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Strong Lensing Mass Reconstruction: from Frontier Fields to the Typical Lensing Clusters of Future Surveys

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Abstract. Driven by the unprecedented wealth of high quality data that is accumulating for the Frontier Fields, they are becoming some of the best-studied strong lensing clusters to date, and probably the next few years. As will be discussed intensively in this focus meeting, the FF prove transformative for many fields: from studies of the high redshift Universe, to the assembly and structure of the clusters themselves. The FF data and the extensive collaborative effort around this program will also allow us to examine and improve upon current lens modeling techniques. Strong lensing is a powerful tool for mass reconstruction of the cores of galaxy clusters of all scales, providing an estimate of the total (dark and seen) projected mass density distribution out to 0.5 Mpc. Though SL mass may be biased by contribution from structures along the line of sight, its strength is that it is relatively insensitive to assumptions on cluster baryon astrophysics and dynamical state. Like the Frontier Fields clusters, the most "famous" strong lensing clusters are at the high mass end; they lens dozens of background sources into multiple images, providing ample lensing constraints. In this talk, I will focus on how we can leverage what we learn from modeling the FF clusters in strong lensing studies of the hundreds of clusters that will be discovered in upcoming surveys. In typical clusters, unlike the Frontier Fields, the Bullet Cluster and A1689, we observe only one to a handful of background sources, and have limited lensing constraints. I will describe the limitations that such a configuration imposes on strong lens modeling, highlight measurements that are robust to the richness of lensing evidence, and address the sources of uncertainty and what sort of information can help reduce those uncertainties. This category of lensing clusters is most relevant to the wide cluster surveys of the future.

Keywords. galaxies: clusters: general, gravitational lensing

Current and future wide-field surveys are to discover thousands of new galaxy clusters, many of which will be gravitational lenses (e.g., Bleem *et al.* 2014). Most of these clusters will *not* be similar to the Frontier Fields in terms of their strong lensing (SL) power, and are more likely to exhibit SL constraints from only a handful of background lensed galaxies. Even with extensive followup, additional constraints will not be recovered, simply because the SL cross section is not large enough in most clusters. Moreover, follow-up data (e.g., redshifts of background sources, high resolution imaging) will be very limited and incomplete. In order to prepare for the SL mass modeling needs of future surveys, and for the discovery thousands of clusters with relatively poor SL evidence, we must understand the limitations and strengths of SL modeling in light of the expected sparse lensing evidence. Our study leverages our recent SL work on the Frontier Fields clusters (Johnson *et al.* 2014, Sharon & Johnson 2015) and ongoing work on the Sloan Giant Arcs Survey (M. Gladders *et al.*, in prep), where SL models inform studies of highly magnified background sources (e.g., Sharon *et al.* 2014, Dahle *et al.* 2014, Wuyts *et al.* 2014).

The Gini Coefficient in Lensed Galaxies. The Gini coefficient is a quantitative measure of the inequality with which the light is distributed in a galaxy. In a forthcoming series of papers by Florian *et al.* we study ray-tracing simulations of lensed galaxies and demonstrate that the Gini coefficient is generally preserved through gravitational lensing. The importance of this finding, is that a quantifiable morphological properties of lensed galaxies can be robustly measured, even without knowledge of the lensing magnification or a detailed lens model. We demonstrate that combined with color information the Gini coefficient can be used to identify or confirm sets of multiple images of the same background source. Multiple images of the same background source fall on well-defined loci in Gini-color space. This identification technique performs better than color alone or even color-color information. In a follow up paper (Sharon *et al.* in prep) we will test this approach on Frontier Fields data.

The Strengths and Limitations of SL modeling. The limited constraints in most SL clusters, such as the hundreds discovered in SGAS, limit our ability to compute robust, detailed lens models. We consider how the locations of SL constraints and the availability of spectroscopic redshifts affect the statistical uncertainty on mass and magnification. We model real cluster data (e.g., FF, A1689 and A2218) and simulated data (e.g., “Ares” by M. Meneghetti). We generate a host of models, each based on a different subset of the lensing constraints. To test the statistical uncertainty, we compare the lensing outputs to those of a “fiducial” model which uses as constraints > 100 arcs, approximately evenly distributed around the cluster. This model represents the best possible Lenstool model for each cluster. We note that this investigation is insensitive to systematic uncertainties, such as structure along the line of sight. Our findings indicate that the statistical scatter at small ($\lesssim 100$ pc) and large ($\gtrsim 600$ kpc) clustercentric projected radii are significant, and the enclosed mass within these regions are crude extrapolations of the lens model. However, the mass enclosed within the projected radii where the lensing constraints exist, i.e., around the critical curve, is a robust measurement with statistical uncertainty of $< 5\%$. This is true in most cases, but may fail in clusters where the distribution of lensing constraints is preferentially on one side of the cluster. The redshift of background sources can be left as a free parameter in most current SL modeling algorithms. We caution against making strong statements on the distribution of dark matter in the cluster, in particular on its radial slope, as the unknown redshift shows strong correlation with some of the dark mater halo parameters.

References

Bleem, L. E., Stalder, B., de Haan, T., *et al.* 2015, *ApJS* , 216, 27
Dahle, H., Gladders, M. D., Sharon, K., *et al.* 2013, *ApJ* , 773, 146
Johnson, T. L., Sharon, K., Bayliss, M. B., *et al.* 2014, *ApJ* , 797, 48
Sharon, K. & Johnson, T. L. 2015, *ApJ* (letters), 800, L26
Sharon, K., Gladders, M. D., Rigby, J. R., *et al.* 2014, *ApJ* , 795, 50
Wuyts, E., Rigby, J. R., Sharon, K., & Gladders, M. D. 2012, *ApJ* , 755, 73