Aspects of the negative mode problem in quantum tunneling with gravity

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Very probable (the first order) cosmological phase transitions took place in the early stages of evolution of our Universe. They typically proceed due to quantum tunneling phenomenon via new phase (true vacuum) bubbles nucleation in the old phase (metastable vacuum) and subsequent growth of these bubbles. While in flat space-time metastable vacuum is well investigated, when gravity is taken into account it is more involved task and there are still some open problems. One of them is the negative mode problem, which is the appearance of infinitely many states with negative energy in the spectrum of linear perturbations about some Euclidean solutions, describing vacuum decay. In spite of the fact that the negative mode problem in metastable vacuum decay with gravity was discovered 34 years ago [1] and many different groups worked on this topic [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], no complete solution of this problem was found till now. In our presentation, using combined analytic and numerical approach we demonstrate that for the generic polynomial scalar field potentials the negative mode problem shows up for parameter values far from Planckian, i.e. it is not related to the physics at the Planck scale [14]. The same time we found [14] that for the Standard model Higgs like potential problem does not appear at the realistic values of the potential parameters and negative mode problem shows up only near the Planck scale. Since the analysis of differences between Lagrangian and Hamiltonian approaches to the negative mode problem showed [15] advantages of the later method, our present study is based on the Hamiltonian approach [3, 5].

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