D01:
Ultimate Physics Analysis

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Why “Ultimate”?

- The aim is to develop a sound analysis method to use **all information** contained in **multiple** data sets
    - In practice, we restrict ourselves to quasi-linear regime where the amplitude of fluctuations is less than unity

Why “Ultimate”?

- The keyword is **“cross-correlations”**
- The starting point of D01 is to use all information contained in *two-point* statistics
    - Believe it or not, even this has not been done fully
- We ignore for the moment three-point and higher-order statistics

LSS = Large-scale Structure; CMB = Cosmic Microwave Background

D01: The Team

I. Kayo — Tokyo Univ. of Tech

R. Makiya, E. Komatsu, S. Saito — MPA / Kavli IPMU

K. Takahashi — Kumamoto Univ.

I. Kayo
- **LSS**
- **Lensing**

R. Makiya
- **LSS**
- **Hot Gas**

E. Komatsu
- **LSS**
- **CMB**

S. Saito
- **LSS**
- **Ly-alpha**

K. Takahashi
- **LSS**
- **21cm**

LSS = Large-scale Structure; CMB = Cosmic Microwave Background

The First “Acceleration Champions”!!

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Tokyo Univ. of Tech

R. Makiya

E. Komatsu

S. Saito

MPA / Kavli IPMU

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Kumamoto Univ.

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- **LSS**
- **21cm**

***Joint analysis*, fully taking into account the mutual cross-correlation**

Science Goals

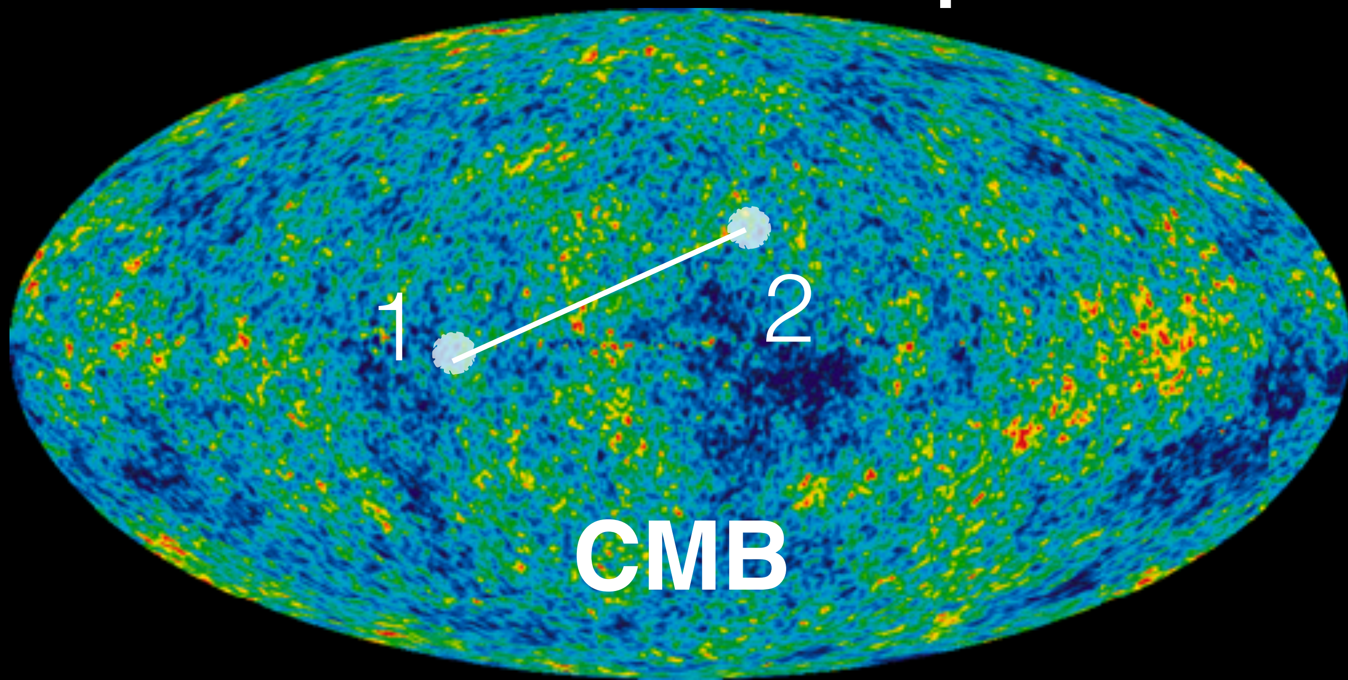
- The main scientific motivations for the “ultimate physics analysis” are three-folds:

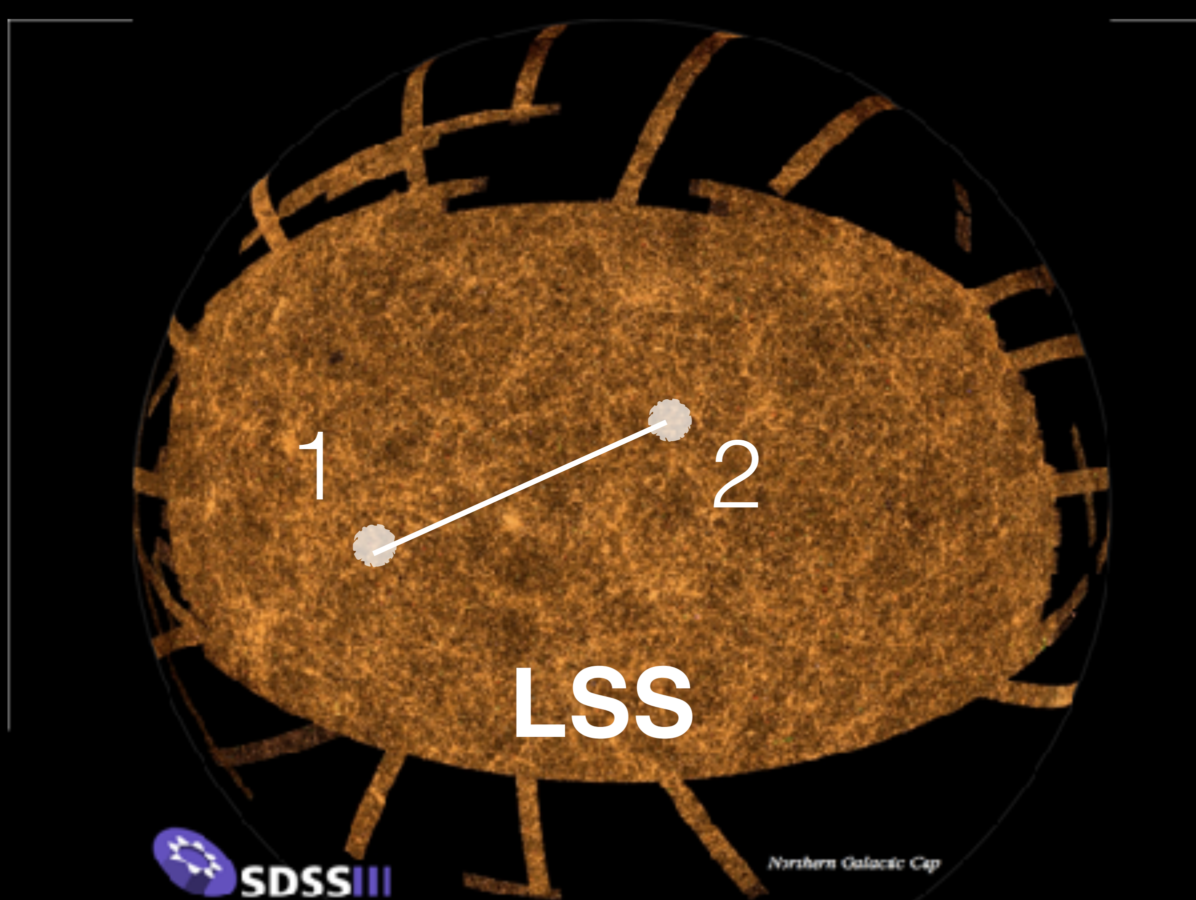
B02,03,04 Falsify the ΛCDM model by **ruling out Λ**

B01,02,03 Detect, or rule out, the inverted mass hierarchy of the neutrino mass by **measuring $\sum m_\nu < 0.1$ eV** [95% CL]

B01 Find definitive evidence for inflation by **measuring primordial gravitational waves in the CMB**

Traditional Method: Auto 2-point Correlation





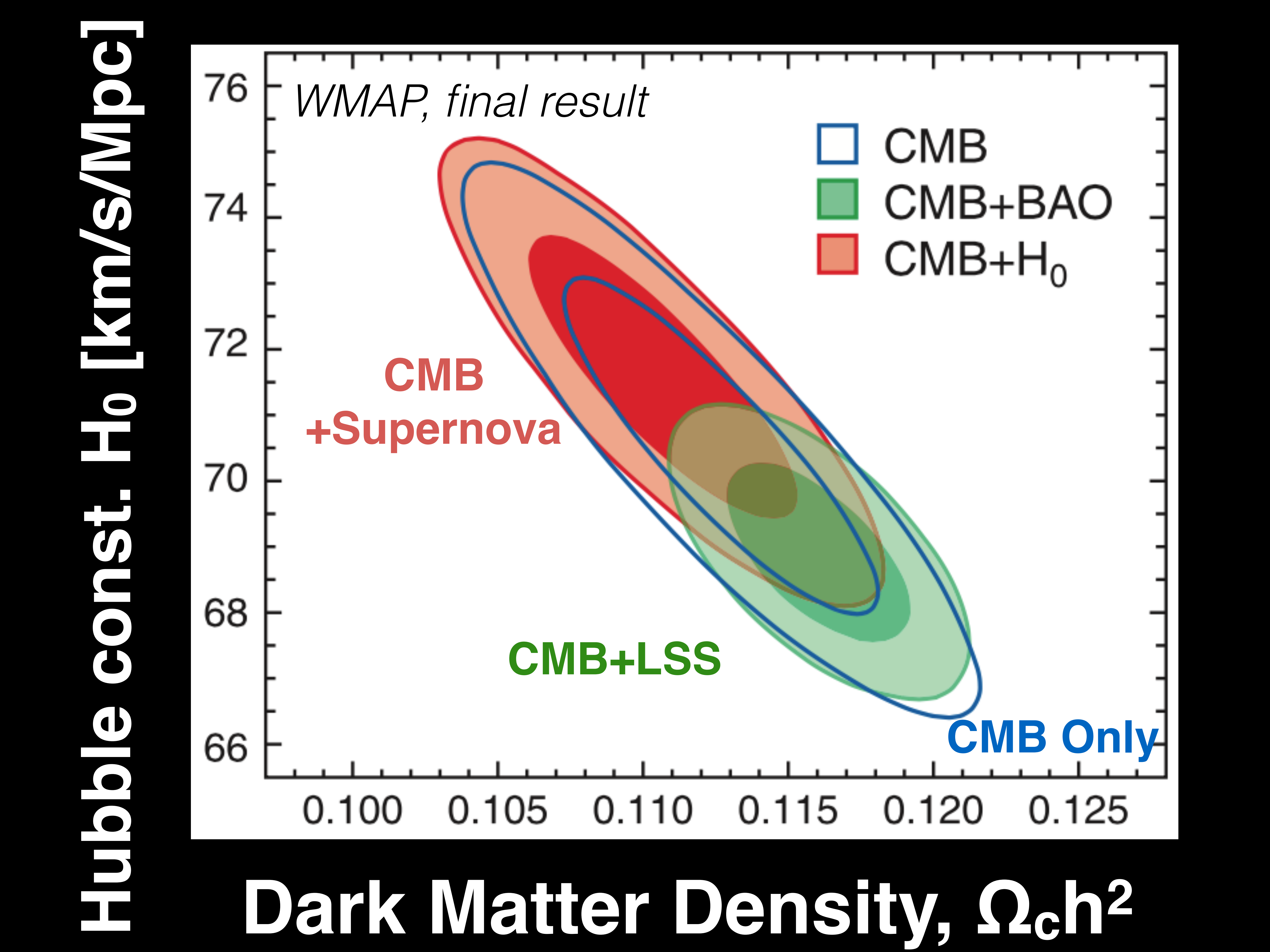
$T_{CMB}(1) \times T_{CMB}(2)$

Cosmology

Joint Constraints

Cosmology

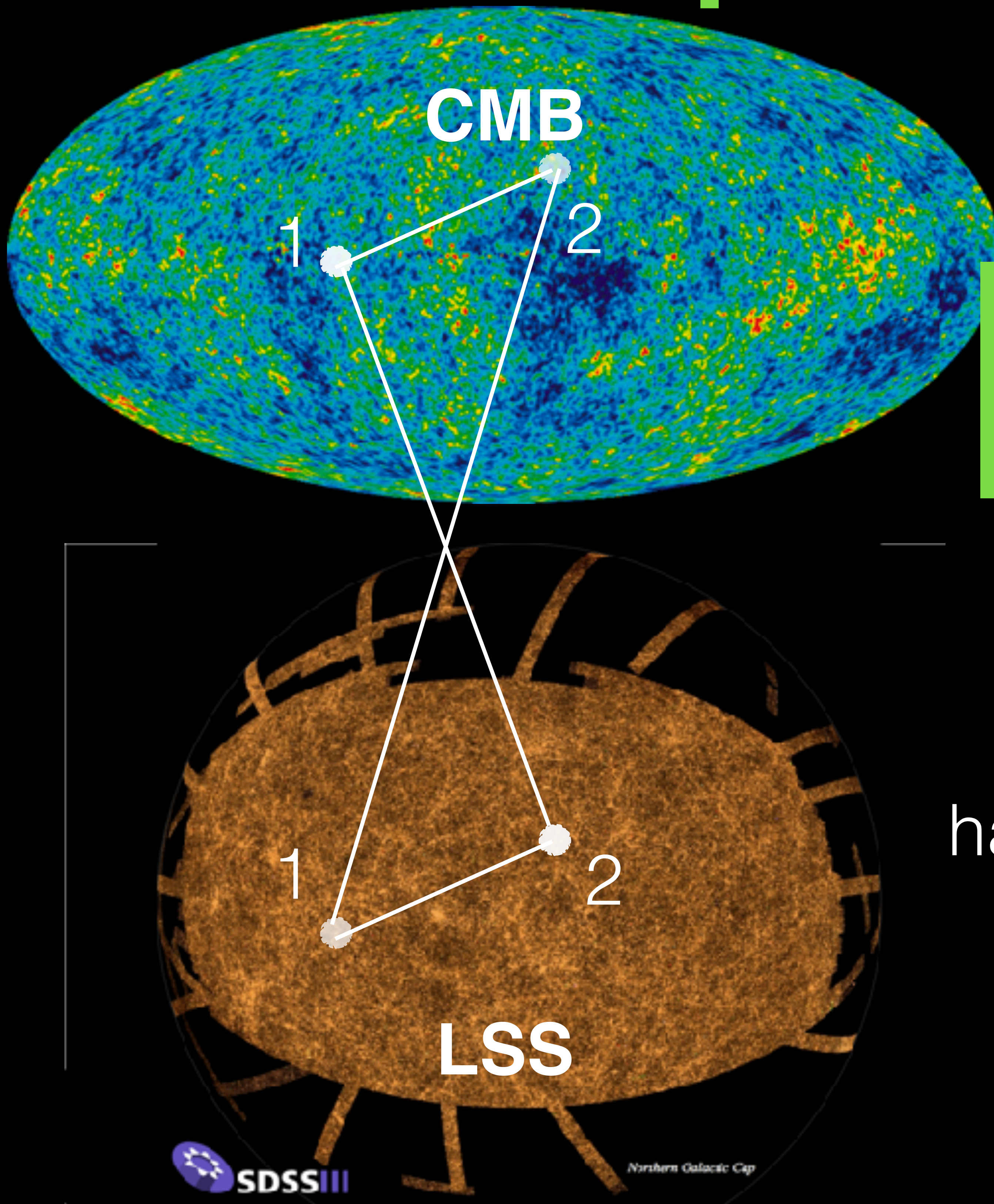
$n_{gal}(1) \times n_{gal}(2)$



WMAP, final result
CMB
CMB+BAO
CMB+H0
CMB
+Supernova
CMB+LSS
CMB Only
76
74
72
70
68
66
0.100
0.105
0.110
0.115
0.120
0.125
Hubble const. H0 [km/s/Mpc]
Dark Matter Density, Ωch2

Our Approach:

Cross 2-point Correlation



$T_{CMB}(1) \times T_{CMB}(2)$

$T_{CMB}(1) \times n_{gal}(2)$

$n_{gal}(1) \times T_{CMB}(2)$

$n_{gal}(1) \times n_{gal}(2)$

Some cross-correlations
have been considered partially
in the previous study,
but **never systematically**

Bayesian Joint Analysis

- **Joint analysis including all the cross-correlations** between CMB, spectroscopic LSS, and imaging LSS

- let us write the conditional probability of cosmological parameters, given the data X, as **P(parameters|X)**

- Conventional method：P(parameters) =

  P_1(parameters|**CMB**) x P_2(parameters|**specLSS**) x P_3(parameters|**imagingLSS**)

- Our approach：**P(parameters)**

  = P(parameters | CMB, specLSS, imagingLSS)

What creates cross-correlations?

SpecLSS	**CMB**	**ImagingLSS**
3D galaxy map Velocity fields	Lensed CMB ISW Thermal SZ Kinetic SZ	Matter density

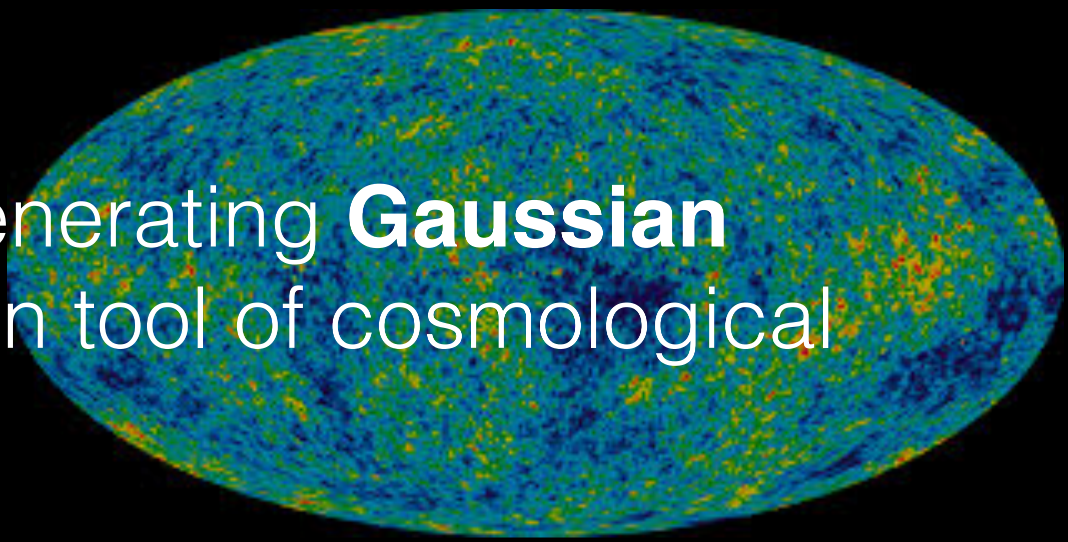
$$P(\text{param.}) = P_1(\text{param.}|\text{CMB}) \times P_2(\text{param.}|\text{specLSS}) \times P_3(\text{param.}|\text{imagingLSS})$$

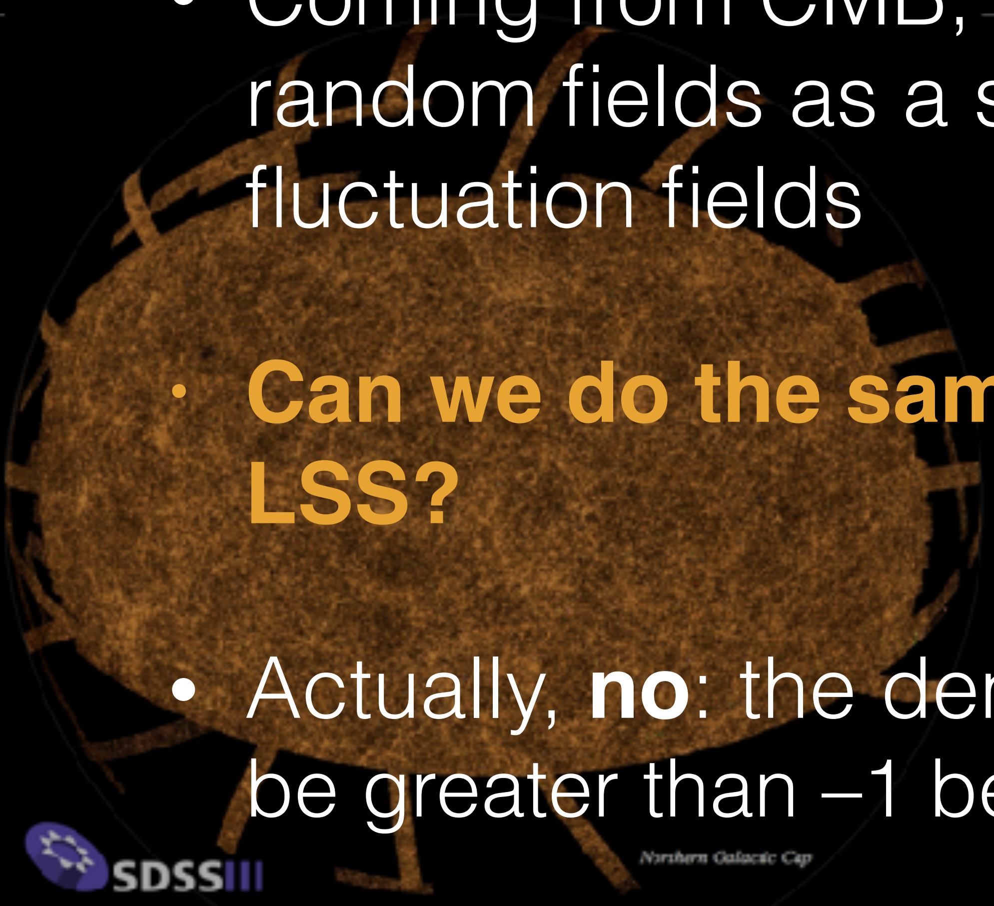
$$\mathbf{P(\text{param.}) = P(\text{param.}\ |\ \text{CMB, specLSS, imagingLSS})}$$

Tool: Log-normal Simulation

- The goal of D01 is to develop tools to determine the cosmological parameters given the data, including all the cross-correlations
- To do this, we need simulations that we <u>understand</u>

Tool: Log-normal Simulation





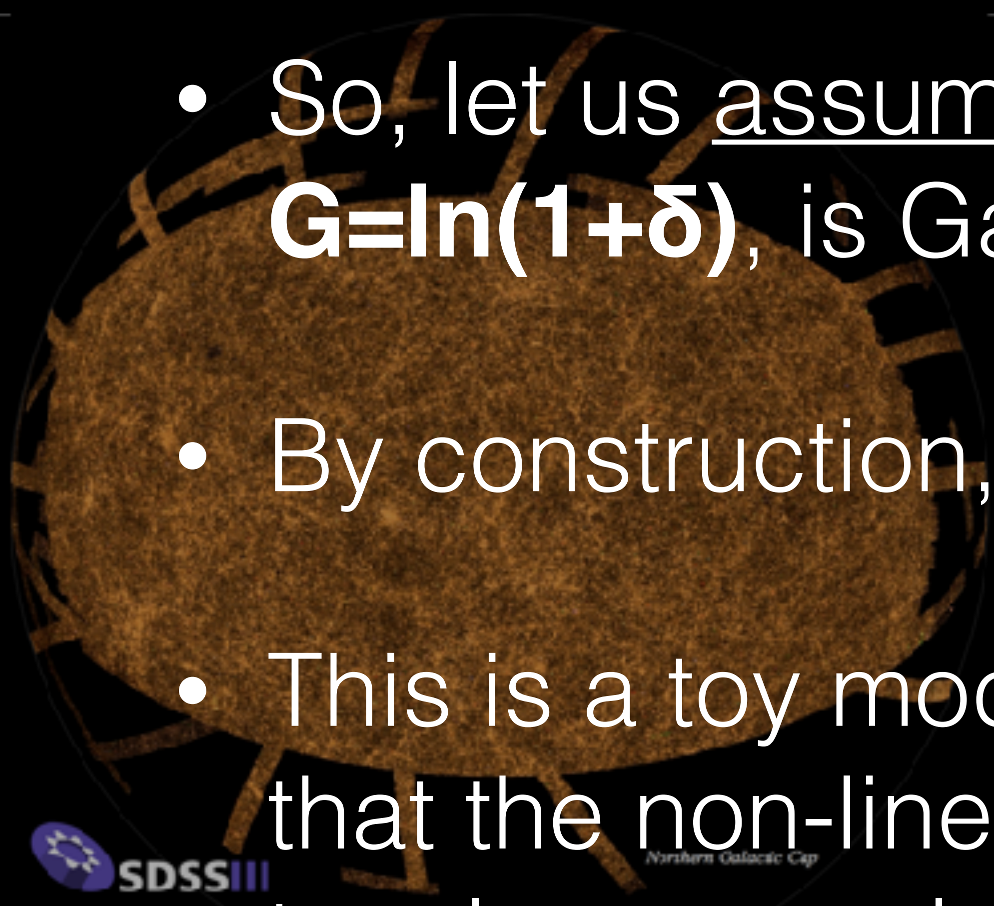
- Coming from CMB, I am used to generating **Gaussian** random fields as a simple simulation tool of cosmological fluctuation fields

- **Can we do the same for generating density fields of LSS?**

- Actually, **no**: the density fluctuation field, $\delta=\rho/\rho_{mean}-1$, must be greater than -1 because the density, ρ, must be positive

- For LSS, the variance of δ is of order unity or greater. Therefore, a Gaussian distribution gives regions with $\delta<-1$, which is unphysical

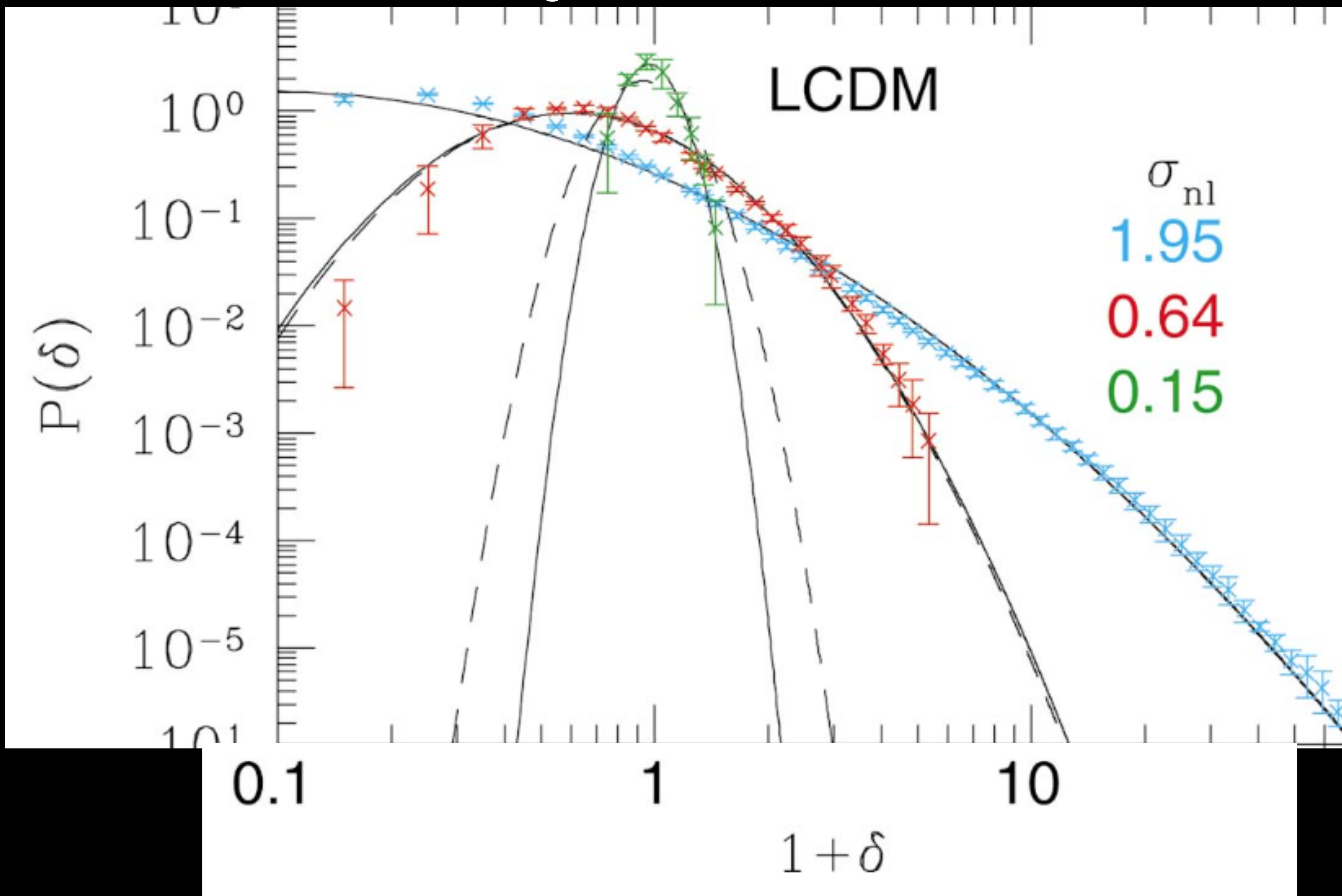
Tool: Log-normal Simulation



- So, let us assume that a logarithm of δ, **$G=\ln(1+\delta)$**, is Gaussian, instead of δ itself
- By construction, **$\delta=\exp(G)-1\geq-1$** is satisfied
- This is a toy model, but N-body simulations show that the non-linear, evolved density field is close to a log-normal distribution, as shown by **Kayo, Taruya and Suto (2001)**

Kayo, Taruya & Suto (2001)

Log-normal Distribution from N-body Simulation



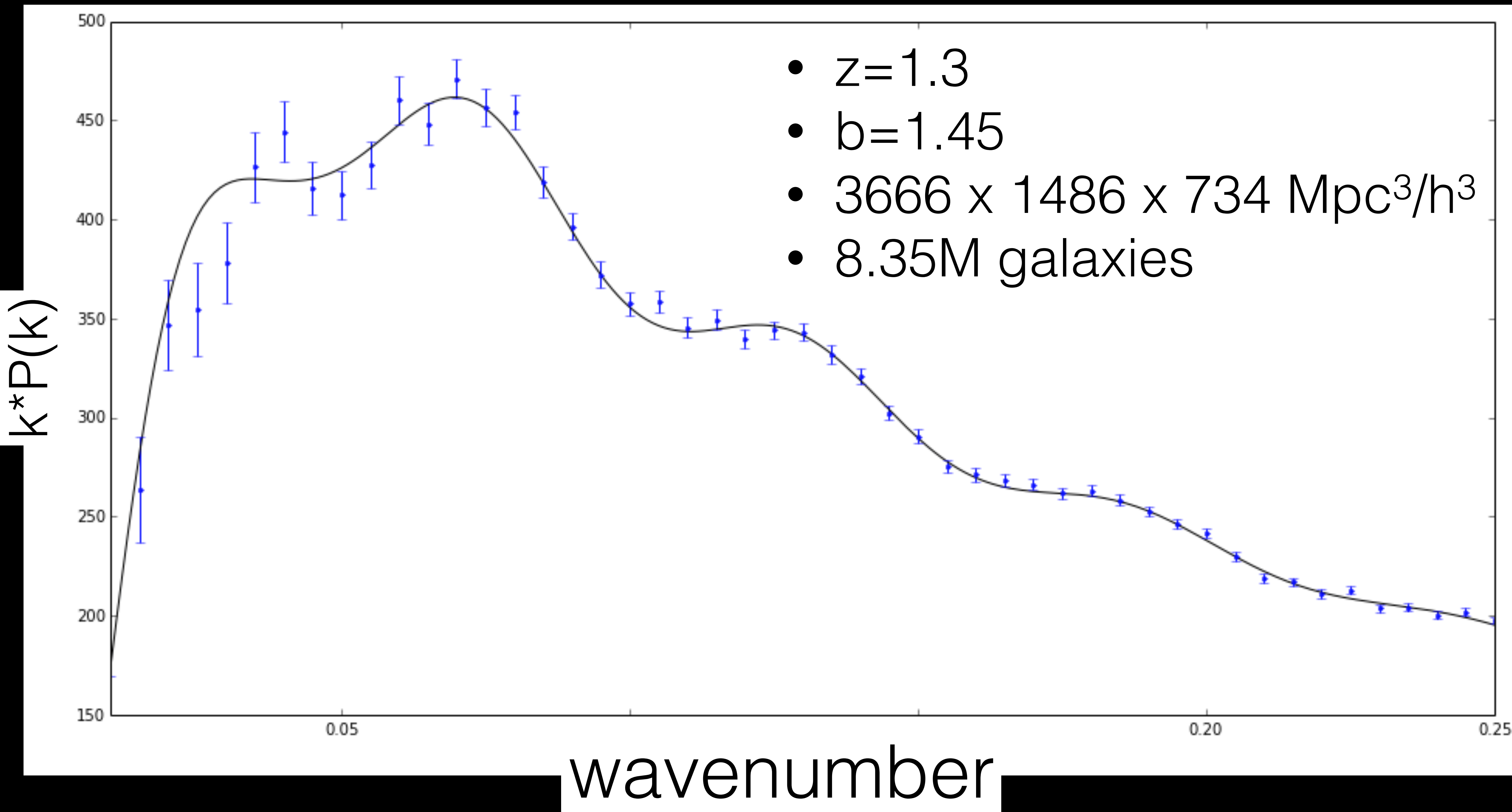
Log-normal Simulation?

- Everyone is running N-body and/or hydro simulations. Why log-normal simulation now?
- The physics inputs to N-body/hydro sims are known, but the outcome is not known because of non-linearities
  - This will be a problem when we develop tools to infer the parameters: lack of precision model to fit the data

Tool:Log-normal Simulation

- But, we know what the outcome of log-normal simulation is. We can fit the log-normal simulation data with no model uncertainty
- Understanding the non-linear physics is also important but it is a separate question, which is being addressed by the other group, e.g., A03. **Complementarity**

Example



- Average of **500** realisations

Public Code Release!

1. **Lognormal_galaxies** [Makiya] **ready to go**
    - Agrawal, Makiya, et al "*Log-normal Simulation in Redshift Space*" in prep
2. **Lognormal_lens** [Kayo] **packaging started**
    - Makiya, Kayo, et al. "*Log-normal Simulation of Weak Lensing*" [tentative]
3. **Lognormal_im** [Saito] "im" means "intensity mapping"
    - Saito, Makiya, et al. "*Intensity Mapping with Sparse Sampling*" [tentative]

One more thing…

Is there anything new here?

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Yes, and wait until the last talk by R. Makiya of this session.