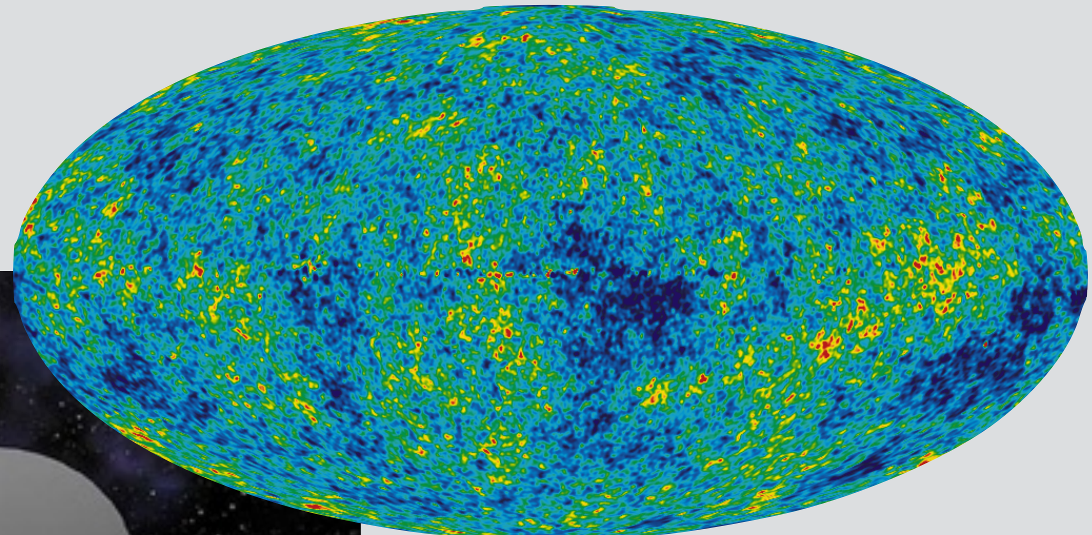
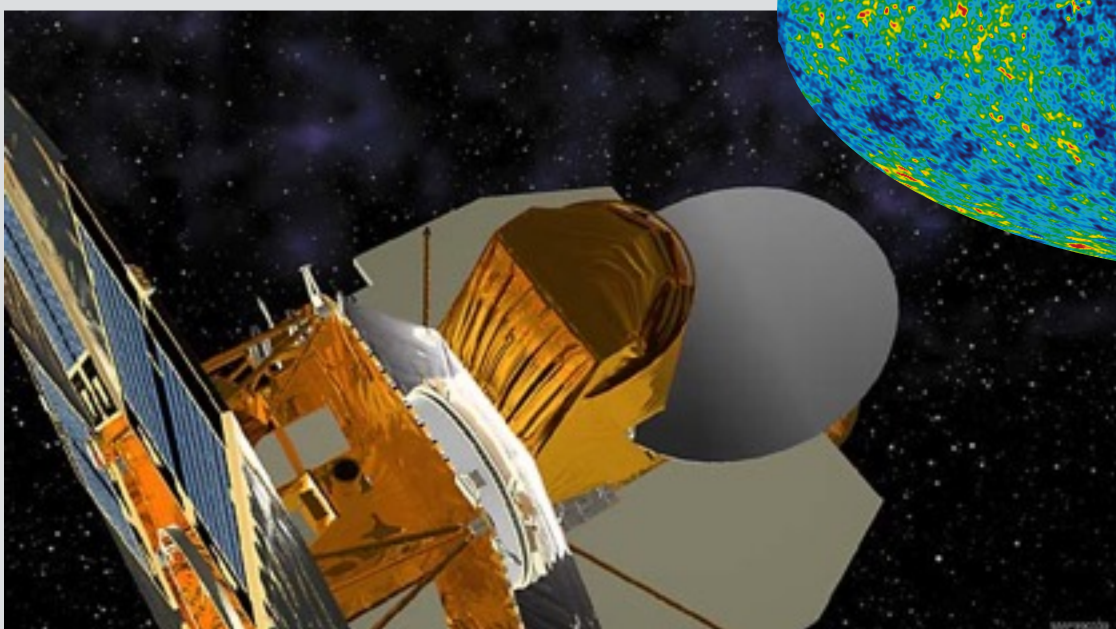
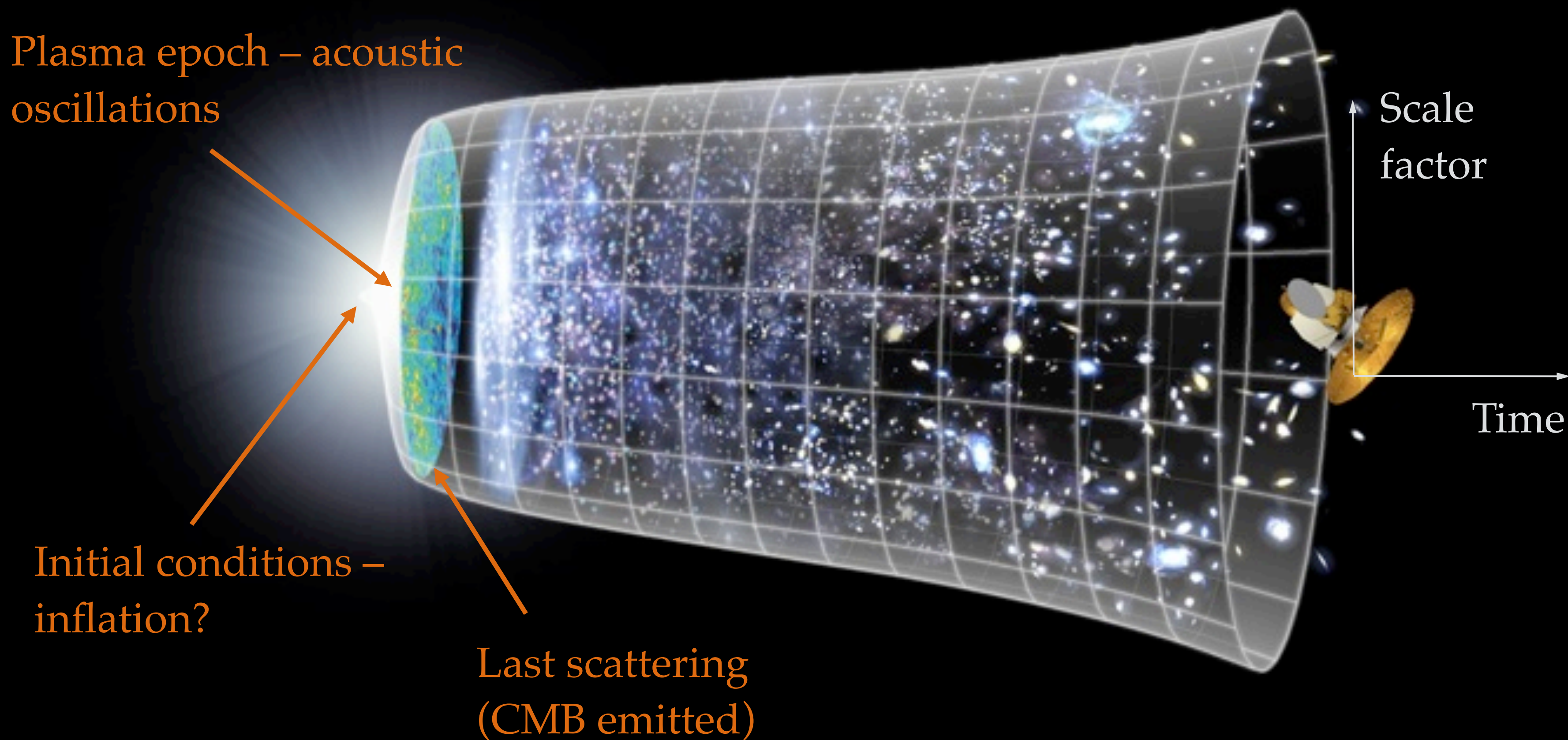
WMAP
and the
Standard Model of Cosmology





EPSHEP/2019 Cocconi Prize Talk 2019 July 15 Gary Hinshaw for the WMAP Team

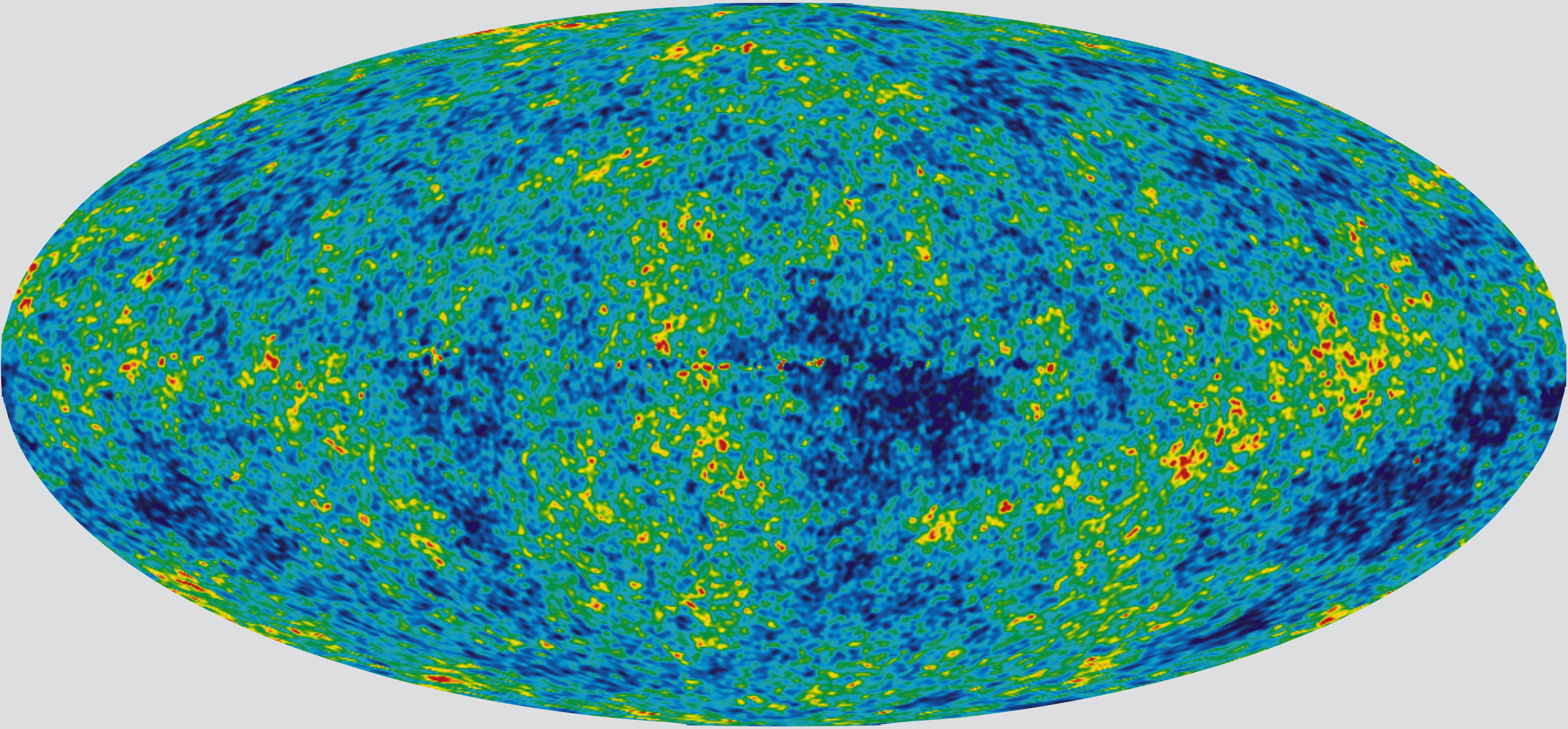
Cosmology Timeline



CMB photons propagate (nearly) freely across the universe since last scattering, preserving an image of conditions at the time of their emission. The CMB is the oldest light in the universe.

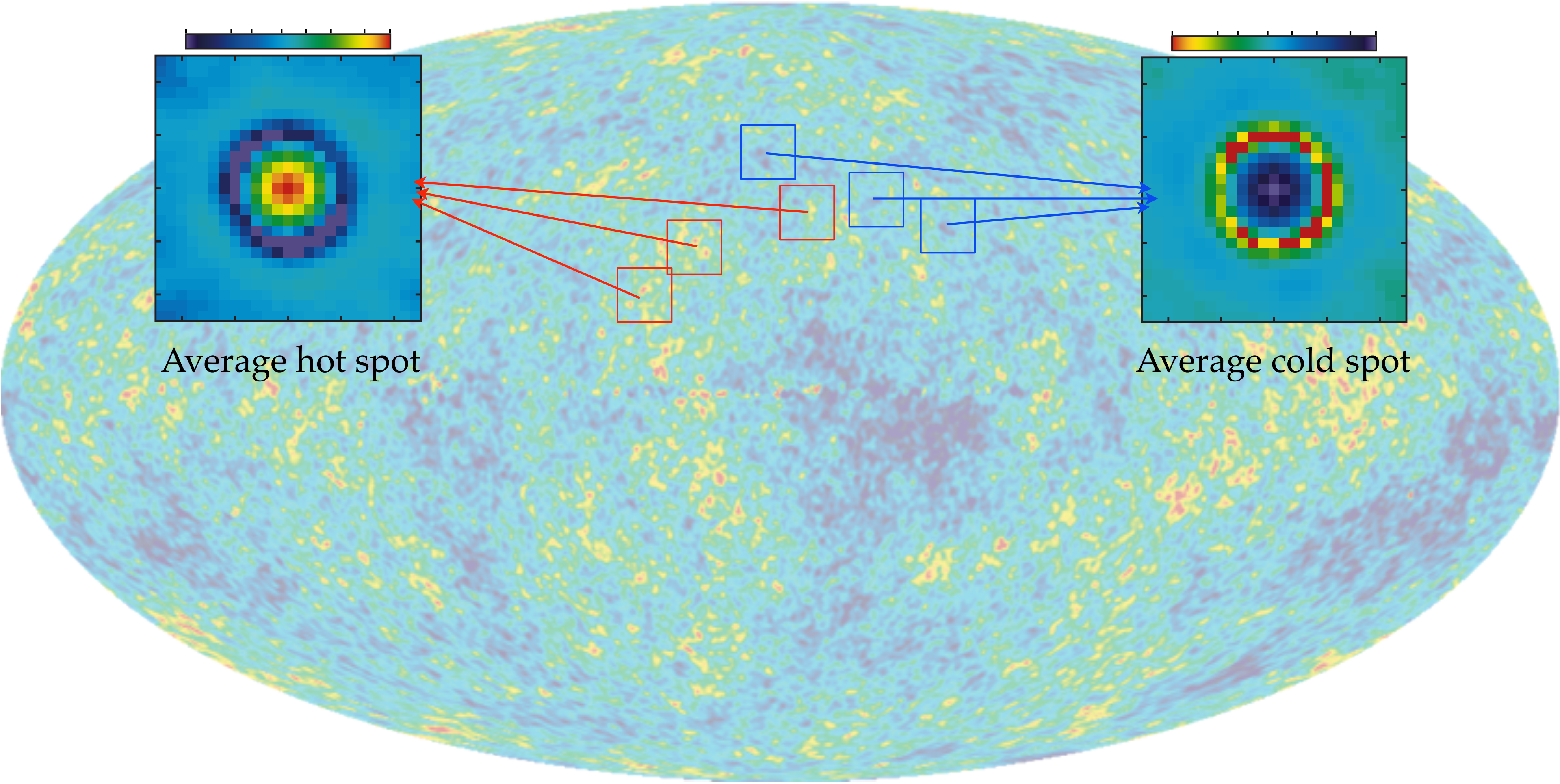
NASA/WMAP Science T

WMAP's Foreground-cleaned CMB Map



The universe at age 380,000 years: the final conditions of the early universe and the initial conditions of the late universe.

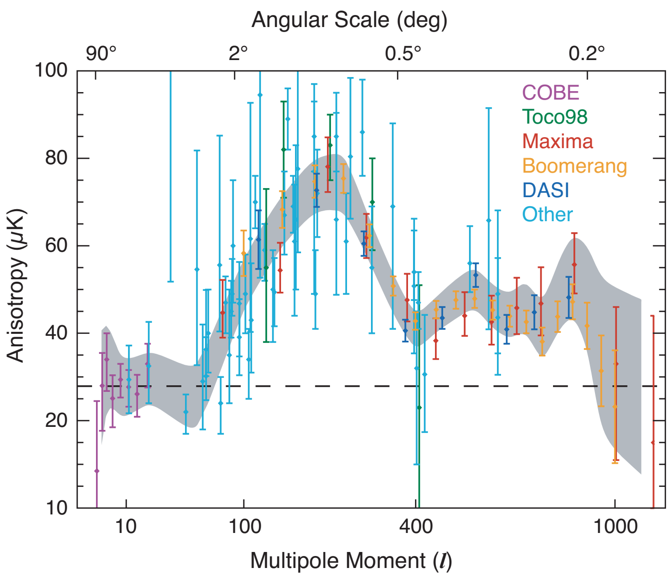
Acoustic Oscillations in the CMB



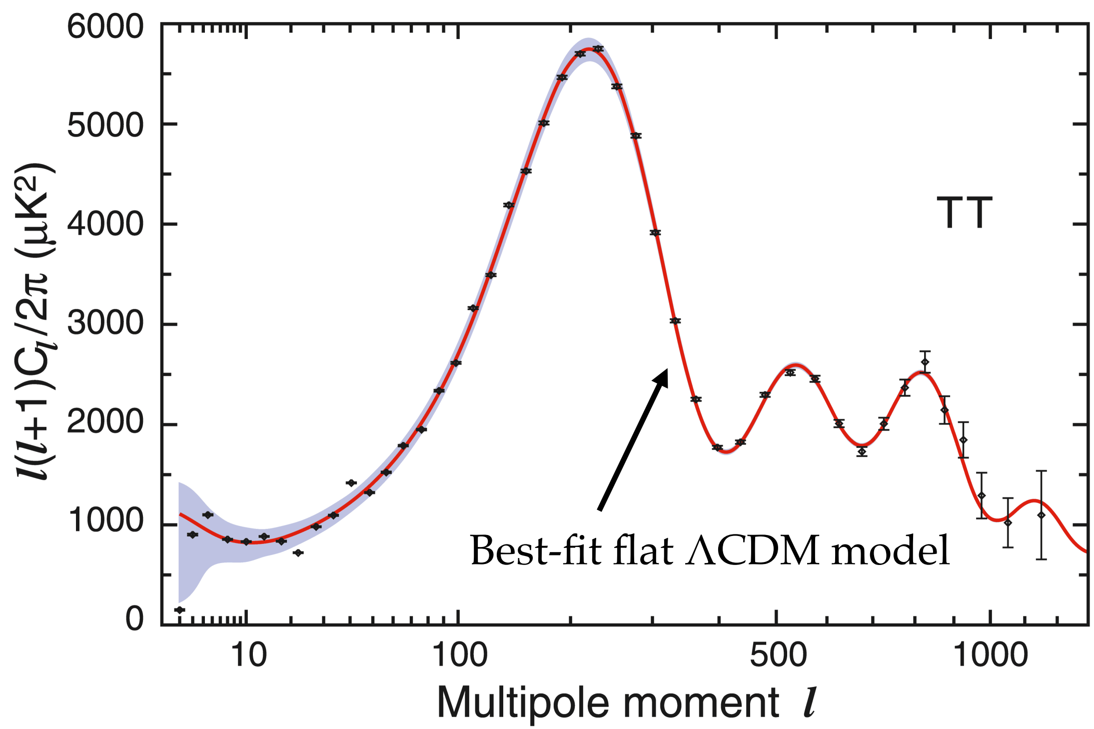
The most distinctive and important signature in the CMB is the acoustic sound front that surrounds every hot & cold spot in the map.

The Angular Power Spectrum

Pre-WMAP



Final WMAP



Measurements of the fluctuation power before (*left*) and after (*right*) WMAP. The peak profile in real space produces coherent oscillations in Fourier space.

ΛCDM Stress Test

ΛCDM:

WMAP performed a stress test on the Standard Model of Cosmology:

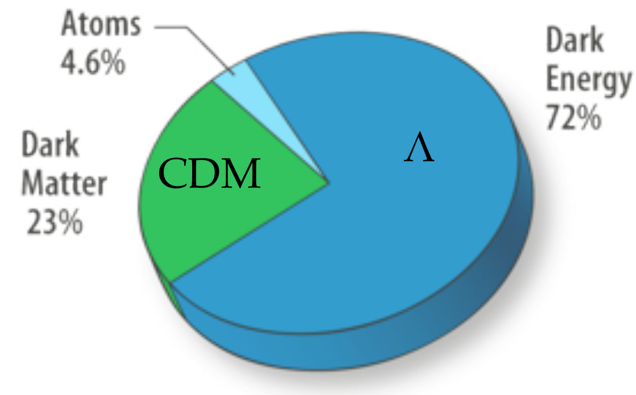
a spatially flat universe with gaussian, adiabatic initial fluctuations (possibly seeded by inflation), dominated by dark energy (Λ) and dark matter (CDM).

The 6-parameter ΛCDM model was able to fit more than 1,000 power spectrum points extremely well. The WMAP data produced a factor of ~70,000 reduction in the allowable ΛCDM parameter volume: e.g. the age of the universe is 13.77 ± 0.059 Gyr.

Cosmological results from Planck are consistent with, and extend the WMAP results. For modes measured by both experiments, the Planck and WMAP power spectra are within 1-sigma of each another.

Looking ahead:

- Understand the nature of dark matter and dark energy.
- Recent measurements of the Hubble constant using "local" techniques (distance ladder and lensing time delays) appear to be inconsistent with the values forecast from CMB and BAO measurements. There is no obvious way to reconcile these data at the moment.



Testing Cosmological Inflation

Inflation:

WMAP data supported 5 predictions of cosmological inflation, which posits a spatially flat universe with gaussian, adiabatic, initial fluctuations, drawn from a "tilted" power spectrum of primordial fluctuations.

- In conjunction with local Hubble constant measurements, WMAP constrains the curvature "density" of the universe to be less than 1% of the critical density.
- The fluctuations are observed to be consistent with a gaussian random field, with quantitative limits on the 3-point skewness (f_{NL}).
- The well-defined acoustic peak structure limits non-adiabatic fluctuations (e.g. isocurvature modes) to be sub-dominant (<6% for uncorrelated modes).
- Negative TE correlations on ~5 degree angular scales requires adiabatic perturbations on super-horizon scales.
- In conjunction with ACT, SPT, and BAO data, WMAP data determine that the spectrum of density fluctuations is not scale-invariant ($n_s = 0.9579 \pm 0.0082$).

Looking ahead:

- Test inflation further by searching for the imprint of primordial gravity waves from inflation as imprinted on the CMB "B-mode" polarization.

from the WMAP Team