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Hierarchical Cosmology Constraints through Strong Gravitational Lensing

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Strong gravitational lensing, a phenomenon where the gravitational field of a massive foreground galaxy distorts and magnifies the light from a distant background source, provides a unique astrophysical laboratory. It uniquely bridges studies of the very large and the very small, enabling simultaneous investigation of the internal structure of galaxies and the global geometry of the universe. This dual capability makes it a powerful tool for probing the two most significant constituents of the modern universe: dark matter and dark energy. Research on galaxy mass distributions via strong lensing pertains to the nature of dark matter, while the use of lensing as a cosmological probe informs our understanding of dark energy. However, these two lines of inquiry are inherently intertwined.

This thesis focuses on developing a self-consistent framework to investigate both the redshift evolution of galaxy mass distributions and cosmological parameters, with the aim of decoupling their mutual dependencies. We first present a model-independent method to study the mass profile evolution in lens galaxies. By training a non-parametric artificial neural network (ANN) on Type Ia supernova data to reconstruct the distance-redshift relation, we compare the inferred distance ratios with predictions from lens models. Applied to a combined sample of 161 lenses, this approach measures a significant redshift evolution in the extended power-law mass density slope, with the total mass profile steepening at lower redshifts. The method was validated with mock data based on LSST forecasts, which also project high precision for future large samples.

We subsequently extend this framework to a hierarchical cosmological analysis using distance ratios derived from strong lensing. A Fisher-based sensitivity study identifies "sensitivity valleys" in the lens-source redshift plane where cosmological constraining power diminishes. By incorporating the prior on mass-profile evolution calibrated in the first part of the study, we reconstruct distance ratios from lensing observables and compare them to cosmological predictions. This hierarchical scheme allows for joint constraints on both mass-profile evolution and cosmological parameters within a single, unified analysis. The degeneracies between these probes are broken by incorporating external datasets. In a flat wCDM model, combining strong lensing distance ratios with \textit{Planck} CMB data yields a constraint on the dark energy equation of state parameter of $w = -1.52^{+0.18}_{-0.19}$. In the flat w_ϕCDM model, adding DESI BAO data provides a measurement of the matter density parameter $\Omega_m = 0.256^{+0.031}_{-0.018}$. This work establishes a robust, integrated methodology for advancing our understanding of galaxy evolution and cosmology through the large sample of strong gravitational lensing.

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