Cosmology from weak lensing:

The S_8 tension

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UNIVERSITY OF CAMBRIDGE

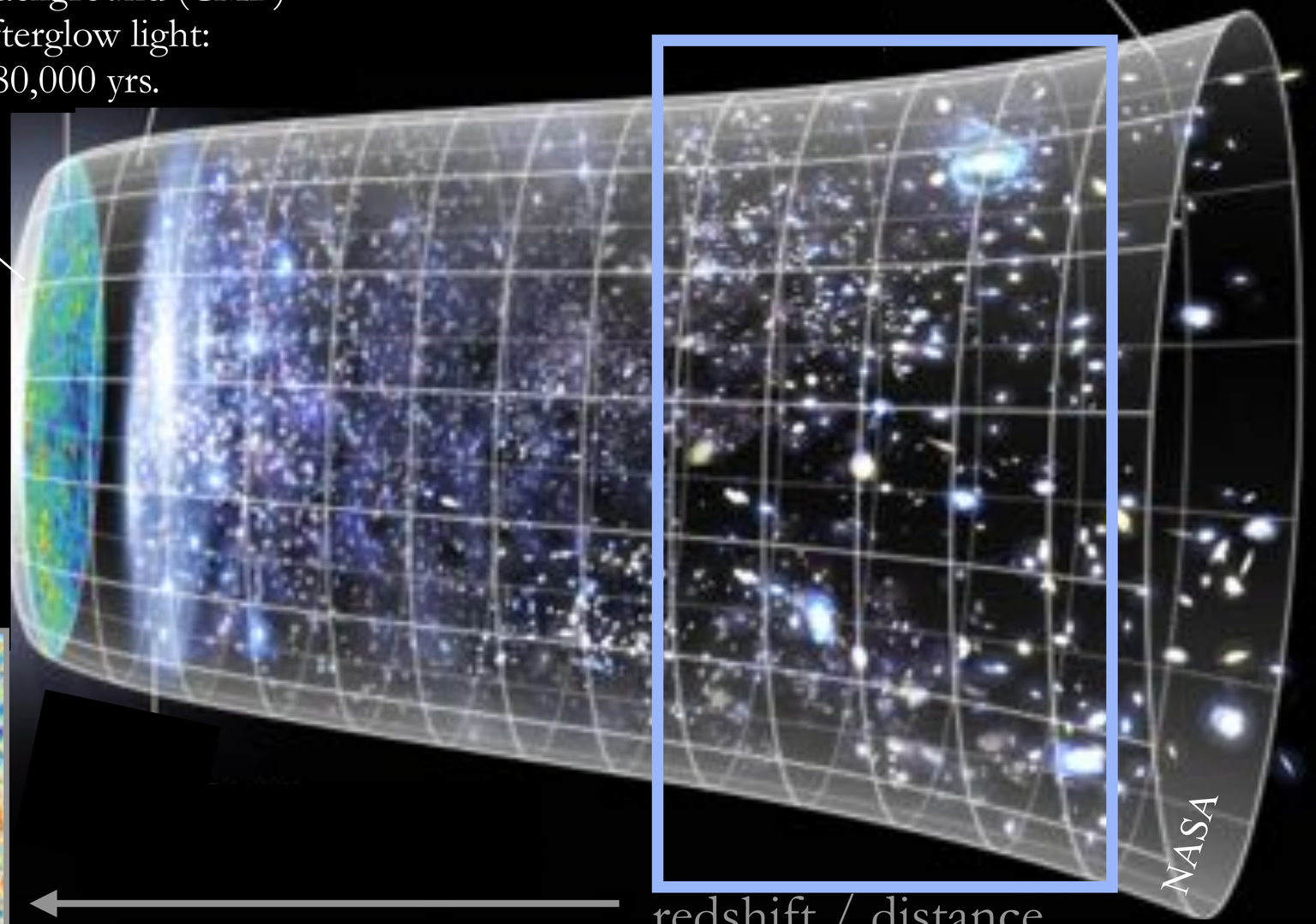
- Weak lensing cosmology & the S_8 tension
- Lensing in practice
- Understanding the S_8 tension: a non-linear solution

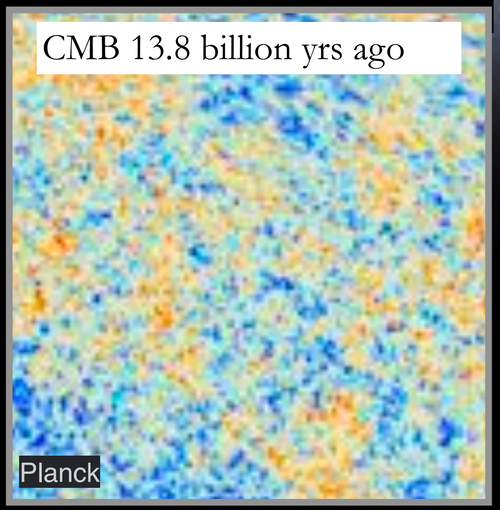
Cosmic Microwave Background (CMB) afterglow light: 380,000 yrs.

Dark energy accelerated expansion

Large-scale structure observations

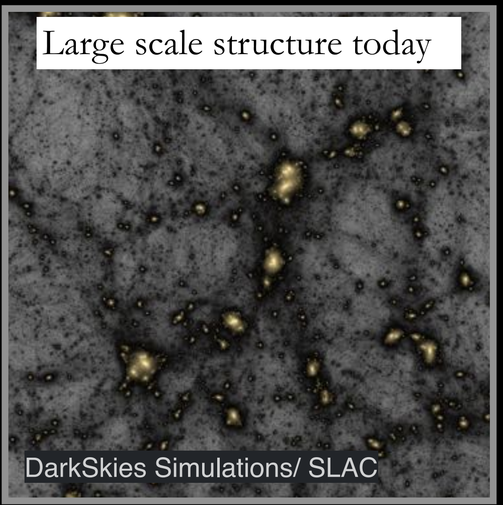
Quantum fluctuations



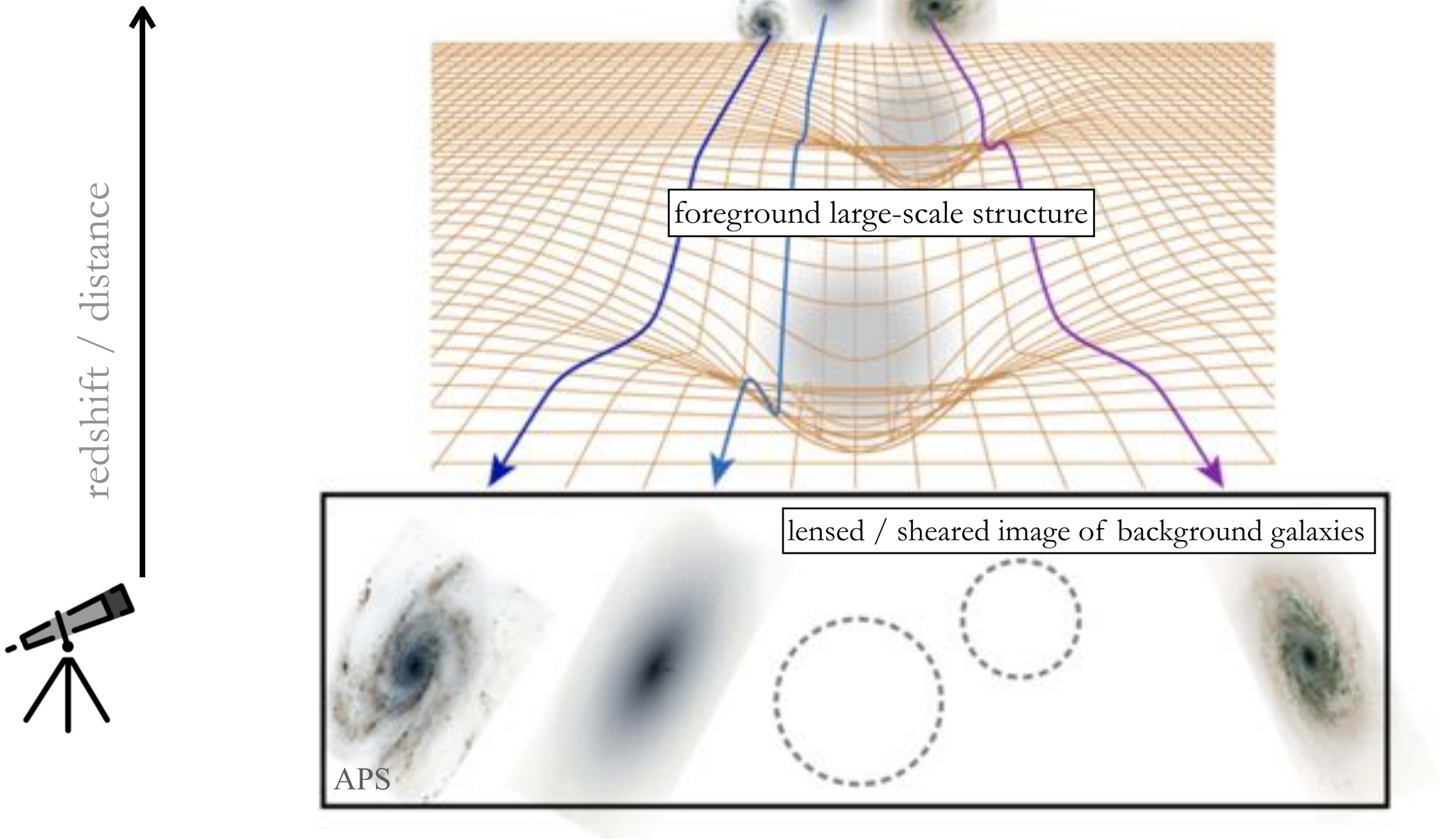


redshift / distance

time since CMB



Weak lensing cosmology

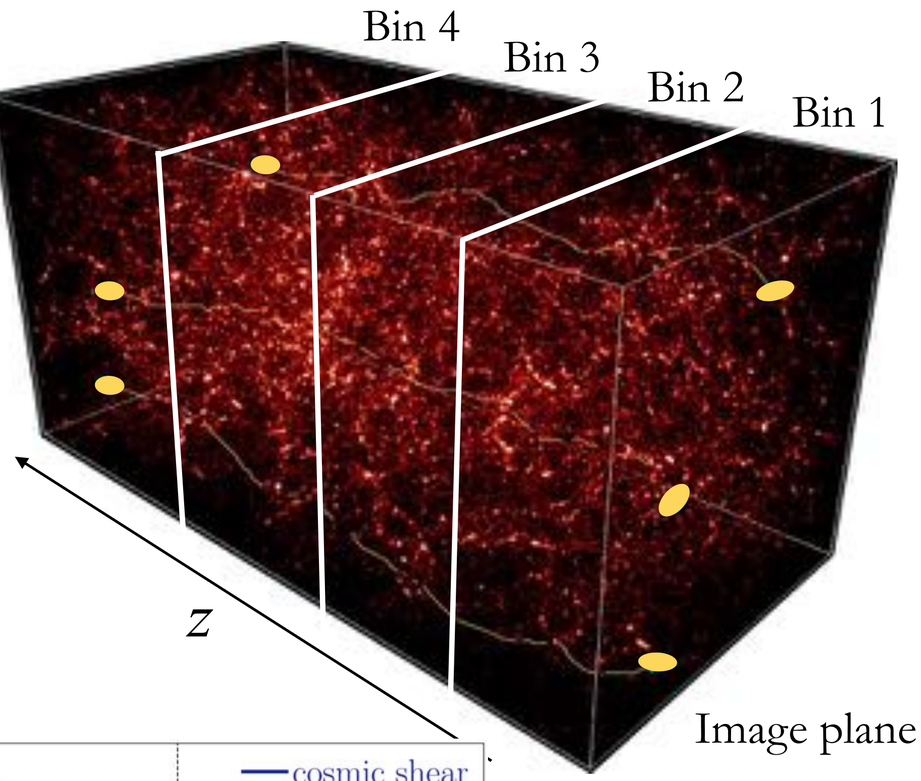


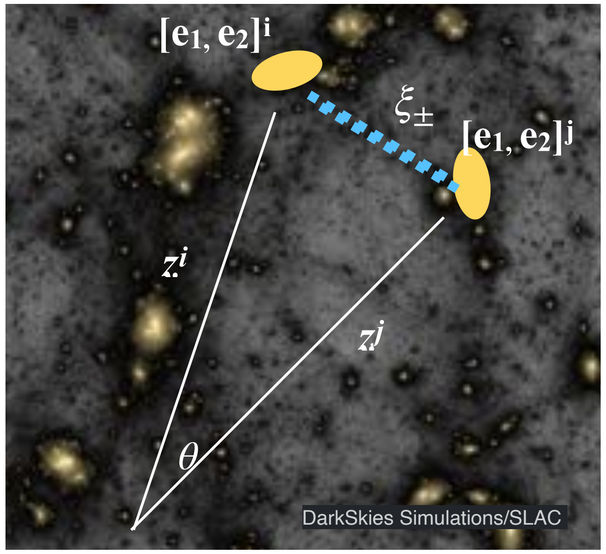
Weak lensing cosmology

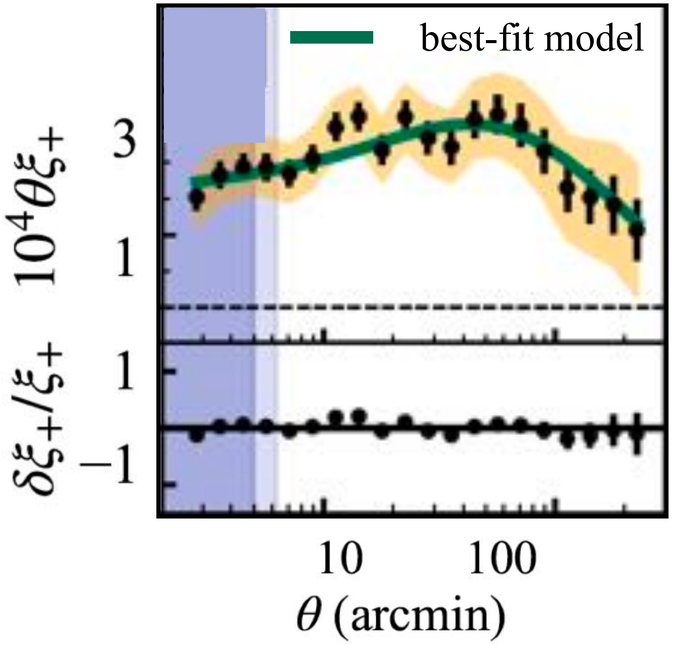
Light from distant galaxies passes the same foreground structure.

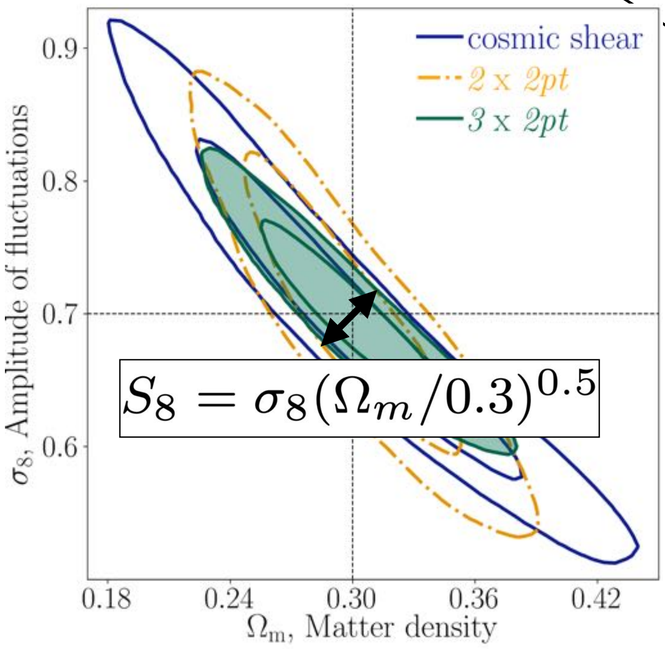
We measure the correlation of the **shapes** of source galaxy pairs [i,j] as a function of angular radius and to model the signal, we estimate the distribution of redshifts of the galaxy sample.

Do analysis tomographically, *i.e.* in **redshift** bins.

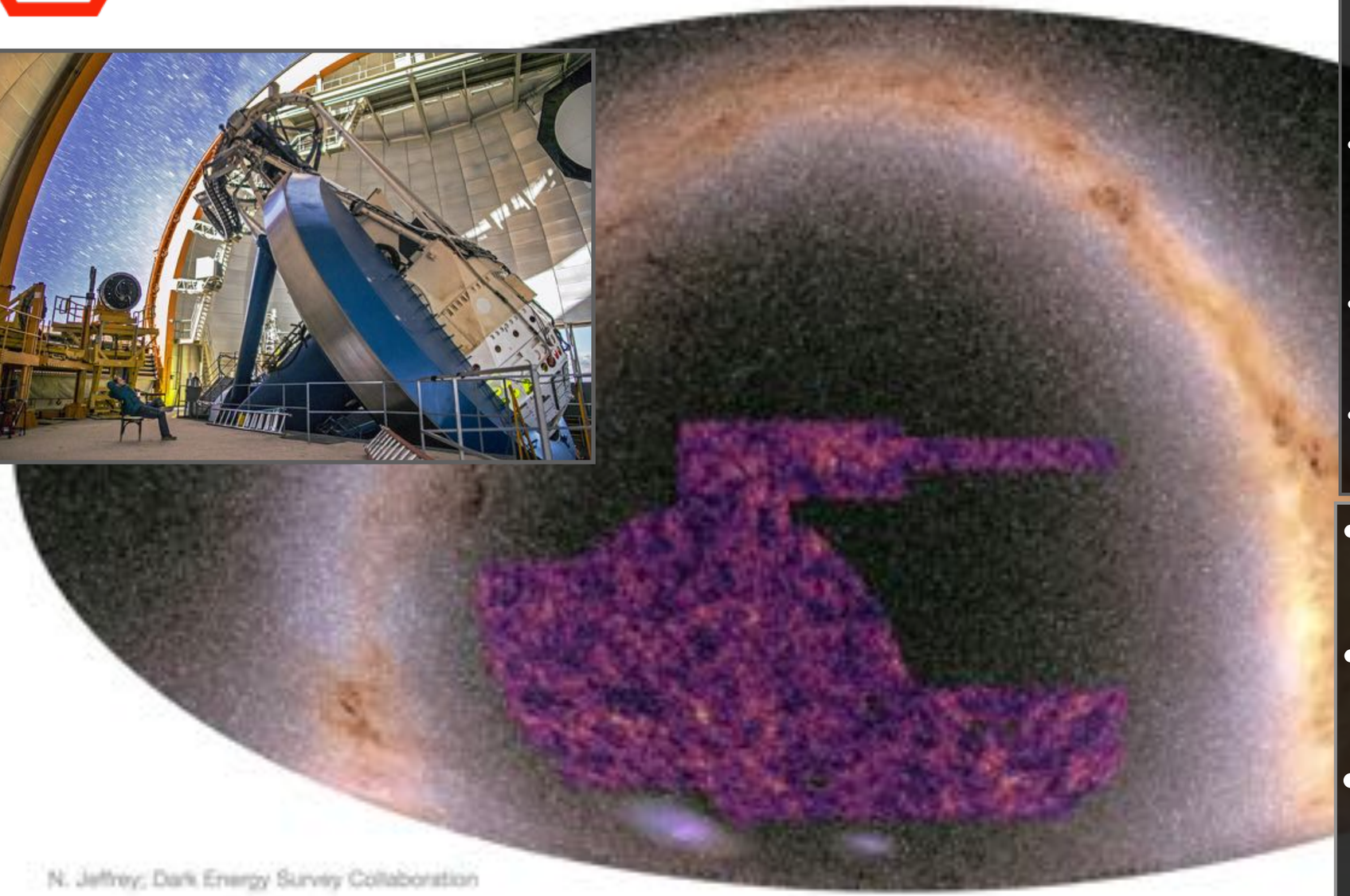








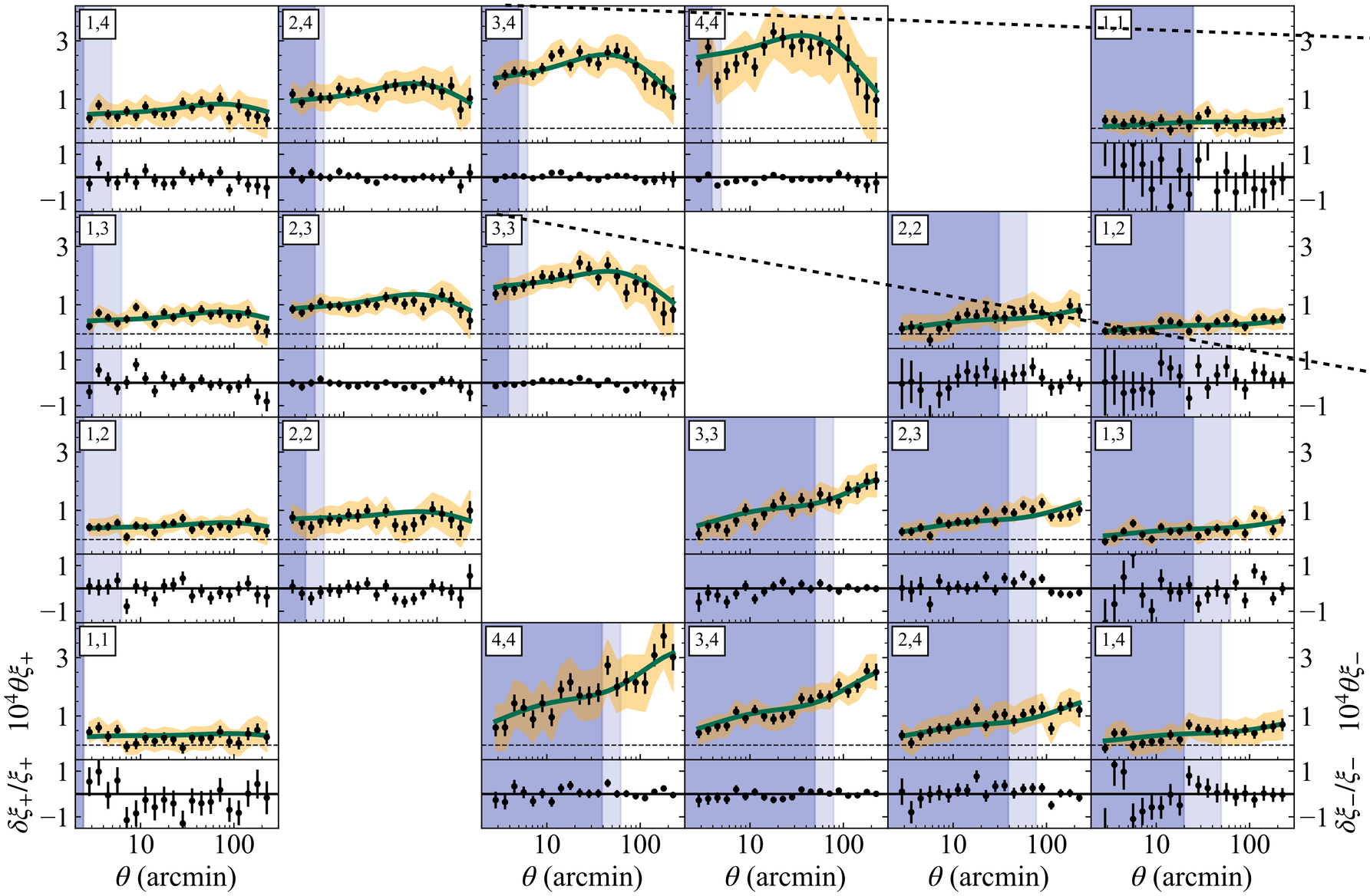
Dark Energy Survey: Y3

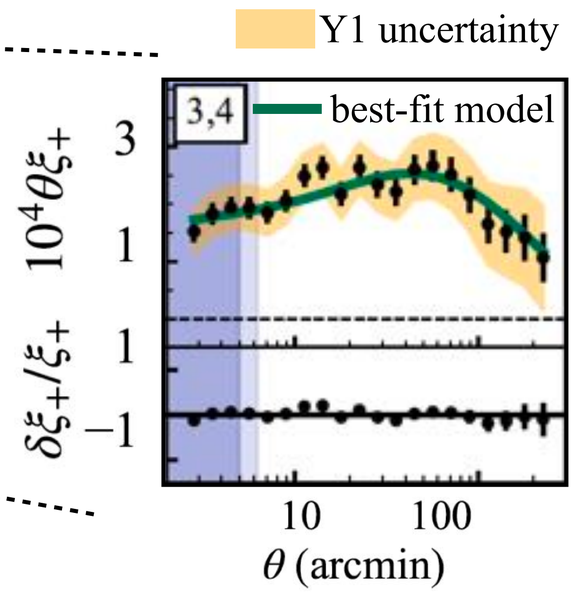


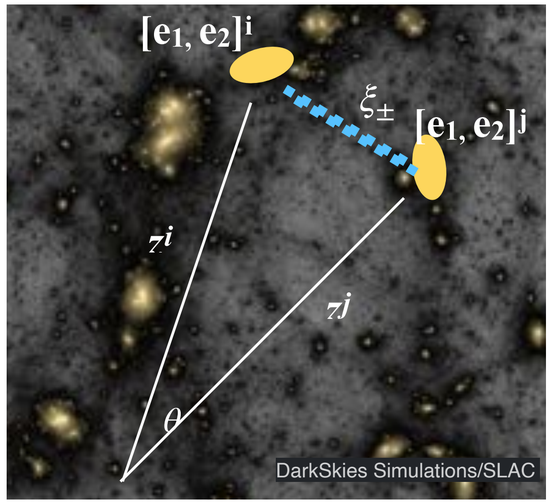
- Survey status: 6 yrs observations complete on the 4m CTIO Blanco Telescope
- 5000 sq. deg., observing in *(u)griz(Y)* filters
- Wide+Deep survey strategy
- DECam: a 570 Mpix camera 3 sq. deg. field of view

- Y3: 2013-2016 data
- **Full area:** 5000 sq. deg.
- **100M galaxies**
- Mean redshift ~ 0.63

Weak lensing measurements today: >100 million DES galaxies



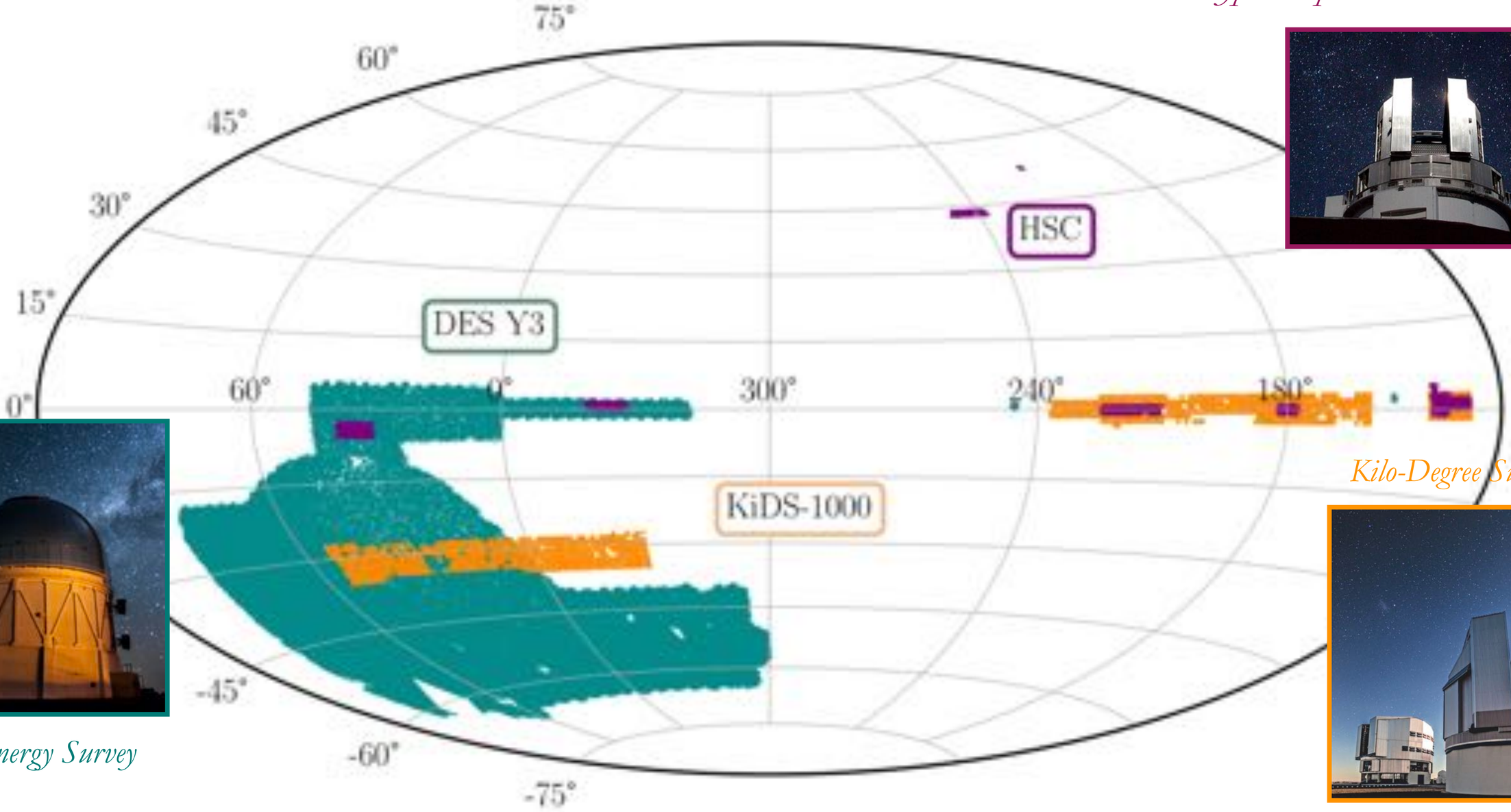




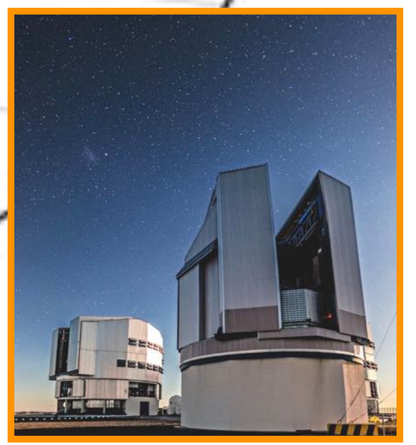
Lensing surveys

Hyper-Supreme Camera Survey

Dark Energy Survey



Kilo-Degree Survey



Lensing surveys: the S_8 tension

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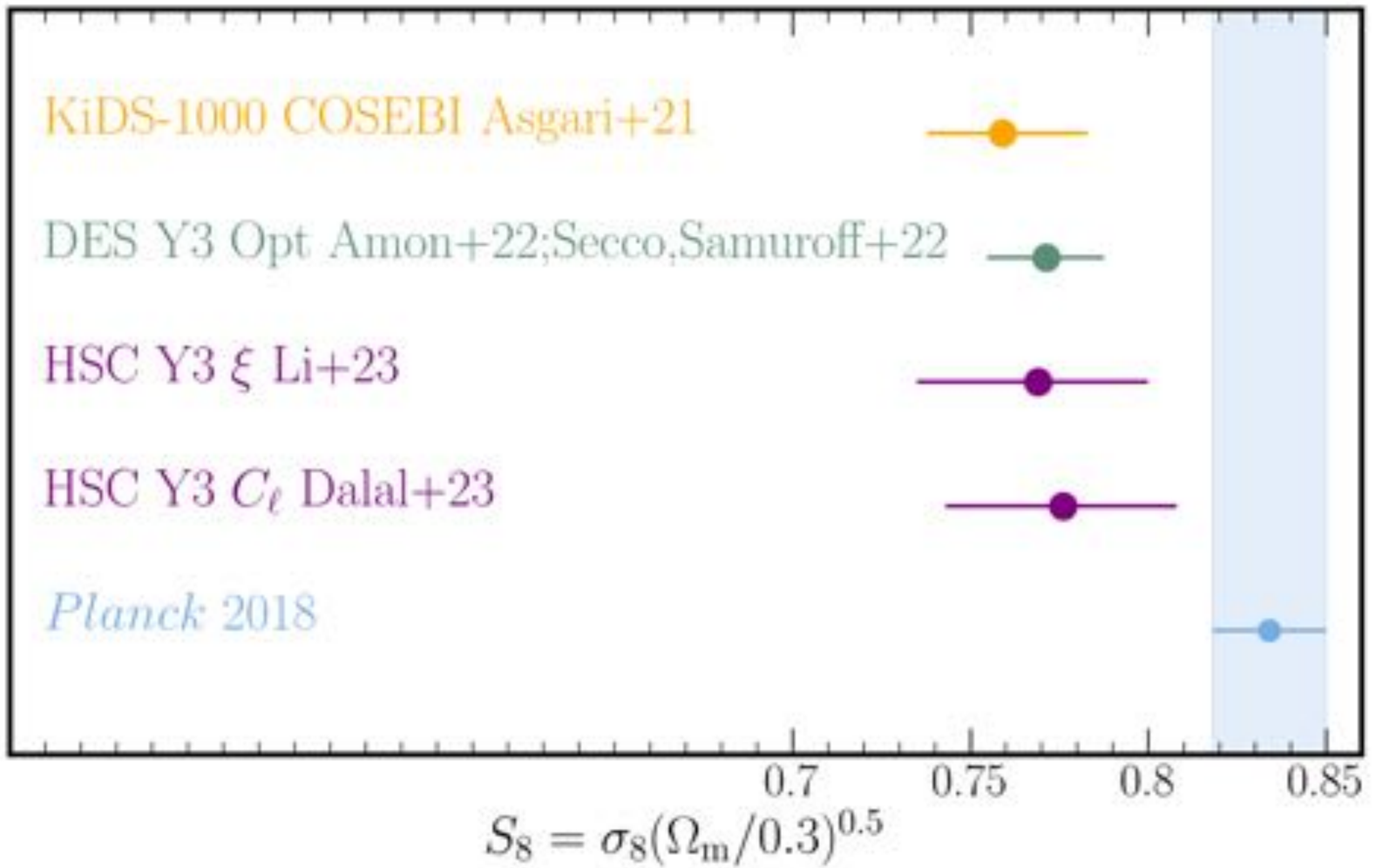

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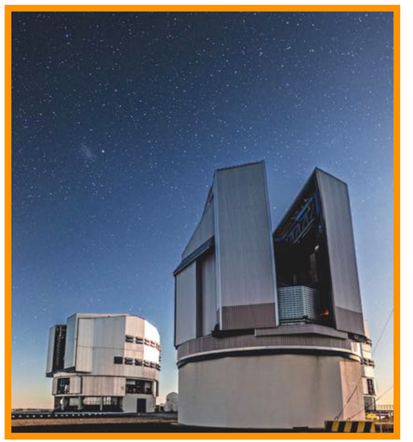
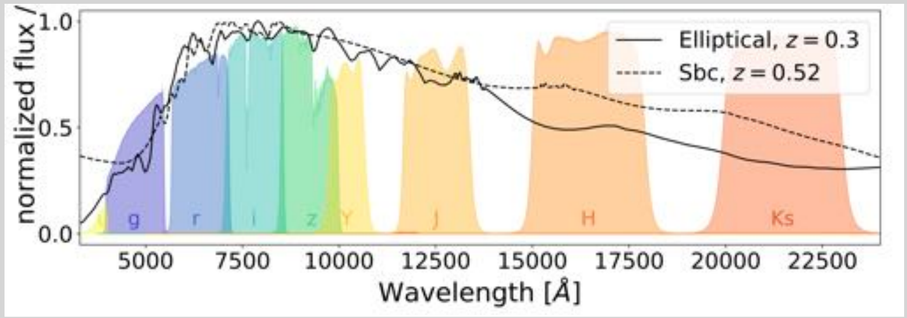


Cosmic shear *usual suspects*

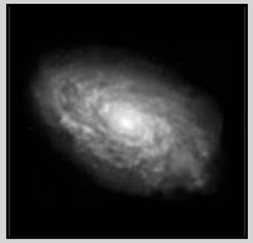
Redshift calibration

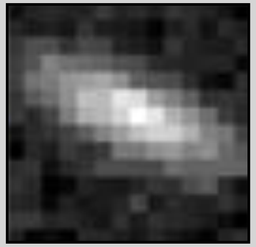
Challenge: Estimating the distances to galaxies using only a few colours

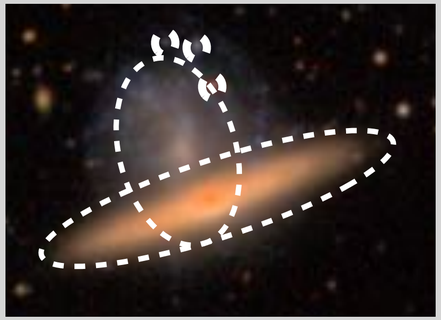


Shear calibration: blending

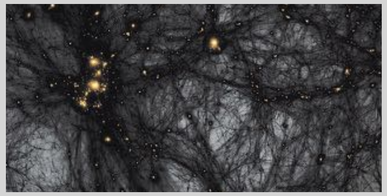
Challenge: Galaxies are not only sheared, but smeared, blurred, pixellated, noisy & blended







Intrinsic alignments



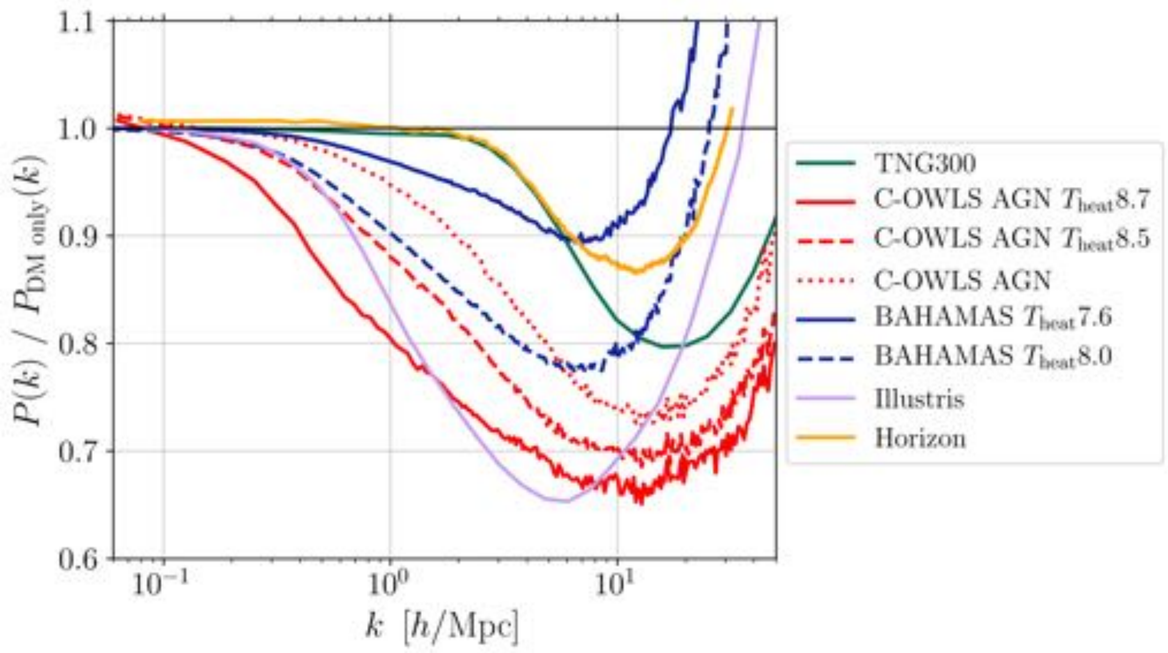
Challenge: Galaxies intrinsically aligned (IA). Is the IA model well-suited to late-type galaxies, which dominate lensing samples? Is it flexible enough to encompass our lack of understanding of this effect?

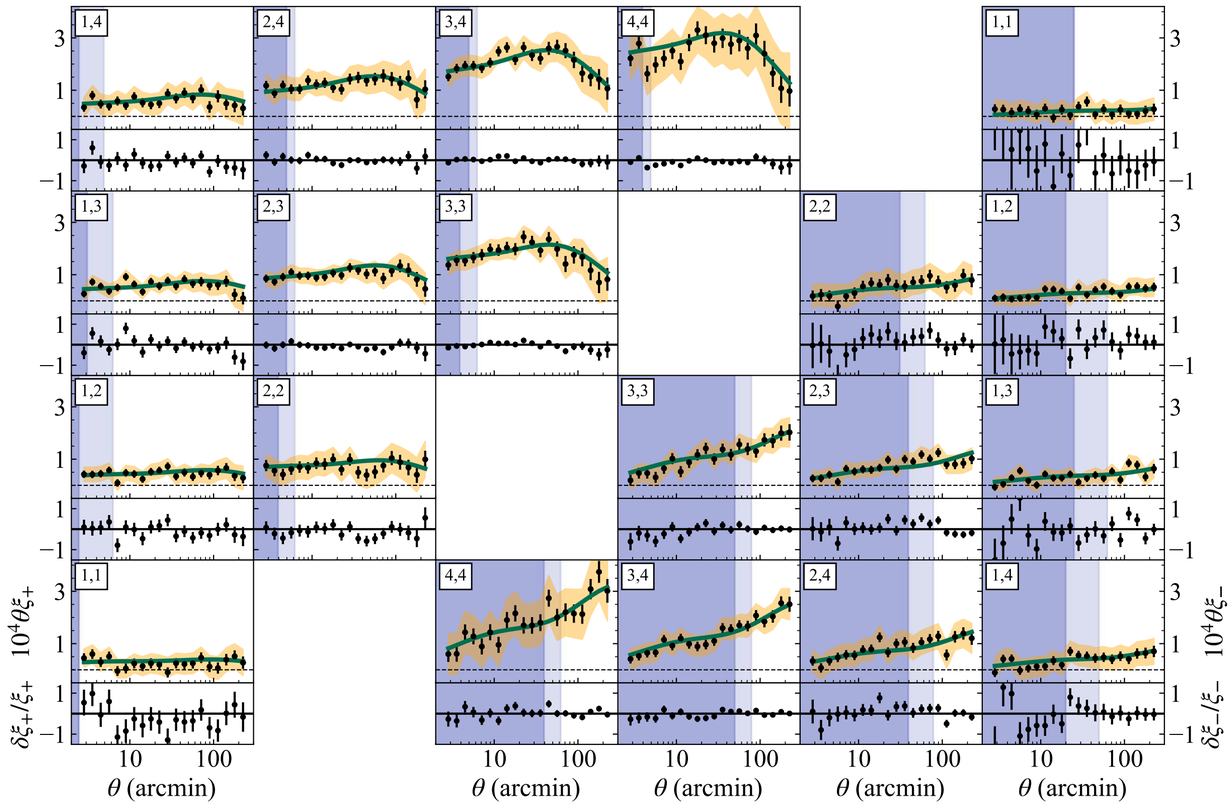
Scale cuts & baryonic effects

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.

Mitigating baryonic effects

Hydrodynamical sims predict a large range in the extent of AGN feedback





1. Model with flexibility & uncertainty

   Derived from a halo model approach
   Calibrated on BAHAMAS simulations

2. Toss small-scales

   Cut data until bias <0.1sigma

Cosmic shear *usual suspects*

Redshift calibration

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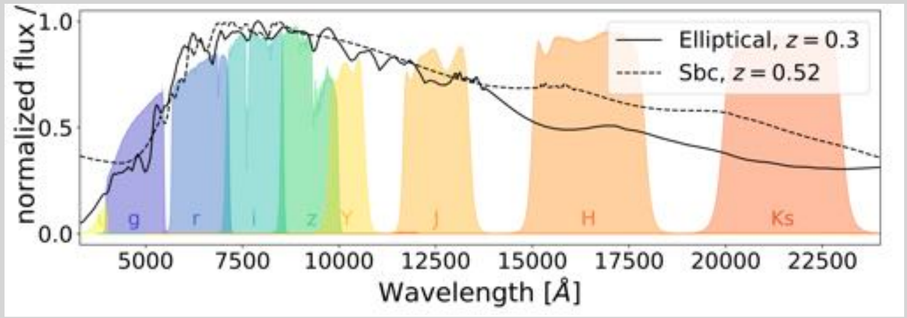

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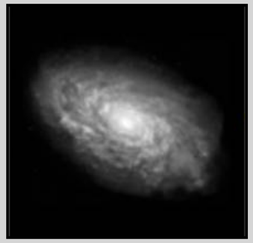

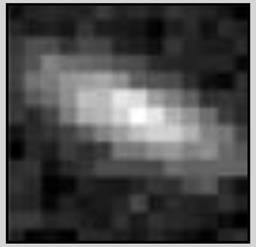

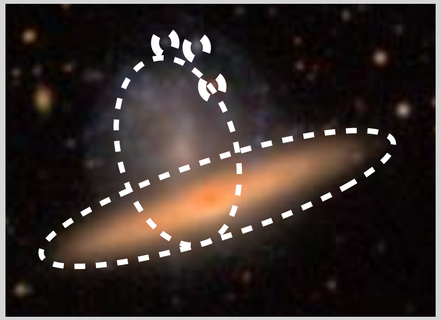

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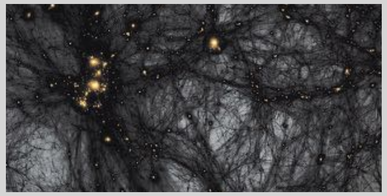

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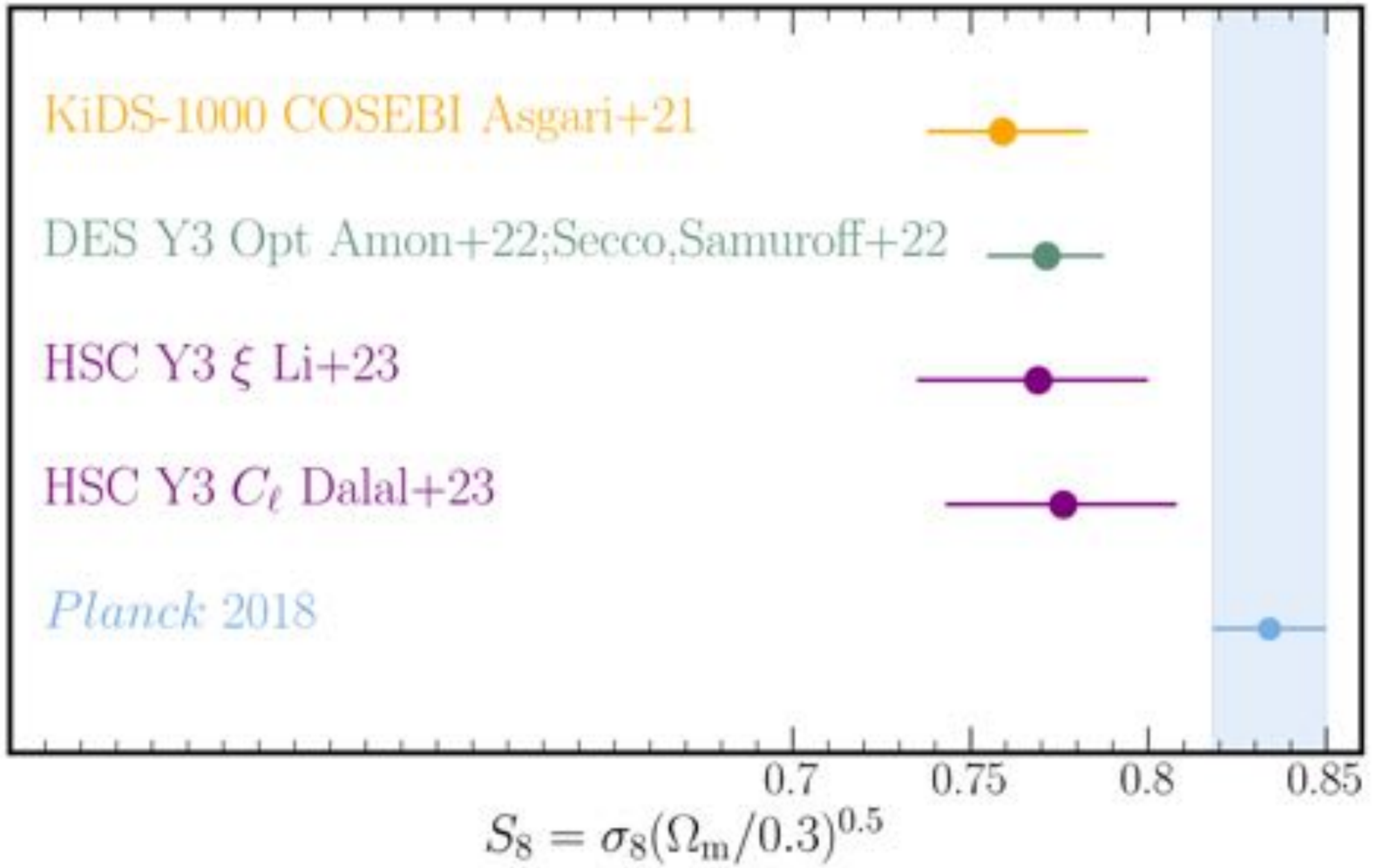
Accurate lensing is hard!
…But we've made incredible progress.

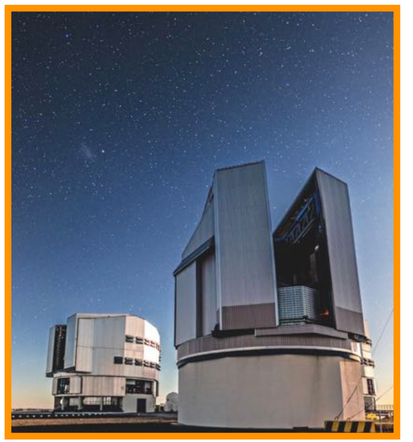
Lensing surveys: the S_8 tension

Hyper-Supreme Camera Survey

Dark Energy Survey



Kilo-Degree Survey

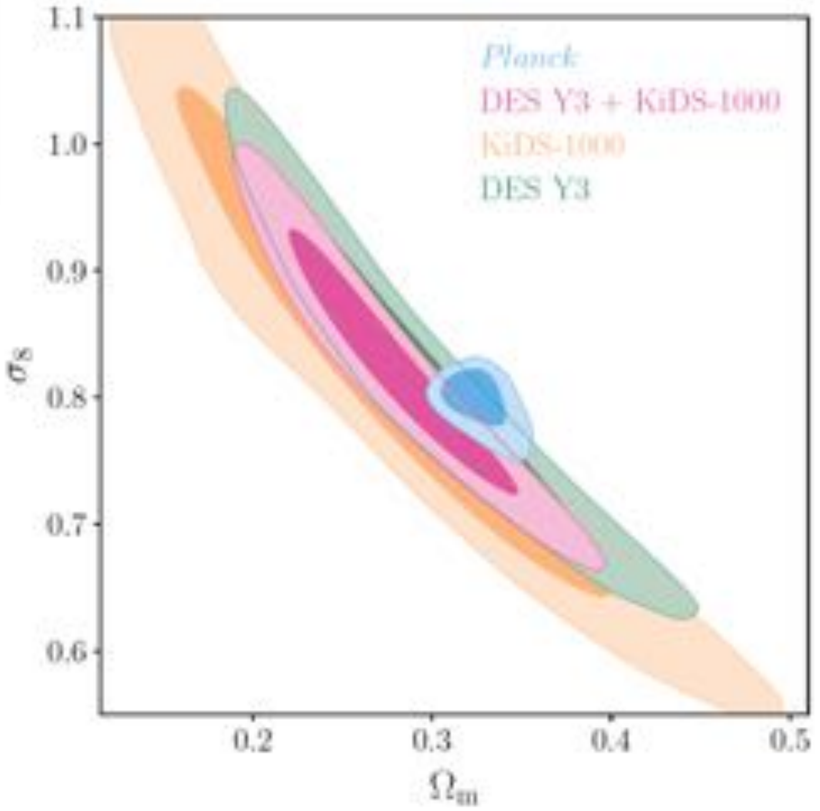


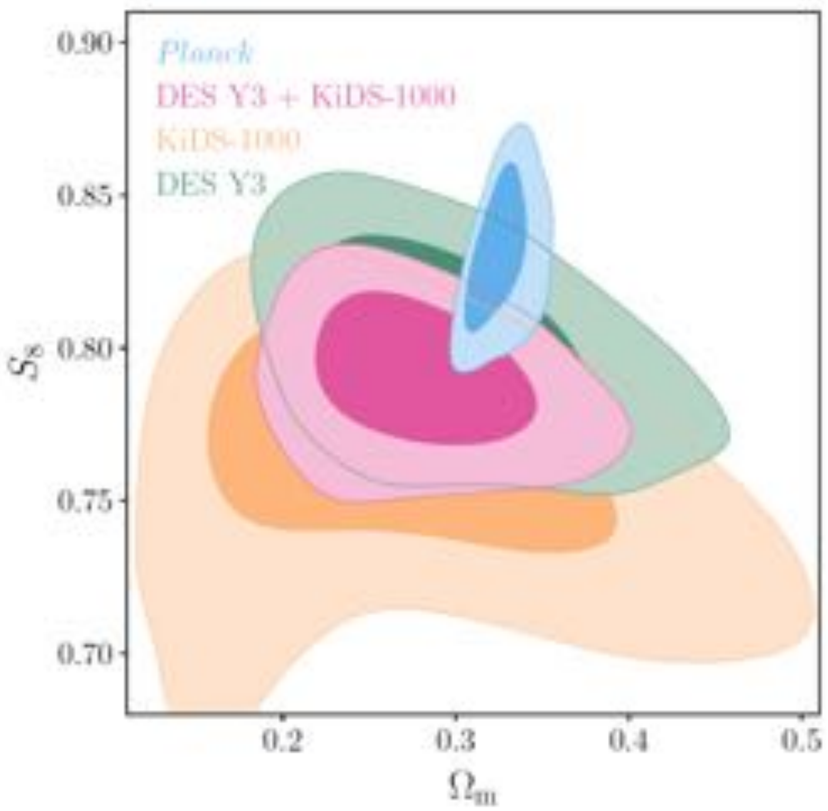
Lensing surveys: the S_8 tension *on equal footing

[*DES & KiDS Collaboration 23*]

Analysis choices matter!
To assess the lensing consistency or combine, surveys need to be analysed consistently.

- *Sampler **
- *Cosmological parameters sampled*
- *Priors on cosmological parameters*
- *Non-linear power spectrum modelling **
- *Scales measured **
- *Intrinsic alignment model **
- *Baryon effects mitigation **
- *Statistics used*
- *Tension metric*

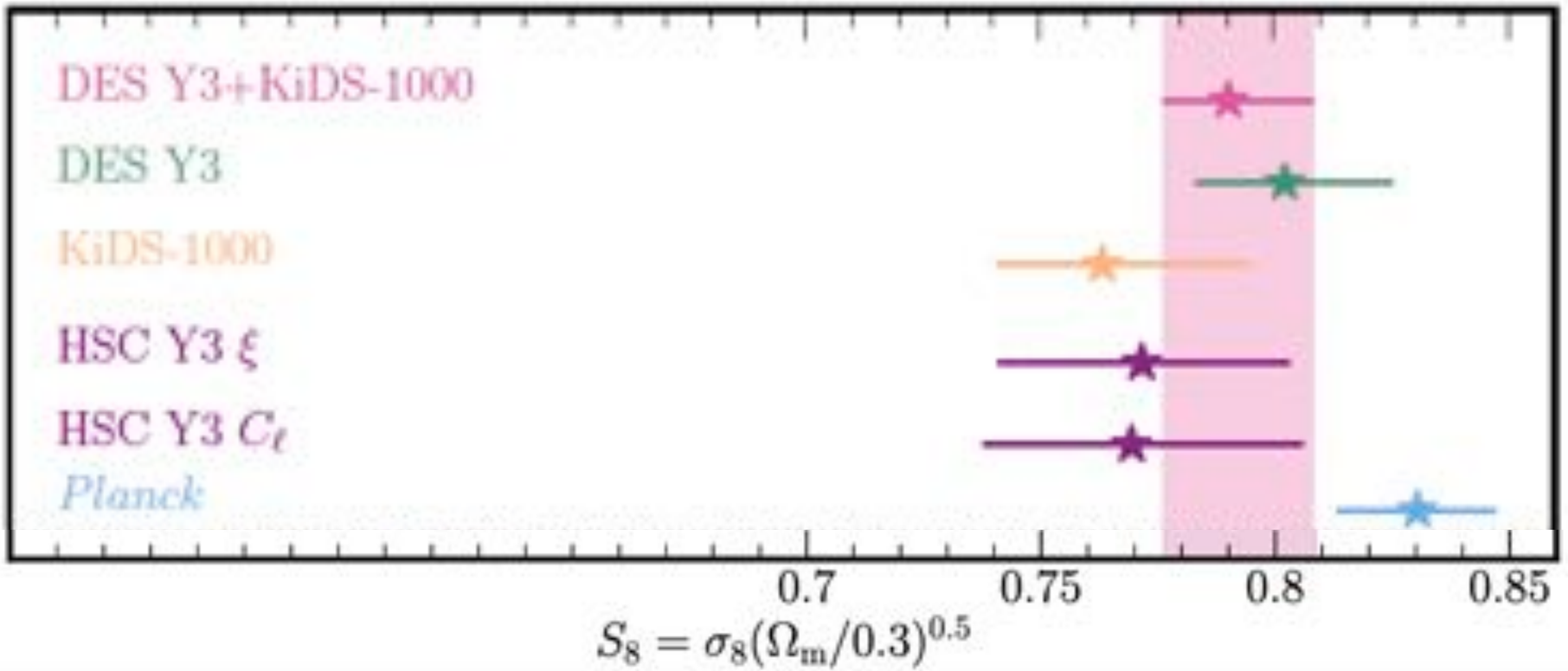




KiDS: Asgari, Heymans
DES: Porredon, Samuroff
KiDS & DES: Amon, Choi

Lensing surveys: the S_8 tension

[*DES & KiDS Collaboration 23*]



- KiDS-1000 + DES Y3 constraints are 1.7σ lower than *Planck*.
- HSC Y3 is low by <2σ.

Lensing surveys: the S_8 tension

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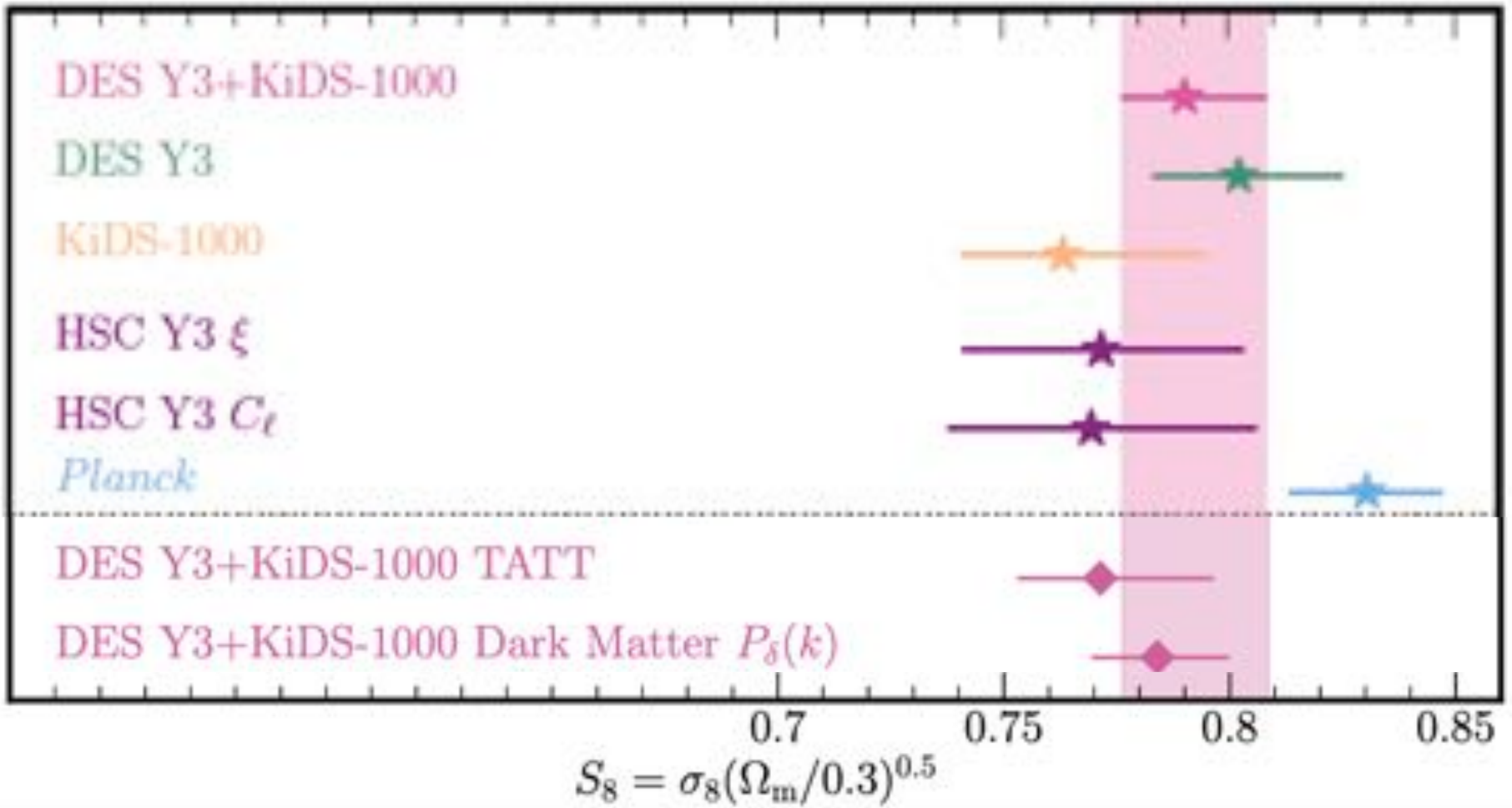


- KiDS-1000 + DES Y3 constraints are 1.7σ lower than *Planck*.
- HSC Y3 is low by <2σ.
- Level of tension sensitive to astrophysics - intrinsic alignments and baryonic feedback

Picking apart the S_8 tension

- Is it early Universe vs late?
- Is it a lensing thing?
- Is it a lensing and clustering thing?
- Is it small scales vs large scales?

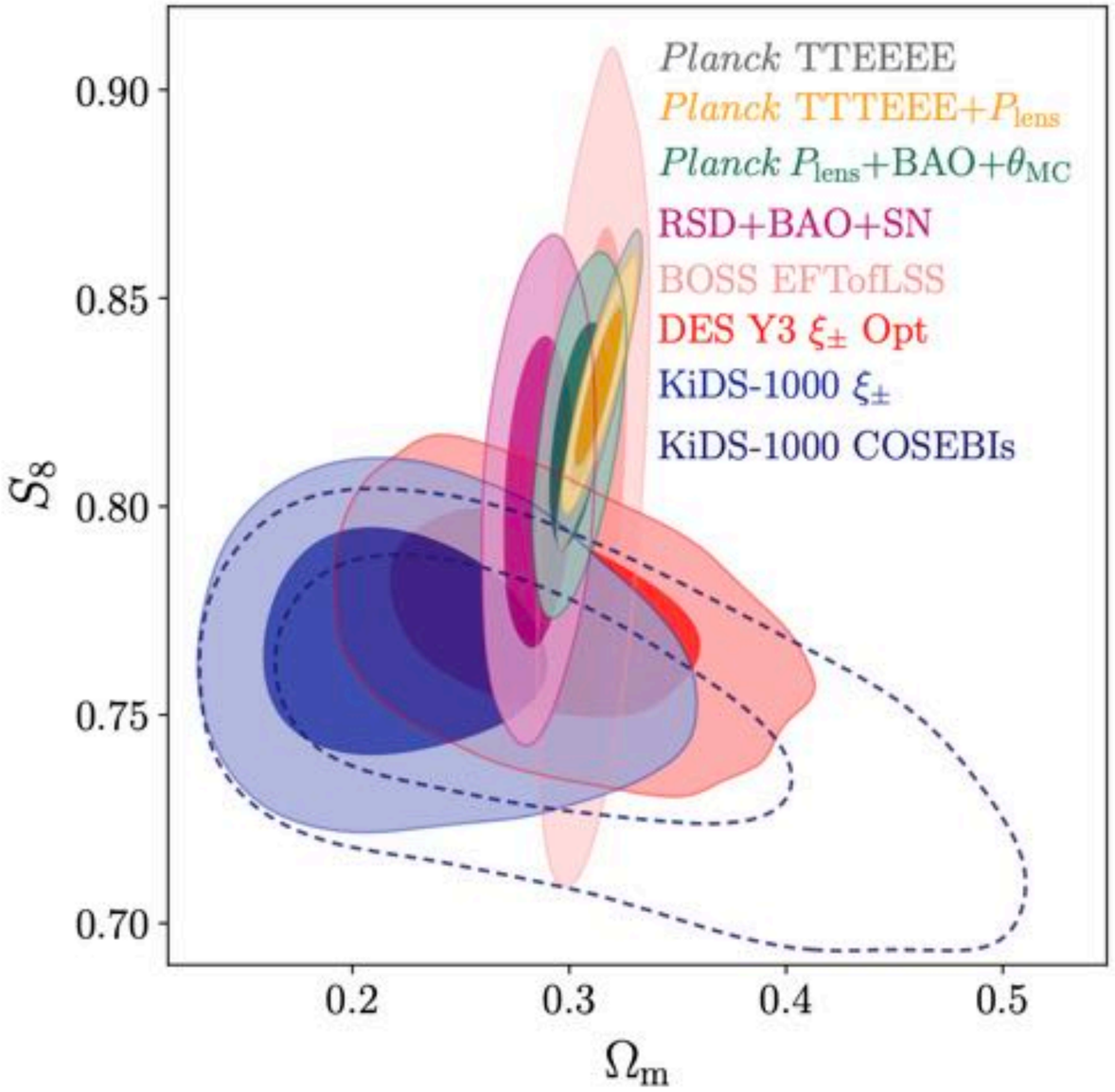
Tested with BOSS + KiDS, DES, HSC

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

[*Amon & Robertson et al 2022*]

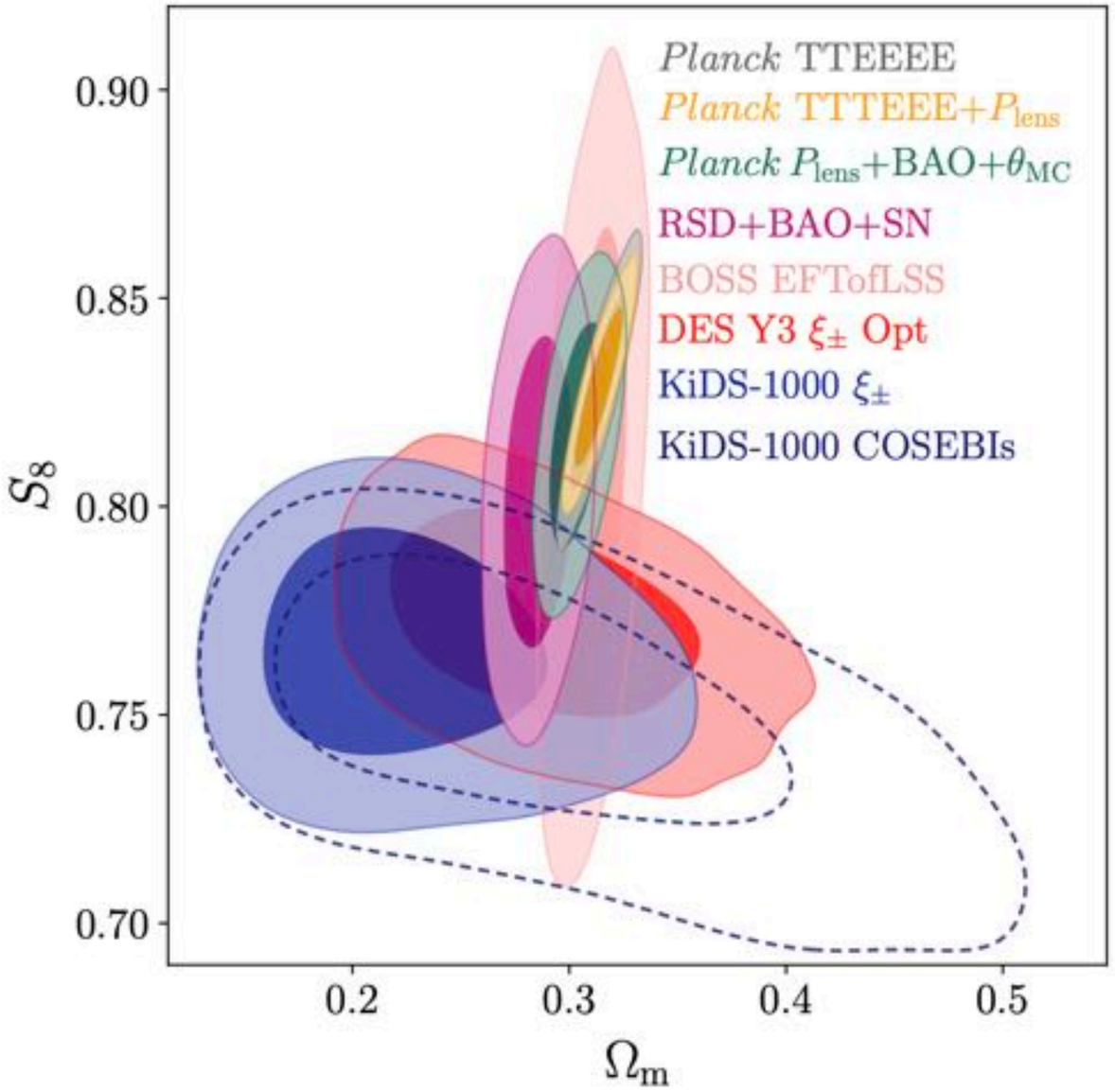
Picking apart the S_8 tension

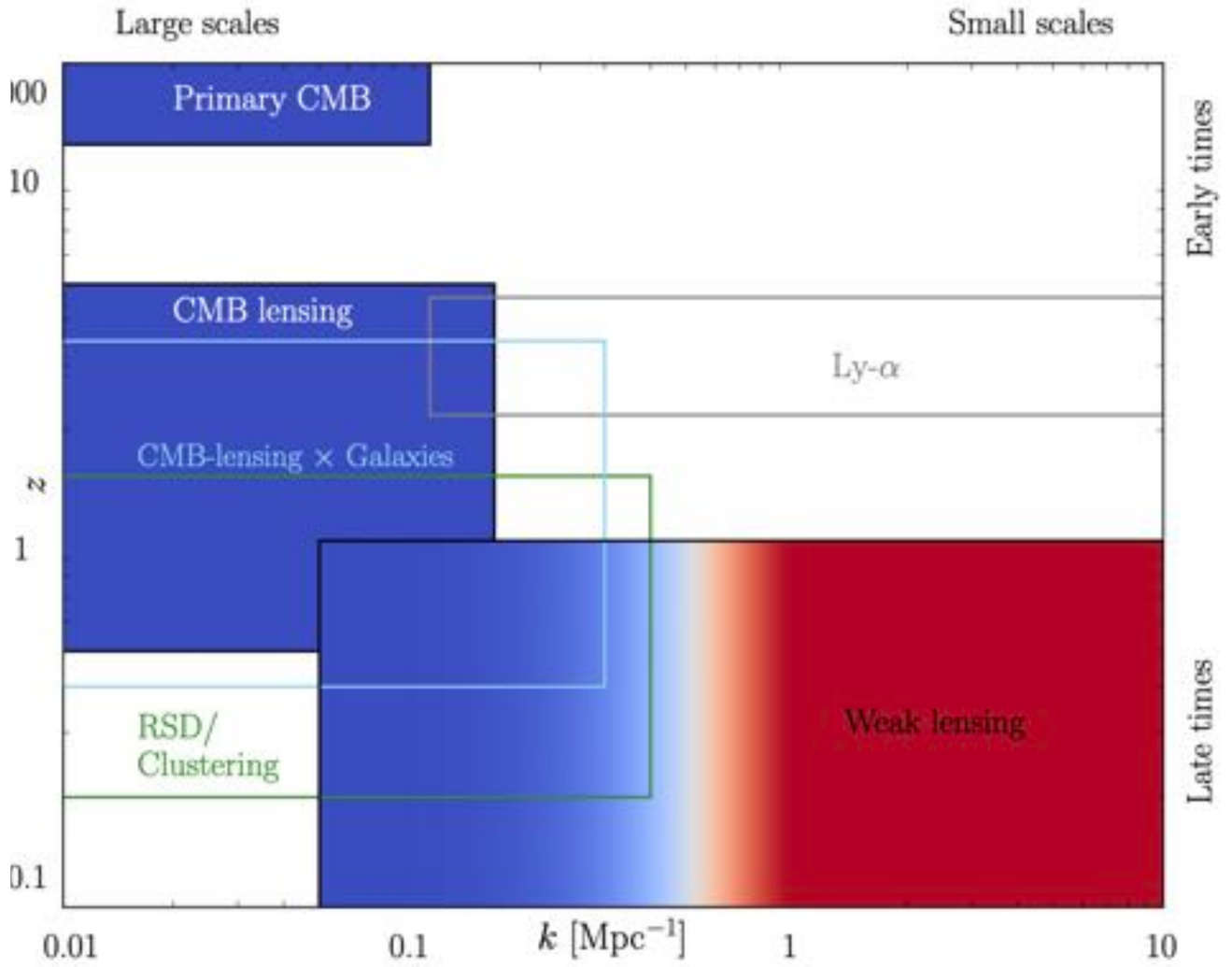
[*Amon & Efstathiou 22*]



- *Planck* LCDM and lensing surveys in tension
- CMB lensing agrees with *Planck* LCDM
- RSD not yet decisive - currently agrees with both lensing and *Planck* LCDM
- **CMB lensing cross-correlations not shown

Picking apart the S_8 tension





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

"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'.

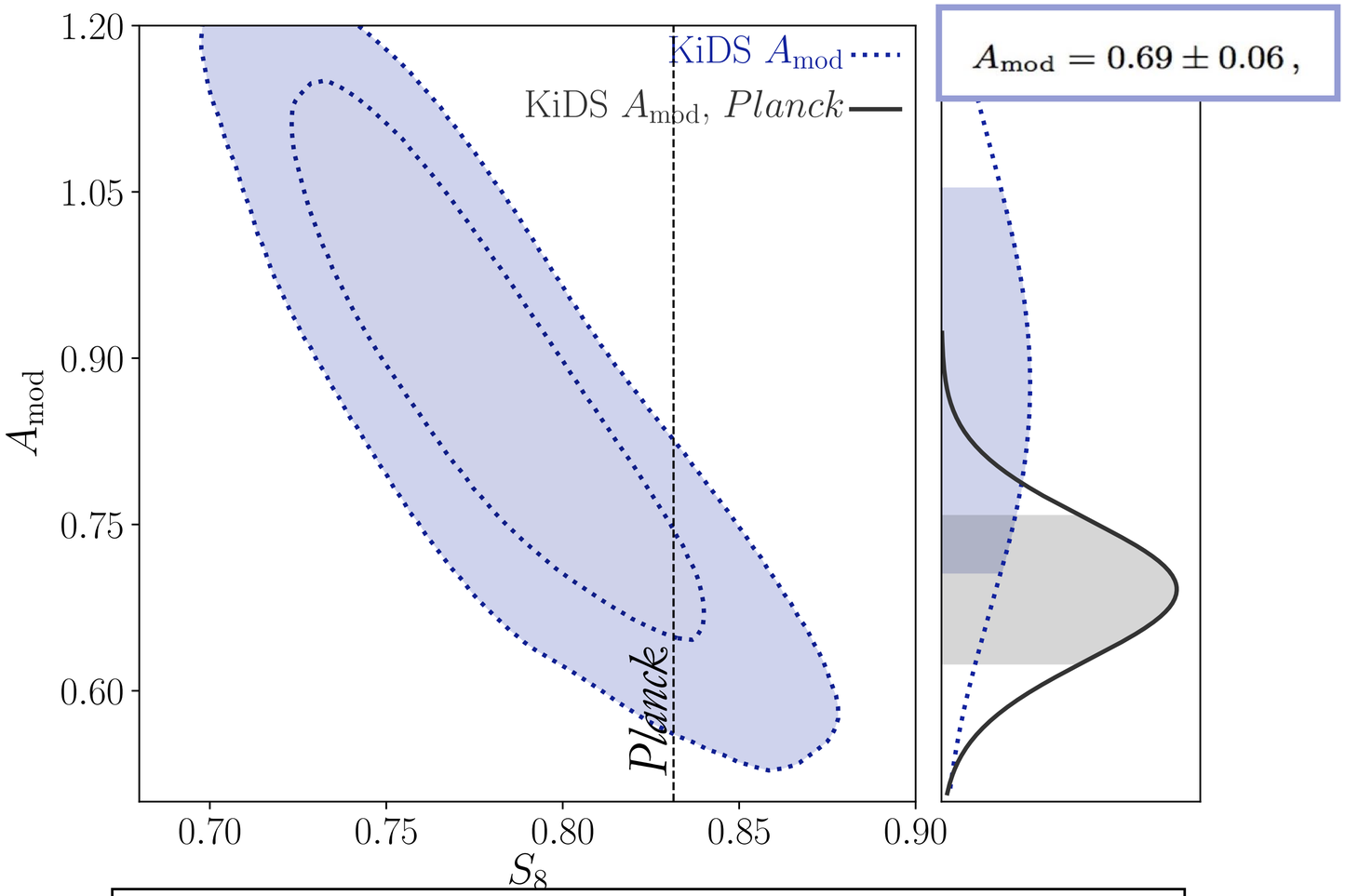
don't understand galaxies

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

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

A non-linear solution to the S_8 tension?

[*Amon & Efstathiou 22*]



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

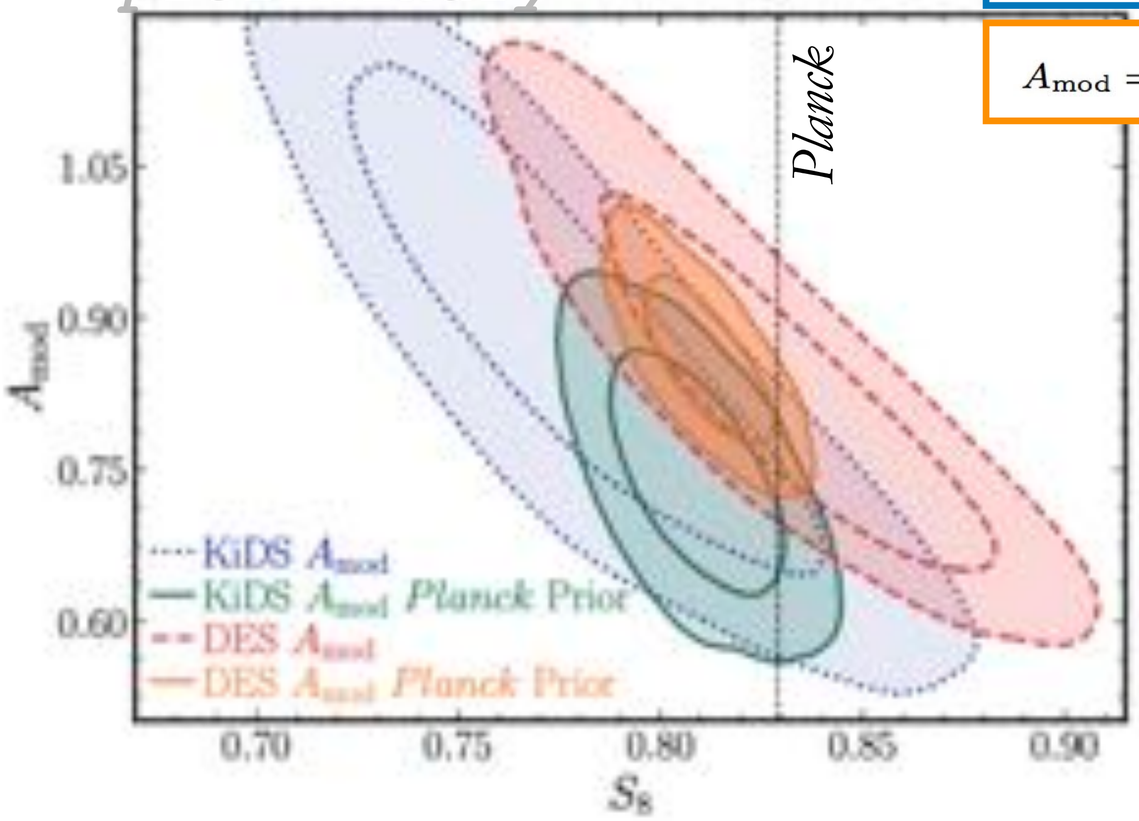
A non-linear solution to the S_8 tension II

[*Preston, Amon & Efstathiou 23*]

preliminary

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

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



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A non-linear solution to the S_8 tension II

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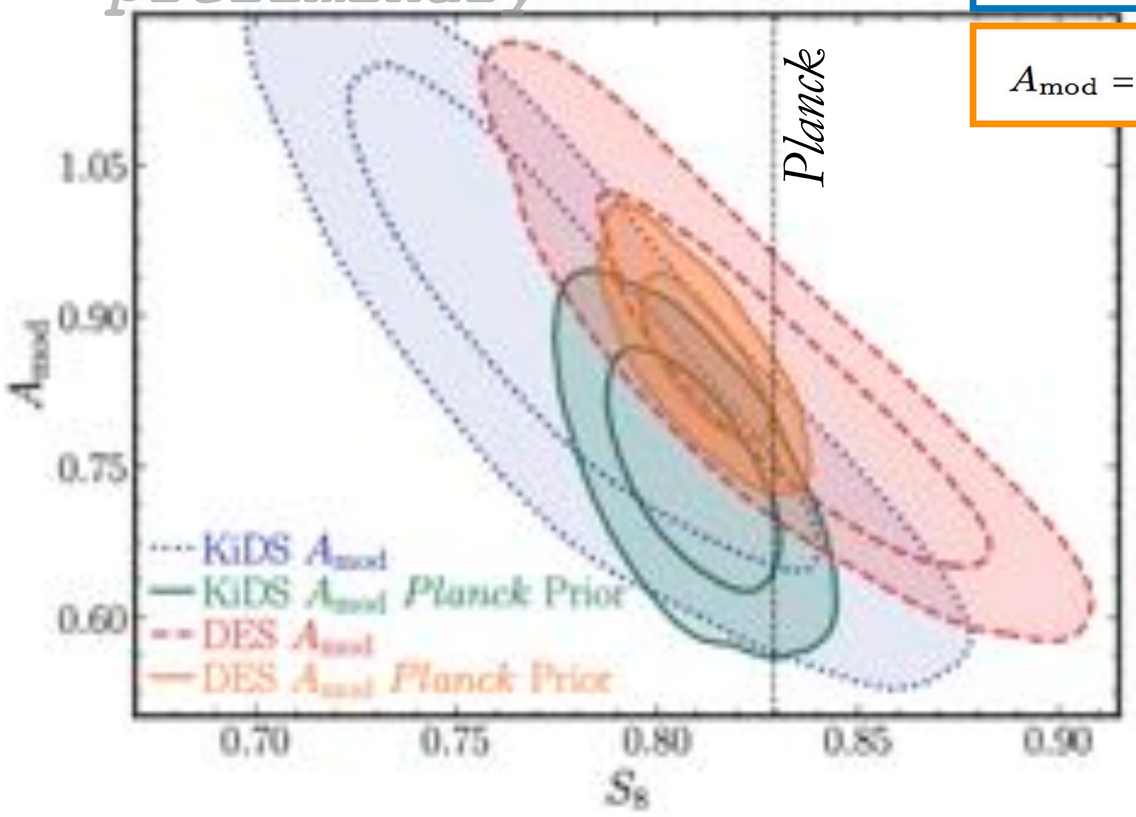
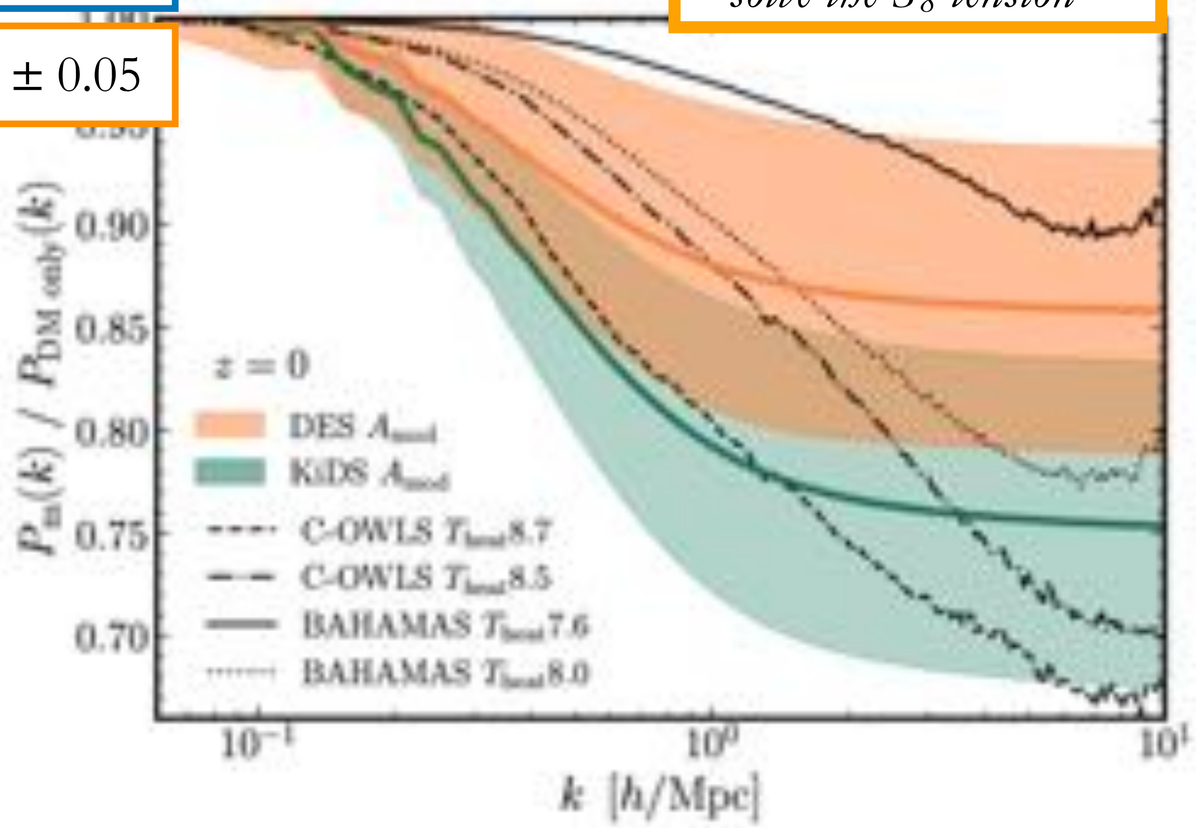
required suppression to solve the S_8 tension





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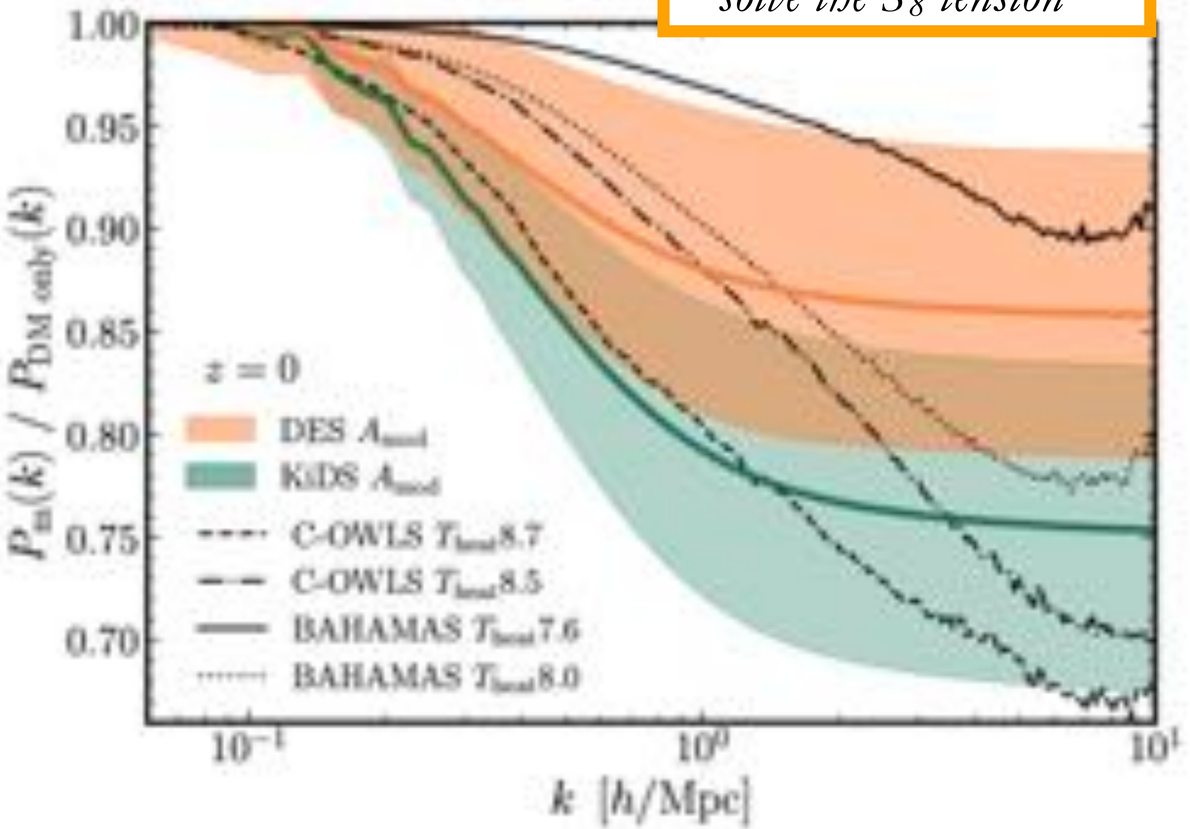
S_8 tension: baryonic physics or new dark matter properties?

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

Do we understand baryonic feedback well enough to claim

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

required suppression to solve the S_8 tension



[*Preston, Amon & Efstathiou 23*]

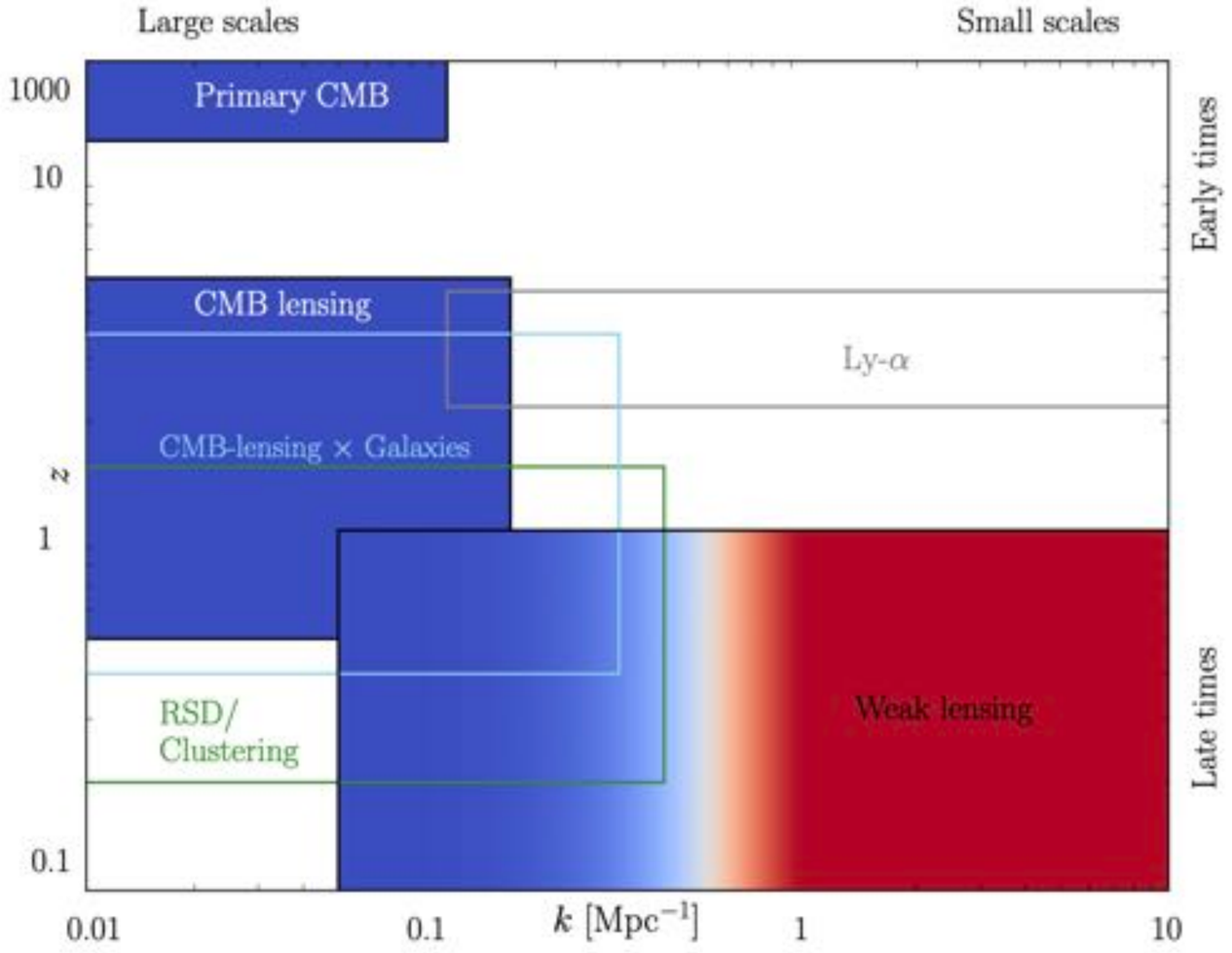
S_8 tension: baryonic physics or new dark matter properties?

Do we understand baryonic feedback well enough to claim

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

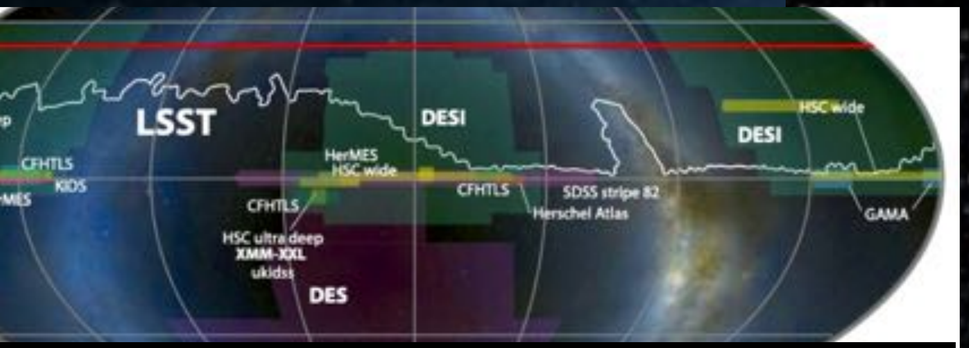
The data is coming to test our hypothesis!

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



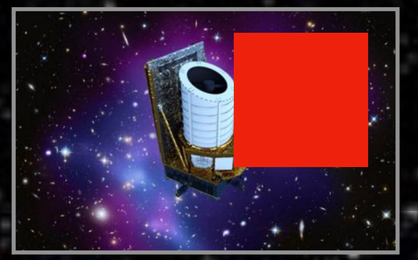
[*Preston, Amon & Efstathiou 23*]

The decade for observational cosmology



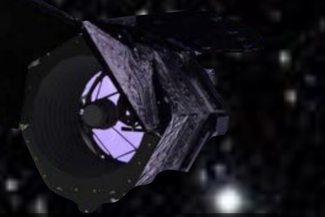
AdvACT / CMB S4

Advanced Atacama Cosmology Telescope



Vera Rubin Observatory

Roman Space Telescope



Euclid Space Telescope

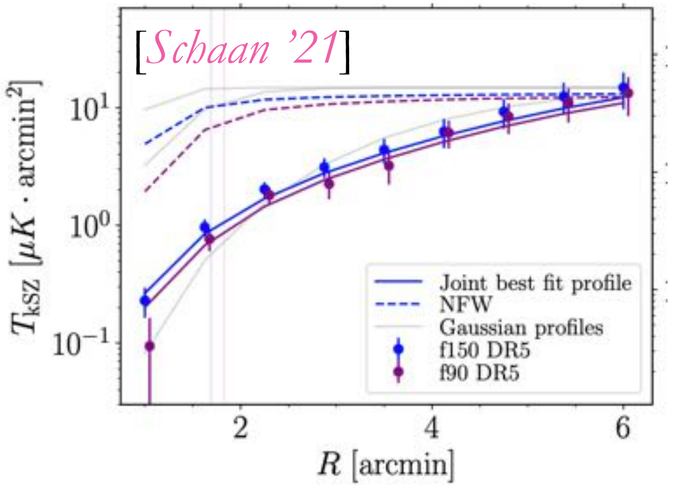
Dark Energy Spectroscopic Instrument

Dark Energy Survey

Test the scale-dependence of S_8 constraints

Scrutinise non-linear modelling

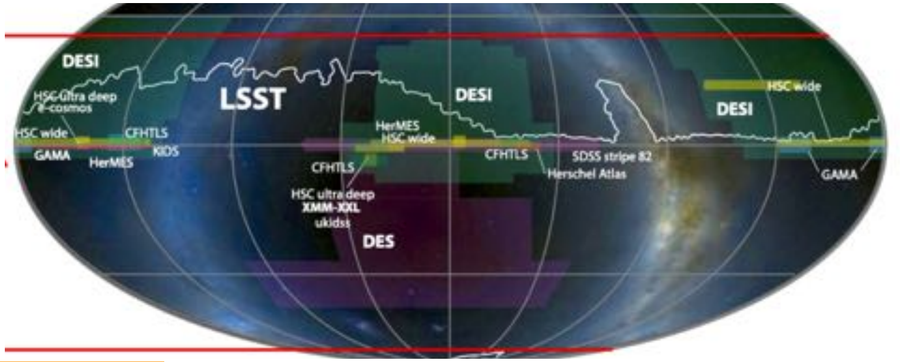
Distinguishing the baryonic feedback



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

Lensing probes the distribution of matter on small scales

AdvACT / CMB S4

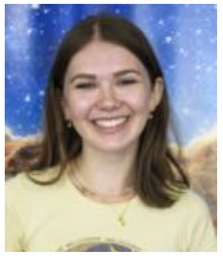


Testing new modelling approaches with DES:

Are these models sufficiently flexible and do they give consistent results?

Reverse engineer the problem:

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



Leah Bigwood

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

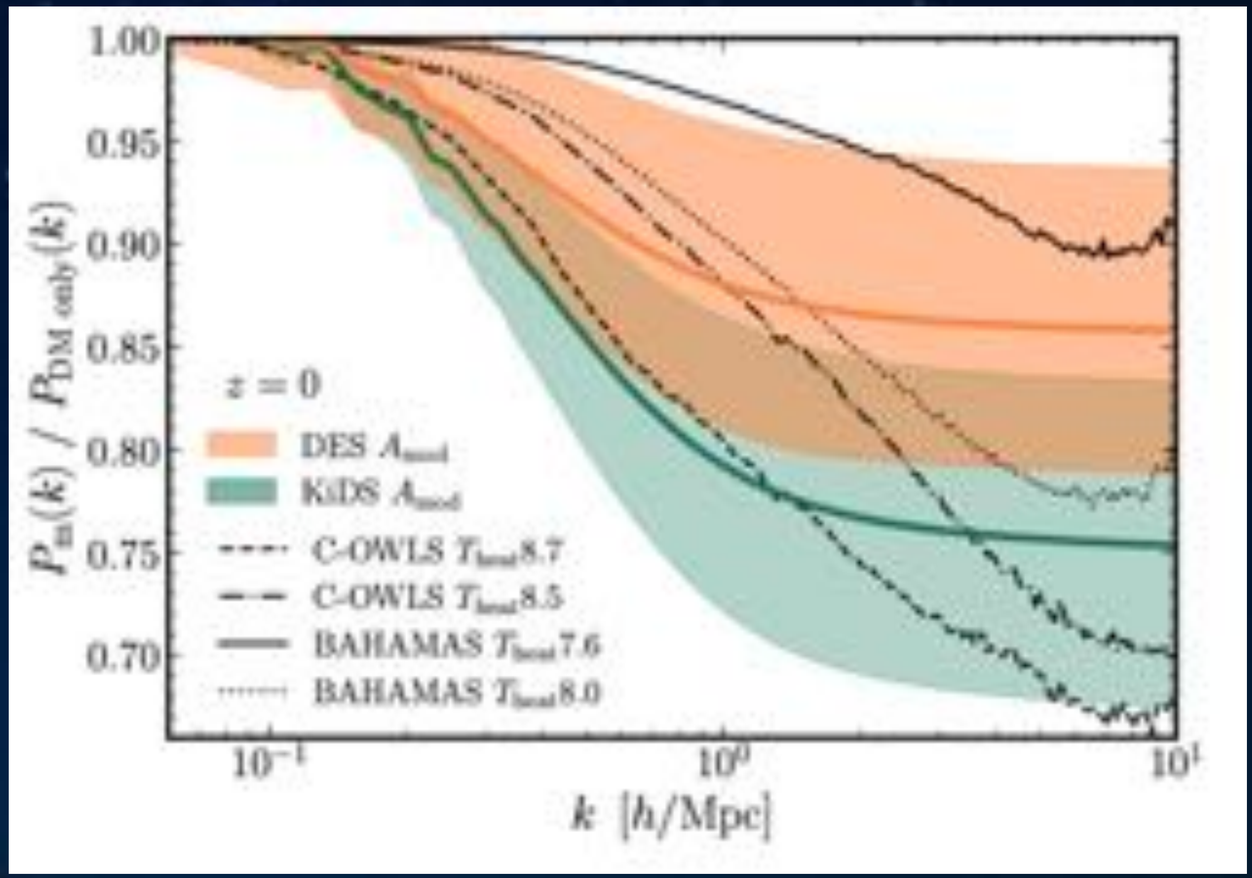
Summary

- **Advancements built to utilise the statistical power of the DES Year 3 and deliver robust cosmology**
  Stay tuned for DES Y6!

- The lensing community is working together to compare analysis choices and combine data.
  KiDS-1000+DES Y3 out now!

- A*ll* lensing surveys find a **low value for S_8** than the *Planck* constraint.

- **Correction to the spectrum on non-linear scales may resolve the S_8 tension: either due to baryonic effects or non-standard dark matter**



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