Energy – Spacetime Equivalence

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Abstract

In this essay the equivalence between mass/energy and spacetime is postulated, so that matter, energy and spacetime can be transformed into one another. This has major implications in the physics of Black Holes and in cosmology. It is argued that no central singularity arises inside a Black Hole, no remnant is left once it has evaporated and unitarity is conserved by means of gravitational radiation. The possible origin of the cosmological constant is briefly discussed.

1 Introduction

Since it's introduction in the laws of Thermodynamics, energy conservation has become one of the central postulates of Nature. From a formal point of view it arises from the invariance of the action of a system to time translations via Noether's theorem. No experiment has ever found a violation of this principle and it's been used to predict missing components, (*e.g.* the neutrino). But in General Relativity energy is a slippery concept. For example, the Cosmological Constant seems to violate its conservation.

In 1905 Einstein derived the most famous equation of all Physics: $E = mc^2$. This establishes an equivalence between Mass and Energy so that one can be converted into the other. The implications of this are far reaching and thoroughly validated in multiple experiments. Mass is routinely converted into Energy in Nuclear Reactors, and Energy is converted into Mass to synthesize the heaviest elements of the Periodic Table.

In this essay it is argued that, in order to respect the principle of conservation, Energy must take even more distinct forms that previously considered. Namely, as well as mass, energy must be equivalent to spacetime.

2 Energy–Spacetime Equivalence

To establish the equivalence we consider a covariant quantity, namely the line element:

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu$$

We postulate a relation of the form $E \propto \Delta s^2$, with a proportionality constant built from the fundamental constants c, $\hbar$, G. Dimensional analysis leads to:

$$E = c^{\frac{11}{2}} \hbar^{-\frac{1}{2}} G^{-\frac{3}{2}} \, \Delta s^2$$

The proportionality constant evaluates to $C \equiv c^{\frac{11}{2}} \hbar^{-\frac{1}{2}} G^{-\frac{3}{2}} = 7.488 \cdot 10^{78} \ kg \cdot s^{-2}$. That's a big number. The line element equivalent to an electron would be $\Delta s^2 = \frac{m_e c^2}{C} = 10^{-92} \ m^2$ (a Planck's unit of area is $l_p^2 = 2.61 \cdot 10^{-70} \ m^2$). The equivalent of a supermassive Black Hole of $10^6 \ M_\odot$ would be about $10^{-29} \ m^2$. We need an enormous amount of energy to create a significant amount of spacetime.

This suggests that the coupling parameter between matter and spacetime should be quite high, probably somewhere near the GUT scale. The only places in the Universe, other than the Big Bang, where this conversion could take place are the Black Holes. Specifically near the central singularity and in the final stages of evaporation.

3 Black Holes

Let's consider the implications of the previous equivalence to Black Holes. Figure 1 shows the Carter–Penrose diagram of a Universe with a Black Hole forming at the origin of coordinates and subsequently evaporating. The black dashed line is the origin $r = 0$. The red line at 45° is the event horizon of the BH. The green line is a spatial hypersurface that represents what we may call the inflation horizon. In this region the temperature is high enough to transform the infalling matter into new spacetime. The point P where both hypersurfaces intersect marks the end of the BH. Hence, the BH is the region bounded by the two hypersurfaces.

The blue curve is the world-line of an astronaut orbiting the BH. Once she reaches the causal future of P she can measure the gravitational radiation emanating from the inflation horizon. After that, she notices that the origin of coordinates has shifted further away from her.

The magenta curve represents the world-line of a particle falling inside the BH. Past the event horizon it inevitably hits the inflation horizon where it's converted into spacetime. From then onwards its information content is transferred to gravitational waves that are measured by the astronaut at the point R. We see that unitarity is preserved.

The previous picture suggests that the actual accelerated expansion of the Universe might be caused by the evaporation of Primordial Black Holes creating new spacetime. The measured value of the cosmological constant should constrain the coupling parameter between matter and spacetime.

4 Summary and Discussion

It is postulated that a Quantum Theory of Gravity should take into consideration the creation and anihilation of quanta of Spacetime in order to preserve the

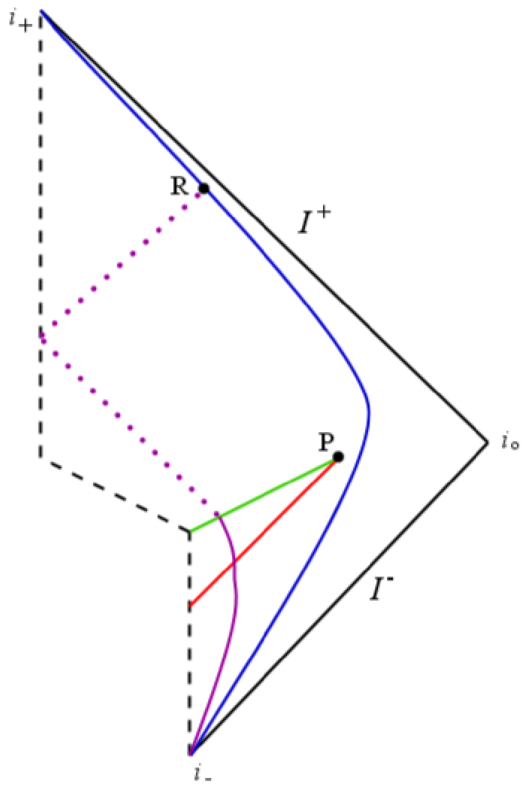

Figure 1: Carter–Penrose diagram of a Black Hole

Principle of Energy Conservation. It is argued that this would prevent the formation of singularities inside BH's and would preserve unitarity, hence offering a possible solution to the BH information problem.

According to the proposed energy-spacetime equivalence the particles of the Standard Model should be stable and would not spontaneously decay to spacetime quanta. On the other hand, that means that spacetime quanta are not stable and should decay to matter particles. It's half-life should be orders of magnitude beyond the current age of the Universe, but in the long term spacetime would disappear into matter and the Universe would contract again. It would finally reach a high enough density to make a new Big Bang and start a new cosmological cycle.

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