Towards Total Neutrino Mass Constraints through Multi-Wavelength Gravitational Lensing Measurements

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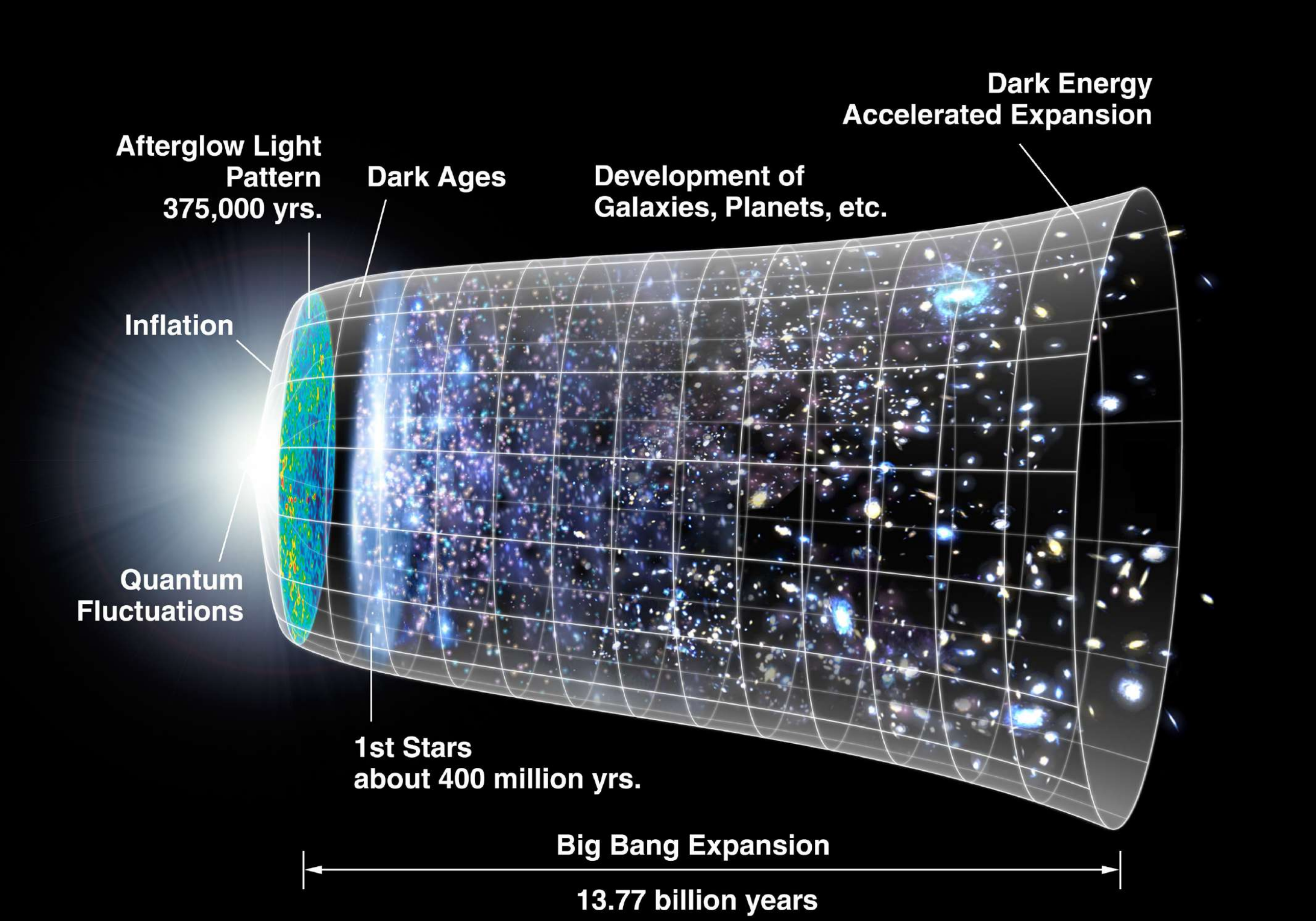
Outline

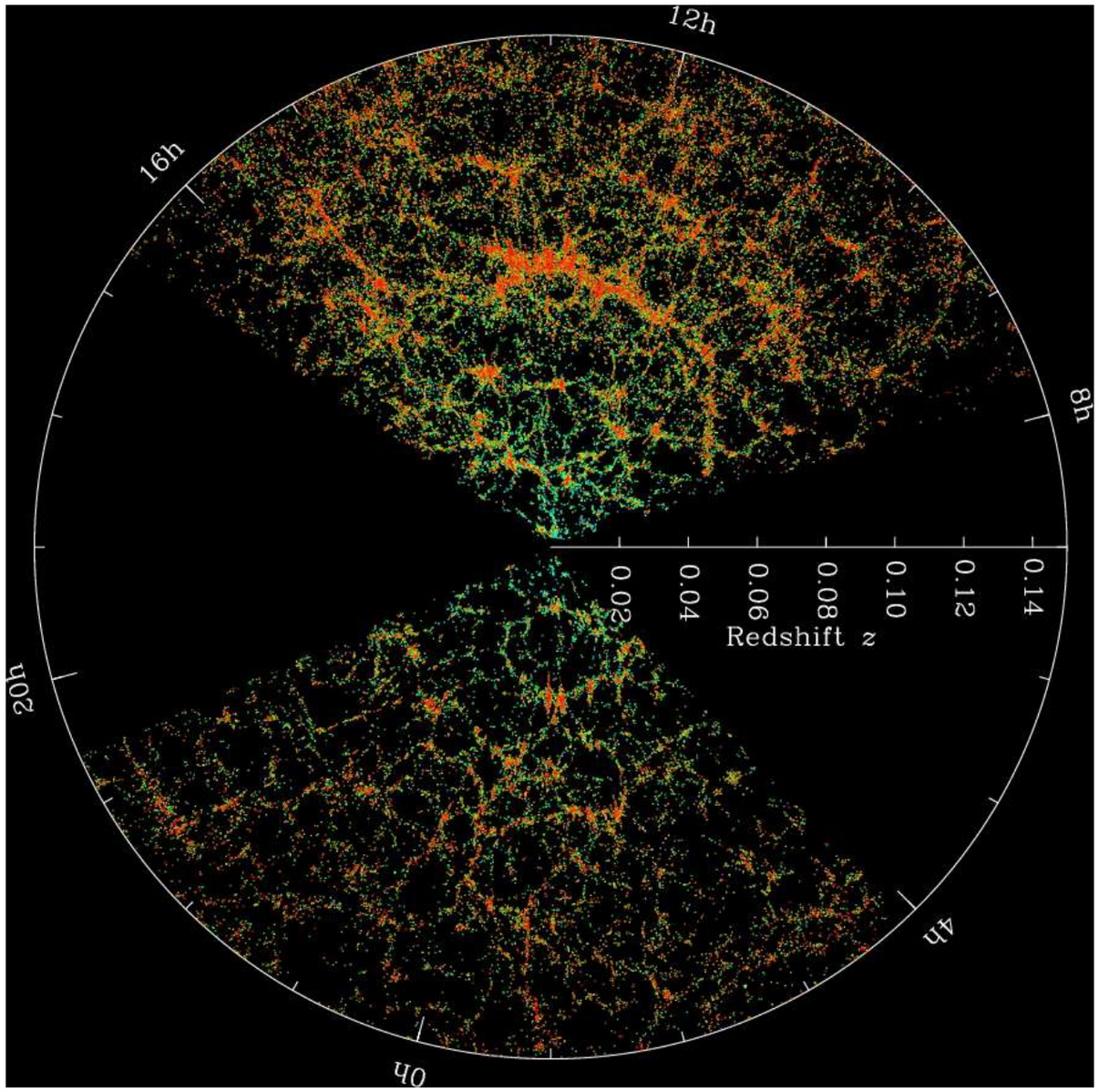
- Large scale structure of the Universe
- Neutrinos in large scale structure
- Galaxy cluster number count
- Gravitational lensing as a cluster mass estimator
- Pushing the maximum redshift by combining Subaru Hyper Suprime-Cam (HSC) and CMB experiments


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years

Credit: NASA

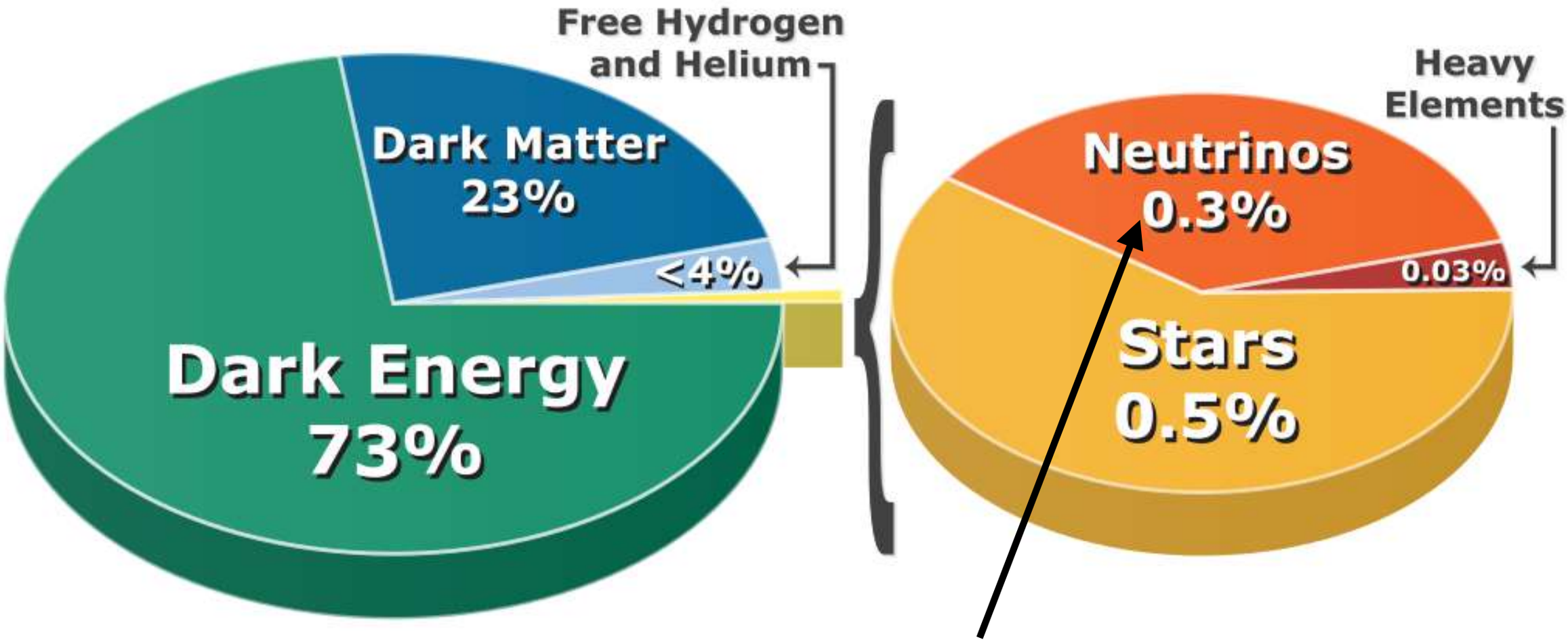
Large Scale Structure (LSS)

- LSS of the universe was formed from small scales (stars) to large scales (galaxies and galaxy clusters).
- Time evolution of LSS tells us what the universe consists of, e.g., dark matter and dark anergy, and their natures.
- Since we do not know the initial condition of the universe, we need to rely on summary statistics, e.g., cluster number counts and matter power spectrum.



Credit: SDSS

Neutrinos matter!



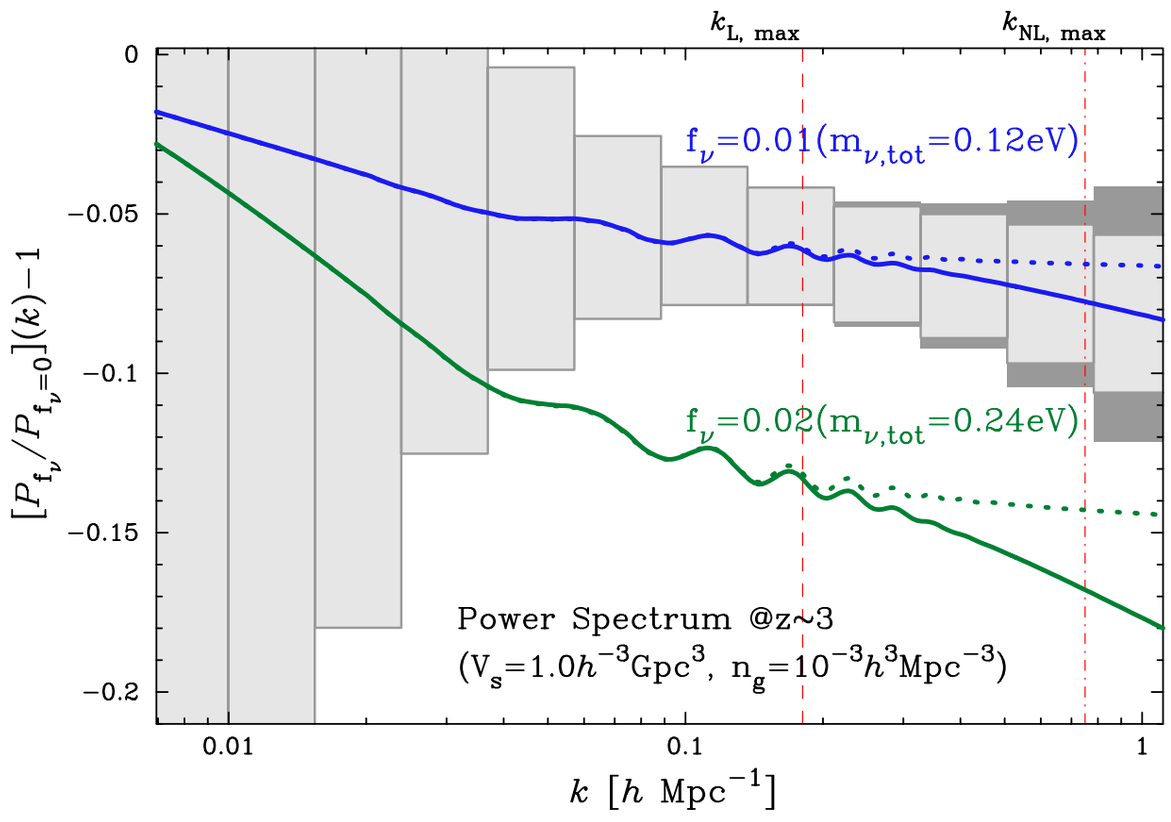
Upper Limit!

Neutrinos in LSS

- Due to the large free streaming, massive neutrinos do not cluster at small scales, but do at large scales.

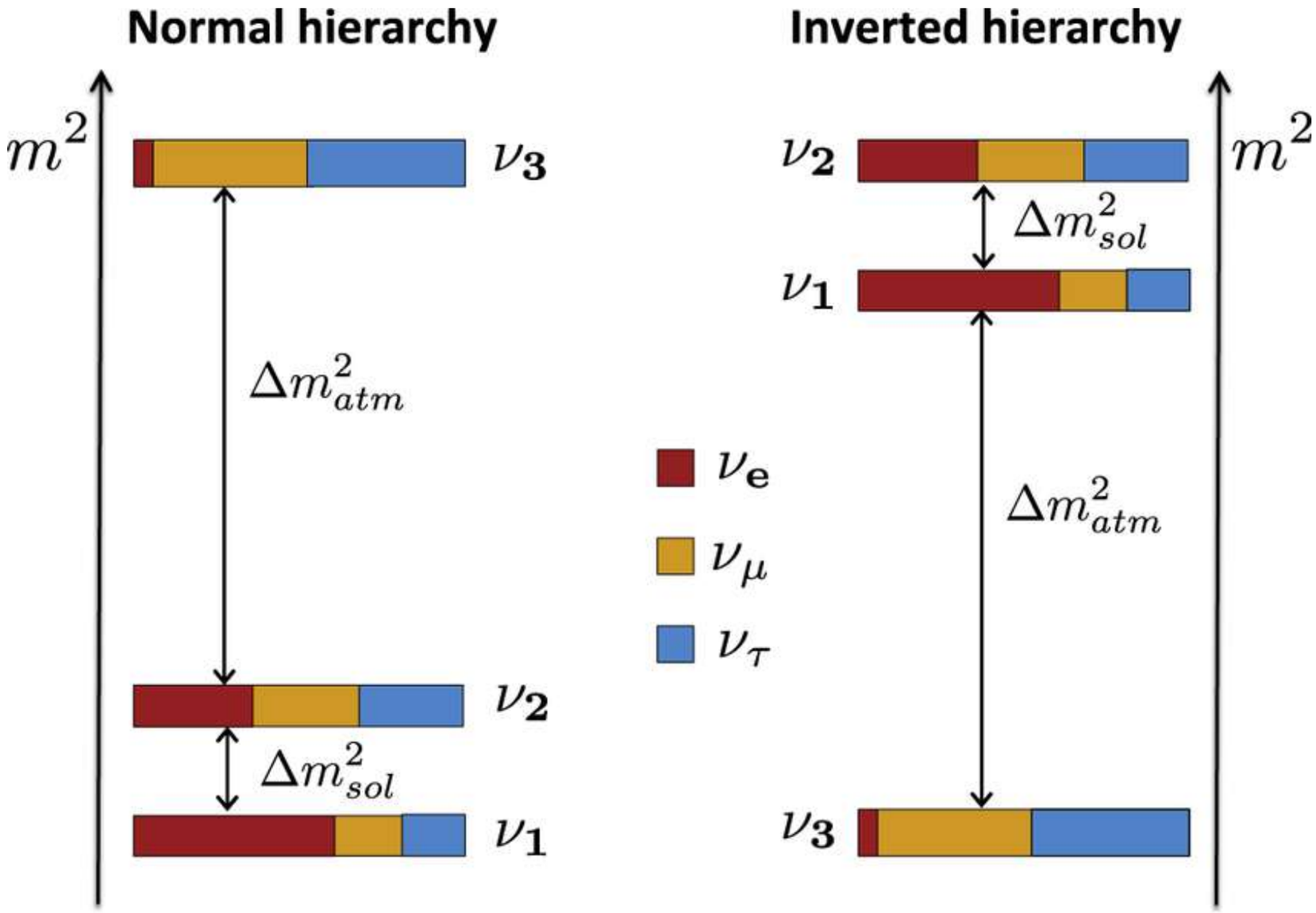
- Small scale structures are suppressed by massive neutrinos.

- We can place an upper limit on total neutrino mass through large scale structure measurements.



Saito, Takada, and Taruya (2008)

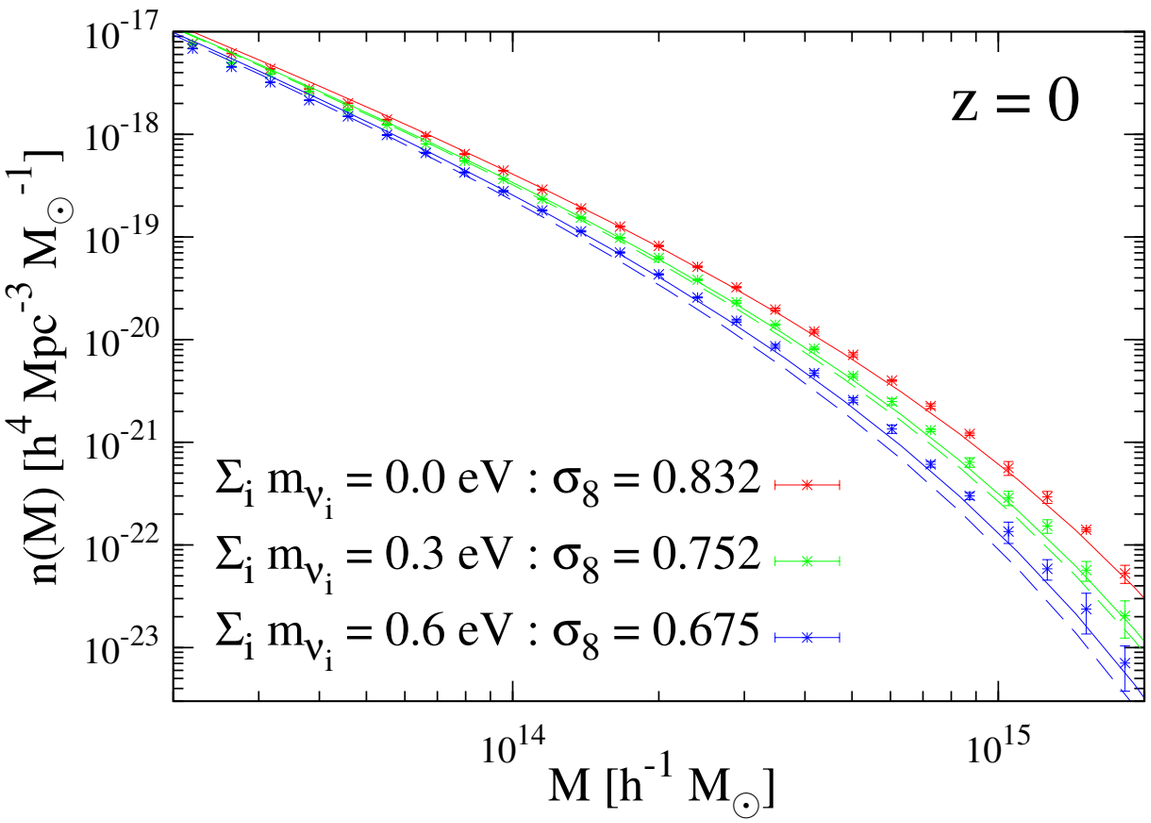
Neutrino Mass Hierarchy

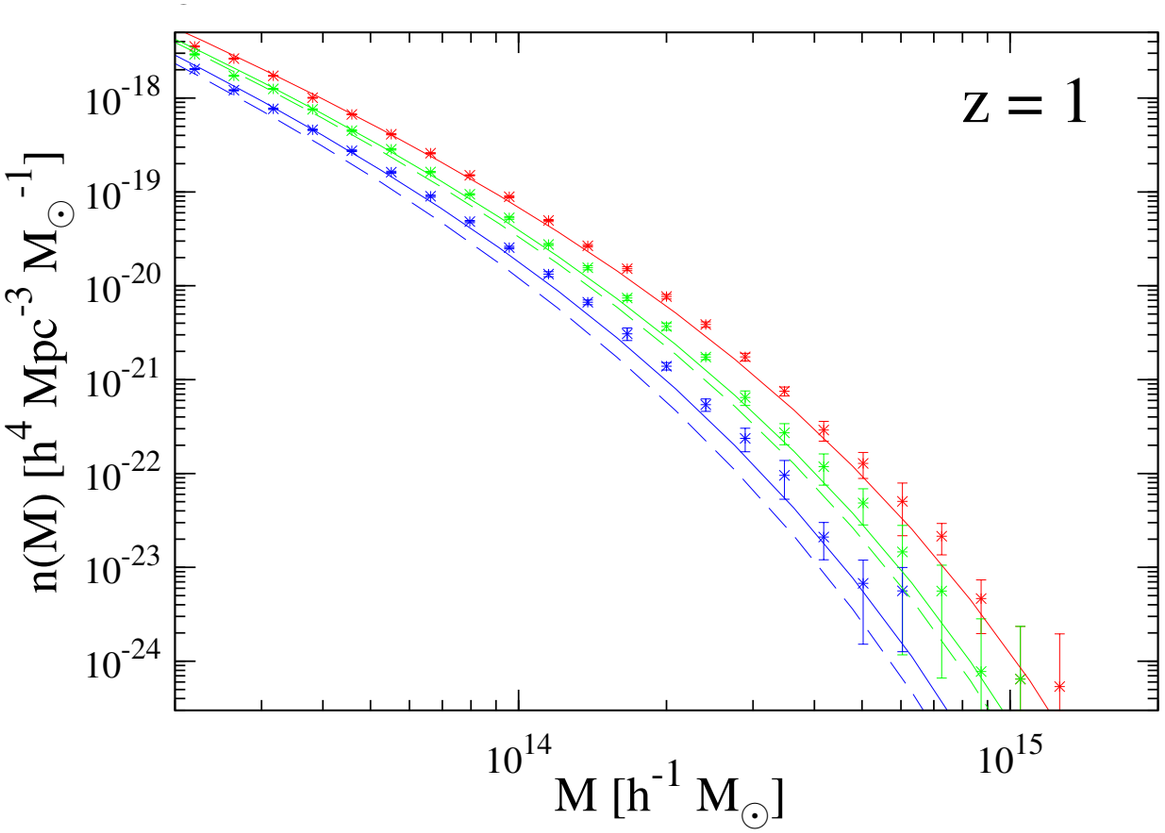


$$\sum m_\nu > 0.058 \text{ eV}$$

Adrián-Martínez et al. (2016)

Cluster Number Count





- Cluster number count is one of the powerful probes of LSS.
- Neutrinos suppress cluster formation and changes cluster evolution.

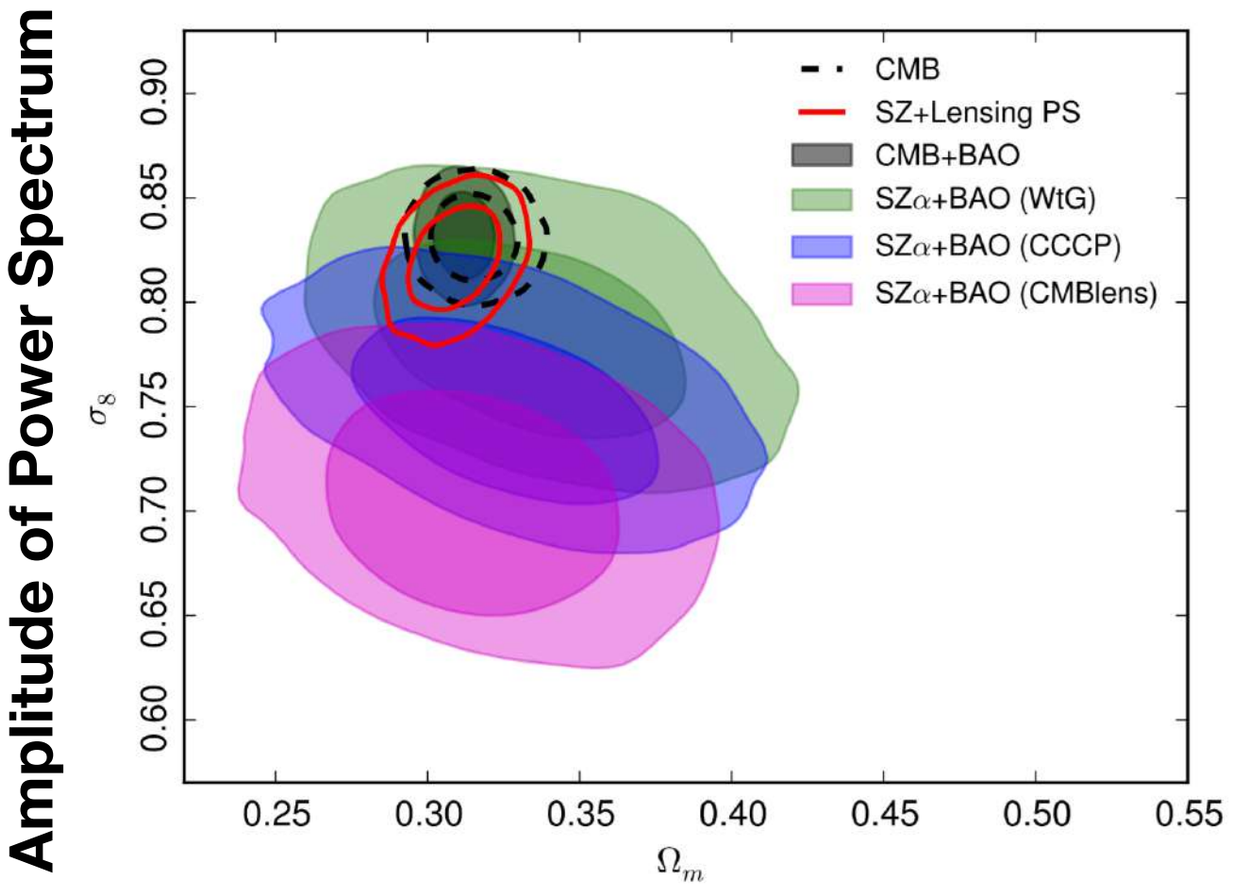
Costanzi et al. (2013)

Cluster Mass Calibration

- The number of galaxy clusters detected by Planck is smaller than the prediction from the primary CMB measurement.

- Estimating cluster mass is tricky, e.g., from X-ray and SZ observables, one needs to assume hydrostatic equilibrium.

- Cluster mass should be calibrated before talking about anything about neutrinos!



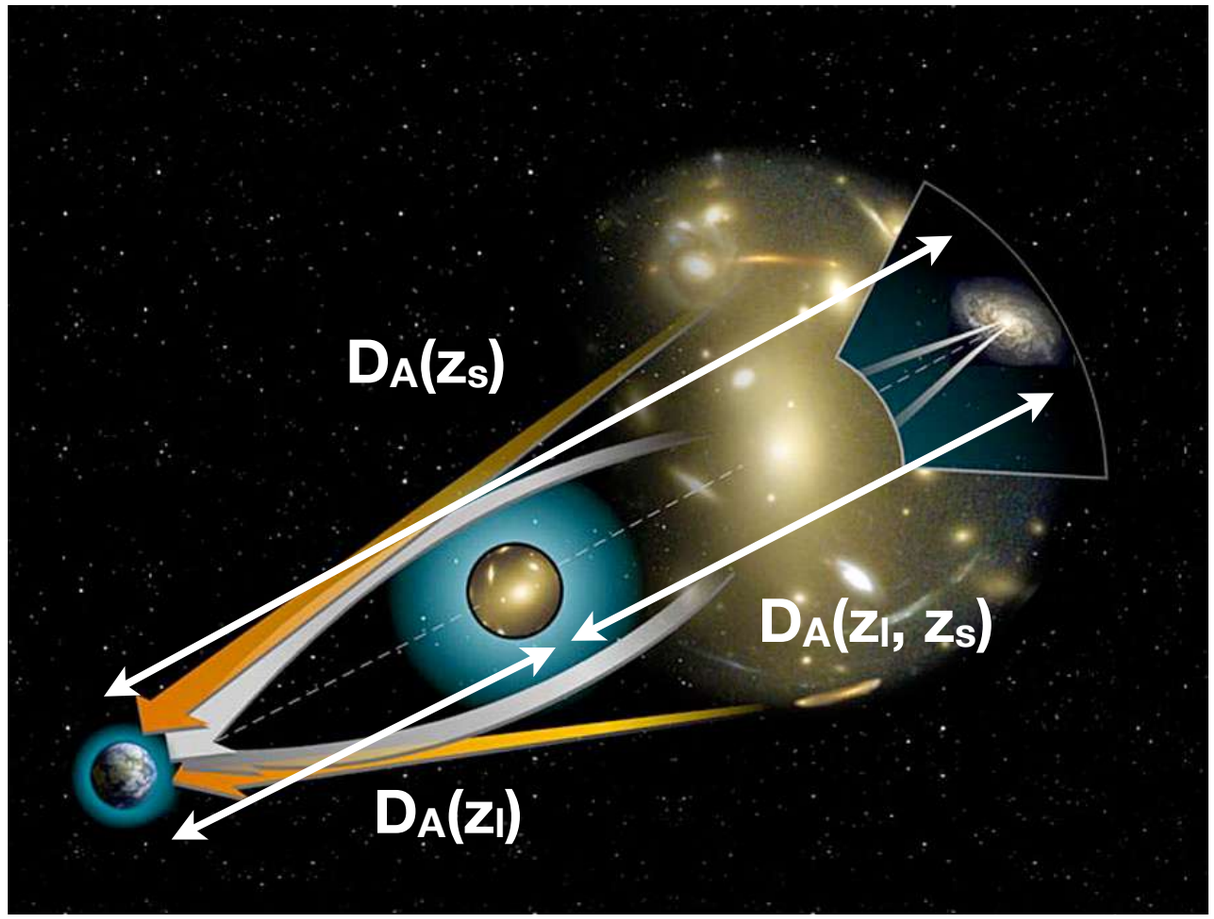
Planck 2015 XXIV

Mass Calibration by Weak Lensing

lensing shear — **matter (lens)**

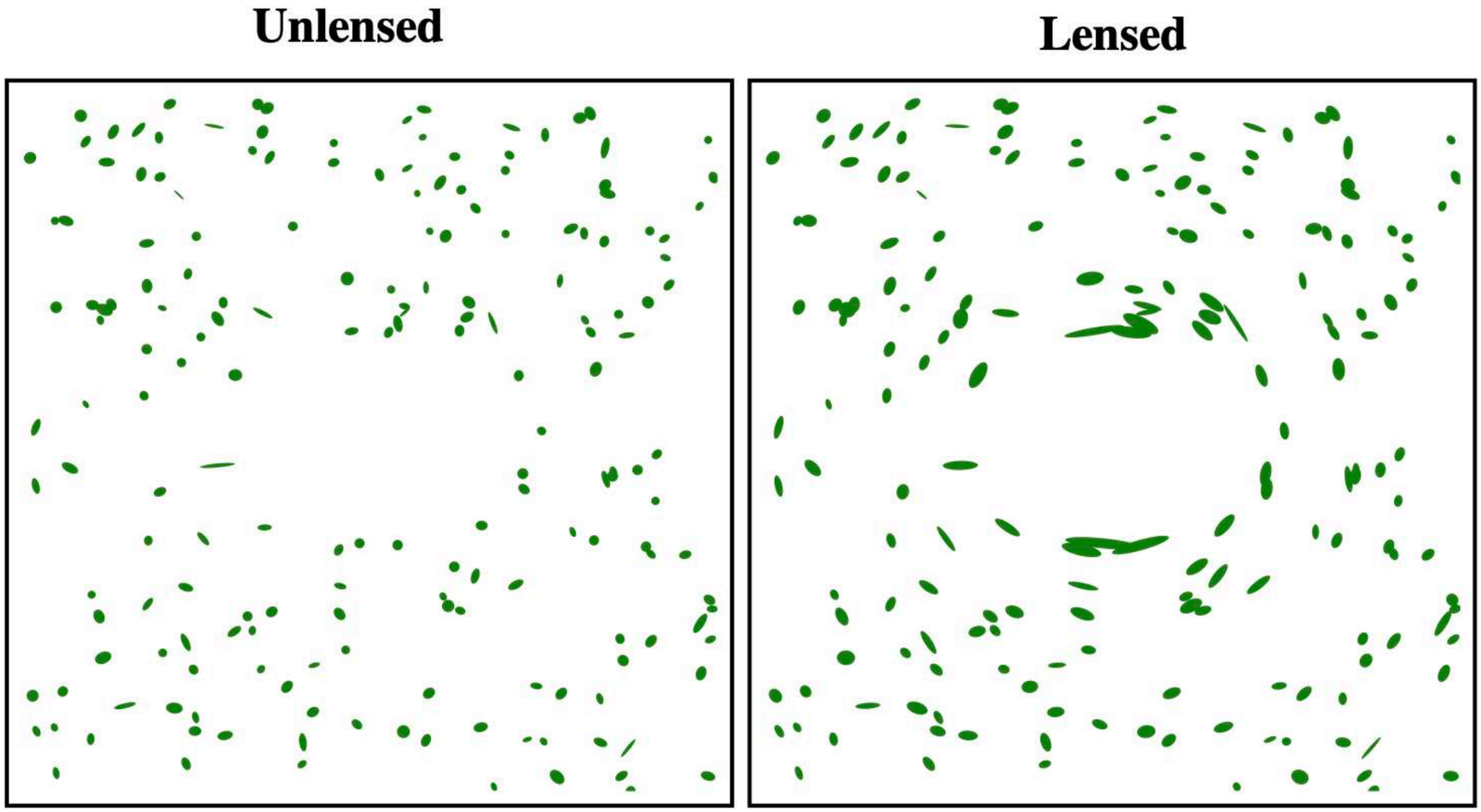
$$\gamma \propto \frac{D_A(z_l, z_s) D_A(z_l)}{D_A(z_s)} \delta(z_l)$$

lensing efficiency



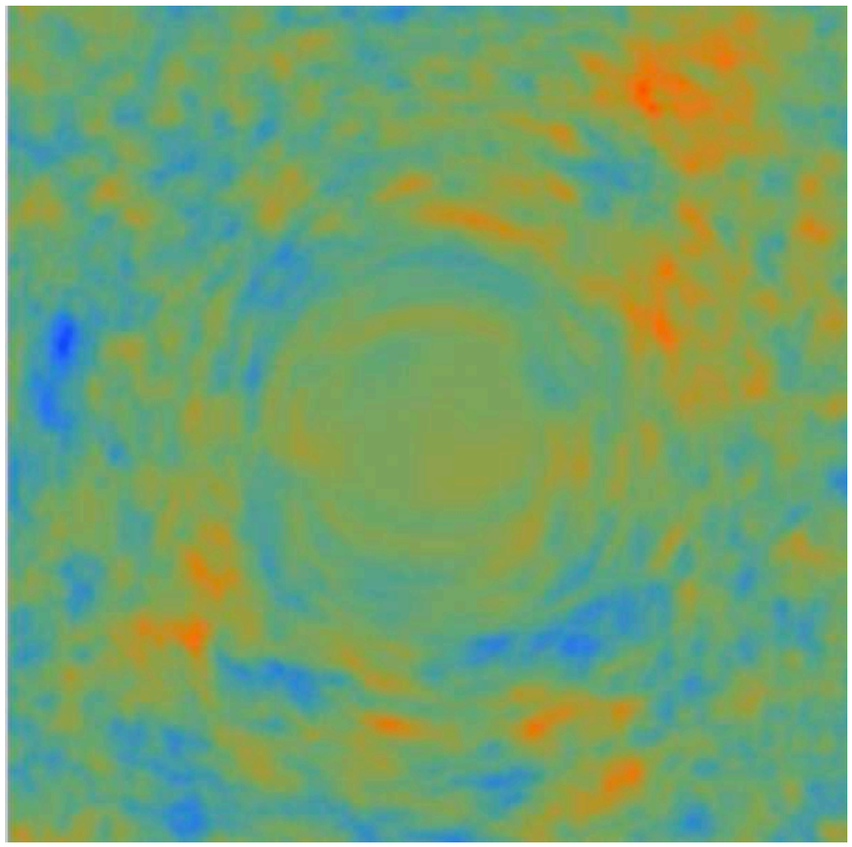
Direct measurement of matter distribution, including dark matter, around galaxy clusters

Mass Calibration by Weak Lensing

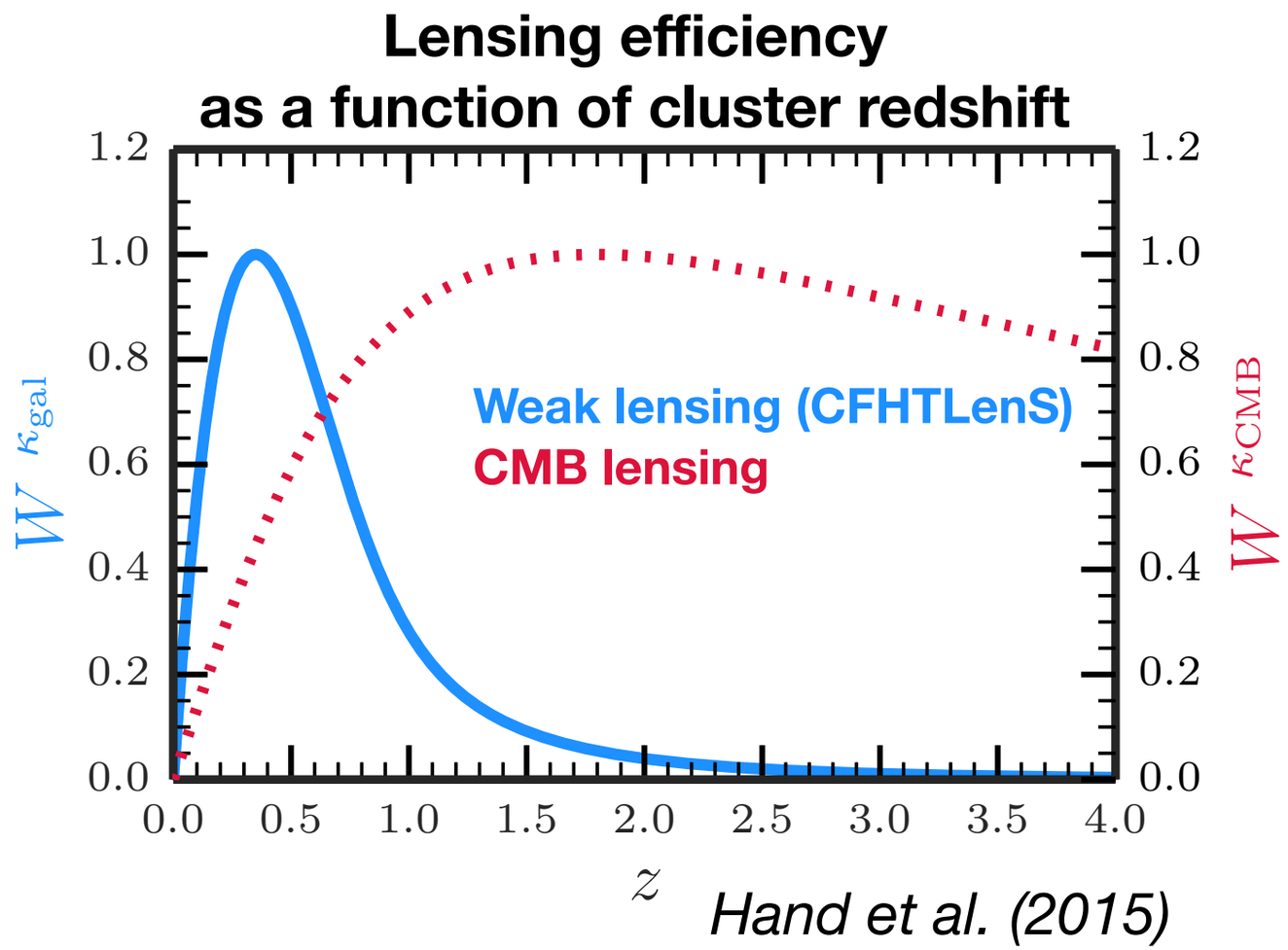


Weak lensing is the best tool to calibrate cluster mass, but we need a good telescope and instrument.

Mass Calibration by CMB Lensing



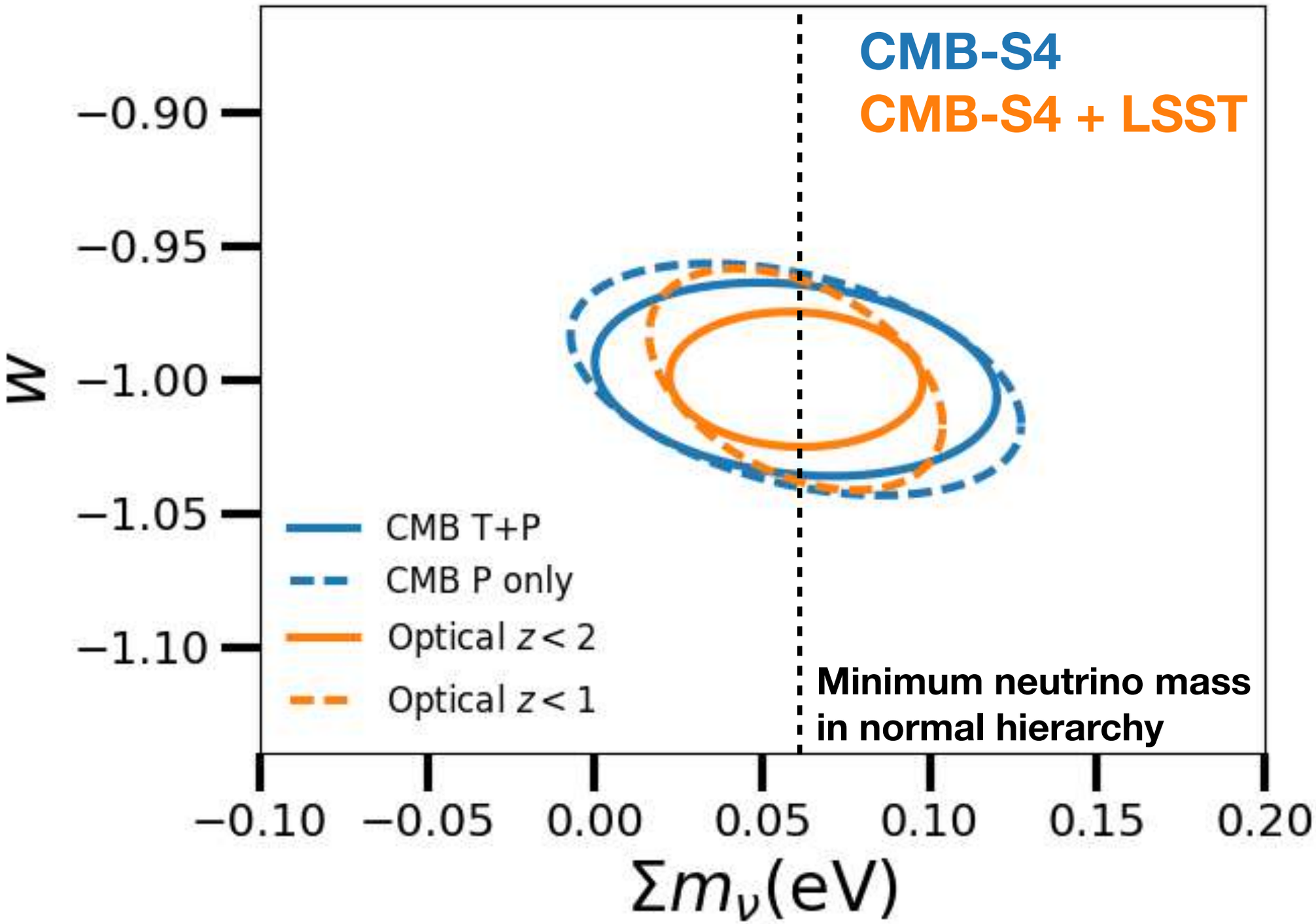
Credit: W. Hu



Hand et al. (2015)

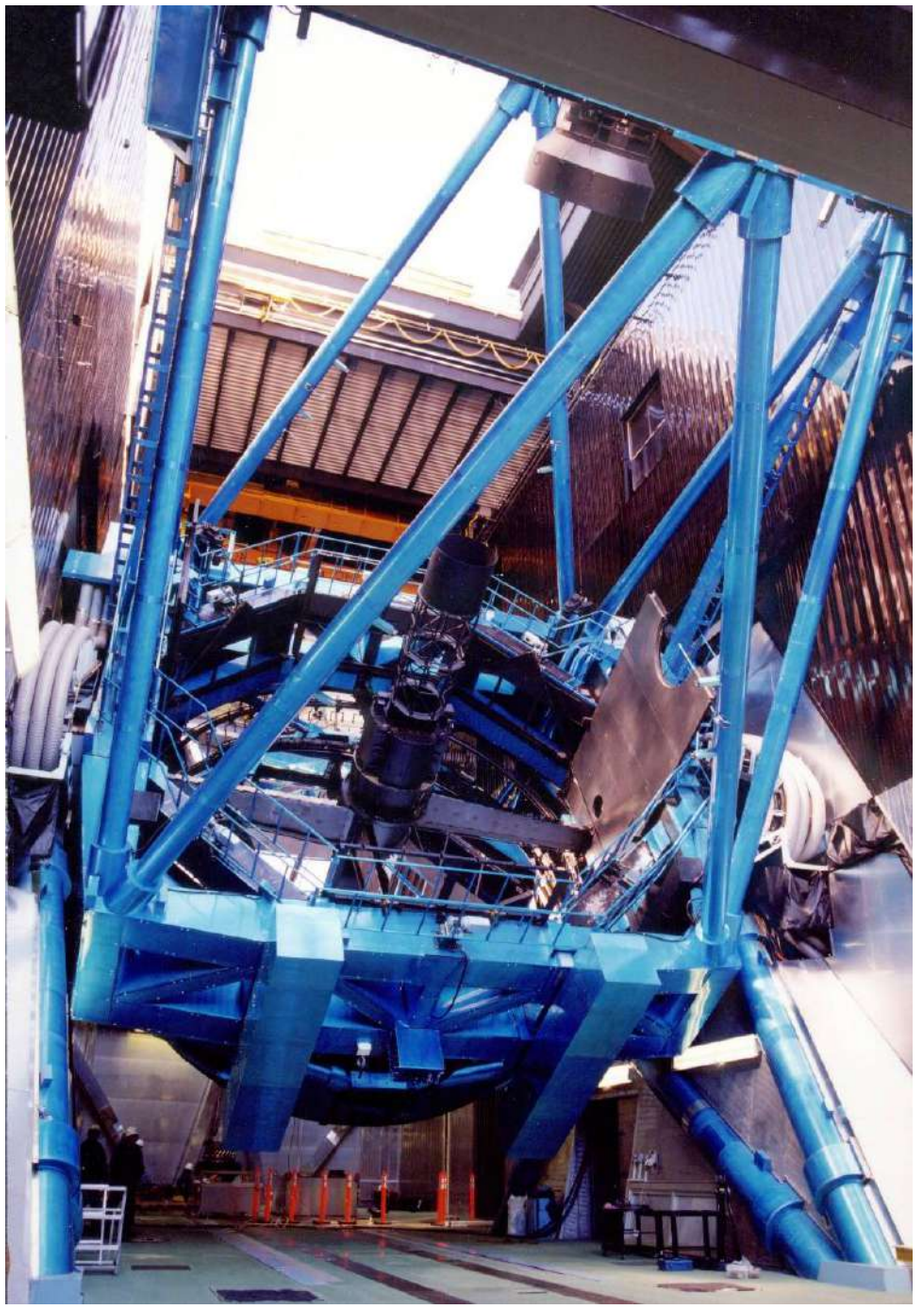
CMB lensing allows us to measure high-z cluster mass

What We Will See in 2020s



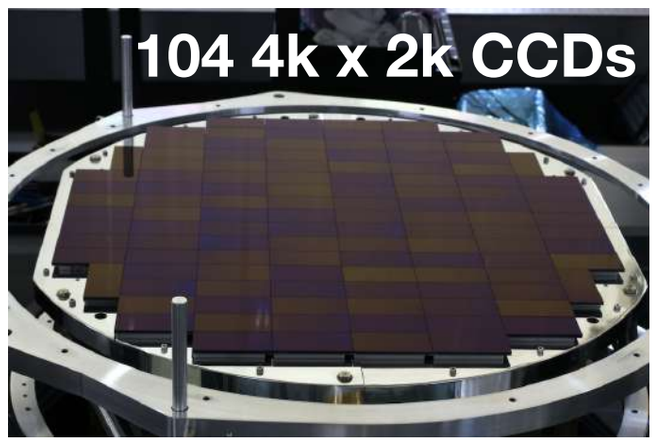
*Madhavacheril, Battaglia, and **HM** (2018)*

Subaru HSC



Credit: NAOJ

- Newly developed wide-field camera at the Subaru Telescope
- Best instrument for weak lensing
  - Light-gathering power: 8.2m primary mirror
  - Superb image quality: ~260 actuators
  - Large field-of-view: 1.8 deg^2
- Wide-field survey started in 2014
  - Wide area: 1,400 deg^2
  - Limiting magnitude: i_{lim}~26



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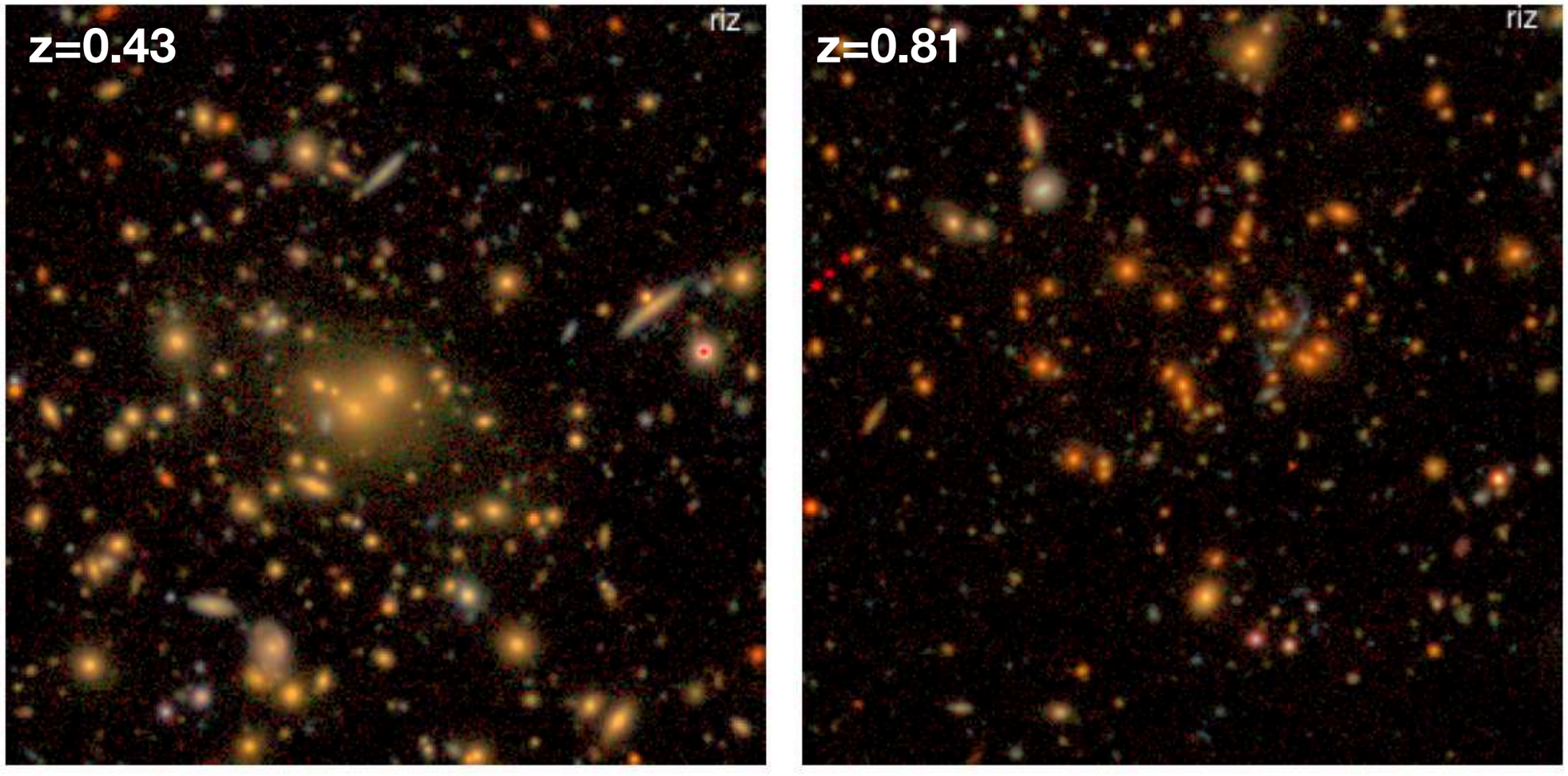
NAOJ
National Astronomical Observatory of Japan

IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

PRINCETON UNIVERSITY

中央研究院
天文及天文物理研究所
ACADEMIA SINICA
Institute of Astronomy and Astrophysics

HSC CAMIRA Clusters

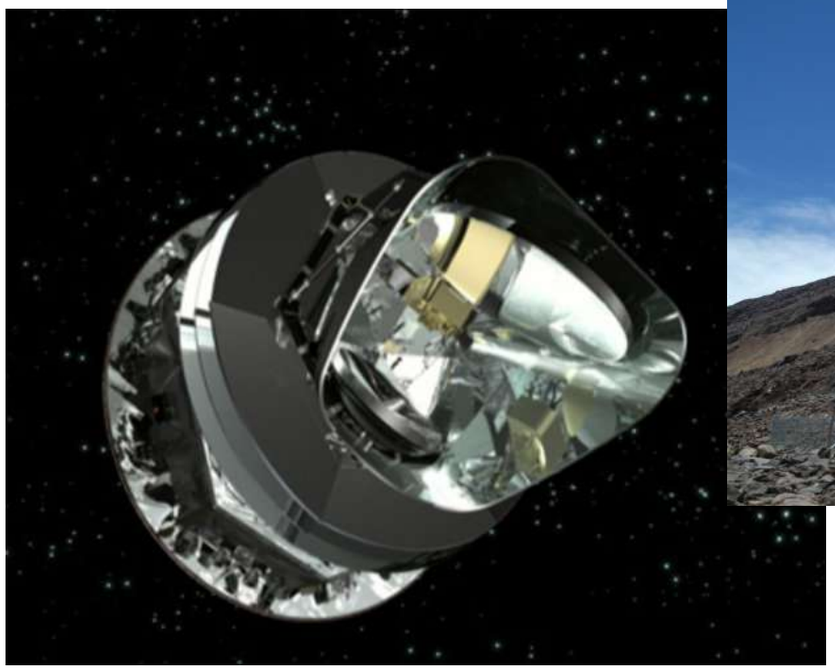


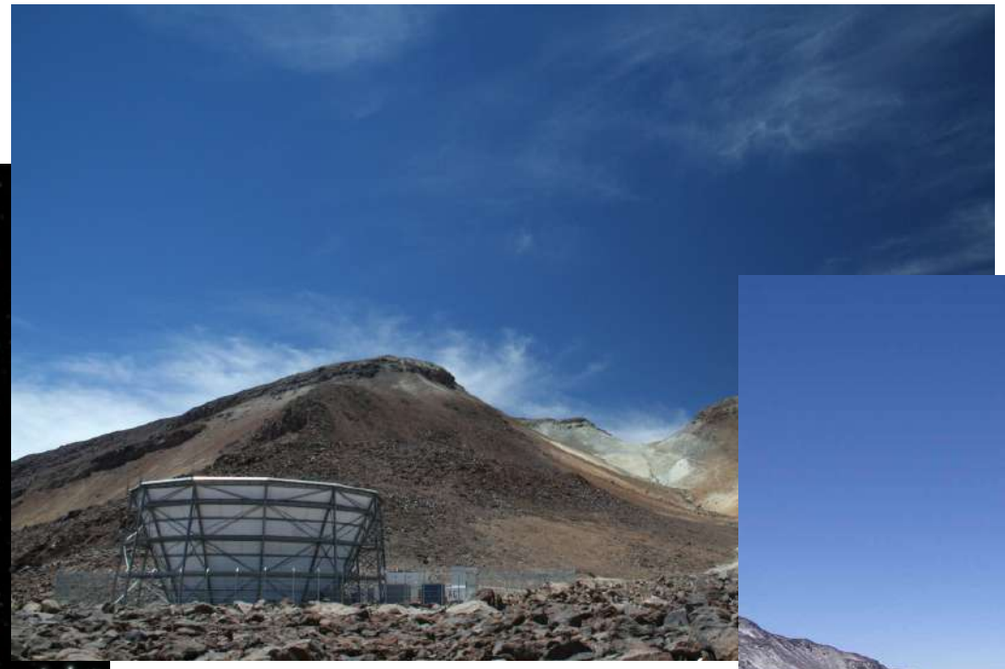
HSC can find galaxy clusters up to z~1.1
(can be extended if NIR data is combined)

*Oguri, …, **HM**, et al. (2018)*

CMB Experiments

Planck Satellite





ACT

Simons Array

We have started looking into Planck CMB lensing by CAMIRA clusters

Credit: ESA/ACT/Simons Array

Summary

- Cluster number count is a powerful tool to constrain the total neutrino mass.

- Cluster mass should be calibrated to achieve a precision cluster cosmology.

- Optical weak lensing/CMB lensing is suitable for calibrating low-z/high-z cluster mass.

- We have started looking into Planck CMB lensing by HSC clusters!