

Cosmic structure growth and SKA

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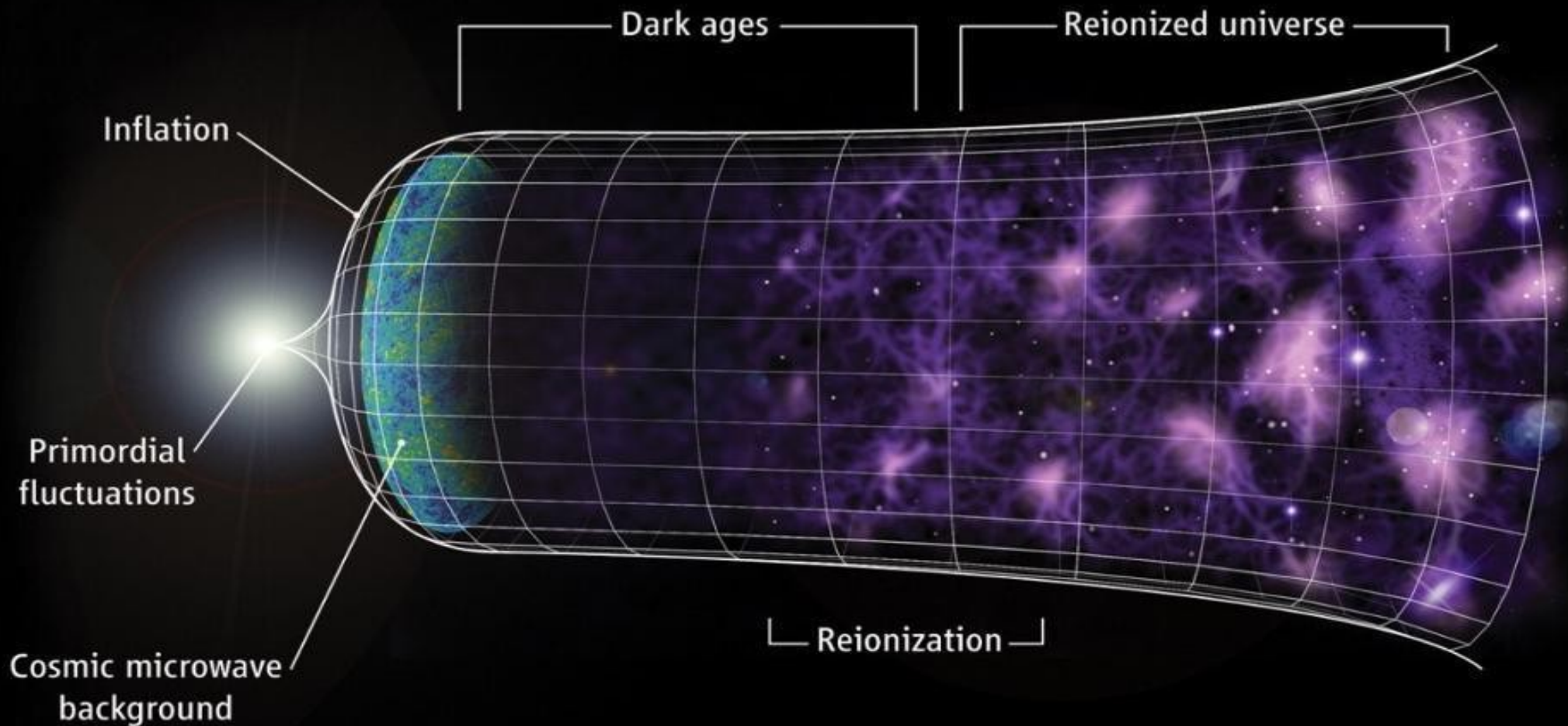
Zakopane (17/06/2024)

Outline

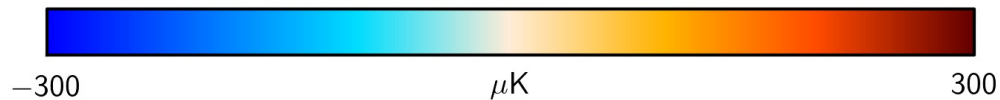
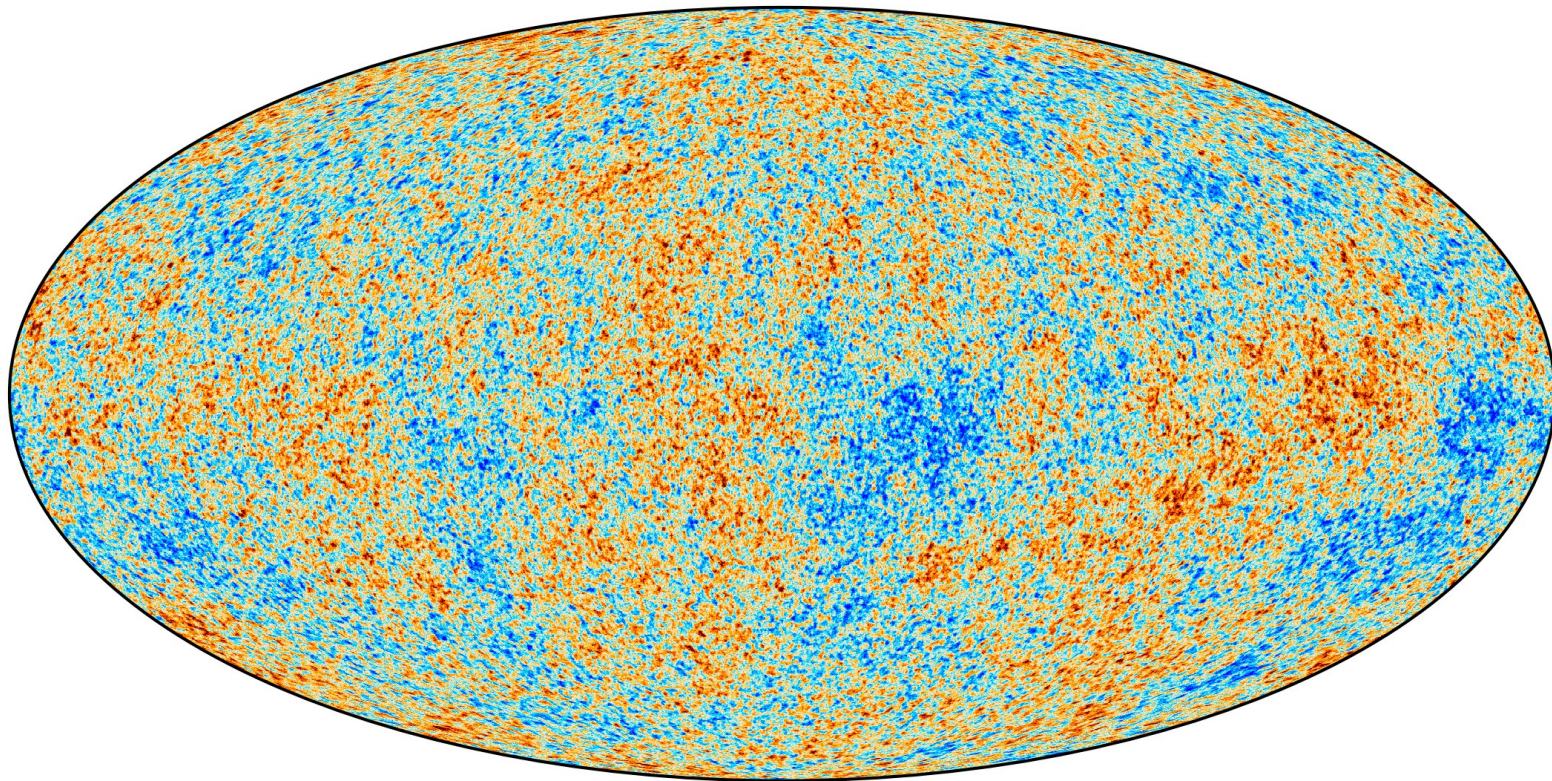
- Standard cosmology
- Cosmic structure growth
- Confronting theory with data
- Prediction from SKA

Standard cosmology

Standard cosmology



Cosmic microwave background



- ★ Isotropic on large scales, but, anisotropic on small scales at the order of $O(-5)$.
- ★ The most standard probe is CMB, the most standard data combination is CBS.

Planck Collaboration, 1807.06209.

ΛCDM

ΛCDM = Cosmological Constant + CDM

6 basic parameters

$\omega_c, \omega_b, n_s, A_s, \theta, \tau$

Actually, many underlying assumptions

Problems

- Cosmological constant problem
- Coincidence problem
- Cosmological tensions
- ...

Cosmic structure growth

Growth index

$$f(a) \equiv d \ln D(a) / d \ln a = \Omega_m^\gamma(a)$$

★ $\gamma=0.55$ corresponds to LCDM. (Li-Min Wang and P. J. Steinhardt, 1998)

$$D(a) \equiv \delta(a) / \delta(a = 1)$$

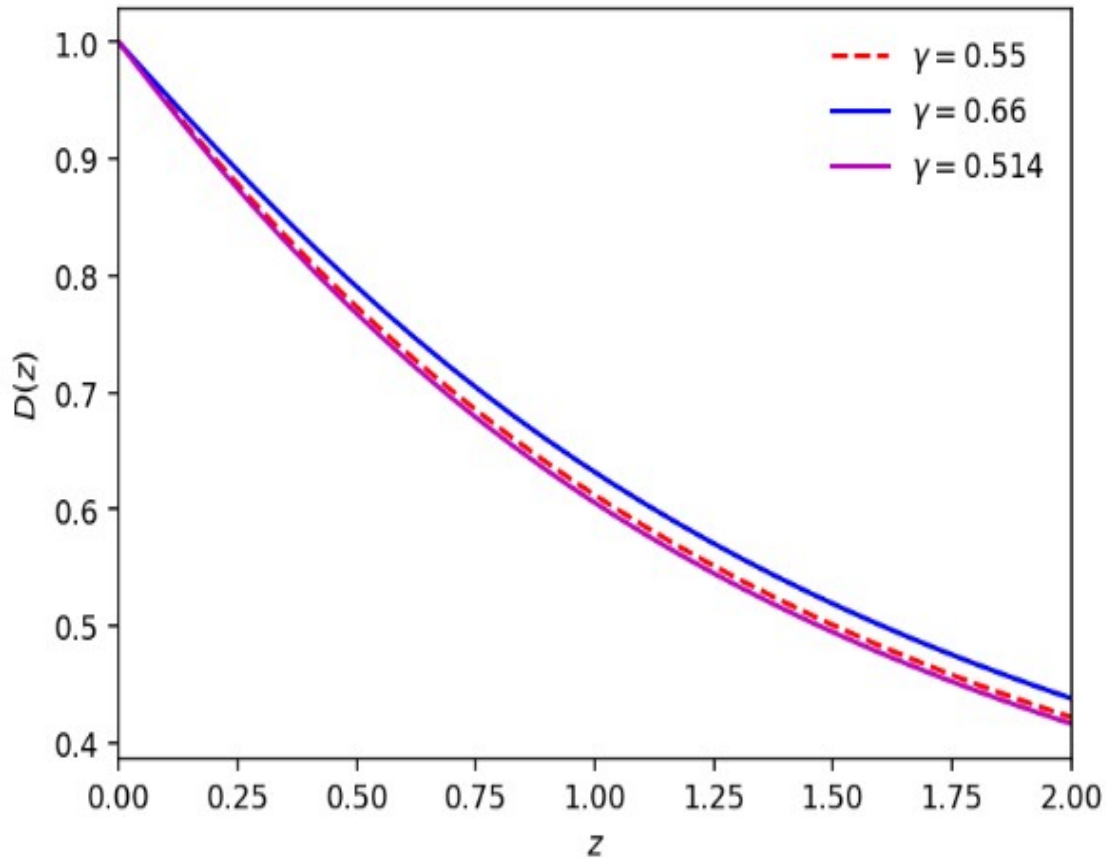
★ $\gamma < 0.55$: enhanced growth

$$D(\gamma, a) = \exp - \left(\int_a^1 da \frac{\Omega_m(a)^\gamma}{a} \right)$$

★ $\gamma > 0.55$: suppressed growth

$$P(\gamma, k, a) = D^2(\gamma, a) P_{\Lambda\text{CDM}}(k, a)$$

Growth index

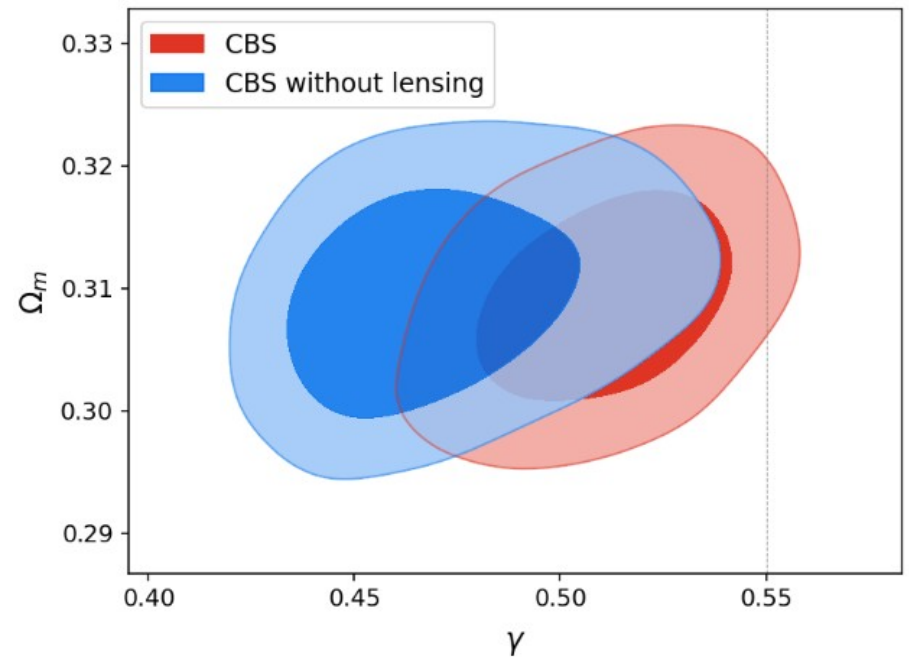
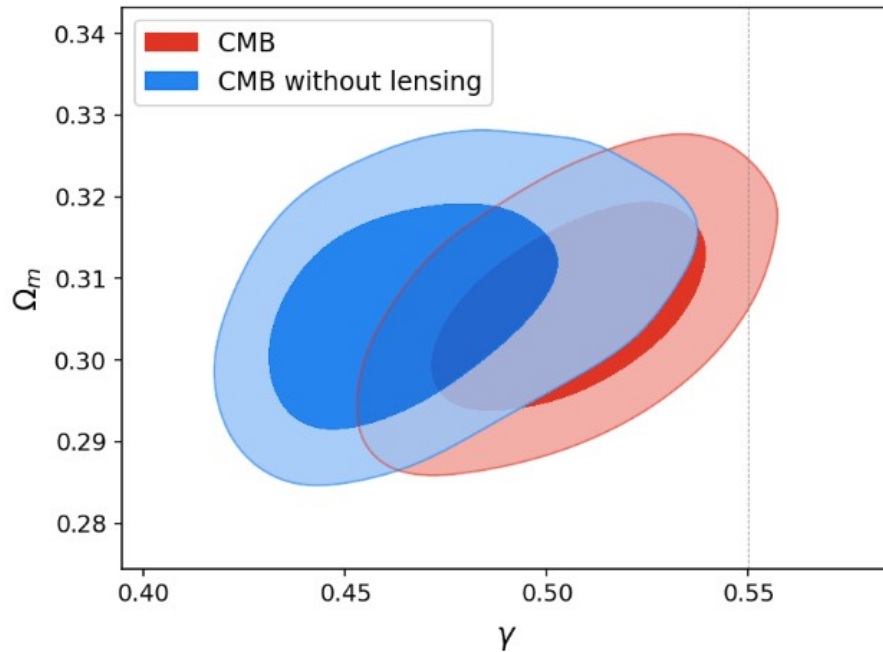


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★ $\gamma < 0.55$: enhanced growth

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CMB

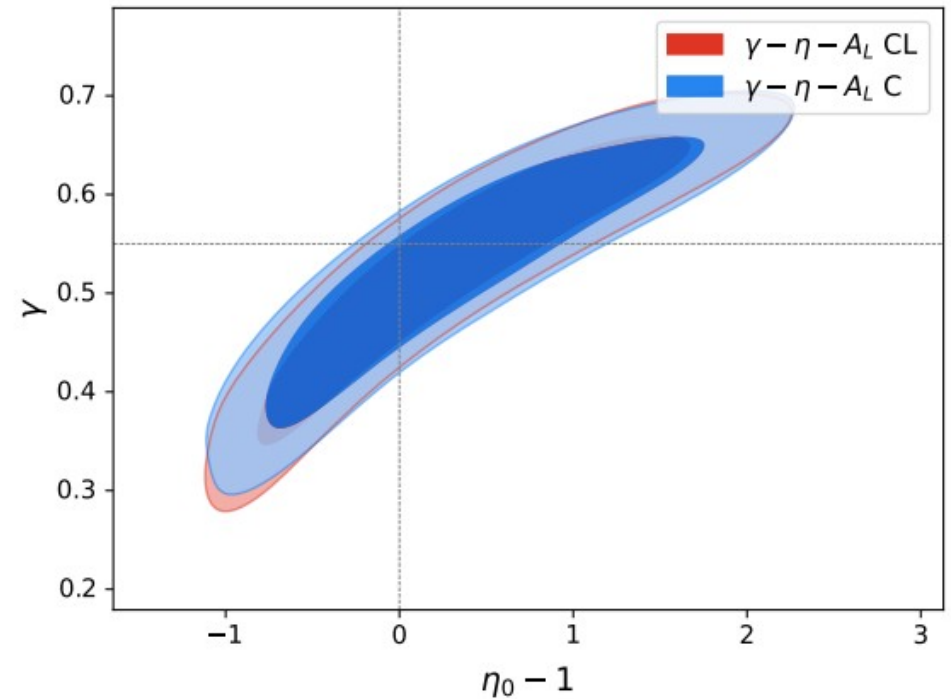
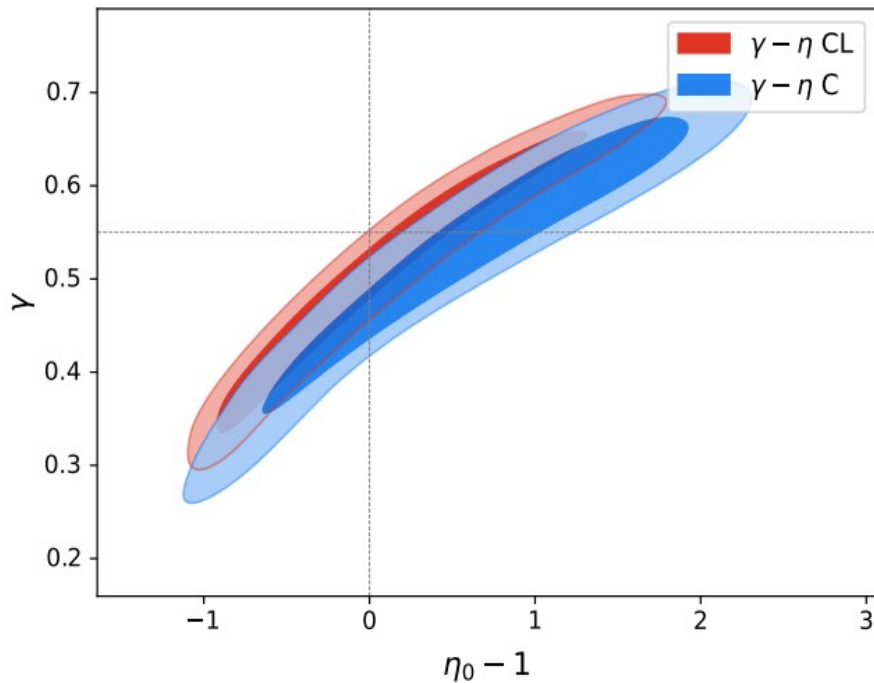


- ★ With CMB lensing, CBS gives $0.511^{+0.022}_{-0.019}$, which is a 2σ signal.
- ★ Without CMB lensing, CBS gives $0.470^{+0.017}_{-0.029}$, which is a 3σ evidence.
- ★ Planck CMB lensing data can reduce the significance of enhanced structure growth.

CMB

$$ds^2 = -(1 + 2\Phi)dt^2 + a^2(1 - 2\Psi)dx^2 \quad -k^2\Phi(k, a) \equiv 4\pi Ga^2\mu(k, a)\rho(k, a)\delta(k, a)$$

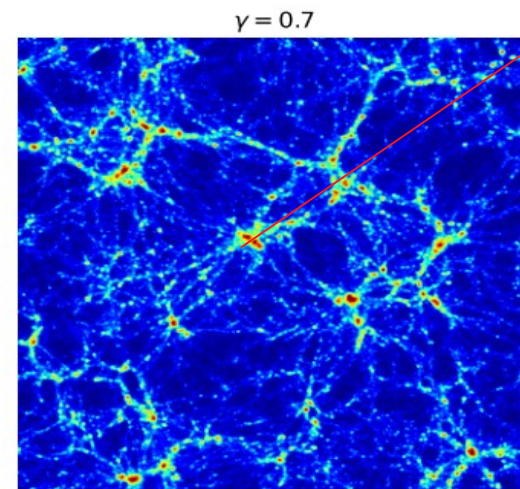
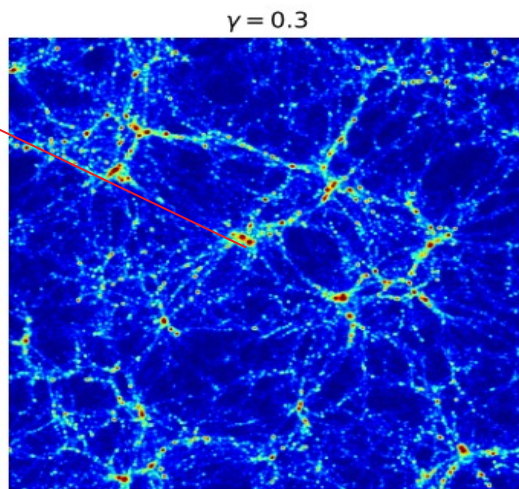
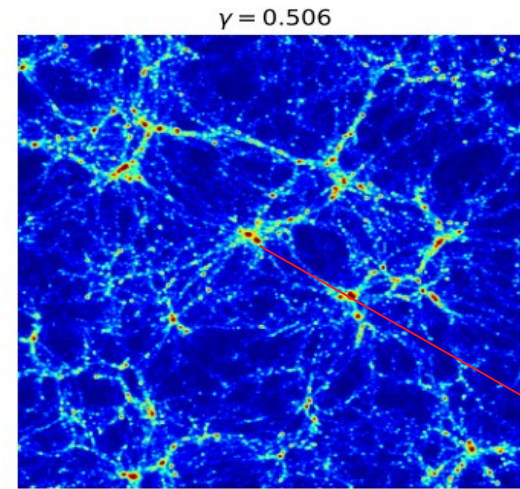
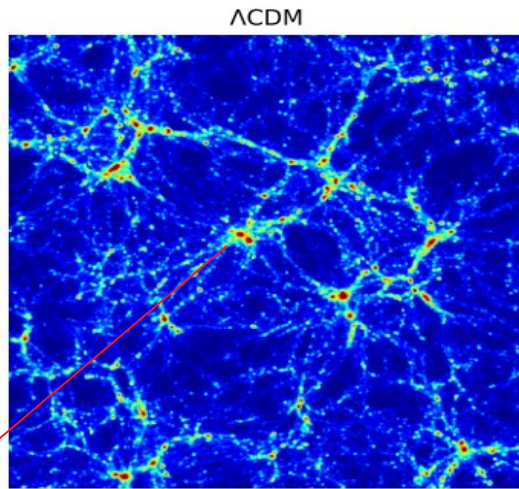
$$\eta(k, a) \equiv \Psi(k, a)/\Phi(k, a) \quad \mu = \frac{2}{3}\Omega_m(a)^{\gamma-1} \left[\Omega_m(a)^\gamma + 2 - 3\gamma + \frac{3}{2}(\gamma - 1)\Omega_m(a) \right]$$



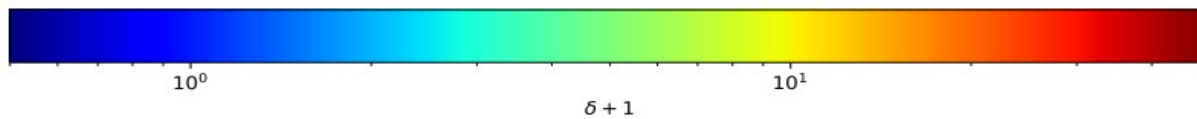
- ★ The signal **disappears** when considering both anisotropic stress and CMB lensing amplitude.
- ★ It is too early to claim the evidence of enhanced structure growth. (N.Nguyen et al. 2302.01331)

Cosmological simulations

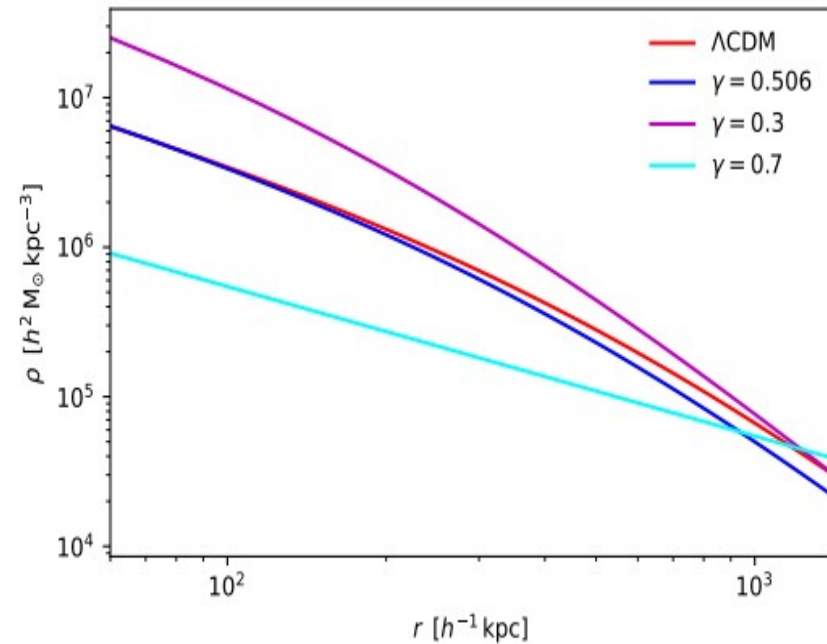
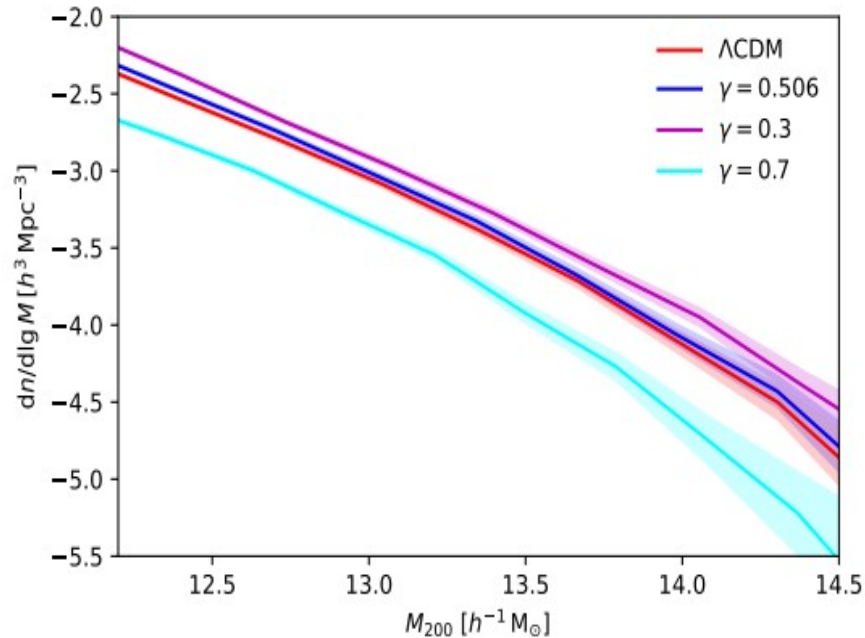
Different



Different



Statistical analysis of simulations



When $\gamma < 0.55$, halo mass function is obviously larger than that in ΛCDM , and has more halos in the whole halo mass range.

For $\gamma = 0.3$, the halos will be more compact than in ΛCDM . For best fit $\gamma = 0.506$ from CMB-only constraint, halos have lower densities than in ΛCDM at large radius.

SKA forecast

SKA



A composite image of the future SKA telescopes, blending what already exists on site with artist's impressions.

SKA



The existing antennas of South Africa's MeerKAT radio telescope (on the right; actual photo) will be incorporated into SKA-Mid (the SKA dishes are on the left in this composite image)

HI galaxy redshift survey

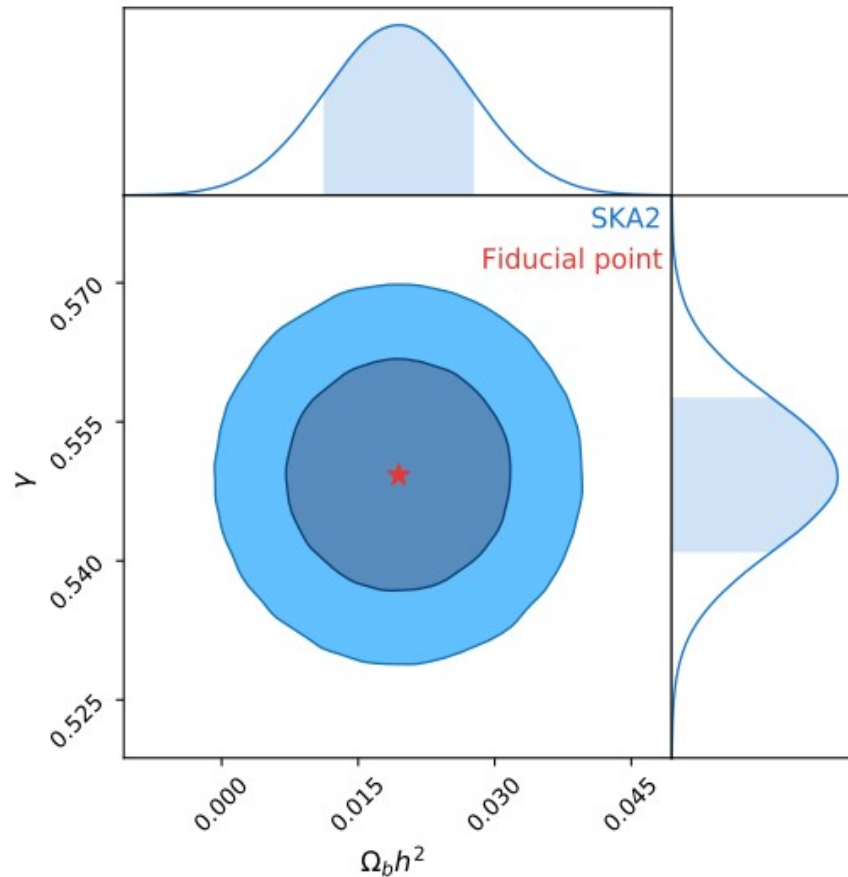
$$P_g(\gamma, k, z) = [b(z) + f\xi^2]^2 e^{-\frac{[k\sigma_{\text{NL}}(z, \xi)]^2}{2}} P(\gamma, k, z)$$

$$F_{\alpha\beta} = \frac{1}{2} \int \frac{d^3k}{(2\pi)^3} V_{\text{eff}}(k) \left(\frac{\partial \ln S_T}{\partial p_\alpha} \frac{\partial \ln S_T}{\partial p_\beta} \right)$$

Here we use the HI galaxy redshift survey SKA Phase 2 to forecast.

SKA2 is expected to achieve an rms flux sensitivity $S \approx 5 \mu\text{Jy}$ covering a sky area of 30000 deg^2 for 10000 hours. SKA2 aims to produce a catalogue of one billion HI galaxies in the redshift range $z \in (0.18, 1.84)$, Which is far beyond any planned optical or near infrared experiments when $z \in (0, 1.4)$.

Strong constraining power



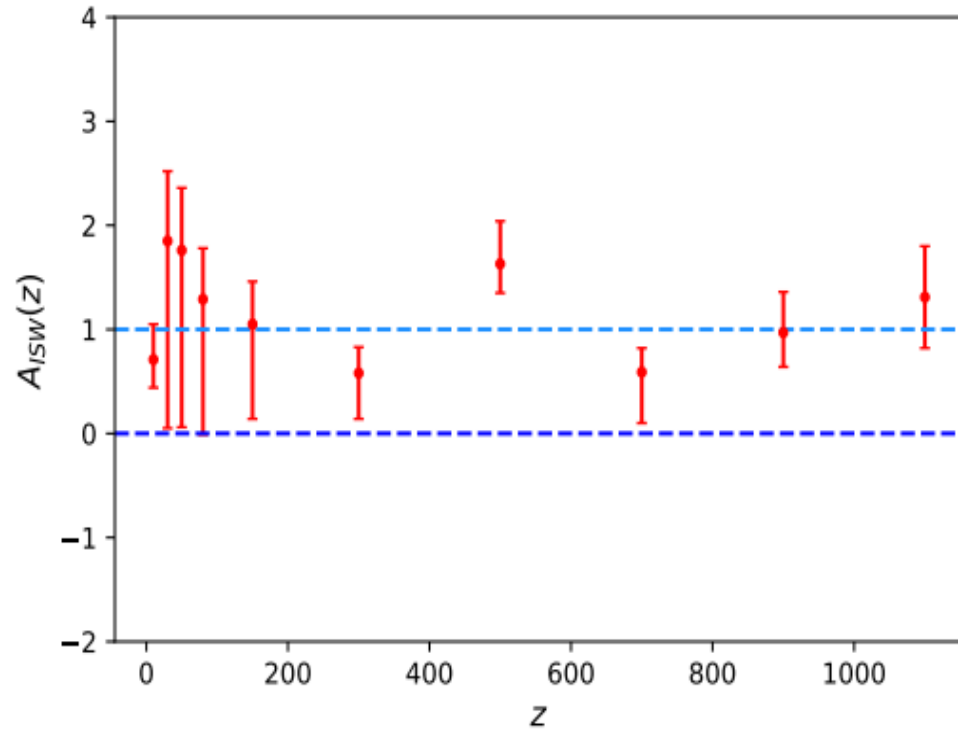
Parameters	SKA2	Planck
$\sigma(\gamma)$	0.0083	0.022
$\sigma(H_0)$	0.19	0.54
$\sigma(\sigma_8)$	0.00079	0.006

- ★ Assuming perfect foreground subtraction.
- ★ Optimistically theoretical limit from SKA2.

Your takeaways

- ★ Current data can't give any signal of enhanced or suppressed growth of cosmic structure when considering CMB lensing amplitude and anisotropic stress of relativistic species simultaneously.
- ★ Cosmological simulations is consistent with our simple theoretical prediction.
- ★ SKA2 can improve the constraining power on the growth index parameter by a factor of three relative to Planck.

A new punch on the nose of LCDM



In light of Planck CMB data, we find a 2σ deviation from LCDM at redshift $z = 500$ using tomographic ISW effect.

DW, Olga Mena, 2402.18248

谢谢！
Thanks!
Gracias!