Constraining the axiverse with reionization

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Based on 2506.19096 and 2507.03535

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2507.03535

2506.19096

目 录

contents

PART 01

Axion Production&Decay

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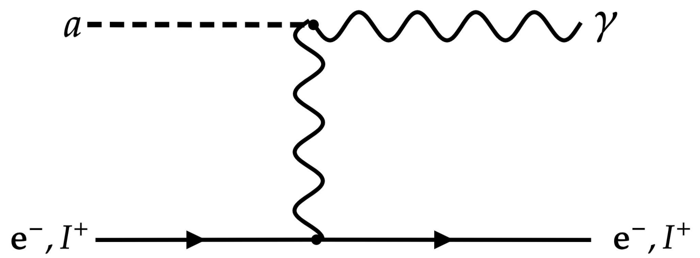
Axion production

Axion freeze-in via axion photon coupling

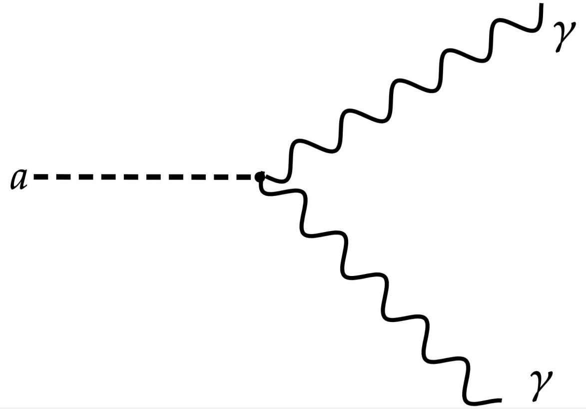
$$\mathcal{L}_{a\gamma\gamma} = -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} ,$$

Primakoff process



$$\mathcal{F}_{\rm Prim} \equiv \frac{\rho_{\rm Prim}}{\rho_{\rm DM}} = \frac{3.4 \times 10^{-3} A_{\rm Prim}}{\sqrt{g_*(T_{\rm reh})}} \left(\frac{T_{\rm reh}}{10\,{\rm MeV}}\right) \left(\frac{g_{a\gamma\gamma}}{10^{-11}\,{\rm GeV}^{-1}}\right)^2 \left(\frac{m_a}{1\,{\rm MeV}}\right) .$$

Inverse decay



$$\mathcal{F}_{\rm Id} = A_{\rm Id} \frac{1.42 \times 10^{-4}}{\sqrt{g_*(T')}} \left(\frac{g_{a\gamma\gamma}}{10^{-11}\,{\rm GeV}^{-1}}\right)^2 \left(\frac{m_a}{0.1\,{\rm MeV}}\right)^2 \times \left(\frac{T'}{T_{\rm Id}} \frac{(4(\frac{T_{\rm Id}}{T'})^2 - 1)^{3/2}}{3^{3/2}} \frac{\coth(0.1\frac{T_{\rm Id}}{T'})}{\coth(0.1)}\right)_{T'=\min[T_{\rm Id}, T_{\rm reh}]}$$

Mudit Jain+ 2406.01678

Axion decay into photons

- **Axion decay lifetime**

$$\tau = 3 \times 10^{-5}\, t_U \left(\frac{m_a}{\mathrm{MeV}}\right)^{-3} \left(\frac{g_{a\gamma\gamma}}{10^{-13}\mathrm{GeV}^{-1}}\right)^{-2}$$

- **Ionization fraction**

$$X_e = \frac{n_e}{n_H}\,,$$

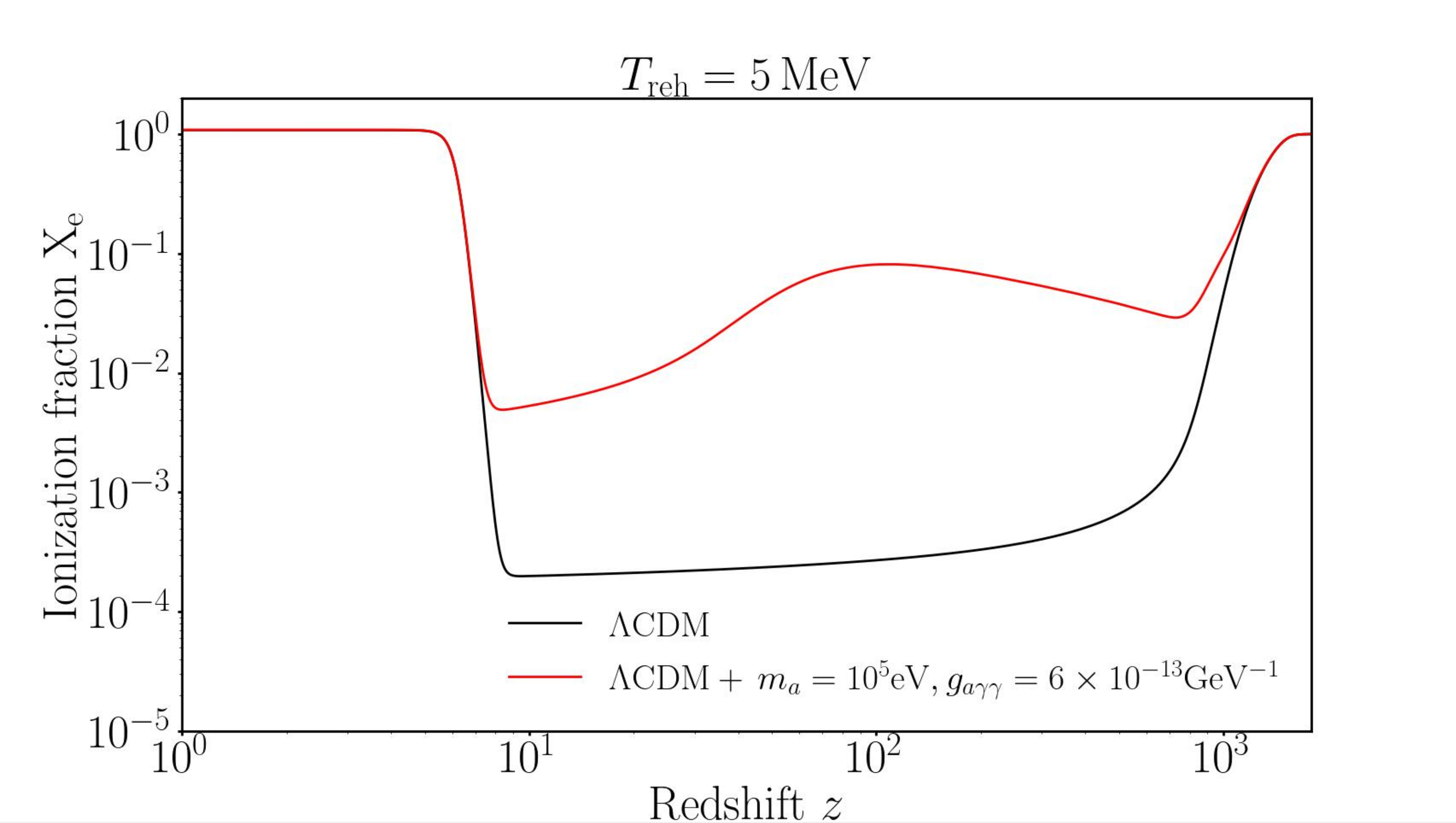
$$(1+z)H(z)\frac{dX_e}{dz} = C_H\left(-\beta_H(T_\gamma)(1-X_e)e^{\frac{-E_{H,2s1s}}{T_\gamma}} + X_e^2 n_H \alpha_H(T_b)\right) - I_x\,,$$

$$(1+z)\frac{dT_b}{dz} = 2T_b + \frac{8}{3}\frac{\rho_\gamma \sigma_T}{m_e H(z)}\frac{X_e}{1+f_{\mathrm{He}}+x_e}(T_b - T_\gamma) - \frac{2}{3}\frac{(1+z)\frac{dE}{dVdz}|_{\mathrm{dep,heat}}}{n_H(1+f_{\mathrm{He}}+x_e)}\,,$$

$$I_x = \frac{dE}{dVdt}\Big|_{\mathrm{dep,ion}}\frac{1}{n_H E_i} + (1-C_H)\frac{dE}{dVdt}\Big|_{\mathrm{dep,exc}}\frac{1}{n_H E_{H,1s2p}}\,,$$

Cosmic ionization history with axion decay

- **Reionization history with one axion decay**



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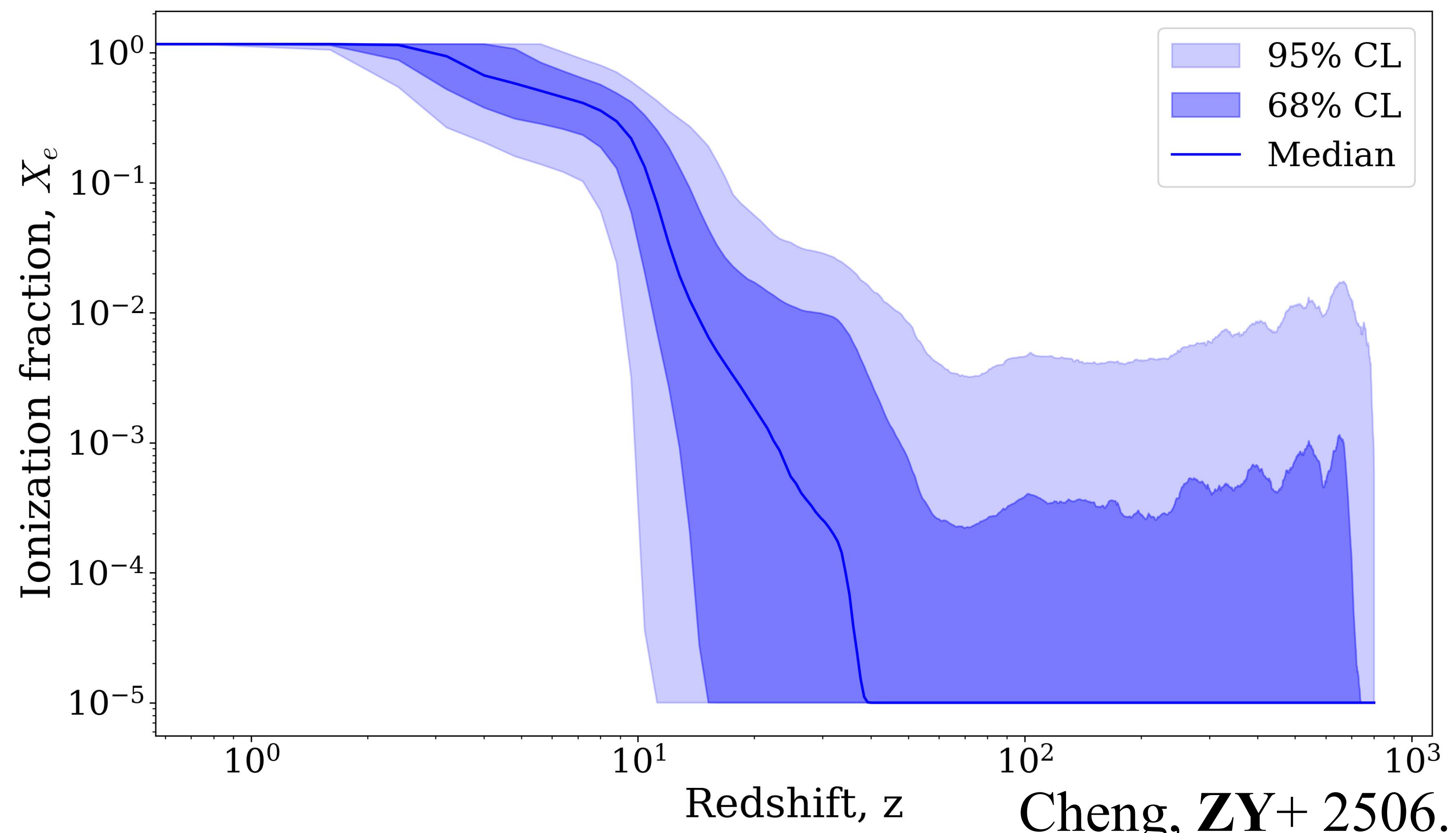
Model independent method for reionization history reconstruction

We develop a Gaussian Process Regression to constraint the ionization fraction

We use *Planck* low-*l* EE polarization to compute the high redshift optical depth τ_{highz}



$$\tau_{\mathrm{highz}} = \int_{z_c}^{z_{\max}} \sigma_T \, n_e(z) \frac{\mathrm{d}z}{(1+z)H(z)}$$

$$z_c \in [20, 40]$$

$$z_{\max} = 800$$

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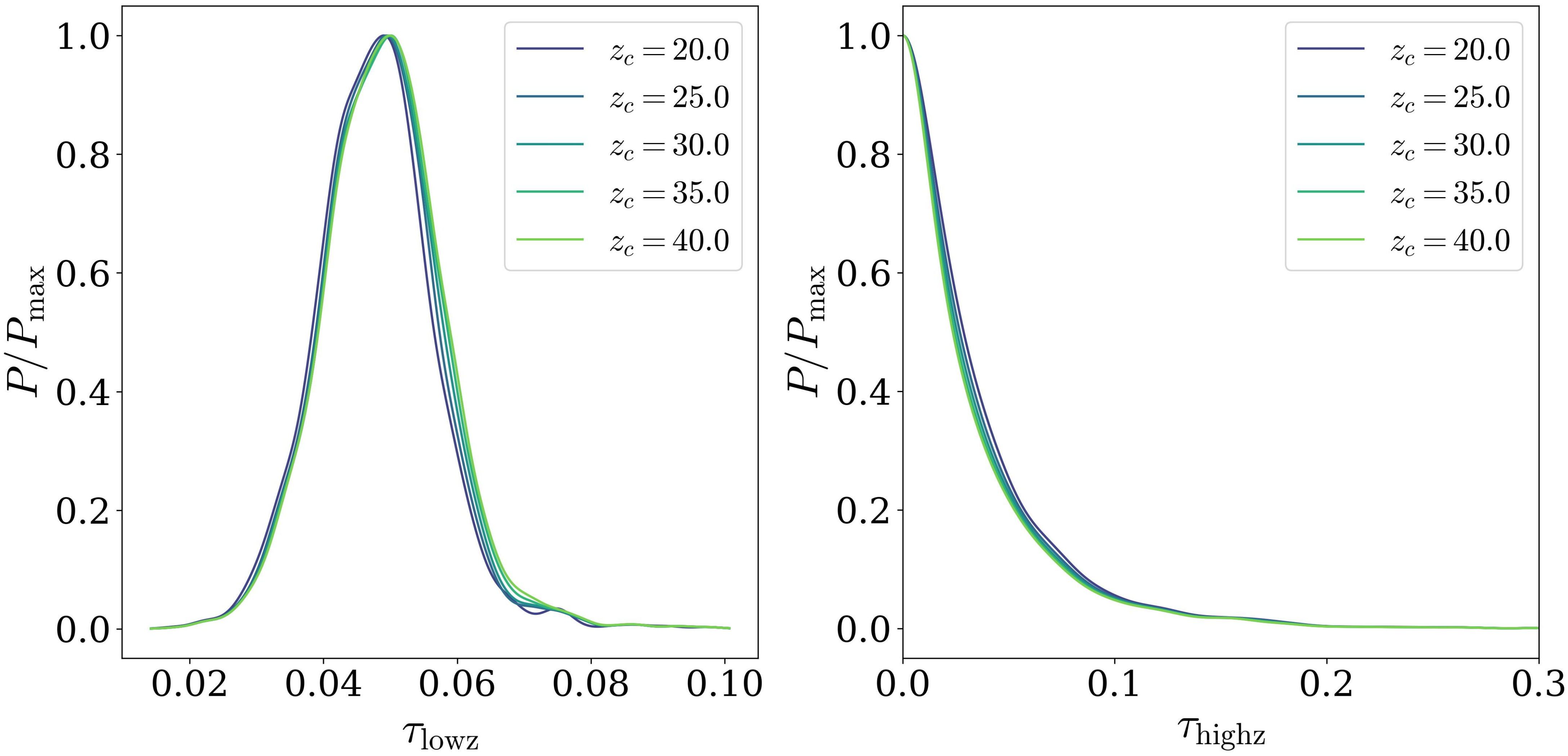
Model independent method for reionization history reconstruction



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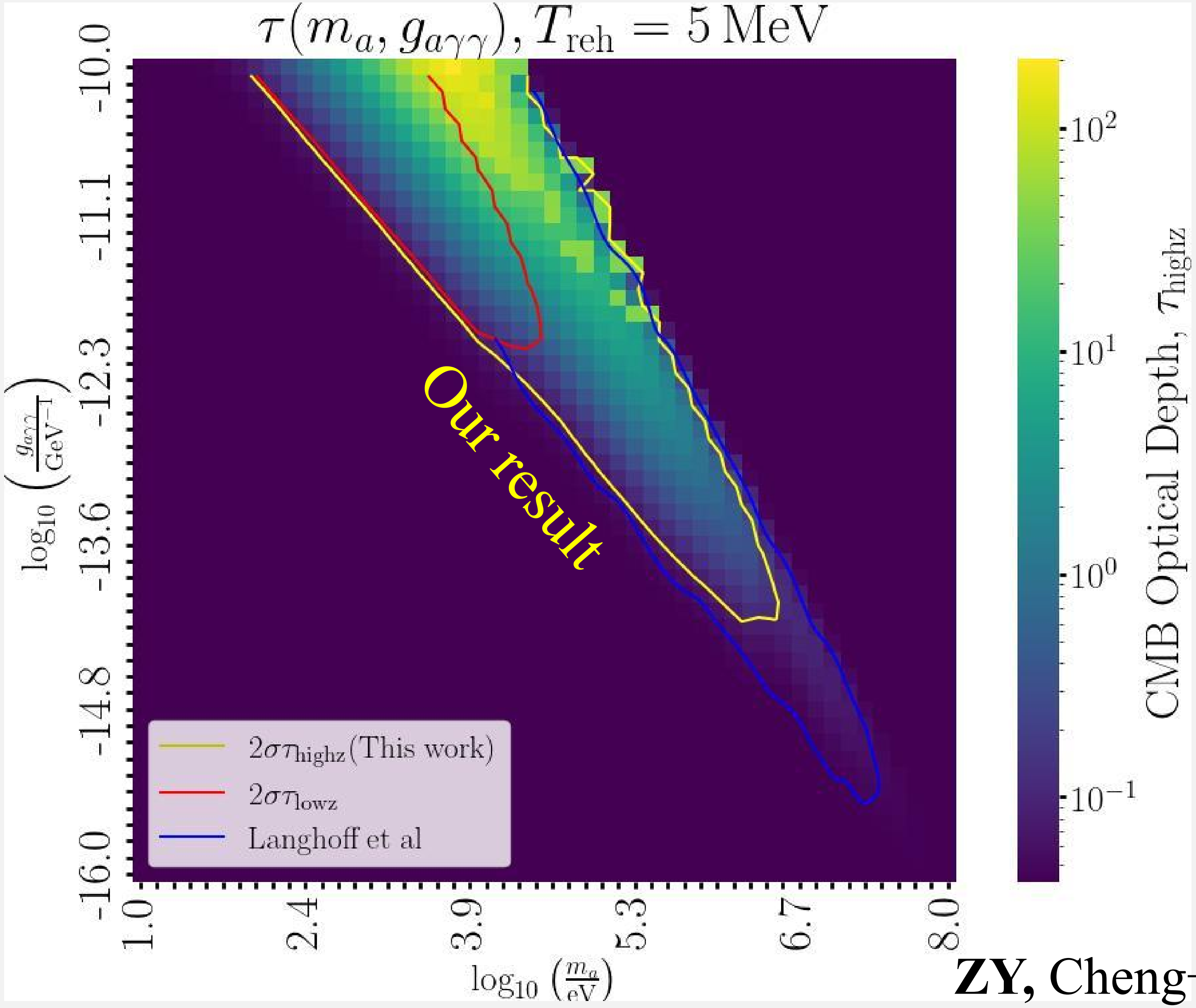
Single axion decay parameter space with low reheating temperature



Our result is more conservative but more robust than the traditional methods

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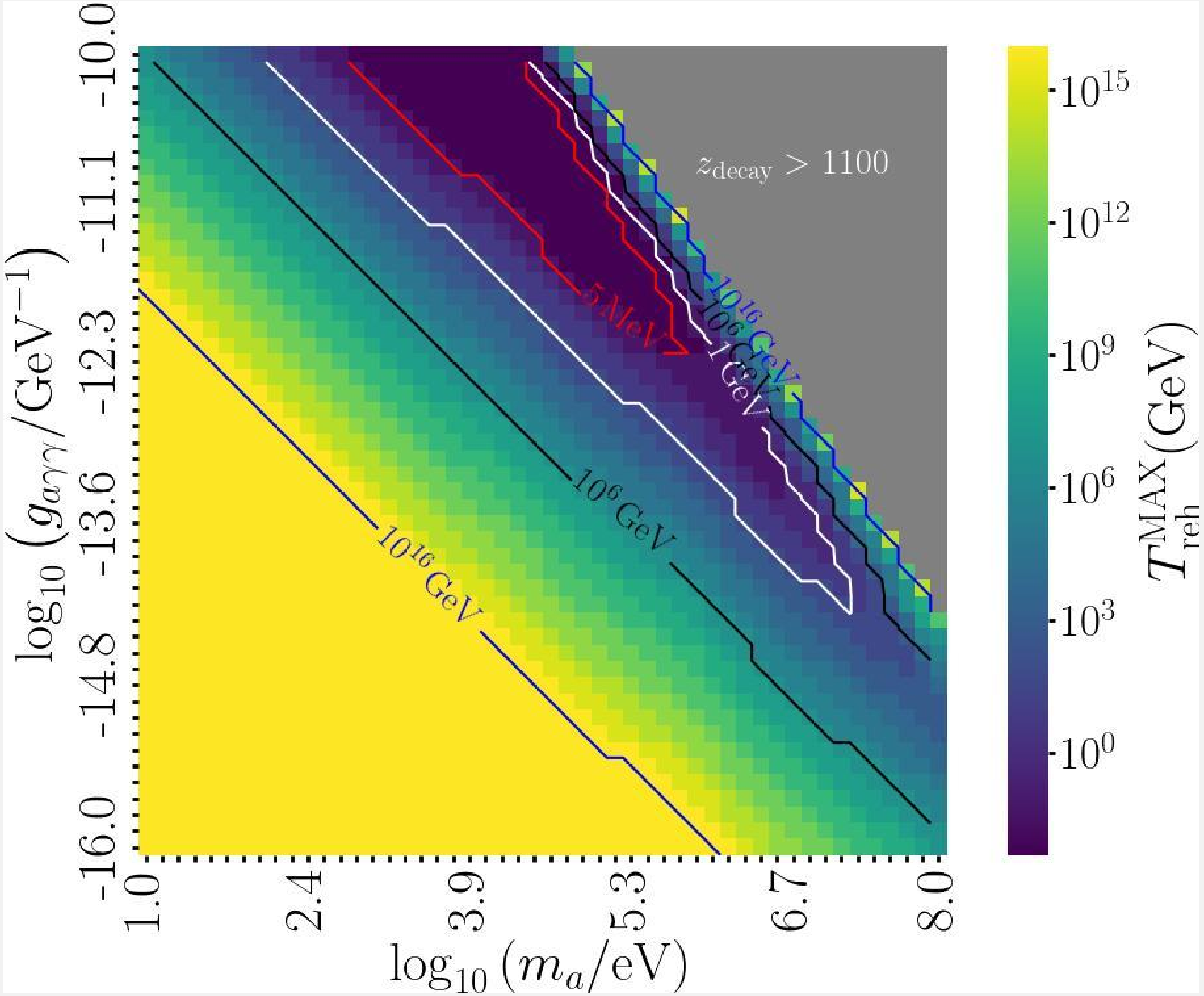
The maximum reheating temperature of single axion decay



Maximum allowed reheating temperature goes from 5 MeV to 10^{16} GeV

Constraint from： BBN Primordial gravitational waves

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PART 02

String Axiverse ionization

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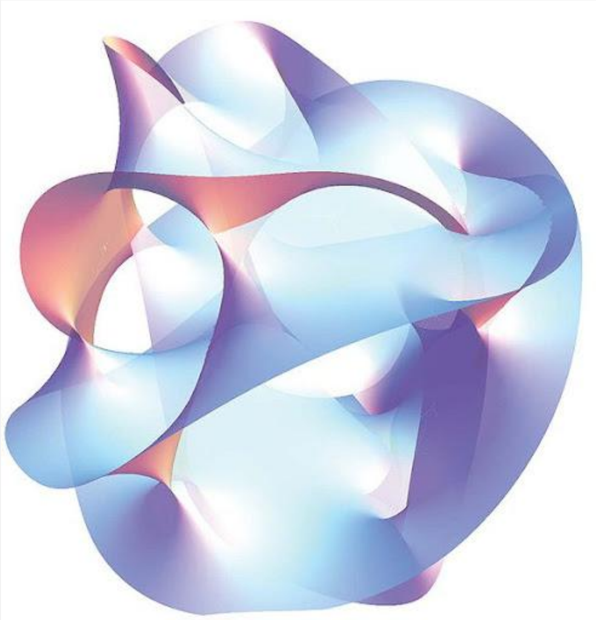
String axions



the index i runs from 1 to $h_{1,1}$ and the fields a(x) give rise to axions in the closed string sector

$$C_4 = \sum_i a_i(x)\omega_i(y)$$

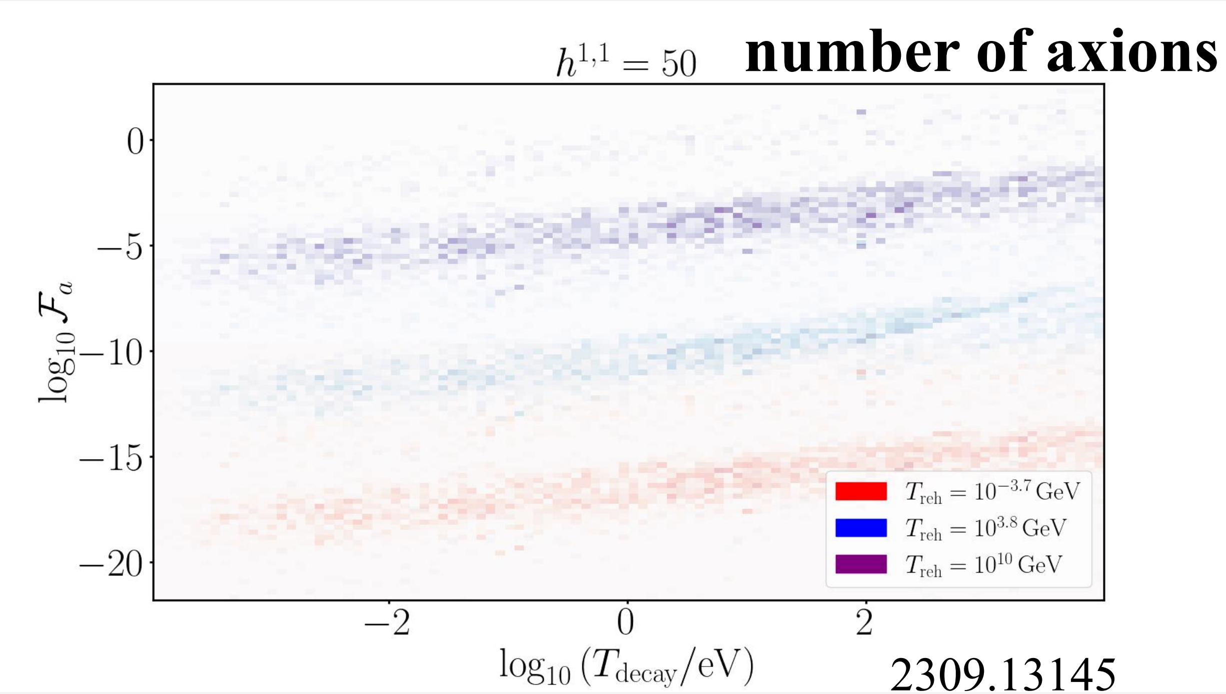
the couplings of all the axions to electromagnetism:

$$\mathcal{L}_{a\gamma\gamma} = -\frac{1}{4}\sum_i g^i_{a\gamma\gamma}\phi_i F_{\mu\nu}\tilde{F}^{\mu\nu} \,,$$

String axion abundance

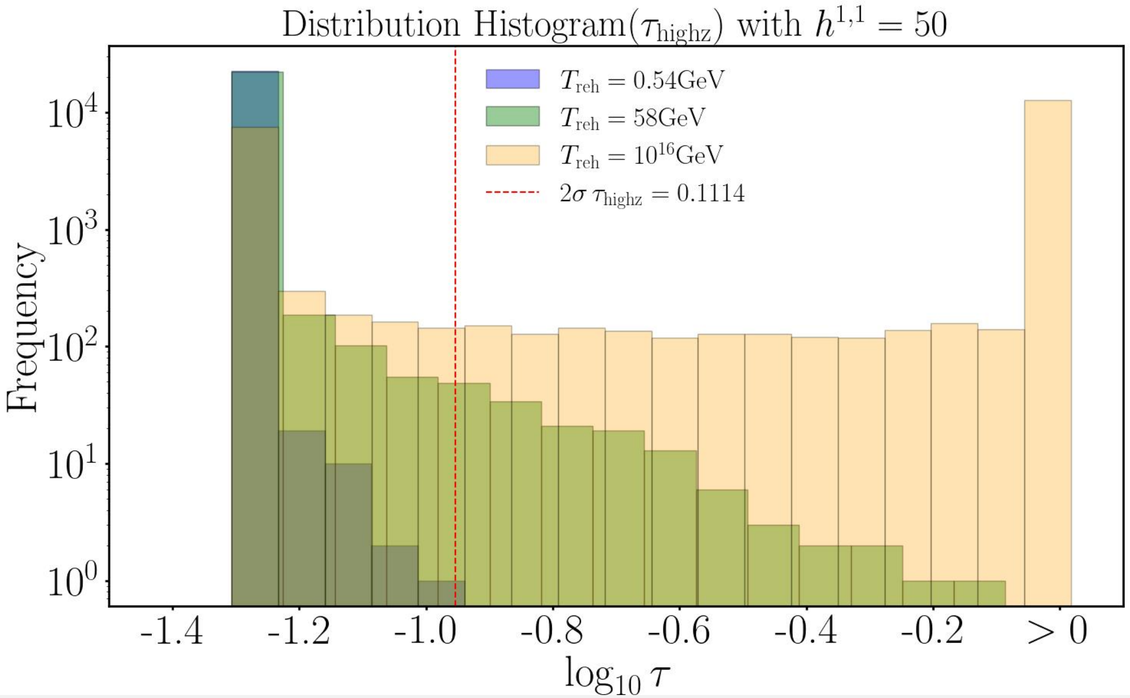
Masses&couplings for multi-axions are predicted within string theory see Gendler+2309.13145

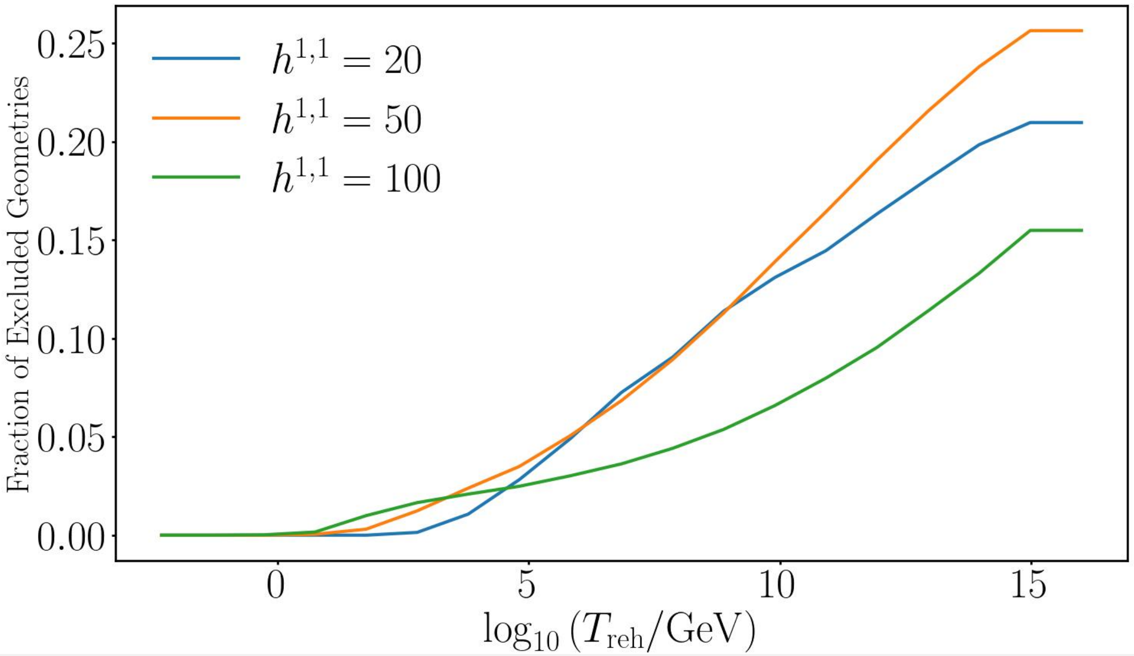
We obtain abundance and lifetime for each axion in a given theory



We want to constrain ensembles from string theory

Main results





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For $h_{1,1}$ = 20, 50, 100, we find that approximately 15%, 15%, and 10% of the models in the ensemble prefer $T_{reh} < 10^{10}$ GeV at 95% CL.

PART 03

Conclusion

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Conclusion

- We have got a new model-independent constraint on CMB optical depth τ_{highz} by using GPR driven CMB data analysis which can nearly consistent with full power MCMC CMB analysis thus we can do a feasible and faithfully test to axiverse with many axions decay.
- For $h_{1,1}$ = 20, 50, 100, we find that approximately 15%, 15%, and 10% of the models in the ensemble prefer $T_{reh} < 10^{10}$ GeV at 95% CL.

谢 谢！

Thanks