Galaxy clusters in the Dark Energy Survey

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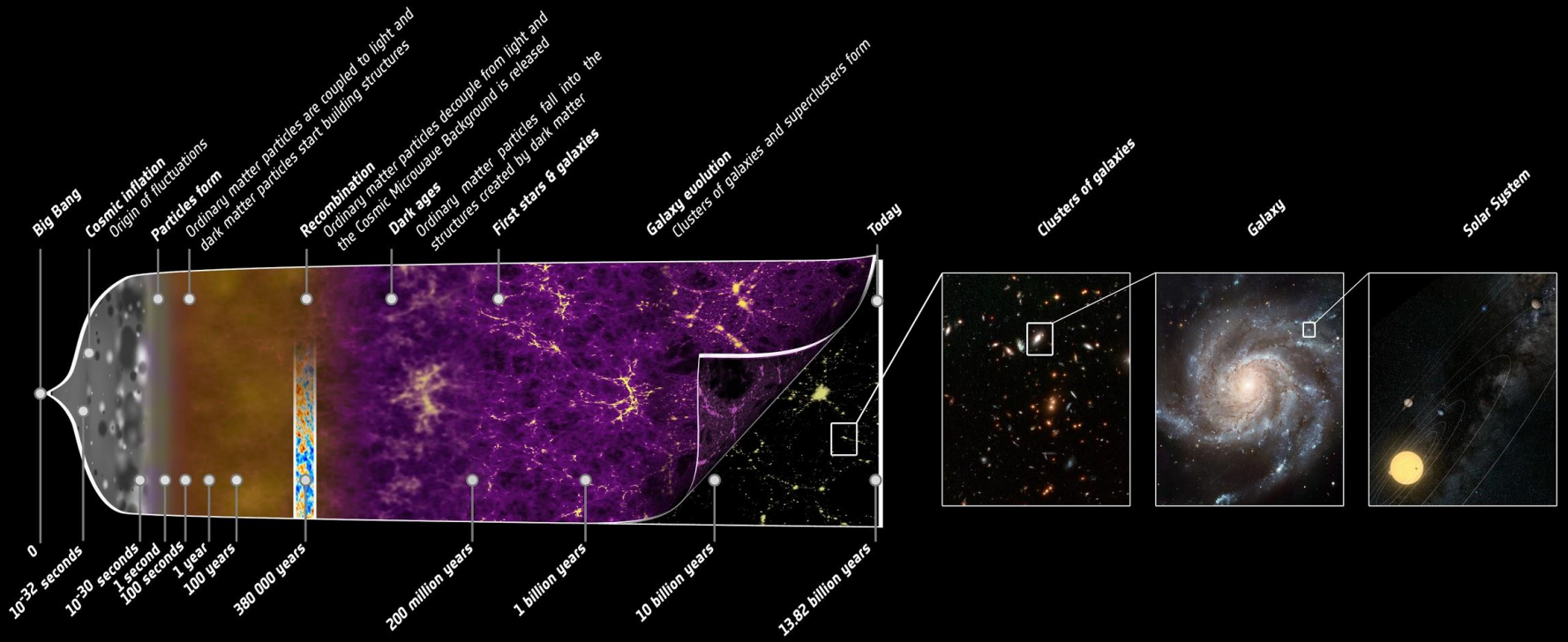
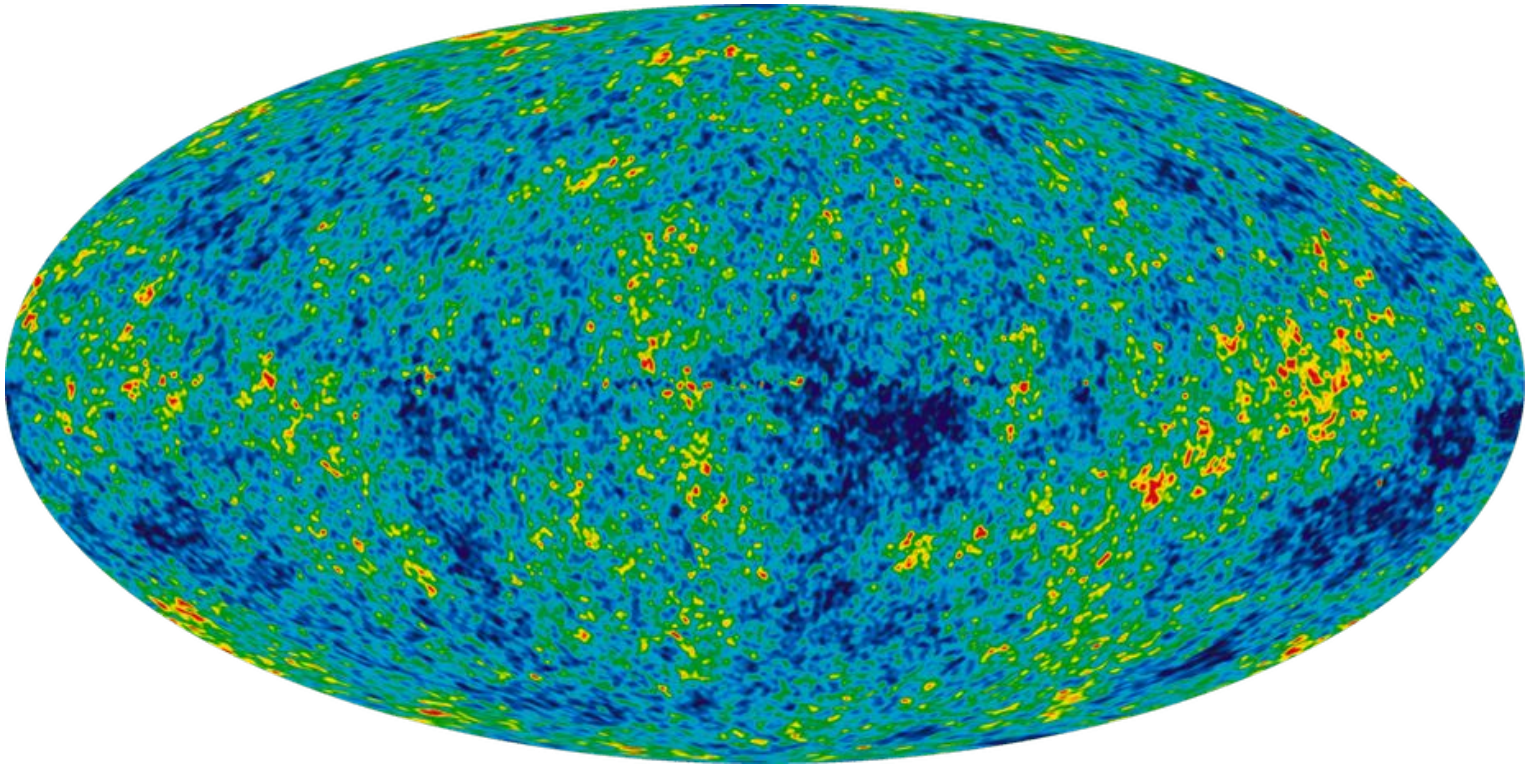
History of the Universe



History of the Universe - the beginning



CMB is smoking gun of a Big Bang

Courtesy of Planck collaboration

A long time ago
in a galaxy far, far away....

A long time ago
in a galaxy far, far away....

(20 years ago)

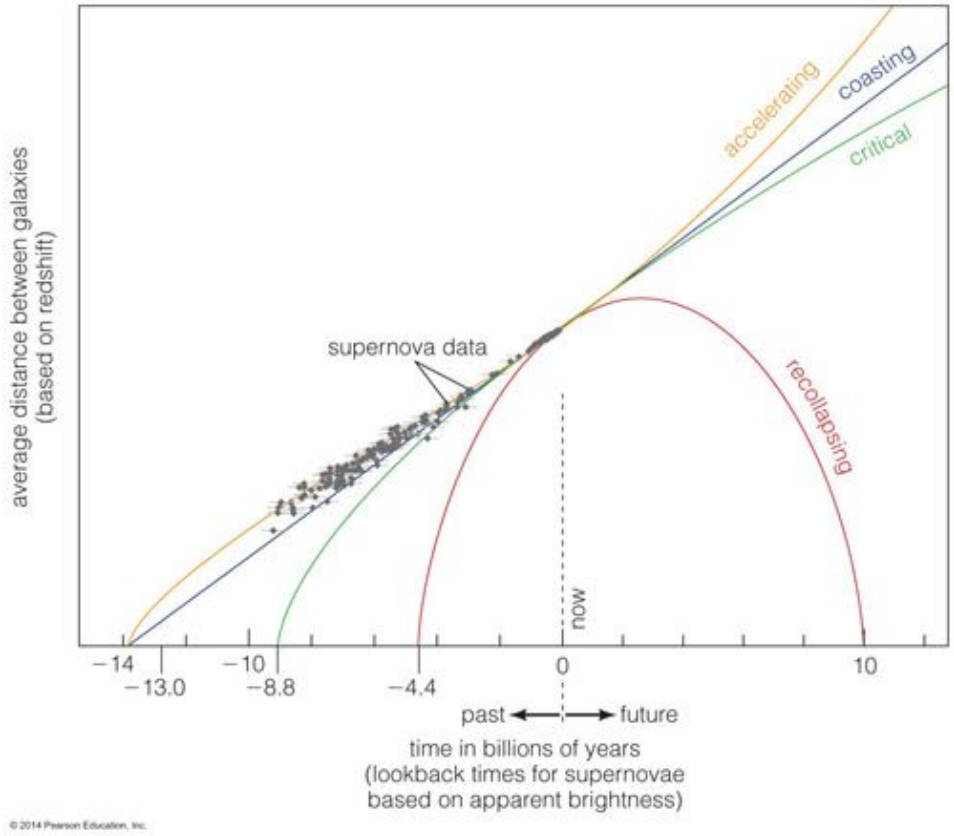
Big question

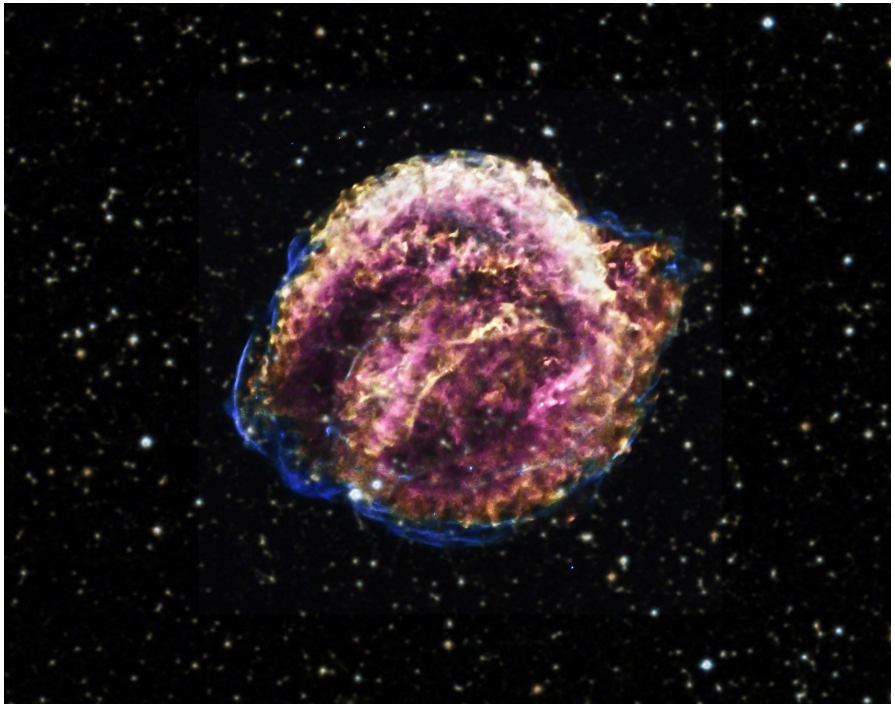
How fast is the Universe expanding?

Big question

How fast is the Universe expanding?

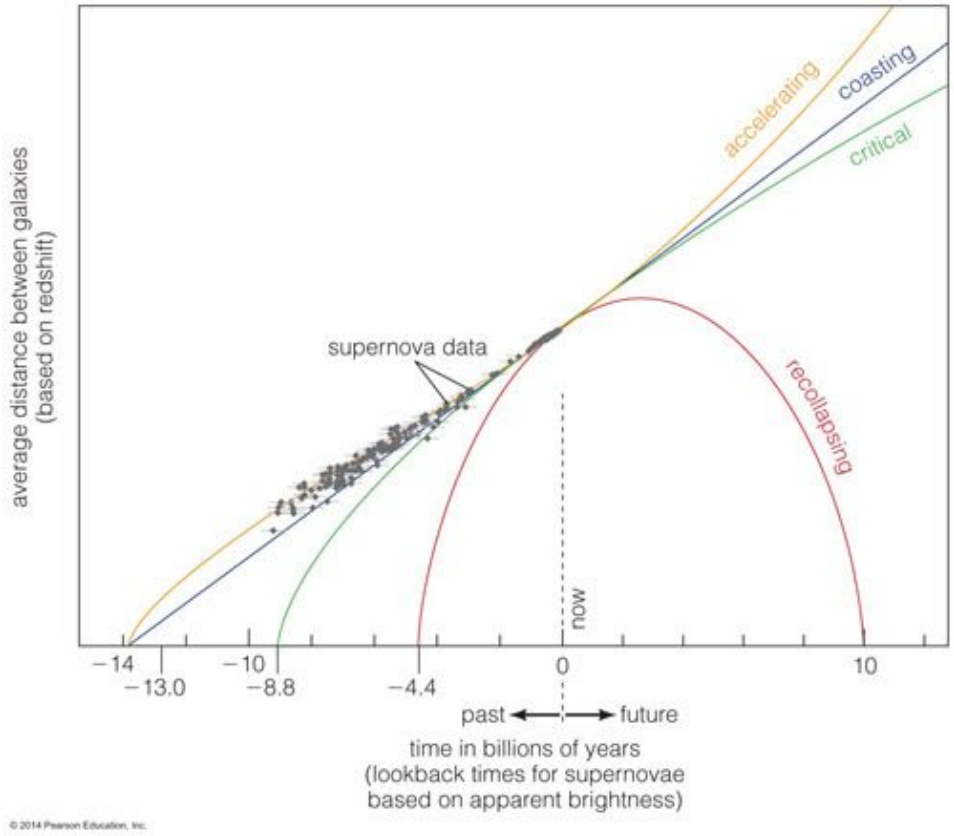
Expansion rate w/ supernovae





Discovery papers are Riess+ (1998) and Perlmutter+ (1999)

Surprising result…



Gravity can push?!?

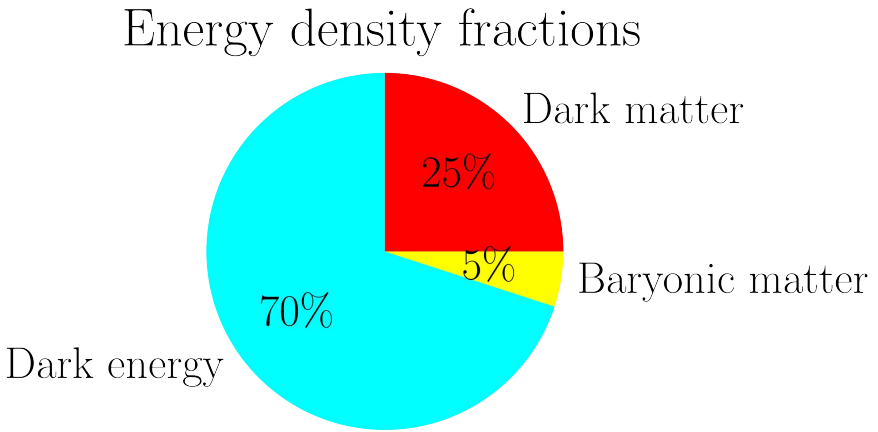
Two possibilities:

1. New form of energy (dark energy) with repulsive gravity (negative pressure)
2. We don't understand gravity at large scales (unlikely)

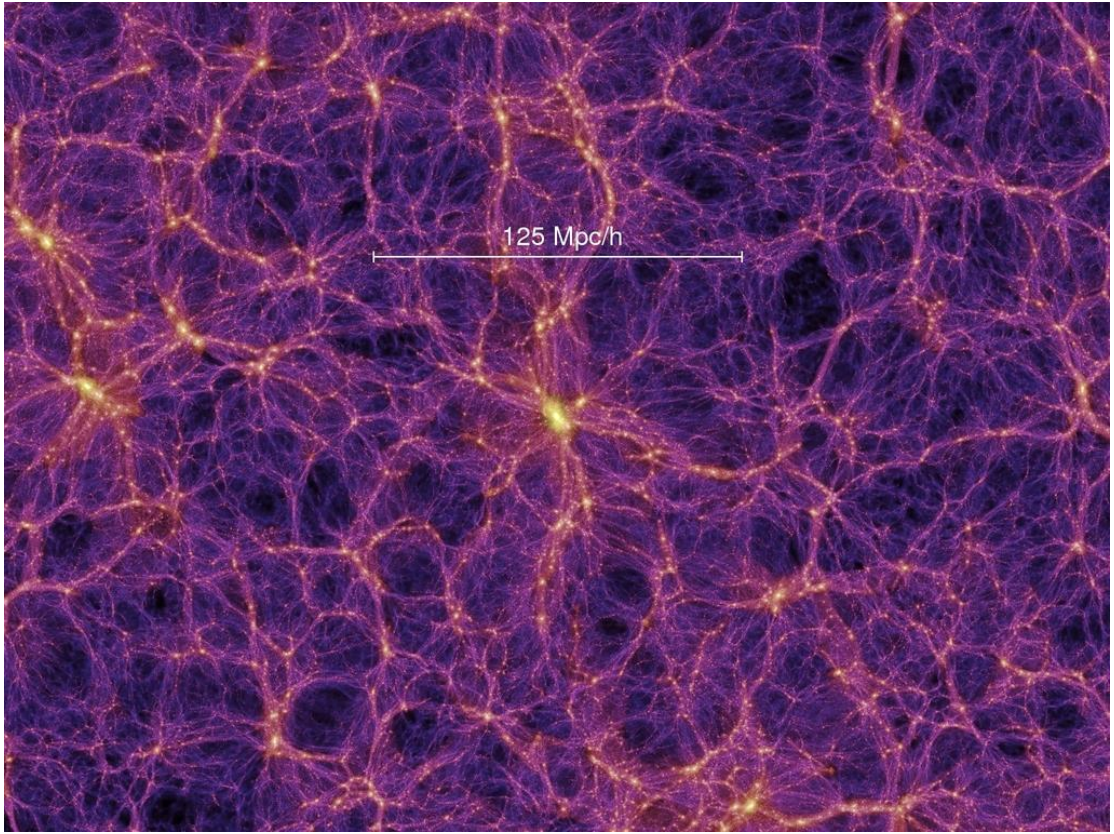
Bottom line

Observation of **accelerated expansion** of the Universe is clear evidence of **new physics**.

Learning about **dark energy** is the number one goal in observational cosmology today.



Large scale structure



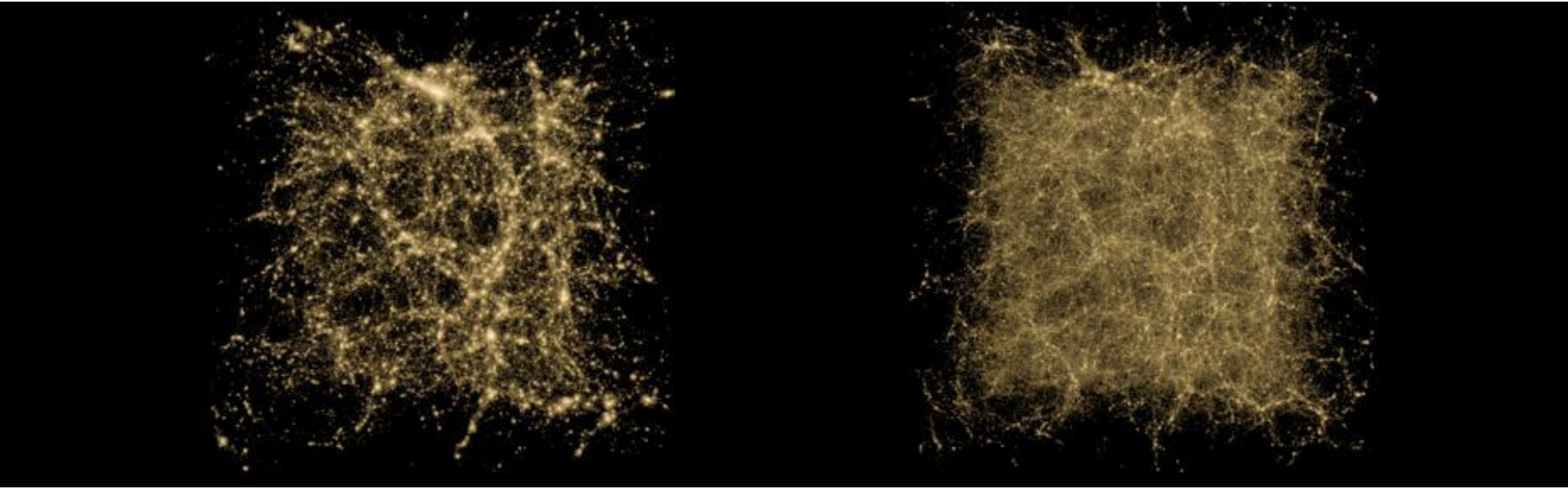
Large scale structure of the Universe is an ideal probe of DE.

This is an example of a *simulation* of the LSS called Millennium.

You are seeing:

- Dark matter halos (yellow)
- Cosmic web (purple)
- Voids (black)

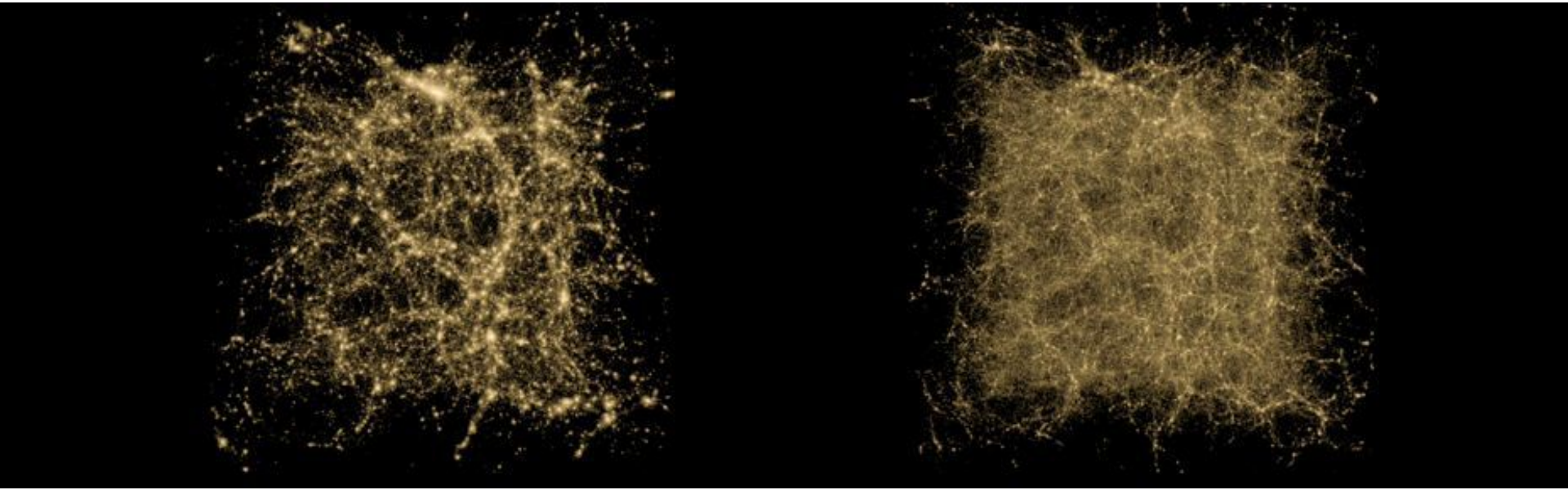
Structure probes cosmology!



Lots of matter - little dark energy

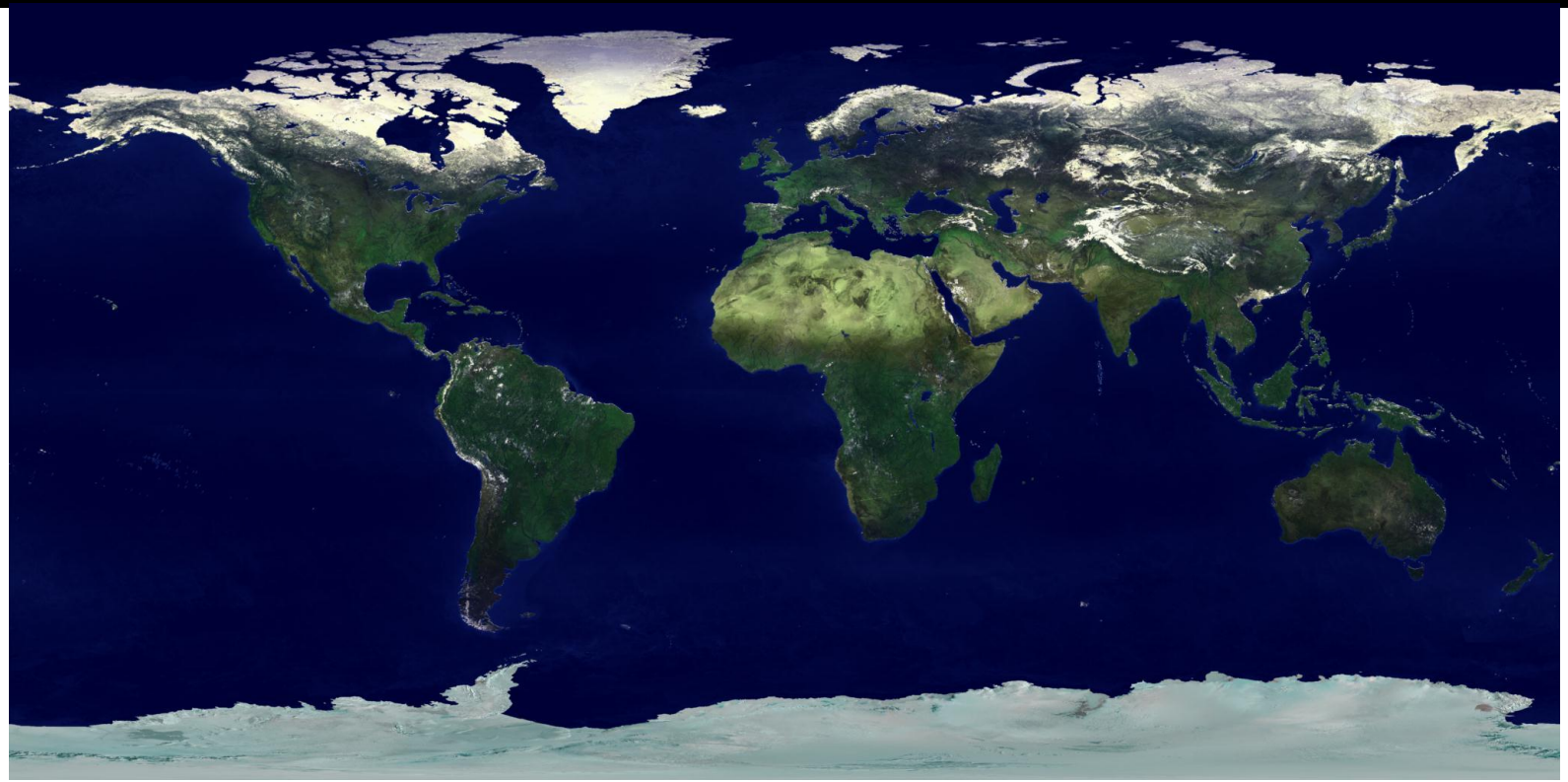
Lots of dark energy - little matter

But wait...



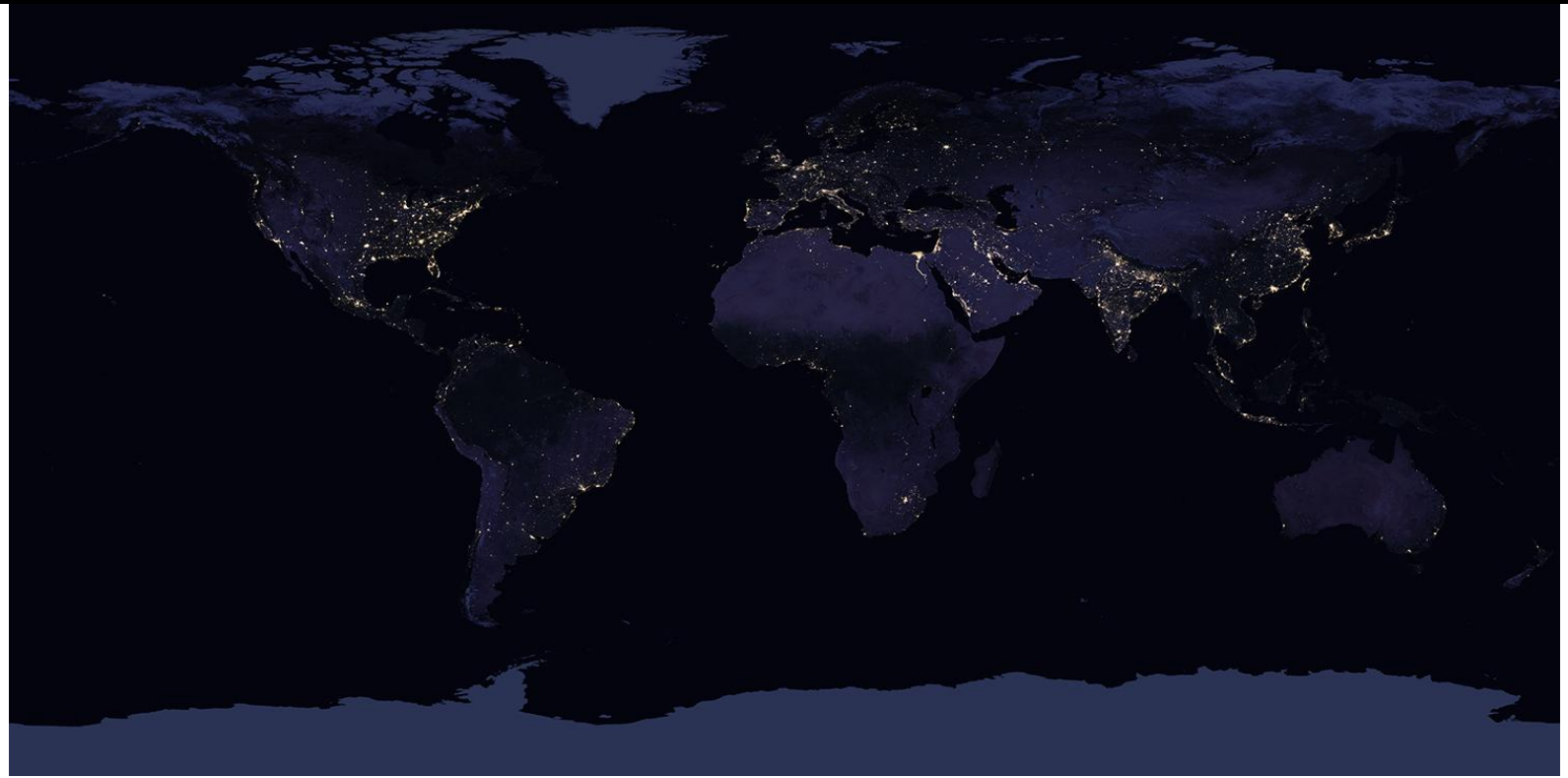
Why is it hard to tell these two apart?

Why measuring structure is hard



We want to measure the mass distribution like this...

Why measuring structure is hard



but all we have is this.

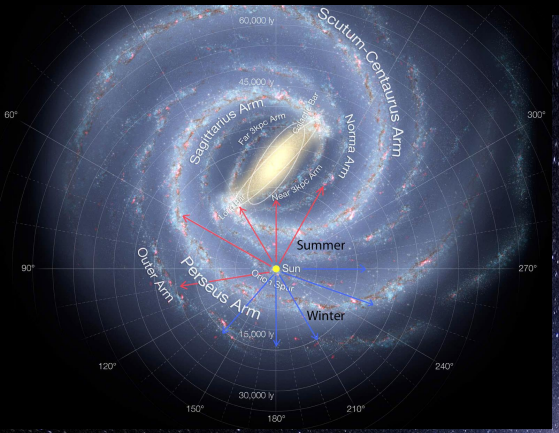
Dark Energy Survey @ Cerro Tololo I.A. Observatory

Dark Energy Survey:

- 5000 sq. deg.
- CTIO is in Chile
- Photometry using Dark Energy Camera
- Lifetime of 5.5 years
- Goal is to measure dark energy

Image courtesy of DES

Dark Energy Survey @ Cerro Tololo I.A. Observatory



Dark Energy Survey:

- 5000 sq. deg.
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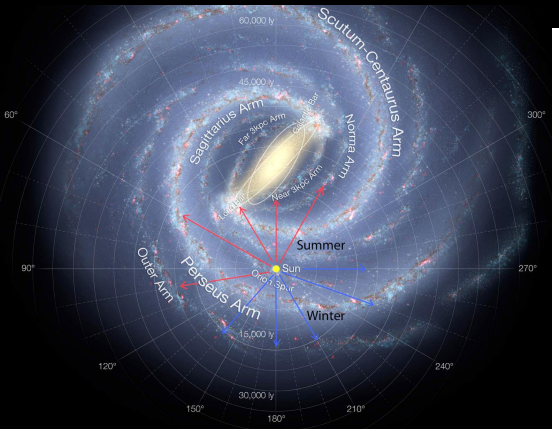
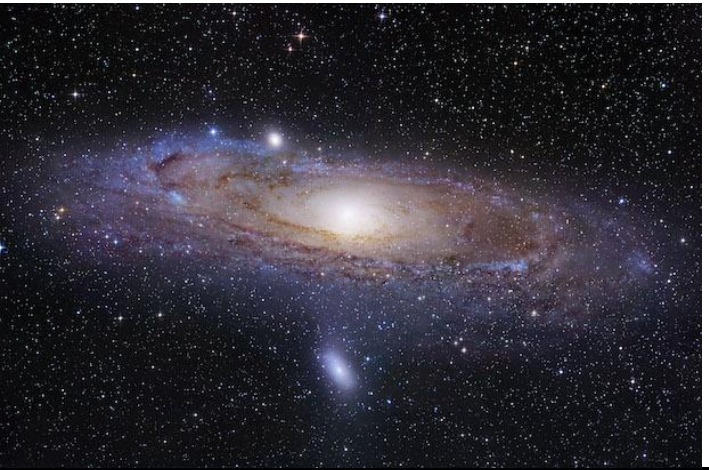
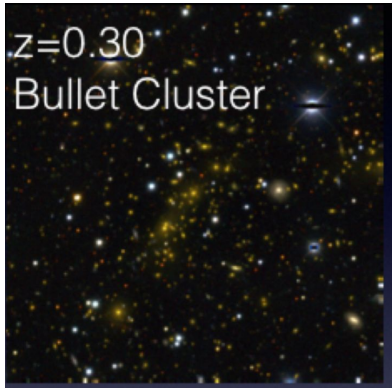
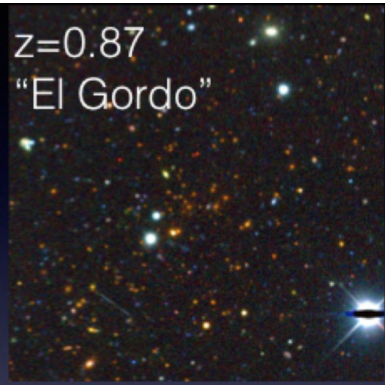
Images courtesy of DES & ESO

Galaxies and galaxy clusters

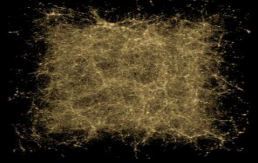








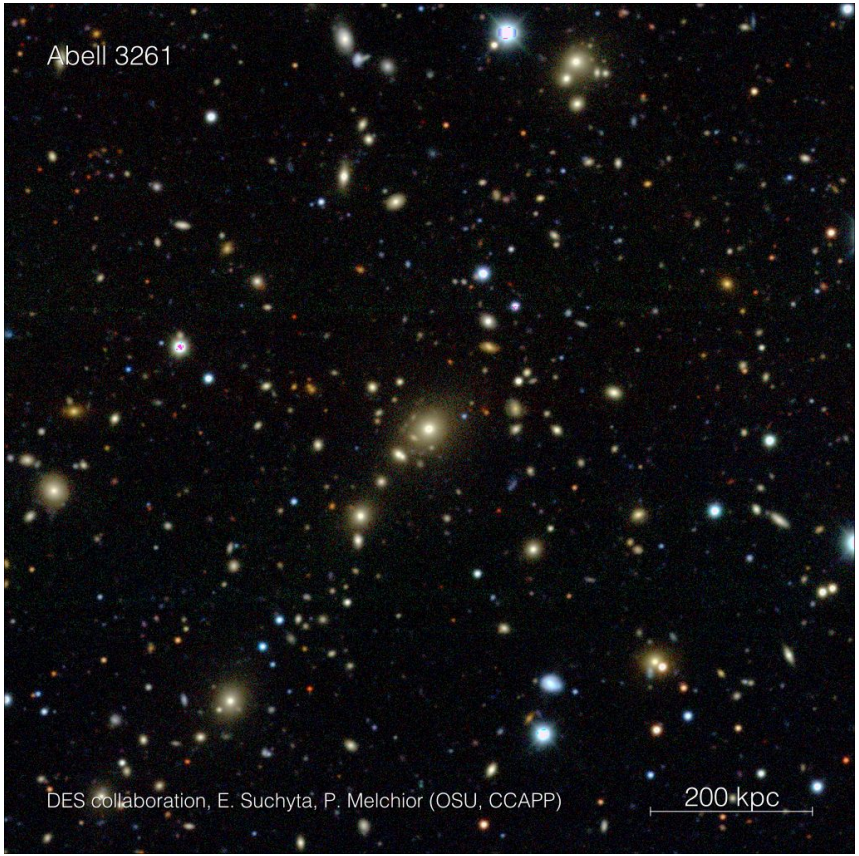
More clusters = more structure



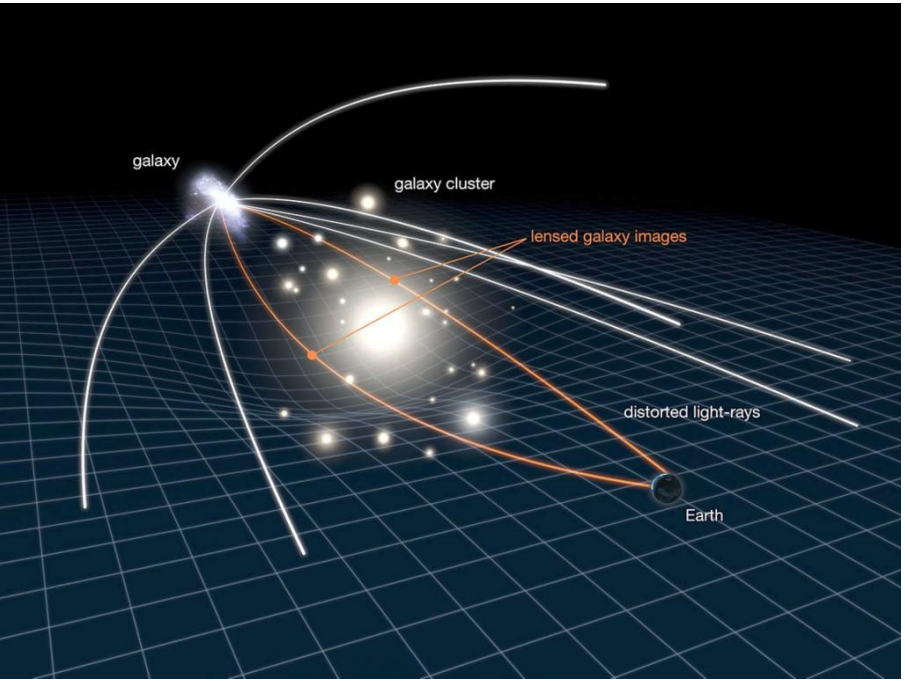
Key ingredients for cluster cosmology

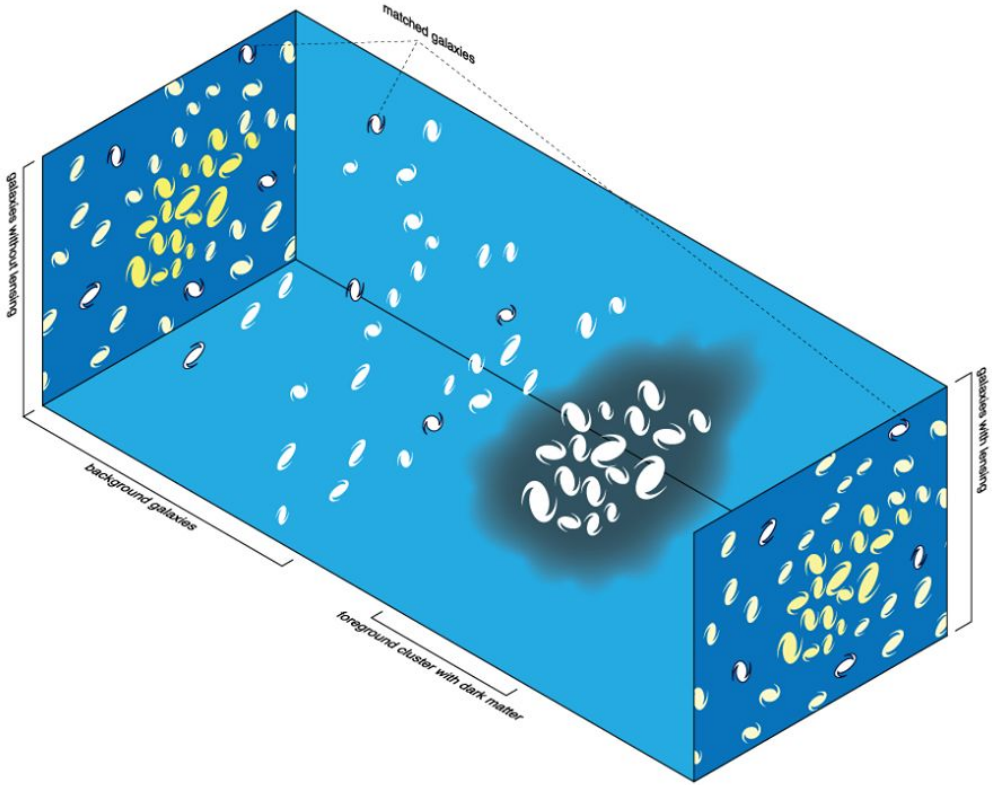
1. Cluster masses
   - Obtained from gravitational lensing

2. Cluster Abundances
   - number of clusters as a function of mass and time

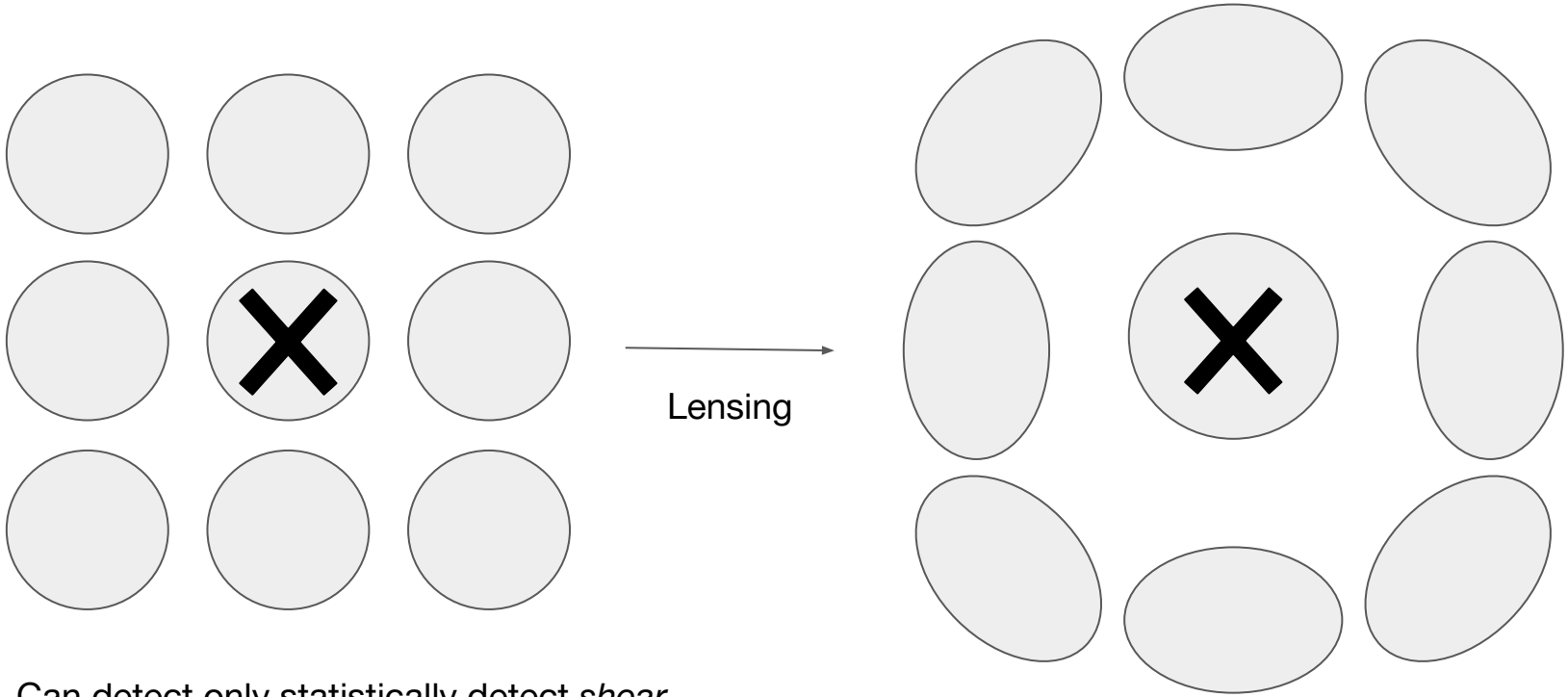


Cluster masses from gravitational lensing



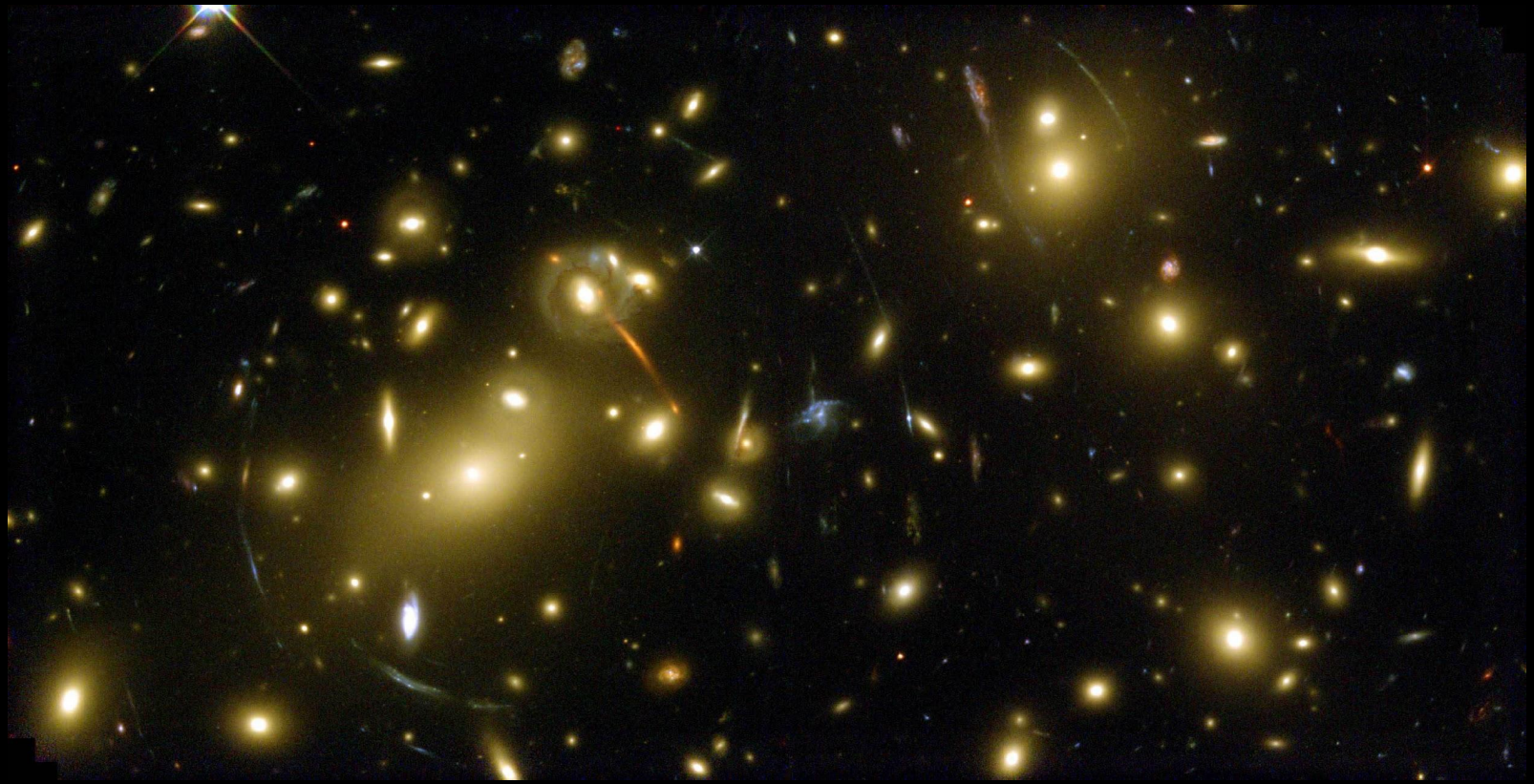


Weak gravitational lensing



Can detect only statistically detect *shear*.
Mean tangential ellipticity of *background galaxies* is sensitive to *cluster mass*.

Abell 2218 - gravitational lensing



Cluster weak lensing profiles

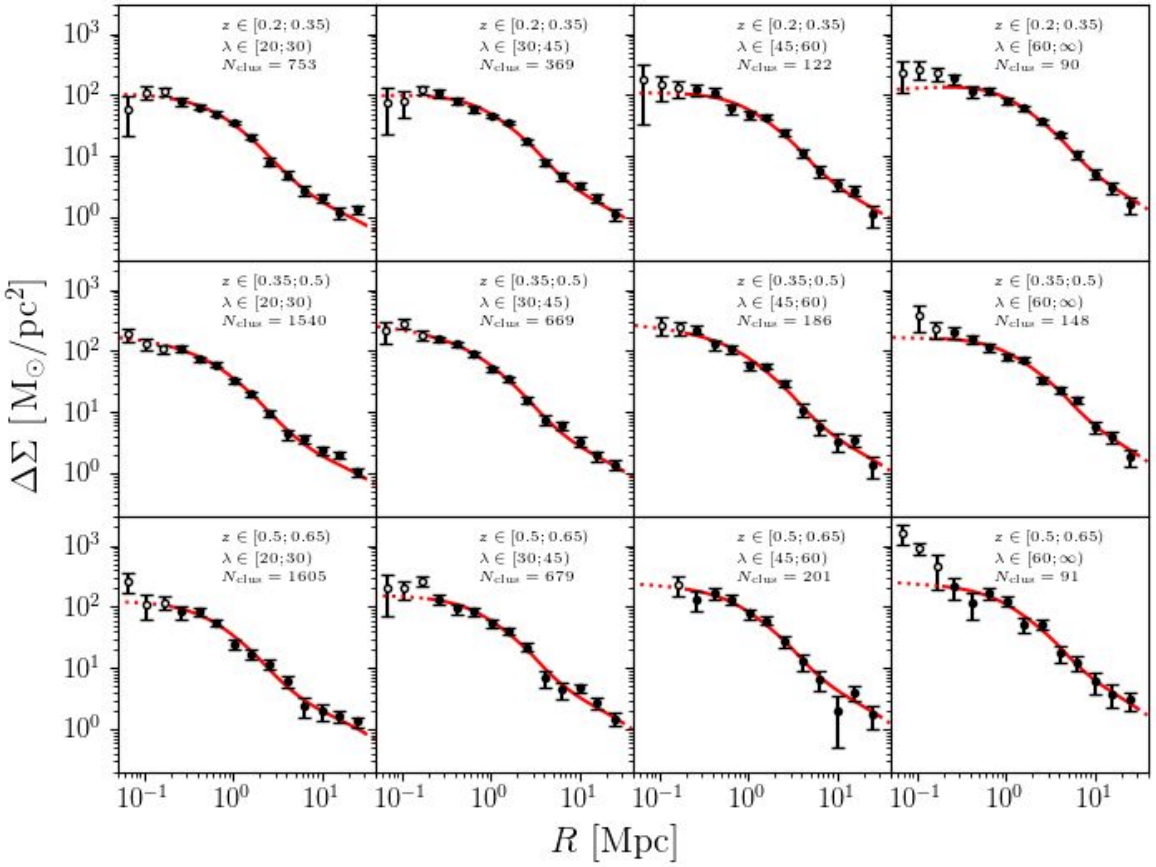
Cluster sample split by **redshift** (top to bottom) **richness** (left to right)

Black points:

- (differential) **surface mass density profile**
- Proportional to tangential shear

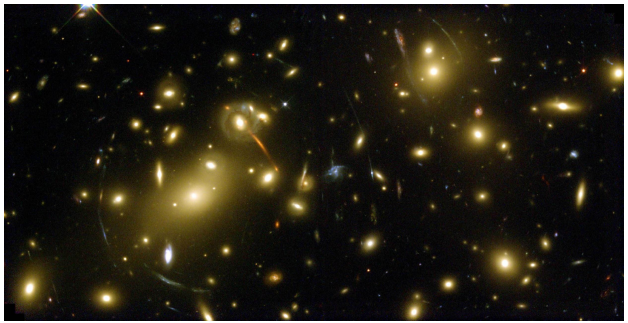
Red line:

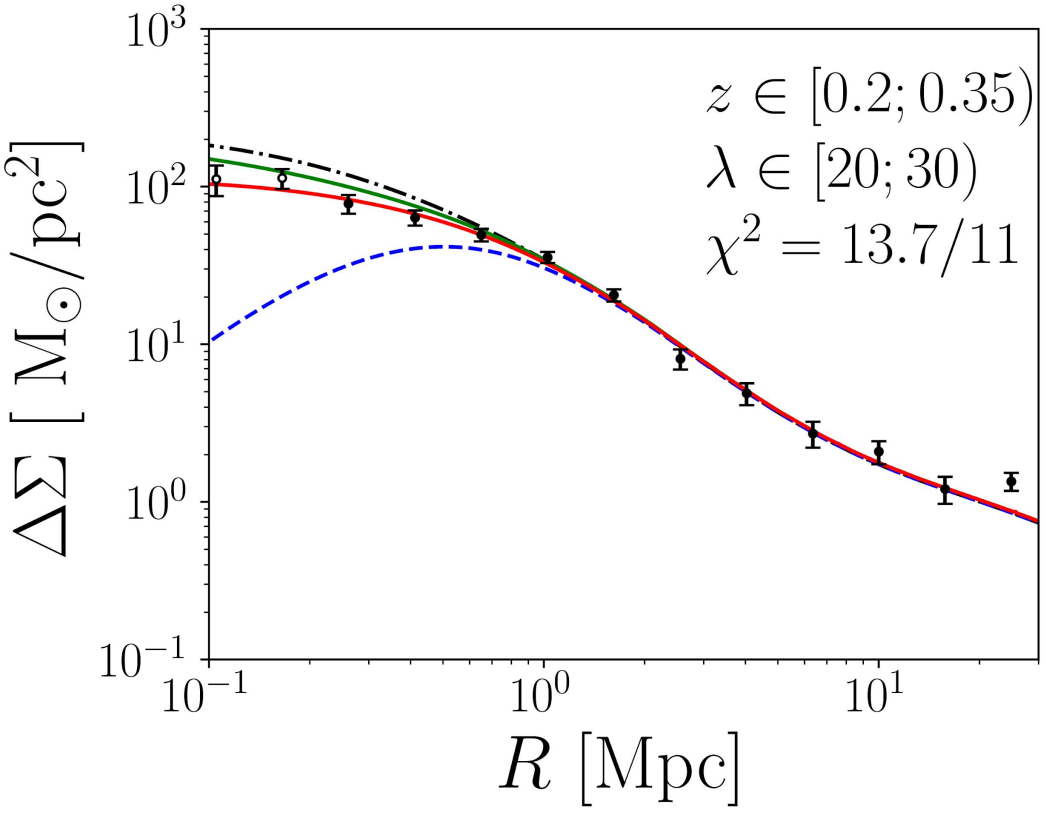
- best fit model



Lensing model + systematics

Lensing model:
- centered (black .-)
- miscentered (blue -)
- shapes, distances, membership dilution (red)
- triaxiality+proj. (not shown)





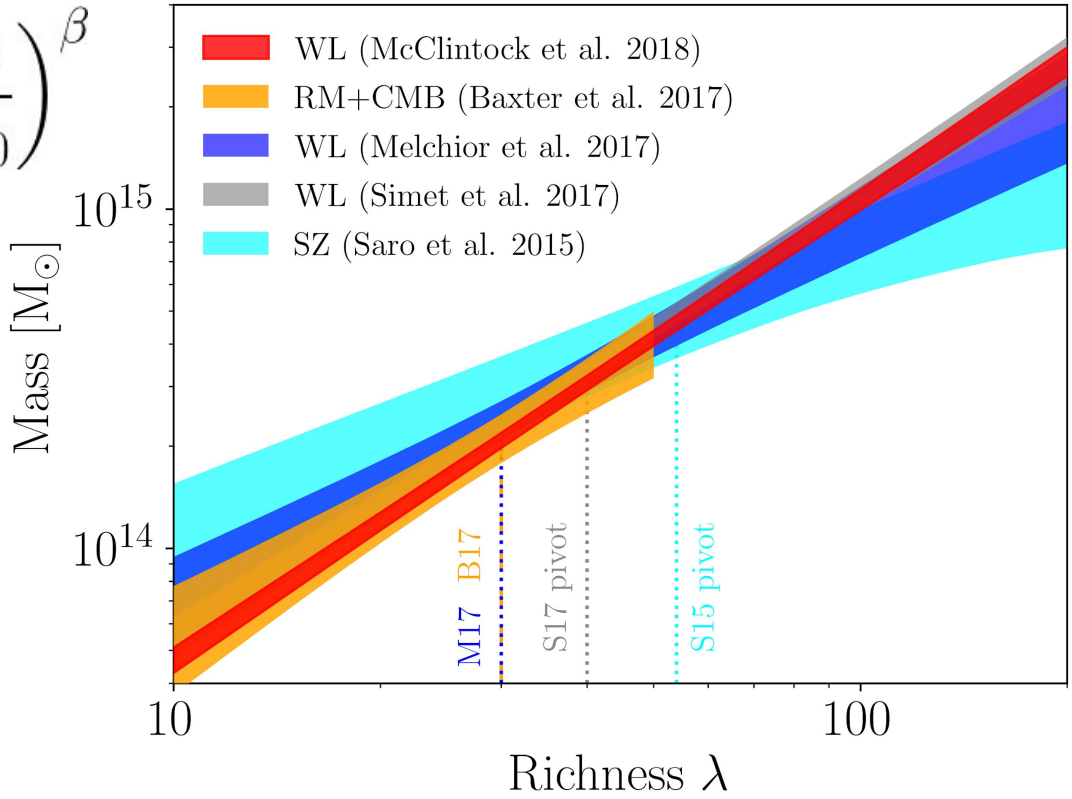
End result - cluster mass--richness relation

$$\langle M|\lambda, z\rangle = M_0 \left(\frac{\lambda}{\lambda_0}\right)^{\alpha} \left(\frac{1+z}{1+z_0}\right)^{\beta}$$

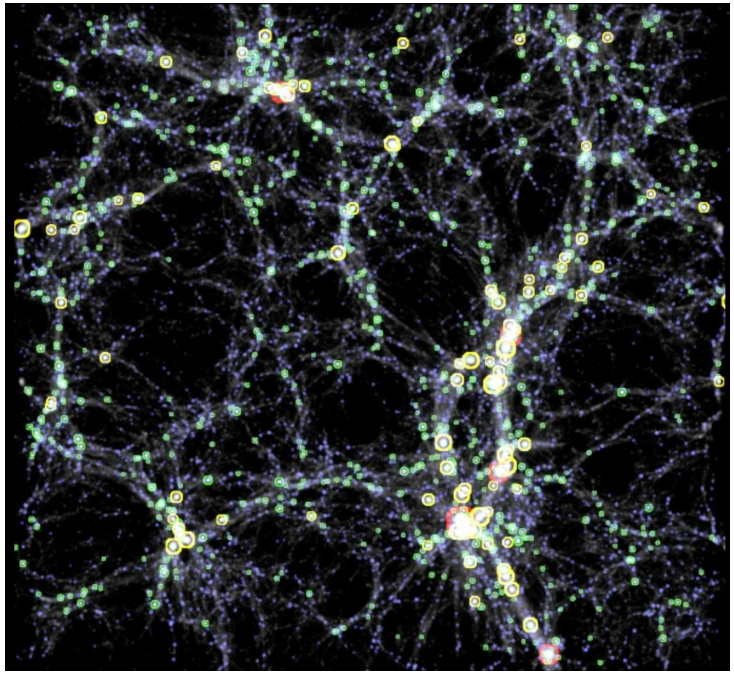
Power law in:

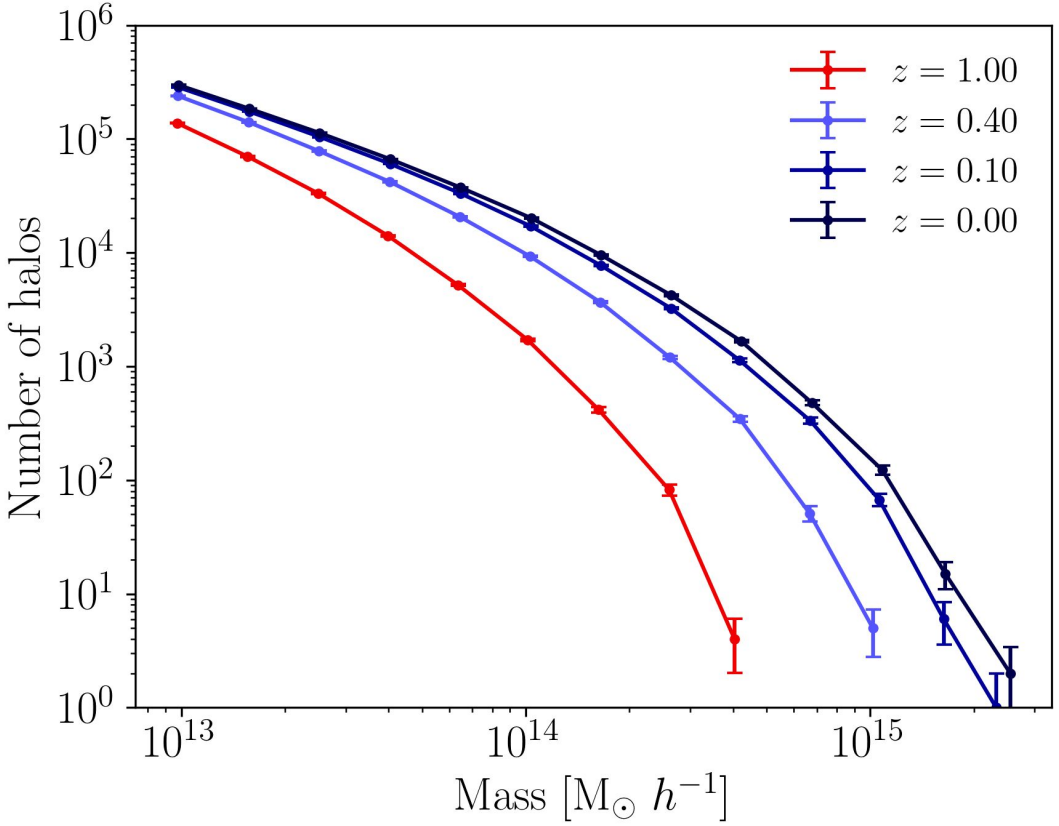
- Richness (# of galaxies)
- Redshift (cluster age)

5% calibration of the normalization (M_0)

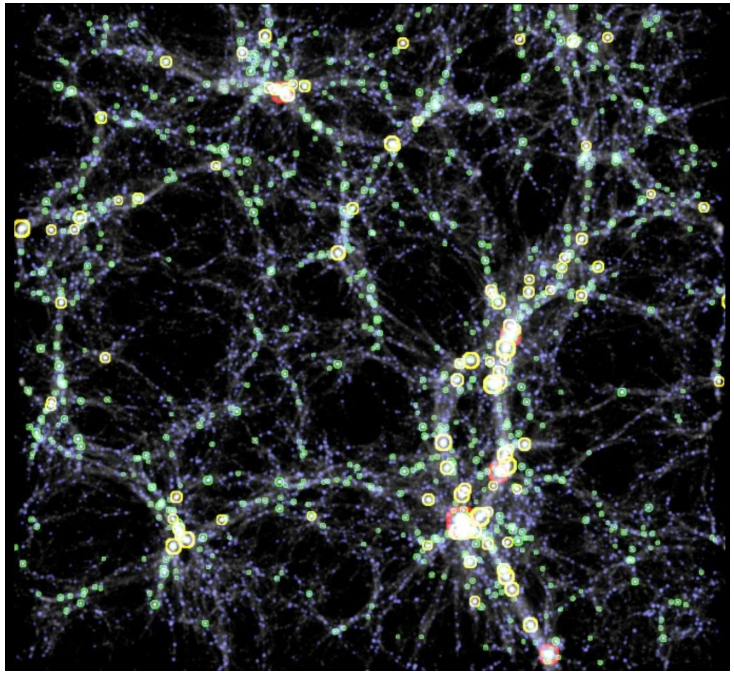


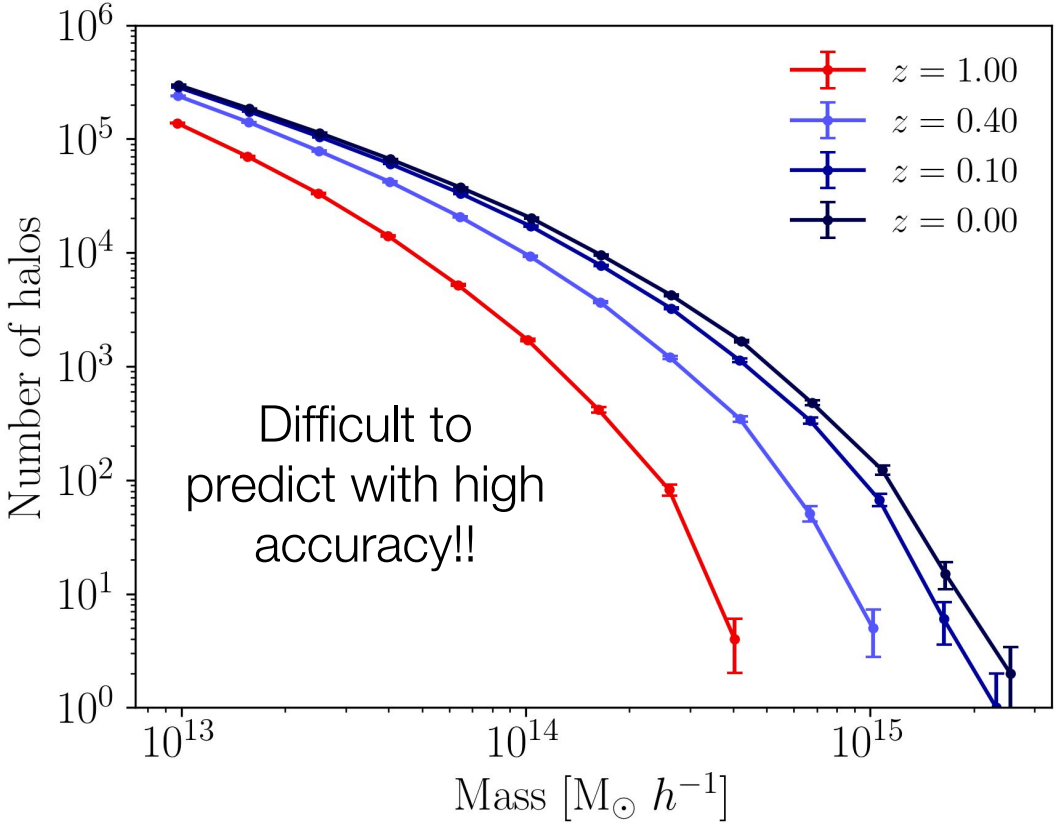
Cluster abundances



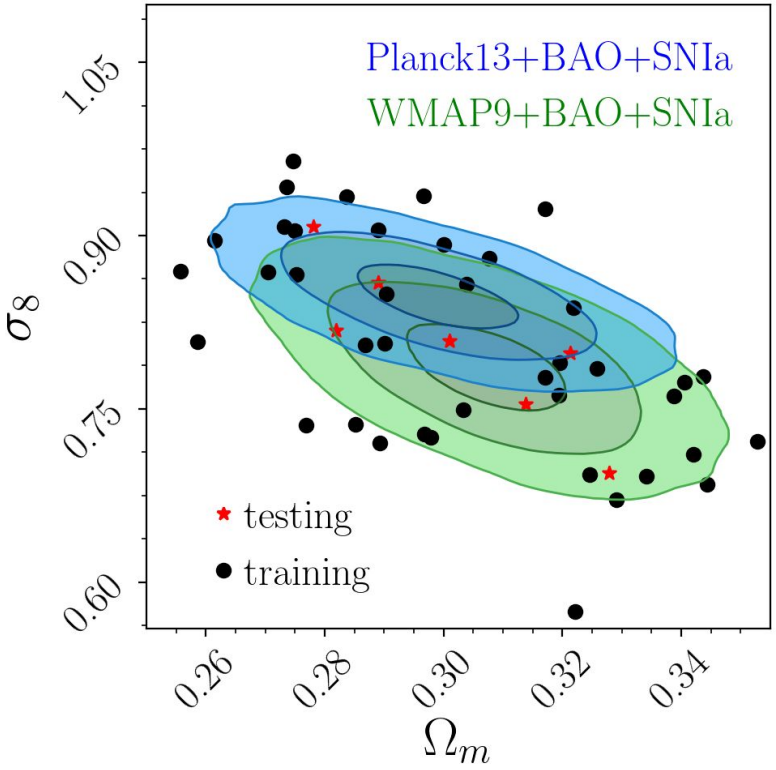


Cluster abundances - PROBLEM!





Solution - interpolate between simulations



Suite of **simulations** (40 training, 35 testing)

Spread out in a 7 dimensional cosmological parameter space

- 2 dimensions shown here

Measure cluster abundance in sims

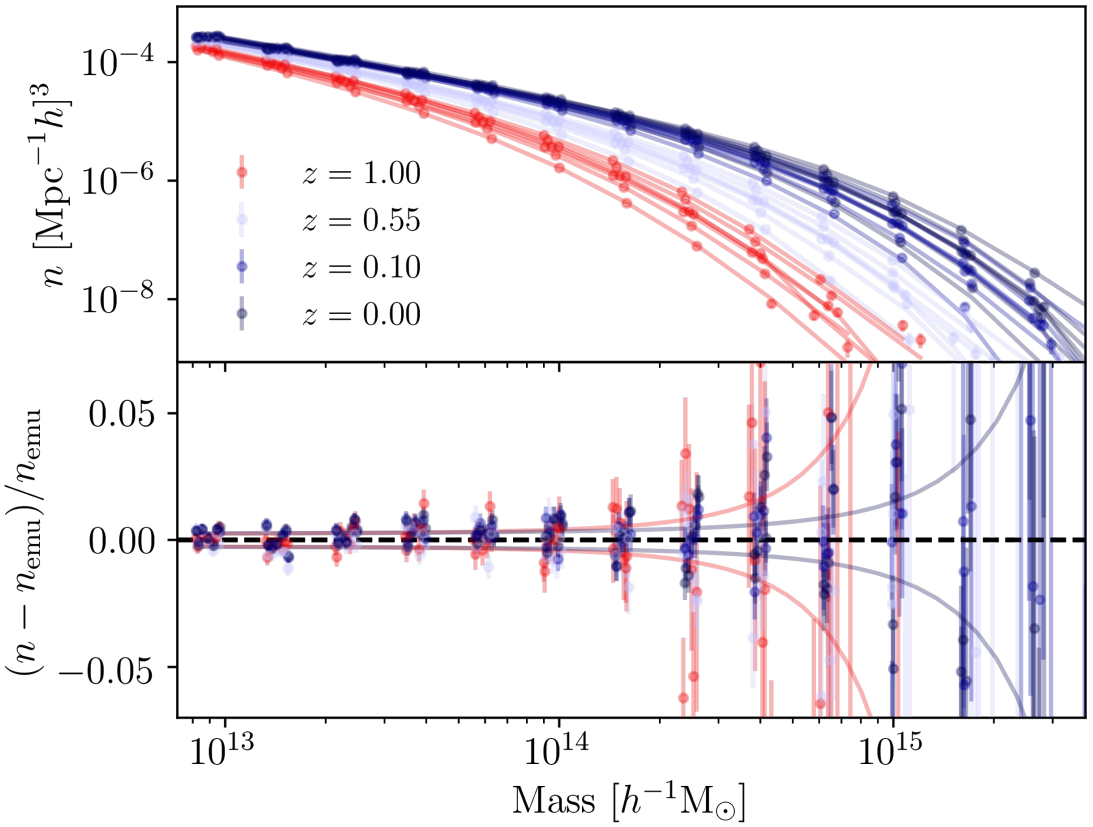
Use **machine learning** techniques to **interpolate** between simulations.

Test simulations

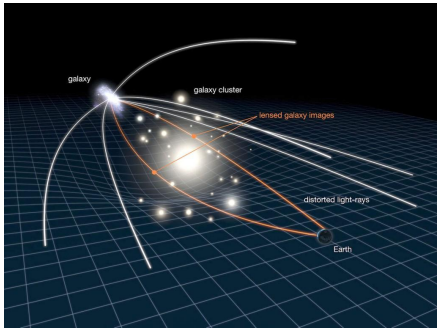
Predicting abundance at arbitrary cosmology is crucial!

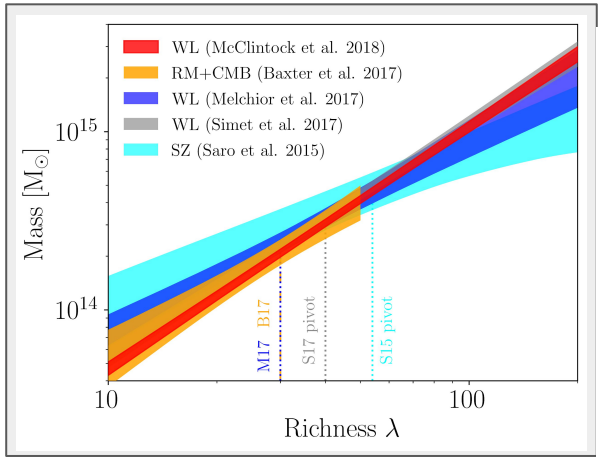
Training simulations were less accurate than the testing simulations.

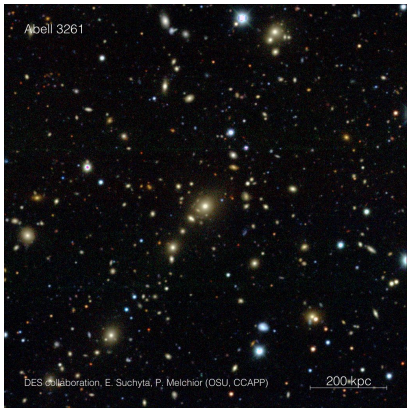
Achieved ~1% accuracy for interesting mass scales.

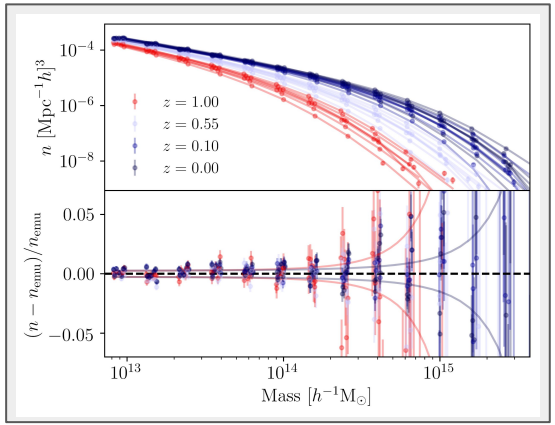


Enabling galaxy cluster cosmology in DES









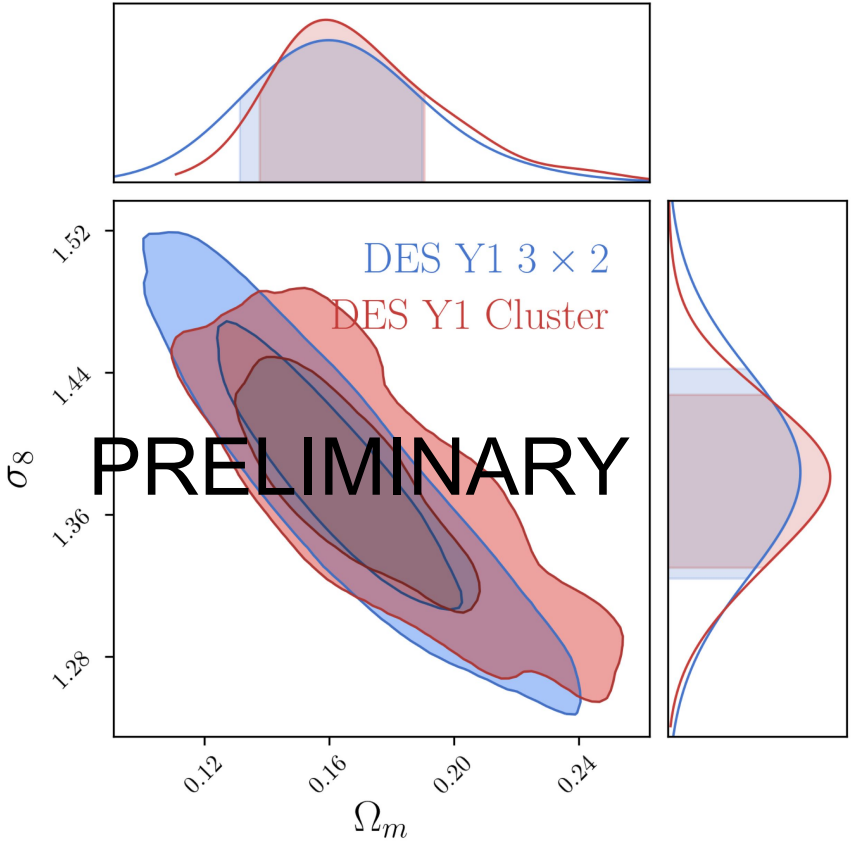
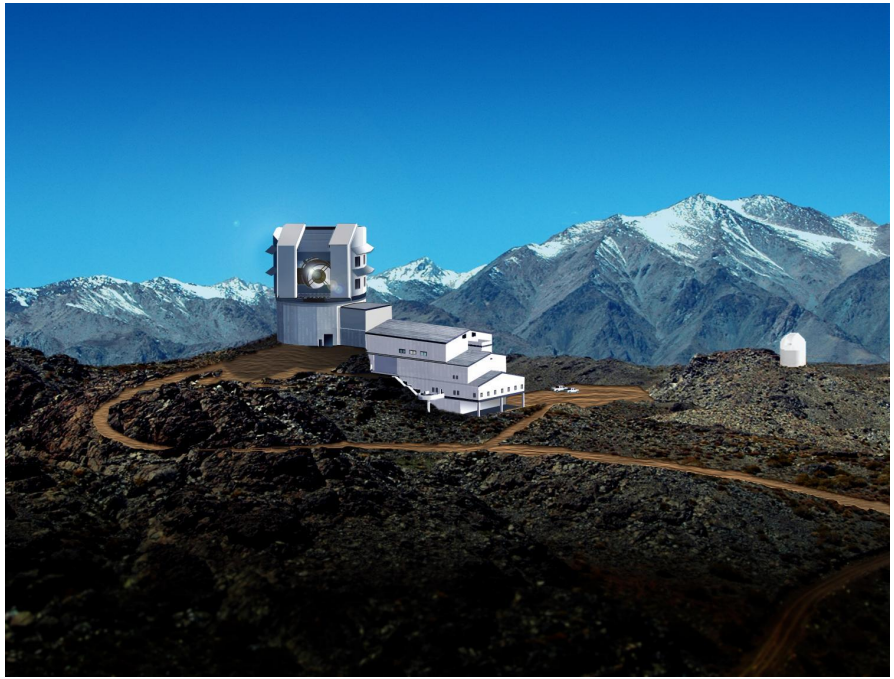


Image courtesy of M. Costanzi

But wait, there's more!

LSST - the next generation

Large Synoptic Survey Telescope



LSST - first light in 2021

Most powerful cluster cosmology experiment of the next decade. You get to use it!

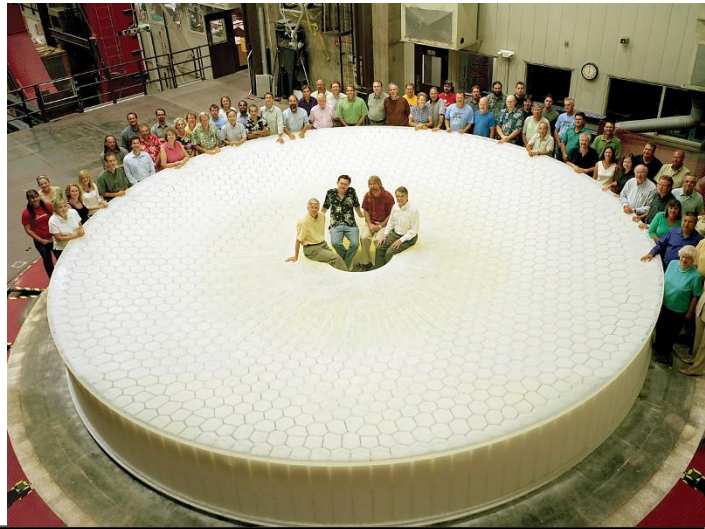
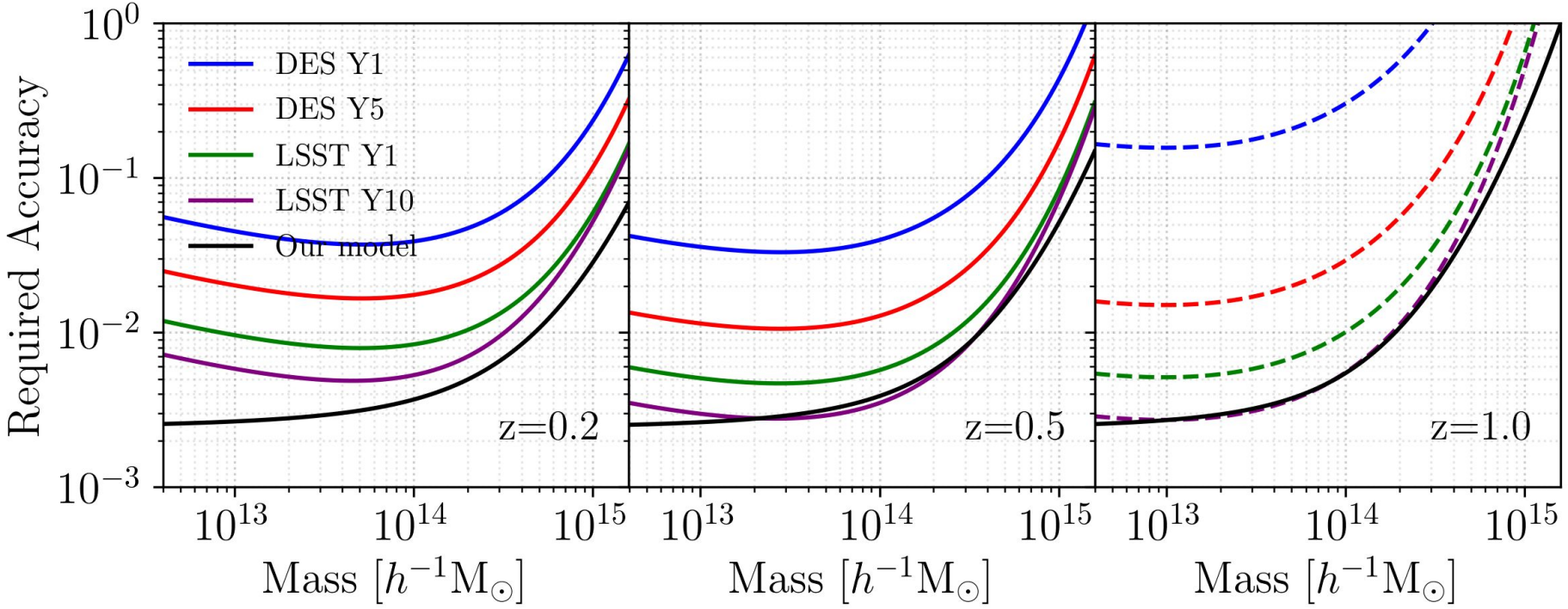


Image courtesy of LSST

Models needed for LSST!



All analyses in LSST era will be **systematics limited**

We need you need to figure it out!

Thank you!

UA Cosmology:
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DES working group:
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