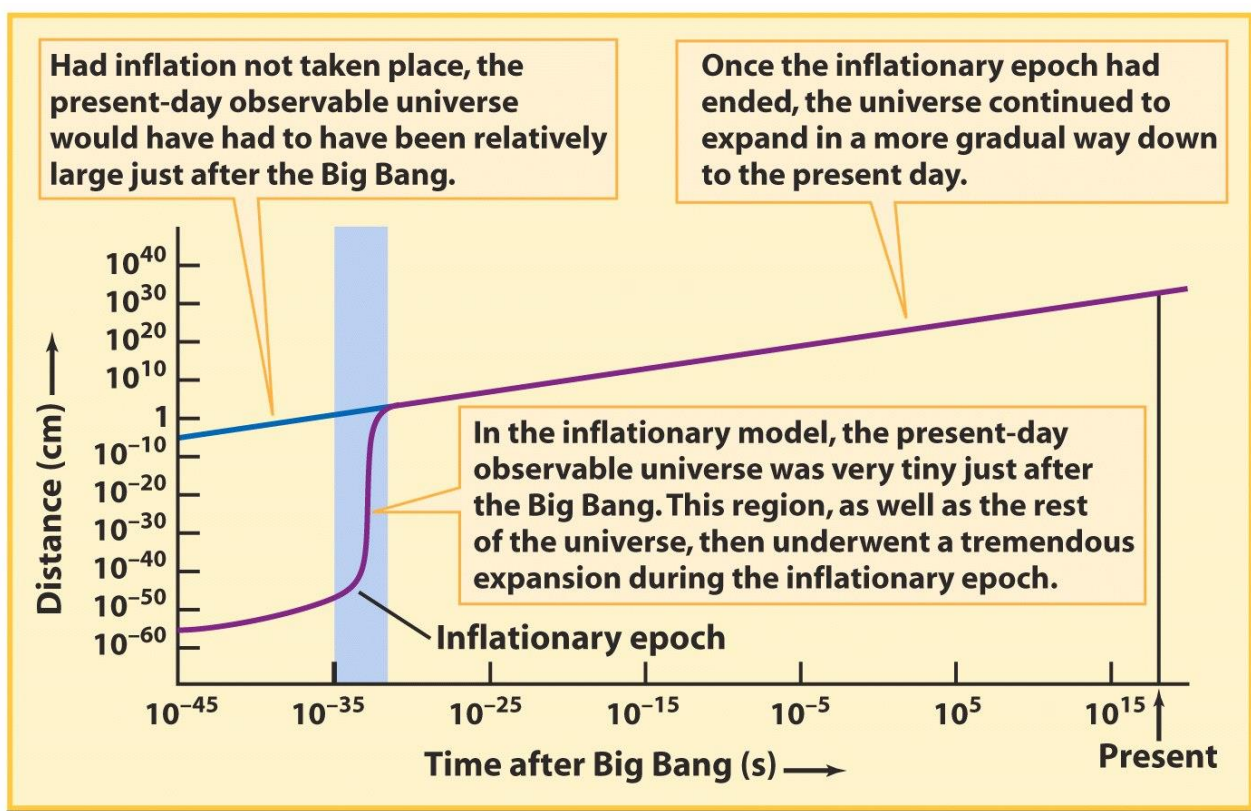


## The Fireball Theory or Big Bang Theory

In a small fraction of a second the temperature, density and composition of the universe changed dramatically.

In other words, the universe would have quickly evolved.

This evolution slowed down as the universe expanded, but that evolution and expansion has continued until the present day.

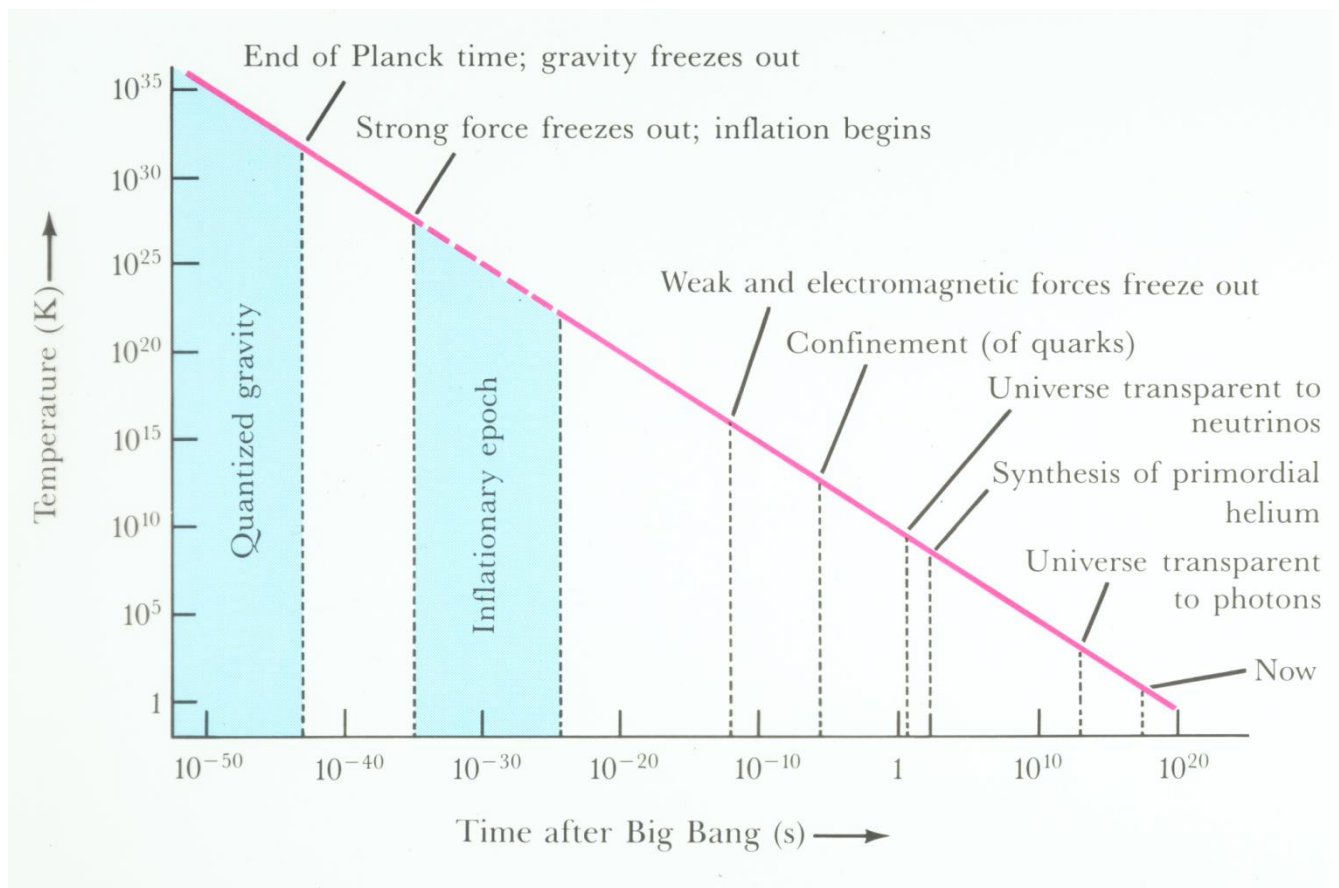


The temperature of the universe is defined in terms of the ambient radiation filling it vis-à-vis the laws of radiation.

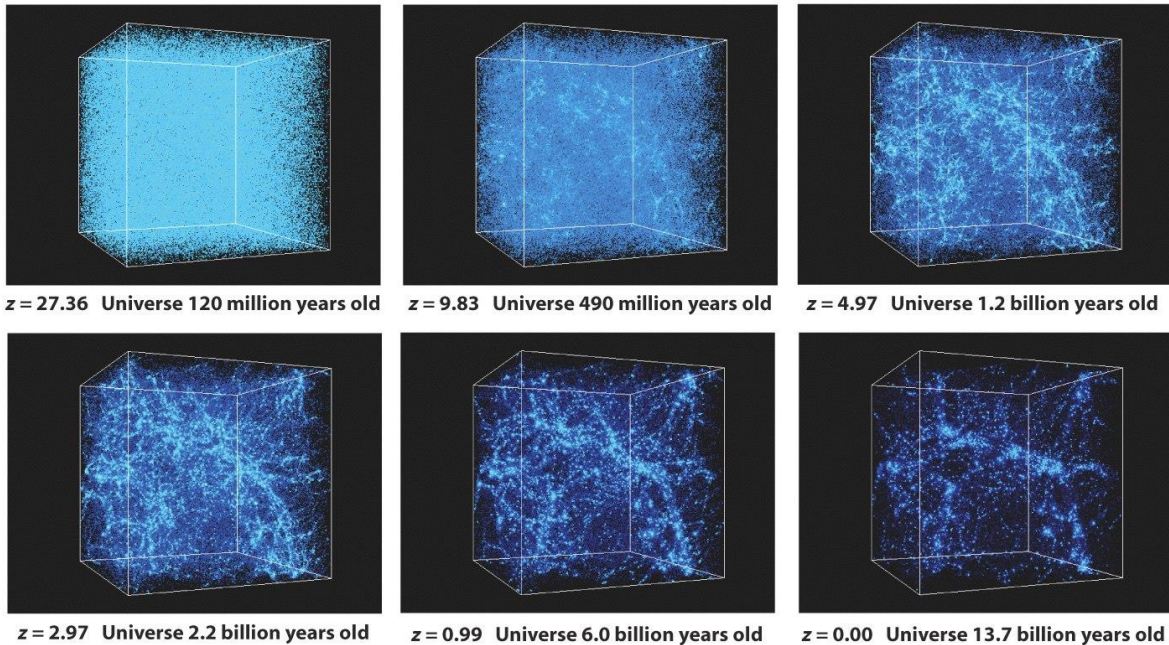
That is, the spectrum of the radiation filling the universe can be matched with a Planckian curve for some temperature and the peak intensity of the spectrum will be at a wavelength corresponding to a temperature given by Wien's Law.

Gamow predicted that such radiation should have a black body spectrum indicative of a temperature of about 3K.

Such radiation was detected by Penzias and Wilson at the Bell Labs in New Jersey in 1963, thereby confirming the Big Bang Theory. For this discovery, Penzias and Wilson received the Nobel Prize in Physics. Unfortunately, Gamow, like Hubble, never received such an award.



Astronomers use supercomputers to simulate how the large-scale structure of the universe arose from primordial density fluctuations



## Chronology of the Fireball Theory

Time	Temp(K)	Events
0	$>10^{32}$	<p>Primordial atom comes into existence and instantly begins to expand as a result of instabilities. The universe is dominated by gamma rays at first but these quickly are converted to hyperons.</p> <p>Temperature, pressure, and density decrease as the universe expands.</p>

$10^{-43}$ sec	$10^{32}$	Not possible to know what the universe was like before this. End of what is known as the Planck Time. Gravity separates from the grand unified force.
$10^{-35}$ sec	$10^{27}$	Inflationary expansion of the universe begins as a result of the energy released from the decoupling of the strong and electroweak forces. This is an ultra rapid expansion.
$10^{-32}$ sec		Inflationary expansion of the universe ends.
$10^{-12}$ sec	$10^{15}$	The electroweak force separates into the electromagnetic and weak forces.
$10^{-6}$ sec	$10^{10}$	Hyperons decay into protons, neutrons, and electrons, which are now stable particles, that is the quarks are confined.
14 sec		Protons collide and undergo thermonuclear fusion (TNF)
3 min	$10^6$	TNF ends since temperature is now too low. There has only been time for helium nuclei to form and no heavier nuclei. <b>Pristine chemical composition of the universe is set at 72% H and 28% He.</b>
$4 \times 10^5$ yrs	3000	Electrons captured by nuclei to form neutral atoms. Universe becomes transparent to electromagnetic radiation. It is not possible to see what the universe was like before this time.
$100 \times 10^6$ yrs		Turbulence and inhomogeneities in the gas filling the expanding universe lead to gravitational aggregations called protogalaxies and some very massive stars. The protogalaxies were probably dwarf galaxies.
$800 \times 10^6$ yrs		Protostars begin to form in the protogalaxies. Furthermore, the galaxies are colliding and merging to form larger galaxies.

As the protostars gravitationally contract and heat up, TNF begins to take place in the cores of the protostars. The reaction is:

$4\text{H} \longrightarrow \text{He}$ , and eventually  $\text{He} \longrightarrow \text{C}, \text{O}, \text{Ne}, \text{Si}, \text{ \& Mg}$ .

**Then Supernova eventually occur, ejecting material into the galaxies and thereby enriching the interstellar medium with heavy elements.**

Dust then forms in the interstellar media of the galaxies.

New generations of stars form, incorporating these heavy elements into their compositions.

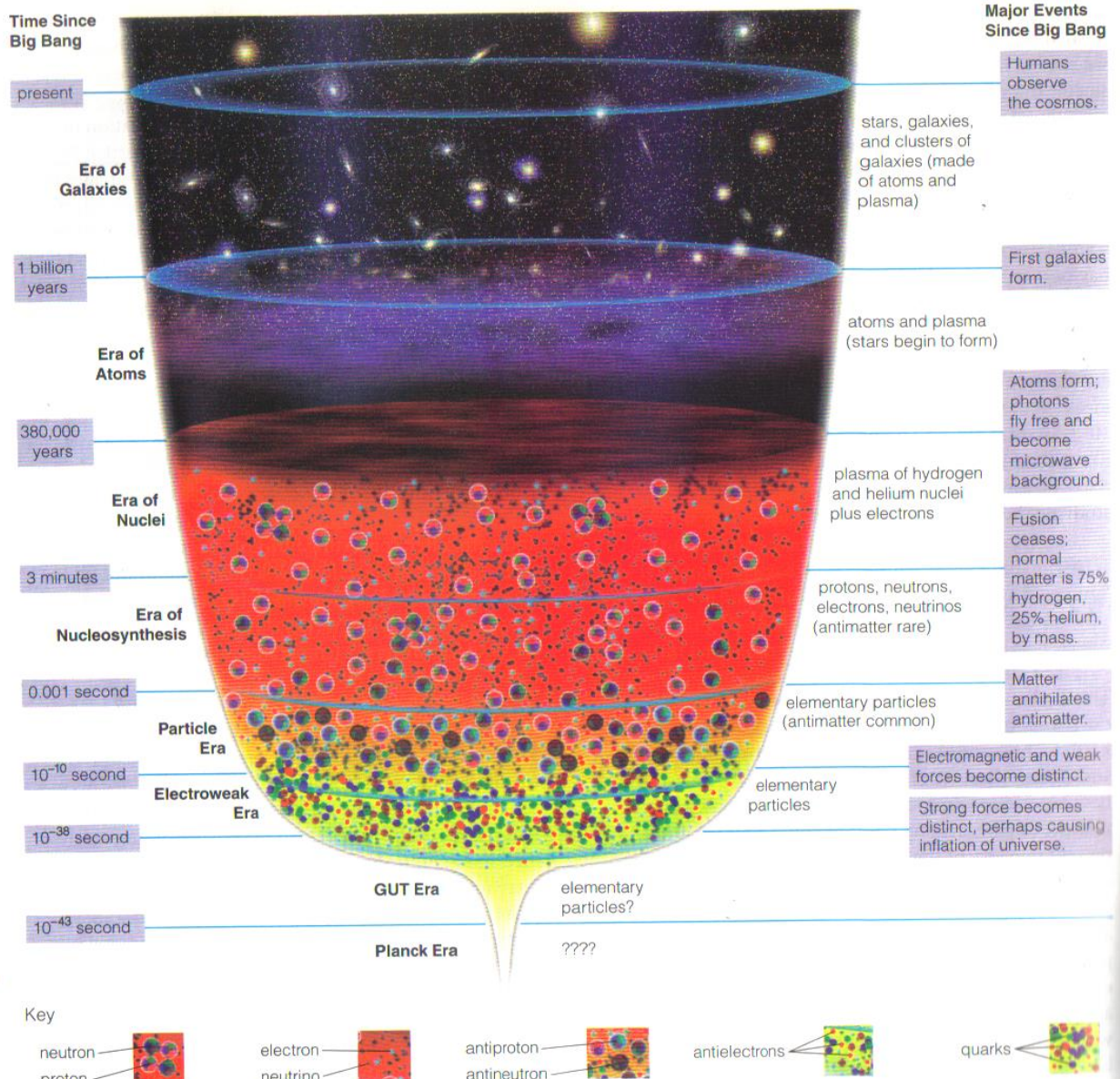
**These stars continue the process of changing the chemical composition of the interstellar media in the galaxies.**

$6.5 \times 10^9$  yrs      The Solar nebula separates from the interstellar medium in the Milky Way galaxy and undergoes gravitational contraction.

$8.4 \times 10^9$  yrs      Planets form around the central condensation of the Solar Nebula, the latter becoming the Sun. ( $4.6 \times 10^9$  years ago)

$10 \times 10^9$  yrs      Primitive life forms, in the form of single cells, develop on the 3rd planet from the Sun. (3.5 billion years ago)

$13.5 \times 10^9$  yrs      2.9K      Today. **Here we are!**



**Figure 1:** This diagram summarizes the eras of the universe. The names of the eras and their ending times are indicated on the left, and the state of matter during each era and the events marking the end of each era are indicated on the right.