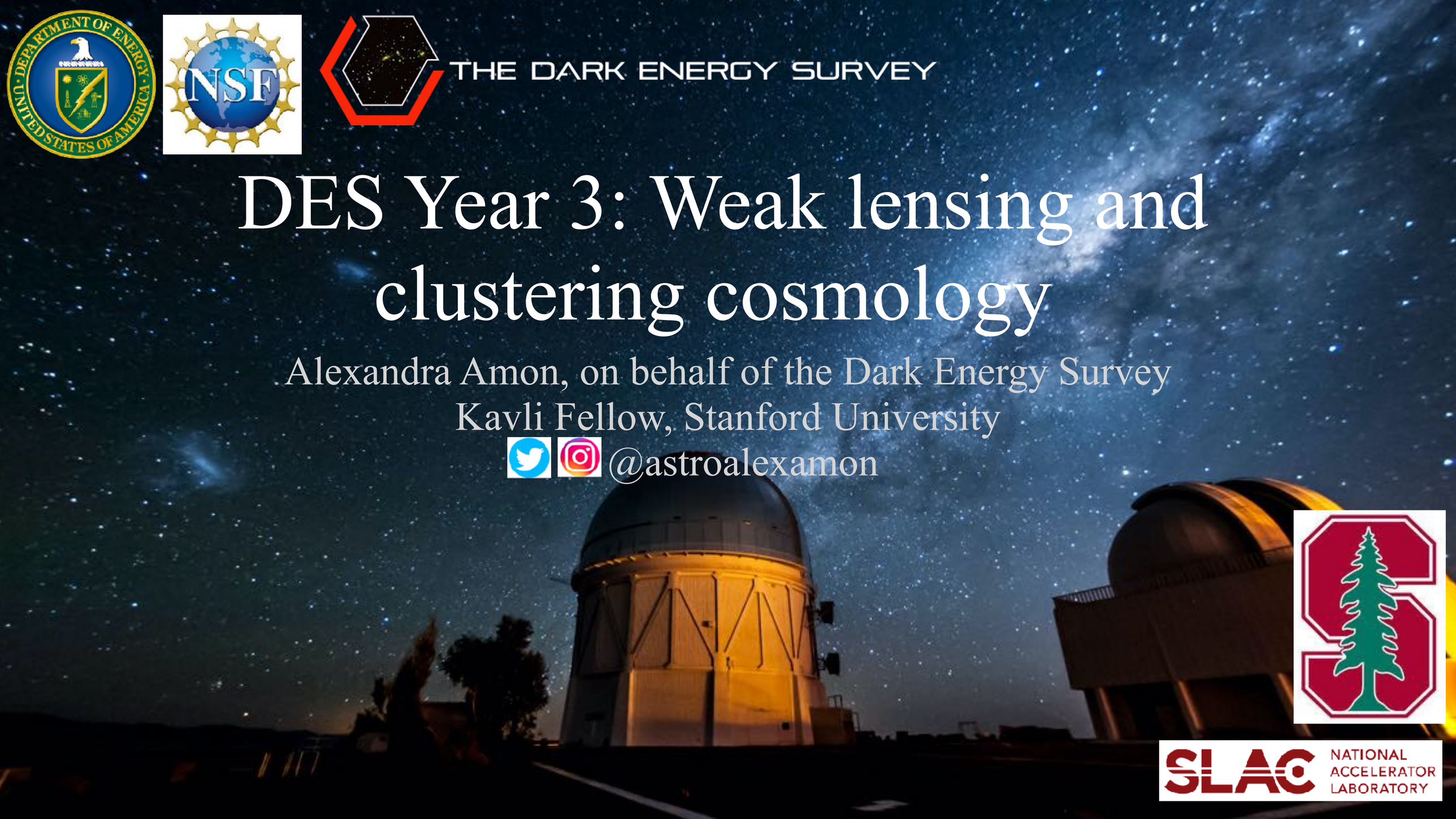


DES Year 3: Weak lensing and clustering cosmology

Alexandra Amon, on behalf of the Dark Energy Survey
Kavli Fellow, Stanford University
@astroalexamon



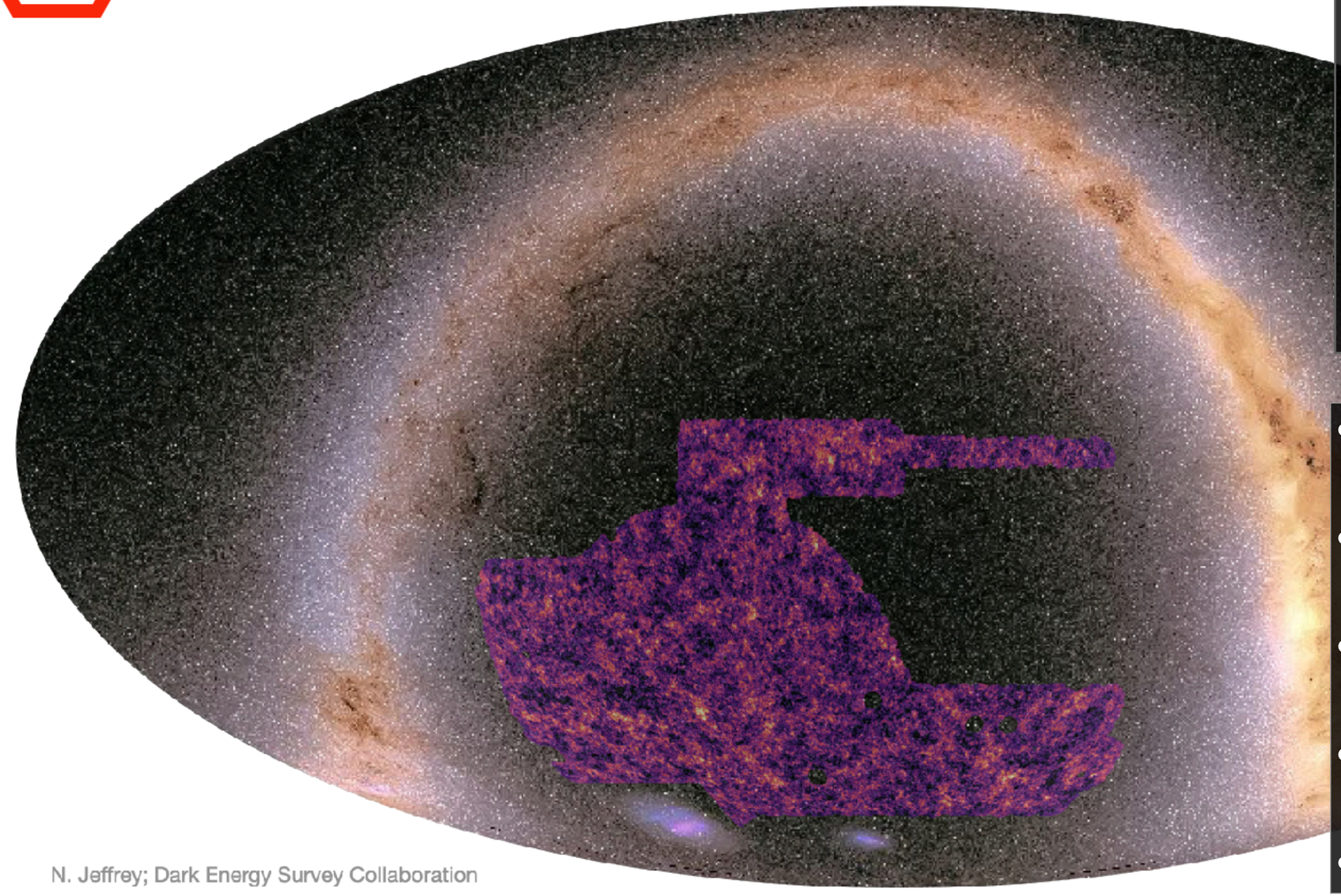
THE DARK ENERGY SURVEY

Image credit: Agnes Ferte

DES Y3: the most powerful weak-lensing catalog & *'3x2-point'*
Data systematics: novel methods
Astrophysical systematics : conservative modelling choices
The Big picture: cosmological constraints in context
Outlook: cosmic shear going forward

SLAC NATIONAL ACCELERATOR LABORATORY

Dark Energy Survey: Y3

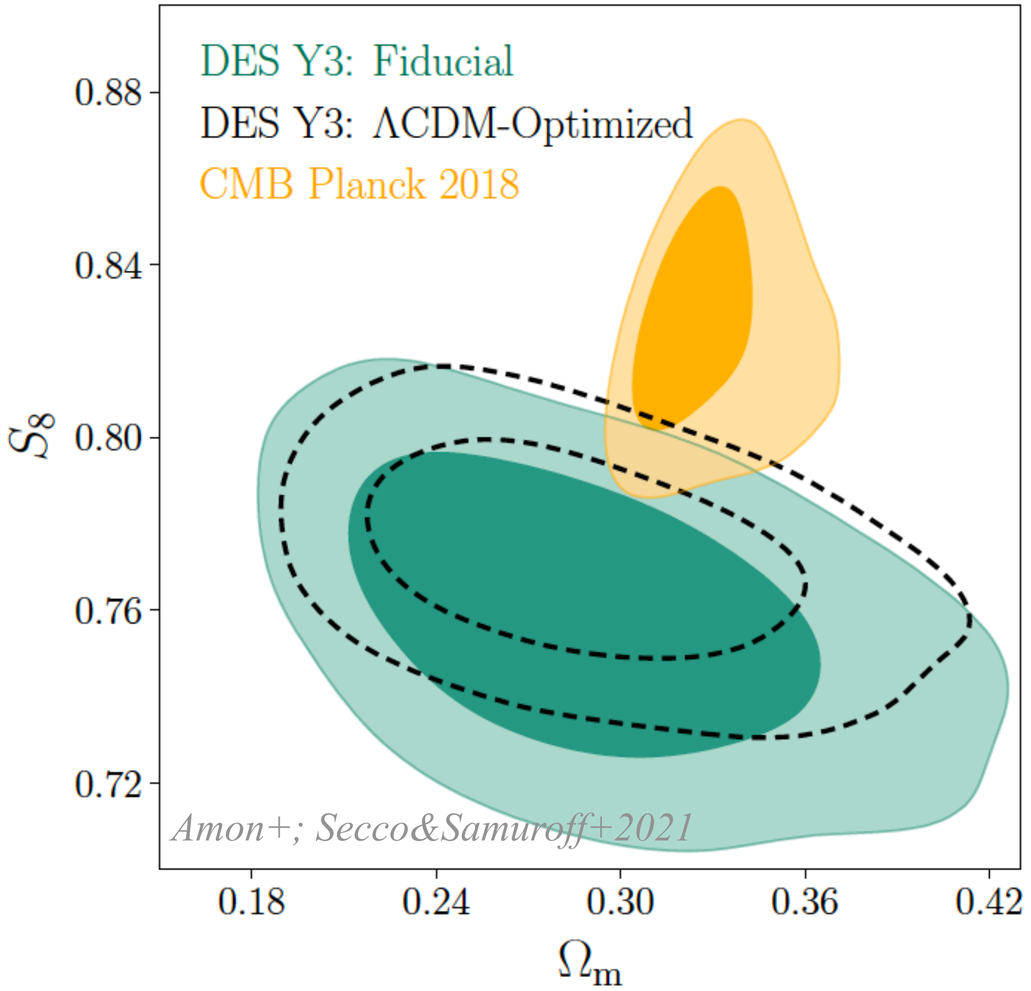


- Survey status: 6 yrs observations complete on the 4m CTIO Blanco Telescope
- 5000 sq. deg., observing in *(u)griz(Y)* filters
- DECam: a 570 Mpix camera 3 sq. deg. field of view

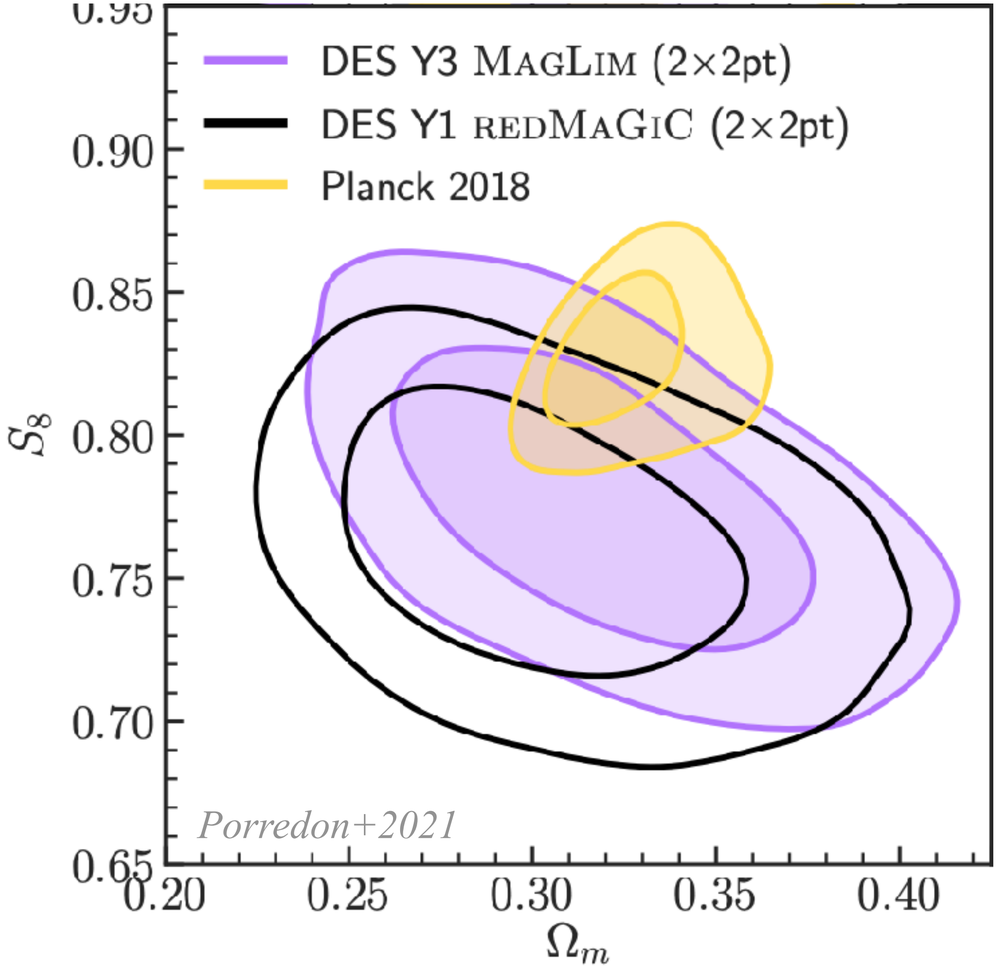
- Y3: 2013-2016 data
- Wide+Deep survey strategy
- **Full area:** 5000 sq. deg.
- 100M galaxies
- Mean redshift ~ 0.63

DES Y3 cosmological constraints

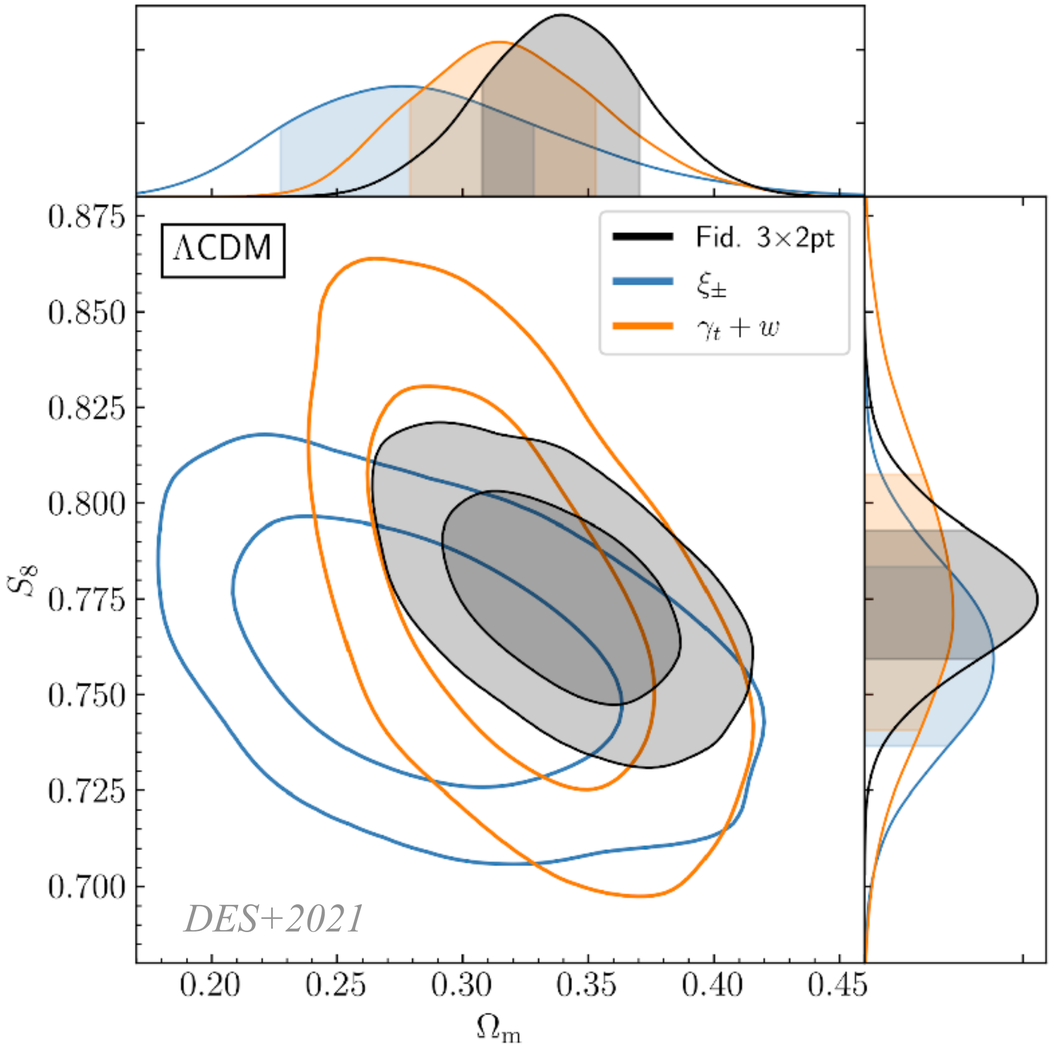
cosmic shear



'2x2pt'



DES Y3 3x2pt



A factor of 2.1 improvement in signal-to-noise from DES Year 1.

No significant evidence of inconsistency between **DES Y3 3x2pt** and *Planck* CMB at 0.7-1.5σ or p=0.13-0.48.

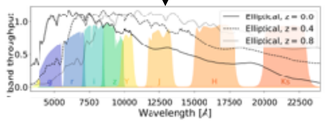
In ΛCDM:
$S_8 = 0.776^{+0.017}_{-0.017}$ (0.776)
$\Omega_m = 0.339^{+0.032}_{-0.031}$ (0.372)
$\sigma_8 = 0.733^{+0.039}_{-0.049}$ (0.696)

In *w*CDM:
$\Omega_m = 0.352^{+0.035}_{-0.041}$ (0.339)
$w = -0.98^{+0.32}_{-0.20}$ (−1.03)

DES Y3 *3x2pt* : pixels to cosmology

Wide Field Images

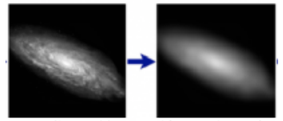
Sevilla, Bechtol +



Deep Field Photometry

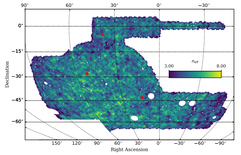
Hartley, Choi, Amon +

Survey selection



Point Spread Function Modelling

Jarvis, Bernstein, ***Amon +***



Shape catalogue

Gatti*, Sheldon,* ***Amon +***

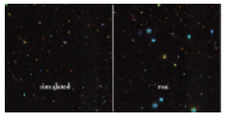
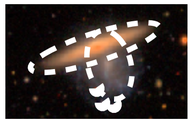
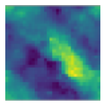


Image simulations

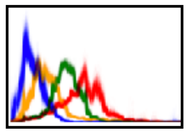


Blending & calibration

MacCrann, Becker, McCullough, Amon+



Redshift calibration



Redshift distributions

Myles, Alarcon, Amon +
Gatti, Giannini +

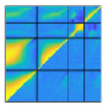
Cawthon +
Porredon +
Giannini +

Lens clustering sample

2-point function measurements

Methods

Sanchez, Prat +
Cordero, Harrison +
Campos + ; Doux +



Covariance

Friedrich +

Galaxy clustering

Monroy +

Galaxy-galaxy lensing

Prat +

‘2x2’ cosmology

Pandey, *Krause +*
Porredon +
Elvin-Poole, MacCrann +

Cosmic shear cosmology

Amon +
Secco, Samuroff +

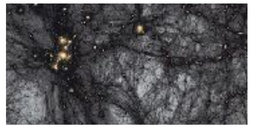
$P(\mathbf{p}|\hat{\mathbf{D}}, M) \propto \mathcal{L}(\hat{\mathbf{D}}|\mathbf{p}, M)P(\mathbf{p}|M)$

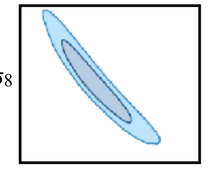
Analysis choices and modelling

Krause +

Mock analysis

de Rose +





‘3x2’ cosmology

coordinated by Michael Troxel , Elisabeth Krause, Scott Dodelson

Mitigate experimenter bias

Muir +

Leadership positions:
DES Deep Fields
Shear Validation
Cosmic Shear

https://pollev.com/alexandraamon538

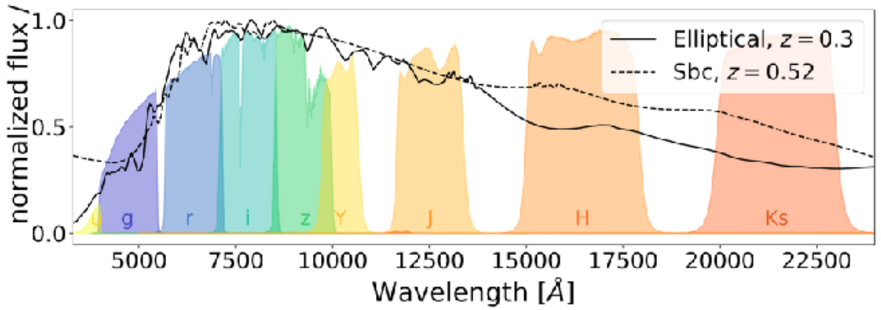
Respond at **PollEv.com/alexandraamon538**

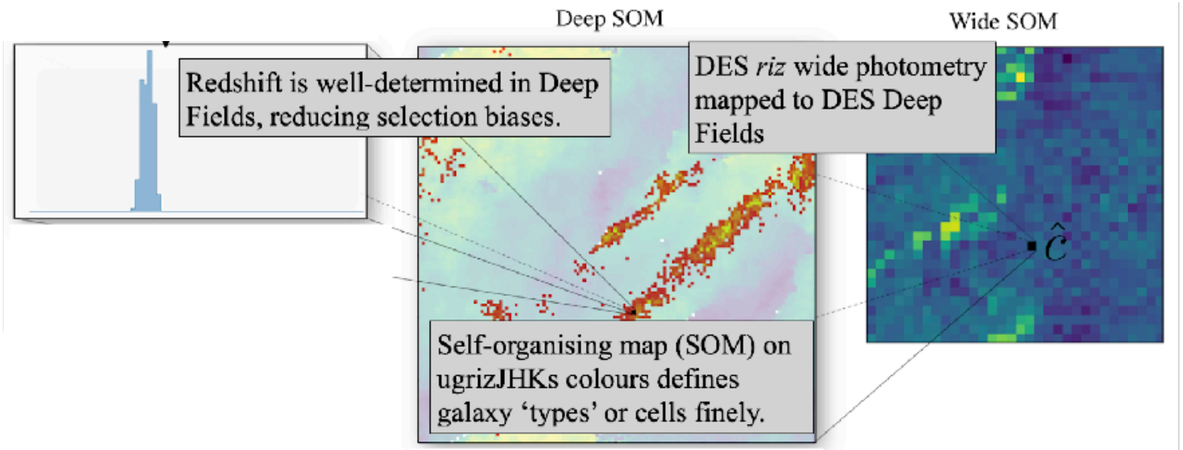
What part of the DES Y3 analysis are you worried about?

- Redshift calibration
- Shape calibration
- Intrinsic alignments
- Baryonic effects
- 2x2 Maglim Results
- Summer hols: DES Y3 is great!

DES Y3: novel framework for redshift calibration

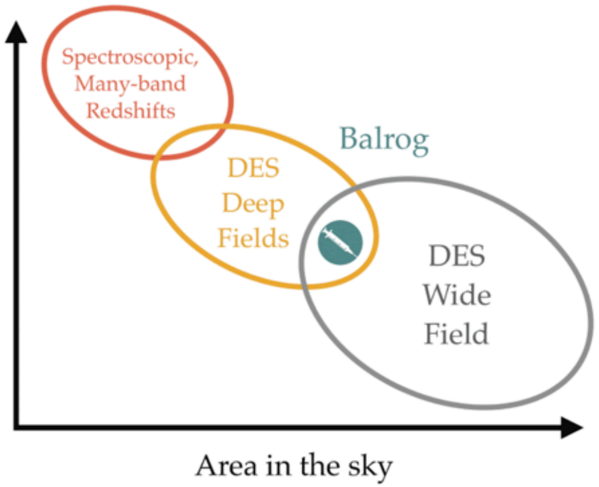
1. Breaks colour-redshift degeneracies with a **Deep-Wide survey strategy** *(Hartley, Choi. Amon+)* and a machine-learning approach





Adapted from Buchs, Davis, Gruen

(Myles, Alarcon, Amon +2020)



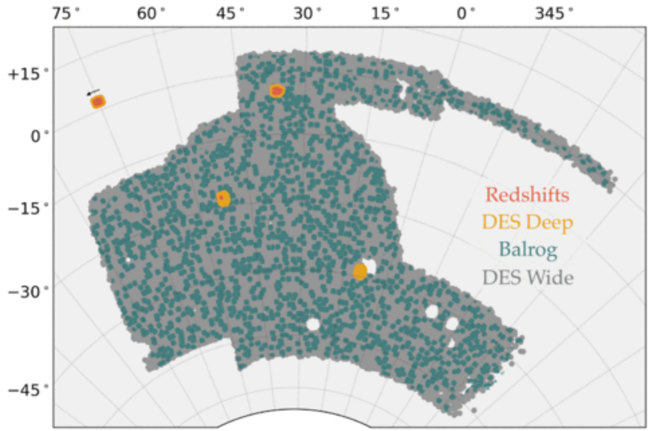


Image credit: Carles Sanchez
Deep Fields: Hartley, Choi, Amon +2020
Balrog: Everett +2020

DES Y3: novel framework for redshift calibration

1. Breaks colour-redshift degeneracies with a **Deep-Wide survey strategy** *(Hartley, Choi. Amon+)* and a machine-learning approach

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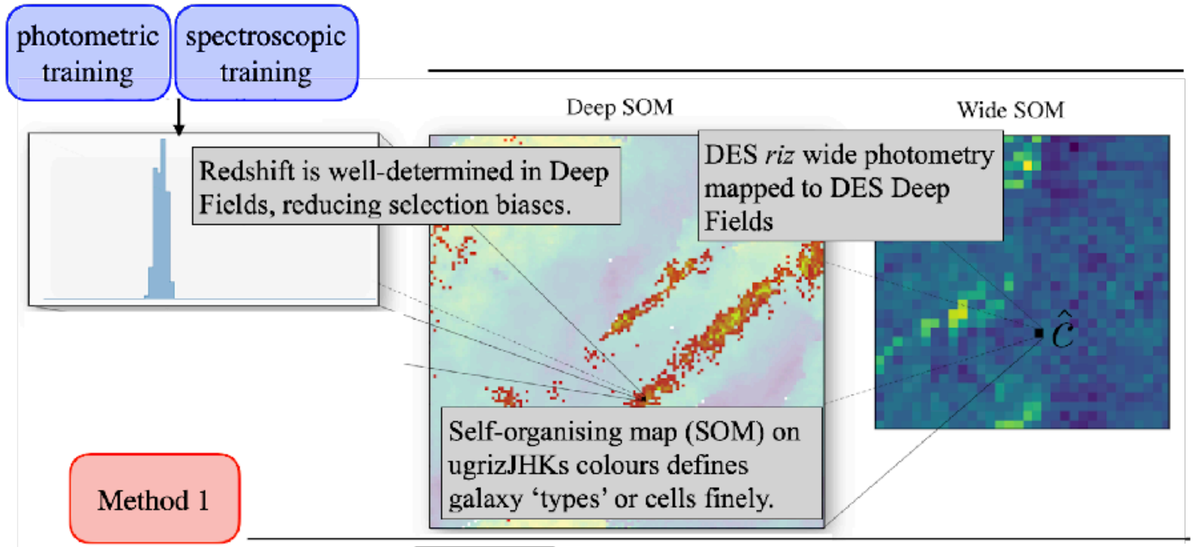

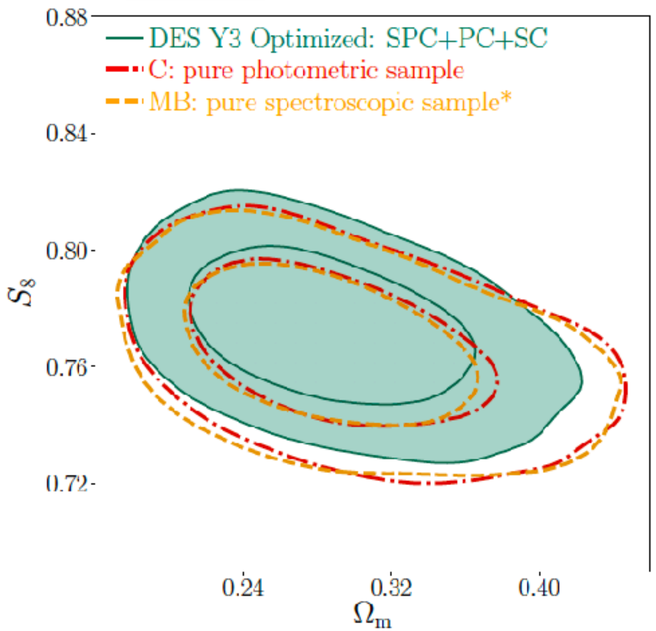

(Myles, Alarcon, Amon +2020)

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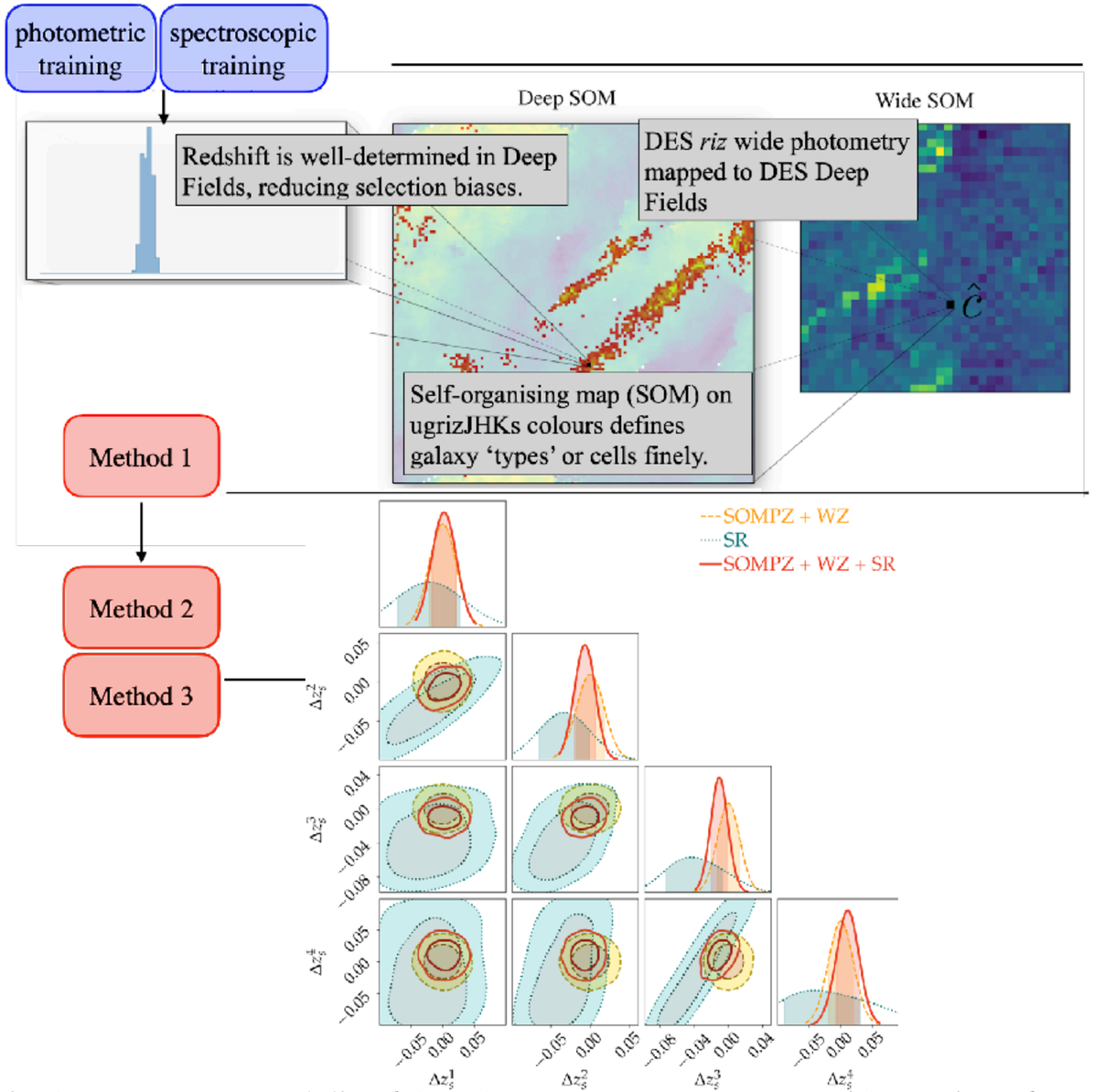

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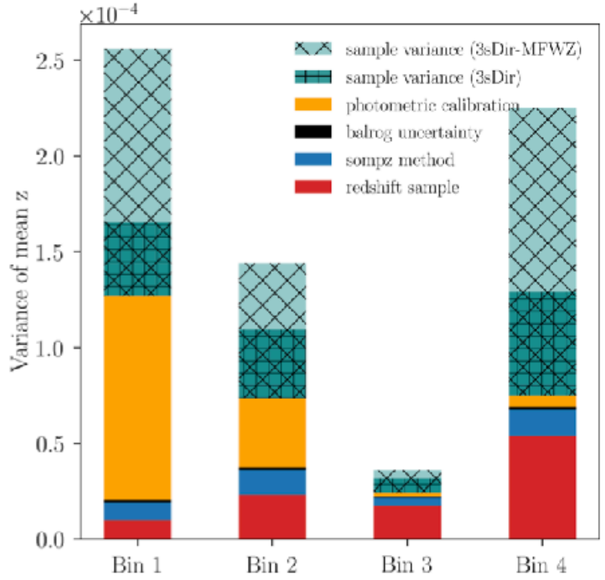
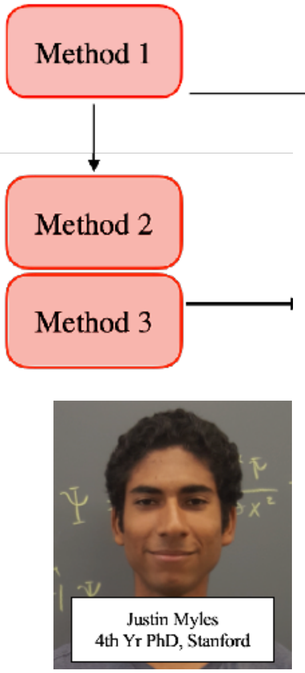
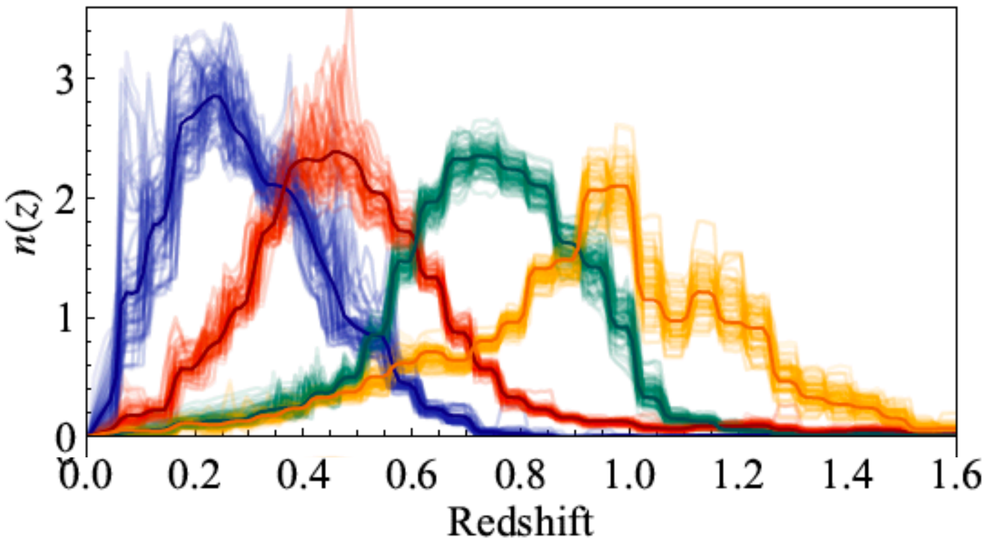
(Myles, Alarcon, Amon +2020)







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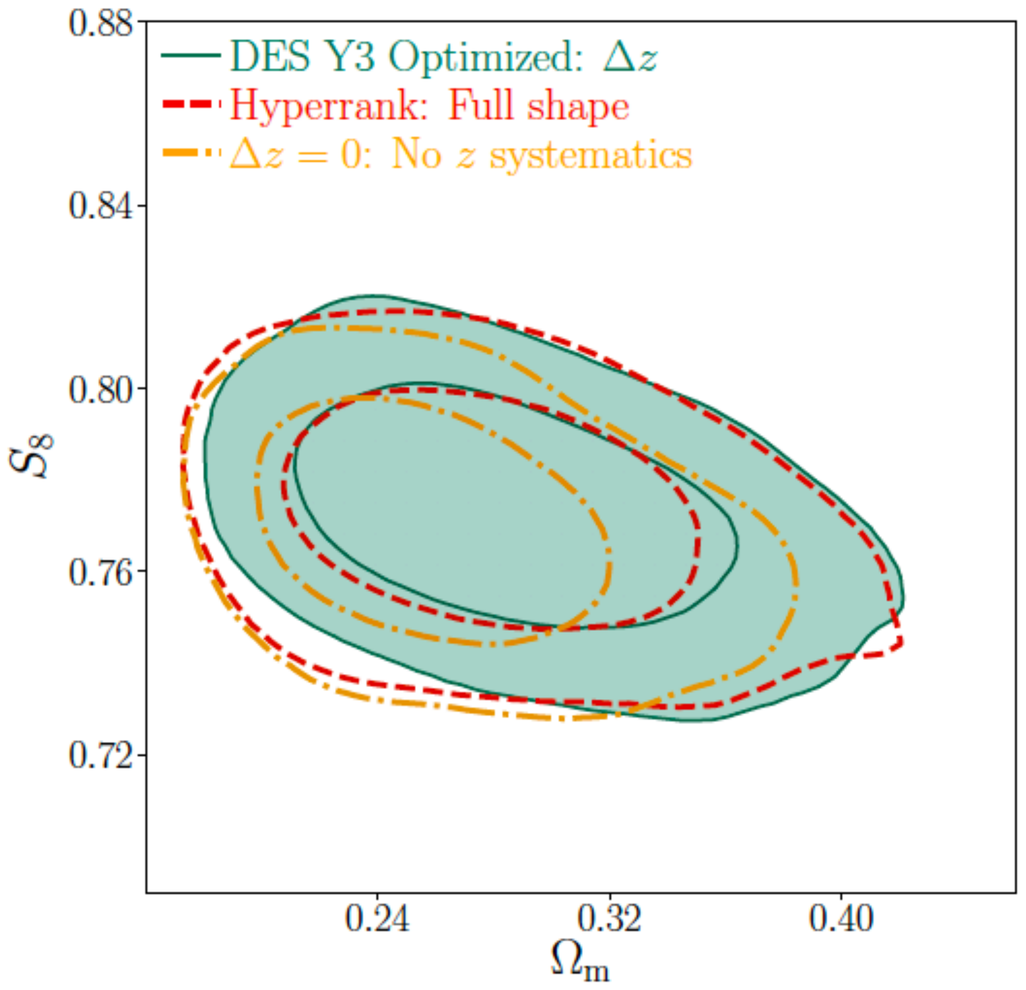
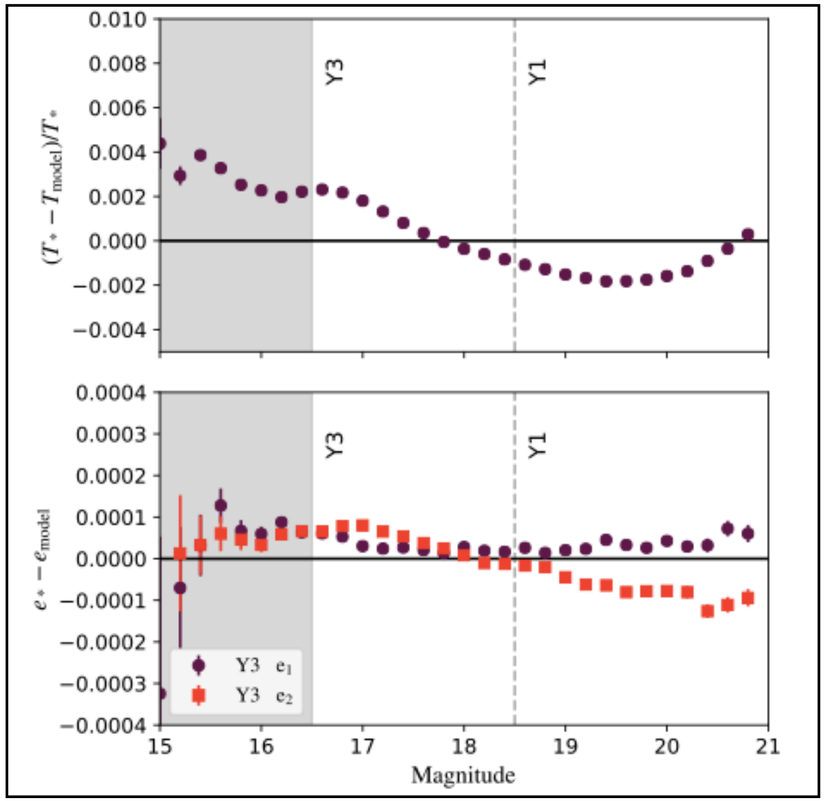
5. Can marginalise over ensemble with Hyperrank *(Cordero+)*

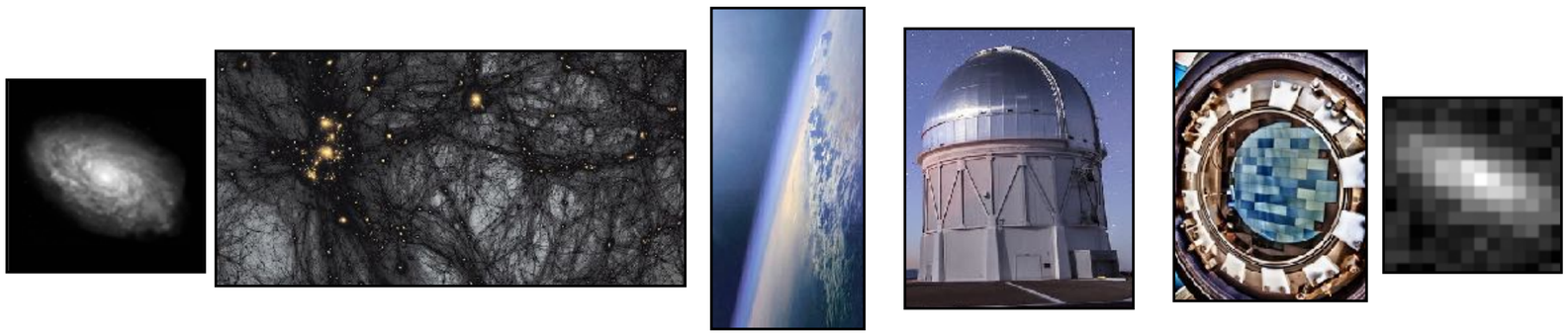
(Myles, Alarcon, Amon +2020)



DES Y3: calibration to account for ‘blending’

1. New Point Spread Function modelling *(Jarvis, Bernstein, Amon+)* :



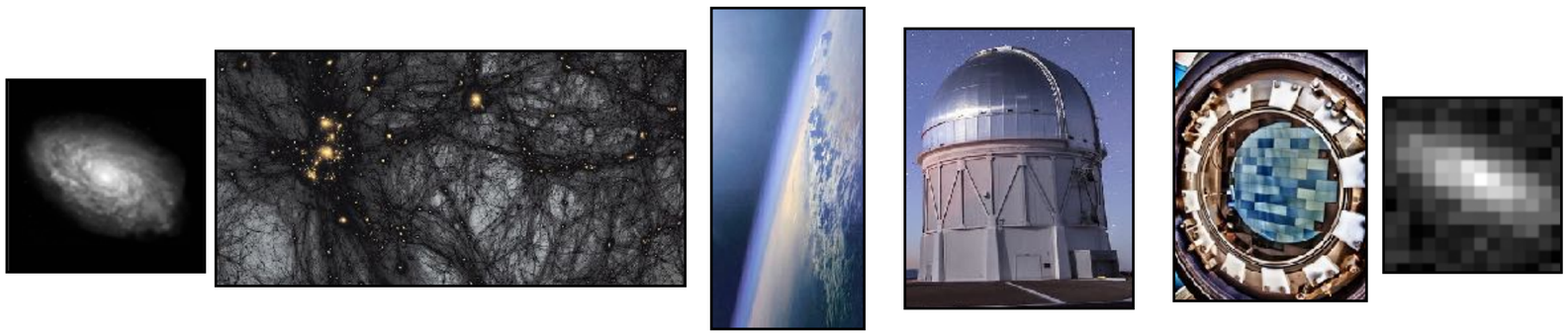


DES Y3: calibration to account for ‘blending’

1. New Point Spread Function modelling *(Jarvis, Bernstein, Amon+)* and extended suite of tests on the metacalibration catalogue *(Gatti, Sheldon, Amon+)*.

Bin	no. objects	$n_{\rm eff}$	σ_e	$\langle R_\gamma \rangle$	$\langle R_{\rm s} \rangle$
Full	100 204 026	5.590	0.268		
0	24 940 465	1.476	0.243	0.7636	0.0046
1	25 280 405	1.479	0.262	0.7182	0.0083
2	24 891 859	1.484	0.259	0.6887	0.0126
3	25 091 297	1.461	0.301	0.6154	0.0145

$$\langle R_{\rm s} \rangle_{i,j} = \frac{\langle e_i \rangle^{\rm s_+} - \langle e_i \rangle^{\rm s_-}}{\Delta\gamma_j}$$

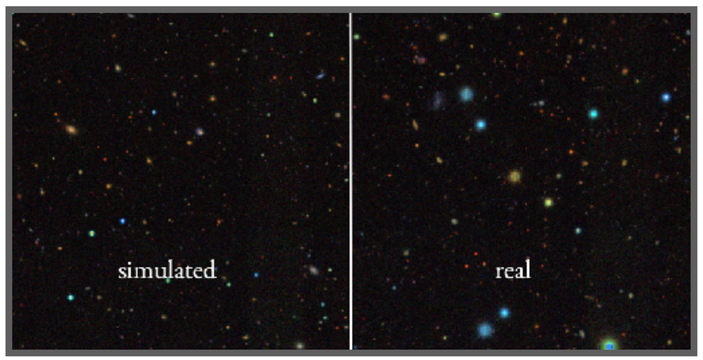


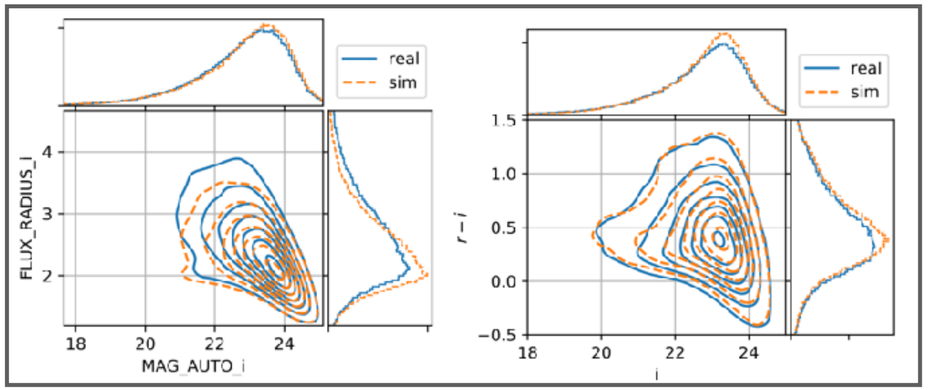
DES Y3: calibration to account for ‘blending’

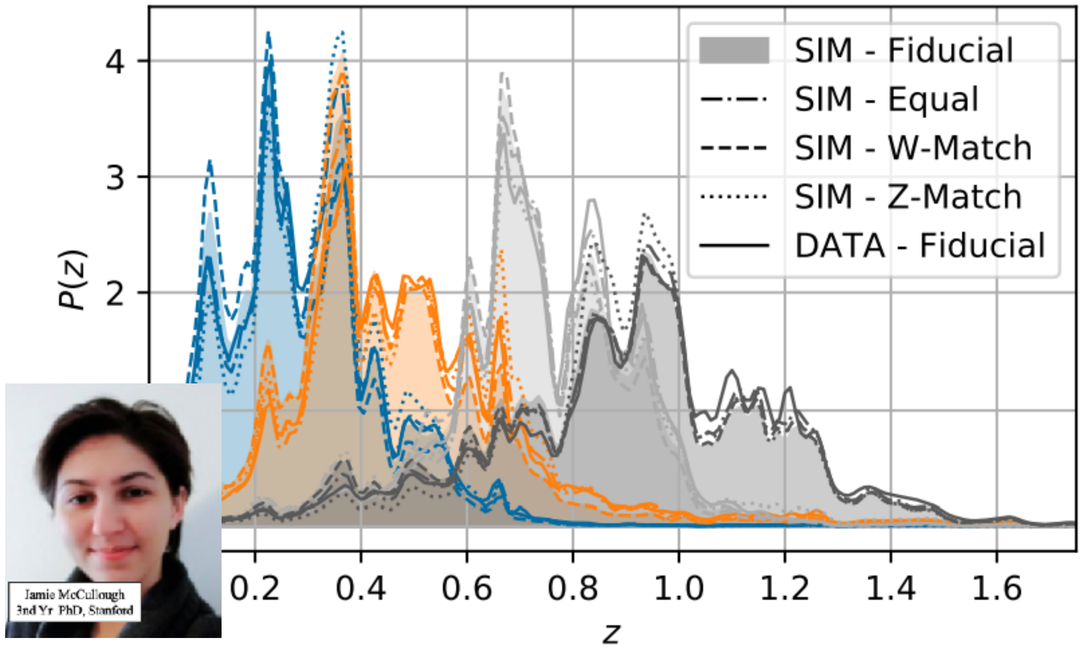
1. New Point Spread Function modelling *(Jarvis, Bernstein, Amon+)* and extended suite of shape catalogue tests *(Gatti, Sheldon, Amon+)*.

2. Developed **image simulations** that are well-matched to data used as a testing bed

3. Perform the full **redshift analysis on simulations** to understand shear redshift-dependent effect of crowded galaxy fields







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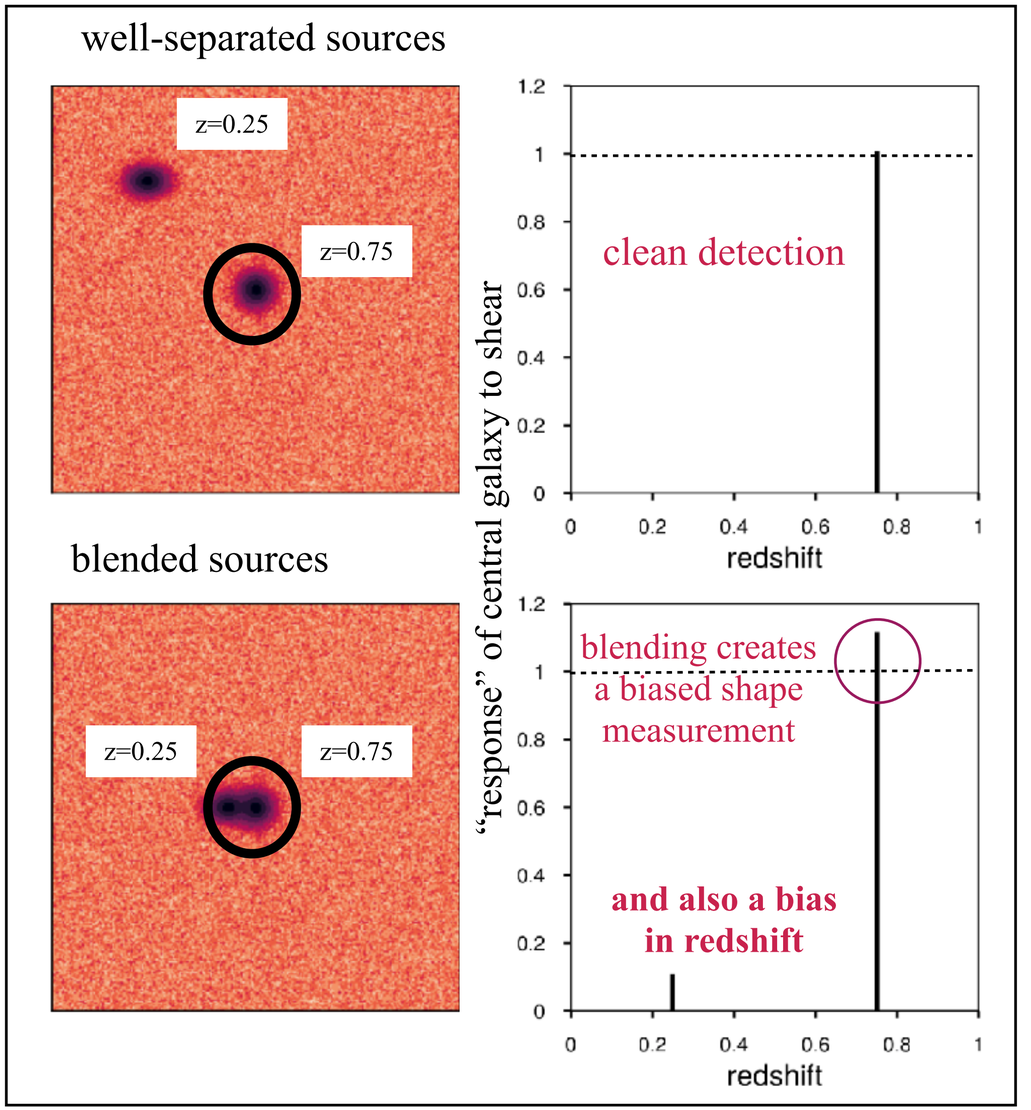
4. **Detected that measured shapes ‘respond’ to the shear of galaxies at other redshifts.**

5. Modelled and accounted for the impact of blending as a redshift-mixing effect

(MacCrann, Becker, McCullough, Amon+2020)



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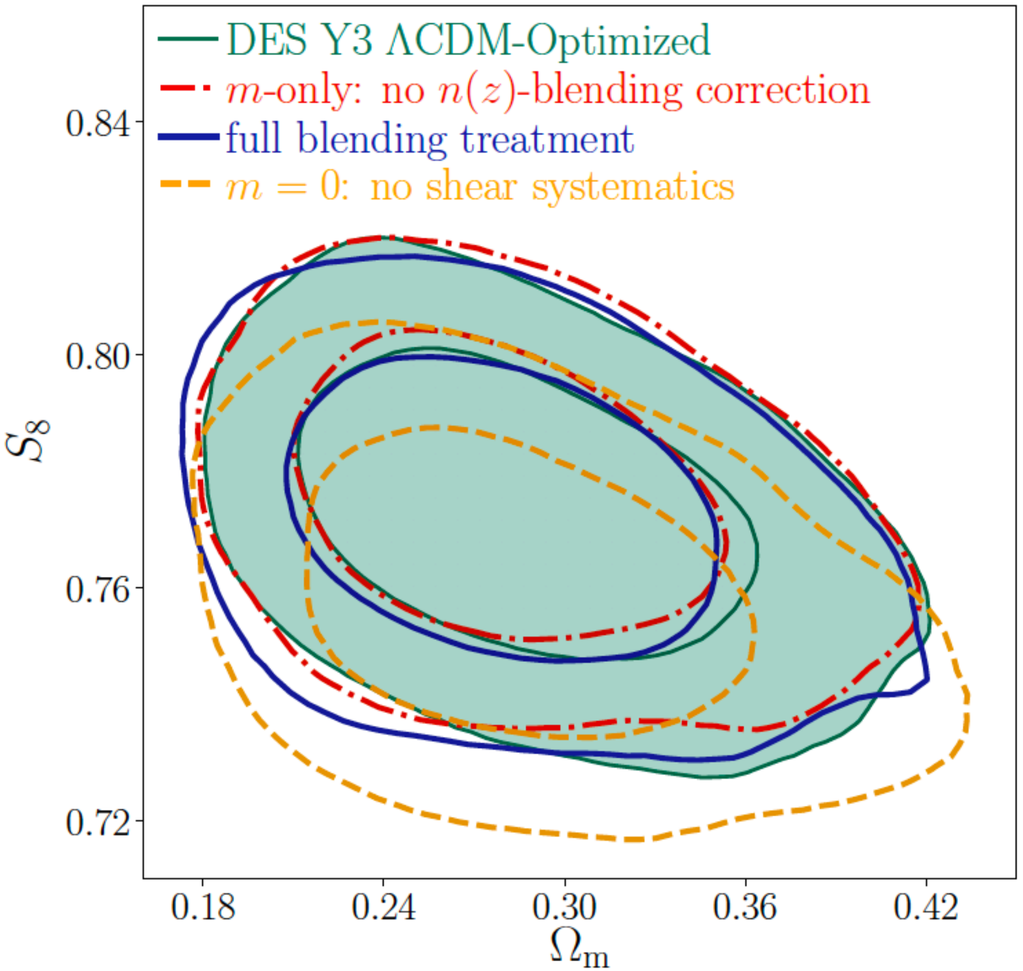


Amon, Gruen, Troxel, MacCrann, Dodelson+2021

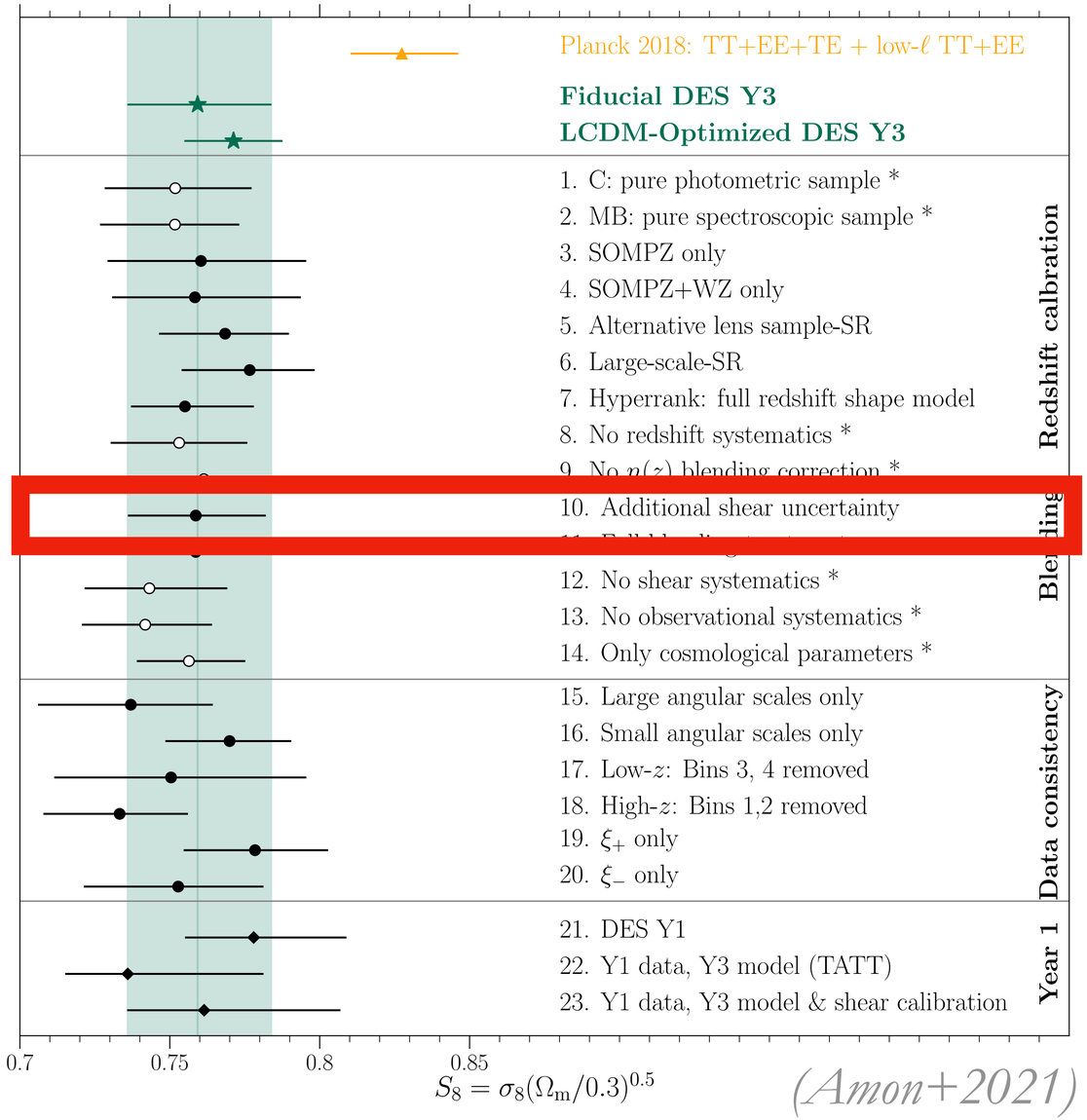
DES Y3: calibration to account for ‘blending’

Understanding blending in the future:

- clustering in the simulations, estimated in Martinet+2019 as an upper bound of 1% effect

- We tested that the cosmic shear results were stable to this additional uncertainty

- With Jamie McCullough, Daniel Gruen and others, we are doing more detailed investigations of blending effects using the DES Y3 image simulations.

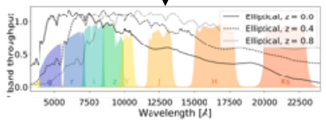


(Amon+2021)

DES Y3 *3x2pt* : pixels to cosmology

Wide Field Images

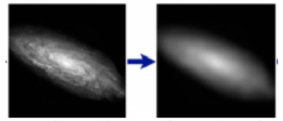
Sevilla, Bechtol +



Deep Field Photometry

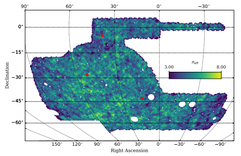
Hartley, Choi, Amon +

Survey selection



Point Spread Function Modelling

Jarvis, Bernstein, ***Amon +***



Shape catalogue

Gatti*, Sheldon,* ***Amon +***

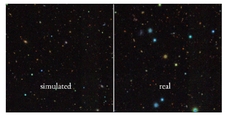
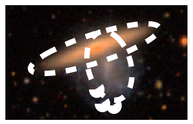
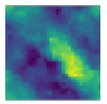


Image simulations

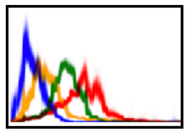


Blending & calibration

MacCrann, Becker, McCullough, Amon+



Redshift calibration



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Gatti, Giannini +

Cawthon +
Porredon +
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2-point function measurements

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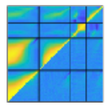
Cordero, Harrison +
Campos + ; Doux +



Covariance

Friedrich +

Galaxy clustering

Monroy +

Galaxy-galaxy lensing

Prat +

‘2x2’ cosmology

Pandey, *Krause +*
Porredon +
Elvin-Poole, MacCrann +

Cosmic shear cosmology

Amon +
Secco, Samuroff +

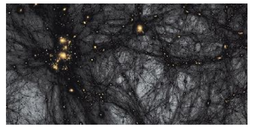
$P(\mathbf{p}|\hat{\mathbf{D}}, M) \propto \mathcal{L}(\hat{\mathbf{D}}|\mathbf{p}, M)P(\mathbf{p}|M)$

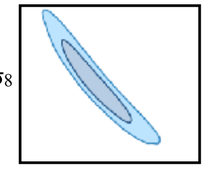
Analysis choices and modelling

Krause +

Mock analysis

de Rose +





‘3x2’ cosmology

coordinated by Michael Troxel , Elisabeth Krause, Scott Dodelson

Mitigate experimenter bias

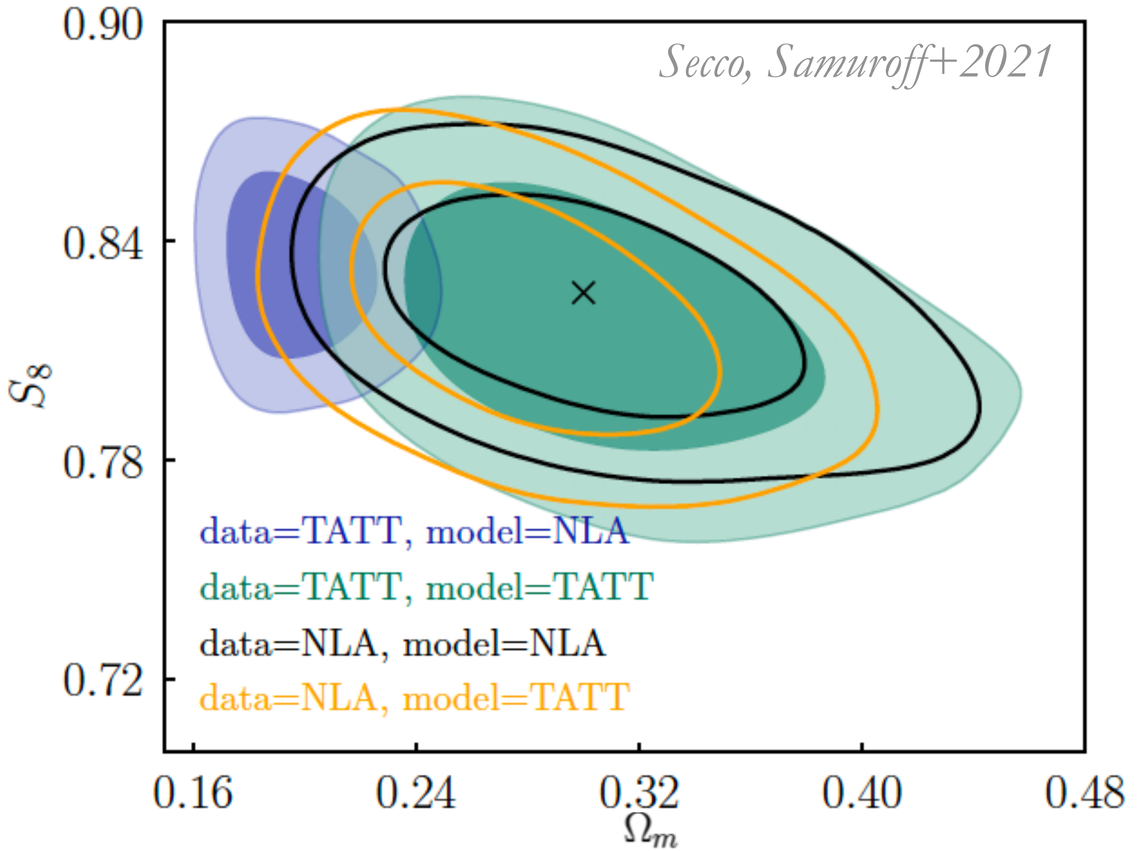
Muir +

Leadership positions:
DES Deep Fields
Shear Validation
Cosmic Shear

DES Y3: model choices

Intrinsic alignments: Tidal Alignment & Tidal Torquing model, TATT

- TATT is a superspace of the NLA model
- physically motivated to account for late-types
- simulated tests found NLA model can bias cosmology*



Baryonic effects: eliminate small-scale measurements

DES Y3: model choices

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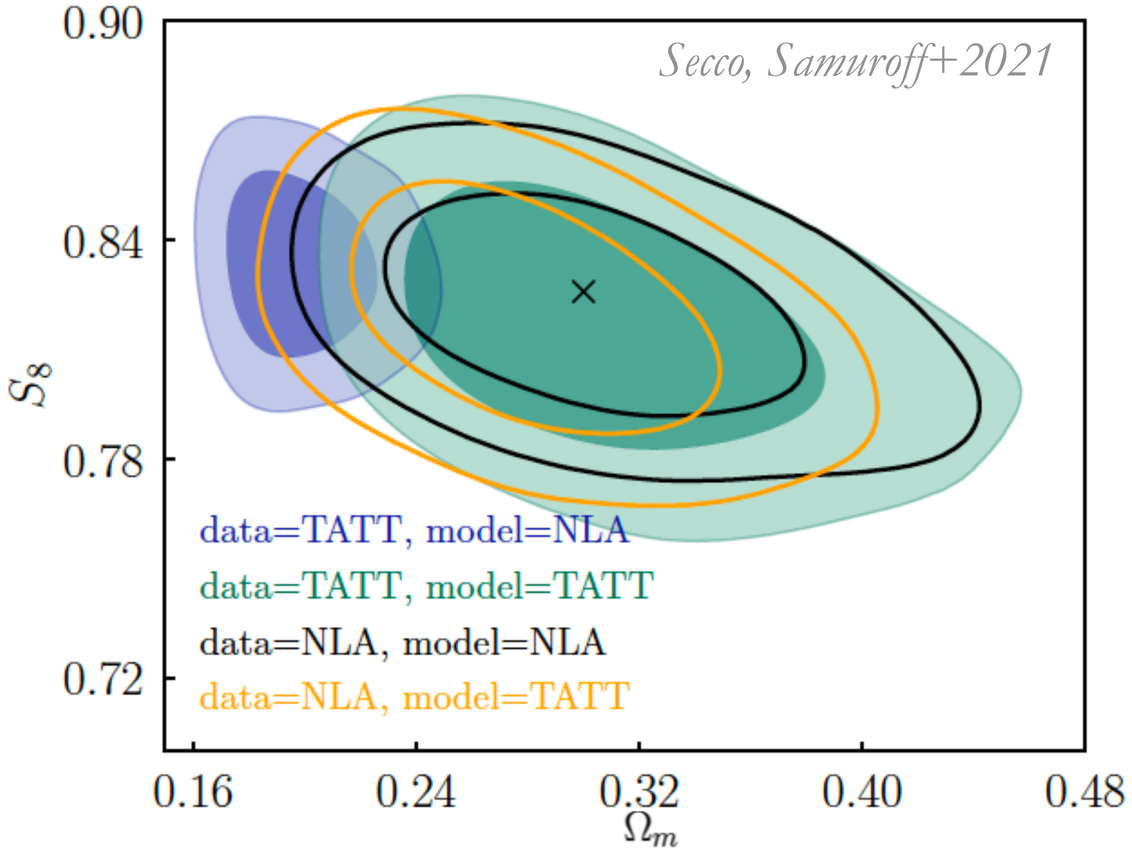
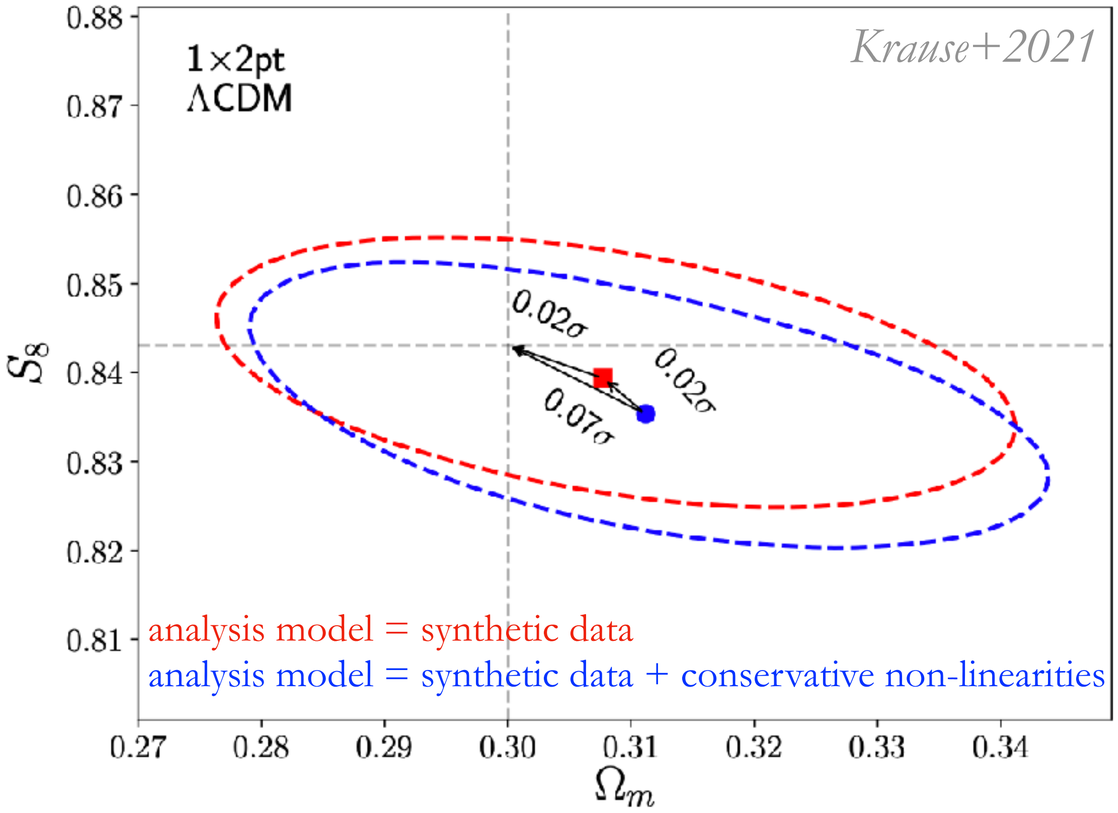


Baryonic effects: eliminate small-scale measurements

- Bracket impact of effect with OWLS-AGN hydro-simulation
- Threshold of bias in 3x2pt cosmology constraints is 0.3σ
- Simulated tests find a maximum bias of 0.1σ for cosmic shear



DES Y3: model choices

Cosmology (7 parameters):
ΛCDM/wCDM with massive neutrinos

Astrophysical model (9 parameters):
- Galaxy bias
- Magnification (fixed)
- Intrinsic Alignments (TATT)

Control non-linear modeling uncertainties through scale cuts
(Krause+, DeRose+)

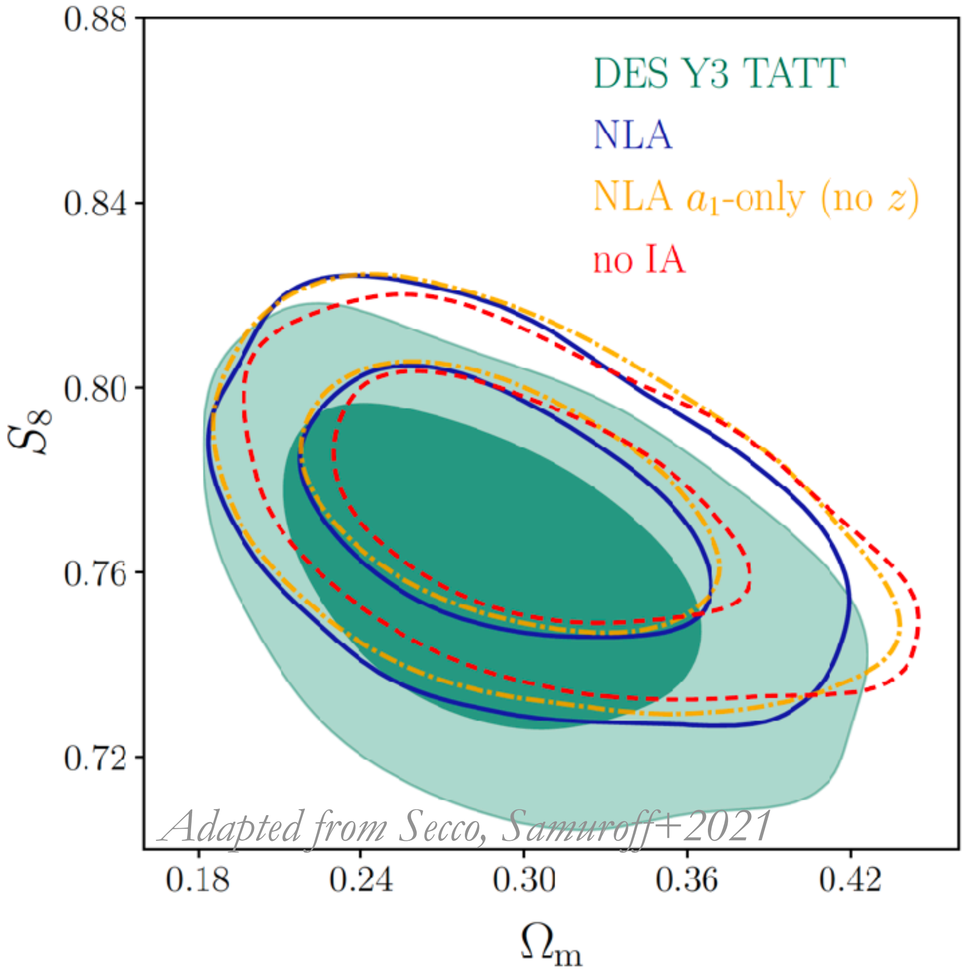
Calibration systematics (16 parameters)

Parameter		Prior
Cosmology		
$\Omega_{\rm m}$	Flat	$(0.1, 0.9)$
$10^9 A_{\rm s}$	Flat	$(0.5, 5.0)$
$n_{\rm s}$	Flat	$(0.87, 1.07)$
$\Omega_{\rm b}$	Flat	$(0.03, 0.07)$
h	Flat	$(0.55, 0.91)$
$10^3\Omega_\nu h^2$	Flat	$(0.60, 6.44)$
w	Flat	$(-2.0, -0.33)$
Lens Galaxy Bias		
$b_i (i \in [1,4])$	Flat	$(0.8, 3.0)$
Lens magnification		
$C_{\rm l}^1$	Fixed	1.21
$C_{\rm l}^2$	Fixed	1.15
$C_{\rm l}^3$	Fixed	1.88
$C_{\rm l}^4$	Fixed	1.97
Lens photo-z		
$\Delta z_{\rm l}^1 \times 10^2$	Gaussian	$(-0.9, 0.7)$
$\Delta z_{\rm l}^2 \times 10^2$	Gaussian	$(-3.5, 1.1)$
$\Delta z_{\rm l}^3 \times 10^2$	Gaussian	$(-0.5, 0.6)$
$\Delta z_{\rm l}^4 \times 10^2$	Gaussian	$(-0.7, 0.6)$
$\sigma_{z,{\rm l}}^1$	Gaussian	$(0.98, 0.06)$
$\sigma_{z,{\rm l}}^2$	Gaussian	$(1.31, 0.09)$
$\sigma_{z,{\rm l}}^3$	Gaussian	$(0.87, 0.05)$
$\sigma_{z,{\rm l}}^4$	Gaussian	$(0.92, 0.05)$
Intrinsic Alignment		
a_i $(i \in [1,2])$	Flat	$(-5, 5)$
η_i $(i \in [1,2])$	Flat	$(-5, 5)$
$b_{\rm TA}$	Flat	$(0, 2)$
z_0	Fixed	0.62
Source photo-z		
$\Delta z_{\rm s}^1 \times 10^2$	Gaussian	$(0.0, 1.8)$
$\Delta z_{\rm s}^2 \times 10^2$	Gaussian	$(0.0, 1.5)$
$\Delta z_{\rm s}^3 \times 10^2$	Gaussian	$(0.0, 1.1)$
$\Delta z_{\rm s}^4 \times 10^2$	Gaussian	$(0.0, 1.7)$
Shear calibration		
$m^1 \times 10^2$	Gaussian	$(-0.6, 0.9)$
$m^2 \times 10^2$	Gaussian	$(-2.0, 0.8)$
$m^3 \times 10^2$	Gaussian	$(-2.4, 0.8)$
$m^4 \times 10^2$	Gaussian	$(-3.7, 0.8)$

DES Y3: model choices

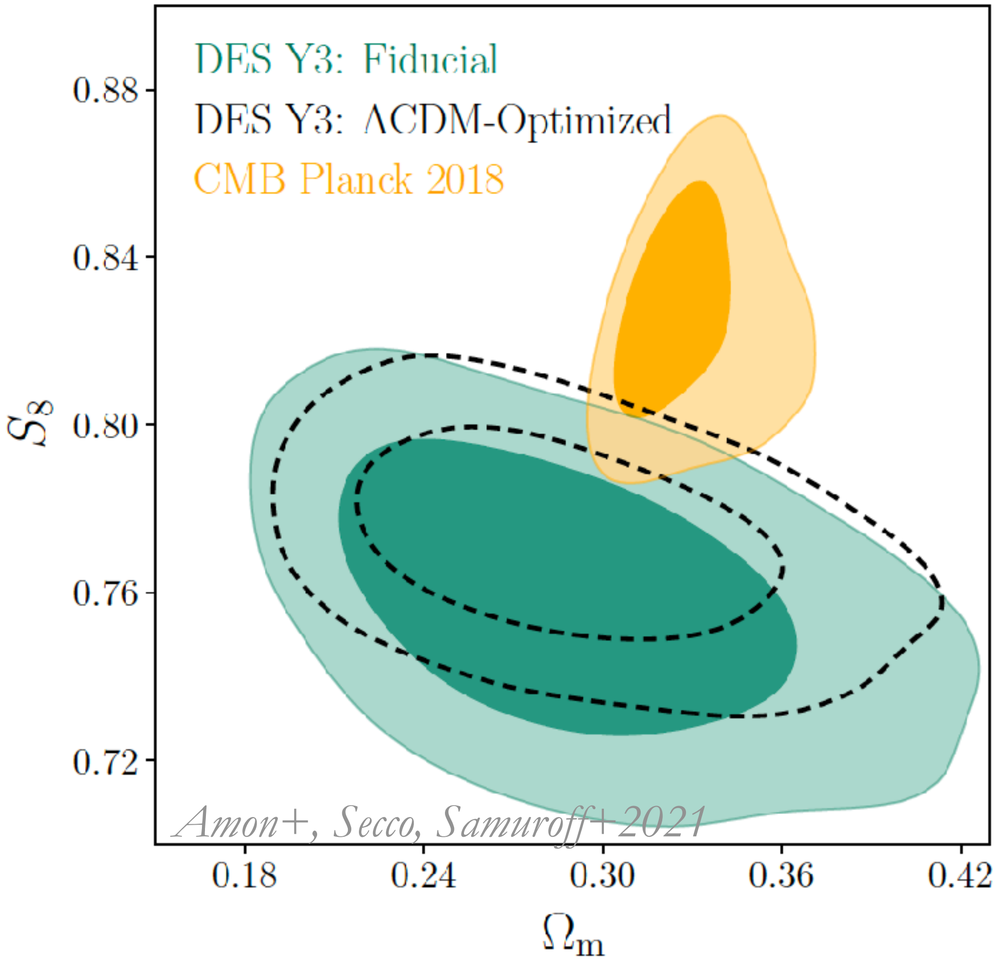
Intrinsic alignments:

Cosmology stable with the simpler NLA and NLA a1-only model.



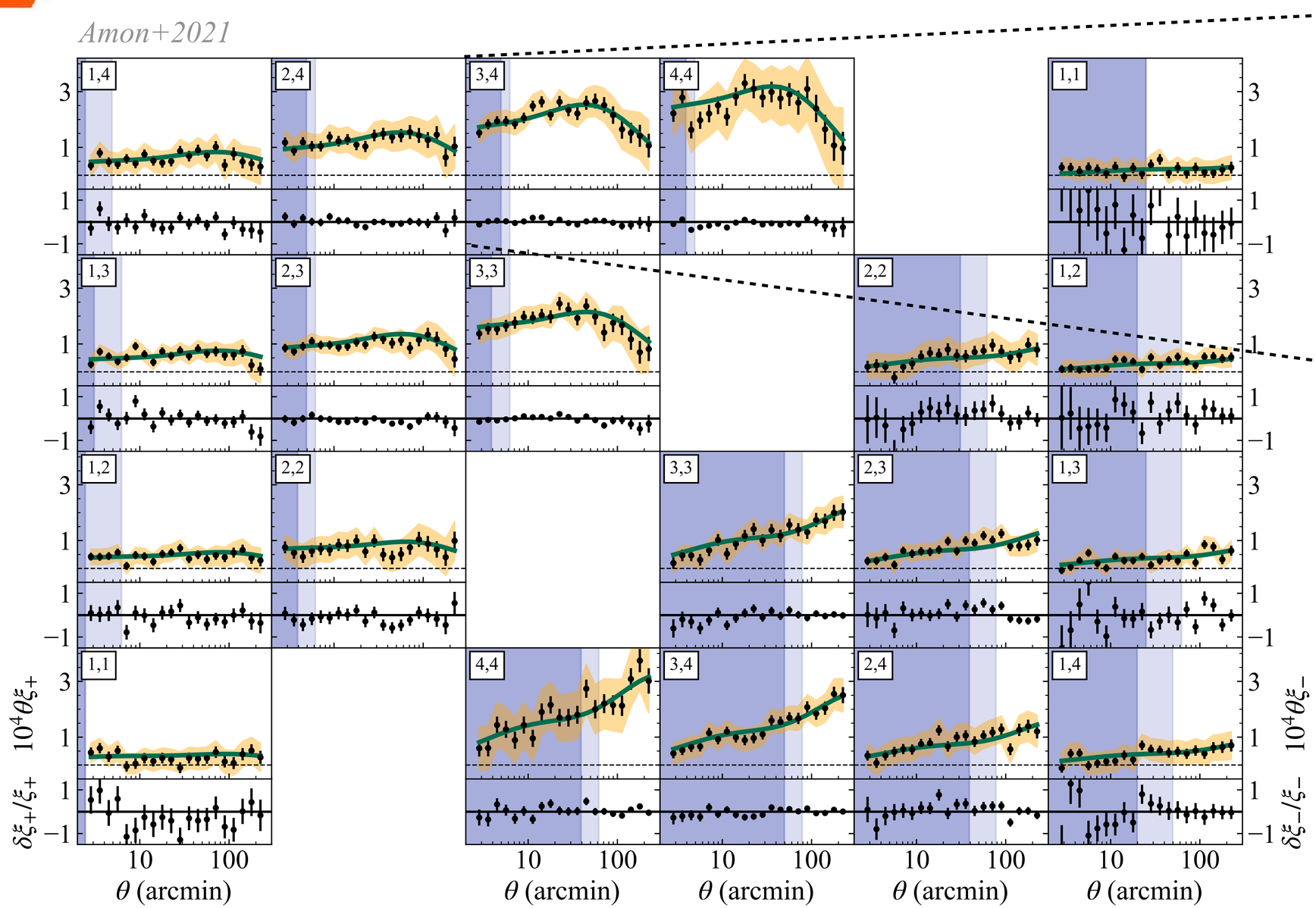
Baryonic effects:

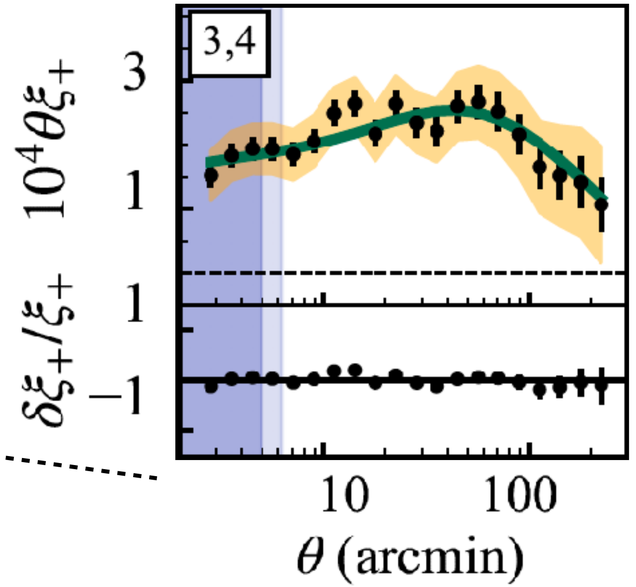
LCDM-Optimized analysis that uses more small-scale information gives consistent results with the Fiducial



DES Y3: model choices

Amon+2021





Y1 uncertainty

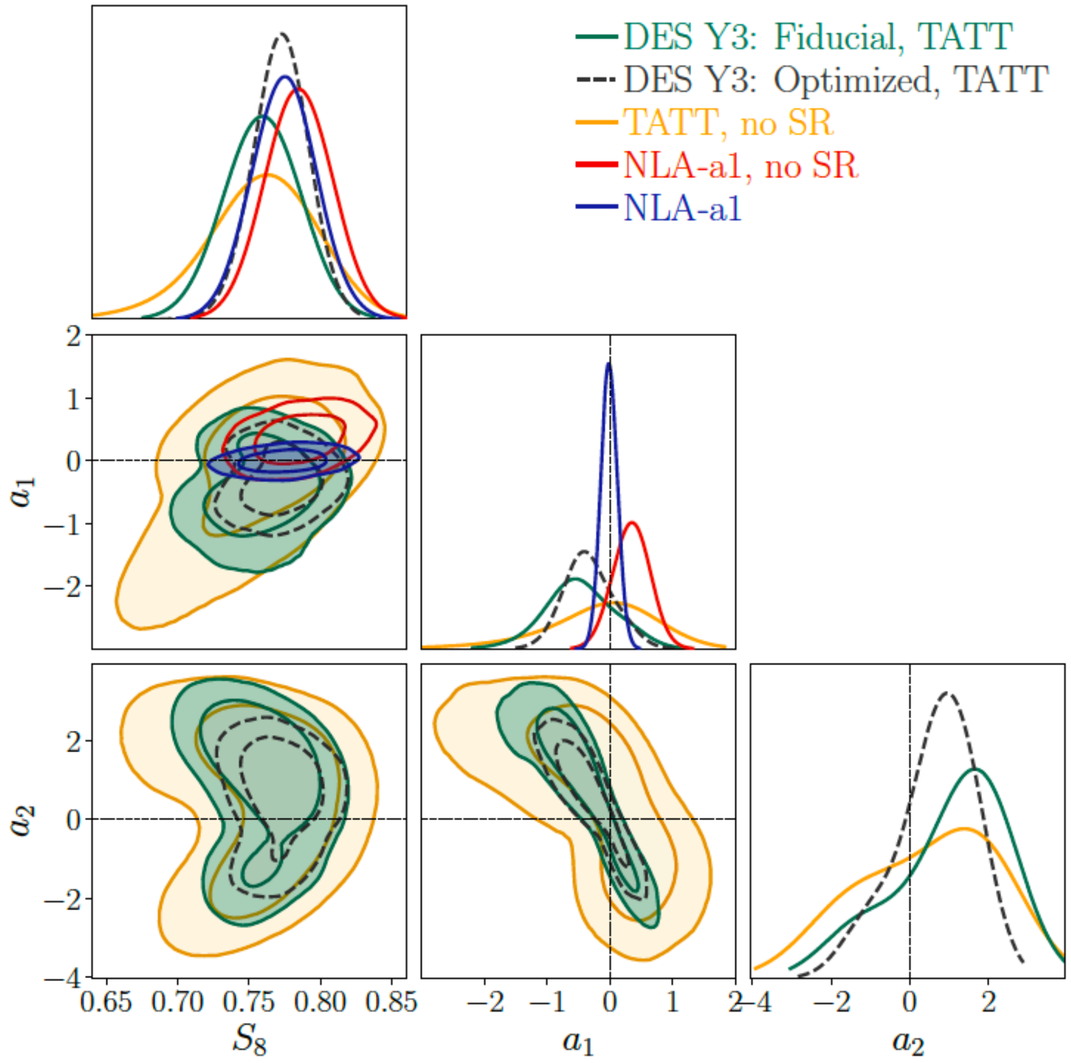
best-fit model

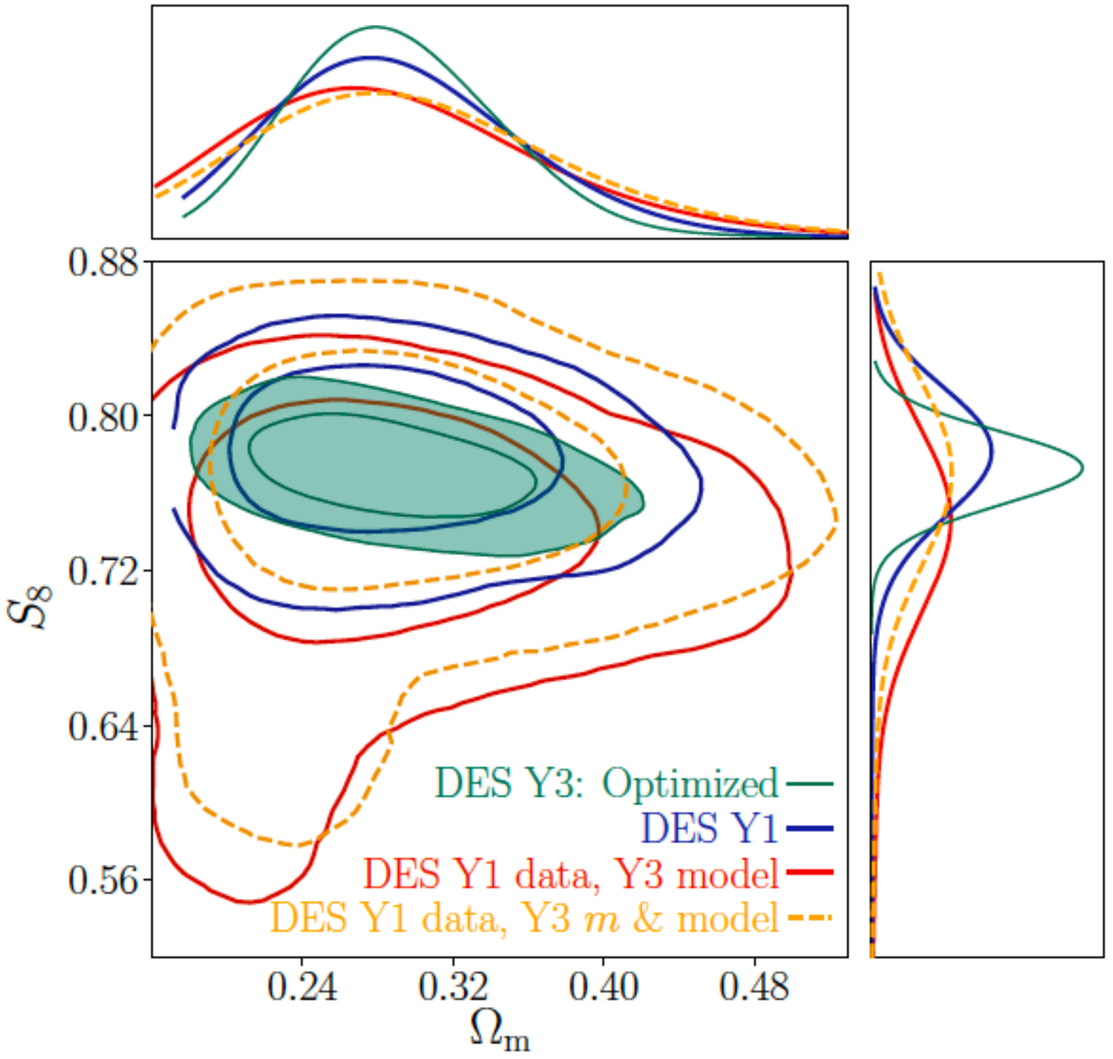
Fiducial scale cuts

LCDM-Optimized

DES Y3: conservative model choices

Amon, Gruen, Troxel, MacCrann, Dodelson+2021



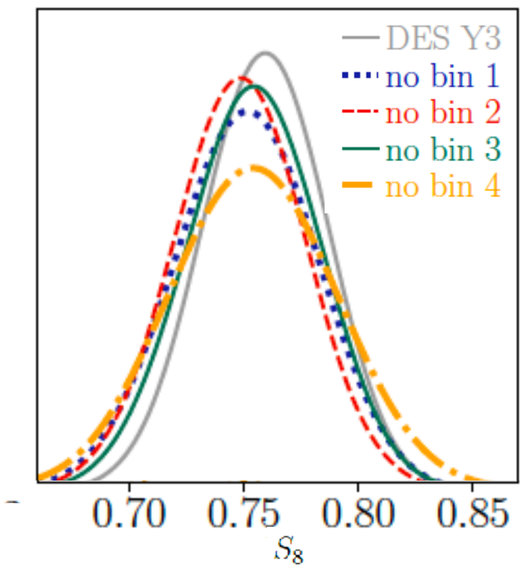


DES Y3: internally consistent

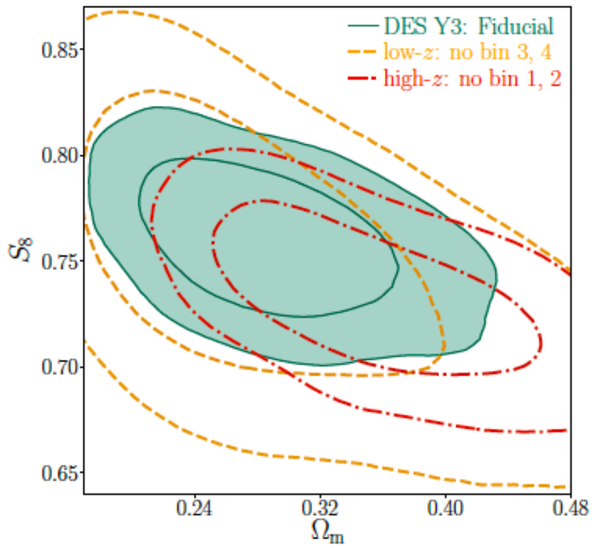
- Internal consistency as a model check
- Assess at the parameter level and with Posterior Predictive Distribution (PPD), with a threshold of model fit p>0.01 (methodology in *Doux, Baxter+2020*)
- DES Y3 cosmic shear consistent across redshift, angular scales and correlation function statistic

Amon, Gruen, Troxel, MacCrann, Dodelson+2021

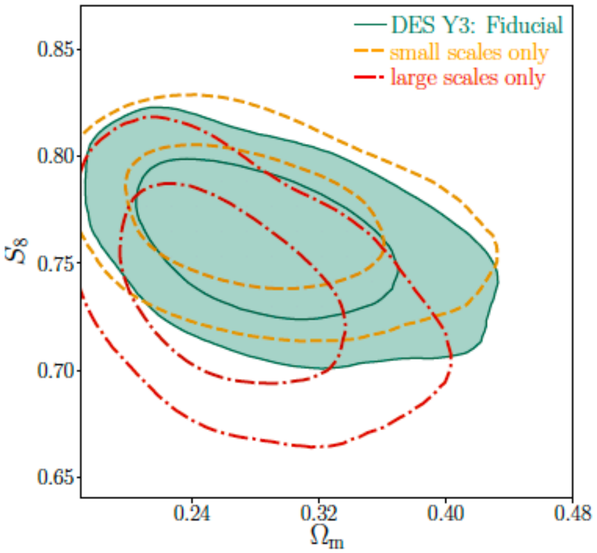
Redshift



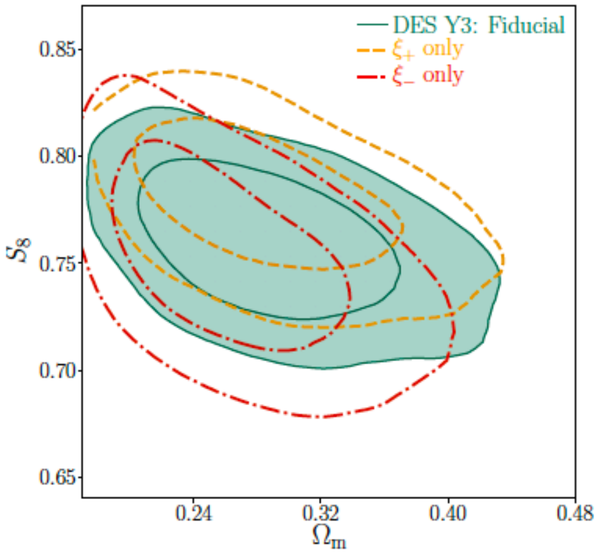
Redshift



Angular scales



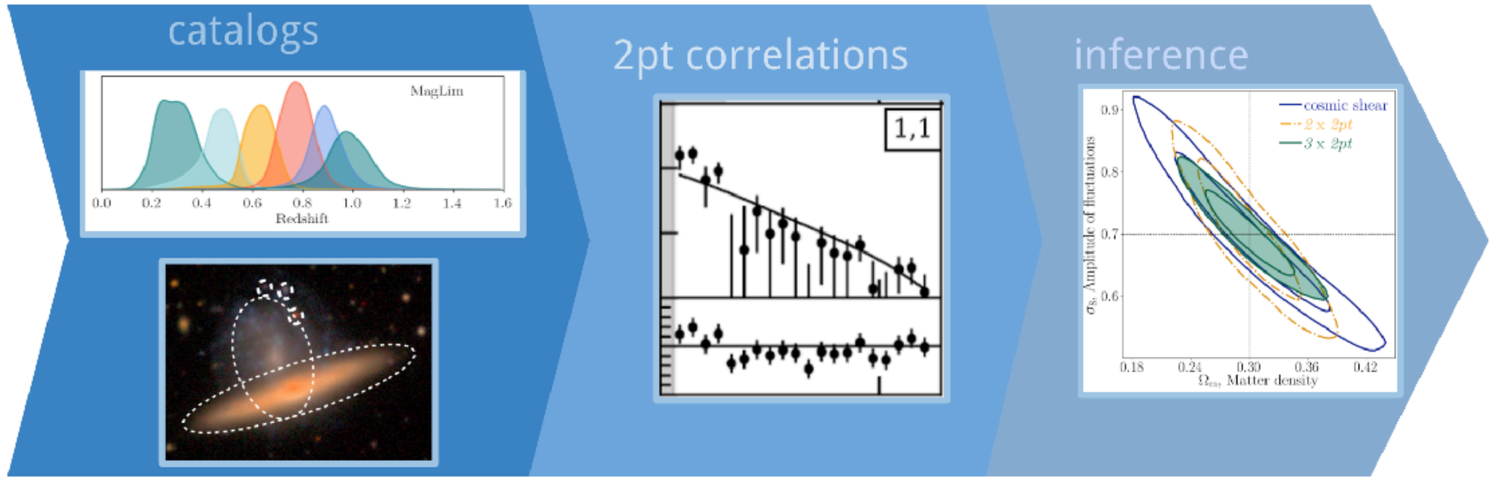
Statistics



DES Y3: mitigating experimenter bias

We minimize observer bias using a 3-stage blinding strategy. Before 'unblinding' we froze:

- Modeling choices & calibration priors
- Data vector measurements
- Planned list of robustness tests & combinations with external data

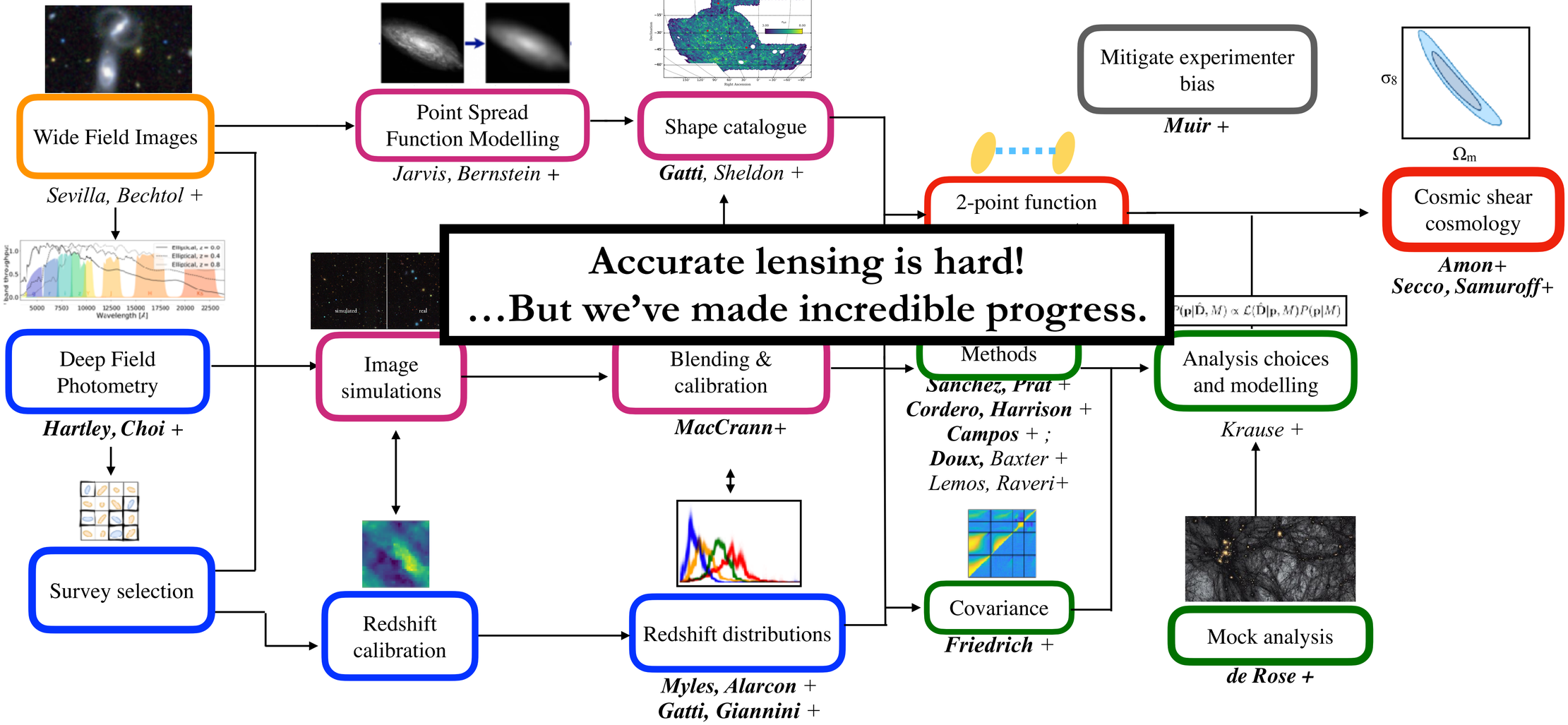


1 **Catalog:** rescale galaxy ellipticities by an unknown factor

2 **Correlation functions:** transform summary statistics to mimic unknown change in wCDM parameters (Muir+2020)

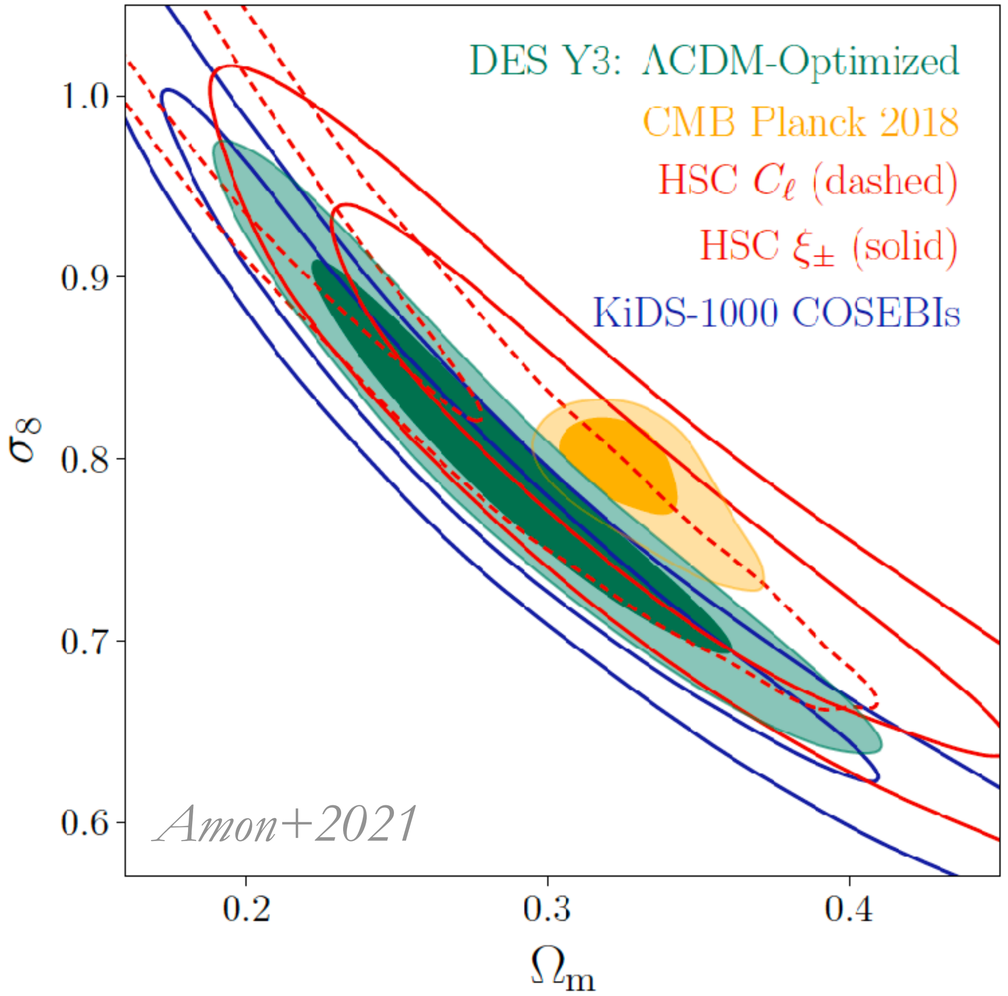
3 **Parameters:** shift axes of posterior plots by unknown offset

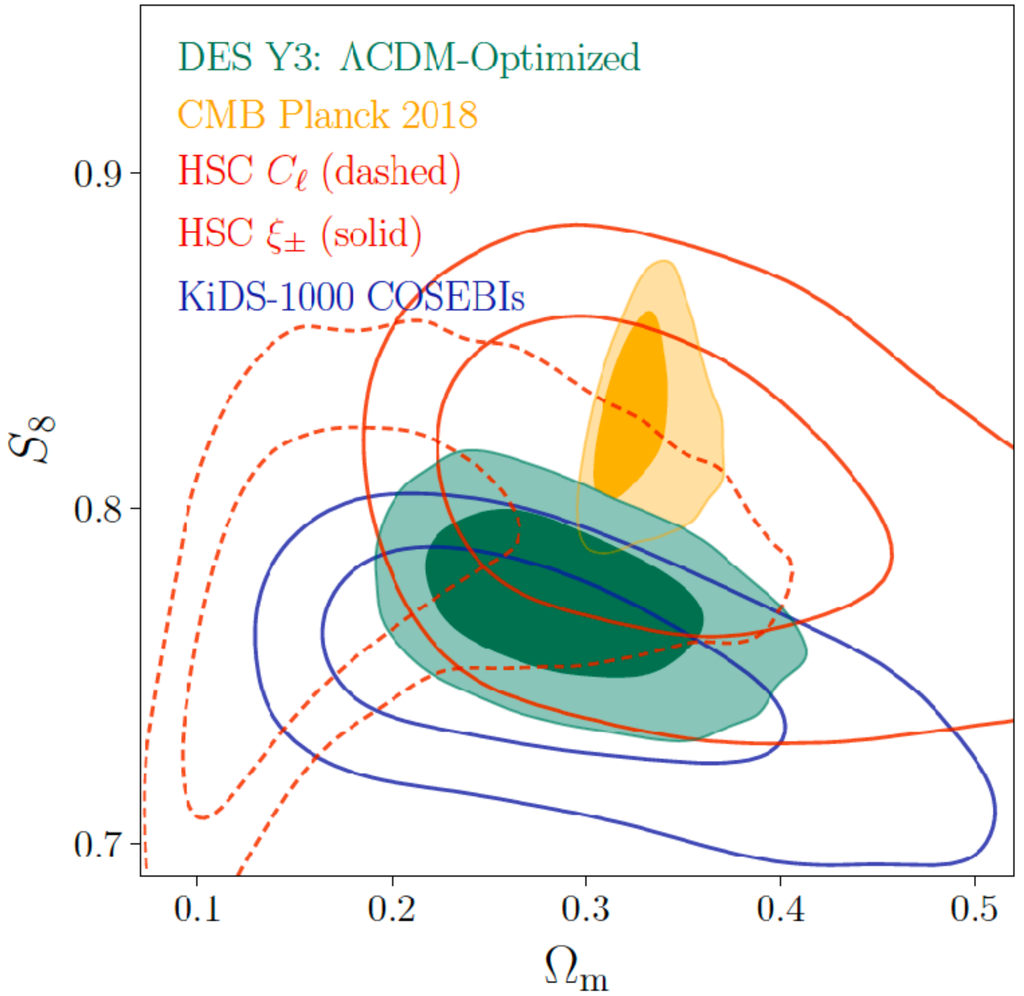
DES Y3 : pixels to cosmology



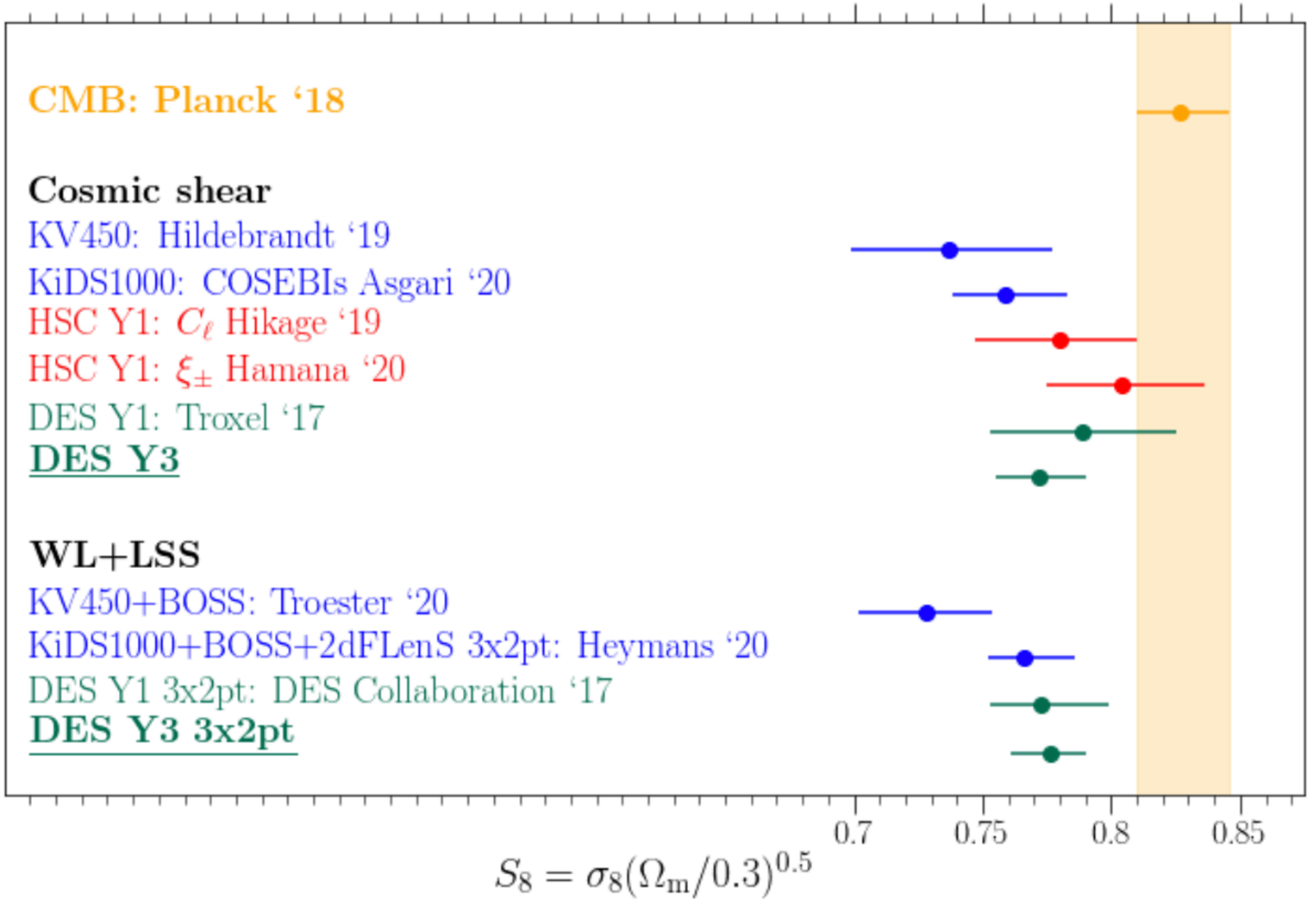
The lensing perspective on S_8 consistency

We find no significant evidence of inconsistency between **DES Y3 shear** and *Planck* CMB at ~2σ or p=0.05 > 0.01.





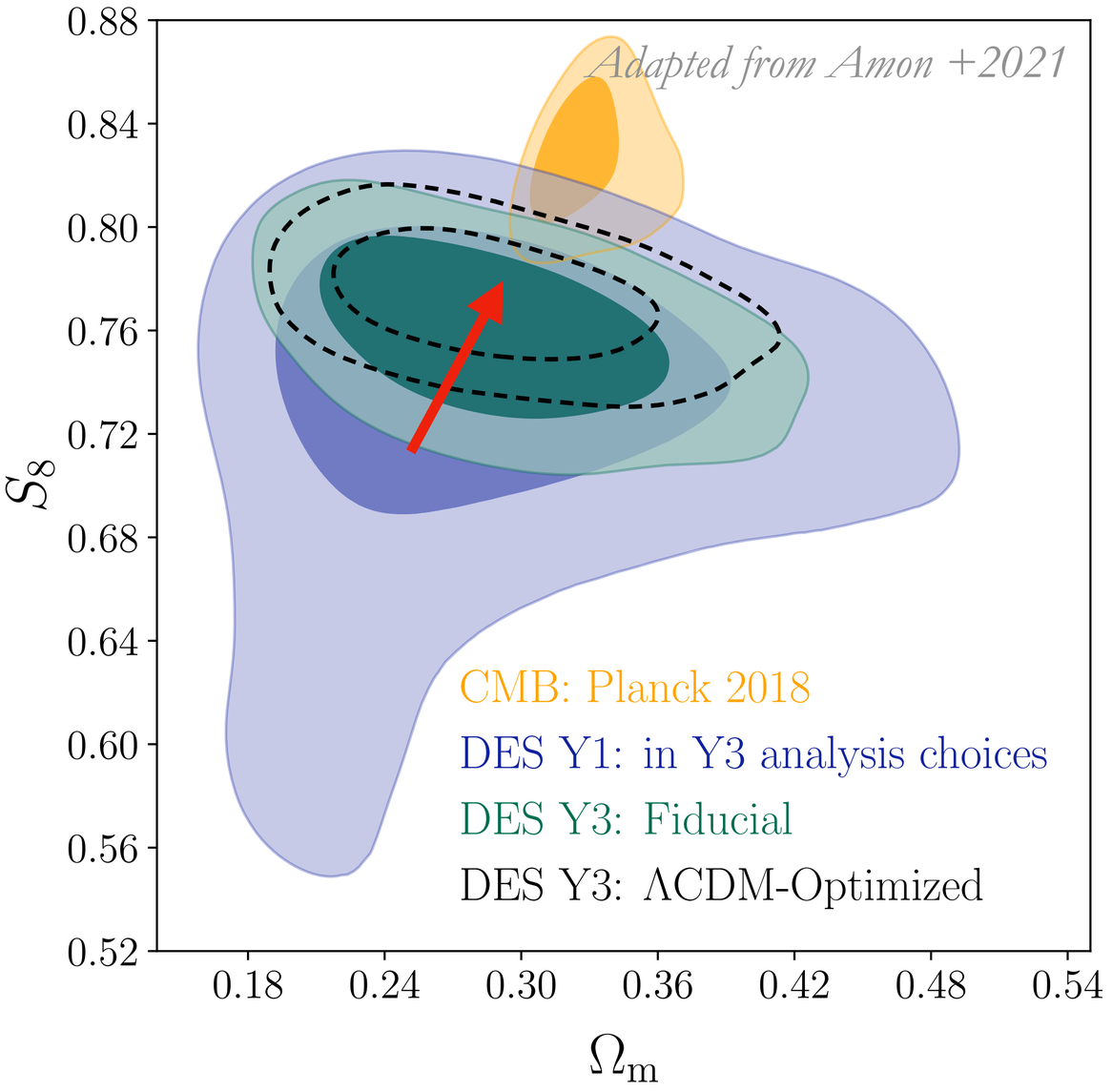
The lensing perspective on S_8 consistency



The lensing perspective on S_8 consistency

When comparing on equal footing with consistent analysis choices,

DES LCDM-Optimised represents a x1.5 improvement over the Fiducial Y3
and a x2 improvement over DES Y1.
—-> Gains in statistical power have, in both cases, shown no increase in S_8 tension with planck.

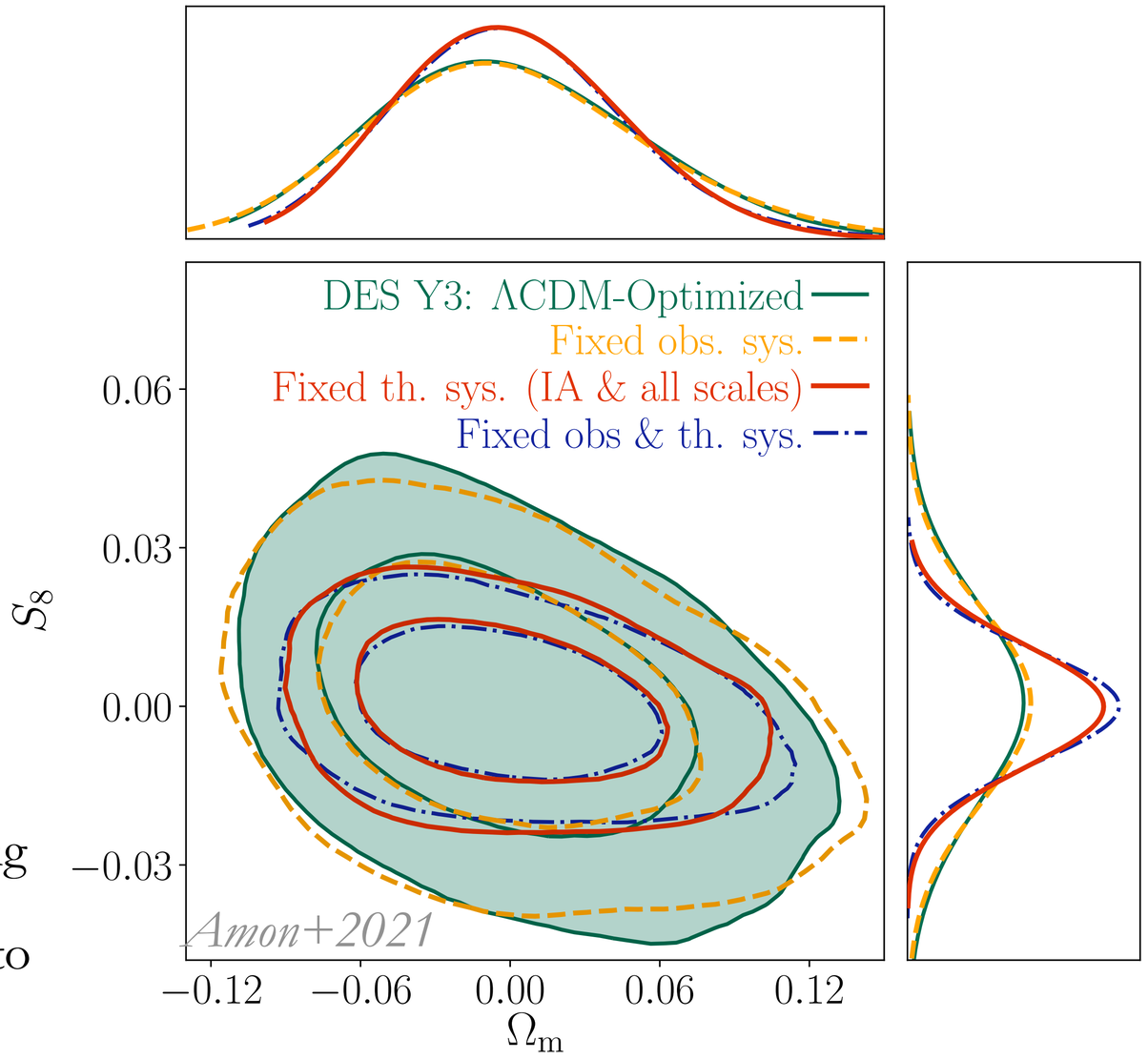


Looking ahead for cosmic shear

Tested the impact of fixing uncertainties in the analysis to their best fit values:

Redshift and shear calibration uncertainties negligible in the Y3 analysis.*

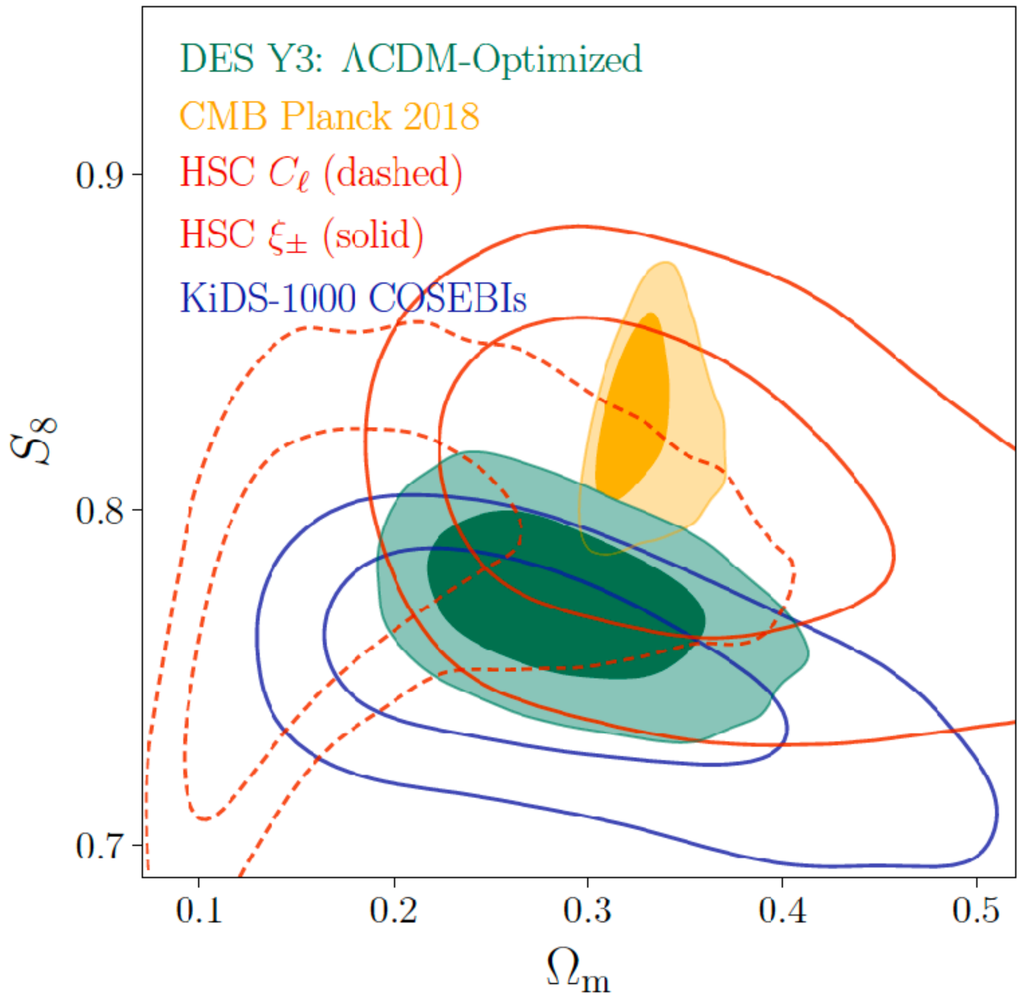
Fixing theoretical systematics, both intrinsic alignment modelling and small-scale baryonic effects (by using all scales) improves the S8 constraining power by ~2.**



* Maintaining their accuracy is still crucial and challenging

** Future decreases in measurement noise may not lead to concomitant decreases in cosmological uncertainties.

Looking ahead for cosmic shear : KiDS + DES !



Novel advancements built to utilize the statistical power of the DES Y3 data

DES Y3 cosmology stable to data calibration and modelling choices

Y3 finds a slightly higher clustering amplitude and matter density than in DES Y1, and a factor of ~2 improvement in power

and no significant evidence for inconsistency in ΛCDM between DES and *Planck*