N-body simulation for non-standard cosmology and 21cm intensity mapping

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Outline

Tensions in Modern Cosmology

Non-standard Cosmology

N-body Simulation

21cm Intensity Mapping

Summary

Overview

Tensions in Modern Cosmology

- H_0 tension between CMB and local measurement
- S_8 tension between CMB and weak lensing

Non-standard Cosmology

- Maybe LCDM model is wrong
- Modified gravity?
- Different dark matter and dark energy model?

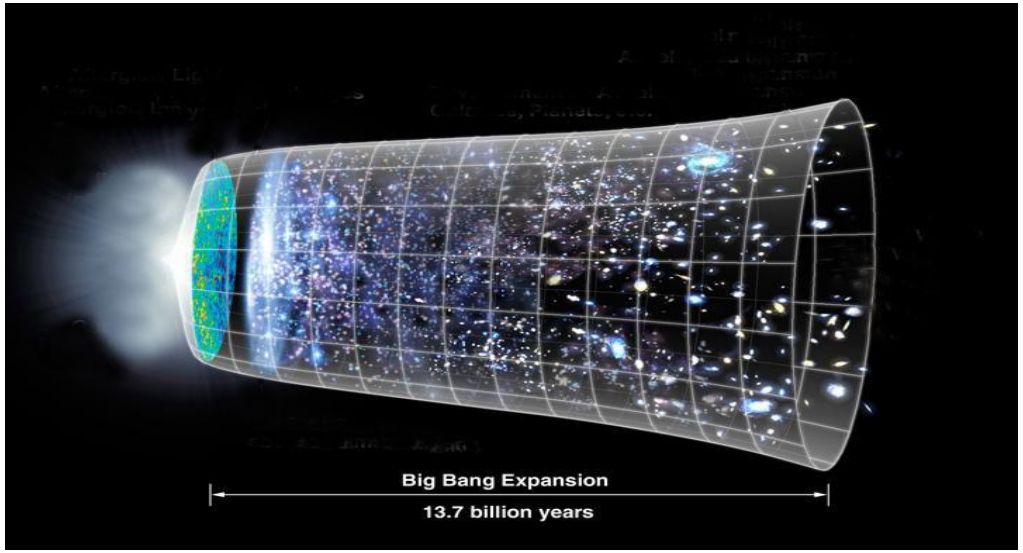
Simulation and Observation

- N-body Simulation for better prediction
- New observations such as 21cm Intensity Mapping
- Generating Mocks for observations
- BINGO telescope

Cosmology standard model

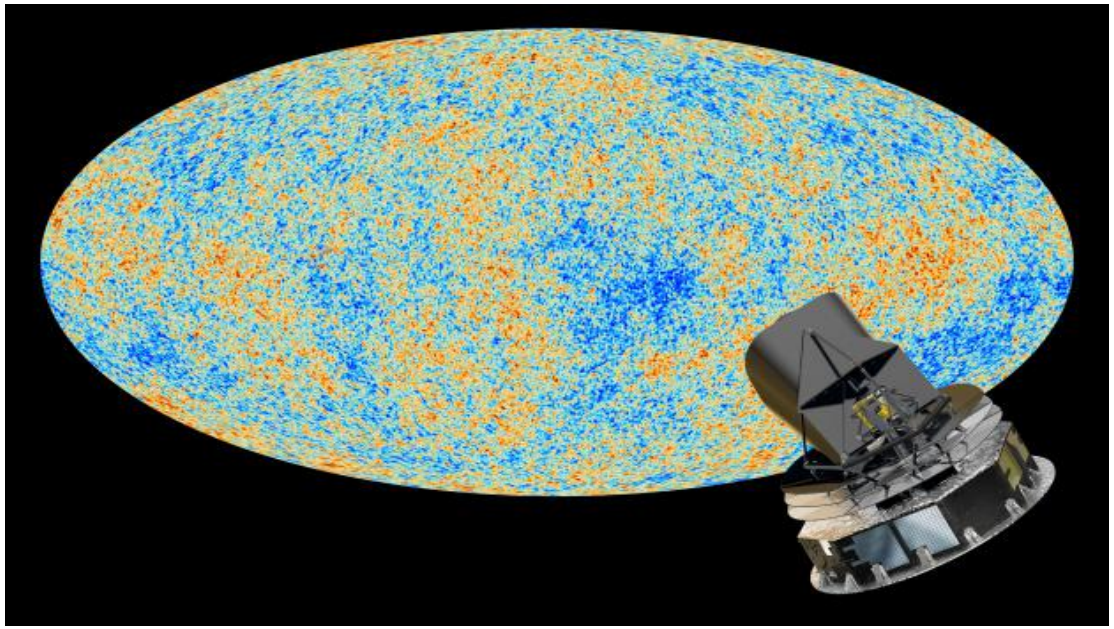
THE STANDARD MODELS

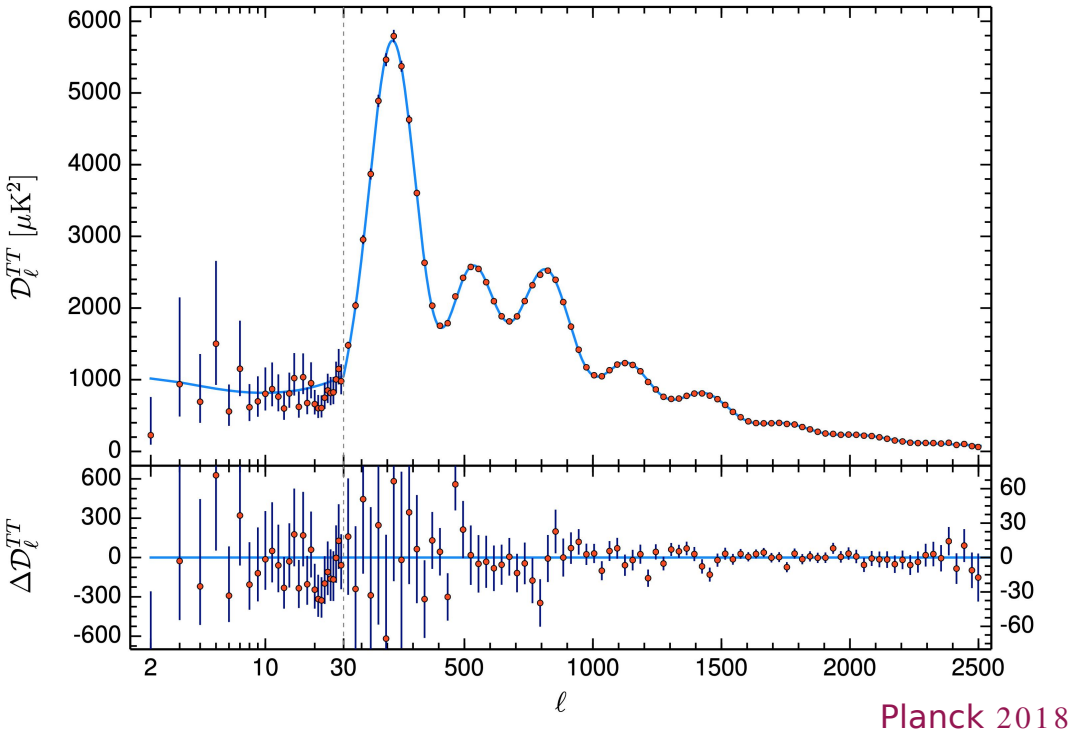
	PARTICLE PHYSICS	COSMOLOGY
What it is	A quantum-mechanical theory of the fundamental building blocks of matter and three of the four forces of nature	A theory of the content and evolution of the universe
Ingredients	The roster of known fundamental particles and a mathematical clockwork that explains the origins of the weak, strong, and electromagnetic forces in terms of mathematical symmetries	Generic definitions of dark matter and dark energy, Einstein's theory of gravity, and the concept of inflation—the notion that the infant universe ballooned at greater-than-light speed
Accomplishments	Accounts for everything seen with atom-smashers so far	Through computer simulations, reproduces statistically the properties of the cosmic microwave background, the distribution of the galaxies, etc.
Shortcomings	Doesn't include gravity, dark matter, or dark energy. Doesn't account for neutrino mass. Possesses curious, arbitrary structure	Doesn't explain what dark matter or dark energy are, or how inflation happened



- LCDM model
- Dark Enegy (Cosmological Constant) , Cold DM, Inflation (Primodial fluctuation, initial condition of structure)
- Basic version: 6 parameters
- Evolution of the expansion
- Large scale structure (galaxy and matter) and CMB
- Good explanation and fits to almost all observations

Precision Cosmology

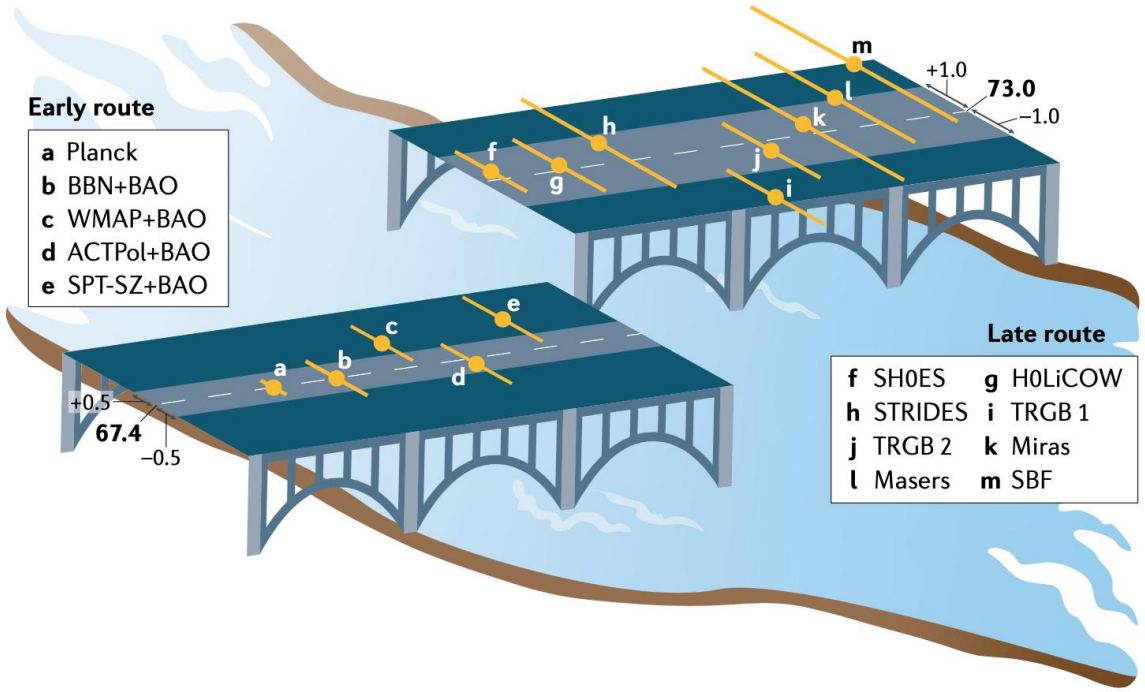


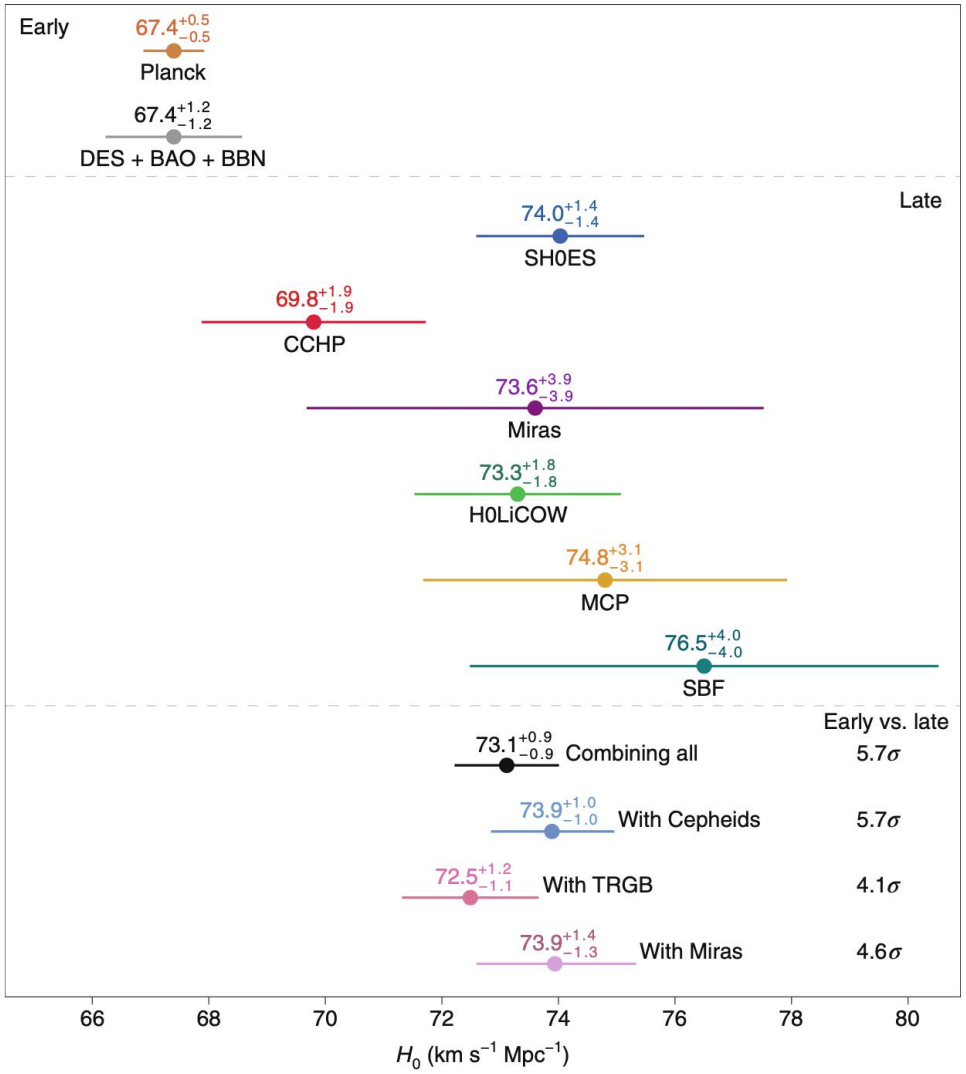


Planck 2018

- CMB precise measurement: precision cosmology
- Observation of fluctuation (TT angular power spectrum, polarization, CMB lensing, SZeffect etc) : Precise cosmological probe
- Determine the cosmological parameters precisely
- 6 parameters: 5 within 1% precision (acoustic angular scale within 0.03%) , reionization optical depth about 13%
- "Era of Precision Cosmology"

Tension between Early and Late Universe

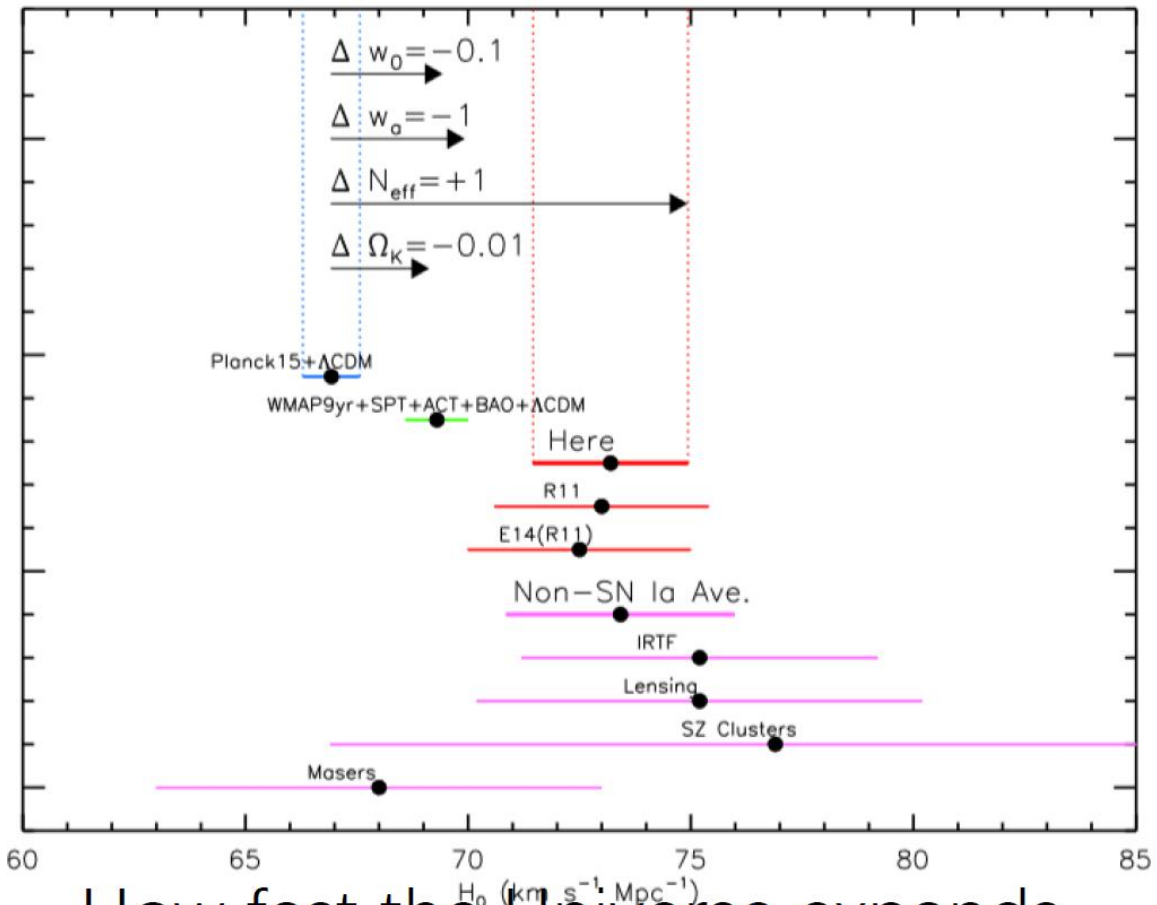




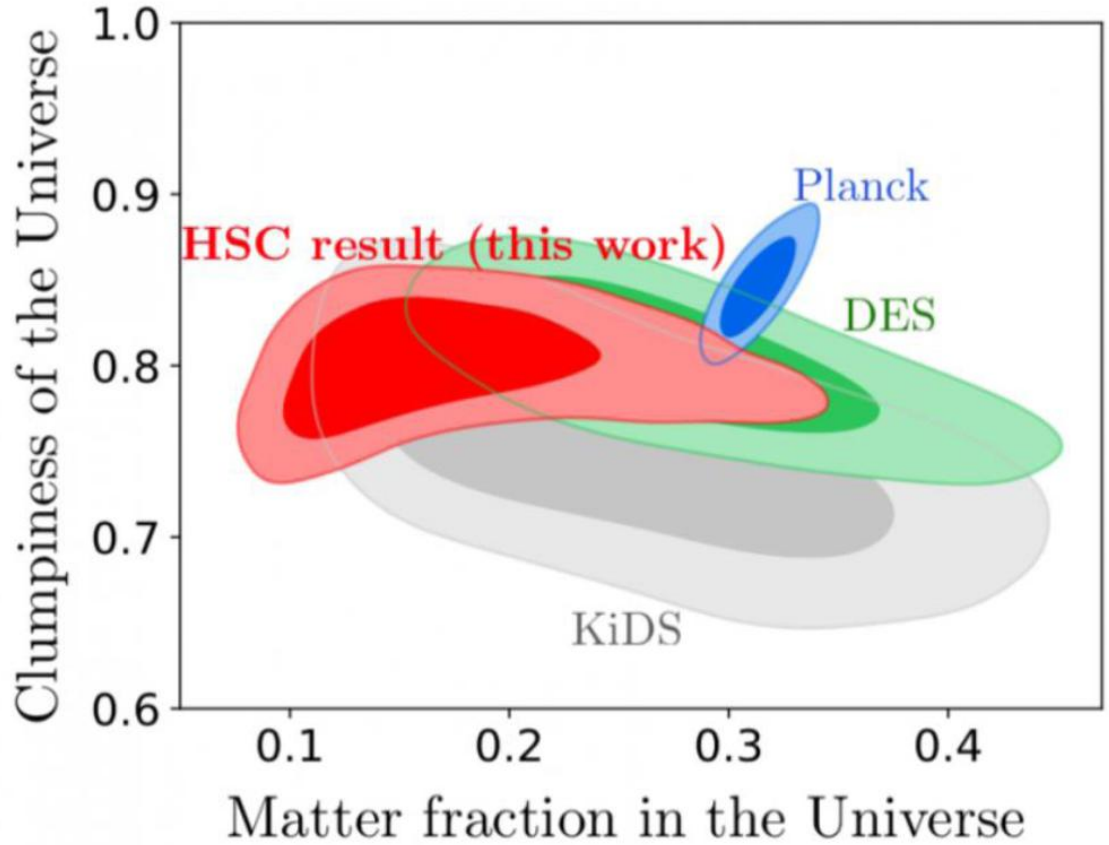
- Planck: very precise, even perfect
- Late time: different groups, methods, techs, consistent
- Hard to blame systematic uncertainty
- Next step: Gaia, strong lensing, CMB polarization, standard siren……
- Paricle physics standard model: solar neutrino problem
- Cosmology: new physics beyond standard model?

Verde, Treu & Riess, NA 2019
Riess, NRP 2020

Tensions in ΛCDM model



How fast the Universe expands



Riess+2016 and HSC collaboration

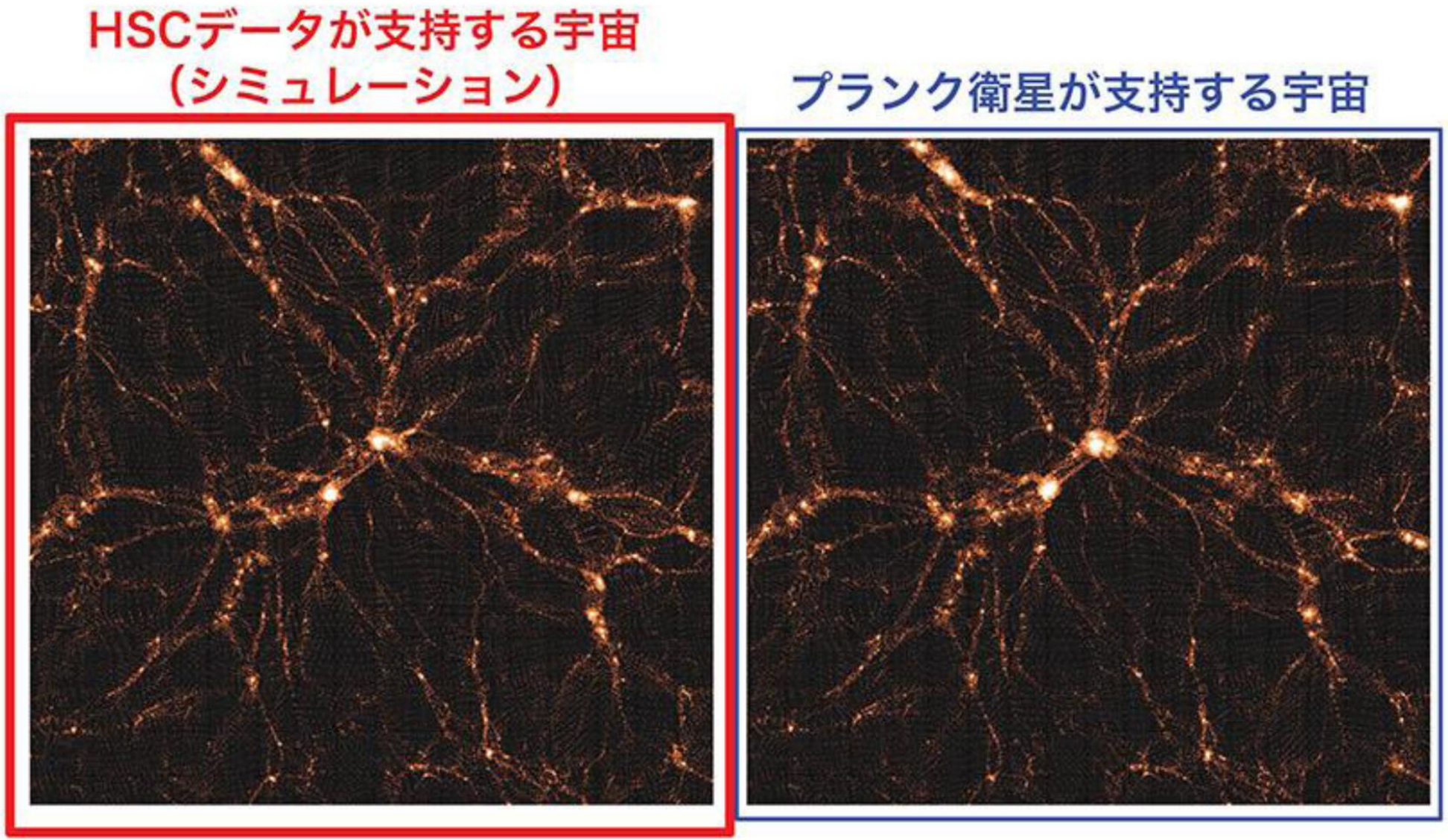


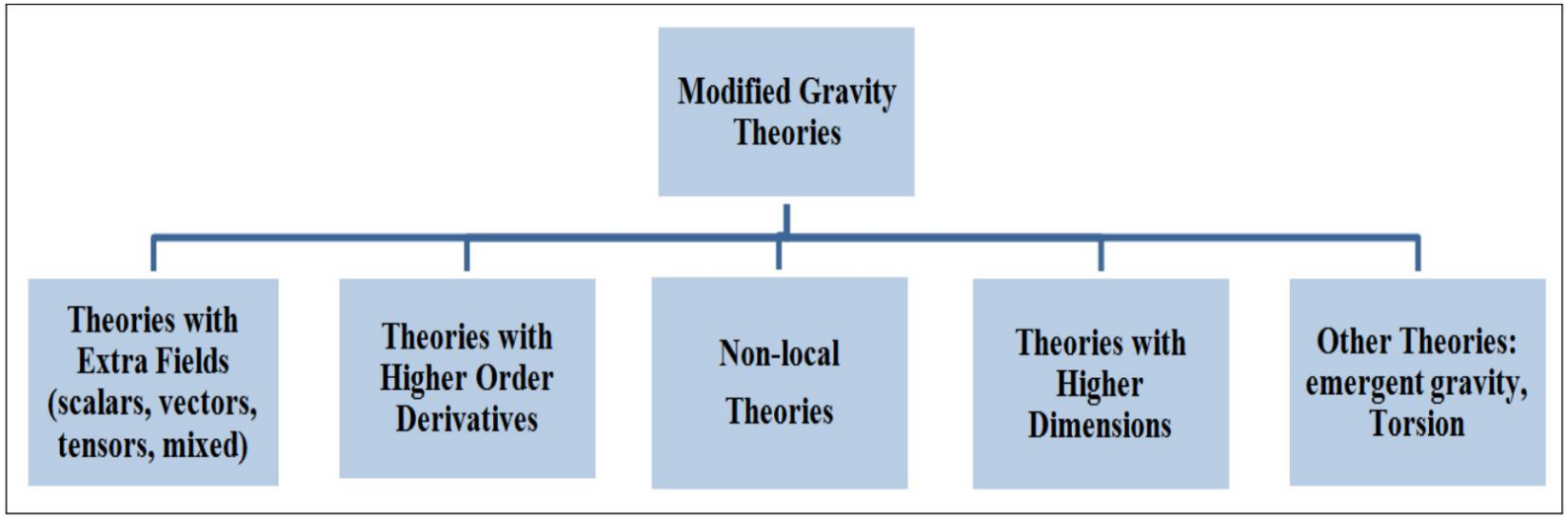
Image provided by Takahiro Nishimichi Kavli IPMU

Introduction of modified gravity

In order to explain the accelerating expasion, cosmological constant was introduced in GR

$$S_{GR} = \int d^4x\sqrt{-g}\left[\frac{R-2\Lambda}{16\pi G} + \mathcal{L}_M\right],$$

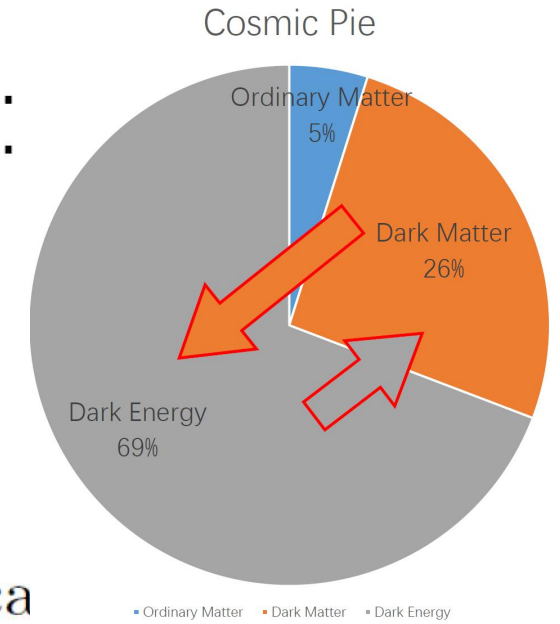
We can also modify the gravity theory



arxiv:1806.10122

Interacting Dark Energy (IDE) Model:

a phenomenological classification



- $\dot{\rho_m} + 3H\rho_m = Q$
- $\dot{\rho_d} + 3H(1+\omega_d)\rho_d = -Q$
- $Q = 3\xi_1 H\rho_m + 3\xi_2 H\rho_d$

TABLE I: Phenomenologica

Model	Q	w
I	$3\xi_2 H\rho_d$	$-1 < w_d < -1/3$
II	$3\xi_2 H\rho_d$	$w_d < -1$
III	$3\xi_1 H\rho_c$	$w_d < -1$
IV	$3\xi H(\rho_c + \rho_d)$	$w_d < -1$

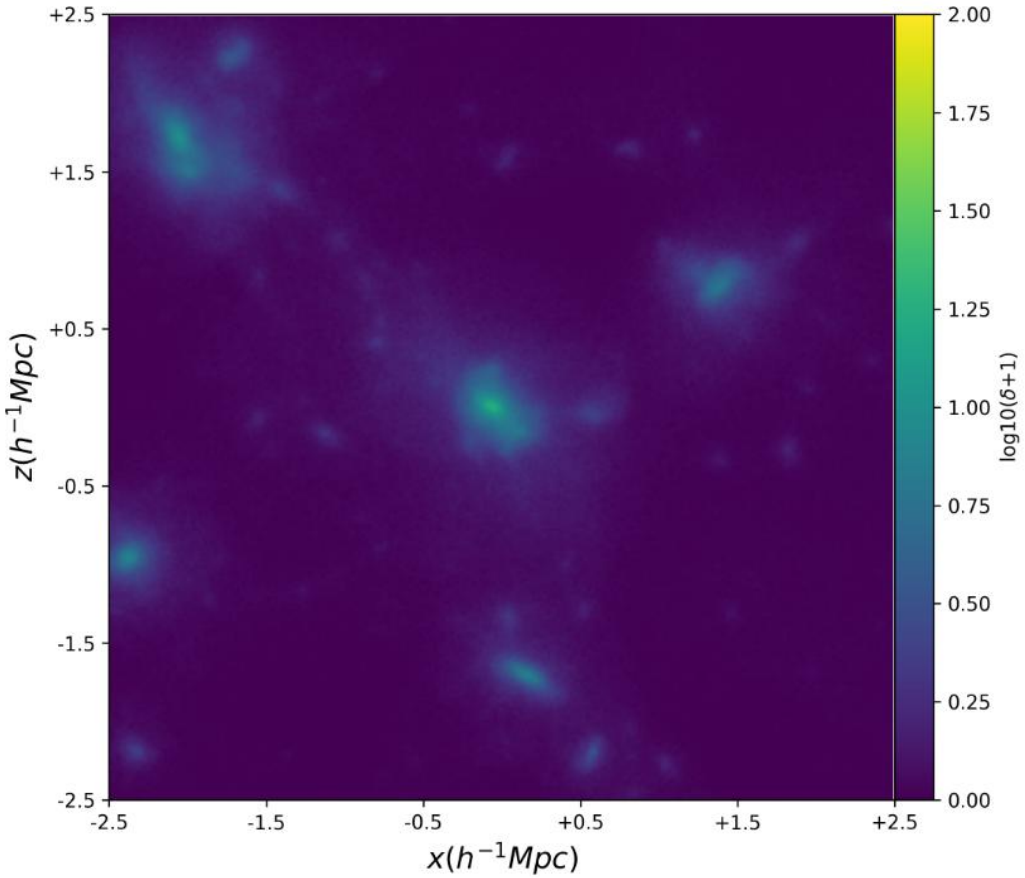
N-body Simulation

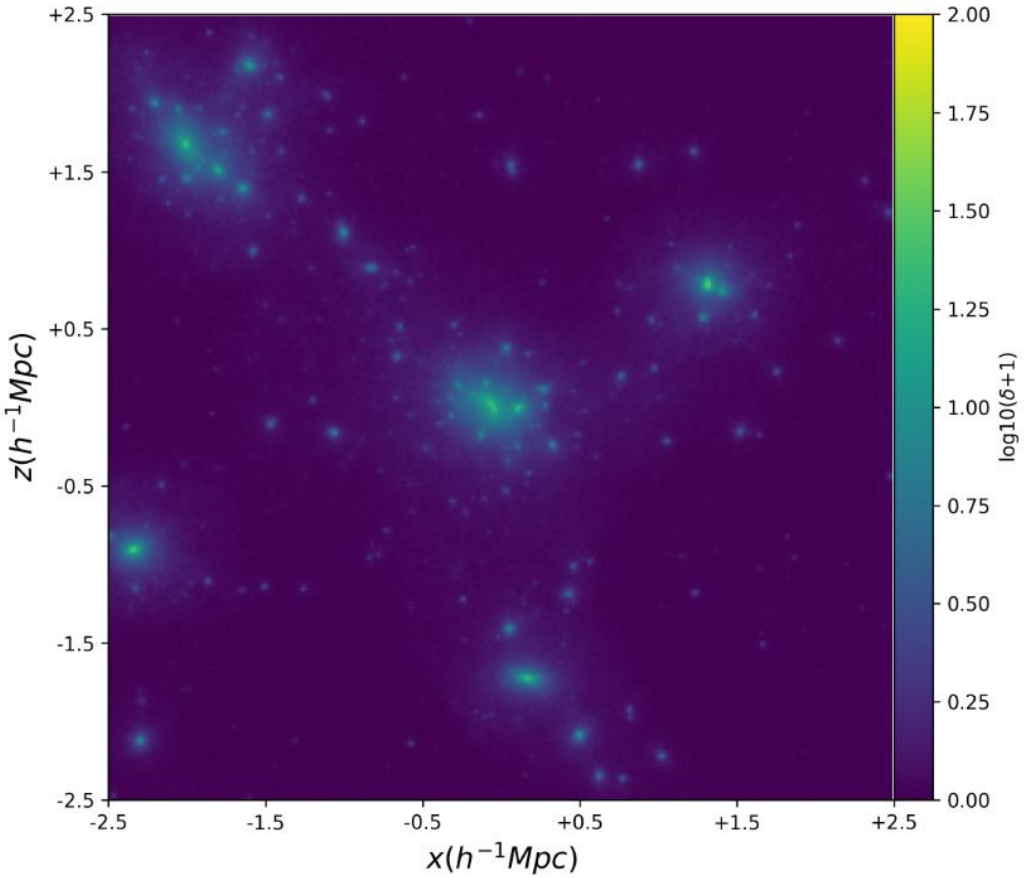
- Nonlinear structure formation can tell us more than background evolution and linear perturbation
- We need N-body simulation to make predictions

  - $H^2 = H_0^2\left(\frac{\Omega_r}{a^4} + \frac{\Omega_m}{a^3} + \frac{\Omega_k}{a^2} + \Omega_\Lambda\right) \Longrightarrow H^2 = H_0^2(\sum \Omega_i(a))$
  - $\dot{\rho_m} + 3H\rho_m = 0 \Longrightarrow \dot{\rho_m} + 3H\rho_m = Q$
  - $\nabla\dot{v_m} + H\nabla v_m = \nabla^2\Psi \Longrightarrow \nabla\dot{v_m} + [H + \alpha(a)]\nabla v_m = \nabla^2\Psi$
  - $\nabla^2\Psi = -\frac{3}{2}H^2\Omega_m\Delta_m \Longrightarrow \nabla^2\Psi = -\frac{3}{2}H^2\Omega_m\Delta_m[1 + \beta(a,k)]$

Zhang+2018 PRD

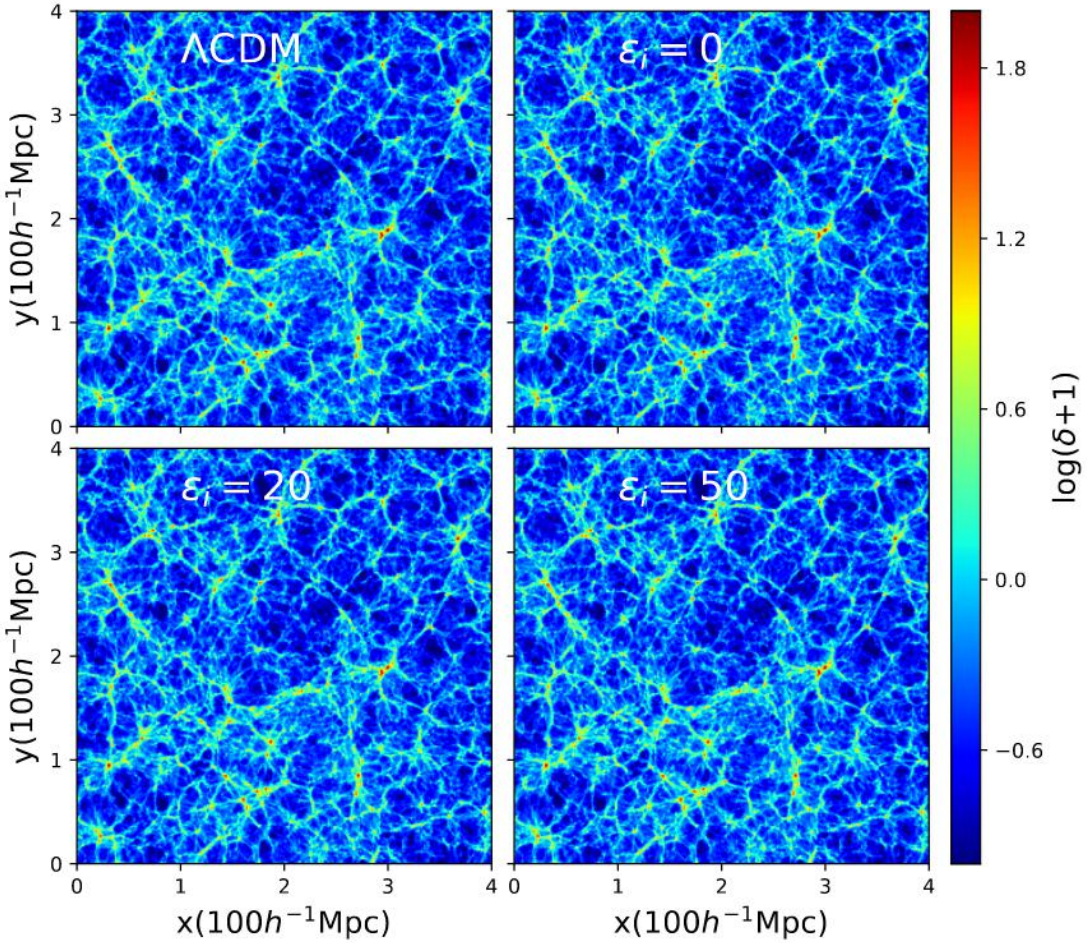
Result about Fuzzy Dark Matter

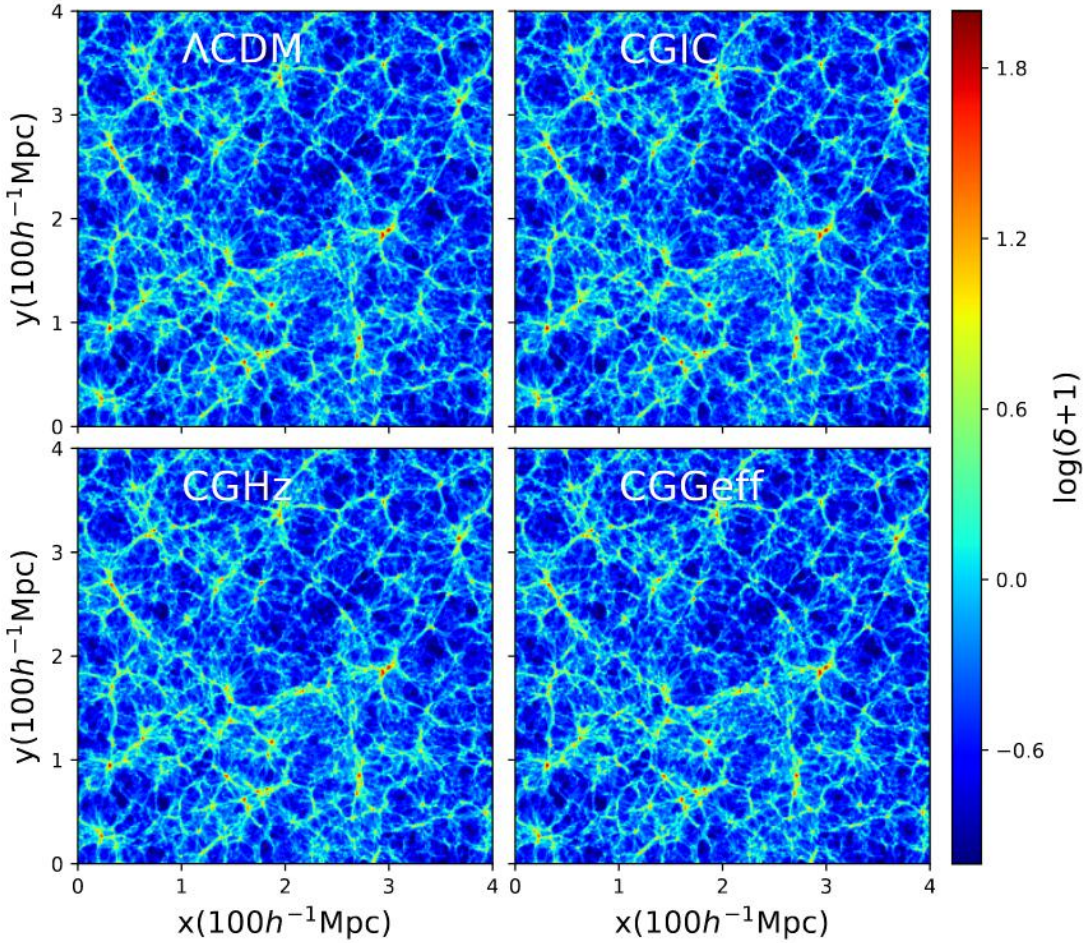




Zhang+2017 ApJ

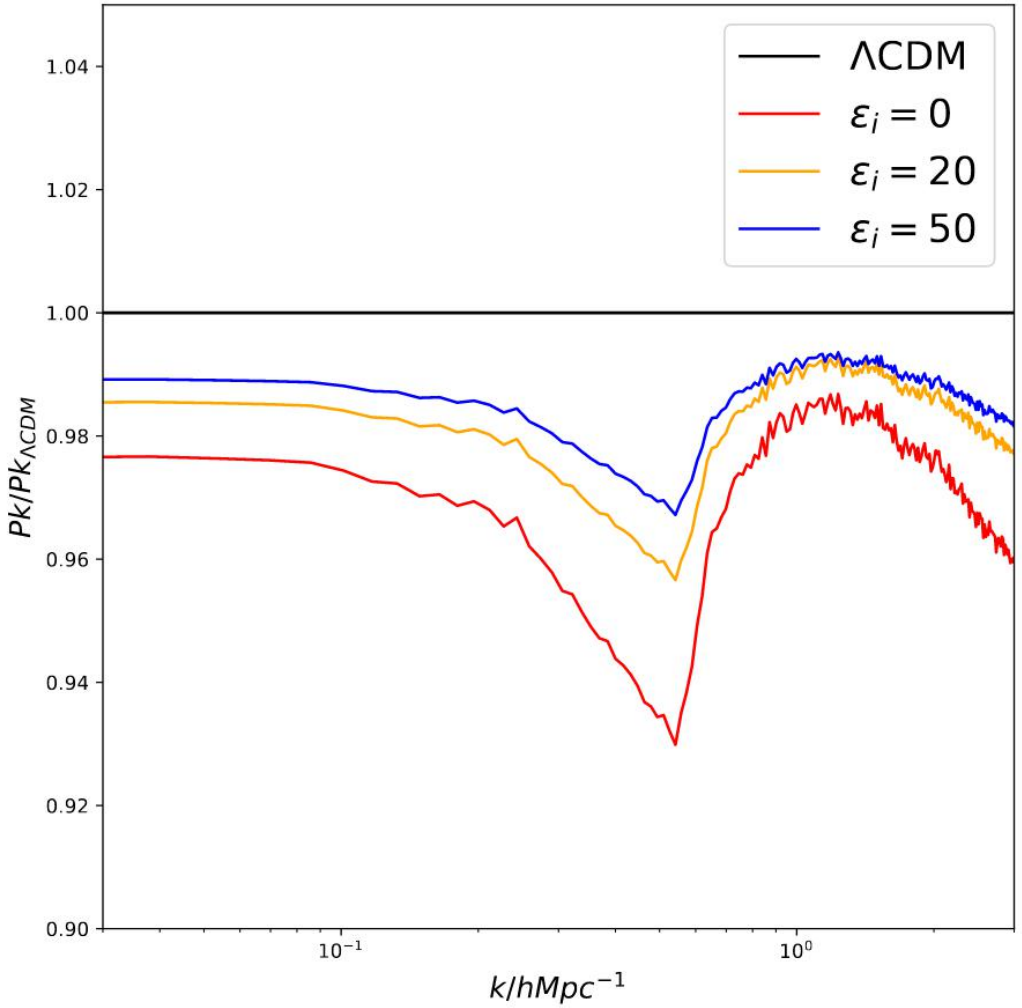
Result about Cubic Galileon

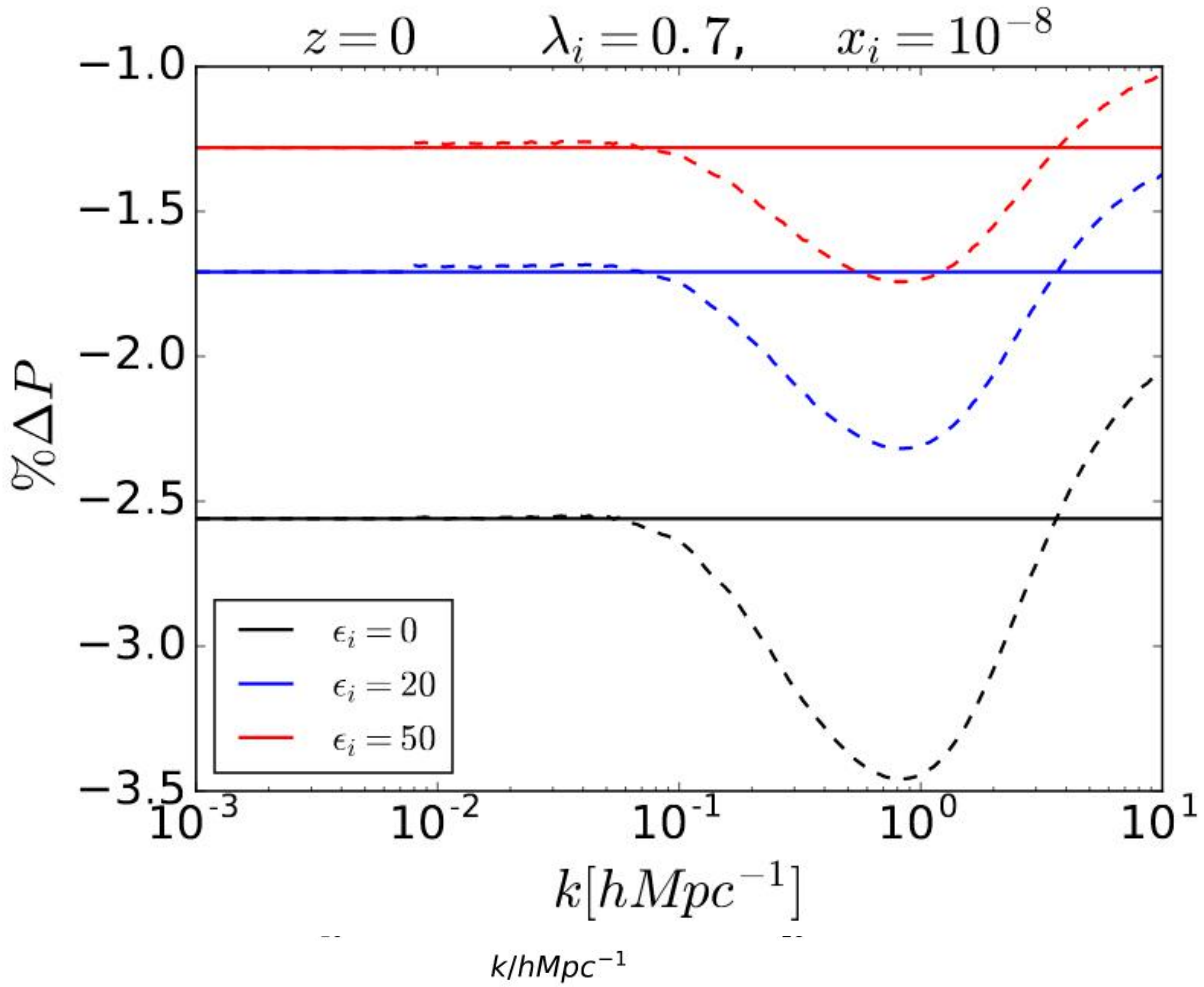




Zhang+2020 PRD

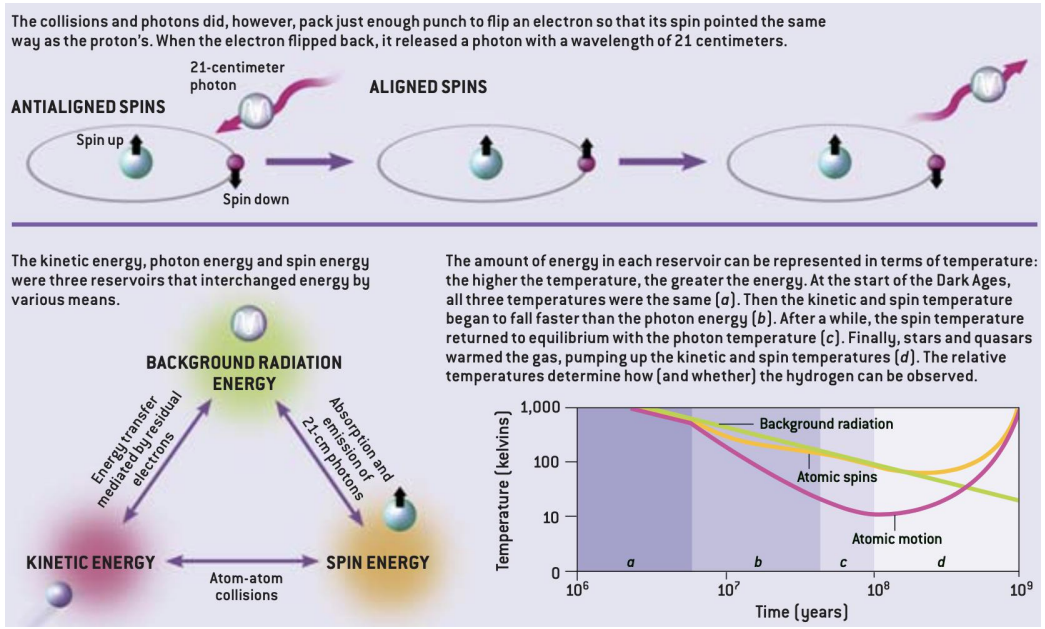
Result about Cubic Galileon

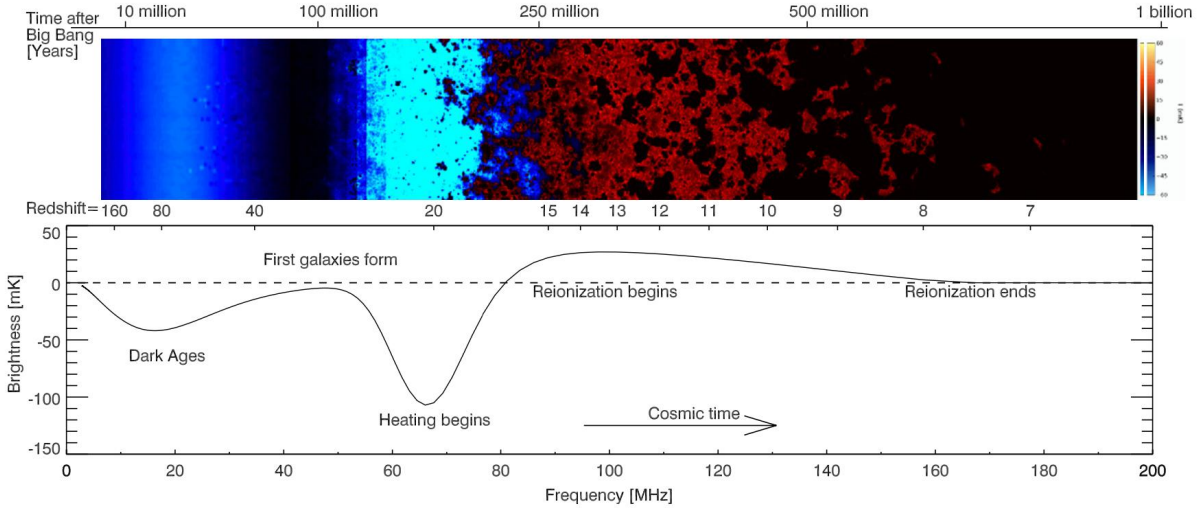


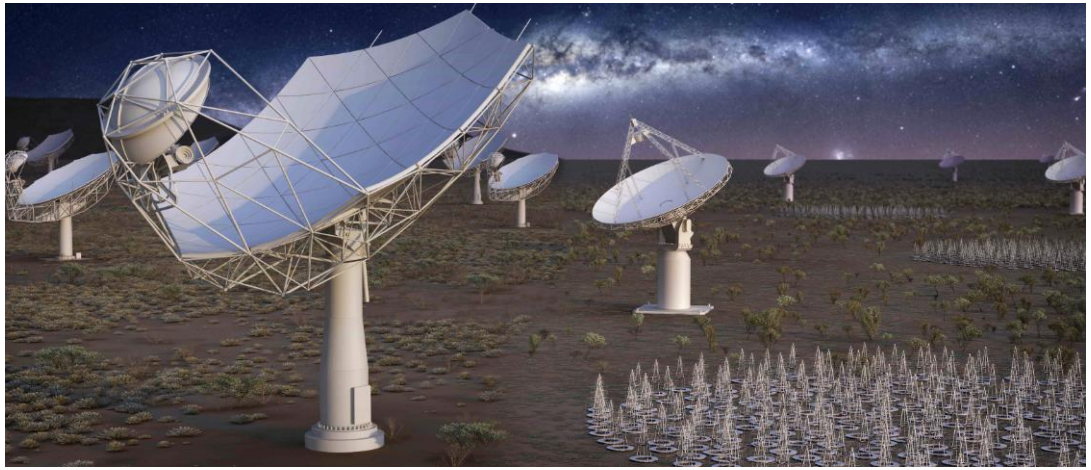


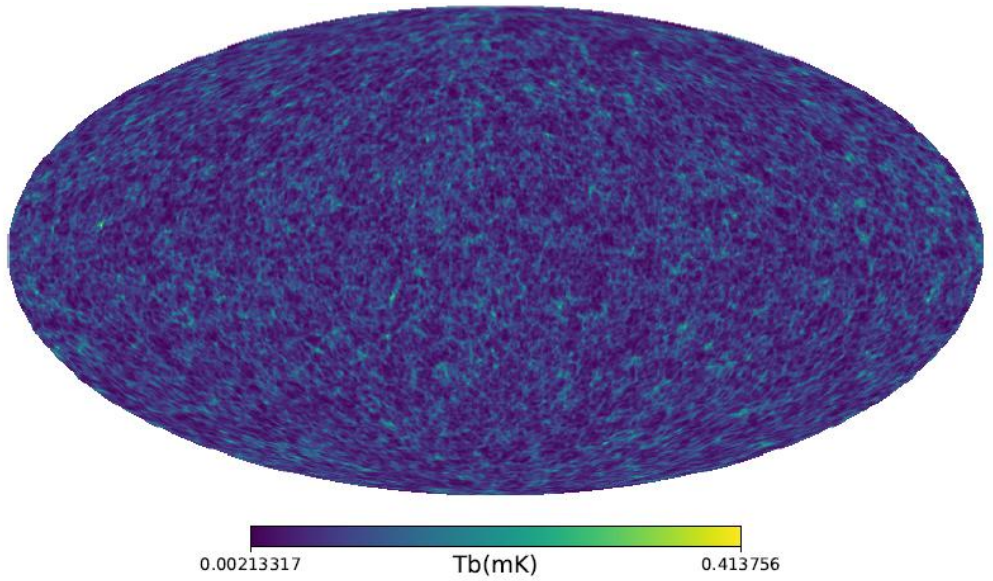
Zhang+2020 PRD

21cm Intensity Mapping

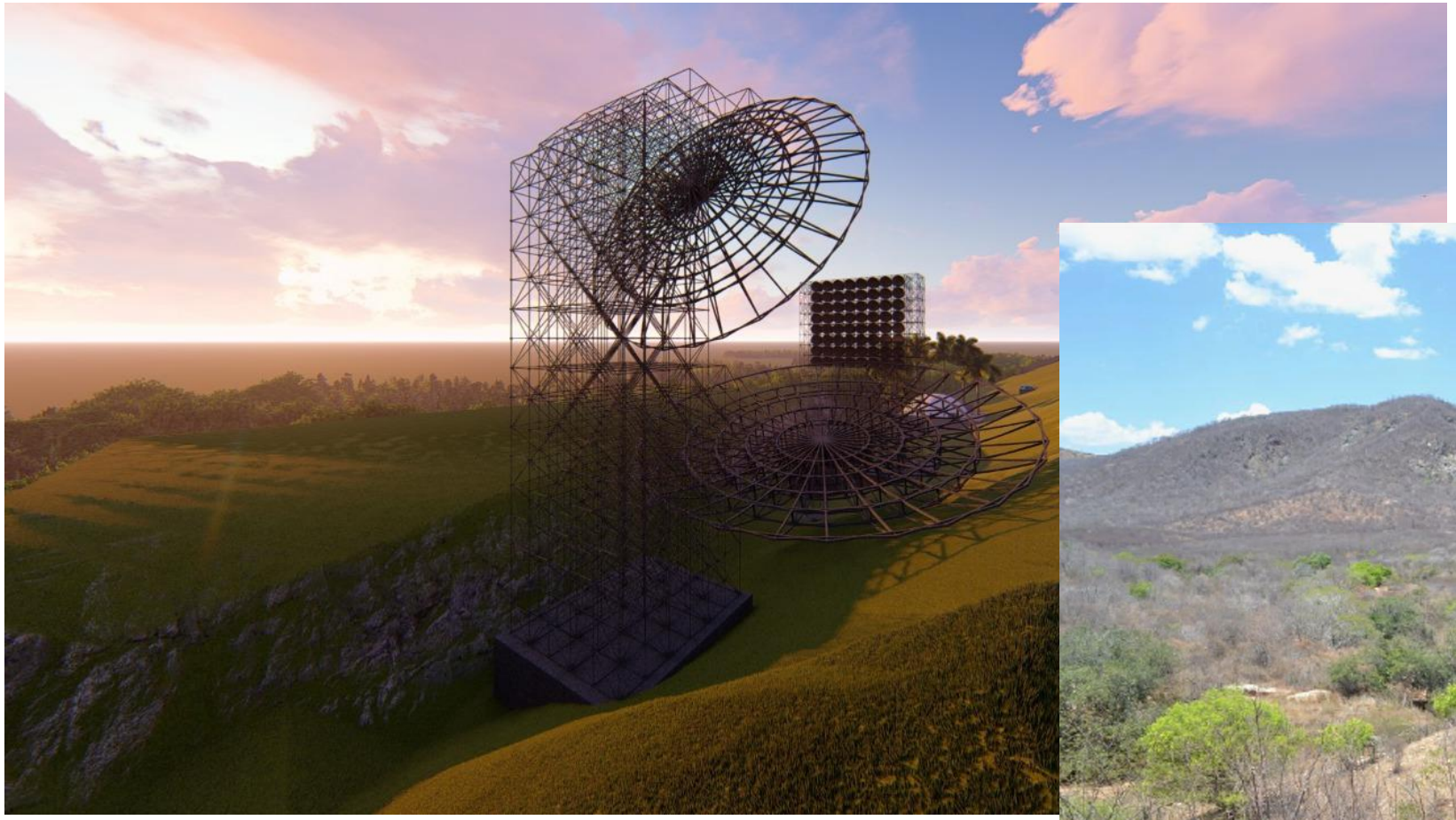






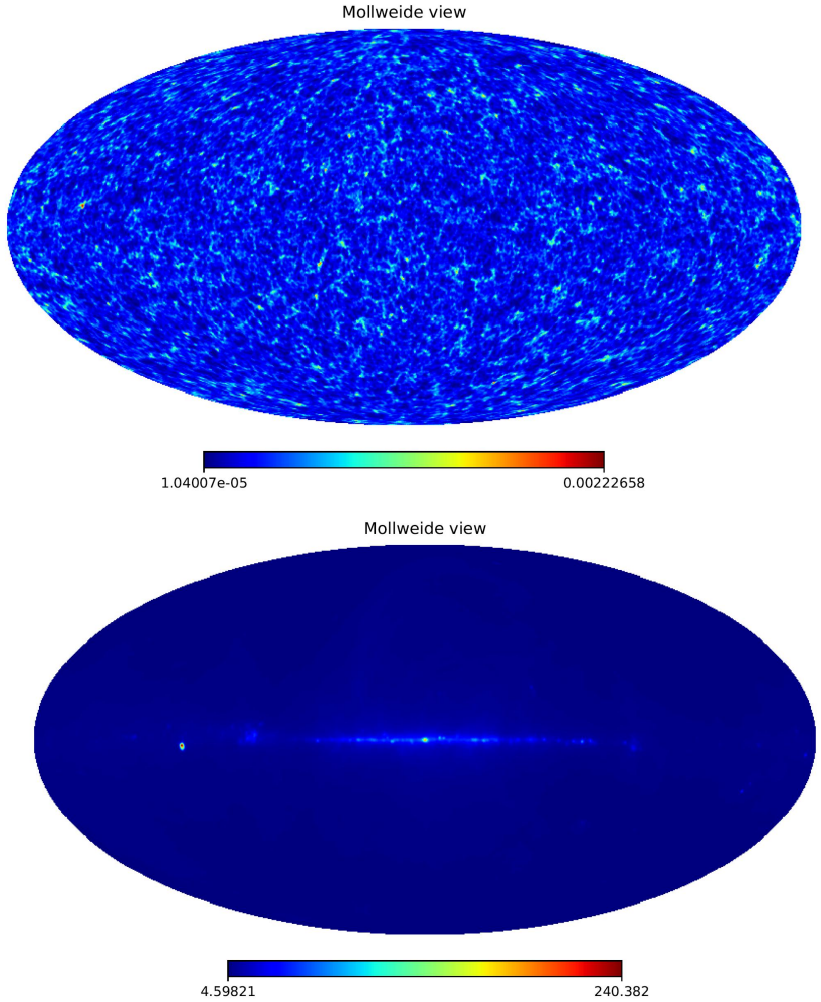


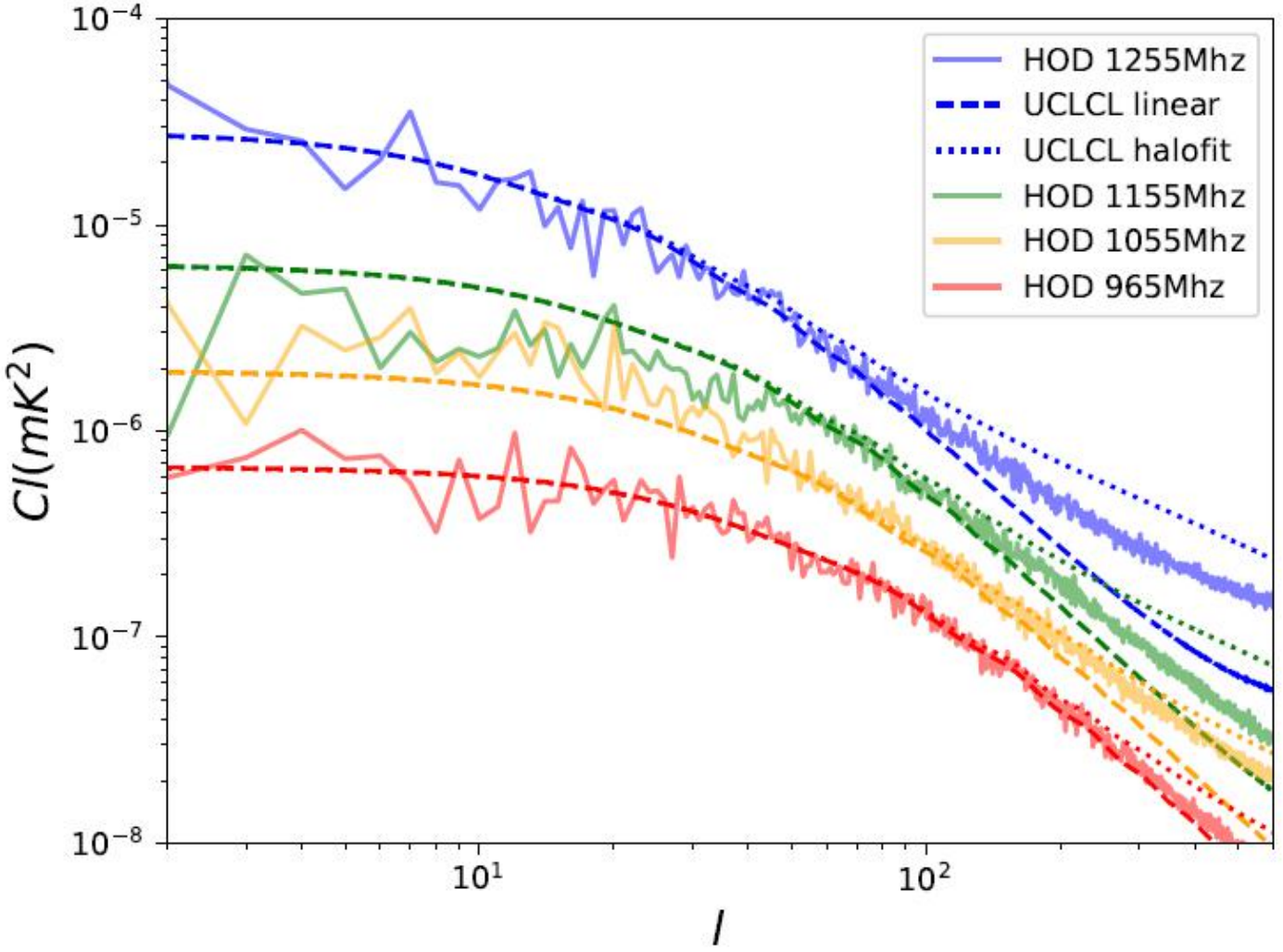
BINGO telescope



In Brazil, 40m dish
960 - 1260 Mhz
start observing in 2021-22

Mock can help us





Summary

- Tensions from different observations indicate “beyond standard model”
- To test the model, we need highly precise prediction and nonlinear calculation
- N–body simulation can help us get various predictions for different models
- New observations like 21cm intensity mapping is coming
- Mocks, generated by N–body simulation can help us test our technique and then cosmology