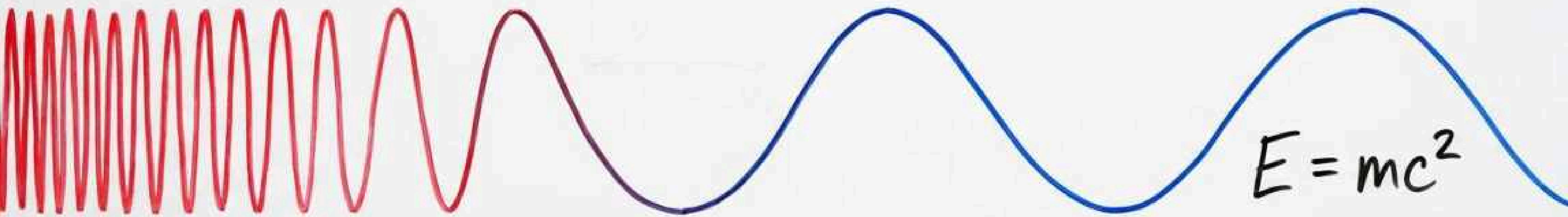
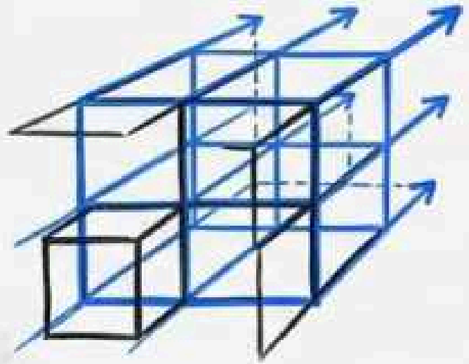
The Big Bang and Its Afterglow

Lecture 3: A Visual Cosmology

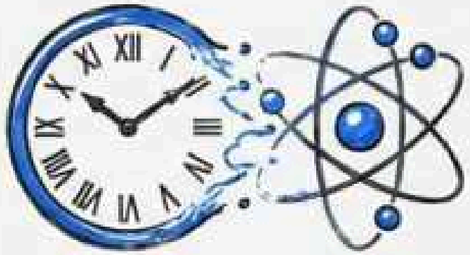


The Big Bang Theory



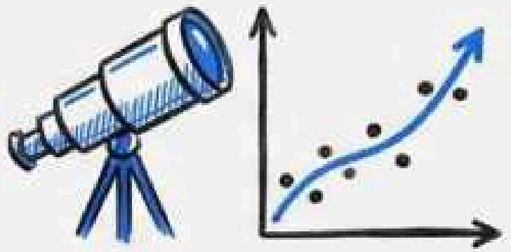
The Claim

What does the Big Bang theory actually claim?



The Timeline

What happened in the first few minutes and the first 380,000 years?



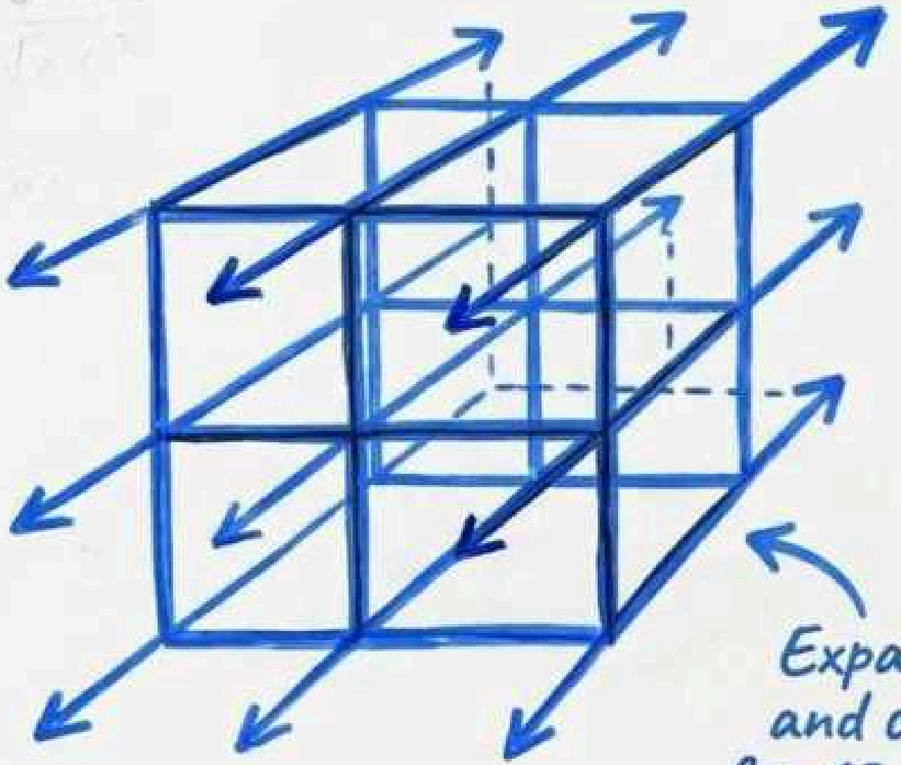
The Evidence

What is the empirical evidence that convinced the scientific community?



NOT an explosion at a point in space.

DOES NOT say what came before.



An evolution from an extremely hot, dense state.

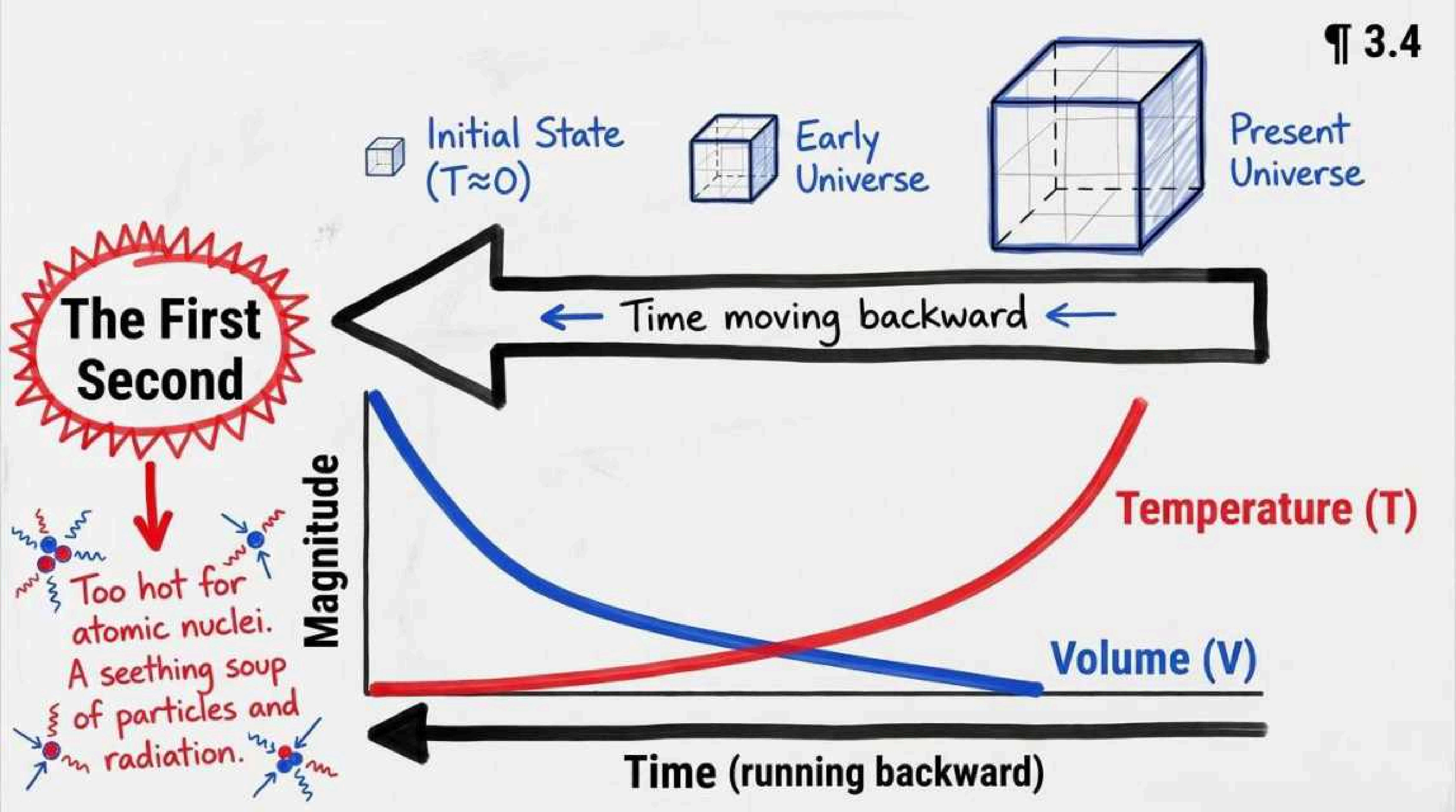
Steady State Theory



Big Bang Theory

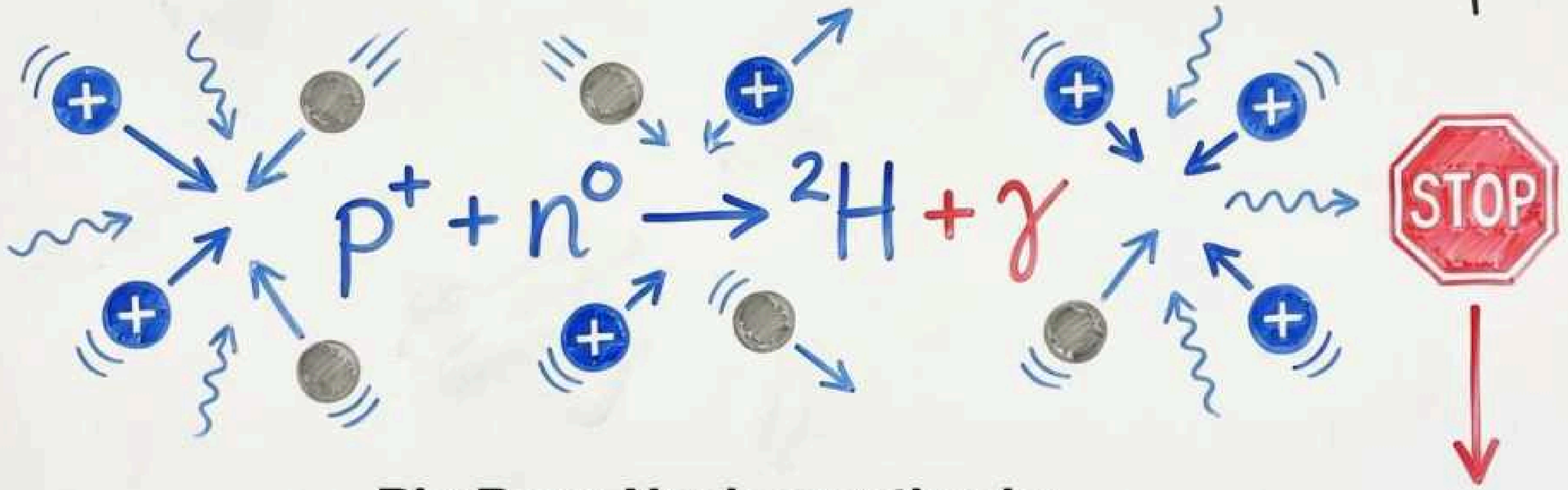
1949: Fred Hoyle coins the term on BBC Radio.

Intended only to contrast his own steady state theory against the rival idea—not to mock it. The vivid name stuck.


Initial State
(T≈0)
Early
Universe
Present
Universe
The First
Second
Time moving backward
Too hot for
atomic nuclei.
A seething soup
of particles and
radiation.
Magnitude
Temperature (T)
Volume (V)
Time (running backward)

Nuclear Furnace

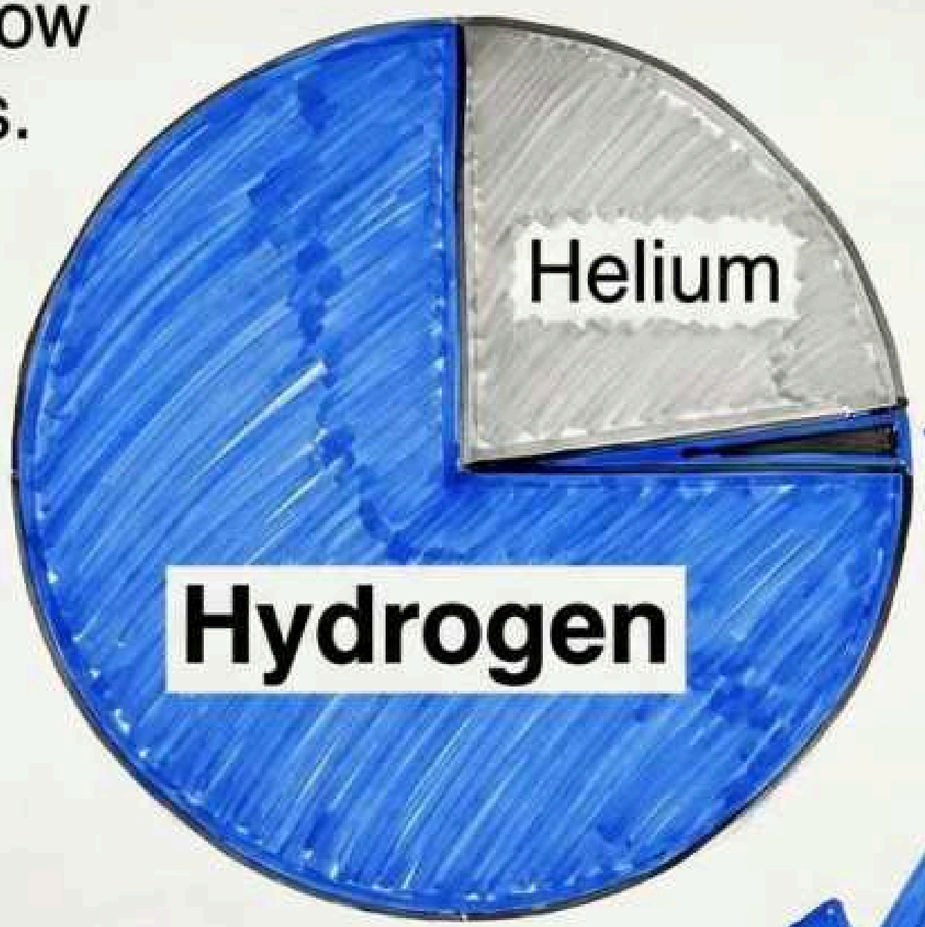
1 second — A few minutes



Big Bang Nucleosynthesis:
Protons and neutrons fuse to form nuclei of light elements.

Universe becomes too cool and thin for fusion to continue.

1948: Ralph Alpher &
George Gamow
publish calculations.

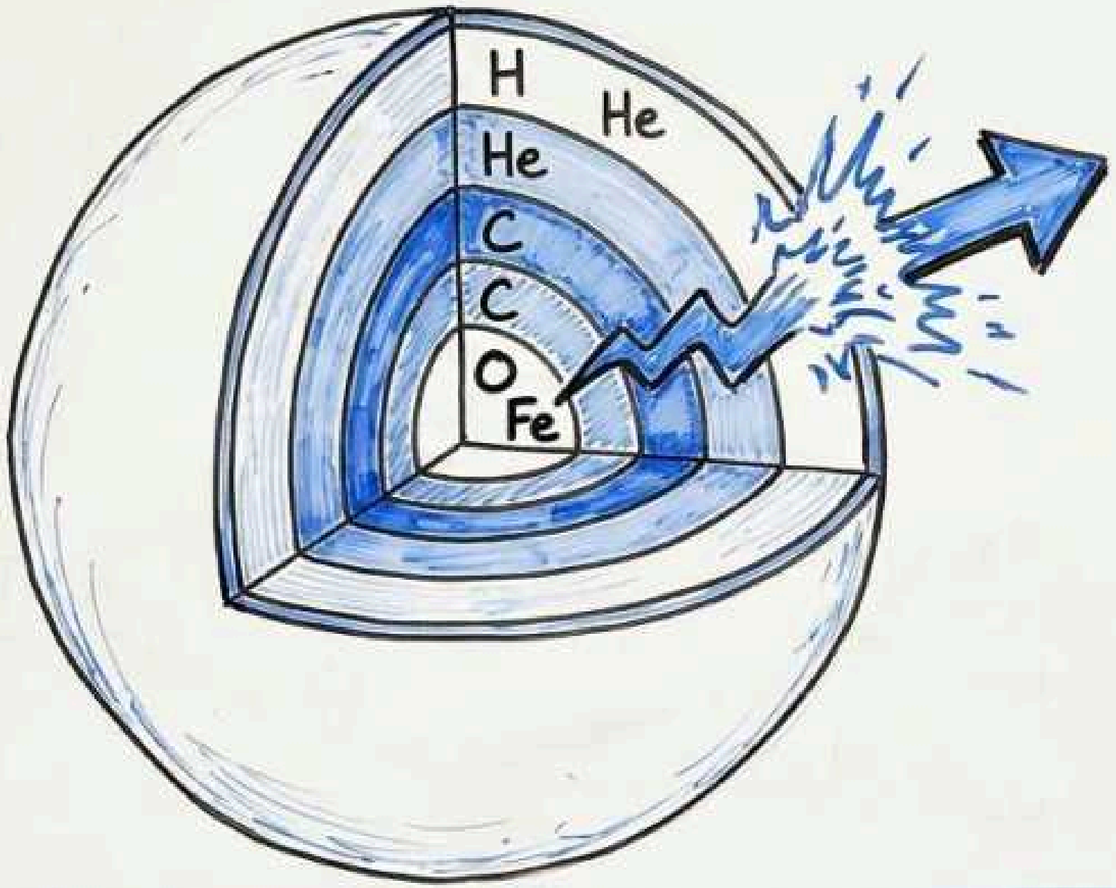






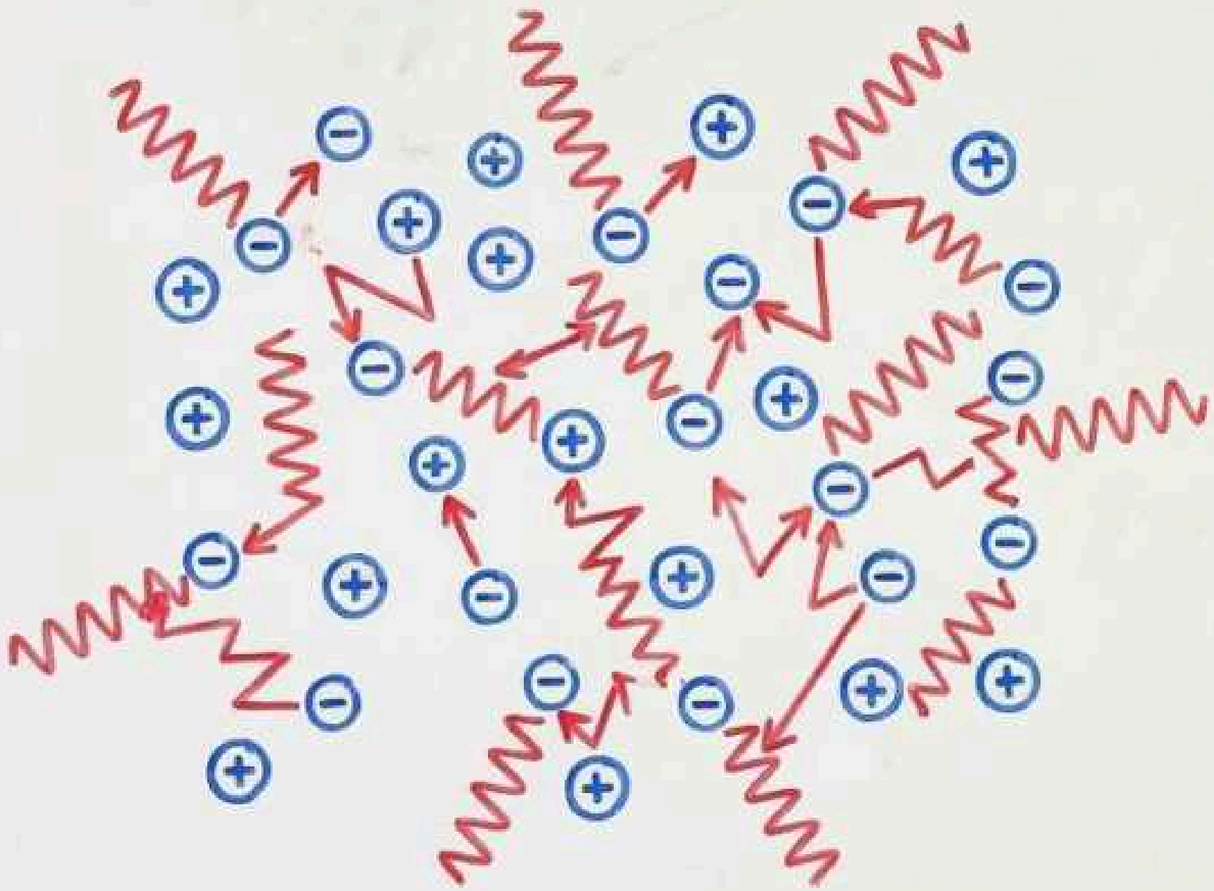
Observations of the oldest stars and gas clouds match these predictions closely. A major success.

Heavier elements were NOT made in the Big Bang.



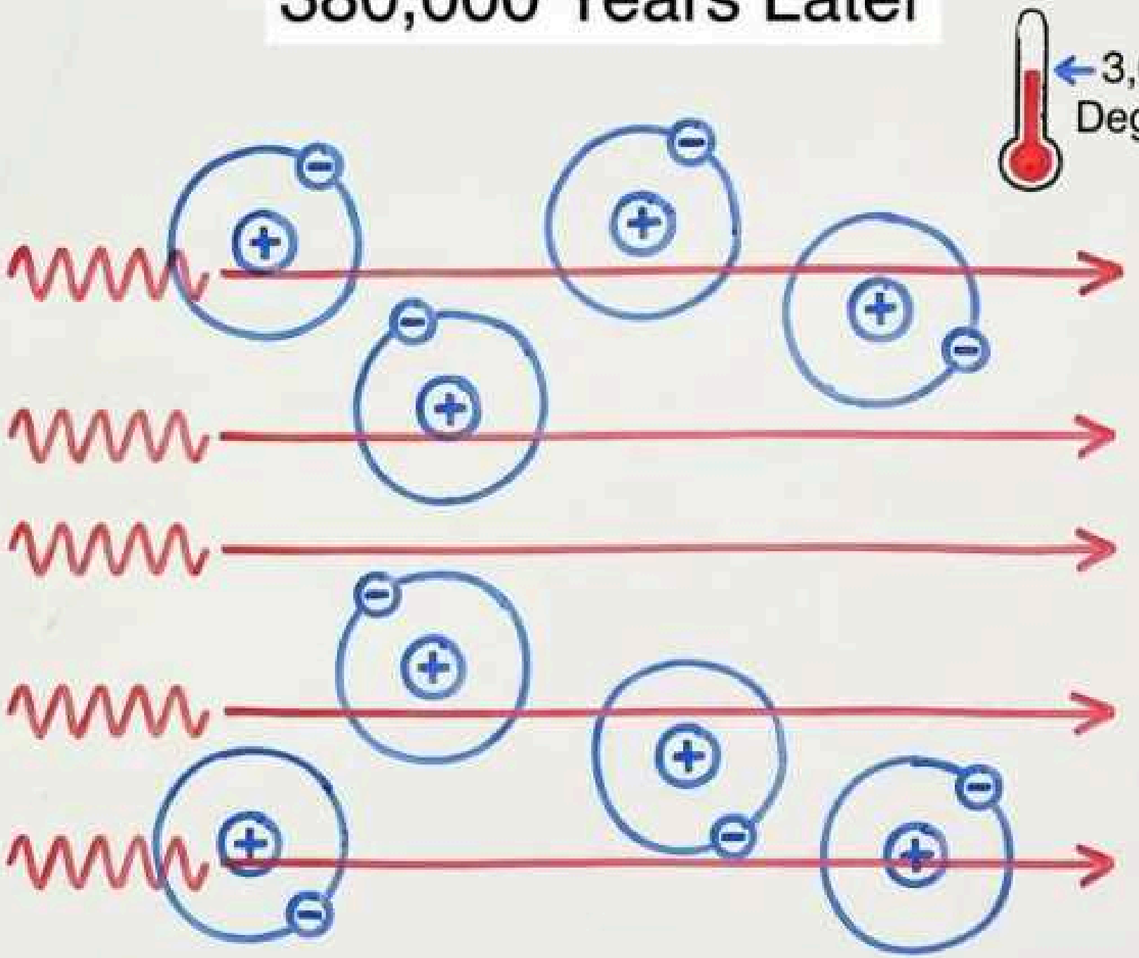
The carbon in your body and the oxygen you breathe were forged in stars that lived and died before the Sun was born.

Next Few Hundred Thousand Years



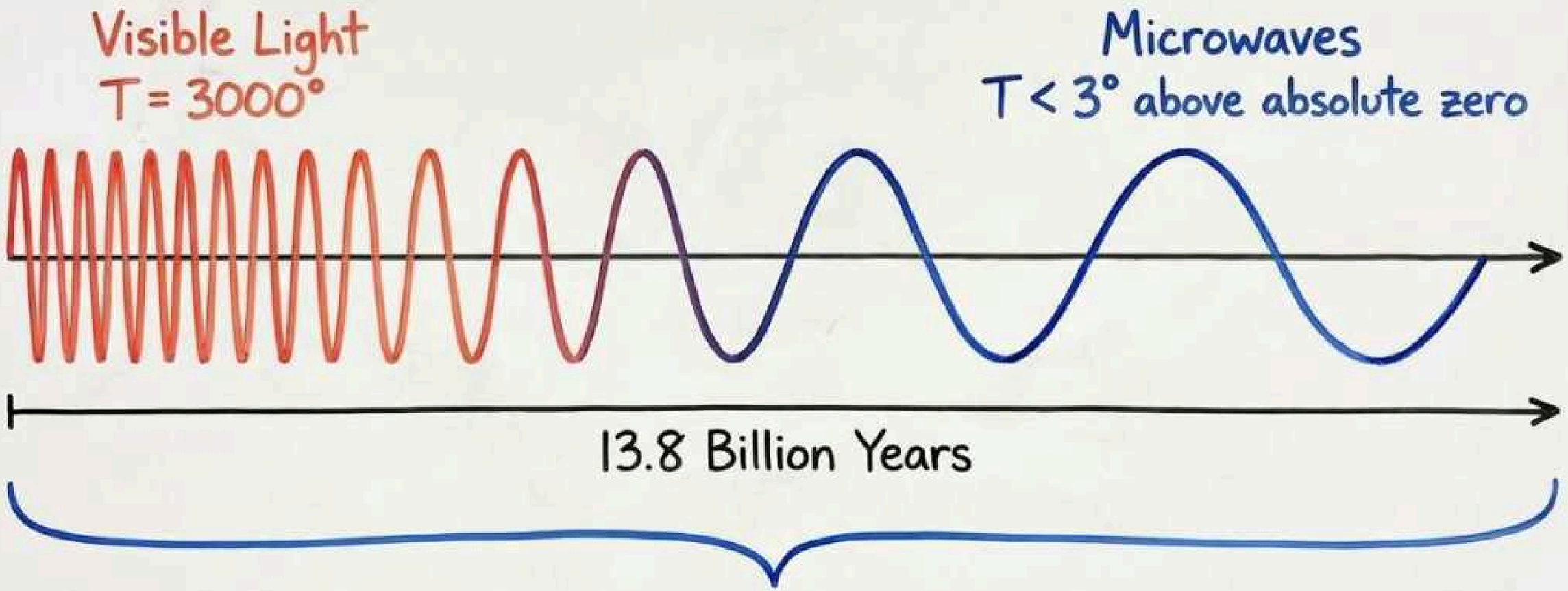
Hot fog of charged particles.
Light cannot travel far.

380,000 Years Later



Electrons join nuclei. Suddenly,
the universe becomes transparent.

The Afterglow of the Big Bang.



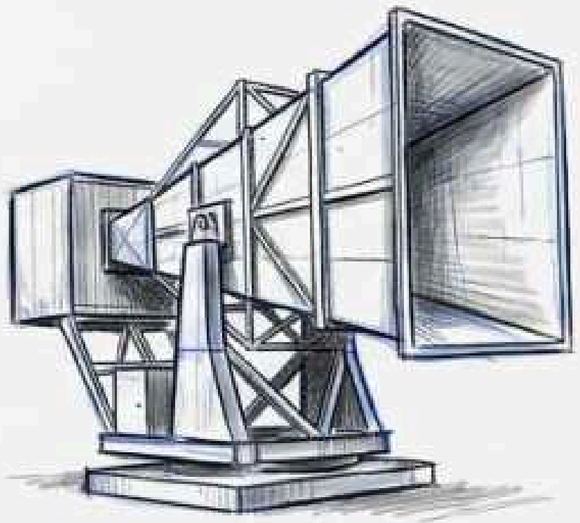
Light stretched by the expansion of space, shifting from visible light to microwaves. Coming from every direction in the sky.

1948 Prediction

Ralph Alpher & Robert Herman predict radiation should exist at ~5 degrees above absolute zero. (Largely forgotten).

The Cosmic Microwave Background

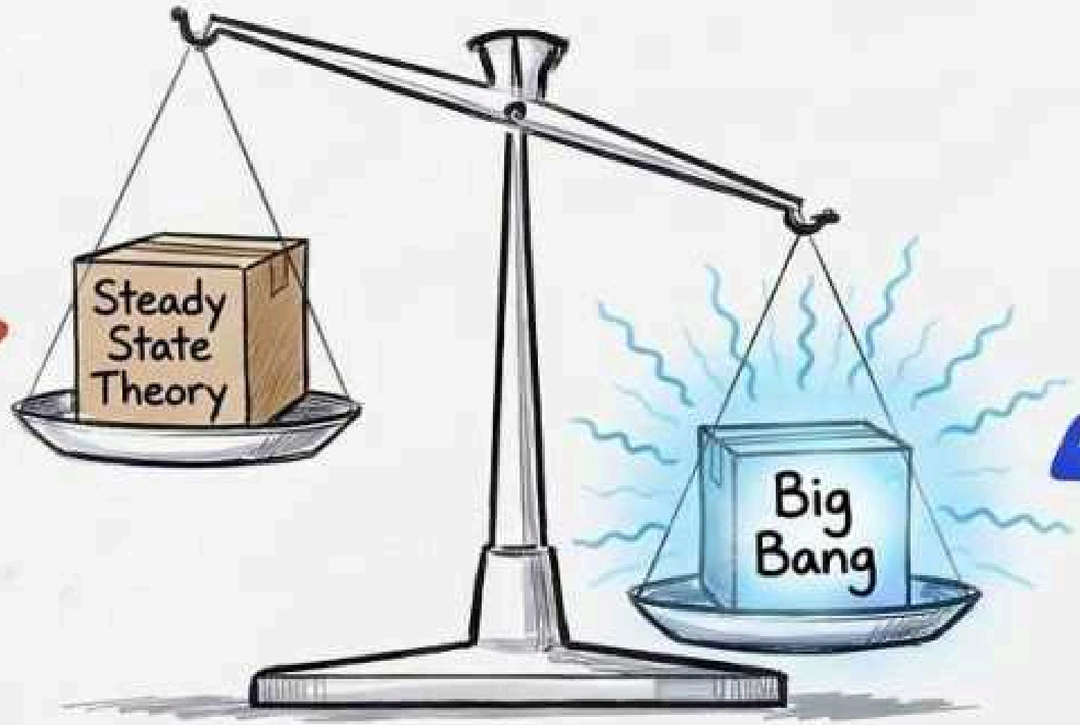
1964 Discovery



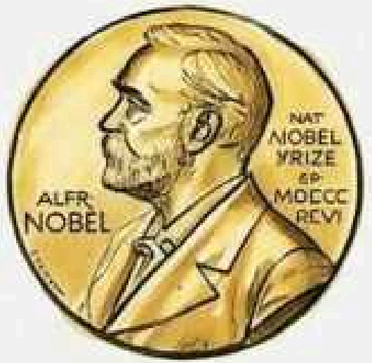
Arno Penzias & Robert Wilson find a persistent hiss coming from every direction.

The Discovery was a Turning Point.

No natural explanation for a uniform glow.



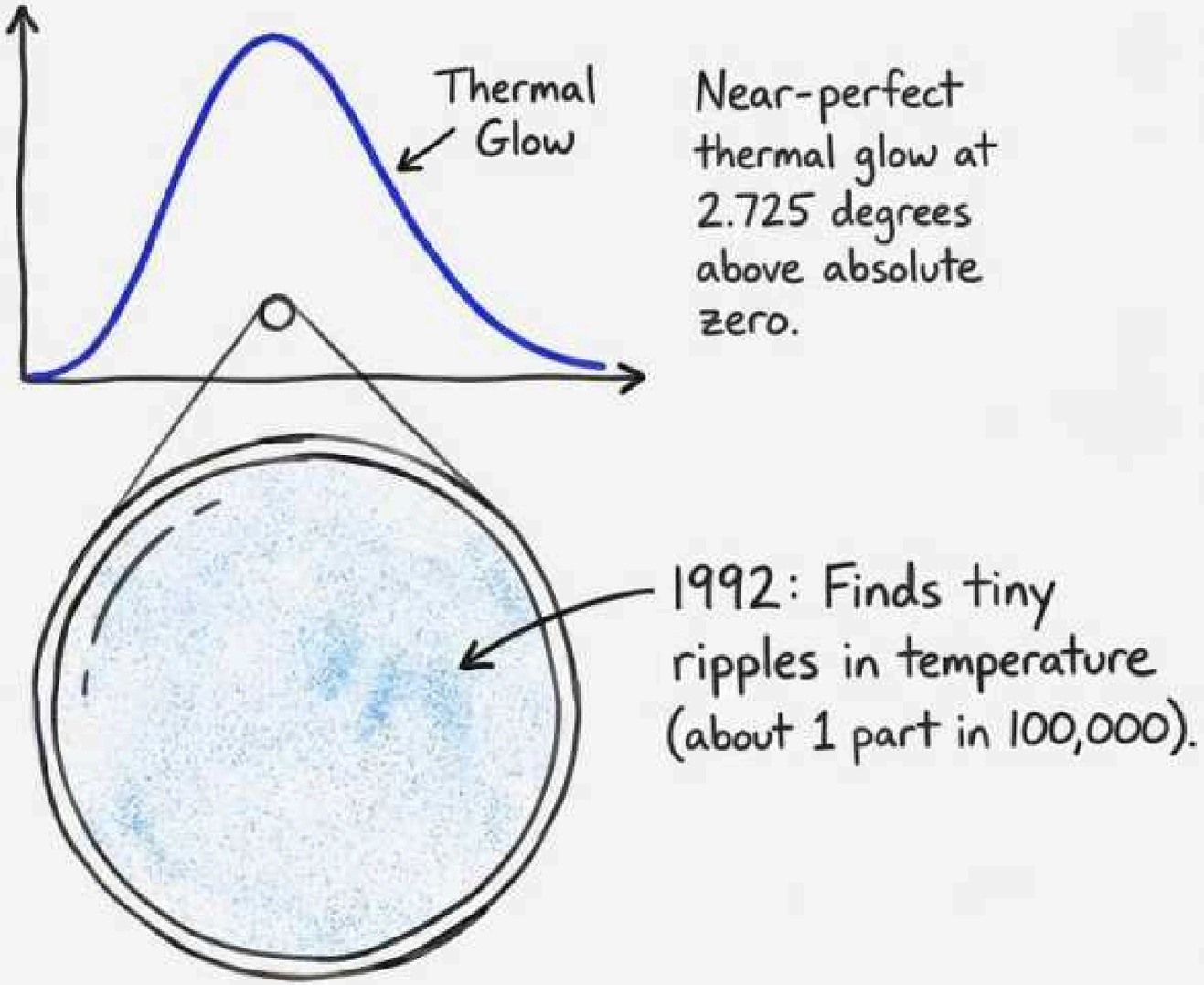
Predicted the uniform glow.



Penzias and Wilson share the Nobel Prize in Physics in 1978.

Most cosmologists accept the Big Bang.

COBE Satellite (1989)



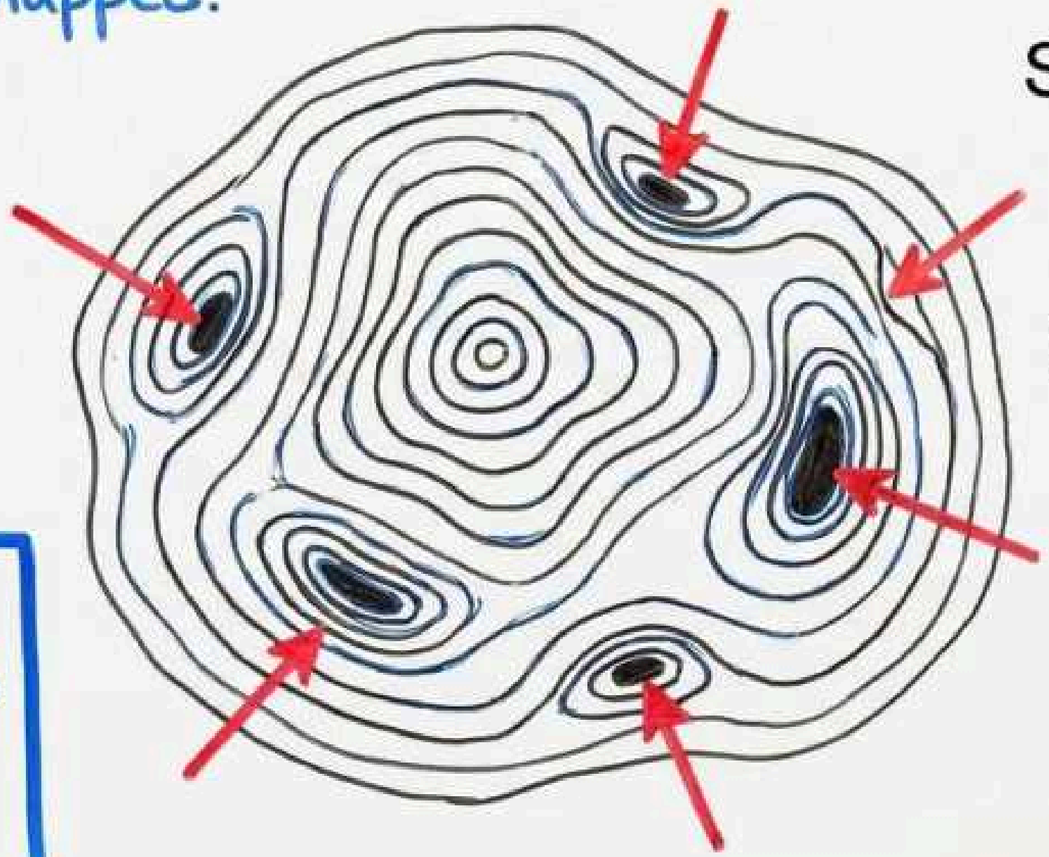
John Mather and George Smoot share the Nobel Prize in 2006.

The Seeds of Structure.

¶ 3.13

WMAP (2001) ⟶ Planck (2009)

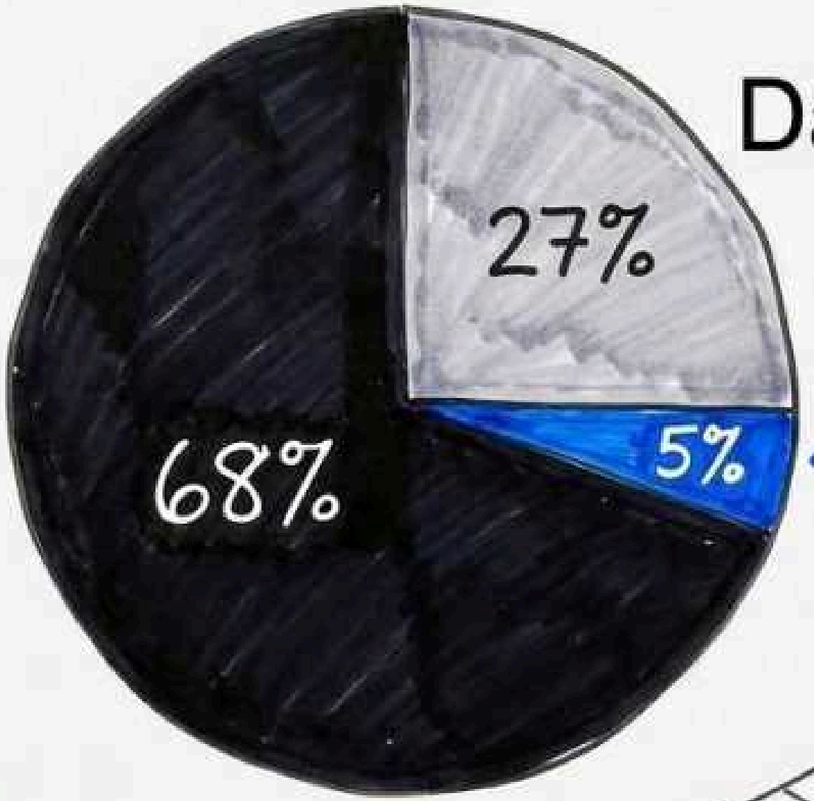
Fine detail mapped.

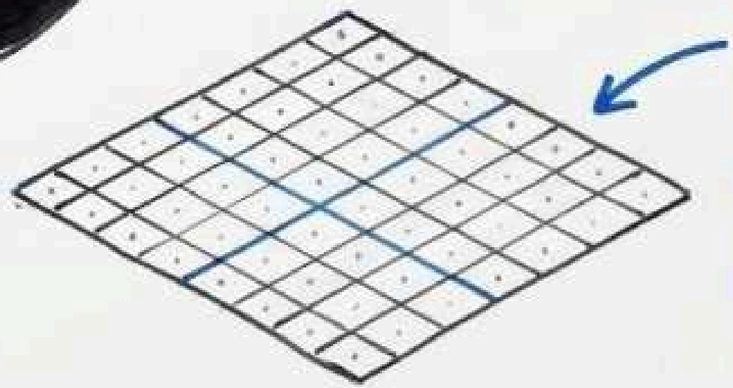


Slightly denser regions act as gravitational wells, gathering into galaxies and clusters.

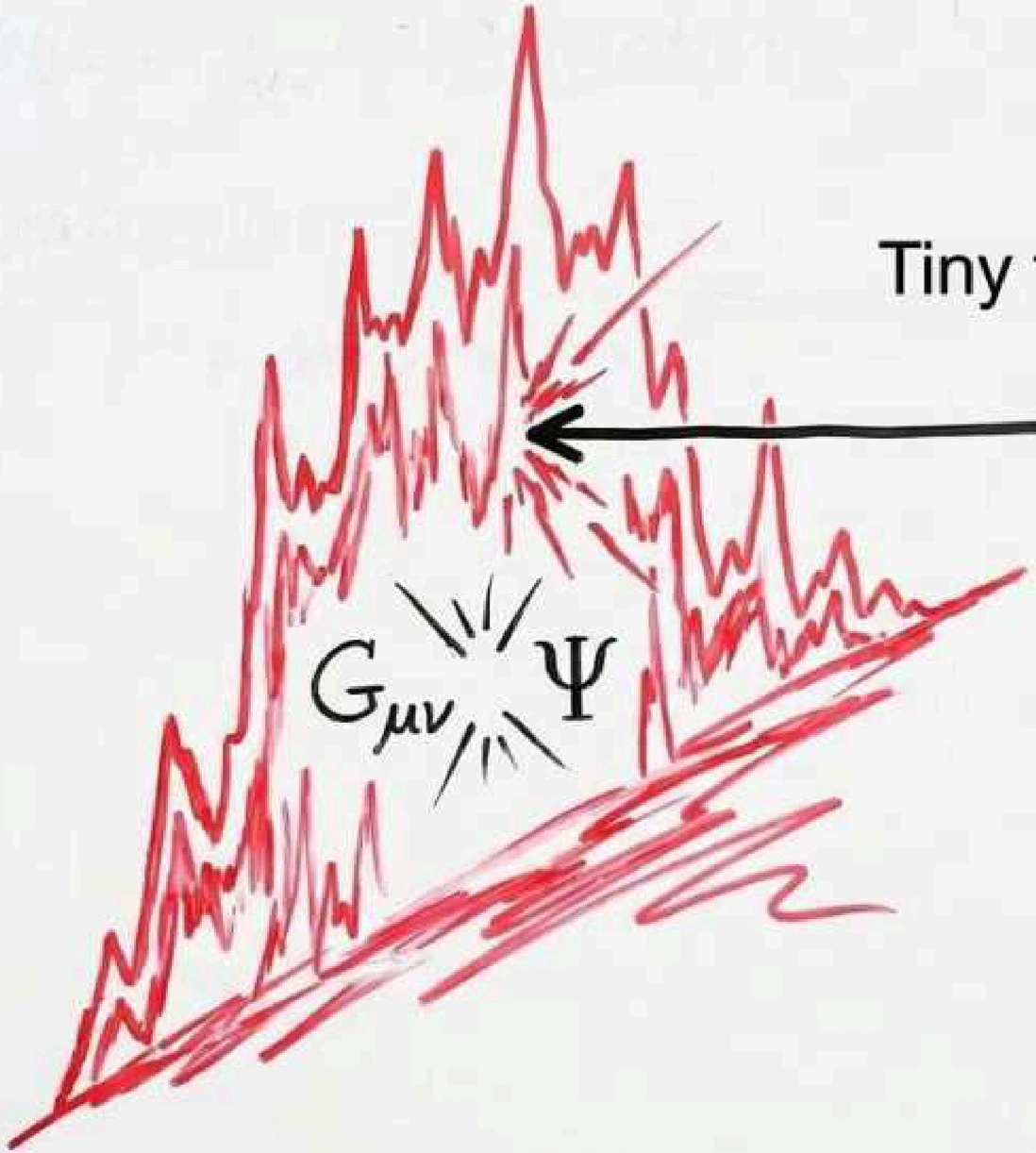
Pattern of ripples allows measurement of universe's age, shape, and contents.

The Planck Satellite Final Results (2018). ¶ 3.14





Space on large scales appears almost perfectly flat.



Tiny fraction of a second onward:
Very well described.

LIMIT OF CURRENT PHYSICS:
Densities and temperatures become extreme. We lack a theory unifying General Relativity with Quantum Mechanics.

What happened at time zero, if there was one, is unknown.

Precision Check: Two entirely independent methods agree.

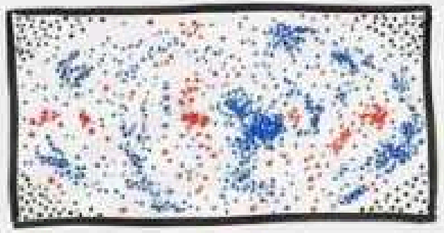
Nucleosynthesis Era



Distant Gas Clouds

Measurements of Deuterium (Heavy Hydrogen).

CMB Era



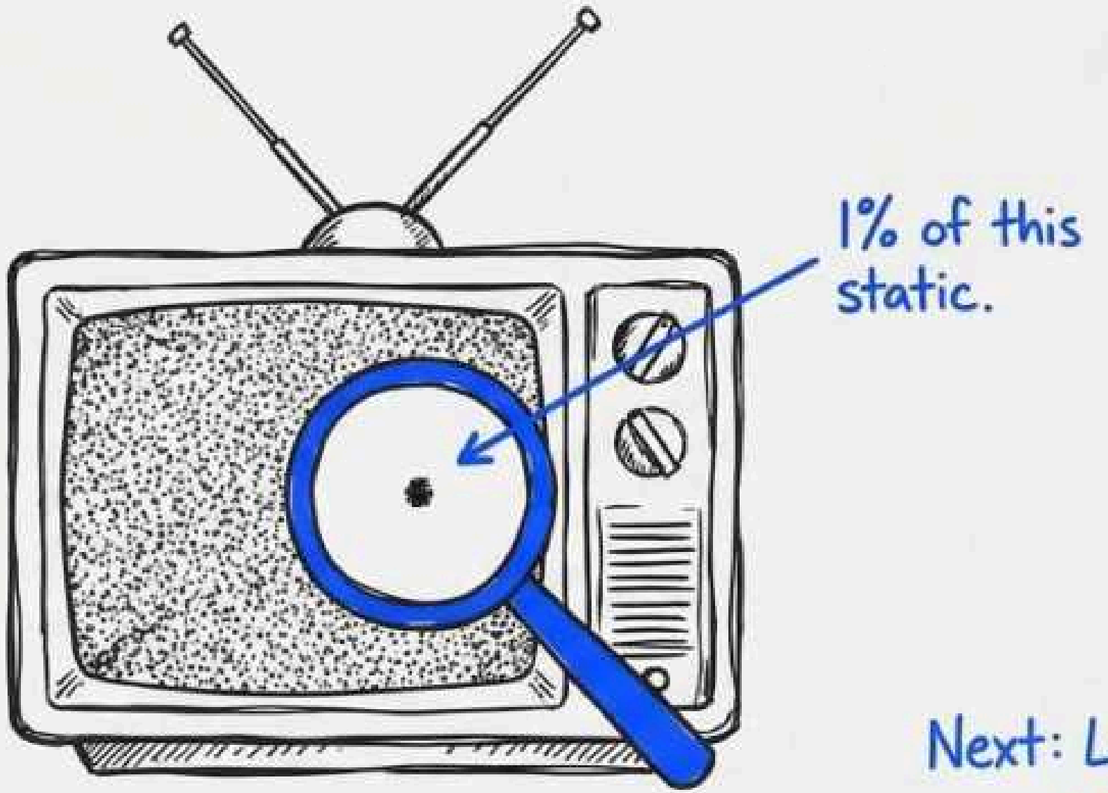
Cosmic Microwave Background

Pattern of Tiny Temperature Ripples.

$\Omega_b \approx 5\%$

(Ordinary Matter = 5%)

A Closing Exercise: Tune an old analogue TV or radio between stations. You are detecting light that has travelled for 13.8 billion years.



Next: Lecture 4 – Galaxies and Dark Matter.