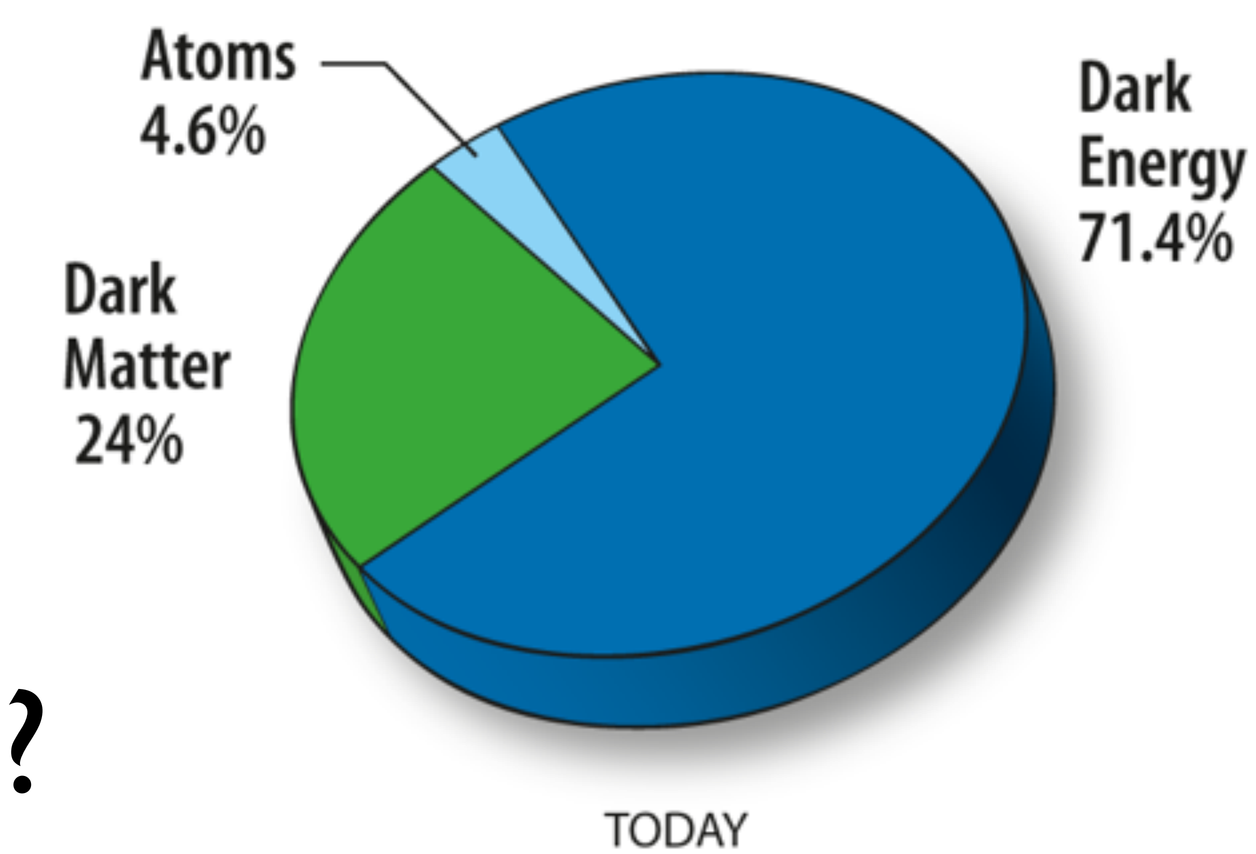
Division of Physical Cosmology

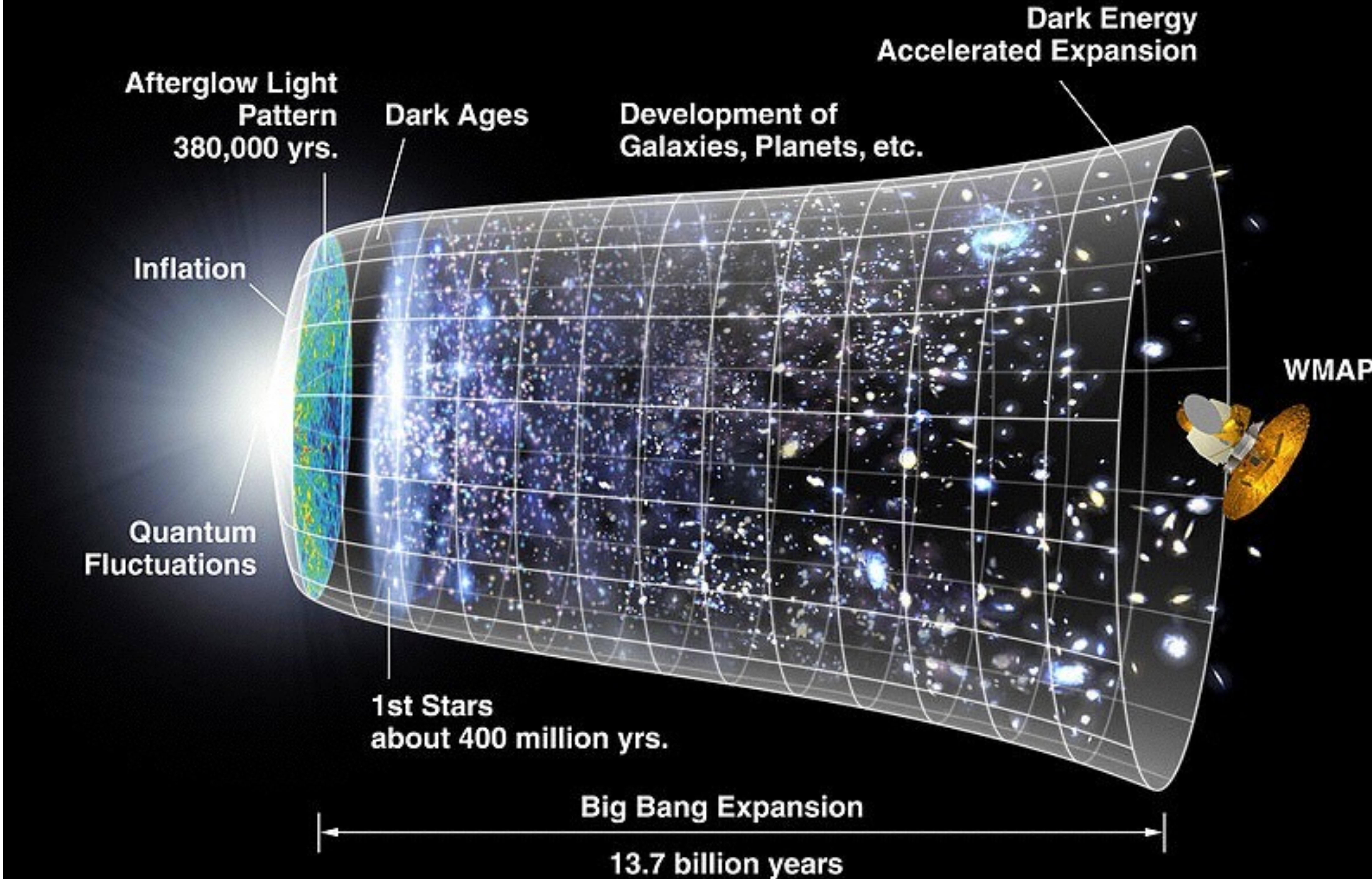
MPI für Astrophysik

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?

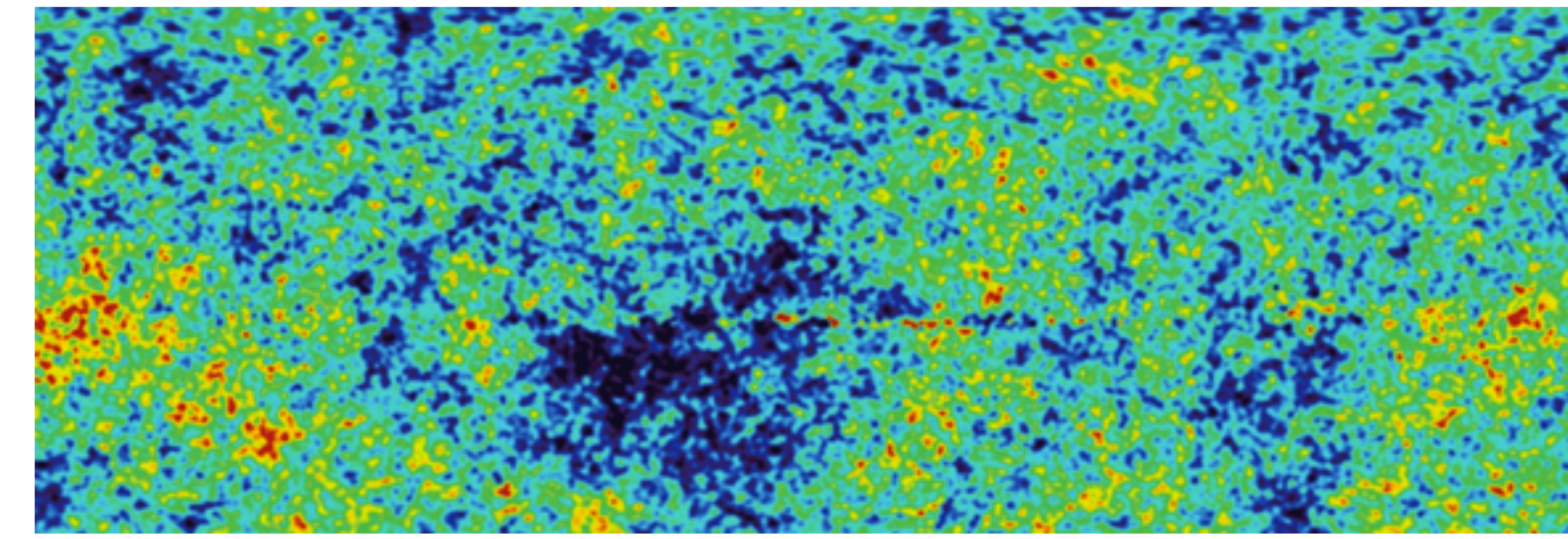


We use both theory and observational data to seek answers to these major questions.

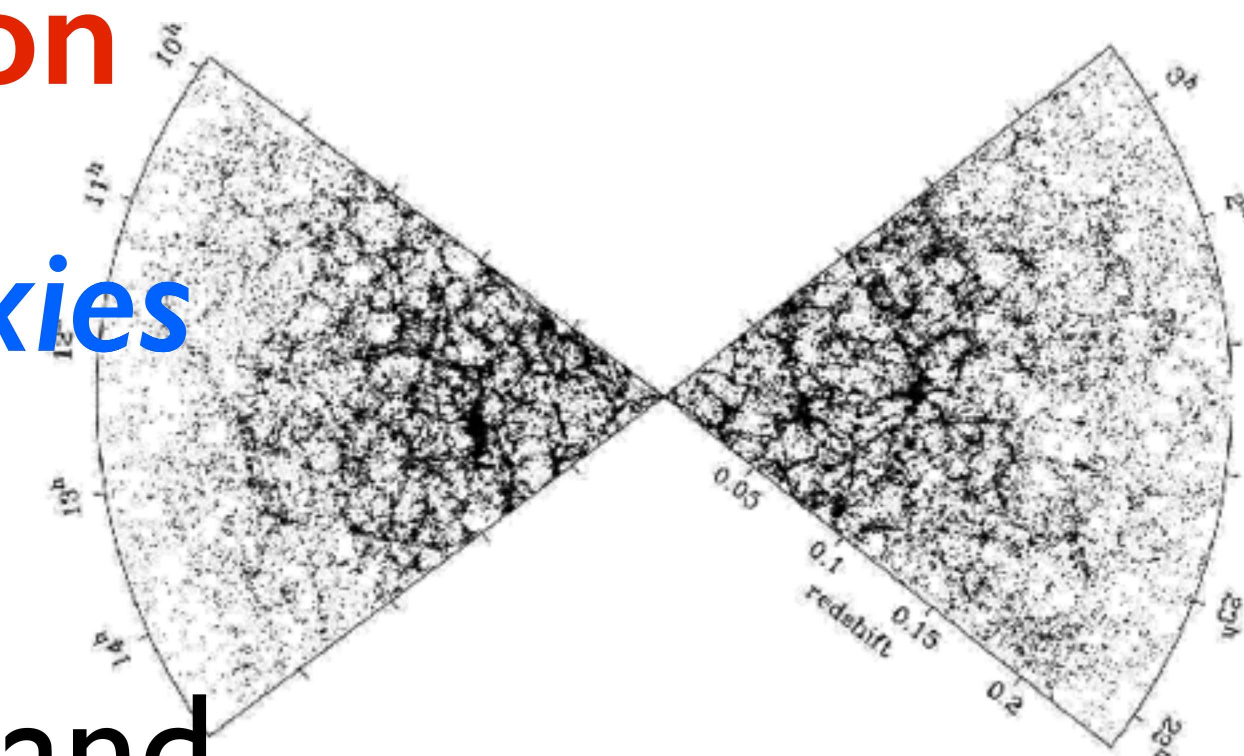

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

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**

- *Gravitational lensing*
  - Distribution of **dark matter**

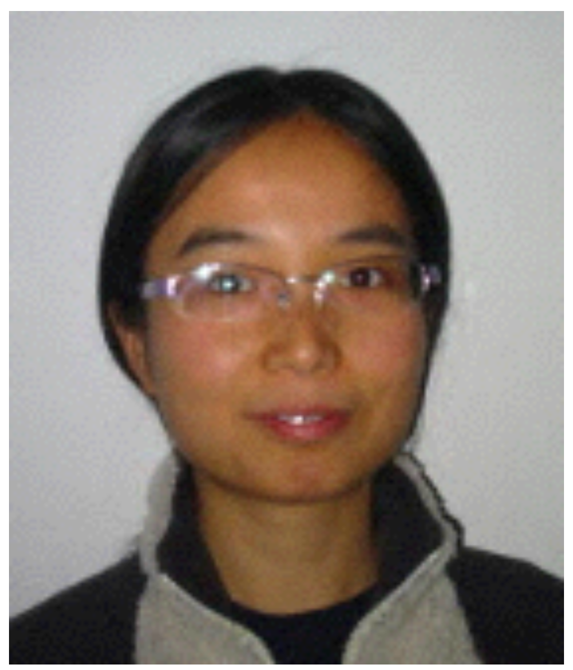
10 Members (as of today)

- Director
  - *Prof. Dr. Eiichiro Komatsu*
- Scientific staff member
  - *Dr. Fabian Schmidt*
- Junior members
  - Three postdoctoral fellows
  - Five Ph.D. students
- 3 female; 7 male members

Recent Research Highlights

- ***First*** **analytical model for non-thermal pressure in galaxy clusters**

Xun Shi



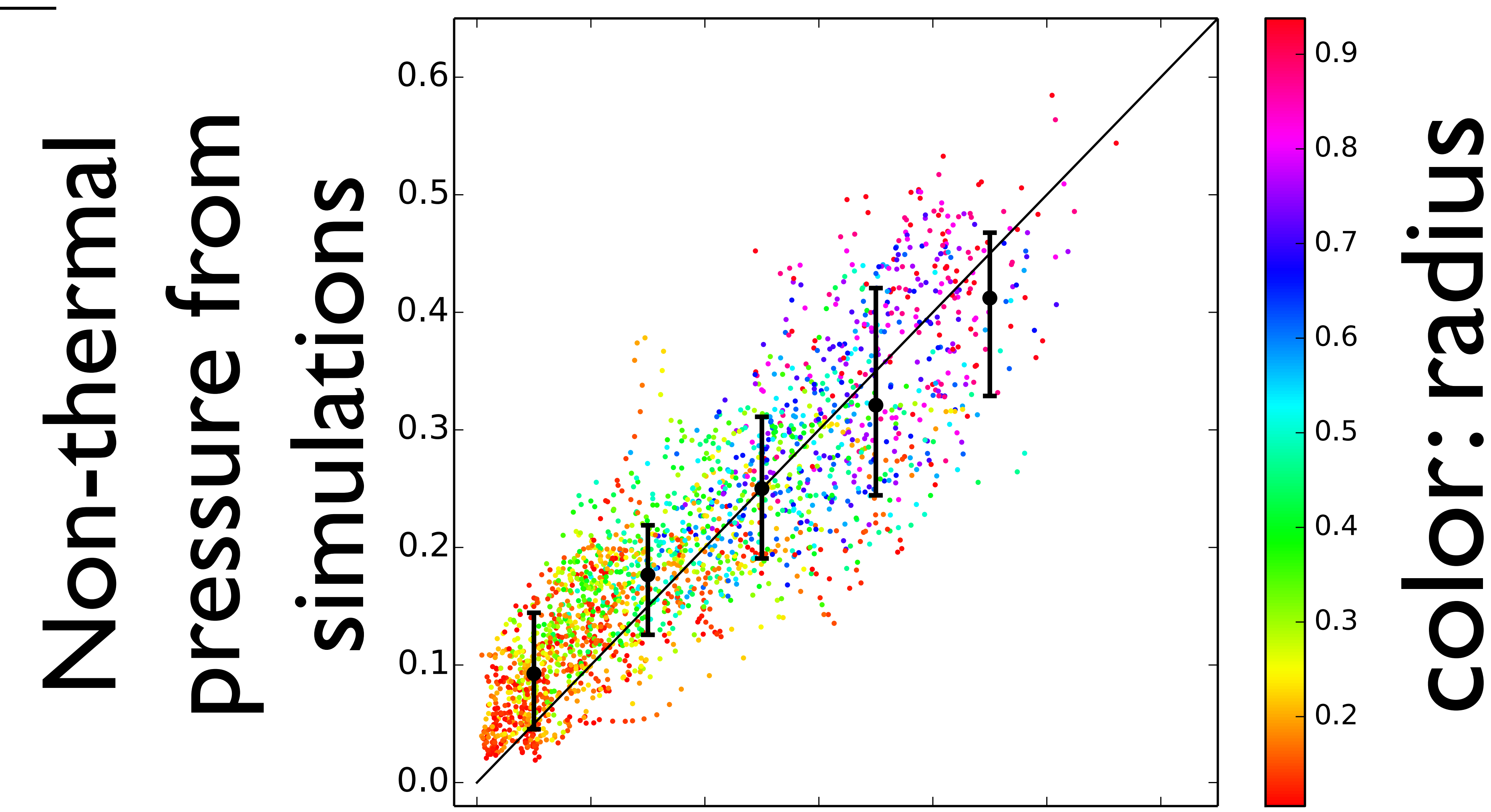
- *Shi & Komatsu (2014); Shi, Komatsu, Nelson & Nagai (2015)*
- Gave a clear physical understanding of the origin and evolution of non-thermal motion in galaxy clusters

$$\frac{1}{\rho_{\rm gas}(r)}\frac{\partial[P_{\rm th}(r)+P_{\rm non-th}(r)]}{\partial r}=-\frac{GM(<r)}{r^2}$$

[$\sigma^2=P/\rho_{\rm gas}$]

$$\frac{d\sigma^2_{\rm nth}}{dt}=-\frac{\sigma^2_{\rm nth}}{t_{\rm d}}+\eta\frac{d\sigma^2_{\rm tot}}{dt}$$

New equation to describe evolution of non-thermal (nth) velocity dispersion



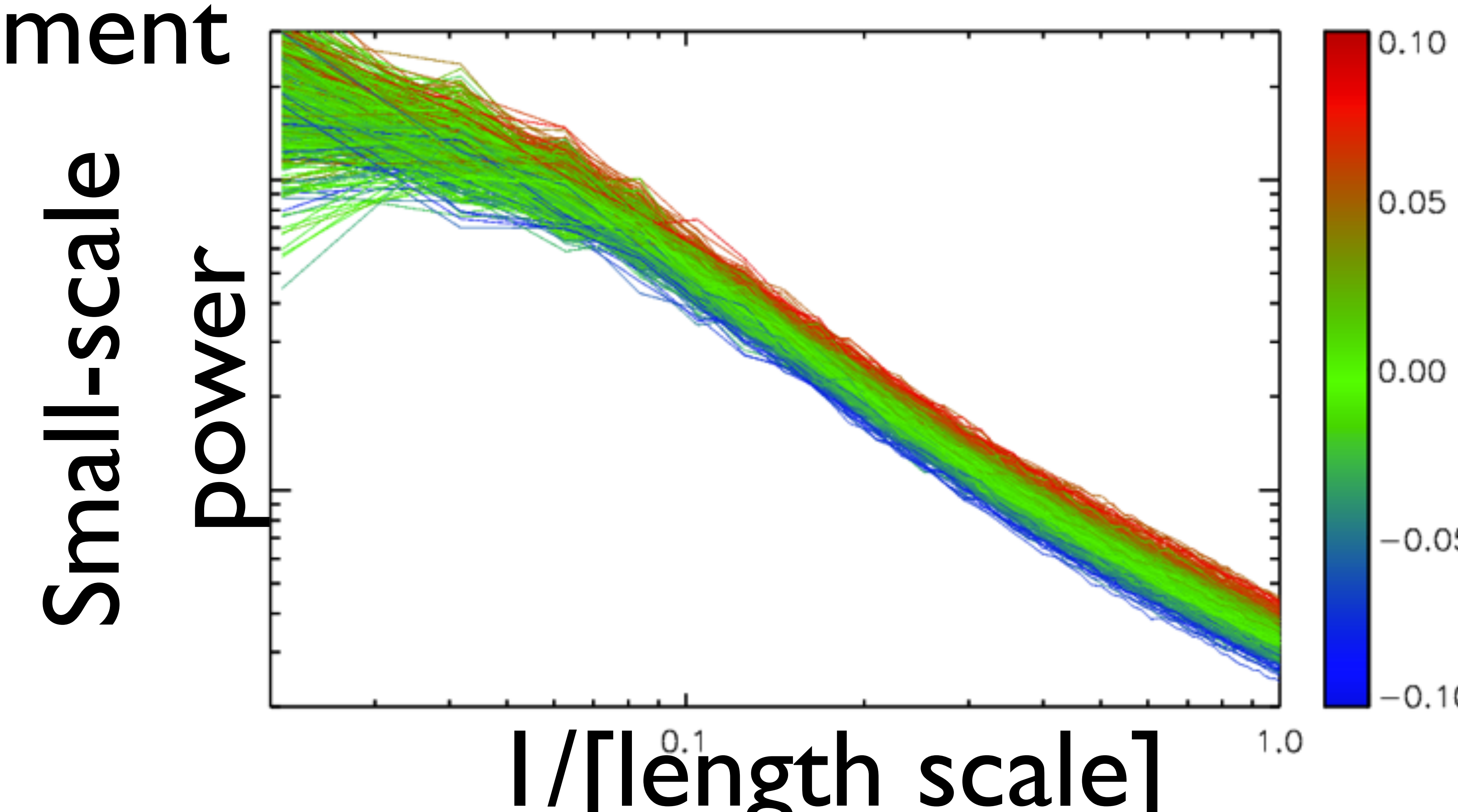
Non-thermal pressure calculated

Recent Research Highlights

- ***New observable*** of the large-scale structure of the universe: position-dependent power spectrum

Chi-Ting Chiang

- *Chiang, Wagner, Schmidt & Komatsu (2014); Wagner, Schmidt, Chiang & Komatsu (2015)*
- It allows us to quantify how the cosmic structures develop on small scales depending on the large-scale environment



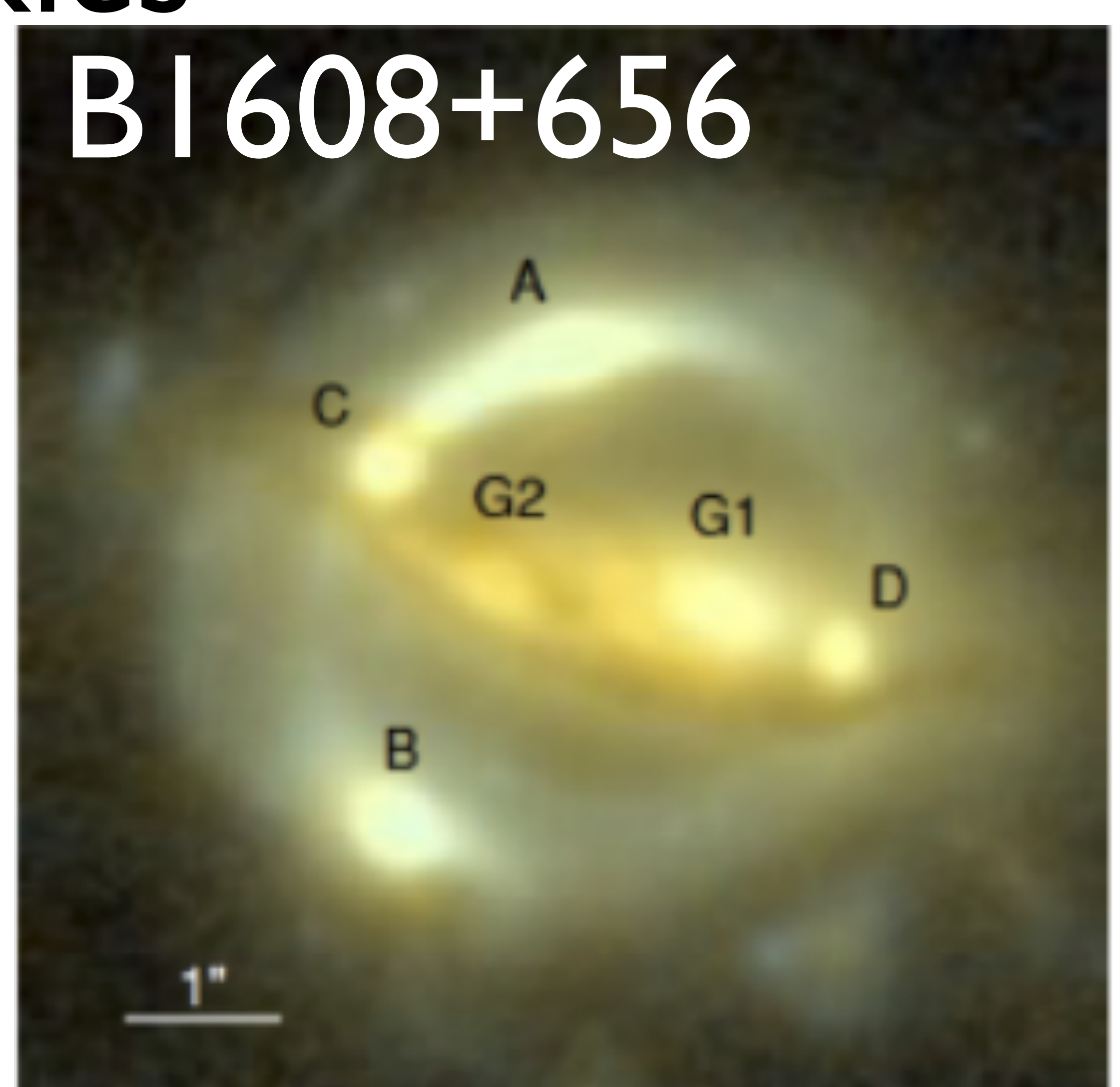
Large-scale density fluctuation:
Red=large
Blue=small

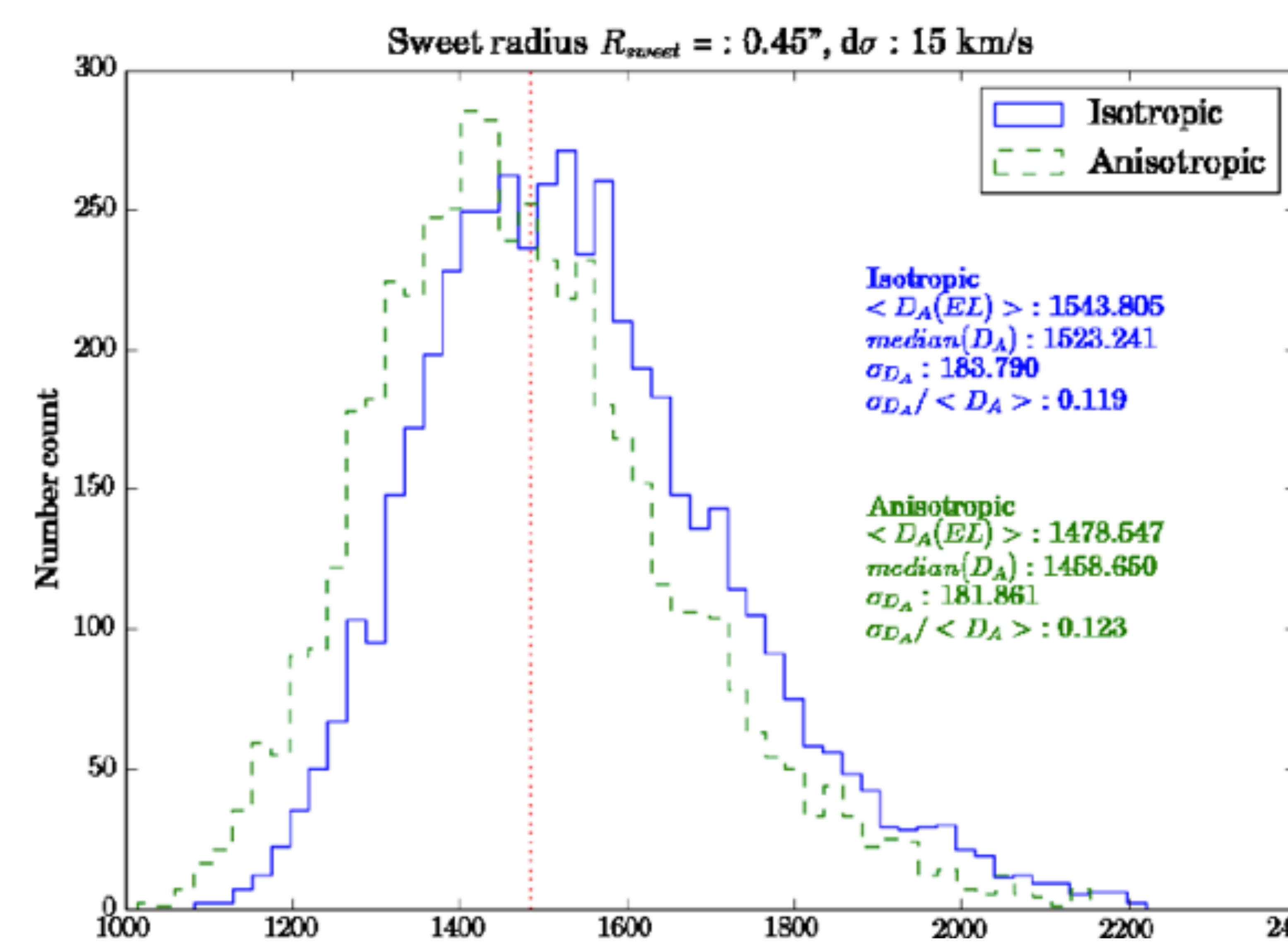
Recent Research Highlights

- ***New cosmological rulers***: gravitational lenses

Inh Jee

- *Jee, Komatsu & Suyu (2014)*
- Showed that measurements of gravitational lensing time-delays and velocity dispersion of stars can be combined to infer angular diameter distances to lens galaxies

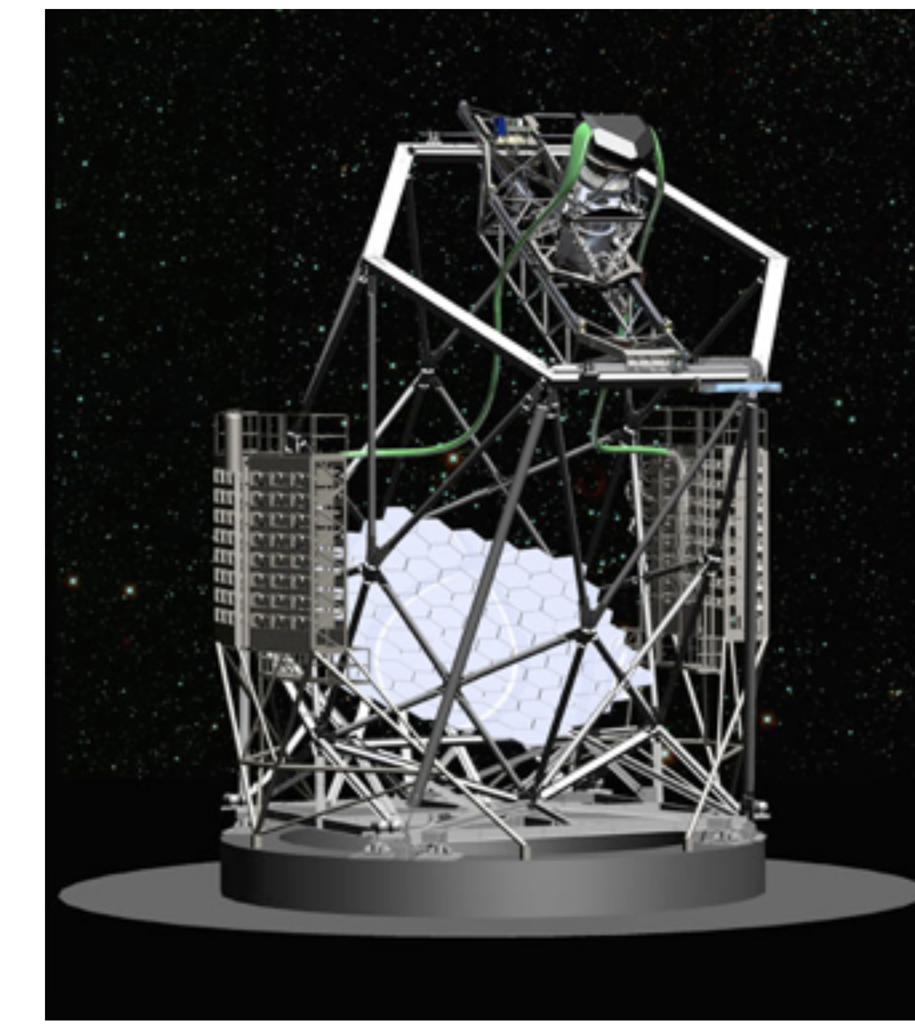




Distribution of inferred distance

Possible Thesis Projects (EK)

- Students will mainly be involved in **the LSS projects:**



  - Komatsu is involved in a new galaxy survey project called “Hobby-Eberly Telescope Dark Energy Experiment” (**HETDEX**), which begins this year

Data Analysis

  - One project is to analyse the data to obtain 3-dimensional positions of Lyman-alpha emitting galaxies (LAEs; **z=1.9–3.5**), measure the spatial correlations and physical properties of LAEs

Theory

  - Another project is to develop the theoretical model of the spatial correlations including the effects of **neutrinos and peculiar velocities** to extract cosmological parameters from the data

third-order matter power spectrum, $P_{\delta\delta}(k)$, as

$$P_g(k) = P_0 + \tilde{b}_1^2\left[P_{\delta\delta}(k) + \tilde{b}_2 P_{b2}(k) + \tilde{b}_2^2 P_{b22}(k)\right],$$

where P_{b2} and P_{b22} are given by

$$P_{b2} = 2\int \frac{d^3\mathbf{q}}{(2\pi)^3} P_L(q) P_L(|\mathbf{k}-\mathbf{q}|) F_2^{(s)}(\mathbf{q}, \mathbf{k}-\mathbf{q}),$$

and

$$P_{b22} = \frac{1}{2}\int \frac{d^3\mathbf{q}}{(2\pi)^3} P_L(q)\left[P_L(|\mathbf{k}-\mathbf{q}|) - P(q)\right],$$

respectively, with $F_2^{(2)}$ given by

$$F_2^{(s)}(\mathbf{q}_1, \mathbf{q}_2) = \frac{5}{7} + \frac{2}{7}\frac{(\mathbf{q}_1\cdot\mathbf{q}_2)^2}{q_1^2 q_2^2} + \frac{\mathbf{q}_2\cdot\mathbf{q}_2}{2}\left(\frac{1}{q_1^2} + \frac{1}{q_2^2}\right).$$

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)