

Information & the Dark Energy Survey

Adam Amara

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12/15

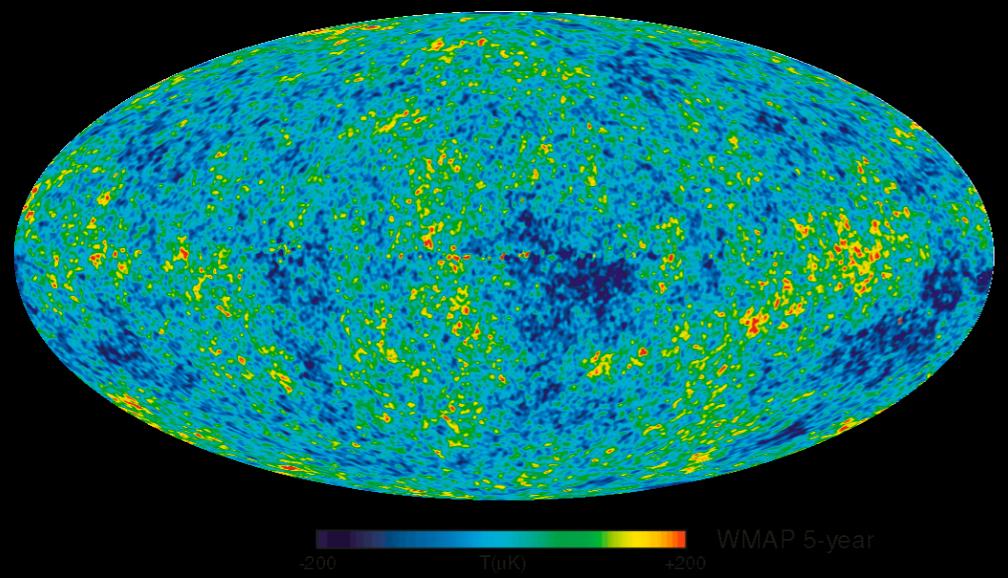
Work with: Alex Refregier, Sebastian Seehars, Sebastian Grandis,
Andrina Nicola, Joel Akeret and the DES collaboration

Information Content of Experiments

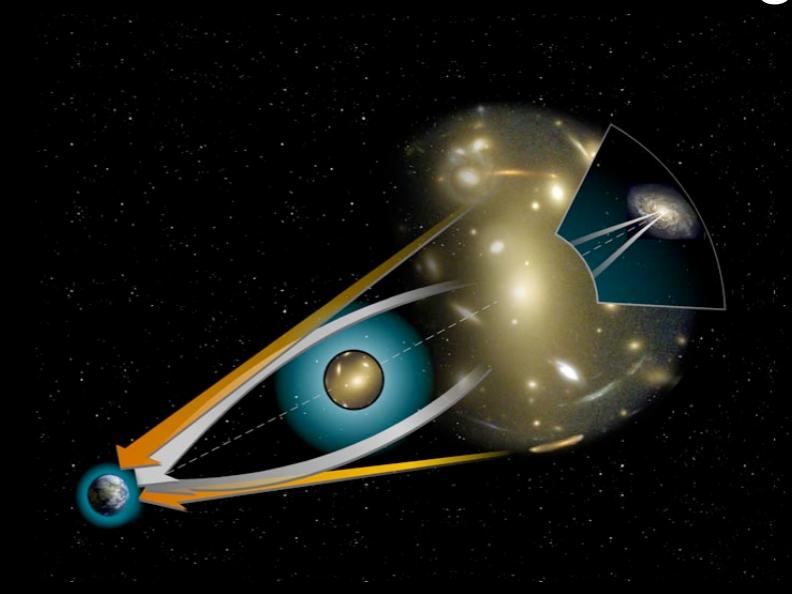
DES
(Dark Energy Survey)

Cosmological Probes

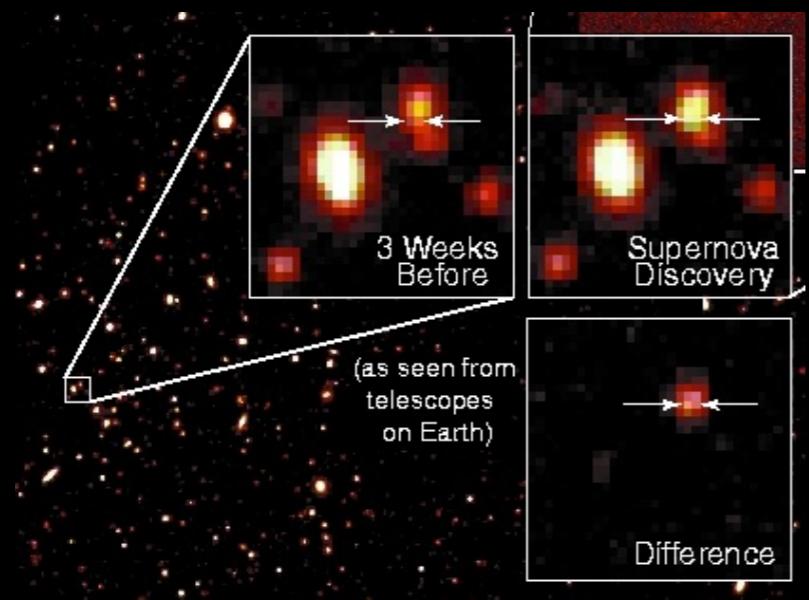
Cosmic Microwave Background



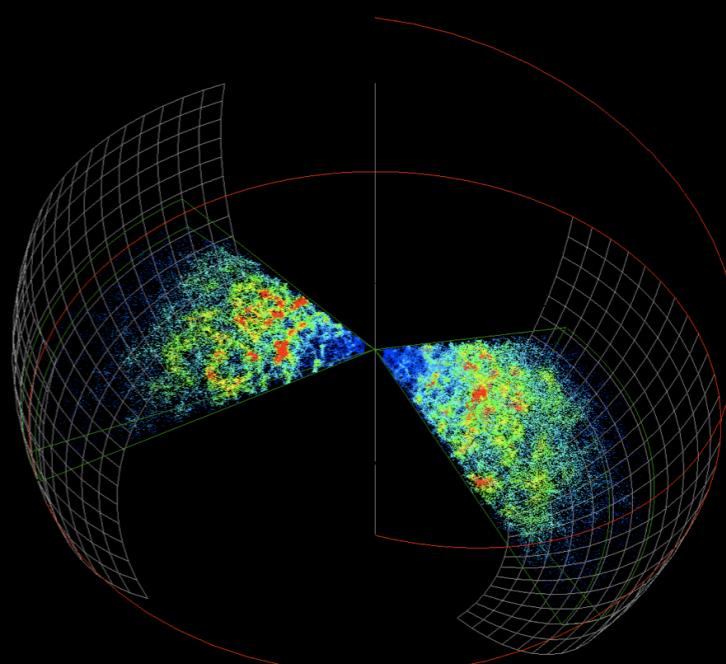
Gravitational Lensing



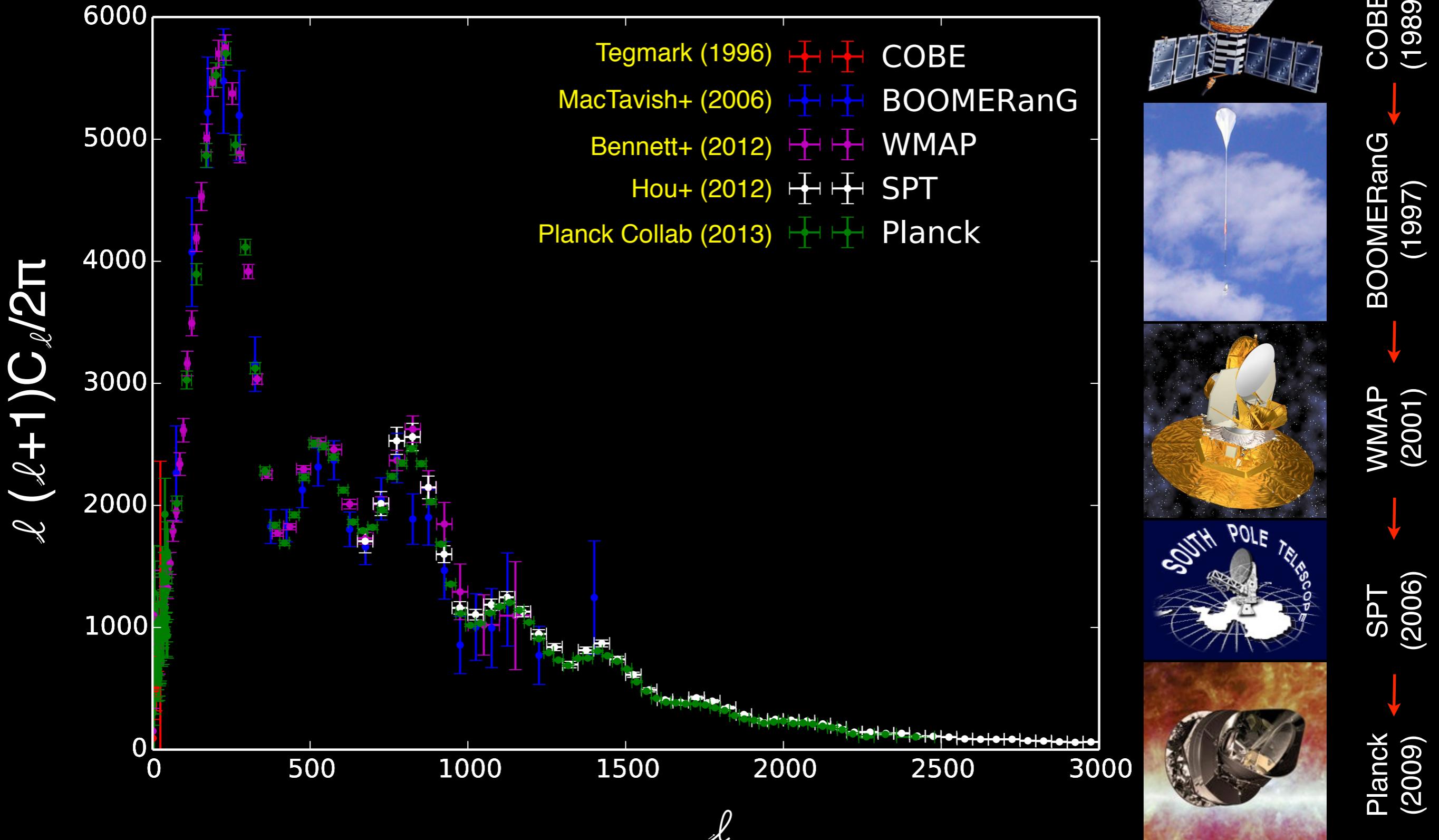
Supernovae



Galaxy Clustering



Cosmic Microwave Background



WMAP 9
Hinshaw+
(2013)

Parameter	WMAP	+eCMB	+eCMB+BAO	+eCMB+ H_0	+eCMB+BAO+ H_0
Fit parameters					
$\Omega_b h^2$	0.02264 ± 0.00050	0.02229 ± 0.00037	0.02211 ± 0.00034	0.02244 ± 0.00035	0.02223 ± 0.00033
$\Omega_c h^2$	0.1138 ± 0.0045	0.1126 ± 0.0035	0.1162 ± 0.0020	0.1106 ± 0.0030	0.1153 ± 0.0019
Ω_Λ	0.721 ± 0.025	0.728 ± 0.019	0.707 ± 0.010	0.740 ± 0.015	$0.7135^{+0.0095}_{-0.0096}$
$10^9 \Delta_R^2$	2.41 ± 0.10	2.430 ± 0.084	$2.484^{+0.073}_{-0.072}$	$2.396^{+0.079}_{-0.078}$	2.464 ± 0.072
n_s	0.972 ± 0.013	0.9646 ± 0.0098	$0.9579^{+0.0081}_{-0.0082}$	$0.9690^{+0.0091}_{-0.0090}$	0.9608 ± 0.0080
τ	0.089 ± 0.014	0.084 ± 0.013	$0.079^{+0.011}_{-0.012}$	0.087 ± 0.013	0.081 ± 0.012
Derived parameters					
t_0 (Gyr)	13.74 ± 0.11	13.742 ± 0.077	13.800 ± 0.061	13.702 ± 0.069	13.772 ± 0.059
H_0 (km s $^{-1}$ Mpc $^{-1}$)	70.0 ± 2.2	70.5 ± 1.6	68.76 ± 0.84	71.6 ± 1.4	69.32 ± 0.80
σ_8	0.821 ± 0.023	0.810 ± 0.017	$0.822^{+0.013}_{-0.014}$	0.803 ± 0.016	$0.820^{+0.013}_{-0.014}$
Ω_b	0.0463 ± 0.0024	0.0449 ± 0.0018	0.04678 ± 0.00098	0.0438 ± 0.0015	0.04628 ± 0.00093
Ω_c	0.233 ± 0.023	0.227 ± 0.017	0.2460 ± 0.0094	0.216 ± 0.014	$0.2402^{+0.0088}_{-0.0087}$
z_{eq}	3265^{+106}_{-105}	3230 ± 81	3312 ± 48	3184 ± 70	3293 ± 47
z_{reion}	10.6 ± 1.1	10.3 ± 1.1	10.0 ± 1.0	10.5 ± 1.1	10.1 ± 1.0

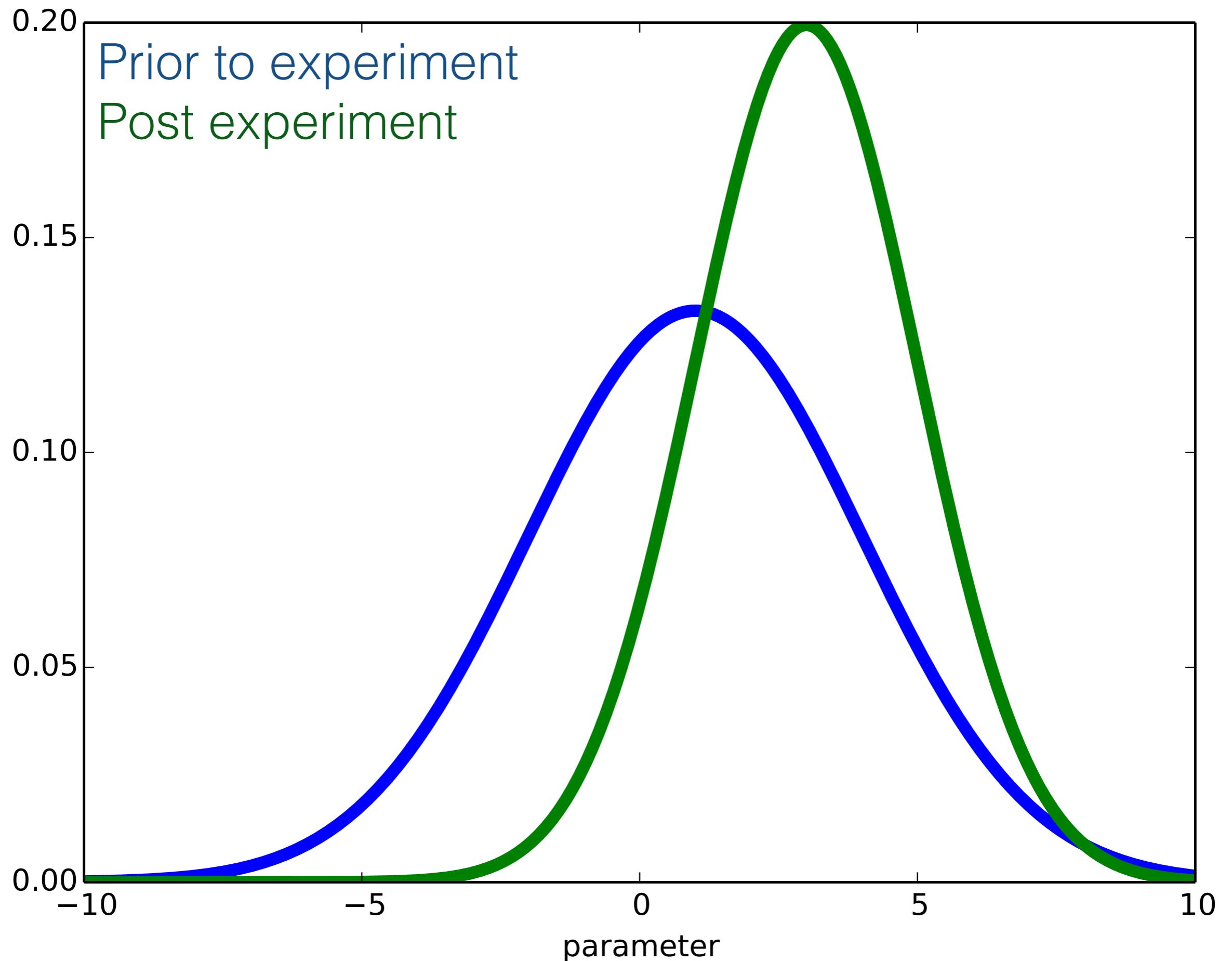
Planck
(2013)

Parameter	Planck+WP		Planck+WP+highL		Planck+lensing+WP+highL		Planck+WP+highL+BAO	
	Best fit	68% limits	Best fit	68% limits	Best fit	68% limits	Best fit	68% limits
$\Omega_b h^2$	0.022032	0.02205 ± 0.00028	0.022069	0.02207 ± 0.00027	0.022199	0.02218 ± 0.00026	0.022161	0.02214 ± 0.00024
$\Omega_c h^2$	0.12038	0.1199 ± 0.0027	0.12025	0.1198 ± 0.0026	0.11847	0.1186 ± 0.0022	0.11889	0.1187 ± 0.0017
$100\theta_{\text{MC}}$	1.04119	1.04131 ± 0.00063	1.04130	1.04132 ± 0.00063	1.04146	1.04144 ± 0.00061	1.04148	1.04147 ± 0.00056
τ	0.0925	$0.089^{+0.012}_{-0.014}$	0.0927	$0.091^{+0.013}_{-0.014}$	0.0943	$0.090^{+0.013}_{-0.014}$	0.0952	0.092 ± 0.013
n_s	0.9619	0.9603 ± 0.0073	0.9582	0.9585 ± 0.0070	0.9624	0.9614 ± 0.0063	0.9611	0.9608 ± 0.0054
$\ln(10^{10} A_s)$	3.0980	$3.089^{+0.024}_{-0.027}$	3.0959	3.090 ± 0.025	3.0947	3.087 ± 0.024	3.0973	3.091 ± 0.025
Ω_Λ	0.6817	$0.685^{+0.018}_{-0.016}$	0.6830	$0.685^{+0.017}_{-0.016}$	0.6939	0.693 ± 0.013	0.6914	0.692 ± 0.010
σ_8	0.8347	0.829 ± 0.012	0.8322	0.828 ± 0.012	0.8271	0.8233 ± 0.0097	0.8288	0.826 ± 0.012
z_{re}	11.37	11.1 ± 1.1	11.38	11.1 ± 1.1	11.42	11.1 ± 1.1	11.52	11.3 ± 1.1
H_0	67.04	67.3 ± 1.2	67.15	67.3 ± 1.2	67.94	67.9 ± 1.0	67.77	67.80 ± 0.77
Age/Gyr	13.8242	13.817 ± 0.048	13.8170	13.813 ± 0.047	13.7914	13.794 ± 0.044	13.7965	13.798 ± 0.037
$100\theta_*$	1.04136	1.04147 ± 0.00062	1.04146	1.04148 ± 0.00062	1.04161	1.04159 ± 0.00060	1.04163	1.04162 ± 0.00056
r_{drag}	147.36	147.49 ± 0.59	147.35	147.47 ± 0.59	147.68	147.67 ± 0.50	147.611	147.68 ± 0.45

What are the central values?

Have things changed?

Are things consistent?



RELATIVE ENTROPY

$$D(P_1 || P_2) = \int_{\mathcal{S}} dX P_1(X) \log \frac{P_1(X)}{P_2(X)}$$



Seehars et al (2014)

Kullback & Leibler (1951)

RELATIVE ENTROPY

Constraints from Data A



$$D(P_1 \parallel P_2) = \int_{\mathcal{S}} dX P_1(X) \log \frac{P_1(X)}{P_2(X)}$$



Constraints from Data A and B



Seehars et al (2014)

Kullback & Leibler (1951)

RELATIVE ENTROPY

$$D(P_1 || P_2) = \int_{\mathcal{S}} dX P_1(X) \log \frac{P_1(X)}{P_2(X)}$$



Seehars et al (2014)

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RELATIVE ENTROPY

$$D(P_1 || P_2) = \int_{\mathcal{S}} dX P_1(X) \log \frac{P_1(X)}{P_2(X)}$$

≥ 0

Zero if and only if P_1 equals P_2



Seehars et al (2014)

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RELATIVE ENTROPY

Invariant under parameter transformations

$$D(P_1 || P_2) = \int_S dX P_1(X) \log \frac{P_1(X)}{P_2(X)} \geq 0$$

Zero if and only if P_1 equals P_2

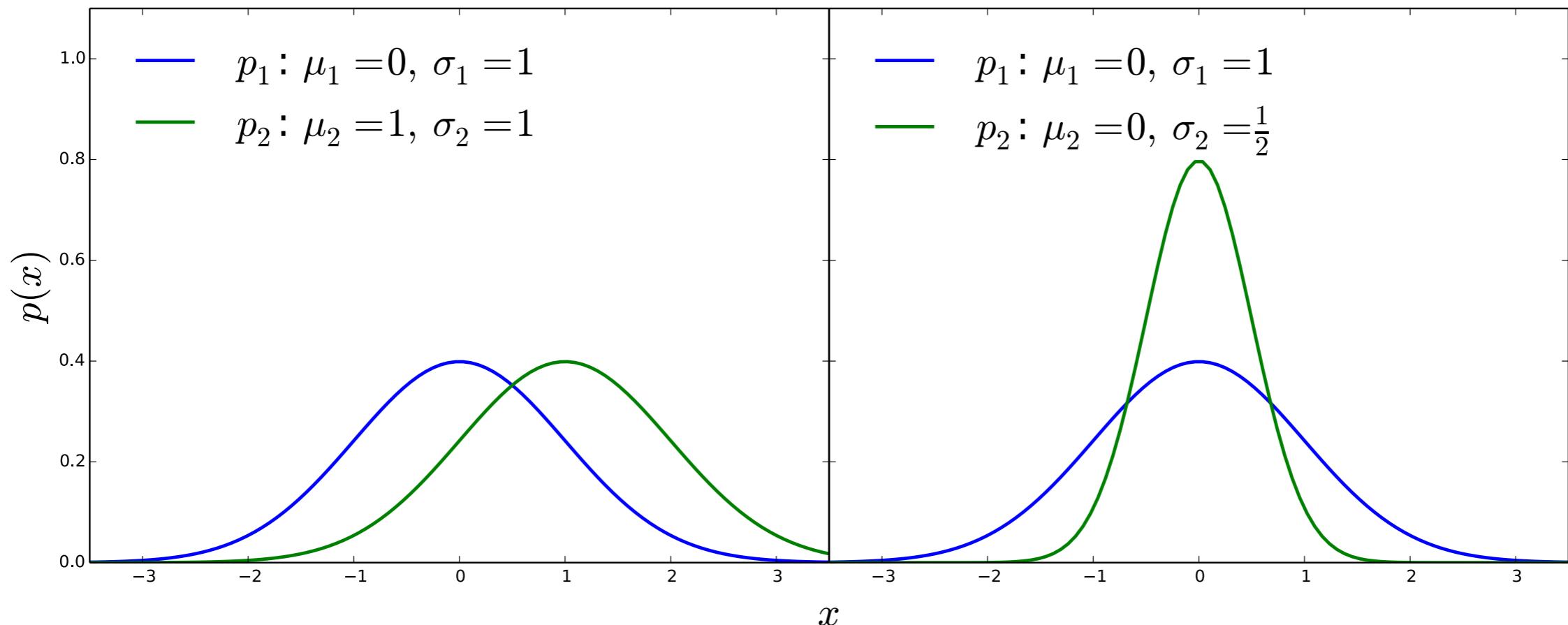


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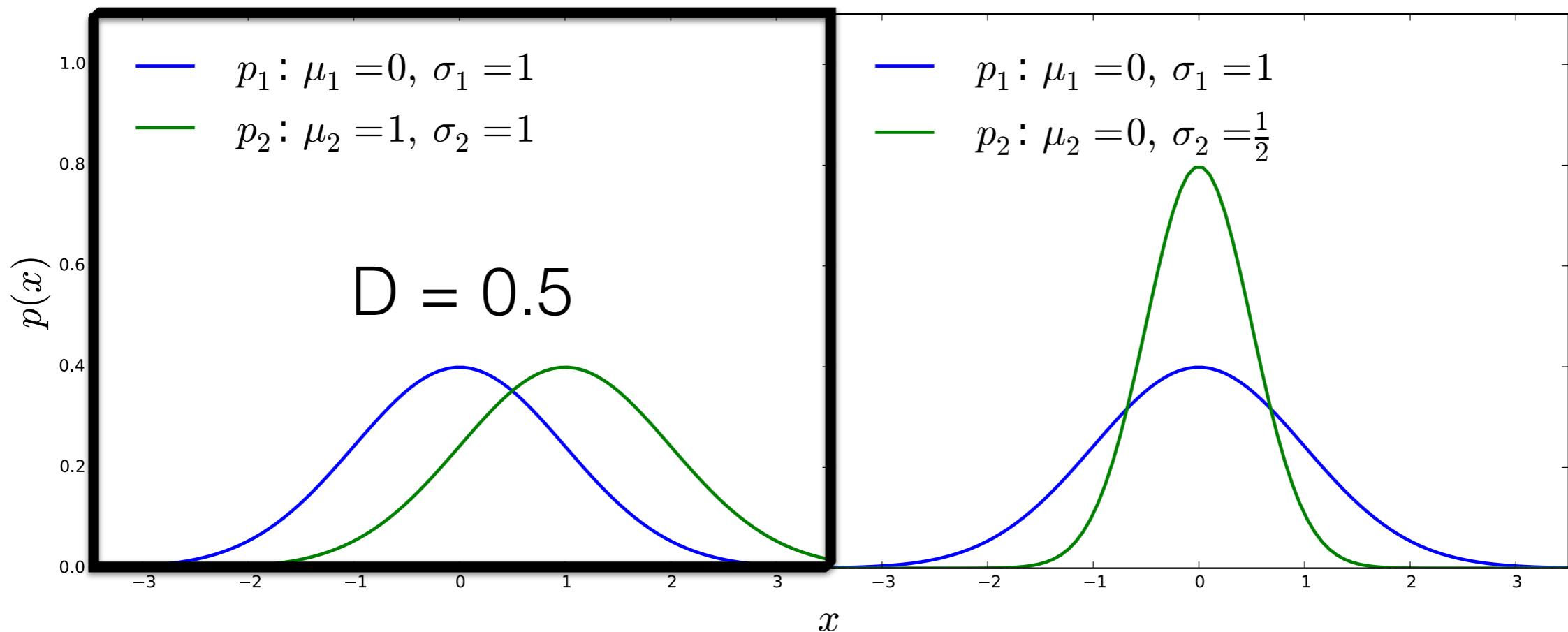
NORMAL DISTRIBUTIONS

$$D(P_2 || P_1) = \frac{1}{2} \left(\left(\frac{\mu_1 - \mu_2}{\sigma_1} \right)^2 + \left(\frac{\sigma_1}{\sigma_2} \right)^2 - \log \left(\frac{\sigma_1}{\sigma_2} \right)^2 - 1 \right)$$



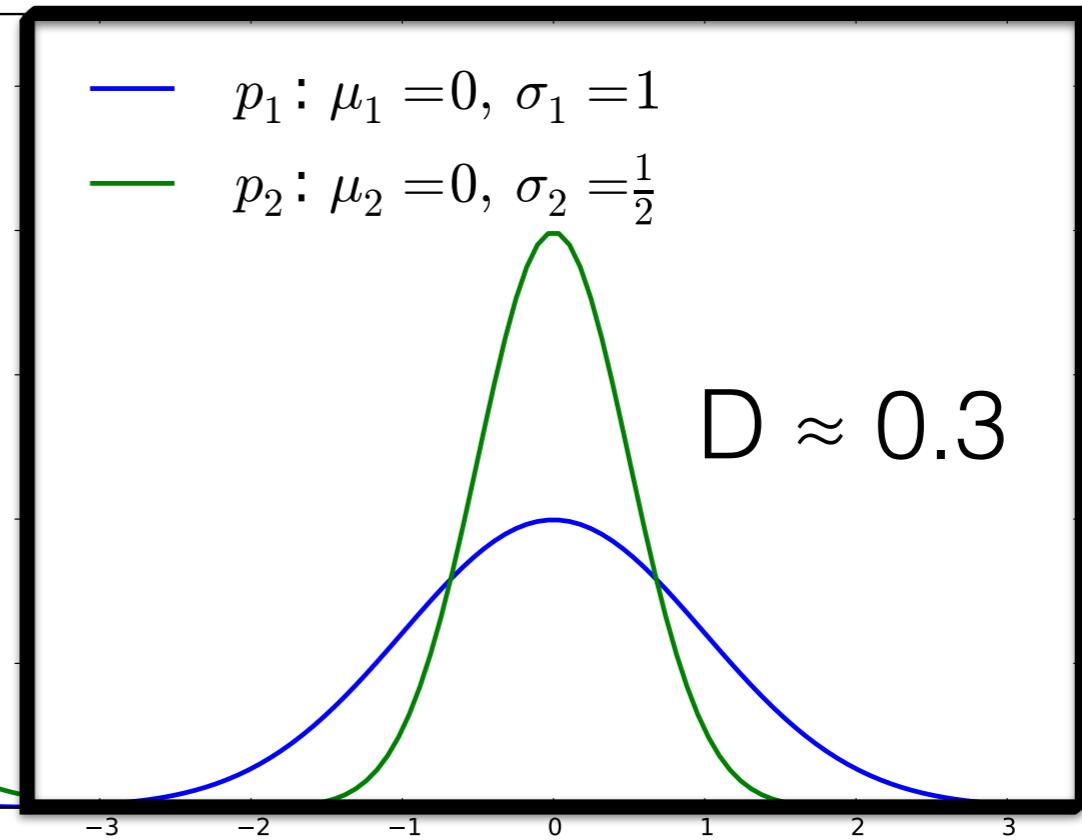
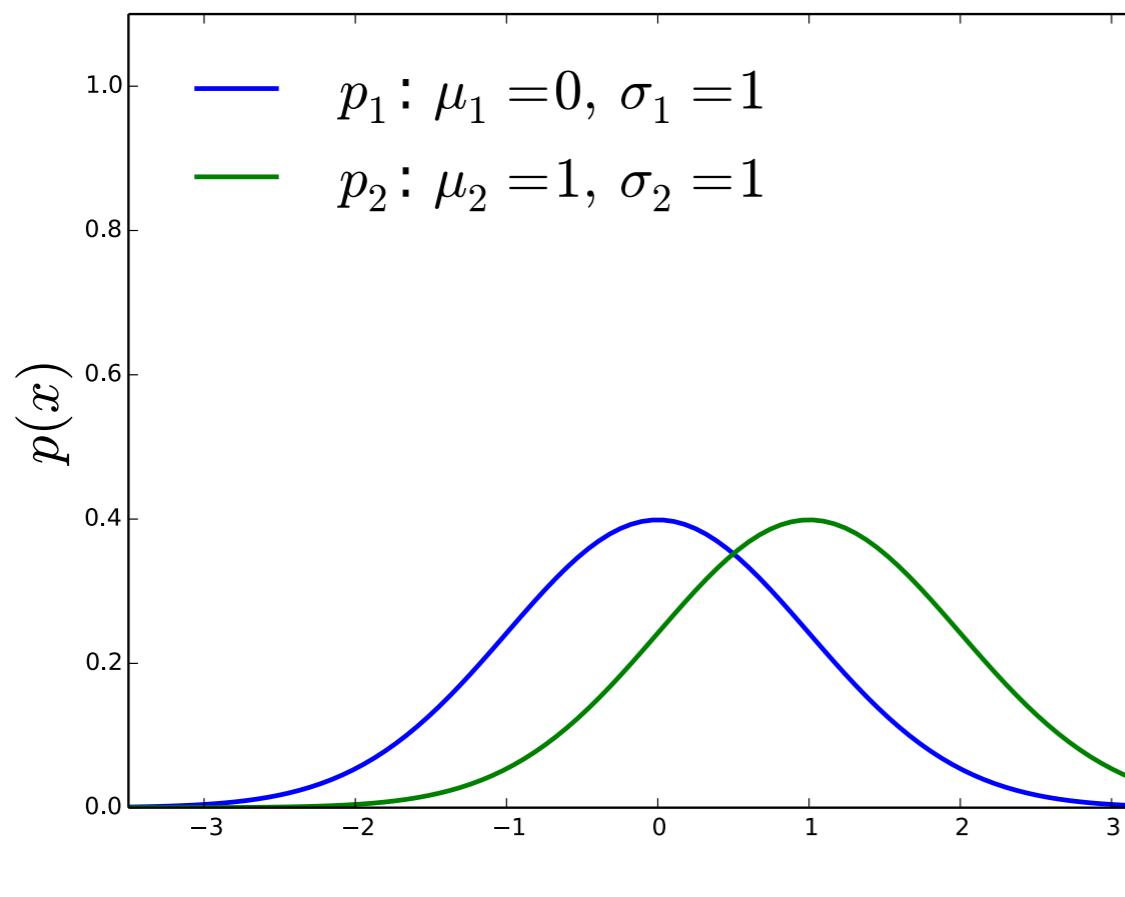
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NORMAL DISTRIBUTIONS & LINEAR MODEL

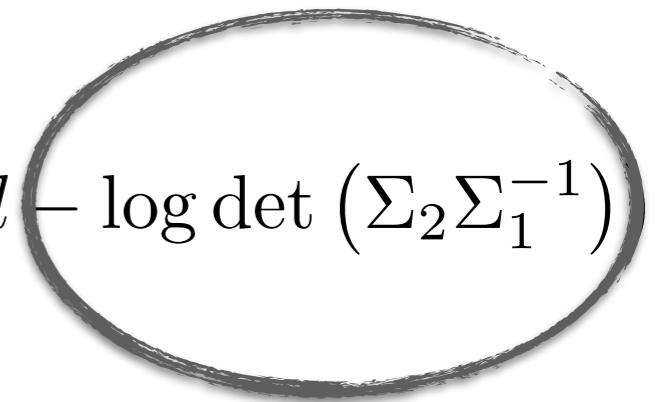
$$D(p_2||p_1) = \frac{1}{2} \left((\mu_1 - \mu_2)^T \Sigma_1^{-1} (\mu_1 - \mu_2) + \text{tr}(\Sigma_2 \Sigma_1^{-1}) - d - \log \det(\Sigma_2 \Sigma_1^{-1}) \right)$$



Seehars et al (2014)

NORMAL DISTRIBUTIONS & LINEAR MODEL

$$D(p_2||p_1) = \frac{1}{2} ((\mu_1 - \mu_2)^T \Sigma_1^{-1} (\mu_1 - \mu_2) + \text{tr}(\Sigma_2 \Sigma_1^{-1}) - d - \log \det(\Sigma_2 \Sigma_1^{-1}))$$



$\langle D \rangle \leftrightarrow$ Expected relative entropy



Seehars et al (2014)

NORMAL DISTRIBUTIONS & LINEAR MODEL

Surprise



$$S = D(p_2 || p_1) - \langle D \rangle$$

$$D(p_2 || p_1) = \frac{1}{2} \left((\mu_1 - \mu_2)^T \Sigma_1^{-1} (\mu_1 - \mu_2) + \text{tr}(\Sigma_2 \Sigma_1^{-1}) - d - \log \det(\Sigma_2 \Sigma_1^{-1}) \right)$$

$$\langle D \rangle$$



Expected relative entropy



Seehars et al (2014)

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Hinshaw+
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BOOMERANG	→	WMAP 9	22.5	18.4	4.1	1.6	0.07
WMAP 9	→	WMAP 9 + SPT	4.3	2.1	2.2	2.1	0.04
WMAP 9	→	Planck + WP	29.8	7.9	21.9	6.5	0.0002

BOOMERANG: MacTavish et al. (2003)

WMAP 3, 5, 7, 9: Spergel et al. (2007), Dunkley et al. (2009),
 Larson et al. (2011), and Bennett et al. (2013)

WP: WMAP 9 polarisation data

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Seehars et al (2014)

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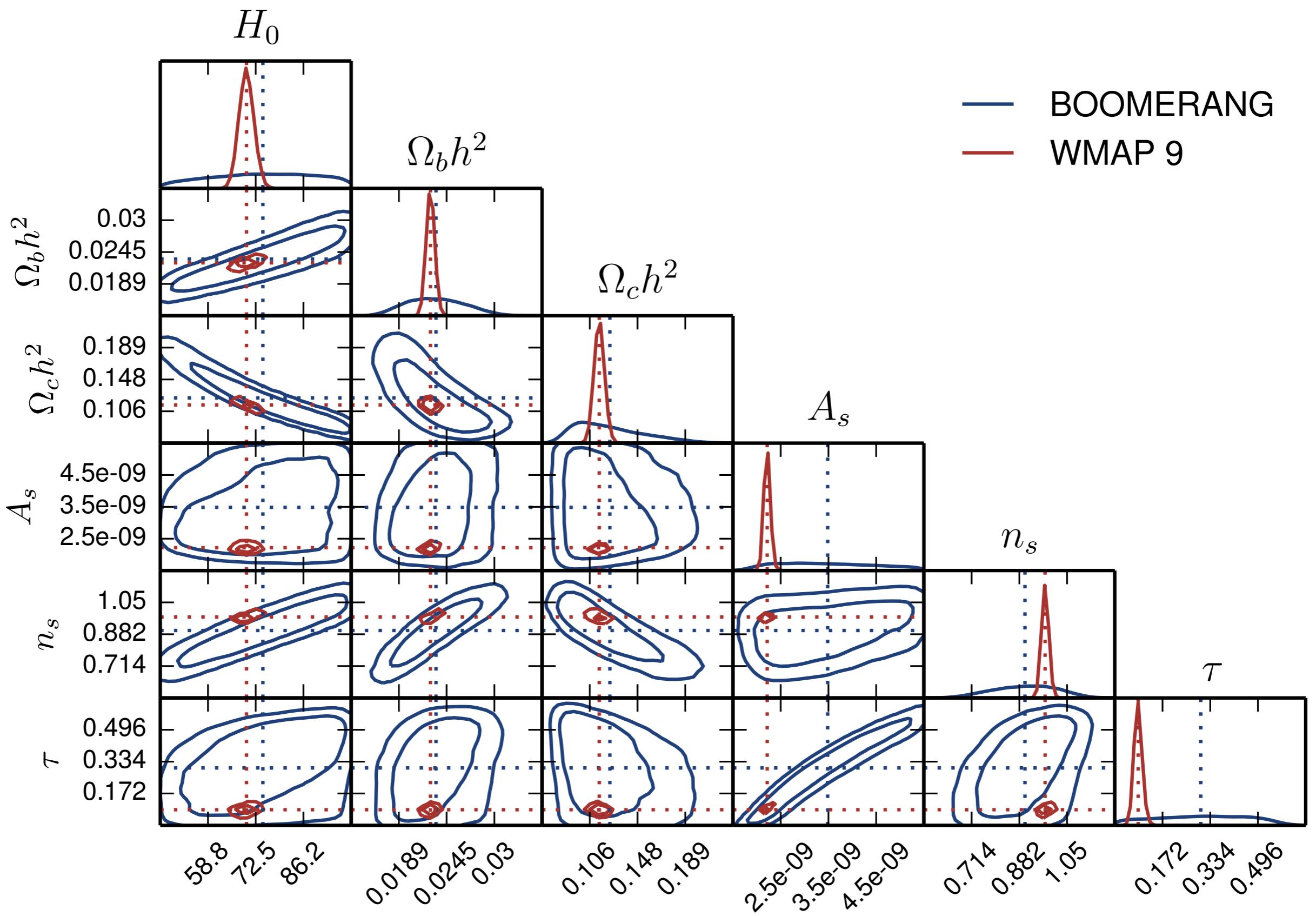
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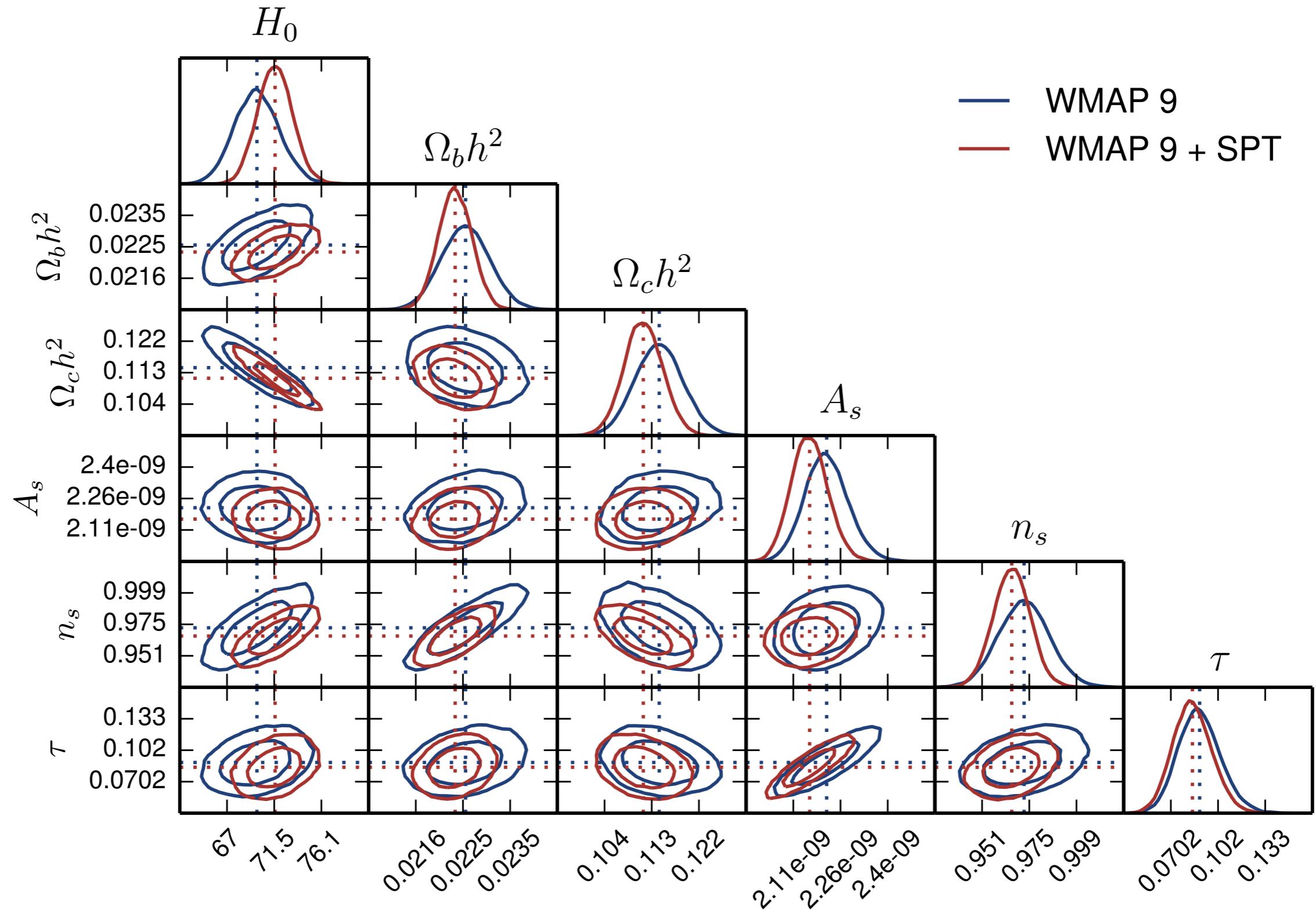
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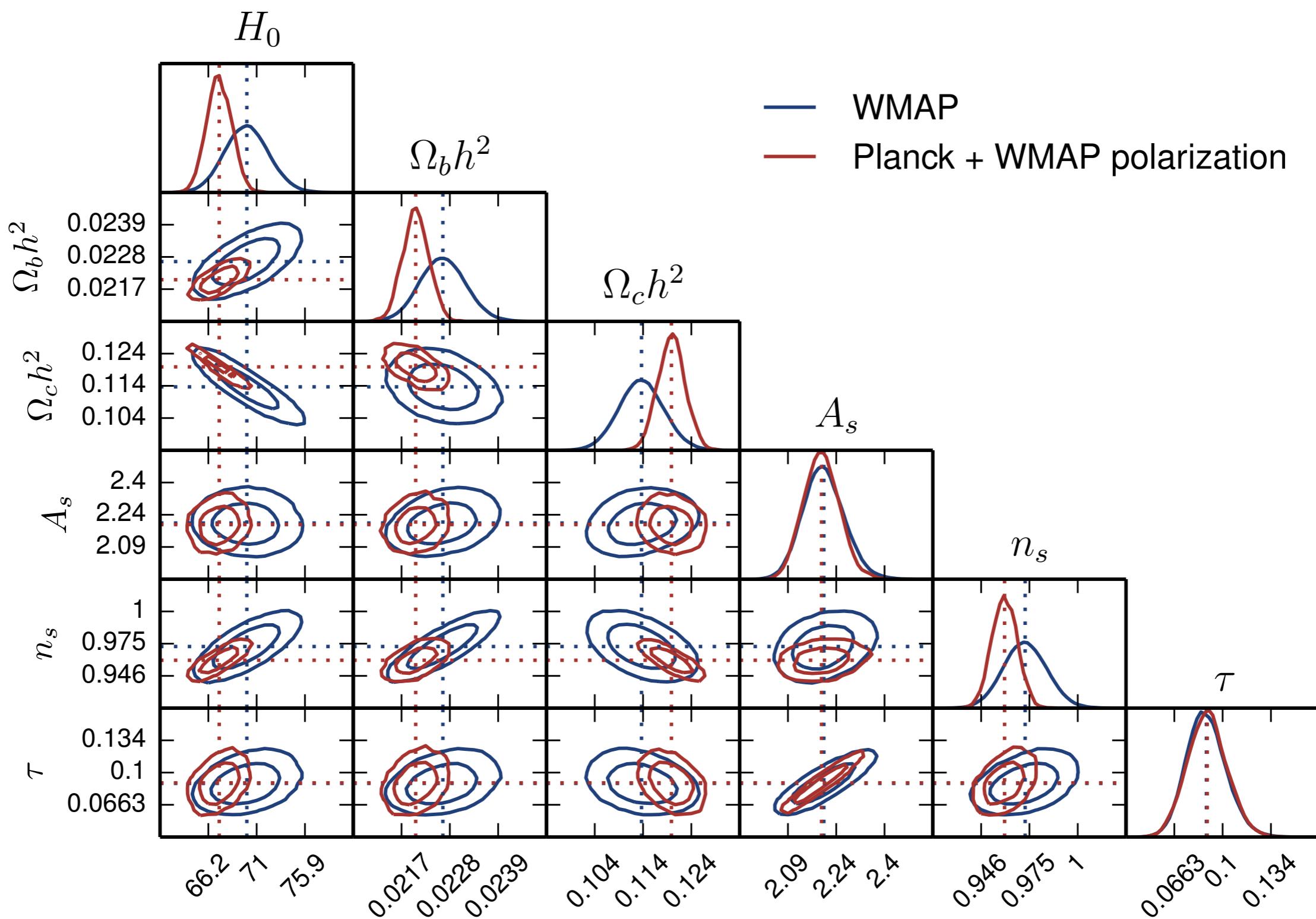
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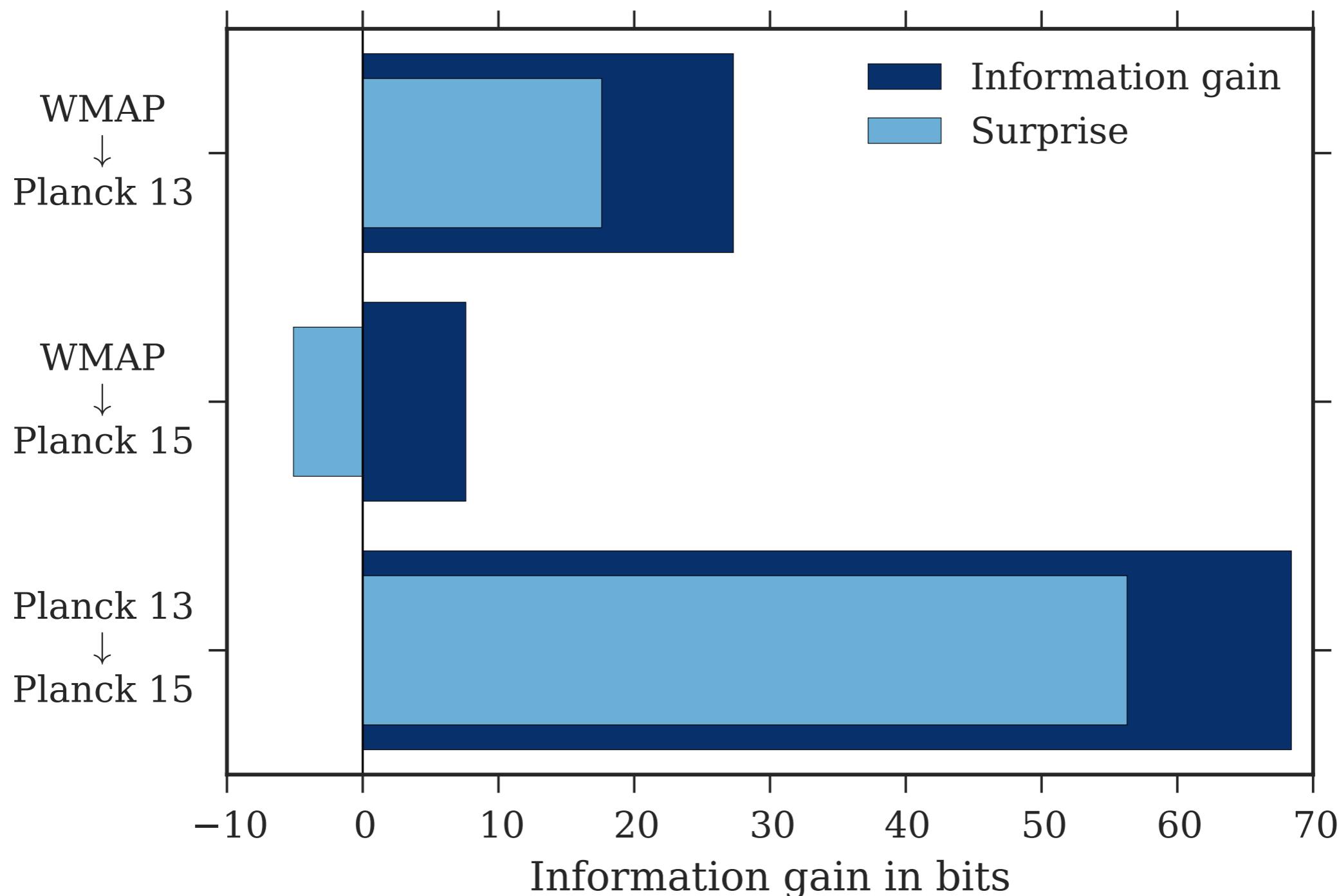
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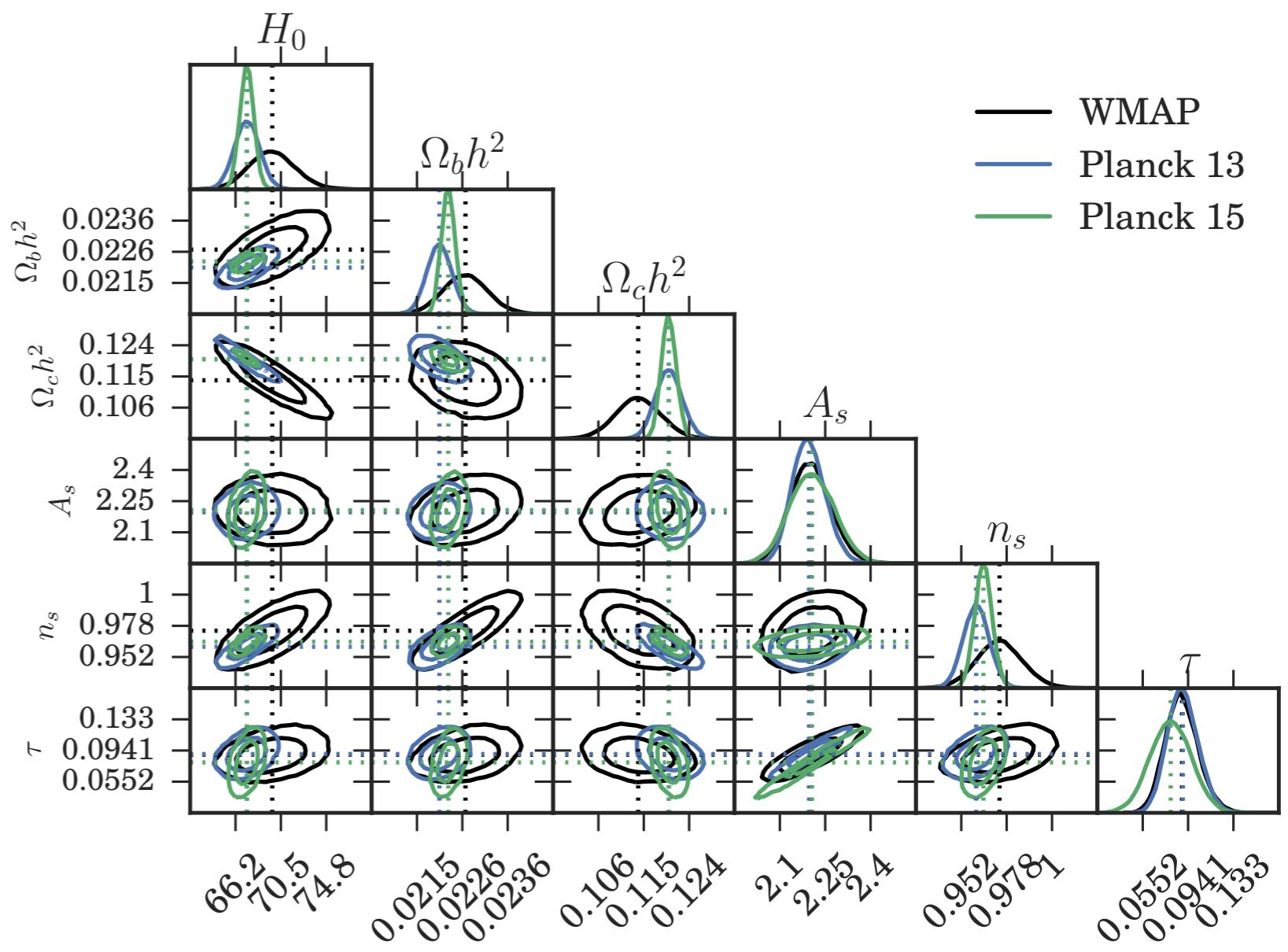
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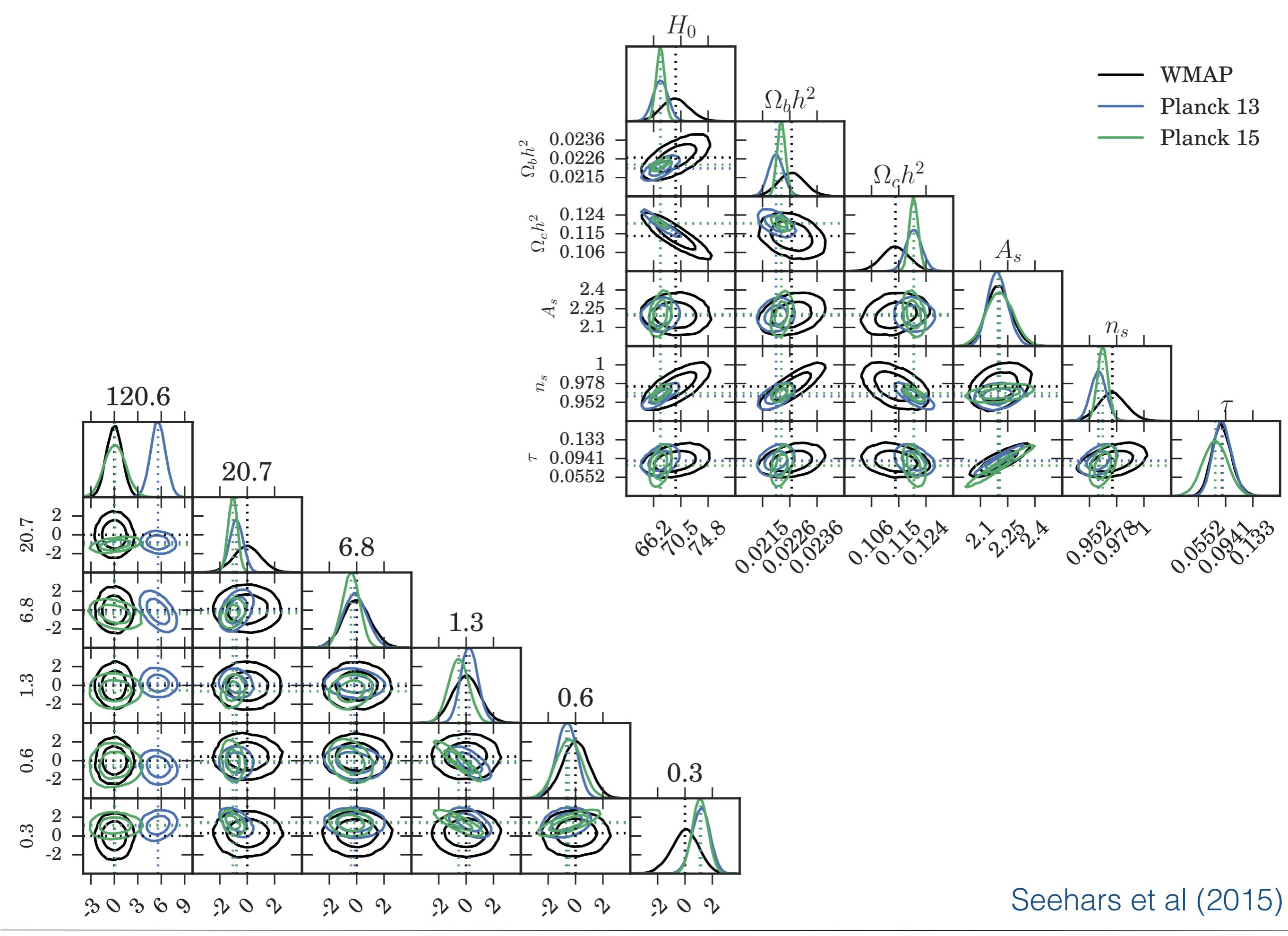
Seehars et al (2014)



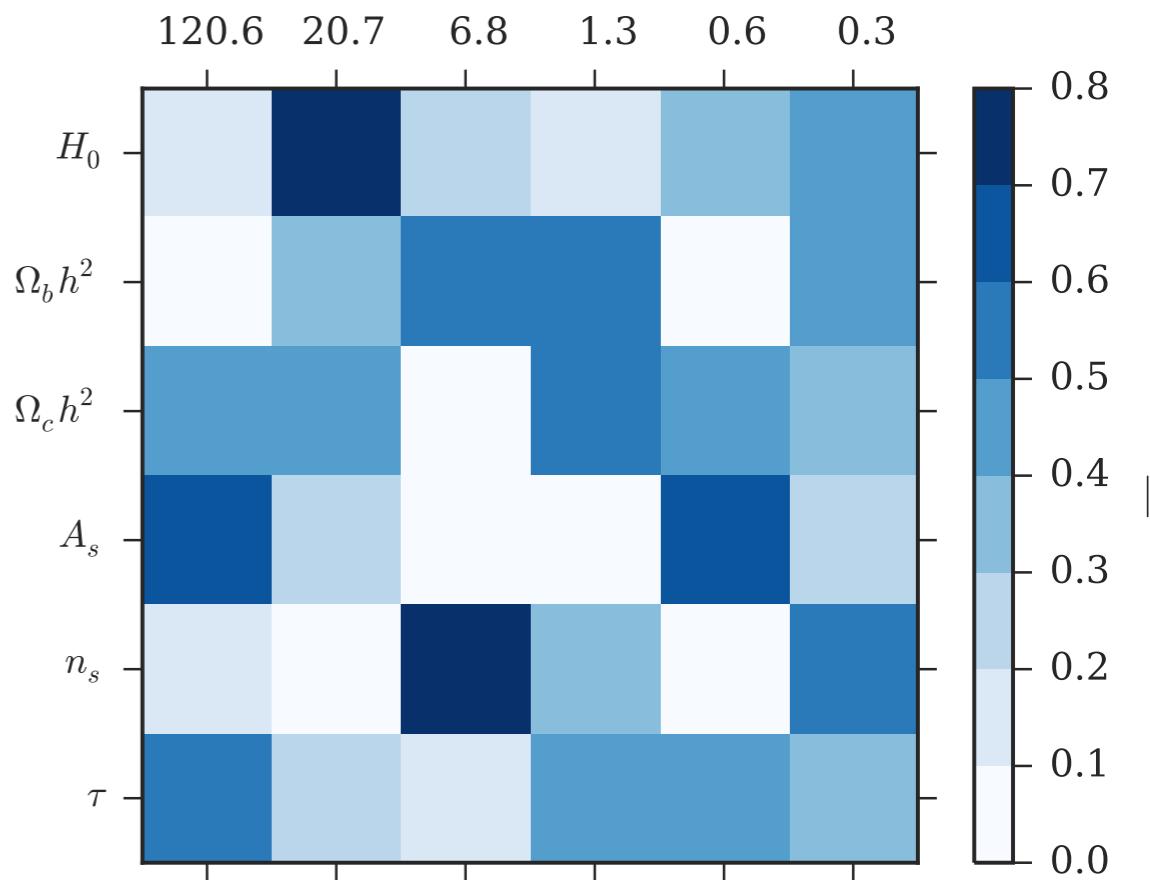
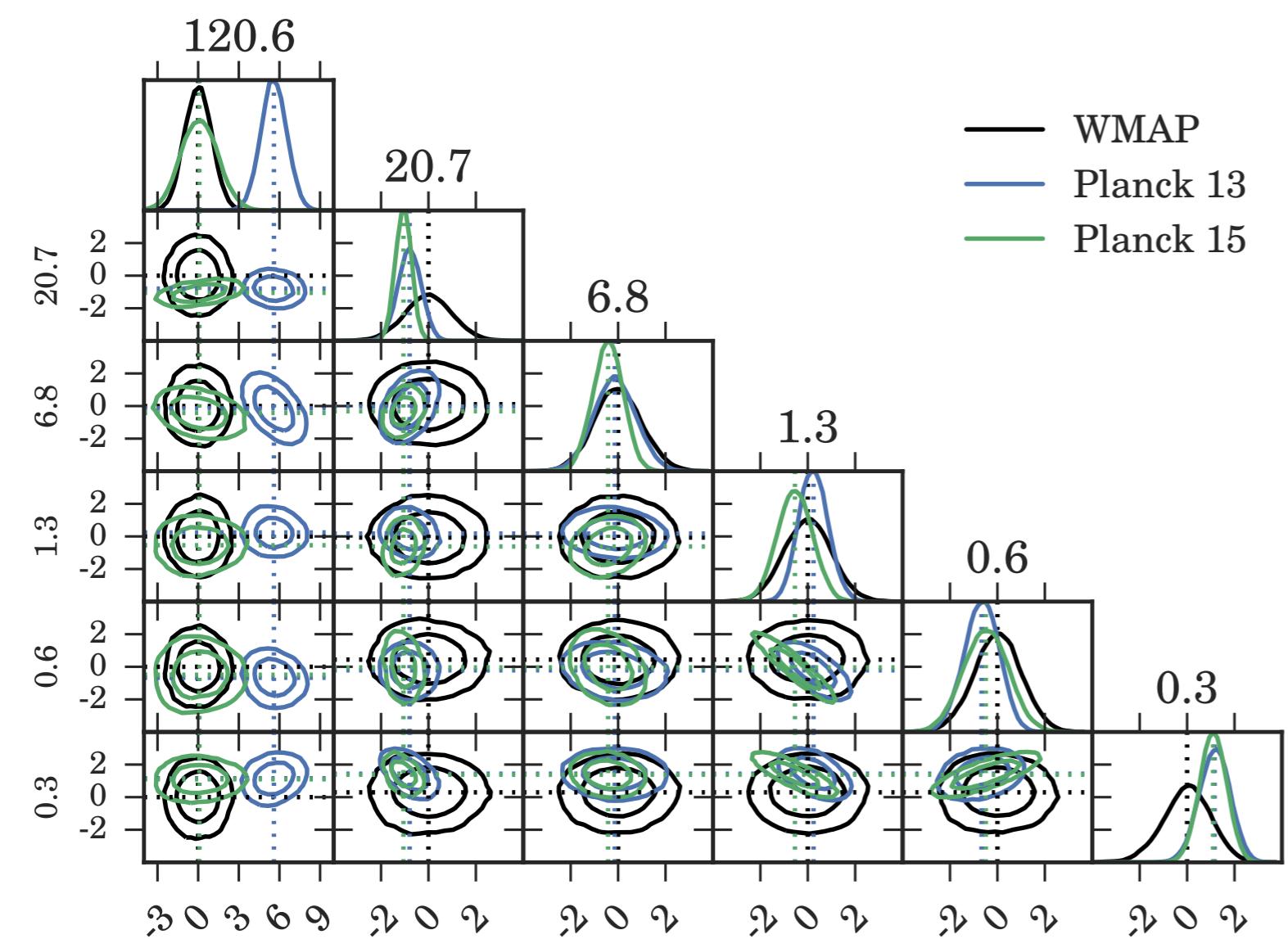
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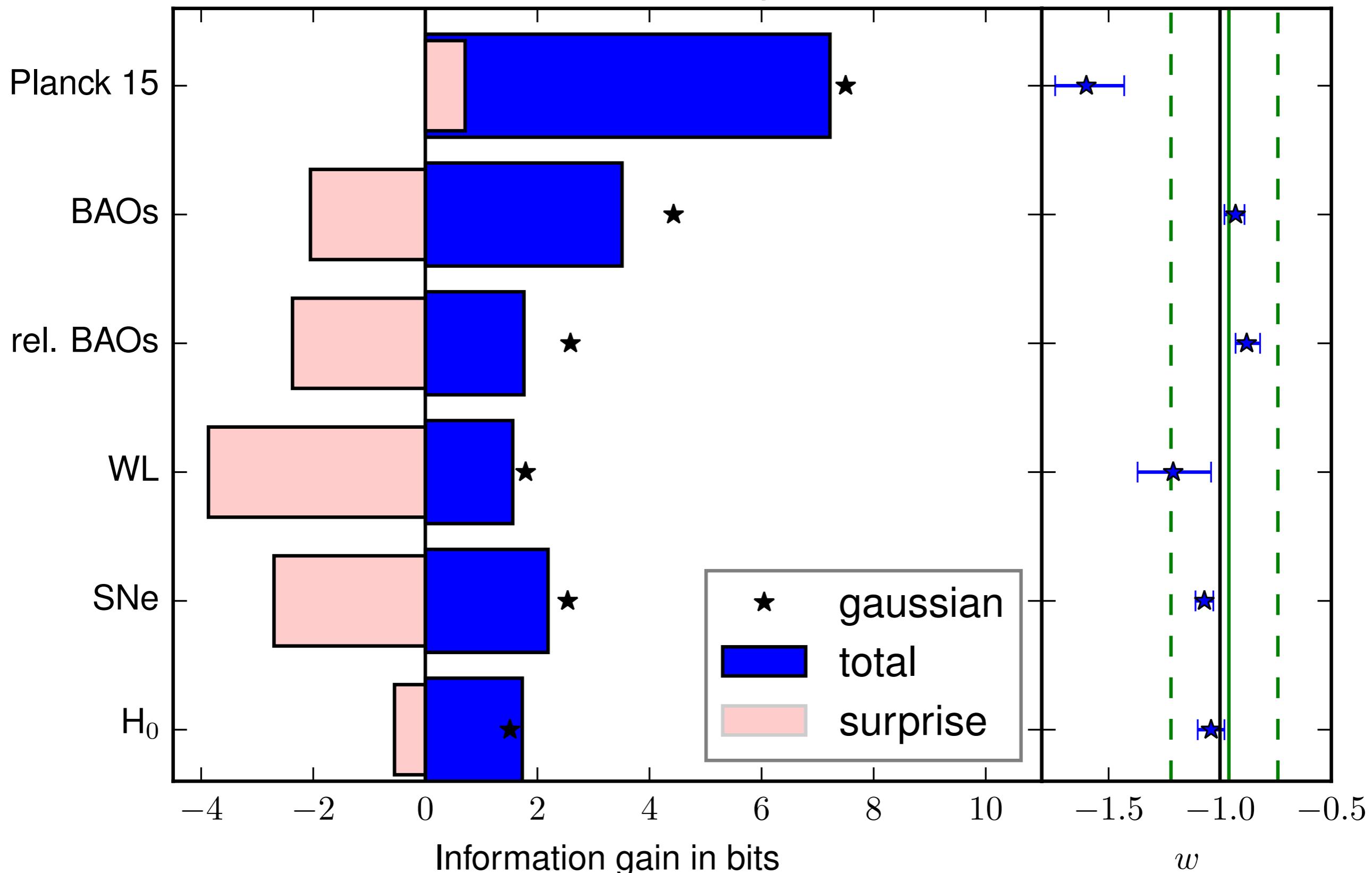


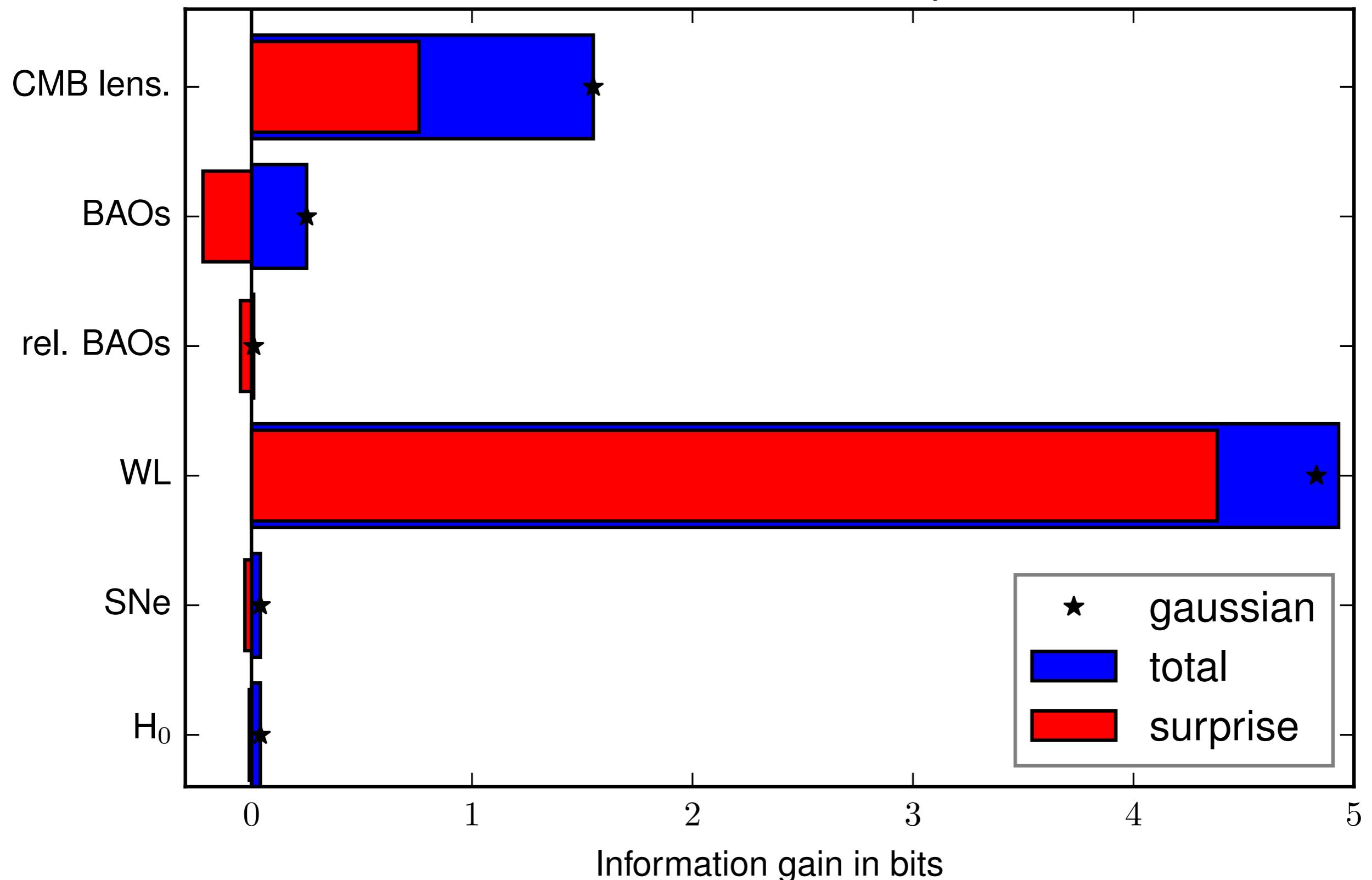
Seehars et al (2015)



Seehars et al (2015)

What about the other probes?

flat w CDM, WMAP 9 prior

flat Λ CDM, Planck 15 prior

Where to next?

The Dark Energy Survey



Dark Energy Survey Collaboration

Fermilab, UIUC/NCSA, University of Chicago,
LBNL, NOAO, University of Michigan, University of
Pennsylvania, Argonne National Lab, Ohio State
University, Santa-Cruz/SLAC/Stanford, Texas A&M





Overview

Blanco telescope at CTIO

- 4m primary focus
- built new dedicated camera - 570 megapixel
- 2.2 deg² field of view
- thick CCDs for near infrared light

Two multiband surveys:

- 5000 deg sq. *grizY* to mag 24
- 30 deg² deep survey, 6 days cadence

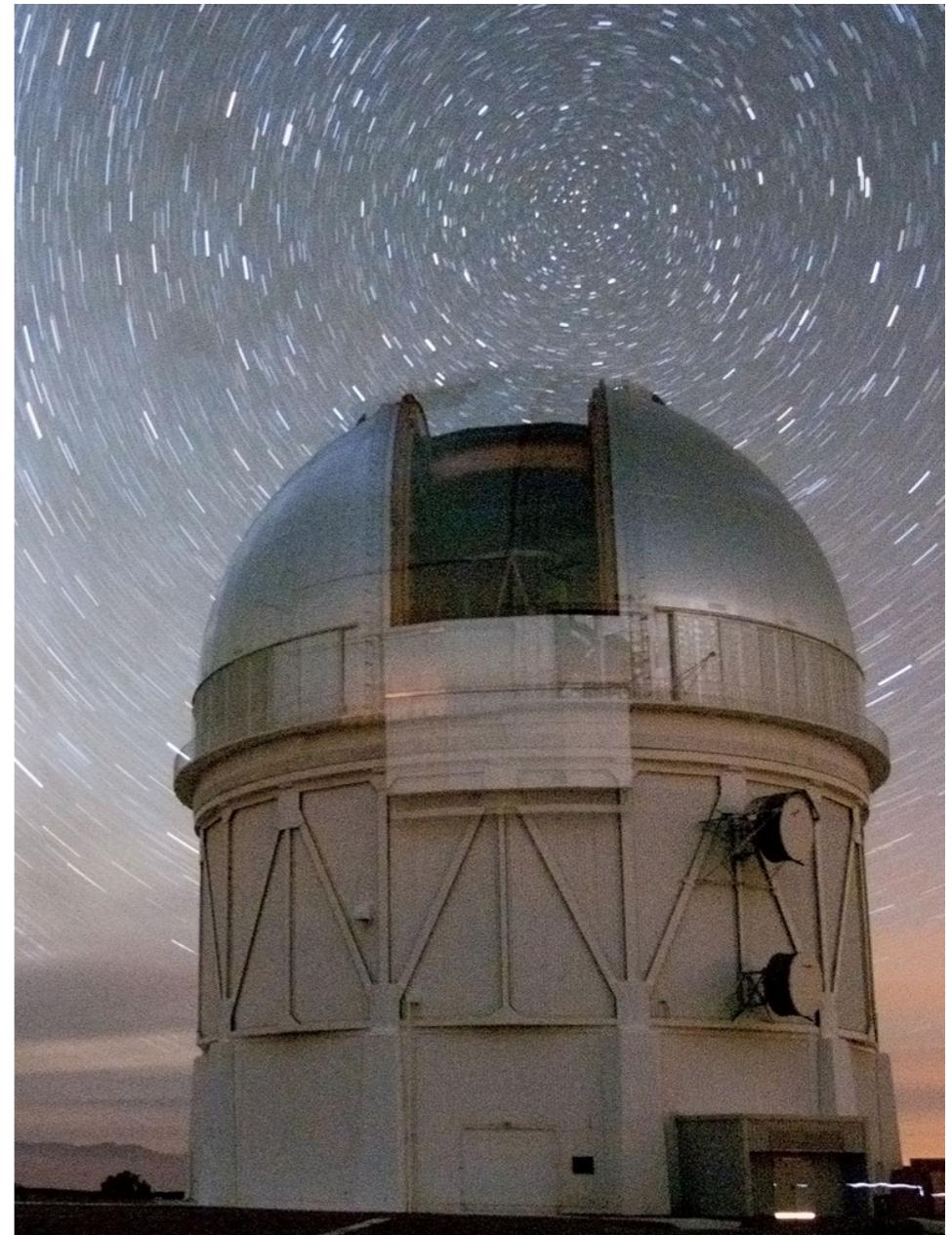
Survey using four complementary techniques:

1. Cluster counts
2. Weak gravitational lensing
3. Large-scale structure
4. Supernovae

International collaboration:

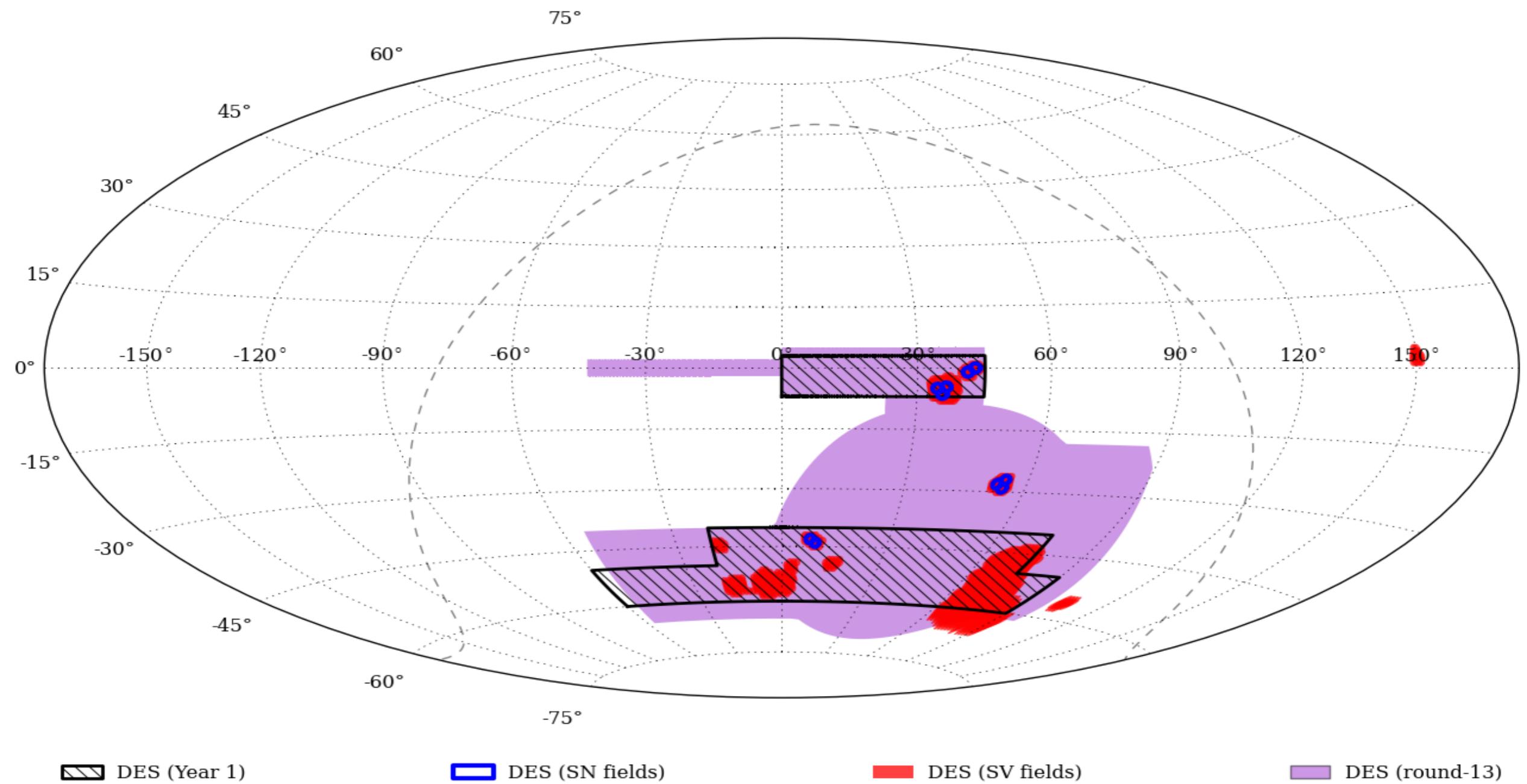
300 members, 26 institutions, 7 countries

Survey: 2013-2018, 525 nights



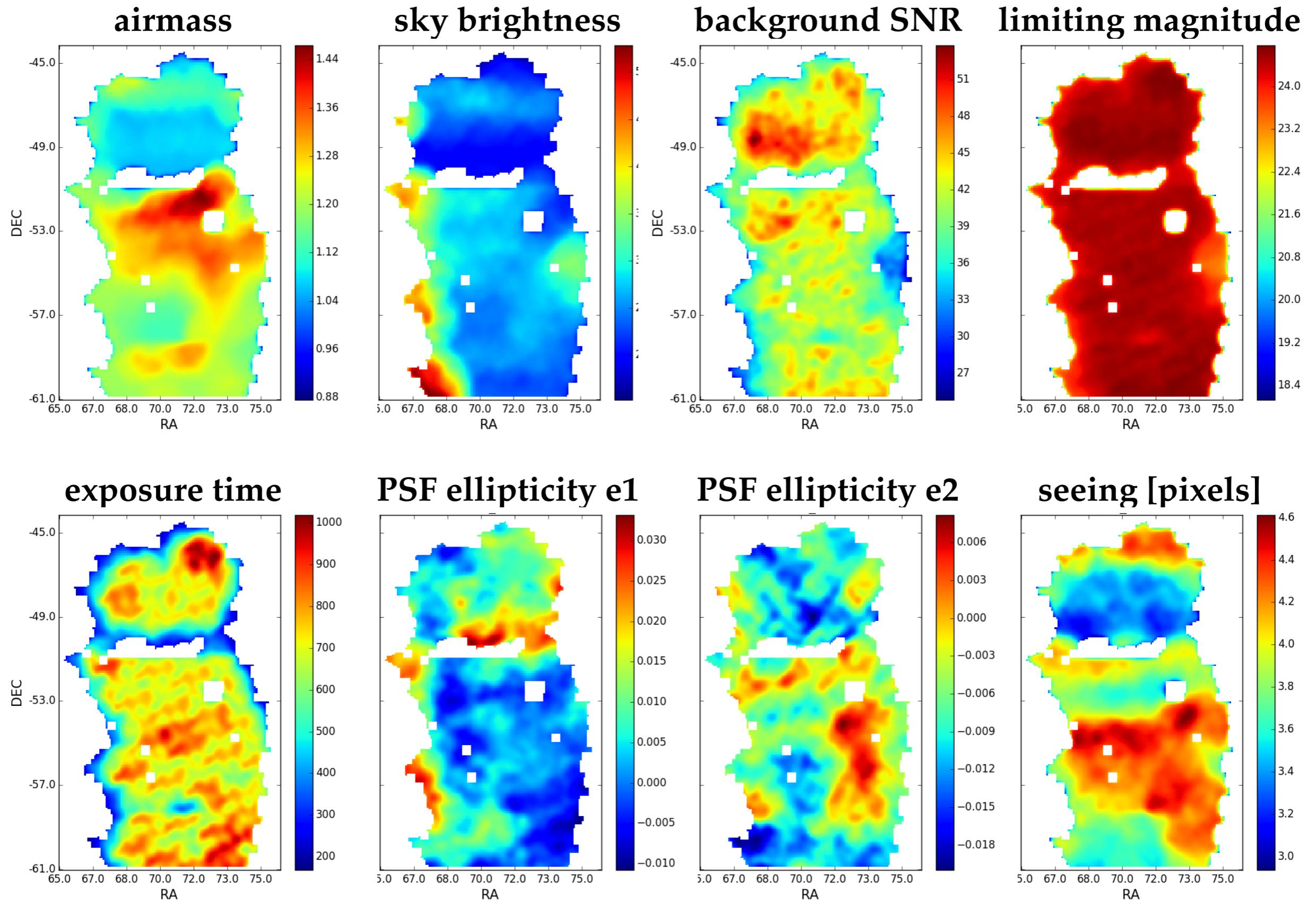


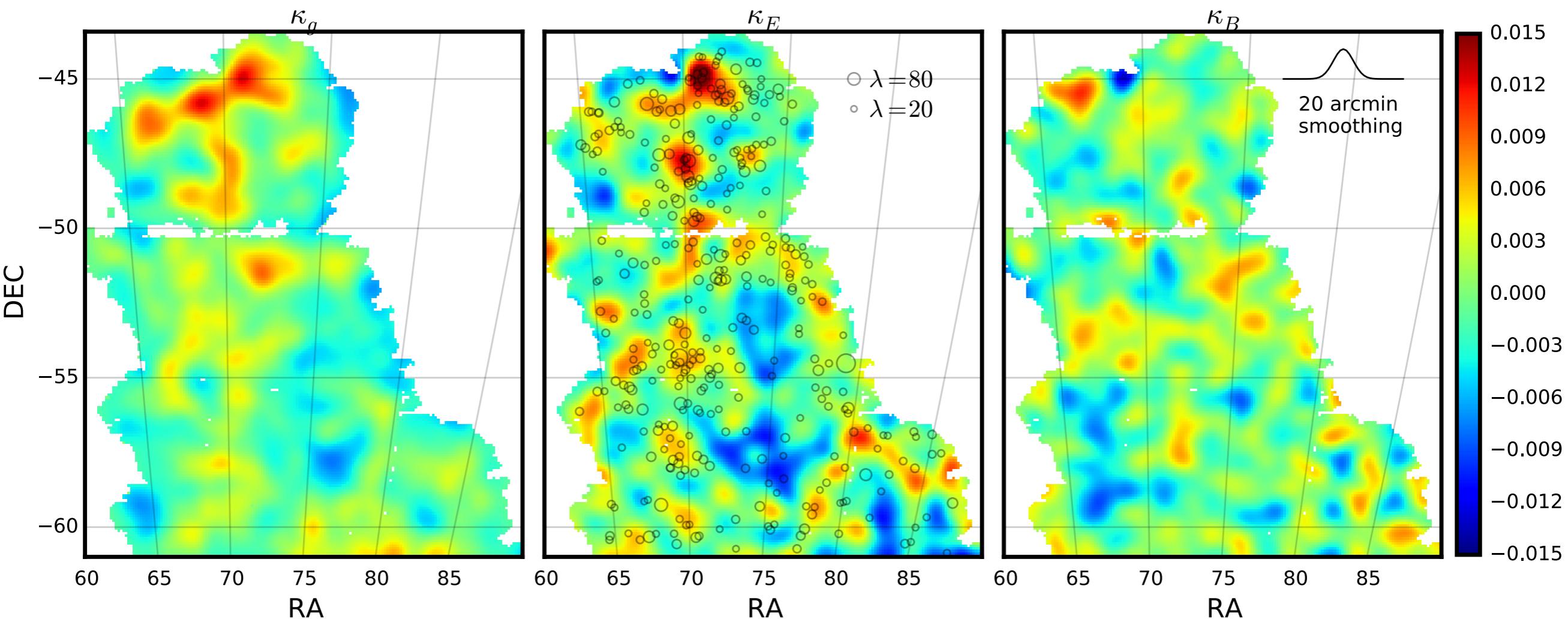
Footprint



year 0 (science validation) - 180 deg², 10 tilings (full depth)
year 1 - 2500 deg², 4 tilings, overlapping STP, VHS, BOSS
5 years - 5000 deg²

Tracking Systematics Maps





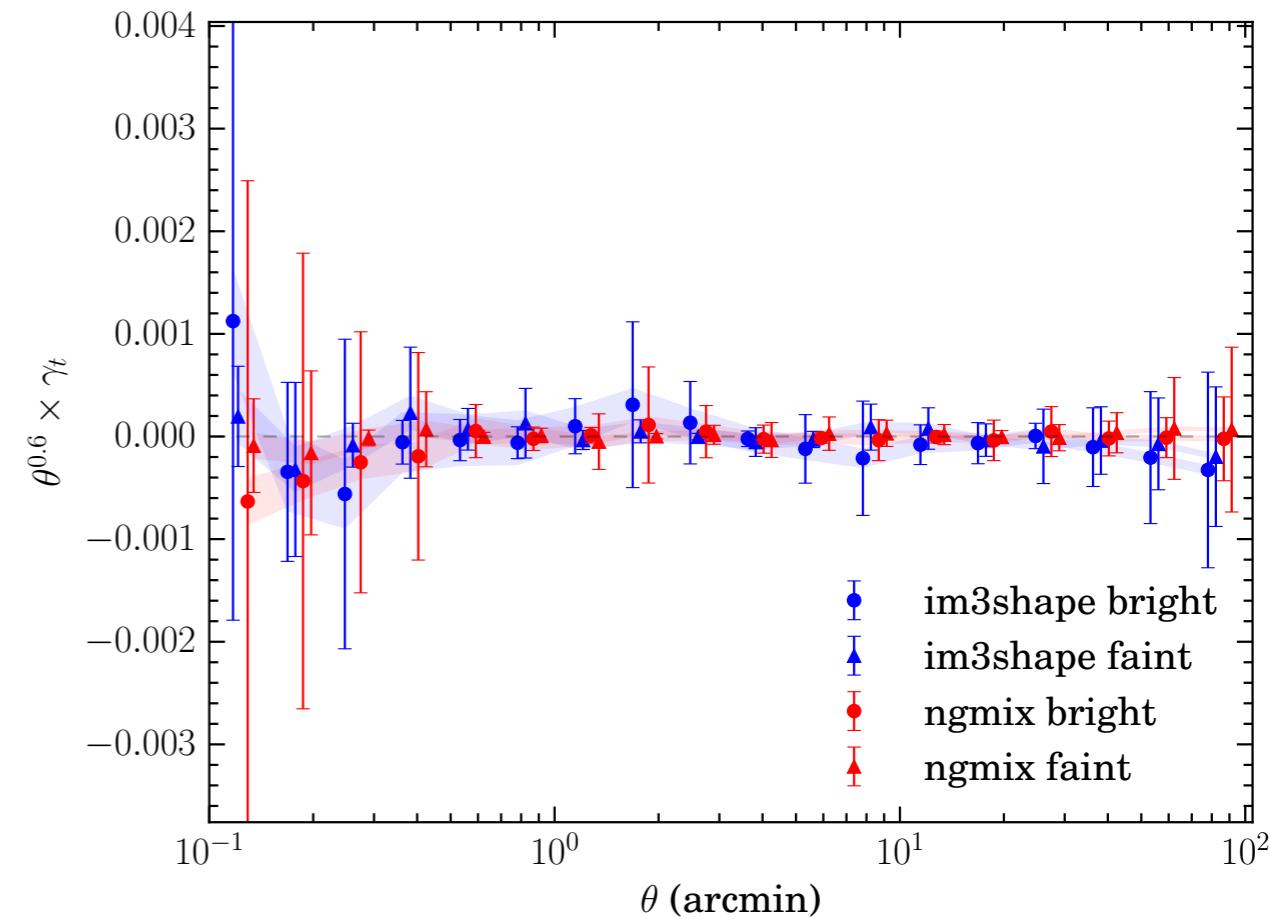
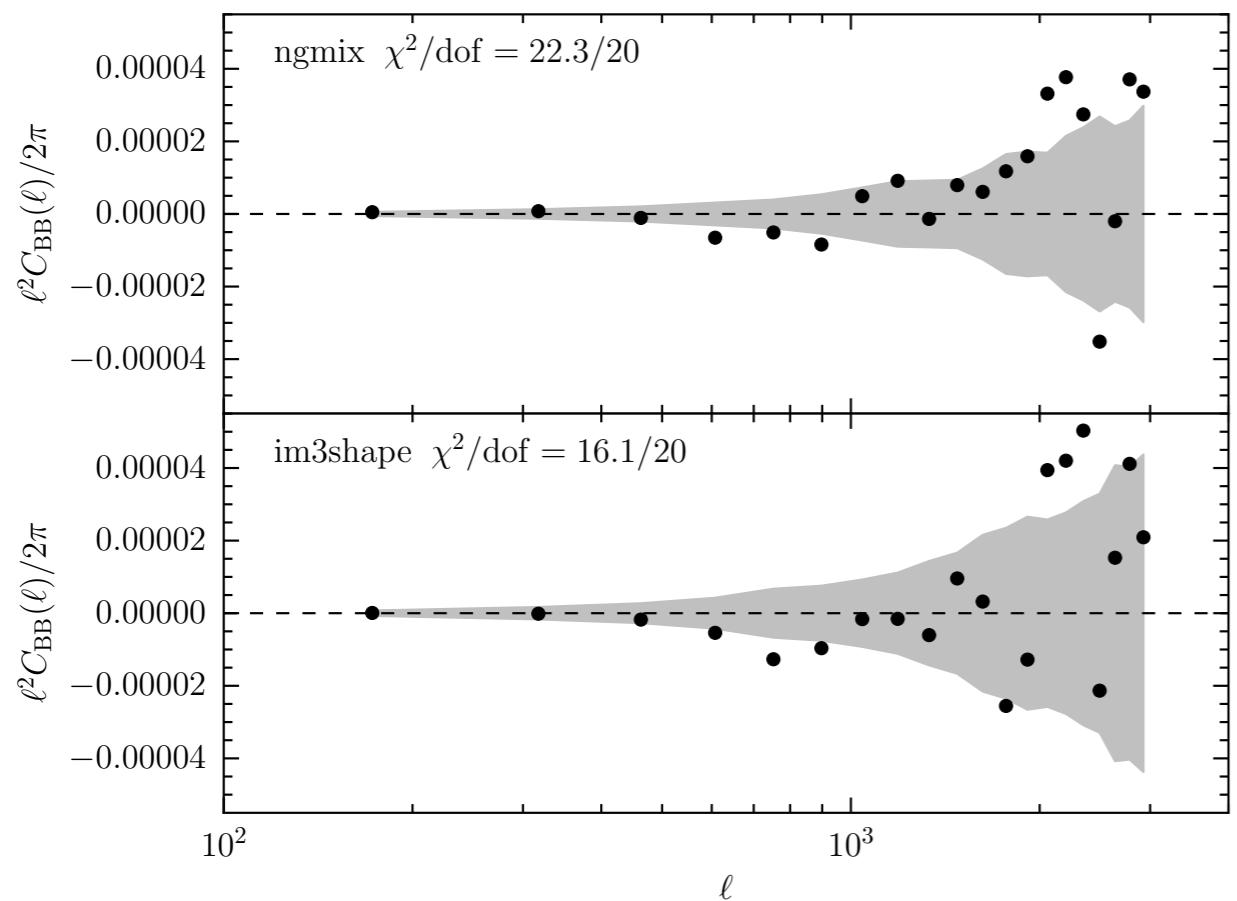
Chang et al PRL (2015)
Vikram et al PRD (2015)

Science Verification Results

Cosmology	DES Collaboration (arXiv:1507.05603)
Shear Catalogs	Jarvis et al (arXiv:1507.05603)
Photometric redshift	Bonnett et al (arXiv:1507.05909)
Systematics maps	Leistedt et al (arXiv:1507.05647)
Shear Power Spectra	Becker et al (arXiv:1507.05598)

Cosmic Shear

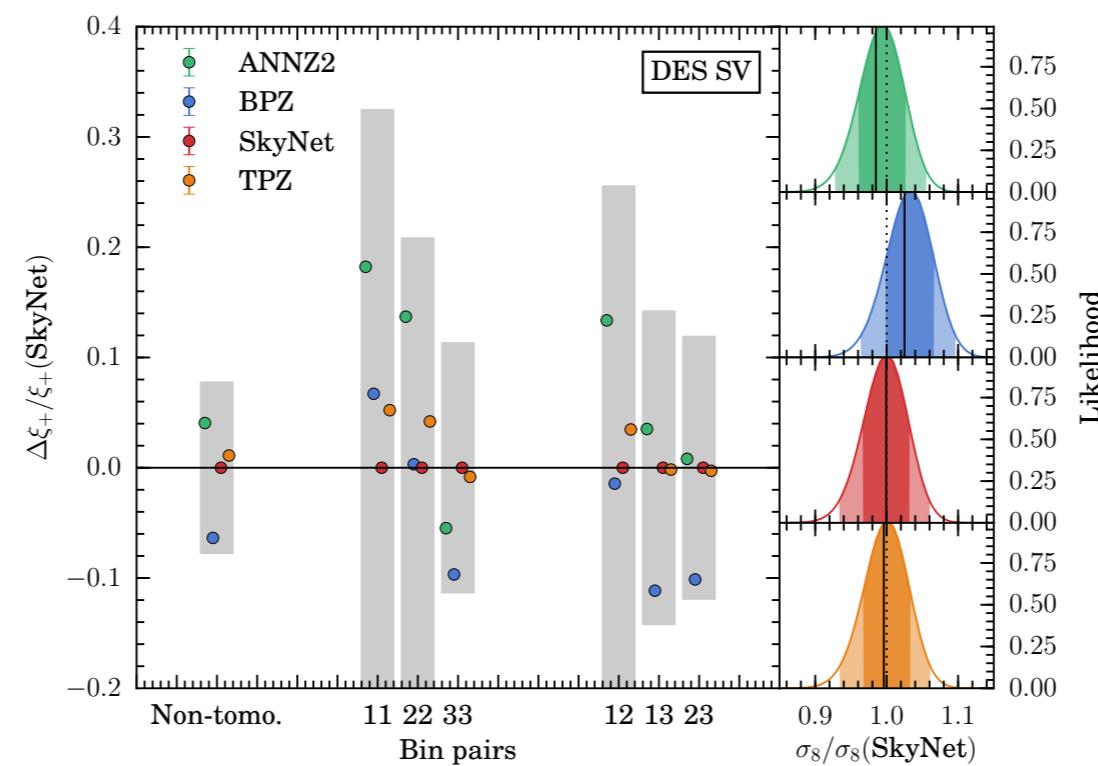
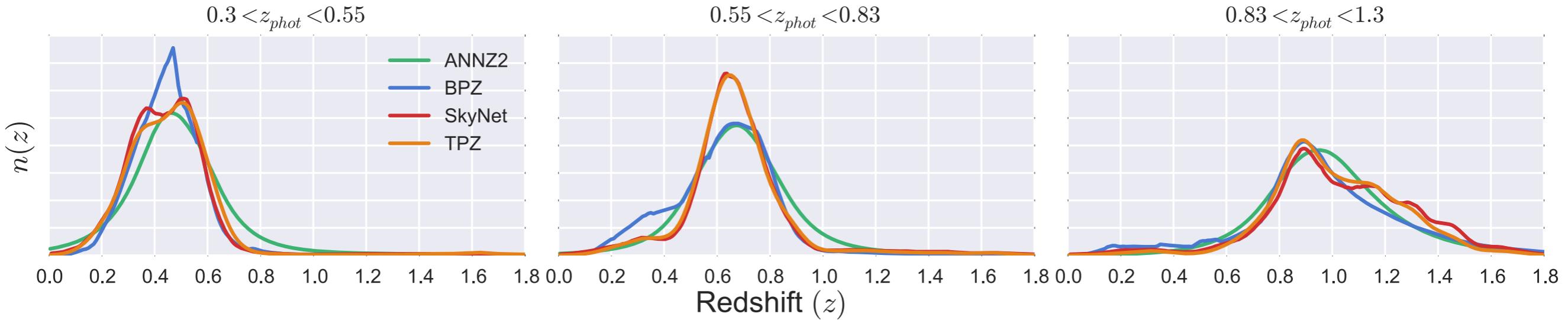
Jarvis et al (arXiv:1507.05603)



Agreement between Im3shape and NGMix better than 5%

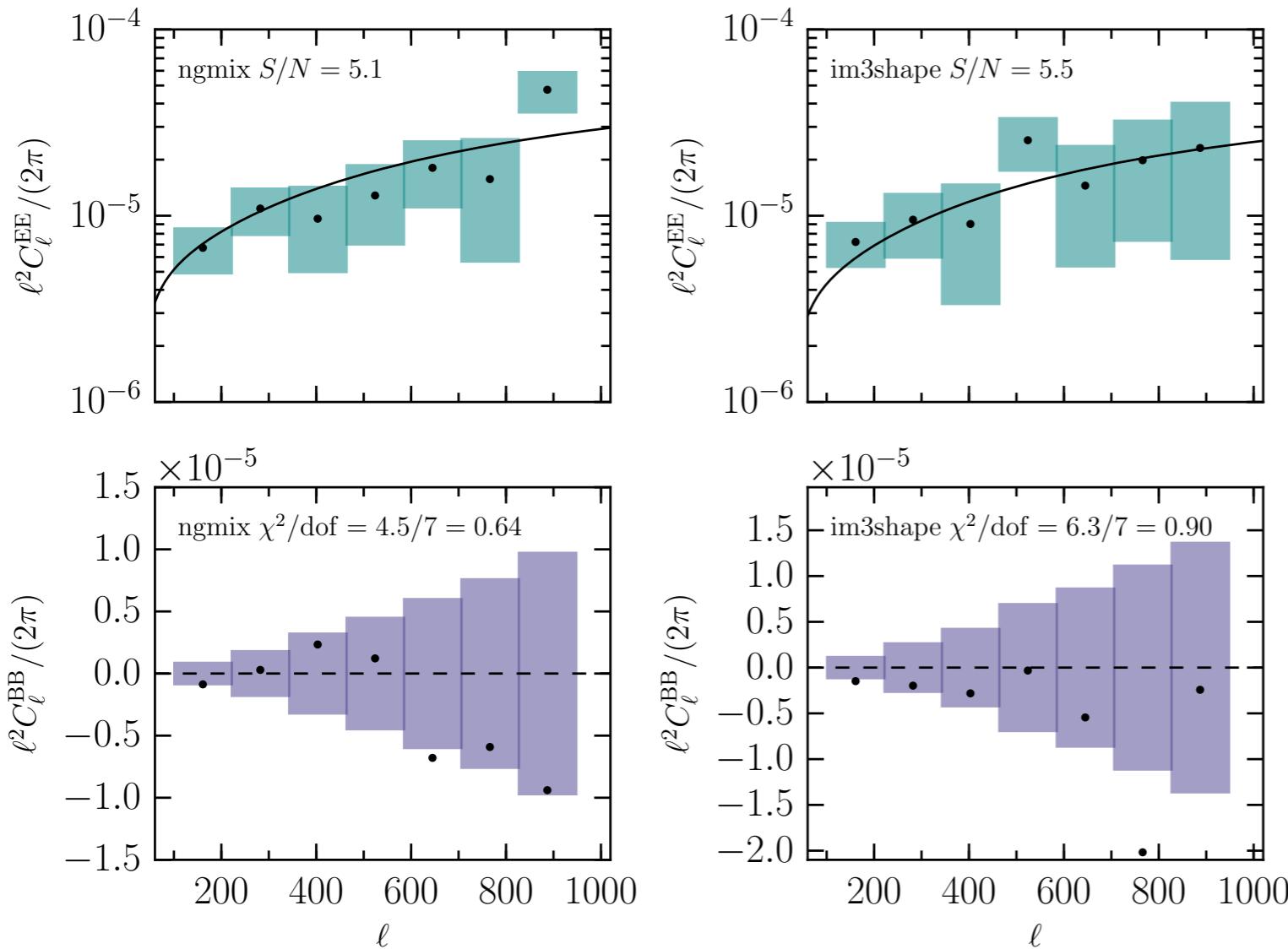
Redshift

Tomographic bins, NGMIX sample

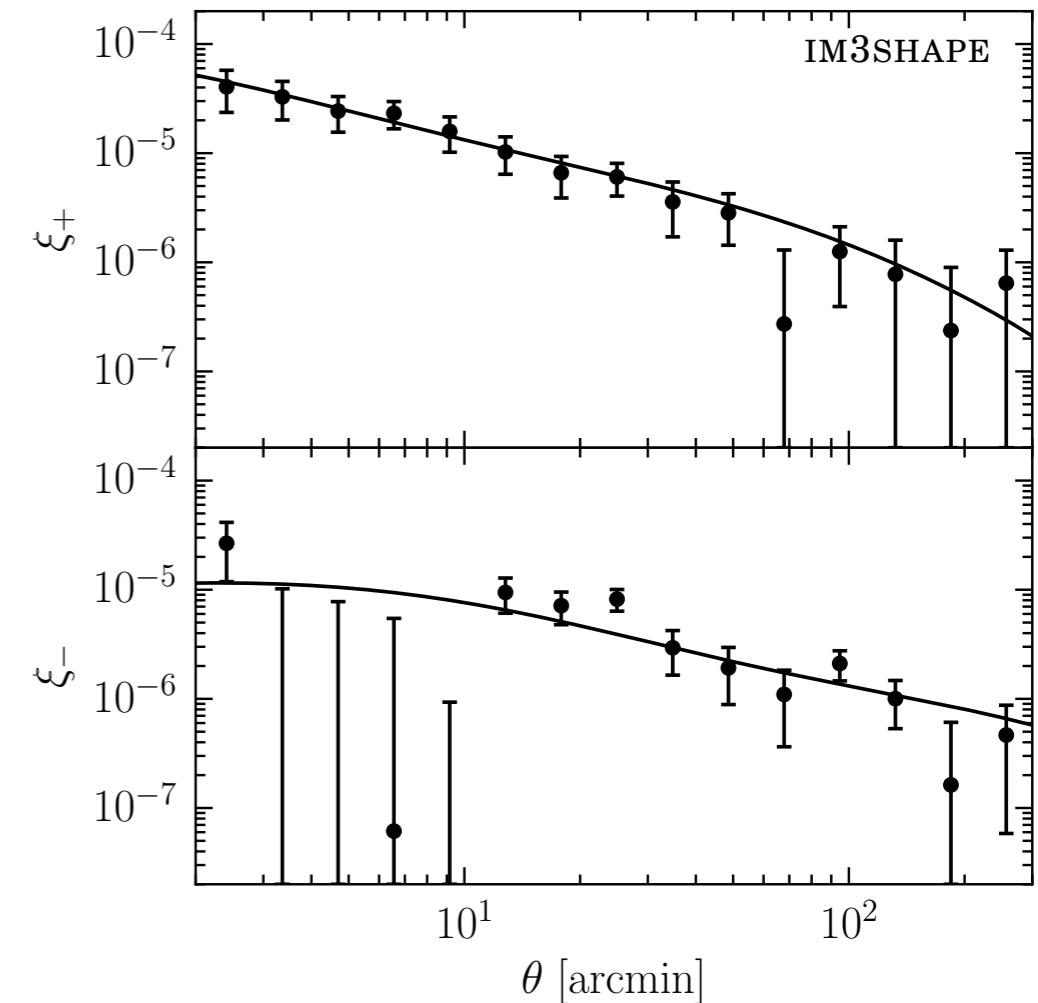
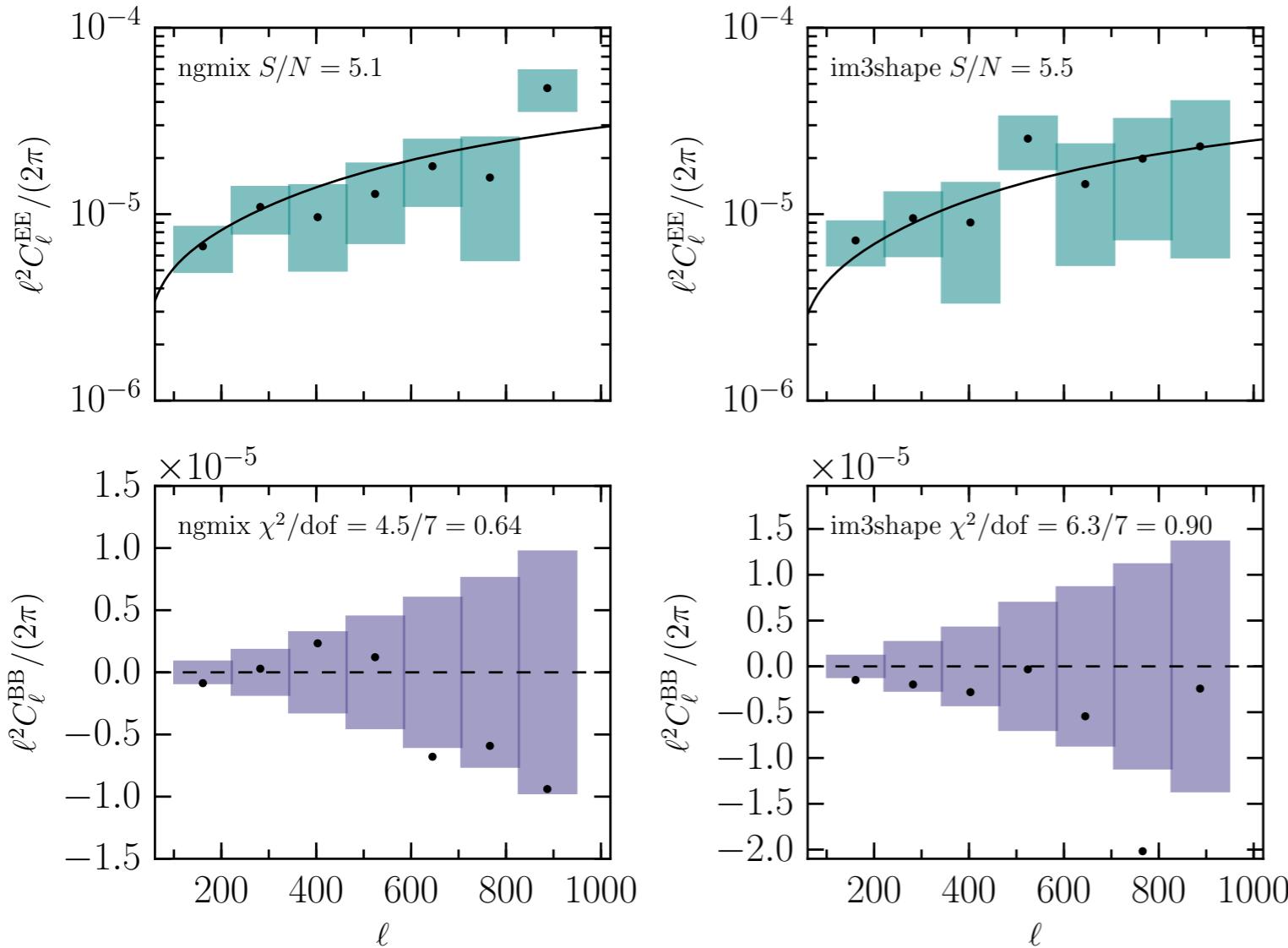


Bonnett et al (arXiv:1507.05909)

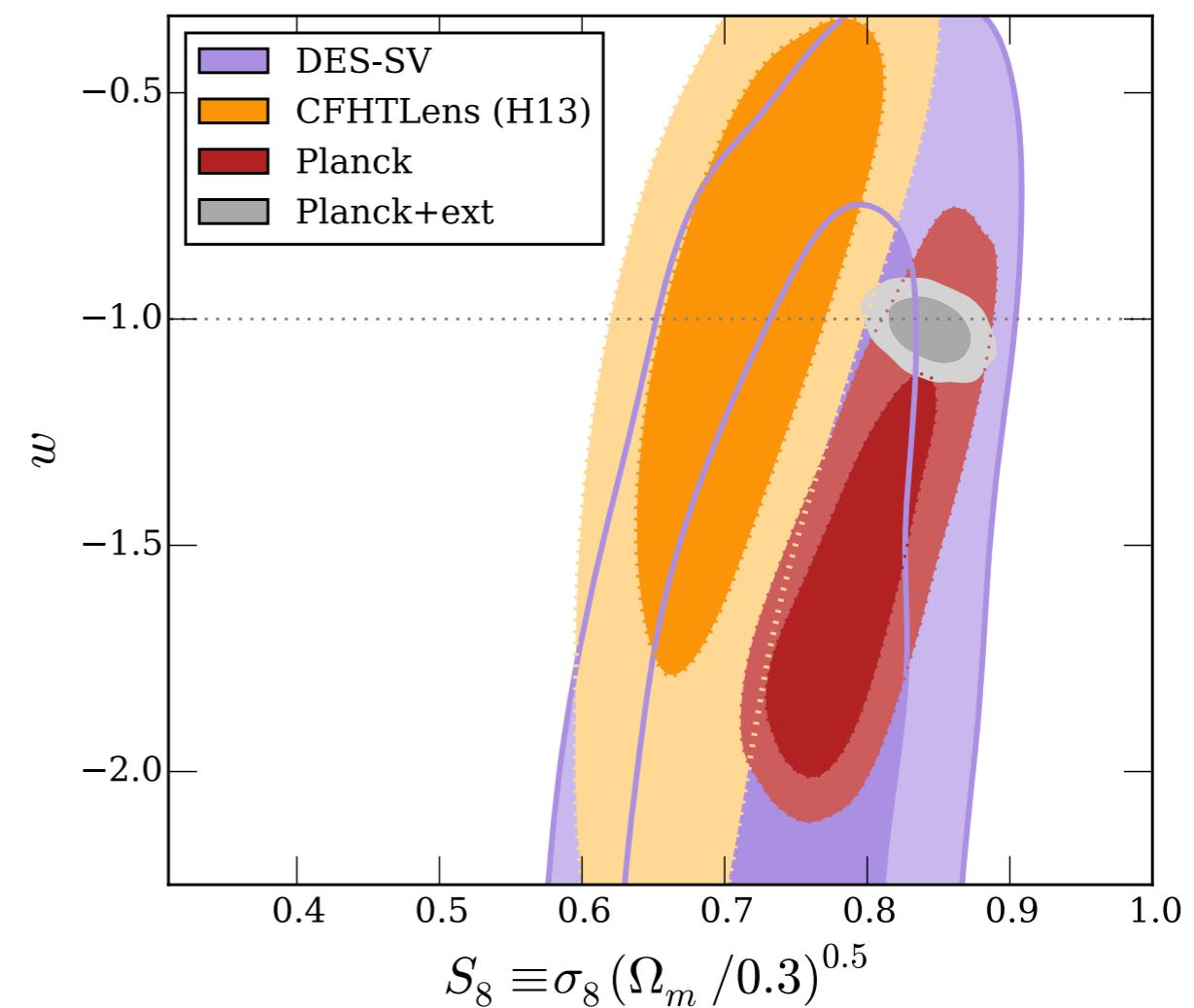
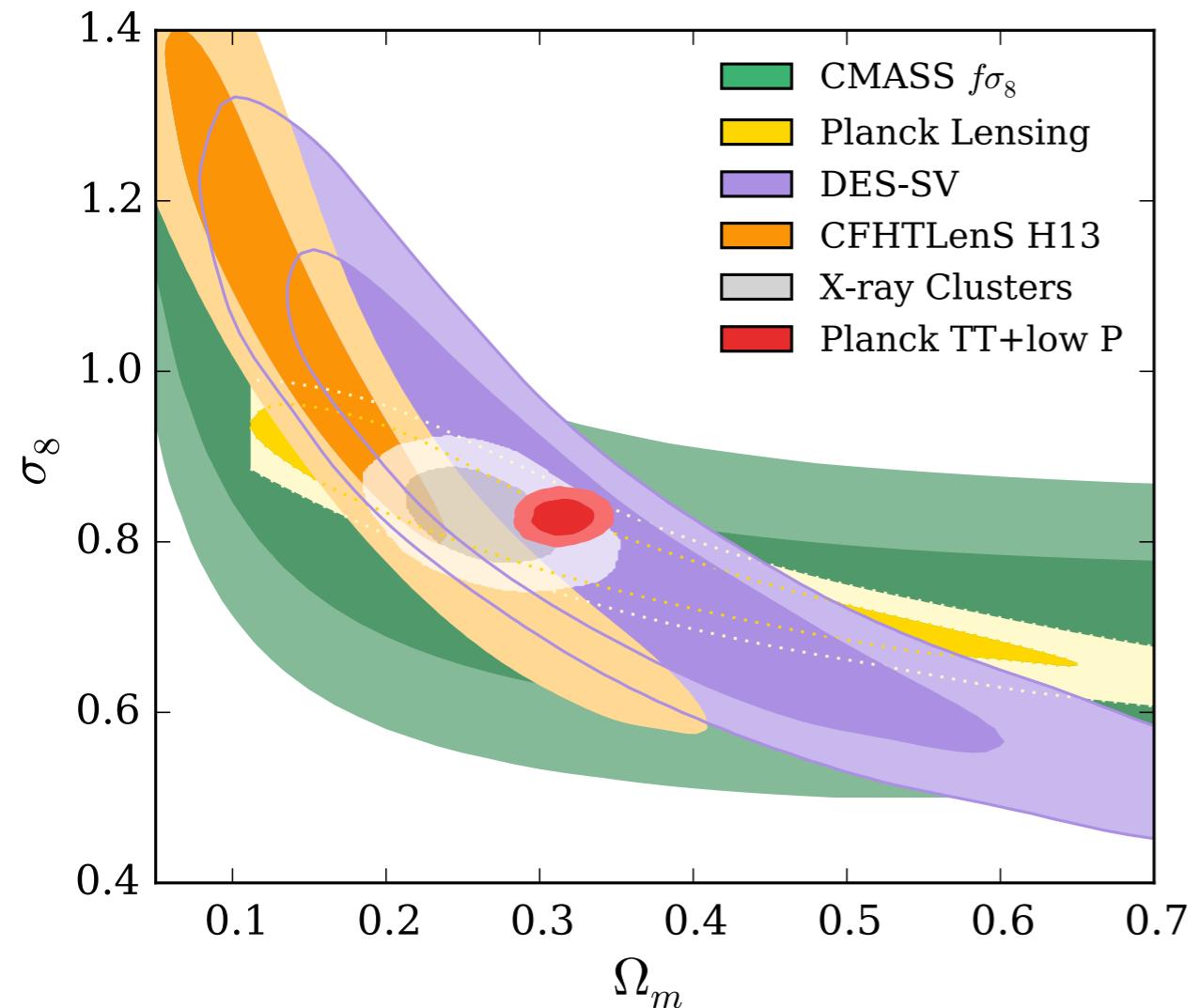
Shear Power Spectrum



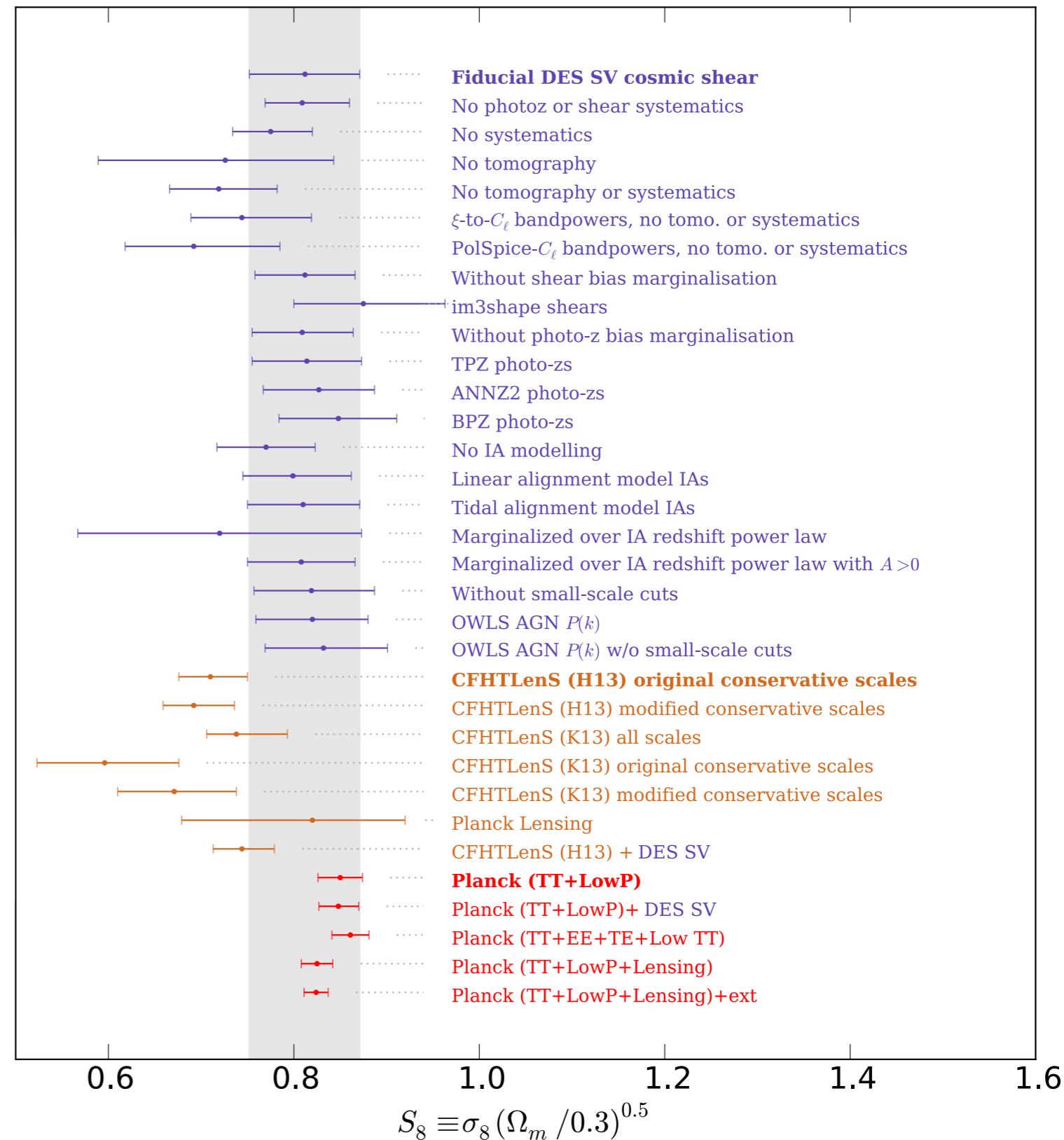
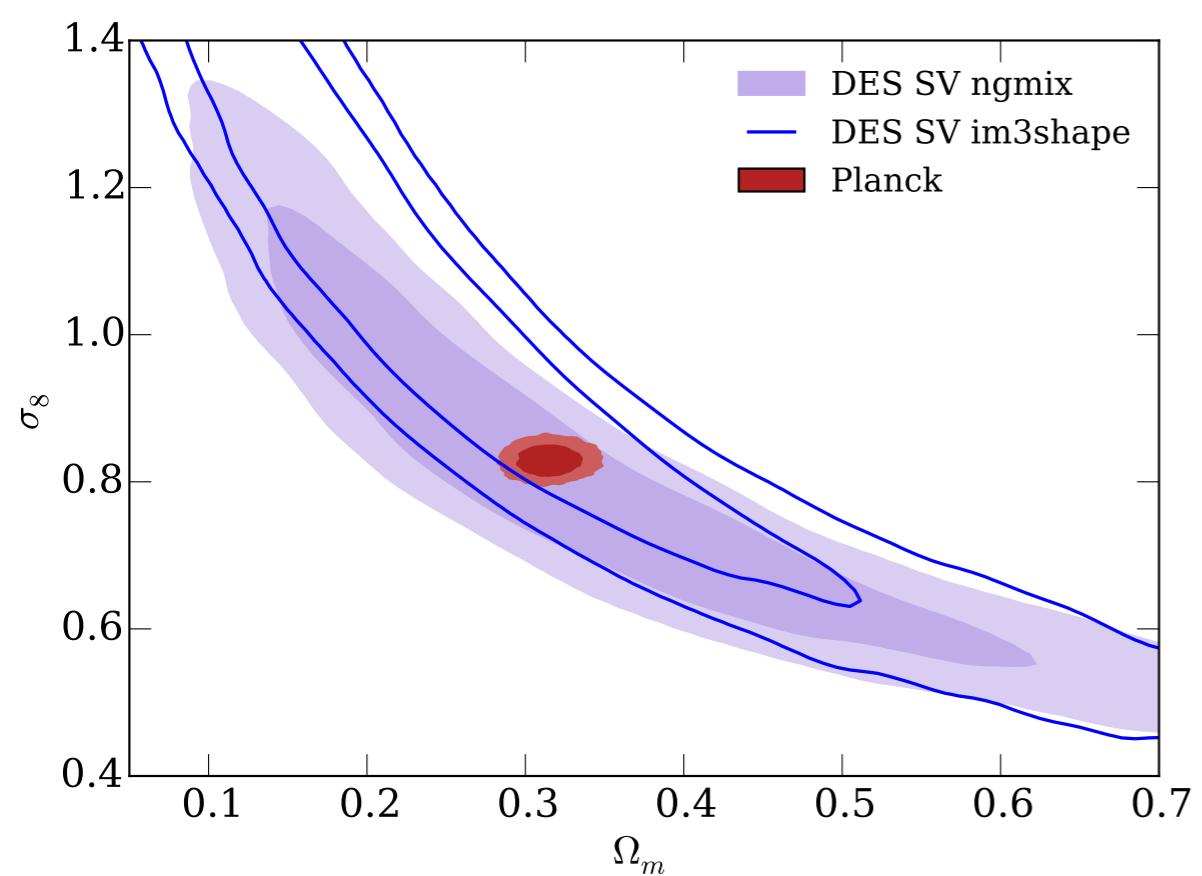
Shear Power Spectrum



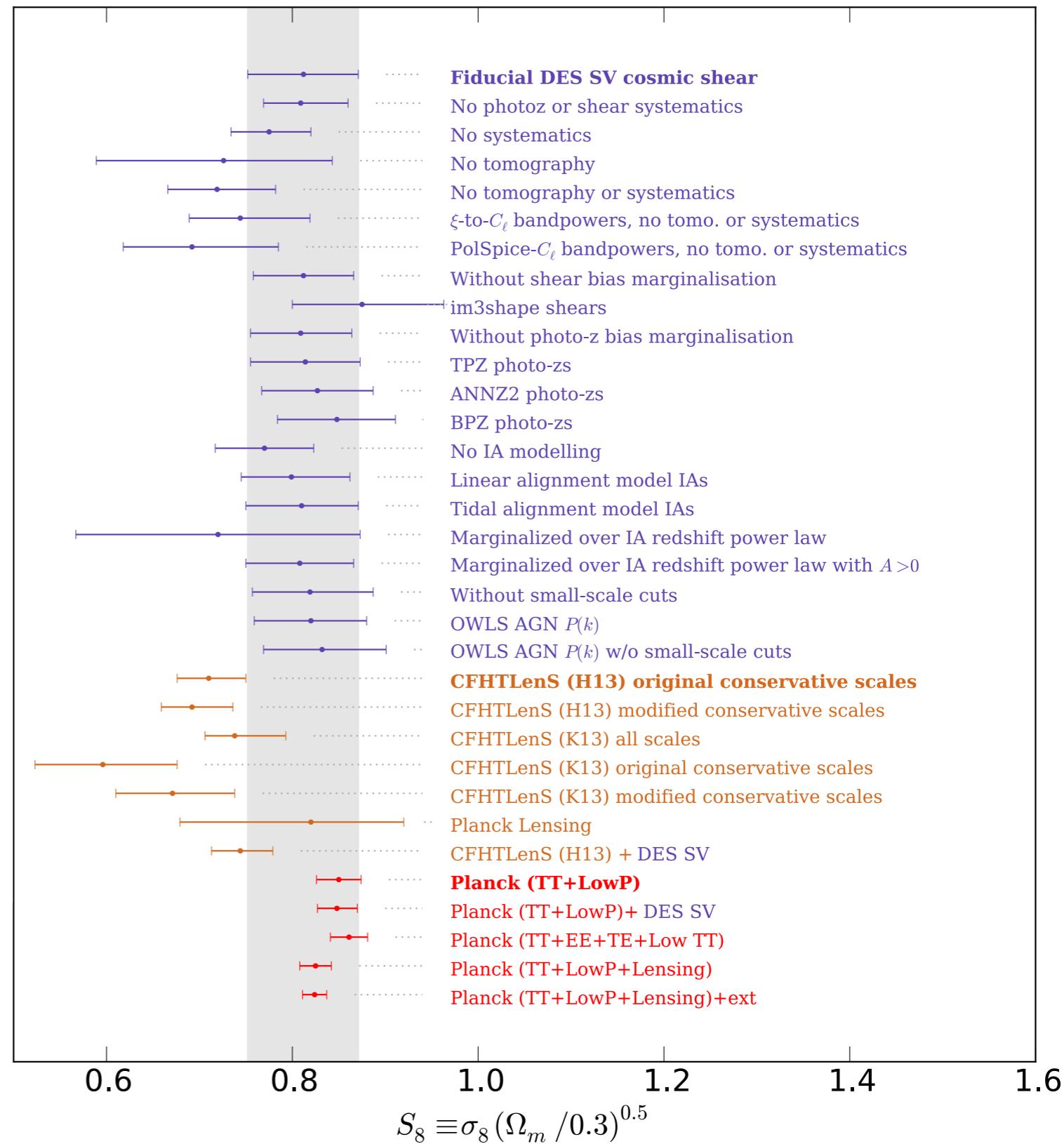
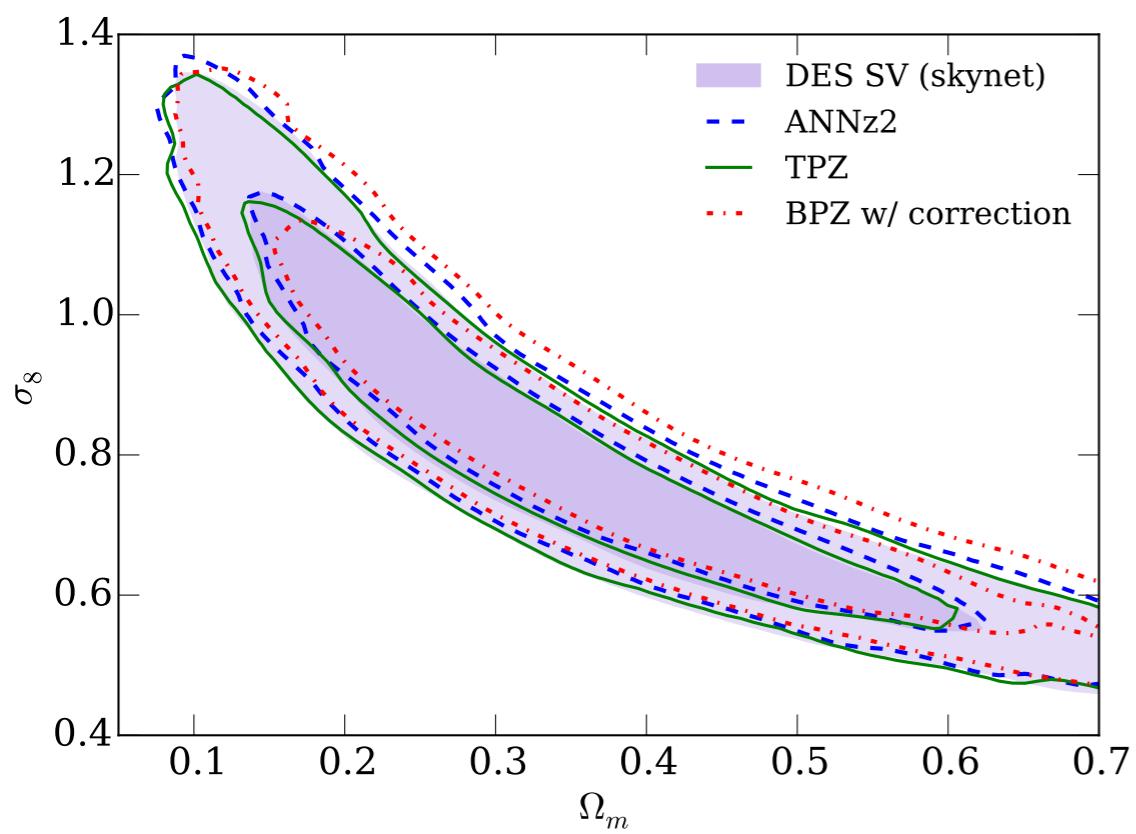
Cosmology



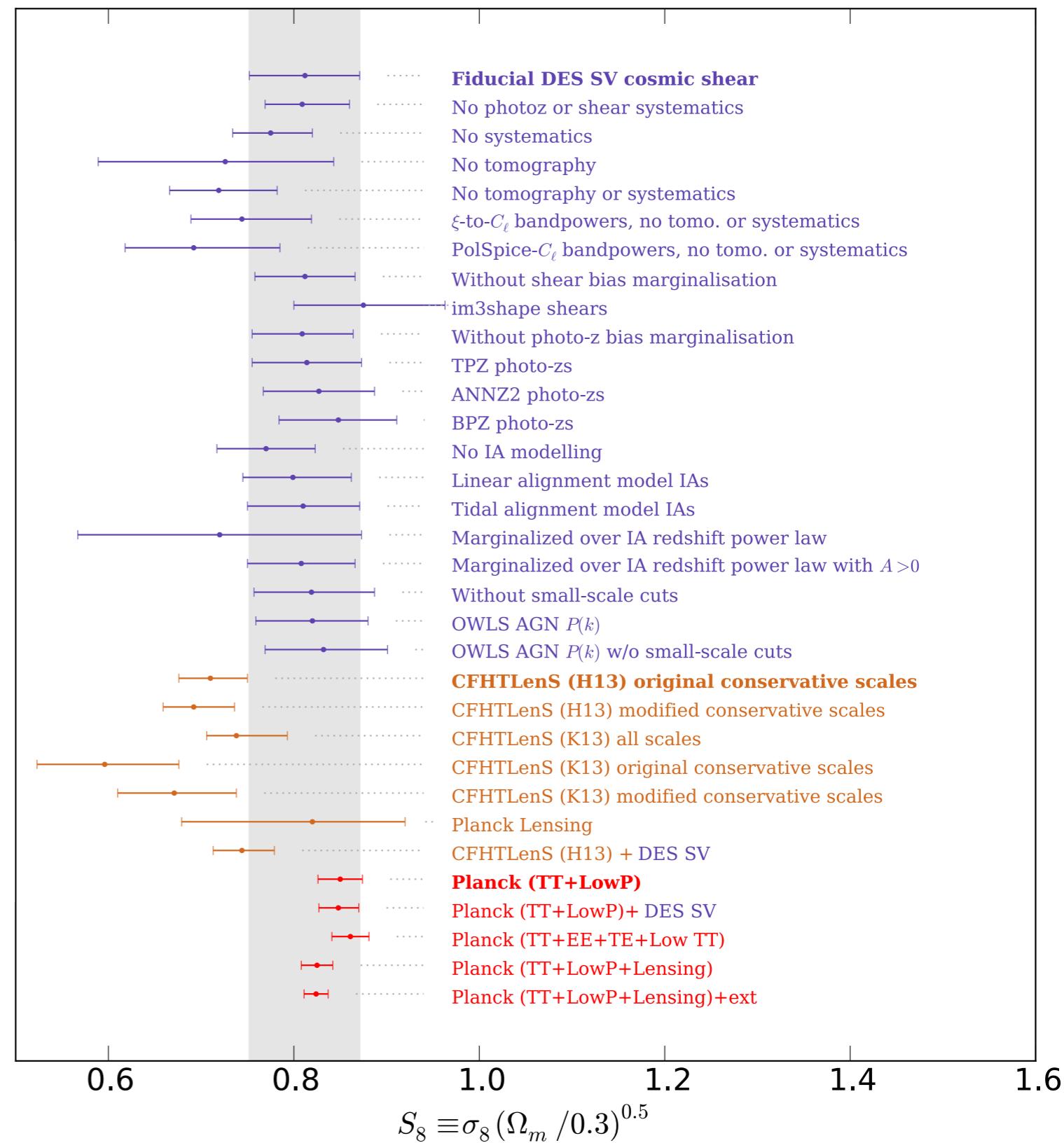
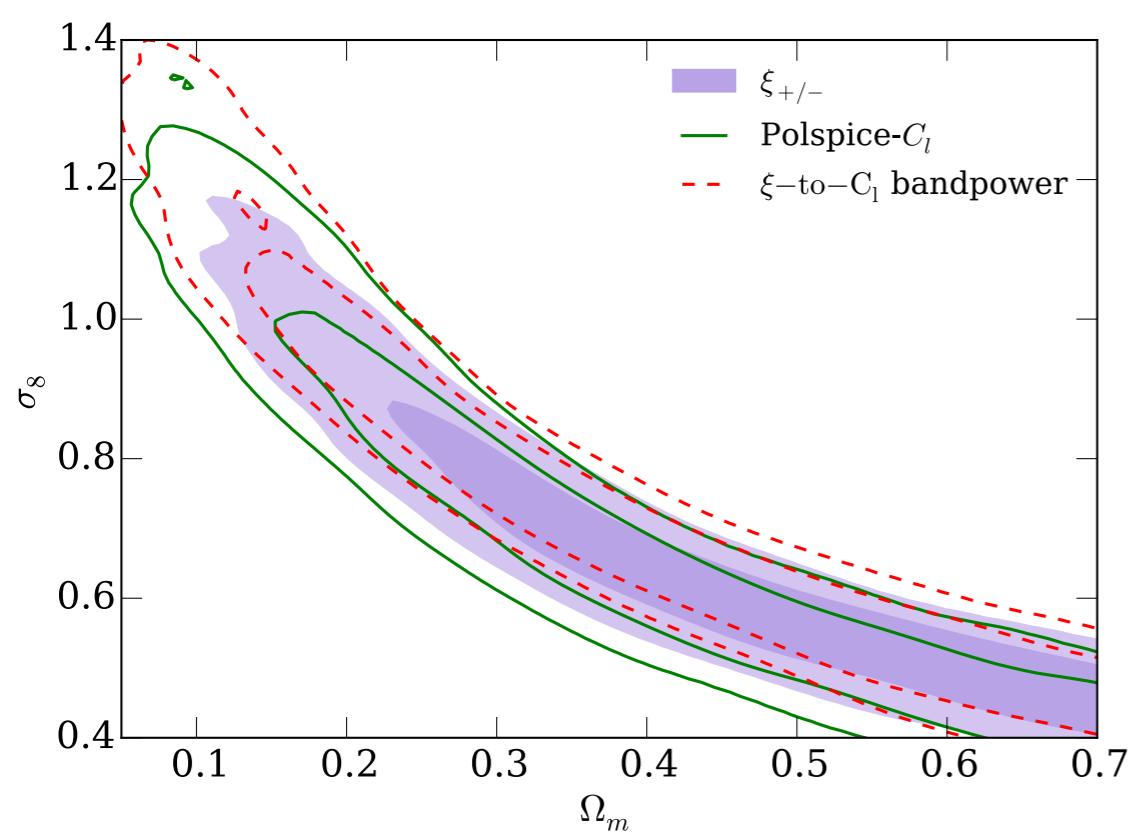
Robustness



Robustness



Robustness



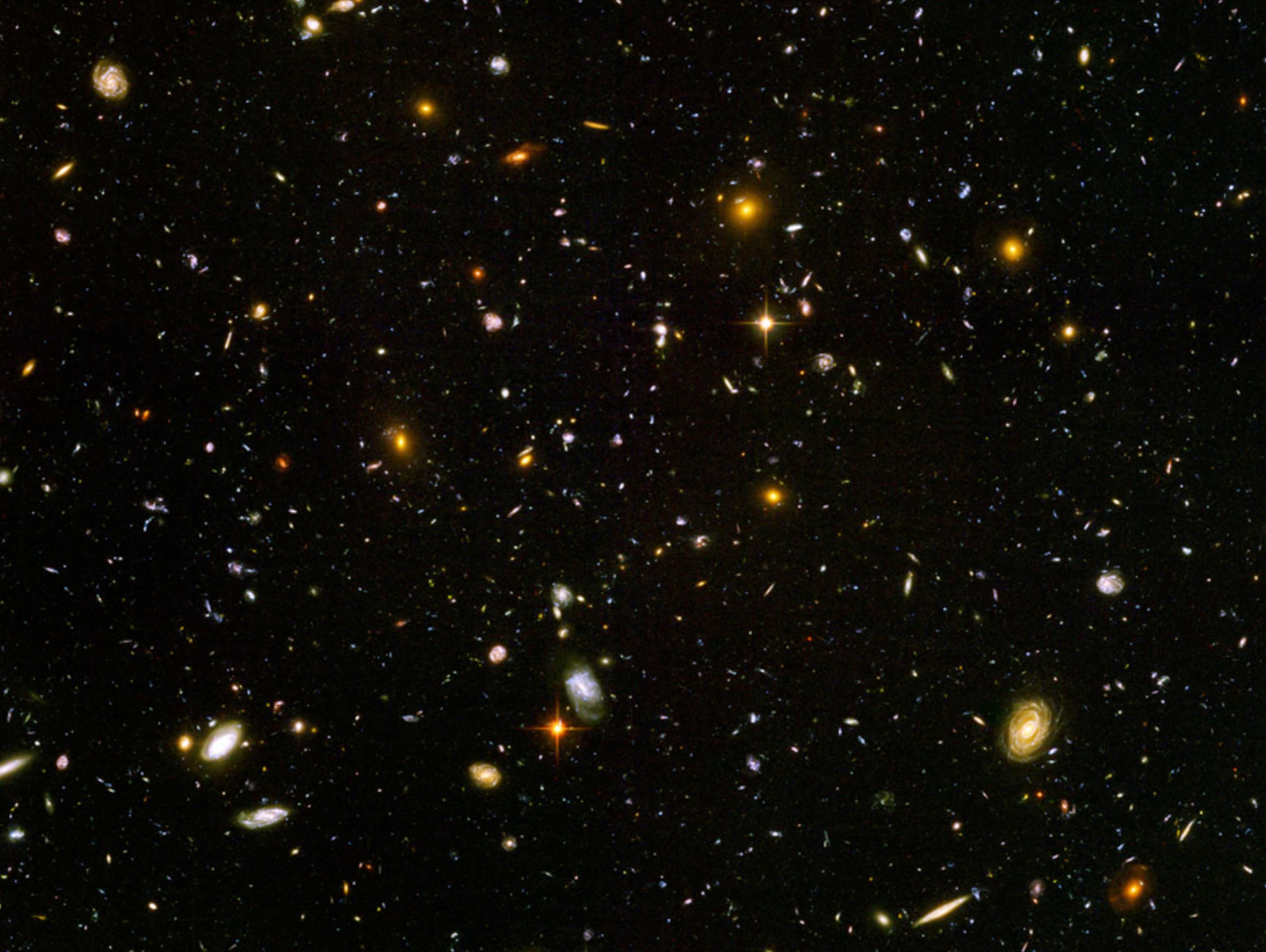
New set of results due by AAS

Currently analysing the Y1 data

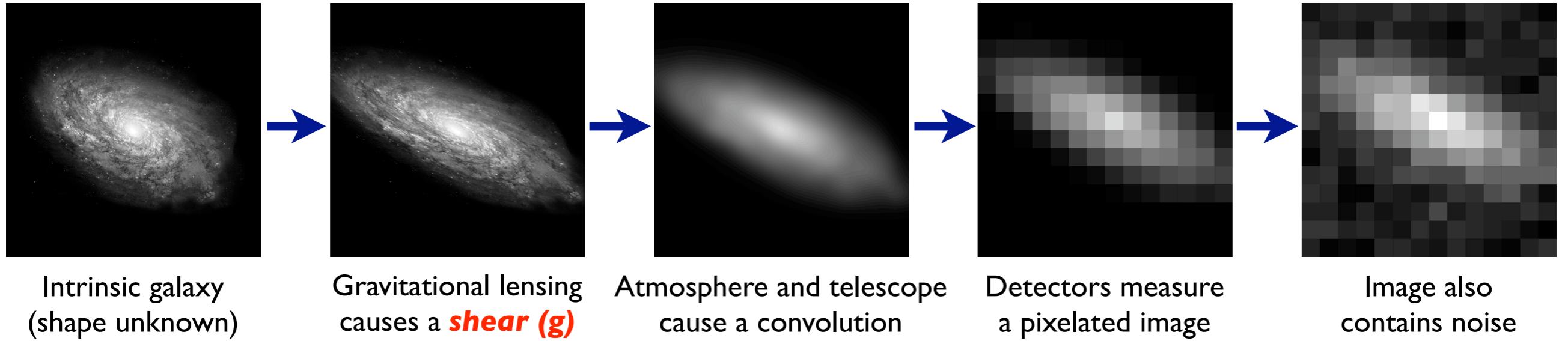
First cosmology results for Y1 in 2016

Information Content of Experiments

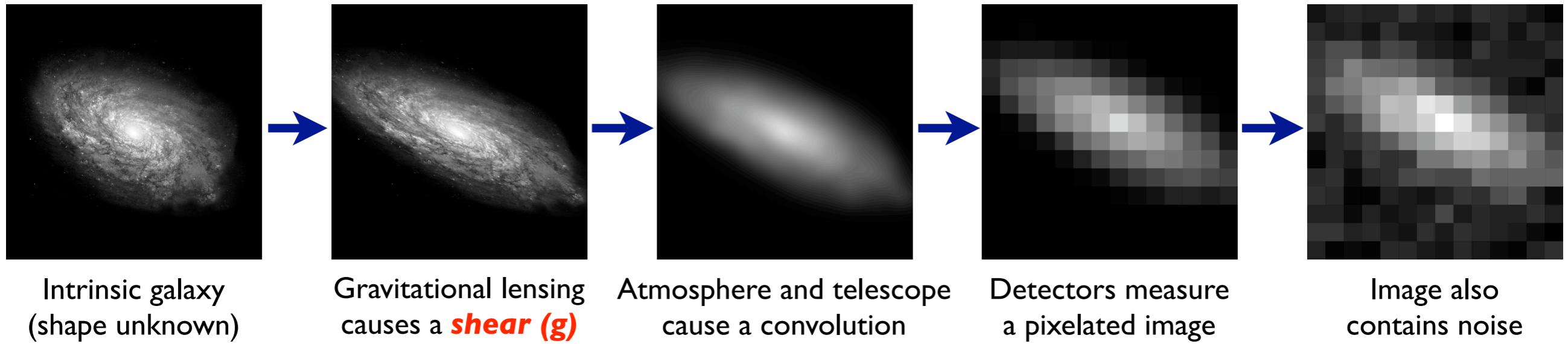
DES
(Dark Energy Survey)



Shape Measurement Problems



Shape Measurement Problems



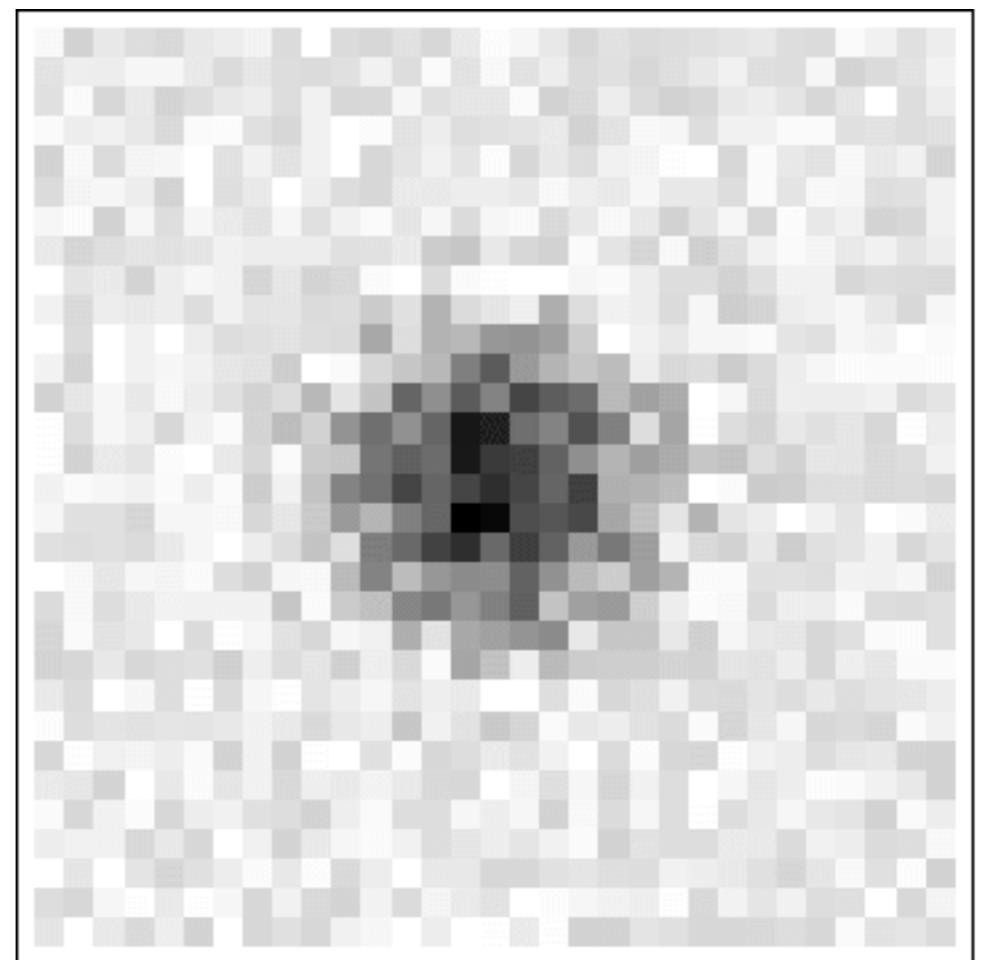
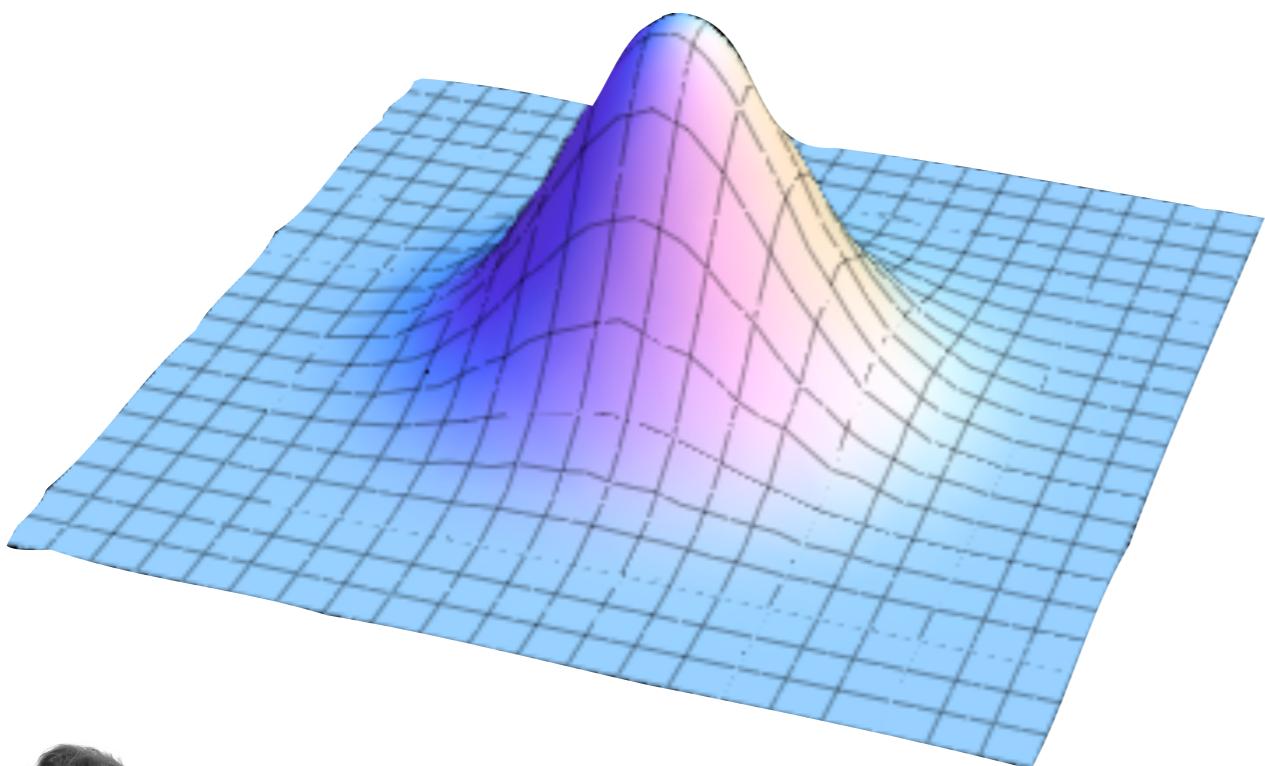
Approach till now

Generic Shape
measurement methods

Calculate calibration factor (minimising
simulations)

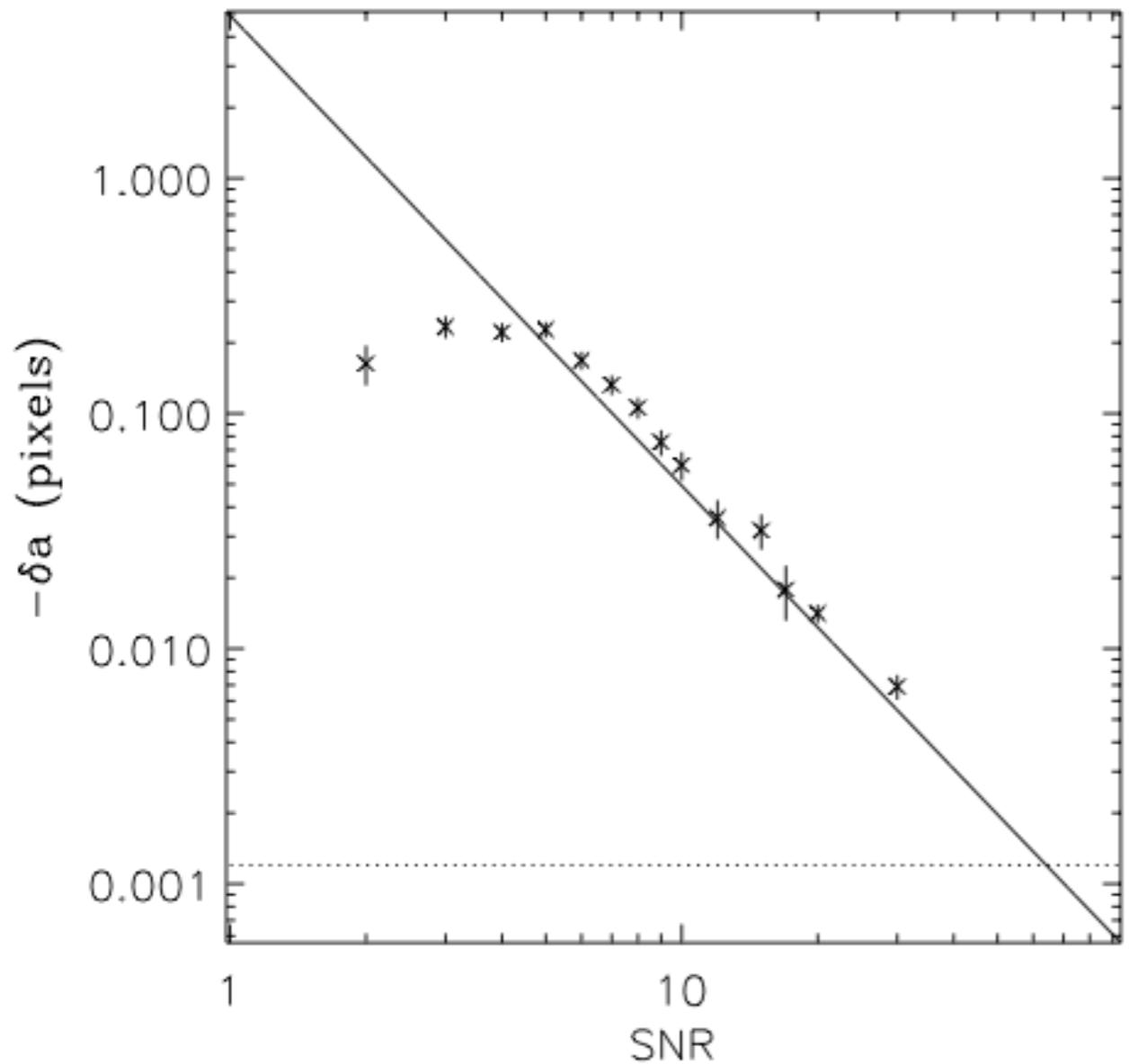
Trend towards more complex methods

Toy Model: Measuring the Size of a 2D Gaussian



Refregier, AA, + 2013

Measurement Biases



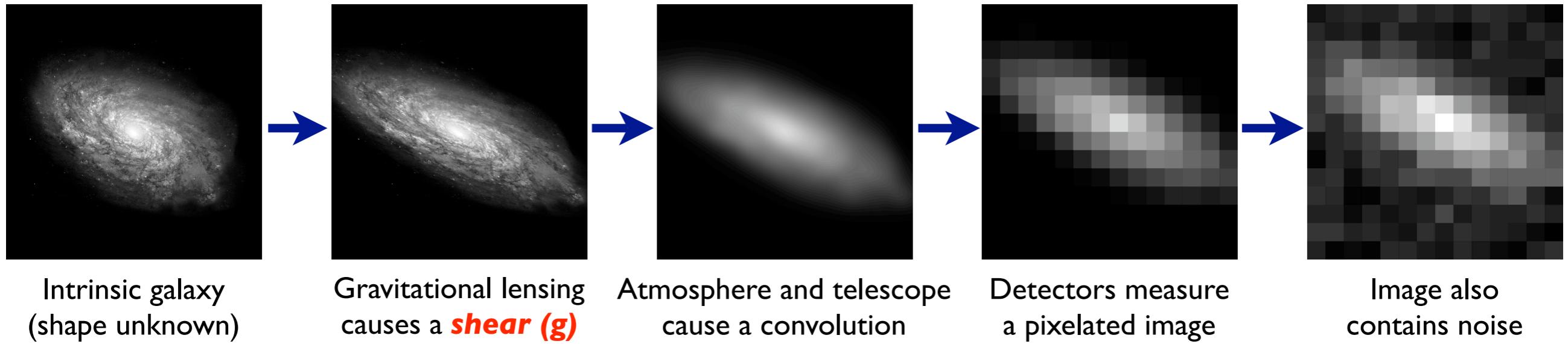
$$\delta a_i \simeq -\frac{1}{2} F_{ij} F_{kl} B_{jkl} \propto 1/\text{SNR}^2$$

$$F_{ij} = \sum_p \frac{1}{\sigma_p^2} \frac{\partial f}{\partial a_i} \frac{\partial f}{\partial a_j}$$

$$B_{ijk} = \sum_p \frac{1}{\sigma_p^2} \frac{\partial f}{\partial a_i} \frac{\partial^2 f}{\partial a_j \partial a_k}$$

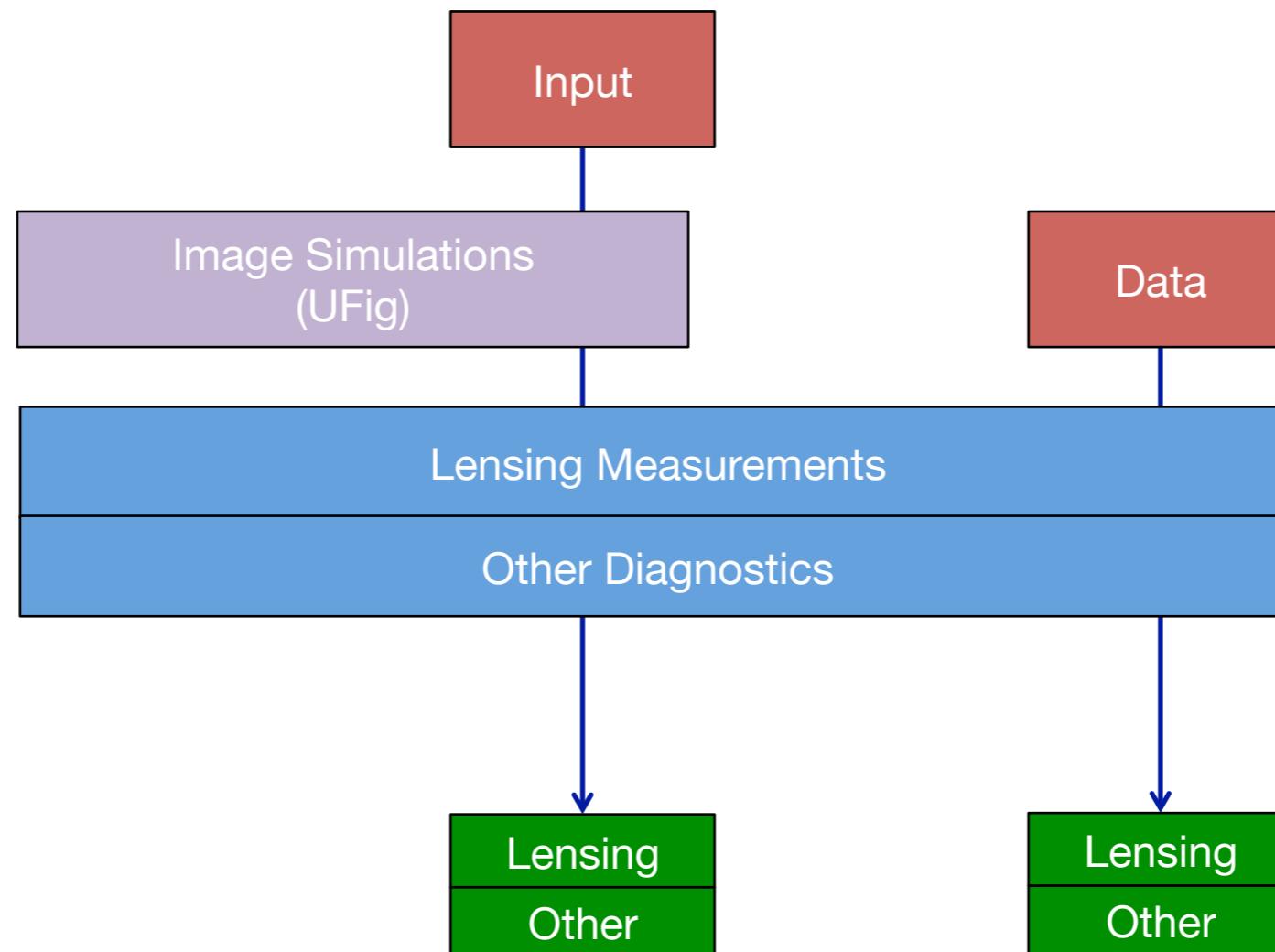
Refregier, AA, + 2013

Shape Measurement Problems

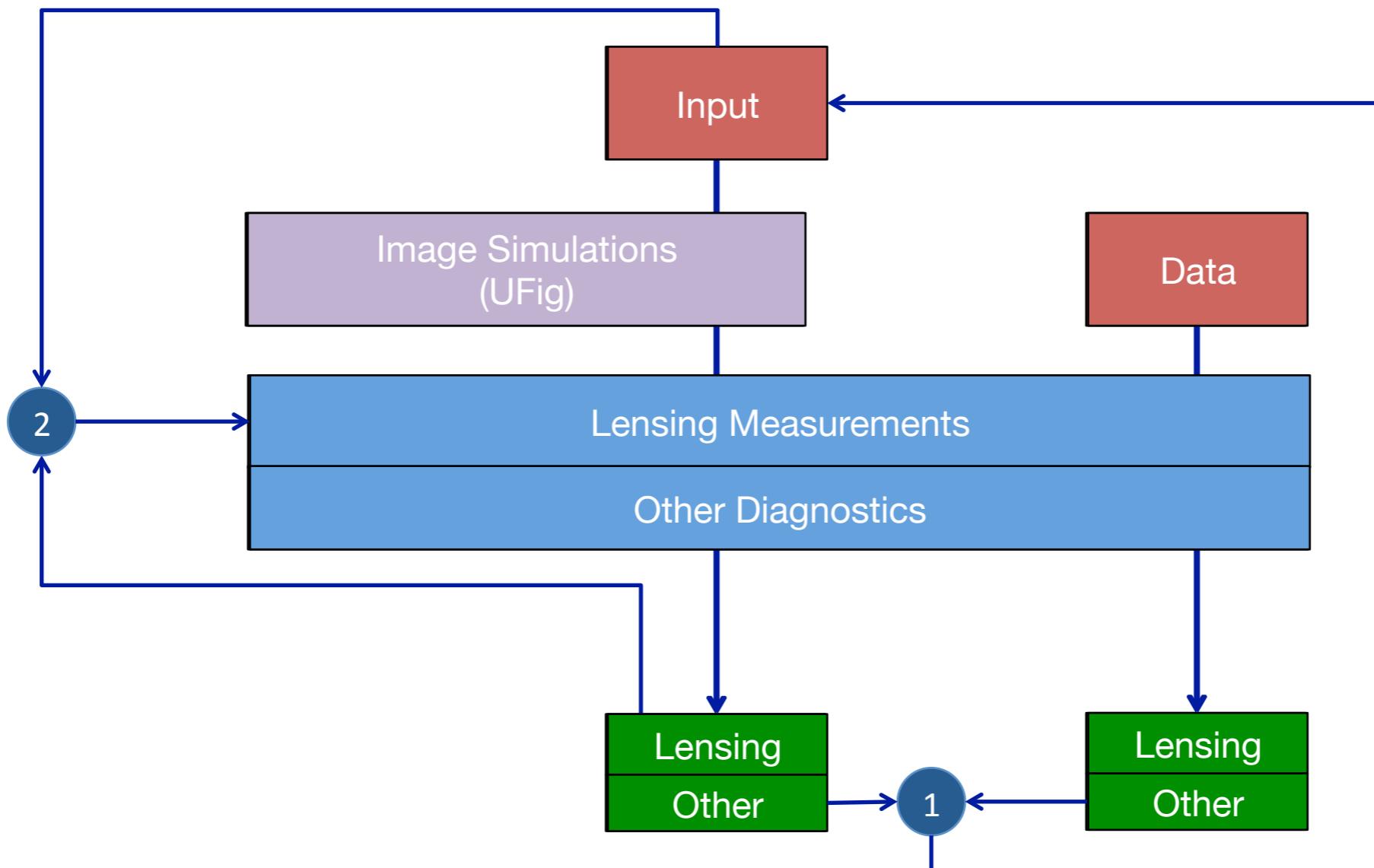


Approach till now	Our new approach - MCCL
Generic Shape measurement methods	Specific analysis need only work for specific data (data centric)
Calculate calibration factor (minimising simulations)	Simulation explicitly at the heart of analysis method (empirical calibrations)
Trend towards more complex methods	Simplest possible method that we can get away with (speed)

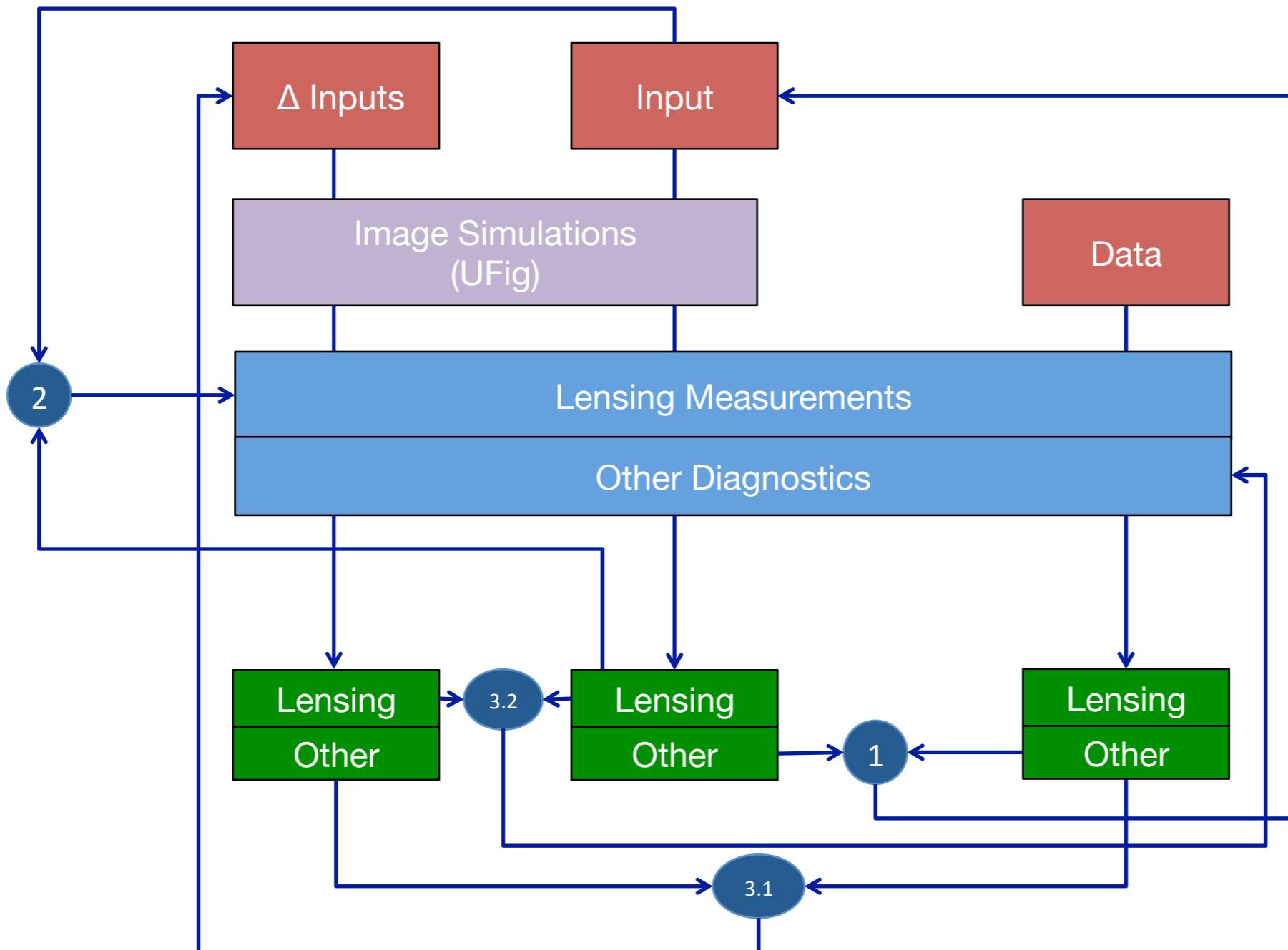
Monte Carlo Control Loops



Monte Carlo Control Loops

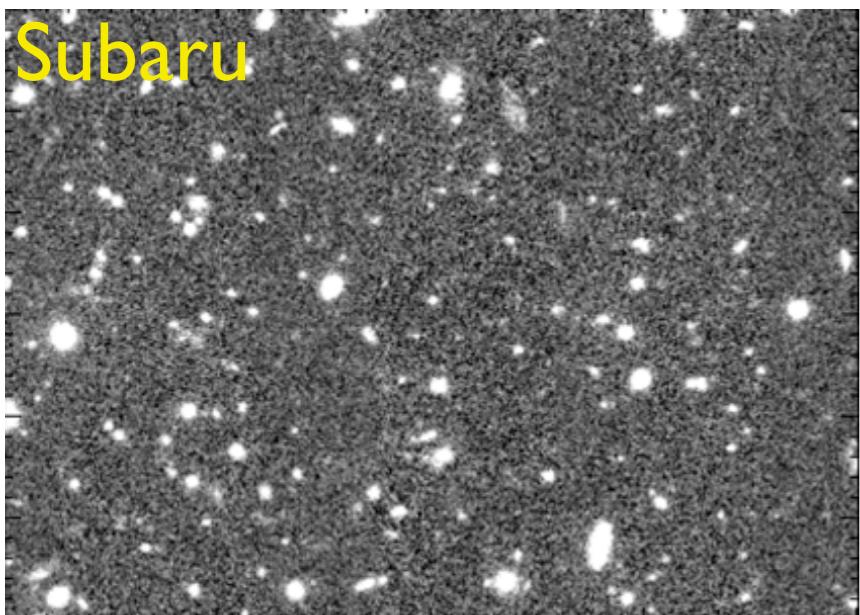


Monte Carlo Control Loops

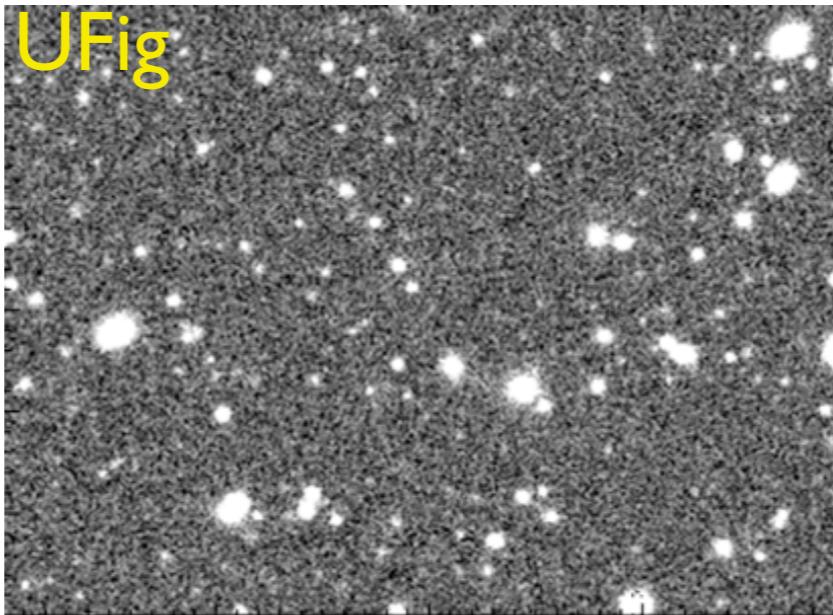


Ultra Fast Image Generator (UFig)

Subaru



UFig



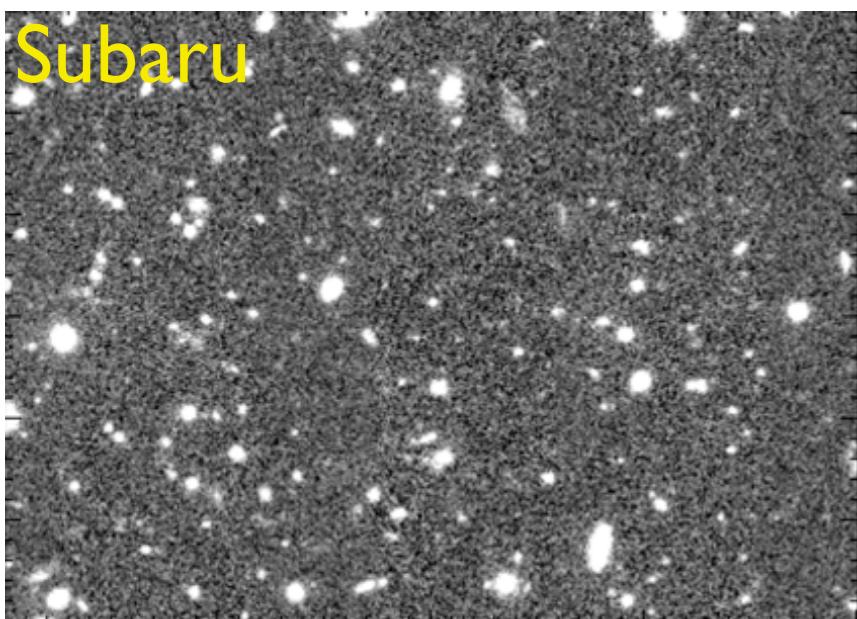
Speed the driving factor

As fast as SExtractor (or faster)
Subaru Image (0.25
deg², R~26, 10k×8k) generated in:
30sec on a laptop
30μsec per galaxy

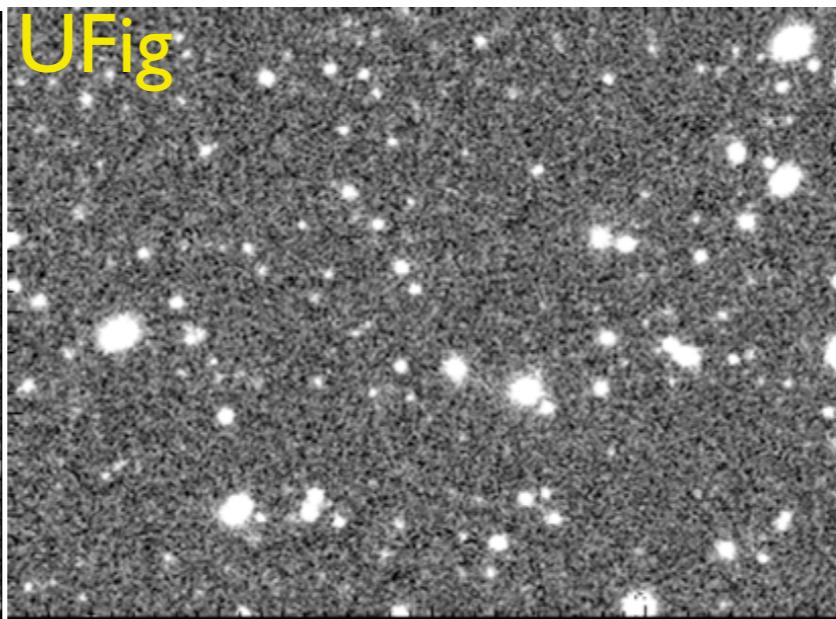


Ultra Fast Image Generator (UFig)

Subaru



UFig



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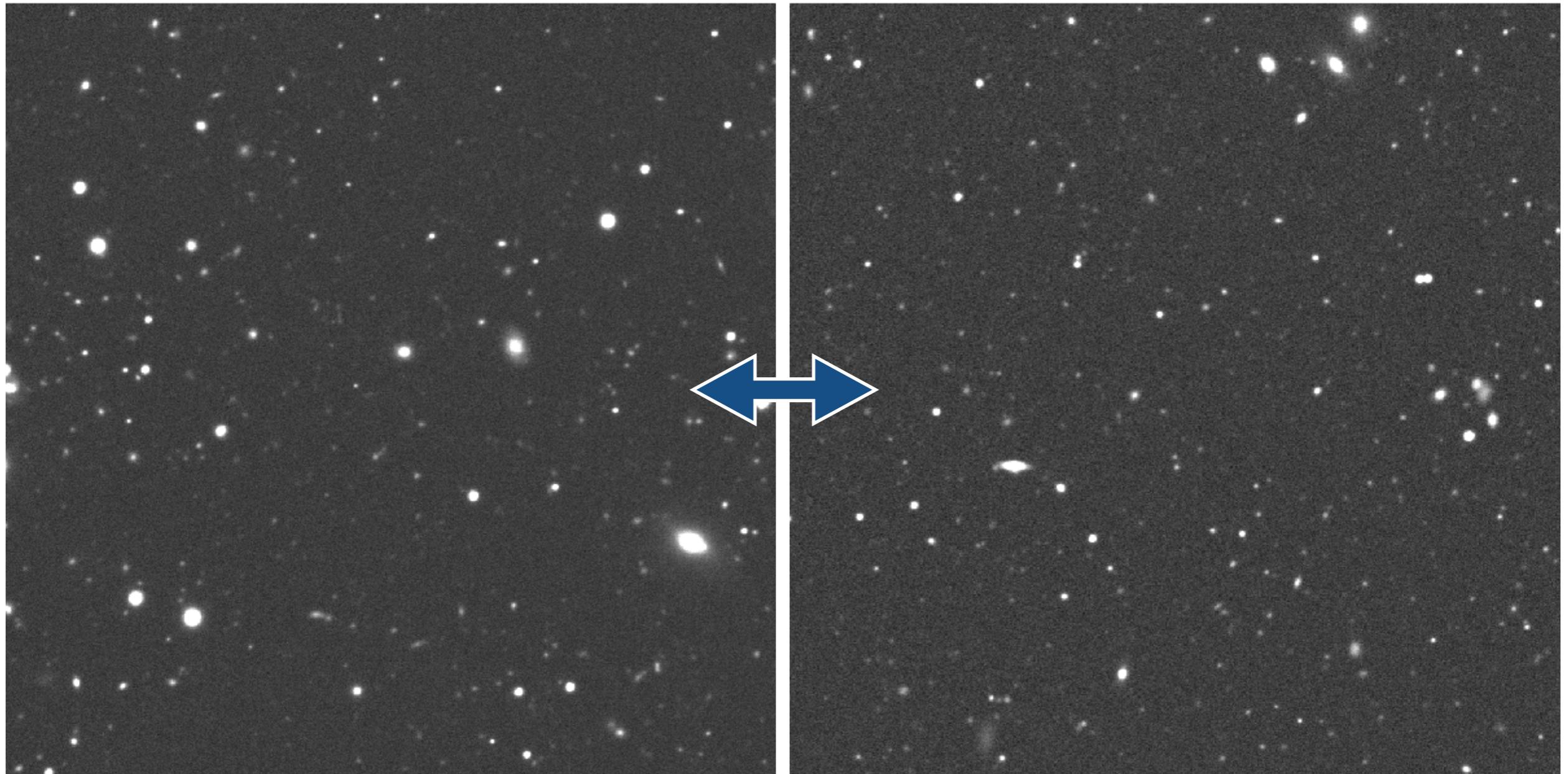
HOPE: A Python Just-In-Time compiler
for astrophysical computations

Akeret et al 2014
<http://hope.phys.ethz.ch>

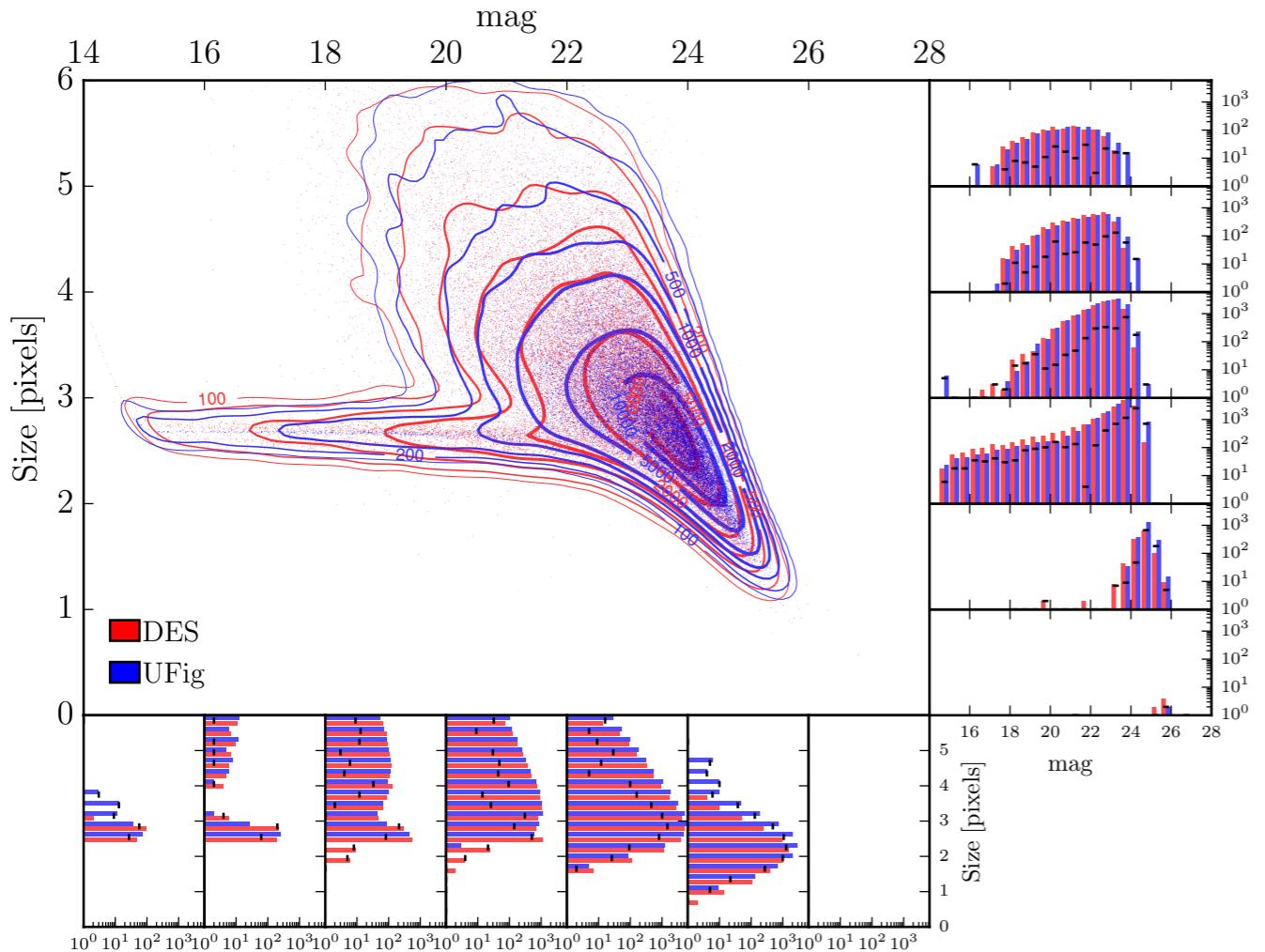


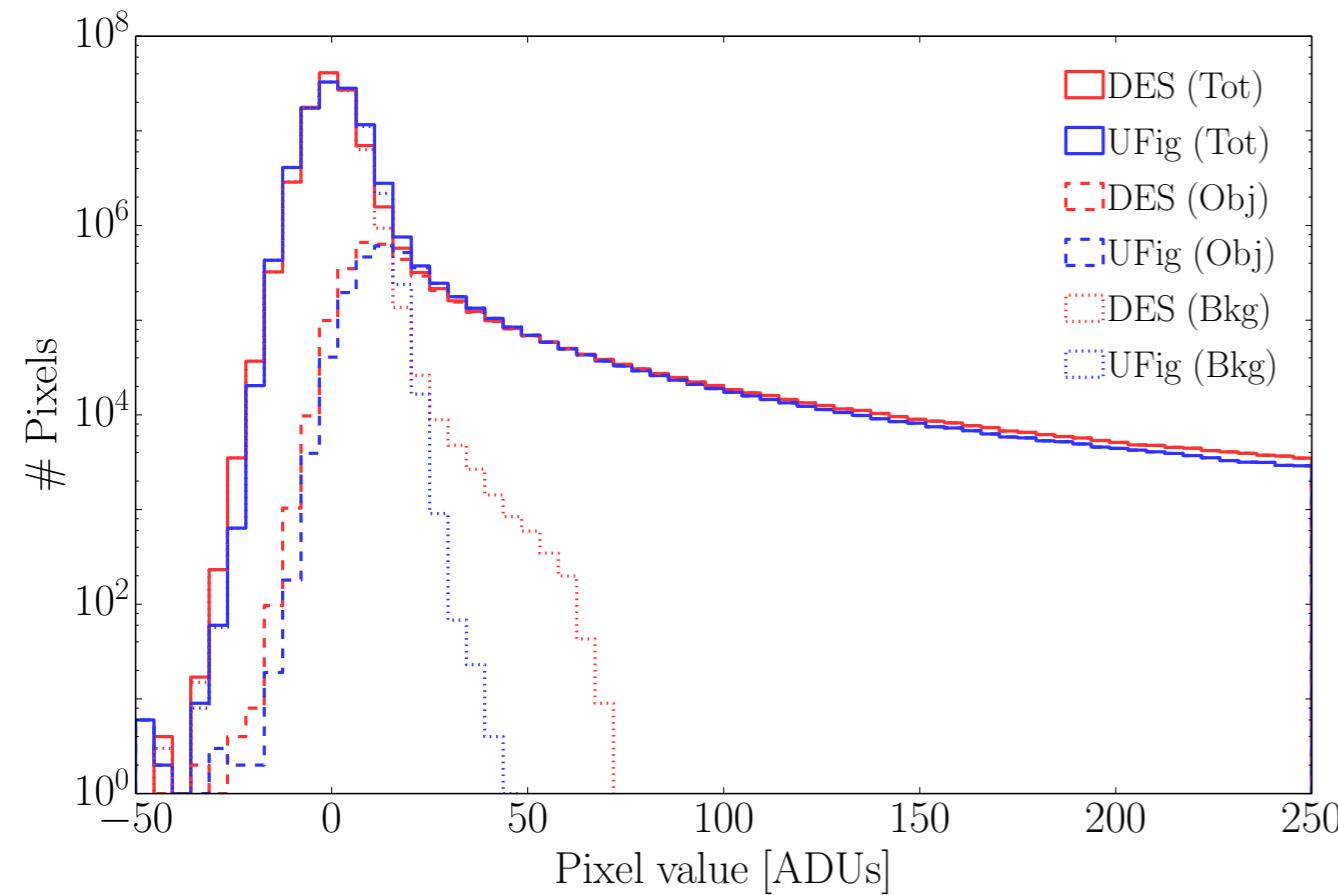
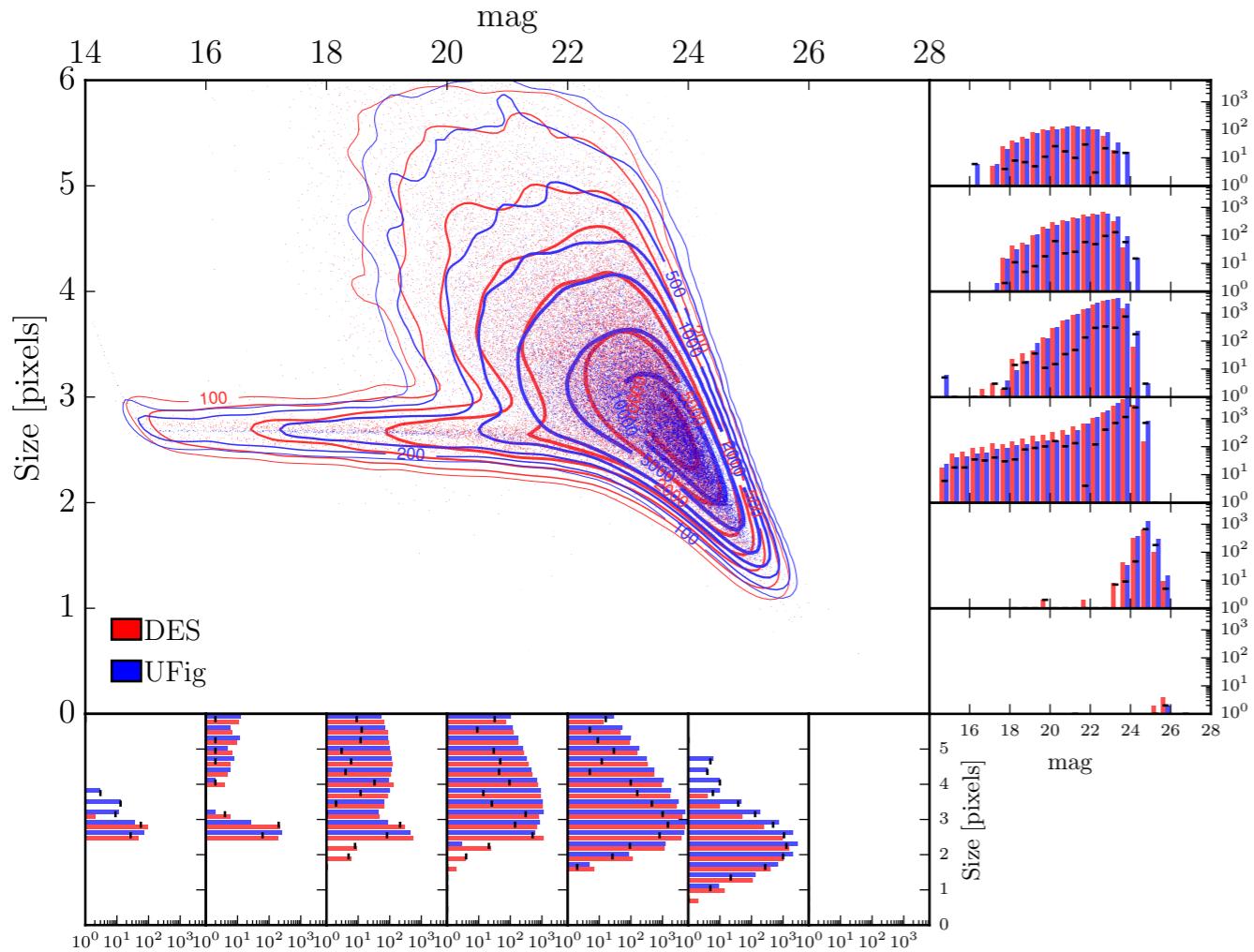
	Python (NumPy)	Numba	Cython	Nuitka (NumPy)	PyPy (NumPy)	numexpr (8 cores)	HOPE	C++
Fibonacci	57.4	65.7 ^a	1.1	26.7	21.1	—	1.1	1.0
Quicksort	79.4	— ^b	4.6	61.0	45.8	—	1.1	1.0
Pi sum	27.2	1.0	1.1	13.0	1.0	—	1.0	1.0
10 th order	2.6	2.2	2.1	1.2	12.1	1.4	1.1	1.0
Simplify	1.4	1.5 ^{ab}	1.8	1.4	23.2	0.6	0.015	1.0
Pairwise distance	1357.8 (8.7)	1.8	1.0	1247.7 (9.5)	277.8 (60.4)	—	1.7	1.0
Star PSF	265.4	250.4 ^a	46.2	234.6	339.5	—	2.2	1.0

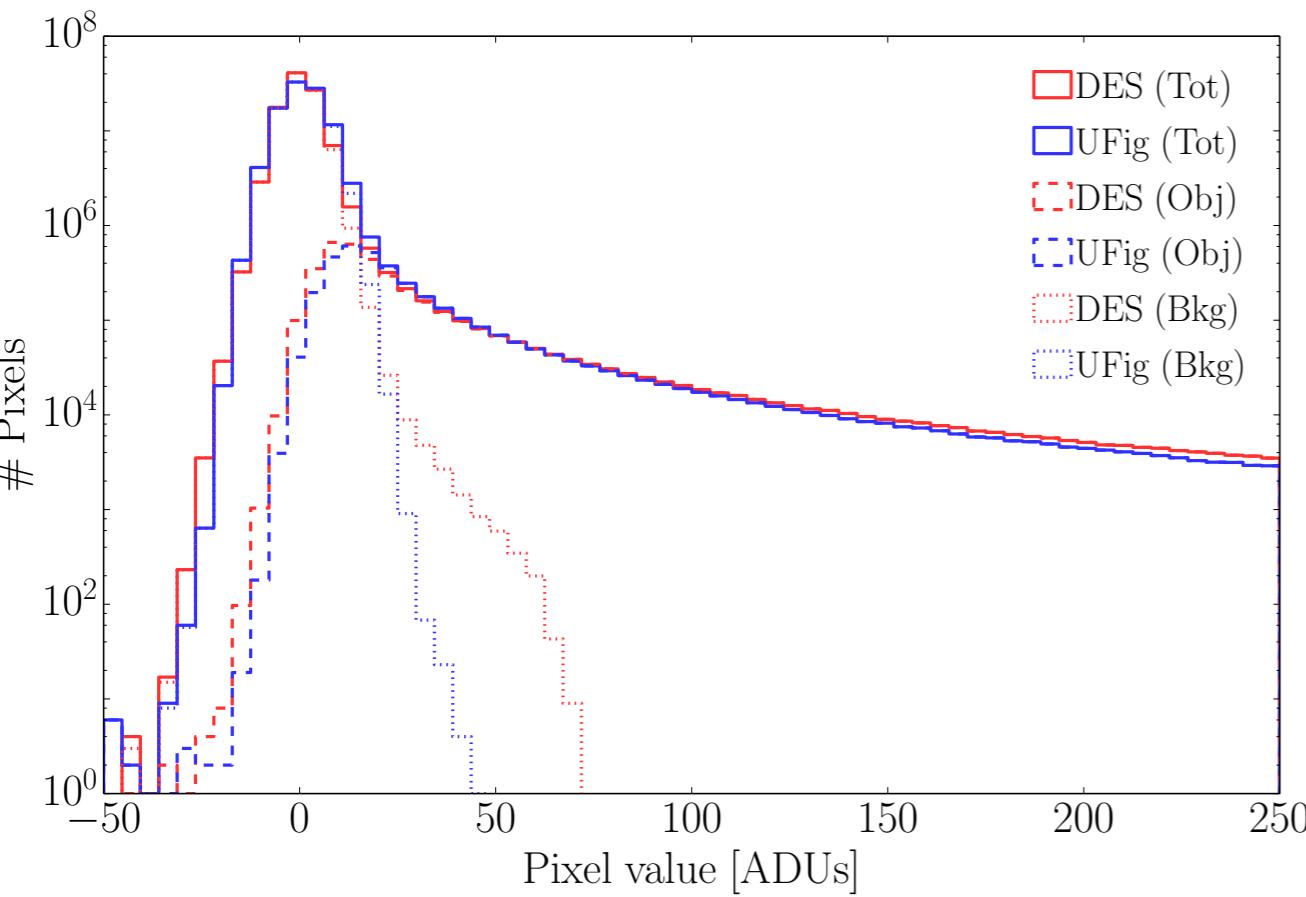
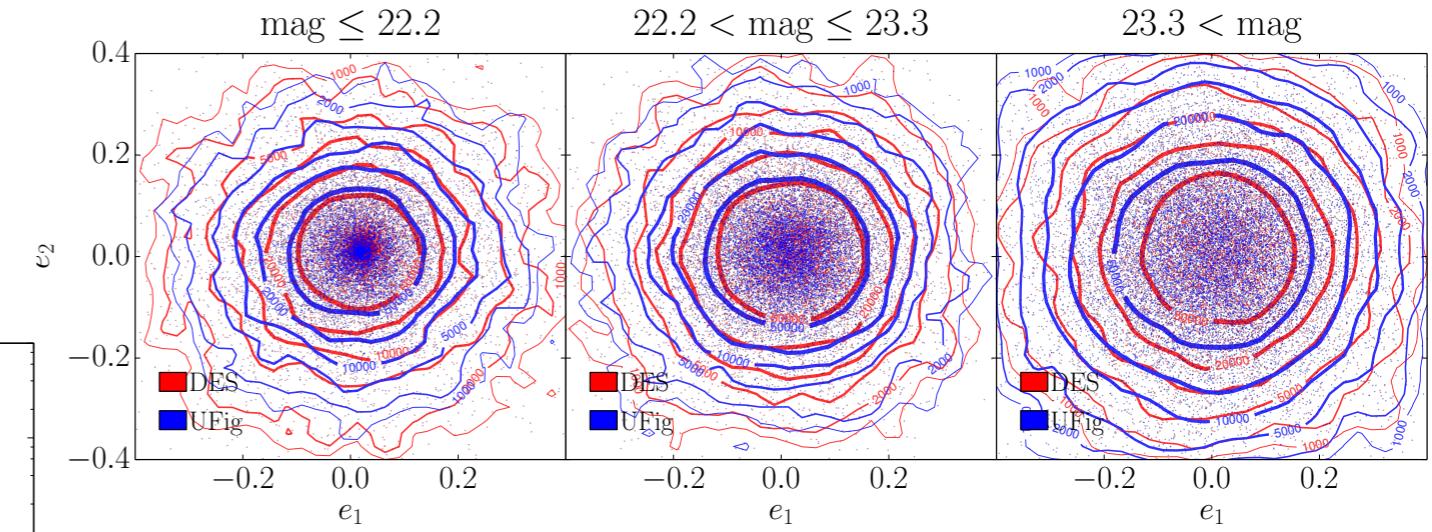
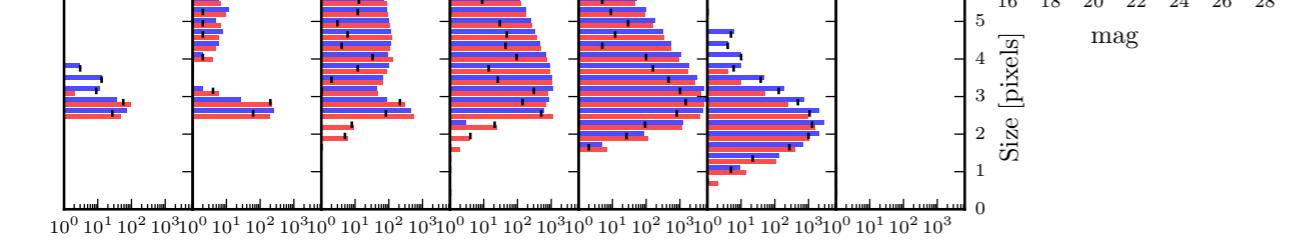
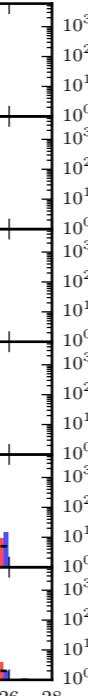
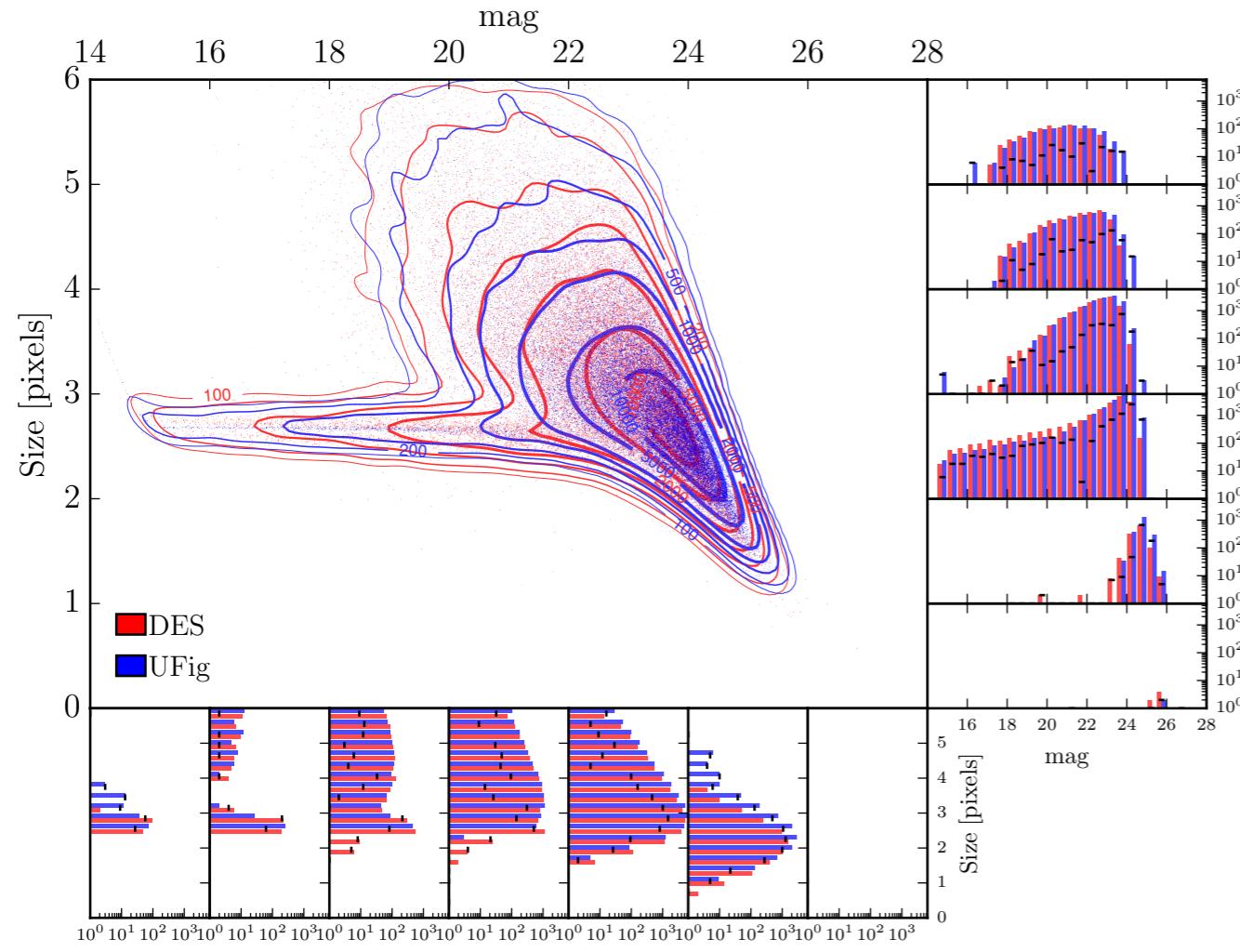
Calibrating Shear measurement

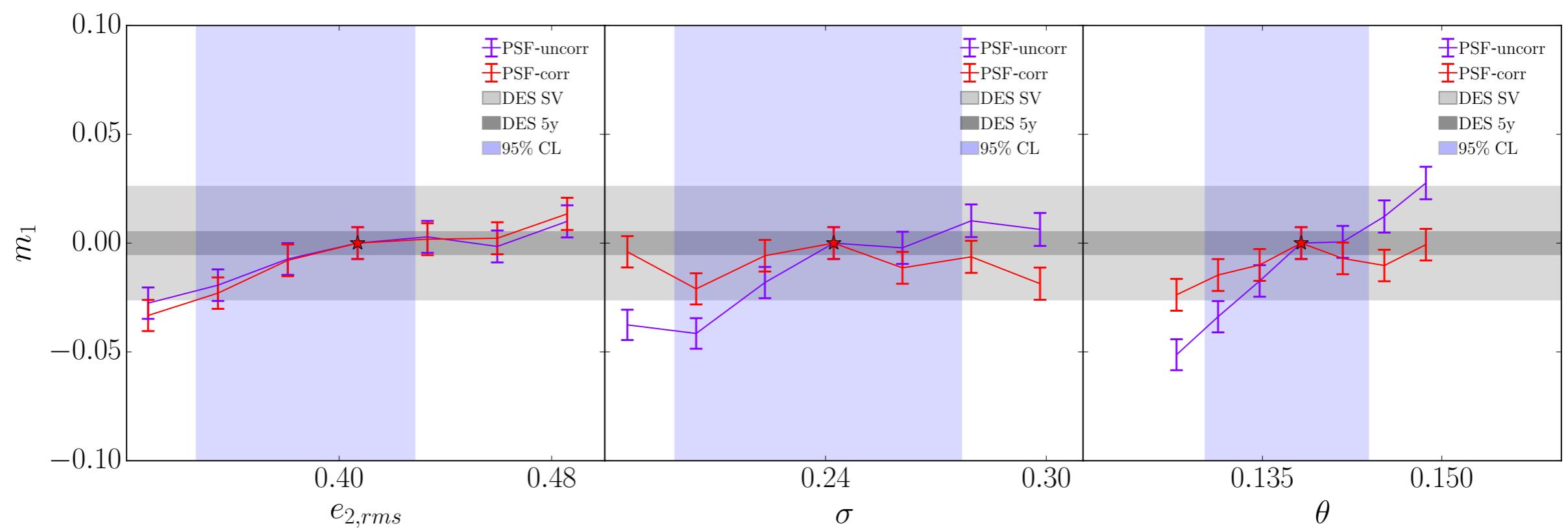
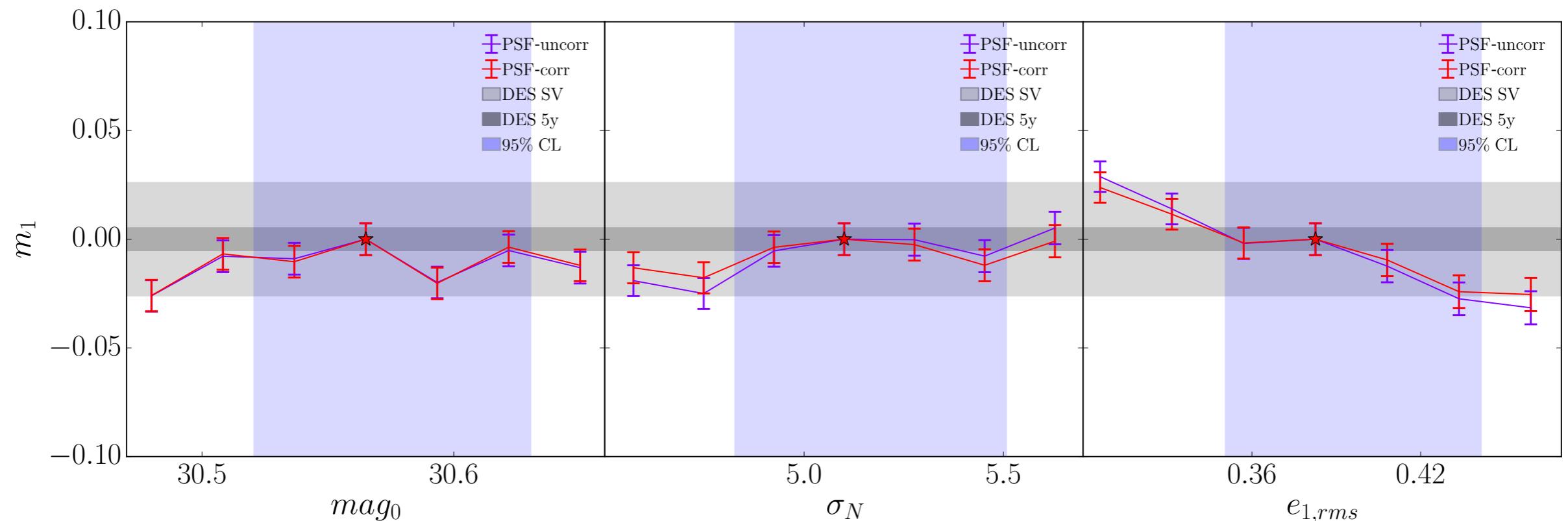


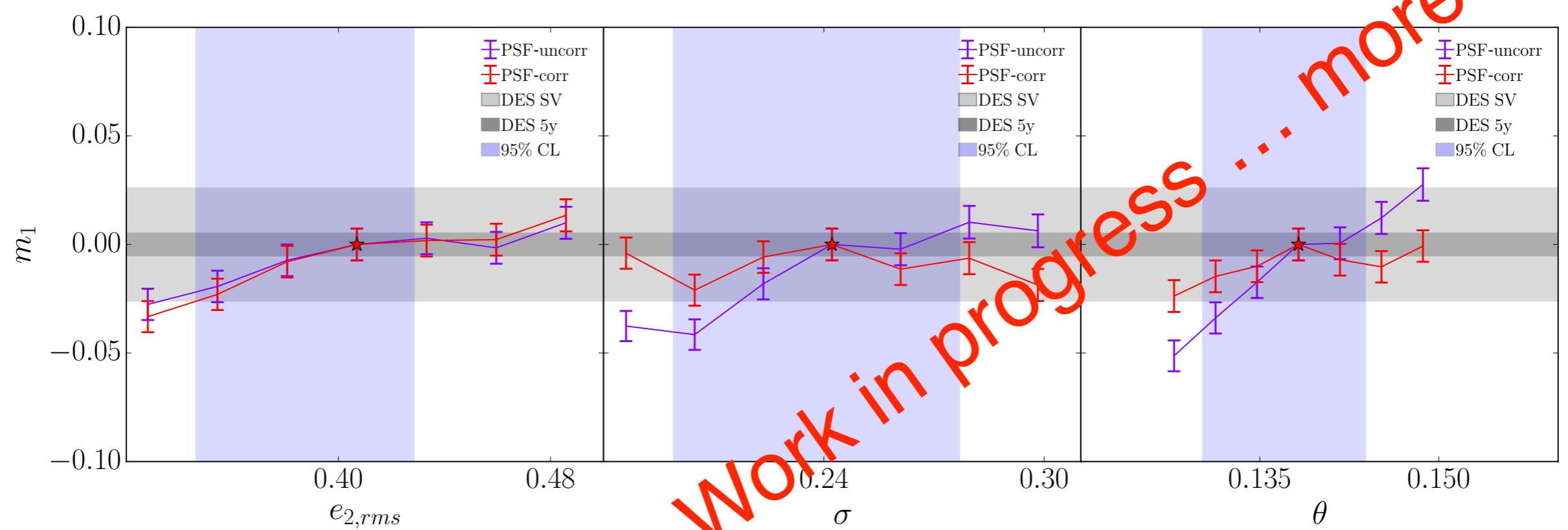
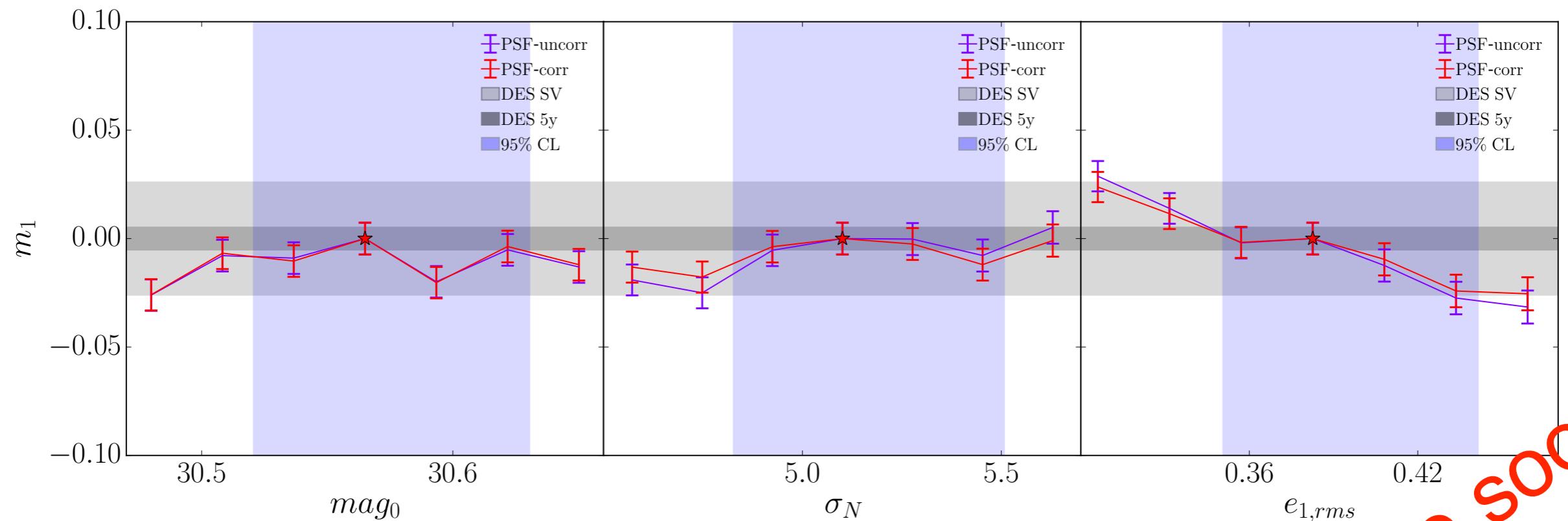
Bruderer et al (2015)











Work in progress ... more soon

