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Gravitational Dynamics from the Most General Entropy-Area Relation

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The connection between gravity and thermodynamics provides a profound perspective on the nature of spacetime dynamics. Jacobson famously demonstrated that the Einstein field equations can be derived by assuming the Bekenstein–Hawking relation, in which the entropy is proportional to the area of local Rindler horizons, within the framework of equilibrium thermodynamics. However, when this entropy–area relation is modified, non-equilibrium thermodynamic contributions become essential. For instance, when spacetime curvature explicitly enters this relation, the resulting field equations reduce to the $f(R)$ class of modified gravity. In this work, we address the question: \emph{what are the gravitational field equations arising from the most general entropy–area relation?} Employing non-equilibrium thermodynamic formalism, we derive the corresponding field equations for an arbitrary functional dependence $S = \alpha f(A)$. As a concrete application, we examine the case of Tsallis entropy, characterized by the non-additivity parameter δ. We show that the resulting cosmological equations—comprising the two Friedmann-like equations and a new non-equilibrium constraint—constitute an overdetermined system for any value $\delta \neq 1$. The only mathematically self-consistent solution corresponds to $\delta \equiv 1$, which exactly recovers the standard ΛCDM model. Our results thus demonstrate that, contrary to previous claims based on incomplete equilibrium approaches, Tsallis cosmology does not provide a dynamically consistent alternative to standard cosmology when non-equilibrium effects are properly taken into account.

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