

Astro190 time is scarce!

- ★ I will be looking for the fast lane through the key content
- ★ We will be deviating from the chronological approach of the text

George Gamow



It took less than an hour to make the atoms, a few hundred million years to make the stars and planets, but five billion years to make man!

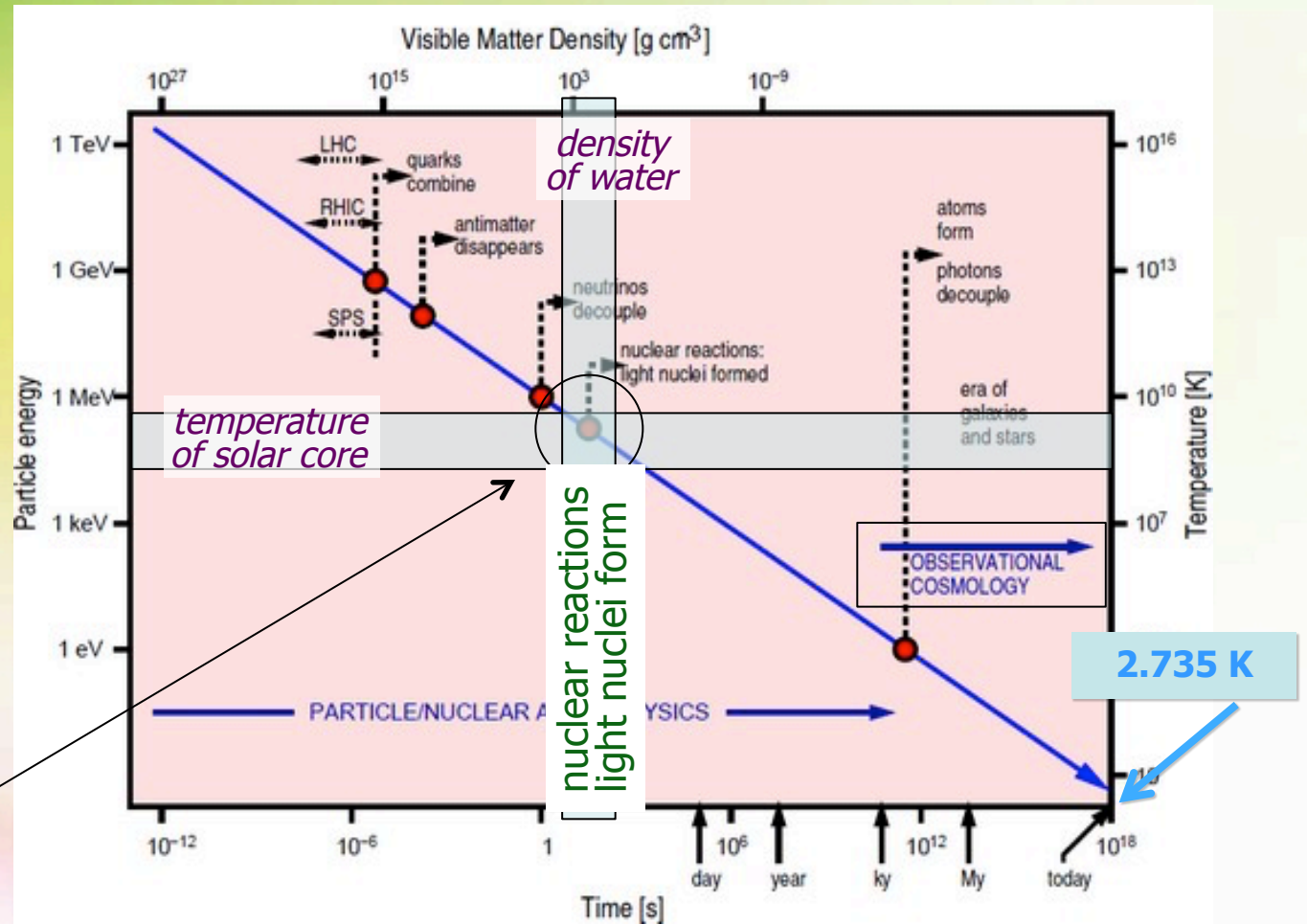
— *George Gamow* —

AZ QUOTES

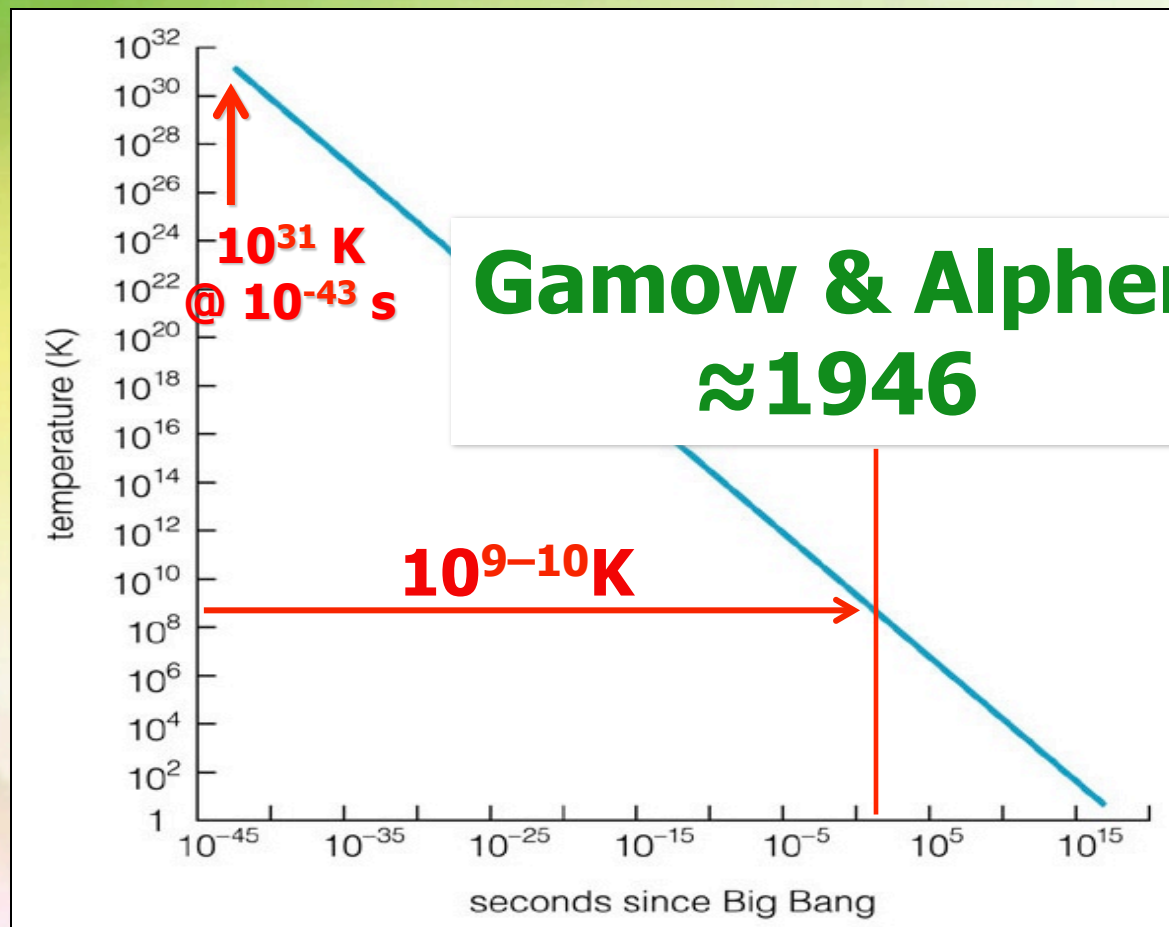
Making Cosmic Helium

Helium is forged by nuclear fusion of protons and neutrons

Need high temperatures and densities

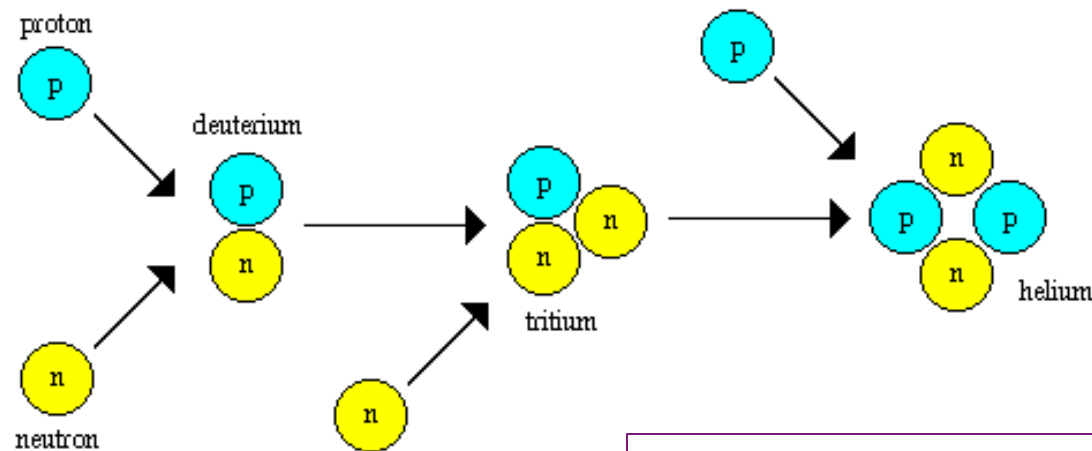
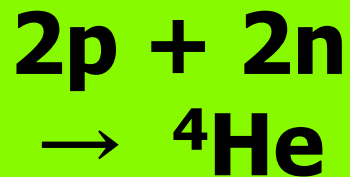


Making Cosmic Helium



Making Cosmic Helium

as the Universe cools, protons and neutrons can fuse to form heavier atomic nuclei

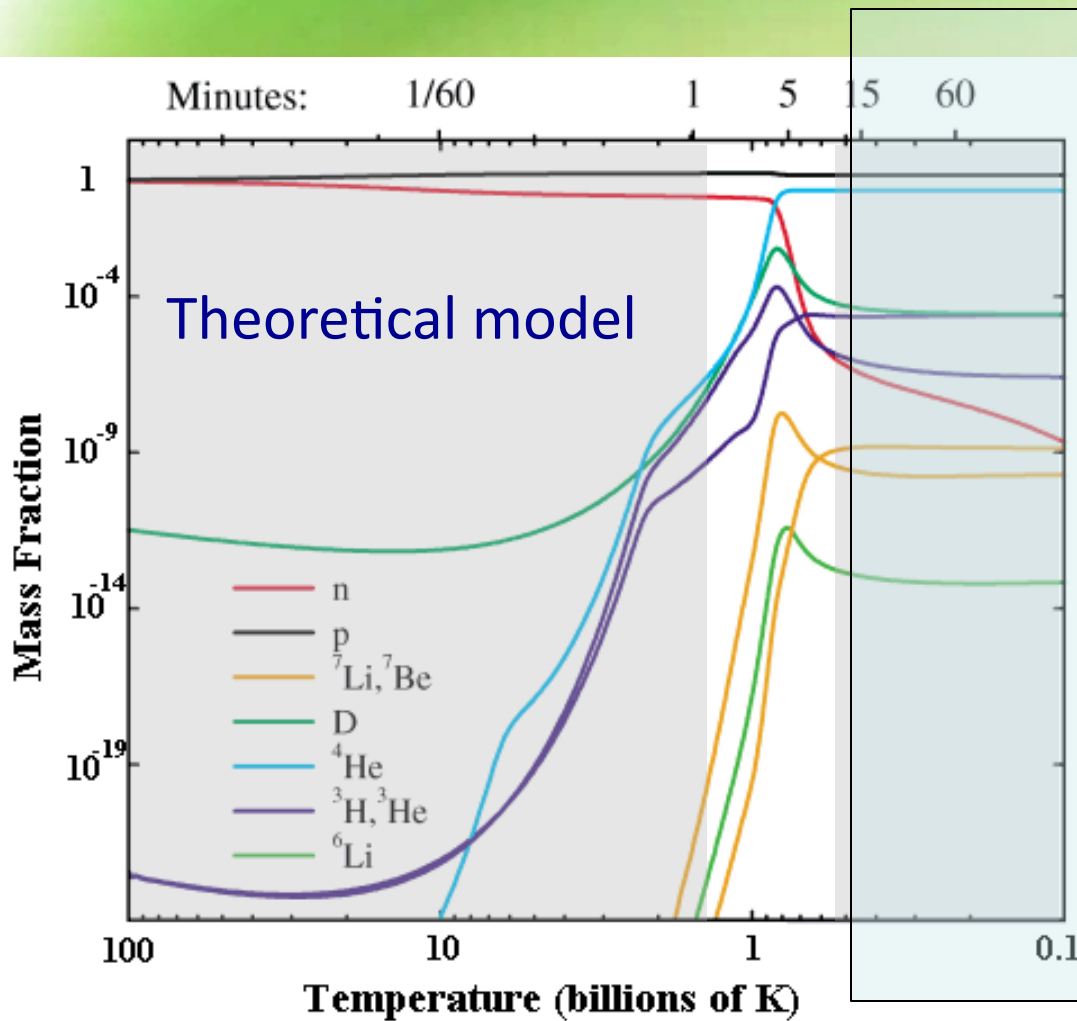


requires high temperatures

Once upon a time, as the Universe was cooling, plentiful protons and neutrons forged into heavier nuclei that could survive.

- This episode was brief (≈ 10 minutes).
- Before this all nuclei were quickly destroyed by very energetic collisions.
- After this era it was too cool for charged particles to overcome their repulsive electric forces and to partake in nuclear reactions. Moreover, neutrons vanished after 10 min as they decayed into protons and electrons.

Making Cosmic Helium

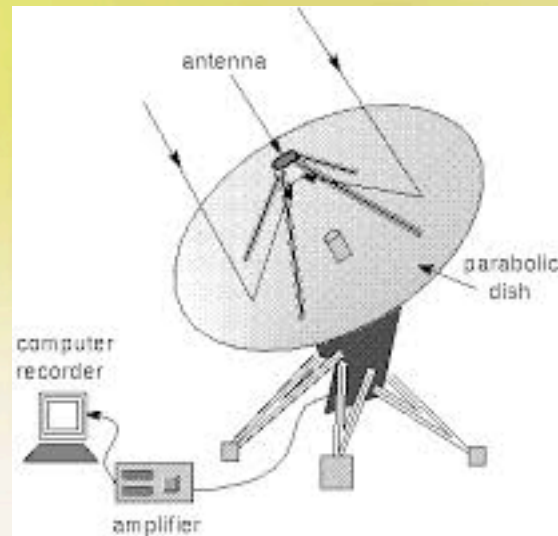


H:He:all other \approx
100:10:0.001

Elements beyond
He produced
later in stars

1950s, 60s . . . present

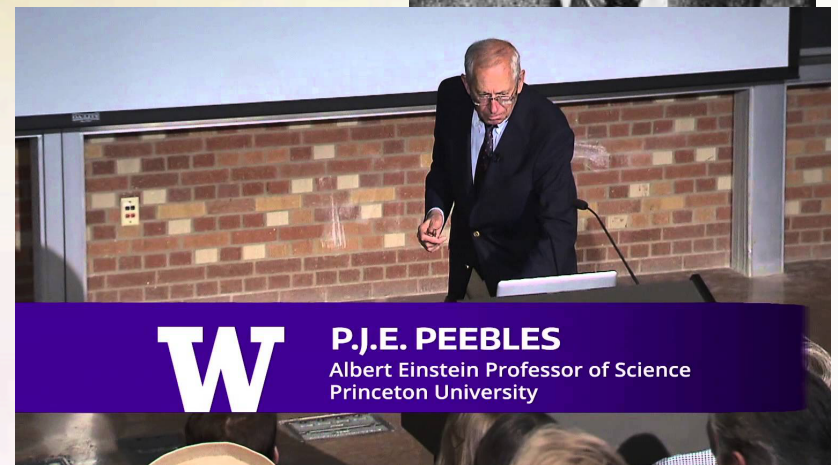
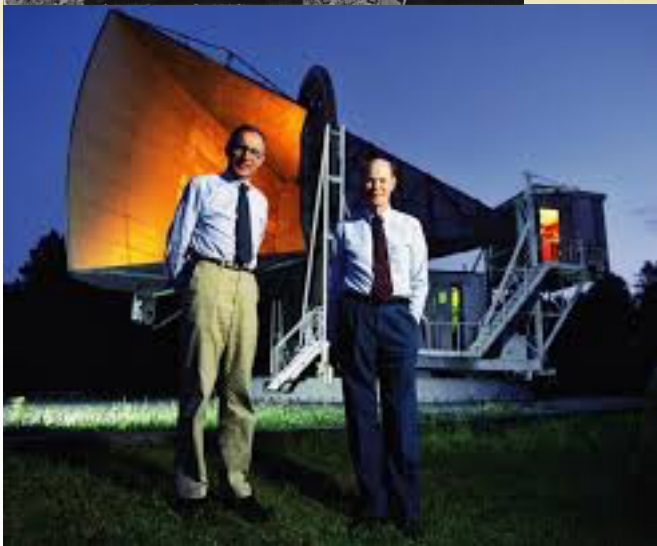
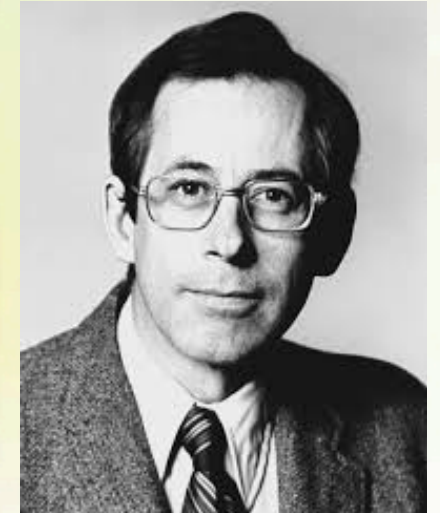
- ★ Radar/radio astronomy becomes ready for cosmic studies.



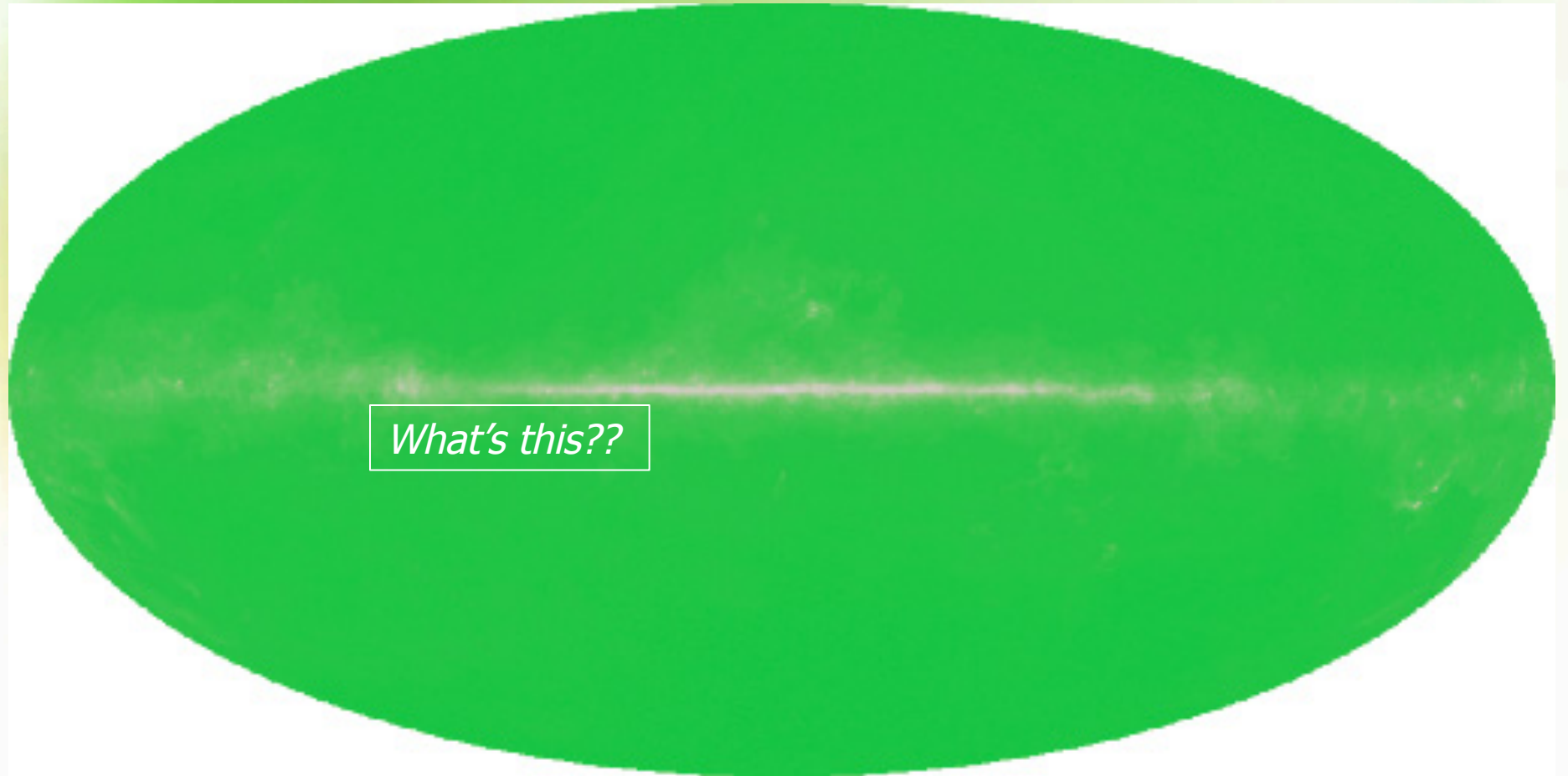
A radio telescope reflects radio waves to a focus at the antenna. Because radio wavelengths are very large, the radio dish must be very large.



1964: Cosmic Background Radiation (CMB): Hot “Embers” of the Big Bang seen at a redshift of 1000 (radio)

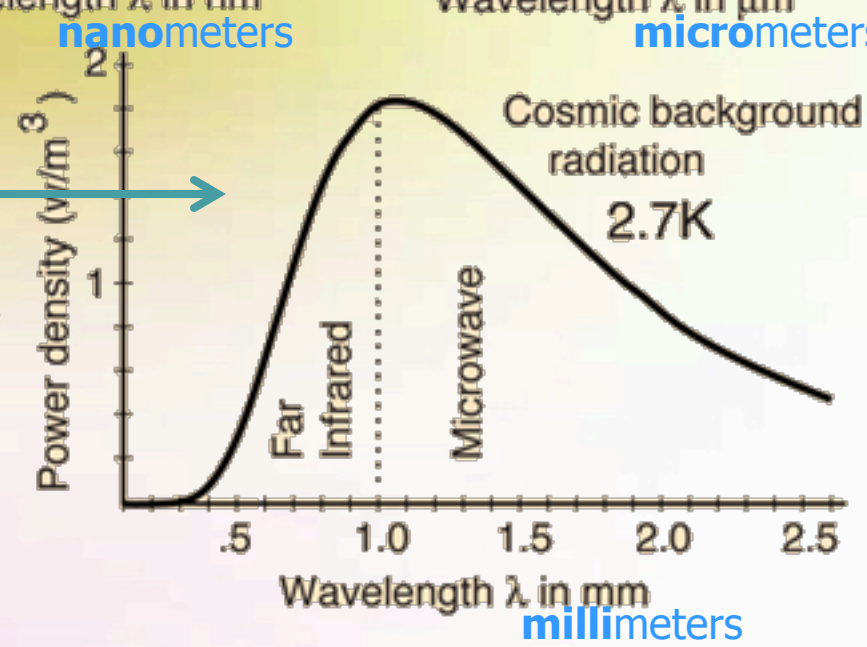
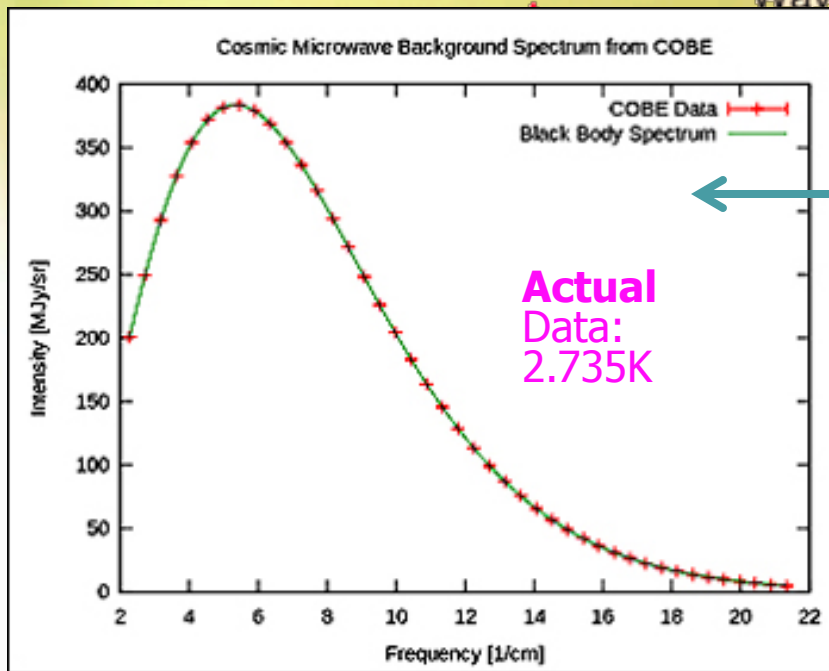
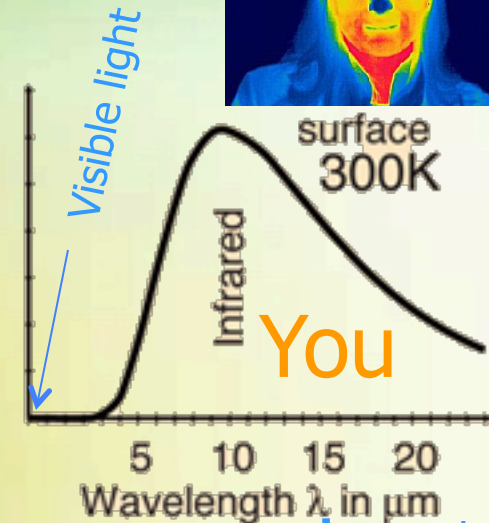
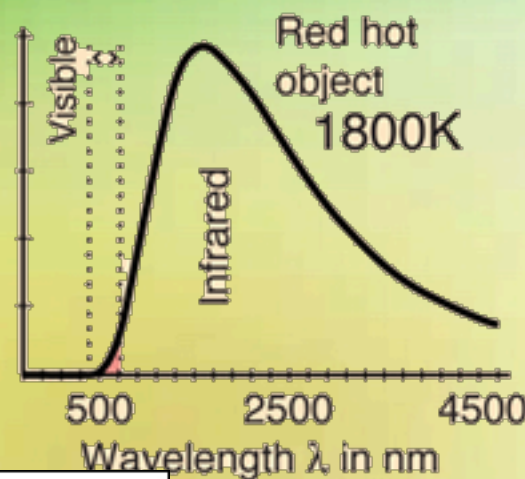
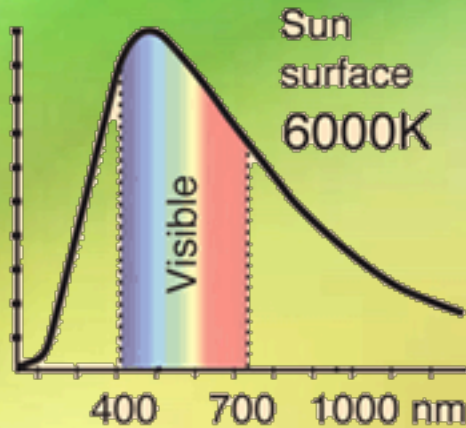
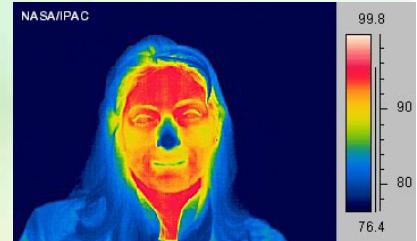


Discovery of the CMB (1964)

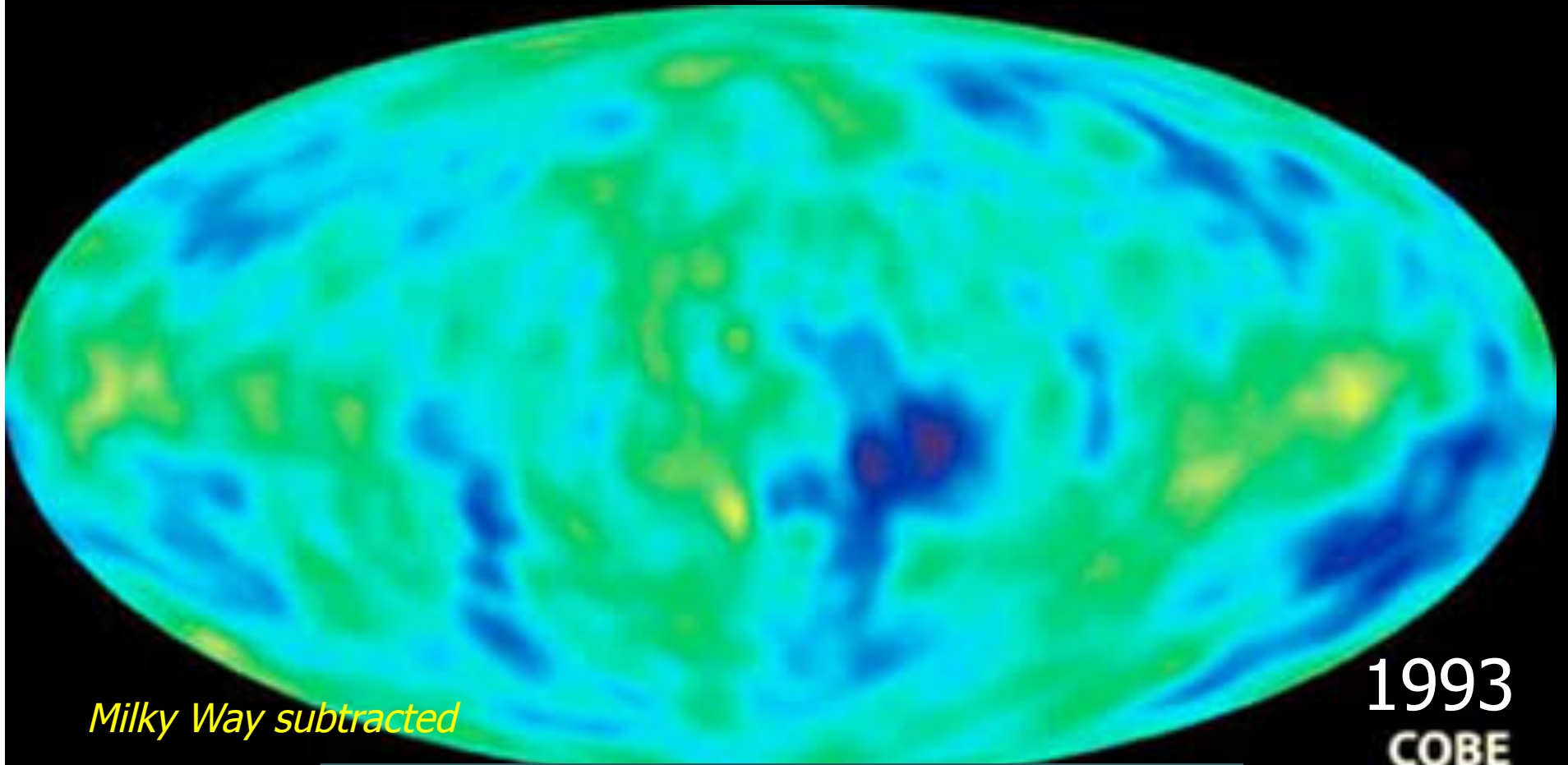


First all-sky "map" of the CMB

CMB Temperature



CMB: Telltale Ripples

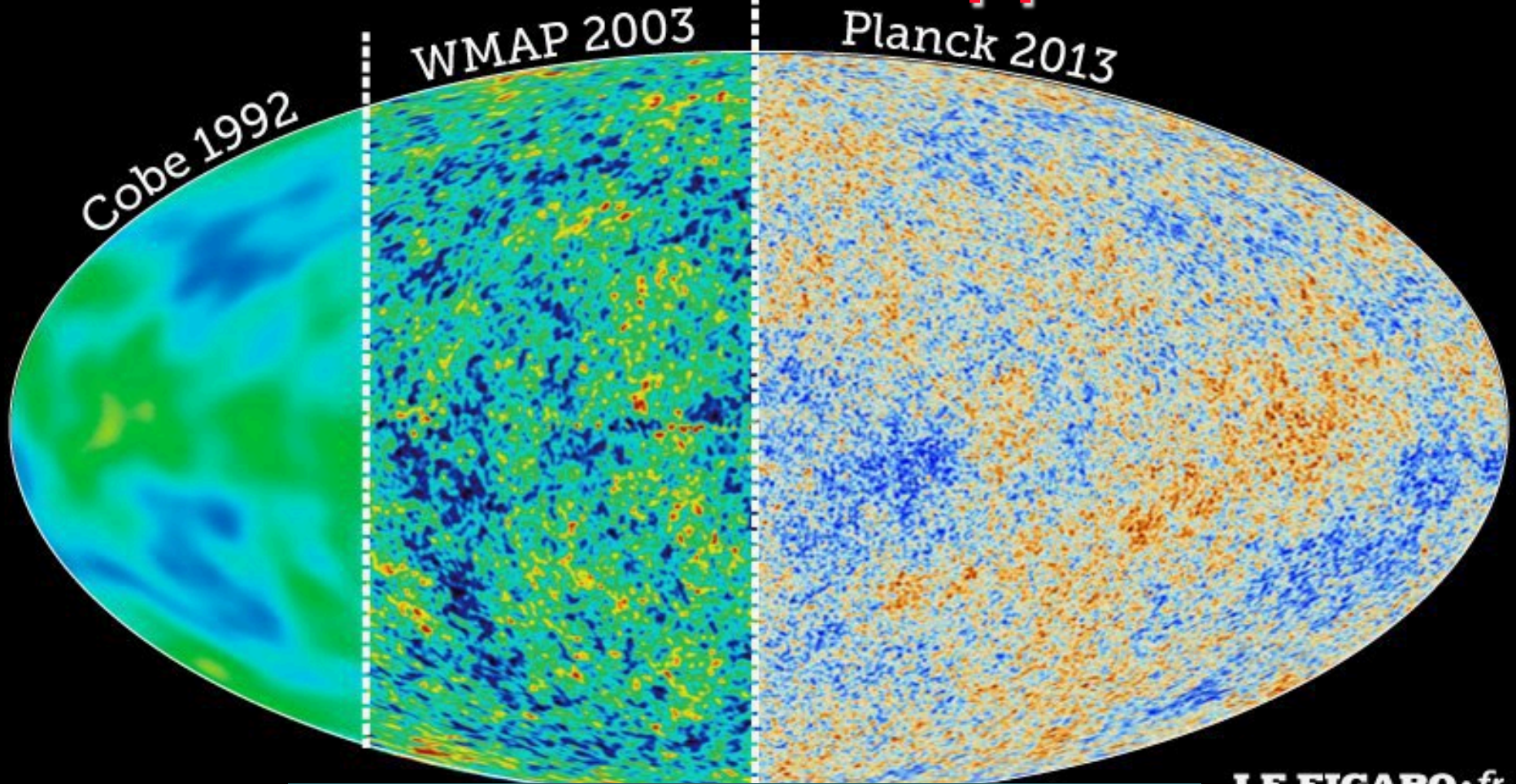


Milky Way subtracted

1993
COBE

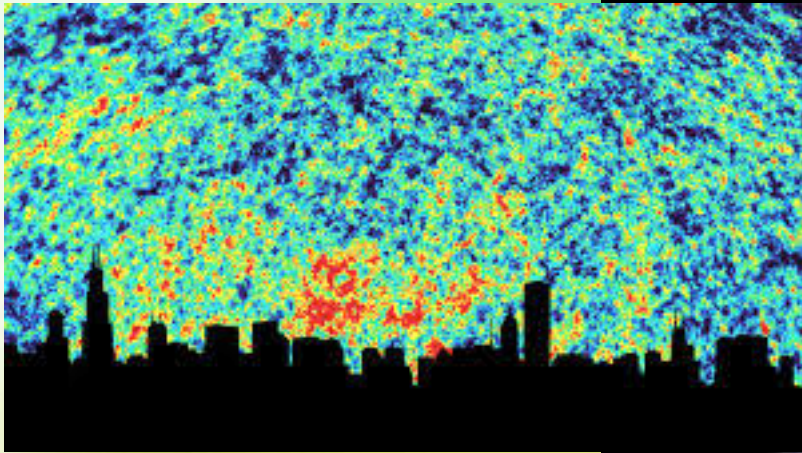
"ripples" in the CMB are tiny!! **1:1,000,000**
The irregularities are greatly exaggerated!

CMB: Telltale Ripples

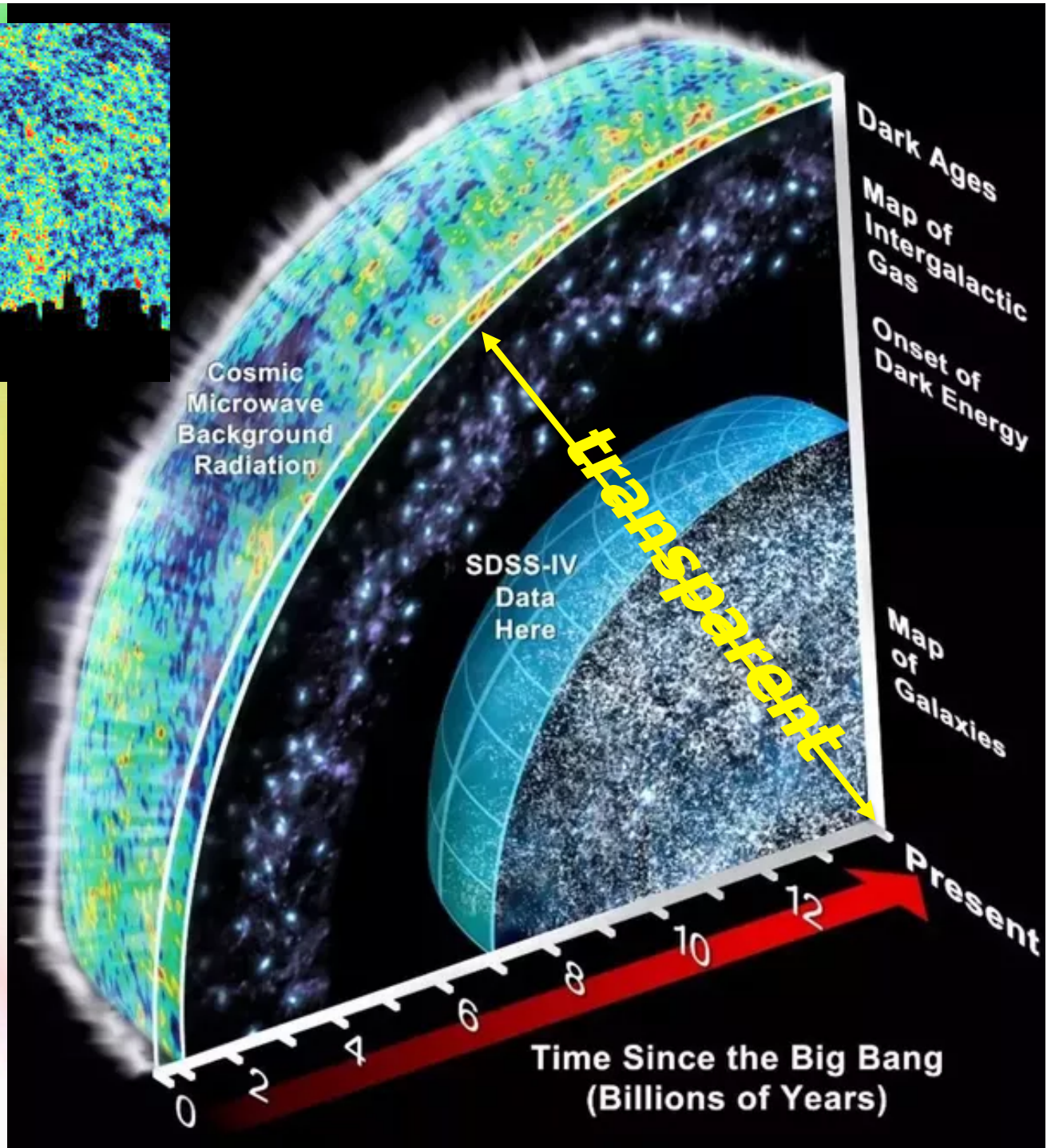


"ripples" in the CMB are tiny!! **1:1,000,000**
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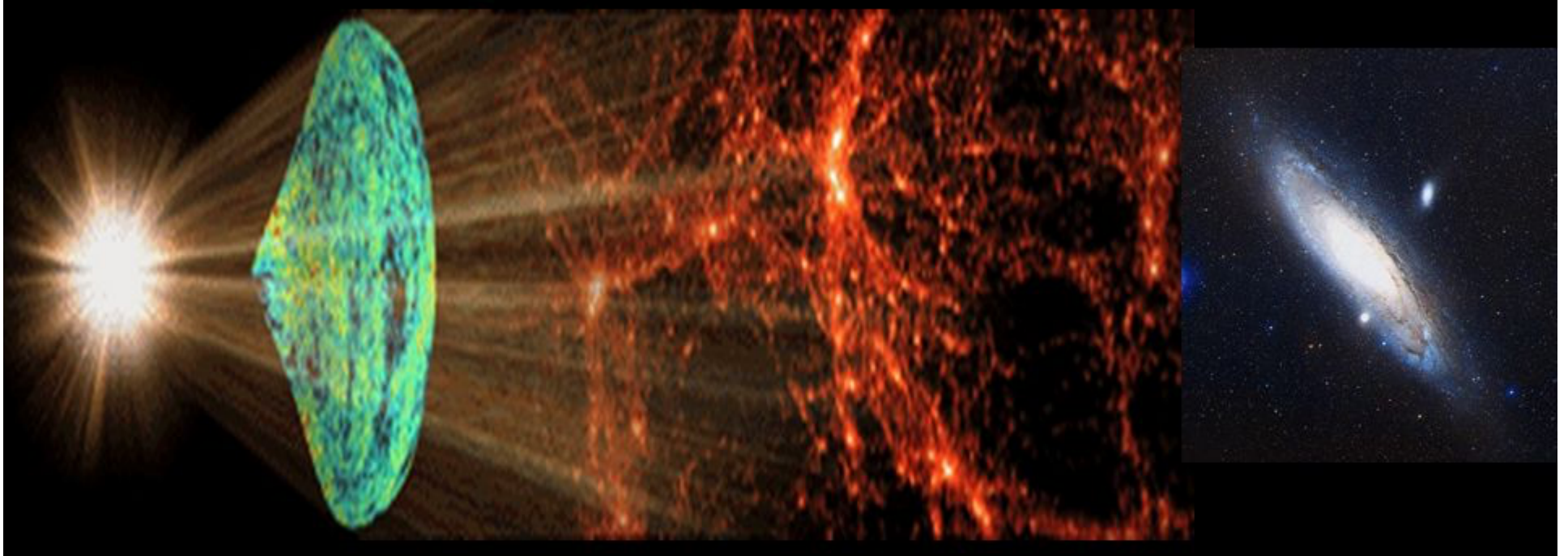
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Gamov, Alpher (1948) realized that relic heat might be observable now provided that the Universe had once been opaque.



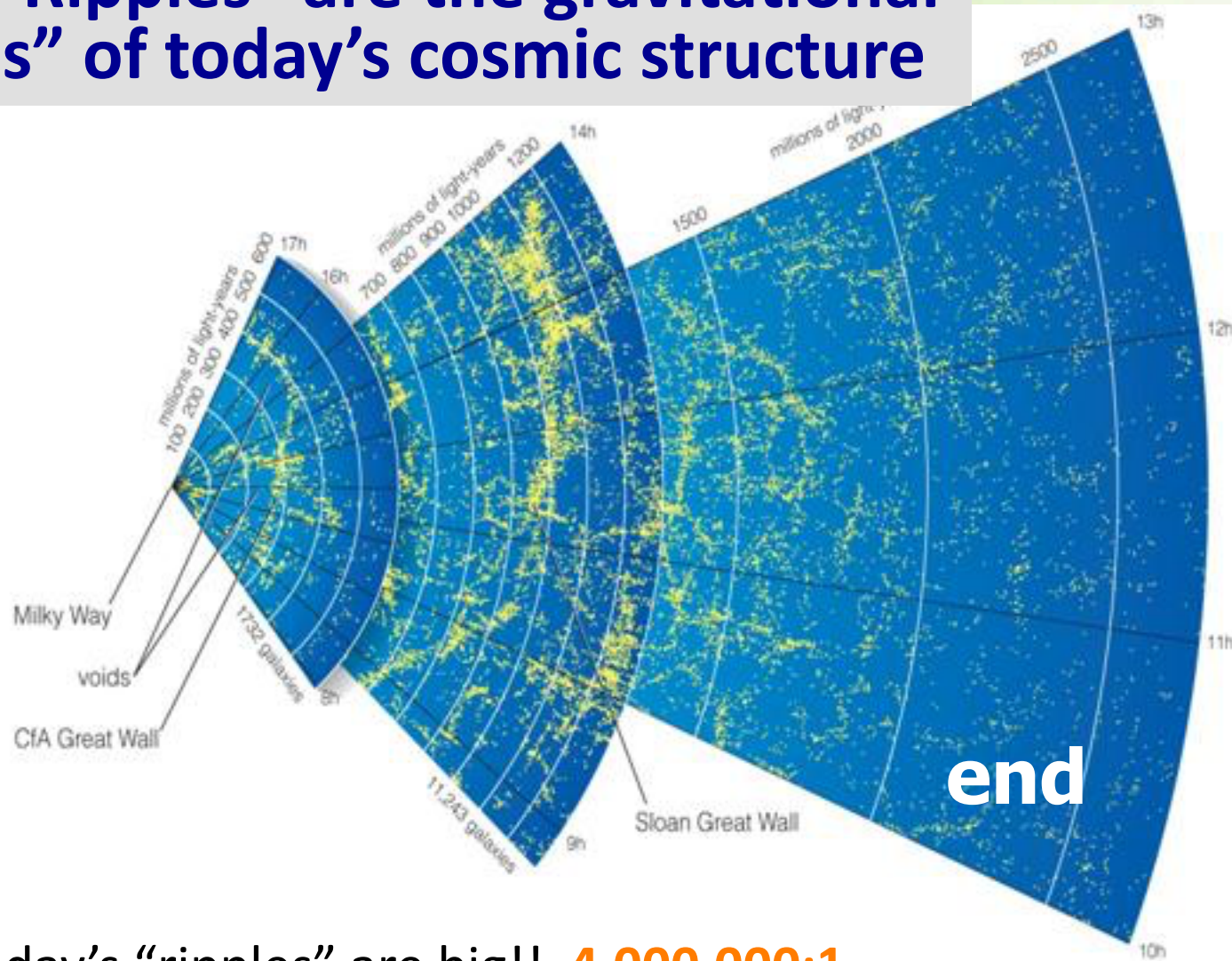
The “Standard Model” takes shape



1. The early opaque universe contains the seeds of today's structure
2. The transparency of gas after the end of the CMB unleashes gravity.
3. Gravity quickly gets down to work crafting galaxy clusters from lumps.

Origins of Present Structure

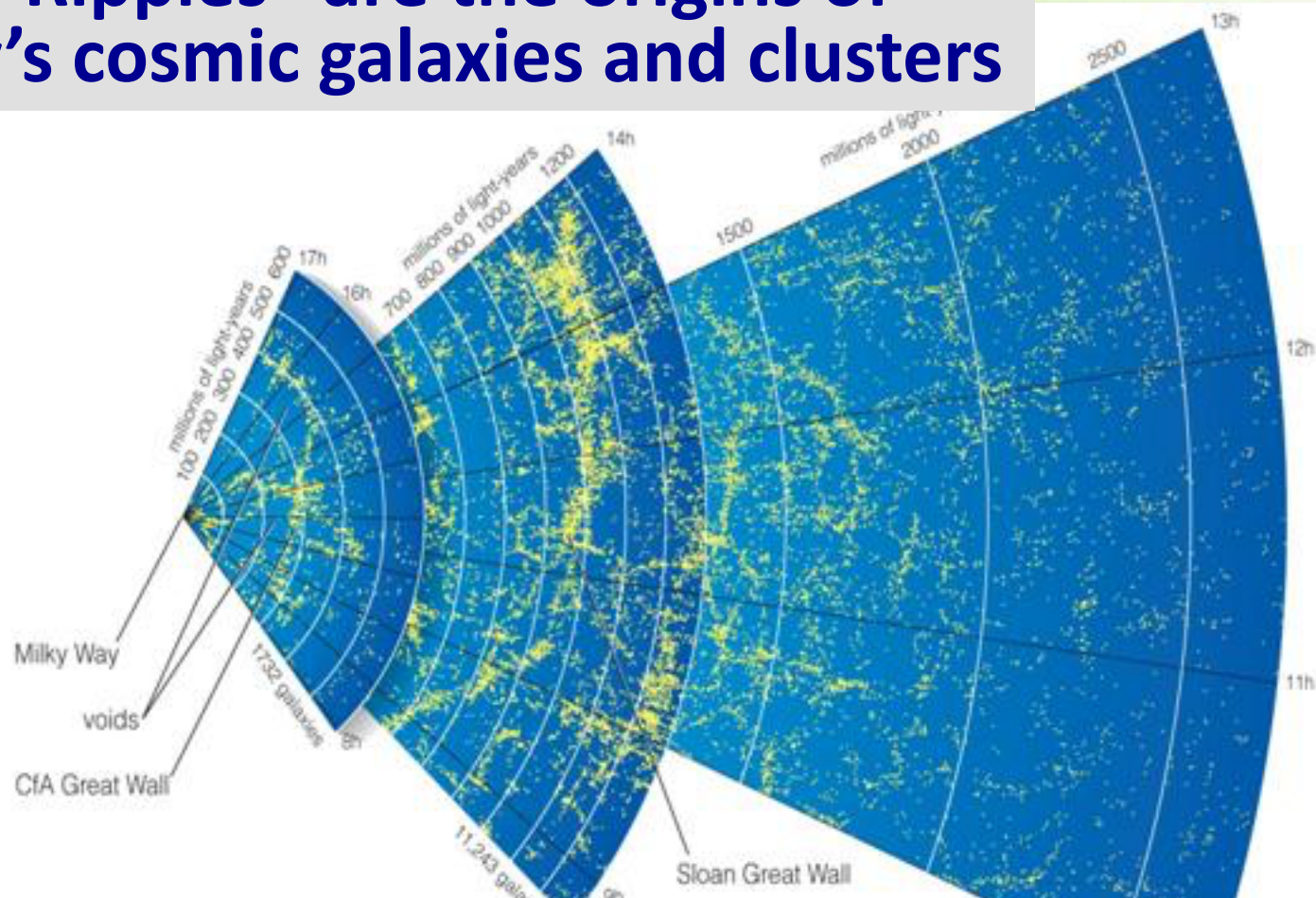
CMB “Ripples” are the gravitational “seeds” of today’s cosmic structure



Today’s “ripples” are big!! **4,000,000:1**

This Structure Tells a Story

CMB “Ripples” are the origins of today’s cosmic galaxies and clusters



We are very lucky that the ripples at the very earliest times enabled galaxies and clusters to form. Chapter 5, page 138, 150, 153+.