

Gravity, Null Surfaces and Thermodynamics

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In this talk I will explore the consequences of the gravity-thermodynamics connection for an arbitrary null surface and highlight the thermodynamic significance of various geometrical quantities. In particular, I will demonstrate the following results:

- Given a Vector field v^a , one can construct three currents: (a) the Noether current $J^a(v)$, (b) the gravitational momentum $P^a(v)$ and (c) the reduced gravitational momentum $\mathcal{P}^a(v)$. Interestingly enough, one can attribute *thermodynamic* meaning to these quantities which are usually considered to be *geometrical*. For example, the conserved current J^a , associated with the time-development vector ξ^a of the spacetime, leads to a conserved charge (i.e., integral of $u_a J^a(\xi)$ defined either on a spacelike surface or on a null surface) that can be related to the boundary heat density Ts , where T is the Unruh-Davies temperature and s stands for entropy density [? ? ? ? ?].
- The notion of gravitational momentum P^a can be generalized 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.
- 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.
- One can associate with any null surface the two null vector fields ℓ_a, k_a with $\ell_a k^a = -1$ and ℓ_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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