VECTOR DARK RADIATION AND GRAVITATIONAL WAVE PROPAGATION

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IPARCOS

GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

VNIVERSITAS COMPLVTENSIS MATRITENSIS

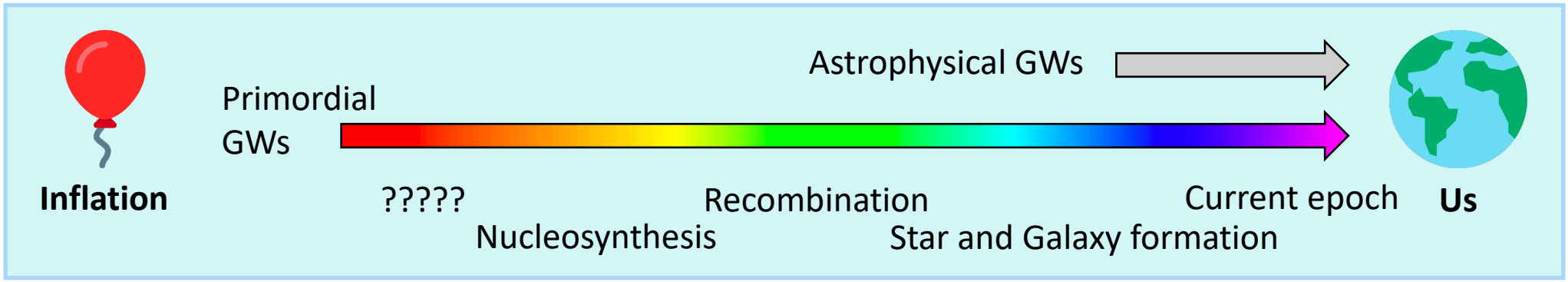
INTRODUCTION

- Radiation: ɣ, ν, something else…?

$$\Delta N_{\text{eff}} = N_{\text{eff}} - 3.046 < 0.28$$

Axio Vector fields! try?

- Relevant in the Early Universe: Primordial GWs.



Our Model

$$S = \int \mathrm{d}^4x \sqrt{-g}\left(-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{\lambda}{4}\left(A_\mu A^\mu\right)^2\right)$$

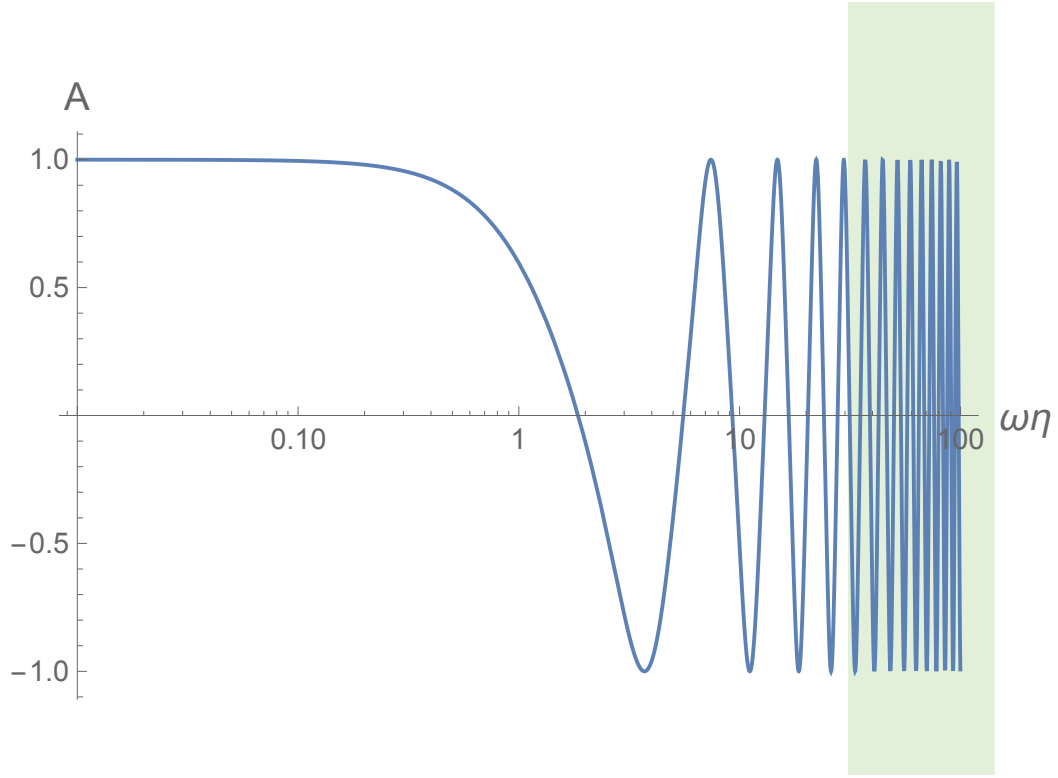
2-parameter model (ω, Ω_A)

- Linearly polarised $A_\mu(\eta) = (0,0,0,A_z)$

$$A_z = A_0\,\mathrm{cn}\left(\sqrt{\lambda}A_0\eta; 1/2\right)$$

- Fast oscillation $\omega = \sqrt{\lambda}A_0 \gg \mathcal{H}$ ensures isotropy (Cembranos et al., 2012)

$$p = \rho/3 \propto a^{-4}$$



GW-Propagation Modification

$$\delta G_{ij}^{(TT)} = 8\pi G \delta T_{ij}^{(TT)}$$

Geometric Side

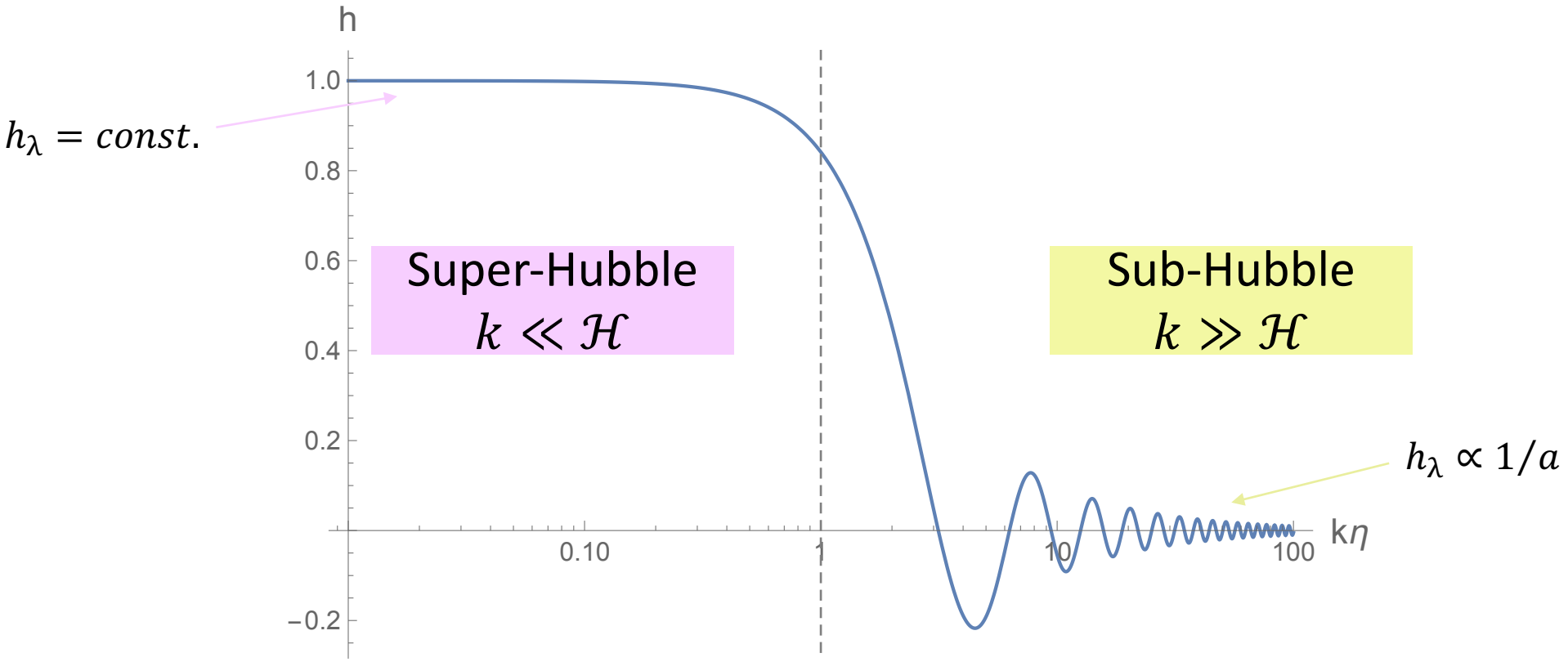
- GR, with FLRW metric.
- h_{ij}
- Two degrees of freedom: (+, x) polarizations.

Content of the Universe Side

- $T_{ij}^{(TT)}(g_{\mu\nu}, A_\mu)$
- Terms proportional to h_{ij}.
- No source terms.

GWs in Vacuum

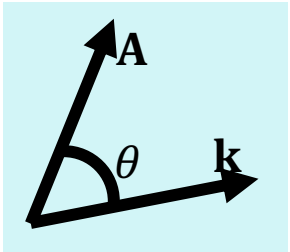
$$h_\lambda'' + 2\mathcal{H}h_\lambda' + k^2 h_\lambda = 0$$



GWs WITH OUR MODEL

$$h_\lambda'' + 2\mathcal{H}h_\lambda' + \left[k^2 + \frac{6H_0^2\Omega_A \sin^2\theta}{a^2}\left(\left(3 + 2\delta_{+,\lambda}\sin^2\theta\right)\mathrm{cn}^4(\omega\eta; 1/2) - 1\right)\right]h_\lambda = 0$$

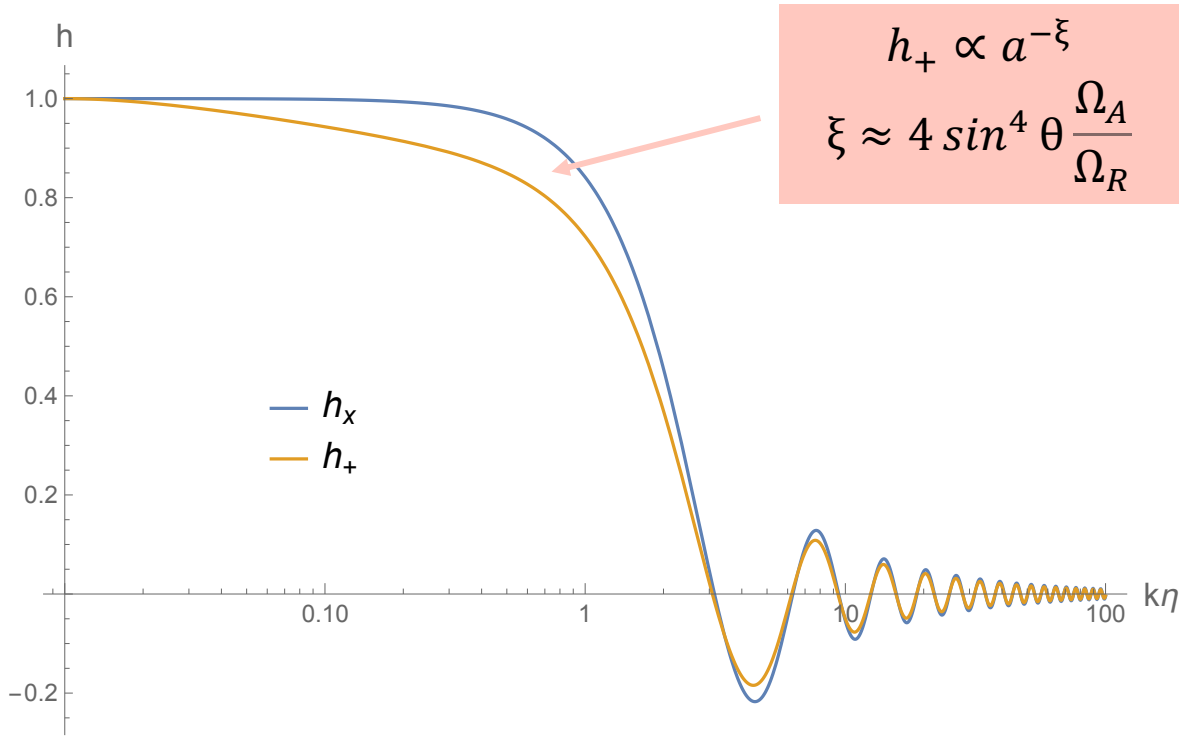
Anisotropic



Polarising

Relevant early on

Induces suppression



$$h_+ \propto a^{-\xi}$$

$$\xi \approx 4\,sin^4\,\theta\,\frac{\Omega_A}{\Omega_R}$$

Results: Stokes Parameters

Power Spectra

$$\langle h_+(\eta, \mathbf{k}) h_+^*(\eta, \mathbf{k}') \rangle = \delta^{(3)}(\mathbf{k} - \mathbf{k}') P_+(\mathbf{k}, \eta)$$

$$\langle h_\times(\eta, \mathbf{k}) h_\times^*(\eta, \mathbf{k}') \rangle = \delta^{(3)}(\mathbf{k} - \mathbf{k}') P_\times(\mathbf{k}, \eta)$$

Stokes Parameters

$I \quad Q \quad \cancel{U} \quad \cancel{V}$

Tensor power spectrum

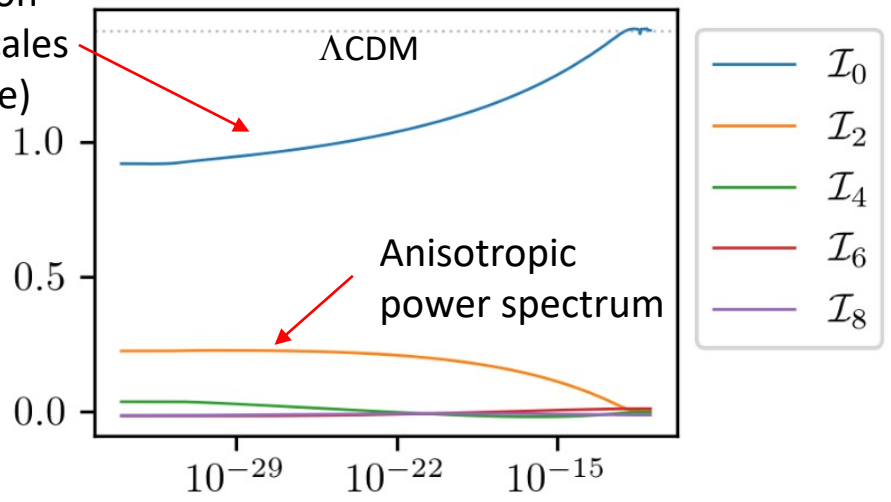
$$\mathcal{I} = \frac{P_+ + P_\times}{P_{+,SM} + P_{\times,\mathrm{SM}}}$$

Linear polarization

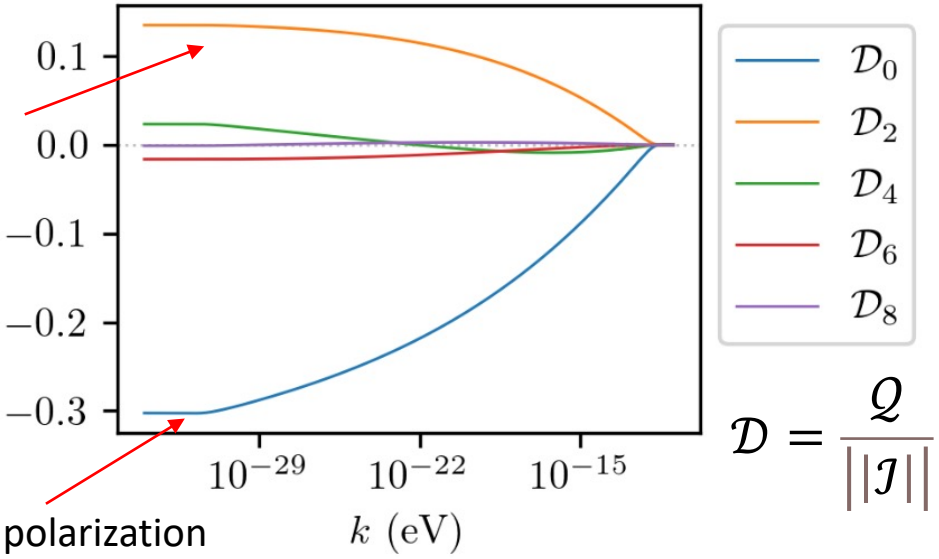
$$\mathcal{Q} = \frac{P_+ - P_\times}{P_{+,SM} + P_{\times,\mathrm{SM}}}$$

$\Omega_A = \Omega_R/100\,, \omega = 2500$ Hz

Suppression at large scales (monopole)



Anisotropic polarization



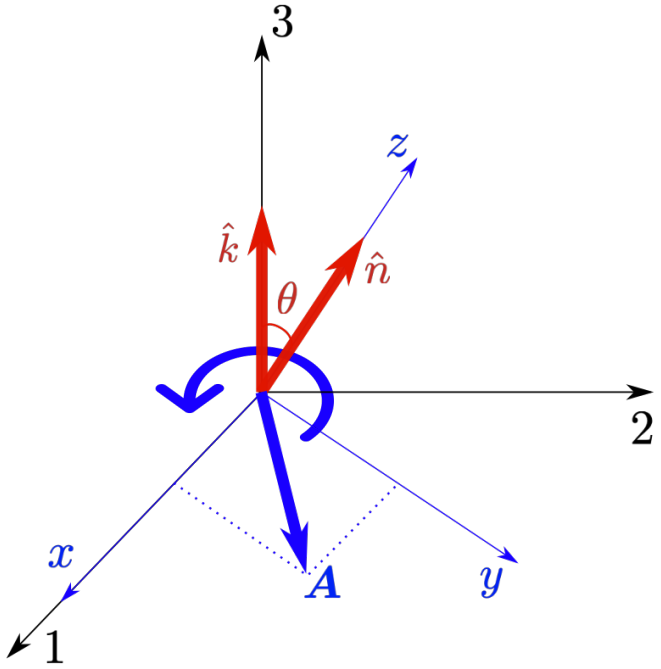
Linear polarization at large scales

$$\mathcal{D} = \frac{\mathcal{Q}}{||\mathcal{I}||}$$

Quick Glance: Another Solution

Spinning vector field

$$A_\mu(\eta) = \alpha\,(0, \cos\omega\eta\,, \sin\omega\eta\,, 0)$$



$$h_+'' + 2\mathcal{H}h_+' + k^2 h_+ + \frac{2\Omega_A H_0^2}{a^2}\left[(F+B)h_+ + Mh_\times\right] = 0$$

$$h_\times'' + 2\mathcal{H}h_\times' + k^2 h_\times + \frac{2\Omega_A H_0^2}{a^2}\left[(F-B)h_\times + Mh_+\right] = 0$$

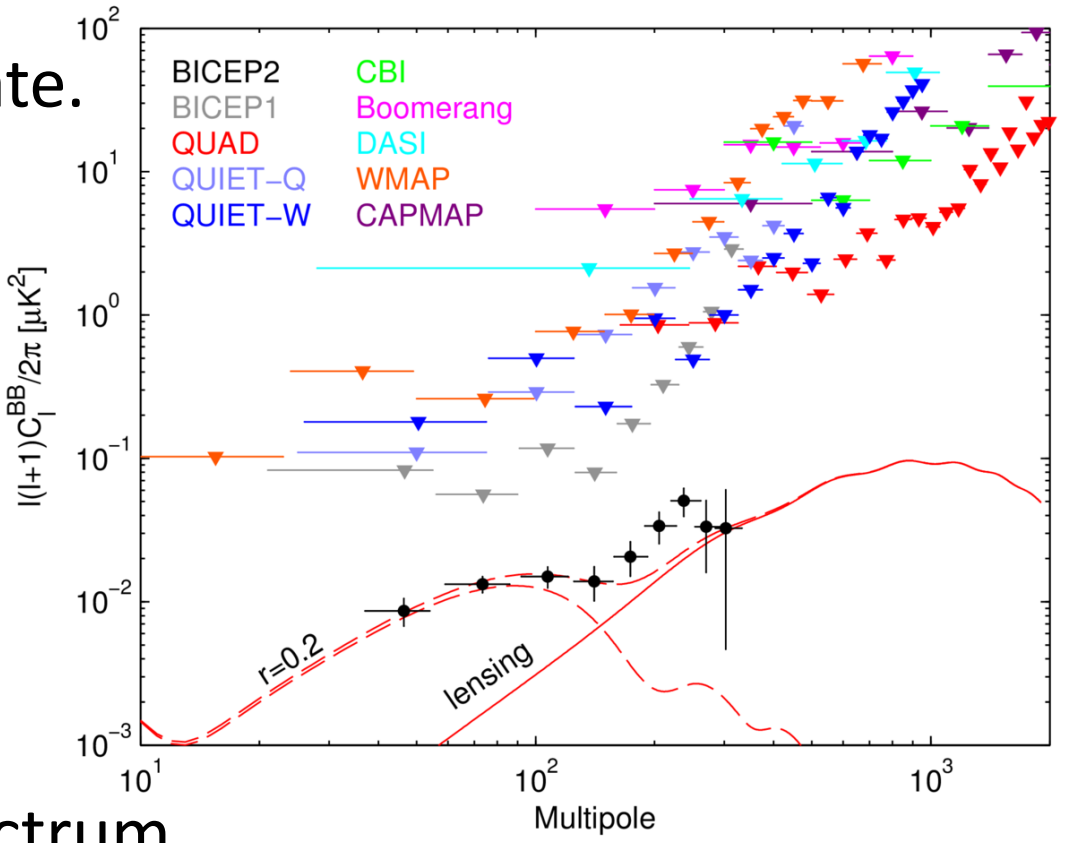
Still polarising

Now there is mixing!

- Non-zero Stokes U
- Can convert linear into circular polarization

CONCLUSIONS

- Vector dark radiation: Interesting candidate.
- Rich phenomenology on GWs:
  - Anisotropy
  - Polarization
  - Suppression
- Potential effect on low-ℓ CMB power spectrum.



The End

Thank you!