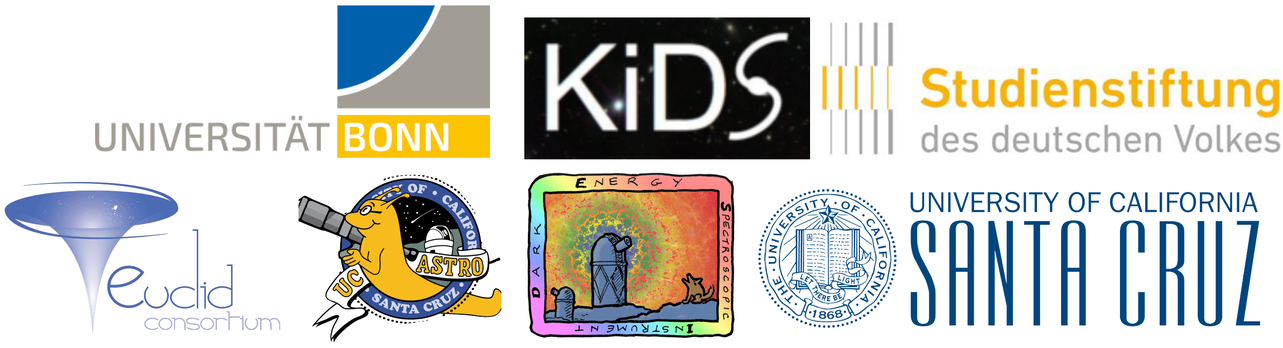
Securing Confidence in Cosmic Shear

Towards robust treatments of astrophysical systematics in Stage-IV surveys

For the Cosmology-BCCP LBNL-Physics-Astronomy Cosmology seminar
2025/01/21

Sven Heydenreich

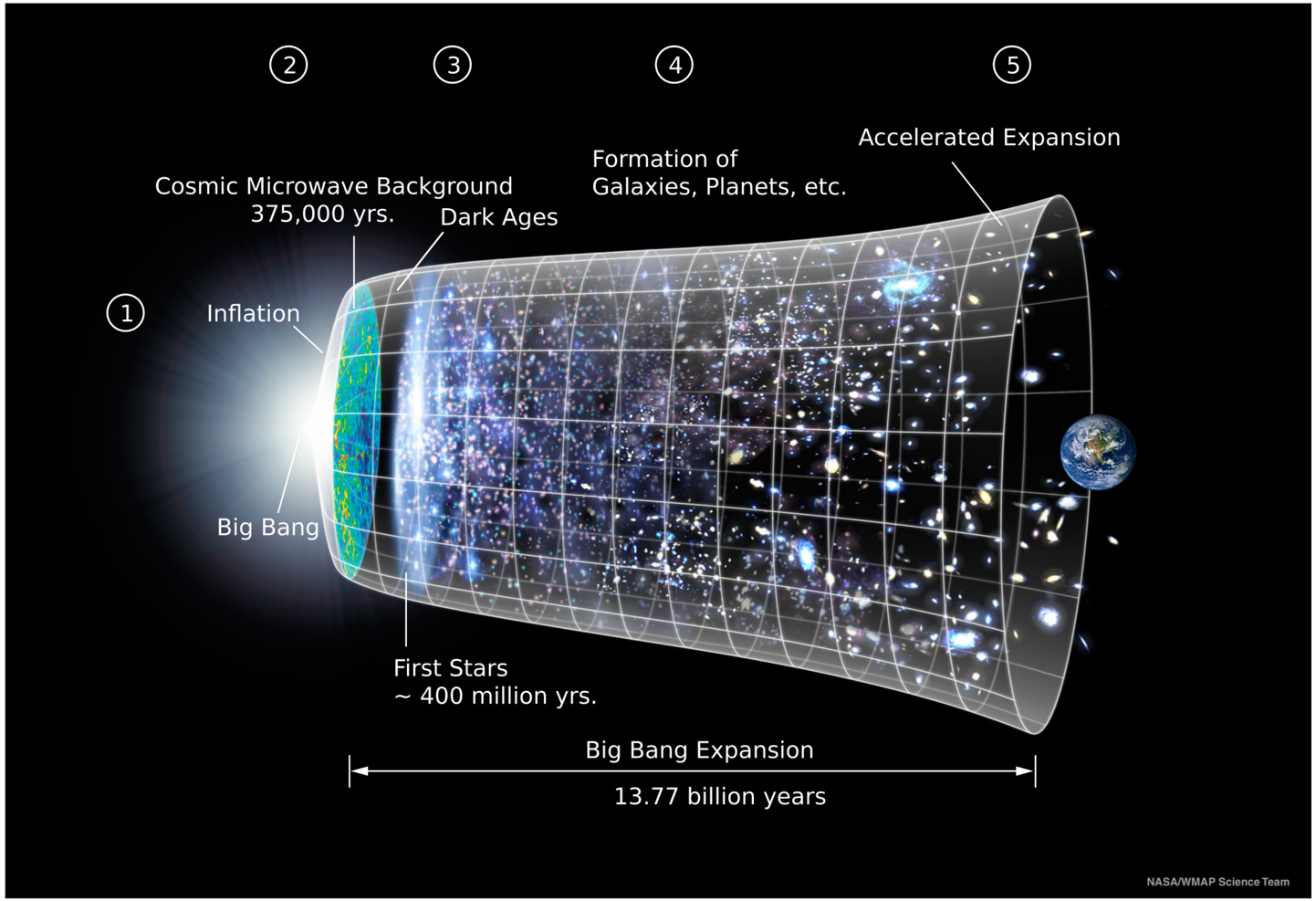


About me

- Master's: University of Bonn
  The effects of varying depth in cosmic shear surveys
- PhD: University of Bonn
  Higher-order statistics in cosmic shear
- Now: UC Santa Cruz
  Galaxy-Galaxy lensing in the DESI survey

KiDS
Studienstiftung des deutschen Volkes
euclid consortium
UNIVERSITÄT BONN
UNIVERSITY OF CALIFORNIA SANTA CRUZ

Why go beyond CMB?



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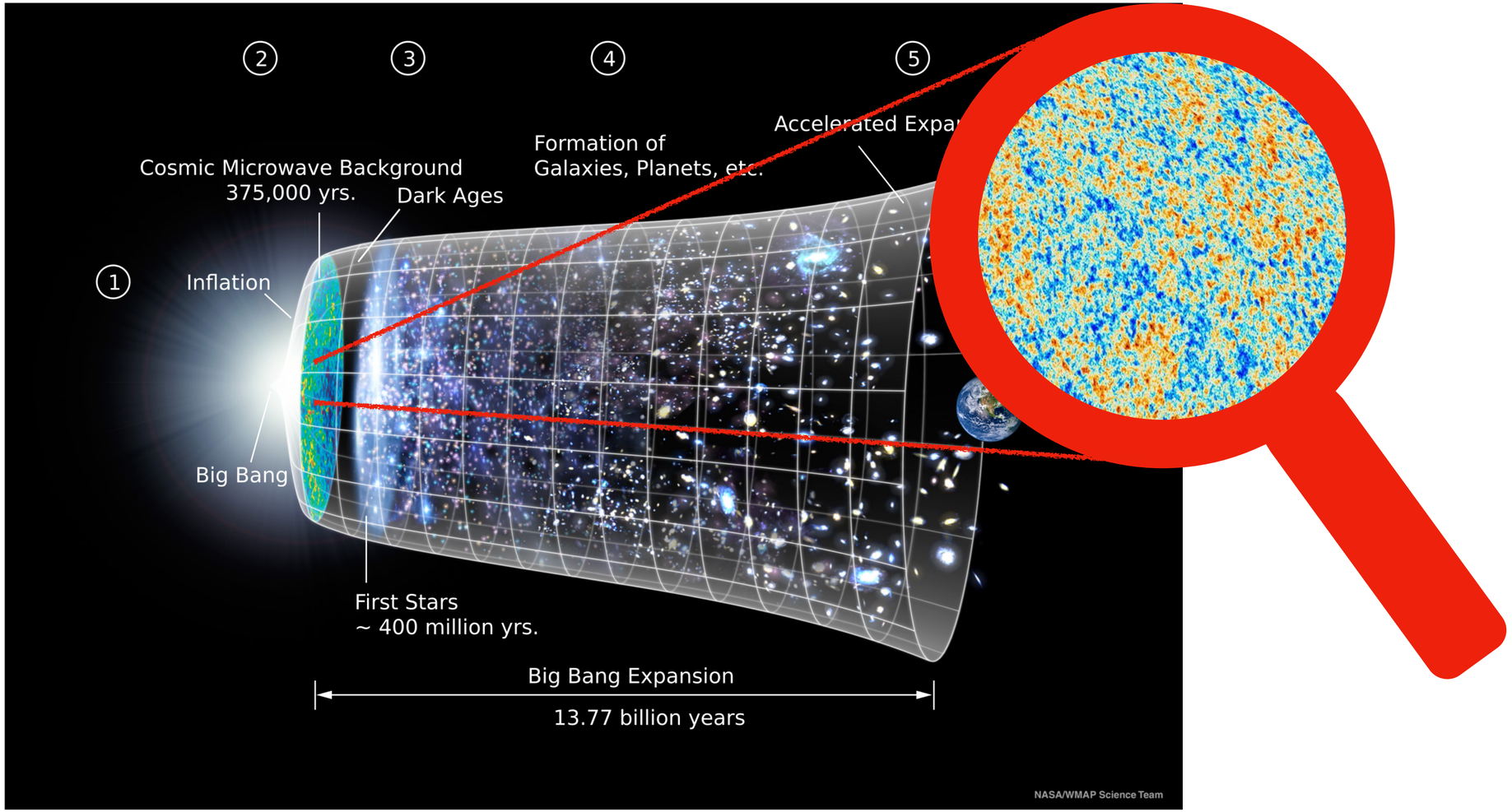

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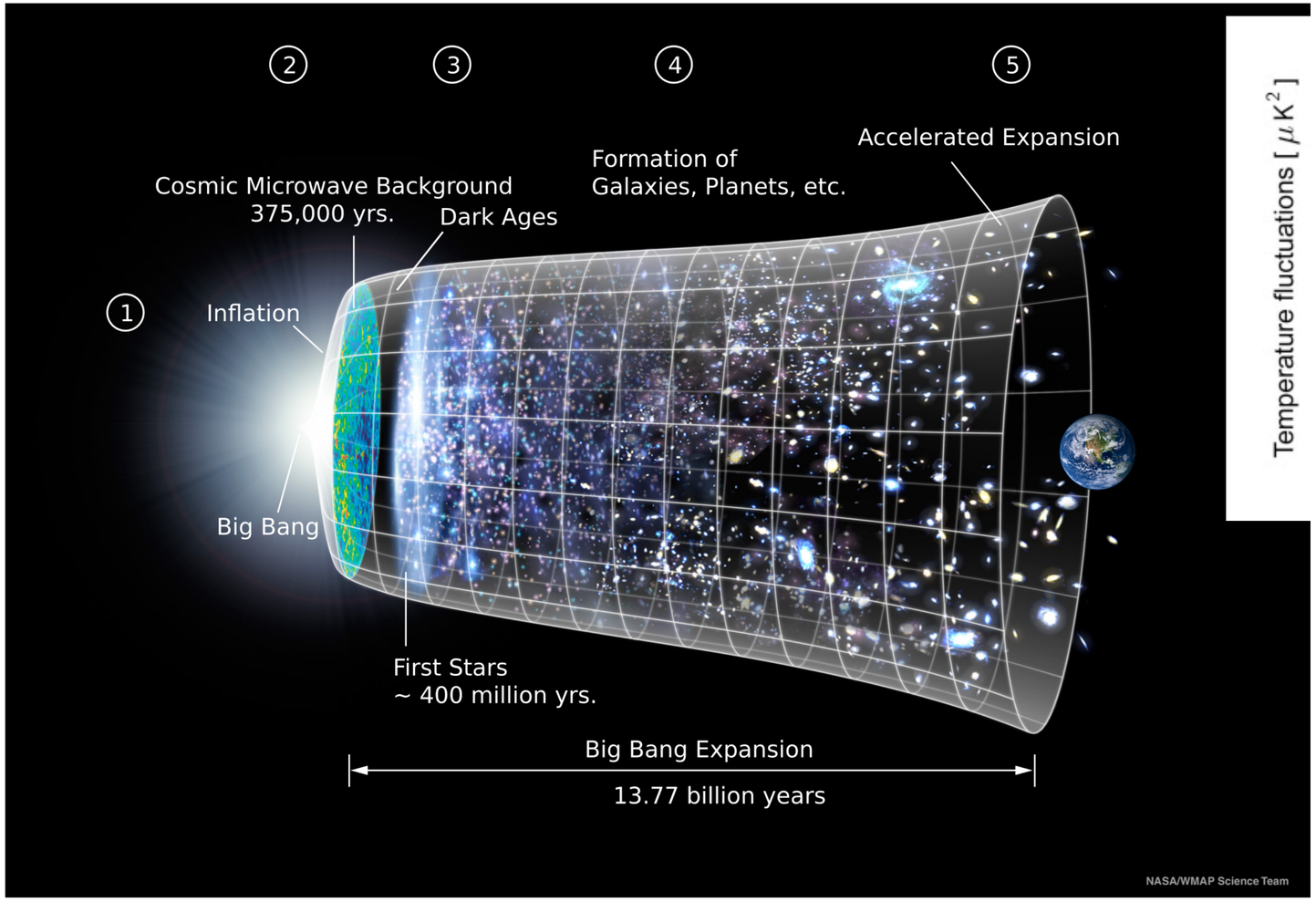

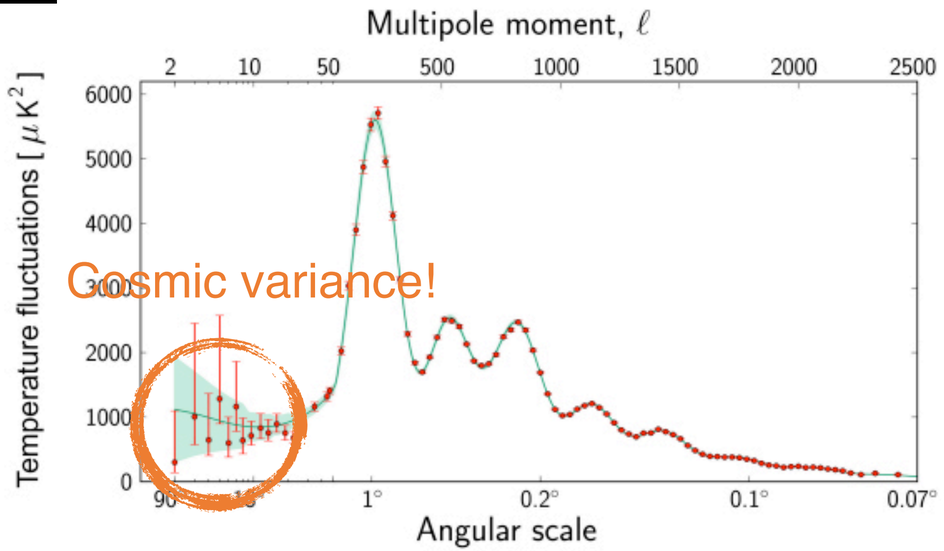

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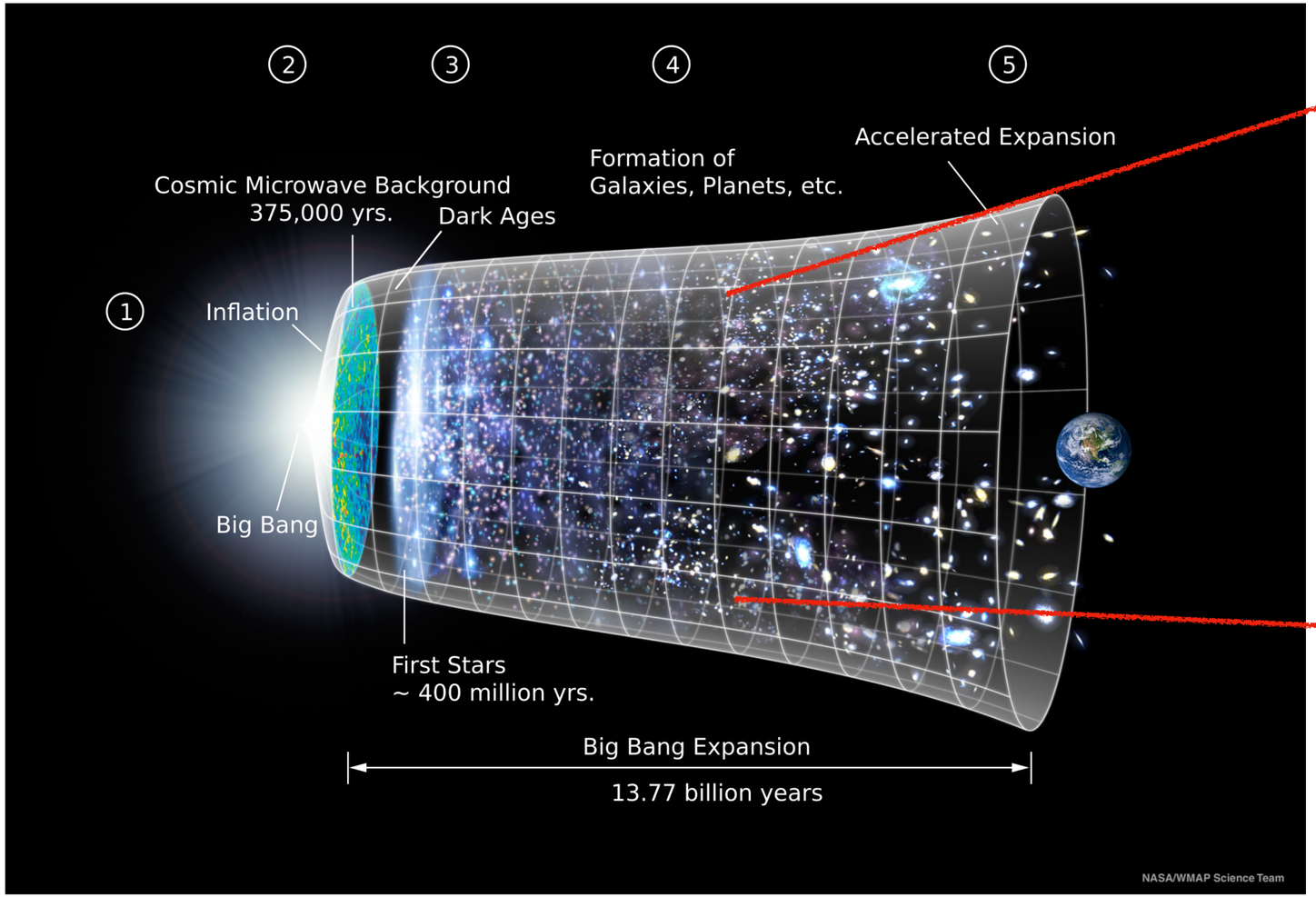
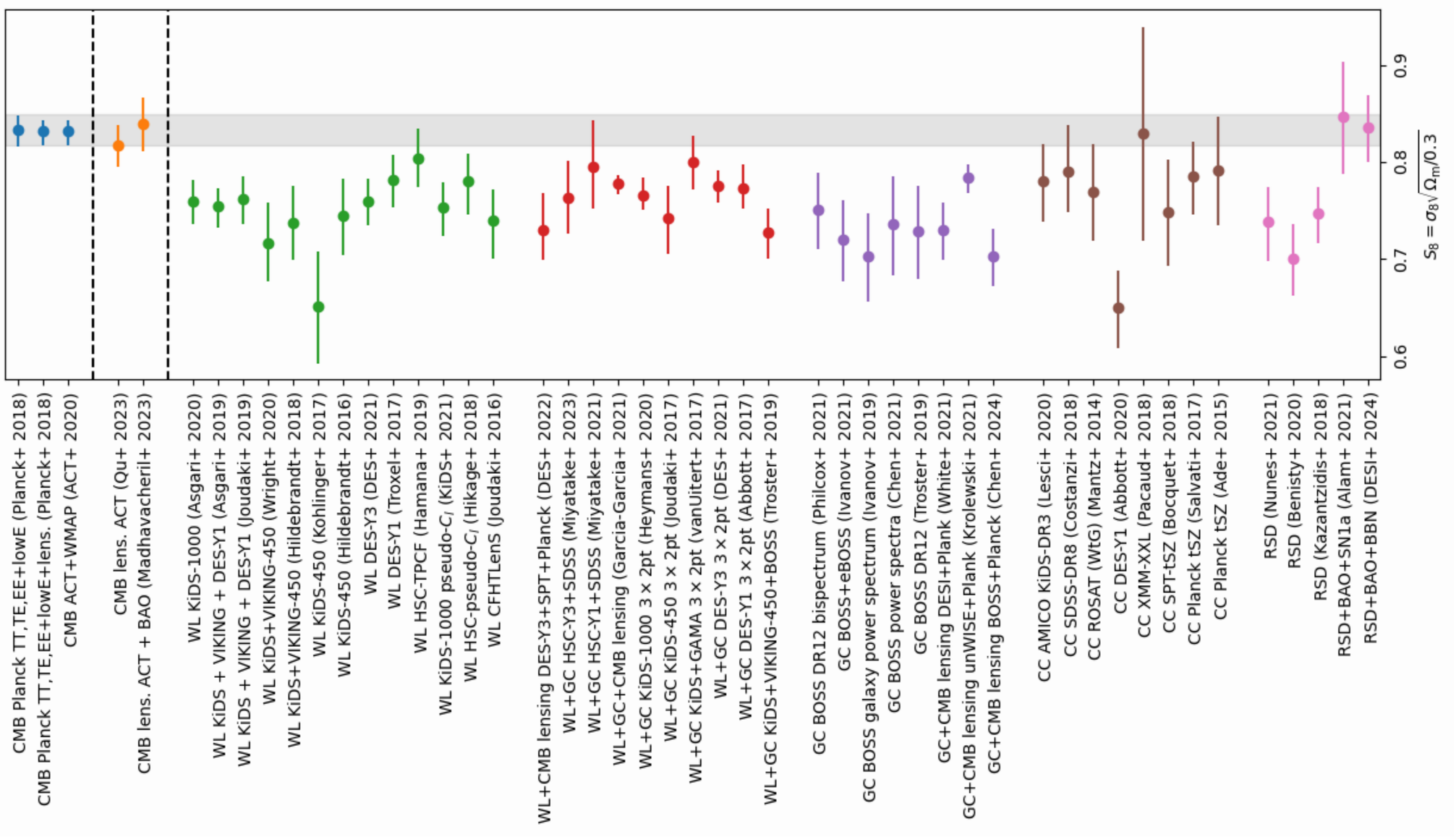
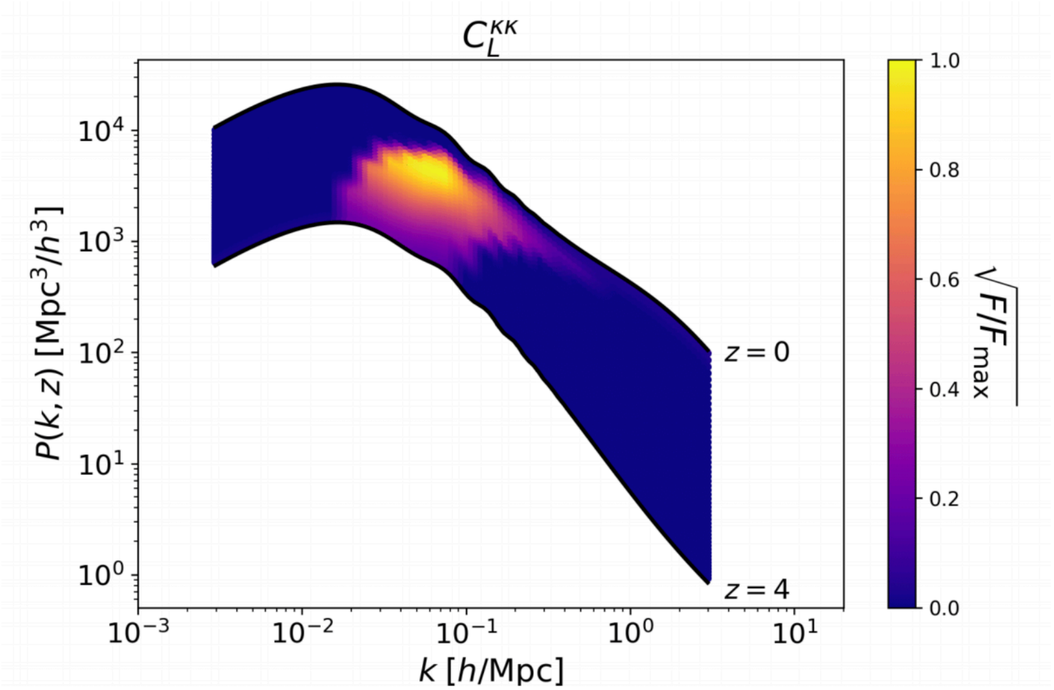
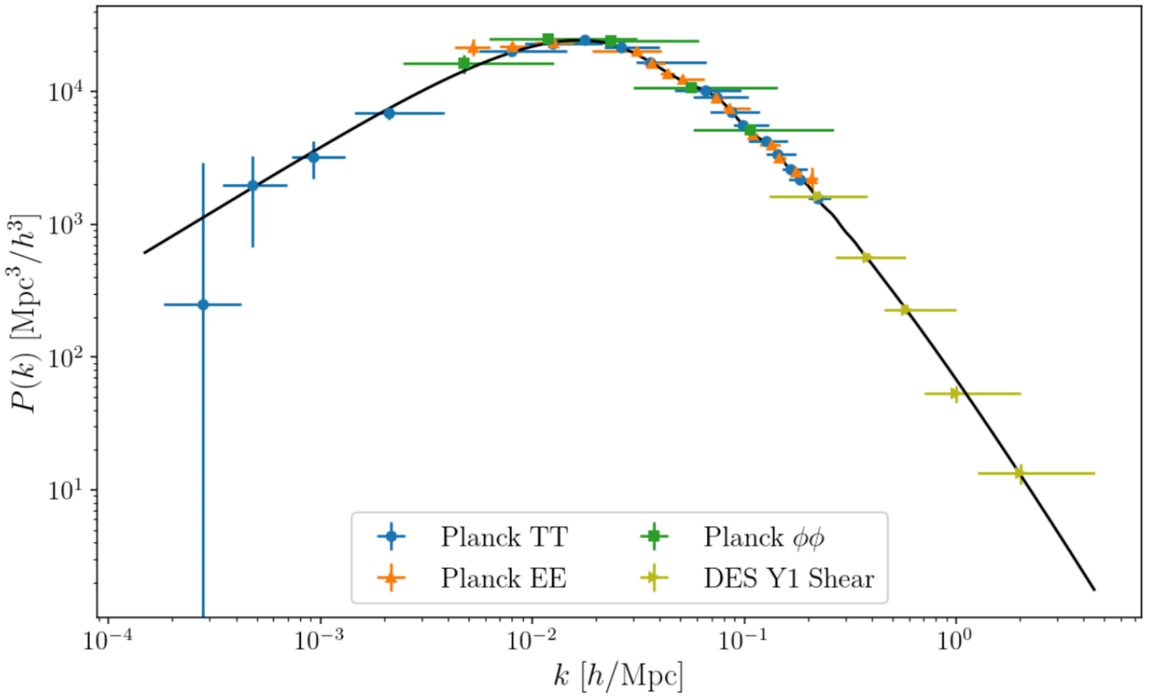


The S_8 'tension'



Redshift and scale dependence of different probes





Preston et al. (2023), Credit: Alex Laguë

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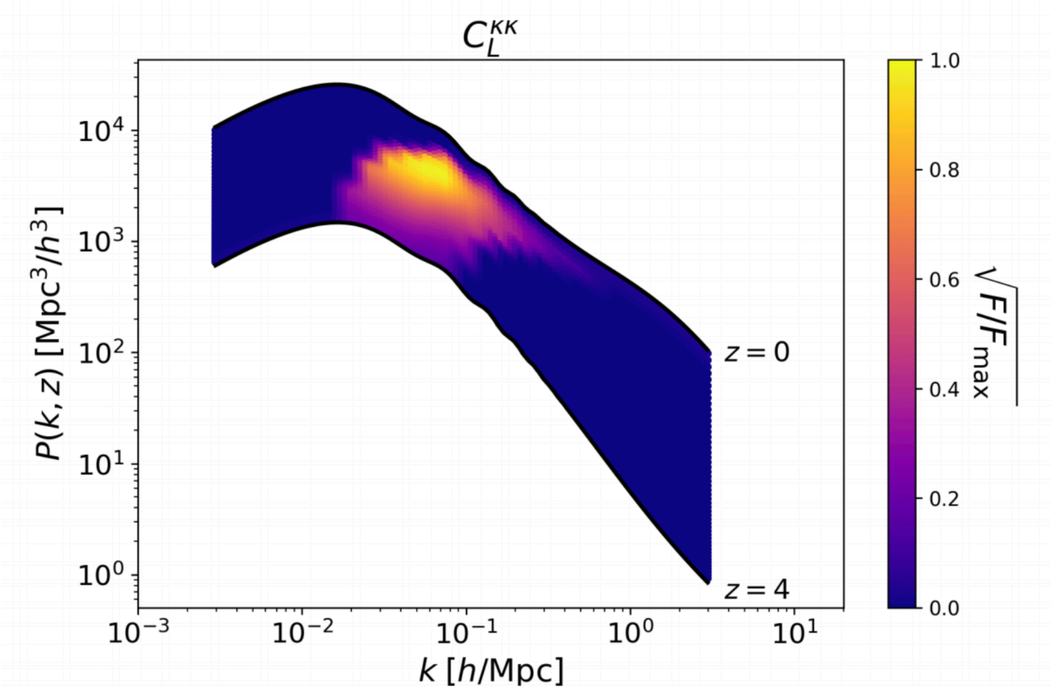
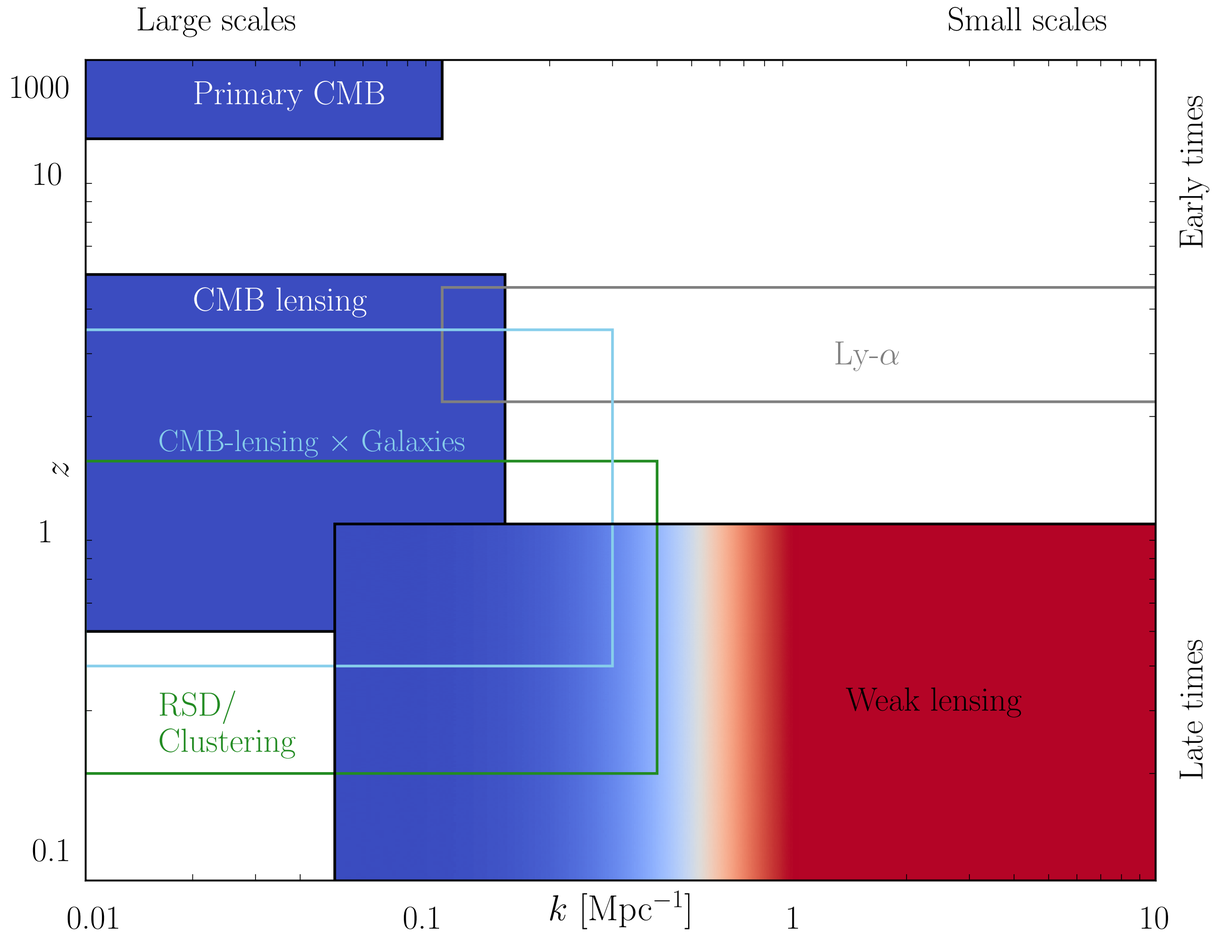
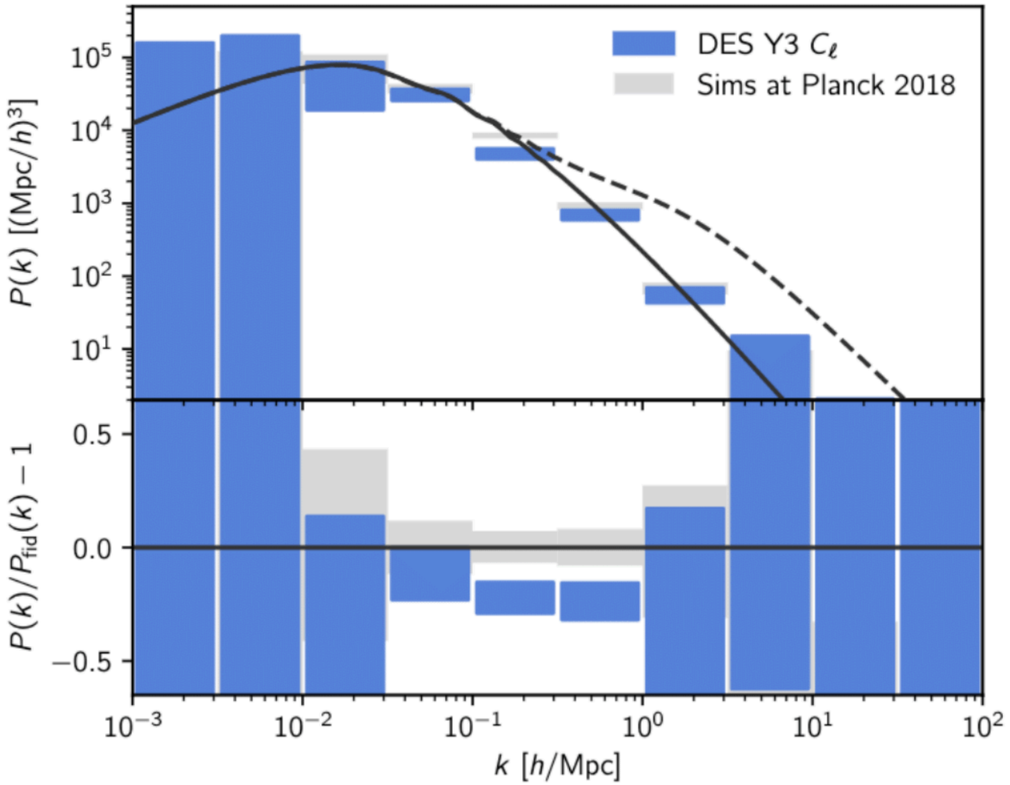
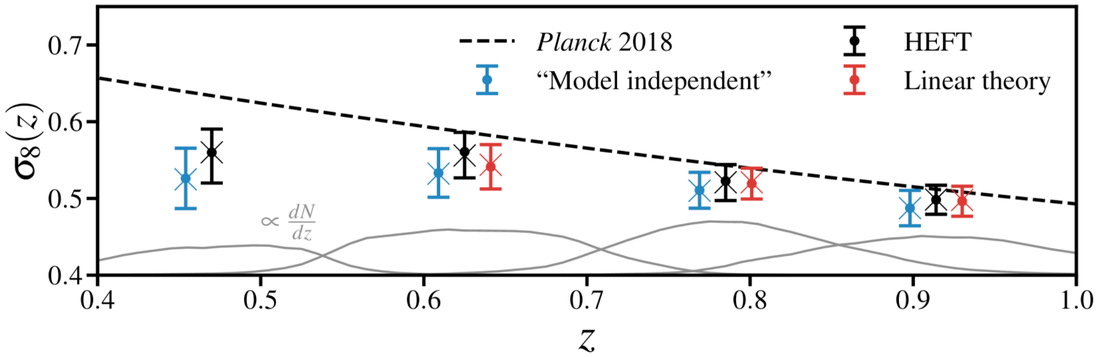


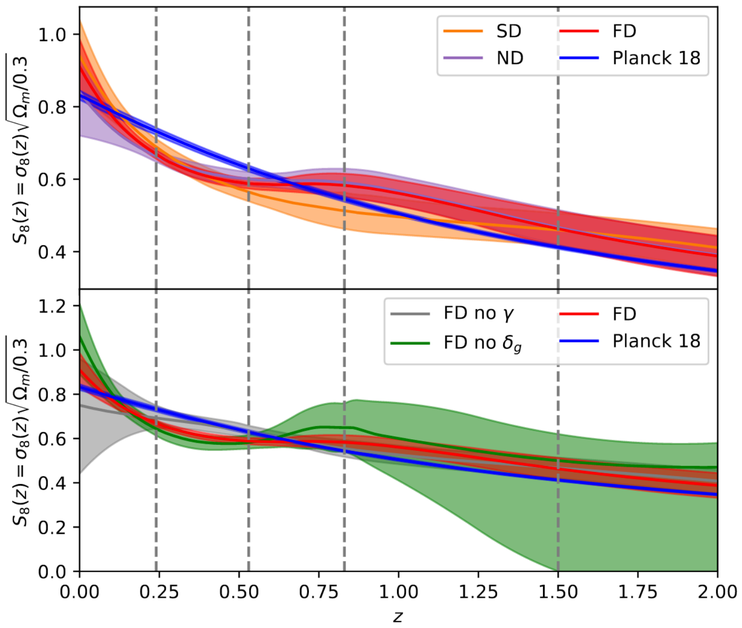


Preston et al. (2023), Credit: Alex Laguë

S_8 tension in (k,z)-space







Sailer et al. (2024), Doux et al. (2022), Garcia-Garcia et al. (2021)

Cosmic shear systematics

Imaging systematics

- Shear measurement
- Color-redshift relation
- PSF subtraction
- CCD-related systematics
- Blending
- Variable selection function
- ...

Astrophysical systematics

- Baryon feedback
- Intrinsic alignments
- Inhomogeneous source samples
- ...

Modelling uncertainties

- Nonlinear structure formation
- Higher-order corrections (Limber, Born, reduced shear, ...)
- Neutrinos
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Statistical difficulties

- Impact of priors
- Non-Gaussian likelihoods
- Projection effects
- Tension metrics
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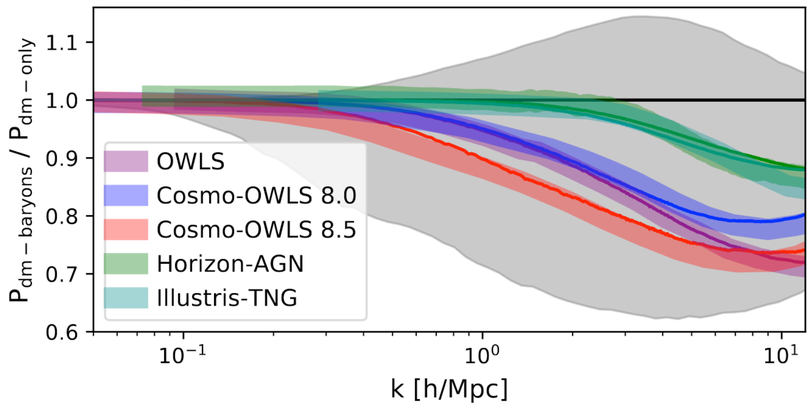
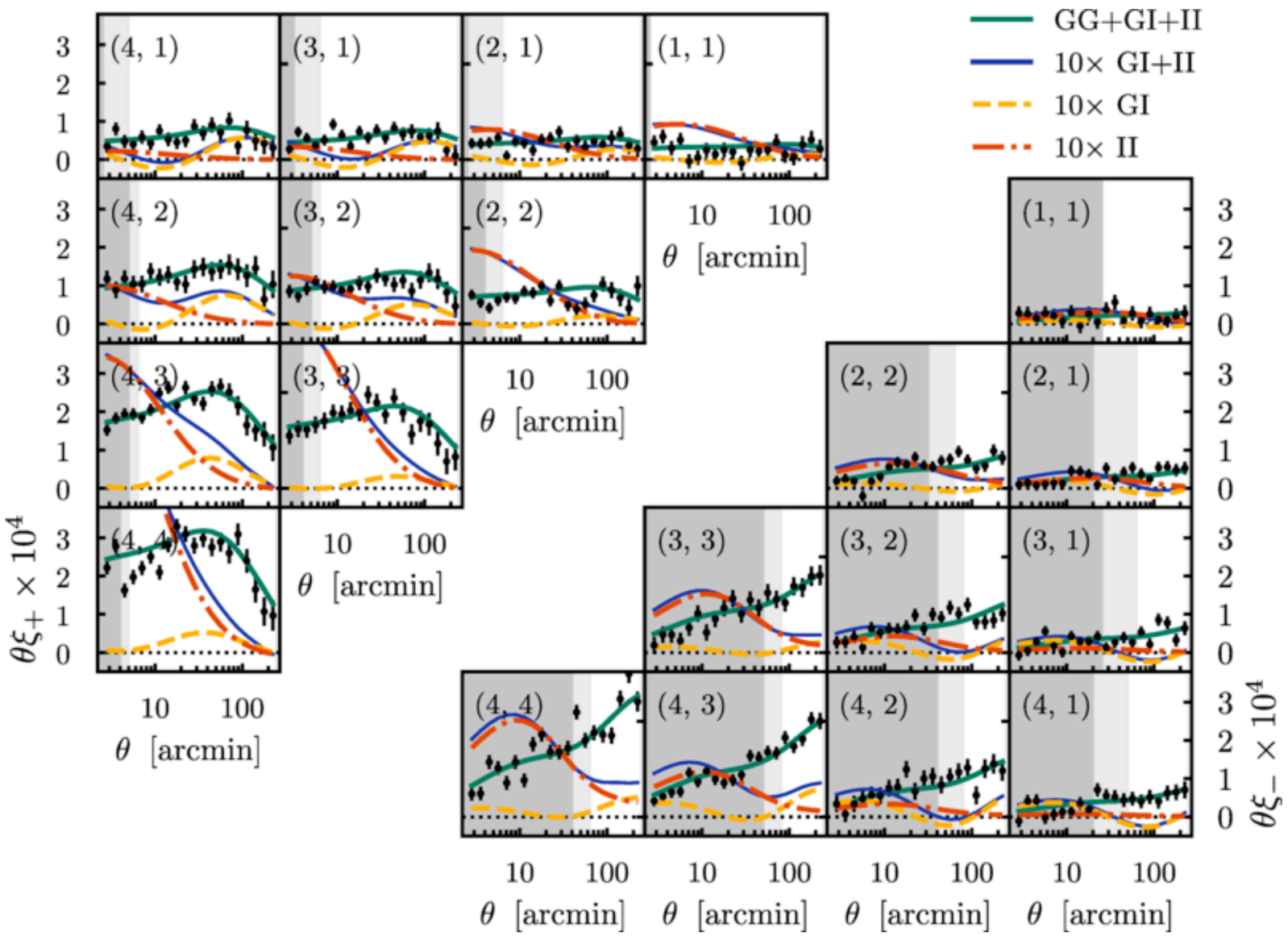


Baryon feedback, Schneider et al. (2020)

Could the S_8 tension be systematics?



Secco et al. (2022)

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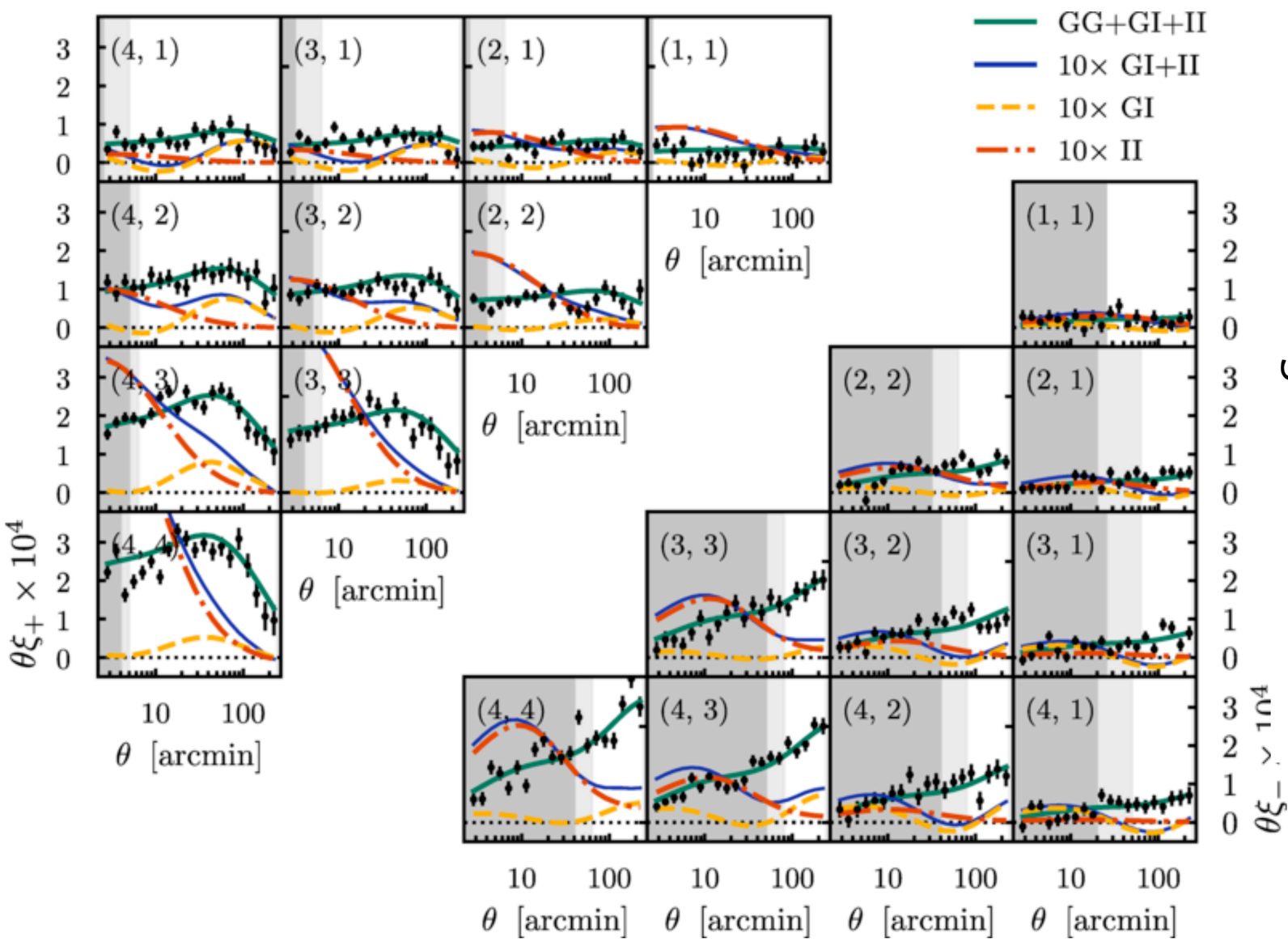

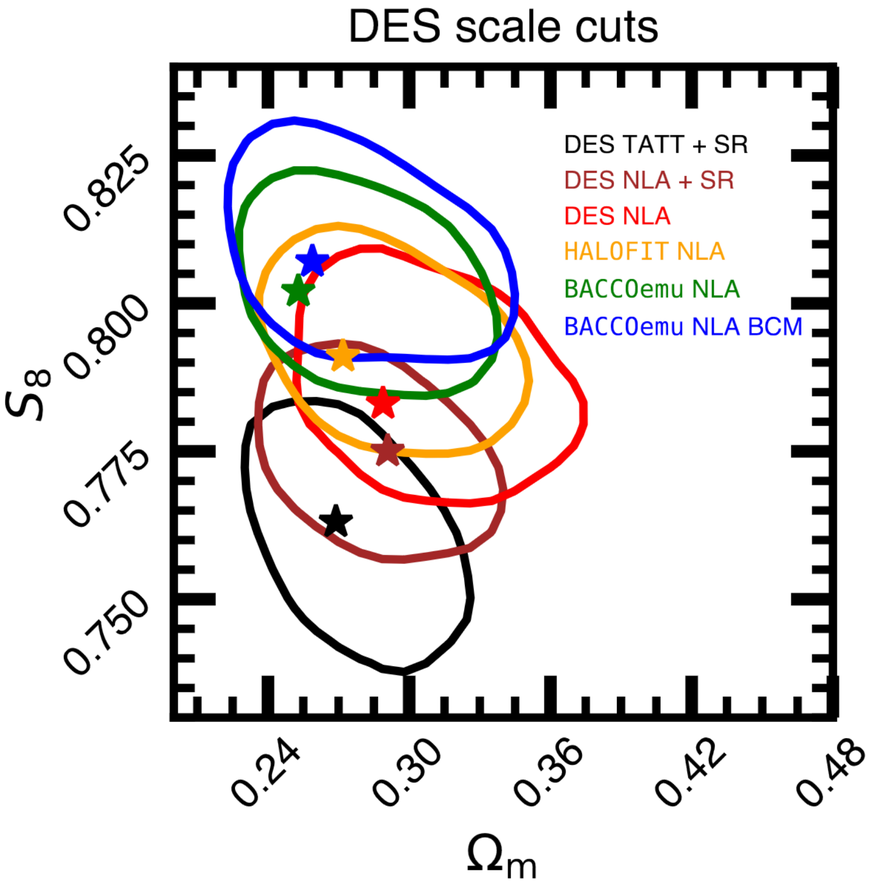

Secco et al. (2022), Arico et al. (2023)

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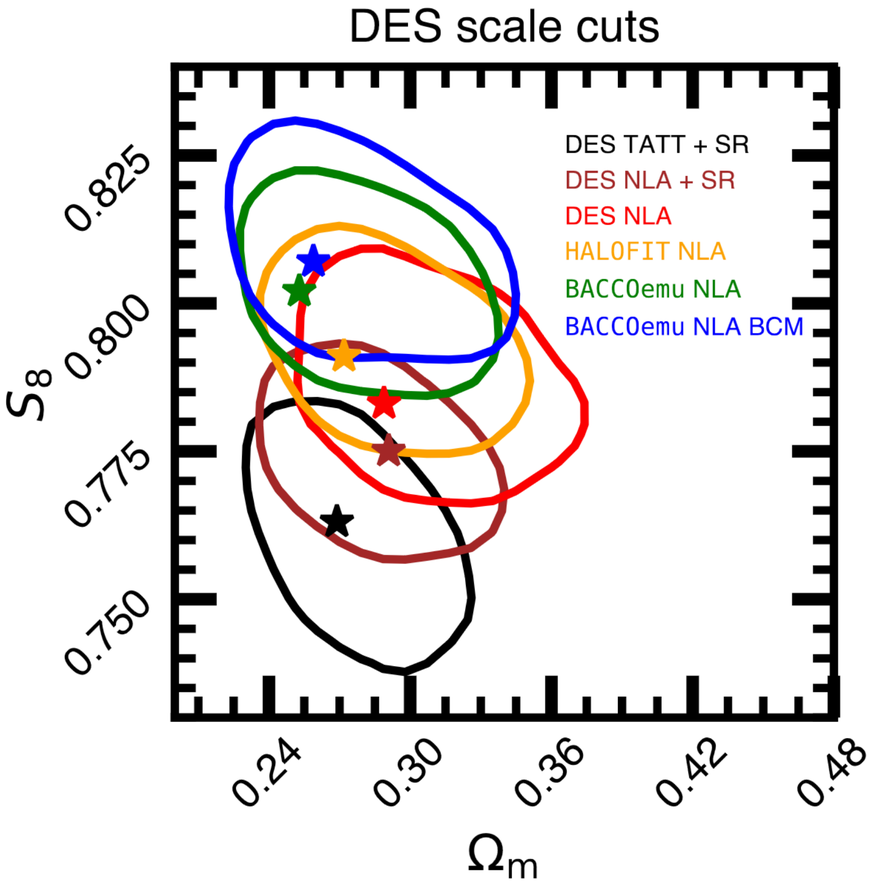

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How do we make sure it's not?

- Independent teams, pipelines, and analysis choices (DES, KiDS, HSC -> Euclid, Rubin, Roman)
- Independent/combined probes (i.e. $n \times 2\text{pt}$)
- Blinding!
- B-modes!
- Higher-order statistics
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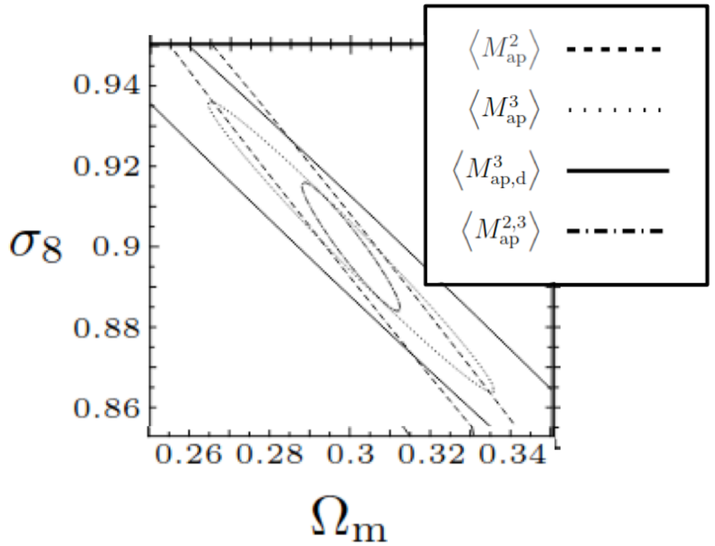
How do higher order statistics help with systematics?

- Break degeneracies
- Information from non-Gaussian structure



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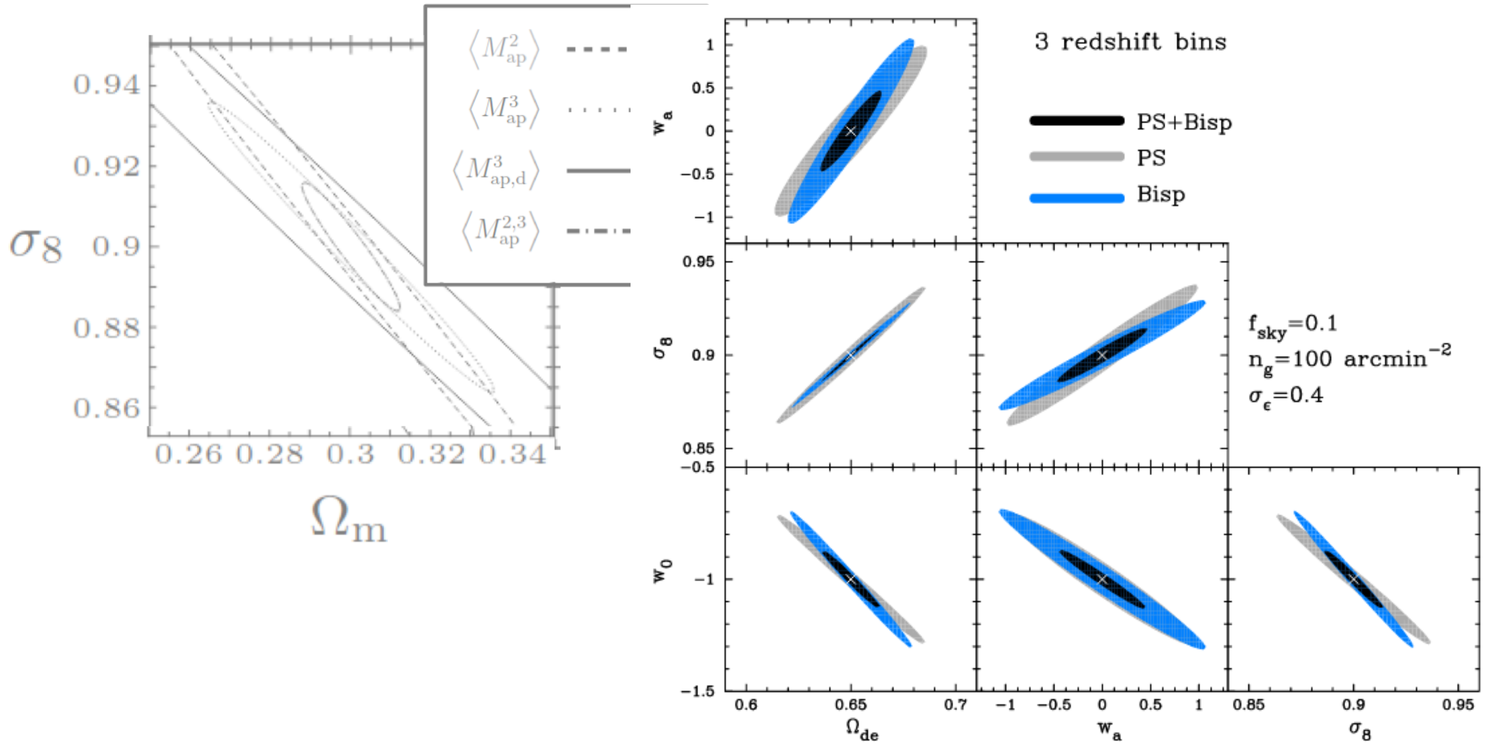

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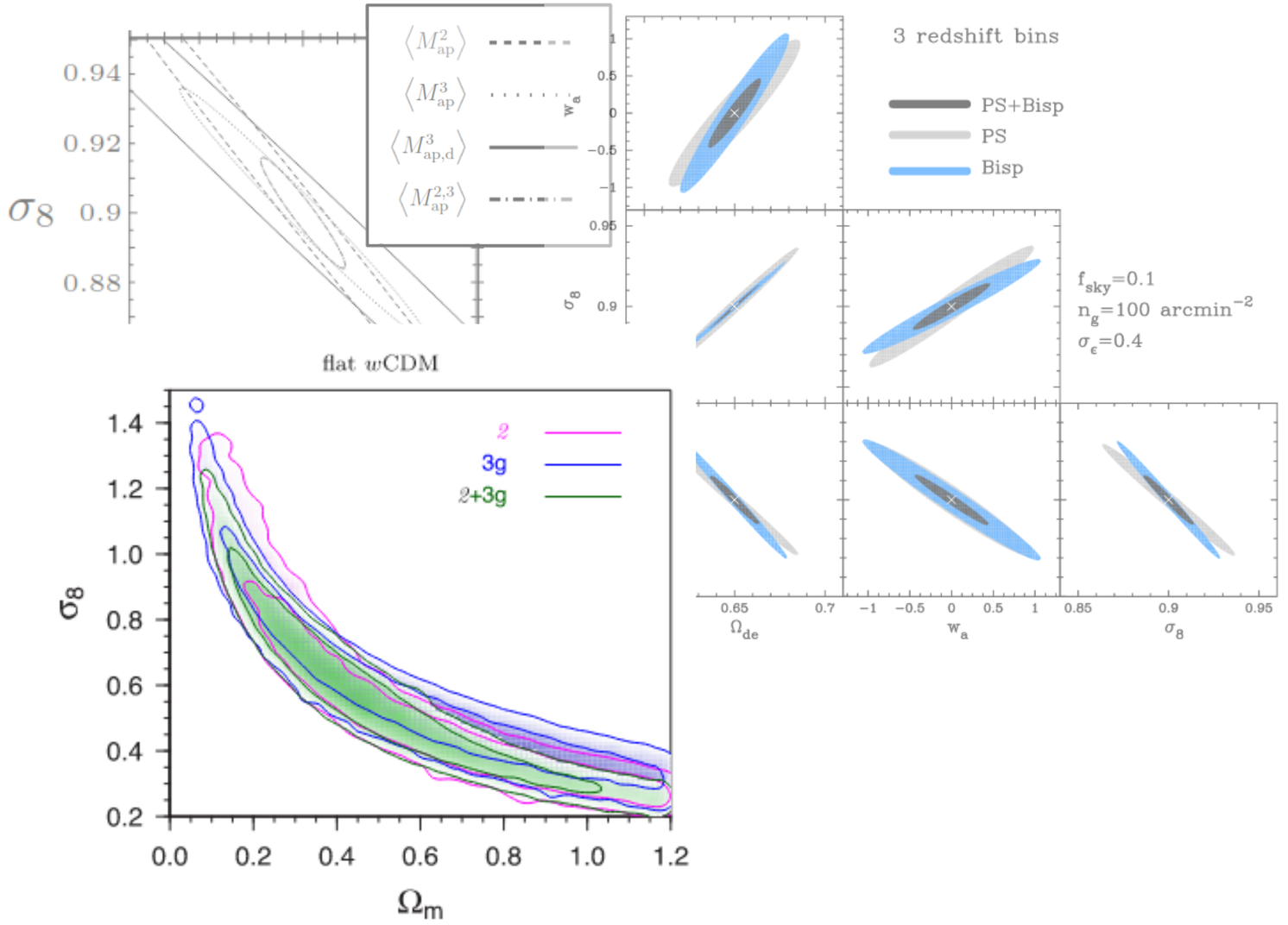

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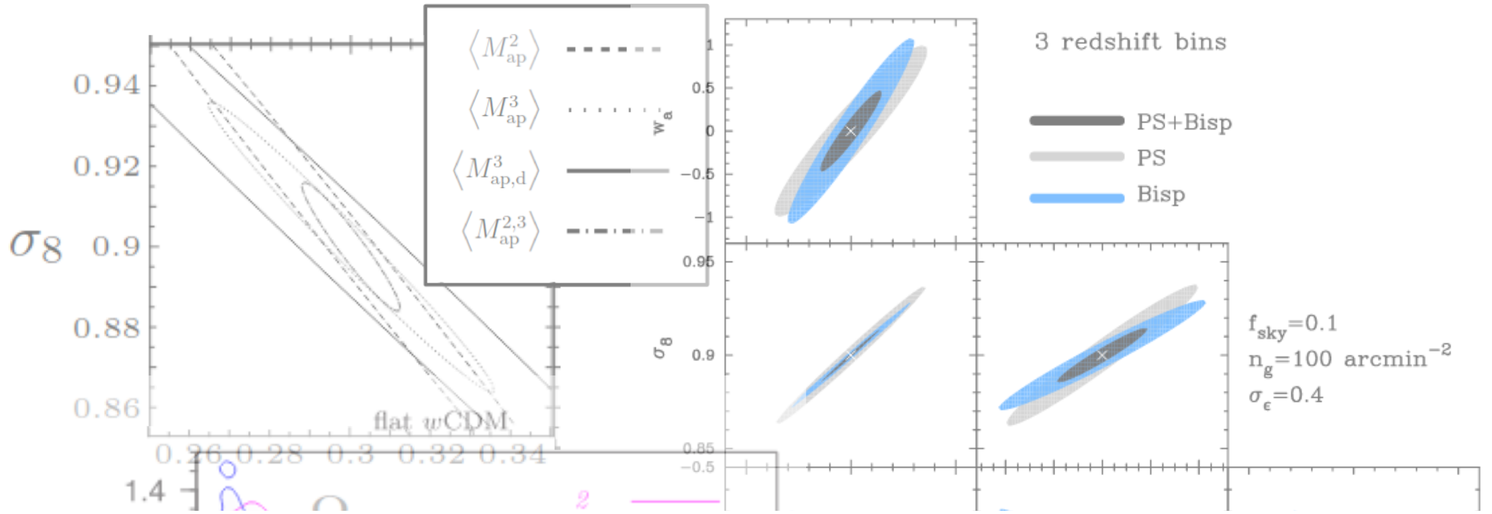

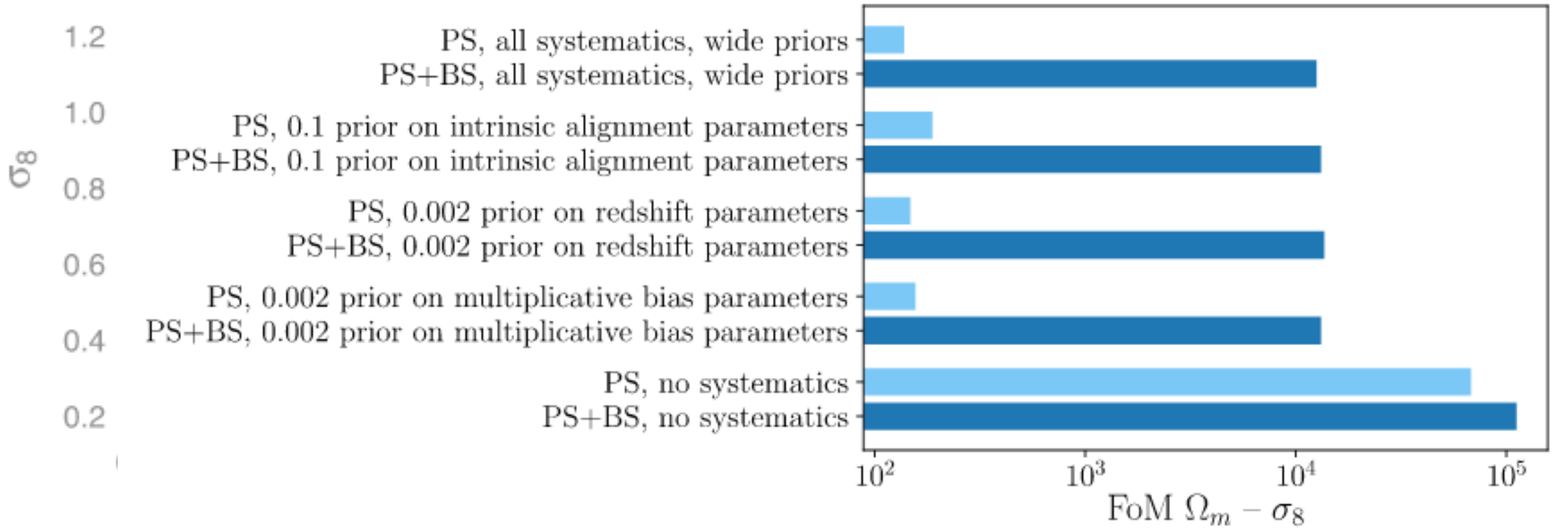

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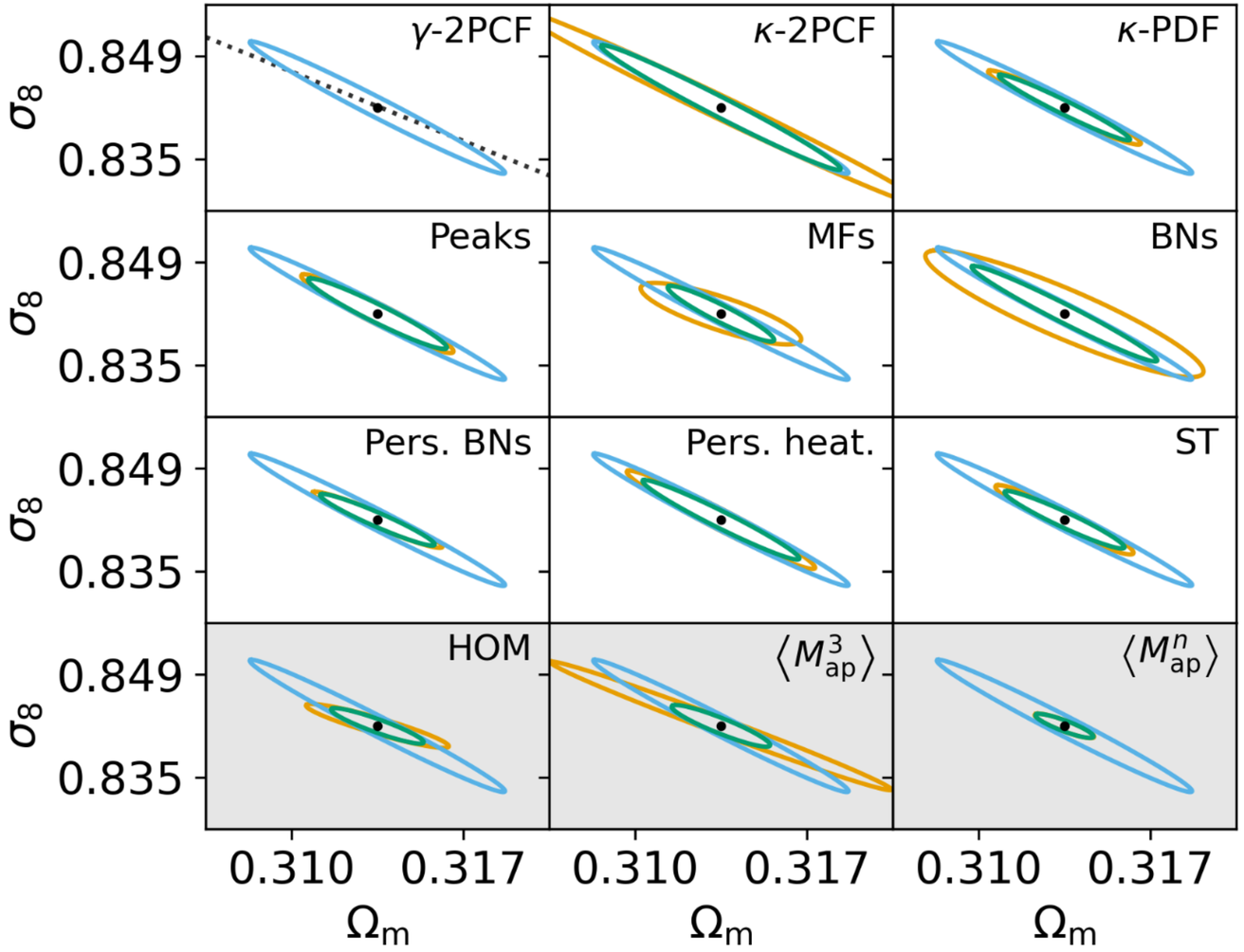
Higher-order cosmic shear statistics



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+ forward modeling
+ density split statistics
+ neural networks
+ many others

Euclid collaboration (2023, incl. Heydenreich)

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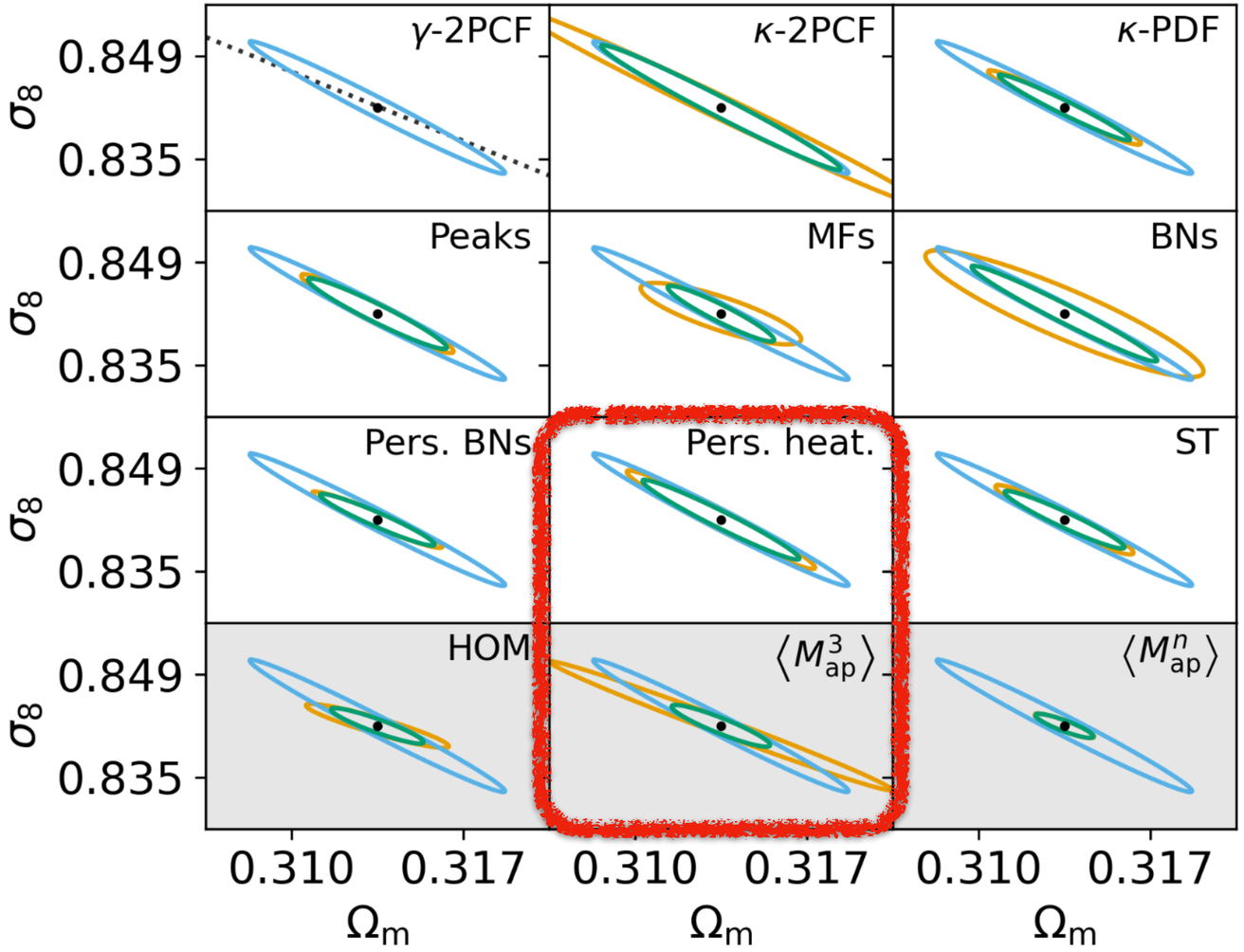

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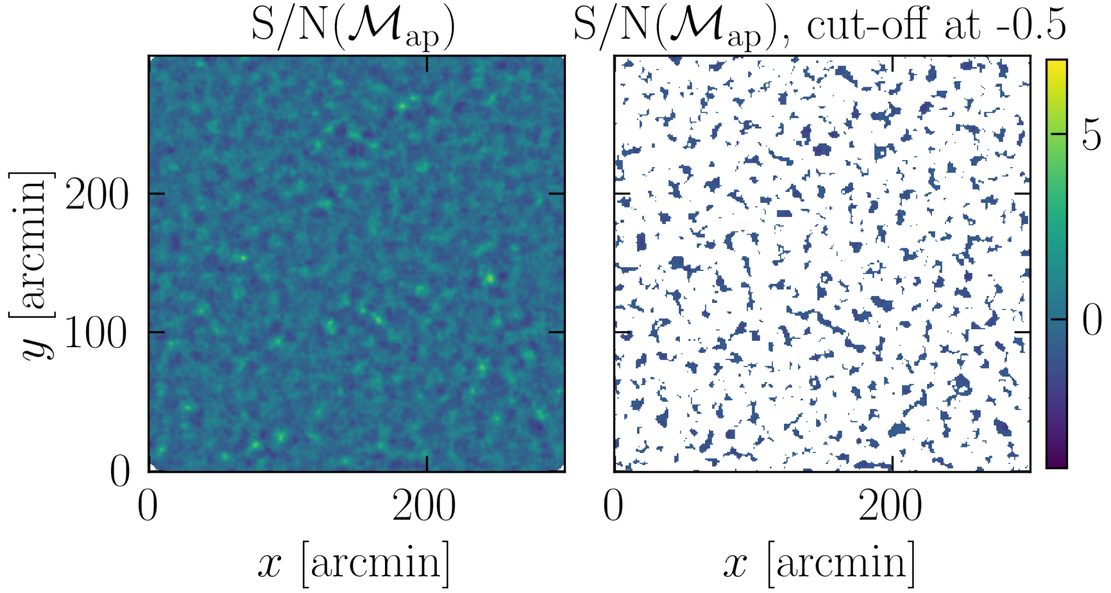
Persistent homology



Heydenreich et al. (2022)

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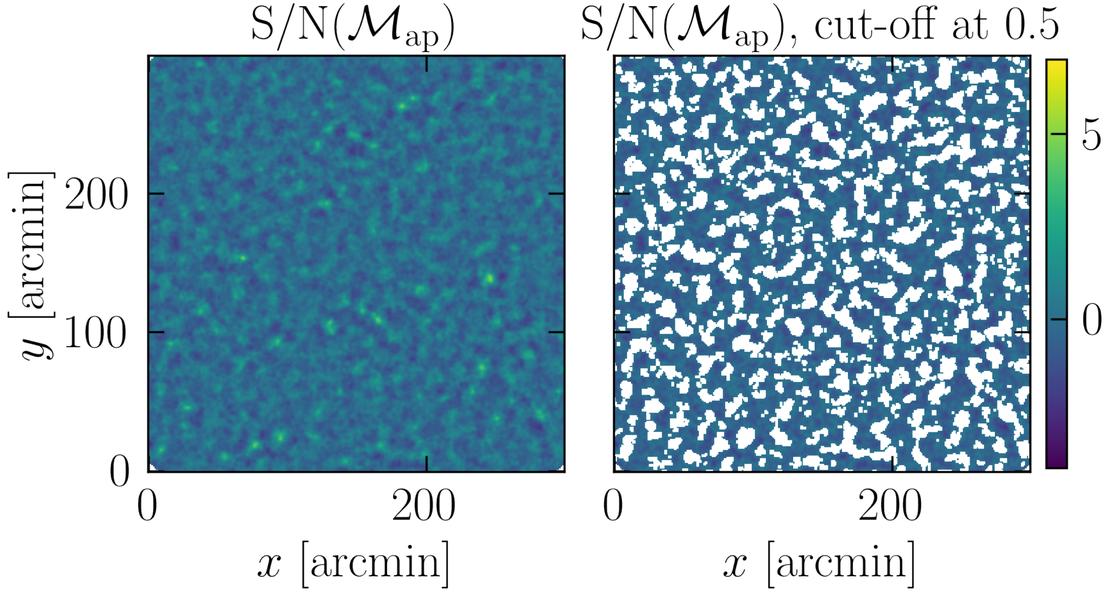

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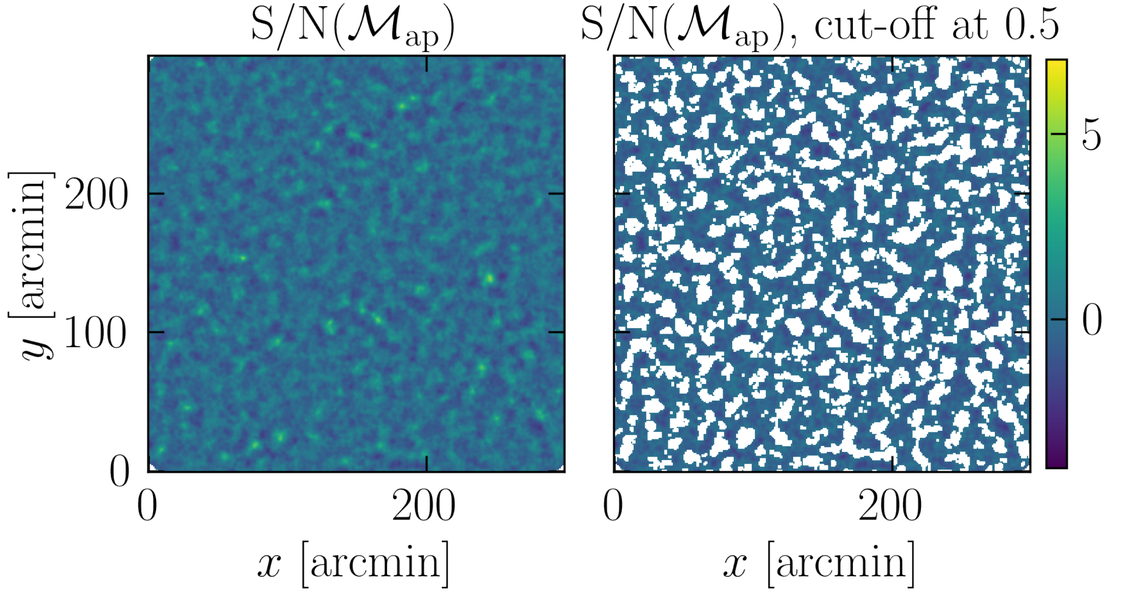

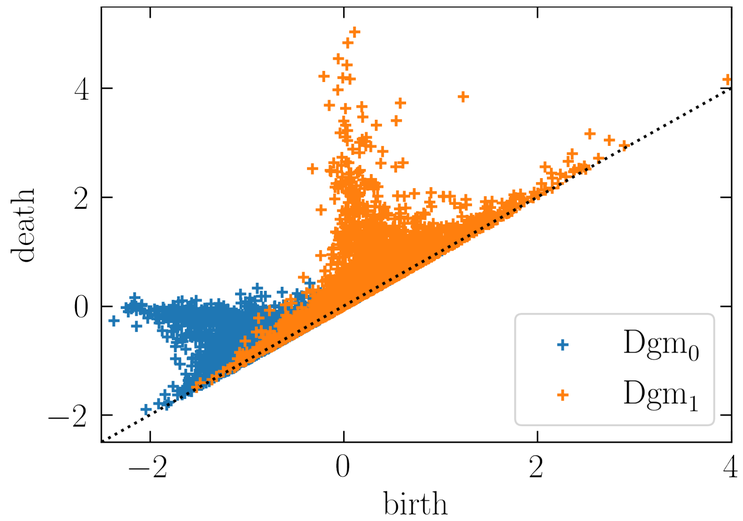

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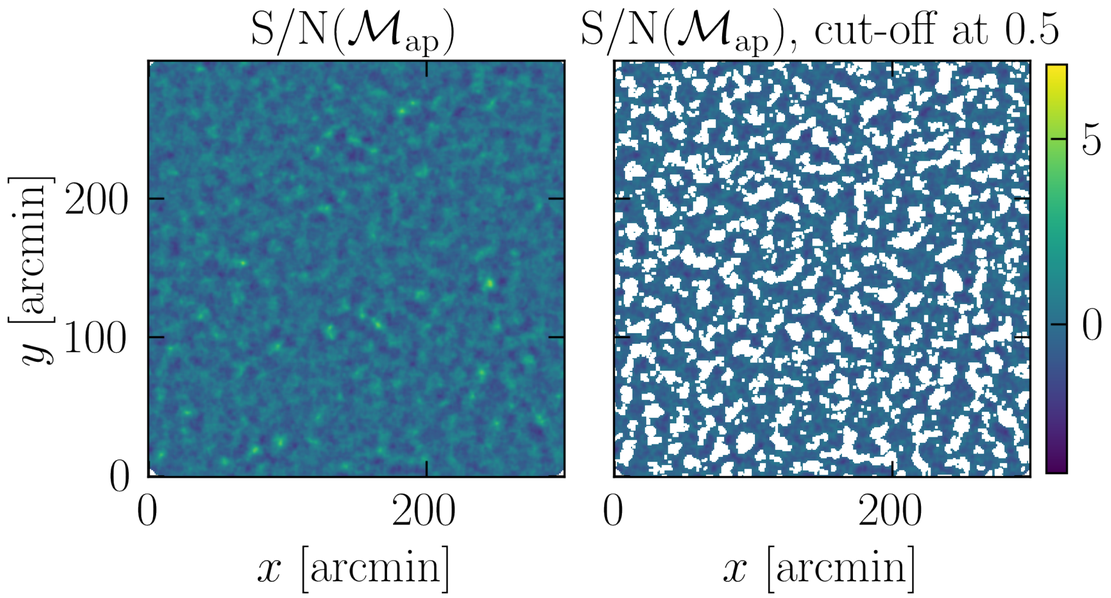
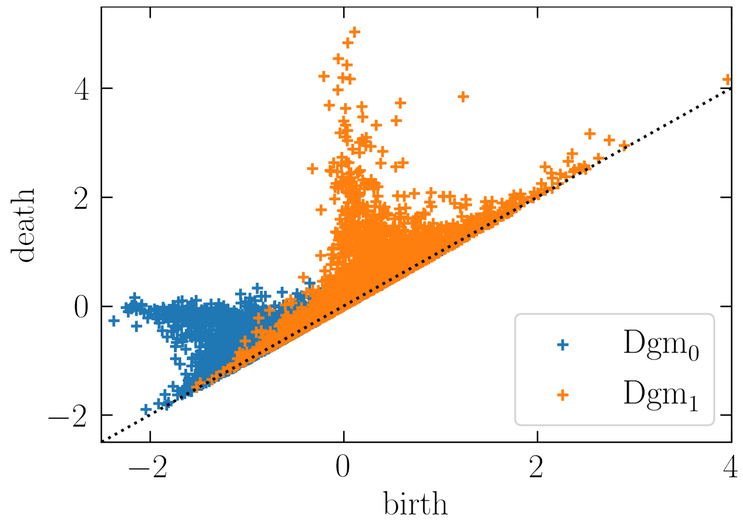
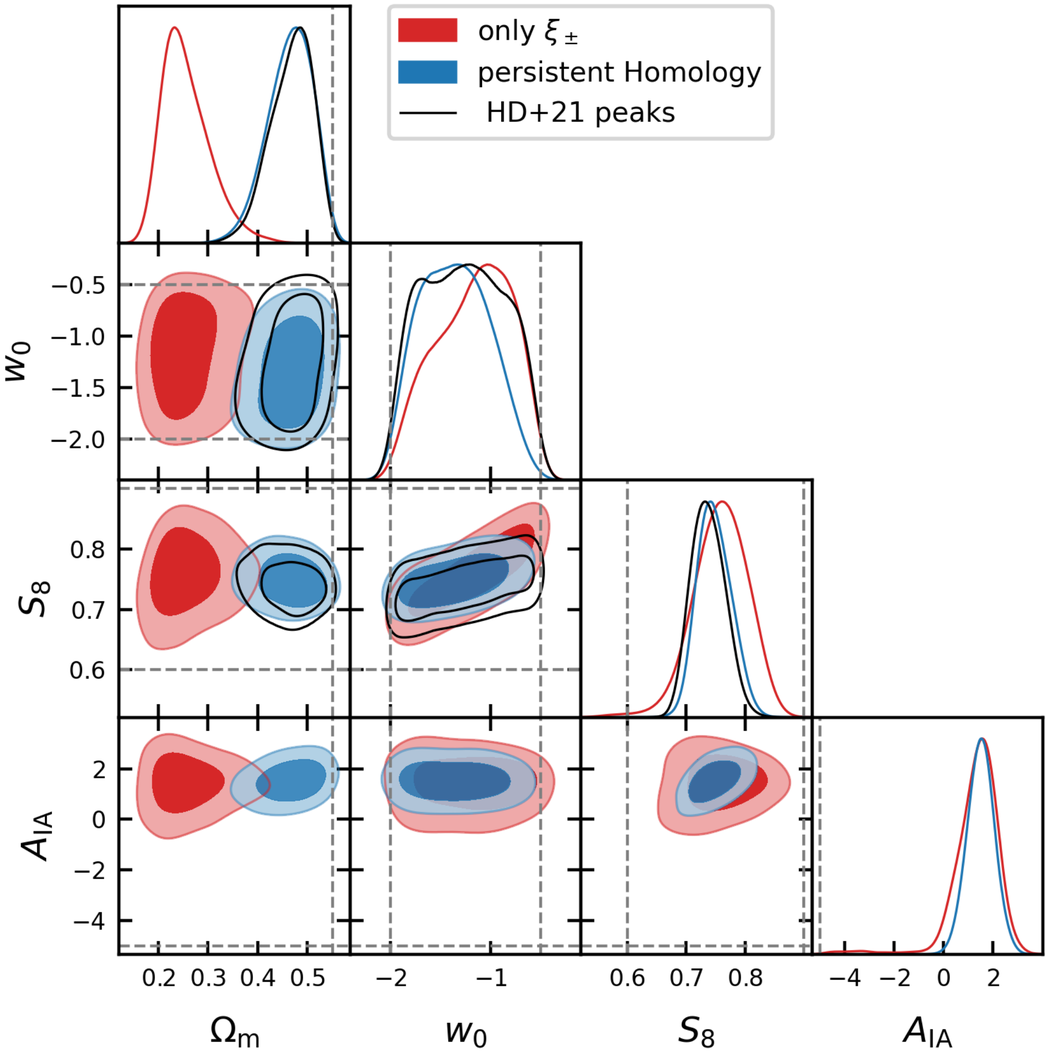
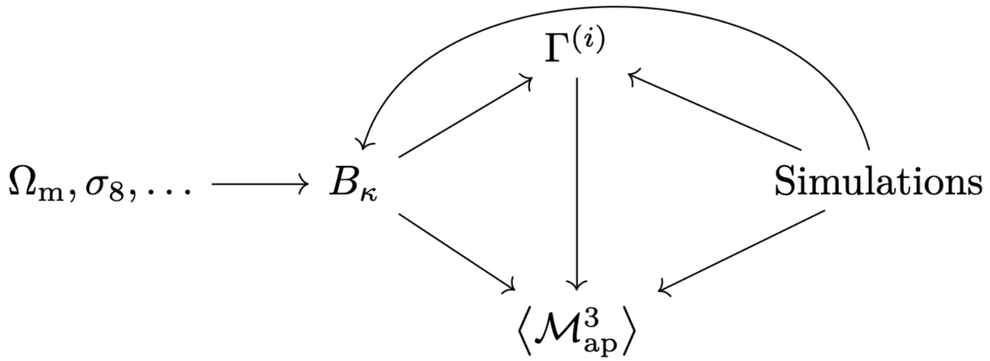






Heydenreich et al. (2022)

Third-order cosmic shear



Adapted from Heydenreich et al. (2023)

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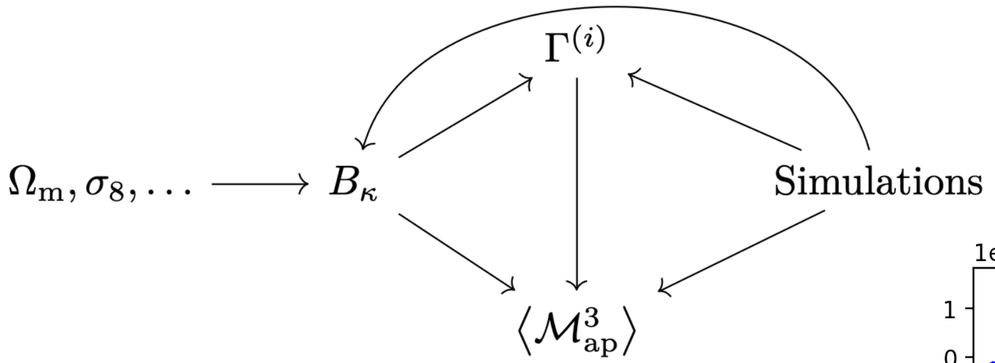

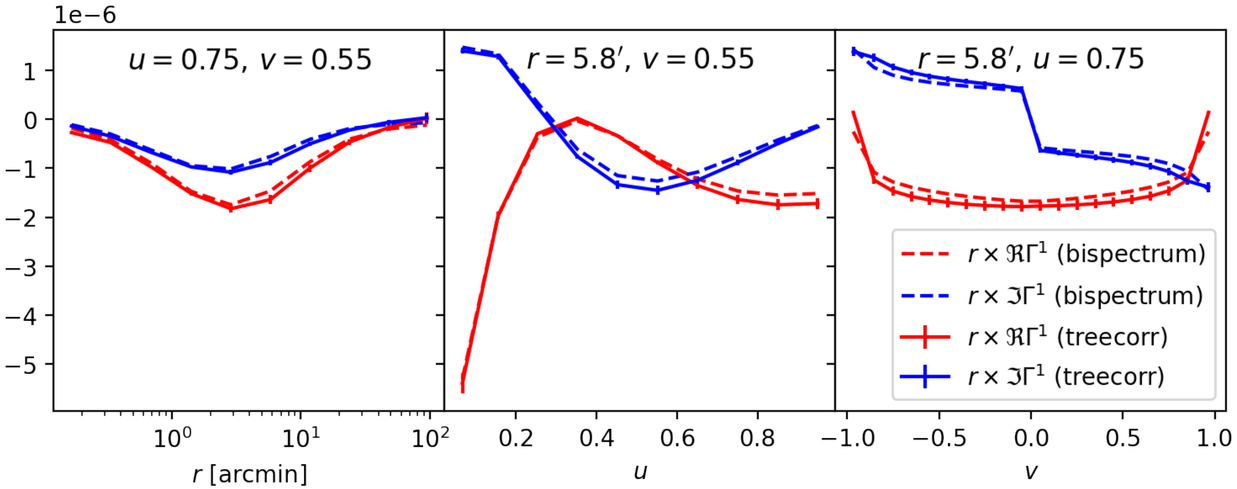

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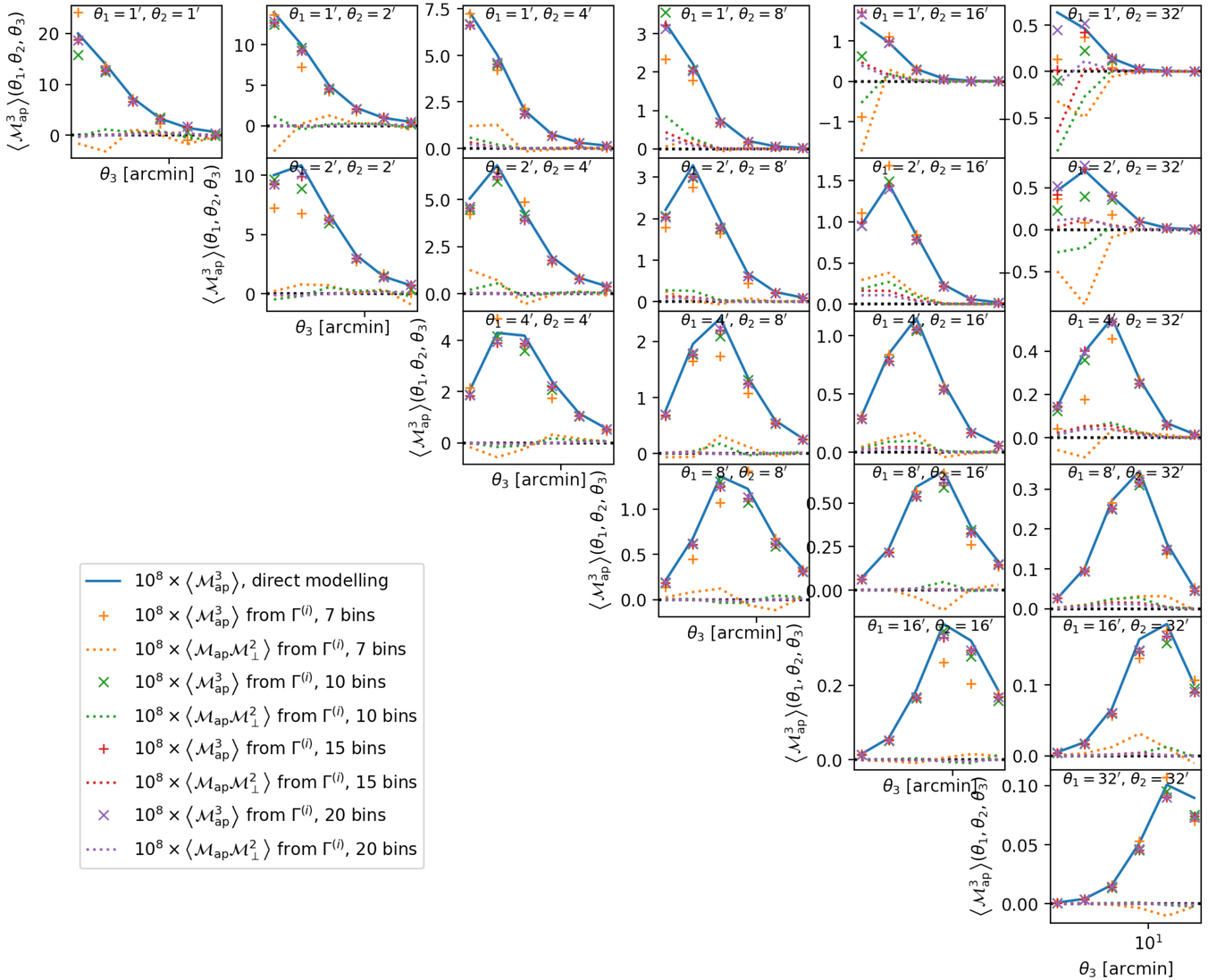

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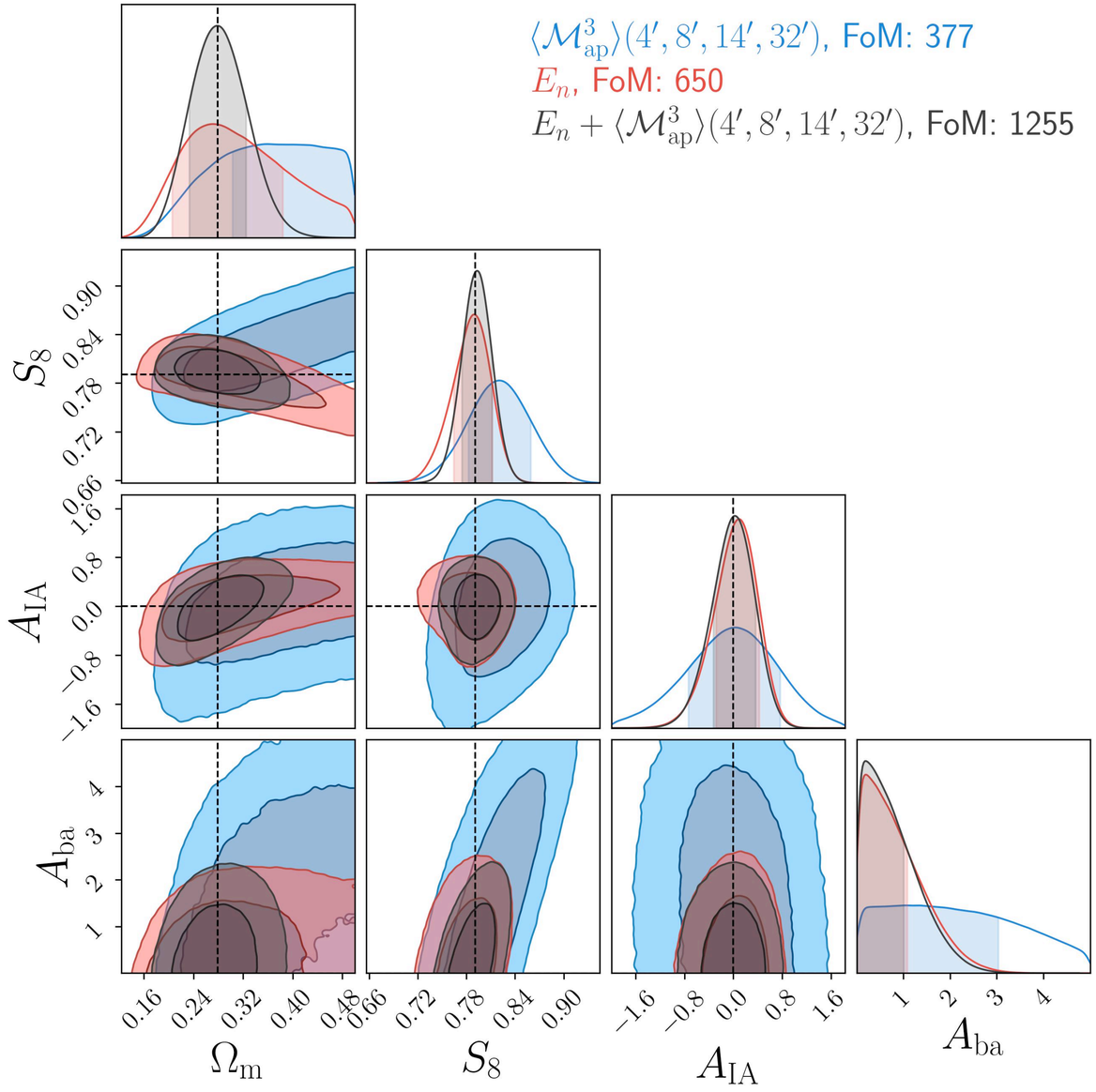

Burger et al. (2024, incl Heydenreich)

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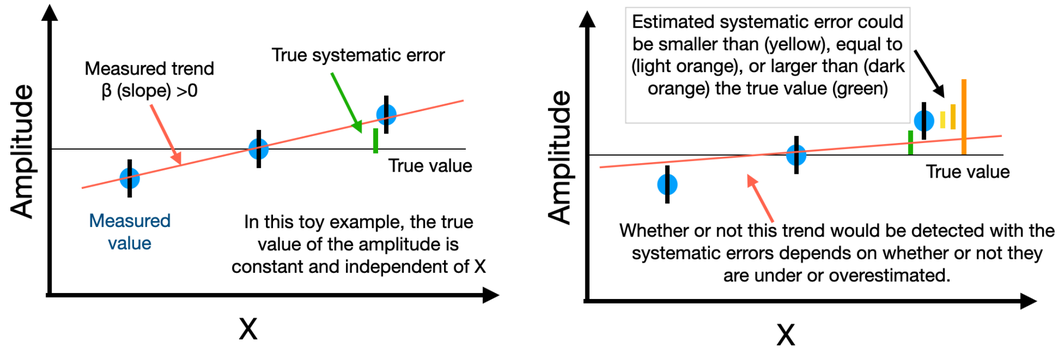
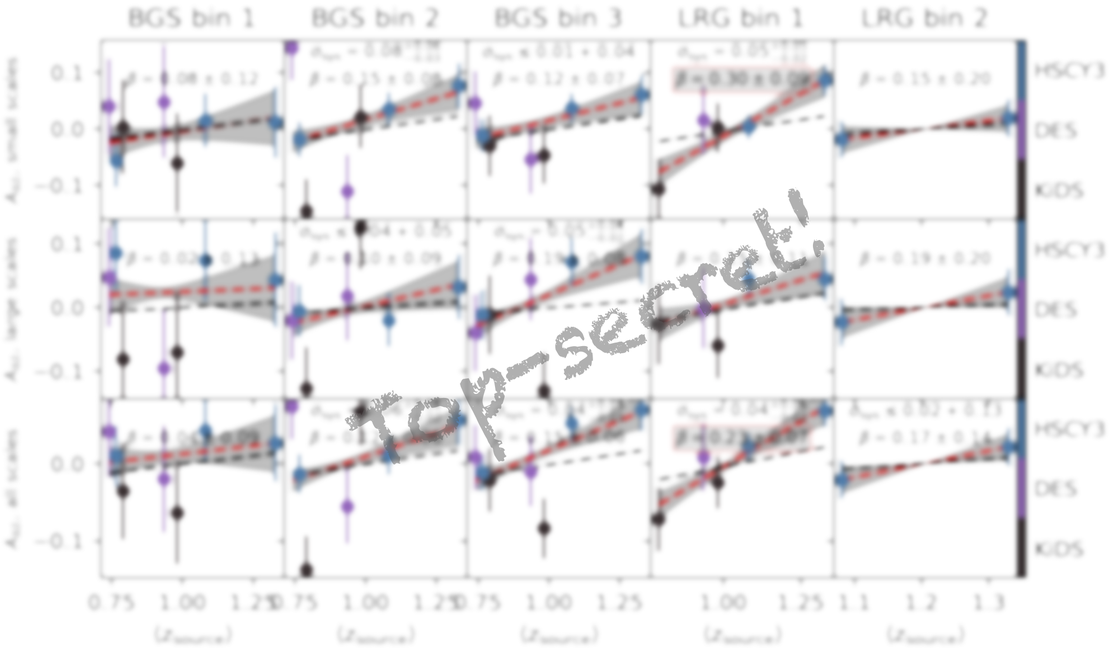
Preview: Directly constraining GGL systematics with DESI

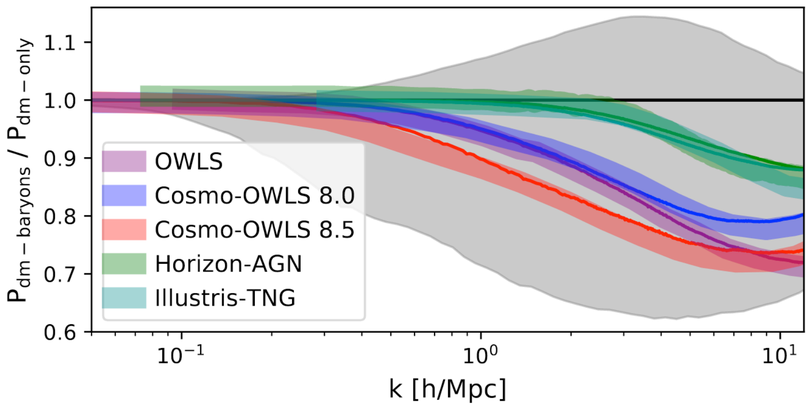
- Look for trends and excess scatter in excess surface density $\Delta\Sigma$
- $\Delta\Sigma$ is a physical quantity, should only depend on DESI galaxy sample!



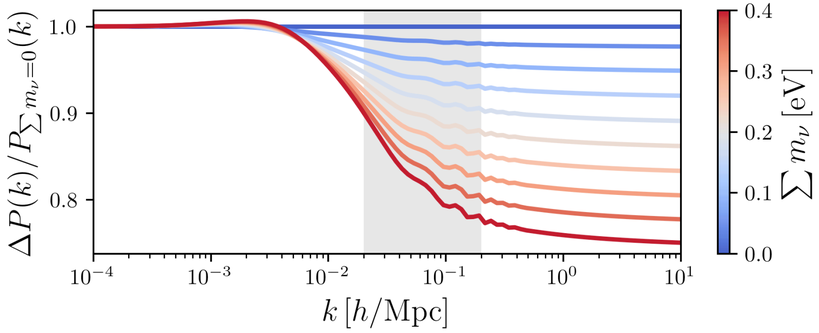


Leauthaud et al. (2022), Heydenreich et al. (to be submitted)

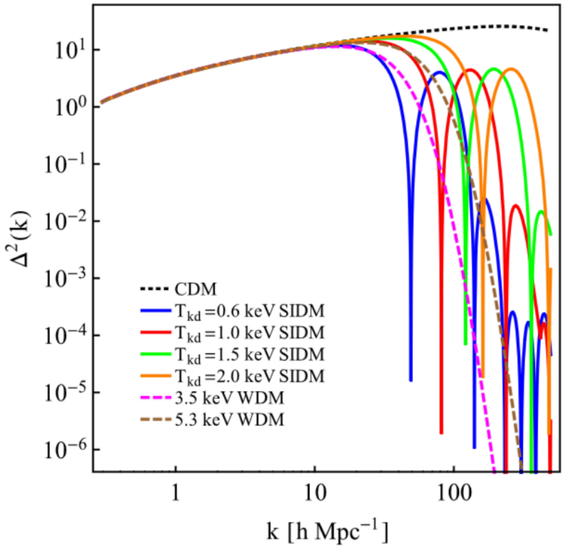
Baryons vs Dark Matter models



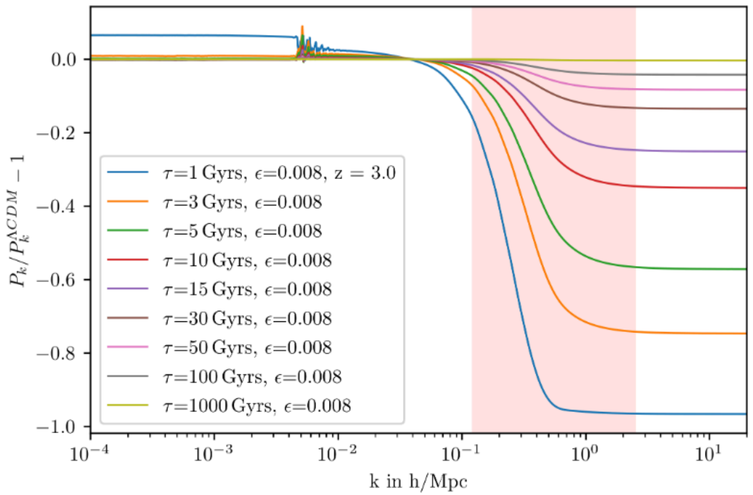
Baryon feedback, Schneider et al. (2020)



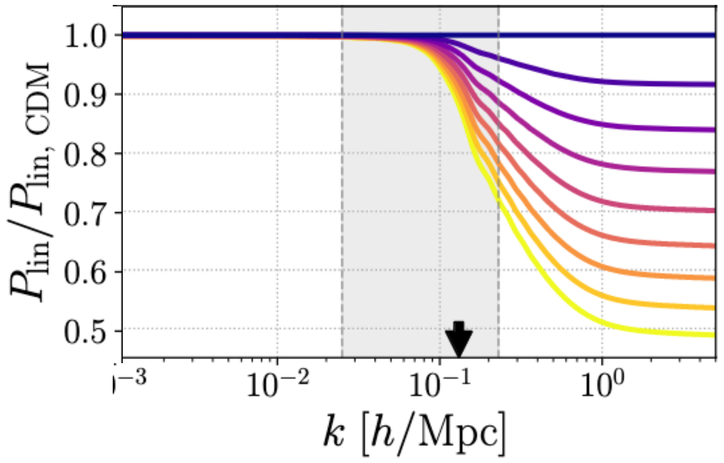
Massive Neutrinos,
DESI Collaboration (2024)



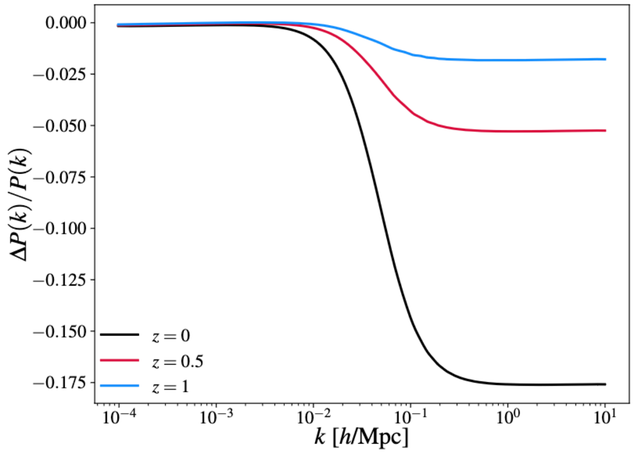
Self-interacting DM, Huo et al. (2018)



Decaying DM, Fuß et al. (2022)

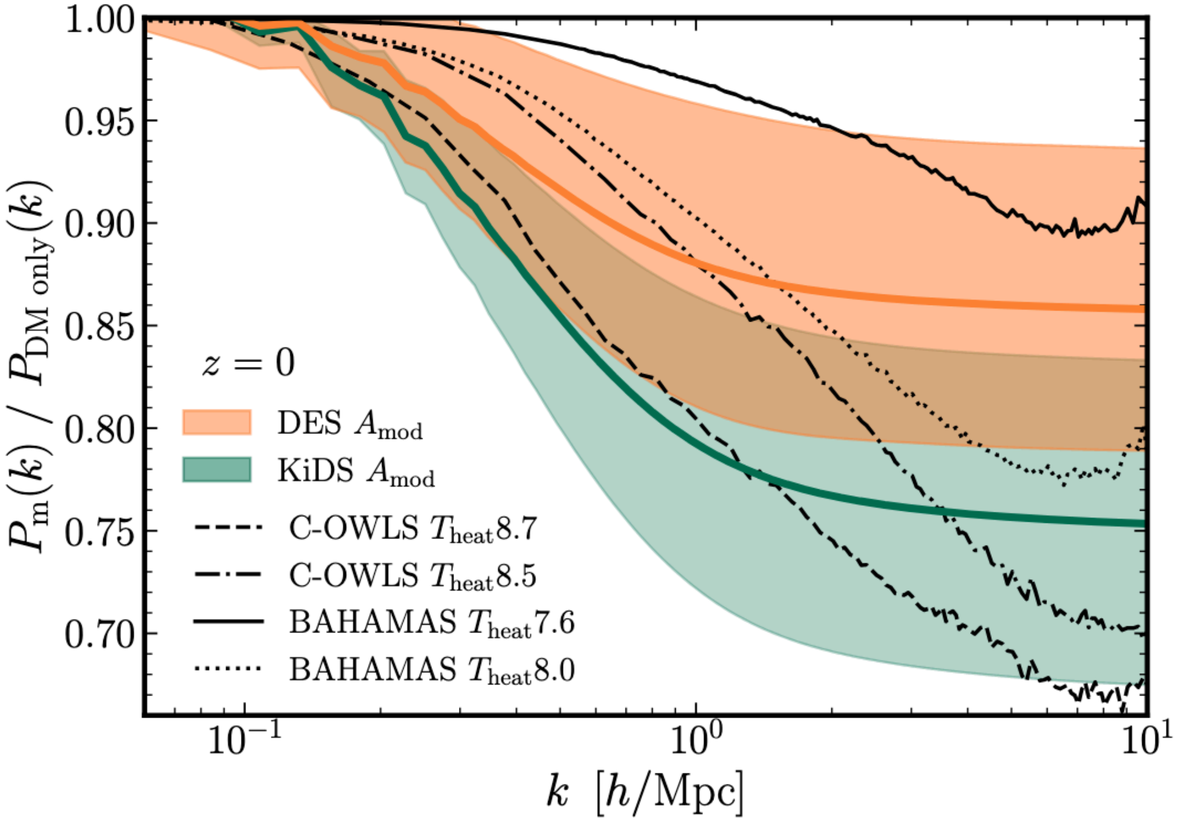


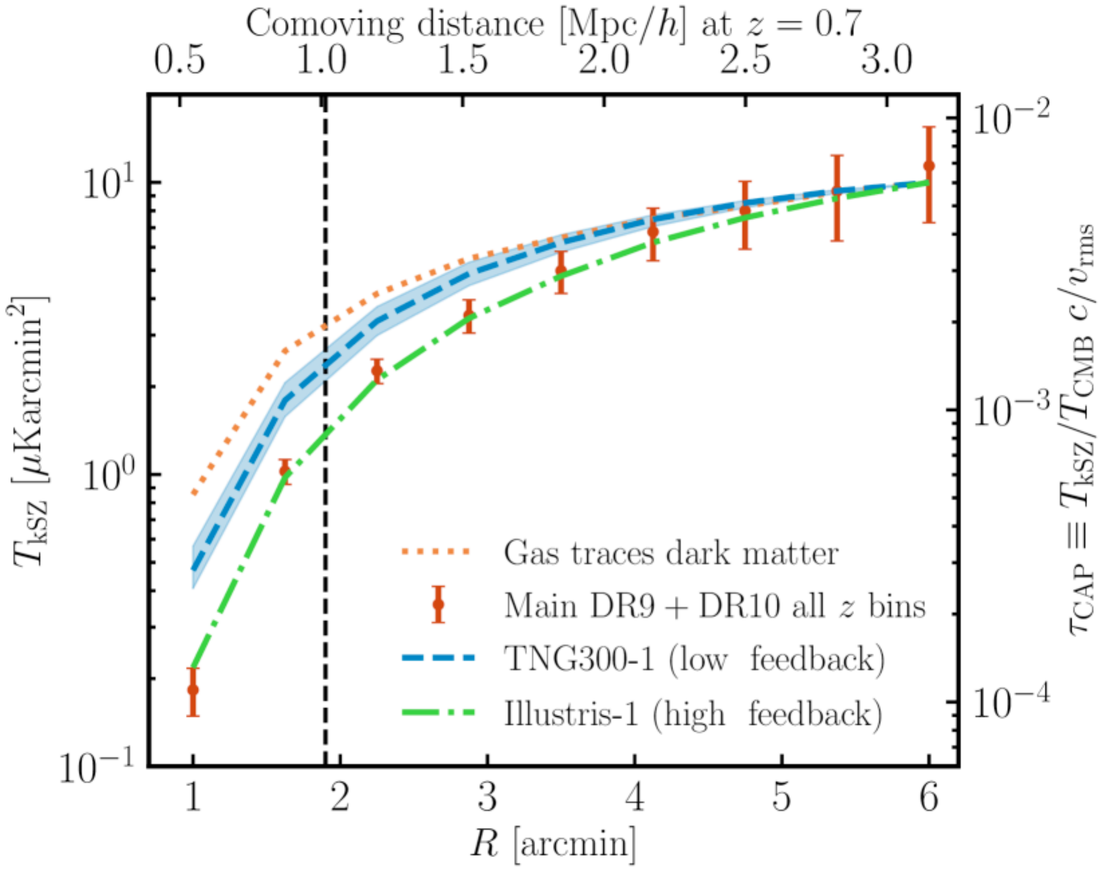
Ultralight Bosons, Laguë et al. (2022)



DM-DE coupling, Poulin et al. (2022)

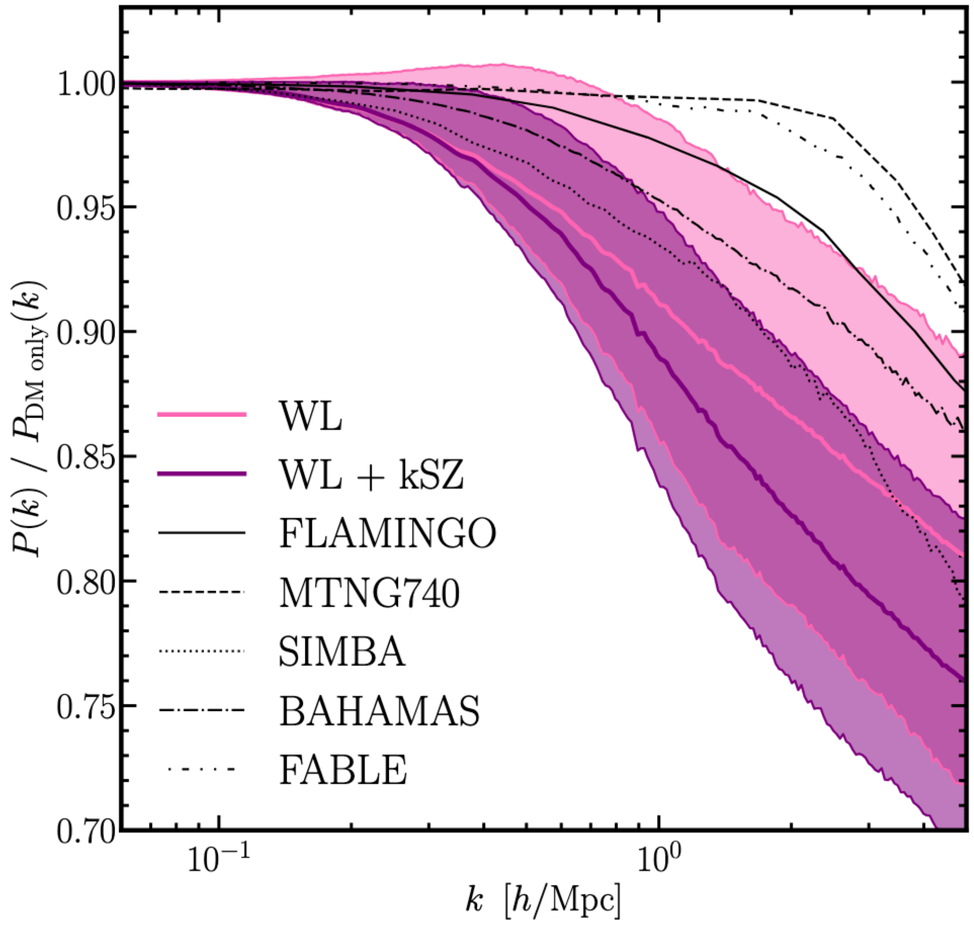
Baryon feedback as a solution for S_8 discrepancies

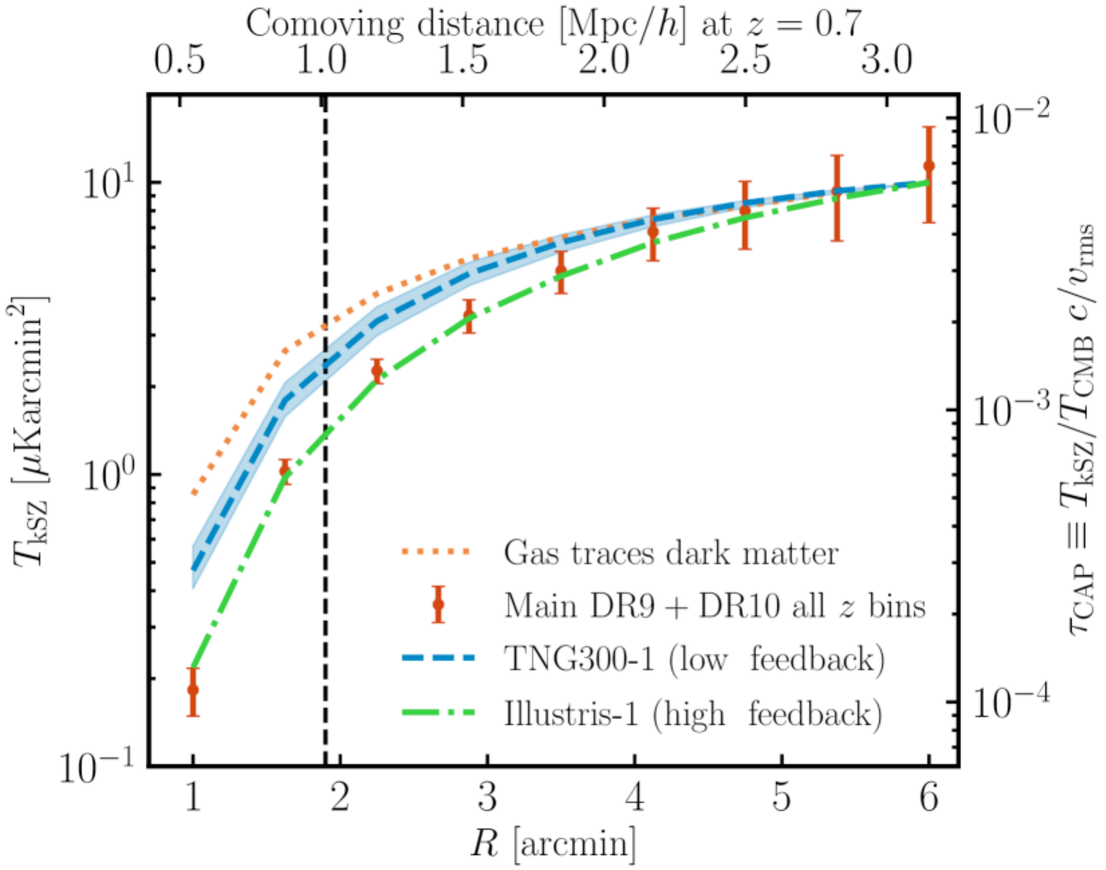




Bigwood et al. (2024), Preston et al. (2023), Hadzhiyska et al. (2024)

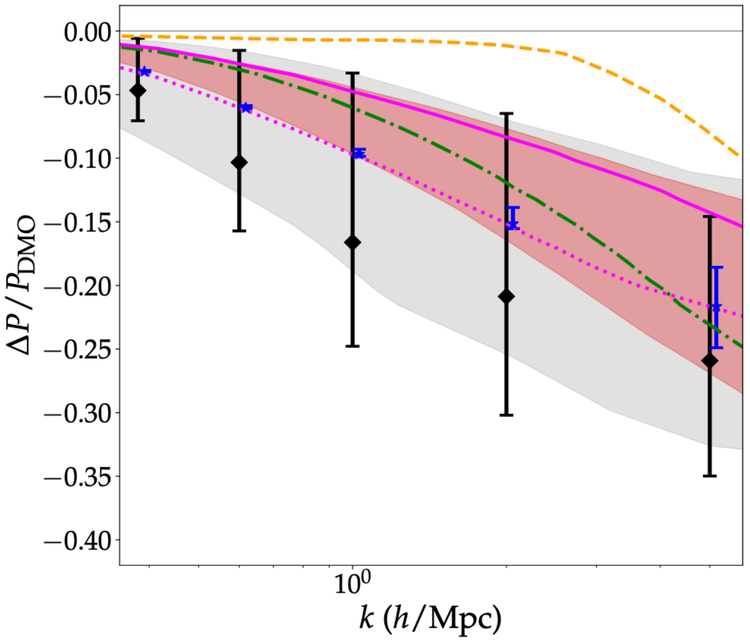
Baryon feedback as a solution for S_8 discrepancies

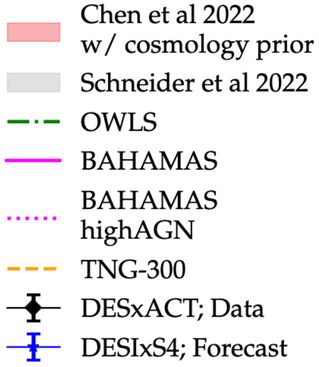


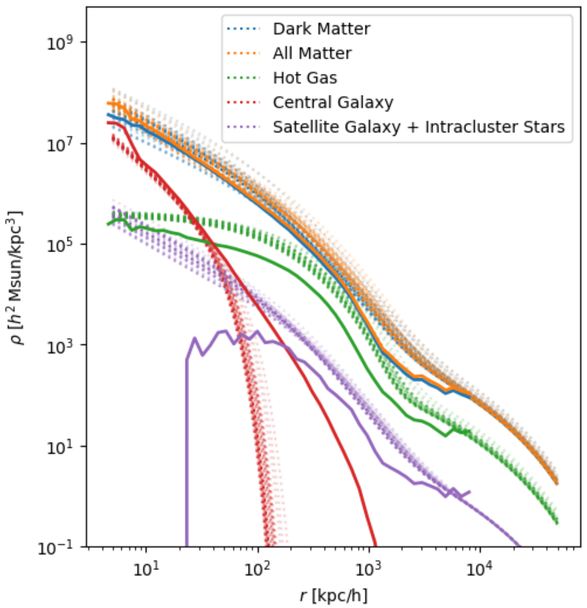


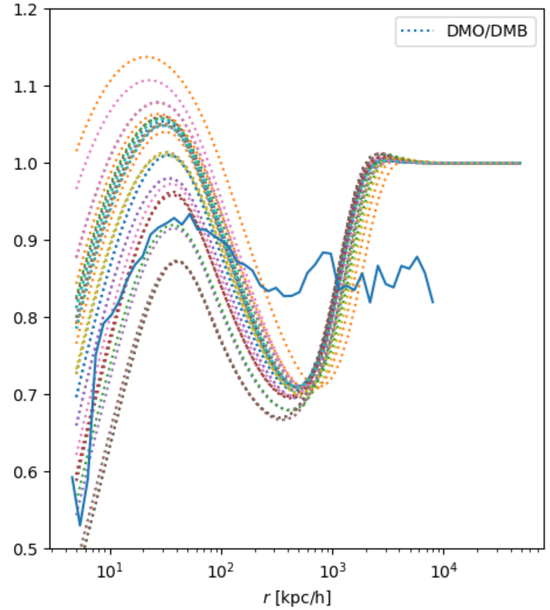
Bigwood et al. (2024), Preston et al. (2023), Hadzhiyska et al. (2024)

Solution to baryon feedback: Use GGL x SZ (or FRB, X-ray, ...)



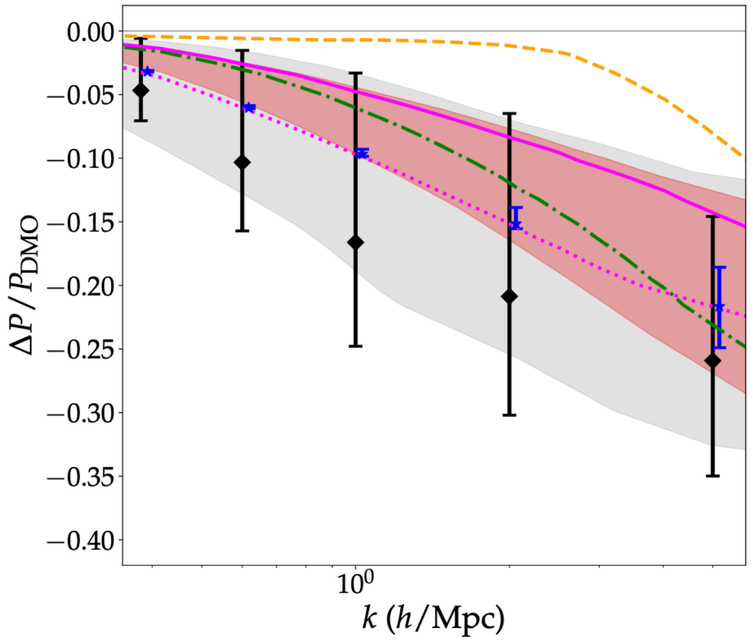


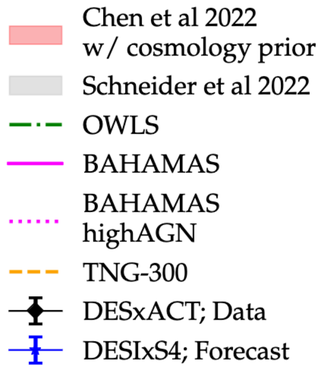


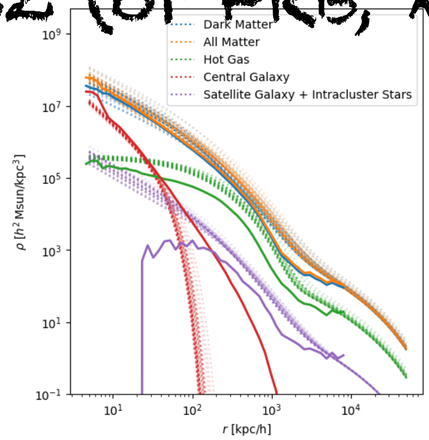


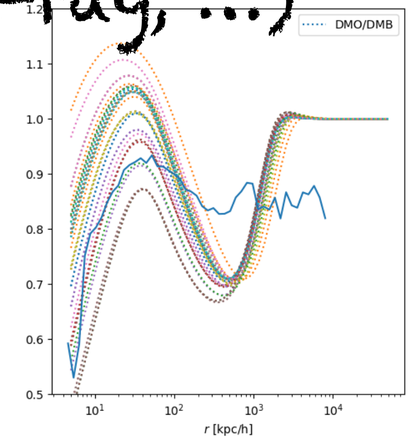
Pandey et al. (2023)

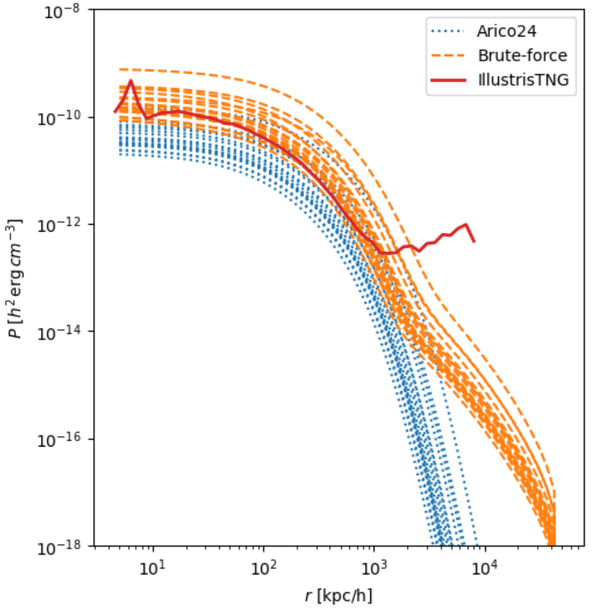
Solution to baryon feedback: Use GGL x SZ (or FRB, X-ray, ...)

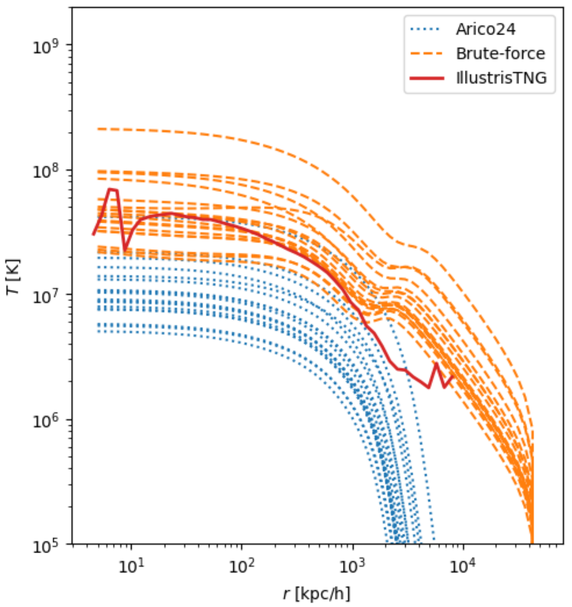










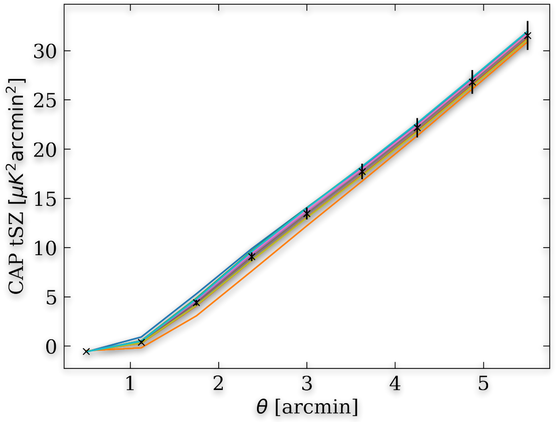


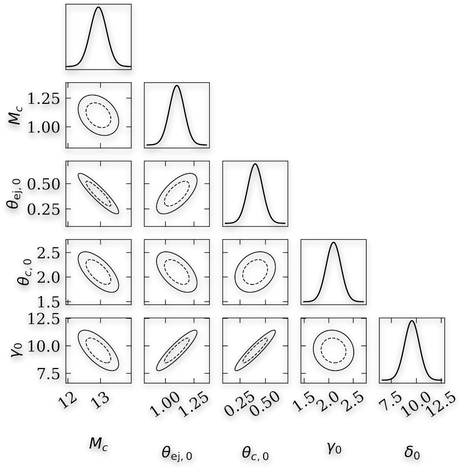
Pandey et al. (2023)

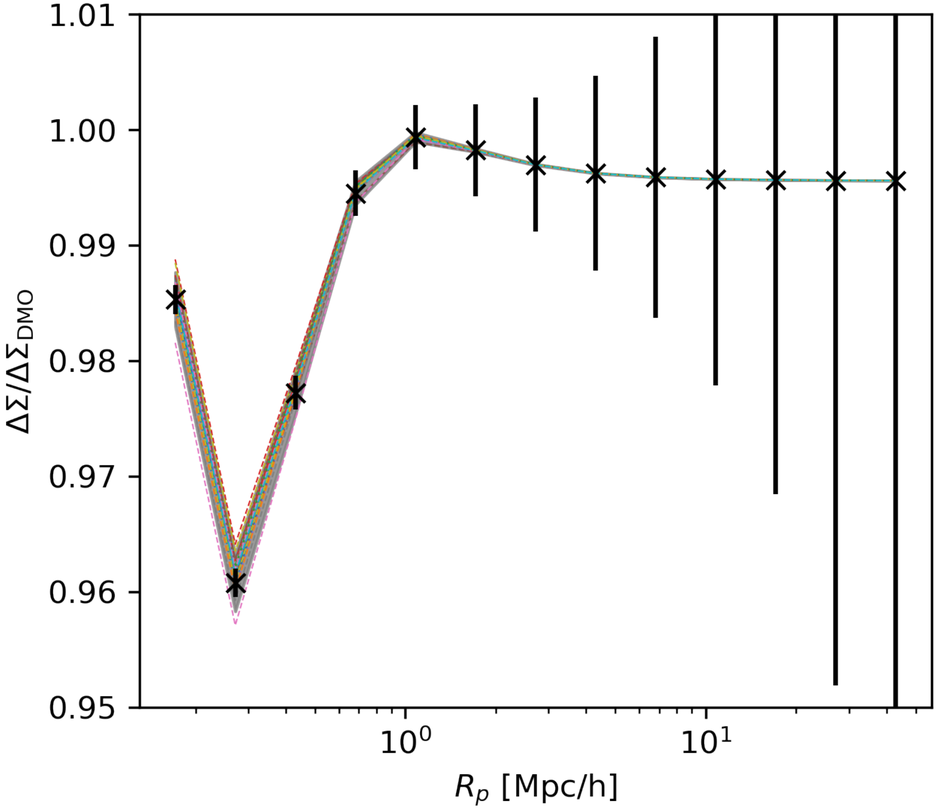
Constraining Baryons with DESI(-II)

Baryon feedback

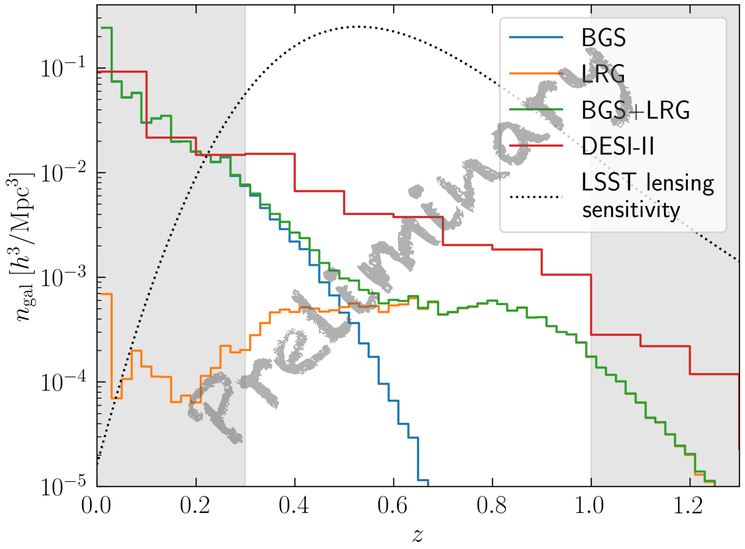
- SZ signal from DESI(-II) x SO
- GGL signal from DESI(-II) x Rubin
- Constrain power suppression on small scales

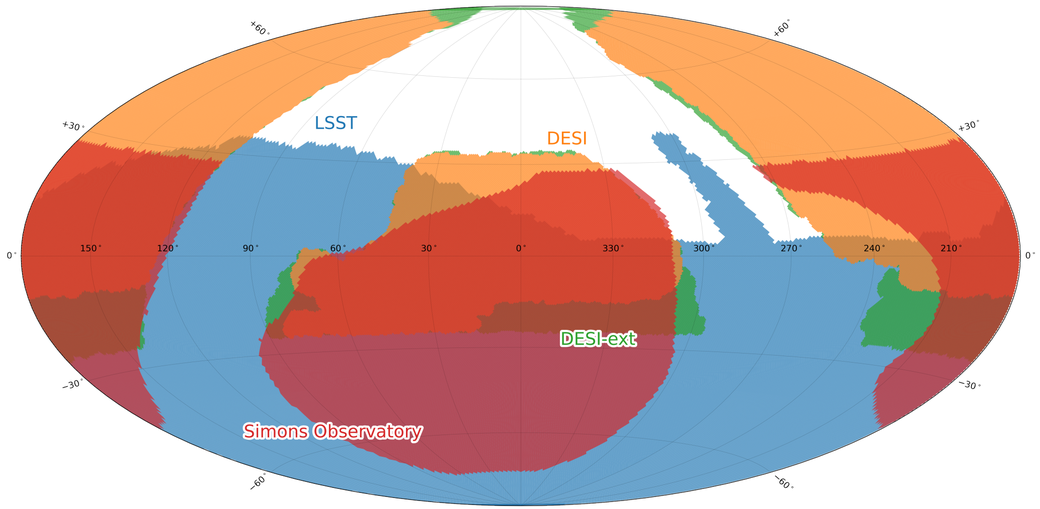




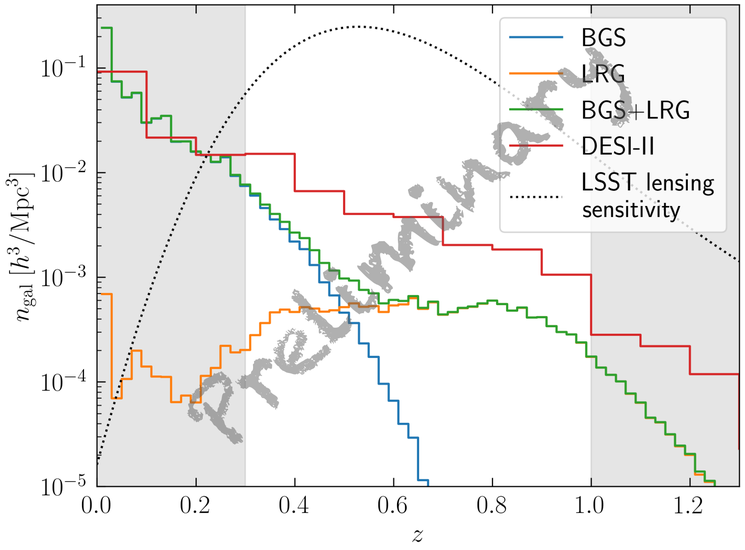


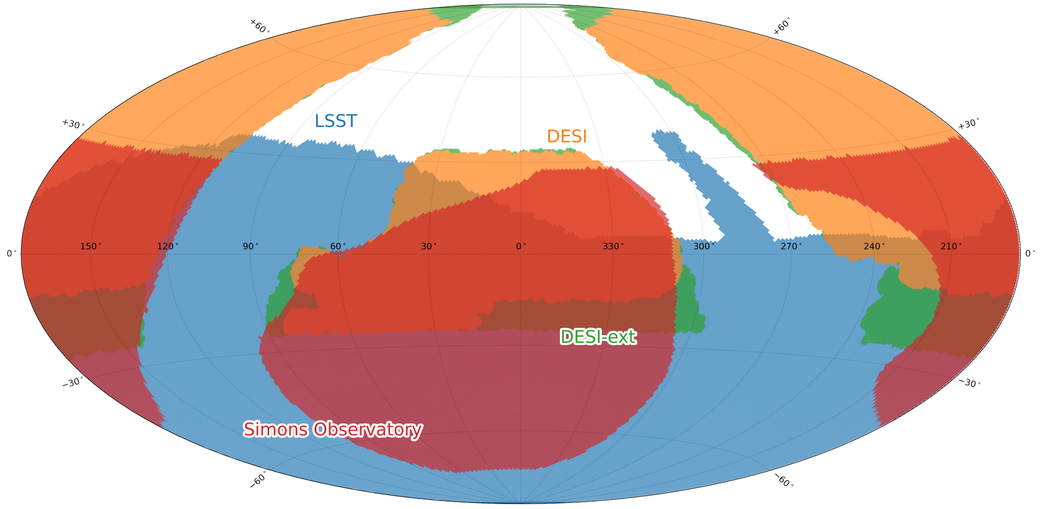
DESI-II – a high density sample

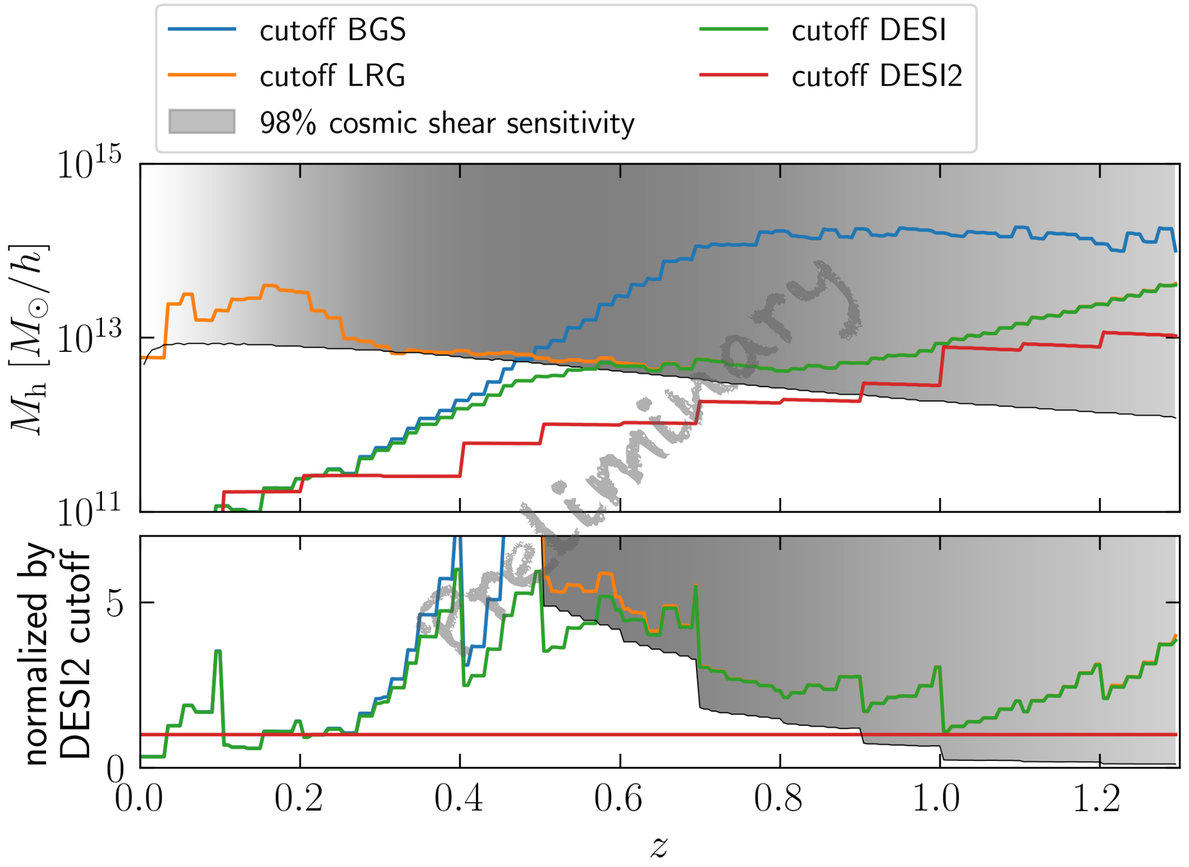




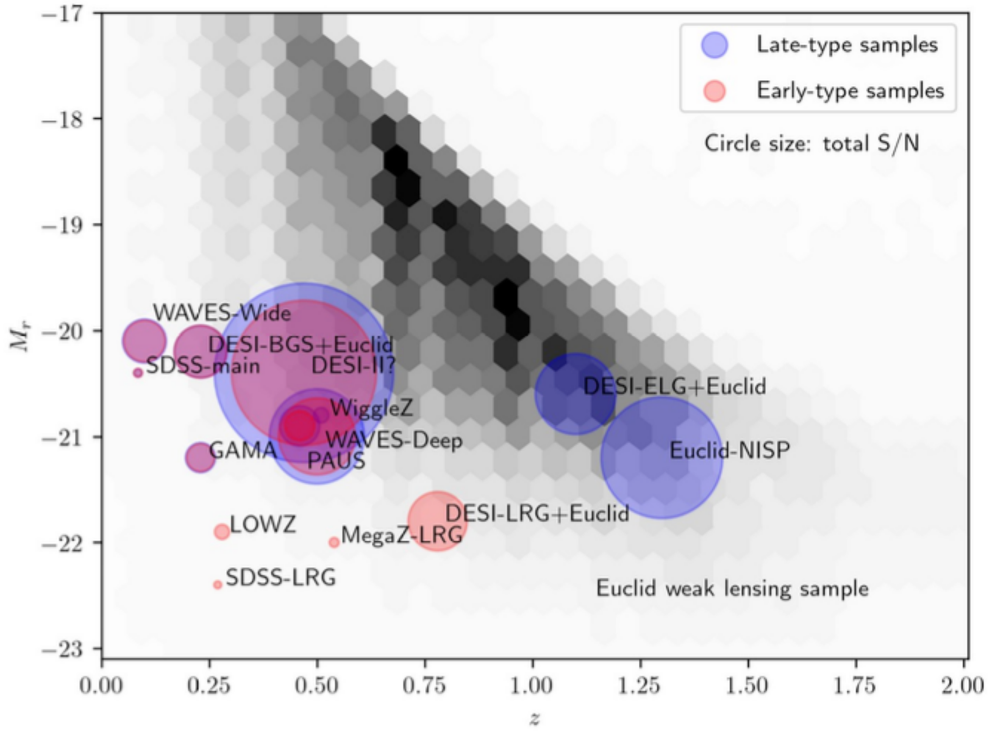
DESI-II – a high density sample







Intrinsic Alignments with DESI(-II)

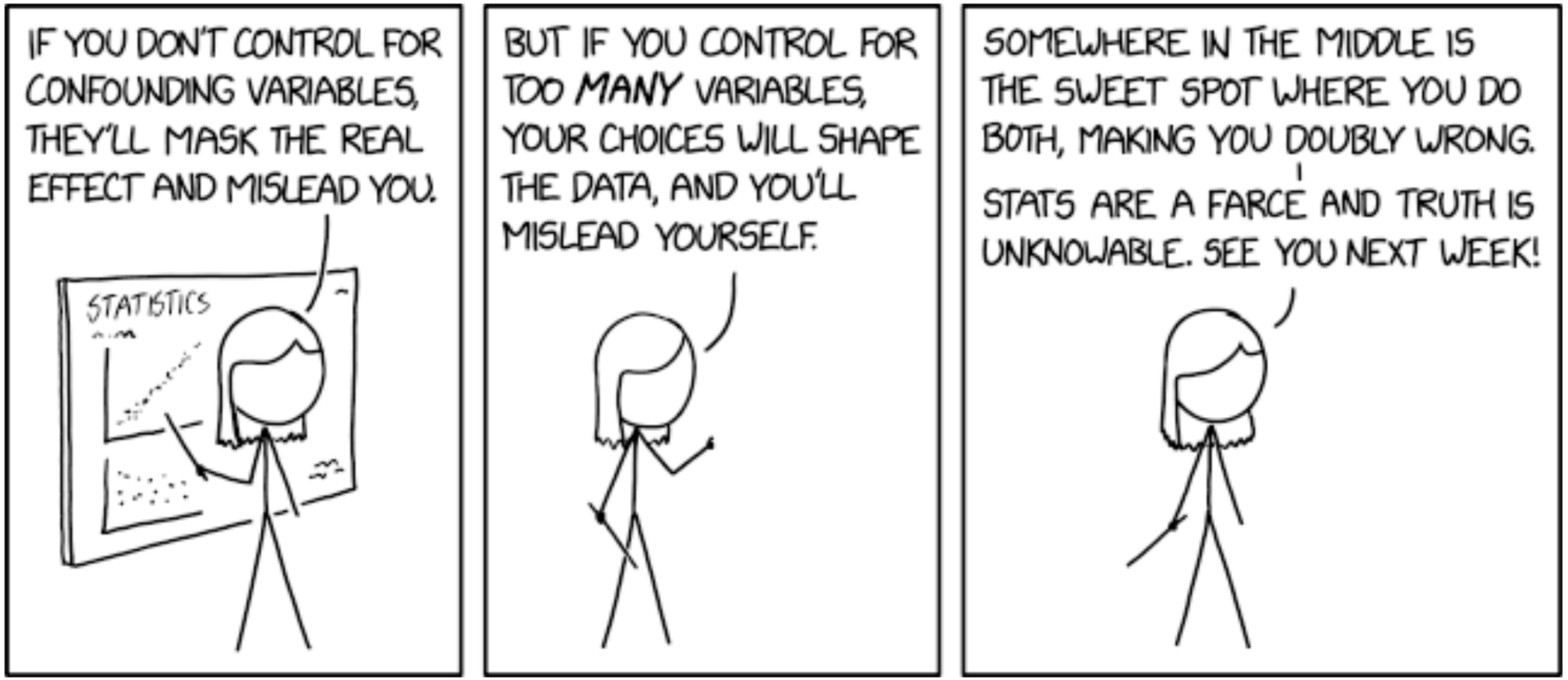


Credit: Benjamin Joachimi

Main takeaways

- Constraints without confidence have limited use
- We should not only report cosmological parameters, but constraints on $P(k,z)$
- Higher-order statistics + combined probes enable independent tests of systematics
- The DESI-II high-density sample promises to be an amazing test bed for astrophysical systematics
- We have to figure out how to disentangle (astrophysical) systematics and dark matter models

Thank you for listening!



Randall Munroe/xkcd