Dark Neutrino interactions make Gravitational Waves Blue

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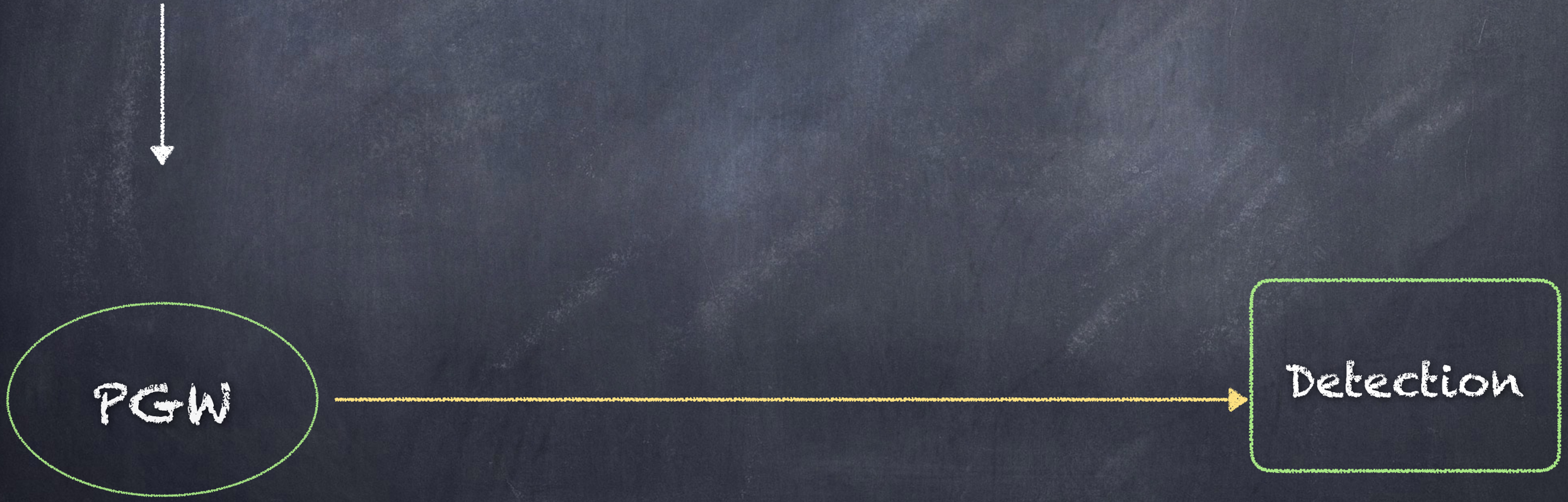
Introduction



Introduction

$\sim 10^{15}$ 10^{9} 10^{3} 0 N

SM Neutrino Decoupling

CMB

Inflation

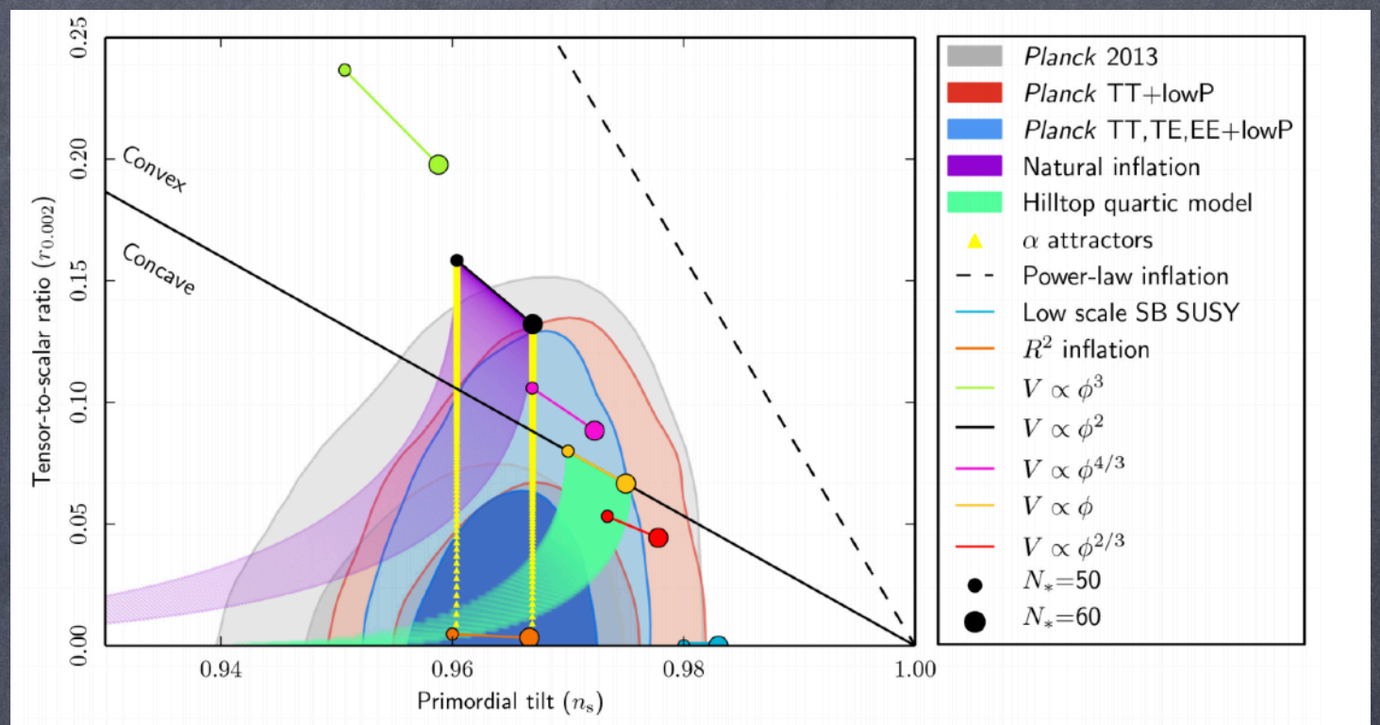


Fig. 12. Marginalized joint 68 % and 95 % CL regions for n_s and r at $k = 0.002\,\mathrm{Mpc}^{-1}$ from *Planck* compared to the theoretical predictions of selected inflationary models. Note that the marginalized joint 68 % and 95 % CL regions have been obtained by assuming $dn_s/d\ln k = 0$.

Planck Collaboration, 2015

PGW

Detection

Introduction

Different n_T

$$k^3 P_h(k) = A_* \left(\frac{k}{k_*}\right)^{n_T}$$

PGW → Detection

Introduction

Inflation /source

This simplified picture is not quite accurate

PGW

Detection

Introduction

Inflation /source

Interactions of free streaming particles

Change the anisotropic stress of the medium

PGW

Detection

Propagation depends crucially on anisotropic stress of the medium

Introduction

Inflation /source

Interactions of free streaming (Neutrinos) particles

PGW

Detection

Neutrino interactions modify GW Spectrum

Introduction

Inflation /source

Different n_T

Tilt the spectrum

Neutrino Interaction

Enhance signal at small scale

PGW

Stops free-streaming of Neutrinos

CMB / Direct Detection

A model of neutrino interaction

Dark-matter Neutrino Interaction

Potentially can also
solve small
scale problems in ΛCDM

Neutrino
self interactions

A model of neutrino interaction

$$SU(2)_W \times U(1)_Y \times SU(3)_l \times U(1)_L \times U(1)_D$$

Effective Model

$$\mathcal{L} \supset Y \frac{1}{\Lambda} \left(H^\dagger l\right)\left(\psi\chi\right)$$

Mediator

SM singlet

DM

A model of neutrino interaction

$$SU(2)_W \times U(1)_Y \times SU(3)_l \times U(1)_L \times U(1)_D$$

Effective Model

$$\mathcal{L} \supset Y \frac{1}{\Lambda} \left(H^\dagger l\right) \left(\psi\chi\right)$$

Mediator

SM singlet

DM

UV Completion

$$\mathcal{L} \supset Y_N \, N \left(H^\dagger l\right) + Y_{\bar{N}} \, N^c \left(\psi\chi\right) + M_N \, N N^c$$

Heavy Sterile neutrino

A model of neutrino interaction

$$SU(2)_W \times U(1)_Y \times SU(3)_l \times U(1)_L \times U(1)_D$$

$$\mathcal{L} \supset Y \frac{1}{\Lambda} \left(H^\dagger l\right)(\psi\chi)$$

Mediator

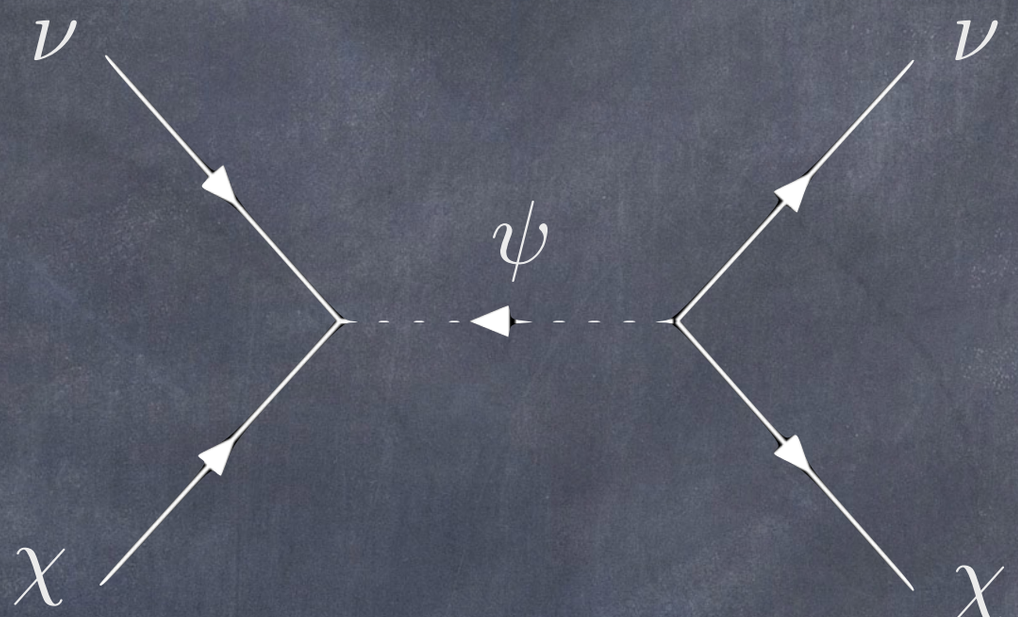
SM singlet

DM

EWSB

$$y\nu(\psi\chi)$$

A model of neutrino interaction



$\sigma_{\chi\nu}$

Degenerate mass → $\sigma^{(0)}$

Non-degenerate mass → $\sigma^{(2)} \left(\frac{T_\nu}{1.95\ \mathrm{K}} \right)^2$

Dimensionless

$$u^{(0)} = \left(\frac{\sigma^{(0)}}{\sigma_{\mathrm{Th}}} \right) \left(\frac{100\mathrm{Gev}}{m_\chi} \right)$$

$$u^{(2)} = \left(\frac{\sigma^{(2)}}{\sigma_{\mathrm{Th}}} \right) \left(\frac{100\mathrm{Gev}}{m_\chi} \right)$$

Interaction strength

How does it affect GW ??

GW Evolution

Dominant contribution
Neutrino

$$\frac{\partial^2}{\partial\eta^2}\mathcal{D}_q + 2aH\frac{\partial\mathcal{D}_q}{\partial\eta} + q^2\mathcal{D}_q = 16\pi a^2 G\pi_q^T$$

GW mode

Anisotropic Stress

Neutrino interaction enhances GW

Dominant contribution

Neutrino

$$\frac{\partial^2}{\partial\eta^2}\mathcal{D}_q + 2aH\frac{\partial\mathcal{D}_q}{\partial\eta} + q^2\mathcal{D}_q = 16\pi a^2 G\pi_q^T$$

GW mode

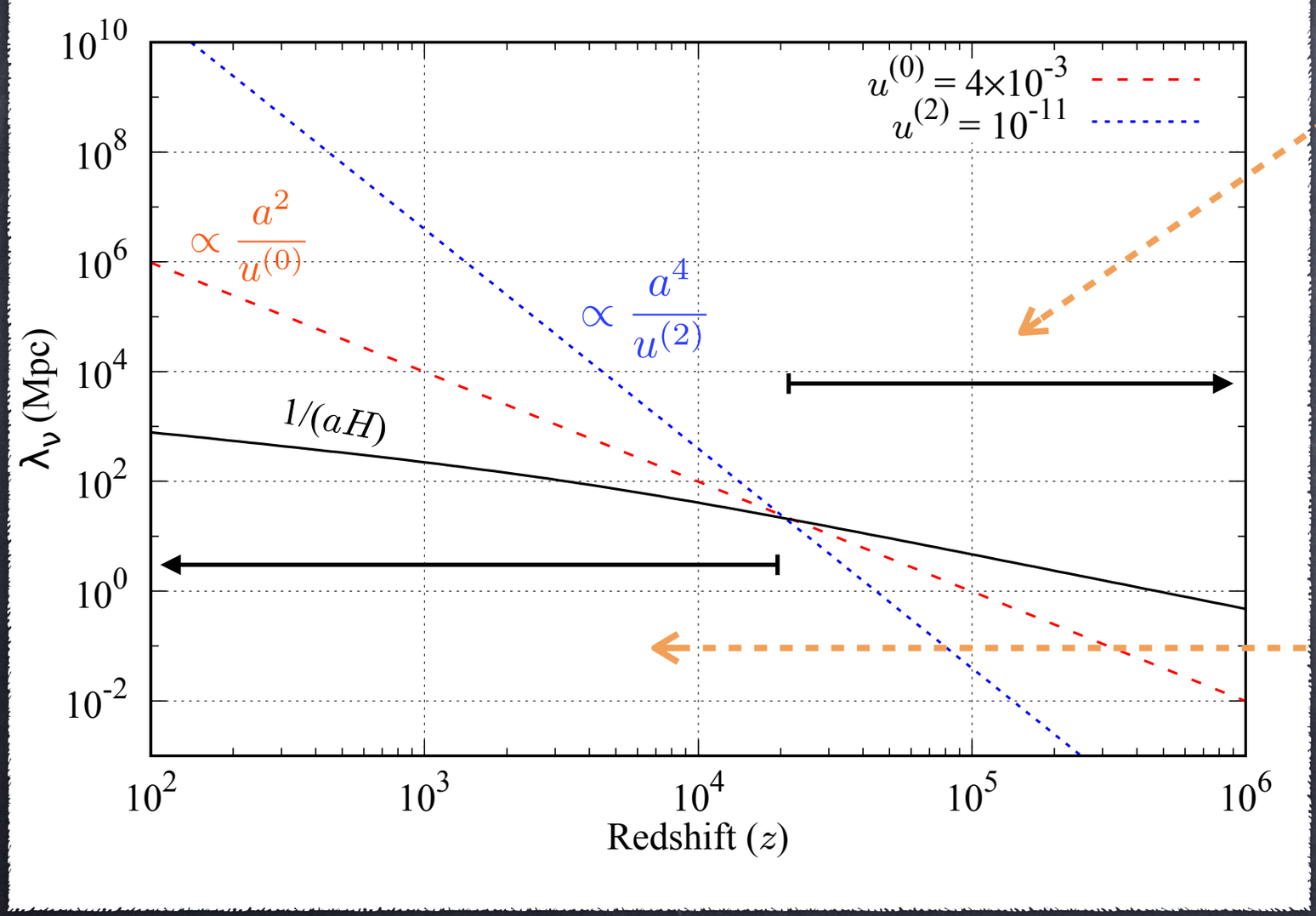
Suppressed due to $\sigma_{\chi\nu}$

Mean free path of Neutrino

Mean free path > Hubble scale

(depends on $u^{(0)}, u^{(2)}$)

Mean free path of Neutrino

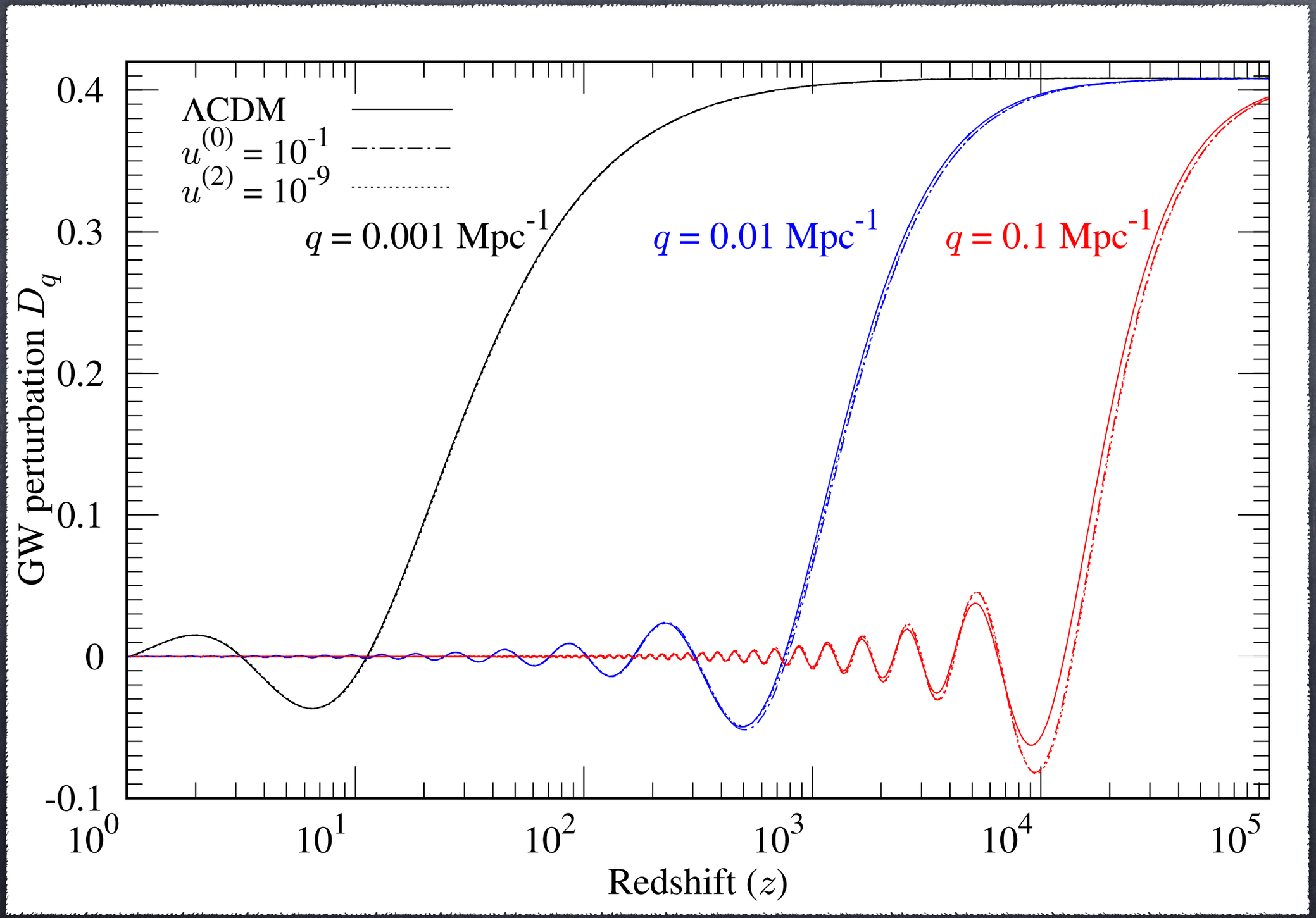


GW wave mode entering horizon here would be enhanced compared to ΛCDM

Modes entering here Will have same Evolution as ΛCDM

Comparison with Hubble

Neutrino interaction enhances GW



Effect on CMB B mode

Review of CMB B mode

Quadrupolar Anisotropy
At Last scattering surface

Polarisation in
CMB

Polarisation signal
of CMB

scalar + tensor (GW)

tensor (GW)

E mode

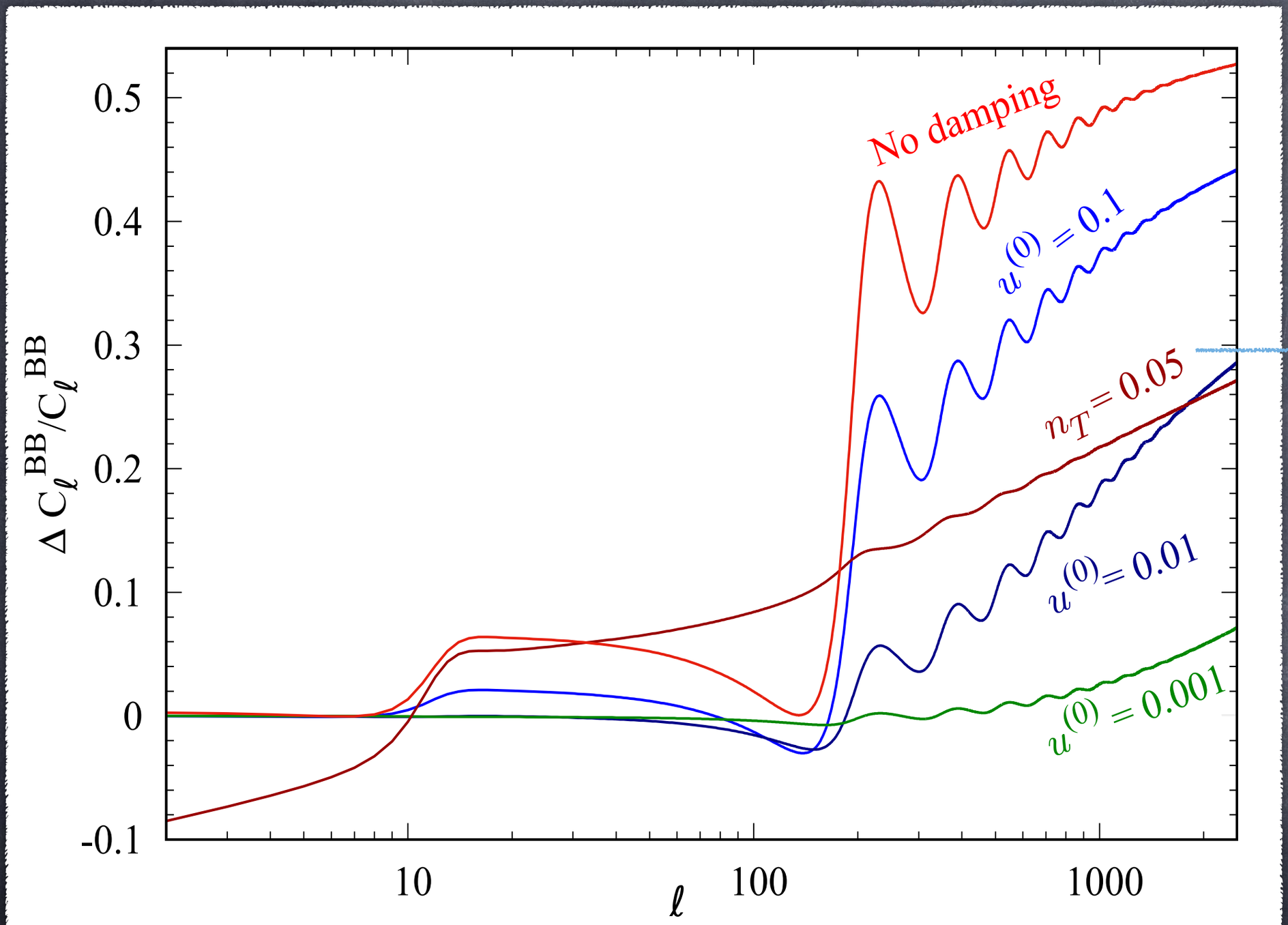
B mode

E mode

Gravitational
lensing

B mode

Neutrino interaction enhances B modes at small scale



Changing tensor Spectral index

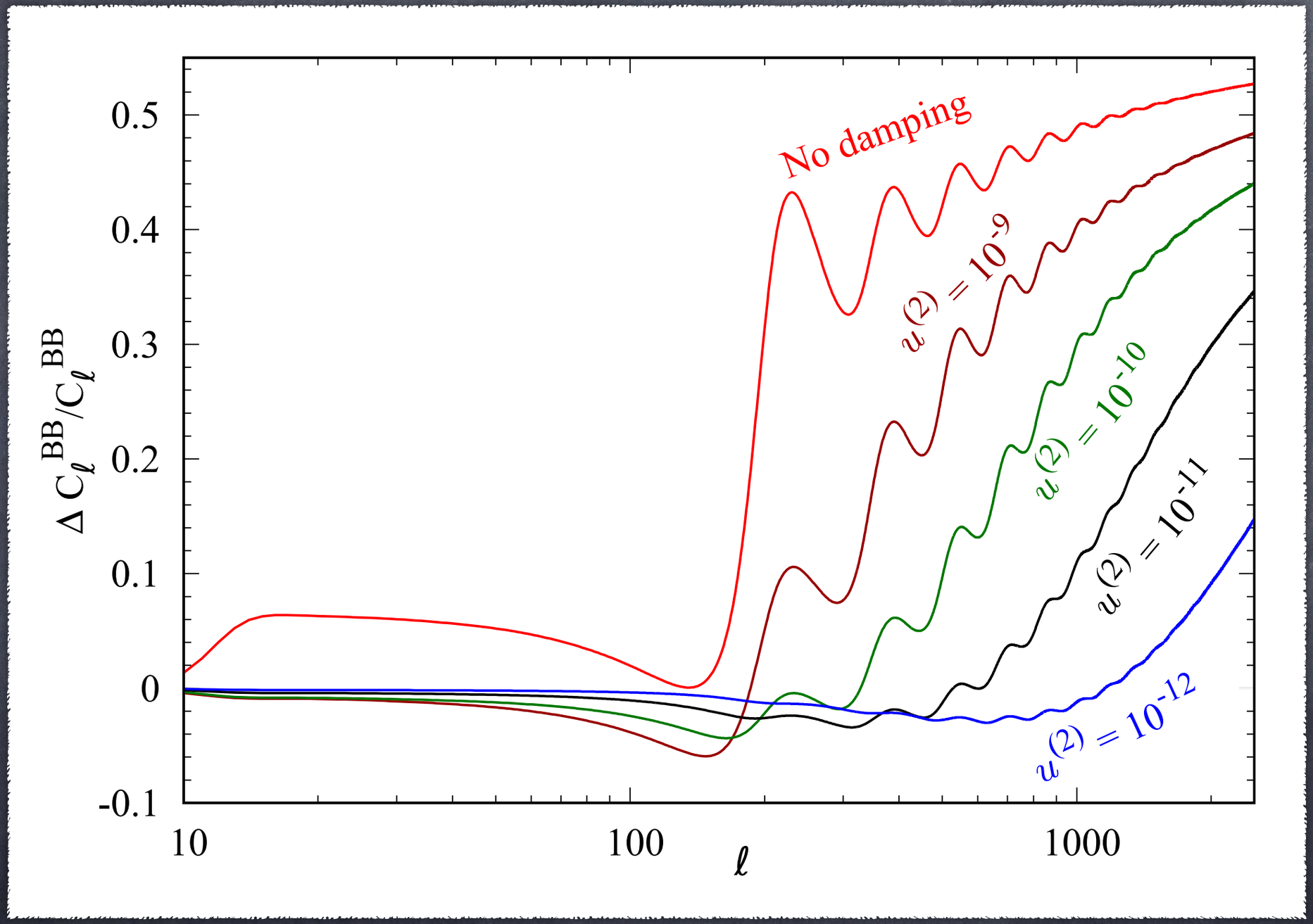
Blue Spectrum $(n_T > 0)$

For ΛCDM $n_T \sim 0$

Fraction change of CMB BB for T_ν independent cross-section

*SG, Rishi Khatri, Tuhin S. Roy, 2017

Neutrino interaction enhances B modes at small scale



Fractional change of unlensed CMB BB for T_ν^2 dependent cross-section

Conclusion

There is rich information (BSM) hidden in the CMB B modes spectrum beyond just the tensor to scalar ratio.

Arxiv:1711.09929