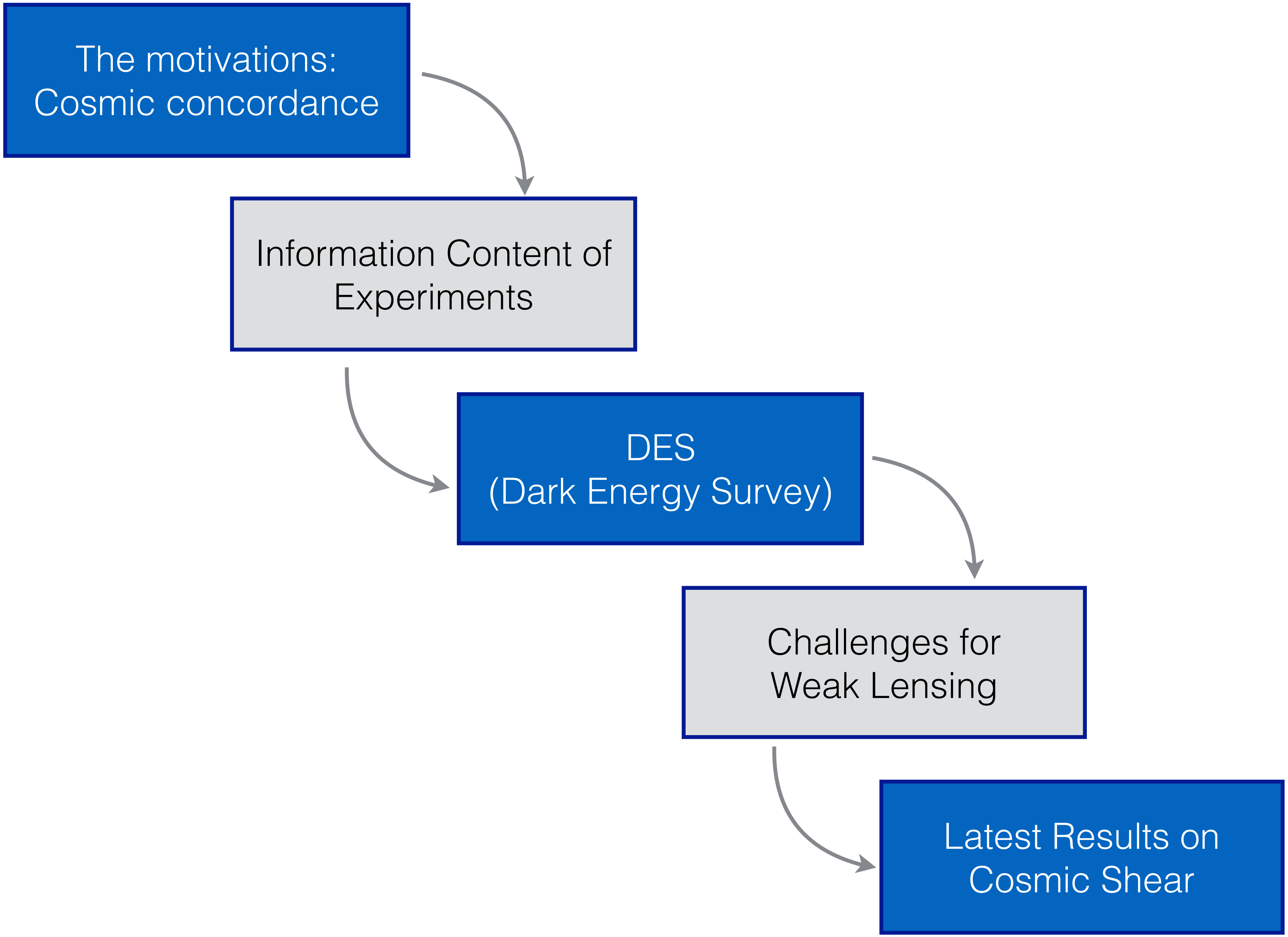
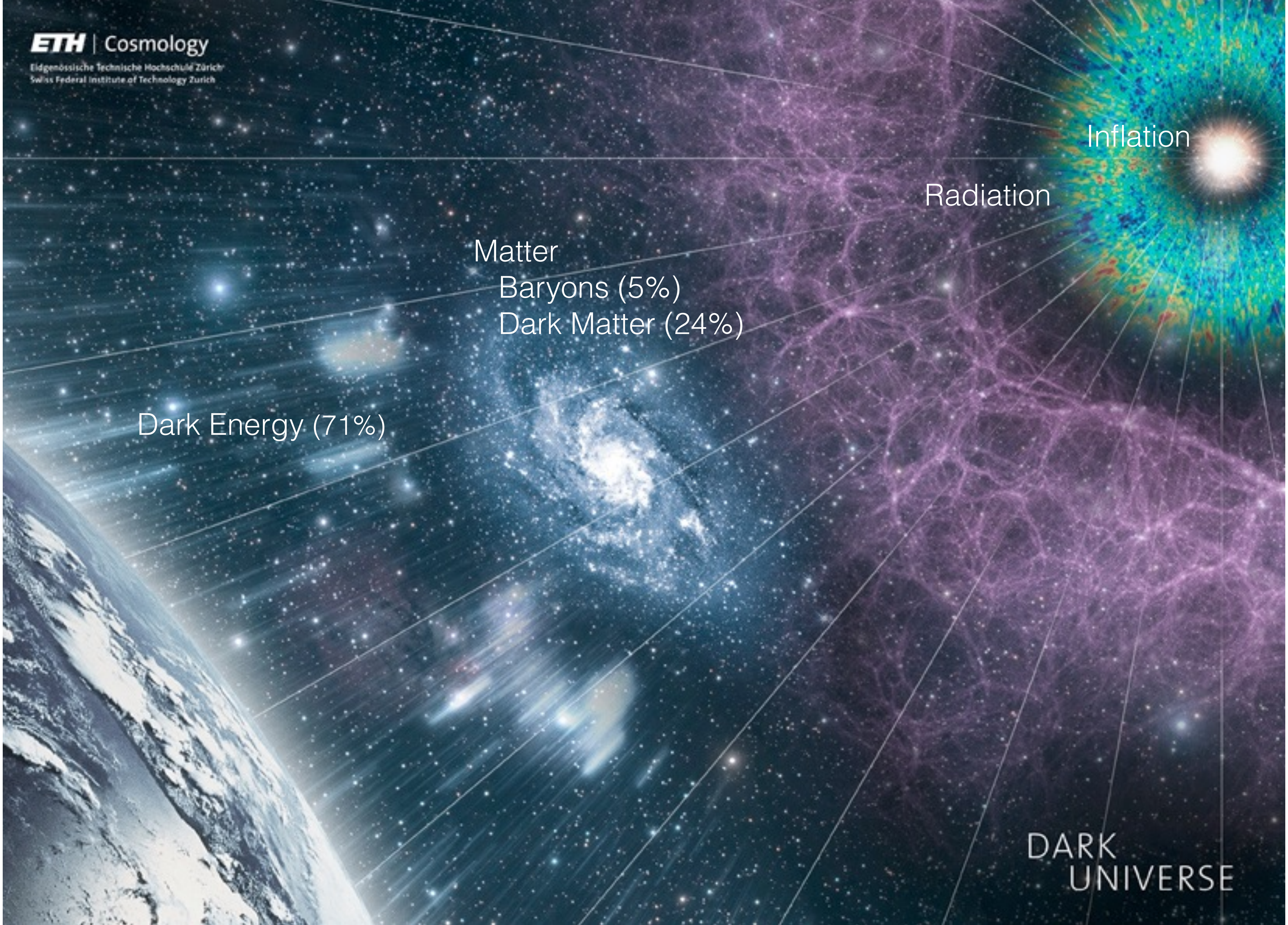
ΛCDM & Beyond

Adam Amara

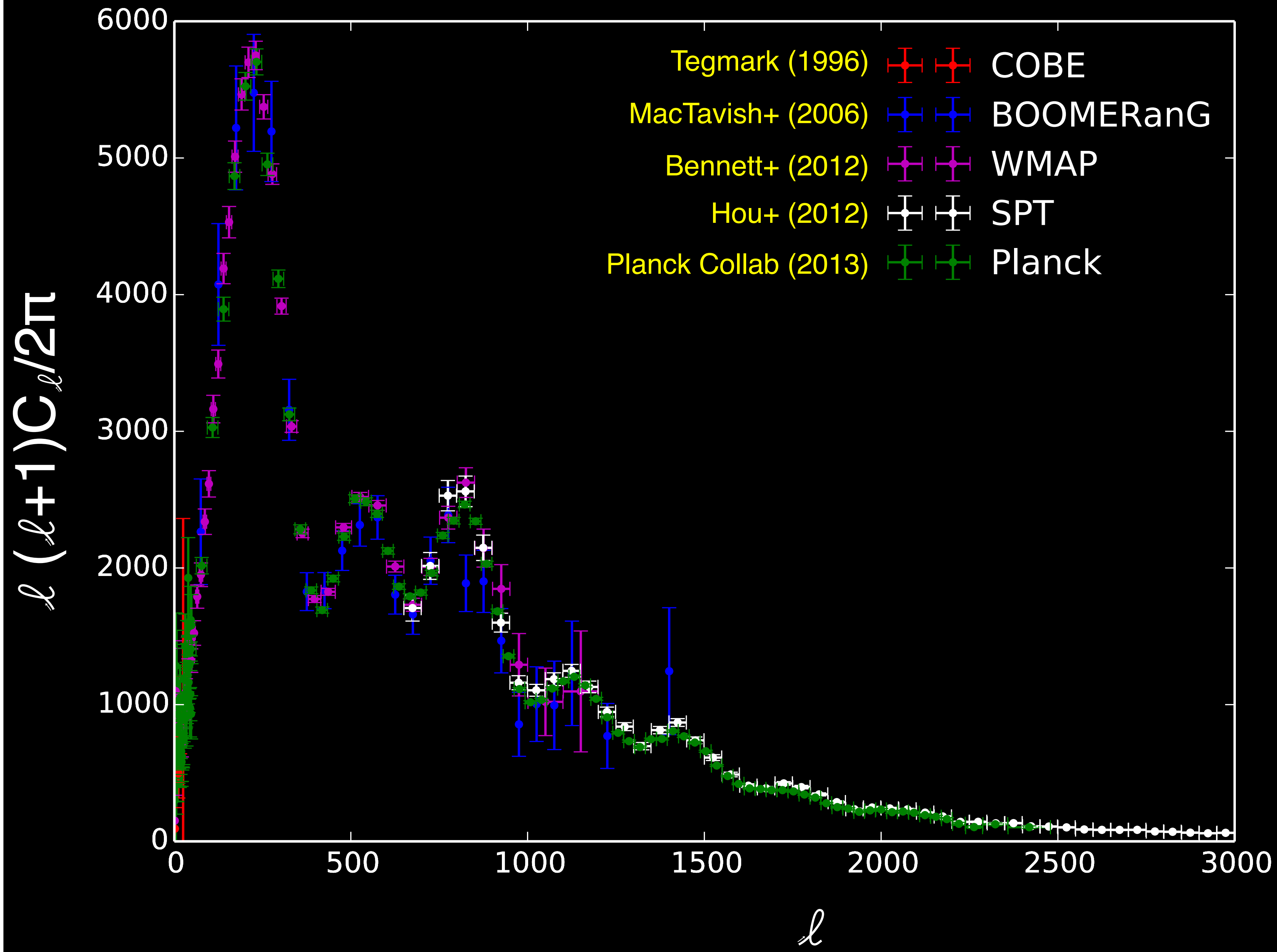
ETH zürich

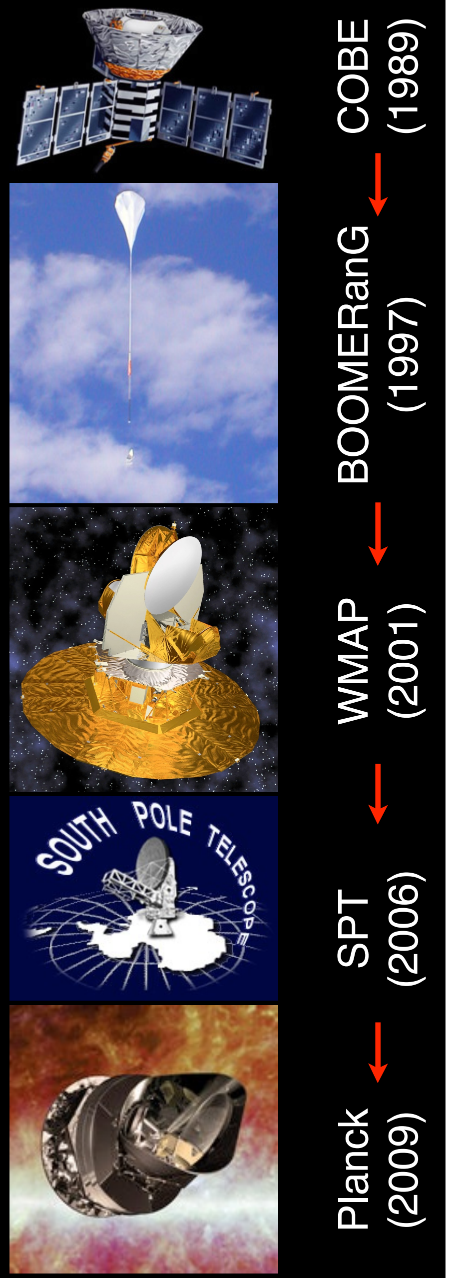
09/15

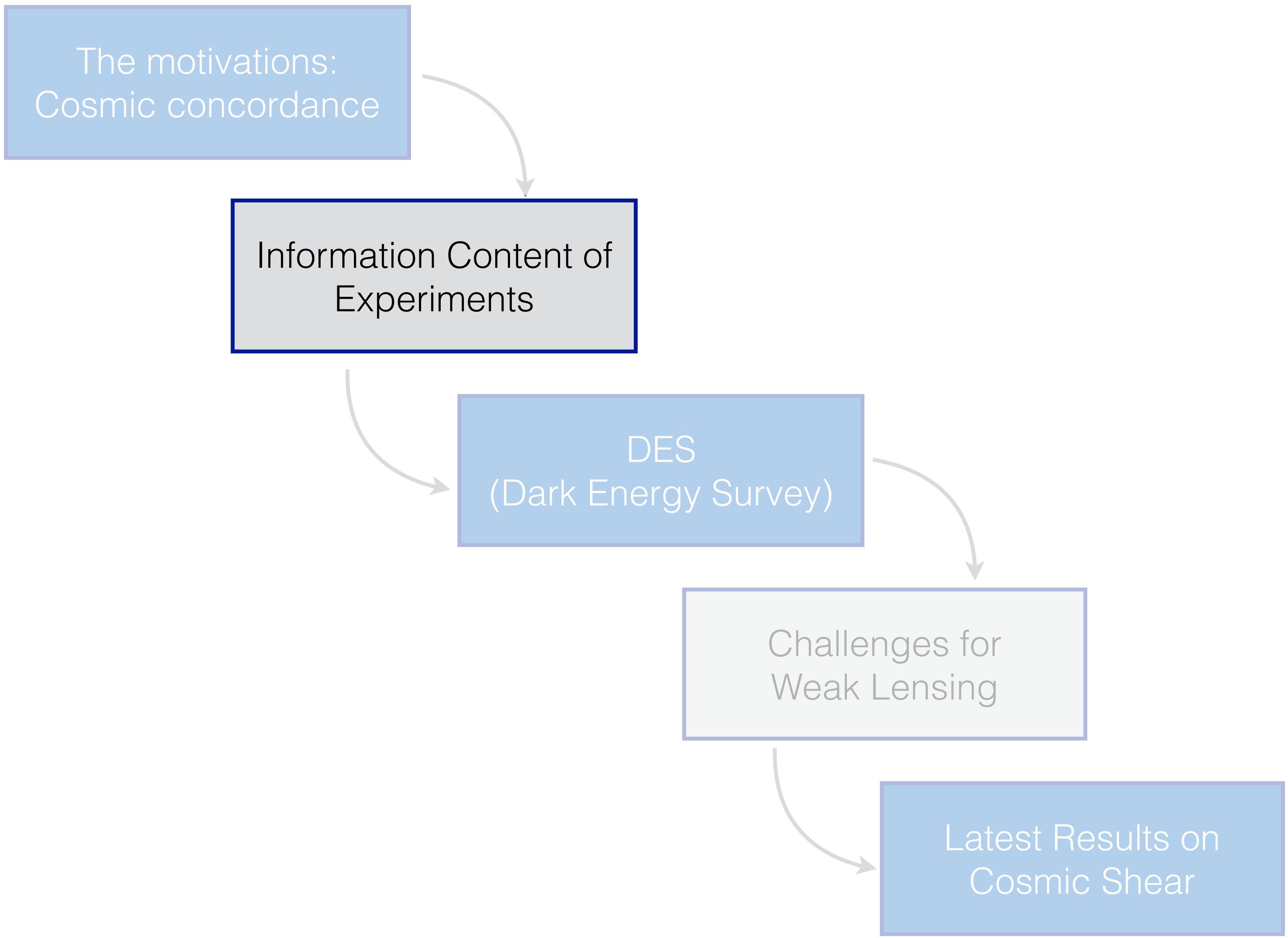

The motivations:
Cosmic concordance
Information Content of
Experiments
DES
(Dark Energy Survey)
Challenges for
Weak Lensing
Latest Results on
Cosmic Shear


ETH | Cosmology
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
Inflation
Radiation
Matter
Baryons (5%)
Dark Matter (24%)
Dark Energy (71%)
DARK
UNIVERSE

Cosmic Microwave Background






The motivations:
Cosmic concordance
Information Content of
Experiments
DES
(Dark Energy Survey)
Challenges for
Weak Lensing
Latest Results on
Cosmic Shear

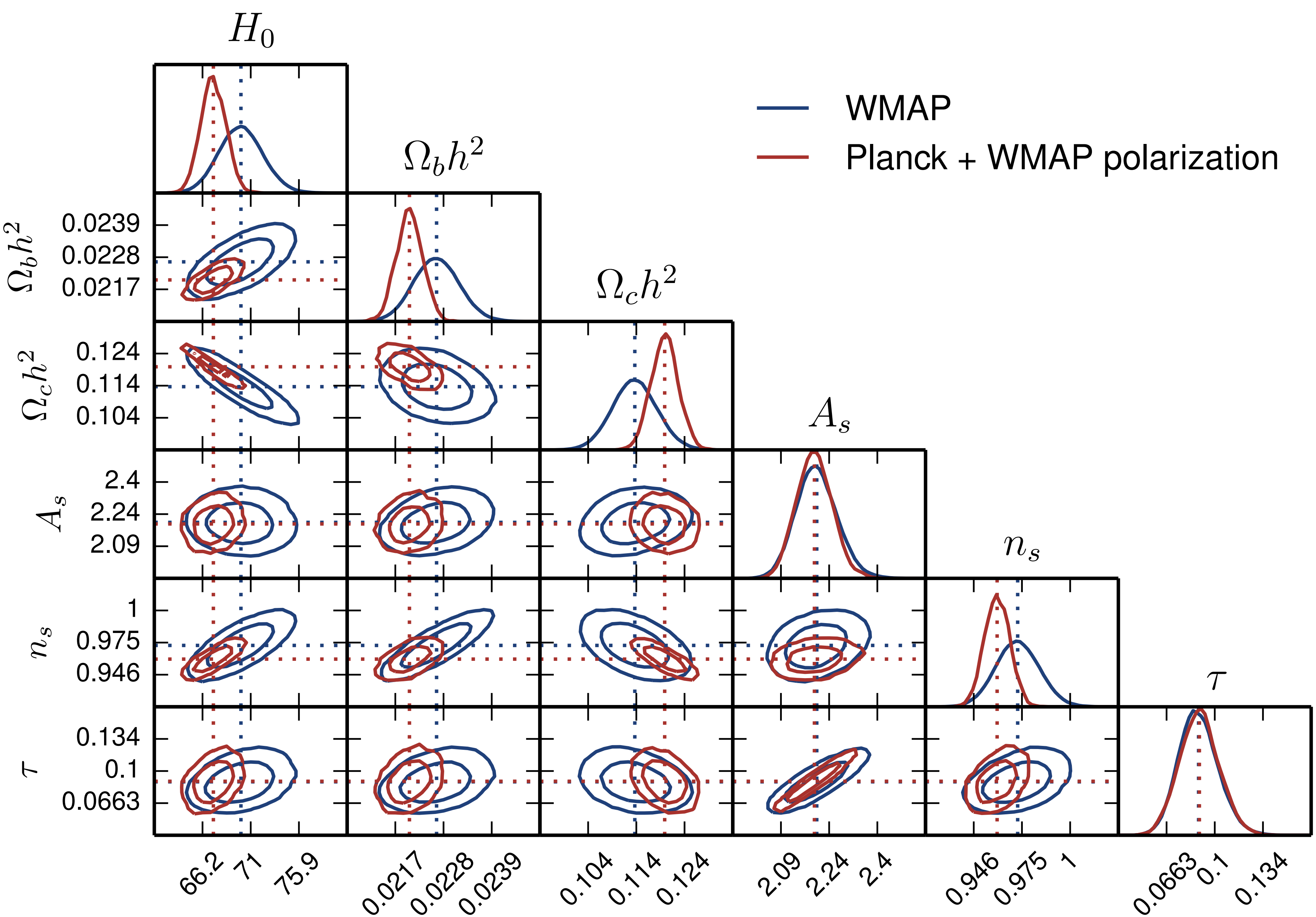
WMAP 9

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	$0.7135^{+0.0095}_{-0.0096}$
$10^9 \Delta^2_{\mathcal{R}}$	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)

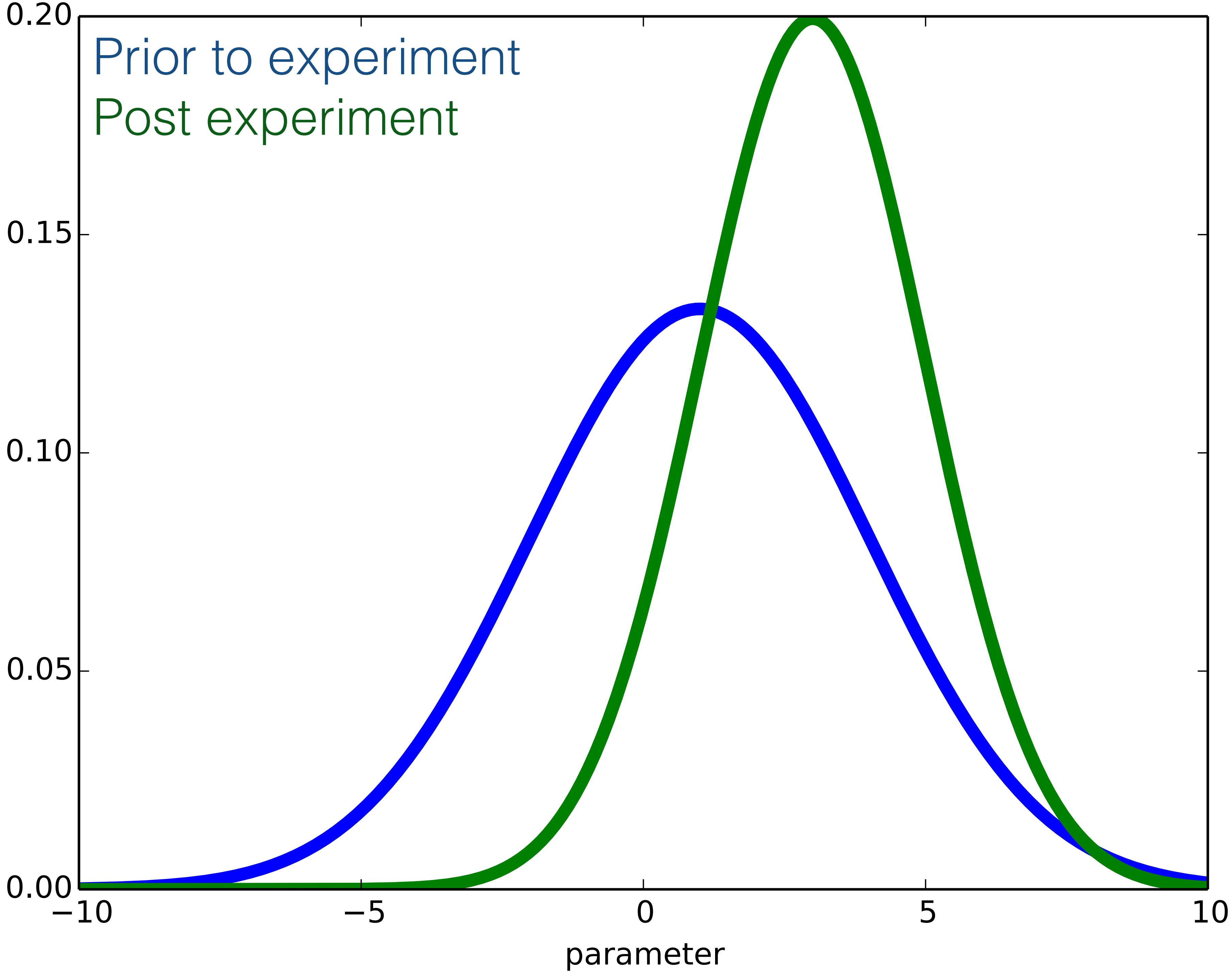
Parameter	*Planck*+WP Best fit	*Planck*+WP 68% limits	*Planck*+WP+highL Best fit	*Planck*+WP+highL 68% limits	*Planck*+lensing+WP+highL Best fit	*Planck*+lensing+WP+highL 68% limits	*Planck*+WP+highL+BAO Best fit	*Planck*+WP+highL+BAO 68% limits
$\Omega_b h^2$	0.022032	0.02205 ± 0.00028	0.022069	0.02207 ± 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
$100\theta_{MC}$	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


H_0
$\Omega_b h^2$
$\Omega_c h^2$
A_s
n_s
τ
WMAP
Planck + WMAP polarization
0.0239
0.0228
0.0217
0.124
0.114
0.104
2.4
2.24
2.09
1
0.975
0.946
0.134
0.1
0.0663
66.2
71
75.9

What are the central values?

Have things changed?

Are things consistent?



Prior to experiment
Post experiment
0.20
0.15
0.10
0.05
0.00
−10
−5
0
5
10
parameter

RELATIVE ENTROPY

Constraints from Data A

neter transformations

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

≧0

Constraints from Data A and B

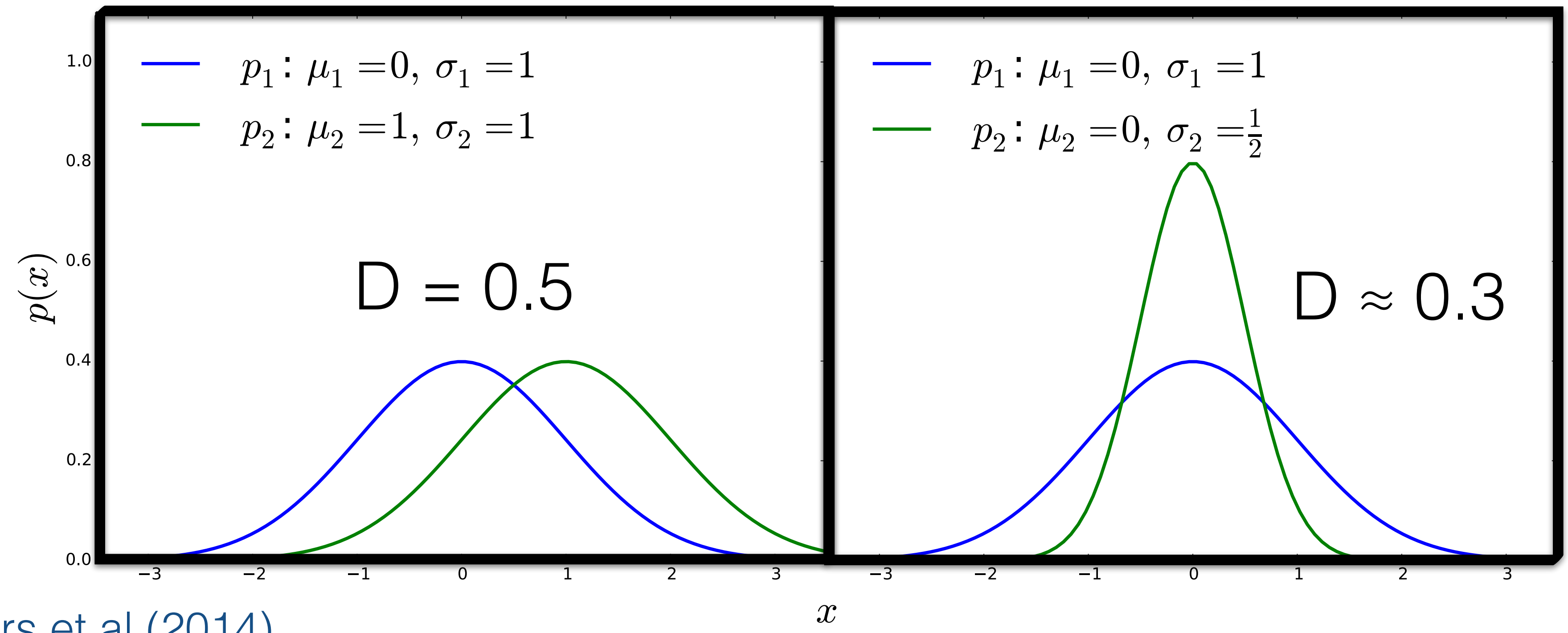
equals P_2

Seehars et al (2014)

Kullback & Leibler (1951)

NORMAL DISTRIBUTIONS

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



Seehars et al (2014)

NORMAL DISTRIBUTIONS & LINEAR MODEL

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

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

$\langle D \rangle$ ⟷ **Expected relative entropy**

Seehars et al (2014)

APPLICATION TO WMAP CONSTRAINTS

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	$0.7135^{+0.0095}_{-0.0096}$
$10^9 \Delta^2_{\mathcal{R}}$	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

Data combination[a]			D	$\langle D \rangle$	S	$S/\sigma(D)$
WMAP	$\rightarrow$	WMAP + eCMB	2.1	1.7	0.4	0.5
WMAP + eCMB	$\rightarrow$	WMAP + eCMB + BAO	1.3	1.0	0.3	0.8
WMAP + eCMB	$\rightarrow$	WMAP + eCMB + H0	0.4	0.3	0.1	0.1
WMAP + eCMB	$\rightarrow$	WMAP + eCMB + BAO + H0	0.9	1.1	-0.2	-0.2

WMAP: Bennett+ 2013
eCMB: SPT (Keisler+ 2011) and ACT (Das+ 2011)
BAO: 6dFGS (Beutler+ 2011), SDSS (Padmanabhan+ 2012, Anderson+ 2012), and WiggleZ (Blake+ 2012)
H0: Riess+ 2009

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	$0.7135^{+0.0095}_{-0.0096}$
$10^9 \Delta^2_{\mathcal{R}}$	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)

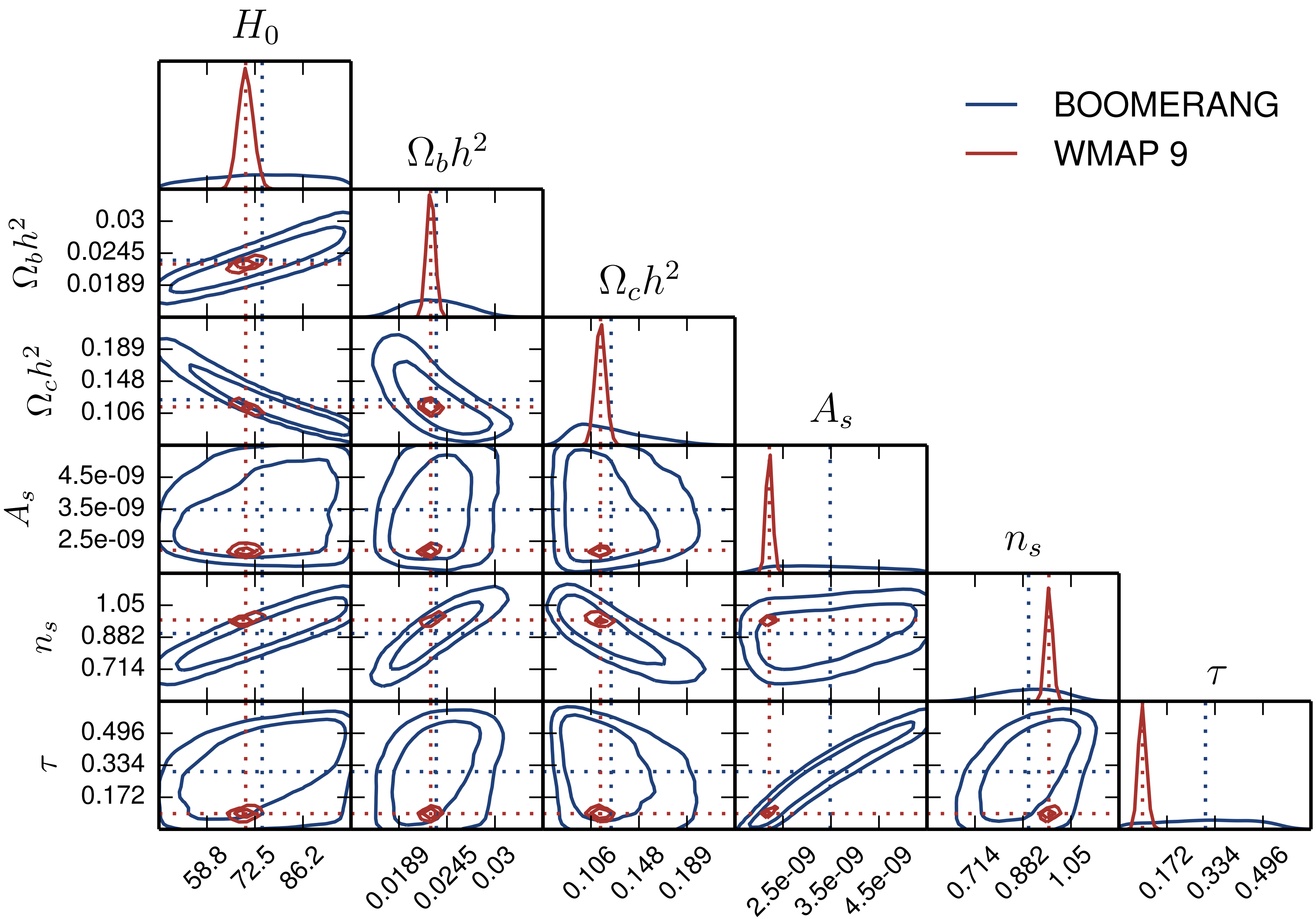
Parameter	*Planck*+WP Best fit	*Planck*+WP 68% limits	*Planck*+WP+highL Best fit	*Planck*+WP+highL 68% limits	*Planck*+lensing+WP+highL Best fit	*Planck*+lensing+WP+highL 68% limits	*Planck*+WP+highL+BAO Best fit	*Planck*+WP+highL+BAO 68% limits
$\Omega_b h^2$	0.022032	0.02205 ± 0.00028	0.022069	0.02207 ± 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
$100\theta_{MC}$	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

APPLICATION TO CMB DATA

Data combination[a]			Gaussian approximation[b]				
			D	$\langle D \rangle$	S	$S/\sigma(D)$	p-value[d]
BOOMERANG	→	WMAP 9	22.5	18.4	4.1	1.6	0.07
WMAP 3	→	WMAP 5	7.7	2.2	5.5	5.3	0.001
WMAP 5	→	WMAP 7	1.4	1.0	0.4	0.6	0.2
WMAP 7	→	WMAP 9	1.5	1.2	0.3	0.4	0.3
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
WMAP 9 + SPT	→	Planck + WP + SPT	27.8	6.6	21.2	6.5	0.0002
Planck	→	Planck + WP	1.2	2.2	−0.9	−0.9	0.08

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
SPT: Story et al. (2013)
Planck: Ade et al. (2013)

Seehars et al (2014)



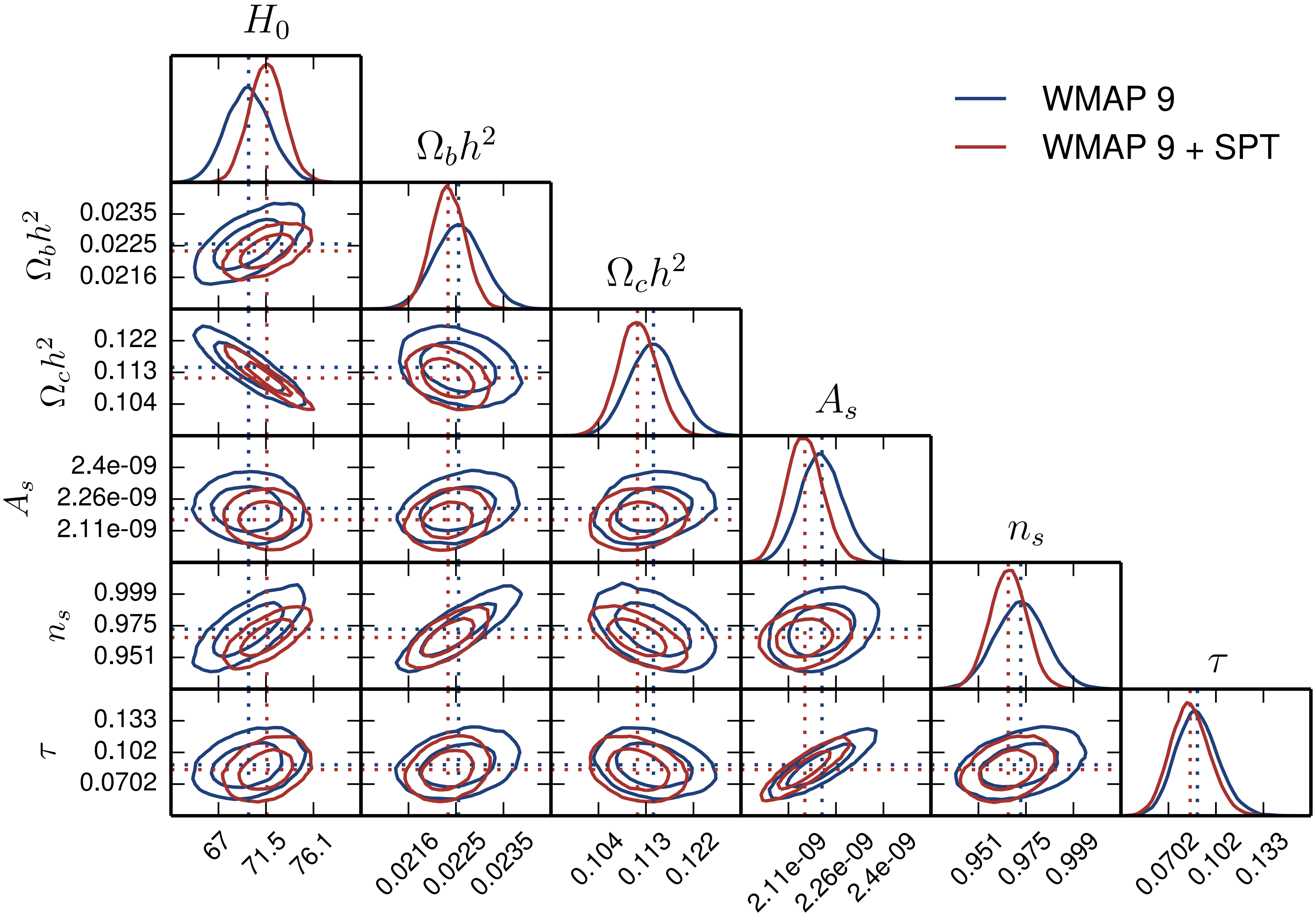
Seehars et al (2014)

APPLICATION TO CMB DATA

Data combination[a]			Gaussian approximation[b]				
			D	$\langle D \rangle$	S	$S/\sigma(D)$	p-value[d]
BOOMERANG	→	WMAP 9	22.5	18.4	4.1	1.6	0.07
WMAP 3	→	WMAP 5	7.7	2.2	5.5	5.3	0.001
WMAP 5	→	WMAP 7	1.4	1.0	0.4	0.6	0.2
WMAP 7	→	WMAP 9	1.5	1.2	0.3	0.4	0.3
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
WMAP 9 + SPT	→	Planck + WP + SPT	27.8	6.6	21.2	6.5	0.0002
Planck	→	Planck + WP	1.2	2.2	−0.9	−0.9	0.08

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
SPT: Story et al. (2013)
Planck: Ade et al. (2013)

Seehars et al (2014)



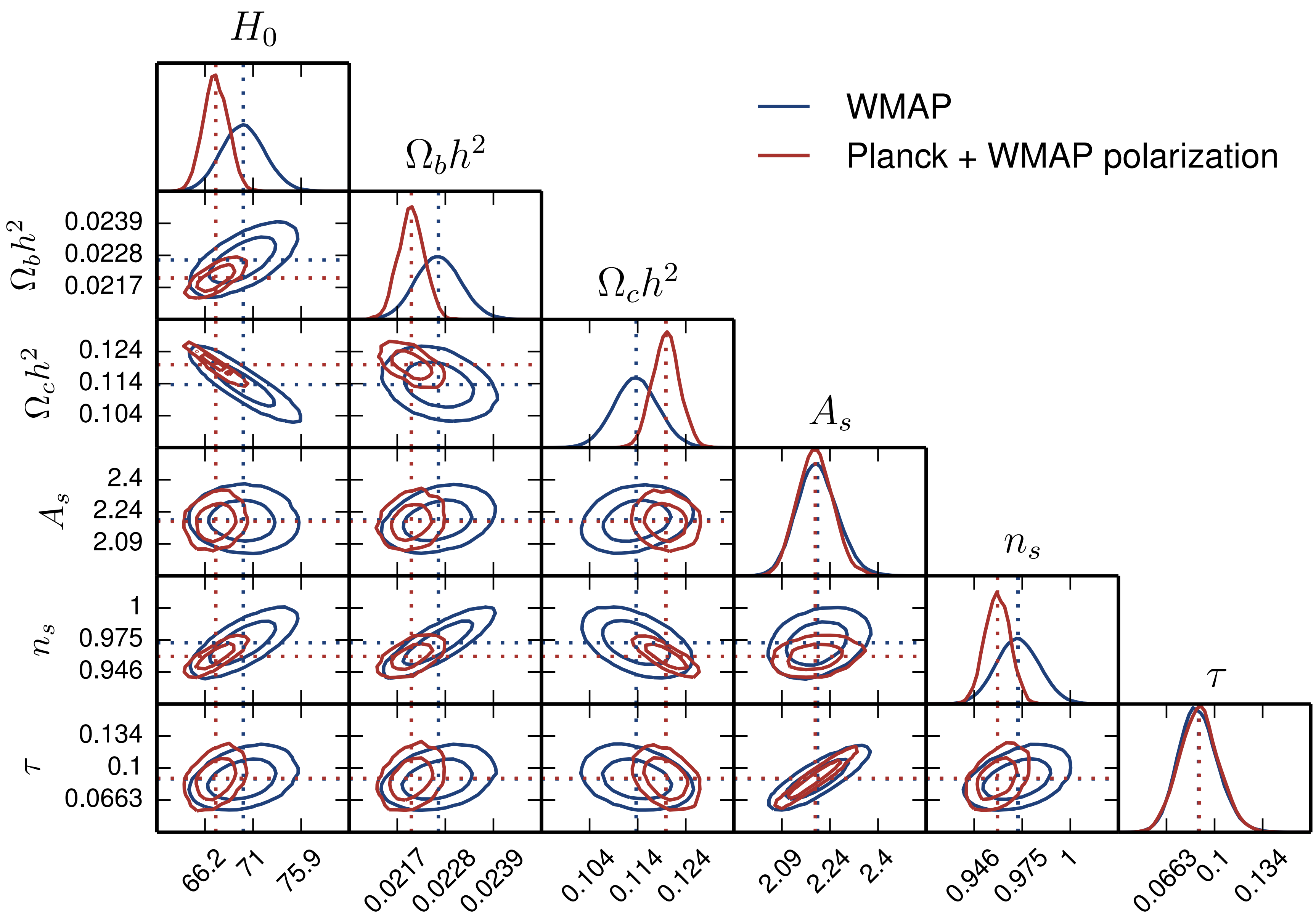
Seehars et al (2014)

APPLICATION TO CMB DATA

Data combination[a]			Gaussian approximation[b]				
			D	$\langle D \rangle$	S	$S/\sigma(D)$	p-value[d]
BOOMERANG	→	WMAP 9	22.5	18.4	4.1	1.6	0.07
WMAP 3	→	WMAP 5	7.7	2.2	5.5	5.3	0.001
WMAP 5	→	WMAP 7	1.4	1.0	0.4	0.6	0.2
WMAP 7	→	WMAP 9	1.5	1.2	0.3	0.4	0.3
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
WMAP 9 + SPT	→	Planck + WP + SPT	27.8	6.6	21.2	6.5	0.0002
Planck	→	Planck + WP	1.2	2.2	−0.9	−0.9	0.08

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
SPT: Story et al. (2013)
Planck: Ade et al. (2013)

Seehars et al (2014)



Seehars et al (2014)

APPLICATION TO CMB DATA

Data combination[a]			Gaussian approximation[b]				
			D	$\langle D \rangle$	S	$S/\sigma(D)$	p-value[d]
BOOMERANG	$\rightarrow$	WMAP 9	22.5	18.4	4.1	1.6	0.07
WMAP 3	$\rightarrow$	WMAP 5	7.7	2.2	5.5	5.3	0.001
WMAP 5	$\rightarrow$	WMAP 7	1.4	1.0	0.4	0.6	0.2
WMAP 7	$\rightarrow$	WMAP 9	1.5	1.2	0.3	0.4	0.3
WMAP 9	$\rightarrow$	WMAP 9 + SPT	4.3	2.1	2.2	2.1	0.04
WMAP 9	$\rightarrow$	Planck + WP	29.8	7.9	21.9	6.5	0.0002
WMAP 9 + SPT	$\rightarrow$	Planck + WP + SPT	27.8	6.6	21.2	6.5	0.0002
Planck	$\rightarrow$	Planck + WP	1.2	2.2	−0.9	−0.9	0.08

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
SPT: Story et al. (2013)
Planck: Ade et al. (2013)

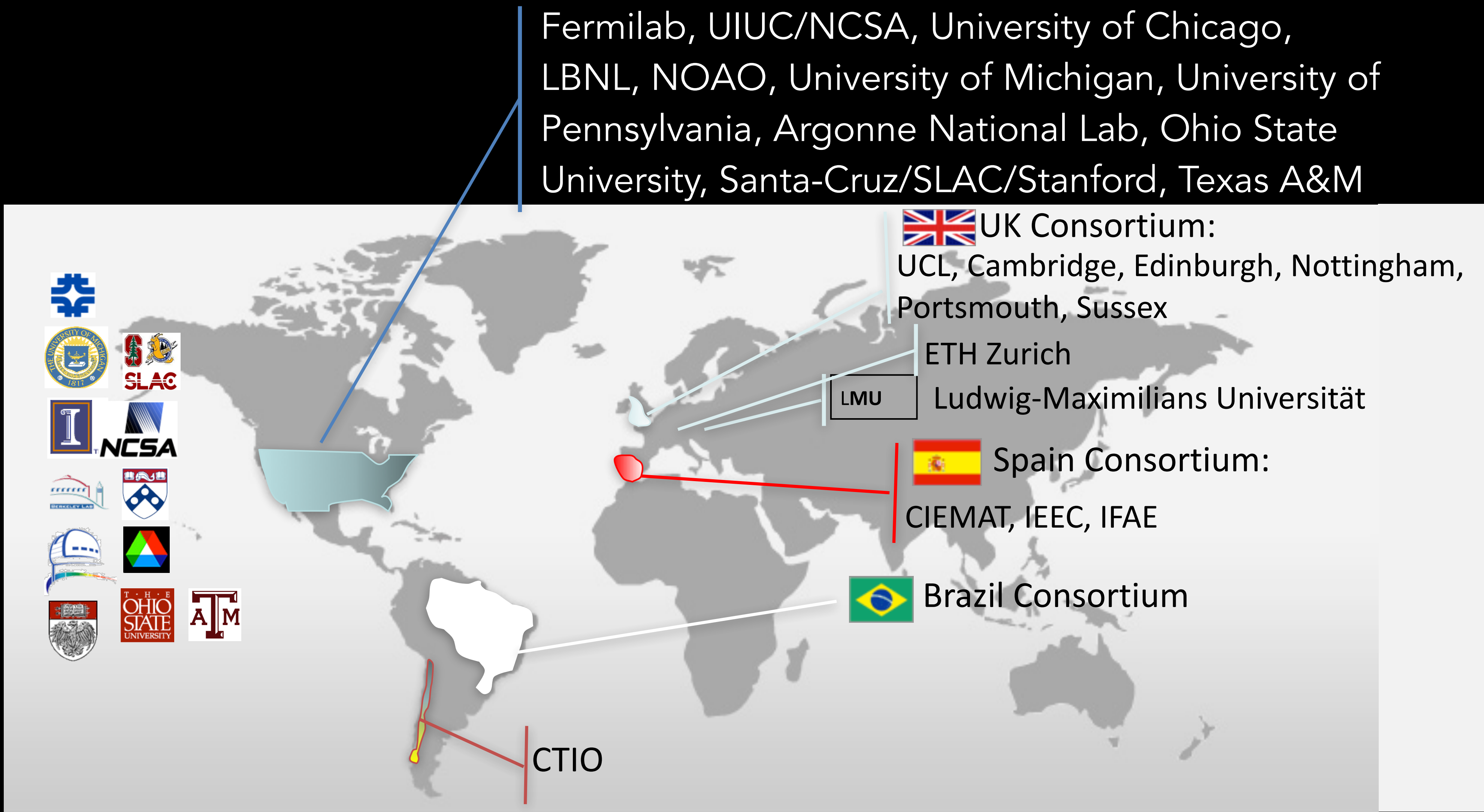
Seehars et al (2014)

Where to next?

- The motivations: Cosmic concordance
- Information Content of Experiments
- **DES (Dark Energy Survey)**
- Challenges for Weak Lensing
- Latest Results on Cosmic Shear

The Dark Energy Survey

Dark Energy Survey Collaboration



Overview

Blanco telescope at CTIO

- 4m primary focus
- built new dedicated camera - 570 megapixel
- 2.2 deg^2 field of view
- thick CCDs for near infrared light

Two multiband surveys:

- 5000 deg sq. *grizY* to mag 24
- 30 deg^2 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

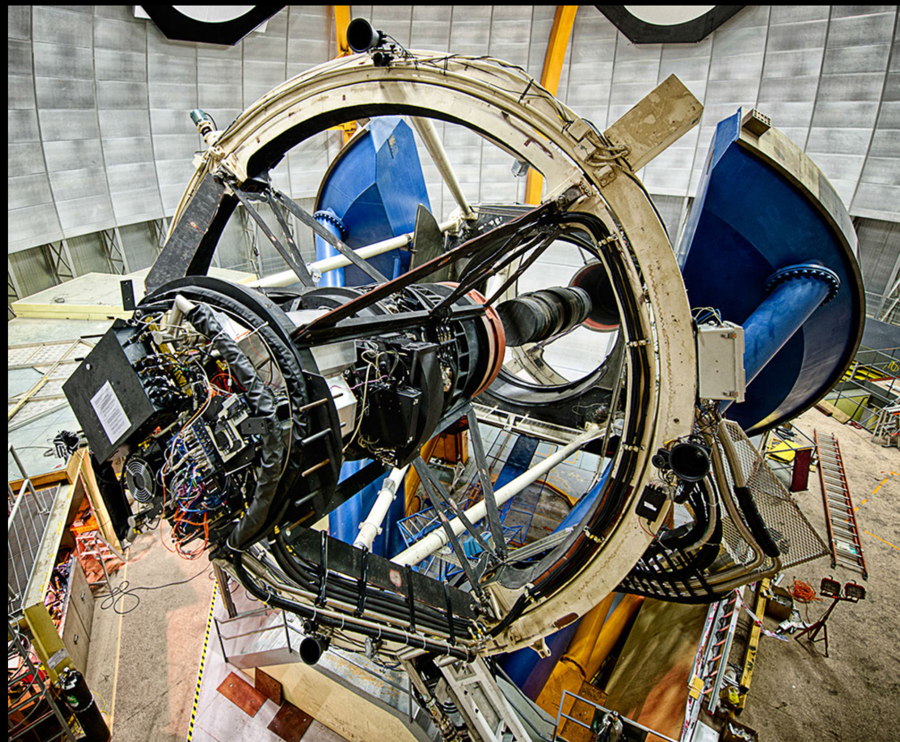
Survey: 2013-2018, 525 nights

The Dark Energy Survey

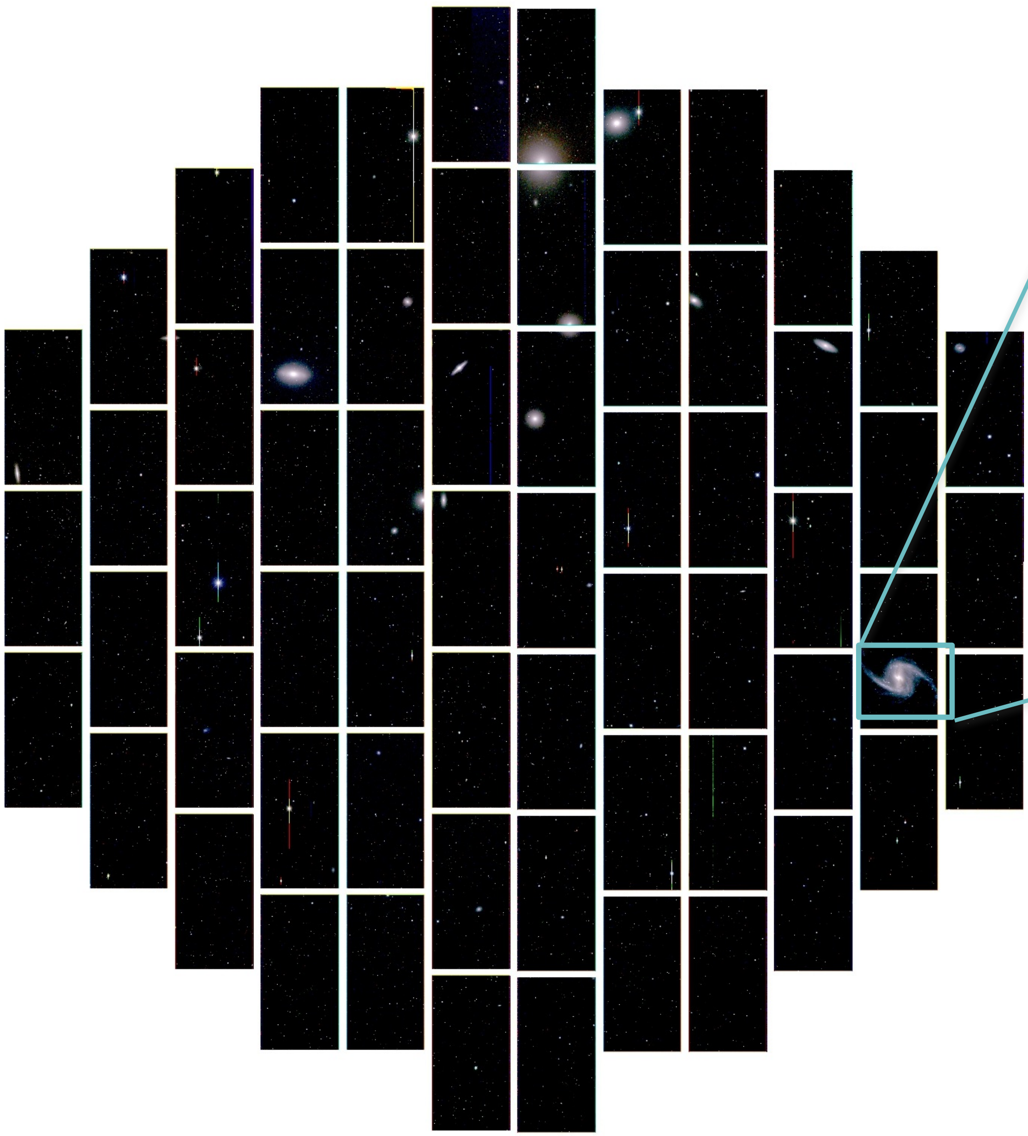
- Two surveys:
  - Wide fields - 5000 deg^2 in grizY to g=24
  - SN 1a - repeated visits over 30 deg^2

- Built new camera for CTIO Blanco telescope
  - 570 Mpixels
  - 3 deg^2 FOV
  - Facility instrument

- Five-year Survey
  - 525 nights (Aug - Feb)

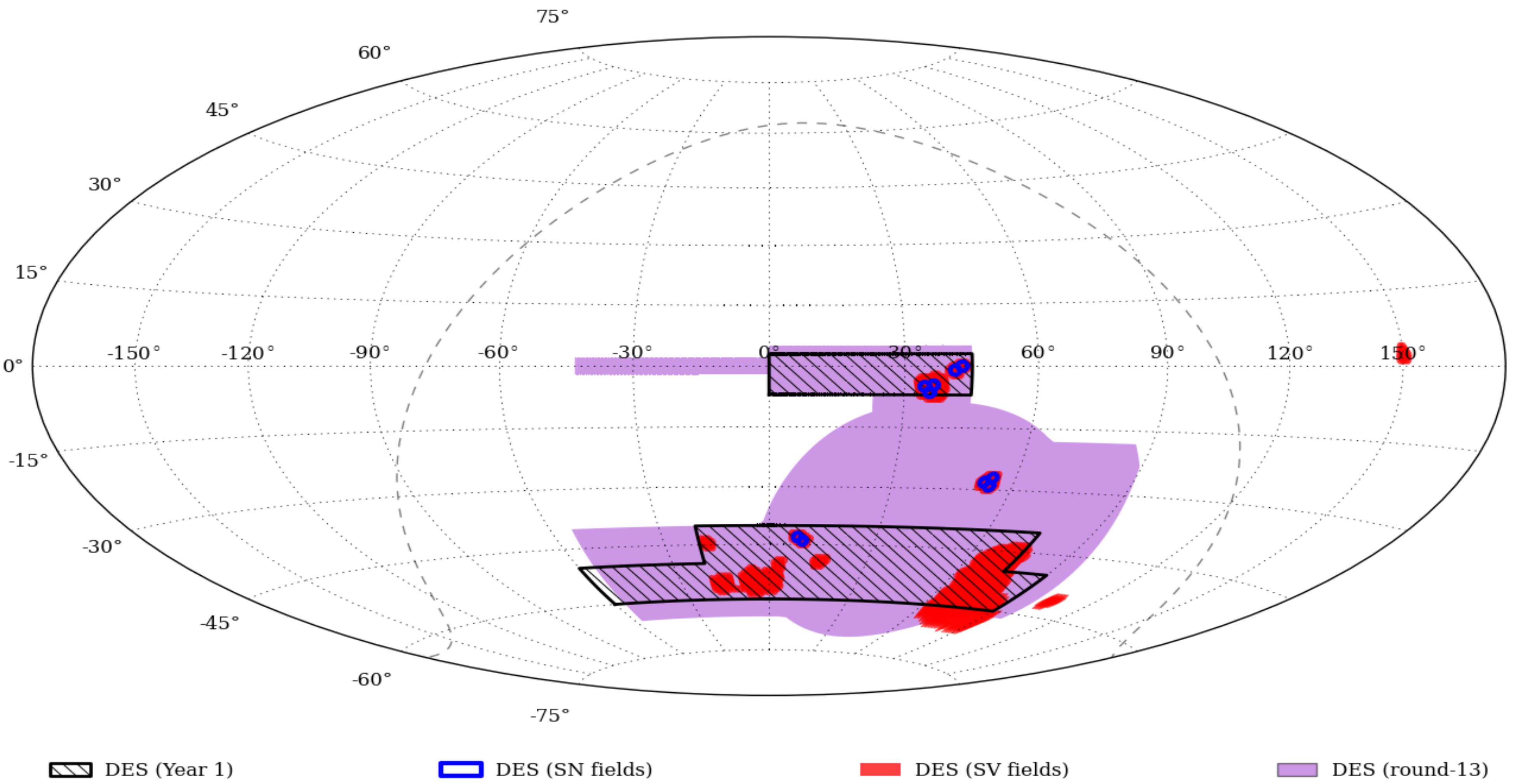


THE DARK ENERGY SURVEY



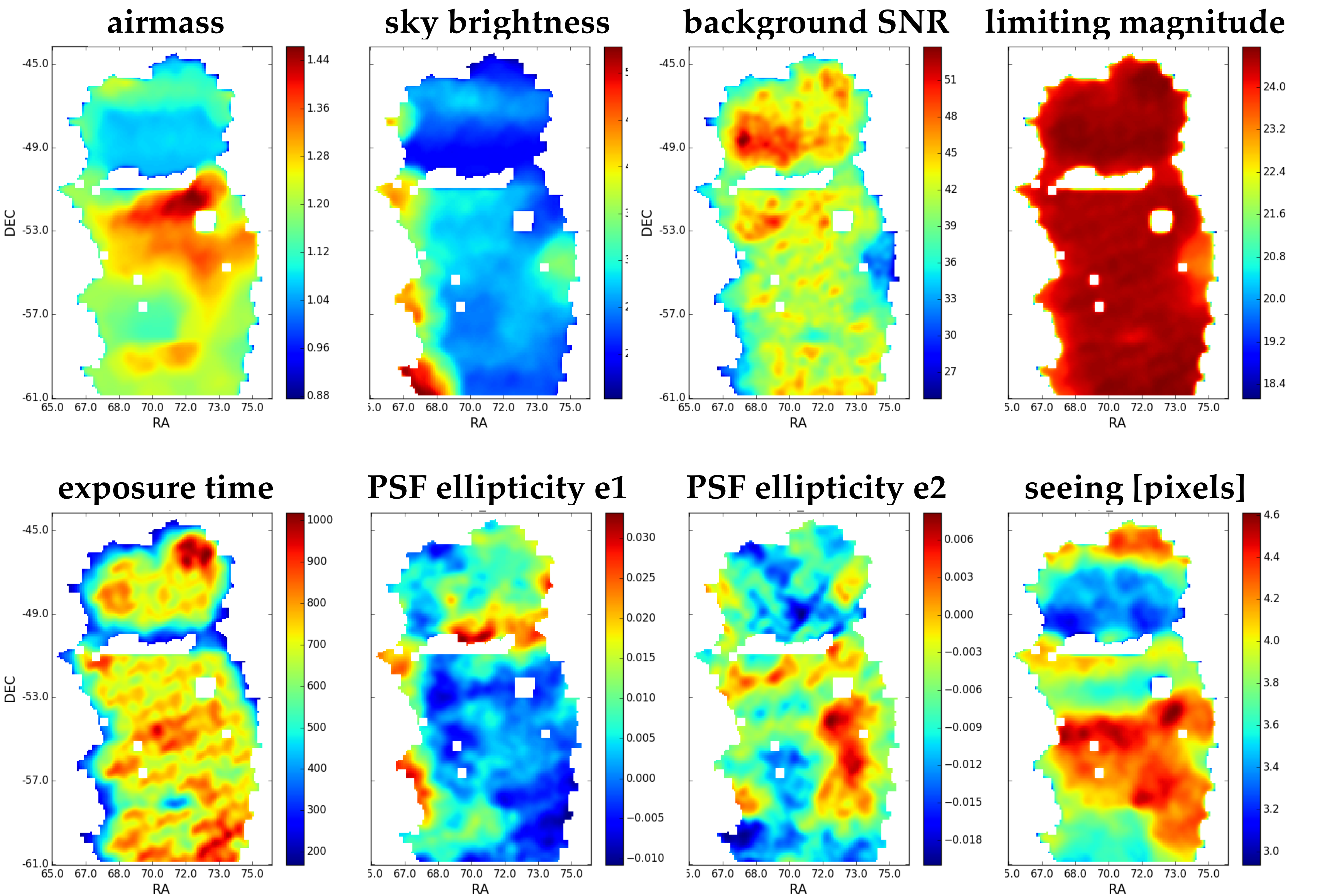
moon to scale

Footprint



year 0 (science validation) - 180 deg^2, 10 tilings (full depth)
year 1 - 2500 deg^2, 4 tilings, overlapping STP, VHS, BOSS
5 years - 5000 deg^2

Tracking Systematics Maps



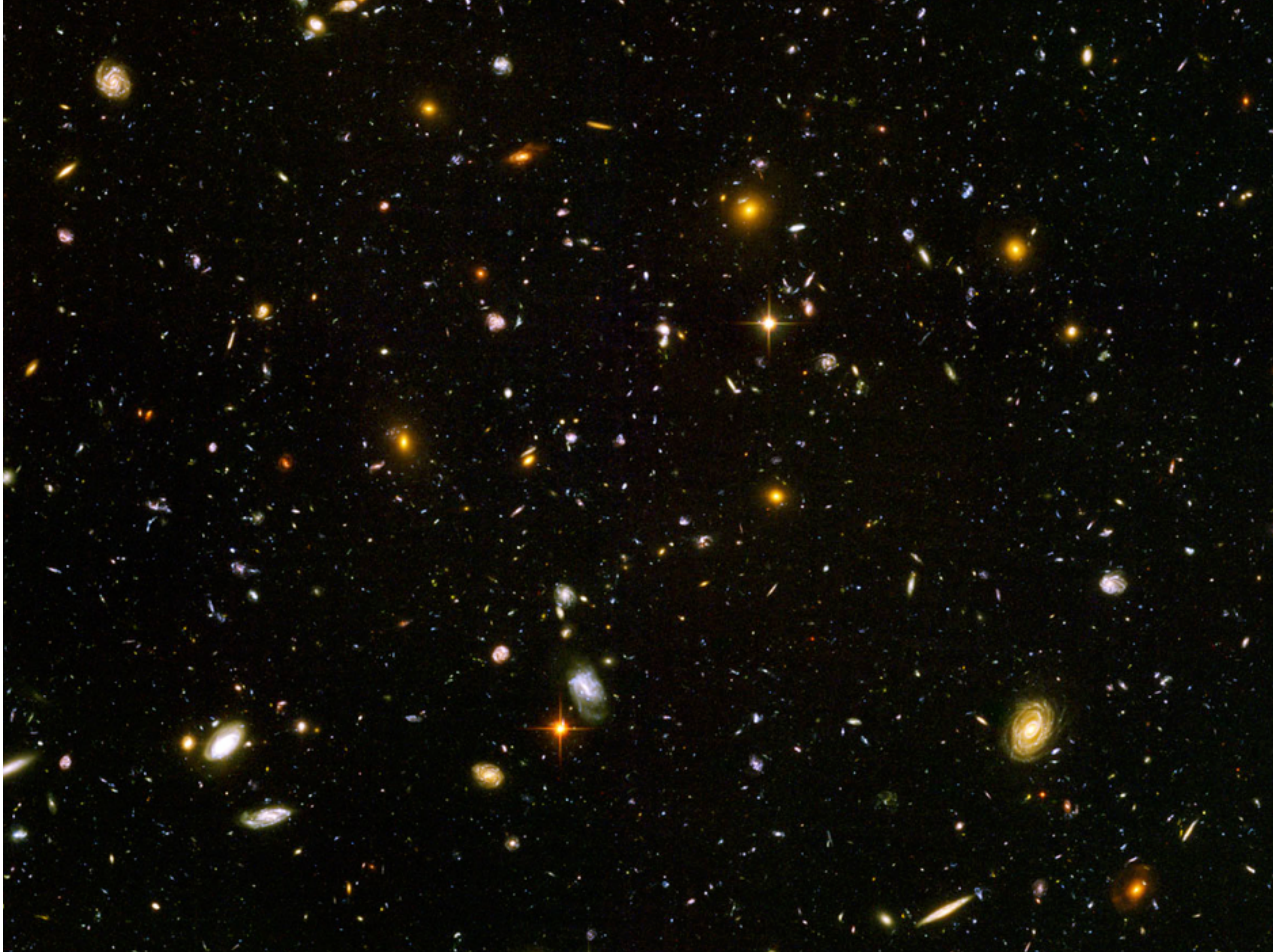
The motivations:
Cosmic concordance

Information Content of
Experiments

DES
(Dark Energy Survey)

Challenges for
Weak Lensing

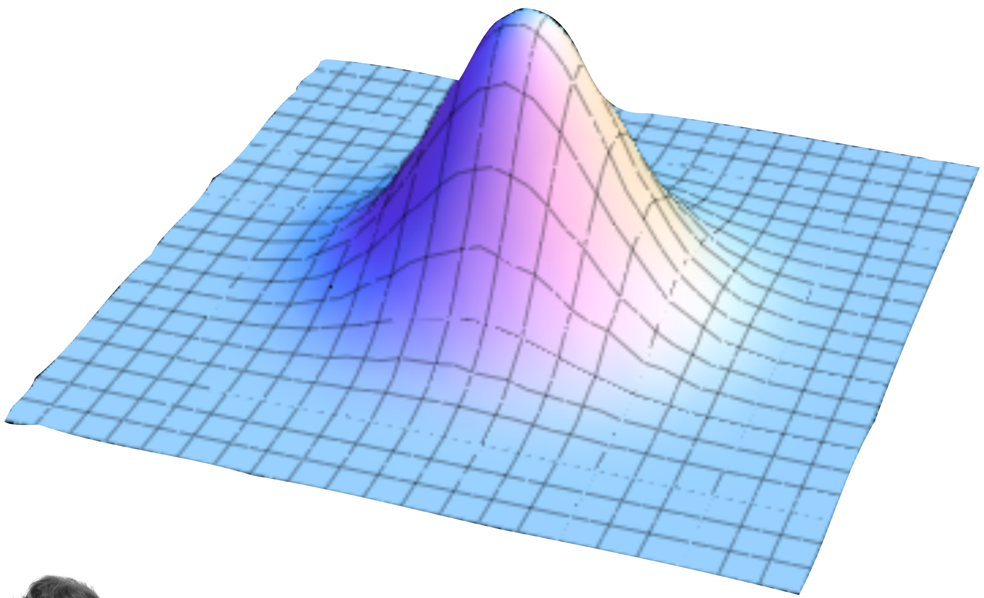
Latest Results on
Cosmic Shear

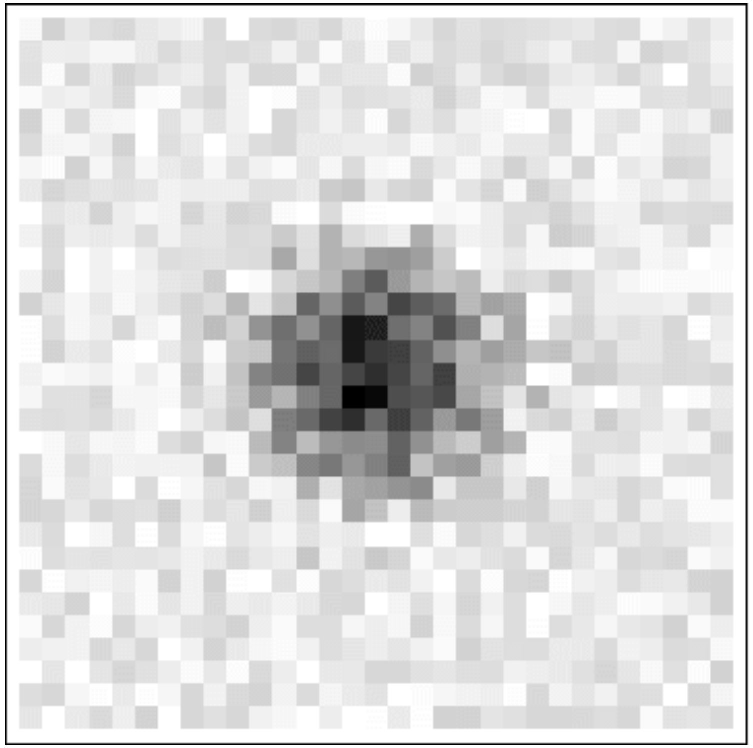


Shape Measurement Problems

Approach till now
Generic Shape measurement methods
Calculate calibration factor (minimising simulations)
Trend towards more complex methods

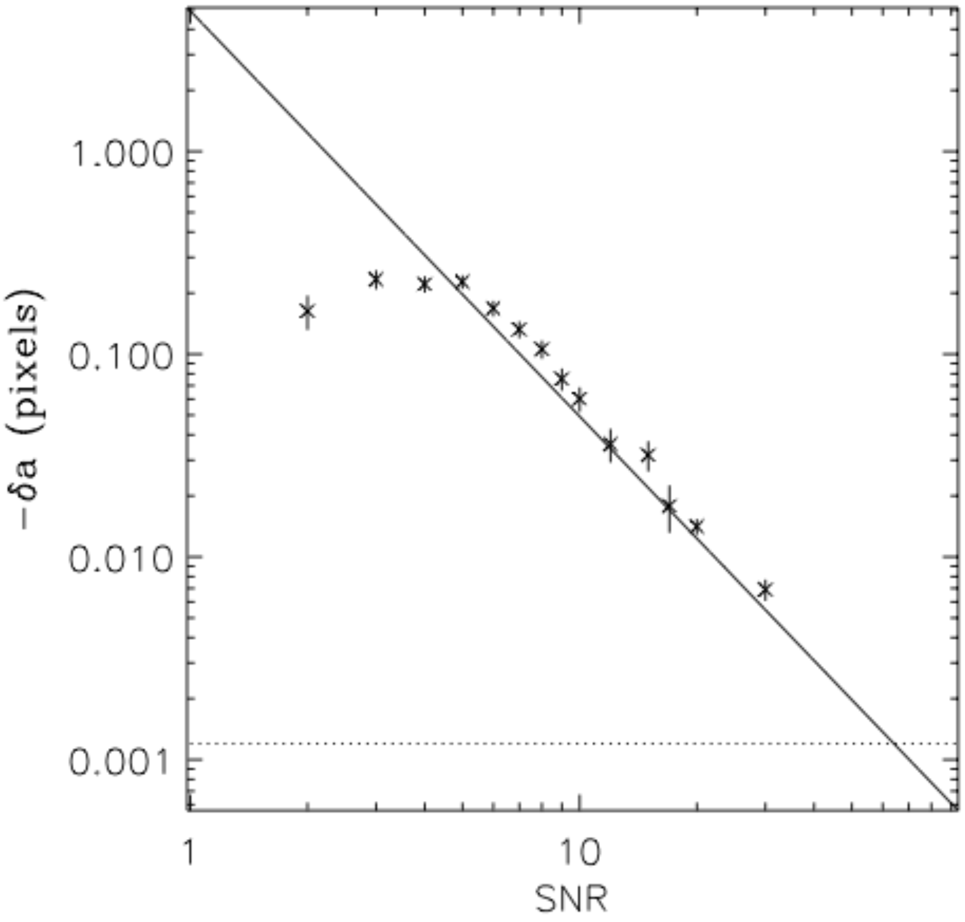
Toy Model: Measuring the Size of a 2D Gaussian





Refregier, AA, + 2013

Measurement Biases



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

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

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

Refregier, AA, + 2013

Shape Measurement Problems

Intrinsic galaxy (shape unknown)

Gravitational lensing causes a ***shear (g)***

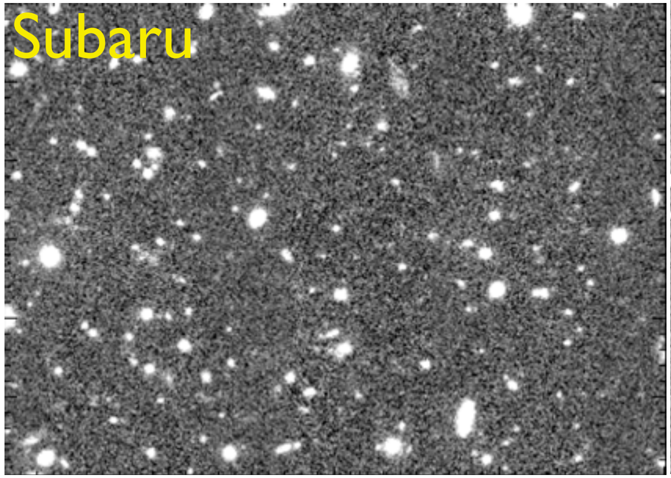
Atmosphere and telescope cause a convolution

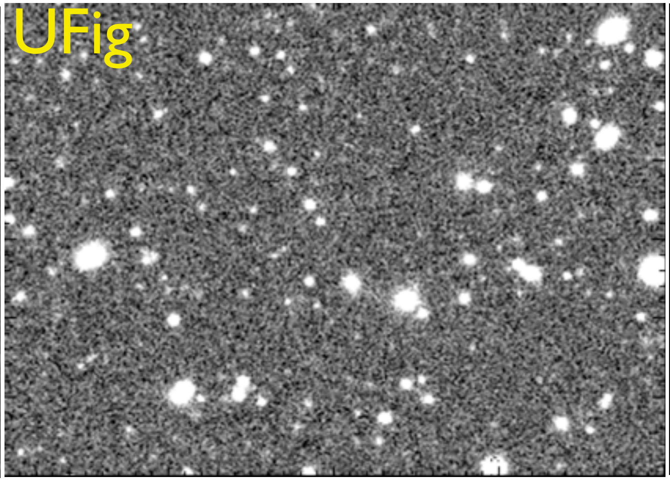
Detectors measure a pixelated image

Image also contains noise

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)

Ultra Fast Image Generator (UFig)





Speed the driving factor

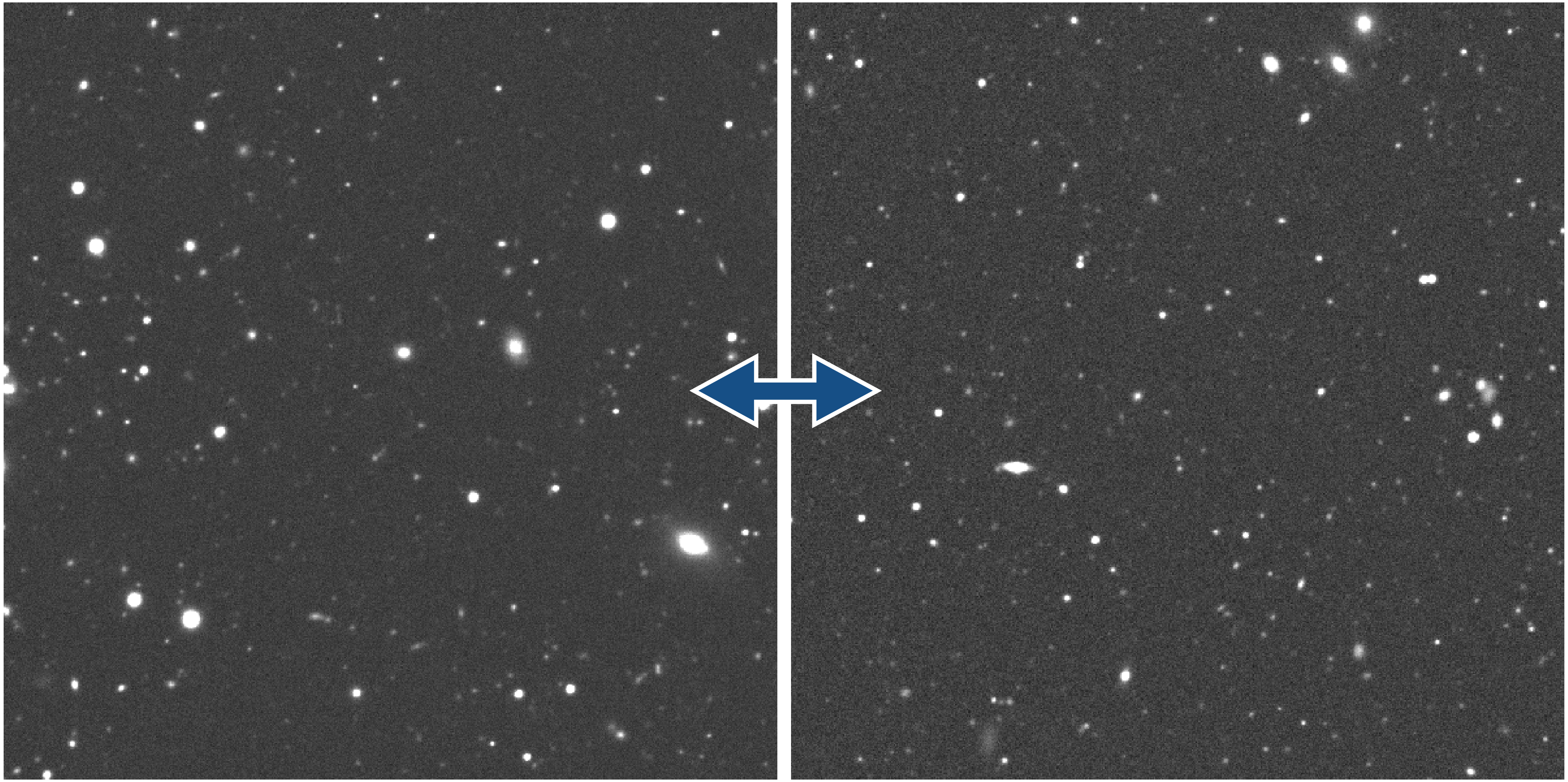
As fast as SExtractor (or faster)
Subaru Image (0.25 deg2,R~26,10k×8k) generated in:
- 30sec on a laptop
- 30μsec per galaxy

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

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

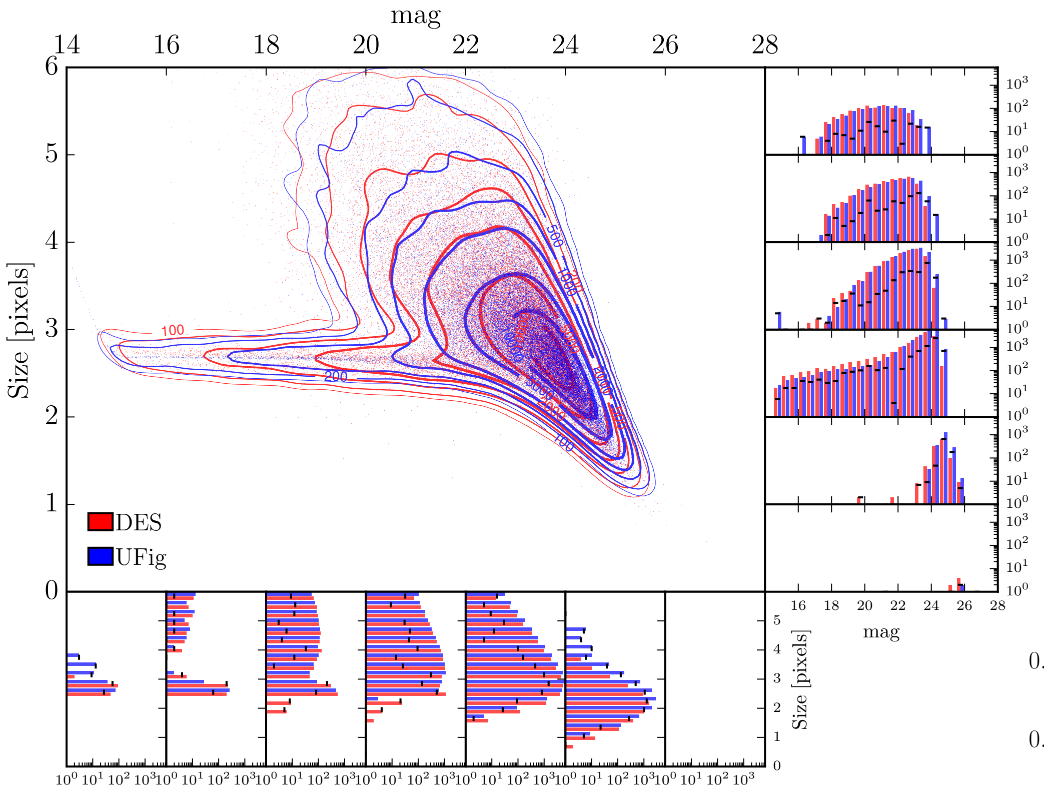
	Python (NumPy)	Numba	Cython	Nuitka (NumPy)	PyPy (NumPy)	numexpr (8 cores)	HOPE	C++
Fibonacci	57.4	65.7[a]	1.1	26.7	21.1	—	1.1	**1.0**
Quicksort	79.4	—[b]	4.6	61.0	45.8	—	1.1	**1.0**
Pi sum	27.2	**1.0**	1.1	13.0	**1.0**	—	**1.0**	**1.0**
10^{th}order	2.6	2.2	2.1	1.2	12.1	1.4	1.1	**1.0**
Simplify	1.4	1.5[ab]	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**

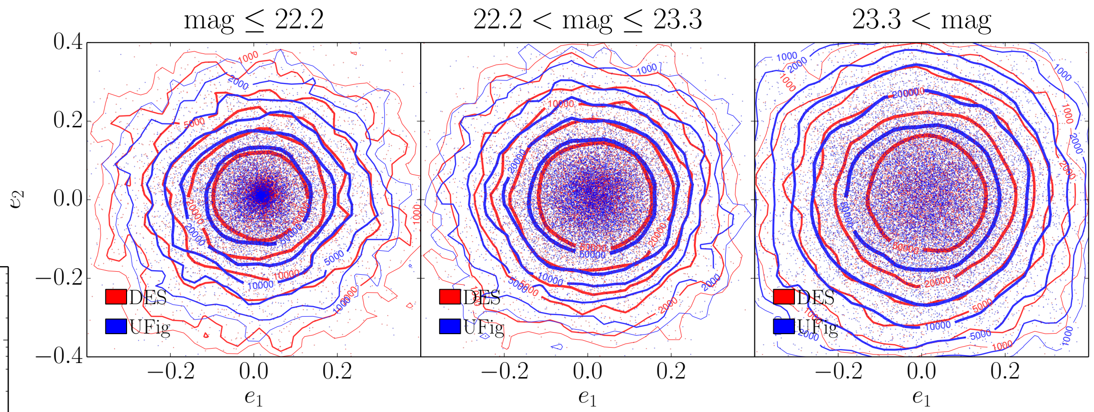
Calibrating Shear measurement

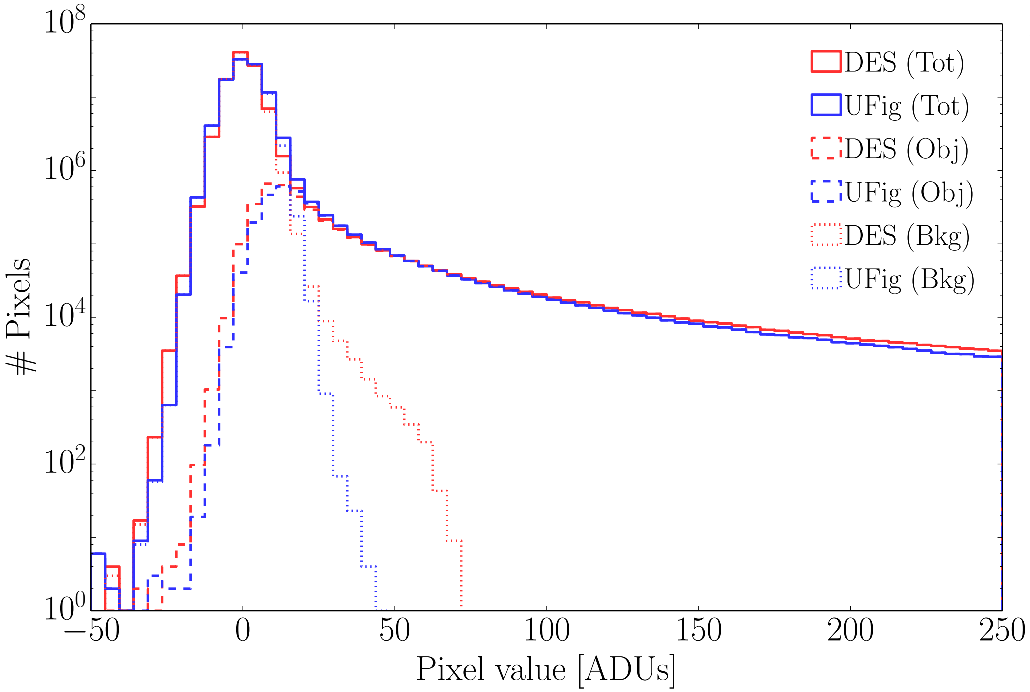


Bruderer et al (2015)

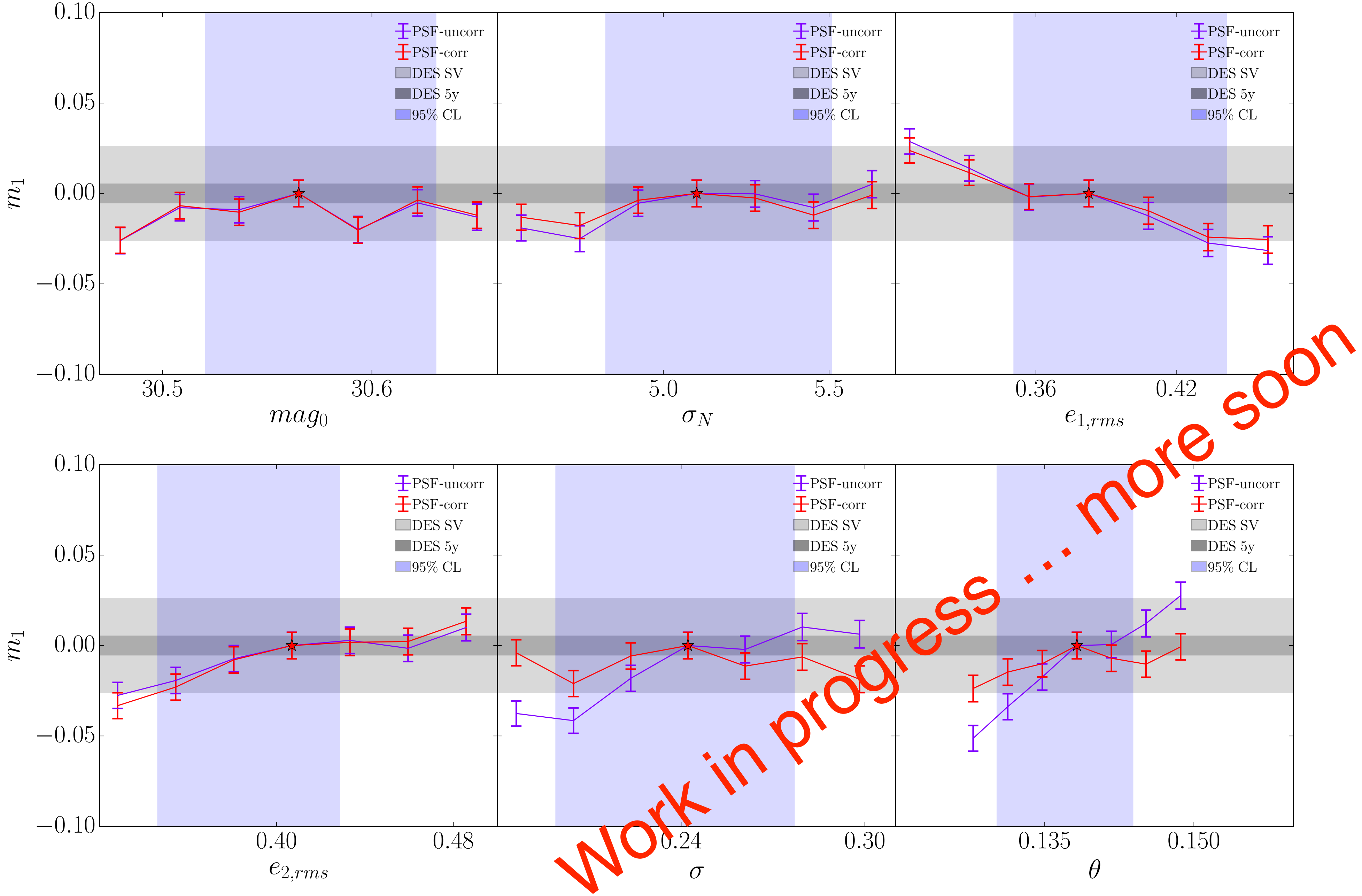
Bruderer et al (2015)

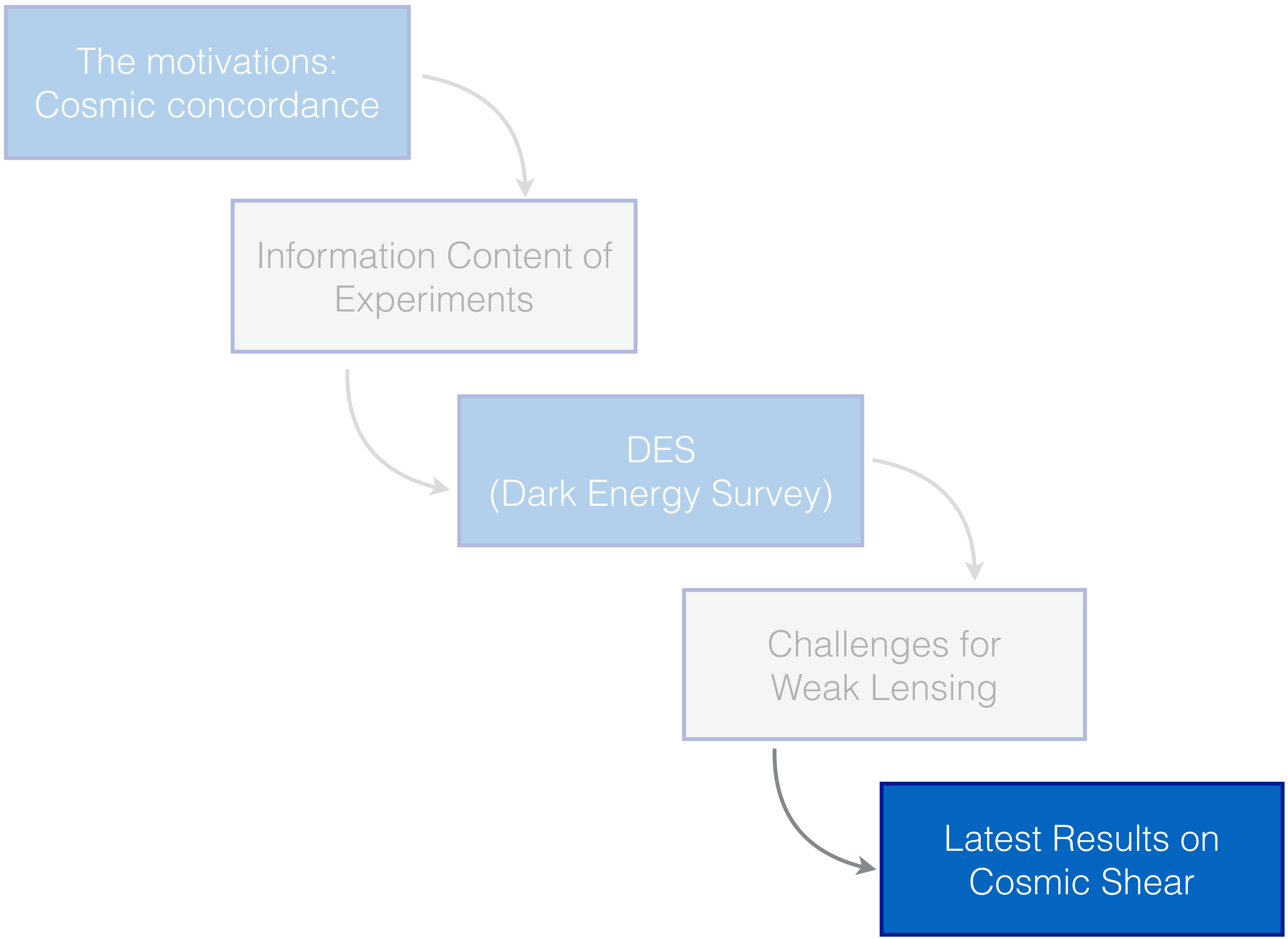






Bruderer et al (2015)



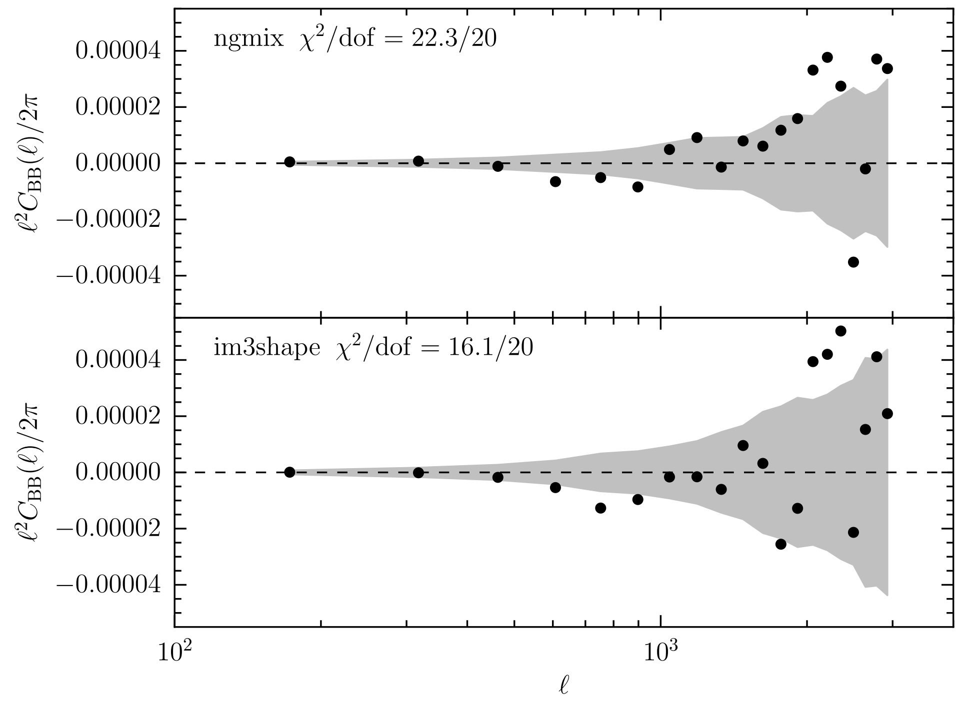

The motivations:
Cosmic concordance
Information Content of
Experiments
DES
(Dark Energy Survey)
Challenges for
Weak Lensing
Latest Results on
Cosmic Shear

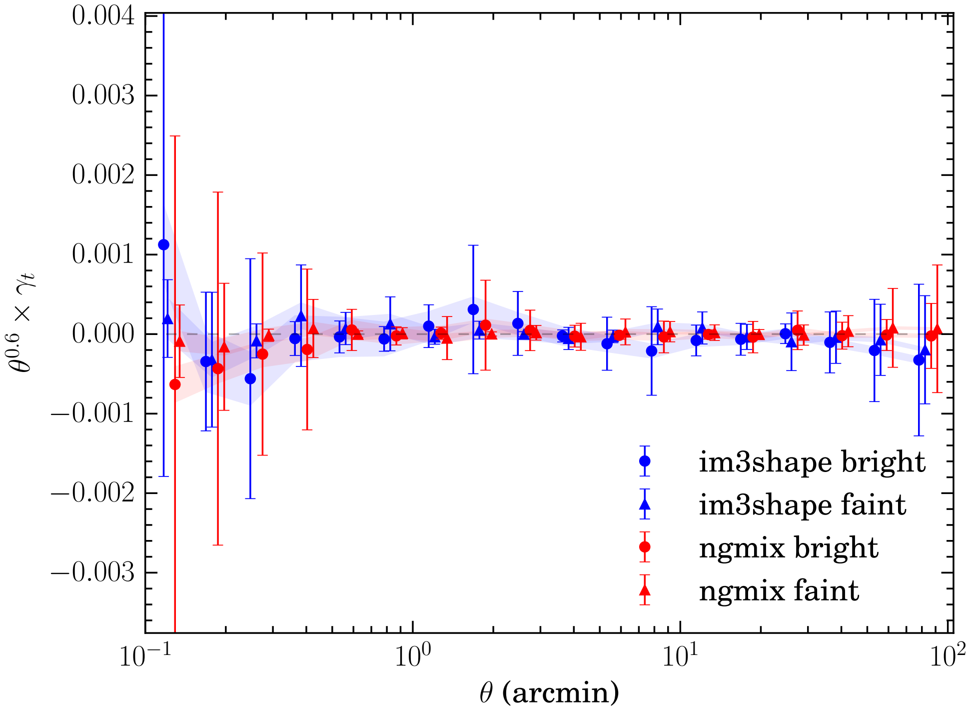
Science Verification Results

Cosmlogy	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

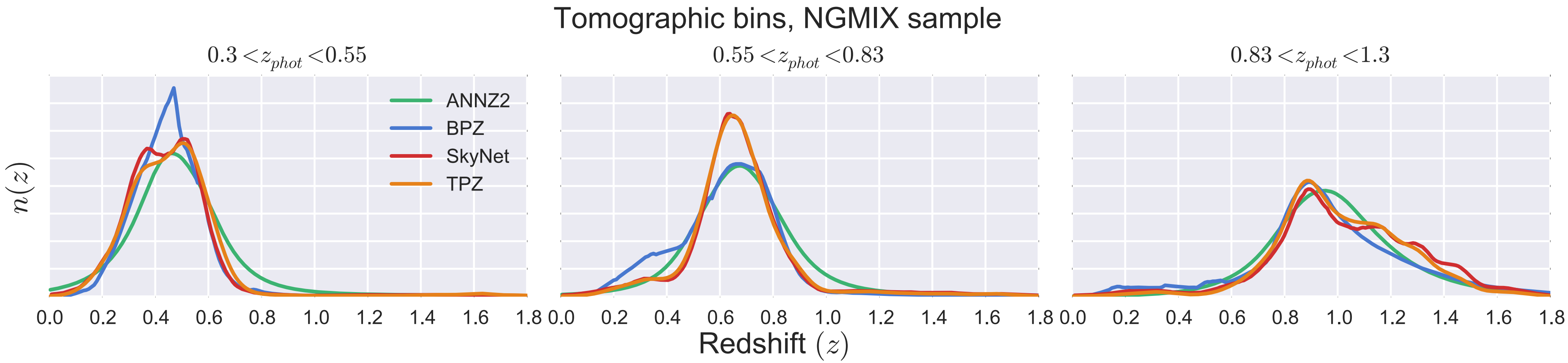
Jarvis et al (arXiv:1507.05603)

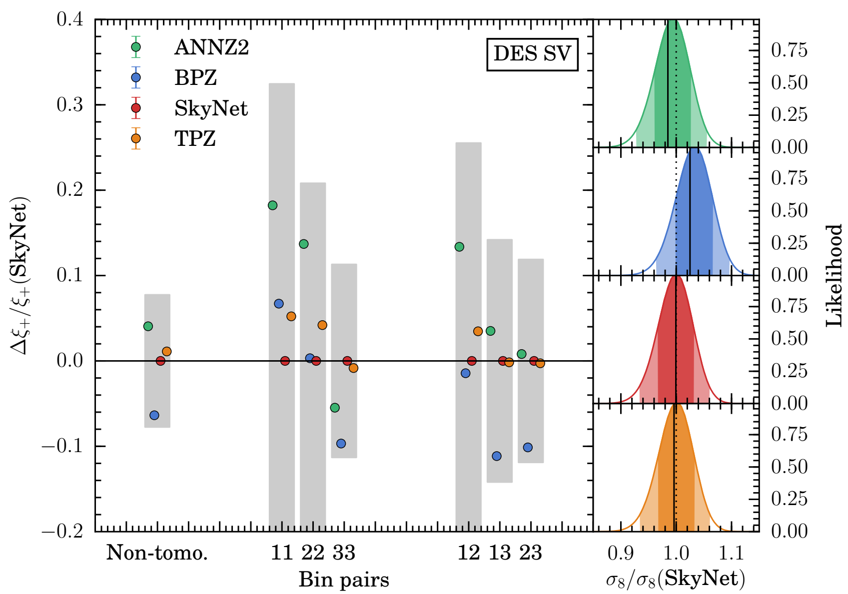




Agreement between Im3shape and NGMix better than 5%

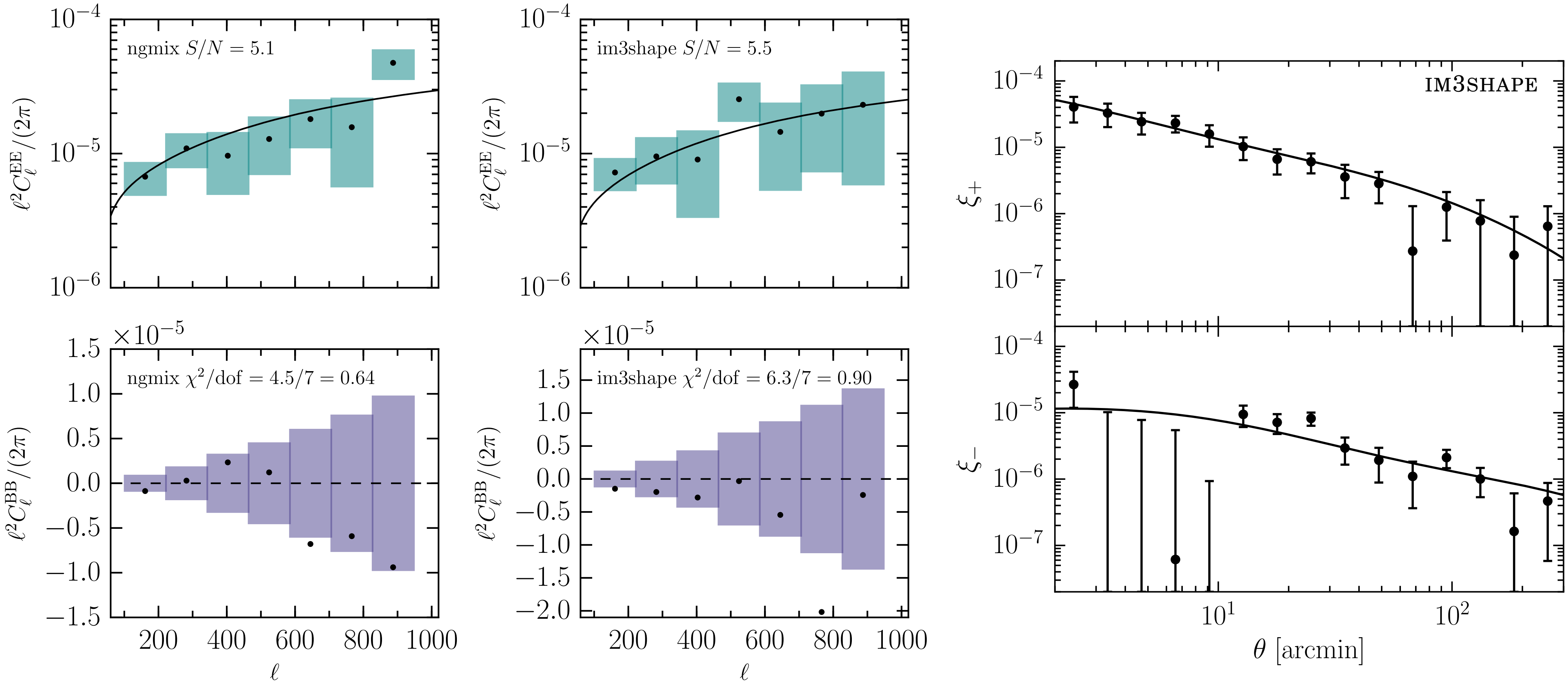
Redshift



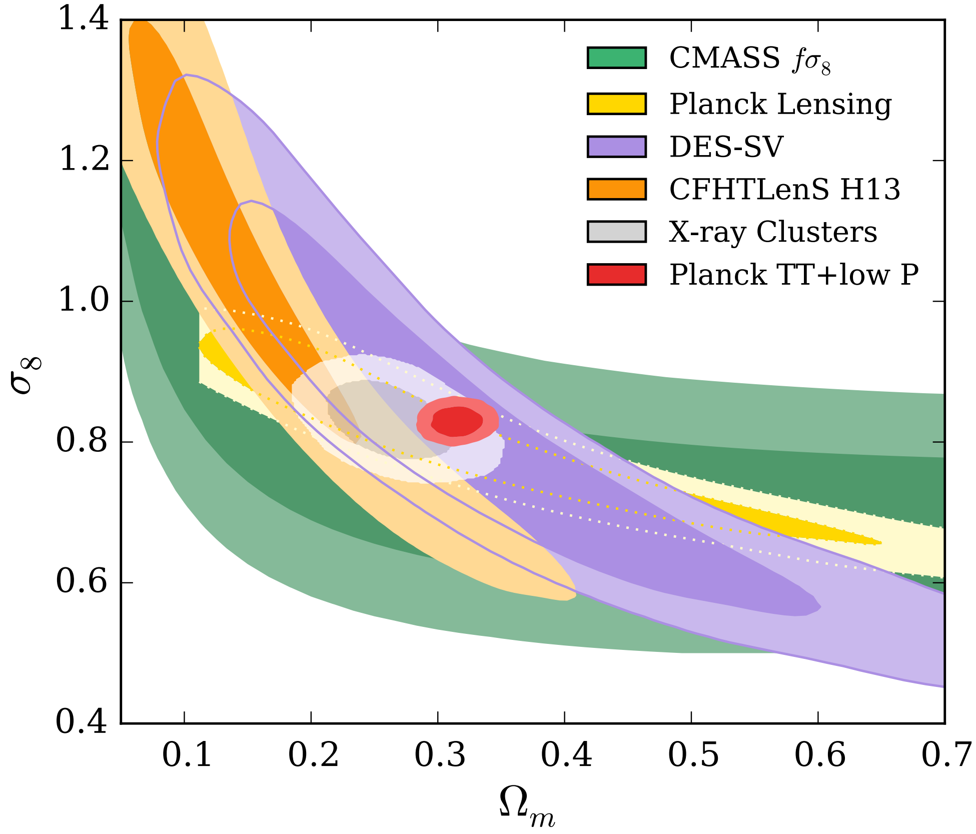


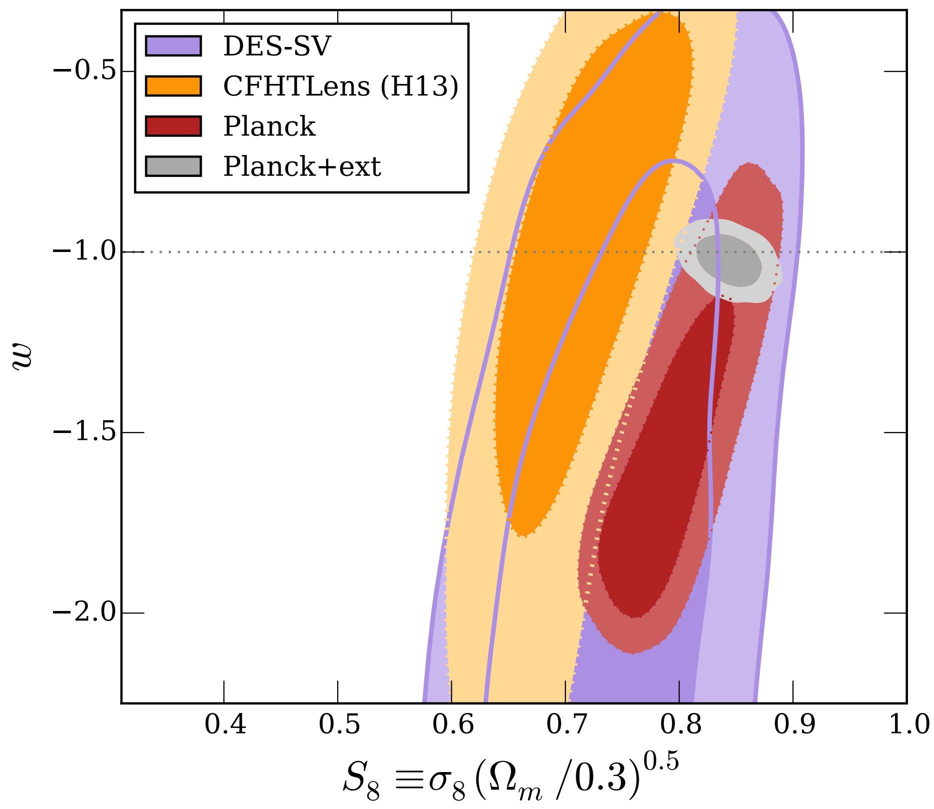
Bonnett et al (arXiv:1507.05909)

Shear Power Spectrum

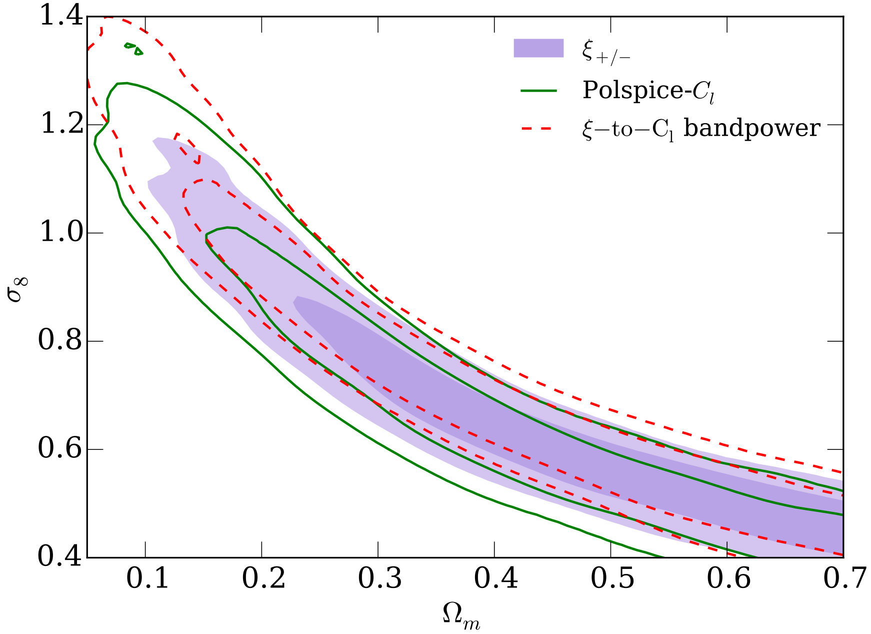


Cosmology

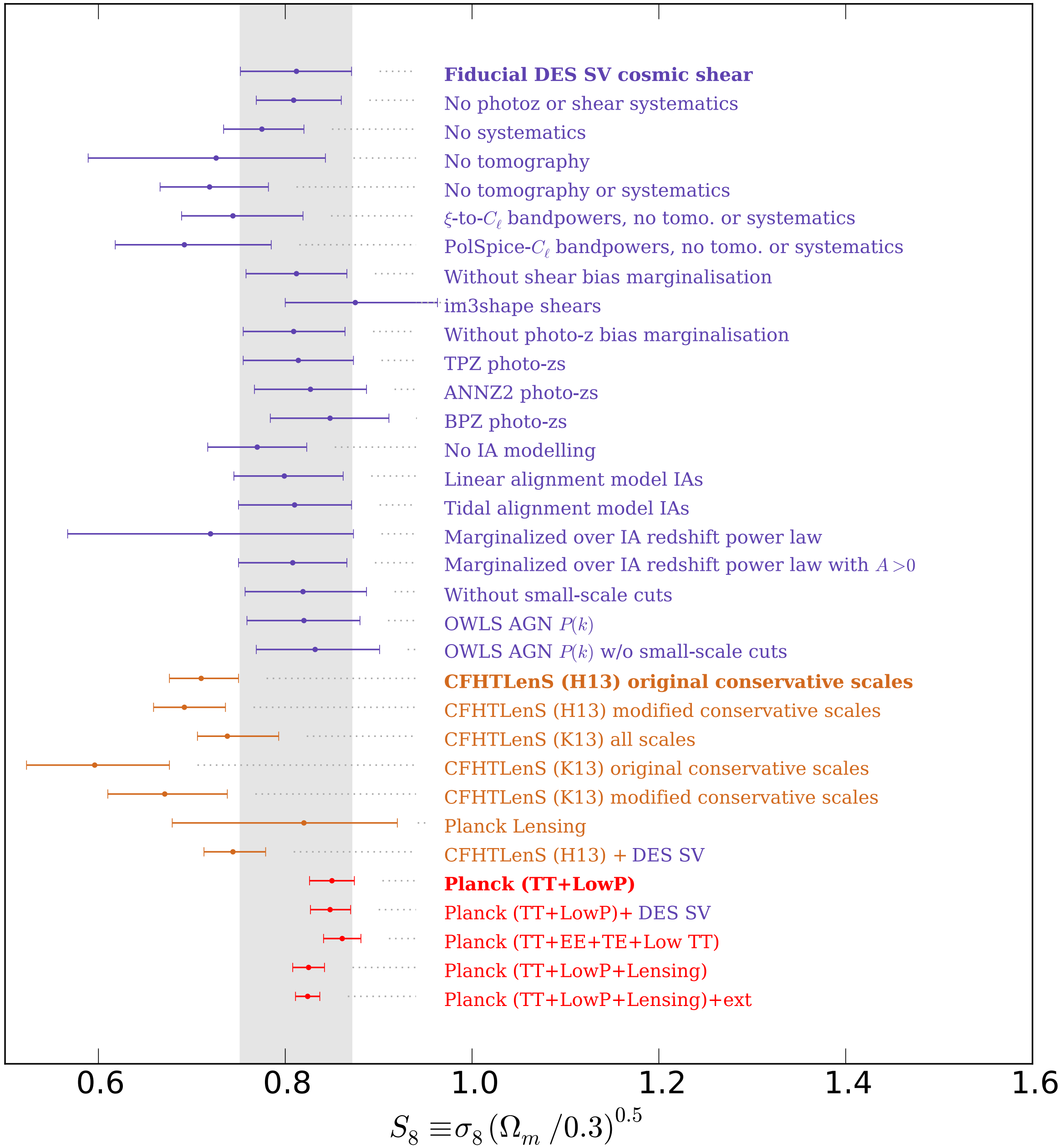

CMASS $f\sigma_8$
Planck Lensing
DES-SV
CFHTLenS H13
X-ray Clusters
Planck TT+low P
σ_8
Ω_m
1.4
1.2
1.0
0.8
0.6
0.4
0.1
0.2
0.3
0.4
0.5
0.6
0.7


DES-SV
CFHTLens (H13)
Planck
Planck+ext
w
$S_8 \equiv \sigma_8 (\Omega_m / 0.3)^{0.5}$
−0.5
−1.0
−1.5
−2.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0

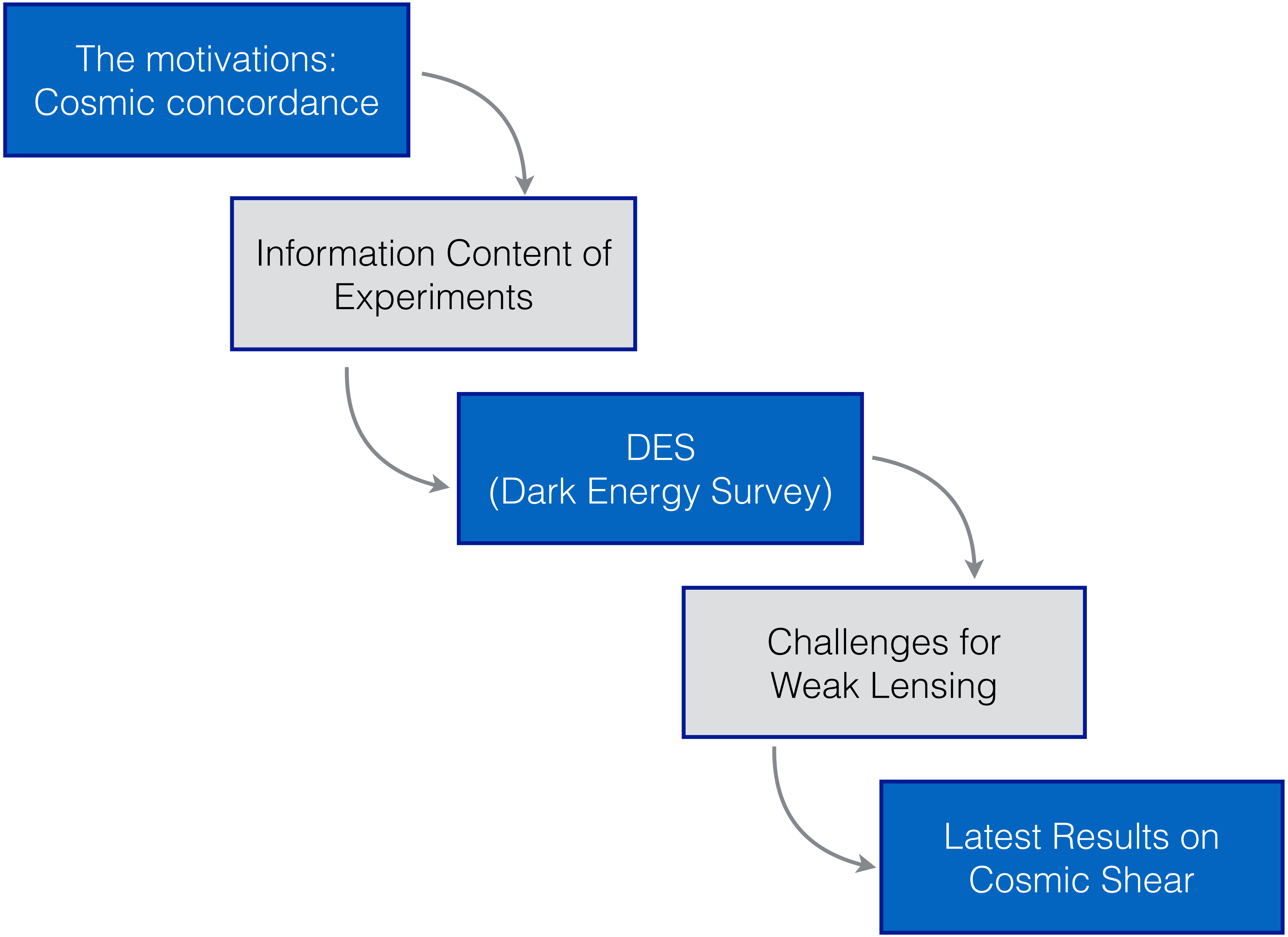
Robustness



1.4
1.2
1.0
0.8
0.6
0.4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
σ_8
Ω_m
$\xi_{+/-}$
Polspice-C_l
ξ−to−C_l bandpower



Fiducial DES SV cosmic shear
No photoz or shear systematics
No systematics
No tomography
No tomography or systematics
ξ-to-C_ℓ bandpowers, no tomo. or systematics
PolSpice-C_ℓ bandpowers, no tomo. or systematics
Without shear bias marginalisation
im3shape shears
Without photo-z bias marginalisation
TPZ photo-zs
ANNZ2 photo-zs
BPZ photo-zs
No IA modelling
Linear alignment model IAs
Tidal alignment model IAs
Marginalized over IA redshift power law
Marginalized over IA redshift power law with $A>0$
Without small-scale cuts
OWLS AGN $P(k)$
OWLS AGN $P(k)$ w/o small-scale cuts
CFHTLenS (H13) original conservative scales
CFHTLenS (H13) modified conservative scales
CFHTLenS (K13) all scales
CFHTLenS (K13) original conservative scales
CFHTLenS (K13) modified conservative scales
Planck Lensing
CFHTLenS (H13) + DES SV
Planck (TT+LowP)
Planck (TT+LowP)+ DES SV
Planck (TT+EE+TE+Low TT)
Planck (TT+LowP+Lensing)
Planck (TT+LowP+Lensing)+ext
0.6
0.8
1.0
1.2
1.4
1.6
$S_8 \equiv \sigma_8 (\Omega_m/0.3)^{0.5}$


The motivations:
Cosmic concordance
Information Content of
Experiments
DES
(Dark Energy Survey)
Challenges for
Weak Lensing
Latest Results on
Cosmic Shear