This one weird trick could solve the σ_8 tension!

(You will never guess what!)

Markus R. Mosbech

February 19, 2021

University of Sydney

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Introduction

Our paper

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CPPC-2020-17

Prepared for submission to JCAP

The full Boltzmann hierarchy for dark matter-massive neutrino interactions

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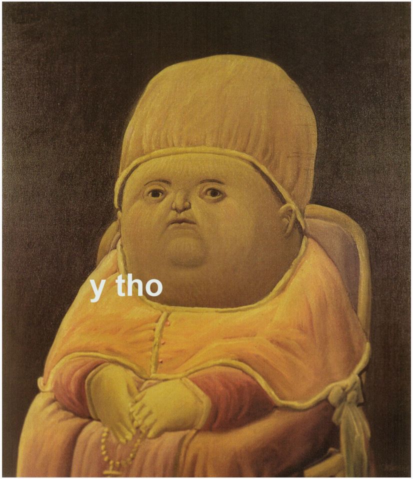
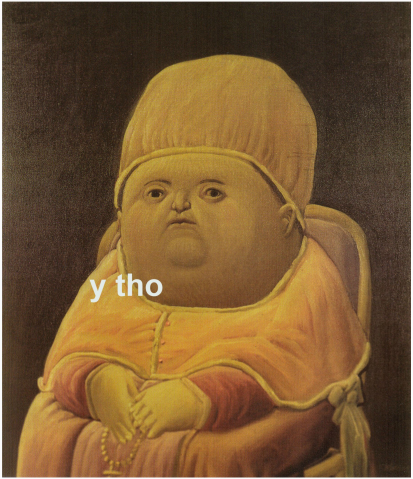
Why this?



Why this?

- Why not?



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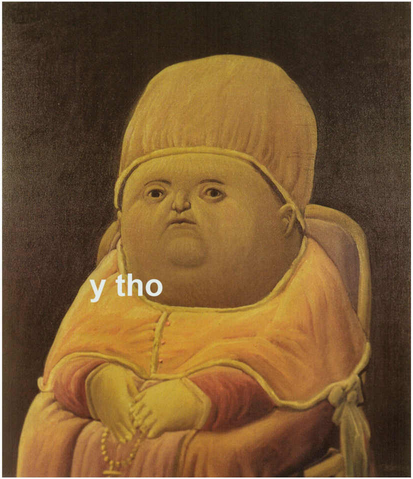
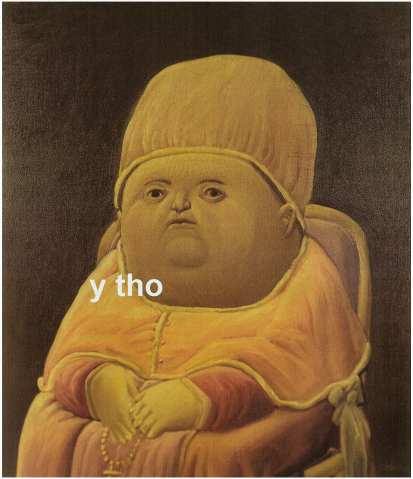
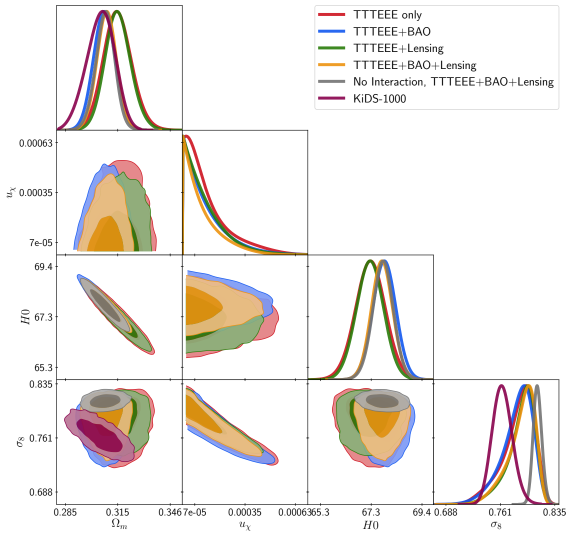


Why this?

- Why not?
- Cosmo parameters - H_0, σ_8
- Neutrinos and DM



Outcome



TTTEEE only
TTTEEE+BAO
TTTEEE+Lensing
TTTEEE+BAO+Lensing
No Interaction, TTTEEE+BAO+Lensing
KiDS-1000
0.00063
0.00035
7e-05
u_χ
69.4
67.3
65.3
$H0$
0.835
0.761
0.688
σ_8
0.285
0.315
0.346
Ω_m
7e-05
0.00035
0.00063
u_χ
65.3
67.3
69.4
$H0$
0.688
0.761
0.835
σ_8

The Boltzmann Equation

General Boltzmann Equation

$$P^{\alpha}\frac{\partial f}{\partial x^{\alpha}} - \Gamma^{\gamma}_{\alpha\beta}P^{\alpha}P^{\beta}\frac{\partial f}{\partial P^{\gamma}} = m\left(\frac{\partial f}{\partial \tau}\right)_{C}$$

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$$f(\mathbf{x}, \mathbf{p}, \tau) = f_0(p) \left[1 + \Psi(\mathbf{x}, \mathbf{p}, \tau) \right]$$

$$\frac{\partial \Psi}{\partial \tau} + i \frac{p}{E} \left(\mathbf{k} \cdot \hat{\mathbf{n}} \right) \Psi + \frac{d \ln f^{(0)}(p)}{d \ln p} \left[\dot{\phi} - i \frac{E}{p} \left(\hat{\mathbf{k}} \cdot \hat{\mathbf{n}} \right) \psi \right] = \frac{1}{f_0} \left(\frac{\partial f}{\partial \tau} \right)_C$$

Cold dark matter

$$\dot{\delta}_{\mathrm{cdm}} = -\theta_{\mathrm{cdm}} + 3\dot{\phi}$$

$$\dot{\theta}_{\mathrm{cdm}} = -\frac{\dot{a}}{a}\theta_{\mathrm{cdm}} + k^2\psi$$

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$$K_\chi \equiv \frac{\rho_\nu + P_\nu}{\rho_\chi} = \frac{(1 + w_\nu)\rho_\nu}{\rho_\chi}$$

Cold dark matter

$$\dot{\delta}_{\rm cdm} = -\theta_{\rm cdm} + 3\dot{\phi}$$

$$\dot{\theta}_{\rm cdm} = -\frac{\dot{a}}{a}\theta_{\rm cdm} + k^2\psi + K_\chi \dot{\mu}_\chi \left(\theta_\nu - \theta_\chi\right)$$

$$K_\chi \equiv \frac{\rho_\nu + P_\nu}{\rho_\chi} = \frac{(1+w_\nu)\rho_\nu}{\rho_\chi}$$

$$\dot{\mu}_\chi \left(\theta_\nu - \theta_\chi\right) = \frac{3}{4} k \, \frac{\int p^2 dp \, p f^{(0)}(p) \, C_\chi(p) \left(\frac{\theta_\chi E_\nu(p)}{3k f^{(0)}(p)} \frac{df^{(0)}(p)}{dp} + \Psi_1 \right)}{\int p^2 dp \, p f^{(0)}(p)}$$

Neutrinos

$$\frac{\partial \Psi_0}{\partial \tau} = -\frac{pk}{E_\nu(p)}\Psi_1 - \dot{\phi}\frac{d\ln f^{(0)}(p)}{d\ln p}$$

$$\frac{\partial \Psi_1}{\partial \tau} = \frac{1}{3}\frac{pk}{E_\nu(p)}\left(\Psi_0 - 2\Psi_2\right) - \frac{E_\nu(p)\,k}{3p}\psi\frac{d\ln f^{(0)}(p)}{d\ln p}$$

$$\frac{\partial \Psi_l}{\partial \tau} = \frac{1}{2l+1}\frac{pk}{E_\nu(p)}\left(l\Psi_{l-1} - (l+1)\Psi_{l+1}\right), \quad l \geq 2$$

Neutrinos

$$\frac{\partial \Psi_1}{\partial \tau} = [...] - C_\chi \frac{v_\chi E_\nu(p)}{3f^{(0)}(p)} \frac{df^{(0)}(p)}{dp} - C_\chi \Psi_1 \,,$$
$$\frac{\partial \Psi_2}{\partial \tau} = [...] - \frac{9}{10} C_\chi \Psi_2 \,,$$
$$\frac{\partial \Psi_l}{\partial \tau} = [...] - C_\chi \Psi_l, \quad l \geq 3 \,,$$

Neutrinos

$$\frac{\partial \Psi_1}{\partial \tau} = [\ldots] - C_\chi \frac{v_\chi E_\nu(p)}{3f^{(0)}(p)} \frac{df^{(0)}(p)}{dp} - C_\chi \Psi_1 \ ,$$

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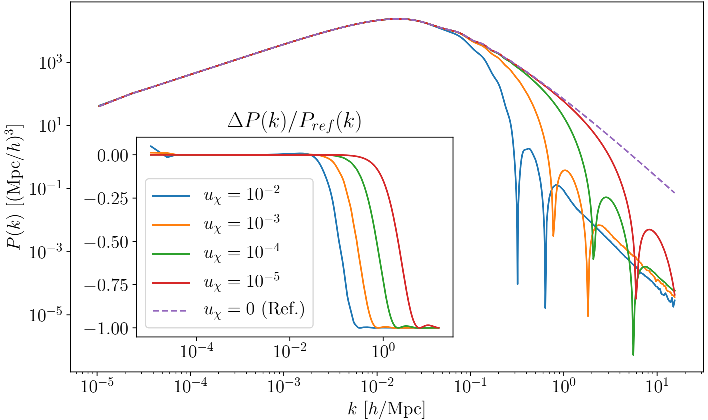
$$\frac{\partial \Psi_l}{\partial \tau} = [\ldots] - C_\chi \Psi_l, \quad l \geq 3 \ ,$$

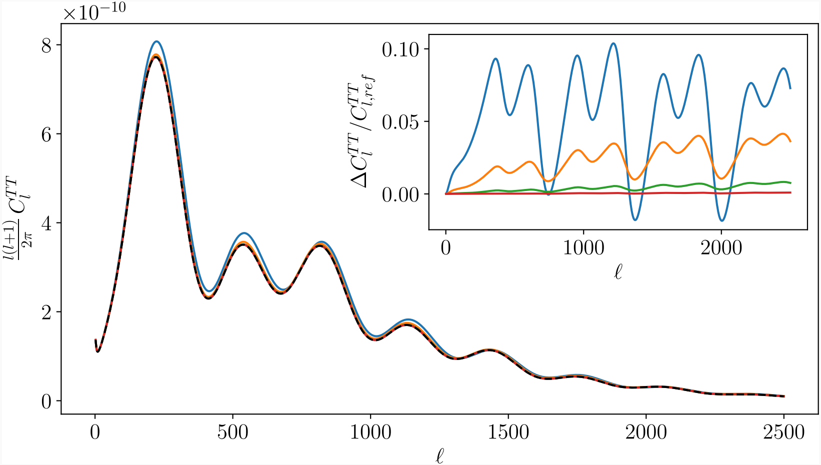
$$C_\chi = a\, u_{\nu\chi}\, \frac{\sigma_{\rm Th} \rho_\chi}{100\,{\rm GeV}} \frac{p^2}{E_\nu^2}, \qquad u_{\nu\chi} = \frac{\sigma_0}{\sigma_{\rm Th}} \left(\frac{m_\chi}{100\,{\rm GeV}} \right)^{-1}$$

Results

Matter power spectrum



CMB power spectrum



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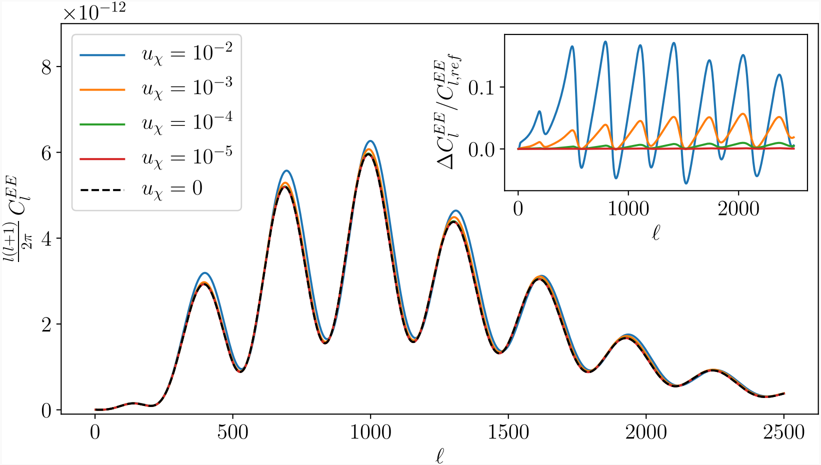

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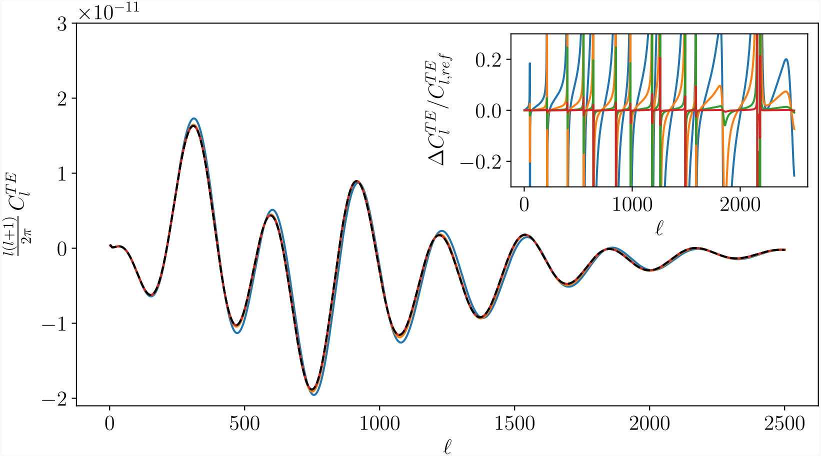
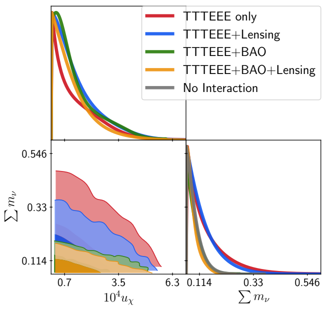
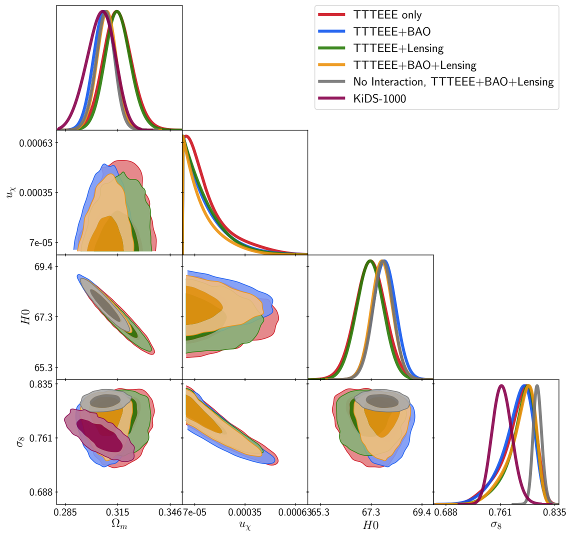


Posteriors


TTTEEE only
TTTEEE+Lensing
TTTEEE+BAO
TTTEEE+BAO+Lensing
No Interaction
0.546
0.33
0.114
$\sum m_\nu$
0.7
3.5
6.3
$10^4 u_\chi$
0.114
0.33
0.546
$\sum m_\nu$

Posteriors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65.3
67.3
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0.761
0.835
σ_8

Boring numbers

	Planck + Lensing + BAO
$100\,\omega_b$	$2.24^{+0.03}_{-0.03}$
ω_{DM}	$0.119^{+0.002}_{-0.002}$
$100\,\theta_s$	$1.0419^{+0.0010}_{-0.0004}$
$\ln 10^{10} A_s$	$3.05^{+0.03}_{-0.03}$
n_s	$0.967^{+0.007}_{-0.010}$
τ_{reio}	$0.057^{+0.017}_{-0.014}$
u_χ	$3.34 \cdot 10^{-4}$
$\sum m_\nu$ [eV]	0.14
H_0 [km/s/Mpc]	$67.6^{+1.0}_{-1.0}$
σ_8	$0.81^{+0.01}_{-0.06}$

fin