The Rulers of Fermi and Planck in Two Entangled Universes

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ABSTRACT- The Holographic Principle is applied in 3-D and 2-D universes described by volume and surface of a sphere having a radius in the scale of the cosmological constant. Making the equality between the degrees of freedom furnished by the holographic description of them, we find the radius of the observable universe. While doing this, weak interaction coupling and quantum gravity play their role.

1 – Introduction

Fermi [1] and Planck [2], two outstanding physicists, gave seminal contributions to the development of the modern physics. Planck's scale [3] provides the Planck length (L_{Pl}) as a ruler which becomes very relevant in the realm of quantum gravity.

Meanwhile, by considering a modified Fermi coupling of the weak interactions (G_F*), and inspired in the definition of the Planck's units, a Fermi scale was introduced in [4]. There [4] was defined the second Fermi length (L_{SF}). The word second, is to avoid confusion with the Fermi length which appears in the treatment of the transport properties of the free electrons in metals. Here we will take the second Fermi length (L_{SF}) as a Fermi's ruler.

Inspired in a work of Cohen, Kaplan and Nelson [5] and also in also in a conjecture advanced by Zee [6], we have introduced in reference [7], R_Λ , a length related to the cosmological constant scale, defined as the geometric average between the infrared and (R_u) and ultraviolet (L_{Pl}) cut offs of an effective field theory of gravity.

In the present work we are considering a sphere which radius is taken as the "cosmological constant radius", namely R_Λ. To the volume of this sphere we will associate a three dimensional (3-D) universe and to its surface a two dimensional (2-D) one. These two universes are entangled by fixing the radius of the sphere as the cosmological constant radius.

Is the aim of the present work is to treat this problem, by applying the Holographic Principle (HP) [8,9,10] to both universes.

2 – HP in 2 – D and 3 – D applied to the cosmological sphere

First we use the ideas of Zee [6] and Cohen, Kaplan and Nelson [5], as a means to define the cosmological constant radius. We write

$$R_{\Lambda} = (Y L_{Pl})^{1/2}. \quad (1)$$

In (1), Y is a semi-perimeter of a circle having a radius equal the radius of the universe, namely

$$Y = \pi R_{u}. \quad (2)$$

Now let us consider a momentum defined in a curved space as ($\hbar = 1$)

$$P_{SF}^{C} = \pi / L_{SF}. \quad (3)$$

Then, a modified Fermi ruler can be defined as

$$X = 1 / p_{SF}^{C} = L_{SF} / \pi. \quad (4)$$

Next, following McMahon [10], we present formulations of the HP for the 3-D and 2- D cases.

Here we quote two postulates of HP as stated by McMahon, but adapted to the present calculations. First in 3-D case, they are

. The total information content in a volume of space is equivalent to a theory that lives only on the surface area that encloses the region.

. The boundary of a region of this volume contains at most a single degree of freedom per modified Fermi area.

The 2 – D case

Inspired in McMahon [10], the holographic principle in 2-d can be stated as

. The total information content of a 2-d universe, in this case a spherical surface of radius R_Λ, can be registered in the perimeter of one of its maximum circles.

.. The boundary of this spherical surface, here the perimeter of its maximum circle, contains at most a single degree of freedom per twice the Planck length.

Now, let us calculate the number of degree of freedom in the spherical surface. We write

$$N_{surface} = 4\pi\, R_\Lambda^{\,2} / (2X)^{\,2}. \qquad (5)$$

Next, we estimate the number of degree of freedom contained in the perimeter of its maximum circle. We have

$$N_{perimeter} = 2\pi\, R_{\Lambda} / (2\, L_{Pl}). \qquad (6)$$

The “entanglement” between these two universes is reached making the requirement that

$$N_{perimeter} = N_{surface}. \qquad (7)$$

This equality implies that

$$R_{\Lambda} = X^2 / L_{Pl} \qquad \text{or equivalently} \qquad Y = X^4 / L_{Pl}^{3}. \qquad (8)$$

By considering (2) and (4), we finally can write

$$R_u = (L_{SF})^4 / (\pi^5\, L_{Pl}^{3}). \qquad (9)$$

As can be seen in (9), the radius of the observed universe can be estimated by the knowledge of the values of the Fermi and the Planck rulers, if we assume the entangled condition given by (7).

We may numerically evaluate (9), by taking $L_{SF} = 1.07 \times 10^{-19}$ m [4], and $L_{Pl} = 1.616 \times 10^{-35}$ m obtaining

$$R_u = 1.01 \times 10^{26}\ \text{m}. \qquad (10)$$

3 – Concluding remarks

In this work we applied the HP in universes of two and three dimensions, described by the surface and the volume of a sphere having a radius equal the cosmological radius.

We used four times the squared modified second Fermi length as a unit cell area in order to count the number of degrees of freedom in the holographic surface of the 3-D universe, and twice of the Planck length as the unit cell size to estimate the number of degrees of freedom contained in the holographic perimeter of the maximum circle of the 2-D universe.

Making the equality between the degrees of freedom contained in the holographic representations of these two "entangled" universes we were able to estimate the radius of the observable universe.

We did this, partially inspired in a paper by Manley [11] who advanced the idea that the radius of the observable universe could be inferred from the following hypothesis:

"A compromise between the quantity of information stored in the observable universe of radius R can be computed as the number of square unit cells of length equal to twice the Planck length L_P covering the spherical surface of radius R (according to the holographic principle [8,9,10]), but also as the number of cubic unit cells of edge equal to twice the proton's length contained in the sphere of the same radius R".

Indeed in a recent paper [12], Roberto Onofrio conjectured that weak interactions could be a manifestation of gravity when investigated through high energy probes (short distances).

Meanwhile, Roberto Onofrio [12] assumes that weak interactions should be considered as empirical evidences of quantum gravity at the Fermi scale. The "second" length estimated by Onofrio [12], is approximately one order of magnitude greater ($\sim 10^{-18}$ m) than that which is used in the present work (1.07×10^{-19} m). This comes from the fact that Onofrio used the expectation value of the Higgs field to fix the Fermi scale of energy, instead the unitary scale threshold we have used in [4].

References

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