Accurate Cosmology from LSST

Cosmic Cosmic Shear

• Shear measurement
  – The problem
  – International Challenges
  – Impact of morphologies

• Intrinsic alignments
  – Must be taken into account
  – Calibration using cross-correlations

• Photometric redshift requirements
The potential of cosmic shear

Example for optical ground-based surveys
Dark Energy Task Force report astro-ph/0609591
The Future

- DARK ENERGY SURVEY
- KiDS
- AFTA
- HSC
- EUCLID
- LSST
The potential of cosmic shear

Example for optical ground-based surveys
Dark Energy Task Force report astro-ph/0609591
Cosmic Shear: Potential systematics

Galaxy shape measurement

Intrinsic alignments

Photometric redshifts

Accuracy of predictions
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Accuracy of predictions
Galaxy shape measurement

Intrinsic galaxy (shape unknown) → Gravitational lensing causes a *shear* ($g$) → Atmosphere and telescope cause a convolution → Detectors measure a pixelated image → Image also contains noise

Causes
$\Delta b/a \sim 0.03$

Measure
$b/a \pm 0.3$

The GREAT08 Challenge Handbook
Bridle et al 2010
Galaxy shape measurement

Causes $\Delta b/a \sim 0.03$ to 1%

Measure $b/a \pm 0.3$

The GREAT08 Challenge Handbook
Bridle et al 2010
Typical data

object 197, SNR 23, image

model

weight

residuals

Image

Model

Weight

Residuals
Shear TESTing Programme

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STEP 1:

See also STEP 2: Massey et al.
GREAT08: Separate the issues

Figure 2. Upper panel: Schematic of the galaxy parameters used in LowNoise Blind. Each realisation corresponds to a different set of FITS image file containing 10,000 galaxies. The schematic looks identical for LowNoise Known. For RealNoise Known there are 100 shears per branch in place of 5. The bottom row of boxes represents galaxies with the same properties as the penultimate row, but rotated by 90 degrees.

Lower panel: Schematic of the galaxy parameters used in RealNoise Blind.

Bridle et al 2010
GREAT08 Results in Detail

See also GREAT10 Kitching et al

Bridle et al 2010
Sersic model fitting shear measurement codes

- LensFit
- Multifit
- Im3shape

See also currently popular non-Sersic methods: DEIMOS, FDNT, shapelets
Model bias due to realistic galaxy morphologies

ABSTRACT

How well do we need to know what galaxies really look like to measure dark energy from cosmic shear?

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Key words: methods: statistical, methods: data analysis, techniques: image processing, cosmology: observations, gravitational lensing: weak, dark energy

1 TO DOS

• Revise Fig. 2 and 3
• Add curves to Fig. 6 at finite SNR
• Add data points to Fig. 8 for HST at finite SNR
• Add another curve to Fig. 8 with intermediate parameter between Subaru and DES to investigate why error on mean for DES is smaller than for Subaru.
• Plot mean and error on $m_1$ as a function of redshift based on photo-z estimates in SHERA catalog and extrapolate to total number of available galaxies in HST COSMOS field. With this plot we will be able to provide an answer to the question whether the HST field is enough data to calibrate DES.
• SHERA dictates galaxy images need to have a SNR $\gtrsim 100$.

However at a SNR of 100, the difference between HST, Subaru and DES is not that large, suggesting that the same instrument can be used for acquiring calibration data. So how deep and large does a deep drilling, high SNR area need to be for Subaru, DES or LSST? Get necessary information, i.e. galaxy density as a function of magnitude and redshift from Adam’s paper.

• What role does seeing and FWHM play? Can we quantify how much better the calibration sample needs to be and does this rule out the possibility of using the same instrument for acquiring the calibration data?

2 INTRODUCTION

Model bias calibration of DES with COSMOS or Instrument dependence of model bias calibration

• Starting point: Lisa’s paper investigates the question what model bias is and where it comes from and concludes that there is need to calibrate DES data as science requirements are not met.
• The question to be addressed in this paper is how does the instrument and observation parameters influence shear measurement and in particular model bias? In this context interesting parameters to be explored are:

(i) PSF type and size, in particular we will analyse PSFs from earth-based and space instruments. For the former we assume a Moffat profile with varying FWHM and shape (i.e. $c_0000 RAS$)
Model bias due to realistic galaxy morphologies
How many galaxies do we need to observe, to know enough about their morphologies?

Hirsch et al in prep, Voigt et al in prep
How many galaxies do we need to observe, to know enough about their morphologies?

Hirsch et al in prep, Voigt et al in prep
References:
Mandelbaum, Rowe et al 2013 The GREAT3 Challenge Handbook
Rowe, Mandelbaum et al 2013 The GalSim Toolkit
GREAT3 PSFs and PSF variation

Fig 7. Left: The optical PSF (no atmospheric contribution) for the ground-based "variable PSF" branch at 5×5 grid positions across a simulated FOV, going all the way to the edge where aberrations are large. Right: Same as left, for the space-based model. Both are shown on a logarithmic scale. These include some (stochastic) added aberrations at a level used for the challenge. The space-based optical PSF model is more constant across the field than the ground-based model because of different assumed field-dependent aberrations.

5.2.2. Atmospheric PSFs. Atmospheric turbulence is the primary contributor to the PSF in ground-based data. Our model for the ground-based PSF is that of a large (≥2 m) ground-based telescope taking long exposures without adaptive optics. To properly simulate the profile and the spatial variation of the atmospheric PSFs, we consider the following construction based on a combination of high-fidelity atmospheric turbulence simulations and observational data. Further technical details regarding the design of our atmospheric PSFs can be found in Appendix G.

We invoke the LSST Image Simulator (PhoSim, LSST Science Collaborations and LSST Project, 2009; Connolly et al., 2010; Peterson et al., in prep.), a high-fidelity photon ray-tracing image simulation tool, for this purpose. PhoSim adopts an atmospheric turbulence model similar to that used in the adaptive optics (AO) community (Roggemann and Welsh, 1995; 17 https://dev.lsstcorp.org/trac/wiki/IS_phosim).

Fig 8. As in Fig. 6, anisotropy pattern in a 2°×2° field, for a 2 minute exposure at a 4-meter telescope. The plot title gives the median PSF shear. The color scale indicates the fractional change in size of the atmospheric PSF as a function of position.

Our choice to use a sheared Kolmogorov profile (without any higher-order distortions) is a simplification compared to reality, but the simulations suggest that for reasonable exposure times and telescope sizes, it is quite close to correct. Hence we consider our prescription to be realistically complex enough for an interesting test.

Fig. 9 shows a comparison between the power spectrum and correlation functions of the lensing shears, the atmospheric PSF anisotropies, and the ellipticity of the optical space- and ground-based PSF model (in the latter case, after convolving with a circular, typical-sized atmospheric PSF). Here we have omitted the aberrations other than the design residual to get an idealized version of the results for the optical PSF model. This plot shows the most important scales for the various systematics compared to the weak lensing shears. For example, we see that the lensing power spectrum is below that of the atmospheric PSF anisotropies on large scales (small θ). However, for nearly all relevant scales on our grid, the atmospheric PSF anisotropy is larger than the lensing power spectrum.
Shear measurement issues for LSST

- Noise bias calibration
- Knowledge of galaxy morphologies
- Iterative PSF reconstruction
- Deblending
- Stacking vs simultaneous fits
- Wavelength dependent PSF
- Flux dependent PSF
- Star selection effects

All to be developed with suites of simulations

See DESC Whitepaper for more details
Cosmic Shear: Potential systematics

Galaxy shape measurement

Intrinsic alignments

Photometric redshifts

Accuracy of predictions
Lensing by dark matter causes galaxies to appear aligned.
Intrinsic alignments (II)

Intrinsic alignments (II)  
Face-on view

Tidal stretching causes galaxies to align  
Adds to cosmic shear signal

Intrinsically Aligned (I)

Intrinsically Aligned (I)
Intrinsic-shear correlation (GI)

Hirata & Seljak 2004
Intrinsic-shear correlation (GI)
Face-on view

Gravitationally sheared (G)

Intrinsically aligned (I)

Galaxies point in opposite directions
Partially cancels cosmic shear signal
Effect on cosmic shear of changing $w$ by 1%

Intrinsic Alignments (IA)

Cosmic Shear

Normalised to Super-COSMOS
Heymans et al 2004
Intrinsic Alignments (IA)

Effect on cosmic shear of changing $w$ by 1%
Ignoring Intrinsic Alignments is Bad!
Badness depends on assumed model
IA removal methods

• Nulling methods
  – Nulling for GI
  – Removing red galaxies (Schrabback et al 2010)

• Model fitting methods
  – Simple model (King & Schneider 2003, through to Heymans et al 2013)
  – Arbitrary flexibility (Bernstein 2009, Bridle & King 2007, Kitching & Taylor 1005.2063, Joachimi & Bridle 2010, …)

• Addition of radio polarization (Brown & Battye 1005.1926)

• Addition of shear-position correlations
  – Back of envelope (Zhang 1003.5219)
  – In modelling method (Bernstein 2009, Joachimi, SB 2010)
Use of shear-position correlations

Shear-shear correlations
- Measure mostly dark matter

Shear-position correlations
- Measure mostly intrinsic alignments

Position-position correlations
- Traditional galaxy survey observable
Forecast Joint Constraints from Position 2-point Observables

Cosmic shear

\[ C_{\epsilon \epsilon}^{(ij)} (\ell) = C_{GG}^{(ij)} (\ell) \]

\[ C_{mn}^{(ij)} (\ell) = C_{gg}^{(ij)} (\ell) \]

\[ C_{ne}^{(ij)} (\ell) = C_{gG}^{(ij)} (\ell) \]

Intrinsic Alignments

\[ C_{IG}^{(ij)} (\ell) + C_{IG}^{(jij)} (\ell) + C_{II}^{(ij)} (\ell) \]

\[ C_{gm}^{(ij)} (\ell) + C_{gm}^{(jij)} (\ell) + C_{mm}^{(ij)} (\ell) \]

Galaxy clustering

\[ C_{gG}^{(ij)} (\ell) + C_{gI}^{(ij)} (\ell) + C_{mG}^{(ij)} (\ell) + C_{ml}^{(ij)} (\ell) \]

Cosmic magnification

Angular power spectra are sourced by underlying 3D power spectra: Dark matter \( P(k) \), galaxy \( P(k) \), IA \( P(k) \), galaxy-DM cross, IA-DM cross

Joachimi & Bridle 2010
Shear alone (ee), fixed IAs

Shear alone (ee), marg IAs

ee, ne, nn, fixed IAs

ee, ne, nn, marg IAs
Intrinsic Alignment work for LSST

Build a physically motivated model $f(z, k, L, c)$ from observational programme

- Using existing/planned speczs and photozs
  - Self-calibration from imaging surveys

- Calculate desired survey requirements
  - Synergy with photoz calibration fields?

and come up with

- motivated functional forms from simulations.
- Test IA removal methods on simulations in non-linear regime
Cosmic Shear: Potential systematics

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Accuracy of predictions
Photometric Redshifts for LSST

• Need precise redshifts to eliminate intrinsic alignments
  – Improved use of colour information
  – Use of additional e.g. morphology information?
Requirements on Photoz Precision

![Graphs showing the variation with photometric redshift](image)

More stringent requirements on photoz accuracy with IAs

Kirk, Laszlo, Bridle, Bean 2011
Photometric Redshifts for LSST

• Need precise redshifts to eliminate intrinsic alignments
  – Improved use of colour information
  – Use of additional e.g. morphology information?

• Need accurate redshifts to measure cosmology – need spectra
  – Spectra from representative training set
  – Development and use of cross-correlation methods
  – MOONS, VIMOS, 4MOST, SKA HI, Euclid
Requirements on Photoz Accuracy

Need the mean redshift of galaxies to better than 0.01 (0.003 with no cross-correlations)

Same for knowledge of scatter

\[ N_{spec} = \frac{2\delta_z^2(1 + z)^2}{\Delta^2\sigma_z} \]

Translates to 100s of galaxies per z bin in a complete sample

Or cross-correlation between spectra and imaging catalogues
Cross-correlation of shapes and spectra

Red: different sky
Blue: same sky

Southern Hemisphere spectra
MOONS
VIMOS
4MOST
SKA HI
Euclid

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Conclusions

• Shear measurement
  – International Challenges to set the pace
  – Calculate necessary knowledge of galaxy morphologies
  – Long list of calculations still to do (see DESC WP)

• Intrinsic alignments
  – Can’t be ignored
  – Can be self-calibrated
  – Lots of additional information available

• Photometric redshift calibration
  – Accuracy a greater worry than precision
  – May influence spectroscopic survey design