At the beginning of 20th century two theories revolutionized physics: the theory of quantum mechanics and Einstein's theory of relativity. The theories have greatly widened our understanding of the physical world and became two cornerstones of physics. In order to describe the world coherently, they should be unified. Einstein was the first person who raised the problem. He argued that atoms would have to radiate not only electromagnetic but also gravitational energy and therefore quantum mechanics would have to modify not only the electrodynamics but also the theory of gravitation. The problem of merging quantum mechanics and general relativity still remains open. The hypothetical theory unifying them is called quantum gravity. We will investigate one of the candidate theories called spin foams. In this theory the geometries of space-time are described by quantum foams. The quantum geometries of space are discrete: the quanta of space can be thought of as quantized "grains" of space. Spin foams are histories of such quantum geometries and describe quantum geometries of space-time.

Before a physical theory can be accepted it needs to be experimentally verified. In quantum gravity this means that the theory should predict new physical phenomena that reflect quantum nature of gravitational interaction. In this project we will focus on possible effects in the very early stages of the evolution of the Universe and at the center of a black hole. General relativity predicts that the Universe started from the Big Bang and since then it is expanding. According to this theory at the moment of Big Bang the density and the temperature of the Universe were infinite. It also predicts black holes – regions where the gravitational interaction is so strong that even light cannot escape from it. According to this theory at its center curvature of space-time becomes infinite. However, it is commonly believed that such infinities cannot appear in real world and therefore general relativity does not adequately describe neither the early stages of the evolution of the Universe nor the center of a black hole but quantum gravity should be used instead.

We will investigate if Loop Quantum Gravity resolves the classical singularities. A research based on studies of simplified models shows that Big Bang singularity is replaced by a Big Bounce. The quantum gravitational imprints on the Cosmic Microwave Background radiation have been recently calculated. Our first goal will be to verify if the results based on the simplified models are reproduced in the full theory.

Our second goal will be to study a (quantum) gravitational collapse leading to a formation of black hole. We will investigate if the singularity inside the black hole is resolved by quantum effects. This may shed some new light on a scenario recently proposed by the research group lead by prof. Carlo Rovelli. They argue that due to quantum effects, black holes can tunnel into white holes and explode. This process may be a source of radio and gamma bursts. Detection of such signals would be the first direct observation of quantum gravitational phenomenon.

A study of the quantum gravity effects is very challenging. Therefore we will develop new mathematical and computer methods and perform simulations on powerful computer cluster of National Centre for Nuclear Research.