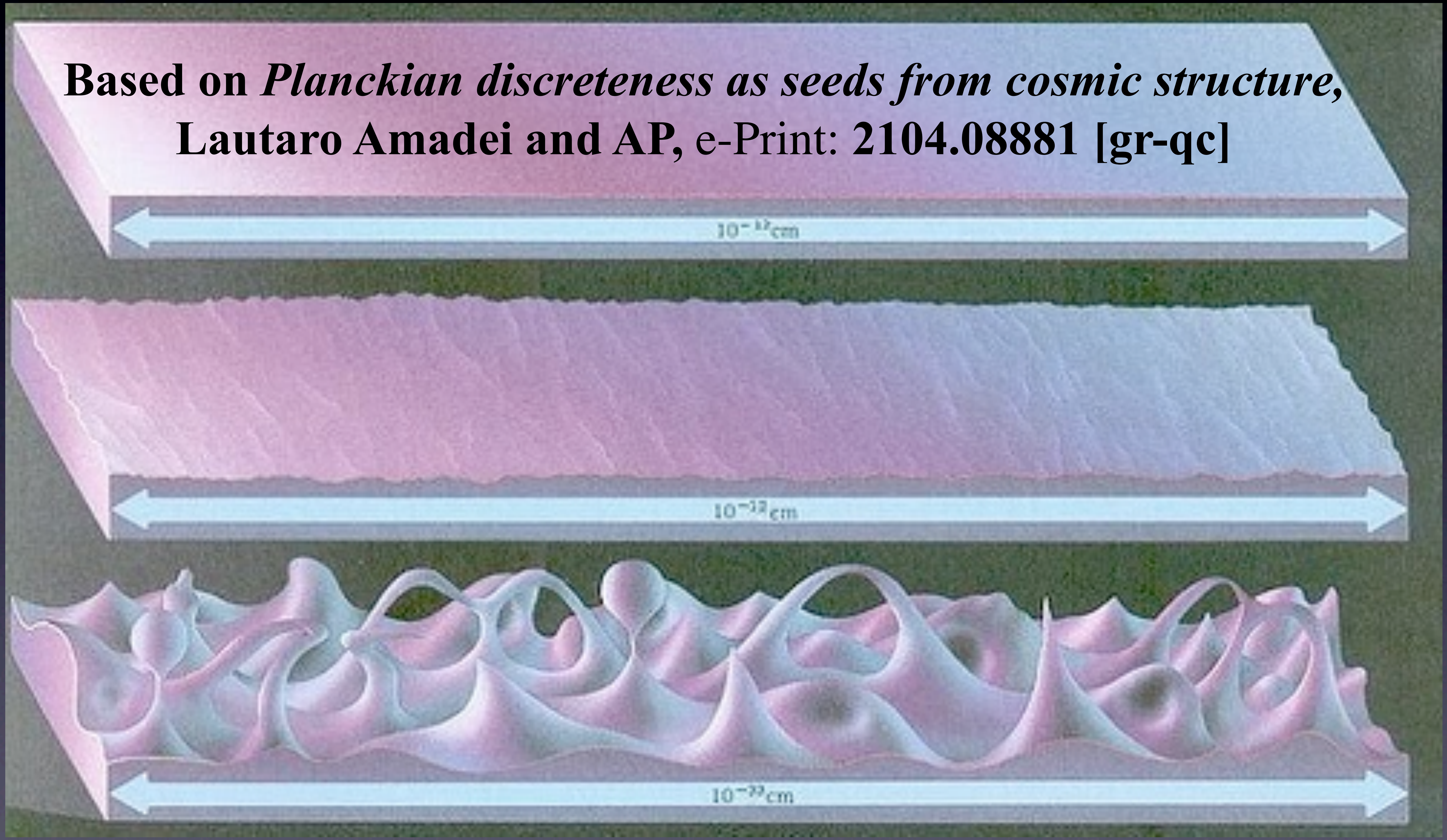
Planckian discreteness as seeds for cosmic structure

Loops 22, July 2022



Based on ***Planckian discreteness as seeds from cosmic structure,***
Lautaro Amadei and AP, e-Print: **2104.08881 [gr-qc]**

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Can we produce a phenomenology of Planckian discreteness?

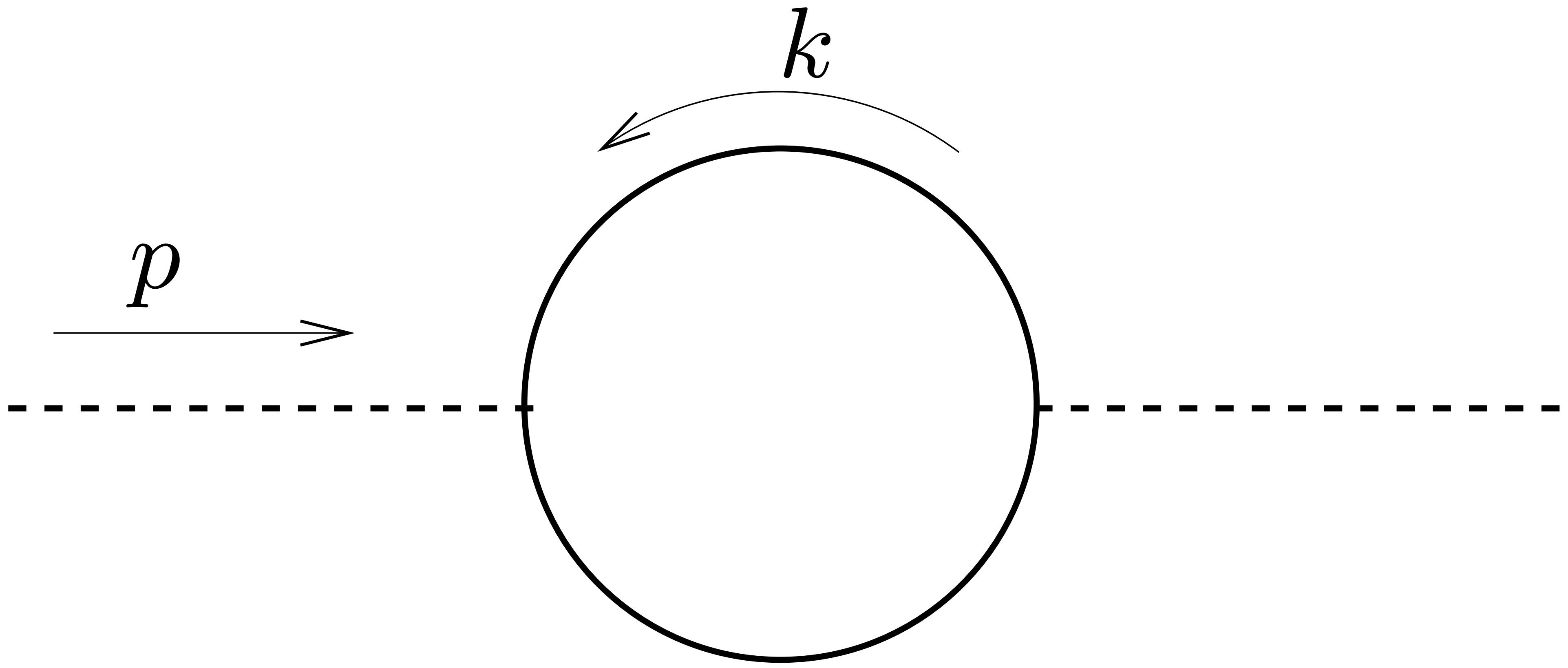
Radiative corrections make Lorentz violation percolate to low energies

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{m_0^2}{2}\phi^2 + \bar{\psi}(i\gamma^\mu\partial_\mu - M_0)\psi + g_0\phi\bar{\psi}\psi.$$

$$\frac{i}{\gamma^\mu p_\mu - m_0 + i\epsilon} \to \frac{if(|\mathbf{p}|/\Lambda)}{\gamma^\mu p_\mu - m_0 + \Delta(|\mathbf{p}|/\lambda) + i\epsilon},$$

$$\frac{i}{p^2 - M_0^2 + i\epsilon} \to \frac{i\tilde{f}(|\mathbf{p}|/\Lambda)}{p^2 - M_0^2 + \tilde{\Delta}(|\mathbf{p}|/\lambda) + i\epsilon}.$$

Collins, AP, Sudarsky, Urrutia, Vusetich; *Phys. Rev. Letters*. 93 (2004).

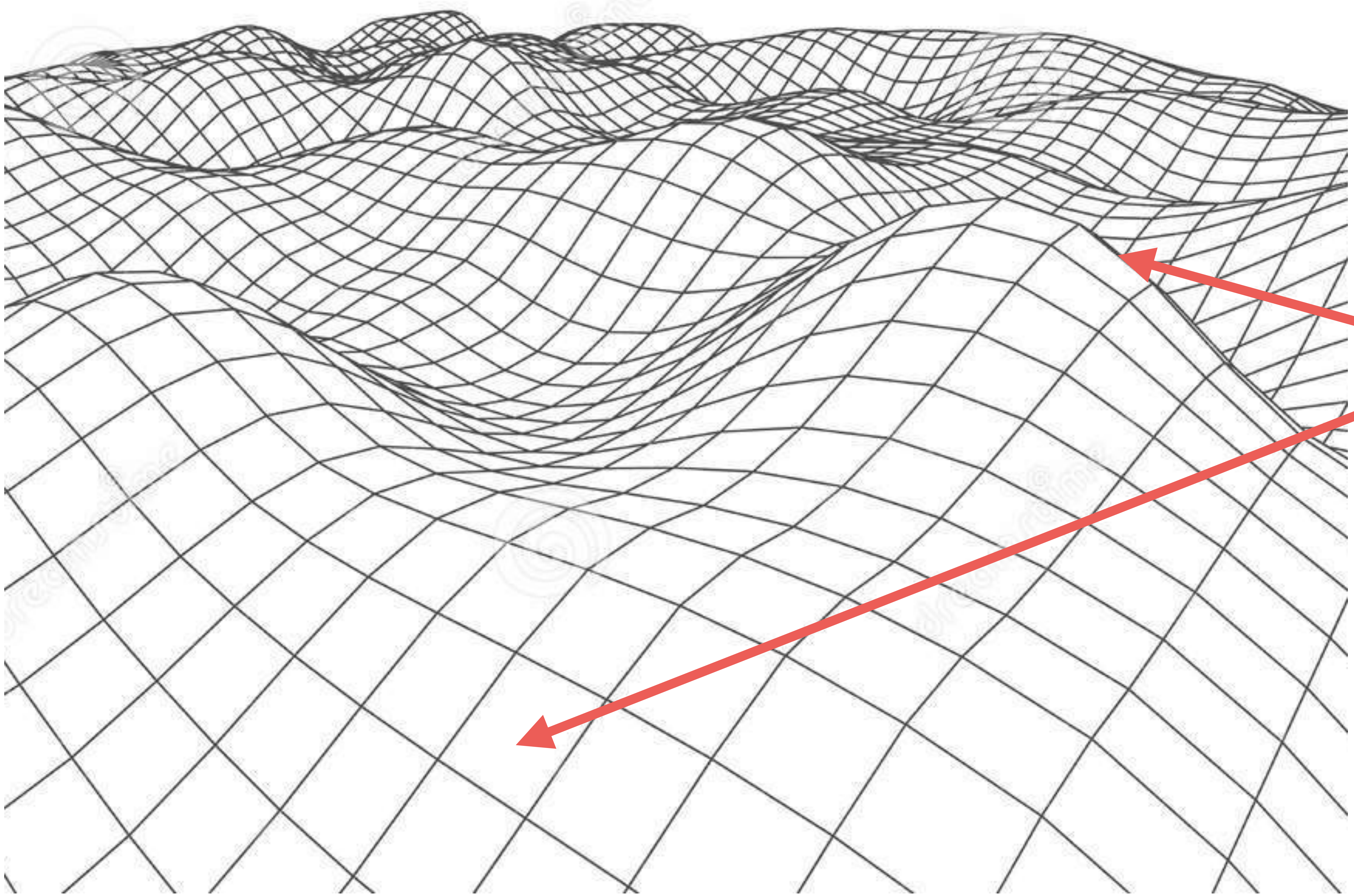


$$\Pi(p) = A + p^2 B + p^\mu p^\nu W_\mu W_\nu \tilde{\xi} + \Pi^{(\mathrm{LI})}(p^2) + \mathcal{O}(p^4/\Lambda^2)$$

$$\boxed{\tilde{\xi} = \frac{g^2}{6\pi^2}\left[1 + 2\int_0^\infty dx\, x f'(x)^2\right]}$$

WAY OUT: Observables in QG are relational, discreteness must be relational

Discreteness and Lorentz invariance



Discreteness **could** manifest itself in regions of non trivial curvature

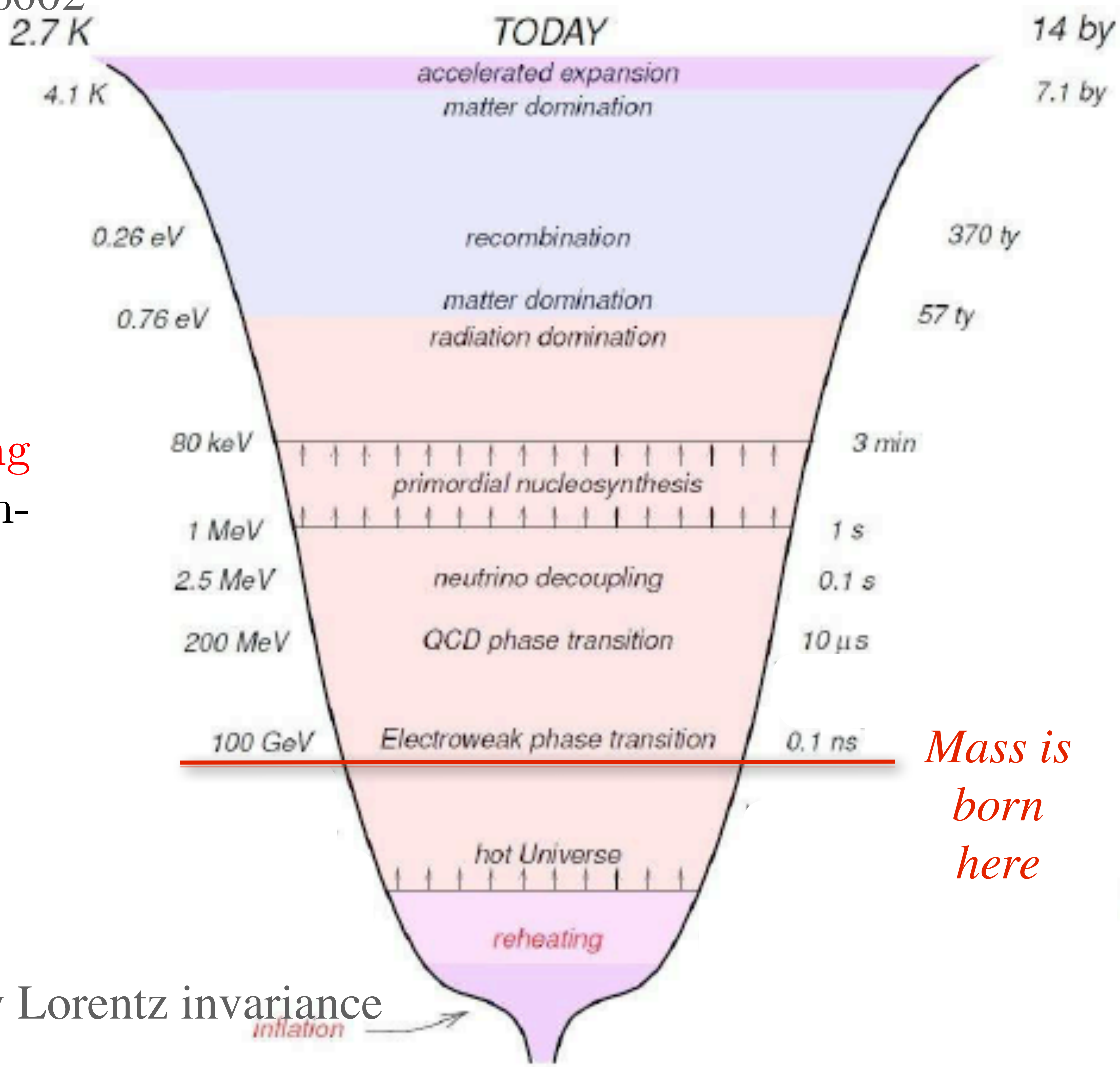
A model predicting the observed cosmological constant

T. Josset, AP and D. Sudarsky, *Phys.Rev.Lett*. 118 (2017) 2, 021102.
AP. D. Sudarsky and J.D. Bjorken *Int.J.Mod.Phys.D* 27 (2018) 14, 1846002
AP and D. Sudarsky, *Phys.Rev.Lett*. 122 (2019) 22, 221302

$$\mathbf{R}_{ab} - \frac{1}{2}\mathbf{R}g_{ab} = 8\pi\mathbf{T}_{ab} - \underbrace{\left[\Lambda_0 + \int_\ell \mathbf{J}\right]}_{\text{Dark Energy }\Lambda} g_{ab}$$

Assuming that the cosmological constant $\Lambda = 0$ at the big-bang then the diffusion effect generates it during the electro-weak transition when massive-spinning particles first appear.

$$\boxed{\Lambda \approx \gamma \frac{m_t^4 T_{\rm ew}^3}{m_p^7} m_p^2 \approx \gamma \underbrace{\left(\frac{T_{\rm ew}}{m_p}\right)^7}_{\approx 10^{-120}} m_p^2}$$



The model is compatible with the constraints imposed by low energy Lorentz invariance

Collins, AP, Sudarsky, Urrutia, Vusetich;
Phys. Rev. Letters. 93 (2004).

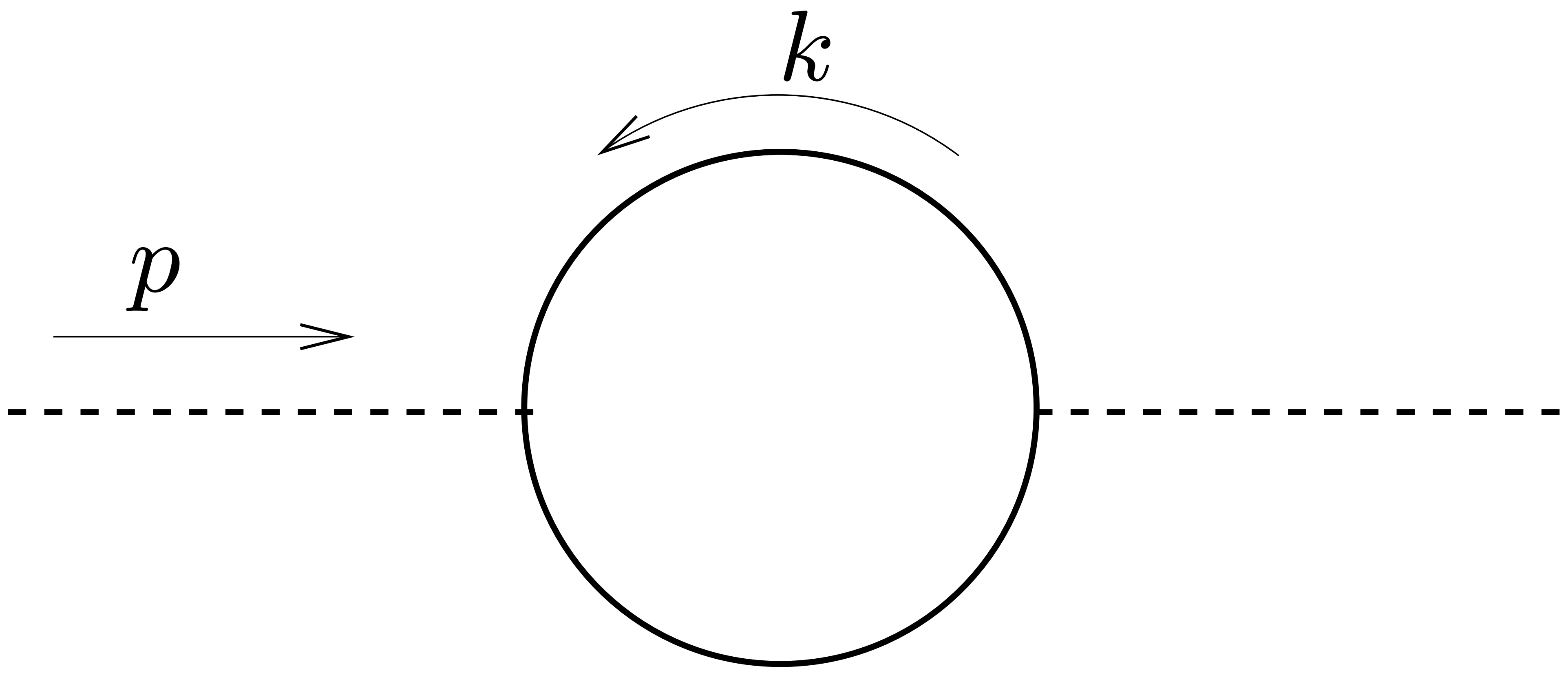
What effects could be observable after the EW era?

Collins, AP, Sudarsky, Urrutia, Vusetich;
Phys. Rev. Letters. 93 (2004).

Lorentz violating operators in EQFT must be suppressed by the scalar curvature. The leading operators dimensionally allowed are:

$$O_1 = \lambda_1 \, \xi^\mu \nabla_\mu \phi \mathbf{R} = \lambda_1 \dot{\phi} \mathbf{R}$$

$$O_2 = \lambda_2 \xi^\mu \bar{\psi} \gamma_\mu \psi \frac{\mathbf{R}}{m_p}$$

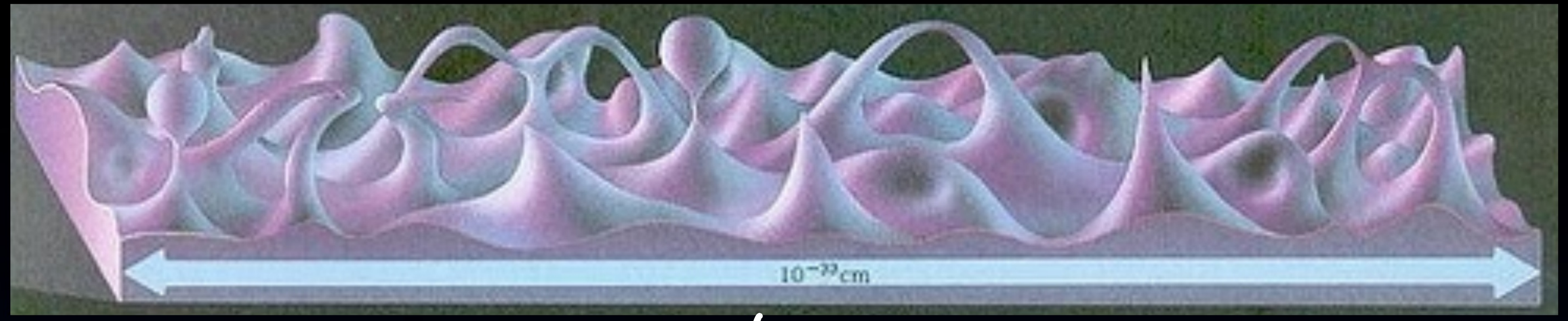


Constraints from present experiments and observations

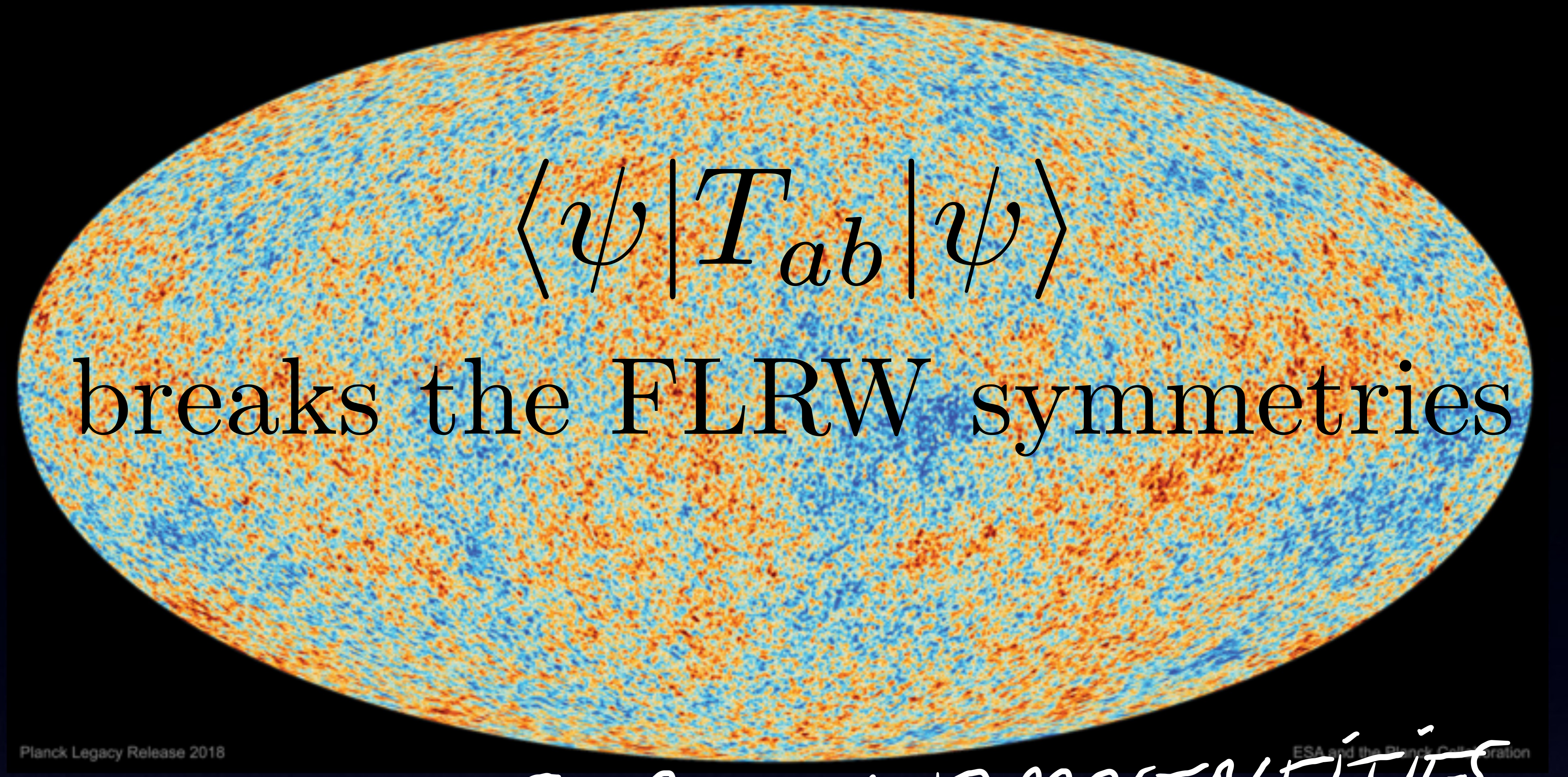
$$T > 10^{-8} T_p = 10^{11} \mathrm{GeV}$$

V. Alan Kostelecky and Neil Russell. Data Tables for Lorentz and CPT Violation. Rev. Mod. Phys., 2011.

INFLATION



PLANCKIAN GRANULARITY



CMB INHOMOGENEITIES

A COSMOLOGICAL MODEL WHERE:

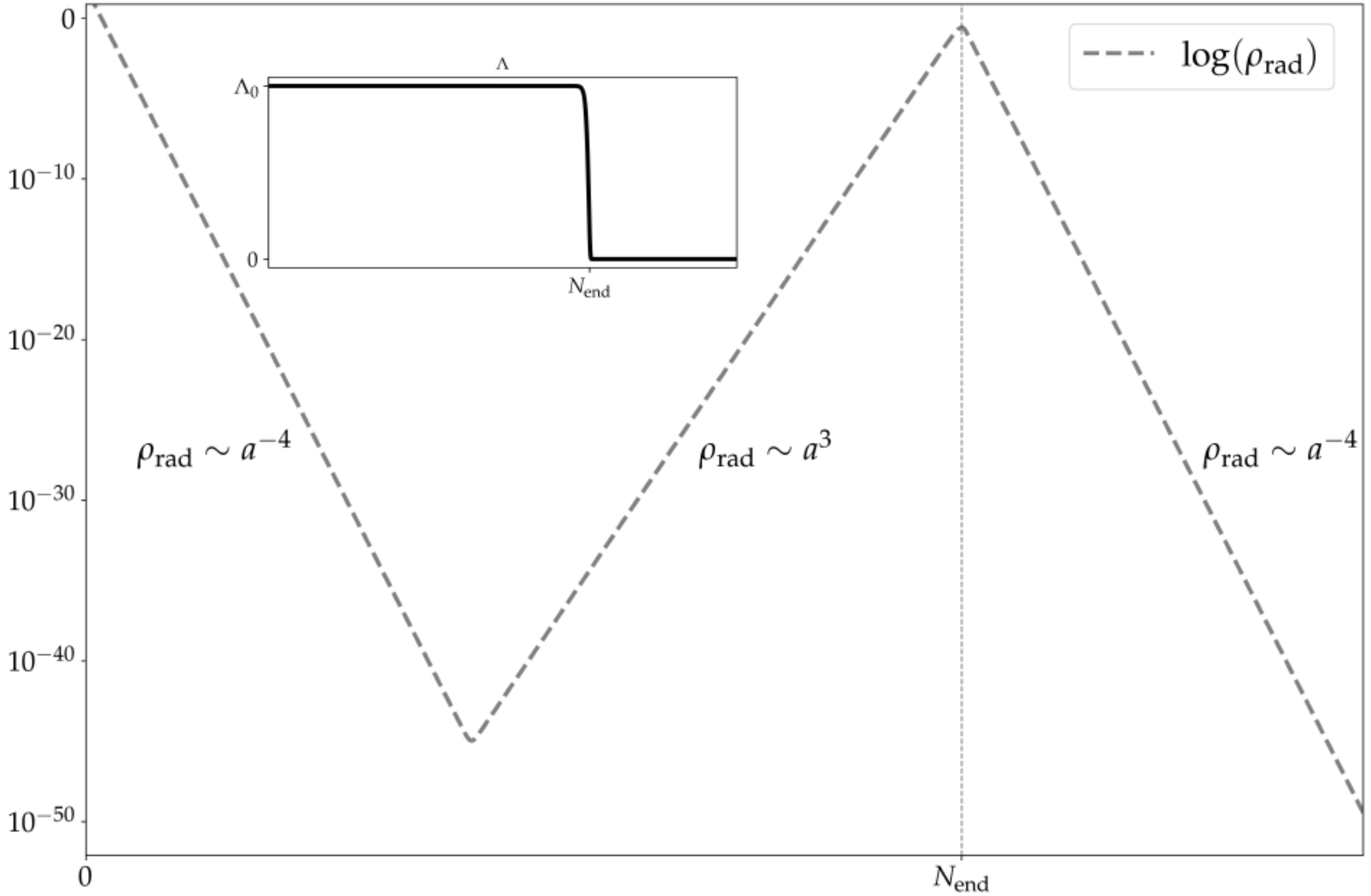
1) THE COSMOLOGICAL CONSTANT DECAYS FROM ITS INITIAL PLANCK SCALE NATURAL VALUE

2) INHOMOGENEITIES IN THE CMB ARISE FROM PLANCKIAN DISCRETENESS

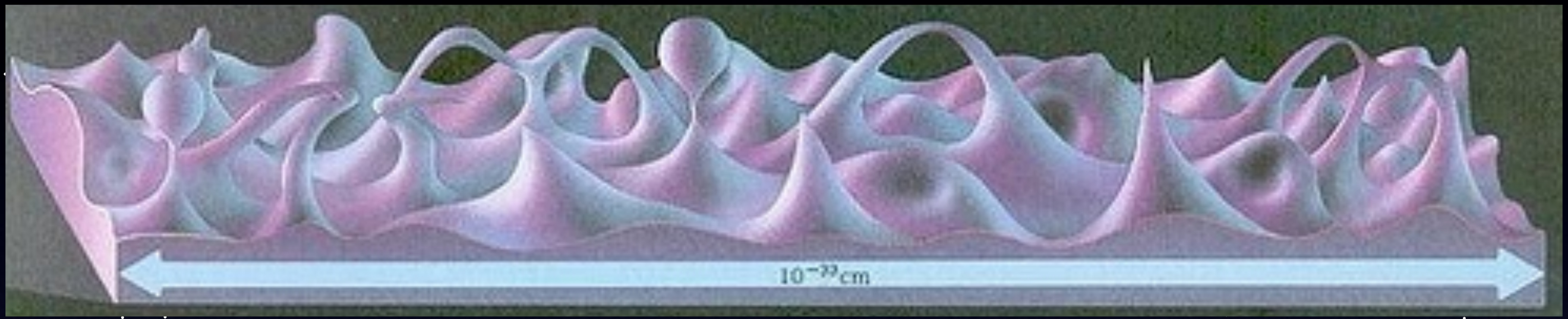
THE MODEL: A cosmological constant starting at its natural Planckian value decaying exponentially in UNIMODULAR TIME.

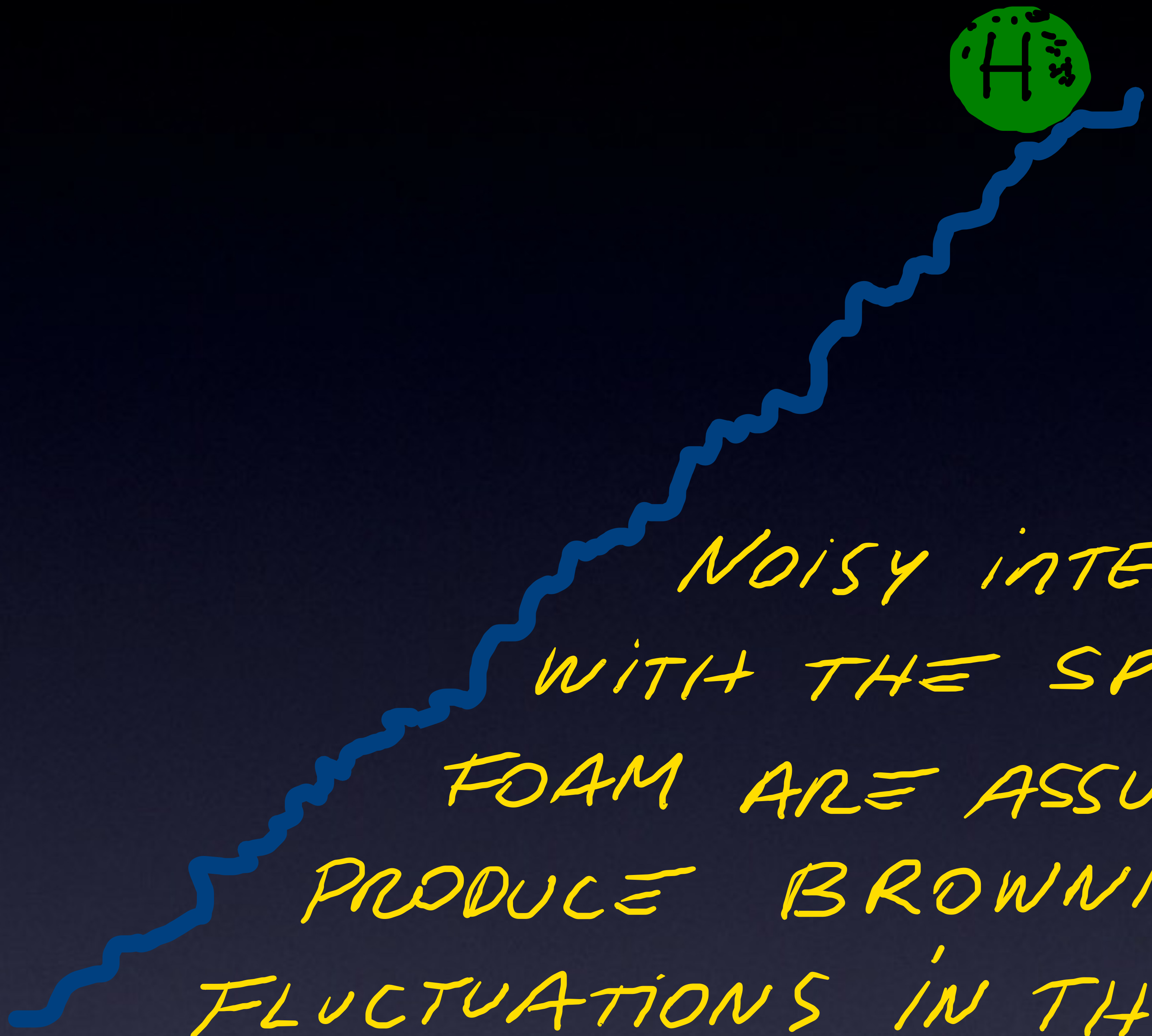
$$ds^2 = -d\tau^2 + a^2(\tau)d\vec{x}^2 \qquad\qquad ds^2 = -a^{-6}dt^2 + a^2 d\vec{x}^2$$

$$\Lambda(t) = \Lambda_0 \exp(-\beta m_p t)$$



THE HIGGS SCALAR EVOLVES IN SUCH SPACETIME AND INHERITS PERTURBATIONS FROM PLANCKIAN INHOMOGENEITIES.



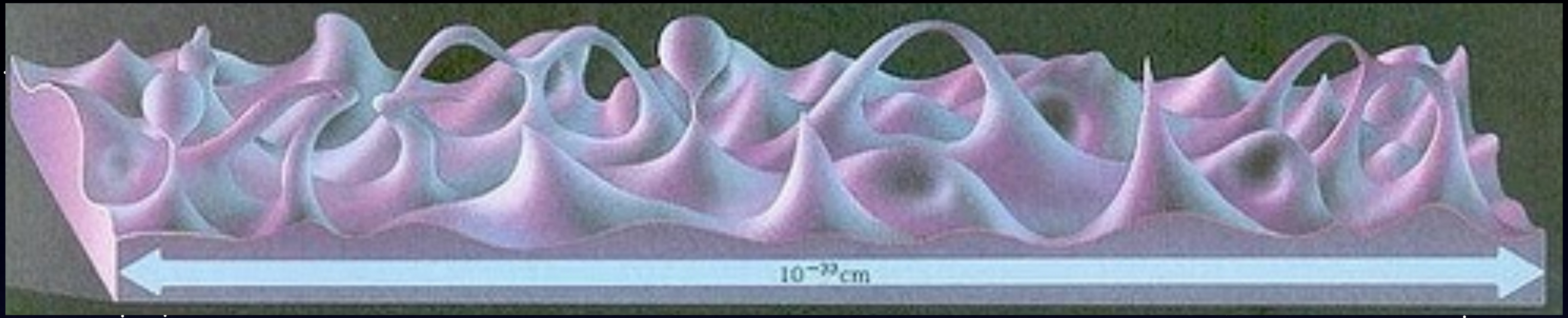


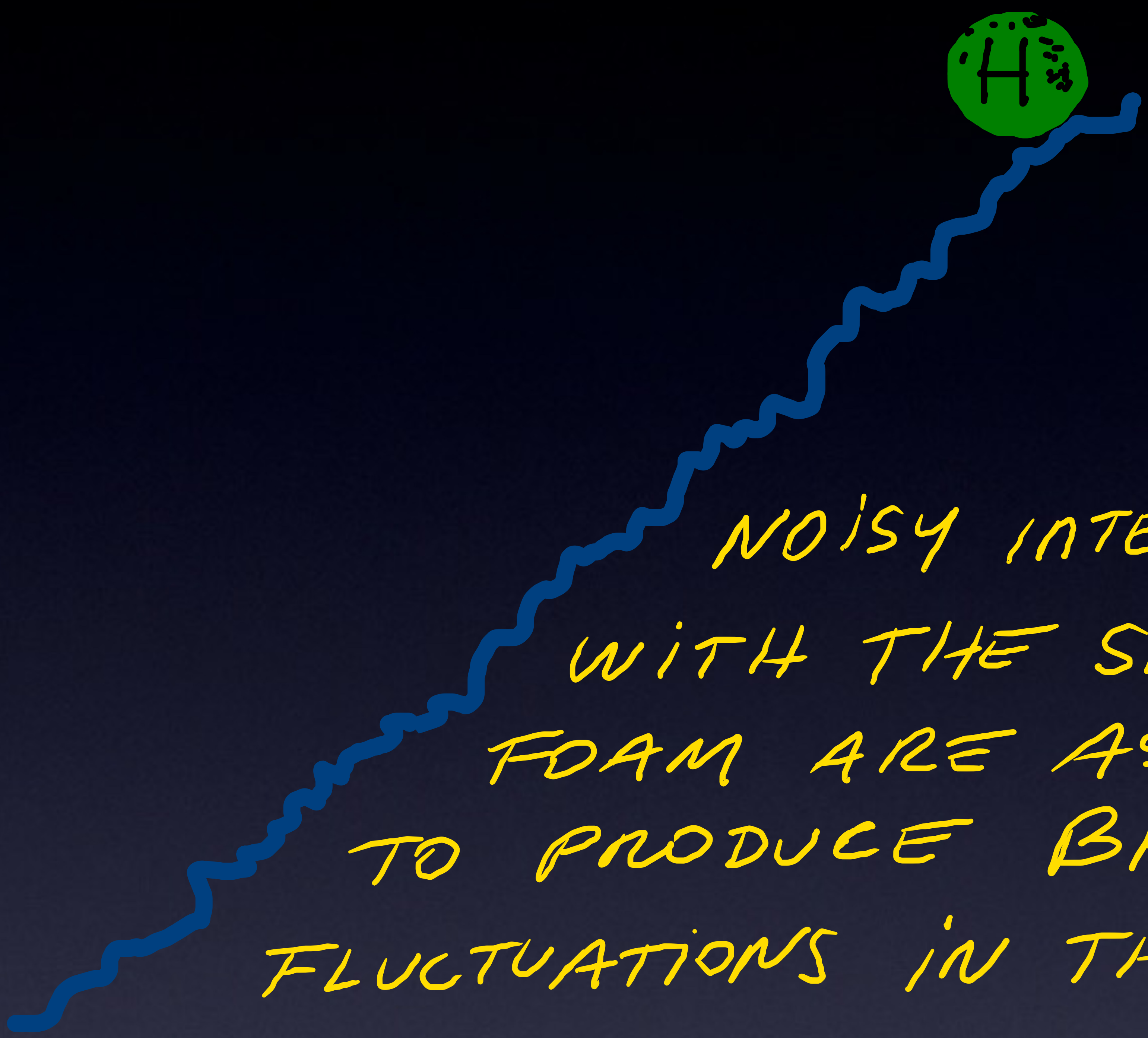
NOISY INTERACTIONS WITH THE SPACETIME FOAM ARE ASSUMED TO PRODUCE BROWNIAN FLUCTUATIONS IN THE HIGGS SCALAR.

BUT NOISE IS AT THE PLANCK SCALE

... WHICH BREAKS SCALE INVARIANCE ☹

THE HIGGS SCALAR EVOLVES IN SUCH SPACETIME AND INHERITS PERTURBATIONS FROM PLANCKIAN INHOMOGENEITIES.





NOISY INTERACTIONS WITH THE SPACETIME FOAM ARE ASSUMED TO PRODUCE BROWNIAN FLUCTUATIONS IN THE HIGGS SCALAR.

BUT NOISE IS AT THE PLANCK SCALE

De Sitter expansion RESTORES SCALE INVARIANCE TO PERTURBATIONS!!

KNOWING THE POWER SPECTRUM ALLOWS FOR THE COMPUTATION OF THE AVERAGE VALUE OF THE ENERGY MOMENTUM TENSOR

$$\boxed{\langle \delta\phi(\vec{x})\delta\phi(\vec{x})\rangle = \frac{1}{(2\pi)^3}\int dk^3 P_{\delta\phi}(k)}$$

$$\begin{aligned}
\langle T_{ab}\rangle &= -\frac{\Lambda m_p^2}{8\pi} g_{ab} + \langle \nabla_a(\phi_0+\delta\phi)\nabla_b(\phi_0+\delta\phi) - \frac{1}{2} g_{ab}\left(\nabla_c(\phi_0+\delta\phi)\nabla^c(\phi_0+\delta\phi) + 2V((\phi_0+\delta\phi))\right)\rangle \\
&= T^{(0)}_{ab} + \underbrace{\langle \nabla_a\delta\phi\nabla_b\delta\phi\rangle - \frac{1}{2} g_{ab}\left(\langle \nabla_\alpha\delta\phi\nabla^\alpha\delta\phi\rangle + \frac{d^2V(\phi_0)}{d\phi^2}\langle \delta\phi^2\rangle\right)}_{\langle \delta T_{ab}\rangle}
\end{aligned}$$

INFLATIONARY "CONVEYOR BELT"

$$\frac{dW^{\text{pert.}}}{d\tau} \equiv \frac{d\langle\delta\rho^{(2)}\rangle}{d\tau} + 2\frac{\dot{a}}{a}\langle\delta\rho^{(2)}\rangle - \frac{\dot{a}}{a}\frac{d^2V(\phi_0)}{d\phi^2}\langle\delta\phi^2\rangle = \gamma H^5$$

APROX. CONSTANT (GEOMETRIC) ENERGY INPUT into SCALAR field perturbations

$$\langle\delta\rho^{(2)}\rangle \equiv \langle\delta T_{00}\rangle = \frac{1}{2\pi^2}\int_{\mu}^{aH_0} dk k^2 \left(\frac{k^2}{2a^2} + \frac{1}{2}\frac{d^2V(\phi_0)}{d\phi^2}\right) P_{\delta\phi}(k)$$

$$P_{\delta\phi}(k) = \frac{4\pi^2\gamma H^2}{k^3}$$

The WEINBERG Theorem: connecting fluctuations of the Higgs during inflation to inhomogeneities seen at the CMB

$$\frac{\delta\rho_k^{(1)}}{\dot{\rho}_0} = -\frac{\mathcal{R}_k}{a(\tau)}\int_{\mathcal{T}}^{\tau} a\left(\tau'\right)d\tau' \approx -\frac{\mathcal{R}_k}{H_0} \qquad \delta\mathbf{R}^{(3)} = -4\vec{\nabla}^2\mathcal{R}$$

$$\Phi_k = \Psi_k = \mathcal{R}_k\left(-1 + \frac{H(\tau)}{a(\tau)}\int_{\mathcal{T}}^{\tau} a\left(\tau'\right)d\tau'\right) \approx 0$$

$$\mathcal{R}_k = -H_0\frac{\delta\rho_k^{(1)}}{\dot{\rho}_0}$$

$$\boxed{P_{\mathcal{R}} \approx \frac{9\pi^2\gamma}{k^3\lambda^2}\left(1 + 4\lambda\log\left(\frac{k}{k_0}\right)\right).}$$

RELATING PREDICTIONS TO OBSERBATIONS

$$N^2 \approx \frac{9\pi^2\gamma}{\lambda^2} \approx 1.9\times10^{-10}$$

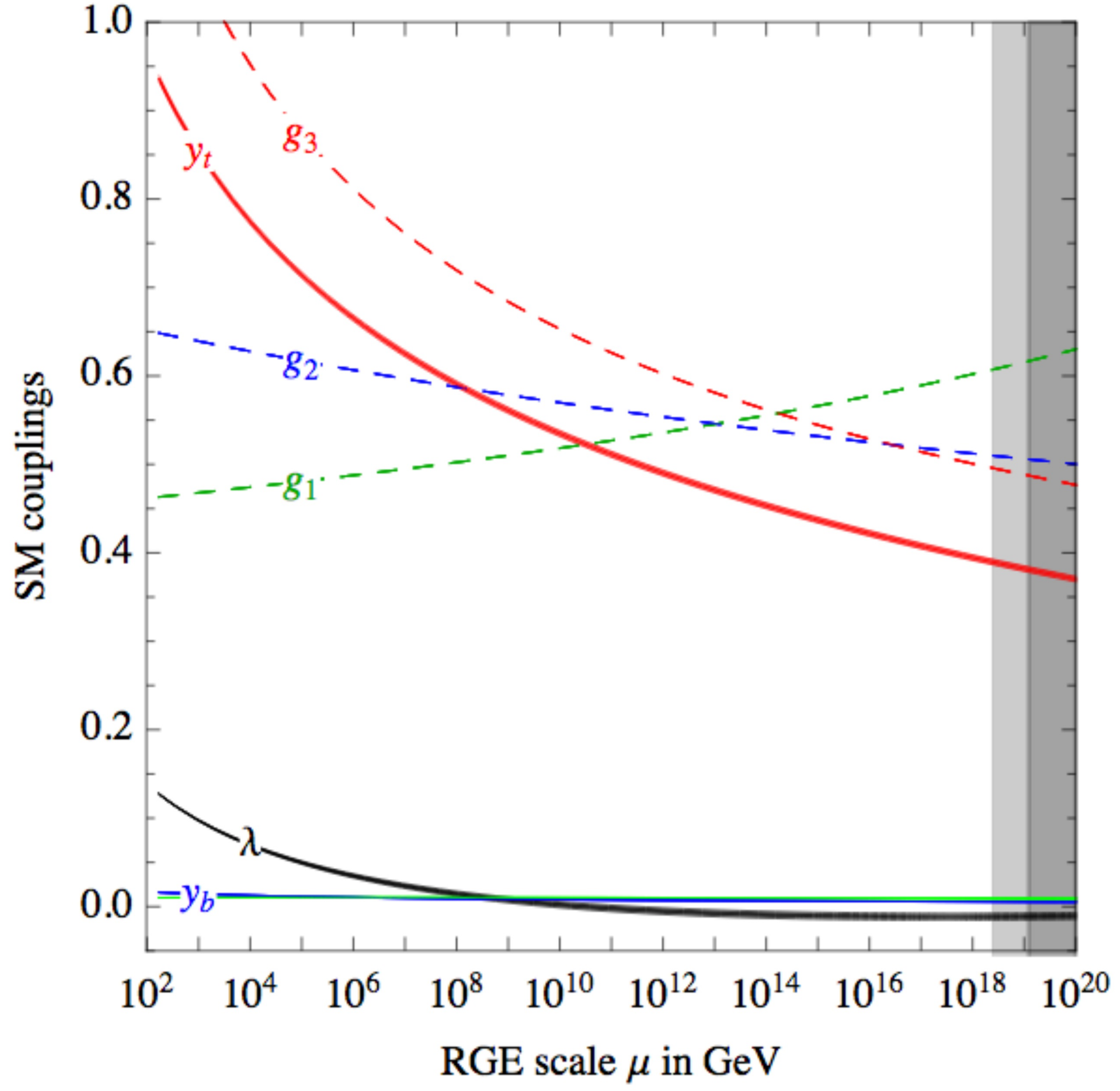
$$n_{\mathrm{s}} - 1 \equiv \frac{d\log(k^3 P_{\mathcal{R}})}{d\log k} \approx 4\lambda + \mathscr{O}\left[\lambda^2\log\left(\frac{k_{\max}}{k_0}\right)\right]$$

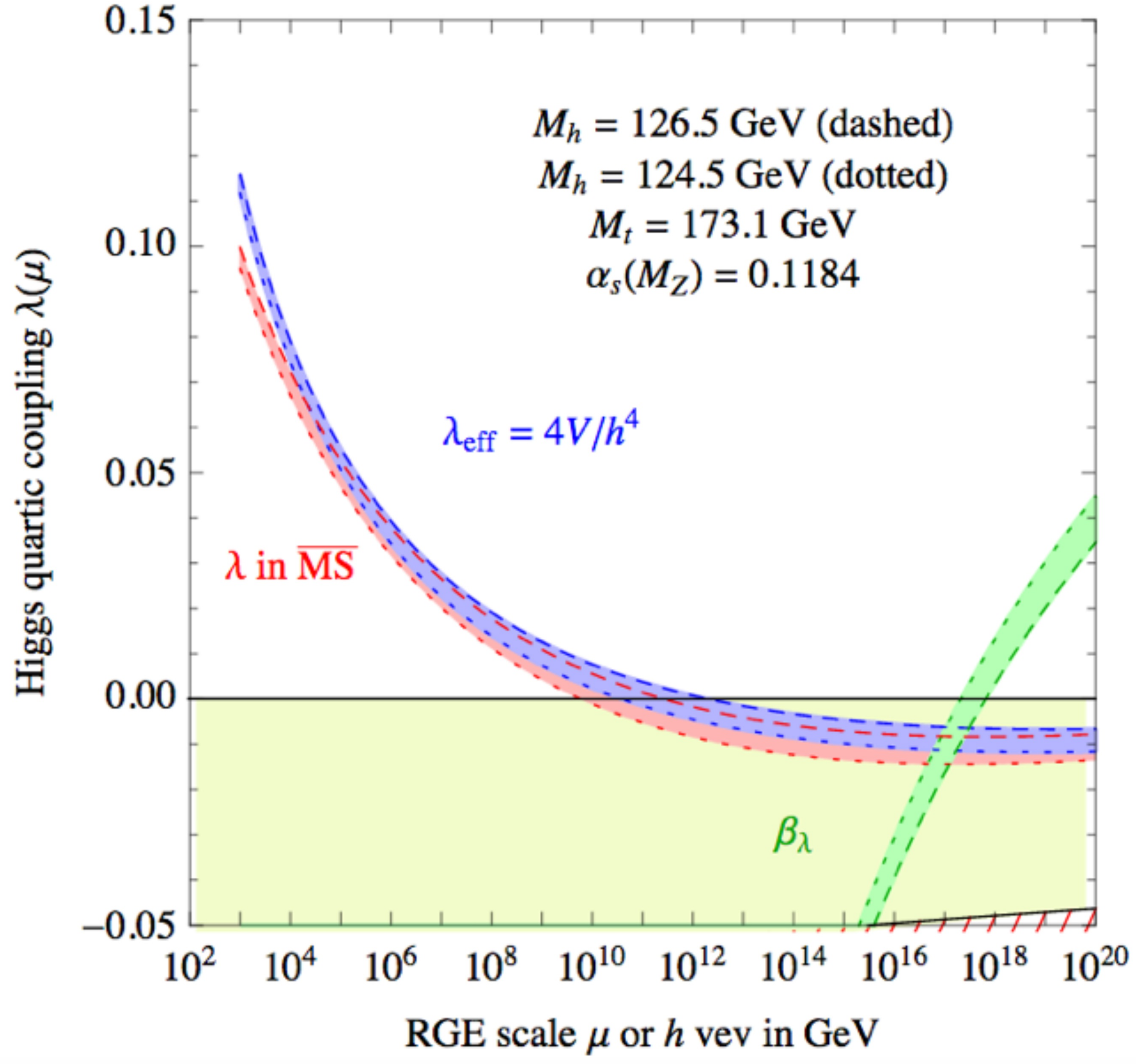
Planck, Y. Akrami et al., "Planck 2018 results. X. Constraints on inflation," Astron. Astrophys. 641 (2020) A10, arXiv: 1807.06211.

$$\gamma \approx 10^{-16} \approx \frac{m_{\mathrm{H}}}{m_p}$$

$$\lambda = -(1.3\pm0.7)\times10^{-2}$$

Renormalization Group Flow of the Couplings of the Standard Model





From G. Degrassi, S. Di Vita, J. Elias-Miro, J. R. Espinosa, G. F. Giudice, G. Isidori, and A. Strumia, “Higgs mass and vacuum stability in the Standard Model at NNLO,” JHEP 08 (2012) 098, arXiv:1205.6497.

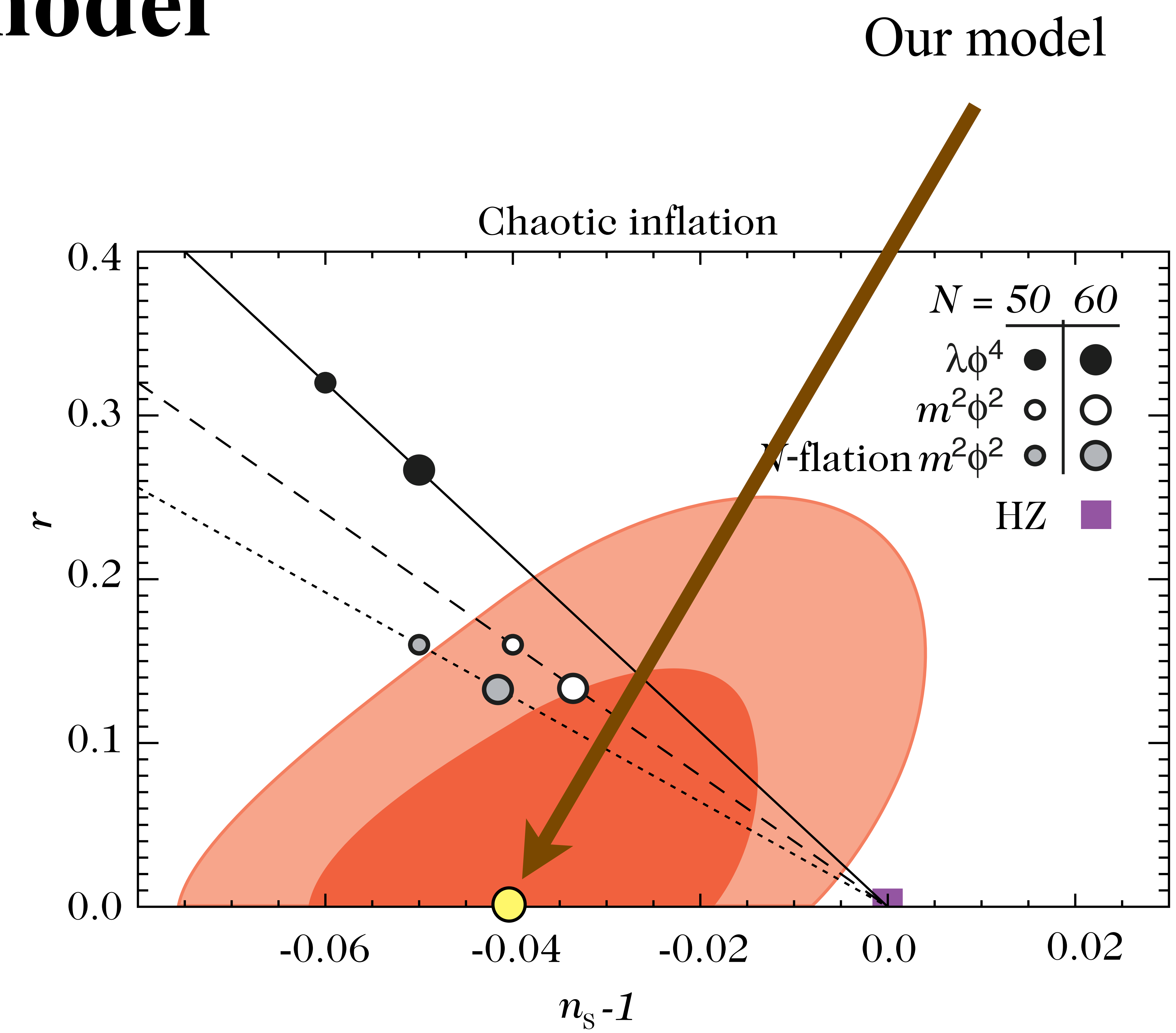
Predictions of the model

$$n_s - 1 \equiv \frac{d\log(k^3 P_{\mathcal{R}})}{d\log k} \approx 4\lambda + \mathscr{O}\left[\lambda^2 \log\left(\frac{k_{\max}}{k_0}\right)\right]$$

Planck, Y. Akrami et al., “Planck 2018 results. X. Constraints on inflation,” Astron. Astrophys. 641 (2020) A10, arXiv: 1807.06211.

$$\left.\begin{aligned} dn_s/d\ln k &= -0.0045 \pm 0.0067, \\ n_s &= 0.9641 \pm 0.0044, \\ n_{s,0.002} &= 0.979 \pm 0.021, \end{aligned}\right\} \quad \begin{aligned}&68\,\%, \text{ TT,TE,EE} \\ &\text{+lowE+lensing,}\end{aligned}$$

$$\left.\begin{aligned} dn_s/d\ln k &= -0.0041 \pm 0.0067, \\ n_s &= 0.9659 \pm 0.0040, \\ n_{s,0.002} &= 0.979 \pm 0.021, \end{aligned}\right\} \quad \begin{aligned}&68\,\%, \text{ TT,TE,EE} \\ &\text{+lowE+lensing} \\ &\text{+BAO,}\end{aligned}$$



Running of the spectral index

$$\frac{dn_s}{d\log k} = -0.0005 + \mathscr{O}(\lambda^3).$$

Nearly vanishing tensor to scalar ratio

$$r \approx 0$$

Discussion

Discreteness at the Planck scale might be at the root of important theoretical and observational puzzles

* Decoherence with Planckian degrees of freedom open a natural channel for the resolution of BH info paradox

* Diffusion with Planckian degrees of freedom might explain the tiny cosmological constant in cosmology

* Interactions with the Planckian granularity can lead to a spectrum of perturbations in the CMB compatible with observations where

$\langle \psi | T_{ab} | \psi \rangle$ breaks the FLRW symmetries