Weak-lensing masses accuracy and precision

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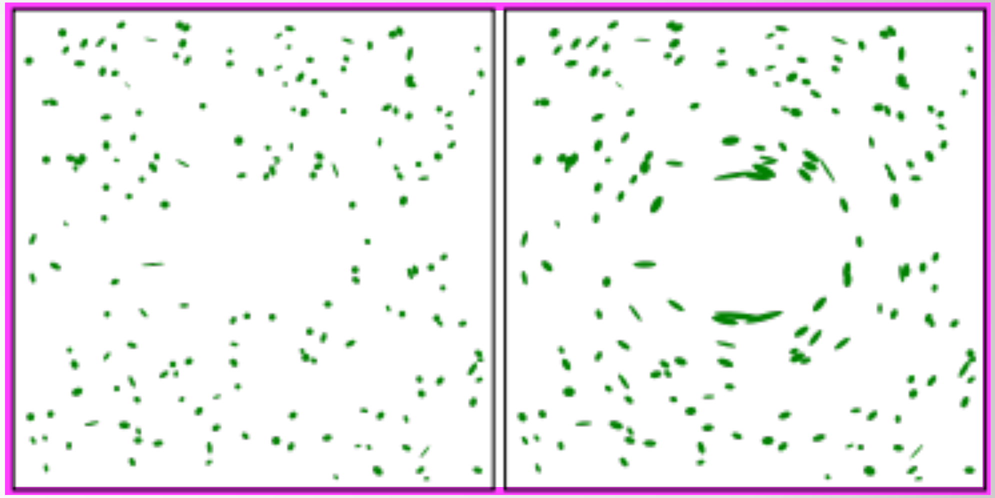
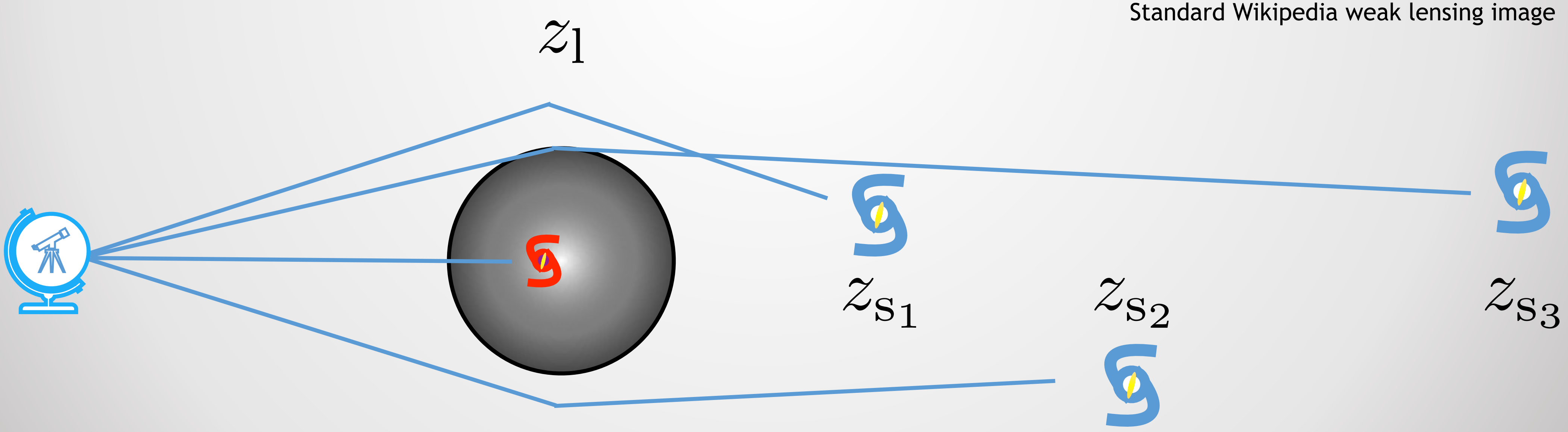
U.S. DEPARTMENT OF ENERGY
Office of Science

Cluster weak-lensing

- Shear measurement
- Photometric redshift distribution
- Source galaxy selection
- Mass determination



Standard Wikipedia weak lensing image



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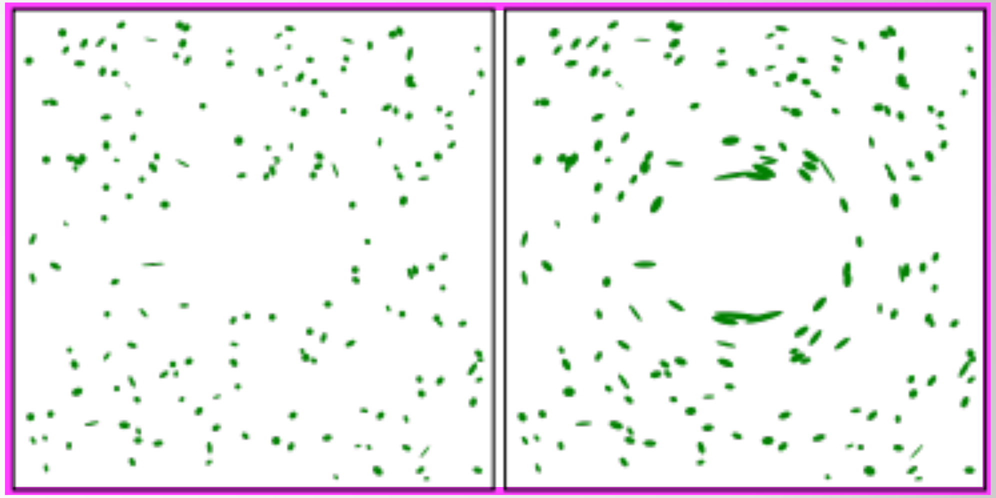

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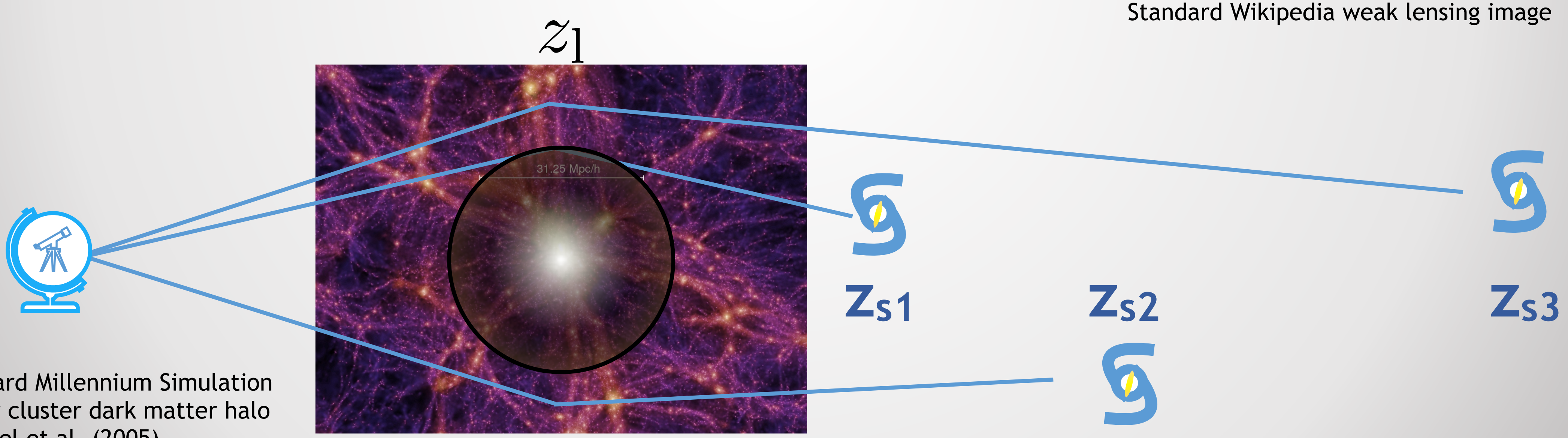


Standard Millennium Simulation galaxy cluster dark matter halo Springel et al. (2005)

Weak-lensing cluster sample

CCCP and MENeaCS: (updated) weak-lensing masses for 100 galaxy clusters

Ricardo Herbonnet[1,2*], Cristóbal Sifón[3,2], Henk Hoekstra[2], Yannick Bahé[2], Remco F. J. van der Burg[4], Jean-Baptiste Melin[5], Anja von der Linden[1], David Sand[6], Scott Kay[7], David Barnes[8]

MENeaCS

Multi Epoch Nearby Cluster Survey

Most X-ray luminous clusters in the local Universe

~50 galaxy clusters

$0.05 < z < 0.15$ $M_{200} > 10^{14}\ M_\odot$

deep *r* band CFHT observations

seeing < 0.8” $20 < m_r < 24.5$

CCCP

Canadian Cluster Comparison Project

Hoekstra et al. 2012

Hoekstra, Herbonnet et al. 2015

~50 galaxy clusters

$0.15 < z < 0.55$ $M_{200} > 3\times10^{14}\ M_\odot$

deep *r* band CFHT observations

seeing < 0.9” $22 < m_r < 25$

Combined this is the largest sample with individual weak-lensing cluster masses

Source redshift distribution

Observations lack colour information to estimate reliable redshifts.
We use COSMOS as a reference field, matching galaxies in our data to COSMOS.

~2% uncertainty

Shear calibration

Calibration of KSB algorithm with large suites of image simulations that mimic the CFHT observations.
(Hoekstra, Herbonnet et al. 2015)

~2% uncertainty

Source sample selection

Cannot differentiate cluster galaxies from source galaxies, instead use boost correction
Statistically correct for unsheared galaxies in the source sample.

~2% uncertainty

Mass modelling

Used two different methods to infer cluster mass from shear profile:
NFW fitting and
deprojected aperture masses

Test pipelines on cluster simulations

Mass modelling

Complementary methods:

- NFW fitting and aperture masses use different radial ranges
- Aperture masses have less strict assumption about cluster density profile

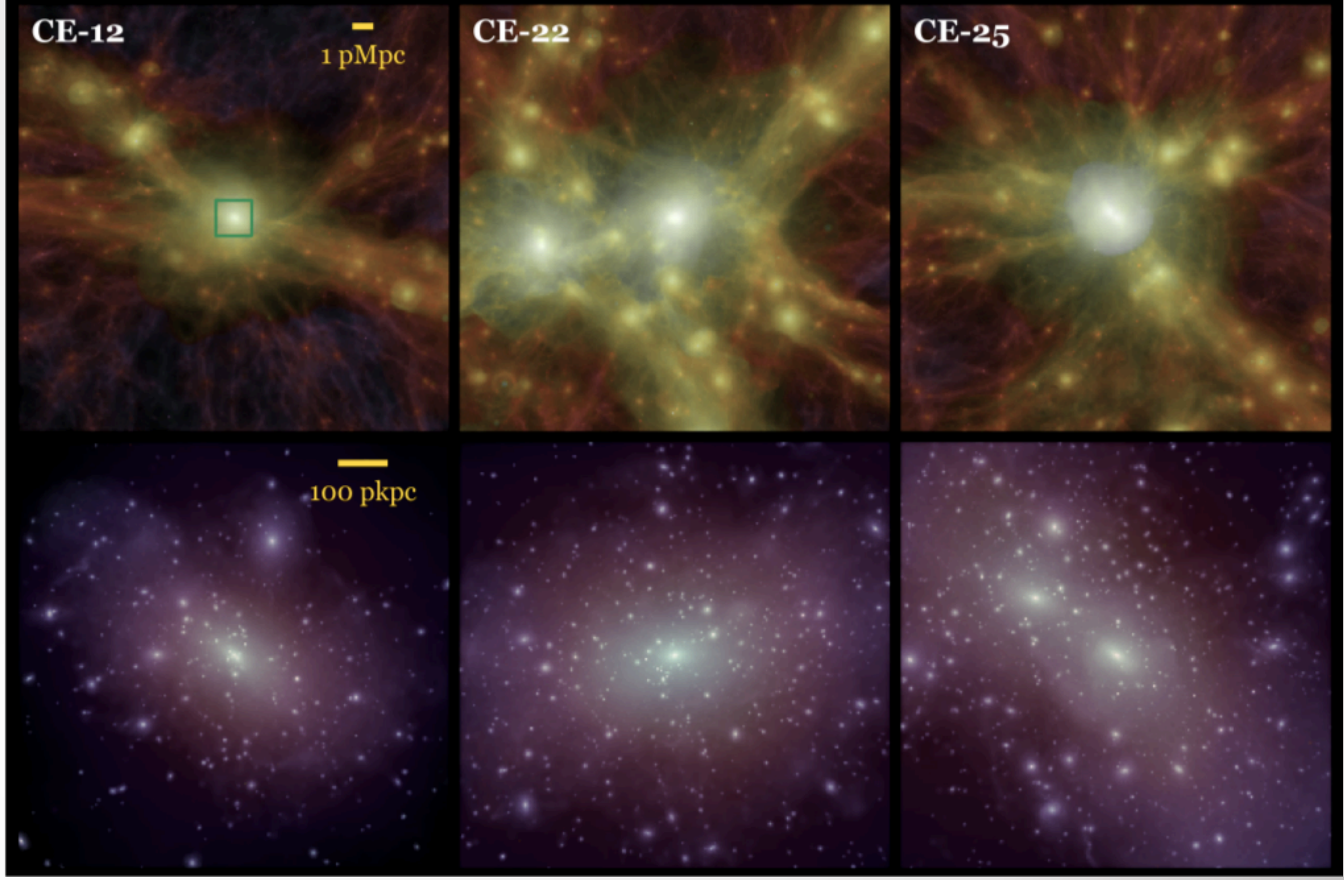
Mocked up shear profiles in HYDRANGEA cluster simulations and checked our two mass modelling pipelines

Quantitatively we find

~5 ± 3% bias for NFW profile fitting

~3 ± 2% bias for aperture masses

consistent with works in the literature



HYDRANGEA (Bahé et al. 2017, Barnes et al. 2017) are high resolution hydrodynamical simulations of galaxy clusters with dark matter and realistic baryonic effects

Centres of zoom-in regions, simulated with AGNdT9 variant of EAGLE simulatons (Schaye et al. 2015, Crain et al. 2015)

Cluster cosmology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Scaling relation with *Planck* mass proxy M_{SZ} for 61 clusters:

1-b = 0.84 ± 0.04 (stat) ± 0.05 (syst.)

Slightly higher, but consistent with most studies:

1-b=0.8 used for the 2015 *Planck* cosmological analysis,

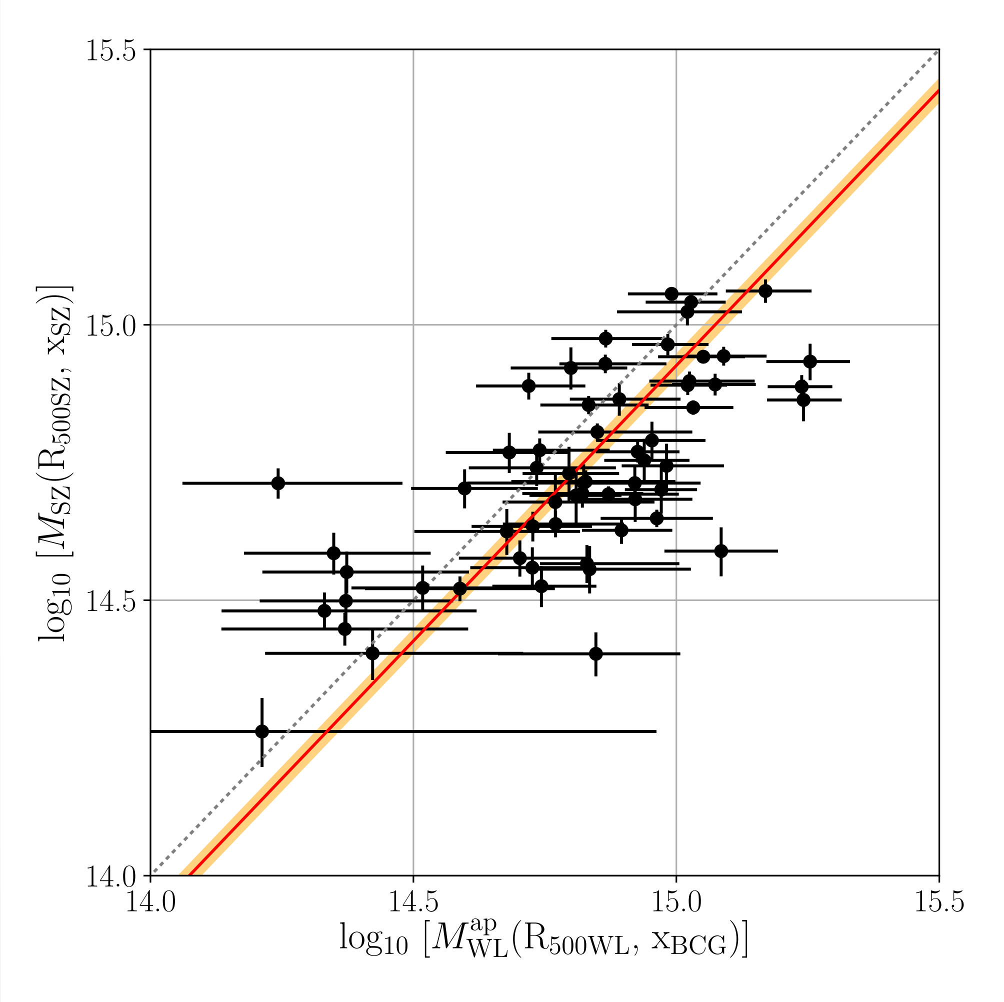
0.76 ± 0.05 (stat) ± 0.06 (syst.) (Hoekstra, Herbonnet et al. 2014),

0.71 ± 0.10 (Zubeldia & Challinor 2019),

0.69 ± 0.07 (Von der Linden et al. 2014),

(Non exhaustive list!)

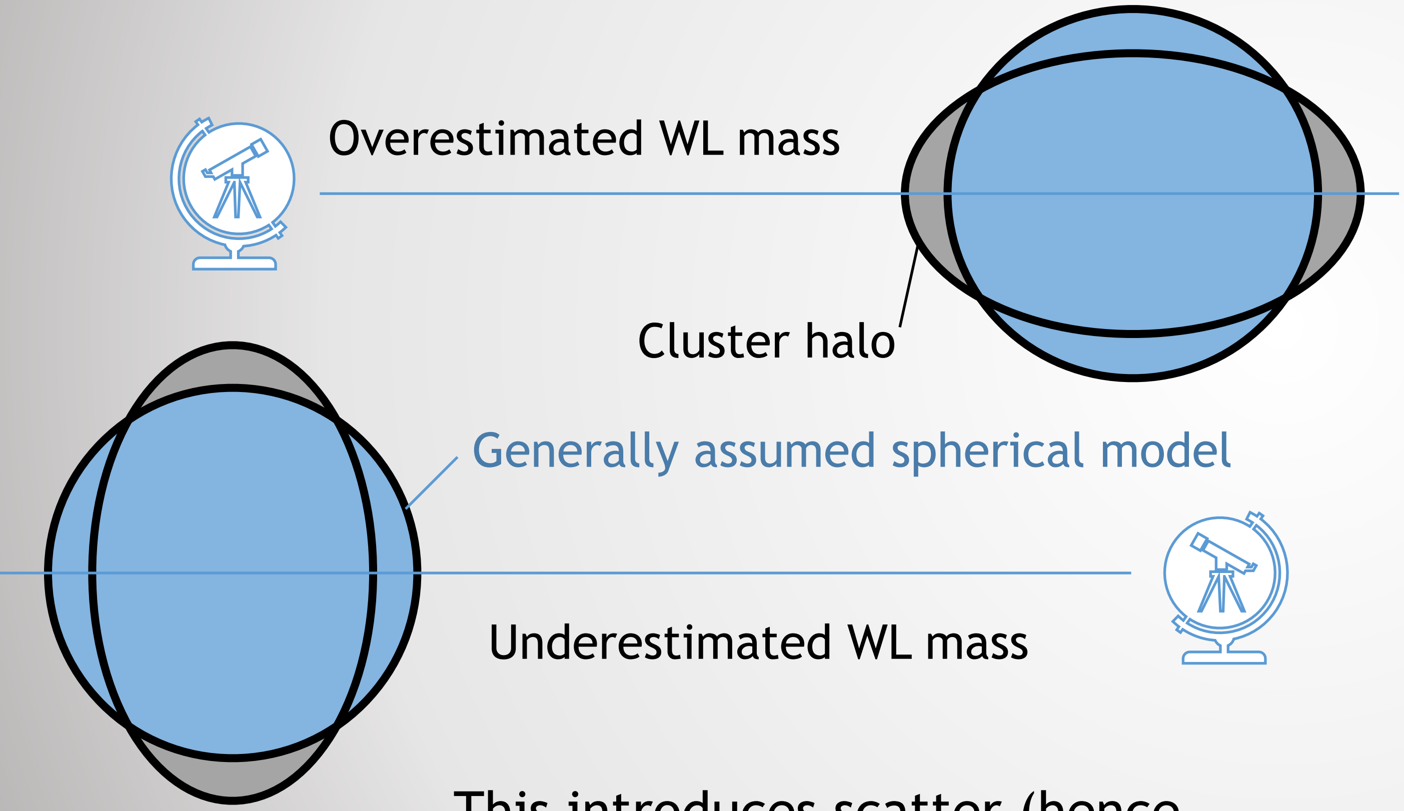
No significant trend with mass or redshift, different selections can change 1-b by 1.5**σ**



Halo orientation and weak-lensing masses

Ellipticity of Brightest Cluster Galaxies as tracer of halo orientation and weak-lensing mass bias

Ricardo Herbonnet[1*], Anja von der Linden[1], Steven W. Allen[2,3,4], Adam B. Mantz[2,3], Pranati Modumudi[5], R. Glenn Morris[2,4] Patrick L. Kelly[6]



This introduces scatter (hence large samples like MENeaCS+CCCP) and possibly selection bias

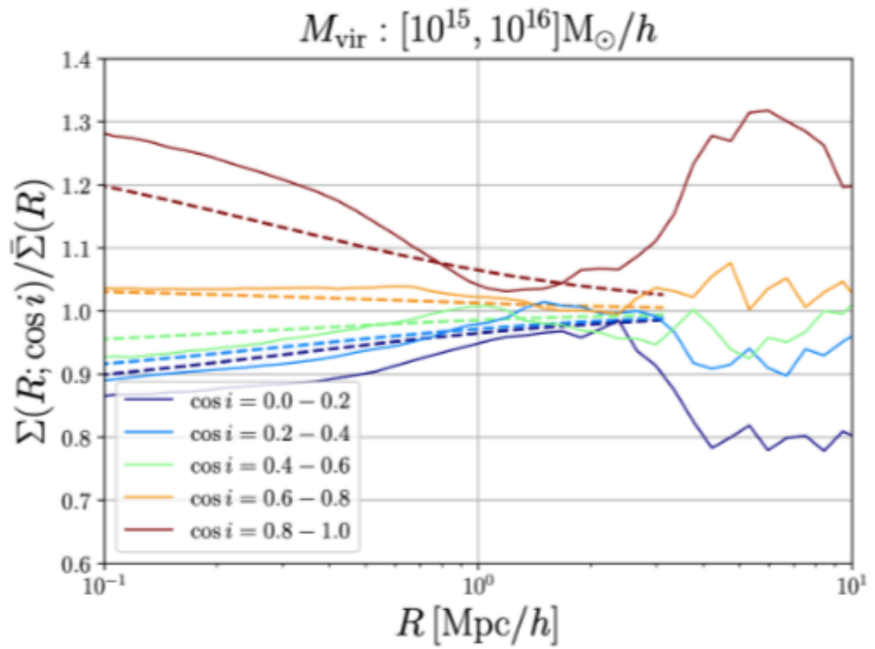


Figure 3. The ratios of the surface mass density profiles for different halo orientations (*solid lines*), which are the same as solid lines in the lower panels of Figure 2 are compared with those predicted by the triaxial halo model of Jing & Suto (2002) (*dashed lines*). The surface mass density profiles of the triaxial halo model are computed using the method developed in Oguri et al. (2003) and Oguri & Blandford (2009).

Seen in simulations e.g. Osato et al. 2018

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Weighing the Giants

Von der Linden et al. 2014, Kelly et al. 2014, Applegate et al. 2014, Mantz et al. 2015, 2016

~50 galaxy clusters
selected on X-ray luminosity

deep 5-band SUBARU observations
Chandra X-ray observations

Weak lensing masses (with photo-zs)
and gas masses

Proxy for halo orientation

Baryonic material follows dark matter distribution, brightest cluster galaxy (BCG) should be aligned with the halo

In projection the <u>ellipticity of the BCG</u> is a proxy for halo orientation along the line-of-sight and <u>should correlate with scatter in weak-lensing mass</u>

Measured BCG ellipticity with Galfit and visually checked results

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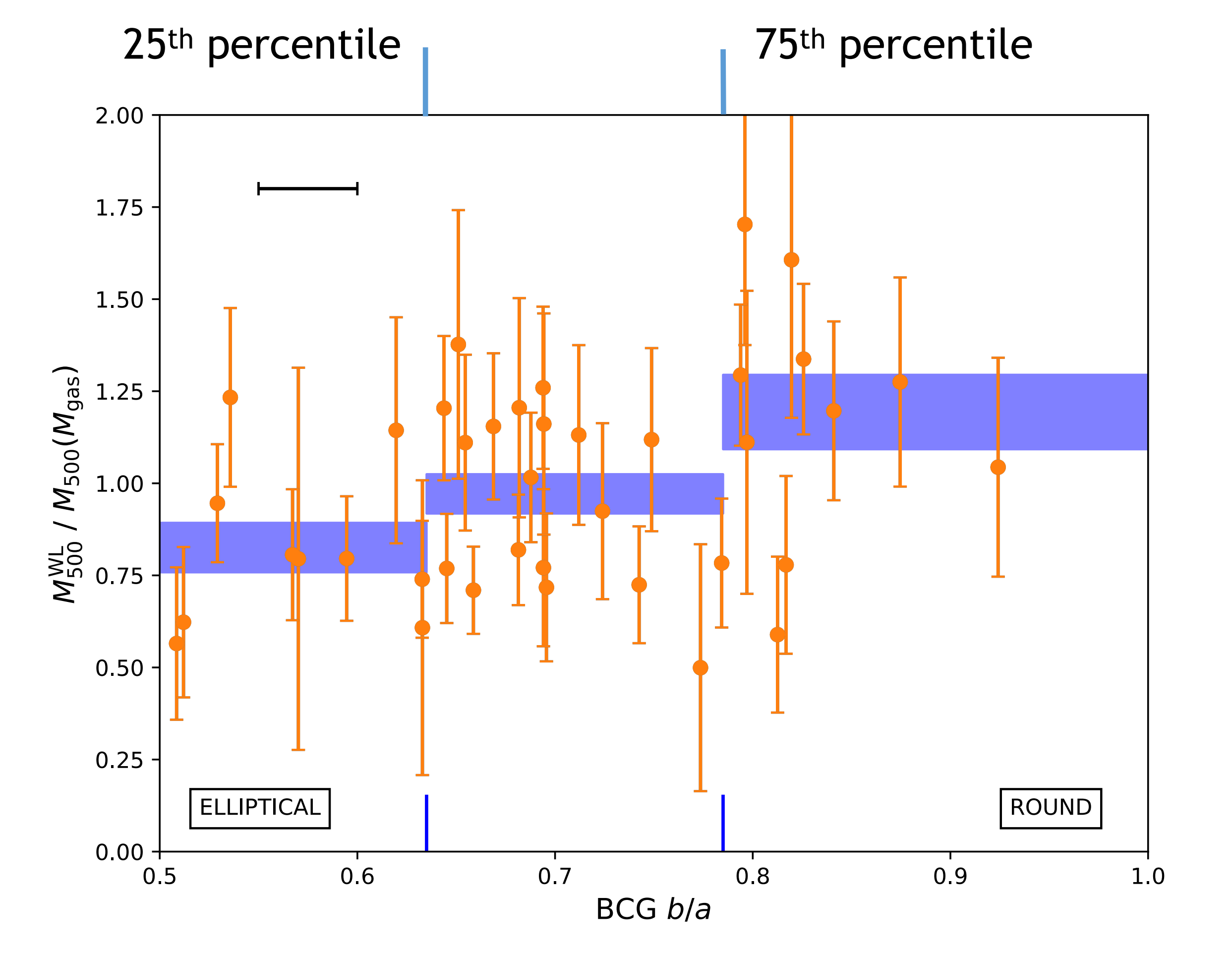


Total mass from low-scatter mass proxy

Most elliptical BCGs show WL masses underestimating total mass by ~20%

Roundest BCGs show WL masses overestimating total mass by ~20%

Good agreement with simulations, which predict ~20% scatter due to halo orientation

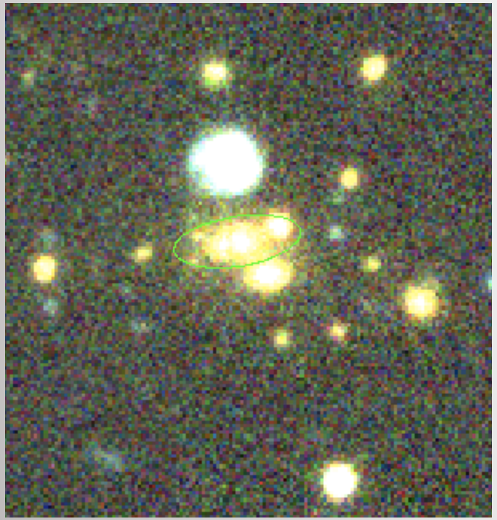
BCG could help to mitigate selection bias in optically selected clusters and tighten cosmological constraints

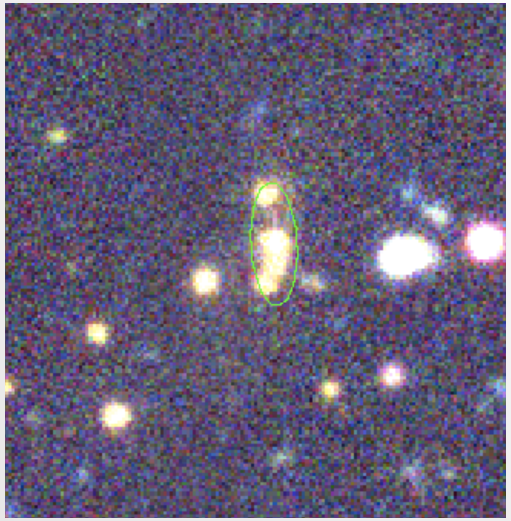
redMaPPer BCGs in DES

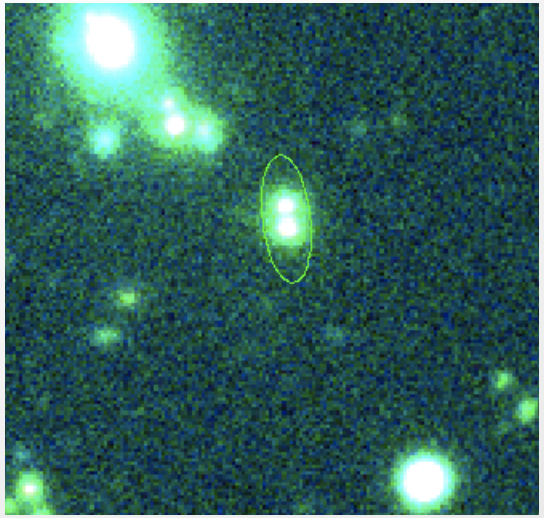
Many clusters in DES

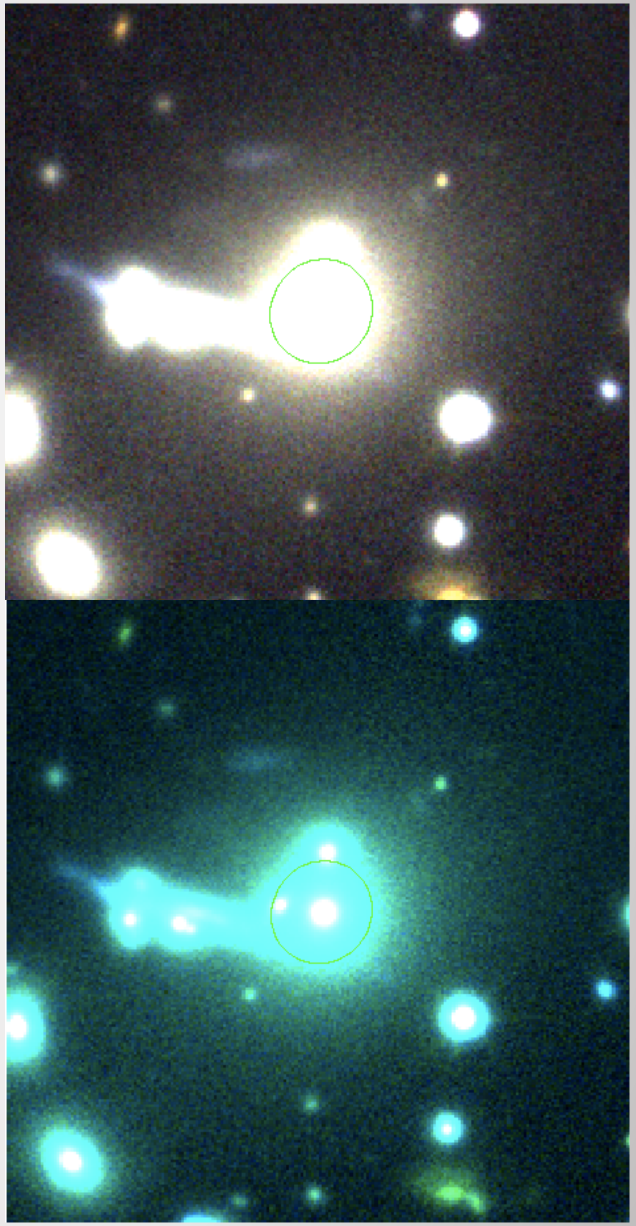
Use automatically determined ellipticity measurements?

Some examples of ngmix SOF ellipticity, most of which look good :)









Systematics in cluster lensing

Shear calibration

Source redshift distribution

Source sample selection

Mass modelling

can already be constrained to 5%

Improvements for LSST:
Metacalibration (still needs testing in cluster fields)
6-band photometry
More work on simulations will help, incorporating selection functions (CLMM)

Statistics in cluster lensing

LSST will provide the best answer to shape noise, provided that blending can be sorted out

BCG shape measurements are a promising tool to reduce the 20% scatter inherent to cluster lensing

More testing is ongoing and verification in simulations necessary to assess the benefit for cluster cosmology

Ricardo Herbonnet

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