Weak Lensing: Status and Prospects

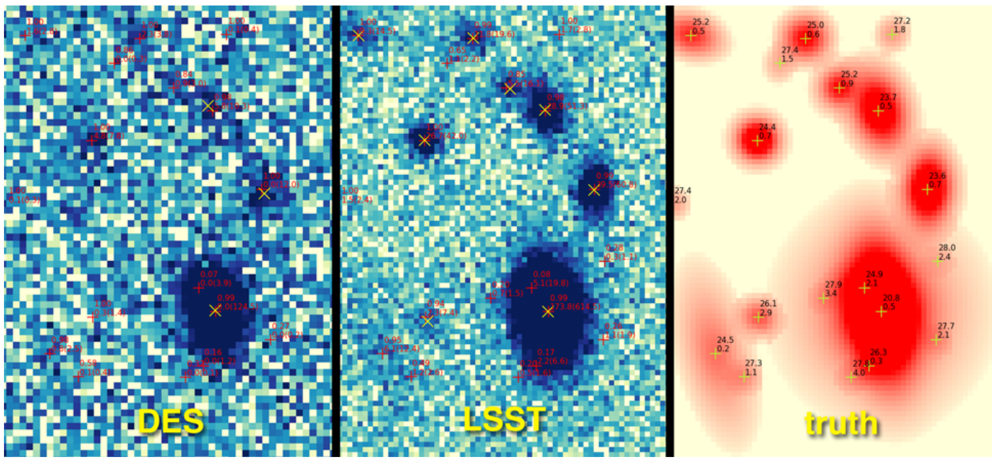

Image: David Kirkby & the LSST DESC WL working group

Image: lsst.org

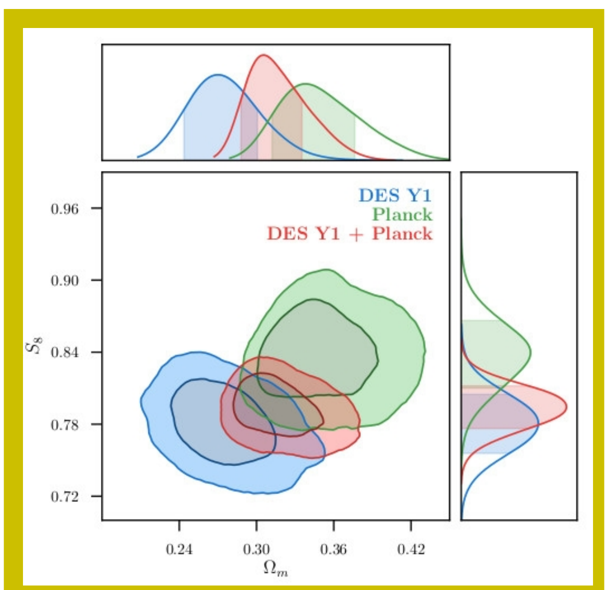

Figure: DES Collaboration 2017

Danielle Leonard
Carnegie Mellon University

for LSST DESC
June 25, 2018

Outline

- Review of weak lensing
- Completed and ongoing weak lensing efforts
- Upcoming weak lensing surveys
- Weak lensing with LSST
- Conclusions

Gravitational lensing

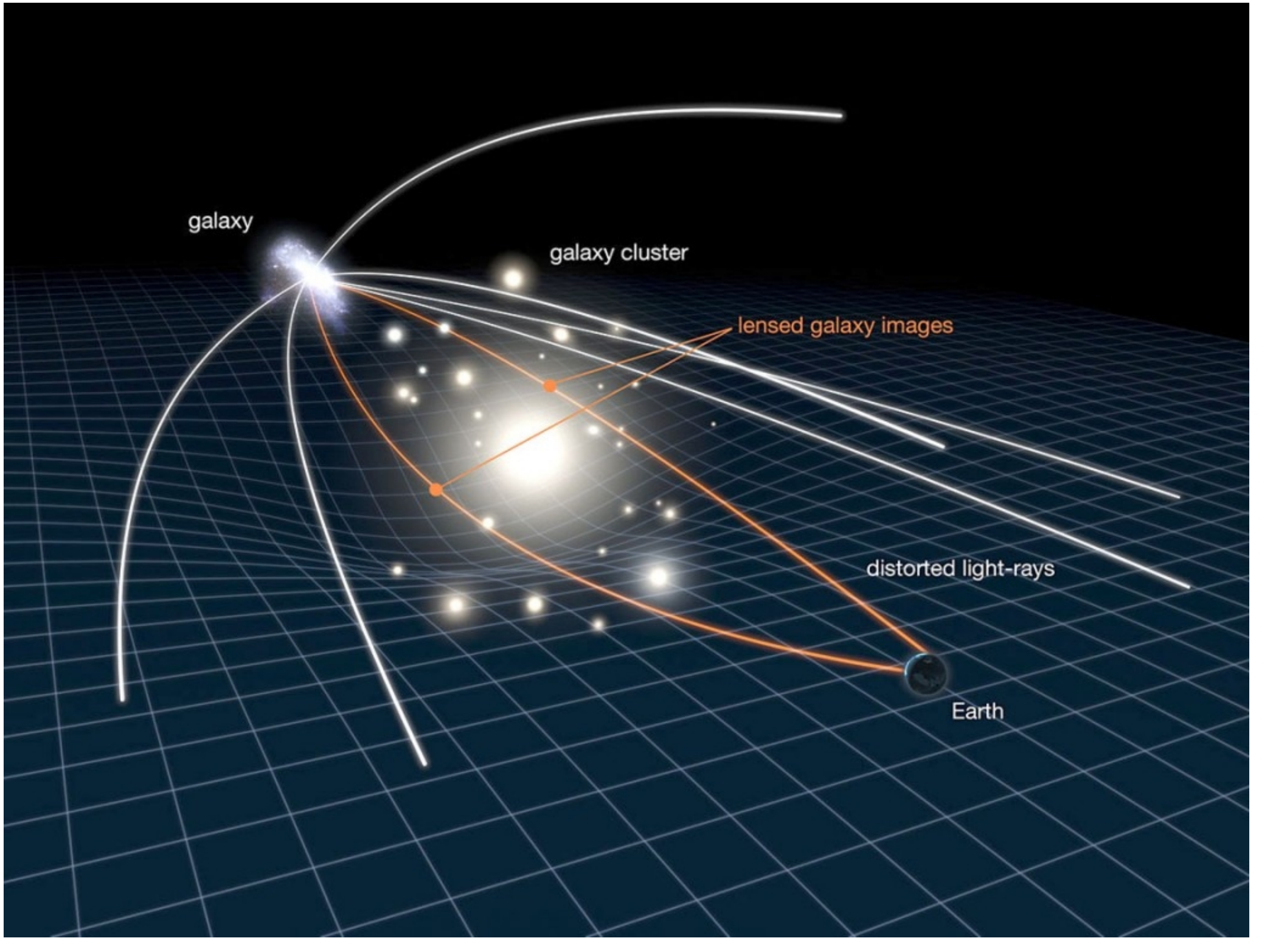

Image: cfhtlens.org

Strong gravitational lensing

Image: NASA, A. Fruchter and the ERO team

Multiply imaged objects.

Visibly ‘arced’ images.

Powerful cosmological probe.

Not the subject of this talk.

Weak gravitational lensing

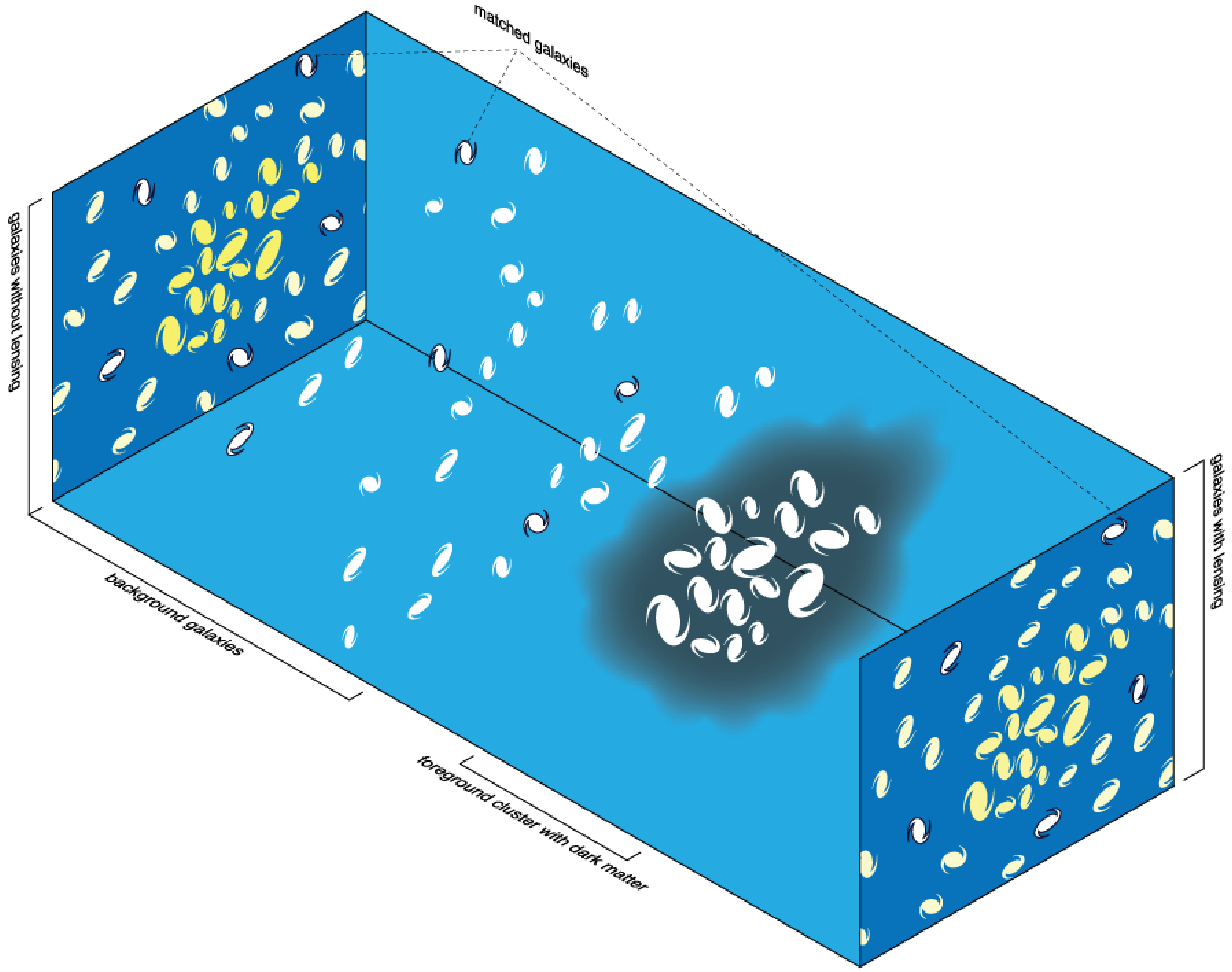

Image by Michael Sachs [CC BY-SA 3.0 or GFDL], via Wikimedia Commons

Weak gravitational lensing

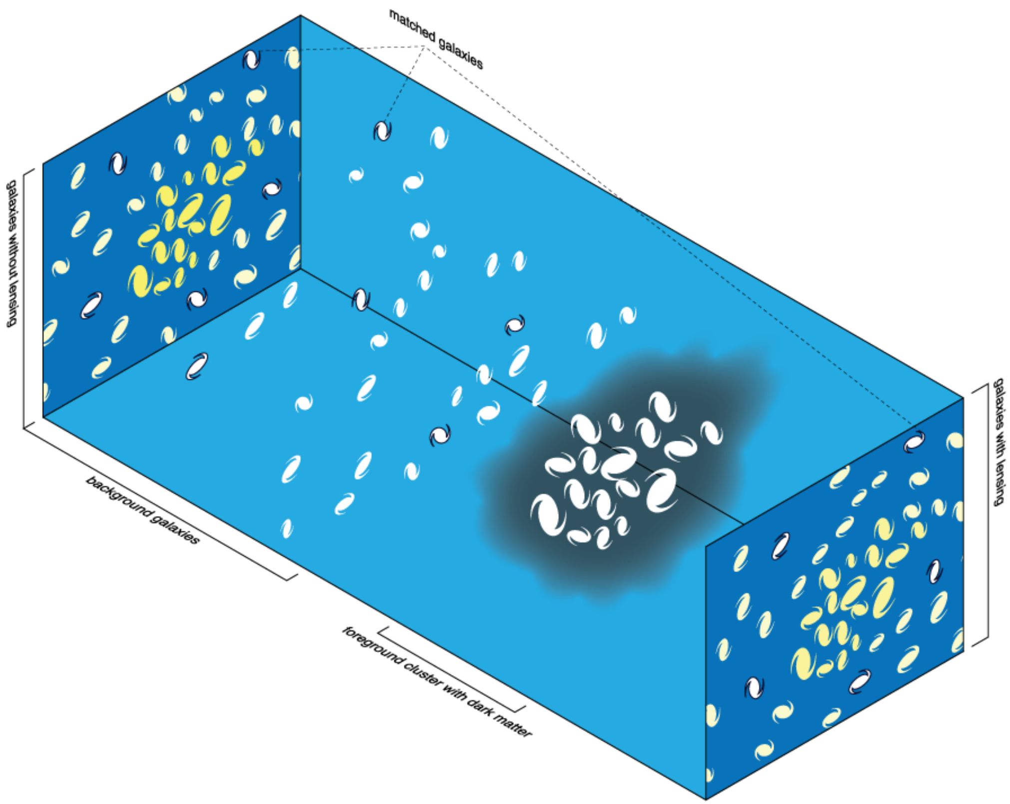

Image by Michael Sachs [CC BY-SA 3.0 or GFDL], via Wikimedia Commons

Common observables

Cosmic shear:
Correlation between the shape of one background galaxy and the shape of another background galaxy.
Shape x Shape

Galaxy - galaxy lensing:
Correlation between the shape of a background galaxy and the position of a foreground galaxy
Shape x Position

Cosmic shear + Galaxy - galaxy lensing + Galaxy clustering (Position x Position) = **3 x 2 pt analysis** (see e.g. DES)

→ Powerful combined constraint on growth, geometry, and relationship between galaxies and dark matter.

→ Combining probes helps mitigate systematic effects.

Weak lensing statistics

ξ_+ , ξ_- : Cosmic shear

γ_t : Galaxy-galaxy lensing

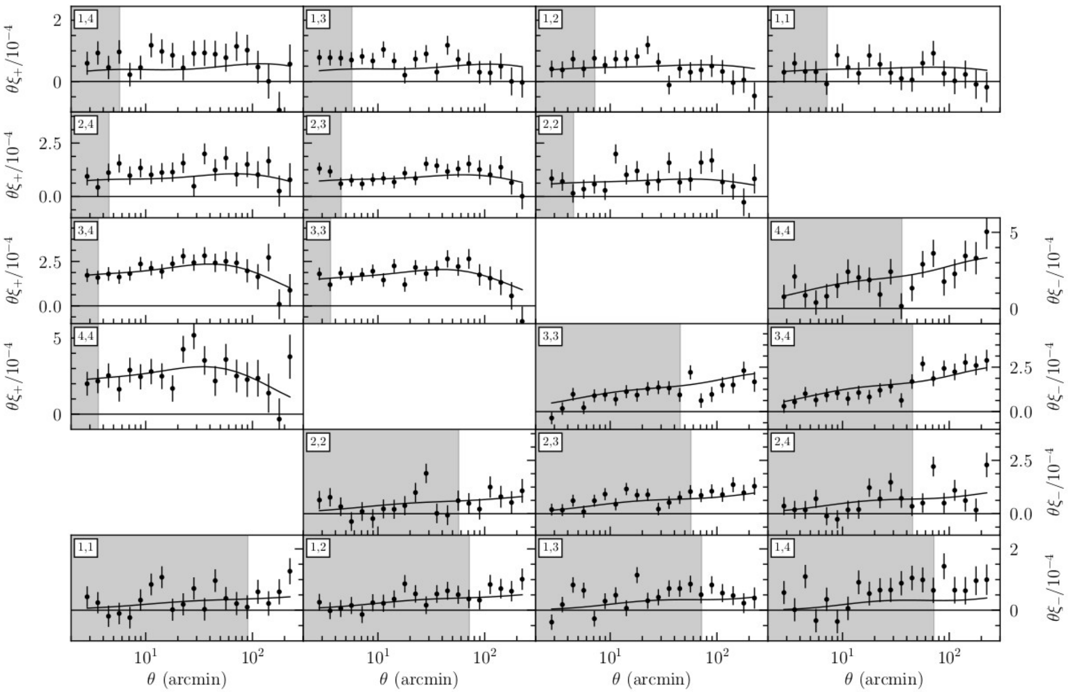

Image: Troxel et al. 2017, 1708.01538

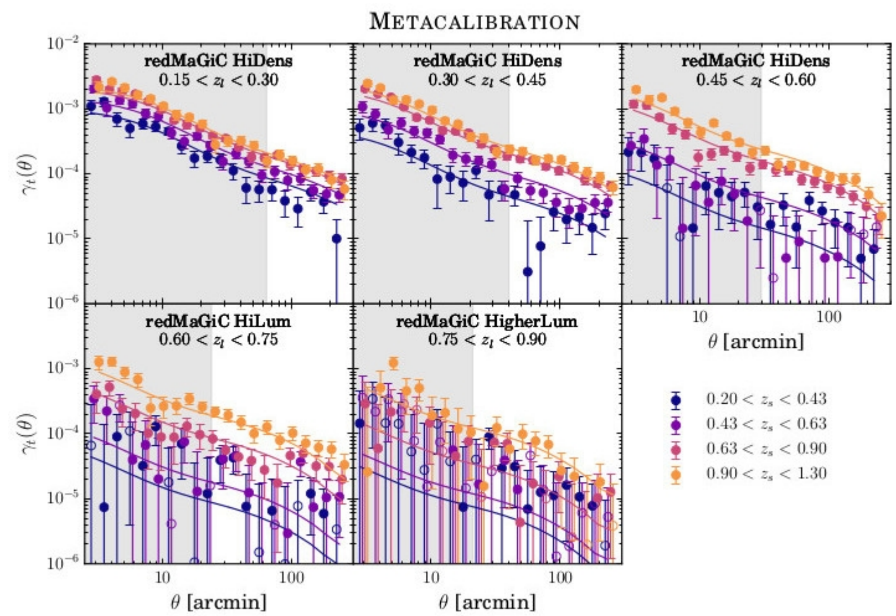

Image: Prat et al. 2017, 1708.01537

These are common real-space statistics
– Fourier-space analysis is also possible!

Weak lensing is most sensitive to:

Ω_{M} : fractional energy density of matter today

σ_8 : directly related to the amplitude of primordial fluctuations

w : equation of state of dark energy

Σ : modifications (vs GR) to the trajectories of photons around massive bodies

But degeneracies exist between these parameters (and with others) – for best constraints, we need multi-probe analyses

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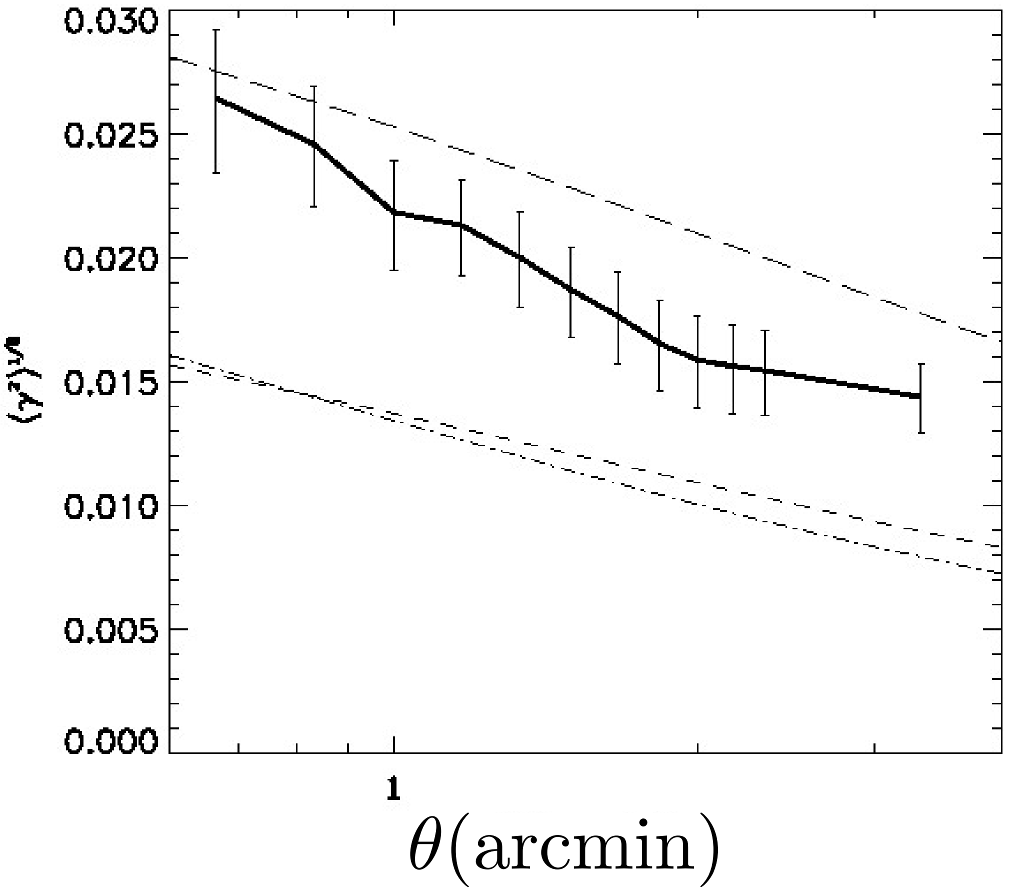
First detection of weak lensing



First detection of gravitational lensing by large scale structure:
Van Waerbeke et al. 2000, using CFHTLS data

Completed lensing surveys: two examples

SDSS I & II

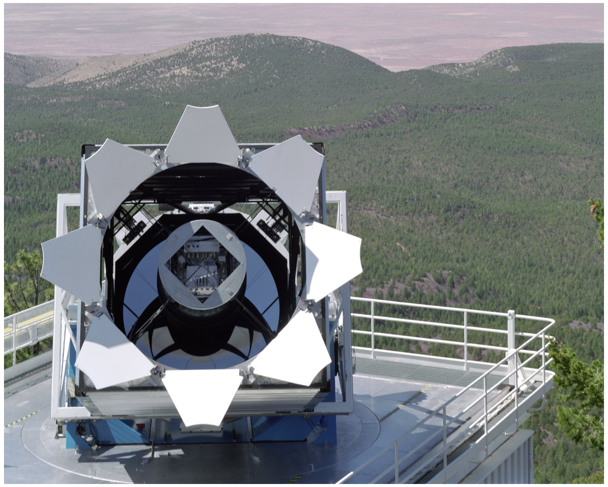


Image: sdss.org

Data collection: 2000 – 2008

Larger area: ~ 10,000 square degrees

Limiting magnitude of ~ 22 (shallower)

CFHTLenS

Image: cfht.hawaii.edu

Data collection: 2003 – 2009

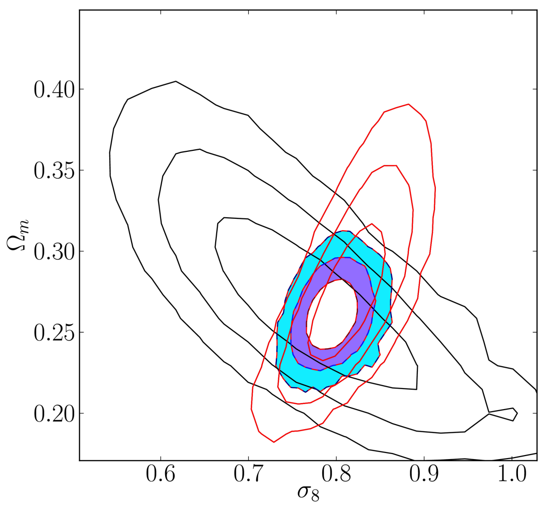
Smaller area: ~ 154 square degrees

Limiting magnitude of ~ 24.5 (deeper)

See also: COSMOS, Deep Lens Survey (DLS), RCSLenS

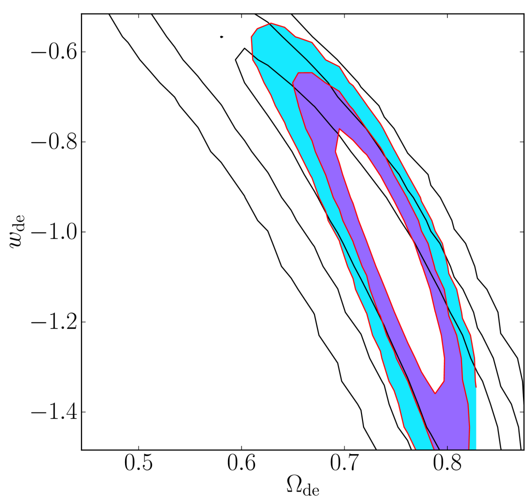
Completed lensing surveys: two examples

SDSS I & II



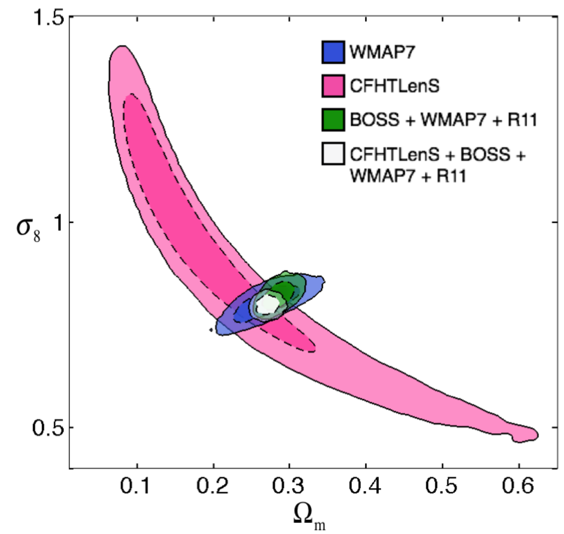
Red: WMAP7

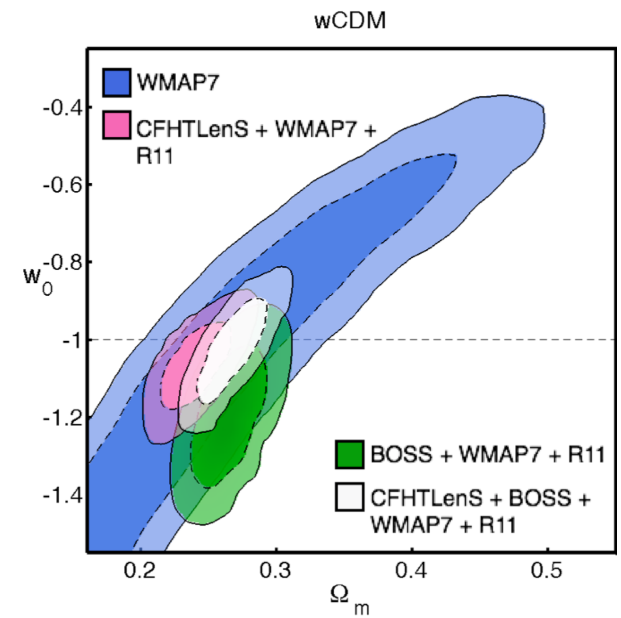
Black: SDSS (g-g lensing)



Images: Mandelbaum et al. 2013

CFHTLenS





Images: Heymans et al. 2013

Major ongoing lensing surveys

Dark Energy Survey (DES)

Image: fnal.gov (Reidar Hahn)

Hyper-Suprime Cam (HSC)

Image: phys.org

Kilo-Degree Survey (KiDS)

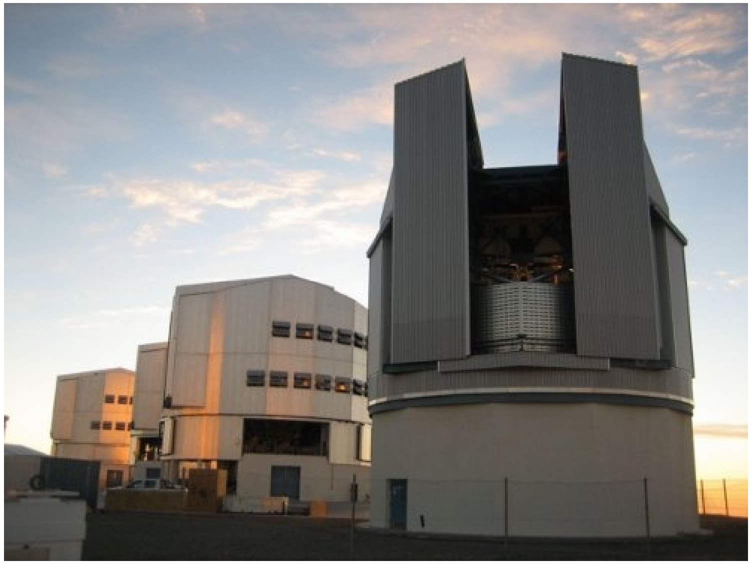


Image: kids.strw.leidenuniv.nl

Dark Energy Survey (DES)

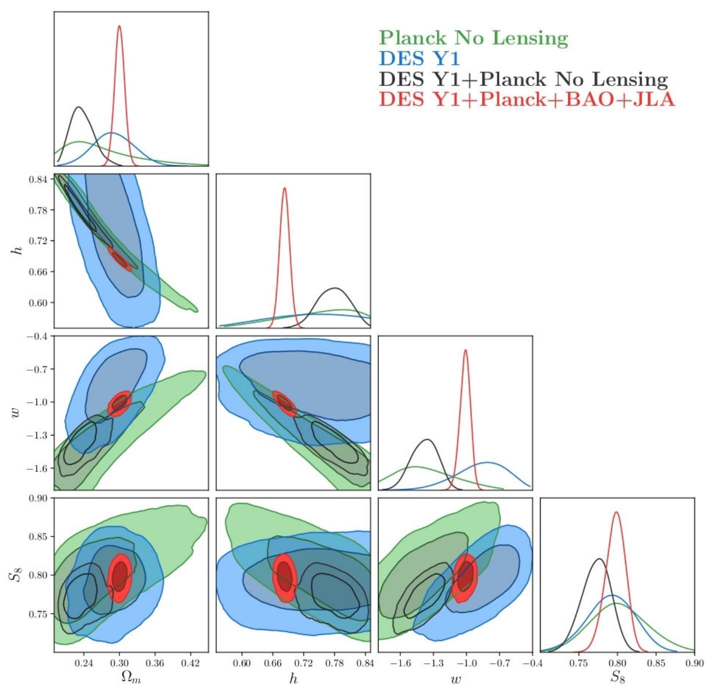
Final anticipated area: 5000 deg^2

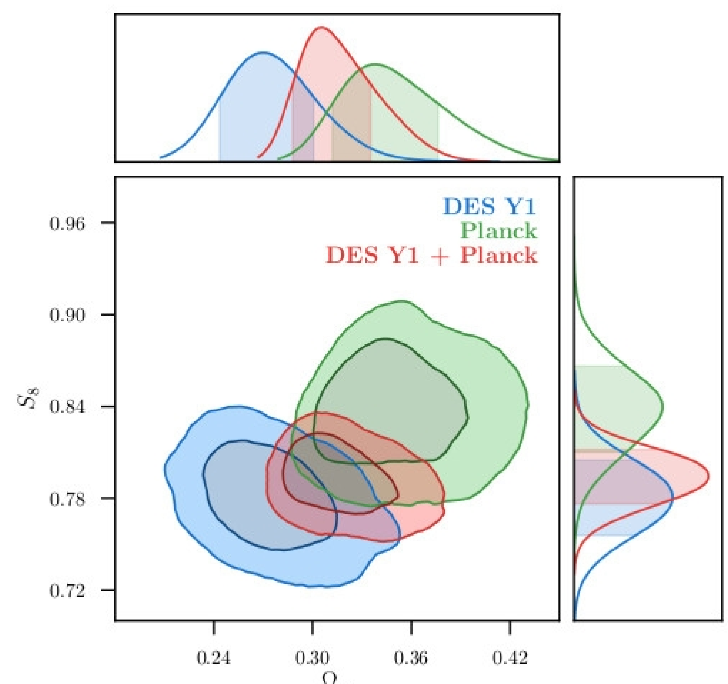
Depth: ~ 24 (r-band)

Data collection: 2013 – 2018

Year 1 data key analysis released (~1300 square degrees). Some image-level data released, Y1 data vectors soon to follow.

Image: fnal.gov (Reidar Hahn)





Figures: DES Collaboration et al. 2017

Kilo-Degree Survey (KiDS)

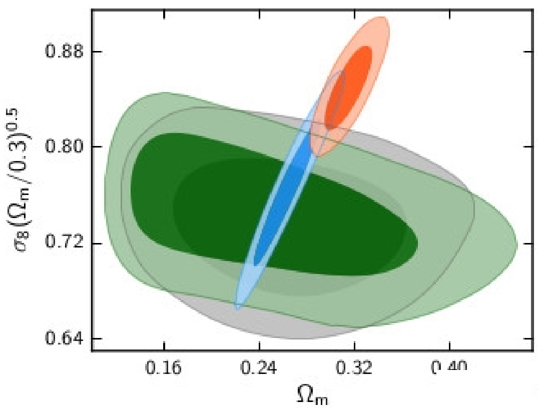
Final anticipated area: 1500 deg^2

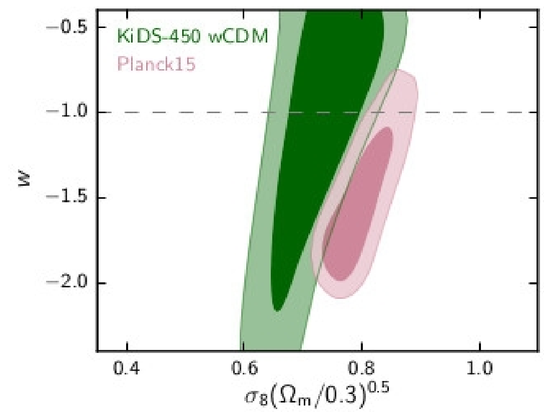
Depth: ~ 24 – 25

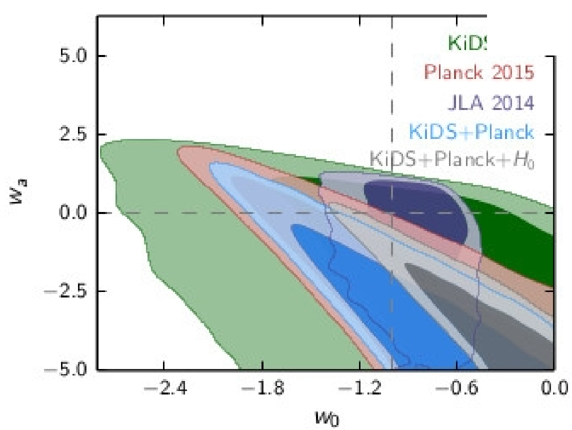
Data collection: 2011 - ongoing

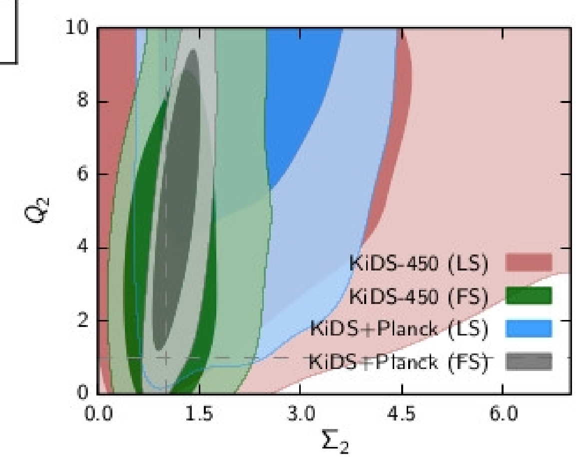
First 450 square degrees of data public
Corresponding cosmology analysis released

Image: kids.strw.leidenuniv.nl









Figures: Hildebrandt et al. 2017, Joudaki et al. 2017

Hyper-Suprime Cam (HSC)

Final anticipated area: 1400 deg^2

Data collection: 2013 – 2019

Depth: 24.5

First set of papers released, including description of shear catalog for 137 square degrees

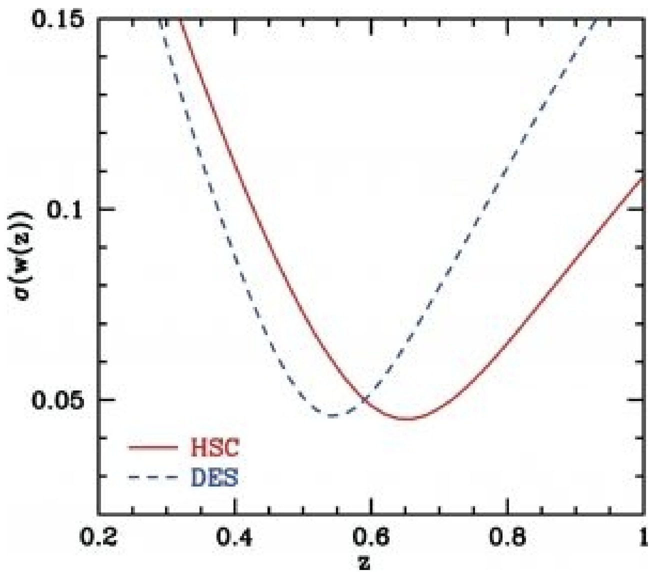


Image: hsc.mtk.nao.ac.jp/ssp/science/weak-lensing-cosmology/

Image: phys.org

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Major upcoming lensing surveys

The Large Synoptic Survey Telescope (LSST)

Image: lsst.org

Euclid

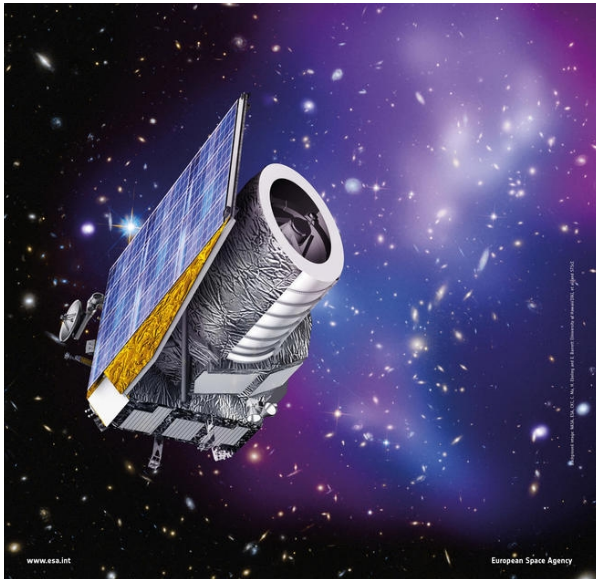

Image: ESA

The Wide Field Infrared Survey Telescope (WFIRST)

Image: Harris Corporation / TJT Photography

Euclid

Survey area: 15,000 deg^2

Lensing source density: 30 / arcmin^2

Scheduled launch: 2021

Space mission (European Space Agency)

Ground-based observatories to get redshifts

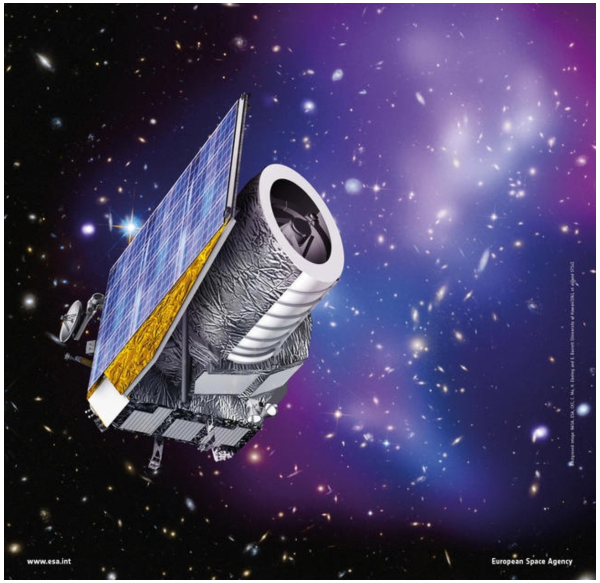

Image: ESA

LSST

Main survey area: 18,000 deg^2

Lensing source density: 26 / $arcmin^2$

Data collection: 2023 - 2033

Ground-based

Will have some spectroscopy

Image: lsst.org

WFIRST

Survey area: 2,200 deg^2

Lensing source density: 45 / arcmin^2

Scheduled launch: mid - 2020s

Space mission (NASA)

Some spectroscopy is planned

Image: Harris Corporation / TJT Photography

Existing and upcoming lensing surveys

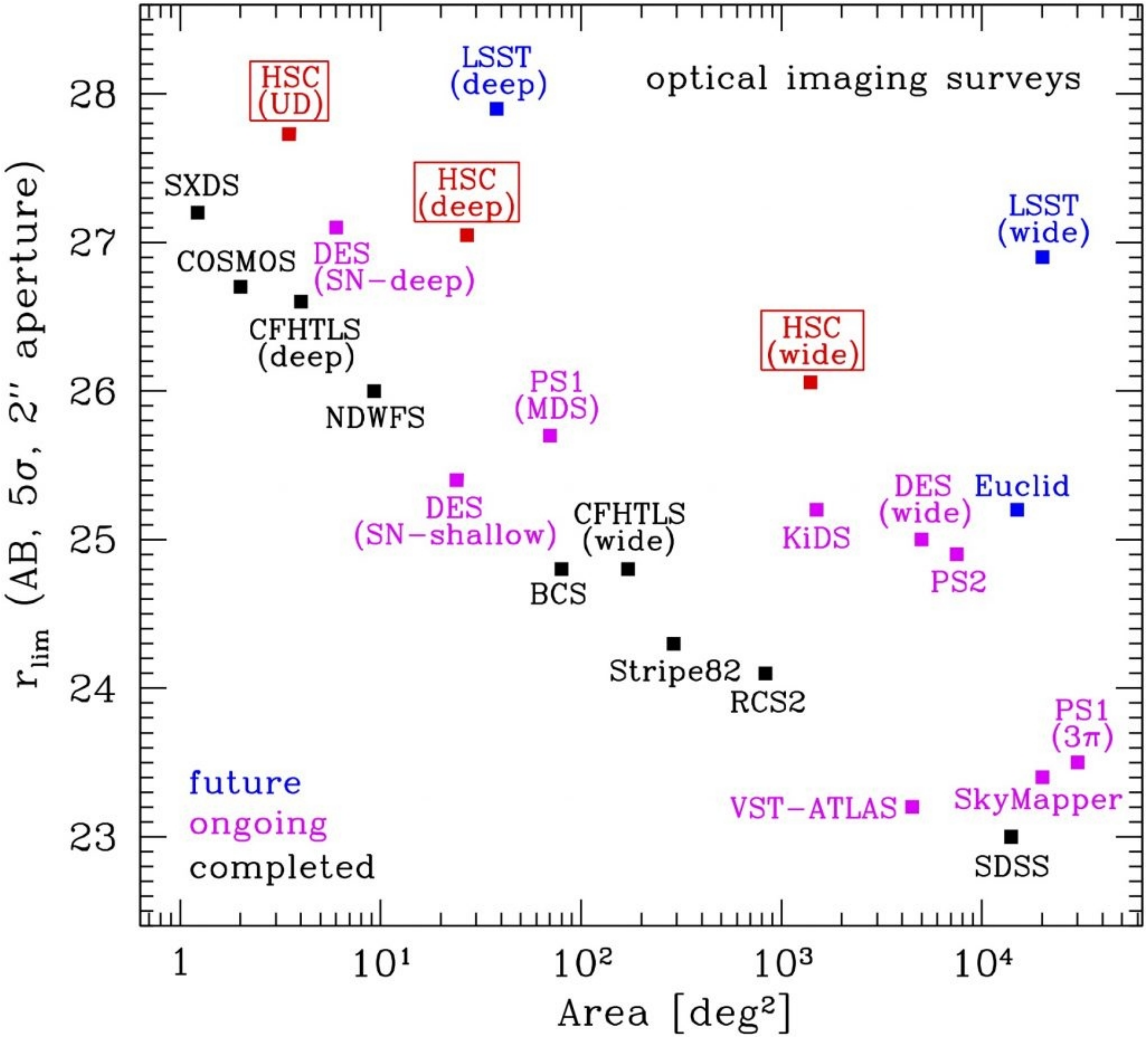

Image: hsc.mtk.nao.ac.jp/ssp/science/weak-lensing-cosmology/

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Cosmology with LSST

Large Scale Structure

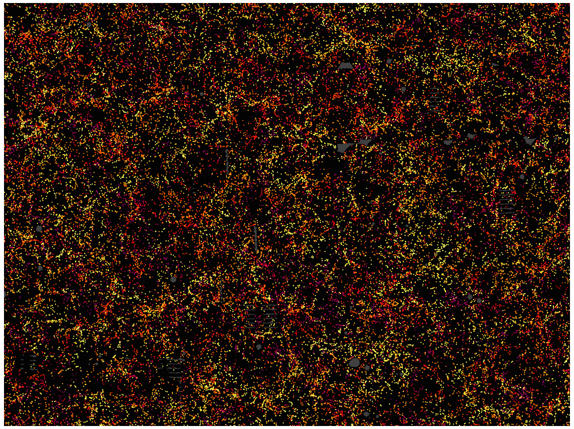


Image: Daniel Eisenstein & SDSS Collaboration

Weak lensing

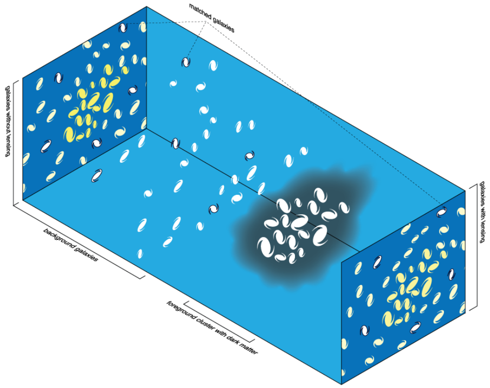


Image: Michael Sachs, via Wikimedia Commons

Cluster cosmology

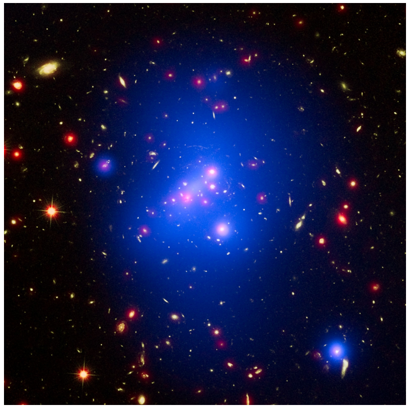


Image: ESA / NASA

Supernovae

Image: NASA / ESA

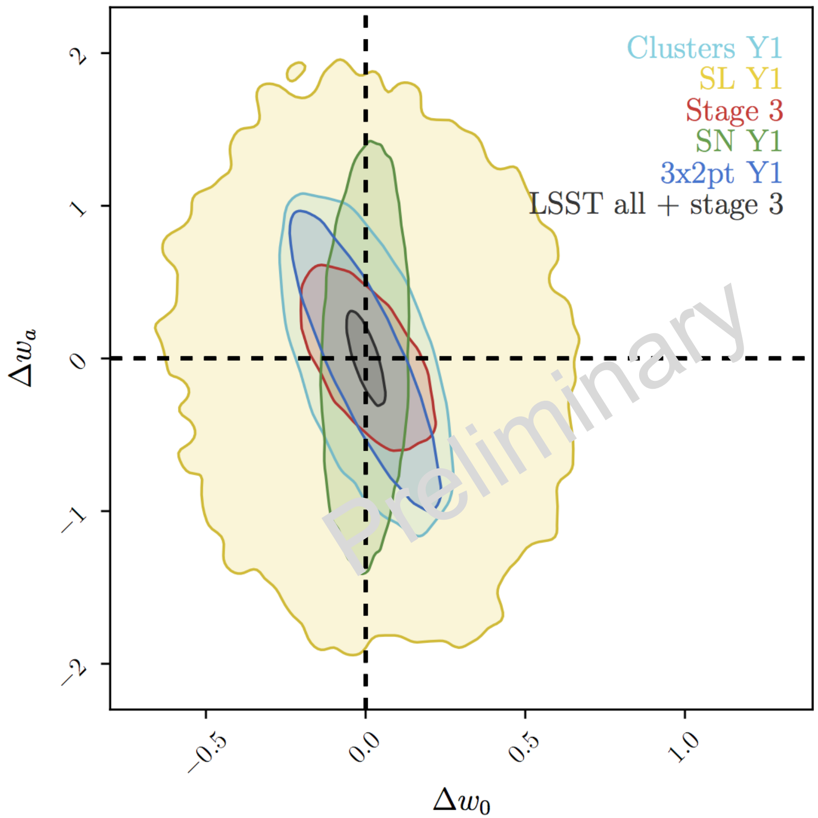
Strong lensing

Image NASA, A. Fruchter and the ERO team

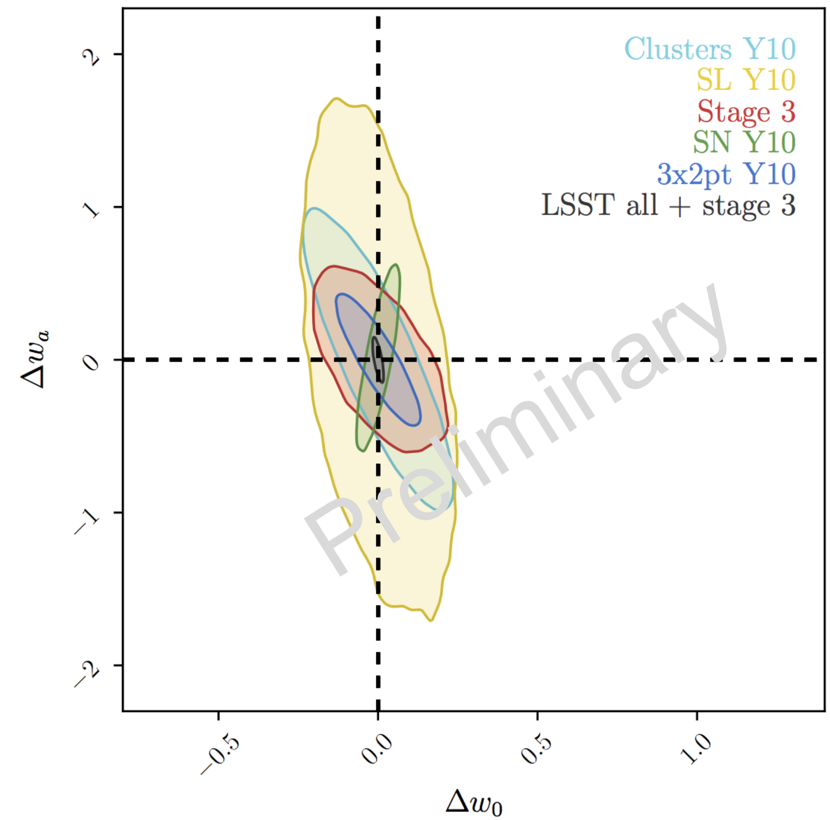
Not all independent: multi-probe analysis is key

Cosmology with LSST

With 10% of LSST data (1 year)



With 100% of LSST data (10 years)



Forecast 68% confidence intervals for LSST individual probes and a multi-probe analysis

Figures: LSST DESC Science Requirements Document v 0.99, T. Collett, T. Eifler, E. Gawiser, R. Hlozek, R. Mandelbaum et al.

Weak lensing with LSST

3 x 2 point
- Shape x Shape
- Shape x Position
- Position x Position

Mass mapping

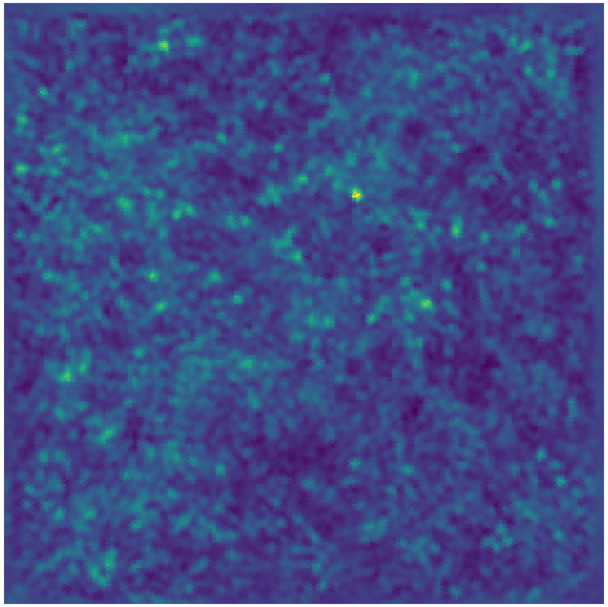


Image: LSST DESC mass mapping task force (WL working group)

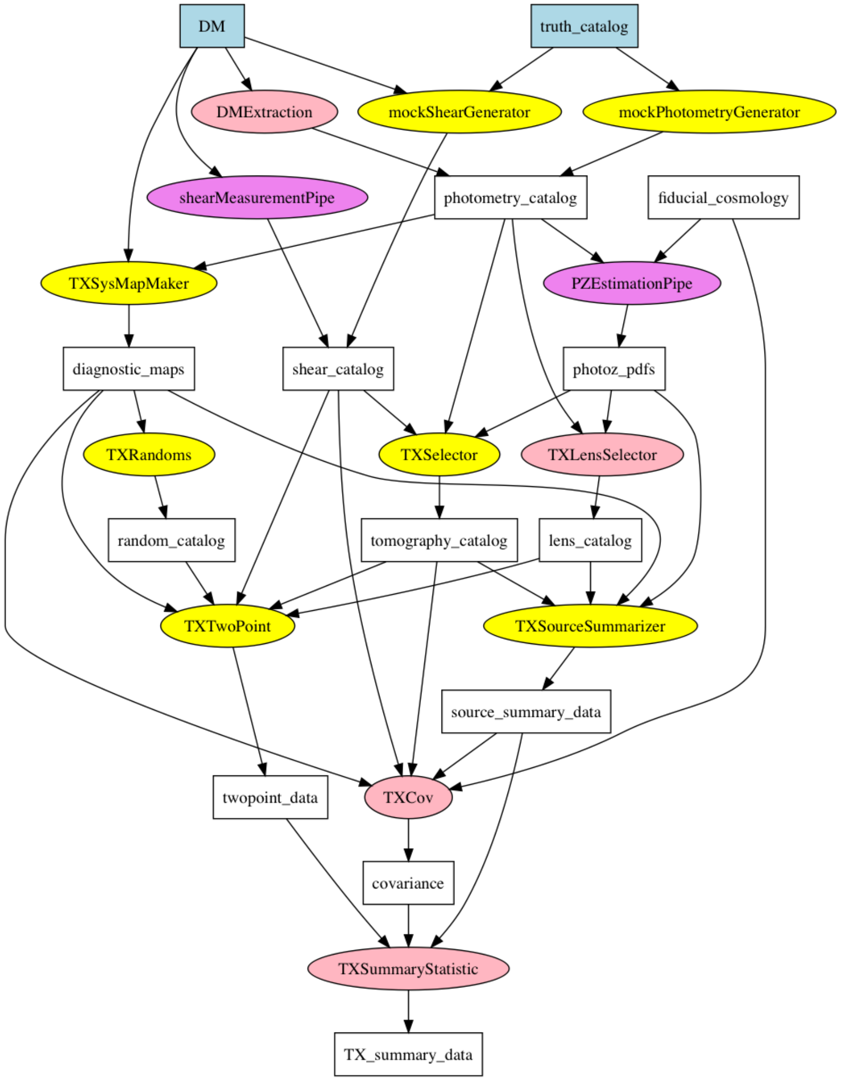
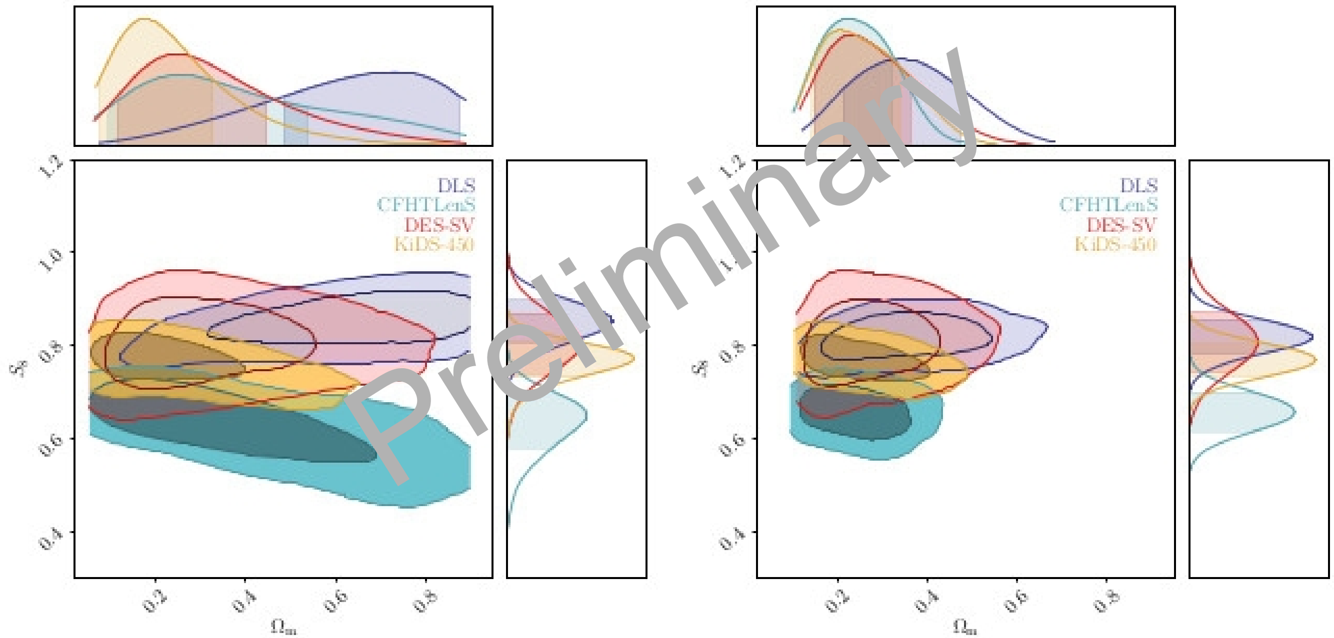


Image: Joe Zuntz & LSST DESC 3 x 2 pt developers

Weak lensing with LSST

Re-analysis of public data from current lensing surveys with the (under-development) LSST DESC pipeline

→ Analysis choices matter!



Chang, Wang, Dodelson, LSST DESC WL+LSS Working Groups et al. 2018, in prep

Weak lensing with LSST

With great statistical power comes great responsibility …

- Shear estimation
- Photometric redshifts
- Covariance estimation
- Intrinsic alignments
- Baryonic effects
- Point-spread function
- De-blending
- and more

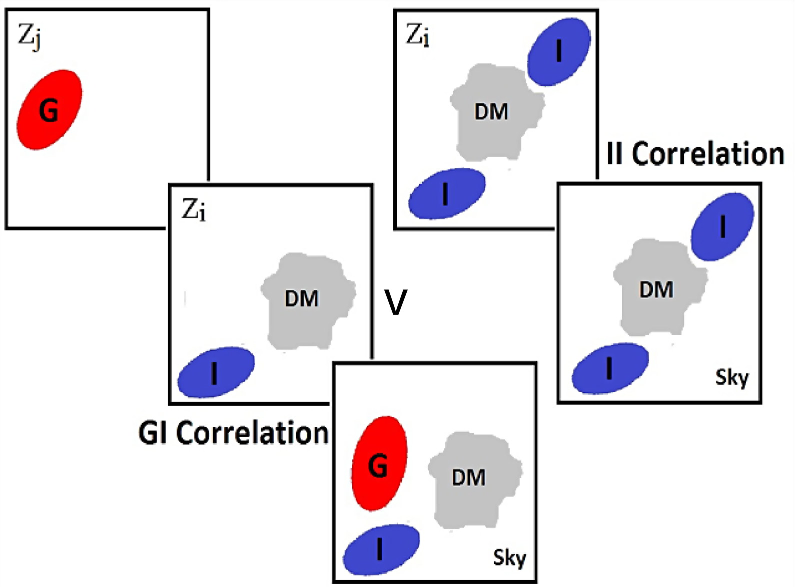


Image: Troxel & Ishak 2012, 1203.2138

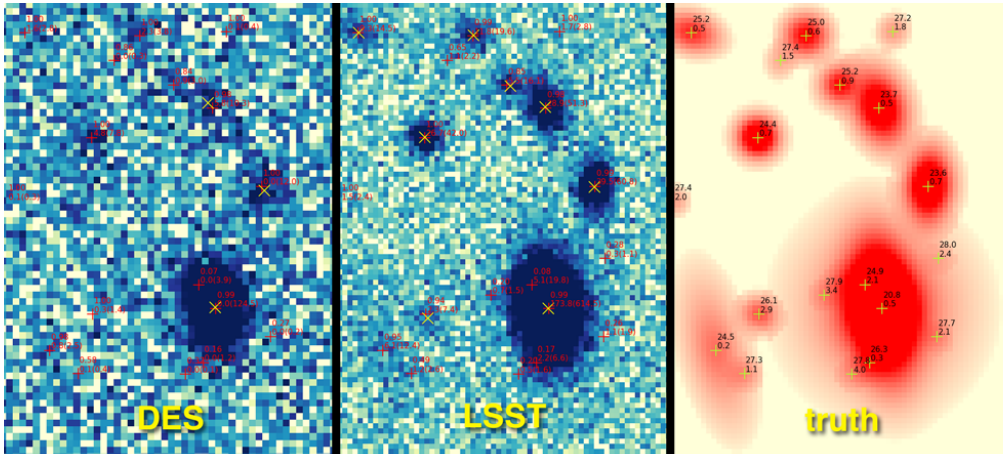


Image: David Kirkby, LSST DESC WL working group

Shear estimation advances

Metacalibration

Apply artificial shear to images to get shear response

Sheldon & Huff 2017, Huff & Mandelbaum 2017

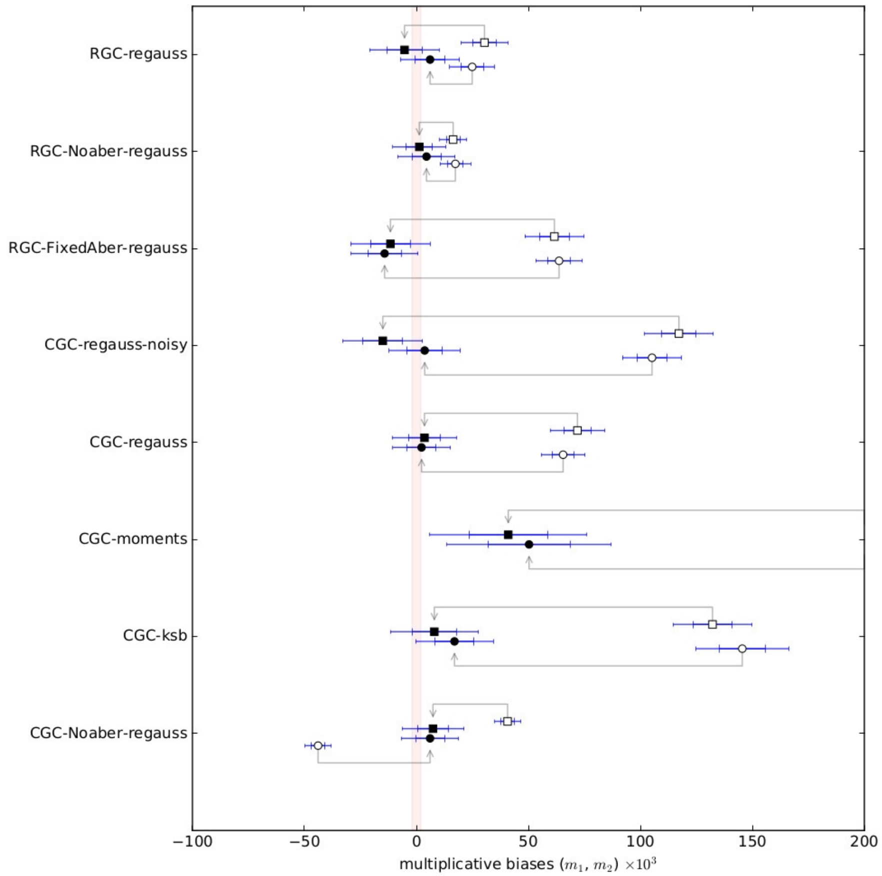


Figure: Huff & Mandelbaum 2017

Bayesian Fourier Domain

Treat the ensemble in Fourier space rather than using individual shapes in real space

Bernstein et al. 2014, 2016

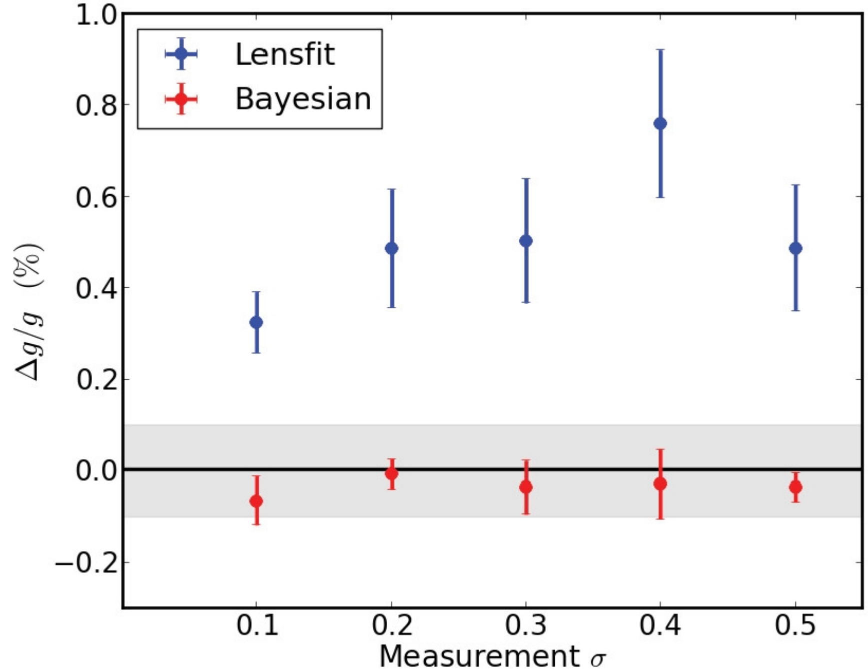
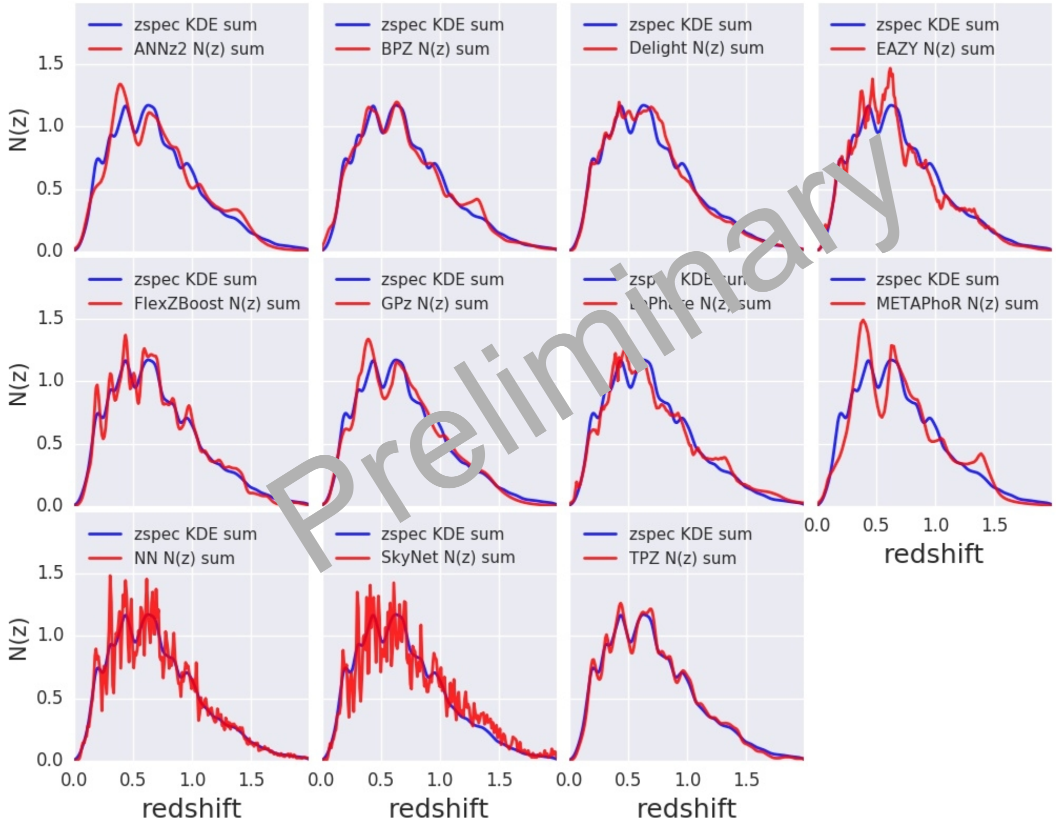


Figure: Bernstein et al. 2014

Photometric redshifts



Source galaxy n(z) estimated using different photo-z codes (red) vs spectroscopic ("true") distribution (blue)

LSST DESC Photo-z Working Group 2018, In preparation

Covariance estimation

Assumptions must be carefully examined. e.g: Does the non-Gaussianity in the likelihood of weak lensing observables cause biased parameter inference? (Lin et al. 2018, in prep)

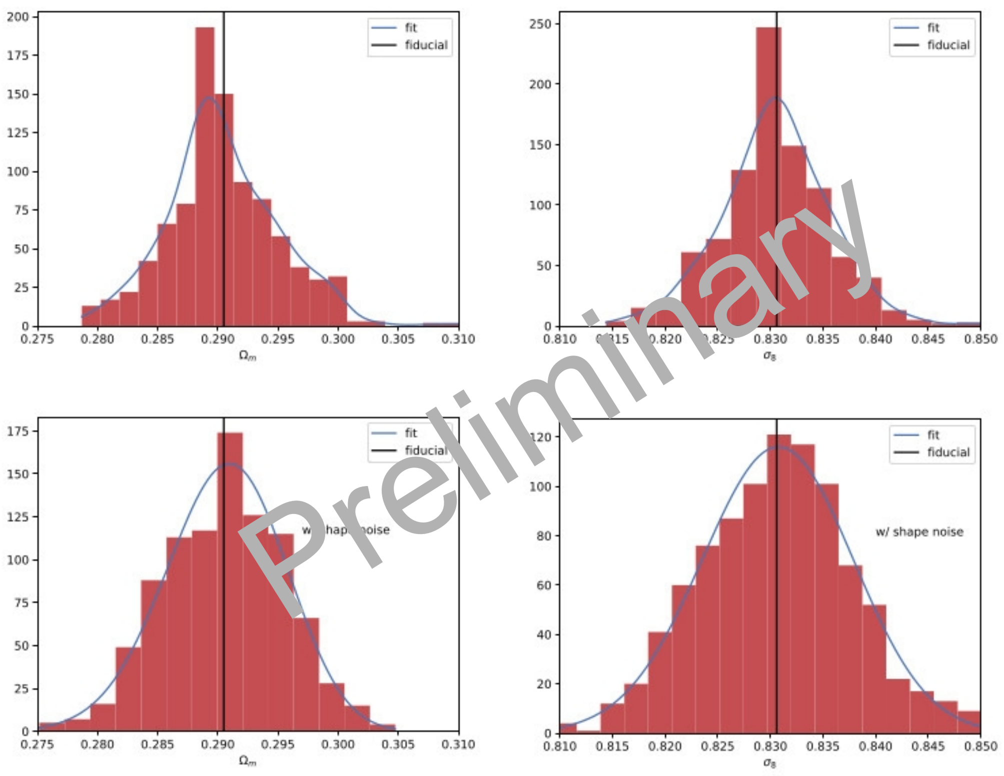


Figure: Lin et al. 2018, in preparation

Intrinsic alignments

Intrinsic correlations in galaxy shapes contaminate weak lensing signals.

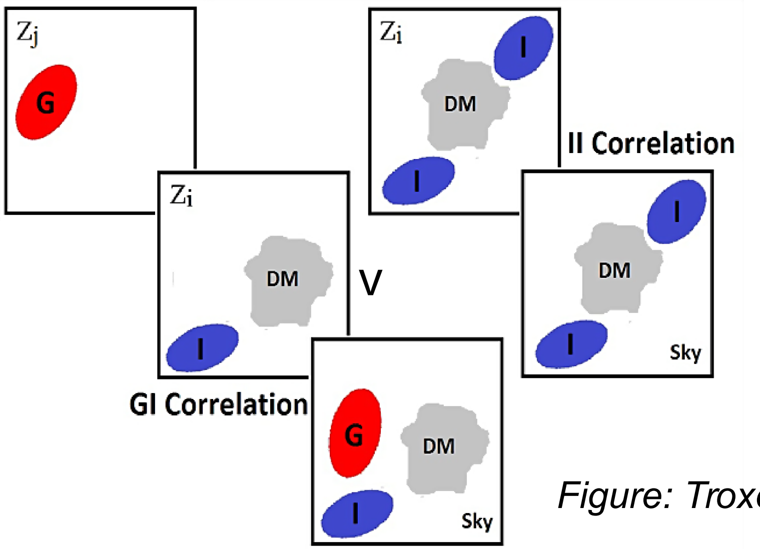


Figure: Troxel & Ishak 2012

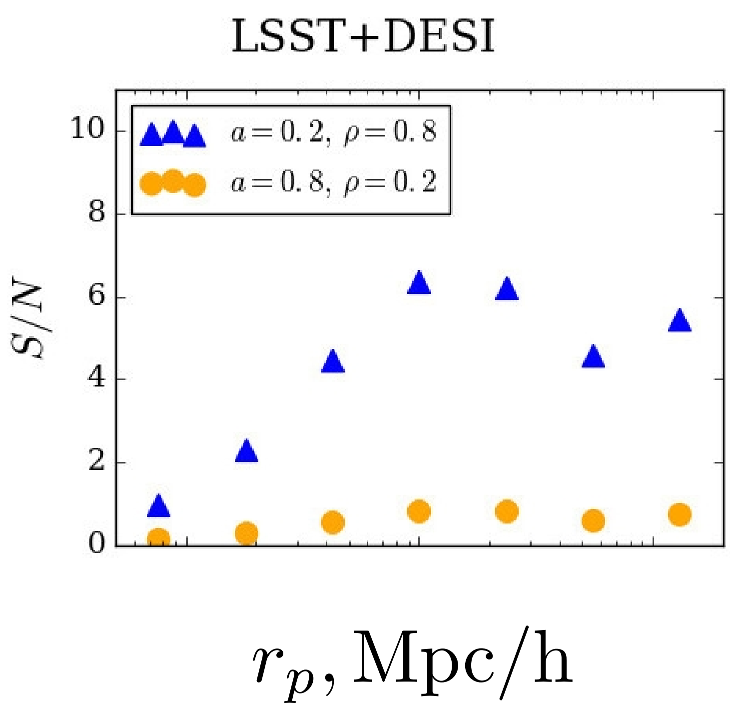


Figure: DL & Mandelbaum (LSST DESC) 2018

Recent LSST DESC work on intrinsic alignments:

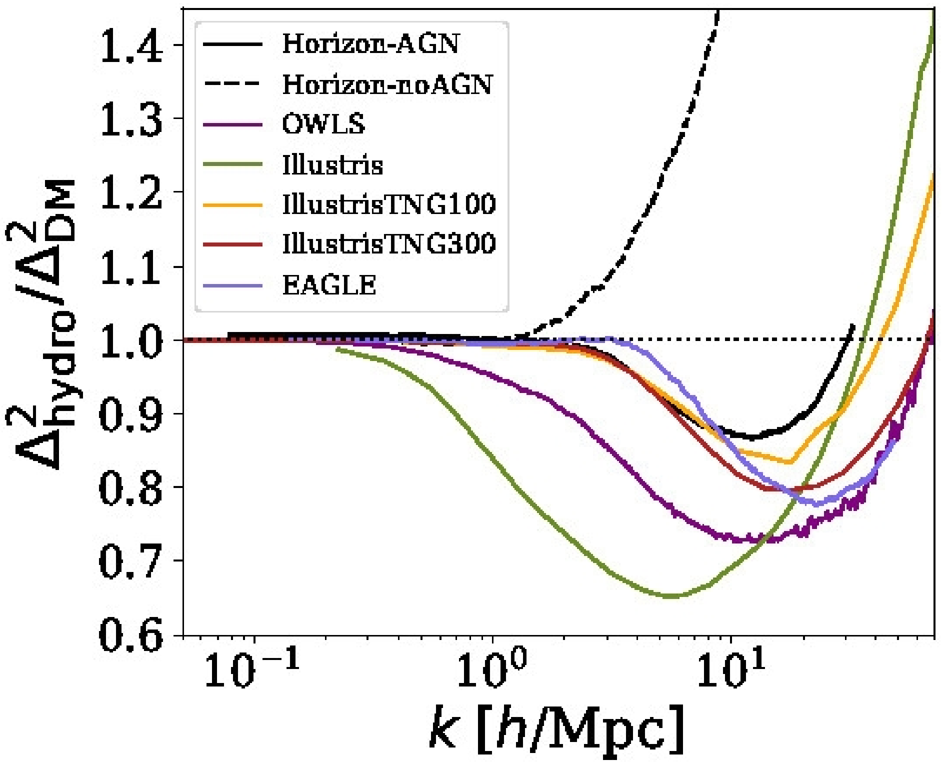
- self-calibration (Lin, Troxel, Ishak)

- using multiple shear estimates to measure intrinsic alignment scale dependence (DL & Mandelbaum, 2018)

Baryonic effects

At small scales, cosmological observables are affected by bayonic processes, e.g. the behaviour of Active Galactic Nuclei.

Figure: Chisari et al. 2018

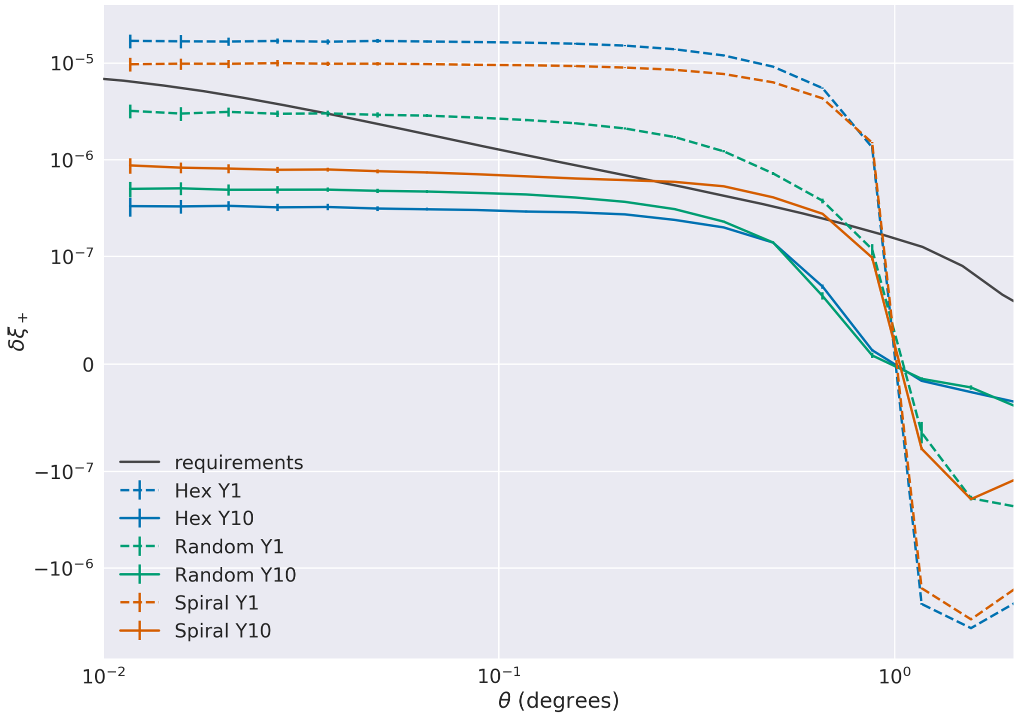


We can explore the effect of different mechanisms in hydrodynamical simulations.

Other options include clever removal of modes which are most sensitive to baryonic physics (see Eifler et al. 2015, Huang et al. in prep).

Point spread function (PSF)

Effects from the atmosphere and telescope optics can cause spurious correlations in shapes of galaxy images.



One way to minimize this is by ‘dithering’ exposures in a particular pattern.

Almoubayyed et al. in prep

De-blending

Deeper images → More galaxies which overlap

Previously: throw out overlapping galaxies. This is not feasible.

"In the Wide layer of (HSC data), 58% of all objects are members of blends; this increases to 66% and 74% in the Deep and UltraDeep layers, respectively."
- Bosch et al. 2018

Problem for photometric redshifts as well as shear estimation.

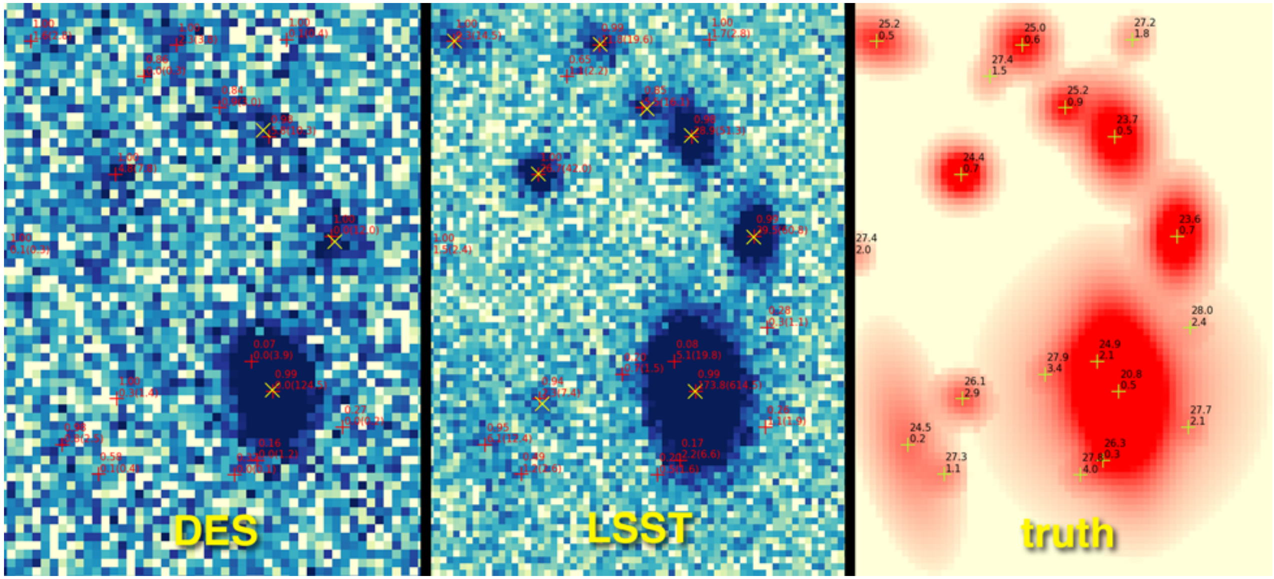


Image: David Kirkby, WL working group

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Summary & Conclusion

Current surveys (DES, KiDS, HSC) have begun to provide impressive cosmological constraints which will improve with further releases.

LSST as well as Euclid and eventually WFIRST will act as the next generation, with amazing statistical power.

To take full advantage, we need to overcome challenges in systematic error mitigation, covariance estimation, photometric redshifts, shear estimation, and more. Progress is ongoing.

Danielle Leonard
(Carnegie Mellon University)

for LSST DESC
June 25, 2018