university of groningen

Primordial Gravitational Waves in non-Minimally Coupled Chromo-Natural Inflation

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Based on: E. Dimastrogiovanni, M. Fasiello, **MM**, L. Pinol, 2023, *arXiv:2303.10718*

Outline

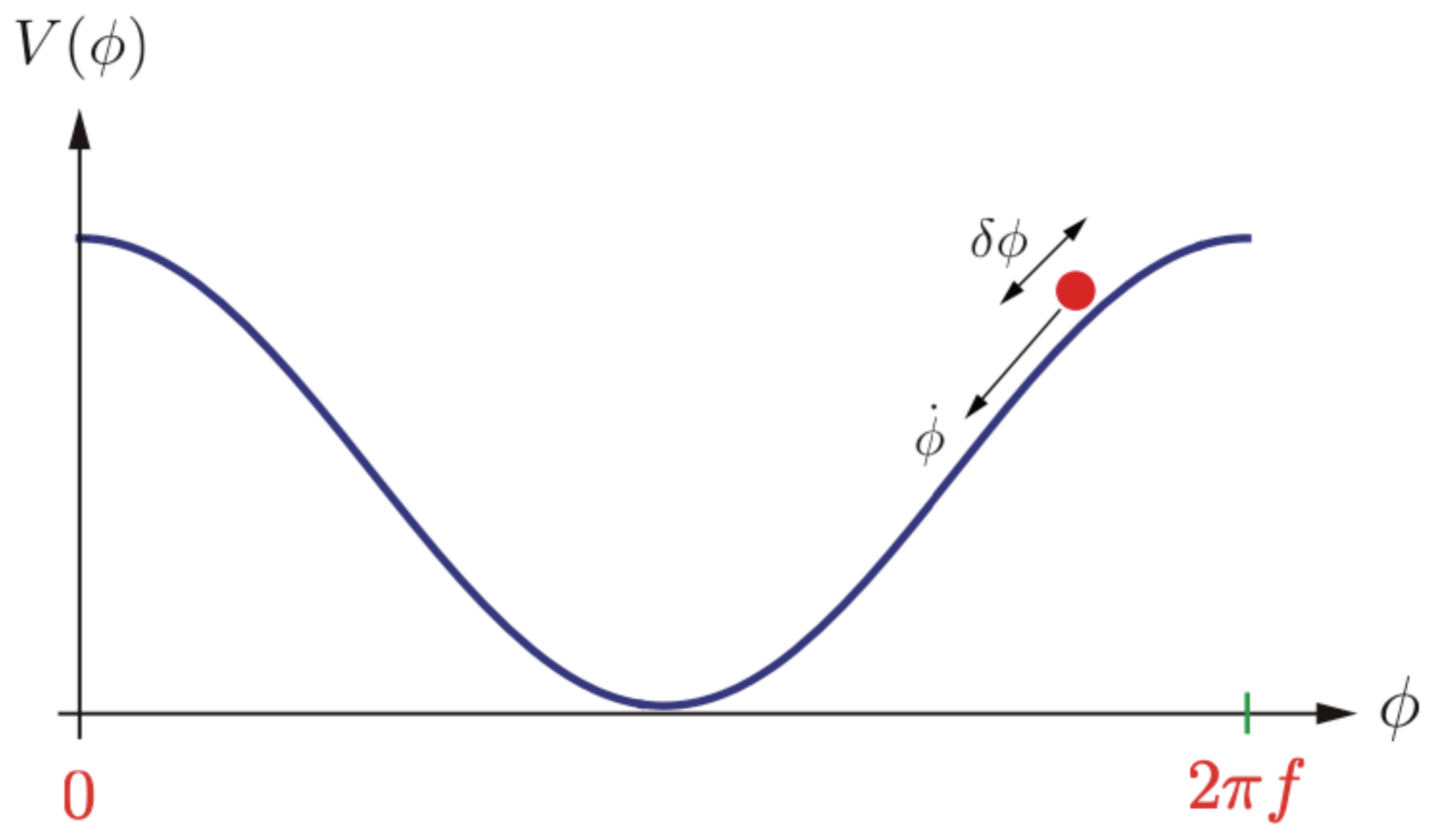
* Motivations
* Background and perturbations evolution
* CMB observables
* Sourced background of primordial GWs

Motivations

Natural inflation

Freese, Frieman, Olinto, 1990

shift symmetry protects from large quantum corrections ✓



D. Baumann, 2009

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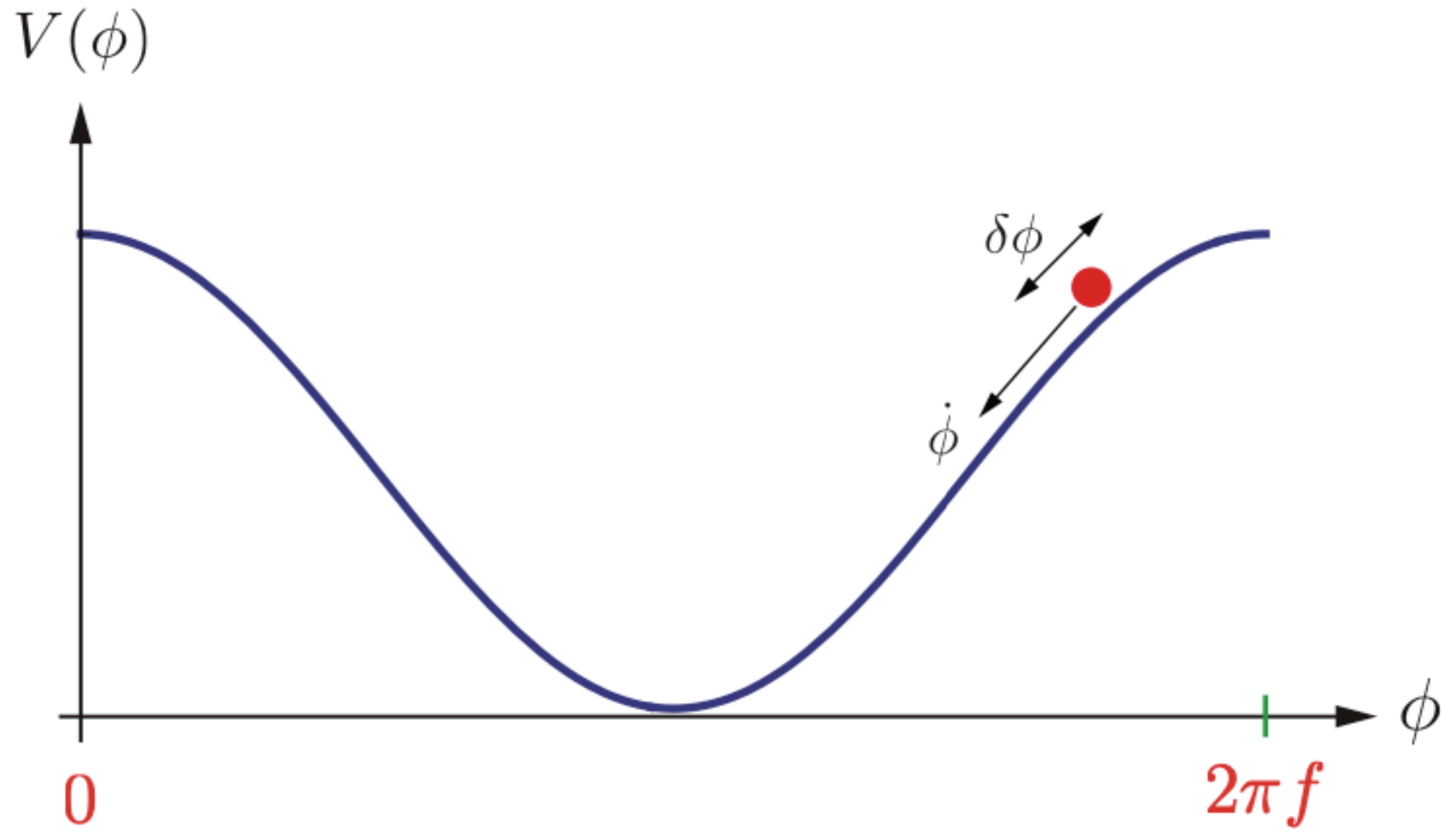
↕

tension with CMB measurements ✗



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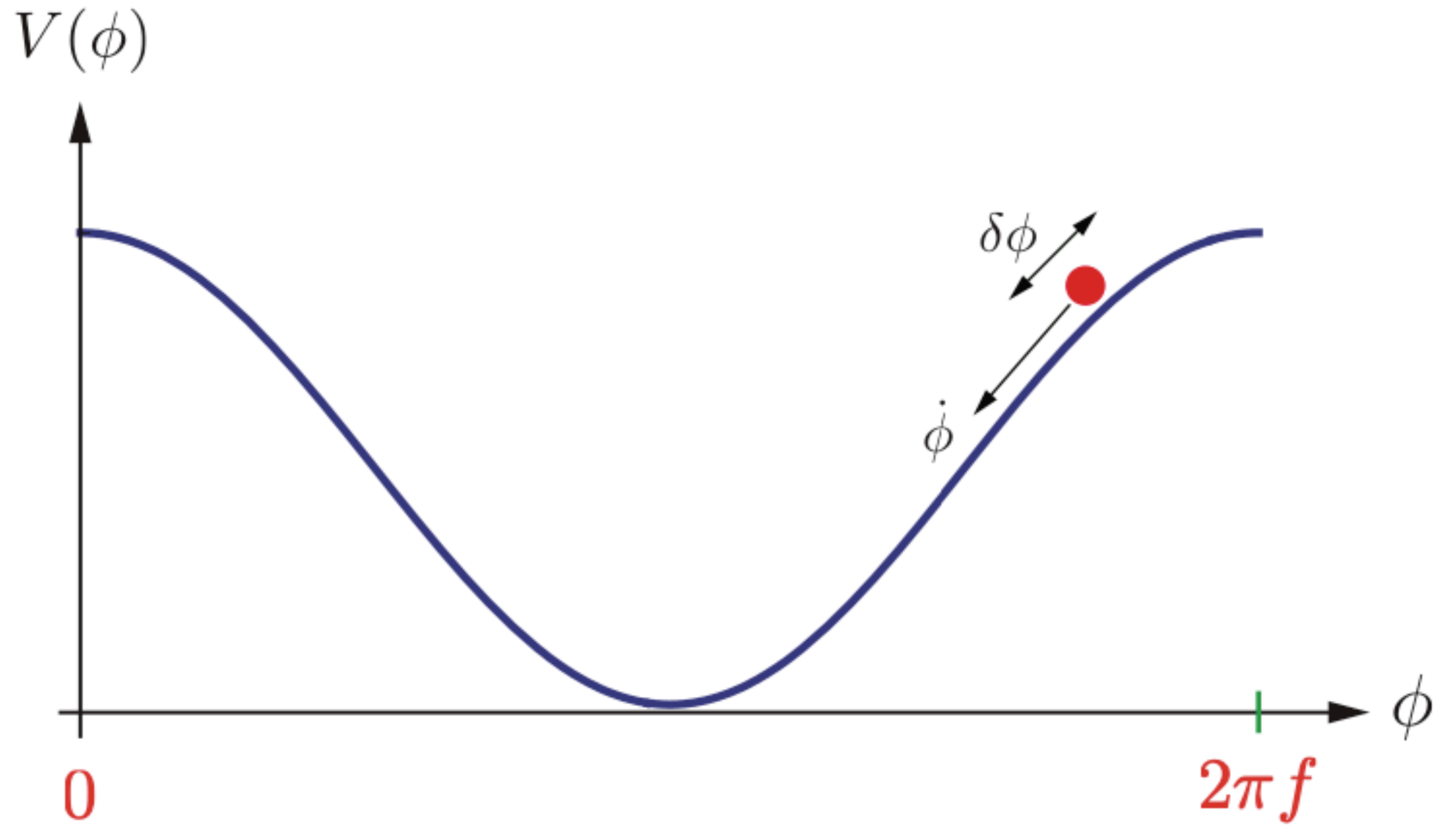

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additional friction from gauge fields

Anber, Sorbo, 2010

Chromo-natural inflation

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blue-tilted and chiral GW signal ✓

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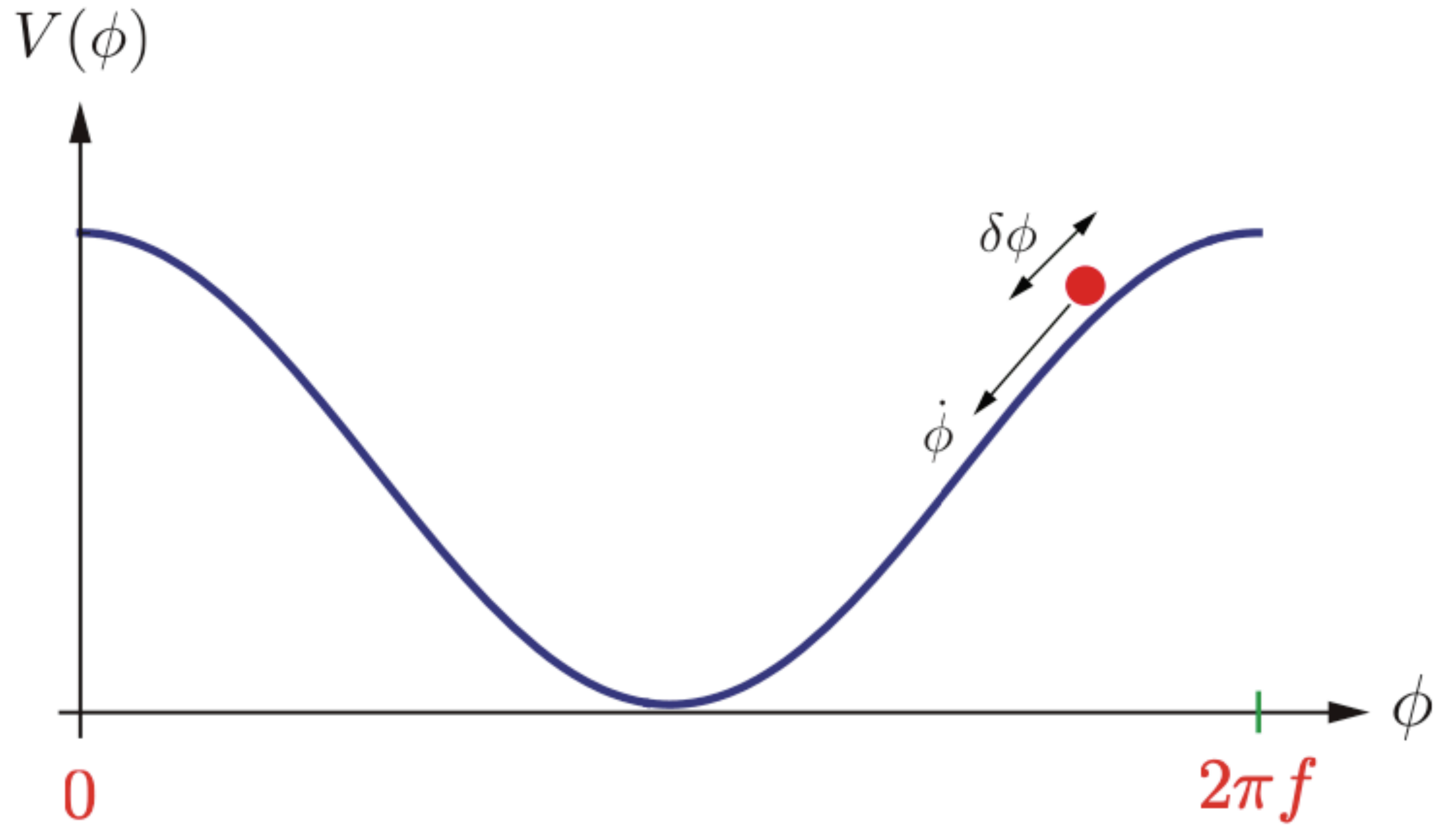

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blue-tilted and chiral GW signal ✓

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GW overproduction ✗

↓

further step is needed

?

See Matteo's talk…

The model

Idea: non-minimal coupling with the Einstein tensor

first introduced in UV-protected natural inflation

Germani, Kehagias, 2011

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu - g\epsilon^{abc} A^b_\mu A^c_\nu$$

$$\mathcal{L} = \frac{M_{\rm Pl}^2}{2} R - \frac{1}{2}\left(g^{\mu\nu} - \frac{G^{\mu\nu}}{M^2}\right)\partial_\mu\chi\partial_\nu\chi - V(\chi) - \frac{1}{4}F^{a\mu\nu}F^a_{\mu\nu} + \frac{\lambda\chi}{8f\sqrt{-g}}\epsilon^{\mu\nu\rho\sigma}F^a_{\mu\nu}F^a_{\rho\sigma}$$

$$V(\chi) = \mu^4\left(1 + \cos\frac{\chi}{f}\right)$$

Chern-Simons coupling

M^{-2} : strength of non-minimal coupling $\longleftrightarrow$ $M \to \infty$: chromo-natural limit

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M^{-2} : strength of non-minimal coupling $\longleftrightarrow$ $M \to \infty$: chromo-natural limit

$\longrightarrow$ additional friction unrelated to GW production ✓

Background dynamics

Axion background: $\chi(t)$

gauge friction

$$\left(1+\frac{3H^2}{M^2}\right)\ddot{\chi}+3H\left(1+\frac{3H^2}{M^2}\right)\dot{\chi}+V'(\chi)=-\frac{3g\lambda}{f}HQ^3$$

→ additional friction from the non-minimal coupling if $\frac{H}{M}\gg 1$

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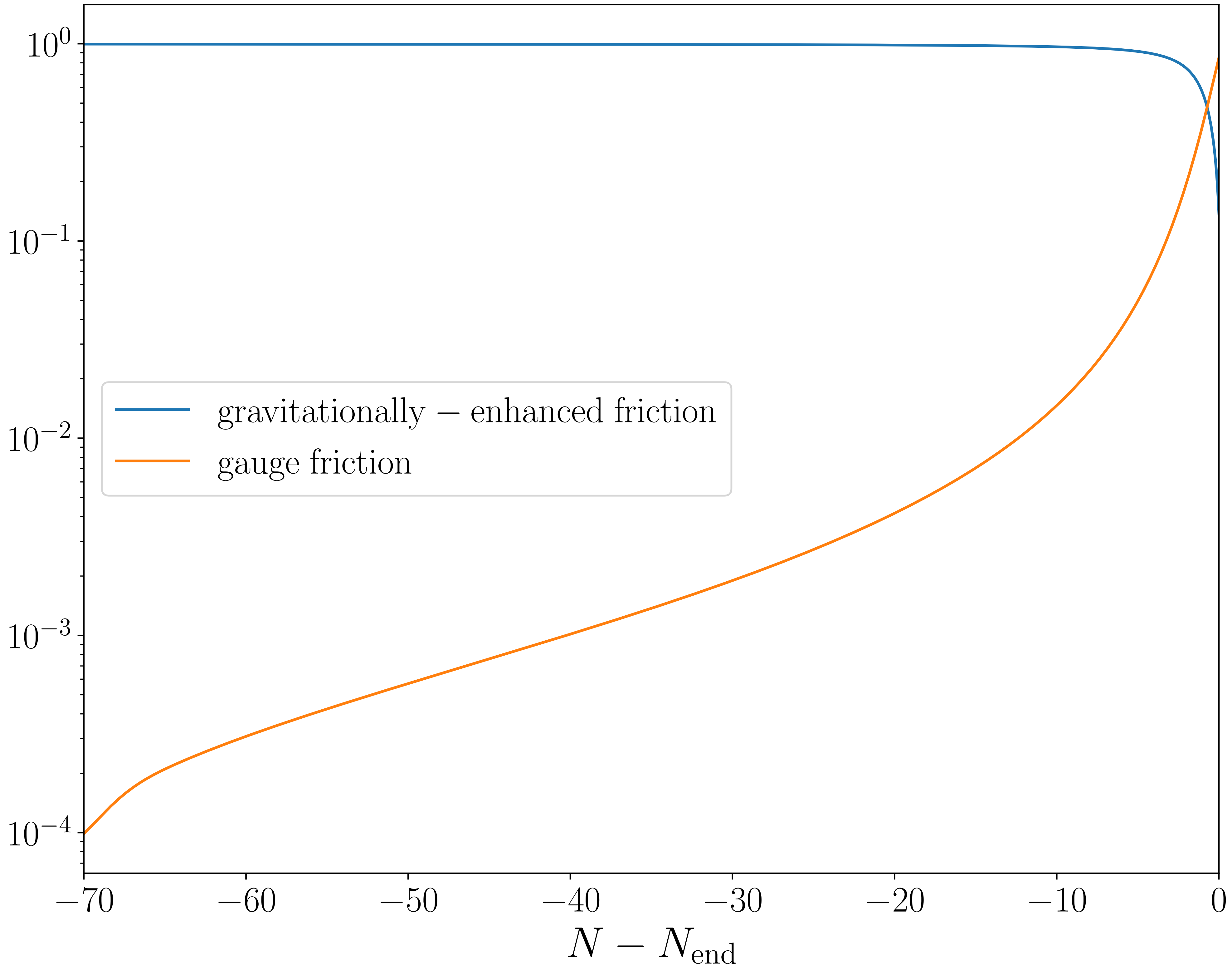
$\longrightarrow$ additional friction from the non-minimal coupling if $\frac{H}{M}\gg 1$

Gauge field background: $A_0^a=0,\qquad A_i^a=\delta_i^a a(t)Q(t)$

$$\ddot{Q}+3H\dot{Q}+2H^2Q+2g^2Q^3=\frac{g\lambda}{f}\dot{\chi}Q^2$$

Gravitationally-enhanced friction



In the limit $\frac{H}{M} \gg 1$

Gravitationally-enhanced friction dominating at large scales ⟷ Gauge friction increasing at later times

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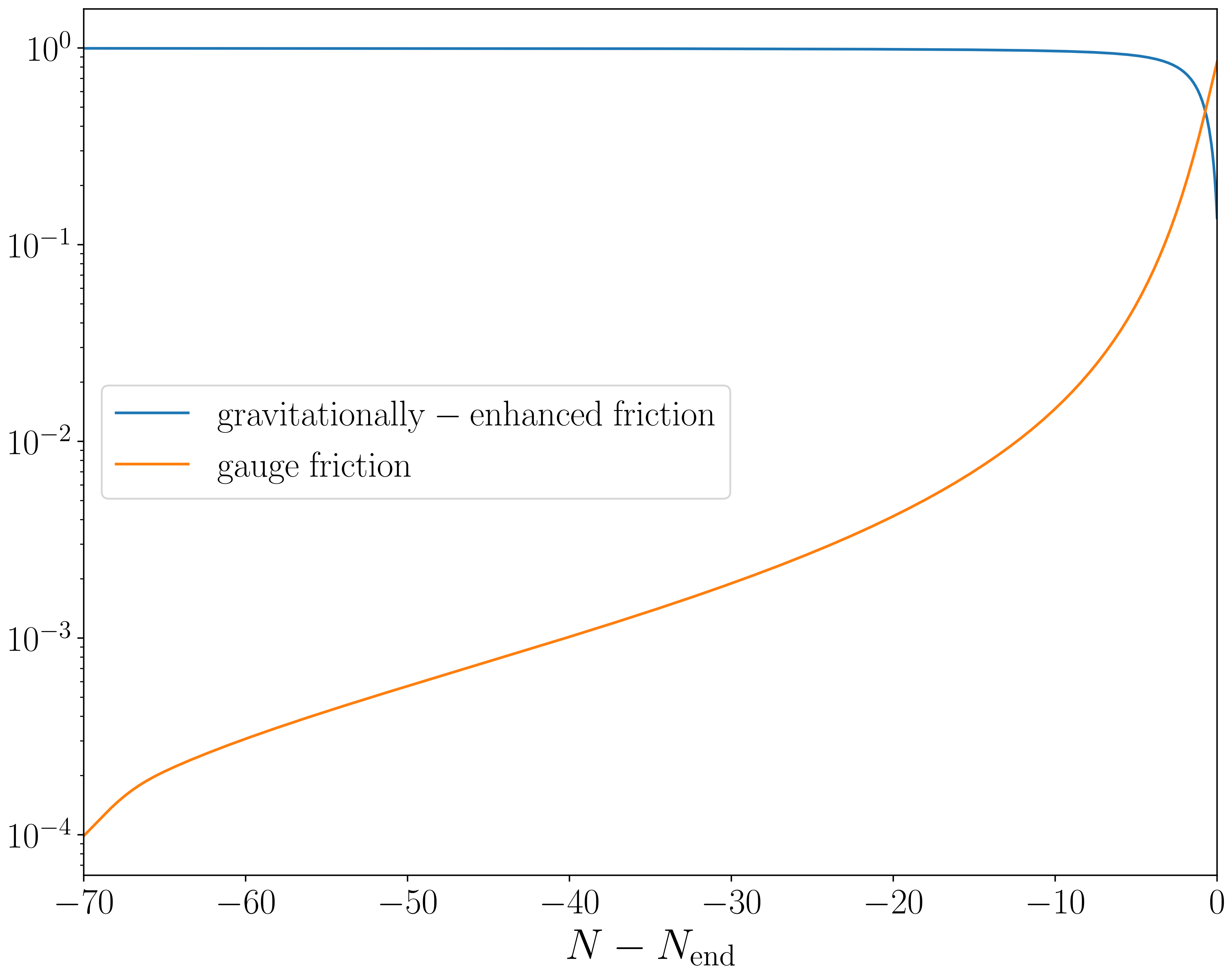

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long-enough inflation without GW overproduction

✔

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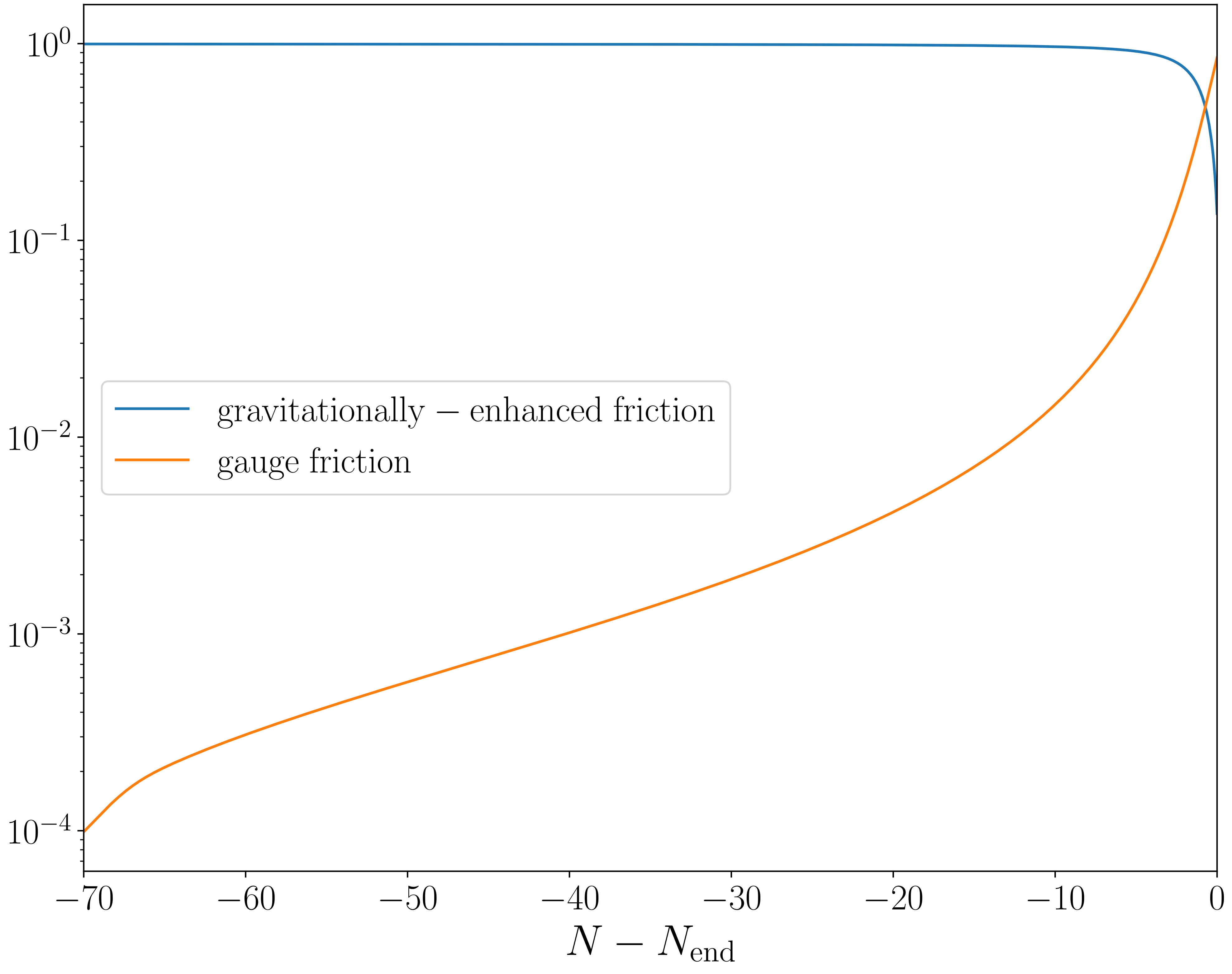

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↓ sourced GWs at smaller scales ✔

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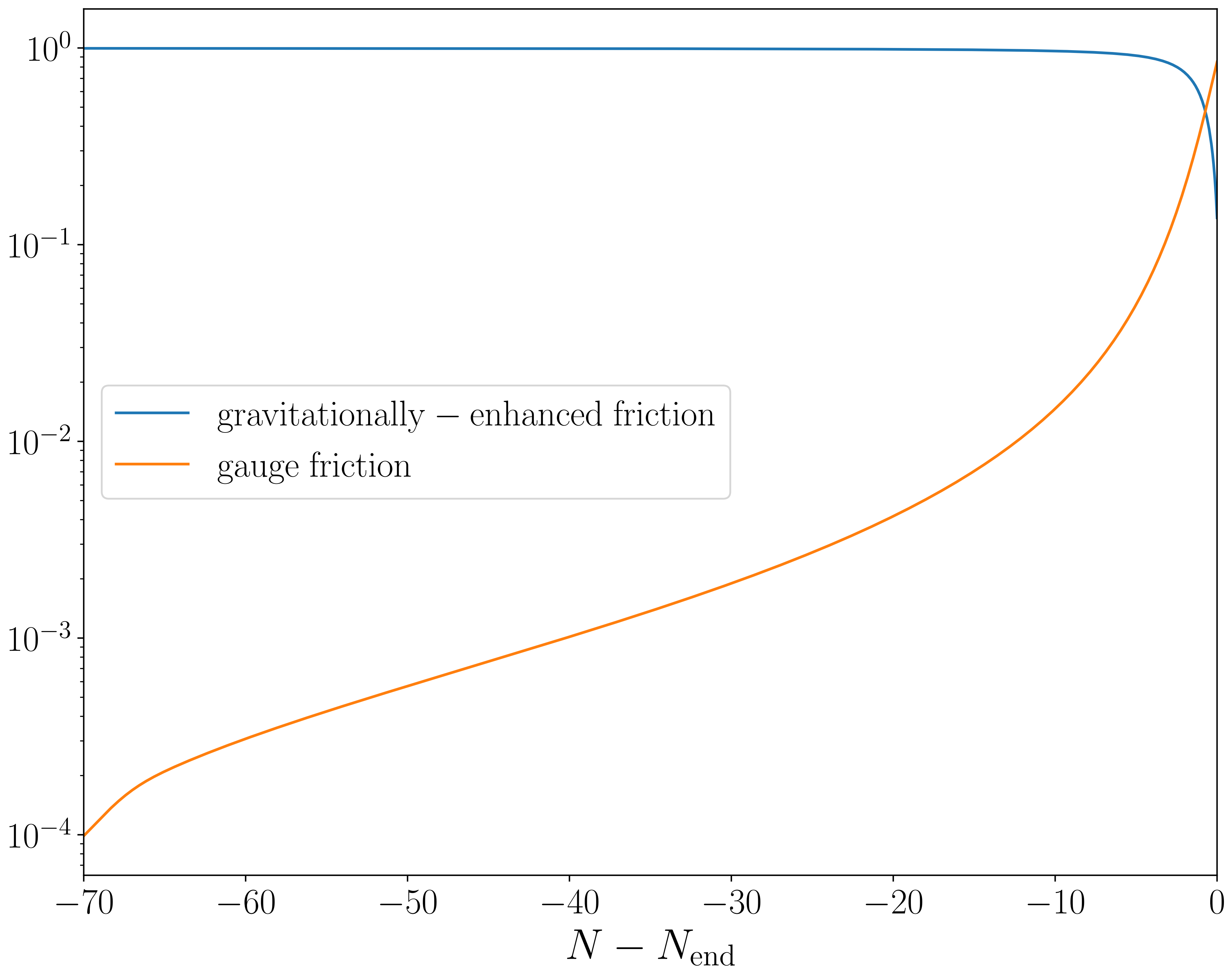

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↓ sourced GWs at smaller scales ✔

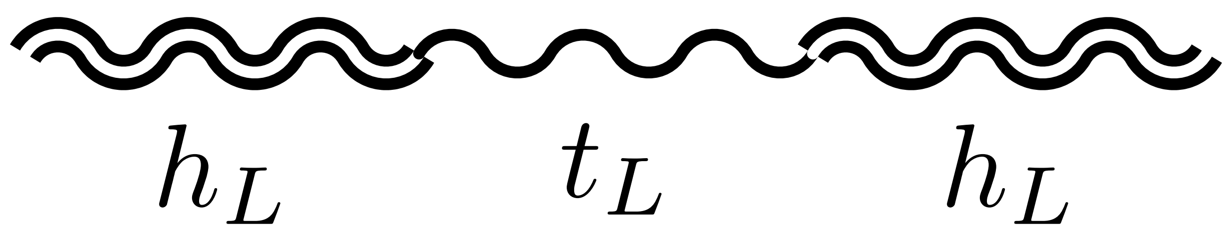
⟶ expectation: viable model with detectable GW signal ?

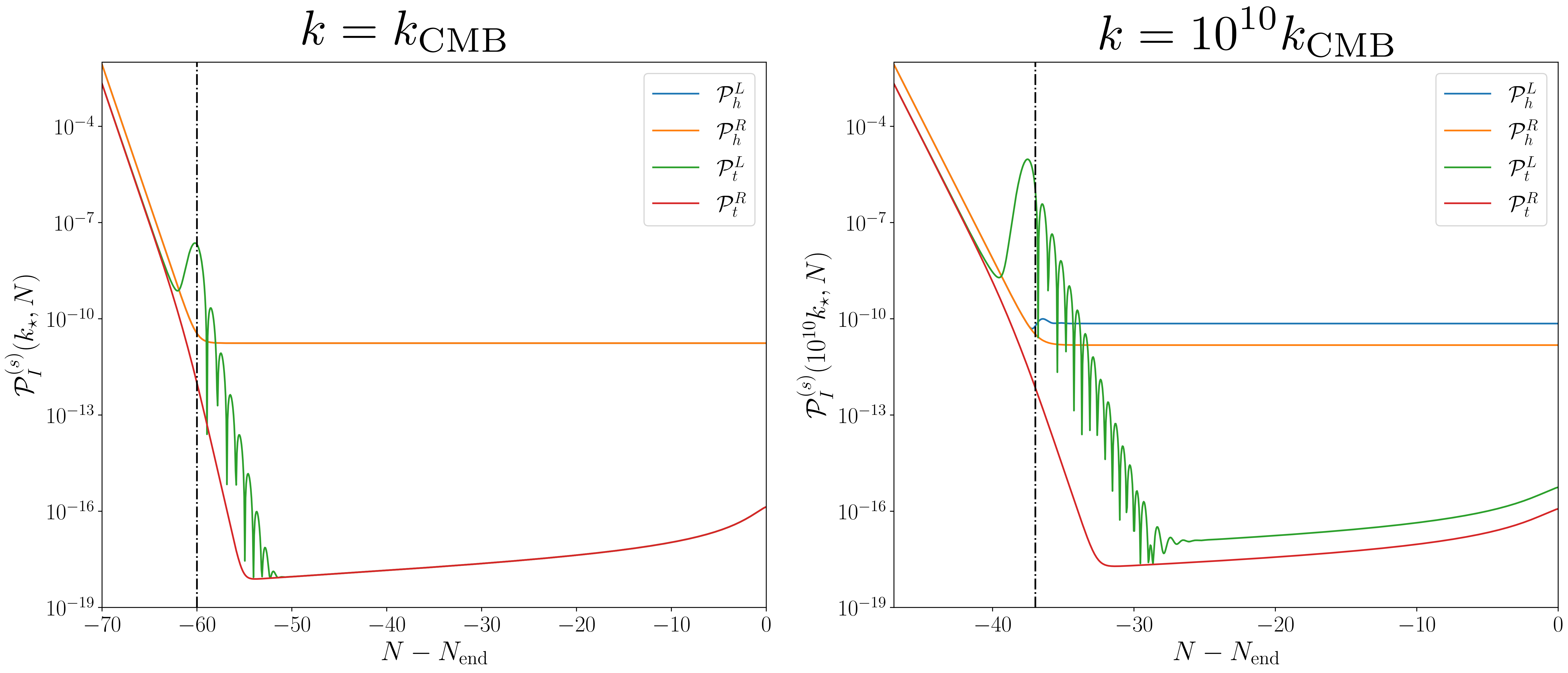
Chiral GW production

Gauge tensors $\delta A_i^a \supset t_{ia}$: $$\frac{\mathrm{d}^2}{\mathrm{d}x^2} t_{L,R} + \left[1 + \frac{2(1+m_Q^2)}{x^2} \mp \frac{2(2m_Q + m_Q{}^{-1})}{x}\right] t_{L,R} = 0$$

with $m_Q \equiv \frac{gQ}{H}$ and $\dot{m}_Q > 0$ $\longrightarrow$ $t_L \propto \exp(m_Q)$ enhanced at small scales

Linear coupling with metric tensors





Constraints from CMB

Scalar spectrum $\langle\zeta(\vec{k})\zeta(\vec{k}')\rangle = (2\pi)^3\delta^3(\vec{k}+\vec{k}')\mathcal{P}_\zeta(k)$ with $\zeta \simeq -\frac{H}{\dot{\chi}}\delta\chi$

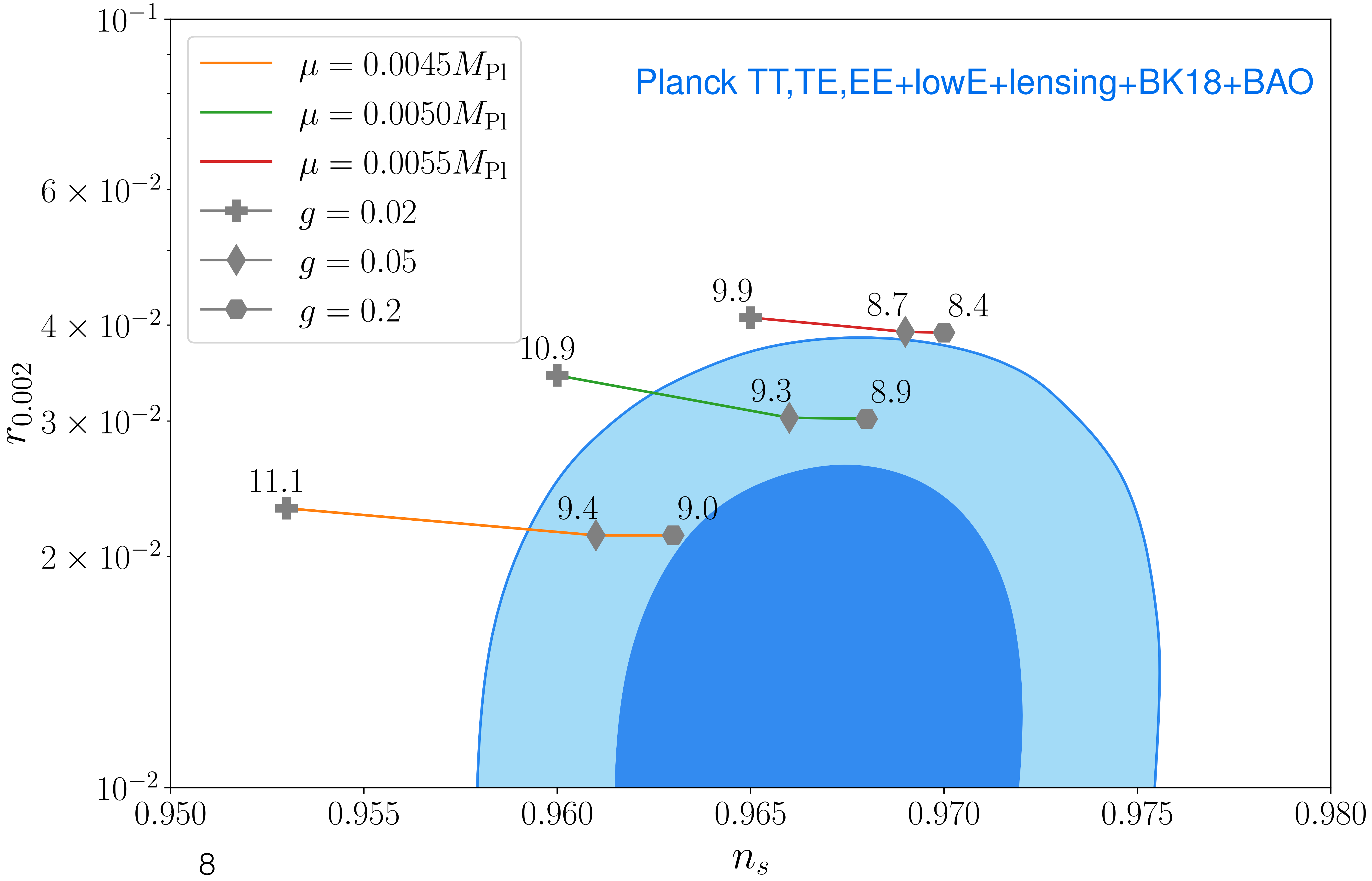
Tensor spectrum $\sum_{i,j}\langle h_{ij}(\vec{k})h_{ij}(\vec{k}')\rangle = (2\pi)^3\delta^3(\vec{k}+\vec{k}')\mathcal{P}_h(k)$

Observables

$$r \equiv \frac{\mathcal{P}_h}{\mathcal{P}_\zeta} \qquad n_s - 1 \equiv \frac{\mathrm{d}\ln\mathcal{P}_\zeta}{\mathrm{d}\ln k}$$

with constraint:

$$\mathcal{P}_\zeta(k_{\mathrm{CMB}}) \simeq 2.1\times10^{-9}$$



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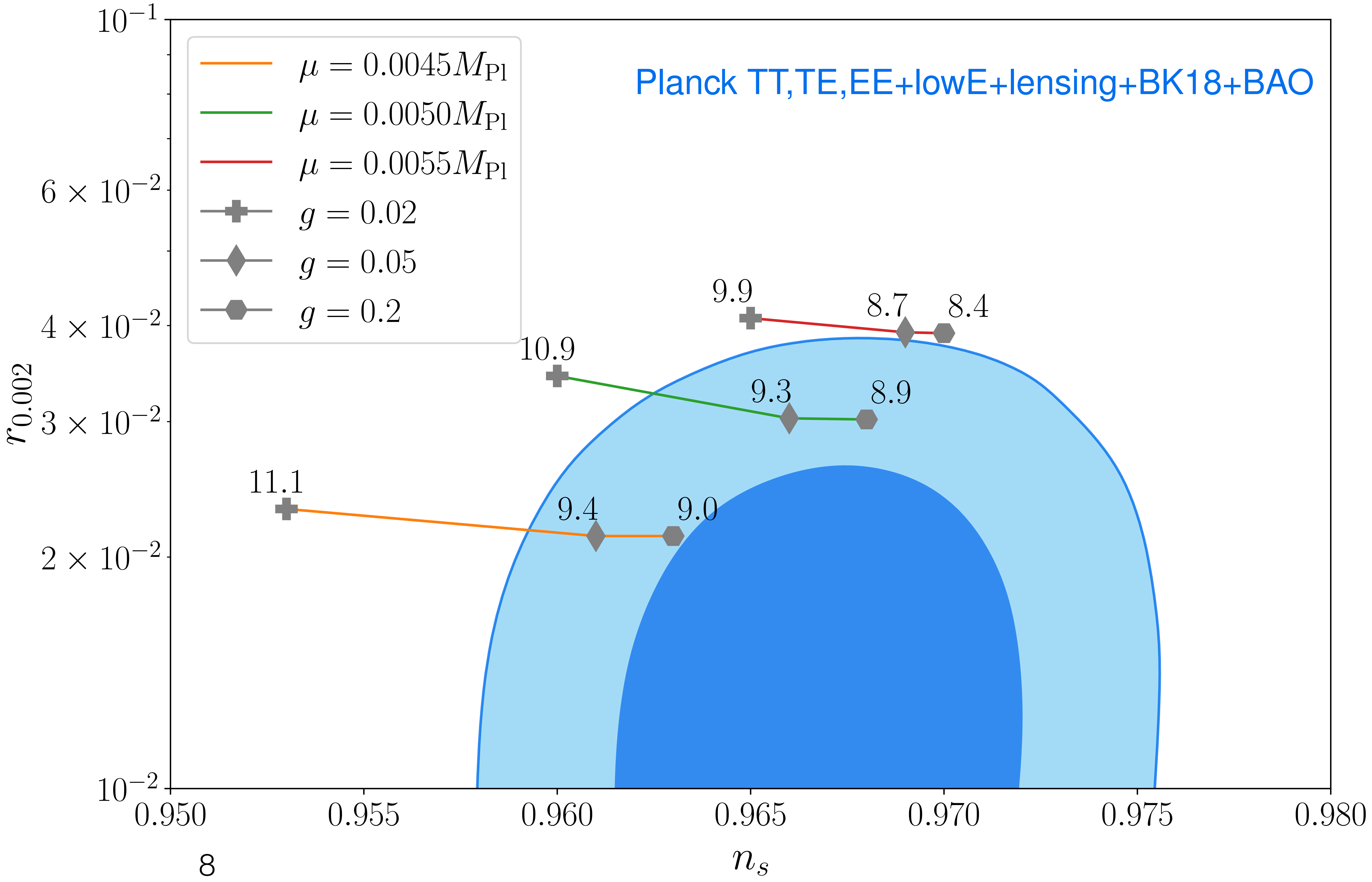
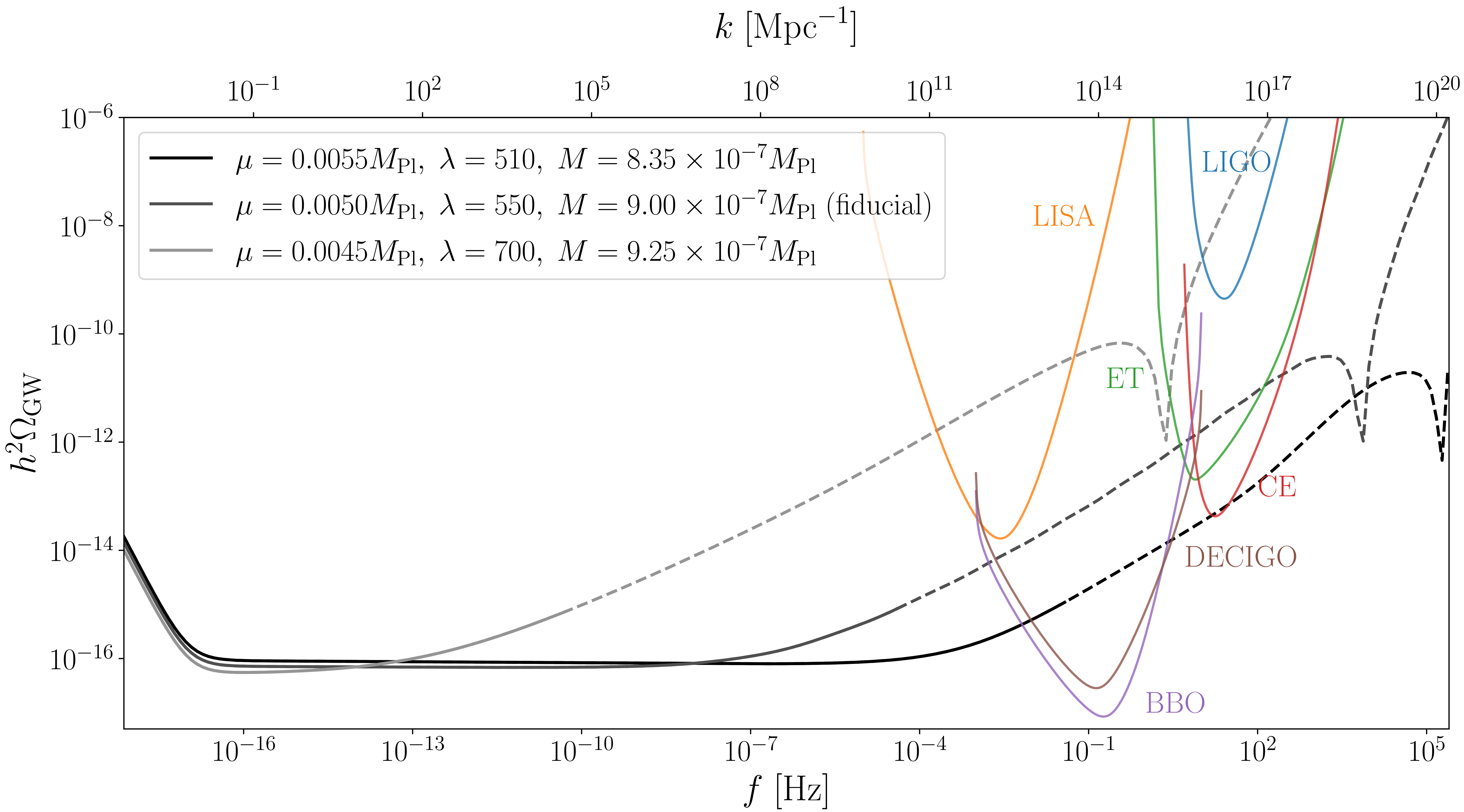
→ observationally viable



Sourced background of GWs

Sourced GWs $\propto \exp(m_Q)$ $\longrightarrow$ blue (and chiral) spectrum



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Sourced GWs $\propto \exp(m_Q)$ ⟶ blue (and chiral) spectrum

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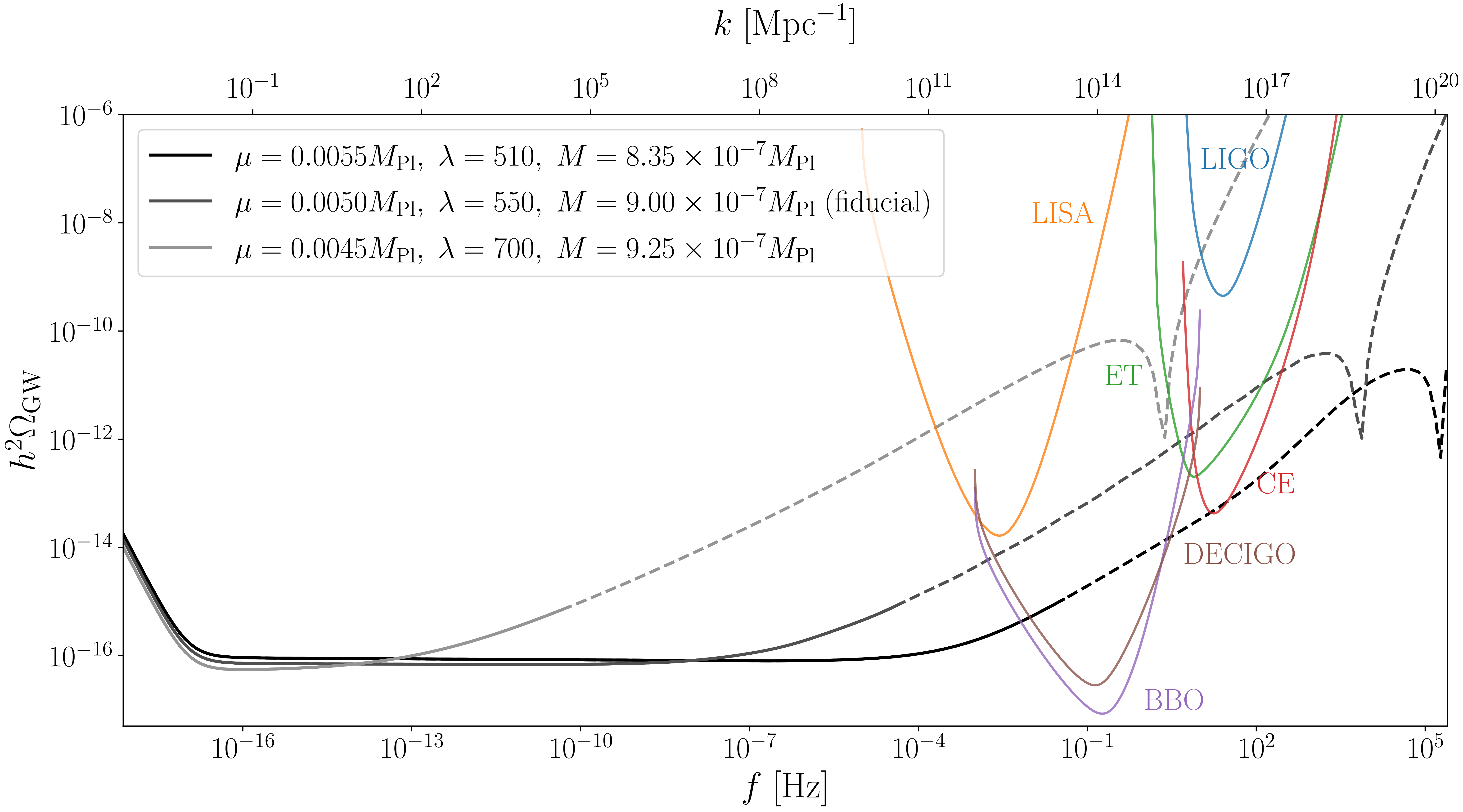
detectable by
future interferometers



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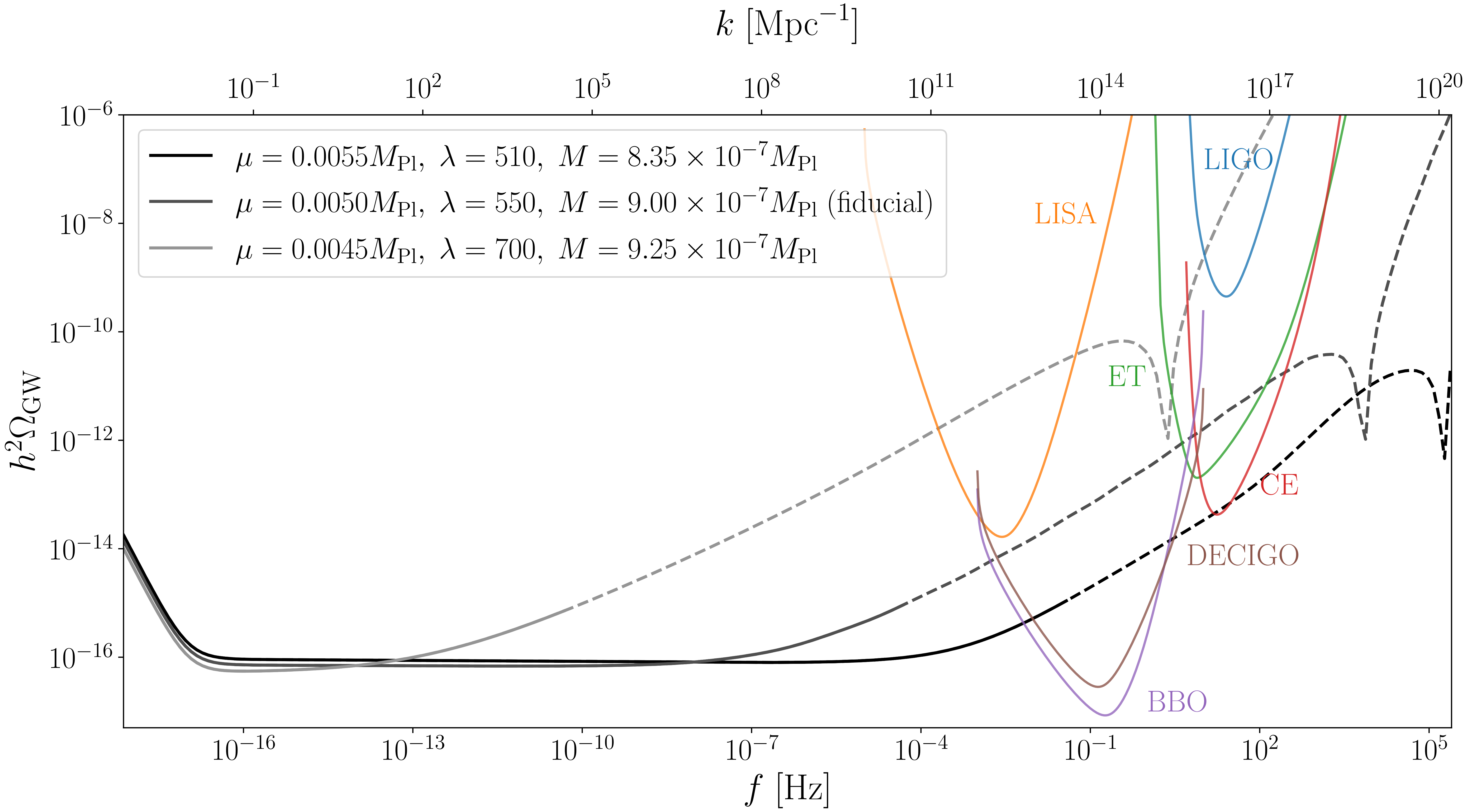
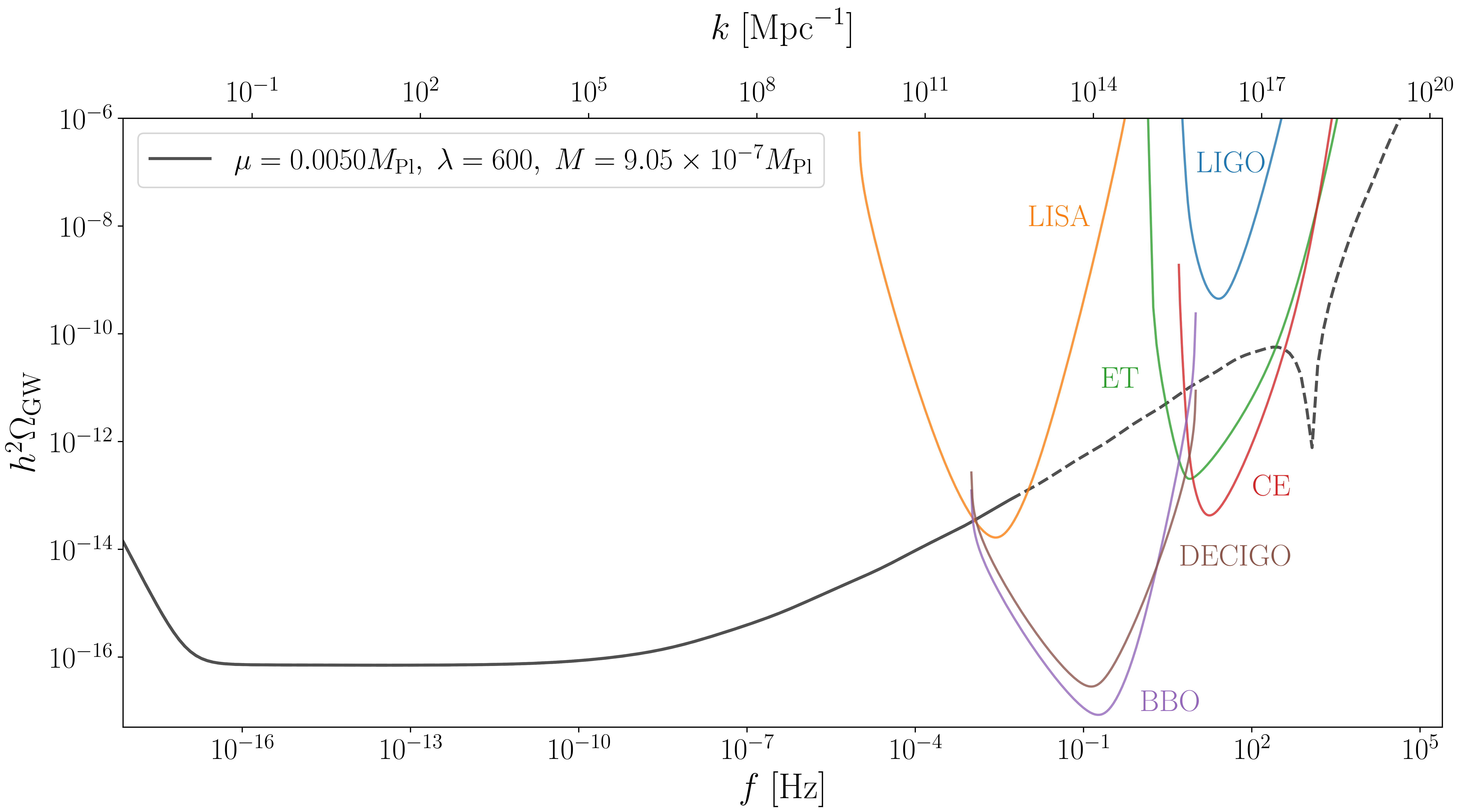


! Very conservative bound on m_Q from backreaction

Dimastrogiovanni et al. 2016
Ishiwata et al. 2022
Peloso, Sorbo, 2022

Sourced background of GWs



(Weaker but still) conservative bound on m_Q

Conclusions

By means of the non-minimal coupling with gravity in CNI:

* GW overproduction avoided in a long-enough period of inflation
* Distinct signature: blue and chiral GW spectrum (possibly detectable)

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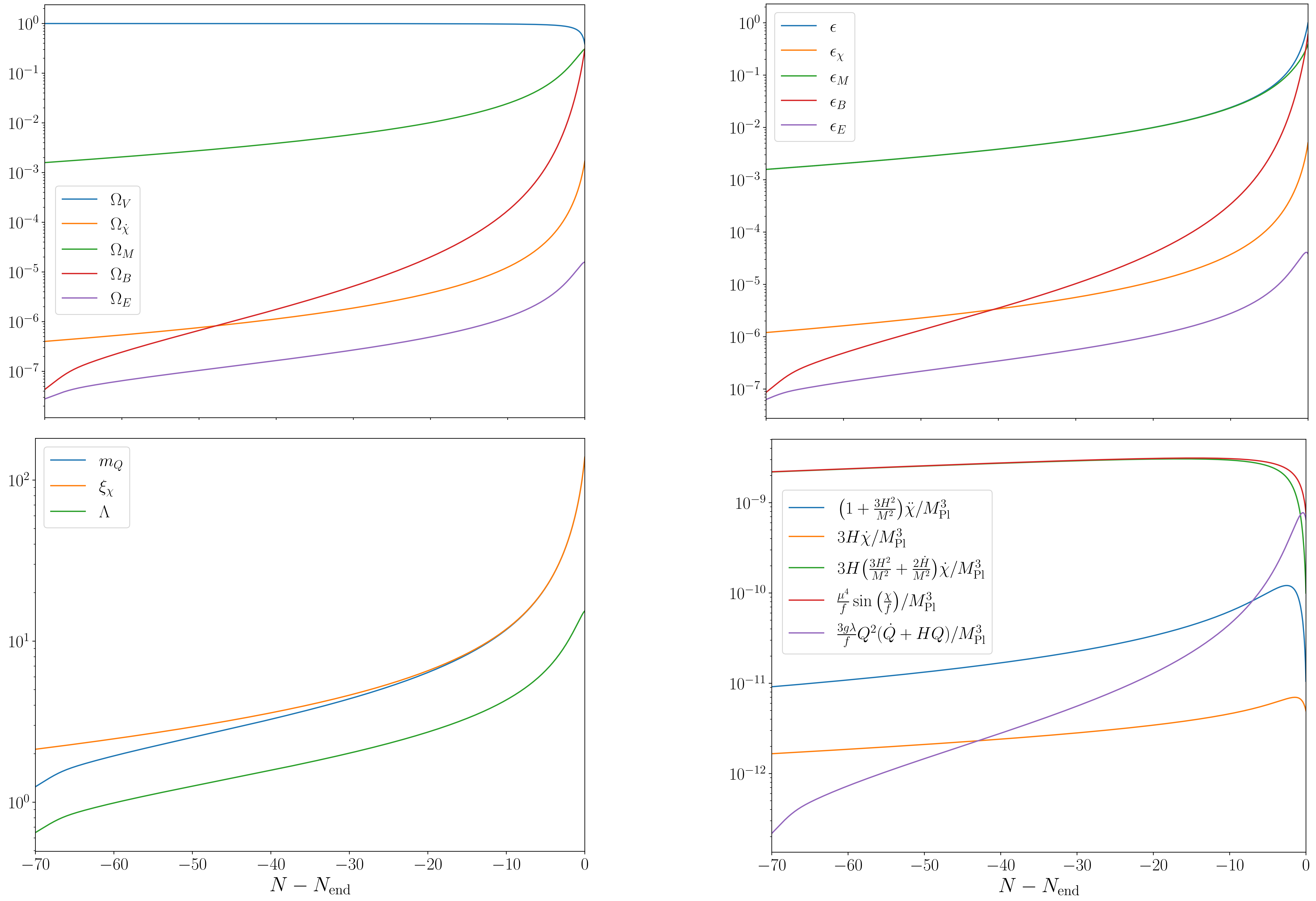
Thank you for the attention!



Ω_V
$\Omega_{\dot\chi}$
Ω_M
Ω_B
Ω_E
ϵ
ϵ_χ
ϵ_M
ϵ_B
ϵ_E
m_Q
ξ_χ
Λ
$\left(1+\frac{3H^2}{M^2}\right)\ddot\chi/M_{\rm Pl}^3$
$3H\dot\chi/M_{\rm Pl}^3$
$3H\left(\frac{3H^2}{M^2}+\frac{2\dot H}{M^2}\right)\dot\chi/M_{\rm Pl}^3$
$\frac{\mu^4}{f}\sin\left(\frac{\chi}{f}\right)/M_{\rm Pl}^3$
$\frac{3g\lambda}{f}Q^2(\dot Q+HQ)/M_{\rm Pl}^3$
$N-N_{\rm end}$
$N-N_{\rm end}$

Tensor perturbations

$$\partial_x^2 h_{L,R} + \left(1 - \frac{2}{x^2}\right) h_{L,R} = \frac{2\sqrt{\epsilon_E}}{x}\partial_x t_{L,R} + \frac{2\sqrt{\epsilon_B}}{x^2}\left(m_Q \mp x\right) t_{L,R}$$

$$\partial_x^2 t_{L,R} + \left[1 + \frac{2}{x^2}\left(m_Q\xi \mp x(m_Q + \xi)\right)\right] t_{L,R} = -\frac{2\sqrt{\epsilon_E}}{x}\partial_x h_{L,R} + \frac{2}{x^2}\left[(m_Q \mp x)\sqrt{\epsilon_B} + \sqrt{\epsilon_E}\right] h_{L,R}$$

Canonical normalization: $h_{L,R} \equiv \frac{aM_{\rm Pl}}{2}\left(h_+ \pm i h_\times\right)$ $\quad t_{L,R} \equiv a\left(t_+ \pm i t_\times\right)$

Gauge-field background evolution

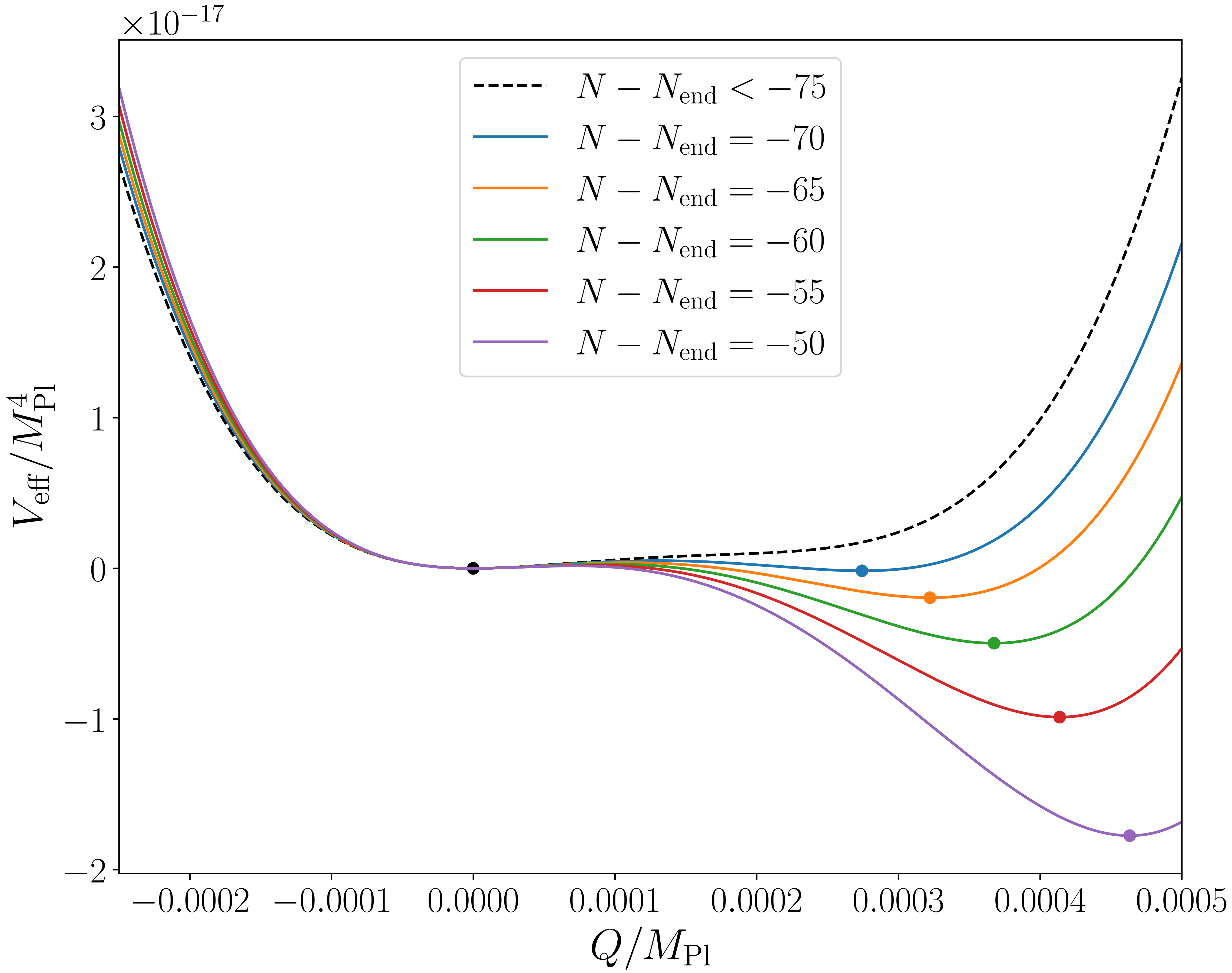
Effective potential: $$V_{\rm eff}(Q) = H^2Q^2 - \frac{g\lambda\mu^4}{27f^2H}\frac{M^2}{H^2}\sin\frac{\chi}{f}\,Q^3 + \frac{g^2}{2}Q^4$$

$Q_{\rm min} \neq 0$ develops and increases with time

↓

Lower bound on M : $$\frac{H^2}{M^2} < \frac{\lambda\mu^4}{36f^2H^2}\sin\frac{\chi}{f}$$

⟶ $$Q_{\rm min} \simeq \mathcal{O}(1)\frac{\lambda\mu^4M^2}{18gf^2H^3}\sin\frac{\chi}{f}$$



Perturbations

Axion scalar

$\delta\chi$

Gauge-field scalars

$\delta A_i^a \supset \delta Q,\ \delta M$

Metric tensors

$\delta g_{ij} \supset h_{ij} \longrightarrow h_{L,R}$

Gauge-field tensors

$\delta A_i^a \supset t_{ia} \longrightarrow t_{L,R}$

Canonical quantization: $\hat{\Delta}_a(\tau, \mathbf{k}) = \mathcal{D}_{a\alpha}(\tau, k)\hat{a}_\alpha(\mathbf{k}) + \mathcal{D}^*_{a\alpha}(\tau, k)\hat{a}^\dagger_\alpha(-\mathbf{k})$

Equations of motion: $$\mathcal{D}'' + 2K\mathcal{D}' + \left(\Omega^2 + K'\right)\mathcal{D} = 0$$