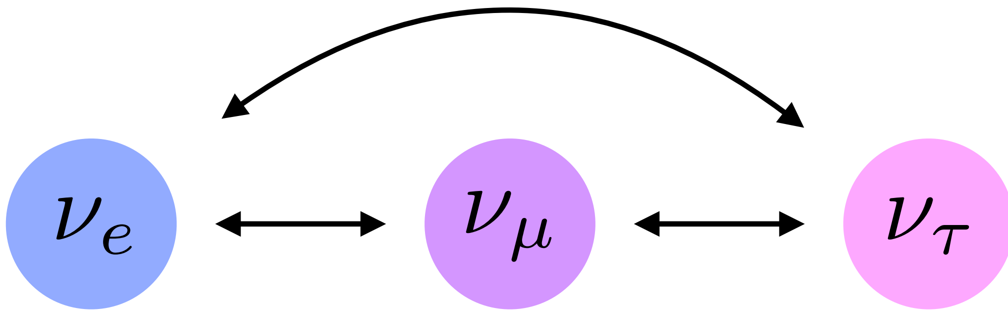
Probing the Neutrino Mass Mechanism with the CMB

Samuel J. Witte
University of Valencia (IFIC)

arXiv:1909.04044
(In collaboration with Miguel Escudero)

Neutrino Masses



Neutrino Oscillations

SNO (2001), Super-K (1998), …

$$m_{\nu,i} > 0$$

$$m_{\nu,j} > 0$$

Not included in SM

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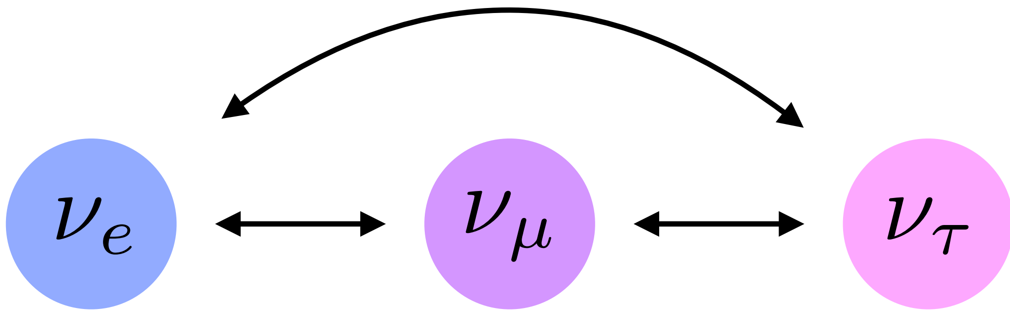

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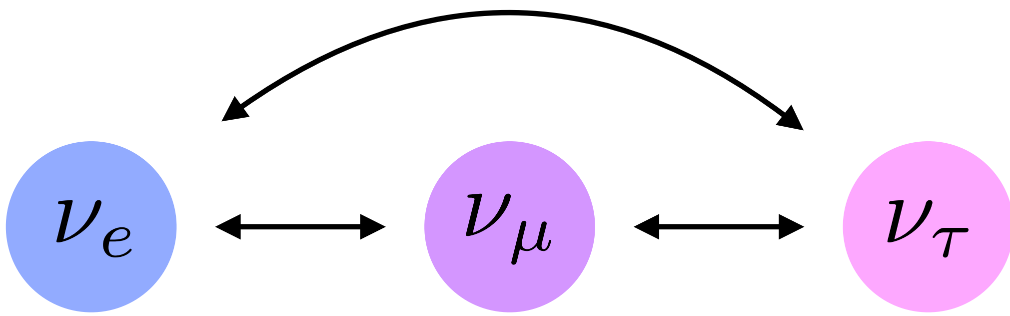
Dirac Neutrinos

$$\mathcal{L} \supset \lambda_\nu \, \bar{\ell} \, H \, \nu_R + h.c.$$

$$\lambda_\nu \lesssim 10^{-12}$$

Without more, unnatural yukawa…

Neutrino Masses



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Majorana Neutrinos

+ Majorana mass term: $m \, \overline{\nu^c} \, \nu$

Exploit seesaw

Minkowski (1977), Yanagida (1979), Gell-Mann et al (1979), Glashow(1980), Mohapatra et al (1980)

Explain smallness of neutrino masses

The Majoron

Majorana mass $m\,\overline{\nu^c}\,\nu$ violates $B-L$

1.) Broken Explicitly

2.) Broken Spontaneously

$\swarrow \qquad \searrow$

a.) Local symmetry

b.) Global symmetry

$\downarrow$

pseudo goldstone boson ϕ

Chikashige, Mohapatra, Peccei (1981)

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Majoron mass? D-5 Planck-scale operators (?): $m_\phi \sim \sqrt{\beta}\left(\frac{v_L}{v_H}\right)^{3/2}$ keV

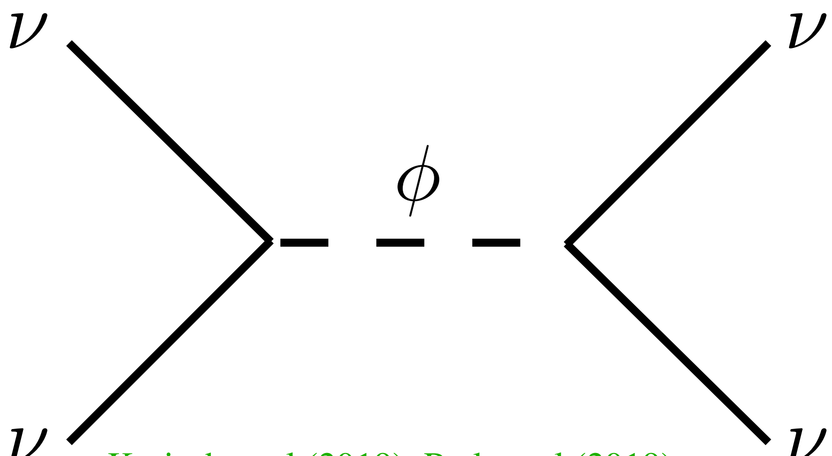
Rothstein, Babu, Seckel (1993),
Akhmedov, Berezhiani, Mohapatra, Senjanovic (1992)

Assuming v_L >> v_H

Majoron Cosmology

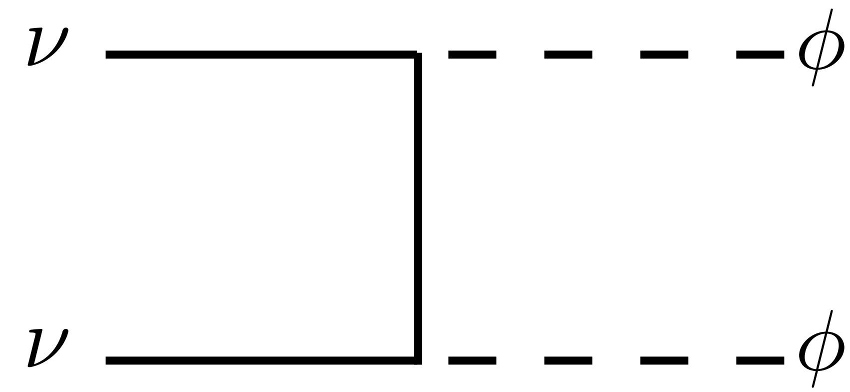
(**Not complete list of references)

Neutrino annihilations and scattering



Kreisch et al (2019), Park et al (2019),…

…



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Require large couplings to be relevant — nearly ruled out by current experiments

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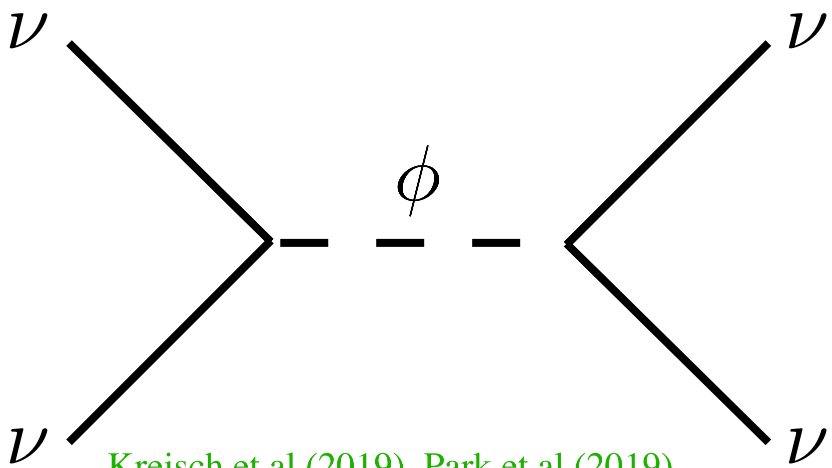

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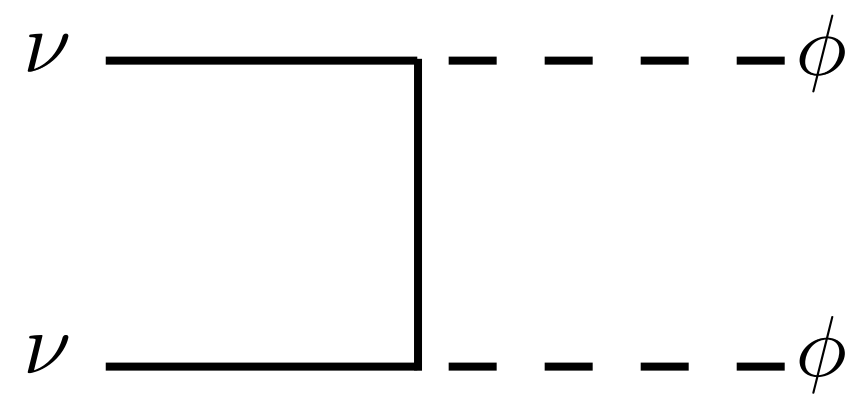

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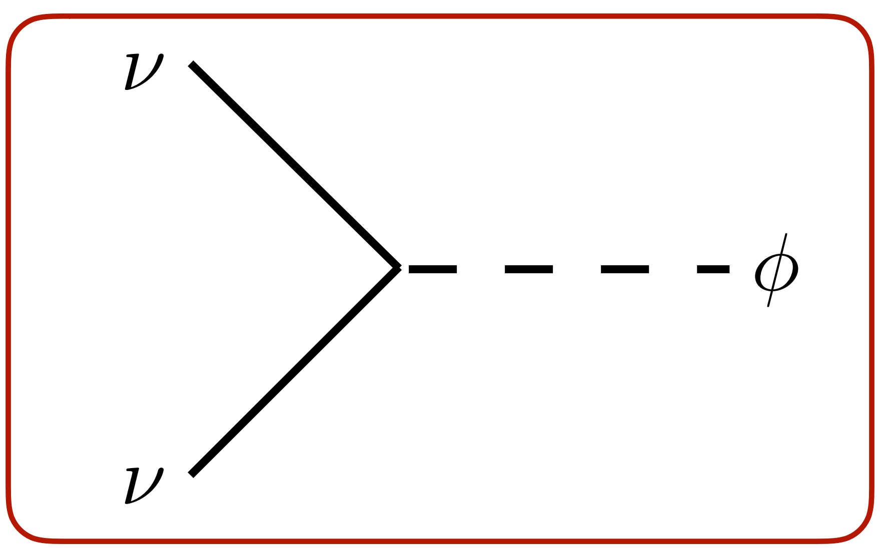
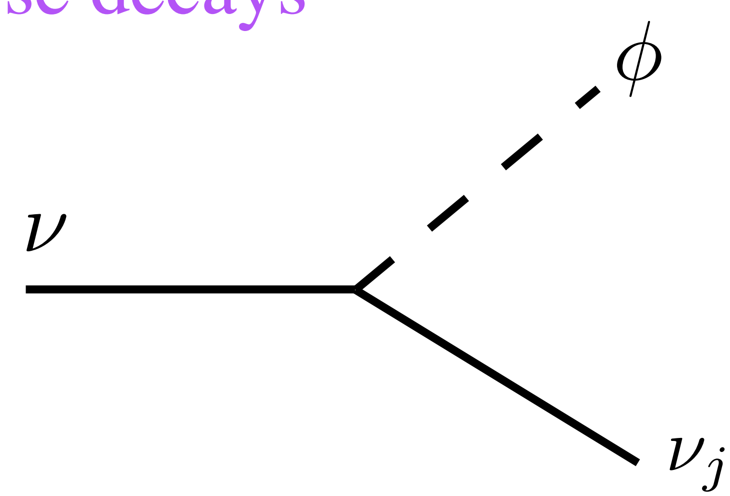
Neutrino decays and inverse decays



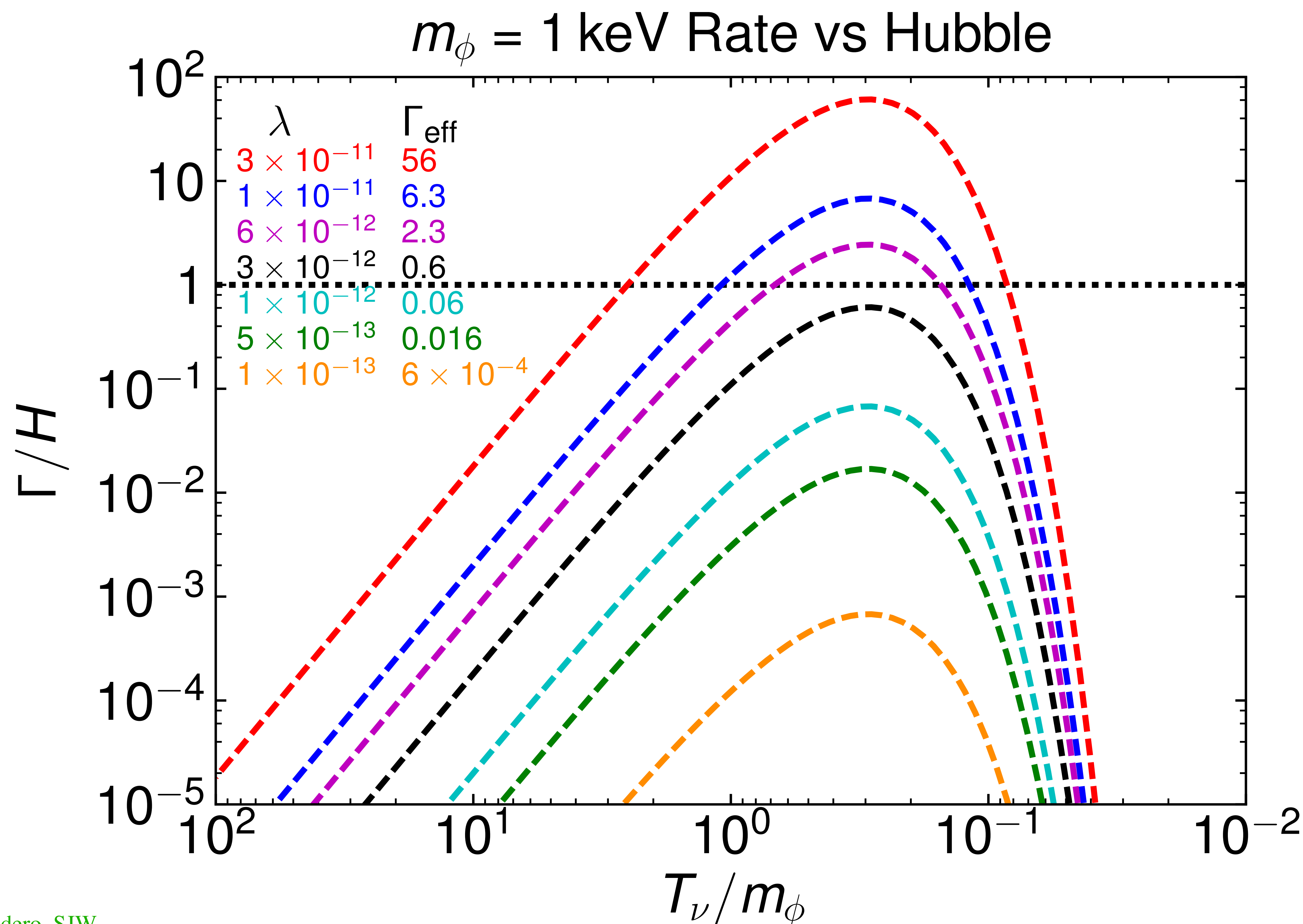


Archidiacono et al (2013), Escudero et al (2019), …

$m_\phi \in [0.1\,\mathrm{eV},\,\mathrm{MeV}]$ $\quad \lambda \sim [10^{-15}, 10^{-6}]$

Requires: $m_\phi < m_\nu$

Majoron Thermalization



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Majoron Thermalization

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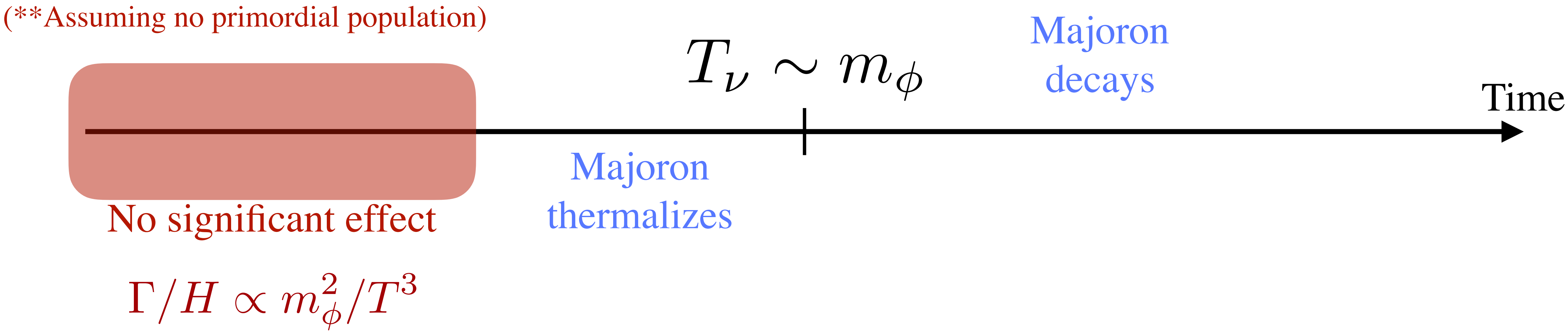
Evolution of Thermal Majoron



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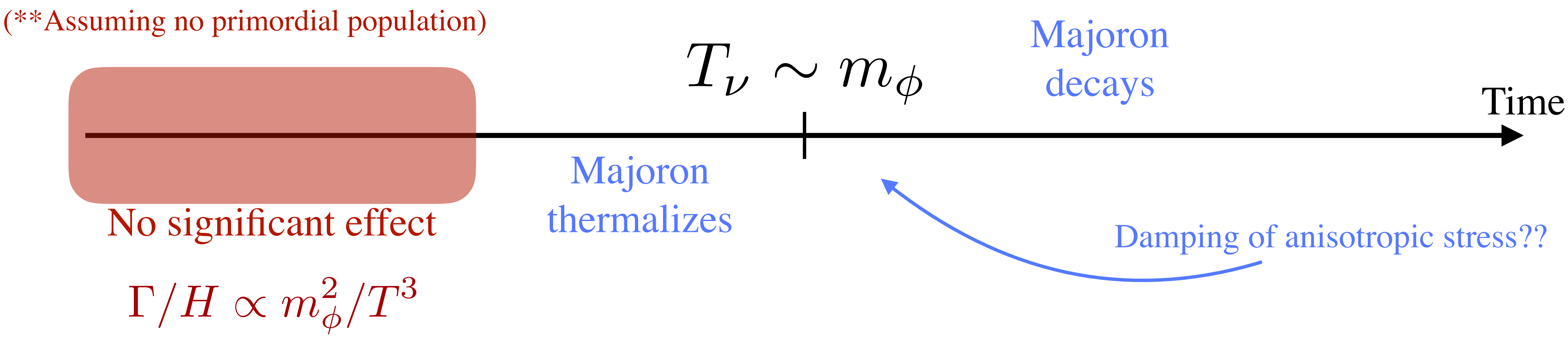

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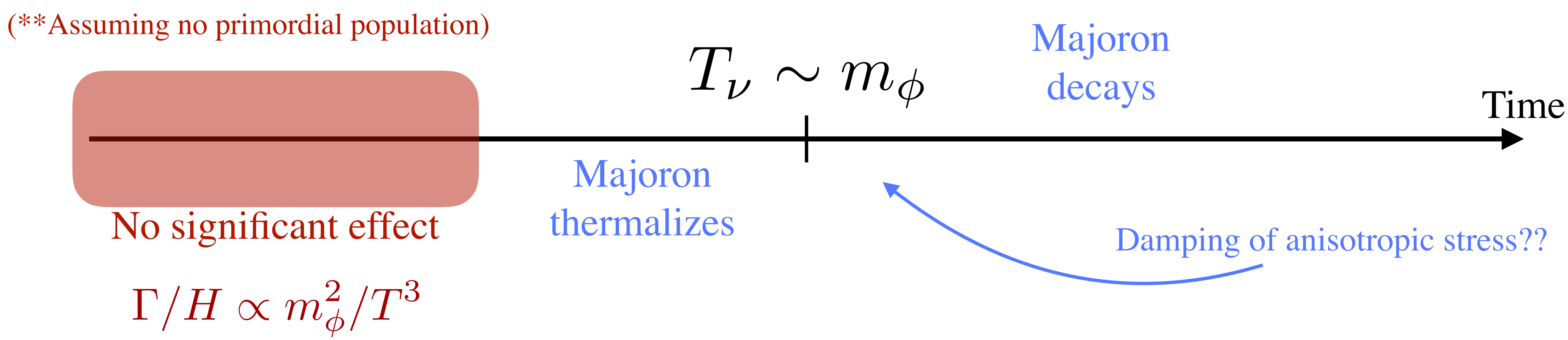

<u>Two Potential Effects:</u> Chacko et al (2003)

1.) If majoron decays before recombination, $\Delta N_{\text{eff}} \simeq 0.11$

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2.) If majoron thermalizes near recombination, damping of anisotropic stress

Bashinsky and Seljak (2003)

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$m_\phi \lesssim \mathcal{O}(100)\,\text{eV}$

Primordial Majorons

Thus far we have assumed no primordial population…

Sterile neutrinos thermalize if $T_{RH} \gtrsim 5 \times m_N$ (**type-I seesaw)

Easily generating thermal majoron population

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Entropy conservation: $$\Delta N_{\rm eff}\big|_{\rm BBN} \simeq 0.027 \qquad (\text{if} \quad m_\phi \lesssim \text{MeV})$$

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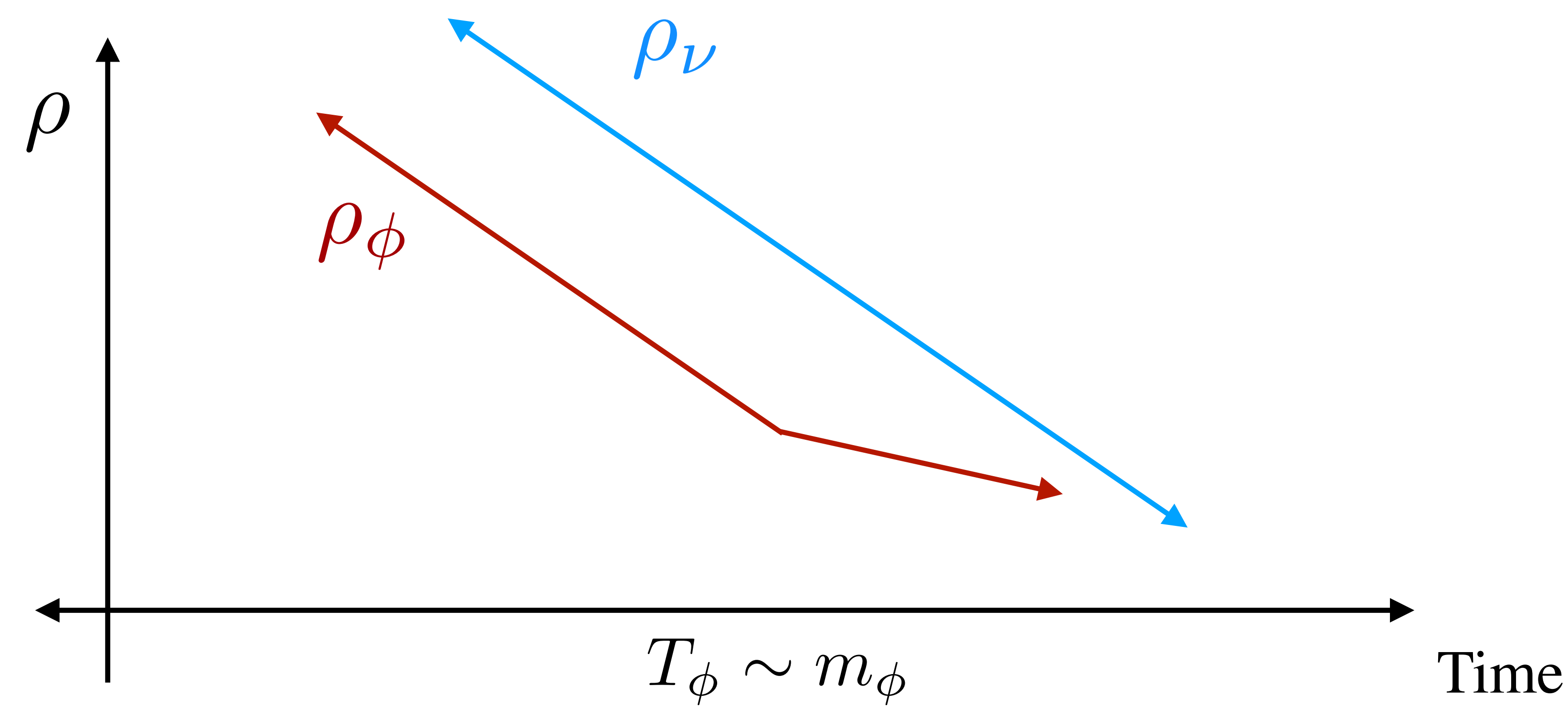
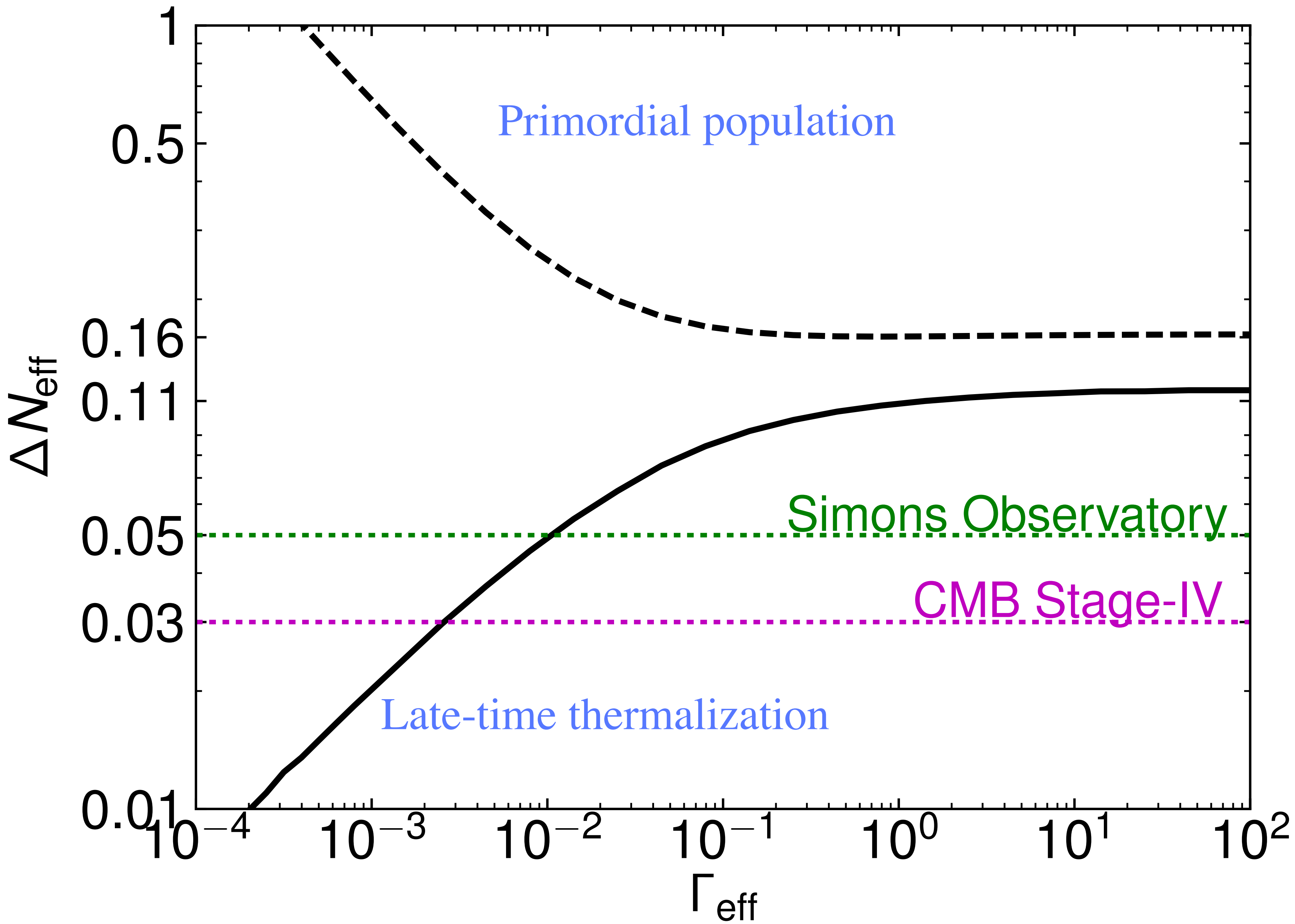
Entropy conservation: $\Delta N_{\rm eff}\big|_{\rm BBN} \simeq 0.027$ $(\text{if} \quad m_\phi \lesssim \text{MeV})$

If coupling small enough…



ΔN_{eff}



$$\Gamma_{\text{eff}} \equiv \left(\frac{\lambda}{4\times 10^{-12}}\right)^2 \left(\frac{\text{keV}}{m_\phi}\right)$$

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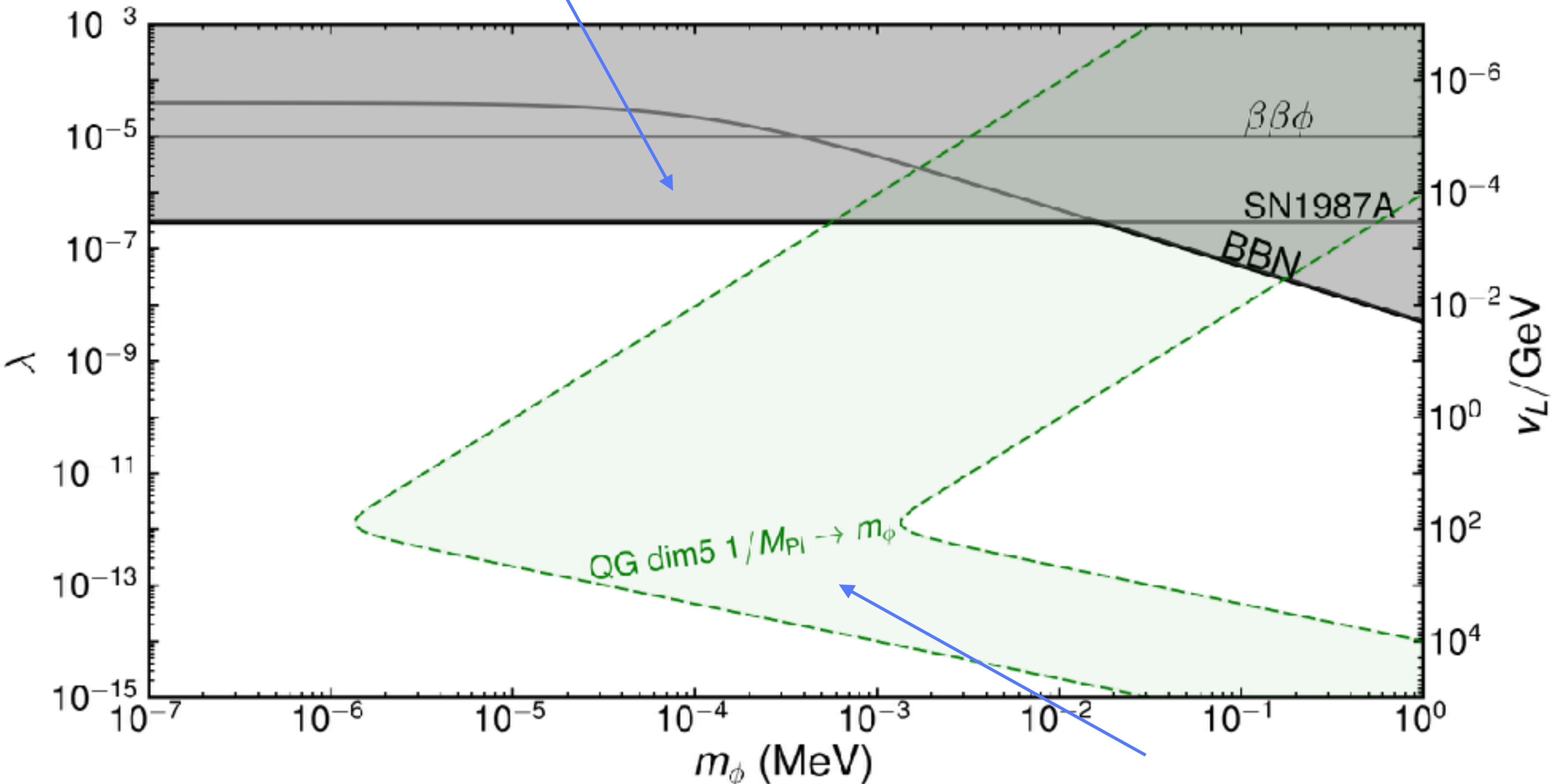
Majoron Cosmology

Excluded



Dim-5 QG Mass Prediction

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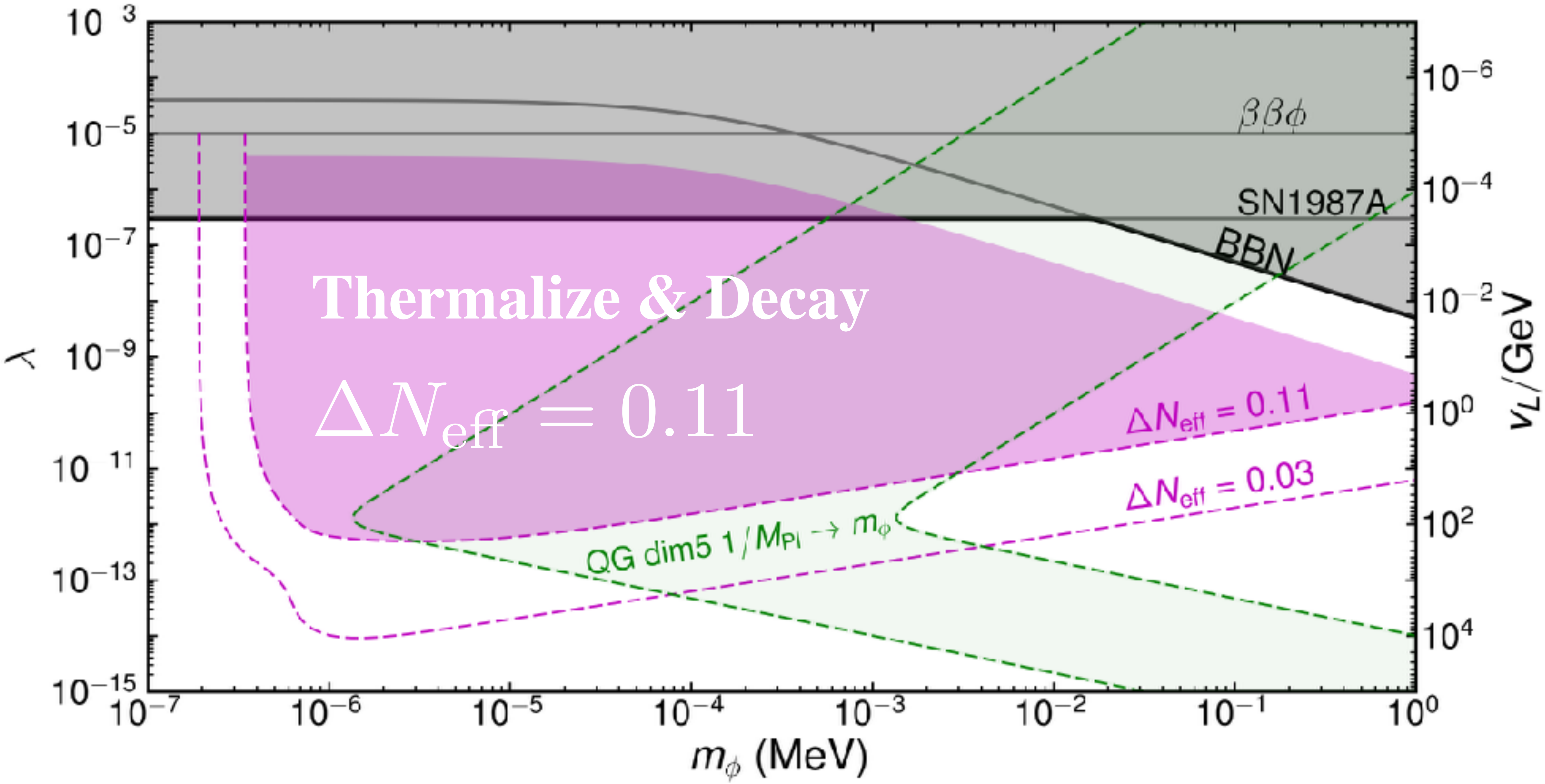
Majoron Cosmology



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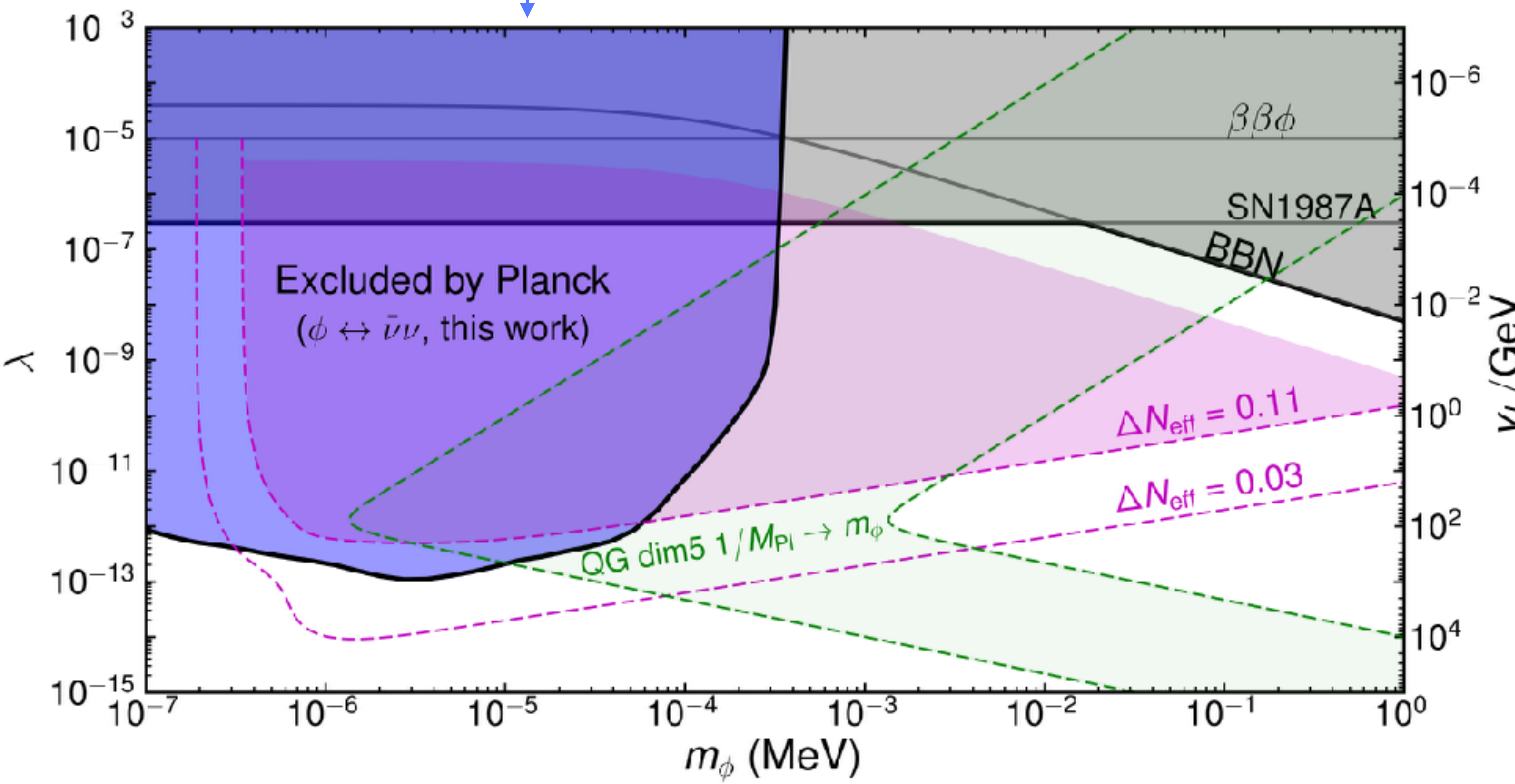
Majoron Cosmology

Excluded from perturbation damping



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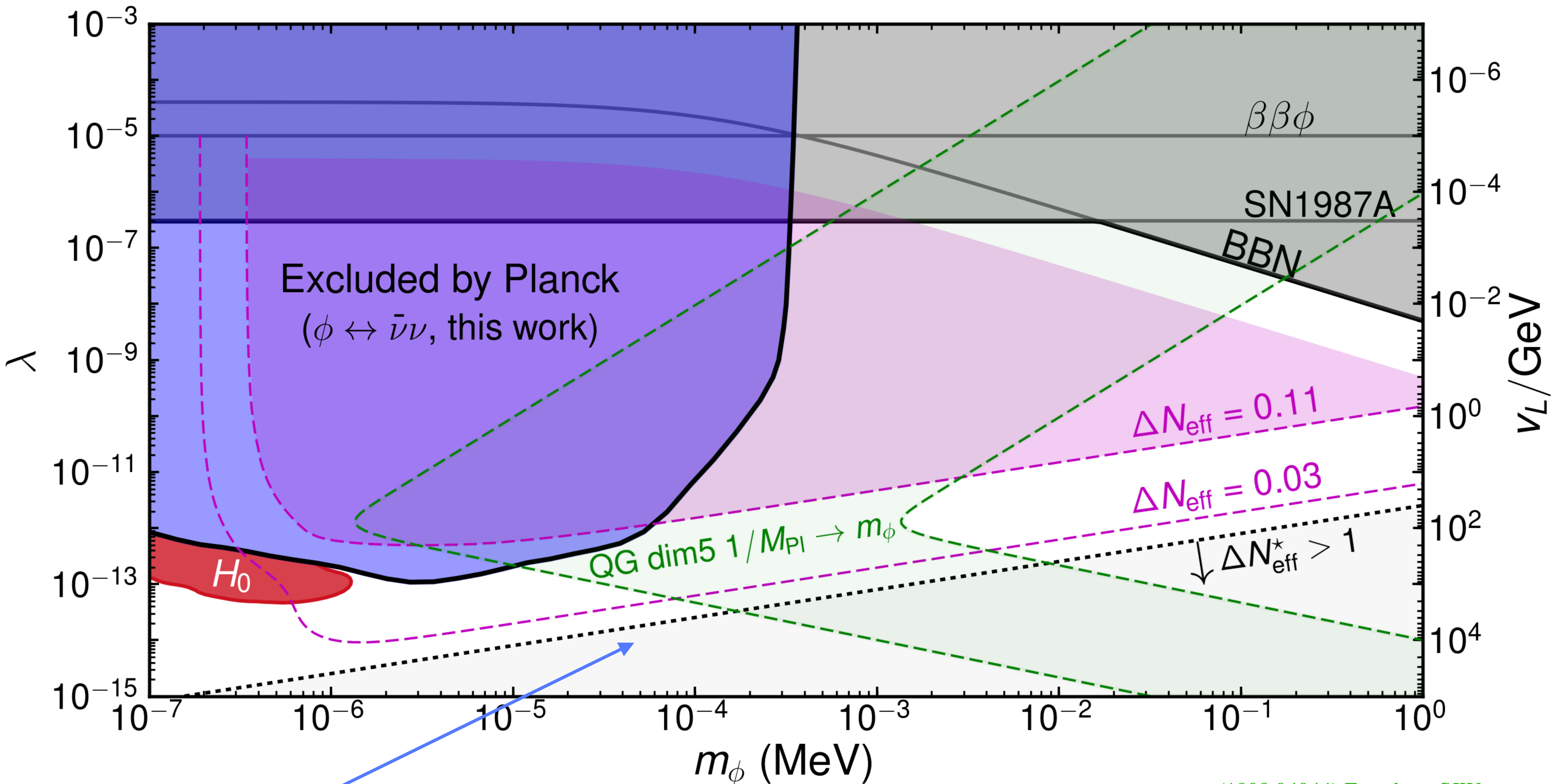
Majoron Cosmology



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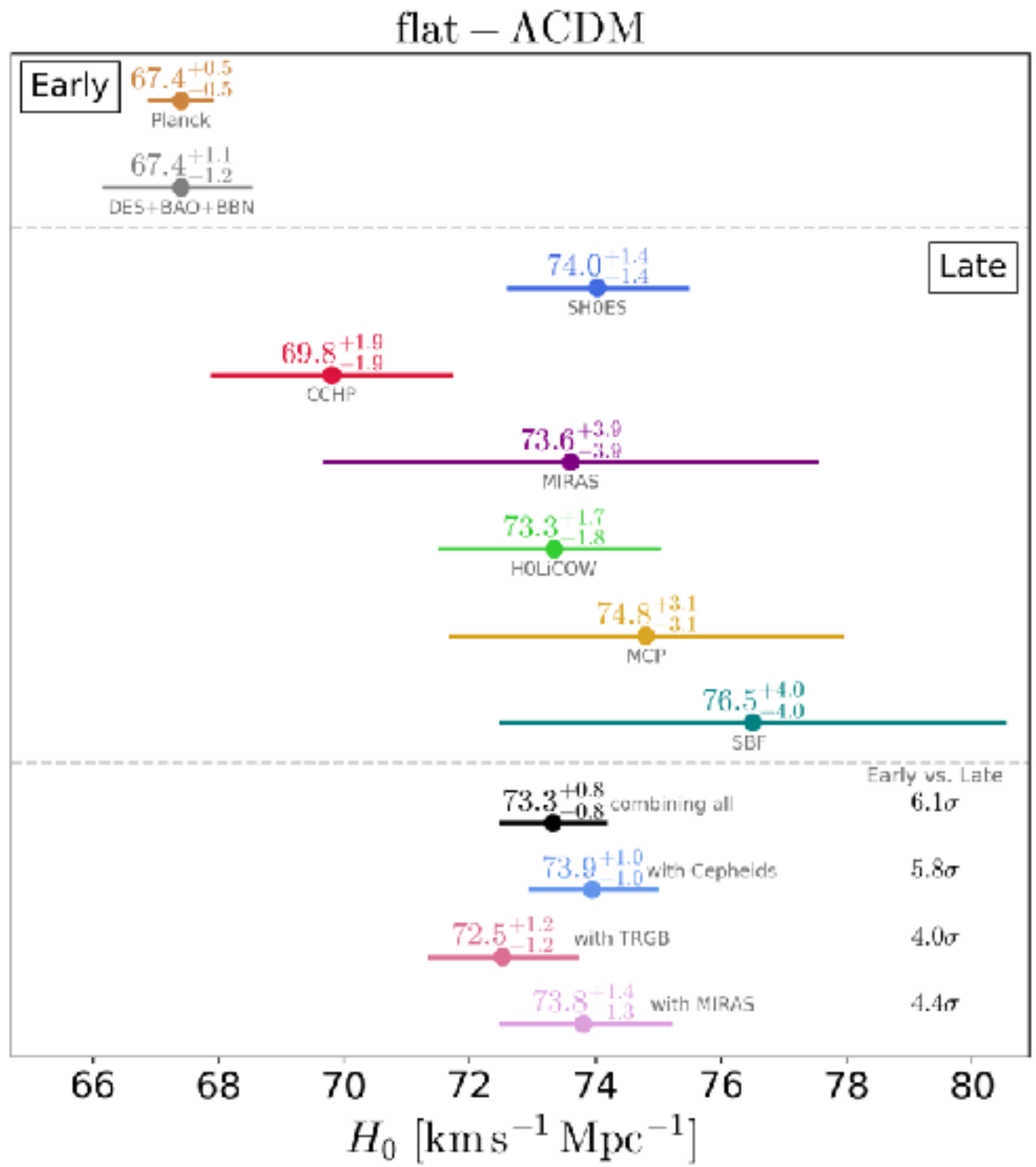
Excluded if primordial population

Hubble Tension



1907.10625, Figure by Vivien Bonvin

Hubble Tension

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Proposed solutions:

-Novel neutrino 2-to-2 interactions $+\Delta N_{\rm eff}$ Kreisch et al (2019), Park et al (2019), Archidiacono et al (2016), Di Valentino et al (2018)

-Exotic dark energy Poulin et al (2018), Agrawal et al (2019), Lin et al (2019), Di Valentino et al (2019)

-Dark sector interactions Bringmann et al (2018), Pandey et al (2019), Raveri et al (2019), Yang et al (2019)

-Modified gravity Renk et al (2017), Khosravi et al (2018), Lin et al (2019)

⋮

See e.g. Blinov et al (2019)

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Concerns:

- Phenomenological viability See e.g. Blinov et al (2019)
- Model complexity (# parameters and fine tuning?)
- Model appeal (Unphysical features? Well-motivated?)
- Quality of solution (Effect on posterior? Chi-squared fit?)

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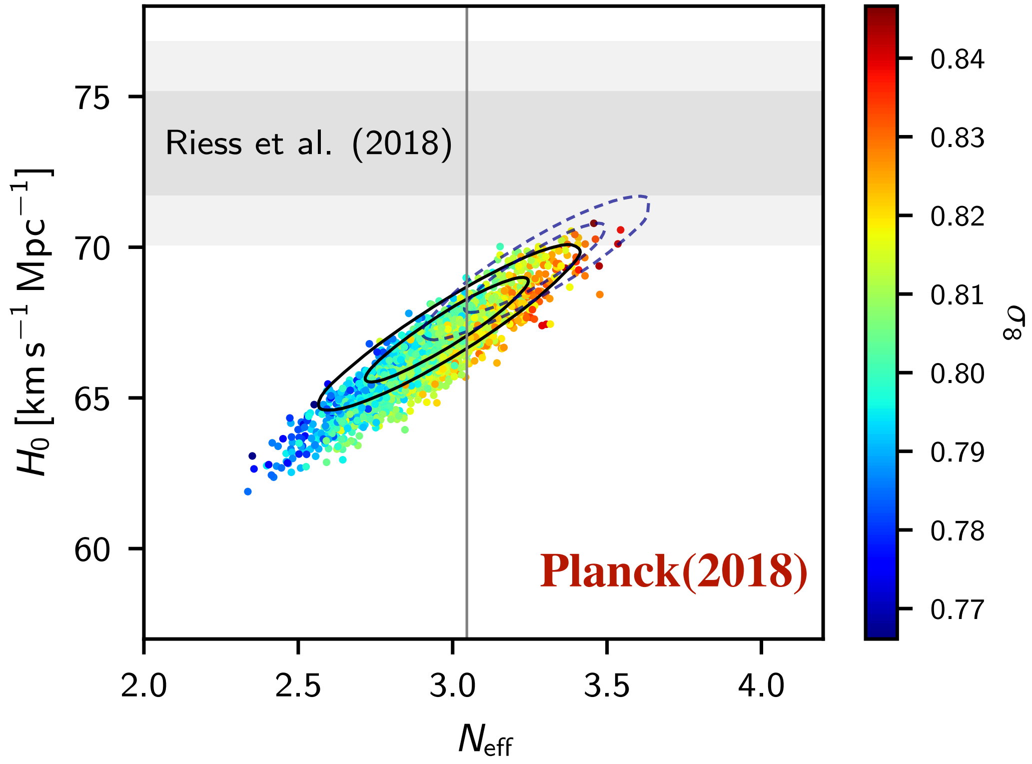
Partial resolution just with $\Delta N_{\rm eff}$ Bernal et al (2016), Morstell and Dhawan (2018)



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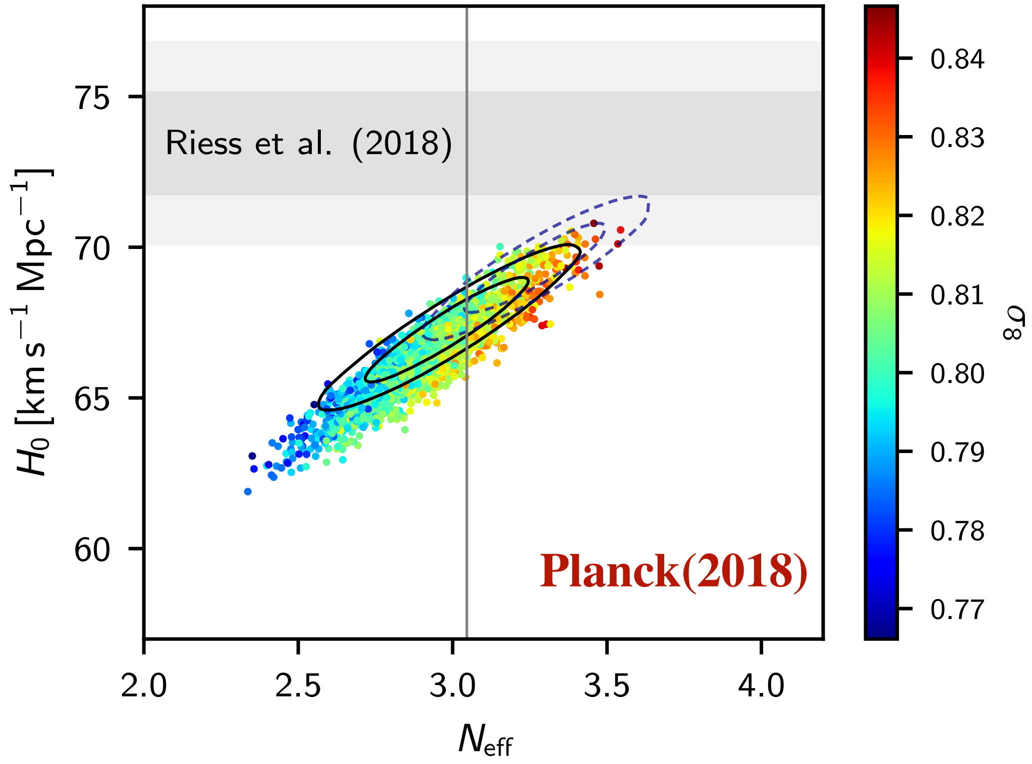
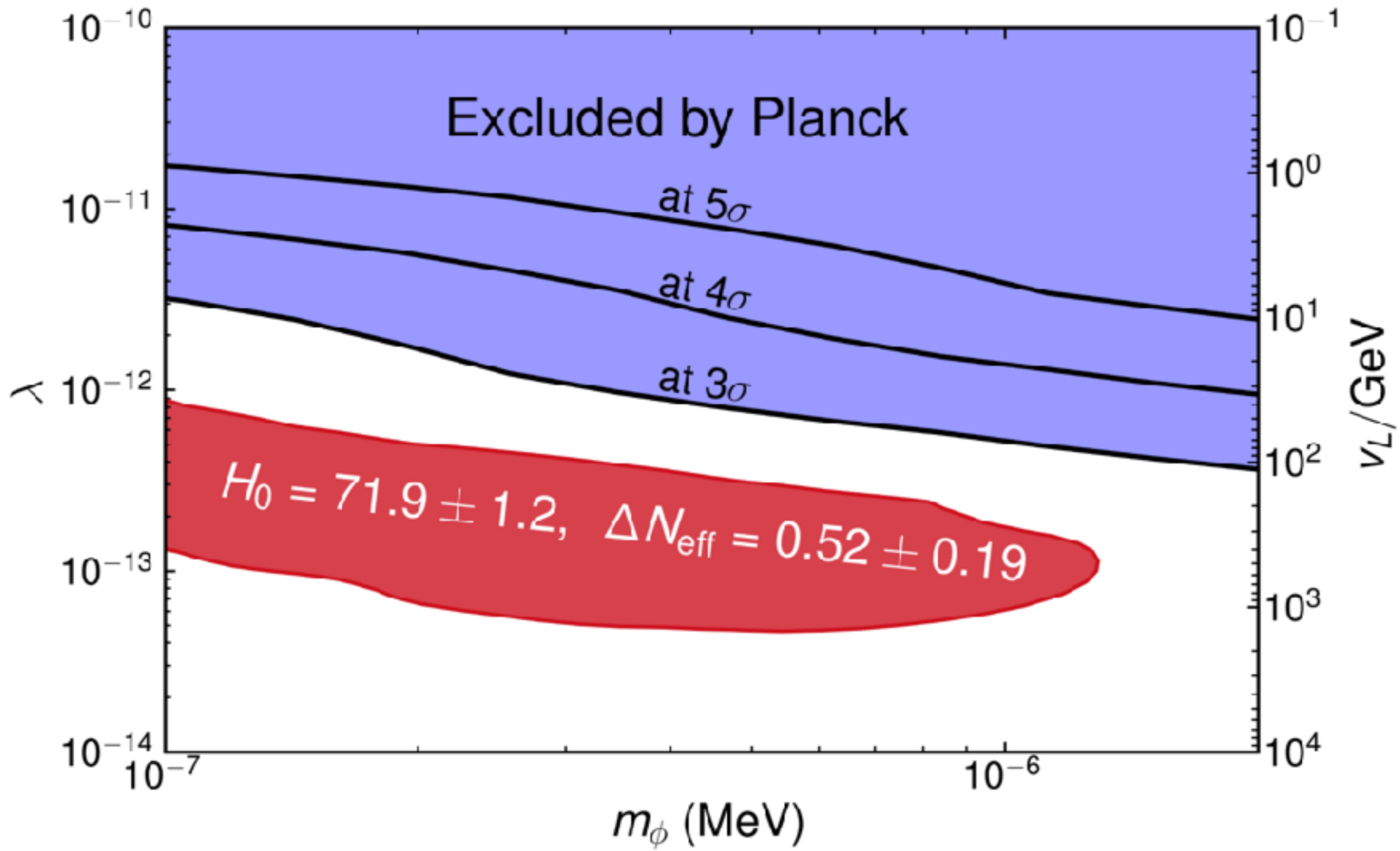


+ majoron interactions

Partial degeneracy with Neff:

- Allows for larger values of H0 while ***improving*** Planck fit

Hubble Tension



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Conclusions

- CMB provides powerful probe of pGBs arising in neutrino mass models

In context of type-I seesaw, Planck currently probing SSB scales ~ TeV

Should reheating temperature be sufficiently high, future CMB experiments may be capable of probing most of parameter space (for this mass range**)

- Does the Hubble tension point to beyond ΛCDM ?

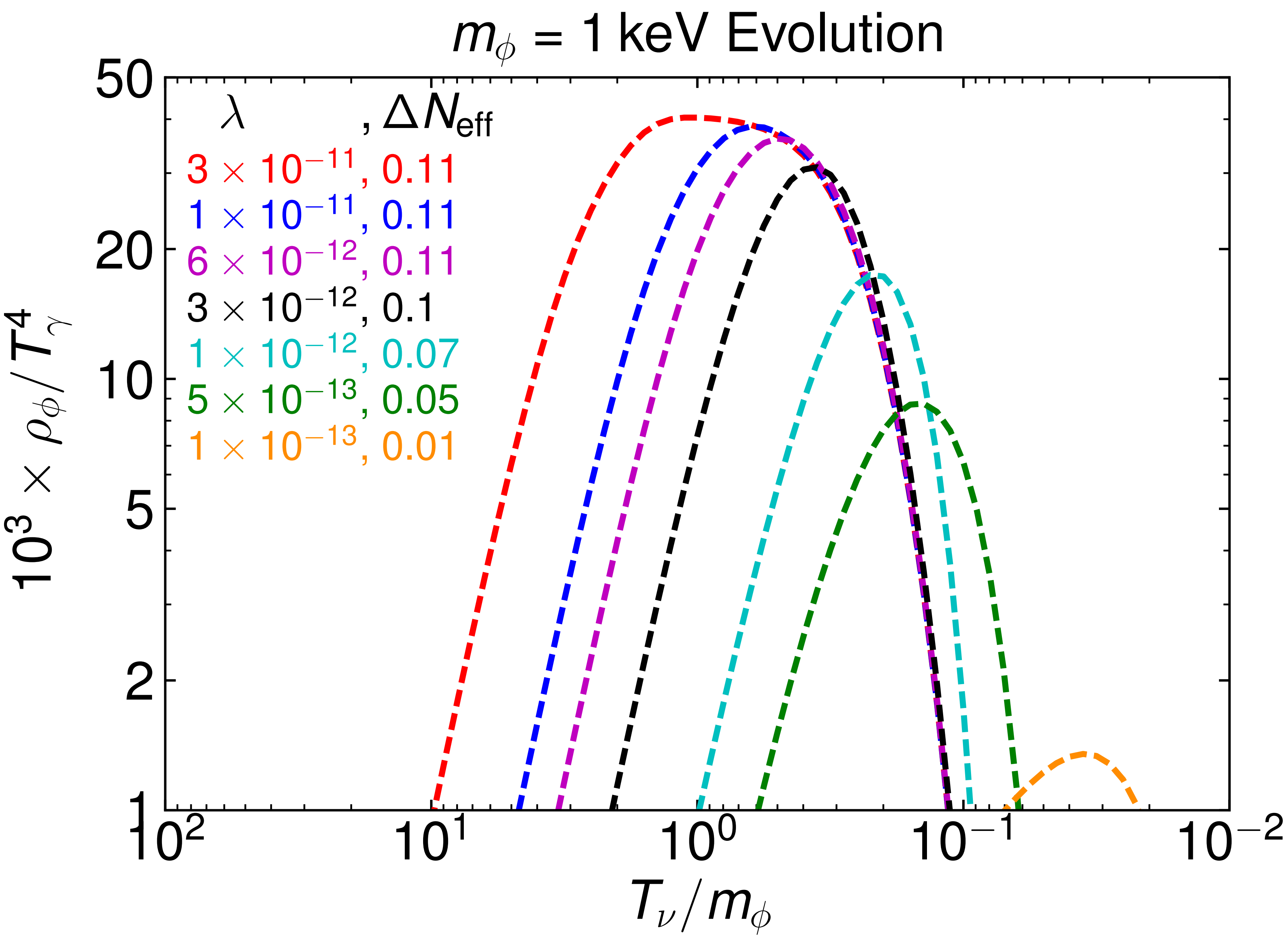
Majoron is well-motivated extension of SM that, when combined with $\Delta N_{\text{eff}} \sim 0.5$ can ameliorate H0 tension

Preferred parameter space: $m_\phi \sim 0.5\,\text{eV}$

$\lambda \sim 10^{-13}$ (Type-I Seesaw: $v_L \sim$ TeV)

Back-Up

Majoron Thermalization



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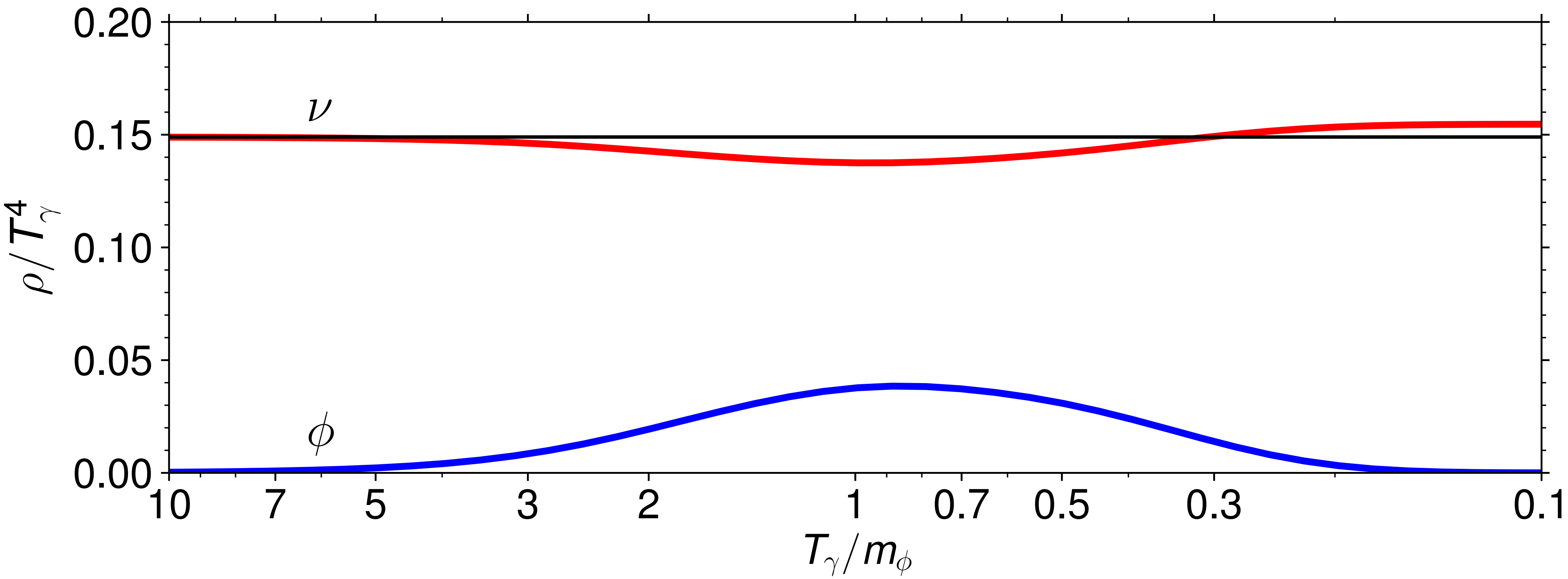
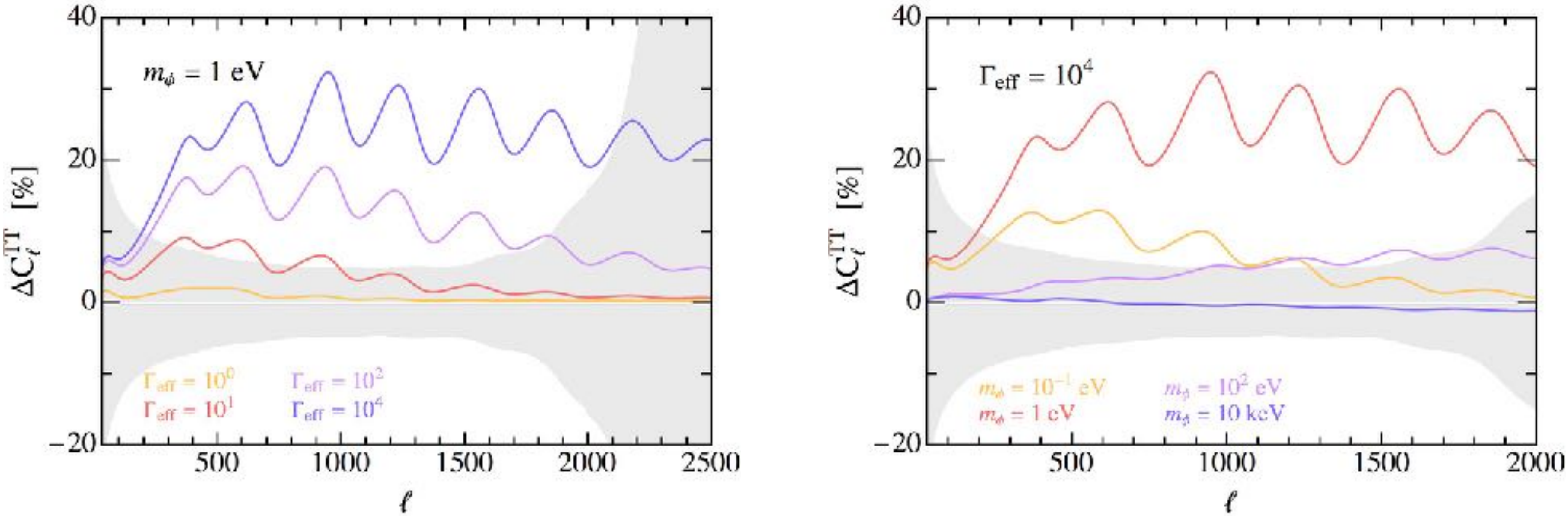


Temperature Cls



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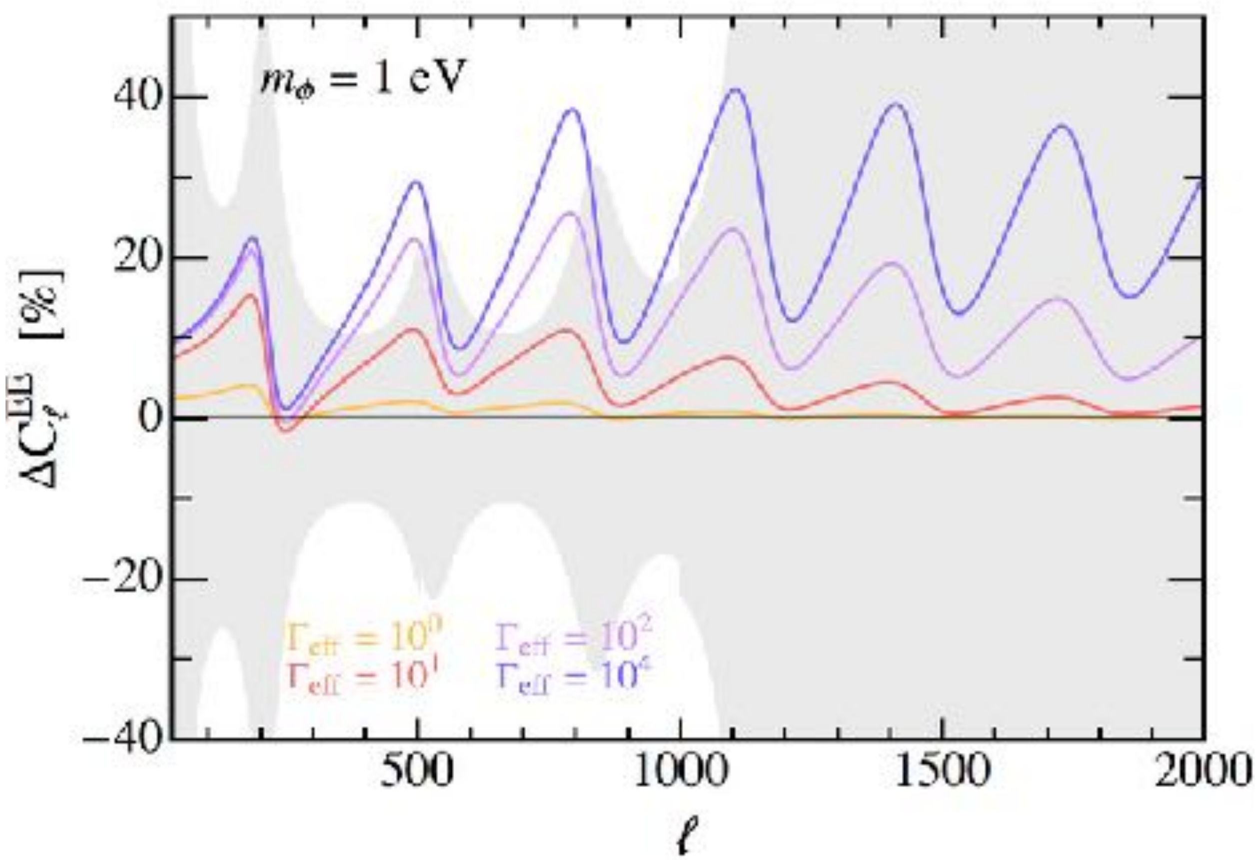
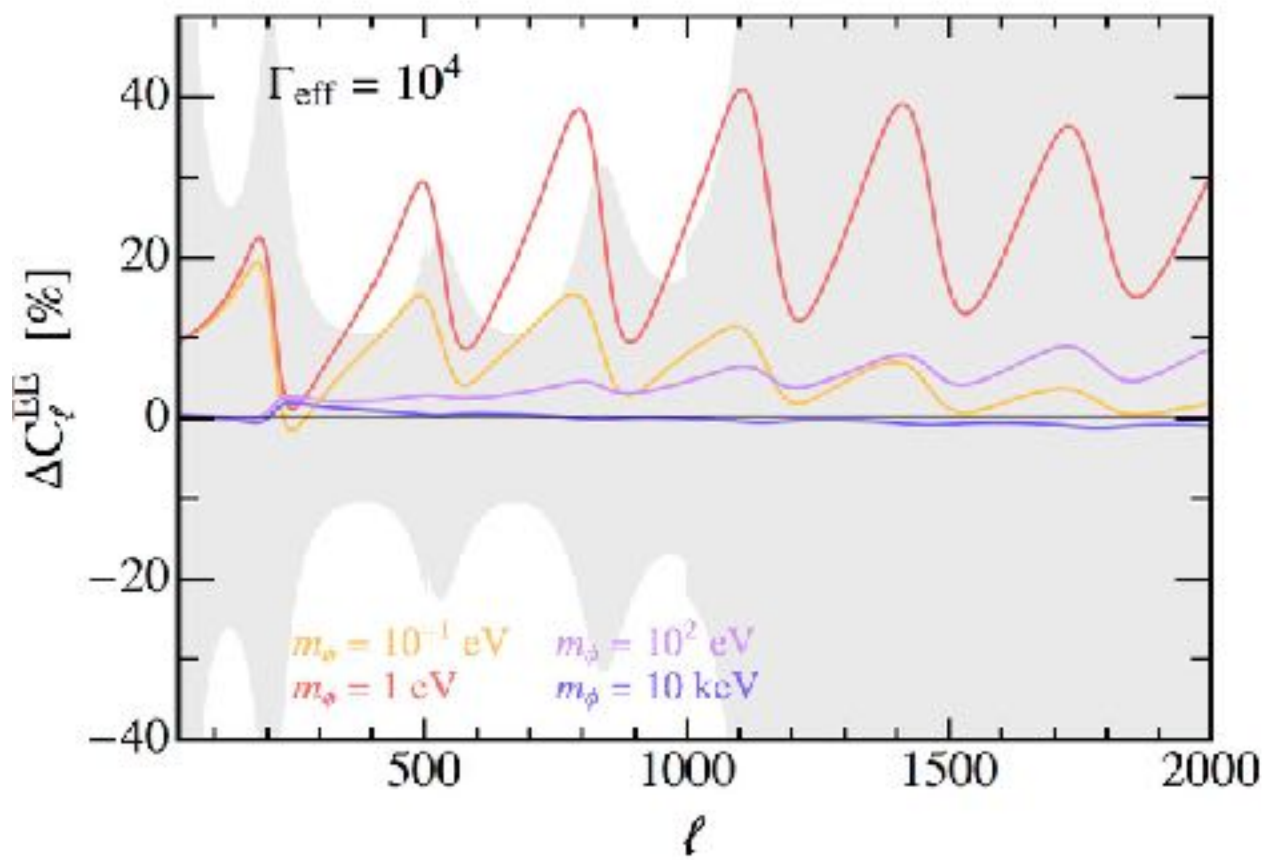
Polarization Cls





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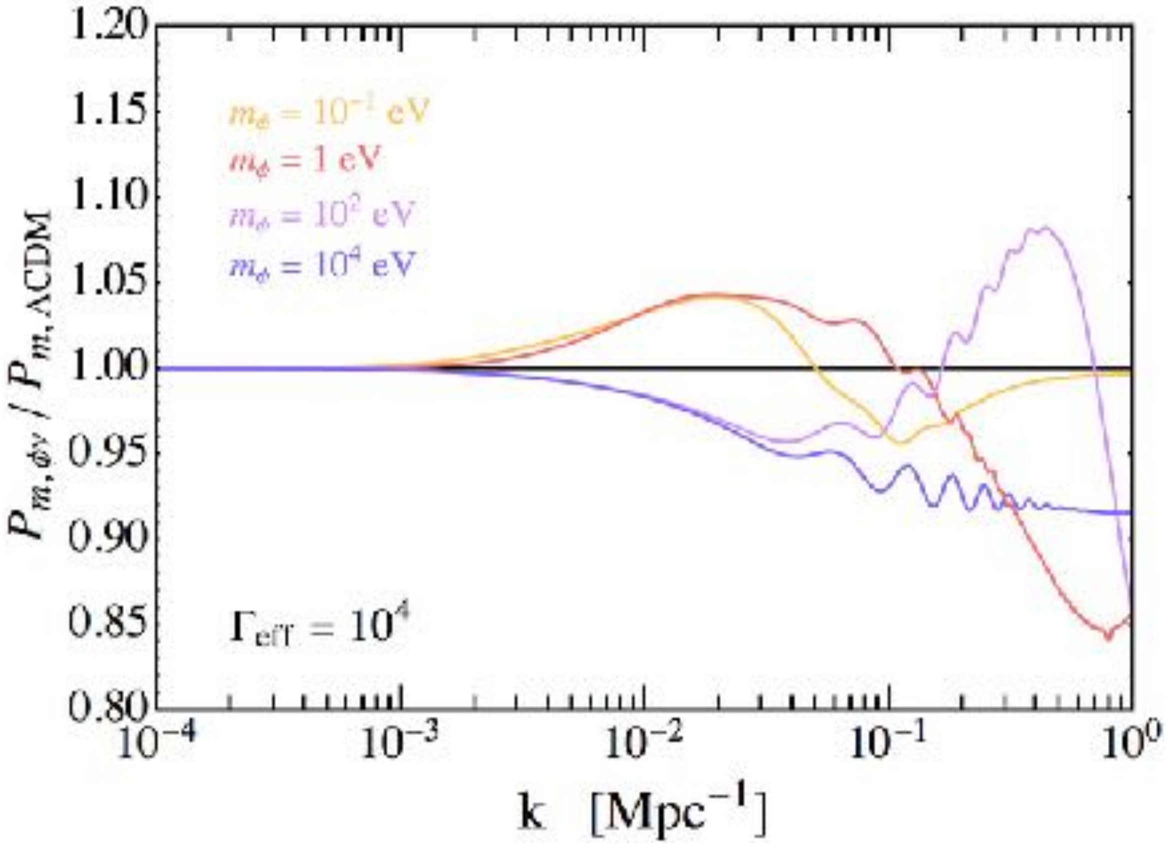
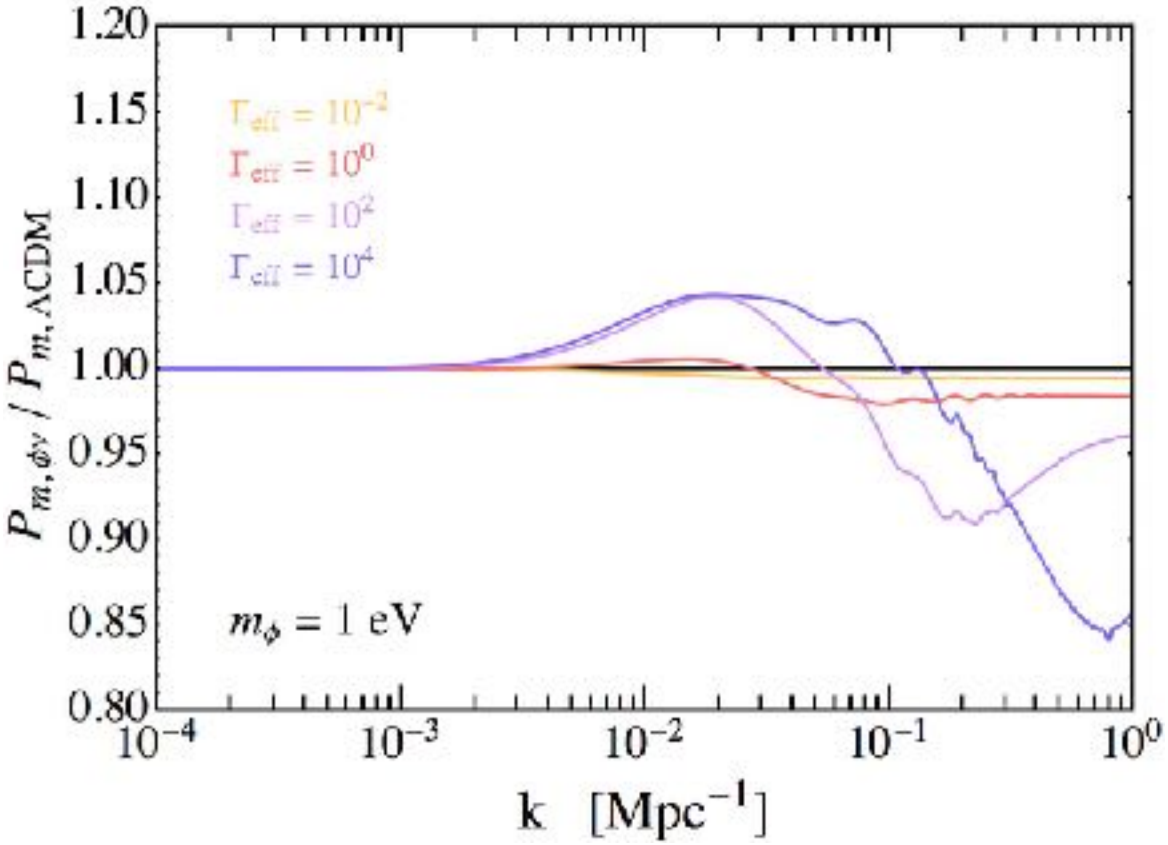
Matter Power Spectrum





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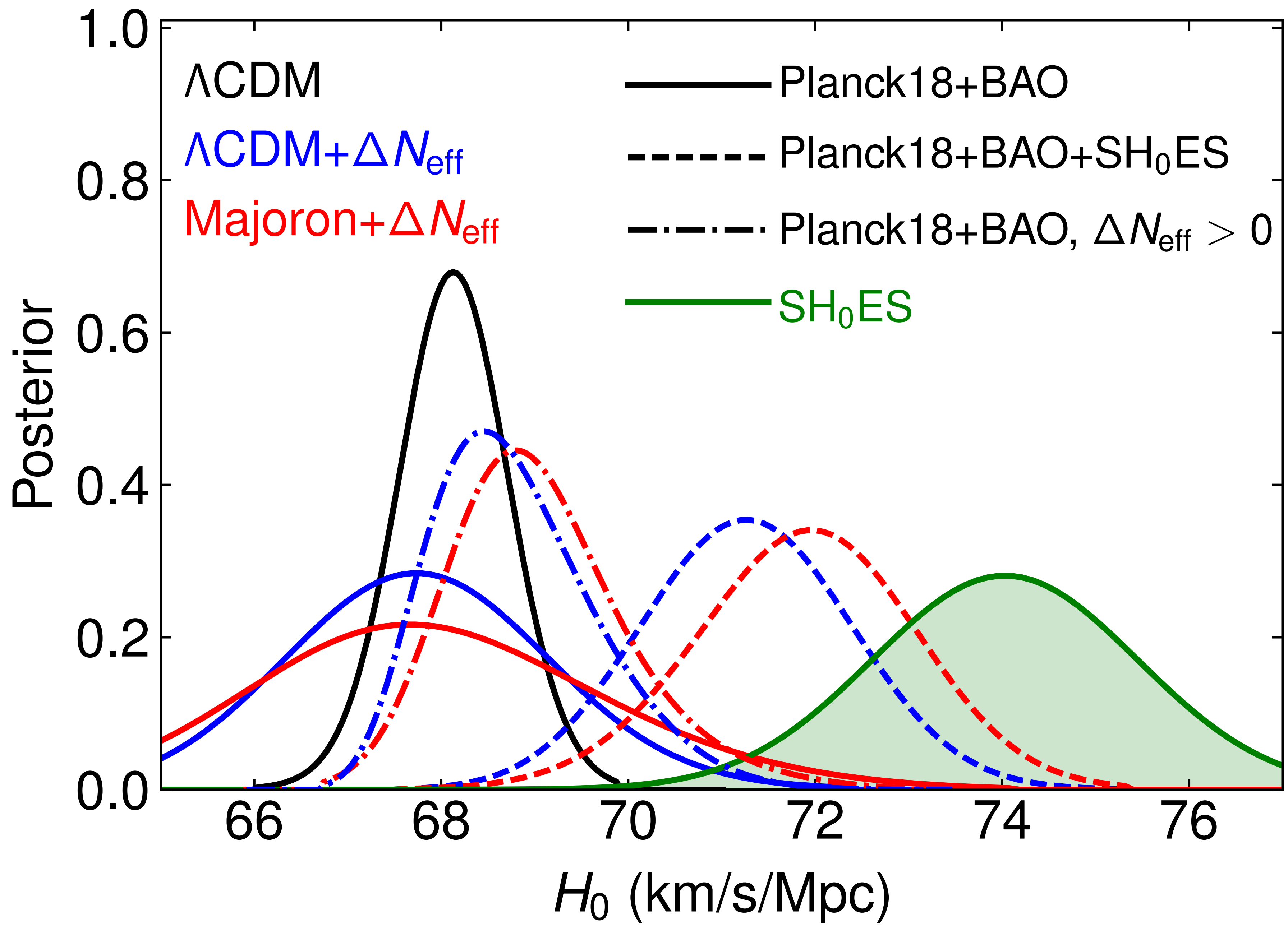
Hubble Tension



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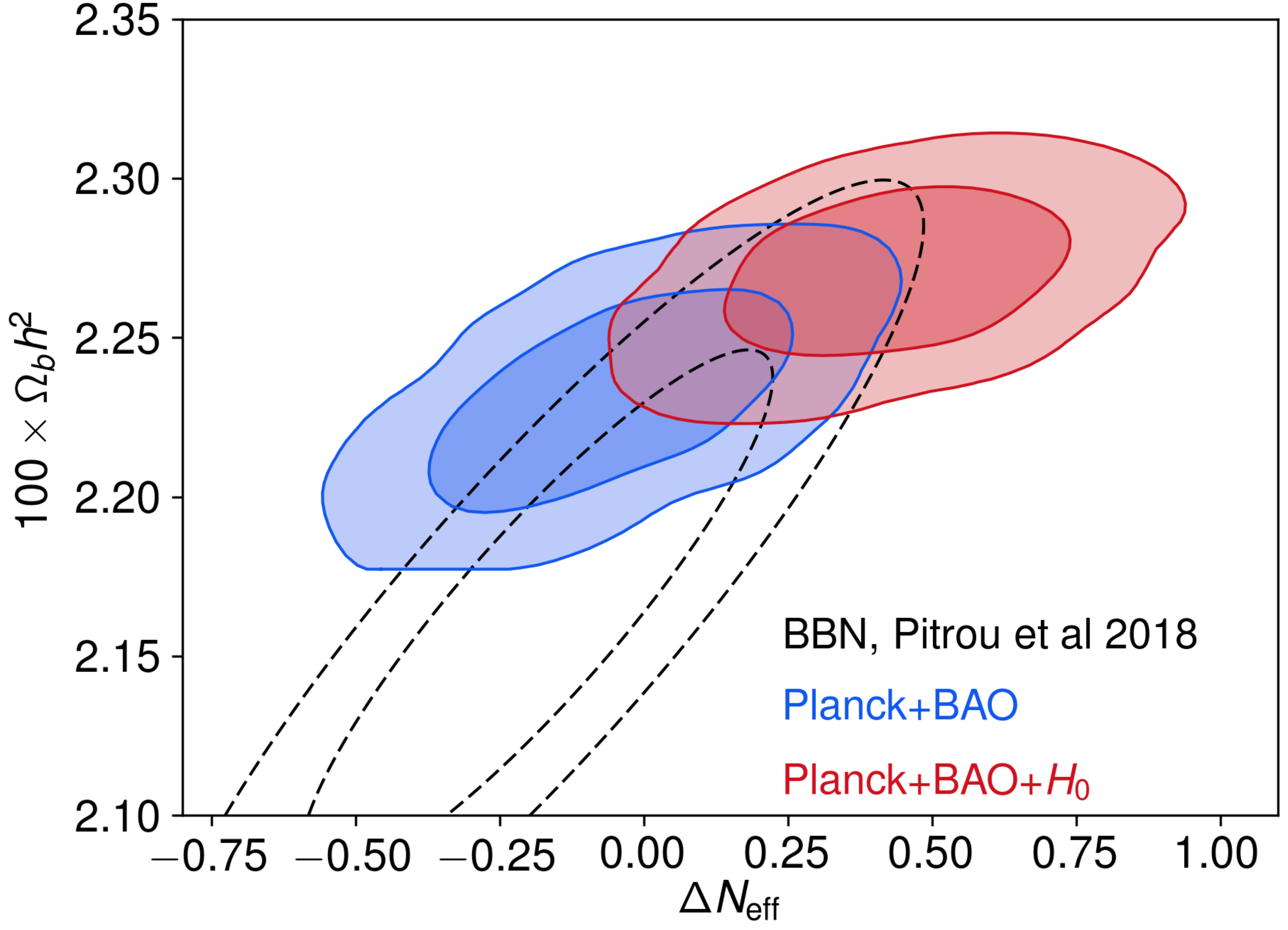
BBN



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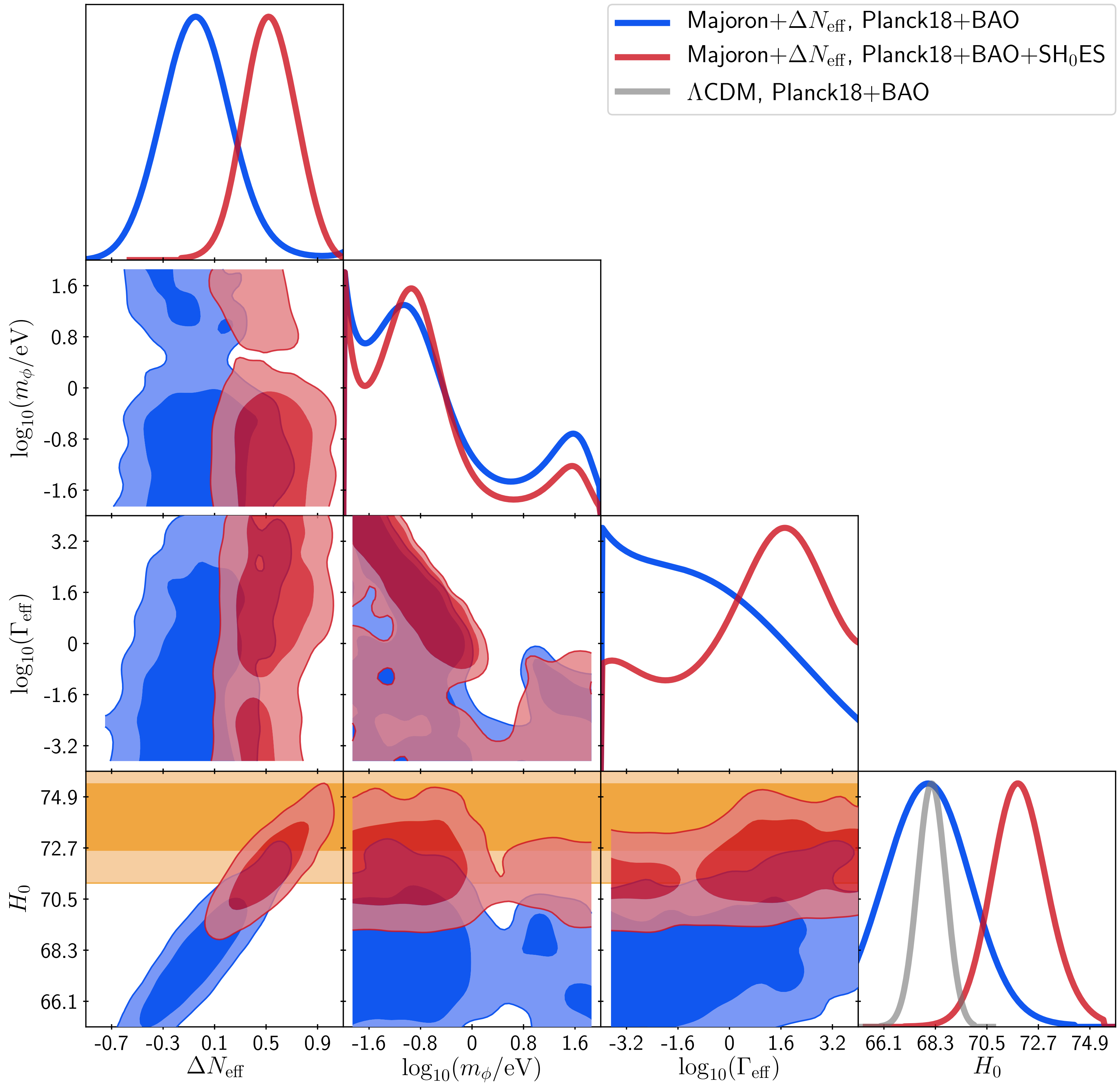
Majoron+$\Delta N_{\rm eff}$, Planck18+BAO
Majoron+$\Delta N_{\rm eff}$, Planck18+BAO+SH$_0$ES
ΛCDM, Planck18+BAO
$\log_{10}(m_\phi/\mathrm{eV})$
$\log_{10}(\Gamma_{\rm eff})$
H_0
$\Delta N_{\rm eff}$
-0.7 -0.3 0.1 0.5 0.9
-1.6 -0.8 0 0.8 1.6
-3.2 -1.6 0 1.6 3.2
66.1 68.3 70.5 72.7 74.9