Precision Cosmology with Subaru HSC and PFS

(… after 10yrs efforts …)

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arXiv:1809148 appeared TODAY!!

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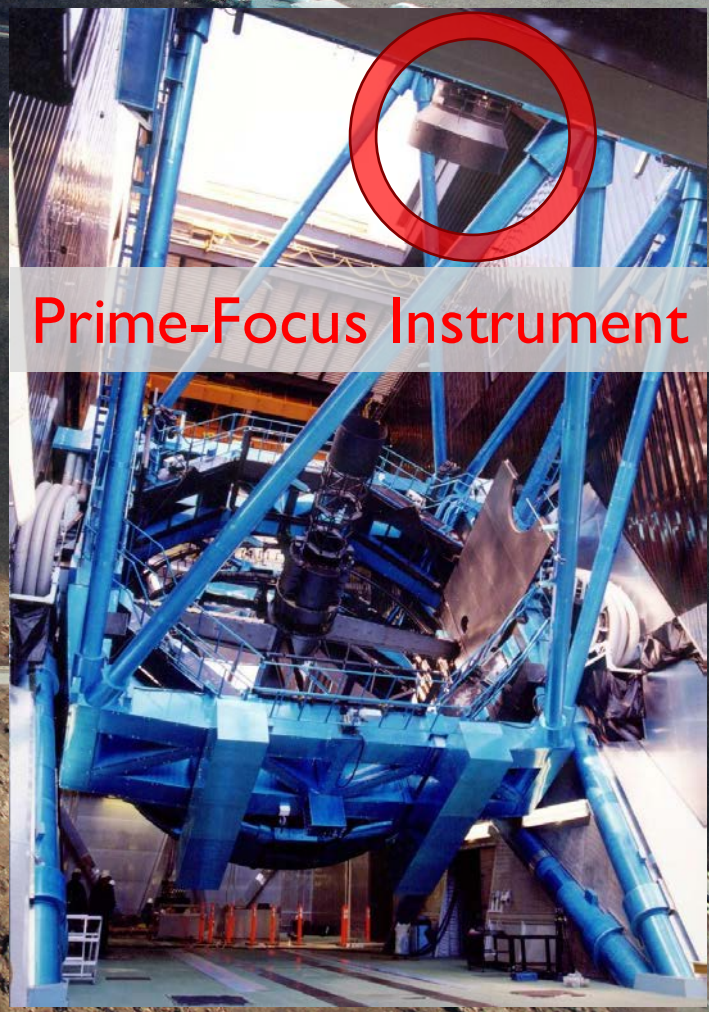
東京大学 THE UNIVERSITY OF TOKYO

wpi

8.2m Subaru telescope

SuMIRe Prime Focus Spectrograph



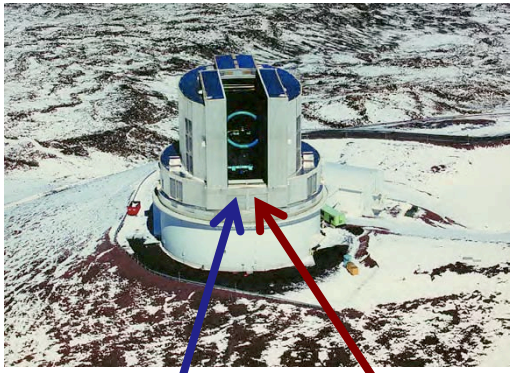
Prime-Focus Instrument

Subaru Telescope
(NAOJ)

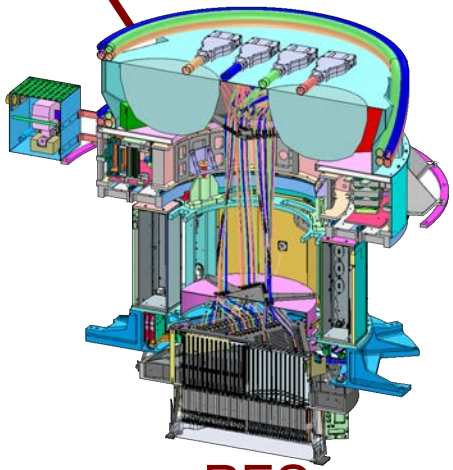
@ summit of Mt. Maunakea (4200m), Big Island, Hawaii

SuMIRe = Subaru Measurement of Images and Redshifts

- *Wide-field* camera (Hyper Suprime-Cam: HSC): 1.5 deg. FoV
- *Wide-field* multi-object spectrograph (Prime Focus Spectrograph: PFS): simultaneous spectroscopic observation of 2400 objects over ~1.3 deg. FoV
- Keep the Subaru Telescope a world-leading telescope in the TMT era
- Precise **images** of 1B galaxies
- Measure **distances** of ~4M galaxies
- **Do SDSS-like survey at z>1**

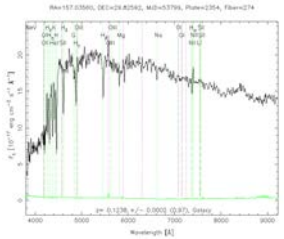


Subaru (NAOJ)



PFS

HSC

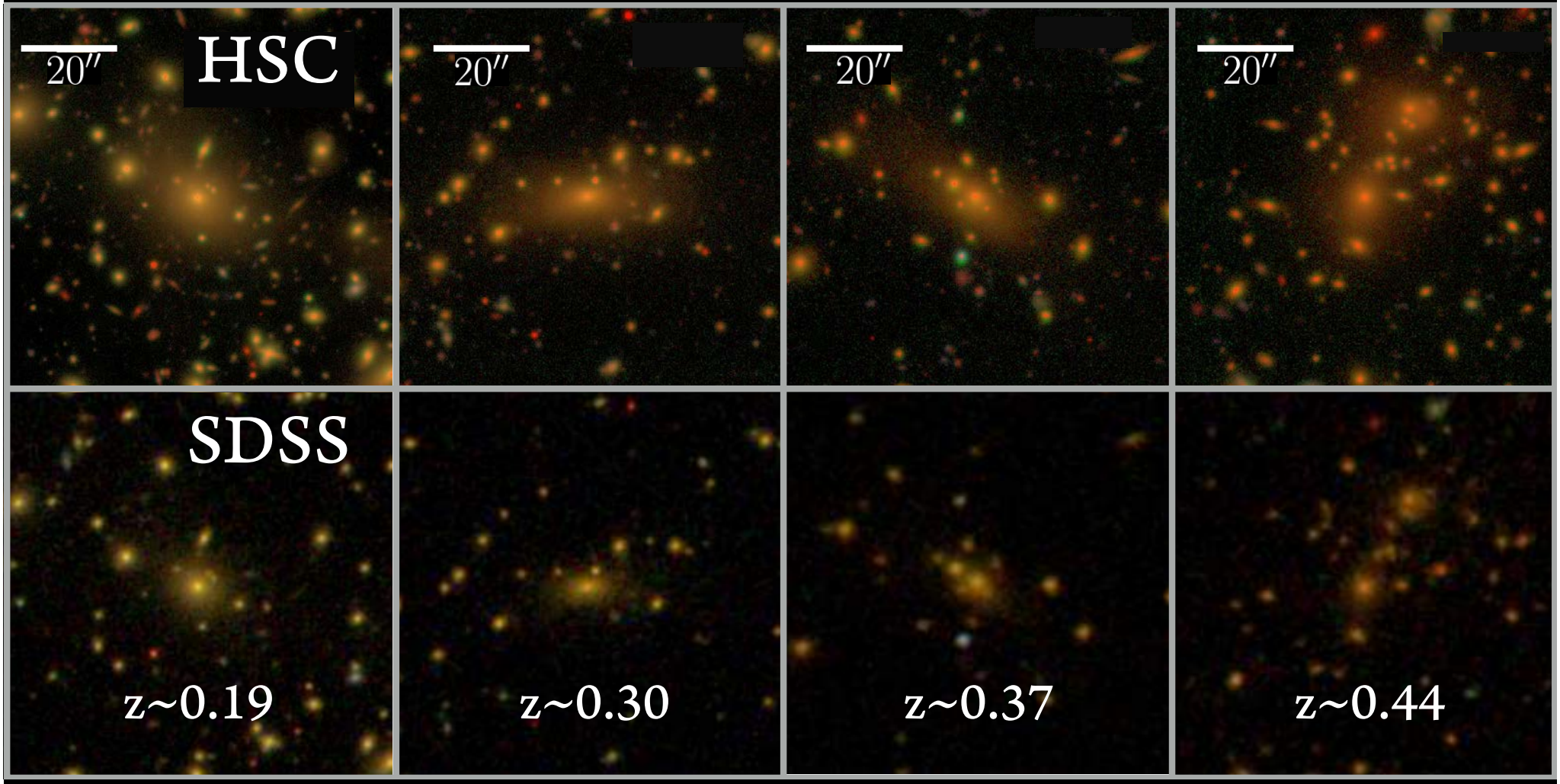


Hyper Suprime-Cam FoV

wide

- **Fas**
- a cos

~50,000

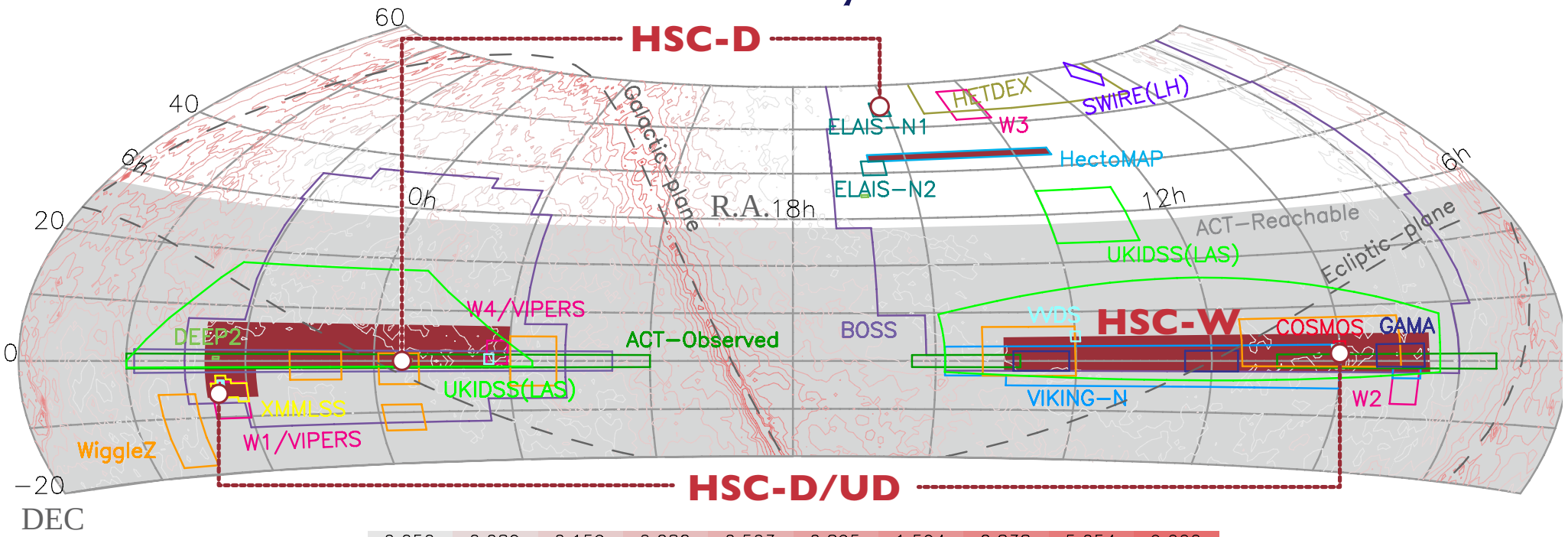


Huang et al. 2017

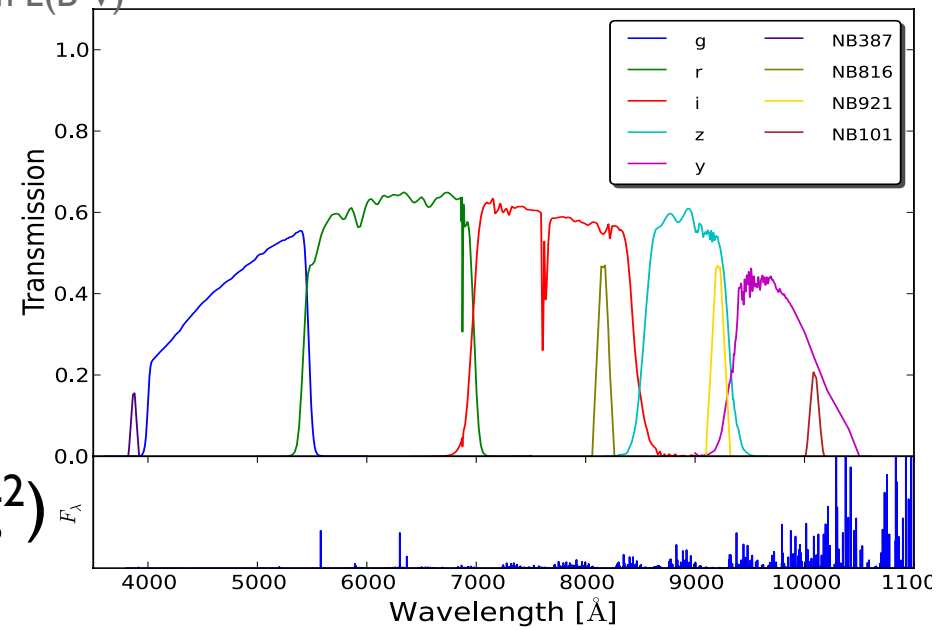
Subaru-**300**-nights HSC project (2014 -)

International collaboration (Japan, Taiwan, Princeton U.)

HSC Survey Fields

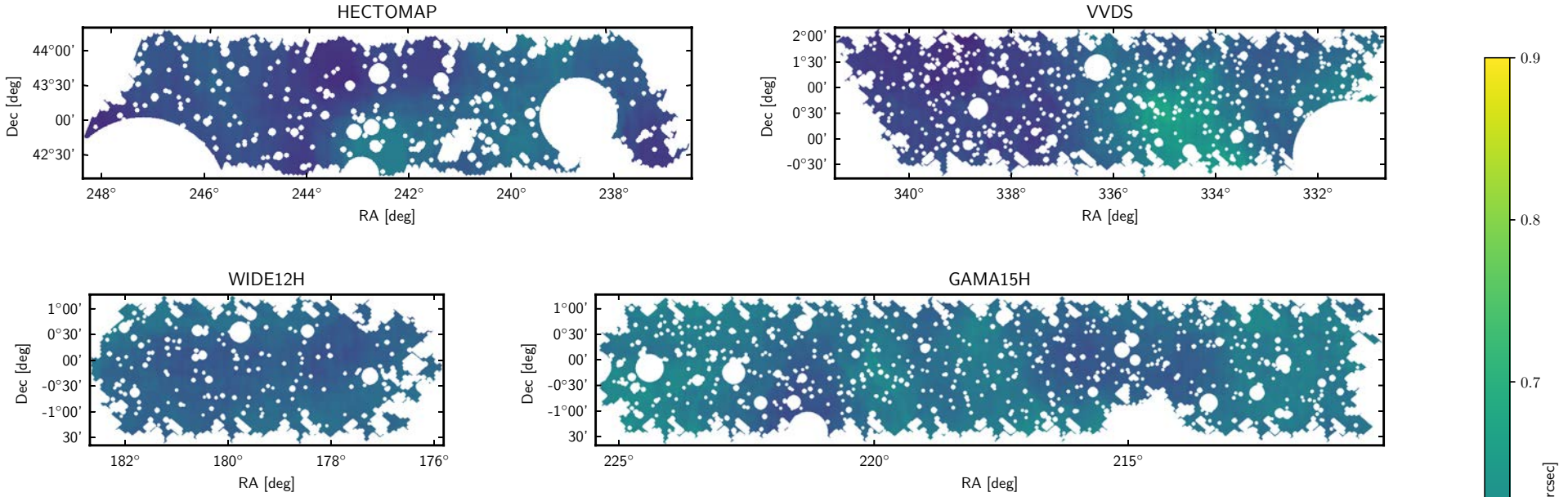


- 2014 – 2019
- Three survey layers
  - Wide (i~26, grizy, 1400 deg^2)
  - Deep (i~27, grizy+NBs, 28 deg^2)
  - Ultra-D (i~28, grizy+NBs, 3.5 deg^2)



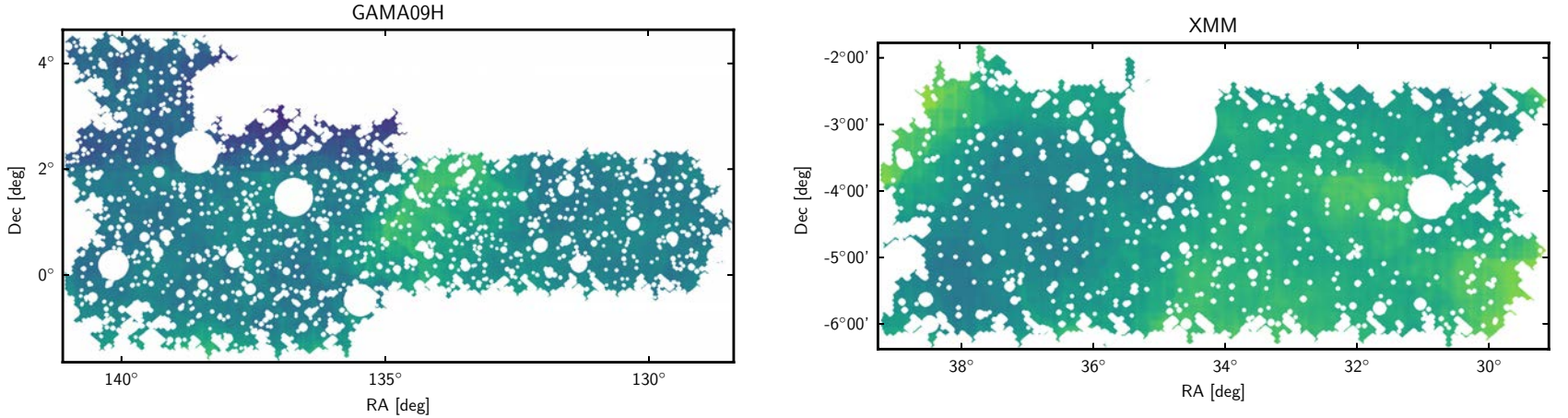
Subaru HSC = superb image quality

6 fields (~140 sq. deg. in total)



Subaru HSC typically **0.6" seeing** FWHM (spatial resolution)

⇔ DES: ~0.9"

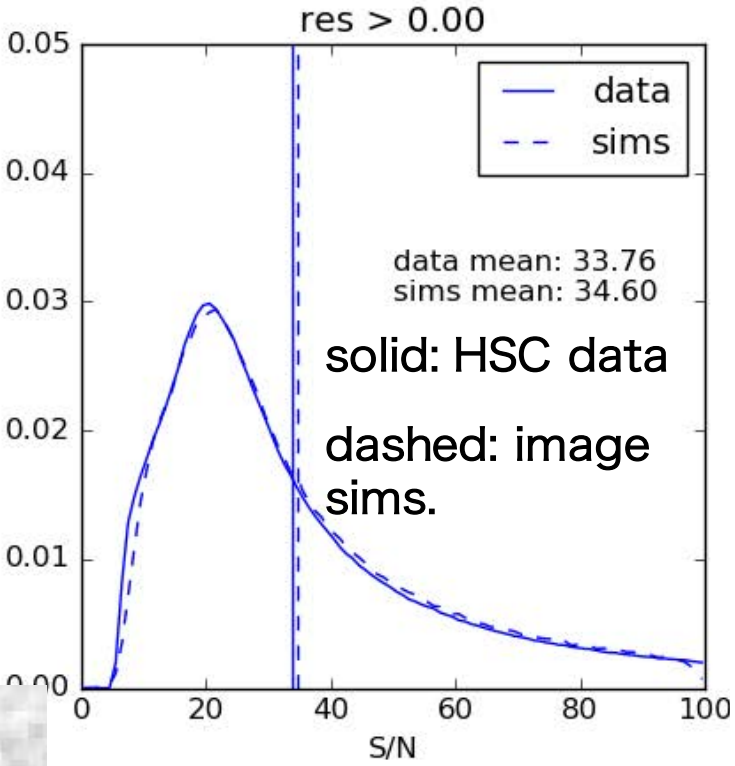


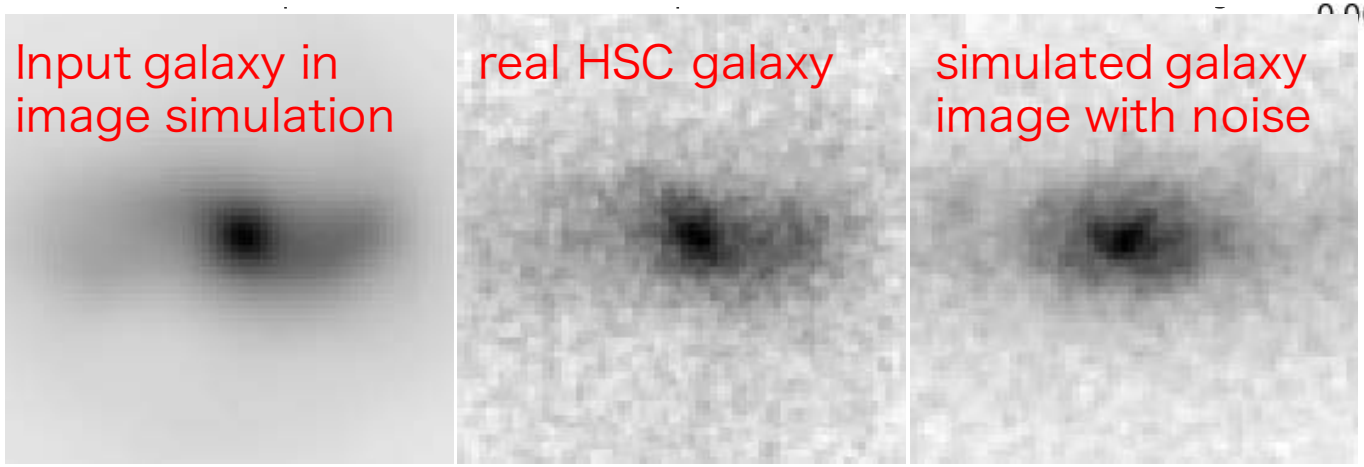
HSC galaxy shape catalog

R. Mandelbaum
(CMU)

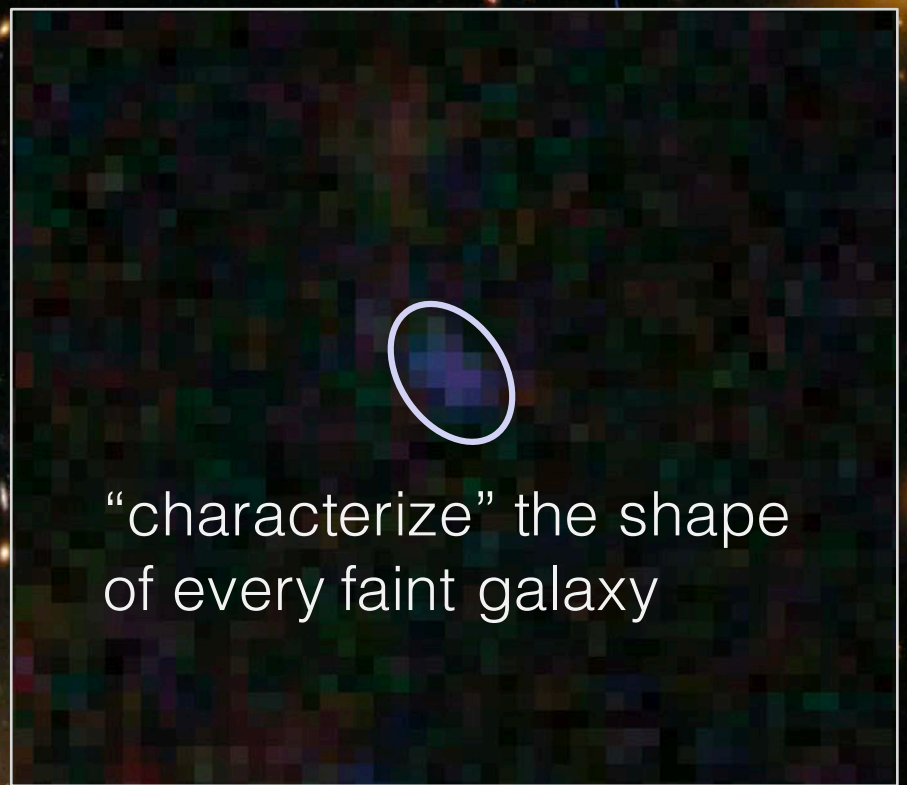
Hironao Miyatake
(Nagoya/IPMU)

- Developed the pipeline for galaxy shape measurement
- Tested/validated the galaxy shape catalog with sophisticated image simulations
- **~10M galaxies (~20 gals/sq. arcmin., ~140 sq. deg.)**
- Ready to use for weak lensing science





Weak gravitational lensing (shear)

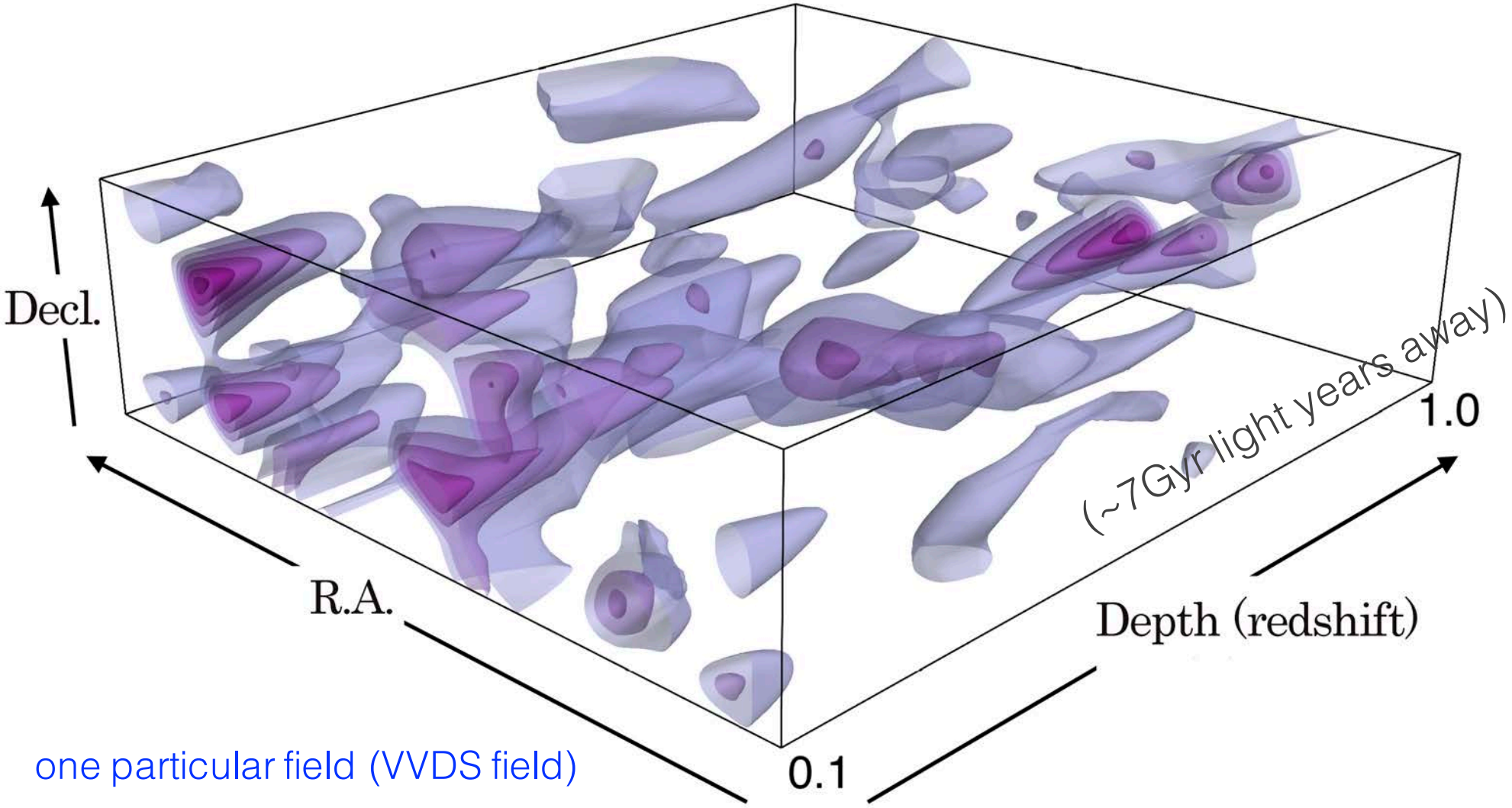


"characterize" the shape
of every faint galaxy

Unprecedented wide and deep 3D DM map

Oguri et al. 18

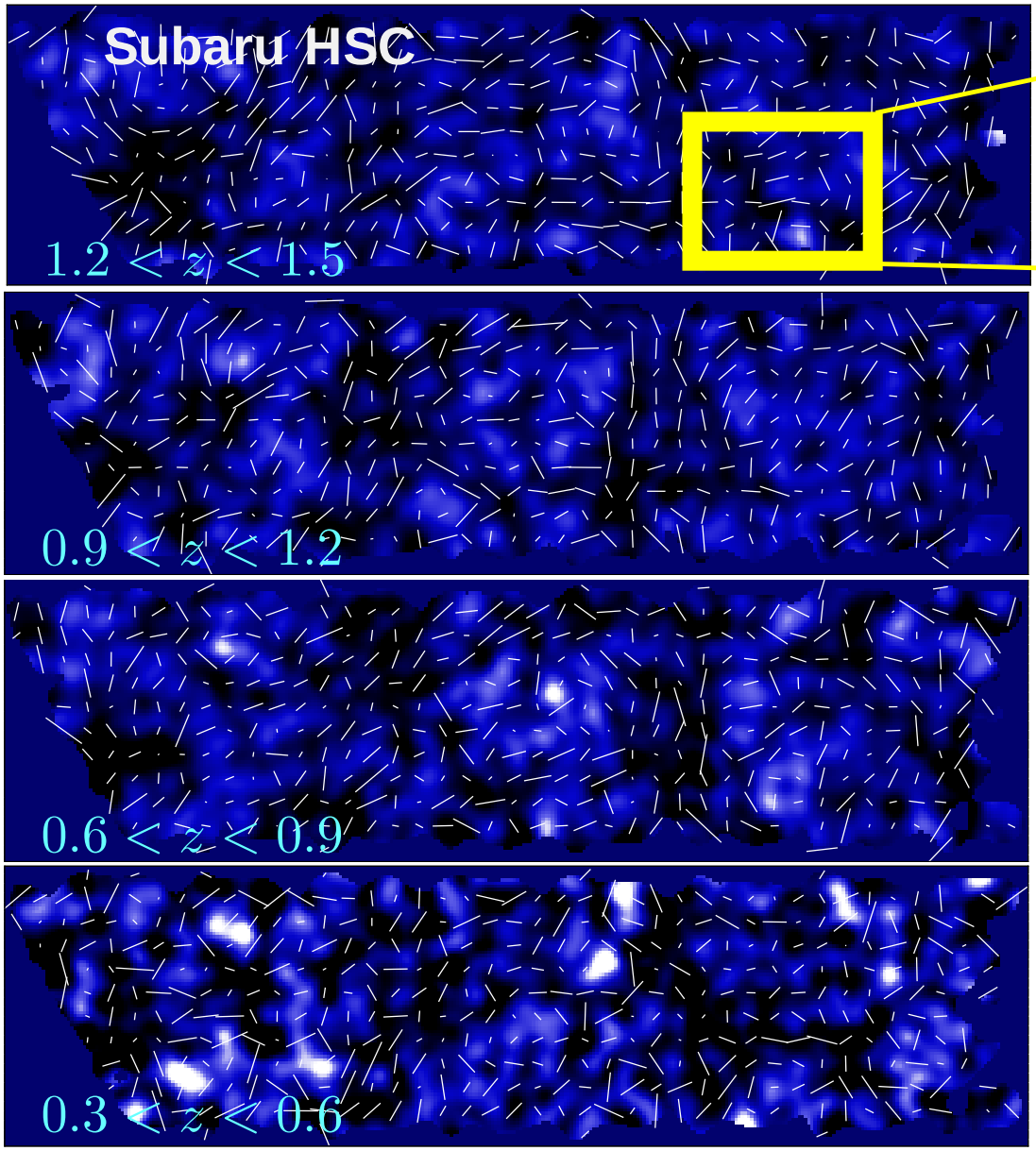
Largest 3D dark matter map



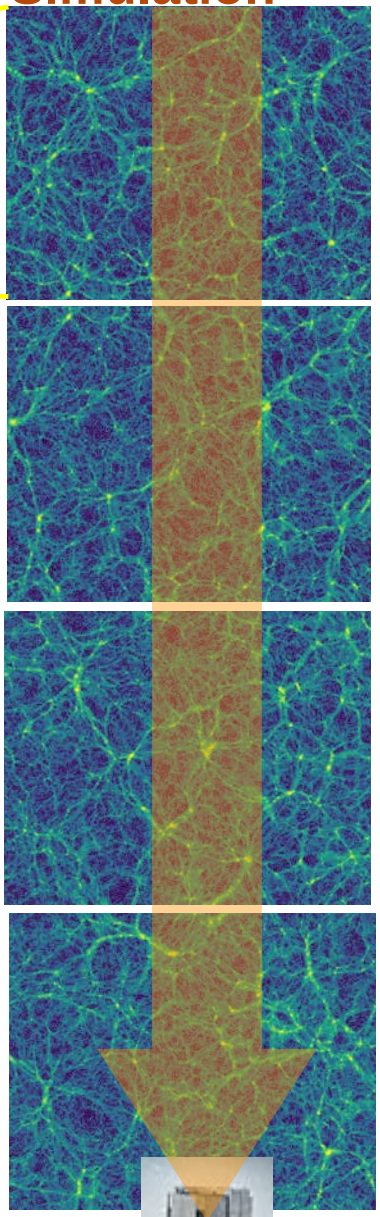
one particular field (VVDS field)

Weak lensing tomography

shape + photo-z



Simulation



~6G yrs ago

~5G yrs ago

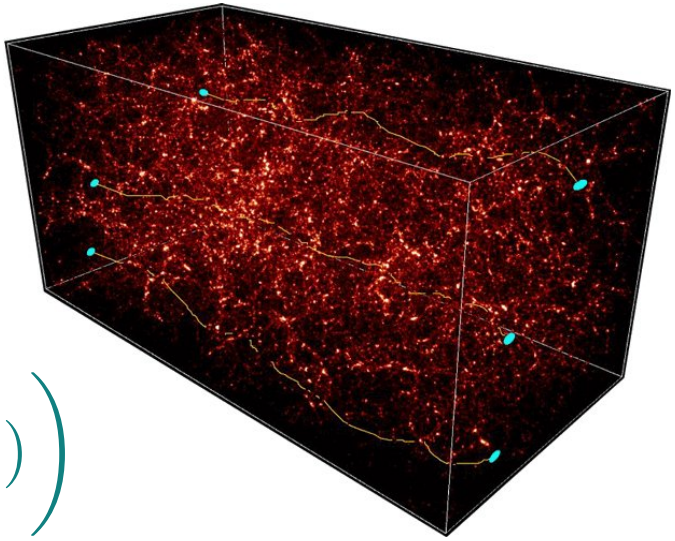
~4G yrs ago

~3G yrs ago

Subaru telescope

Hikage, Oguri+ 18

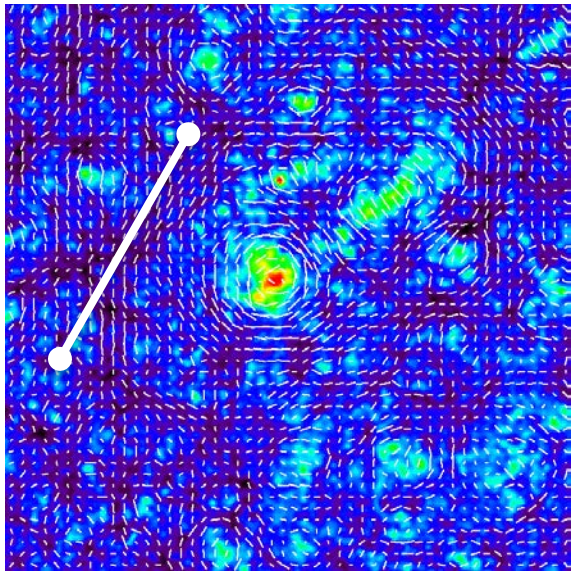
Cosmic shear cosmology



- Pros
  - Can measure “total” matter power clustering

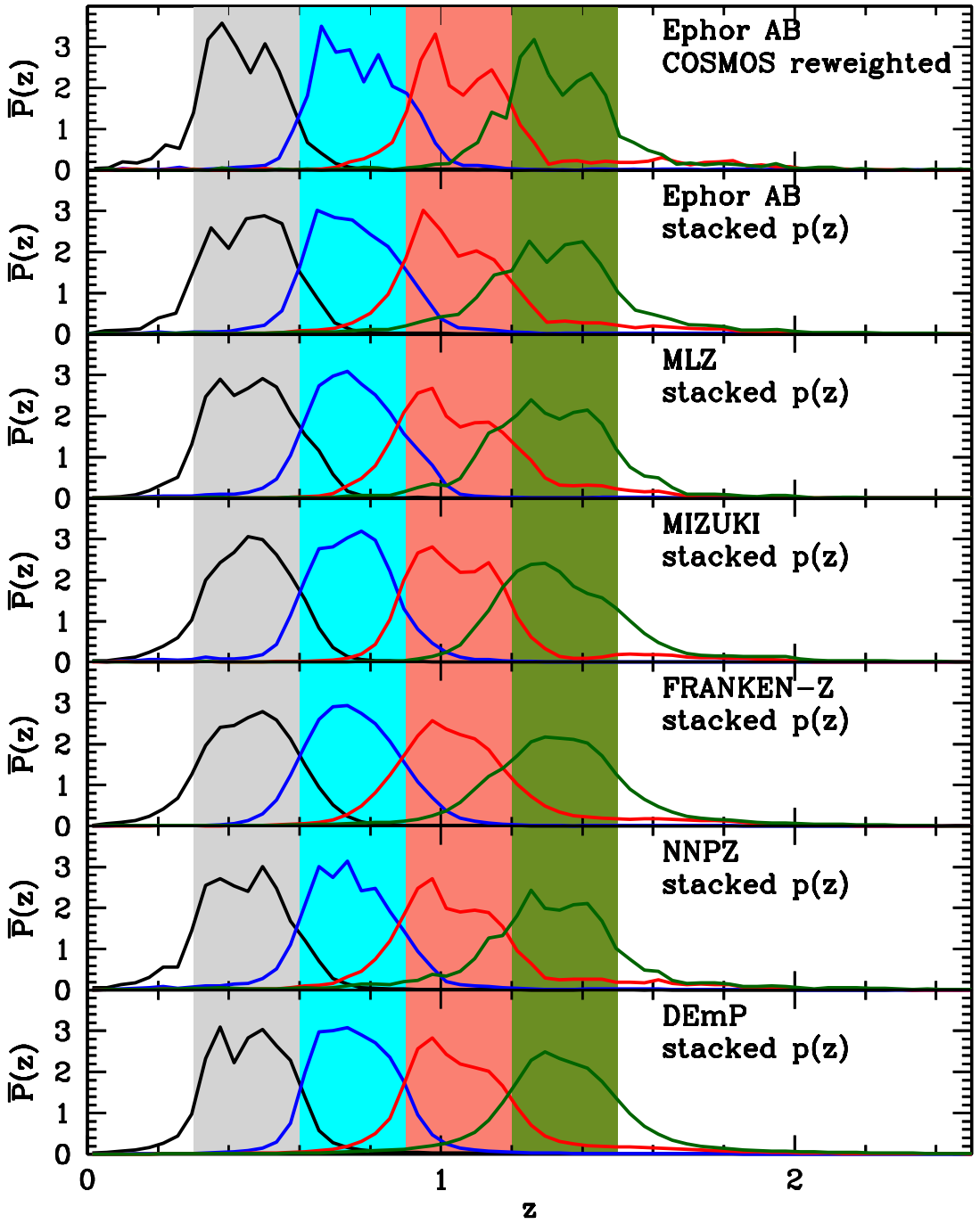
$$C_\ell = \int \mathrm{d}\chi \; W_{\mathrm{GL}}(\chi)^2 \chi^{-2} P_{\mathrm{m}}^{\mathrm{NL}}\left(k = \frac{\ell}{\chi}; z(\chi)\right)$$

- Cons
  - All the systematic errors additively contribute the measurements (⇔ g-g lensing)
  - Challenges: Photo-z errors and baryonic physics
  - HSC data are very deep compared to DES: precursor of LSST



Cosmic shear tomography

- Used photo-z's of each galaxy to have **4 tomographic bins**
- Used the **HSC-Wide depth data of COSMOS field** for galaxies after the WL cut to calibrate the photo-z errors
- Test the results against the different photo-z catalogs

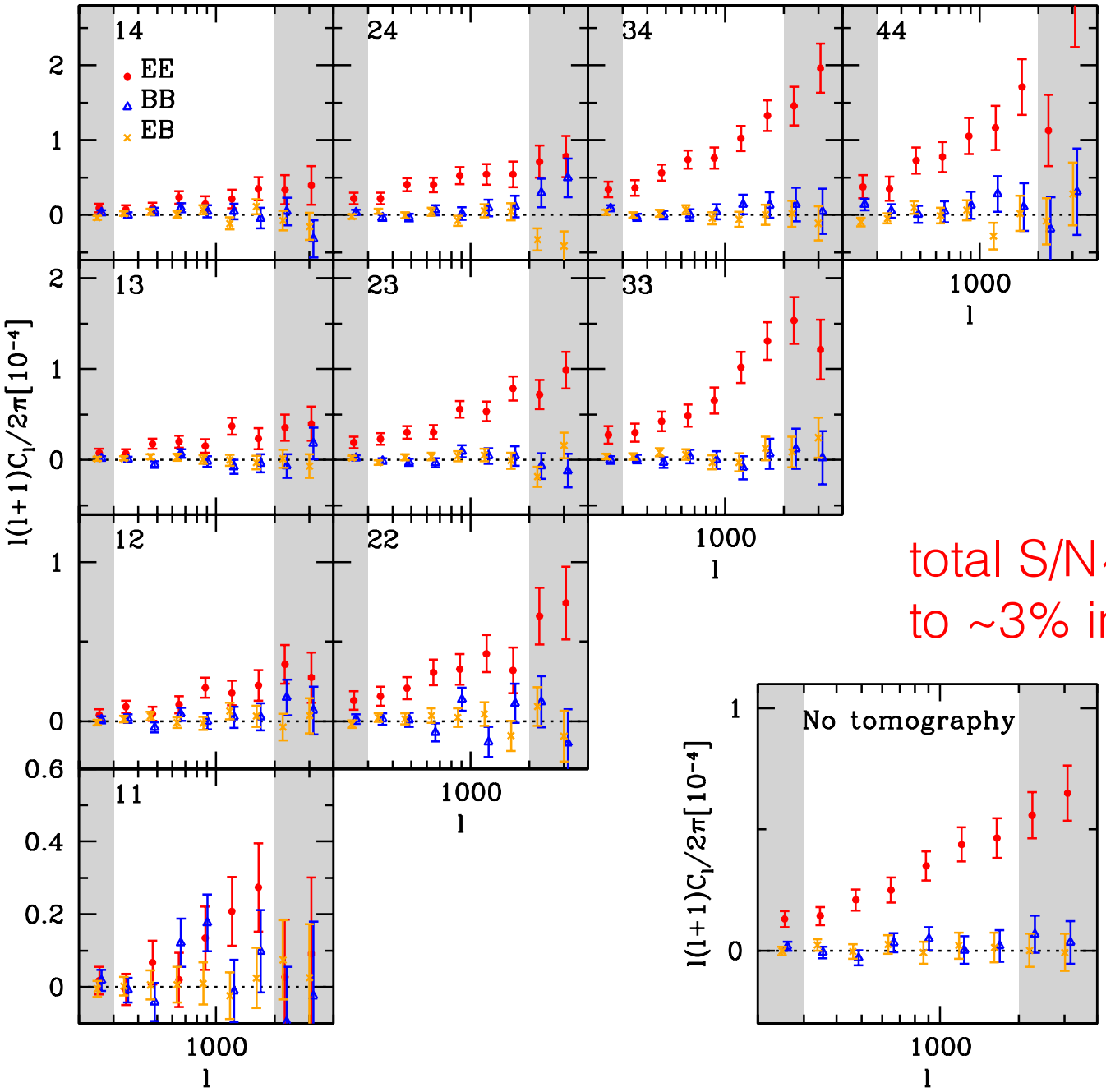


Hikage, Oguri+ 18

Pseudo-power spectrum estimator
(Hikage, MT, Hamana, Spergel 11)

$$\tilde{E}_{\ell m} \pm i\tilde{B}_{\ell m} = \int \mathrm{d}^2\mathbf{n}\; w(\mathbf{n})\,[\gamma_1(\mathbf{n}) \pm i\gamma_2(\mathbf{n})]\,Y_{\ell m}(\mathbf{n}$$

$$\hat{C}_l^{EE} = \mathbf{M}_{ll'}^{-1}\left[C_{l'}^{EE} - N_{l'}\right]$$



137 sq. deg.
0.3<z<1.5
300<ell<1900
n_eff~16.5 arcmin^{-2}
Used ~10M galaxies

total S/N~16, corresponding to ~3% in S_8

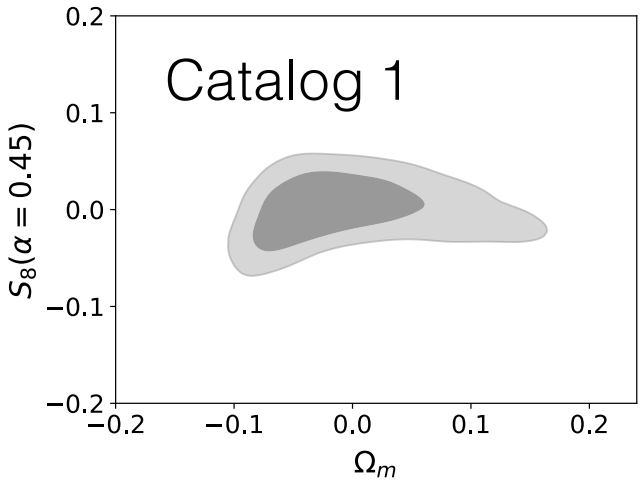
$$S_8 \equiv \sigma_8\,(\Omega_{\mathrm{m0}}/0.3)^{0.45}$$

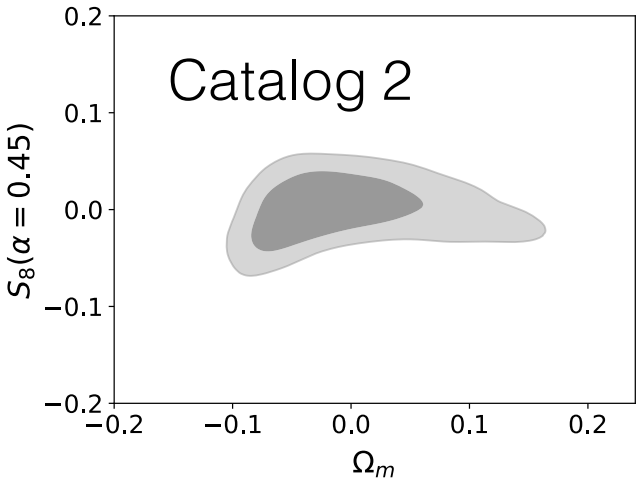
Hikage, Oguri+ 18

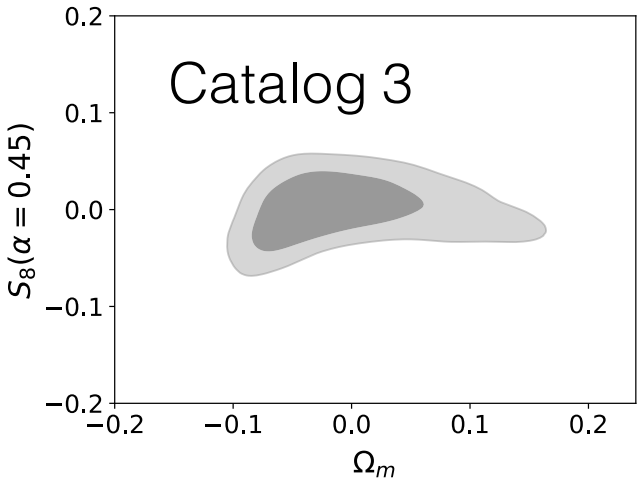
Hikage, Oguri+ 18

Blind analysis

- To avoid "confirmation or human bias"
- **3 catalogs**: one is real, but other 2 catalogs are fake (no one knows which one is real
- Do not see the actual values of parameters in the parameter inference
- Do not compare with other results (such as Planck)
- Made various tests for more than 1 year

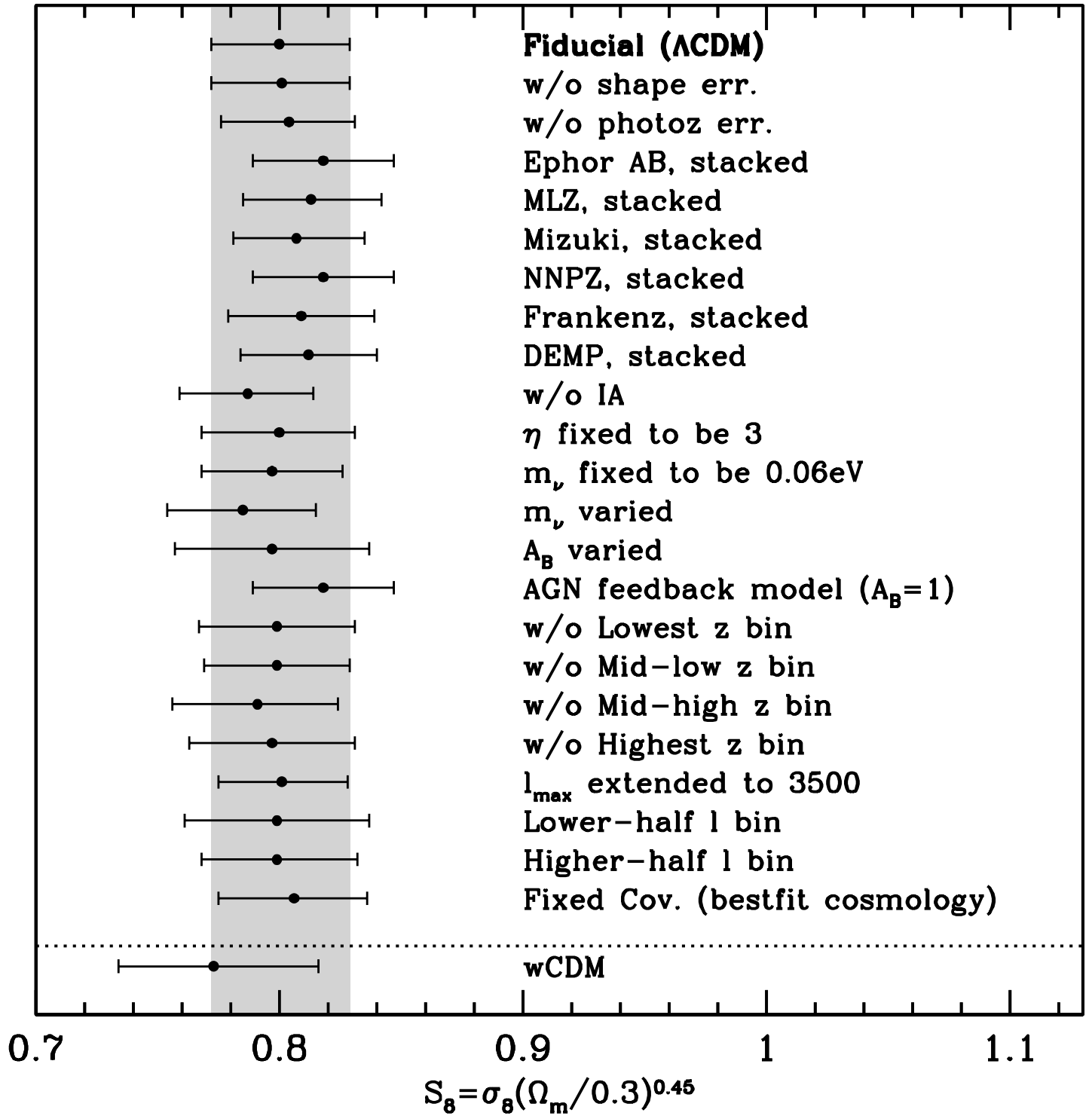




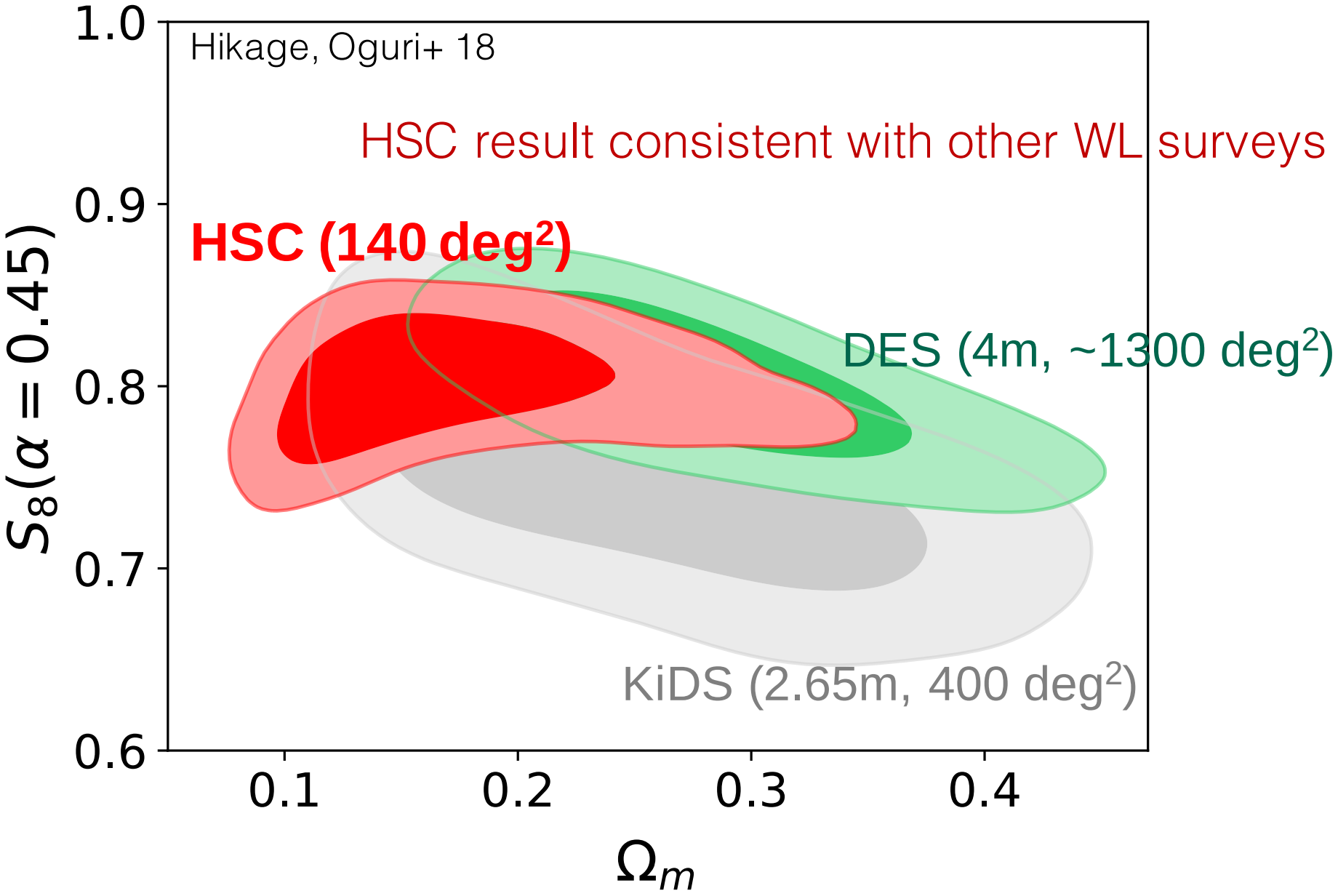


Hikage, Oguri+ 18

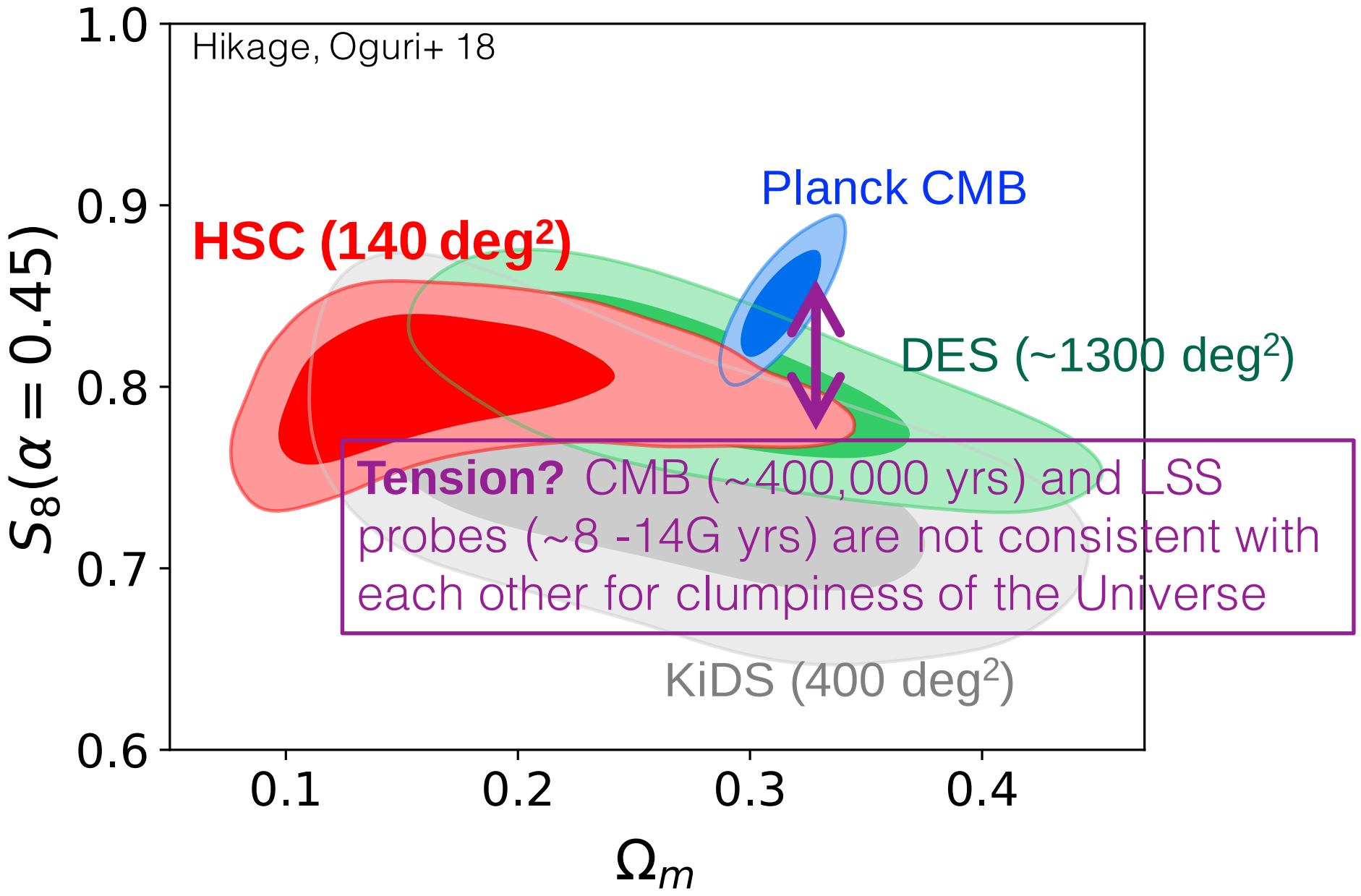
test, test, test...



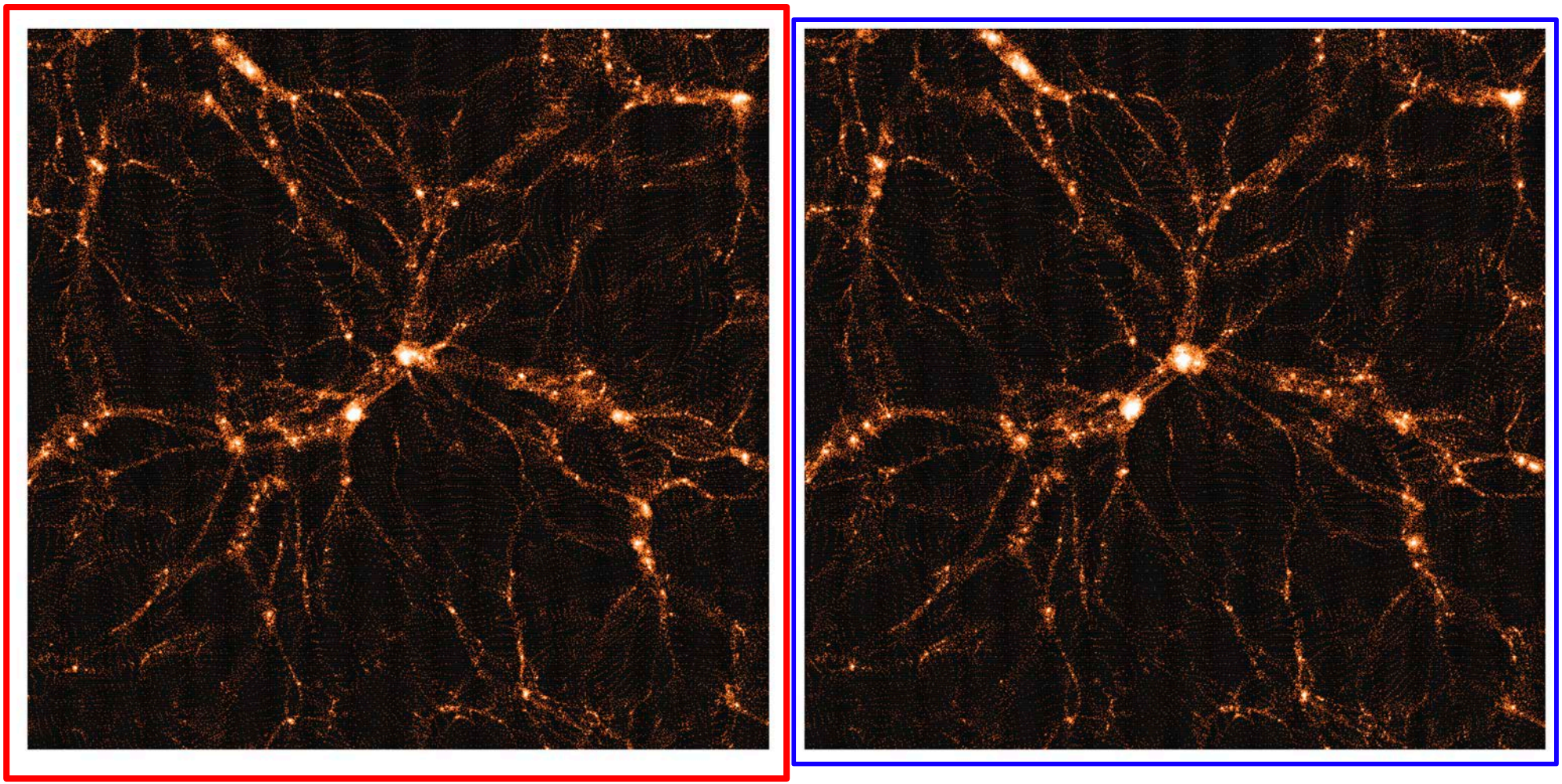
After unblinding on 26 June



After unblinding on 26 June

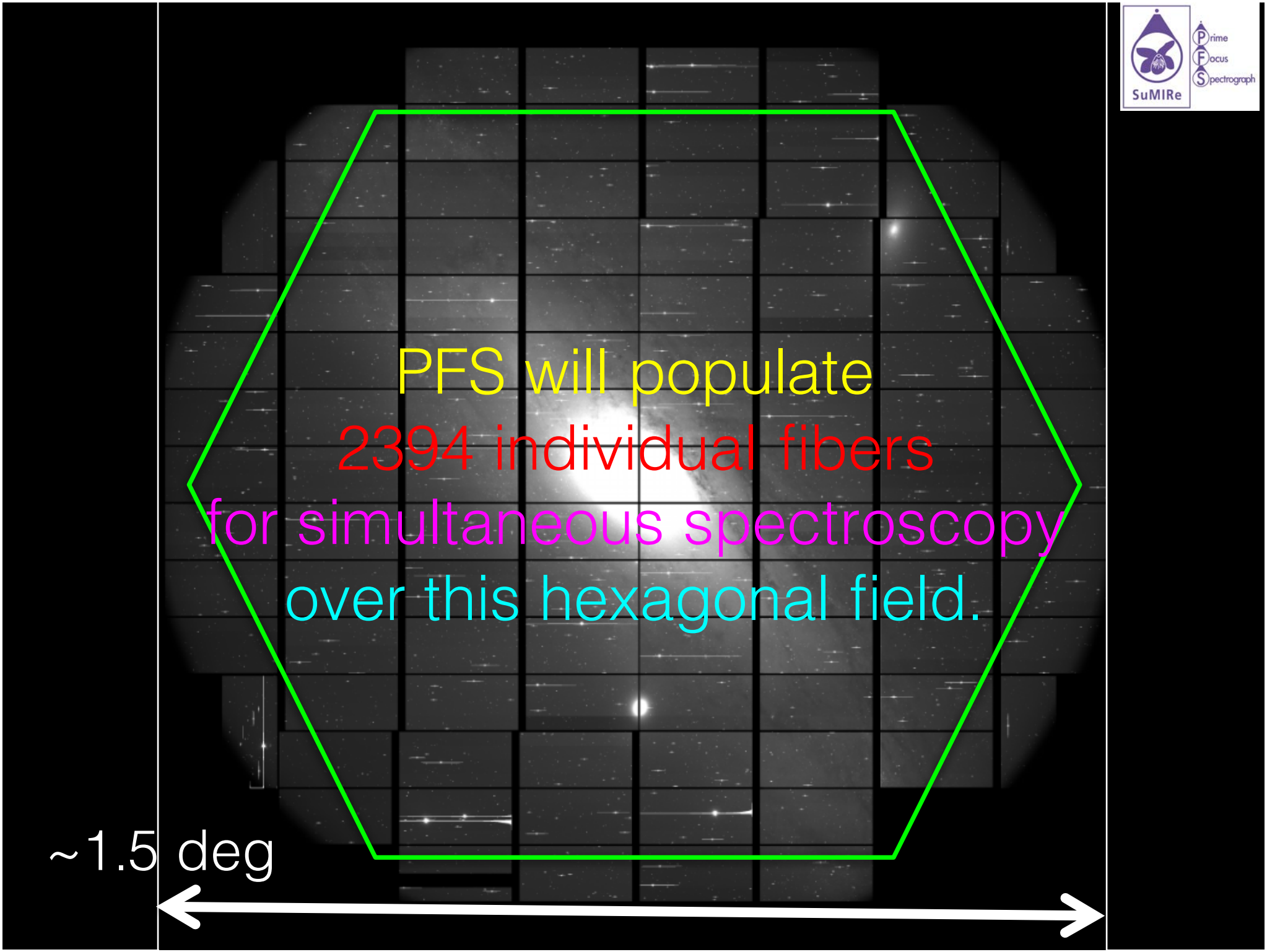


HSC preferred universe Planck preferred universe



simulated dark matter distribution in the Universe today

PFS collaboration


PFS will populate
2394 individual fibers
for simultaneous spectroscopy
over this hexagonal field.
~1.5 deg
Prime Focus Spectrograph
SuMIRe


SuMIRe
Prime
Focus
Spectrograph

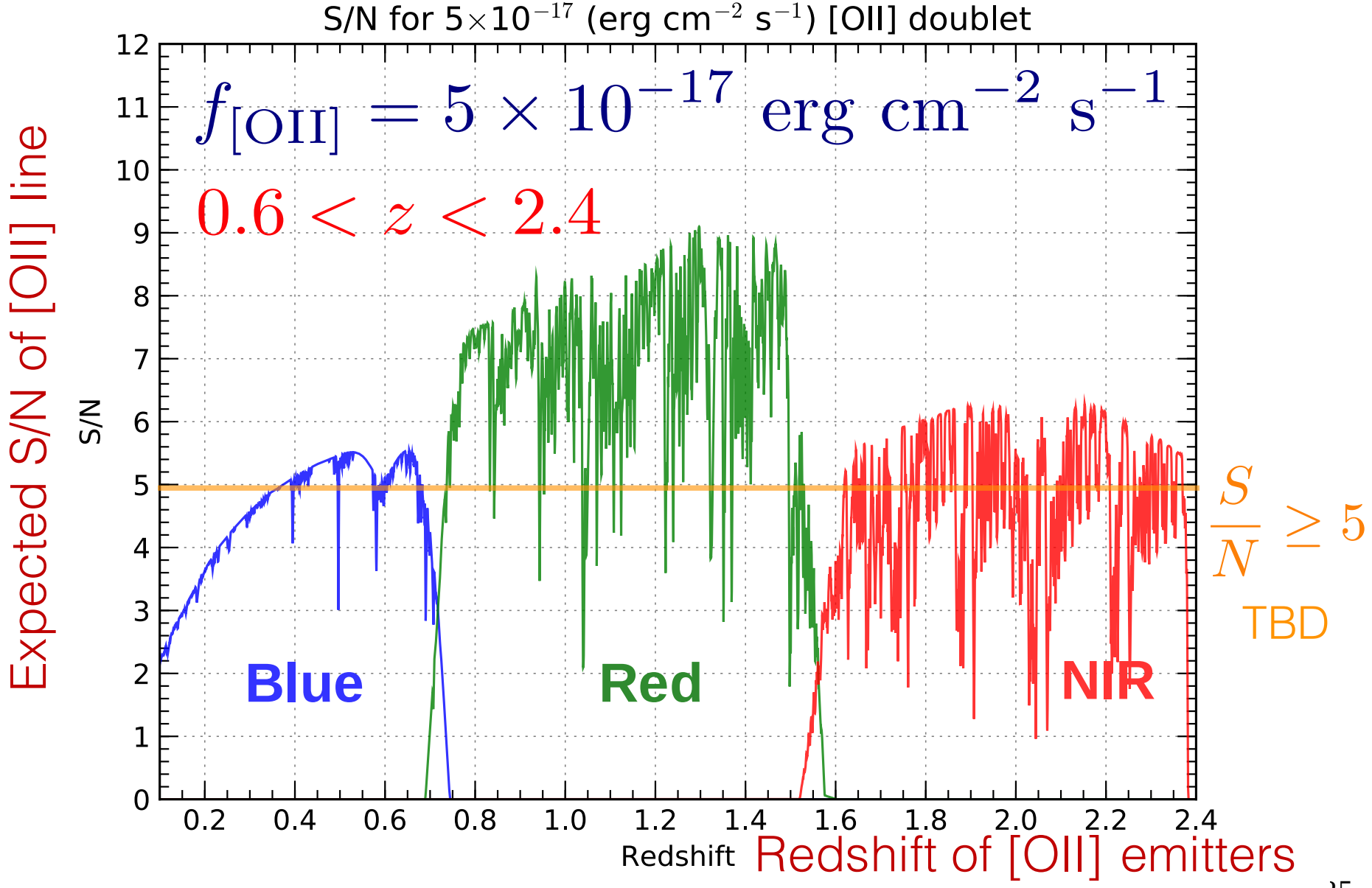
PFS Specifications

Number of fibers	2400		
Field of view	1.3 deg (hexagonal-diameter of circumscribed circle)		
Fiber diameter	1.13" diameter at center	1.03" at the edge	
Spectrograph	Blue	Red	NIR
Wavelength range [nm]	380-650	630-970 (706-890)	940-1260
Central resolving power	~2350	~2900 (~5000)	~4200
Detector type	CCD	CCD	HgCdTe

- Share WFC with HSC
- 4 spectrographs for 600 fibers each
- **λ=380-1260nm with 3 arms** (⇔ 360-980nm for DESI)
- Fiber density: **2200/sq. degs** (⇔ ~140 for 2.5m BOSS; ~600 for 4m DESI)
- The medium resolution mode (R~5000) for the red arm is also available

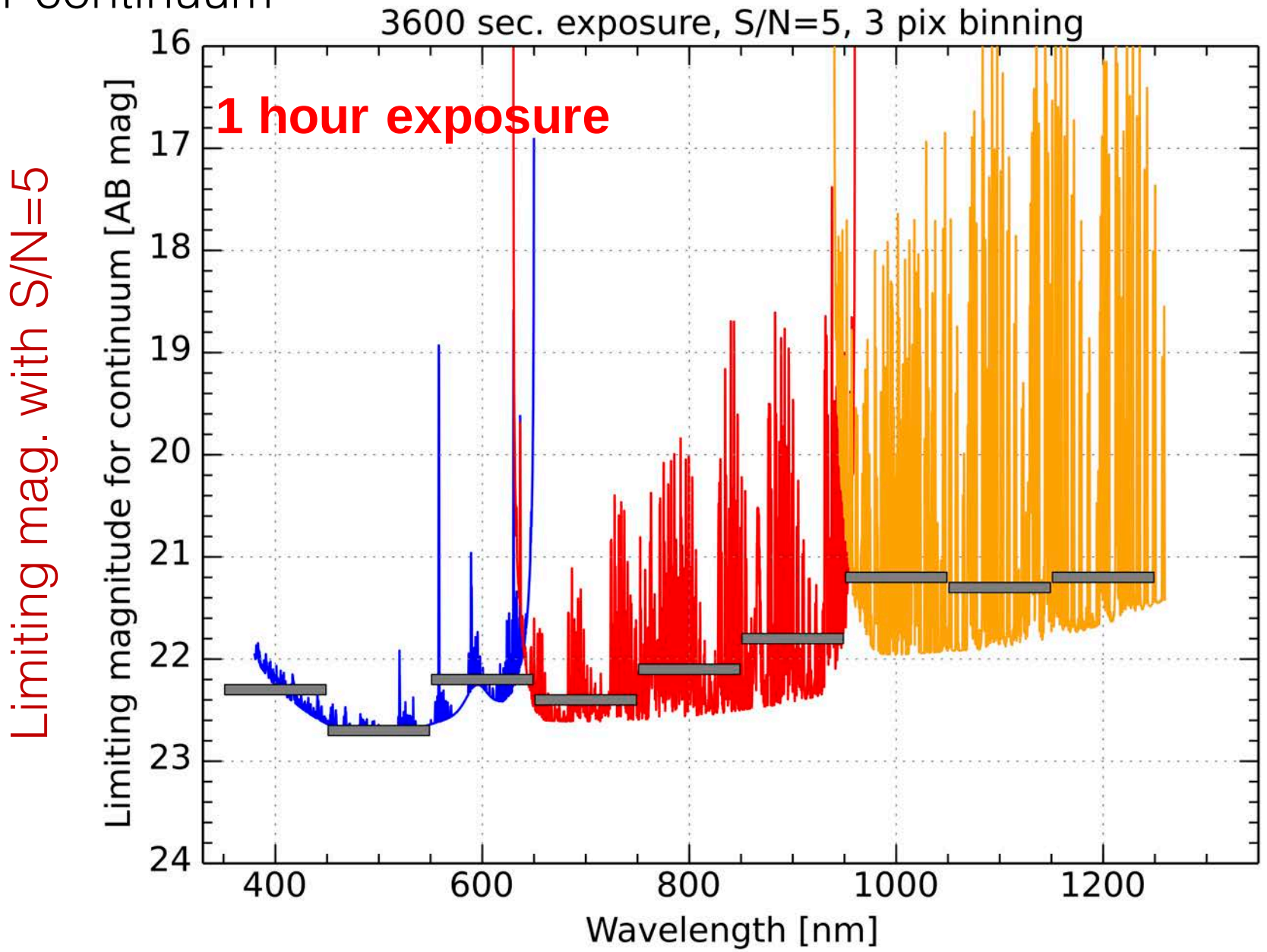
Power of 8.2m Subaru

- Subaru allows a detection of [OII] emission lines even with 15min exposure



Power of 8.2m Subaru

- For continuum



Scientific drivers: Three Pillars

All science cases are based on a spectroscopic follow-up of objects taken from the HSC imaging data

- Cosmology (~100 nights): 1400 sq. degrees
  - ~4M redshifts of emission-line galaxies
  - BAO and RSD at each of 6 redshift bins over 0.8<z<2.4
  - Cosmology with the joint experiment of WL and galaxy clustering (HSC/PFS)
- Galaxy Evolution (~100 nights): ~15 deg^2
  - A unique sample of galaxies (~0.5M) up to z~2, with the aid of the NIR arm
  - Dense sampling of faint galaxies (also many pairs of foreground/background gals)
  - Studying cosmic reionization with a sample of LAEs, LBGs and QSOs
- Galactic Archaeology (~100 nights): Milky Way/M31/dSphs
  - ~1M star spectra for measuring their radial velocities
  - Use the 6D phase-space structure, in combination with GAIA in order to study the origin of Milky Way (also use the M31 survey)
  - Use a medium-resolution-mode survey of ~0.1M stars to study the chemo-dynamical evolution of stars in Milky Way

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Review

Review

Extragalactic science, cosmology, and Galactic archaeology with the Subaru Prime Focus Spectrograph

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summary

- Achieved precision cosmology with Subaru Hyper Suprime-Cam (HSC) data!
  - Determined S_8 (clumpiness of the Universe) to a **3.6% accuracy**
  - Still based on ~10% of the full dataset (a factor of 4 more data already taken)
  - The full HSC data can make a rigorous test of ΛCDM model or could **discover a new physics**
- Prime Focus Spectrograph well underway
  - Simultaneous spectroscopic observation of 2400 objects
  - Envision we will start the large survey program from 2021 (spectroscopic follow-up of HSC stars/galaxies)