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Inflation from Fermion Condensation: Dynamics and Observational Signatures

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Inflation is conventionally described in terms of fundamental scalar fields whose microscopic origin remains unknown. We propose [1,2] a fundamentally different mechanism in which inflation emerges from fermion condensates generated by torsion-induced four-fermion interactions in Einstein–Cartan–Holst gravity. Starting from a purely fermionic theory, we derive a two-condensate effective description whose inflationary dynamics resembles hybrid inflation but exhibits a qualitatively new exit mechanism. The central result is the emergence of a density-driven waterfall transition. During inflation, axial charge production continuously increases the fermion density and the associated chiral chemical potential. Solving the finite-density gap equation, we show that above a critical axial density the condensate no longer admits a symmetry-broken solution. Inflation therefore terminates through the evaporation of the condensate itself rather than through the inflaton crossing a critical field value. This mechanism naturally triggers rapid energy transfer to fermionic degrees of freedom and provides a microscopic realization of instant preheating. The post-transition condensate is unstable to fragmentation into charged non-topological solitons. These objects can subsequently collapse into primordial black holes, generating a calculable relic population whose properties are determined by the same condensate dynamics that drives inflation [3]. Because the underlying theory is intrinsically chiral and connected to dynamical Chern–Simons gravity, the scenario simultaneously predicts parity-violating signatures [4]. The framework unifies inflation, reheating, soliton formation, primordial-black-hole production, and parity-violating phenomenology within a single gravitationally induced fermion-condensation mechanism. It provides a composite alternative to scalar-field inflation and identifies correlated observational signatures that can test the role of spacetime torsion in the early Universe.

References [1] S. Alexander, P. Chen, J. Liu, A. Marciano, M. Sasaki and X. L. Su, Hybrid inflation from fermion condensation, *Phys. Lett. B* 873 (2026), 140193 doi:10.1016/j.physletb.2026.140193 arXiv:2509.25290 [gr-qc] [2] S. Alexander, P. Chen, J. Liu, A. Marciano, M. Sasaki and X. L. Su, Fermion Condensate Inflation, Dynamical Waterfall Mechanism and Primordial Black Holes, arXiv:2604.21535 [hep-th]. [[3] E. Cotner, A. Kusenko, M. Sasaki and V. Takhistov, Analytic Description of Primordial Black Hole Formation from Scalar Field Fragmentation, *JCAP* 10 (2019), 077 doi:10.1088/1475-7516/2019/10/077 arXiv:1907.10613 [astro-ph.CO]. [4] J. Liu, S. Alexander and A. Marciano, Birefringence in fermion-attenuated gravitational wave power spectrum, *Phys. Lett. B* 866 (2025), 139499 doi:10.1016/j.physletb.2025.139499 arXiv:2501.08240 [gr-qc].

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