

# OBSERVATIONAL COSMOLOGY

## OVERVIEW

DAVID BACON

INSTITUTE OF COSMOLOGY AND GRAVITATION

PORTSMOUTH

# WELCOME TO THE COURSE

---

I will give the course in ~25 min sections,  
followed by a mental break :)

Please put questions at the front

Intended to be **useful to all** - PhD / postdoc / staff,  
cosmology and non-cosmology

Hope to give you **content** to chew on, and  
**reinvigorate** you!

# THANKS

---

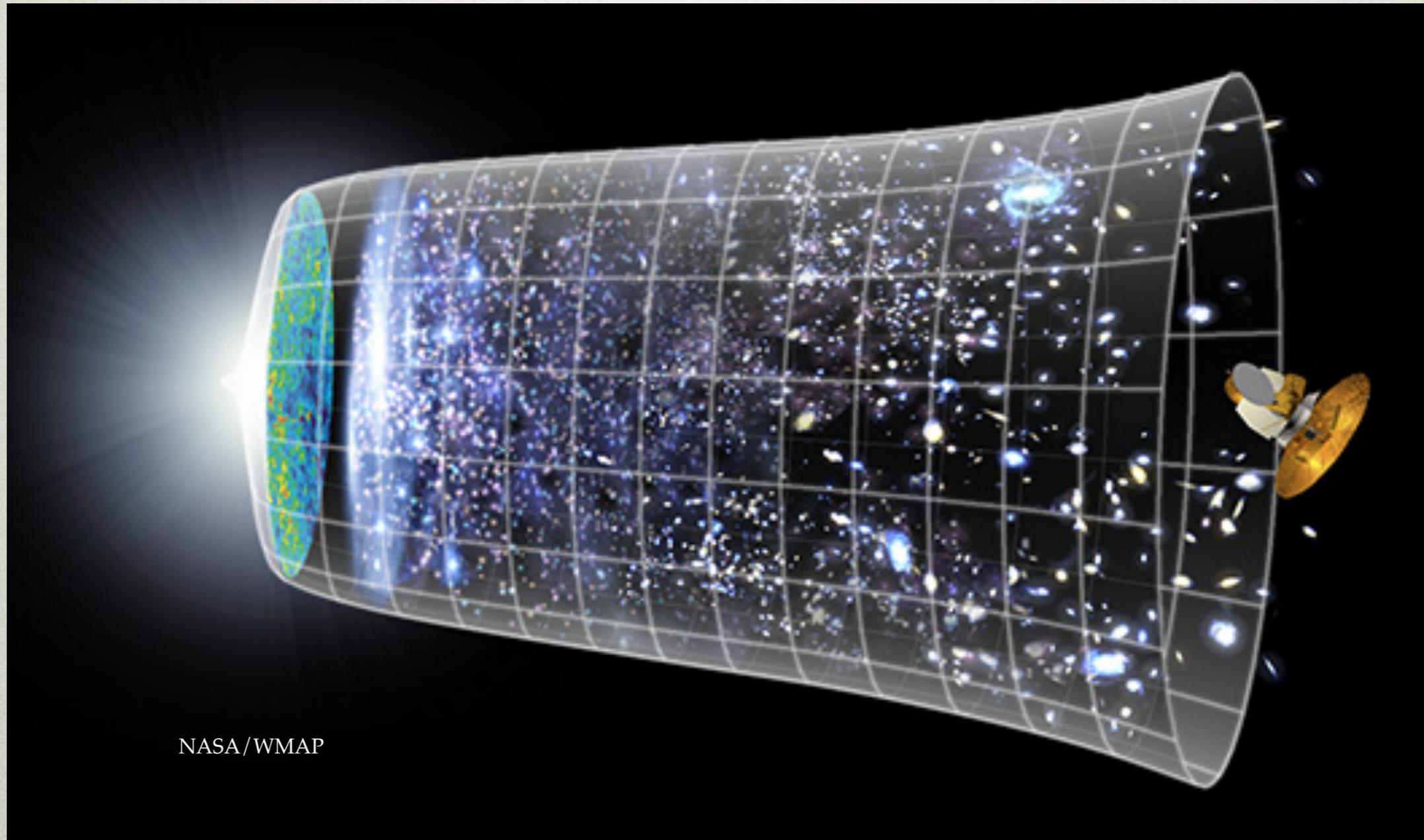
My thanks to Bob Nichol, Will Percival, Kazuya Koyama, Tom Collett, Wojciech Hellwing for sharing expertise and slides.

# OUR COSMOLOGICAL PICTURE



# OUR COSMOLOGICAL PICTURE

---



Basics such as redshift, distance

# THE VISIBLE UNIVERSE

---



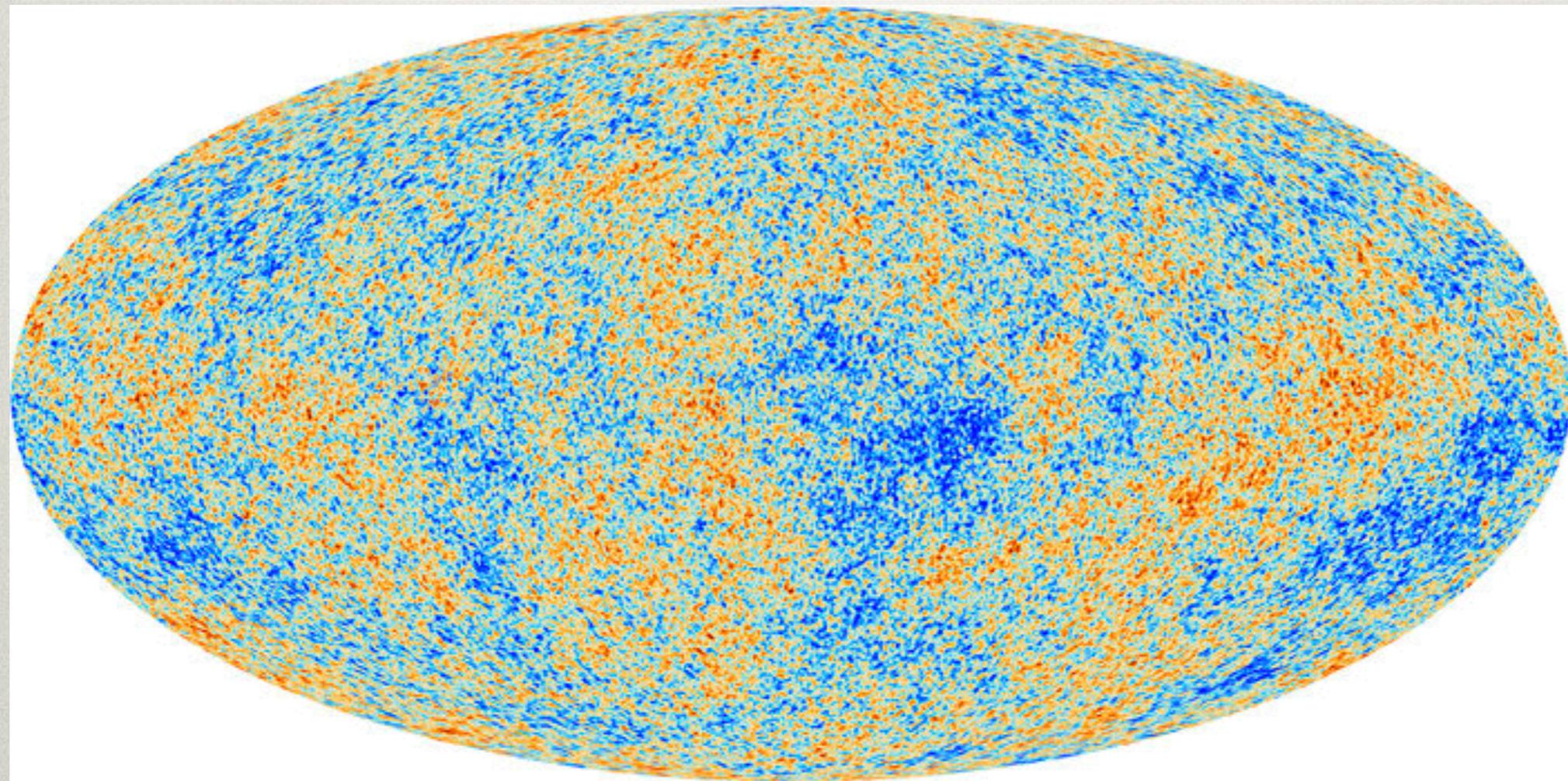
Hubble Ultra Deep  
Field

11 sq arcmin  
~10,000 objects

1 / 10billionth of  
brightness  
sensitive to human  
eye

# THE DISTANT UNIVERSE

---



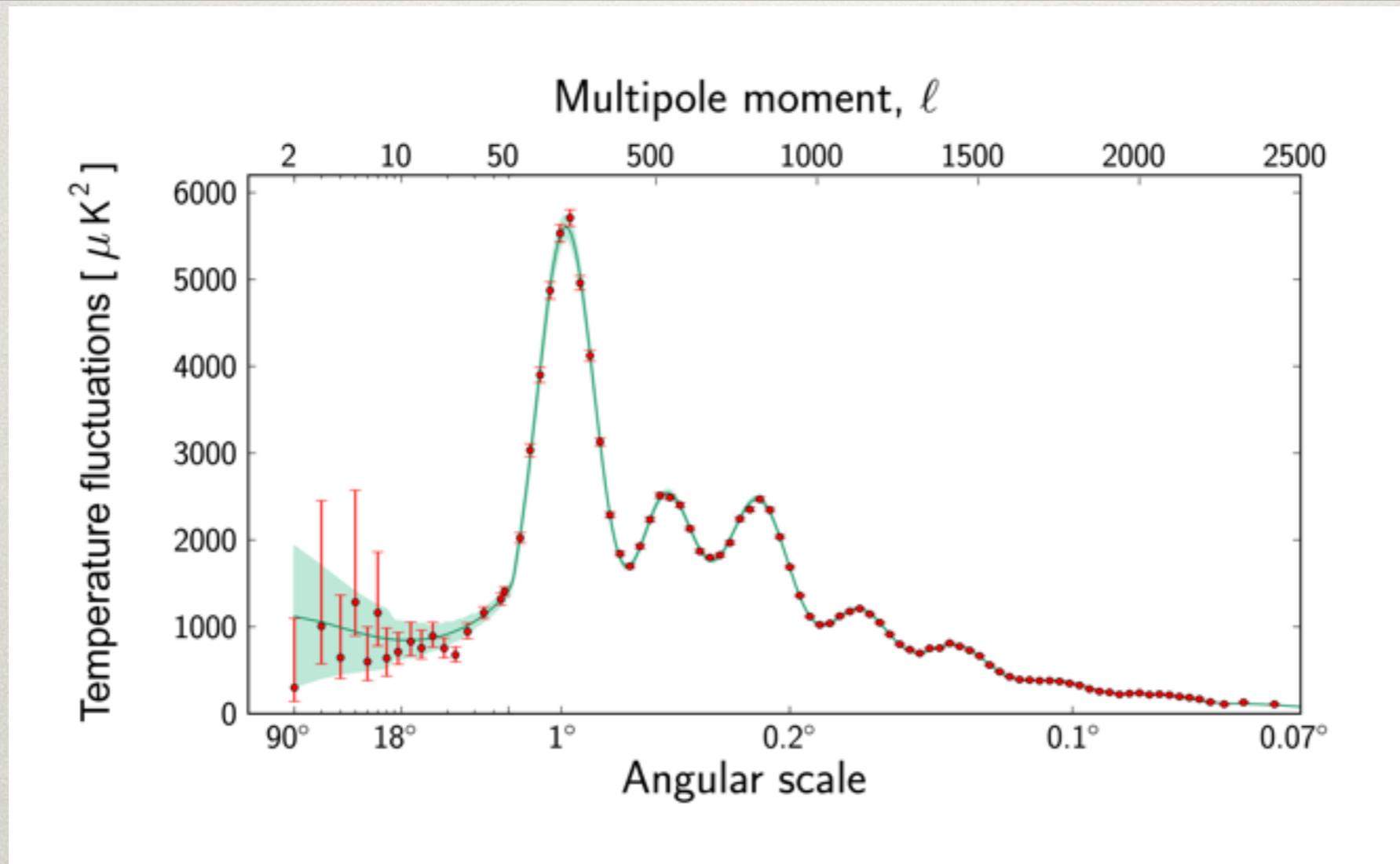
Planck

Oldest observable light - from 380,000 years after Big Bang

Universe finitely old but ancient - 14 billion years

# THE DISTANT UNIVERSE

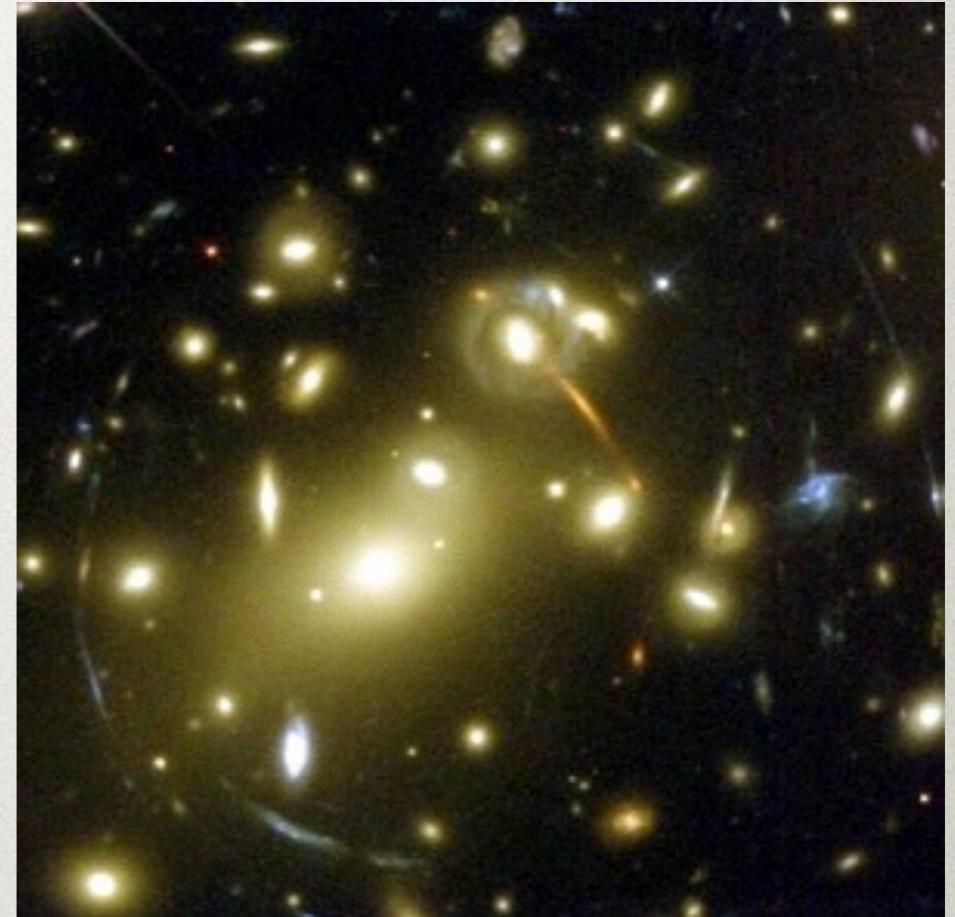
Planck



Statistics contain information about matter content;  
new constituent - dark matter;  
new constituent - dark energy

# DARK MATTER

---



Everywhere we look, there is “too much” gravity acting  
New type of massive particle which interacts with  
gravity?

# DARK ENERGY

---



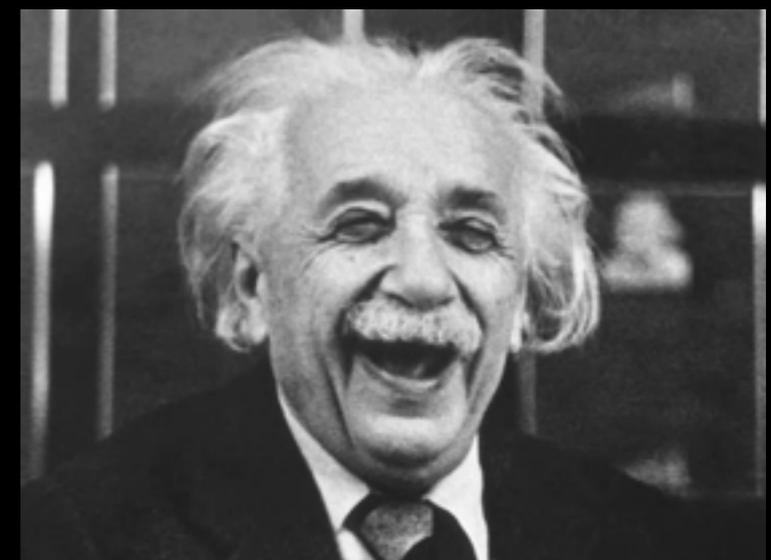
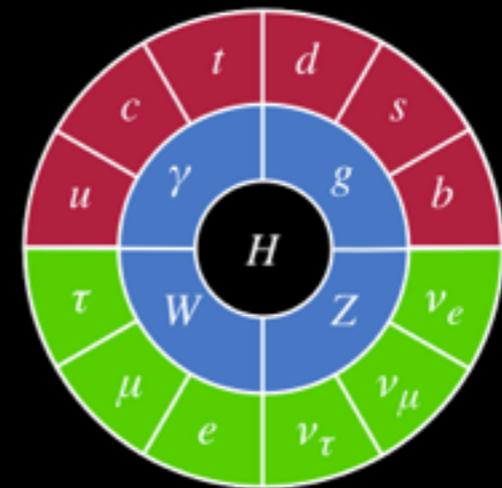
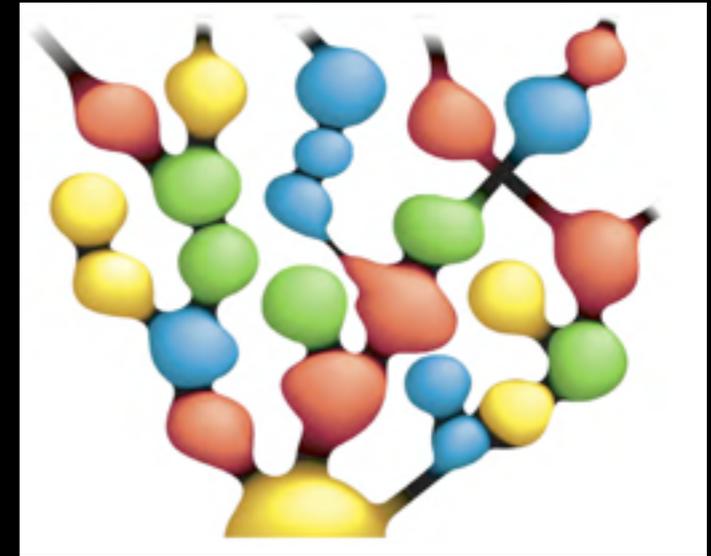
Evidence from probes of geometry (SNe, clustering)  
that expansion is speeding up - why?

# DARK ENERGY

Possible explanations:

- a **vacuum energy**;
- additional **particle field(s)**;
- modification to theory of **gravity**

All are exciting new physics!



# PROBES: SUPERNOVAE 1A

---



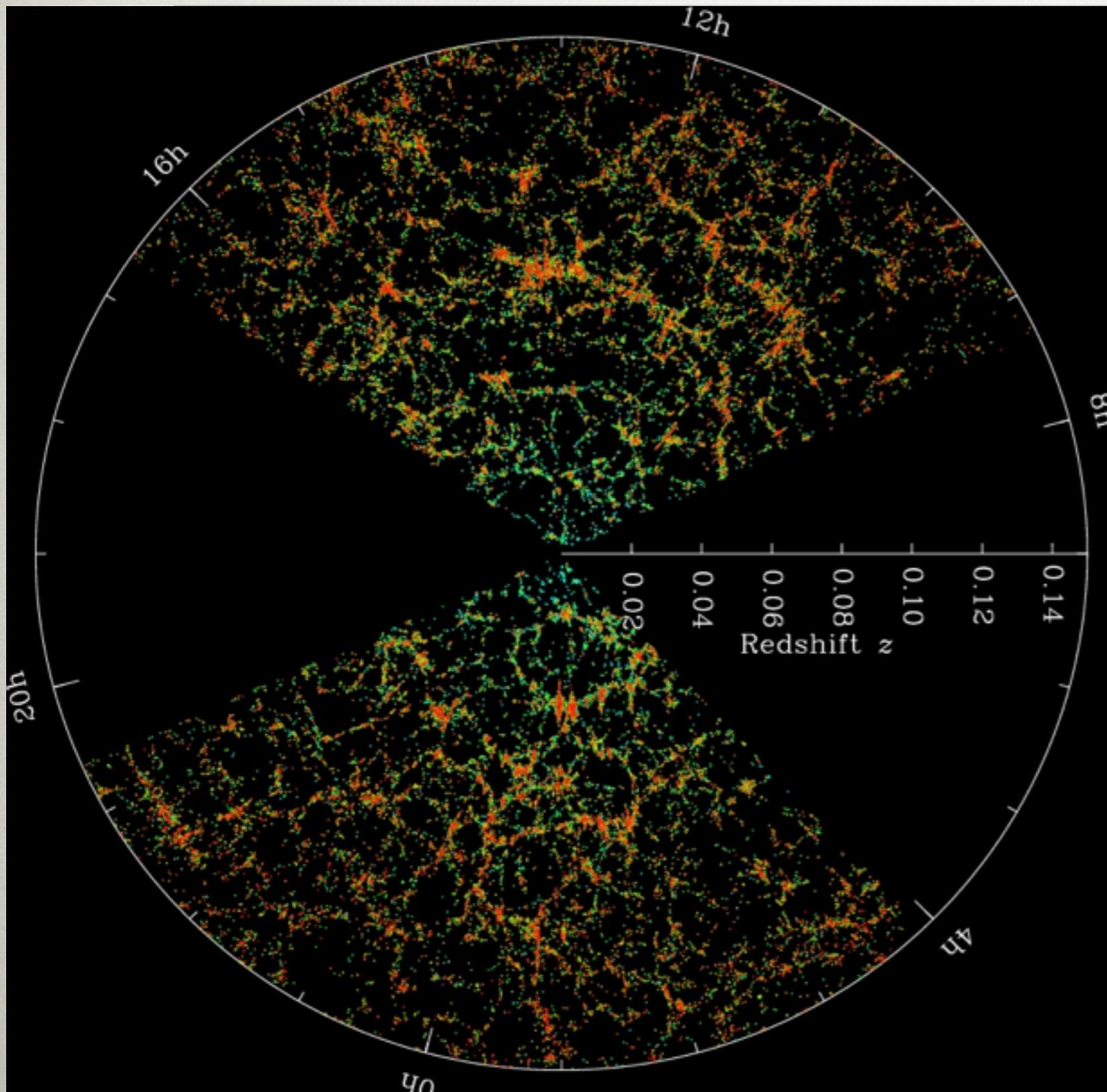
Standardisable candles

Find a relation  
between redshift  
and brightness

Find relation is  
as expected for DE

Like 2.5 billion suns!

# GALAXY CLUSTERING

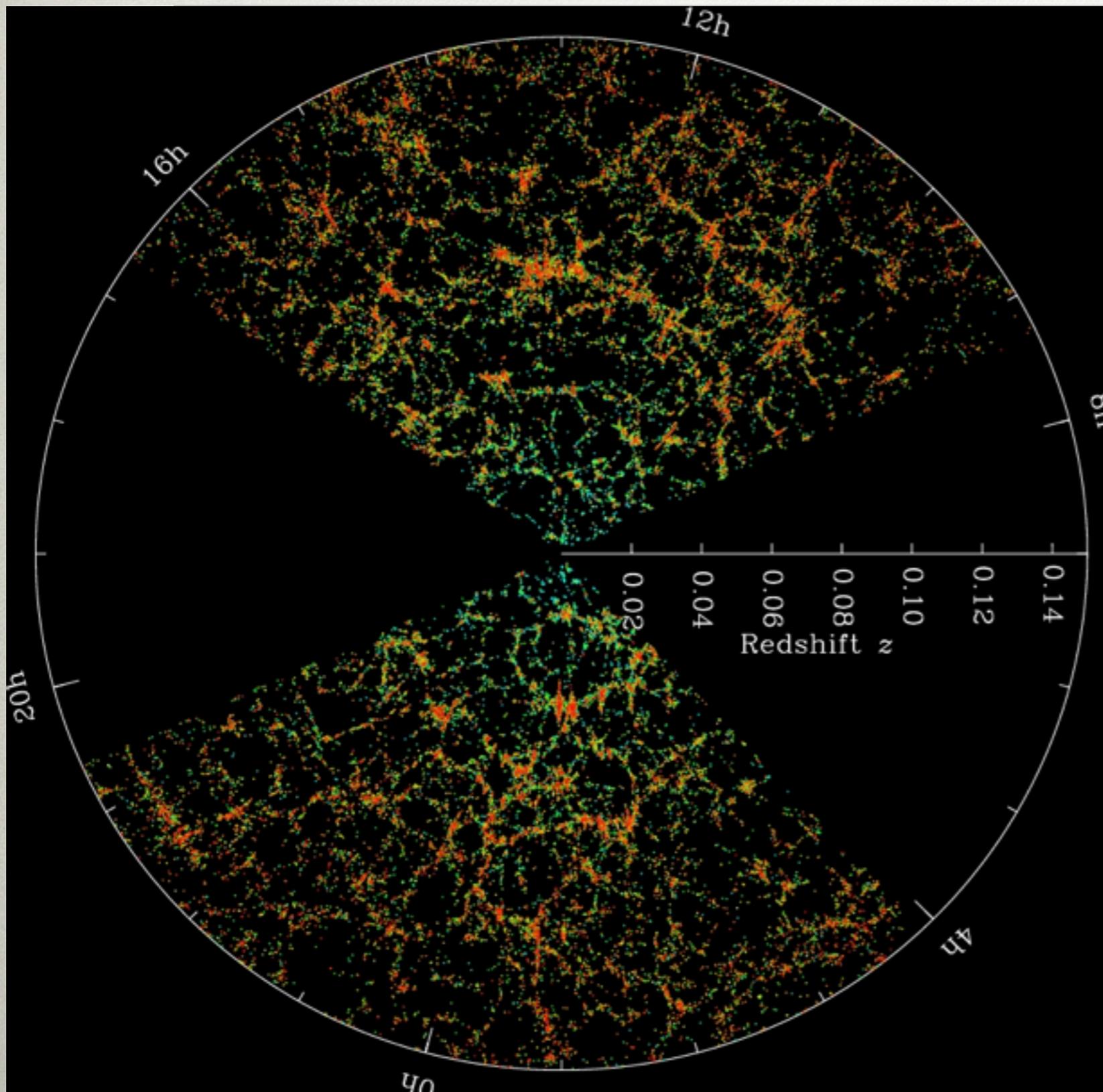


Sloan Digital  
Sky Survey

Galaxies trace out  
a colossal cosmic  
web

A biased tracer of  
underlying DM

# CLUSTERING STATISTICS



How can we describe these patterns?

Can think about correlation function

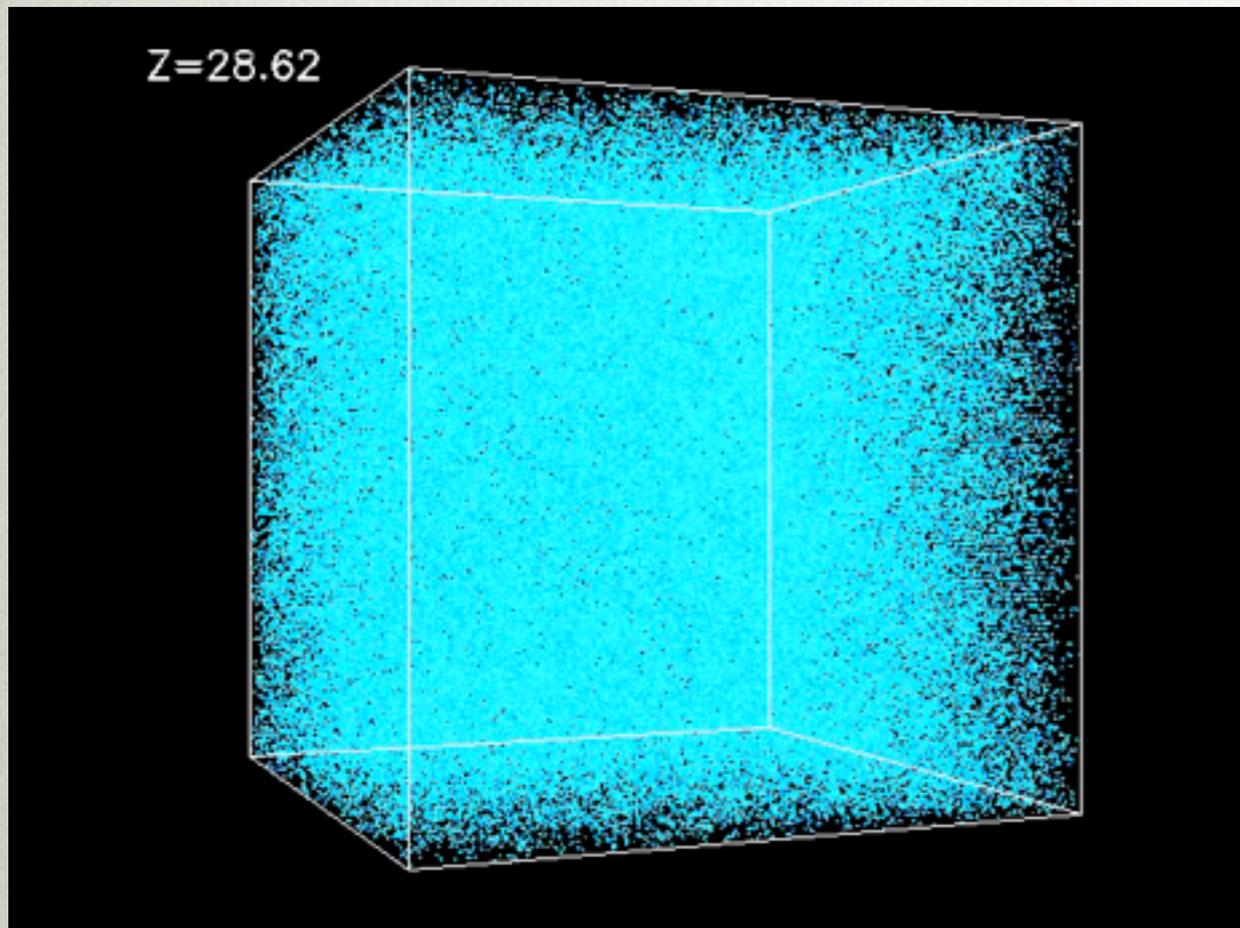
Or equivalent in Fourier space - power spectrum

Higher order stats

# N-BODY SIMULATIONS

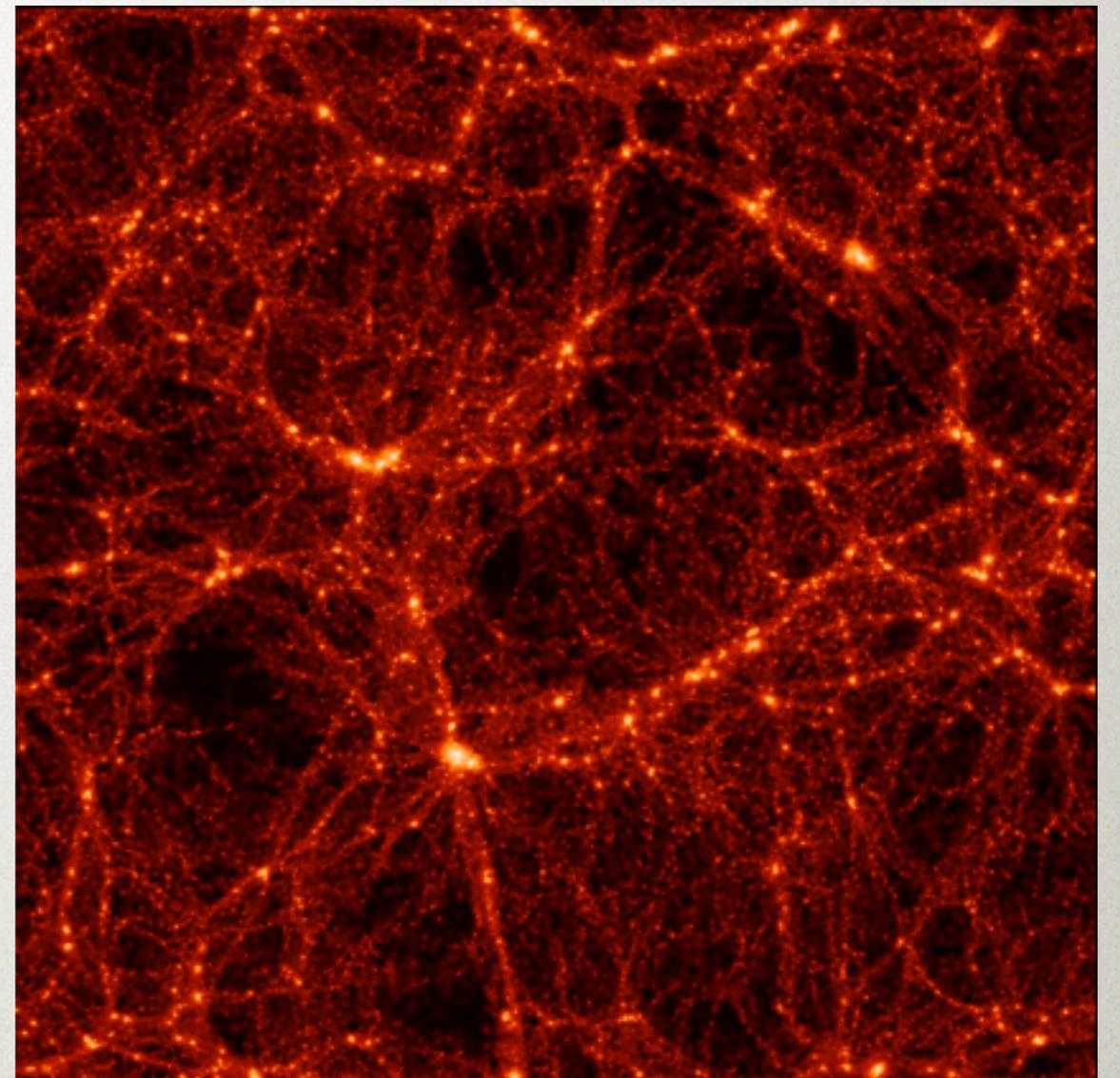
---

LCDM



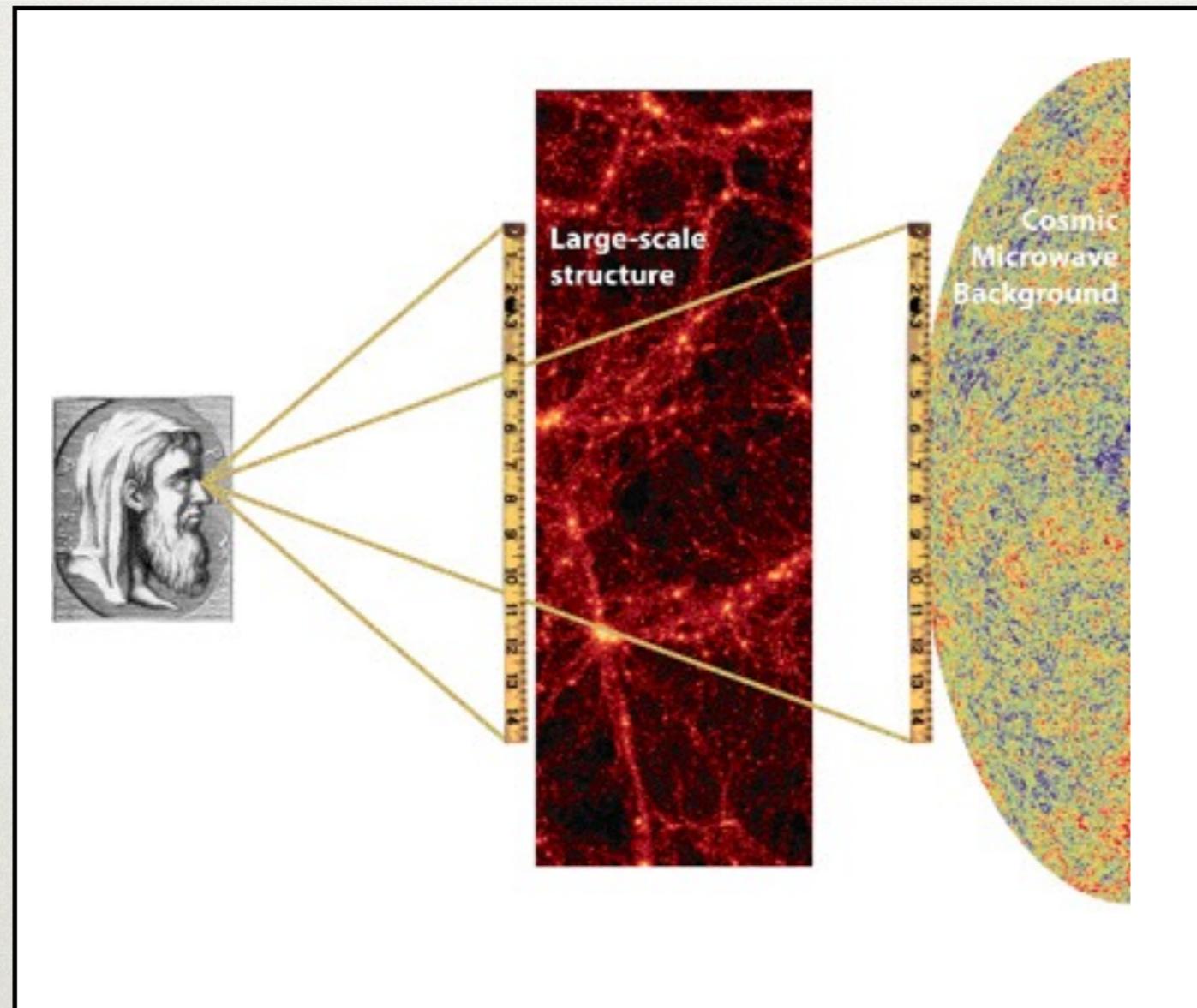
A, Babul

The statistics of the density field can be compared with **galaxy clustering**.



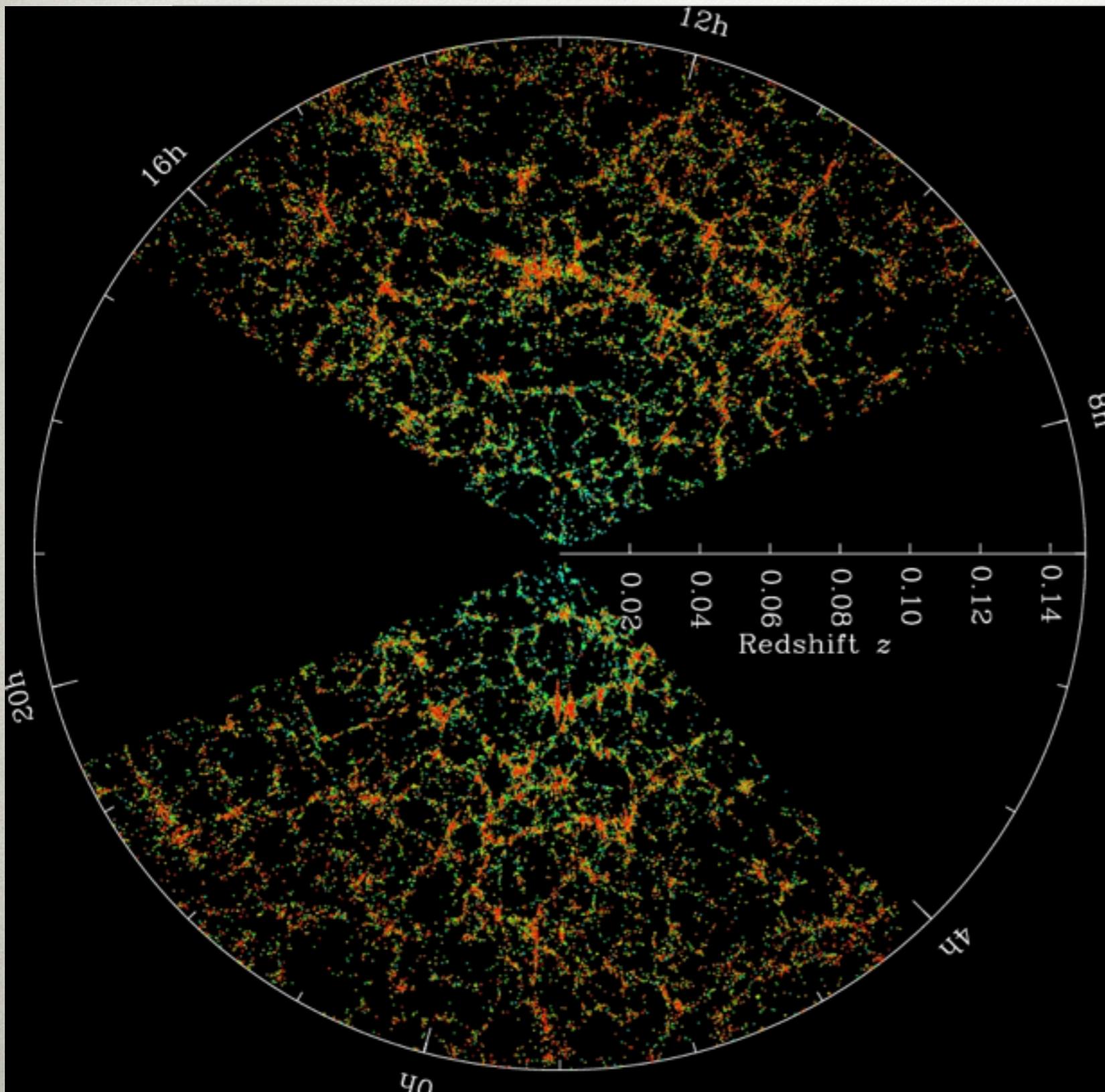
VIRGO consortium

# STANDARD RULER FROM 'BARYON ACOUSTIC OSCILLATIONS'



The pattern expands, so we can chart the expansion history of the Universe, which depends on dark energy.

# VELOCITIES



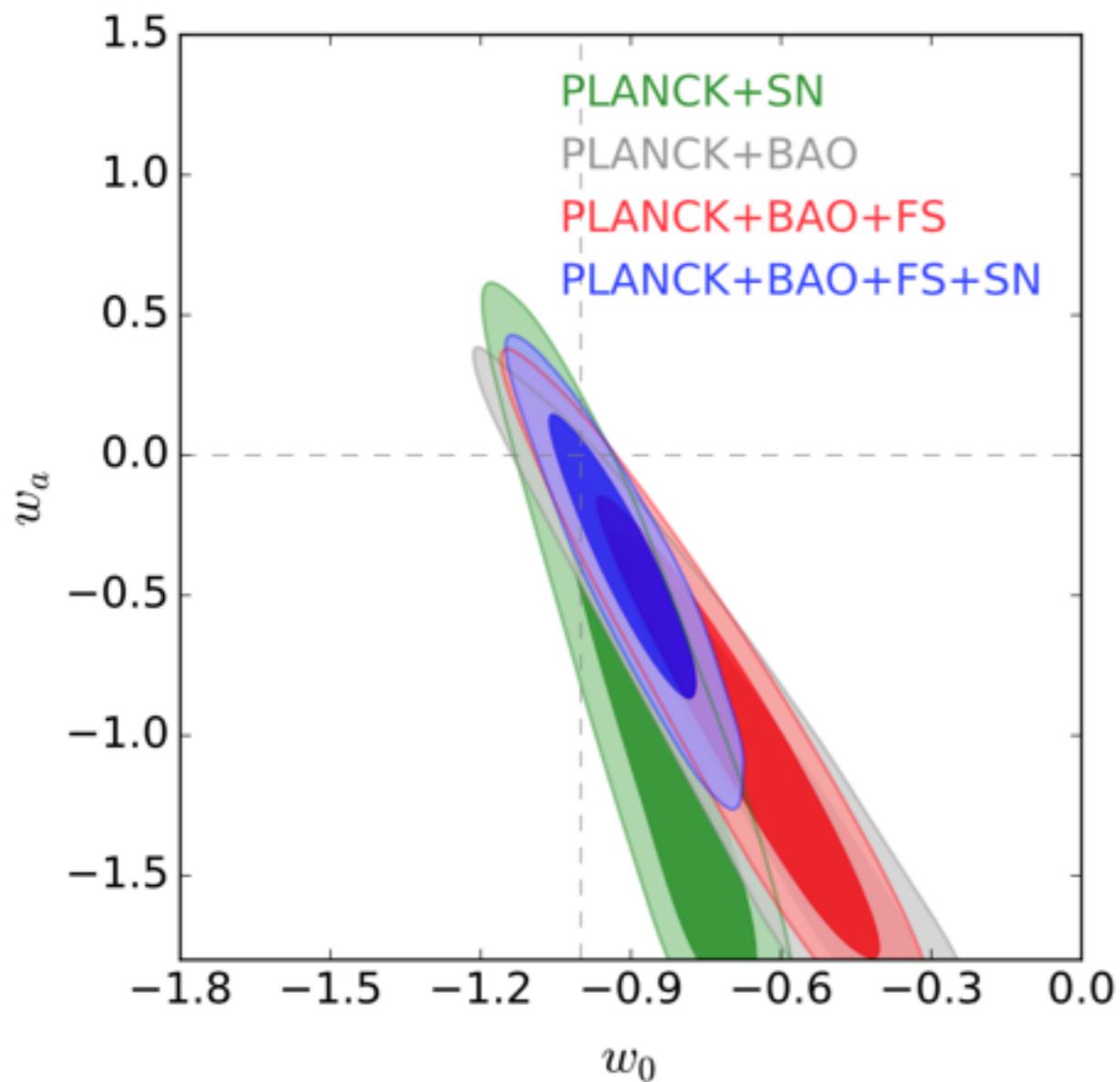
Patterns are distorted by Doppler effect

Allow us to measure rate of growth of structure

Sensitive to DM, DE, gravity

# CONSTRAINTS AND PREDICTIONS

---



Results often shown on plots like this.

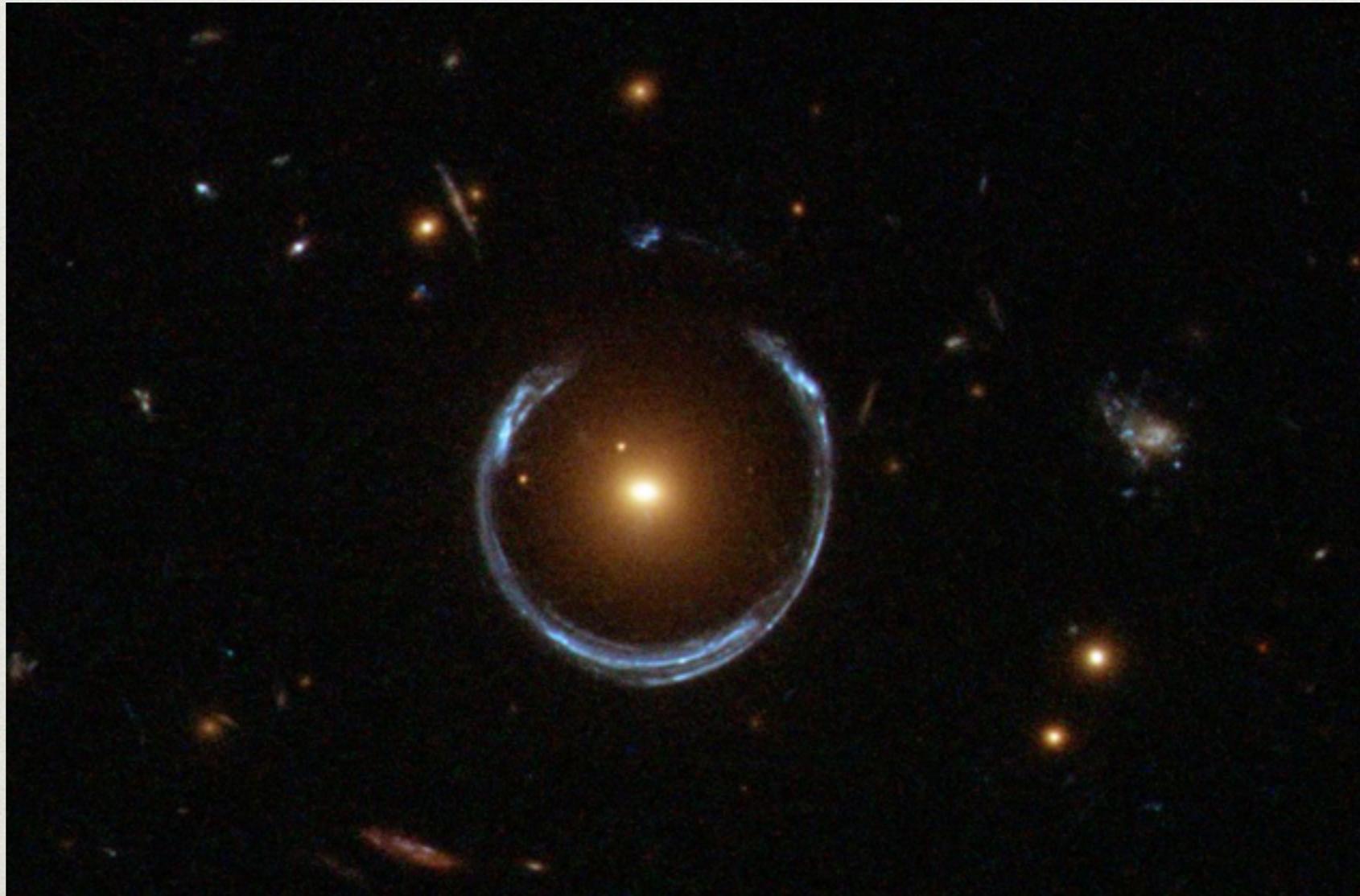
What do they mean?

How are they made?

How do we predict?

# PROBES: STRONG LENSING

---



Light is radically bent by gravity

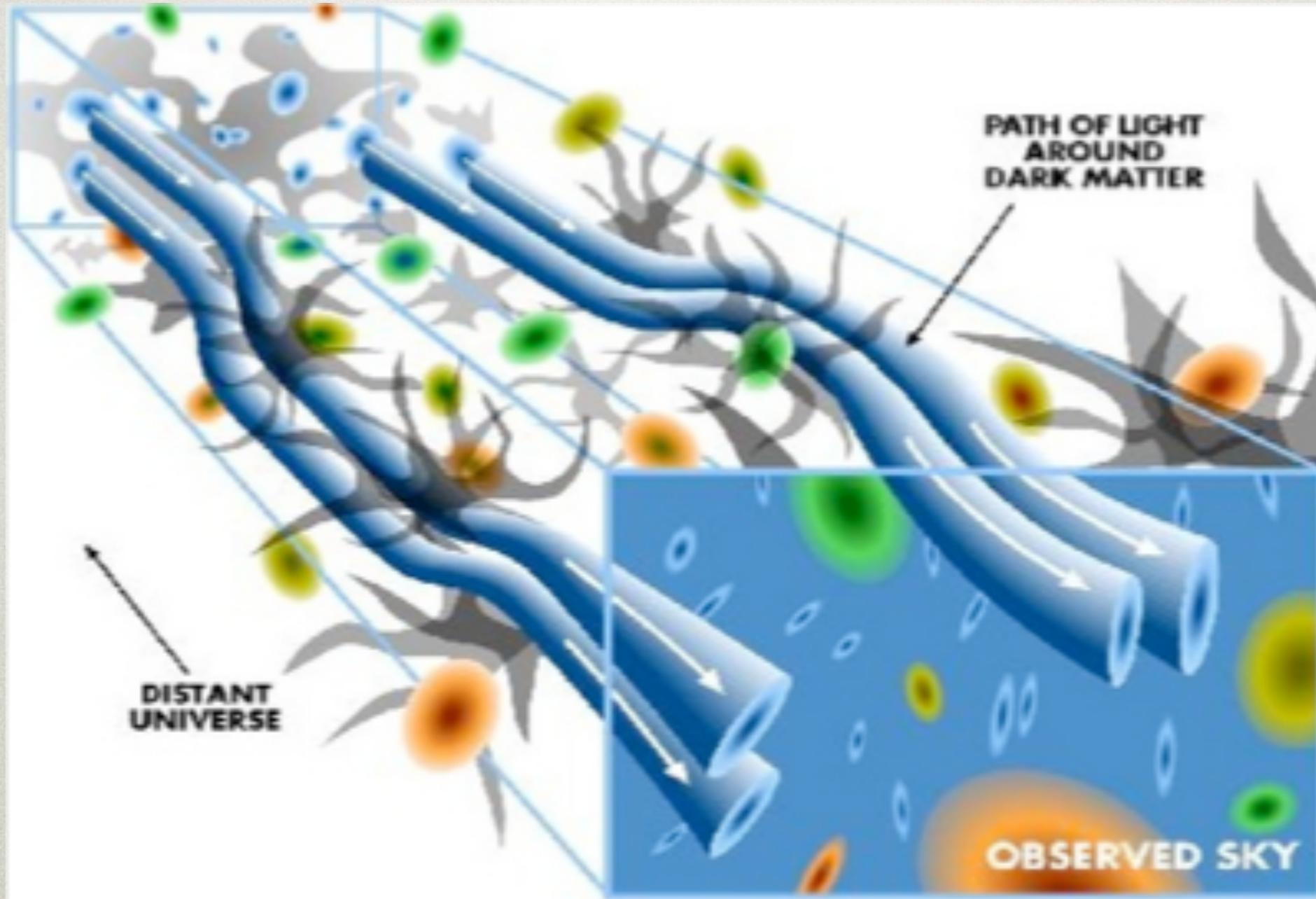
Sensitive to density of lens, geometry of Universe,  
and law of gravity

# PORTSMOUTH

---



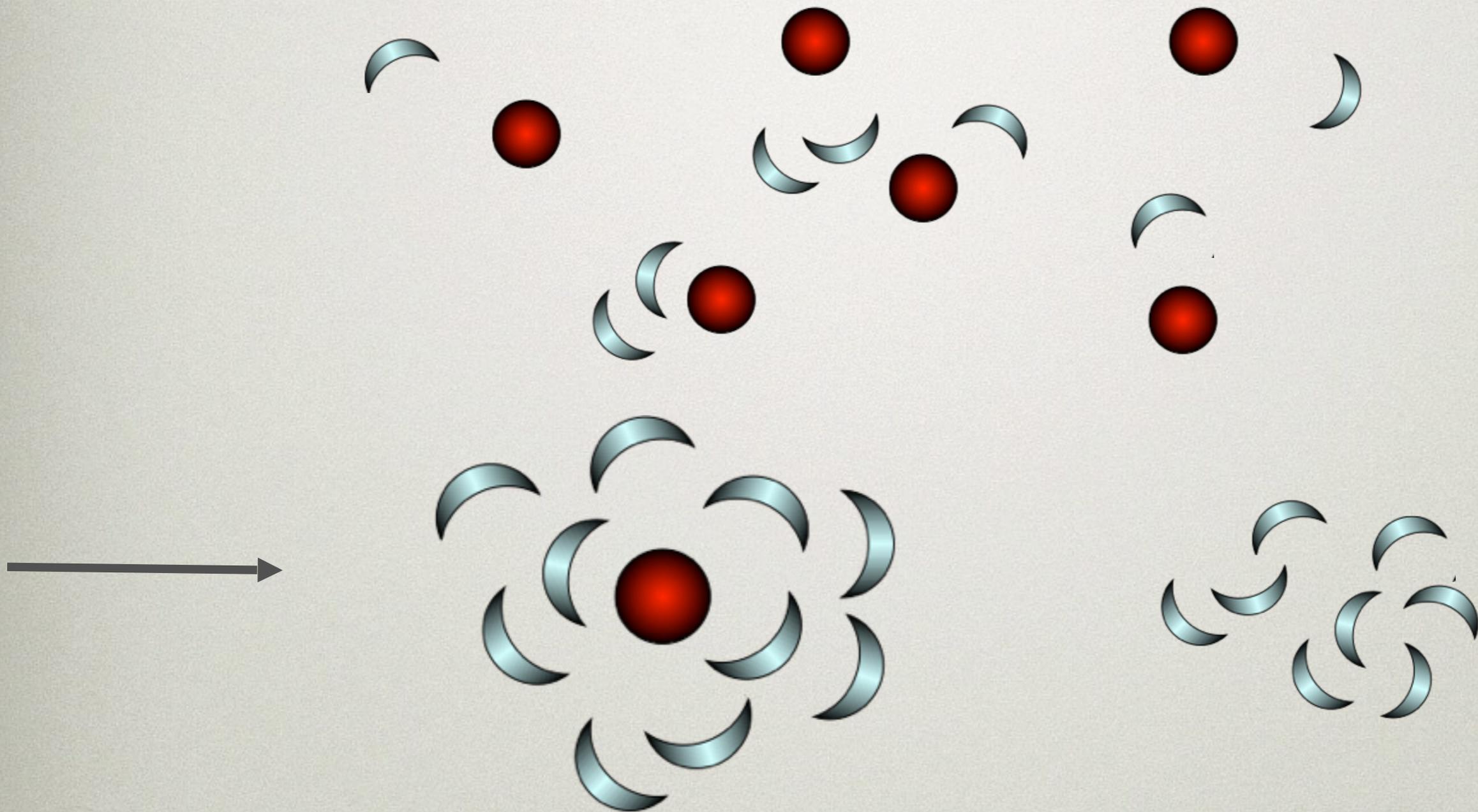
# WEAK LENSING



Galaxy shapes slightly bent by intervening matter  
Sensitive to gravity, matter and geometry

# WEAK LENSING

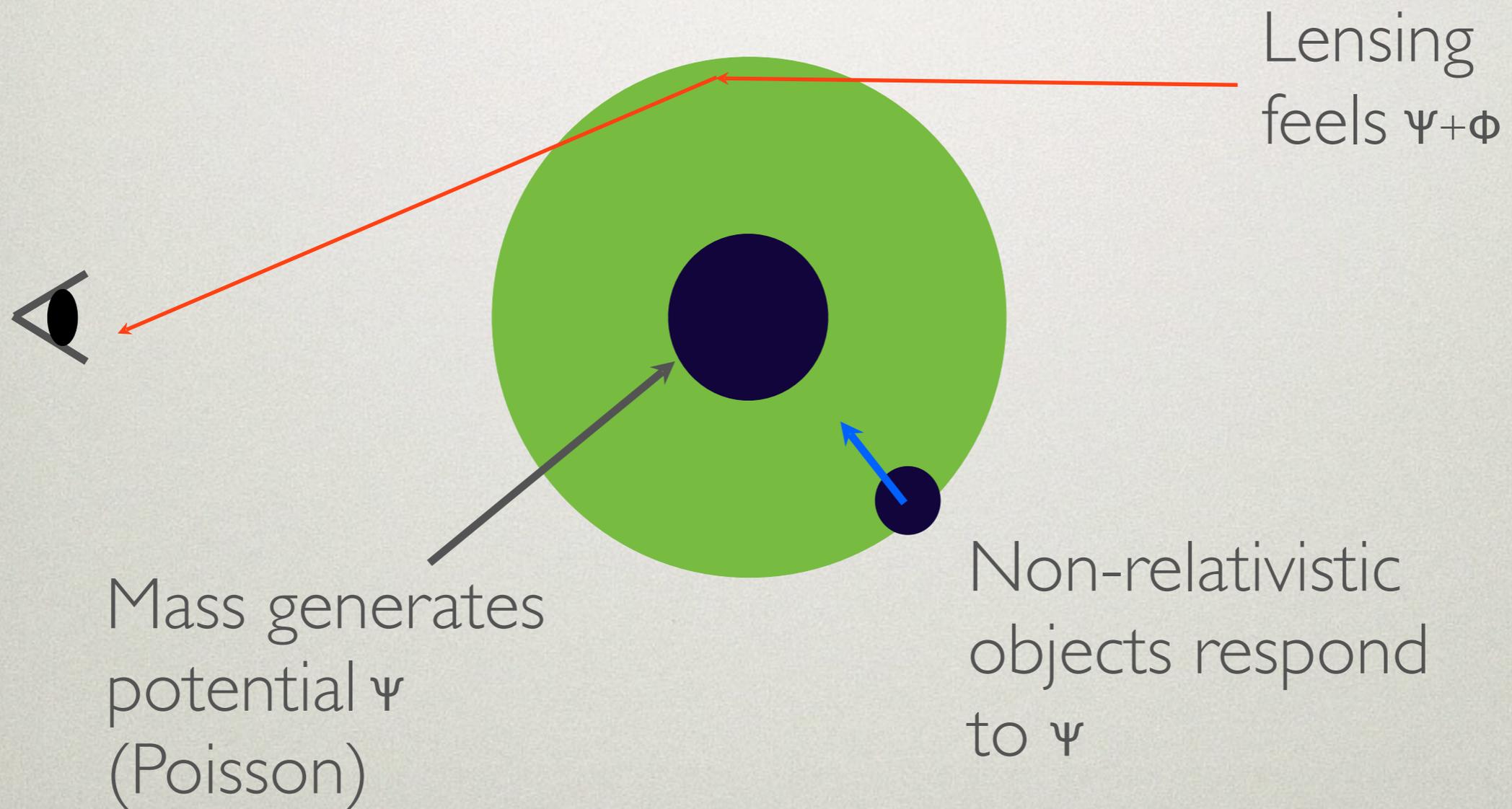
---



Can look at correlations between galaxies and distortions, or distortion-distortion

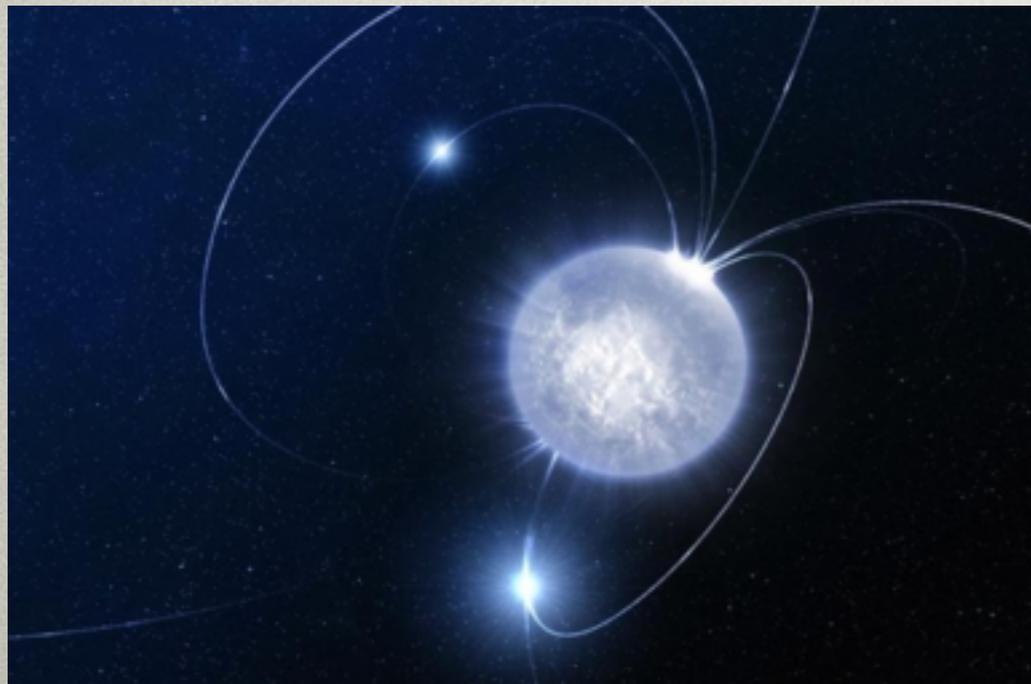
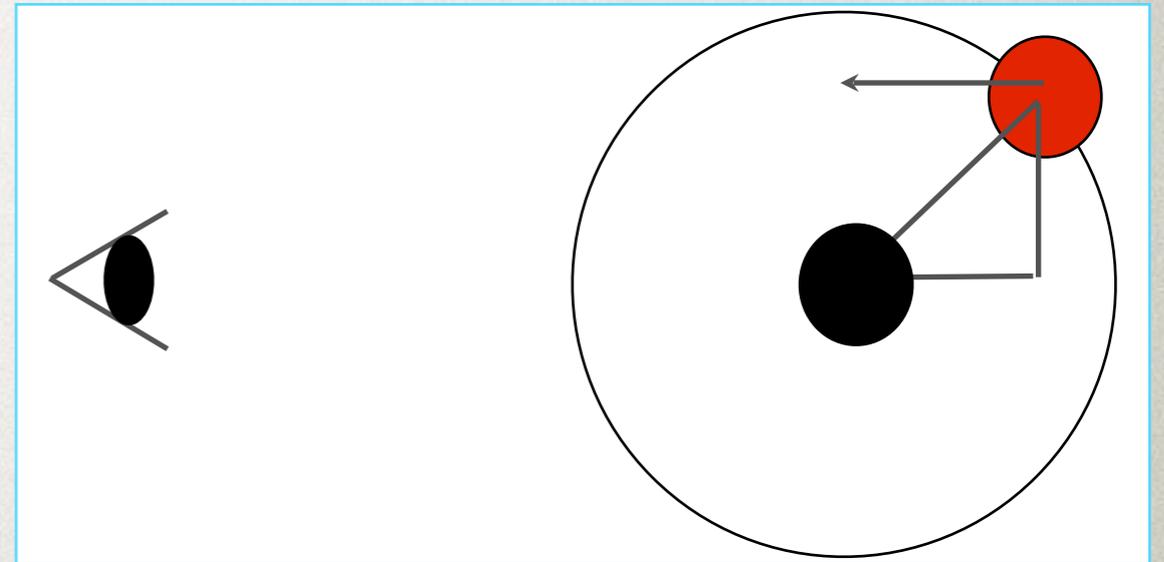
# TESTS OF GRAVITY

---



# OTHER PROBES

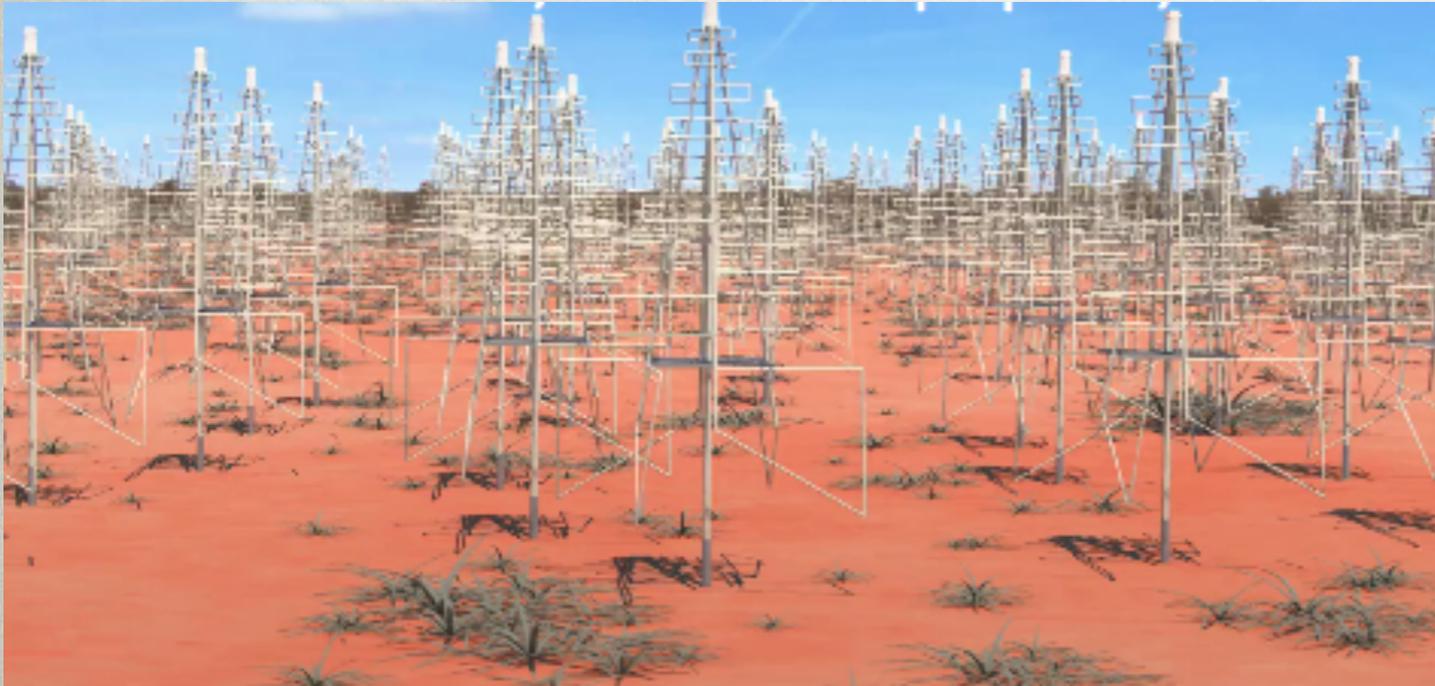
---



A number of further probes to develop to learn about cosmology.

# FUTURE: DIFFERENT WAVELENGTHS

---



Radio cosmology is  
burgeoning



New techniques such  
as intensity mapping  
will make it  
competitive with  
optical

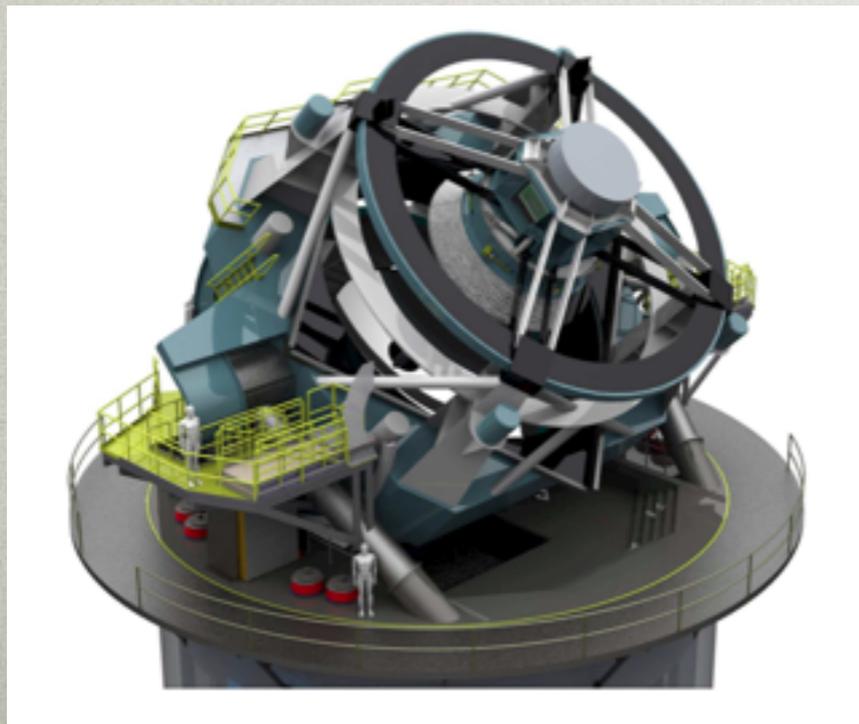
# FUTURE: NEW OPTICAL SURVEYS

---



Major space surveys:  
e.g. Euclid, WFIRST

Major ground-based  
surveys: e.g. LSST, SKA



Combination will be  
incredibly powerful  
for testing detailed  
models of dark sector.

# SUMMARY

---

Cosmology has made **incredible advances** observationally.

It has led to a **very surprising** standard model.

**Dark matter** provides extra gravity on many scales.

**Dark energy** provides an accelerating expansion.

Different '**probes**' work together to give evidence.

**Future surveys** open a golden opportunity!