The Dark Energy Survey (in 10 Minutes)

Noah Weaverdyck
Chamberlain Fellow
Lawrence Berkeley National Lab
NWeaverdyck@lbl.gov

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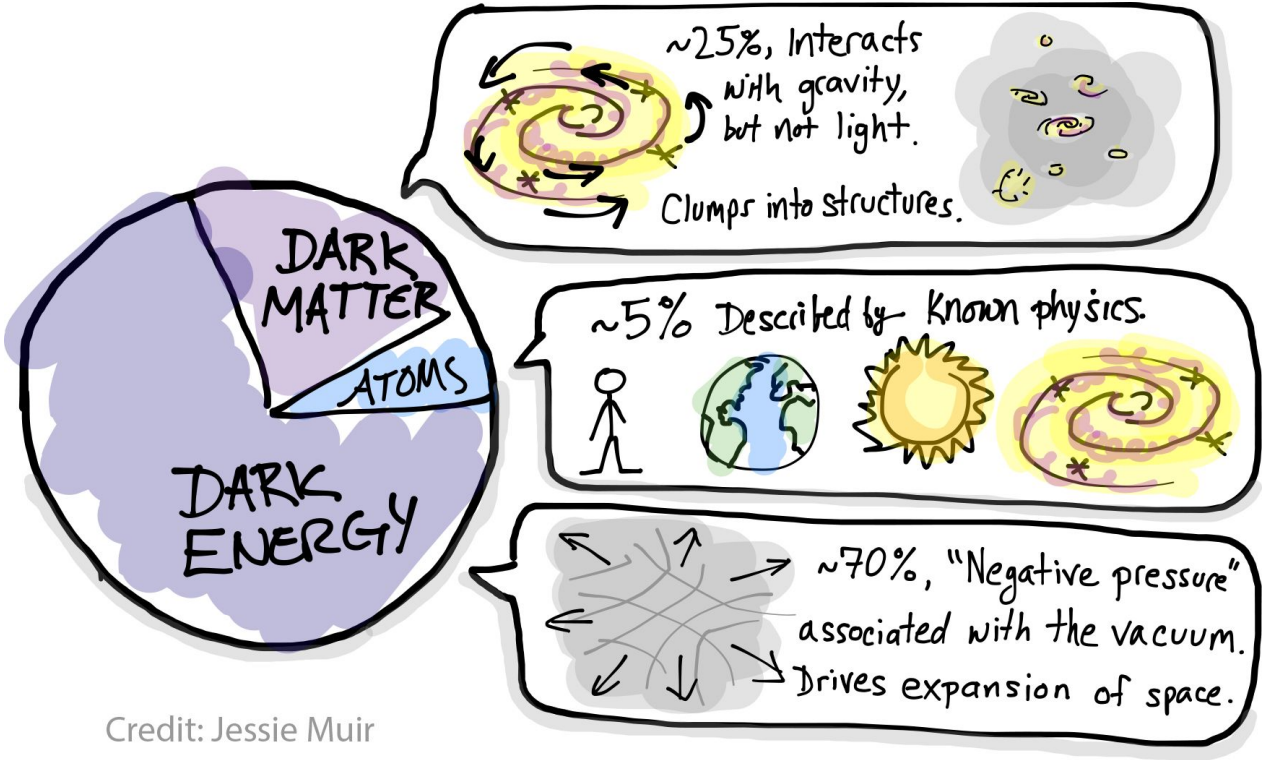
Cosmology

- Dynamics and evolution of the universe at largest scales
- 1910s: develop *theory* to relate space and mass-energy via General Relativity
- 1920s: ability to *observe* large scale structure of cosmos through first detection of other galaxies
- Basic idea: measure *growth of structures* and *expansion history* → constrain cosmological parameters of given theoretical model

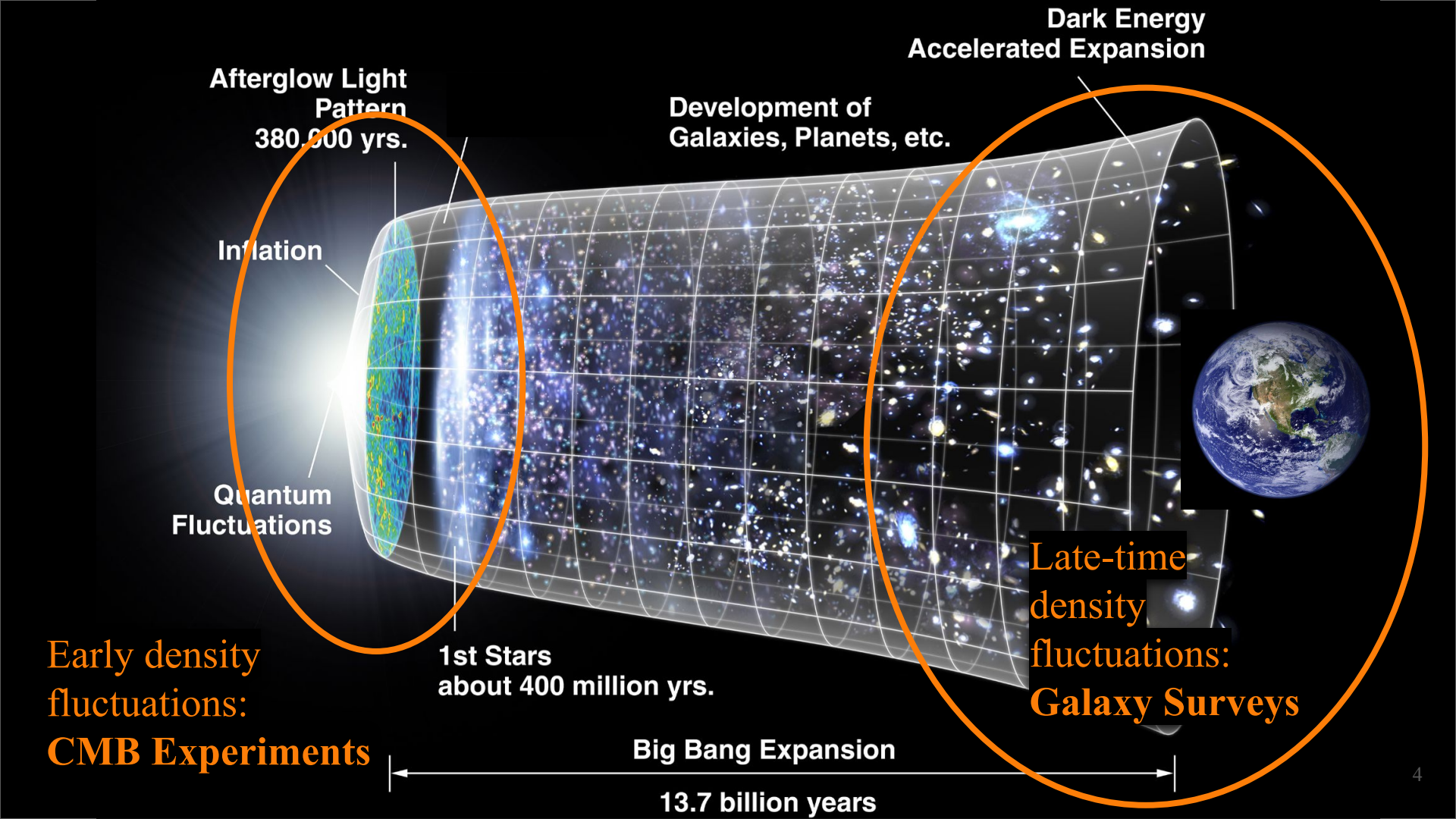
~10+ Mpc, or
30+ million light-years

“Standard Model” of cosmology

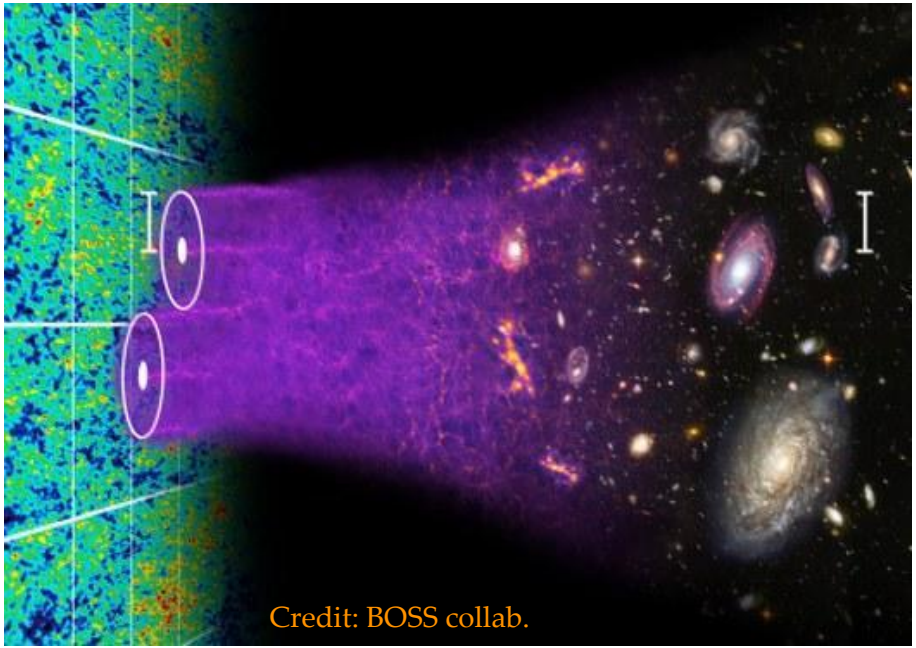
- 6 parameter “ΛCDM”
- Composition (right) + amplitude, scale-dependence of density fluctuations, expansion rate
- Focus: measure these parameters

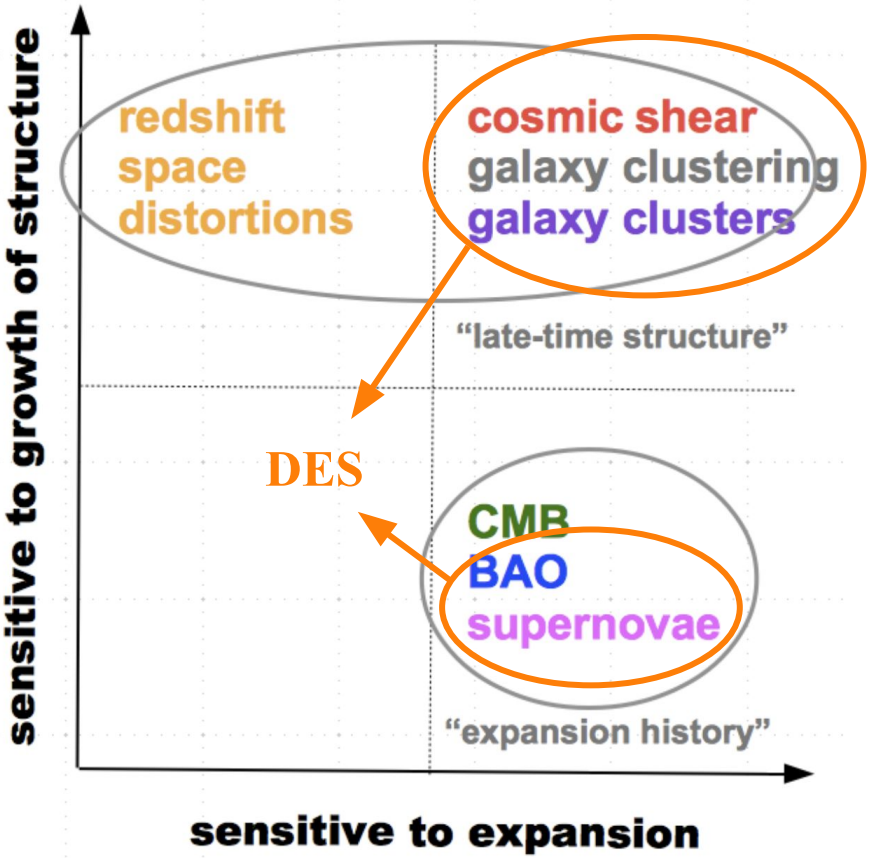


Credit: Jessie Muir


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Late-time
density
fluctuations:
Galaxy Surveys
Early density
fluctuations:
CMB Experiments
Big Bang Expansion
13.7 billion years

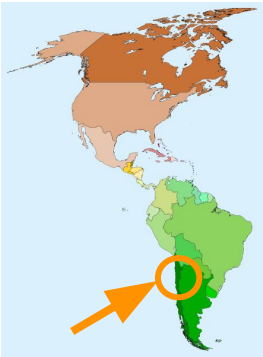
Measurements



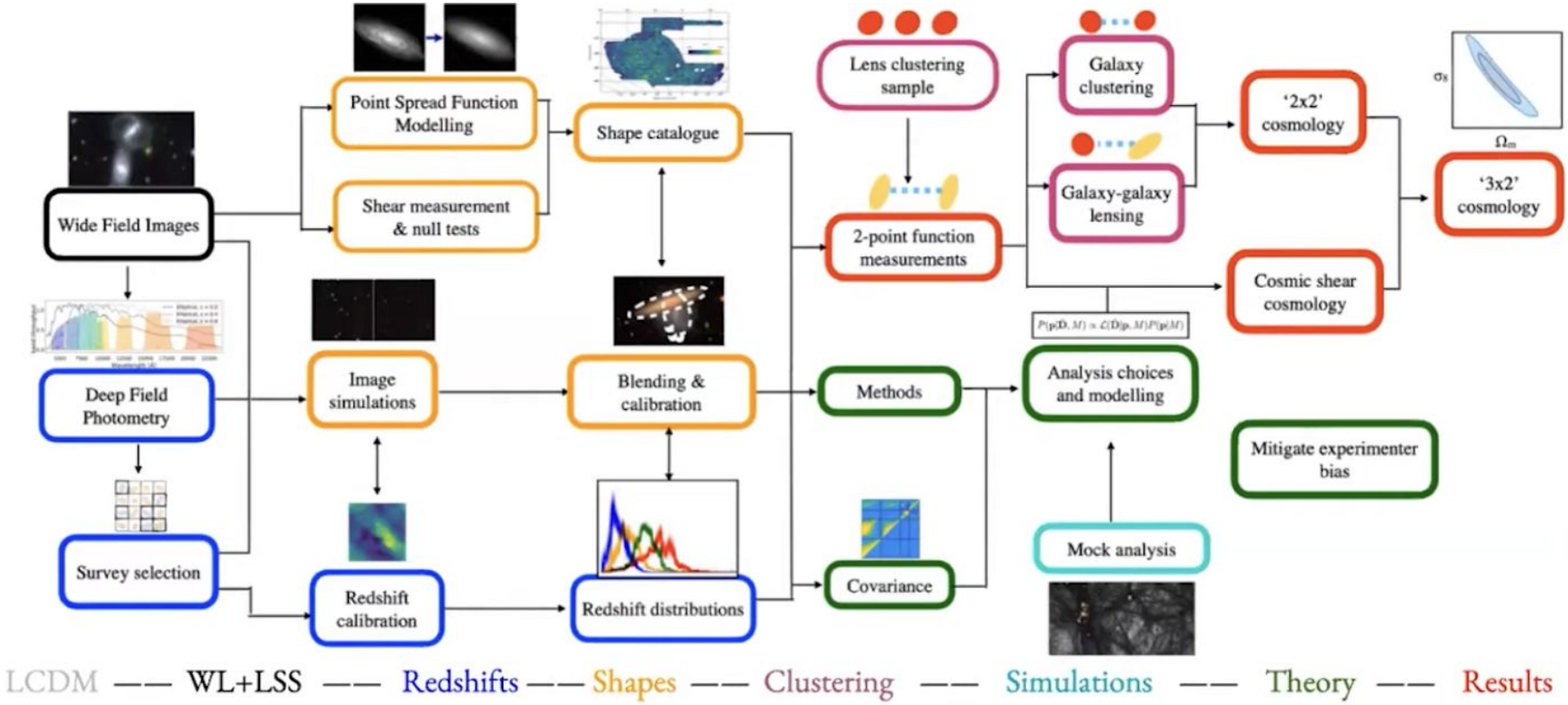


Dark Energy Survey (DES)

- 4-meter optical telescope in Chile
- 1/8 of sky between 2013 - 2019
- >300 million galaxies
- ~400 scientists
  - ~30 institutions
    - 7 countries

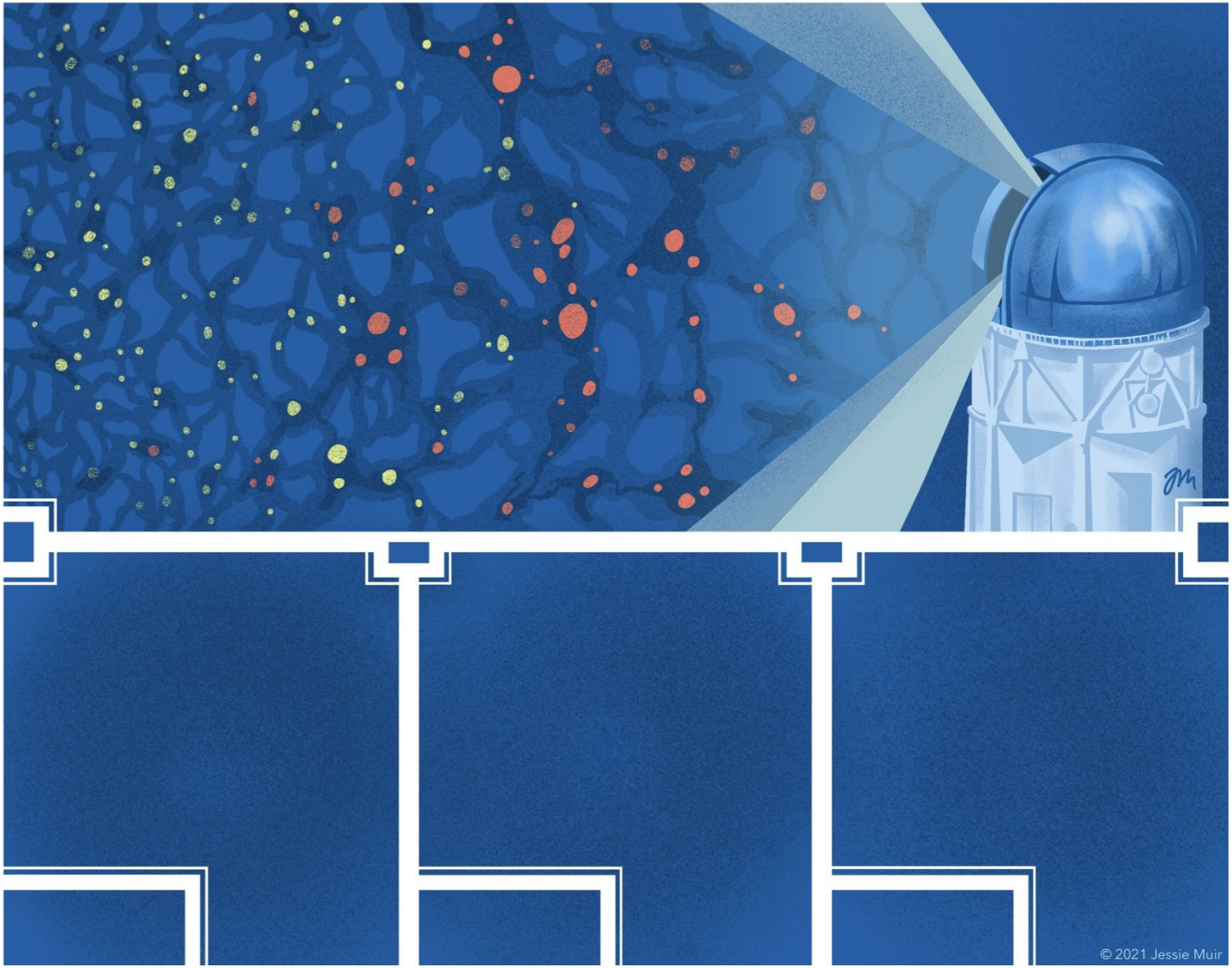


DES: Pixels to Cosmology (3x2pt)



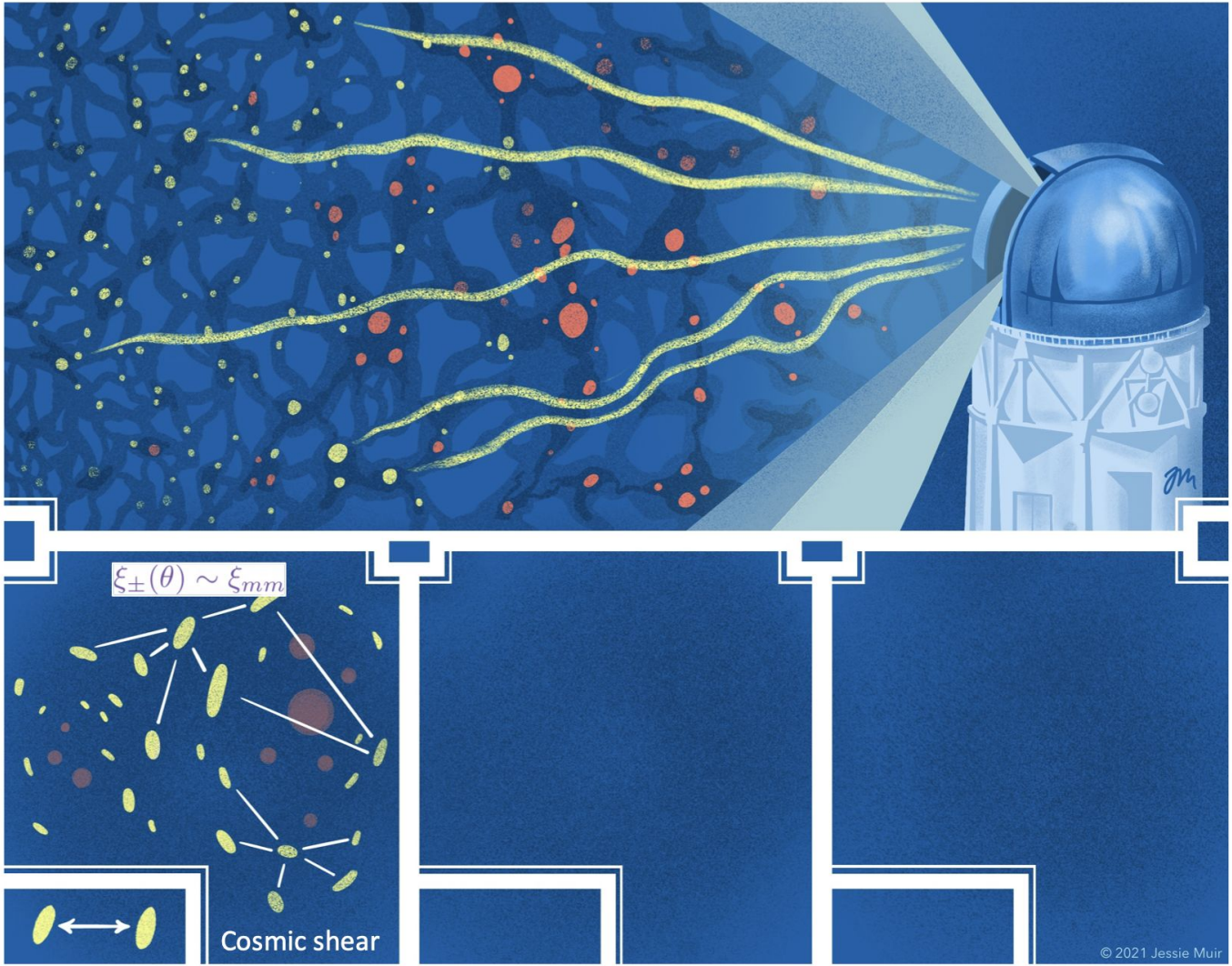
Credit: Alex Amon

“3x2pt”



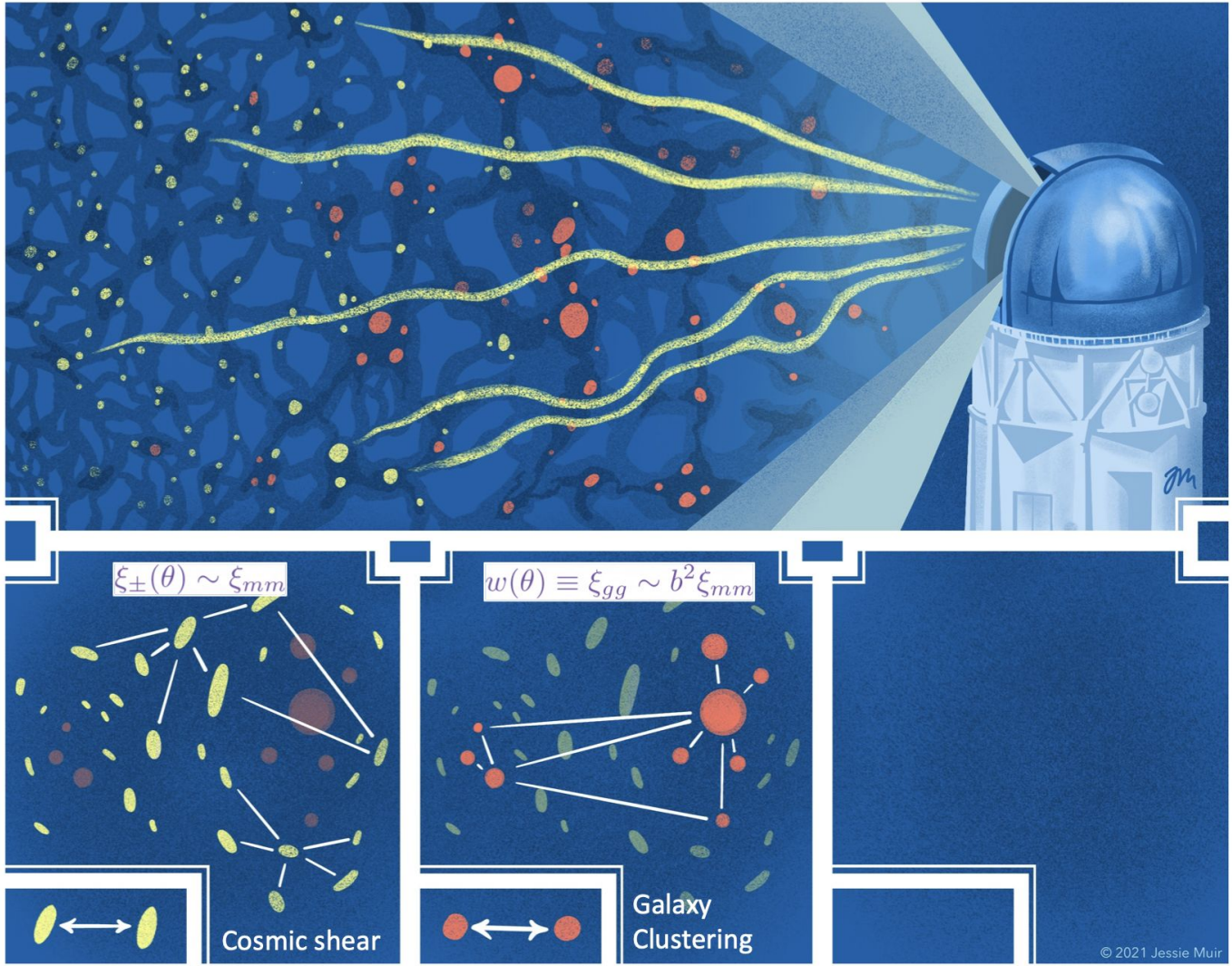
“3x2pt”

- Cosmic Shear



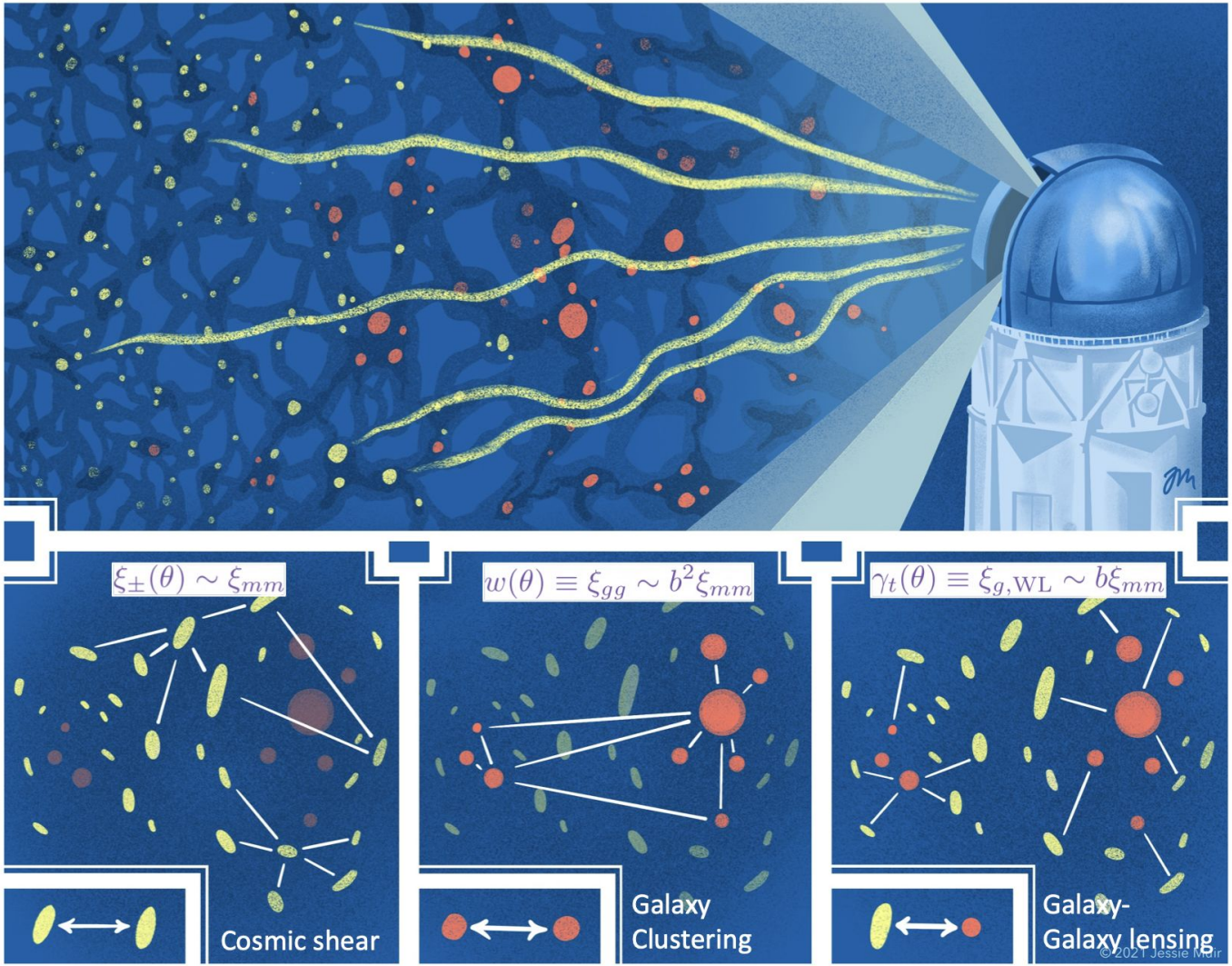
“3x2pt”

- Cosmic Shear
- Galaxy Clustering



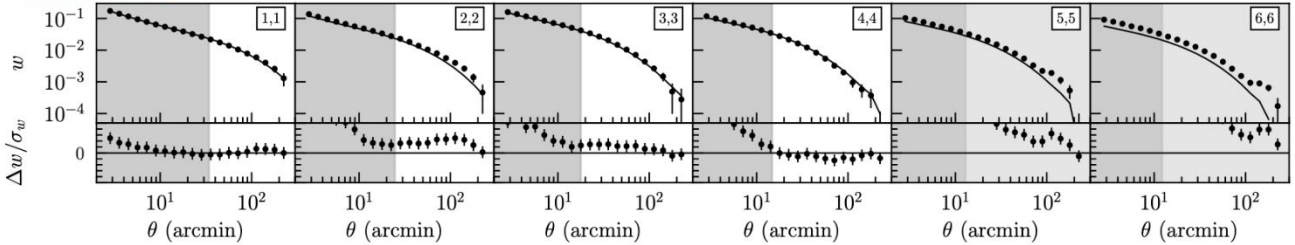
“3x2pt”

- Cosmic Shear
- Galaxy Clustering
- Galaxy-Galaxy Lensing



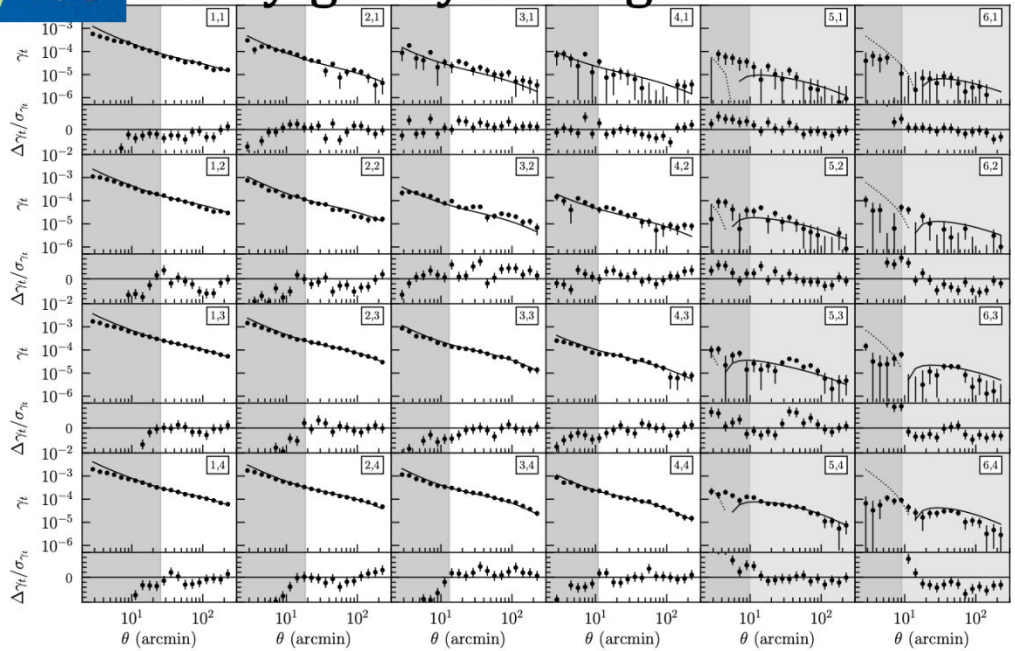
Galaxy clustering

Rodríguez-Monroy, Weaverdyck, et al., arXiv:2105.13540



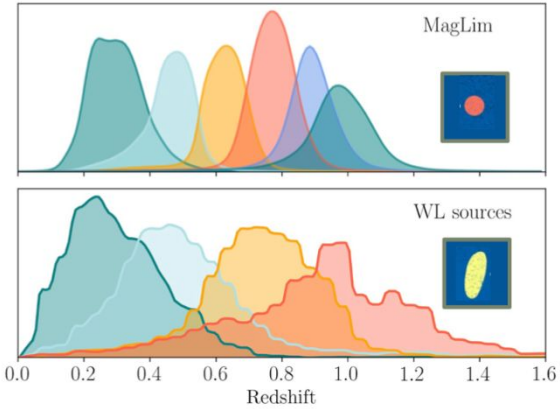
Galaxy-galaxy lensing

Prat et al. [DES], arXiv:2105.13541



Data in practice

Gray: remove data where theory not good enough

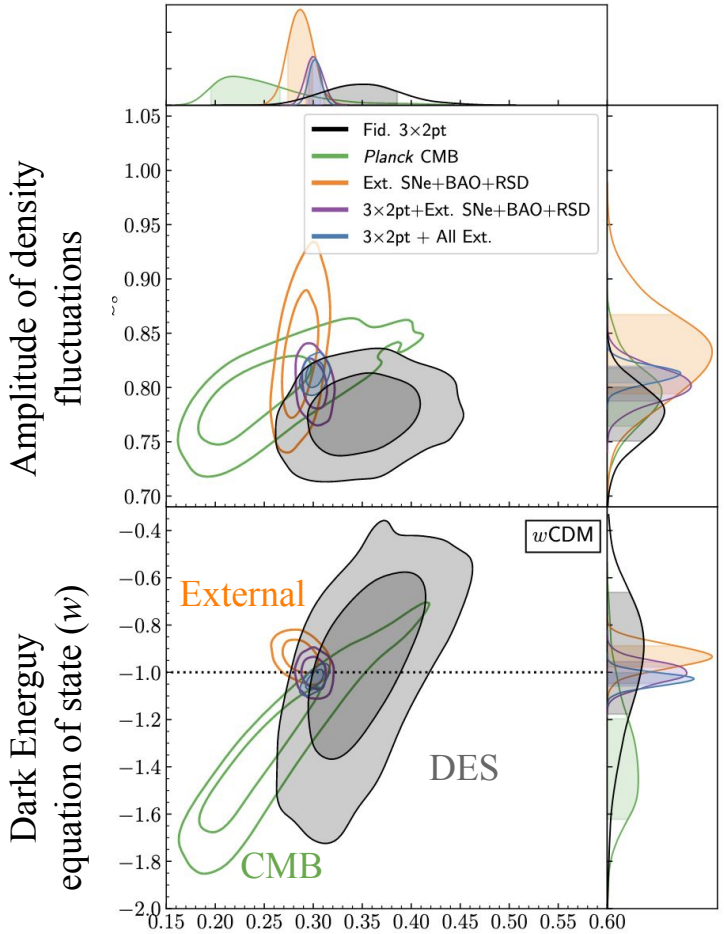


DES Y3 papers on galaxy clustering and weak lensing

1. "Blinding Multi-probe Cosmological Experiments" J. Muir, G. M. Bernstein, D. Huterer et al., arXiv: 1911.05929, MNRAS 494 (2020) 4454
2. "Photometric Data Set for Cosmology", I. Sevilla-Noarbe, K. Bechtol, M. Carrasco Kind et al., arXiv:2011.03407, ApJS 254 (2021) 24
3. "Weak Lensing Shape Catalogue", M. Gatti, E. Sheldon, A. Amon et al., arXiv:2011.03408, MNRAS 504 (2021) 4312
4. "Point Spread Function Modelling", M. Jarvis, G. M. Bernstein, A. Amon et al., arXiv:2011.03409, MNRAS 501 (2021) 1282
5. "Measuring the Survey Transfer Function with Balrog", S. Everett, B. Yanny, N. Kuropatkin et al., arXiv:2012.12825
6. "Deep Field Optical + Near-Infrared Images and Catalogue", W. Hartley, A. Choi, A. Amon et al., arXiv:2012.12824
7. "Blending Shear and Redshift Biases in Image Simulations", N. MacCrann, M. R. Becker, J. McCullough et al., arXiv:2012.08567
8. "Redshift Calibration of the Weak Lensing Source Galaxies", J. Myles, A. Alarcon, A. Amon et al., arXiv:2012.08566
9. "Redshift Calibration of the MagLim Lens Sample using Self-Organizing Maps and Clustering Redshifts", G. Giannini et al., in prep.
10. "Clustering Redshifts – Calibration of the Weak Lensing Source Redshift Distributions with redMaGiC and BOSS/eBOSS", M. Gatti, G. Giannini, et al., arXiv:2012.08569
11. "Calibration of Lens Sample Redshift Distributions using Clustering Redshifts with BOSS/eBOSS", R. Cawthon et al. arXiv:2012.12826
12. "Phenotypic Redshifts with SOMs: a Novel Method to Characterize Redshift Distributions of Source Galaxies for Weak Lensing Analysis" R. Buchs, C.Davis, D. Gruen et al. arXiv:1901.05005, MNRAS 489 (2019) 820
13. "Marginalising over Redshift Distribution Uncertainty in Weak Lensing Experiments", J. Cordero, I. Harrison et al., arXiv:2109.09636
14. "Exploiting Small-Scale Information using Lensing Ratios", C. Sánchez, J. Prat et al., arXiv:2105.13542
15. "Cosmology from Combined Galaxy Clustering and Lensing - Validation on Cosmological Simulations", J. de Rose et al., arXiv:2105.13547.
16. "Robust sampling of cosmological posterior distributions", P. Lemos, N. Weaverdyck, R. Rollins, J. Muir, A. Ferté, A. Liddle et al., in prep.
17. "Assessing Tension Metrics with DES and Planck Data", P. Lemos, M. Raveri, A. Campos et al., arXiv:2012.09554
18. "Dark Energy Survey Internal Consistency Tests of the Joint Cosmological Probe Analysis with Posterior Predictive Distributions", C. Doux, E. Baxter, P. Lemos et al. arXiv:2011.03410, MNRAS 503 (2021) 2688
19. "Covariance Modelling and its Impact on Parameter Estimation and Quality of Fit", O. Friedrich, F. Andrade-Oliveira, H. Camacho et al., arXiv:2012.08568
20. "Multi-Probe Modeling Strategy and Validation", E. Krause et al., arXiv:2105.13548
21. "Curved-Sky Weak Lensing Map Reconstruction", N. Jeffrey, M. Gatti, C. Chang et al., arXiv:2105.13539
22. "Galaxy Clustering and Systematics Treatment for Lens Galaxy Samples", M.Rodríguez-Monroy, N. Weaverdyck, J. Elvin-Poole, M. Crocce et al., arXiv:2105.13540
23. "Optimizing the Lens Sample in Combined Galaxy Clustering and Galaxy-Galaxy Lensing Analysis", A. Porredon, M. Crocce et al., arXiv:2011.03411 PhRvD 103 (2021) 043503
24. "High-Precision Measurement and Modeling of Galaxy-Galaxy Lensing", J. Prat, J. Blazek, C. Sánchez et al., arXiv:2105.13541
25. "Constraints on Cosmological Parameters and Galaxy Bias Models from Galaxy Clustering and Galaxy-Galaxy Lensing using the redMaGiC Sample", S. Pandey et al., arXiv:2105.13545
26. "Cosmological Constraints from Galaxy Clustering and Galaxy-Galaxy Lensing using the Maglim Lens Sample" A. Porredon, M. Crocce et al., arXiv:2105.1354
27. "Cosmology from Cosmic Shear and Robustness to Data Calibration", A. Amon, D. Gruen, M. A. Troxel et al., arXiv:2105.13543
28. "Cosmology from Cosmic Shear and Robustness to Modeling Assumptions", L. Secco, S. Samuroff et al., arXiv:2105.13544
29. "Magnification modeling and impact on cosmological constraints from galaxy clustering and galaxy-galaxy lensing", J. Elvin-Poole, N. MacCrann et al., in prep.
30. "Cosmological Constraints from Galaxy Clustering and Weak Lensing" The DES Collaboration, arXiv2105.13549

Results

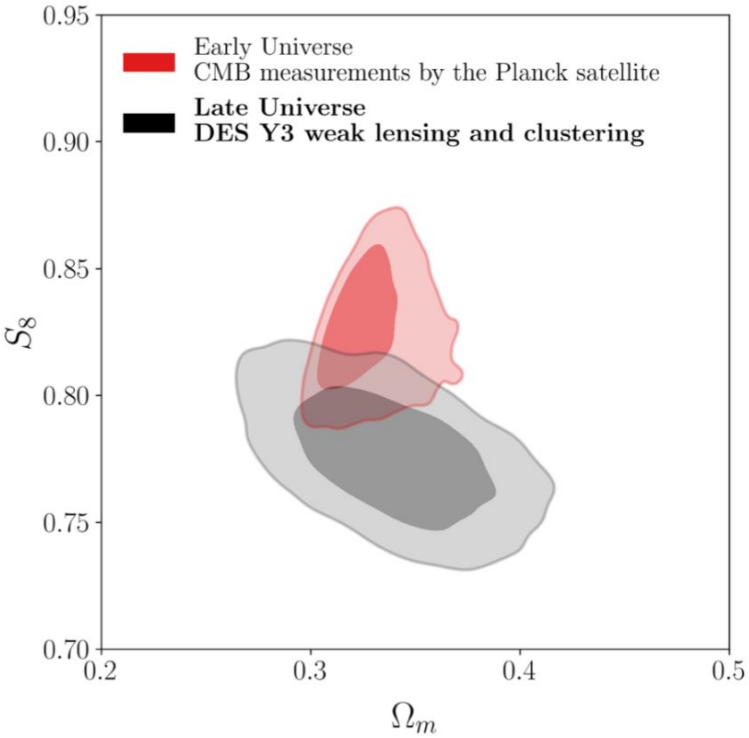
- Most powerful 3x2pt constraints from a single galaxy survey
- 2x improvement in S/N over Year 1
- Highly complementary to other probes!
- No evidence for deviation from w = -1 (ΛCDM, cosmological constant)

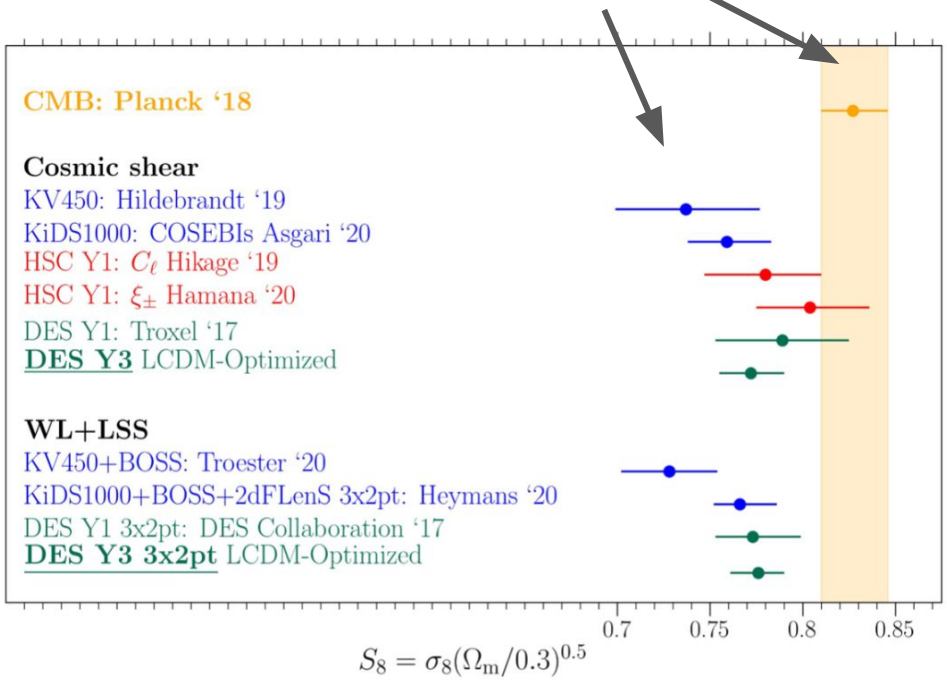


68% and 95% credible intervals

Results

LSS and CMB probes disagree on matter density fluctuations
(assuming LCDM)
No "extended" model yet resolves this





Look for DES Y3 "Extensions to ΛCDM" paper on ArXiv soon!

Looking Forward

- Y3 data released this year
- DES Y6 Legacy Results due in 2023
- Experience from DES crucial for accurate science with Rubin/LSST
- Stage IV surveys: unprecedented statistical improvement → control of systematic errors crucial!

Thank you!

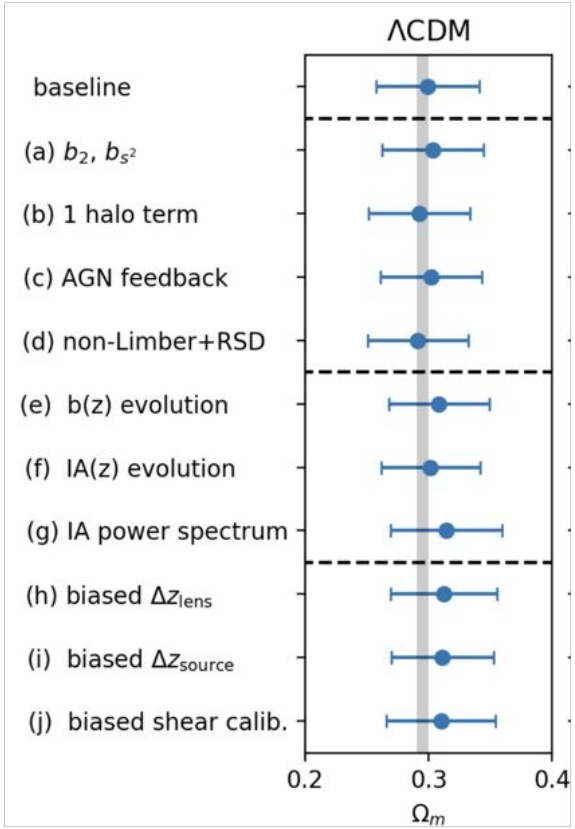
Bonus

DES Y3 Extensions Project (coming soon!)

Led by Agnès Ferté and Jessie Muir

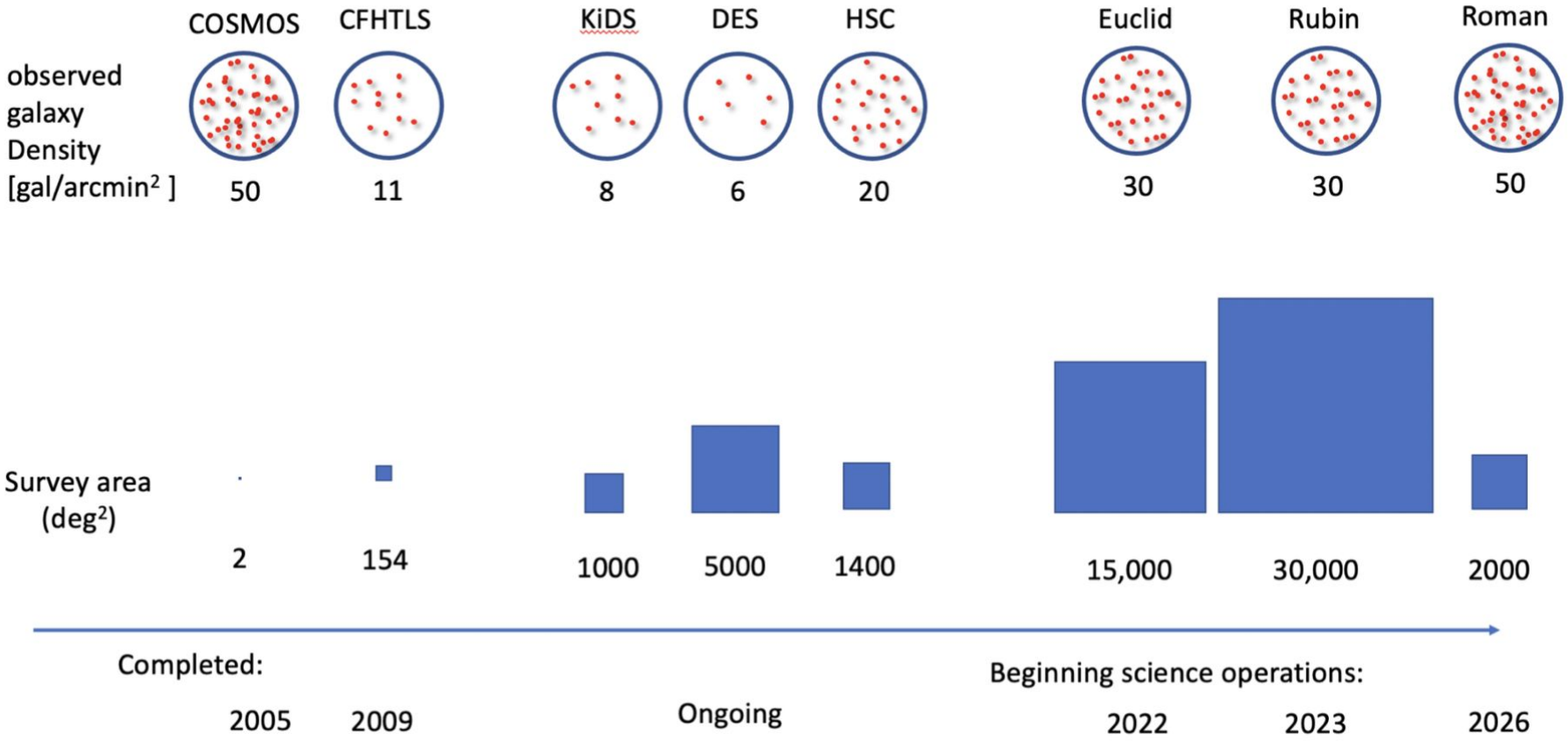
- Testing models beyond *w*CDM:
  - w0wa, Ω_k, modified gravity, sterile neutrinos, etc.
  - **700+ chains**
    (Cosmo model) x (astro model) x (data combo) …

- Key validation step: is inference robust to unmodeled systematics?
  - Contaminate DV (or change model), run chains to verify minor shift in posteriors ($< 0.3\sigma$ for DES Y3)



Krause et al. (DES) 1706.09359

Slide by E. Huff

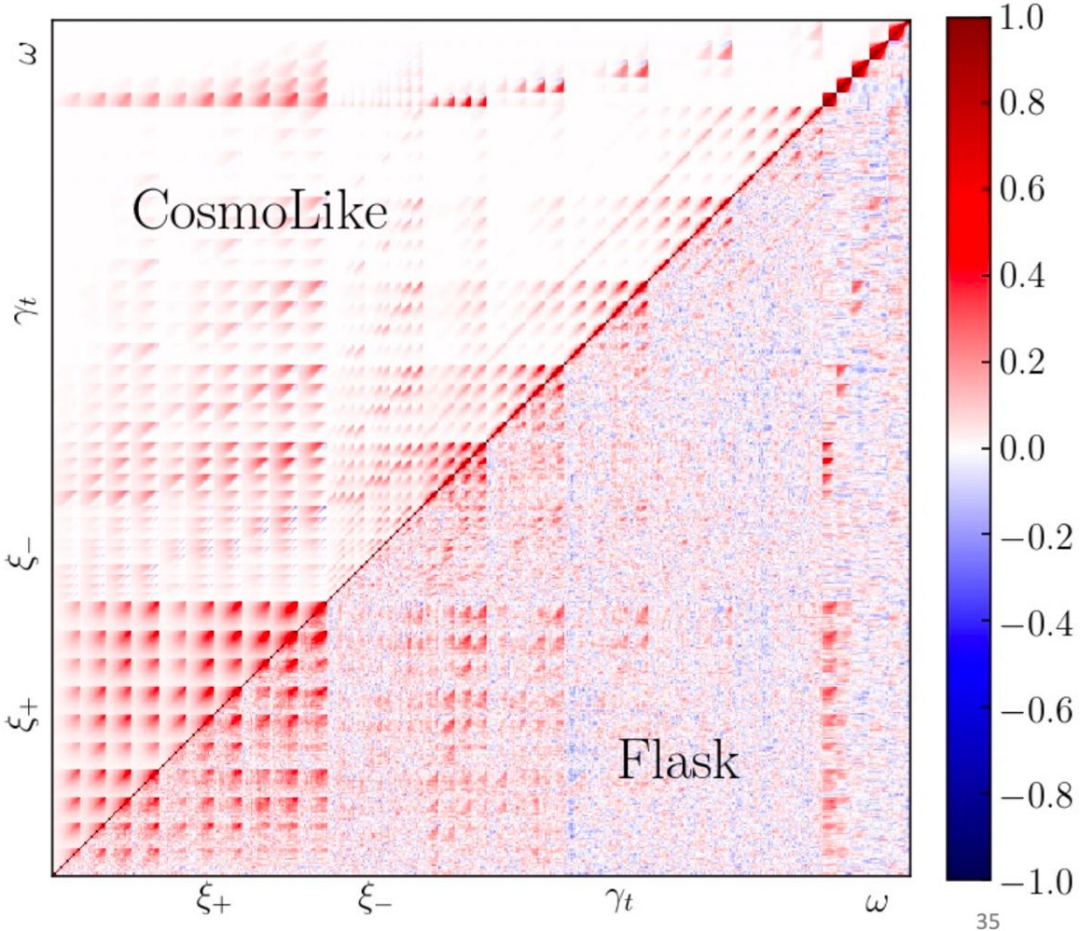


Parameter inference using Bayesian statistical methods

- Gaussian likelihood for 2pt function measurements
- 32 parameter model
  - 7 cosmology parameter
  - 25 astrophysical/systematic
- Robust analysis
  - Two theory pipelines
  - Two lens samples
  - Lots of validation, analysis of mock simulated data

Covariance between 3x2pt datapoints.

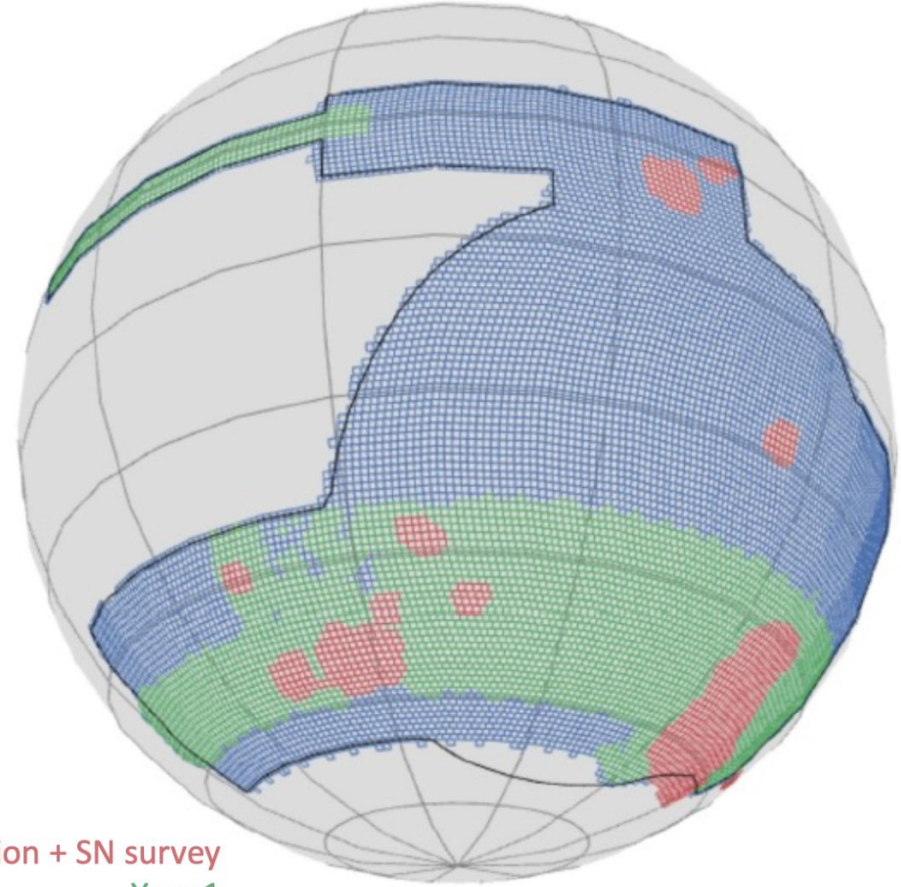
Top: analytic calculations, bottom: simulations (used for validation)



Friedrich et al., arXiv:2012.08568

Status of DES

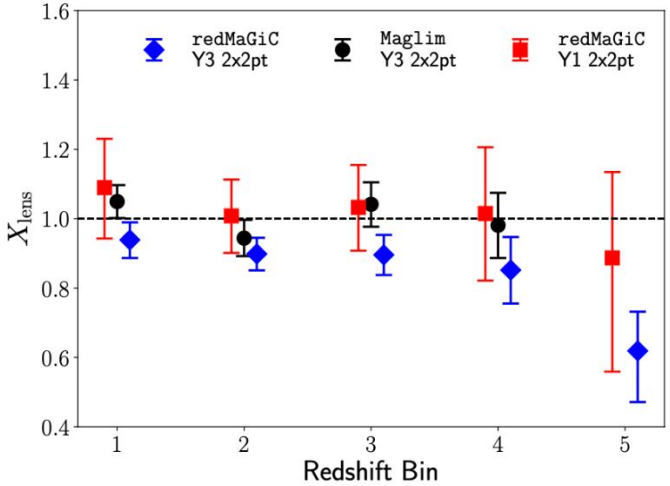
- 5000 square degrees (1/8) of sky
  - Shapes and positions of ~200M galaxies in 5 color bands down to ~23 magnitude
  - Time domain supernovae survey: ~2500 SNe in smaller patches
- Y1 Analysis:
  - ~1/3 survey area at ~50% depth
  - Cosmology results released 2017
- **Y3 Analysis:**
  - Full survey area at ~50% depth
  - Main cosmology results are out, extended model analysis in progress
- Y6 Analysis:
  - Full dataset
  - Analysis in progress

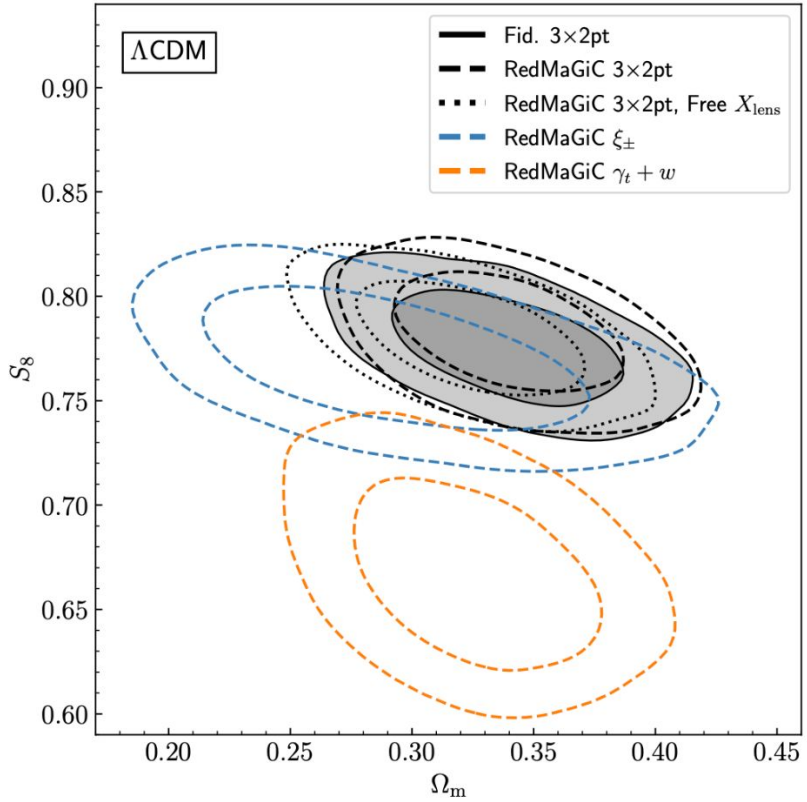


Science verification + SN survey
Year 1
Year 3, Year 6

DES Y3 lens samples and X_{lens}

- Two different lens samples analyzed in parallel:
  - Maglim as fiducial sample
  - Redmagic as alt; was fid in Y1
- Redmagic 2x2pt offset discovered after unblinding
  - X_{lens} parameter fits this well
  - Suggests presence of previously unknown systematic affecting Redmagic galaxy clustering measurement
- 3x2pt results are robust despite this!





$$w(\theta) \sim b^2 \xi_{mm}$$

$$\gamma_t(\theta) \equiv \xi_{g,\mathrm{WL}} \sim X_{\mathrm{lens}} b \xi_{mm}$$