Cosmology from cosmic shear power spectra with Subaru Hyper Suprime-Cam data

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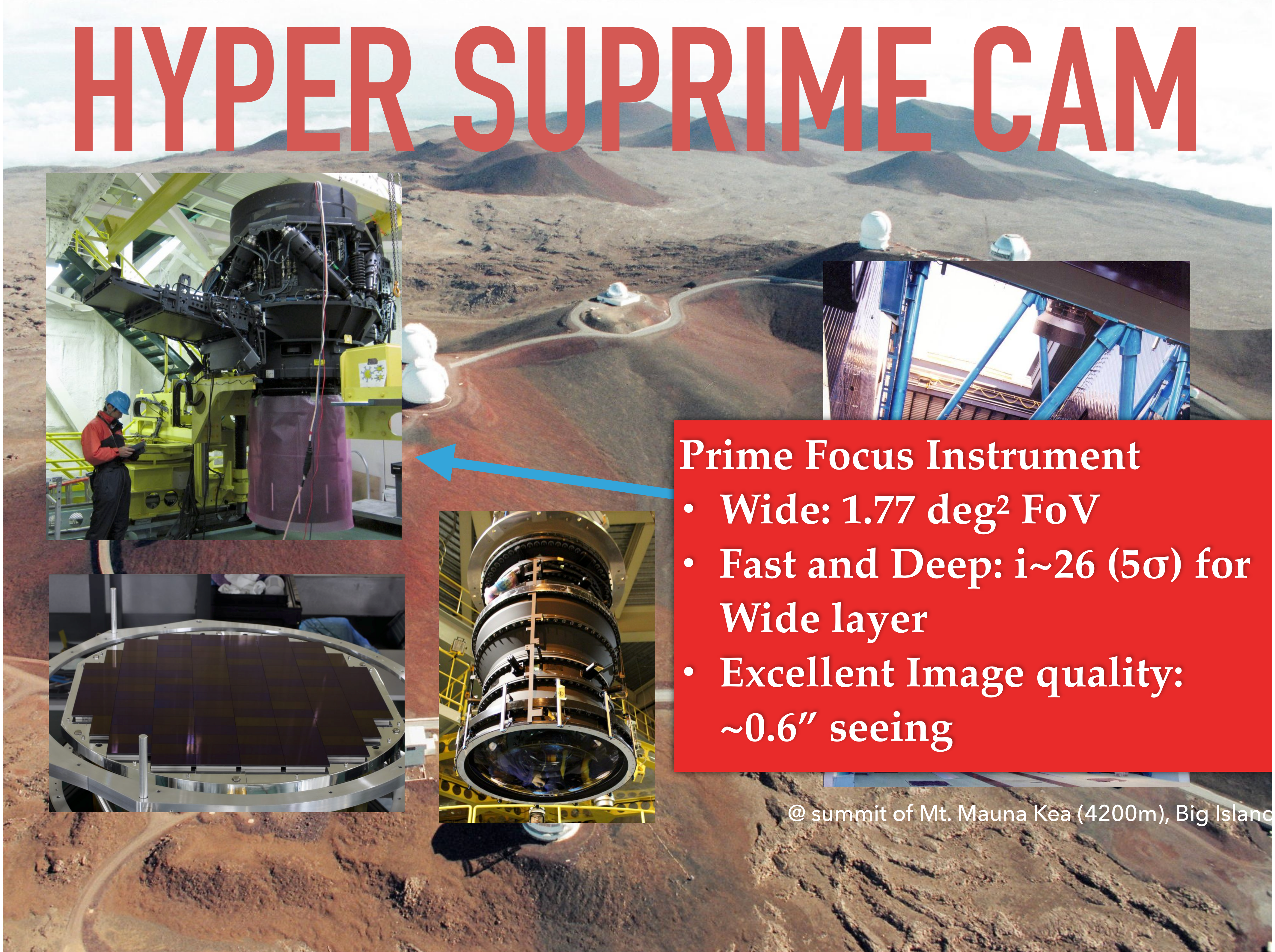
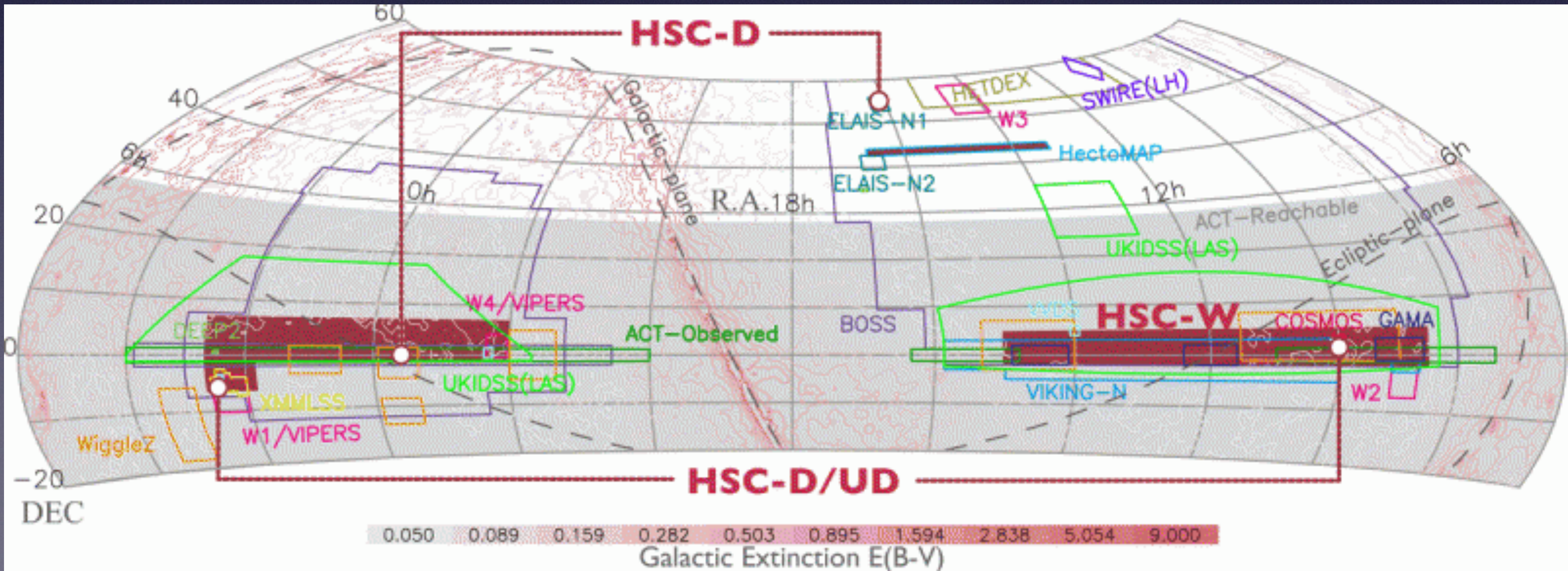
on behalf of HSC WL/photo-z members


SUBARU TELESCOPE
Subaru is Japanese
name of the Pleiades
@ summit of Mt. Mauna Kea (4200m), Big Island


HYPER SUPRIME CAM
Prime Focus Instrument
• Wide: 1.77 deg² FoV
• Fast and Deep: i~26 (5σ) for Wide layer
• Excellent Image quality: ~0.6″ seeing
@ summit of Mt. Mauna Kea (4200m), Big Island

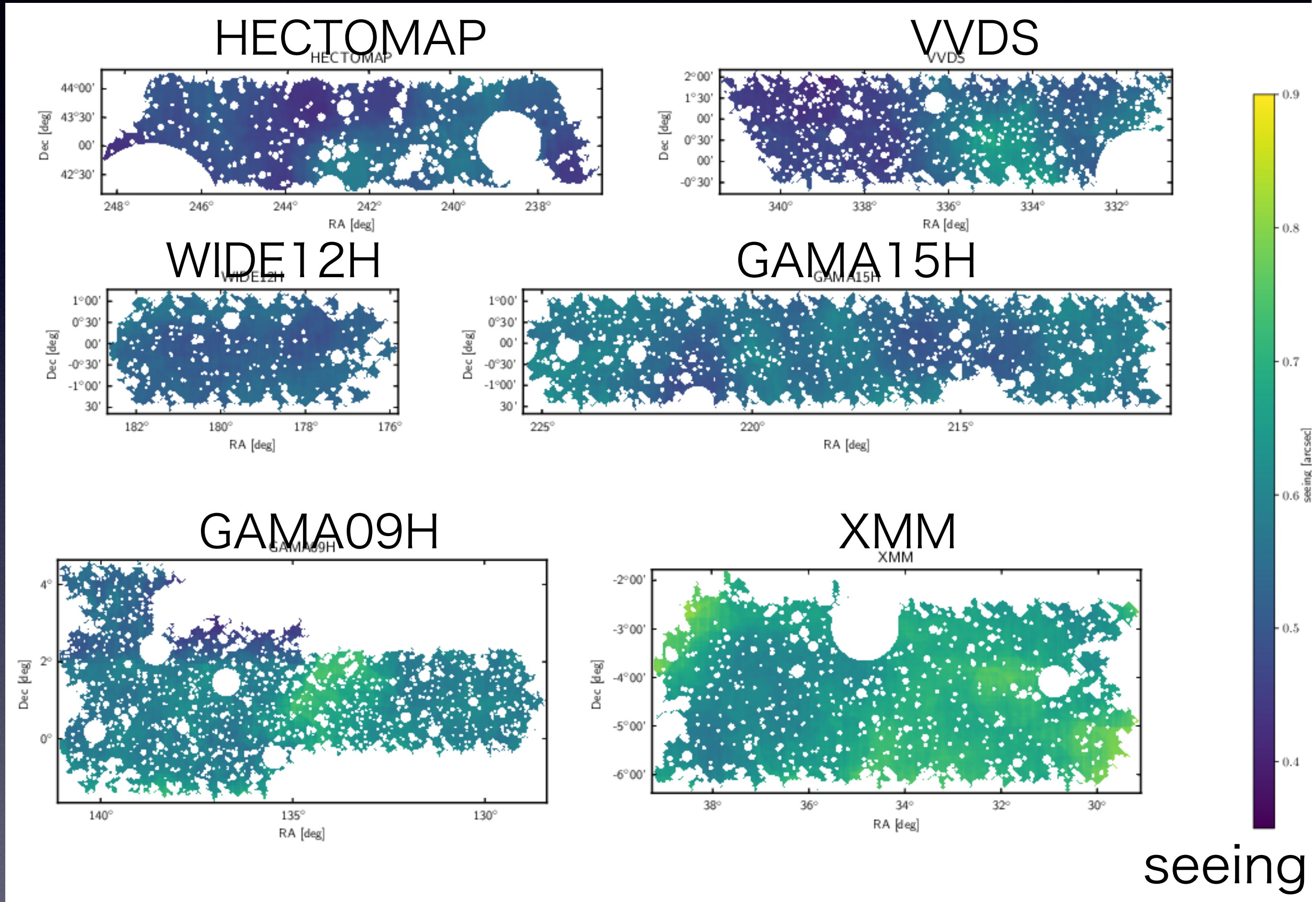
HSC Subaru-Strategic Program

- 300 nights over 5-6 years (started in March 2014)
- grizY+4 narrow bands
- 3 layers: Wide (1400deg^2, r~26), Deep (27deg^2, r~27), Ultradeep (3.5deg^2, r~28) for multiple sciences such as WL, galaxy evolution, high-z galaxies
- HSC field is overlapped with BOSS, ACT, XMM, GAMA, VVDS, VIPERS
- DR1 released in Feb 2017, DR2 will be released this summer



HSC Y1 shear catalog

- Data taken between Mar 2014 and Apr 2016
- 6 fields, 137deg^2
- ReGaussianization method (Hirata & Seljak 2003) to measure shapes
- Selection for 1st year science (e.g., i<24.5, resolution>1/3)
- High number density: n_g=25gals/sq.arcmin
- Internal systematic tests to meet Y1 science requirements

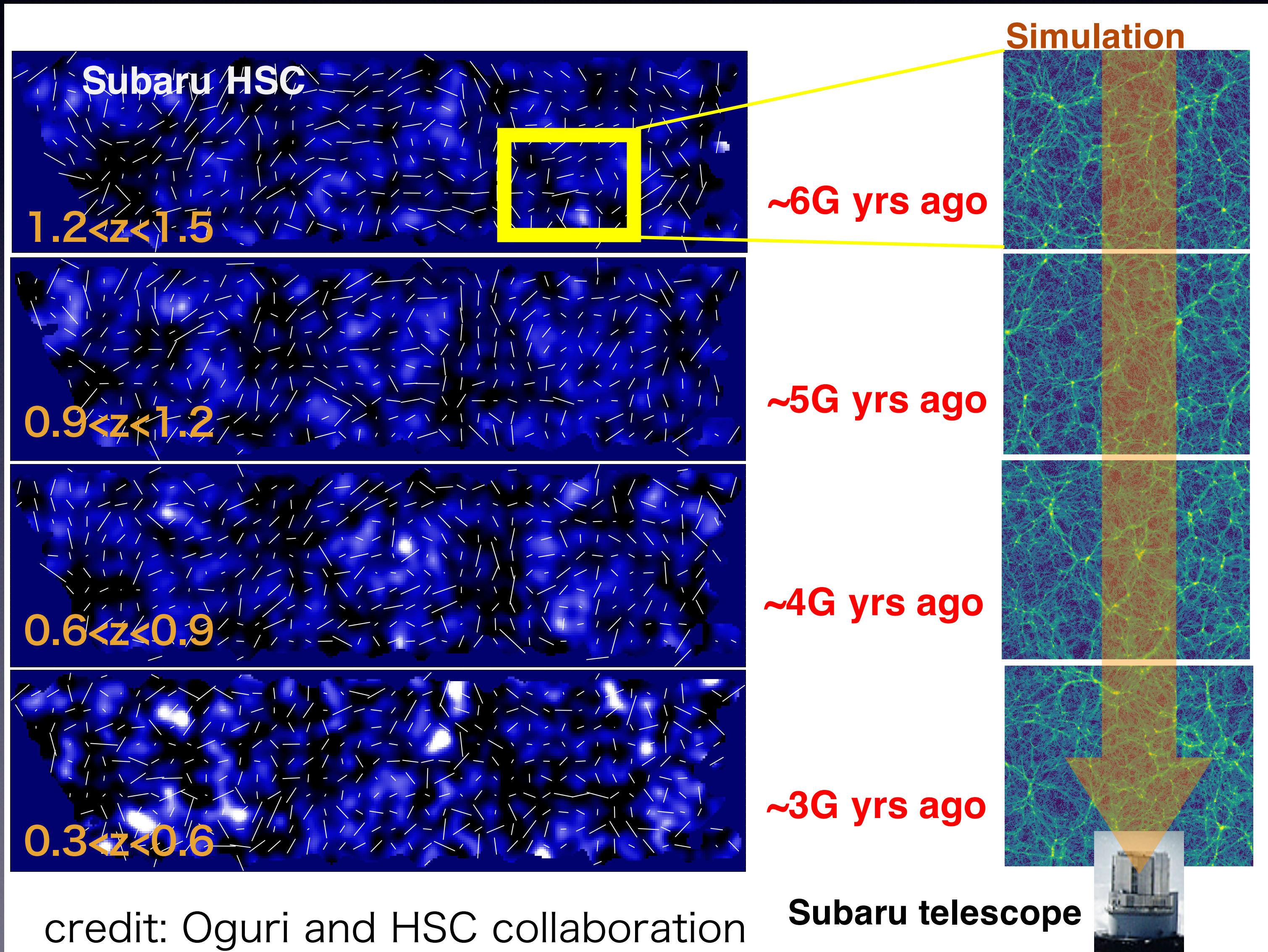


Map of i-band PSF FWHM

Mandelbaum, Miyatake et al. 2018

tomographic analysis

Galaxy samples are divided into 4 redshift bins from 0.3<z<1.5
to extract the information of the growth of matter structure



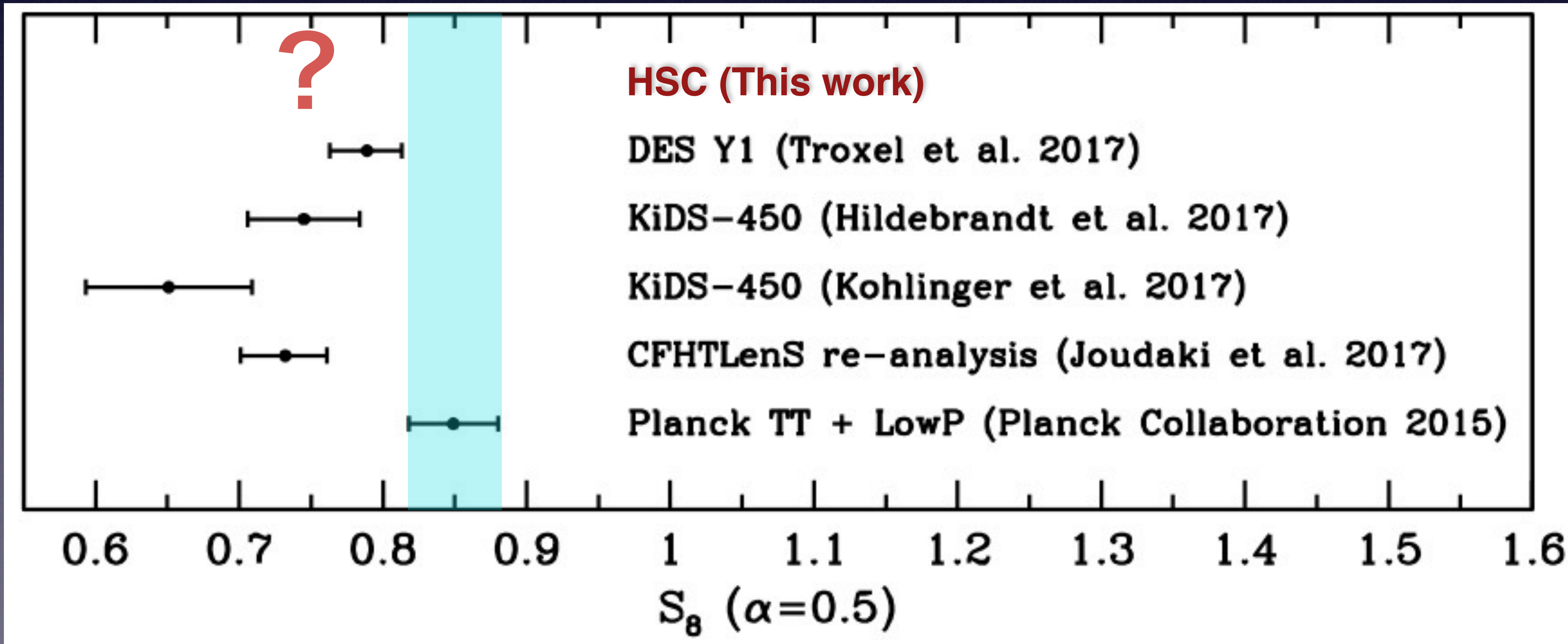
credit: Oguri and HSC collaboration

$$n_{g,eff} = \sum_i e^2_{rms,i}/(\sigma^2_{e,i} + e^2_{rms,i})/\text{area}$$

survey catalog	area [deg^2]	No. of galaxies	$n_{g,eff}$ [arcmin^{-2}]	z range
KiDS-450	450	14.6M	6.85	0.1 – 0.9
DES Y1	1321	26M	5.14	0.2 – 1.3
HSC Y1	137	9.0M	16.5	0.3 – 1.5

Higher number density → lower shape noise

Higher mean redshift → higher lensing signal



Blind analysis

shear multiplicative bias

$$\mathbf{m}^{i}_{\mathrm{cat}} = \mathbf{m}_{\mathrm{true}} + \mathrm{d}\mathbf{m}^{i}_{1} + \mathrm{d}\mathbf{m}^{i}_{2}$$

Only analysis chair can decrypt

Only blinder-in-chief can decrypt

Catalog-level blinding:

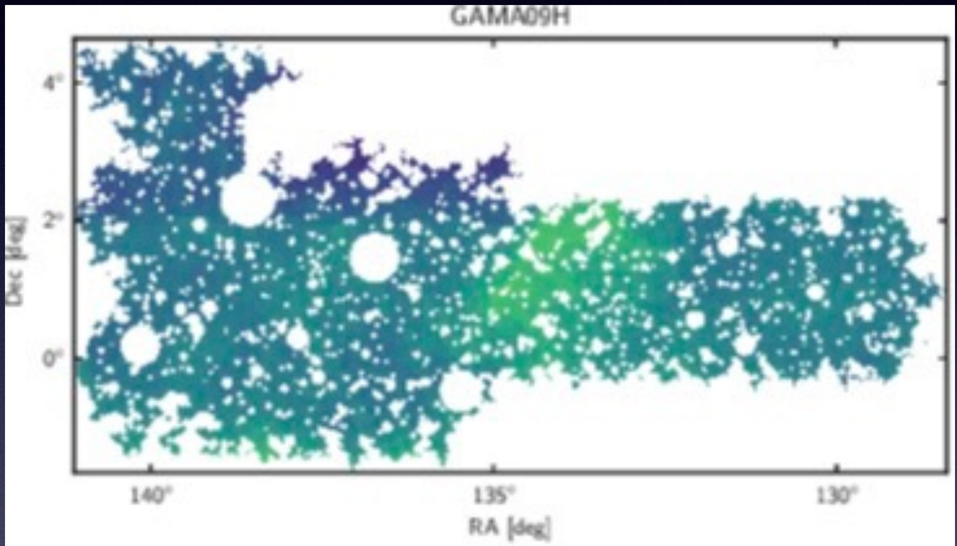
- Each analysis team receive three catalogs with different shear bias corrections: one is true, the other two are fake
- Unblinding needs two passwords from each analysis chair and the blinder-in-chief who is not involved in the analysis

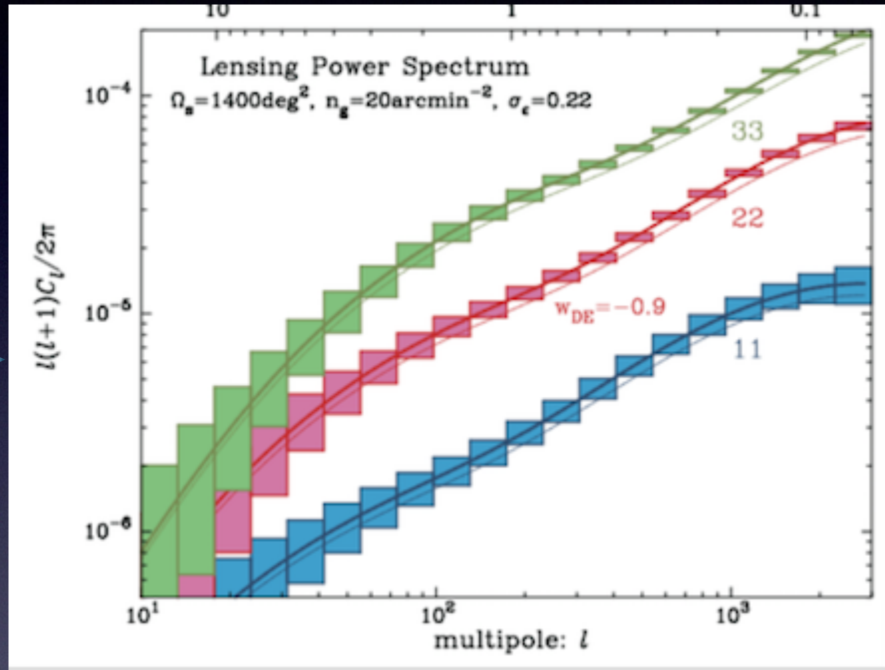
Analysis-level blinding:

- All cosmological plots are shifted to center the contours at zero
- No comparison with other datasets in a blinding phase
- All of systematic tests were done to meet specific criteria before unblinding

Estimators: pseudo-Cl

Survey geometry in lensing is quite have complicated due to bright star masks





- We adopt pseudo-Cl method to get unbiased estimates of lensing power spectrum (e.g., CH, Hamana, Takada, Spergel 2009)

$$C_b^{(\mathrm{true})} = M^{-1}_{bb'} \sum_{\boldsymbol{\ell}}^{|\boldsymbol{\ell}|\in\ell'_b} P_{b'\ell}\left(C_{\boldsymbol{\ell}}^{(\mathrm{obs})} - \langle N_{\boldsymbol{\ell}}\rangle_{\mathrm{MC}}\right)$$

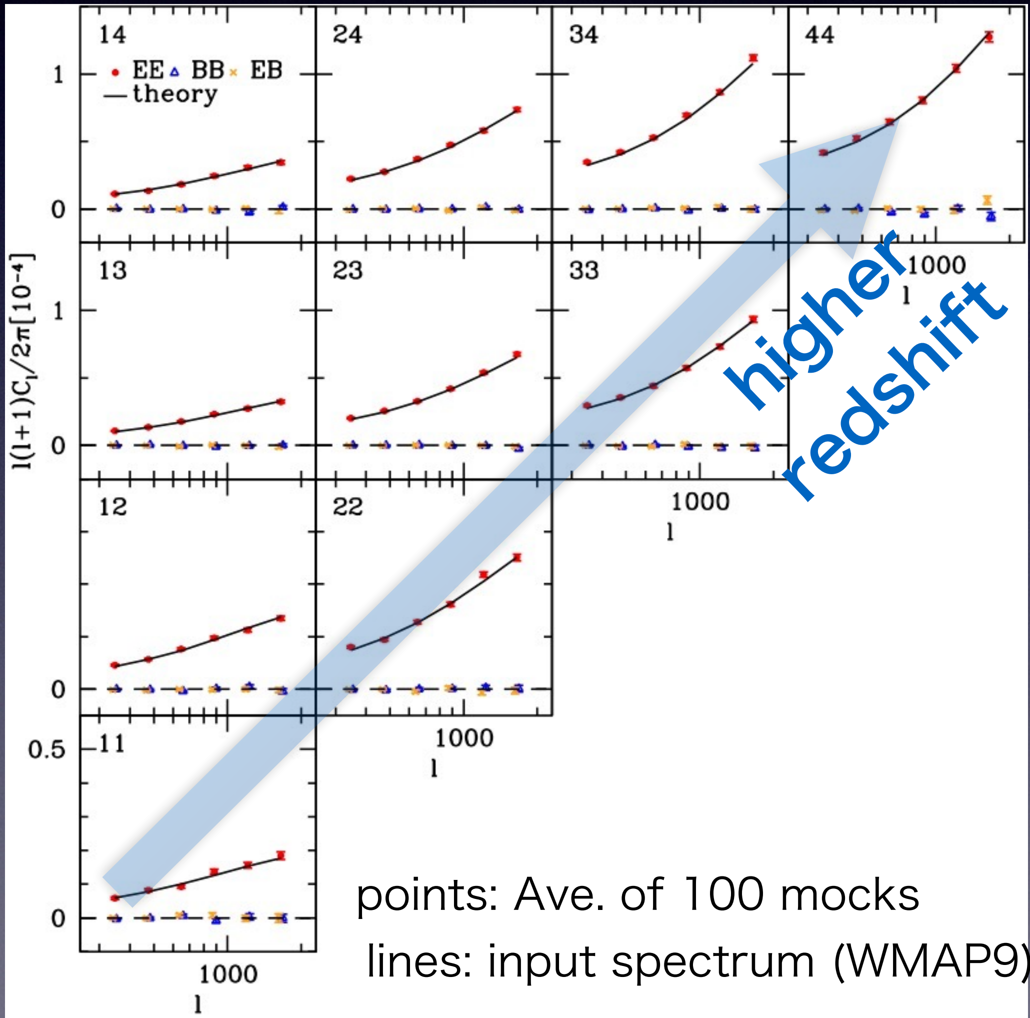
mixing matrix

masked spectrum

shot noise estimated from random rotation

Testing the pseudo-Cl method using HSC mock samples

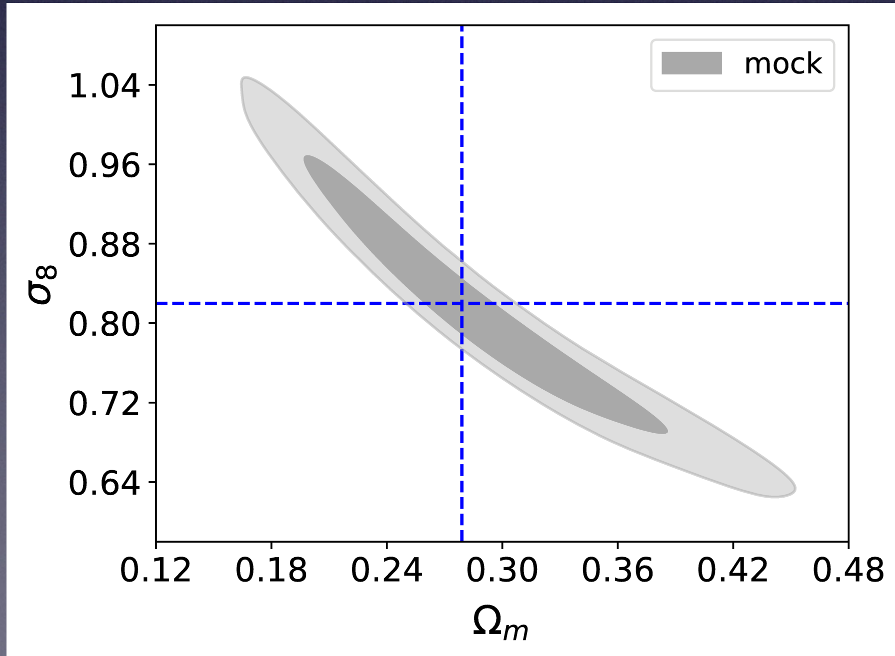
Input spectrum is recovered



points: Ave. of 100 mocks
lines: input spectrum (WMAP9)

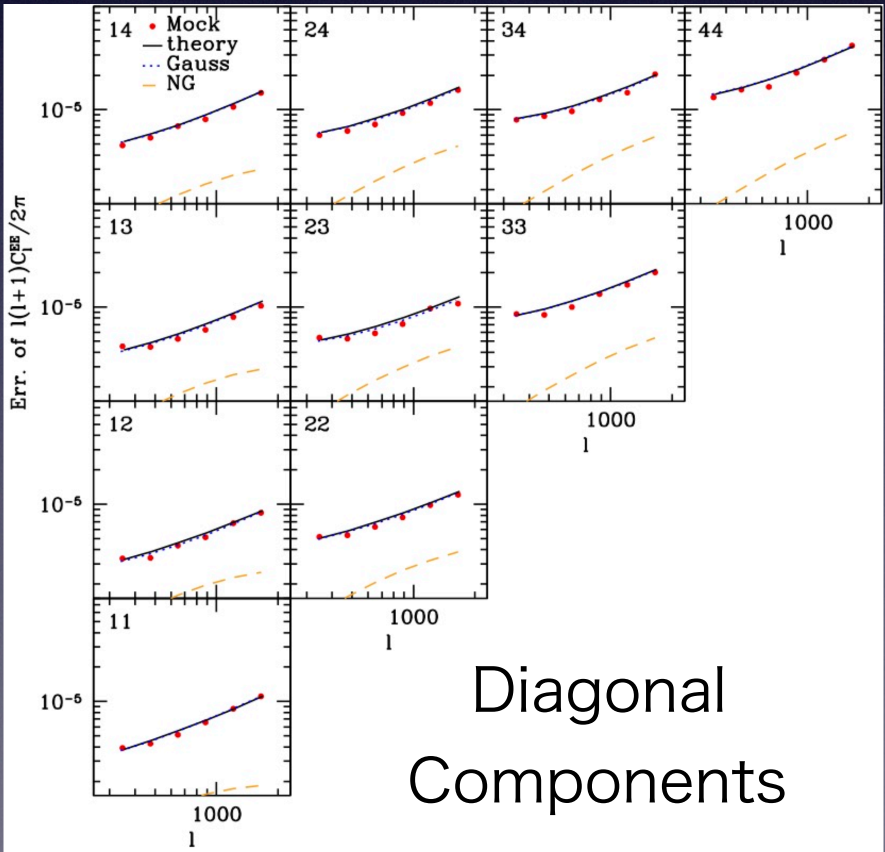
Input cosmology is recovered

parameters	input values	fitted values
S_8	0.791	0.791±0.005
Ω_m	0.279	0.292±0.014
σ_8	0.82	0.801±0.020

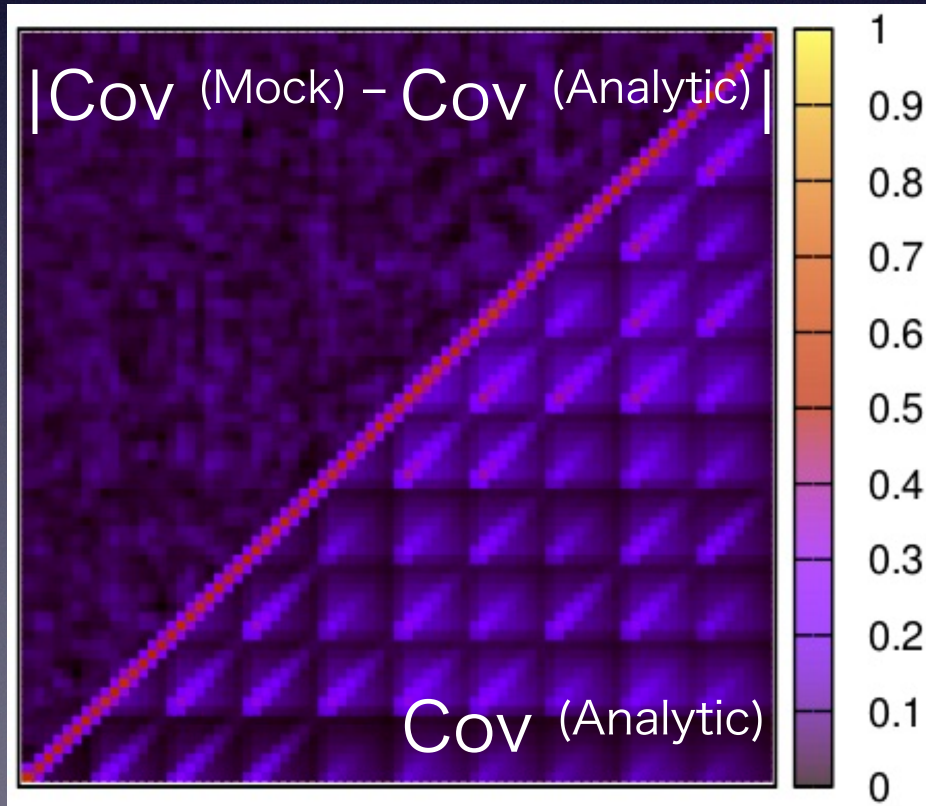


Covariance

- Gaussian, non-Gaussian and super-sample covariance terms
- Based on analytical halo-model + noise covariance directly estimated from data by randomly rotating ellipticities
- Covariance is cosmology-dependent



Diagonal Components



correlation coeffecients

Systematics

1. Residual correlations due to PSF modeling error/PSF leakage

The PSF errors are estimated with the cross-correlations between galaxies and reserved stars that are NOT used in the calibration of PSF

2. Photo-z uncertainty

Fiducial P(z) is estimated by reweighting COSMOS galaxies. Variances among different stacked P(z) are taken into account by shifting mean redshift

3. Intrinsic alignment (IA)

Nonlinear alignment model is adopted with the IA amplitude and power-law index of z-evolution treated as nuissance parameters

4. Baryon feedback effect

We focus on the scales that baryon feedback is insignificant by evaluating the impact of baryons in the most extreme OWLS AGN feedback model

Parameters & Priors

Nested sampling likelihood analysis using “multinest" in MontePython

Parameter	symbols	prior
physical dark matter density	$\Omega_c h^2$	flat [0.03,0.7]
physical baryon density	$\Omega_b h^2$	flat [0.019,0.026]
Hubble parameter	h	flat [0.6,0.9]
scalar amplitude on $k = 0.05\mathrm{Mpc}^{-1}$	$\ln(10^{10} A_s)$	flat [1.5,6]
scalar spectral index	n_s	flat [0.87,1.07]
optical depth	τ	*flat [0.01,0.2]*
neutrino mass	$\sum m_\nu$ [eV]	fixed $(0)^\dagger$, fixed (0.06) or flat [0,1]
dark energy EoS parameter	w	fixed $(-1)^\dagger$ or flat $[-2,-0.333]$
amplitude of the intrinsic alignment	A_{IA}	flat $[-5,5]$
redshift dependence of the intrinsic alignment	η_{eff}	flat $[-5,5]$
baryonic feedback amplitude	A_B	fixed $(0)^\dagger$ or flat $[-5,5]$
PSF leakage	$\tilde{\alpha}$	Gauss $(0.057, 0.018)$
residual PSF model error	$\tilde{\beta}$	Gauss $(-1.22, 0.74)$
uncertainty of multiplicative bias m	$100\Delta m$	Gauss $(0,1)$
photo-z shift in bin 1	$100\Delta z_1$	Gauss $(0, 2.85)$
photo-z shift in bin 2	$100\Delta z_2$	Gauss $(0, 1.35)$
photo-z shift in bin 3	$100\Delta z_3$	Gauss $(0, 3.83)$
photo-z shift in bin 4	$100\Delta z_4$	Gauss $(0, 3.76)$

Cosmology

Intrinsic alignment

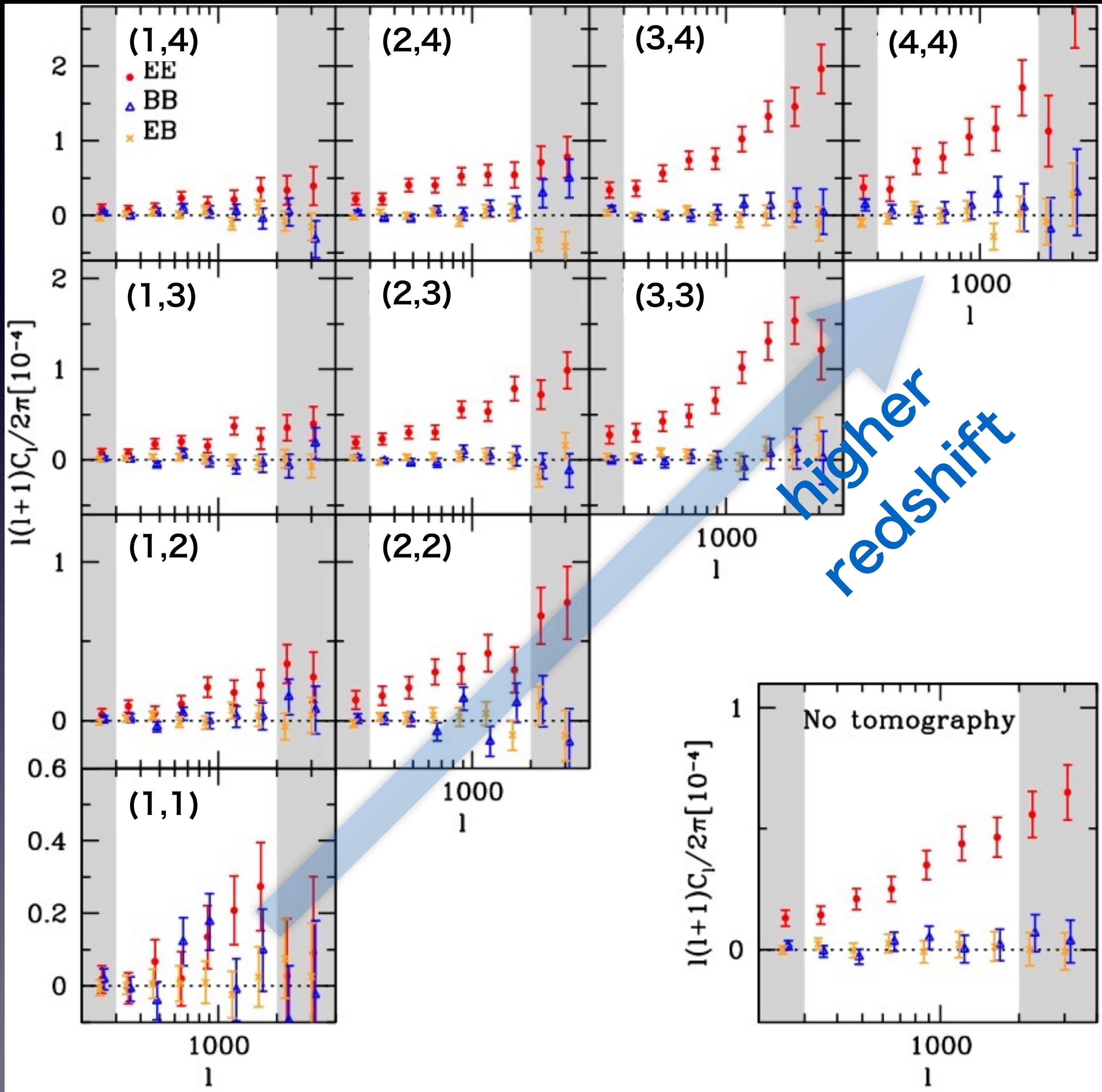
Baryonic effect

PSF modeling error

photo-z uncertainties

Fiducial setup: 5 cosmological and 9 nuisance parameters

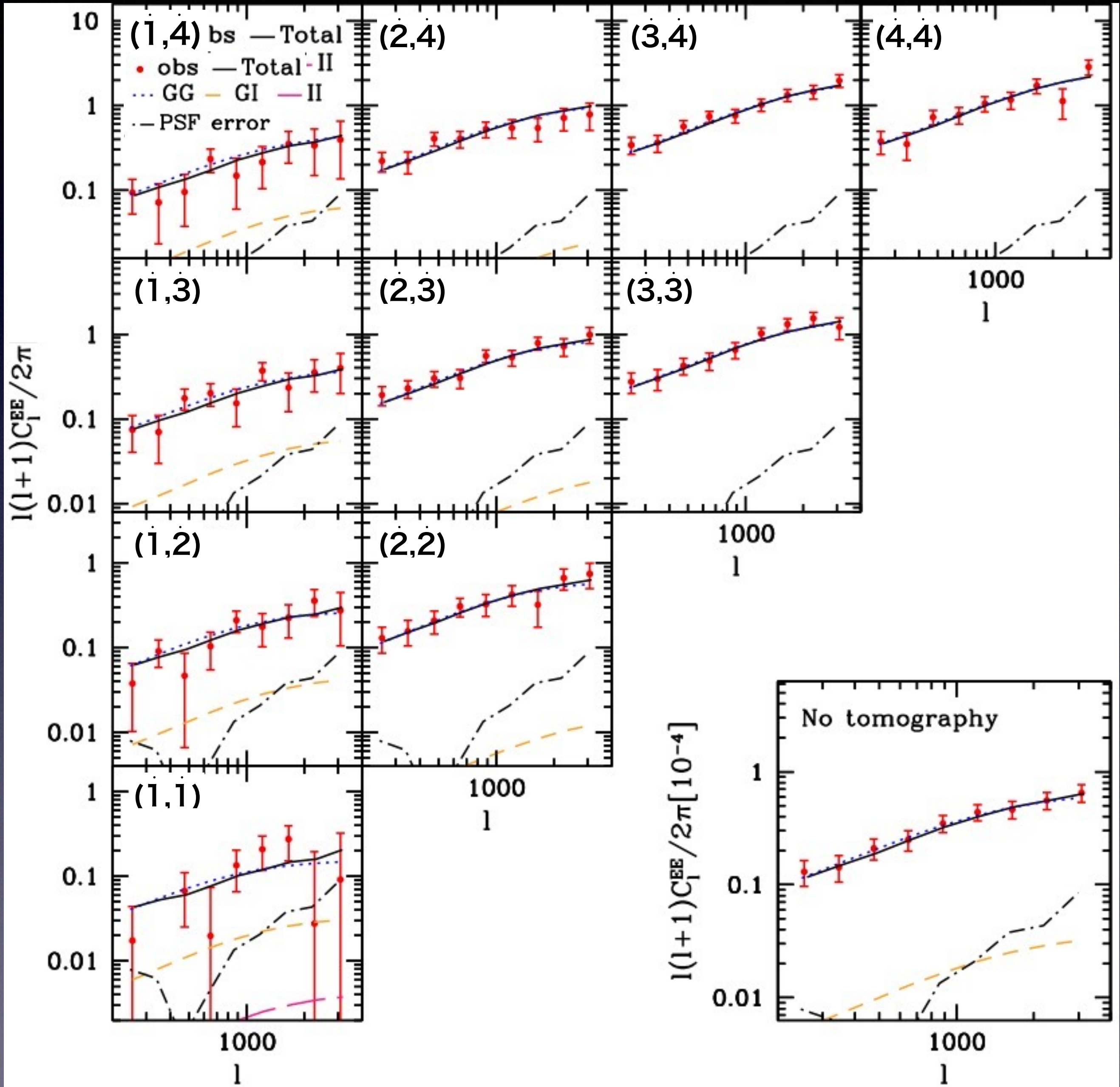
Shear power spectra of HSC Y1 data



- 4-bin tomographic analysis in z range from 0.3 to1.5
- Focus on the scale 300<l<1900 to avoid potential systematic effects
- S/N of cosmic shear (EE mode) is ~16
- BB & EB signals are consistent with zero

bin1: 0.3<z<0.6, bin2: 0.6<z<0.9, bin3: 0.9<z<1.2, bin4: 1.2<z,1.5

Model fitting



Excellent fits of our modeling

χ^2_{min}=45.4 against effective d.o.f=57.1 (p-value is 0.87)

Definition of d.o.f (Raveri & Hu 2018)

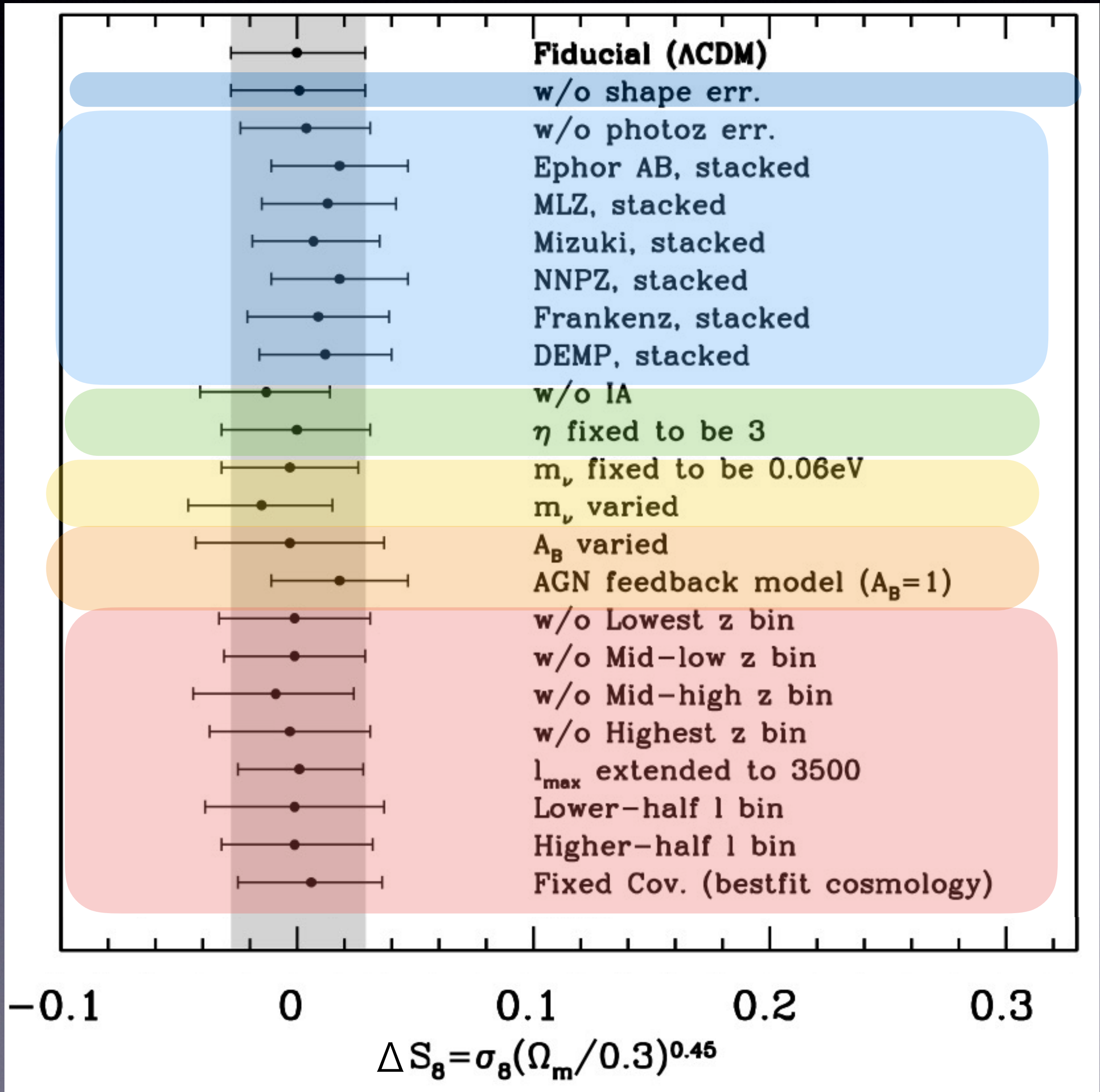
$$\mathrm{DOF} = N_{\mathrm{data}} - N_{\mathrm{eff}}$$

$$N_{\mathrm{eff}} = N_{\mathrm{para}} - \mathrm{tr}[\mathcal{C}_{\mathrm{prior}}^{-1}\mathcal{C}_{\mathrm{post}}]$$

bin1: 0.3<z<0.6, bin2: 0.6<z<0.9, bin3: 0.9<z<1.2, bin4: 1.2<z,1.5

Robustness of S8 constraints

Systematic test was done before unblinding



shape error: <0.1 σ

Photo-z error: ~0.6 σ

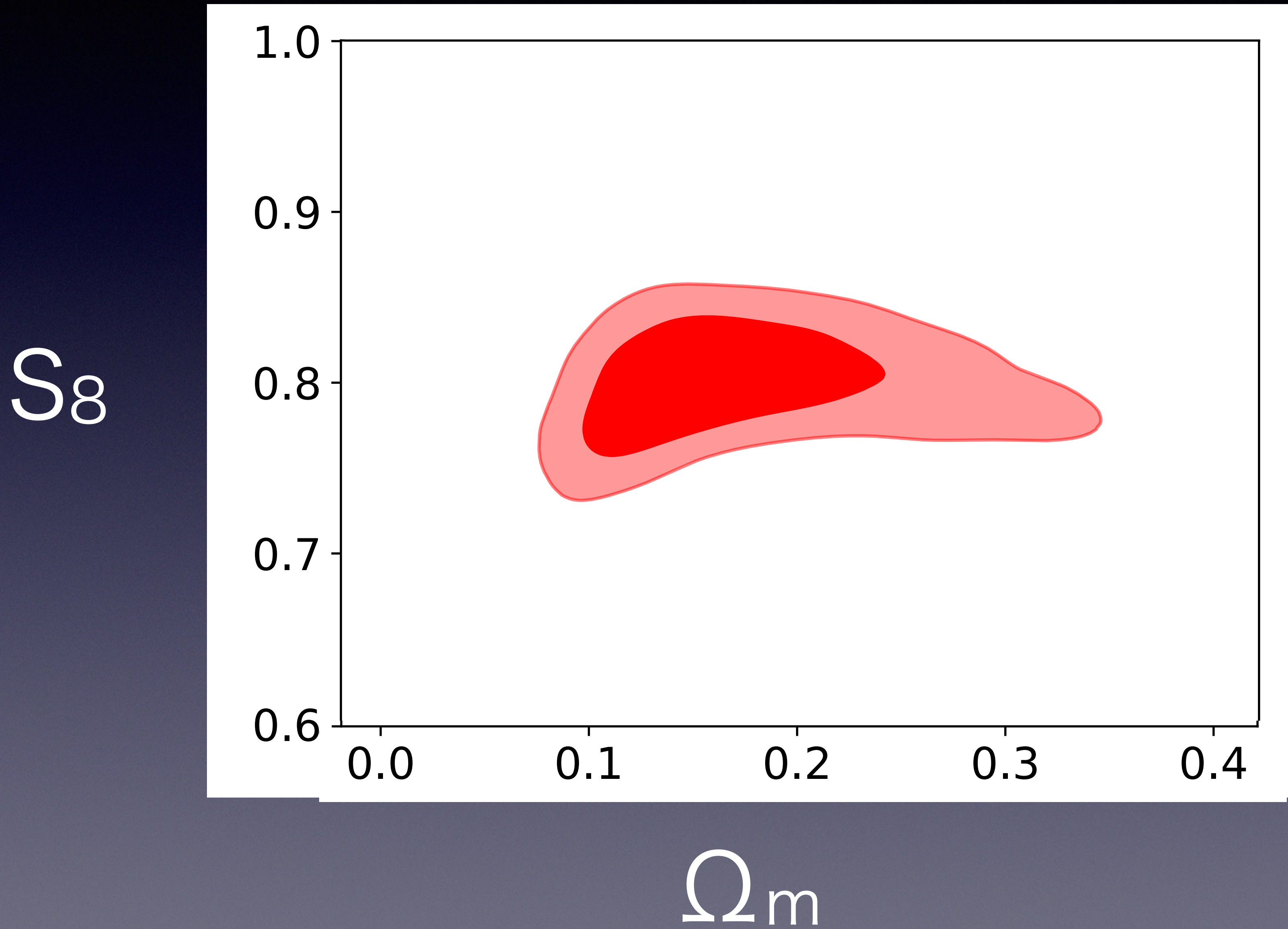
Intrinsic alignment: <0.5 σ

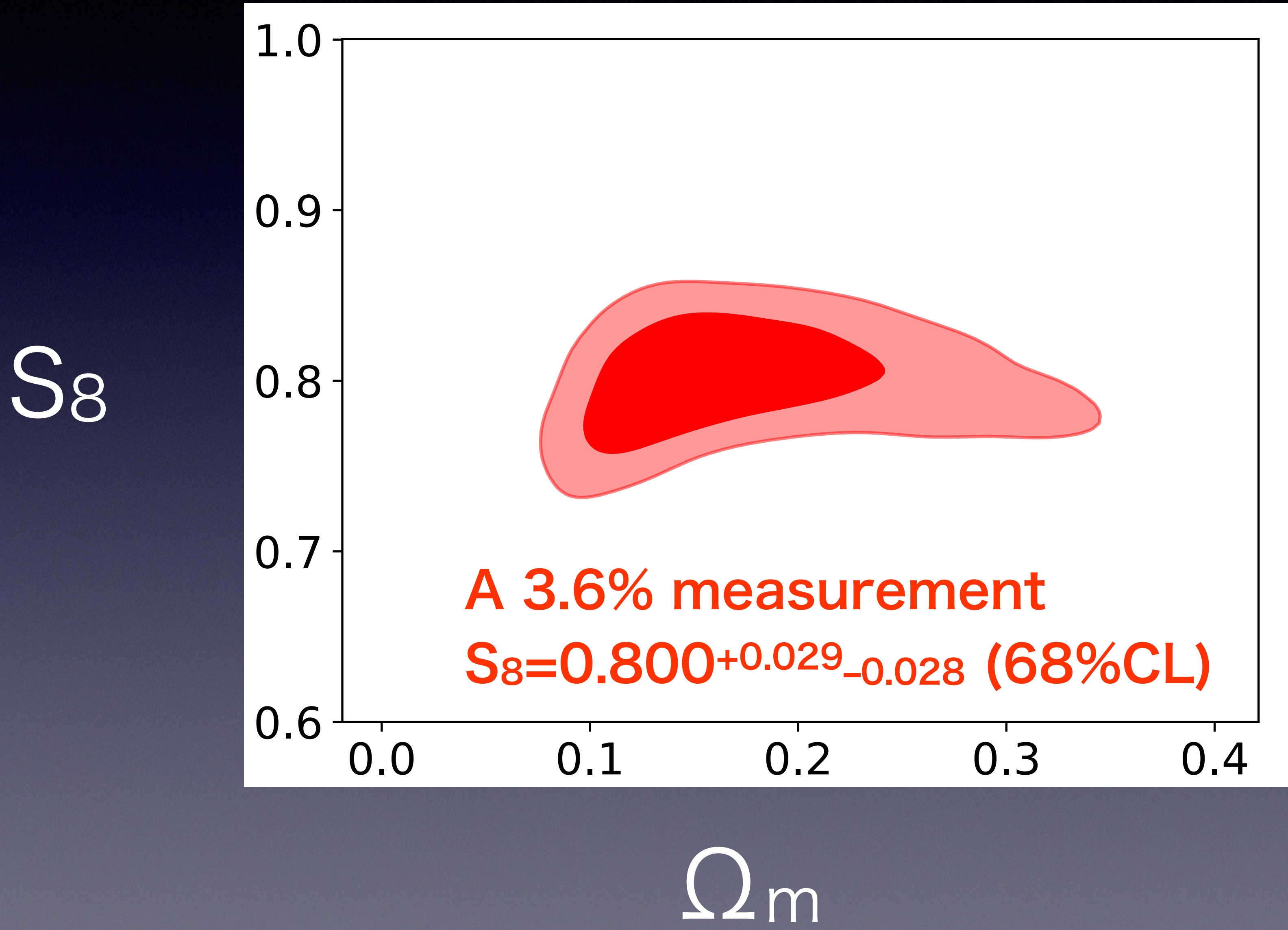
Massive neutrino: < 0.5 σ

Baryonic effect: < 0.6 σ

No significant internal inconsistency

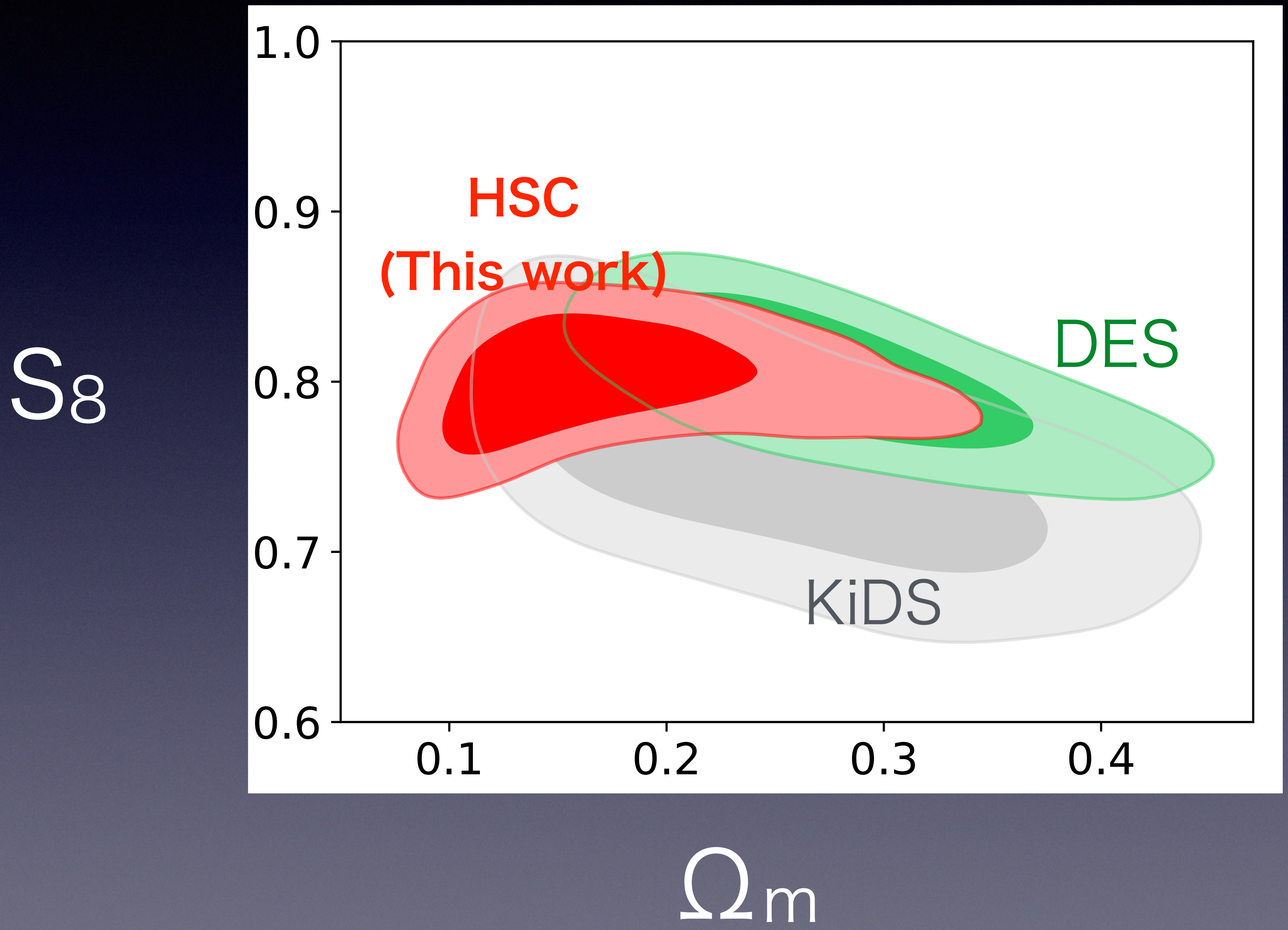
S8 constraint is robust against various systematics


S_8
1.0
0.9
0.8
0.7
0.6
0.0
0.1
0.2
0.3
0.4
Ω_m

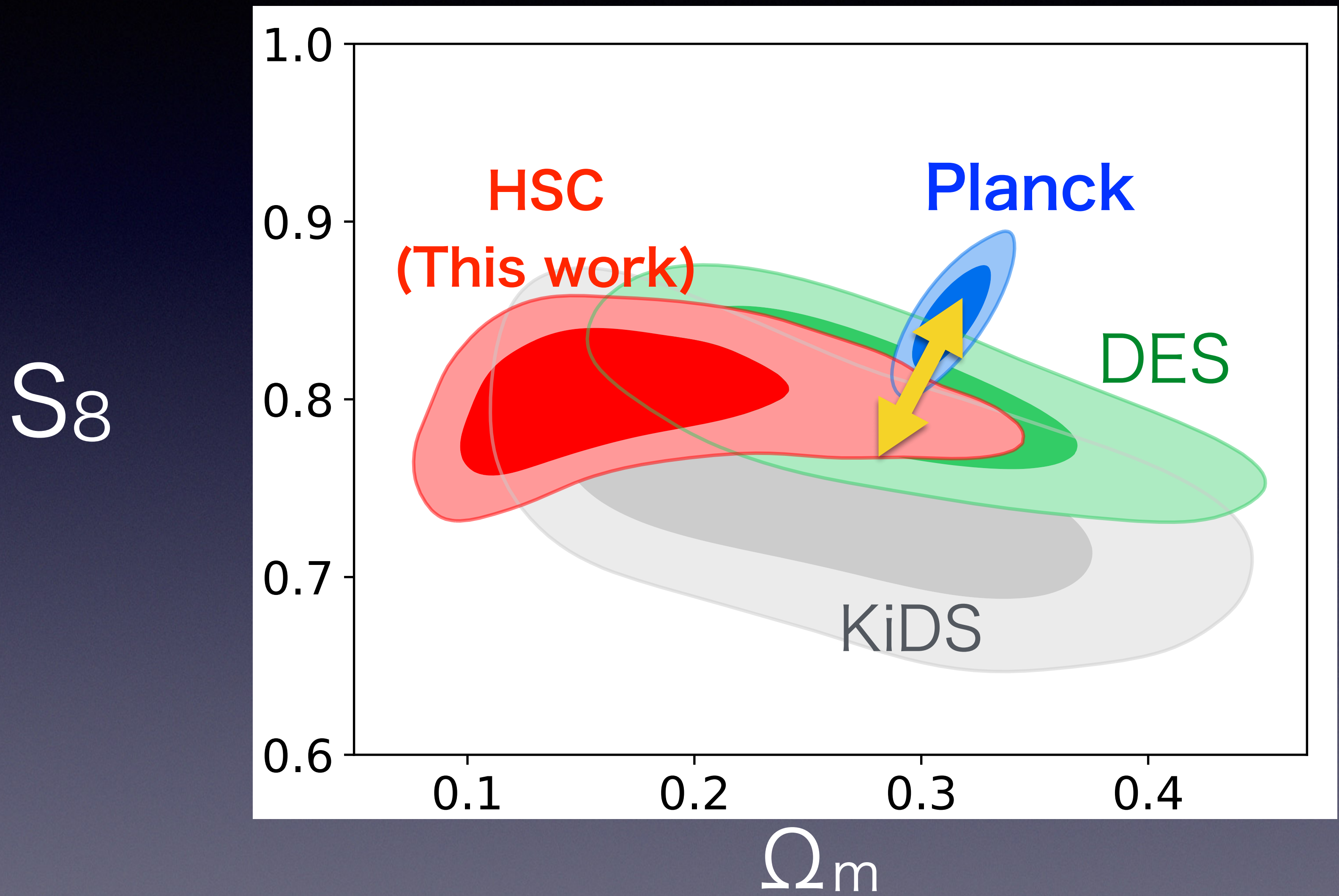


S8
Ωm
1.0
0.9
0.8
0.7
0.6
0.0
0.1
0.2
0.3
0.4
A 3.6% measurement
S8=0.800+0.029−0.028 (68%CL)

Consistent with other lensing surveys

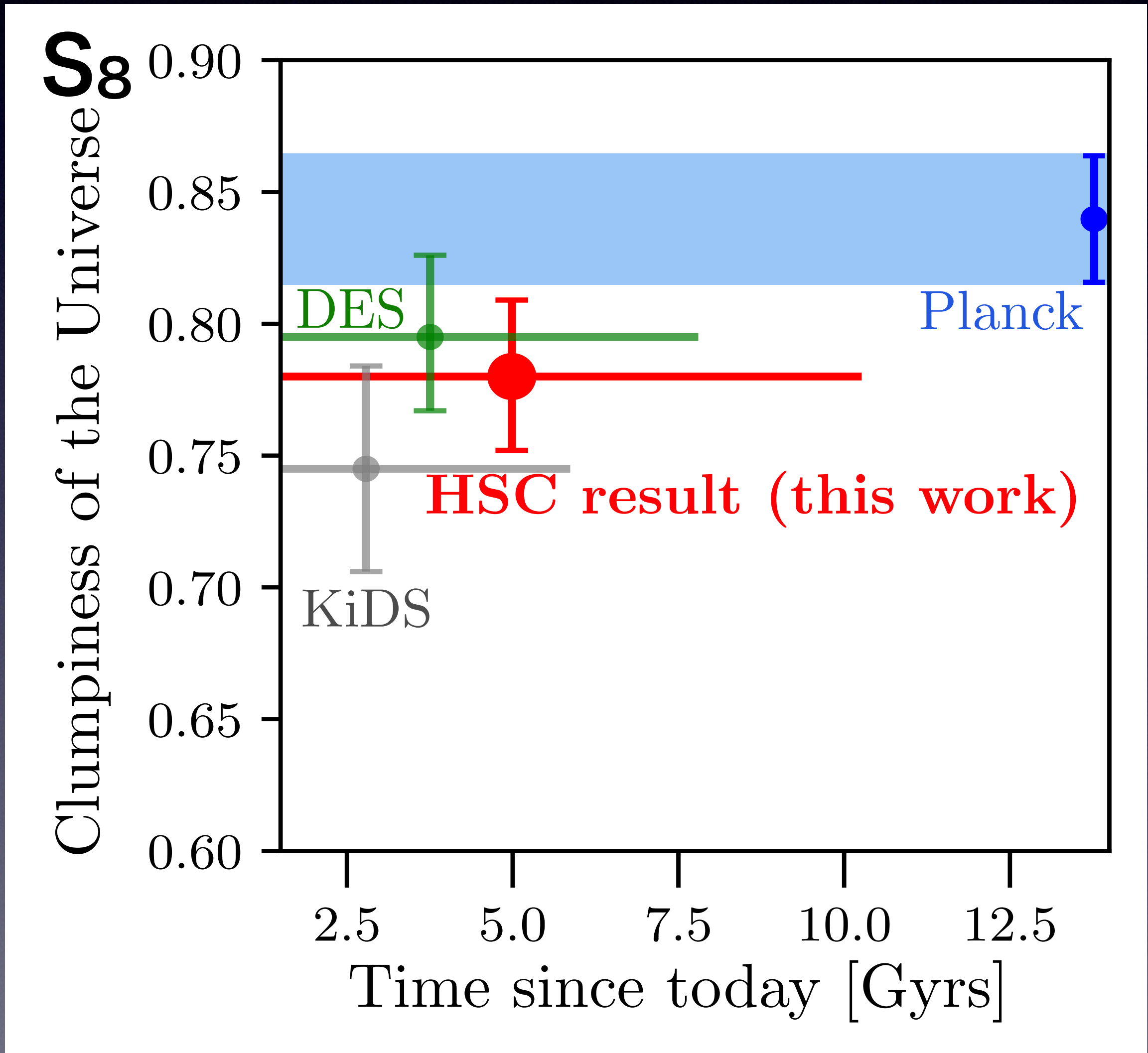


Consistent with Planck



Consistency is evaluated using Bayesian Evidence test and minimum χ^2 based statsitcis (Raveri & Hu 2018)

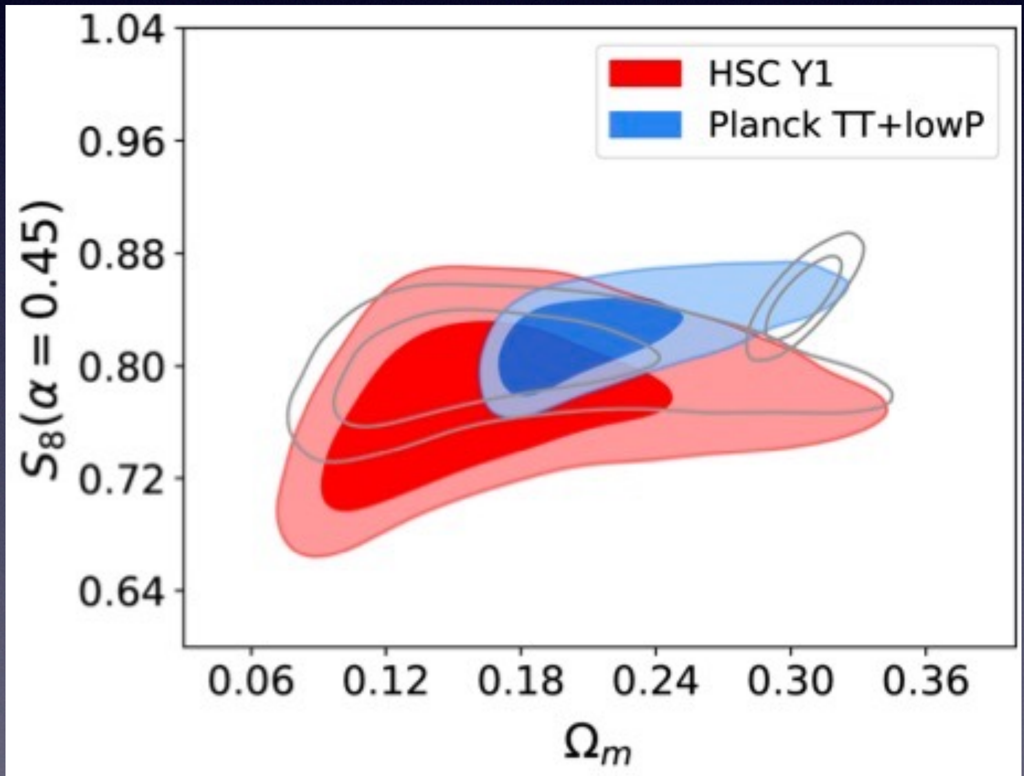
Tensions are real?

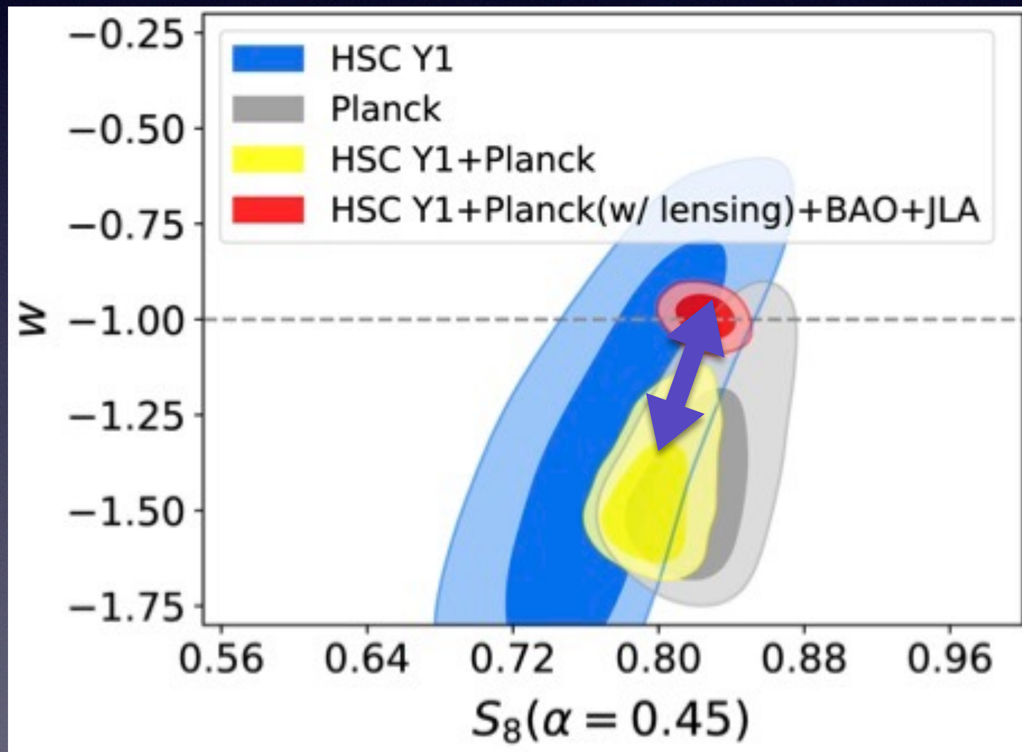


- S_8 from cosmic shear are systematically lower than Planck
  - different datasets
  - different sky regions
  - different team analyses
  - different estimators
- Other systematics or physics beyond ΛCDM

Model extensions: wCDM

Tension of S8 reduces by varying w, though there is no significant preference to favor wCDM from Bayesian evidence





Constraints on w is $-1.45^{+0.16}_{-0.10}$ from HSC+Planck, while adding BAO+SN produces -1.01 ± 0.04.

Summary

- First cosmological analysis from Hyper Suprime-Cam survey
- Blind analysis to test various systematics, such as shear measurement, photo-z, intrinsic alignment, baryon feedback
- 3.6% measurement on $S_8 = \sigma_8 (\Omega_m/0.3)^{0.45} = 0.800^{+0.029}_{-0.028}$ from auto cosmic shear power spectra
- The value is consistent with Planck, but is lower at ~2σ level as other lensing surveys such as DES and KiDS shows
- Other cosmological analyses (e.g., g-g lensing + g clustering analysis led by Miyatake) are on-going
- HSC Y1 is just 11% of HSC planned survey. Stay tuned for upcoming results