Interacting dark sectors from neutrino mixing, H0 tension and LSS

Martin Schmaltz BU

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Daniel Aloni
Harvard postdoc

Melissa Joseph
Utah postdoc

Cara Giovanetti
NYU - PhD student

Eashwar Sivarajan
BU - PhD student

Hengameh Bagherian
Harvard - PhD student

Asher Berlin
Fermilab

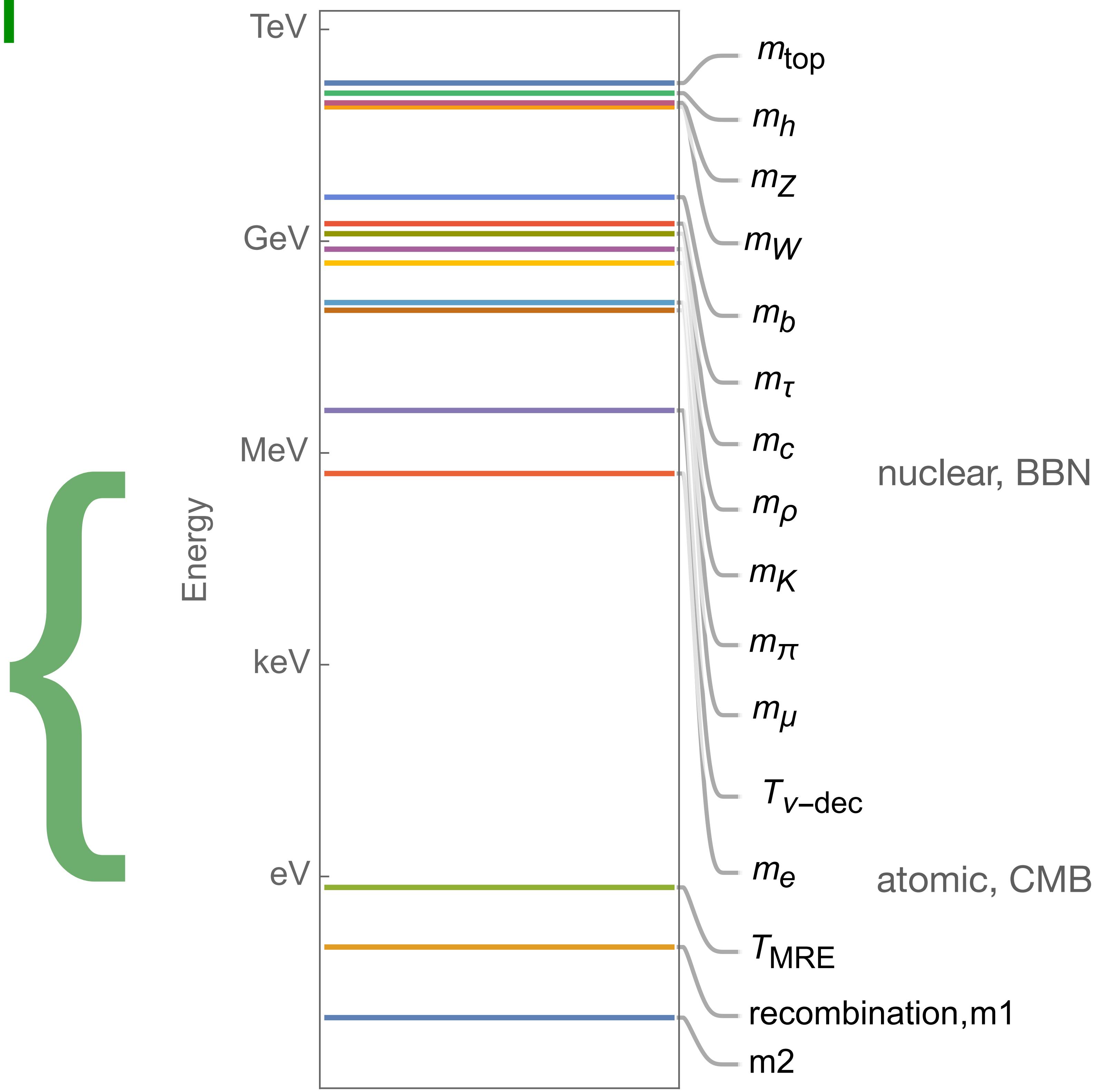
Neal Weiner
NYU

Outline

- the ΛCDM “desert”
- populating a dark sector from the neutrinos after BBN
- applications, summary, outlook

The ΛCDM desert

empty?



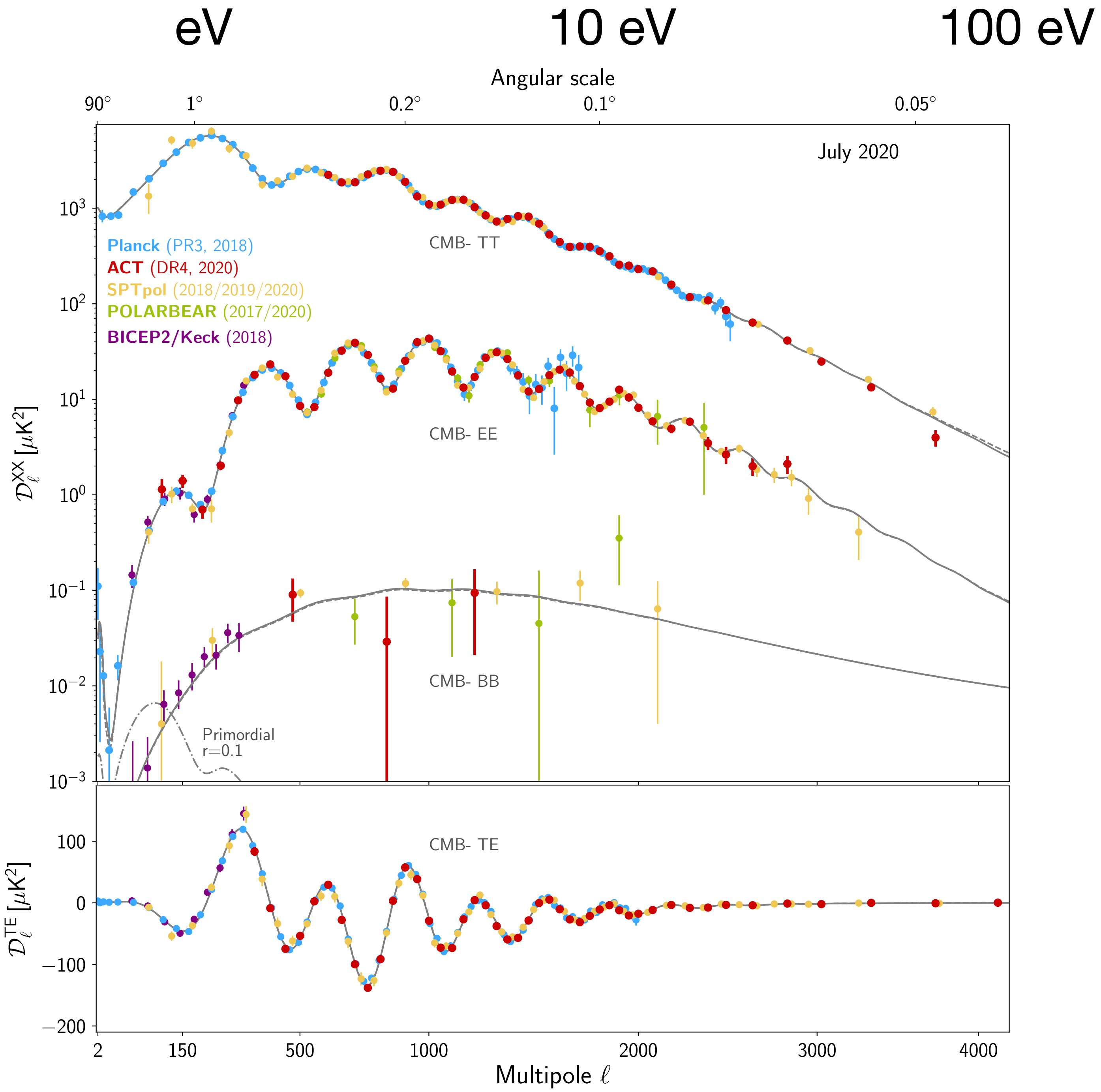
What is in the eV-MeV desert?

What is in the eV-MeV desert?

data!

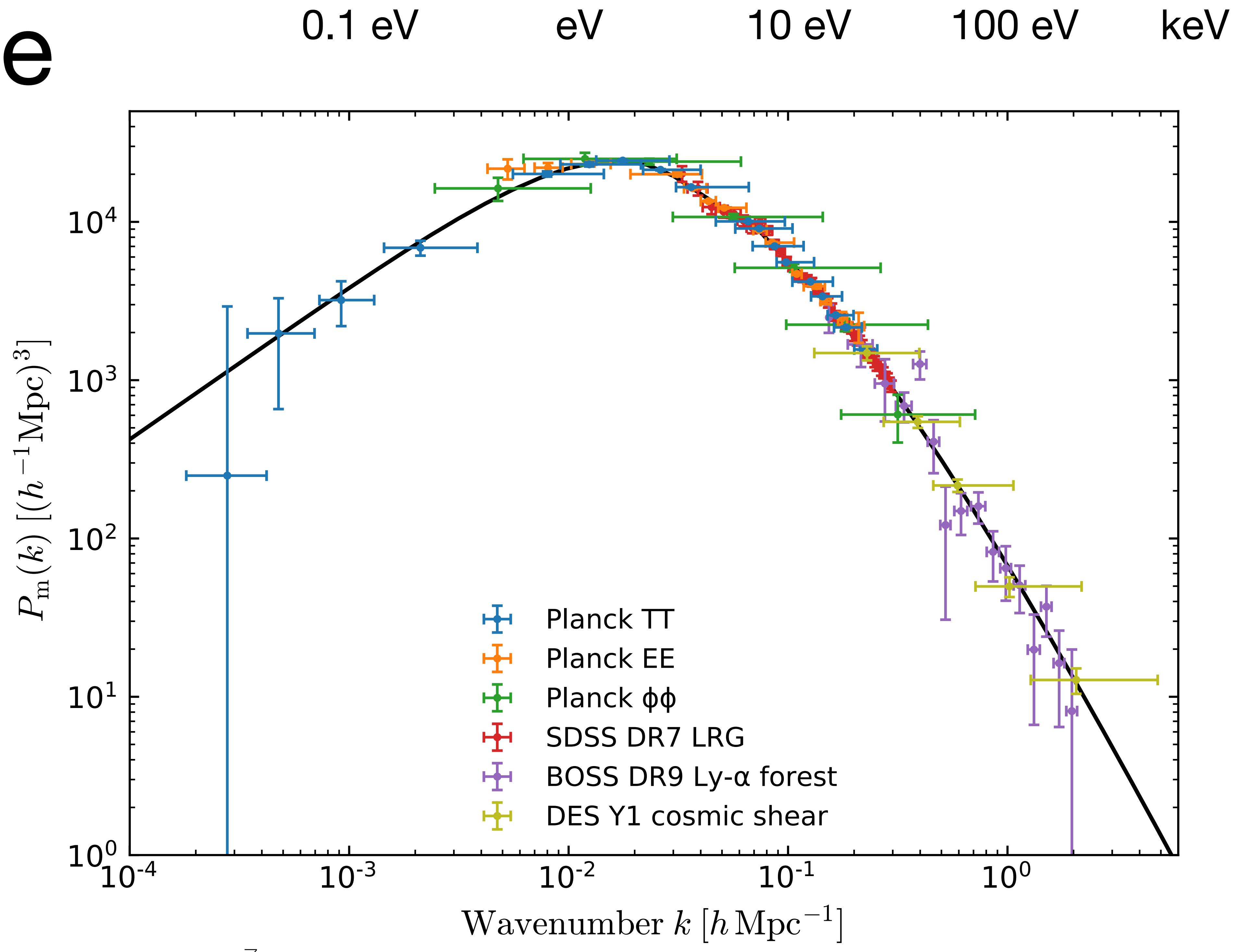
data in the eV-MeV desert

CMB



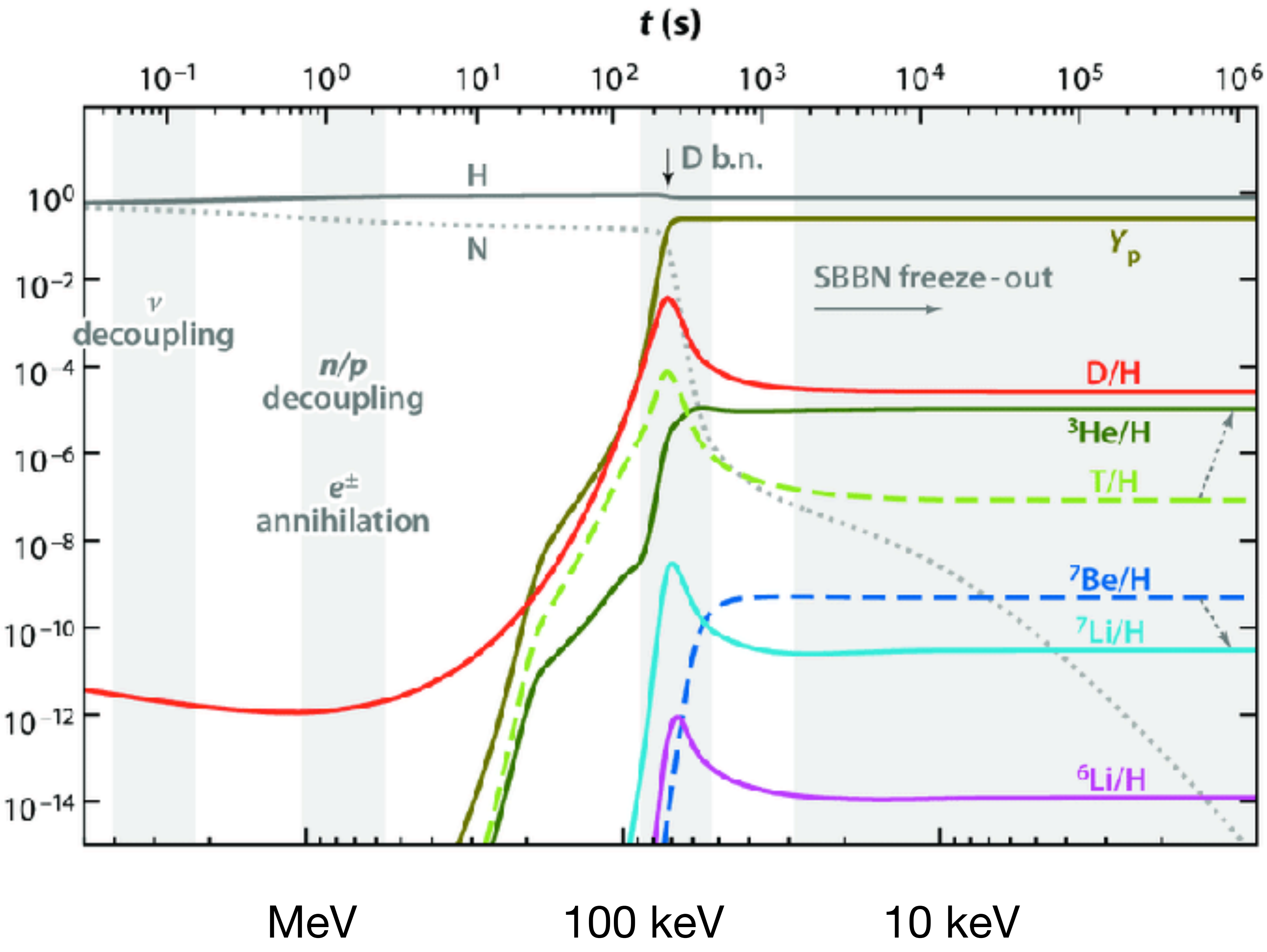
data in the eV-MeV desert

Large Scale Structure



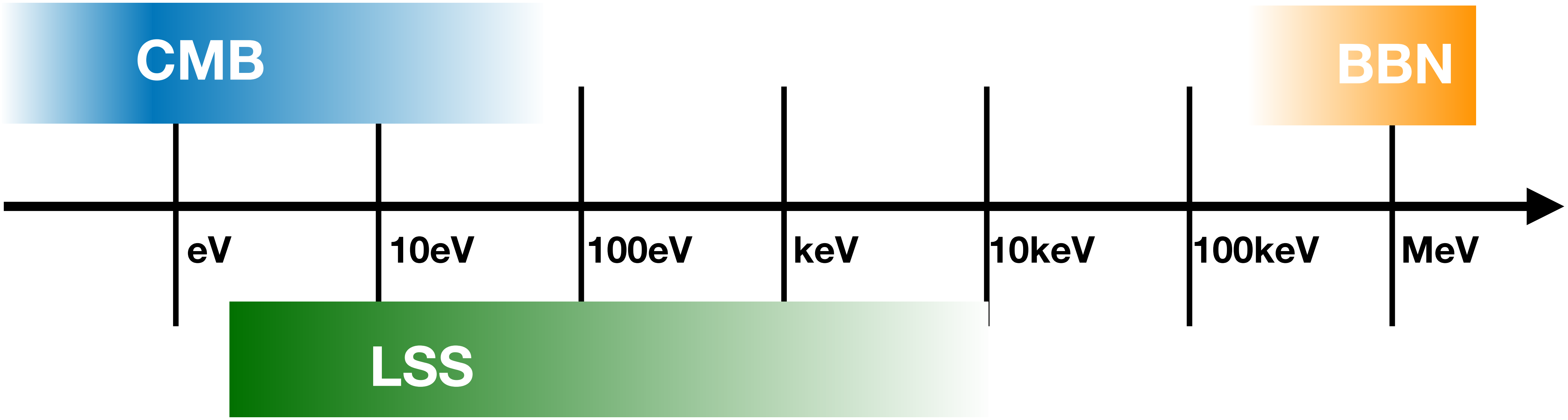
data in the eV-MeV desert?

BBN



This is the era of the experimental exploration of the desert

today: WMAP, SDSS, Planck, BOSS, ACT, SPT,…



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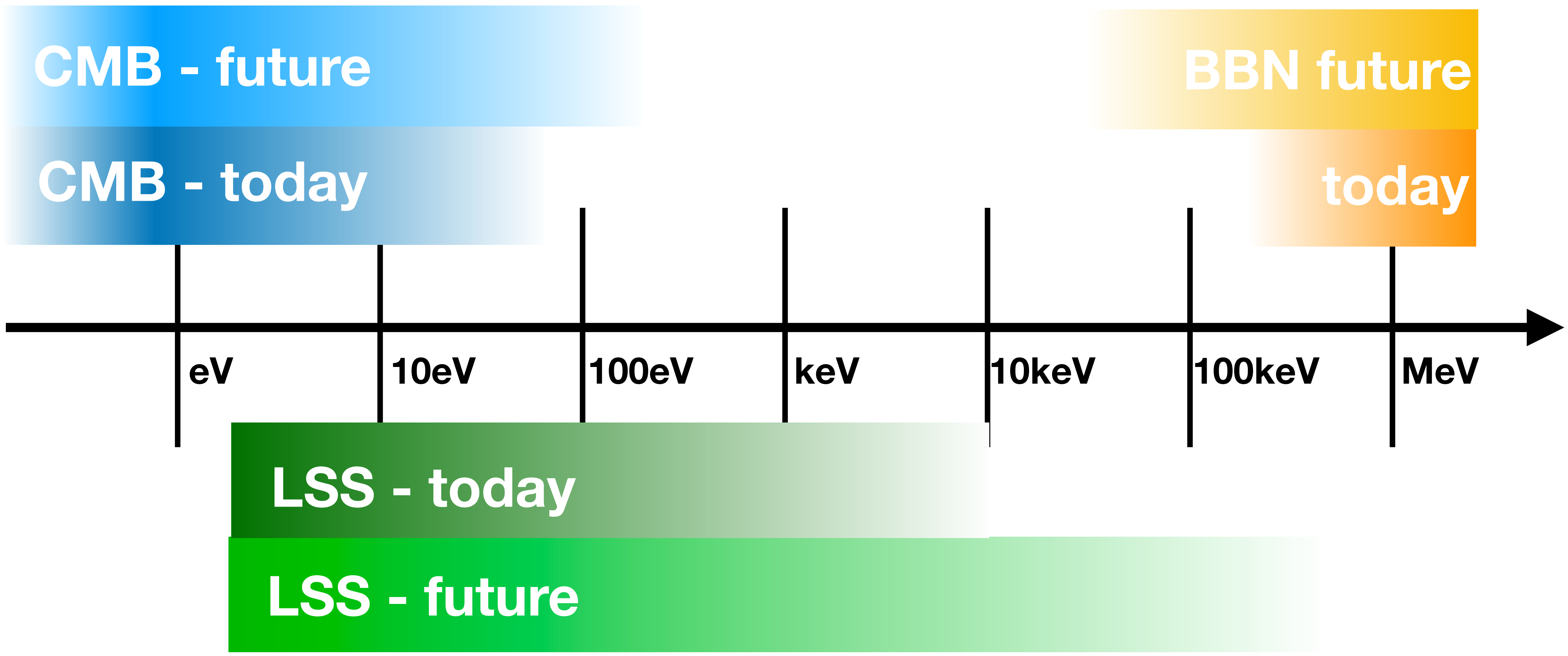


future: Rubin, EUCLID, Roman, Simon’s O, CMB-S4, …

What else is in the eV-MeV desert?

data - anomalies

What else is in the eV-MeV desert?

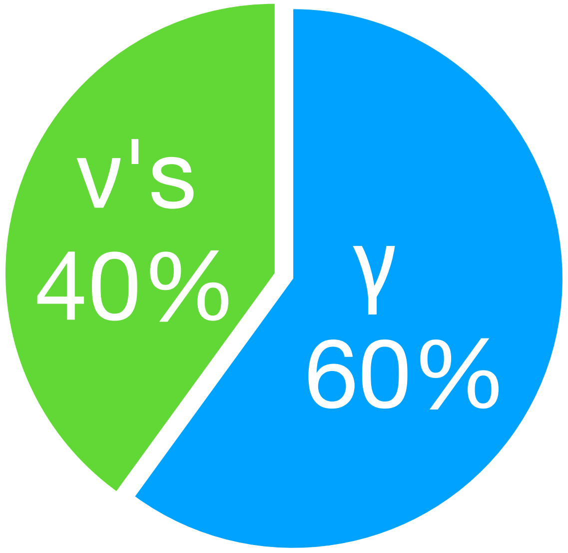
data - anomalies

H_0	Hubble Tension
S8,Lyα	LSS Tensions
D/H	Deuterium abundance

- The desert provides a great opportunity to probe and discover new physics thresholds between eV-MeV scales

- What new physics might we expect to see?

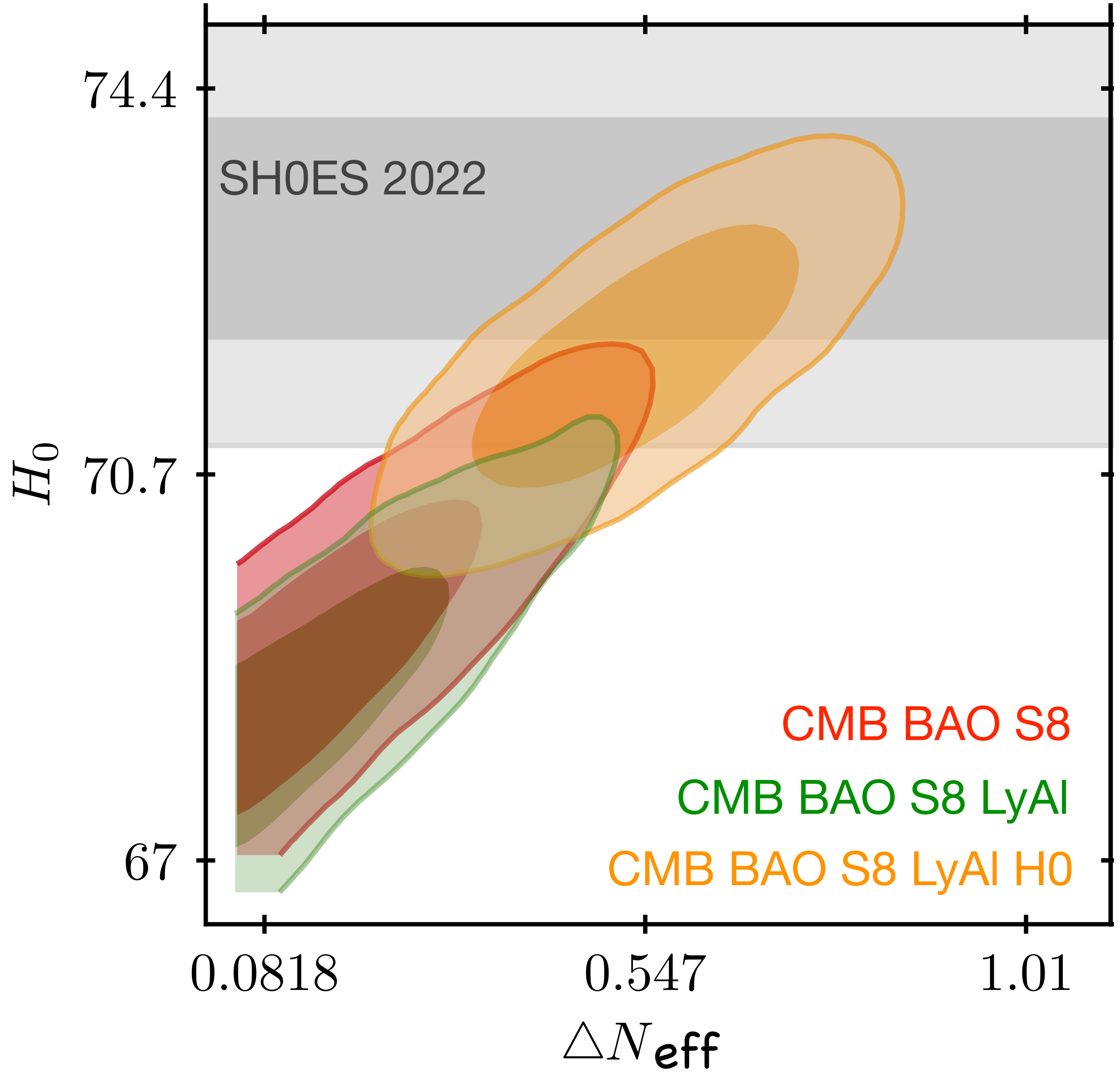
The universe is radiation dominated for T > eV



Most natural expectation:

a dark sector with radiation N_{eff}

Neff can address the Hubble tension



idea:

$$\theta_s \propto r_s(N_{\rm eff})H_0$$

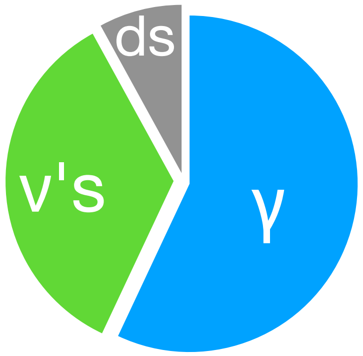
measured CMB peak locations

Neff lowers the sound horizon

=> infer larger H0 from CMB fit

want ΔNeff~0.6

Want extra radiation to have observable consequences but not ruled out (e.g. H_0 wants ΔN_{eff} ~ 0.6)

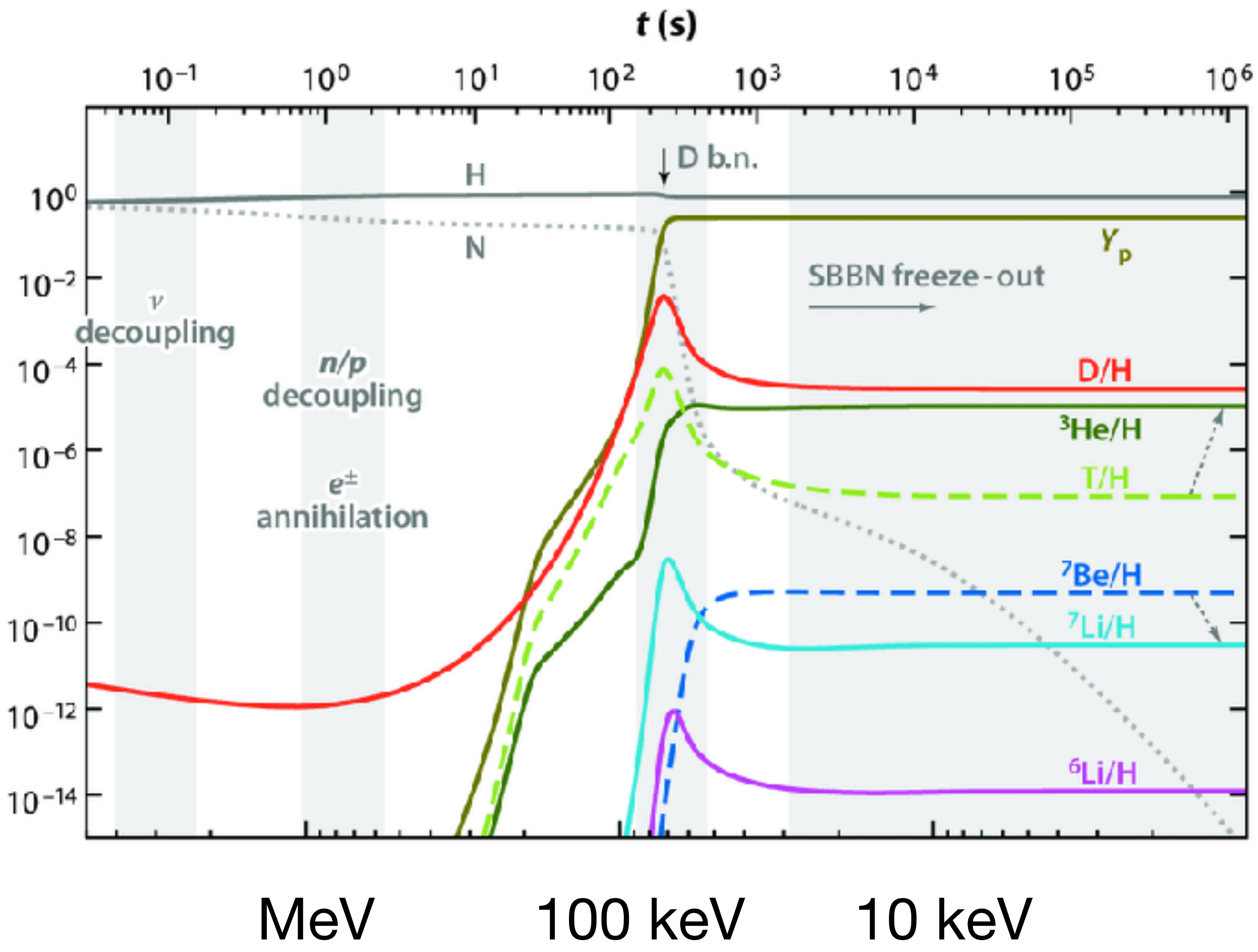


1. How can this be natural?
2. Isn't ΔN_{eff} ~ 0.6 ruled out by BBN?

Idea: populate a dark sector by thermalizing it from the neutrinos after BBN

A.Berlin, N.Blinov 1807.04282
D.Aloni, M.Joseph, M.Schmaltz, N.Weiner 2301.10792

BBN constraints on Neff (95%)



well measured (1%):

Helium	Y_p
Deuterium	D/H
~~Lithium~~	~~^{7}Li/H~~

Fields Olive 2022

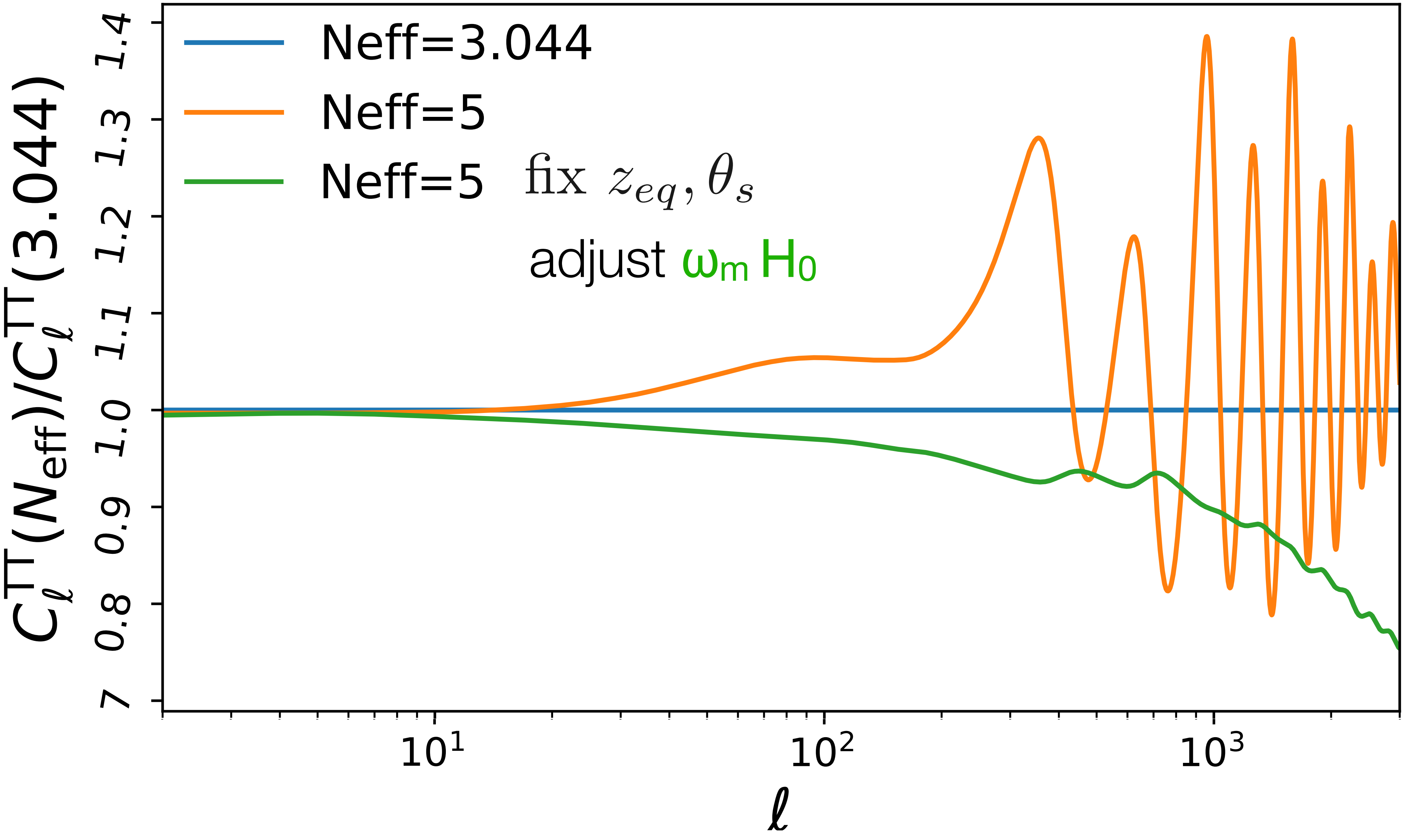
$$BBN + Y_p + D : \qquad \Delta N_{eff} < 0.41$$

$$CMB : \qquad \Delta N_{eff} < 0.51$$

$$CMB + BBN + Y_p + D : \qquad \Delta N_{eff} < 0.23$$

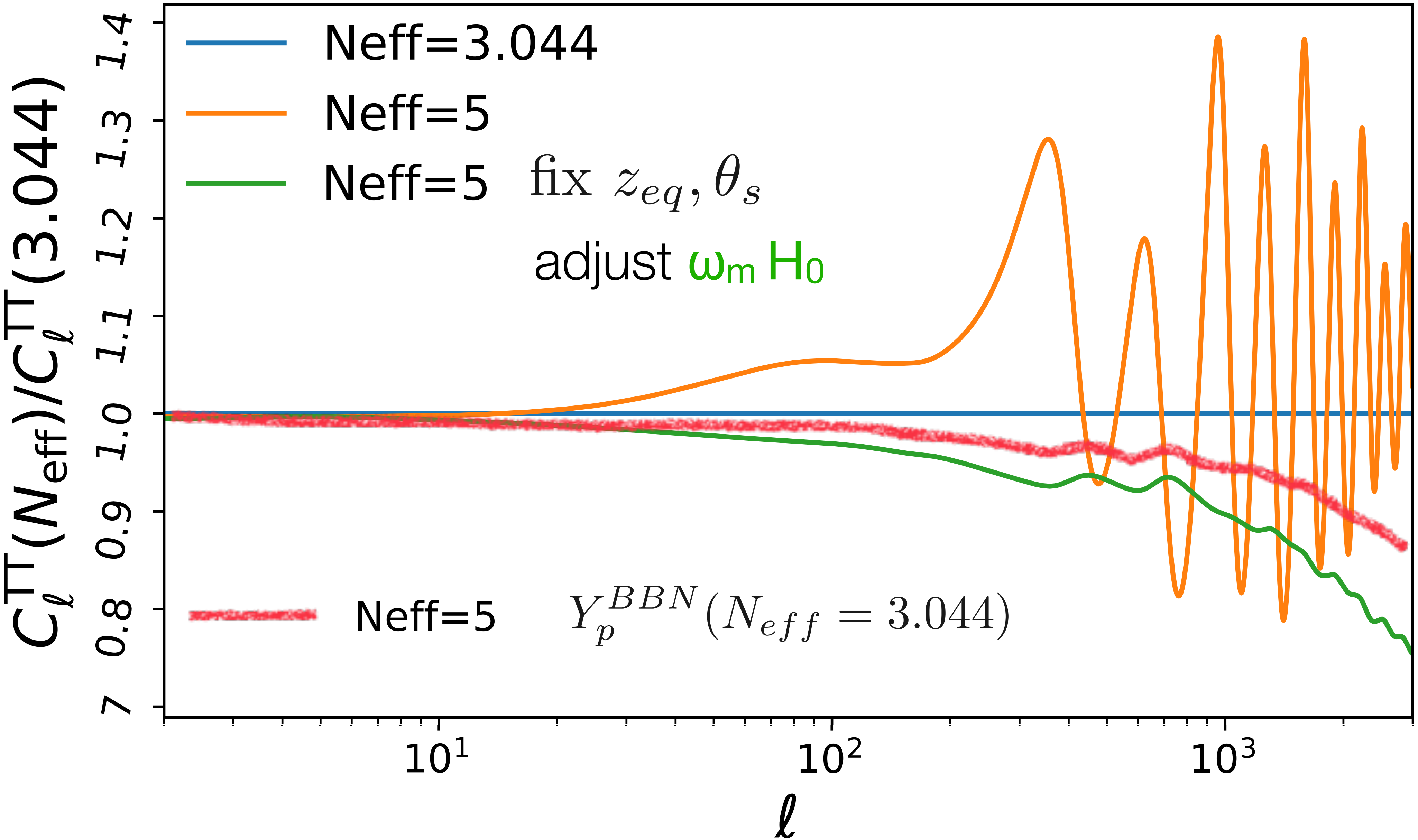
Yeh Shelton Olive Fields 2022

Effect of ΔNeff on the CMB



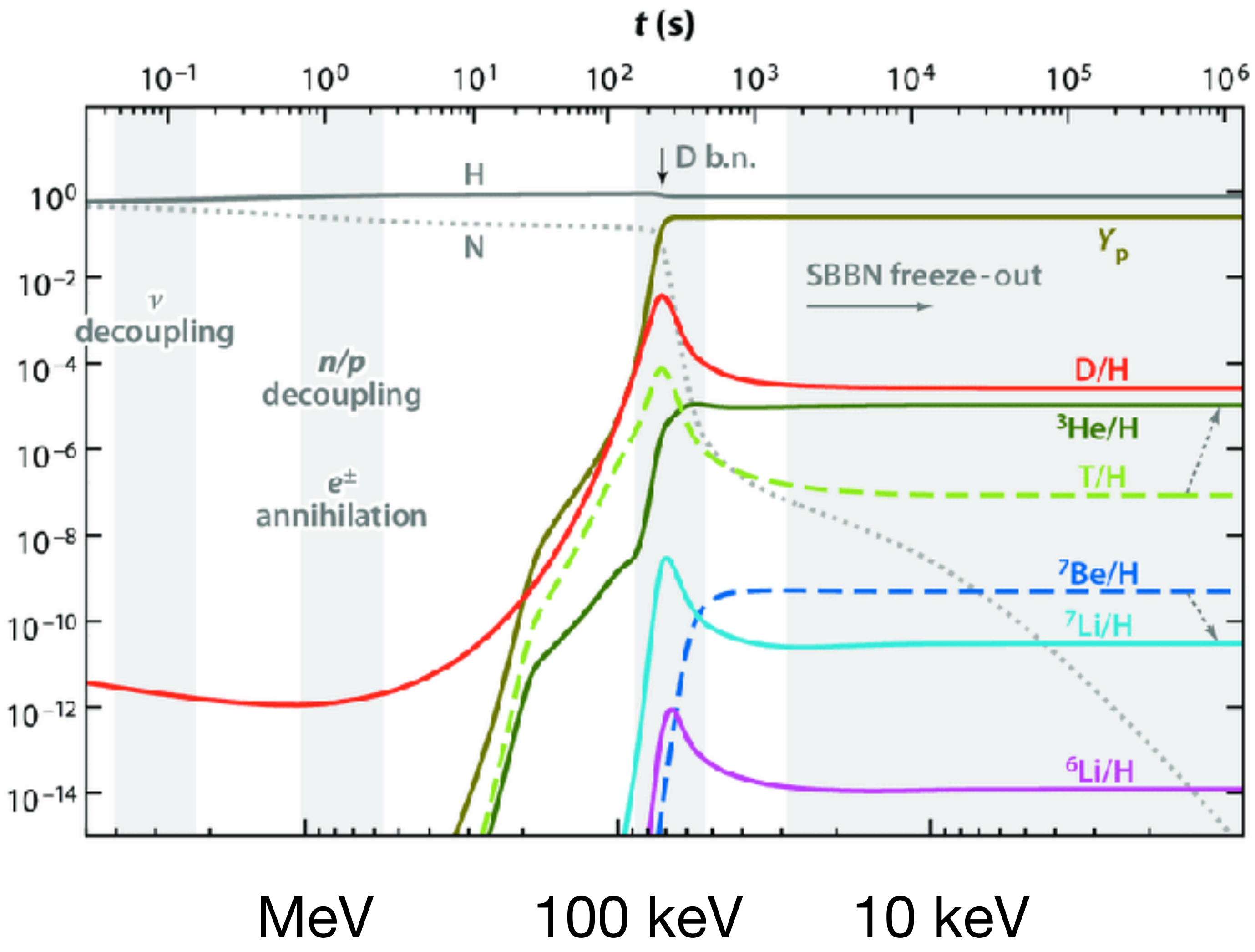
Martina Gerbino

Effect of ΔNeff on the CMB



Additional damping due to modified Helium abundance (from Neff during BBN) makes CMB bound on Neff much stronger

BBN constraints on Neff (95%)



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Helium	Y_p
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Fields Olive 2022

$$\begin{aligned} BBN + Y_p + D : &\quad \Delta N_{eff} < 0.41 \\ CMB : &\quad \Delta N_{eff} < 0.51 \\ CMB + BBN + Y_p + D : &\quad \Delta N_{eff} < 0.23 \end{aligned}$$

Yeh Shelton Olive Fields 2022

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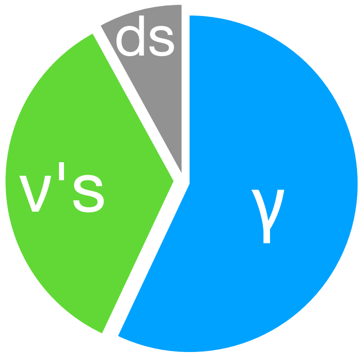

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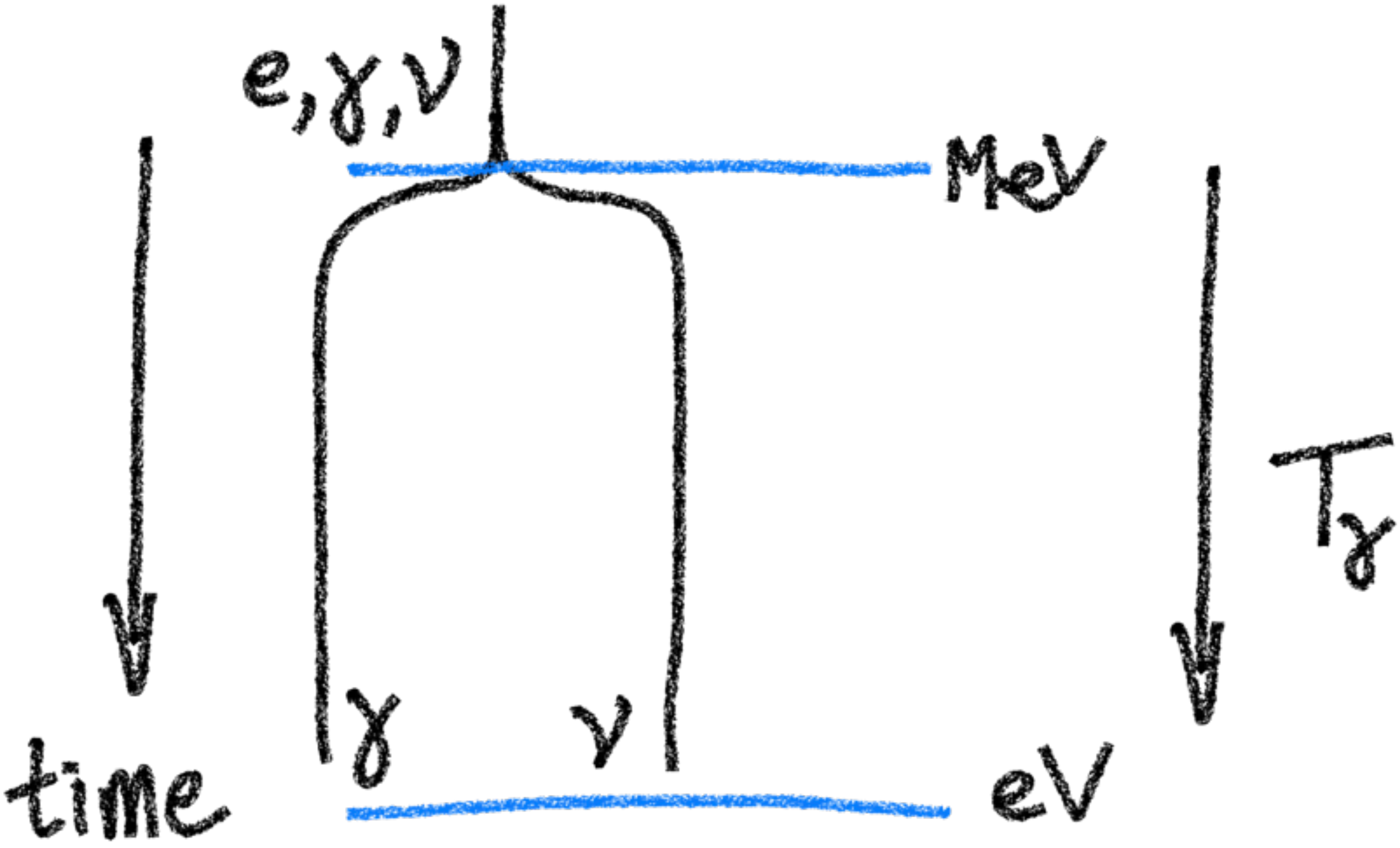
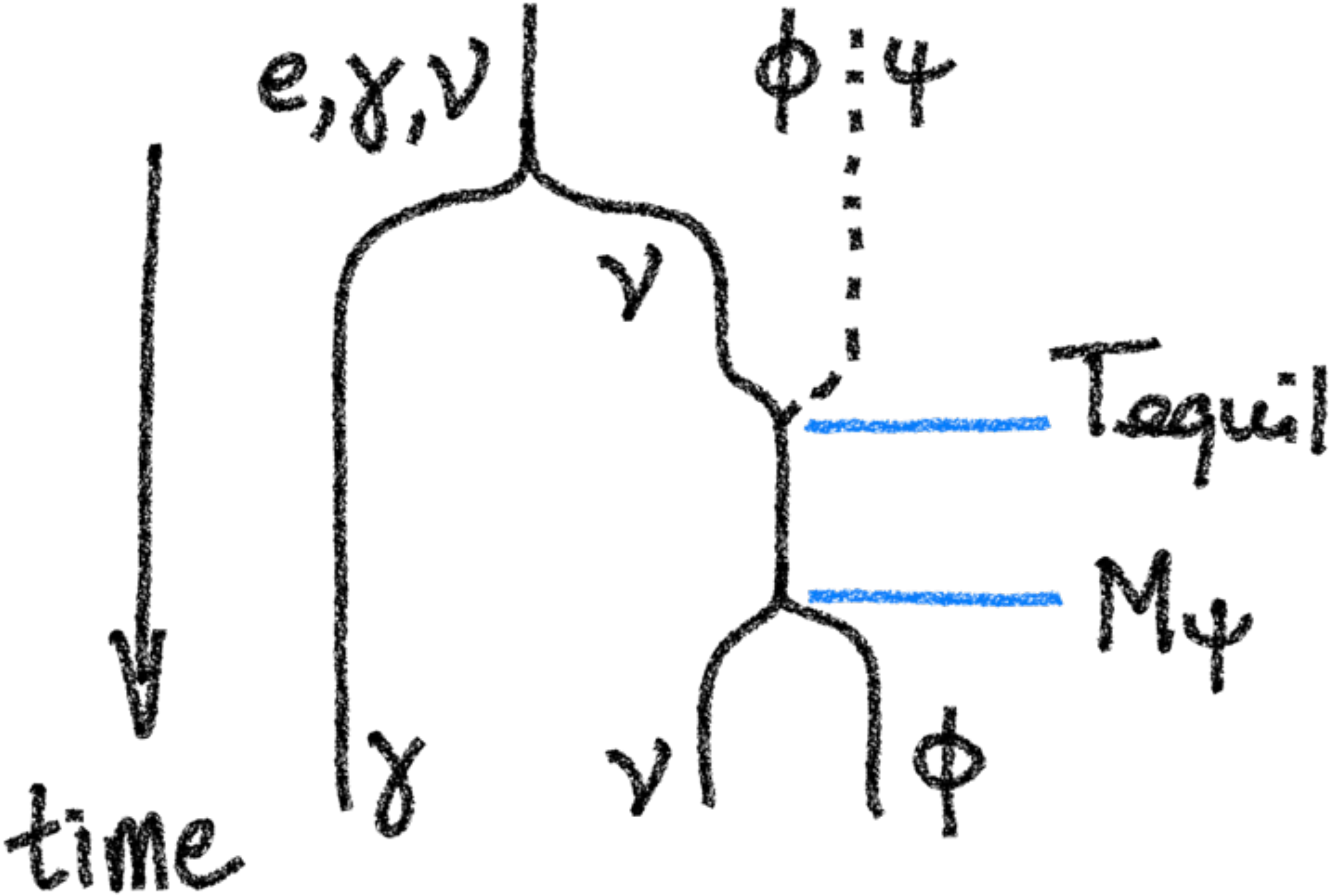
ΛCDM cosmological history



Alternative cosmological history



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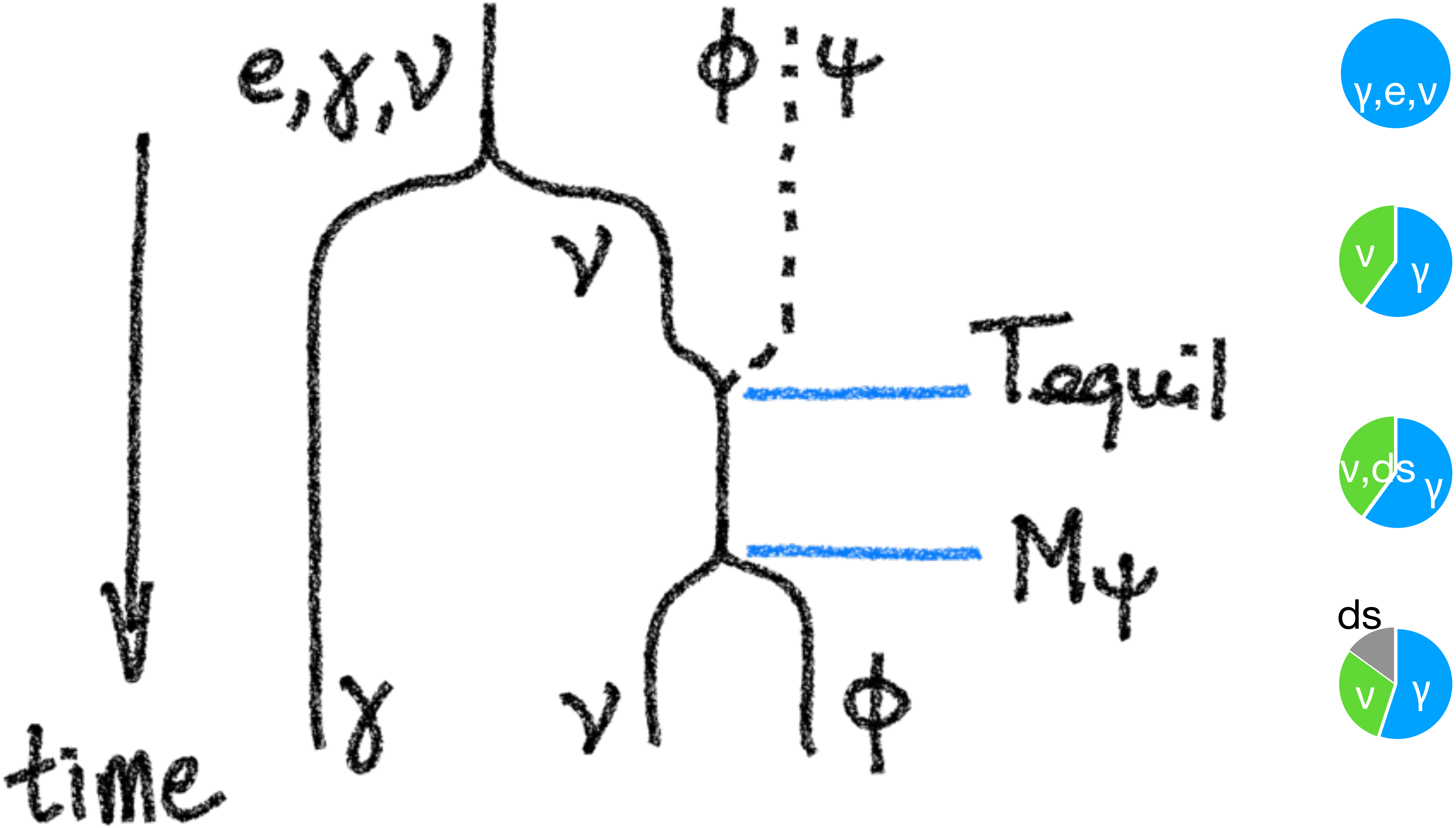


A very simple model

(Aloni,Joseph,Schmaltz,Weiner 2301.10792)

$$\mathcal{L} \sim m_\psi \psi\psi + m_{mix} \nu\psi + \lambda \phi\psi\psi$$

dark fermion mass

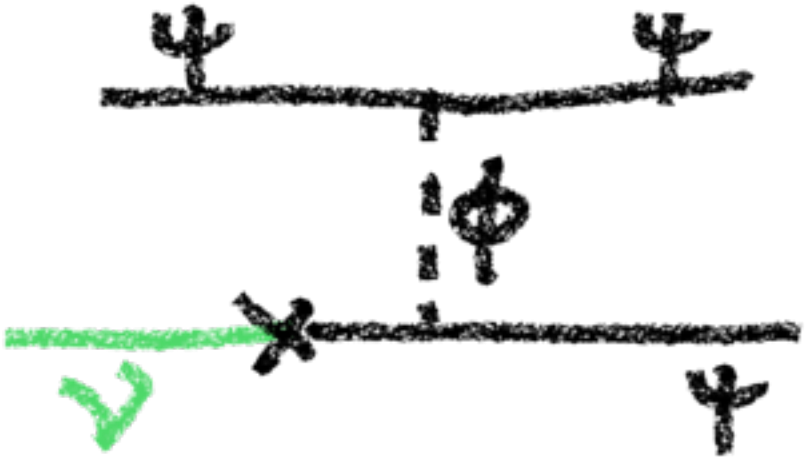
mixing with ν

Thermalizing through the neutrino portal

(c.f. Dodelson-Widrow with secret interactions B.Dasgupta,J.Kopp)

$$\nu \xrightarrow[\text{oscillation}]{} \cos\theta\,\nu + \sin\theta\,\psi \xrightarrow[\text{scattering}]{} \overset{\nu \qquad \psi}{\begin{pmatrix} \cos^2\theta & \\ & \sin^2\theta \end{pmatrix}}$$

$$\Gamma_{\nu\to\psi} = \frac{1}{4}\sin^2\theta_M\,\Gamma_{\psi\,\text{scattering}}$$



Thermalizing through the neutrino portal

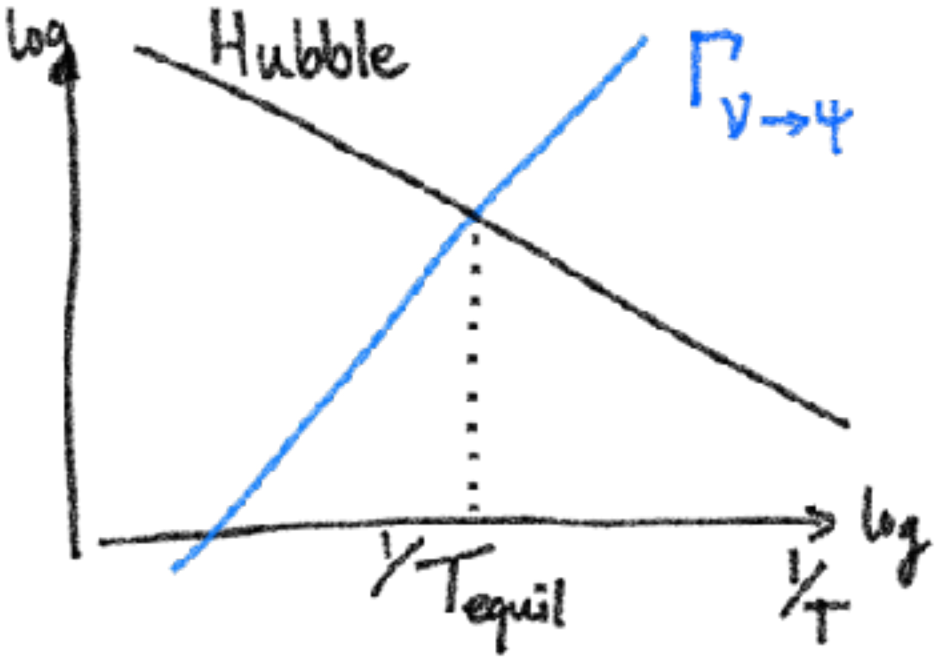
$$\Gamma_{\nu\to\psi} = \frac{1}{4}\sin^2(2\theta_m)\,\Gamma_{\text{int}}$$

θ_m is suppressed at high Temperature

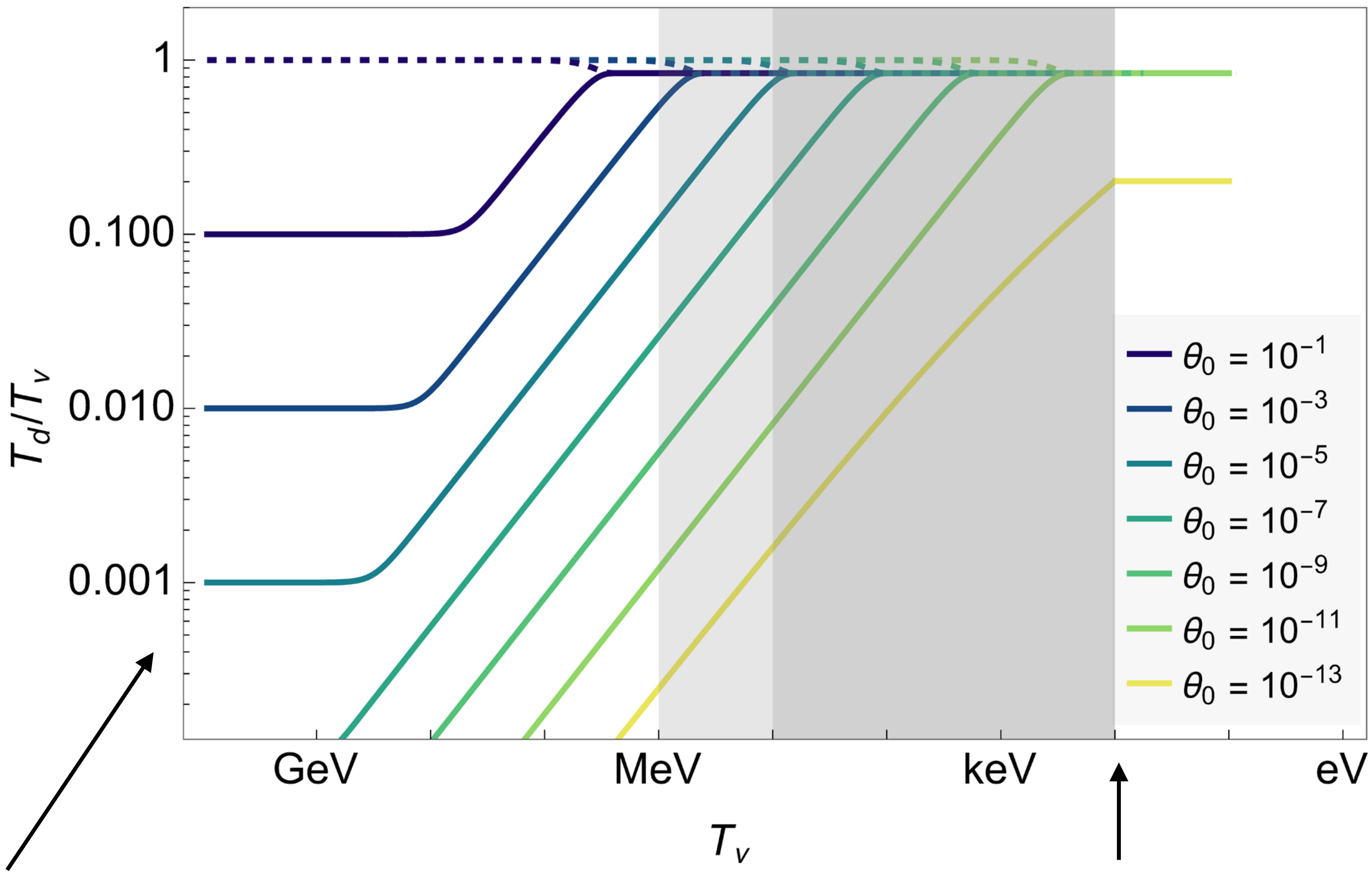
$\Gamma_{\text{int}} \sim \alpha_d^2 T$

$$\sin^2 2\theta_m = \frac{\sin^2 2\theta_0}{(\cos 2\theta_0 - 2E\Delta V_{\text{eff}}/\Delta m^2)^2 + \sin^2 2\theta_0}$$

$$\Gamma_{\nu\to\psi} \simeq \frac{\theta_0^2}{(1+\alpha_d T^2/m_s^2)^2}\,\alpha_d^2 T$$



Dark sector temperature evolution

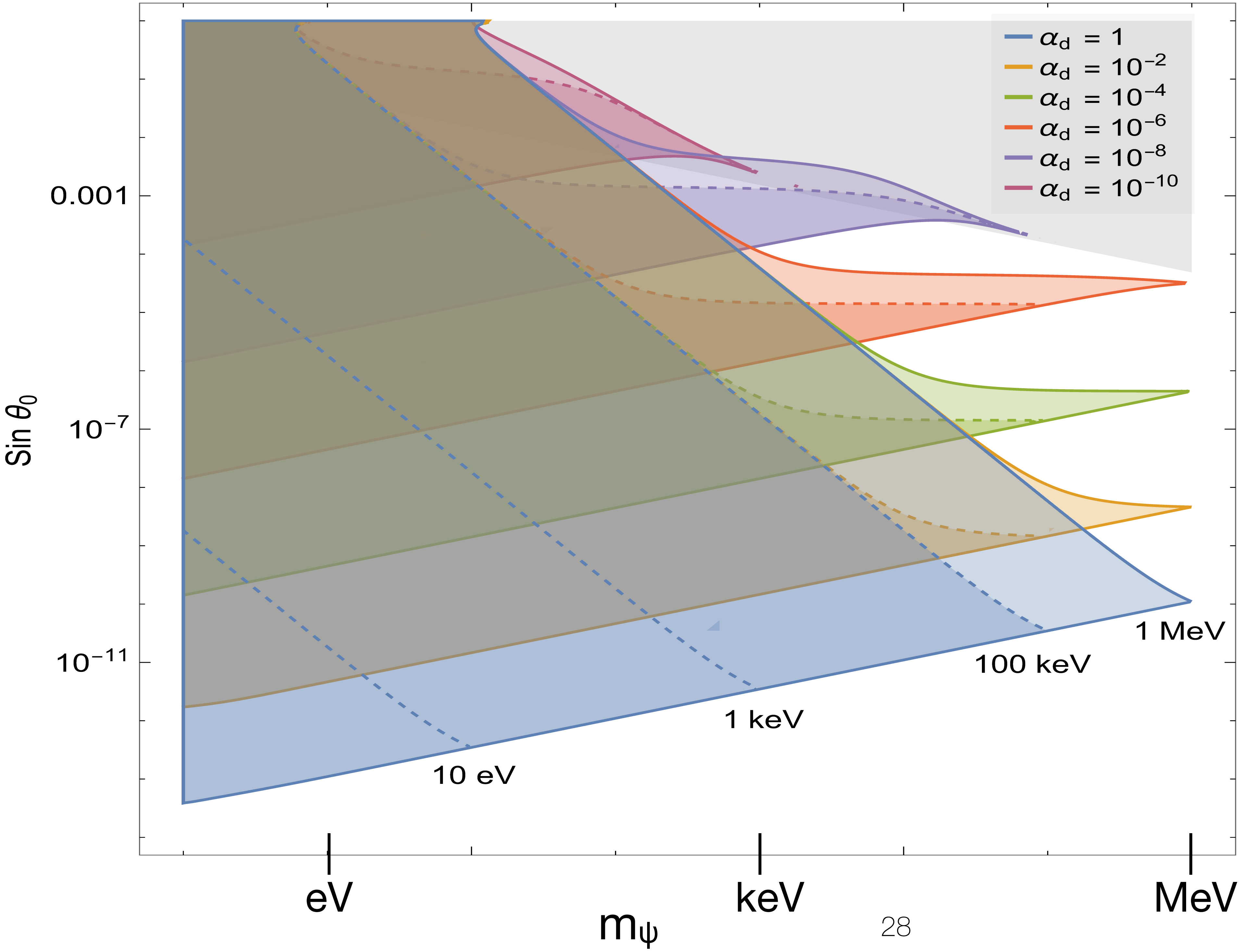


Initial dark temperature from Higgs decay to sterile neutrinos

$$m_\psi = 100\,\mathrm{eV}$$
$$\alpha_d = 1$$

Equilibration is generic and occurs at $T_{equil} \approx m_\psi \left(\frac{\theta_0^2 M_{pl}}{m_\psi}\right)^{1/5}$

Aloni,Joseph,Schmaltz,Weiner 2301.10792



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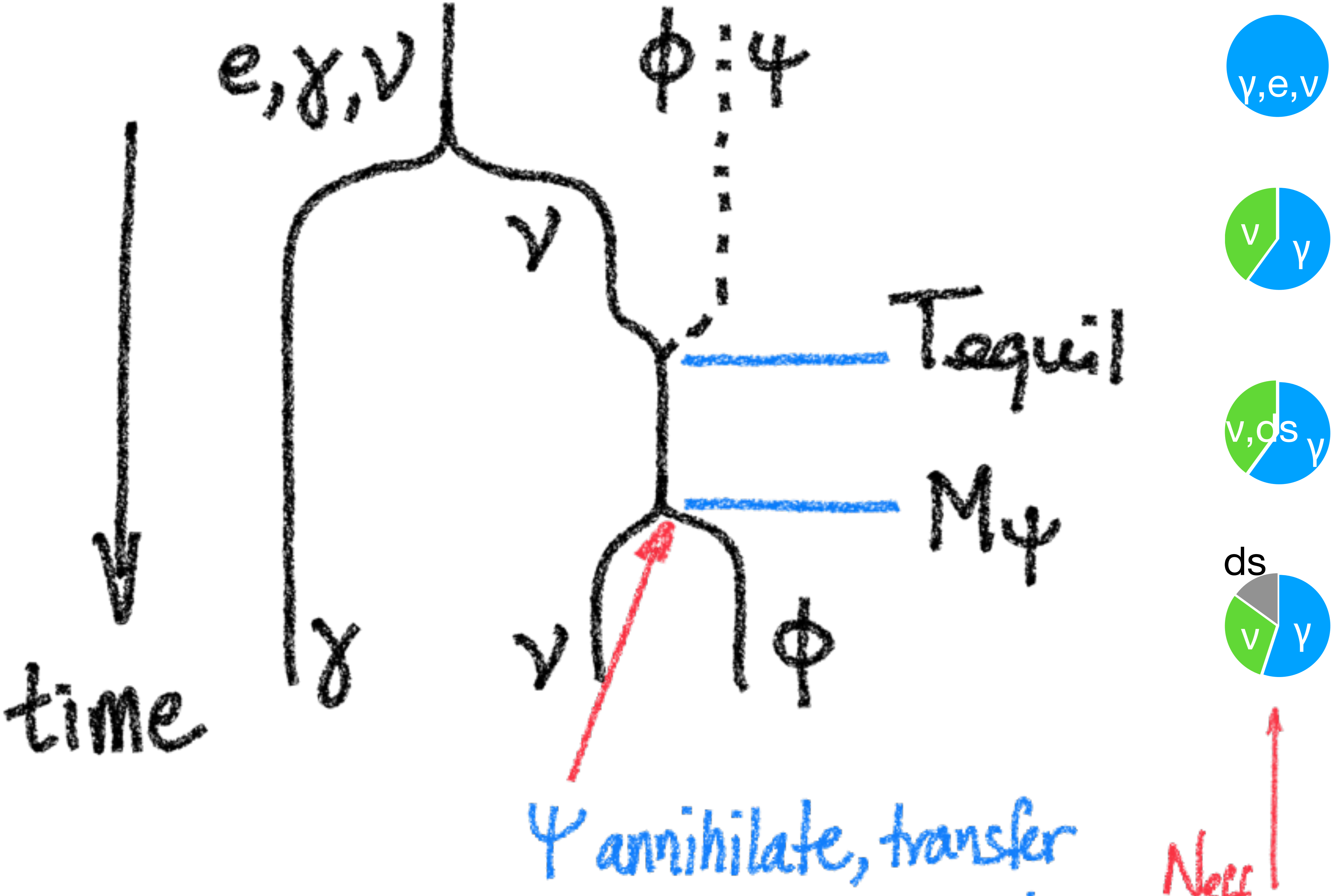


ψ annihilate, transfer their entropy to ν,φ

N_{eff} increases

Recap:

- Can generically thermalize a dark radiation sector below MeV via neutrino portal

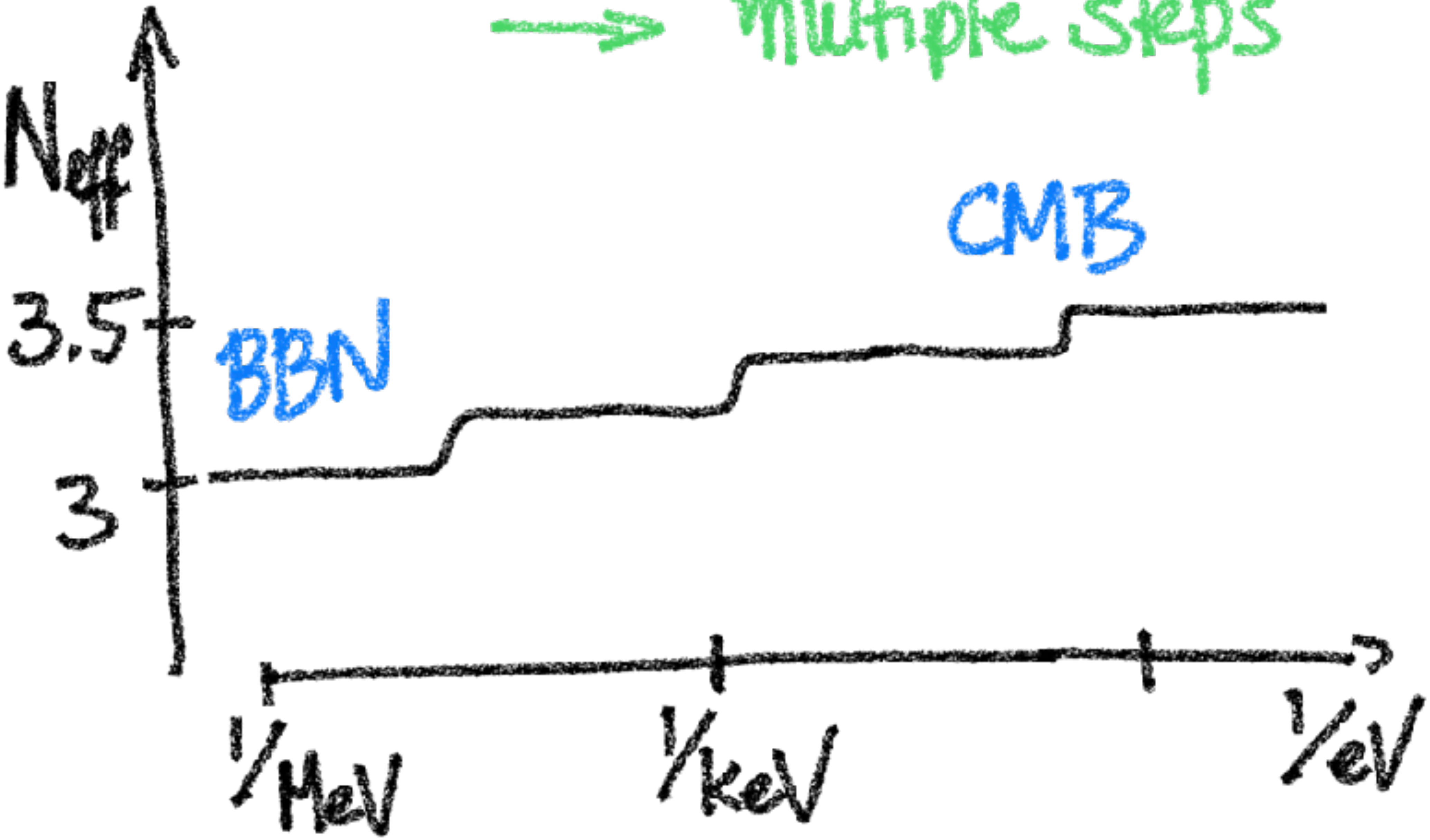
  $\longrightarrow N_{eff}(BBN) = 3$

- massive particles in dark sector annihilate and produce a "step" in N_{eff}

  $\longrightarrow N_{eff}(CMB) = 3 + \Delta N_{eff}$

Multiple massive particles in dark sector

→ multiple steps



Applications - Signatures

- a step in N_{eff} reduces the Hubble tension H_0

Aloni,Berlin,Joseph,Schmaltz,Weiner
2111.00014

- dark matter - dark radiation interaction with a step improves S8

Joseph,Aloni,Schmaltz,Sivarajan,
Weiner 2207.03500

- dark matter - dark radiation interaction with a step fits H_0 and Lyα

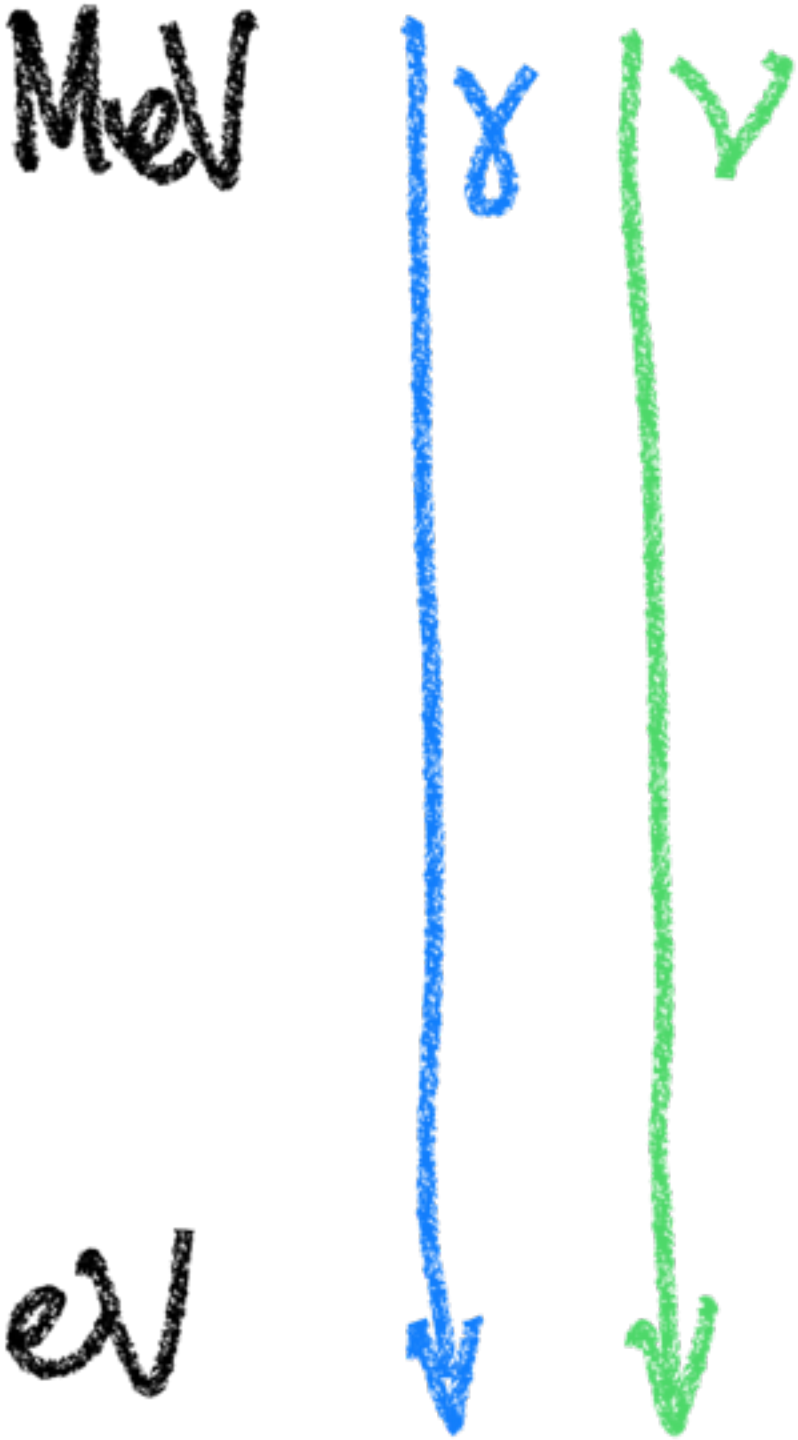
Bagherian,Joseph,Schmaltz,
Sivarajan, in progress

- a step during BBN ~ 100keV modifies D/H

Giovanetti,Schmaltz,Weiner, in progress

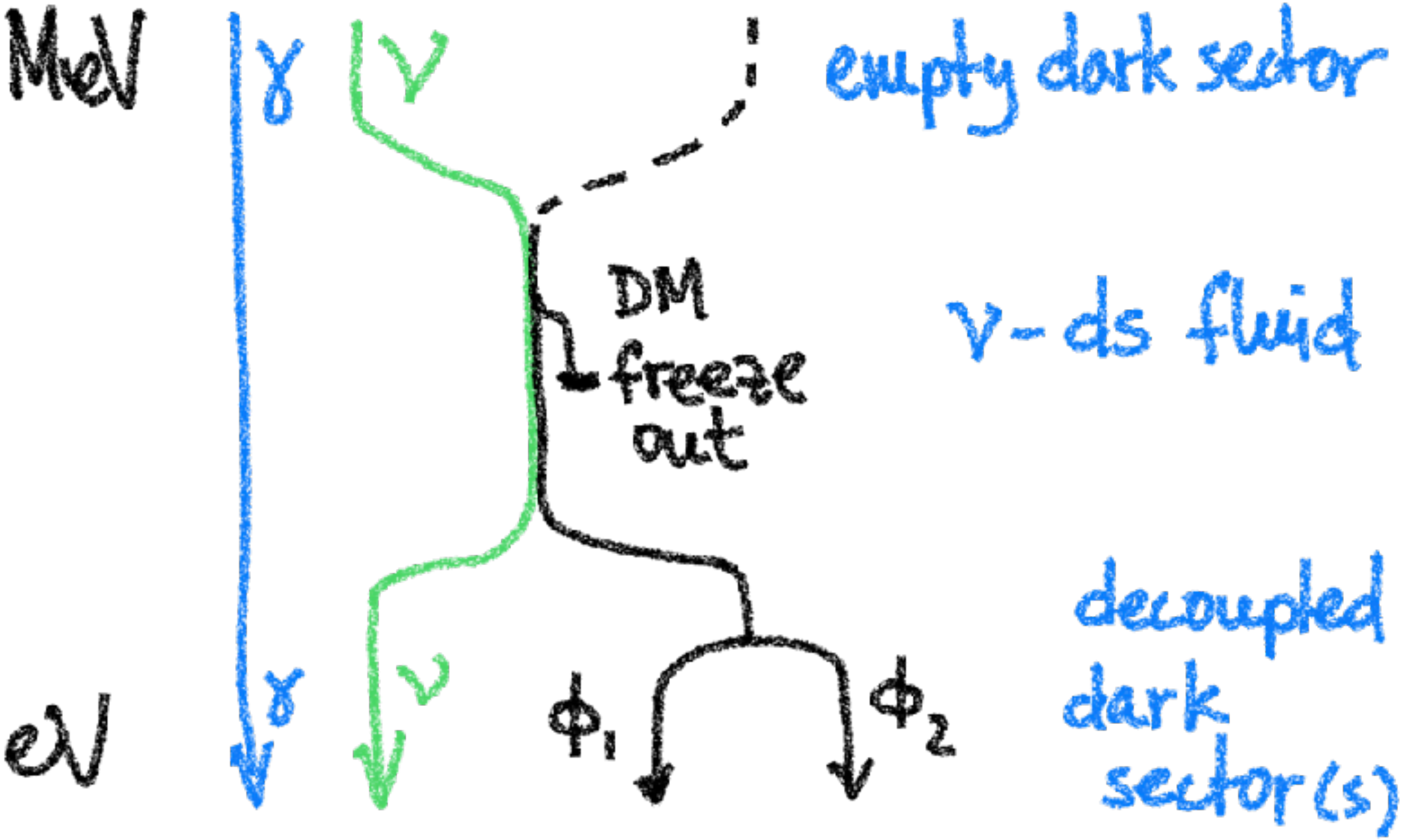
Summary

ΛCDM desert



no thresholds

Desert populated through the ν-portal



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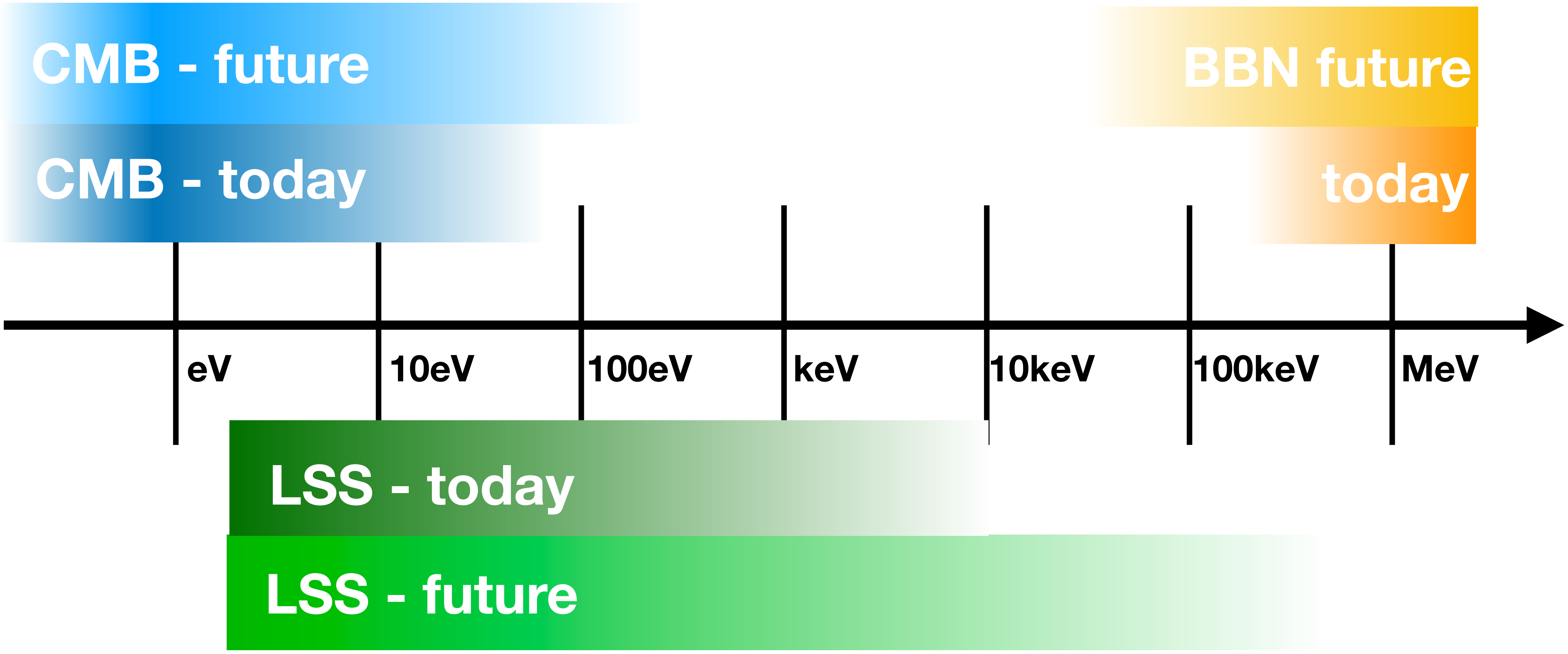


future: Rubin, EUCLID, Roman, Simon’s O, CMB-S4, …

much more data is coming!

CMB: Simons Observatory (first light 4/2024)
Advanced SO (5-10 years)
CMB-S4 (10 years?)

LSS: DESI (first data), Euclid (final commissioning)
Vera Rubin Observatory - LSST (2025)

H_0 Supernovae: JWST (observing), TRGB (ongoing)

GW: LIGO 100 NS-NS mergers + optical (2030)
Einstein Telescope (2035?)

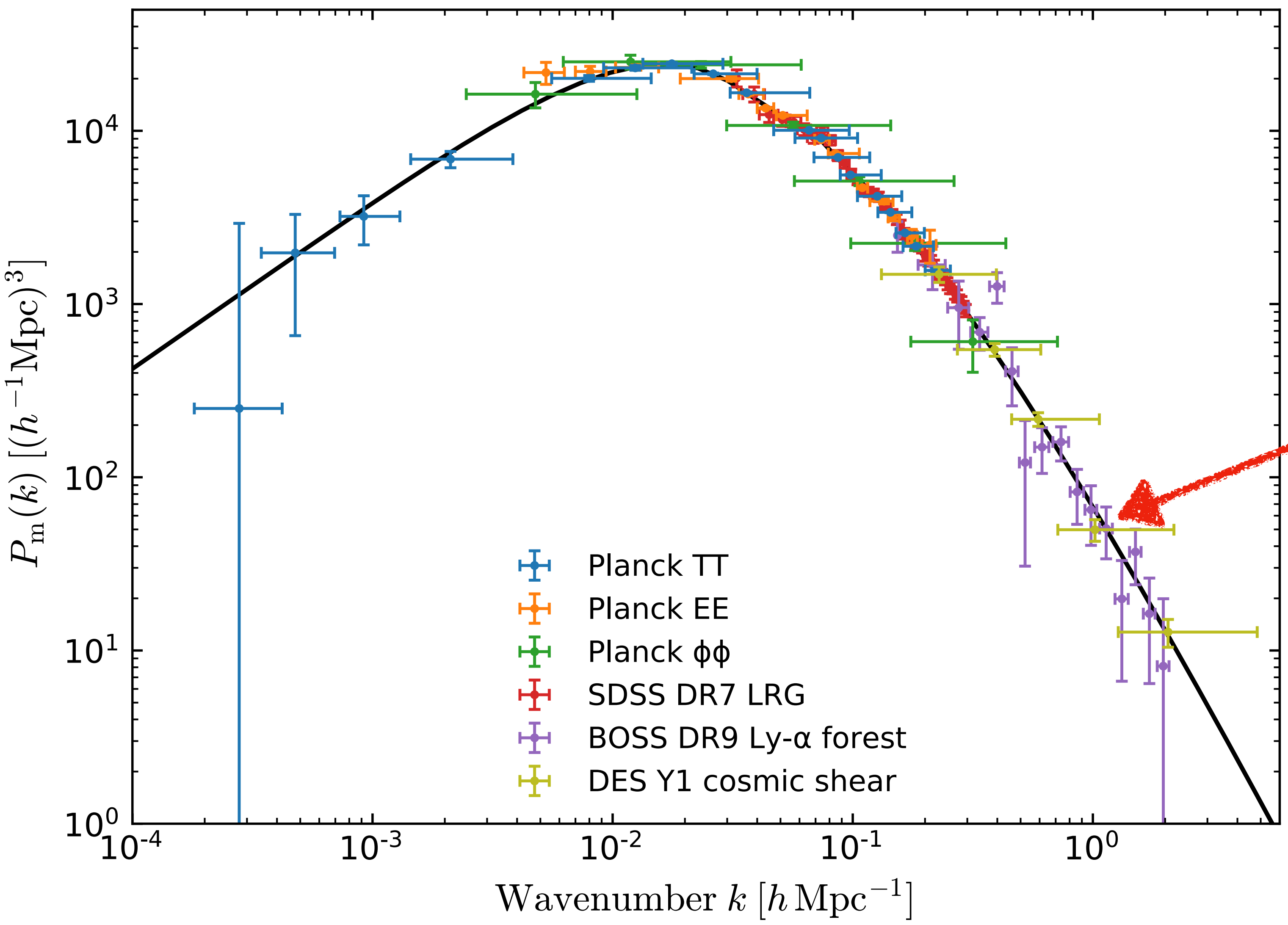
Back up!

Lyman-alpha

Neff models for H_0 confront LyAl

1D LyAlpha flux power spectrum of SDSS DR14 BOSS + eBOSS quasars

For EDE analysis see: Samuel Goldstein,[1,*] J. Colin Hill,[1] Vid Iršič,[2,3] and Blake D. Sherwin[4,2] arxiv: 2023.00746



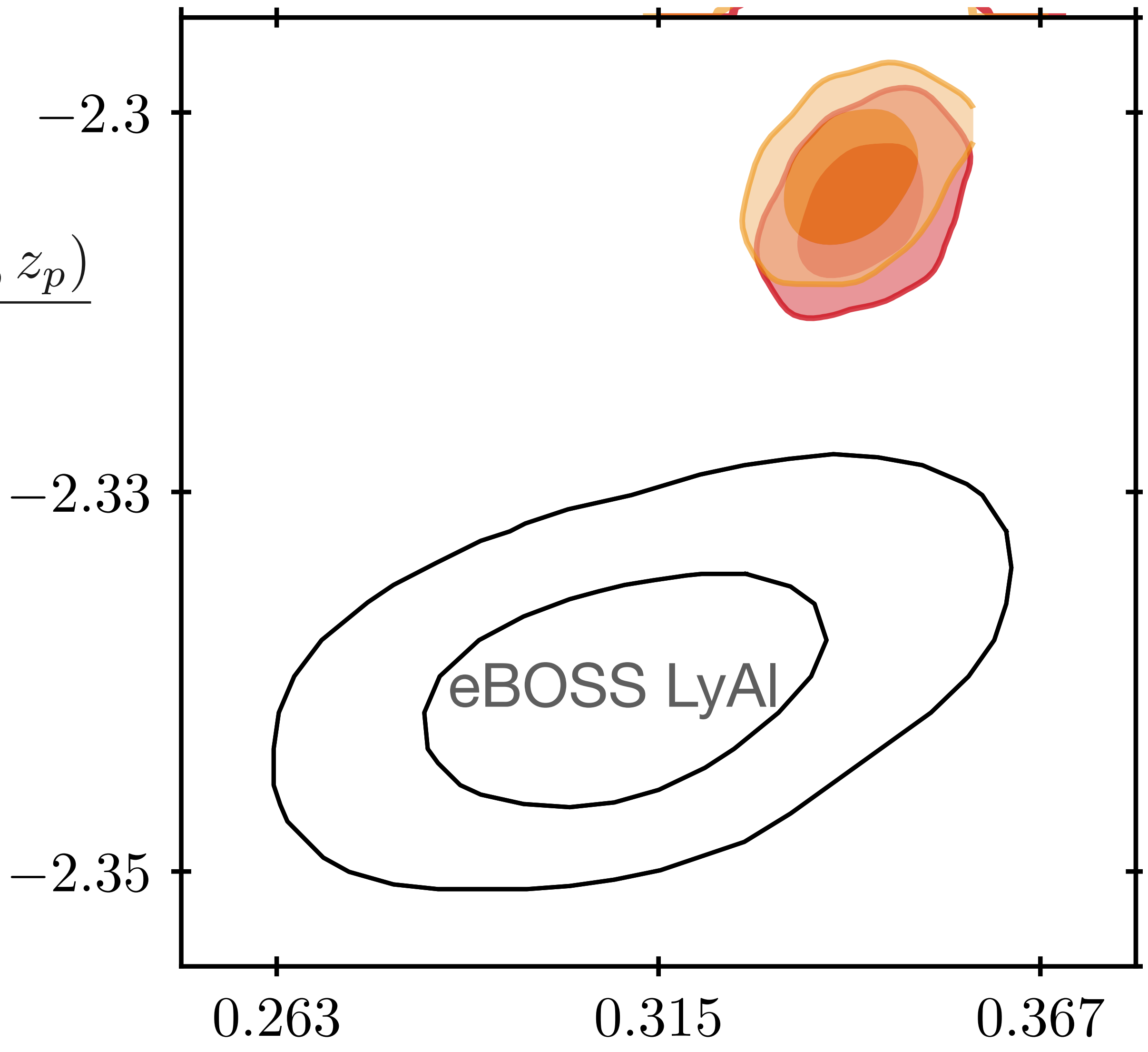
Simplified likelihood fixes amplitude and slope at

$k_p = 1$ h/Mpc
$z_p = 3$

ΛCDM is not steep enough

slope

$$n_L = \frac{d\ln P_{\rm lin}(k_p, z_p)}{d\ln k_p}$$

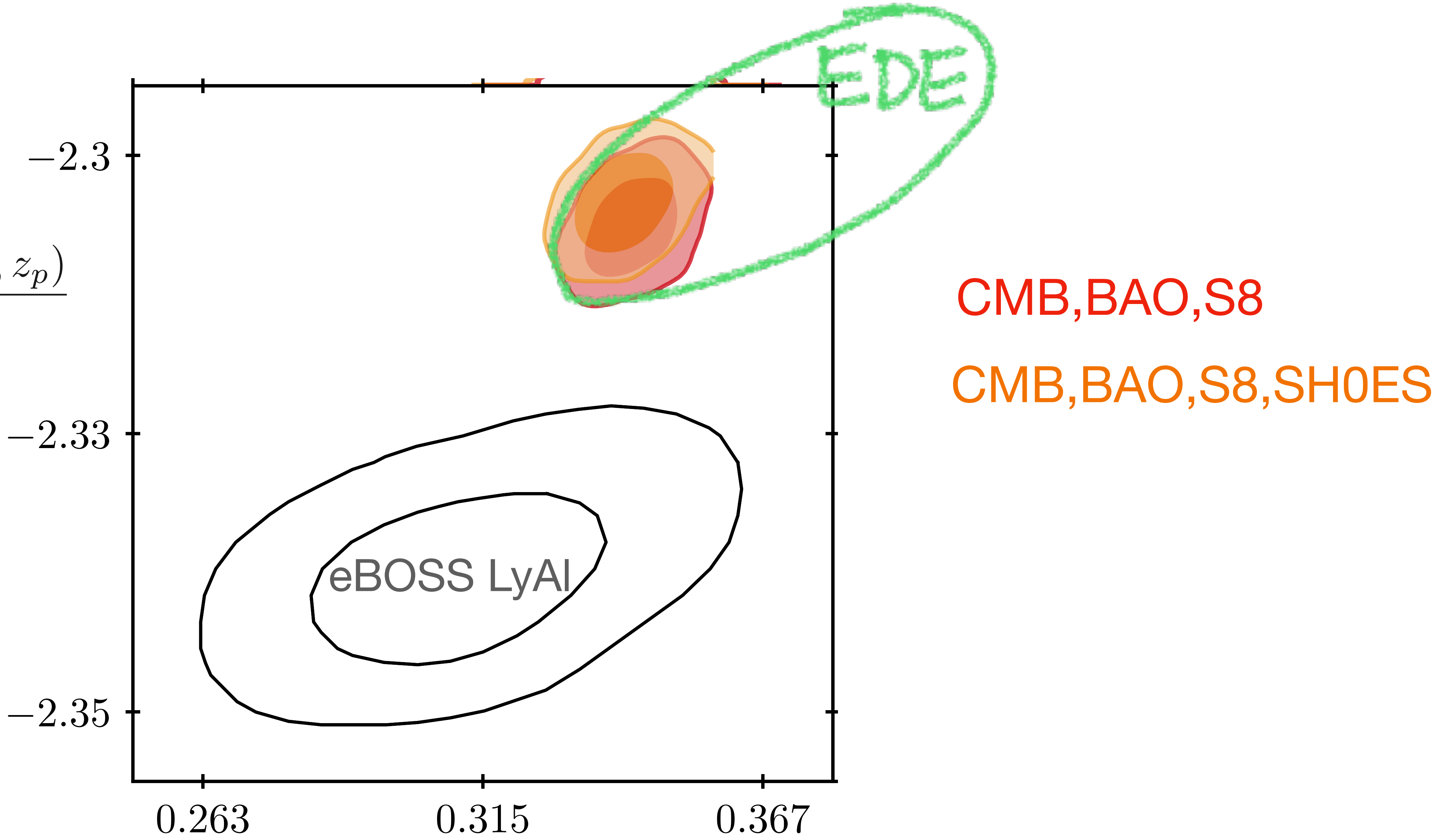


CMB,BAO,S8

CMB,BAO,S8,SH0ES

amplitude $\Delta_L^2 \equiv k_p^3 P_{\rm lin}(k_p, z_p)/(2\pi^2)$

EDE cannot fit both H0 and LyAl



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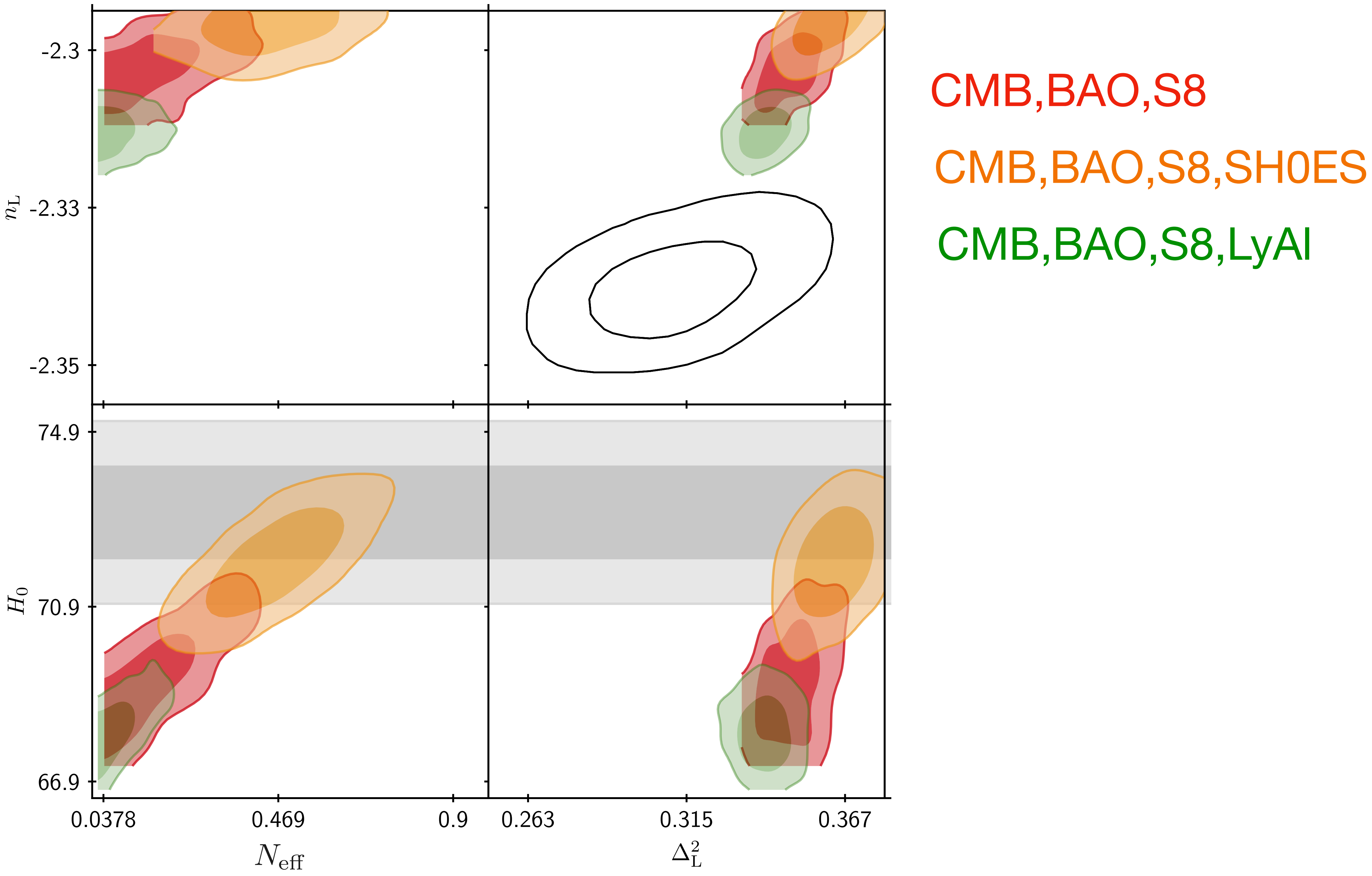
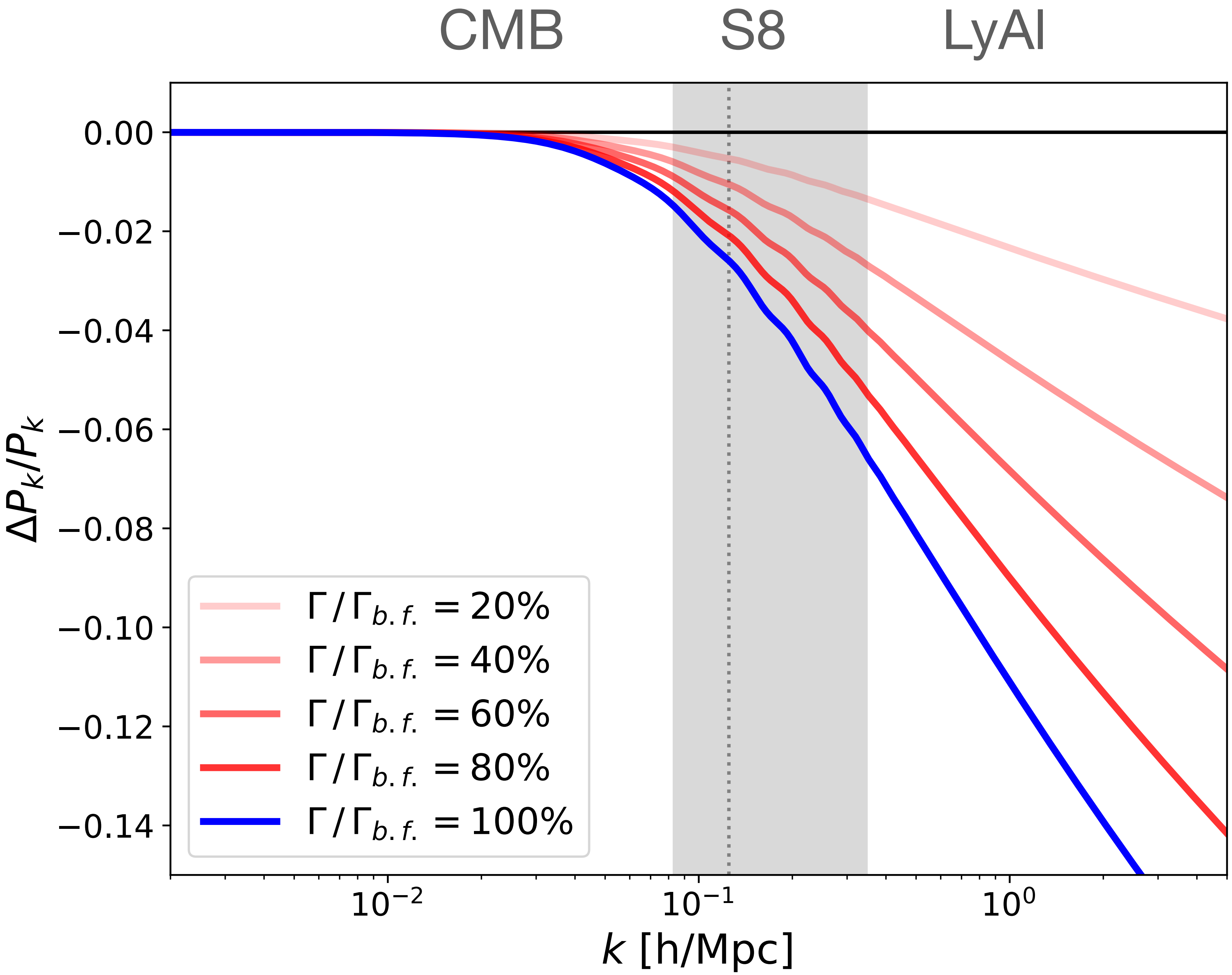
amplitude $\Delta_L^2 \equiv k_p^3 P_{\rm lin}(k_p, z_p)/(2\pi^2)$

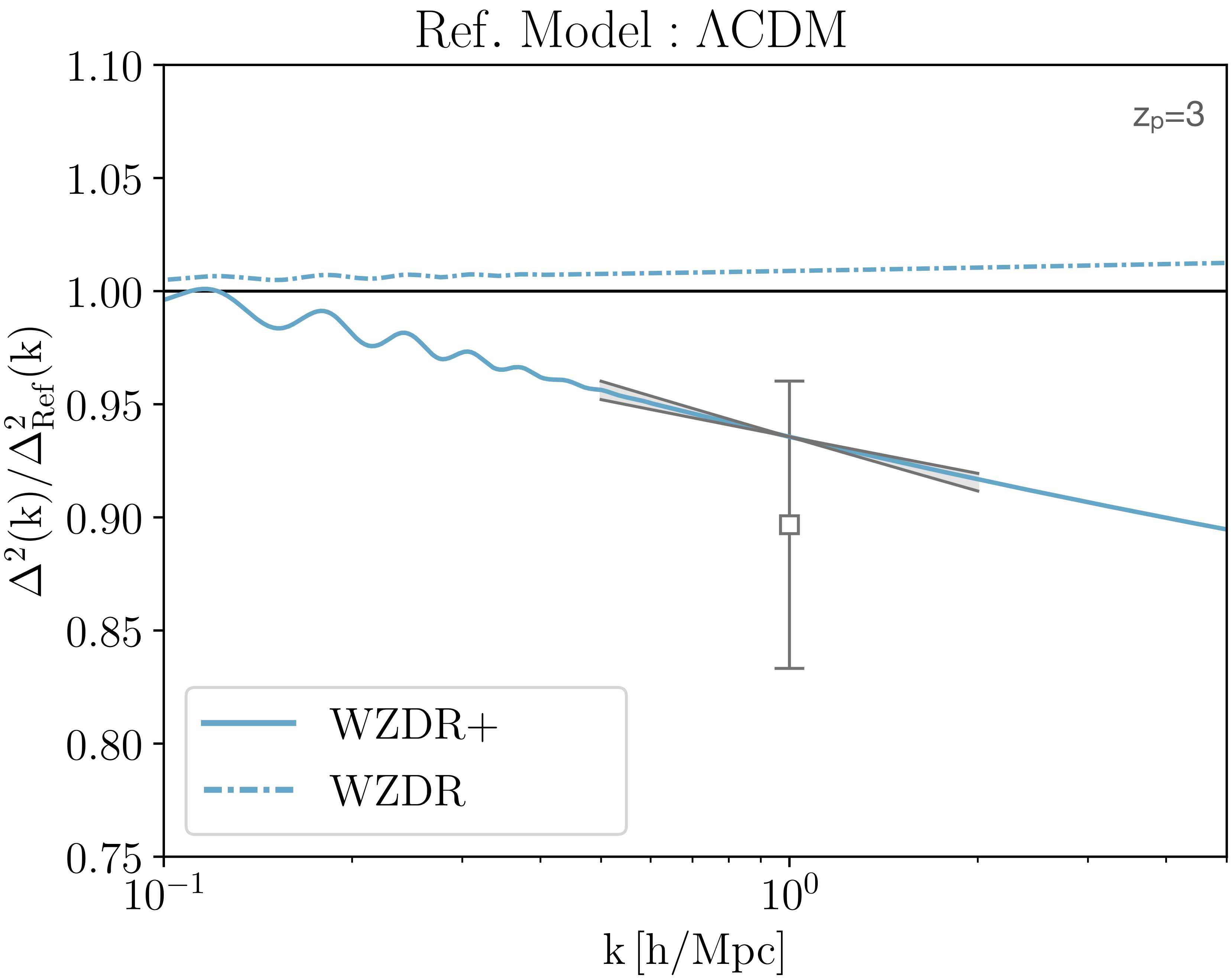
Neff models cannot fit both H0 and LyAl (WZDR)



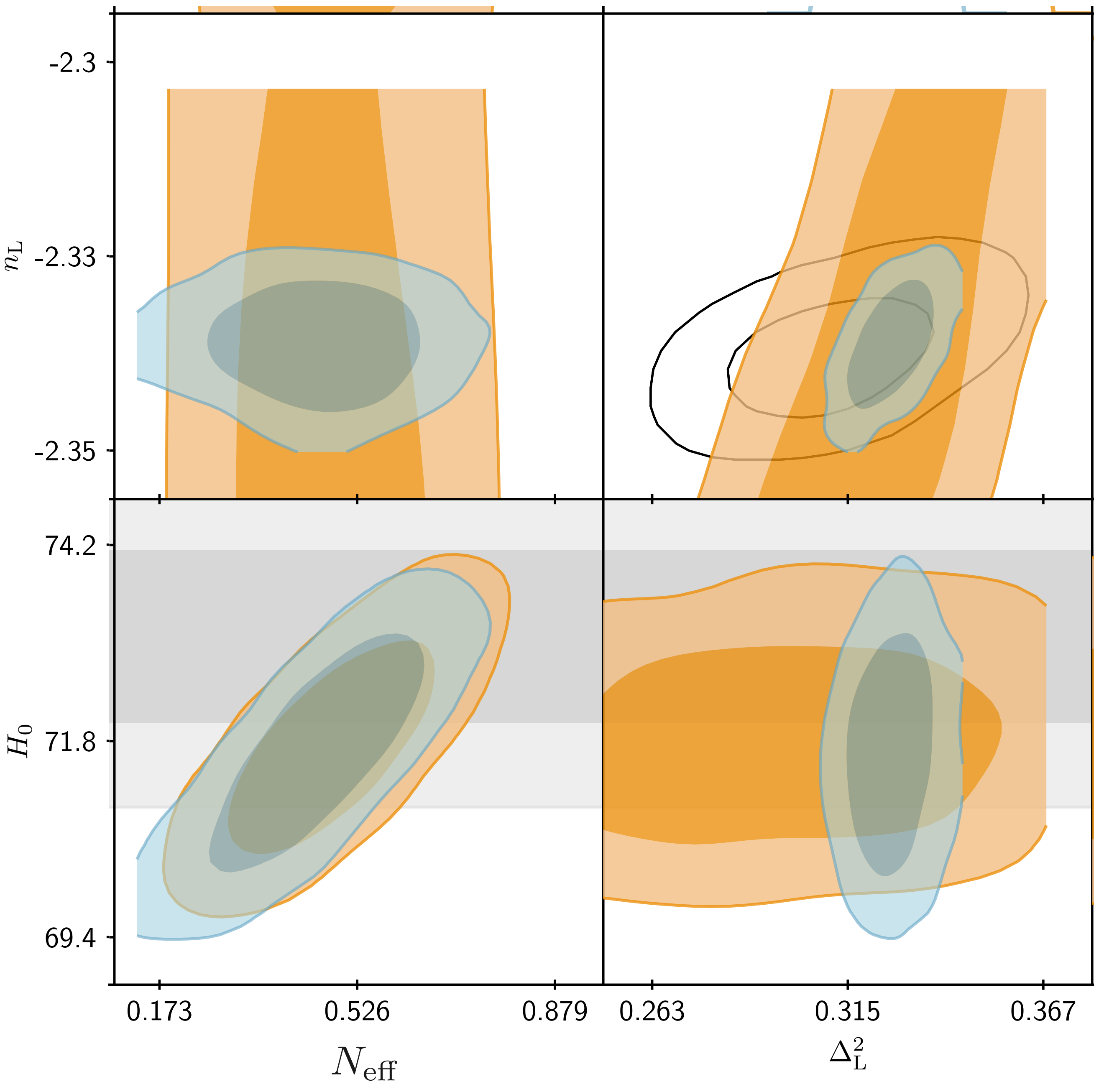
WZDR+ power spectrum suppression for varying DM-DR interaction strengths Γ



WZDR+ with DM-DR interaction fit to CMB,BAO,S8,LyAl



DM-DR interaction models fit H0 and LyAl (WZDR+)



CMB,BAO,S8,SH0ES

CMB,BAO,S8,
SH0ES,LyAl

Implications of the Non-Observation of ^{6}Li in Halo Stars for the Primordial ^{7}Li Problem

Brian D. Fields[a] **Keith A. Olive**[b]

Also, inferring the observed primordial lithium abundance would now require the use of detailed stellar and cosmic-ray nucleosynthesis models. So for the near term, ^{7}Li would seem unlikely to be a reliable independent probe of BBN–a situation similar to the current status of primordial ^{3}He determinations [137]. It remains to be seen whether future observations can chart a new way to measure primordial ^{7}Li unambiguously and precisely, but we remain ever optimistic.