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Rubin x DESI Cosmology

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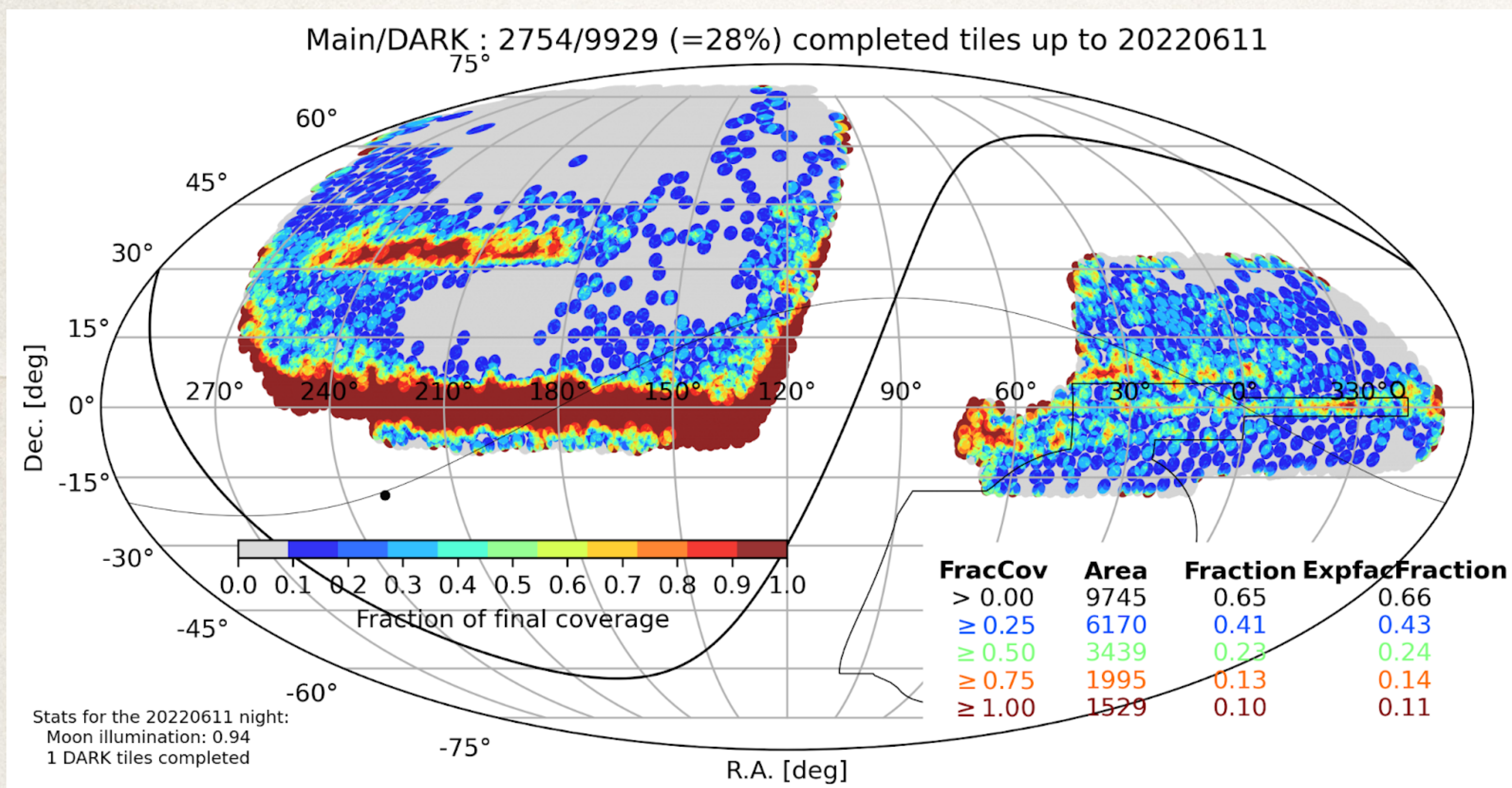
What large-scale structure science is enabled by overlapping DESI and Rubin observations?

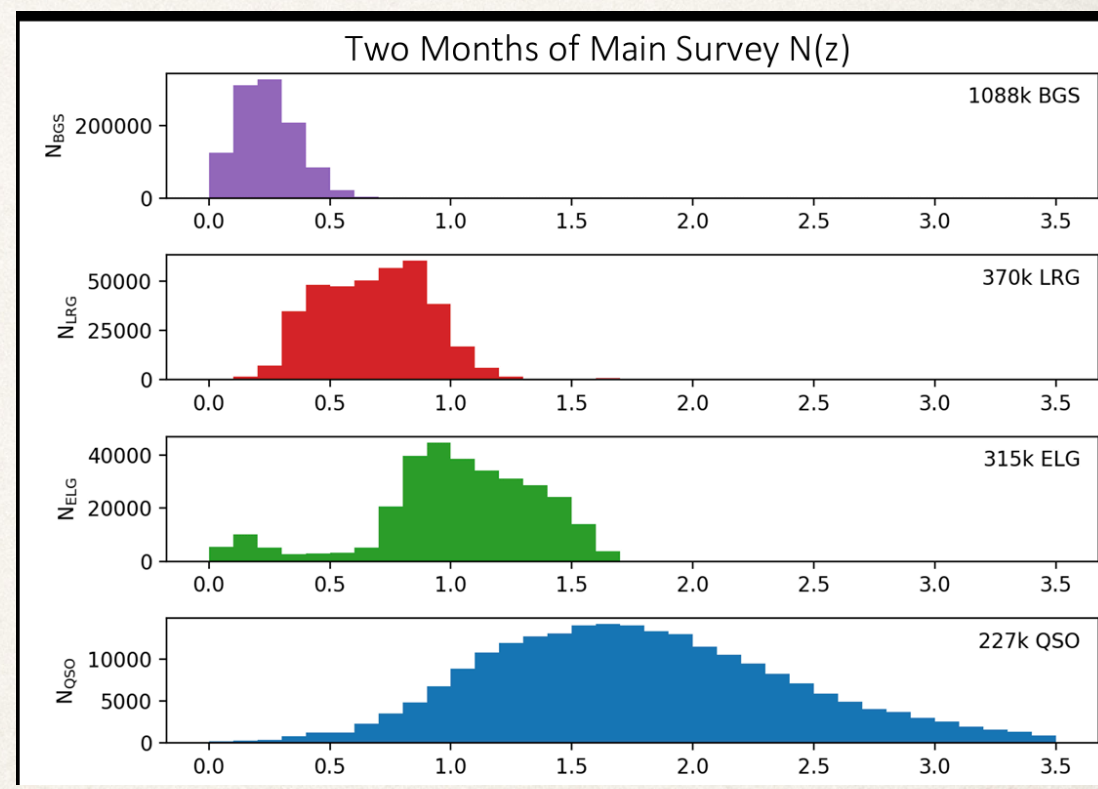
An incomplete list:

- Redshifts
  - Photometric redshift calibration
  - "Clustering" redshifts
- Galaxy intrinsic alignments
- Galaxy-galaxy lensing around spectroscopic lenses
  - Combination with redshift-space distortions
  - Baryonic effect mitigation with kinetic Sunyaev-Zel'dovich

What is DESI?

14k square degrees
40M redshifts over 5 years
5 target classes





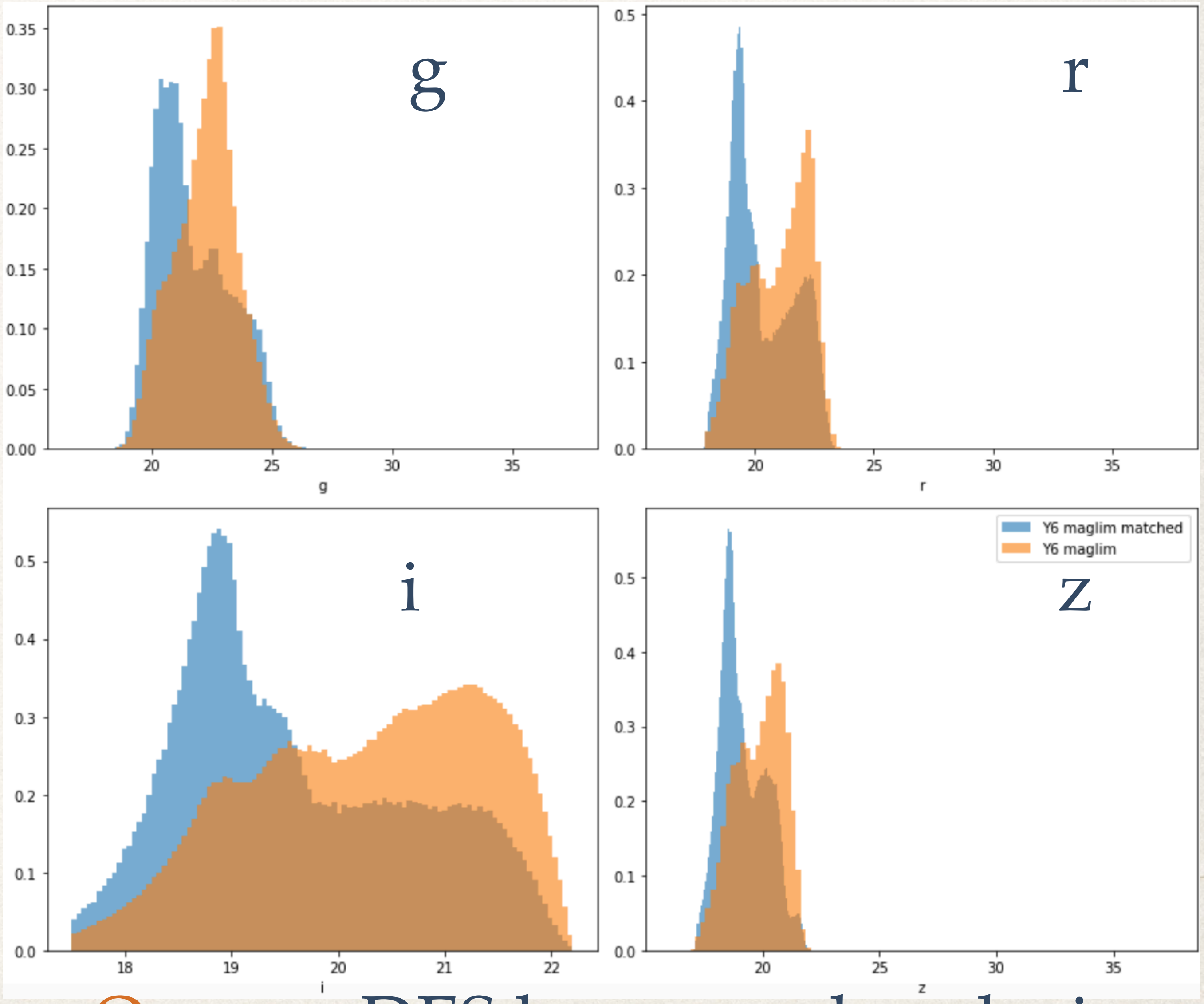
redshift

Redshifts — Direct n(z) estimation

Need accurate redshifts for most Rubin science.

Default DESI targeting overlaps with color space relevant for photometric "lens" galaxies and weak lensing "source" galaxies.

Credit: Noah Weaverdyck

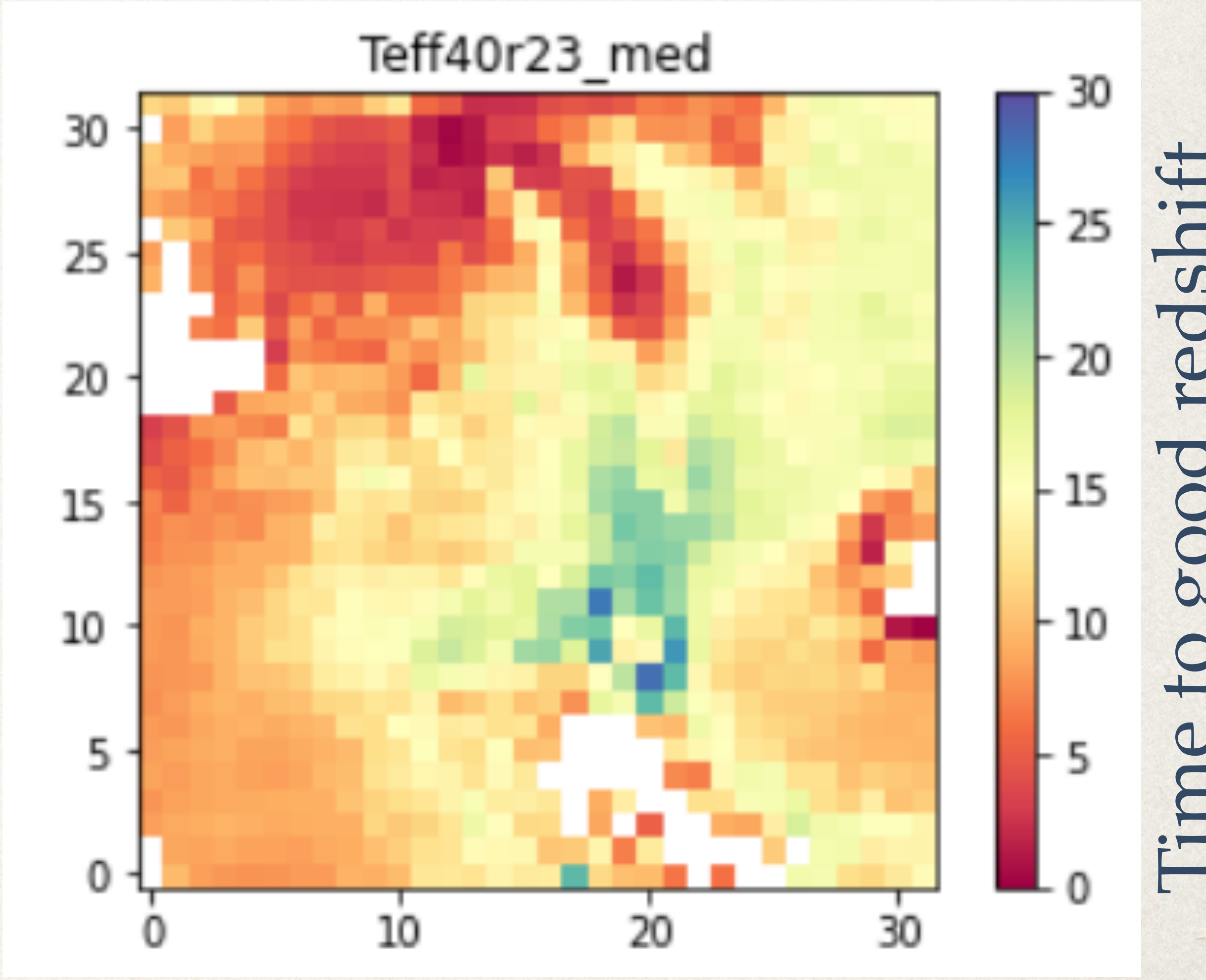


Orange: DES lens sample galaxies.
Blue: Matched DESI spectra.

Redshifts — Direct n(z) ~~estimation~~ measurement

DESI secondary programs can remove significant uncertainty
when directly overlapping with photometric samples.

- Pre-define cuts on samples via Self-Organizing Map to ensure accessible, fair sample
- Can carve out samples that balance ease of obtaining spec-z vs. galaxy density.

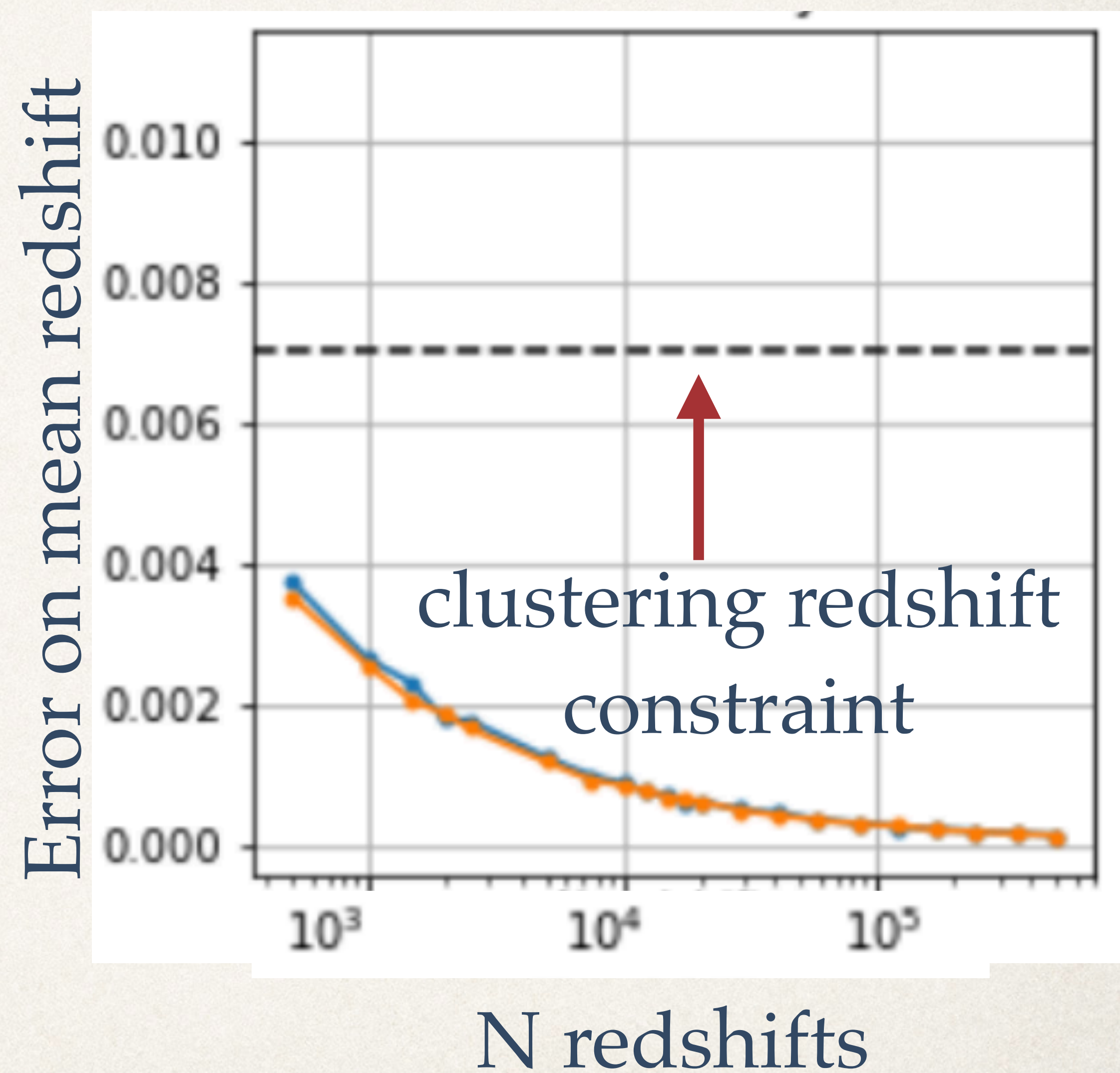


Credit: Noah Weaverdyck

Redshifts — Direct n(z) ~~estimation~~ measurement

Test case using DES "MagLim" sample show that even with a few hundred redshifts per SOM cell, we can do significantly better than clustering redshifts.

Weak-lensing source samples are more difficult, but we plan on investigating what fraction of weak-lensing source galaxies can be calibrated with DESI spectroscopy.

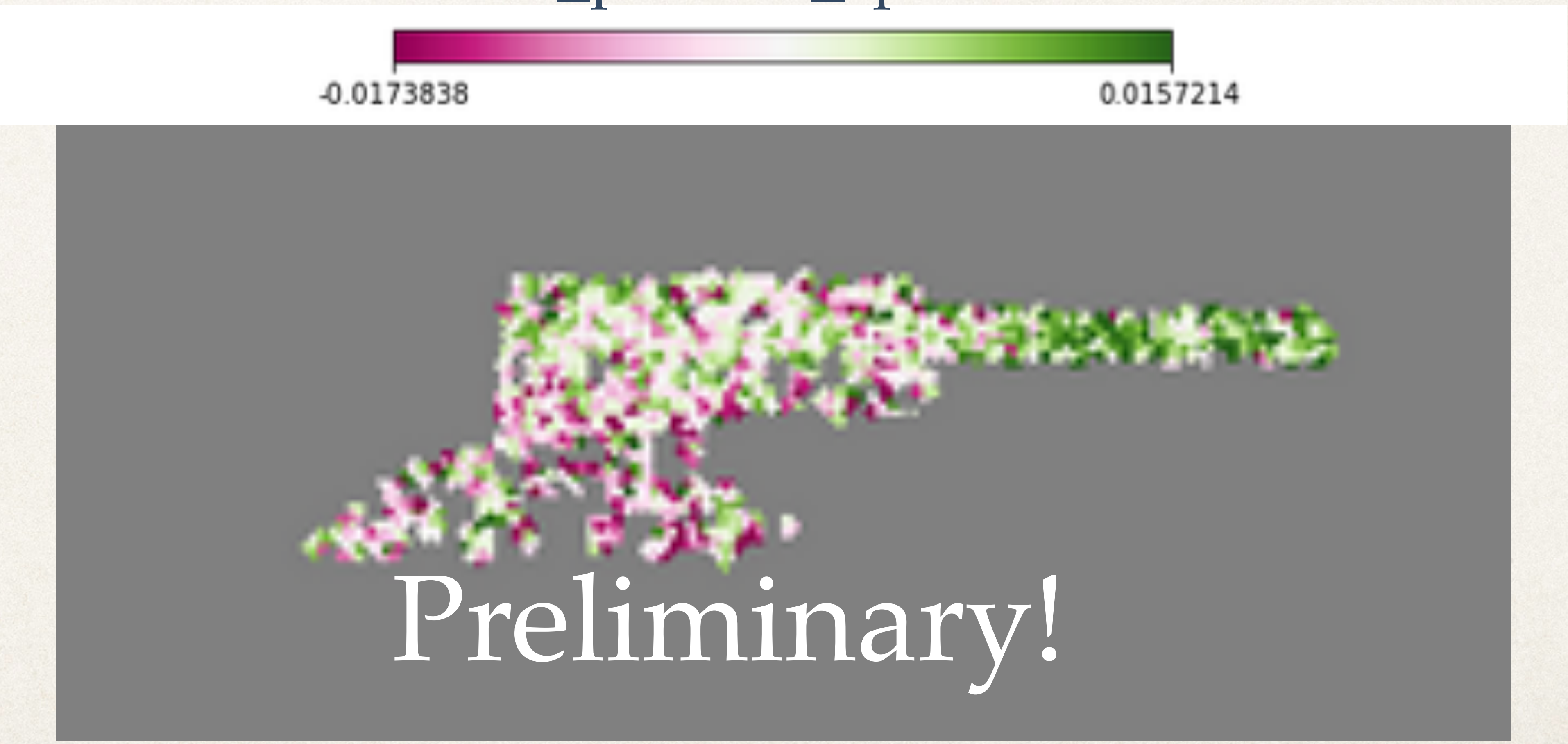


Credit: Noah Weaverdyck

Redshifts — Direct n(z) ~~estimation~~ measurement

Can map out spatial inhomogeneity of color-redshift relation, imparted by non-uniform observing conditions.

z_phot - z_spec



Credit: Noah Weaverdyck

Redshifts — cross-correlation

Cross-correlations between spectroscopic and photometric galaxies constrains product of redshift distribution and bias.

$$\bar{w}_{\mathrm{ur}} = \int_{z_{\mathrm{min}}}^{z_{\mathrm{max}}} n_{\mathrm{u}}(z) n_{\mathrm{r}}(z) b_{\mathrm{u}}(z) b_{\mathrm{r}}(z) \bar{w}_{\mathrm{mm}}(z) dz$$

$$n_{\mathrm{u},i}(z_j) \propto \bar{w}_{\mathrm{ur}}(z_j) \frac{1}{b_{\mathrm{u}}(z_j)} \frac{1}{b_{\mathrm{r}}(z_j)} \frac{1}{\bar{w}_{\mathrm{mm}}(z_j)}$$

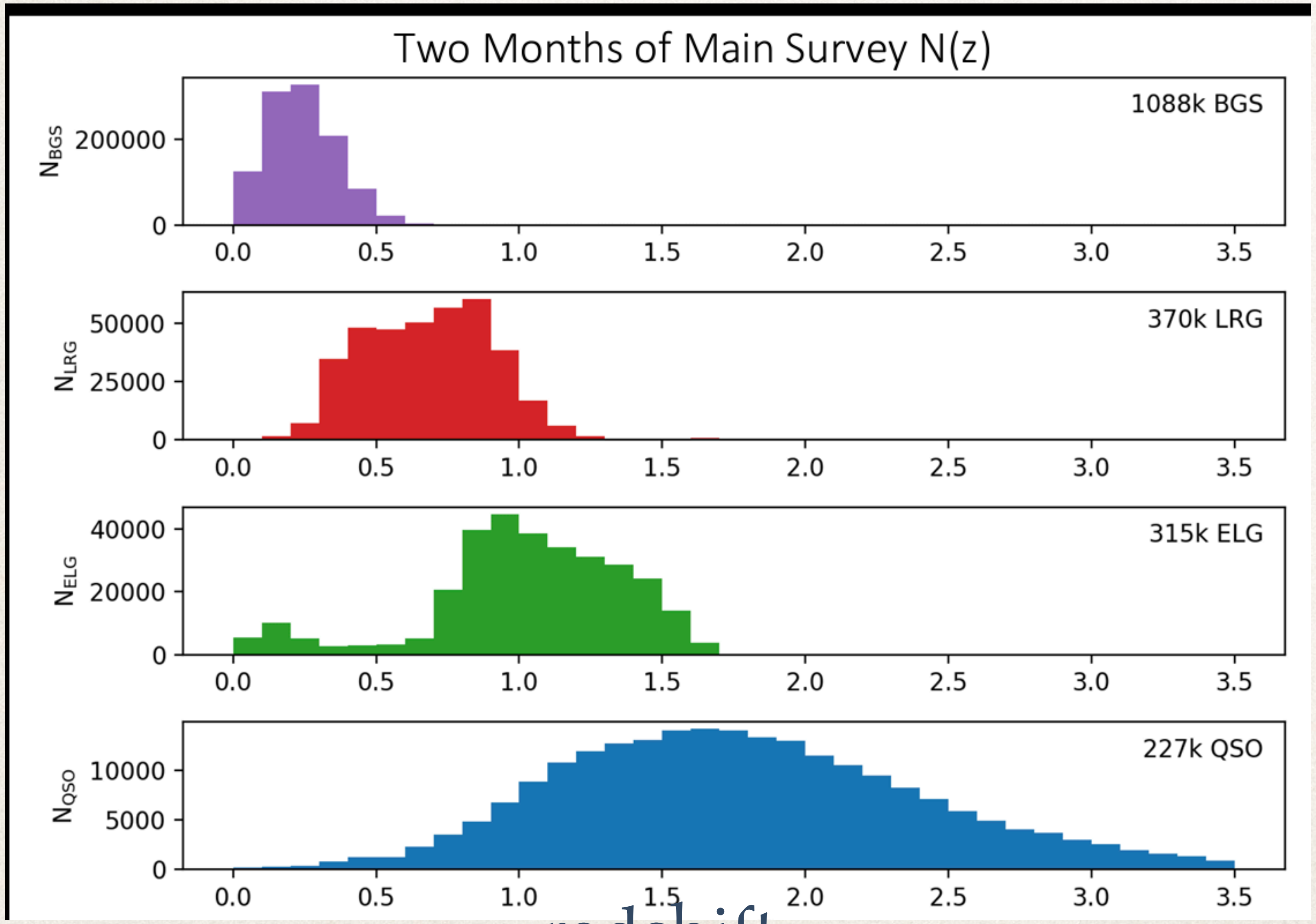
For galaxy-galaxy lensing and galaxy clustering using photometric galaxies, this is the quantity that we need for our theoretical models.

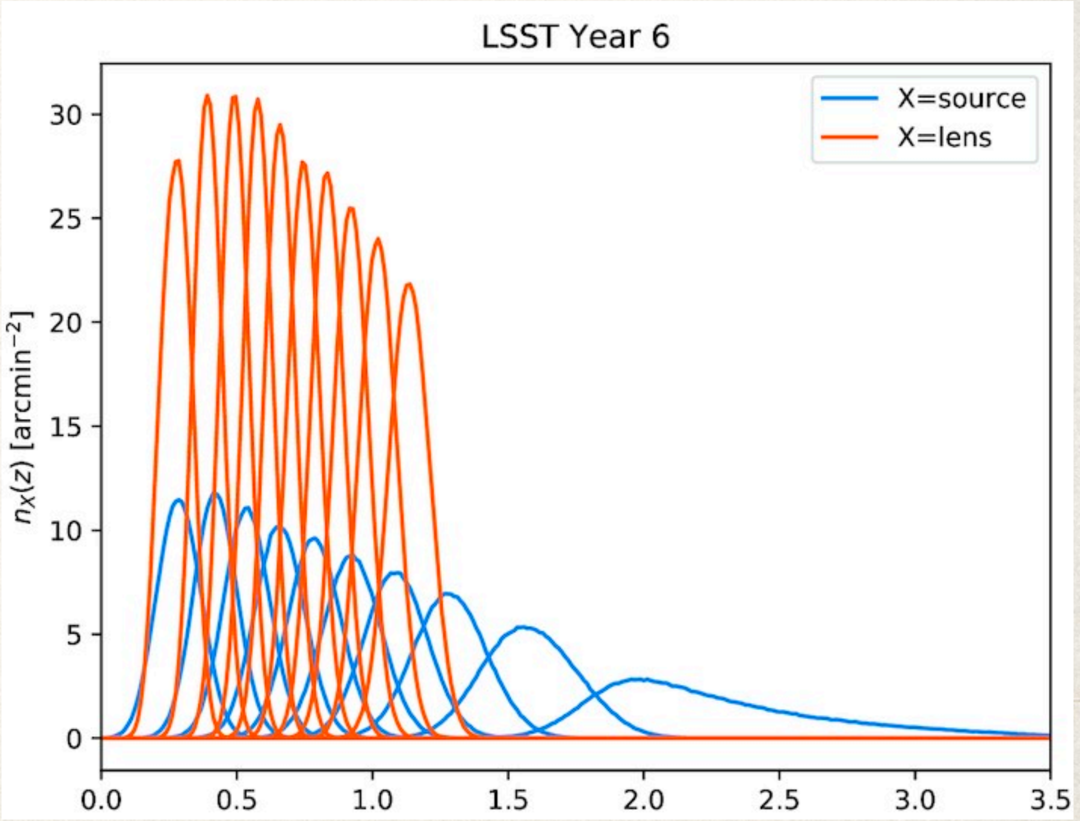
For source samples, the same algorithm is possible, but a method for estimating the source sample galaxy b(z) is necessary.

Redshifts — cross-correlation

Rubin lens samples will overlap entirely with DESI BGS, LRG and ELG samples. Including QSOs covers all source samples.

Fang et al. 2022





redshift

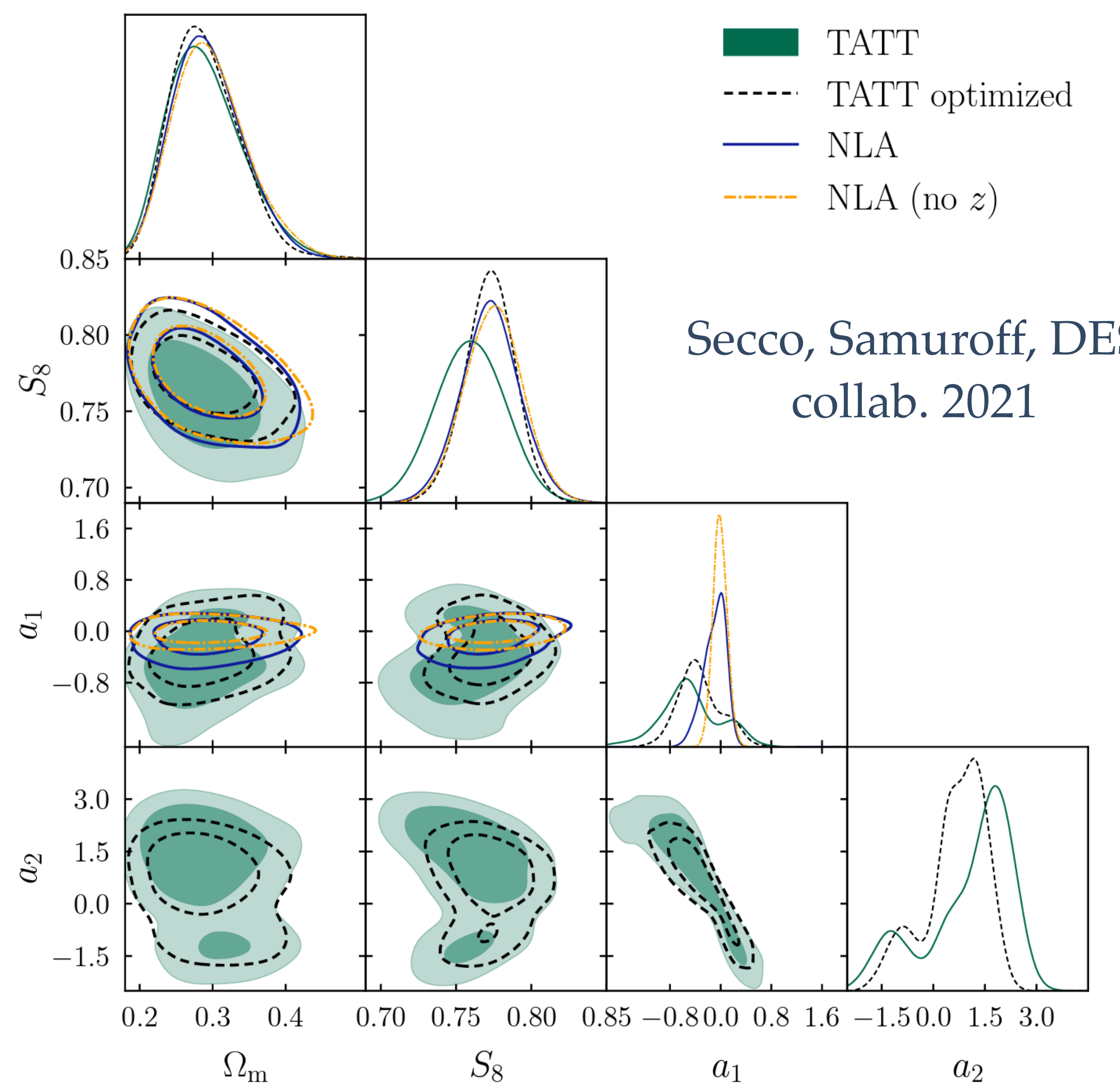
redshift

Galaxy Intrinsic Alignment

$$\langle\gamma\gamma\rangle = \langle\gamma^G\gamma^G + \gamma^G\gamma^I + \gamma^I\gamma^I\rangle = \xi_{GG} + \xi_{GI} + \xi_{II}$$

IA contamination is currently one of the dominant uncertainties in cosmic shear studies.

In DES Y3, degradation of constraints going from simplest considered model to a more complex model was ~40% in S8.

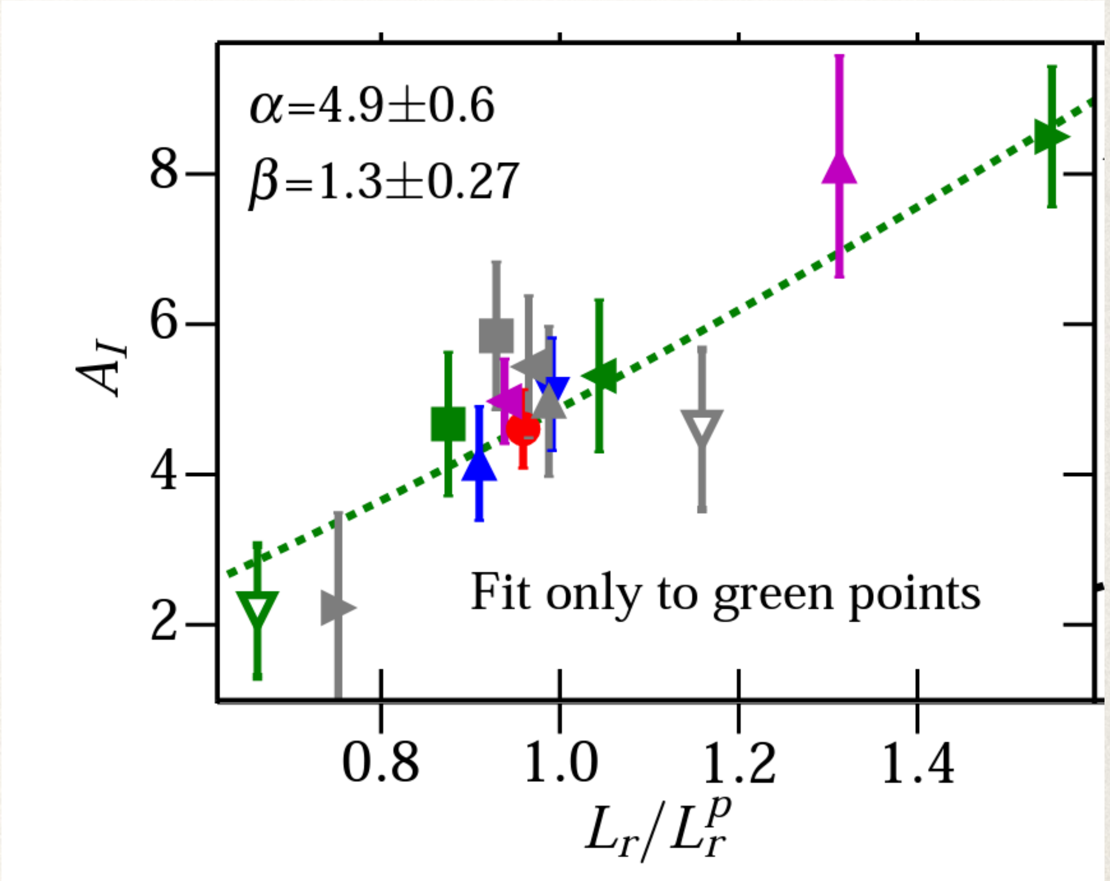


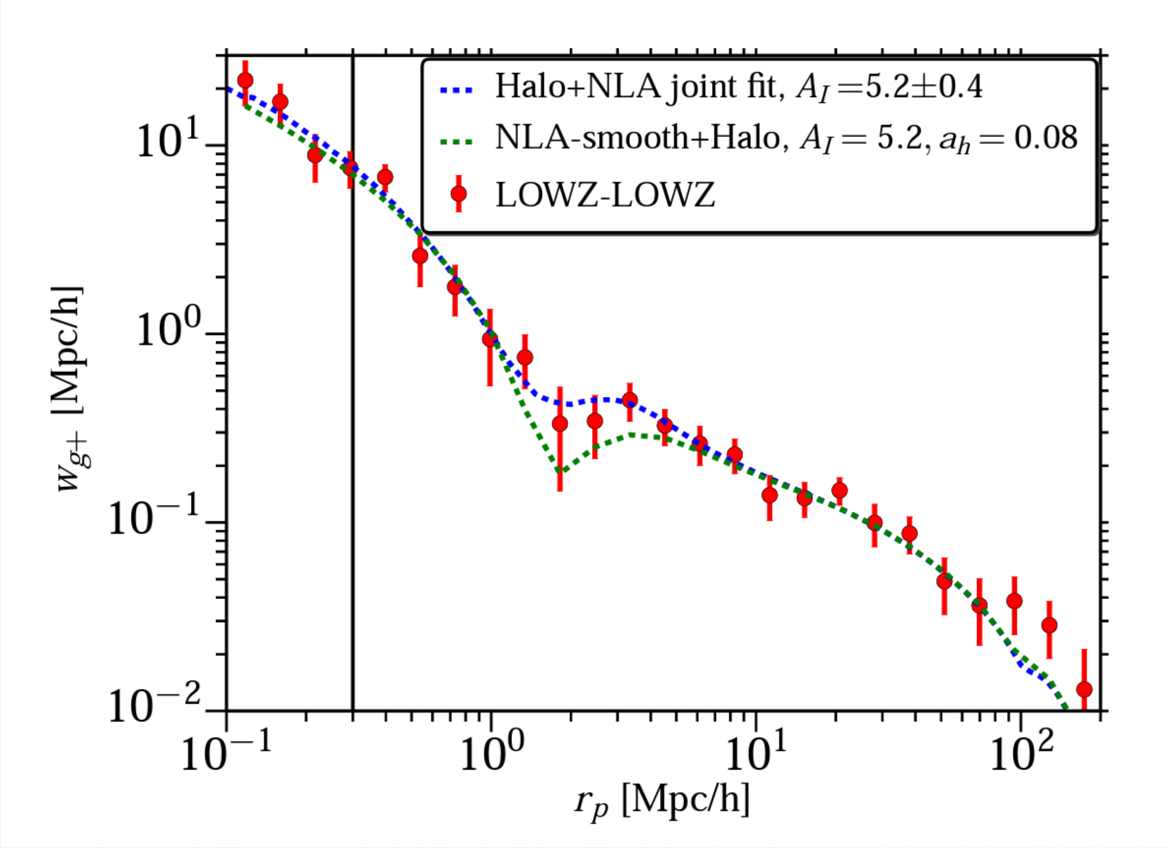
Secco, Samuroff, DES collab. 2021

Intrinsic Alignment

With spectroscopy, IA models can be probed with high signal-to-noise directly on the data.

Can be used to inform models applied in cosmological constraints.



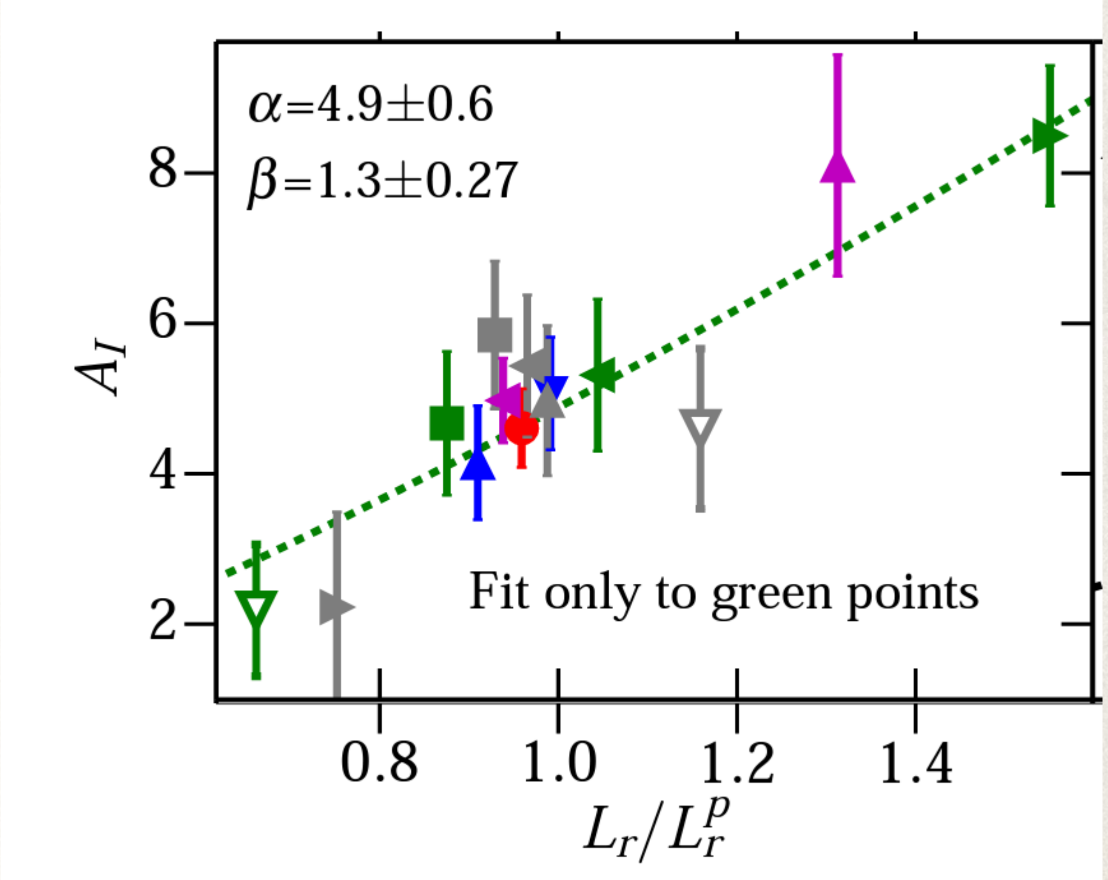


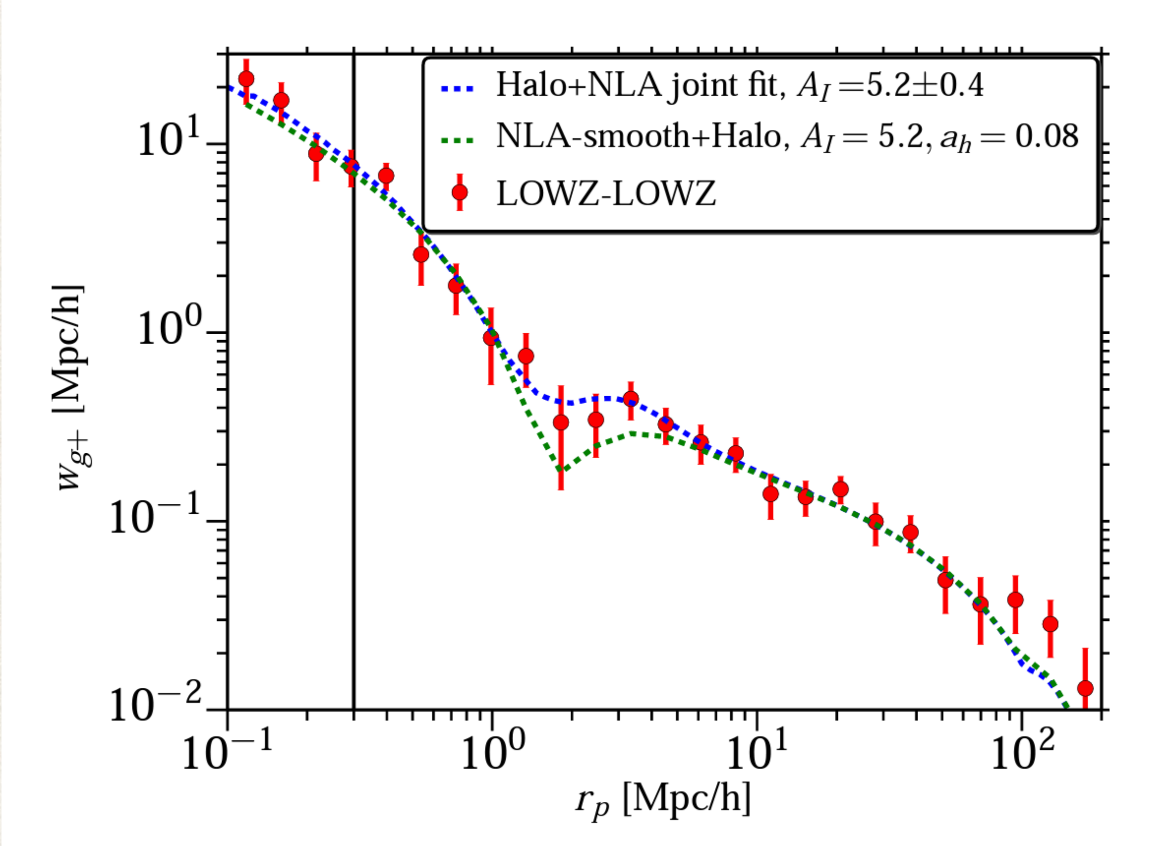
Singh et al. 2015

Intrinsic Alignment

DESI BGS and ELG data will significantly extend the range of galaxies types that this measurement can be made with beyond previous analyses focusing on LRGs.

Dedicated programs also possible.





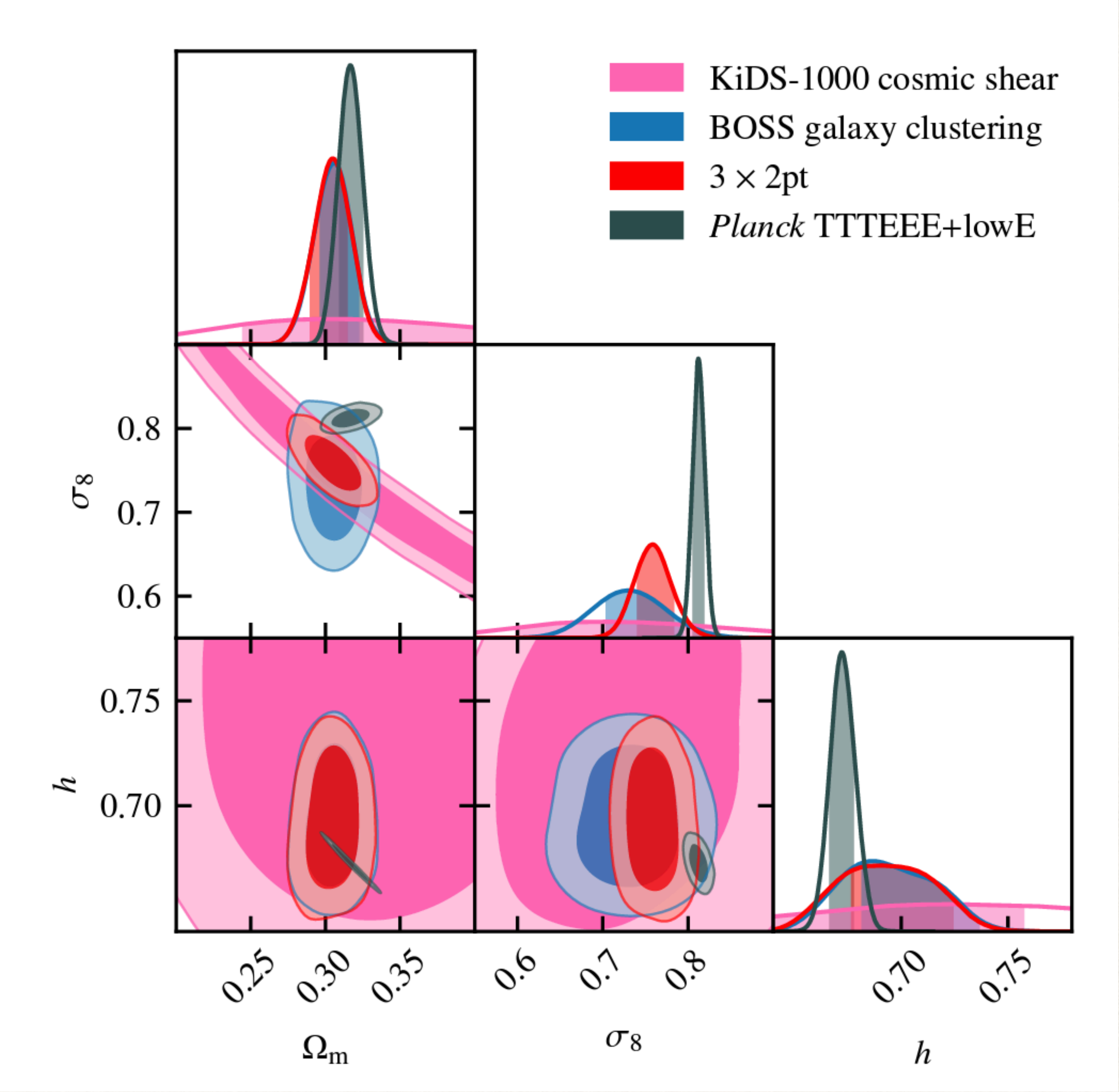
Singh et al. 2015

Galaxy Lensing + RSD

Significant degeneracy breaking is possible when combining galaxy lensing and RSD measurements.

Allows for tests of differences between newtonian and lensing potentials predicted by modifications to GR.

DESI will be the optimal galaxy sample to overlap with for GGL (compared to Euclid / PFS).



Heymans et al. 2021

Mitigation of Baryonic Effects

Kinetic Sunyaev-Zel'dovich is a probe of the product of electron number density and electron velocity.

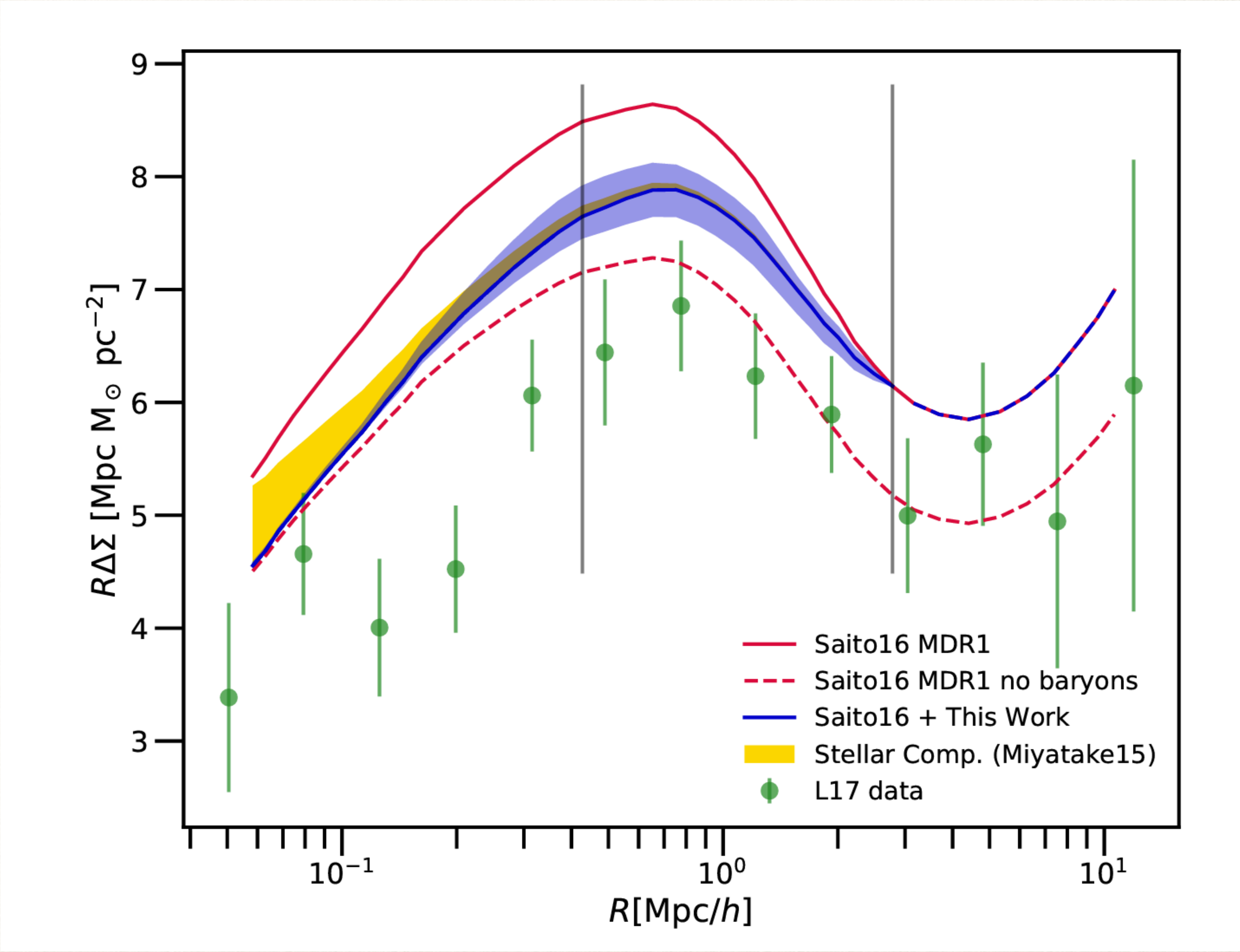
$$\frac{\delta T_{\rm kSZ}(\hat{\boldsymbol{n}})}{T_{\rm CMB}} = -\int \frac{d\chi}{1+z} n_e(\chi\hat{\boldsymbol{n}}, z)\sigma_T \; e^{-\tau(z)} \; \frac{\boldsymbol{v}_e \cdot \hat{\boldsymbol{n}}}{c},$$

With a spectroscopic survey, the velocity field can be reconstructed, such that the stacked kSZ around galaxies is a direct probe of their baryon profiles

$$\boldsymbol{\nabla} \cdot \boldsymbol{v} + f \boldsymbol{\nabla} \cdot \left[\left(\boldsymbol{v} \cdot \hat{\boldsymbol{n}} \right) \hat{\boldsymbol{n}} \right] = -aHf \; \frac{\delta_g}{b}$$

Mitigation of Baryonic Effects

Can thus be used to reduce uncertainty due to the impact of baryonic physics on the modeling of GGL using spectroscopic galaxies as lenses.



Amodeo et al 2022, Schaan, Ferraro, et al. 2022

Summary

- Cross correlations between Rubin and DESI will mitigate significant systematic errors in LSST DESC “Key” analyses
  - DESI spectroscopy can get redshifts for significant portions color space that is not spectroscopically calibrated.
  - Clustering cross correlations will allow for robust calibration of redshift distributions and bias evolution for Rubin “lens” samples
  - Direct IA measurements with DESI will aid in IA model selection/validation
  - Combining RSD and galaxy-galaxy lensing of Rubin sources around DESI galaxies will be a powerful cosmological probe in it’s own right