Clusters mass measurement using weak lensing

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Gravitational lensing

All observables derive from a scalar field:
«the projected mass»

\[
\nabla^2 \psi = \frac{8\pi G}{c^2} \int \frac{D_L D_{LS}}{D_S} \rho \, d\ell
\]

Effects on the image of an object (weak regime):
→ Rotation
→ Displacement
→ Magnification
→ Shear

Ellipticity:
\[
\epsilon_{gal} = \left( \frac{g_{m,xx} - g_{m,yy}}{g_{m,xx} + g_{m,yy}} \right) + i \left( \frac{g_{m,xy}}{g_{m,xx} + g_{m,yy}} \right)
\]

Relation between ellipticity and shear:
\[
\epsilon_{gal} = \epsilon_{int} + g
\]
Introduction: cosmology with weak-lensing

Shear as a cosmological probe: Cosmic shear

Best current results: CFHTLenS
Fields = 154 deg$^2$
$n_g = 11$ arcmin$^{-2}$
$400 < l < 5000$

The probe is at the top of LSST priority list

LSST forecast (Ivezic et al. 2014)

\[
C_l = \int_0^\infty d\chi \left( \frac{3}{2} \Omega_m H_0^2 \int_\chi^\infty d\chi' \frac{dn}{d\chi'} (1 - \frac{\chi'}{\chi}) \right)^2 P_{\delta} (k = l/\chi, z(\chi))
\]

(Lin et al. 2011)
Shear as a cosmological probe: Lensing by clusters of galaxy (I)

Weighting the Giants I
(1208.0597)

Contours of mass distribution

\[ \theta = \pi/2 \]

\[ \frac{\gamma_1}{\gamma_2} = \frac{g_m_{xx} - g_m_{yy}}{g_m_{xx} + g_m_{yy}} \]

\[ \frac{\gamma_2}{\gamma_1} = \frac{g_m_{xy}}{g_m_{xx} + g_m_{yy}} \]

Shear VS radius

The signal is strong.
Convenient training!
Masses are measured using a mass proxy from SZ decrements from Planck: this is the largest source of uncertainty (20%). New methods use lensing. Uncertainty of 8% on the absolute mass scale of clusters.

Weighting the Giants IV (1407.4516)

Masses from gas mass fraction
Shear as a cosmological probe: Lensing by clusters of galaxy (II)

Planck Collaboration 2015. results. XXIV.

\[ \sigma_8 \]

\[ \Omega_m \]
The goal is to contribute by an independent analysis chain for cross-checks.

Two proposals submitted and accepted:
The objective is to increase the sample of clusters → 5% uncertainty on the mass calibration.
Introduction: cosmology with weak-lensing

From raw images to shear measurement

Impact of the brighter-fatter on the observed shape of a galaxy

Observation

« true » PSF

brighter-fatter

Reconstructed ellipticity

« true » galaxy

quantifying the problem:

Usual parametrization of shear bias

\[ \hat{\gamma} = (1 + m)\gamma + c \]

Impact of a 1% « brighter-fatter » on the LSST

\[ m \approx 0.027 \]

Meanwhile, the requirement is

\[ m_{req} \approx 0.003 \]
Correction at the pixel level for the Subaru Camera

Brighter-fatter effect before and after redistribution of charges

Subaru Camera - Stars second moments

$\sigma(x, y)$ vs. flux pixel max. [kADU]
Introduction: cosmology with weak-lensing

From raw images to shear measurement

Data reduction pipeline

- Brighter-fatter correction
- Raw images corrected

- Calibration frames
- Skyflat, domeflat, bias
- Preprocessing
- Masterflat, Masterbias

- Data sets
- 10 clusters, 900 images in 5 bands

- Flatfielding
- \((\text{raw image} - \text{masterbias}) / \text{masterflat}\)

- Objects detection
- Catalog of objects

- Simultaneous astrometry
- High quality WCS

- Stacking
- High density catalog

- Shape measurement
- Identification of stars and galaxies

- Galaxy catalogs
  - … morphometry

- Star catalogs
  - … photometry
Simultaneous Astrometry

An astrometric solution is:
a map from pixel coordinates to celestial coordinates (WCS).

The game of simultaneous astrometry is to:

→ Adjust WCS of a series of images,
→ Associate their catalogs of objects,
→ Associate this catalog to an external catalog to fix the sidereal coordinates,
→ Adjust the sidereal positions of common objects and the WCS taking the measurement errors into account.

rms = 0.015 arcsec for DES (Jarvis et al. 2015)
Introduction: cosmology with weak-lensing

From raw images to shear measurement

Why do we want simultaneous astrometry?

Strong contribution from the centroid bias

\[ \text{An error } \delta x_0 \rightarrow \text{inflates } gm_{xx} \propto \delta x_0^2 \]

(Bernstein & Jarvis 2001)

Multiplicative bias as a function of S/N for DES shape pipeline (Gruen et al. 2013) (1304.0764)

S/N of our input catalog

![Graph showing multiplicativity bias as a function of S/N](image)
**High precision determination of the positions of faint objects**

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19 galaxies/arcmin²

34 galaxies/arcmin²
Introduction: cosmology with weak-lensing

From raw images to shear measurement

From the catalogs to science

- Galaxy catalogs
  - morphometry
- Ellipticity
- Shear
- Deconvolution of the PSF

- Star catalogs
  - photometry
- PhotoZ
  - redshift
- Zero Point using SDSS

Science
- Cluster mass measurement
How to measure the ellipticities of the galaxies?

Shear inference methods:
- Moments-based methods: (Fourier-space, real-space), (Sersic profiles, shapelets),
- Maximum likelihood: (model fitting methods: Sersic profiles, shapelets, ...)
- Bayesian (full, partial, hierarchical...)
- Neural network
Conclusion