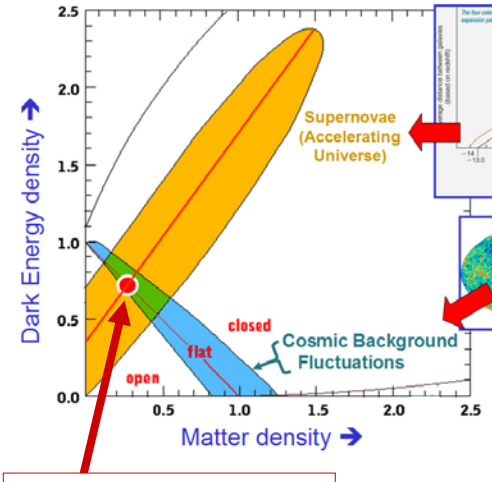
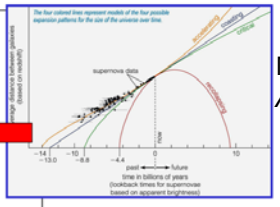
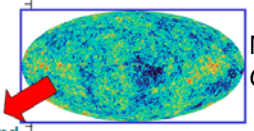
What is the Universe Made Of ?

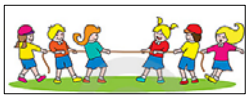




Measures *Acceleration*



Measures *Curvature*

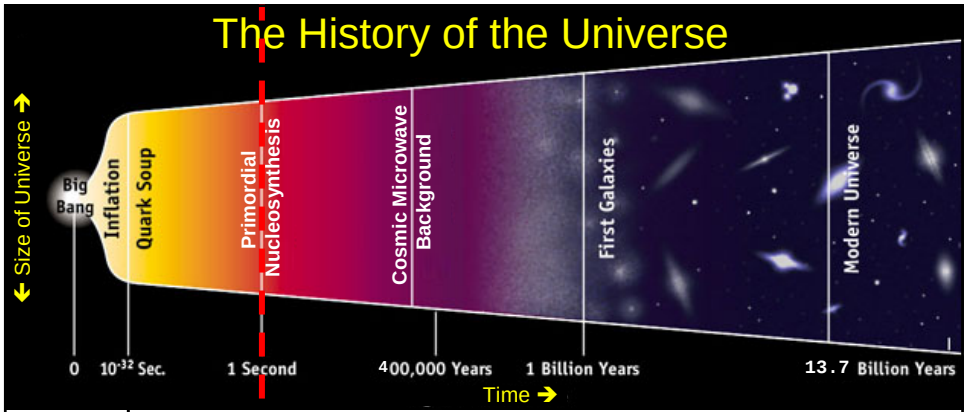


4% Normal Matter
23% Dark Matter
73% Dark Energy

Acceleration = (Dark Energy) – (Matter)

Curvature = (Dark Energy) + (Matter)

The History of the Universe



Planck time — Inflation

Formation of H, He, Li

Decoupling of CMB

Galaxy Formation

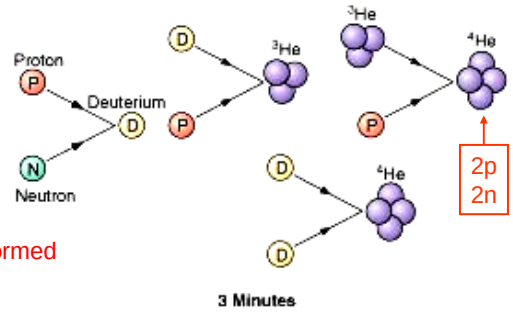
Now

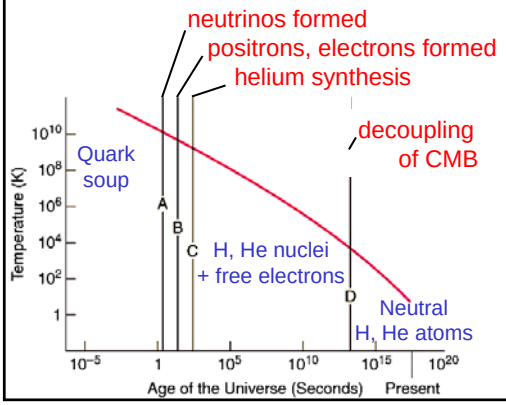
Hot (10^{32} K) → (10^{9} K) → (3000 K) → Cool (3 K)

High density → Low density

Where did Hydrogen and Helium come from?

- Nucleosynthesis in the Big Bang.
- First 3 minutes.

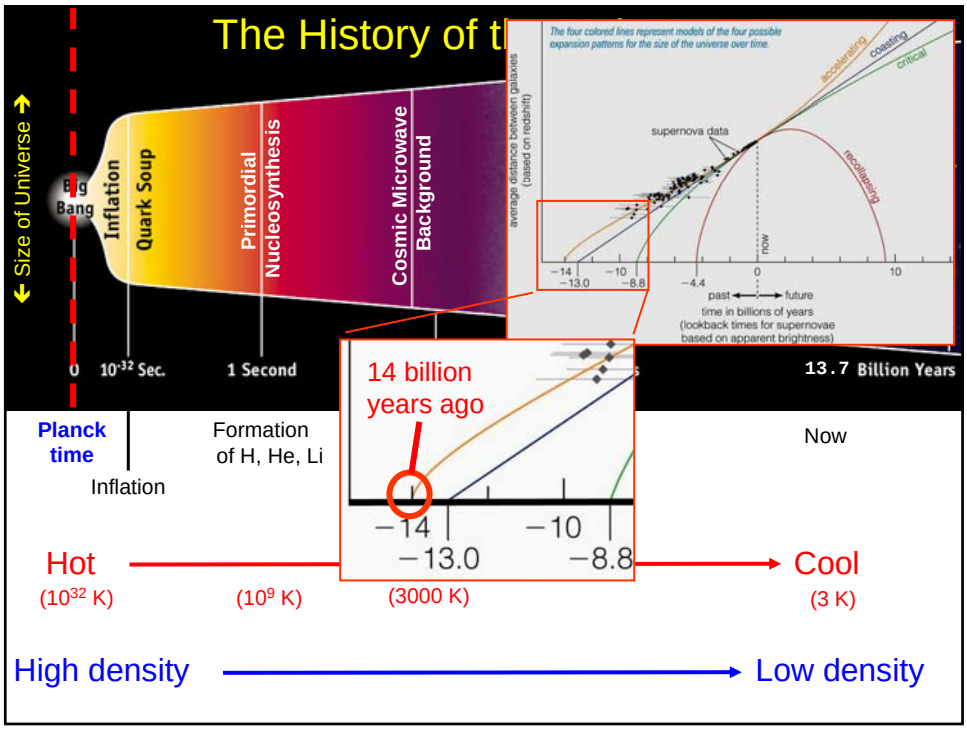


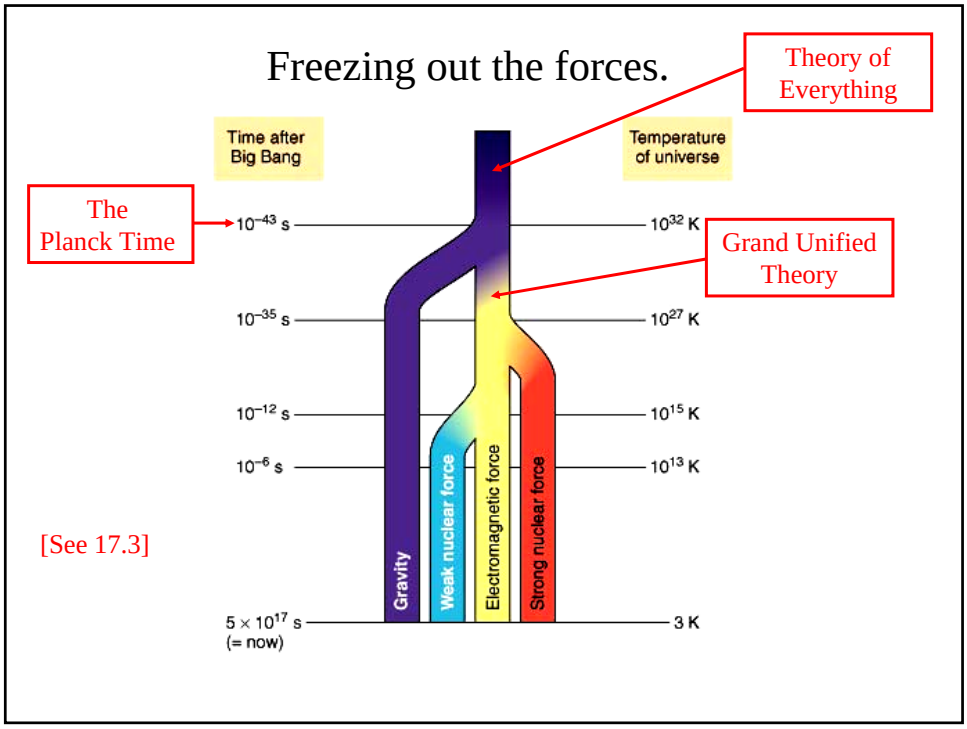


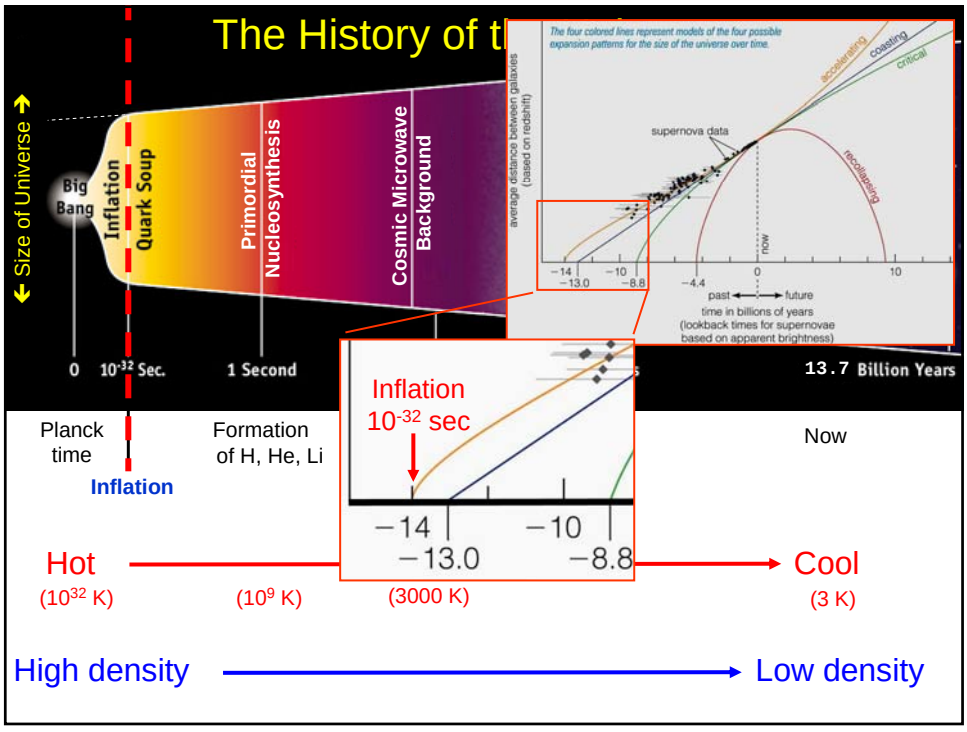
Produced 75% H
25% He

Some Lithium also formed

Then all heavier elements formed by *stars*.



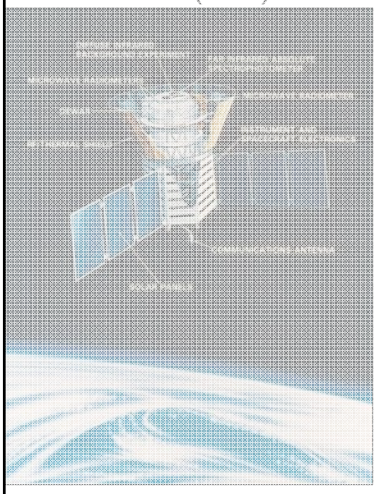

Freezing out the forces.
Theory of Everything
Time after Big Bang
Temperature of universe
The Planck Time
Grand Unified Theory
10^{-43} s
10^{32} K
10^{-35} s
10^{27} K
10^{-12} s
10^{15} K
10^{-6} s
10^{13} K
Gravity
Weak nuclear force
Electromagnetic force
Strong nuclear force
5×10^{17} s (= now)
3 K
[See 17.3]


The History of t
Size of Universe
Big Bang
Inflation
Quark Soup
Primordial Nucleosynthesis
Cosmic Microwave Background
0
10^{-32} Sec.
1 Second
13.7 Billion Years
supernova data
accelerating
coasting
critical
recollapsing
now
past
future
time in billions of years (lookback times for supernovae based on apparent brightness)
Inflation 10^{-32} sec
−14
−13.0
−10
−8.8
Planck time
Inflation
Formation of H, He, Li
Now
Hot
(10^{32} K)
(10^{9} K)
(3000 K)
Cool
(3 K)
High density
Low density

The Cosmic Microwave Background

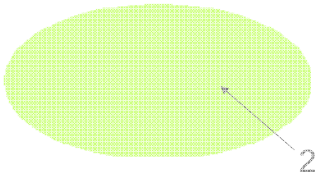
Comes from all directions

COBE satellite (1989)



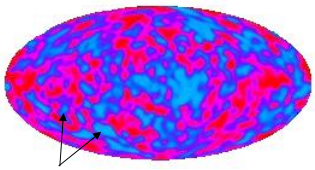
Whole-Earth Map

Whole-Sky Maps



Blue = 0°K
Red = 4°K

2.73°K



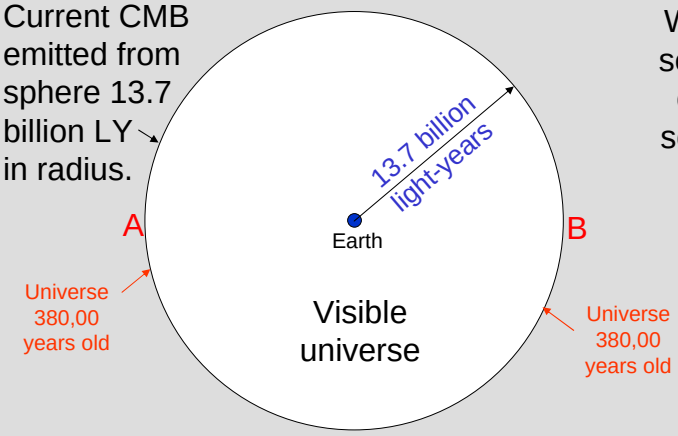
Blue = 2.7302°K
Red = 2.7300°K

Seeds of future galaxies and galaxy clusters

Where did these "seeds" come from???

The Horizon

Current CMB emitted from sphere 13.7 billion LY in radius.

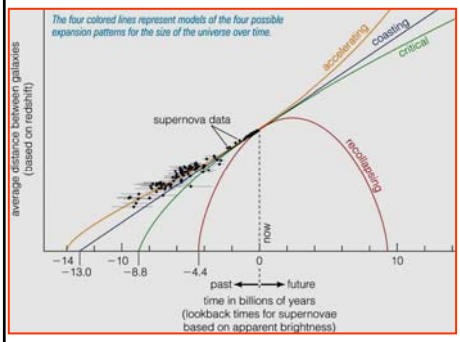


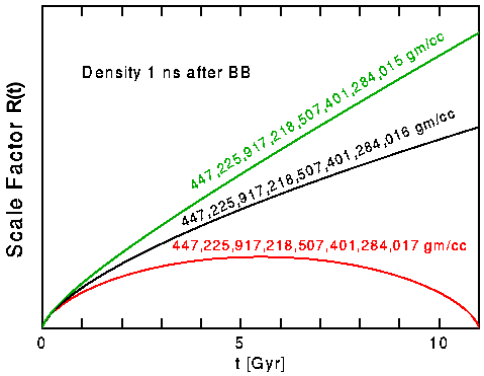
We will only see this part of universe sometime in future.

The Horizon Problem: Causality

- Points A and B have *never* communicated.
- How do they know how to have almost *exactly* the same conditions?

What happened back at the Big Bang?





The Flatness Problem:

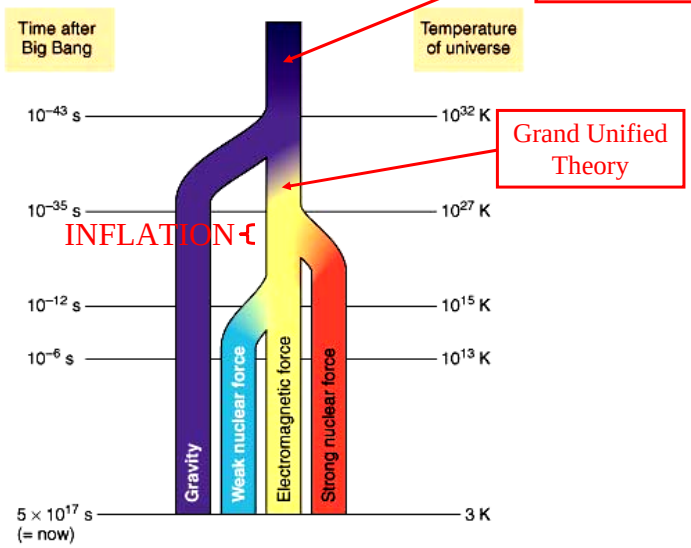
- Early universe: Dark Energy not important.
- Flatness required gravitational, kinetic energy in exact balance.

Critical Density

  - But this requires incredible precision at start (t = 0).

Freezing out the forces.

Theory of Everything

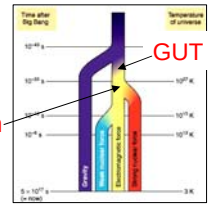


[See Fig 17.3]

The solution: Inflation

(probably)

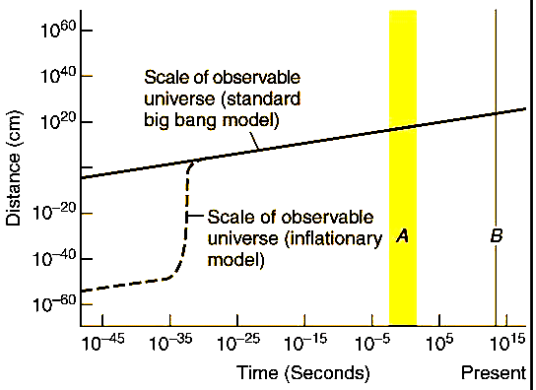
(maybe)



Extremely rapid expansion of universe

- due to release of energy in "phase change".
- like ice to water.

Universe became 10^{30} times larger within 10^{-36} seconds.

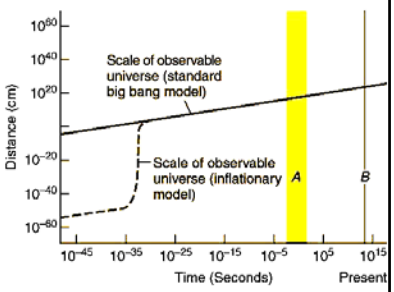


[See Section 17.3]

1,000,000,000,000,000,000,000,000,000,000

What does inflation predict for geometry of present universe?

Universe became 10^{30} times larger within 10^{-36} seconds.



- Predicts a flat universe
- Solves horizon problem.
- Expands quantum fluctuations to create seeds of galaxies.