Three Smoothing Mechanisms in Early Cosmology:
Inflaton, Geometric, and Lamphrodyne Relaxation

Flyxion

Independent Researcher

June 2026

Abstract

We propose a classification of early-universe smoothing mechanisms into three structurally distinct classes: inflaton smoothing, in which an auxiliary scalar field with tuned potential drives metric expansion; geometric smoothing, in which quantum-corrected gravitational dynamics generate an expansion phase without a separate inflaton; and lamphrodyne relaxation, in which cosmological homogenization arises from admissibility-reducing dynamics in a scalar-vector-entropy plenum, without global metric expansion. The recent result of Liu, Quintin, and Afshordi— quantum quadratic gravity (QQG) inflation published in *Physical Review Letters* 136, 111501 (2026)—establishes geometric smoothing as a theoretically coherent alternative to the inflaton paradigm. We treat QQG as a rigorous benchmark and ask the next question: if smoothing can emerge from quantum gravity alone, can it emerge from relaxation dynamics alone? We formalize the Relativistic Scalar-Vector Plenum (RSVP) framework as a candidate Class 3 mechanism, define the lamphrodyne background state, introduce the field-space admissibility metric, and derive the lamphrodyne relaxation parameter η_{lamph} from admissibility geometry. We construct the effective anisotropic stress tensor of the relaxing plenum and define the formal structure of the tensor power spectrum $P_h(k)$ and tensor-to-scalar ratio r_{RSVP}; their explicit evaluation requires the plenum field correlators, which the prototype action makes calculable in principle but which are not derived here. We provide a phenomenological estimate of the scalar spectral index using a multifield GR analogy, and introduce admissibility crossing as the RSVP-native freeze-out condition that a complete perturbation theory must employ. We identify an empirical fork: a detection of $r > 10^{-2}$ constrains RSVP to explain any tensor residue from plenum anisotropic stress, while a robust upper bound below this floor would strongly challenge the simplest QQG realization. The paper's primary contribution is not adjudicating between frameworks but establishing that Class 3 smoothing is formally tractable as an effective field theory program with defined observational targets and explicit falsification conditions.

Contents

1 Introduction **3**
- 1.1 The Inflationary Paradigm . . . 3
- 1.2 The Inflaton Problem . . . 3
- 1.3 The QQG Development . . . 4
- 1.4 A Different Question . . . 4

2 A Taxonomy of Smoothing Mechanisms **5**
- 2.1 What Requires Explanation . . . 5
- 2.2 Three Classes of Solution . . . 5
- 2.3 Why Three Classes? . . . 6
- 2.4 Ontology Versus Mechanism . . . 7

3 Quadratic Quantum Gravity as Benchmark **7**
- 3.1 Action and Scale Invariance . . . 8
- 3.2 RG Flow and Dimensional Transmutation . . . 8
- 3.3 Strong Coupling and Ghost Confinement . . . 9
- 3.4 Emergence of General Relativity . . . 9
- 3.5 Observable Predictions . . . 10

4 RSVP Cosmology **10**
- 4.1 The Scalar-Vector Plenum . . . 10
- 4.2 Redshift Without Expansion . . . 11

5 Lamphrodyne Background Dynamics **11**
- 5.1 The Homogeneous Relaxation State . . . 11

5.2 The Irreversibility Condition 12
5.3 Admissibility Volume and Field-Space Geometry 12
5.4 Irreversibility and Admissibility Loss 13

6 The Lamphrodyne Relaxation Parameter **14**
6.1 Motivation by Analogy 14
6.2 Definition 15
6.3 Physical Interpretation 15
6.4 Slow Relaxation Condition 16
6.5 A Prototype RSVP Action 16
6.6 Euler–Lagrange Equations 17
6.7 Operational Definition of Admissibility 18
6.8 Admissibility Dissipation and Total Loss Budget 19
6.9 Admissibility Horizons and Causal Coherence 19

7 Perturbations of the Relaxing Plenum **20**
7.1 Linearization 20
7.2 Sector Classification 20

8 Tensor Signatures of Lamphrodyne Relaxation **21**
8.1 Sources of Tensor Modes 21
8.2 Effective Anisotropic Stress Tensor 21
8.3 Tensor Power Spectrum 22
8.4 Tensor-to-Scalar Ratio 22
8.5 Tensor Suppression and Spectral Tilt 23
8.6 Admissibility Crossing as the Native Freeze-Out Condition 24

9 The Empirical Fork **25**
9.1 The QQG Tensor Floor 25
9.2 RSVP Predictions: Three Cases 26
9.3 Falsification Matrix 26

10 Ontological Economy and the Large-N Question **27**
10.1 Why QQG Requires Large N 27
10.2 The Empirical Status of the Large-N Sector 27
10.3 Relaxation Cosmology as an Alternative 28

11 Discussion **28**
11.1 Inflation After the Inflaton 28
11.2 What Remains to Be Explained 29
11.3 Toward an RSVP Consistency Relation 29
11.4 Multifield Analogy and Preliminary Spectral Estimate 30
11.5 Falsifiability of RSVP 31
11.6 Future Observations 32

12 Conclusion **32**

1 Introduction

1.1 The Inflationary Paradigm

The standard cosmological model inherits three observational requirements that are not explained by the hot big bang alone. The horizon problem asks why causally disconnected regions of the cosmic microwave background (CMB) share a temperature to one part in 10^5. The flatness problem asks why the spatial curvature of the universe is tuned to within observational bounds across many orders of magnitude in scale factor. The structure problem asks why primordial density perturbations exhibit a nearly scale-invariant power spectrum. Inflation—a phase of accelerated expansion in the very early universe—was introduced to resolve all three simultaneously [7, 10, 1].

In its standard formulation, inflation is driven by a scalar field ϕ, the inflaton, rolling slowly down a potential $V(\phi)$. The slow-roll conditions $\epsilon \ll 1$ and $|\eta| \ll 1$, where

$$\epsilon = \frac{M_{\mathrm{Pl}}^2}{2}\left(\frac{V'}{V}\right)^2, \qquad \eta = M_{\mathrm{Pl}}^2 \frac{V''}{V}, \tag{1}$$

ensure that the potential energy dominates over kinetic energy, sustaining a quasi-de Sitter expansion phase. The inflationary paradigm is empirically powerful: it predicts a nearly scale-invariant scalar spectral index $n_s \approx 1 - 2/N$ and a tensor-to-scalar ratio $r \approx 16\epsilon$, both in agreement with CMB observations at leading order [14].

1.2 The Inflaton Problem

Despite its empirical success, the inflaton paradigm carries well-known theoretical liabilities. The shape of $V(\phi)$ must be specified by hand; no derivation from a UV-complete theory of gravity selects a unique potential. The inflationary literature contains hundreds of viable potential forms, most differing only in their predictions for r and n_s at sub-percent precision. This proliferation—the landscape of inflationary models—is not a scientific failure so much as a symptom of under-determination: the paradigm is consistent with almost any slow-roll potential that fits a plateau [13].

Reheating presents a second ambiguity. Inflation must end, and the universe must transition from a cold, potential-energy-dominated state to the hot radiation- dominated era of standard big-bang nucleosynthesis. The mechanism of this transition—perturbative decay of the inflaton, parametric resonance, instant preheating—is not predicted by the inflationary framework itself but must be appended [9]. The reheating temperature T_{reh} is largely unconstrained, introducing a significant uncertainty in the mapping between inflationary observables and CMB scales.

1.3 The QQG Development

The recent result of Liu et al. [11] represents a qualitatively different approach. Rather than introducing an inflaton field, they begin with the action of quadratic gravity,

$$S_{\text{QQG}} = -\int d^4x\, \sqrt{-g} \left(\frac{R^2}{\xi} + \frac{C^2}{2\lambda} \right), \tag{2}$$

where R is the Ricci scalar, $C^2 \equiv C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma}$ is the Weyl tensor contraction, and ξ, λ are dimensionless coupling constants. This theory is renormalizable—in contrast to general relativity—and is asymptotically free in the ultraviolet (UV), meaning the couplings vanish as energy $\mu \to \infty$ [6, 2].

The inflationary phase in QQG does not arise from a classical potential but from one-loop renormalization group (RG) running of the coupling $\xi(\mu)$. Pure R^2 gravity is exactly scale-invariant; any constant-curvature spacetime—including de Sitter—extremizes the action. The running breaks this exact invariance through a quantum conformal anomaly [5], generating a logarithmic correction that stabilizes a quasi-de Sitter attractor. In the large-N limit, with $N \sim \mathcal{O}(10^5\text{–}10^6)$ matter fields contributing to the beta functions, the spectral index and tensor-to-scalar ratio are predicted to lie in the region preferred by current CMB data, including the ACT results that place Starobinsky inflation under mild tension [12].

A structural prediction of the QQG scenario is a minimum tensor-to-scalar ratio

$$r_{\text{QQG}} \gtrsim 10^{-2}, \tag{3}$$

arising from the requirement that the theory avoid its strong-coupling regime before reheating is complete. This bound is not a free parameter but a consequence of the theory's internal consistency conditions.

1.4 A Different Question

The significance of QQG for the present paper is not its viability as an inflationary model. Its significance is structural: QQG demonstrates that cosmological smoothing can emerge from the intrinsic dynamics of a fundamental theory, without an auxiliary inflaton field. Once this possibility is admitted, inflationary expansion becomes one member of a broader class of smoothing mechanisms rather than the unique solution to the horizon and flatness problems.

This paper asks whether a third class of smoothing mechanism is formally tractable: relaxation without expansion. The RSVP framework—based on a coupled scalar-vector-entropy plenum—proposes that early-universe homogenization arises from the directional reduction of admissible unresolved field configurations, driven by entropy production in the plenum rather than by metric expansion. We formalize this proposal, derive its analogue of slow-roll parameters, and identify the observational signatures that distinguish it from both Class 1 (inflaton) and Class 2 (geometric) smoothing.

2 A Taxonomy of Smoothing Mechanisms

2.1 What Requires Explanation

The observational targets that any smoothing mechanism must address are the following. First, CMB isotropy: the temperature anisotropy $\Delta T/T \sim 10^{-5}$ across the last scattering surface, including regions that were not in causal contact under standard big-bang evolution. Second, large-scale homogeneity: the matter distribution is statistically isotropic and homogeneous on scales above approximately $100\, h^{-1}$ Mpc. Third, the primordial power spectrum: scalar perturbations are nearly scale-invariant with spectral index $n_s \approx 0.965$ and amplitude $A_s \approx 2.1 \times 10^{-9}$ [14]. Fourth, primordial tensor modes: no detection as of 2026, with current upper bounds $r < 0.036$ at 95% confidence [3].

2.2 Three Classes of Solution

Class 1: Inflaton smoothing. An auxiliary scalar field ϕ with potential $V(\phi)$ drives a phase of accelerated metric expansion. The expansion causally connects regions that would otherwise be disconnected. Smoothing is achieved by dilution: any initial anisotropy or curvature is stretched to scales far beyond the Hubble horizon. The slow-roll parameters ϵ and η control the duration and observables of the inflationary phase.

Class 2: Geometric smoothing. No auxiliary scalar is introduced. An inflationary phase emerges from quantum corrections to the gravitational action itself. In QQG, the one-loop RG running of the coupling $\xi(\mu)$ breaks the exact scale invariance of R^2 gravity, generating a quasi-de Sitter attractor. The mechanism is geometrical in the sense that no matter field carries the inflationary energy; the gravitational sector alone generates the expansion. Nevertheless, the output is still a period of accelerated metric expansion, and the observational predictions—scalar spectrum, tensor spectrum, spectral tilt—are structurally similar to Class 1, differing in their specific values of n_s and r.

Class 3: Lamphrodyne relaxation. No metric expansion is invoked. Cosmological smoothing arises from the directional relaxation of a coupled scalar-vector-entropy plenum toward states of lower admissibility complexity. The apparent homogeneity of the CMB is not the result of causal contact established during an expansion phase but the thermodynamic equilibrium texture of a plenum that has undergone irreversible entropy-producing relaxation. Cosmological redshift is reinterpreted as an entropy-gradient effect in the scalar field S rather than a consequence of metric expansion.

2.3 Why Three Classes?

Any smoothing mechanism must answer two fundamental questions: what drives homogenization, and is metric expansion required to achieve it? These two questions generate the classification naturally. If homogenization requires expansion, the question becomes whether the expansion is driven by an auxiliary matter field (Class 1) or by the gravitational sector itself (Class 2). If homogenization does not require expansion, a third possibility opens (Class 3), in which field-space relaxation produces the same observational regularities without a de Sitter phase.

Class	**Driver**	**Expansion required?**
1 (Inflaton)	Auxiliary scalar ϕ	Yes
2 (Geometric)	Quantum-corrected gravity	Yes
3 (Lamphrodyne)	Admissibility relaxation	No

The classification is not ad hoc. It follows from asking which of the two questions is answered differently. Class 1 and Class 2 share the same answer to the expansion question and differ only in the source of the driving energy. Class 3 gives a different answer to both questions. It is therefore a genuinely distinct mechanism, not a variant of inflation with a non-standard energy source.

2.4 Ontology Versus Mechanism

The distinction between Class 2 and Class 3 is not merely technical. Both replace the inflaton with something more fundamental; they disagree about whether "fundamental" means a quantum-corrected metric or a relaxing plenum. Class 2 retains metric expansion as the physical mechanism of smoothing, deriving the driving force from geometry rather than matter. Class 3 rejects the necessity of expansion altogether, proposing that the observational signatures attributed to inflation—isotropy, homogeneity, scale-invariant perturbations—can be generated by admissibility-reducing dynamics in field space without the universe ever undergoing a de Sitter phase.

This distinction carries empirical content. If the early universe underwent a de Sitter phase, whether driven by an inflaton (Class 1) or by quantum gravity (Class 2), primordial tensor modes are generated by quantum fluctuations of the metric during that phase. If the early universe instead underwent lamphrodyne relaxation (Class 3), tensor modes arise from a different source—anisotropic stress in the relaxing plenum—and their amplitude, tilt, and spectral shape may differ from the inflationary prediction.

3 Quadratic Quantum Gravity as Benchmark

Class 2 geometric smoothing encompasses any framework in which an inflationary phase emerges from the quantum-corrected gravitational sector without an auxiliary inflaton. Several such proposals exist, including Starobinsky $R + R^2$ inflation [15], asymptotic safety scenarios, induced gravity models, and higher-curvature extensions of GR. We use the specific QQG scenario of Liu et al. [11] as our primary benchmark because it is the most recent Class 2 model to make a structural falsification prediction—the tensor floor $r \gtrsim 10^{-2}$—and because it has been tested against the most current CMB data including ACT DR6. The classification of smoothing mechanisms developed here is independent of the fate of this particular model; if the Liu–Quintin–Afshordi scenario were falsified, the Class 2 category would remain and would be occupied by other geometric smoothing proposals. The empirical fork described in Section 9 should therefore be read as a comparison between Class 2 and Class 3 smoothing in general, with QQG serving as the sharpest available Class 2 representative.

3.1 Action and Scale Invariance

The QQG action of Liu et al. [11] is equation (1) above. In homogeneous and isotropic backgrounds, the Weyl tensor $C_{\mu\nu\rho\sigma}$ vanishes identically, so the background dynamics are controlled entirely by the R^2/ξ term. Without RG running, pure R^2 gravity is exactly scale invariant: both Minkowski and (anti-)de Sitter spacetimes are solutions. This scale invariance is analogous to the classical conformal invariance of Yang-Mills theory before the introduction of a mass scale through dimensional transmutation.

3.2 RG Flow and Dimensional Transmutation

The one-loop beta functions derived by Buccio et al. [4] are

$$\beta_\xi = \frac{d\xi}{d\ln\mu} = -\frac{1}{(4\pi)^2}\frac{\xi^2 - 36\lambda\xi - 2520\lambda^2}{36}, \tag{4}$$

$$\beta_\lambda = \frac{d\lambda}{d\ln\mu} = -\frac{1}{(4\pi)^2}\frac{(1617+90N)\lambda - 20\xi\lambda}{90}, \tag{5}$$

where N encodes the matter field content through $N = \frac{1}{60}N_{\text{scalar}} + \frac{1}{5}N_{\text{vector}} + \frac{1}{20}N_{\text{fermion}}$. The running coupling $\xi(\mu)$ exhibits a maximum at some scale μ_{max} and subsequently decreases, crossing zero at the tachyon divide μ_0. Liu et al. [11] identify the inflationary epoch with the regime of decreasing ξ above the tachyon divide.

In the large-N limit, the solution is approximately

$$\xi(\mu) \simeq \frac{35\lambda_0^2\ln(\mu/\mu_0)}{8\pi^2[1+\lambda_{tH}\ln(\mu/\mu_0)]}, \tag{6}$$

where $\lambda_{tH} \equiv \lambda_0 N/(4\pi)^2$ is a 't Hooft-like coupling. The inflation potential in the Einstein frame takes the approximate form

$$V(\varphi) \simeq \frac{35\lambda_0^2\mu_0^4}{128\pi^2\lambda_{tH}}\left(1 - \frac{\sqrt{6}\,\mu_0}{\lambda_{tH}\varphi}\right), \tag{7}$$

a slowly varying plateau that supports slow-roll inflation without a separately introduced inflaton field.

3.3 Strong Coupling and Ghost Confinement

The Weyl term C^2 introduces a massive spin-2 ghost: a field carrying negative kinetic energy. In perturbative QQG this field generates an unbounded Hamiltonian if treated in isolation. Liu et al. [11] adopt the proposal of Holdom and Ren [8] that, analogously to quarks in QCD, ghost degrees of freedom are confined once QQG reaches its strong-coupling scale. The end of inflation, the tachyon divide, and the onset of strong coupling are argued to be nearly coincident—a result that is empirically suggested by the parameter analysis but remains a conjecture awaiting nonperturbative verification.

3.4 Emergence of General Relativity

Perhaps the most radical claim in Liu et al. [11] is not that inflation can be derived from quantum gravity. It is that general relativity itself is not fundamental. The QQG framework proposes that Einstein's theory emerges as an infrared effective field theory from the strong-coupling limit of a UV-complete renormalizable theory. The logical chain is:

$$\text{UV Fixed Point} \;\rightarrow\; \text{RG Running} \;\rightarrow\; \text{Quasi-de Sitter Inflation} \;\rightarrow\; \text{Strong Coupling} \;\rightarrow\; \text{Emerge} \tag{8}$$

This is conceptually analogous to the emergence of nuclear physics from QCD: the low-energy effective description (GR, nuclear physics) is not a fundamental theory but a phase of a deeper one. In QQG, the Planck mass M_{Pl} is not a fundamental input but an emergent scale arising when the 't Hooft-like coupling λ_{tH} surpasses unity and the perturbative QQG description breaks down. An Einstein-Hilbert term with effective M_{Pl} then appears as the leading term of the low-energy effective action, and the universe enters its familiar radiation-dominated era.

The title of Liu et al. [11]—"Ultraviolet Completion of the Big Bang"—reflects this ambition. The paper is not primarily proposing a new inflation model; it is proposing a new origin for the entire gravitational framework within which inflation operates. This framing is directly relevant to RSVP, which shares the structural intuition that the familiar low-energy description is not fundamental: in QQG, spacetime geometry is emergent from a UV gravitational phase; in RSVP, spacetime geometry is an effective description of plenum dynamics. The disagreement between the frameworks is over what lies beneath, not over whether the familiar description is fundamental.

3.5 Observable Predictions

The scalar spectral index and tensor-to-scalar ratio predicted by QQG are

$$n_s \sim 1 - \frac{4}{3N_e}, \qquad r \sim 8\left(\frac{2\lambda_{tH}^2}{N_e^4}\right)^{1/3}, \tag{9}$$

where $N_e \sim 50$–60 is the number of inflationary e-folds. The viable parameter space requires $N \sim 10^5$–10^6 matter fields and $\lambda_{tH} \in [0.1, 1]$. The structural lower bound on the tensor-to-scalar ratio,

$$r_{\text{QQG}} \gtrsim 10^{-2}, \tag{10}$$

follows from $r \sim \lambda_{tH}^{-2/3}$ and the perturbativity bound $\lambda_{tH} \lesssim 1$. This bound is falsifiable by next-generation B-mode experiments including LiteBIRD and CMB-S4.

4 RSVP Cosmology

4.1 The Scalar-Vector Plenum

The Relativistic Scalar-Vector Plenum (RSVP) describes the early universe through three coupled fields defined on a four-dimensional spacetime manifold $\mathcal{M}$: a scalar field Φ encoding local energy density and constraint-satisfaction; a vector field $\mathbf{v}$ encoding directed entropy flux and local flow; and a scalar entropy field S encoding thermodynamic irreversibility and admissibility state. The field equations governing their joint evolution are derived from an action principle supplemented by admissibility constraints, the latter encoding the requirement that the plenum remain in a physically accessible region of field space.

The RSVP framework does not begin with a metric ansatz. Rather, the effective metric perceived by observers arises from the gradient structure of S: regions in which ∇S is large correspond to what standard observers would interpret as high-redshift regions, since photon traversal across an entropy gradient accumulates a frequency shift without metric expansion. The effective Hubble law in RSVP is therefore a statement about entropy-gradient accumulation rather than recession velocity.

4.2 Redshift Without Expansion

In standard cosmology, the cosmological redshift of a photon traveling from emission redshift z_e to an observer is attributed to the stretching of its wavelength by metric expansion: $1 + z = a(t_{\text{obs}})/a(t_{\text{em}})$. In RSVP, no global scale factor $a(t)$ is introduced. Instead, a photon traversing a region of entropy gradient ∇S accumulates a phase shift proportional to the integrated entropy contrast along its path. The effective redshift is

$$1 + z_{\text{RSVP}} = \exp\left(\int_{\text{path}} \kappa \, |\nabla S| \, d\ell\right), \tag{11}$$

where κ is a coupling constant between the photon propagator and the entropy field, and $d\ell$ is the proper path element. At leading order in a slowly varying S, this reproduces a Hubble-like distance-redshift relation with effective Hubble parameter $H_{\text{eff}} \sim \kappa \langle |\nabla S| \rangle$.

This reinterpretation is not merely definitional. It predicts that the distance-redshift relation will exhibit small deviations from the standard ΛCDM prediction at high redshift, where the entropy gradient structure of the plenum departs from homogeneity. These deviations are in principle observable with future spectroscopic surveys, though their amplitude depends on the specific background solution $S_0(t)$ derived in Section 5.

5 Lamphrodyne Background Dynamics

5.1 The Homogeneous Relaxation State

We define the lamphrodyne epoch as the cosmological phase during which the RSVP plenum undergoes homogeneous, isotropic, irreversible relaxation from an initial state of high admissibility complexity toward a state of low admissibility complexity. The background is characterized by spatially homogeneous field configurations

$$\Phi = \Phi_0(t), \qquad \mathbf{v} = \mathbf{v}_0(t) = \mathbf{0}, \qquad S = S_0(t), \tag{12}$$

where the vanishing of $\mathbf{v}_0$ follows from the isotropy of the background: a nonzero background vector field would select a preferred spatial direction, violating statistical isotropy. The vector field $\mathbf{v}$ therefore contributes to the background only through its fluctuations, which are treated in Section 7.

The background evolution equations for $\Phi_0(t)$ and $S_0(t)$ follow from the RSVP field equations in the homogeneous limit. Their specific form depends on the choice of kinetic terms and coupling functions in the RSVP action, which we leave partially general here while imposing the constraints required by admissibility geometry.

5.2 The Irreversibility Condition

The defining property of the lamphrodyne epoch is that the volume of the unresolved admissible configuration space $\mathcal{A}_{\text{unresolved}}$ decreases monotonically in time:

$$\frac{d}{dt}\,\text{Vol}(\mathcal{A}_{\text{unresolved}}) < 0. \tag{13}$$

This is the plenum-theoretic statement of the second law of thermodynamics during the relaxation epoch. It rules out background solutions along which admissibility volume increases—which would correspond to a physical unsmoothing of the plenum—and selects the thermodynamically privileged direction of evolution.

Equation (13) provides a natural arrow of time for the lamphrodyne epoch that is absent from inflationary frameworks. In Class 1 and Class 2 smoothing, the thermodynamic arrow of time must be imposed separately from the dynamical equations; inflation itself is time-reversible at the level of the field equations. In RSVP, the arrow of time is primitive: relaxation is admissibility loss, and admissibility loss is by definition irreversible.

5.3 Admissibility Volume and Field-Space Geometry

Let $\mathcal{F} = \{(\Phi, \mathbf{v}, S)\}$ denote the field-space manifold of the RSVP plenum. We equip $\mathcal{F}$ with a Riemannian metric G_{AB} derived from the kinetic terms of the RSVP action, so that the kinetic energy of the plenum fields takes the form

$$\mathcal{T} = \frac{1}{2} G_{AB}\dot{\phi}^A\dot{\phi}^B, \tag{14}$$

where $\phi^A = (\Phi, v^i, S)$ collectively denotes the plenum field components. The metric G_{AB} is positive definite when the kinetic terms are non-degenerate, which we assume throughout.

The admissibility volume functional $\text{Vol}(\mathcal{A})$ assigns to each point $\phi^A \in \mathcal{F}$ a real number measuring the volume of the set of configurations consistent with the admissibility constraints at that point. The gradient

$$\nabla_{\mathcal{F}} \log \mathrm{Vol}(\mathcal{A}) \tag{15}$$

is a vector field on $\mathcal{F}$ pointing in the direction of steepest increase of log-admissibility-volume. During lamphrodyne relaxation, the plenum evolves in the direction of decreasing $\mathrm{Vol}(\mathcal{A})$, which is opposite to this gradient.

Concretely, the admissibility volume at a point $\phi^A \in \mathcal{F}$ is defined by

$$\mathrm{Vol}(\mathcal{A}) = \int_{\mathcal{A}} \sqrt{\det G}\, d\Phi\, dS\, d^3v, \tag{16}$$

where $\sqrt{\det G}$ is the Riemannian volume element of the field-space metric G_{AB}. This expression is manifestly geometric: it measures the metric volume of the admissible region in $\mathcal{F}$, making $\mathrm{Vol}(\mathcal{A})$ a coordinate-invariant quantity rather than a metaphorical one. As the plenum relaxes and constraints are resolved, the set $\mathcal{A}$ shrinks and $\mathrm{Vol}(\mathcal{A})$ decreases, in accordance with the irreversibility condition (13).

To make the geometry concrete, consider the simplest non-degenerate field-space metric consistent with the RSVP field content:

$$ds^2_{\mathcal{F}} = d\Phi^2 + \alpha_v\, |d\mathbf{v}|^2 + \alpha_S\, dS^2, \tag{17}$$

where $\alpha_v > 0$ and $\alpha_S > 0$ are positive coupling constants encoding the relative contributions of the vector and entropy fields to the field-space geometry. In this metric, $\det G = \alpha_v^3\, \alpha_S$ (with three spatial components of $\mathbf{v}$), and the admissibility volume element is $\sqrt{\det G}\, d\Phi\, dS\, d^3v = \alpha_v^{3/2} \alpha_S^{1/2}\, d\Phi\, dS\, d^3v$. The physical RSVP metric G_{AB} will in general depend on the fields themselves and on the admissibility constraints; equation (17) is a linearized approximation valid near a background point in $\mathcal{F}$.

5.4 Irreversibility and Admissibility Loss

In the Spherepop formalization of irreversible event calculus, the collapse operator Pop and the refusal operator Refuse describe the asymmetric resolution of unresolved configurations: a configuration either collapses to a resolved state (Pop) or is refused (Refuse), but neither operation is reversible. At the level of the lamphrodyne background, this structure is captured by the single condition (13): the set of unresolved admissible configurations shrinks. We do not require the full Spherepop apparatus for the present calculation; we require only that the background evolution satisfies the irreversibility condition.

The irreversibility condition also implies that the background trajectory in $\mathcal{F}$ is not time-reversible. This is in contrast to the de Sitter solution in QQG, which is an exact solution of the classical equations and is time-symmetric. The lamphrodyne background is thermodynamically directed from the outset, which is the formal ground for the claim that Class 3 smoothing provides an arrow of time without additional postulation.

Proposition 1 (Monotonic Admissibility Loss)**.** *Suppose that* $\mathrm{Vol}(\mathcal{A}_{\mathrm{unresolved}})$ *is bounded below by zero and that the irreversibility condition* $d\,\mathrm{Vol}(\mathcal{A}_{\mathrm{unresolved}})/dt < 0$ *holds throughout the lamphrodyne epoch. Then* $\mathrm{Vol}(\mathcal{A}_{\mathrm{unresolved}})$ *converges to a finite non-negative limit as* $t \to \infty$*.*

Proof. The function $t \mapsto \mathrm{Vol}(\mathcal{A}_{\mathrm{unresolved}}(t))$ is strictly decreasing by the irreversibility condition and bounded below by zero by assumption. A monotone decreasing function bounded below converges. □ □

Remark 1. *The limiting value* $\mathrm{Vol}(\mathcal{A}_{\mathrm{unresolved}}) \to V_\infty \geq 0$ *represents the irreducible residual admissibility volume: the set of configurations that cannot be resolved by the lamphrodyne dynamics alone. If* $V_\infty = 0$*, the relaxation is complete and the plenum reaches a fully resolved state. If* $V_\infty > 0$*, a permanently unresolved residue persists, which may correspond to the observed large-scale structure of the universe—the non-trivial texture that survives after smoothing is complete.*

6 The Lamphrodyne Relaxation Parameter

6.1 Motivation by Analogy

In slow-roll inflation, the parameters ϵ and η measure, respectively, the steepness and curvature of the inflaton potential. Their smallness is the condition under which the inflationary background is approximately de Sitter and perturbation theory is under control. The spectral observables n_s and r are directly expressed in terms of ϵ and η through the consistency relations of inflationary perturbation theory.

For RSVP, the analogous role is played by a parameter measuring the rate at which the admissibility relaxation gradient changes during the lamphrodyne epoch. We define this parameter from admissibility geometry rather than by importing the slow-roll definition.

6.2 Definition

Definition 1 (Lamphrodyne Gradient Parameter). *Let $\mathcal{F}$ be the field-space manifold of the RSVP plenum with metric G_{AB}, and let* $\mathrm{Vol}(\mathcal{A})$ *be the admissibility volume functional. Define the* lamphrodyne gradient parameter *as*

$$\epsilon_{\text{lamph}} = \frac{\|\nabla_{\mathcal{F}} \log \mathrm{Vol}(\mathcal{A})\|}{H_{\text{eff}}}, \tag{18}$$

where $H_{\text{eff}} \sim \kappa \langle |\nabla S| \rangle$ is the effective Hubble parameter from entropy-gradient traversal, and the norm is taken with respect to the field-space metric G_{AB}. The parameter ϵ_{lamph} measures the magnitude of the admissibility gradient in units of H_{eff}: it is the lamphrodyne analogue of the slow-roll parameter ϵ_{infl}, measuring the steepness of the admissibility descent.

Definition 2 (Lamphrodyne Relaxation Parameter). *Define the* lamphrodyne relaxation parameter *as*

$$\eta_{\text{lamph}} = -\frac{1}{H_{\text{eff}}} \frac{d}{dt} \log \epsilon_{\text{lamph}}, \tag{19}$$

measuring the fractional rate of change of ϵ_{lamph}, normalized by H_{eff}. Small $|\eta_{\text{lamph}}|$ implies that the admissibility gradient is nearly constant in time—the lamphrodyne analogue of the slow-roll condition $|\eta_{\text{infl}}| \ll 1$.

6.3 Physical Interpretation

The primary new object introduced in this framework is ϵ_{lamph}. It measures the magnitude of the admissibility gradient in field space, normalized by the effective Hubble parameter: it is the generalized descent rate of the relaxation trajectory on $\mathcal{F}$. In this respect ϵ_{lamph} plays exactly the role that ϵ_{infl} plays in slow-roll inflation: it quantifies how steeply the system is descending its governing landscape, whether that landscape is a scalar potential (inflation) or an admissibility volume functional (lamphrodyne relaxation).

The parameter η_{lamph} is then a derived curvature measure: it quantifies how rapidly ϵ_{lamph} itself is changing. Small $|\eta_{\text{lamph}}|$ means that the descent rate is nearly constant—the relaxation is in a controlled, nearly uniform regime. This is the lamphrodyne analogue of the slow-roll condition $|\eta_{\text{infl}}| \ll 1$, which ensures that ϵ_{infl} varies slowly enough for inflationary perturbation theory to be valid.

The hierarchy is therefore:

$$\epsilon_{\text{infl}} \leftrightarrow \epsilon_{\text{lamph}} \quad \text{(primary: rate of landscape descent)}, \tag{20}$$

$$\eta_{\text{infl}} \leftrightarrow \eta_{\text{lamph}} \quad \text{(derived: rate of change of descent rate)}. \tag{21}$$

In inflation, ϵ determines the tensor-to-scalar ratio at leading order via $r = 16\epsilon$, while η controls the tilt via $n_s - 1 \approx -2\epsilon - \eta$. In RSVP, the conjecture (48) assigns to ϵ_{lamph} the analogous primary role in determining r_{RSVP}, with η_{lamph} entering as a correction. The key difference from inflation is that ϵ_{lamph} and η_{lamph} are defined on the field-space manifold $\mathcal{F}$ via the admissibility volume functional, without reference to any potential. They characterize the geometry of the admissibility landscape rather than the curvature of an inflaton potential.

6.4 Slow Relaxation Condition

We say that the plenum is in a *slow relaxation* regime when $|\eta_{\text{lamph}}| \ll 1$. In this regime, the admissibility gradient is nearly constant, and the background trajectory in $\mathcal{F}$ is approximately a geodesic of the field-space metric G_{AB} deformed by the admissibility gradient. This condition is the prerequisite for perturbation theory around the lamphrodyne background to be controlled, in the same way that slow roll is the prerequisite for inflationary perturbation theory.

6.5 A Prototype RSVP Action

A complete cosmological theory requires a dynamical principle from which both the background evolution and the perturbation equations can be derived. The present paper does not claim that the final RSVP action has been uniquely identified. Nevertheless, it is useful to exhibit a minimal prototype action capturing the essential field content and demonstrating that the formal program is well posed as an effective field theory.

We consider the provisional action

$$S_{\text{RSVP}} = \int d^4x \sqrt{-g} \left[\frac{M_{\text{Pl}}^2}{2} R - \frac{1}{2} \nabla_\mu \Phi \, \nabla^\mu \Phi - V(\Phi) - \frac{1}{2} \nabla_\mu S \, \nabla^\mu S - W(S) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \xi_1 S \, F_{\mu\nu} F^{\mu\nu} \right. \tag{22}$$

where $F_{\mu\nu} = \nabla_\mu v_\nu - \nabla_\nu v_\mu$ is the field-strength tensor of the vector field v_μ. The scalar Φ represents constraint density, v_μ represents directed entropy flow, and S represents admissibility entropy. The interaction terms proportional to ξ_1 and ξ_2

provide the lowest-order couplings between the sectors while preserving locality and general covariance. The Einstein-Hilbert term is included to establish the connection between RSVP dynamics and the emergent spacetime metric; in the deep lamphrodyne epoch, the curvature terms are subdominant and the dynamics are dominated by the plenum sector.

The purpose of this action is not to establish a unique realization of RSVP but to demonstrate that the framework admits a conventional effective field theory representation from which perturbative calculations can in principle proceed. We note a conceptual tension that this prototype does not fully resolve: the paper claims that global metric expansion is not the smoothing mechanism, yet the action includes a standard Einstein-Hilbert term $\frac{M_{\rm Pl}^2}{2}R$. Two resolutions are possible. In the phenomenological embedding (Option B), the metric is present and dynamical, but the inflationary phase is replaced by lamphrodyne relaxation as the source of primordial perturbations—the redshift mechanism is then a subdominant correction from the entropy gradient coupling, not a replacement for expansion. In the full emergent-metric program (Option A), the Einstein-Hilbert term is absent and the effective metric is derived from plenum correlators; this is technically demanding and left for future work. The present paper adopts the phenomenological embedding for all perturbative calculations, and all such calculations should be read as estimates within that embedding rather than consequences of the full emergent-metric claim. The field-space metric G_{AB} introduced in Section 5.3 is derived from the kinetic matrix of action (22): at quadratic order in the fields, G_{AB} takes the diagonal form consistent with the toy metric (17) with $\alpha_S = 1$ and α_v determined by the vector kinetic term.

6.6 Euler–Lagrange Equations

Variation of the prototype action (22) with respect to Φ, S, and v_ν yields the field equations

$$\Box\Phi - V'(\Phi) + \xi_2\,\Box S = 0, \tag{23}$$
$$\Box S - W'(S) + \xi_2\,\Box\Phi + \xi_1\,F_{\mu\nu}F^{\mu\nu} = 0, \tag{24}$$
$$\nabla_\mu[(1 - 4\xi_1 S)\,F^{\mu\nu}] = 0. \tag{25}$$

These equations describe the coupled evolution of the scalar constraint field, the entropy field, and the directed entropy-flow sector. The coupling ξ_2 mixes the Φ and S equations; the coupling ξ_1 introduces a curvature-like backreaction of the entropy field on the vector sector.

The homogeneous lamphrodyne background corresponds to $\Phi = \Phi_0(t)$, $S = S_0(t)$, $v_\mu = 0$, for which $F_{\mu\nu} = 0$ identically and the field equations reduce to the coupled ordinary differential equations

$$\ddot{\Phi}_0 + 3H_{\text{eff}}\dot{\Phi}_0 + V'(\Phi_0) - \xi_2(\ddot{S}_0 + 3H_{\text{eff}}\dot{S}_0) = 0, \tag{26}$$

$$\ddot{S}_0 + 3H_{\text{eff}}\dot{S}_0 + W'(S_0) - \xi_2(\ddot{\Phi}_0 + 3H_{\text{eff}}\dot{\Phi}_0) = 0, \tag{27}$$

where we have included a friction term proportional to H_{eff} as the leading-order coupling of the plenum dynamics to the background rate of entropy-gradient traversal. These equations are the starting point for the explicit derivation of the lamphrodyne background trajectory $(\Phi_0(t), S_0(t))$ that the perturbation calculation requires.

6.7 Operational Definition of Admissibility

The admissibility volume $\text{Vol}(\mathcal{A})$ introduced in Section 5.3 becomes physically meaningful only once membership in $\mathcal{A}$ is specified by a constitutive condition. For the prototype theory (22), we define admissible configurations as those satisfying

$$C[\Phi, v, S] \leq 0, \qquad C \equiv \omega^2 - \omega_c^2, \tag{28}$$

where $\omega = |\nabla \times \mathbf{v}|$ is the local vorticity magnitude of the vector field and $\omega_c > 0$ is a critical vorticity threshold. The admissible region is therefore

$$\mathcal{A} = \{(\Phi, \mathbf{v}, S) : |\nabla \times \mathbf{v}| \leq \omega_c\}. \tag{29}$$

Configurations with vorticity exceeding ω_c are interpreted as thermodynamically unresolved: they carry unresolved rotational structure that the lamphrodyne dynamics have not yet dissipated. The admissibility volume is then

$$\text{Vol}(\mathcal{A}) = \int_{C \leq 0} \sqrt{\det G}\, d\Phi\, dS\, d^3v, \tag{30}$$

and its decrease in time is controlled by the dissipation of vorticity through the vector field equation (25). The irreversibility condition $d\,\text{Vol}(\mathcal{A}_{\text{unresolved}})/dt < 0$ is therefore not imposed externally but follows dynamically from equation (25): as vorticity is dissipated, the admissible region expands and the unresolved complement shrinks.

6.8 Admissibility Dissipation and Total Loss Budget

Define the admissibility dissipation rate

$$\Gamma_A = -\frac{d}{dt}\,\mathrm{Vol}(\mathcal{A}_{\text{unresolved}}) > 0 \tag{31}$$

during the lamphrodyne epoch. The admissibility evolution equation is

$$\frac{d}{dt}\,\mathrm{Vol}(\mathcal{A}_{\text{unresolved}}) = -\Gamma_A, \tag{32}$$

integrating to

$$\mathrm{Vol}(\mathcal{A}_{\text{unresolved}})(t) = \mathrm{Vol}_0 - \int_0^t \Gamma_A(\tau)\,d\tau. \tag{33}$$

By the Monotonic Admissibility Loss Proposition, the integral converges as $t \to \infty$. Define the total admissibility loss budget

$$\Delta_A = \int_0^\infty \Gamma_A(t)\,dt < \infty. \tag{34}$$

The quantity Δ_A is a finite, theory-dependent constant that characterizes the total extent of relaxation undergone by the plenum during the lamphrodyne epoch. It plays a role analogous to a total entropy-production budget: just as thermodynamic processes are bounded by the total available free energy, lamphrodyne relaxation is bounded by Δ_A. A large Δ_A corresponds to a plenum that undergoes extensive smoothing; a small Δ_A corresponds to a nearly pre-resolved initial state. The connection between Δ_A and the observed amplitude of primordial perturbations A_s is a prediction target of the RSVP perturbation program.

6.9 Admissibility Horizons and Causal Coherence

A central objection to any non-inflationary smoothing mechanism concerns causal coherence: if regions were never in causal contact, what physically enforces their approach to a common equilibrium? Inflation answers this by altering causal structure via accelerated expansion; QQG inherits the same answer. RSVP requires a different account.

We define an admissibility propagation cone $\mathcal{C}_A$ by the condition

$$ds_A^2 = -c_A^2\,dt^2 + d\mathbf{x}^2 = 0, \tag{35}$$

where c_A is the characteristic speed at which admissibility information propagates through the plenum. The corresponding admissibility horizon is

$$d_A(t) = \int_0^t c_A(\tau)\, d\tau. \tag{36}$$

In the prototype action (22), c_A is determined by the sound speeds of the coupled (Φ, S, v) system. If the entropy-field sound speed c_S and vorticity propagation speed c_v are both superluminal with respect to the effective metric speed during the deep lamphrodyne epoch—which is possible if the plenum dynamics precede the emergence of the standard metric—then $d_A(t)$ at early times exceeds the effective particle horizon of the emergent spacetime description.

This provides a concrete mechanism by which large-scale coherence may be established in the plenum before the effective metric description is valid. Regions that appear causally disconnected in the FLRW description were, in the plenum picture, connected by admissibility propagation during the epoch when $c_A > c_{\text{eff}}$. This is the RSVP analogue of the inflationary resolution of the horizon problem, and it makes a testable prediction: the coherence length of primordial perturbations in RSVP is set by d_A rather than the comoving Hubble radius at horizon crossing, which implies a distinct dependence of the perturbation spectrum on scale that differs from the inflationary prediction at very large scales ($k \to 0$).

7 Perturbations of the Relaxing Plenum

7.1 Linearization

We expand the RSVP fields around the homogeneous background:

$$\Phi = \Phi_0(t) + \delta\Phi(t, \mathbf{x}), \quad \mathbf{v} = \delta\mathbf{v}(t, \mathbf{x}), \quad S = S_0(t) + \delta S(t, \mathbf{x}). \tag{37}$$

The linearized field equations are obtained by varying the RSVP action to first order in the perturbations. In Fourier space, the perturbations decompose into scalar, vector, and tensor sectors under the spatial rotation group $SO(3)$.

7.2 Sector Classification

The scalar sector contains perturbations in $\delta\Phi$ and δS, together with the longitudinal part of $\delta\mathbf{v}$. These mix under the linearized equations and produce the scalar power spectrum $P_s(k)$, which must match the observed CMB anisotropy amplitude $A_s \approx 2.1 \times 10^{-9}$.

The vector sector contains the transverse part of $\delta\mathbf{v}$. In standard cosmology, vector perturbations decay during radiation domination and are observationally irrelevant. In RSVP, where there is no metric expansion, the transverse vector perturbations do not decay by dilution and may persist to late times. Their contribution to the CMB anisotropy must be suppressed by the dynamics of the lamphrodyne epoch, which requires either that $\delta\mathbf{v}_\perp$ is small initially or that it decays through entropy production.

The tensor sector contains the transverse-traceless (TT) part of the perturbations. In the absence of metric fluctuations, tensor perturbations in RSVP arise entirely from the anisotropic stress of the plenum fields, as we now derive.

8 Tensor Signatures of Lamphrodyne Relaxation

8.1 Sources of Tensor Modes

In standard inflationary cosmology, tensor perturbations—primordial gravitational waves—arise from quantum fluctuations of the metric during the de Sitter phase. Their amplitude is set by the Hubble parameter during inflation: $P_h \sim H_{\rm inf}^2/M_{\rm Pl}^2$. In QQG, the same mechanism operates, with $H_{\rm inf}$ determined by the RG-improved potential.

In RSVP, no de Sitter phase occurs, so metric quantum fluctuations are not the source. Tensor perturbations arise instead from the anisotropic stress of the relaxing plenum. Three sources contribute at quadratic order in the plenum fields.

8.2 Effective Anisotropic Stress Tensor

The effective anisotropic stress tensor of the RSVP plenum is

$$T_{ij}^{\rm eff} = \alpha\, v_i v_j + \beta\, \partial_i S\, \partial_j S + \gamma\, \partial_i \Phi\, \partial_j \Phi, \tag{38}$$

where α, β, γ are coupling coefficients determined by the RSVP action, and indices are spatial. This tensor is symmetric and, in general, has both trace and traceless parts. The trace part contributes to the effective pressure of the plenum; the transverse-traceless part sources gravitational waves.

The TT projection of (38) is

$$\Pi_{ij}^{TT} = \Lambda_{ij,kl}\, T_{kl}^{\text{eff}}, \tag{39}$$

where $\Lambda_{ij,kl} = P_{ik}P_{jl} - \frac{1}{2}P_{ij}P_{kl}$ is the TT projection operator and $P_{ij} = \delta_{ij} - \hat{k}_i\hat{k}_j$ is the transverse projector for wavevector $\mathbf{k}$.

8.3 Tensor Power Spectrum

The tensor power spectrum sourced by the anisotropic stress of the plenum is

$$P_h(k) = \frac{4}{M_{\text{Pl}}^4} \int \frac{d^3q}{(2\pi)^3}\, G_{\text{ret}}^2(k,\tau)\, \Lambda_{ij,kl}\Lambda_{ij,mn}\, \langle T_{kl}^{\text{eff}}(\mathbf{q}) T_{mn}^{\text{eff}}(\mathbf{k}-\mathbf{q})\rangle, \tag{40}$$

where $G_{\text{ret}}(k,\tau)$ is the retarded Green function for the tensor mode equation, and the angle brackets denote the two-point correlator evaluated in the lamphrodyne background state.

The two-point correlators of the plenum fields in Fourier space are

$$\langle \delta v_i(\mathbf{k})\, \delta v_j(\mathbf{k}')\rangle = (2\pi)^3 \delta^{(3)}(\mathbf{k}+\mathbf{k}')\, P_v(k)\, \delta_{ij}, \tag{41}$$

$$\langle \delta S(\mathbf{k})\, \delta S(\mathbf{k}')\rangle = (2\pi)^3 \delta^{(3)}(\mathbf{k}+\mathbf{k}')\, P_S(k), \tag{42}$$

$$\langle \delta \Phi(\mathbf{k})\, \delta \Phi(\mathbf{k}')\rangle = (2\pi)^3 \delta^{(3)}(\mathbf{k}+\mathbf{k}')\, P_\Phi(k), \tag{43}$$

where $P_v(k)$, $P_S(k)$, $P_\Phi(k)$ are the individual power spectra of the plenum field fluctuations, to be derived from the linearized field equations of the lamphrodyne epoch.

8.4 Tensor-to-Scalar Ratio

The tensor-to-scalar ratio in RSVP is defined as

$$r_{\text{RSVP}} = \frac{P_h(k_*)}{P_s(k_*)}, \tag{44}$$

where $k_* \approx 0.05\,\text{Mpc}^{-1}$ is the CMB pivot scale. Substituting the contributions from each plenum field source,

$$r_{\text{RSVP}} = F(\alpha, \beta, \gamma, P_v, P_S, P_\Phi, \eta_{\text{lamph}}), \tag{45}$$

where F is a functional that depends on the plenum coupling coefficients, the individual field power spectra, and the lamphrodyne relaxation parameter. In the slow-relaxation limit $|\eta_{\text{lamph}}| \ll 1$, r_{RSVP} simplifies and can be expressed as a power law in η_{lamph}, analogously to the inflationary consistency relation $r = 16\epsilon$.

The derivation of the full functional F requires the explicit power spectra P_v, P_S, P_Φ, which in turn require solving the linearized RSVP field equations on the lamphrodyne background. This is the primary open calculation of the present framework; we present the formal structure here and note that the derivation of r_{RSVP} as a function of η_{lamph} is the analog of deriving $r = 16\epsilon$ in inflation—a result that required the full apparatus of inflationary perturbation theory and was not available at the time the inflationary paradigm was first proposed.

8.5 Tensor Suppression and Spectral Tilt

The tensor spectral index n_t is defined by $P_h(k) \propto k^{n_t}$. In slow-roll inflation $n_t = -r/8 \approx -2\epsilon$, giving a slightly red spectrum. In QQG the tilt is similarly red. In RSVP, the tensor spectrum is sourced by plenum anisotropic stress rather than de Sitter vacuum fluctuations, which generically produces a different tilt.

A key feature of the prototype action is the coupling $\xi_1 S F_{\mu\nu} F^{\mu\nu}$, which modifies the effective gauge kinetic function of the vector field to $(1 - 4\xi_1 S)$. This is a kinetic rescaling, not a Proca mass. It does not generate an $m_v^2 v_\mu v^\mu$ term; producing a genuine vector mass would require an additional Stückelberg or Higgs sector not present in the current prototype action. The distinction matters for the tensor suppression mechanism: a kinetic rescaling by factor $(1 - 4\xi_1 S_0)$ suppresses the vector propagator amplitude by $|1 - 4\xi_1 S_0|^{-1}$ relative to the unrescaled case, while a Proca mass suppresses it by $(k^2 + m_v^2)^{-1/2}$. The suppression mechanisms are qualitatively different.

Within the prototype action as written, the tensor amplitude is suppressed relative to the inflationary vacuum amplitude by the smallness of the anisotropic stress correlators. The effective coupling ratio

$$\mathcal{R}_{\text{sup}} \equiv \frac{\alpha^2}{|1 - 4\xi_1 S_0|^2} \cdot \frac{H_{\text{eff}}^2}{M_{\text{Pl}}^4} \tag{46}$$

controls the overall amplitude of $P_h(k)$ relative to the scalar spectrum. For $(1 - 4\xi_1 S_0)$ of order unity and $\alpha \ll M_{\text{Pl}}$, the tensor-to-scalar ratio is suppressed relative to the inflationary value $r = 16\epsilon_{\text{lamph}}$. The exact suppression depends on the background value of S_0 during the lamphrodyne epoch, which requires solving the full background equations (23) –(24).

Regarding the spectral tilt: the k-dependence of $P_h(k)$ is inherited from the k-dependence of the plenum correlators. For a vector field with kinetic function $(1 - 4\xi_1 S_0)$ varying slowly in time, the vector power spectrum $P_v(k)$ will be approximately scale-invariant at scales $k \gg H_{\text{eff}}$ and will turn over at $k \sim H_{\text{eff}}$. The resulting tensor tilt n_t^{RSVP} is therefore expected to be near zero or slightly positive (blue) at scales $k \gtrsim H_{\text{eff}}$, in qualitative contrast to inflation's red tilt. A blue tensor tilt is a structural prediction of sourced tensor mechanisms and would provide a distinctive observational signature of Class 3 smoothing, independent of the amplitude.

8.6 Admissibility Crossing as the Native Freeze-Out Condition

A more fundamental issue for the perturbation theory underlies both the scalar and tensor calculations. In inflationary perturbation theory, modes freeze when $k = aH$: the mode wavelength exceeds the Hubble horizon, and perturbations stop evolving. In QQG the same mechanism operates because the inflationary phase is still de Sitter. In RSVP, there is no metric expansion, so Hubble horizon crossing does not occur in the standard sense. The scalar spectrum derivation in Section 11.4 used the phenomenological GR embedding precisely to have access to $k = aH$ as a freeze-out condition, at the cost of importing FRW and Friedmann dynamics.

The RSVP-native freeze-out condition is admissibility crossing: a mode k freezes when

$$k \cdot d_A(t) \sim 1, \tag{47}$$

where $d_A(t) = \int_0^t c_A(\tau)\, d\tau$ is the admissibility horizon. Modes with $k \cdot d_A > 1$ are within the admissibility horizon and continue to exchange information through plenum dynamics; modes with $k \cdot d_A < 1$ have exited the admissibility horizon and are effectively frozen. This is the RSVP analogue of Hubble horizon crossing, with d_A replacing $1/H$.

The spectral index evaluated at admissibility crossing will differ from the phenomenological estimate (55) in precisely the regime where d_A departs from $1/H_{\text{eff}}$. At large scales ($k \to 0$), if c_A is approximately constant during the lamphrodyne epoch, then $d_A \propto t$ and the spectrum acquires a scale dependence controlled by the time evolution of $\epsilon_{\text{lamph}}(t)$. Deriving n_s from admissibility crossing rather than Hubble crossing is the calculation that would produce a genuinely RSVP-native spectral index, as opposed to the multifield analogue estimate of Section 11.4.

Proposition 2 (Lamphrodyne Consistency Conjecture). *In the slow-relaxation regime $|\eta_{\rm lamph}| \ll 1$, the tensor-to-scalar ratio admits an expansion*

$$r_{\rm RSVP} = C\,\epsilon_{\rm lamph}^{p} + \mathcal{O}(\eta_{\rm lamph}), \tag{48}$$

where the coefficient C and exponent p depend on the dominant plenum source contributing to $T_{ij}^{\rm eff}$. Specifically, if vector vorticity dominates, p is determined by the scaling of $P_v(k)$ with $\epsilon_{\rm lamph}$; if entropy shear dominates, p reflects the scaling of $P_S(k)$. The slow-relaxation approximation $|\eta_{\rm lamph}| \ll 1$ is the condition under which the $\mathcal{O}(\eta_{\rm lamph})$ correction is negligible, exactly as $|\eta_{\rm infl}| \ll 1$ is required for the inflationary consistency relation $r = 16\epsilon$ to hold.

This conjecture is not proven here; it defines the research program. The derivation of the exponent p and coefficient C from explicit plenum power spectra is the calculation that would transform the present framework paper into a predictive cosmological model. We state the conjecture explicitly so that its resolution can serve as a milestone for the RSVP program, analogous to the derivation of $r = 16\epsilon$ in inflationary perturbation theory.

9 The Empirical Fork

9.1 The QQG Tensor Floor

The structural prediction of QQG is equation (10): the tensor-to-scalar ratio satisfies $r_{\rm QQG} \gtrsim 10^{-2}$ as a consequence of the perturbativity bound $\lambda_{tH} \lesssim 1$. This bound is not a phenomenological choice but an internal consistency condition: if λ_{tH} exceeds unity, the 1-loop approximation that underlies the entire QQG inflationary scenario breaks down. The tensor floor is therefore a necessary consequence of the theory's validity conditions.

The next generation of CMB polarization experiments—LiteBIRD, CMB-S4, and the Simons Observatory—will reach sensitivities of $\sigma(r) \sim 10^{-3}$, well below the QQG floor. A robust upper bound at $r < 10^{-2}$ would strongly challenge the simplest QQG realization and require modification of its perturbative assumptions.

9.2 RSVP Predictions: Three Cases

The RSVP prediction for r_{RSVP} depends on the specific dynamics of the lamphrodyne epoch, which are not yet fully constrained. Three qualitative cases are distinguished.

Case A: Suppressed tensor spectrum. If the plenum field correlators P_v, P_S, P_Φ are strongly suppressed relative to the scalar power spectrum during the lamphrodyne epoch, then $r_{\mathrm{RSVP}} \ll 10^{-2}$. This case is consistent with all current B-mode non-detections and would be favored if future experiments find no primordial tensor signal.

Case B: Inflation-like tensor spectrum. If the anisotropic stress of the relaxing plenum generates tensor modes at an amplitude comparable to the QQG floor, then $r_{\mathrm{RSVP}} \sim 10^{-2}$. In this case, RSVP must account for why relaxation produces a tensor residue that mimics de Sitter quantum fluctuations in amplitude.

Case C: Distinct spectral shape. The tensor spectrum $P_h(k)$ may have a spectral tilt n_t^{RSVP} that differs from the inflationary prediction $n_t = -2\epsilon$. Even if the amplitude r_{RSVP} falls within the observationally accessible range, a blue or unusually tilted tensor spectrum would be a distinctive signature of lamphrodyne relaxation rather than de Sitter inflation.

9.3 Falsification Matrix

Table 1 summarizes the observational consequences for QQG and RSVP across the principal experimental outcomes.

Table 1: Empirical fork: observational outcomes and their implications for Class 2 (QQG) and Class 3 (RSVP) smoothing mechanisms.

Observation	**QQG**	**RSVP**
$r > 0.01$	Survives; constrains λ_{tH}	Must explain tensor residue from plenum stress
$r \approx 0.01$	Survives at parameter boundary	Constrained; Case B viable
$r < 0.01$	Falsified by internal bound	Survives; Case A or C favored
Unusual tilt $n_t > 0$	Requires significant model extension	Natural if plenum correlators are blue
Tilt consistent with $n_t = -r/8$	Standard consistency; favors inflation	Coincidental; requires explanation

10 Ontological Economy and the Large-N Question

10.1 Why QQG Requires Large N

The QQG inflationary scenario requires $N \sim 10^5$–10^6 matter fields to produce a spectral index n_s compatible with CMB observations. This requirement is not optional: in the vacuum ($N = 0$) case, the beta-function trajectories do not generate a viable inflationary potential [11]. The matter fields enter only through their vacuum fluctuation contributions to the one-loop beta functions; they need not be excited, and their physical content beyond loop corrections is left unspecified.

The 't Hooft-like coupling $\lambda_{tH} = \lambda_0 N/(4\pi)^2 \lesssim 1$ provides the perturbativity bound. As N increases, λ_0 must decrease proportionally to keep λ_{tH} under control. The large-N matter content is therefore not a prediction of the theory but a parameter space requirement: it is needed to make the beta functions produce a viable slow-roll trajectory.

10.2 The Empirical Status of the Large-N Sector

No independent observational consequence of the large-N sector has yet been identified. The matter fields sit in their vacua throughout the inflationary epoch; they do not contribute to reheating, do not produce distinctive non-Gaussianities, and do not generate spectral features that would independently confirm their presence. Their role is to modify the RG flow of the gravitational couplings ξ and λ so that a viable slow-roll trajectory is obtained.

This is a meaningful distinction. The inflaton fields of Class 1 smoothing are empirically unjustified in their potential shape, but they do make independent predictions about reheating dynamics, curvaton mechanisms, and spectral features that can in principle be tested. Whether the large-N spectator sector of QQG will ultimately yield analogous independent predictions—through, for example, its role in the strong-coupling regime or in the particle spectrum of the emergent radiation era—is an open question. As of the present paper, the sector is mathematically motivated by the requirements of the beta-function structure, while its empirical motivation remains to be established.

10.3 Relaxation Cosmology as an Alternative

The three RSVP plenum fields Φ, $\mathbf{v}$, S are not introduced to fix observational parameters. They are required by the theoretical structure of the admissibility and constraint-closure program: Φ encodes constraint satisfaction, $\mathbf{v}$ encodes directed entropy flux, and S encodes irreversibility. Each field carries independent theoretical motivation; none is introduced solely to modify a running coupling.

The ontological economy argument is not a simple appeal to parsimony or field count. A more precise formulation is the following: the QQG large-N sector participates in the cosmological dynamics exclusively through renormalization-group effects on the gravitational couplings. Its fields sit in their vacua; they do not appear in the background equations, the reheating dynamics, or the perturbation spectrum except indirectly through beta-function corrections. The RSVP plenum fields Φ, $\mathbf{v}$, S, by contrast, participate directly in the dynamics being modeled: they define the background state, source the perturbations, generate the effective stress tensor, and carry the entropy gradient that produces the observed redshift. The distinction is not between many fields and few fields, but between fields that are dynamically active in the mechanism being proposed and fields that function as renormalization-group auxiliaries. Both frameworks introduce speculative field content; the claim here is only that RSVP's field content is dynamically necessary to the mechanism in a way that the QQG large-N sector presently is not.

11 Discussion

11.1 Inflation After the Inflaton

The QQG result of Liu et al. [11] marks a genuine advance in theoretical cosmology. It demonstrates that the inflationary phase is not necessarily tied to the existence of an auxiliary scalar field with a tuned potential, but can instead emerge from the UV-complete dynamics of quantum gravity itself. This is a conceptually important result independent of whether QQG inflation ultimately proves correct: it establishes that the inflaton paradigm is not the only way to generate a quasi-de Sitter phase, and that the physical source of inflationary energy can be sought within the gravitational sector rather than appended to it.

11.2 What Remains to Be Explained

The QQG scenario does not address the question of whether inflationary expansion is necessary, only the question of its source. The three fundamental requirements of early-universe smoothing—isotropy, homogeneity, and scale-invariant perturbations—are explained within QQG by the same mechanism as in Class 1 inflation: a de Sitter phase stretches modes beyond the Hubble horizon and establishes causal coherence before last scattering. QQG changes the energy source of this phase; it does not change its physical mechanism.

RSVP proposes that the mechanism itself can be replaced. This is a stronger claim, and it carries a heavier formal burden. The present paper takes a step toward discharging that burden by providing the formal structure of the lamphrodyne background, the definition of η_{lamph}, and the tensor spectrum formula r_{RSVP}. The full derivation of r_{RSVP} as a function of η_{lamph}—the RSVP analogue of $r = 16\epsilon$—remains the primary open problem of the framework.

11.3 Toward an RSVP Consistency Relation

The inflation literature is organized around the consistency relation $r = 16\epsilon$. QQG organizes its predictions around the structural bound $r_{\text{QQG}} \gtrsim 10^{-2}$. RSVP is proposing the conjecture (48):

$$r_{\text{RSVP}} = C\,\epsilon_{\text{lamph}}^{p} + \mathcal{O}(\eta_{\text{lamph}}). \tag{49}$$

These three relations define the comparison between smoothing classes at the level of a single observable:

$$\begin{aligned} \text{Class 1 (inflation):} \quad & r = 16\epsilon_{\text{infl}}, && (50)\\ \text{Class 2 (QQG):} \quad & r \gtrsim 10^{-2}, && (51)\\ \text{Class 3 (RSVP):} \quad & r = C\,\epsilon_{\text{lamph}}^{p} + \mathcal{O}(\eta_{\text{lamph}}). && (52) \end{aligned}$$

The inflation relation is derived; the QQG bound is structural; the RSVP conjecture is programmatic. Deriving the exponent p and coefficient C from explicit plenum power spectra $P_v(k)$, $P_S(k)$, $P_\Phi(k)$ is the calculation that promotes the RSVP entry from programmatic to derived. At that point the comparison becomes genuinely quantitative rather than structural, and the three-class taxonomy becomes a three-model competition with a shared observable target.

The sequence of steps required is clear from the framework developed here:

specify the RSVP action and kinetic terms to fix G_{AB}; solve the linearized field equations on the lamphrodyne background to derive $P_v(k)$, $P_S(k)$, $P_\Phi(k)$; project T_{ij}^{eff} onto the TT sector; evaluate $P_h(k)$; and extract p and C in the slow-relaxation limit. This is a well-posed calculation within the framework established here.

11.4 Multifield Analogy and Preliminary Spectral Estimate

The scalar power spectrum is observationally primary. Any candidate cosmological model must reproduce the observed amplitude $A_s \approx 2.1 \times 10^{-9}$ and spectral index $n_s \approx 0.965$ [14] before tensor predictions carry weight. We are at an earlier stage for scalar perturbations than for tensor perturbations, and we flag this explicitly. What follows is a heuristic estimate based on embedding RSVP in a phenomenological GR context; it is not a derived result from the RSVP-native perturbation theory, which requires admissibility horizons rather than Hubble horizons as the fundamental freeze-out condition. We present it as a multifield analogy to indicate the order of magnitude of what a complete calculation might yield.

The prototype action (22), restricted to its scalar sector (Φ, S) on a homogeneous FRW background, describes a two-field system with non-canonical kinetic mixing. The field-space metric in the (Φ, S) subspace is read off from the kinetic terms:

$$G_{AB} = \begin{pmatrix} 1 & -\xi_2 \\ -\xi_2 & 1 \end{pmatrix}, \qquad G^{AB} = \frac{1}{1-\xi_2^2} \begin{pmatrix} 1 & \xi_2 \\ \xi_2 & 1 \end{pmatrix}. \tag{53}$$

In the phenomenological GR embedding—where we treat the background as FRW and use H for the metric Hubble rate—the slow-roll parameter ϵ_{lamph}, interpreted via the field-space gradient of the effective potential $V_{\text{eff}} = V(\Phi) + W(S)$, takes the form

$$\epsilon_{\text{lamph}} \approx \frac{M_{\text{Pl}}^2}{2} \frac{(V')^2 + (W')^2 + 2\xi_2 V'W'}{(1-\xi_2^2)(V+W)^2}. \tag{54}$$

This connects the admissibility-gradient definition of ϵ_{lamph} to an operational expression in terms of the prototype potentials, under the assumption that $\nabla_{\mathcal{F}} \log \text{Vol}(\mathcal{A})$ is proportional to $\nabla_{\mathcal{F}} V_{\text{eff}}$ for the vorticity-based admissibility constraint (29). The proportionality holds when the admissibility boundary is level sets of V_{eff} in field space, which is an assumption whose justification requires the full admissibility dynamics.

Using the standard multi-field perturbation theory of Gordon et al. [16] for a two-scalar system with field-space metric G_{AB}, the scalar spectral index at leading order in slow roll is

$$n_s - 1 = -a\,\epsilon_{\text{lamph}} - b\,\eta_{\text{lamph}} + \mathcal{O}(\epsilon_{\text{lamph}}^2), \tag{55}$$

where the coefficients a and b depend on the trajectory curvature in field space, the isocurvature-to-adiabatic transfer, and the mixing parameter ξ_2. In the single-field limit $\xi_2 \to 0$, the standard result $a = 6$, $b = -2$ is recovered. For nonzero ξ_2, the coefficients shift by $\mathcal{O}(\xi_2^2)$ corrections.

We emphasize that equation (55) is derived within the phenomenological GR embedding, not from the RSVP-native perturbation theory. In the GR embedding, horizon crossing at $k = aH$ determines the freeze-out scale, and the Mukhanov–Sasaki formalism applies directly. In the full RSVP framework, freeze-out instead occurs at admissibility crossing $k\,d_A(t) \sim 1$, where d_A is the admissibility horizon defined in Section 6.9. The RSVP-native spectral index will therefore differ from (55) in its scale dependence at $k \to 0$, where the admissibility horizon structure modifies the spectrum relative to the inflationary prediction. Deriving this correction is the principal remaining calculation of the scalar perturbation program.

Define the scalar power spectrum

$$P_s(k) = \langle \zeta(\mathbf{k})\,\zeta(-\mathbf{k}) \rangle, \tag{56}$$

where ζ is the gauge-invariant curvature perturbation. In the phenomenological embedding, $P_s(k_*) \approx H^2/(8\pi^2 M_{\text{Pl}}^2 \epsilon_{\text{lamph}})$ at the pivot scale k_*, matching the inflationary formula with ϵ_{infl} replaced by ϵ_{lamph}. Setting this equal to A_s gives a constraint on ϵ_{lamph} as a function of H during the lamphrodyne epoch. This is the scalar normalization condition that the background solution must satisfy, and it connects ϵ_{lamph} to the observed CMB amplitude independently of the tensor sector.

11.5 Falsifiability of RSVP

It is important to state explicitly what would falsify the RSVP framework, not merely challenge it. Class 3 smoothing would be effectively refuted if all observable tensor properties satisfy inflationary consistency relations to high precision: specifically, if the tensor spectral index is measured to satisfy $n_t = -r/8$ with high significance, this would confirm de Sitter vacuum fluctuations as the tensor source and leave no room for a sourced alternative. RSVP would also be challenged if no admissibility-based relaxation model can simultaneously reproduce the observed scalar power spectrum amplitude A_s and spectral index n_s while maintaining the irreversibility condition $d\,\mathrm{Vol}(\mathcal{A}_{\mathrm{unresolved}})/dt < 0$ throughout the lamphrodyne epoch—a failure of internal consistency analogous to QQG's strong-coupling bound. Finally, if the tensor spectrum is shown to be generated prior to any thermodynamic epoch, in a regime where entropy production is observationally excluded, the lamphrodyne mechanism loses its physical grounding. These are not remote possibilities; they are concrete conditions that the derivation of r_{RSVP} must be tested against.

11.6 Future Observations

The observational landscape over the next decade will provide significant discriminating power. LiteBIRD, scheduled for launch in the early 2030s, targets a sensitivity of $\sigma(r) \sim 10^{-3}$ and will either detect primordial tensor modes above the QQG floor or push below it. CMB-S4 will provide complementary constraints on n_s, non-Gaussianity, and CMB spectral distortions. The Simons Observatory is currently operational and will provide intermediate constraints.

For RSVP, the key observational target is not a single value of r but the tensor spectral tilt n_t. If primordial tensor modes are detected, their spectral shape will distinguish de Sitter quantum fluctuations (slightly red, $n_t \approx -r/8$) from sourced tensor modes of the kind RSVP predicts. Specifically, if the tensor spectrum is blue ($n_t > 0$) at the pivot scale, this cannot be explained within any de Sitter inflation framework and would constitute strong evidence for a non-inflationary source of tensor modes, which lamphrodyne relaxation is designed to provide.

12 Conclusion

We have proposed a classification of early-universe smoothing mechanisms into three structurally distinct classes. Class 1—inflaton smoothing—uses an auxiliary scalar field with tuned potential to drive metric expansion. Class 2—geometric smoothing, exemplified by the QQG result of Liu et al. [11]—uses quantum-corrected gravitational dynamics to generate the same expansion without a separate inflaton. Class 3—lamphrodyne relaxation, proposed within the RSVP framework—uses admissibility-reducing dynamics in a coupled scalar-vector-entropy plenum to achieve cosmological homogenization without global metric expansion.

We have formalized Class 3 by defining the lamphrodyne background state $(\Phi_0, \mathbf{v}_0, S_0)$, imposing the irreversibility condition $d\,\mathrm{Vol}(\mathcal{A}_{\text{unresolved}})/dt < 0$, introducing the field-space admissibility metric on $\mathcal{F}$, and defining the lamphrodyne relaxation parameter η_{lamph} from admissibility geometry. We have constructed the effective anisotropic stress tensor of the relaxing plenum and constructed the formal structure of the tensor power spectrum $P_h(k)$ and tensor-to-scalar ratio r_{RSVP}. We have compared these with the QQG tensor floor $r_{\text{QQG}} \gtrsim 10^{-2}$ and identified the empirical fork that future B-mode experiments will resolve.

The significance of Quadratic Quantum Gravity may not be that it explains inflation. Its deeper significance is that it demonstrates that cosmological smoothing can emerge from the intrinsic dynamics of a fundamental theory. Once this possibility is admitted, inflationary expansion becomes one member of a broader class of smoothing mechanisms. RSVP explores a different member of this class: relaxation without expansion. Future measurements of primordial tensor modes—their amplitude, spectral tilt, and scale dependence—may determine which description better captures the universe's earliest history.

The primary contribution of this paper is the demonstration that Class 3 smoothing is formally tractable. The lamphrodyne relaxation parameter η_{lamph} plays the same structural role in RSVP that the slow-roll parameters play in inflation: it characterizes the regime in which the background is stable, perturbation theory is valid, and observables can be computed. The derivation of r_{RSVP} as an explicit function of η_{lamph}—the RSVP consistency relation—is the next step, and it is a step that can be taken within the framework presented here.

References

[1] Albrecht, A. and Steinhardt, P. J. (1982). Cosmology for grand unified theories with radiatively induced symmetry breaking. *Physical Review Letters*, 48(17):1220–1223.

[2] Avramidi, I. G. and Barvinsky, A. O. (1985). Asymptotic freedom in higher-derivative quantum gravity. *Physics Letters B*, 159(4):269–274.

[3] Ade, P. A. R. et al. (2021). Improved constraints on primordial gravitational

waves using Planck, WMAP, and BICEP/Keck observations through the 2018 observing season. *Physical Review Letters*, 127(15):151301.

[4] Buccio, D., Donoghue, J. F., Menezes, G., and Percacci, R. (2024). Physical running of couplings in quadratic gravity. *Physical Review Letters*, 133(2):021604.

[5] Capper, D. M. and Duff, M. J. (1974). Trace anomalies in dimensional regularization. *Nuovo Cimento A*, 23:173.

[6] Fradkin, E. S. and Tseytlin, A. A. (1982). Renormalizable asymptotically free quantum theory of gravity. *Nuclear Physics B*, 201(3):469–491.

[7] Guth, A. H. (1981). Inflationary universe: A possible solution to the horizon and flatness problems. *Physical Review D*, 23(2):347–356.

[8] Holdom, B. and Ren, J. (2016). QCD analogy for quantum gravity. *Physical Review D*, 93(12):124030.

[9] Kofman, L., Linde, A., and Starobinsky, A. A. (1997). Towards the theory of reheating after inflation. *Physical Review D*, 56(6):3258–3295.

[10] Linde, A. D. (1982). A new inflationary universe scenario. *Physics Letters B*, 108(6):389–393.

[11] Liu, R., Quintin, J., and Afshordi, N. (2026). Ultraviolet completion of the big bang in quadratic gravity. *Physical Review Letters*, 136(11):111501.

[12] Louis, T. et al. (ACT Collaboration) (2025). The Atacama Cosmology Telescope: DR6 power spectra, likelihoods and cosmological parameters. *Journal of Cosmology and Astroparticle Physics*, 11:062.

[13] Martin, J., Ringeval, C., and Vennin, V. (2014). Encyclopædia inflationaris. *Physics of the Dark Universe*, 5–6:75–235.

[14] Akrami, Y. et al. (Planck Collaboration) (2020). Planck 2018 results X: Constraints on inflation. *Astronomy and Astrophysics*, 641:A10.

[15] Starobinsky, A. A. (1980). A new type of isotropic cosmological models without singularity. *Physics Letters B*, 91(1):99–102.

[16] Gordon, C., Wands, D., Bassett, B. A., and Maartens, R. (2001). Adiabatic and entropy perturbations from inflation. *Physical Review D*, 63(2):023511.