

Seeing spots on the microwave sky

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Outline

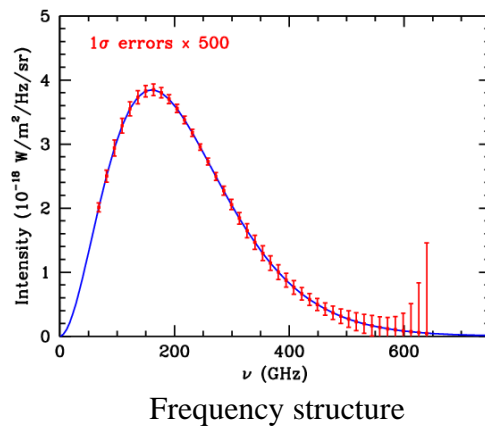
- What is the microwave background.
- Quick review of theory.
- Some recent data.
- The big picture.

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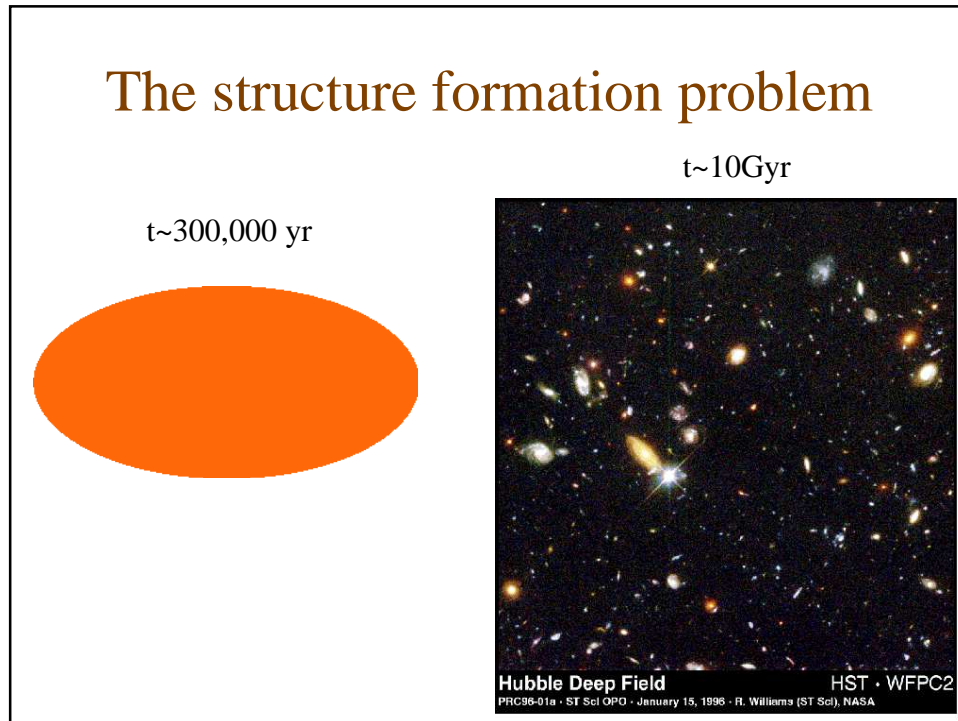
What is the “microwave background”?

- Relic radiation left over from when the universe was hot and dense.
- Cooled by the expansion of the universe to a current temperature of 3K.

CMB: A summary (a 1 parameter model)



Spatial structure
(real data from a
Billion \$ satellite)



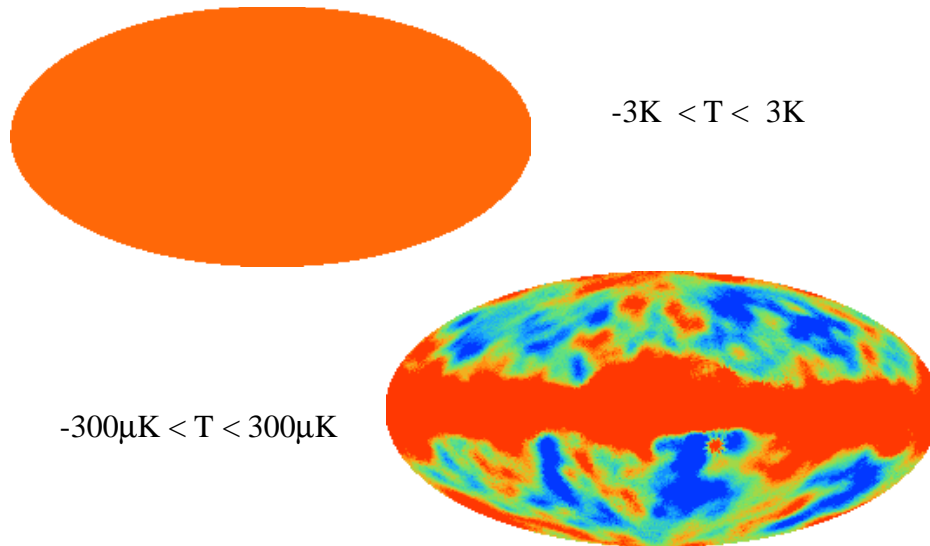
Gravitational instability

- Gravity acts as an efficient “amplifier” of irregularity.
- If we have an appropriate initial noise source we can grow it, through gravitational instability, into the structures we see today.
- The fluctuations that gave rise to galaxies, clusters, superclusters, super-duper-clusters, etc must have been present as seeds even at t~300,000yr!

Searches for CMB anisotropy

- The CMB discovery by Penzias & Wilson gave an upper limit of 10% (i.e. 0.3K).
- Theorists predicted 1-10%.
- The upper limits shrank to <1%.
- Theorists predicted 0.1%.
- The upper limits shrank to <0.1%
- Theorists predicted 0.01%.
- The upper limits ...

The 1992 (COBE) discovery ...



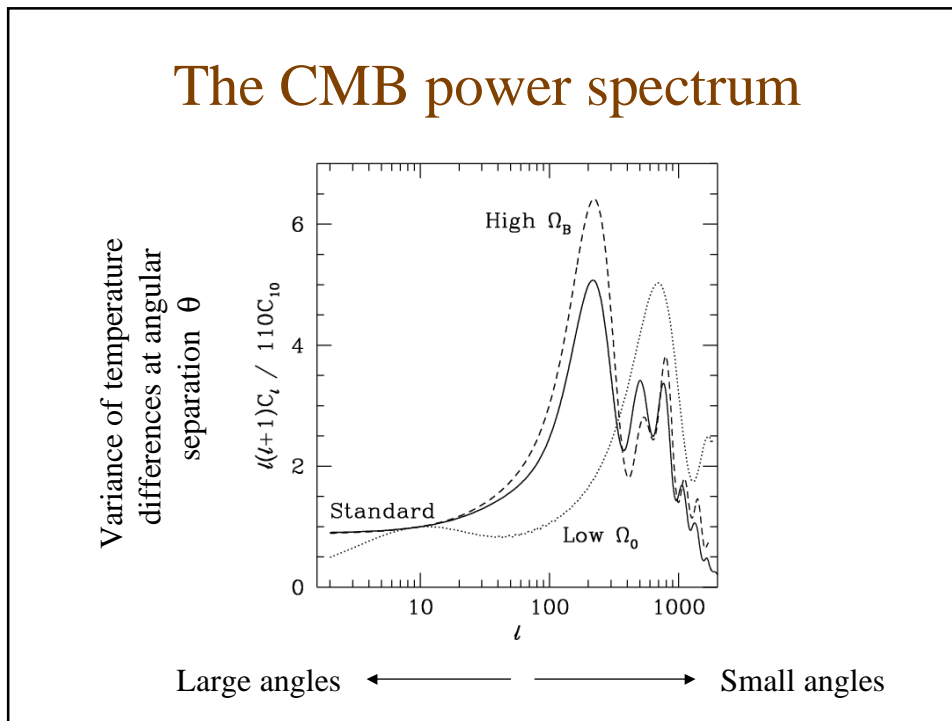
The paradigm ...

- At early times the universe was a hot, dense plasma of protons and electrons (and γ).
- The CMB γ s were “tightly coupled” to the p+e. A fluid approximation is valid.
- Today’s structure grew through gravitational instability -- potentials exist at early times.

There should be gravity-sourced sound waves in the primeval plasma.

The paradigm ...

- As the universe expands it cools. p+e (re)combine to form H (suddenly, but not instantaneously).
- The universe undergoes a transition from opaque to transparent ...the photons are set free.



Theory

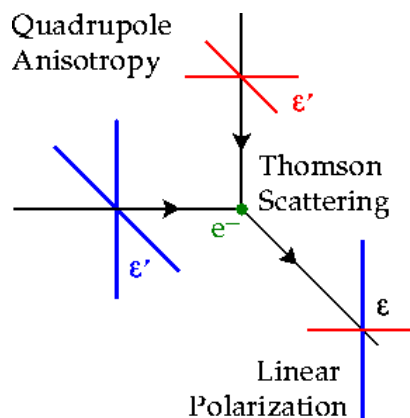
- Calculations involve linear perturbation theory.
- Well understood and under control.
- CMB power spectrum encodes information about the model of structure formation, the constituents of the universe, the nature of the dark matter and the “background” cosmology.

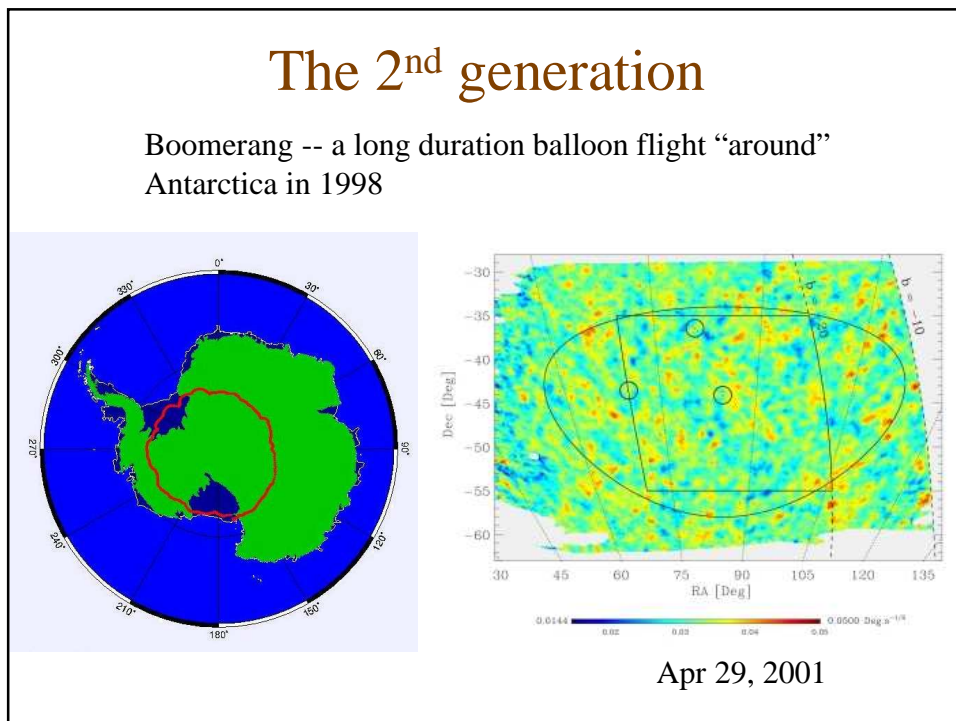
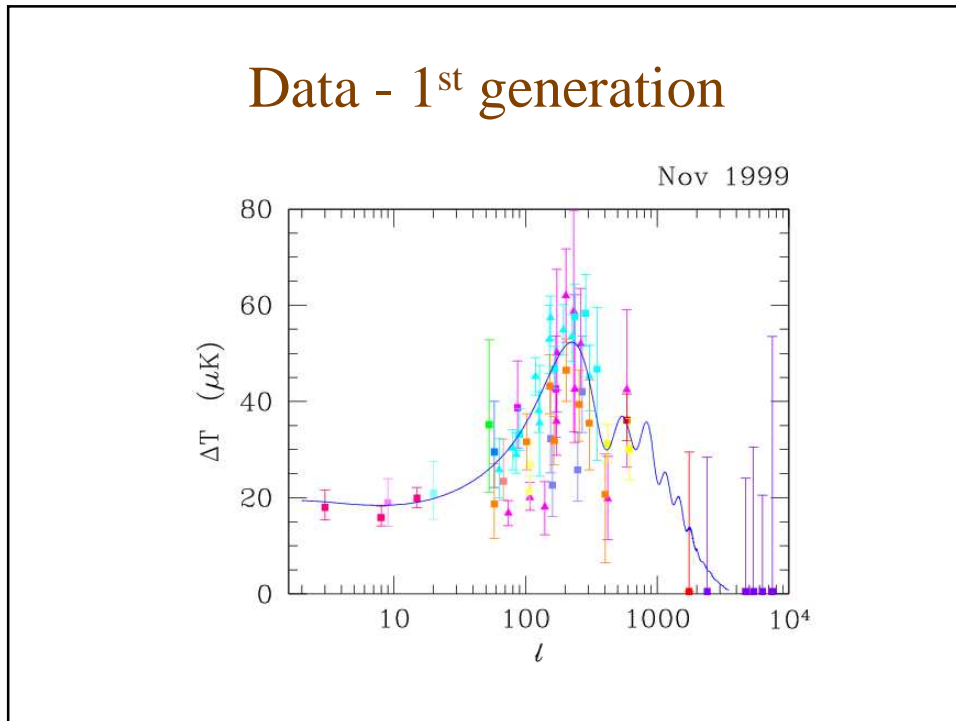
The promise ...

- Fitting models allows us to extract $O(10)$ cosmological parameters to $\sim 1\%$.
- Cosmology independent model constraints.
- Model independent cosmology constraints.
- Redundant checks of the paradigm.

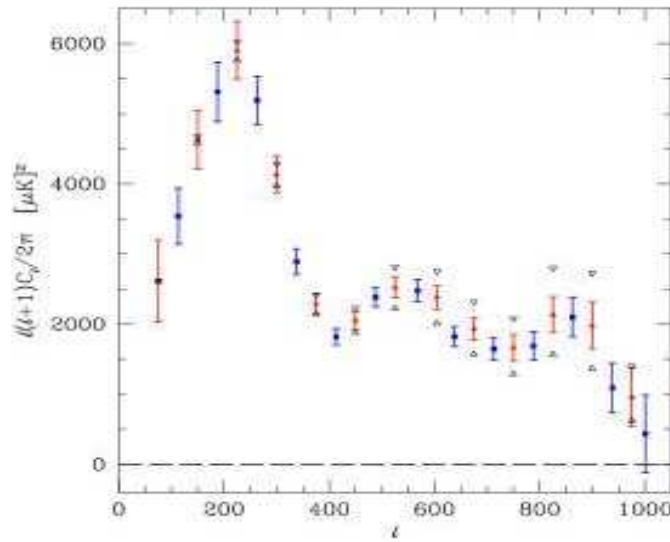
For example:

If the fluctuations live on the last scattering surface they should be polarized.

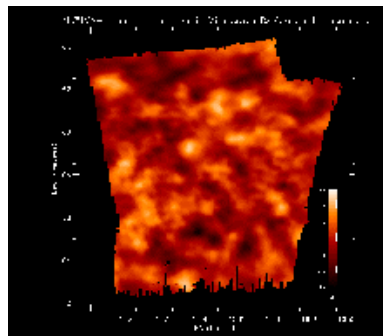
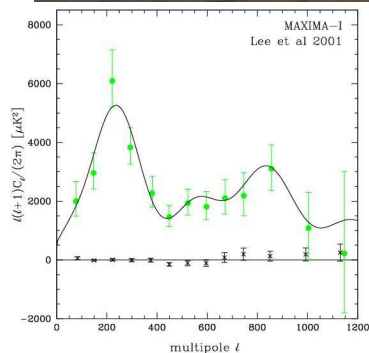




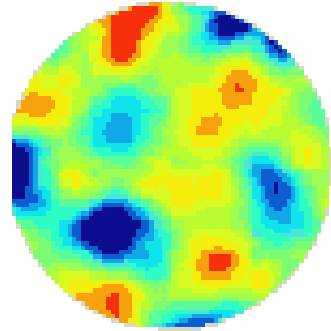
The peaks appear ...



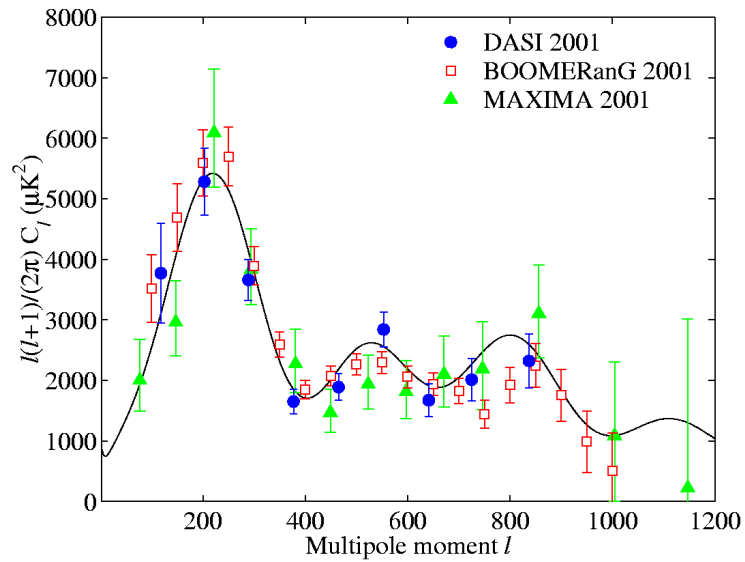
Concurrently: MAXIMA



...and then DASI



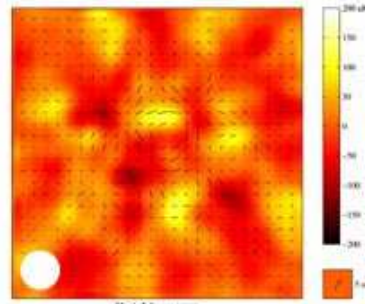
With pretty good agreement!



And the last piece of the puzzle: Polarization!



DASI at the south pole

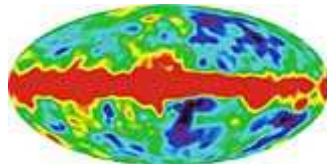


Sep 19, 2002

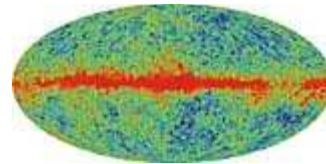
The 3rd generation ...



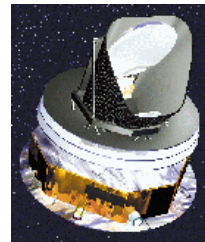
COBE (1996)



MAP (2006?)



...and in 2007(?) *Planck*



What have we learned from the CMB?



Monty Python,
The Life of Brian

All right. But apart from the sanitation, the medicine, education, wine, public order, irrigation, roads, the fresh water system, and public health ...

What have the Romans ever done for us?

-- Reg, spokesman for the People's Front of Judea.

The 'A' list

- Gravitational instability in a DM dominated universe grew today's structure.
- There are peaks in the CMB spectrum!
 - Space is pretty flat (just like Euclid said).
 - The baryon density agrees with BBN.
 - The universe (re)combined.
- The CMB is polarized at the predicted level.

The 'B' list

- Something like inflation happened.
- The large-scale structure of space-time appears to be simple.
- The gravity wave contribution to the anisotropy is not large.
- There are (many) constraints on non-standard physics at recombination.

The 'C' list

- Cosmological parameters will be (are?) precisely determined.
- We will learn a lot about early universe physics.
- We will learn even more about non-linear astrophysics.
- This will be a hard act to follow!

The End