A Novel Einstein Radius Lensing Framework for Galaxy Mass Decomposition: Deriving Central Dark Matter Fractions and Their Scaling With Stellar Dynamics

Kramer, Zoe (School: South Eugene High School)

Dark matter dominates galaxy mass, but determining its central distribution depends on precise decomposition of total mass into dark and baryonic matter components. This study introduces a new strong lensing-based framework using the Einstein radius as a standardized aperture to eliminate persistent model-dependent biases in galaxy mass decomposition. I analyze 40 grade-A early-type galaxy lenses from the S4TM survey and derive the central dark matter fraction within the Einstein radius. This framework reveals a significant positive correlation between central dark matter fraction and stellar velocity dispersion, establishing a direct observational relation between visible galaxy dynamics and invisible dark matter structure. Monte Carlo simulations and bootstrap resampling show the scaling relation is robust to sample composition and lensing uncertainties. Additionally, I identify stellar mass normalization as the dominant source of uncertainty. Parameter recovery demonstrates that the Einstein radius framework achieves higher precision than existing approaches. This study (1) introduces a more rigorous method for galaxy mass decomposition; (2) establishes a direct observational correlation between central dark matter fraction and stellar velocity dispersion; and (3) quantifies the effect of lensing and modeling uncertainties on scaling relations.

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