Explaining the beginnings of the Universe or determining what happens inside black holes requires a theory which unifies Einstein theory of general relativity and quantum physics. Physicists like to name such theory as a theory of quantum gravity. One of such theories (still under construction) known under the name of Loop Quantum Gravity (LQG) predicts that surrounding us space is not a continuous object but instead it is woven out of tiny mesh consisting of extremely short links and known in Physics as the spin-networks. Because of that structure the areas of surfaces and volume of regions of space can take only set of discrete values (although being extremely close to each other), very much like the energy levels in atoms.

The younger sister of LQG sharing its structure but formed out of simpler mathematical models applied to the Universe as a whole, known as Loop Quantum Cosmology (LQC) predicted on the other hand, that instead of starting at the singular big bang our Universe existed before what we expected to be a point of its creation. According to (yet experimentally unconfirmed) mathematical models of this theory, what we see as observed Universe is simply an epoch – an eon connected to an older epoch of contracting universe through phenomenon known as a big bounce.

We expect that the phenomena found in LQC should also be a feature of the full and unsimplified theory of LQG. However in attempt of describing more comliated physical situations, like for example the evolution of inhomogeneities in the universe from the previous pre-bounce epoch to ours the predictions of LQC may be inaccurate. LQC being a simplified model may not be sufficient to well describe the physical processes in the universe near the bounce. Therefore it is important to improve existing form of LQC by looking at a universe from the point of view of a full LQG (being in itself too complicated to use it directly). The aim of our project is to build a way of simplifying LQG in a way, which allows us to control, how much we are throwing out by simplifying and how big an error in predictions each simplification generates and at the same time allows to incorporate more of features of full theory than already present in LQC. We then plan to use the improved method to identify the form of possible hints of quantum nature of spacetime by looking at the structure of the so called Cosmic Microwave Background (which reflects the structure of inhomogeneities in early Universe). This in turn offers a potential for observational verification whether LQG really describes our physial reality.

The second goal of our project regards investigating properties of black holes: Einstein theory of general relativity predicts that inside a black hole a space ends in a singularity – a boundary beyond which making any physical predictions is not possible. On the other hand the simple models of LQC already "replaced" big bang singularity with a big bounce, which in turn allows to extend our physical predictions beyond what we thus far considered as the entire physical reality. We then do hope that the similar situation occurs with the singularity inside a black hole. Our project is in part aimed as systematic verification of this expectation through rigorous calculations. If indeed the black hole singularity is replaced by something akin to a big bounce then any black hole can either eventually (after an extremely long time) explode back as a so called white hole or it may create inside itself another universe as large and rich as ours.