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Research Papers

CONTRIBUTION OF THE VARIOUS THERMODYNAMICAL PARAMETERS IN THE STUDY OF BLACK HOLE THERMODYNAMICS

Ranjan Prasad
Research Scholar, Dept. of Physics, B.N. Mandal University, Madhepura, Bihar
&
Dr. Umashanker Choudhary
Associate Professor and Head Nirmail College Nirmali, Supaul, Bihar

ABSTRACT

This paper presents the black hole discovery in the early 1970s,which radiate as black bodies has radically affected our understanding of general relativity. The basis was of horizon thermodynamics as research the thermodynamic stability of black holes constructed in very general relativity way and Gauss–Bonnet gravity. For black hole in Gauss-Bonnet gravity negative pressure can be feasible, but only local stable black hole exists in this case. In non–vacuum cases, the research can derive the equation of state, P=P (V,T). After that in the framework of horizon thermodynamics there was only five thermodynamic variables E, P, V, T, S. It is not necessary to consider concrete matter fields, which may contribute to the pressure of black hole thermodynamic system. It has shown that P>0 is the necessary P>0 condition for black holes in very general relativity to be thermodynamically stable, in this condition research cannot be satisfied by many black holes in general relativity. All the research to the requirements of stable equilibrium in conventional thermodynamics, the research starts from these thermodynamic variables to calculate the heat capacity at constant pressure and Gibbs free energy and analyze the local and global thermodynamic stability of black holes.

KEY-WORDS: Black hole, Thermodynamics, Black bodies & Quantum gravity.

INTRODUCTION

It is appropriate to start a review of black hole thermodynamics with the above quotation by S. Chandrasekhar. The quote brings out the fundamental characteristics of a black hole: The Universality. The properties of a black hole are independent of the details of the collapsing matter, and this universality is ultimately related to the fact that black holes could be the thermodynamic limit of underlying quantum gravitational degrees of freedom.[1]

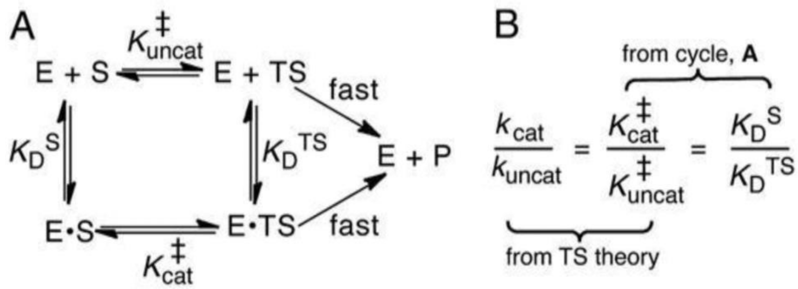

Fig.-1

Therefore, the classical and semi–classical properties of black holes are expected to provide important clues about the nature of quantum gravity. A significant obstacle in constructing a theory of quantum gravity is the absence of any experimental or observational result. The only "test" we can imagine is the theoretical and mathematical consistency of the approach. The understanding of the fundamental laws of black hole mechanics could be a necessary constraint on the theory of quantum gravity. The modern understanding of the properties of black hole starts with the resolution of the "Schwarzschild Singularity" using Kruskal-Szekeres coordinates. These coordinates cover that entire spacetime manifold of the maximally extended vacuum spherically symmetric solution of the Einstein's field equation and are well–behaved everywhere outside the physical singularity at the origin, in particular at the position $r = 2M$. The next important step is the discovery of the rotating asymptotically flat vacuum black hole solution by Roy Kerr. The solution exhibited various interesting and generic properties of a stationary black hole in general relativity. The existence of Ergosphere and Superradiance show how to extract energy and angular momentum from the black hole.[2] The study of these phenomena leads to a significant result; the area of the black hole can never be decreased using these processes. For example, using the Penrose process, it is possible to extract energy from the black hole, and as a result, the mass of the black hole decreases. At the same time, the process slowed down the rotation, and the net effect only increases the area.

The Various Versions of the First Law

The first law of black hole mechanics has several avatars, and we need to distinguish the different formulations of the first law. In ordinary thermo dynamics, the first law is the statement of the conservation of energy. The total energy can not be destroyed or created, but can always be converted into another form of energy. The statement is mathematically described by the difference equation $\Delta U = Q - W$. The change of the internal energy U of the system is equal to the difference of the heat supplied Q, and the work done W by the system. The conservation of energy is built-in into the dynamics of general relativity. So, what we mean by the first law is the Clausius theorem [3]which involves the notion of the entropy. Consider a system under quasi- static change which is subjected to an infinitesimal amount of heat $\bar{d}Q$ from the surrounding. The heat change is an inexact differential, and therefore the total heat Q is not a state function. It is then assured that there exists a state function called the "entropy" S such that the temperature of the system acts as an integrating factor relating the change in entropy to the heat supplied as $T\, ds = \bar{d}Q$. The Clausius theorem ensures the existence of the state function entropy associated with a thermodynamic equilibrium state of the system..

First Law and Ambiguities of Physical Process in Black Hole Entropy

The entropy of a stationary black hole with a regular bifurcation surface in an arbitrary diffeomorphism invariant theory of gravity is given by Wald's formula as,

$$S_W = -2\pi \int_B \frac{\partial L}{\partial R_{abcd}} \in_{ab} \in cd \sqrt{h} d^{D-2}x = \frac{1}{4}\int_B (1+\rho)_\omega \sqrt{h} D^{D-2}x$$

Where $\cup^{ab} = k_a l_b - k_y l_a$ is the bi-normal of the bifurcation surface and ρ_w represents the contribution from higher curvature terms. As discussed in, the ambiguities in the Noether charge construction doesn't affect the Wald entropy in case of a stationary black hole. However, if the horizon is involved in a dynamical process, i.e., for no stationary black holes, the Wald entropy formula no longer holds and turns out to be ambiguous up to the addition of terms of the form,

$$\Delta S_W = \int \Omega dA,$$

Where $\Omega = (p^{\theta}k^{\theta}l + q^{\sigma}k^{\sigma}l)$ and $\sigma_k\ \sigma_l = \sigma k\ ab^{\sigma ab}\ 1$. Note that, a term in Ω contains an equal number of k and 1 indices and hence combine to produce a boost invariant object, although they individually transform non-trivially under boost. The coefficients p and q are entirely arbitrary and can not be determined from the equilibrium state version of the first law.

Classical Black Hole Thermodynamics

From the forgoing it is apparent that energy can flow not just into black holes but also out of them, and they can act as an intermediary in energy exchange processes. Energy extraction is maximally efficient when the horizon area does not change, and processes that increase the area are irreversible, since the area cannot decrease. The analogy with thermodynamic behavior is striking, with the horizon area playing the role of entropy.

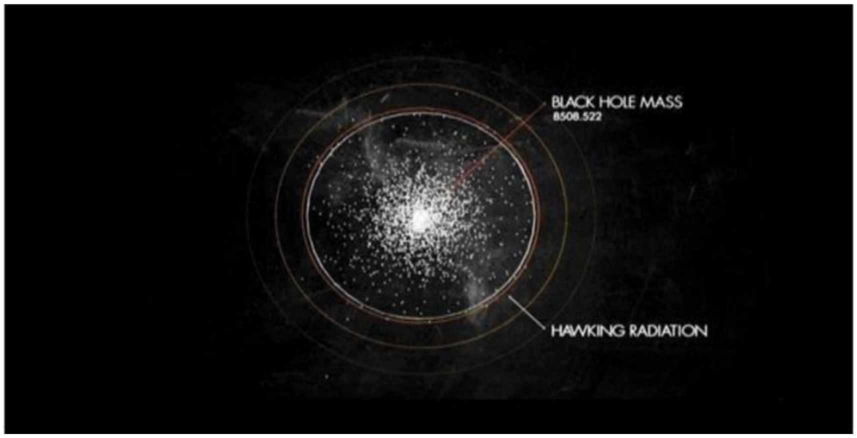

Fig.-2

This analogy was vigorously pursued as soon as it was recognized at the beginning of the 1970's, although it had what appeared at first to be several glaring flaws:

F1, the temperature of a black hole vanishes;
F2, entropy is dimensionless, whereas horizon area is a length squared;
F3 the area of every black hole is separately non-decreasing, whereas only the total entropyis nondecreasing in thermodynamics.

By 1975[4] it was understood that the resolution to all of these flaws lies in the incorporation of quantum theory, as has so often been the case in resolving thermodynamic conundrums. A black hole has a Hawking temperature proportional to Planck's constant $\hbar$, the entropy is one fourth the horizon area divided by the Planck length squared ($\hbar G/c^3$), and the area can decrease via Hawking radiation. [5-8]Rather than jumping now immediately into the subject of quantum black hole thermodynamics, it is worth discussing first the classical aspects of the theory.

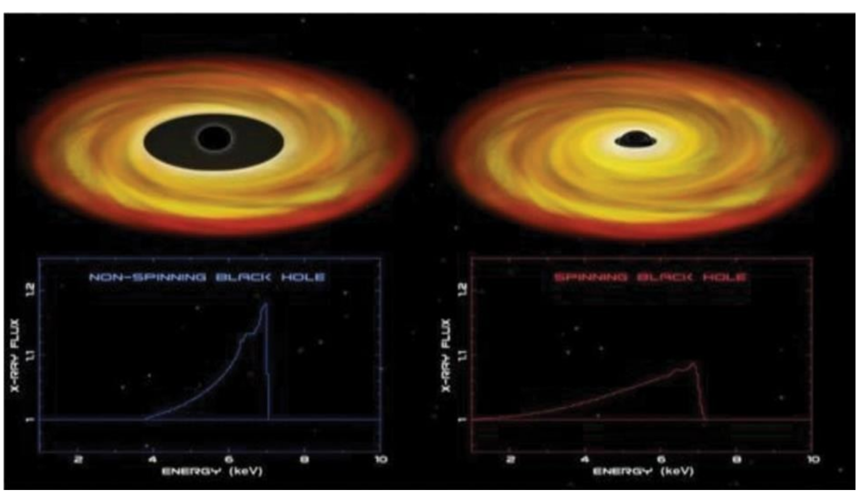

Fig-3

These are important in their own right, and they form the foundation for quantum black hole thermodynamics. But also it is intriguing to see what can be inferred without invoking quantum theory, and it may teach us something about the deeper origins of gravitation. In proceeding this way we are following more or less the path that was taken historically.

CONCLUSIONS:

This paper focuses on Black hole thermodynamics which provides a powerful constraint on any proposal to understand the quantum gravitational origin of black hole entropy. The area law has motivated significant progress in theoretical physics, most importantly the holographic principle. Similarly, the pioneering work by Jacobson where he considered the concept of local Rindler horizons and showed that Einstein field equations could be derived from thermodynamic considerations hints a deep thermodynamic origin of the full dynamics of gravity. Similar results are proven in a more general context by Padmanabhan and collaborators. They have shown that the field equation of any higher curvature gravity theory admits an intriguing thermodynamic interpretation. Interestingly, the result is also valid beyond black hole horizons and for any null surface in space–time. These fascinating results lead an alternative approach “the emergent gravity paradigm” to understand the dynamics of gravity. There is also a local gravitational first law of thermodynamics formulated using the local stretched light cones in the neighborhood of any event. This result indicates that certain geometric surfaces–stretched future light cones–which exist near every point in every space time, also behave as if they are endowed with thermodynamic properties. All these results seem to suggest that the thermodynamic properties of space time transcends beyond the usual black hole event horizon.

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