Lecture 24 28 April 2009

- **SCIENCE TOPICS**: The First 3 Minutes and the Cosmic Microwave Background.
- **READING** Ch.17, Sections 17.2-17.7
- **PRACTICE: Ch 17** Review: 1, 2, 5, 6 Self-test: 1, 2, 5, 6, 10, Problems: 4, 5

HOMEWORK 09:
Due Thursday, 30th April 2009, 11:59pm
FINALS: Friday 8th May 2009, 08:00am

Finals

- Test 04 *and* Comprehension 03
- ***Friday*, 8th May 2009**, (***NO*** make-up)
  - 08:00-09:50am, this room
- Lecture 19 (2nd half) to end of course
  - Topics:
    - Stellar Evolution
    - Black Holes
    - Galaxies, Dark Matter and the Hubble Expansion
    - The first 3 minutes, the CMB, Dark Energy and The Fate of the Universe

The History of the Universe

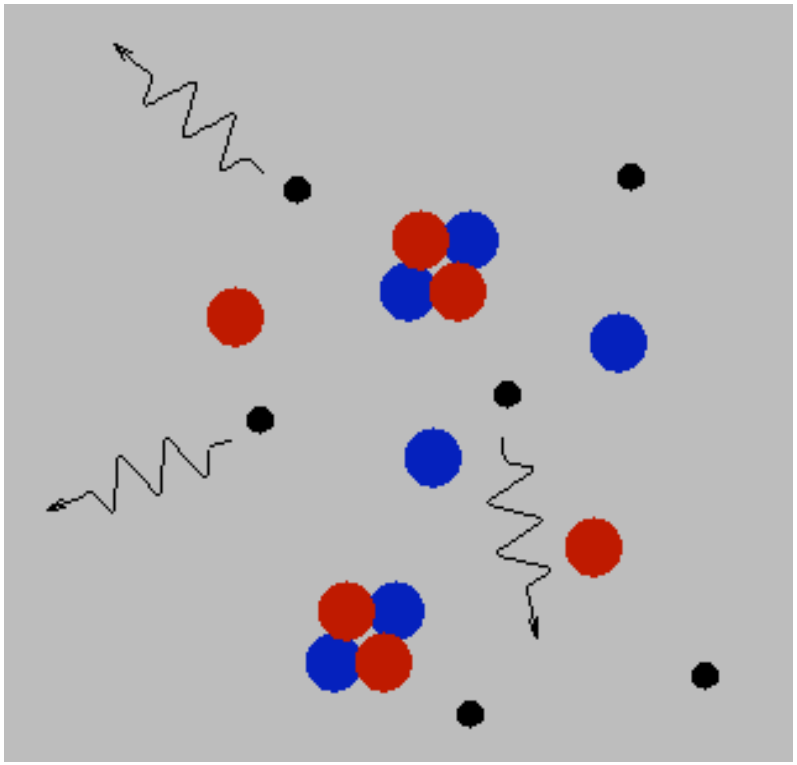
- t = 0
- t = 10^{-43} sec
- t = 10^{-35} sec
- t = 10^{-6} sec
- t = 3 mins (180 sec)

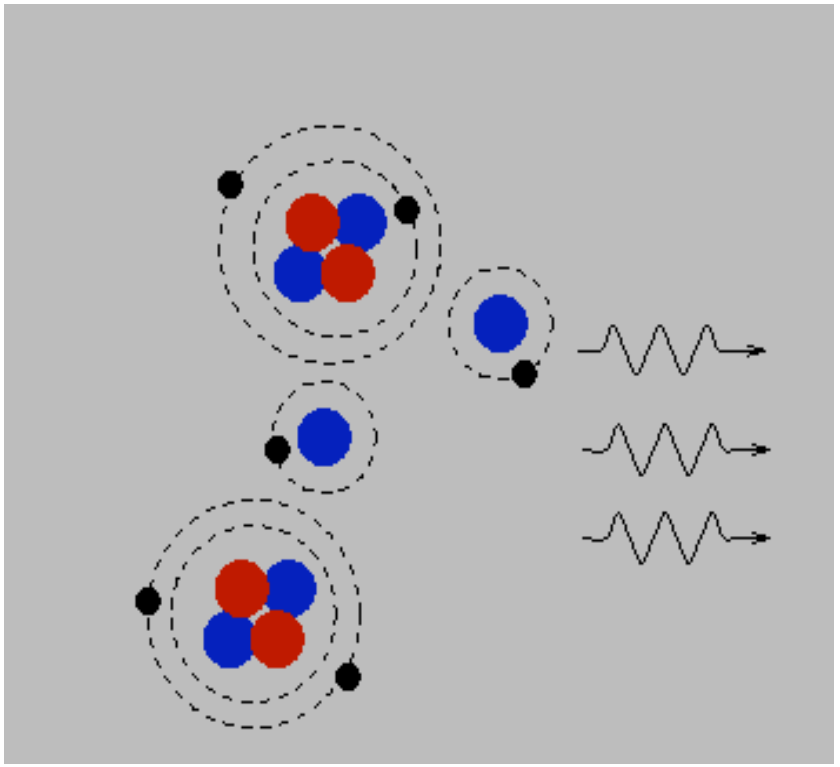
Big Bang Nucleosynthesis (BBNS)

- The production, in the early Universe of the *nuclei* of light elements.
- **Main product: Helium-4 (He)** Also: Deuterium (D); Helium-3; Lithium-7 (Li); Beryllium-9 (Be)
- "Boron bottleneck"
- After ~3 minutes, composition of the Universe is more or less set (by mass):
  - 75% H
  - 25% He-4
  - 0.01% He-3; Li-7; Be
  - ***No*** heavy (C, N, O) elements.

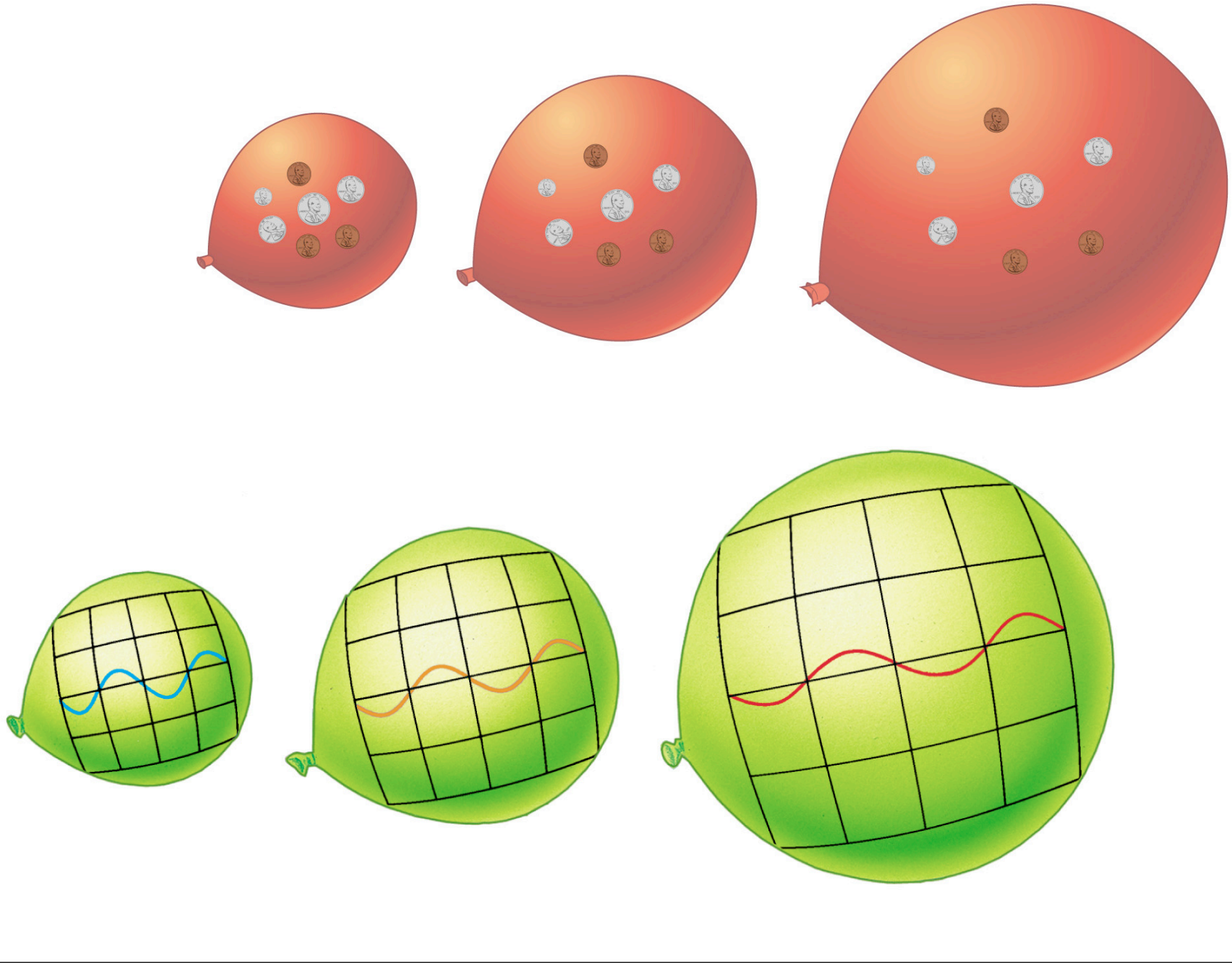
The History of the Universe

- t = 0
- t = 10^{-43} sec
- t = 10^{-35} sec
- t = 10^{-6} sec
- t = 3 mins (180 sec)
- t = 380,000 years (1×10^{13} sec)

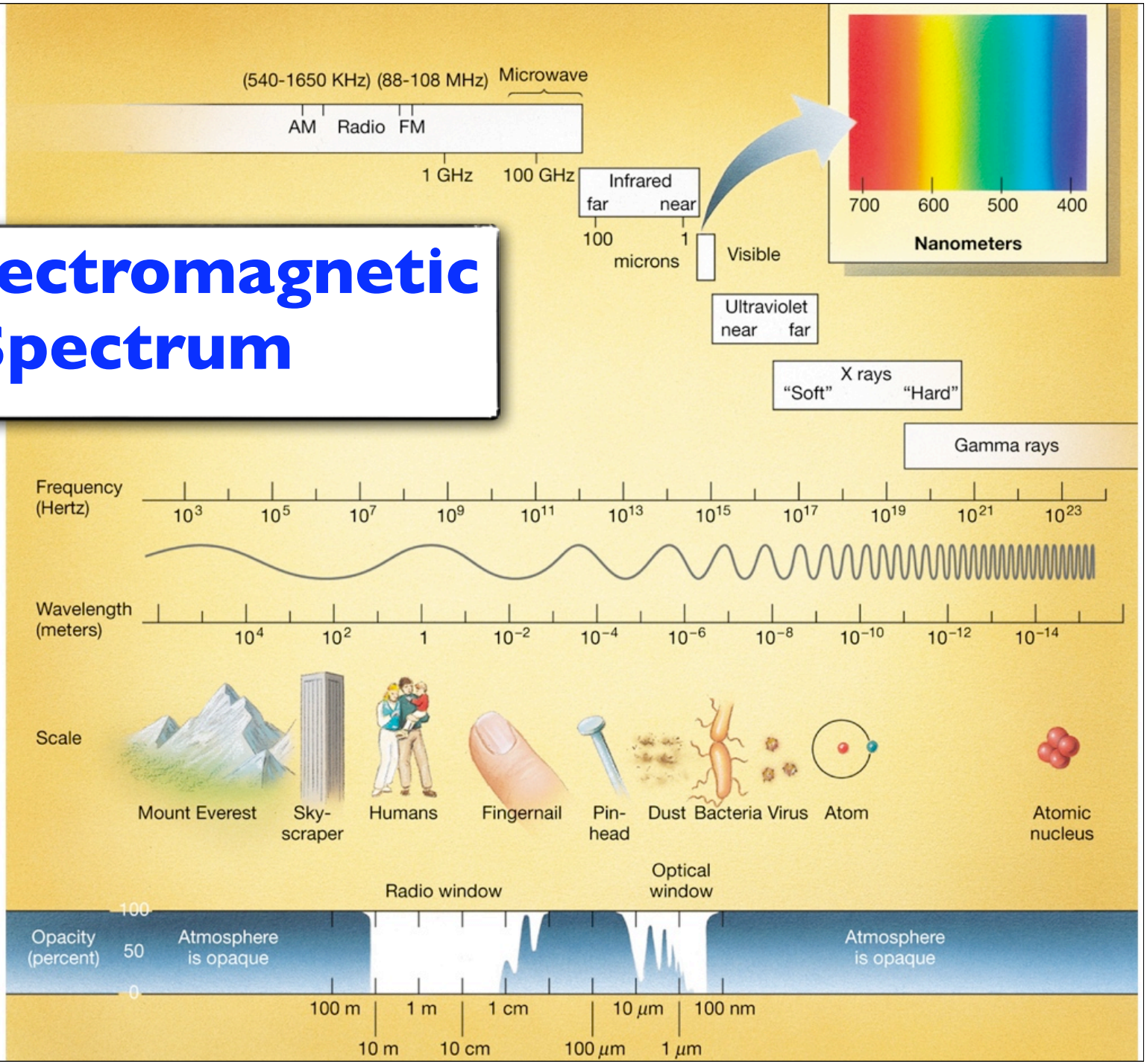




- "Recombination". Universe cools down enough that electrons can join and begin to orbit nuclei. Atoms form.
- "Decoupling". Photons can now travel unimpeded.



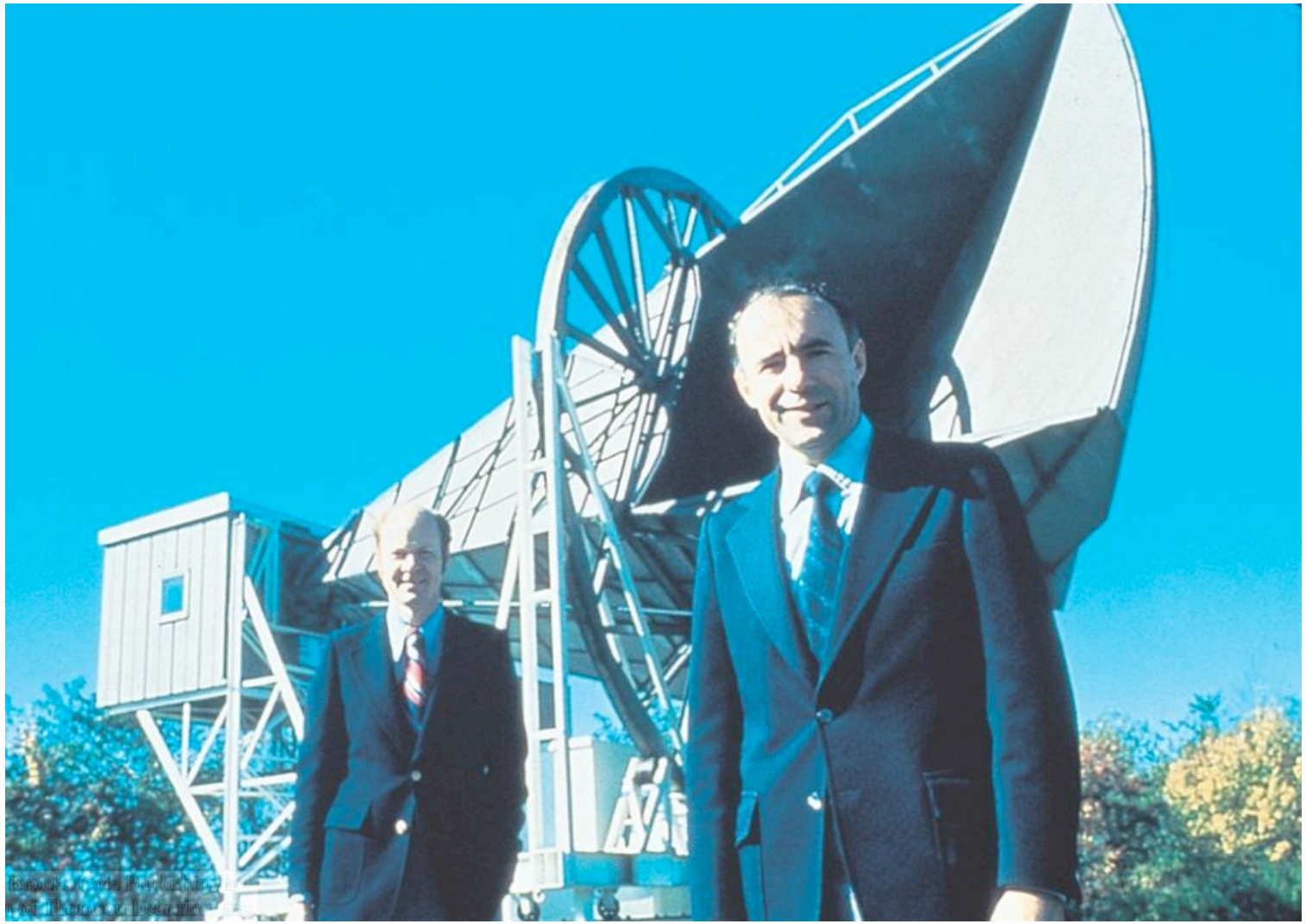
The Electromagnetic Spectrum



The Cosmic Microwave Background

- The "heat" left over from the Big Bang.
- The expansion of the Universe has redshifted this radiation so that today we detect it as microwaves coming from all around us, from deep space.

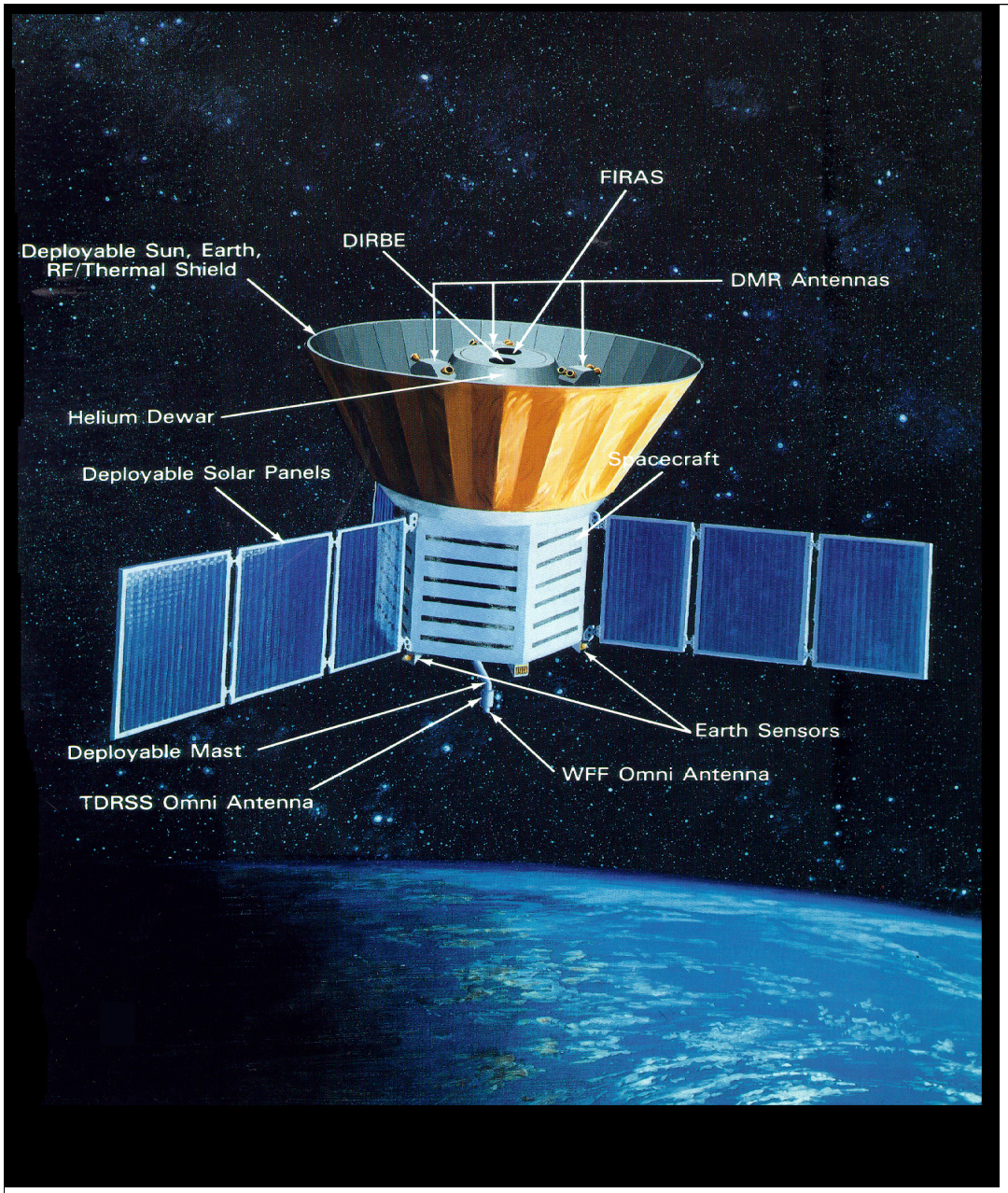
Penzias and Wilson (1963)



- Received the Nobel Prize (1978).

The Cosmic Microwave Background

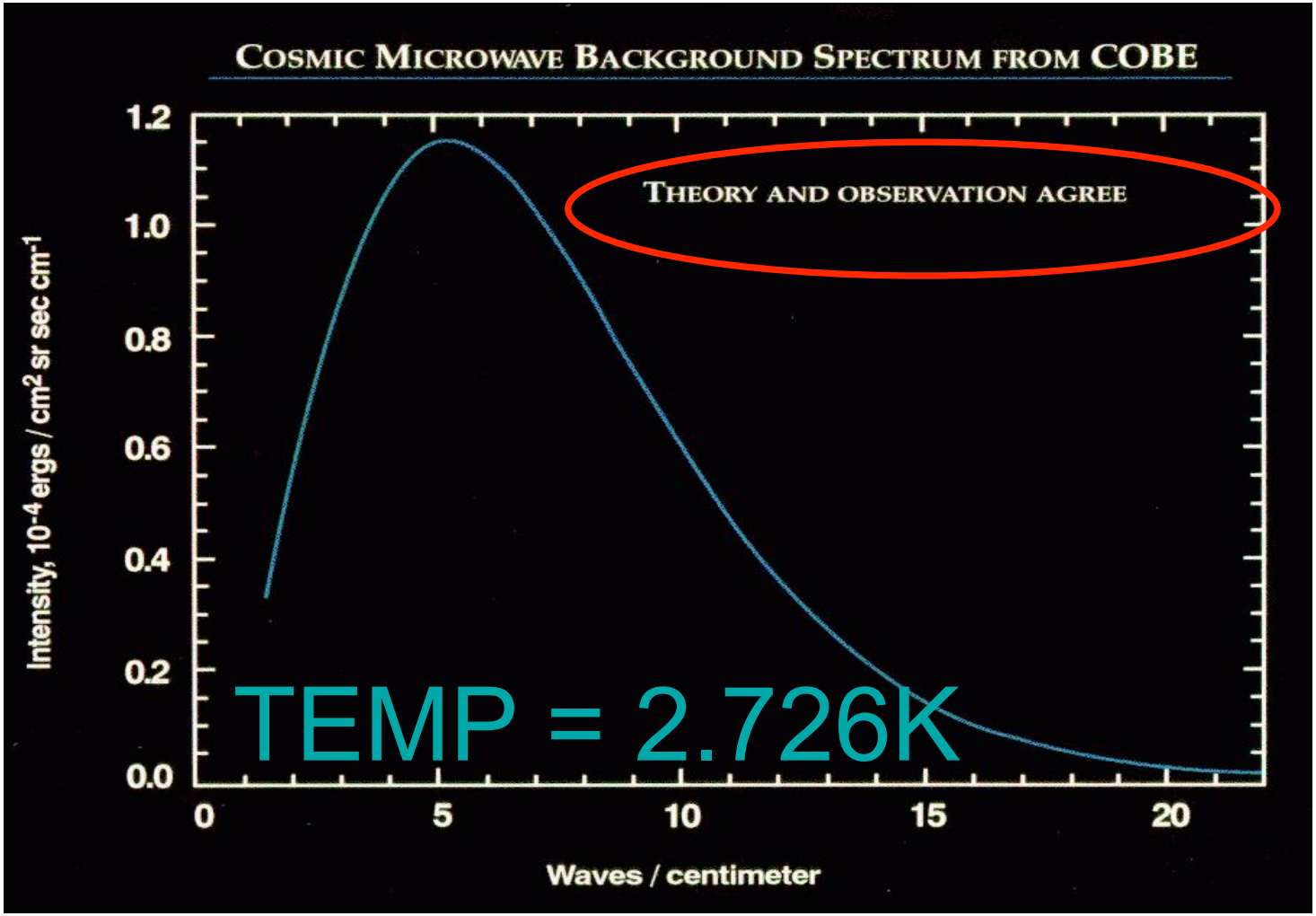
- The "heat" left over from the Big Bang.
- The expansion of the Universe has redshifted this radiation so that today we detect it as microwaves coming from all around us, from deep space.
- First detected in 1960s. *HUGE* confirmation of the Big Bang theory.
- Today, we can measure the CMB *very* well. Use satellites to measure the temperature and temperature *differences* of the Universe.
- These microwaves can tell us a great amount about the Universe; its age, what it is made of and its fate....



COBE (1992)

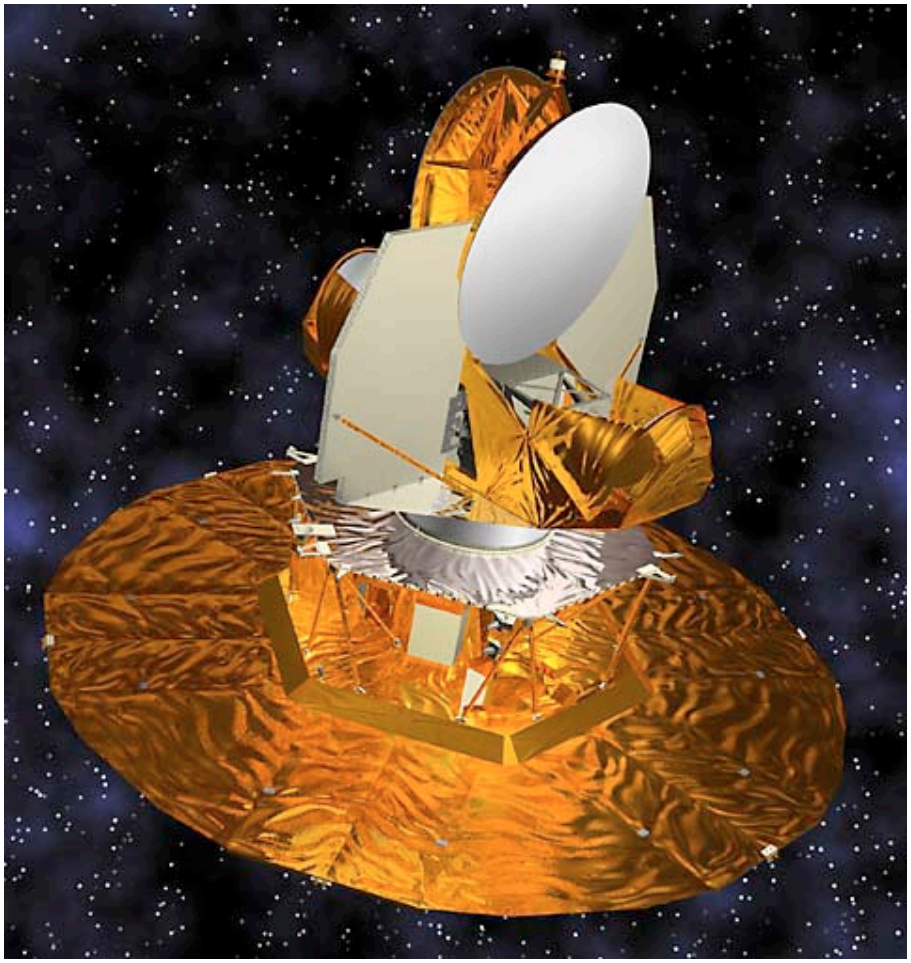
- A sensitive microwave detector.
- Can make very accurate *predictions and measurements* of the temperature of CMB.
- And COBE found…

The CMB has a "blackbody spectrum"!!

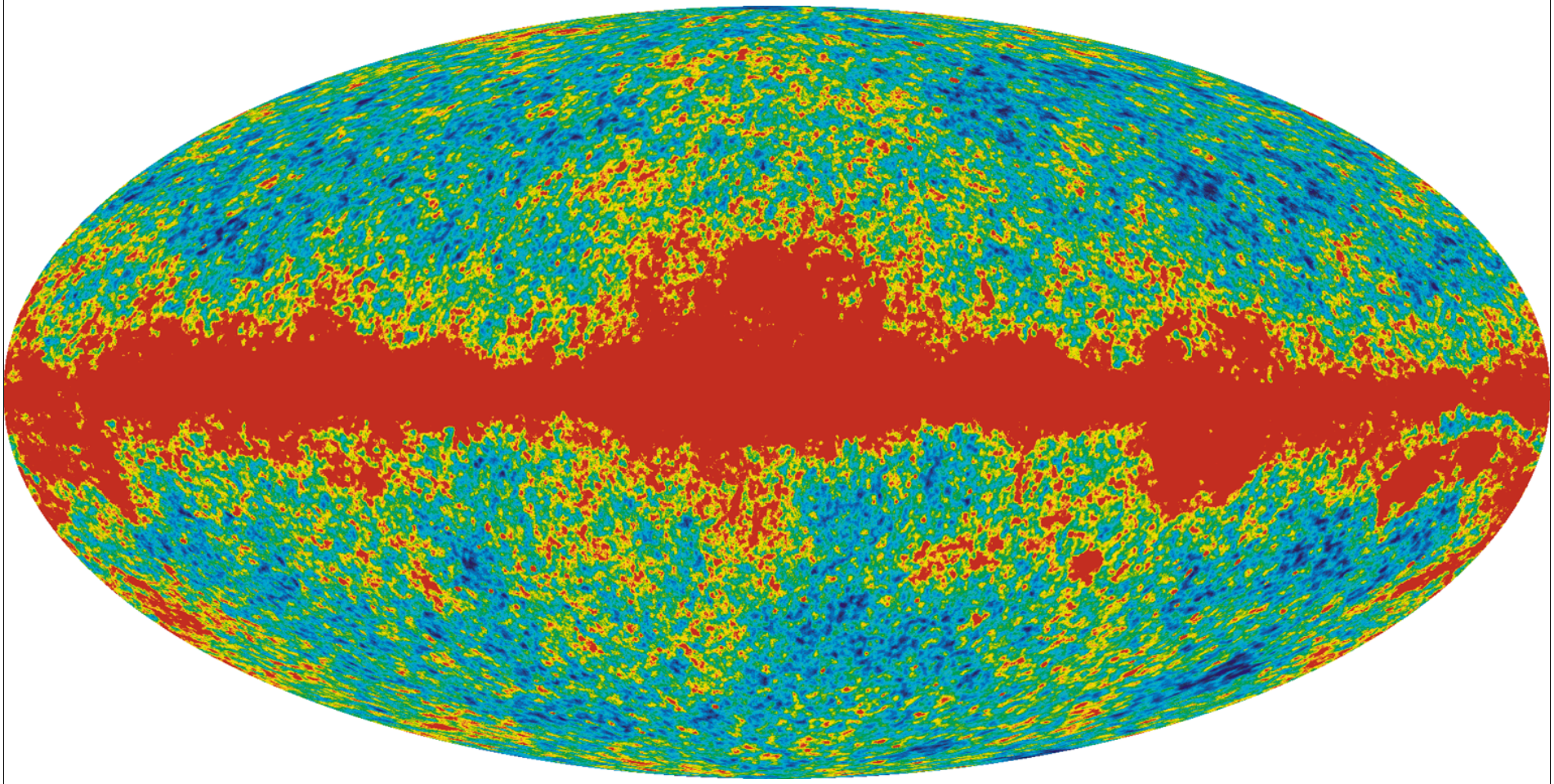


1) Very cold 2) Temperature differences are tiny

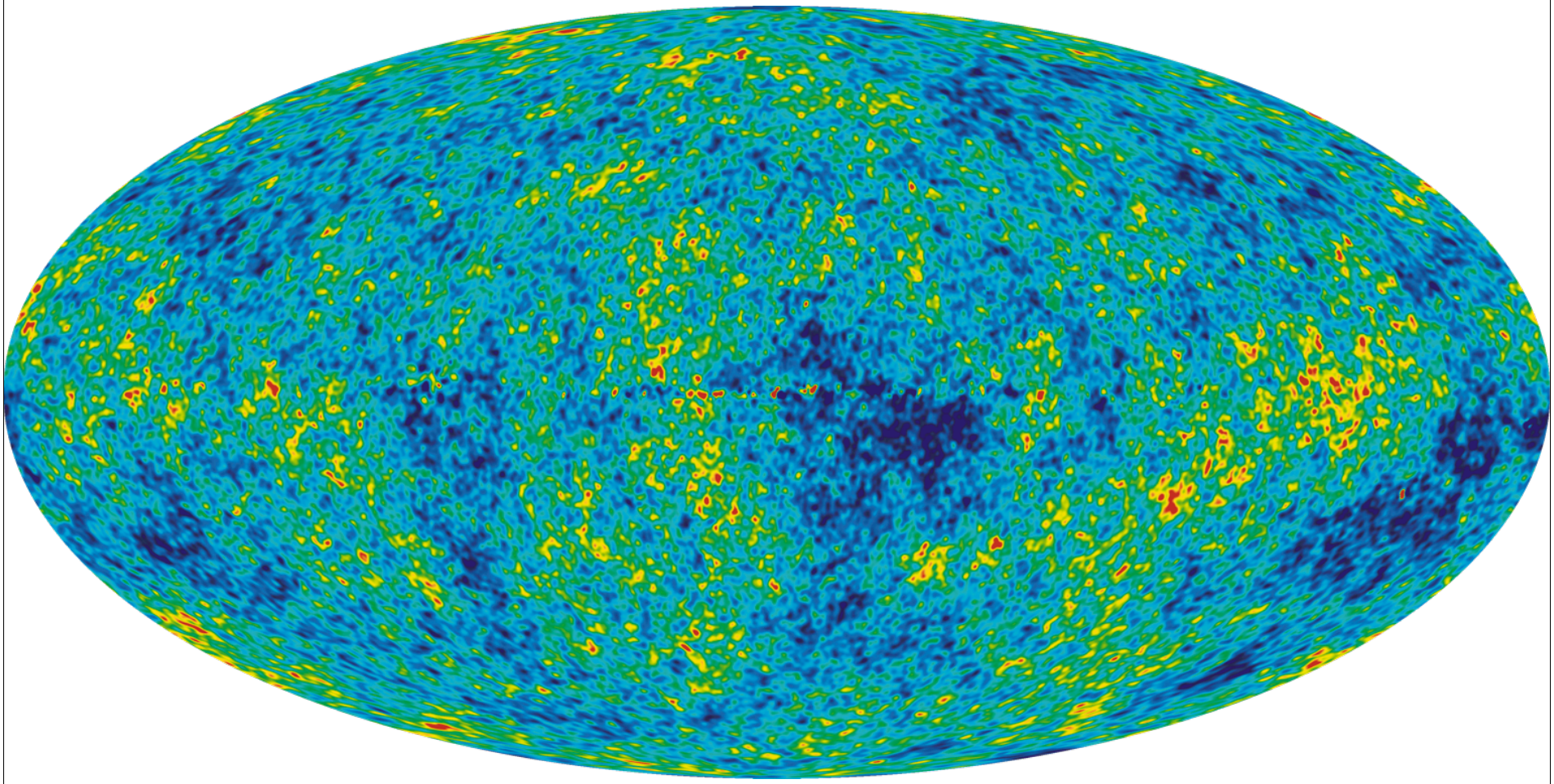
WMAP (2003)



- Orbiting just under a million miles from the Earth
- Measures the *(very small)* temperature differences of the microwaves



Equivalent of a 1-day-old baby picture of 80 year old person



By comparing the picture of the *very young* Universe with what we see today, can find out about the future…

The History of the Universe

- t = 0
- t = 10^{-43} sec
- t = 10^{-35} sec
- t = 10^{-6} sec
- t = 3 mins (180 sec)
- t = 380,000 years ($1x10^{13}$ sec)
- t = 400 million - 1 billion years ($1\text{-}3x10^{16}$ sec)
- t = 13.7 billion years ($\sim 1x10^{17}$ sec)