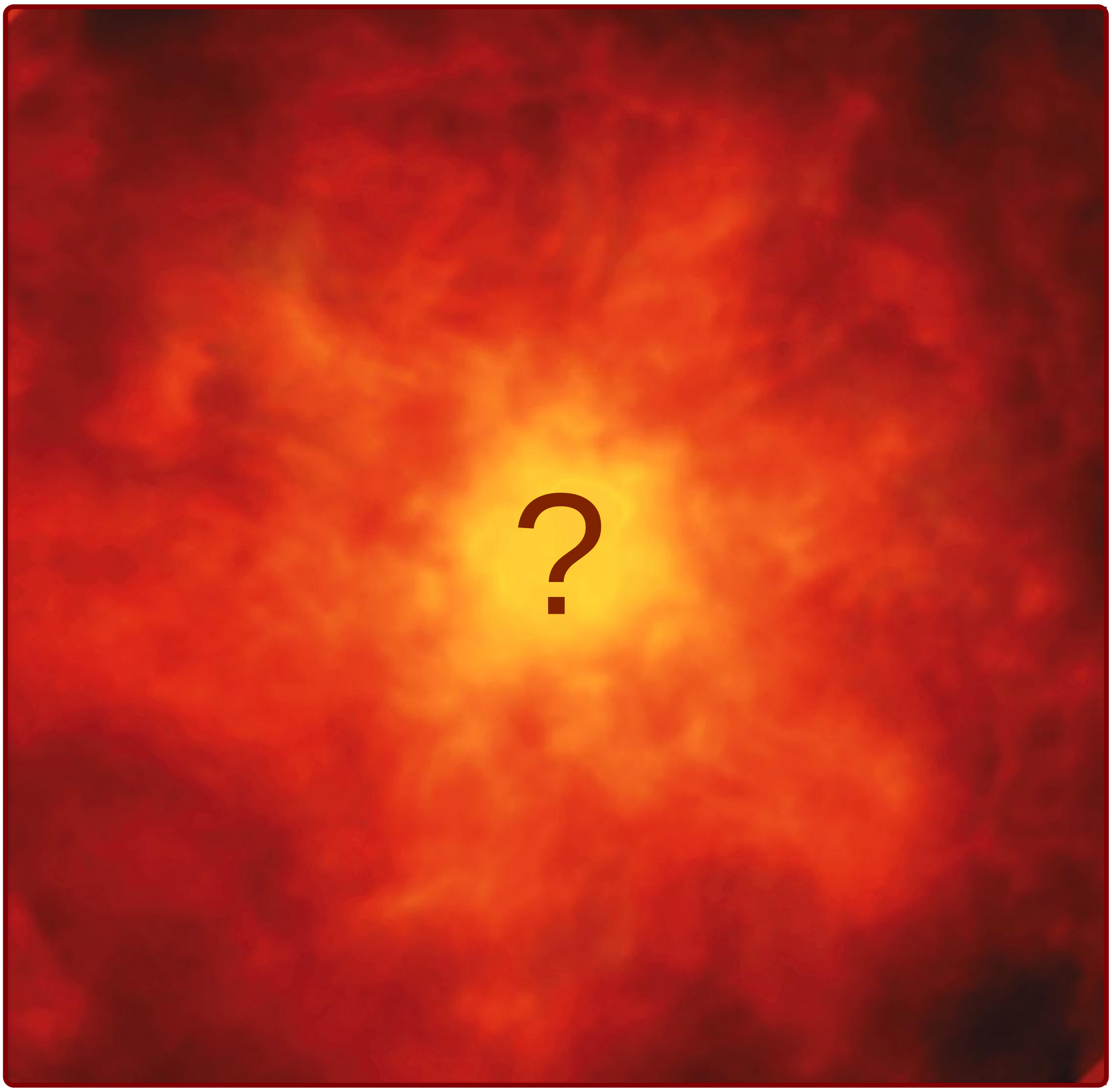
# The story of the Universe

## From the Big Bang to today's Universe

# Quantum gravity era

# $10^{-43}$ s

## Gravity separates as a force, the other forces remain as one (Grand Unification)




**t < $10^{-43}$ s : The Big Bang**

The universe is considered to have expanded from a single point with an infinitely high energy density (infinite temperature). Is there a meaning to the question what existed before the big bang?

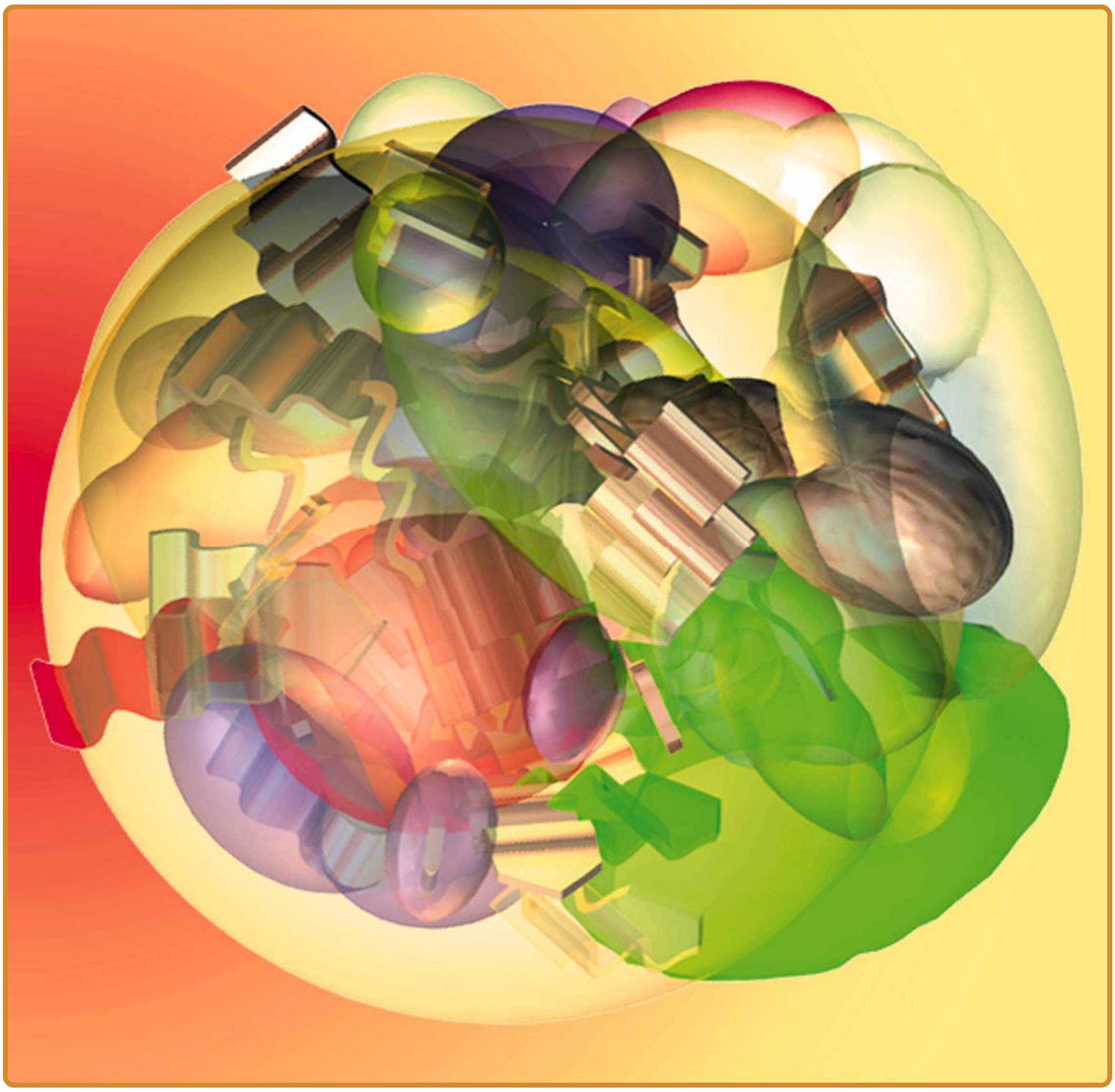
**t ≈ $10^{-43}$ s, $10^{32}$ K ($10^{19}$ GeV, $10^{-34}$ m) : Gravity "freezes" out**

All particle types (quarks, leptons, gauge bosons, and undiscovered particles e.g.Higgs, sparticles, gravitons) and their anti-particles are in a thermal equilibrium (being created and annihilated at equal rate). These coexist with photons (radiation). Through a phase transition gravity "froze" out and became distinct in its action from the weak, electromagnetic and strong forces. The other three forces could not be distinguished from one another in their action on quarks and leptons. This is the first instance of the breaking of symmetry amongst the forces.

# Grand unification era

# $10^{-35}$ s

## Inflation ceases, expansion continues
## Grand Unification breaks. Strong and electroweak forces become distinguishable



### t ≈ $10^{-35}$ s, $10^{27}$ K ($10^{16}$ GeV, $10^{-32}$ m) : Inflation

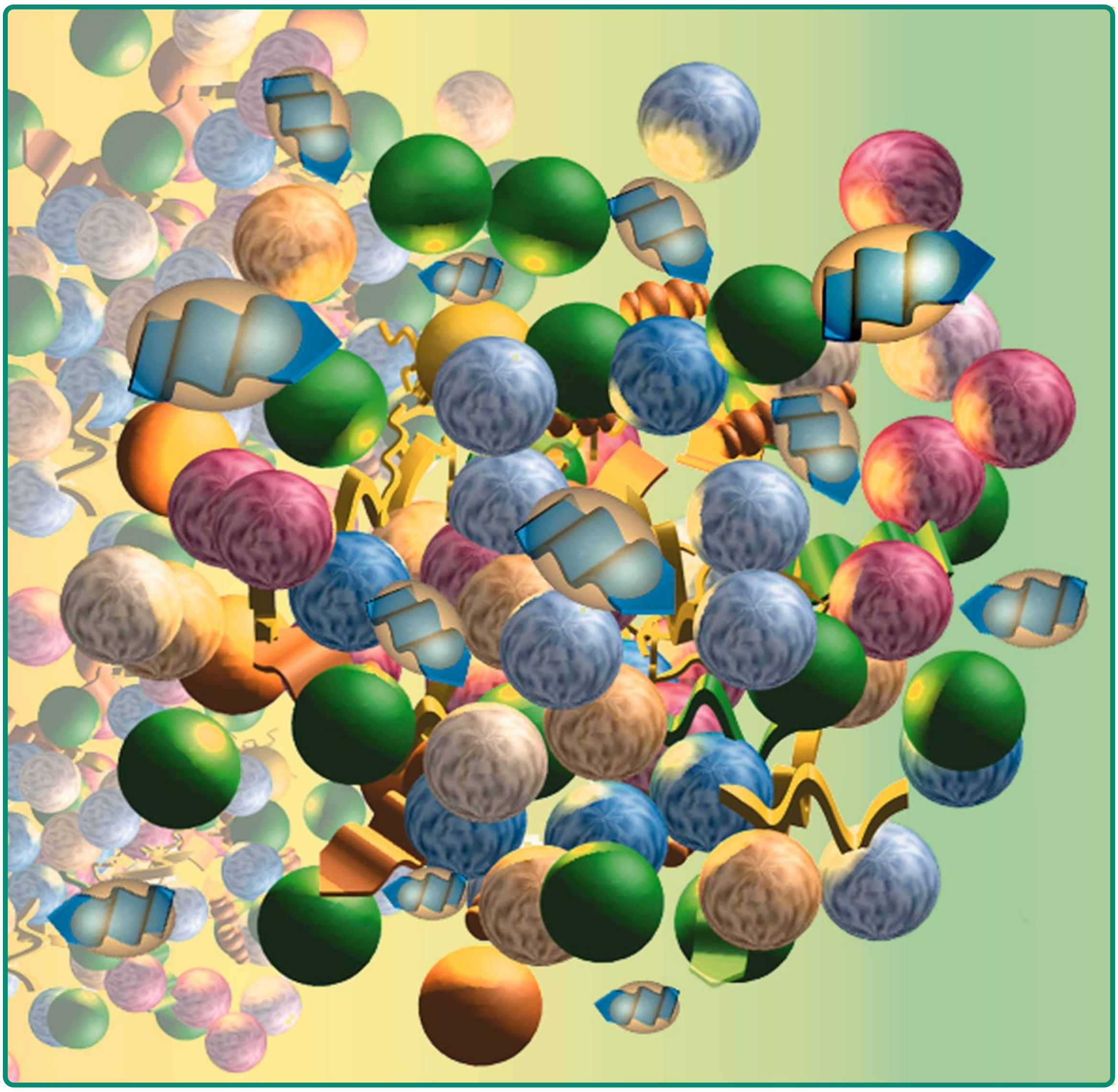
The rate of expansion increases exponentially for a short period. The universe doubled in size every $10^{-34}$ s. Inflation stopped at around $10^{-32}$ s. The universe increased in size by a factor of $10^{50}$. This is equivalent to an object the size of a proton swelling to $10^{19}$ light years across. The whole universe is estimated to have had a size of ~$10^{23}$ m at the end of the period of inflation. However the presently visible universe was only 3 m in size after inflation. This solves the problems of ‘horizon’ (how is it possible for two opposing parts of the present universe to be at the same temperature when they cannot have interacted with each other before recombination) and ‘flatness’ (density of matter is close to the critical density).

### t ≈ $10^{-32}$ s : Strong forces freezes out

Through another phase transition the strong force "freezes" out and a slight excess of matter over anti-matter develops. This excess, at a level of 1 part in a billion, is sufficient to give the presently observed predominance of matter over anti-matter. The temperature is too high for quarks to remain clumped to form neutrons or protons and so exist in the form of a quark gluon plasma. The LHC can study this by colliding together high energy nuclei.

# Electroweak era
# $10^{-10}$ s

## Electroweak force splits

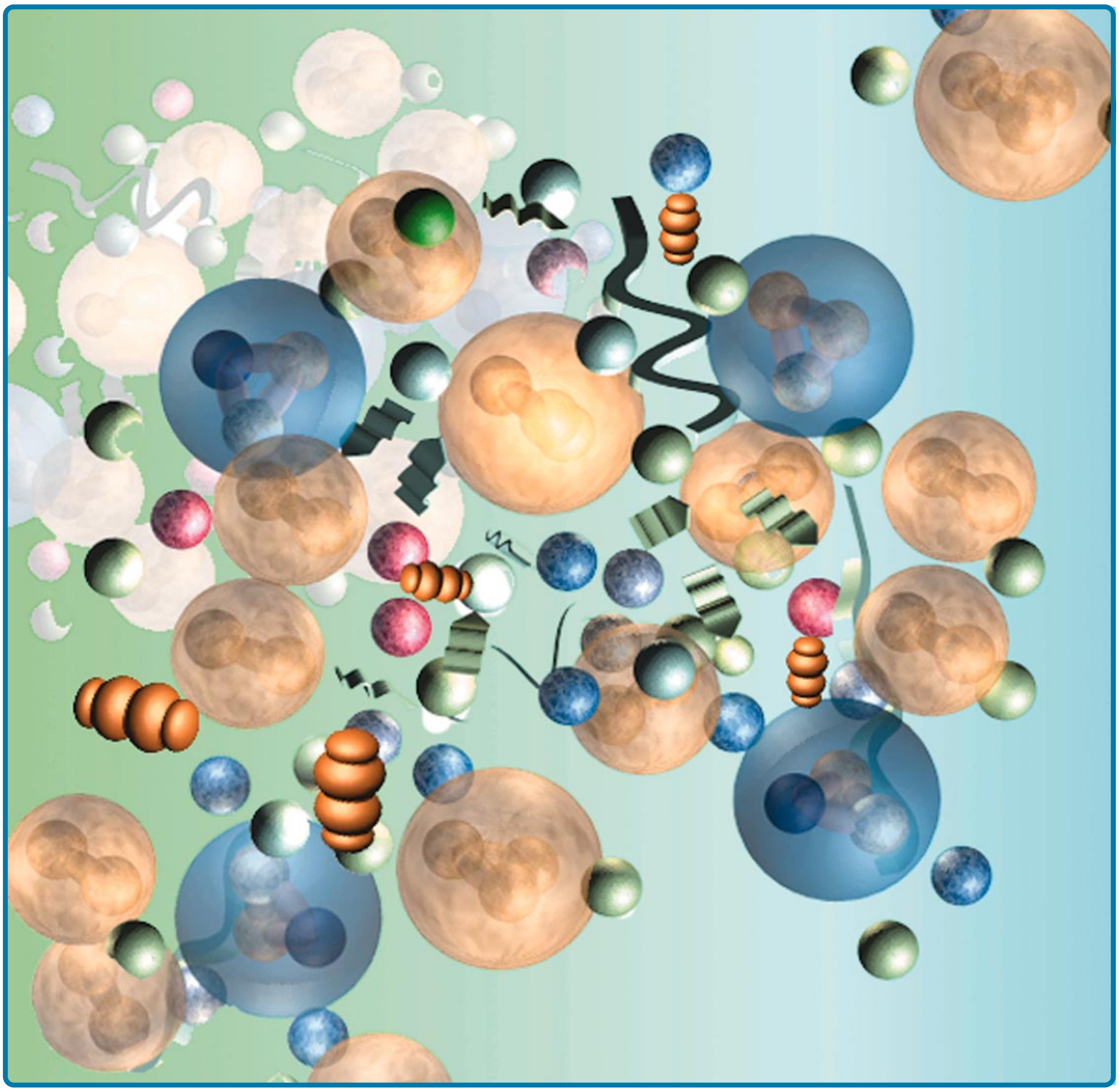


**$t \approx 10^{-10}$ s, $10^{15}$ K (100 GeV, $10^{-18}$ m) : Electromagnetic and Weak Forces separate**

The energy density corresponds to that at LEP. As the temperature fell the weak force "freezes" out and all four forces become distinct in their actions. The antiquarks annihilate with the quarks leaving a residual excess of matter. W and Z bosons decay. In general unstable massive particles disappear when the temperture falls to a value at which photons from the black-body radiation do not have sufficient energy to create a particle-antiparticle pair.

# Protons and neutrons form
# $10^{-4}$ s

## Quarks combine to make protons and neutrons



**$t \approx 10^{-4}$ s, $10^{13}$ K (1 GeV, $10^{-16}$ m) : Protons and Neutrons form**

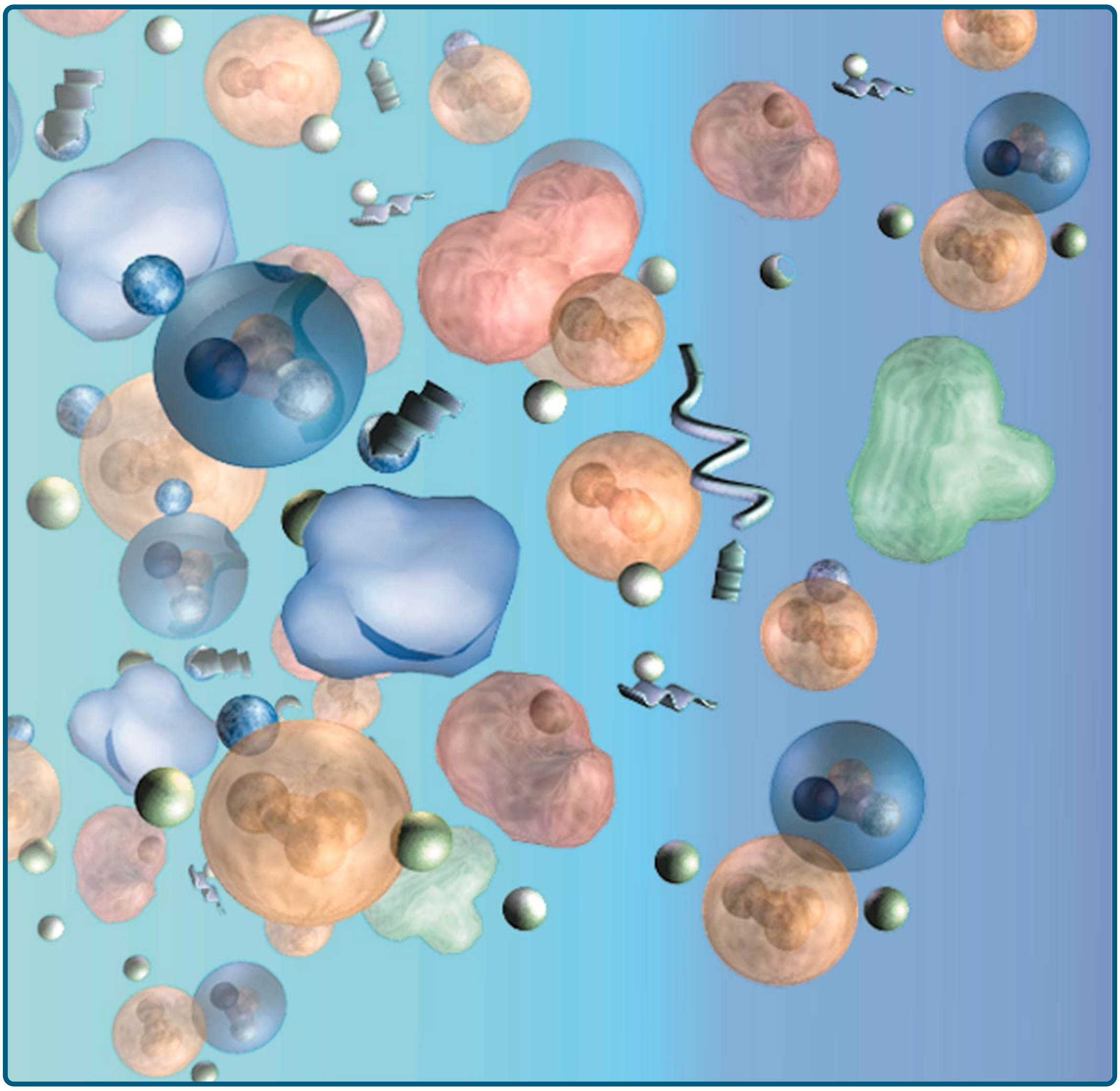
The universe has grown to the size of our solar system. As the temperature drops quark-antiquark annihilation stops and the remaining quarks combine to make protons and neutrons.

**$t = 1$ s, $10^{10}$ K (1 MeV, $10^{-15}$ m) : Neutrinos decouple**

The neutrinos become inactive (essentially do not participate further in interactions). The electrons and positrons annihilate and are not recreated. An excess of electrons is left. The neutron-proton ratio shifts from 50:50 to 25:75.

# Nuclei are formed
# 100 s

## Protons and neutrons combine to form helium nuclei

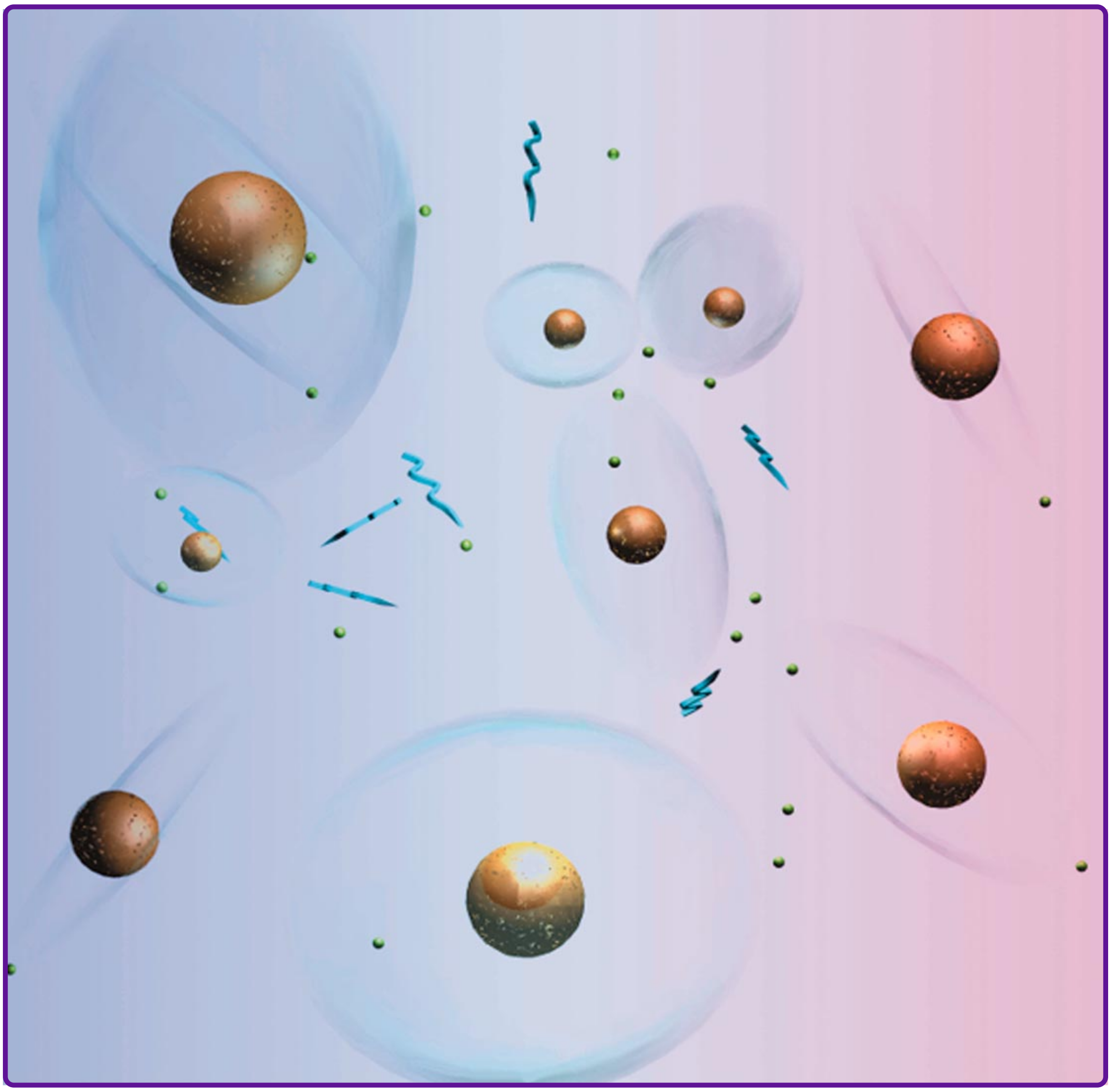


**t = 3 minutes, $10^9$ K (0.1 MeV, $10^{-12}$ m) : Nuclei are formed**

The temperature is low enough to allow nuclei to be formed. Conditions are similar to those that exist in stars today or in thermonuclear bombs. Heavier nuclei such as deuterium, helium and lithium soak up the neutrons that are present. Any remaining neutrons decay with a time constant of ~ 1000 seconds. The neutron-proton ratio is now 13:87. The bulk constitution of the universe is now in place consisting essentially of protons (75%) and helium nuclei. The temperature is still too high to form any atoms and electrons form a gas of free particles.

# Atoms and light era
# 300000 years

## The Universe becomes transparent and fills with light



**t = 300 000 years, 6000 K (0.5 eV, $10^{-10}$ m) : Atoms are created**

Electrons begin to stick to nuclei. Atoms of hydrogen, helium and lithium are created. Radiation is no longer energetic enough to break atoms. The universe becomes transparent. Matter density dominates. Astronomy can study the evolution of the Universe back to this time.

# Galaxy formation
# 1000 million years

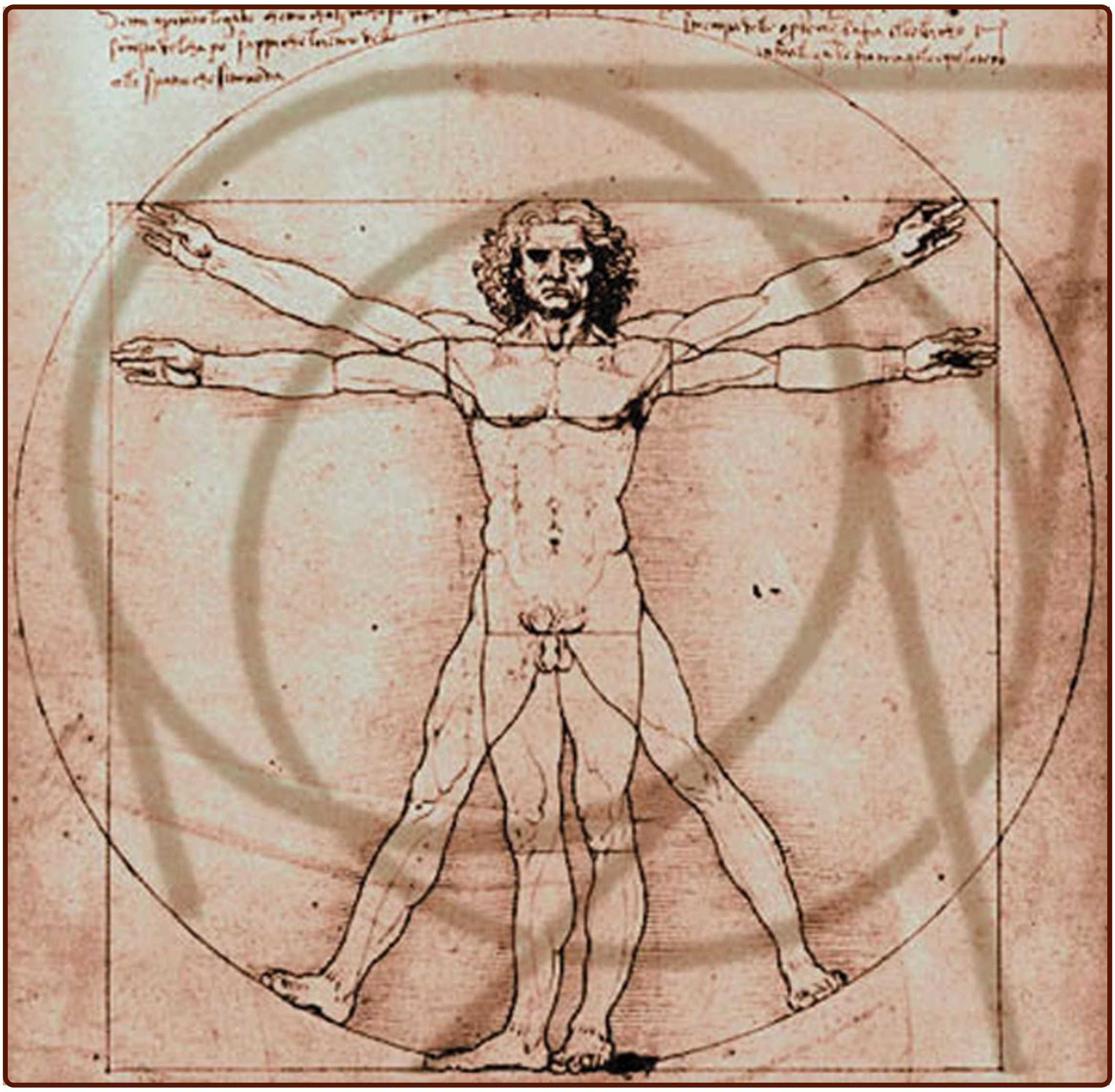
## Galaxies begin to form

### t = $10^9$ years, 18 K : Galaxy Formation

Local mass density fluctuations act as seeds for stellar and galaxy formation. The exact mechanism is still not understood. Nucleosynthesis, synthesis of heavier nuclei such as carbon up to iron, starts occurring in the thermonuclear reactors that are stars. Even heavier elements are synthesized and dispersed in the brief moment during which stellar collapse and supernovae explosions occur.

# Today
# 15000 million years

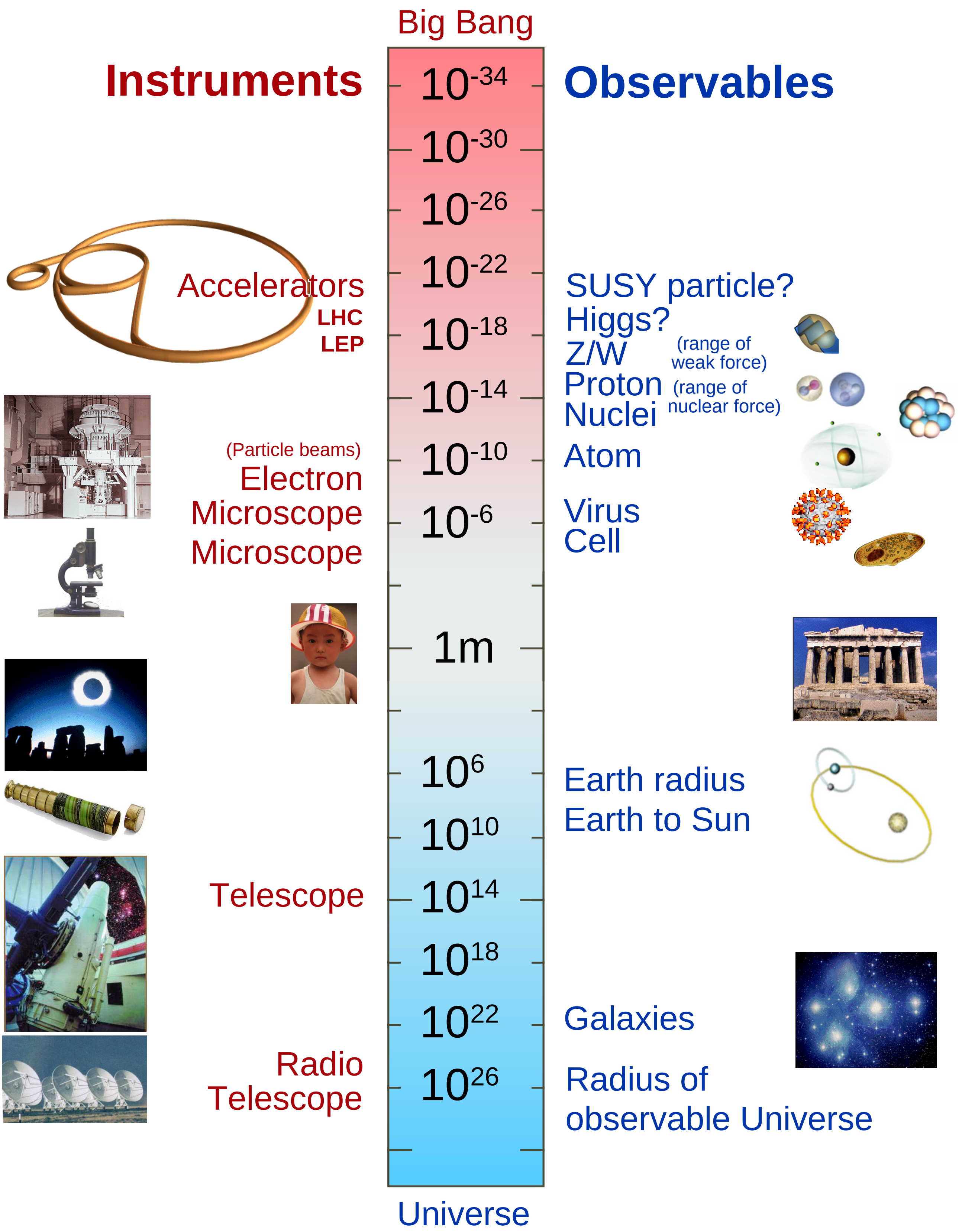
## Man begins to wonder where it all came from



**t = 15 x $10^9$ years, 3 K : Humans**

The present day. Chemical processes have linked atoms to form molecules. From the dust of stars and through coded messages (DNA) humans emerge to observe the universe around them.

# The size of things



# Particle Physics

Aim to answer the two following questions

- What are the elementary constituents of matter?

- What are the fundamental forces that control their behavior at the most basic level?