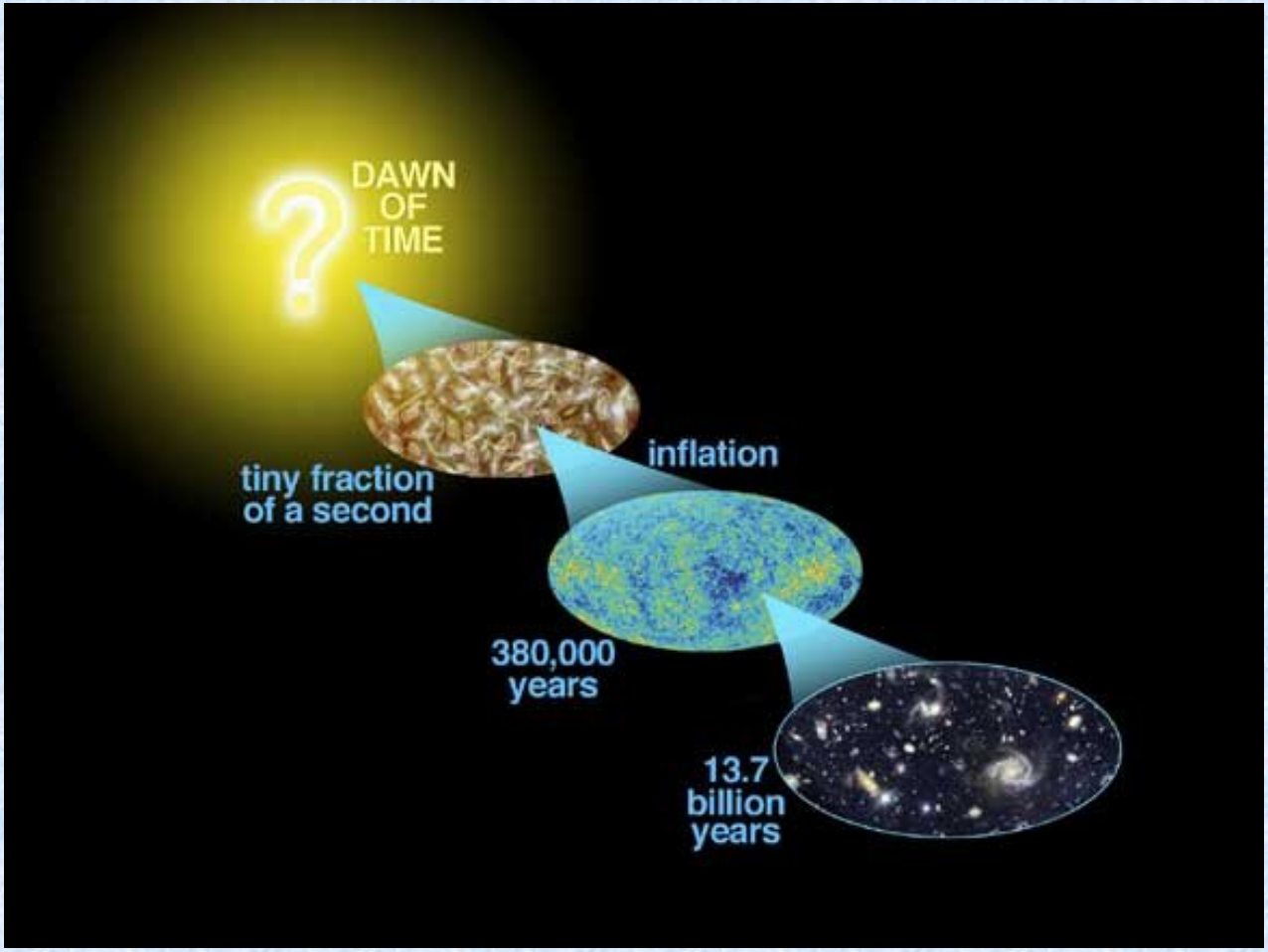
Physics 133: Extragalactic Astronomy and Cosmology



Lecture 14; March 3 2014

Previously. Applications of lensing

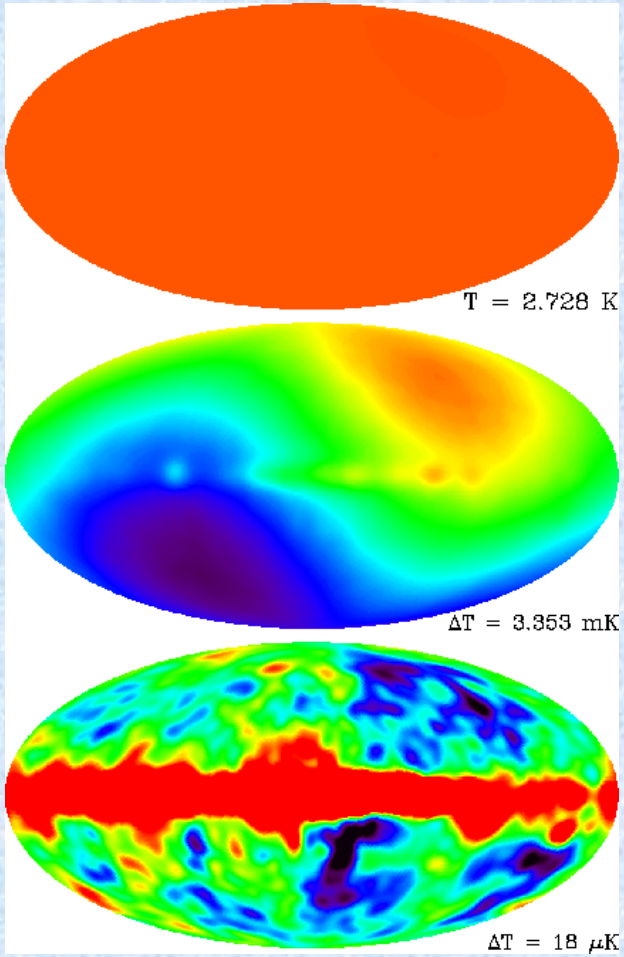
- Measure mass of galaxies, clusters planets.
- Test the cosmological model by measuring substructure
- Cosmography
- Test gravity
- Properties of dark matter

Outline:

- Cosmic microwave background
  - Summary of properties
  - Saha's Equation and recombination
  - (Re)combination and decoupling
  - Temperature fluctuations
  - Origin of the fluctuations
  - Cosmography: results from Planck

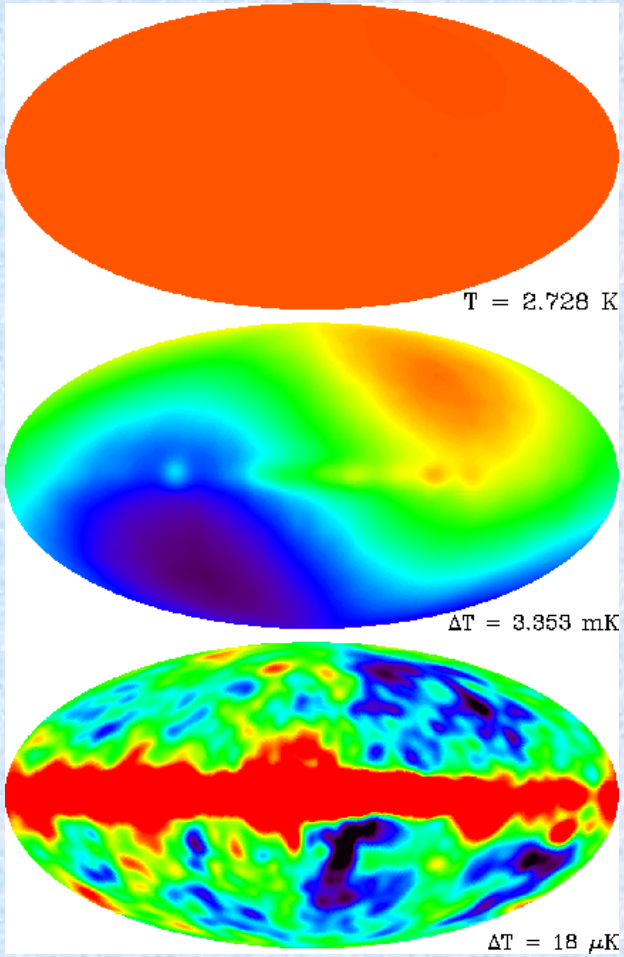
The CMB: basic properties

- CMB photons:
  - Energy density: 0.261 MeV/m^3
  - Number density: 4e8/m^3
- Baryons:
  - Energy density 210 MeV/m^3
  - Number density: 0.22/m^3
- Ratio:
  - η = n(baryons)/n(CMB)=5e-10



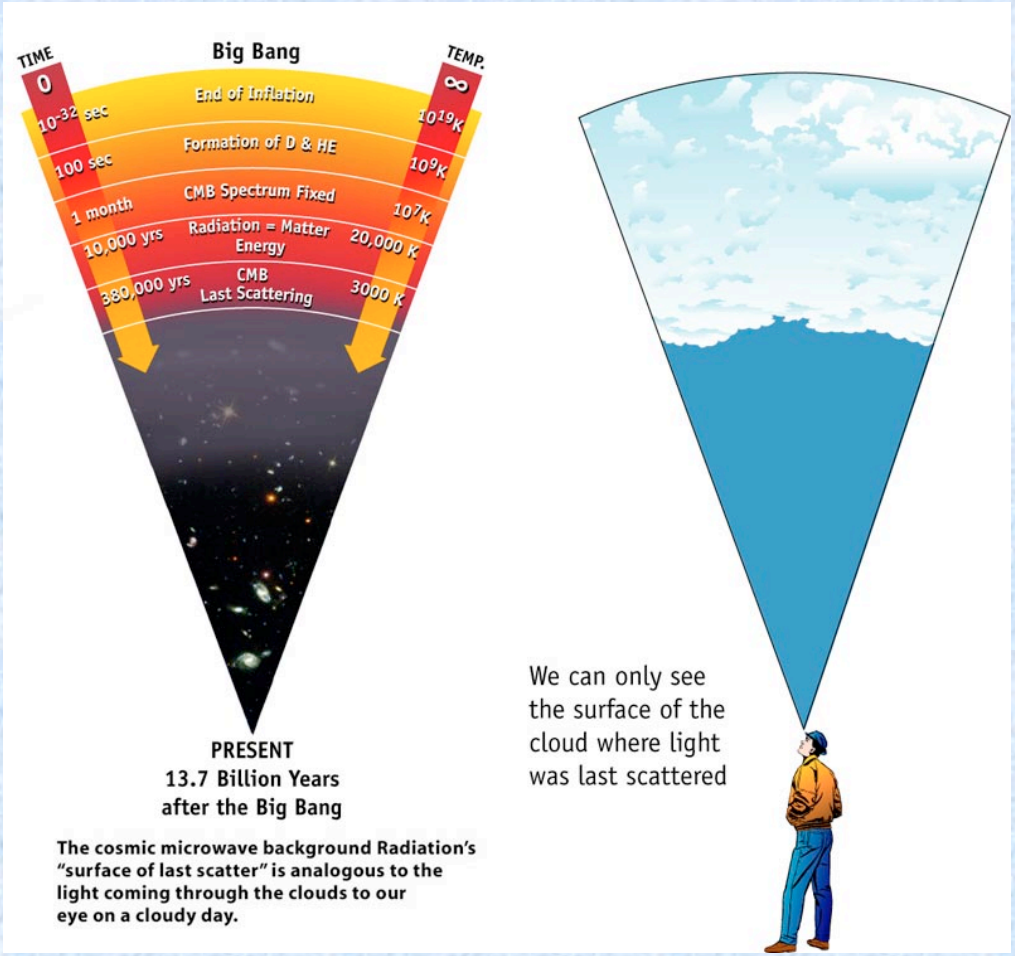
What are the three main COBE results?

1. The CMB is a blackbody within 1 part in 10,000
2. There is a dipole corresponding to the motion of the Earth with respect to the CMB
3. There are temperature fluctuations:
    1. $\langle(\delta T/T)^2\rangle^{1/2} = 1.1e\text{-}5$



The standard interpretation is that the CMB is left over from an early Epoch when the universe was hot (Hot Big Bang)

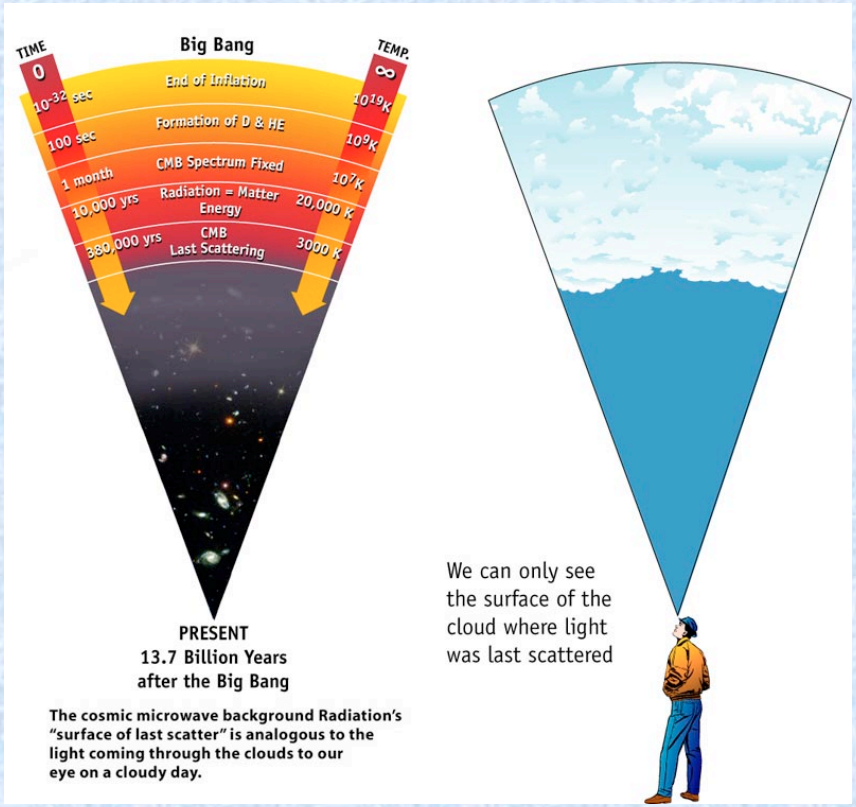
The origin of the CMB: Where/When does it come from?



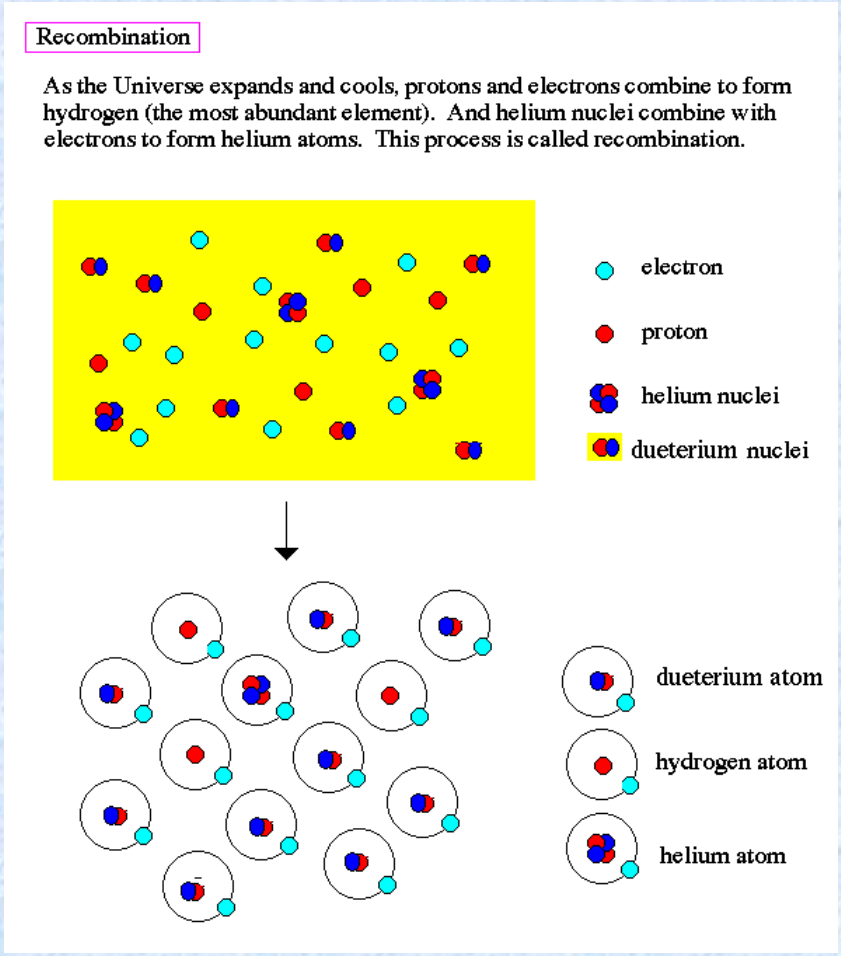
The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.

Three key epochs

- Recombination
  - z~1370
- Decoupling
  - z~1100
- Last scattering surface
  - z~1100



Recombination

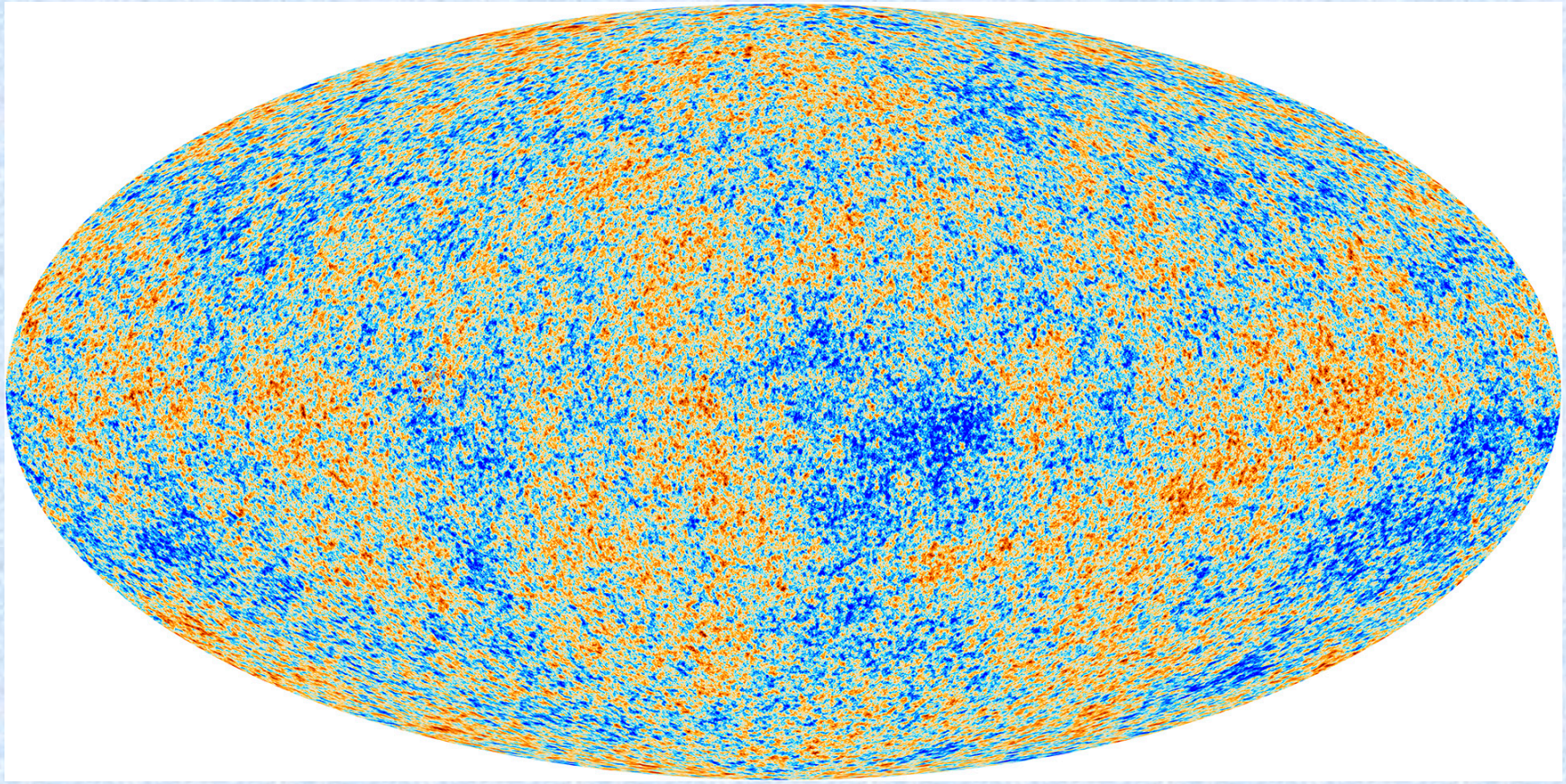


[Hydrogen case: blackboard]

Decoupling and last scattering surface

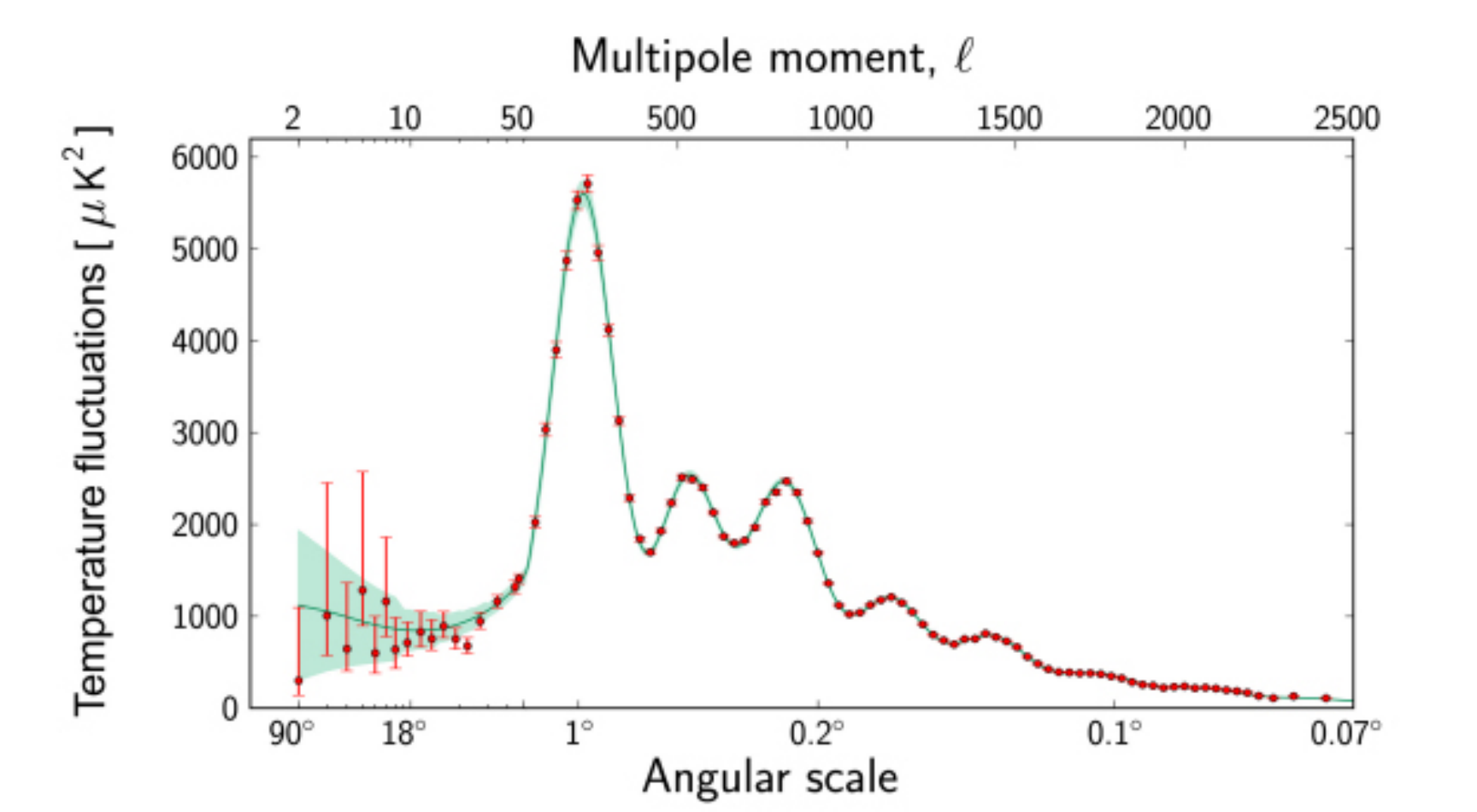
[blackboard]

The CMB: current view



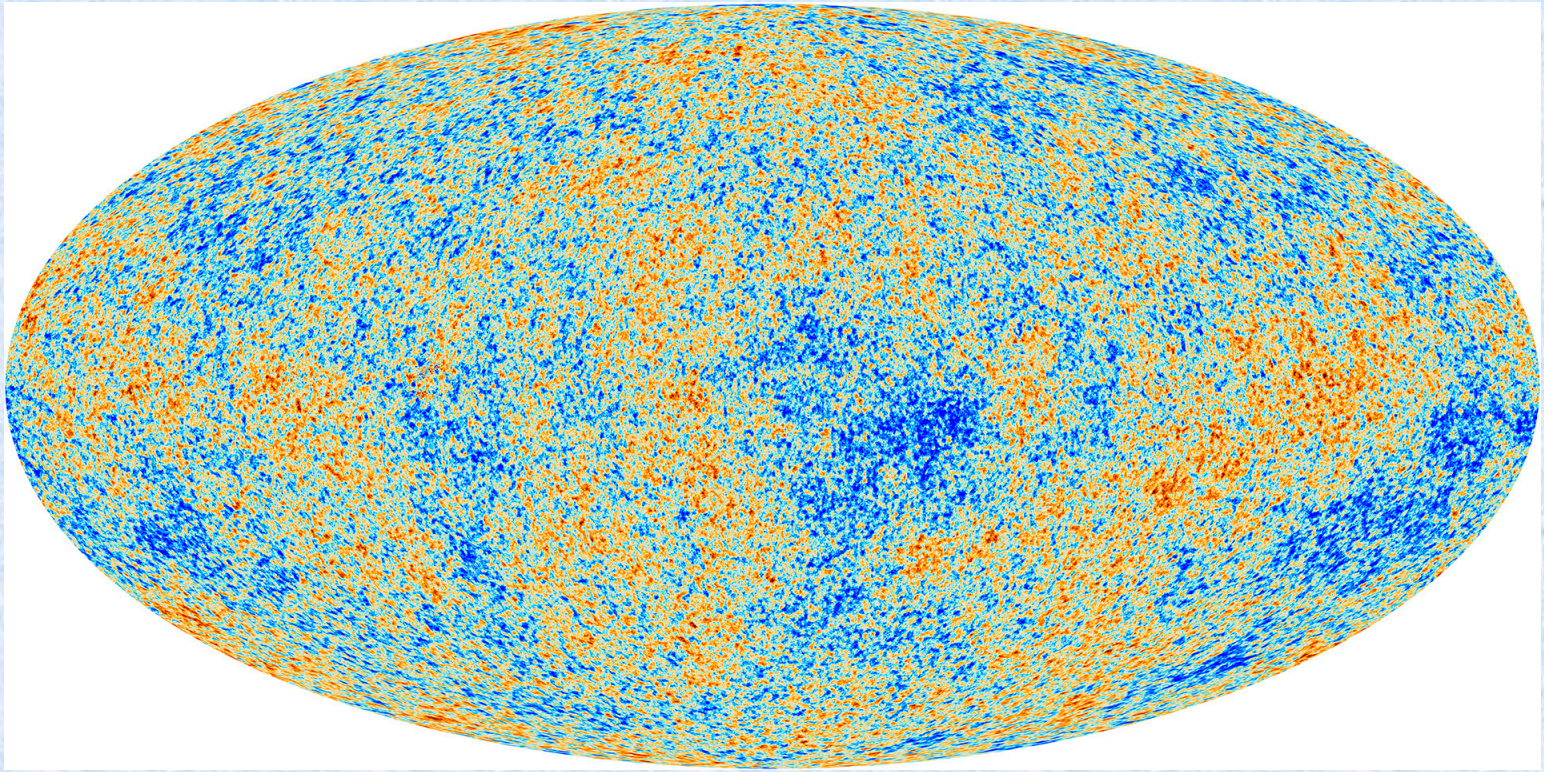
How do we interpret this map? We need statistical tools.

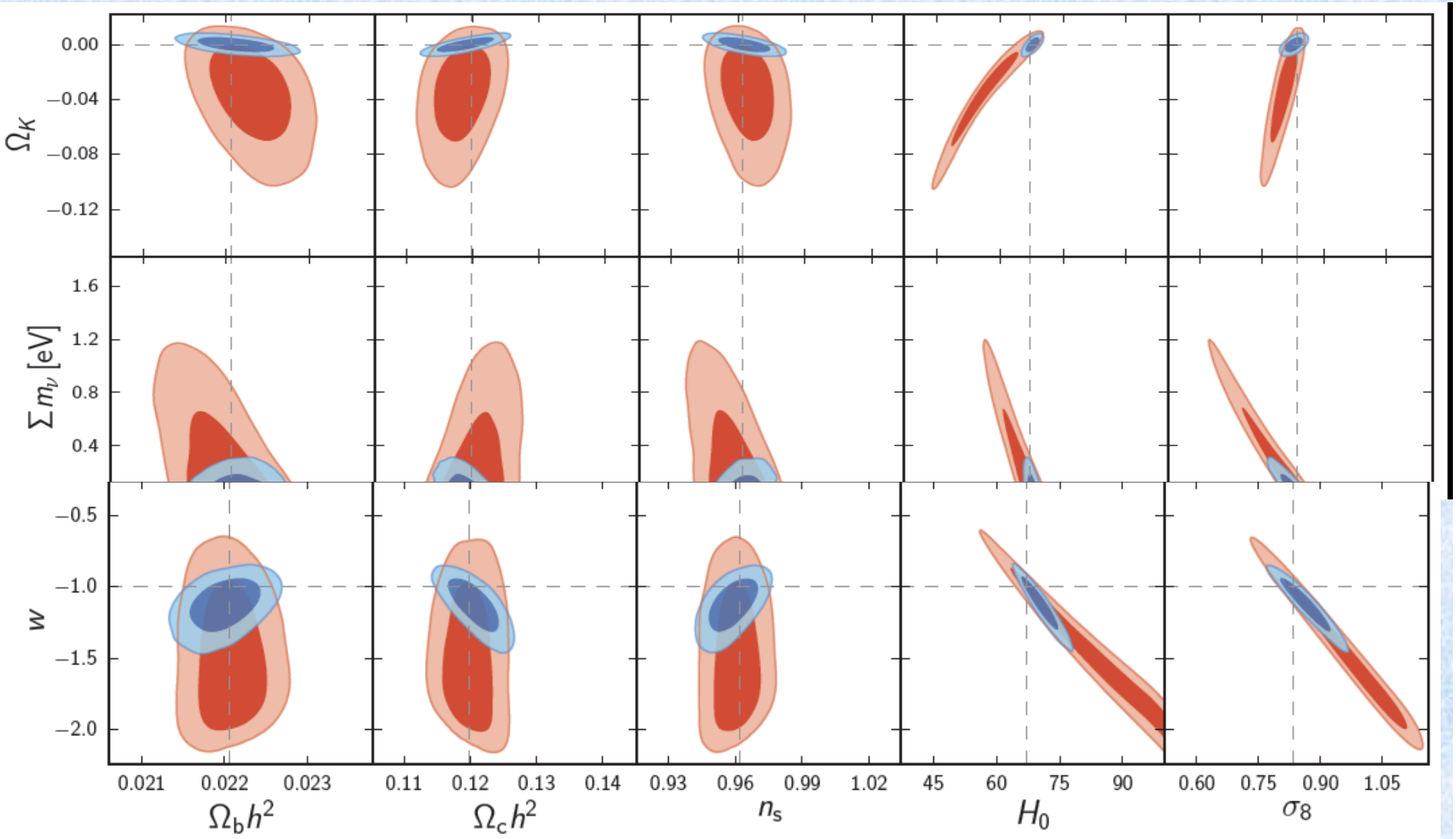
The CMB: current view



What is this? Anisotropy of the CMB as a function of angular scale

Anisotropy and cosmography.




0.00
−0.04
−0.08
−0.12
Ω_K
1.6
1.2
0.8
0.4
Σm_ν [eV]
−0.5
−1.0
−1.5
−2.0
w
0.021
0.022
0.023
$\Omega_b h^2$
0.11
0.12
0.13
0.14
$\Omega_c h^2$
0.93
0.96
0.99
1.02
n_s
45
60
75
90
H_0
0.60
0.75
0.90
1.05
σ_8

Planck XVI

Summary

- The CMB gives us a view of the universe at z~1100 (last scattering surface)
- This is very close to the epoch of recombination, when nuclei captured electrons to form atoms z~1300
- CMB fluctuations are generated by fluctuations in the gravitational field at the time of last scattering
- The angular scale of the fluctuations gives us information on the content of the universe.

The End

See you on Wednesday!