Cosmology with Subaru HSC survey

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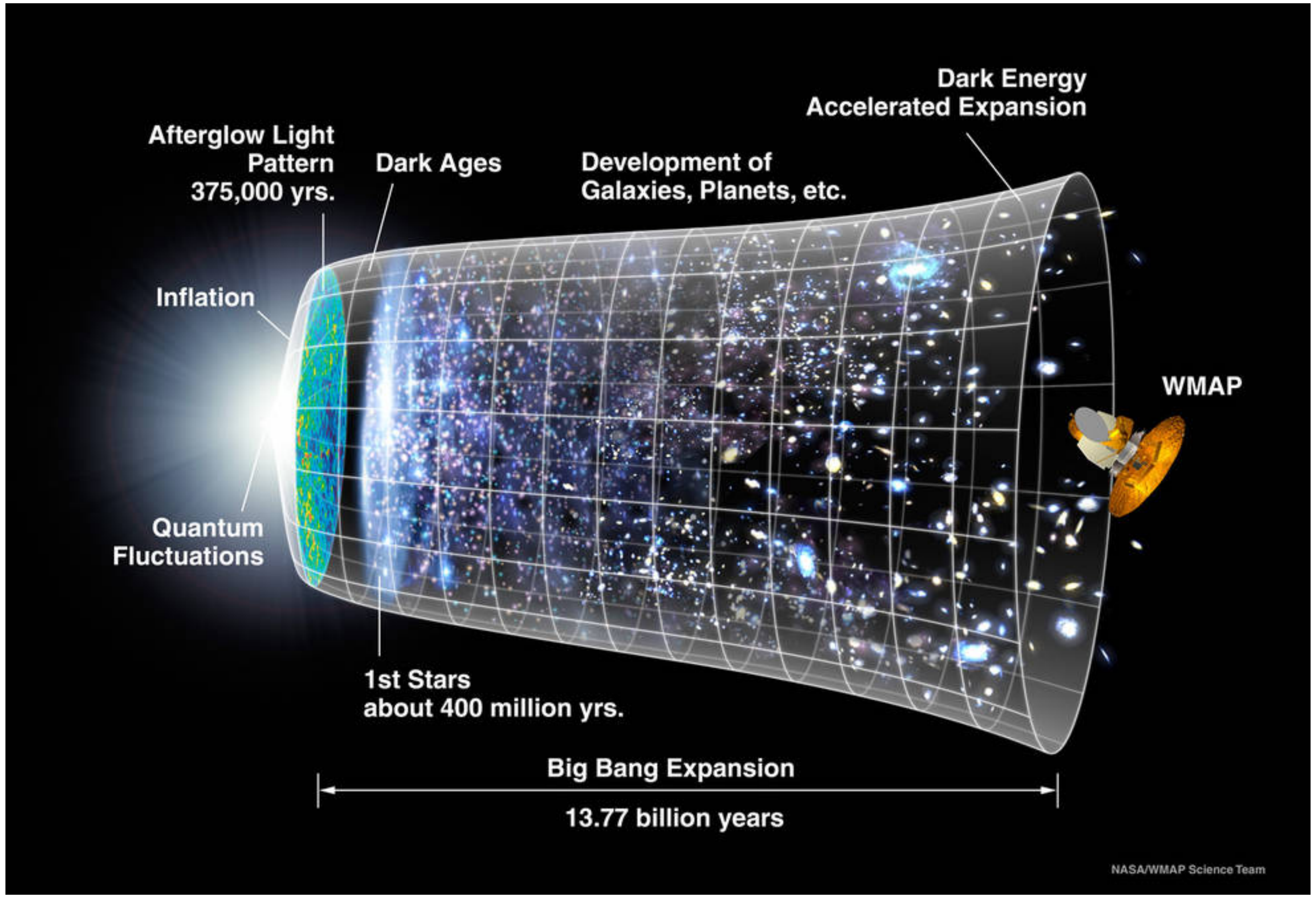
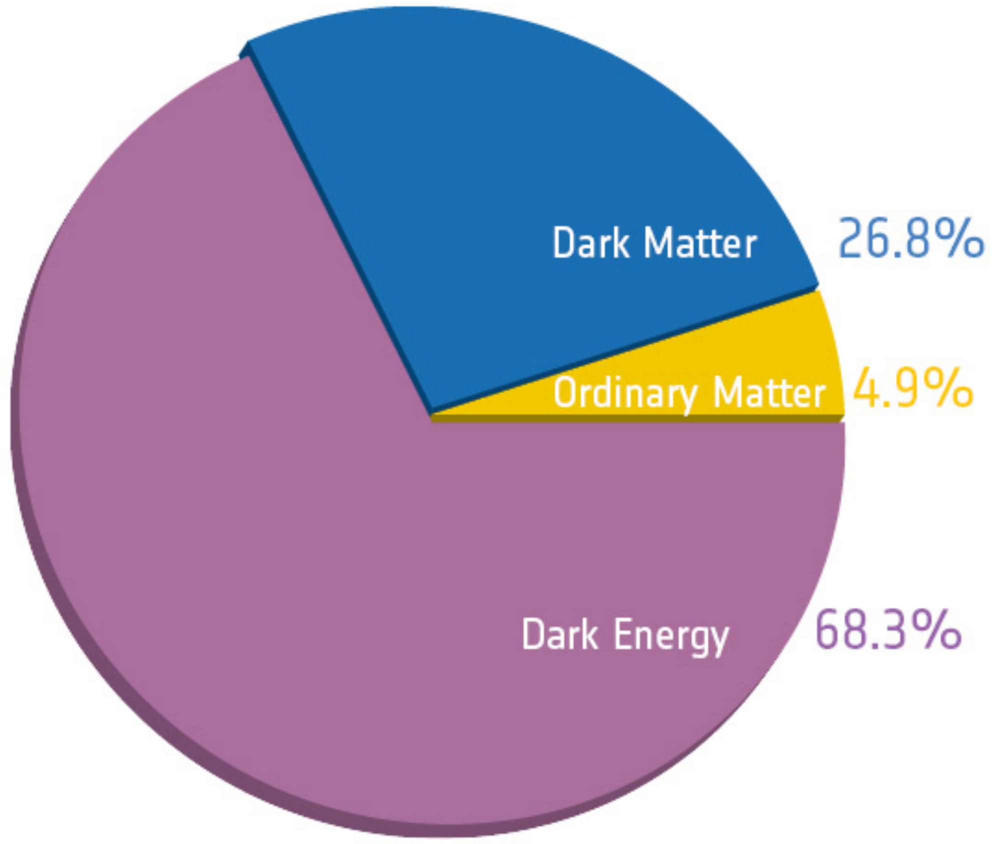
In collaboration with Hironao Miyatake, Surhud More, Xiangchong Li, Masahiro Takada, Roohi Dalal, Tianqing Zhang, Rachel mandelbaum, Michael Strauss, and many others in HSC Collaboration

FY2022 "What is dark matter? - Comprehensive study of the huge discovery space in dark matter"

Observational cosmology

Standard model of the universe





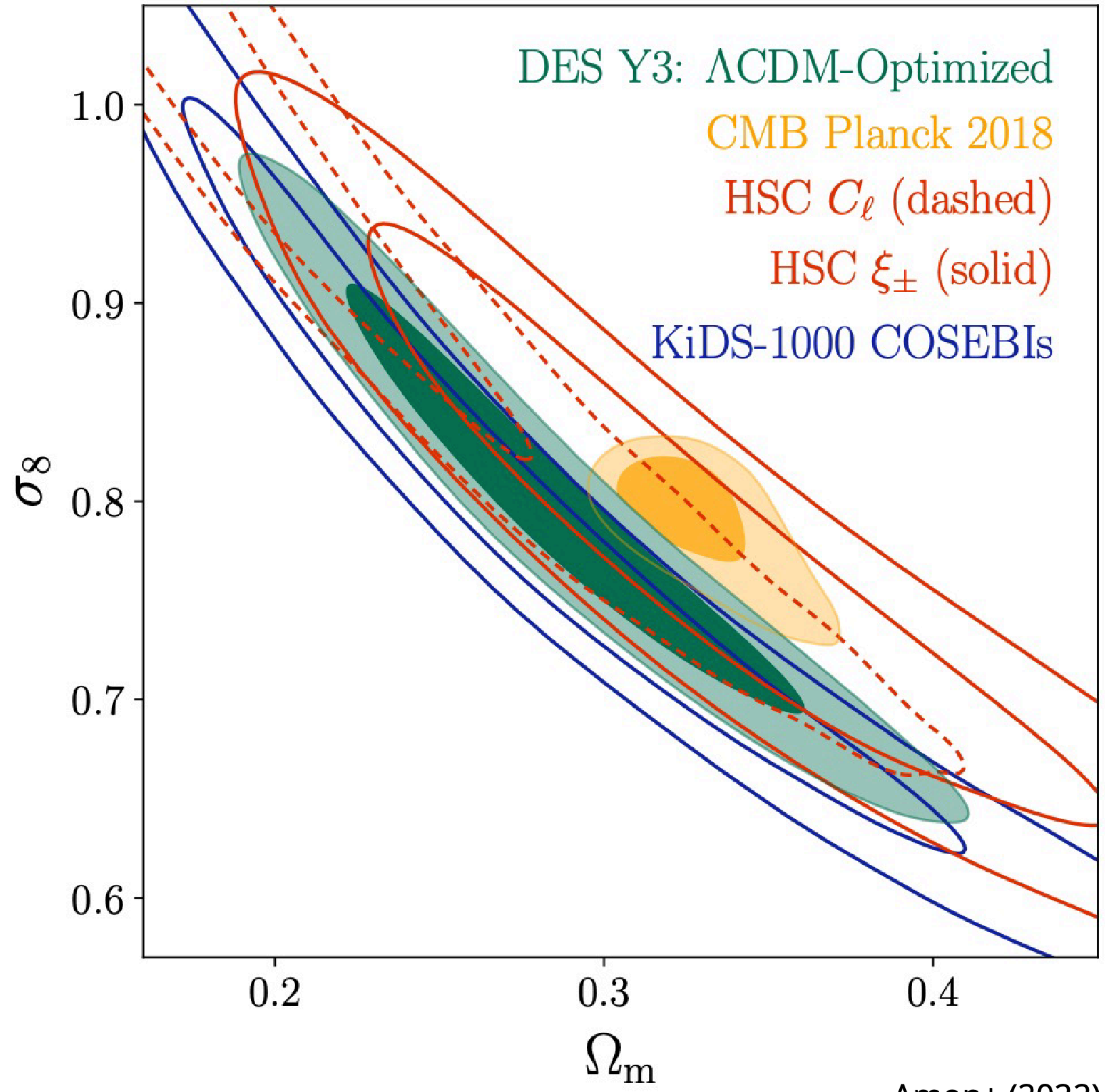
credit: NASA

- Standard model of the universe = ΛCDM model
  - Cosmology constant (Λ) + Cold Dark Matter (CDM)
  - Inflation seeds fluctuation → Structure formation
- CMB, accelerating expansion (SNe), galaxy clustering
- The era of **Precision cosmology**
  - Determining cosmo param at percent level.

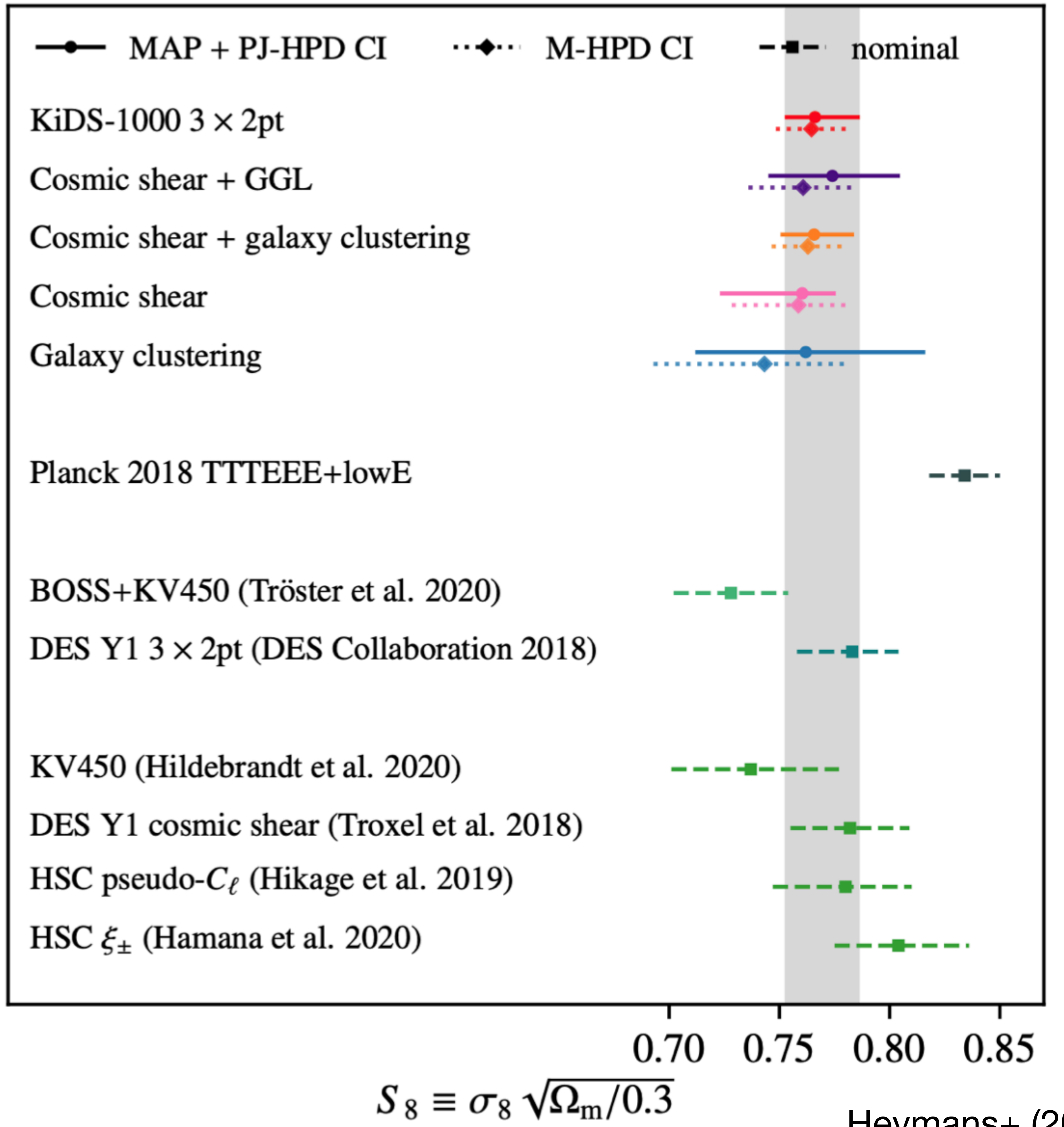
Break down of ΛCDM?

S_8 tension between early- vs Late-time universe

$S_8(\text{galaxy}) < S_8(\text{CMB})$



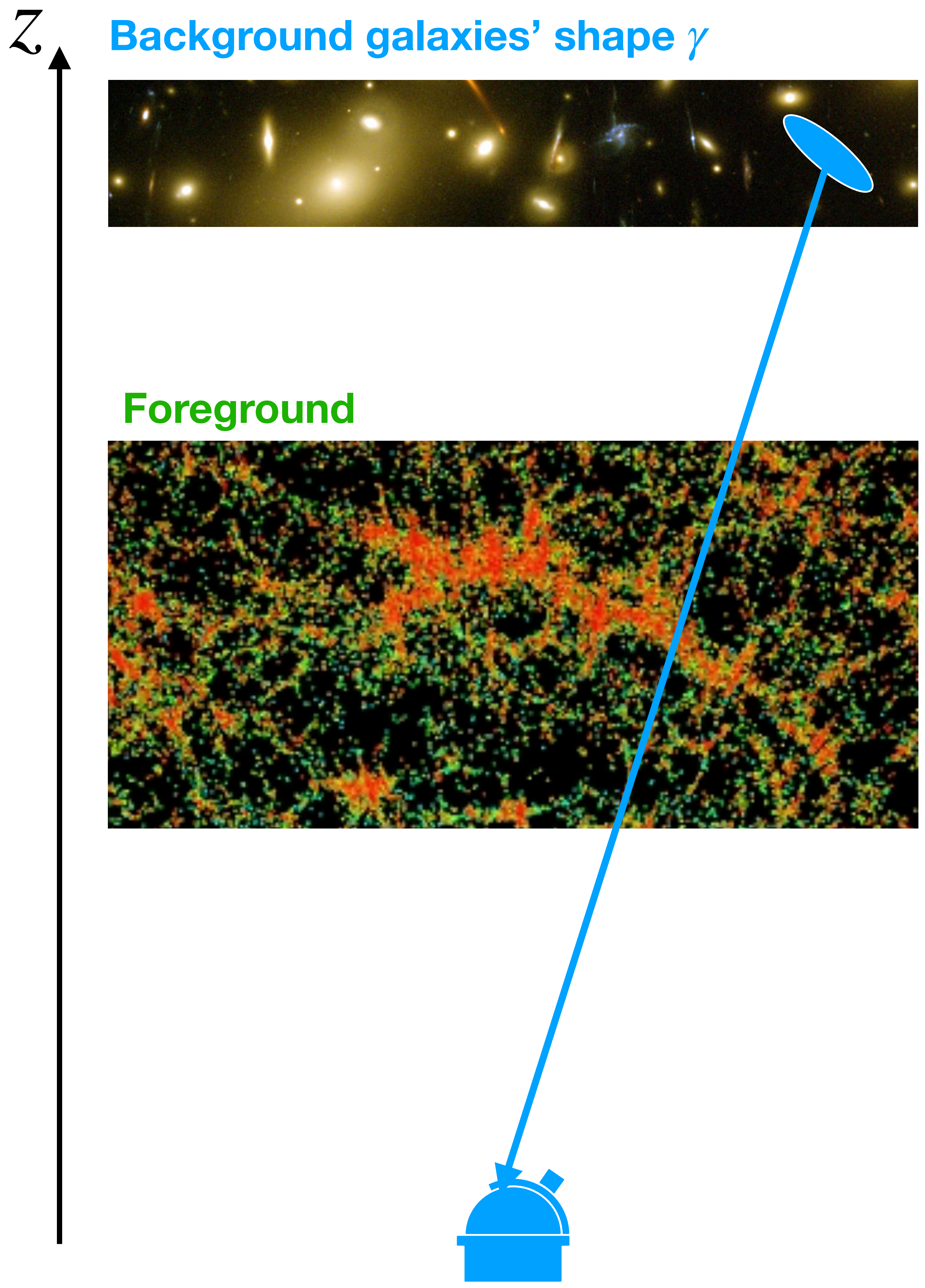
Amon+ (2022)



Heymans+ (2020)

Weak lensing

Gravitational lensing effect by large-scale structure

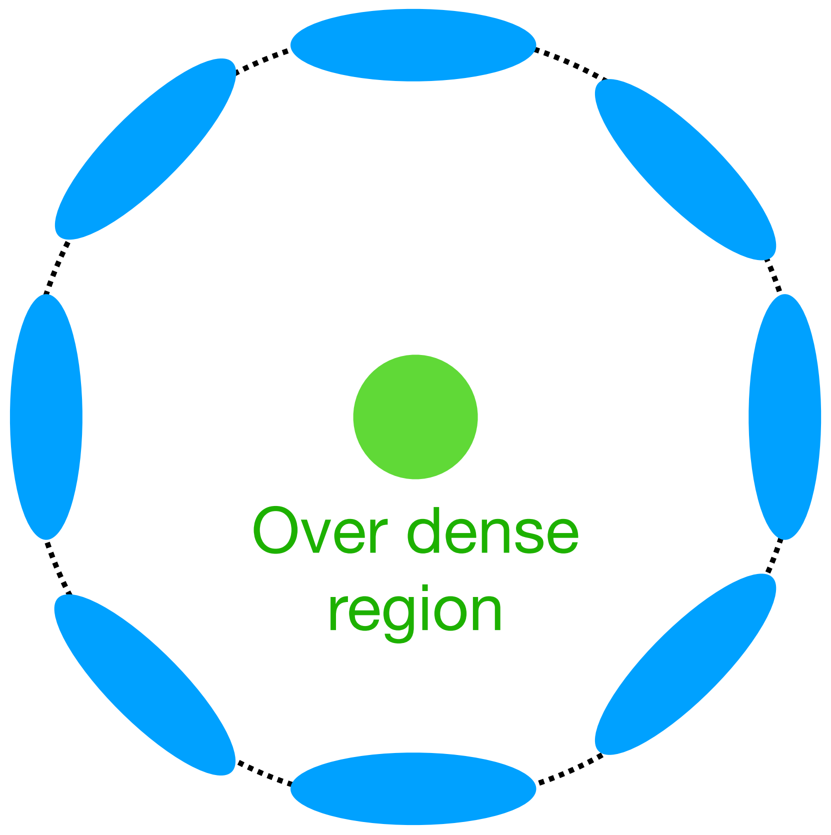


Weak lensing

- The **shape of background galaxy** is distorted by the gravitational lensing effect by **foreground matter distribution**

$$\text{Shear: } \gamma \propto \Omega_{\mathrm{m}} \int \mathrm{d}z_{\mathrm{l}} \frac{D_A(z_{\mathrm{l}}) D_A(z_{\mathrm{l}}, z_{\mathrm{s}})}{D_A(z_{\mathrm{s}})} \delta_{\mathrm{m}} \propto \Omega_{\mathrm{m}} \sigma_8^{1/2}$$

Tangential mode



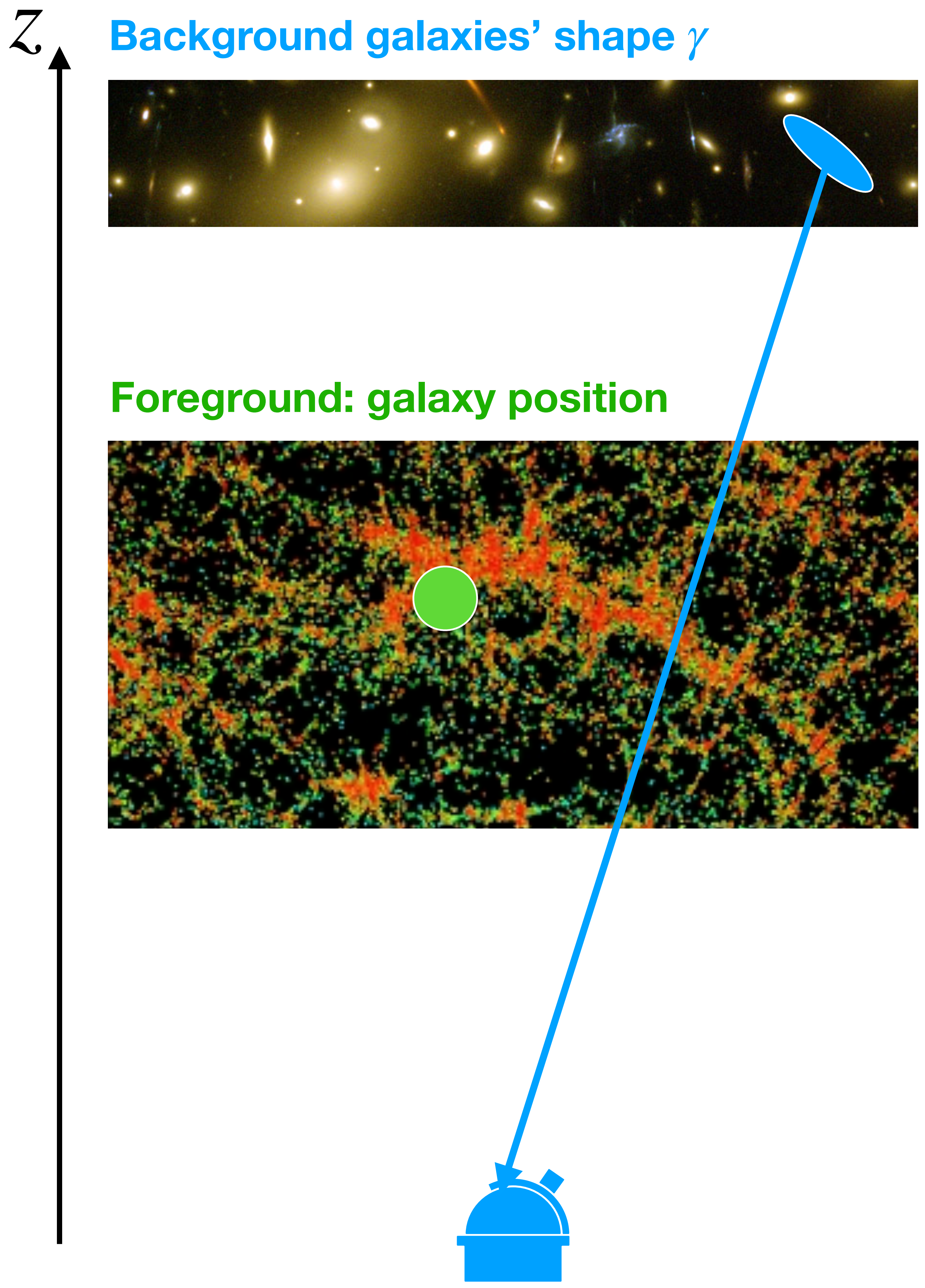
The coherent pattern of background galaxies' shapes

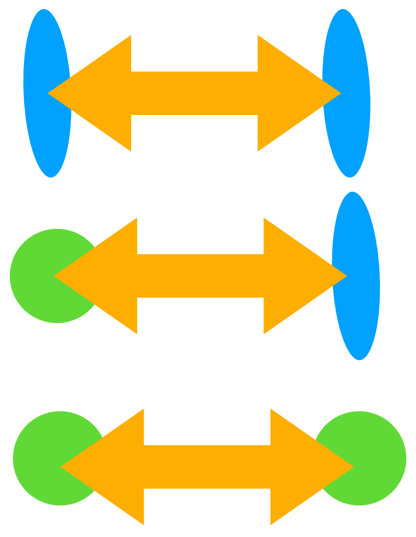
→ the foreground matter distribution

Credit: NASA/ESA and sdss.org, edited by SS

Joint analysis of three two point correlation functions

3x2pt = cosmic shear + galaxy-galaxy lensing + galaxy clustering





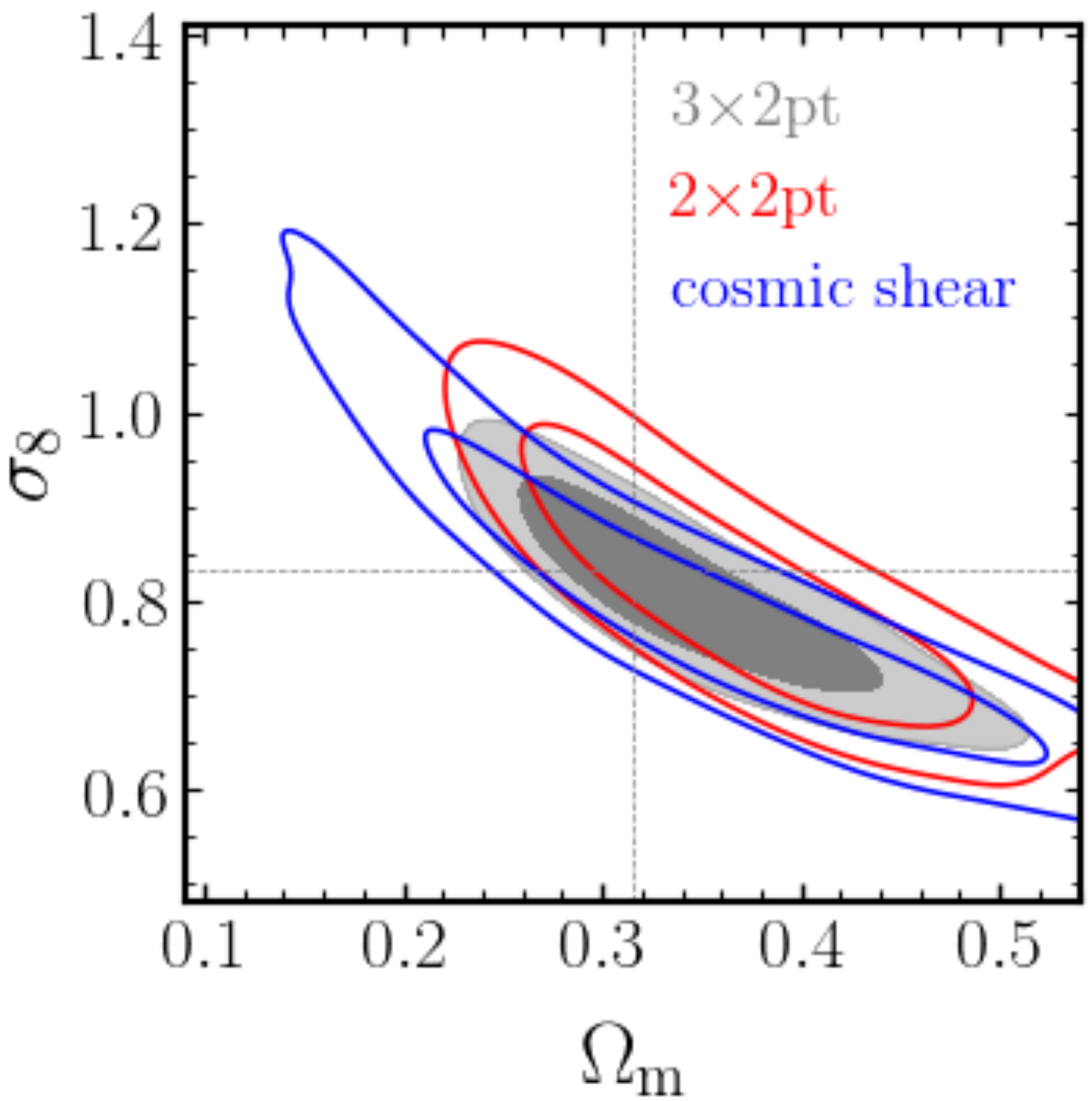
Cosmic shear: Shape-shape correlation

Galaxy-galaxy lensing: Position-shape correlation

Galaxy clustering: position-position correlation

2x2pt = Galaxy-galaxy lensing + Galaxy clustering

3x2pt = Cosmic shear + Galaxy-galaxy lensing + Galaxy clustering

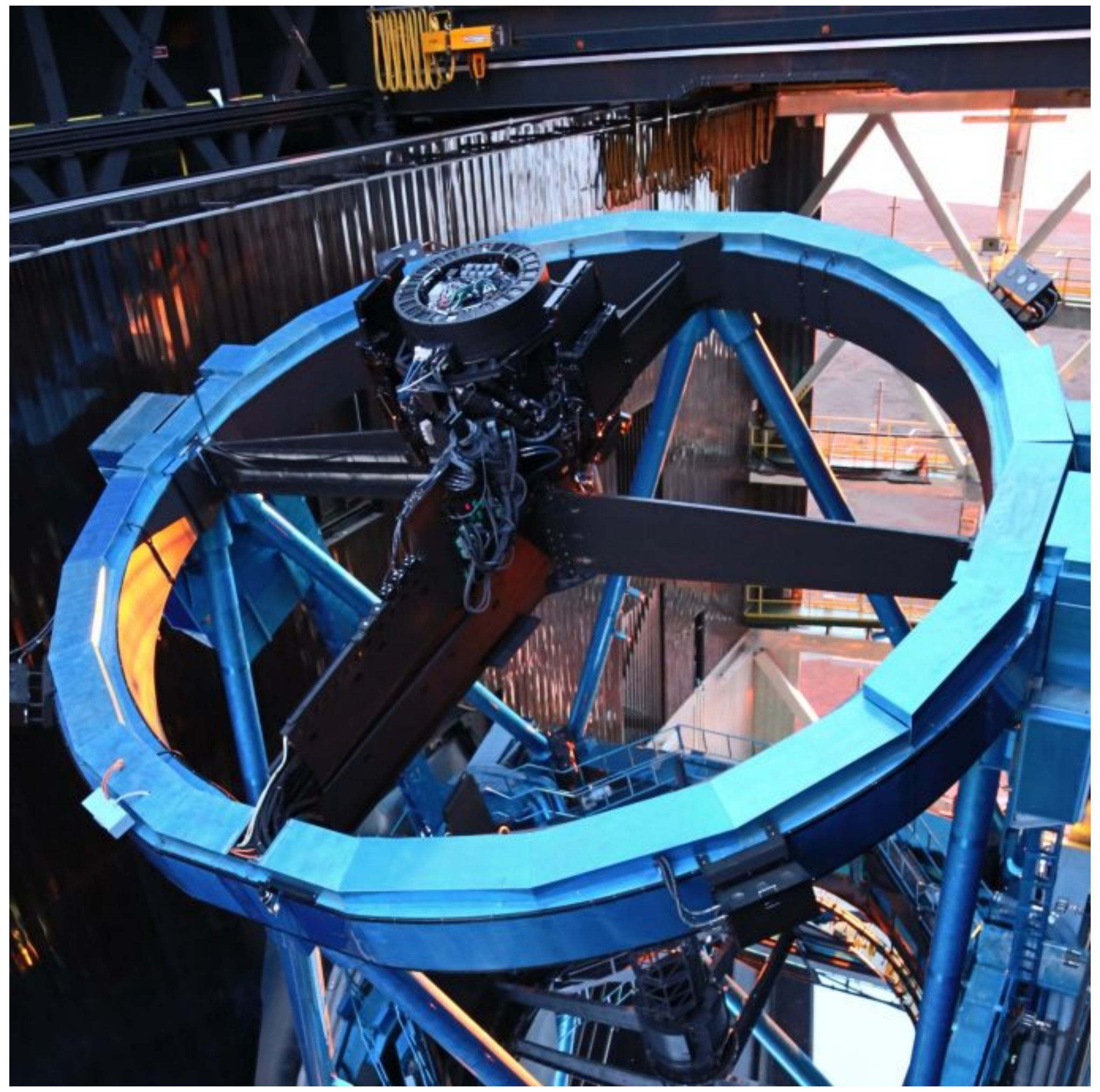


Credit: NASA/ESA and sdss.org, edited by SS

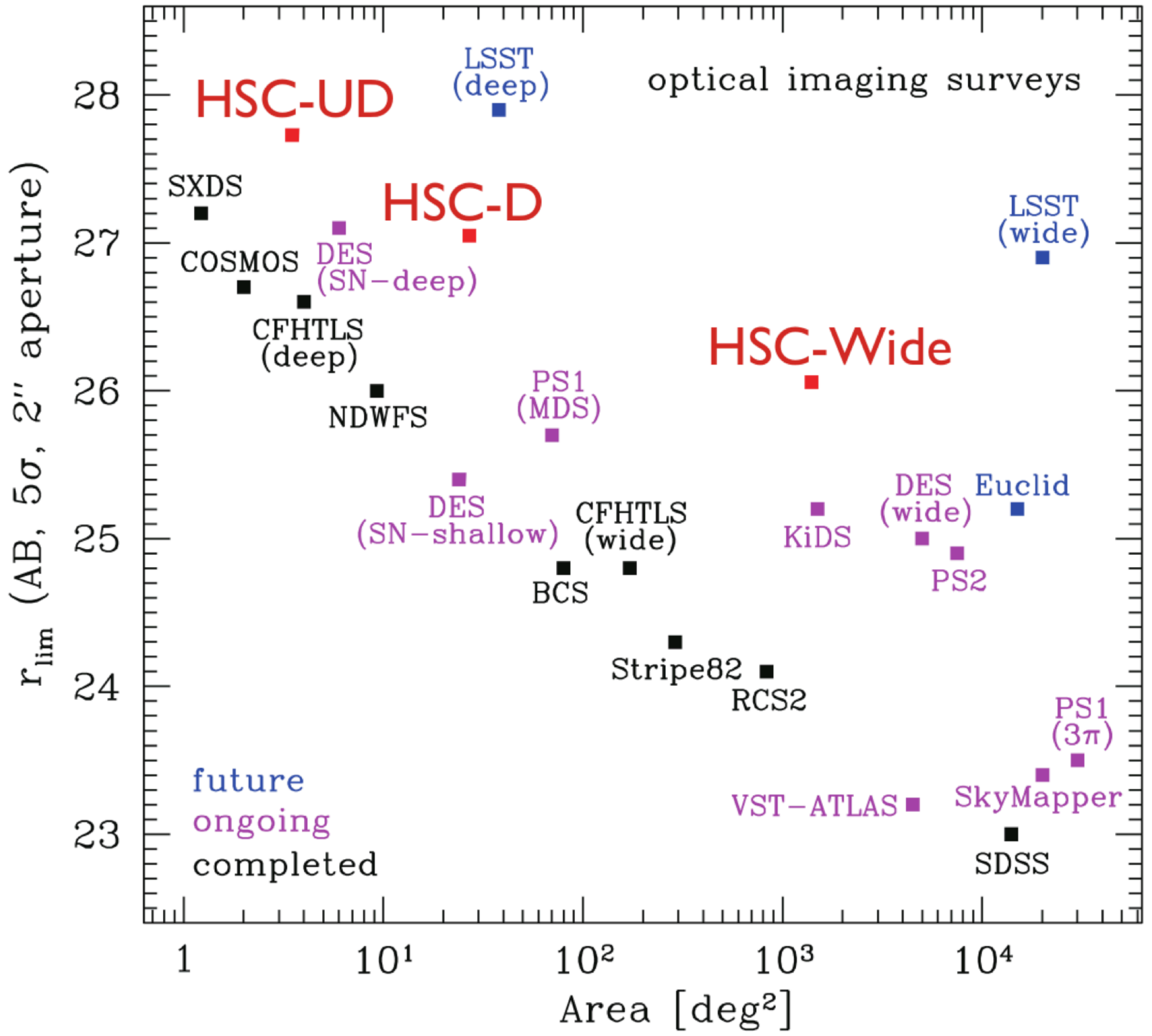
Subaru Hyper Suprime-Cam (HSC)

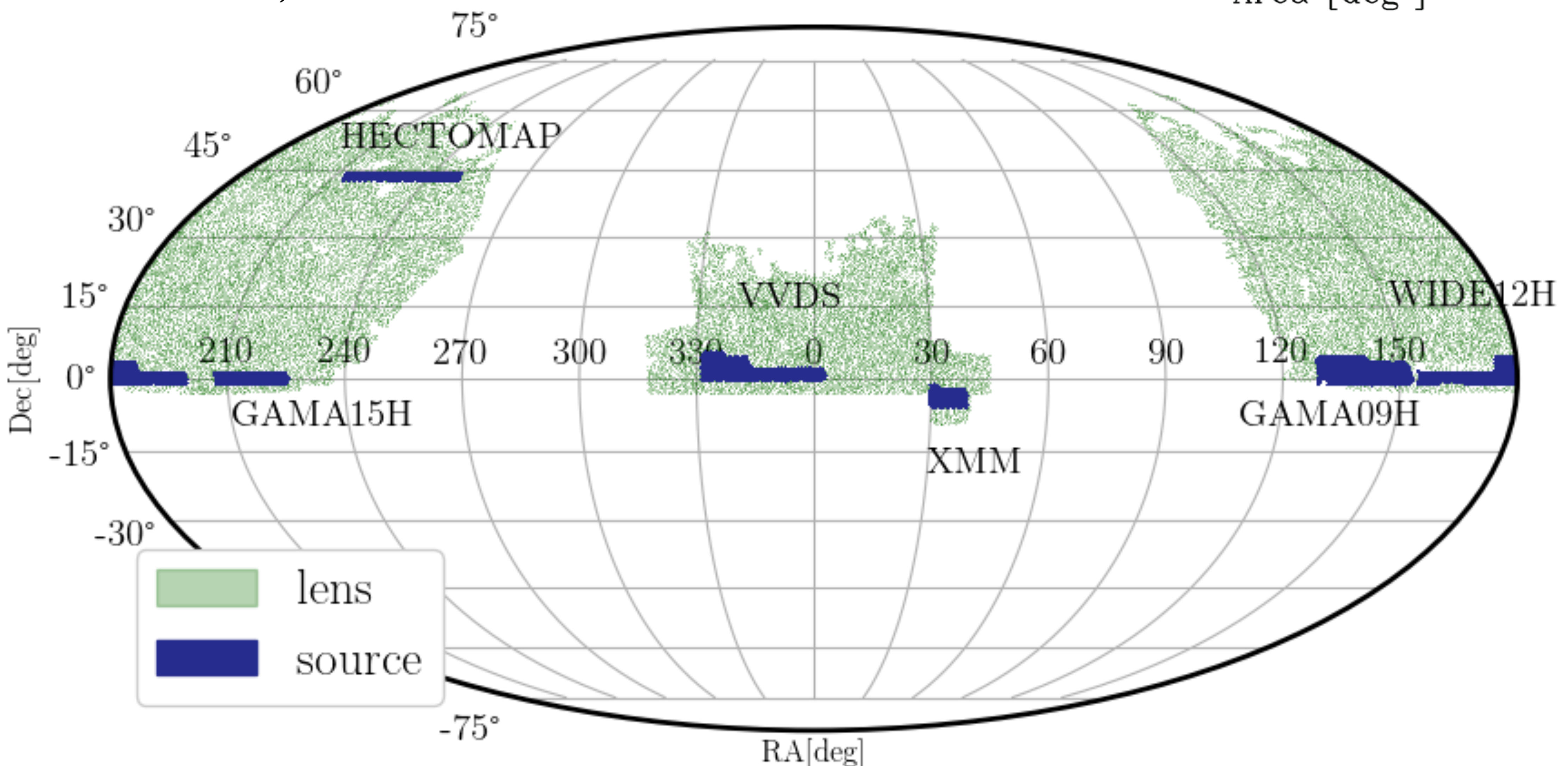
Shape catalog (Li+ 2022)

- High quality image of galaxy shape **PSF** $\sim 0.6''$
- Light collecting power of Subaru telescope
  → Deep imaging survey
  → high number density of galaxies per unit area
    - **HSC:** $n_s \sim 20\ \mathrm{gals/arcmin^2}$
    - DES: $n_s \sim 6.4\ \mathrm{gals/arcmin^2}$
    - KiDS: $n_s \sim 8.5\ \mathrm{gals/arcmin^2}$
- HSC-Y3 Shape catalog
  - Area = $430\mathrm{deg}^2$
  - Shape measurements based on image simulation
  - Shear estimation bias: $|\delta m| < 9 \times 10^{-3}$



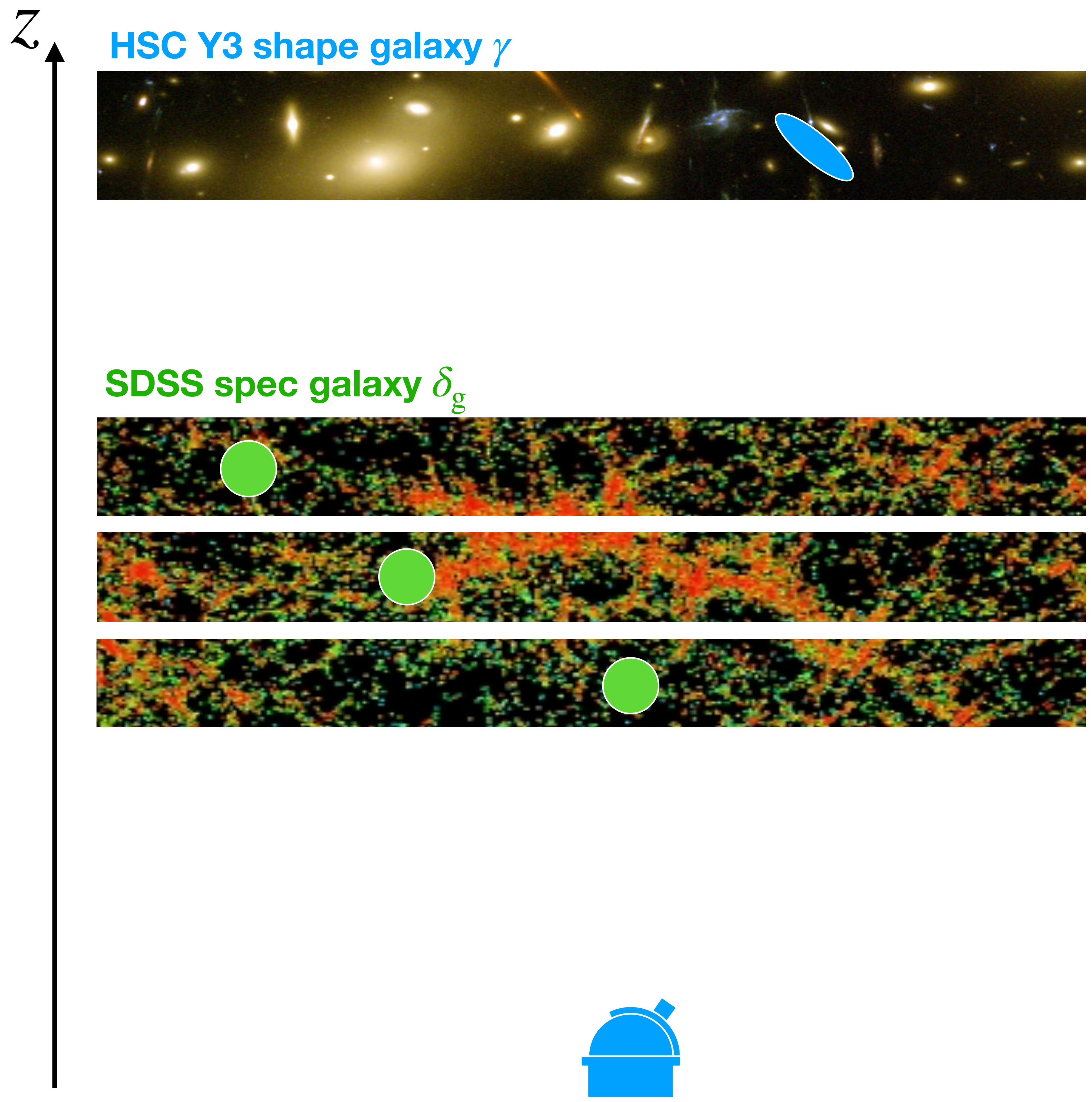
Credit: HSC-SSP, NAOJ





3x2pt analysis with Subaru HSC and SDSS

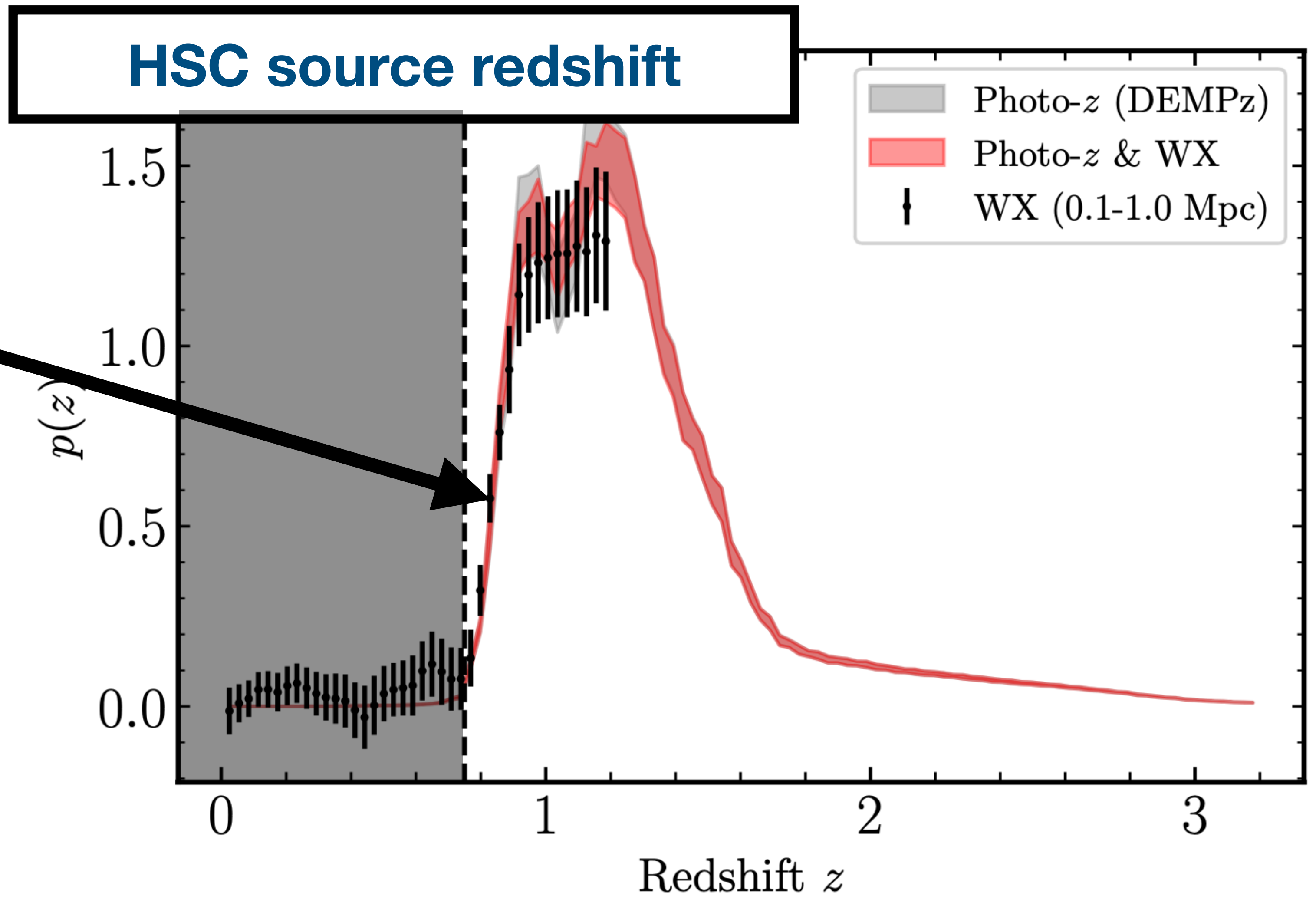
Galaxy sample definition for 3x2pt analysis

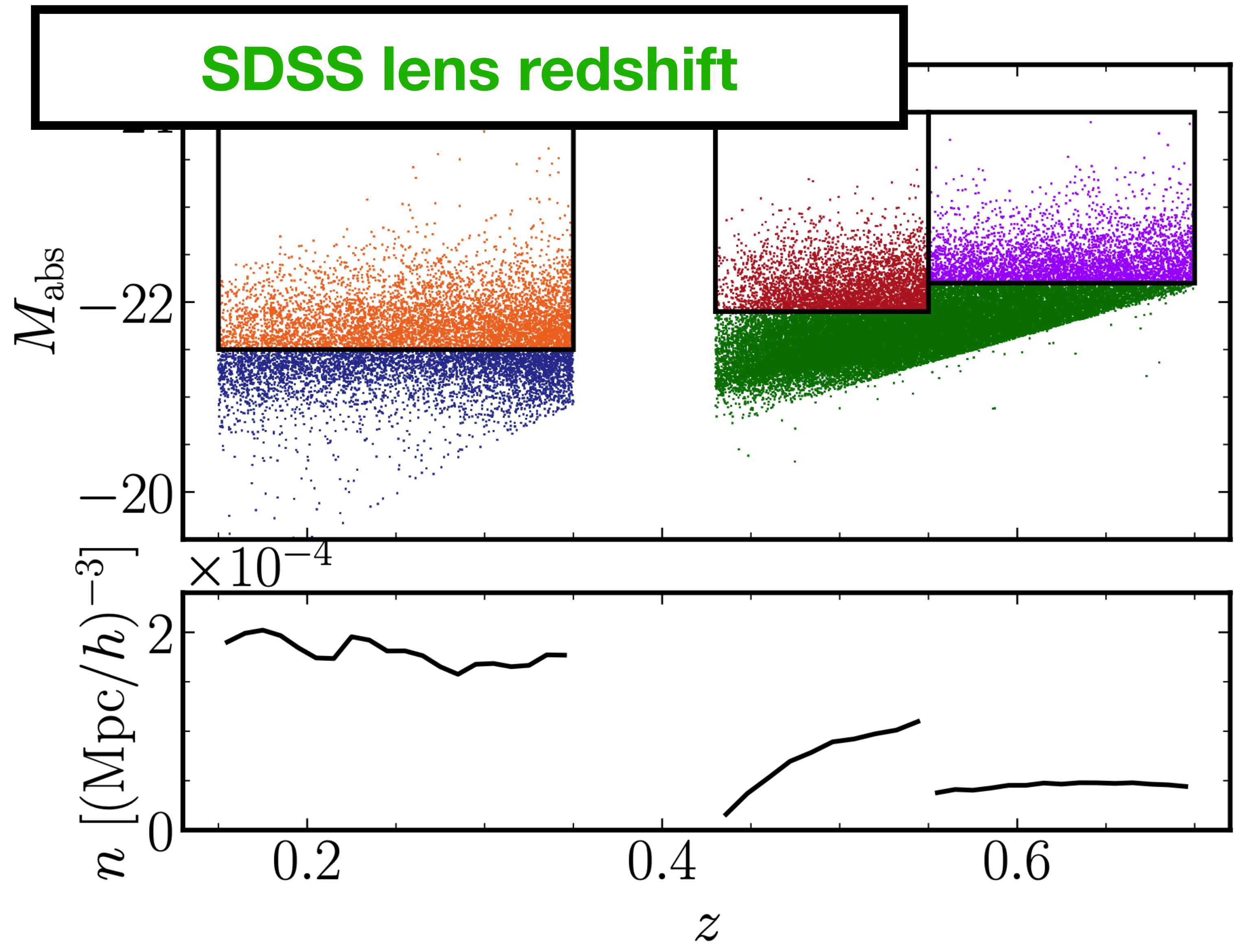


HSC Y3 shape catalog

Selected source galaxies
well beyond SDSS lens galaxies

$$\int_{z_{\mathrm{l,max}}+0.05}^{7} P(z_s)dz_s \geq 0.99$$



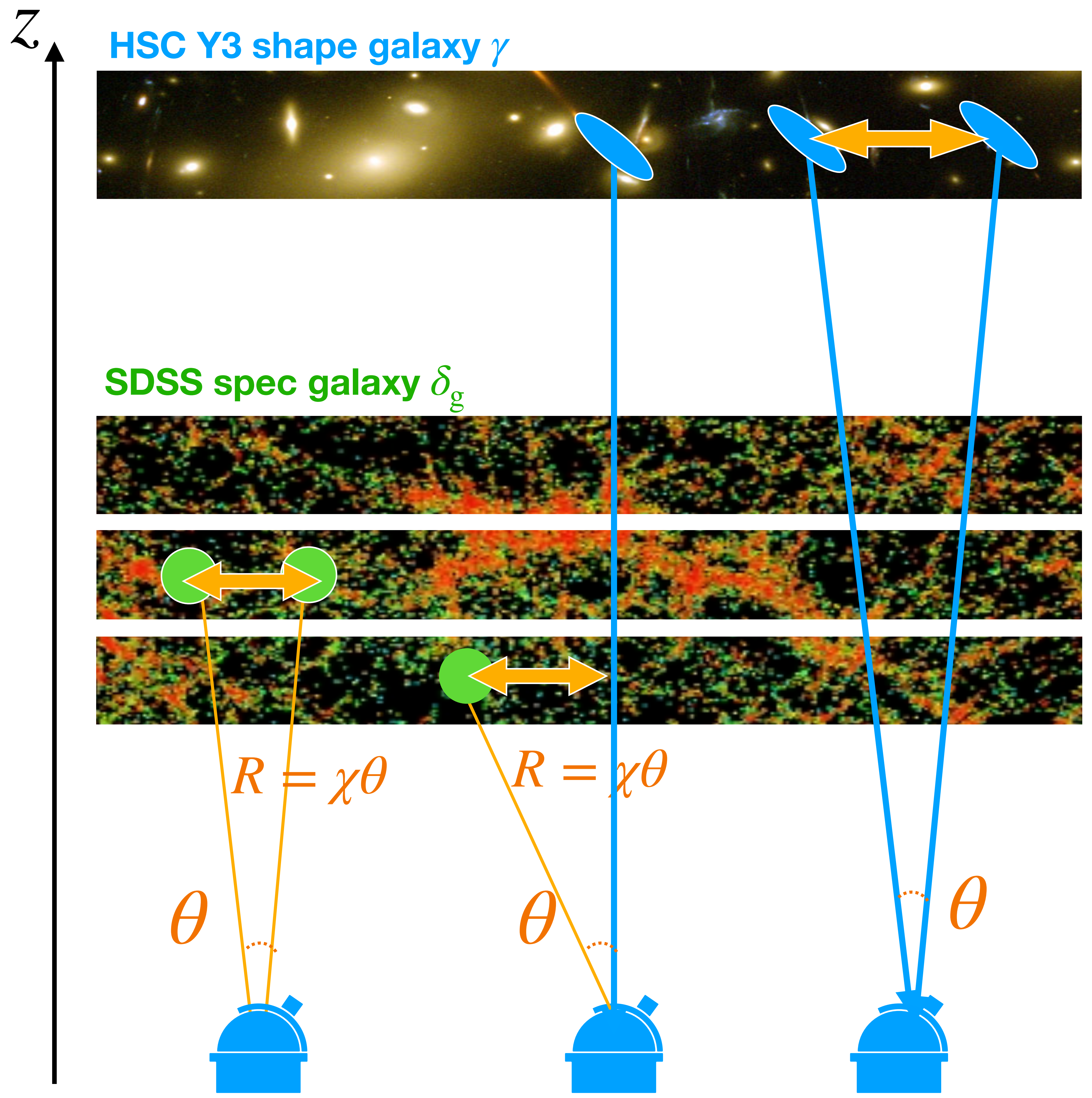


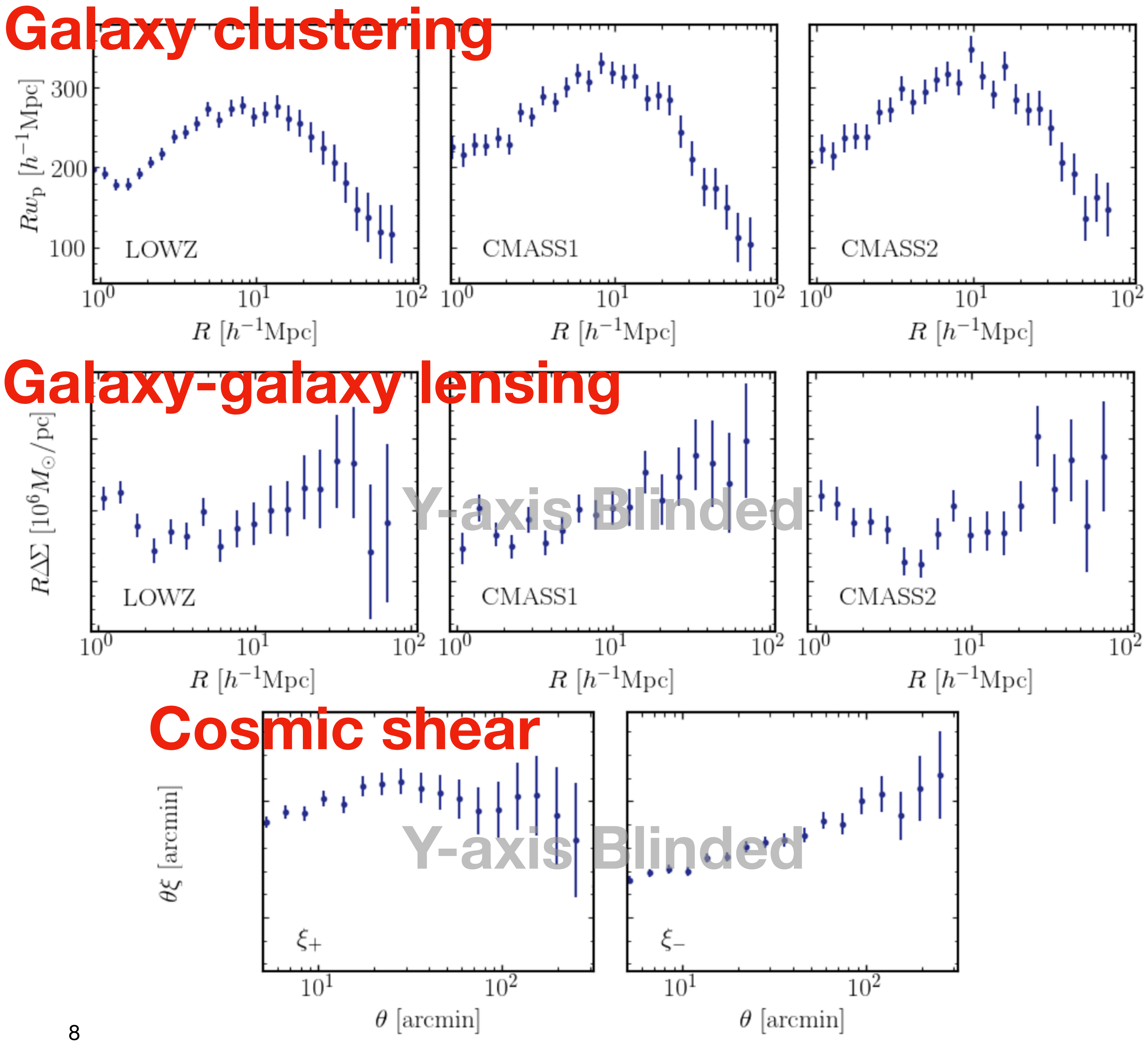
SDSS DR11 spectroscopic galaxy

- Area $\sim 8000\ \mathrm{deg}^2$
- Three redshift bins
- Luminosity cut
  → avoiding redshift evolution of galaxy property in each bin.

3x2pt analysis with Subaru HSC and SDSS

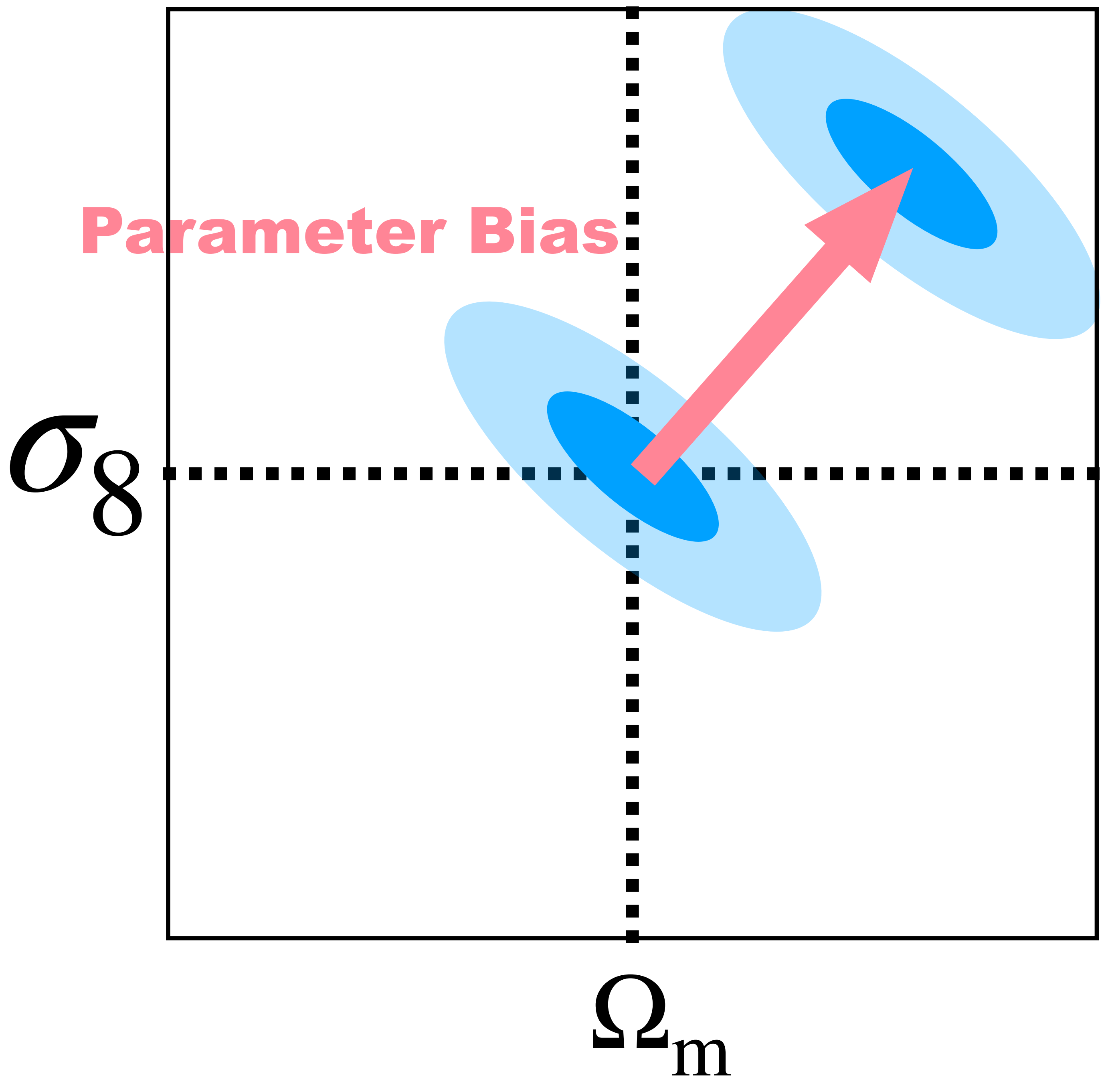
wide field imaging survey





Challenges for the precision cosmology with HSC

Precision and Robustness



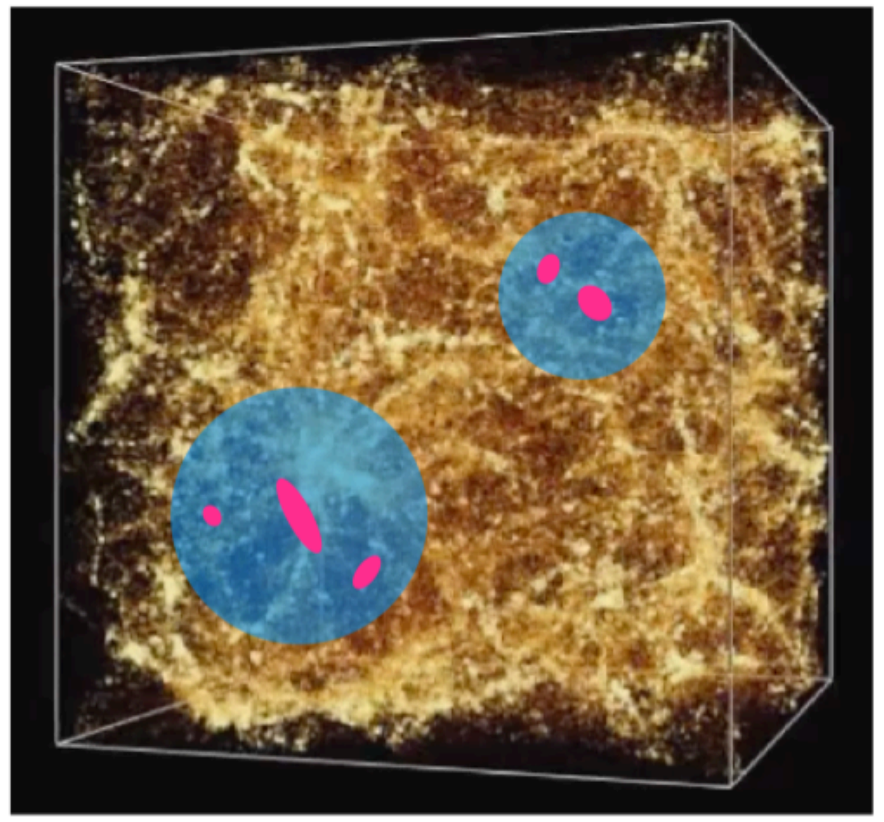
For the precision cosmology…

- Model uncertainty
  - Galaxy bias, baryonic effect
  - Scale cut
- Photo-z uncertainty
- Internal consistency of probes
- Confirmation bias

Halo-based model

Modeling down to smaller scale

- Accurate prediction of **nonlinear clustering**
- Proper treatment of uncertainties in **galaxy-halo connection**



Dark matter
Dark matter halo
Galaxy

Credit: ESA

Cosmological params

$(\Omega_{\mathrm{m}}, \sigma_8, \cdots) \rightarrow \xi_{\mathrm{hh}}(r; M_1, M_2),\ \xi_{\mathrm{hm}}(r; M) \rightarrow \xi_{\mathrm{gg}}(r),\ \xi_{\mathrm{gm}}(r) \rightarrow$ Observables $w_{\mathrm{p}}(R)$, $\Delta\Sigma(R)$

Dark Emulator:
Emulates the halo's 2PCF on N-body
(Nishimichi+ 2019)

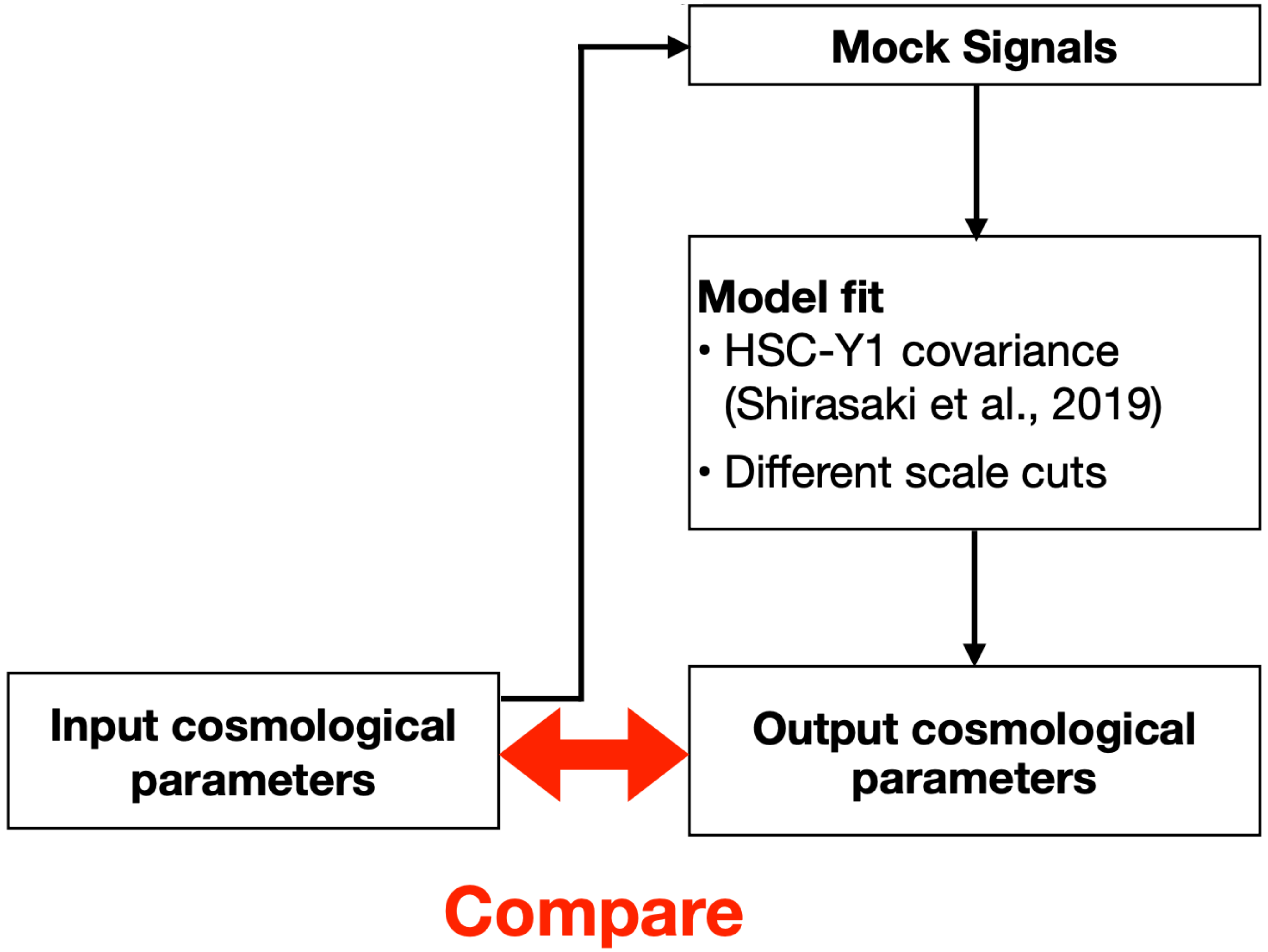
HOD model:

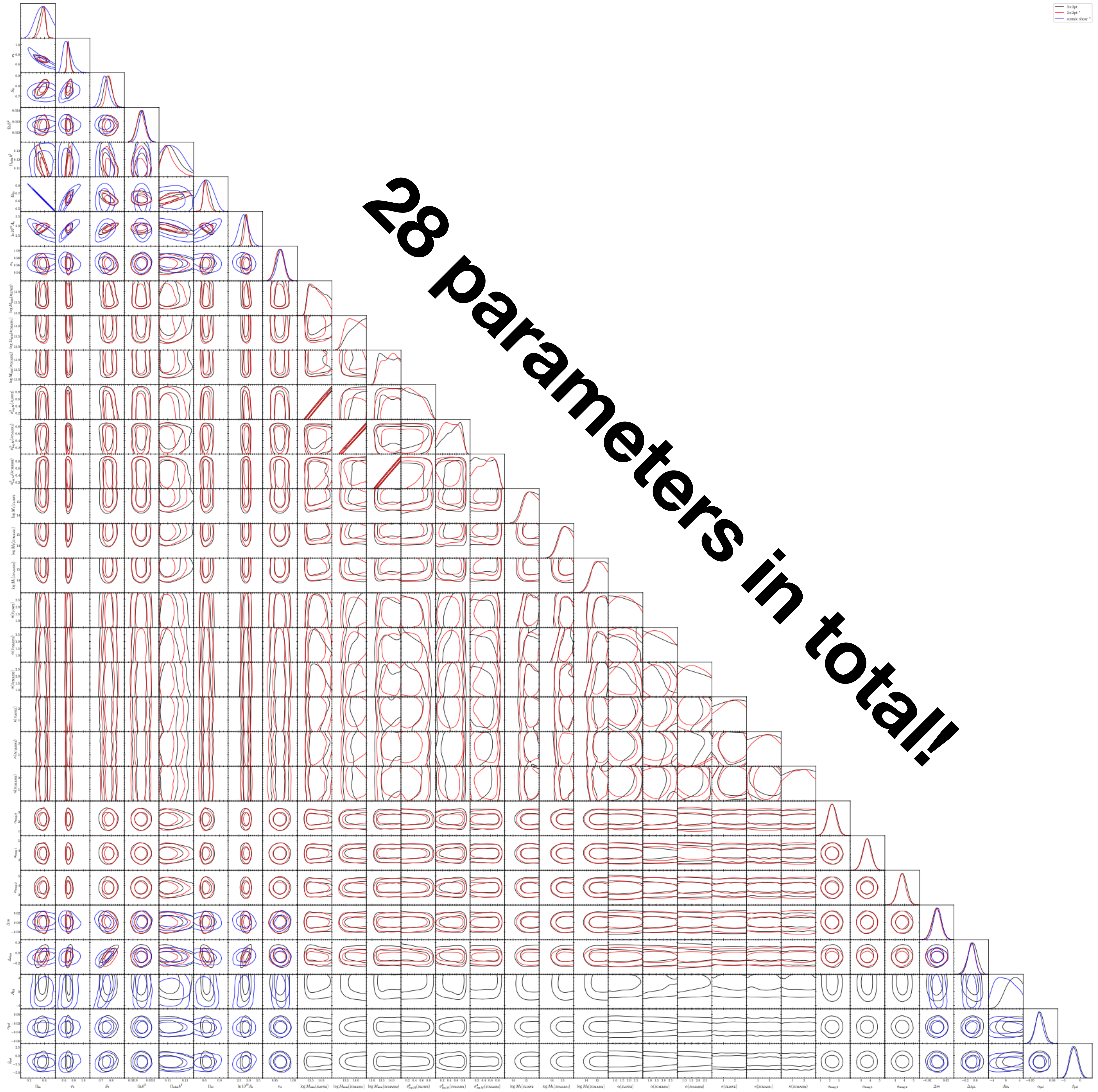
- $\langle N_{\mathrm{c}}\rangle(M)$, $\langle N_{\mathrm{s}}\rangle(M)$: **HOD**
- **Galaxy distribution profile:** $u_{\mathrm{s}}(r; M)$

$$P_{\mathrm{gm}}(k) = \frac{1}{\bar{n}_{\mathrm{g}}} \int \mathrm{d}M \frac{\mathrm{d}n_{\mathrm{h}}}{\mathrm{d}M} \langle N_{\mathrm{c}}\rangle(M) \left[1 + \lambda_{\mathrm{s}}(M) \tilde{u}_{\mathrm{s}}(k; M, z)\right] P_{\mathrm{hm}}(k; M)$$

Validation of model

Mock challenge





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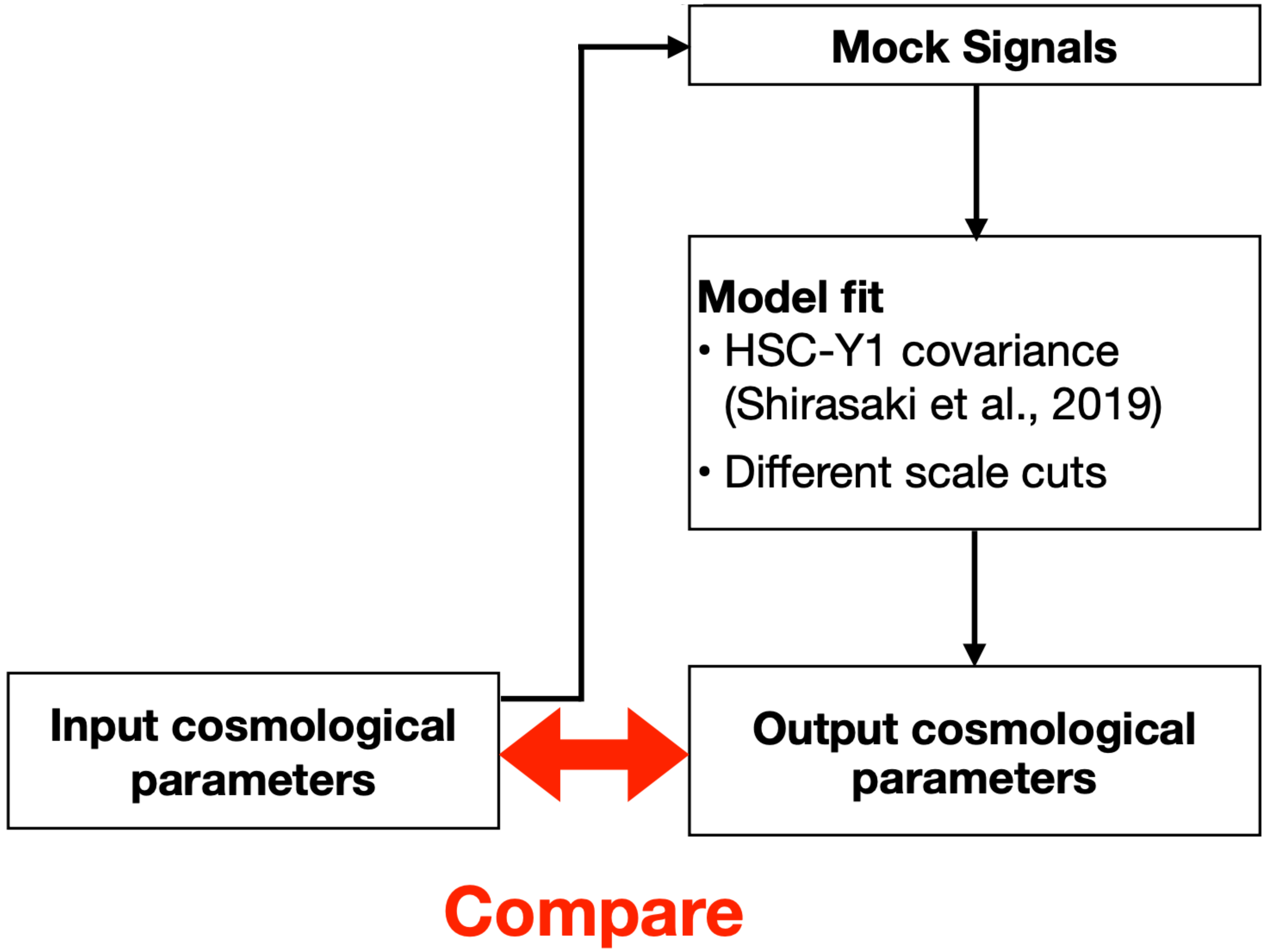

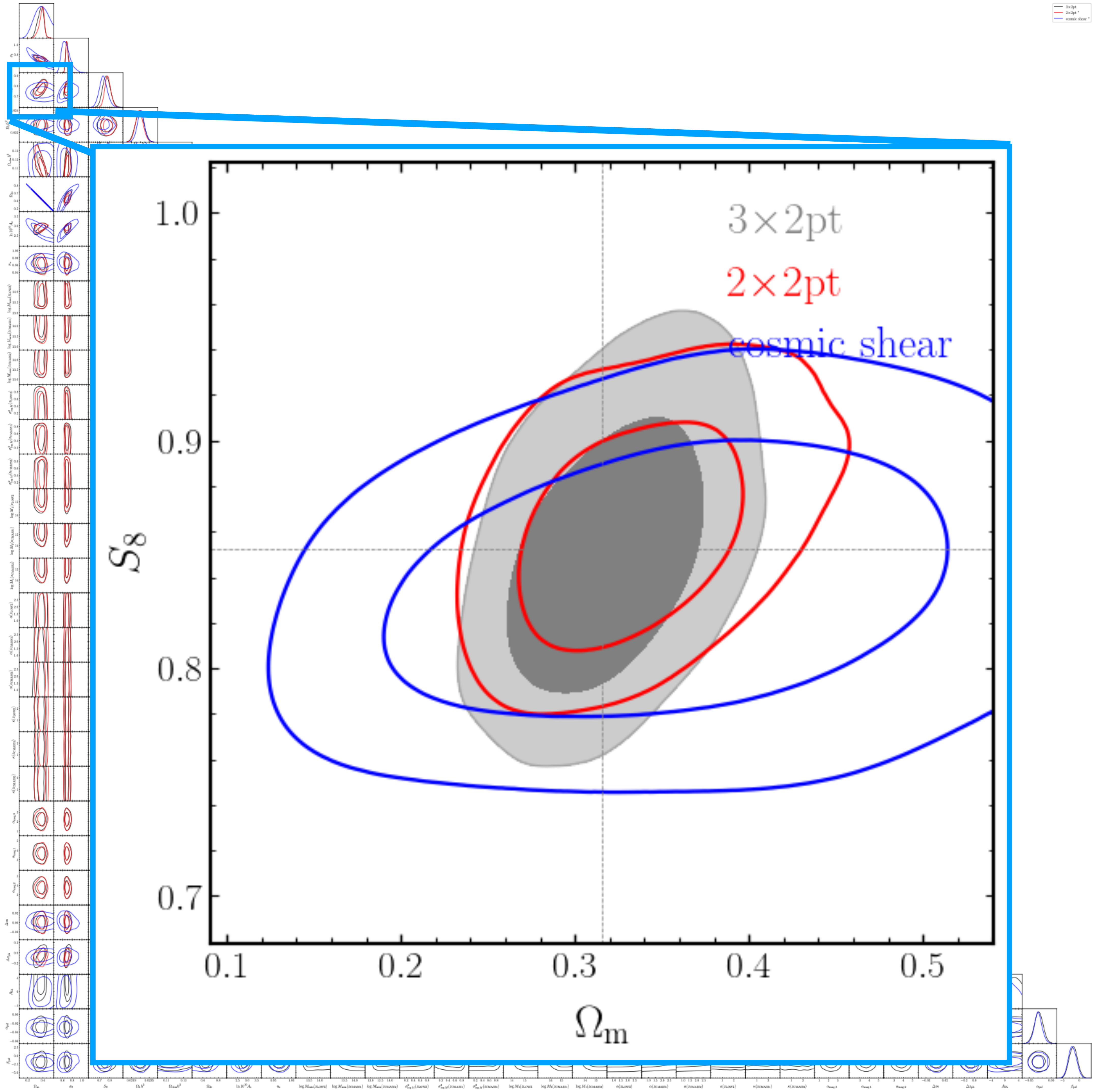

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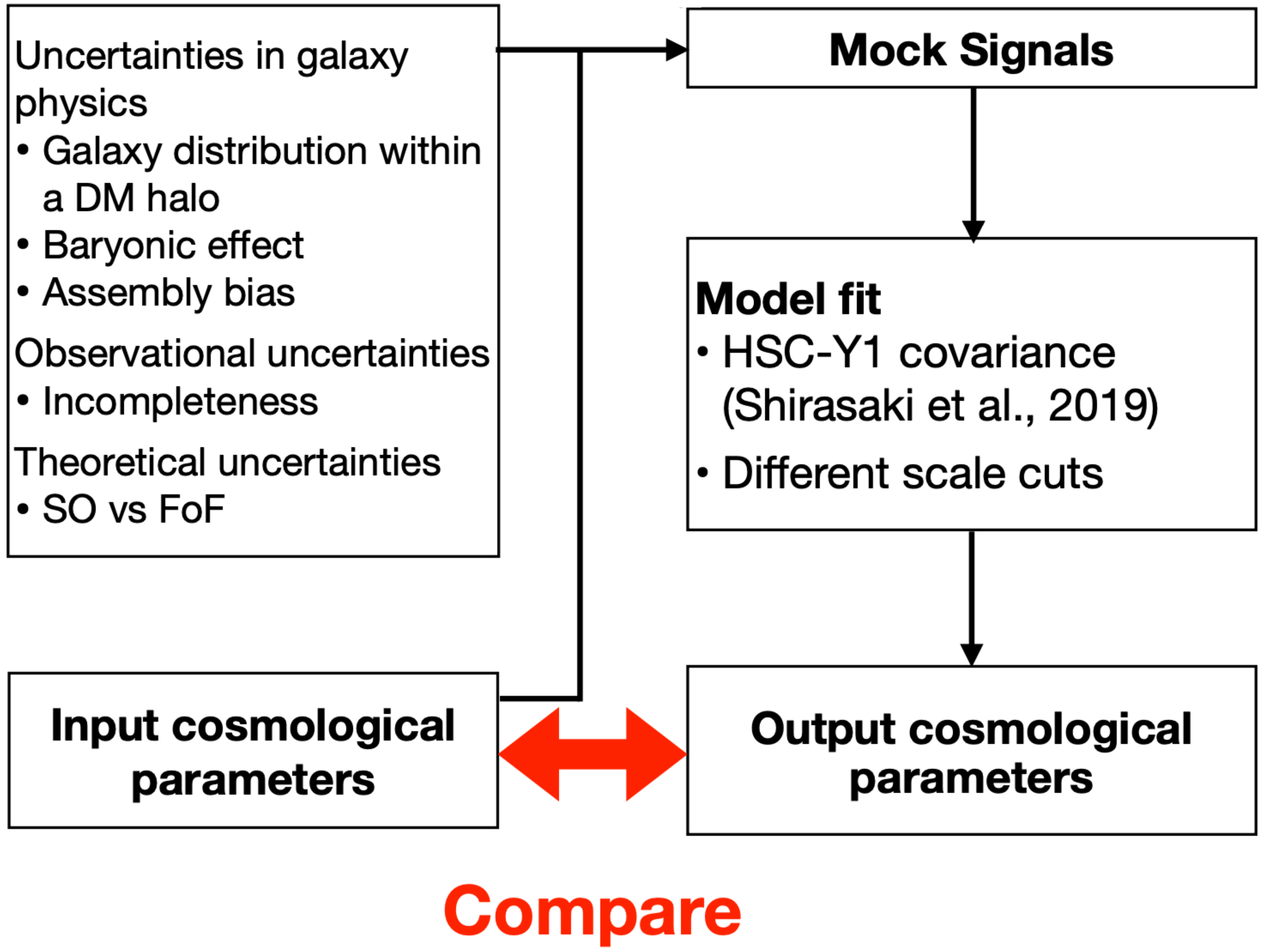
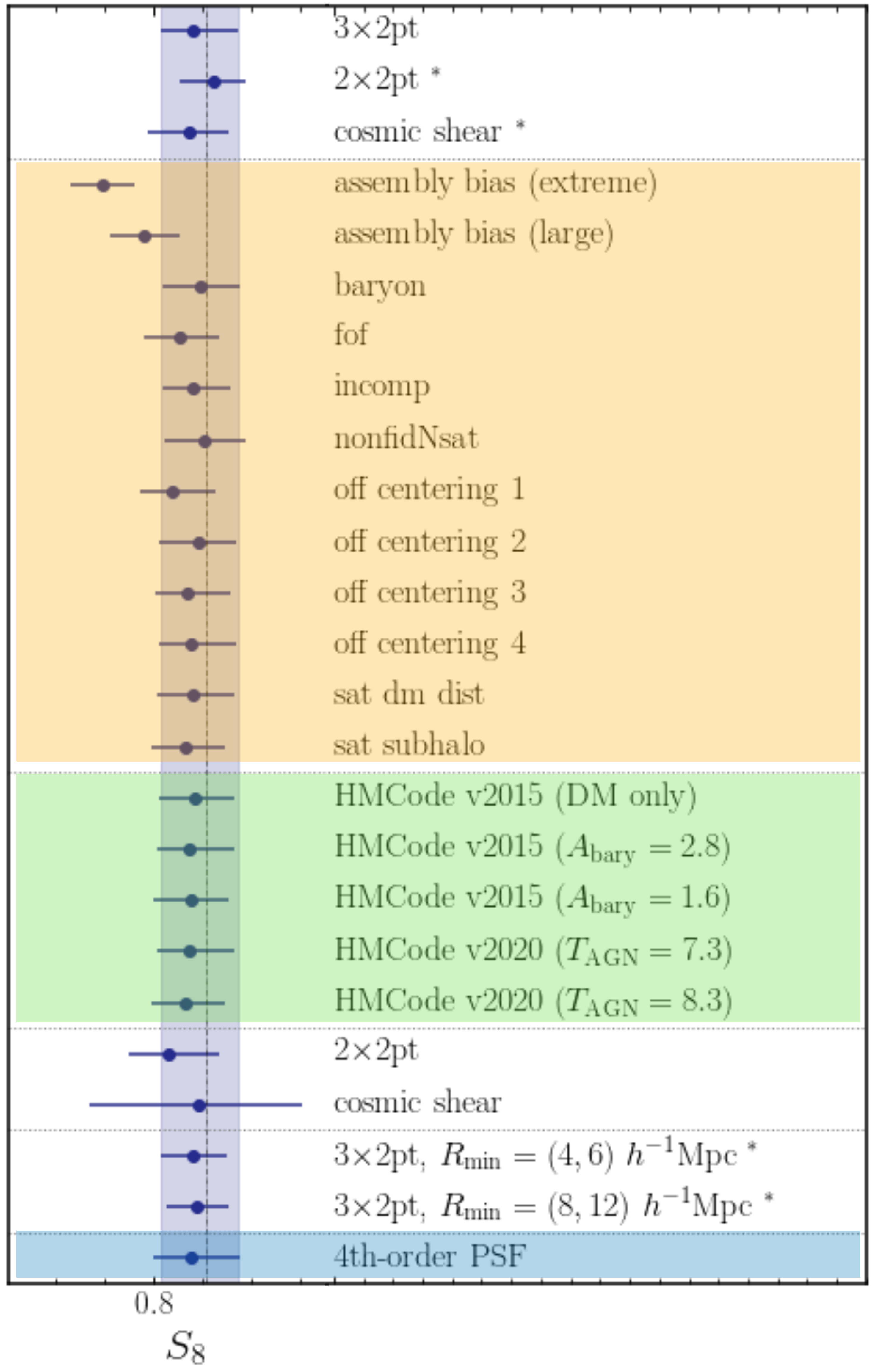




fiducial

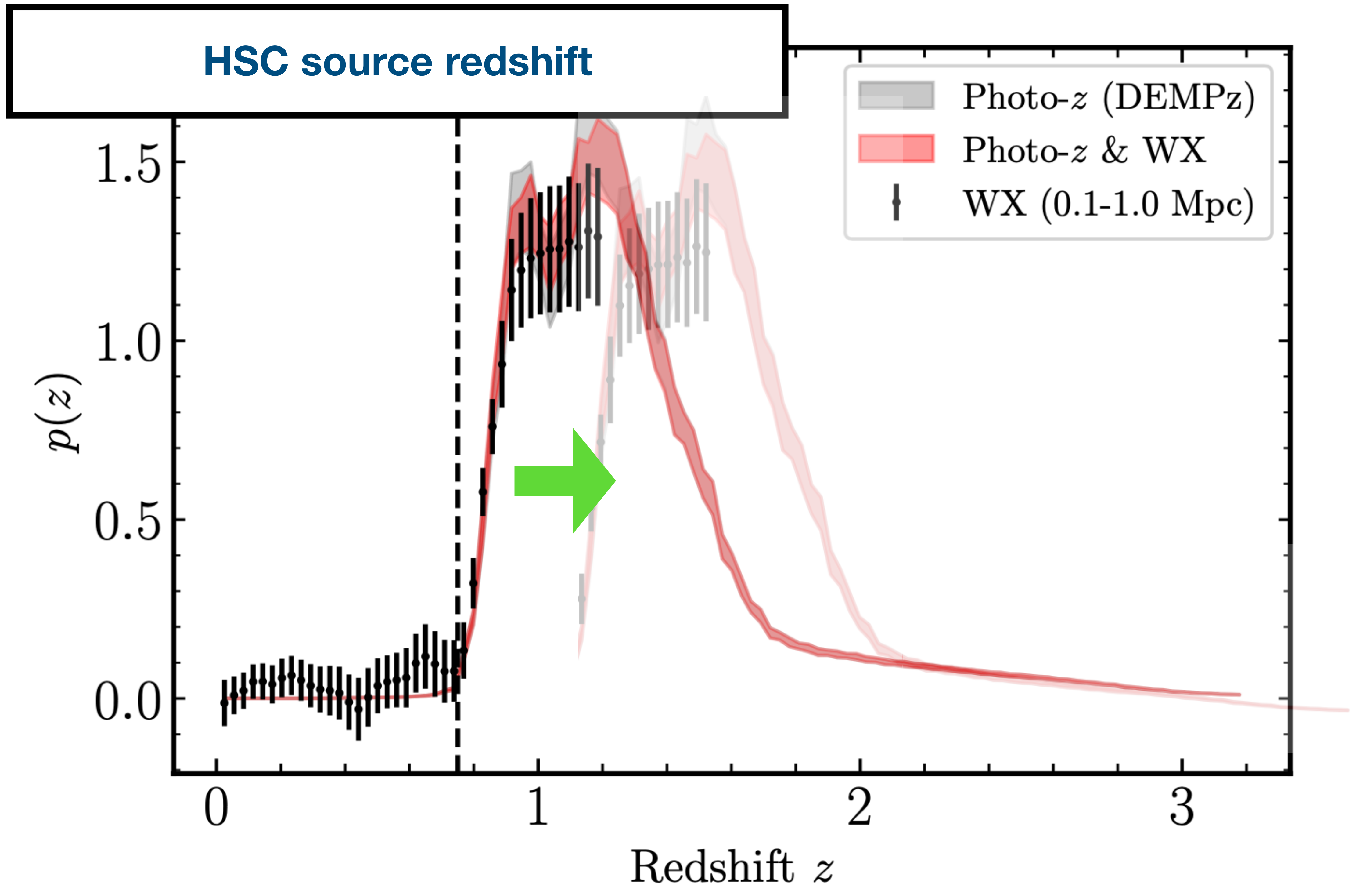
Uncertainties in galaxy-halo connection

Baryonic effect on cosmic shear

Residual PSF leakage on cosmic shear

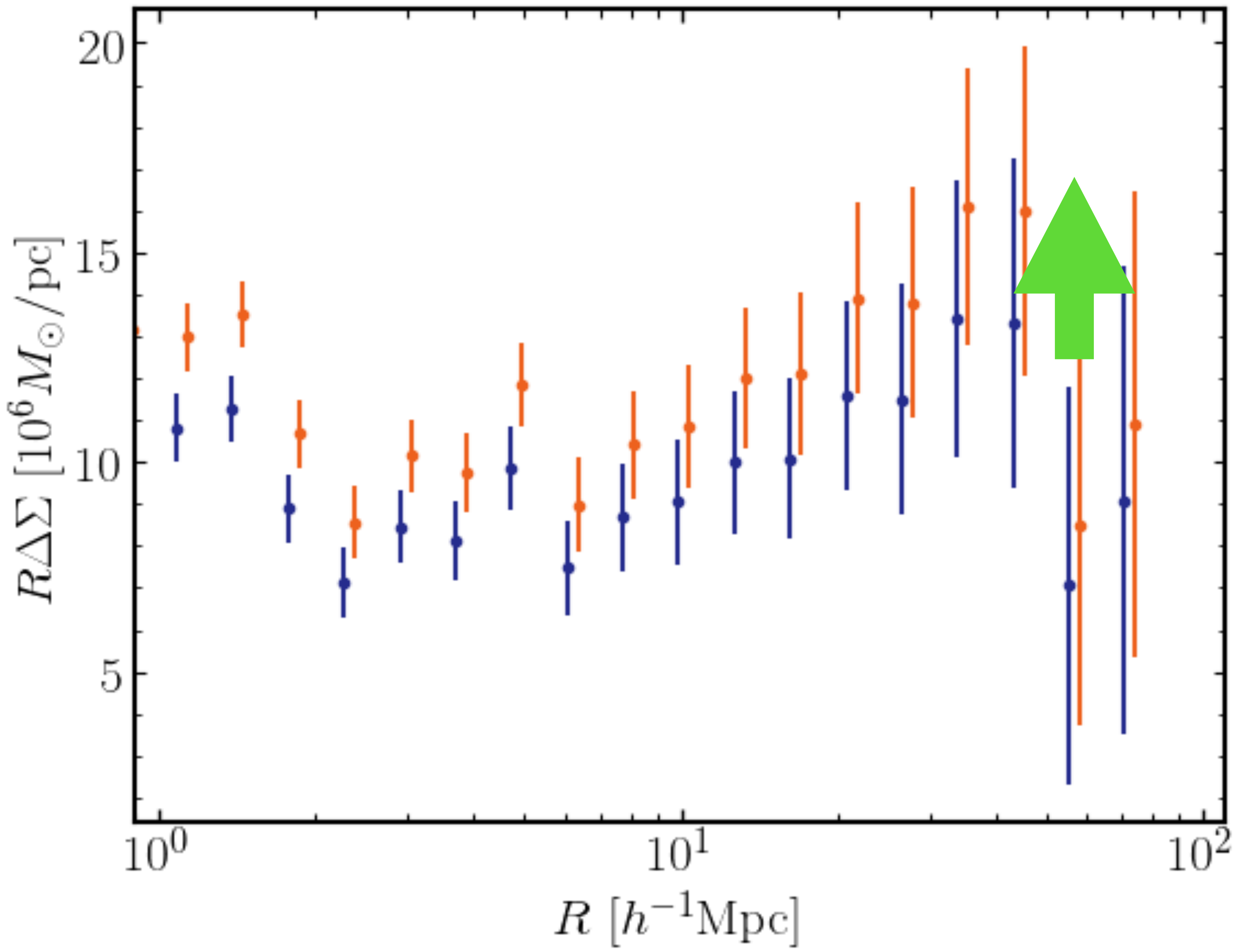
Photo-z uncertainty

photo-z error



Potential photo-z bias

- Less galaxies at high redshift → less calibrated
- Calibration data is limited to COSMOS field $(2\ \mathrm{deg}^2)$



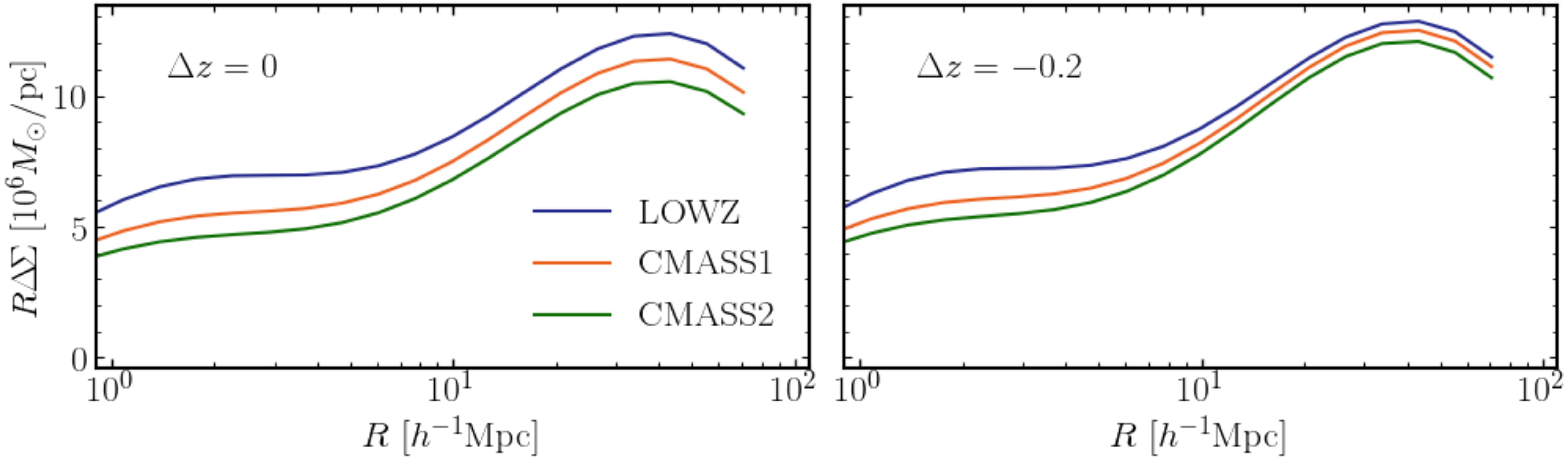
Wrong photo-z estimate causes wrong amplitude of lensing signal

→ causes the bias in S_8!

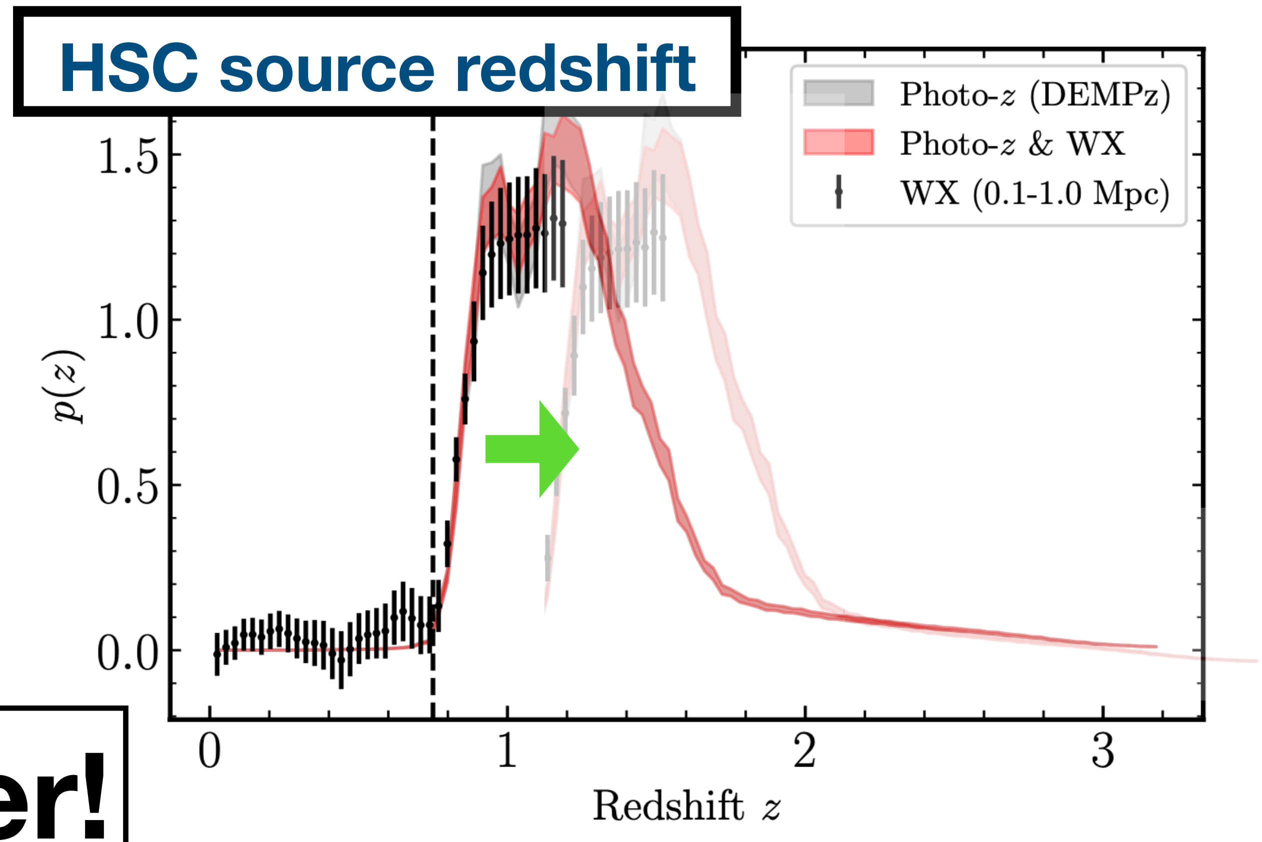
Photo-z uncertainty

Self-calibration of photo-z

Self-calibration of photo-z bias with multiple lens bins (Oguri&Takada 2010)
Ratio of $\Delta\Sigma$ in different lens bin gives source redshift information.



We Introduce the photo-z bias parameter $p^{\mathrm{true}}(z) = p^{\mathrm{est}}(z + \Delta z_{\mathrm{ph}})$
→ evaluate the model with Δz_{ph}



Without replying on any prior information of photo-z, we can automatically calibrate the photo-z bias.

The most conservative analysis in the weak lensing analyses ever!

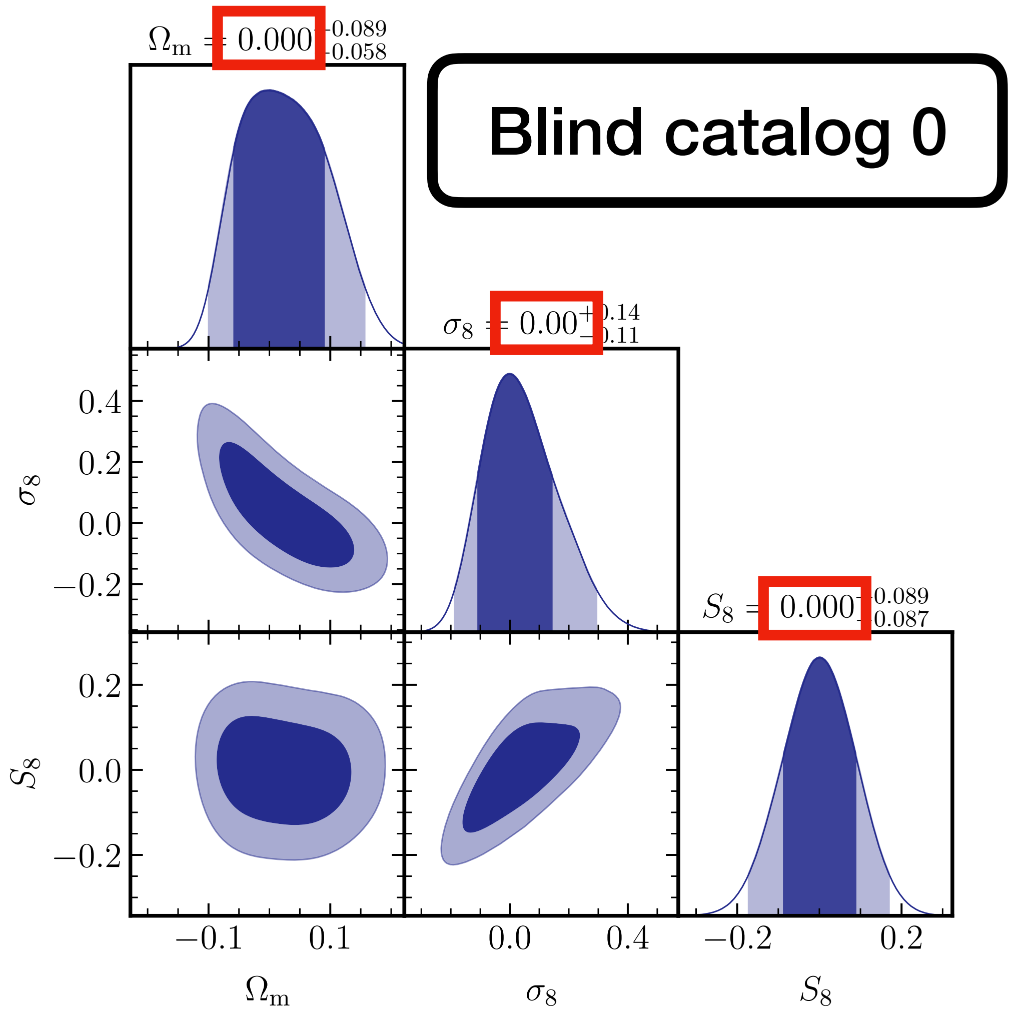
Blind analysis

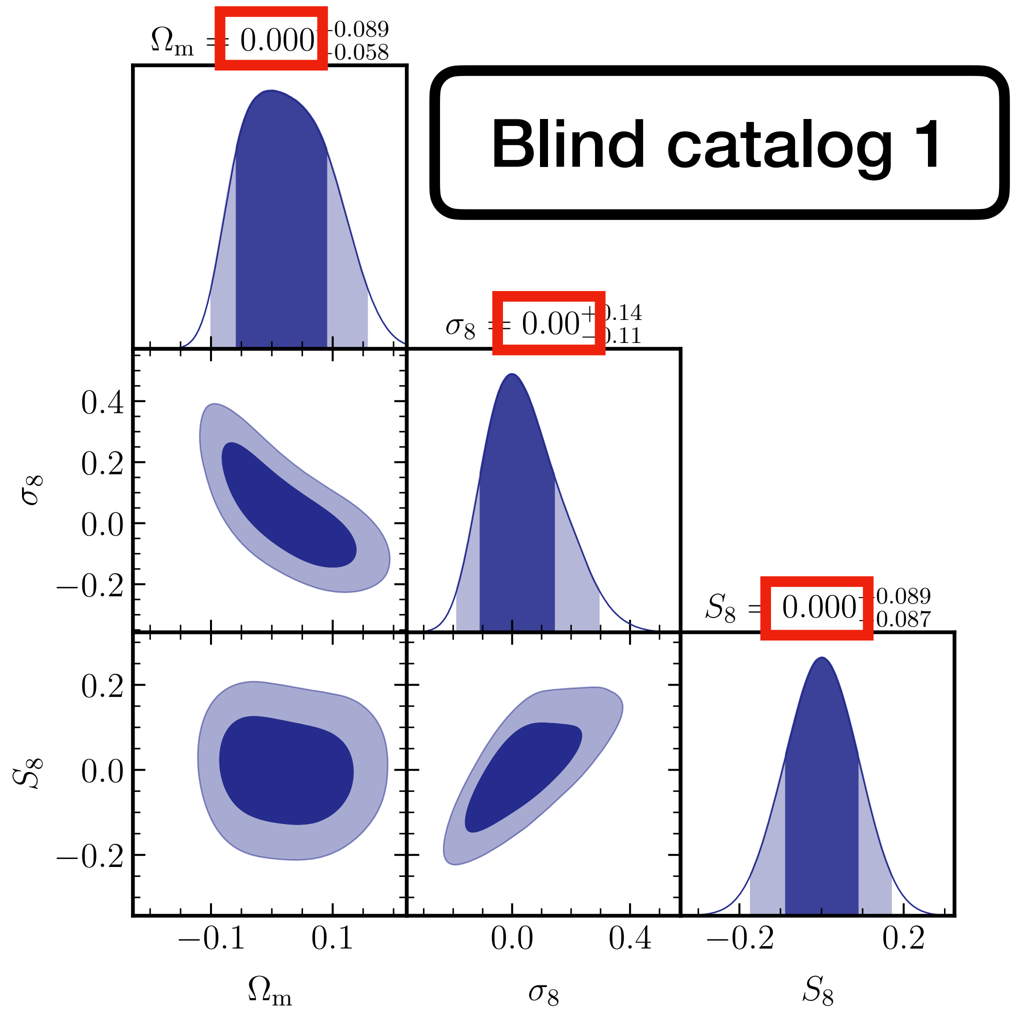
We performed blind analysis to avoid confirmation bias.

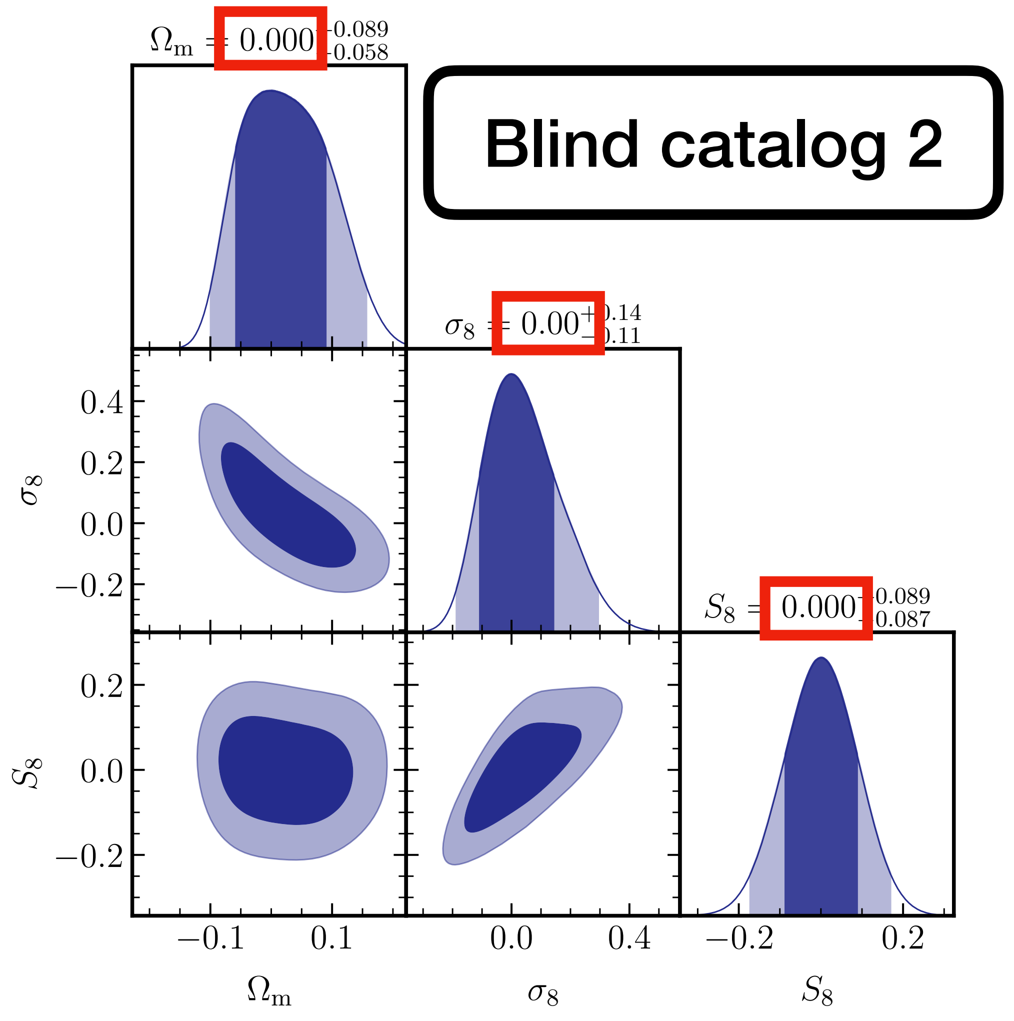
- **Catalog level blinding:** we analyze three shape catalogs, one of which is true catalog but the others are fake.

- **Analysis level blinding:** we shift the cosmological parameter by its central value → This prevent us to direct comparison to external results

We do not change the result after unblinding.







- Model validation
- Systematics test
- Scale cut
- Internal consistency test
- Code review

Freeze analysis setup

Unblind
- Open the cetral value
- Open the true catalog

2022 Dec

Post unblind analysis
- Comparion to external result

If a problem is found, we come back to the test stage.

Summary

HSC-Y3 cosmology results are coming soon!

- The 3x2pt HSC-Y3 analyses are unblinded in Dec 2022.
  Papers are in collaboration review.

- HSC-Y3 cosmology projects will come out together
  early April! Keep an eye on them!

  - 3x2pt (SS, Miyatake, More+)

  - Cosmic shear tomography in Real space (Li+)

  - Cosmic shear tomography in Fourier space (Dalal+)





Thank you!