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Gravity or Complexity?

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Abstract— Construction of Einstein field equations for the freely falling shell is explained. Modifications of gravitational theory from Newtonian view to quantum complexity is analyzed and discussed. Gravity has been revisited and treated as component of quantum complexity. Proposed cause of bodies falling into the black hole may be due to the changes occurring in the quantum complexity. Trajectory of infalling object is derived with trajectory of quantum complexity. A possible connection for quantum mechanics and general relativity is discussed. Some specialized theories such as holographic principle is also discussed for gravity which treat gravity as illusion. Relationship between gravitational attraction and changes in quantum complexity is elaborated.

Keywords—Gravity, Illusion of gravity, Holographic principle, Quantum complexity, Complexity and gravity, Quantization of gravity

I. Introduction

Gravity is an amazing area of research for scientists. Gravity holds all classical objects in the universe. Theory of Gravity has very long scientific tradition. In the beginning theory of motion of massive objects was proposed by Aristotle [1]. He had great confidence on his idea that there is no effect or no motion without any cause. He initiated that the downward falling of heavily massive objects was due to their inherent nature. These findings were modified by Sir Issac Newton. In addition to these revolutions, Einstein reconstructed the theory with equivalence principle. Developments on quantum theories led the theory of gravitation with new insights. In this work, theory of gravity is presented with changes over different periods. Developments from Newtonian gravity to complexity theory of gravity is analyzed and discussed. In section II fundamental aspects of gravitational theories are discussed. In section III Einstein's modified view of gravity is elaborated. In section IV quantization of gravity and holographic principle is discussed. Relationship between quantum complexity and gravity is analyzed in later sections.

II. Fundamental Explanation

Until the emergence of Newtonian mechanics, the science of gravity had not drawn much attention. Newton himself found that 'gravity' was the only reason for inward attraction of massive objects. Newton presented his view on theory of gravity in 1686 [2].

He suggested that force between the massive objects are directly proportional to their masses and inversely proportional to the square of the distances separating the masses..

$$F \propto \frac{M_1 M_2}{r^2} \tag{1}$$

with gravitational constant

$$F = -G\frac{M_1 M_2}{r^2} \tag{2}$$

The theory of gravitation was verified in laboratory by Henry Cavendish in 1798 [4]. It took more than 110 years from publication of Newton's result and 71 years after his last breath. This rule dominated the physics world for more than 200 years until Einstein modified it. At the same period of time Galileo Galilee also demonstrated an experiment of two free falling objects. Without the air resistance they would reach the ground with same period of time from their initial positions. In Galileo Galilee's thought experiment [5] (may be conducted in leaning tower of Pisa) he realized that the speed of falling bodies were independent of their weight. Recent consistent experimental results proved those predictions are correct. A French satellite also verified these results [6]. The data showed that objects with different masses would fall exactly the same rate under the influence of gravity. In cosmology the Newtonian work led to evolution of equation with forces are related.

$$m\dot{v} = -G\frac{Mm}{r^2} \tag{3}$$

putting $m = \frac{4\pi\rho r^3}{3}$ and $r = r_0(t)$ the equation becomes

$$\frac{\ddot{a}}{a} = \frac{4\pi\rho G}{3} \quad (4)$$

The Newtonian derived gravitational force produced the cosmological evolution equations.

III. EINSTEIN'S VIEW OF GRAVITY

Einstein had his own visualized ideas and derivations on his theory of relativity [7]. He generalized the theory of relativity using gravity. He approached the gravity with equivalence principle. The theory estimated the curvature of the space-time using the associated mass and energy. A free falling experiment is proposed to explain the behavior of gravity.

For an observer inside a free falling lift, a pseudo-force which he experiences against the direction of falling is defined as the gravity. He claimed his discovery in a general simplified formula as

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} - \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu} \quad (5)$$

The above equation can be understood easily. The parameters of this equation are $R_{\mu\nu}$ Riemann curvature tensor, *R* Ricci scalar, $g_{\mu\nu}$ metric tensor, $T_{\mu\nu}$ energy momentum tensor or the stress energy tensor and *G* gravitational constant. The Einstein field equation resembles with derivation for a free falling ball made of non interacting particles. To do this a sphere of non interacting cloud of particles is set to fall freely. The sphere undergoes physical changes due to free fall. The shape of sphere changes to spheroid from sphere. The free falling causes the ball to be compressed and elongated. Changes in volume are expressed in the second order time derivative.

$$\left.\frac{\ddot{V}}{V}\right|_{t=0} = -\frac{1}{2}(\rho + P_x + P_y + P_z) \quad (6)$$

Change in the volume of the ball affects the energy density and the pressure of the ball. So the equation consists of pressure and energy density variables.

Parameters of the equation are energy density and pressures over directions. The pressure is derived from the momentum density. The stress energy tensor preserves the changes in volume of the sphere in the second order derivative. The concluded equation expresses that positive energy density and positive pressure curve over the space-time is similar to the free falling ball trajectory that changes its shape due to gravity. It has generalized the gravity as not a force, but as a manifestation of space-time.

Einstein field equation assumes the stress energy tensor explaining the cause for the gravity. The $\mathrm{R}_{\mu\nu}$ Riemann tensor expresses the curvature of the space-time. When either the energy or pressure is increased, the curvature will be in a greater magnitude. Ricci scalar *R* explains the changes in the volume of the sphere. The stress energy tensor changes the volume of the ball equivalent to the changes of the space-time. The stress energy tensor is also related with the cosmological constant Λ. Einstein introduced that term to explain the expansion of the universe. Later on the cosmological constant term is left from the equation due to the findings from American Physicist Edwin Hubble. In 1931 Hubble showed the relationship between the velocity and distance relative to an extra galactic nebula [11]. From Newtonian cosmology the FRW cosmology equation for an expanding universe is derived with cosmological constant included

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} + \frac{\Lambda c}{3} + \frac{kc^2}{a^2} \quad (7)$$

With G- Newton's gravitational constant , c - Velocity of light , Λ - cosmological constant , a- scale factor and $k = -1$, 0, 1 for negative, flat and positive curved space respectively. These findings led Einstein to adopt an expanding model of universe [9]. By this model of Einstein the gravity was modified as the manifestation of space-time, alternate to the attraction between two massive objects which was previously explained by Newton. The Einstein equation also provides solutions for tidal forces, gravitational collapse and gravitational waves using this model.

IV. QUANTIZATION OF GRAVITY AND HOLOGRAPHIC PRINCIPLE

In general, the gravity is related with the geometry. The physics of 19th century was dominated by the laws of quantum mechanics. Theory of gravity also changed considerably with the evolution of quantum mechanics. Necessary principle was needed to explain he gravity in the sense applicable to quantum mechanics. Though the Einstein's theory of relativity fits very well to celestial objects, in the microscopic scales, the gravity cannot be included. At the quantum level, any of the effects of gravity could not be observed. The approach of quantum view in the gravity is explained by quantum gravity theory [10]. Quantization of gravity is a tedious and tough process. Developments on theories of black holes and string theory also led to the attempts of quantization of gravity. Black holes are the objects, which are formed due to the gravitation collapse. As the quantum field theory deals with infinite degrees of freedom, it loses its consistency in front of huge gravitating objects such as black holes. That was the reason why the string theory emerged to solve the infinite dimensions problem. The string theory deals with the quantization associated with a model assuming a collection of strings. The quantum field theory suggested that, the existence of point particles is the excitations of local field. The string theory deals the same phenomenon with miniature strings instead of point particles. Solutions of black holes attempts to connect the quantum mechanics with the relativity, by the famous works by Einstein and his colleagues [11] [12]. Classical general wormhole solutions is related to quantum mechanical entanglement connectivity solutions. In general, the connecting conjecture is explained as ER=EPR paradox [13]. For the same problem, the black hole string theory puts forward a new principle called "holographic principle". The idea of **holographic principle** was first proposed by Hooft [14]. He proposed a model for reduction of dimensions for quantum gravity. For the same theory the string theory interpretations is given by Susskind [13]

An amazing and useful review on holographic principle and its developments is provided by Bousso [15]. Theory of quantum mechanics allows one to store the information of 3D spatial structure in 2D projected holographic image.

This principle predicts that every object in the universe may be treated as a collection of microstates of a hologram that is projected on the horizon of the universe. With collective cells of information, the hologram will have its full visualization. A collective holographic image will be illuminated at the horizon with each of its sub constituents. In similar formalism, the universe will appear as 2D image of 3D space at the horizon . The same idea is applicable to the theory of gravity. Any higher dimensional object can be optimized to lowered dimensions using a compactification process. Gravity works very well in 3 dimensional world. Compactification of 3 dimensional space into 2 dimensional space leads to compactification of gravitational phenomenon in a simpler version. With this visualization, the 3D gravitational attraction may be calculated in a 2D manifestation. Since Holographic principle is related to black hole entropy, the Entropy of a black hole is proportional to its area. Entropy S

$$S = \frac{A}{4G} \tag{8}$$

The 3D image of the black hole may be projected as an image on a screen that is placed near a black hole. As light bends around the black hole, the entire surface of it is projected as an image on the screen. Area of the projected 2D image of the black hole is proportional to its entropy.

The visible world can be treated as a 2D holographic picture of 3D space, then the gravity is delegated as an illusion. Thus the gravity is treated as an illusion in quantum mechanics, instead of manipulation of space-time and instead of attraction between massive objects. The holographic principle affirms that the gluons act like gravitons in higher dimensions. Strings with various thickness will not interact themselves. The gluon (string force constant) also connects quarks. At the higher dimensions, the gluon chain resembles the gravity.

DISCUSSION

Quantum complexity and gravity

Quantum complexity uses minimum number of gates required to construct a unitary operation S. The quantum complexity theory solved many iterated problems of black holes such as information paradox and interior of the black holes [16]. Quantum complexity theory predicts an increase in complexity as an object approach towards the black hole and it reaches a maximum at the interior of the black hole. In general, the structure of black hole is compared to the structure of an onion. Towards the core of the onion, the layers gets thicker and harder. Resembling onion, the interior of the black hole will have more complexity compared to its horizon [17]. A general question may arise if there is any relationship between complexity and gravity? The possible answer is yes. Theoretical perditions affirms that there is a connection between quantum complexity and gravity. Objects falling towards a gravitating celestial body has the trajectory same as the trajectory of increment of quantum complexity. All the upward thrown objects will reach back the ground until the escape velocity is obtained by the object. Thus increment of distance from the gravitating object is due to the increment of quantum complexity. But the complexity will not be minimum at all times. As the time flows, the complexity will increase and the object will start to fall back as a massive object would do. The gravity has another persuasion due to the quantum mechanics of the black holes. To relate the force of attraction with complexity, the acceleration is related to quantum complexity. In Rindler space, accelerated path leads an object to escape from the black hole. The acceleration will make an object to revolve around the black hole with constant radial path 'r'. The path of infalling object is expressed [18] as

$$r = e^{-\alpha t} \tag{9}$$

With $\alpha = \lambda$ is called as Lyapunov exponent. If $\alpha > 1$ it violates the constraint of relativity and it will travel with velocity greater than the velocity of light. And the trajectory will be along the horizon. This trajectory solves wormhole paradox, which allows an observer to move along a wormhole to reach entangled part of a black hole. Escaping to parallel universe will also be possible with this kind of trajectory. With $\alpha < 1$ the object will escape to the infinity without falling into the black hole. With $\alpha = 1$ the trajectory will lead to the horizon and the object will fall into the black hole. Falling into the black hole happens due to the increment of complexity at $\alpha = 1$. Objects are attracted gravitationally in this condition and is due to the increment of complexity .

In Rindler coordinate, the object has to have change in acceleration in order to avoid from gravitational pull of a black hole. The acceleration of the objects works against the gravitational pull of the black hole. For constant path of the object, the complexity should exhibit zero time derivative. A string stretched horizon has the thickness greater than the plank's length so that the horizon can hold more complexity. For any infalling object towards black hole, the trajectory of complexity may increase. This trajectory resembles a particle trajectory in real space. An infalling object which is at a very large distance from the horizon, at initial time *t*=0, will be with a very low complexity. As the distance from the horizon decreases, the complexity may increase. Hence, the object will experience more gravity with changes in quantum complexity. The complexity principle can be extended to modified gravity with dark energy component [20].

These treatments explored has allowed us to view gravity not only as a force field or illusion but also as a variation in complexity.

V. Conclusion

In the attempt to connect the quantum mechanics with gravity, constraints emerged needed to be overcome with logic. The main constraint is quantum uncertainty principle. The quantum mechanics proved that the momentum and space cannot be measure simultaneously due to the uncertainty principle. But in classical relativity, curvature plays the main role on gravity. To connect gravity with quantum mechanics a huge curvature is necessary. This is the principle cause for holographic principle to deal the gravity as two dimensional illusion. This avoids the gravity with gluon interactions. These solutions provide the mathematical consistency for gravitational solutions in higher dimensions. Gravity acts as an illusion in this treatment when compiled with black hole information paradox and holographic principle [14]. The holographic principle is believed to solve the unsolved problems of the beginning of the universe by quantizing the gravity. However, the particles grow as the momentum increases. This finding was based upon quantum information that spreads near the horizon of the black holes. Similarly some other paradoxes such as ER=EPR explains the relation between the quantum mechanics and general relativity are also discussed. The escape velocity of a black hole is $v_{es} = \sqrt{\frac{2GM}{R}}$ with $R = \frac{2GM}{c^2}$. So for a particle escape away from the black hole it should work against the increment of complexity. The gravity was envisaged so far as just a force of attraction for the long period of scientific evolution. That has been changed with many theoretical developments such as quantum mechanics. The physics will not stop its evolution until the ultimate goal of grand unification is reached and these treatments allow us to visualize gravity as an increase of quantum complexity leading one to solve many constraints that remain unsolved is standard model.

Appendix

Flow of momentum in a direction is expressed as force in corresponding direction. Flow of momentum in x direction is

$$\left(\frac{P_x}{area.Time}\right).$$

Time derivative of momentum will give force

$$\frac{1}{area}\frac{dP}{dt} = \frac{1}{area}\frac{d}{dt}mv \qquad \text{(A1)}$$

Which gives $= \frac{1}{area}(Force)$

Force per unit area results stress.

$$\frac{Force}{area} = Stress \qquad \text{(A2)}$$

So that it has been derived that flow of momentum per unit area and per unit time will result in the stress.

$$\left.\frac{\ddot{V}}{V}\right|_{t=0} = -\frac{1}{2}(\rho + P_x + P_y + P_z) \qquad \text{(A3)}$$

The matrix related with change is space-time derived by equivalence principle.

Also right hand side of equation can be explained in a matrix form

$$\begin{pmatrix} \rho & \cdots & \cdots & \cdots \\ \cdots & P_x & \cdots & \cdots \\ \cdots & \cdots & P_y & \cdots \\ \cdots & \cdots & \cdots & P_z \end{pmatrix} \qquad \text{(A4)}$$

The matrix related to change in space-time is derived using equivalence principle.

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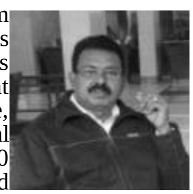

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