Measuring Intrinsic Alignments of Galaxies in Clusters

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Abstract

Weak gravitational lensing is a powerful probe in cosmology, particularly for mapping the distribution of dark matter and measuring the mass of galaxy clusters. However, the lensing signal can be contaminated by inherent correlations between galaxy shapes. In this project, we investigate such intrinsic alignments of galaxies in clusters using data from the Dark Energy Survey (DES). Specifically, we measure how well central galaxies tend to align with the cluster orientation and how satellite galaxies tend to align with the central galaxy orientation. We find that central galaxies do tend to align with their clusters, in good agreement with results from previous studies.

Introduction

The unknown cause of the universe's accelerated expansion is called dark energy. The Dark Energy Survey (DES) studies dark energy using weak gravitational lensing, a phenomenon where the deflection of light from distant objects by intervening matter causes slight distortions in their image shapes. Light rays from objects near each other on the sky are lensed by the same structures, so their image shapes are correlated by weak lensing. These correlations allow us to use weak lensing to infer the distribution of matter (shown in Figure 1) and analyze how dark energy affects the formation of large-scale structure.

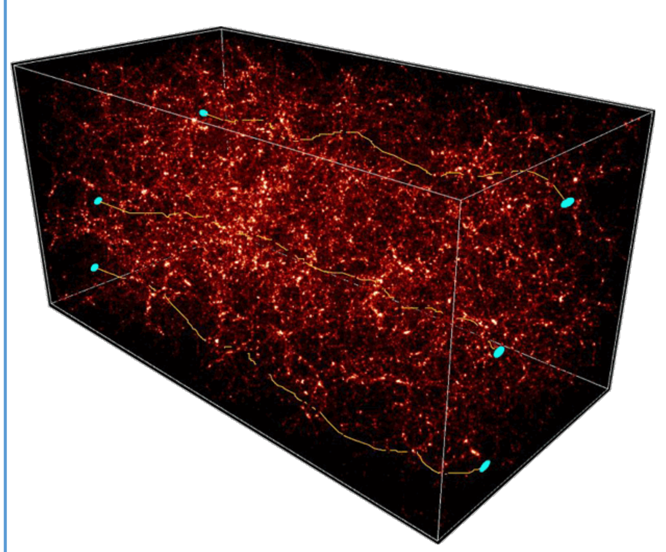

Figure 1. The paths of a light ray from three different galaxies are slightly deflected by weak lensing. Adapted from the HETDEX website.

Weak lensing relies on precise measurements of the effect of lensing on galaxy shapes. However, galaxies are not oriented randomly—they have natural tendencies to align in certain directions, called intrinsic alignments. These tendencies significantly contaminate weak lensing measurements if unaccounted for, so there has been much effort over the past several decades aimed at measuring, understanding, and mitigating the effects of intrinsic alignments (Troxel and Ishak, 2015).

On large scales, galaxies tend to form clusters, each with a central galaxy surrounded by satellite galaxies. One type of intrinsic alignment within clusters is central galaxy alignment, which refers to the tendency of the central galaxy major axis to align with that of its host cluster. A recent study, Huang et al. (2016), measured central galaxy alignments in clusters using data from the Sloan Digital Sky Survey (SDSS), a survey similar to DES. DES looks deeper than SDSS, so we can now study intrinsic alignments at higher redshifts. This project seeks to measure intrinsic alignments, specifically central galaxy alignments, in DES data to compare results with previous SDSS measurements in preparation for exploring intrinsic alignments in the deeper universe.

Objectives

- Measure intrinsic alignments of galaxies in clusters using data from DES
- Compare intrinsic alignment measurements with previous work

Methods

The red-sequence Matched-filter Probabilistic Percolation (redMaPPer) cluster finding algorithm groups galaxies into clusters based on photometric (brightness-reliant) galaxy samples from astronomical survey data (Rykoff et al., 2014). We used the following catalogs:

- Y1A1 redMaPPer (cluster)
- DES Year 1 METACALIBRATION (shape)

We measured central galaxy alignment in two ways:

Position Angle Difference

Defined as the angle between the central galaxy major axis and the major axis of the overall cluster. Measuring this requires an approximation of the cluster shape via the distribution of satellites. Combining this with central galaxy ellipticities allows us to calculate position angle difference. We approximated cluster shapes with two methods:

- Second moments: The method used in Huang et al. (2016). We calculated the reduced second moments of the satellite positions with Equation 1 and used Equation 2 to find the overall cluster position angle (direction East of North).

$$M_{xx} = \frac{\sum_i p_{mem,i} \frac{x_i^2}{r_i^2}}{\sum_i p_{mem,i}}$$

Equation 1. The reduced second moments of satellite positions. x is the distance from central in RA (y is in Dec), r is the angular distance from central, and p_{mem} is the probability of membership.

$$\frac{1-b/a}{1+b/a}(\cos 2\beta, \sin 2\beta) = (M_{xx} - M_{yy}, 2M_{xy})$$

Equation 2. The relationship of second moments to shape. b/a is the minor-to-major axis ratio and β is the position angle.

- Quadrant grid: We placed a set of axes on the central galaxy, rotated at different angles θ, and counted the satellites in the 4 quadrants q_1, q_2, q_3, q_4 (clockwise order) for each theta. The count difference $m = q_1 + q_3 - q_2 - q_4$ was our metric for fitting the position angle. We created a model for m as a function of θ, Equation 3, assuming isotropic satellite distribution about the central. Fitting the parameters r and β by minimizing chi-squared (shown in Figure 2) gave the axis ratio and position angle of the overall cluster.

$$m(\theta) = \frac{n}{2\pi}\left(\tan^{-1}\left(r\tan\left(\theta-\beta+\frac{\pi}{2}\right)\right) + \tan^{-1}\left(r\tan\left(\theta-\beta-\frac{\pi}{2}\right)\right) - 2\tan^{-1}(r\tan(\theta-\beta))\right)$$

Equation 3. The model for m as a function of θ. n is the number of satellites in the cluster. Parameters: axis ratio r and phase shift β (position angle).

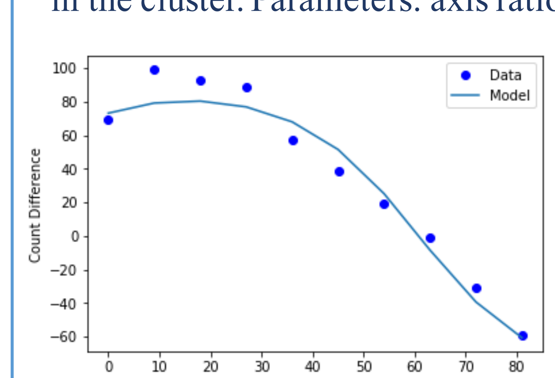

Figure 2. The model for count difference fit to the data of a random cluster.

Central Galaxy Alignment Angle

Defined as the angle between the central galaxy major axis and the line connecting it to a satellite galaxy, shown in Figure 3. This is a direct observable that we calculated from satellite positions and central galaxy ellipticities in the catalogs.

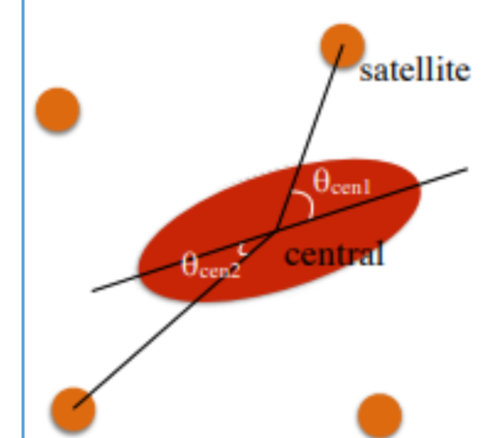

Figure 3. Central galaxy alignment angle. Adapted from Huang et al. (2016).

Results

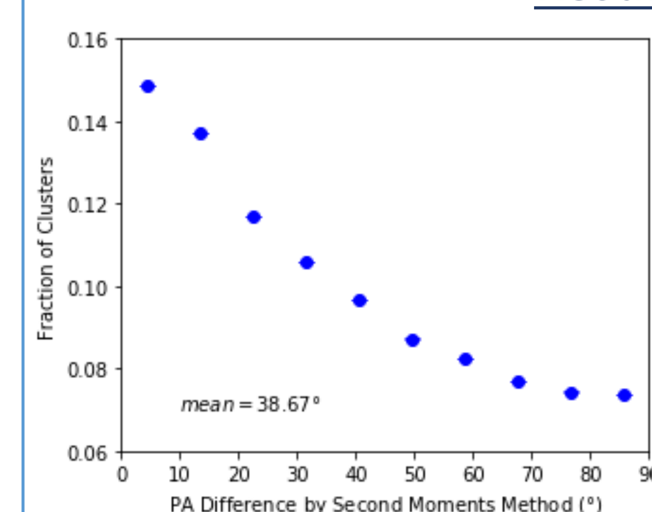

Figure 4. The distribution of position angle difference as measured by second moments.

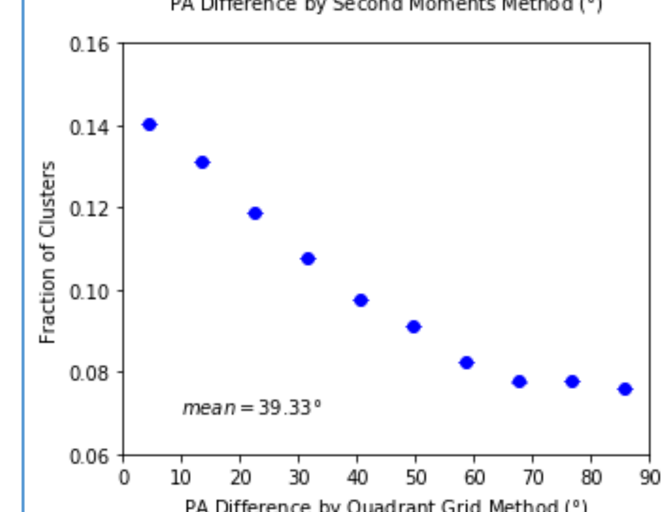

Figure 5. The distribution of position angle difference as measured by the quadrant grid method.

- Our novel quadrant grid method agrees very well with the previously used method.
- Trends toward zero indicate that central galaxies tend to align with the overall cluster shape.
- Trends and mean position angle difference agree with Huang et al. (2016), which found a mean position angle difference of 35.07°.

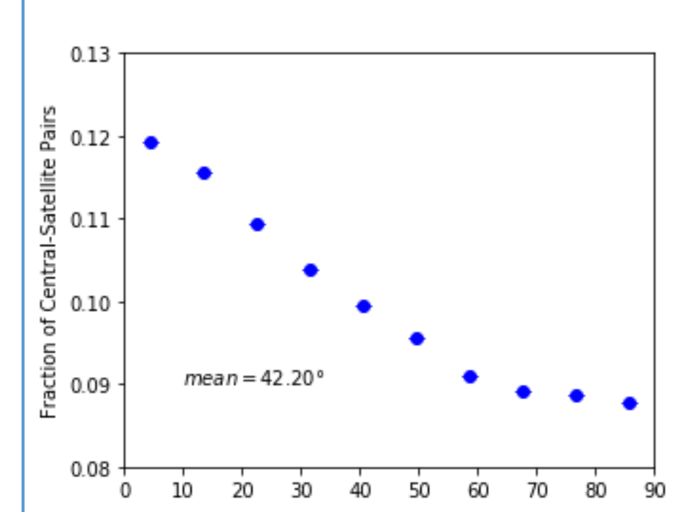

Figure 6. The distribution of central galaxy alignment angle.

- Trend toward zero indicates that satellite galaxies tend to reside along the central galaxy major axis.
- Trend and mean central galaxy alignment angle agree with Huang et al. (2016), which found a mean central galaxy alignment angle of 41.42°.

Summary

We found that measurements of intrinsic alignments over the full sample of redMaPPer clusters in DES agree very well with the same measurements done on SDSS data in Huang et al. (2016). Our results show strong signals for central galaxy alignment, with the position angle difference signal being slightly stronger than the central galaxy alignment signal. This also confirms the effectiveness of our novel quadrant grid method for measuring the overall shapes of clusters by their satellite galaxy distributions.

Future Work

After comparing our results with previous work, we intend to use the DES data to measure intrinsic alignments as a function of redshift and search for a possible evolution over time. Another possibility is to use the cluster position angles calculated in this work to check that the satellite galaxies of a cluster adhere to the shape of the underlying dark matter halo. We would do this by cutting out sections of the DES mass map that correspond to cluster locations, rotating them to align their major axes, and stacking them to cancel out the noise. The result should be the clear shape of an average dark matter halo. This work is part of a paper in preparation to be submitted to the Monthly Notices of the Royal Astronomical Society.

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