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Systematics errors in strong lens modeling

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Abstract. We investigate how varying the number of multiple image constraints and the available redshift information can influence the systematic errors of strong lens models, specifically, the image predictability, mass distribution, and magnifications of background sources. This work will not only inform upon Frontier Field science, but also for work on the growing collection of strong lensing galaxy clusters, most of which are less massive and are capable of lensing a handful of galaxies.

Keywords. galaxies: clusters: general, gravitational lensing

Gravitational lensing is powerful tool for revealing the dark mass distributions of galaxy clusters and for magnifying the background universe. Accurate and precise strong lens modeling is vital to projects such as the Frontier Fields (FF) since the magnification can affect number counts and luminosities. Lens modeling algorithms can make robust estimates of the statistical errors; however, the systematics are more difficult to quantify. The accuracy of a model depends highly on the availability of strong lensing constraints (i.e., multiple image systems) and precise measurements of their redshifts. Here we outline some of the first efforts to quantify systematic errors in strong lens modeling.

This work is motivated by two questions: (1) how does the number of multiple image systems used in a lens model influence the systematic errors, and (2) how does the availability of redshift information influence systematics? We test these questions by modeling the simulated cluster Ares, a semi-analytic cluster created by M. Meneghetti built in similarity to the FF clusters. Ares is one of the clusters used in the lens modeling comparison study, which compares the outputs of different lens modeling codes using identical inputs. The work we present here instead compares models built using identical modeling software but different inputs.

We created a "fiducial" lens model of the cluster Ares using all of the available multiple image systems ($n = 66$) and known redshifts from the simulations, using the publicly available lensing software Lenstool (Jullo *et al.* 2007) and following methods similar to Johnson *et al.* (2014). This model produces masses and magnification maps similar to the simulation "truth". The fiducial model represents the best model that can be produced when information is available. The cluster was then modeled again using the same parameterization and priors as the "fiducial model", but using random subsets of image systems ($n = 5, 10, 15...$). Additionally, some of those images were selected to have hidden redshift information, meaning only the positions were used as constraints and the redshift was left as a free parameter in the model.

Image predictability: The image plane (IP) rms scatter is a measure of a model's ability to accurately predict the locations of multiple images. We compute the IP rms scatter for all models using a common set of multiple images and find that: (1) adding more

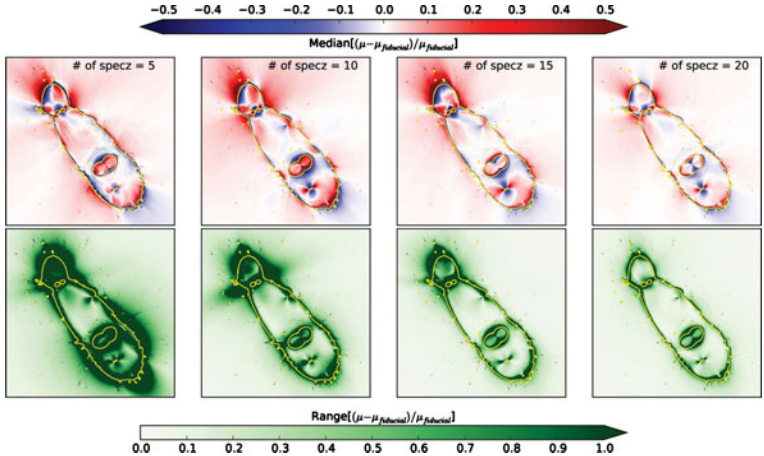

Figure 1. Magnification errors ($z = 9$) for models of the simulated cluster Ares using different numbers of multiple image systems in the model (all spectroscopic). The top row shows the bias in magnification compared to the magnification obtained from the fiducial model median value for a set of 10 unique models. The bottom row shows the spread magnification error, or range of magnifications obtained for each pixel out of a set of 10 unique models. The yellow line is the $z = 9$ critical curve of the fiducial model.

image systems with spectroscopic redshifts will in lower the IP rms, and (2) once ~ 10 spectroscopic image systems have been added, adding more systems will not improve the IP rms.

Mass distribution: We compute the radial mass profile for each model and find that all models using more than five image systems are within $\sim 5\%$ of the fiducial model and true profile out to 1 Mpc and within about $\sim 2\%$ at the Einstein radius of the cluster where the multiple images are located.

Magnification: We compare the magnification maps of each model to the fiducial model (see Figure 1) and find that the magnification error is lowest ($< 10\%$) for relatively low magnifications ($\mu < 10$) and along the long edges of the critical curve. The bias in magnification is difficult to predict for a given number of image systems used in the model; however, the spread in magnification error decreases as more image systems are added when comparing different models the same n.

In summary, IP rms and mass are fairly robust quantities compared to the magnification. The deflection angles and surface mass density are computed from derivatives of the lensing potential, while magnification is a non-linear combination of derivatives; thus, we expect errors on magnification not to behave in a straight-forward manner. More work will need to be done before we can begin to quantify those errors.

We plan to carry out similar studies using the FF clusters, which are ideal due to their wealth of multiple image systems and spectroscopic redshifts. Not only will quantifying strong lensing systematics be helpful for the science of the FF, it will be helpful for the many current and future cluster surveys. The FF clusters are unique in their ability to lens many objects; most galaxy clusters are only capable of producing a handful of multiple image systems and will be too many in number for complete spectroscopic follow-up. Thus, these clusters are more prone to systematic errors.

References

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