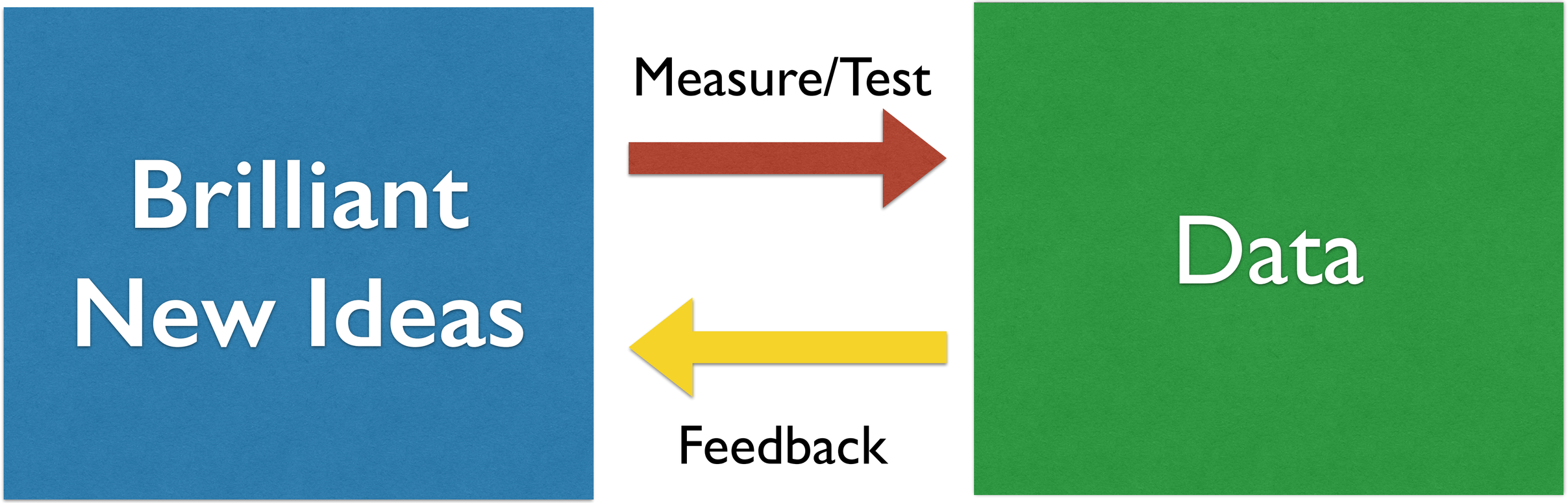
# Department of Physical Cosmology

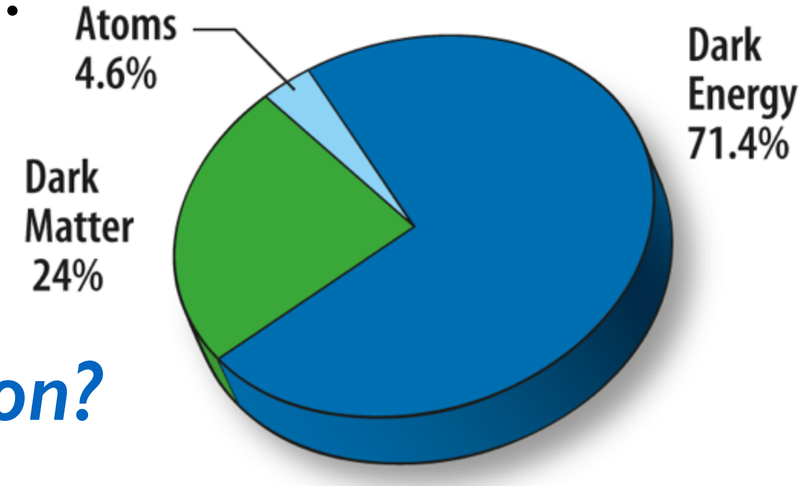

# MPI für Astrophysik

# Basic Routine



# Four Big Questions in Cosmology

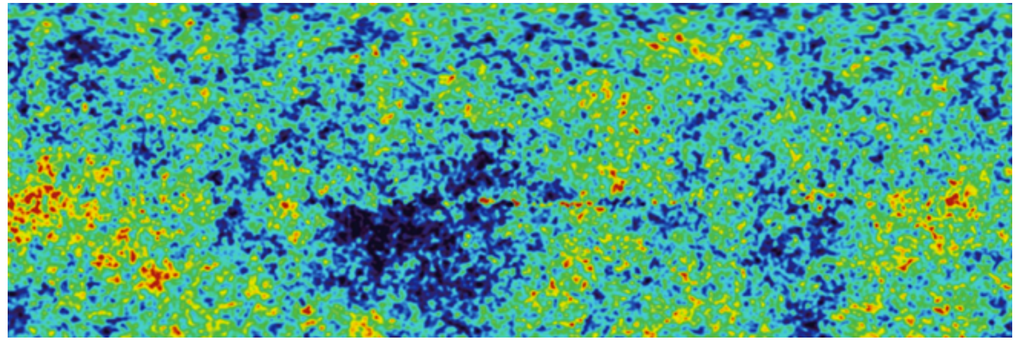
- Members of the Physical Cosmology Division seek answers to **FOUR** big questions in cosmology:
  - ***How did the Universe begin?***
    [What is the physics of inflation?]
  - ***What is the origin of the cosmic acceleration?***
    [What is the nature of dark energy?]
  - ***What is the nature of dark matter?***
  - ***What is the mass of neutrinos?***



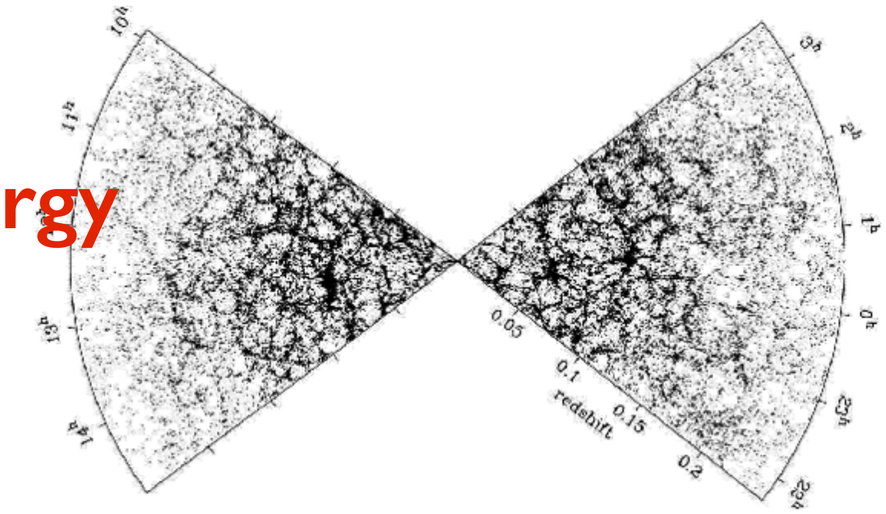

We use both **theory** and **observational data** to seek answers to these major questions

# Main Tools

- *Cosmic Microwave Background (CMB)*
  - Fossil light of the Big Bang
  - Excellent probe of the early universe: **Inflation**



- *Large-scale structure (LSS): distribution of galaxies and galaxy clusters*
  - Probing the late-time universe: **dark energy** and **mass of neutrinos**



Dark Energy
Accelerated Expansion

Afterglow Light
Pattern
380,000 yrs.

Dark Ages

Development of
Galaxies, Planets, etc.

Inflation

WMAP

Quantum
Fluctuations

1st Stars
about 400 million yrs.

Big Bang Expansion

13.7 billion years

# 10 Members (as of today)

- Director
  - *Prof. Dr. Eiichiro Komatsu*
- Scientific staff member
  - *Dr. Fabian Schmidt*
- Junior members
  - Three postdoctoral fellows
  - Five Ph.D. students
- 4 female; 6 male members

# Example: Latest PhD Thesis

*Chi-Ting Chiang*
*[now at Stony Brook, NY]*

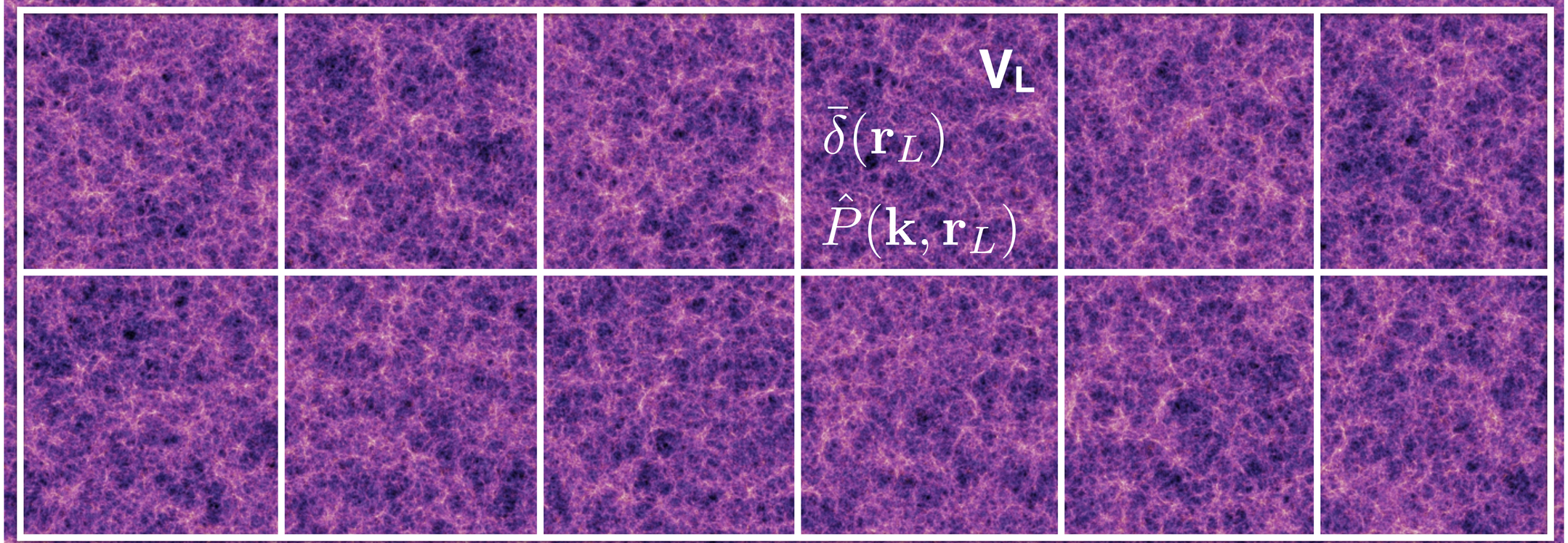

- **How does the cosmic structure depend on the surrounding environments?**

# Simple Statistics

$$\bar{\delta}(\mathbf{r}_L) = \frac{1}{V_L}\int_{V_L} d^3r\ \delta(\mathbf{r})$$

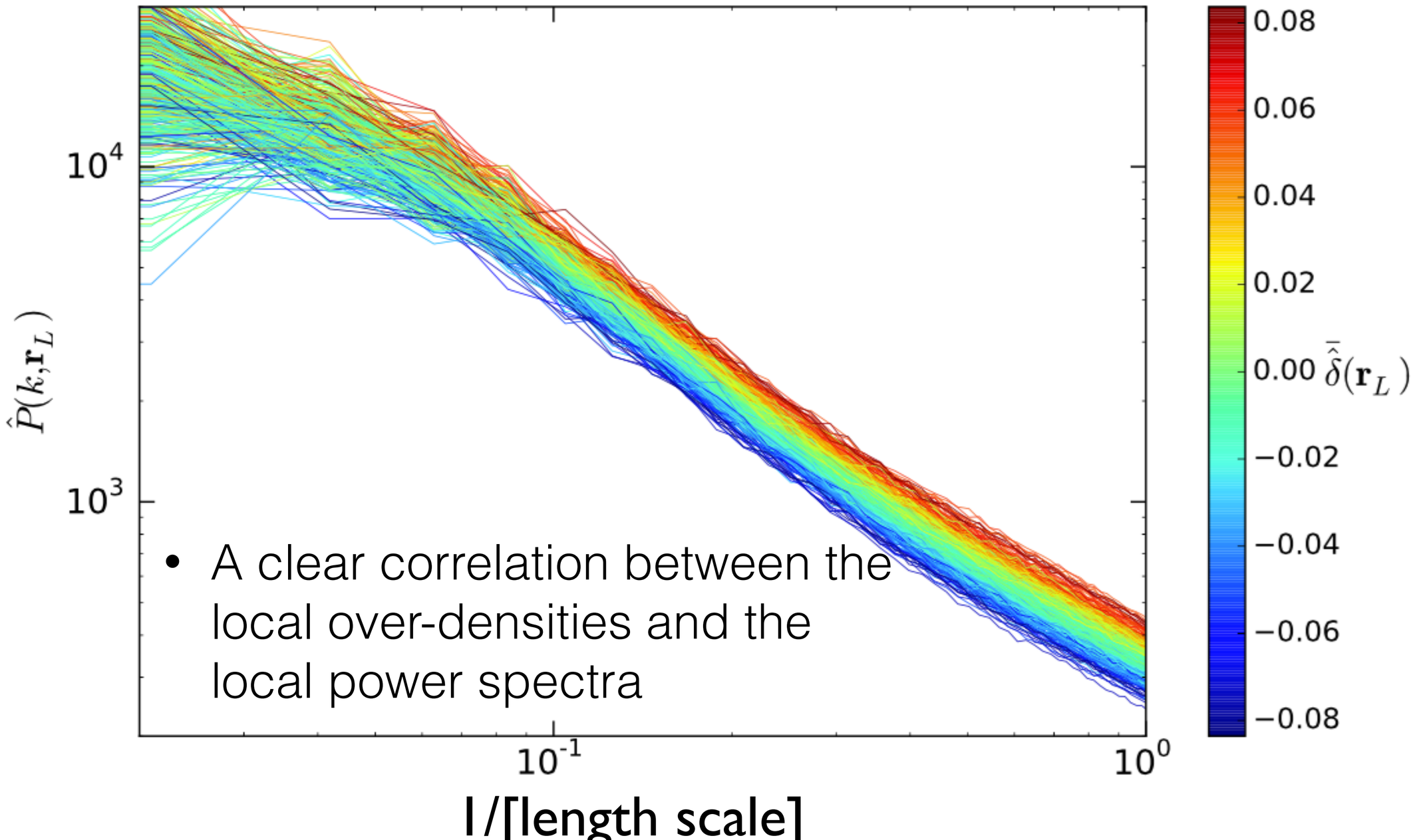
$$\hat{P}(\mathbf{k}, \mathbf{r}_L) \equiv \frac{1}{V_L}|\delta(\mathbf{k}, \mathbf{r}_L)|^2$$

500 Mpc/h




- Divide the survey volume into many sub-volumes $V_L$, and compare locally-measured power spectra with the corresponding local over-densities

# Position-dependent $\hat{P}(k)$

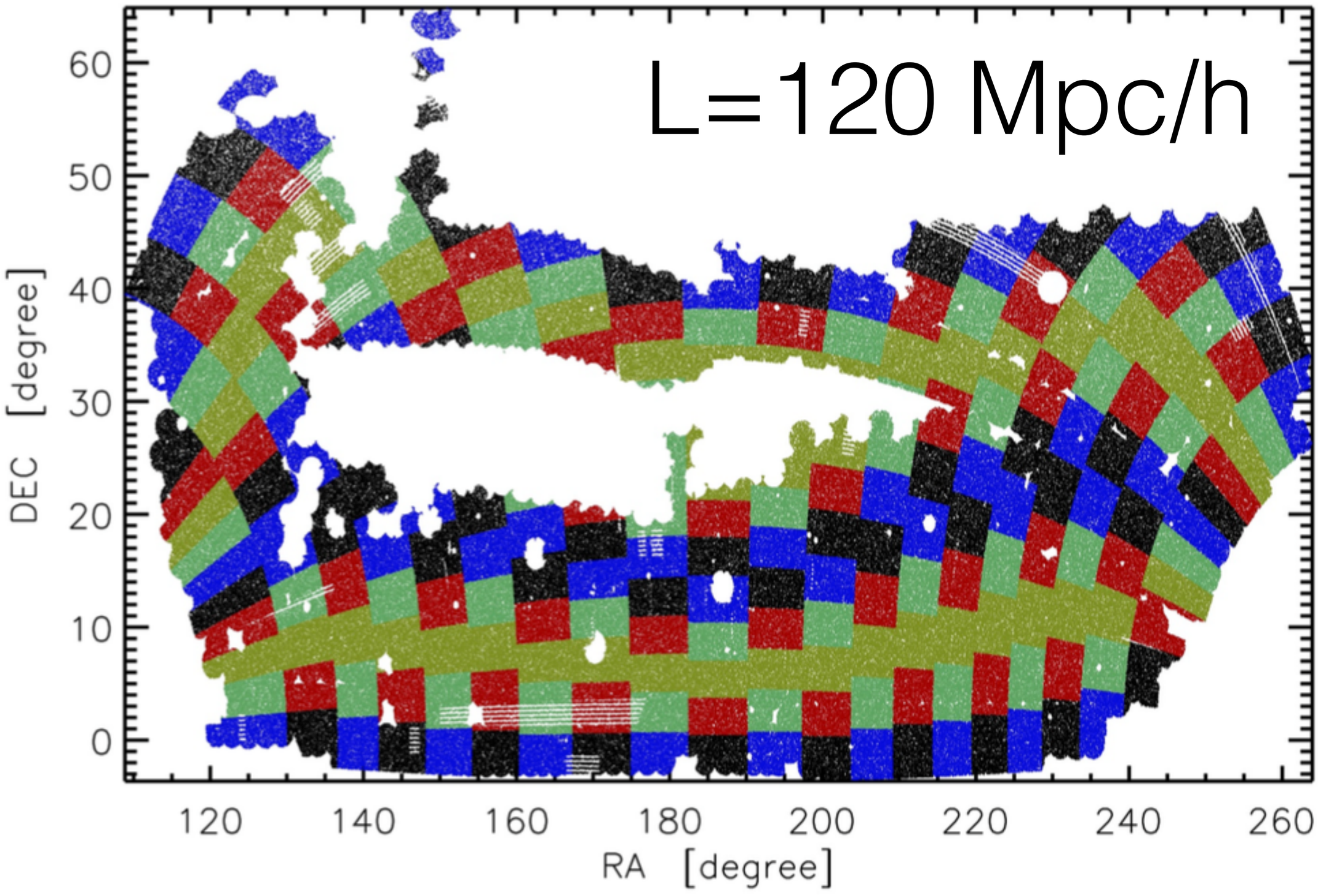


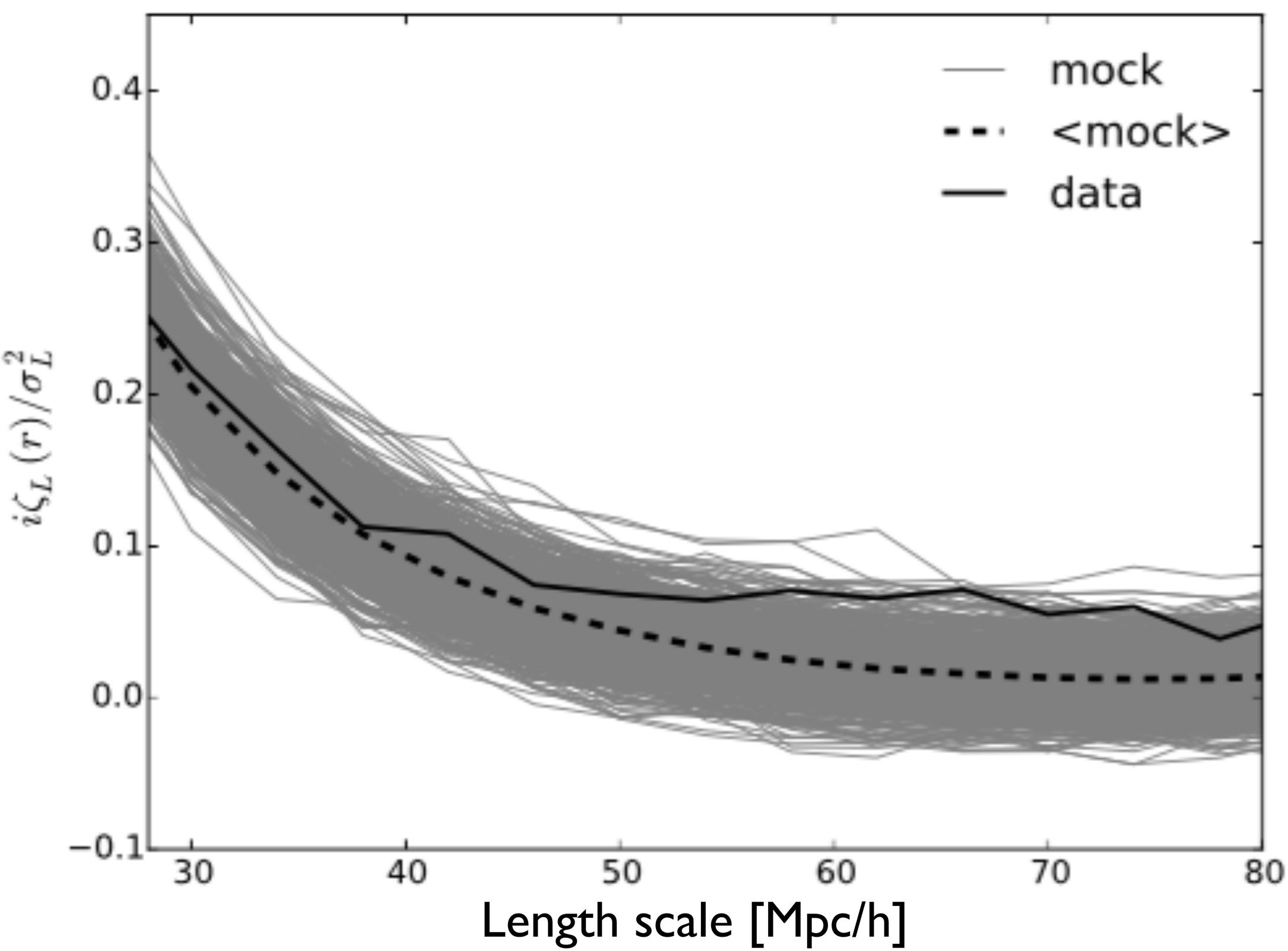

- A clear correlation between the local over-densities and the local power spectra

# New Theoretical Formula

$$P(k,a|\bar{\delta}) = \tilde{P}\left(k, a\left[1-\frac{1}{3}\bar{\delta}(a)\right]\right)\left[1+\left(2-\frac{1}{3}\frac{d\ln k^3 P(k,a)}{d\ln k}\right)\bar{\delta}(a)\right]$$

- Do we see this in the real universe?


L=120 Mpc/h
DEC [degree]
60
50
40
30
20
10
0
120
140
160
180
200
220
240
260
RA [degree]


mock
<mock>
data
0.4
0.3
0.2
0.1
0.0
−0.1
30
40
50
60
70
80
$i\zeta_L(r)/\sigma_L^2$
Length scale [Mpc/h]

Idea

Data

mock

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data

**7.4σ** measurement of the environmental dependence of the structure formation

$i\zeta_L(r)/\sigma_L^2$

0.4

0.3

0.2

0.1

0.0

−0.1

30

40

50

60

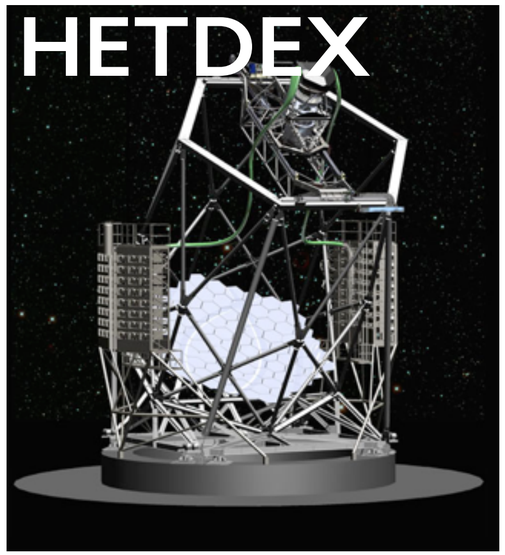
70

80

Length scale [Mpc/h]

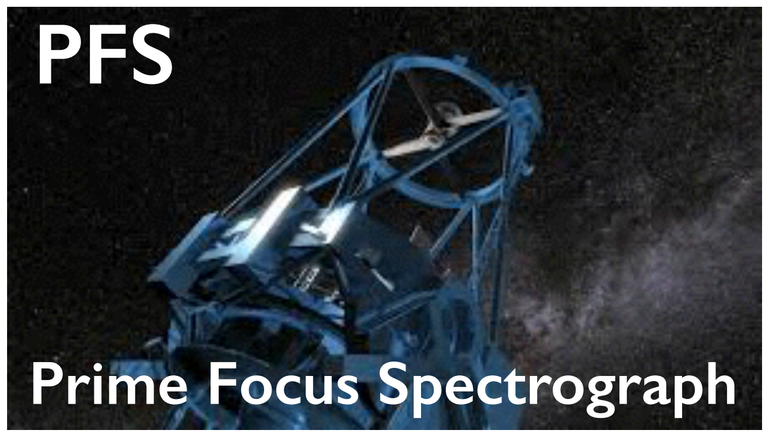
# A Plenty of Exciting New Data Are Coming to Our Group

2016 2019 2025 2030




Galaxy survey in 1.9<z<3.5
using a 10-m telescope in Texas

*Dark energy, neutrino mass*




Galaxy survey in 0.8<z<2.4
using a 8-m telescope
in Hawaii

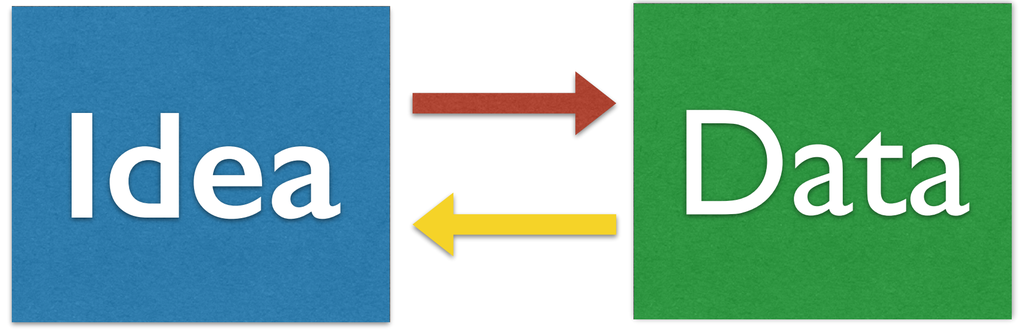
*Dark energy, neutrino mass*


Polarisation of CMB to
detect gravitational waves

*Inflation*

# A Typical Thesis Structure

- Chapter 1: Introduction
- Chapter 2: Brilliant New Idea
- Chapter 3: Methodology and Tests
- Chapter 4: Application to the Real Data
- Chapter 5: Exciting New Results
- Chapter 6: Conclusions



# Possible Thesis Projects (FS)

- Modified Gravity (MG) and Inflation, **using the LSS**
  - Understanding the relation between galaxies, dark matter, and the initial conditions from inflation
  - Testing General Relativity on cosmological scales, using measurements of velocities and gravitational lensing
  - Looking for imprints of inflation in large-scale structure: gravitational waves and mode coupling (non-Gaussianity)