A galaxy-galaxy lensing measurement by cross correlating optical and radio data

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Introduction
Gravitational Lensing
Basics of WGL

- Fundamental lensing equation

\[ \Theta_s = \Theta - \frac{D_{ls}}{D_s} \alpha = \Theta - \alpha(\Theta) \]

- Distortions are of the order of 1%

\[ \alpha(\Theta) = \frac{\partial \Theta_s}{\partial \Theta} = \begin{bmatrix} 1 - \kappa - \gamma_1 & \gamma_2 \\ \gamma_2 & 1 - \kappa + \gamma_1 \end{bmatrix} \]

- Where

- \( \kappa \) is the convergence

- \( \gamma \) is the shear
Basics of WGL

- Requires prior knowledge of the galaxy intrinsic sizes
- Ellipticities are directly related to the shear $\gamma$

\[ \mathcal{E}^{\text{obs}} = \mathcal{E}^{\text{int}} + \gamma + \mathcal{E}^{\text{noise}} \]

\[ \hat{\gamma} = \frac{1}{N} \sum_{i=1}^{N} \gamma_i \]
Ring statistics

- **Binning**

- **Optimized shear estimators**

\[ \hat{\gamma}_t = \gamma_1 \cos(2\varphi) + \gamma_2 \sin(2\varphi) \]

\[ \hat{\gamma}_r = -\gamma_1 \sin(2\varphi) + \gamma_2 \cos(2\varphi) \]

\( \Phi \) is the angle formed when moving counter clockwise from the x-axes to the great circle connecting the pair of galaxies.
Ring statistics

- Shear is a headless vector
- Decomposed into B-mode and E-mode components

- E-mode is related to the tangential shear
- B-mode related to the rotated shear
- Rotated shear – non physical – used to trace systematics
- The aperture mass $m_{ap}$ is related to the tangential shear
Weak lensing studies

- A probe of the dark Universe
  - Directly probing the total mass of the lensing source with out the need of any assumptions
  - Sensitive to the geometry of the Universe and growth of structure

- A probe of different size objects
  - Galaxies
  - Groups/Clusters of galaxies
  - Large scale structure
Weak lensing studies

- Most of WGL studies have been performed in the optical/NIR
  - Much higher source counts
  - No redshifts for radio sources
  - Mature stage of source extraction and shape measurements

- Radio Weak Lensing advantages
  - Well known and deterministic beam pattern
  - Sources at higher redshifts
  - Polarisation information
A g-g lensing measurement using radio data

- **Aim:** Prove that RWL can be done
- **Used method:** Ring statistics

**Requirements:**
- A sample of background radio sources
  - VLA FIRST
- A sample of lenses
  - SDSS
  - BCGs
  - X-ray selected clusters

**Prior to measurements:** Systematics quantification and correction
Results ???
Results ???
Tests for systematics
Tests for systematics
Correcting the systematics
Correcting the systematics
Simulations

- **Inputs**
  - Fluxes/sizes from FIRST
  - Redshifts from $S^3$
  - Shear/over-density maps from a set of realistic simulations
  - Contamination template approximating the FIRST contamination

- Generates a distribution of galaxies that have a shear signal and a shape distortion to their ellipticities

- Additional $e_1$ and $e_2$ component simulating the intrinsic ellipticities of the galaxies
Simulations
Simulations
Simulations
Results – lenses SDSS sources

Our study
- $R_{200} = 0.12 \pm 0.02$ Mpc $h^{-1}$
- $M_{200} = (4.63 \pm 2.02) \times 10^{11}$ $M_\odot h^{-1}$
- $\Theta_e = 0.22 \pm 0.03$ `''
- $\Sigma_u = 88 \pm 9$ km/s

Archival
- $R_{200} = 0.15$ Mpc $h^{-1}$ (Parker et al 2007)
- $M_{200} = 7.6 \times 10^{11}$ $M_\odot h^{-1}$ (Parker et al 2007)
- $\Theta_e = 0.267 \pm 0.005$ `'' (Velander et al 2013)
- $\Sigma_u = 97.9 \pm 1$ km/s (Velander et al 2013)
Our study

\( R_{200} = 0.60 \pm 0.10 \text{ Mpc} h^{-1} \)

\( M_{200} = (2.63 \pm 1.20) \times 10^{13} \text{ M}_\odot h^{-1} \)

\( \Theta_e = 2.8 \pm 0.5 \arcmin \)

\( \Sigma_u = 361 \pm 31 \text{ km/s} \)

Archival

\( R_{200} = 0.7 \text{ Mpc} h^{-1} \) (Sheldon et al 2009)

\( M_{200} = (2.85 \pm 1.13) \times 10^{13} \text{ M}_\odot h^{-1} \) (CFHTlens)
Results – lenses Matched SDSS-FIRST sources

\[ R_{200} = 0.86 \pm 0.15 \text{ Mpc} \, h^{-1} \]
\[ M_{200} = (7.75 \pm 3.45) \times 10^{13} \text{ M}_\odot h^{-1} \]
\[ \Theta_e = 5.9 \pm 0.9 \text{ arcsec} \]
\[ \Sigma_u = 519 \pm 43 \text{ km/s} \]
Conclusions

- Shown that RWL can be performed
- WGL studies with data collected from the image plane
- Provided independent measurement to the optical/NIR WGL studies
- Detected massive sizes for optical/radio matched objects

THANK YOU FOR YOUR TIME