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Thesis Abstract:

The distribution of matter in the Universe contains a wealth of information about the energy content in the Universe, its properties, and evolution.
It can be studied in two very different regimes. First, in gravitationally bound systems like galaxies, cluster of galaxies etc.; second, in the large scale structure (LSS) of the Universe. Each of these regimes have specific applications and they collectively improve the understanding of the theory of structure formation and cosmology.
Firstly, clusters of galaxies are the largest gravitationally bound structures in the Universe, consisting of hundreds of galaxies and intra-cluster gas moving in the potential well of the large dark-matter component. Because of their deep potential well, high density and high temperature of their gas, the clusters can be studied with probes like gravitational lensing, X-ray observations etc., and provide cosmic laboratories to study the interactions of baryons and dark-matter, or non-standard properties of dark-matter, if any. Secondly, the LSS is formed due to the evolution of tiny perturbations in the initial density field via gravitational instability and many baryonic processes. By studying the distribution of matter in the LSS, it is possible to constrain the initial conditions and/or the cosmological parameters.
In this PhD dissertation, I focussed on these two aspects and successfully concluded five scientific papers, which are attached in this manuscript:
We studied the distribution of matter in three clusters of galaxies and reconstructed their mass distribution using a non-parametric technique in strong gravitational lensing. In two of these clusters, we found significant offset between the density peaks and the nearest galaxy. We discussed weather these offsets could have an astrophysical origin or be an indication of self-interactions of dark-matter particles. Continuing in the same vein, we studied the effect on time delay, between different images of the same source, of the mass distribution of the lensing clusters.
We found that in clusters where the steepness degeneracy is already broken by multiple background sources at diffrent redshifts, time delay information can be used to constrain the lopsidedness of the cluster core.
In other work, we built an analytical model for the matter power spectrum that describes the matter density fluctuations statistically (only to second order). The model is computationally inexpensive and predicts the matter power spectrum to a
percent level accuracy up to k 0.7h 1Mpc.
Furthermore, we studied the effects of baryons on the sky-projected weak lensing shear power spectrum. We argued that these effects become significant at small scales of 5000 and if ignored, it will bias the interpretation of the cosmological parameters to many sigma.
Finally, we reconstructed the mass maps of six Hubble Frontier Field clusters. Their mass distribution shows elongation, multiple-cores, and many sub-structures indicating a recent major merger. We also quantified their clustering properties with the power spectrum of the mass field and compared them with Lambda-CDM simulated clusters.