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On the Relation of Entropy with Gravity

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Muhammad Hamza Waseem, Syeda Sitara Wishal Fatima, Khadija Maryam

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Abstract

This paper hypothesizes a connection between gravity and entropy. Gravity, which has not been successfully unified with other fundamental forces yet, is now alternatively explained as an entropic force that is caused by change in information associated with the positions of material bodies. We consider the statistical definition of entropy and ultimately conclude that gravity and entropy are two sides of the same coin and their inter-conversion is what we call 'time'.

Introduction

We now know all of the four fundamental forces of nature. The most universal of which is clearly gravity.

Gravity is intimately connected with the nature of space-time as explained by Einstein. At large distances, gravity dominates while at smaller scales, it is very weak. And thus it is considerably harder to combine gravity with quantum mechanics than other forces for a grand unified theory. The attempts to unify gravity with other forces at microscopic level may not be the right approach as it leads to many contradictions and paradoxes.

The second law of Thermodynamics states, "In any cyclic process the entropy will either increase or remain the same."[1] Entropy is a measure of disorder or multiplicity of a system, or the amount of energy unavailable to do work. For an isolated system, the natural course of events takes it to a more disordered and higher entropic state.

Gravity, on the other hand, knows attraction only and thus tends to keep the things in orderly state by keeping them close to one another and thus reducing the volume occupied as well as the possibilities of the possible states.

In this paper, we try to draw a hypothesis on the relation between gravity and entropy, which is based on questions like "Do gravity and entropy complement each other?", "Can one exist without the other?" and "Is there any common denominator between the two?"

We make the modern theory of "Entropic Gravity" our assumption, which states that gravity is an entropic force and not a fundamental interaction but a consequence of physical systems' natural tendency to increase their entropy.

We conclude by stating a relation between entropy and gravity and discussing its implications.

Fundamental Forces of Nature

All the forces of nature can be simplified down to four most fundamental of forces, which are gravitational, electromagnetic, strong nuclear and weak nuclear. The holy grail of physicists has been to unify all of these forces in one all-encompassing theory, often termed as grand unified theory or theory of everything. It has not been possible to successfully unify gravity with the other three fundamental forces unified, which leads to the possibility that combining gravity with other forces at microscopic levels may not be the right approach after all.

Entropic Force and Gravity

Interest in the concept of entropic forces has risen considerably since 2011 when E. Verlinde proposed to interpret the force in Newton's second law and gravity as entropic forces. An entropic force in a system is a force that results from the entire system's thermodynamic tendency to increase its entropy, rather than from a particular underlying microscopic force.[2]

In statistical mechanics, entropic force is an effective macroscopic force that originates in a system with many degrees of freedom by the statistical tendency to increase its entropy. There is no fundamental field associated with entropic force

In 2009, Erik Verlinde argued that gravity can be explained as an entropic force.[3] He claimed that gravity is a consequence of the "information associated with the positions of material bodies".

The entropy of a Black Hole can be computed by quantum gravity theories. From quantum gravity calculations, it turns out that the entropy of a Black Hole is proportional to the surface of its event horizon.[4]

Space and Information

Space gives meaning to position and momentum, which implies that space is a storage for information associated usually with matter. Considering the statistical view of entropy, the number of possibilities of micro-states of information depends on the size of the storage i.e. space considered.

For those that are technically inclined, the exact statistical definition is

Entropy = (Boltzmann's constant k) x logarithm of number of possible states

$$Entropy = k \log(N)$$

Since the logarithm of a number always increases as the number increases, we see that the more possible states that the system can be in, the greater the entropy. In our case, the larger the space, the larger is the number of possible states and hence the greater is the entropy. Therefore, if an isolated system expands, its entropy increases.

Entropy of the Expanding Universe

Modern cosmology states that the universe is accelerating and expanding continuously and therefore has its entropy being increased every moment. It is moving from a less entropic to a more entropic state. During this expansion, some particles may stumble upon one another and will have gravitational attraction between them, thus getting ordered. Entropy may decrease at that particular portion of space but it is at the expense of increase in entropy in its surroundings so that the net entropy increases. Moreover, as the universe is expanding, the effective gravity is decreasing (in accordance with Newton's law of universal gravitation) because of increase in distances among matter.

Gravity and Disorder

Gravity tries to keep things together through attraction and thus tends to lower statistical entropy. The universal law of increasing entropy (2nd law of thermodynamics) states that the entropy of an isolated system which is not in equilibrium will tend to increase with time, approaching a maximum value at equilibrium. At equilibrium, entropy change is zero. If we assume the universe to be an isolated system, once it attains equilibrium i.e. maximum entropy, the gravity has to vanish from it altogether because if it does not, the entropy will start moving from high to low and time's arrow will reverse. Another possibility is that the net effect of entropy due to gravity and the net effect of entropy because of expansion of the universe have to cancel each other at equilibrium, which is a rare possibility since the net effect of gravitational entropy is negligible as compared to the latter one.

Gravity as an Outcome of Entropy

If the first possibility is indeed true, the next question is: what triggers the gravity to disappear? Maximum entropy does that.

Considering the weak effect of gravitational entropy, the big bang, and the 13.8 billion years age of the universe[5] , we say that gravity and entropy have a reciprocal existence, meaning that increase in one causes decrease in the other. And the universe, as we currently know it, is moving from lowest entropy and strongest gravity i.e. just before big bang toward highest entropy and weakest gravity. In other words, entropy was all gravity in the beginning and gravity is changing into entropy, and perhaps this change is called time or time's arrow.

Conclusion

We have claimed that entropy and gravity are one and the same thing i.e. they are inter-convertible, just like mass and energy are. But due to some reason, the conversion from gravity into entropy is or seems to be uni-directional, which we call time's arrow. It gives rise to the question: will the time's arrow reverse direction once maximum entropy is attained, revealing that it is a slow oscillation of inter-conversion between entropy and gravity? Will there be an anti big bang and another big bang after that? We do not know yet.

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