Probing Inflation and Reionization with Large-Scale CMB Polarization

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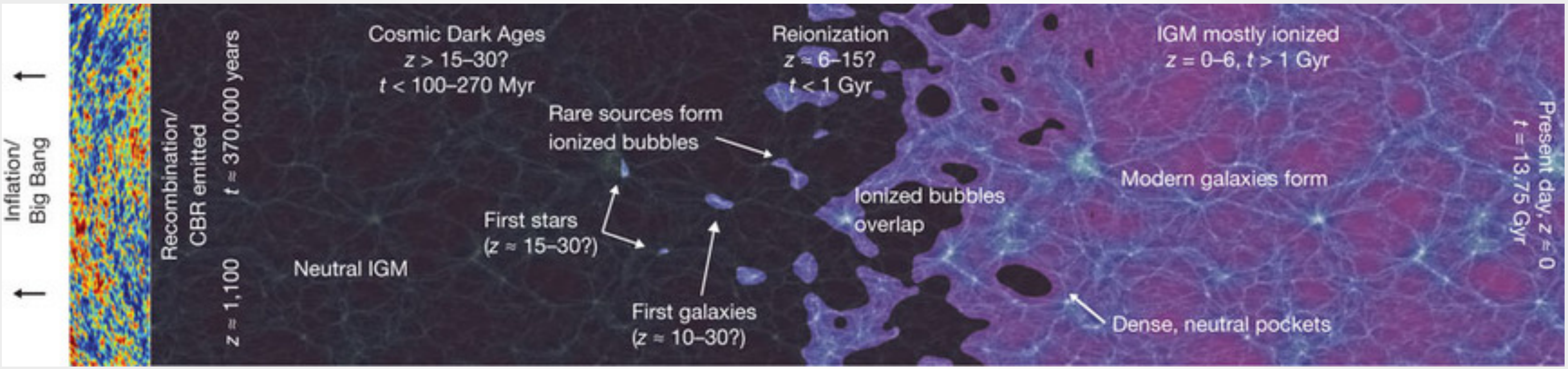
Part I - The Epoch Of Reionization



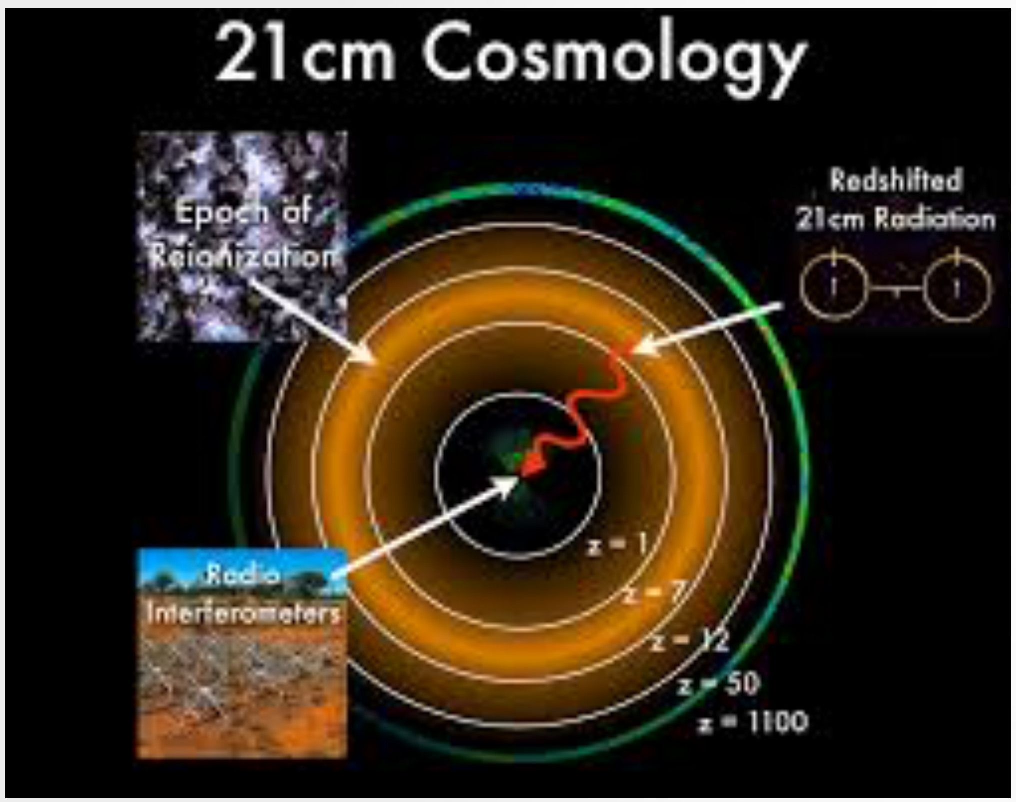
First stars: source of ionizing radiation

Difficult to model: radiative transfer + big volume

One of the least understood aspects of cosmology

How Can We Probe The EOR?

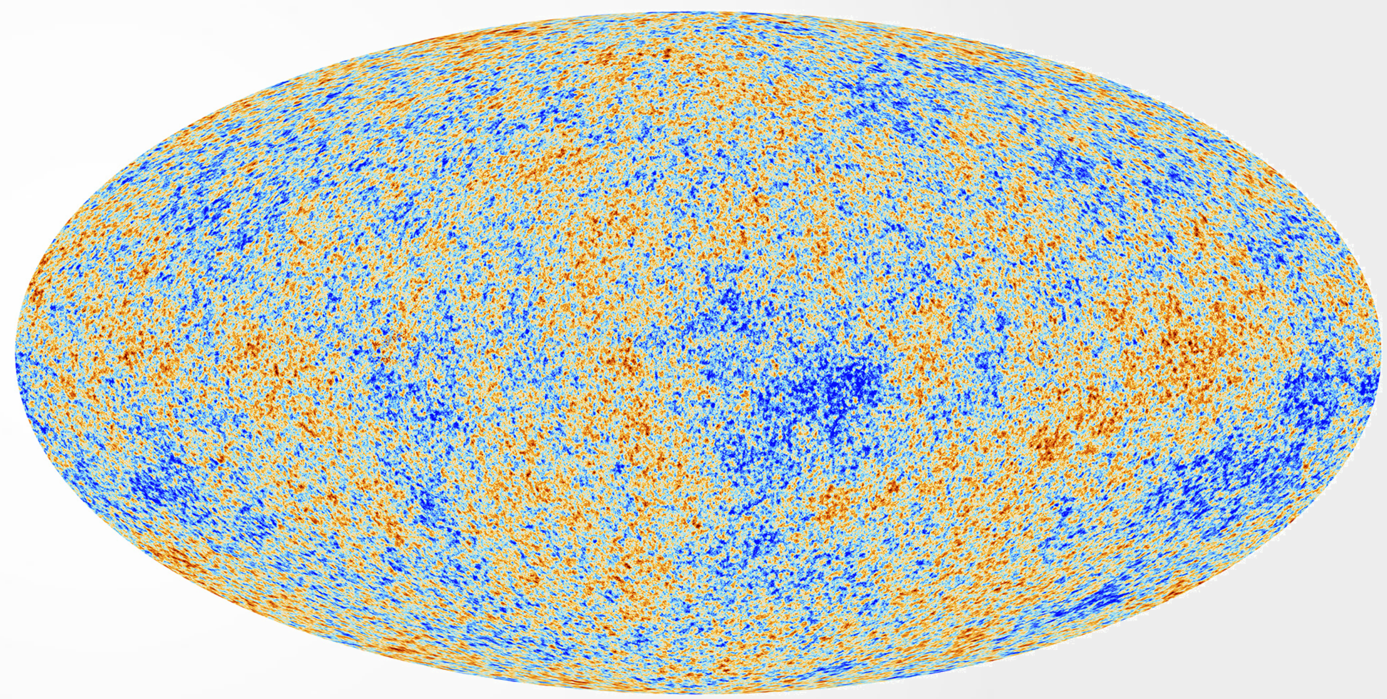
21 cm



Better than Cosmic Variance

Atmosphere limits redshift range

Cosmic Microwave Background



Measure more than total optical depth

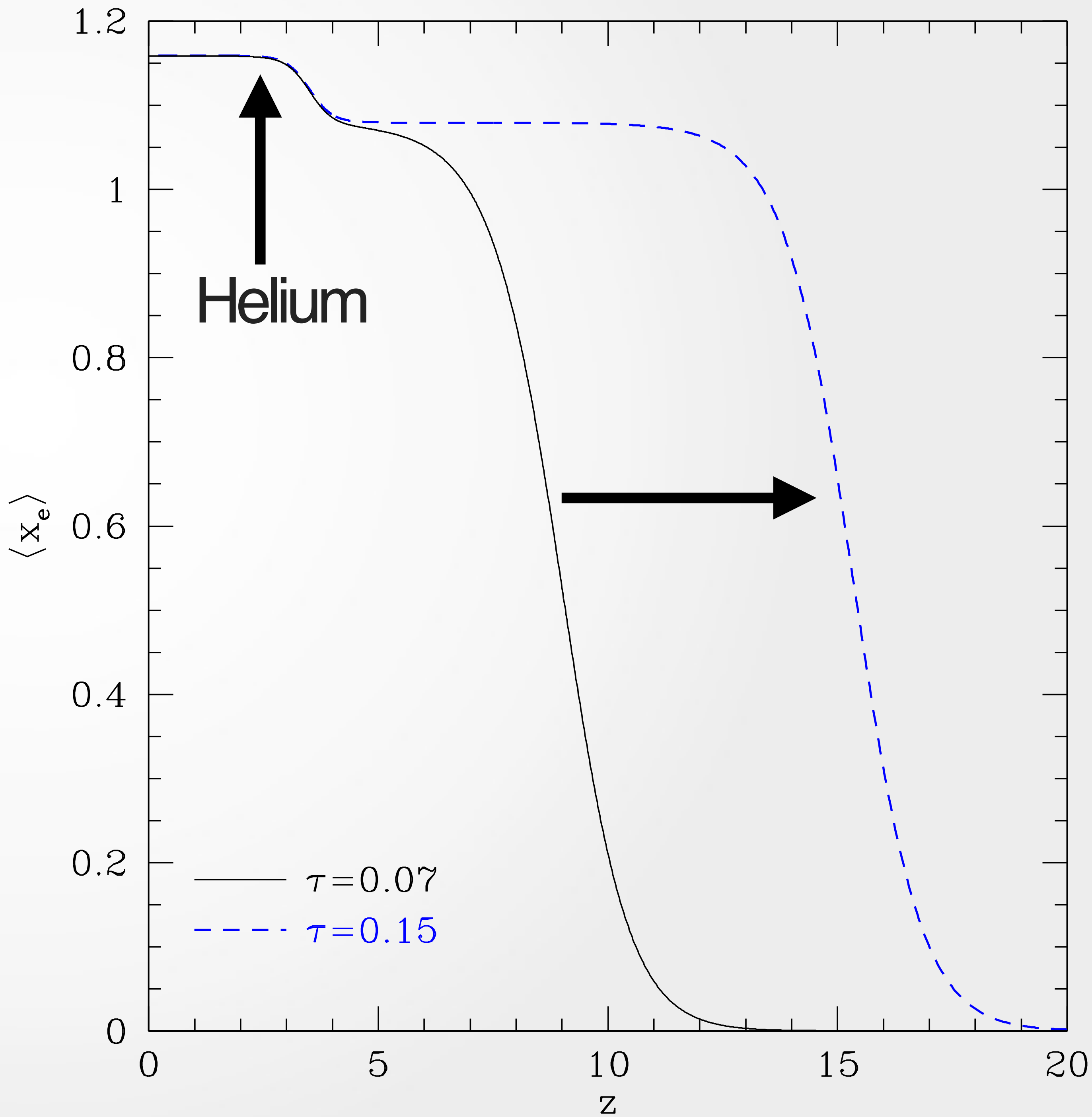
Limitations: Cosmic Variance

Hypothesis: The Instantaneous Reionization Model

Higher optical depth implies transition at higher redshift

$$\tau(z_1, z_2) \propto \int_{z_1}^{z_2} dz \frac{(1+z)^2}{H(z)/H_0} x_e(z)$$

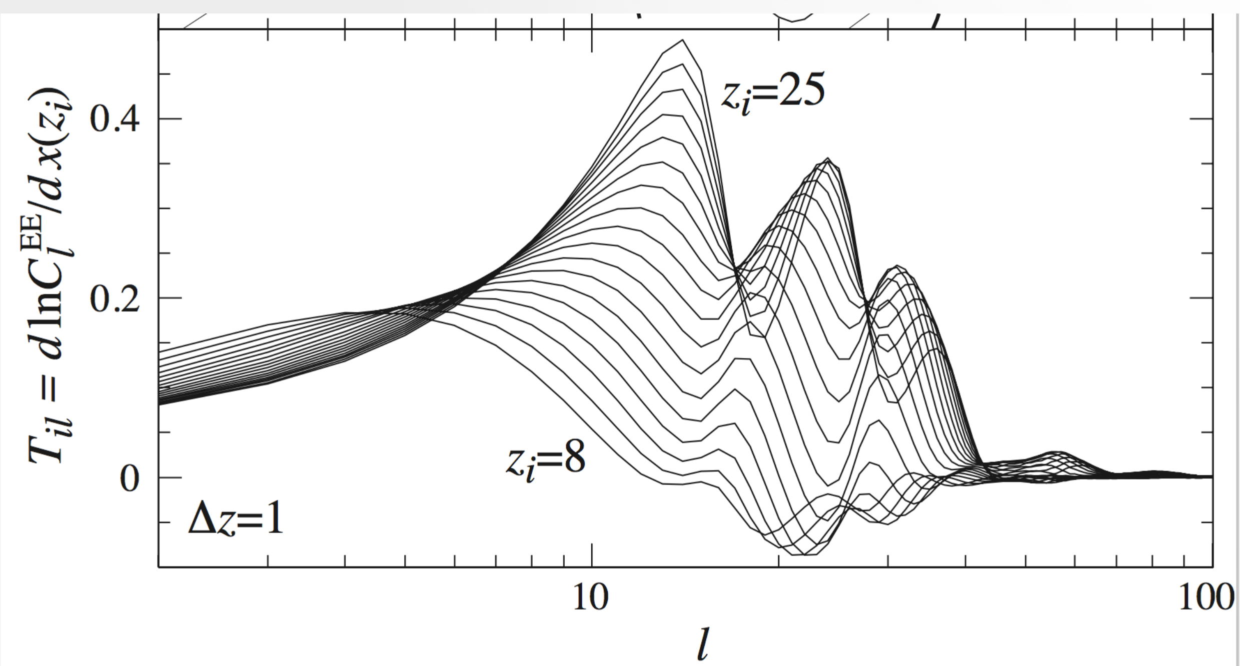
The only free parameter given tau is the transition width.

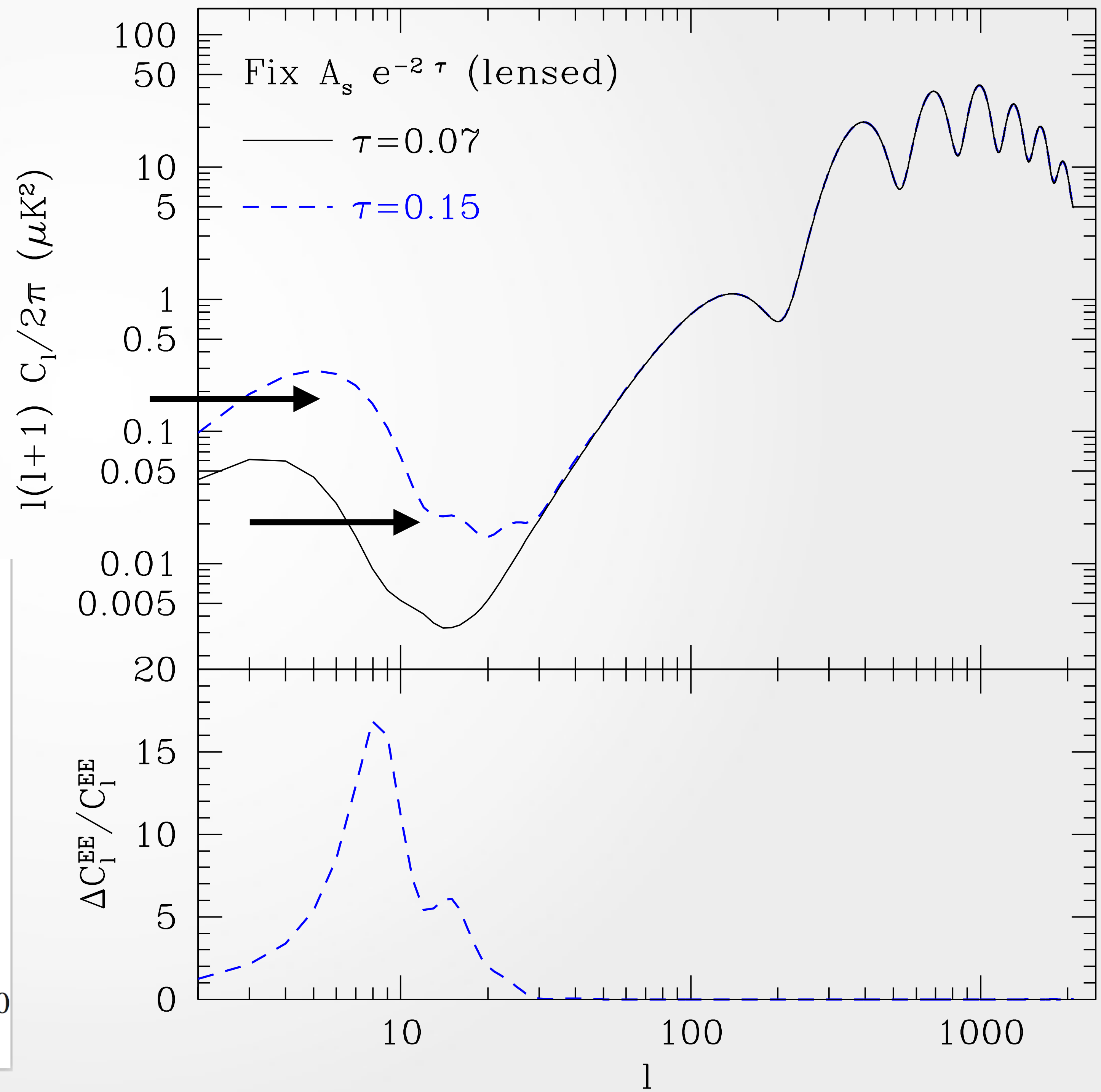


Hypothesis: The Instantaneous Reionization Model

Low and high redshift behavior are linked together

higher redshift => higher l





Beyond IRM: Principal Components Analysis

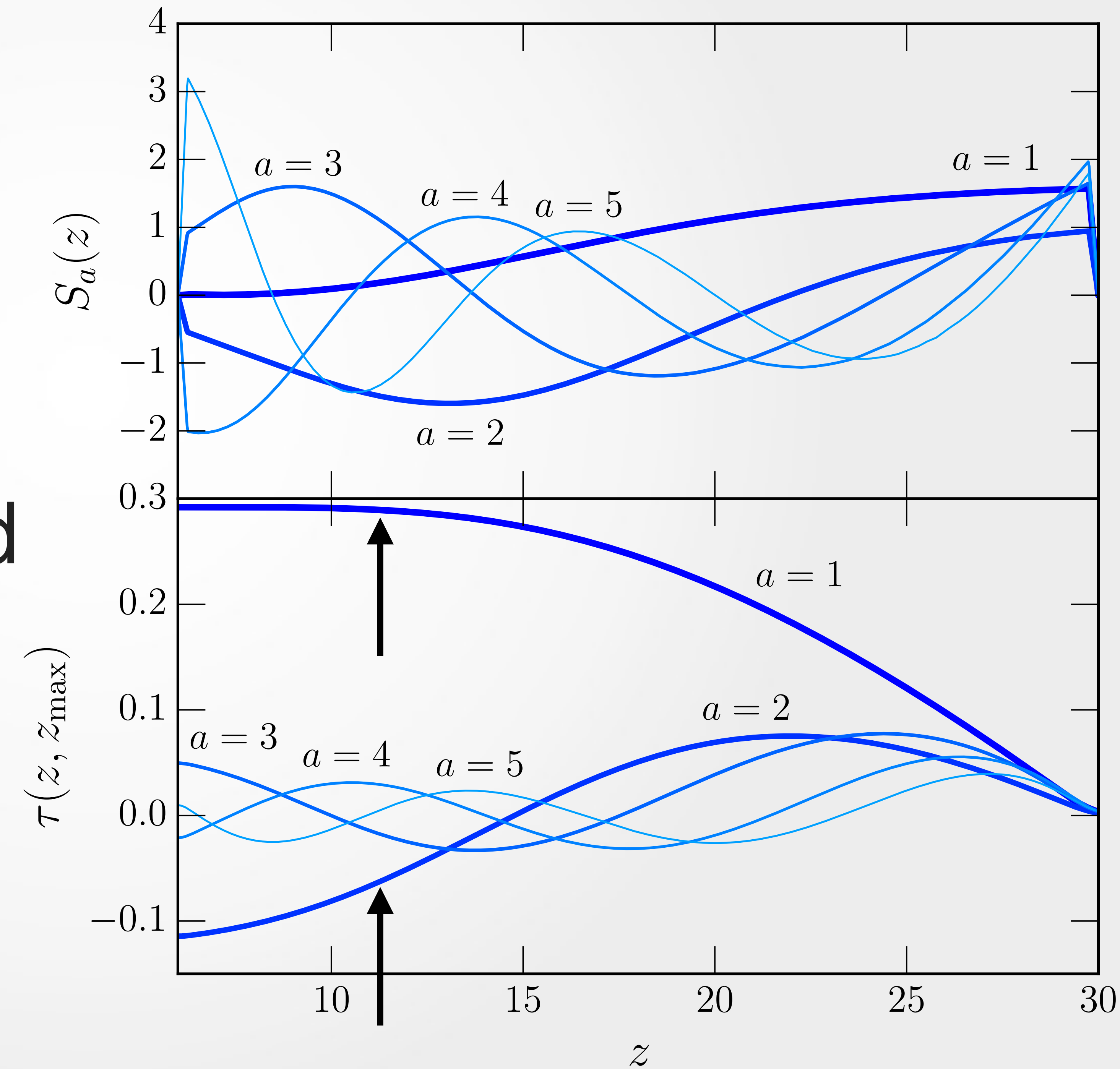
Eigenvectors covariance

$$x_e(z) = x_e^{\mathrm{fid}}(z) + \sum_a m_a S_a(z)$$

Lower PCs: better constrained

a=1 ~ average optical depth

a=2 ~ Difference high-low z

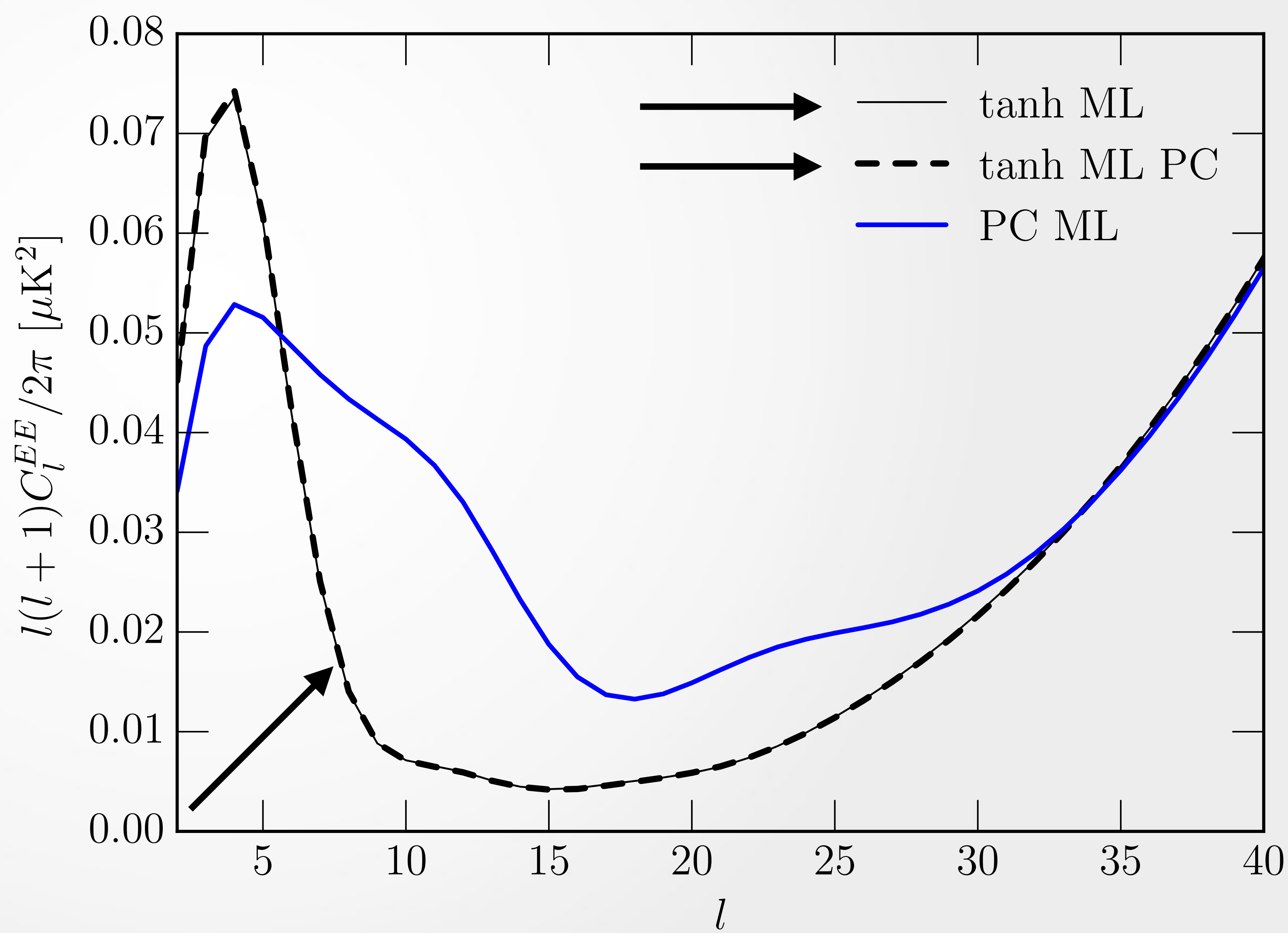


PCA: Completeness

5 PCs are complete!

Complete in polarization

error < cosmic variance



PCA Results On The EOR

Chen He

↑

@ JPL

V. Miranda

↑

@ Job market

Wayne Hu

↑

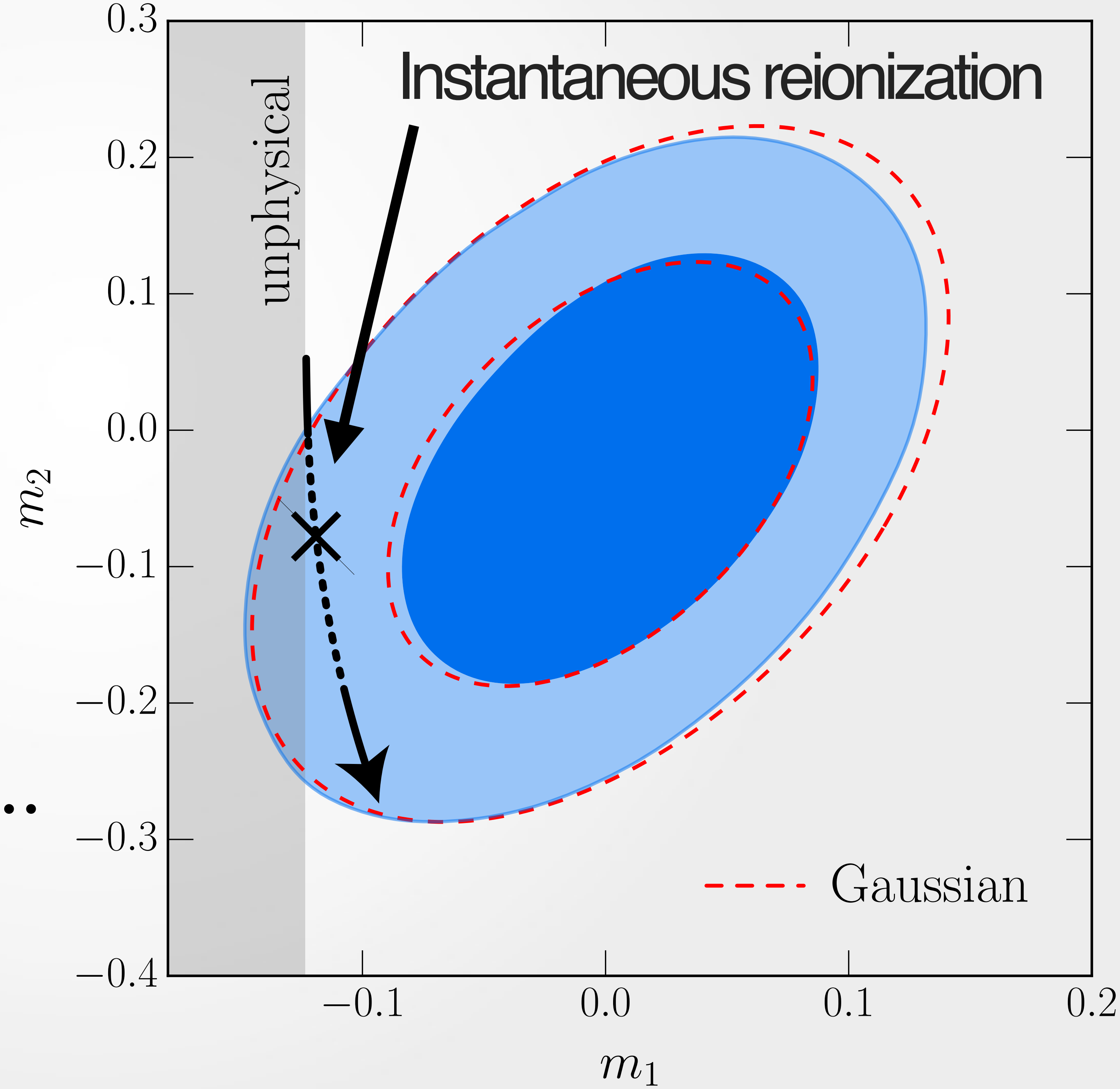
Has tenure

PCA Results On The EOR

Is IRM favored by the data?

$$x_e(z) = x_e^{\mathrm{fid}}(z) + \sum_a m_a S_a(z)$$

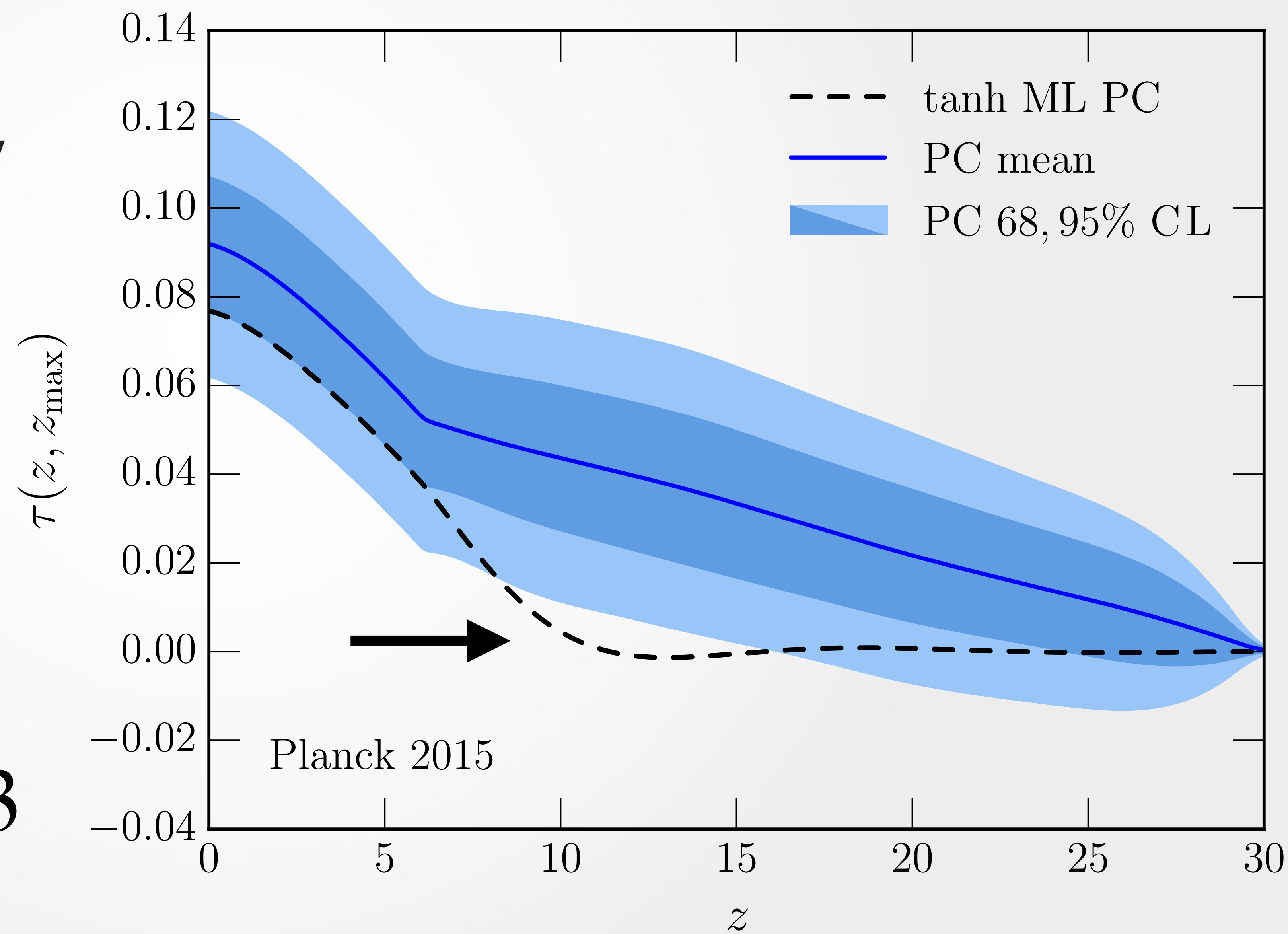
$$\sigma(m_1) < \sigma(m_2) < \sigma(m_3) < \ldots$$



PCA Results On The EOR

Does the IRM spuriously disfavor high redshift sources?

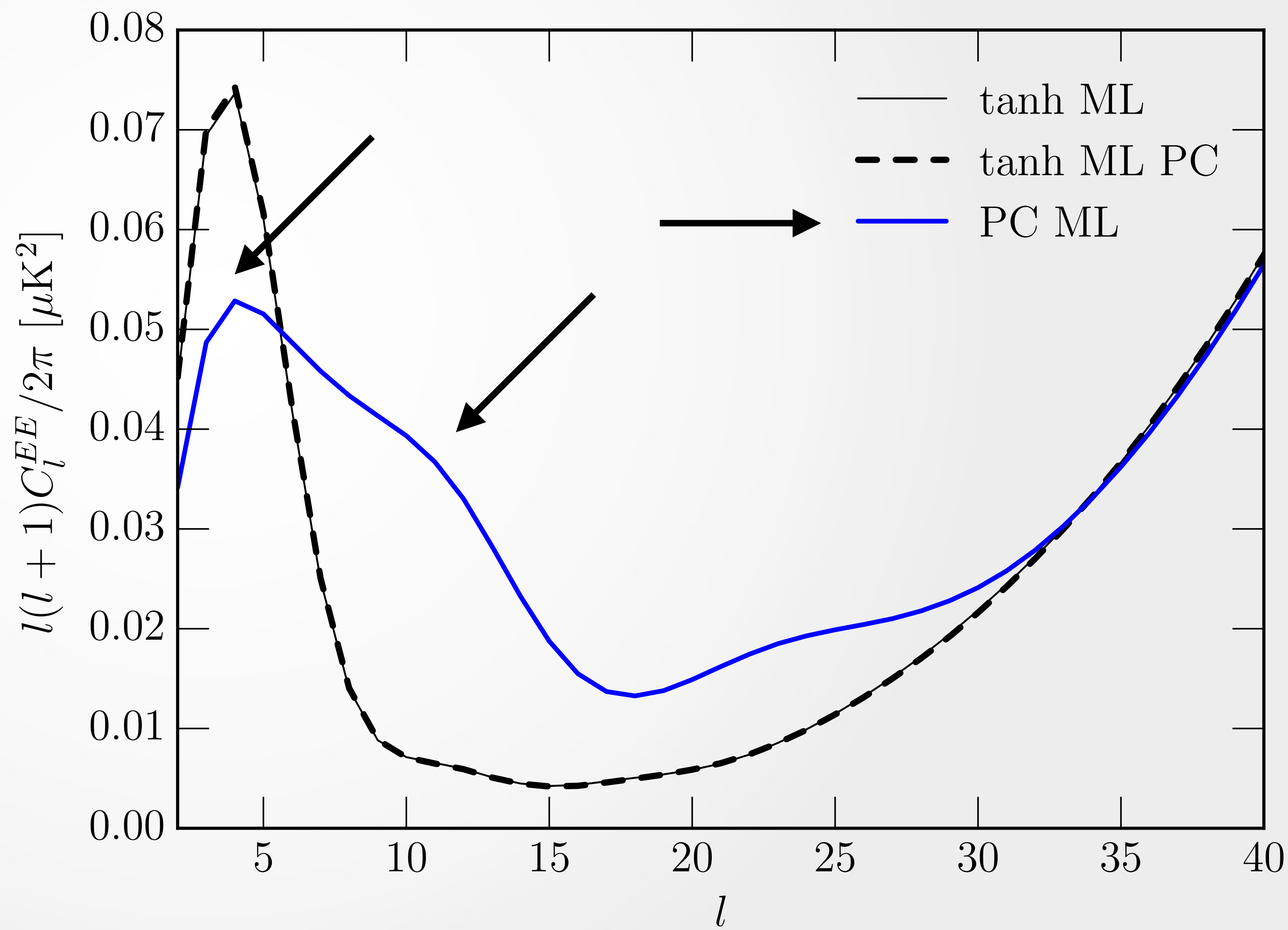
$$\tau_{PC}(z = 15, z_{max}) = 0.033$$



PCA Results On The EOR

What the polarization spectrum look like?

Presence of high redshift sources does **NOT** imply unreasonable tau



PCA: Completeness

Forward Modeling Only

Can models with metal-free stars be the source of the high redshift signal?

Chen He

V. Miranda

Wayne Hu

→

Adam Lidz

Source Of High Redshift Ionization: Pop-III?

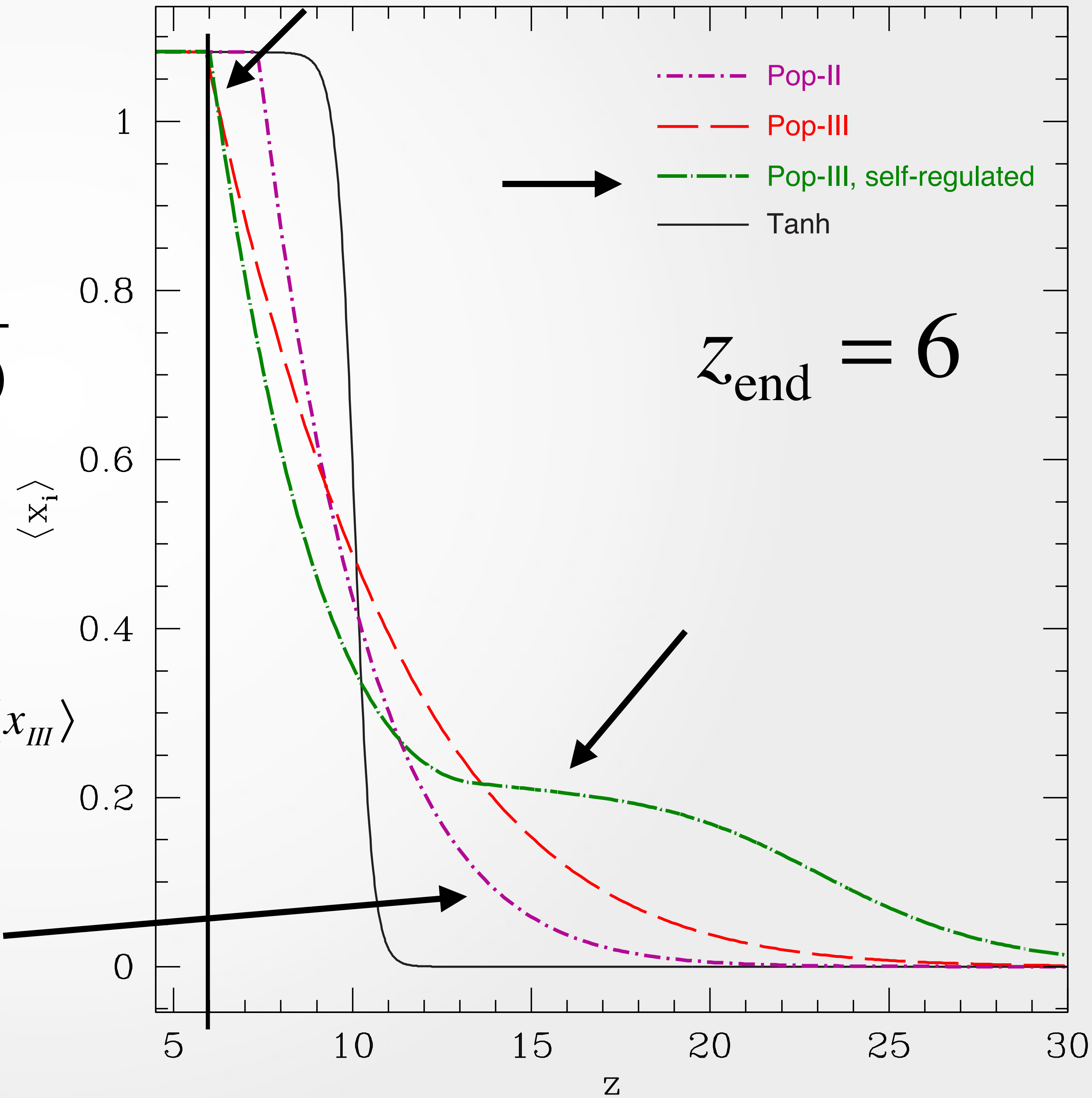
We solve the following ODE

$$\frac{d\langle x_i \rangle}{dt} = \frac{d}{dt}\left(\zeta_{II} f_{c,II} + \zeta_{III} f_{c,III}\right) - \frac{\langle x_i \rangle}{\bar{t}_{\rm rec}(z)}$$

Efficiency

$$\langle x_T \rangle \neq \langle x_{II} \rangle + \langle x_{III} \rangle$$

Baseline model (Pop-II stars)



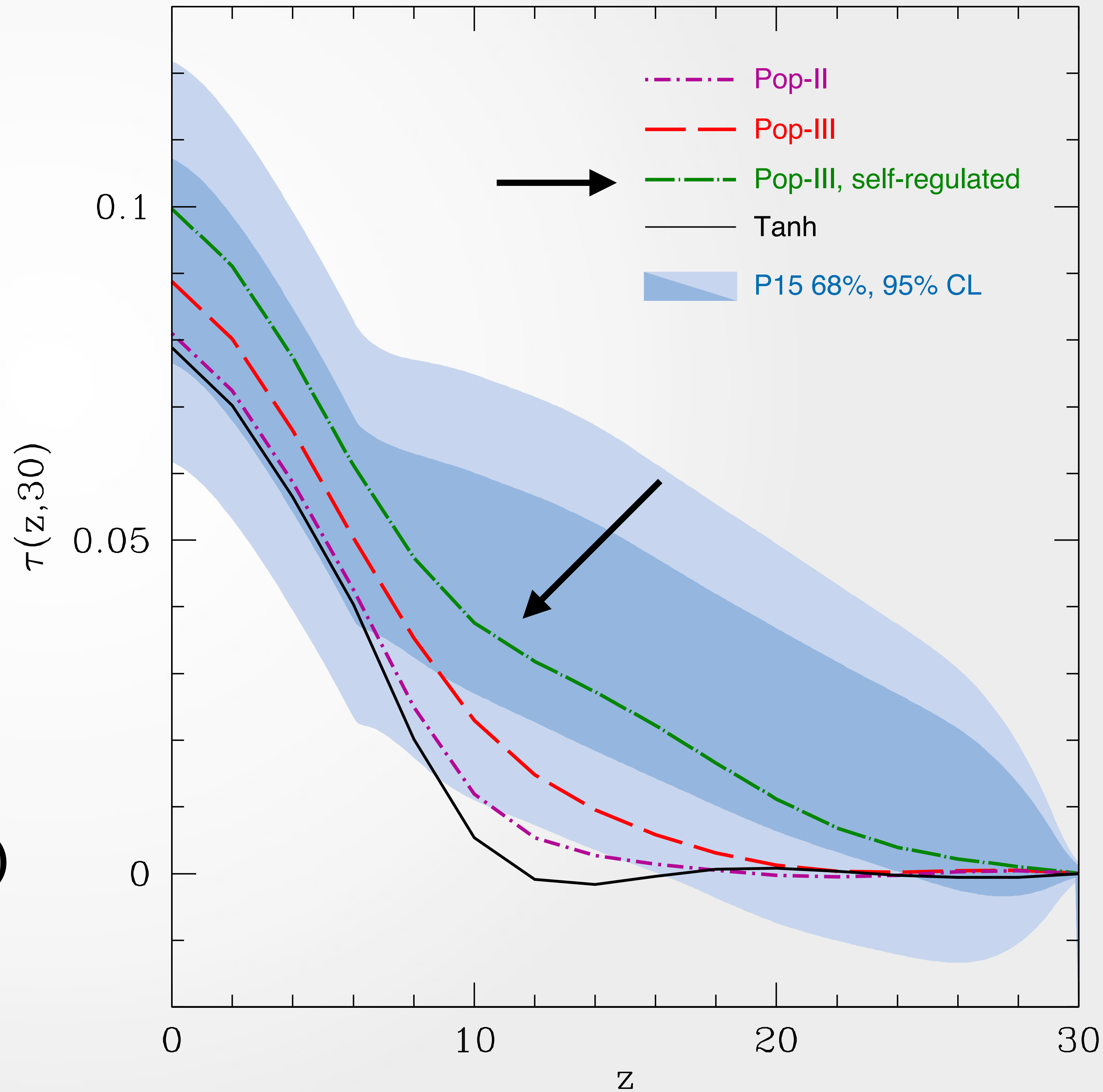
Source Of High Redshift Ionization: Pop-III?

PC Projection

$$m_a = \frac{1}{24}\int_6^{30} dz\, S_a(z)\left[\langle x_e\rangle(z) - \langle x_e^{\rm fix}\rangle(z)\right]$$

Then evaluate optical depth

$$\tau(z_1,z_2) = \tau^{\rm fid}(z_1,z_2) + \sum m_a \tau_a(z_1,z_2)$$



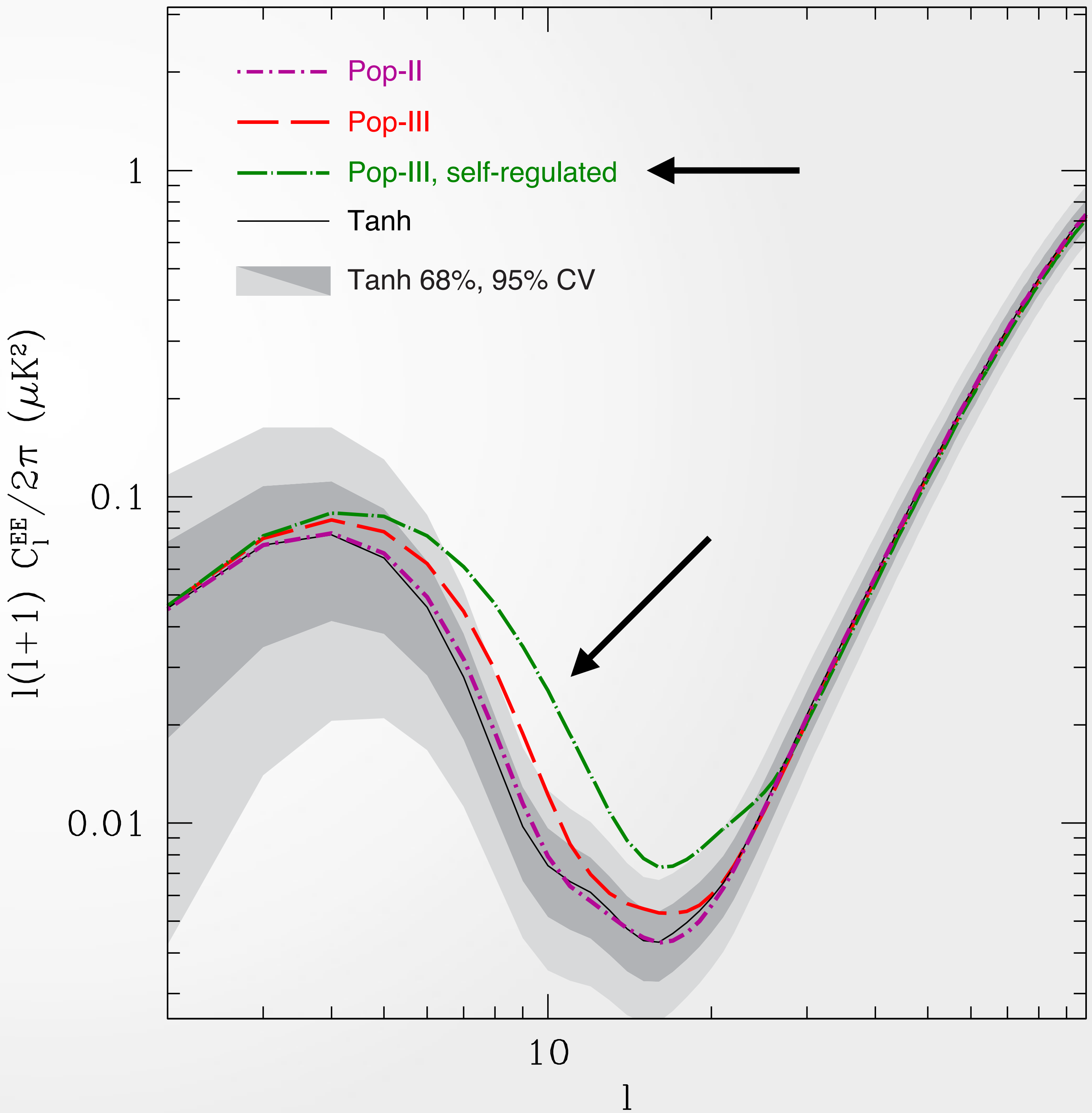
Vinicius Miranda, Postdoctoral Researcher, University of Pennsylvania

Source Of High Redshift Ionization: Pop-III?

Get polarization spectrum

Shades = CV assuming instantaneous ionization is the correct model*

*Tricky type of question

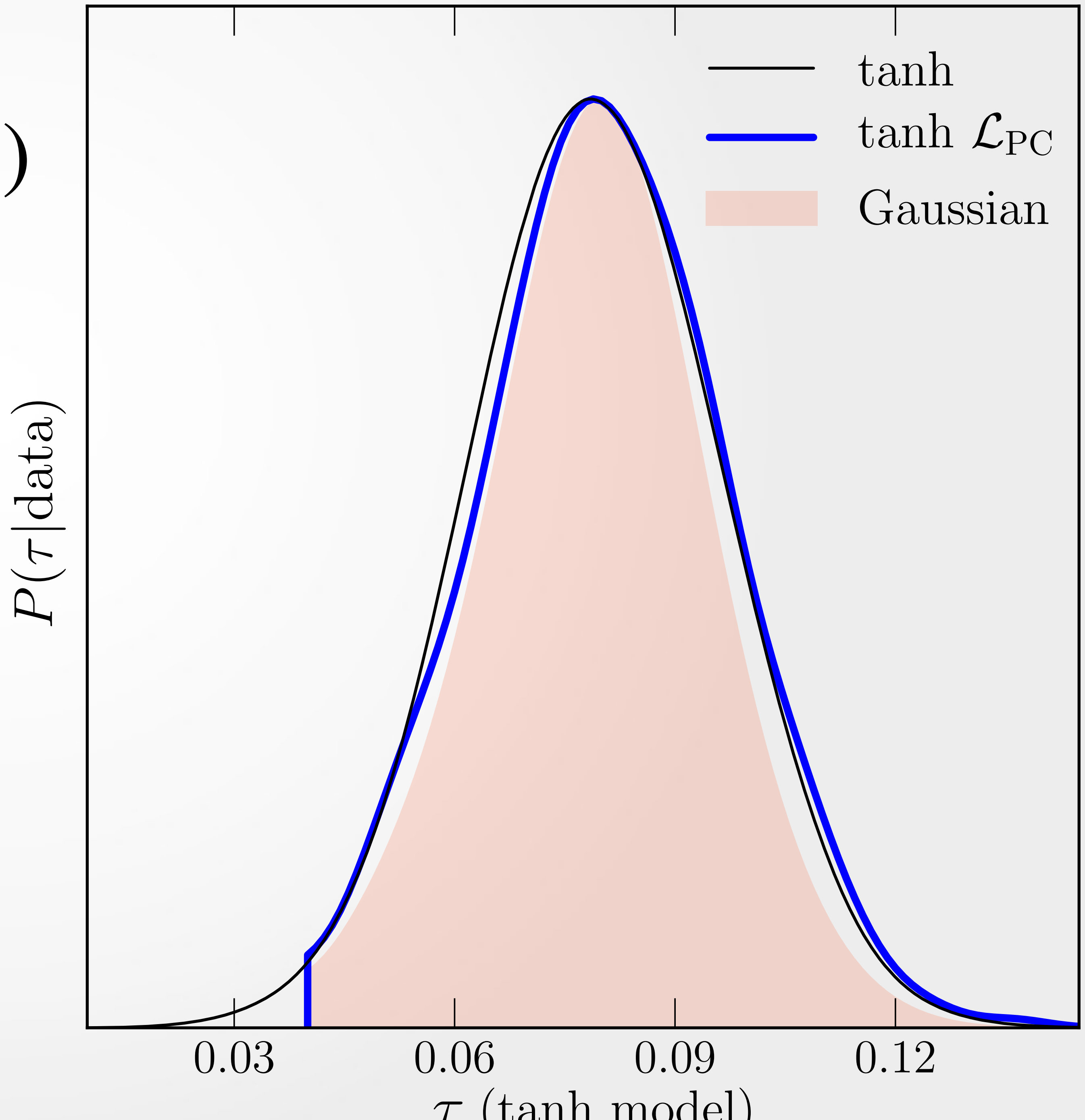


Make Results Useful to Everyone: PCA Fast Likelihood

$$\mathcal{L}_{\rm PC}(\text{data}\,|\,\mathbf{m}) = \sum_{i=1}^{N} w_i K_f(\mathbf{m} - \mathbf{m}_i)$$

Your Favorite model

MCMC models



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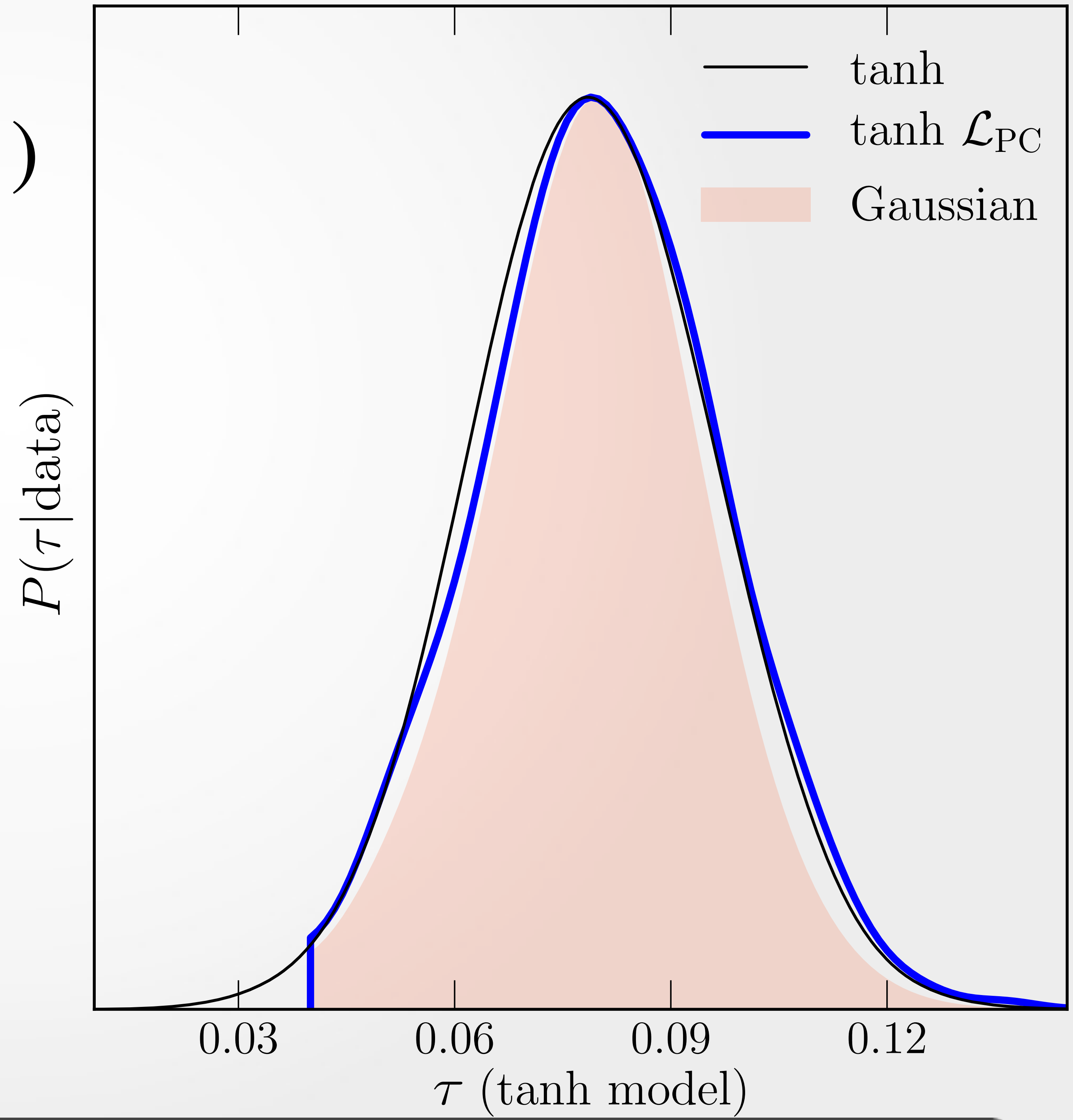
Make Results Useful to Everyone: PCA Fast Likelihood

$$\mathcal{L}_{\rm PC}(\mathrm{data}\,|\,\mathbf{m}) = \sum_{i=1}^{N} w_i K_f(\mathbf{m}-\mathbf{m}_i)$$

Chain multiplicities

Kernel (Gaussian)

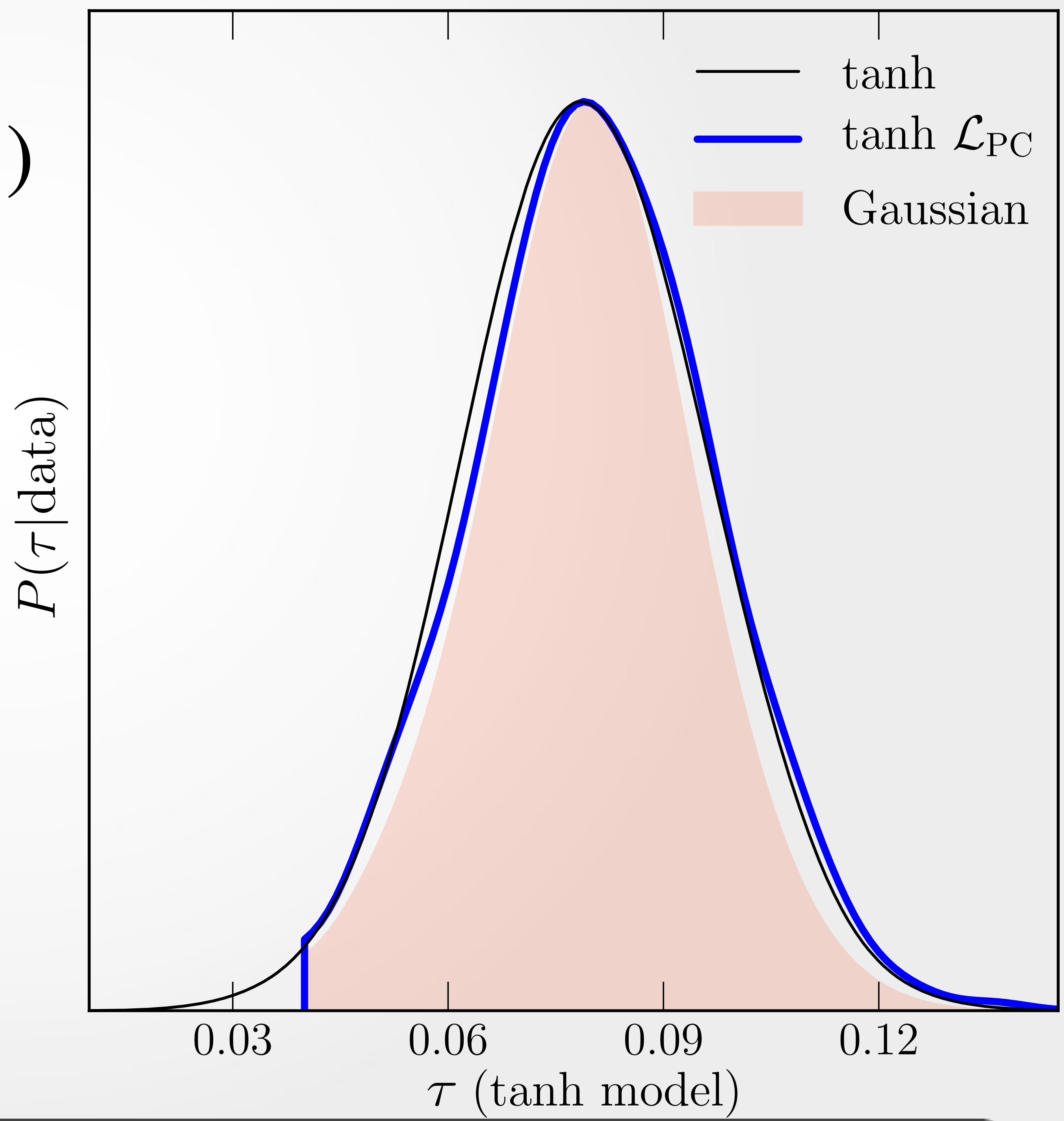


Make Results Useful to Everyone: PCA Fast Likelihood

$$\mathcal{L}_{\rm PC}(\mathrm{data}\,|\,\mathbf{m}) = \sum_{i=1}^{N} w_i K_f(\mathbf{m}-\mathbf{m}_i)$$

Good: fast (no CAMB)

Bad: needed ~10x more chain points than normal convergence



What Our Results Means for 21-cm, neutrinos, CMB-S4…

$$\tau_{\mathrm{PC}}(z=15, z_{\max}) = 0.033$$

- CMB-S4: neutrino mass constraints with lensing
- Optical Depth is one of the highest sources of error
- 21-cm claims they can measure tau better than CV
- This claim will fail if our result is not due to systematics

Part II - Inflationary Features

Georges Obied

Cora Dvorkin

Chen He

V. Miranda

Wayne Hu

The Generalized Slow-Roll Approximation

$$\ln \Delta^2_{\mathcal{R}} = I_0(k) + \ln[1 + I_1^2(k)]$$

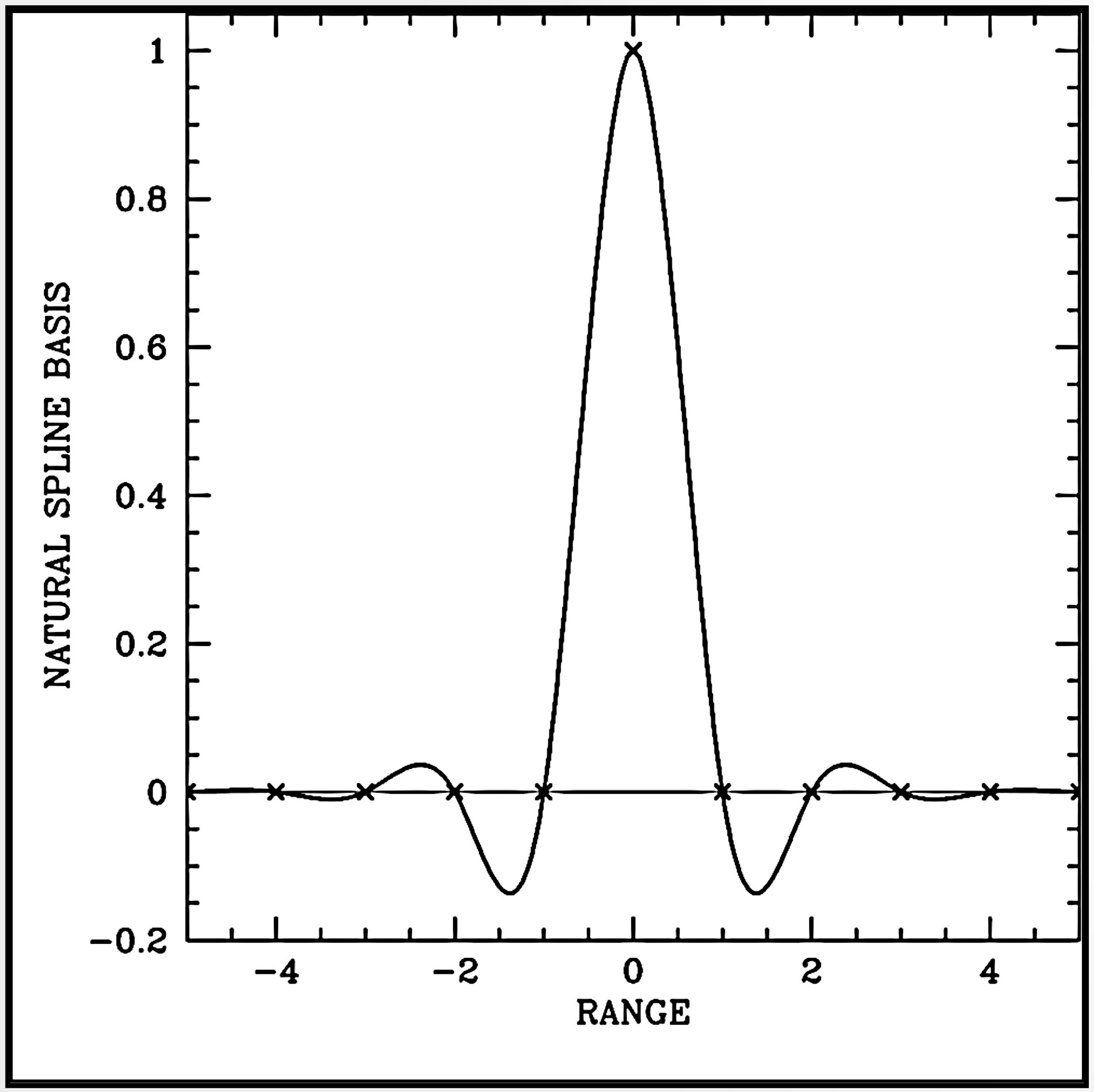
$$I_j(k) \propto \int d\ln s \mathrm{W}_j(ks) \mathrm{G}'(\ln s)$$

Cora Dvorkin

Wayne Hu

Single kernel encompasses power spectrum observables

Kernel Expansion: Non-Parametric Spline Basis



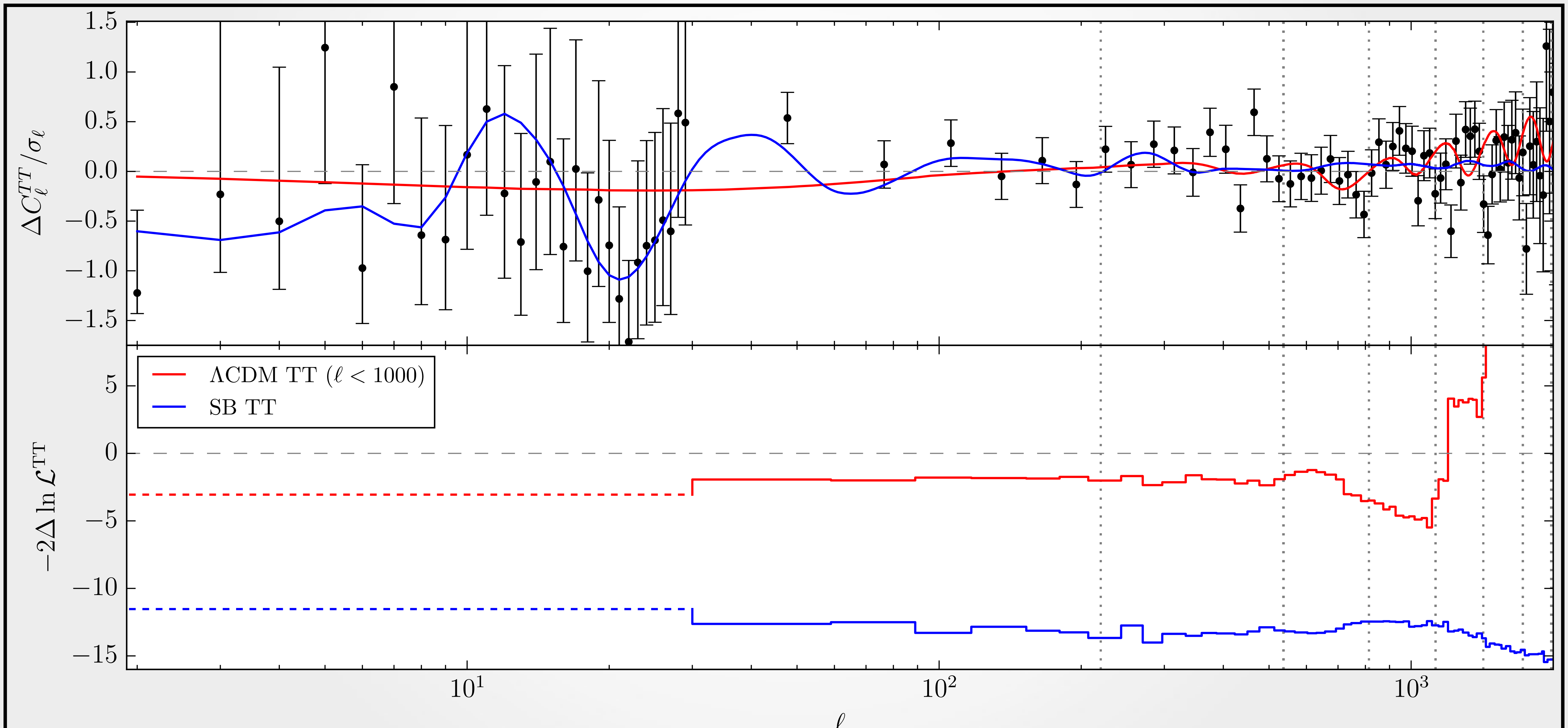
$$G'(\ln s) = (1 - n_s) + \sum_i B_i(\ln s) w_i$$

SB: more efficient than PCAs for localized features



V. Miranda C. Dvorkin W. Hu

WMAP/Planck l~20 Features on Temperature Spectrum

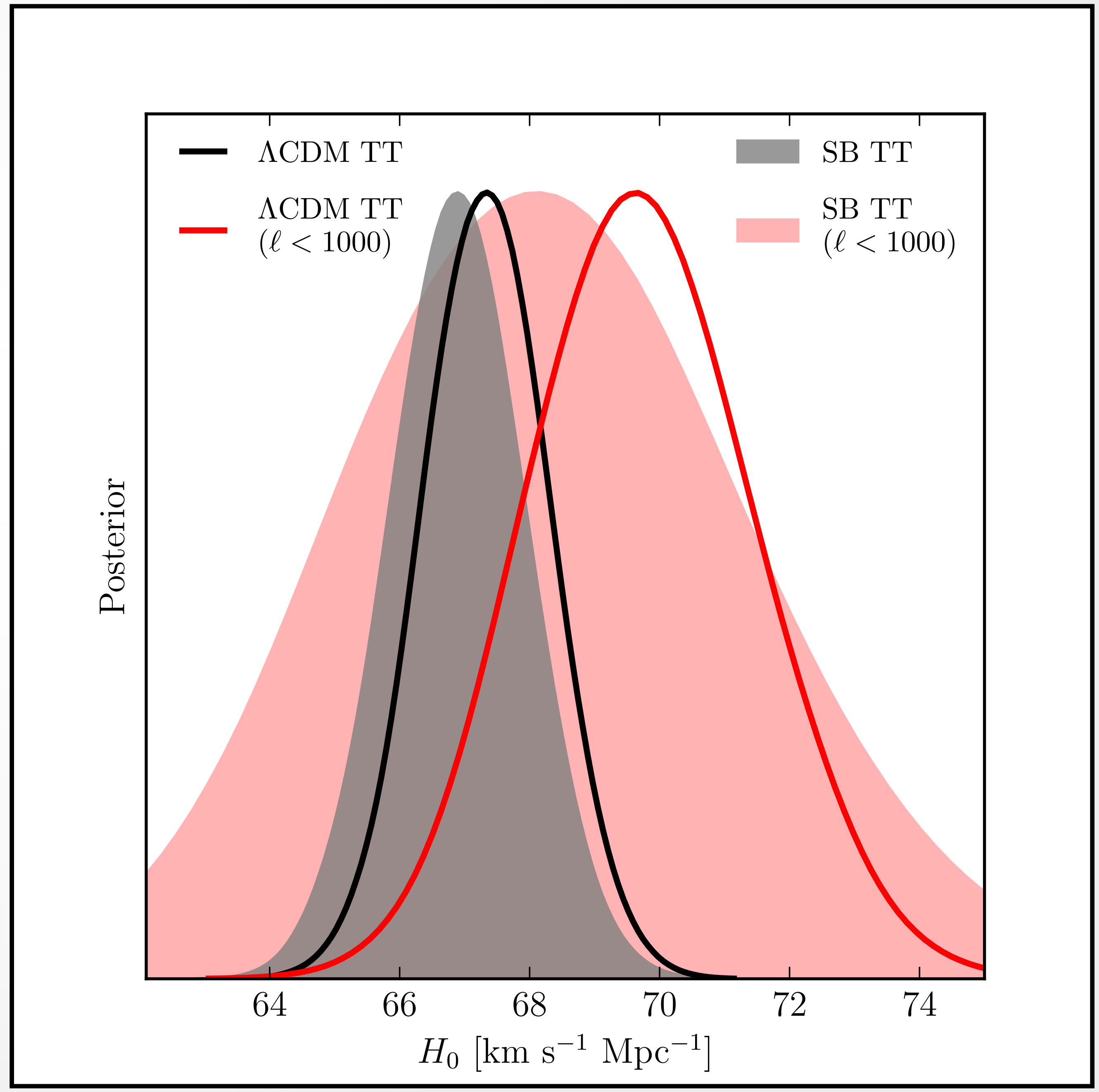


Features Affect Inferences On The Hubble Constant

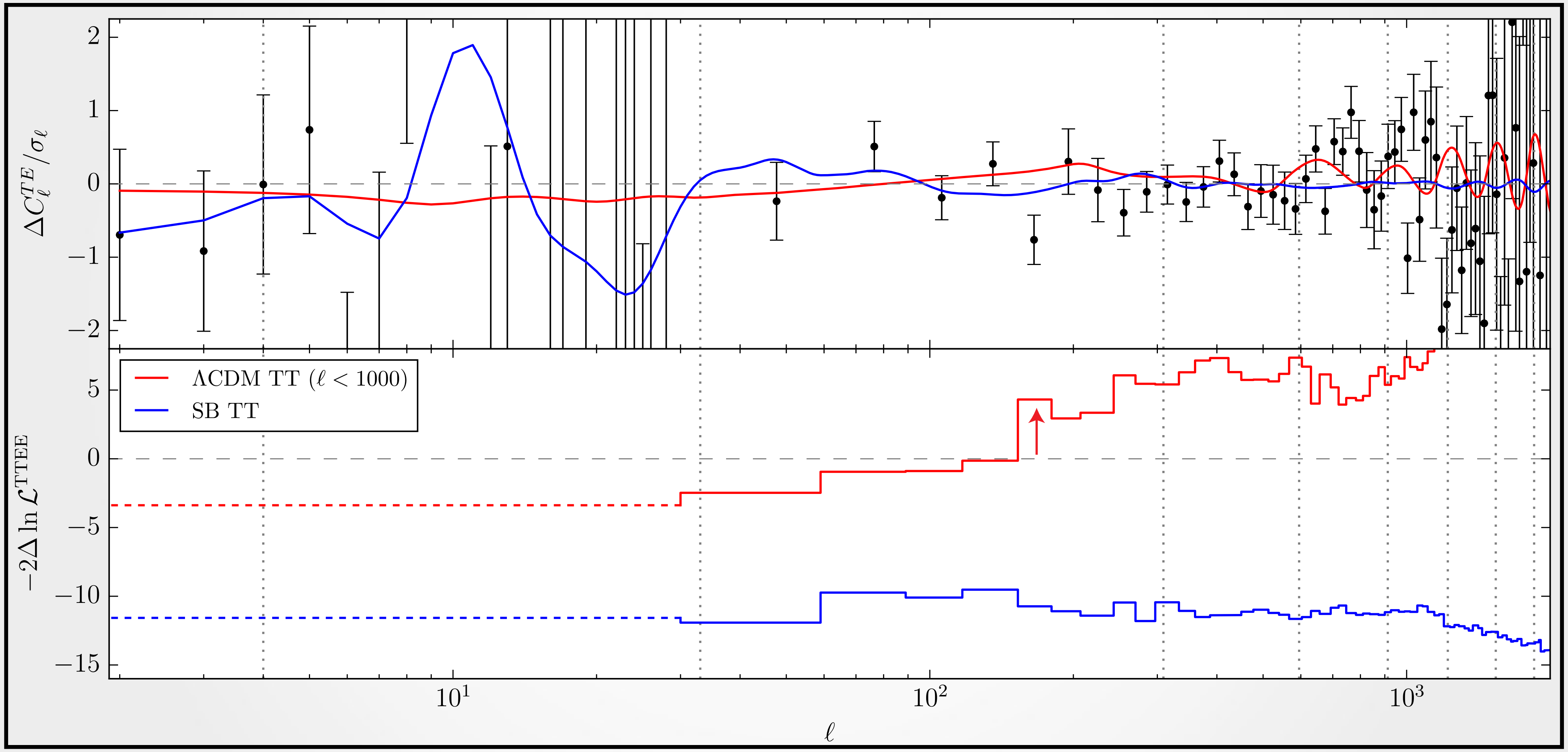
Features in inflation impact

H0 predictions

(especially if lmax < 1000)



WMAP/Planck l~20 Features On TE Spectrum



Also impacts TE -> what about reionization?

Near Future: Combined Analysis (Stay Tuned)

Inflationary vs. Reionization Features from *Planck* 2015 Data

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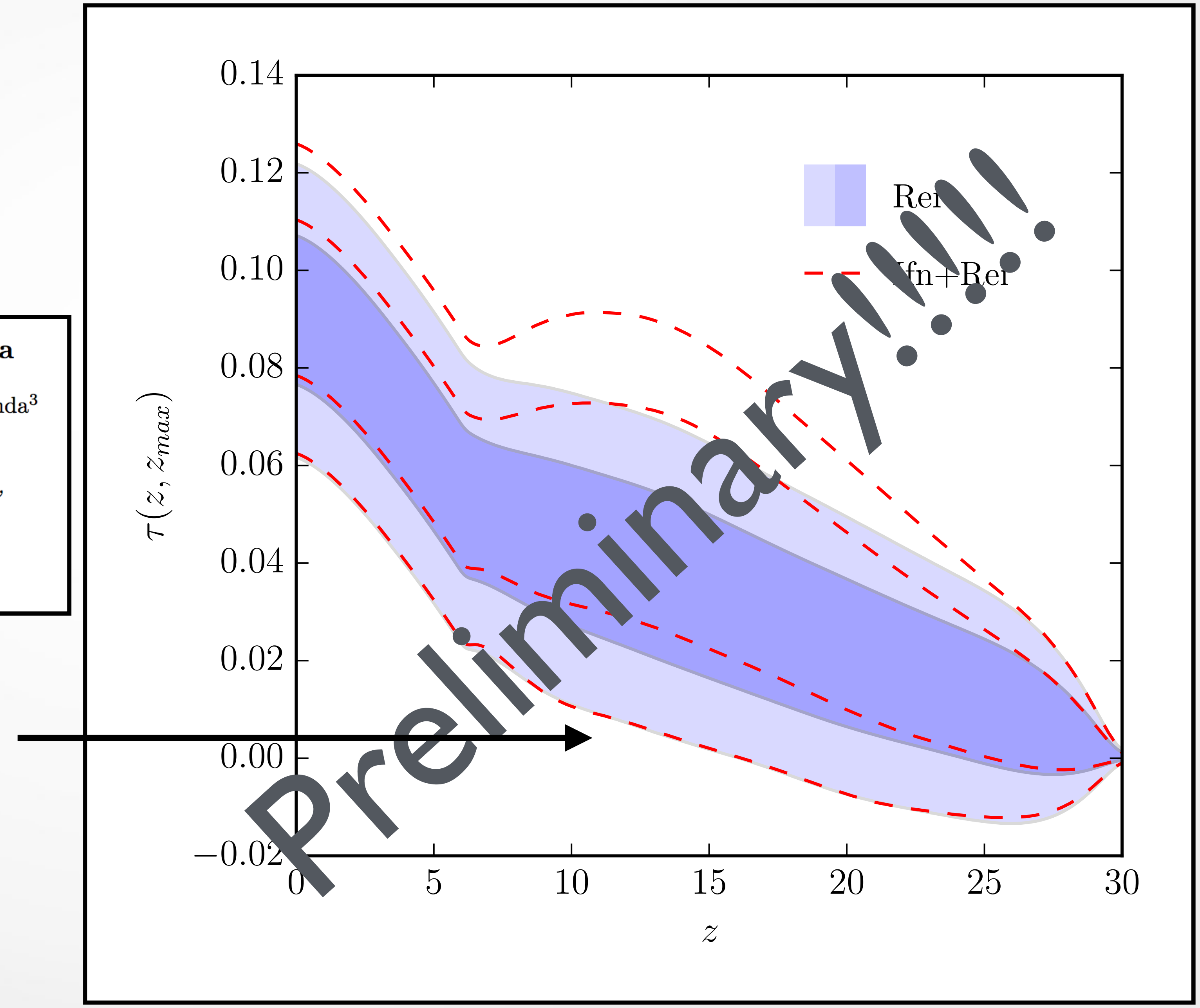

B-MODE from Space - Berkeley - Vinicius Miranda

Conclusions