Contribution ID: **37** Type: **Short Talk**

# Promoting Fluctuation Theorems into Covariant Forms

*Friday, 12 December 2025 14:20 (20 minutes)*

The principle of covariance, a cornerstone of modern physics, asserts the equivalence of all inertial frames of reference. Fluctuation theorems, as extensions of the second law of thermodynamics, establish universal connections between irreversibility and fluctuation in terms of stochastic thermodynamic quantities. However, these relations typically assume that both the thermodynamic system and the heat bath are at rest with respect to the observer, thereby failing to satisfy the principle of covariance. In this Letter, by introducing covariant work and heat that incorporate both energy-related and momentum-related components, we promote fluctuation theorems into covariant forms applicable to moving thermodynamic systems and moving heat baths. We illustrate this framework with two examples: the work statistics of a relativistic stochastic field and the heat statistics of a relativistic Brownian motion. Although our Letter is carried out in the context of special relativity, the results can be extended to the nonrelativistic limit. Our Letter combines the principle of covariance and fluctuation theorems into a coherent framework and may have applications in the study of thermodynamics relevant to cosmic microwave background as well as the radiative heat transfer and noncontact friction between relatively moving bodies.
Phys. Rev. Lett. 134, 237102 (2025)

**Presenter:** PEI, Jihui (Peking University)

**Session Classification:** Friday