Weak lensing: state of the art and future prospects

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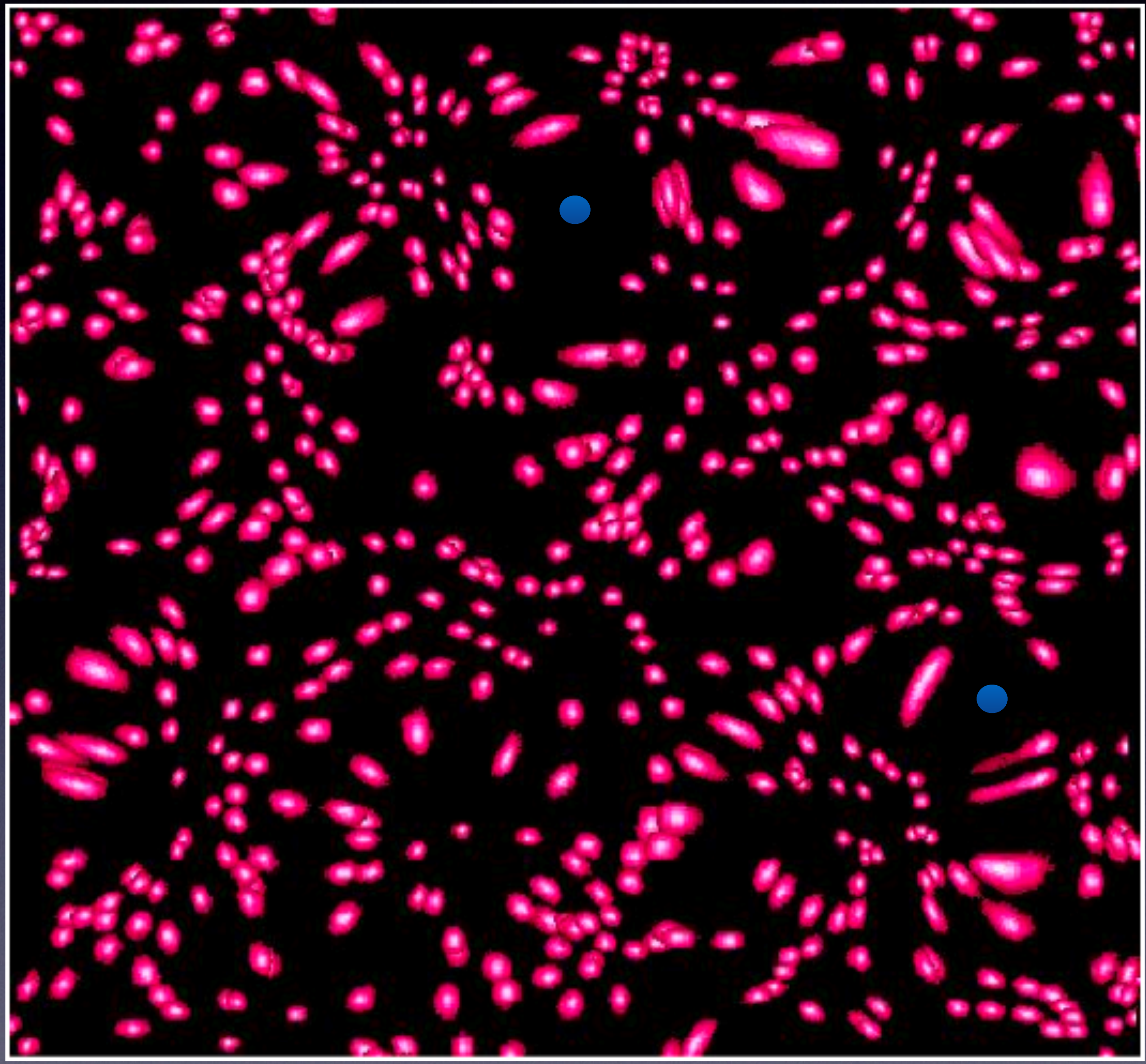
September 2019

Weak lensing

Deflection (and observed “shear”) depends on:

- Projected mass
- Separation on sky (impact parameter)
- Separation between us, lens, source

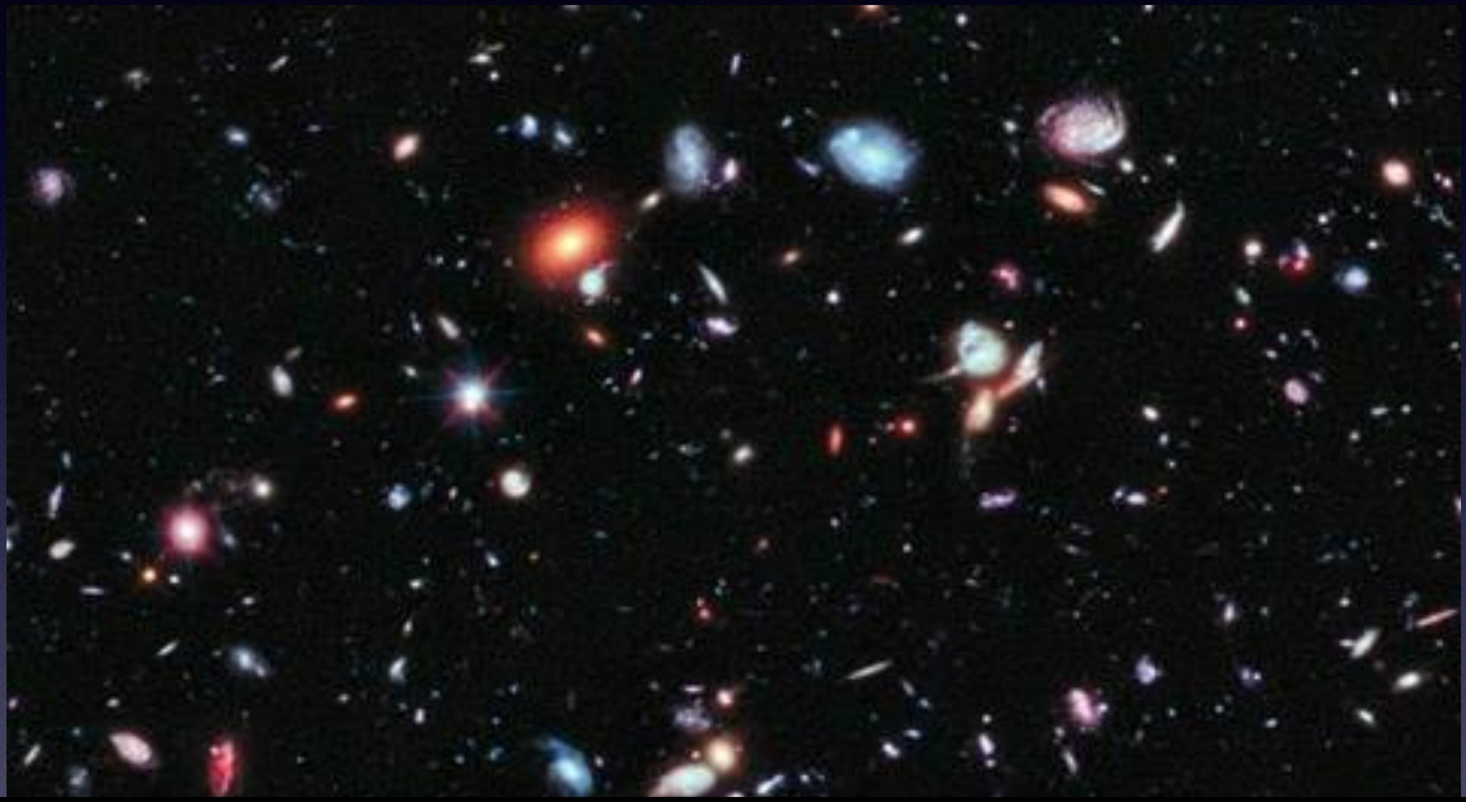


Coherent shape-shape (shear-shear) alignments
OR
Coherent foreground position-background shape alignments

Galaxies aren’t round

NASA / ESA / IPAC / Caltech / STScI / ASU

Galaxies aren’t round

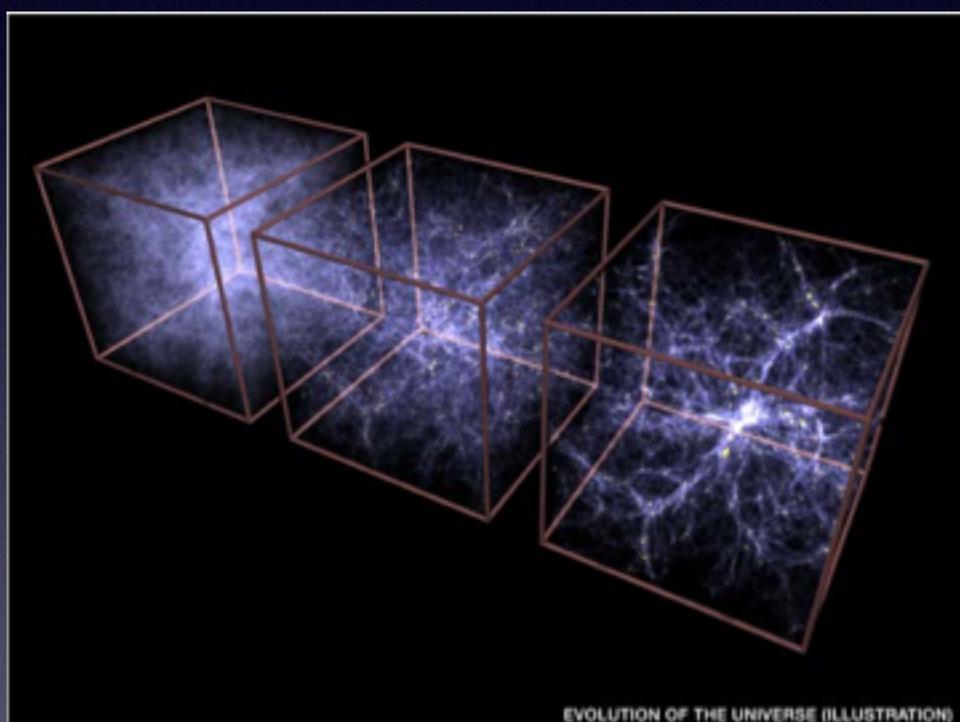


We measure weak lensing statistically: look for coherent galaxy shape distortions (<~1%) underneath the ~30%-level ellipticities (=statistical error).

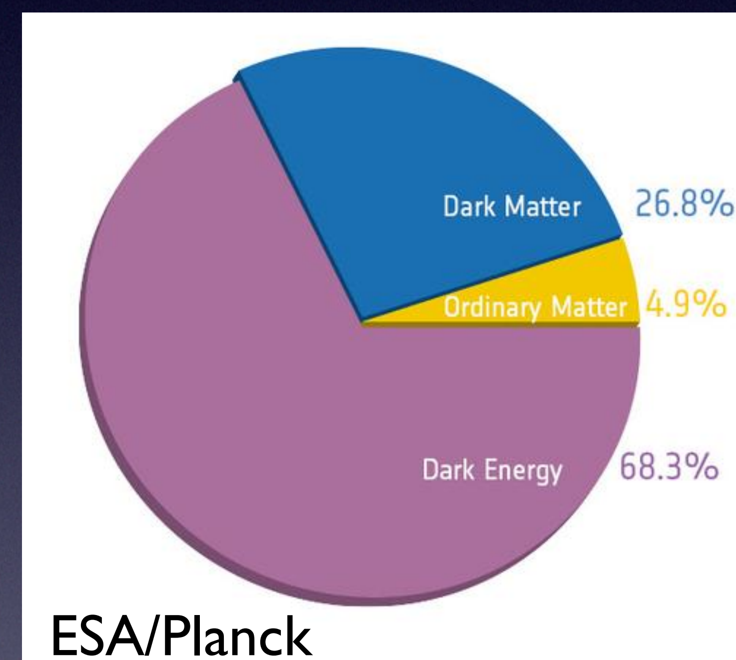
NASA / ESA / IPAC / Caltech / STScI / ASU

Why should you care about weak lensing?

Structure growth!



Dark matter and dark energy!



Theory of gravity!

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Galaxy-dark matter connection!

Early concept of weak lensing in the era of LSST

Starting in 2003: shear-shear (cosmic shear) got lots of attention

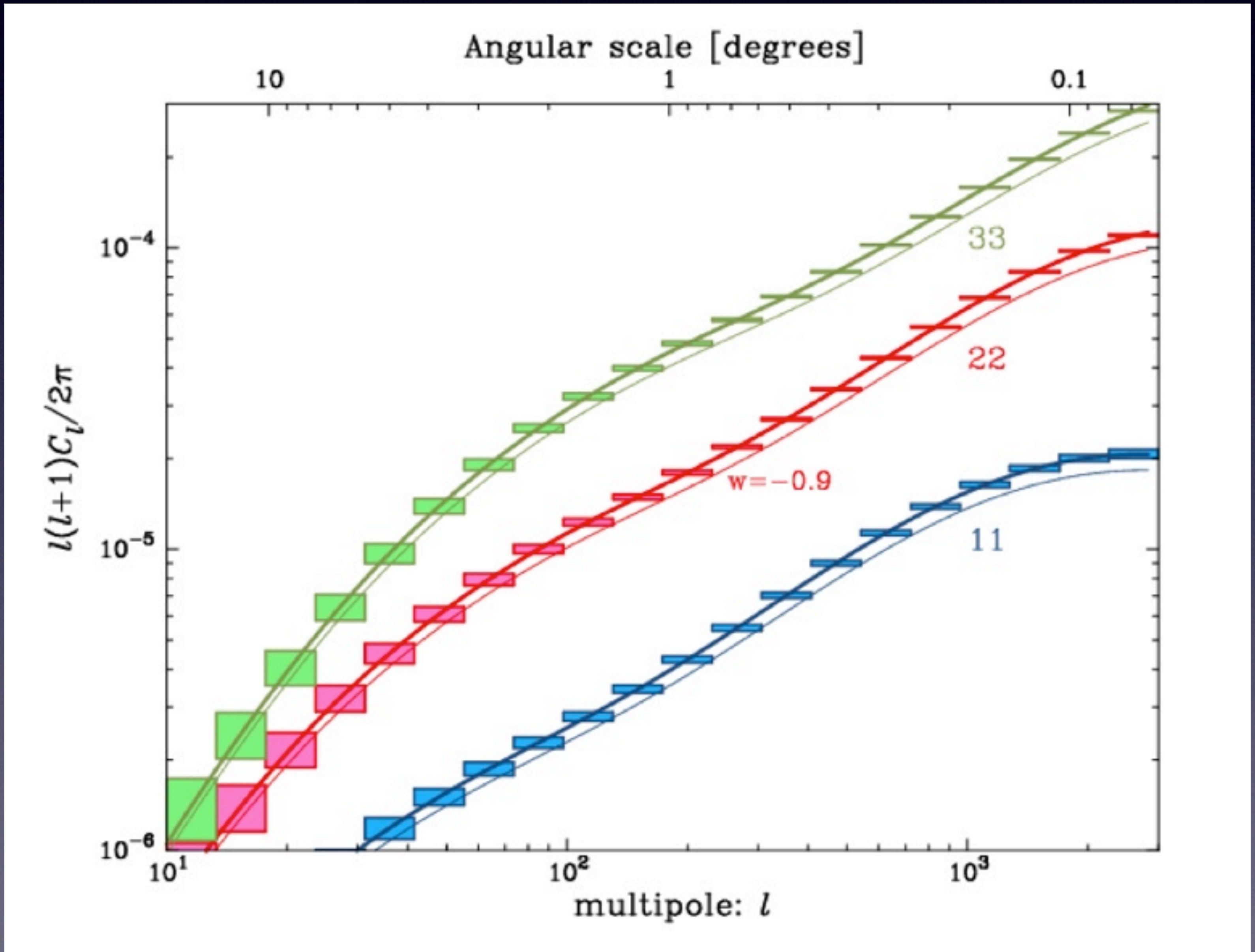
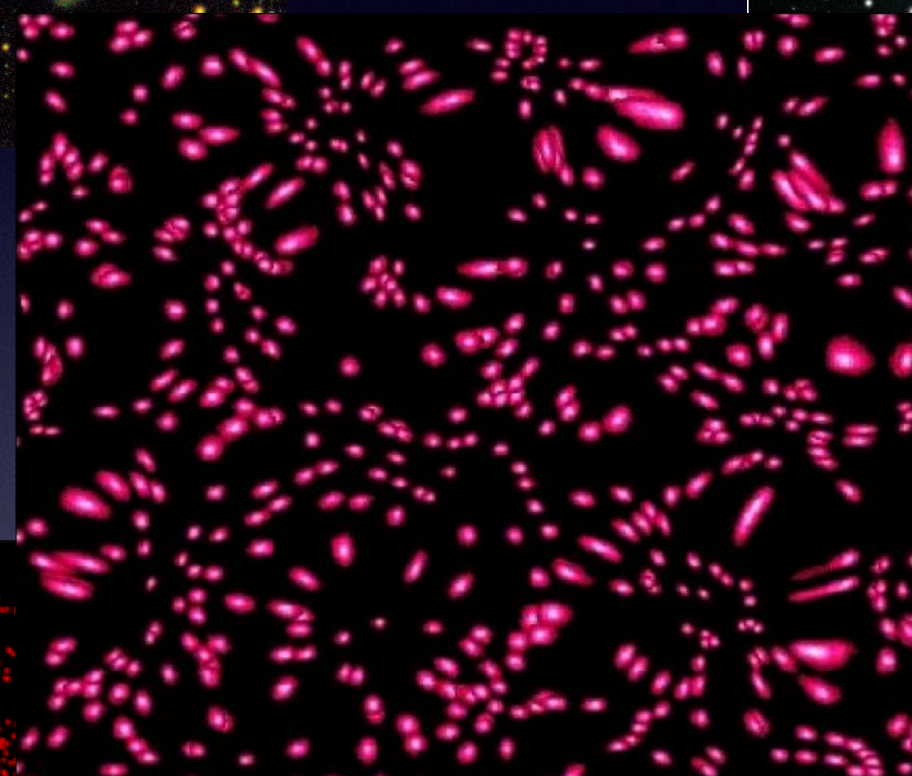


Image credit: LSST science book

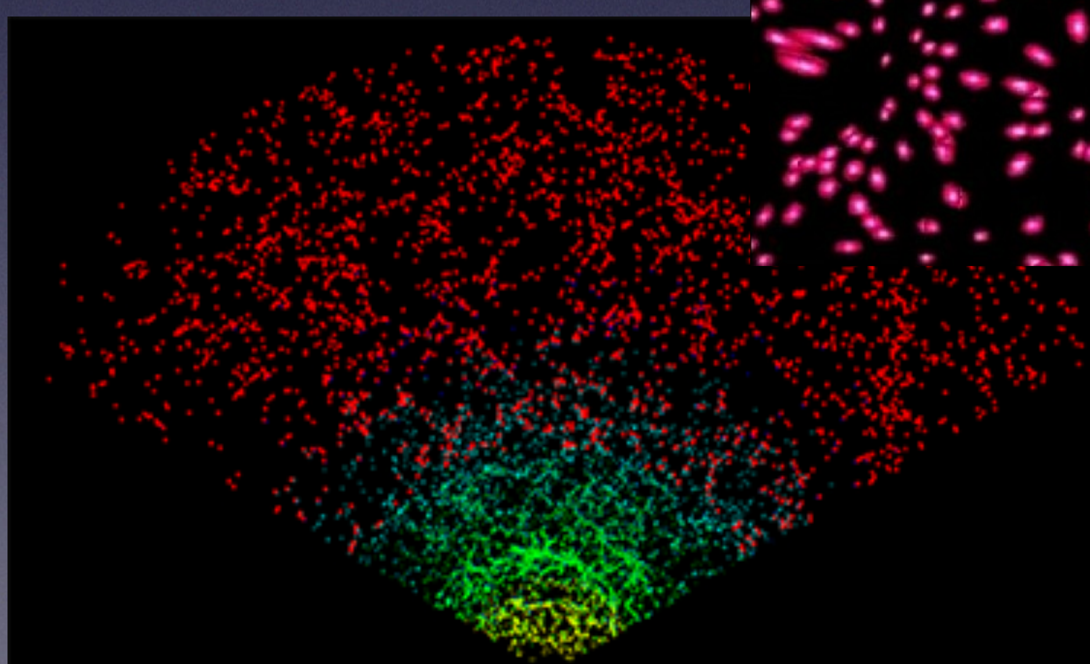
Now the landscape is richer

2d (2+1d?)
galaxy
density field

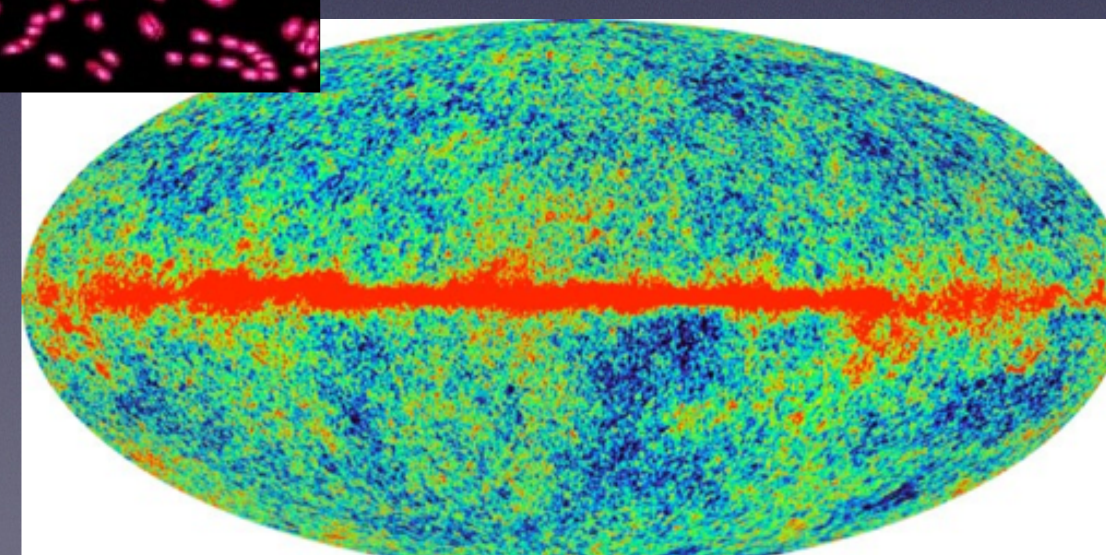
Lensing magnification



Lensing
shear



3d galaxy density +
peculiar velocity field

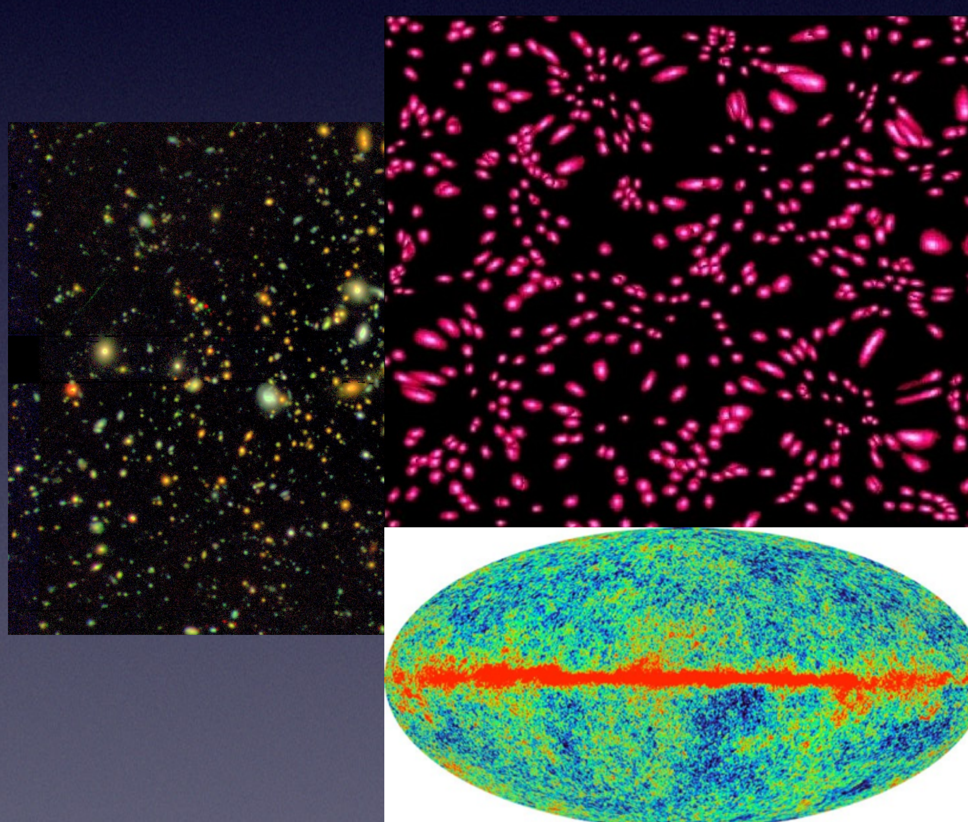


Cosmic microwave background

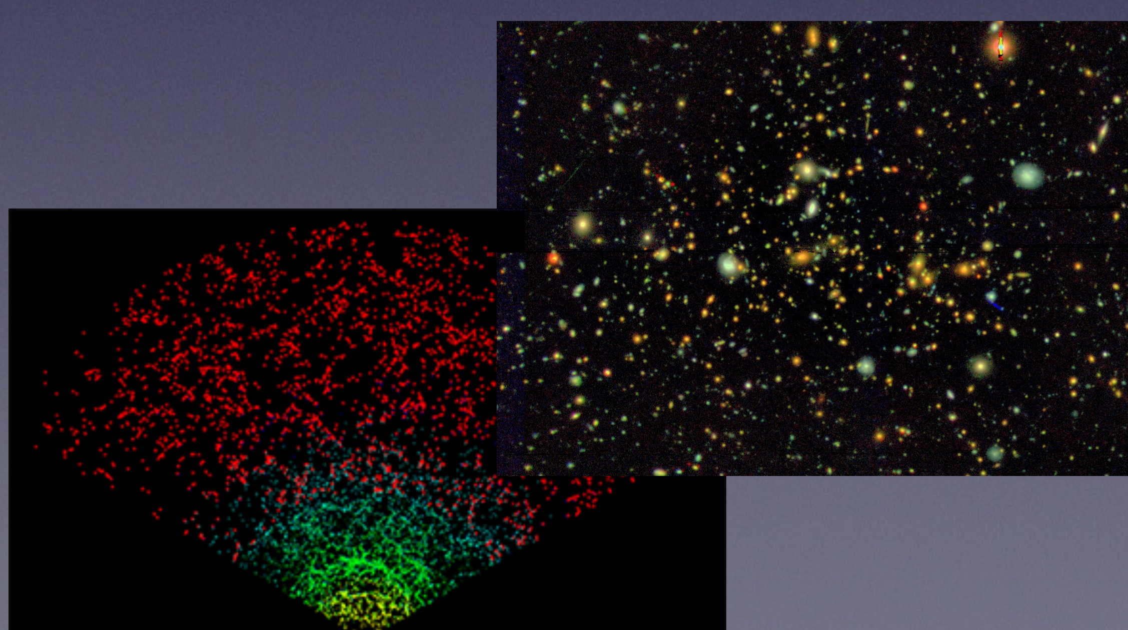
Cross-correlations

- Additional information about cosmological structure growth
- Self-calibration of systematic uncertainties (given a sufficient model)

Example 2: 3x2pt analysis



Example 1: cross-correlations with spec-z sample to constrain photo-z errors

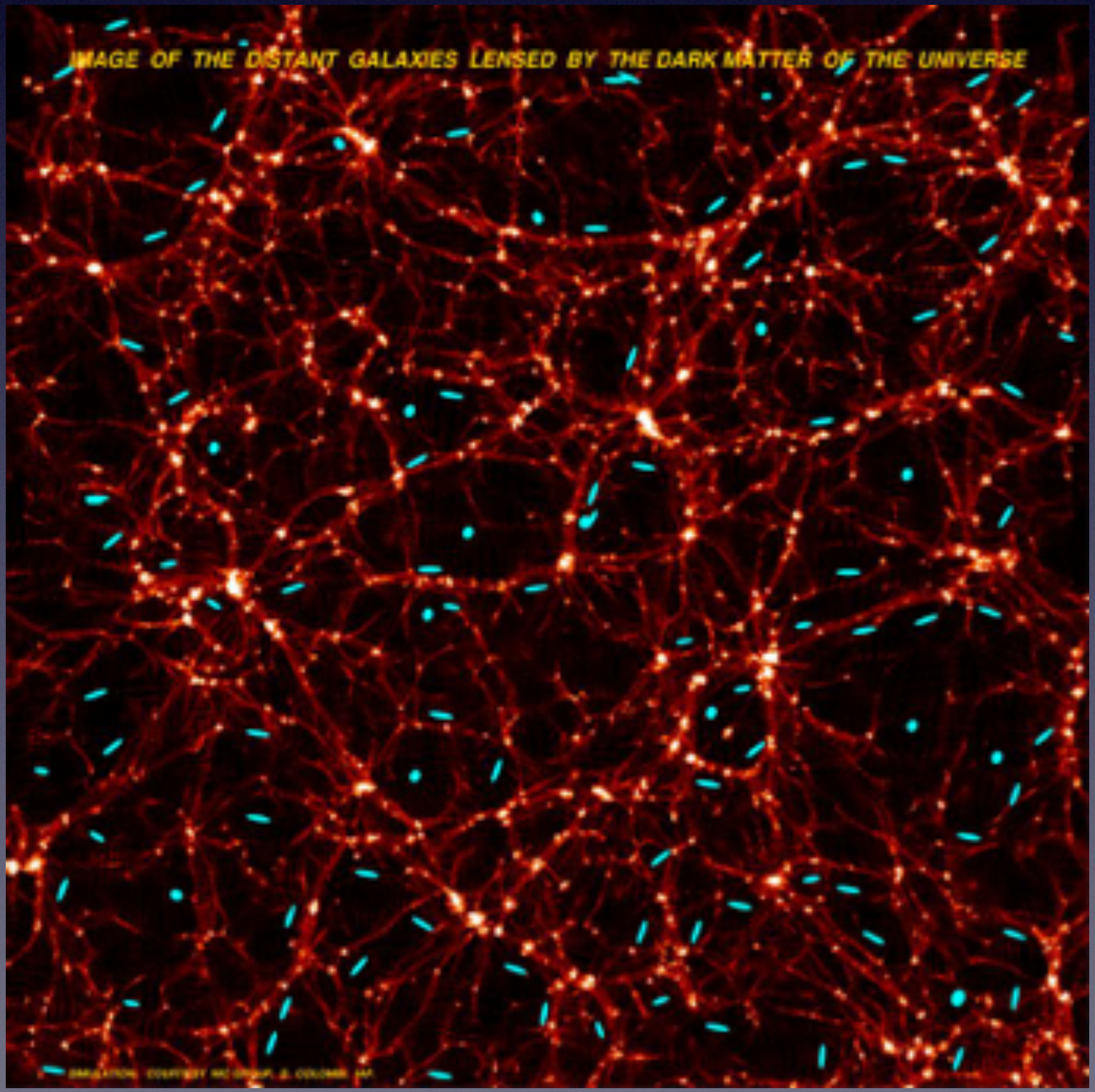


Example 3: combine galaxy and CMB lensing to extend redshift reach, calibrate systematics

Current state of the art

3x2pt:

Combining all possible shear-shear, shear-galaxy, and galaxy-galaxy combinations across redshift bins



Tomography requires catalogs with:

1. Galaxy positions
2. Galaxy shear estimates
3. Galaxy redshift estimates (photo-z or p(z))

Systematic uncertainties

Weak lensing for precision cosmology

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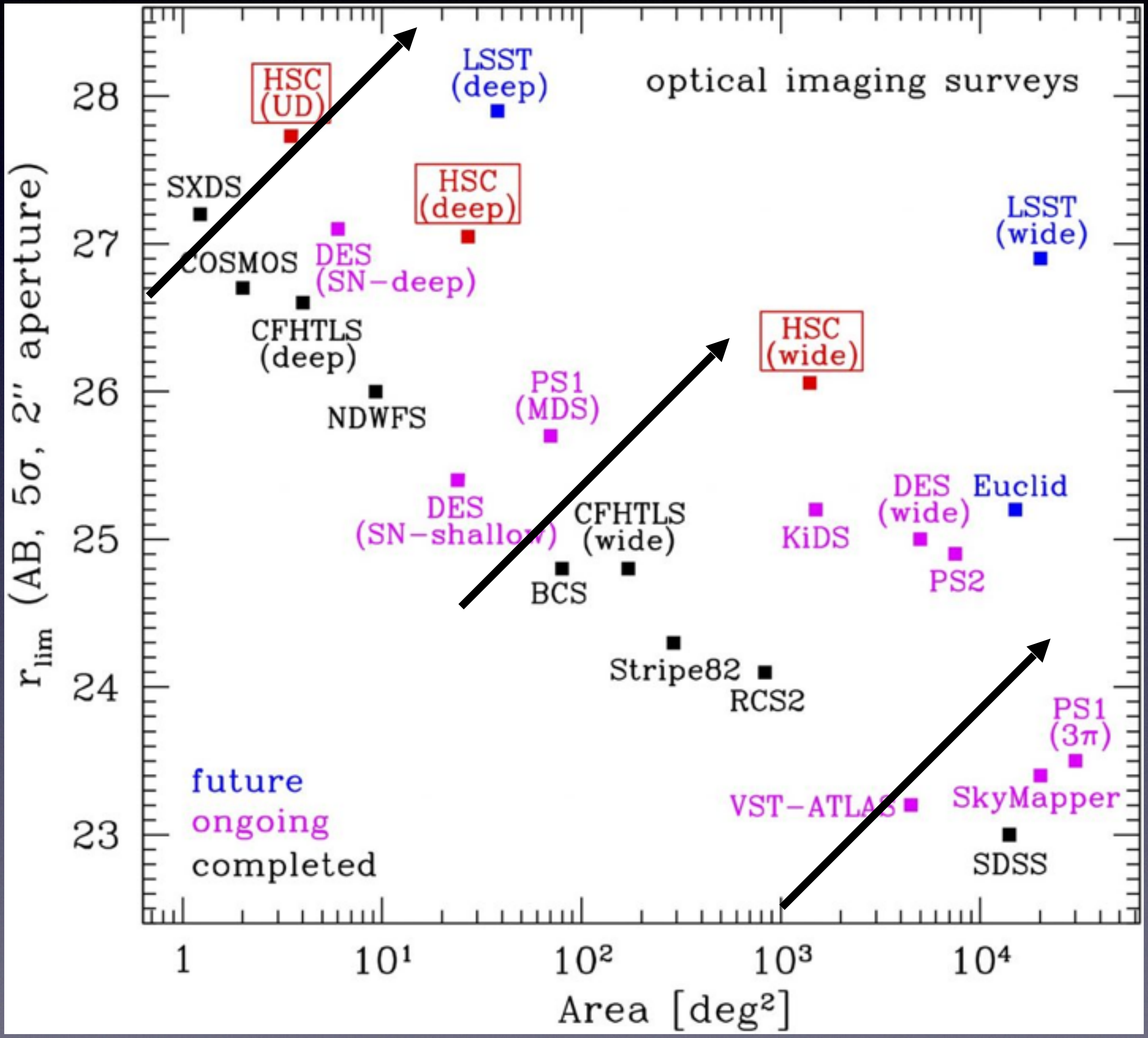
Abstract

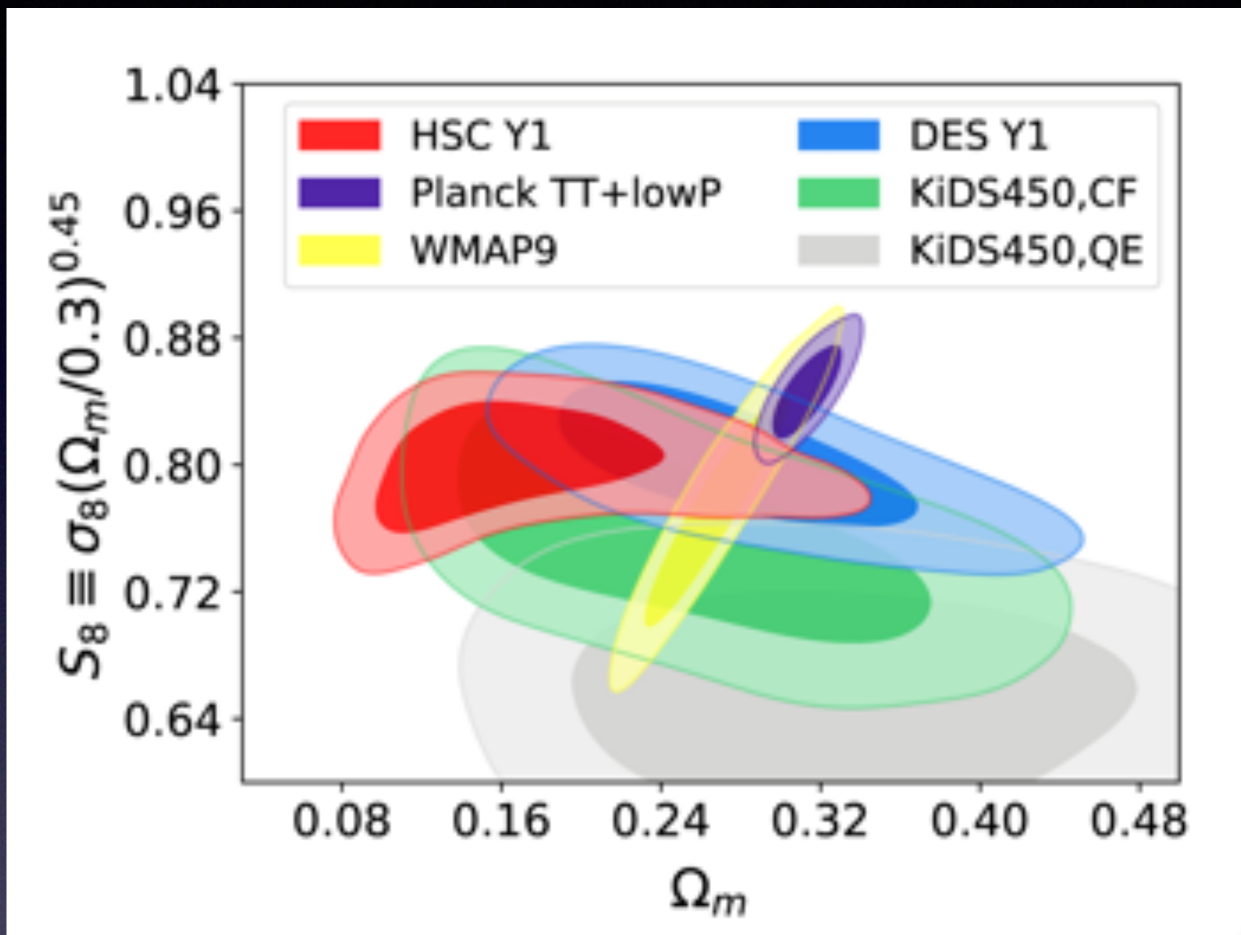
Weak gravitational lensing, the deflection of light by mass, is one of the best tools to constrain the growth of cosmic structure with time and reveal the nature of dark energy. I discuss the sources of systematic uncertainty in weak lensing measurements and their theoretical interpretation, including our current understanding and other options for future improvement. These include long-standing concerns such as the estimation of coherent shears from galaxy images or redshift distributions of galaxies selected based on photometric redshifts, along with systematic uncertainties that have received less attention to date because they are subdominant contributors to the error budget in current surveys. I also discuss methods for automated systematics detection using survey data of the 2020s. The goal of this review is to describe the current state of the field and what must be done so that if weak lensing measurements lead toward surprising conclusions about key questions such as the nature of dark energy, those conclusions will be credible.

ARA&A (2018);
arxiv:1710.03235

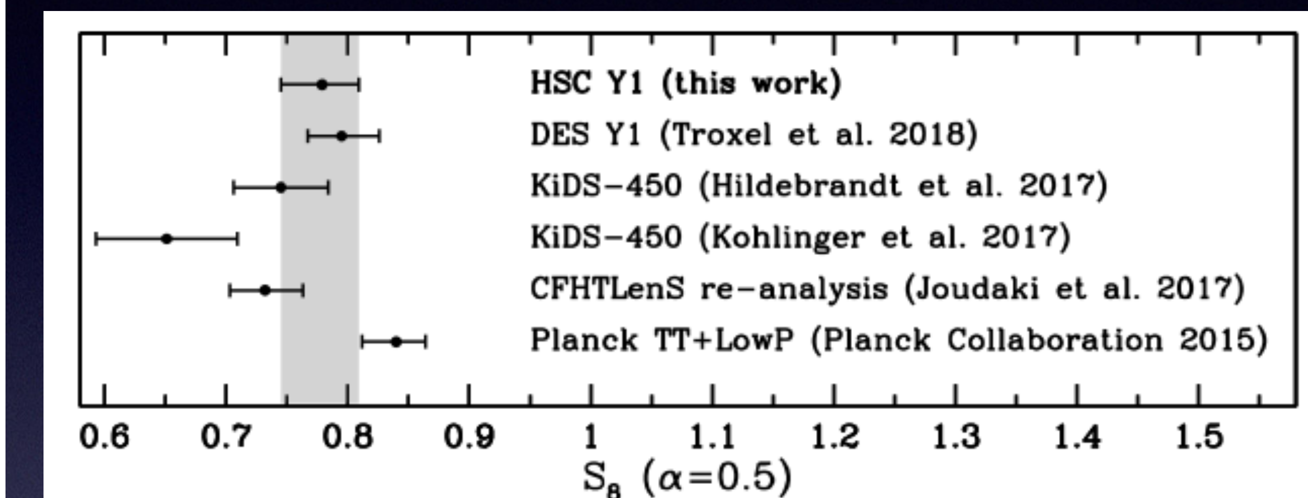
The current and future survey context
(with apologies to WFIRST)



Cross-survey comparisons



Hikage+18

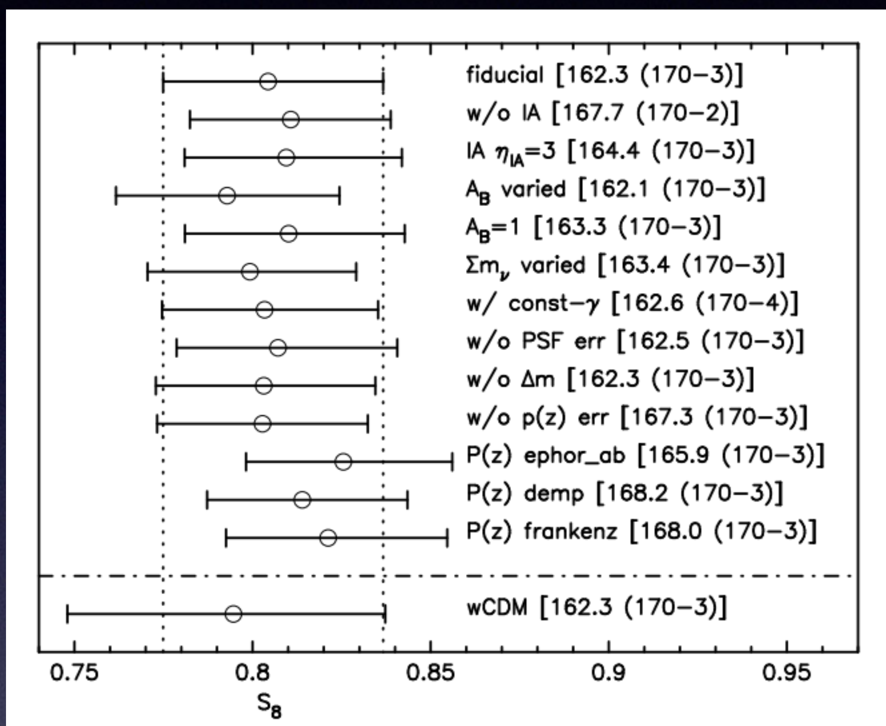


S_8 consistently a bit lower than Planck; some work required to get a combined constraint.

Next-generation surveys (coming soon!) will be even more powerful and require better understanding of systematics.

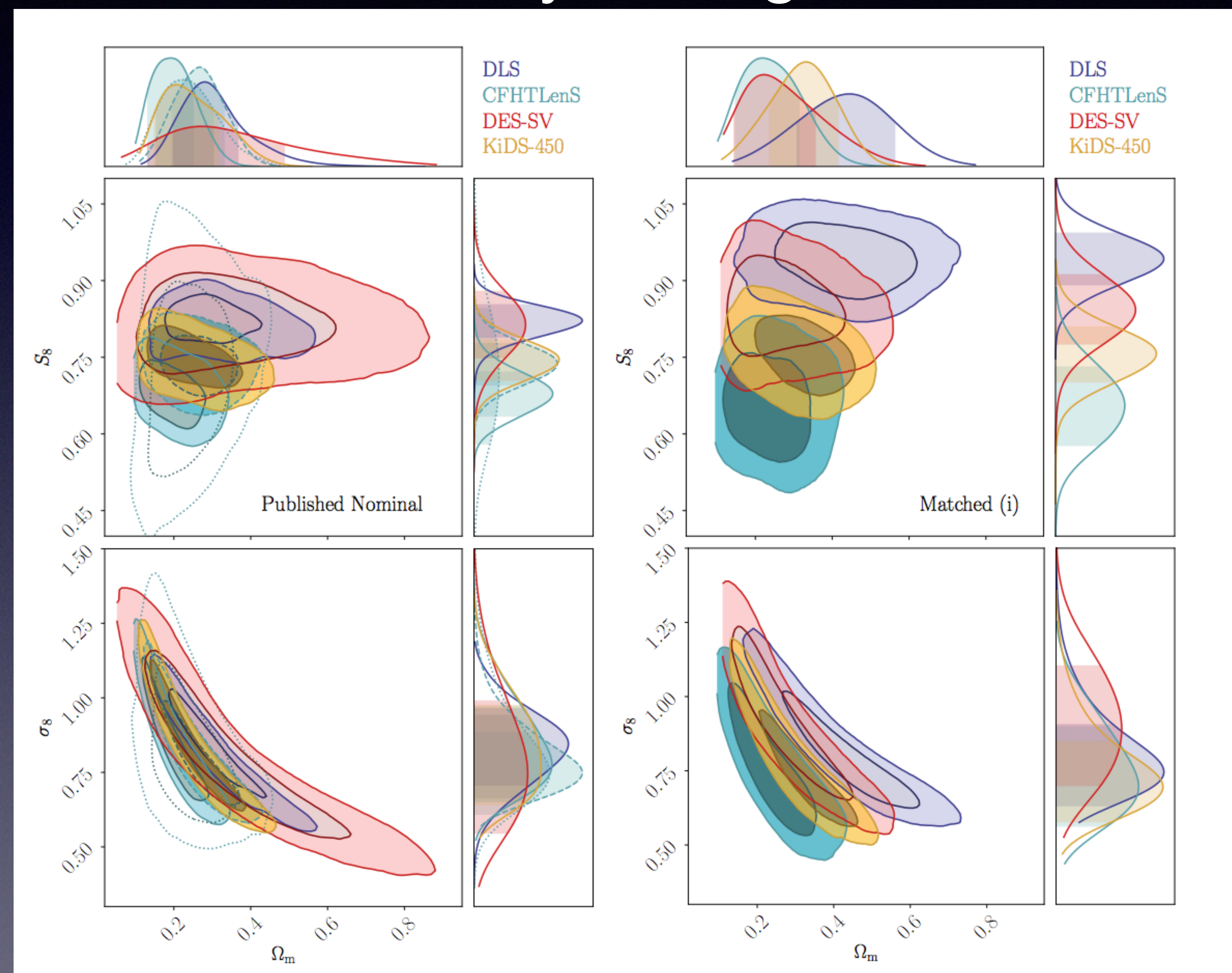
Digging deeper

Hamana+19



Sensitivity to systematics models

Chihway Chang+19



Sensitivity to analysis choices

Digging deeper

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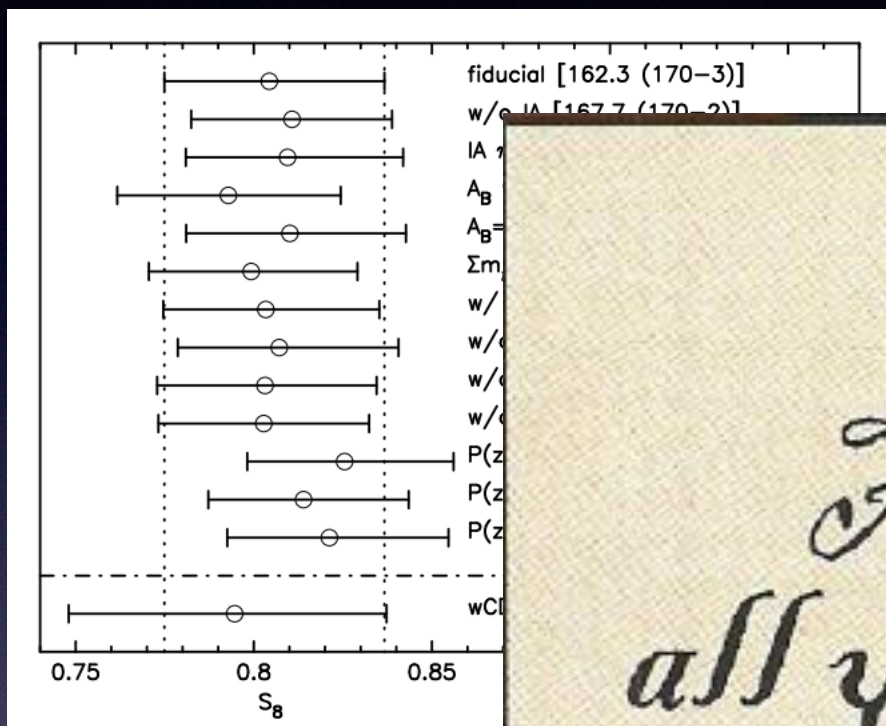


Chihway Chang+19

Sensitiv... systematics

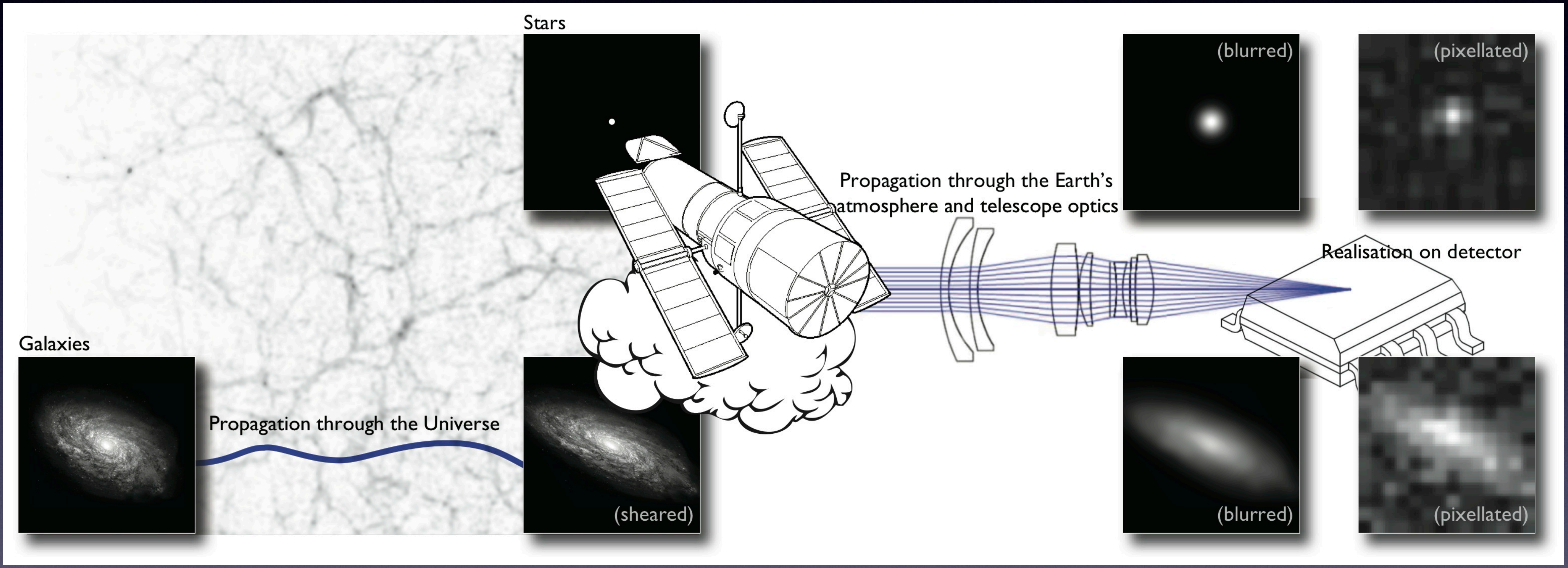
Sensitivity to analysis choices

Status summary

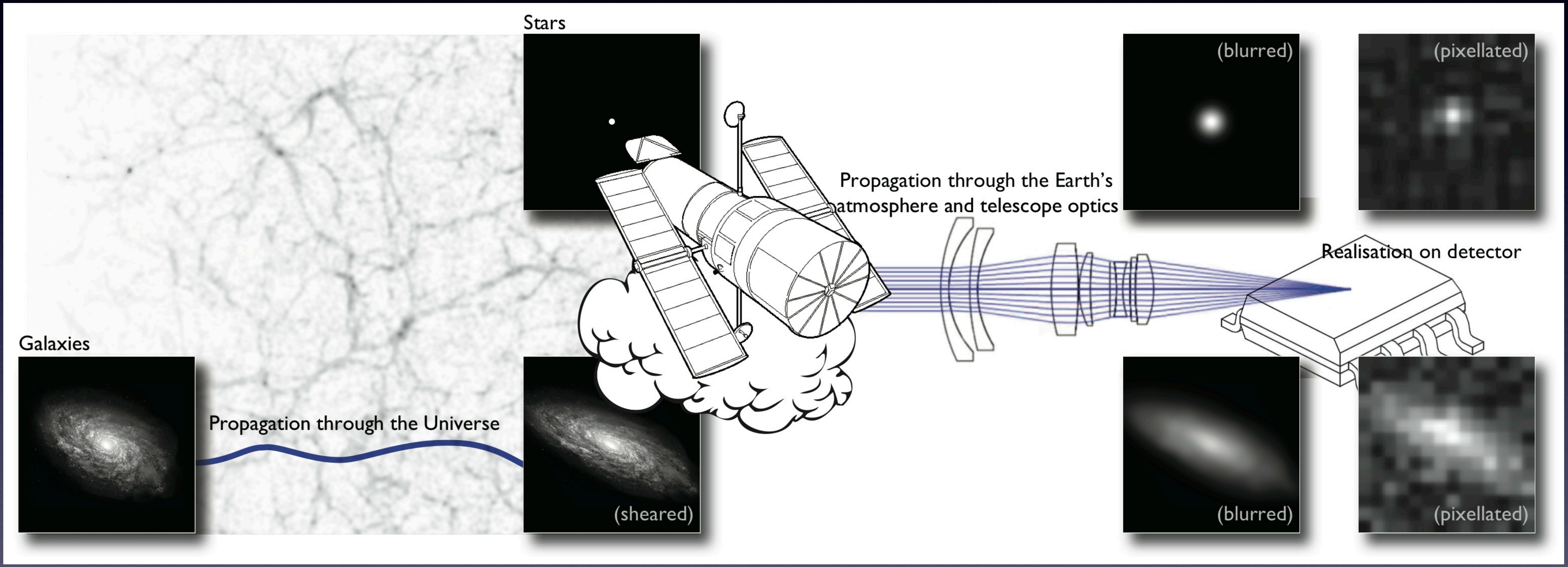
- There are *weak* signs of tension between the amplitude of the power spectrum inferred from WL and CMB.
- Weak lensers have been identifying analysis choices that can lead to ~0.1-0.5 sigma shifts in results, and are working to reconcile and understand these further.
- Corresponding systematic uncertainties are at the level of a few %.
- Testbeds provided by collaborations working on upcoming surveys (LSST Dark Energy Science Collaboration, Euclid) may be key to understanding these.

Now for a series of opinions

Weak lensers can shift focus from shear inference in isolation



Weak lensers can shift focus from shear inference in isolation



This is a challenging non-linear inverse problem that we must solve at low resolution and S/N.
But we have done so… there are two principled shear inference methods **for Nyquist sampled images of isolated galaxies!**

Weak lensers can shift focus from shear inference in isolation

Huff & Mandelbaum (2017); Sheldon & Huff (2017)

d 

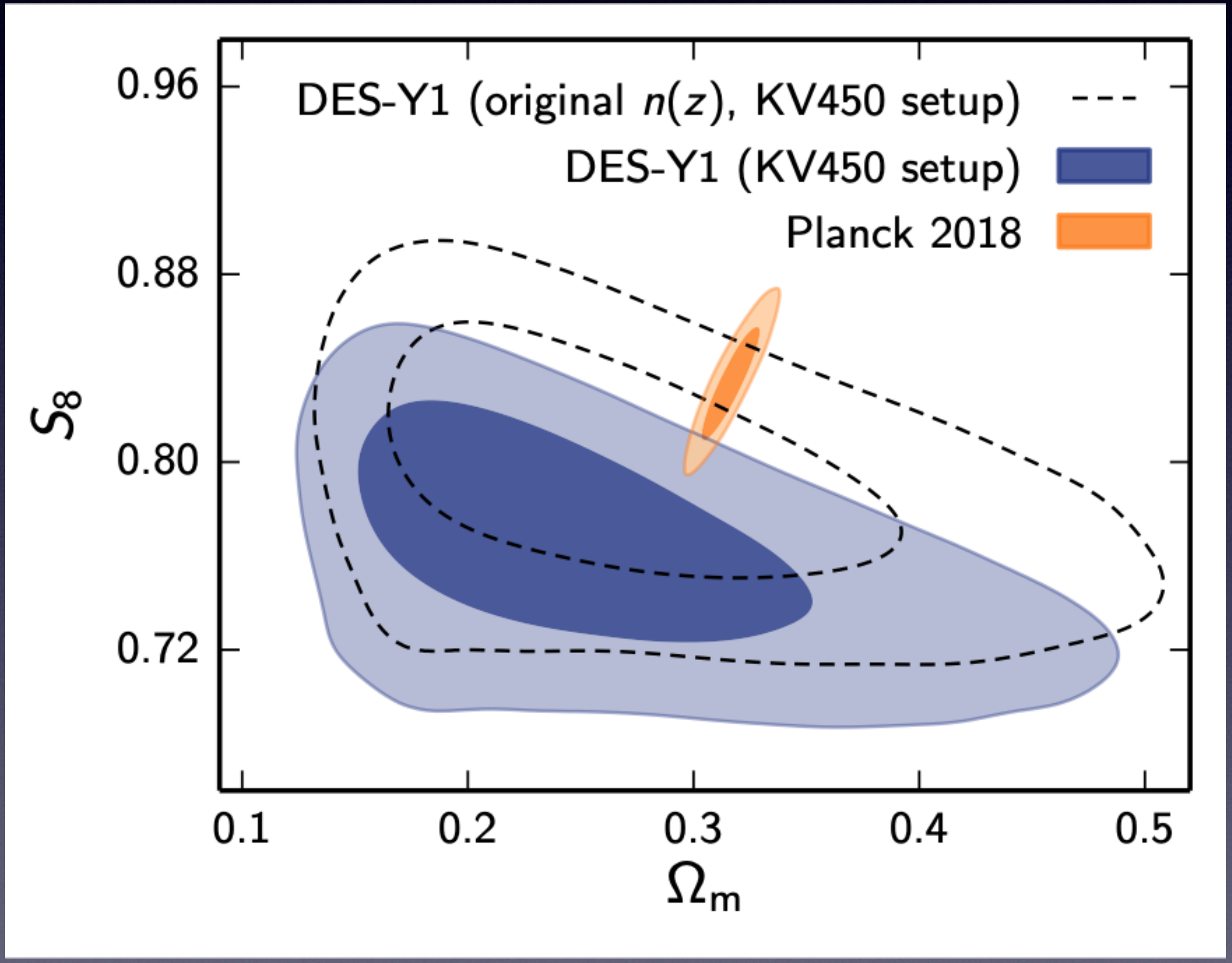
d(shear)

d 

d(systematic)

Metacalibration: measure the response of the entire measurement pipeline with the correct galaxy population!

Redshifts are the largest problem area for ongoing WL surveys



Joudaki+19

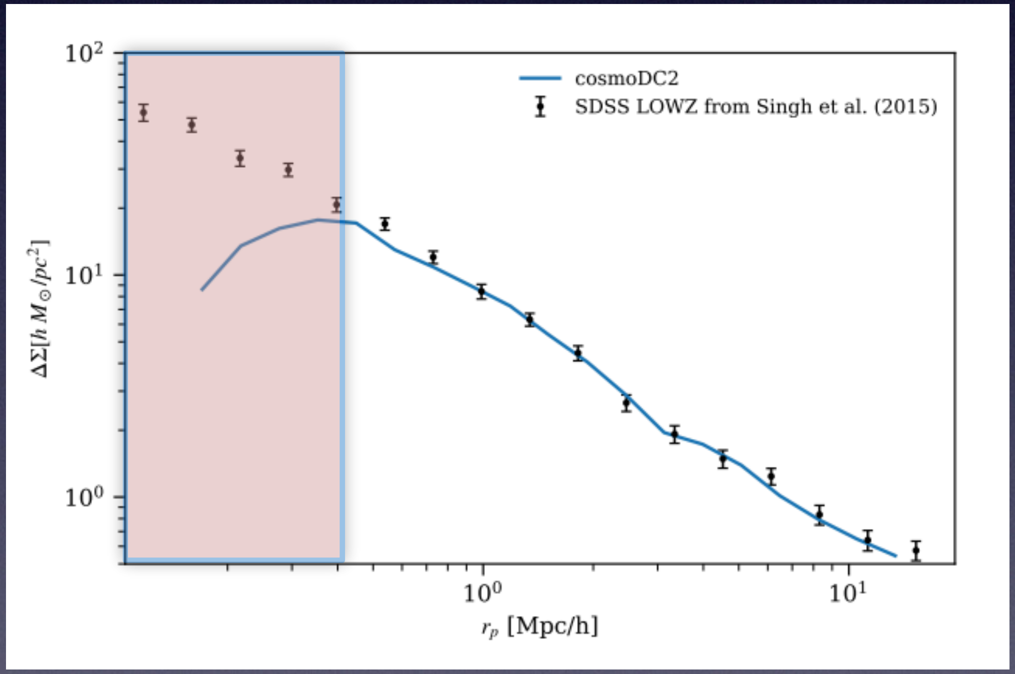
Current limitations in spec-z samples limit all photo-z calibration methods.

Over-reliance on COSMOS 30-band photo-z could couple systematics in all surveys.

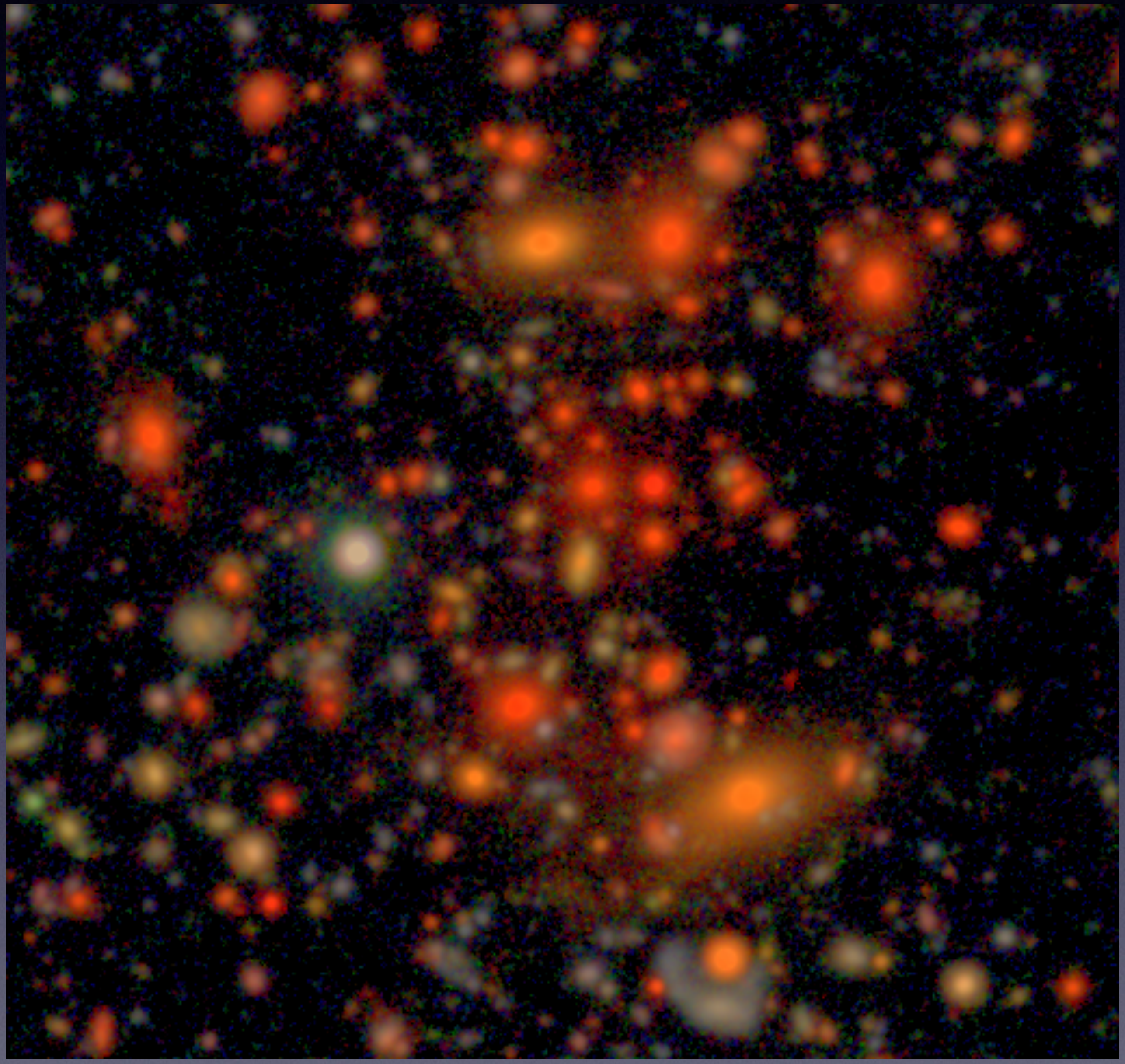
No fair comparison of methodology on consistent mock catalogs.

Redshifts are the largest problem area for ongoing WL surveys

- Fair method comparison using realistically complex mock catalogs could improve our understanding of methodology.
    - For example: CosmoDC2 (Korytov+19, LSST DESC)
- Existence of spec-z samples from DESI, 4MOST will simplify this problem for LSST.

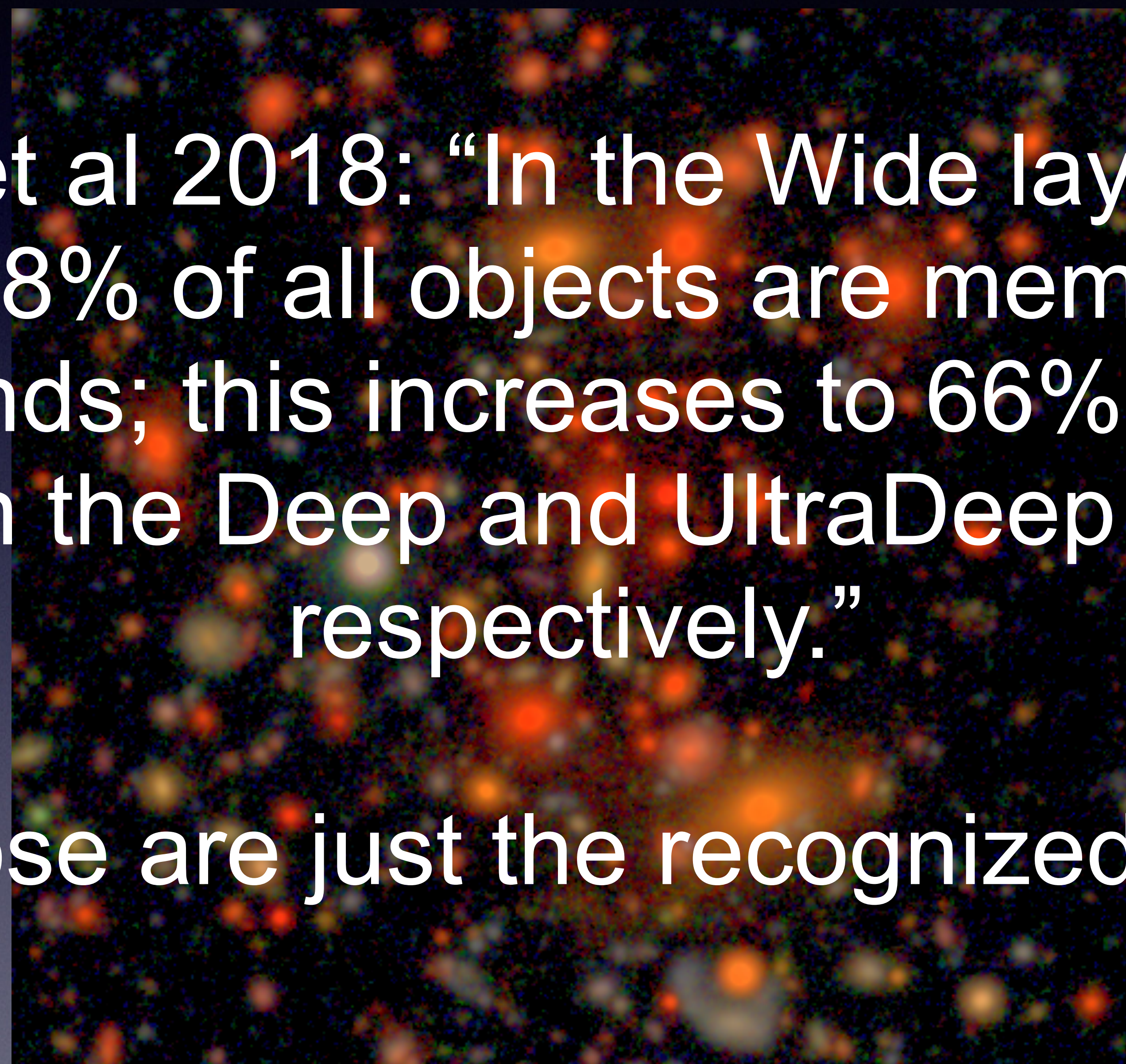


Blending as the glue that binds: a new era of coupled problems



HSC ultradeep: it’s ~~turtles~~ galaxies all the way down

Blending as the glue that binds: a new era of coupled problems



Bosch et al 2018: “In the Wide layer of the SSP, 58% of all objects are members of blends; this increases to 66% and 74% in the Deep and UltraDeep layers, respectively.”

And those are just the recognized blends!

HSC ultradeep: it’s ~~turtles~~ galaxies all the way down

Blending as the glue that binds: a new era of coupled problems

- Blending can confuse (and couple) object selection, shear and photo-z estimates for objects that are nearby on the sky.
- There is no perfect deblender.

➡ No matter how much deblending technology improves, we will have to forward model its joint effects on object selection and measurement.

It will take some work to avoid a “race to the bottom”

(Phrase courtesy of Eric Gawiser)

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Of order 20 papers validating analysis methods

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LSST, Euclid, or WFIRST WL cosmology results

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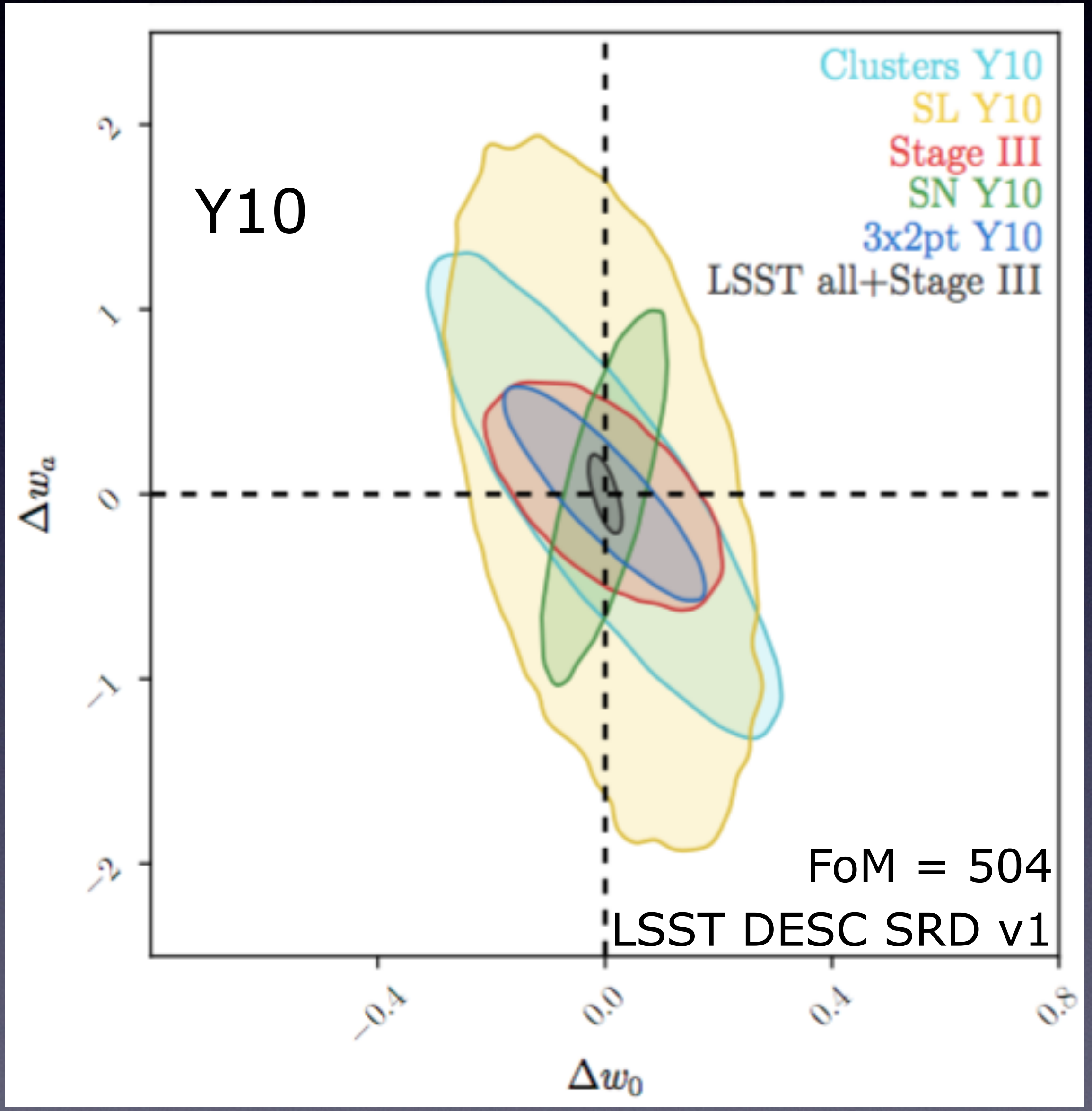
→

LSST, Euclid, or WFIRST WL cosmology results

This calls for an appropriate level of coordination:
Independent analyses and/or implementations of key algorithms
AND
Development of tool sets that enable comparison of the ingredients in a case where ground truth is known

Conclusions

- Ongoing WL surveys have made substantial progress in understanding key sources of systematic uncertainty.
- Joint analysis of cross-correlations is powerful approach to self-calibrating (some) systematic uncertainties.
- Blending effects force us to forward-model their impacts on cosmological observables, and couple analysis stages together.
- We have an opportunity to race to the top, not the bottom. The future is bright!



The LSST DESC science requirements document v1, https://arxiv.org/abs/1809.01669