

Research Synopsis:

Gravitational lensing is the phenomenon by which massive celestial bodies such as galaxies or galaxy clusters curve spacetime, effectively bending light from a background object, typically a distant quasar or a supernova (SN) [Arendse et al., 2025]. This work is focused on strong lensing, where the foreground object (in our case, a massive galaxy) is massive enough to produce multiple images of the background object (in our case, Type Ia Supernova (SNIa)). Lensing is caused by luminous and dark matter in the foreground galaxy. Thus, Gravitational lens modelling is one way we can probe the dark matter profile of the lensing galaxy [Torres-Ballesteros and Castañeda, 2022]. Lens modelling is the process of reproducing properties of the lensed images, such as their positions and magnifications, by modelling different parametric dark matter profiles. No previous work has managed to model a perfect lens, leaving either position or magnification anomalies. This suggests that either our parametric models fail to capture the full complexity of a galaxy's dark matter profile or that lens modelling as a technique inherently leaves anomalies. In anticipation of the observation of thousands of new lensed supernovae (SN) and quasars from future surveys, such as the Legacy Survey of Space and Time (LSST), it is necessary to assess the accuracy of current gravitational lens modelling techniques. We present a novel approach to test if lens modelling can determine the underlying lensing galaxy dark matter profile by using mock strong lenses of a SNIa using the IllustrisTNG suite of simulations. The mock lenses are made with a parametric dark matter profile, enabling unblinding after lens modelling and allowing us to compare with the real profile, something unavailable to us in real observations. Since we are blinded from the correct model, we follow all the procedures of a real observation. We aim to determine if lens modelling will reveal the correct model by matching the observed positions and magnifications. We also aim to quantify the magnitude of anomalies left by each model. Finally, we add an external shear to our models to determine how much of an improvement can be made in our predictions by simply adding shear.

Our data is a FITS image of a lensed SNIa as well as an image of the lensing galaxy simulating a post-SNIa observation. We are provided with the redshifts of both the lensing galaxy and the SN, as well as other relevant details of the observation. We begin by fitting the four lensed images individually with a Gaussian using the program *Imfit*. We further run an MCMC on the images and extract their respective positions and magnifications. We use the software package *Glaic* to construct lens models. For the purposes of this project, we will consider five parametric lens models: Single Isothermal Ellipsoidal (SIE), power law (POW), Navarro-Frenk-White (NFW), cored-SIE and Einasto (EIN). We make a series of models with these profiles first using only the positions of the images as a constraint and then with both the positions and magnifications as constraints. We then repeat this process with an external shear component.

We find that none of the lens models alone can reproduce the positions or the magnifications of all the images within 1σ and leave position and magnification anomalies. However, NFW and EIN are the closest to matching both the positions and magnifications and especially outperform the other models in predicting the magnifications. We find that all models are consistently able to predict the position of the brightest image within 1σ , but the predictions for the other images are nowhere close to 1σ . Importantly, all models converge on common model parameters, such as ellipticity and position angle. Another trend we observe is that the models with only the positions as constraints match the observed positions better than the position and magnification-constrained models. When we add shear to the models, these results change significantly. With shear, all the models are able to predict the image positions within 1σ for the position-only constraint models, but the magnifications are still outside the 1σ range. For these models, the position anomalies are on the order of 10 micro-arcsec. The

position and magnification-constrained models follow a similar trend, however, the position anomalies are much larger. Again, NFW and EIN give the best results and are fairly close in their predictions.

The inability of all the models to predict the positions and magnifications of the images indicates that lens modelling might inherently leave anomalies, considering one of the profiles we have modelled is the real profile used to generate the mock image. The scale of the position and magnification anomalies is fairly significant, though most of the models have far worse magnification anomalies. The shear models demonstrate the ability of shear to essentially resolve position anomalies and seriously undermine the common practice of adding shear to lens models to improve modelling results. The lens we are using is fairly isolated and should not require a shear component. However, adding a shear component improves predictions for all models, most likely due to adding a series of free parameters. Thus, even though unphysical, adding shear can provide the best results. This indicates that more serious consideration needs to be given to understanding the cause for lensing anomalies as well as if adding shear is physical.

References:

N. Arendse, E. Mortsell, L. Weisenbach, E. Hayes, S. Thorp, S. Dhawan, A. Goobar, S. Guerrini, J. O. Hjortlund, J. Johansson, and C. Lemon. Microlensing of lensed supernovae zwicky iptf16geu: constraints on the lens galaxy mass slope and dark compact object fraction, 2025. URL <https://arxiv.org/abs/2501.01578>.

D. A. Torres-Ballesteros and L. Castañeda. γ -relensing/ γ : Reconstructing the mass profile of galaxy clusters from gravitational lensing. *Monthly Notices of the Royal Astronomical Society*, 518(3):4494–4516, Nov. 2022. ISSN 1365-2966. doi: 10.1093/mnras/stac3253. URL <http://dx.doi.org/10.1093/mnras/stac3253>.