Quantitative Analysis of Systematic Errors in Hubble Constant Determination by Gravitational Lens Modeling

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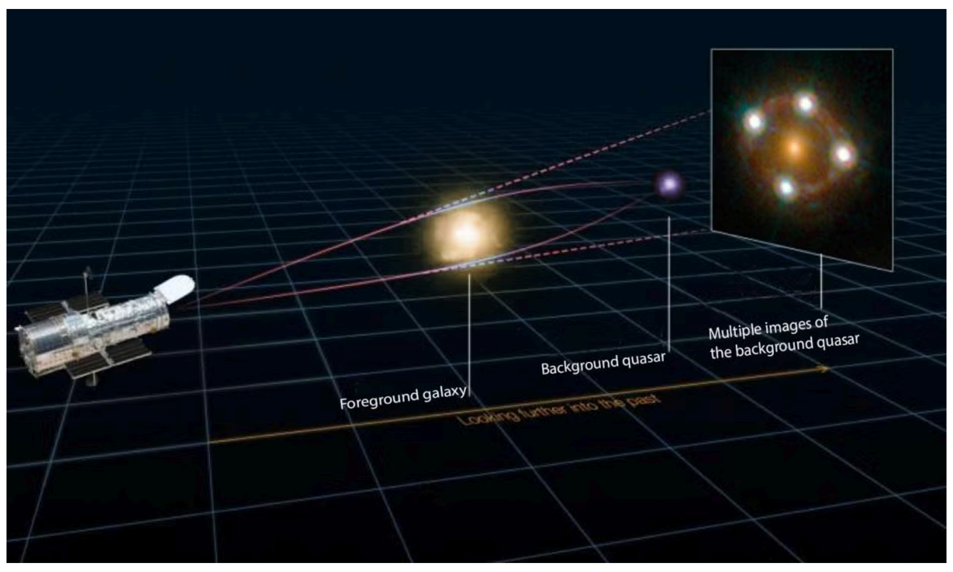
ABSTRACT

Time delays between the multiply lensed images in a strong gravitational lens system, together with lensing galaxy mass distribution derived from lens modeling have been a promising one-step measurement for cosmological constants, especially the Hubble constant. In this project, we performed a blind **lens model analysis on a mock quadruply lensed supernova system** using mock Hubble Space Telescope imaging simulated by IllustrisTNG, and used it to **estimate the bias in Hubble constant determination by time delay cosmography**.

INTRODUCTION

The Hubble constant indicates the expansion rate of the universe. Currently, there is a significant discrepancy between H0 measurements from the early and late universe. To resolve such tension, gravitational lensing provides a one-step solution as it is completely **independent of both the supernovae and CMB analyses**.

When light from a quasar or supernova passes through a galaxy, it is bent by the warped spacetime due to gravity, creating multiple images. The times taken for light to arrive at different image positions are different. This effect is called 'time delays'.



In theory, precise time delay measurements combined with accurate information on the galaxy's mass distribution, can yield an accurate H0. In practice, before applying this approach, **its systematic errors must be quantified**.

Time Delays, Mass Distribution, Hubble constant

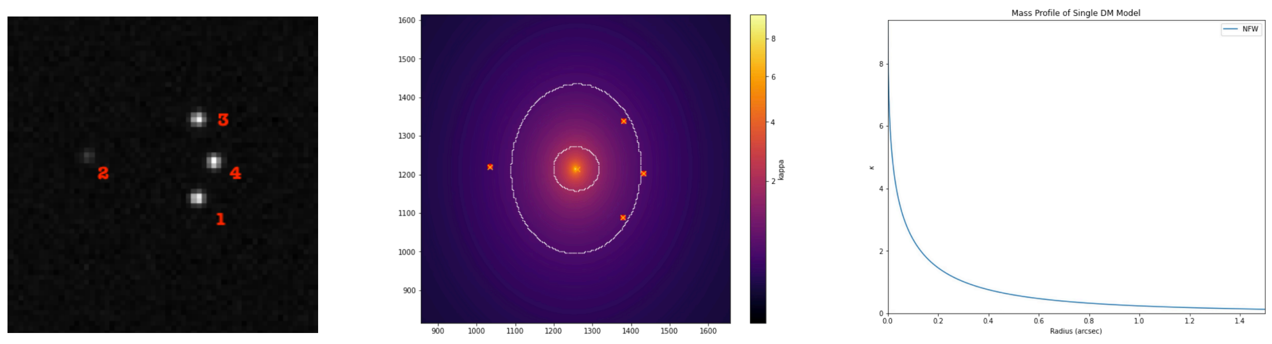
time delays: $$t(\theta,\beta) = \frac{D_{\Delta t}}{c}\left[\frac{(\theta-\beta)^2}{2} - \phi(\theta)\right]$$

Angular diameter distance:
$$D_c = \frac{c}{H_0}\int \frac{dz'}{E(z')}$$

METHODOLOGY

First, we use glafic to construct gravitational lens models for a mock multiply-lensed supernova system in nearby universe. The constraints imposed on modeling include positions, magnifications, and time delays. To start, I will implement just a dark halo profile and test different proposed mass profiles (e.g. SIE, Power Law, NFW).

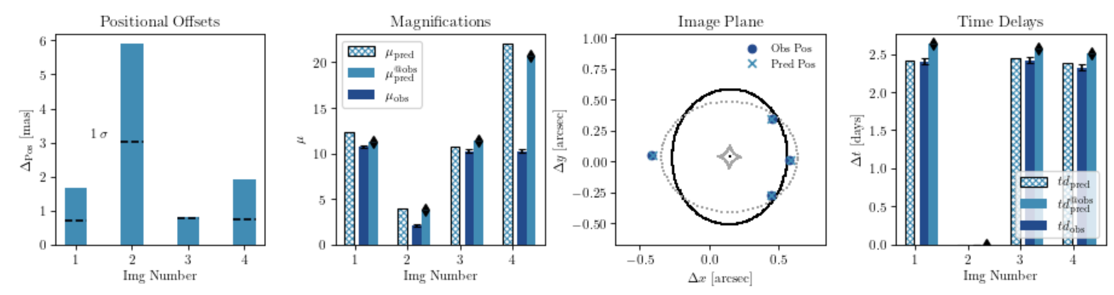
Then we add additional ingredients to the models, including **nearby perturbers** and **a baryonic mass profile** to see their effects on the models. After the models are finished, we **compare the predicted galaxy mass distribution from the modeling results with the actual galaxy mass distribution** to analyze the discrepancies. I will also compare the Hubble constant value predicted by the models with the one used for the simulation. In this case, the systematic error of using lens modeling to determine Hubble constant is quantified.



RESULTS

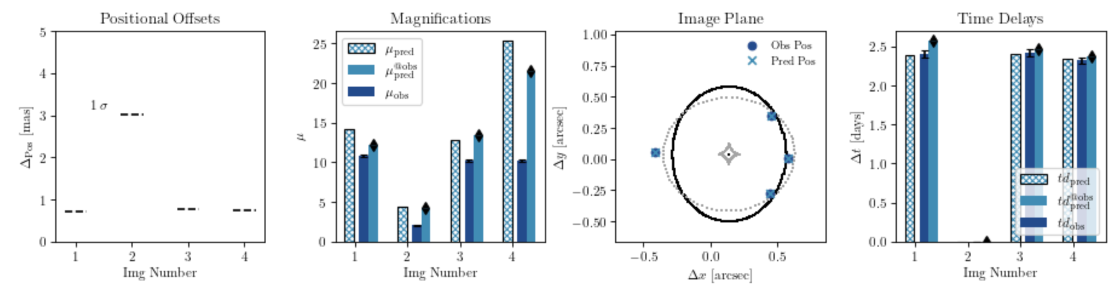
- **Single Dark Halo Profile Models**

We find models with a single DH profile generally **cannot reproduce all constraints** within 1 sigma errors. There is an anomaly for magnifications at the fourth image for every models. The H0 predictions for single-profile model are round 70 km/s/Mpc.



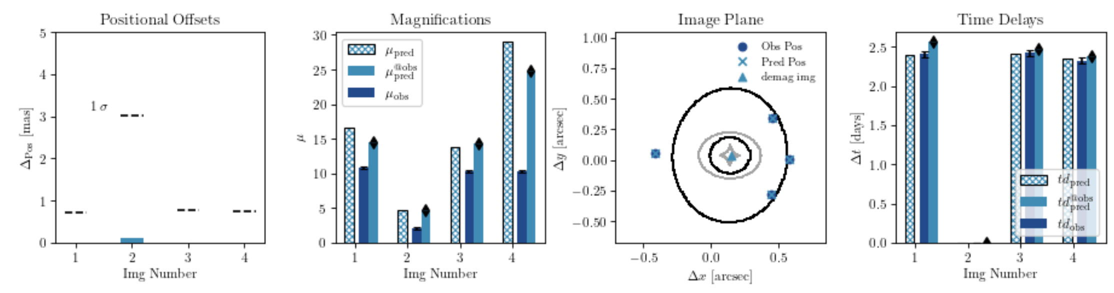
- **Single Dark Halo Profile + external shear**

We find that adding an external shear to the single-profile model can **effectively resolve position anomalies**. The H0 predictions for these models are around 68 km/s/Mpc.



- **Composite models (Dark Halo + Baryonic matters)**

We find that the galaxy light is well-fitted as a double Sersic profile. By adding the fitted light profile to the lens models, we find that position anomalies are resolved in a certain level. The H0 predictions from composite models are around 68 km/s/Mpc.



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Wong, K. C., Suyu, S. H., Auger, M. W., Bonvin, V., Courbin, F., Fassnacht, C. D., Halkola, A., Rusu, C. E., Sluse, D., Sonnenfeld, A., Treu, T., Collett, T. E., Hilbert, S., (2016). H0licow – iv. lens mass model of he 04351223 and blind measurement of its time-delay distance for cosmology. Monthly Notices of the Royal Astronomical Society, 465(4):4895–4913.