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

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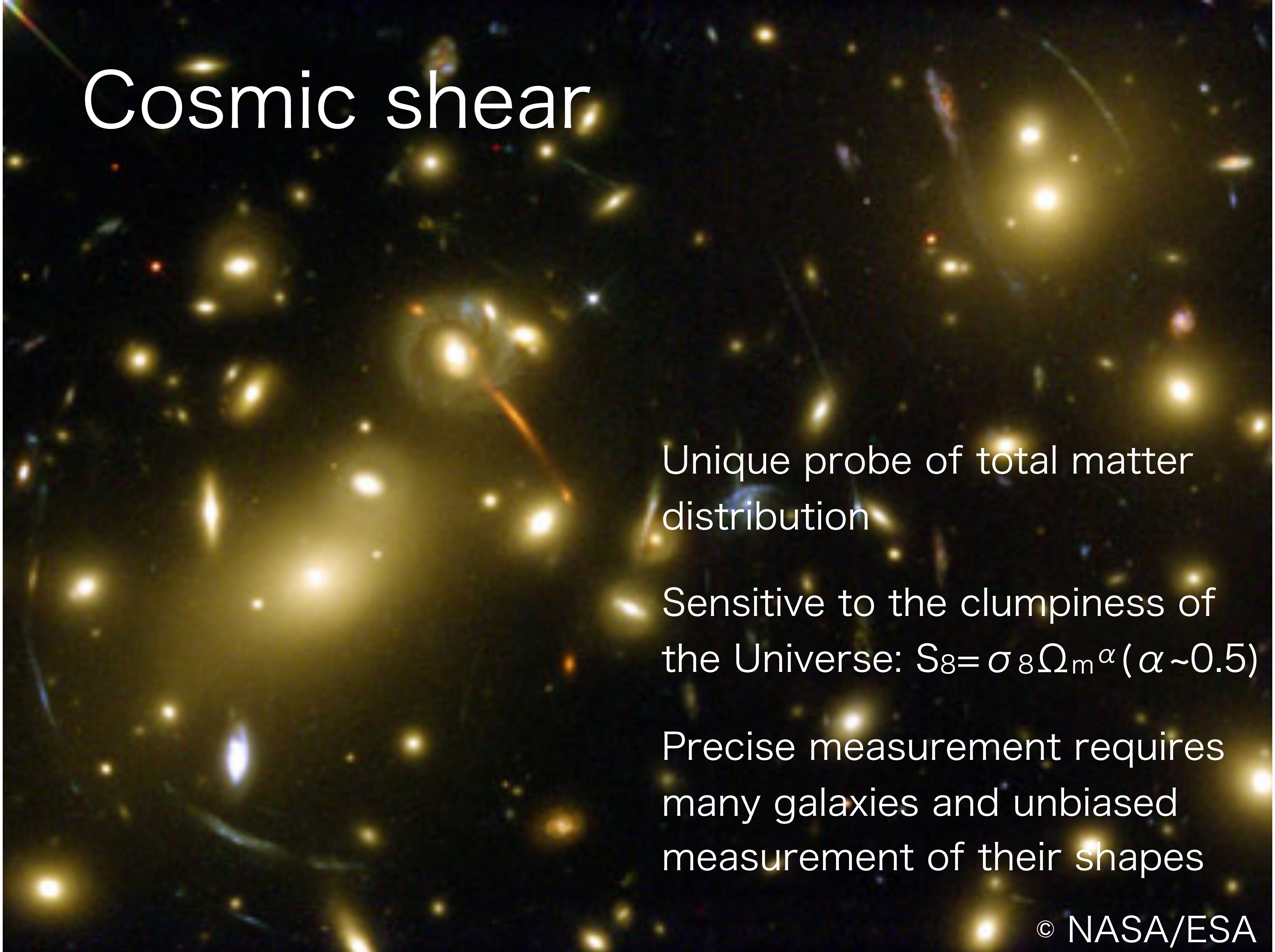
on behalf of HSC WL team

arXiv: 1809.09148

accepted for publications in PASJ

Cosmic shear

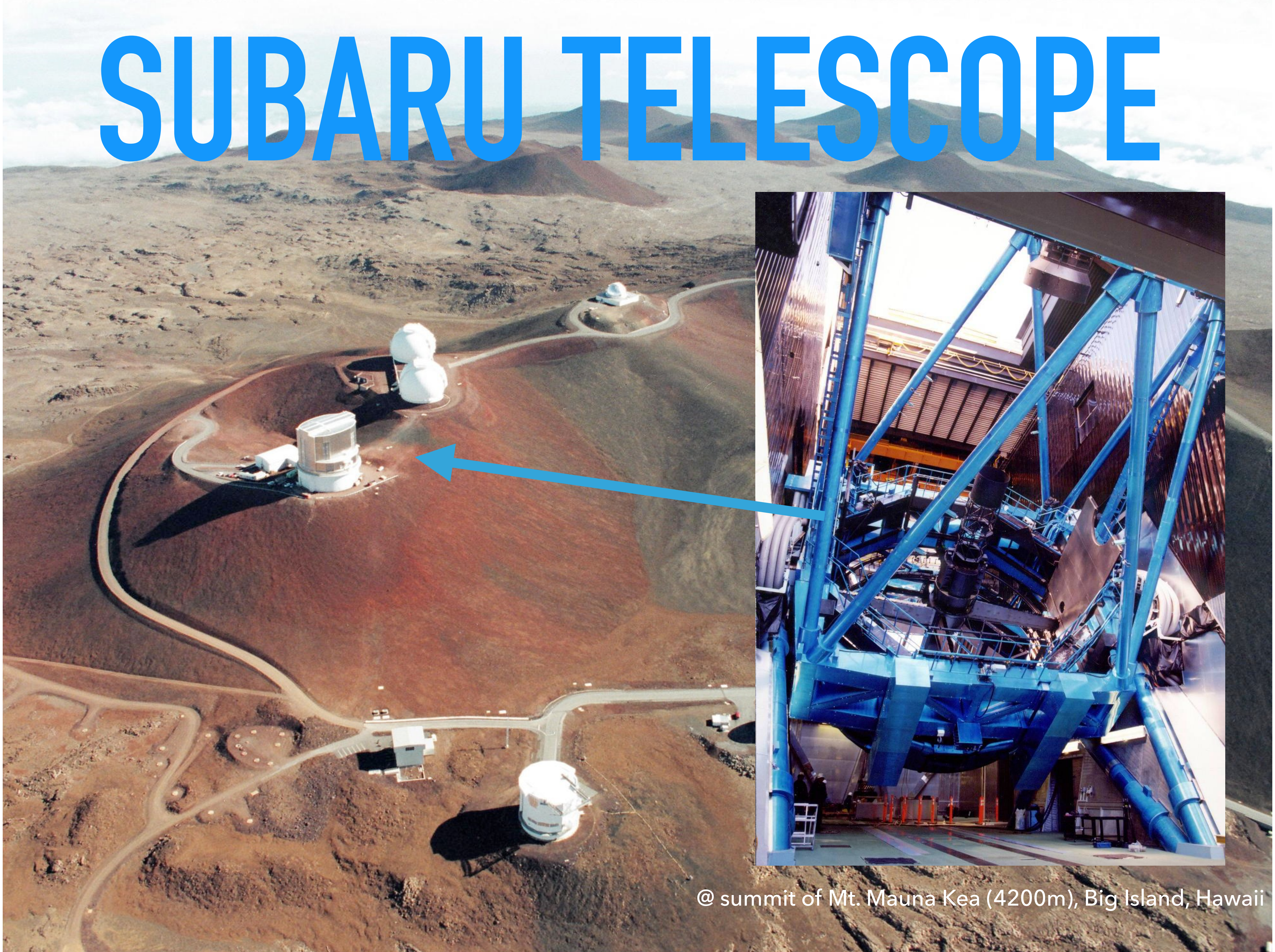


Unique probe of total matter distribution

Sensitive to the clumpiness of the Universe: $S_8 = \sigma_8 \Omega_m^{\alpha}$ (α~0.5)

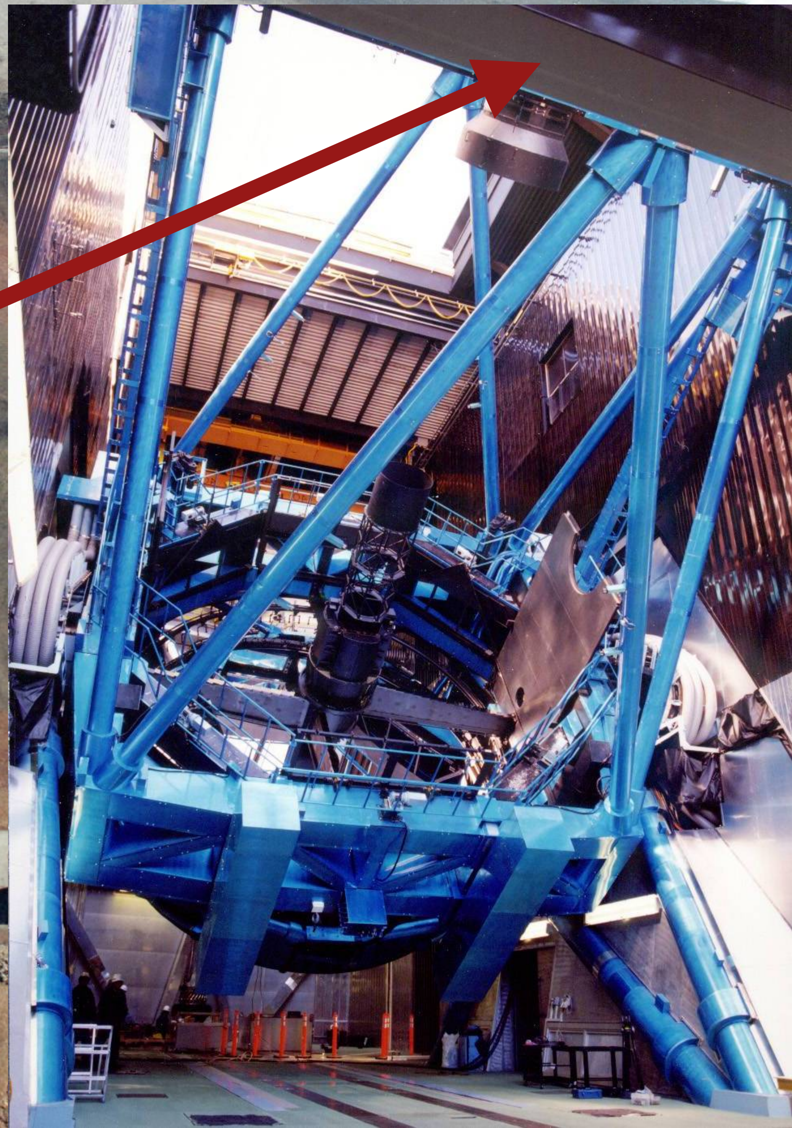
Precise measurement requires many galaxies and unbiased measurement of their shapes

SUBARU TELESCOPE



@ summit of Mt. Mauna Kea (4200m), Big Island, Hawaii

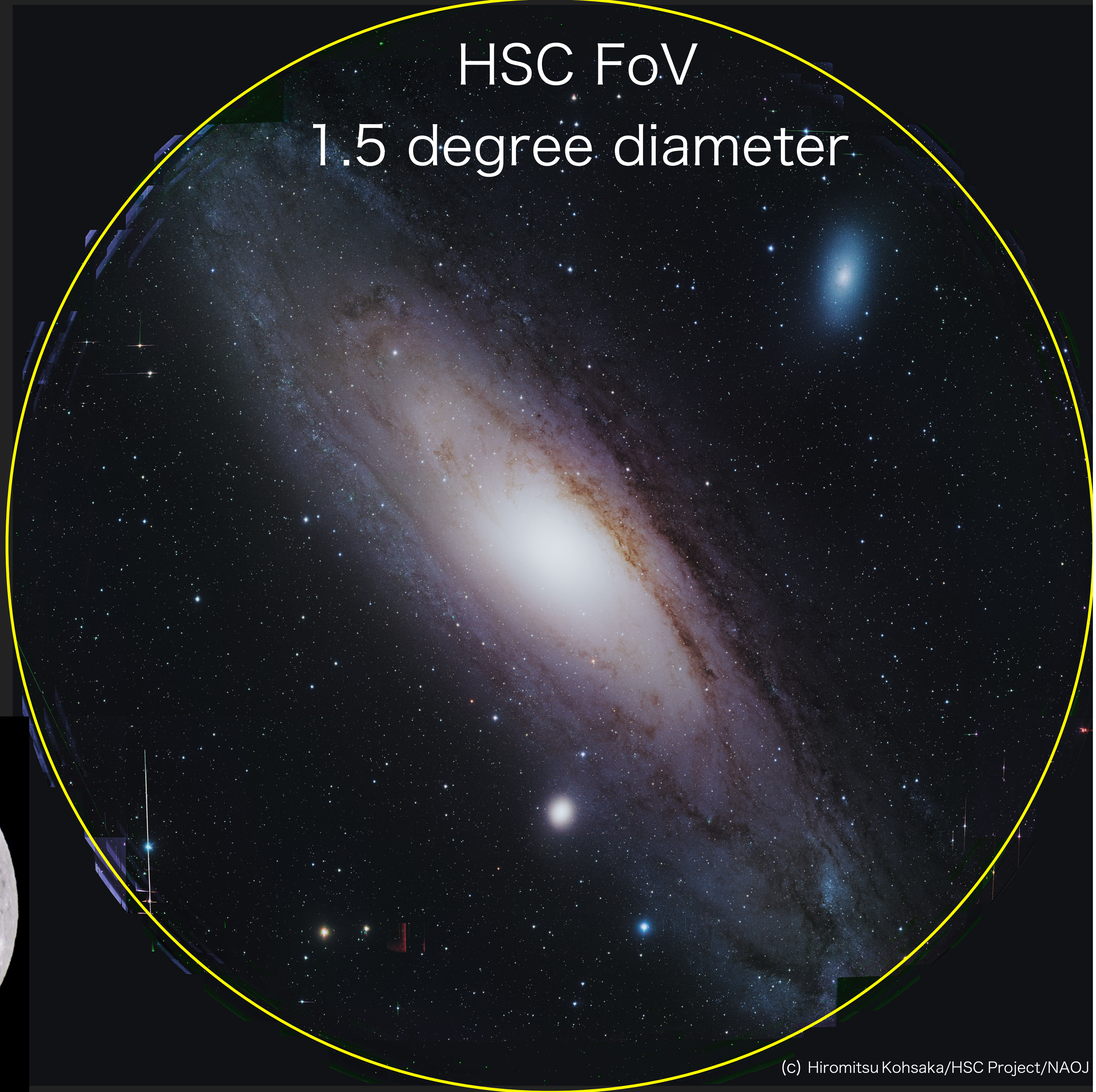
HYPER SUPRIME CAM (HSC)



3m, 3t, 116 CCDs

@ summit of Mt. Mauna Kea (4200m), Big Island, Hawaii

WIDE


HSC FoV
1.5 degree diameter
(c) Hiromitsu Kohsaka/HSC Project/NAOJ

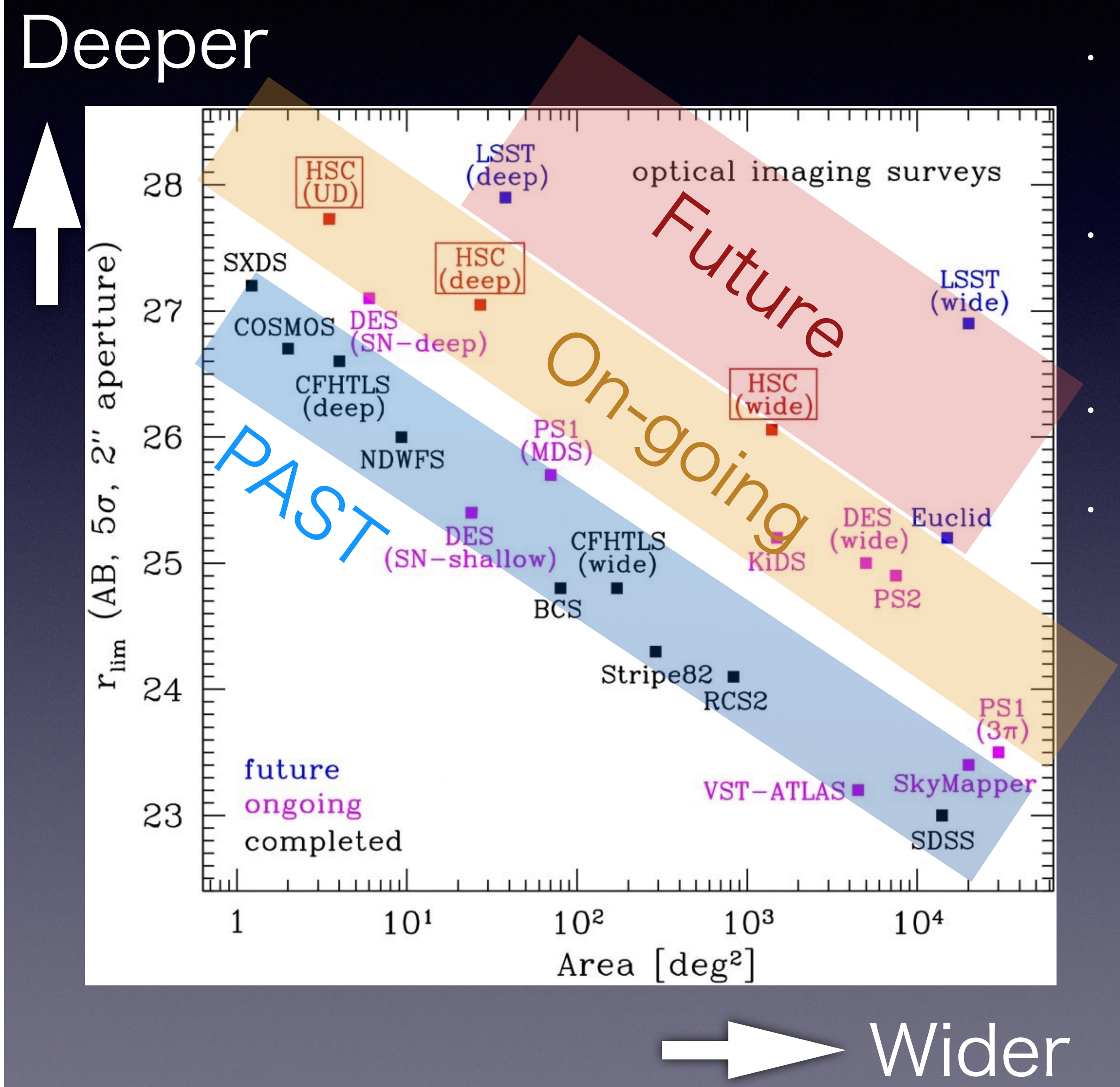
DEEP & SHARP

i-26 (5σ) in 20mins

~0.6" seeing

(c) Princeton, HSC project

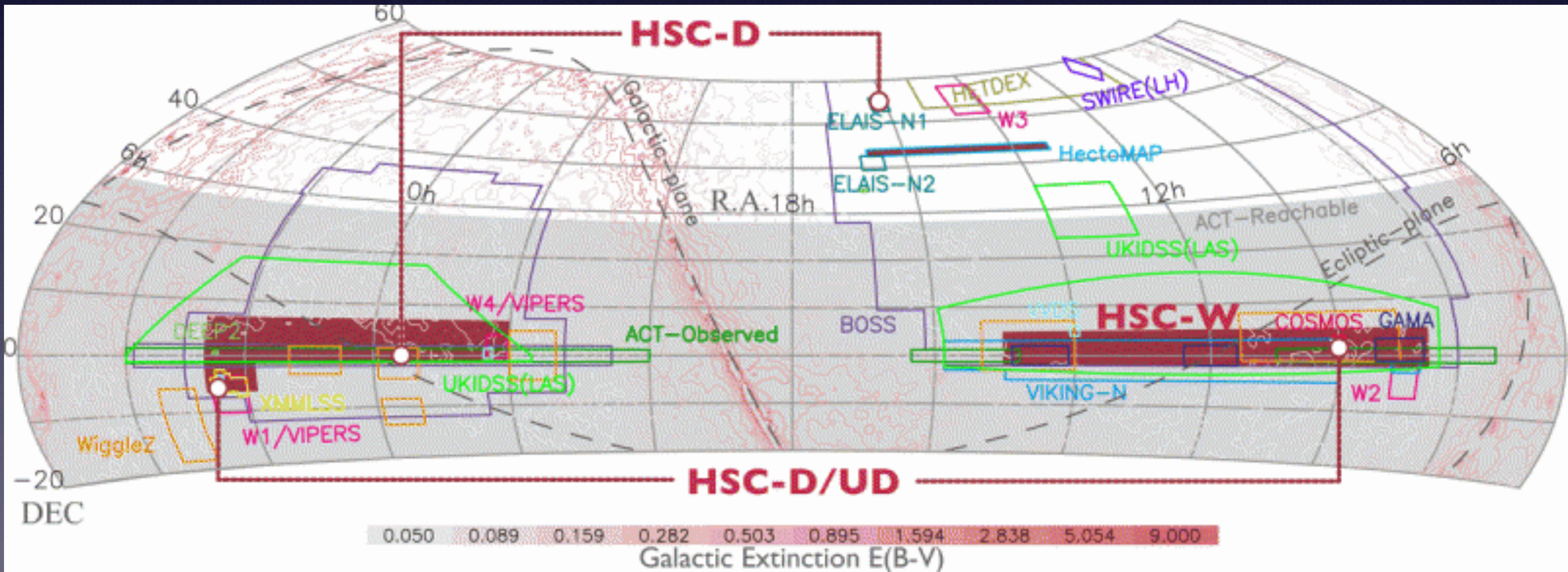
HSC Subaru-Strategic Program (SSP)



- Wide-imaging survey project using HSC
- 300 nights over 5-6 years (started from March 2014)
- 5 broadbands (grizY)+4NBs
- 3-layers imaging survey:
  - Wide (1400deg², r~26)
    WL, cosmology
  - Deep (27deg², r~27)
    galaxy evolution
  - Ultradeep (3.5deg², r~28)
    cosmic reionization

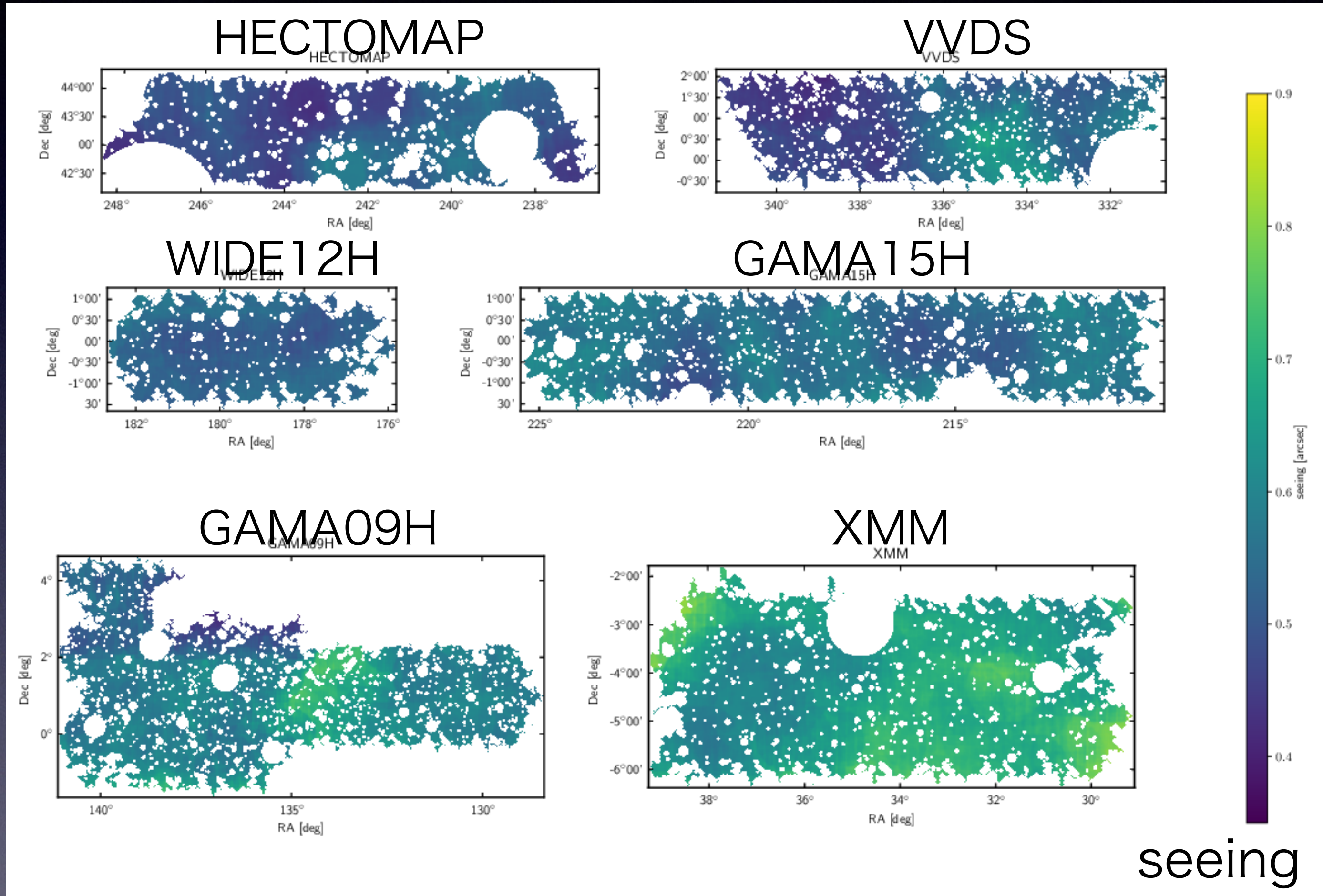
Survey Location

- HSC survey fields are selected to overlap with other surveys such as BOSS, ACT, XMM, COSMOS, GAMA, VVDS, VIPERS…
- DR1 was released in Feb 2017, DR2 will be released in May 2019



HSC Y1 shear catalog

- Data taken by Apr 2016 (11% of planned data)
- 6 fields, 137deg^2
- ReGaussianization method (Hirata & Seljak 2003) to measure shapes
- Conservative cut of galaxies for Y1 science (e.g., i<24.5, resolution>1/3)
- High number density: n_g=25gals/sq.arcmin



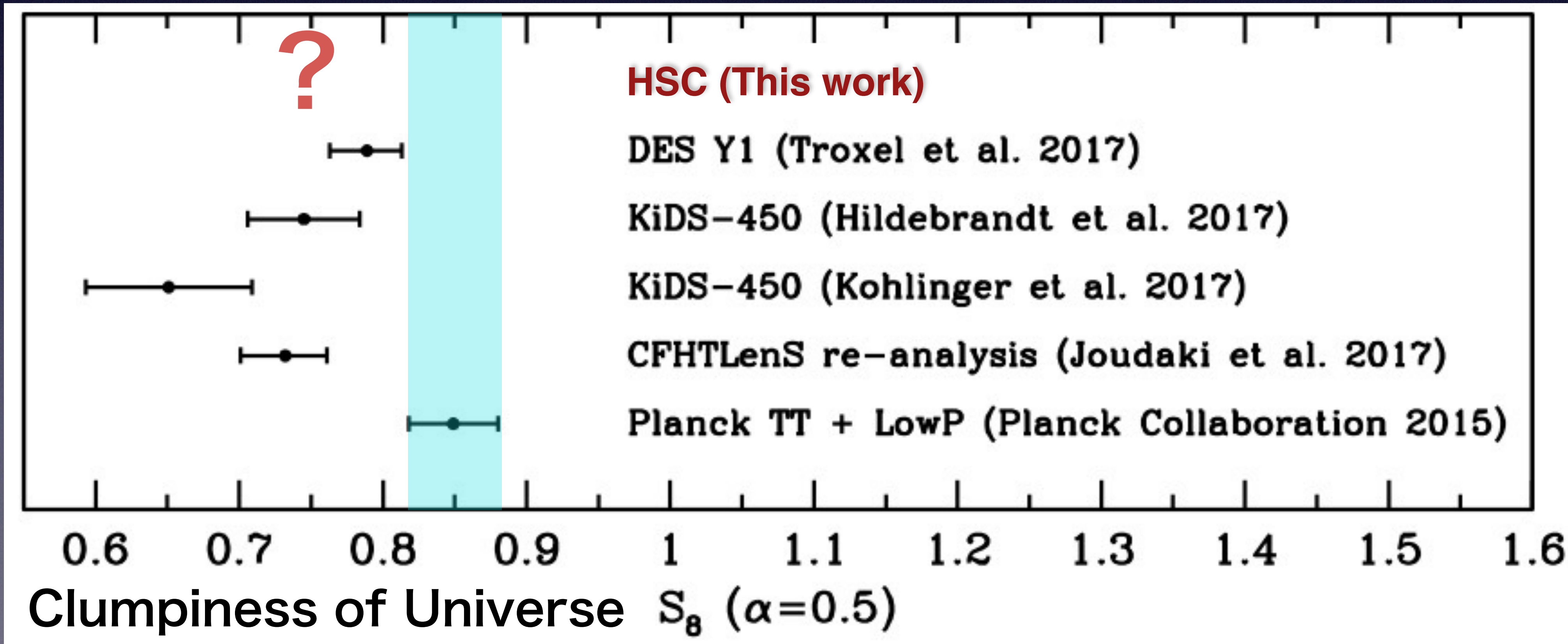
Map of i-band PSF FWHM

Mandelbaum, Miyatake et al. 2018

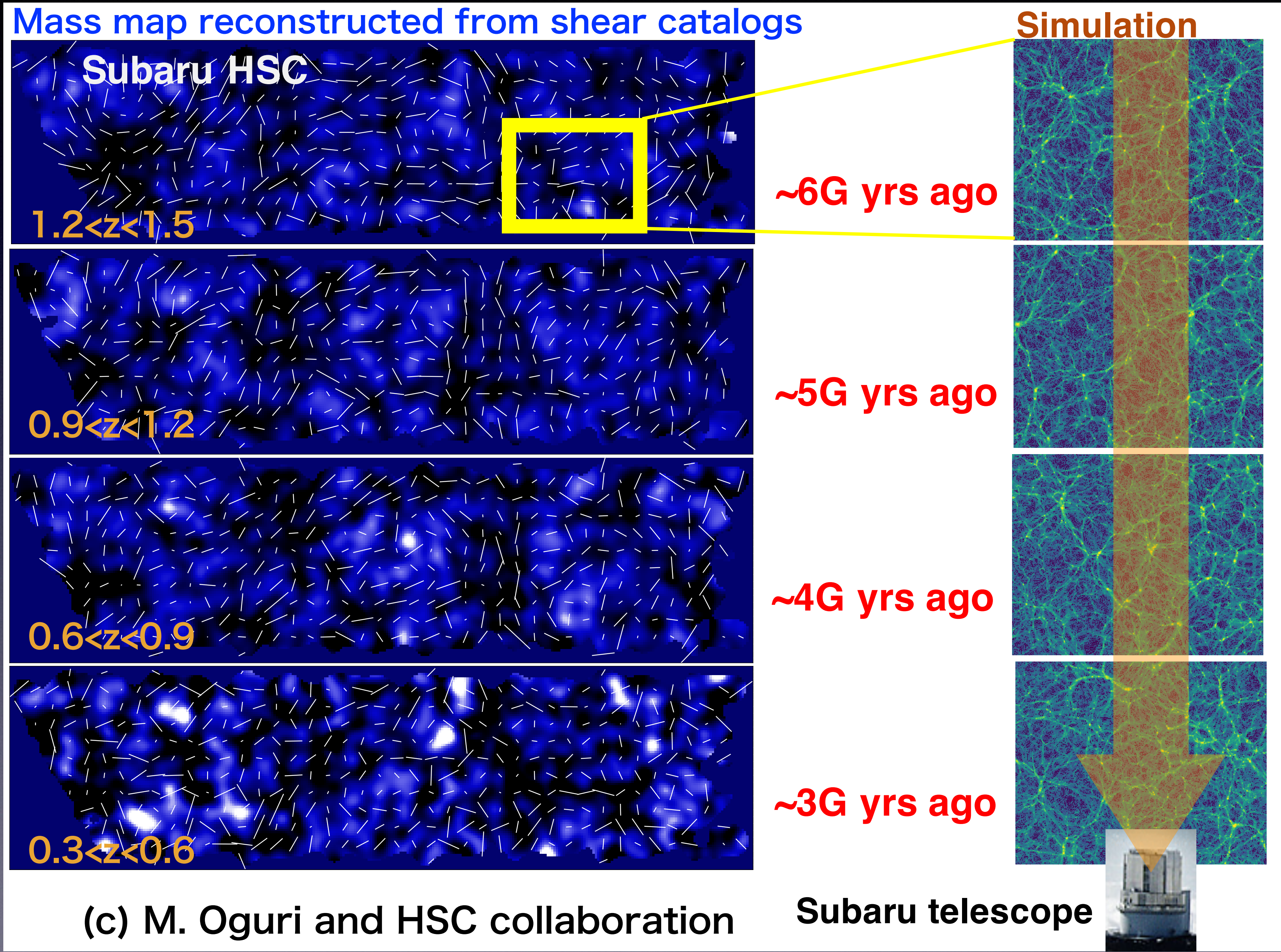
$n_{g,eff} = \sum_i e^2_{rms,i}/(\sigma^2_{e,i} + e^2_{rms,i})/\text{area}$

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

HSC enables us to measure cosmic shear upto higher redshift with lower shape noise



tomographic analysis



Blind analysis

shear multiplicative bias

$$\mathrm{m}^i_{\mathrm{cat}} = \mathrm{m}_{\mathrm{true}} + \mathrm{dm}^i_1 + \mathrm{dm}^i_2$$

Only analysis chair can decrypt

Only blinder-in-chief can decrypt

Catalog level

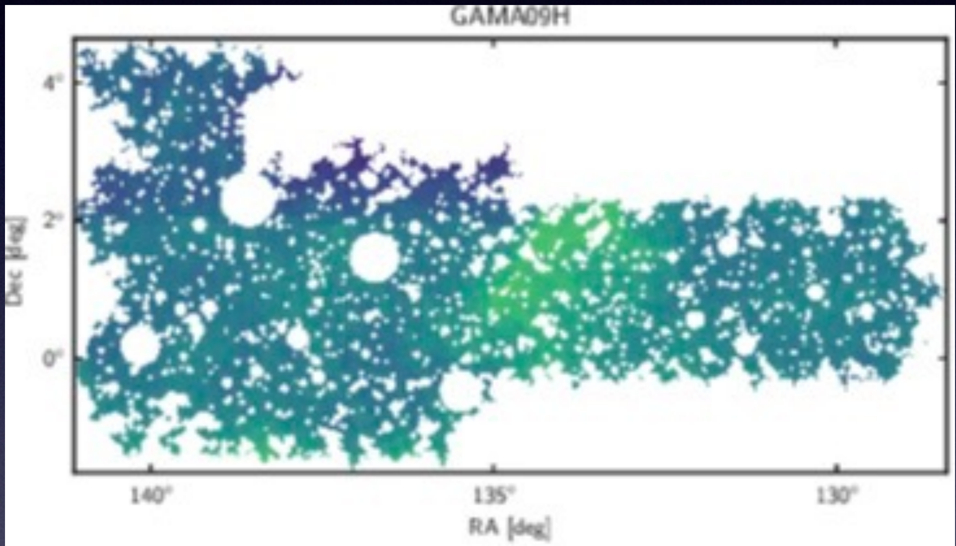
- Each analysis team receive three catalogs with different shear bias corrections: one is true, the other two are fake
- Unblinding needs two passwords from each analysis chair and the blinder-in-chief who is not involved in the analysis

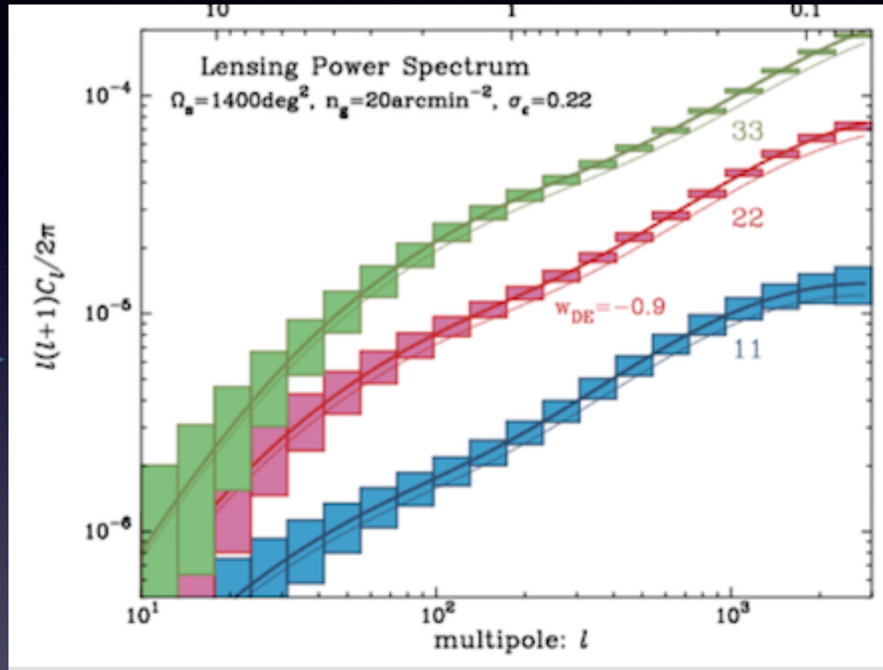
Analysis level

- Central values of posterior distributions are blinded
- No comparison with other data 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 complicated due to bright star masks





Pseudo-Cl method gives unbiased estimates of lensing power spectrum (CH, Hamana, Takada, Spergel 2011)

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

inverse of mixing matrix

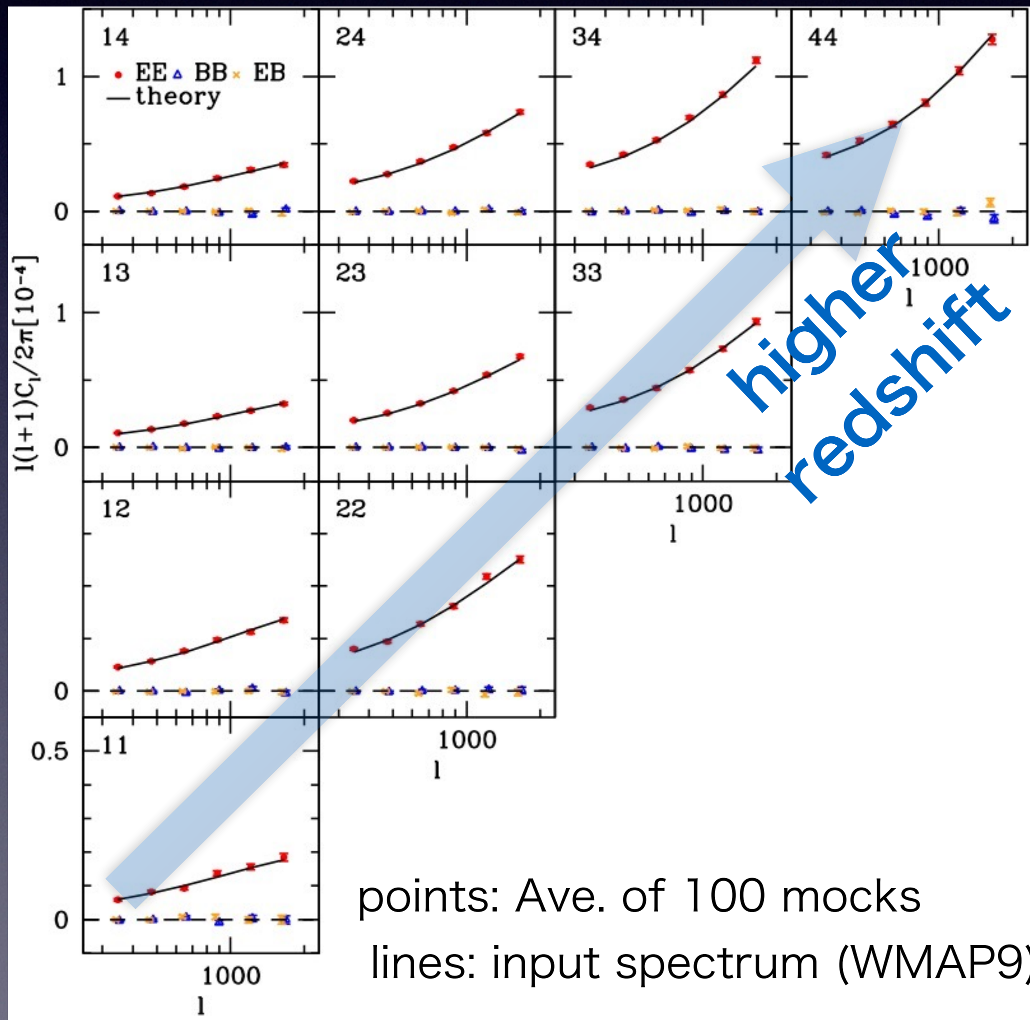
masked spectrum

shot noise estimated from random rotation

Testing the pseudo-Cl method using HSC mock catalogs

- HSC mocks made from all-sky lensing simulations (Takahashi+ 2017, Oguri+ 2018, Shirasaki+)
  - Sky positions of sources are identical to data
  - Each source redshift is given from the photo-z PDF
  - Size of each source ellipticity is same as data, but the directions is randomly rotated
  - Convert observed ellipticity to simulated one

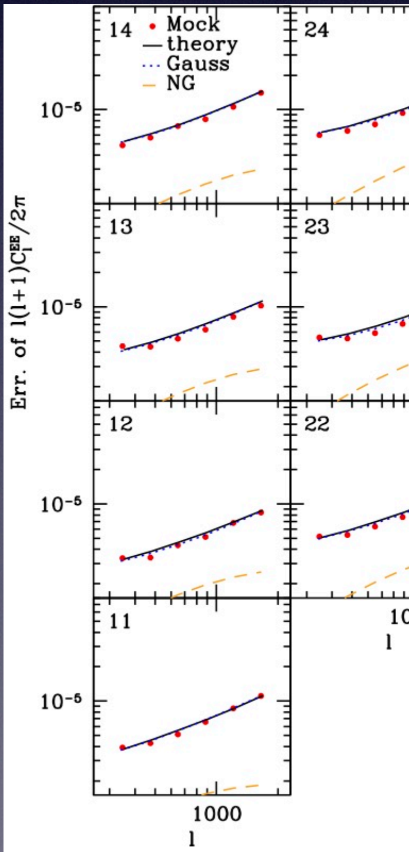
Input spectrum is recovered



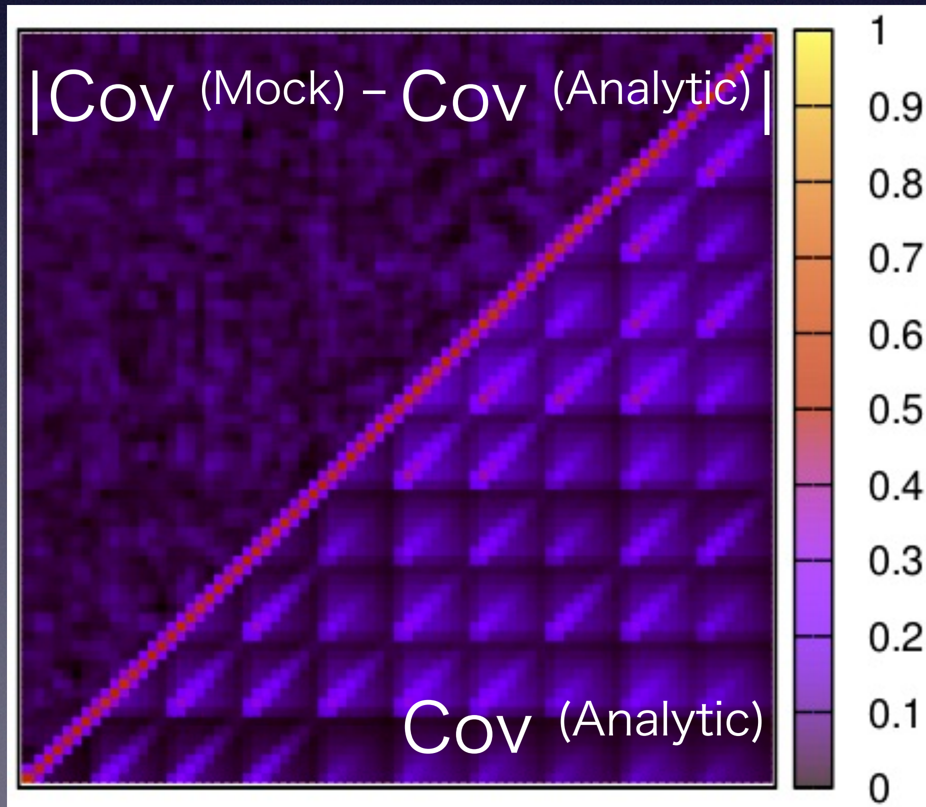
points: Ave. of 100 mocks
lines: input spectrum (WMAP9)

Covariance

- Gaussian, non-Gaussian and super-sample covariance terms
- Based on analytical halo-model + noise covariance directly estimated from data by randomly rotating galaxy shapes
- Cosmology-dependence in covariance is included

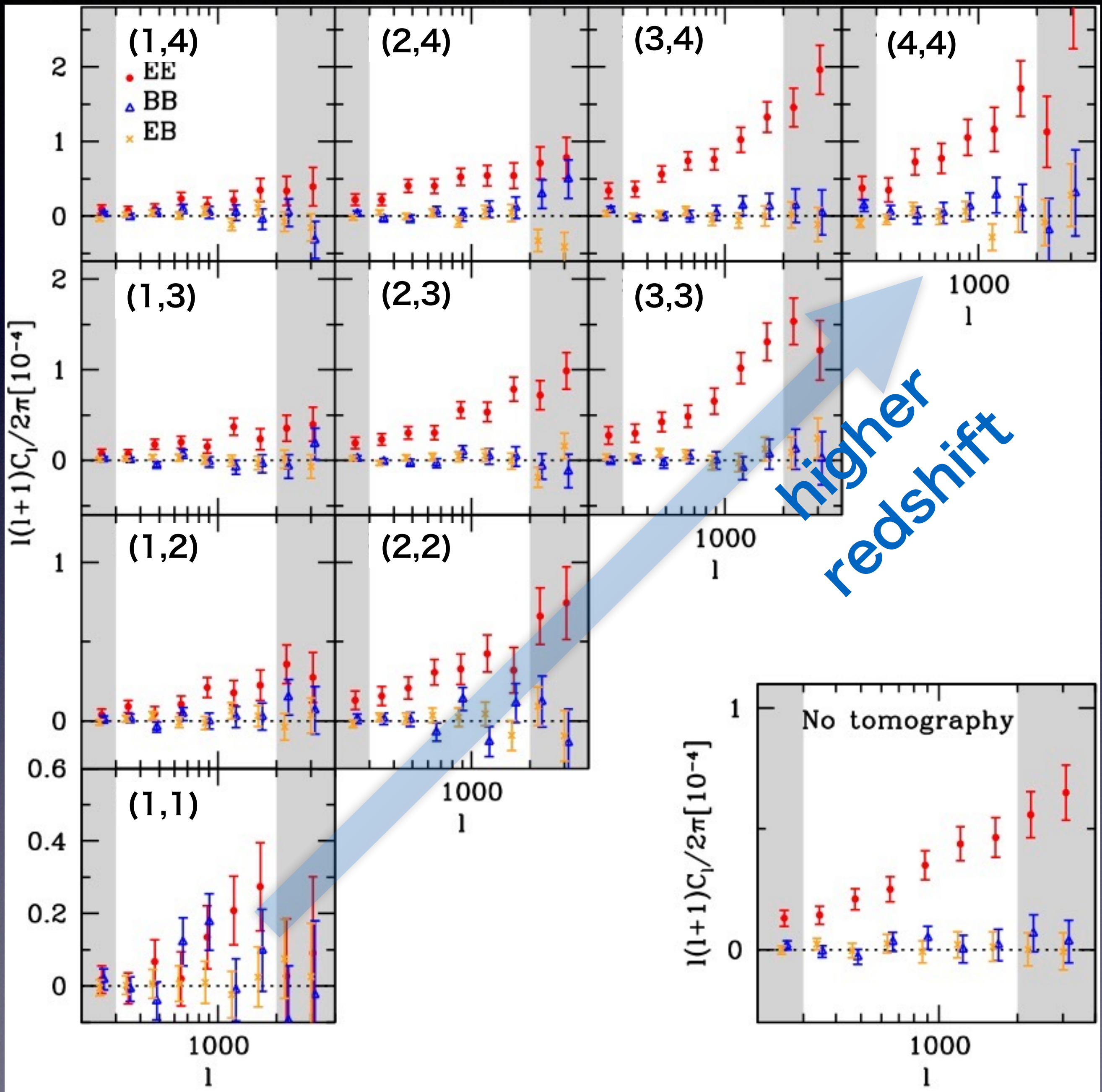


Diagonal Components



correlation coeffecients

Cosmic shear tomographic power spectra



- 4-bin tomography in the range of 0.3<z<1.5
- Focused on the scale 300< ℓ<1900 to avoid potential systematic effects:
  high ℓ: baryon feedback
  low ℓ: residual shape noise
- 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

Systematics

1. **Residual correlations due to PSF modeling error**

   PSF modeling 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**

   Source redshift distribution is estimated by re-weighting COSMOS 30-band data. Variances among different stacked P(z) are taken into account by shifting mean redshift

3. **Intrinsic alignment (IA)**

   Nonlinear alignment model is adopted. IA amplitude and power-law index of z-evolution are treated as nuisance parameters

4. **Baryon feedback effect**

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

Parameters & Priors

Nested sampling likelihood analysis using “multinest" in MontePython

Fiducial setup: 5 cosmological and 9 nuisance parameters

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

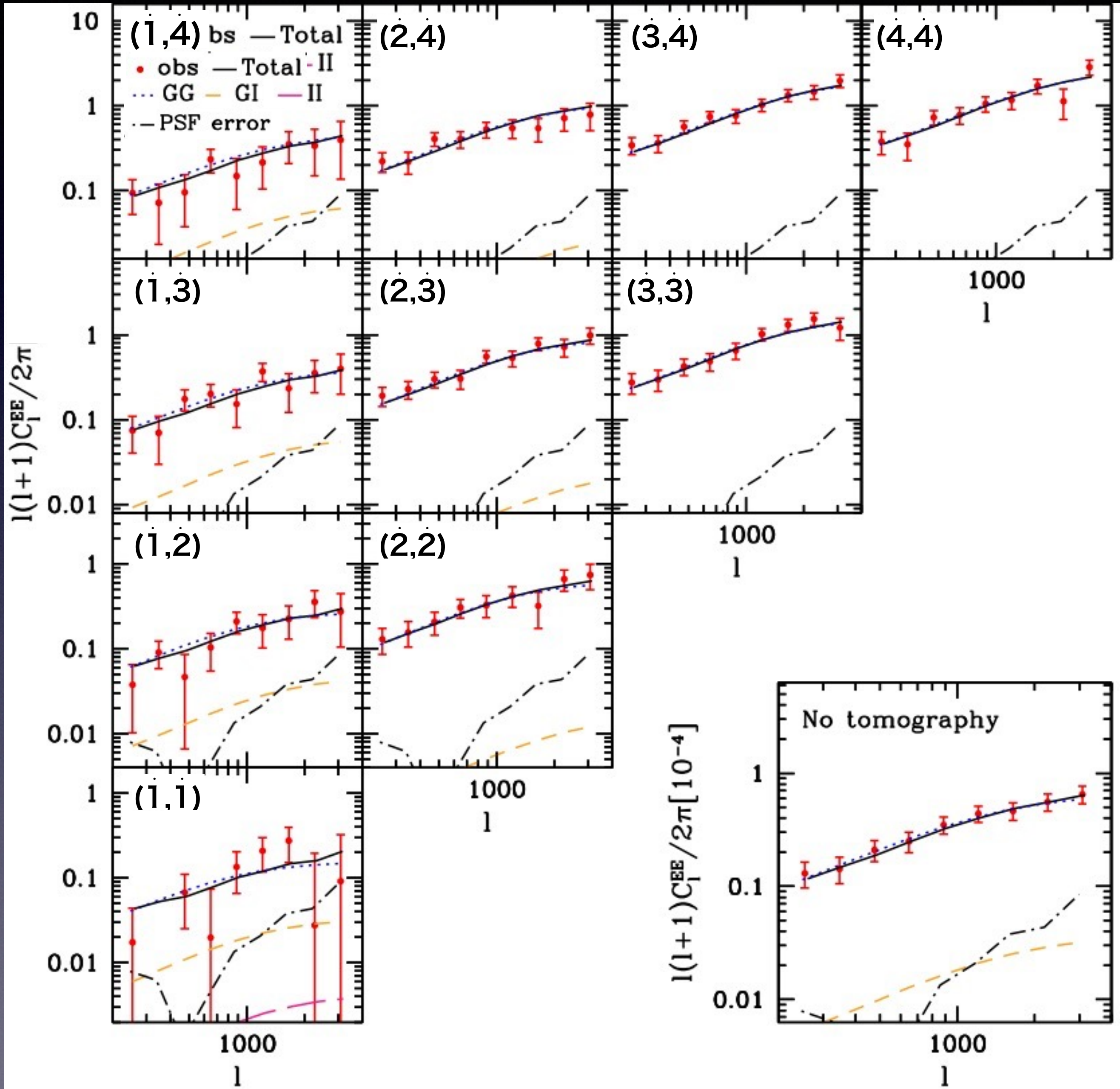
Intrinsic alignment

Baryonic effect

PSF modeling error

photo-z uncertainties

Model fitting



Excellent fits:

χ^2_{min}=45.4 against effective d.o.f=57.1

(p-value is 0.87)

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

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

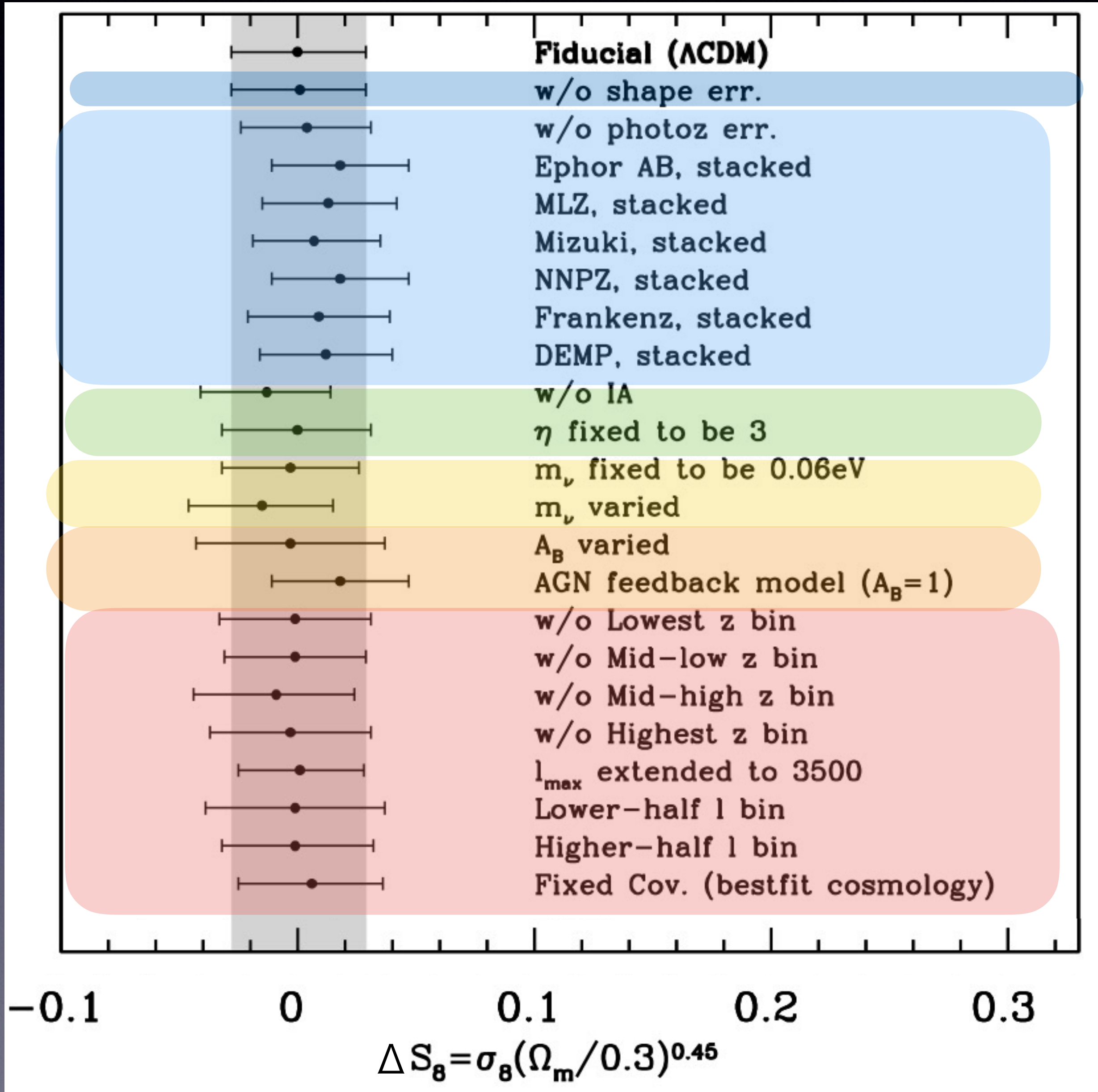
$$N_{\mathrm{eff}} = N_{\mathrm{para}} - \mathrm{tr}[\mathcal{C}_{\mathrm{prior}}^{-1}\mathcal{C}_{\mathrm{post}}]$$

prior-dominated parameters (e.g., Ω_b, n_s) are not counted in N_{eff}

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 S_8 constraints

Central value is shifted to zero before unblinding



shape error: <0.1 σ

Photo-z error: ~0.6 σ

Intrinsic alignment: <0.5 σ

Massive neutrino: < 0.5 σ

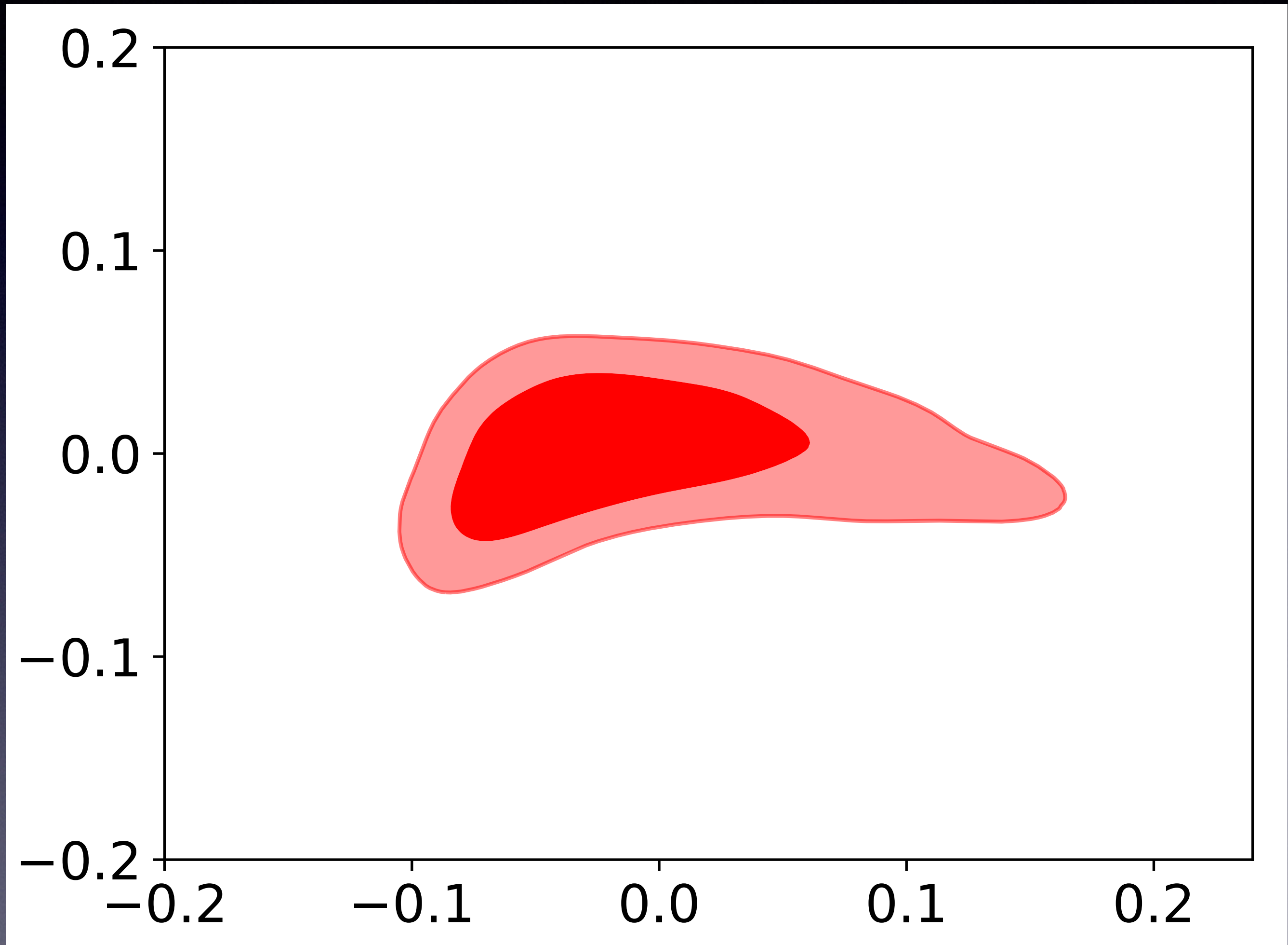
Baryonic effect: < 0.6 σ

No significant internal inconsistency

S_8 constraint is robust against various systematics

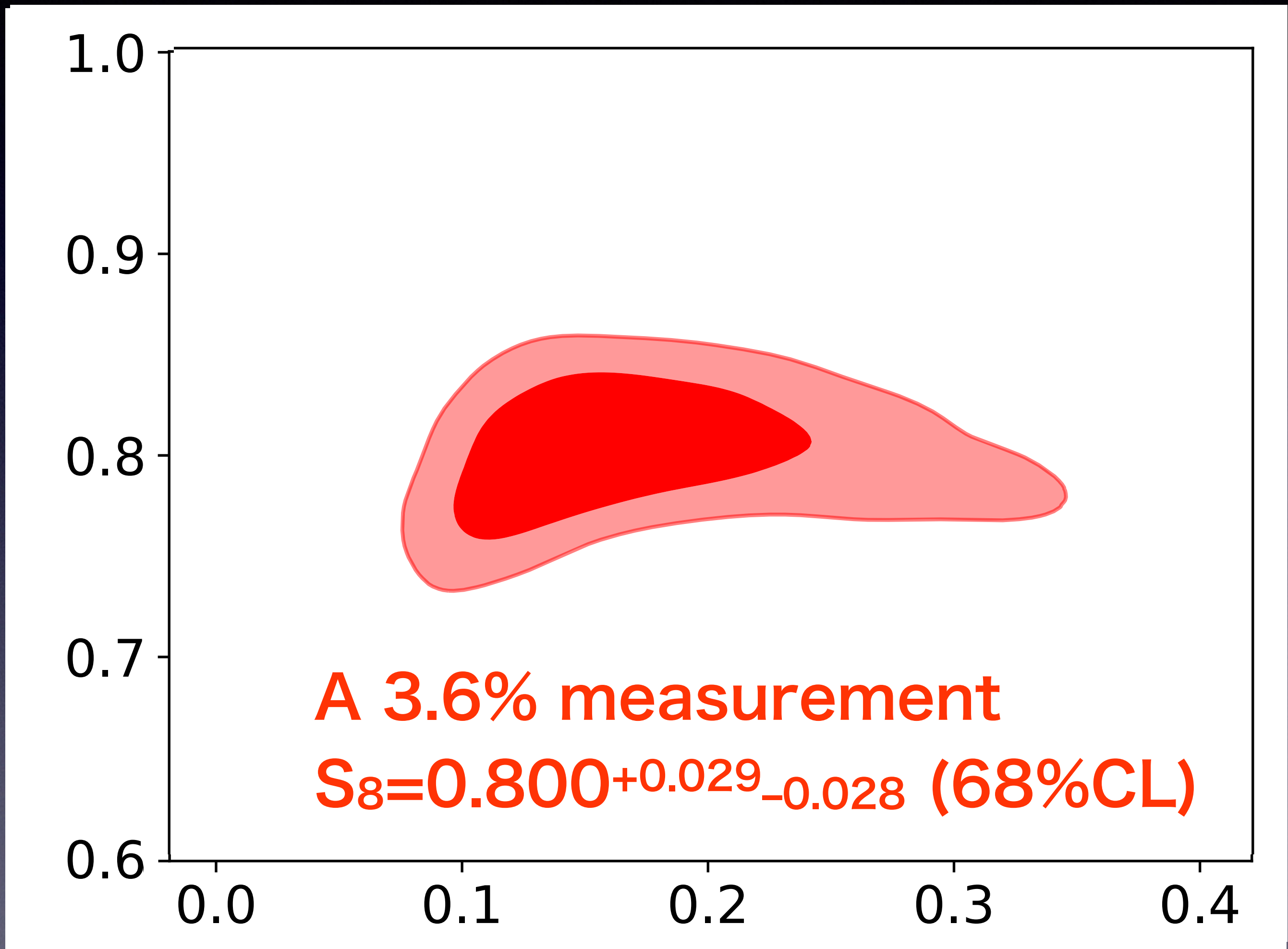
Before Unblinding

S8



Ωm

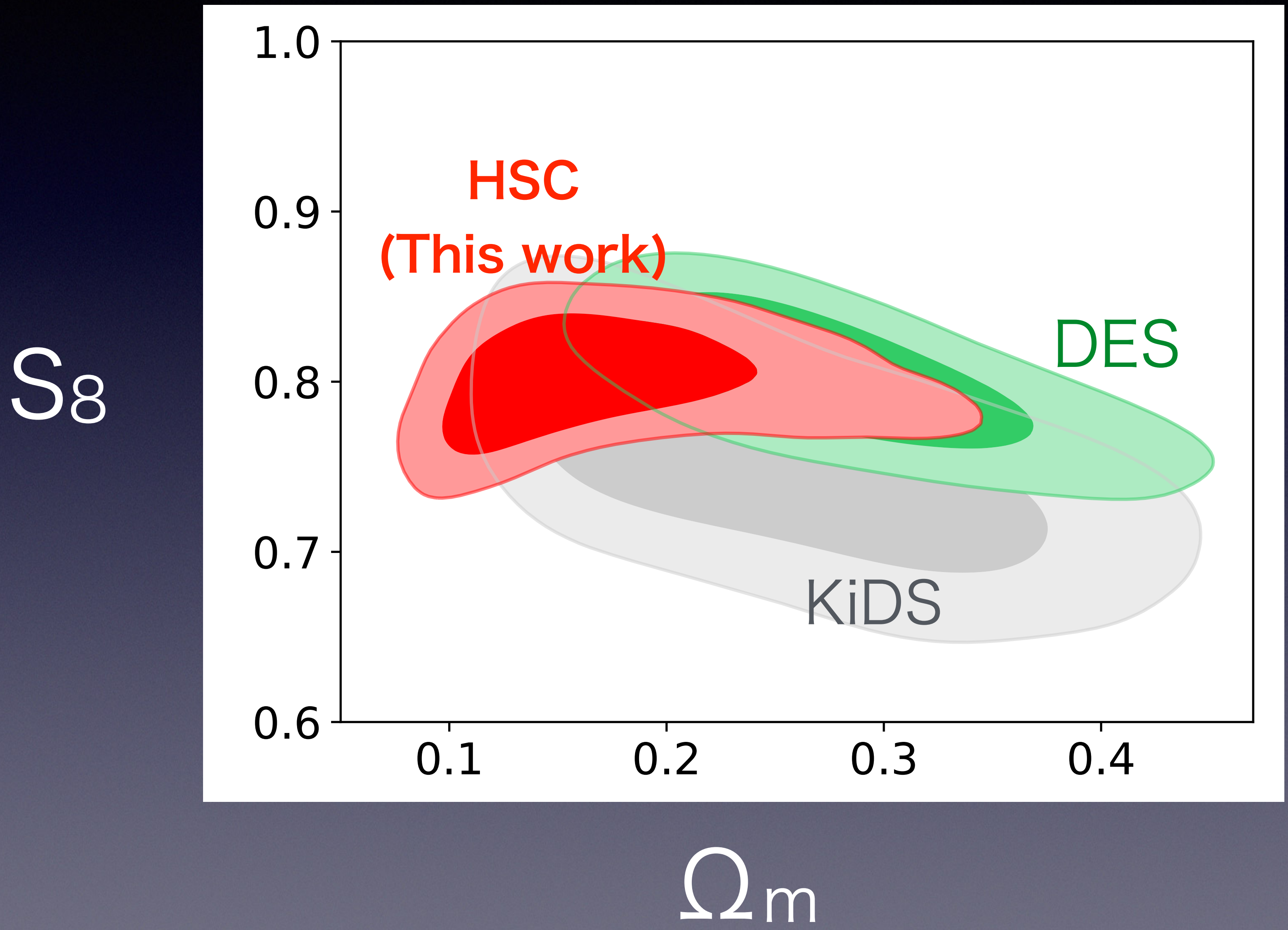
After Unblinding



S_8

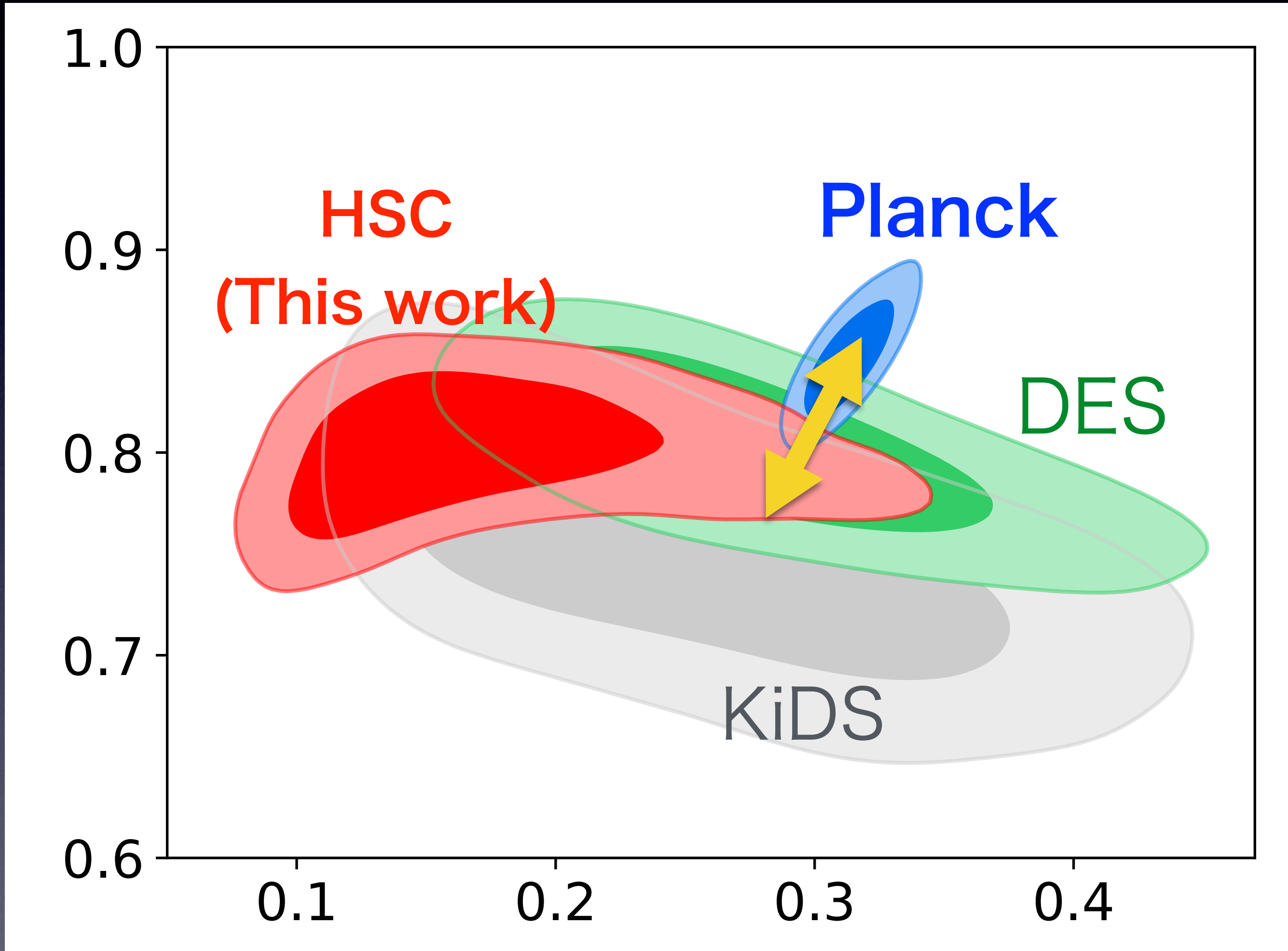
Ω_m

Consistent with other lensing surveys



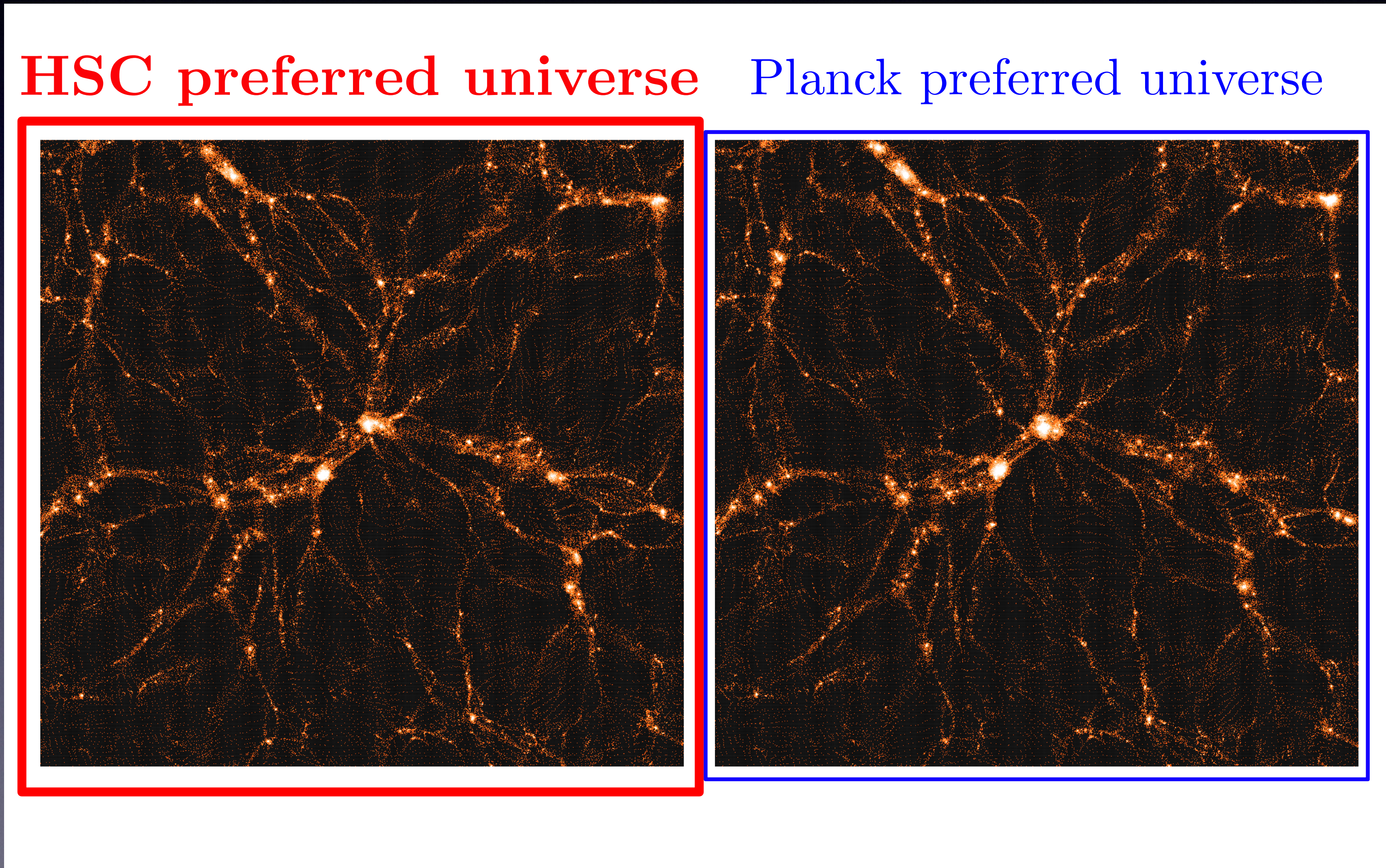
Consistent with Planck but smaller S_8

S_8



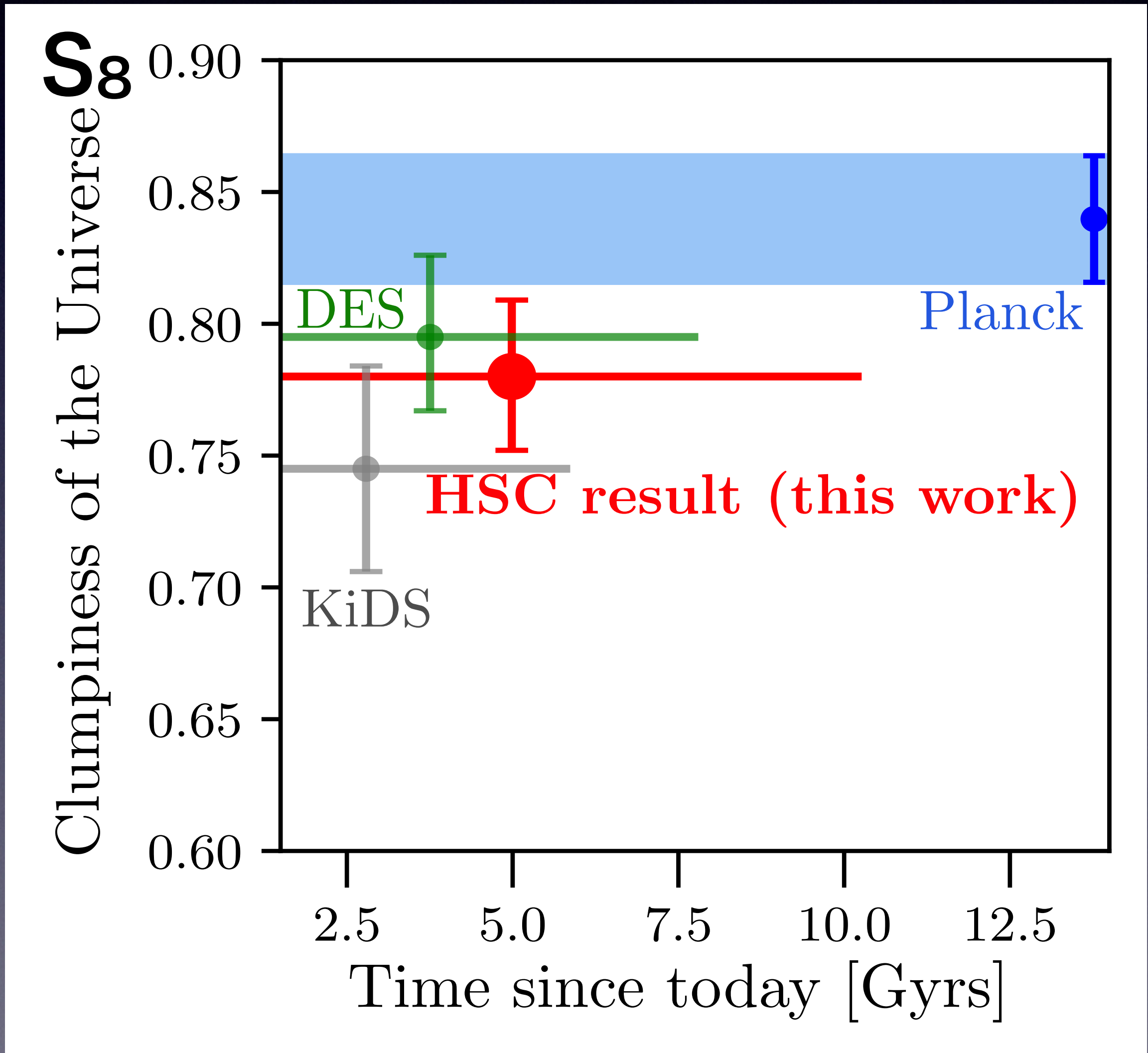
No significant inconsistency between Planck and HSC from Bayesian Evidence and Raveri & Hu concordance estimators

HSC prefers less clumpy universe than Planck predictions



(c) T. Nishimichi

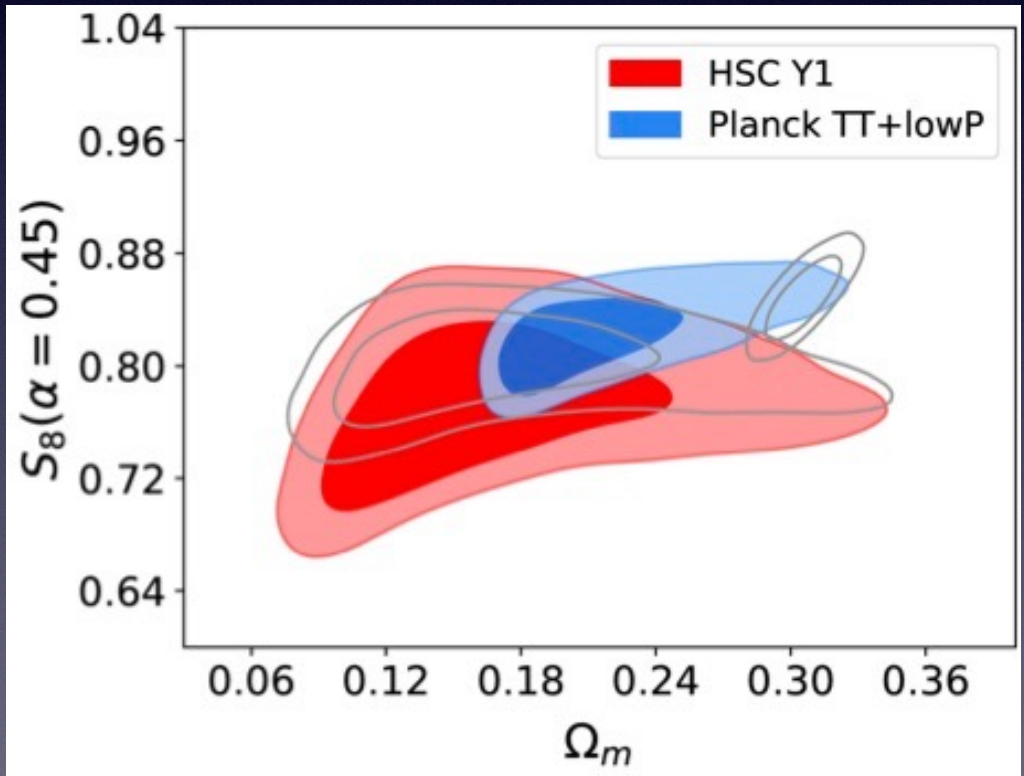
Tensions are real?

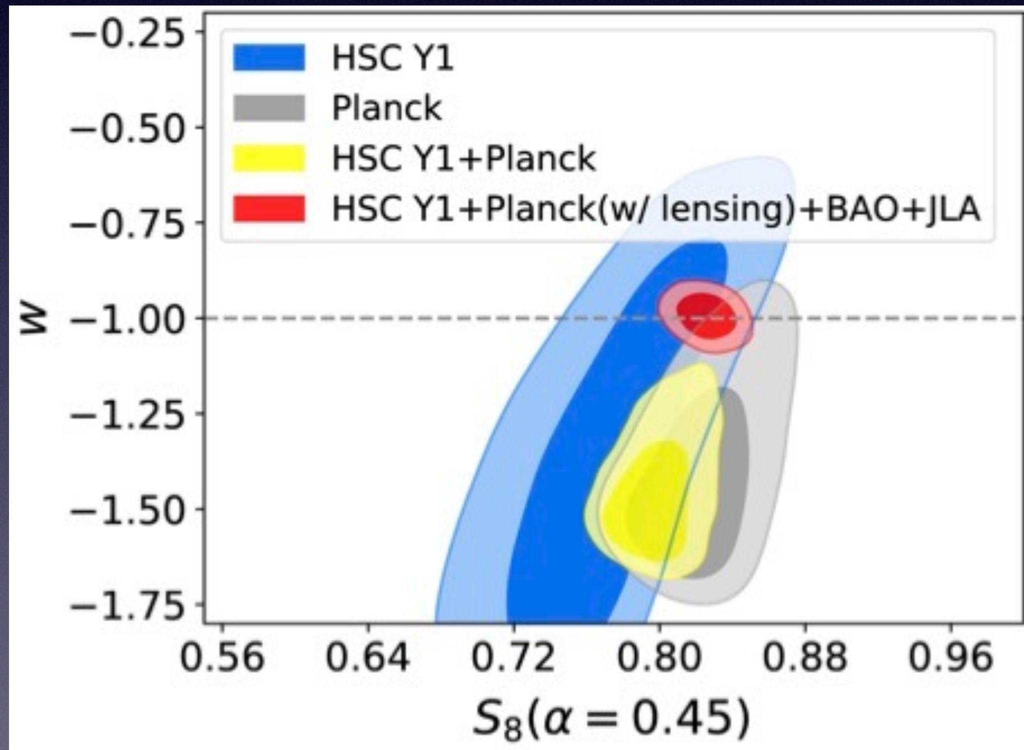


- S_8 from cosmic shear are systematically lower than Planck from
  - different datasets
  - different sky regions
  - different team analyses
  - different estimators
- This may indicate physics beyond ΛCDM (e.g., dynamical dark energy, non-minimal neutrino mass, modified gravity)

Model extensions: wCDM

Tension of S_8 reduces by varying w, though there is no significant preference to favor wCDM from Bayesian evidence





Future prospect

- Current data is just 11% of HSC planned data
- Future HSC data can give much tighter constraint on S_8
- Other cosmological analyses are on-going:
  - cosmic shear with real-space statistics by T. Hamana
  - HSCxBOSS → H. Miyatake's talk
  - HSCxACT → A. Nicola's talk

Summary

- First cosmological analysis from Hyper Suprime-Cam survey
- Blind analysis to test various systematics: PSF modeling error, 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
- HSC is consistent with Planck, but has lower S_8 at ~2σ level similar to DES and KiDS
- Other cosmological analyses are on-going
- Stay tuned for upcoming results!