EINSTEIN'S EQUIVALENCE PRINCIPLE AND SUSSKIND'S BLACK HOLE COMPLEMENTARITY

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Abstract. There are two complementary descriptions of the fate of the information traversing the event horizon of a black hole, one given by an infalling observer, and the other by an outside observer. According to the black hole complementarity principle, although contradictory, both these descriptions are true, but they cannot lead to an inconsistency because the two observers cannot meet each other.

On the other hand, Einstein's equivalence principle suggests that the black hole complementarity principle should remain the same if we apply it to the Rindler horizon of an accelerated observer instead of the event horizon. But in the case of the Rindler horizon, the two observers can meet each other and compare their records, proving that the observer reporting violent evaporation of the objects approaching the Rindler horizon was in fact wrong. This may reveal a severe limitation imposed by the equivalence principle to Susskind's hypothesis of the black hole complementarity.

Black Hole Information Loss

The principle of *black hole complementarity* was proposed as a possible solution to one of the most important puzzles in fundamental physics [1]. This puzzle is the *black hole information loss*, a challenge raised by Stephen Hawking [2, 3], who observed that the black holes radiate, and eventually evaporate. If the black hole evaporates completely, it seemed that the information reaching the singularity no longer exists. This seems to violate the conservation of information and, by changing the purity of the quantum states, the unitarity of quantum mechanics. In order to save these mandatory features of quantum mechanics, various solutions were proposed [4, 5, 6, 7].

Black Hole Complementarity

To solve this problem, Susskind, Thorlacius and Uglum proposed the *black hole complementarity principle*. Let's assume that an observer (Alice) falls into a large enough black hole, while another observer (Bob) stays outside. Susskind and Lindesay wrote([8], p. 175–176):

> According to the low frequency observer, namely Alice herself, or someone falling with her, nothing special is felt at the horizon. The horizon is harmless and she or her descendants can live for a billion years before being crushed at the singularity.
>
> In apparent complete contradiction, the high frequency observer who stays outside the black hole finds that his description involves Alice falling into a hellish region of extreme temperature, being thermalized, and eventually re-emitted as Hawking radiation.

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The solution proposed by the black hole complementarity principle was that both these statements are true. They may contradict each other, but since the external observer never meets the infalling observer to compare their records, there is no effective contradiction (*cf.* [8], §9.2). It may seem difficult to accept that physics actually admits two contradictory propositions simultaneously, but Susskind appealed to Bohr's complementarity as a precedent. To paraphrase Bohr [9, 10],

No contradiction is a contradiction until it is an observed contradiction.

Einstein's Equivalence Principle *vs.* Black Hole Complementarity

Let us now consider that Bob is moving with a high acceleration relatively to Alice in an almost flat spacetime (far from any black holes). According to the Unruh effect [11, 12, 13], Bob sees that Alice faces a very high thermal activity when approaching the Rindler horizon caused by his own accelerated motion. On the other hand, Alice sees nothing special, of course, because the Rindler horizon is only perceived by Bob. If, after that, Bob stops his acceleration and returns, he finds Alice unaffected by the Unruh effect. This shows that, in fact, Bob's observation is due to his accelerated motion, and does not actually affect Alice. We can see this by analogy to the Lorentz contraction, which doesn't actually affect the object, it only appears so to an observer in relative motion to that object.

Consequently, the black hole complementarity principle has no equivalent in the case of the Rindler horizon. But Einstein's equivalence principle requires that the physical laws remain the same if we replace the event horizon of a black hole with the Rindler horizon of an accelerated observer. If the black hole complementarity principle is true for the event horizon, it has to be true for the Rindler horizon as well.

This shows that there is an incompatibility between the equivalence principle and the black hole complementarity principle.

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