





Ultra-slow-roll in Higgs Inflation

3rd IJMCG

Diego M. Navia Rojas

October 20, 2026

In collaboration with V. H. Cárdenas

Outline

1. Non-minimally coupled Higgs inflation
2. Early ultra-slow-roll dynamics
3. Background integration and initial conditions
4. Linearized perturbations and slow roll comparison
5. Primordial spectrum and CMB consequences
6. Conclusions

Non-minimally coupled Higgs inflation

The Jordan-frame Higgs field h is non-minimally coupled to gravity:

$$\mathcal{S} = \int d^4x\sqrt{-g}\left[-\frac{M_p^2+\xi h^2}{2}R + \frac{(\partial h)^2}{2} - \frac{\lambda}{4}(h^2-v^2)^2\right].$$

With $\hat{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}$ and $\Omega^2 = 1+\xi h^2/M_p^2$, the gravitational coefficient becomes constant. The canonical field χ satisfies

$$\frac{d\chi}{dh} = \frac{\sqrt{1+\xi(1+6\xi)h^2/M_p^2}}{\Omega^2}.$$

The resulting Einstein-frame action is

$$\mathcal{S}_E = \int d^4x\sqrt{-\hat{g}}\left[-\frac{M_p^2}{2}\hat{R} + \frac{1}{2}\hat{g}^{\mu\nu}\partial_\mu\chi\,\partial_\nu\chi - U_E(\chi)\right].$$

Einstein frame potential

The transformed Higgs potential is

$$U_E(\chi(h)) = \frac{\lambda(h^2 - v^2)^2}{4\Omega^4}.$$

At large field values and $\xi \gg 1$,

$$\chi \simeq \sqrt{\frac{3}{2}}\, M_p \ln \Omega^2.$$

In terms of the canonical field, the potential becomes

$$U_E(\chi) \simeq \frac{\lambda M_p^4}{4\xi^2}\left(1 - e^{-\sqrt{2/3}\,\chi/M_p}\right)^2.$$

The plateau height is controlled by λ/ξ^2.

Einstein frame potential

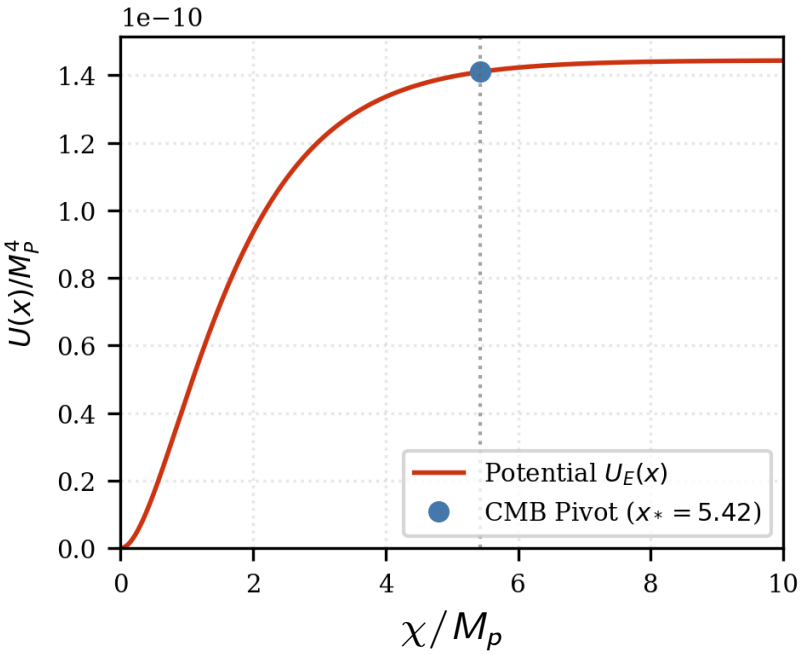


Figure: Einstein-frame potential: $\xi = 15000$, $\lambda = 0.13$.

Horizon-flow hierarchy, with $N = \ln a$:

$$\epsilon_1 \equiv -\frac{\dot{H}}{H^2},$$

$$\epsilon_2 \equiv \frac{d \ln \epsilon_1}{dN},$$

$$\epsilon_{i+1} \equiv \frac{d \ln |\epsilon_i|}{dN} \quad (i \geq 1).$$

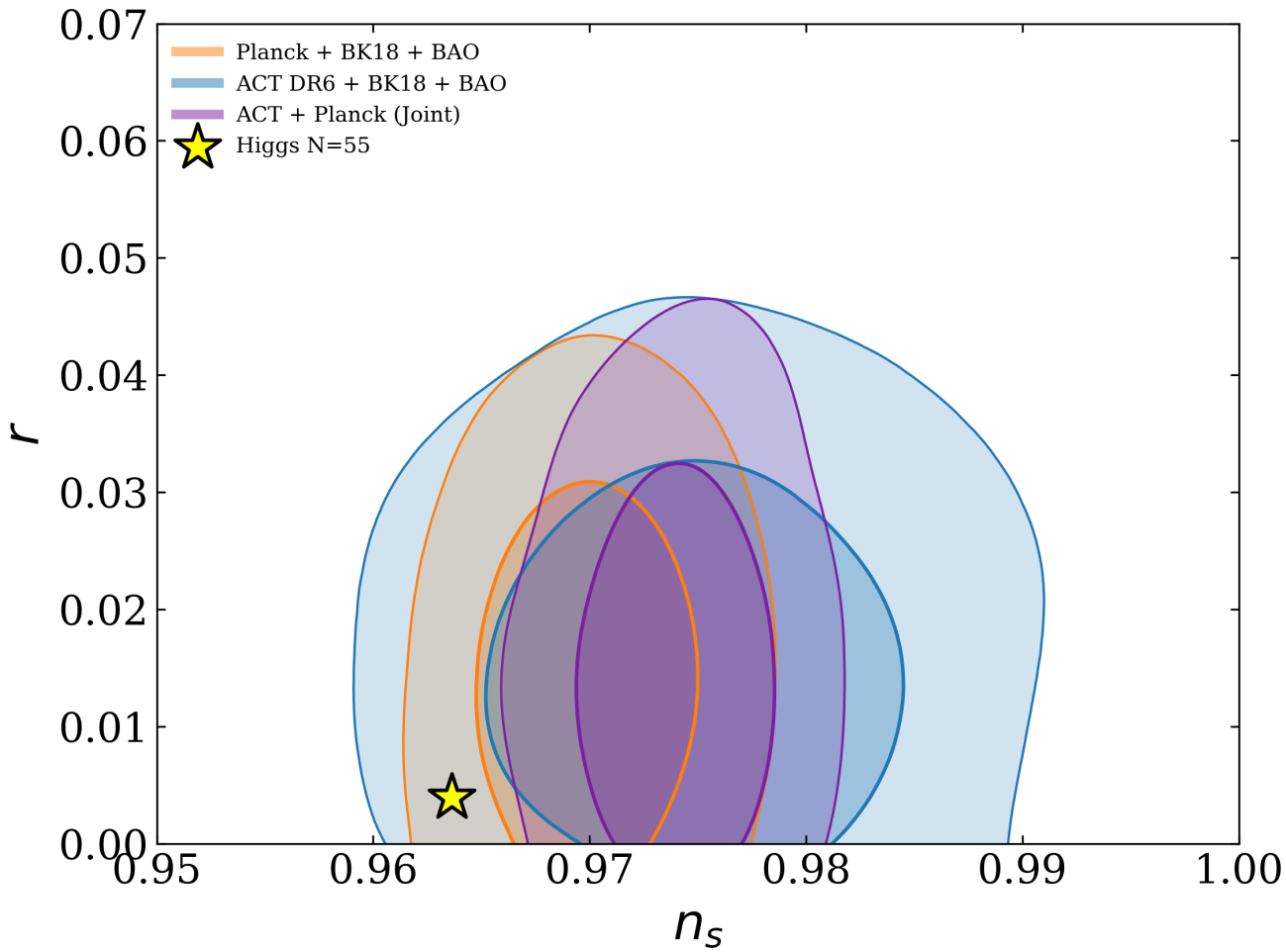
At N_* e-folds before the end, SR gives

$$\epsilon_1 \simeq \frac{3}{4N_*^2}, \qquad \epsilon_2 \simeq \frac{2}{N_*},$$

$$n_s \simeq 1 - \frac{2}{N_*}, \qquad r \simeq \frac{12}{N_*^2}.$$

$$A_s^{\rm SR} \simeq \frac{\lambda N_*^2}{72\pi^2\xi^2}.$$

Slow roll predictions



Early ultra-slow roll

The canonical field obeys

$$\ddot{\chi} + 3H\dot{\chi} + U_{E,\chi} = 0.$$

If $|U_{E,\chi}| \ll 3H|\dot{\chi}|$, the initial velocity decays under Hubble friction:

$$\ddot{\chi} + 3H\dot{\chi} \simeq 0, \qquad \dot{\chi} \propto a^{-3}.$$

For potential-dominated expansion

$$\epsilon_1 = \frac{\dot{\chi}^2}{2M_p^2 H^2} \propto a^{-6}.$$

- As $|\dot{\chi}|$ falls, the gradient becomes relevant again and the trajectory approaches slow roll.

Horizon-flow evolution

Potential-dominated USR limit

$\epsilon_1 \ll 1, \quad \epsilon_2 \simeq -6.$

- The plotted trajectory begins near the USR limit and relaxes toward SR.

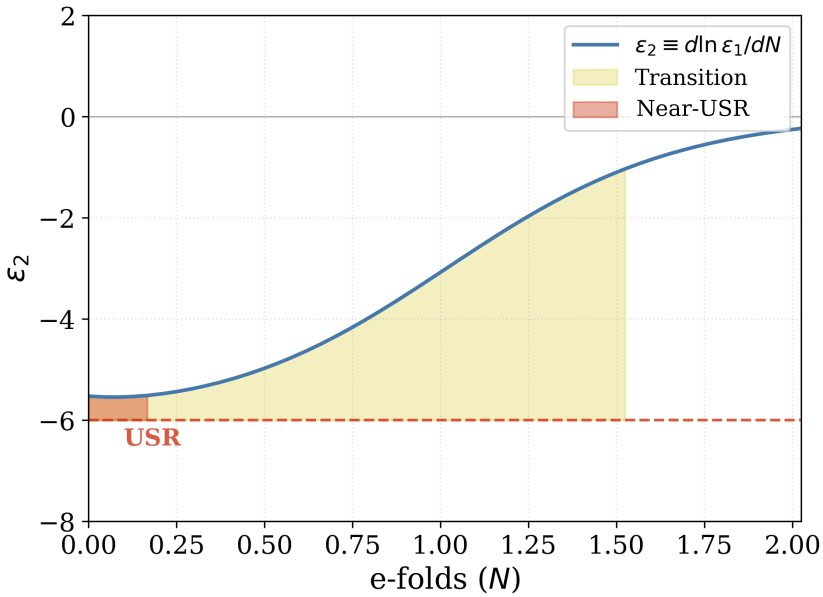


Figure: Evolution of $\epsilon_2(N)$. Dashed line: the USR limit $\epsilon_2 = -6$.

Transient USR heatmap

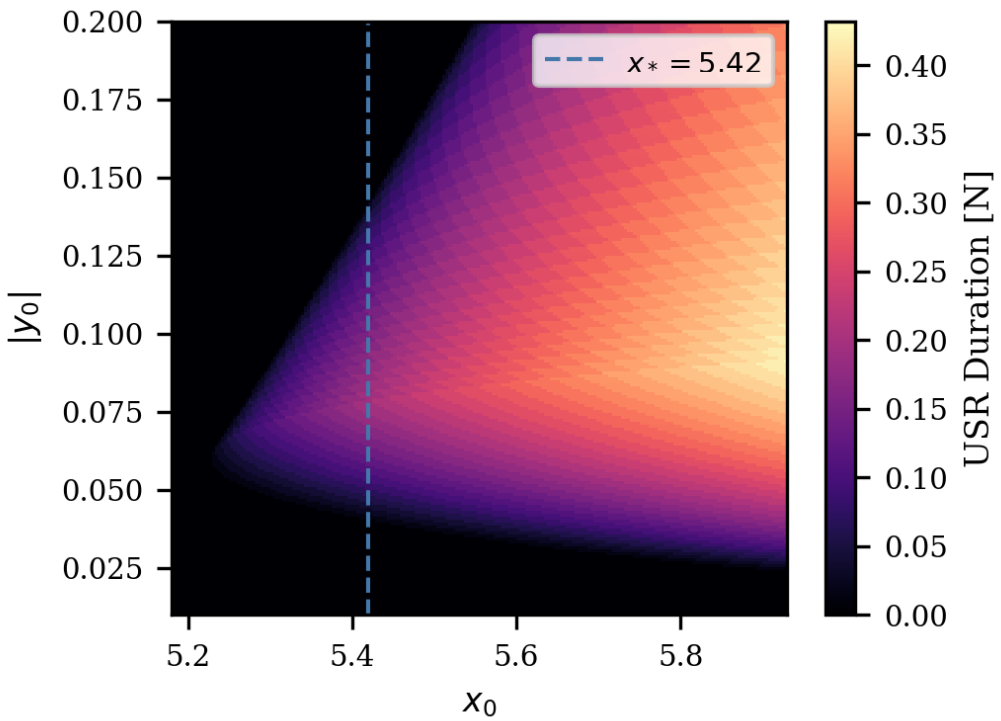


Figure: Near-USR duration: sampled ΔN with $\epsilon_2 < -5.5$ during inflation ($\epsilon_1 < 1$), with $y_0 < 0$ and $\xi = 15000$.

- Early USR occupies an extended region of the initial-condition phase space.
- Near the dashed line, the early-USR phase leaves an imprint on CMB scales.

Superhorizon curvature evolution

For a canonical scalar, $z = a\dot{\chi}/H$ and $z^2 = 2a^2\epsilon_1 M_p^2$. On superhorizon scales,

$$\frac{d}{dt}\left(a^3\epsilon_1\dot{\mathcal{R}}_k\right) \simeq 0, \qquad \mathcal{R}_k = C_1 + C_2\int^t \frac{dt'}{a^3\epsilon_1}.$$

- In SR, $\epsilon_1 \simeq \text{const} \ll 1$: the second solution decays and $\mathcal{R}_k$ approaches a constant.
- In potential-dominated USR, $\epsilon_1 \propto a^{-6}$: the second solution grows approximately as a^3.
- The final spectrum depends on the full transient and its transition to SR, not only on the background at horizon exit.

Primordial power-spectrum amplitude

The canonical mode is $v_k = z\mathcal{R}_k$, with $z = a\dot{\chi}/H$. Its evolution follows the Mukhanov–Sasaki equation:

$$v_k'' + \left(k^2 - \frac{z''}{z}\right) v_k = 0, \qquad ' = \frac{d}{d\tau}.$$

- Evolve each mode through the transient and the subsequent attractor phase to the end of inflation.
- Evaluate $\mathcal{P}_\mathcal{R}(k)$ from the curvature perturbation $\mathcal{R}_k = v_k/z$ at the end of inflation.

The final curvature-mode amplitude gives

$$\mathcal{P}_\mathcal{R}(k) = \frac{k^3}{2\pi^2} |\mathcal{R}_k|^2 = \frac{k^3}{2\pi^2} \left|\frac{v_k}{z}\right|^2.$$

Primordial spectrum of the early transient

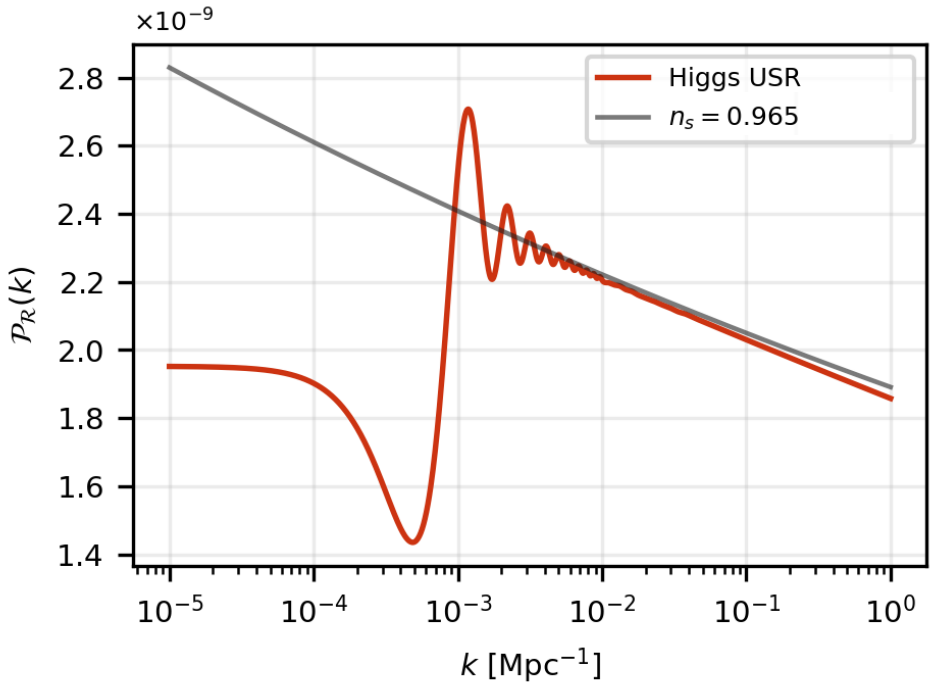


Figure: Benchmark: $x_0 = 5.75$, $y_0 = -0.170$, $N_* = 55$. Solid grey curve: $n_s = 0.965$ power-law reference.

- A localized dip appears at $k_{\rm dip} \simeq 4.8 \times 10^{-4}\ \mathrm{Mpc}^{-1}$.
- The dip is followed by an overshoot and oscillatory recovery.
- At larger k, the spectrum approaches the power-law reference.

We project this scale-dependent feature into the CMB temperature spectrum.

Spectral index comparison

$$n_s^{\rm SR} = 1 - 2\epsilon_{1*} - \epsilon_{2*}, \qquad n_s^{\rm MS} = 1 + \left.\frac{d\ln \mathcal{P}_{\mathcal{R}}^{\rm MS}}{d\ln k}\right|_{k_*}.$$

At $N_* = 60$, the MS slope is obtained by fitting $\ln \mathcal{P}_{\mathcal{R}}^{\rm MS}$ versus $\ln k$ around the pivot k_*.

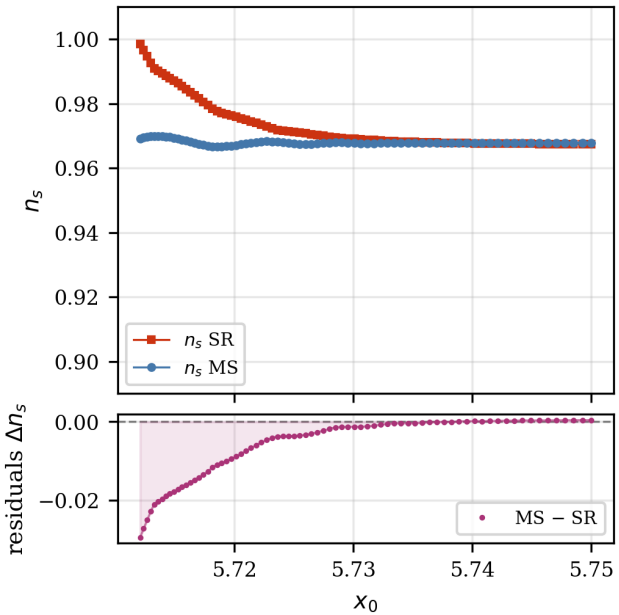


Figure: $y_0 = -0.10$.

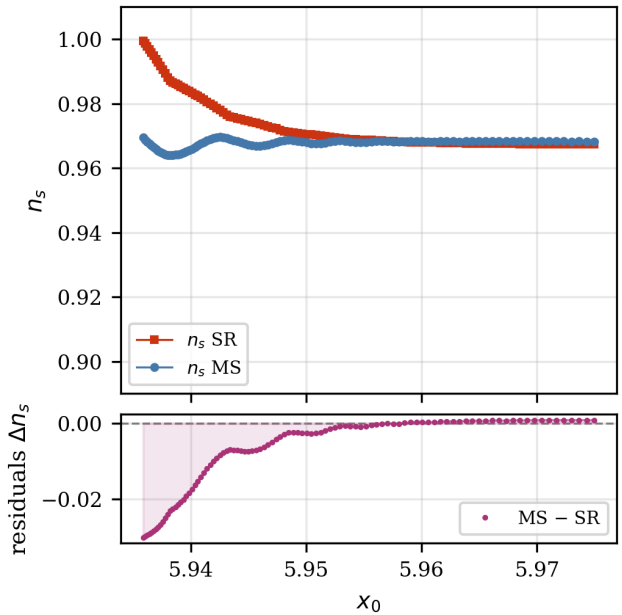


Figure: $y_0 = -0.20$.

Near the transient, $n_s^{\rm SR} \to 1$ while $n_s^{\rm MS} \simeq 0.967$: discrepancies reach ~ 0.03. Larger $|y_0|$ shifts the transition to larger x_0. The estimates approach each other in SR.

Projection into the CMB temperature spectrum

CAMB uses the power spectrum with ΛCDM-consistent parameters:

$$C_\ell^{TT} = 4\pi \int d\ln k\, \mathcal{P}_\mathcal{R}(k) \left|\Delta_\ell^T(k)\right|^2, \qquad D_\ell^{TT} = \frac{\ell(\ell+1)}{2\pi} C_\ell^{TT}.$$

- A scale k contributes to several CMB multipoles, so the primordial dip suppresses power over a range of ℓ.
- We compare the full temperature spectrum with the ΛCDM reference and Planck 2018 data.
- Higgs USR predicts $D_2 \simeq 776.5\ \mu\mathrm{K}^2$, below the ΛCDM value of $1029\ \mu\mathrm{K}^2$ but above the Planck Commander central value of $226\ \mu\mathrm{K}^2$.

Full temperature spectrum

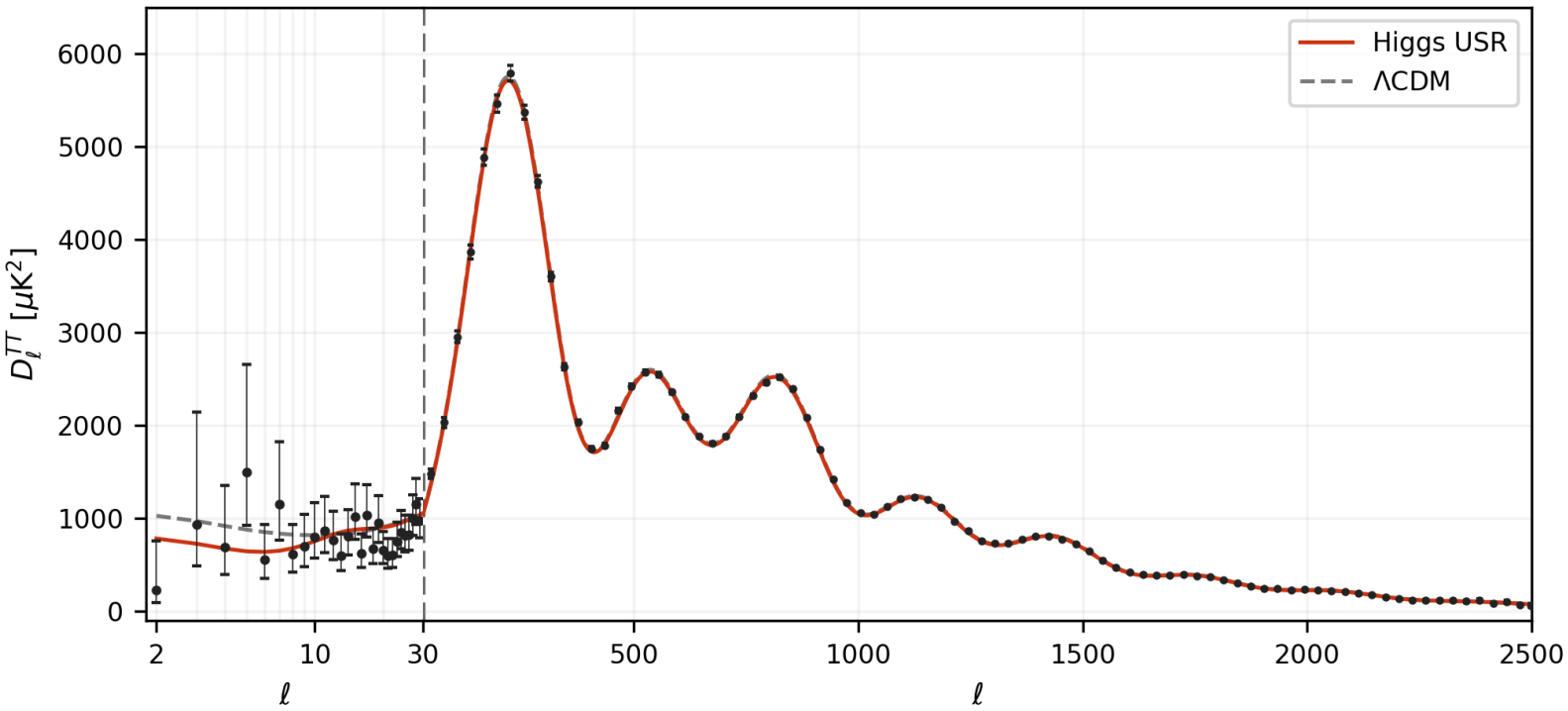


Figure: CAMB temperature spectrum: early-USR benchmark, ΛCDM reference, and Planck 2018 Commander and binned TT data.

- The main visible departure is suppression at low multipoles.
- At high ℓ, the benchmark closely tracks the reference acoustic structure and damping tail.

Low-multipole suppression

	Planck Commander	ΛCDM	Early USR
D_2 $[\mu\mathrm{K}^2]$	$\simeq 226$	1029	776.5

Multipole range	$\Delta\chi^2 = \chi^2_{\mathrm{USR}} - \chi^2_{\Lambda\mathrm{CDM}}$
Low ℓ: 2–29	-1.60
Full spectrum: 2–2508	$+40.7$

$$\frac{D_2^{\mathrm{USR}} - D_2^{\Lambda\mathrm{CDM}}}{D_2^{\Lambda\mathrm{CDM}}} \simeq -24.5\%.$$

The early transient reduces the predicted quadrupole, but does not reproduce the observed central value.

- The primordial feature reduces large-angular-scale power while preserving the CMB acoustic structure.

Conclusions

1. Initial conditions on the tree-level Higgs plateau admit a short early USR transient without a feature in the potential.
2. Early USR occupies an extended region of phase space, with trajectories near the reference field value leaving an imprint on CMB scales.
3. Near the transient, the SR estimate of n_s differs from the numerical MS result by up to ~ 0.03 in the presented scans.
4. Early-USR phase-space trajectories show a dip in the primordial power spectrum at the largest scales.
5. CAMB projects this feature into low-ℓ suppression: D_2 falls by 24.5%, while the acoustic-peak structure is preserved.
6. Early USR provides a mechanism for suppressing large-scale power in a simple non-minimally coupled Higgs model, without adding features to the potential.







3rd International Joint Meeting on Cosmology and Gravitation

Gracias!

Diego M. Navia Rojas