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## Thermodynamical Interpretation of Geometrical Variables Associated with Null Surfaces

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The emergent gravity paradigm interprets gravitational field equations as describing the thermodynamic limit of the underlying statistical mechanics of microscopic degrees of freedom of the spacetime. The connection is established by attributing a heat density Ts to the null surfaces where T is the appropriate Davies-Unruh temperature and s is the entropy density. The field equations can be obtained from a thermodynamic variational principle which extremises the total heat density of all null surfaces. The explicit form of s determines the nature of the theory. We explore the consequences of this paradigm for an arbitrary null surface and highlight the thermodynamic significance of various geometrical quantities. In particular, we show that: (a) A conserved current, associated with the time development vector in a natural fashion, has direct thermodynamic interpretation in all Lanczos-Lovelock models of gravity. (b) One can generalize the notion of gravitational momentum,

introduced in arXiv 1506.03814 to all Lanczos-Lovelock models of gravity such that the conservation of the total momentum leads to the relevant field equations. (c) The thermodynamic variational principle which leads to the field equations of gravity can also be expressed in terms of the gravitational momentum in all Lanczos-Lovelock models. (d) Three different projections of gravitational momentum related to an arbitrary null surface in the spacetime lead to three different equations, all of which have thermodynamic interpretation. The first one reduces to a Navier-Stokes equation for the transverse drift velocity. The second can be written as a thermodynamic identity TdS = dE + PdV. The third describes the time evolution of the null surface in terms of suitably defined surface and bulk degrees of freedom. The implications are discussed.

## Summary

The key conclusions are summarized as:

1) There is considerable amount of evidence to suggest that gravitational field equations have the same status as, say, the equations of fluid mechanics. They describe the macroscopic, thermodynamic, limit of an underlying statistical mechanics of the microscopic degrees of freedom of the spacetime. The macro and micro descriptions are connected through the heat density Ts of the spacetime. Here, the temperature T arises from the interpretation of the null surfaces as local Rindler horizons. The entropy density is a phenomenological input, the form of which determines the theory.

2) Given this structure, one can attribute thermodynamic meaning to several physical quantities which usually considered to be geometrical. For example, one can associate a natural conserved current with the time-development vector of the spacetime and the corresponding conserved charge (defined either on a spacelike surface or on a null surface) can be related to the boundary heat density.

3) One can also define the notion of gravitational momentum  $P^a$  for all the Lanczos-Lovelock models of gravity such that  $\nabla_a(P^a + M^a) = 0$  (where  $M^a$  is the momentum density of matter) for all observers, leads to the field equation of the Lanczos-Lovelock model. This generalizes a previous result for general relativity.

4) The field equations can also be derived from a thermodynamic variational principle, which essentially extremises the total heat density of all the null surfaces in the spacetime. This variational principle can be expressed directly in terms of the total gravitational momentum, thereby providing it with a simple physical interpretation.

5) One can associate with any null surface the two null vector fields  $\ell_a, k_a$  with  $\ell_a k^a = -1$  and  $\ell_a$  being the tangent vector to the congruence defining the null surface, as well as the 2-metric  $q_{ab} = g_{ab} + \ell_a k_b + \ell_b k_a$ . These structures define three natural projections of the gravitational momentum  $(P^a \ell_a, P^a k_a, P^a q_{ab})$ , all of which have thermodynamic significance. The first one leads to the description of time evolution of the null surface in terms of suitably defined bulk and surface degrees of freedom; the second leads to a thermodynamic identity which can be written in the form TdS = dE + PdV; the third leads to a Navier-Stokes equation for the transverse degrees of freedom on the null surface which can be interpreted as a drift velocity.

These results again demonstrate that the emergent gravity paradigm enriches our understanding of the spacetime dynamics and the structure of null surfaces, by allowing a rich variety of thermodynamic backdrops for the geometrical variables.

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