Weak lensing: *wins & worries*

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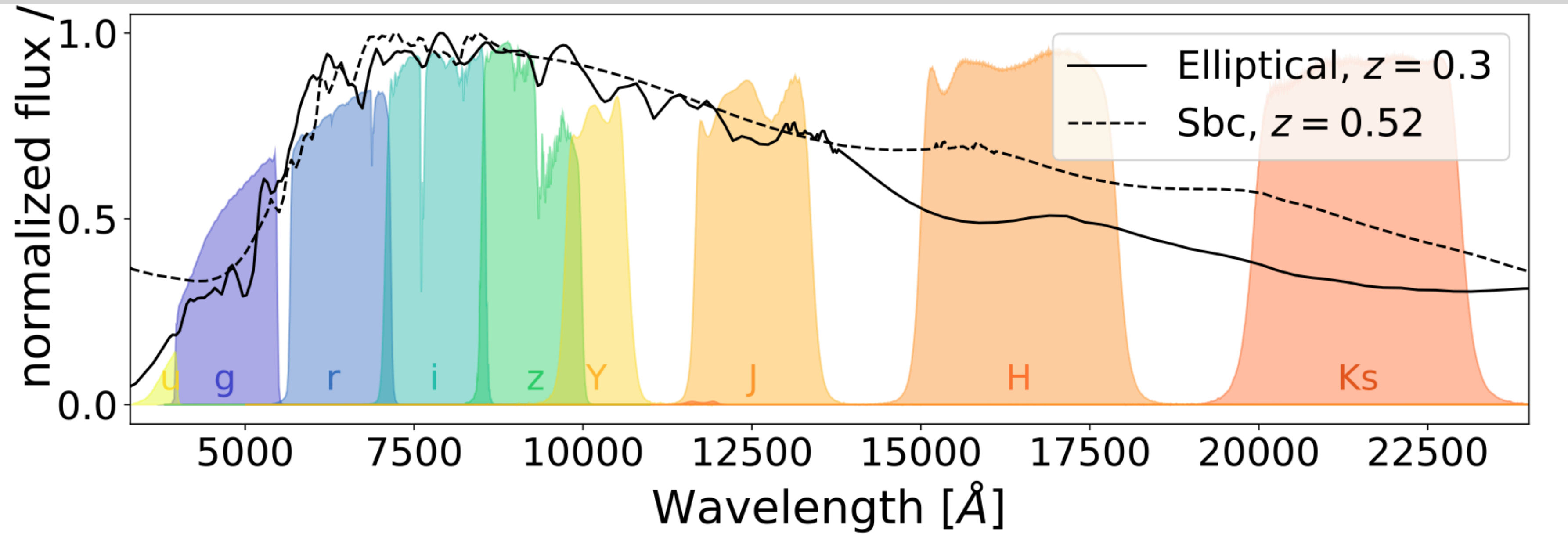
@astroalexamon

UNIVERSITY OF CAMBRIDGE

Cosmic shear *usual suspects*

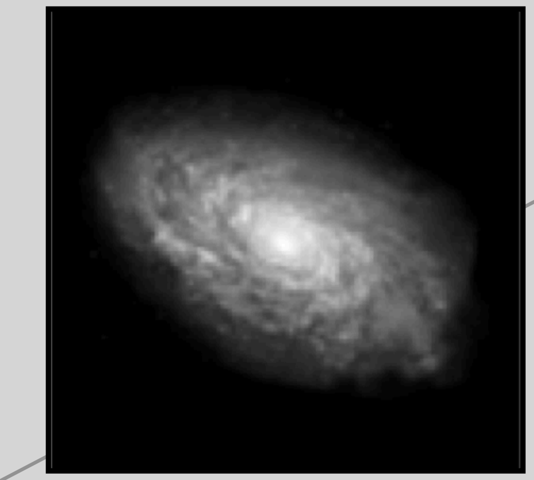
Redshift calibration

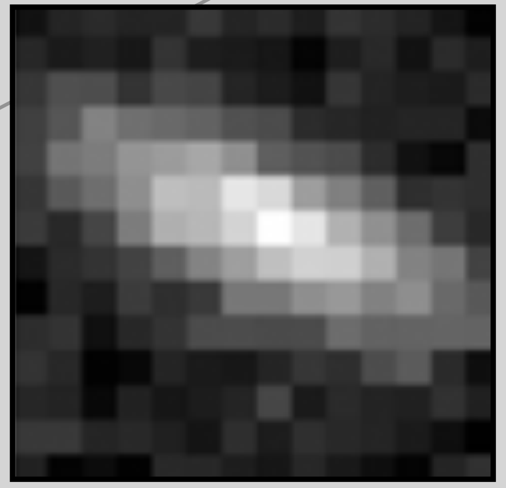
Challenge: Estimating the distances to galaxies using only a few colours

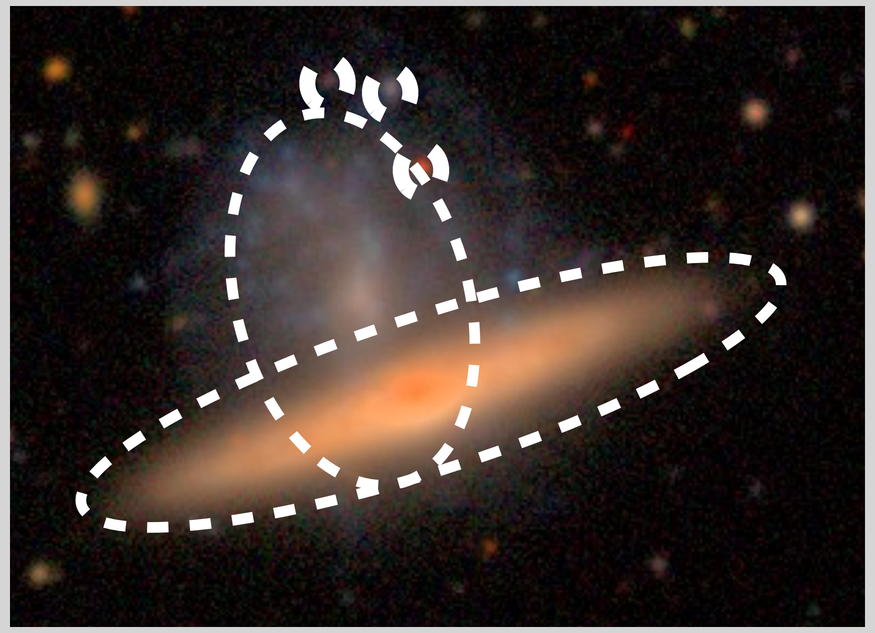


Shear calibration: blending

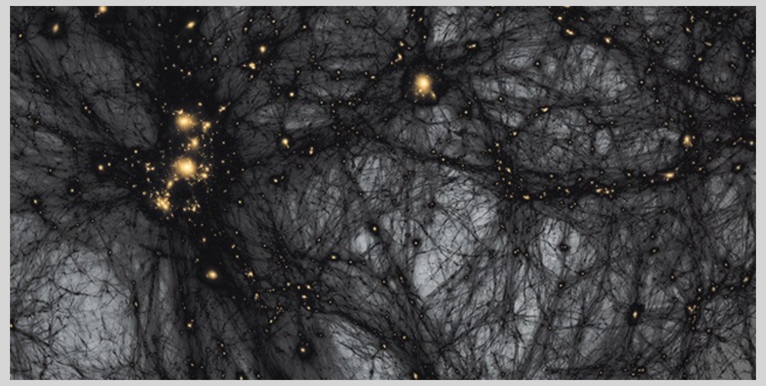
Challenge: Galaxies are not only sheared, but smeared, blurred, pixellated, noisy & blended





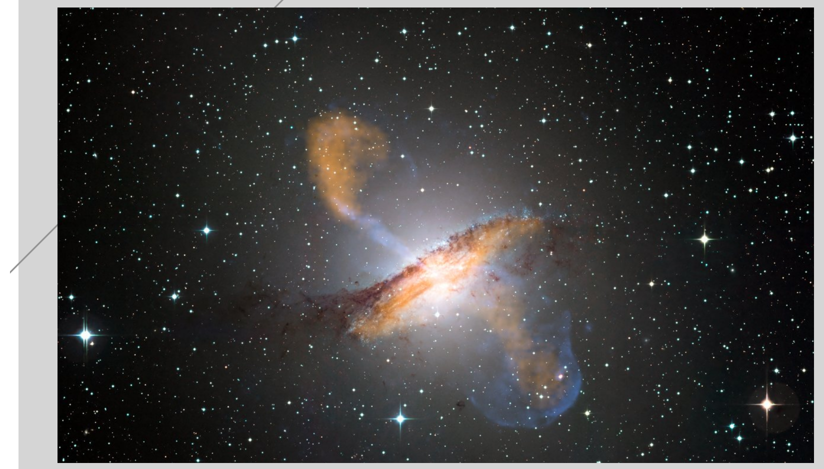


Model choices: intrinsic alignments



Challenge: Galaxies intrinsically aligned (IA). Is the IA model well-suited to late-type galaxies, which dominate lensing samples? Is it flexible enough to encompass our lack of understanding of this effect?

Scale cuts & baryonic effects



Challenge: Baryon feedback in galaxies alters the matter power spectrum on small scales. There is a large uncertainty on the amplitude and the extent of this effect.

Accurate lensing is hard!
…But we've made incredible progress.

The versatility of weak lensing

The data is coming

Weak lensing cosmology

Cosmological inference with systematics

Pixels to cosmology

The S_8 tension: the who's who

Solutions to the S_8 tension: wrong answers only

A non-linear solution to the S_8 tension?

Tackling weak lensing systematics: Headaches and hopes

The future of weak lensing

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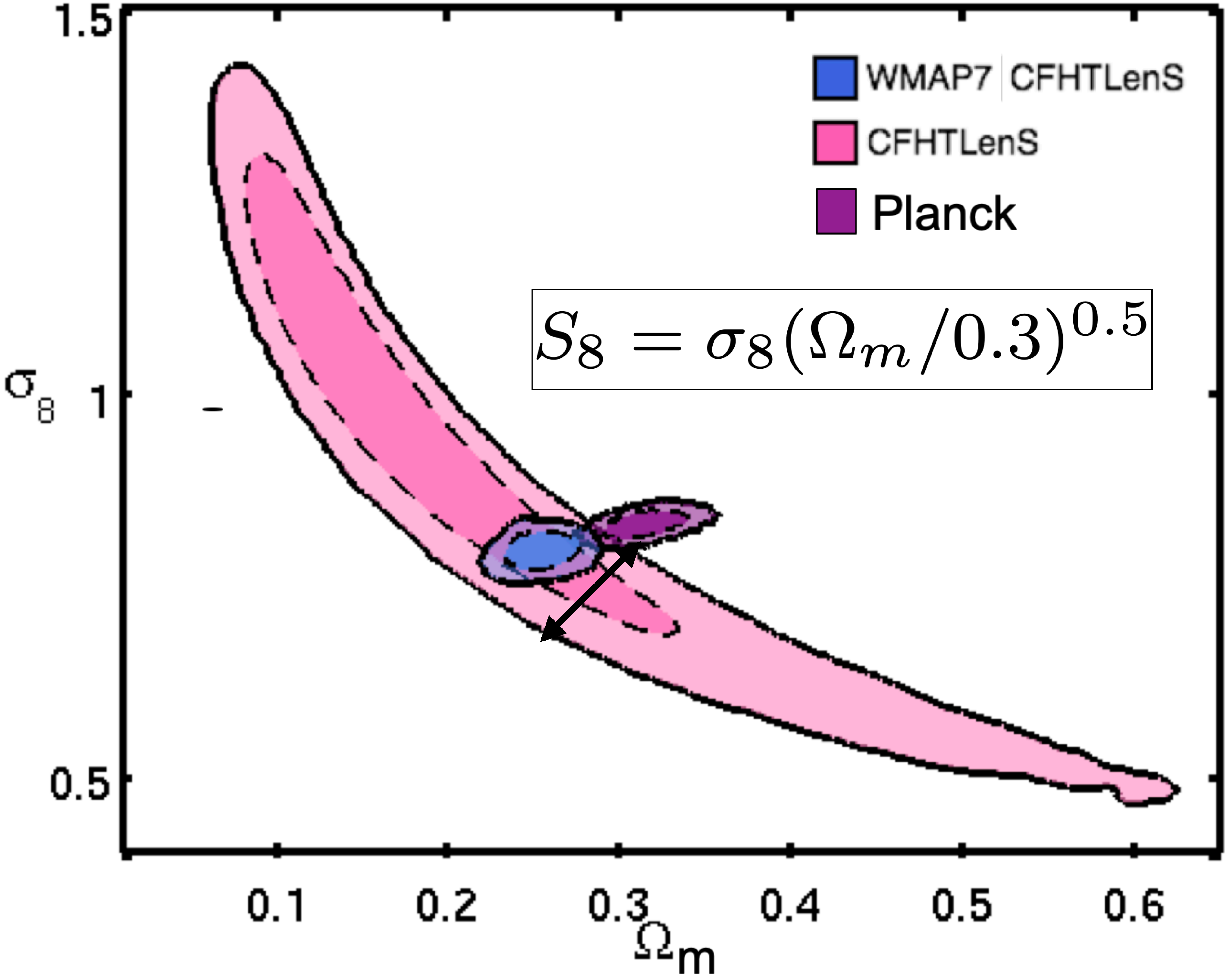
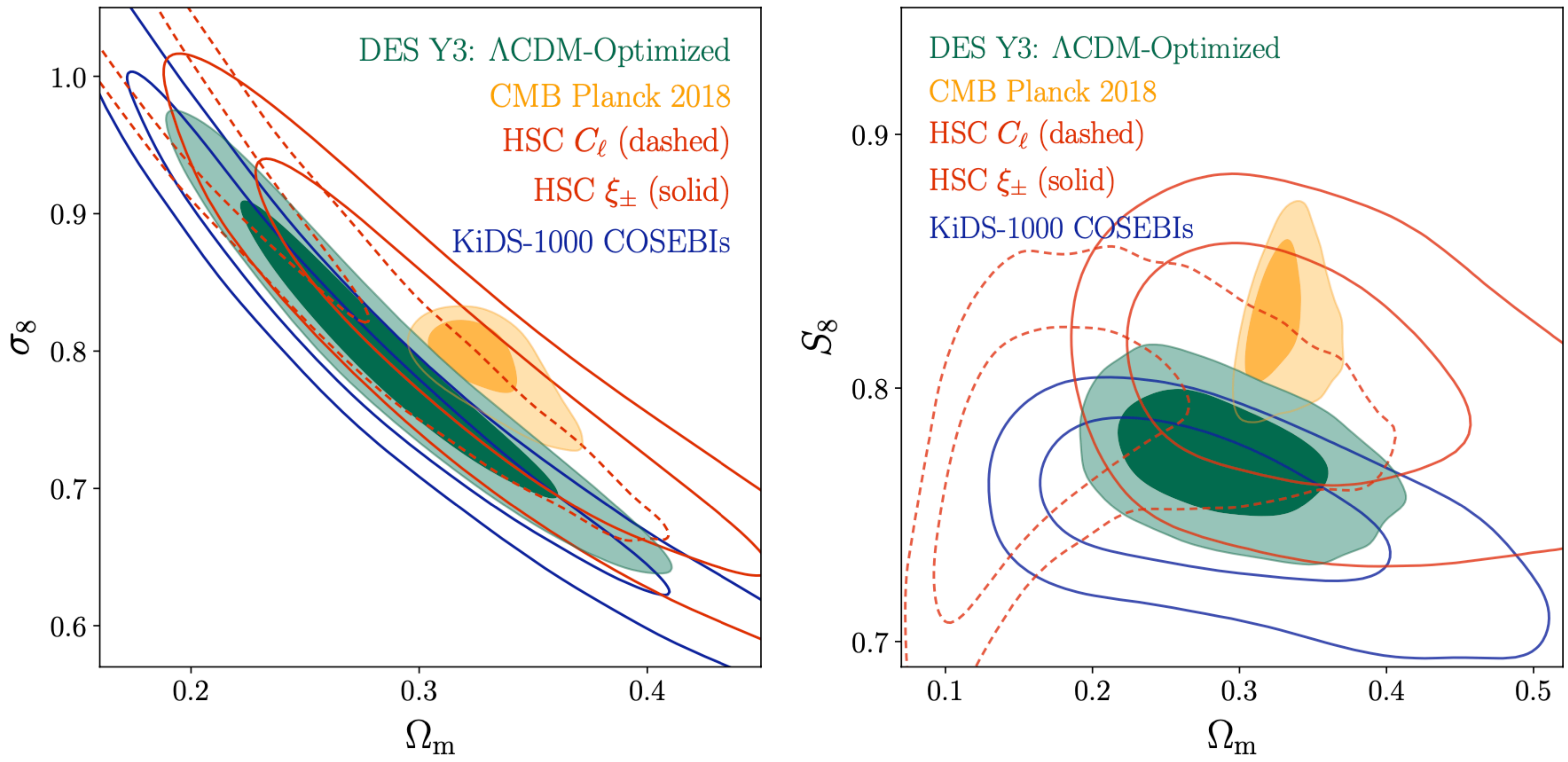
The ‘*OG*’ of the S_8 tension:

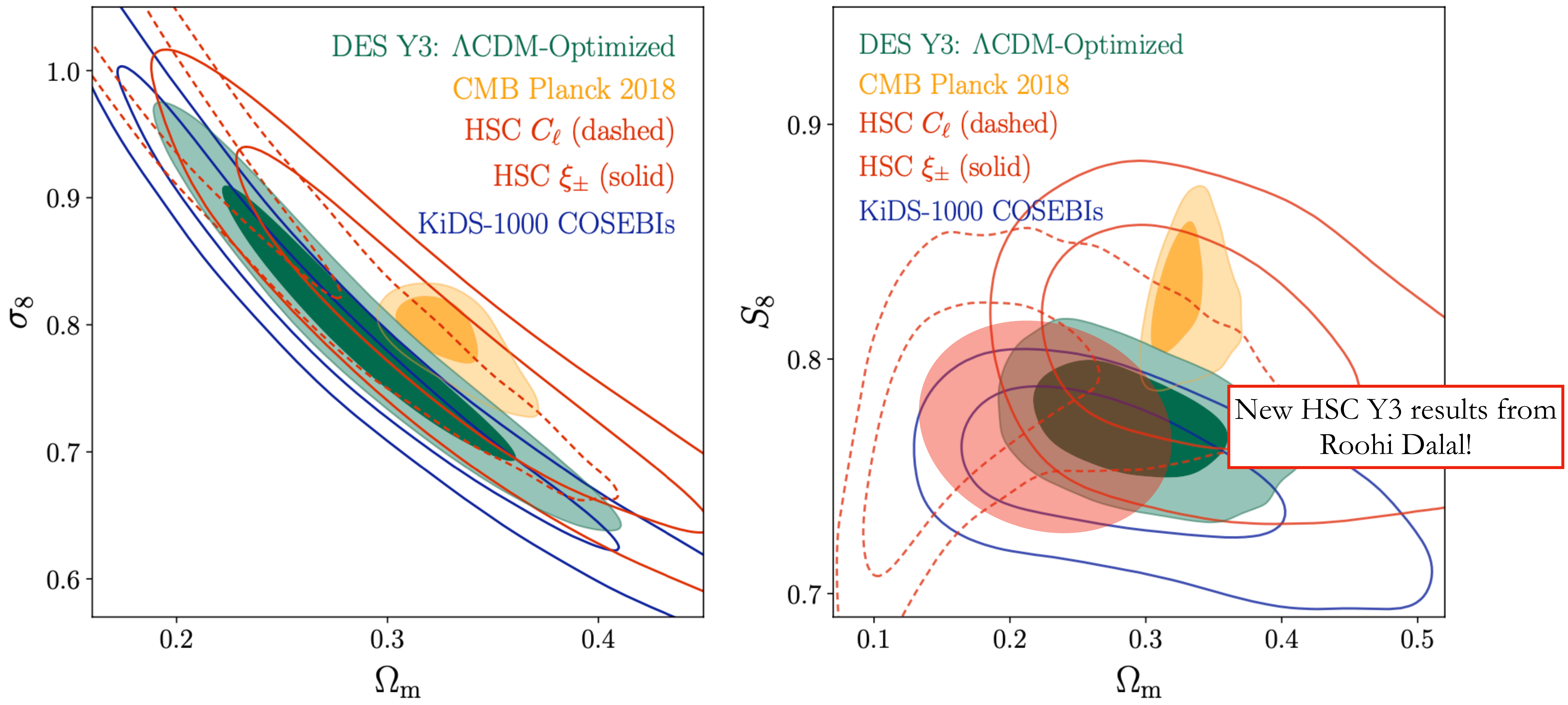
Figure from Catherine Heymans, 2013
~9 million galaxies



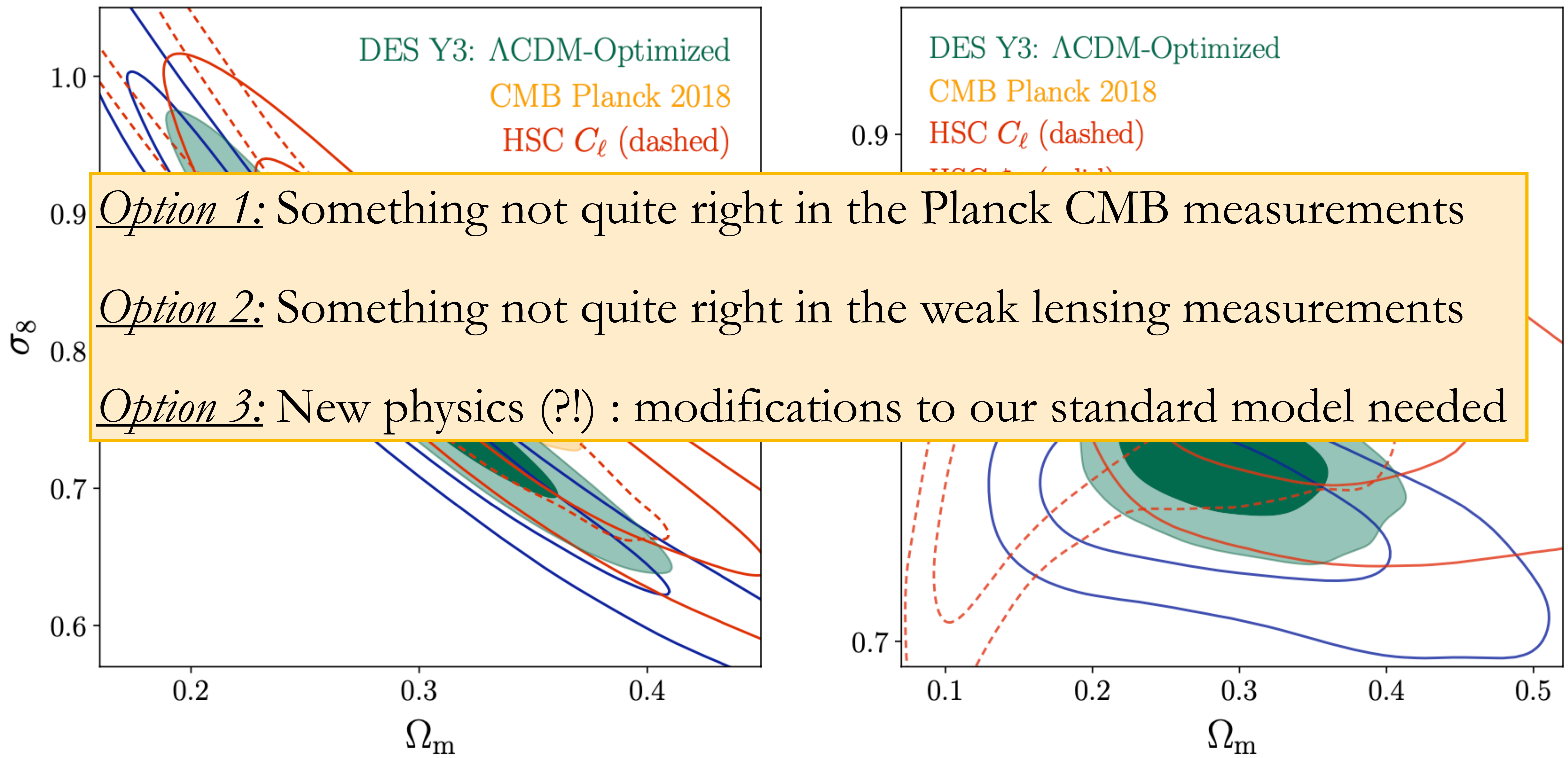
S_8 tension: Weak lensing



S_8 tension:
Weak lensing



S_8 tension:
Weak lensing

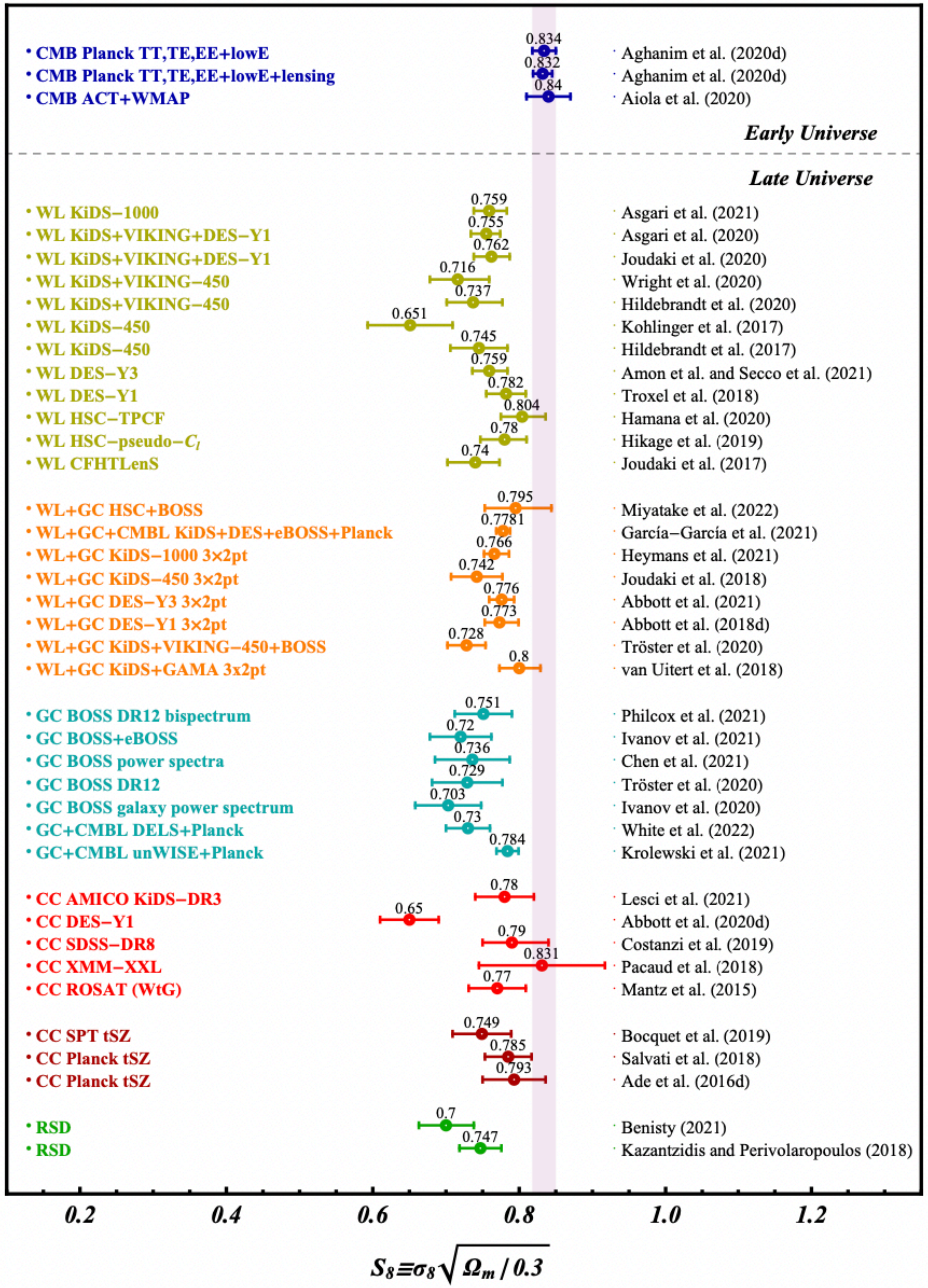


__Option 1:__ Something not quite right in the Planck CMB measurements

__Option 2:__ Something not quite right in the weak lensing measurements

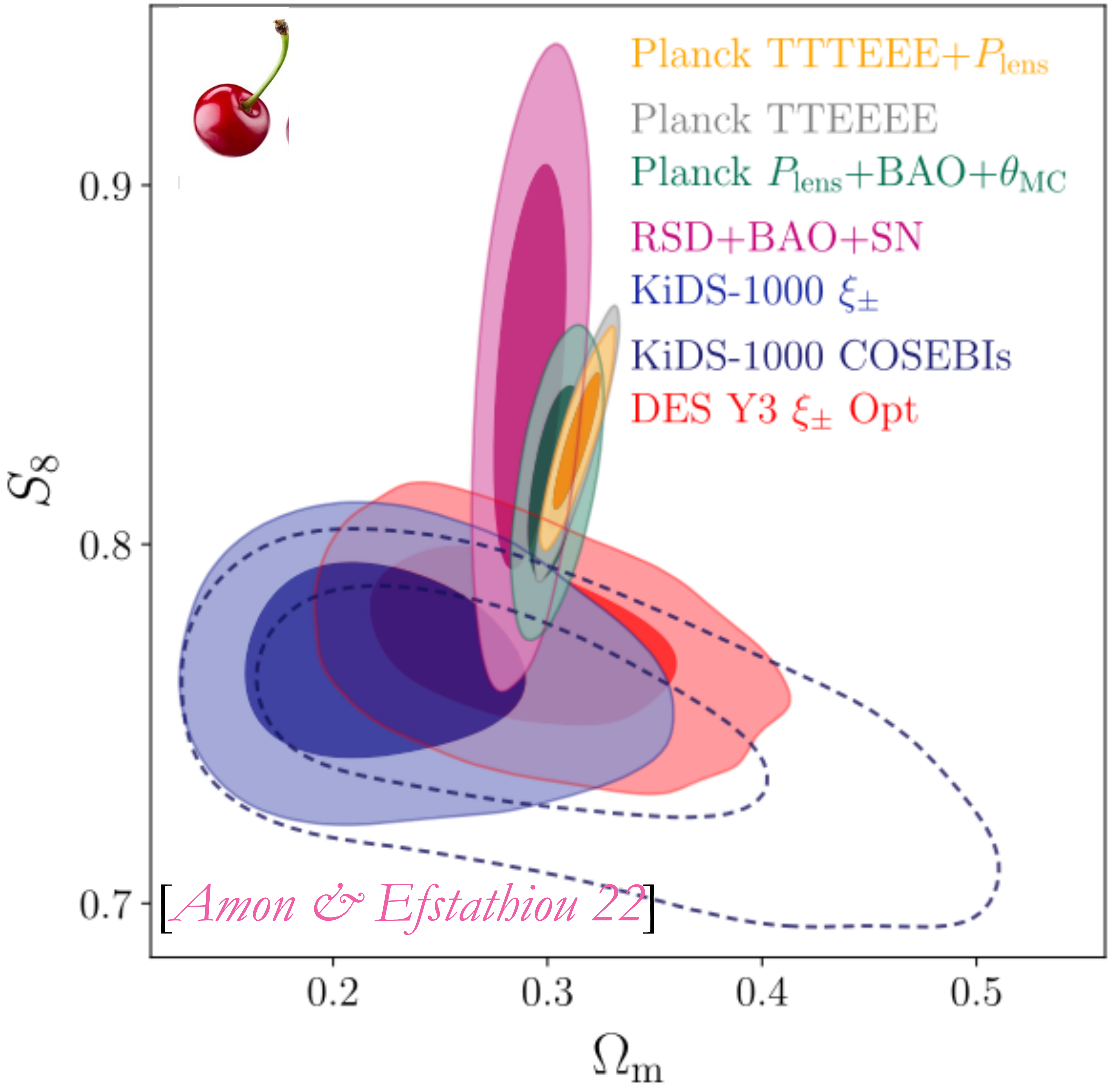
__Option 3:__ New physics (?!) : modifications to our standard model needed

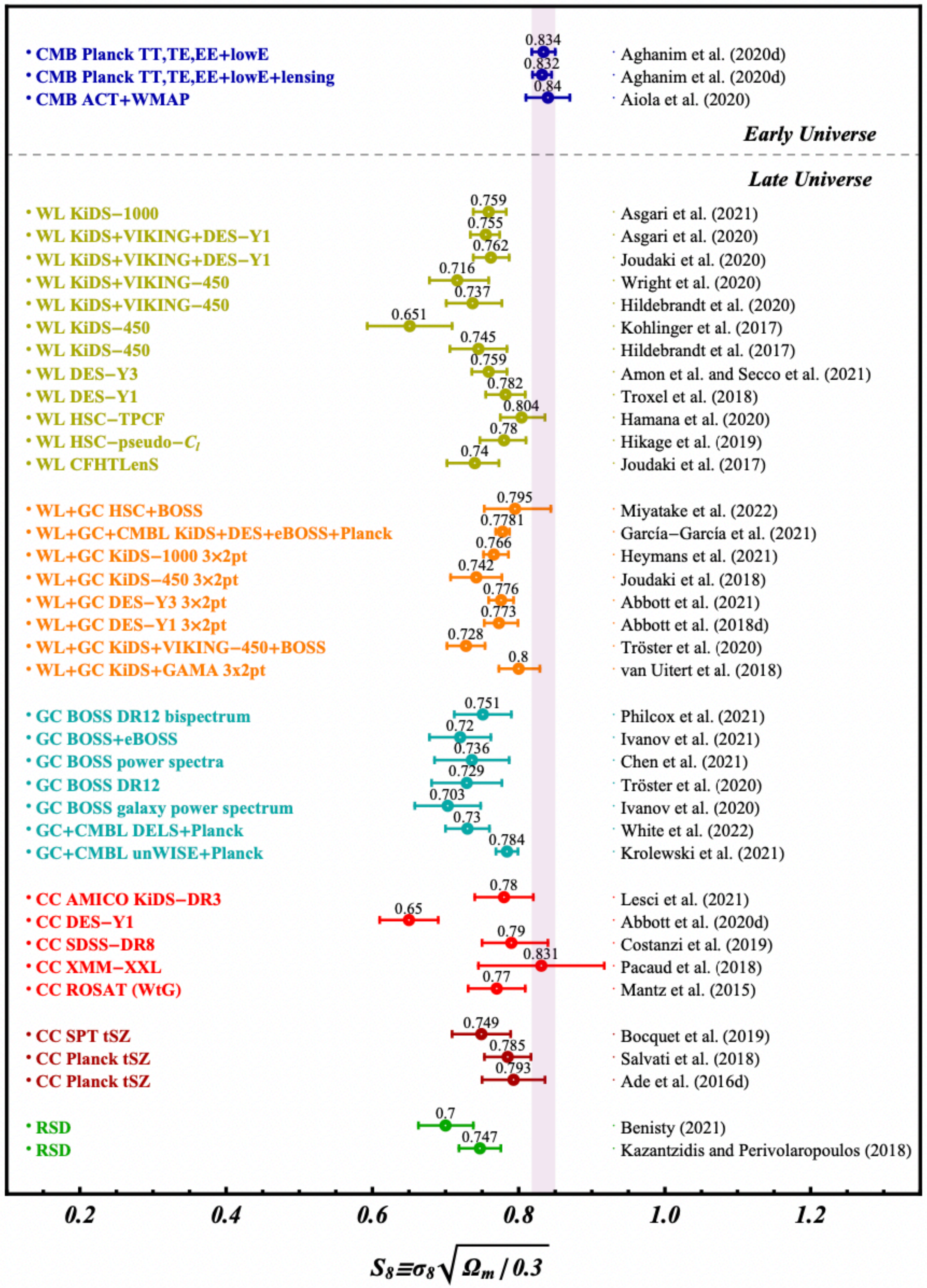
S_8 tension:
Early Universe vs. Late Universe



Watch out for cherry-picking and double counting!

S_8 tension:
Early Universe vs. Late Universe





Watch out for cherry-picking and double counting!

S_8 tension: Weak lensing

Analysis choices matter! To compare the lensing consistency, or to combine, results need to be on the same footing.

First joint KiDS+DES collaboration effort!

with KiDS: Asgari, Heymans
DES: Porredon, Samuroff
KiDS & DES: Amon, Choi

- *MCMC sampler* *
- *Priors on cosmological parameters*
- *Modelling pipeline*
- *Non-linear power spectrum modelling*
- *Scales measured*
- *Intrinsic alignment model* *
- *Baryon effects mitigation*
- *Statistics used*
- *Tension metric*

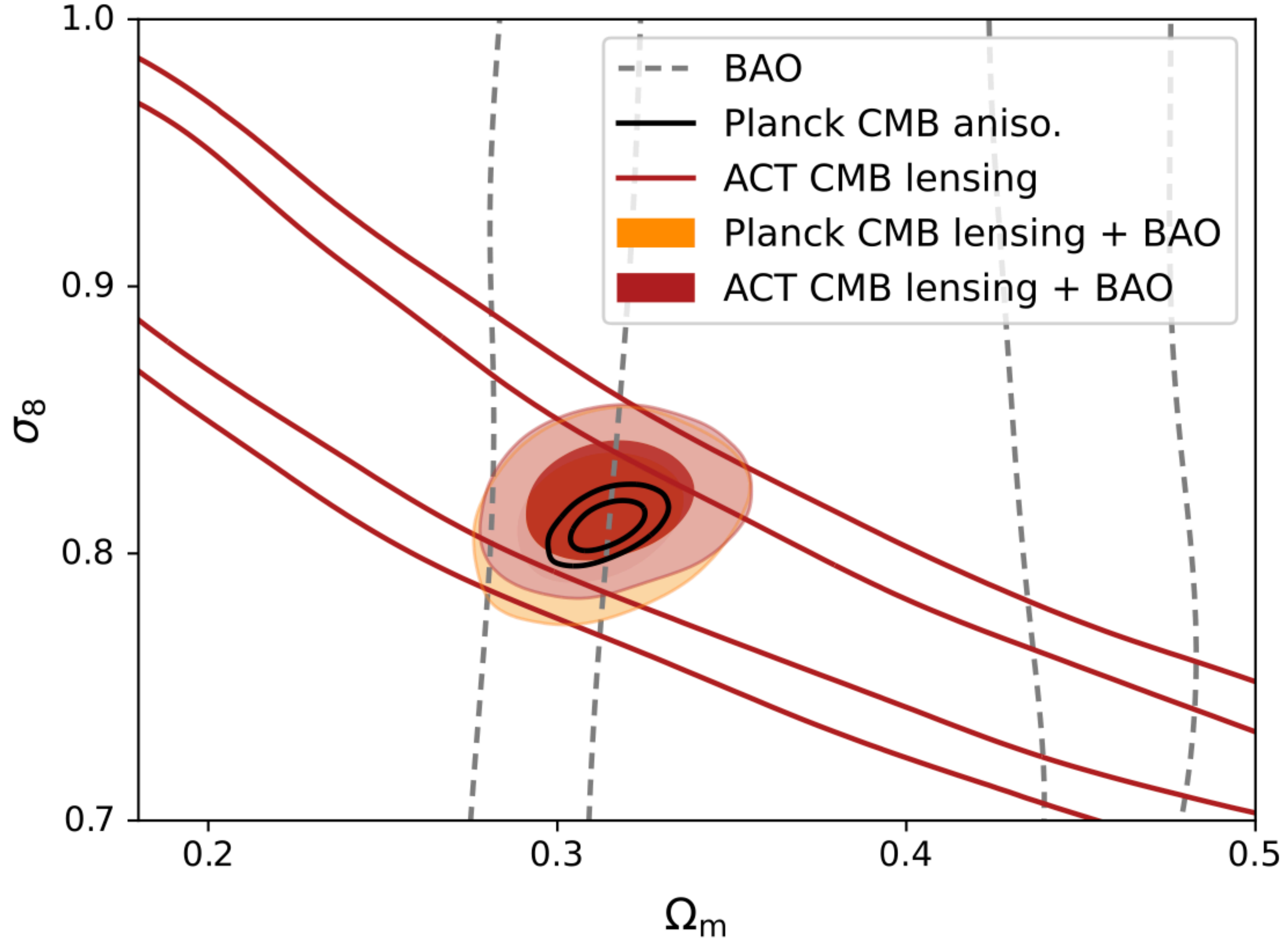
S_8 tension: Weak lensing

- *Weak lensing is 1.5-3 sigma low (3 teams/datasets)*

S_8 tension: CMB lensing

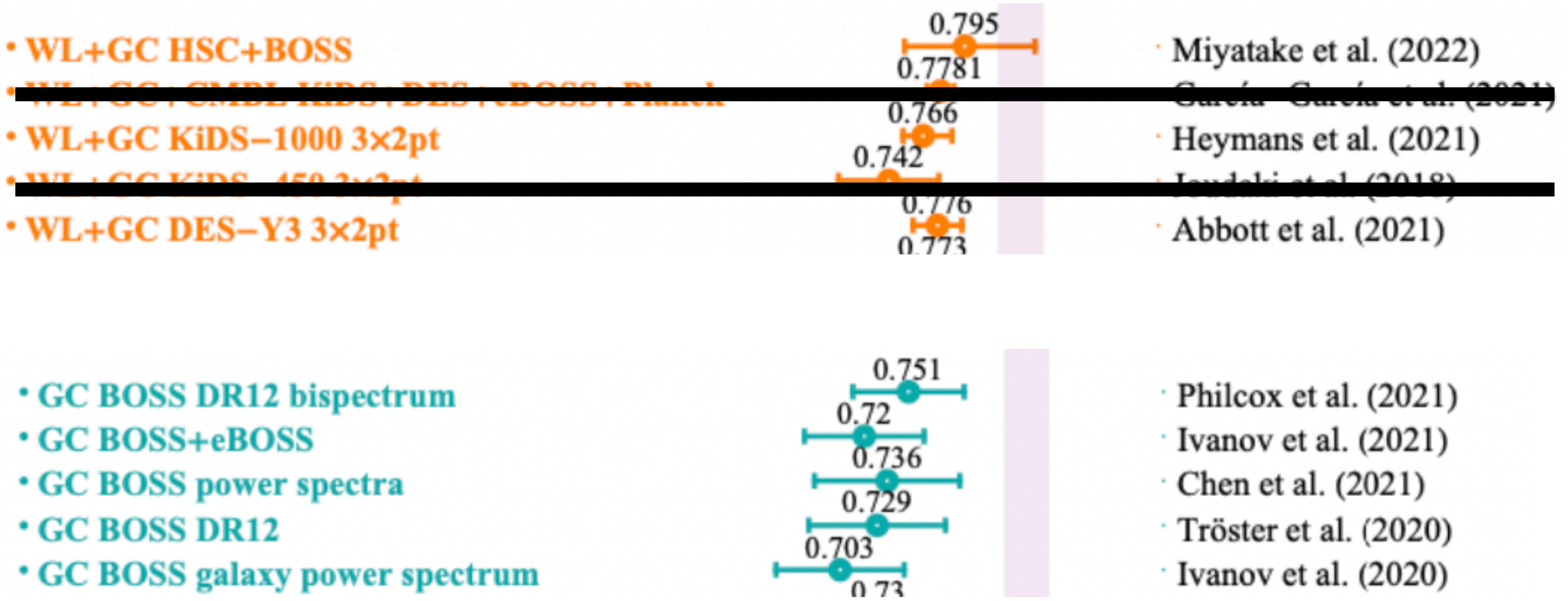
- *CMB lensing in good agreement with primary CMB (2 teams/ datasets)*

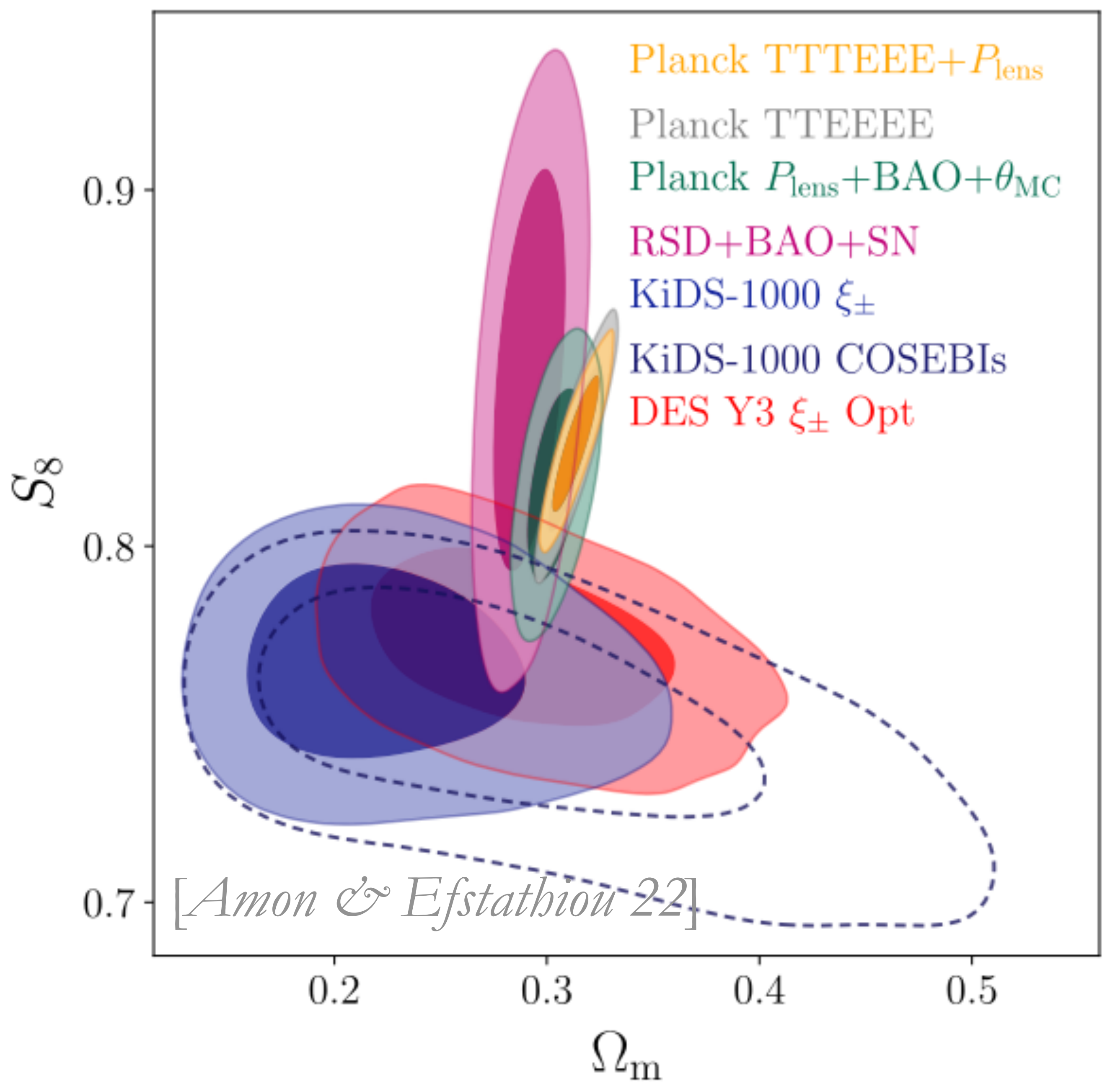
Madhavacheril + Adv ACT 2023

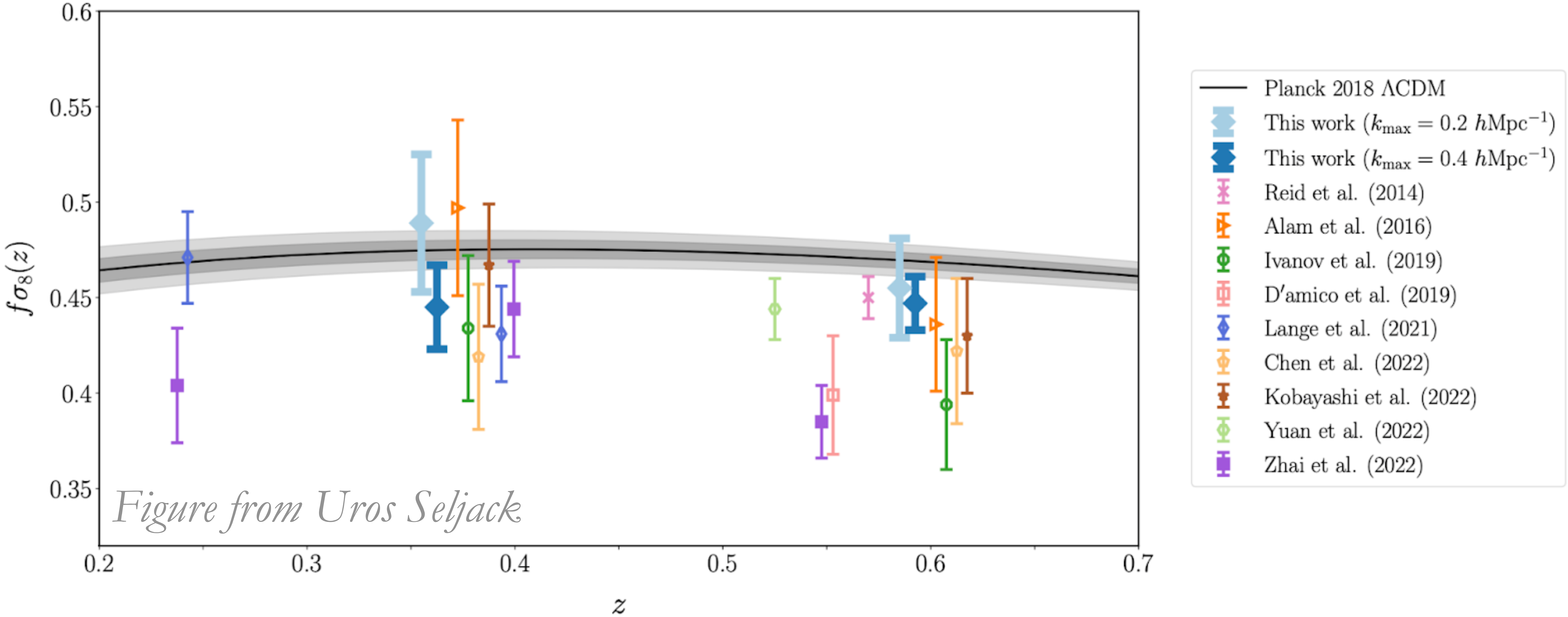


S_8 tension: Clustering / RSD

- ❑ *BOSS standard results are in good agreement with primary CMB*
- ❑ *Typically, galaxy clustering helps to alleviate some of the lensing tension in 3x2*
- ❑ *But, there are some new measurements re-analysing BOSS that claim low S8 - **using the same data sets***



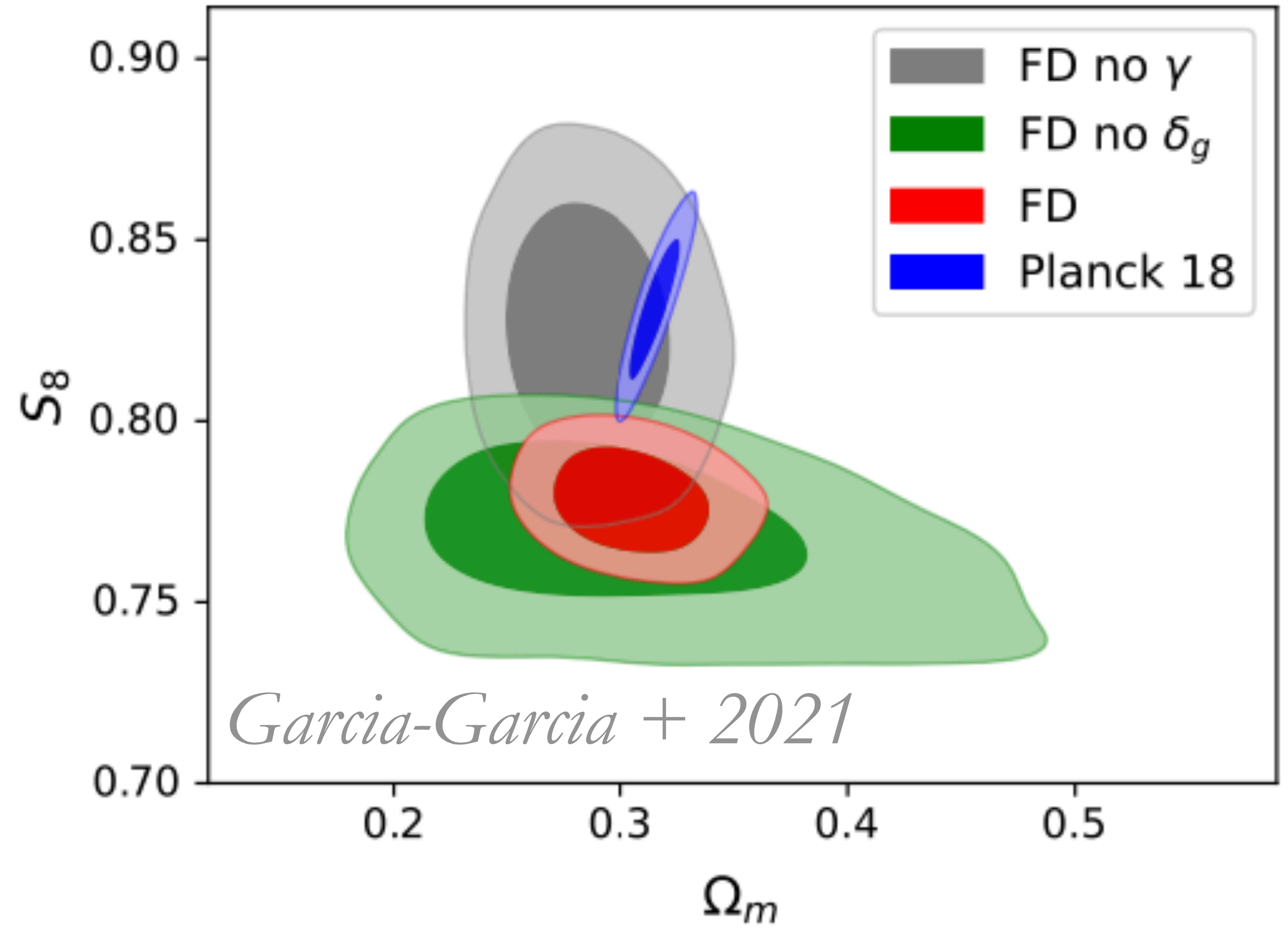


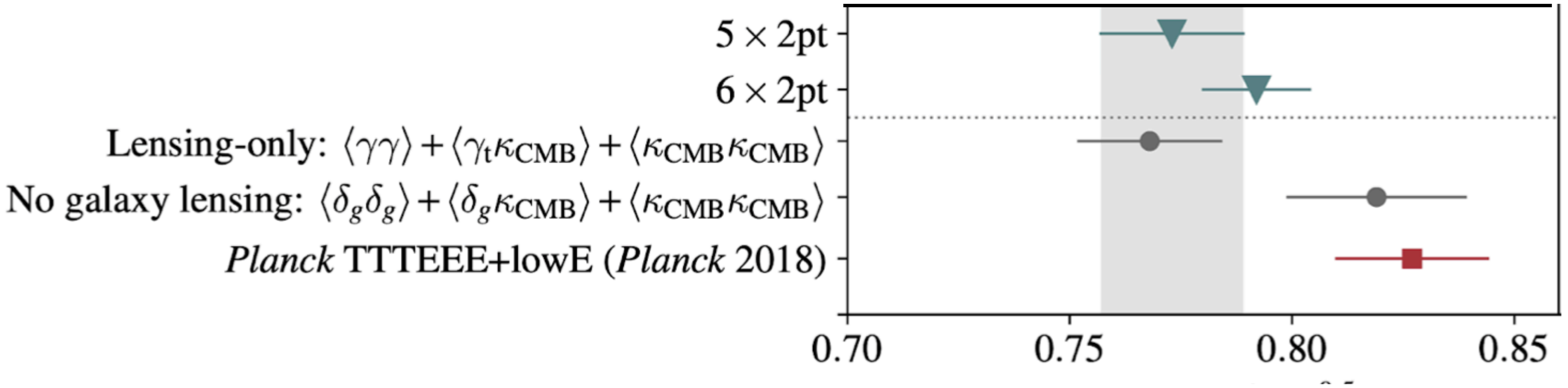


S_8 tension:
CMB lensing x galaxies

- ❑ *This probe also lacks a coherent story*

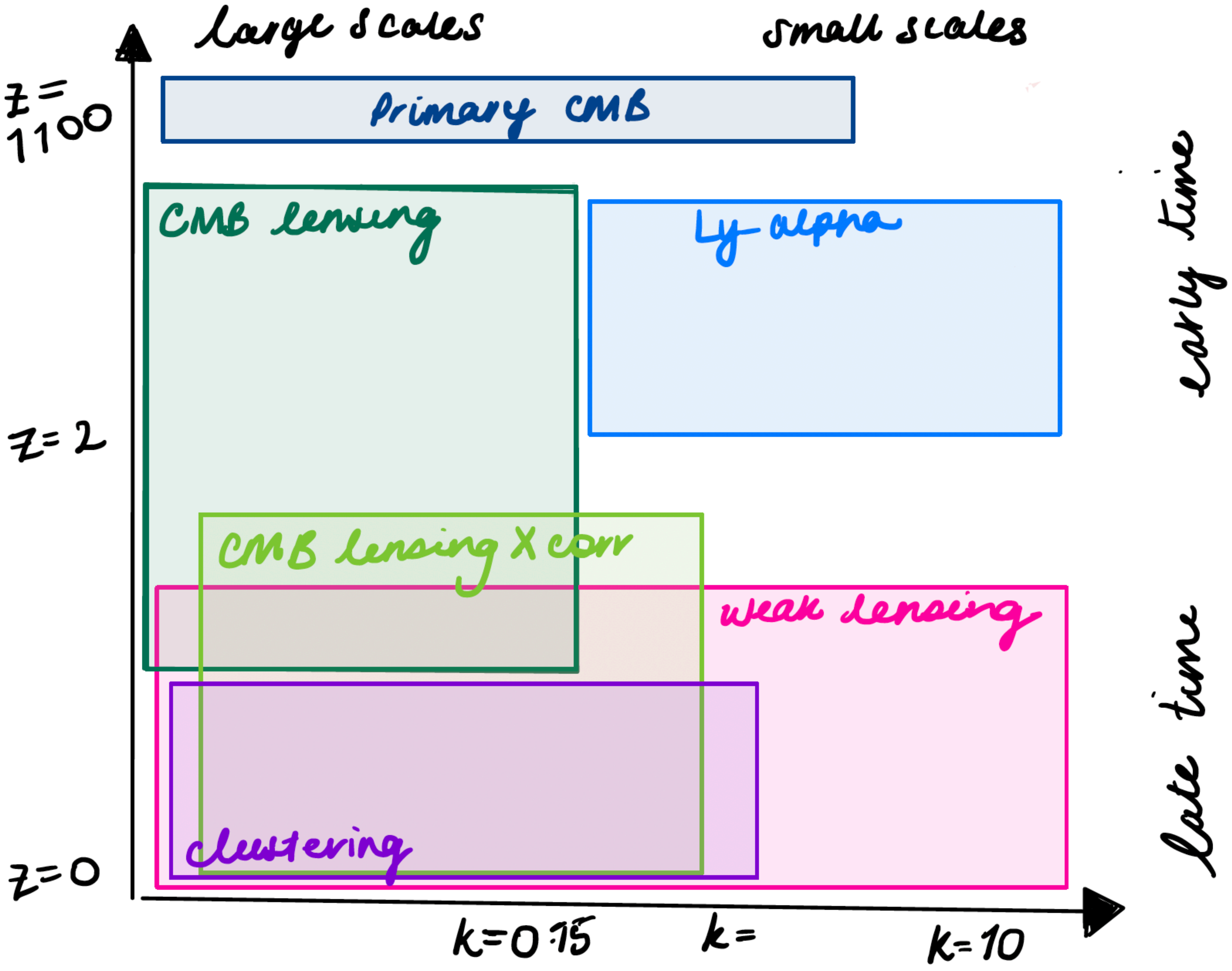
Planck lensing X unWISE galaxies
Planck lensing X DESI imaging
Planck lensing X DESI LRG galaxies
SPT lensing X DES galaxies





DES x SPT

- ❑ *Weak lensing is 1.5-3 sigma low*
- ❑ *CMB lensing agrees with primary CMB*
- ❑ *Clustering / RSD - unclear*
- ❑ *CMB lensing cross-correlations - unclear*
- ❑ *Ly-alpha has an eBOSS result with low S8*



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Weak lensing cosmology
Cosmological inference with systematics
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Solutions to the S_8 tension: wrong answers only
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S_8 tension solution(s)?

H0 and S8 tensions go in different directions.

One fix needed or two?

S_8 tension solutions?

- ❑ Fluctuation? *A bit of a cop-out solution*
- ❑ Gravitational slip?
- ❑ Om shift? *Kind of an unsatisfactory solution*
- ❑ Neutrinos? *Unlikely - but important to understand*

S_8 tension solutions?

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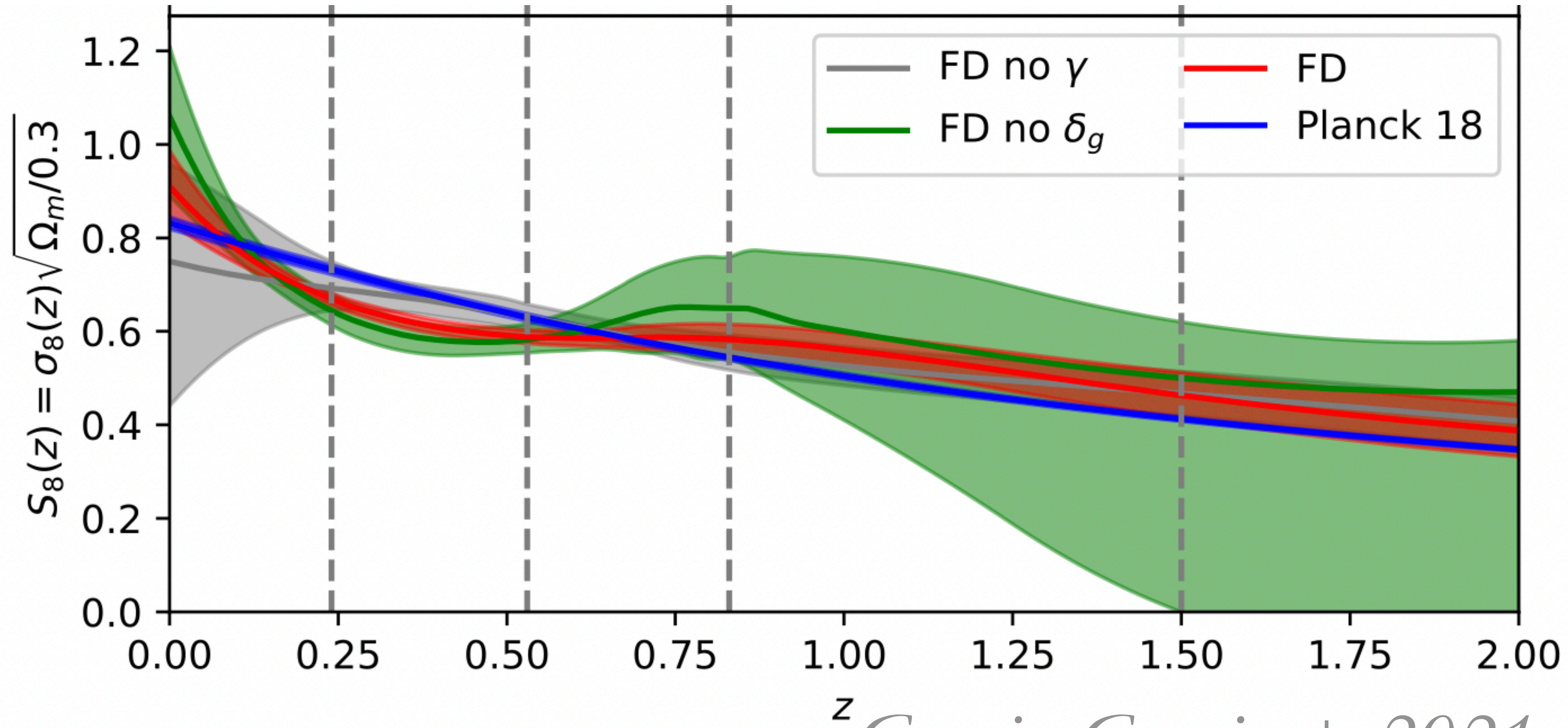
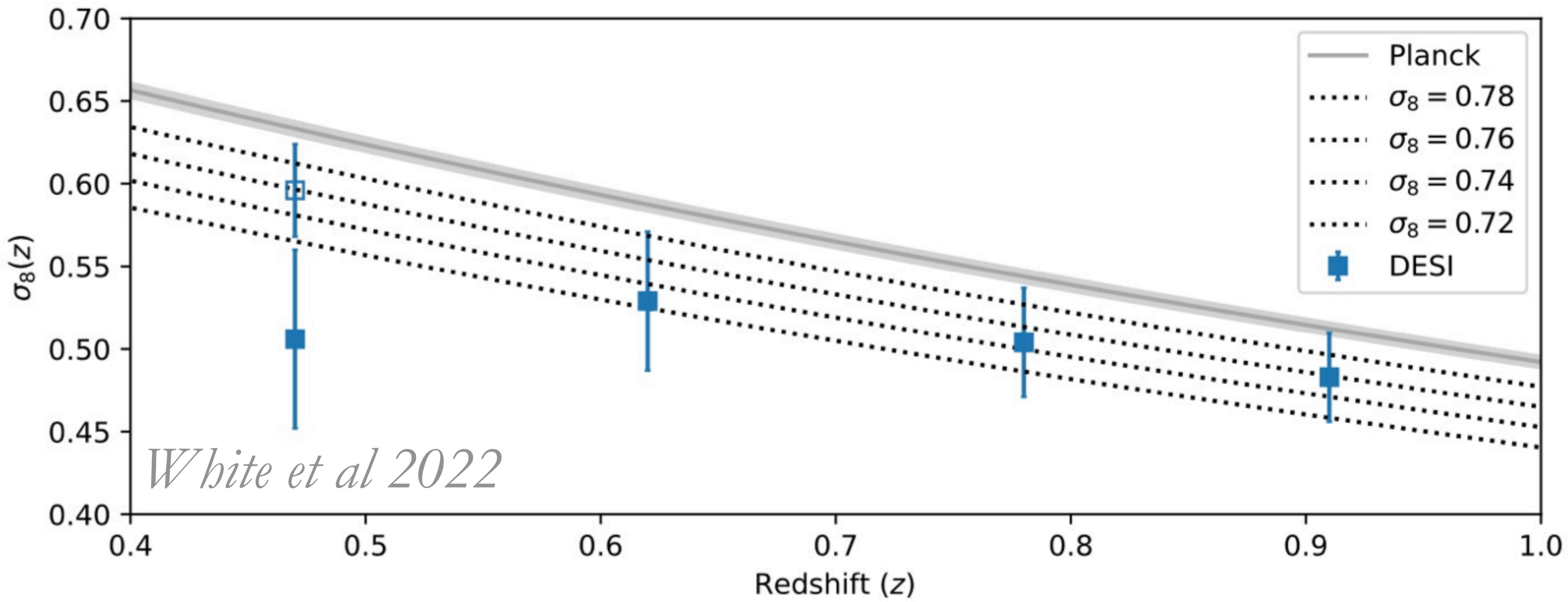
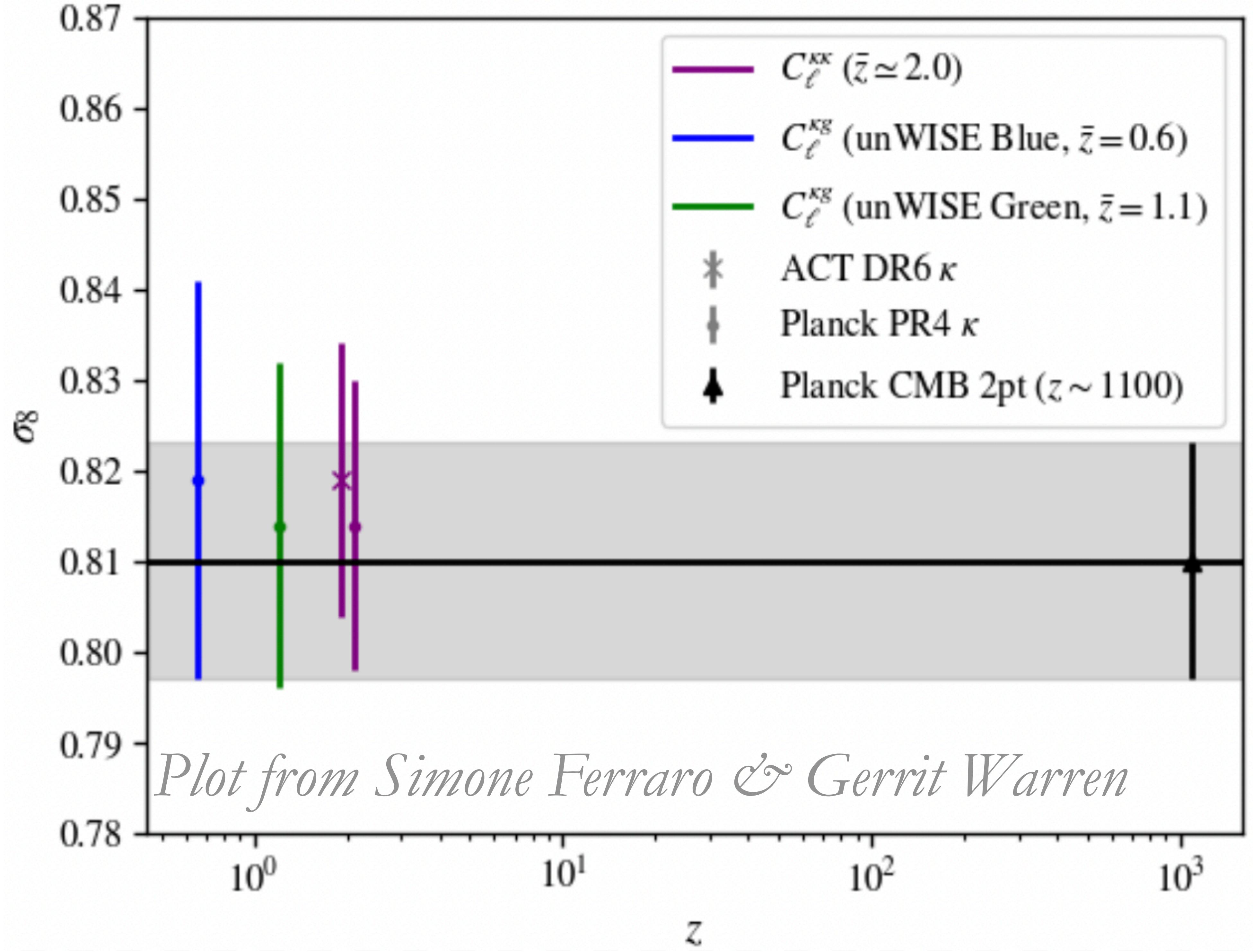
- ❑ Om shift? *Kind of an unsatisfactory solution*
- ❑ Neutrinos? *Unlikely - but important to understand*
- ❑ Some redshift-dependent modified growth?



Garcia-Garcia + 2021





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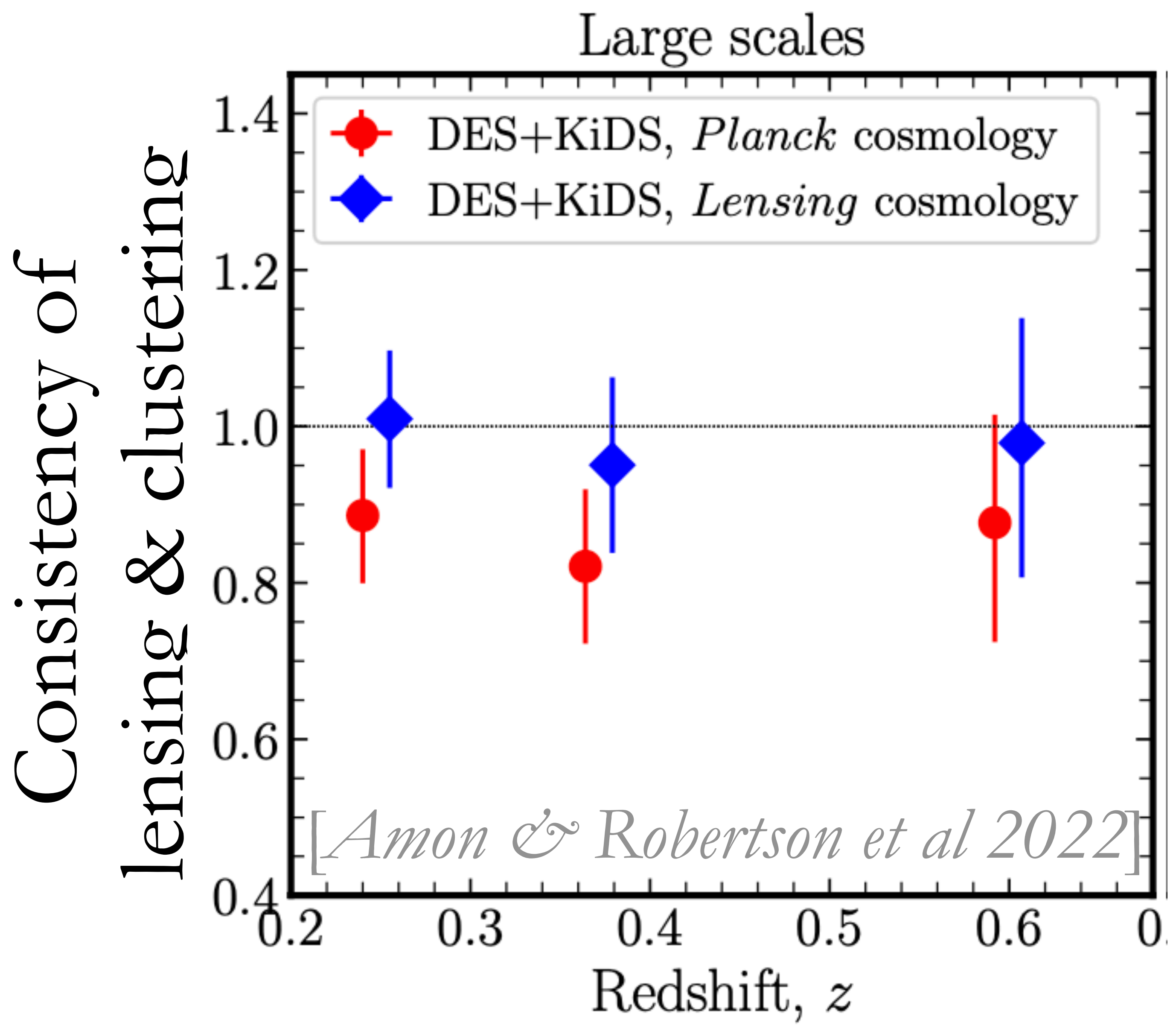
Picking apart the S_8 tension

- Is it early Universe vs late?
- Is it a lensing thing?
- Is it galaxy lensing or clustering, or both?
- Is it small scales vs large scales?



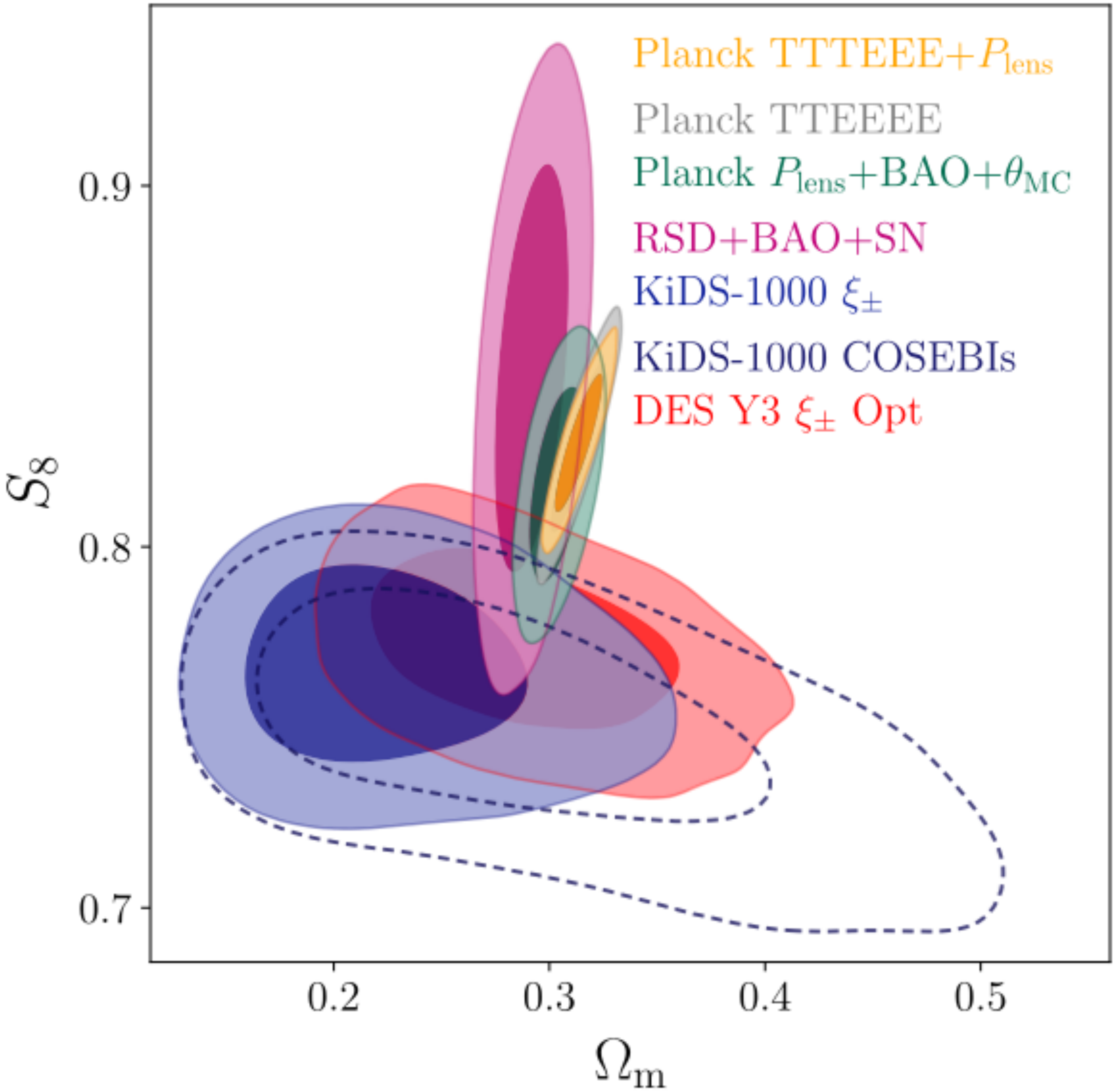
<u>*Test with BOSS + KiDS, DES, HSC*</u>

- *Inconsistency between lensing and clustering driven by small scales*
- *Early vs. late Universe tension not significant on large scales*

Naomi Robertson+ Miyatake, Heymans, White +

S_8 tension

[*Amon & Efstathiou 22*]



A non-linear solution to the S_8 tension?

Alexandra Amon[1⋆], George Efstathiou[1†]
1 *Kavli Institute for Cosmology Cambridge, Madingley Road, Cambridge, CB3 OHA.*

24 June 2022

don't understand galaxies

"That isn't dark matter, sir—you just ~~forgot to take off the lens cap.~~"

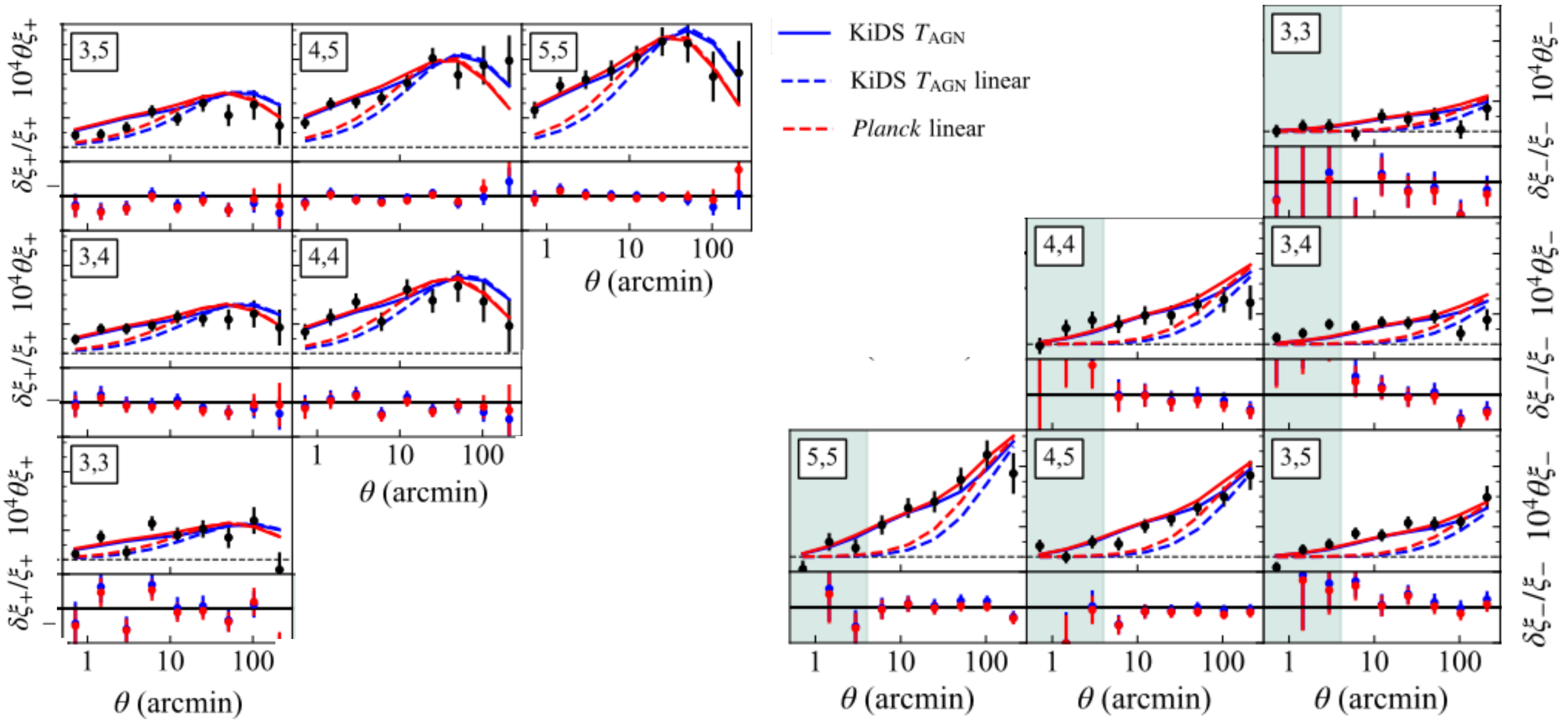
We need something that alters how matter is distributed on 'small scales'.

Is this a **smoking gun for non-standard dark matter?**

Or is it telling us that we don't really understand galaxies ?

S_8 tension

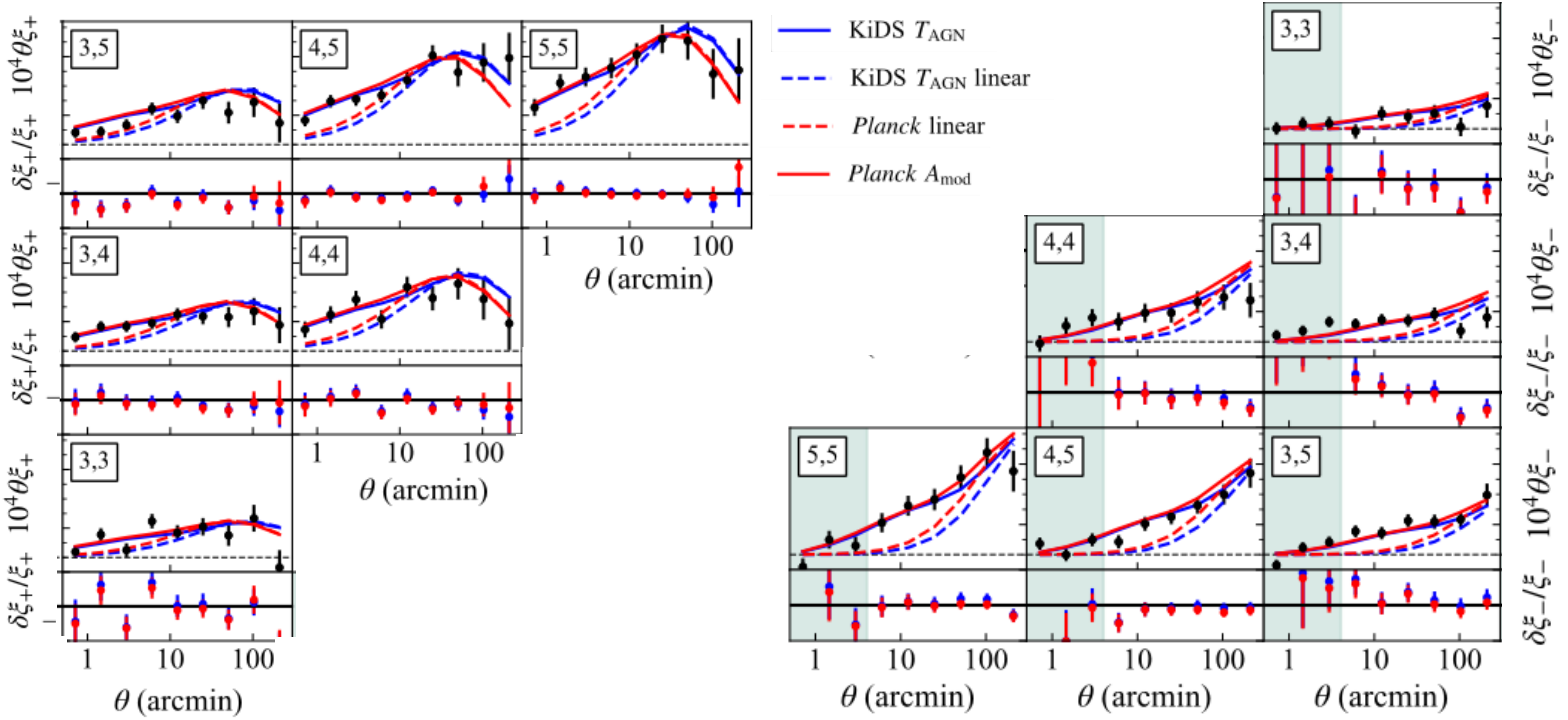
[*Amon & Efstathiou 22*]



A non-linear solution to the S_8 tension?

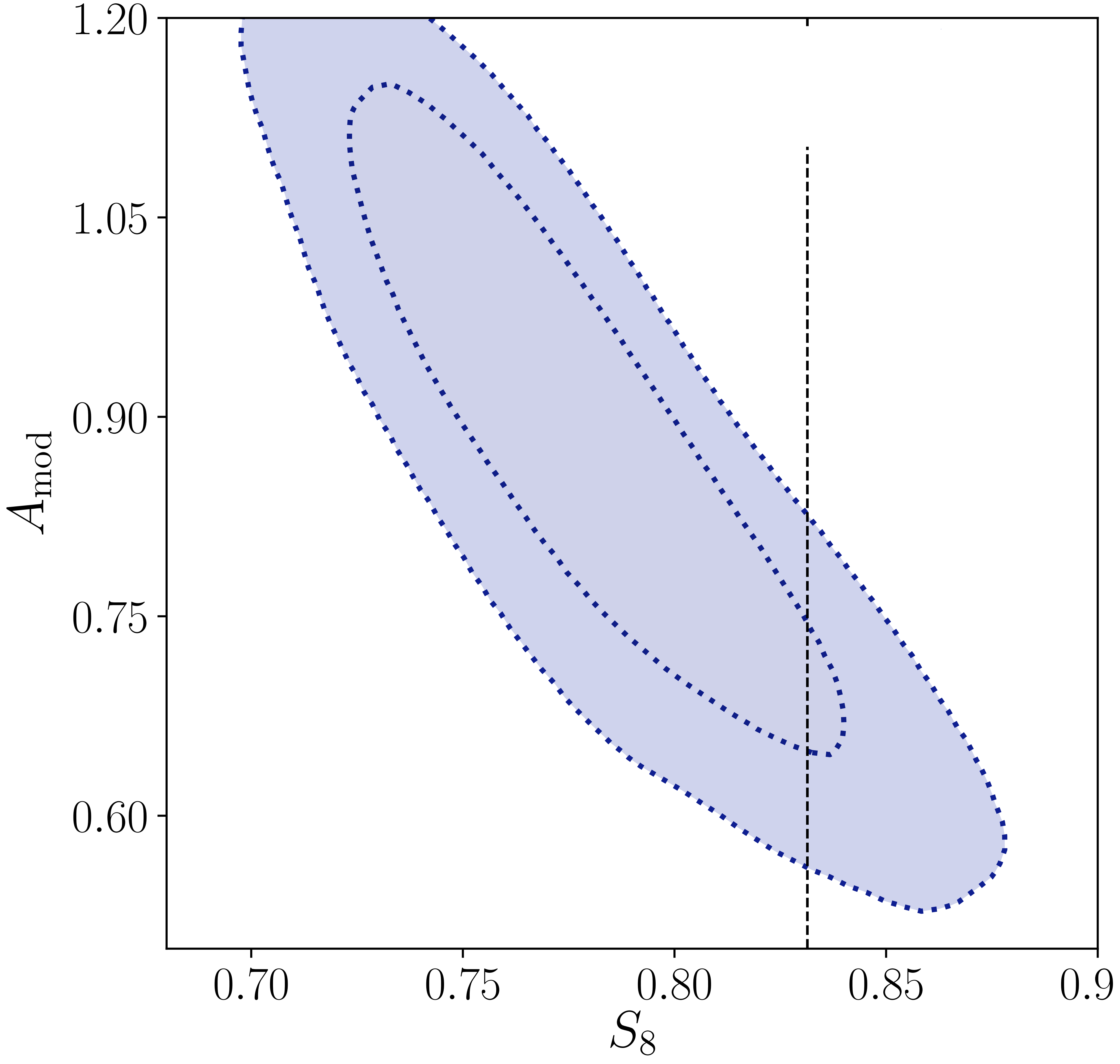
[*Amon & Efstathiou 22*]

- ❑ *Correction to nonlinear spectrum may reconcile Planck cosmology with cosmic shear measurements*



[*Amon & Efstathiou 22*]

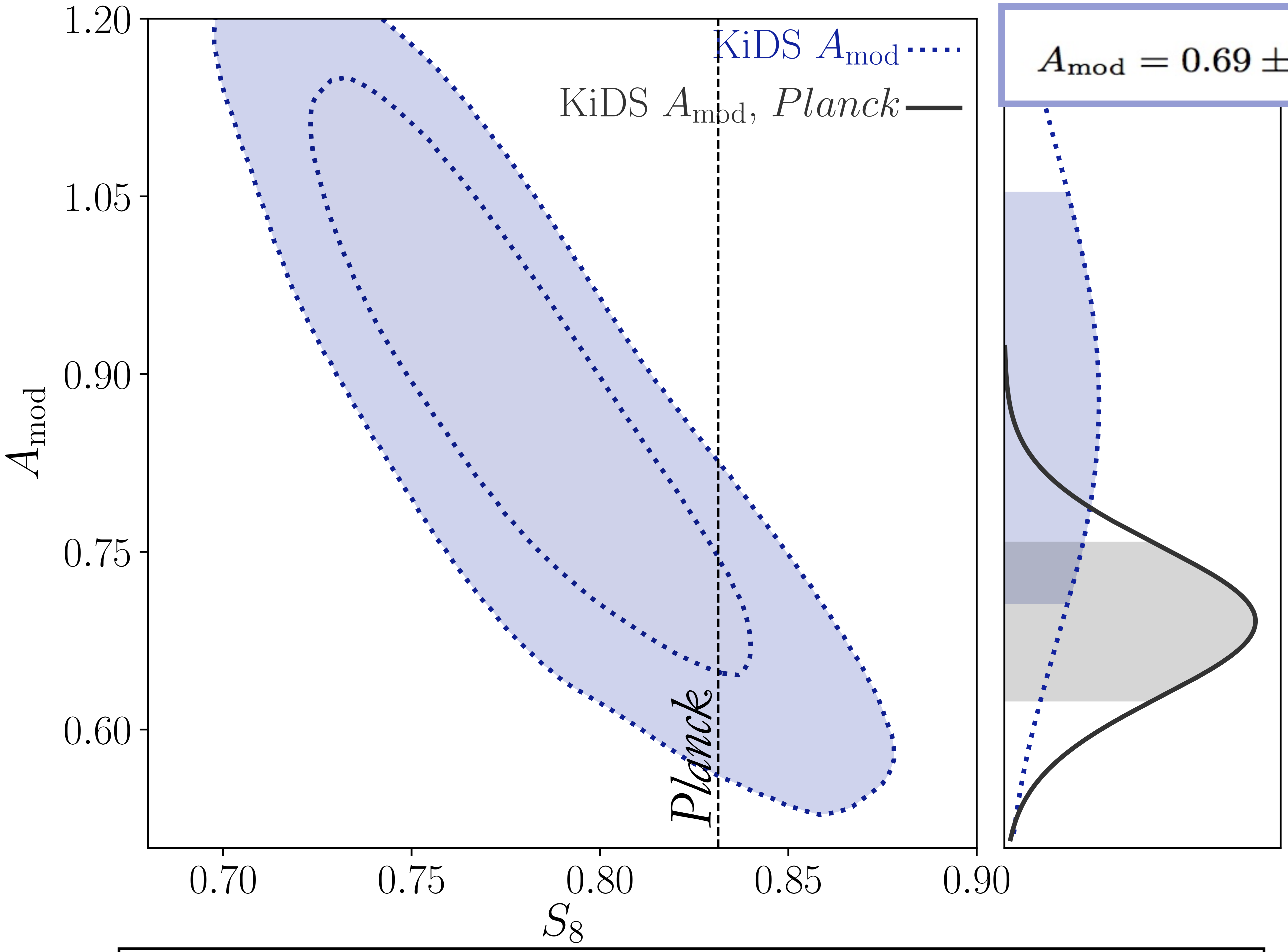
A non-linear solution to the S_8 tension?



$$P_{\rm m}(k,z) = P_{\rm m}^{\rm L}(k,z) + A_{\rm mod}[P_{\rm m}^{\rm NL}(k,z) - P_{\rm m}^{\rm L}(k,z)]$$

[*Amon & Efstathiou 22*]

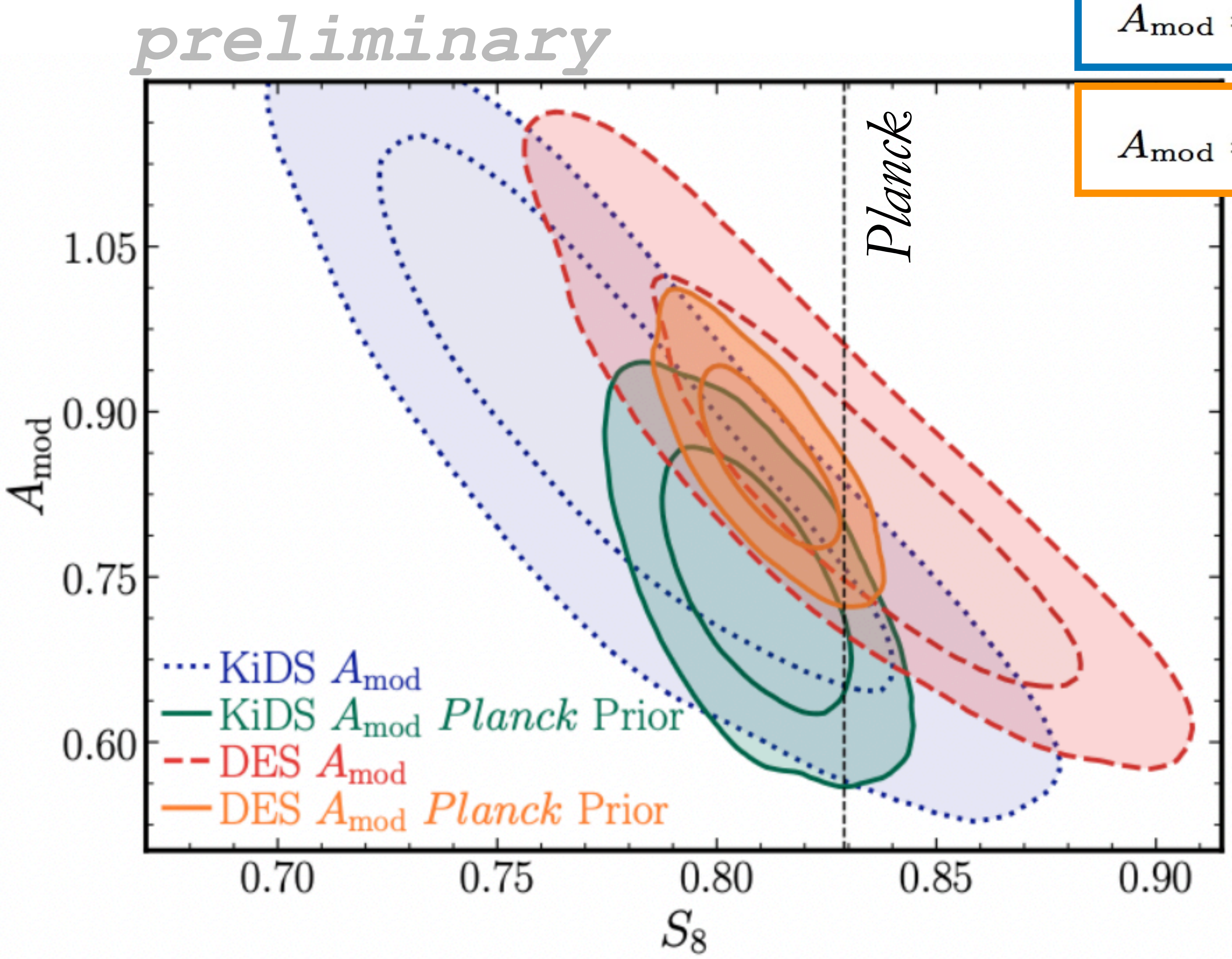
A non-linear solution to the S_8 tension?



$$A_{\rm mod} = 0.69 \pm 0.06\,,$$

$$P_{\rm m}(k,z) = P_{\rm m}^{\rm L}(k,z) + A_{\rm mod}[P_{\rm m}^{\rm NL}(k,z) - P_{\rm m}^{\rm L}(k,z)]$$

A non-linear solution to the S8 tension? New DES constraints!



$A_{\rm mod} = 0.75 \pm 0.07$

$A_{\rm mod} = 0.85 \pm 0.05$

$$P_{\rm m}(k,z) = P_{\rm m}^{\rm L}(k,z) + A_{\rm mod}[P_{\rm m}^{\rm NL}(k,z) - P_{\rm m}^{\rm L}(k,z)]$$

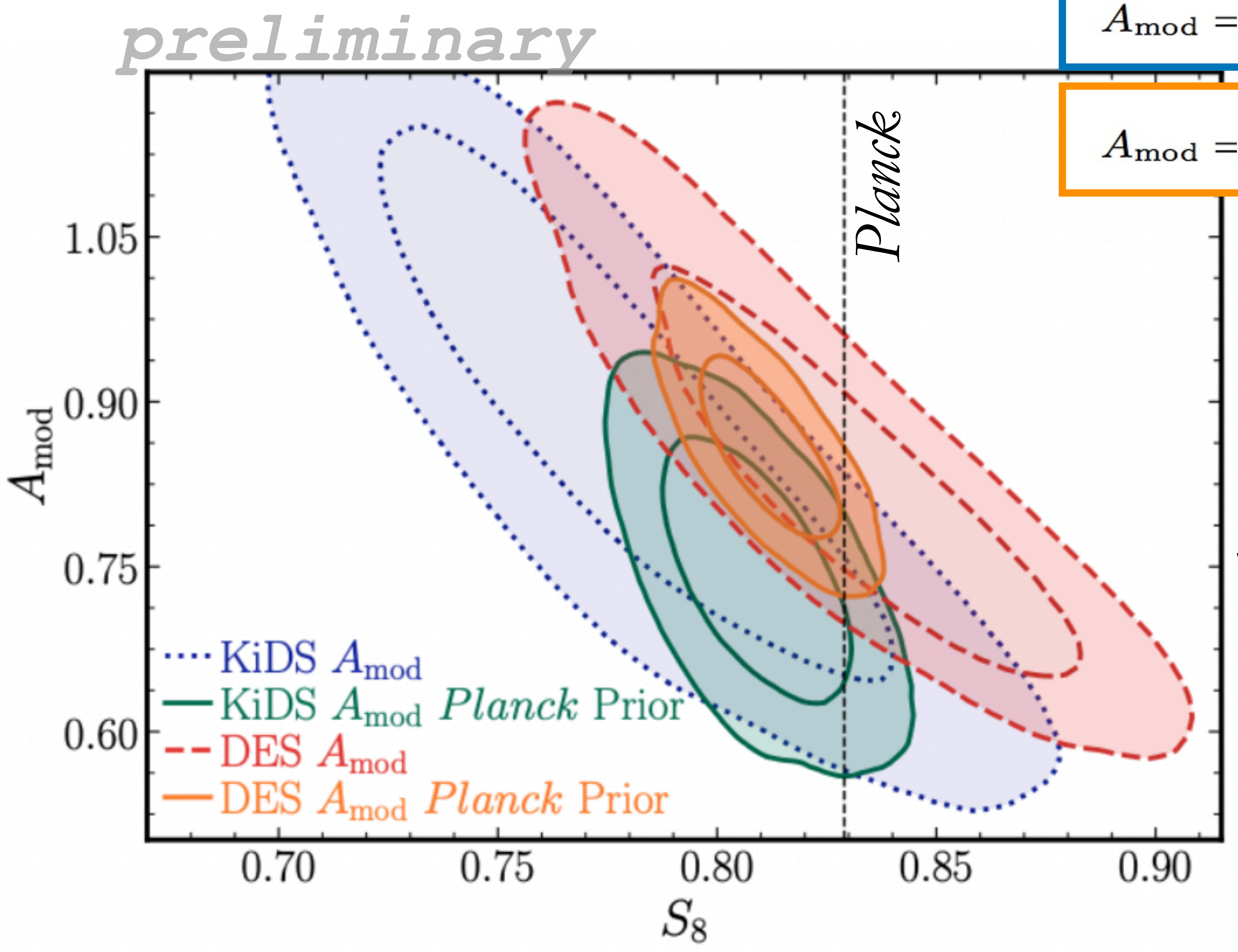
Calvin Preston, Amon & Efstathiou

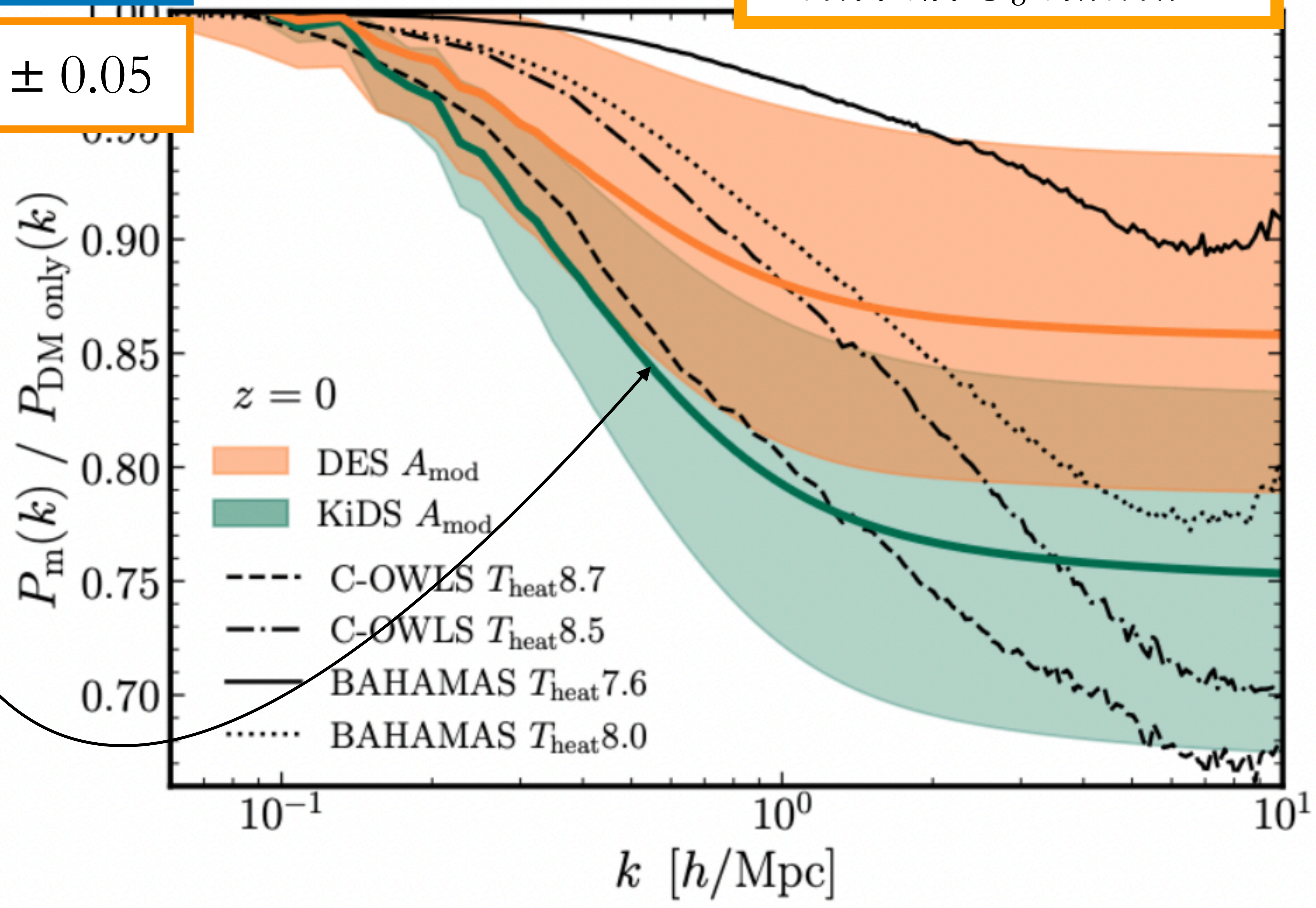
S_8 tension: baryonic physics or new dark matter properties?

$A_{\rm mod} = 0.75 \pm 0.07$

$A_{\rm mod} = 0.85 \pm 0.05$

required suppression to solve the S_8 tension





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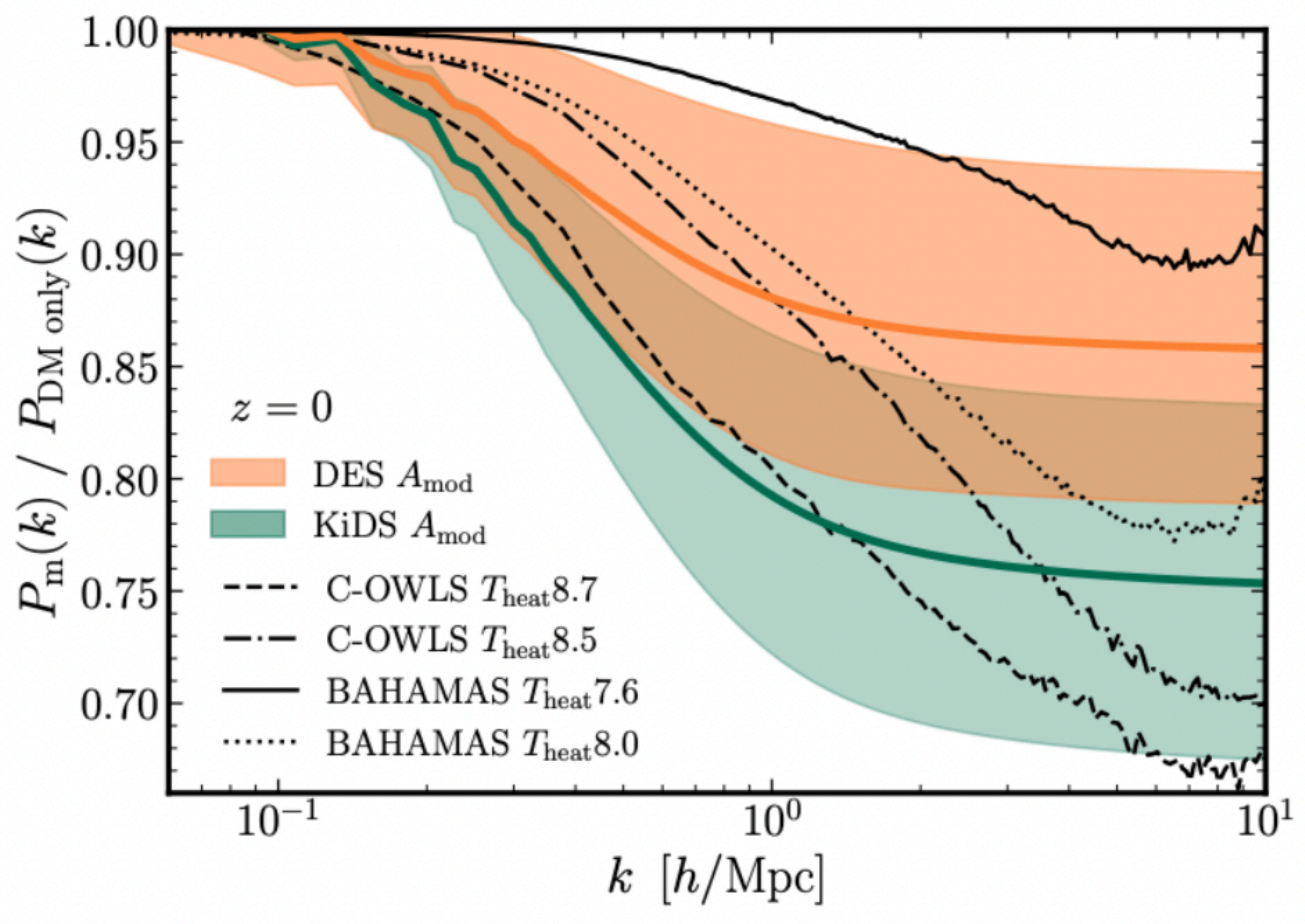
S_8 tension: baryonic physics or new dark matter properties?

$$P_{\rm m}(k,z) = P_{\rm m}^{\rm L}(k,z) + A_{\rm mod}[P_{\rm m}^{\rm NL}(k,z) - P_{\rm m}^{\rm L}(k,z)]$$

Do we understand baryonic feedback well enough to claim

$A_{\rm mod}$ = dark matter physics?

required suppression to solve the S_8 tension



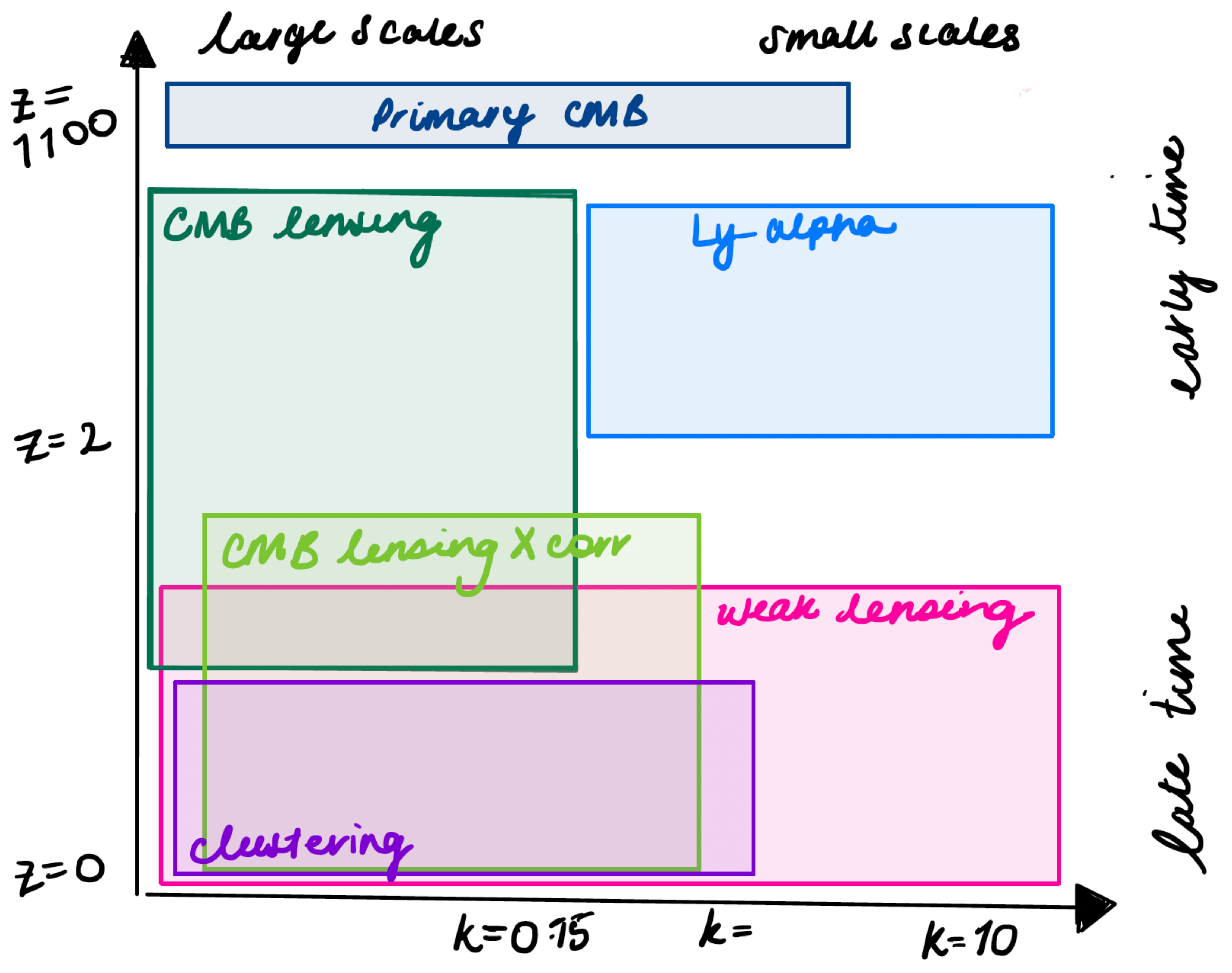
S_8 tension: baryonic physics or new dark matter properties?

Do we understand baryonic feedback well enough to claim

A_{mod} = dark matter physics?

The data is coming to test our hypothesis!

★HSC cosmic shear
★ACT CMB lensing
ACT CMB lensing cross-correlations
DESI clustering/RSD



In the mean time, we can do better with weak lensing…..

The versatility of weak lensing

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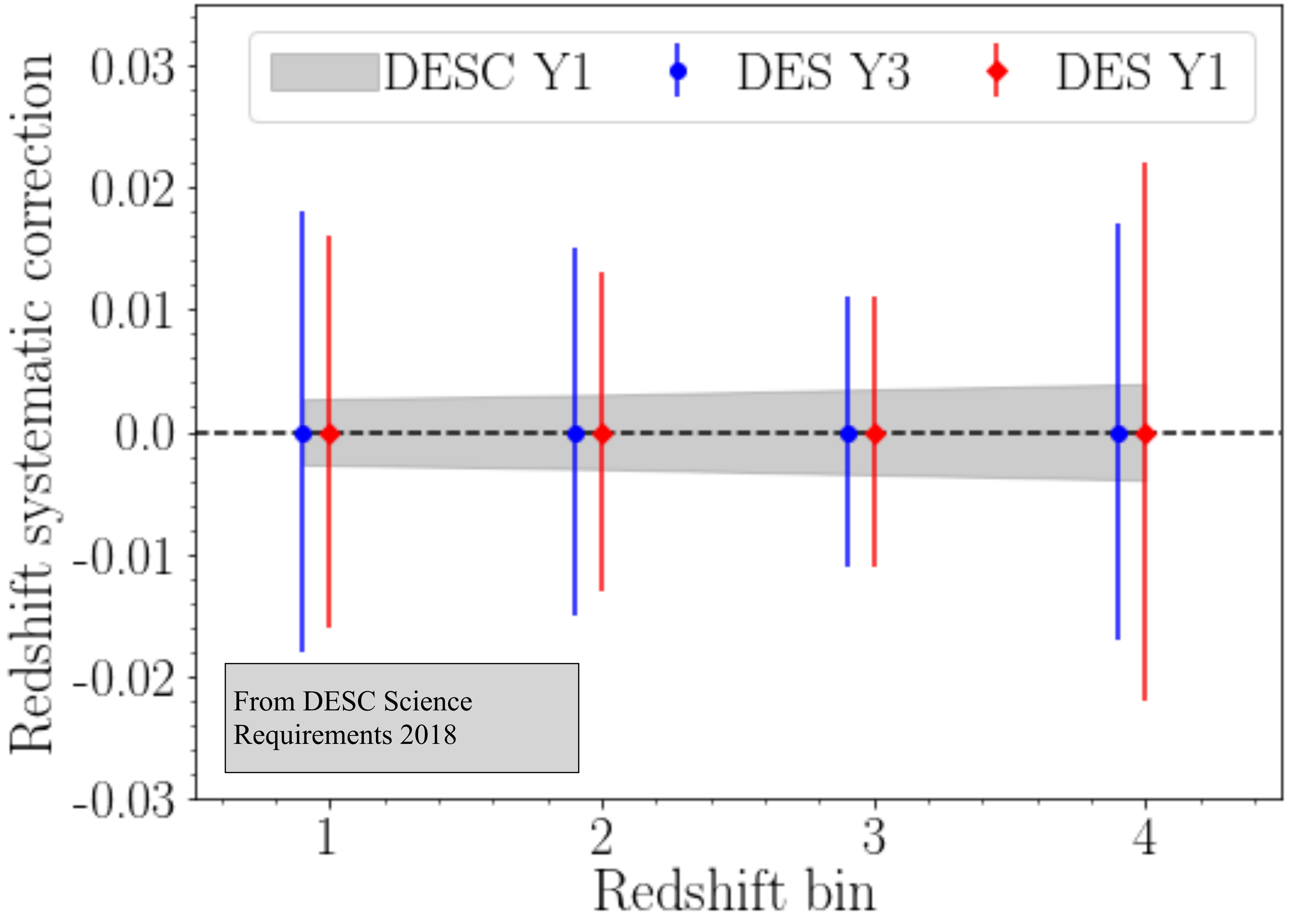
Euclid Space Telescope
Nancy Grace
Roman Space Telescope
Rubin Observatory

Looking ahead: Photo-z calibration headaches

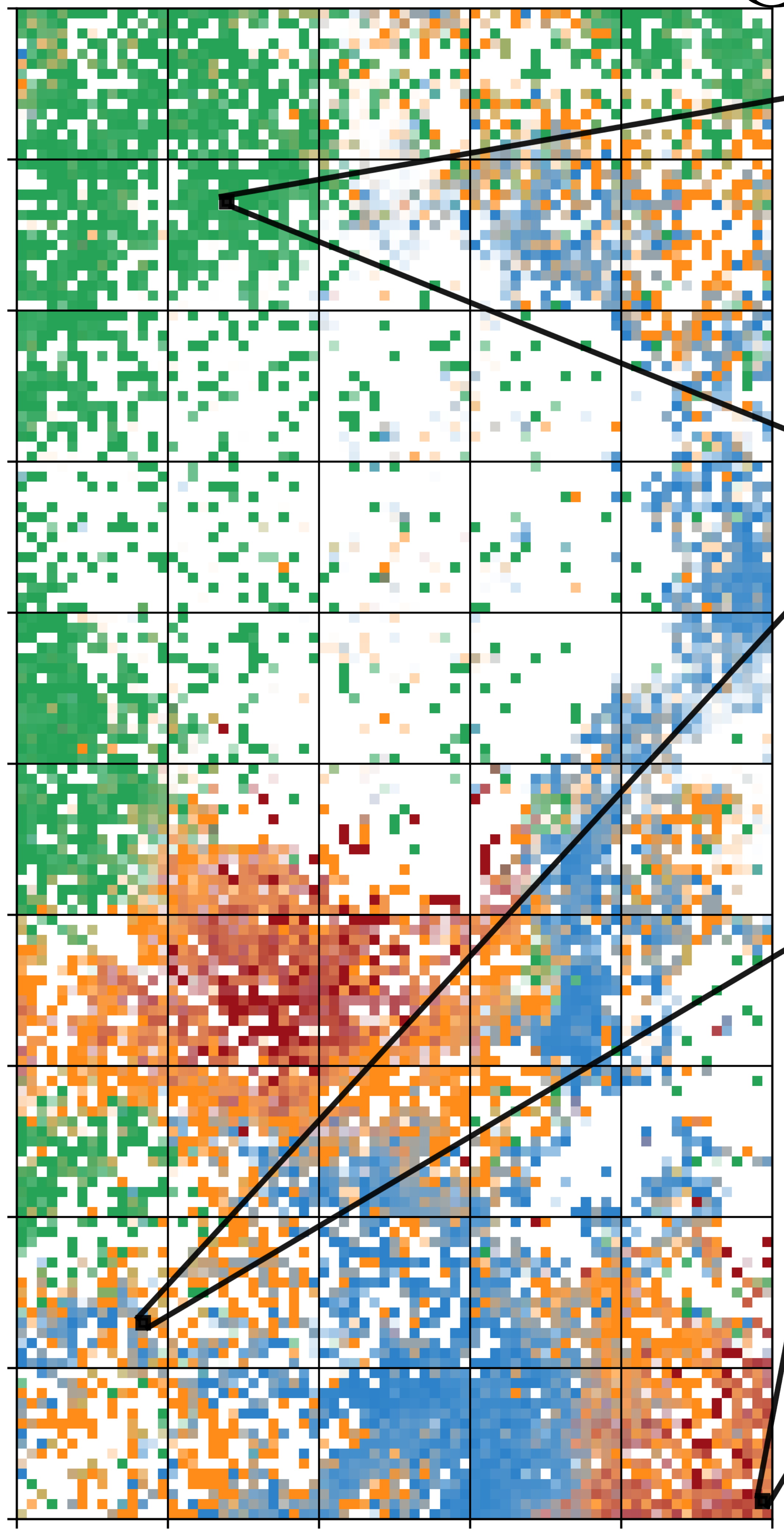
- Colour-redshift degeneracies
- Samples choice
- Selection biases
- Combination of methods
- Propagation of uncertainties
- **Higher redshift woes**
- **Interplay with other systematics**
- **Joint redshift/shape selection effects**

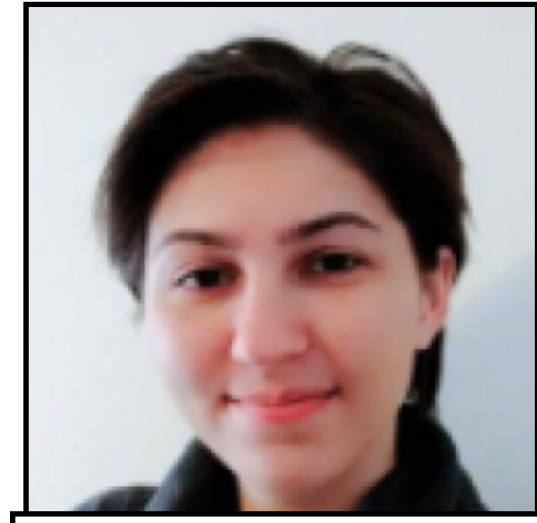


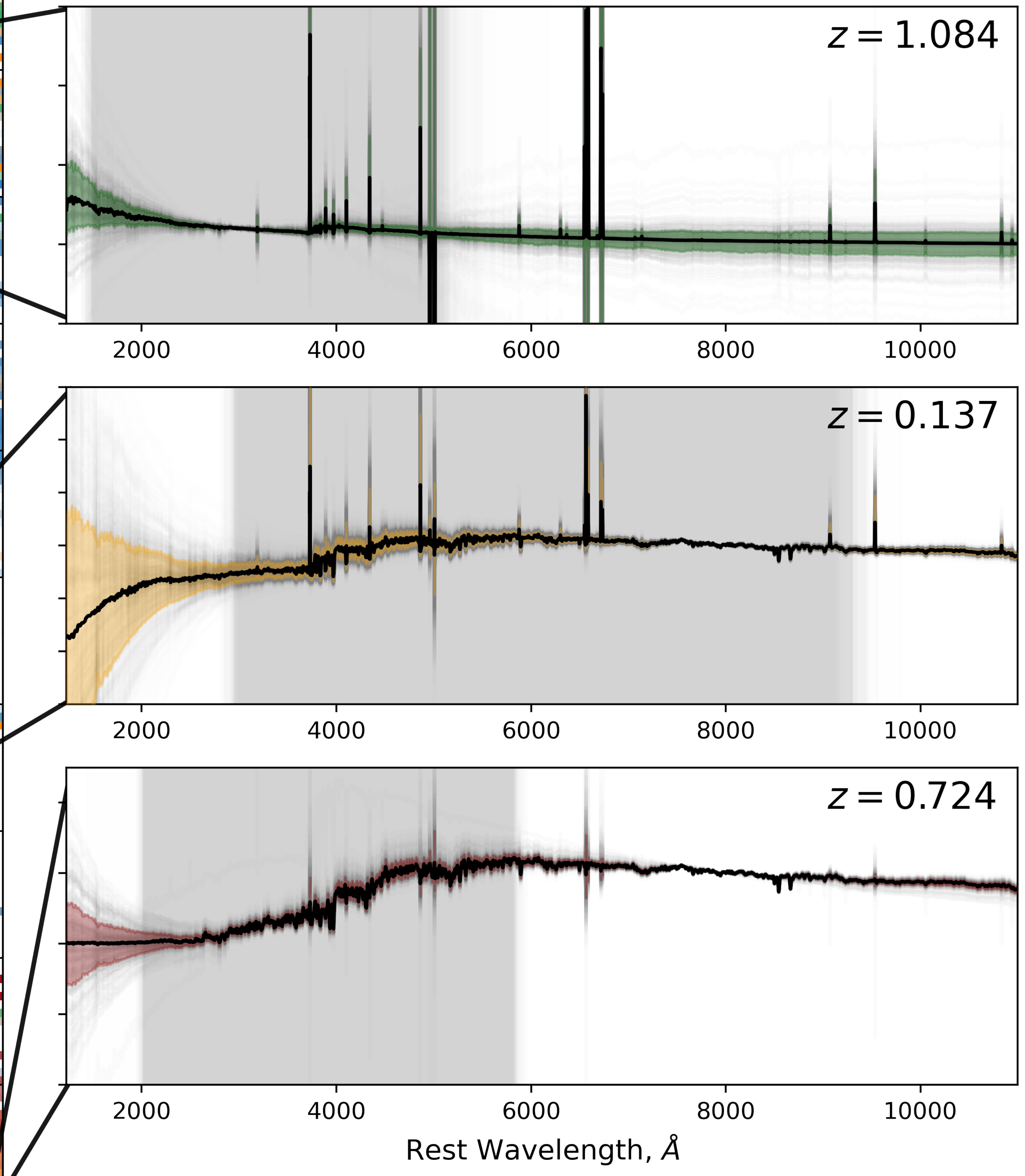
Detailed requirement WL1 (Y10): Systematic uncertainty in the mean redshift of each source tomographic bin shall not exceed $0.001(1+z)$ in the Y10 DESC WL analysis.
Goal WL1 (Y1): Systematic uncertainty in the mean redshift of each source tomographic bin should not exceed $0.002(1+z)$ in the Y1 DESC WL analysis.

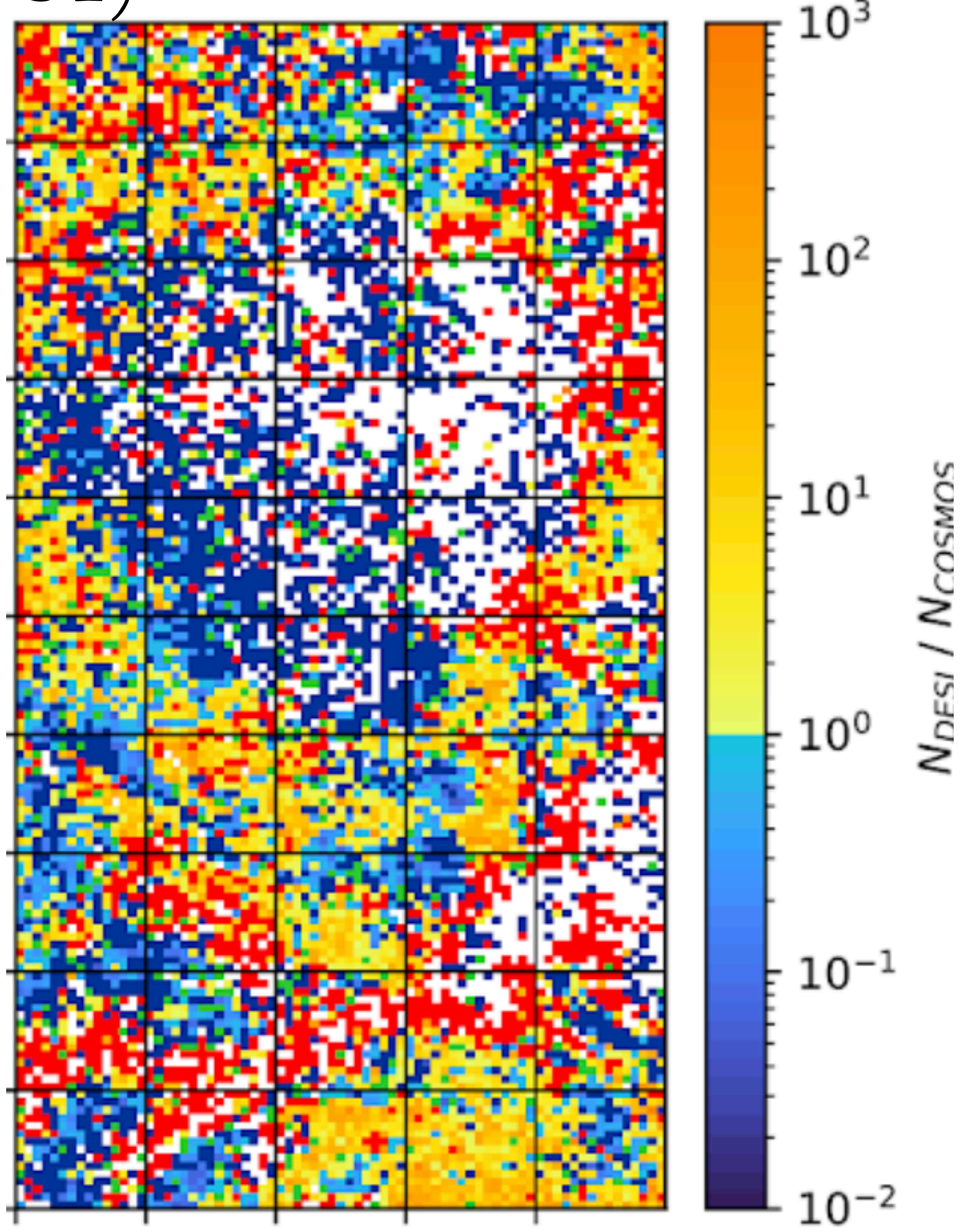
Looking ahead: Photo-z calibration hopes

C3R2, **DC3R2 (DESI)**, 4C3R2 (4MOST)





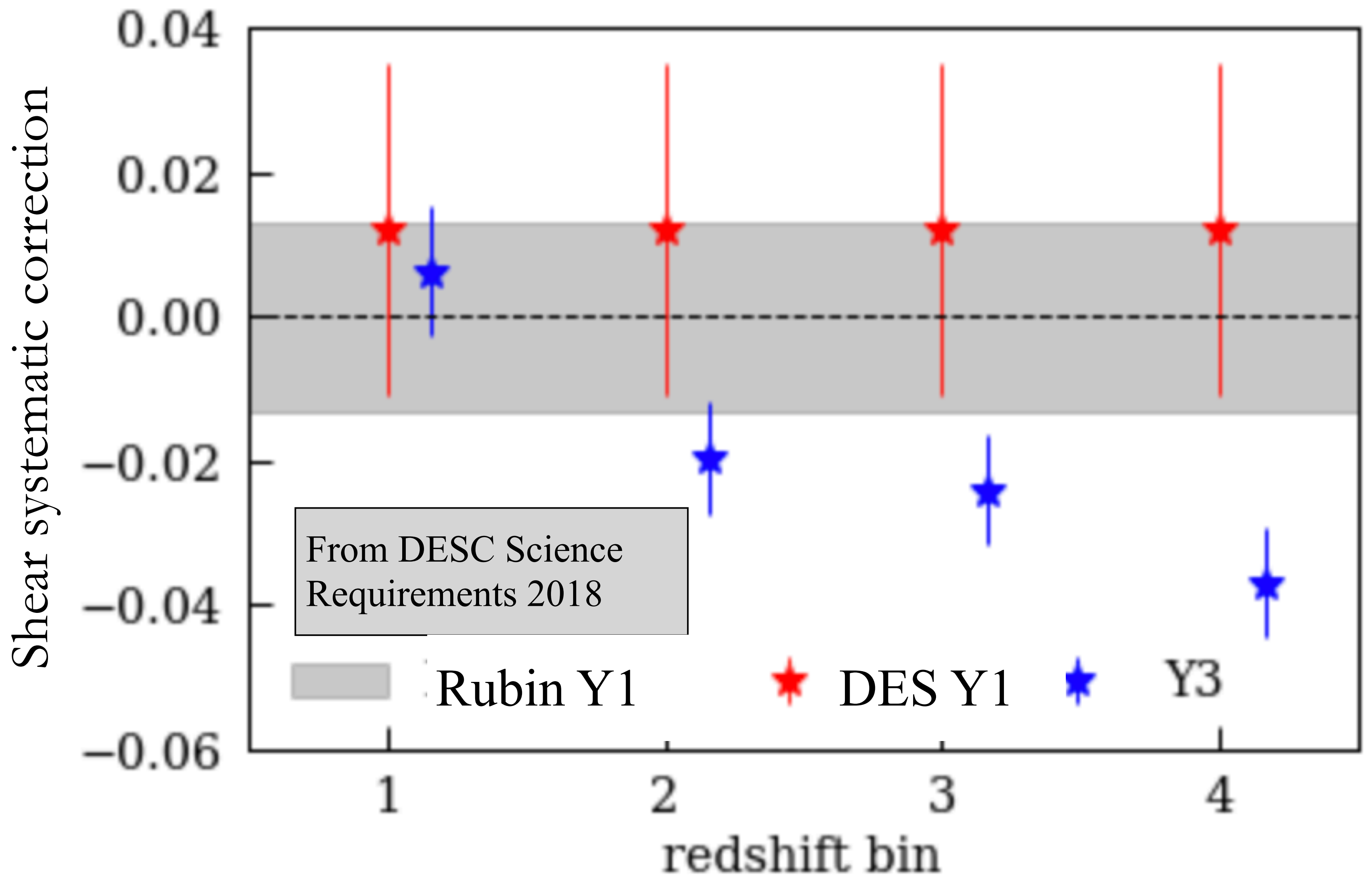




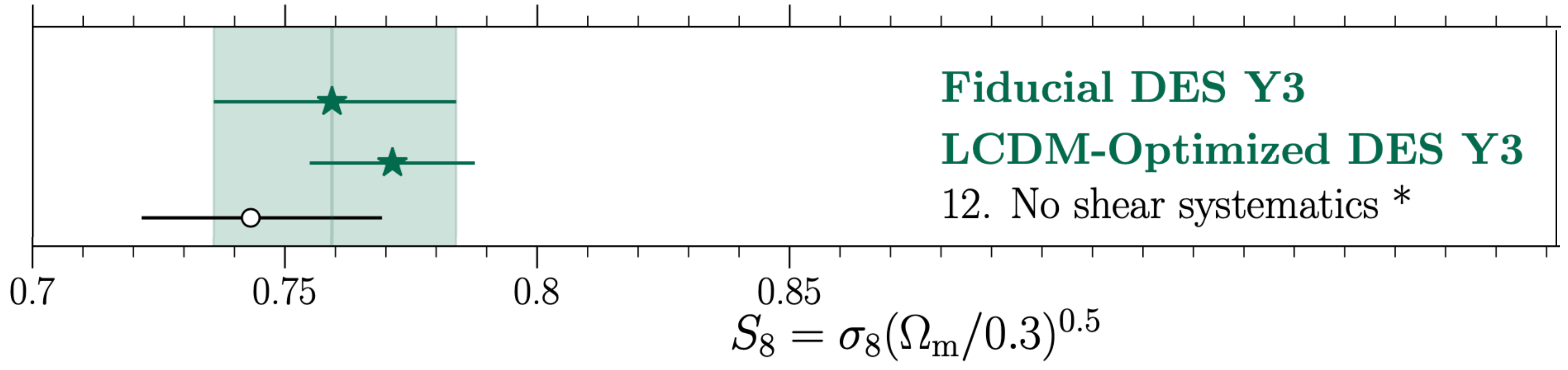
with Daniel Gruen, Aaron Goodman + DESI

Looking ahead: Shear calibration headaches

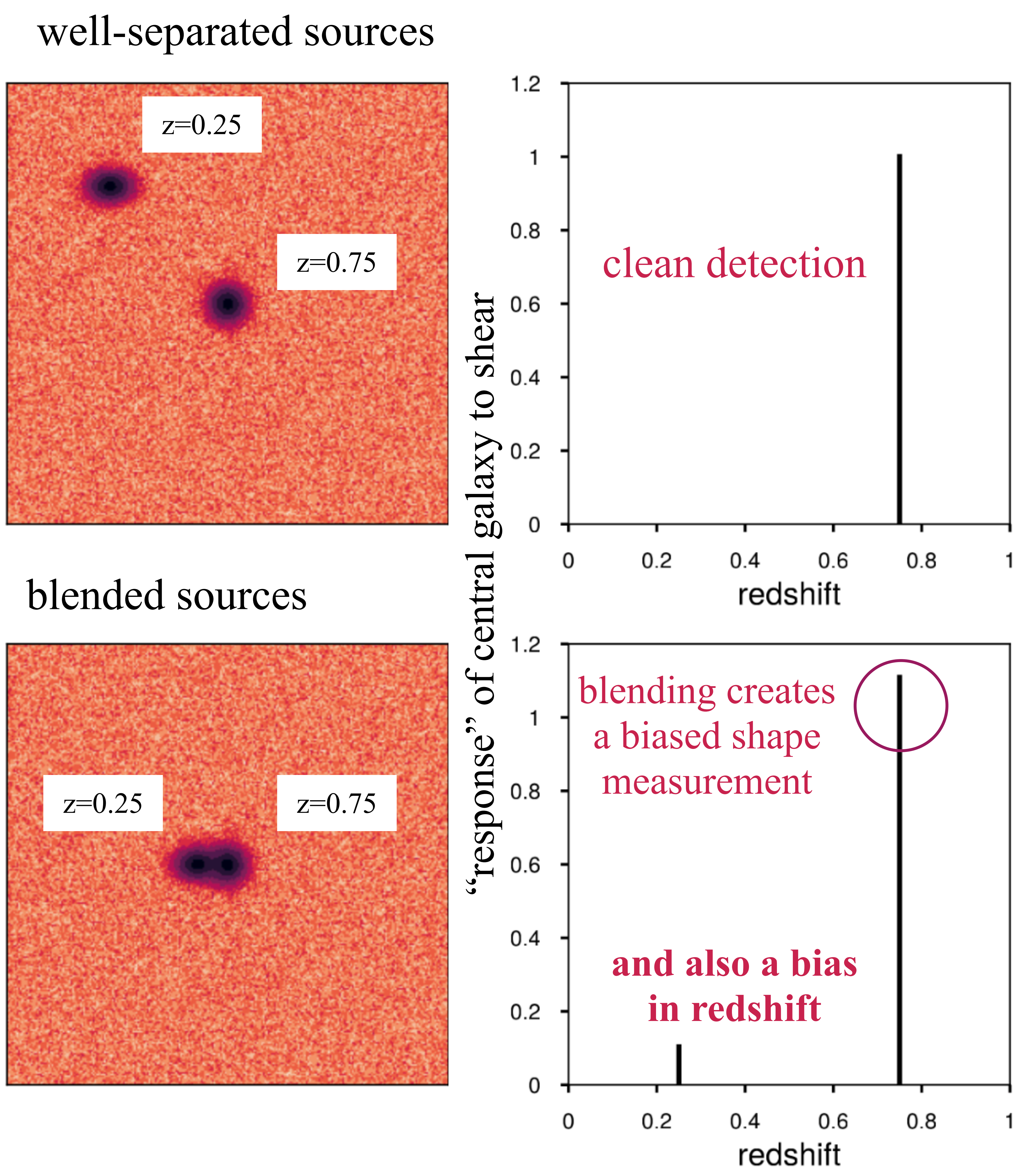
HSC Y1 estimated ~60% recognised blends.
Rubin Y1 estimates >10% unrecognised blends.
Cannot remove blends or de-blend.



More precise corrections in Y3 compared to Y1, with a sharper redshift dependence.



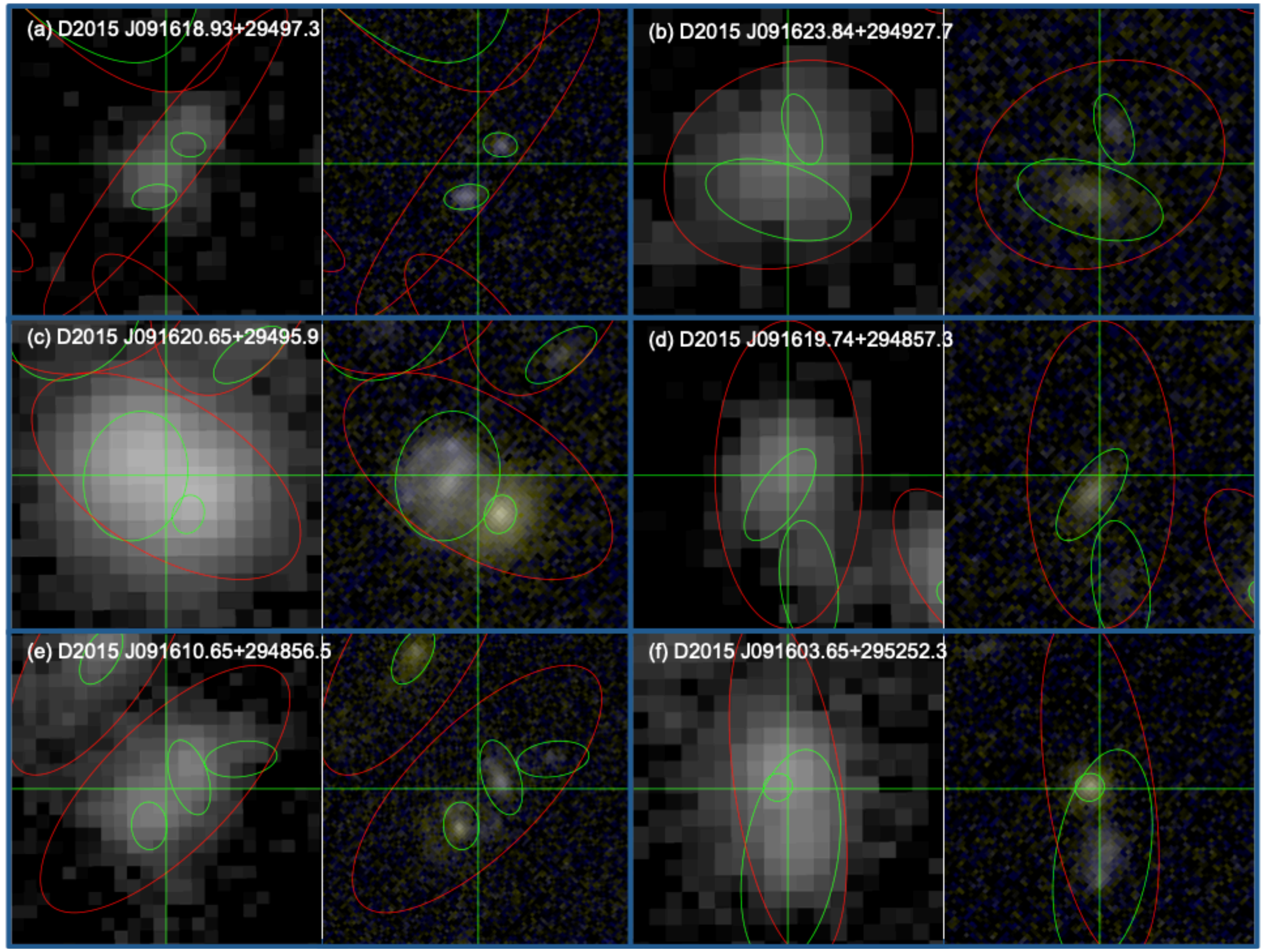
Resulted in a ~1σ shift in S_8.



Blending demands an additional correction and uncertainty on redshift distribution (as well as the shear) that increases with redshift.

Looking ahead: Shear calibration hopes

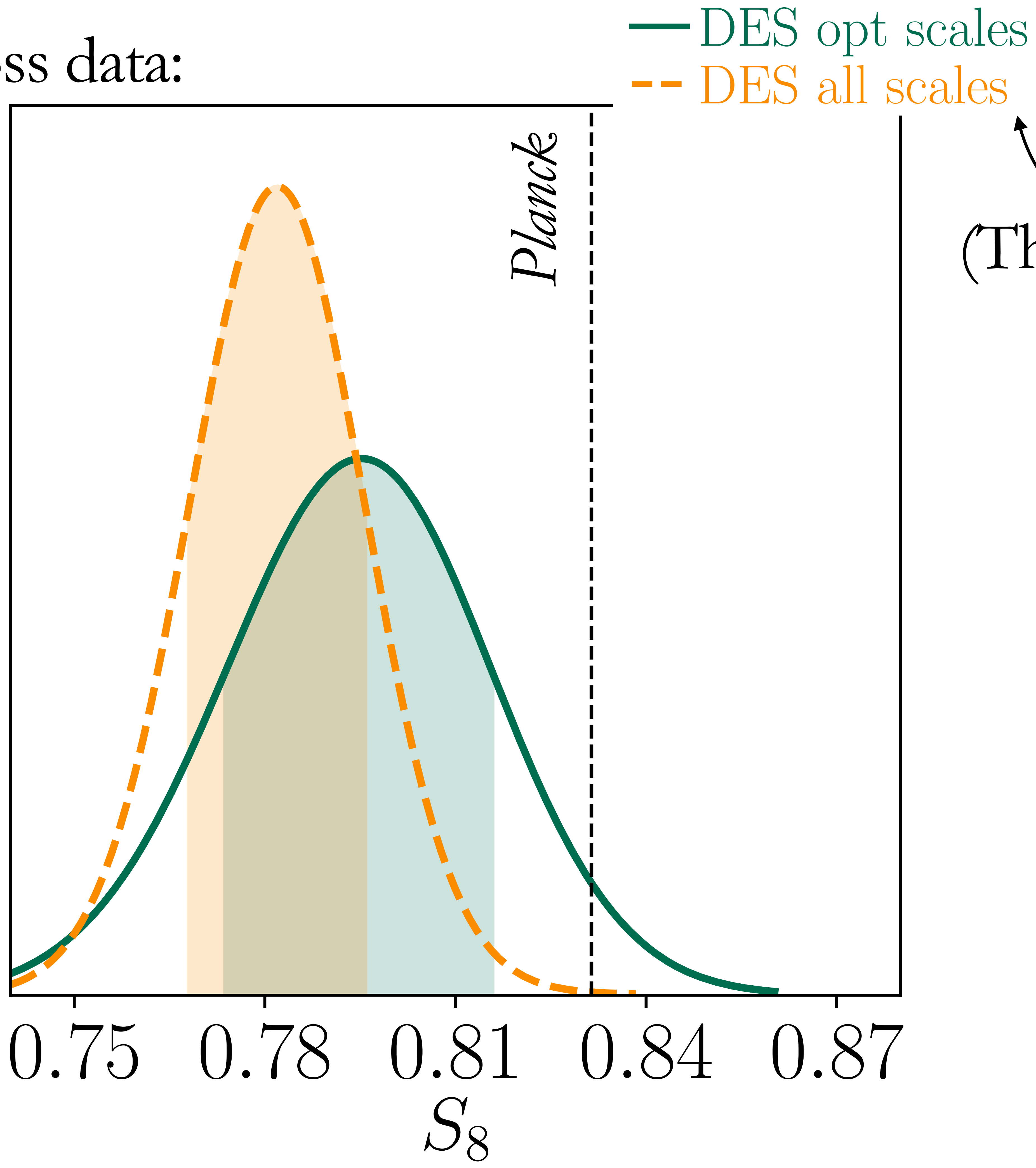
We can make increasingly more realistic image simulations



Euclid + Rubin ?

Looking ahead: Baryonic feedback

Toss data:



(This is wrong)

Alexandra Amon, Cambridge

Looking ahead: Intrinsic alignments hopes

Newer models:

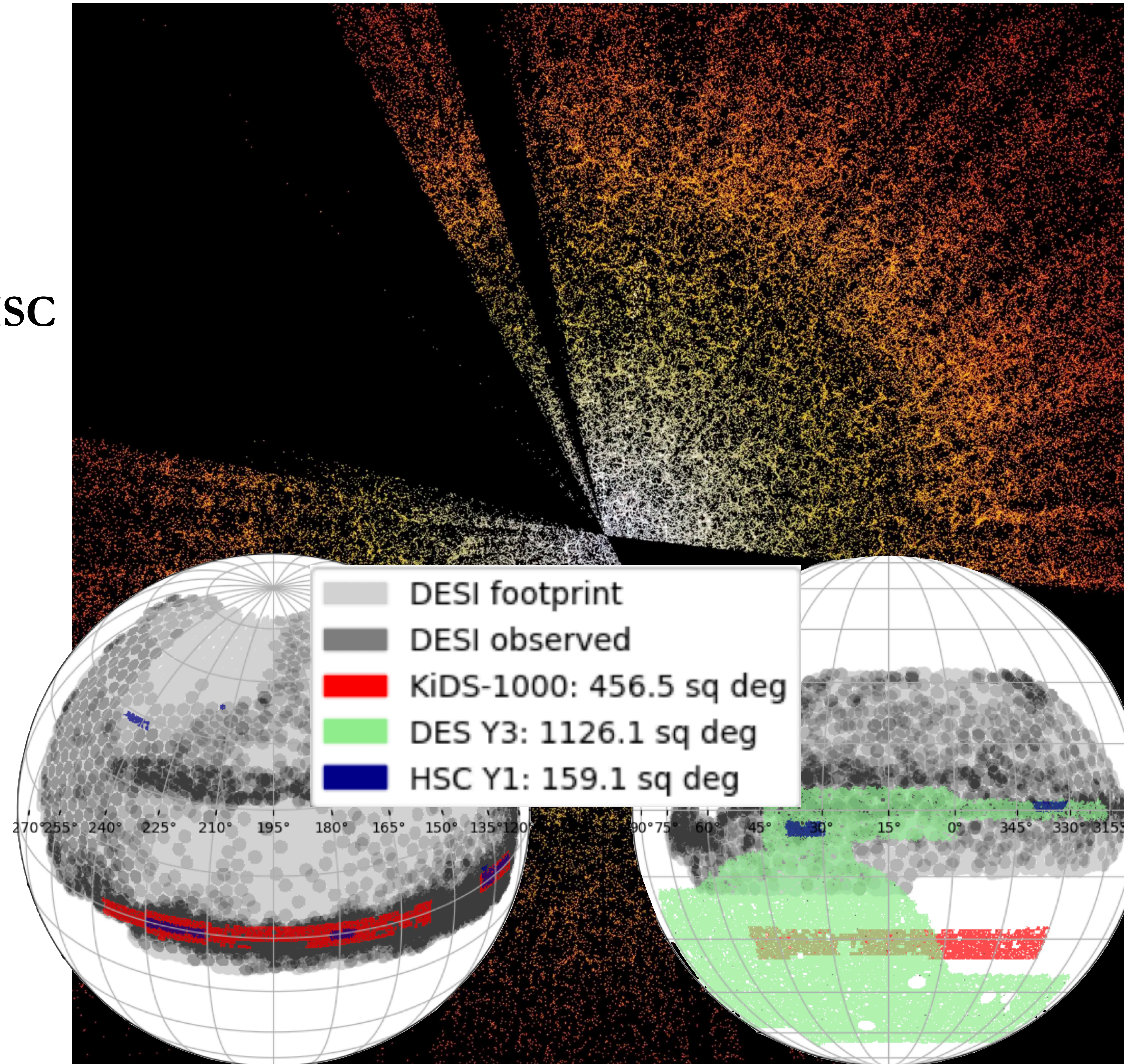
- Halo model (Fortuna+2020)
- EFT (Vlah+2021)

Need observational constraints! DESI + KiDS + DES + HSC
Better understand dependence of the effect on galaxy colour/mass/redshift/luminosity

ELG *0.6 < z < 1.6*
Y1: ~3.5 million (17 million)

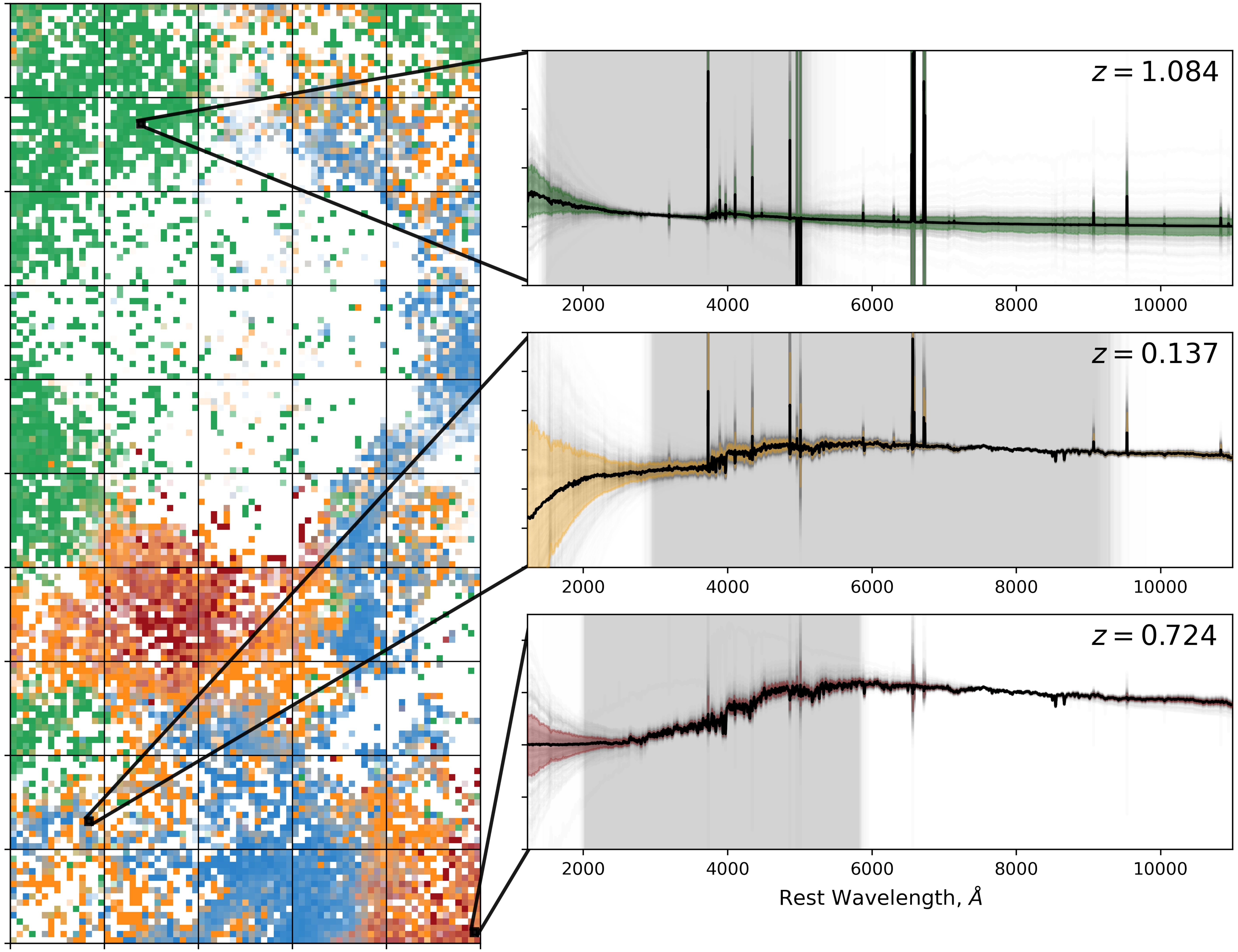
LRG *0.4 < z < 1.0*
Y1: ~2.5 million (6 million)

BGS *0.0 < z < 0.4*
Y1: ~4 million (10 million)



with Niall Jeffery, Benjamin Joachimi+ DESI

Looking ahead: Intrinsic alignments headaches



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LRG ***0.4 < z < 1.0***
Y1: ~2.5 million (6 million)

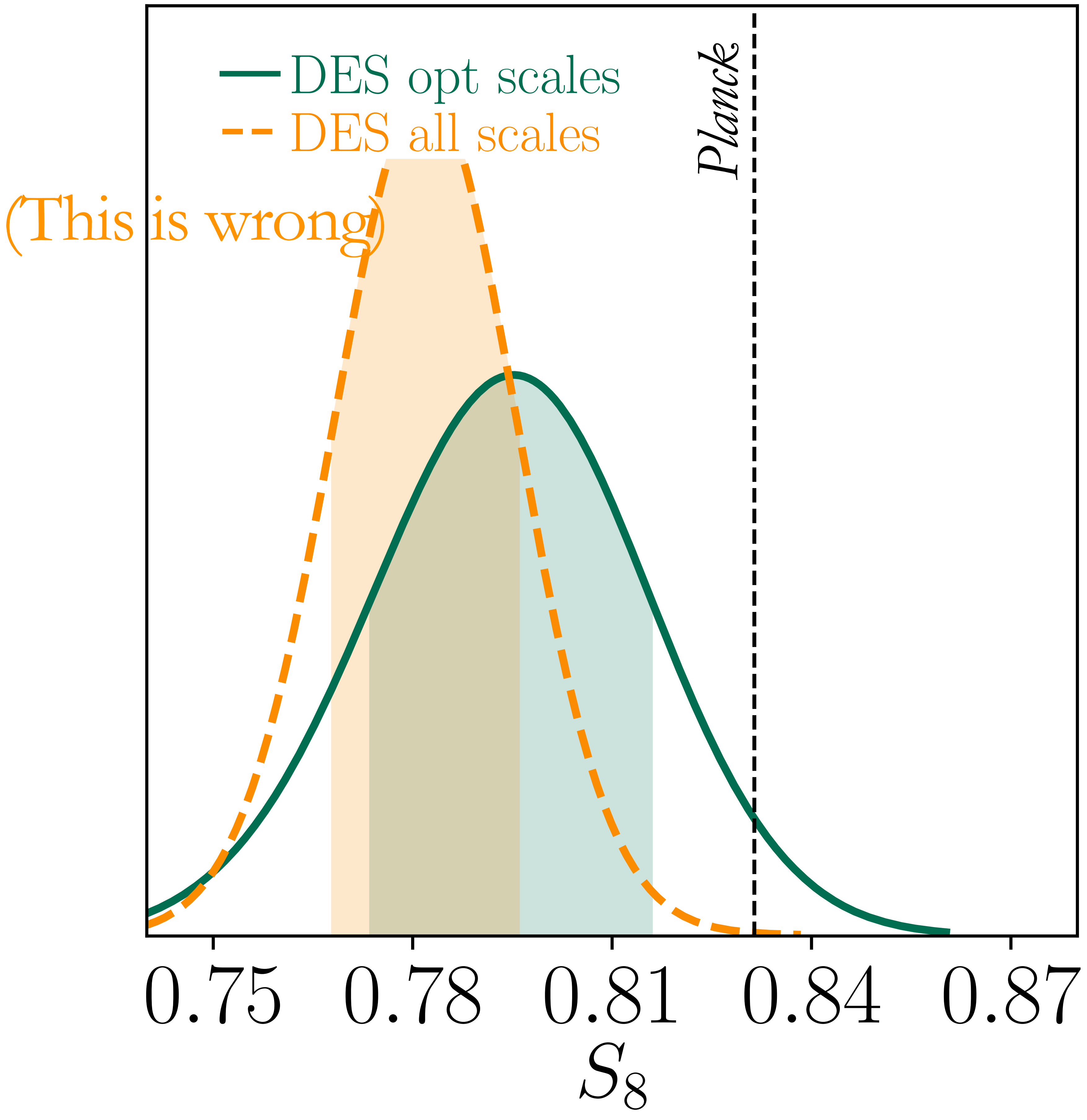
BGS ***0.0 < z < 0.4***
Y1: ~4 million (10 million)

Need spectra for galaxies like the ones in our lensing surveys !

Looking ahead: Baryonic feedback headaches

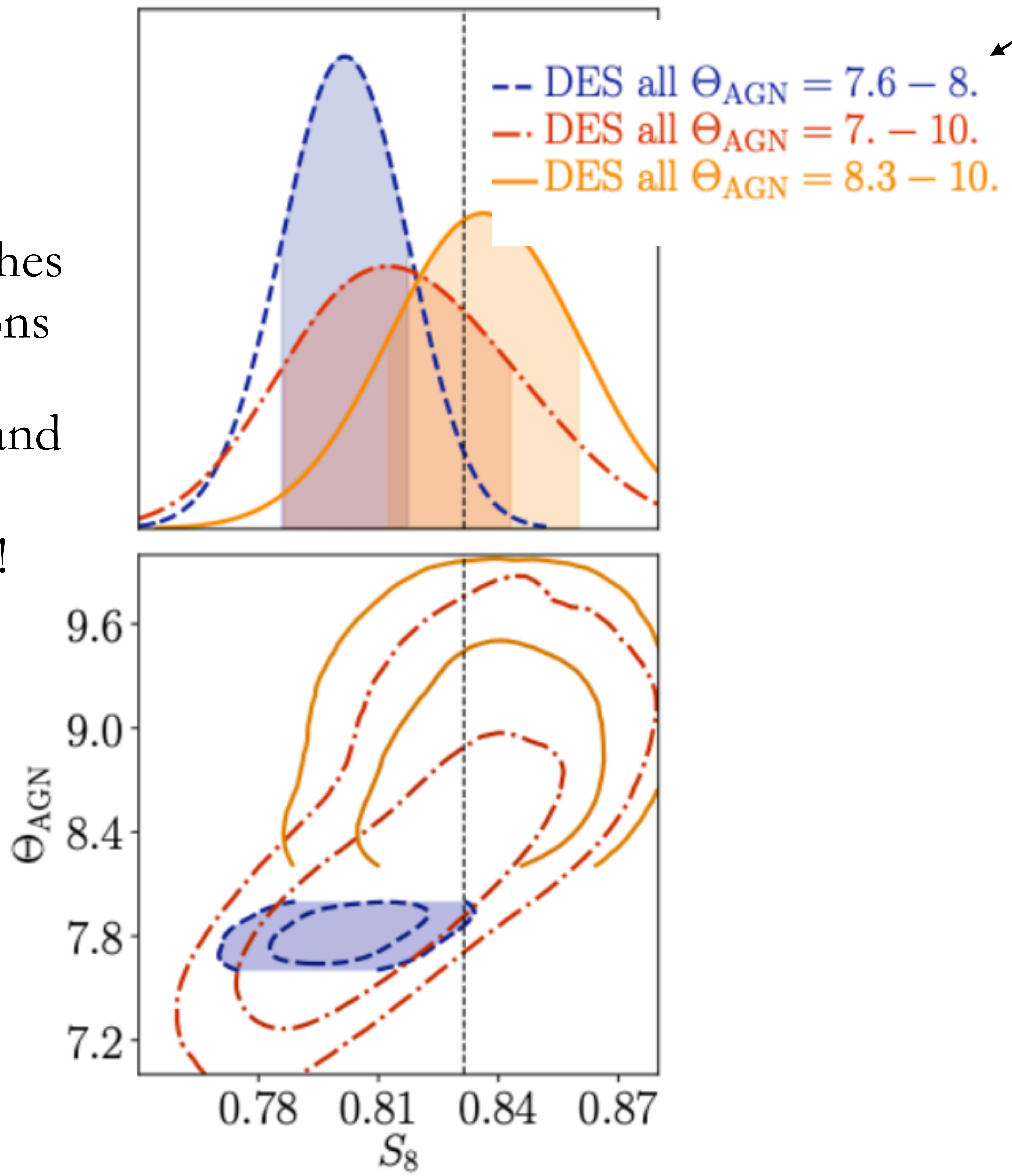
BAHAMAS feedback

We know that there's a lot more power in WL small scales



But current modelling approaches can make dangerous assumptions

We need truly flexible models and if that is the case, the loss in constraining power is the same!



Looking ahead: Baryonic feedback hopes

Baryonification

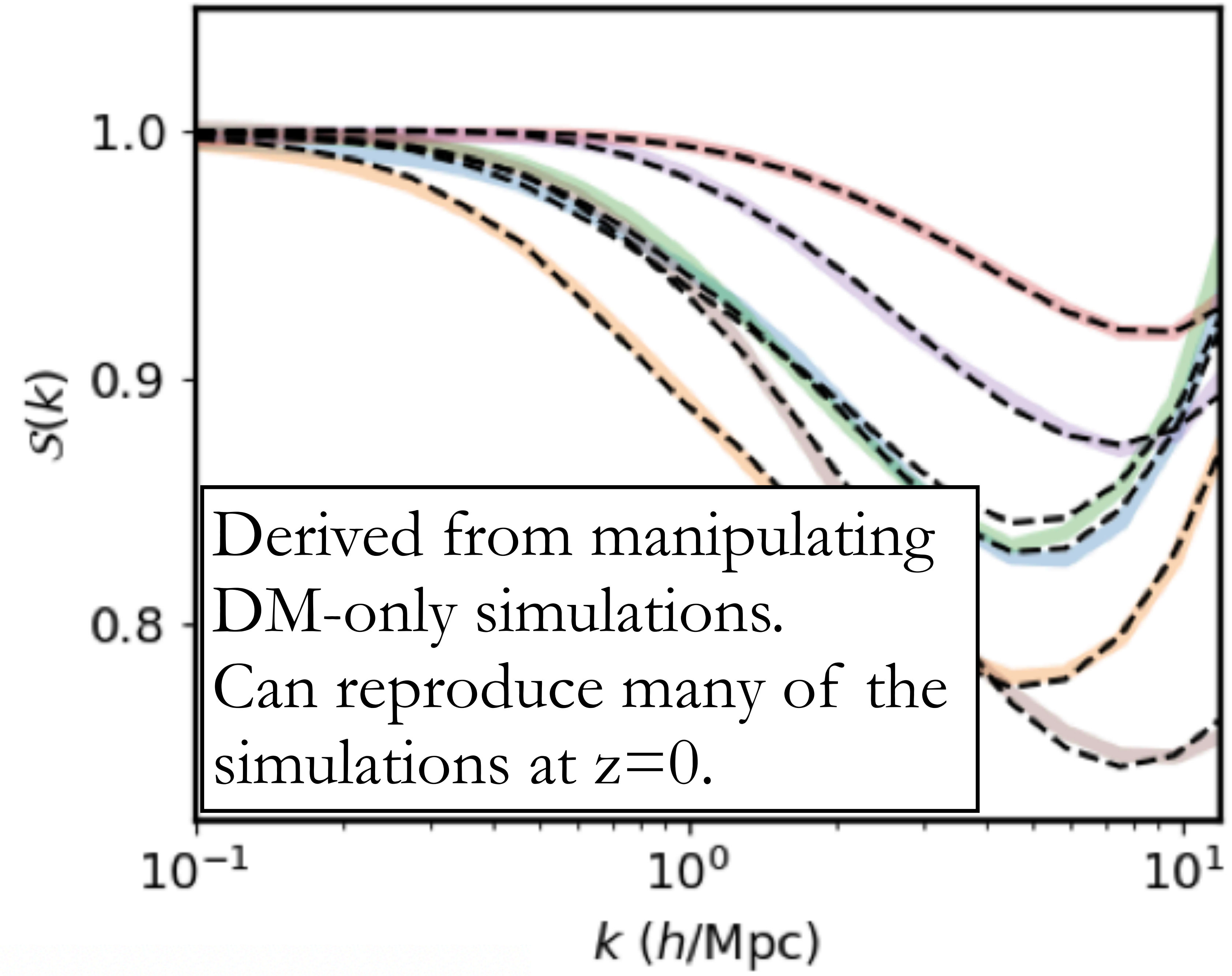
Schneider & Teyssier+2015

<u>New modelling approaches:</u>

HMCode2020

Baryonification →

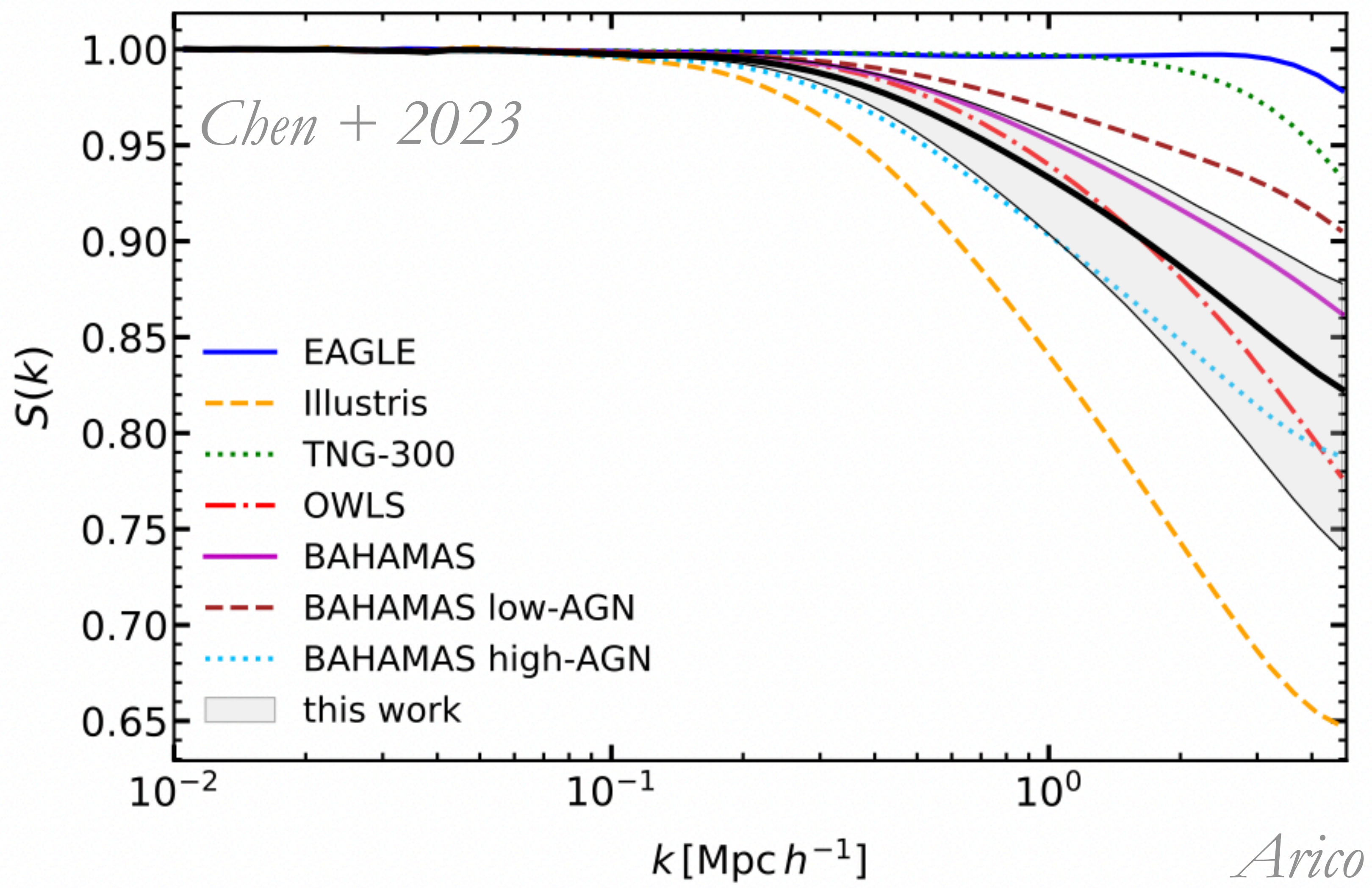
Are these models <u>sufficiently flexible</u> and do they give consistent results?

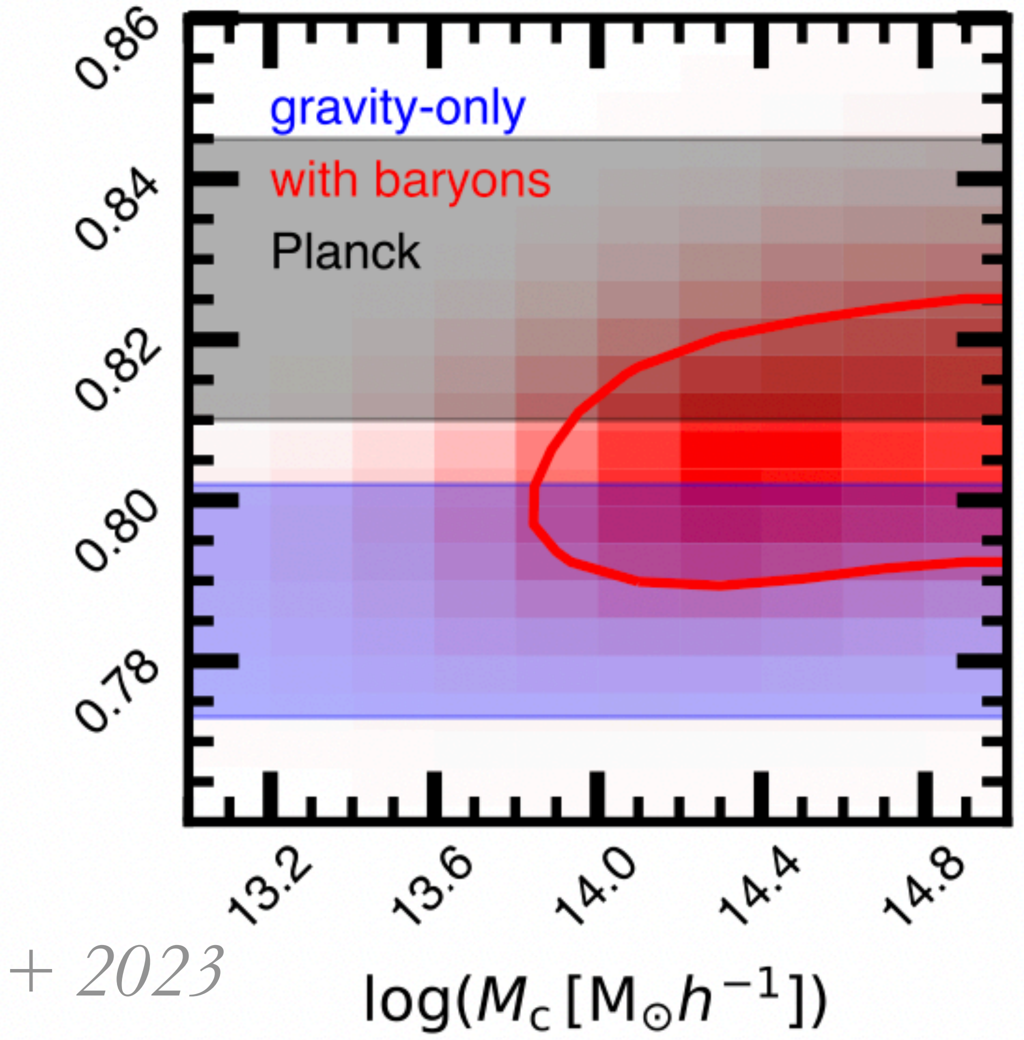


Derived from manipulating DM-only simulations.
Can reproduce many of the simulations at z=0.

<u>Reverse engineer the problem:</u>

Can we 'rule out' any hydro-simulations by analysing cosmic shear with these models?





Arico + 2023

Leah Bigwood + DES

The versatility of weak lensing

The data is coming

Weak lensing cosmology

Cosmological inference with systematics

Pixels to cosmology

The S_8 tension: the who's who

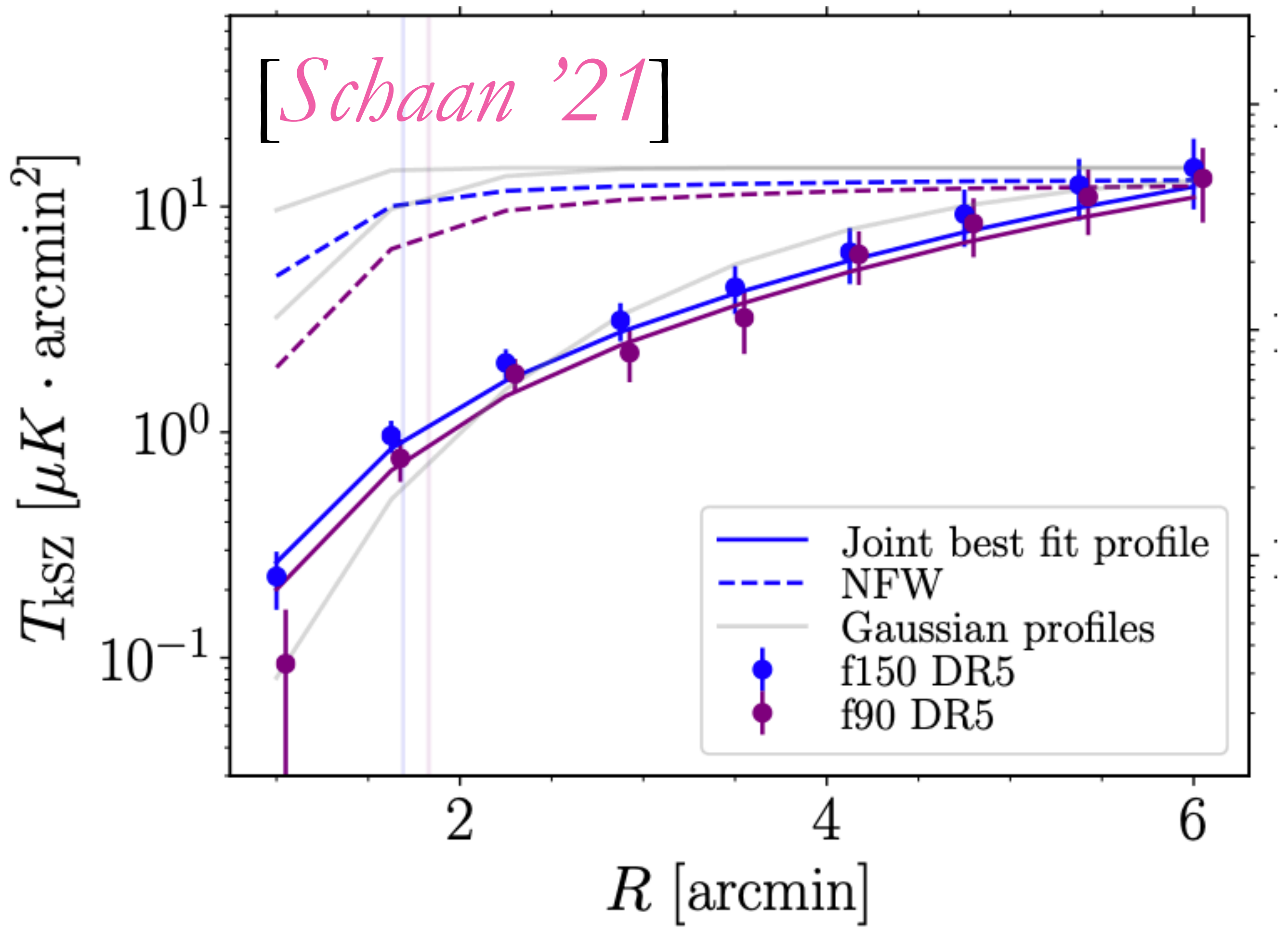
Solutions to the S_8 tension: wrong answers only

A non-linear solution to the S_8 tension?

Tackling weak lensing systematics: Headaches and hopes

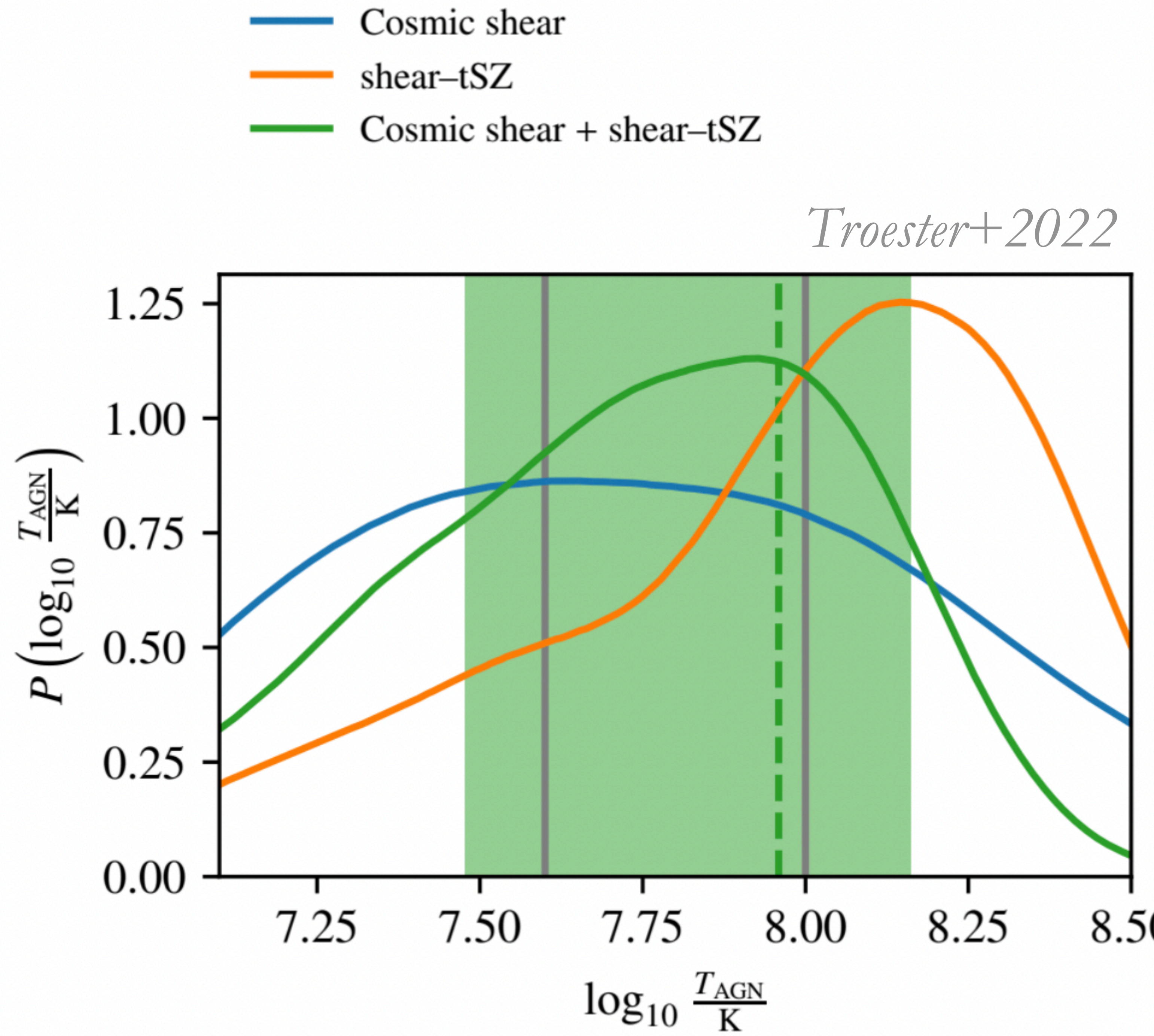
The future of weak lensing

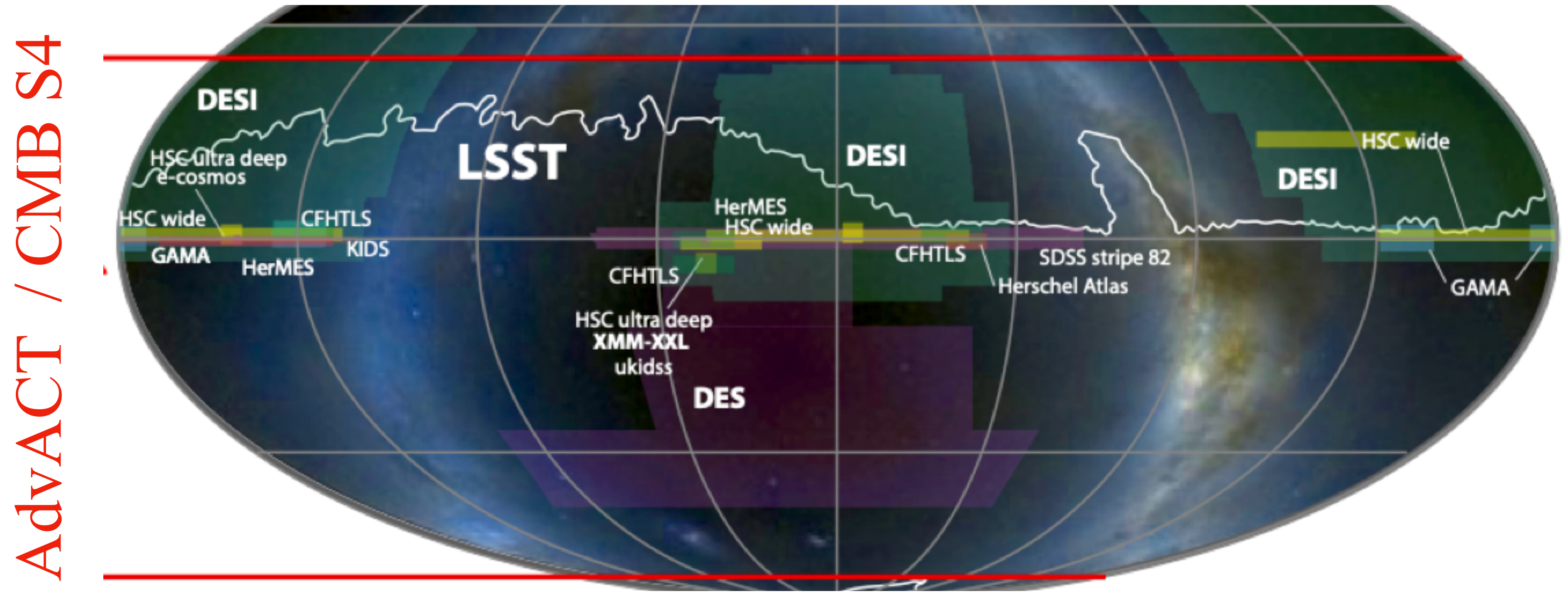
New methods: Use the SZ effect to constrain baryonic feedback

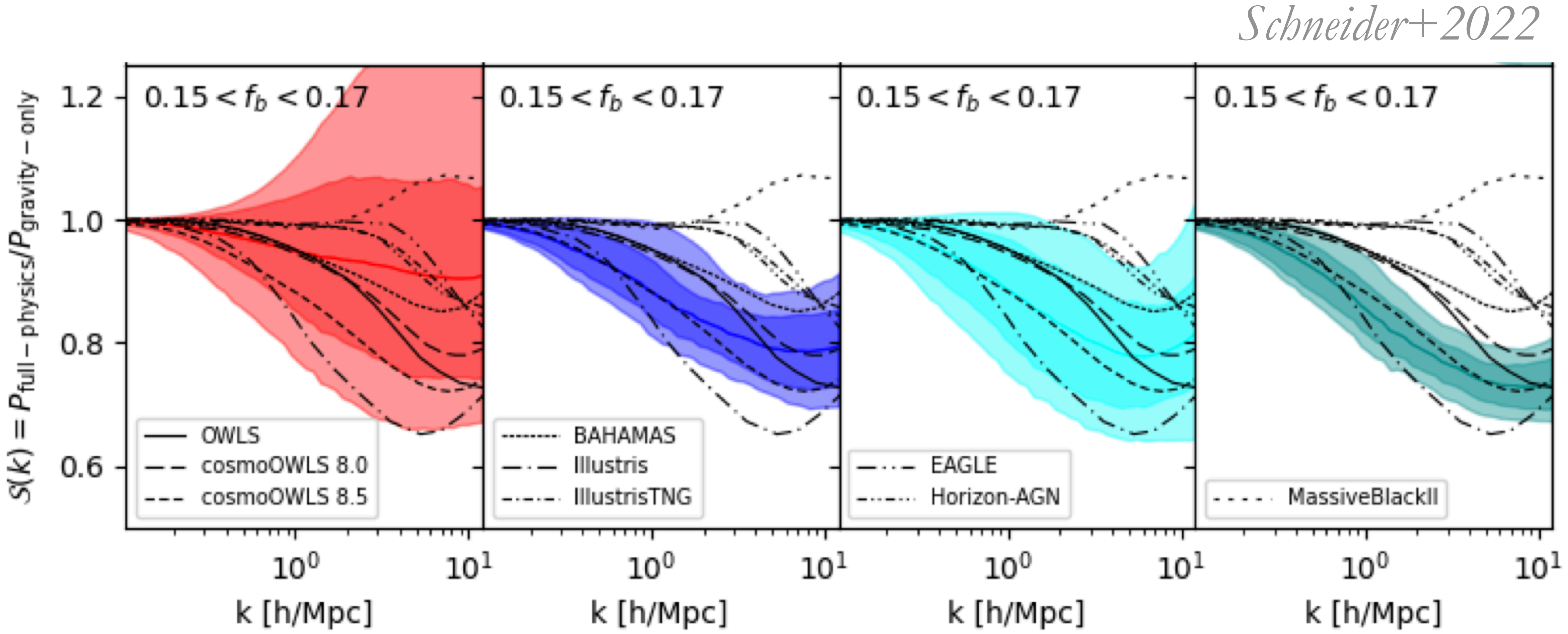


Kinetic Sunyaev-Zeldovich maps the distributions of gas around dark matter halos, giving a handle on the baryonic content.

DES **Lensing** probes the distribution of matter on small scales



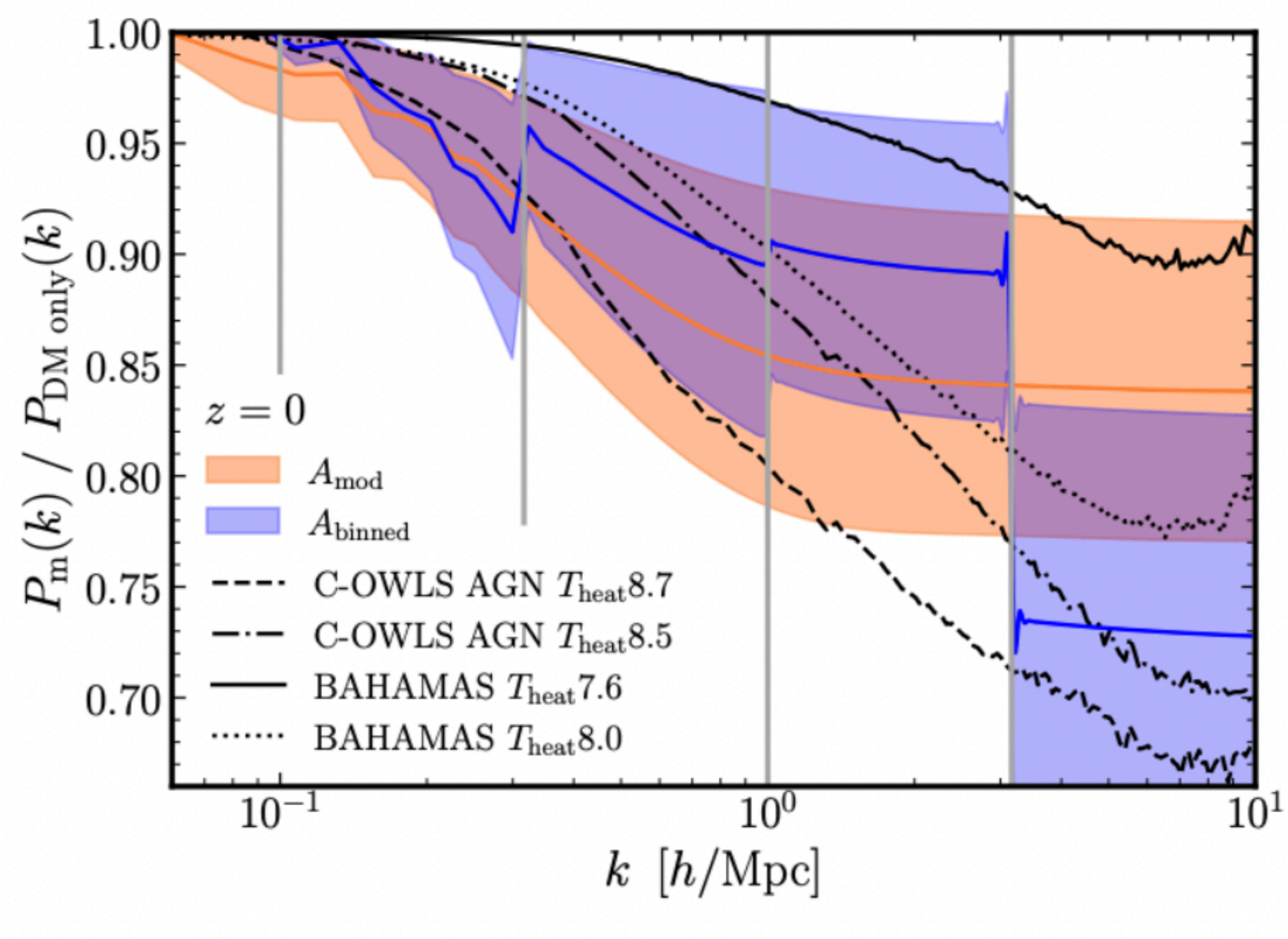


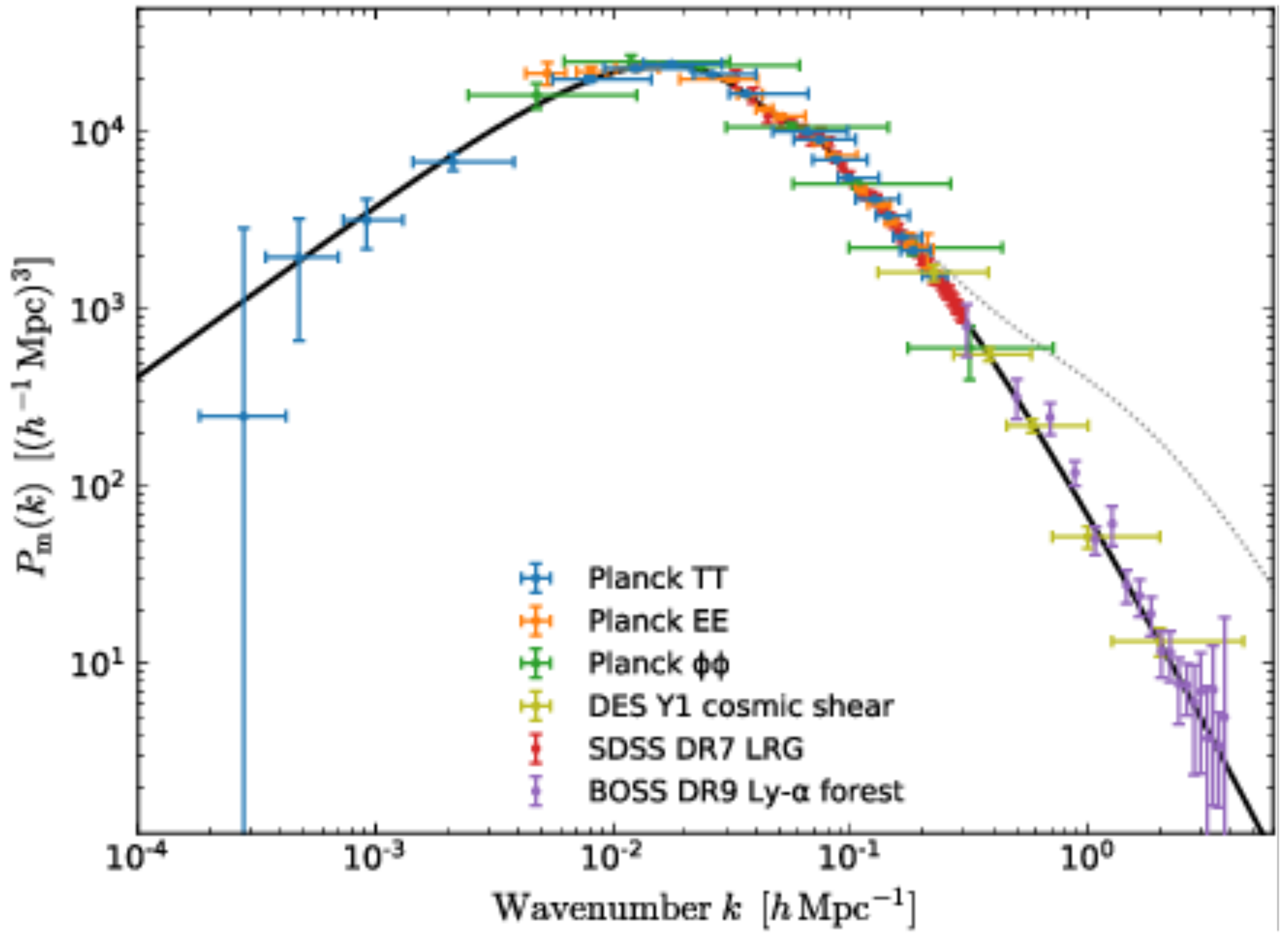


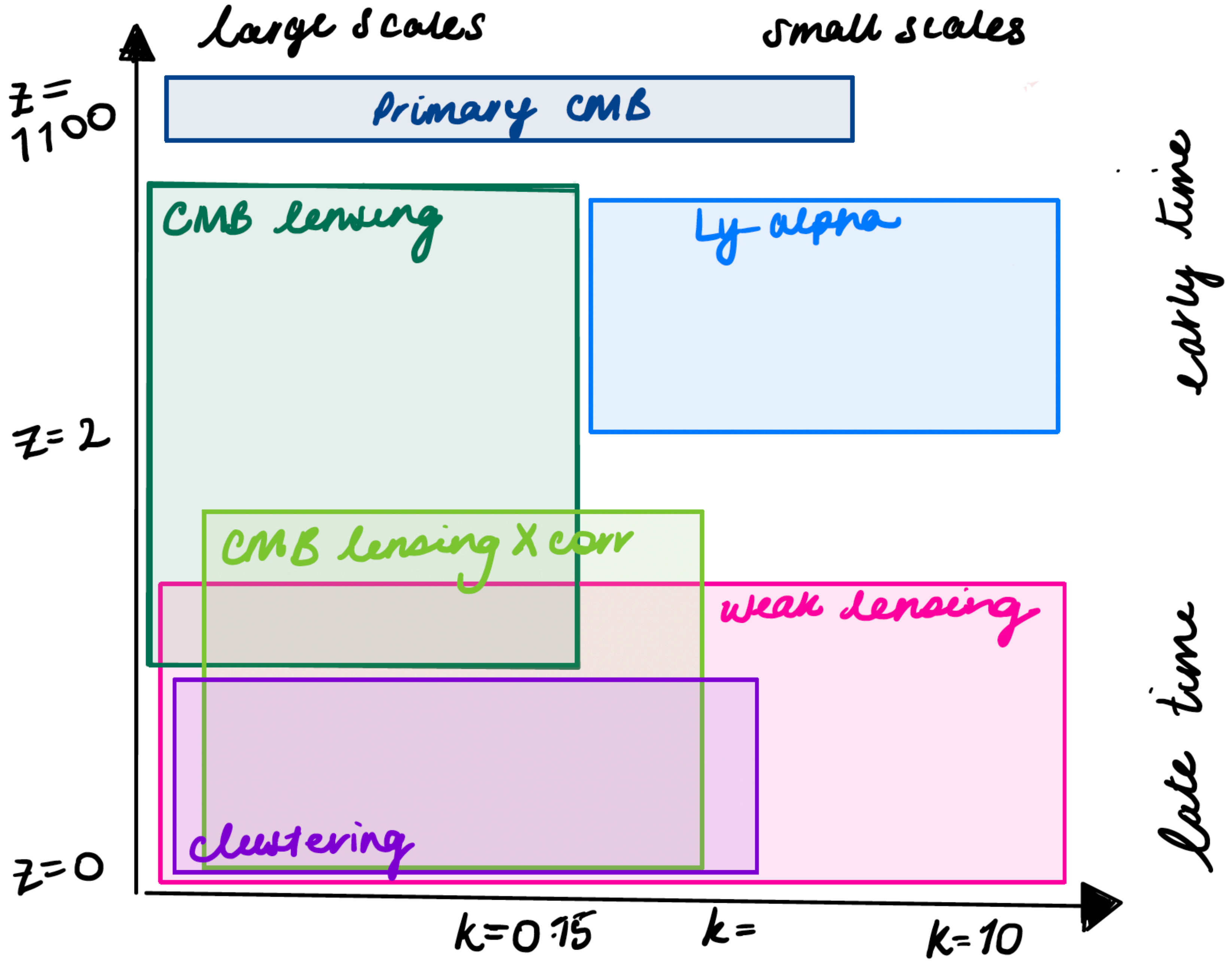
Leah Bigwood

with Manu Schaan, Simo Ferraro, Jo Dunkley + ACT + DES

New methods: Investigate the k and z that drive the tension: P(k, z)

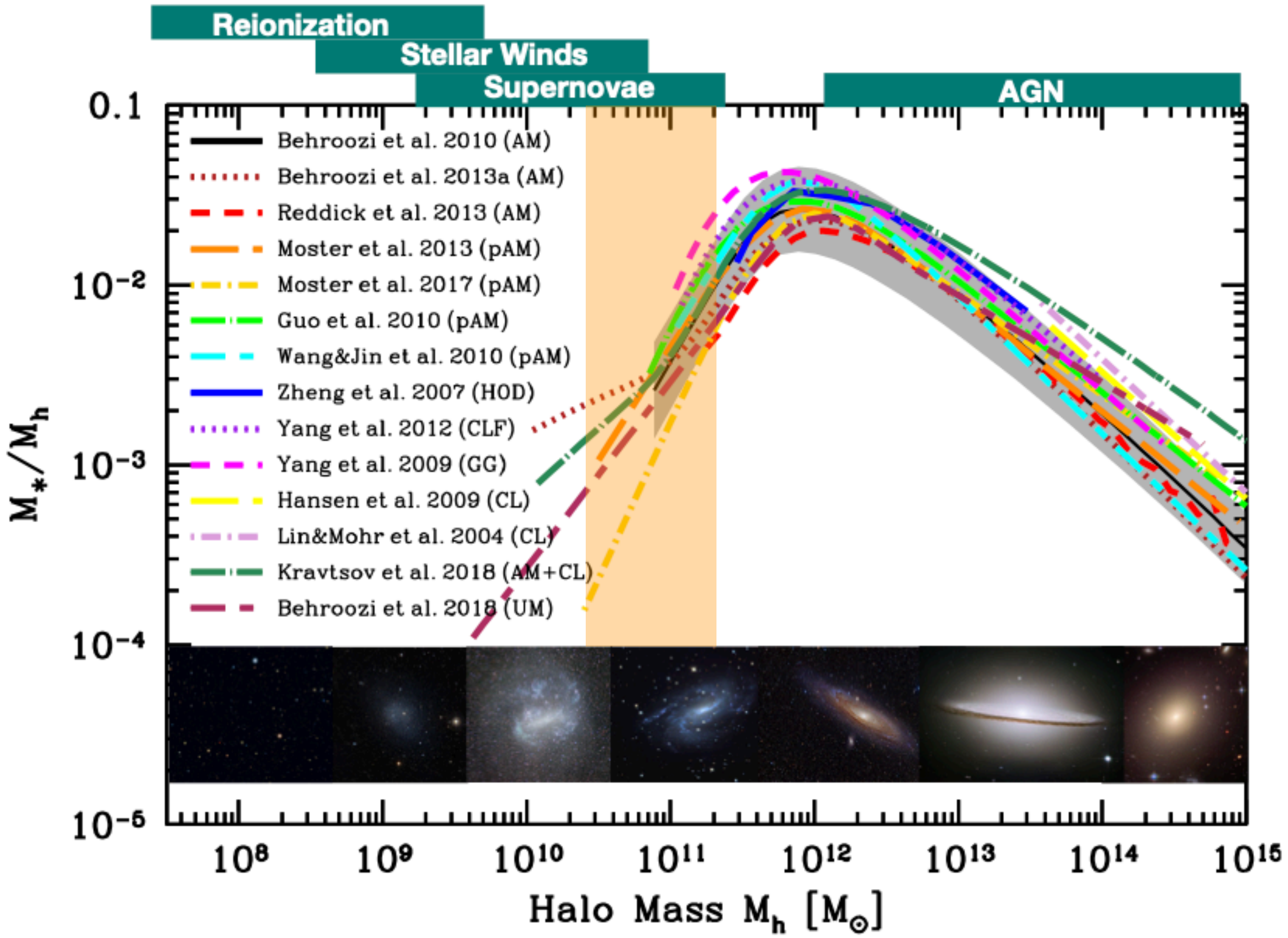


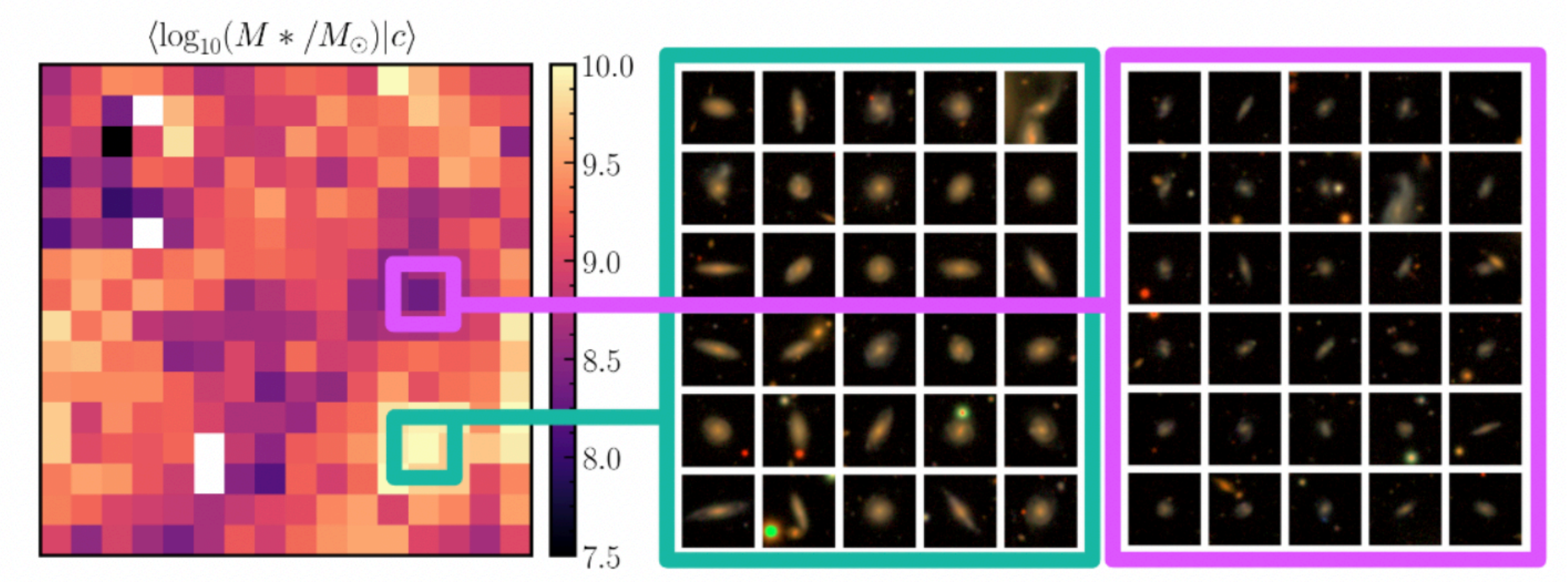


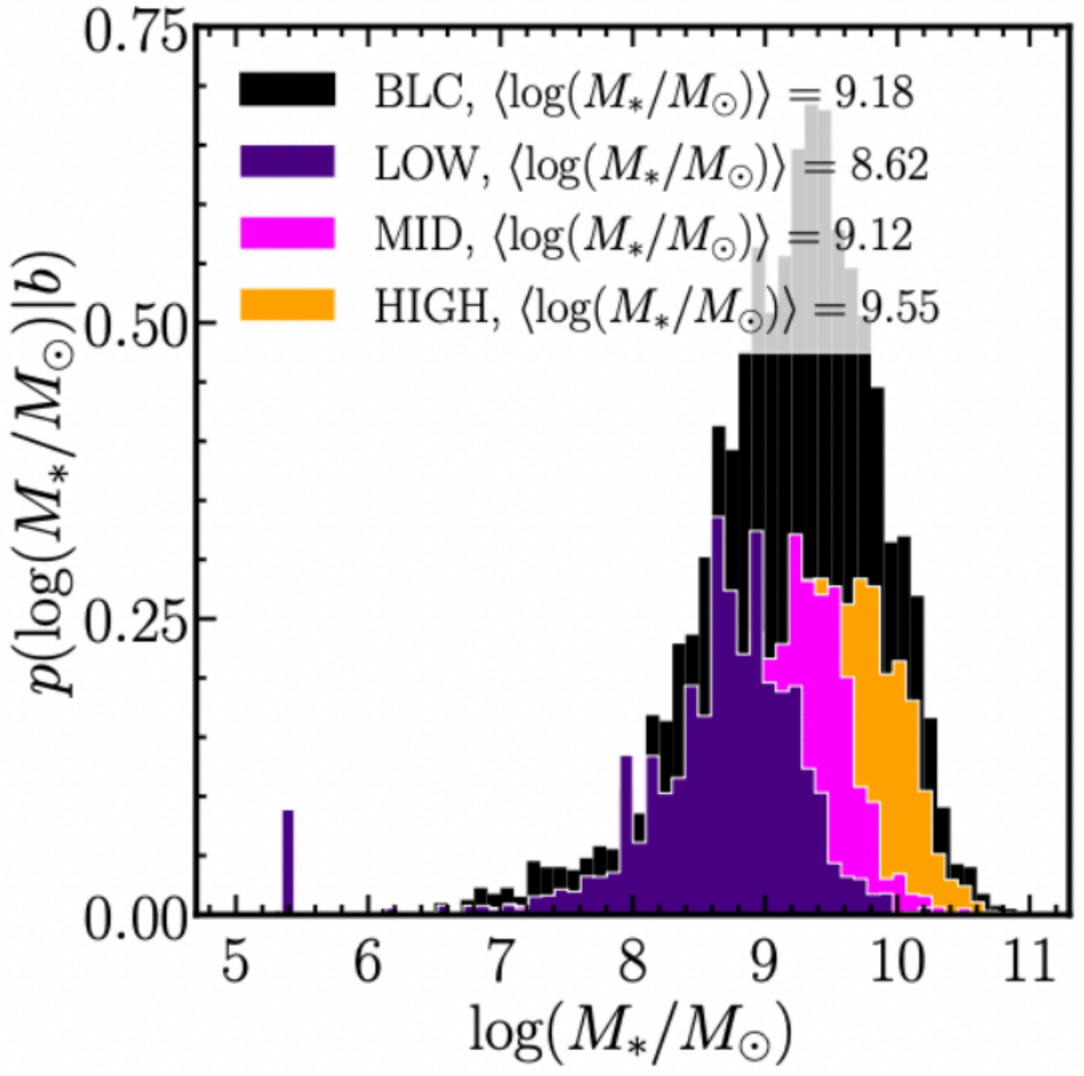


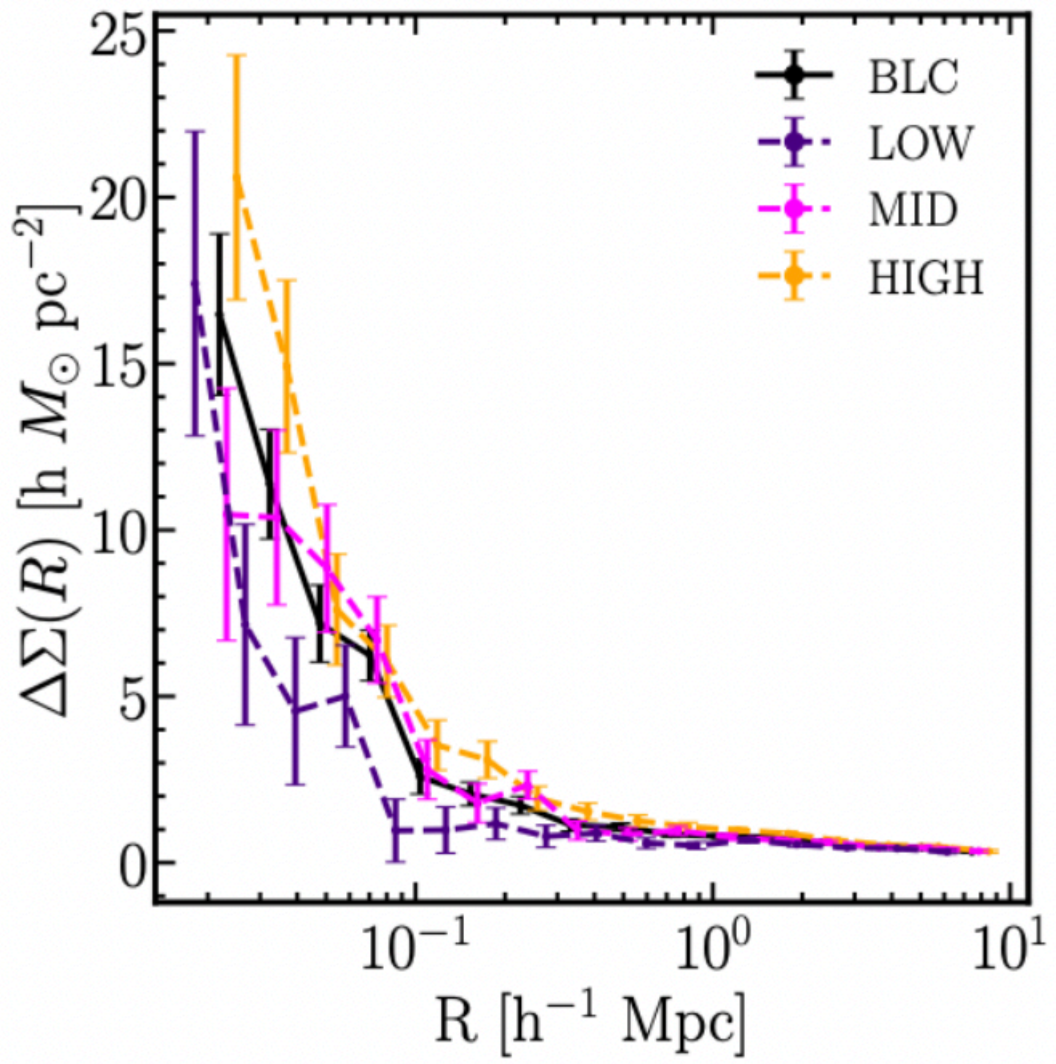
Calvin Preston, George Efstathiou

New methods: Dwarf lensing as a probe of dark matter









Joseph Thornton,
Susmita Adhikari, Yao-Yuan Mao,Risa Wechsler

New methods: Beyond 2pt

3 point lensing — Peaks / voids etc — Field level inference/CNNs

- Opportunity for additional probes that are sensitive to different systematics
- Opportunity to learn about systematics
- Promise of more power - but we should focus on accuracy over precision

What is your weak lensing worry?

- Shear measurement & calibration
- Photometric redshifts
- Modelling baryonic feedback
- Intrinsic alignments
- Something else


Euclid Space Telescope
Nancy Grace
Roman Space Telescope
Rubin Observatory