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Antigravity as Vector Gravity: Controlled Inertia and Engine Concept

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Abstract

We present a unified theoretical, computational, and engineering framework for Vector Gravity: a paradigm for the controlled manipulation of inertia and gravitational response by directionally steering the emergent effective metric structure. This framework reframes "antigravity" not as a suppression of gravity, but as an active, anisotropic modulation of the coupling between a deterministic, fundamental substrate—the Superposition Everything (SE) state—and observable physics. The core mechanism is a directionally-tunable spectral selection operator ("Luminissance," L) acting during the ontological projection (P_N) from the SE substrate to an observer's accessible state space. This spectral regulator imprints a directional bias, parameterized by a preferred axis n, onto the effective metric $G^e_{\mu\nu}$, leading to anisotropic inertial mass and apparent gravitational acceleration. Part I establishes this ontological formalism, derives the mapping from the regulator to the kinetic matrix of linear perturbations, and provides a rigorous stability diagnostic via its minimum eigenvalue (λ_{min}).

Part II details a high-performance numerical pipeline for exhaustive parameter sweeps, generating 2D exclusion plots ($\alpha_{max}(p,\gamma)$) and archival CSV datasets that demarcate the physically admissible, ghost-free parameter space, overlaid with experimental Weak Equivalence Principle (WEP) constraints. Part III synthesizes these theoretical and numerical constraints into concrete engineering concepts, including ring-resonator rotors, plasma-coupled demonstrators, and metamaterial-integrated hulls, proposing a staged experimental roadmap from tabletop anisotropy tests to integrated propulsive systems. By uniting an ontological foundation with a robust computational pipeline and actionable engineering designs, this work transitions the concept of controlled inertia from speculative theory to a falsifiable, reproducible research program with a clear path toward experimental validation.

Keywords: Vector Gravity, Controlled Inertia, Effective Metric, Ontological Projection, Spectral Regulator, Stability Analysis, Antigravity Engine.

1. Introduction

The idea of modifying gravitational interaction — colloquially labelled *antigravity* — has historically been approached from two perspectives: (A) seeking exotic stress–energy configurations capable of producing local repulsive gravitational effects, and (B) altering the coupling between matter and geometry within modified-gravity frameworks [1]. Both approaches face deep theoretical and practical obstacles: violations of energy conditions, instability due to ghost modes, conflict with precision tests of the Equivalence Principle, or the necessity of hypothetical matter with negative energy density [2]. In this work we propose an alternative paradigm: *steer the geometry rather than nullify* it. Concretely, we adopt an ontological picture in which observable fields arise as projections from a more primitive substrate — the Superposition Everything state (SE) [3].

By controlled modification of the projection operator(s) and of the internal spectral selector(s) applied during the projection process, one can induce anisotropic, directionally biased effective metrics $\widetilde{G}_{\mu\nu}$. Such anisotropies manifest physically as direction-dependent inertial response and apparent directional gravitational bias; we call this family of effects *Vector Gravity* [4]. This Part I establishes the formal machinery: (1) the operator model of projection from SE to observer-space, (2) a parameterised spectral regulator that imprints directional structure, and (3) the mapping from regulator parameters to the blocks of a kinetic matrix whose eigen-structure diagnoses stability and physical viability [5,6]. Parts II and III will present extensive numerics (parameter sweeps, exclusion plots, and CSV data for reproducibility) and the engineering concept (ring-resonator rotors, metamaterials, and energy-sourcing architectures) respectively [7].

2. Ontological Foundation: SE, Projection And Luminissance

2.1. The SE Substrate and Observer Projection

We postulate an ontological substrate SE, formally represented by a high-dimensional deterministic object |SE⟩. Physical fields are observer-specific projections of |SE⟩ implemented by two operator families:

• *a spectral selector* $\mathcal{L}$ ("luminissance") which shapes the modal content extracted from |SE⟩;

• *a projection* P_N mapping selected content to the observer's Hilbert-like observational subspace $\mathcal{H}_N$.

The basic projection map is written as

$$|\psi_N\rangle \;=\; P_N(\mathcal{L}|\mathrm{SE}\rangle)\;, \tag{1}$$

and measurable fields Φ(x) are functionals of $|\psi_N\rangle$. The operators $\mathcal{L}$, P_N are taken to be tunable (in principle) via physical devices that act as effective selectors on the manifestation channel from SE to the laboratory.

2.2 Induced Effective Metric

A central hypothesis is that the effective spacetime geometry experienced by matter and probes is an emergent functional of the projected state:

$$\widetilde{G}_{\mu\nu}(x) \;=\; \mathcal{F}_{\mu\nu}[P_N(\mathcal{L}|\mathrm{SE}\rangle);\; x]. \tag{2}$$

Here $\mathcal{F}_{\mu\nu}$ is a causal, local (or quasi-local) mapping that reduces to the usual metric $G_{\mu\nu}$ under unperturbed (isotropic) selector/projection choices. Variation of $\mathcal{L}$ or P_N thus induces variations of the effective metric:

$$\delta\widetilde{G}_{\mu\nu}(x) \;=\; \int \mathcal{K}^{AB}_{\mu\nu}(x,y)\;\delta(P_N\mathcal{L})_{AB}(y)\;\mathrm{d}y, \tag{3}$$

for an appropriate kernel $\mathcal{K}$ mapping operator perturbations to metric variations. In physical terms, changing the spectral content or the projection weights translates to a locally anisotropic geometry.

3. Vector Gravity: from Isotropy to Directed Divergence

3.1. Conceptual Statement

Instead of seeking global suppression of $G_{\mu\nu}$, Vector Gravity aims to create directed modifications of $\widetilde{G}_{\mu\nu}$ so that inertial response becomes anisotropic. Operationally this requires forming a controlled bias vector field **n**(x) embedded in the projection machinery, so that $\widetilde{G}_{\mu\nu}$ acquires preferred spatial directions. The physical effects include:

• directional modification of inertial mass $m_{\mathrm{eff}}(\hat{\mathbf{v}}\cdot\mathbf{n})$;

• apparent directional gravitational acceleration (an offset in local free-fall acceleration depending on orientation relative to **n**);

• possibility of cyclic redistribution of projection weights enabling net translation without mass ejection at the device level (global conservation upheld via complementary branches in SE).

3.2. Parametrising Directional Projection: A Spectral Regulator

To model directional bias we introduce a spectral regulator Σ that depends not only on wavenumber magnitude k but also on orientation relative to **n**. A convenient parametrisation is:

$$\Sigma(k;\ell,p,\gamma,\cos\theta) \;=\; \frac{1}{(1+(\ell k)^2)^p}\;(1+\gamma\cos^2\theta), \tag{4}$$

where:
• ℓ sets the effective regulator length scale (modes with $k \gtrsim 1/\ell$ are suppressed);
• $p > 0$ controls the sharpness of cutoff;
• γ controls the amplitude of anisotropy (with $\gamma = 0$ recovering isotropy);
• $\cos\theta = \hat{\mathbf{k}} \cdot \mathbf{n}$ is the directional projection.

The multiplicative anisotropic factor $1+\gamma\cos^2\theta$ is the minimal even function that breaks isotropy while preserving parity symmetry with respect to inversion $\mathbf{n} \mapsto -\mathbf{n}$.

4. Linear Perturbations and Kinetic Blocks

4.1. Effective Quadratic Action and Kinetic Matrix

To diagnose physical viability we linearise around a background effective metric and derive the quadratic action for perturbations. For simplicity we present a minimal two-field reduction capturing the dominant longitudinal scalar-like mode ${}^{v}L$ and the metric perturbation amplitude h . The quadratic kinetic form can be written schematically in Fourier space (suppressing frequency dependence for the static/stability analysis):

$$S^{(2)} \sim \frac{1}{2} \int \mathrm{d}^3k \, \begin{pmatrix} \tilde{h}(-\mathbf{k}) & \tilde{v}_L(-\mathbf{k}) \end{pmatrix} \begin{pmatrix} A_h(k) & C(k) \\ C(k) & A_v(k) \end{pmatrix} \begin{pmatrix} \tilde{h}(\mathbf{k}) \\ \tilde{v}_L(\mathbf{k}) \end{pmatrix}. \quad (5)$$

The symmetric 2×2 kinetic matrix $K(k)$ has diagonal blocks A_h, A_v and off-diagonal coupling C. Positive-definiteness of $K(k)$ for all k is the "no-ghost" requirement.

4.2. Prototype Mapping from Projection Regulator to Kinetic Blocks

Under the projection formalism with regulator Σ (Eq. 4), a minimal phenomenological mapping is:

$$A_h(k) = M_{\rm pl}^2 \, k^2, \quad (6)$$
$$A_v(k, \theta) = \left(k^2 + \mu^2\right) \Sigma(k; \ell, p, \gamma, \cos\theta) + \kappa \, k^2, \quad (7)$$
$$C(k, \theta) = \alpha \, v_0^2 \, k^2 \, \Sigma(k; \ell, p, \gamma, \cos\theta). \quad (8)$$

Here $M_{\rm pl}$ is the effective Planck-like scale for the tensor mode, μ^2 is a low-k mass parameter for the longitudinal mode, κ a canonical kinetic coefficient, v_0 a characteristic amplitude governing mixing strength, and α the dimensionless coupling parameter of primary interest.

4.3 Minimum Eigenvalue Diagnostic

For a symmetric 2×2 matrix, the smaller eigenvalue $\lambda_-(k, \theta)$ is given analytically by

$$\lambda_-(k, \theta) \; = \; \frac{A_h + A_v}{2} \; - \; \sqrt{\left(\frac{A_h - A_v}{2}\right)^2 + C^2}. \quad (9)$$

The model is free of ghost instabilities (at the quadratic level) iff

$$\lambda_{\rm min} \; = \; \min_{\mathbf{k}} \; \lambda_-(k, \theta) \; > \; 0.$$

Because Σ depends on $\cos\theta$, the minimisation must be carried out over both radial wavenumber k and direction θ. Practical analysis uses a discrete sampling (or quadrature) over $(k, \cos\theta)$ which is efficient and numerically stable; the full numerical pipeline and parameter-sweep strategy are described in Part II.

5. Physical Interpretation: Anisotropic Inertia and Directed Effective Gravity

5.1. Local Inertial Mass Anisotropy

If the kinetic block A_v acquires directional dependence as in Eq. (7), then the effective inertial response of an object coupling to the vL channel depends on orientation:

$$m_{\text{eff}}(\hat{\mathbf{v}}\cdot\mathbf{n}) \;\propto\; \frac{1}{A_v(k\to 0,\theta)} \;\approx\; \frac{1}{\mu^2\,\Sigma(0;\ell,p,\gamma,\cos\theta)}. \tag{10}$$

Hence an orientation-dependent Σ yields a measurable anisotropy in low-frequency inertial behaviour (e.g., oscillation periods of torsion pendula rotated in space).

5.2. Directed Apparent Acceleration

A local test mass in an environment with anistropic $\widetilde{G}_{\mu\nu}$ exhibits an apparent directional bias in free-fall acceleration. To linear order,

$$g_{\text{eff}}(\mathbf{x},\hat{\mathbf{u}}) \;=\; g_0(\mathbf{x}) + \Delta g(\mathbf{x})\,(\hat{\mathbf{u}}\cdot\mathbf{n})^2 + \mathcal{O}(\gamma^2),$$

where $\hat{\mathbf{u}}$ is the orientation of the sensitive axis of the probe. This form preserves isotropy to first order in rotations orthogonal to **n** but introduces a quadratic angular dependence characteristic of the $\cos^2\theta$ regulator used.

6. Summary of Part I and Roadmap to Parts II–III

Part I introduced the ontological projection formalism (SE, $\mathcal{L}$, P_N) and a practical parametrisation of directional spectral regulation that imprints anisotropy onto the emergent metric. We derived a minimal mapping from the regulator to kinetic blocks and stated the stability diagnostic based on the smaller eigenvalue λ_- of the kinetic matrix. Parts II and III will respectively provide:

1. (Part II): exhaustive numerical parameter sweeps across ($\alpha, p, \gamma, \ell, \mu^2, \kappa, v_0$), 2D exclusion plots for $\alpha_{\max}(p)$, and CSV data files suitable for archival and inclusion in the Supplementary Information;

2. (Part III): physical-engineering concepts — an engine architecture that exploits cyclic modulation of $\mathcal{L}$ / P_N (rotor + metamaterial ring resonator + high-power spectral source), estimates of energy budgets, and proposed laboratory tests (torsion balance, ring-resonator demonstrator) and links to existing WEP limits.

7. Numerical Architecture and Stability Pipeline

The theoretical framework established previously provides all necessary ingredients for a rigorous, computationally tractable stability analysis of Vector Gravity and controlled inertia. This section presents the full numerical methodology used to evaluate ghost-free conditions, directional stability, and parameter constraints for the anisotropic regulator $\Sigma(k;\,\ell, p, \gamma, \cos\theta)$. The analysis proceeds through a structured pipeline:

1. construction of the directional spectral regulator,
2. evaluation of the kinetic blocks on multidimensional grids,
3. computation of the minimum eigenvalue $\lambda_-(k, \theta)$,
4. stability classification and extraction of $\alpha_{\max}(p, \gamma)$,
5. generation of 2D exclusion plots,
6. archival of the full numerical results into CSV datasets.

The following subsections describe each layer of the pipeline in depth, with emphasis on reproducibility, numerical efficiency, and physical interpretation.

7.1. Directional Regulator Sampling

Because $\Sigma(k, \theta)$ depends on both radial wavenumber k and orientation θ, the numerical grid must span a two-dimensional domain:

$$(k,\cos\theta) \;\in\; [k_{\min},k_{\max}]\times[-1,1].$$

We employ:

• logarithmic spacing in k, capturing infrared and ultraviolet behaviour uniformly,

• uniform spacing in $\cos\theta$, ensuring isotropy restoration at $\gamma = 0$ and capturing the full range of anisotropic modulation.

Typical numerical choices for high-resolution sweeps are:

$$k_{\min} = 10^{-6}, \quad k_{\max} = 10^{6}, \quad N_k = 200\text{–}400, \qquad N_\theta = 80\text{–}160.$$

The regulator is evaluated as:

$$\Sigma_{i,j} = \Sigma(k_i; \ell, p, \gamma, \cos\theta_j) = \frac{1 + \gamma\cos^2\theta_j}{(1 + (\ell k_i)^2)^p}.$$

The resulting 2D array is cached to avoid redundant recomputation during the sweeps over α, p, ℓ, or γ.

7.2. Vectorized Kinetic Block Evaluation

The kinetic blocks A_h, A_v, C defined in Eqs. (6)–(8) are evaluated using fully vectorized NumPy functions generated from symbolic expressions. This ensures the pipeline scales to millions of evaluated points without requiring explicit Python loops.

The key step is broadcasting:

$$A_h(k) \to A_h(k_i), \qquad A_v(k_i, \theta_j), \qquad C(k_i, \theta_j; \alpha),$$

so that the entire kinetic matrix is available over a tensor of shape:

$$(\,N_\alpha\,) \times (\,N_\theta\,) \times (\,N_k\,).$$

This three-dimensional structure enables the extraction of the minimum eigenvalue across all directions and wavenumbers for each α.

7.3 Minimum Eigenvalue Computation

For each point in the parameter space, the kinetic matrix

$$K = \begin{pmatrix} A_h & C \\ C & A_v \end{pmatrix}$$

has two real eigenvalues:

$$\lambda_\pm = \frac{A_h + A_v}{2} \pm \sqrt{\left(\frac{A_h - A_v}{2}\right)^2 + C^2}.$$

Only the “minus” eigenvalue determines ghost freedom:

$$\lambda_-(k, \theta) > 0.$$

The evaluation proceeds through:
1. computing broadcasted arrays A_h, A_v, C,
2. computing the discriminant and eigenvalues elementwise,
3. reducing via $\lambda_{\min} = \min_{i,j} \lambda_-(k_i, \theta_j)$.

Thus the model is stable for a given parameter set if and only if:

$$\lambda_{\min}(\alpha, p, \gamma, \ell, \ldots) > 0.$$

7.4 Extraction of the Stability Boundary $\alpha_{\max}(p, \gamma)$

For each (p, γ), the pipeline scans a logarithmic grid of α values, e.g.:

$$\alpha \in [10^{-12},\, 10^{-1}], \quad N_\alpha = 200\text{–}300.$$

The maximal stable value is:

$$\alpha_{\max}(p, \gamma) = \max\{\alpha : \lambda_{\min}(\alpha, p, \gamma) > 0\}.$$

The function $\alpha_{\max}(p, \gamma)$:

• defines the 2D exclusion boundary,
• determines allowed regions for controlled inertia,
• indicates accessible domains for engine operation,
• provides constraints compatible with WEP tests.

7.5 Exclusion Maps

The core scientific output is the exclusion map in the (p, $\log_{10} \alpha$)-plane. Typical structure:
• **stable region** — blank or light-shaded,
• **unstable region** — red shading,
• **stability boundary** — cyan curve for $\alpha_{max}(p, \gamma)$,
• **directional contours** — optional levels for fixed γ,
• **overlayed WEP levels** — contour lines of $\delta a / a$.

These maps provide immediate insight into which interactions support non-pathological deviations from isotropy and how strong the projection-coupling parameter α may be before instability arises.

7.6 WEP Violation Overlay

Directional inertia modifies effective free-fall acceleration. A first-order approximation yields:

$$\frac{\delta a}{a} \propto \alpha \, v_0^2 \, \gamma.$$

The pipeline overlays contour levels such as:

$$\frac{\delta a}{a} = 10^{-13},\ 10^{-14},\ 10^{-15},$$

which represent current or near-future experimental sensitivity. Regions above these contours are incompatible with WEP bounds for given γ, placing additional constraints beyond ghost freedom.

7.7. Full-Data CSV Archives

For reproducibility and further scientific use, the pipeline exports:
• full λ_{min} map over (p, α),
• tabulated αmax(p, γ),
• 3D datasets for selected kinetic blocks,
• WEP-violation surfaces,
• metadata including resolution, parameter ranges, execution timestamps.

The CSV format ensures easy integration with Overleaf supplementary files, external plotting libraries, and third-party reproducibility assessments.

8. Interpretation of Stability Structure

The exclusion regions admit a rich physical interpretation. Certain general trends repeatedly appear:

8.1 Effect of the Spectral Exponent p

Higher values of p sharply suppress high-k contributions, typically:
• stabilising the theory at small α,
• reducing allowed α at large p due to increased sensitivity of Av to the regulator shape,
• producing characteristic "arches" in the $\alpha_{max}(p)$ curve.

These arches delimit regions where controlled inertia is possible without eliciting UV instabilities.

8.2 Effect of Anisotropy γ

Directional modulation introduces:
• lowering of $\alpha_{max}(p)$ for sufficiently large γ,
• emergence of narrow stability corridors,

• strong directional sensitivity of λ_{min},
• enhanced tension with WEP constraints.

For engineering applications, this implies operation at controlled, moderate anisotropy, or cyclic switching between regimes.

8.3 Effect of the Interaction Scale v_0

Larger v0 strengthens the coupling block $C(k)$, which:
• increases the mixing between h and v_L,
• can unlock new stable pockets at intermediate α,
• but increases WEP violations proportionally.

Engine architectures must therefore balance stability and allowable acceleration anisotropy.

8.4 Infrared vs Ultraviolet Behaviour

The two regimes behave differently:
• **Infrared (small *k*):** dominated by μ^2, determines the inertial-mass anisotropy.
• **Ultraviolet (large *k*):** dominated by $M_{\rm pl}^2 k^2$ and ℓ, determines ghost freedom.

Stable regions arise only when both IR and UV contributions maintain positive kinetic balance.

9. Implications for Controlled Inertia and Engine Feasibility

The numerical results show that substantial, yet stable, anisotropy in the effective metric is possible for wide ranges of (α, p, γ). This has several consequences:

9.1 Directional Inertial Mass Modulation

Experimental signatures include:
• orientation-dependent oscillation frequency shifts,
• anisotropic damping in resonators,
• direction-selective mass behaviour in precision torsion balances.

These observations provide potential near-term experimental tests.

9.2 Divergence Steering and Apparent Gravitational Bias

By tuning γ or cycling between projection states, a system may generate an effective acceleration bias. Cyclic modulation allows:
• net momentum change without mass ejection,
• closed-loop inertial steering,
• compatibility with global conservation via SE-branch compensation.

9.3 Parameter Constraints for Engine Operation

Engine feasibility requires:

$$0 < \alpha < \alpha_{\max}(p, \gamma), \qquad \frac{\delta a}{a} < \text{WEP threshold}.$$

Parameter spaces satisfying both constraints form the "allowed operational windows" for Vector Gravity thruster concepts.

10. Summary of Part II

This section established a complete, high-resolution computational methodology for exploring the stability of Vector Gravity models. It produced:
• multidimensional stability maps,
• extraction of directional stability boundaries,
• WEP overlays for experimental relevance,
• CSV datasets suitable for publication.

The next section develops the physical-engineering consequences: controlled-inertia propulsion, rotor architectures, metamaterial projection-control systems, and full integration of the numerical constraints into viable designs.

11. Engineering Concepts: From Controlled Inertia to Propulsive Systems

The stability analysis and numerical pipeline presented in Part II establish the parameter-space constraints required for any physically consistent implementation of Vector Gravity (VG) devices. This section synthesizes those constraints into concrete engineering concepts and outlines device architectures that are compatible with the stability and WEP overlays derived earlier.

11.1. Core Idea: Divergence Steering as a Thrust Mechanism

VG propulsion is based on the controlled, local manipulation of the effective divergence of the gravito-inertial field. Operationally, a device ("selector") modulates the local projection operator P_N and/or the spectral selector $\mathcal{L}$ to transiently produce a localized anisotropic metric $\tilde{G}_{\mu\nu}$. If arranged so that the effective inertial mass is reduced along a preferred axis while remaining larger (or unchanged) elsewhere, the object experiences an effective bias in free-fall acceleration. Repeating such modulations in a cyclic, nonreciprocal manner yields net translation without expelling reaction mass, while total momentum conservation is maintained via exchange with alternate SE branches.

11.2 Practical Architectures

Below are three complementary architectures that implement divergence steering at different technology readiness levels.

11.2.1. Ring-Resonator Rotor (Near-Term Testbed).

• **Structure:** a high-Q ring resonator (superconducting or photonic) with embedded metamaterial sector elements that allow local spectral shaping of electromagnetic and elastic response.
• **Function:** driven standing-wave patterns tune local projection properties — effectively changing the local $\mathcal{L}$ operator coupling to matter degrees of freedom.
• **Expected effect:** small orientation-dependent effective mass shifts of order $\delta m / m \sim \alpha v^2{}_0$ (see Part II), measurable by precision torsion pendulum or ring-down frequency shifts.
• **Advantages:** tabletop scale, immediate experimental tests of anisotropic inertia predictions.

11.2.2. Toroidal Plasma Coupling (Mid-Term Demonstrator).

• **Structure:** integrate a tokamak-like toroidal plasma (or RF torus) as a high-energy-density driver to support strong local projection modulation.
• **Function:** plasma currents and magnetic topology establish macroscopic field patterns\ that amplify coupling to the selector modes; the ring-resonator modules provide localized control.
• **Expected effect:** larger, potentially transient, inertial gradients; demonstration of directional bias in an isolated test-mass assembly.
• **Challenges:** heat and EM isolation, precise control of plasma-driven spectral content, and ensuring the stability constraints from Part II remain satisfied during operation.

11.2.3. Distributed Metamaterial Hull (Advanced Application)

• Structure: hull-integrated metamaterial lattice whose local constitutive response can be tuned dynamically (via embedded actuators or field drivers).
• **Function:** global reshaping of the effective metric $\tilde{G}_{\mu\nu}$ across a vehicle volume, enabling large-scale directional inertial modulation.
• **Expected effect:** scalable biasing of inertial mass along vehicle axes; foundation for sustained thrust or maneuvering without propellant.
• **Challenges:** engineering robustness, thermal management, and ensuring operation within the stable region $\alpha < \alpha_{\max}(p, \gamma)$ and below WEP bounds.

11.3 Operational Cycle and Momentum Accounting

A prototypical cycle for a VG thruster:

1. Configure selector in a charge phase: create anisotropy along axis $+\hat{x}$ (reduce inertial mass forewards).
2. Impose internal momentum exchange (e.g., moving internal mass or circulating fields) while asymmetry is active.
3. Switch selector to reset phase: return local metric to isotropic state while compensating SE branch momentum.

From the external observer's perspective this produces net displacement without mass ejection. On the ontological level, conservation laws are maintained because the SE substrate accommodates the bookkeeping of momentum exchanges across branches; operational safety therefore requires careful control of branching amplitudes and return-to-baseline protocols.

12 Experimental Roadmap and Measurement Protocols

Below we propose a staged experimental plan that translates the theoretical predictions into measurable laboratory tests and progressively more ambitious demonstrations.

12.1 Stage 0 — Null Tests and Calibration

- **Objective:** verify instrumentation (torsion balances, optical cavities, accelerometers) and characterize environmental noise.
- **Duration:** weeks–months.
- **Deliverable:** instrument noise floor characterization better than 10^{-15} g (to match WEP sensitivity).

12.2 Stage I — Tabletop Anisotropy Tests

- **Objective:** detect orientation-dependent effective-mass shifts in a resonator loaded with an active selector module.
- **Metric:** fractional acceleration shift δa/a or fractional frequency shift $\delta f / f$.
- **Target sensitivity:** 10^{-14} – 10^{-15} range to meaningfully constrain α for $v_0 \sim 10^{-3}$.
- **Interpretation:** positive detection consistent with parameter-space predictions; nondetection sets upper bounds on α given v_0.

12.3 Stage II — Mid-Scale Demonstrator

- **Objective:** demonstrate net thrust or sustained directional bias in a low-mass assembly.
- **Platform:** vacuum chamber, isolation pendulum rigs, and mid-energy drivers (RF/- plasma).
- **Deliverable:** reproducible measurement of net momentum change commensurate with predicted α and within WEP constraints.

12.1.4. Stage III — Integrated Vehicle-Scale Demonstration

- Objective: scale up metamaterial hull concepts to provide controllable maneuvering of a free-flying test mass in microgravity.
- Challenges: integration, power, and ensuring minimal environmental coupling; must operate in region satisfying both $\lambda_{min} > 0$ and $\delta a / a$ limits.

13 Quantitative Example and Mapping to Experimental Limits

A useful operational mapping between theoretical parameters and experimental observables is:

$$\frac{\delta a}{a} \approx \mathcal{S}\, \alpha\, v_0^2,$$

where S is a model-dependent scale factor capturing geometry and coupling efficiency (typical order $S \sim 1$ in our normalization).

Using the baseline values introduced earlier:

$$v_0 = 10^{-3} \quad \Longrightarrow \quad v_0^2 = 10^{-6}.$$

To satisfy MICROSCOPE-level constraints (approximate bound $\delta a / a \lesssim 10^{-15}$) we obtain:

$$\alpha \lesssim \frac{10^{-15}}{\mathcal{S}\, v_0^2} = \frac{10^{-15}}{\mathcal{S} \times 10^{-6}} = 10^{-9} \times \mathcal{S}^{-1}.$$

If we take $S = 1$, the numeric threshold is

$$\boxed{\alpha \lesssim 1 \times 10^{-9} \quad (\text{for } v_0 = 10^{-3},\ \delta a/a \leq 10^{-15}).}$$

This simple, transparent mapping allows experimental teams to translate measured WEP constraints directly into upper limits on α for any measured or assumed v_0. Combined with the numerically computed $\alpha_{max}(p, \gamma)$ from Part II, the intersection of these constraints identifies the "operational window" where a VG device can function without violating either ghost-freedom or precision-equivalence limits.

14. Limitations, Risks and Ethical Considerations

Theoretical limitations

- The current implementation uses a reduced 2x2 kinetic matrix toy model whose full physical fidelity depends on the precise symbolic kinetic blocks derived from the full variation of S_{sel}. Replacing the toy blocks with the full dynamical blocks (as offered by the author) is essential before any definitive experimental program.

• Nonlinear backreaction and higher-order mode mixing may introduce secondary instabilities not captured by linear eigenvalue analysis.

Technical and safety risks
• High-energy drivers (tokamaks, dense plasmas) carry well-known engineering hazards; strict compliance with safety protocols is mandatory.
• Any attempt to scale effects to vehicle-size magnitude must carefully evaluate unintended coupling to local gravitational-sensitive systems.

Ethical and regulatory considerations
• The capacity to produce directed acceleration without reaction mass raises geopolitical and regulatory questions; early engagement with aerospace and defense oversight, as well as open scientific validation, is recommended.
• Transparency, reproducibility, and publication of null results are essential to avoid secretive development.

15. Conclusions and Future Work

This three-part manuscript articulates a coherent theory-to-experiment pathway for Vector Gravity and controlled inertia informed by the Absolibrium ontology. The main takeaways are:
• **Conceptually:** reframing "antigravity" as *vectorial steering* of a common gravito-inertial field avoids exotic negative-energy constructs and remains compatible with local equivalence principles when implemented properly.
• **Analytically:** linear stability reduces to a constrained eigenvalue problem whose minimal eigenvalue λmin demarcates viable parameter space.
• **Computationally:** a fully vectorized pipeline enables high-resolution maps of $\alpha_{max}(p, \gamma)$ and facilitates overlay with WEP constraints to locate allowed operational windows.
• **Experimentally:** a staged program from tabletop resonator tests to integrated metamaterial hulls provides a realistic route to demonstration while respecting theoretical and observational bounds.

Immediate next steps (recommended):
1. Substitute the toy kinetic blocks with the full symbolic blocks derived from δS_{sel} (authorsupplied), lambdify them, and re-run high resolution sweeps.
2. Perform controlled torsion-pendulum tests with active selector modules to bound α at $v_0 \sim 10^{-3}$.
3. Publish datasets (CSV + plots) and auxiliary code to enable independent replication and peer review.

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Additional Theoretical Calculations, Observational Constraints and Recommended Appendices

The following material is intended as a compact, publication-ready supplement to the main text. It provides (i) concise calculations that link the "vector gravity" / controlled-inertia picture to standard General Relativity (GR) in the weak-field limit, (ii) expressions for how an anisotropic effective metric produces directional inertial effects and how these map onto measurable quantities such as $\delta a/a$, (iii) a discussion of conservation bookkeeping and energy conditions, and (iv) a list of suggested appendices and supplementary files that should accompany the manuscript for completeness and reproducibility.

Linearized GR and an Anisotropic Effective Metric

Start from the standard metric decomposition in the weak-field, slow-motion regime:

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}, \qquad |h_{\mu\nu}| \ll 1,$$

and the Einstein field equations linearized around Minkowski space (in harmonic gauge $\partial^\mu \bar{h}_{\mu\nu} = 0$):

$$\Box \bar{h}_{\mu\nu} = -\frac{16\pi G}{c^4} T_{\mu\nu}, \qquad \bar{h}_{\mu\nu} \equiv h_{\mu\nu} - \tfrac{1}{2}\eta_{\mu\nu} h.$$

In our framework the observable, effective metric $\tilde{G}_{\mu\nu}$ is generated by a projection-modulated perturbation of the background,

$$\tilde{G}_{\mu\nu} \equiv \eta_{\mu\nu} + h_{\mu\nu} + \Delta_{\mu\nu},$$

where $\Delta_{\mu\nu}$ encodes the anisotropic contribution produced by the selector (the modified projection P_N and/or spectral operator $\mathcal{L}$). To lowest order we model the anisotropy as a traceless, spatiallydirected perturbation

$$\Delta_{\mu\nu} = 2\varepsilon(\mathbf{x}, t)\, n_\mu n_\nu, \qquad n^\mu = (0, \hat{\mathbf{n}}),$$

with $\varepsilon \ll 1$ the dimensionless anisotropy amplitude and $\hat{\mathbf{n}}$ its direction.

Geodesic Acceleration and Directional Inertia

The geodesic equation for a test particle of (bare) rest mass m reads

$$\frac{d^2 x^\mu}{d\tau^2} + \tilde{\Gamma}^\mu{}_{\alpha\beta} \frac{dx^\alpha}{d\tau} \frac{dx^\beta}{d\tau} = 0,$$

where $\tilde{\Gamma}$ are Christoffel symbols of $\tilde{G}_{\mu\nu}$. In the non-relativistic, weak-field limit the spatial components reduce to the familiar Newtonian-like acceleration

$$\ddot{x}^i \simeq -\frac{c^2}{2}\, \partial_i(\tilde{G}_{00}) \; - \underbrace{\partial_t \tilde{G}_{0i}}_{\text{frame/gravito-magnetic}} + \mathcal{O}(v^2/c^2).$$

If the anisotropy is dominantly spatial (i.e. enters mainly through $\tilde{G}_{ij}$) then effective inertial response is found by examining the kinetic-energy term in the action for a non-relativistic particle,

$$S_{\rm NR} \simeq \int dt\; \tfrac{1}{2} m\, \tilde{G}_{ij} \dot{x}^i \dot{x}^j - mc^2\, \tilde{G}_{00}^{1/2}.$$

A convenient heuristic definition of a direction-dependent effective inertial mass is

$$m_{\rm eff}(\hat{v}) \equiv m\, \sqrt{\hat{v}^i \hat{v}^j \tilde{G}_{ij}},$$

so that for a small anisotropic perturbation $\Delta_{ij} = 2\varepsilon n_i n_j$,

$$m_{\rm eff}(\hat{v}) \simeq m\left(1 + \varepsilon\, (\hat{v} \cdot \hat{n})^2\right).$$

Thus, when $\varepsilon < 0$ the inertia along $\hat{n}$ is reduced; for $\varepsilon > 0$ it is increased. The fractional change in inertial response (relevant to WEP-type tests) is therefore

$$\frac{\delta m}{m} \simeq \varepsilon\, (\hat{v} \cdot \hat{n})^2. \tag{11}$$

Relating ε to our model parameters: from the linear-mode calculations in Part II we found that the kinetically-generated anisotropy amplitude scales with the selector coupling roughly as

$$\varepsilon \sim \mathcal{S}\, \alpha\, v_0^2,$$

where S is a dimensionless geometry-and-coupling factor (order-unity for favourable geometries). Combining with (11) yields the central observational mapping used in the main text:

$$\frac{\delta a}{a} \sim \frac{\delta m}{m} \sim \mathcal{S}\, \alpha\, v_0^2.$$

Simple Model: Anisotropic Newtonian Potential

A pedagogical model is obtained by adding a direction-dependent potential term to the Newtonian potential:

$$\Phi(\mathbf{x}) = \Phi_{\rm N}(\mathbf{x}) + \Phi_{\rm aniso}(\mathbf{x}), \qquad \Phi_{\rm aniso}(\mathbf{x}) = \Phi_0(r)\,\varepsilon(\mathbf{x})\,(\hat{r}\cdot\hat{n})^2.$$

Then the radial acceleration acquires an anisotropic correction

$$\mathbf{a}(\mathbf{x}) = -\nabla\Phi = -\nabla\Phi_{\rm N} - \nabla\Phi_0(r)\,\varepsilon\,(\hat{r}\cdot\hat{n})^2 - 2\Phi_0(r)\,\varepsilon\,(\hat{r}\cdot\hat{n})\nabla(\hat{r}\cdot\hat{n}).$$

This form is useful to produce explicit predictions for torsion-balance or free-fall experiments by inserting Φ_0 appropriate to the apparatus geometry.

Energy Accounting and Conservation Issues (Bookkeeping)

A physically consistent description must respect global conservation laws. In our ontological picture momentum and energy conservation are preserved globally because the SE substrate carries compensating fluxes between branches. For an external, low-energy effective theory one must ensure the following:

• **Local stress–energy budget:** The selector-induced modification of $\tilde{G}_{\mu\nu}$ can be represented in GR by an effective stress-energy tensor $T^{(\rm eff)}_{\mu\nu}$ that sources the metric perturbation,

$$G_{\mu\nu}[\tilde{G}] = \frac{8\pi G}{c^4}\left(T^{\rm matter}_{\mu\nu} + T^{(\rm eff)}_{\mu\nu}\right),$$

and $T^{(\rm eff)}_{\mu\nu}$ must obey the covariant conservation law $\nabla^\mu T^{(\rm eff)}_{\mu\nu} = 0$ in the effective geometry (alternatively, explicit non-conservation indicates exchange with the hidden SE sector).

• **Energy conditions:** If $T^{(\rm eff)}_{\mu\nu}$ violates standard energy conditions (e.g. NEC, WEC), the effective theory may display instabilities or allow exotic causal structures. Our approach avoids introducing negative local energy densities in the observable sector by assigning compensating balances to the SE branches — but this must be carefully documented when mapping to an effective $T^{(\rm eff)}$.

Post-Newtonian, Gravitational-Wave and other Observational Constraints

Any viable implementation must satisfy the large set of precision tests of gravity. Important constraints include:

(a) Speed of gravity and GW constraints. The near-simultaneous arrival of GW170817 and GRB170817A constrains the speed of gravitational waves c_g to be equal to the speed oflight c to high precision. Modified-metric prescriptions must therefore preserve $c_g = c$ in the regimes probed by LIGO/Virgo, or be suppressed at astrophysical wavelengths. In practice this places constraints on time-derivative and higher-derivative terms in any effective action that couples the selector degrees of freedom to the metric (see e.g. DHOST/Horndeski literature).

(b) Parameterized Post-Newtonian (PPN) bounds. Solar-system tests tightly constrain PPN parameters (e.g. $\gamma - 1$, $\beta - 1$). Any anisotropic contribution $\Delta_{\mu\nu}$ must fall below these bounds on solar-system scales, or be highly localized and short-ranged (controlled by ℓ and the spectral regulator Σ).

(c) WEP / MICROSCOPE bounds. The MICROSCOPE satellite sets $|\delta a/a| \lesssim 10^{-15}$ for composition-dependent accelerations. Using the mapping $\delta a/a \sim S\alpha v^2_0$, this gives an immediate upper limit on α for a given assumed v_0.

(d) Binary pulsar and GW energy-loss tests. Additional constraints come from timing of binary pulsars and orbital decay rates: any new degrees of freedom or effective stress-energy that allow excess energy loss are constrained.

Order-of-Magnitude Estimates and an Example Calculation

Using the simple mapping $\delta a/a \simeq S\alpha v^2_0$, choose $S = 1$ (optimistic coupling) and $v_0 = 10^{-3}$ (baseline used in Part II). Then:

$$v_0^2 = 10^{-6}, \qquad \alpha^{(\rm WEP)}_{\rm max} \lesssim \frac{10^{-15}}{v_0^2} = 10^{-9}.$$

This matches the illustrative estimate given in Part III. If one assumes more conservative coupling $S \sim 10^{-1}$, the allowed α grows by one order of magnitude. Conversely, if selector efficiency is poorer, experimental reach becomes significantly more challenging.

Rough energy/field strength estimate. If the selector-induced anisotropy can be modeled as a (small) contribution to the local metric comparable to an effective potential energy density ueff, dimensional analysis suggests

$$u_{\rm eff} \sim \varepsilon\, M_{\rm scale}^2 c^2,$$

where $M_{\rm scale}$ is the characteristic mass/energy scale controlling the coupling (it could be $M_{\rm Pl}$, or a smaller effective scale depending on the microscopic realization). If $M_{\rm scale} = M_{\rm Pl}$ then even tiny ε correspond to very large energy densities — implying that practically realizable selectors must operate through highly efficient, resonant or topologically-amplified couplings rather than brute-force energy injection.

Recommended Appendices and Supplementary Materials to Include

To make the paper self-contained and reproducible, the following appendices and supporting files should be prepared and archived with the submission:

1. Appendix A: Full symbolic derivation of kinetic blocks. Complete variation $\delta S_{\rm sel}$ → explicit analytic expressions for $A_h(k)$, $A_v(k)$, $C(k)$ in symbolic SymPy-ready form. Include assumptions and simplifications.

2. Appendix B: Linearized mapping to GR. Step-by-step derivation connecting $\Delta_{\mu\nu}$ to an effective $T^{(\rm eff)}_{\mu\nu}$, and demonstration that covariant conservation (or explicit SE exchange terms) is satisfied.

3. Appendix C: Numerical methods and convergence tests. Details of the lambdified functions, grid choices, convergence with k-resolution, and representative timing benchmarks.

4. Appendix D: Experimental protocols. Detailed torsion-balance / resonator experimental recipes, data-analysis pipelines, and suggested control experiments.

5. Supplementary data archive: CSV files with full min_lambda maps, alpha_max(p) curves for all tested combos, plotting scripts, and a compressed package of run metadata.

6. Code repository snapshot (optional): A single-file Python archive (`stability_pipeline_full.py`) with default parameter sets, plus a README explaining how to reproduce the figures and CSVs. If repository hosting is not desired, include the file in the submission ZIP.

Final Remarks on Presentation

When integrating the above calculations into the manuscript, we recommend:

• Keep the main text focused on the conceptual advance (vector steering of the gravito-inertial field) and experimental roadmap.

• Move the algebra-heavy derivations (Appendices A–C) into the SI or appendices so that the main narrative remains readable to a broad audience.

• Explicitly state all assumptions used to relate the model parameters (α, v_0, ℓ, p, κ, μ^2) to observables. Provide at least two worked numerical examples (optimistic and conservative) so readers can immediately appreciate the experimental scale required.

• Carefully document the interpretation of the SE bookkeeping: when mapping the ontological bookkeeping to an effective GR stress tensor, be transparent about the assumptions that permit apparent local non-conservation in the observable sector.

A. Appendix A: Full Symbolic Derivation of The Kinetic Blocks

This appendix provides the full symbolic derivation for the kinetic blocks used in the stability analysis. The presentation contains (1) the analytic expressions used in the paper for $A_h(k)$, $A_v(k)$ and $C(k)$, (2) the SymPy-ready code to reproduce them, and (3) comments on assumptions and minor simplifications used in the numerical implementation.

A.1. Analytic form used in the Pipeline

We use the following minimal symbolic ansatz (consistent with the text in Part II):

$$\begin{aligned} A_h(k) &= M_{\rm pl}^2\, k^2, \\ \Sigma(k;\ell,p) &= \frac{1}{(1+(\ell k)^2)^p}, \\ A_v(k) &= (k^2+\mu^2)\,\Sigma(k;\ell,p) + \kappa\, k^2, \\ C(k) &= \alpha\, v_0^2\, k^2\, \Sigma(k;\ell,p). \end{aligned}$$

These expressions are the ones used in the numerical code. They are the ‘toy/full’ kinetic blocks referenced in the main text and are designed to be straightforwardly replaced by more complicated symbolic outputs derived from the full variational principle when available.

A.2. SymPy-Ready Derivation and Lambdify Wrappe

Below is a fully working SymPy script (to be executed with Python 3.x and sympy/numpy installed) which (i) defines the symbolic expressions, (ii) simplifies them where appropriate and (iii) emits lambdified NumPy functions for fast evaluation in the pipeline.

Listing 1: SymPy script to define and lambdify kinetic blocks

```
# sympy_kinetic_blocks.py
import sympy as sp
# Define symbols
k, ell, p = sp.symbols('k ell p', positive=True, real=True)
Mpl, mu2, kappa = sp.symbols('Mpl mu2 kappa', positive=True, real=True)
alpha, v0 = sp.symbols('alpha v0', positive=True, real=True)

# Spectral regulator
Sigma = 1 / (1 + (ell*k)**2)**p

# Blocks
Ah_sym = Mpl**2 * k**2
Av_sym = (k**2 + mu2) * Sigma + kappa * k**2
C_sym = alpha * v0**2 * k**2 * Sigma

# Optional simplification (keeps expressions readable)
Ah_sym = sp.simplify(Ah_sym)
Av_sym = sp.simplify(Av_sym)
C_sym = sp.simplify(C_sym)

# Lambdify to numpy
import numpy as np
Ah_func = sp.lambdify((k, Mpl), Ah_sym, 'numpy')
Av_func = sp.lambdify((k, ell, p, mu2, kappa), Av_sym, 'numpy')
C_func  = sp.lambdify((k, ell, p, alpha, v0), C_sym, 'numpy')

# Example usage:
# k_grid = np.logspace(-6, 2, 1024)
# Ah_vals = Ah_func(k_grid, 1.0)
# Av_vals = Av_func(k_grid, 1.0, 1.0, 1e-6, 1e-2)
# C_vals  = C_func(k_grid, 1.0, 1.0, 1e-9, 1e-3)
```

A.3. Notes and Assumptions

- We assume all parameters are real and non-negative for the lambdified functions; SymPy symbol declarations above enforce `positive=True` where helpful.
- The spectral regulator Σ can be replaced by any physically motivated filter (e.g. exponential cutoff). If substituting a different functional form, keep the same arguments to the lambdified functions to ensure compatibility with the pipeline.
- When replacing the toy blocks with expressions derived from δS_{sel}, ensure that the final expressions are algebraically simplified and free from large common-factor cancellations (which can degrade numerical precision).

B Appendix B: Linearized Mapping to General Relativity and Effective Stress–Energy

This appendix derives an explicit mapping between a small anisotropic contribution $\Delta_{\mu\nu}$ (introduced by the selector) and an effective stress–energy tensor $T_{\mu\nu}^{(\text{eff})}$ that would reproduce the same metric perturbation within linearized General Relativity.

B.1. Linearized Einstein Equations and Definitions

Start from the linearized Einstein equation (harmonic gauge)

$$\Box \bar{h}_{\mu\nu} = -\frac{16\pi G}{c^4} T_{\mu\nu}, \qquad \bar{h}_{\mu\nu} \equiv h_{\mu\nu} - \tfrac{1}{2}\eta_{\mu\nu} h.$$

Introduce the effective metric

$$\tilde{G}_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} + \Delta_{\mu\nu}.$$

We interpret $\Delta_{\mu\nu}$ as being produced by an effective stress tensor $T^{(\mathrm{eff})}_{\mu\nu}$ and write

$$\Box\overline{\Delta}_{\mu\nu} = -\frac{16\pi G}{c^4}\, T^{(\mathrm{eff})}_{\mu\nu}, \quad \overline{\Delta}_{\mu\nu} \equiv \Delta_{\mu\nu} - \tfrac{1}{2}\eta_{\mu\nu}\Delta.$$

B.2. Example: Traceless Spatial Anisotropy

For the commonly used model

$$\Delta_{\mu\nu} = 2\varepsilon(\mathbf{x},t)\, n_\mu n_\nu, \qquad n^\mu = (0, \hat{n}^i),$$

we obtain (in Cartesian coordinates) a source satisfying

$$T^{(\mathrm{eff})}_{\mu\nu} = -\frac{c^4}{16\pi G}\, \Box\overline{\Delta}_{\mu\nu}.$$

Explicitly, for slowly-varying $\varepsilon(x, t)$ (quasi-static approximation),

$$T^{(\mathrm{eff})}_{00} \simeq -\frac{c^4}{16\pi G}\, \nabla^2 \left(\varepsilon\, (\hat{n}\cdot\hat{n})\right) \sim -\frac{c^4}{16\pi G}\, \nabla^2\varepsilon,$$

and similarly for spatial components

$$T^{(\mathrm{eff})}_{ij} \simeq -\frac{c^4}{16\pi G}\, \nabla^2\big(\varepsilon\, n_i n_j - \tfrac{1}{2}\delta_{ij}\varepsilon\big).$$

B.3 Conservation and Exchange with SE

Note that $\nabla^\mu T^{(\mathrm{eff})}_{\mu\nu} = 0$ is required field-wise for the matter sector to remain covariantly conserved in the effective geometry. If the selector implements an exchange between the observable branch and the SE-substrate, the observable-sector divergence may not vanish alone; instead we have

$$\nabla^\mu\big(T^{\mathrm{matter}}_{\mu\nu} + T^{(\mathrm{eff})}_{\mu\nu}\big) = 0,$$

with the net exchange balanced by currents flowing in SE degrees of freedom. The form of these currents depends on the microscopic model of the selector; we outline a phenomenological parametrization used for numerical tests in the main text:

$$\nabla^\mu T^{(\mathrm{eff})}_{\mu\nu} = J^{(\mathrm{SE})}_\nu(\varepsilon, \partial\varepsilon, \ldots),$$

with $J^{(\mathrm{SE})}_\nu$ small or localized for viable models.

B.4 Energy Conditions

If $T^{(\mathrm{eff})}_{\mu\nu}$ violates energy conditions (WEC/NEC) in the observable sector, local instabilities or exotic causal structures could appear. The ontological bookkeeping of SE allows apparent local violations to be compensated by SE branches; however, when making contact with experiment we restrict to effective $T^{(\mathrm{eff})}$ that do not imply macroscopic negative-energy densities in the lab or solar-system environment.

C. Appendix C: Numerical Methods, Code and Convergence Tests

This appendix contains the full single-file Python pipeline used to produce the stability maps and CSV outputs referenced in the manuscript. The file is self-contained (apart from standard dependencies: `numpy`, `scipy`, `matplotlib`, `sympy`) and is intended to be inserted into the submission PDF as a reproducible artifact. Running it locally will regenerate the figures and CSV outputs used in the paper.

Important: the code below is tuned for clarity and reproducibility. For very large grids use a high-performance machine and consider GPU-accelerated backends (CuPy/JAX) or compiled ufuncs.

Listing 2: stability_pipeline_full.py (single-file pipeline)

```
#!/usr/bin/env python3
# stability_pipeline_full.py
# Single-file stability pipeline: builds min_lambda maps, alpha_max curves,
# saves CSVs and PNGs. Requires numpy, scipy, matplotlib, sympy.

import os
import time
import json
import zipfile
from datetime import datetime
import numpy as np
import matplotlib.pyplot as plt
from matplotlib import ticker
import sympy as sp

# ---------------------------------------------------------
# Configuration (editable)
OUT_ROOT = "./stability_run"
DEFAULT_COMBOS = [
    {"name":"default", "v0":1e-3, "mu2":1e-6, "kappa":1e-2, "ell":1.0},
    {"name":"v0_larger", "v0":3e-3, "mu2":1e-6, "kappa":1e-2, "ell":1.0},
    {"name":"mu2_larger", "v0":1e-3, "mu2":1e-4, "kappa":1e-2, "ell":1.0},
]
DEFAULT_ALPHA_MIN = 1e-12
DEFAULT_ALPHA_MAX = 1e-2
DEFAULT_ALPHA_N = 160
DEFAULT_P_MIN = 0.6
DEFAULT_P_MAX = 2.5
DEFAULT_P_N = 160
DEFAULT_K_MIN = 1e-6
DEFAULT_K_MAX = 1e2
DEFAULT_K_N = 1024
WEP_LEVELS = [1e-13, 1e-14, 1e-15]

# ---------------------------------------------------------
# Prepare symbolic blocks with lambdify
def prepare_symbolic_blocks():
    k, ell, p = sp.symbols('k ell p', positive=True, real=True)
    Mpl, mu2, kappa = sp.symbols('Mpl mu2 kappa', positive=True, real=True)
    alpha, v0 = sp.symbols('alpha v0', positive=True, real=True)

    Sigma = 1 / (1 + (ell*k)**2)**p
    Ah_sym = Mpl**2 * k**2
    Av_sym = (k**2 + mu2) * Sigma + kappa * k**2
    C_sym = alpha * v0**2 * k**2 * Sigma

    Ah_func = sp.lambdify((k,Mpl), Ah_sym, "numpy")
    Av_func = sp.lambdify((k,ell,p,mu2,kappa), Av_sym, "numpy")
    C_func  = sp.lambdify((k,ell,p,alpha,v0), C_sym, "numpy")
```

```
    return {"Ah":Ah_func, "Av":Av_func, "C":C_func}

# ---------------------------------------------------------------
# Smallest eigenvalue for 2x2 symmetric block using closed form
def lambda_minus_from_blocks(Ah, Av, C):
    # Ah, Av, C are arrays (same shape)
    tr = Ah + Av
    diff = Ah - Av
    disc = 0.5 * np.sqrt(diff**2 + 4*C**2)
    lam_minus = 0.5 * tr - disc
    return lam_minus

# ---------------------------------------------------------------
# Compute min_lambda map for a single combo
def compute_min_lambda_map(combo,
                           alpha_min=DEFAULT_ALPHA_MIN, alpha_max=DEFAULT_ALPHA_
                           p_min=DEFAULT_P_MIN, p_max=DEFAULT_P_MAX, p_n=DEFAULT
                           k_min=DEFAULT_K_MIN, k_max=DEFAULT_K_MAX, k_n=DEFAULT_
    blocks = prepare_symbolic_blocks()
    Ah_func = blocks["Ah"]; Av_func = blocks["Av"]; C_func = blocks["C"]

    # Build grids
    alpha_list = np.logspace(np.log10(alpha_min), np.log10(alpha_max), alpha_n)
    p_list     = np.linspace(p_min, p_max, p_n)
    k_grid     = np.logspace(np.log10(k_min), np.log10(k_max), k_n)
    k2_grid    = k_grid**2

    min_lambda_map = np.full((p_n, alpha_n), np.nan)

    Mpl = 1.0
    v0  = combo["v0"]
    mu2 = combo["mu2"]
    kappa = combo["kappa"]
    ell = combo["ell"]

    for ip, p in enumerate(p_list):
        # Precompute Ah and Av for this p
        Ah_k = Ah_func(k_grid, Mpl)
        Av_k = Av_func(k_grid, ell, p, mu2, kappa)
        # reshape for broadcasting
        Ah_mat = Ah_k[None, :]      # shape (1, k_n)
        Av_mat = Av_k[None, :]
        k2_mat = k2_grid[None, :]

        alpha_vec = alpha_list[:, None]  # shape (alpha_n, 1)
        Sig_k = 1.0 / (1.0 + (ell * k_grid)**2)**p
        Sig_mat = Sig_k[None, :]

        # C_mat computed vectorized for all alpha and k
        C_mat = alpha_vec * (v0**2) * k2_mat * Sig_mat  # shape (alpha_n, k_n)
```

```
        # Broadcast Ah and Av across alpha
        Ah_m = np.broadcast_to(Ah_mat, C_mat.shape)
        Av_m = np.broadcast_to(Av_mat, C_mat.shape)

        lam_minus = lambda_minus_from_blocks(Ah_m, Av_m, C_mat)
        lammin_alpha = np.min(lam_minus, axis=1)  # min over k for each alpha

        min_lambda_map[ip, :] = lammin_alpha

    return {
        "alpha_list": alpha_list,
        "p_list": p_list,
        "k_grid": k_grid,
        "min_lambda_map": min_lambda_map
    }

# ——————————————————————————
# Utilities: save CSVs and plotting
def save_minmap_csv(outdir, combo_name, alpha_list, p_list, min_map):
    header = "p\\alpha," + ",".join(f"{a:.6e}" for a in alpha_list)
    rows = []
    for i,p in enumerate(p_list):
        row = ",".join([f"{min_map[i,j]:.6e}" for j in range(min_map.shape[1])])
        rows.append(f"{p:.6e}," + row)
    csv = header + "\n" + "\n".join(rows)
    fname = os.path.join(outdir, f"min_lambda_map_{combo_name}.csv")
    with open(fname, "w") as f:
        f.write(csv)
    return fname

def compute_alpha_max(alpha_list, p_list, min_map):
    # For each p (row) find largest alpha where min_lambda <= 0 (stable)
    alpha_max = np.full(len(p_list), np.nan)
    for i in range(len(p_list)):
        lam_row = min_map[i, :]
        # stable if lam_row <= 0 across all k (note convention)
        stable_idx = np.where(lam_row <= 0)[0]
        if stable_idx.size == 0:
            alpha_max[i] = np.nan
        else:
            alpha_max[i] = alpha_list[stable_idx[-1]]
    return alpha_max

def plot_exclusion_map(outdir, combo_name, alpha_list, p_list, min_map, alpha_ma
    fig, ax = plt.subplots(figsize=(8,5))
    X, Y = np.meshgrid(np.log10(alpha_list), p_list)
    unstable = (min_map > 0)  # True if unstable
    cmap = plt.get_cmap("Reds")
    pcm = ax.pcolormesh(X, Y, unstable.astype(float), cmap=cmap, shading='auto')
    ax.set_xlabel(r'$\log_{10}(\alpha)$'); ax.set_ylabel(r'$p$')
    ax.set_title(f"Exclusion␣map␣({combo_name})")
```

```
    if alpha_max_curve is not None:
        ax.plot(np.log10(alpha_max_curve), p_list, color='cyan', lw=2, label=r'$
    if wep_levels is not None and v0 is not None:
        for lvl, color in zip(wep_levels, ['white','yellow','cyan']):
            # approximate contour alpha corresponding to given delta_a/a ~ alpha
            alpha_level = lvl / (v0**2)
            ax.axvline(np.log10(alpha_level), color=color, ls='--', lw=1)
    ax.legend()
    out = os.path.join(outdir, f"exclusion_map_{combo_name}.png")
    plt.savefig(out, dpi=200, bbox_inches='tight')
    plt.close(fig)
    return out

# ---------------------------
# Main runner
def run_pipeline(out_root=OUT_ROOT, combos=DEFAULT_COMBOS):
    ts = datetime.utcnow().strftime("run_%Y%m%dT%H%M%SZ")
    outdir = os.path.join(out_root, ts)
    os.makedirs(outdir, exist_ok=True)
    meta = {"timestamp":ts, "combos":combos}
    with open(os.path.join(outdir, "meta.json"), "w") as f:
        json.dump(meta, f, indent=2)

    results = []
    for combo in combos:
        name = combo["name"]
        print("Computing combo:", name)
        r = compute_min_lambda_map(combo)
        csv_path = save_minmap_csv(outdir, name, r["alpha_list"], r["p_list"], r
        alpha_max = compute_alpha_max(r["alpha_list"], r["p_list"], r["min_lambda
        # save alpha_max
        alpha_csv = os.path.join(outdir, f"alpha_max_{name}.csv")
        np.savetxt(alpha_csv, np.vstack((r["p_list"], alpha_max)).T, header="p,a
        # plot
        png = plot_exclusion_map(outdir, name, r["alpha_list"], r["p_list"], r["
        results.append({"name":name, "csv":csv_path, "alpha_csv":alpha_csv, "png
    # package into zip
    zip_path = os.path.join(outdir, "stability_outputs.zip")
    with zipfile.ZipFile(zip_path, "w", compression=zipfile.ZIP_DEFLATED) as zf:
        for root, _, files in os.walk(outdir):
            for fn in files:
                if fn == os.path.basename(zip_path): continue
                zf.write(os.path.join(root, fn), arcname=fn)
    print("Run complete. Outputs:", outdir)
    return outdir

if __name__ == "__main__":
    run_pipeline()
```

C.1 Convergence Tests and Recommended Grid Choices

• **k-resolution:** Use $k_n \geq 1024$ for robust identification of narrow spectral instabilities near resonance; for exploratory scans, $k_n = 256$ can be acceptable.
• **alpha / p resolution:** The boundary $\alpha_{max}(p)$ can be steep in p for some combos. Use $\alpha_n \geq 128$, $p_n \geq 128$ as a default. Increase to ~ 256 where the boundary curvature is of interest.
• **Convergence test:** Compute maps with two different k-resolution and ensure $\alpha_{max}(p)$ variations are small (relative change < 1% for target accuracy).
• **Numerical stability:** For very small α or tiny Sigmas, monitor floating-point underflow; prefer `float64`.

D. Appendix D: Experimental Protocols, Apparatus Designs and Data-Analysis Recipes

This appendix provides practical experimental designs and data-analysis steps to test the controlled-inertia / vector-gravity predictions. Each protocol focuses on measuring anisotropic inertial or gravitational effects of the form $\delta a/a \sim \mathcal{S}\alpha v_0^2$.

D.1. Torsion-Balance Experiment (Table-Top)

Goal: Measure direction-dependent differential acceleration between two test masses of different composition or geometry.

Apparatus:
• High-Q torsion fiber, low drift (silica fiber preferred).
• Dumbbell test masses with different compositions (e.g. Al vs. Pt).
• Rotating platform to modulate orientation with respect to the selector axis ˆn.
• Vacuum chamber, thermal stabilization, magnetic shielding.
• Interferometric readout of torsion angle (sub-nrad sensitivity).

Procedure:
1. Calibrate torque sensitivity via known electrostatic torque.
2. Step the orientation of the dumbbell vs. laboratory frame (or continuously rotate) to search for periodic modulation at rotation frequency.
3. Perform long integration runs for several orientation cycles to build signal-to-noise.
4. Cross-check using swapped compositions and reversed orientation to eliminate systematic bias.

Expected signal: A tiny orientation-dependent torque $\boldsymbol{\tau} \sim I\,\delta a$, where I is the moment of inertia of the dumbbell. Using the mapping in Appendix A, $\delta a/a \simeq \mathcal{S}\alpha v_0^2$. For MICROSCOPElimited sensitivities ($\sim 10^{-15}$), table-top search requires extremely resonant amplification or active selectors.

D.2. Ring-Resonator / Rotor Demonstrator (Laboratory-Scale)

Goal: Build a small ring resonator (rotor with engineered metamaterial sectors) to produce a directed inertial gradient and detect a net center-of-mass displacement or anomalous torque.

Design elements:
• Ring structure (radius $R \sim$ 10-100 cm) with sectors whose material properties (permittivity/ permeability/structural resonance) can be dynamically tuned.
• External source for selector activation (RF, microwave or localised plasma / tokamak-style pulses). In early trials use low-power RF to look for tiny transients.
• Precision optical levitation / interferometric position sensing of the rotor center-of-mass.

Measurement recipe:
1. Characterize mechanical and electromagnetic transfer functions.
2. Drive selector pattern in different phasing patterns to produce directional signatures.
3. Record displacement and cross-correlate with drive-phase to extract coherent signals.

D.3. Data Analysis and Systematics Control

• Use lock-in style demodulation referenced to the drive frequency to extract weak coherent signals.
• Run control experiments with the drive off and with scrambled phasing.
• Carefully model thermal drifts, electrostatics, magnetic pickup and radiation pressure; include these as nuisance parameters in the fit.

• When reporting positive signals, insist on replication in an independent apparatus and cross-check with compositional swaps.

E Appendix E: Supplementary Data and Embedded CSV Examples

Below we provide representative small CSV examples which will also be generated by the pipeline. The full high-resolution CSVs (min_lambda maps, alpha_max curves, and run metadata) are produced by the `stability_pipeline_full.py` script and are intended to be included in the submission archive. Because the submission must be self-contained, include the essential CSVs (reduced resolution) inside the PDF as verbatim blocks or as tables.

E.1. Example: alpha_max (sample rows)

```
# p, alpha_max
0.600000, 1.23456e-08
0.612000, 1.21000e-08
0.624000, 1.18000e-08
...
2.500000, NaN
```

E.2 Example: min_lambda map header snippet

```
p\alpha,1.000000e-12,1.291550e-12,1.668101e-12,2.154435e-12,...
6.000000e-01,-1.234567e-05,-1.123456e-05,-9.876543e-06,...
6.120000e-01,-2.345678e-06,-1.987654e-06,-1.234567e-06,...
...
```

F. Appendix F: Checklist before submission

To ensure the submission is reproducible and publication-ready, include all of the following inside the submission ZIP (or embedded in the PDF as requested):

1. This manuscript PDF (with appendices).
2. stability_pipeline_full.py (single-file pipeline).
3. Reduced-resolution CSVs embedded in the PDF; full-resolution CSVs in the ZIP.
4. A README describing how to run the pipeline (Python env, dependencies).
5. Appendices A–D (this file) and the requested supplemental symbolic derivations (SymPy script).
6. Experimental apparatus CAD sketches, control software snippets and a data-analysis Jupyter notebook (recommended).

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