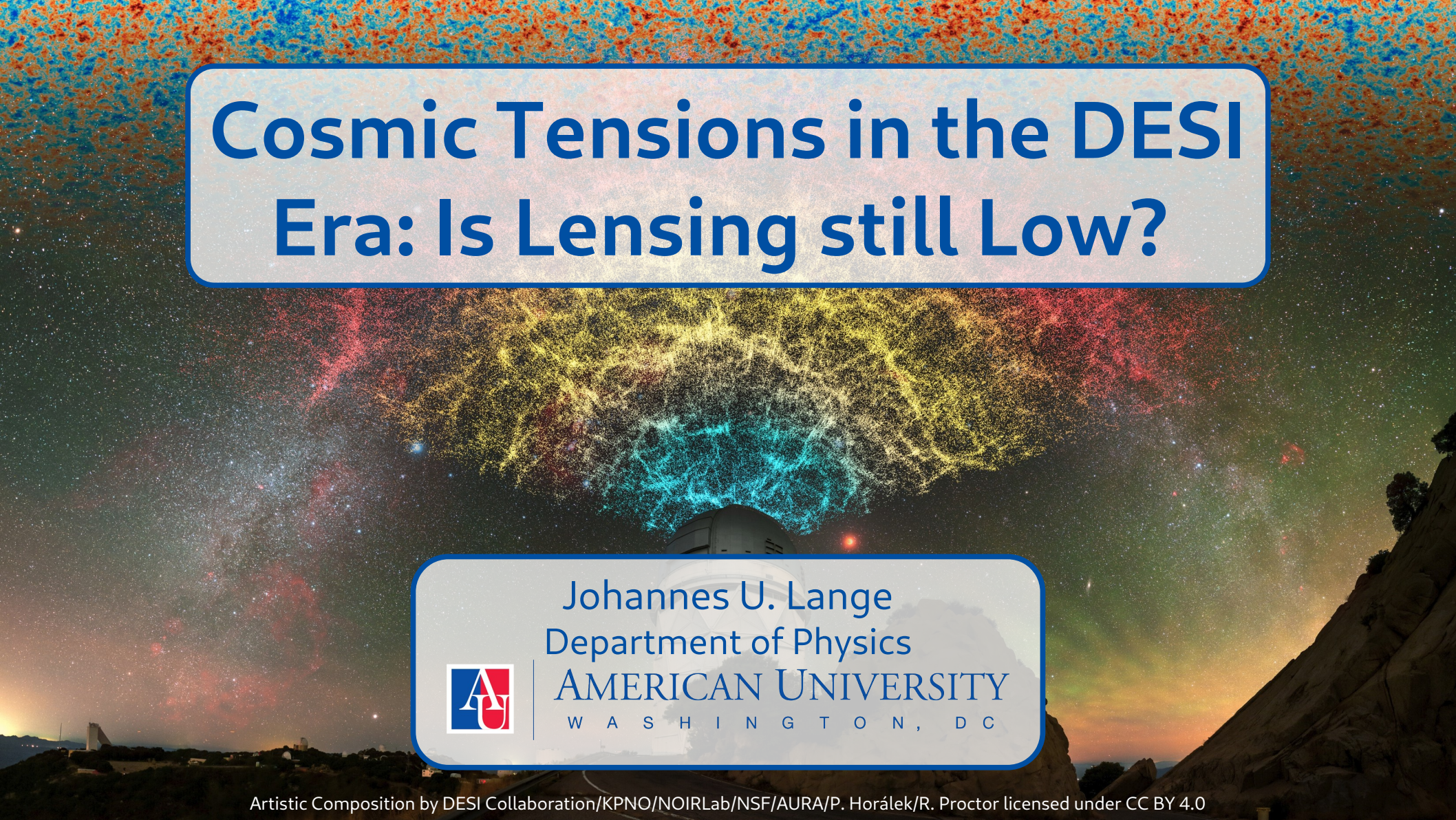
Cosmic Tensions in the DESI Era: Is Lensing still Low?

Johannes U. Lange
Department of Physics
American University
Washington, DC



- ~~R2~~→R1 university in Washington, DC
- small physics department
- 7 tenure-track research faculty
- ~dozen physics majors per year, no grads or postdocs
- teaching 2 courses per semester

Credit: American University

ΛCDM

Dark Energy

- drives late-time expansion of the Universe
- consistent with cosmological constant Λ

What causes the late-time expansion? Modifications to GR, new field or simply Λ?

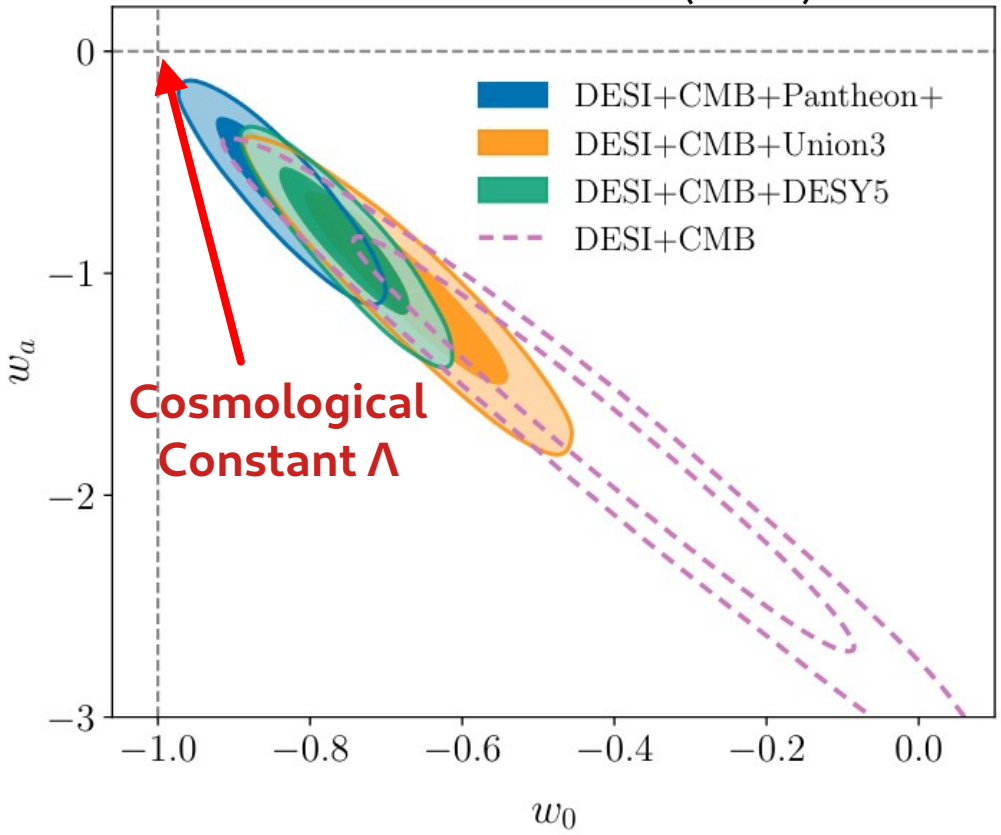
Cold Dark Matter

- negligible thermal velocity
- negligible electromagnetic interactions
- mainly interacts via gravity

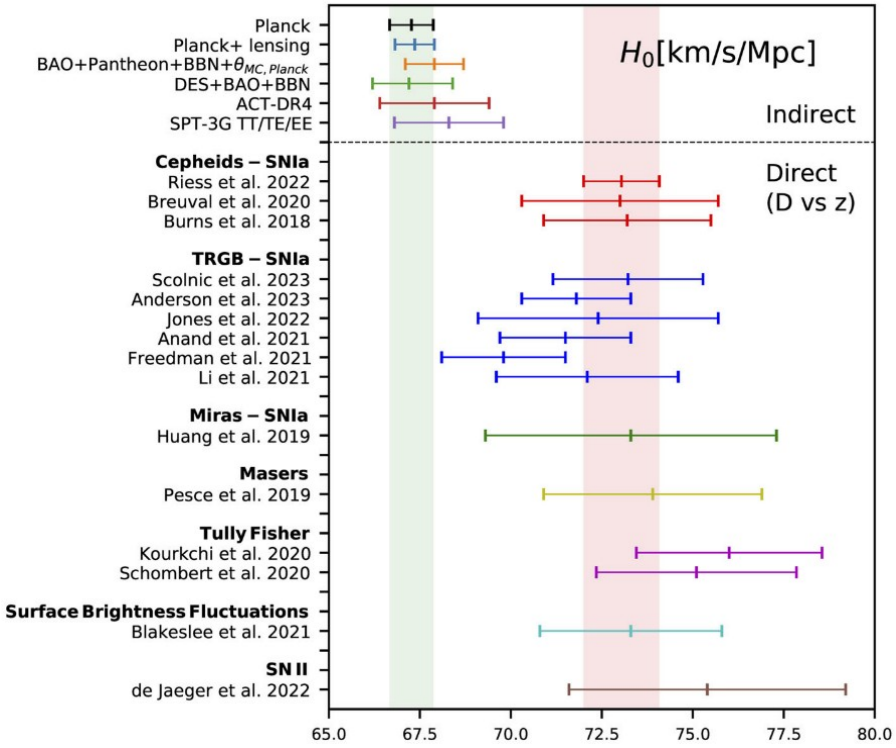
What is the particle nature of dark matter?

Crisis in Cosmology?

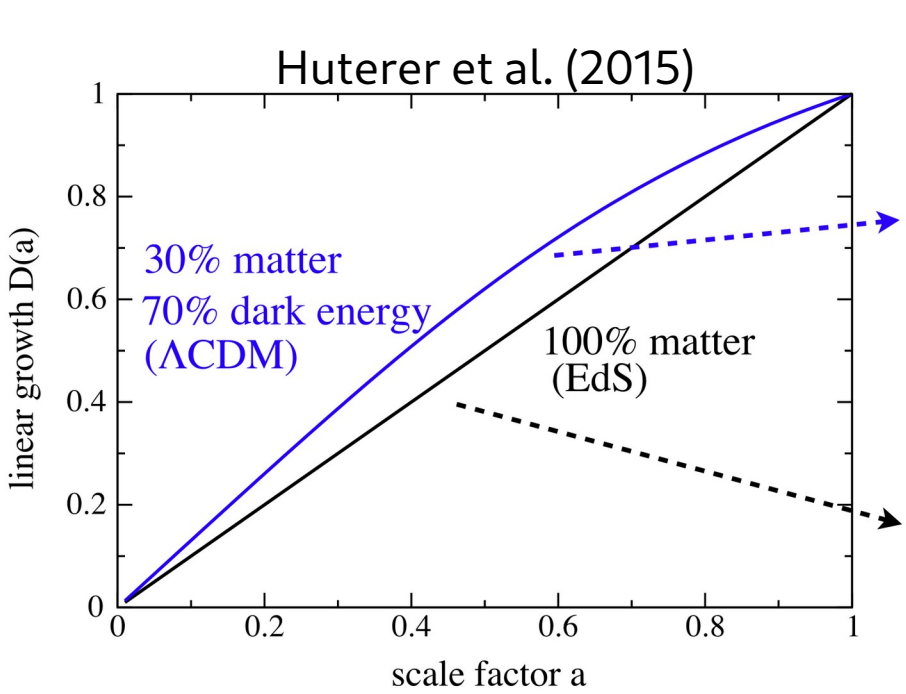
DESI Collaboration (2025)

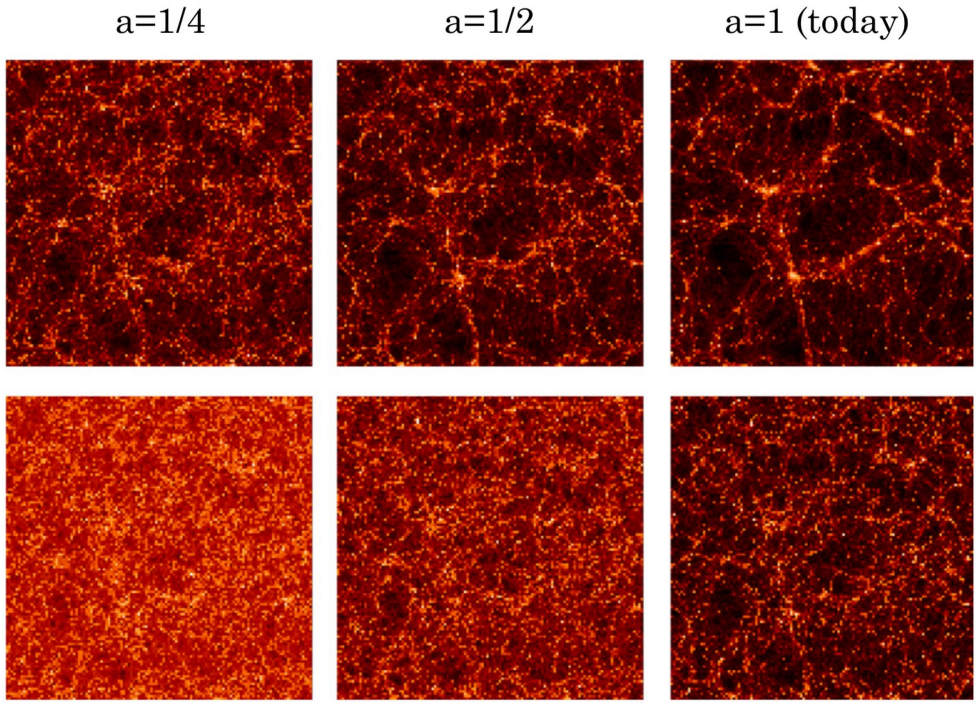


Di Valentino et al. (2021)



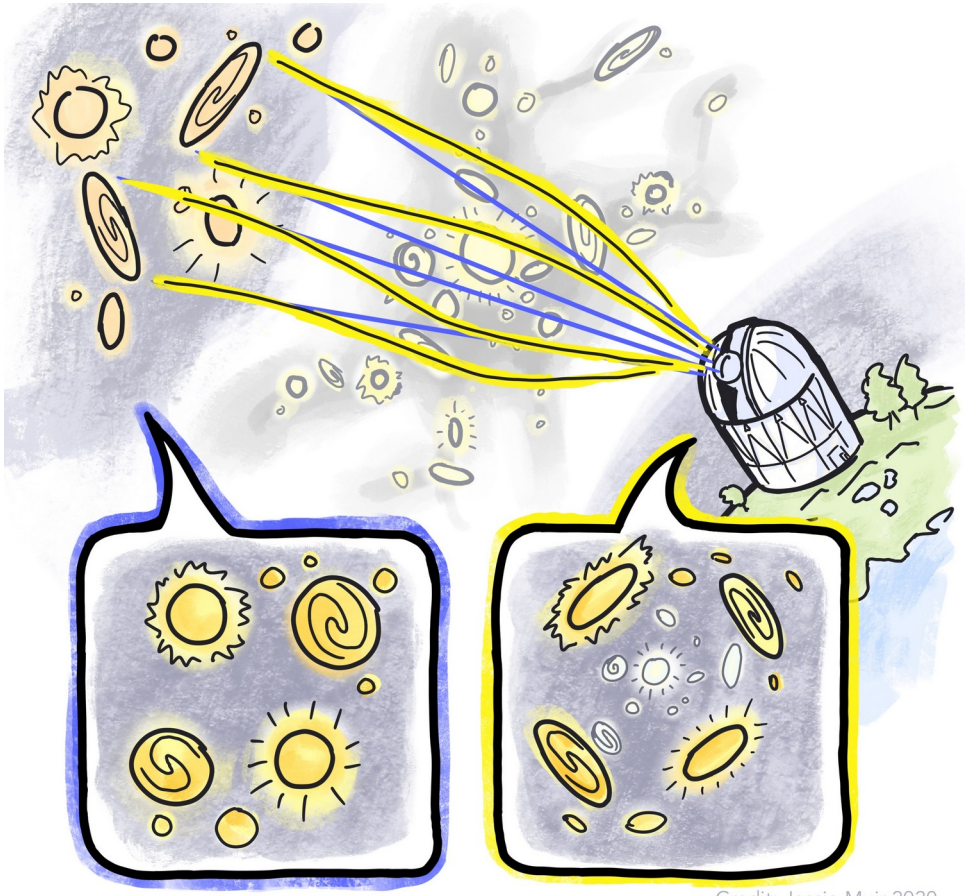
Probing Dark Energy with Cosmic Structure





Dark energy determines growth of structure history.

Weak Gravitational Lensing



Credit: Jessie Muir 2020

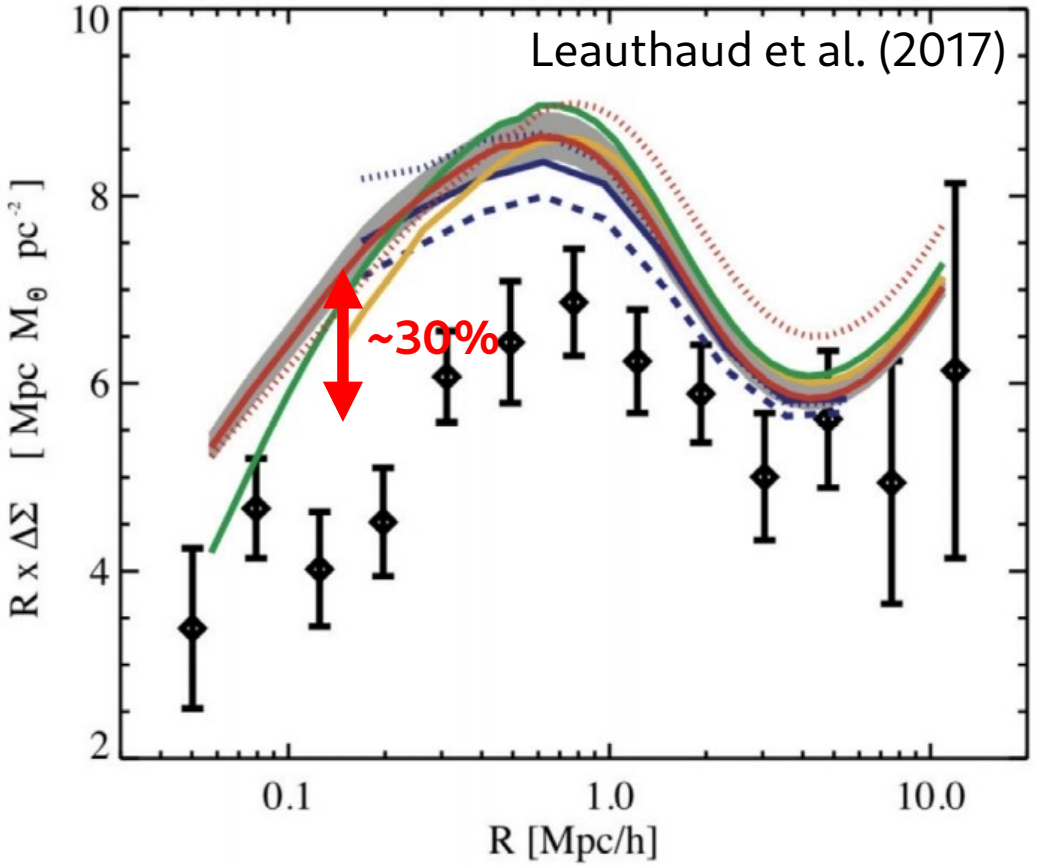
$$\gamma_t = \frac{\Delta\Sigma}{\Sigma_{crit}(z_l, z_s)} \ll 1$$

Complications

- Galaxies have intrinsic ellipticities
- Pixelization
- Point Spread Function
- Photometric Redshifts
- Blending
- …

Lensing is Low: A Cosmic Structure Tension?

Lensing-is-Low-Problem
If we assume ΛCDM with Planck CMB constraints, we overpredict the lensing amplitude on small scales.



The Lensing-is-low Debate

New perspectives on the BOSS small-scale lensing discrepancy for the Planck ΛCDM Cosmology

Johannes U. Lange[1⋆], Xiaohu Yang[2,3], Hong Guo[4], Wentao Luo[2,5] and Frank C. van den Bosch[1]
[1] *Department of Astronomy, Yale University, P.O. Box 208101, New Haven, CT 06511, USA*
[2] *Department of Astronomy, School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China*
[3] *Tsung-Dao Lee Institute, and Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao Tong University, Shanghai 200240, China*
[4] *Key Laboratory for Research in Galaxies and Cosmology, Shanghai Astronomical Observatory, Shanghai 200030, China*
[5] *Kavli Institute for the Physics and Mathematics of the Universe (WPI), University of Tokyo, Kashiwa 277-8583, Japan*

On the halo-mass and radial scale dependence of the lensing is low effect

Johannes U. Lange[1,2⋆], Alexie Leauthaud[1], Sukhdeep Singh[3,4], Hong Guo[5], Rongpu Zhou[6], Tristan L. Smith[7] and Francis-Yan Cyr-Racine[8]
[1] *Department of Astronomy and Astrophysics, University of California, Santa Cruz, CA 95064, USA*
[2] *Kavli Institute for Particle Astrophysics and Cosmology and Department of Physics, Stanford University, CA 94305, USA*
[3] *Berkeley Center for Cosmological Physics, University of California, Berkeley, CA 94720, USA*
[4] *McWilliams Center for Cosmology, Department of Physics, Carnegie Mellon University, Pittsburgh, PA 15213, USA*
[5] *Key Laboratory for Research in Galaxies and Cosmology, Shanghai Astronomical Observatory, Shanghai 200030, China*
[6] *Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[7] *Department of Physics and Astronomy, Swarthmore College, Swarthmore, PA 19081, USA*
[8] *Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM 87106, USA*

Consistent clustering and lensing of SDSS-III BOSS galaxies with an extended abundance matching formalism

Sergio Contreras[1⋆], Jonás Chaves-Montero[2†] and Raul E. Angulo[1,3‡]
[1] *Donostia International Physics Center, Manuel Lardizabal Ibilbidea, 4, 20018 Donostia, Gipuzkoa, Spain*
[2] *Institut de Física d'Altes Energies, The Barcelona Institute of Science and Technology, Campus UAB, E-08193 Bellaterra (Barcelona), Spain.*
[3] *IKERBASQUE, Basque Foundation for Science, 48013, Bilbao, Spain.*

On the "Lensing is Low" of BOSS Galaxies

Ying Zu[1⋆]
[1] *Department of Astronomy, School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China*
[2] *Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao Tong University, Shanghai 200240, China*

The galaxy formation origin of the *lensing is low* problem

Jonás Chaves-Montero[1,2⋆], Raul E. Angulo[1†] and Sergio Contreras[1].
[1] *Donostia International Physics Centre, Paseo Manuel de Lardizabal 4, 20018 Donostia-San Sebastian, Spain.*
[2] *Institut de Física d'Altes Energies, The Barcelona Institute of Science and Technology, Campus UAB, E-08193 Bellaterra (Barcelona), Spain.*

Is the large-scale structure traced by the BOSS LOWZ galaxies consistent with *Planck*?

Zhiwei Shao[1], Ying Zu[1,2] and Huanyuan Shan[3,4]
[1] *Department of Astronomy, School of Physics and Astronomy, and Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao Tong University, Shanghai 200240, China; yingzu@sjtu.edu.cn*
[2] *Key Laboratory for Particle Physics, Astrophysics and Cosmology, Ministry of Education, Shanghai Jiao Tong University, Shanghai 200240, China*
[3] *Shanghai Astronomical Observatory (SHAO), Nandan Road 80, Shanghai 200030, China*
[4] *University of Chinese Academy of Sciences, Beijing 100049, China*

The impact of baryonic physics on the abundance, clustering, and concentration of halos

Gillian D. Beltz-Mohrmann[1] and Andreas A. Berlind[1]
[1] *Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235, USA*

(Received March 9, 2021; Revised July 27, 2021; Accepted August 14, 2021)

Consistent lensing and clustering in a low-S_8 Universe with BOSS, DES Year 3, HSC Year 1 and KiDS-1000

A. Amon,[1,2⋆] N. C. Robertson,[1,2†] H. Miyatake,[3,4] C. Heymans,[5,6] M. White,[7,8] J. DeRose,[8] S. Yuan,[9] R. H. Wechsler,[9,10,11] T. N. Varga,[12,13] S. Bocquet,[14] A. Dvornik,[6] S. More,[15] A. J. Ross,[16] H. Hoekstra,[17] A. Alarcon,[18] M. Asgari,[5,19] J. Blazek,[20,21] A. Campos,[22] R. Chen,[23] A. Choi,[24] M. Crocce,[25,26]

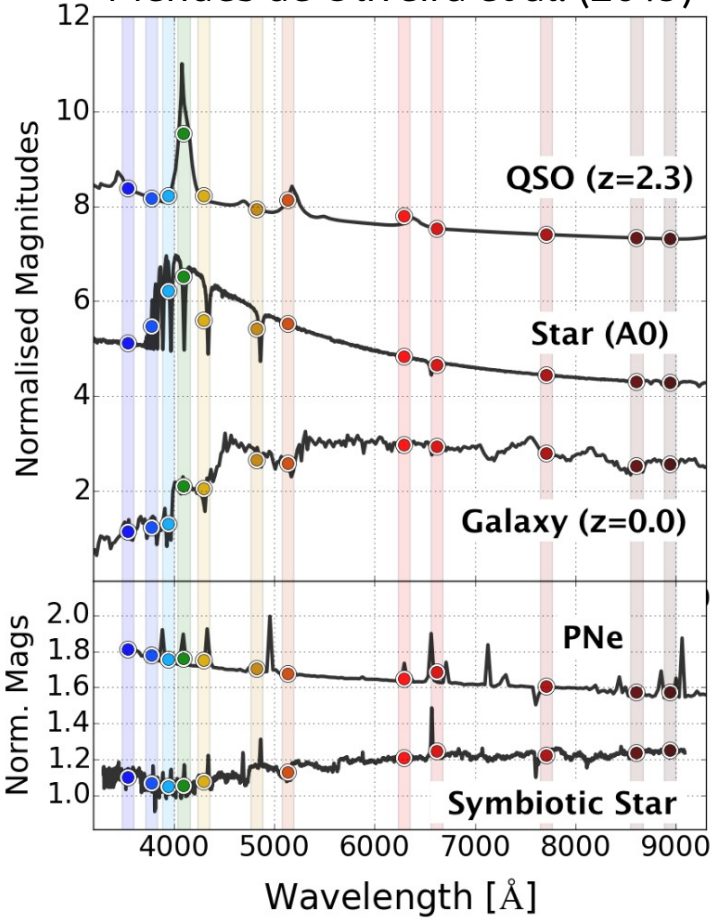
Our Predictions in 2019

We investigate the abundance, small-scale clustering, and galaxy–galaxy lensing signal of galaxies in the Baryon Oscillation Spectroscopic Survey (BOSS). To this end, we present new measurements of the redshift and stellar mass dependence of the lensing properties of the galaxy sample. We analyse to what extent models assuming the Planck18 cosmology fit to the number density and clustering can accurately predict the small-scale lensing signal. In qualitative agreement with previous BOSS studies at redshift $z \sim 0.5$ and with results from the Sloan Digital Sky Survey, we find that the expected signal at small scales ($0.1 < r_\mathrm{p} < 3\,h^{-1}\,\mathrm{Mpc}$) is higher by ~ 25 per cent than what is measured. Here, we show that this result is persistent over the redshift range $0.1 < z < 0.7$ and for galaxies of different stellar masses. If interpreted as evidence for cosmological parameters different from the *Planck* cosmic microwave background (CMB) findings, our results imply $S_8 = \sigma_8\sqrt{\Omega_\mathrm{m}/0.3} = 0.744 \pm 0.015$, whereas $S_8 = 0.832 \pm 0.013$ for Planck18. However, in addition to being in tension with CMB results, such a change in cosmology alone does not accurately predict the lensing amplitude at larger scales. Instead, other often neglected systematics like baryonic feedback or assembly bias are likely contributing to the small-scale lensing discrepancy. We show that either effect alone, though, is unlikely to completely resolve the tension. Ultimately, a combination of the two effects in combination with a moderate change in cosmological parameters might be needed.

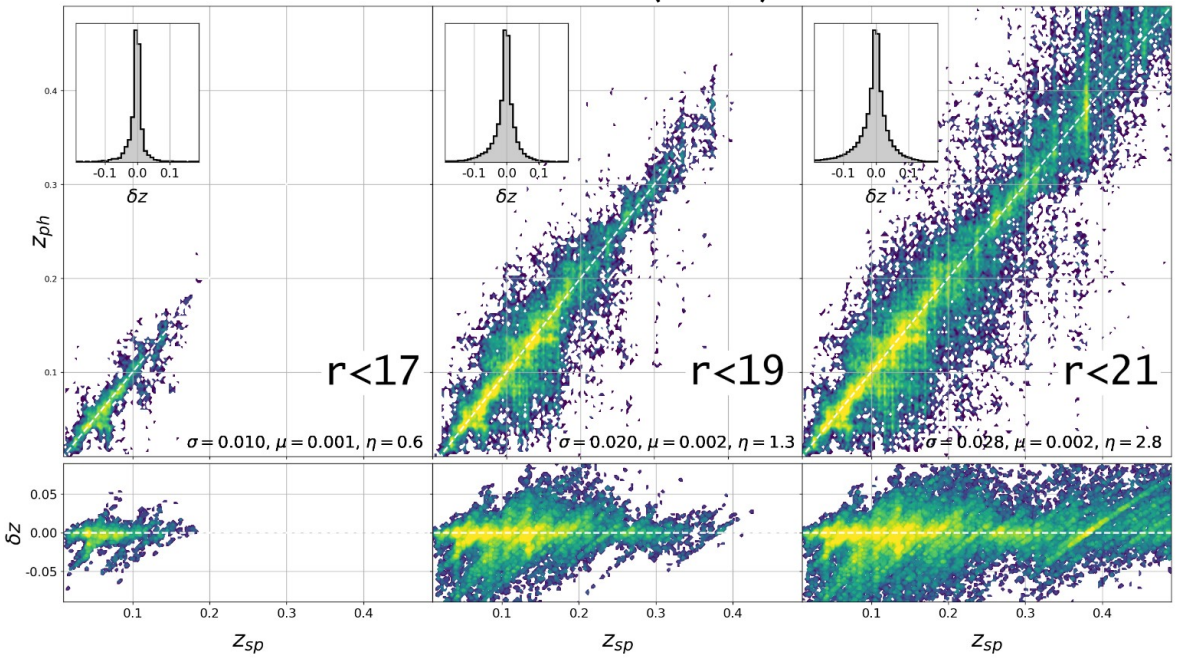
Lensing Measurements

Photometric Redshifts

Mendes de Oliveira et al. (2019)



Molino et al. (2020)

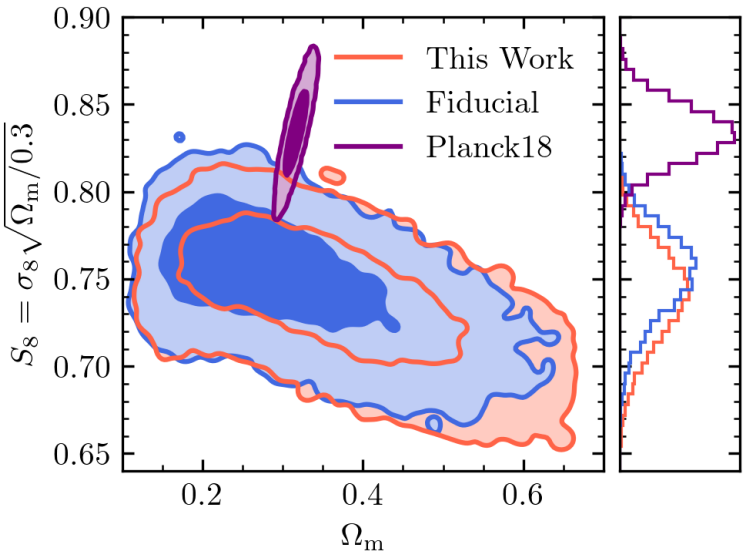


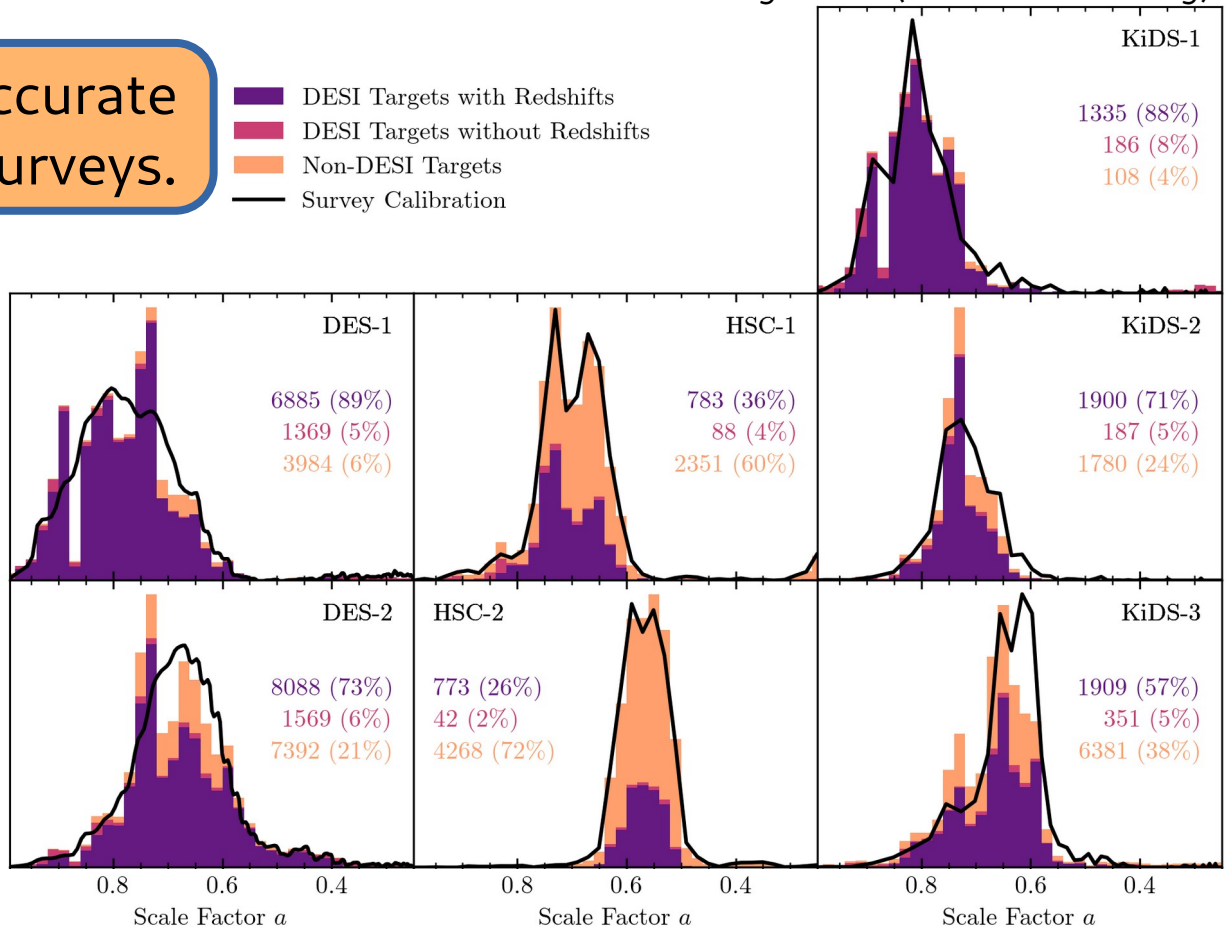
Photometric redshifts alone are not accurate enough for precision weak lensing.

Photometric Redshifts: New Results from DESI

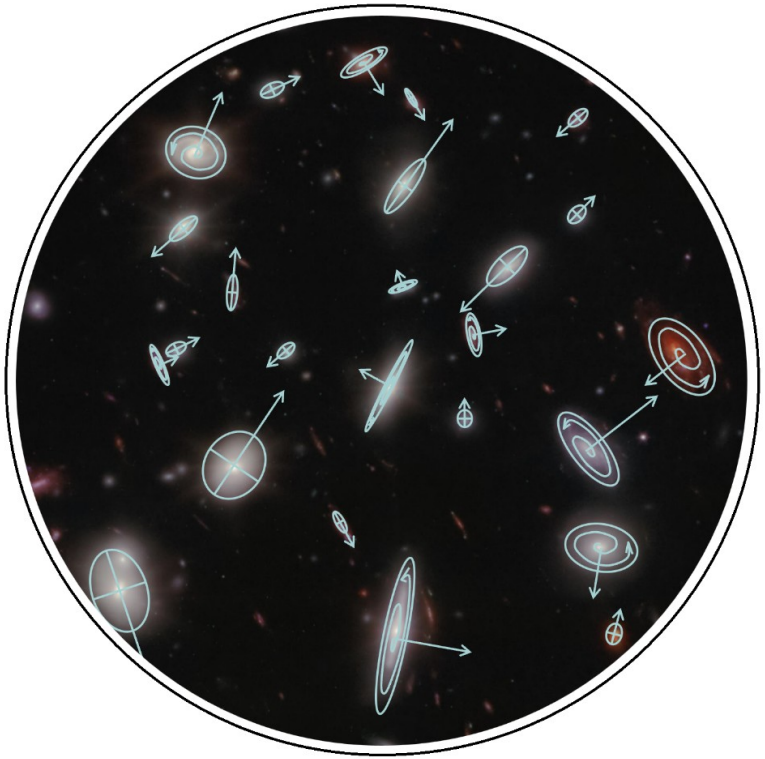
Lange et al. (DESI final reading)

Calibration of photo-z's is accurate enough for stage-III lensing surveys.

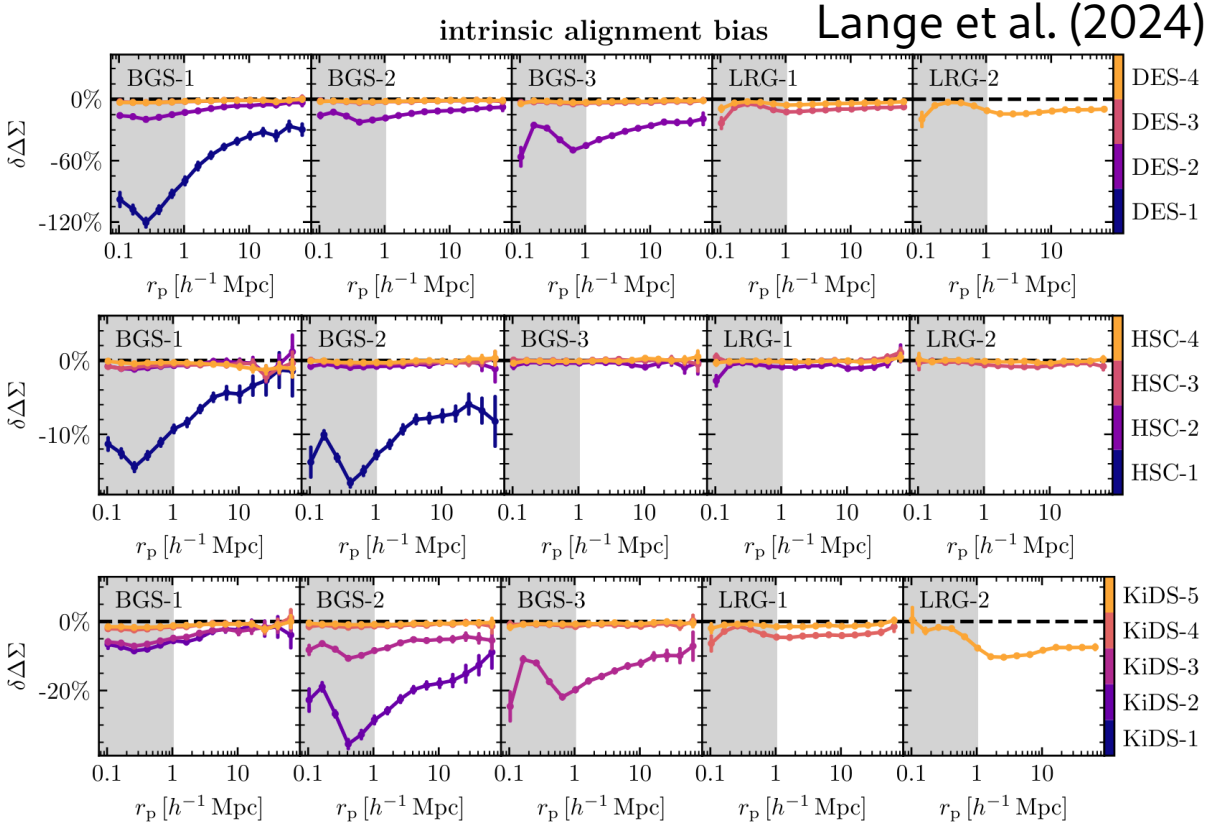




Intrinsic Alignments

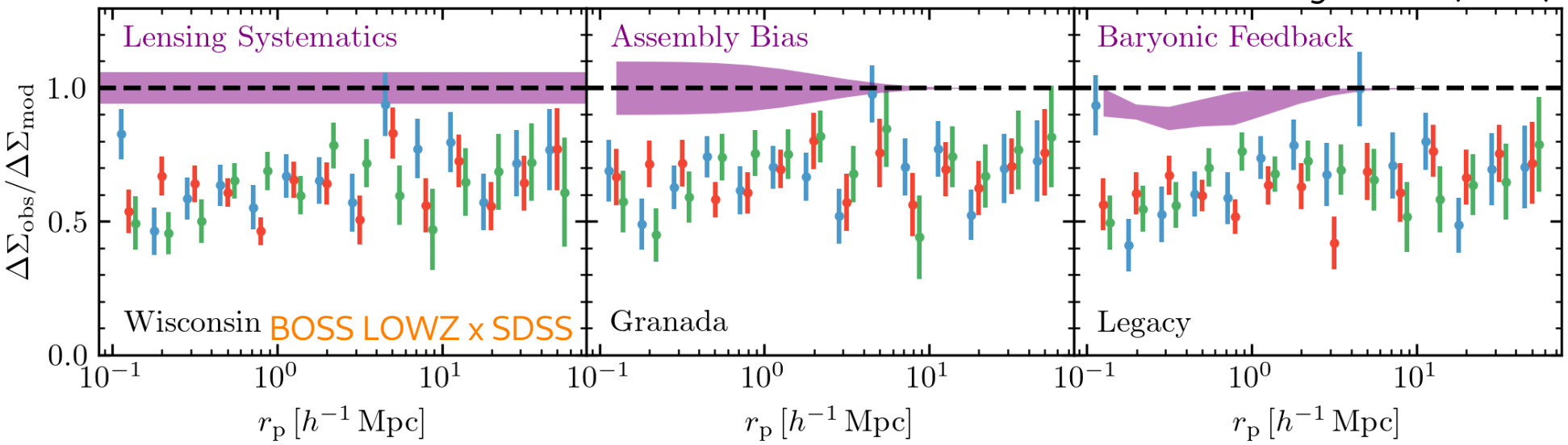


Lamman et al. (2024)



Lensing Measurements with SDSS

Lange et al. (2021)



Older SDSS measurements may be affected by measurement systematics and partially explain lensing-is-low on large scales.

Modeling

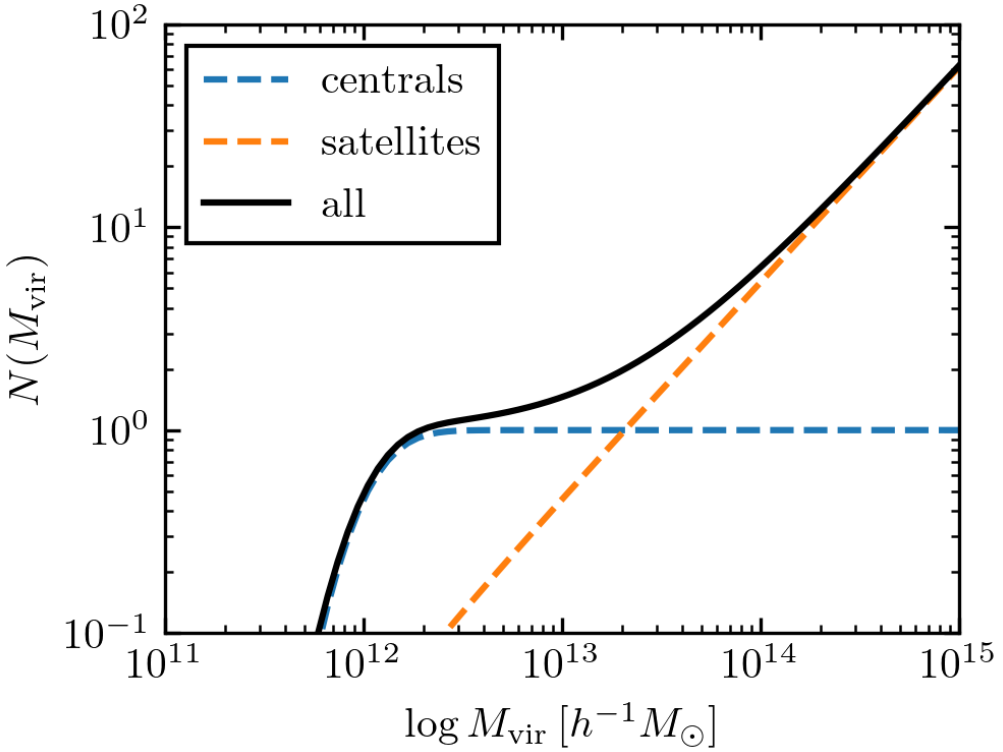
Standard Galaxy Model

Halo Occupation Distribution

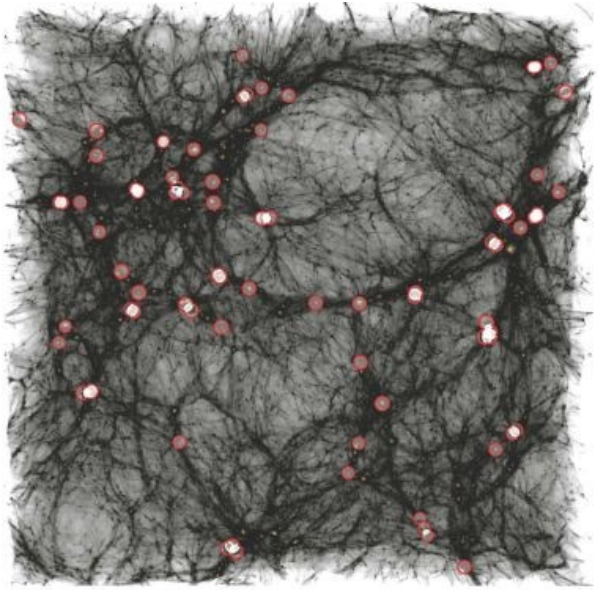
- standard HOD parametrization:
  M_{min}, M_1, M_0, σ_{logM}, α
- central incompleteness f_Γ

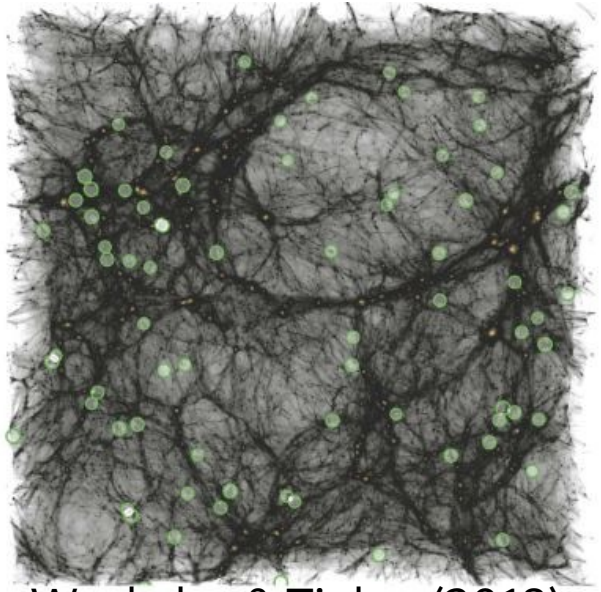
$$\langle N_{\rm cen}|M\rangle = \frac{f_\Gamma}{2}\left(1+{\rm erf}\left[\frac{\log M-\log M_{\rm min}}{\sigma_{\log M}}\right]\right)$$

$$\langle N_{\rm sat}|M\rangle = \left(\frac{M-M_0}{M_1}\right)^{\alpha}$$

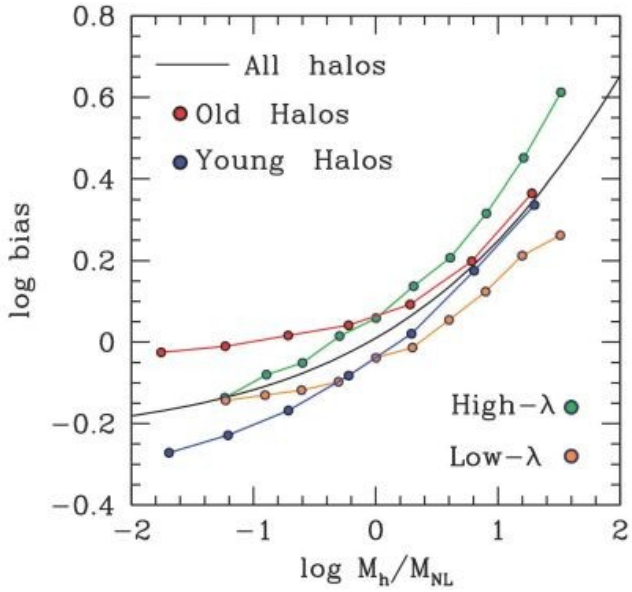


Halo Assembly Bias





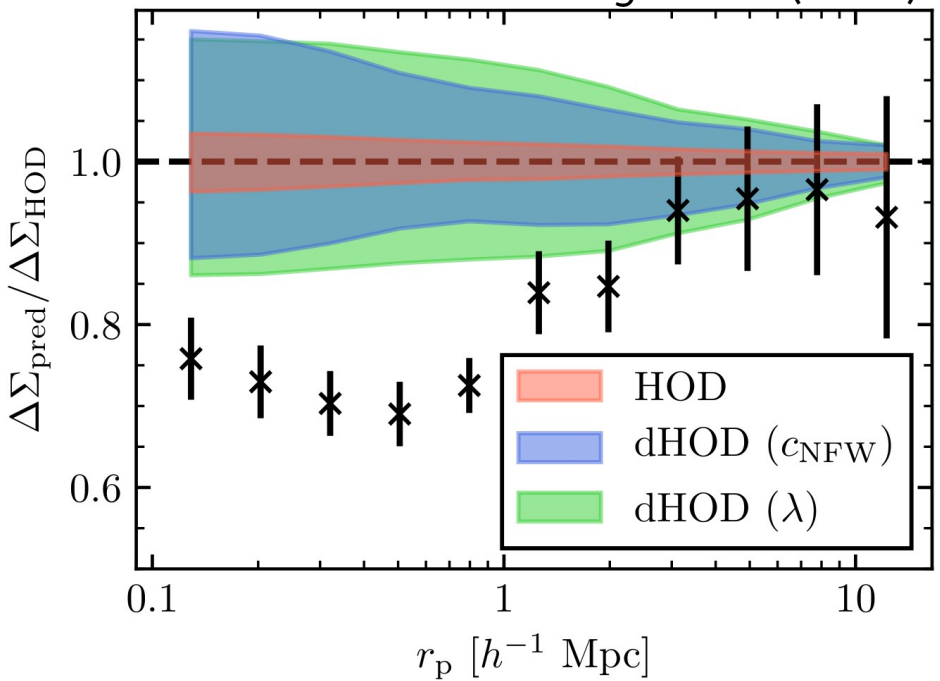
Wechsler & Tinker (2018)



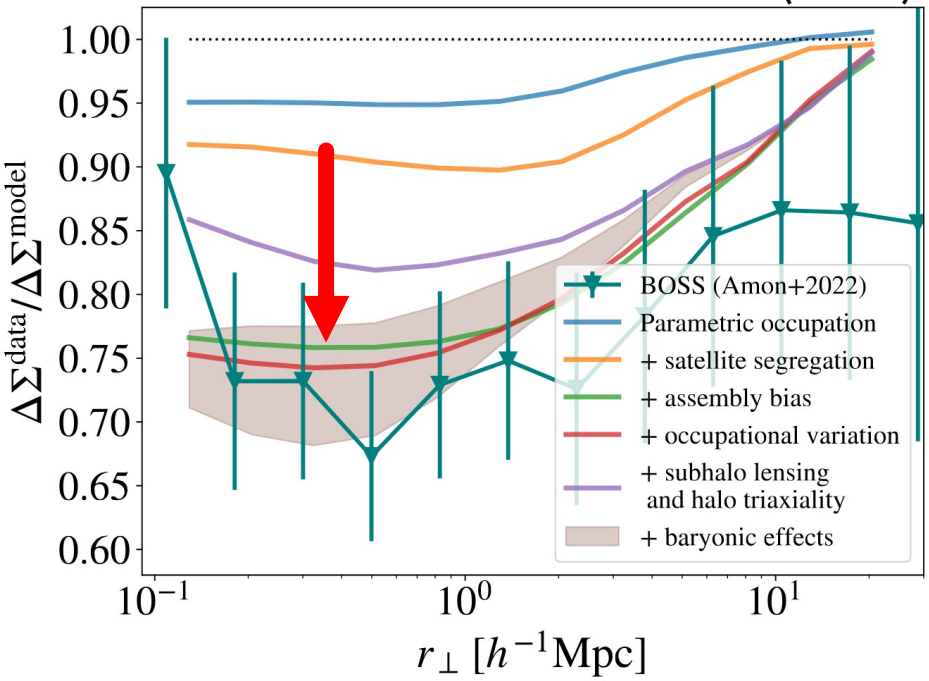
Halo Assembly Bias: The clustering of dark matter halos depends on properties other than halo mass.

Galaxy Assembly Bias

Lange et al. (2019)

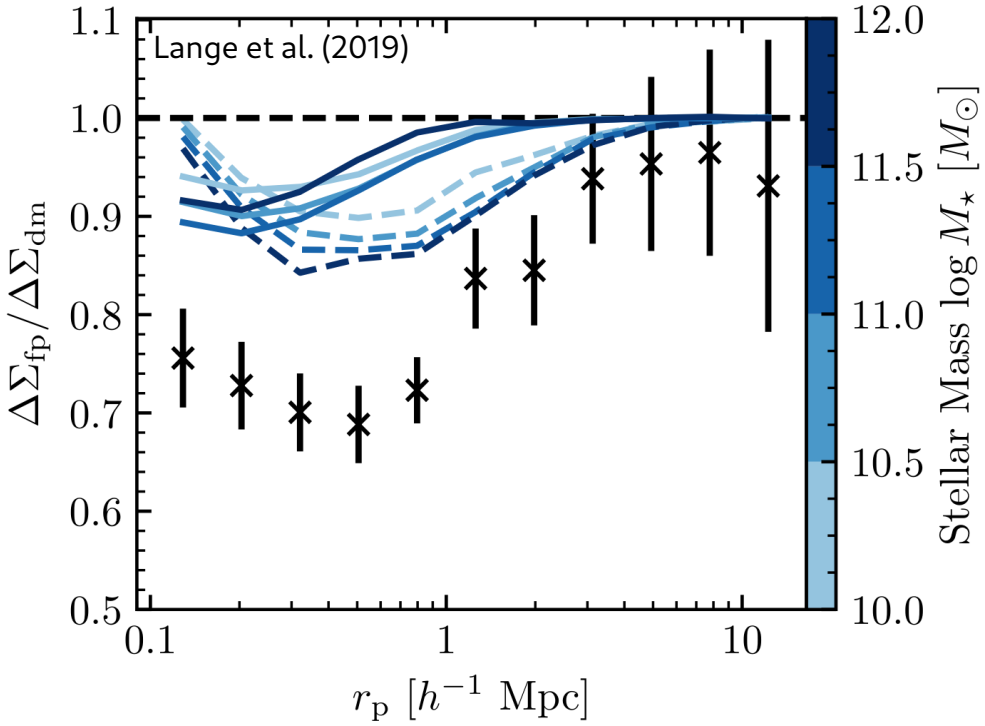


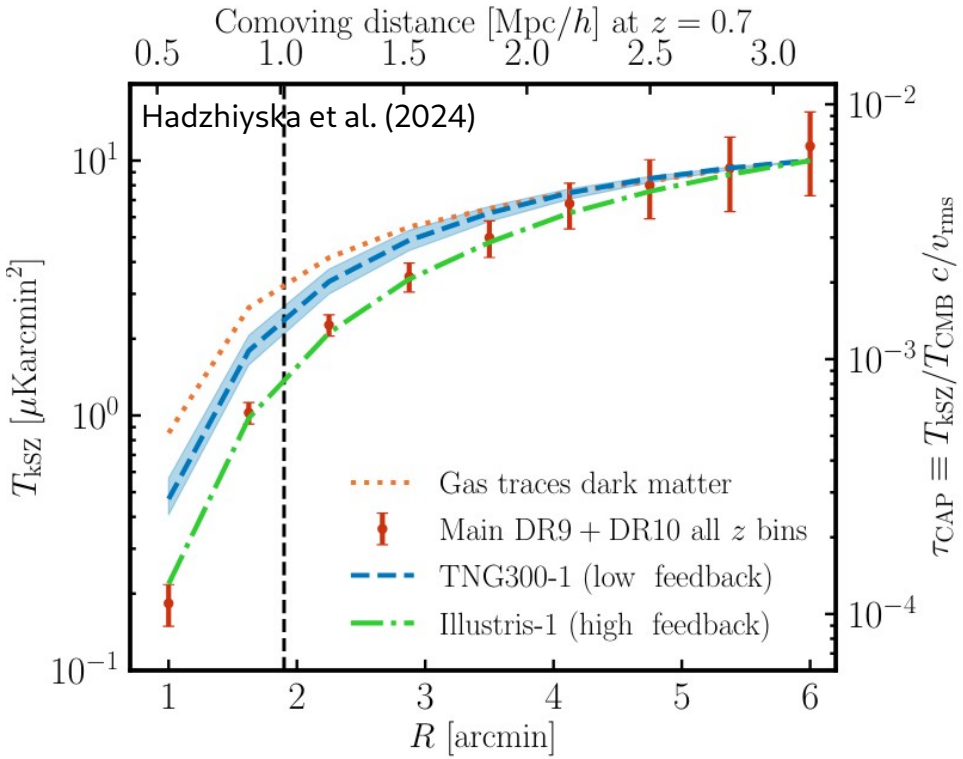
Chaves-Montero et al. (2023)



Galaxy assembly bias can plausibly explain ½ the lensing-is-low problem.

Baryonic Effects



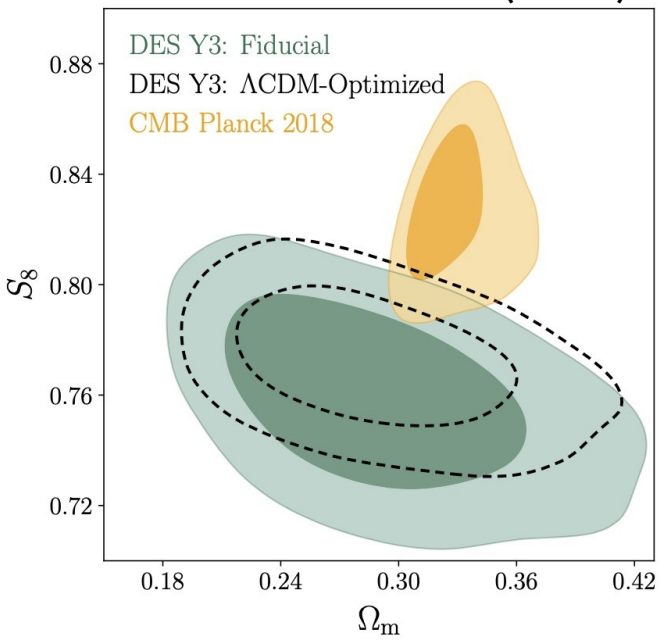


Baryonic feedback seems stronger than initially expected.

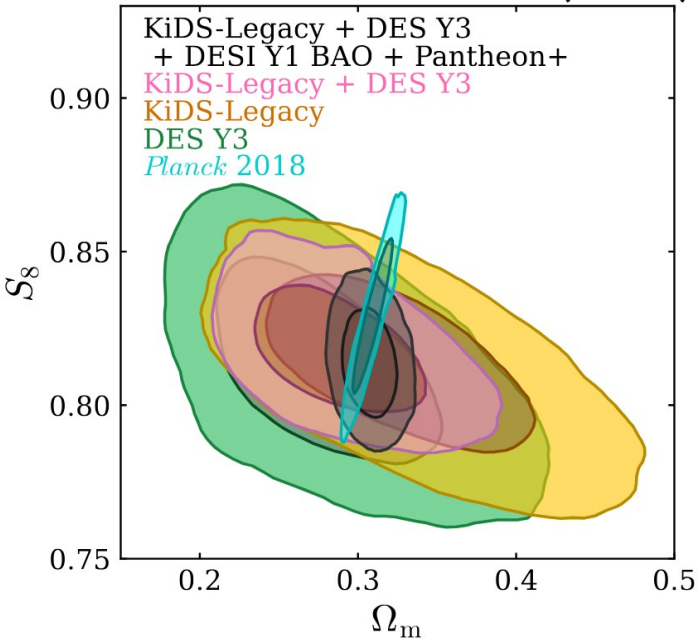
Cosmology

Weak Lensing and the S_8-Tension

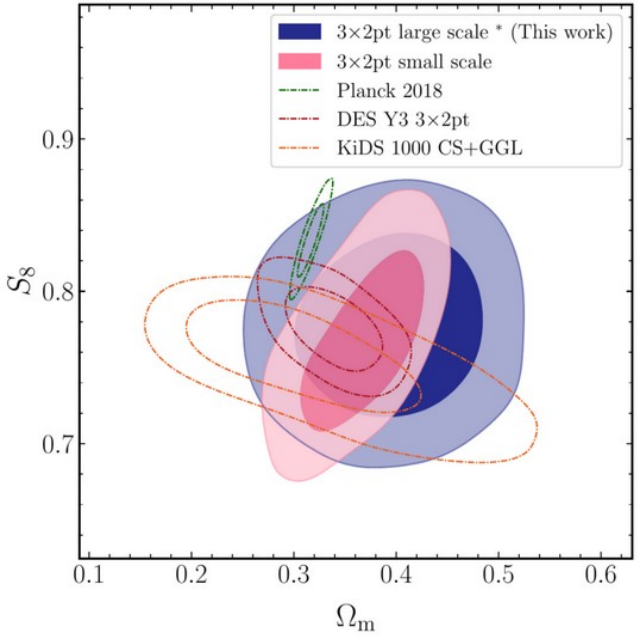
DES – Amon et al. (2021)



KiDS – Stölzner et al. (2025)

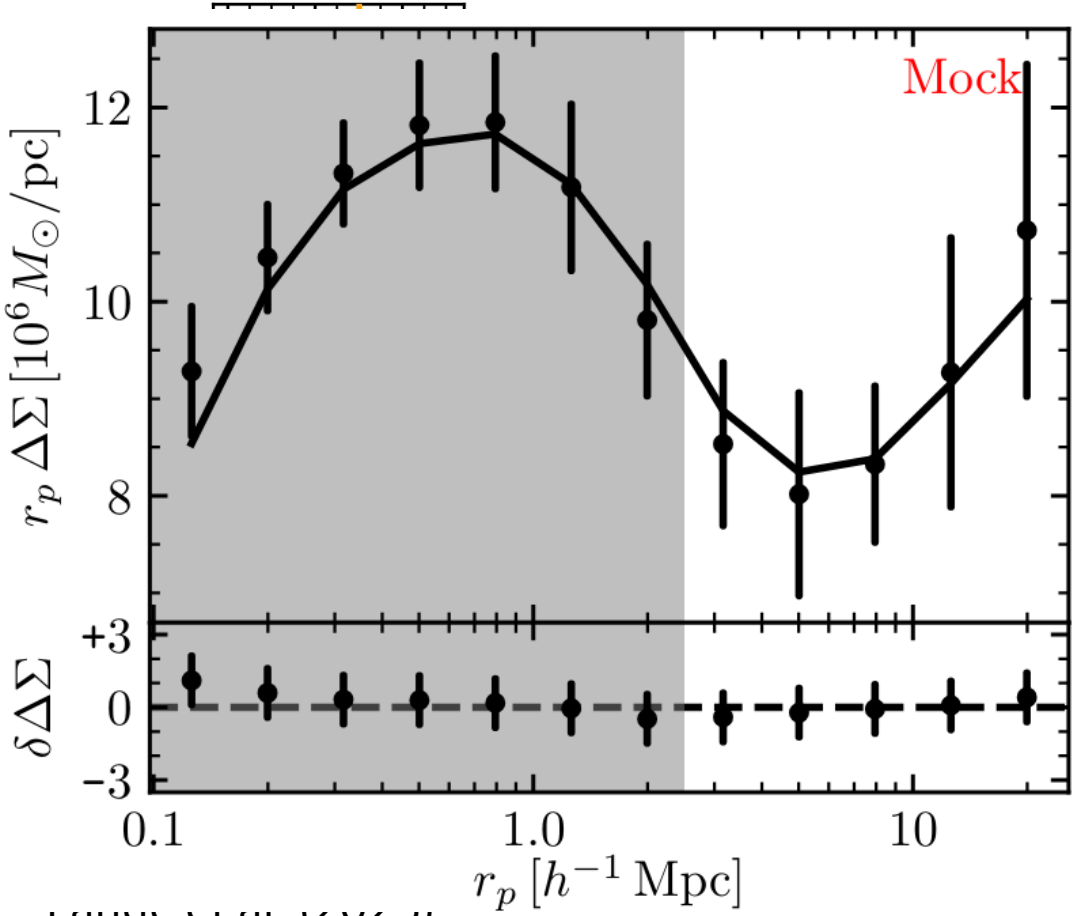


HSC – Sugiyama et al. (2023)



Within ΛCDM, lensing tends to infer S_8 to be below (up to ~3σ) the Planck CMB prediction.

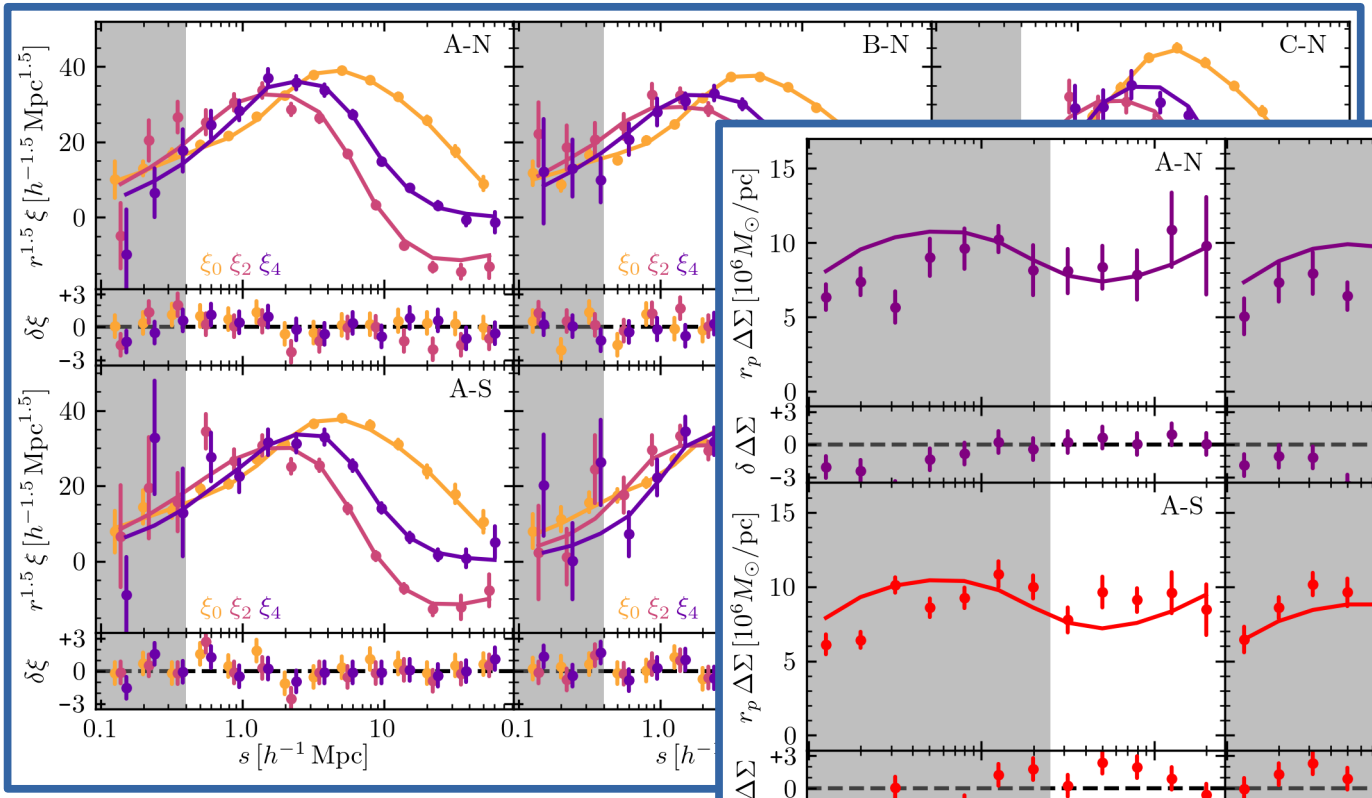
Non-Linear Cosmology: Mock Tests

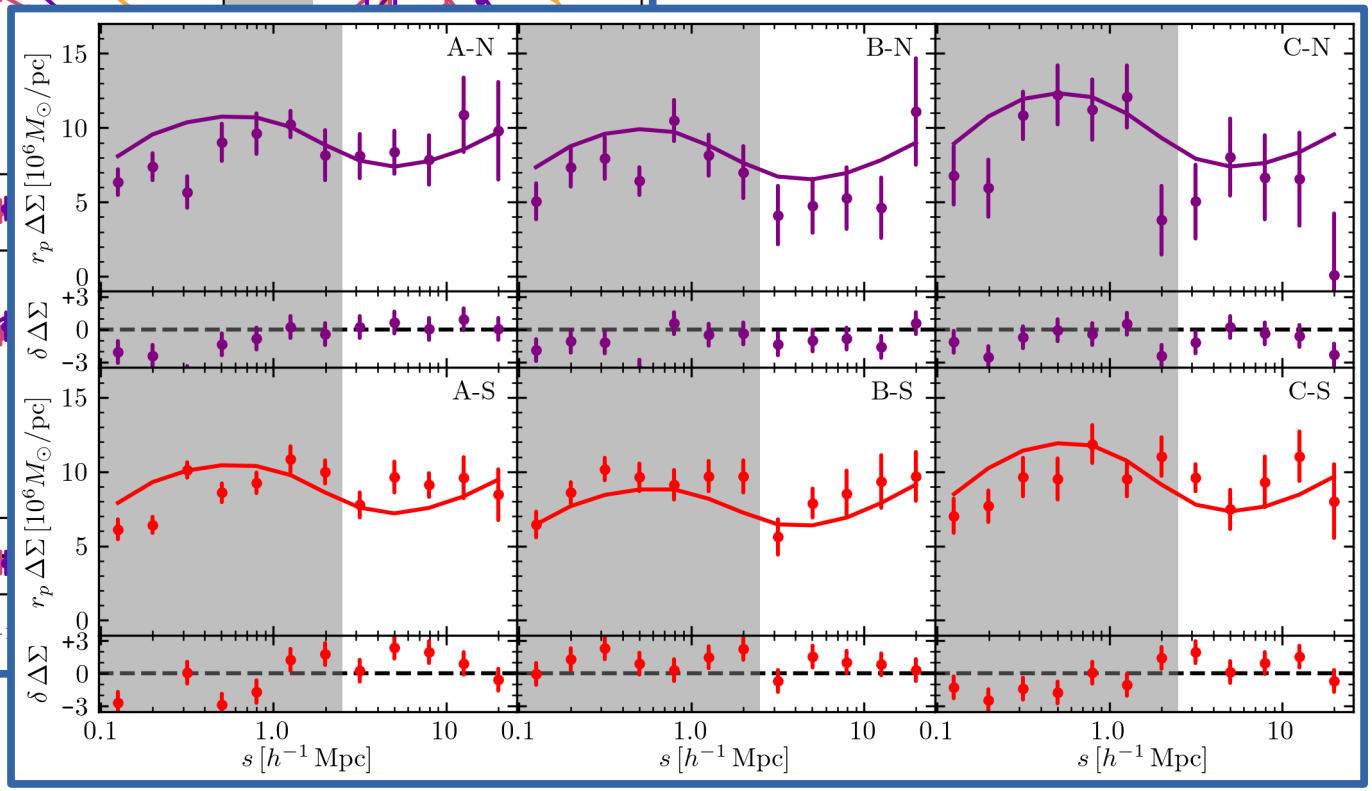


Lange et al. (2023)

- created mocks based on subhalo abundance matching
- analyzed with same pipeline as observations
- no indication of bias in cosmological results

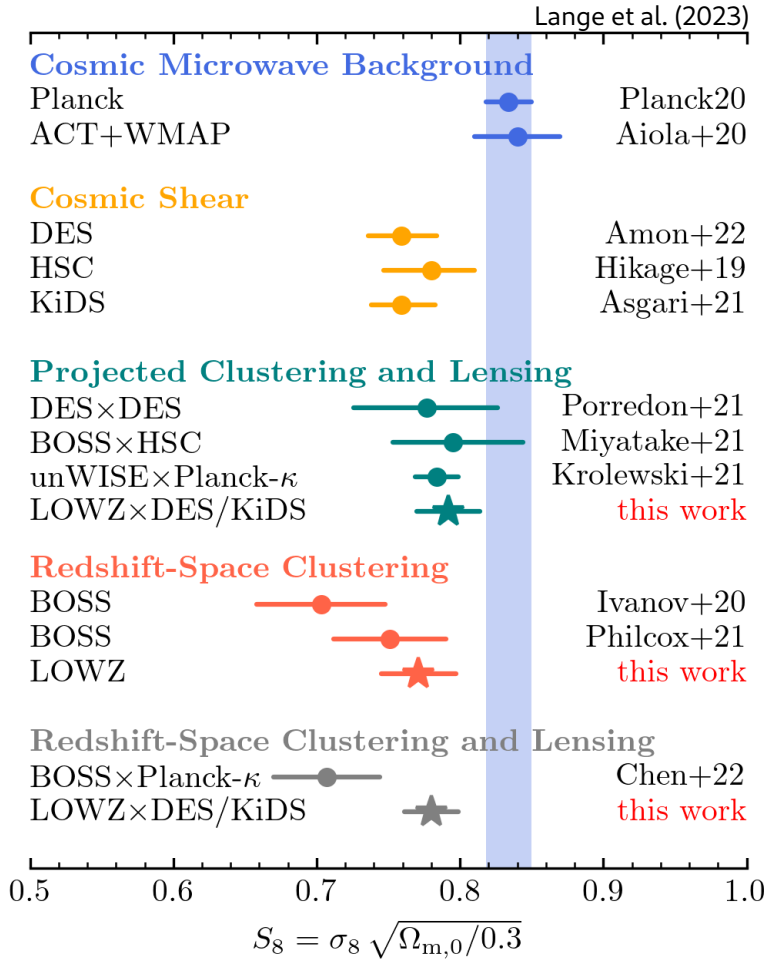
Application to BOSS LOWZ



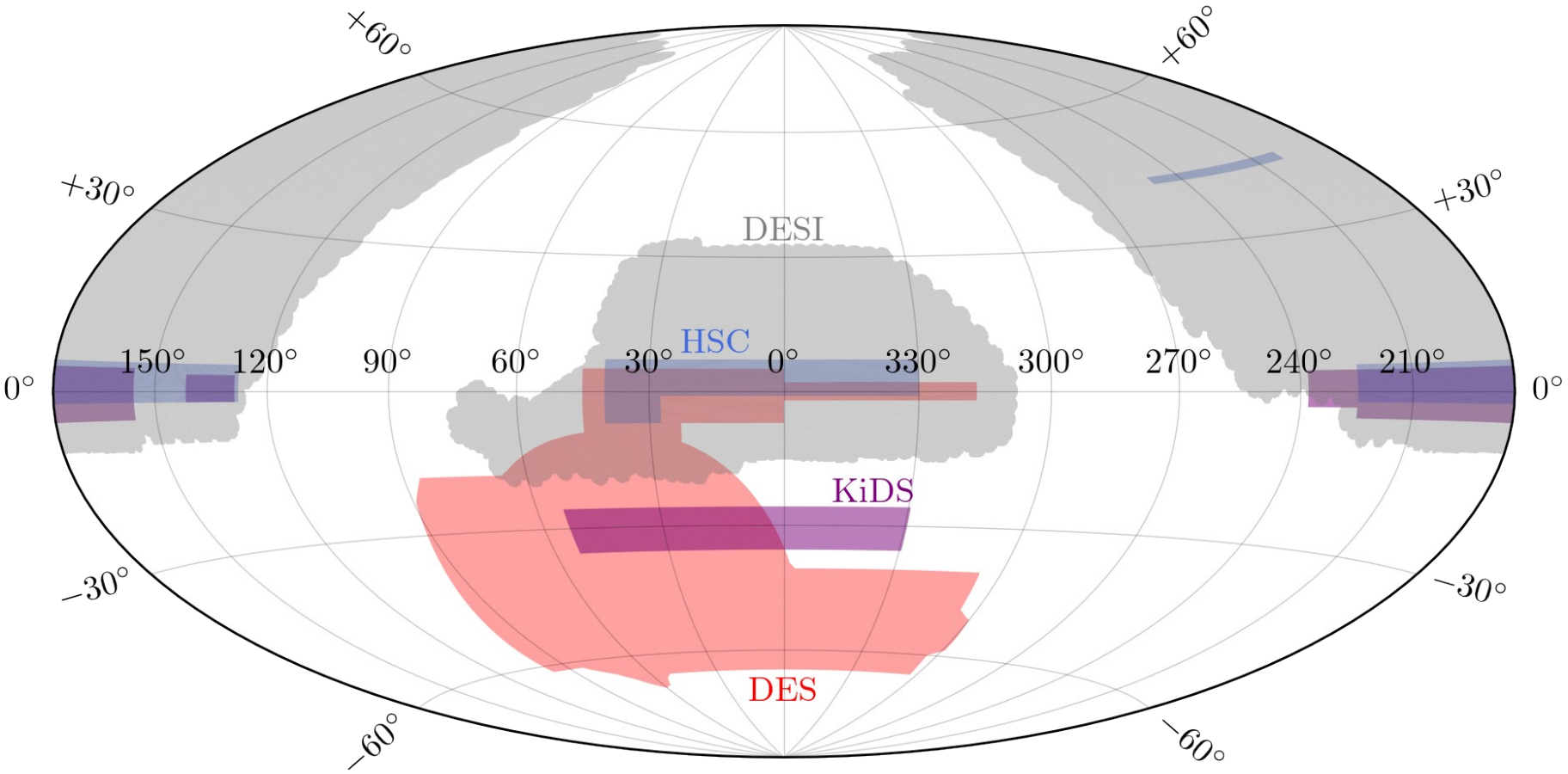


S_8-Tension and Lensing is Low

Lensing-is-low may partially be a manifestation of the S_8-tension (if it exists).

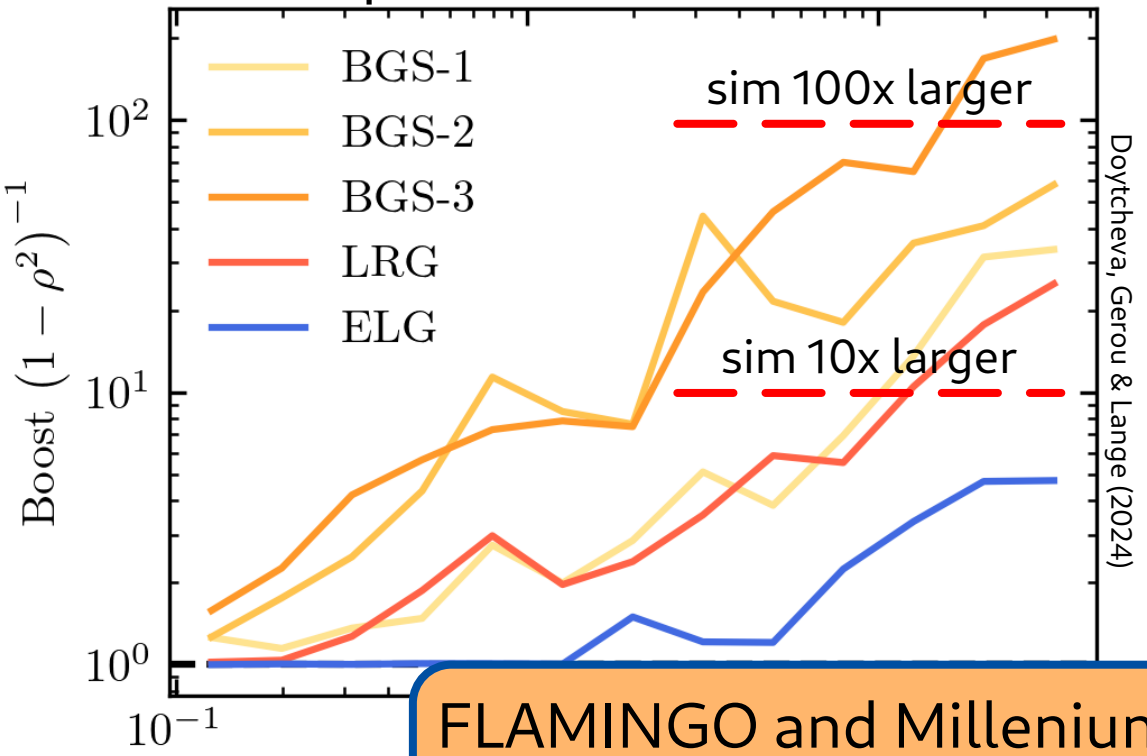


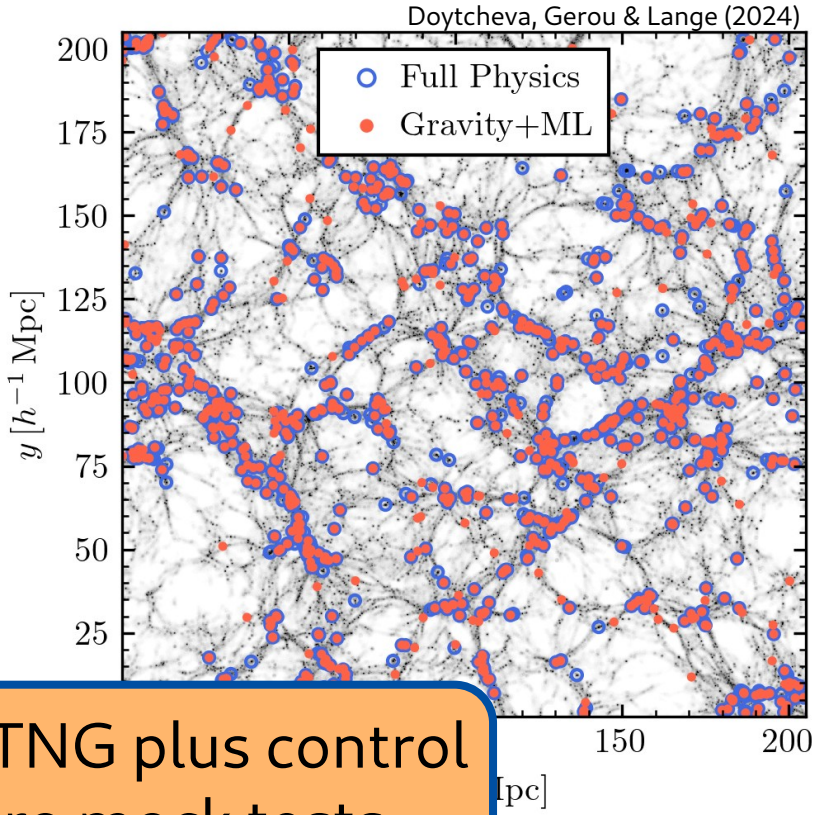
Next Steps: New Measurements



Next Steps: New Mock Tests

Real-Space Correlation Function





FLAMINGO and MilleniumTNG plus control variates enable pure hydro mock tests.

Summary

- lensing-is-low problem: overprediction of small-scale lensing amplitude
- unlikely to be caused by measurement systematics of stage-III lensing surveys
- sensitive to galaxy formation, i.e., assembly bias and baryonic feedback
- may partially be a manifestation of the S_8-tension, future DESI data should tell