The universe is expanding and the pace of this expansion has been increasing for last several billions of years. The cosmic matter-energy budget is dominated by two mysterious components: dark matter and dark energy. The first one is responsible for the emergence of the large-scale structure of the Universe - the cosmic web of galaxies, galaxy clusters and superclusters, separated by enormous voids. The second one leads to the accelerated expansion - without it, the universe would slow down its expansion due to the attractive nature of gravity.

Those few sentences summarize our current knowledge about the Universe on the largest scales, which we have been gathering for many decades by various observations. This has led to the so-called standard cosmological model, in which few parameters are sufficient to describe the past and the future of our Universe. It is based on known physical laws, especially the most accurate theory of gravity so far - the general theory of relativity. While elegant mathematically and consistent with various astronomical measurements, unfortunately it does not provide an explanation about the nature of dark components, especially the dark energy which is responsible for the accelerated expansion of the Universe.

The goal of this project is to get closer to resolving the dark energy problem, by using two independent, however closely related, types of astronomical observations. The first one is galaxy distribution on the largest scales, about which we learn from large cosmological surveys. The second one is the remnant of the very early and hot stage of the Universe: cosmic microwave background, which was emitted when stars and galaxies did not even exist yet, and the cosmos was filled with a mixture of hot gas and light particles (photons). Studying these two probes, we are able to precisely measure most of cosmological parameters, especially the amounts of dark matter and dark energy, which play key roles in the evolution of the Universe.

Large-scale structure and cosmic microwave background characteristics, which we learn about using quite different observational techniques, are inseparably bond together. Photons of the background radiation, travelling through the Universe since the very moment of their emission about 14 billions of years ago, interact in many ways with matter of the large-scale structure. One of such interaction is a change in photons' energy when they approach large masses such as superclusters of galaxies, as well as their “opposites” - cosmic voids. The same structures also slightly curve photon paths, as a result of relativistic gravitational lensing. The scales of those effects depend on the global amount of dark matter and the rate of cosmic expansion, thus on the dark energy itself. In particular, the net change of background photons' energy on their way since the emission to us - known as the Sachs-Wolfe effect - would not take place if not for dark energy.

In the proposed project, both the Sachs-Wolfe effect and background radiation gravitational lensing will be used to study dark energy properties as a function of cosmic time. The basic method consists of direct comparison of background radiation and galaxy distribution statistical properties, as well as in studying the imprint of the latter in the former, created as a result of the above mentioned interactions. Precise all-sky background radiation measurements from the Planck satellite will be used together with the largest available galaxy catalogs, which currently include hundreds of millions of objects. Reliability of the results will be ensured by carefully preparing maps and catalogs. The measurements will be eventually compared with many theoretical models which predict different properties of dark energy, as well with those that postulate deviations from general relativity on the largest scales.