The bright and the dark side of gravitational lensing

Daniel Gruen, Einstein Fellow at SLAC
with Steve Allen, Joe DeRose, Oliver Friedrich, Stefan Hilbert, Elisabeth Krause, Tom McClintock, Peter Melchior, Eduardo Rozo, Eli Rykoff, Erin Sheldon, Tamas Varga, Risa Wechsler, … and the DES Weak Lensing, Simulations, and Theory working groups
The Dark Energy Survey

- 5000 sq. deg. survey in grizY from Blanco @ CTIO, 10 exposures, 5 years, >300 scientists, 28 institutions
- Primary goal: dark energy equation of state
- Probes: Large scale structure, Supernovae, Cluster counts, Gravitational lensing
- Status:
  - SV (150 sq. deg, full depth): data understood, most science done, catalogs at http://des.ncsa.illinois.edu
  - Y1 (1500 sq. deg, 40% depth): data processed, science coming soon
  - Y3 (5000 sq. deg, 50% depth): data being processed
Gravitational lensing

- Matter (also dark) bends space-time (and therefore light rays)
- This causes **shifting**, and **magnification**, and **shearing** of the galaxy image and, in extreme cases, **multiple images**
- **tangential distortion ~ overdensity**

Tangential shear \( \gamma_t(\theta) = \langle \kappa(\theta') \rangle_{\theta'} < \theta - \kappa(\theta) \)

Convergence (surface mass density) \( \kappa = \Sigma / \left[ \frac{c^2}{4\pi G} \frac{D_s}{D_d D_{ds}} \right] \)

- measure masses / growth of structure w/o 'dirty' astrophysics

Source: LSST Science Book
Gravitational lensing by galaxy clusters

RXC J2248.7-4431, z=0.35; DG+2014
Gravitational lensing constrains galaxy cluster scaling relations

- # of massive clusters above threshold in some observable is function of
  - Cosmology
  - Mass-observable relation (MOR)
  - Scatter in MOR
- calibration of MOR w/o astrophysics is possible with weak lensing
- full treatment of systematics required
Weak-lensing mass calibration of redMaPPer galaxy clusters in Dark Energy Survey Science Verification data

P. Melchior\textsuperscript{1*}, D. Gruen\textsuperscript{2†}, T. McClintock\textsuperscript{3}, T. N. Varga\textsuperscript{4}, E. S. Sheldon\textsuperscript{5}, E. Rozo\textsuperscript{3},

... on the arXiv ~ this Friday

ABSTRACT

We use weak-lensing shear measurements to determine the mean mass of optically selected galaxy clusters in Dark Energy Survey Science Verification data. In a blinded analysis, we split the sample of more than 8,000 redMaPPer clusters into 15 subsets, spanning ranges in richness $5 \leq \lambda \leq 180$ and redshift $0.2 \leq z \leq 0.8$, and fit the averaged mass density contrast profiles with a model that accounts for seven distinct sources of systematic uncertainty: shear measurement and photometric redshift errors; cluster-member contamination; miscentering; deviations from the NFW halo profile; halo triaxiality; and line-of-sight projections. We combine the inferred cluster masses to estimate the joint scaling relation between mass, richness and redshift, $\mathcal{M}(\lambda, z) \propto M_0 \lambda^F (1 + z)^G$. We find $M_0 = \langle M_{200m} | \lambda = 30, z = 0.5 \rangle = [2.34 \pm 0.17 \text{ (stat)} \pm 0.12 \text{ (sys)}] \cdot 10^{14} \, M_\odot$, with $F = 1.12 \pm 0.16 \text{ (stat)} \pm 0.04 \text{ (sys)}$ and $G = 0.11 \pm 0.58 \text{ (stat)} \pm 0.12 \text{ (sys)}$. The amplitude of the mass–richness relation is in excellent agreement with the weak-lensing calibration of redMaPPer clusters in SDSS by Simet et al. (2016) and with the Saro et al. (2015) calibration based on abundance matching of SPT-detected clusters. Our results extend the redshift range over which the mass–richness relation of redMaPPer clusters has been calibrated with weak lensing from $z \leq 0.3$ to $z \leq 0.8$. Calibration uncertainties of shear measurements and photometric redshift estimates dominate our systematic error budget and require substantial improvements for forthcoming studies.
How to calibrate the richness-mass relation with weak lensing...

- optically select clusters
- redMaPPer algorithm (Rykoff+2014,2016)
- excellent photo-z, low scatter in richness $\lambda = \#$ of galaxies
- off-centering, projection effects
Weak-lensing mass calibration of redMaPPer galaxy clusters in DES SV

- optically select clusters
- measure shapes of background galaxies
Weak-lensing mass calibration of redMaPPer galaxy clusters in DES SV

- optically select clusters
- measure shapes of background galaxies
- convert to mass density

$$\Delta \Sigma \equiv \overline{\Sigma}(< R) - \overline{\Sigma}(R) = \Sigma_{\text{crit}} \gamma^T(R)$$
Weak-lensing mass calibration of redMaPPer galaxy clusters in DES SV

- optically select clusters
- measure shapes of background galaxies
- convert to mass density accounting for cluster members
Weak-lensing mass calibration of redMaPPer galaxy clusters in DES SV

- optically select clusters
- measure shapes of background galaxies
- convert to mass density
- estimate mass-richness relation

\[
\langle M | \lambda, z \rangle = M_0 \left( \frac{\lambda}{\lambda_0} \right)^{F_\lambda} \left( \frac{1 + z}{1 + z_0} \right)^{G_z}
\]
redMaPPer in SV: Conclusions

- consistent, competitive calibration compared to SDSS lensing (Simet+2016) and SPT SZ (Saro+2015) of redMaPPer clusters
- consistent with $M \propto \lambda$, $\langle M|\lambda,z \rangle = \langle M|\lambda \rangle$
- absolute mass calibration with 9% statistical and 6% systematic error
Weak lensing by DES SV clusters

Sanchez+2016
New statistic: Galaxy troughs

- Trough: (long) cylinder* with galaxy count below some percentile threshold

+ easy to find in photo-z, high S/N of lensing due to suppression of LSS noise,
+ new way of probing structure and gravity in low density regime
+ in the limit of dense tracers, signal is easy to predict and independent of galaxy bias etc.
Measurement in DES SV

- tracers: Rykoff/Rozo redMaGiC galaxies, $0.2 < z < 0.5$, $L > 0.5L^*$, $1/[1000 \, \text{Mpc}^3]$
- troughs = lower quintile in galaxy count
- S/N $\sim 15 >>$ void lensing
- consistent with simple model
- for large scales / tracer count: independent of galaxy bias

DG+2016
Troughs in simulations and Y1 data

correlation matrix

shear around under- and overdense LOS, counts in cells

simulated DES Y1, cosmic variance only

actual DES Y1, blinded and preliminary
Conclusions

- DES SV (3% of survey) has allowed competitive measurements of lensing statistics
  - calibration of optical cluster mass scaling
  - high S/N measurements of the low density Universe
- Focus on systematics control
  - new methods for estimating / marginalizing over lensing systematics
  - without improvements in shape and photo-z biases, these will be the limiting factor in future releases
- Final SV results out ~ this month, Y1 approaching