Rocky and the Rate Ratios

An Adventure

Ge, Cyr-Racine, and Knox
Phys. Rev. D (2023)

Cyr-Racine, Ge, and
Knox Phys. Rev. Lett.
(2022)

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Lloyd Knox **18 March 2023**

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There is sensitivity to Γ/H when $\Gamma \cancel{\gg} H$

BBN Example

Dependence of Helium production on H(z)

p

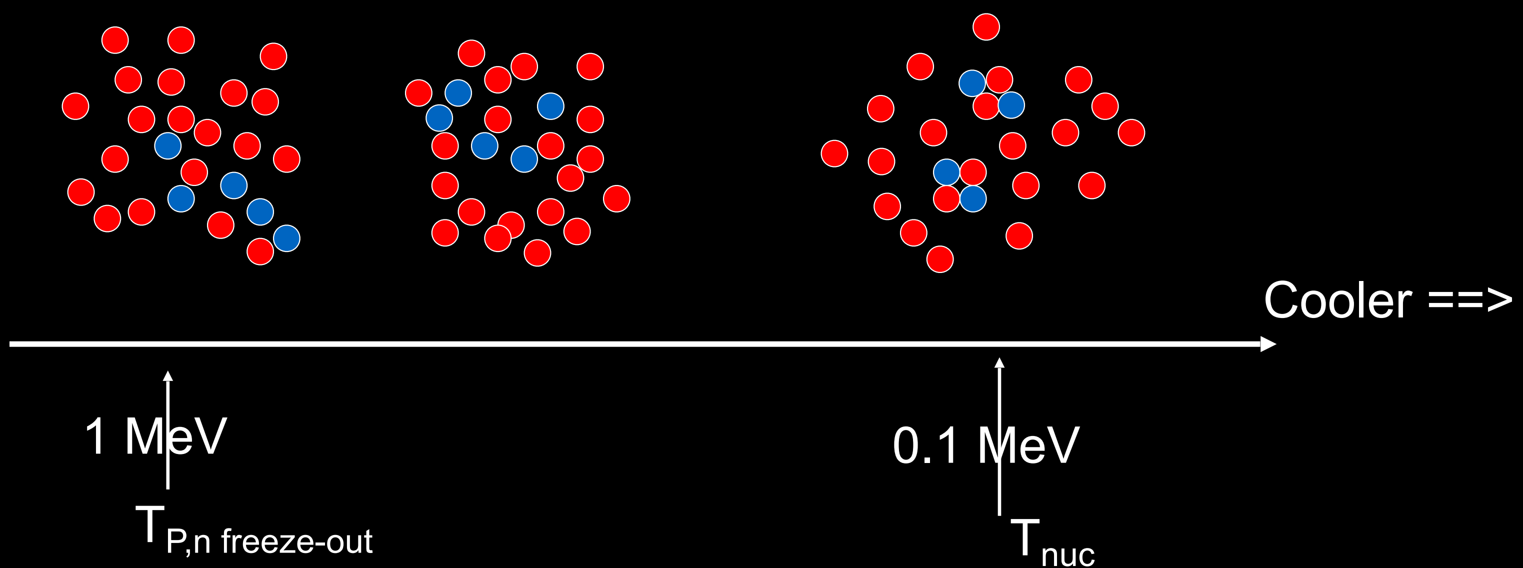
n

Γ here is per-neutron rate of

$p + e \longleftrightarrow n + \nu_e$

If $\Gamma > H$ then

$n_n = n_p \exp(-\Delta mc^2/kT)$



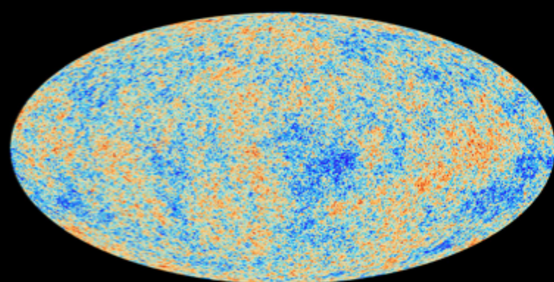
higher H (at given T) ==> $\Gamma = H$ at higher T ==> more neutrons around ==> more Helium

(also less time for neutron decay)

Y_{P} depends on Γ/H

$$\left.\begin{array}{c}\text{Measure } Y_{\mathrm{P}} \\ \text{Know } \Gamma\end{array}\right\} \quad \text{Infer } H$$

What are the important rates that allow for



+

Γ

Infer H (including H_0) ?

All the rates in the relevant Einstein and Boltzmann equations:

$$\sqrt{G\rho_i}$$

$(\text{for each } i = \gamma, \nu, \text{CDM}, \text{baryons}, \Lambda)$

Free Fall

$$\sigma_{\mathrm{T}} n_e$$

Thomson Scattering

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$$\text{Note that this includes } H = \sqrt{\frac{8\pi}{3}\sum_i G\rho_i}$$

FFAT Scaling

$$\Delta T/T(\theta,\phi), Q_{\rm CMB}(\theta,\phi), U_{\rm CMB}(\theta,\phi), \frac{\delta\rho_{\rm m}}{\rho_{\rm m}}(\theta,\phi,z)$$

are all invariant under

$$\sqrt{G\rho_i} \to \lambda\sqrt{G\rho_i}$$

$$\sigma_{\rm T} n_e \to \lambda\sigma_{\rm T} n_e$$

$$A_{\rm S} \to \lambda^{1-n_{\rm S}} A_{\rm S}$$

CGK [Cyr-Racine, Ge, and LK (2022)]

See also Zahn & Zaldarriaga (2003) who got partway there

What good is this?

Two possibilities:

1. **Use it to solve the H_0 problem.** Find a cosmological model that allows for this scaling transformation and use it to reconcile CMB and BAO with higher estimates of the expansion rate today.

2. Use it as a tool for understanding why constraints from observations work out the way they do.

Barriers to implementing FFAT Scaling

$$\sqrt{G\rho_i} \to \lambda\sqrt{G\rho_i} \qquad \sigma_{\mathrm{T}} n_e \to \lambda \sigma_{\mathrm{T}} n_e \qquad A_{\mathrm{S}} \to \lambda^{1-n_{\mathrm{S}}} A_{\mathrm{S}}$$

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We've measured G and
FIRAS has determined $\rho_{\gamma,0}$

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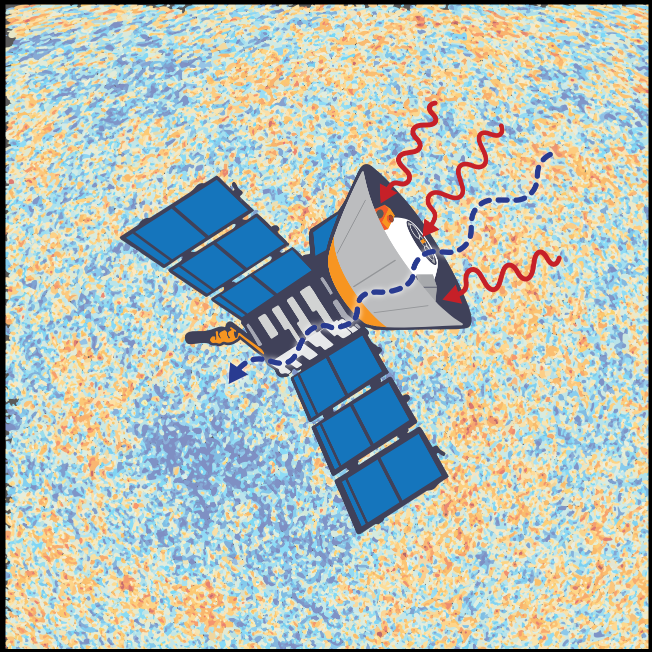

Solution: Introduce a dark photon that allows for

$$\sqrt{G(\rho_\gamma + \rho_{D\gamma})} = \lambda\sqrt{G\rho_\gamma}$$

w/o violating FIRAS constraints

- To satisfy FIRAS we need **dark photons**
- They have to source metric perturbations like light photons do ==> transition from fluid to free streaming ==> we need **dark baryons** to enable dark recombination
- To preserve all the important rate ratios we also need a free-streaming additional light relic that we might call ‘**dark neutrinos.**’

Cosmological whackamole on steroids?

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Maybe not: we get all this from one copy of the standard model of particle physics.
a `mirror world’ dark sector (MWDS)

e.g. Chacko et al. (2006)

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$$n_e(z) = X_e(z) n_B (1 - Y_{\rm P})$$

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Achieve scaling by $1 - Y_{\rm P} \to \lambda(1 - Y_{\rm P})$ and fixing $X_e(z)$

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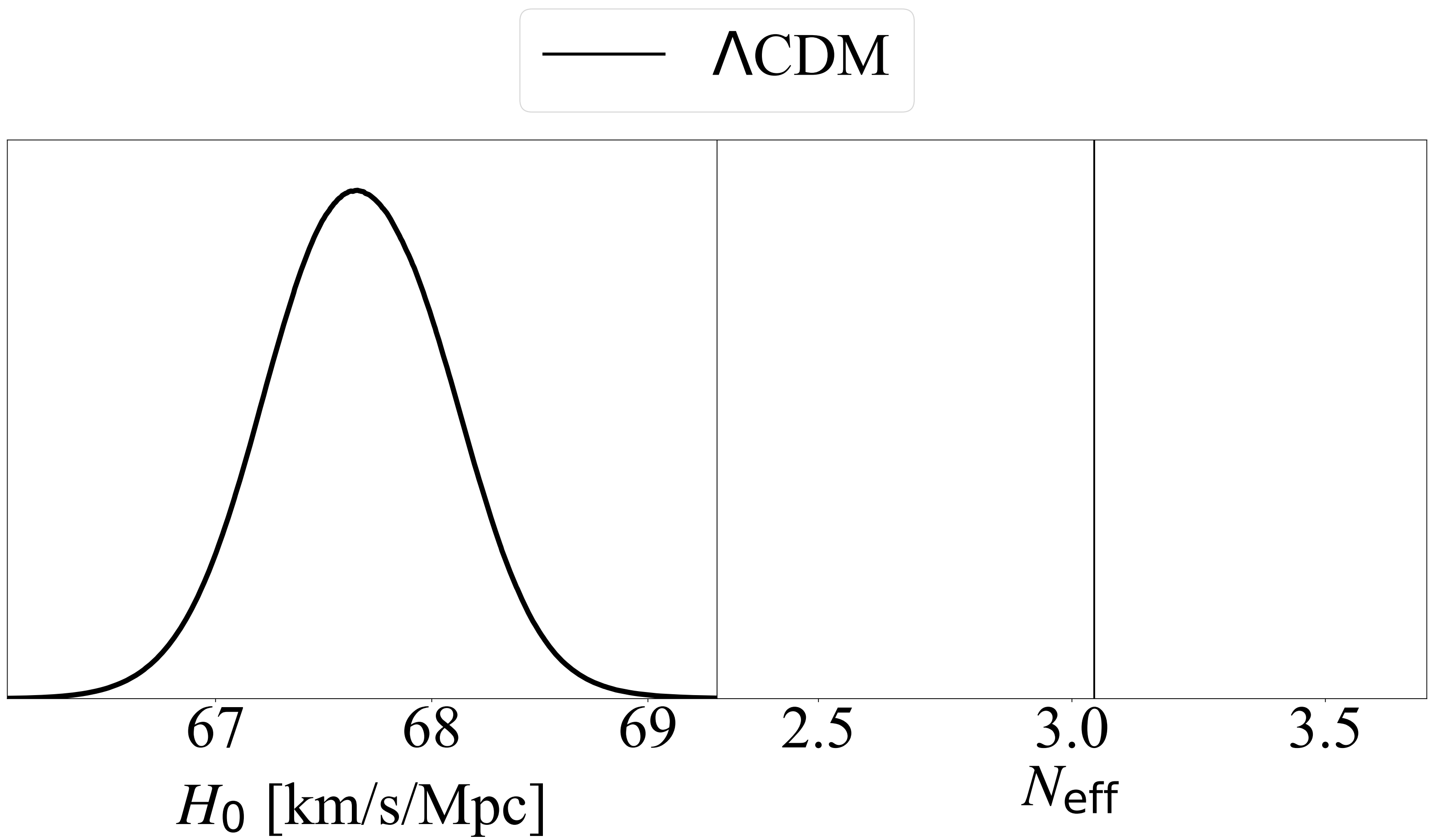
1D marginal posterior probability densities given Planck + BAO



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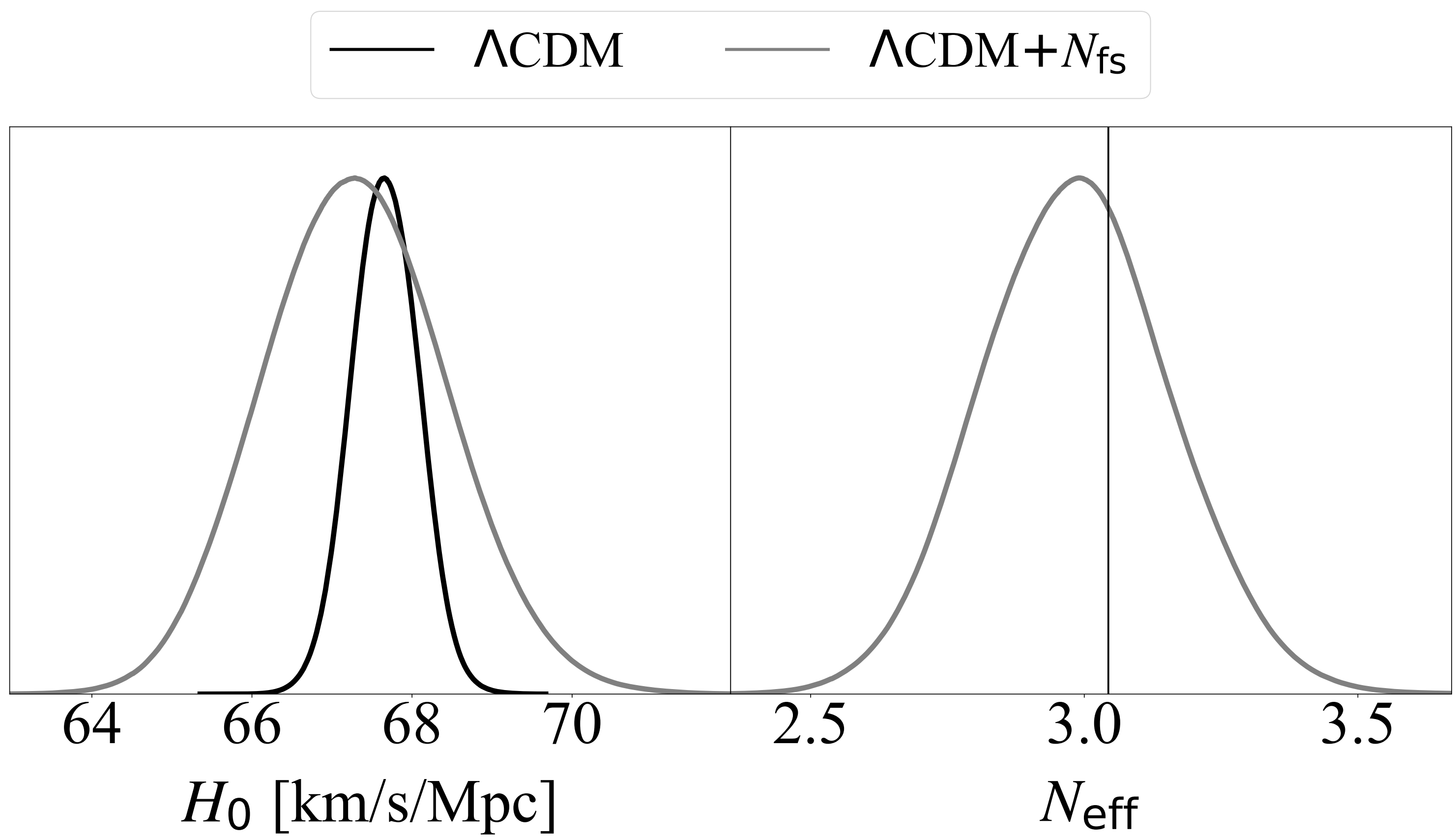

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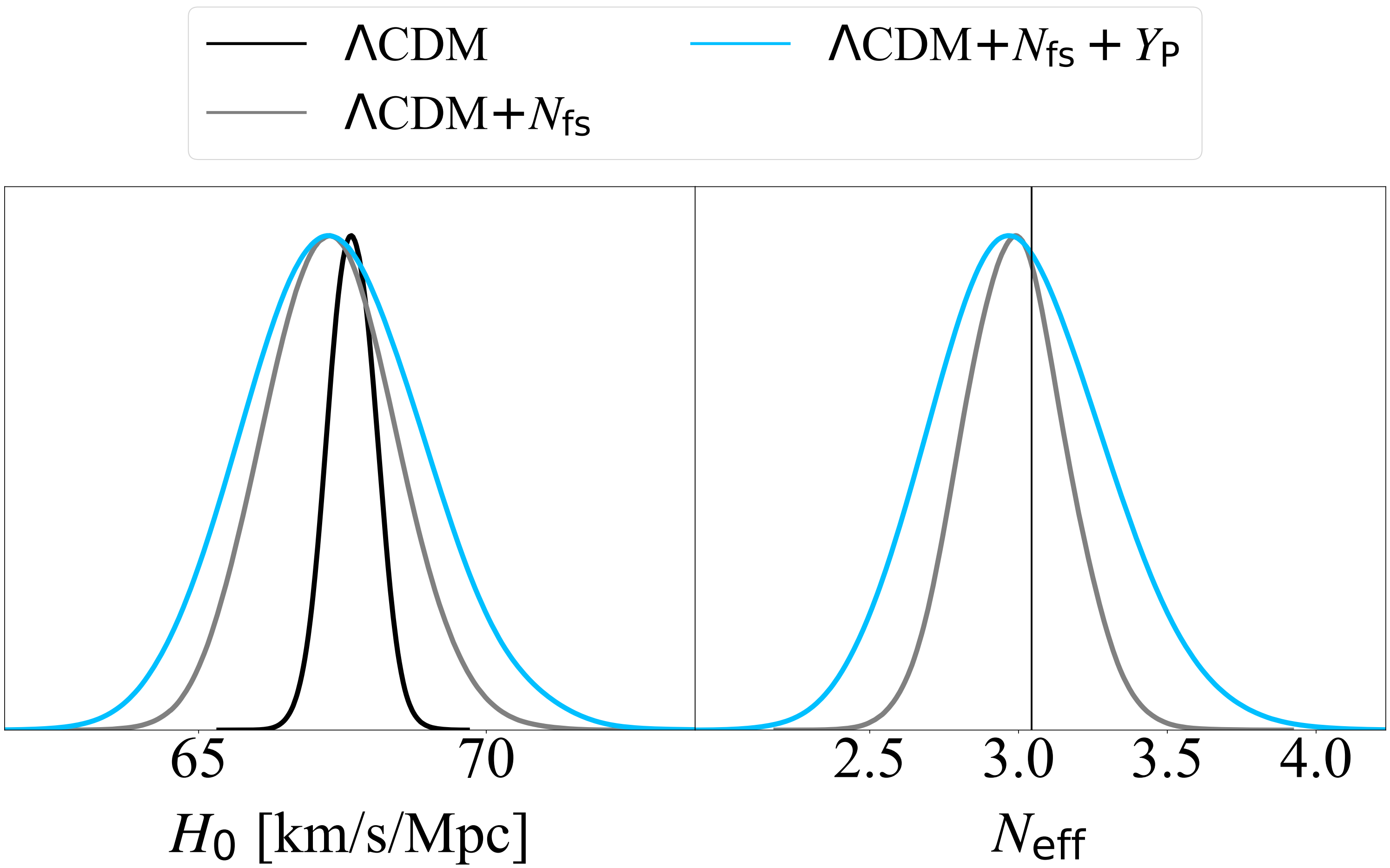

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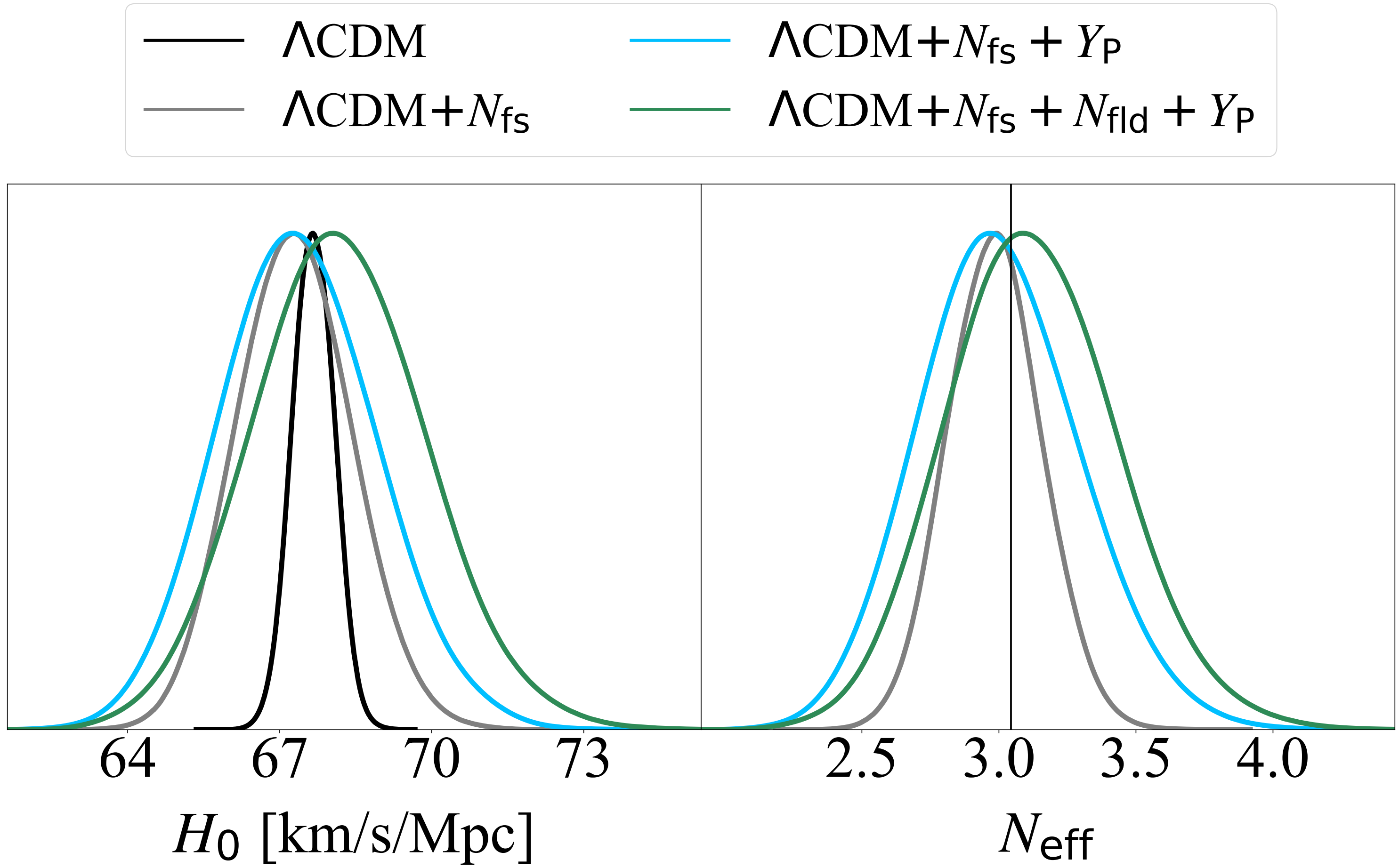

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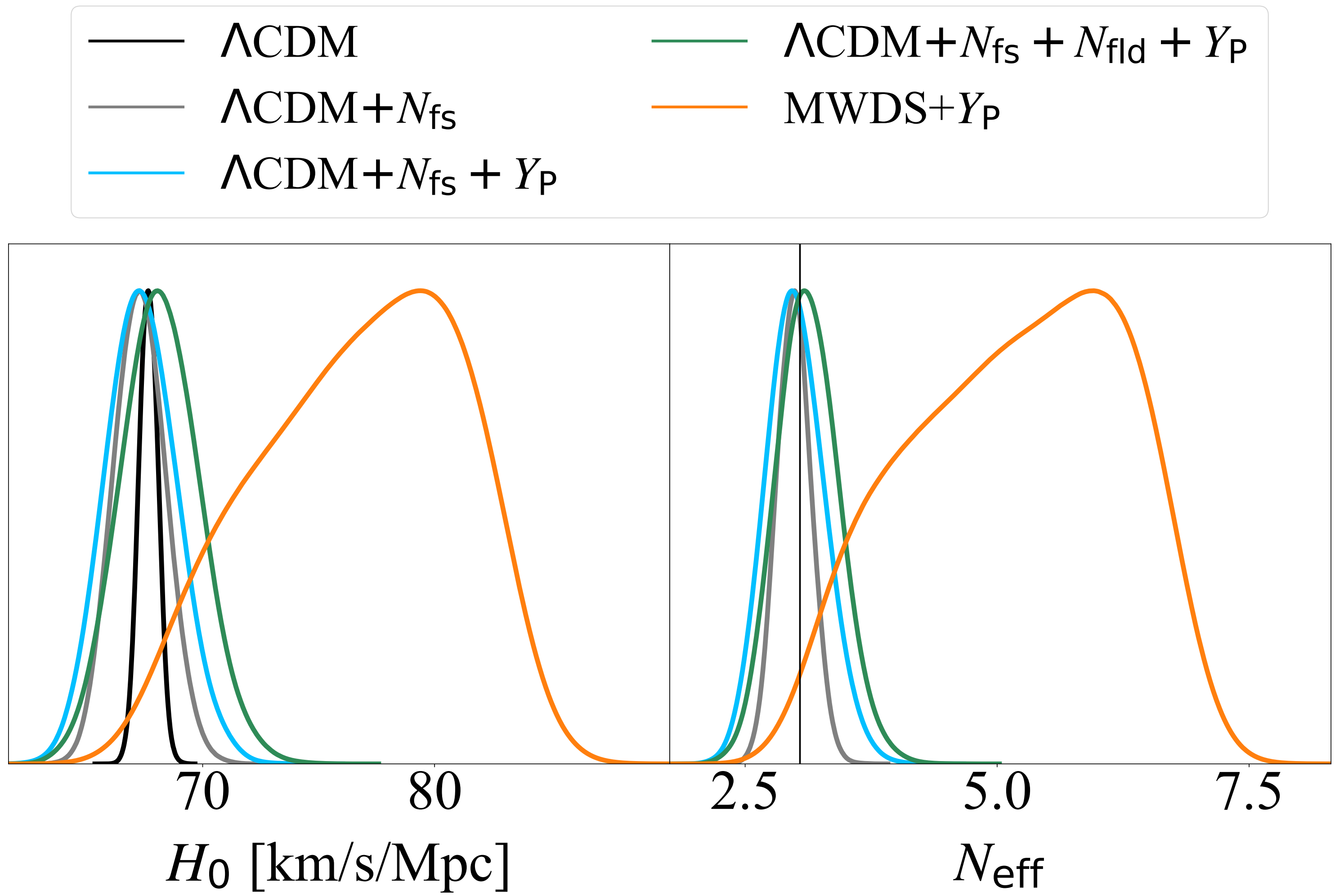

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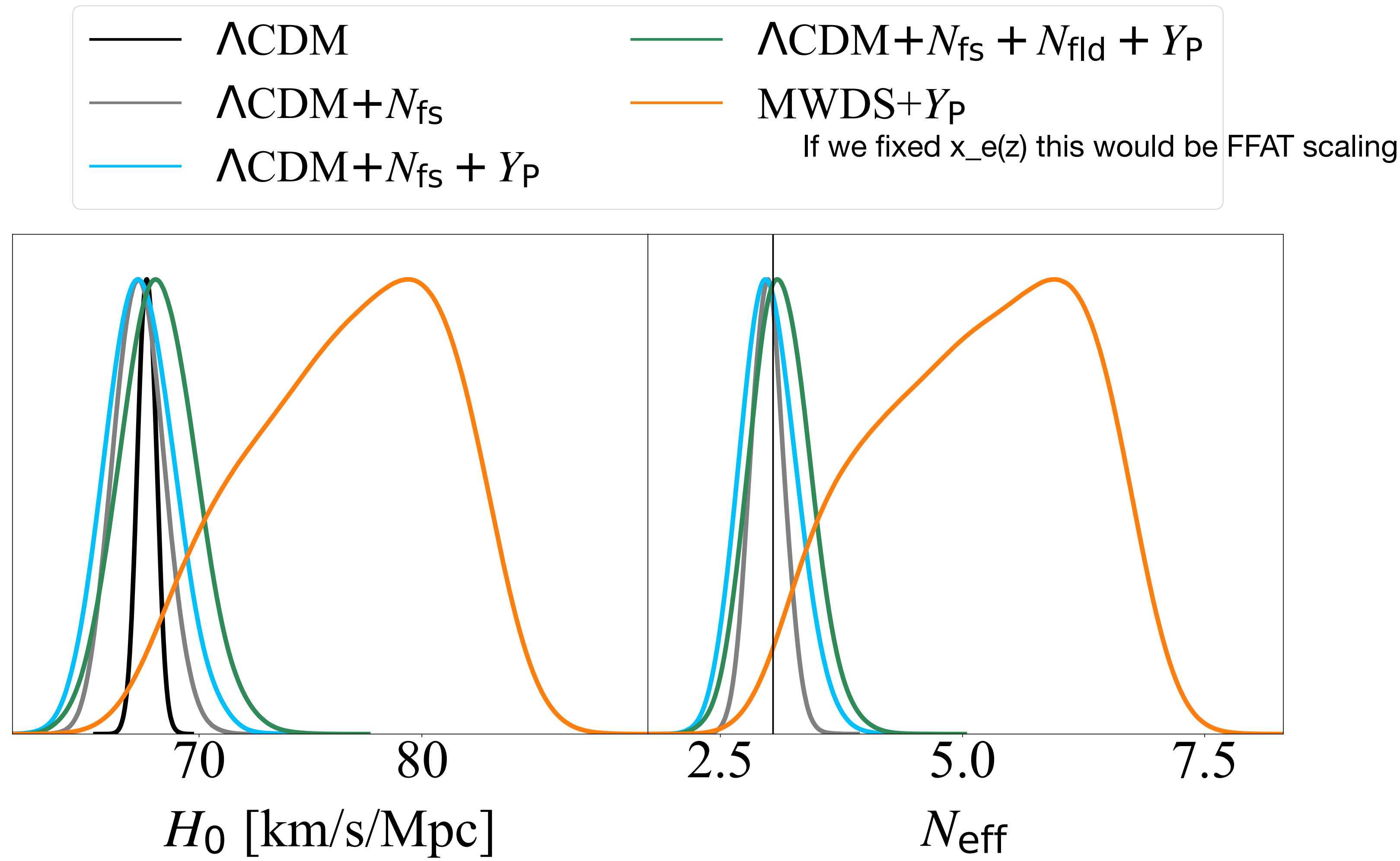
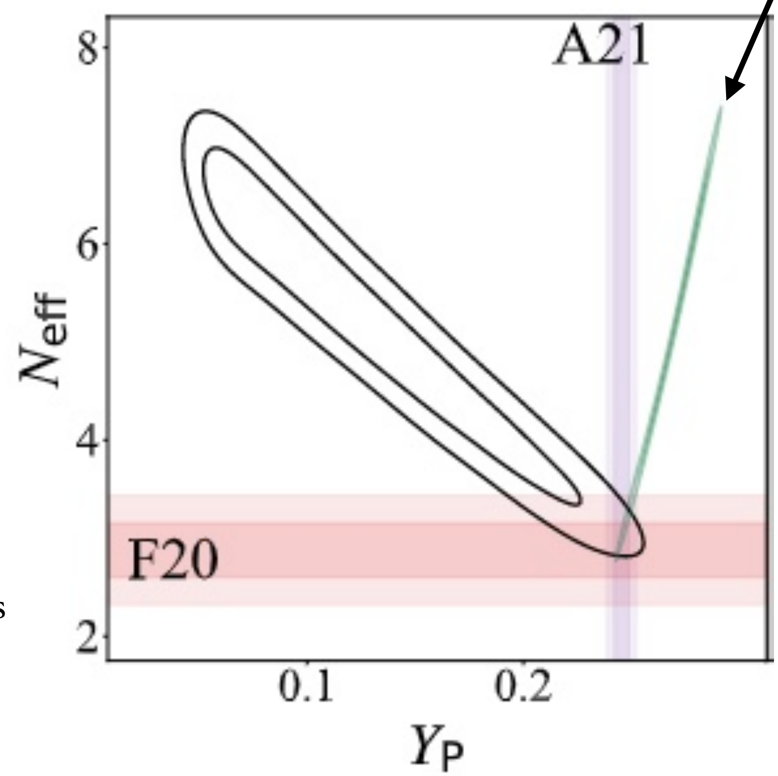


Contours assume
MWDS + free Yp

F20 = constraints on
Neff from BBN + D/H
and Yp measurements
(Fields et al. 2020)

A21 = measurement of
Yp (Aver et al. 2021)

BBN Consistent Yp



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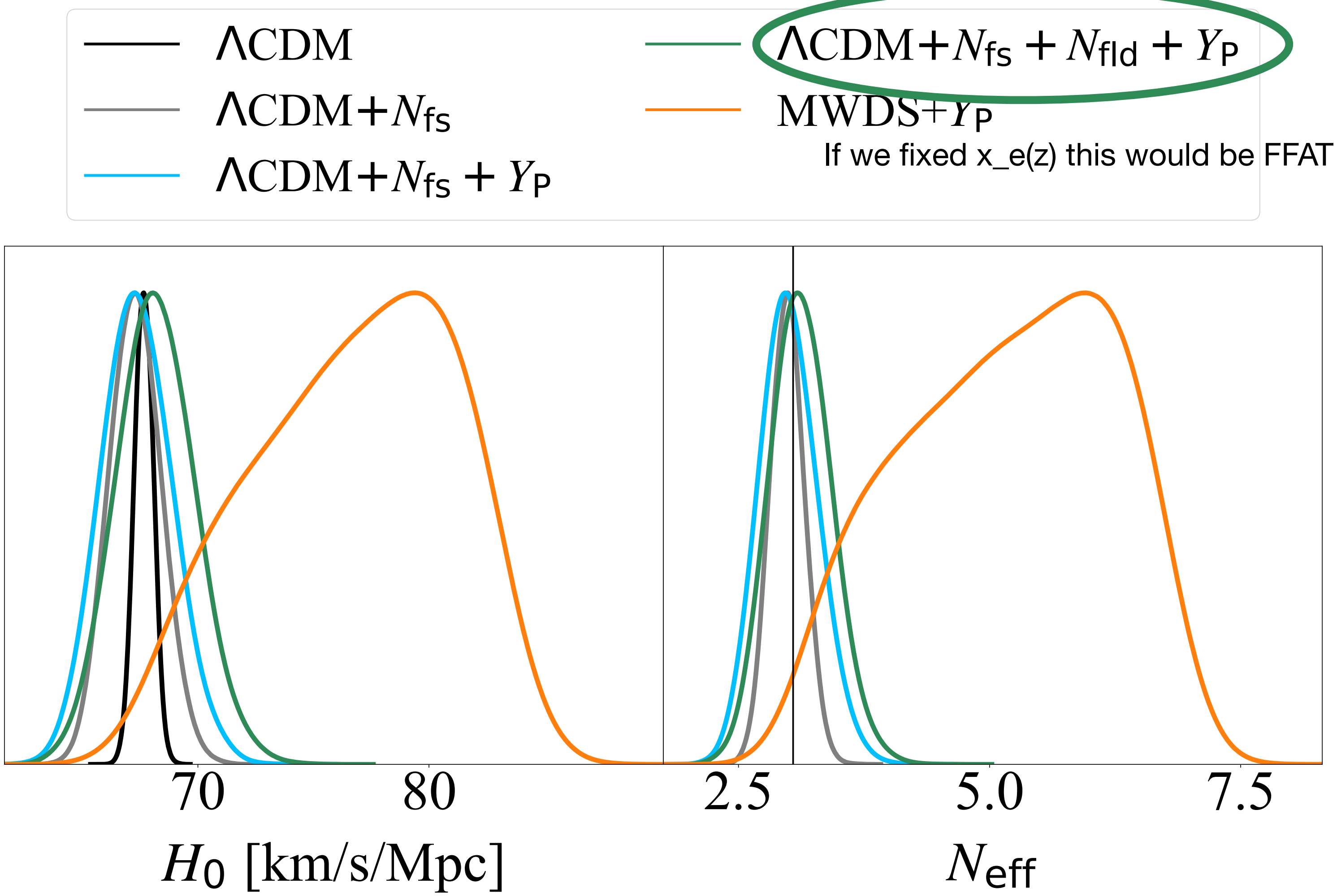
1D marginal posterior probability densities given Planck + BAO

"Mix + Yp"



If we fixed x_e(z) this would be FFAT scaling

MWDS + Yp

Atomic dark matter ————-> fraction of cdm
Dark photons ———————> Dark fluid

Mix + Yp

MWDS + Yp

Atomic dark matter ———-> fraction of cdm
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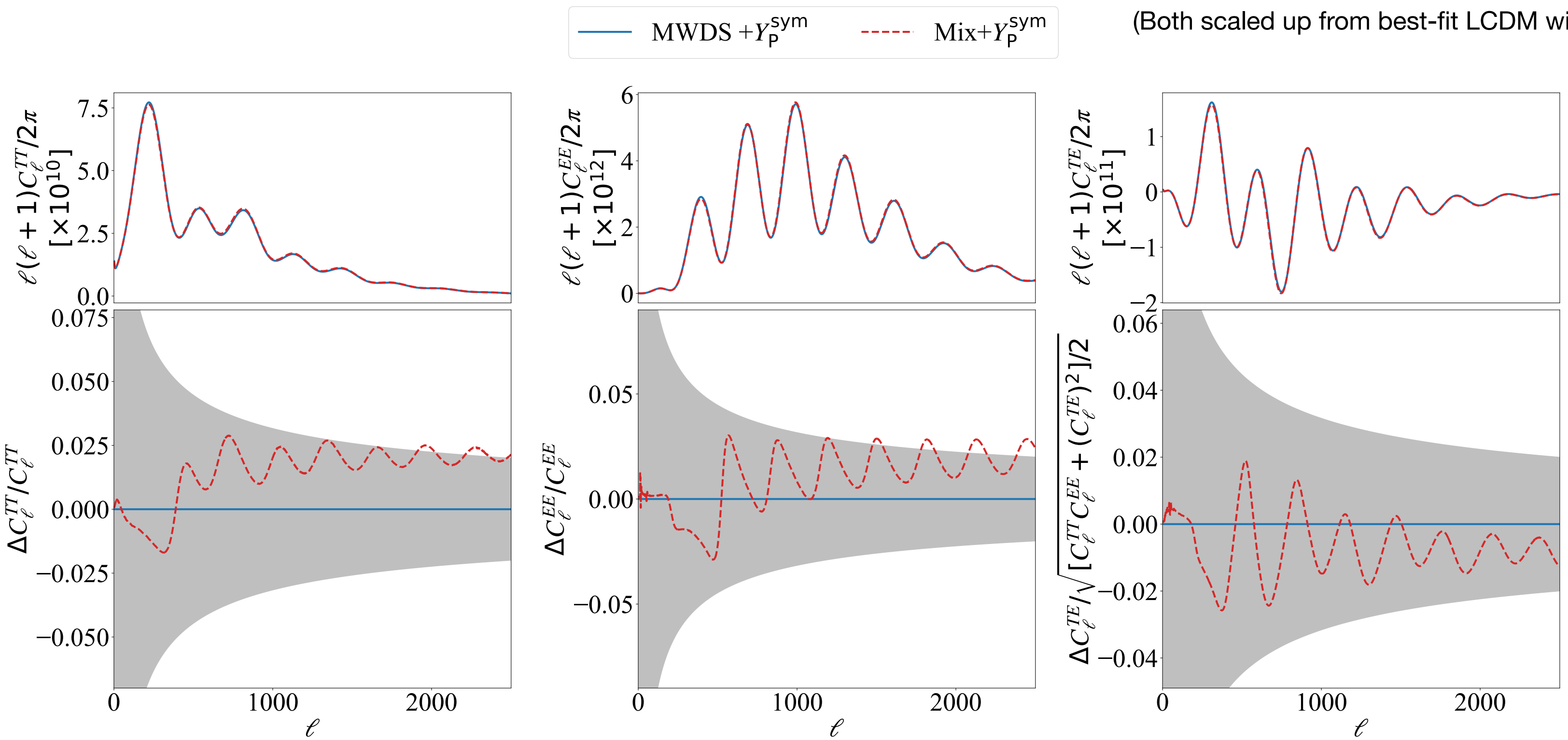
Mix + Yp

Scaling up changes the ratio of
Pressure-supported non-relativistic matter
To pressureless non-relativistic matter

(Both scaled up from best-fit LCDM with lambda = 1.1)



MWDS + Yp

Atomic dark matter ———-> fraction of cdm
Dark photons ————-> Dark fluid

Mix + Yp

Adapted from Ge, Cyr-Racine & Knox (2022)

Categorization of Causes of Light Relics Constraints

Rate ratio change	Prior literature	Quantitative Impact on CMB Power Spectra ($\lambda = 1.1$)
1. $\sigma_{\mathrm{T}} n_{\mathrm{e}}(z)/H(z)$	Hu & White (1996), Zahn & Zaldarriaga (2004), Martins et al. (2010), Hou et al. (2013)	10 to 15%
2. $\frac{\sqrt{\rho_{\mathrm{rad,fs}}}}{\sqrt{\rho_{\mathrm{rad,fluid}}}}$	Bashinksy & Seljak (2004), Follin et al. (2015), Baumann et al. (2016)	5 to 6%
3. $\frac{\sqrt{\rho_{\mathrm{m,pressure}}}}{\sqrt{\rho_{\mathrm{m,pressureless}}}}$	None	2 to 3%
4. recombination rates$/H(z)$	Zahn & Zaldarriaga (2003) and now much better understood	1 to 2%

GCK: Ge, Cyr-Racine, and Knox Phys. Rev. D (2023)
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Bottom Line for this Adventure

- The scaling transformation symmetry is a useful aid to analytic understanding. (We solved the puzzle that started this adventure).
- The model it led us to is quite baroque, conflicts with light element abundance data, probably requires changes away from standard BBN, and leaves the similarity of T and FF scaling unexplained. Zhang and Frieman (2022)
- Future developments could conceivably change this (adventures continue!), but right now I feel it is unlikely that nature is doing something like this.
- The CGK model is an existence proof though that one can make large changes to the underlying model and leave CMB (and other) observables invariant.