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Redshift Evolution of Lensing Galaxy Density Slopes via Model-Independent Distance Ratios

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Strong lensing (SL) systems, which are expected to be massively discovered by the LSST, provide powerful tool for studying cosmology and galaxy structure. The Einstein radius is a robust measure of the total projected mass of the lens. When combined with stellar kinematics it can be used to constrain the radial mass profiles of the lens. However, the observed angular size of the Einstein radius depends also on the cosmological model through the distance ratio D_ls/D_s. Hence, galaxy structure and cosmology become entangled.
Therefore, if one needs to use strong lenses for testing cosmological model one needs to assume the effective model of the lens mass distribution. Usually this is SIS or more general spherically symmetric power-law (PL) model. On the other hand, PL slope parameter γ is being determined from observations assuming a fiducial cosmological model (usually vanilla LCDM model). This creates a vicious circle. In this study, using a compilation of 161 well studied SL systems we attempted at characterizing the PL slope and its possible evolution with redshift using an original cosmological model independent approach. Namely, the distance ratios have been reconstructed using non-parametric regression methods, specifically Artificial Neural Networks (ANN) and Gaussian Processes (GP), applied to the data comprising the Hubble parameter H(z) from cosmic chronometers and luminosity distances D_L(z) from type Ia supernovae. Such reconstruction relates only to what the nature tells us in the data, without assuming any specific cosmological model.
We tested two approaches regarding the lens mass distribution: The first is with a single PL index characterizing the total mass (both dark and luminous). The second one distinguishes γ PL index as describing the total mass ρ{tot}(r)= ρ{tot} r^{-γ} and δ PL index describing luminous matter ρ{lum}(r)= ρ{lum} r^{-δ}. Across various methods, our results show that the total mass becomes more concentrated from redshift z~1 to the present day. In models where the density slope of luminous matter can be different from that of the total mass, we find that the density profile of luminous matter flattens over time. And this model suggests a steeper density slope for luminous mass relative to total mass, consistent with observations from detailed lensing galaxy studies. These findings offer a reference point for leveraging strong lensing systems in cosmological constraints and studying galaxy evolution, with potential applications currently being explored.

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