Abstract

Gravity has captured the curiosity of mankind for centuries. It is one of the four known fundamental forces of nature and the dominant cause for apples falling to the ground, Earth going around the Sun, and the formation of the large scale structures in the Universe. A revolution in our understanding of gravity was brought by Isaac Newton who explained how planets move around the Sun. Another milestone was placed by Albert Einstein who gave us the General Theory of Relativity (GR). It expresses gravity as a fundamental property of the spacetime fabric of the cosmos. The natural application of GR was to construct a model of the entire Universe to understand its evolution. The most accepted model of the Universe backed by observational confirmations is the Lambda Cold Dark Matter or the ΛCDM model. It explains the expanding Universe as well as the formation and evolution of the large scale structure in the Universe. Although the ΛCDM model is consistent with observations, it is not free from challenges and disparities. Explanation of the nature of dark energy and dark matter, accelerated expansion of the Universe, and tensions in estimations of some cosmological parameters (like σ_8 or Hubble tension) have raised questions on the validity of ΛCDM model and a need of its thorough testing on cosmological scales.

One of the many different ways to test cosmological models is to use the Cosmic Microwave Background (CMB) radiation in synergy with probes of the large scale structure like galaxies, galaxy clusters, quasars, etc. In this thesis, we focus on cross-correlation between CMB gravitational lensing potential, estimated from CMB anisotropy maps, and photometric galaxy surveys. The surveys are prone to several systematic errors which can alter the observed redshift distribution of sources and can cause unphysical variations in their number density in the sky. In this thesis, *we study the impact of various systematic effects on CMB gravitational lensing and photometric galaxy surveys cross-correlation measurements and estimation from them cosmological parameters, in particular galaxy bias, amplitude of cross-correlation or σ_8 parameter.*

The photometric redshifts of galaxies are accompanied by errors that generally broadens the shape and changes the median redshift of the galaxy distribution. The redshifts of galaxies are misestimated due to catastrophic errors, which changes the photometric redshift distribution of galaxies. On the other hand systematics like photometric calibration errors, which arise due to fluctuations in the limiting magnitude of surveys, lead to unphysical variations in the number density of galaxies over the survey area. In Chapter 3 we study the impact of these systematic errors on estimation of cross-correlation between CMB lensing potential measured by the *Planck* satellite and photometric galaxy catalogues from the *Herschel* Extragalactic Legacy Project.

Future galaxy surveys will have larger area coverage in the sky and increase in the magnitude depth, thus observing significantly larger number of galaxies than their predecessors. These features of the upcoming surveys will enable us to perform cross-correlation analyses with galaxies divided into redshift bins. These *tomographic* cross-correlation measurements allow us to map the evolution of cosmological parameters and test the validity of cosmological model at different

redshifts. However, tomographic measurements suffer from an additional systematic arising from the redshift bin mismatch of objects due to photometric redshift errors. This issue is addressed in Chapter 4. Using a suite of Monte Carlo simulations of the Rubin Observatory Legacy Survey of Space and Time (LSST) and the *Planck* lensing map we thoroughly study how the scatter of objects between redshift bins biases the inferences based on tomographic cross-correlation analysis and show how to avoid these biases using scattering matrix formalism. We propose and test new, fast method of estimation the scattering matrix which is well-suited for the analysis of upcoming large galaxy surveys. We also demonstrate in Chapter 5 the application of scattering matrix to tomographic analysis of cross-correlation between galaxy catalogue from the Dark Energy Spectroscopic Instrument Legacy Imaging Survey and the *Planck* gravitational lensing map.

The collection of works in this thesis have shown (i) the mitigation strategies of different systematics on cross-correlation measurements of CMB lensing with photometric redshift galaxy catalogues, (ii) that in the case of LSST survey biases in tomographic analysis due to redshift bin mismatch of objects are of order of one standard deviation for the amplitude of cross-correlation and σ_8 parameter, (iii) and that to avoid biases in tomographic analysis one needs to use the scattering matrix approach which properly takes into account redshift bin mismatch of objects.