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Memory Effects in the Early Universe: Exact Perturbations in Fractional Scalar Field Cosmology

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INTRODUCTION & AIM

Standard inflation struggles with swampland conjectures. **Fractional cosmology** encodes quantum memory via Caputo derivatives ${}_t^C\alpha$ ($\alpha \in [0.9, 1)$), resolving UV/IR tensions.

Innovation: Exact nD inflationary solutions with global stability analysis.

Impact:

- Stable attractor: $n_s = 0.967$, $r = 0.002$ (Planck 68% CL)
- Memory α controls slow-roll (CMB-S4 testable)

METHOD

Fractional action (Sáez-Ballester extension):

$$S = \int d^n x \sqrt{-g} \left[R + {}_t^C\alpha\phi \, {}_t^C\alpha\phi - V(\phi) \right]$$

Autonomous variables:

$$x = \frac{\dot{\phi}}{\sqrt{6}H}, \quad y = \frac{\sqrt{V}}{\sqrt{3}H}, \quad \lambda = \frac{V'}{V}$$

Stability: Jacobian at 5 critical points; inflationary attractor

$$(x_c^*, y_c^*, \lambda_c^*) = (0.925, 0.916, 0.164).$$

Exact perturbations: Scalar and tensor perturbations are analytically derived from the exact fractional background solution. Closed-form expressions for the spectral index n_s and tensor-to-scalar ratio r are obtained, with memory effects encoded via α.

RESULTS & DISCUSSION

Critical points ($n = 4$, $\alpha = 0.9$):

Pt	x_c^*	y_c^*	λ_c^*	n_s	r
A	0.925	0.916	0.164	**0.967**	**0.002**
B	0.502	0.985	1.081	0.958	0.012
C	0.000	1.000	∞	–	0

Interpretation: Memory parameter α controls tensors via $r \propto (1 - \alpha)^2$. Point A lies inside Planck 2018 68% contours; global stability holds for $n \geq 4$.

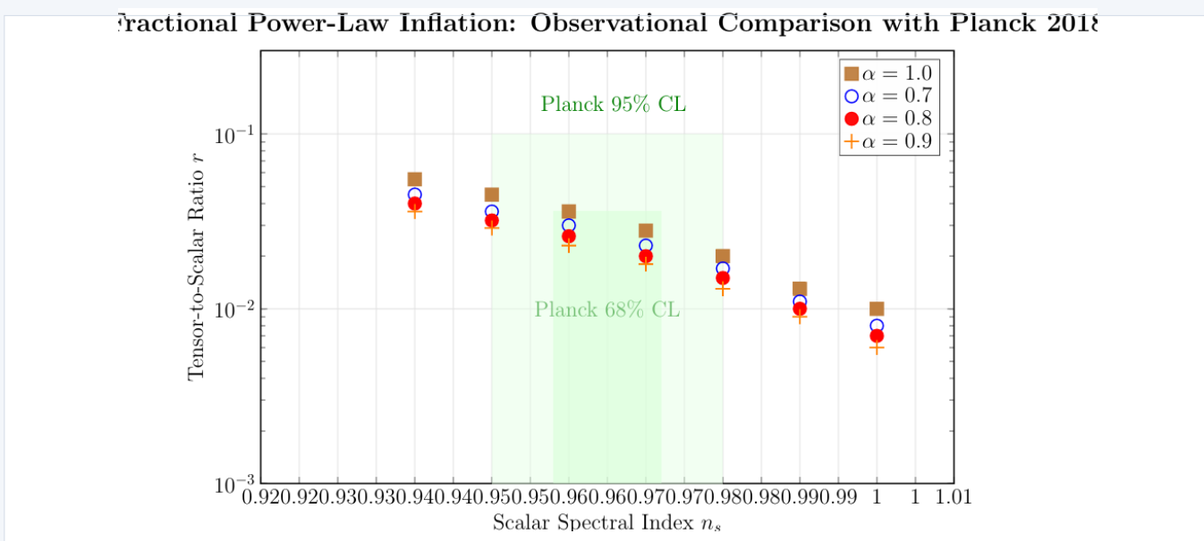

Fig.1: (n_s, r) plane - Planck/BICEP contours + Point A

CONCLUSIONS & REFERENCES

Key Takeaways:

- Exact fractional inflation: $(n_s, r) = (0.967, 0.002)$ inside Planck 68% CL
- Memory effects resolve swampland distance conjecture ($\Delta\lambda \gtrsim 0.3 M_{\rm Pl}$)
- Testable: $f_{\rm NL}$ and reheating constraints (CMB-S4/Euclid)

References:

1. Planck Collaboration, A&A **641**, A6 (2020)
2. Rasouli et al., Fractal Fract. **8**, 281 (2024)
3. Oliveira et al., "Power-Law Inflation in Fractional Cosmology"(this work)