The Treachery of Galaxy Images

This is not a galaxy cluster.

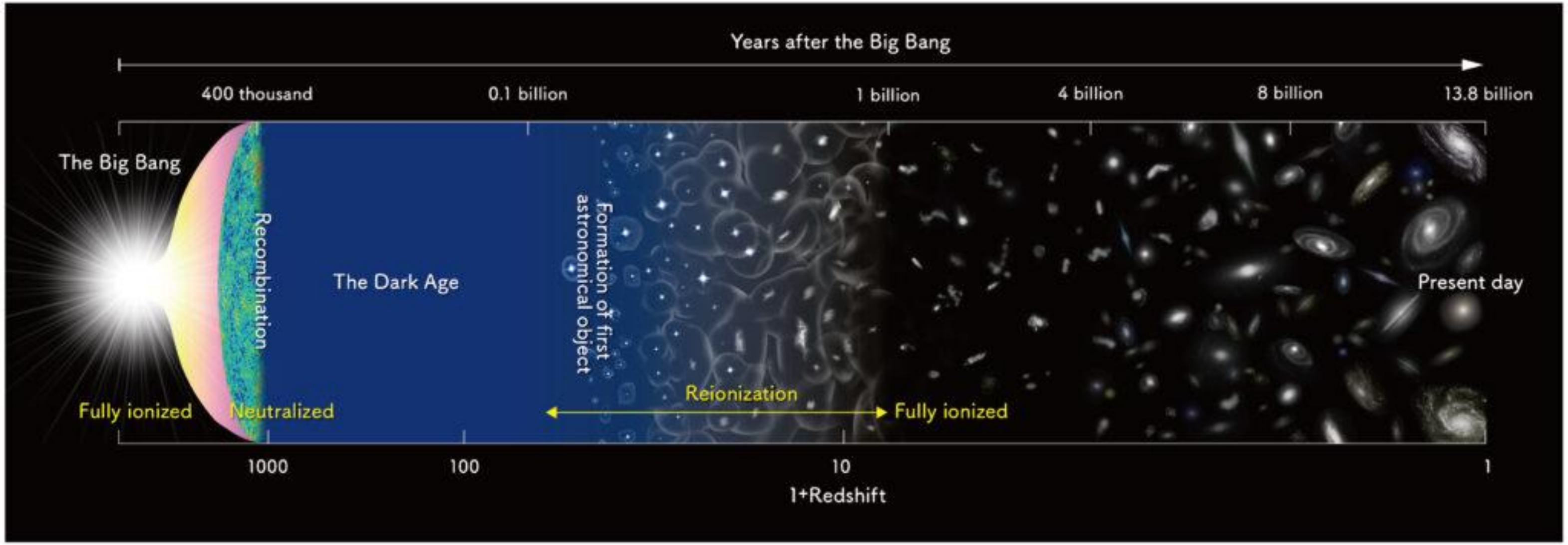
Justin Myles (Stanford)

Work done with many collaborators in DES and advised by Steve Allen, Alex Amon, & Daniel Gruen

Outline

I. Introduction: Cosmology from galaxy images
II. Redshift Calibration for Lensing Surveys
   A. Myles & Alarcón et al. 2021b (MNRAS)
   B. Myles et al. 2022 (submitted to MNRAS)
III. Mass Calibration for Optically-selected Galaxy Clusters
   A. Myles et al. 2021a (MNRAS)
IV. Conclusions and Outlook

The current standard cosmological model, ΛCDM, merits experimental testing.



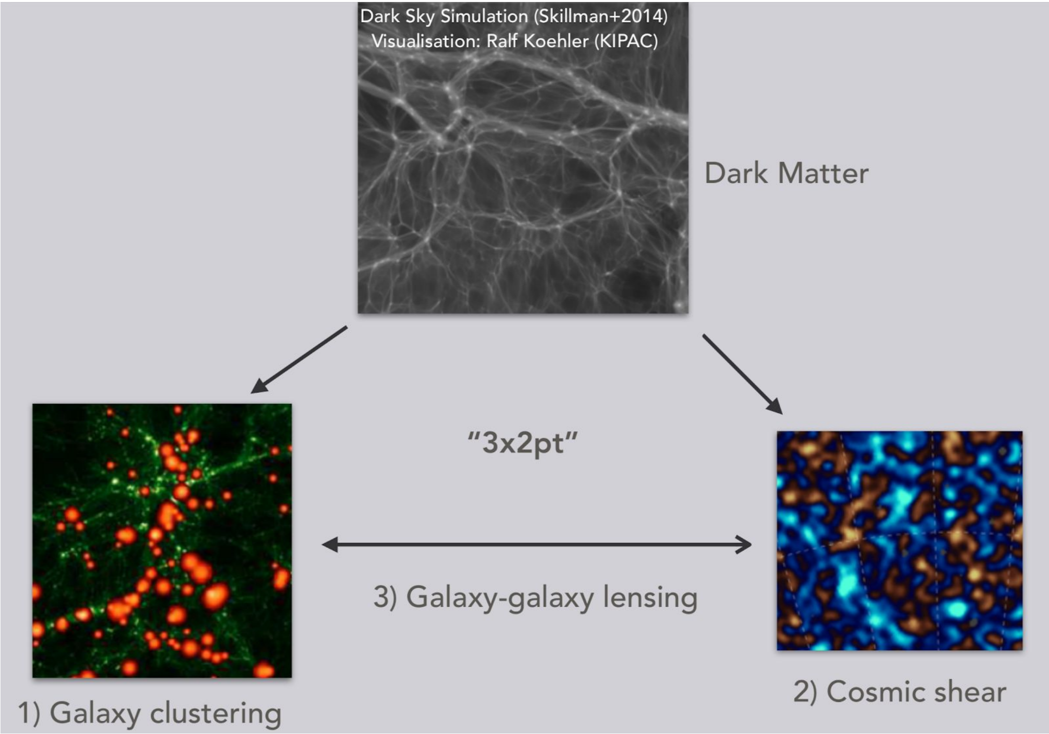
ΛCDM appears to explain observations well, but

1. requires two essential new components beyond the Standard Model
2. requires vacuum energy density very different from expectation
3. shows tension at being able to describe the early and late Universe simultaneously

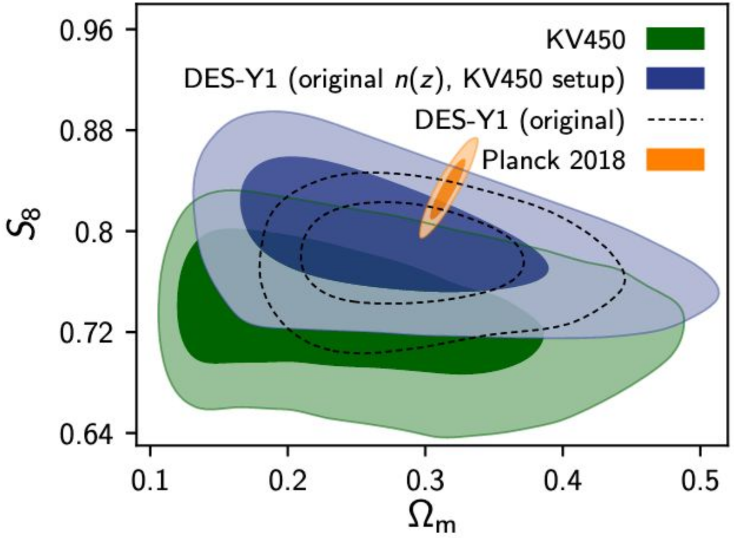
NAOJ/NOAO

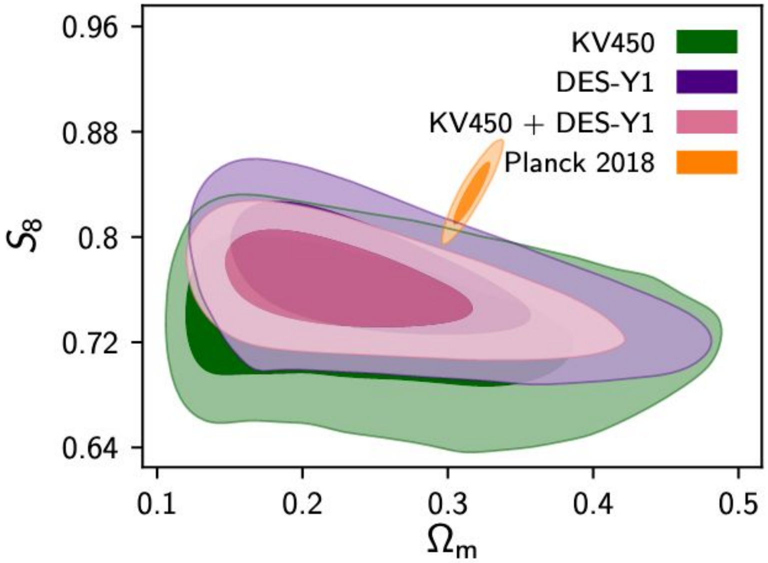
The Dark Energy Survey probes cosmology with statistical measures of structure in the Universe measured by taking images of galaxies.

- 4m Blanco Telescope
- ~5000 sq. deg. wide field survey in *g r i z Y* over 6 years
- >100M Y3 Source Galaxy Catalog
- 27 sq. deg. deep time-domain survey in *u g r i z Y*, ~8 sq. deg of which overlaps with archival *Y J H K*



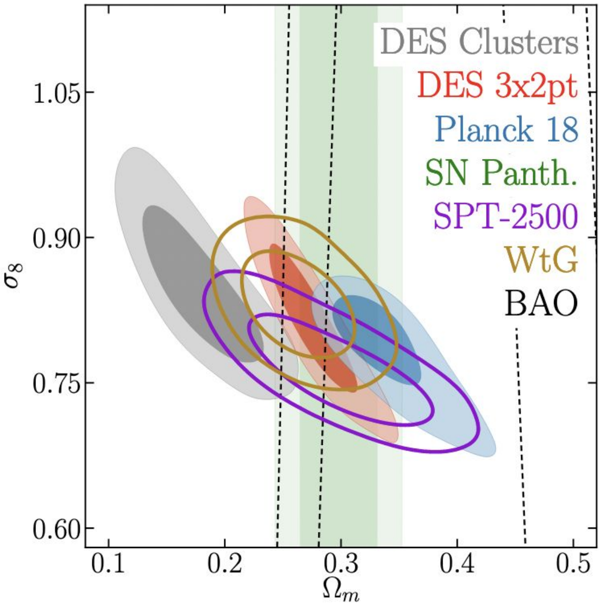
Cosmic shear is host to a consequential debate about redshifts.





Joudaki et al. 2019

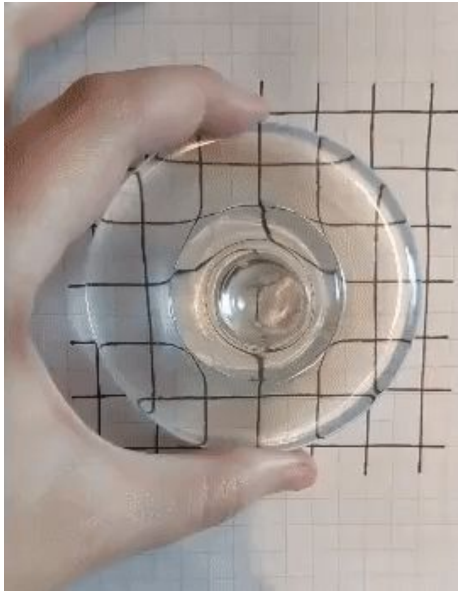
Cluster cosmology is host to a mysterious result relating to the difficulty in measuring cluster masses from optical cluster richness.

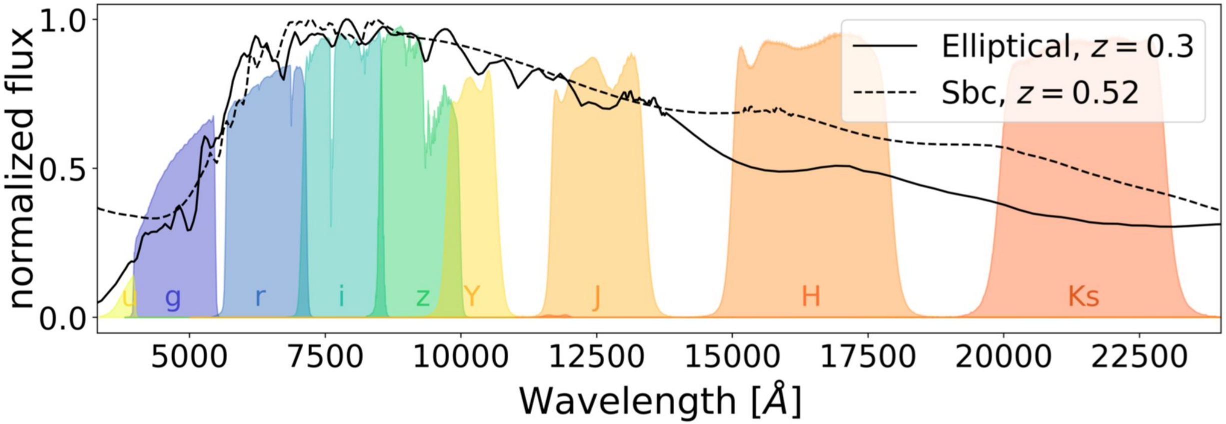


DES Collaboration 2020

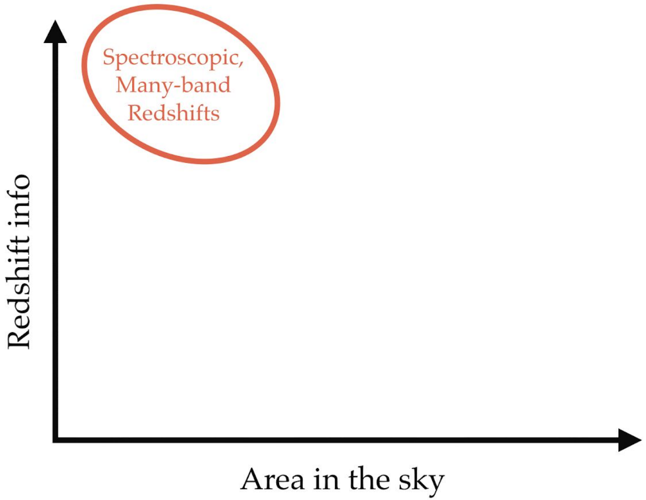
Redshift Calibration for Lensing Surveys

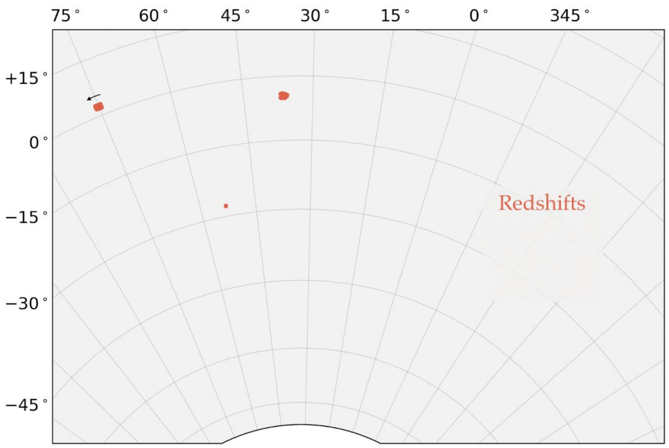
The Treachery of Lensing Images:
we need redshift information to interpret lensing signals, but degeneracies in the statistical color-redshift relation limit our ability to constrain redshift from imaging.





The SOMPZ method of the DES Y3 redshift calibration leverages the DES deep fields to break degeneracies in the statistical color-redshift relation by using spectra only for galaxies with deeper, 8-band data in these fields.

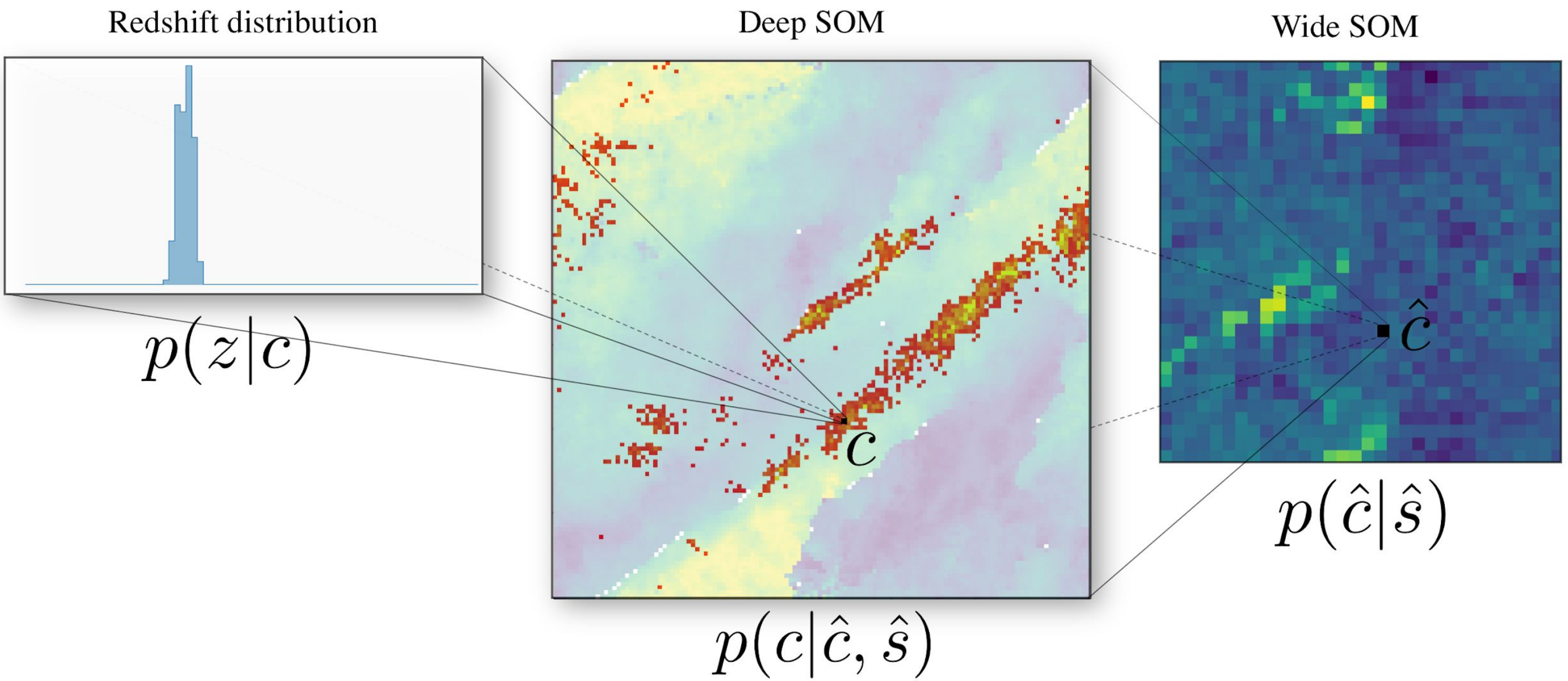




$$p(z|\hat{b},\hat{s}) \approx \sum_{\hat{c}\in\hat{b}} \sum_{c} p(z|c,\hat{b},\hat{s})p(c|\hat{c},\hat{s})p(\hat{c}|\hat{s})$$

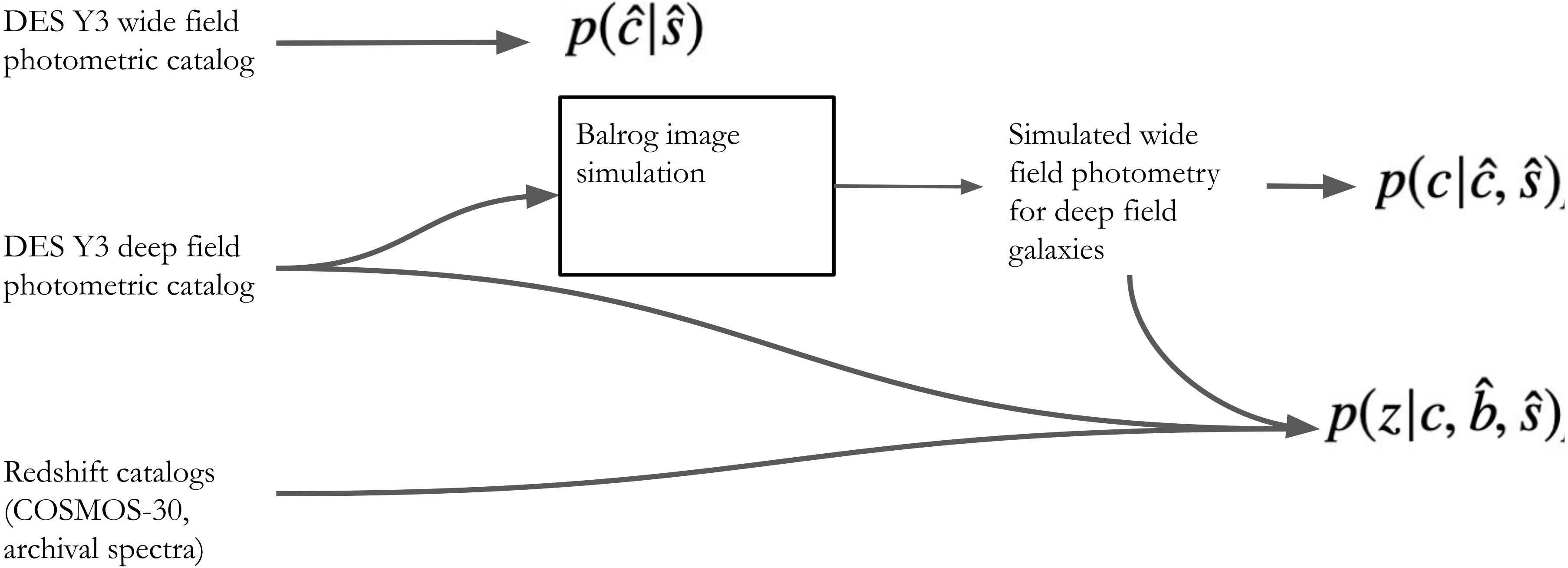
Hartley, Choi, et al. (2021)
Everett et al. (2021)
Myles, Alarcon, Amon, et al. (2021)
Carles Sánchez

We facilitate our calibration with two self-organizing maps that classify galaxies of similar colors into categories called cells.



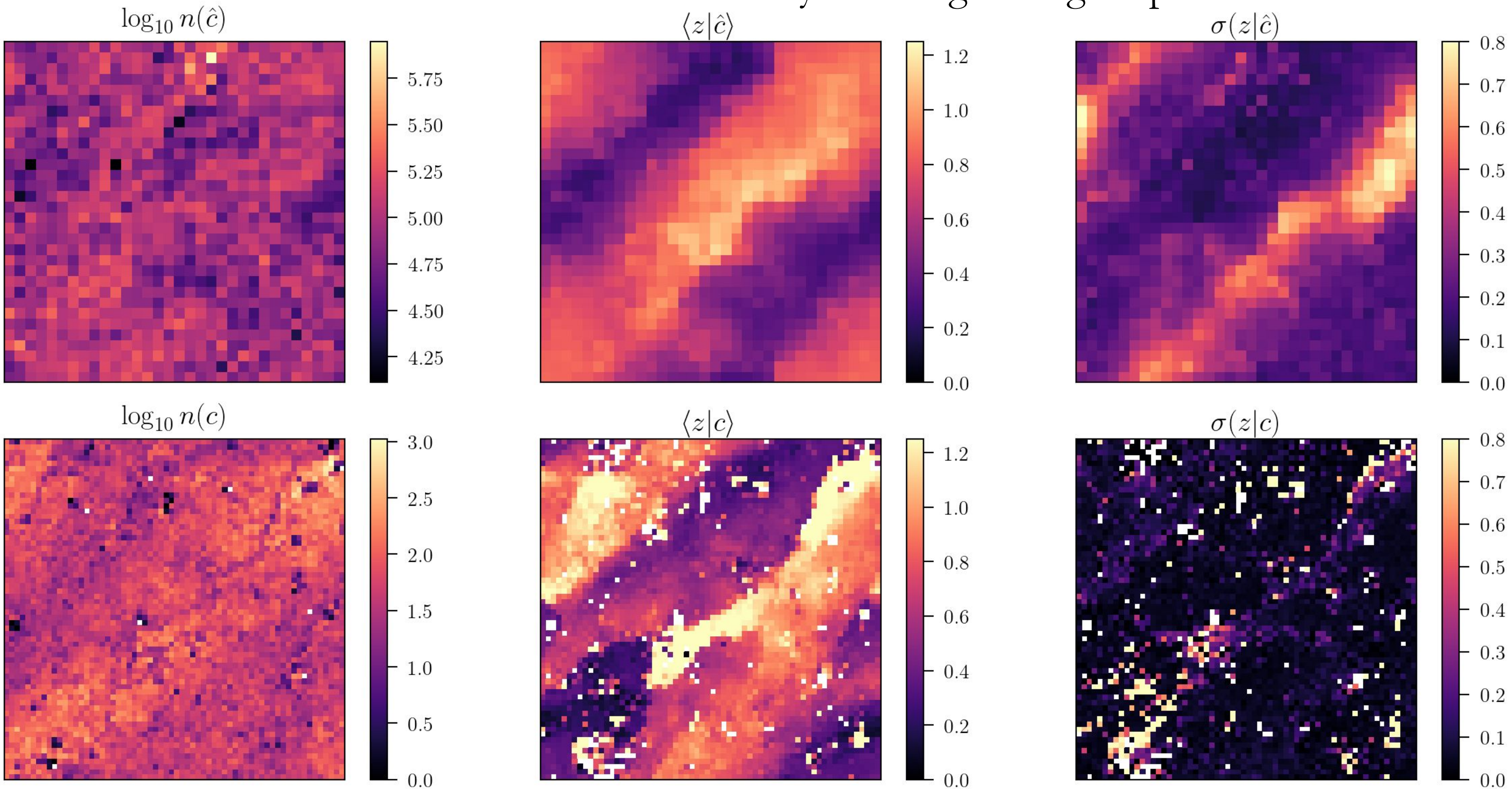
Buchs & Davis et al. 2019

$$p(z|\hat{b},\hat{s}) \approx \sum_{\hat{c}\in\hat{b}} \sum_{c} p(z|c,\hat{b},\hat{s})\,p(c|\hat{c},\hat{s})\,p(\hat{c}|\hat{s})$$



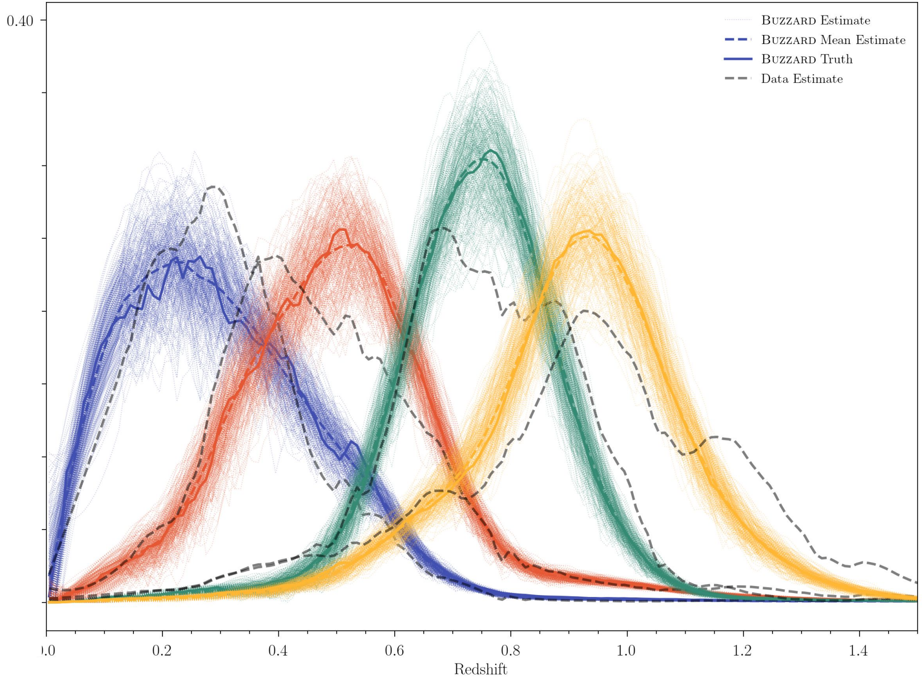
Buchs & Davis et al. 2019

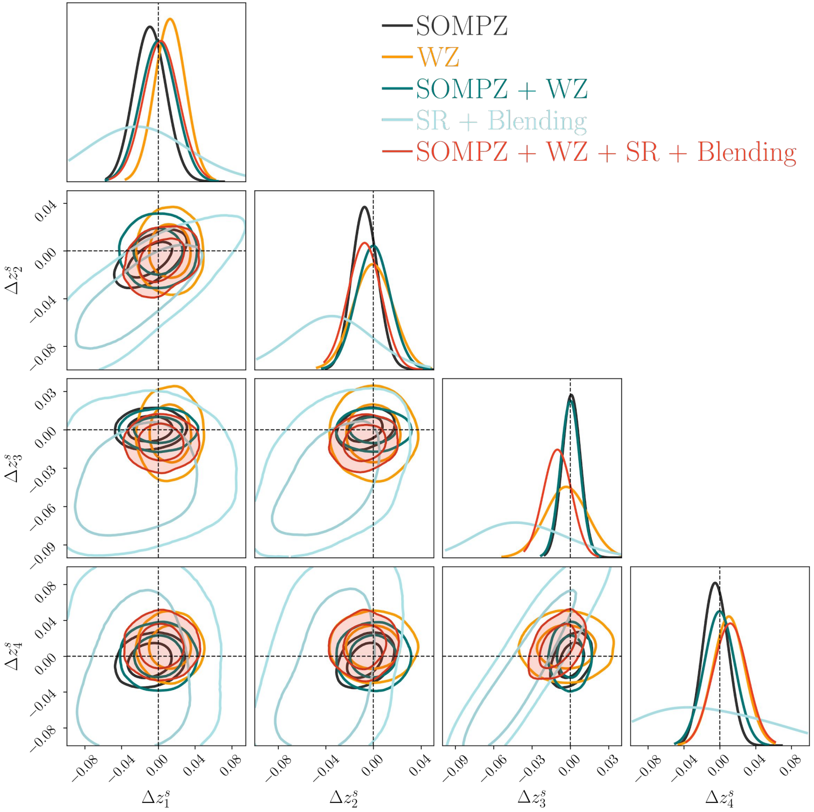
DES Y3 WL Source Galaxy Self-Organizing Maps



Myles & Alarcón et al. 2021 (MNRAS)

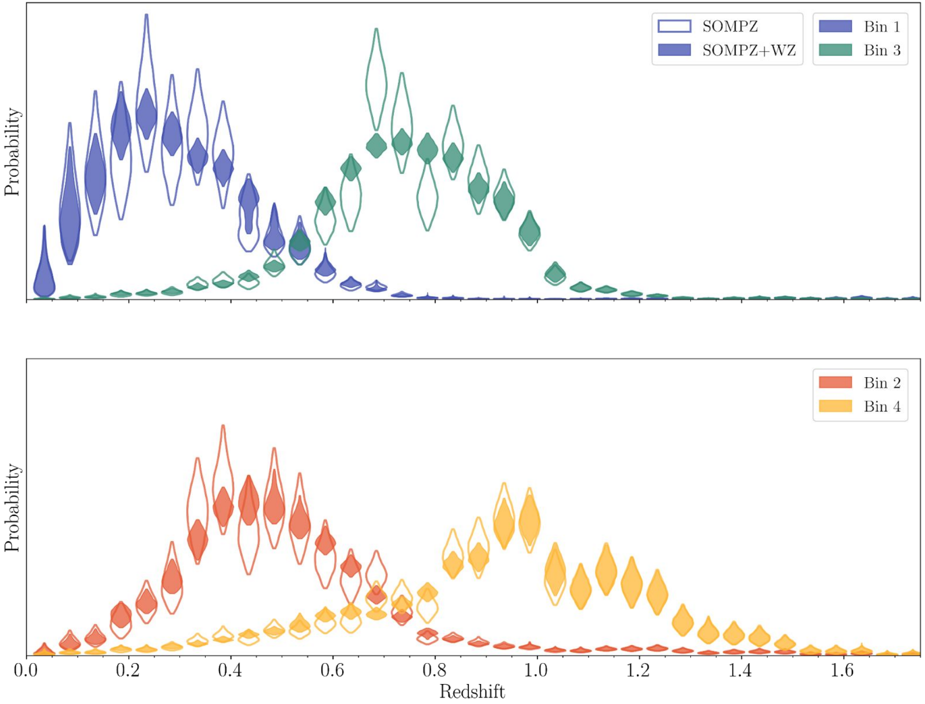
Our method recovers the truth on average in simulations, and is consistent constraints from galaxy clustering and shear ratios.

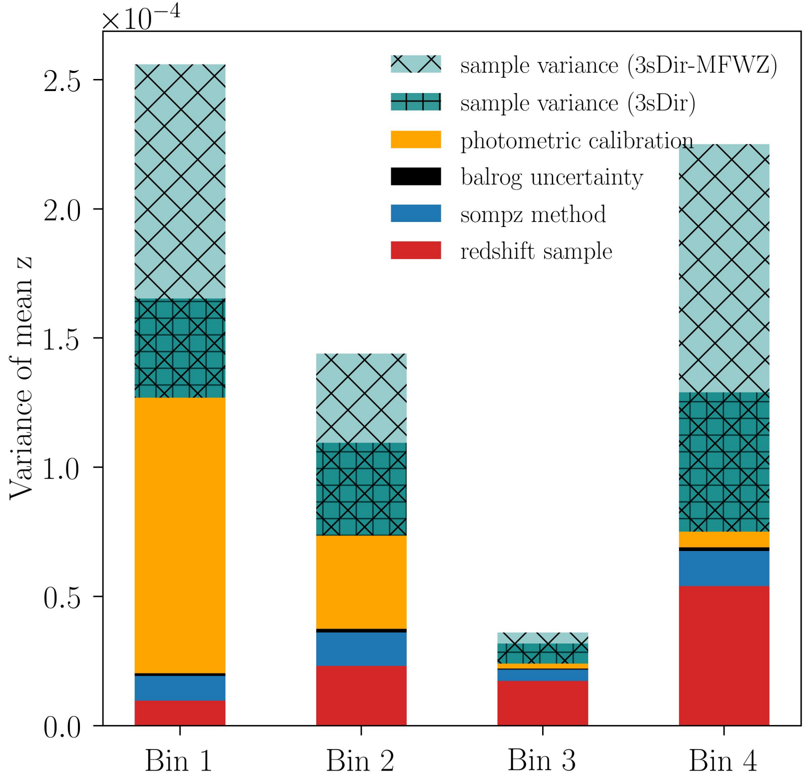




Myles & Alarcón et al. 2021 (MNRAS)

Our cosmology result accounts for the full-shape uncertainty in our estimate on a bin-by-bin basis. This result offers insight into future data needs to improve our redshift constraints.



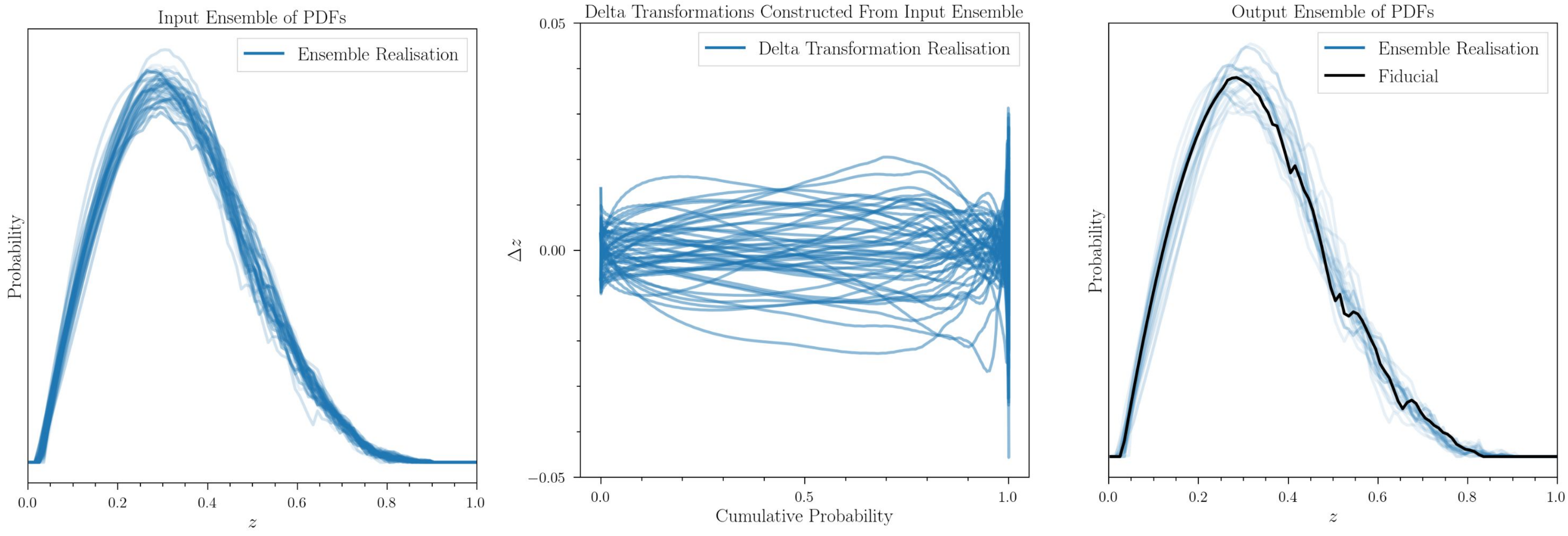


Myles & Alarcón et al. 2021 (MNRAS)

In addition to targeted data collection programs to reduce these uncertainties, we will need improved methods. We propose a new method which we call PITPZ as one piece to that puzzle.

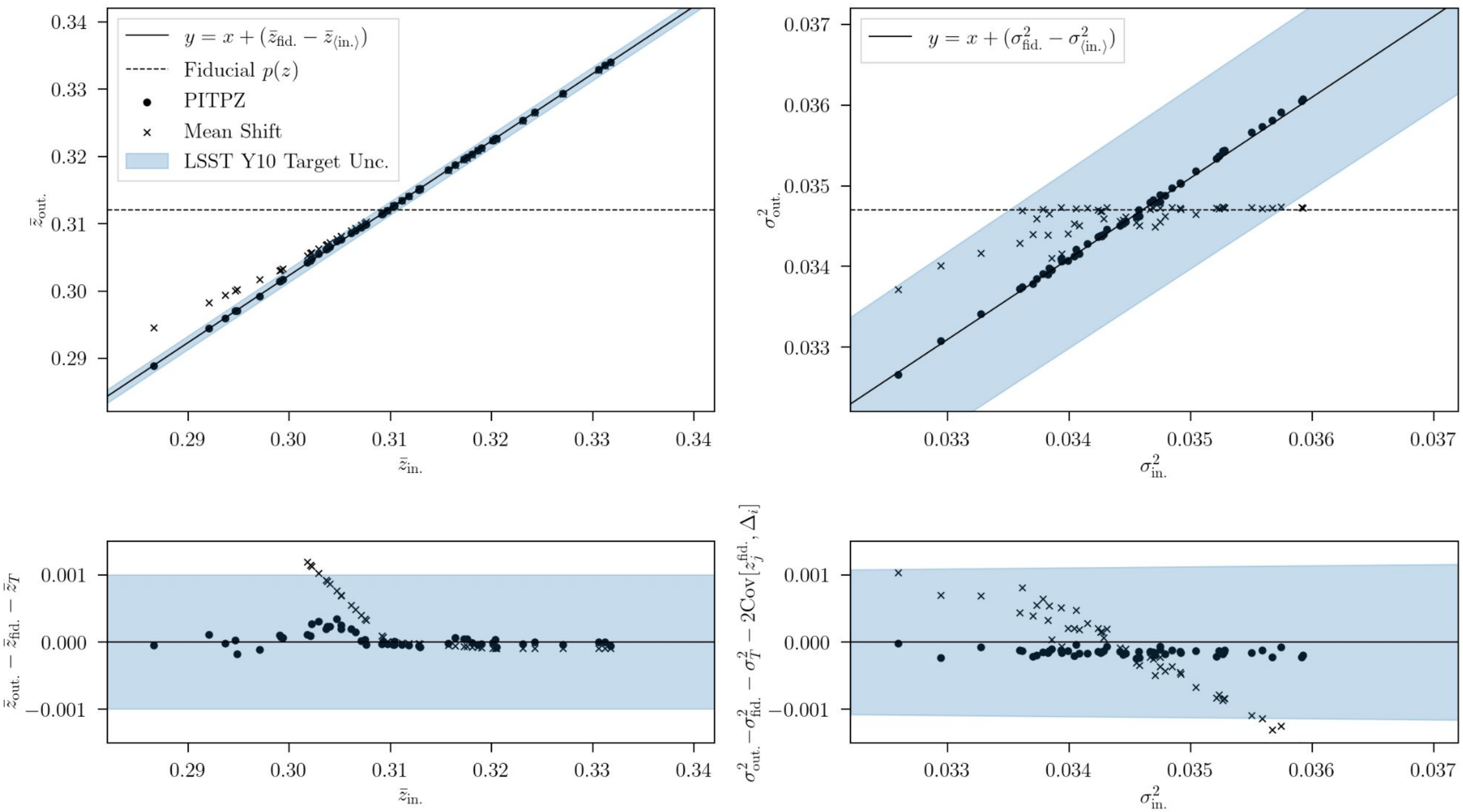
PITPZ is designed to facilitate uncertainty characterization for n(z) by enabling the study of full-shape variations in n(z), rather than only differences in mean z.

The PITPZ method uses probability integral transforms to construct a transformation that transfers full-shape uncertainty information from an input ensemble to produce an output ensemble.



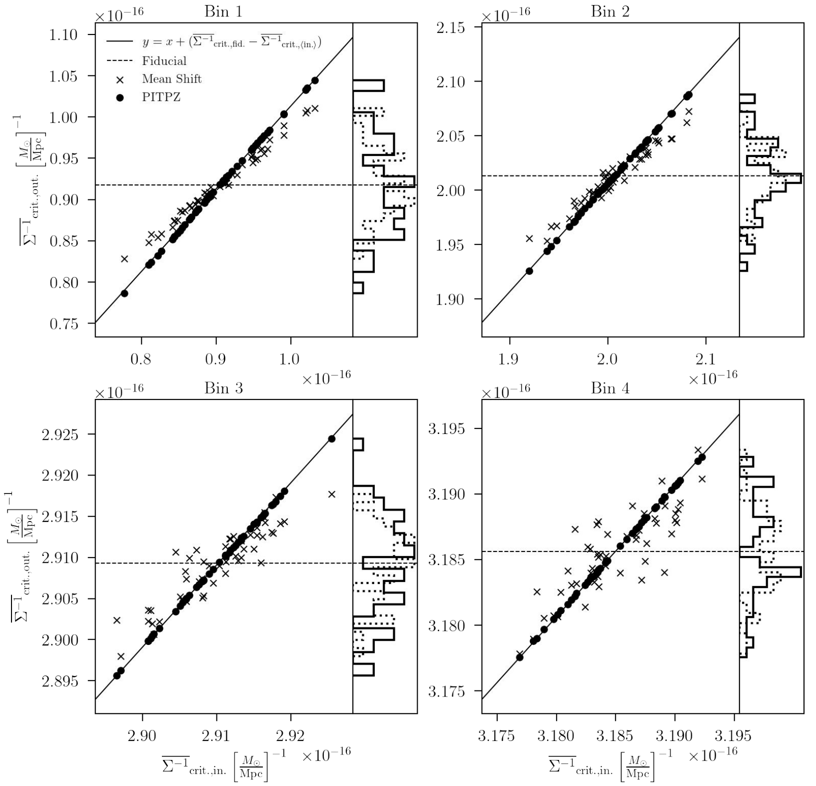
Myles et al. 2022 (submitted to MNRAS)

PITPZ preserves higher-than-mean-order moments of n(z) uncertainty, which will be important for meeting future redshift calibration targets.



Myles et al. 2022 (submitted to MNRAS)

PITPZ preserves true lensing signal uncertainty, which simple mean-shifts cannot do.



Myles et al. 2022 (submitted to MNRAS)

Summary – Redshift Calibration

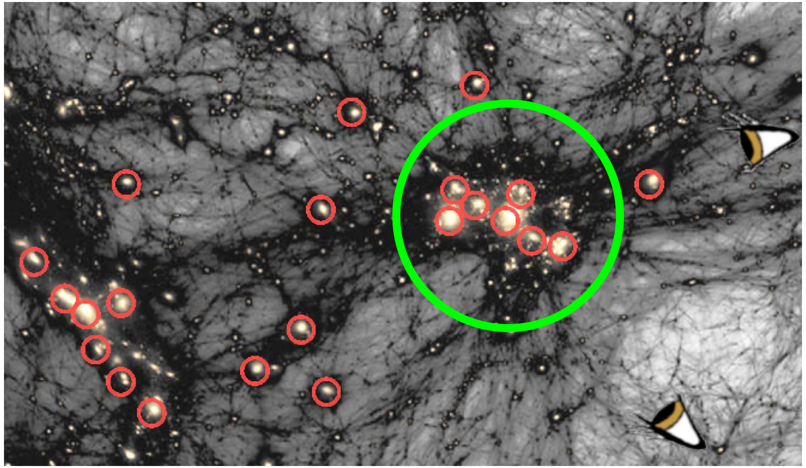
In DES Y3 we have been able to characterize redshift distributions for ~100M galaxies with just riz flux information to ~0.01 in mean redshift, facilitating producing the most statistically significant dataset of its kind.

The state-of-the-art shows clearly how much work remains, and presents a path forward on the data collection aspect of this work.

I propose a new algorithm which I call PITPZ as one piece of the puzzle for the improved methods aspect of future redshift calibration work.

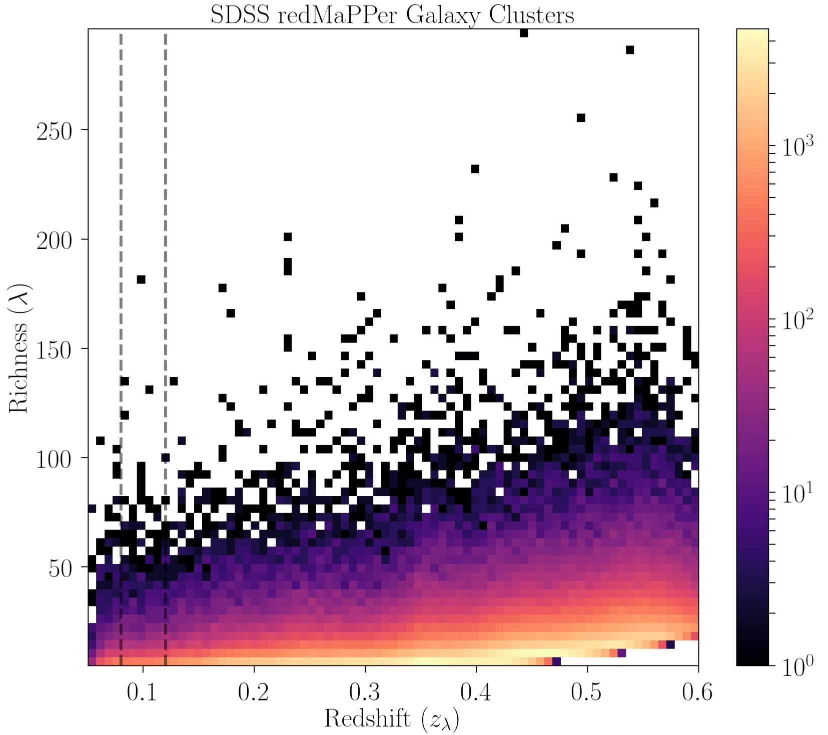
Mass Calibration for Optically-selected Galaxy Clusters

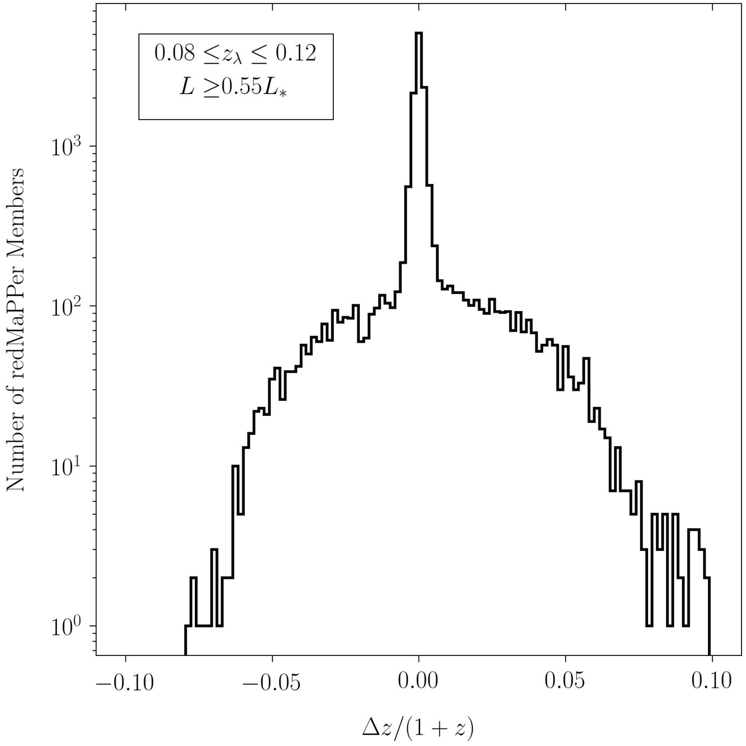
The Treachery of Galaxy Cluster Images:
Interpreting cluster richness requires measuring the distances to cluster galaxies.



Daniel Gruen
Dark Sky Simulations /
Ralf Kaehler, Carter Emmart,
Tom Abel, Oliver Hahn
DES Collaboration. 2020

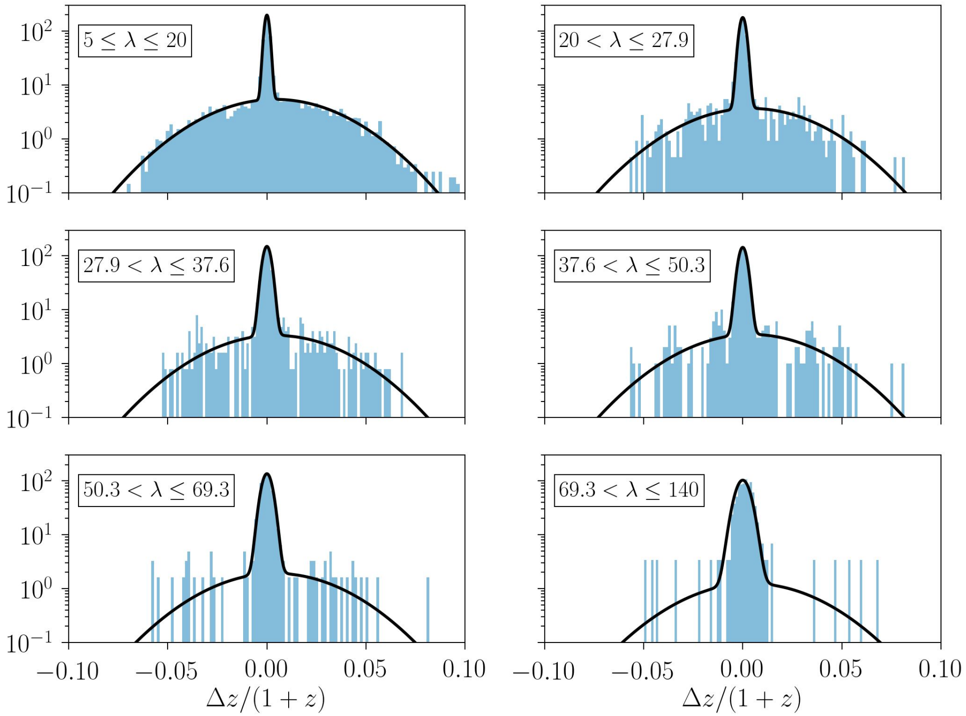
We can use spectroscopy to calibrate projection effects in optically-detected clusters.





Myles et al. 2021 (MNRAS)
Catalog: Rykoff et al. 2014

Projection effects as a function of richness can be quantified using a simple two Gaussian model.

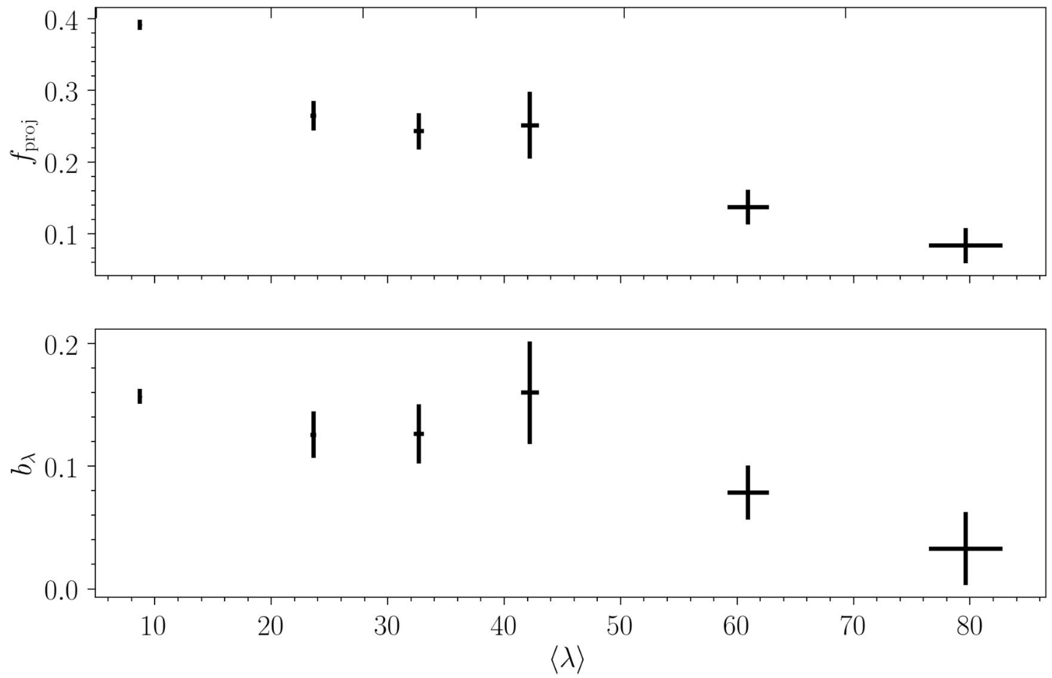


Myles et al. 2021 (MNRAS)

We find evidence for richness dependence of projection effects.

Fraction of galaxies in projection

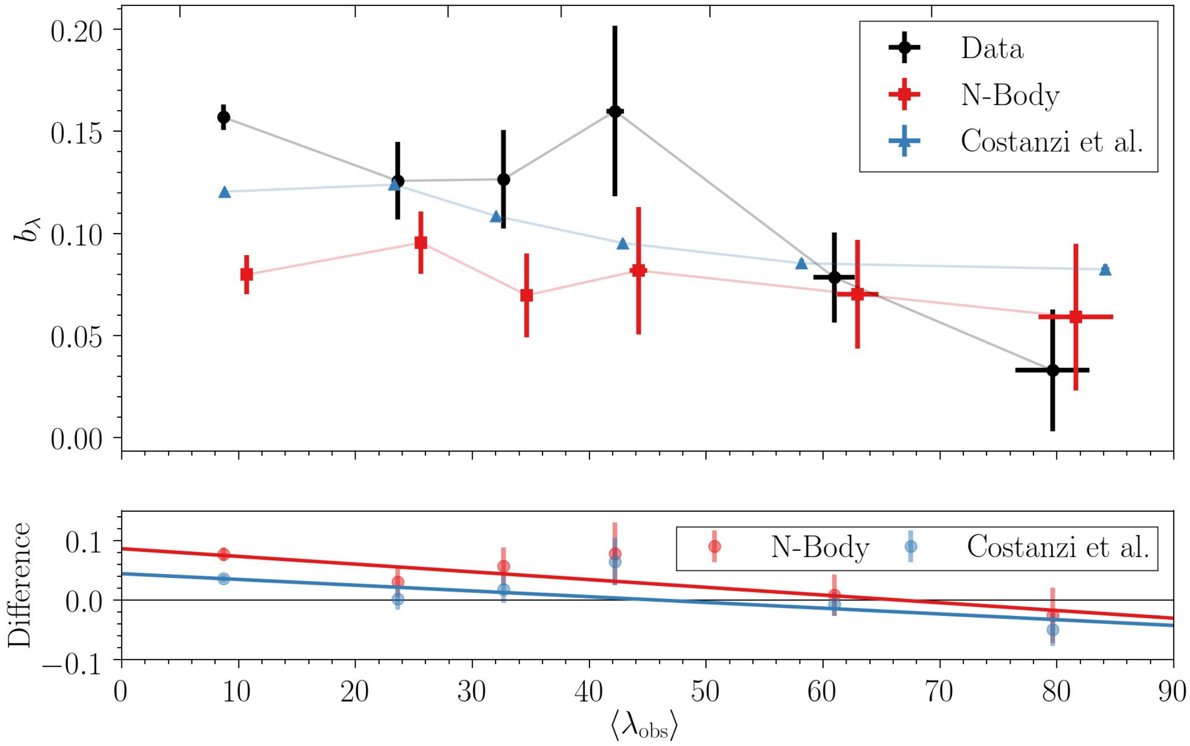
Fraction of richness due to galaxies in projection



Myles et al. 2021 (MNRAS)

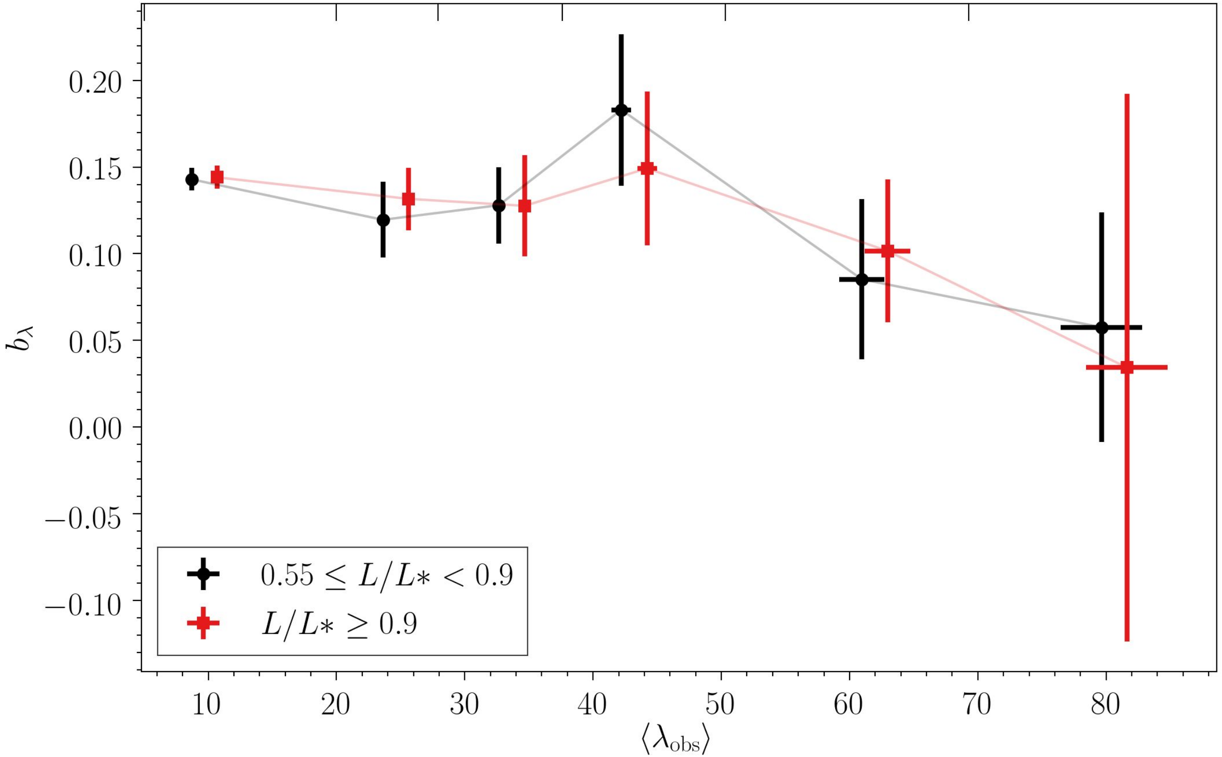
We find evidence for similar amplitude, but steeper richness dependence in our measurement than in recent models.

Fraction of richness due to galaxies in projection



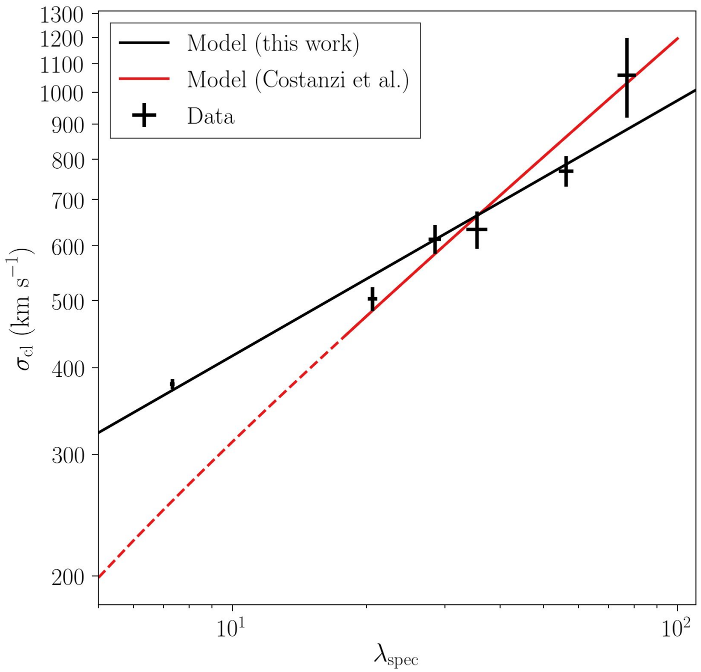
Myles et al. 2021 (MNRAS)

Projection effects are not found to be a strong function of galaxy luminosity.



Myles et al. 2021 (MNRAS)

We find that velocity dispersion scales with spectroscopically calibrated richness in a way consistent with self-similarity.



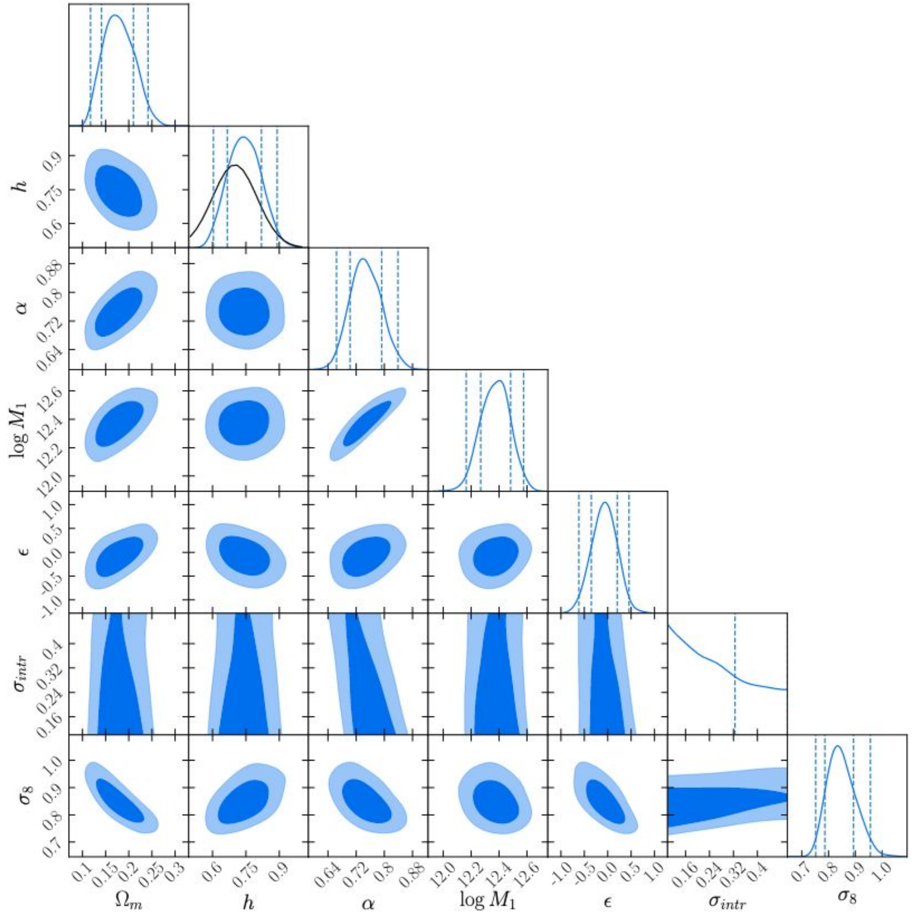
$$\sigma_{\mathrm{cl,\ Myles\ et\ al.}} \propto \lambda_{\mathrm{spec}}^{0.37\pm0.04}$$

$$\sigma_{\mathrm{cl,\ Munari\ et\ al.}} \propto M_{200}^{0.364\pm0.01}$$

$$\lambda_{\mathrm{spec}} \propto M_{200}^{0.98\pm0.11}$$

Myles et al. 2021 (MNRAS)

power-law index of the
mass-richness relation



DES Collaboration 2021

Summary – Cluster Mass Calibration

A first-look shows spectroscopy can help calibrate projection effects and correct optical richness.

This work can be continued with DESI together with supplemental complete spectroscopy for clusters in bins of redshift-richness space to build a model of projection effects as a function of richness and redshift.

Spectroscopic richness offers a path forward not only to constraining cosmology with optically-selected clusters but also to study as-yet not understood lensing systematics on small scales.

Conclusions

Galaxy surveys provide multiple probes of the matter density field with extremely valuable potential upside, but require well-thought-out efforts to control systematic uncertainties.

Weak lensing is on the verge of an enormous increase in data availability, motivating tighter constraints on systematic uncertainties. For redshift calibration, data needs are coming into focus and I propose one improved modeling technique to meet future uncertainty requirements.

Galaxy clusters will soon be measurable down to far lower mass limits across wavelengths with coming surveys; we propose using optical spectroscopy as a key piece for resolving the mass calibration.

Extra Slides

Extra Slides available by email to jmyles@stanford.edu