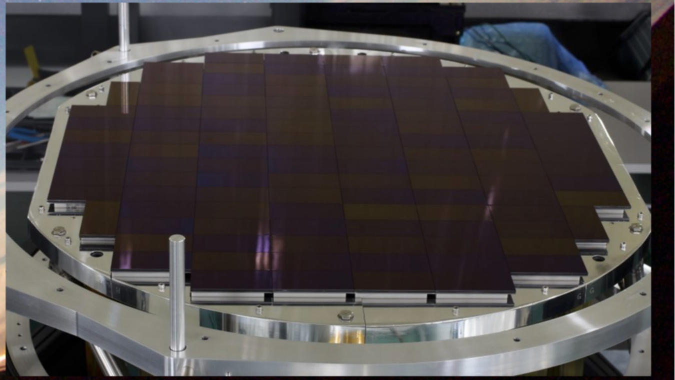
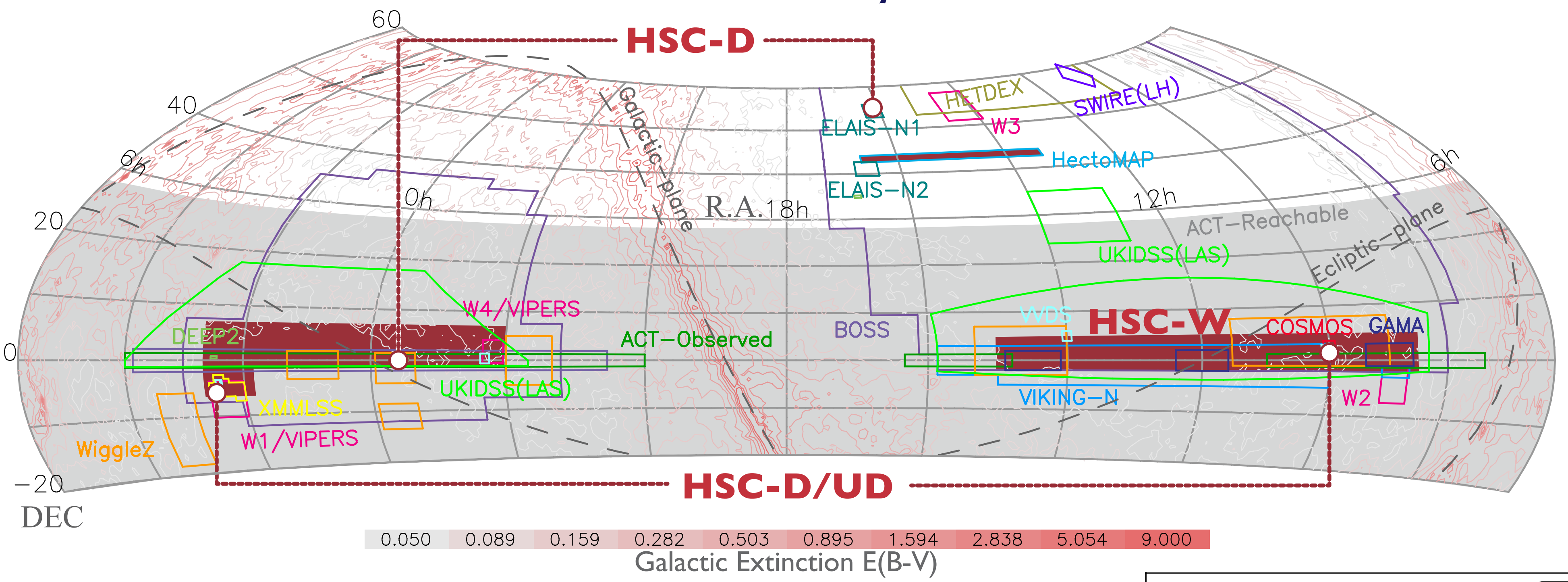
B03 (Subaru PFS (HSC))

Masahiro Takada (Kavli IPMU)

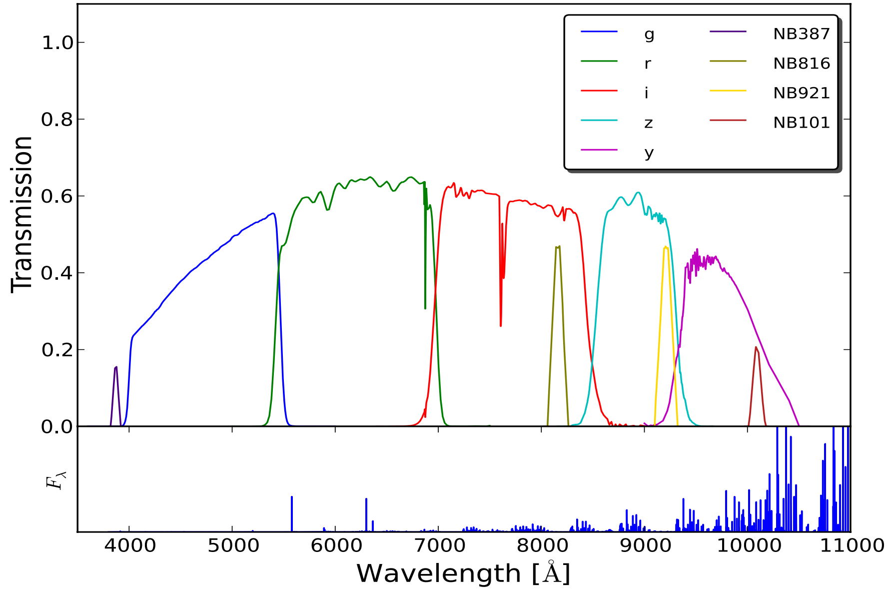
On behalf of Subaru HSC (and PFS) collaboration



Subaru-Wide Survey (2014-2021)

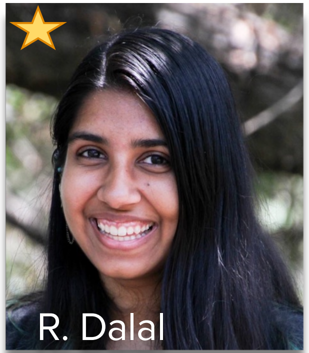


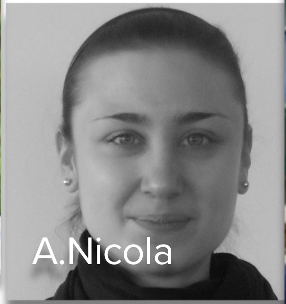
- HSC: 2014 – 2021 (HSC imaging data acquisition are done)
- Broad band filters (grizy) (plus NB filters for Deep/UD fields)
- Various science cases: cosmology, galaxies, AGN, the Milky Way structure, solar system, ….
- HSC-Wide for cosmology (i~26, grizy, ~1100 deg^2)

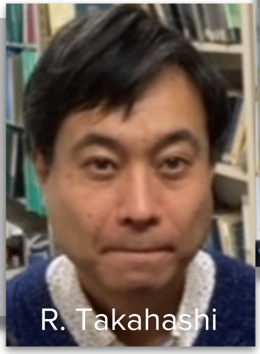


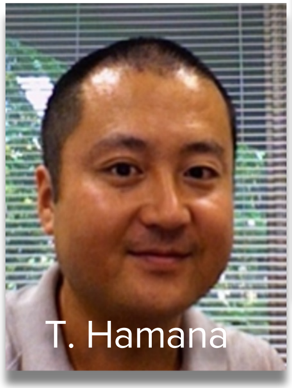
Weak lensing working group

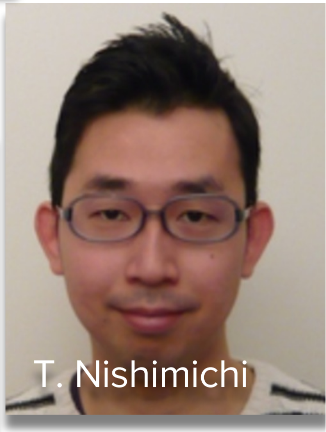
★ junior scientists











And efforts of many more!

Key weal… 023)

- The th… 74, 2)
- A Gen… k Lensing Analysis (**Zhang T.** et al. 202…
- Weak … ic Program three-year shape catalog…
- Hyper… **Li X.**, et al. 2023, PRD, to be submit…
- Hyper… 23, PRD)
- Hyper… -galaxy lensing and cosmic shear …
- Hyper… and SDSS using the Minimal Bias M…
- Hyper… and SDSS using the Emulator Based…

- PRD Viewpoint (NOT Editor's suggestion)

… career scientists leading the … cts marked in bold

Physics VIEWPOINT

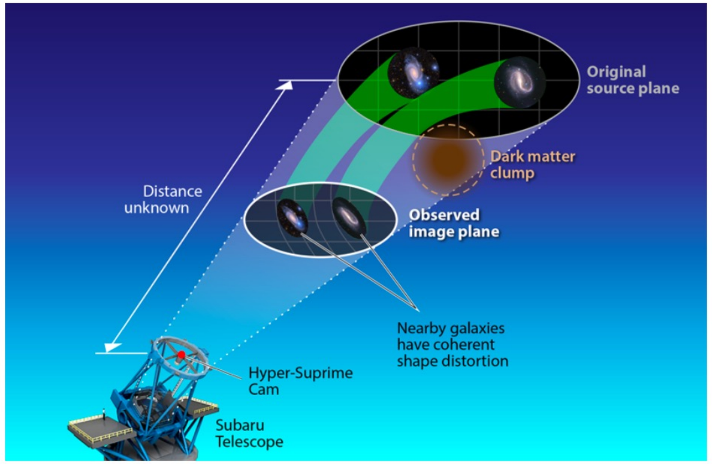
100 papers out of 20,000 papers (<0.5%)

Inconsistency Turns Up Again for Cosmological Observations

A new analysis of the distribution of matter in the Universe continues to find a discrepancy in the clumpiness of dark matter in the late and early Universe, suggesting a fundamental error in the standard cosmological model.

By **Mijin Yoon**

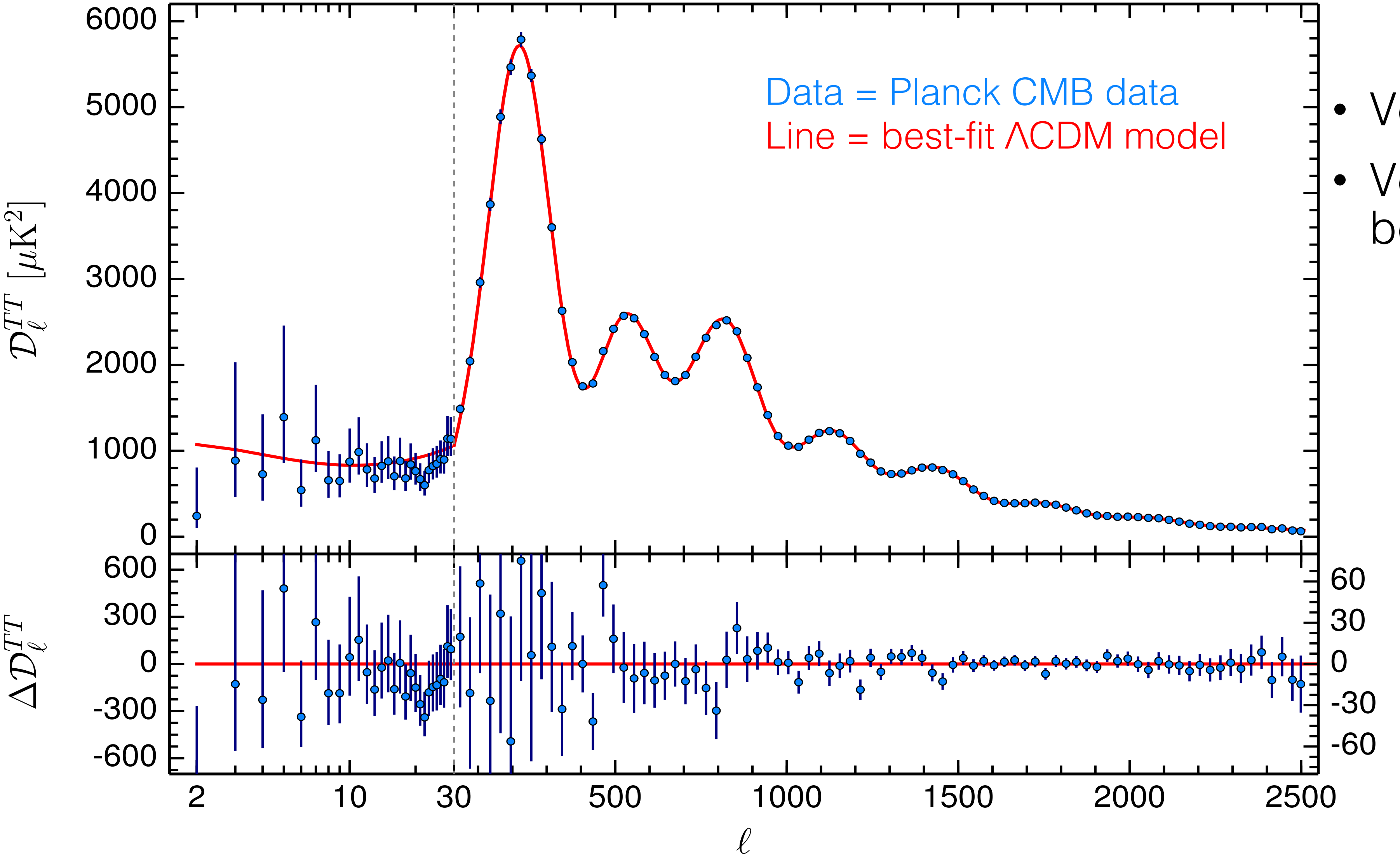
Cosmologists study the Universe by making a vast range of observations using a variety of modern techniques. Each observation can reveal different details about the Universe's composition over a certain period of its history. An astronomical survey—a map of a region of the sky—is a powerful way to scan a large swath of the Universe and the



objects it contains. For example, a weak-lensing survey does that by obtaining sharp images of galaxies, which can then be used to map the distribution of the Universe's matter throughout history. The Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) is one such weak-lensing survey, and it has the highest resolution and the deepest depth of all current weak-lensing surveys. Over the past six years, the HSC-SSP survey team has spent 330 nights scanning 3% of the entire spherical sky, capturing the light emitted by galaxies up to 10 billion years ago. The team has now analyzed 40% of its data [1–5], finding results that are inconsistent with the predictions of cosmological models derived from Planck-satellite data of the early Universe, such as measurements of the Universe's first light. This inconsistency has repeatedly turned up in weak-lensing surveys, suggesting there exists a fundamental defect in the standard cosmological model, known as ΛCDM.

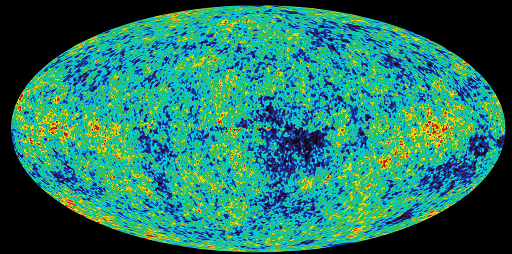
Traditionally, astronomers use light directly emitted from an astrophysical object to investigate the properties of that object. Gravitational-lensing surveys instead use the light emitted from

ΛCDM model: the standard model of the Universe



- Very successful
- Very simple! (too simple to be true?)
  - Dark matter
  - Dark energy
  - Baryon
  - Primordial fluctuations (ns and As, motivated by inflation)
  - (optical depth)

A stringent test of ΛCDM model

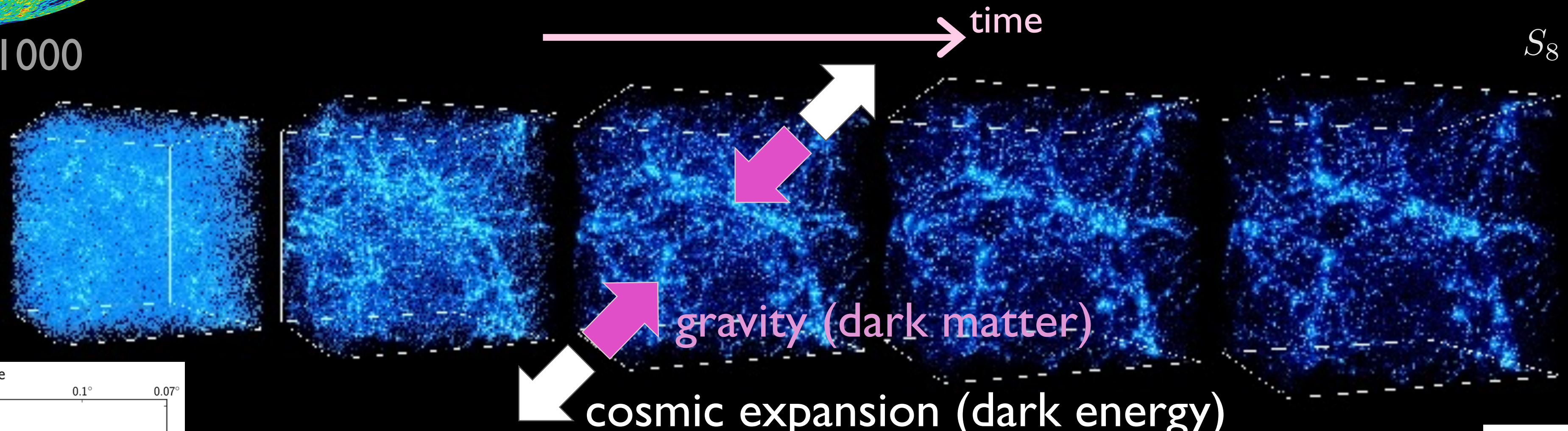


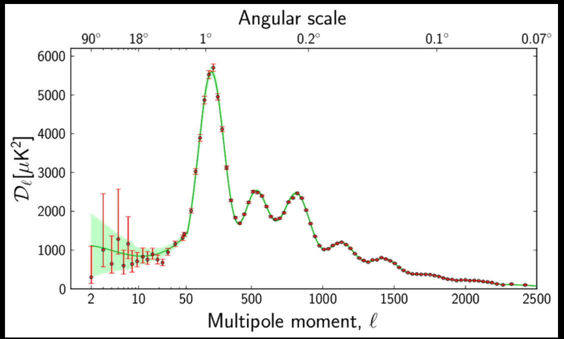
CMB at z~1000

ΛCDM extrapolation

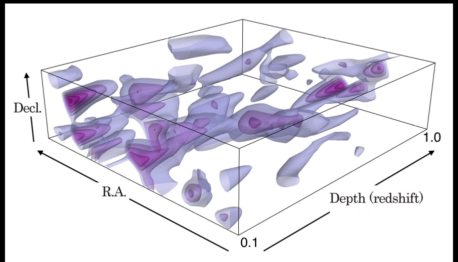
$$\sigma_8^{\rm CMB}(z\sim 0)$$
$$S_8^{\rm CMB}(z\sim 0)$$

$S_8 \equiv \sigma_8(\Omega_{\rm m}/0.3)^{0.5}$





ΛCDM=~6 parameters



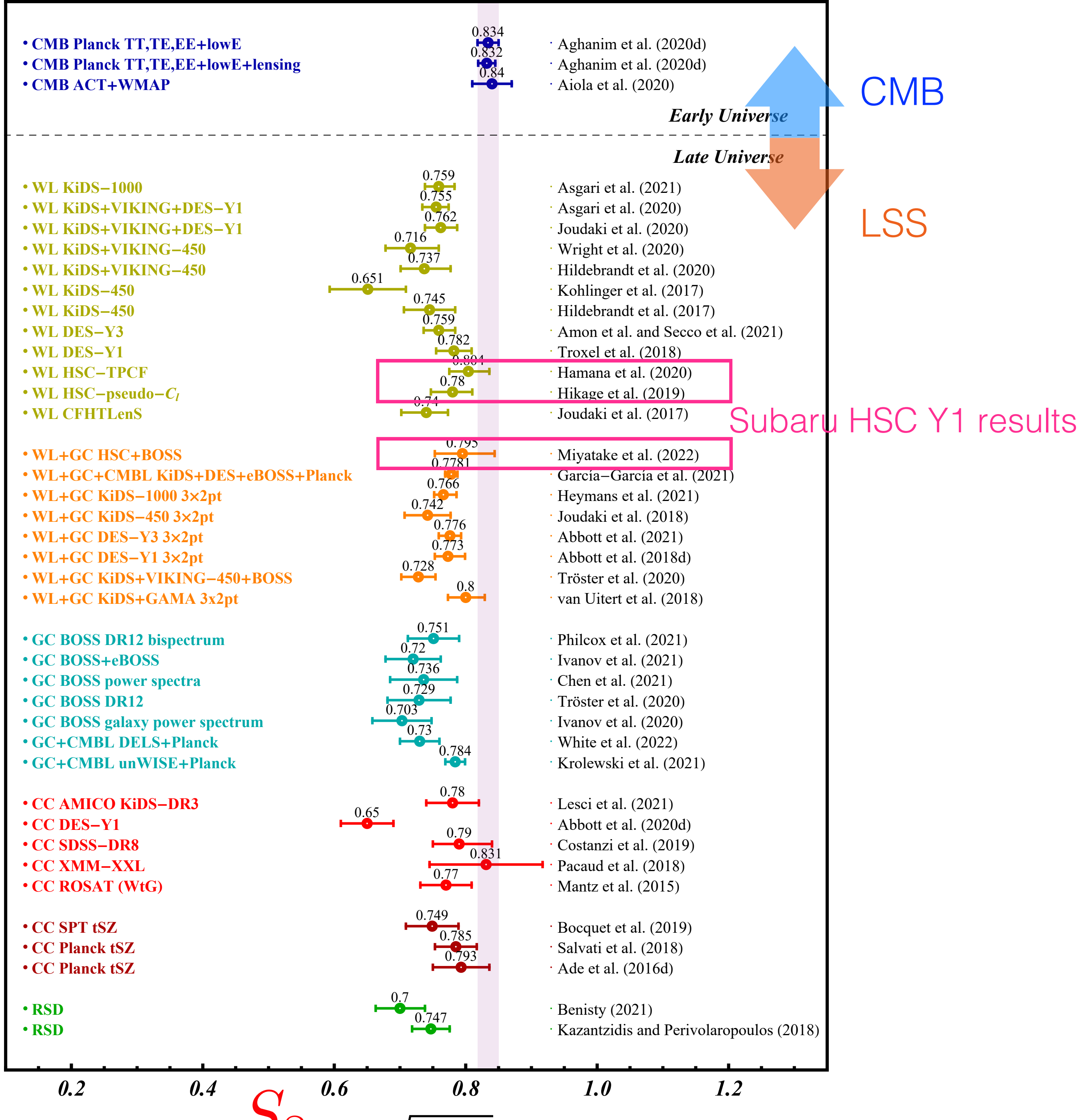
Galaxy surveys directly measure "**lumpiness**" of the late universe

$$\sigma_8^{\rm obs}(z\sim 0),\quad S_8^{\rm obs}(z\sim 0)$$

S8-tension

$$S_8 \equiv \sigma_8 \left(\frac{\Omega_\mathrm{m}}{0.3}\right)^{0.5}$$

- A parameter to characterize "lumpiness" of the late-time universe
- A parameter to which large-scale structure (LSS) probes are most sensitive
- S8 value from most LSS probes displays a "tension" with that from CMB – S8 tension
- Unknown systematics or New physics beyond ΛCDM?

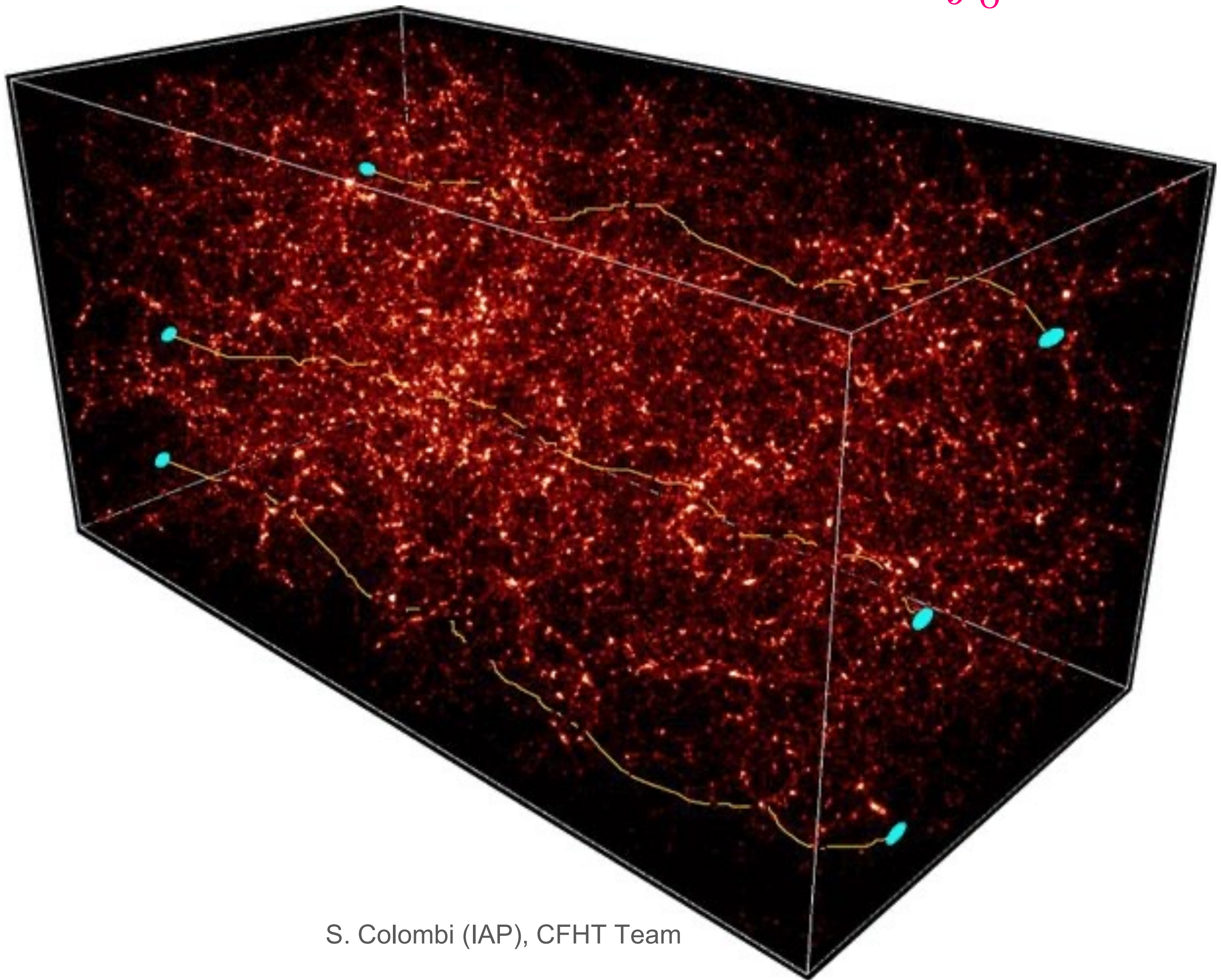


SNOWMASS 2021: Abdalla et al. (2022)

Weak gravitational lensing – a probe of dark matter distribution

$$\gamma = \frac{a-b}{a+b} \sim \Omega_{\rm m} \int_0^{\chi_{\rm s}} {\rm d}\chi\, \chi \left(1 - \frac{\chi}{\chi_{\rm s}}\right) \delta_{\rm m}(\chi, \chi\boldsymbol{\theta}) \sim \sigma_8 \Omega_{\rm m}^{0.5} z_s^{\alpha} \sim S_8 z_s^{\alpha}$$

Ω_m: the amount of matter (incl. dark matter)
δ_m: the matter density fluctuation field

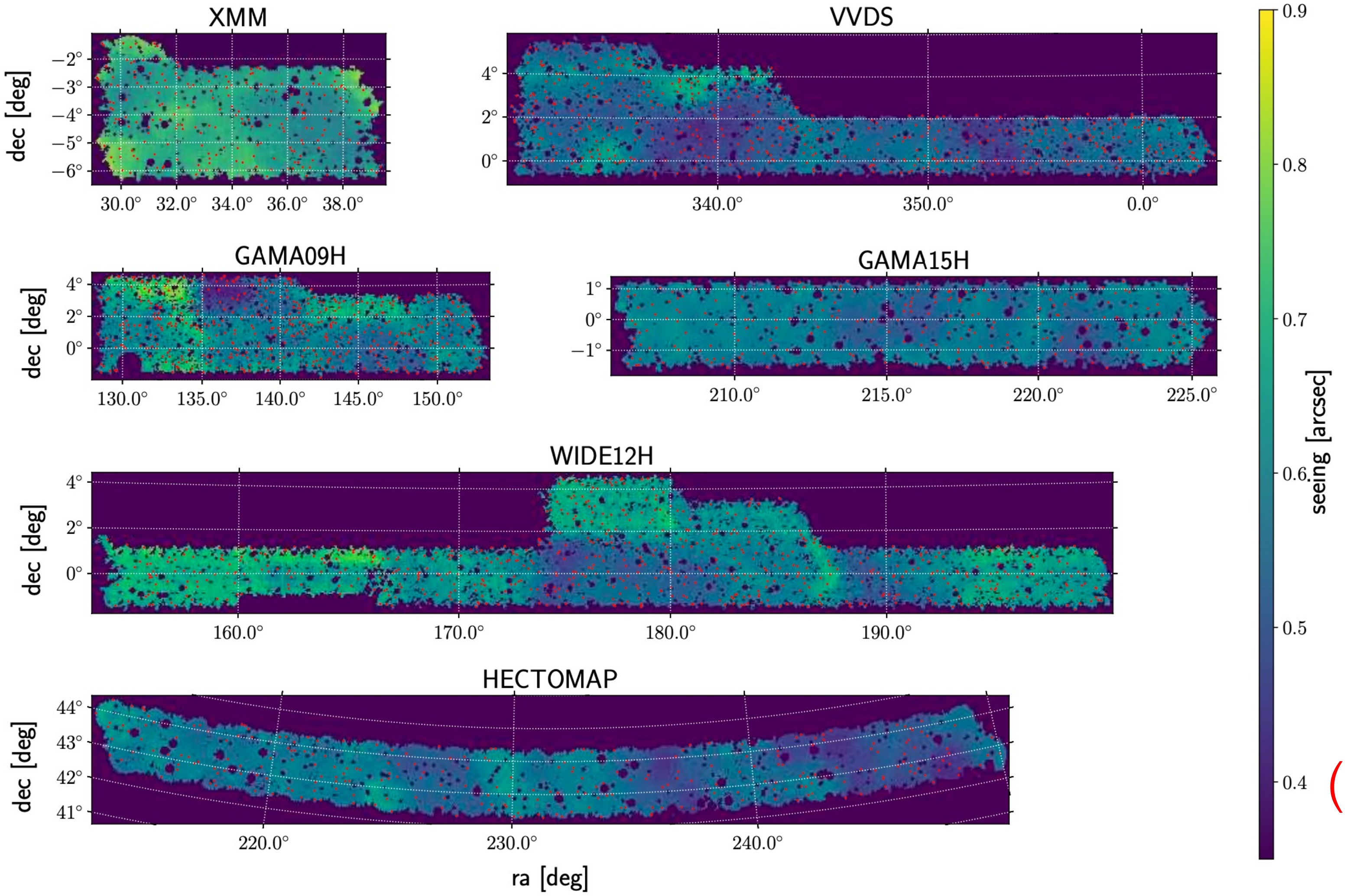


S. Colombi (IAP), CFHT Team

- An image of distant galaxy is distorted
- Lensing distortion (=ellipticity) is a tiny effect, ~ 1% in ellipticity amplitude
- If observed, it can probe the matter fluctuation field along the line-of-sight direction – a powerful way to probe DM distribution
- High-quality image like that of Subaru is crucial for accurate weak lensing measurement

HSC Year 3 galaxy shape catalog

- HSC Year 3 data: ~416 sq. deg. ⇐ Year 1 ~140 sq. deg., a factor of 3 wider
- Galaxy shape catalog: [Xiangchong Li (the former IPMU student), Miyatake et al. 22]
- Used the sophisticated simulated data (using HST) for the calibration



25M galaxies (shapes)

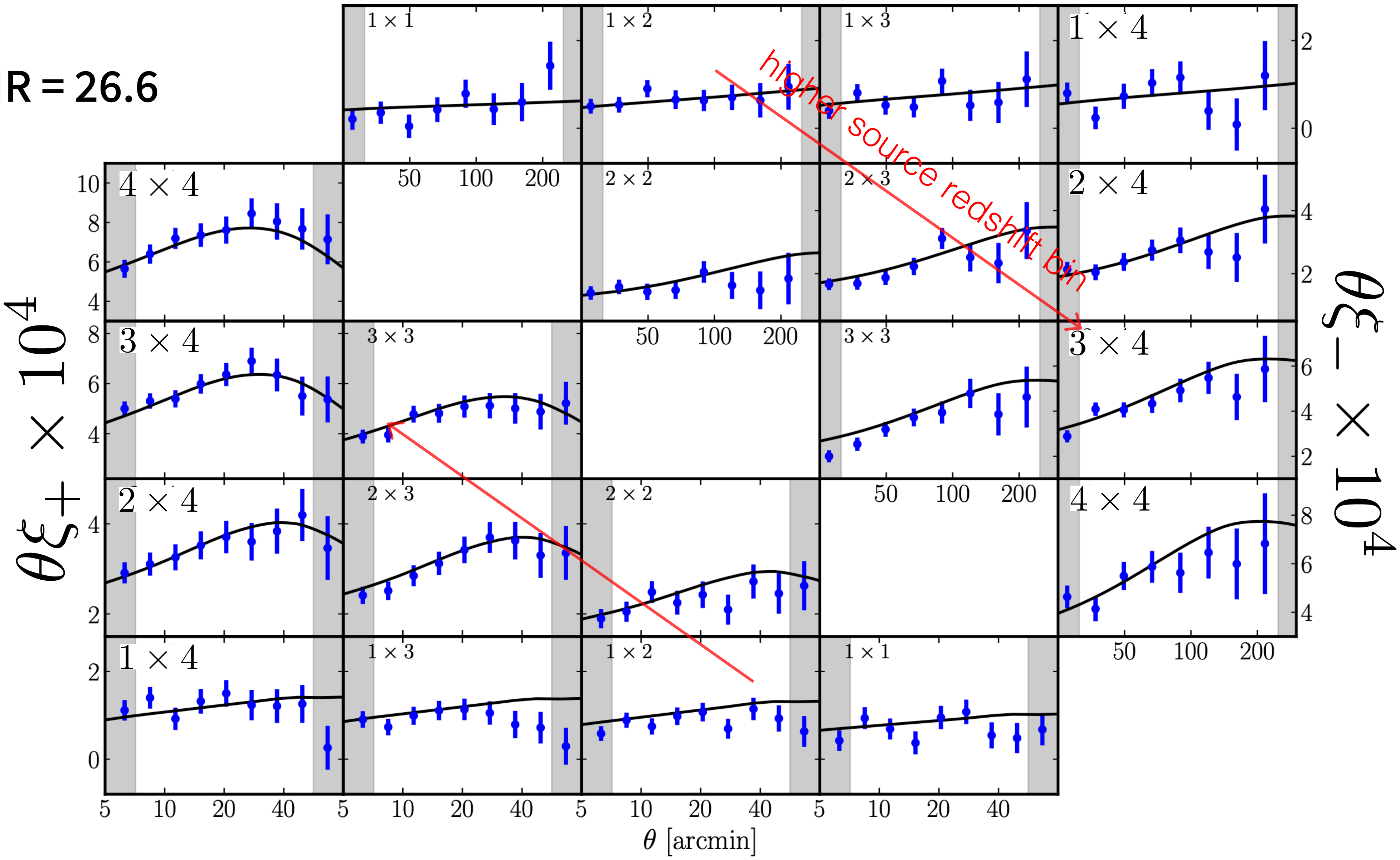
seeing ~0.6 arcsec
(⇔ ~0.9 arcsec for DES)

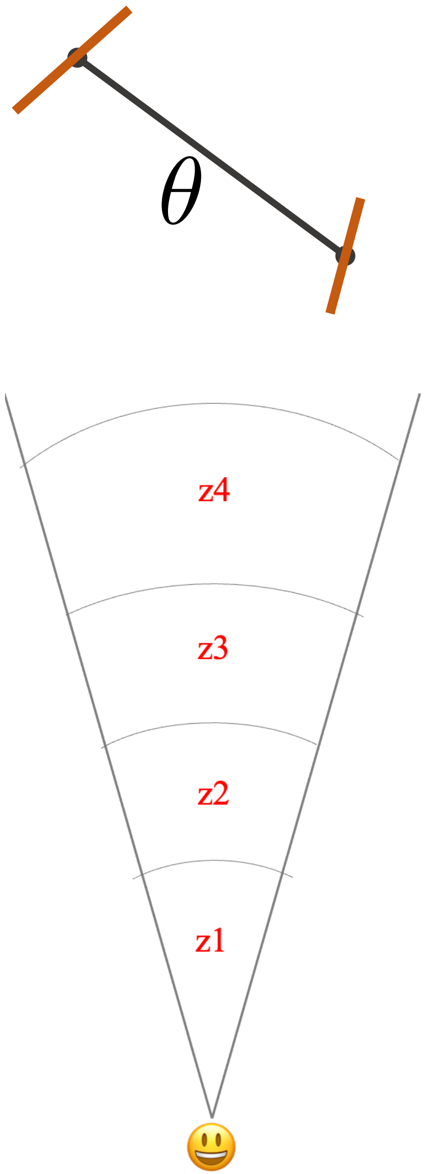
Cosmic shear tomography

Points with error bars: HSC
Solid line: the best-fit ΛCDM model

Li+23; Dalal+23

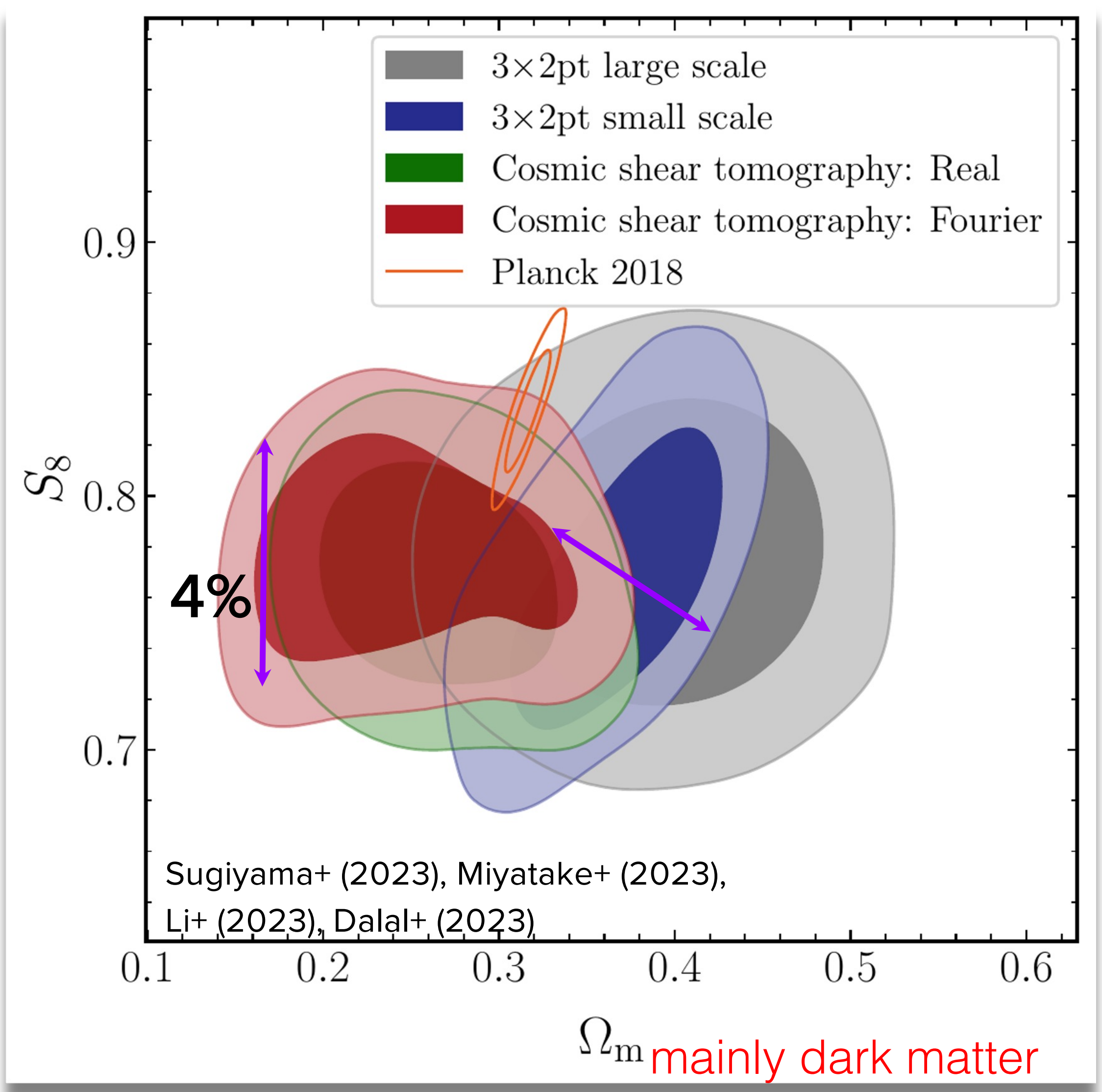
SNR = 26.6

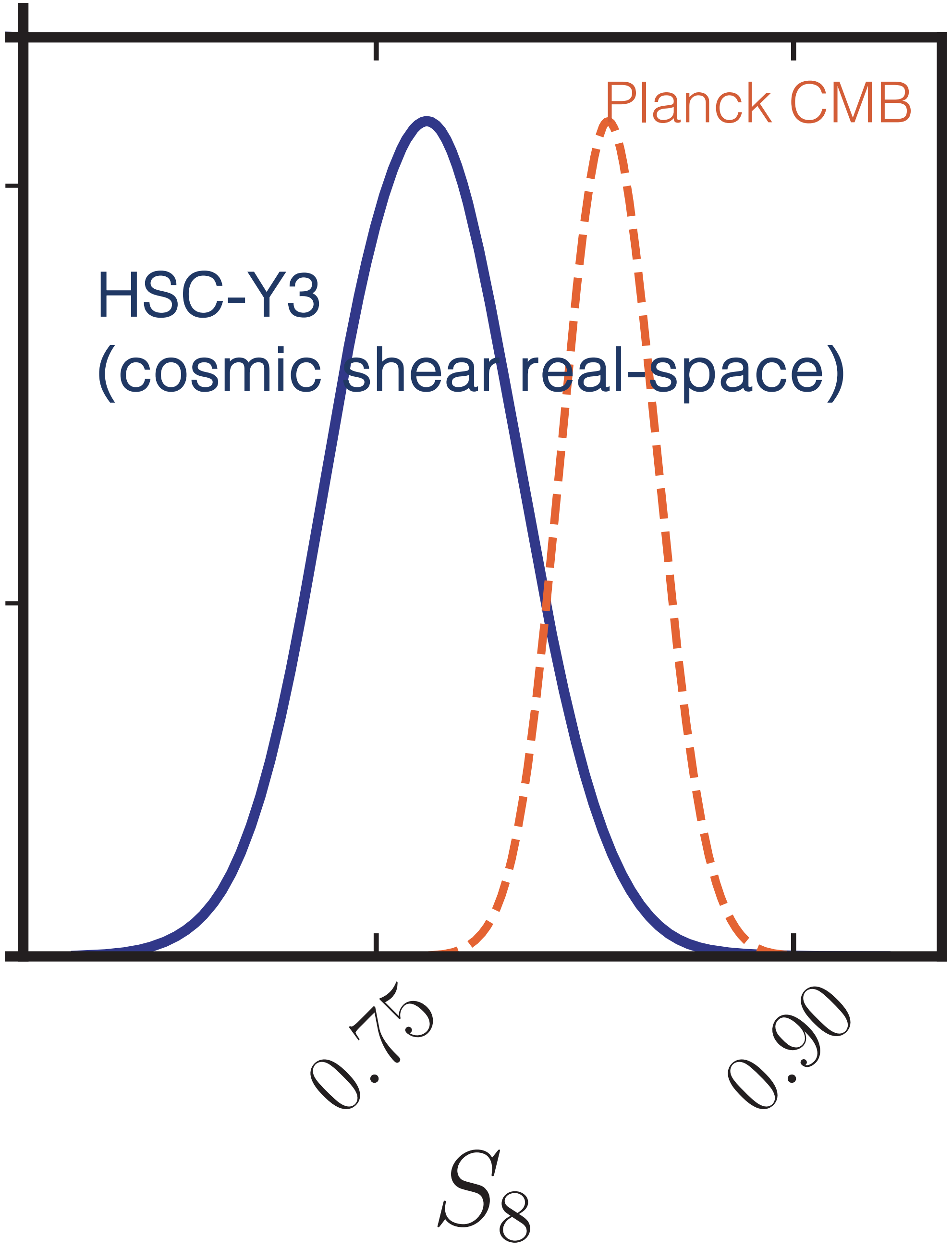




Use "unshaded" range of angular separations (scale cuts) for cosmology inference

Summary of HSC Year 3 co





sult,

e

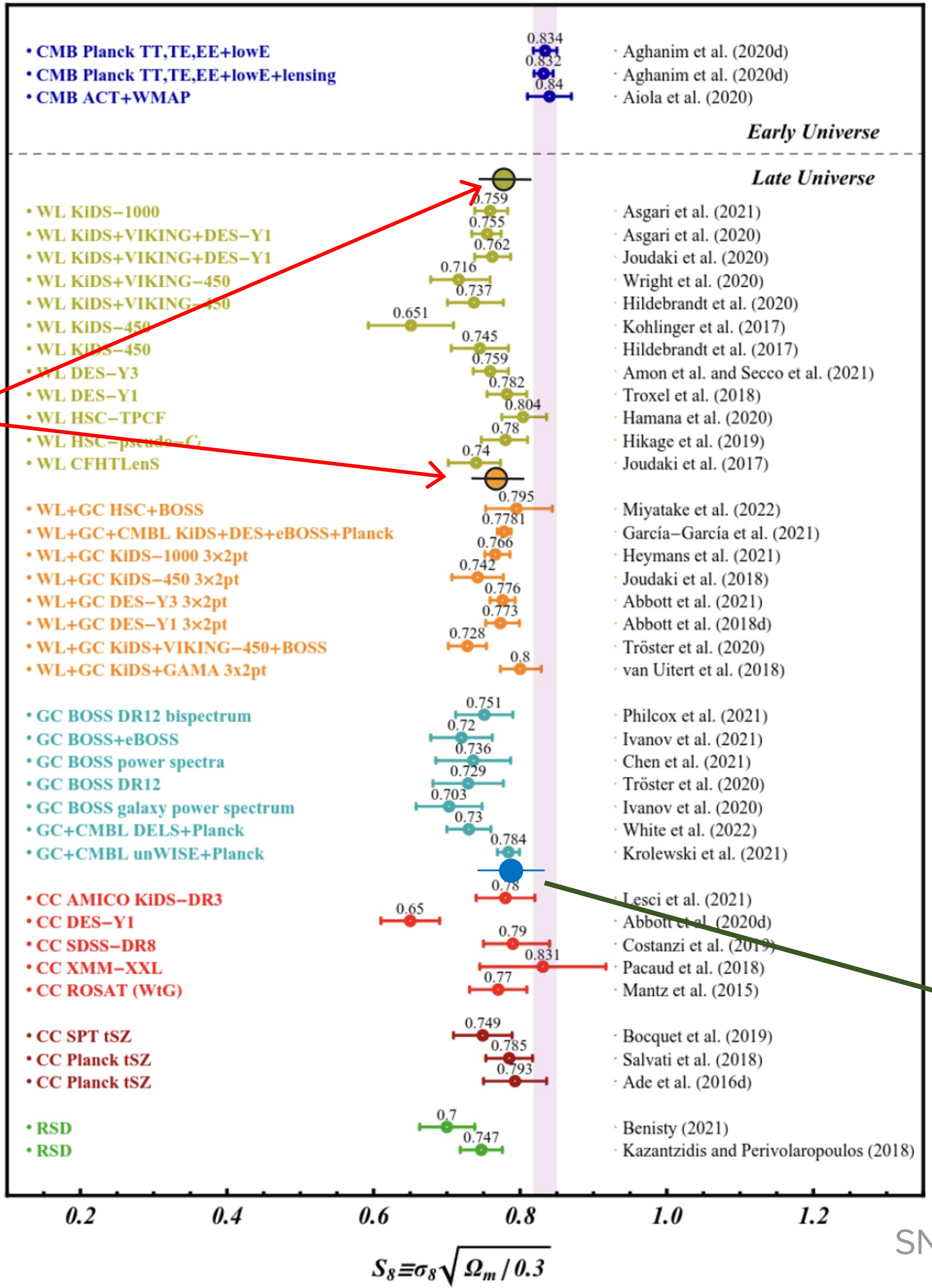
ource

M
rics

S8 tension!

CMB

HSC-Y3



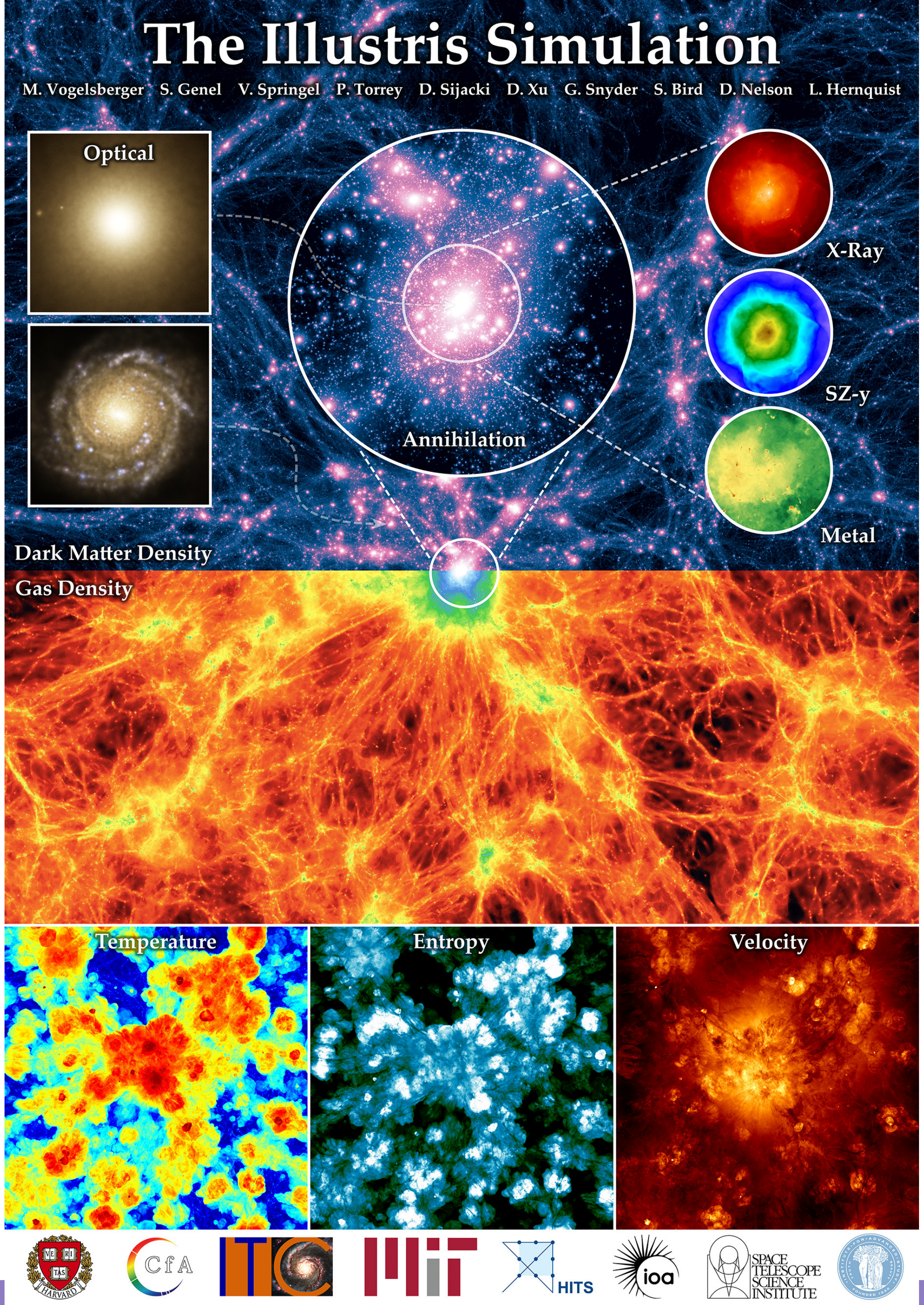
- HSC cosmic shear (real-space)
- HSC cosmic shear (Fourier space)
- HSCxSDSS (3x2pt): mainly from SDSS

Galaxy weak lensing (k~1 h/Mpc, z<1)

Redshift-space galaxy clustering (k~0.1 h/Mpc, z<1)

- Full shape analysis of BOSS with Dark Emulator (Kobayashi, Nishimichi, MT+22)
- Note: the recent CMB lensing results (ACT DR6)

SNOWMASS 2021 Summer study: Abdalla et al. (2022)



The Illustris collboration

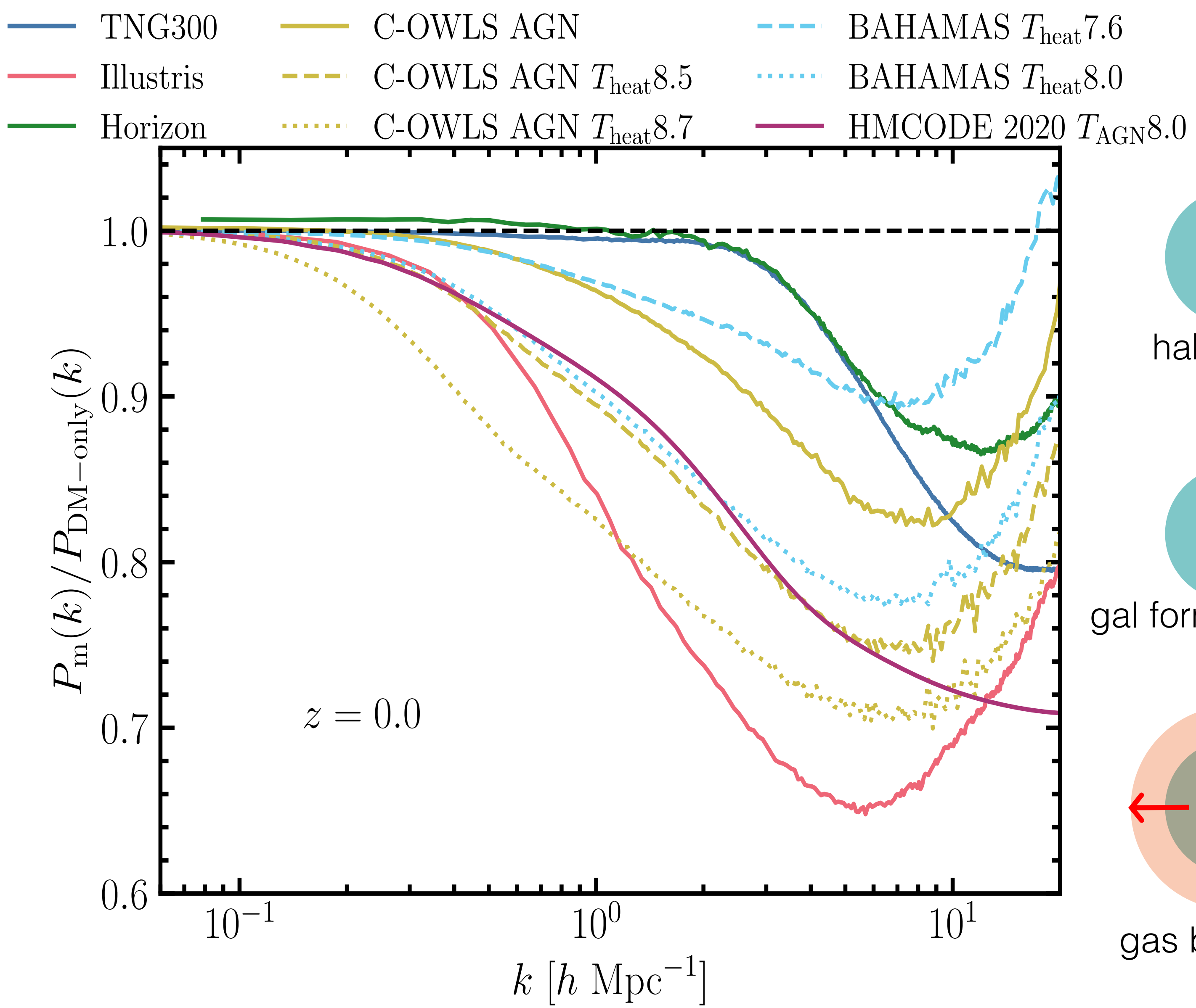
Baryon, baryon, baryon…

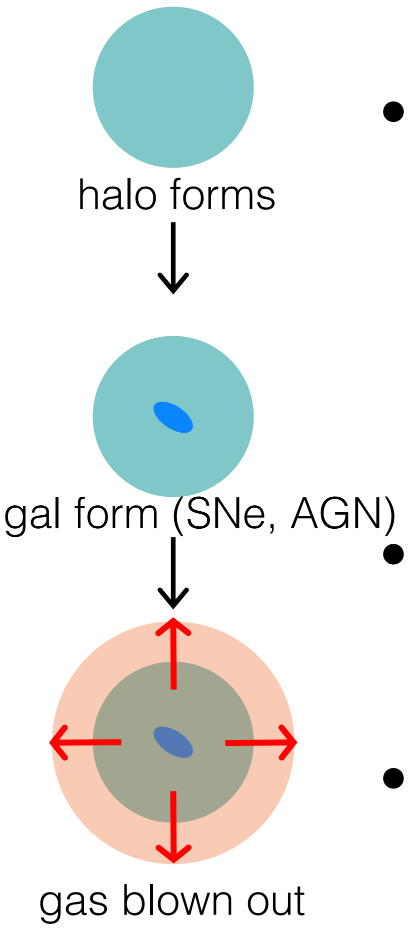
- We are made of baryon! (baryon is VERY important)
- Hence there should be baryon effects, to some level, on the weak lensing observables

See Ryo Terasawa's talk

Ryo Terawasa
(Kavli IPMU)

Baryon… (cont‘d)





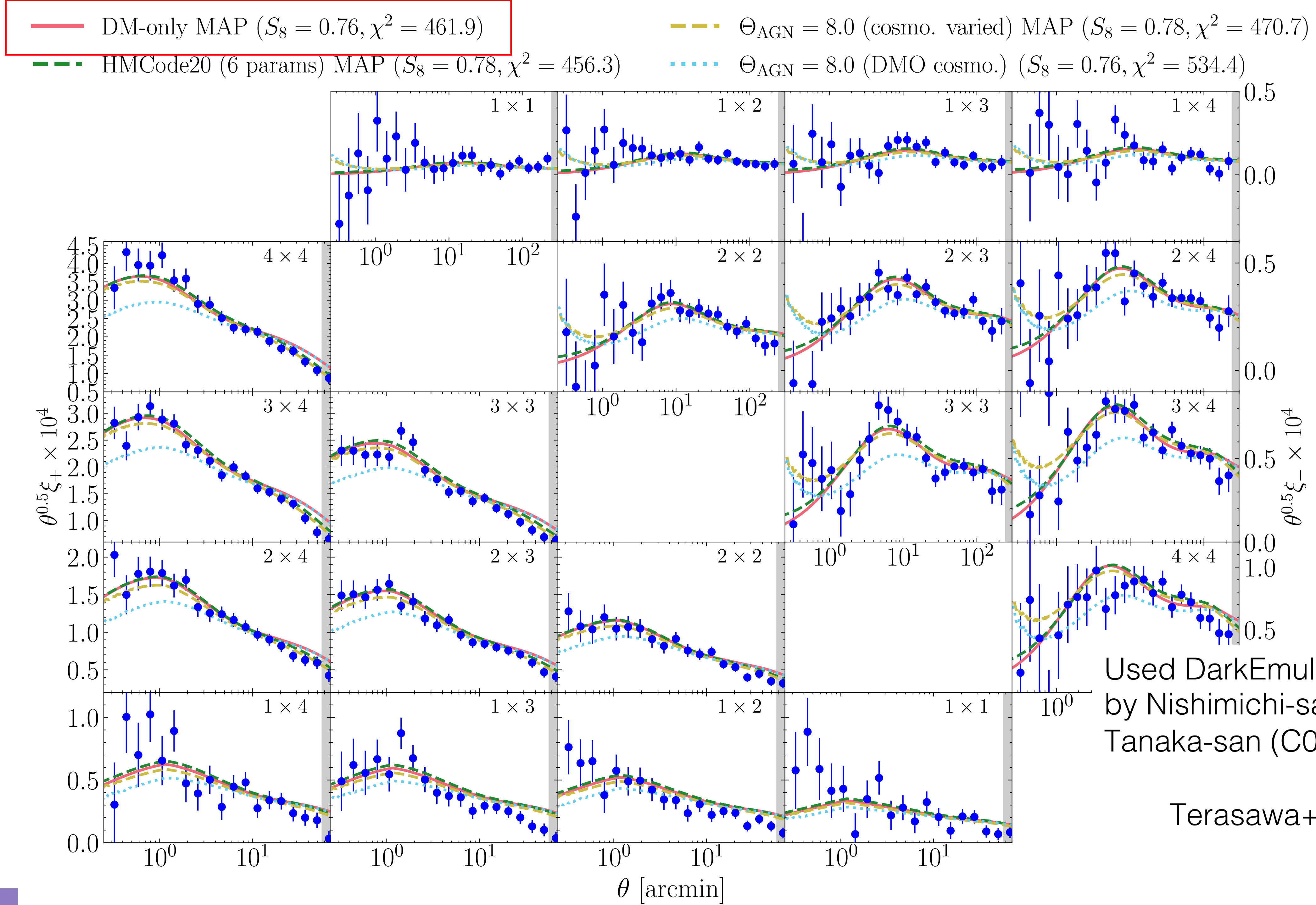
- The baryon effect likely causes a suppression in the matter clustering amplitudes, therefore the cosmic shear amplitude on relevant scales
- The baryon effect is local (from small to large scales)!

$1000\ \mathrm{km/s} \times 1\ \mathrm{Gyr} \sim \mathrm{Mpc}$

$k_{\rm NL} \neq k_{\rm baryon} (k_{\rm NL} < k_{\rm baryon})$

- NL clustering and baryon should have different redshift dependences
- Amon & Efstathiou 22 assumed

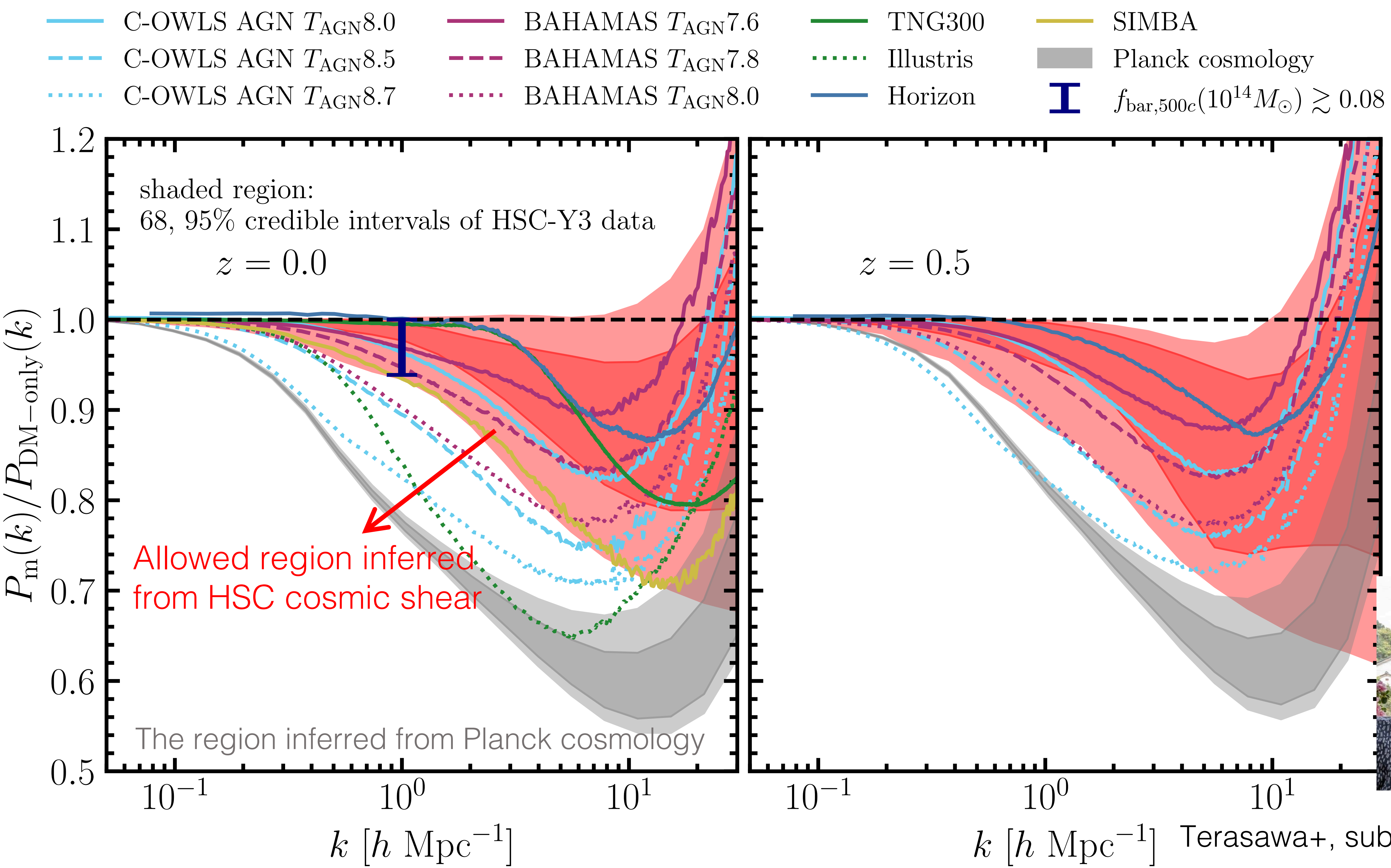
$k_{\rm NL}(z) = k_{\rm baryon}(z)$



Ryo Terasawa
(Kavli IPMU)

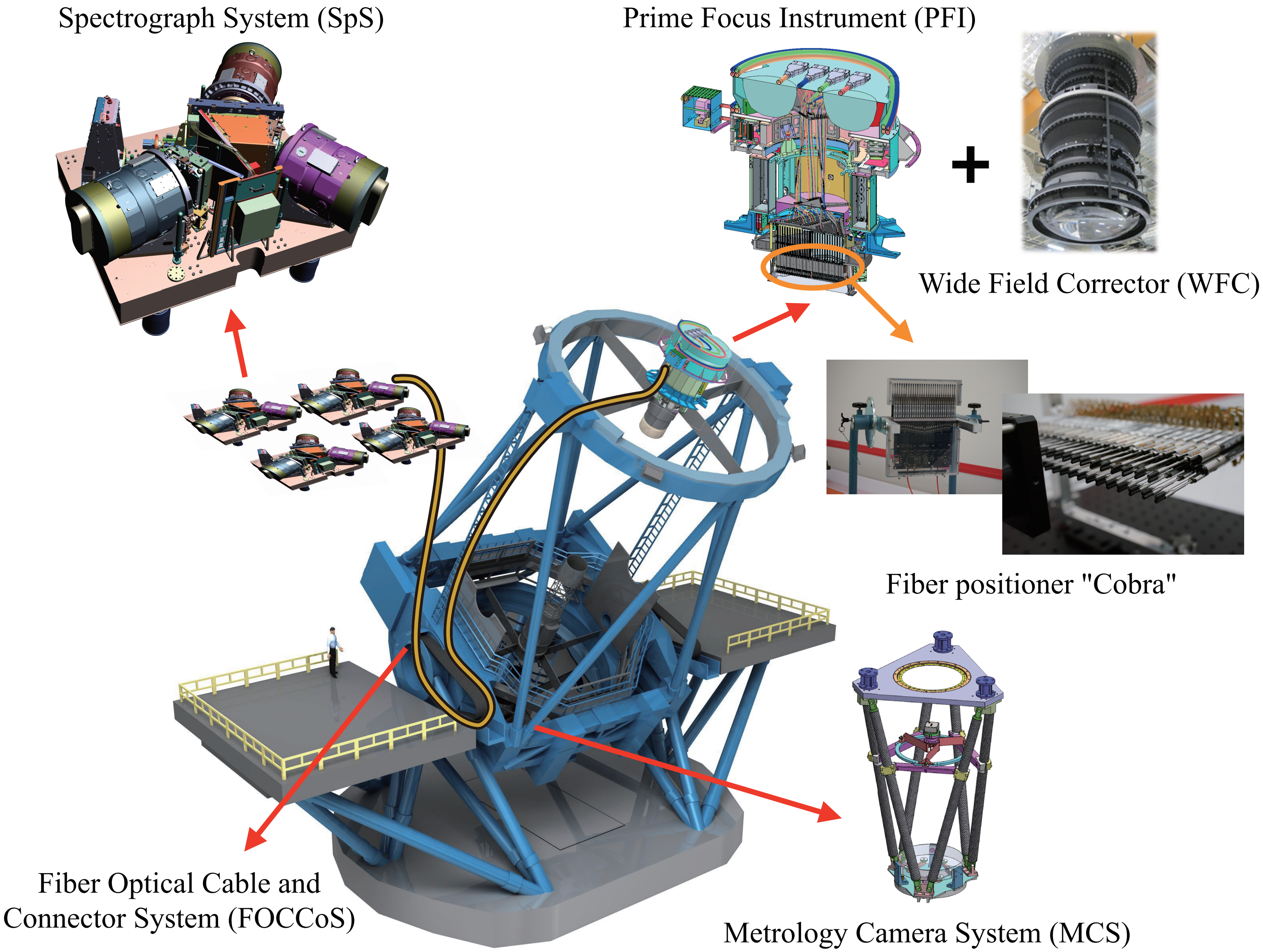
Used DarkEmulator2 developed by Nishimichi-san and Satoshi Tanaka-san (C02)

Terasawa+, submitted soon



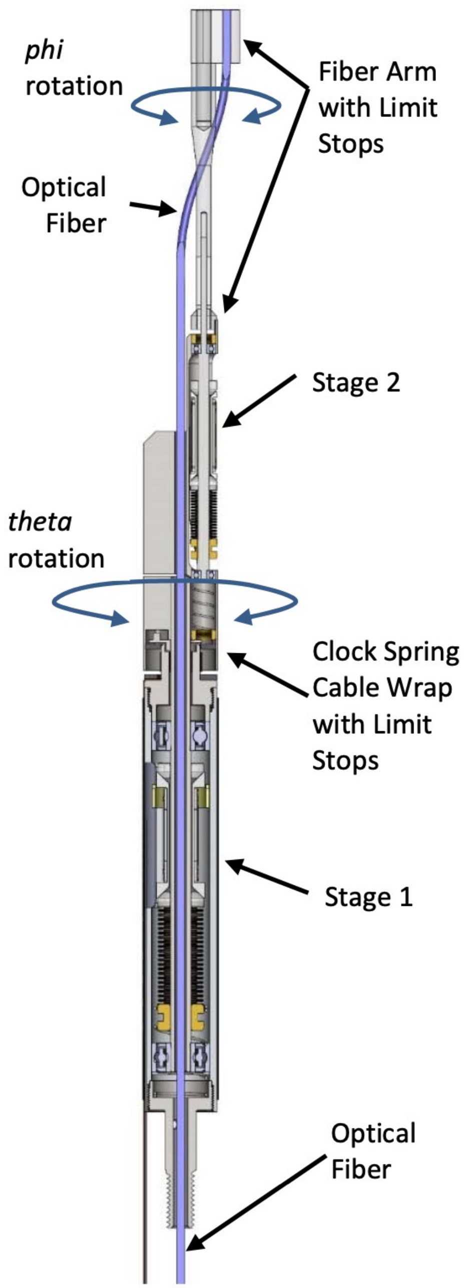
Terasawa+, submitted soon

Subaru Prime Focus Spectrograph

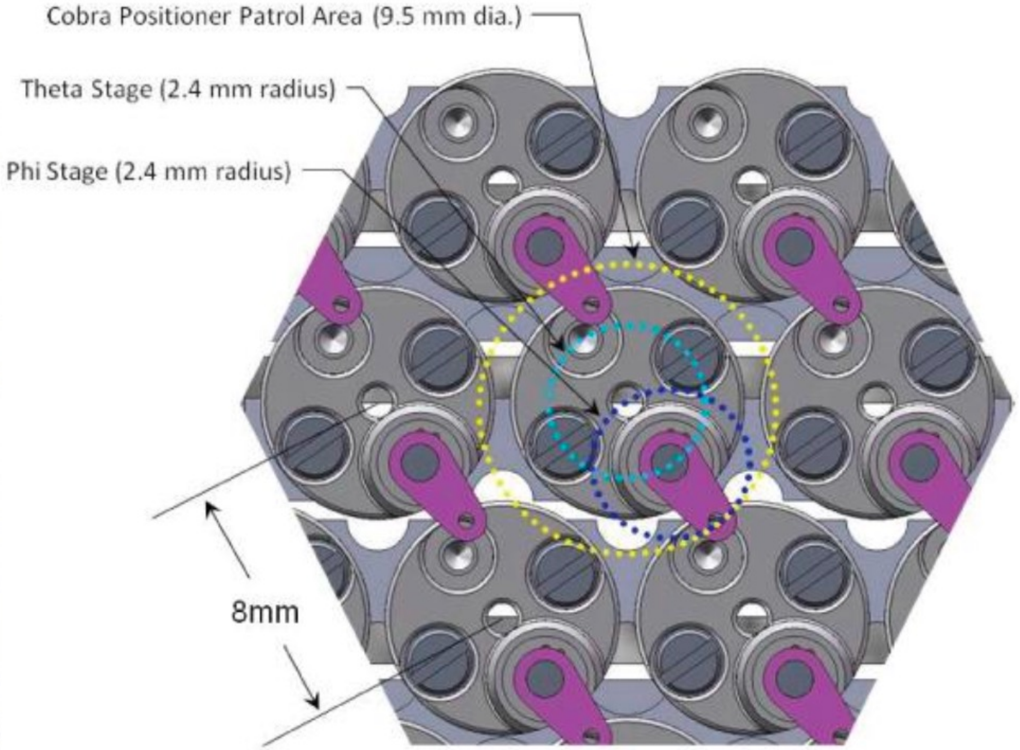


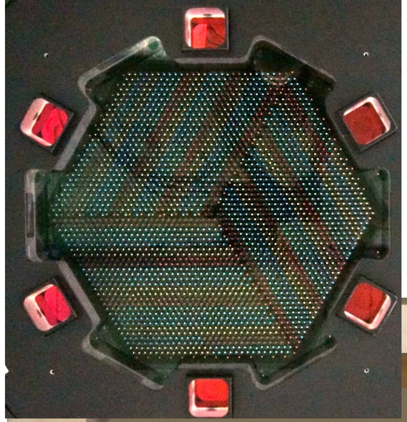
- ~$90M project, being led by Kavli IPMU (PI: Hitoshi Murayama, PM: Naoyuki Tamura, PS: MT)
- Institutes in 6 countries are involved (US, France, Taiwan, Brazil, Germany, China); **MPA/MPE!**
- Mentioned in several places of US Astro2020
- **2400 fibers**, wide field-of-view, [0.38,1.26]nm, 8.2m collecting power
- We will start our large-scale surveys, from early **2024**
- **3 science pillars: Cosmology, Galaxy Evolution, Galactic Archaeology**
- PFS blog: https://pfs.ipmu.jp/blog/ja/

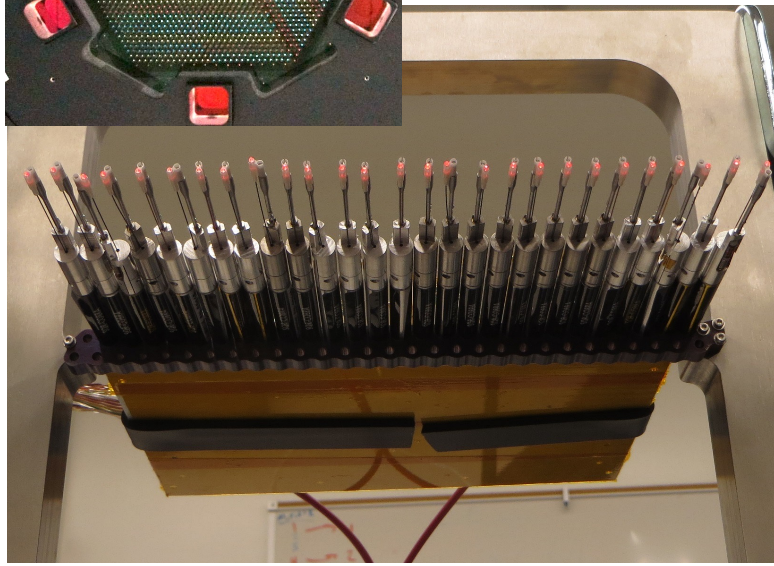
"Cobra" positioner



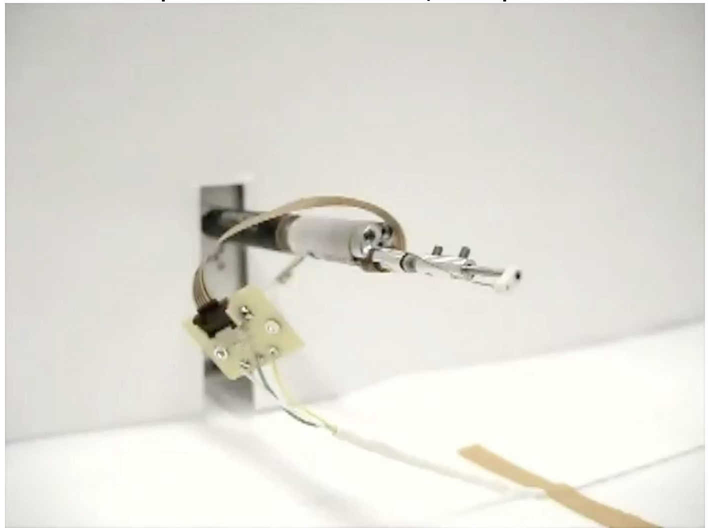
- JPL/Caltech contribution to PFS
- "Critical" component of PFS
- 2394 cobra positioners on the focal plane
- Requirement: ~10μm (0.1") positioning accuracy

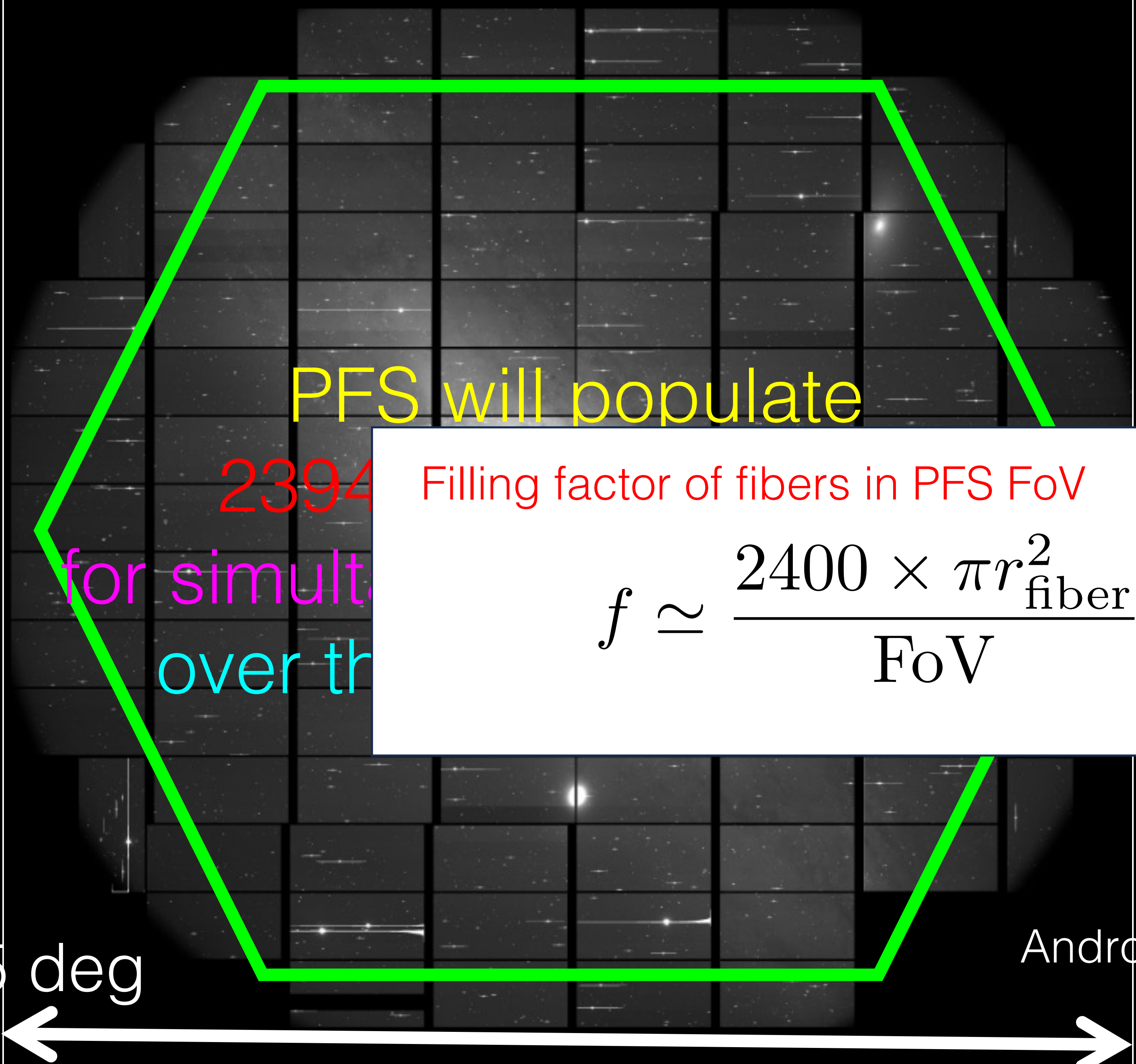






Copra module (57 positioners)





PFS will populate

2394

for simult

over th

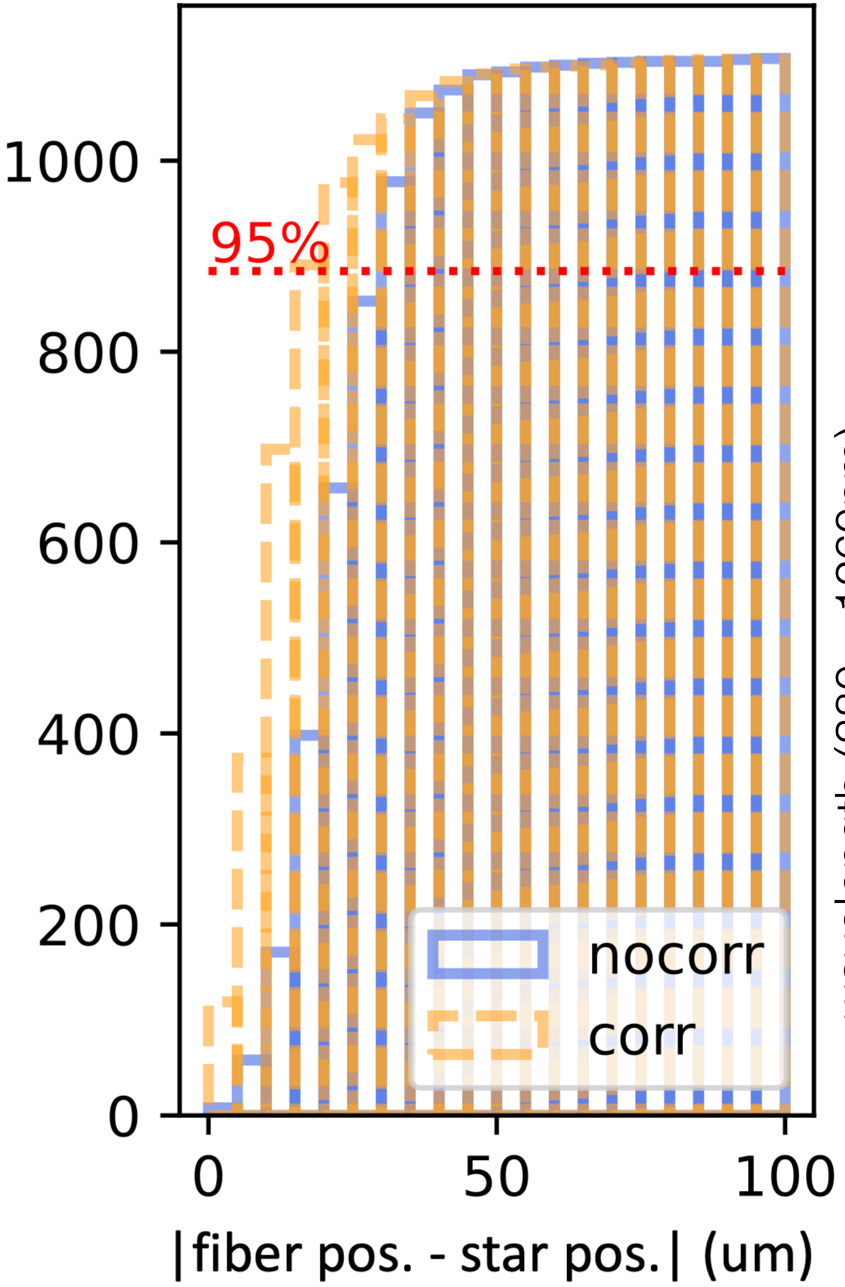
Filling factor of fibers in PFS FoV

$$f \simeq \frac{2400 \times \pi r_{\rm fiber}^2}{\rm FoV} \simeq 0.01\%$$

~1.5 deg

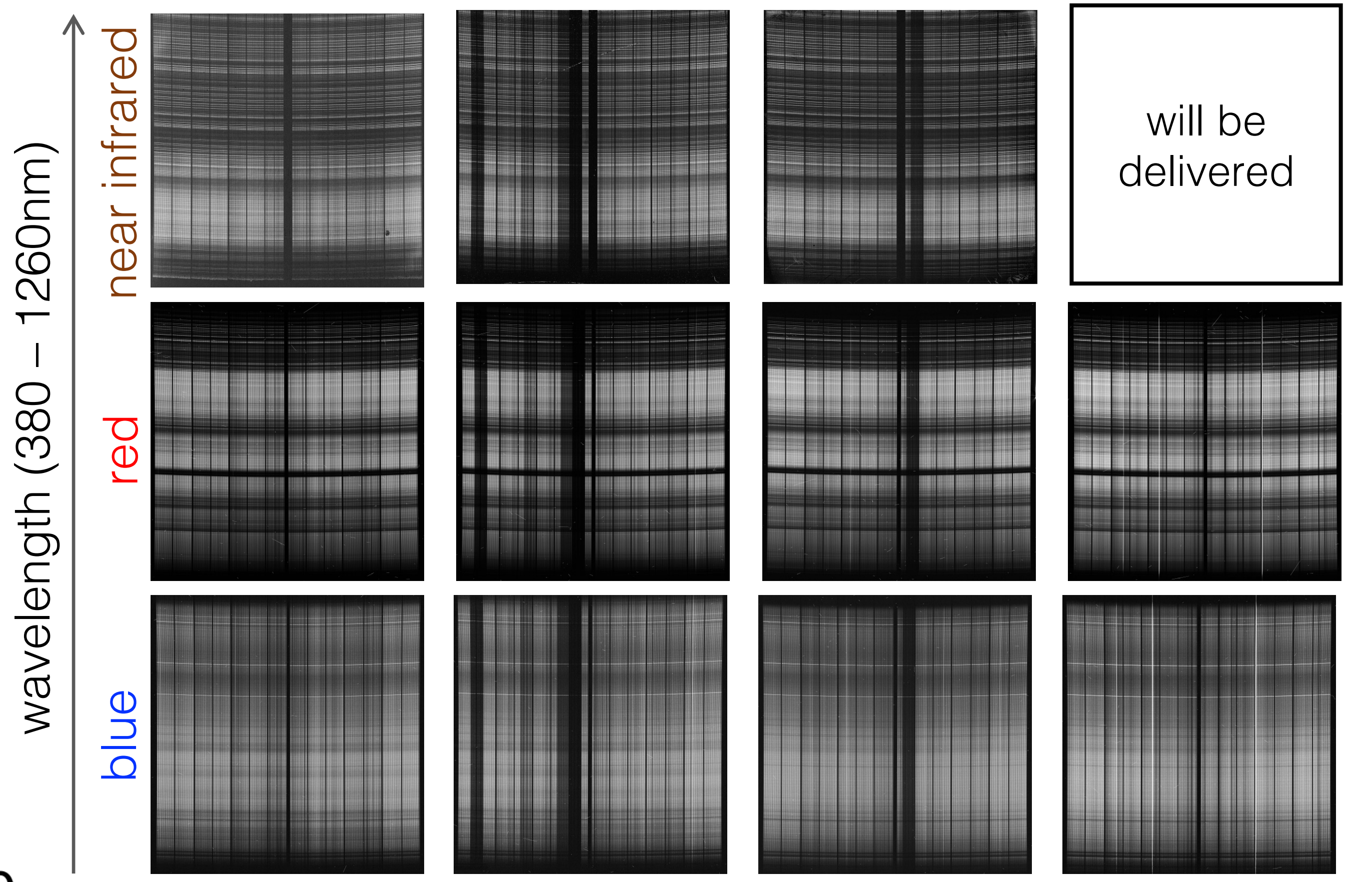
Andromeda Galaxy (M31)

95%: 29.2um (nocorr)
17.7um (corr)



- Now working on the commissioning
- The next commissioning obs from March 8
- PFS survey will start in **2025** (TBD)

Real data of 11 spectrograph modules (Jan, 2024)



~600×4=~2400 fibers

Naoyuki Tamura
(NAOJ)

Yuki Moritani
(NAOJ)

Kiyoto Yabe
(NAOJ)

Summary

- HSC Year 3 cosmic shear cosmology results
  - Junior scientists played a major role
  - The 5 papers selected for Viewpoint in PRD
  - Confirmed the S8 tension – even if the baryonic effect is considered, it seems difficult to explain
- Prime Focus Spectrograph (PFS)
  - Now in the commissioning phase for testing the actual performance of instruments/systems. The next one is from March 8 in HST
  - We plan to begin the 360-night PFS survey in 2025 (finally, 15 years after the PFS project was launched in ~2009)
  - PFS obs. of dwarf galaxies to search for the nature of DM