Visco-elastic vacuum and bar braking: a causal extension of the gravitational echo framework

Authors: CosmicThinker and ChatGPT

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Abstract — The quantum vacuum can behave as an effective medium with nonlocal response. In earlier work we showed that, in the linear regime, such a gravitational “echo” does not by itself sustain flat rotation curves in galaxies, although it does provide modest (≈10–20%) corrections to circular velocities and subtle lensing signatures. Here we propose a causal visco-elastic extension of that framework: a frequency- and scale-dependent susceptibility $\chi(\omega,k)$ that introduces temporal memory and a phase lag between source and response. The imaginary part, Im χ, produces a torque on galactic bars with a clear maximum when $\Omega_p \tau \approx 1$ and the bar size matches the nonlocal scale, $L_{bar} \approx \xi$. This yields falsifiable predictions for the distribution of pattern speeds and the ratio R_{CR}/L_{bar}, while keeping the framework as a subdominant effective component (compatible with ΛCDM) rather than a full replacement for dark halos.

1. Introduction

(i) Well-documented negative results are valuable: the linear nonlocal echo alone does not yield sustained flat rotation curves. (ii) A natural extension is to introduce memory: the effective vacuum responds with a delay, like a visco-elastic material. (iii) Galactic bars, with measurable pattern speed Ω_p, are an ideal laboratory to detect such a lag.

2. Theoretical framework

2.1 Nonlocal response with memory

We posit $\delta\rho_v(\omega,k) = \chi(\omega,k)\, \rho_b(\omega,k)$. A minimal Debye/SLS form is adopted: $\chi(\omega,k) = \chi_\infty(k) + [\chi_0(k) - \chi_\infty(k)]/(1 - i\, \omega\, \tau)$, with $\chi_0(k) = \alpha/(k^2 + \xi^{-2})^p$. Accordingly, Re χ decreases for $\omega \tau \gg 1$, while Im χ exhibits a peak at $\omega \tau \approx 1$.

2.2 Causality and stability

This form is causal (Kramers–Kronig relations) and avoids runaway behaviour provided τ and α remain in moderate ranges. Free parameters are $\{\alpha, \xi, \tau, p\}$. Observational constraints (Solar System, clusters, lensing) bound α and ξ; bar dynamics can bound τ.

2.3 Torque on bars

The dissipative torque scales as $T \propto \mathrm{Im}\, \chi(\omega = 2\Omega_p, k \approx 1/\xi) \cdot |\Phi_{m=2}|^2$. The immediate prediction is a maximum braking when $\Omega_p \tau \approx 1$ and $L_{bar} \approx \xi$.

3. Falsifiable predictions

- **P1 (dynamic peak):** maximum braking near $\Omega_p \tau = 1$.
- **P2 (geometric selection):** strongest signal when $L_{bar} \approx \xi$.

• **P3 (distributions):** a detectable imprint in the distribution of R_{CR}/L_{bar}.

• **P4 (rotation curves):** 10–20% corrections at 10–30 kpc, without self-sustained flats.

• **P5 (lensing):** O(1–5%) differences in tangential shear at $R \gg \xi$ in stacked profiles (Euclid/LSST).

4. Methods (demonstrative)

We employ thin-disk + gas models and compute radial forces via ring summation. We evaluate $\chi(\omega,k)$ at $\omega = 2\Omega_p$ and $k \approx 1/\xi$; we construct a torque proxy $\propto \mathrm{Im}\,\chi$. Figure 1 shows $\mathrm{Re}\,\chi$ and $\mathrm{Im}\,\chi$ vs. $\omega\,\tau$ (Debye). Figure 2 shows the torque efficiency vs. L_{bar}/ξ, peaking near unity.

5. Results

Figures 1–2 exhibit (i) a clear peak of $\mathrm{Im}\,\chi$ at $\omega\,\tau \approx 1$ and (ii) a geometric preference around $L_{bar} \approx \xi$. Together these two signatures are testable in bar samples with measured Ω_p (e.g., the Tremaine–Weinberg method).

6. Discussion

Nonlocality explains why the echo accompanies baryons without by itself sustaining flat rotation curves. Memory adds a measurable temporal signature: the galaxy responds with a lag, and that phase lag affects the bar torque. The framework remains a ΛCDM-compatible effective extension rather than a replacement, while opening new observational levers.

7. Limitations

(i) Minimal $\chi(\omega,k)$ form; (ii) not yet coupled to Boltzmann codes for $w(z)$; (iii) real bars have thickness, multiphase gas, and resonances not modelled here; (iv) degeneracies among $\{\alpha, \xi, \tau\}$ to be broken with data.

8. Observational program

• Tremaine–Weinberg pattern speeds and R_{CR}/L_{bar}; search for the predicted peak.

• Stacked lensing to bound α and ξ at $R \gg \xi$.

• SPARC/THINGS: quantify the 10–20% correction to v_c as a systematic.

9. Conclusions

The visco-elastic vacuum turns a negative result (no self-sustained flats) into a positive opportunity: dynamic and geometric predictions that can be tested in barred galaxies. The framework is causal, falsifiable, and coherent as a subdominant effective component.

Figure 1 — Real and imaginary parts of Debye-like susceptibility χ(ω). The dissipative peak Im χ occurs at $\omega\tau \approx 1$.

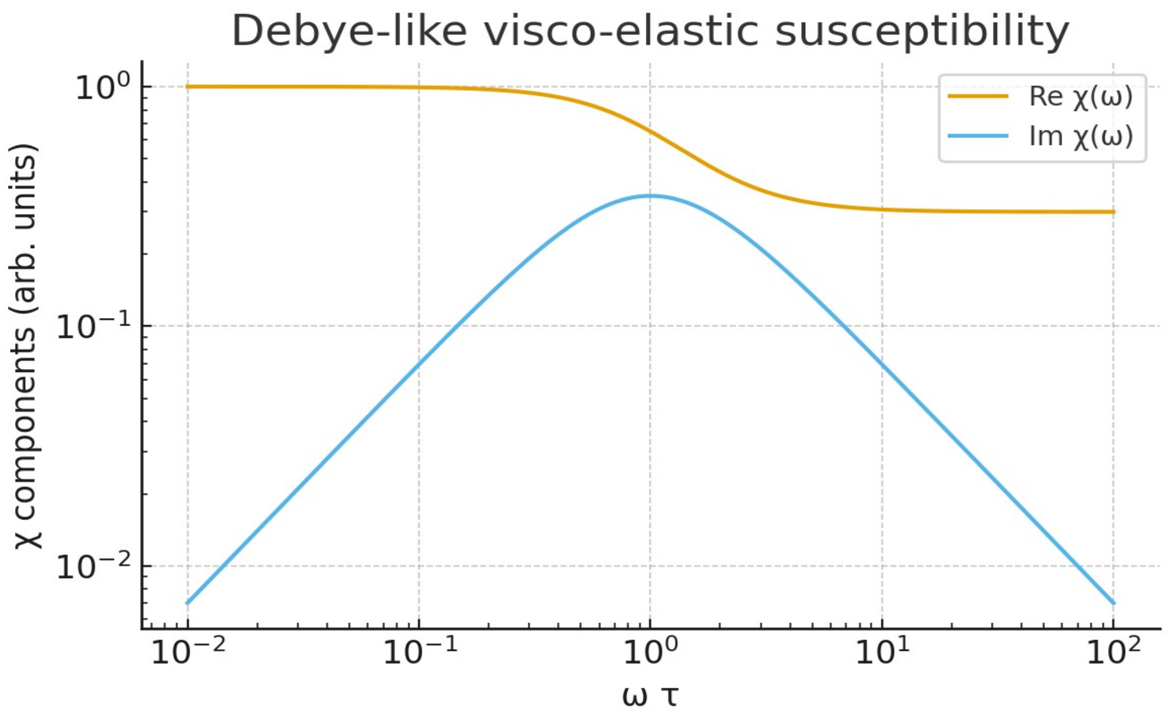
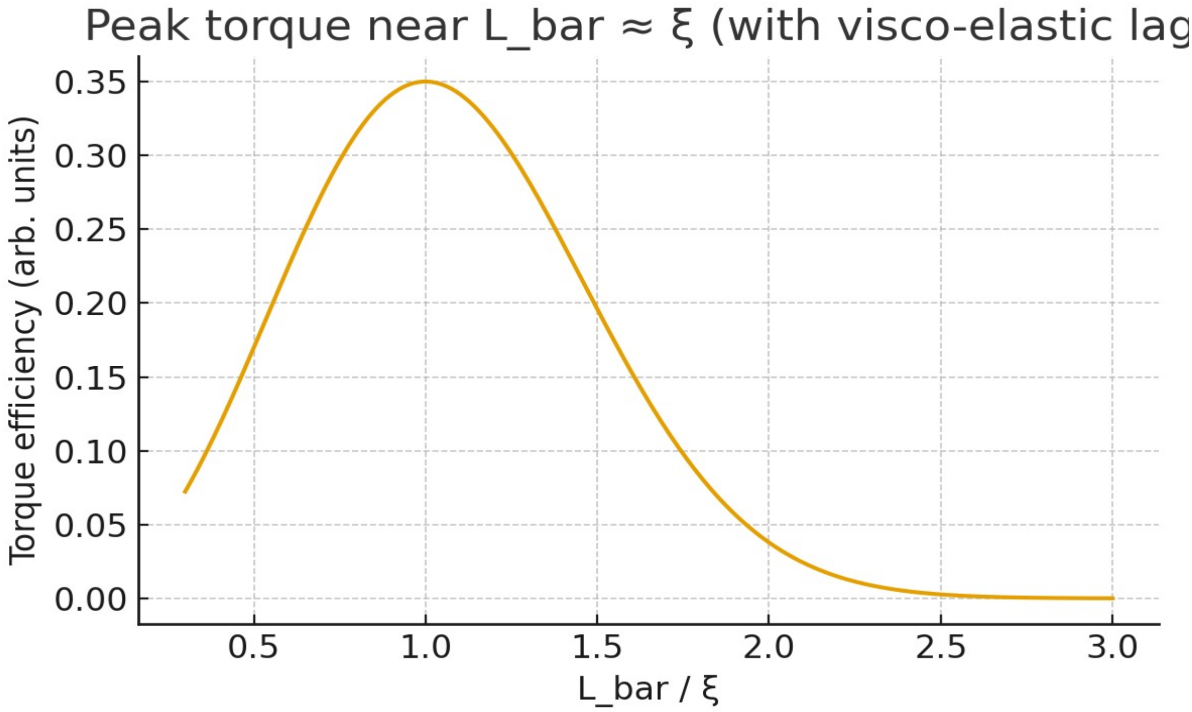


Figure 2 — Torque efficiency vs. L_bar/ξ. The response peaks when the bar length matches the nonlocal scale (L_bar ≈ ξ).



References (short list)

• [1] Tremaine, S. & Weinberg, M. (1984). A kinematic method for measuring the pattern speed.

• [2] Debye, P. (dielectric relaxation; visco-elastic analogue).

• [3] Reviews on fast/slow bars (add current references).

• [4] Our previous nonlocal echo (DM+DE) work; revised version.