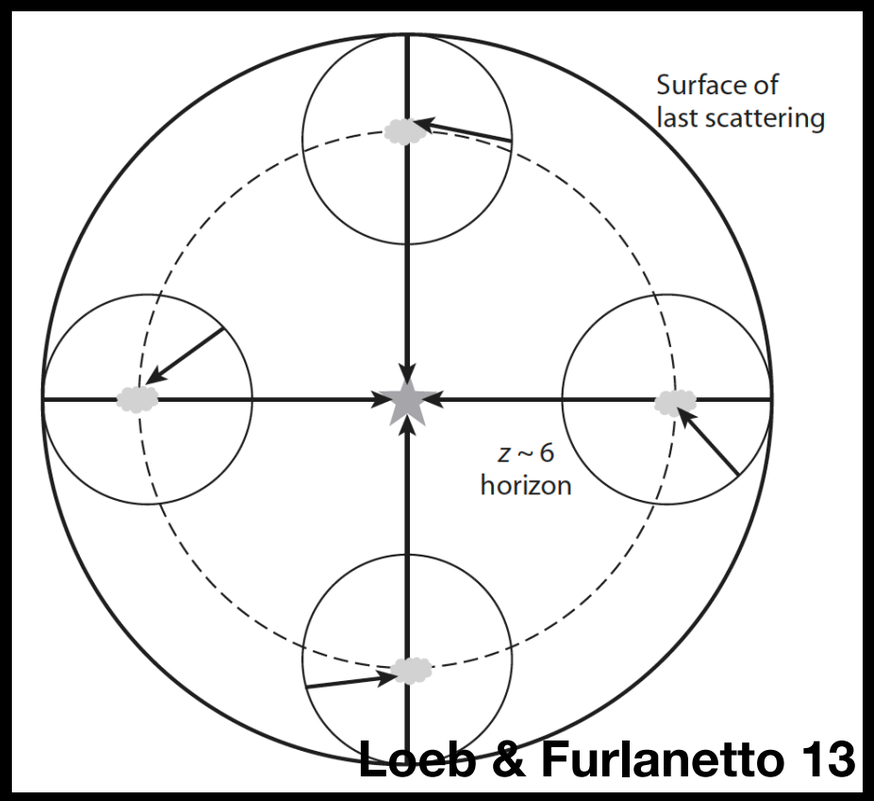
Constraining Pop-III reionization at z>15 using the low-ell CMB

(not promising)

Xiaohan Wu (Harvard CfA)

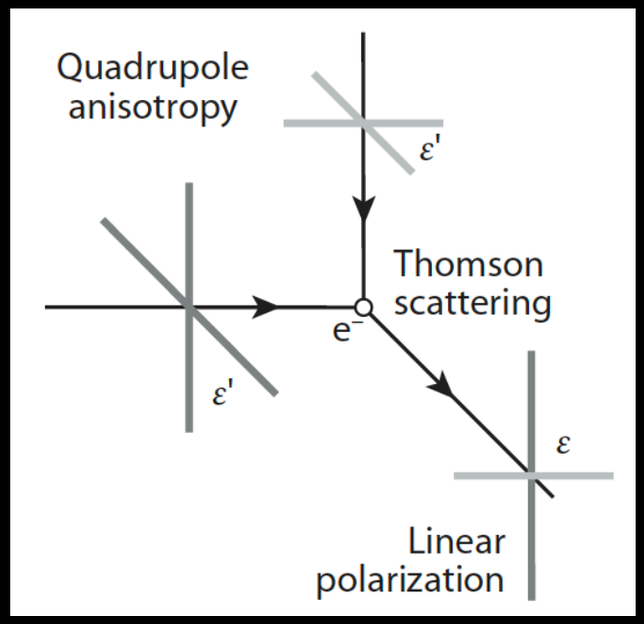
Imprints of reionization on the large-scale CMB E-mode polarization

After reionization occurs…



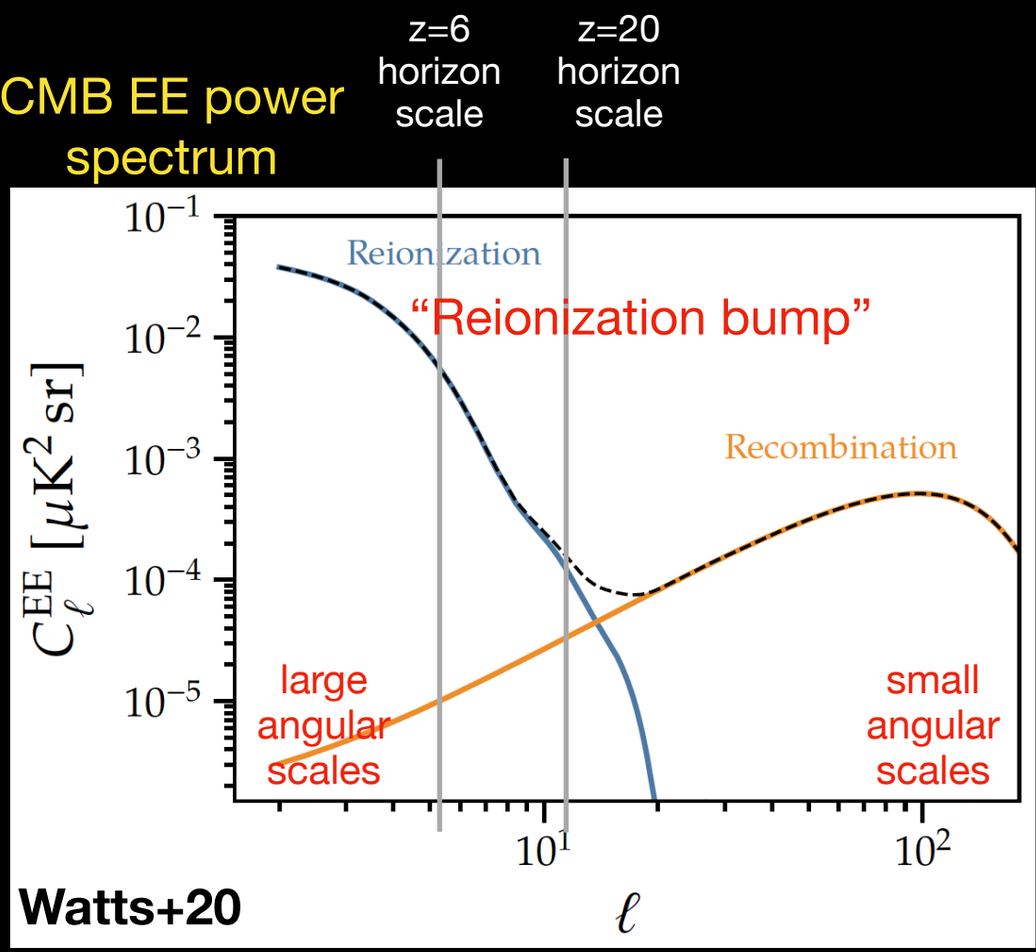
Loeb & Furlanetto 13

A free electron can scatter photons that originated within the causal horizon at that time



Quadrupole anisotropy in the radiation background

CMB EE power spectrum



Watts+20

Large-scale anisotropy in the CMB E-mode polarization;

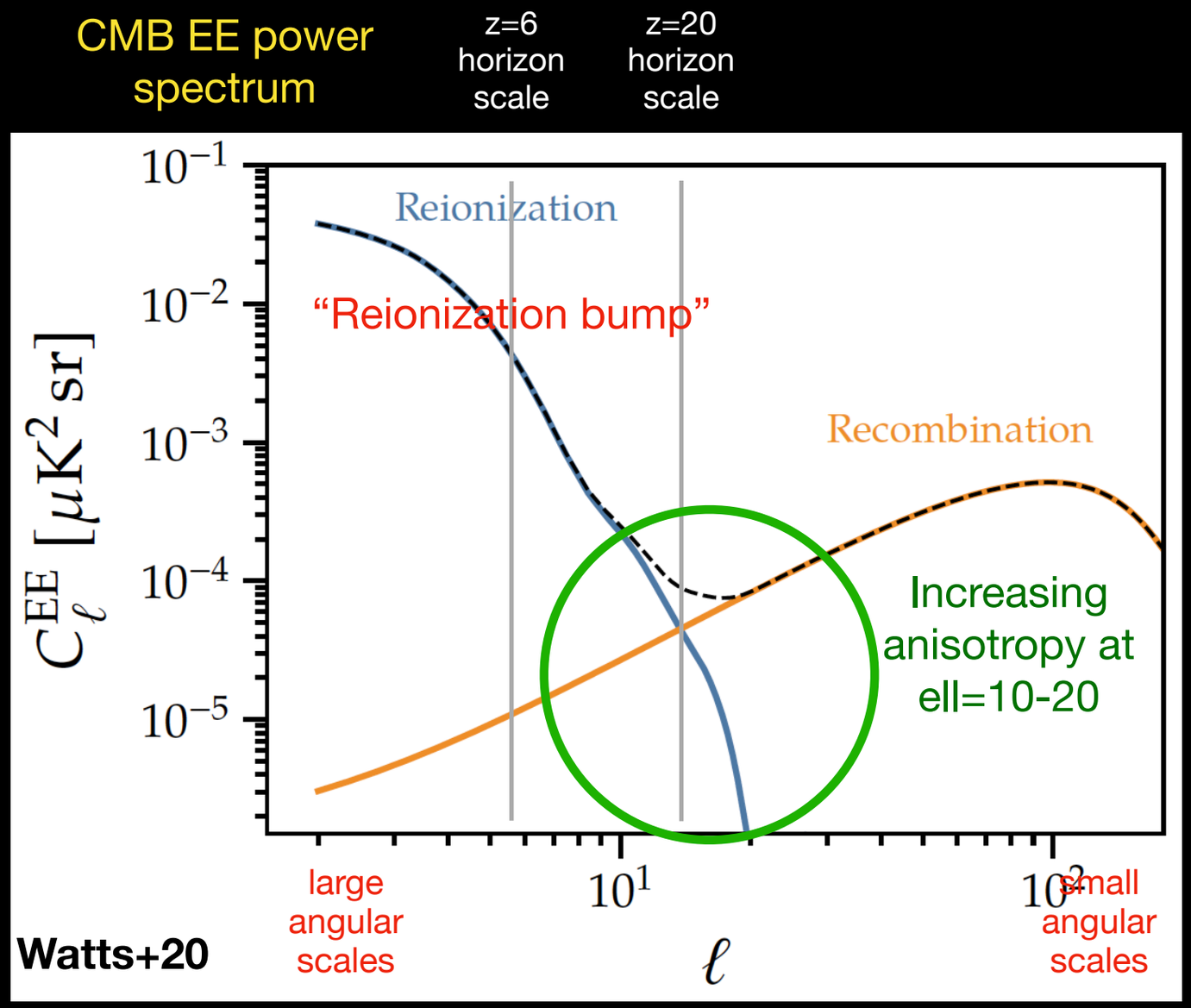
Angular scale π/ℓ = horizon scale at time of scattering / distance

Imprints of reionization on the large-scale CMB E-mode polarization

- More ionization at z>15 → more anisotropy in E-mode polarization at ell=10–20 (ionization at higher z → anisotropy at smaller angular scales), non-zero $\tau(z > 15)$

Large-scale anisotropy in the CMB E-mode polarization;

Angular scale π/ℓ = horizon scale at time of scattering / distance

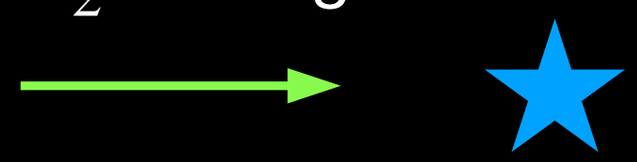


The first generation of stars (Pop-III)

$10^5 - 10^6\ M_\odot$ halos
at z=20–30
$T_{\rm vir} \sim$ a few $100 - 1000$ K

Primordial gas

H_2 formation
H_2 cooling



Star formation:
massive
metal free star
~100 $M_\odot$

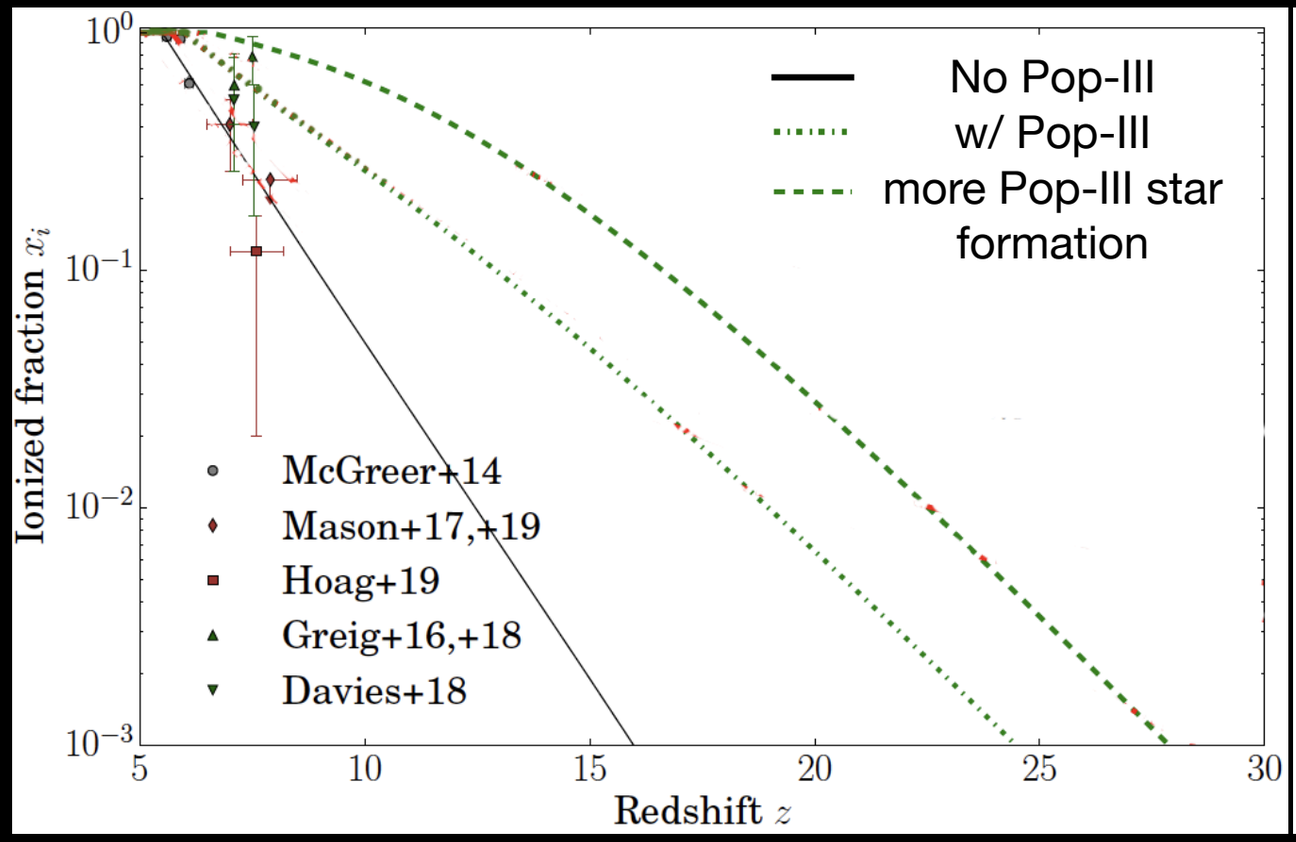
Lyman-Werner
photons (11.2-13.6 eV)
photo-dissociate H_2

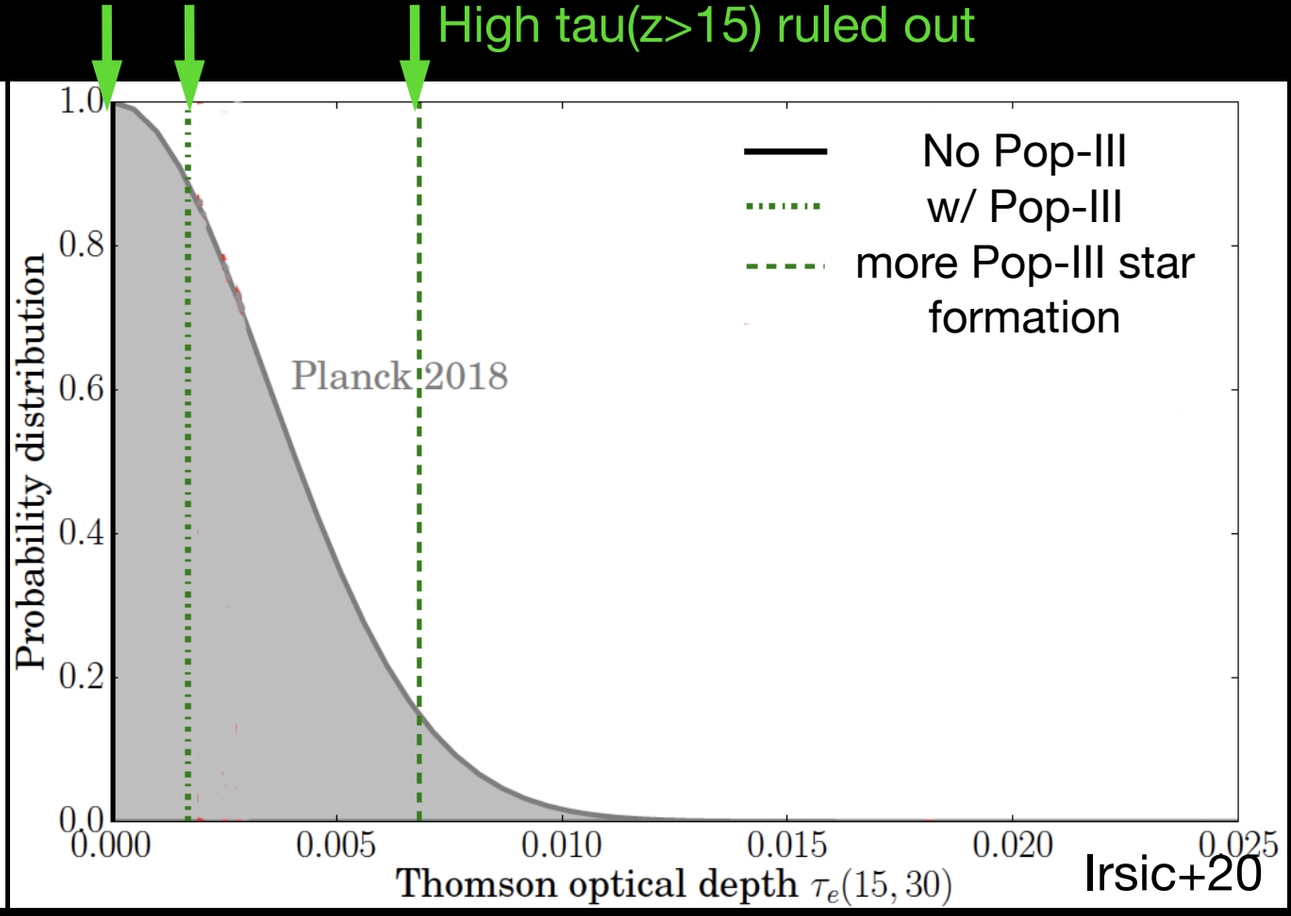
Pop-III star formation self-regulates; star formation rate density
$\lesssim 10^{-5} - 10^{-4}\ M_\odot/{\rm yr}/{\rm Mpc}^3$

Pop-III stars can only ionize ~1–10% of the universe at z>15

Constraining Pop-III models using the low-ell CMB

- Planck 2-sigma upper limit $\tau(z > 15) < 0.006$ can rule out some Pop-III models (but this number has changed now)
- Future CMB surveys can measure EE power at ell=10–20 with higher signal-to-noise and better constrain $\tau(z > 15)$ → rule out more Pop-III models?
- Pop-III modeling is highly uncertain; a lot of models exist

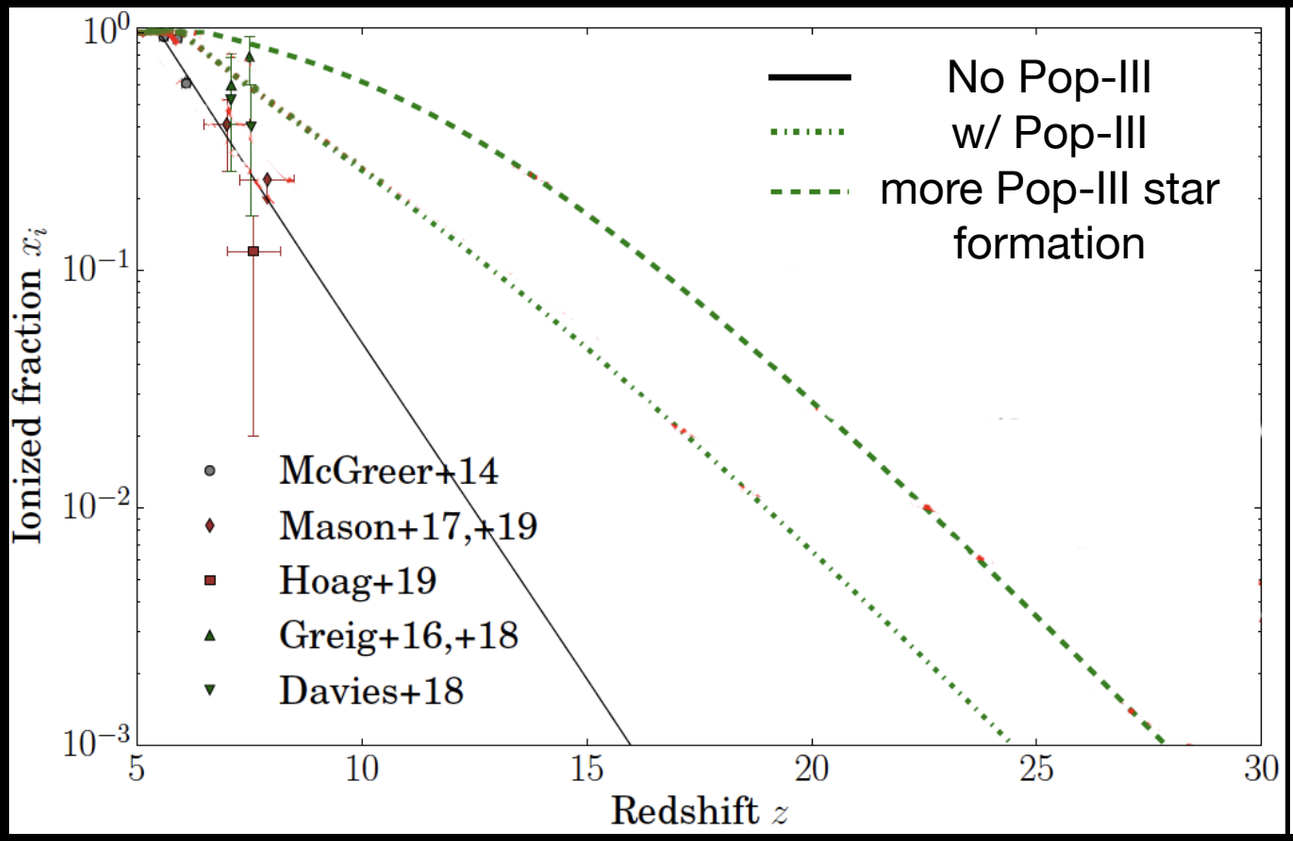




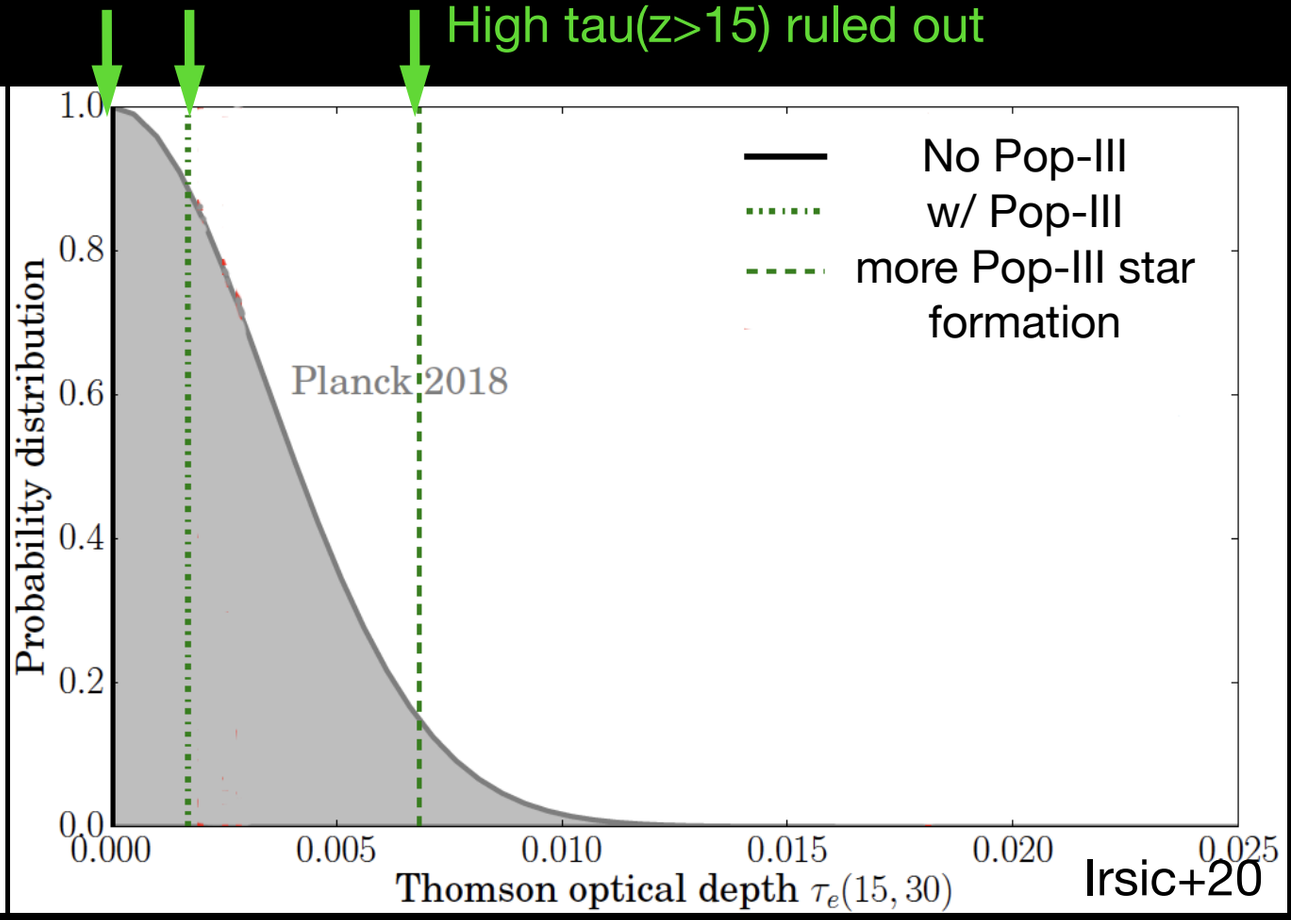
Constraining Pop-III models using the low-ell CMB

- For a larger set of Pop-III parametrizations, what do the models predict about tau(z>15)?
- Will future CMB measurements of tau(z>15) and the EE power at ell=10–20 help constrain Pop-III models?

(Actually no)



High tau(z>15) ruled out



Irsic+20

Reionization with Pop-III

- Calculating the reionization history with the simplest Pop-III model:

Pop-III star formation in
$10^5 - 10^6\ M_\odot$ halos at z=20–30
with a star formation efficiency

Free parameter:
Star formation efficiency
6 values from 0.0001 to 0.03

Lyman-Werner photons form a background and photo-dissociate H2
→ increased minimum halo mass ($M_{\rm min}$) for Pop-III star formation
(e.g. Machacek+01)

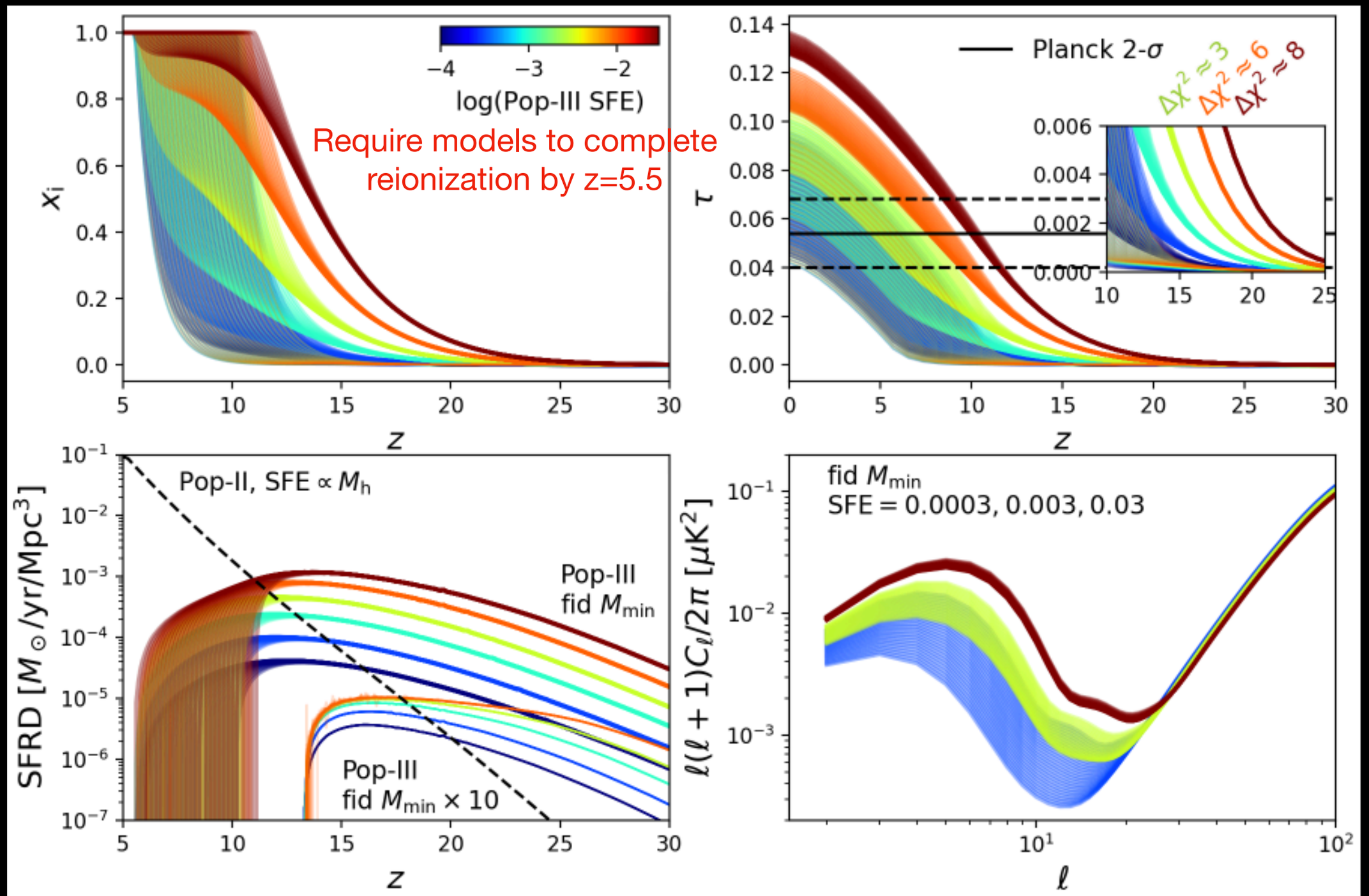
Free parameter:
Strength of LW feedback
e.g. fiducial and strong LW

How many ionizing photons emitted
by Pop-III stars
(+ state-of-the-art Pop-II model)

Reionization history

The resulting huge range of Pop-III models

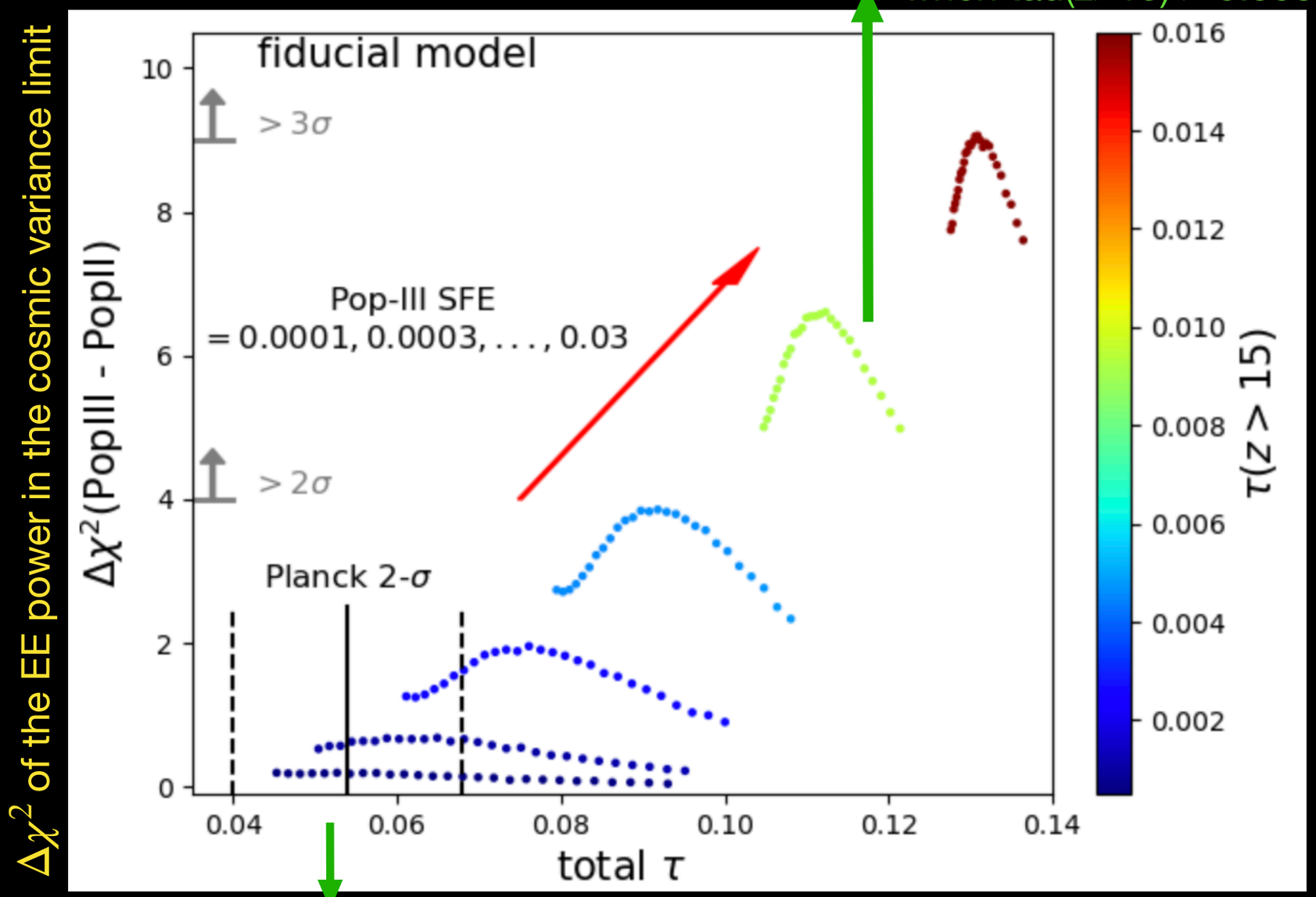
- Compare each Pop-III model to a Pop-II-only model with the same total tau
- $\Delta\chi^2$ of the EE power spectra at ell=2–100 in the cosmic variance limit



Summary of results

- The requirement to satisfy low total tau and endpoint of reionization already *ruled out most of the Pop-III parameter space* (high z structure formation + LW feedback -> hard to get very extended reionization)

Pop-III models get distinguishable from Pop-II-only when tau(z>15) > 0.008



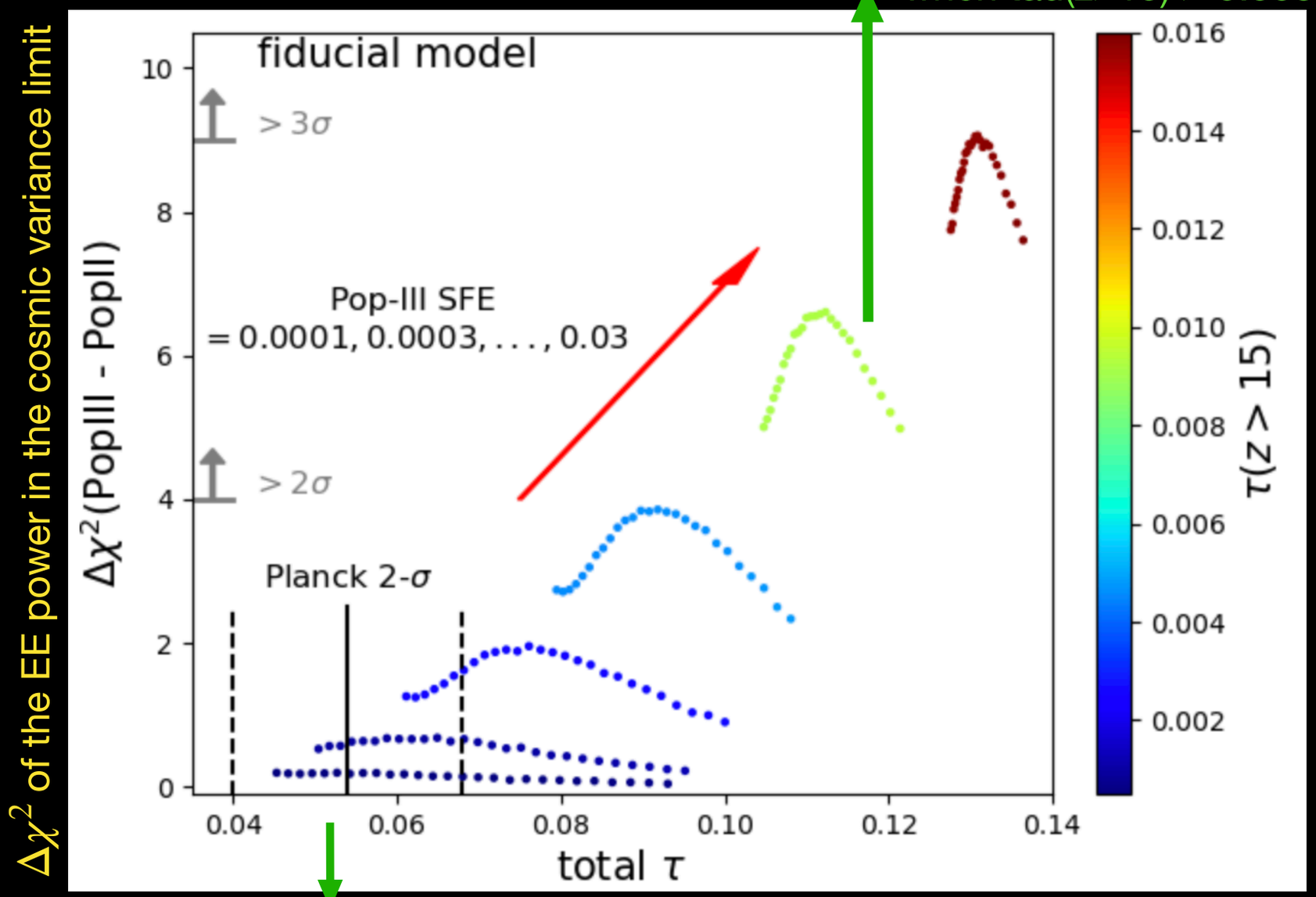
$\Delta\chi^2$ of the EE power in the cosmic variance limit

The low total tau does not allow high tau(z>15)

Summary of results

- The requirement to satisfy low total tau and endpoint of reionization already *ruled out most of the Pop-III parameter space* (high z structure formation + LW feedback -> hard to get very extended reionization)
- Future CMB surveys is unlikely to help constrain Pop-III models

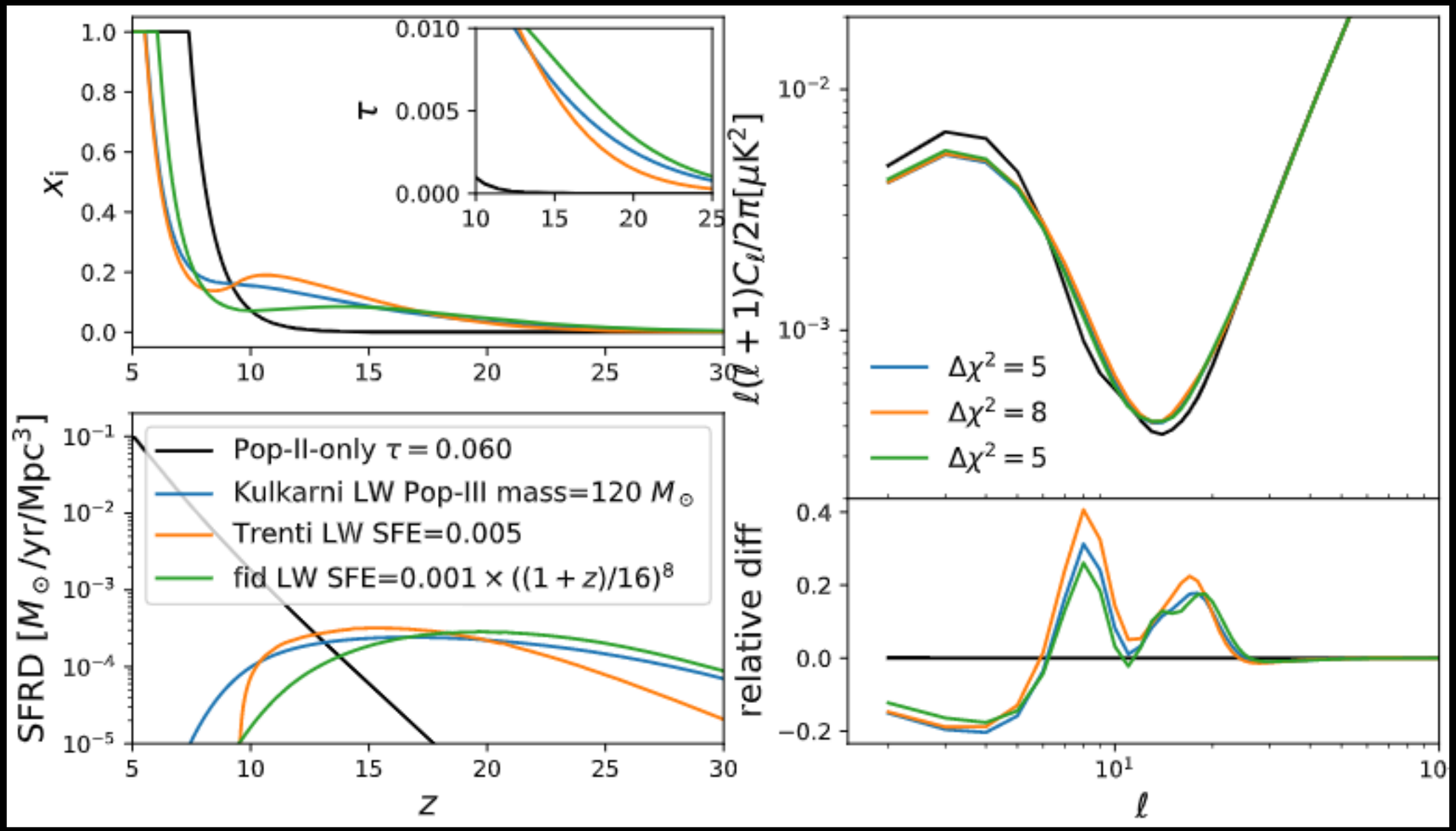
Pop-III models get distinguishable from Pop-II-only when tau(z>15) > 0.008



$\Delta\chi^2$ of the EE power in the cosmic variance limit

The low total tau does not allow high tau(z>15)

More exotic Pop-III models



“Tension” with the Planck tau(z>15)<0.02 2-sigma upper limit?