Cosmic structure growth and SKA

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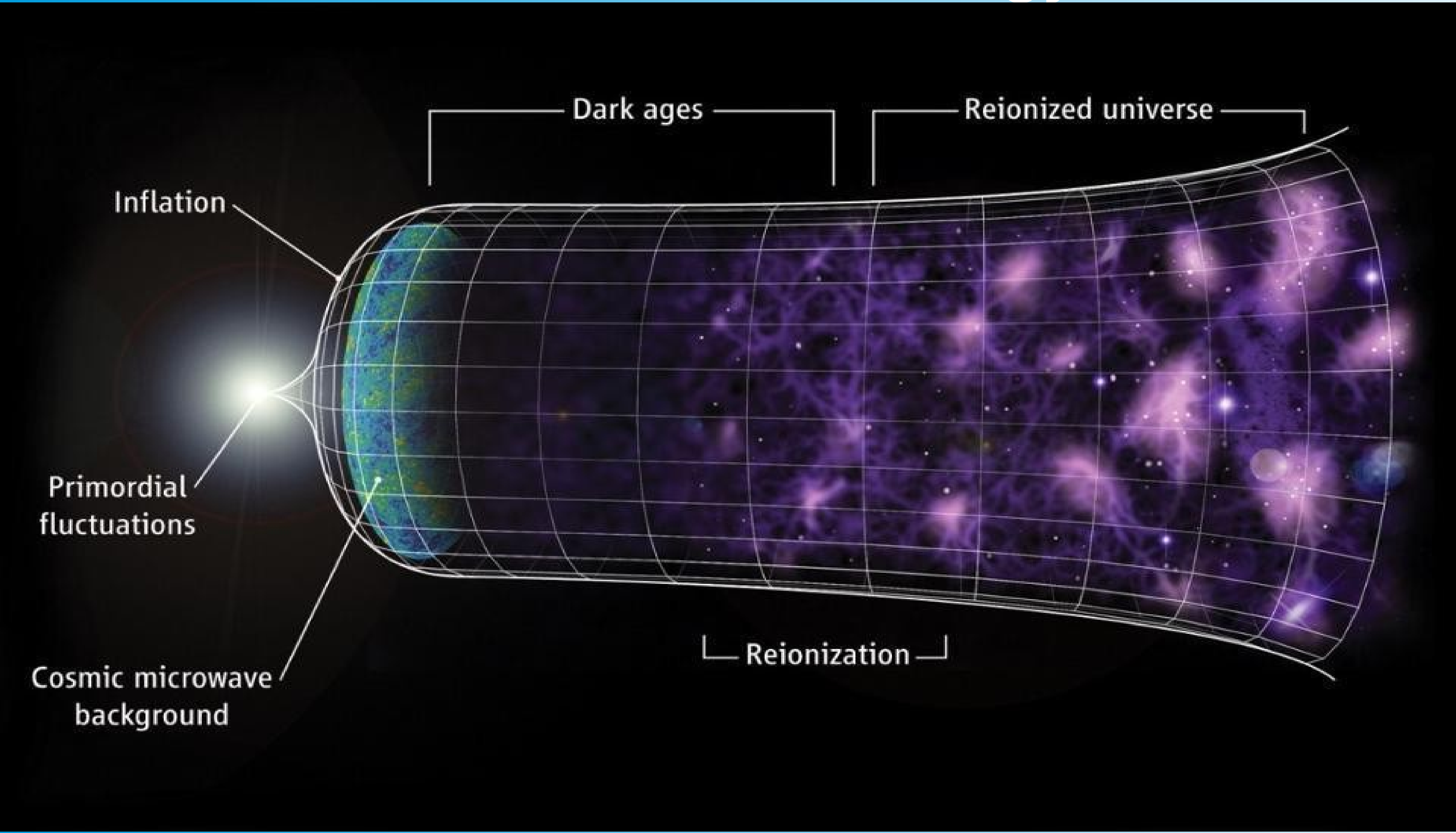
Les Diablerets (20/03/2024)

Outline

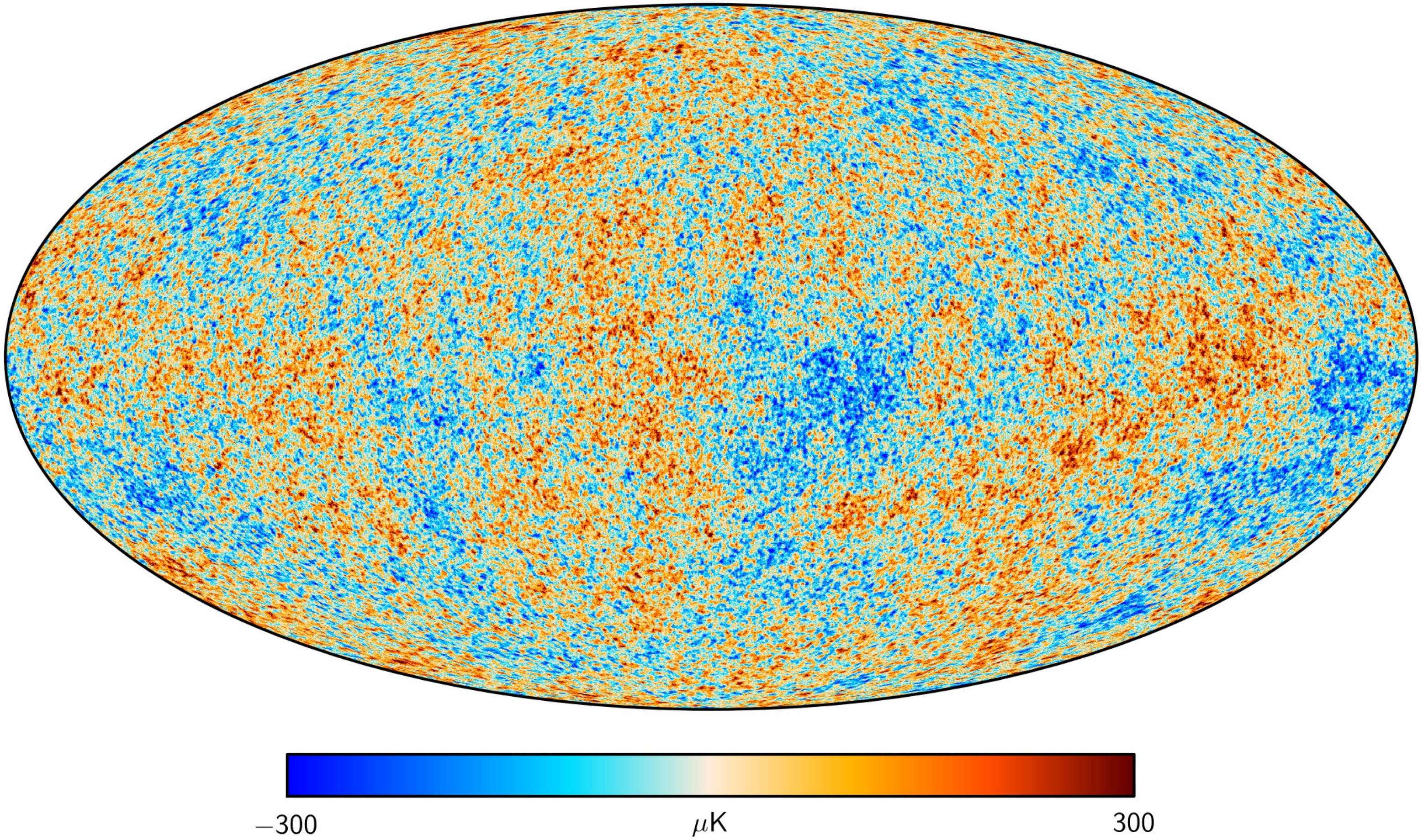
- Standard cosmology
- Cosmic structure growth
- Confronting theory with data
- Prediction from SKA

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.

LCDM

LCDM = Cosmological Constant + CDM

6 basic parameters

ω_c, ω_b, n_s, A_s, θ, τ

Actually, many underlying assumptions

Problems

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

Cosmic structure growth

Growth index

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

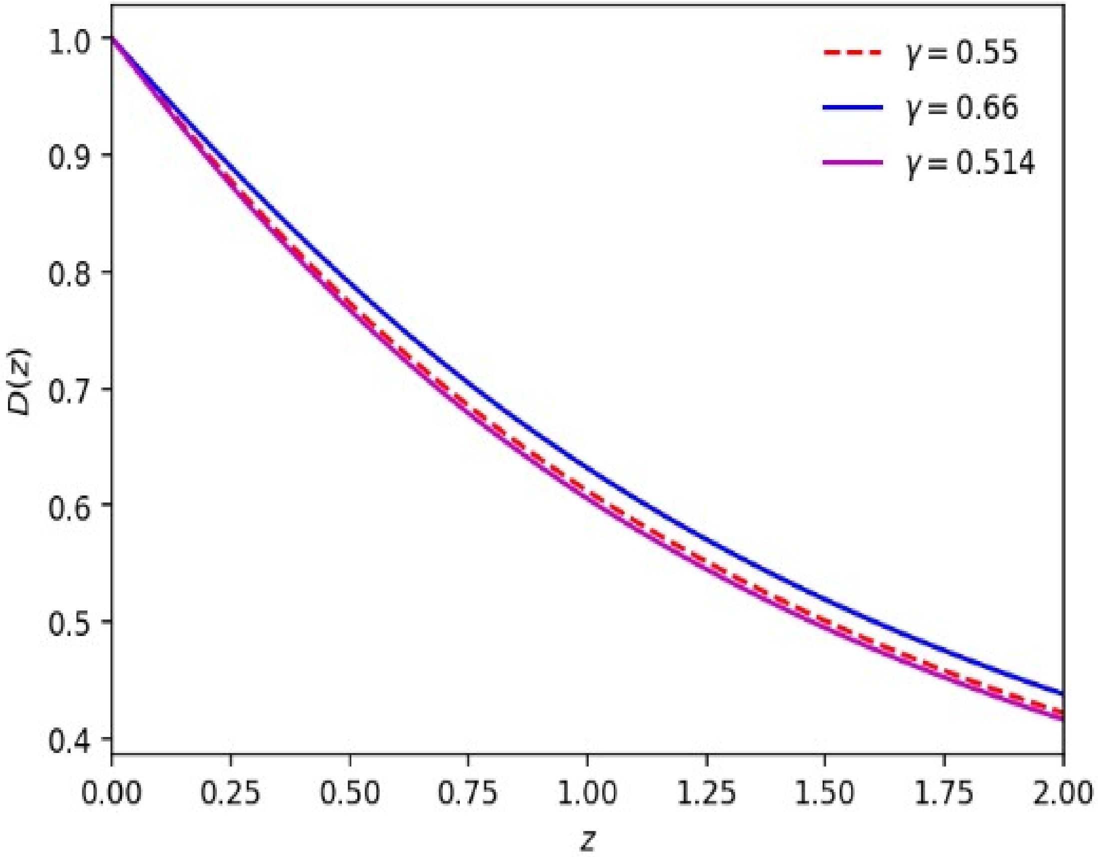
$$D(a) \equiv \delta(a)/\delta(a=1)$$

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

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

- $\gamma=0.55$ corresponds to LCDM. (Li-Min Wang and P. J. Steinhardt, 1998)
- $\gamma<0.55$: enhanced growth
- $\gamma>0.55$: suppressed growth

Growth index



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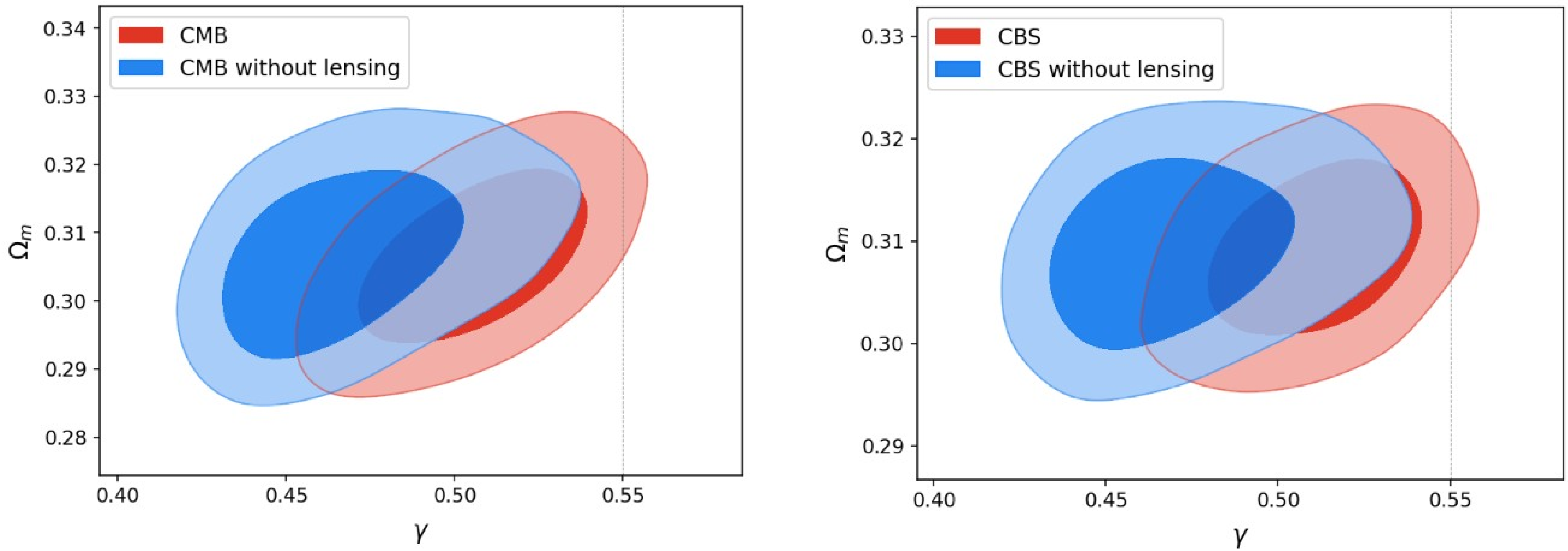
CMB

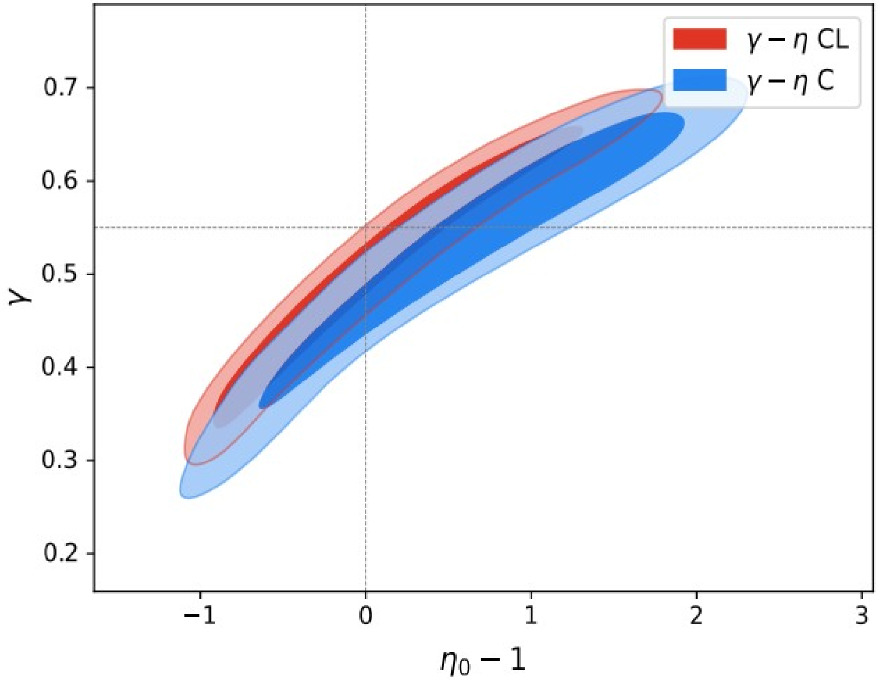


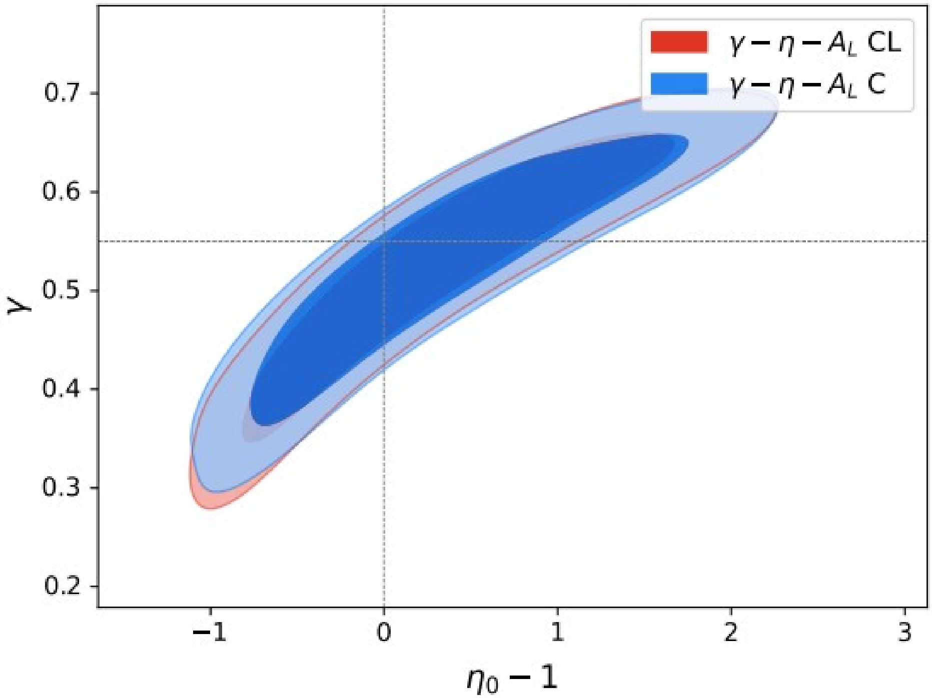
- CMB+BAO+SNe Ia gives $0.511^{+0.022}_{-0.019}$, which is a 2 σ signal.
- Without CMB lensing, CBS gives $^{+0.017}_{-0.029}$, which is a 3 σ evidence.
- Planck CMB lensing data can reduce the significance of enhanced structure growth.

CMB

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

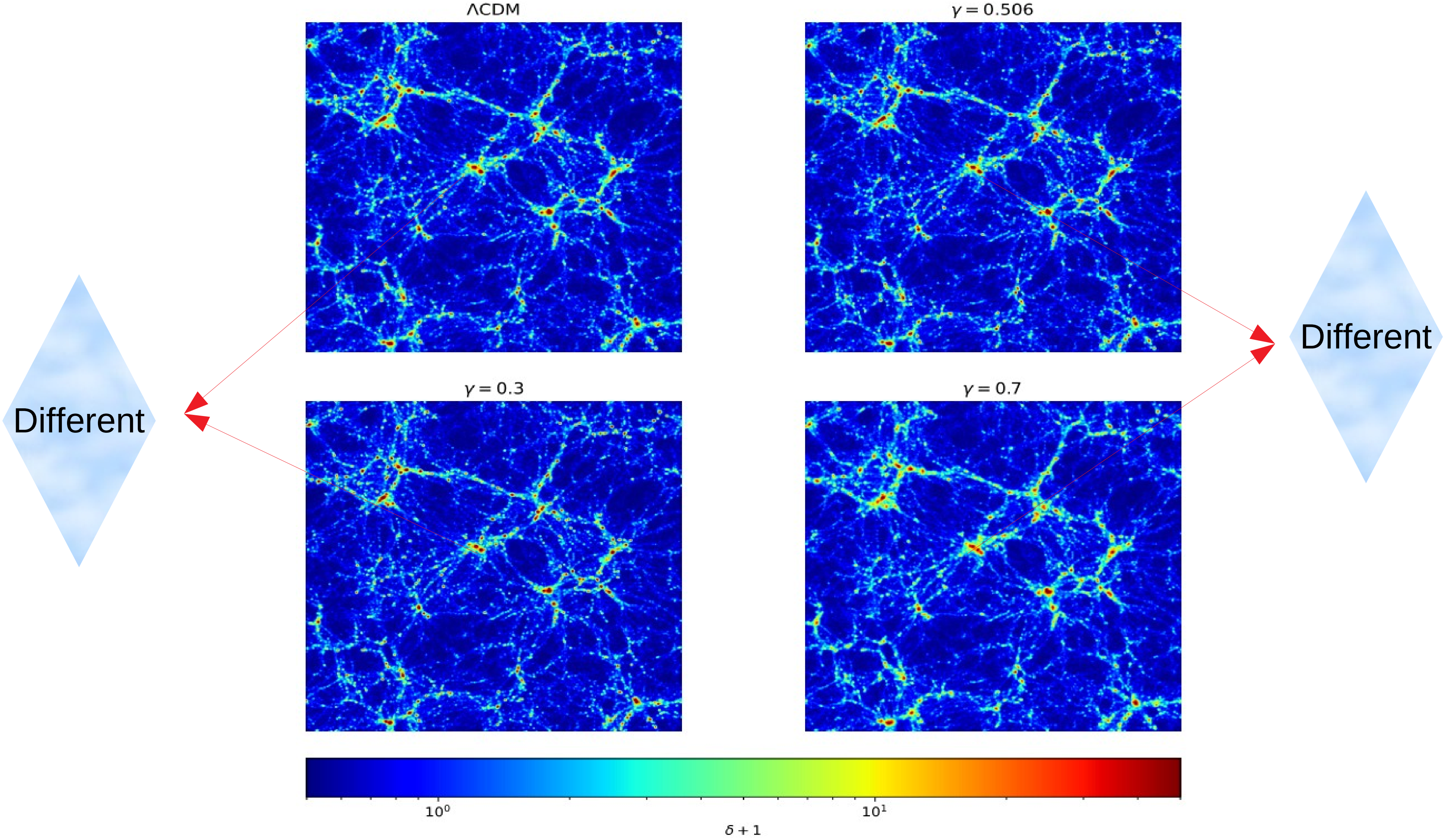
$$\eta(k,a) \equiv \Psi(k,a)/\Phi(k,a) \qquad \mu = \frac{2}{3}\Omega_m(a)^{\gamma-1}\left[\Omega_m(a)^\gamma + 2 - 3\gamma + \frac{3}{2}(\gamma-1)\Omega_m(a)\right]$$



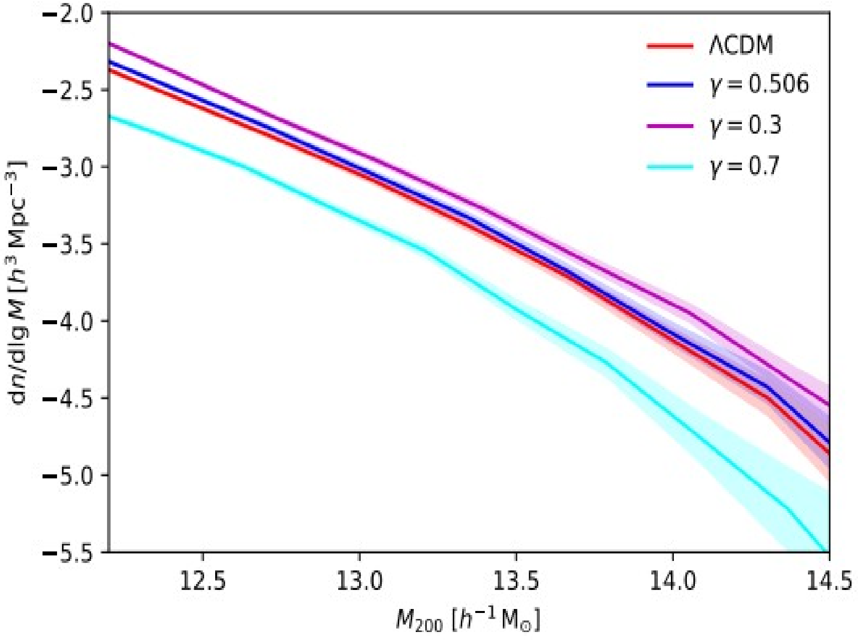


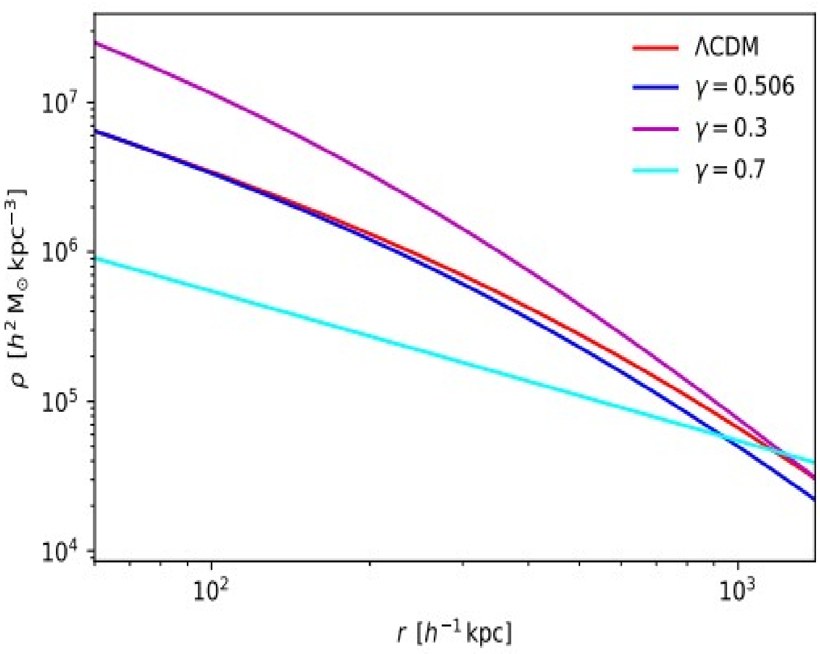
- The signal disappears when considering both anisotropic stress and CMB lensing amplitude.
- It is too early to claim the evidence of enhanced structure growth. (N.Nguyen et al. 2302.01331)

Cosmological simulations



Statistical analysis of simulations





When γ<0.55, halo mass function is obviously larger than that in LCDM, and has more halos in the whole halo mass range.

For γ=0.3, the halos will be more compact than in LCDM. For best fit γ=0.506 from CMB-only constraint, halos have lower densities than in LCDM 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

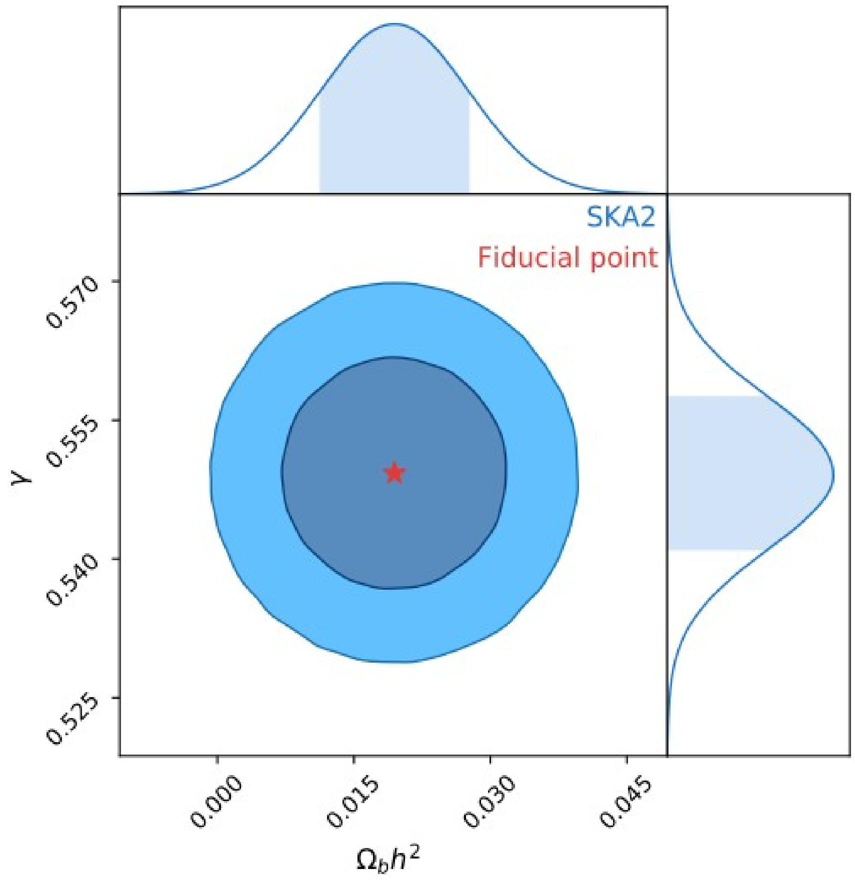
$$P_g(\gamma,k,z)=\left[b(z)+f\xi^2\right]^2 e^{-\frac{\left[k\sigma_{\rm NL}(z,\xi)\right]^2}{2}}P(\gamma,k,z)$$

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

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

SKA2 is expected to achieve an rms flux sensitivity S ≈ 5 μJy 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.

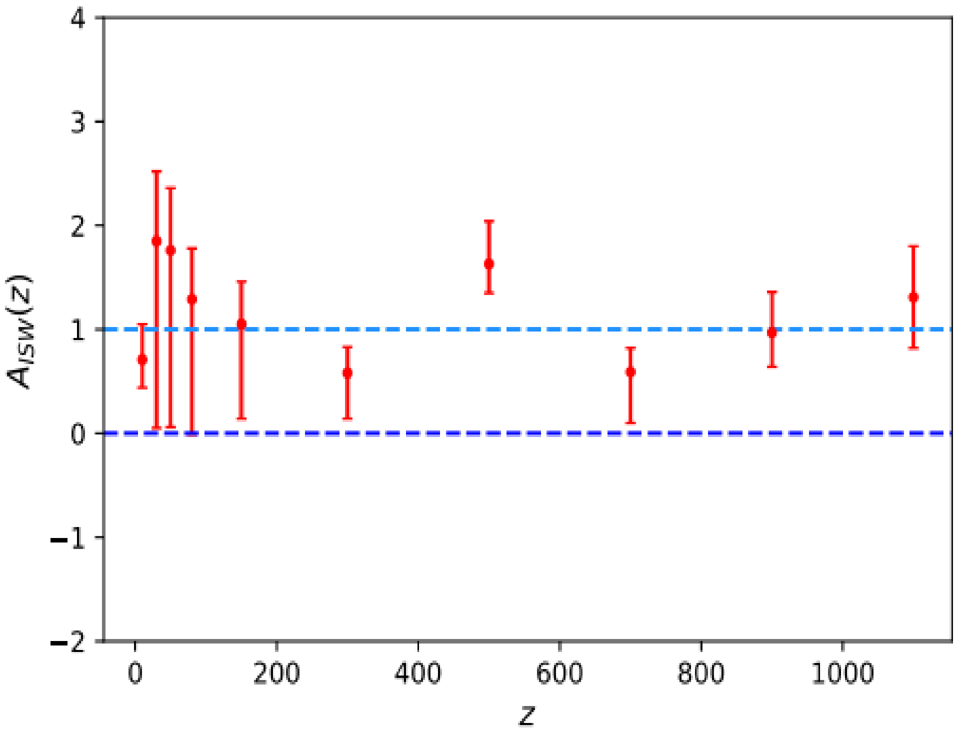
Your takeaways

- 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 of Planck on the growth index parameter by a factor of three.

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!