A new estimator for weak lensing based on IM-Galaxy cross correlation

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Swiss SKA Days
University of Bern
June 20, 2019
Motivation

- Future 21cm surveys will probe high redshifts
- Complementary to the CMB and galaxy surveys
- Test our models in a wider range of distances
- Weak lensing: probe of matter distribution and sensitive to the dynamics of the universe

![Timeline of the Big Bang and reionization](image)
Introduction to weak lensing of galaxies and intensity mapping
Lensing effect on observed galaxies

Shape correlation (cosmic shear)

Needs precise shape measurements

Number density of galaxies

\[ \Delta_{\text{galaxy}}(\hat{n}, z) = b(z)\delta(\hat{n}, z) + (2 - 5s)\nabla^2 \phi \]

magnification bias

Diagram credit: Michael Sachs
Lensing effect on intensity mapping

Lensing conserves surface brightness

\[
\frac{dB}{d\Omega} [W/m^2 d\Omega] = \delta(\mathbf{n}, z)
\]

No first order lensing term added to IM

Remapping of temperature fluctuations

Second and higher order lensing terms

\[
\Delta^{HI}(\hat{n}) \rightarrow \Delta^{HI}(\hat{n} + \nabla \phi)
\]

\[\vec{\alpha} = \nabla \phi\]

\(\phi\): lensing potential

\(\alpha\): deflection angle
Standard estimator for detecting magnification bias
Standard estimator: galaxy-galaxy cross correlation

\[ \Delta^{\text{galaxy}}(\hat{n}, z) = b(z)\delta(\hat{n}, z) + (2 - 5s)\nabla^2 \phi \]

Contamination from density term

\[ E_{\ell}^{\text{st}} = C_{\ell}^{g,g}(z_b, z_f) \]
\[ = b_g(z_b)b_g(z_f)C_{\ell}^{\delta\delta}(z_b, z_f) \]
\[ + \frac{1}{2}b_g(z_f)(2 - 5s(z_b))C_{\ell}^{\delta\phi}(z_b, z_f) \]
\[ + \frac{1}{2}b_g(z_b)(2 - 5s(z_f))C_{\ell}^{\delta\phi}(z_b, z_f) \]
\[ + \frac{1}{4}(2 - 5s(z_b))(2 - 5s(z_f))C_{\ell}^{\phi\phi}(z_b, z_f) \]

Lensing terms
Introduction to the new estimator
Idea of new estimator

\[ C^\text{IM-g}_\ell(z_f, z_b) \]

density + lensing term

\[ C^\text{g-IM}_\ell(z_f, z_b) \]

density
New estimator: $E^\times$

Contamination: reduced by a factor proportional to bias difference

$$E^\times = C^{g-HI}_\ell (z_b, z_f) - C^{HI-g}_\ell (z_b, z_f)$$

$$= \left[ b_g(z_b)b_{HI}(z_f) - b_{HI}(z_b)b_g(z_f) \right] C^{\delta\delta}_\ell (z_b, z_f)$$

$$+ \frac{1}{2} b_{HI}(z_f)(2 - 5s(z_b)) C^{\phi\delta}_\ell (z_b, z_f)$$

$$- \frac{1}{2} b_{HI}(z_b)(2 - 5s(z_f)) C^{\delta\phi}_\ell (z_b, z_f)$$

Lensing terms
Contamination

DESxHIRAX \quad z_b = 1.25 \quad z_f = 1.0

\sim 40\% \text{ for } E^\text{st}

\sim 1\% \text{ for } E^\times

\frac{E^c}{E_f}
Variance

\[ V(\hat{E}^\text{st}) = \frac{1}{(2\ell + 1)f_{\text{sky}}} \left[ C_{\ell}^{g-g}(z_f)C_{\ell}^{g-g}(z_b) + C_{\ell}^{g-g}(z_f, z_b)^2 \right] \]

\[ V(\hat{E}^\times) = \frac{1}{(2\ell + 1)f_{\text{sky}}} \left[ C_{\ell}^{\text{HI-HI}}(z_f)C_{\ell}^{g-g}(z_b) \right. \]
\[ \left. - 2C_{\ell}^{g-g}(z_f, z_b)C_{\ell}^{\text{HI-HI}}(z_f, z_b) \right. \]
\[ + C_{\ell}^{\text{HI-HI}}(z_f, z_b)^2 + C_{\ell}^{g-HI}(z_f, z_b)^2 \]

\[ \left[ b_{g}(z_b)b_{\text{HI}}(z_f) - b_{\text{HI}}(z_b)b_{g}(z_f) \right]^2 C_{\ell}^{\delta\delta}(z_b)C_{\ell}^{\delta\delta}(z_f) \]
Signal-to-noise-ratio

Cosmic variance limited

$$\text{SNR}_{\text{total}} = \sqrt{\sum_{\ell} (\text{SNR}_{\ell})^2}$$

$$E^x \sim 357$$

$$E^{\text{st}} \sim 15$$

Shot noise + thermal noise

Optimistic case

$$E^x \sim 11$$

$$E^{\text{st}} \sim 8$$

DESxHIRAX  

$$z_b = 1.3$$  

$$z_f = 0.8$$
Fisher forecast

DESxHIRAX

$z = [0.8, 1.3]$  

DES

$z = [0.2, 1.3]$  

EuclidxHIRAX

$z = [0.8, 2.5]$  

Euclid

$z = [0.2, 2.5]$
EuclidxSKA ID

$z \in [0.35, 2.5]$  

SKA phase 1 looks at redshift after reionization
SKA1-MID probes $z \in [0.35, 3]$

In optimistic case: EuclidxSKA improves magnificently
In realistic and pessimistic case: we are killed by thermal noise
Conclusion

• The new estimator we introduce reduces contamination and allows closer bins to be used for signal detection.

• It increases signal-to-noise ratio by a factor of ~3 in the redshift range of $z=1.4$ to $z=2$ for EuclidxHIRAX.

• Reduces systematics since it’s built up by the cross correlation of data from two different surveys.
Thank you for your attention