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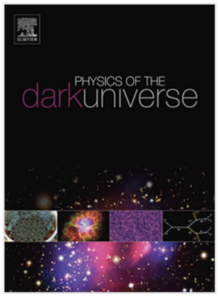

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Uniformly expanding vacuum: a possible interpretation of the dark energy

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Following the spirit of the equivalence principle, we take a step further to recognize the free fall of the observer as a method to eliminate causes that would lead the perceived vacuum to change its original state. Thus, it is expected that the vacuum should be in a rigid Minkowski state or be uniformly expanding. By carefully investigating the impact on measurement caused by the expansion, we clarify the exact meaning of the uniformly expanding vacuum and find that this proposal may be able to explain the current observations of an accelerating universe.
Keywords: Uniformly expanding vacuum, dark energy, Interpretation

I. INTRODUCTION

The word vacuum in present work is defined to be the *classical* spacetime perceived by a free fall observer, thus there is no gravity/gravitation in it. Usually the absence of gravity is treated as equivalent to the vanishing of Riemann tensor. However, in general cases, this is not so obligatory. In fact, as long as the observer is freely falling or geodesic (thus the effect of gravity is neutralized), the (local) spacetime is an vacuum perceived by this observer. For example, free fall in Minkowski spacetime is just inertial motion, and indeed corresponds to the vanishing of Riemann tensor; nevertheless, in de Sitter or anti-de Sitter spacetime free fall is comoving motion where the relevant Riemann tensor obviously does not vanish. A counter-example which deserves special attention is the Friedmann-Lemaître-Robertson-Walker (FLRW) universe. Although everything in this universe is freely falling, the perceived spacetime in radiation or matter dominated era is not an vacuum as defined here, which is because of the ubiquitous existence of perfect fluid. Furthermore, even if the dark energy dominates the universe, as long as it is a non-geometrically emergent effect of an unknown energy density, the perceived spacetime also cannot be looked as a vacuum defined here.

All in all, to define the vacuum in *classical* level, free fall is a crucial element. From the perspective of the equivalence principle, free fall of the observer can remove the effect of gravity and thus results in an equivalent spacetime with no gravity which can be treated as the vacuum. Considering the general case with a cosmological constant whose value may equal to, larger or less than zero, the three possible vacua correspond to three solutions to the vacuum Einstein's field equation with the maximal symmetries. Thus, with the well-accepted perspective which insists that the symmetry is of central importance, it seems that these different vacua should have equal footing, therefore, one can expect that all of these different vacua will play important roles. Surprisedly, all the three vacua indeed have deeply penetrated into theoretical physics: Standard Model of particle physics is built on a Minkowski background [1]; the profound AdS/CFT correspondence [2] endows the anti-de Sitter spacetime with special meaning. Furthermore, it has been well accepted that the most economical way to explain the astonishingly accelerating expansion of our universe [3, 4] is to interpret the dark energy as a positive cosmological constant, the corresponding model has been named as "the concordance ΛCDM model".

However, while the ΛCDM model best fits the data, interpreting dark energy as a positive cosmological constant causes notorious difficulties [5, 6]. The well known example is the serious fine-tuning problem related to it [7]. In addition, after years of efforts, a consistent quantum field theory in de Sitter background is still missing. It is obvious that the combination of quantum field theory with cosmological constant has encountered many problems and subtle issues. This in return implies that a whole new understanding of the vacuum is required to identify the nature of dark energy.

II. UNIFORMLY EXPANDING VACUUM

What is the vacuum when there is no gravity? We want to ask this question again but from some new angles and with new emphases. Following the spirit of the equivalence principle, we take a step further to recognize the free fall of the observer as a method to eliminate causes that would lead the vacuum to change its original state. The previously proposed question then turns into the following form: *What state can the vacuum have when there are no causes responsible for its change*? Then, it is reasonable to expect that, in a well-defined context, the vacuum will maintain its original state if there is no cause to trigger its change. Taking this as a starting point, an inevitable answer to the above question is that *the vacuum should be in a rigid Minkowski state or be uniformly expanding.* However, while the rigid Minkowski state is interpreted as the metric of Minkowski spacetime does not evolve with time, the exact meaning of "uniformly

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