Contribution ID: **37** Type: **not specified**

From Entropy to Geometry

Friday 14 November 2025 15:45 (25 minutes)

The profound connection between gravity and thermodynamics has been firmly established since Jacobson's seminal result, where the Einstein field equations were derived from the Bekenstein–Hawking entropy–area relation under the assumption of local thermodynamic equilibrium on local Rindler horizons. Deviations from this entropy law necessarily induce non-equilibrium corrections, as illustrated by the thermodynamic interpretation of modified gravity f(R) theories.

Motivated by theoretical arguments that the entropy–area relation may admit fundamental generalizations, particularly within non-extensive entropy formalisms, a central question naturally arises: what gravitational dynamics follow from the most general entropy prescription? To address this, we consider an entropy density of the form s = f(a), with no restriction on its dependence on the local horizon area density a. We show that such generalized laws inevitably require a non-equilibrium thermodynamic treatment in order to preserve the covariant conservation of the energy–momentum tensor. Our framework thus provides a systematic method to derive consistent gravitational field equations directly from generalized entropy principles, independently of any underlying Lagrangian formulation.

Previous extensions of the thermodynamics-gravity paradigm, often implemented within the Cai–Kim formalism for homogeneous and isotropic spacetimes, have either neglected the unavoidable non-equilibrium contributions associated with generalized entropies, or absorbed them into an effective energy–momentum tensor. While the latter prescription is viable when the modified gravity action is explicitly known, it is not generally applicable—for instance, in the case of Tsallis entropy, for which no Lagrangian description exists. In contrast, our framework establishes the precise and universal conditions under which consistent field equations emerge from a generalized entropy principle. This constitutes one of the most general non-equilibrium extensions of the thermodynamic derivation of gravity, providing a robust theoretical basis to investigate the gravitational implications of non-extensive entropies.

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