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`cluster−lensing`: A `Python` PACKAGE FOR GALAXY CLUSTERS AND MISCENTERING

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ABSTRACT

We describe a new open source package for calculating properties of galaxy clusters, including NFW halo profiles with and without the effects of cluster miscentering. This pure-`Python` package, `cluster−lensing`, provides well-documented and easy-to-use classes and functions for calculating cluster scaling relations, including mass-richness and mass-concentration relations from the literature, as well as the surface mass density $\Sigma(R)$ and differential surface mass density $\Delta\Sigma(R)$ profiles, probed by weak lensing magnification and shear, respectively. Galaxy cluster miscentering is especially a concern for stacked weak lensing shear studies of galaxy clusters, where offsets between the assumed and the true underlying matter distribution This software has been developed and released in a public GitHub repository, and is licensed under the permissive free MIT license. The `cluster−lensing` package can be downloaded through the Python Package Index, https://pypi.python.org/pypi/cluster-lensing, or directly from GitHub, at https://github.com/jesford/cluster-lensing. Full documentation is available at http://jesford.github.io/cluster-lensing/.

Subject headings: gravitational lensing: weak, galaxies: clusters: general, dark matter, methods: data analysis, methods: numerical

1. INTRODUCTION

Clusters of galaxies are the largest gravitationally collapsed structures to have formed in the history of the universe. As such, they are interesting both from a cosmological as well as an astrophysics perspective. In the former case, the galaxy cluster number density as a function of mass, known as the cluster mass function, is a probe of cosmological parameters including the fractional matter density Ω_{M} and the normalization of the matter power spectrum σ_8. Astrophysically, the deep potential wells of galaxy clusters are environments useful for testing theories of general relativity, galaxy evolution, and gas and plasma physics, among other things (Voit 2005).

The common thread among these diverse investigations is the requisite knowledge of the mass of the galaxy cluster, which is largely composed of its invisible dark matter halo. Although many techniques exist for estimated the total mass of these systems, weak lensing has emerged as somewhat of a gold standard, since it is sensitive to the mass itself, and not to the dynamical state or other biased tracers of the underlying mass. Since weak lensing masses are often considered the "true" masses, against which other estimates are compared (Leauthaud et al. 2010; von der Linden et al. 2014; Hoekstra et al. 2015, e.g.), it is paramount that cluster masses from weak lensing modeling are as unbiased as possible.

- Background about clusters and weak lensing.
- NFW halos (Navarro et al. 1997; Wright & Brainerd 2000)
- composite-NFW fits for weak lensing (Ford et al. 2012, 2014, 2015)
- What is new = miscentering (Johnston et al. 2007; George et al. 2012; Ford et al. 2014, 2015)

2. DESCRIPTION OF THE CODE

- Purpose and general use.
- Relation to existing code
- `SurfaceMassDensity`() class, generic to all NFW halos
- `ClusterEnsemble`() class
- mass-richness functions
- mass-concentration functions
- We use units from the `astropy.units` package (Astropy Collaboration et al. 2013).

3. EXAMPLES

- No miscentering
- With miscentering
- others...

4. FUTURE DEVELOPMENT

Plans for the future.

5. SUMMARY

Summary goes here.

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