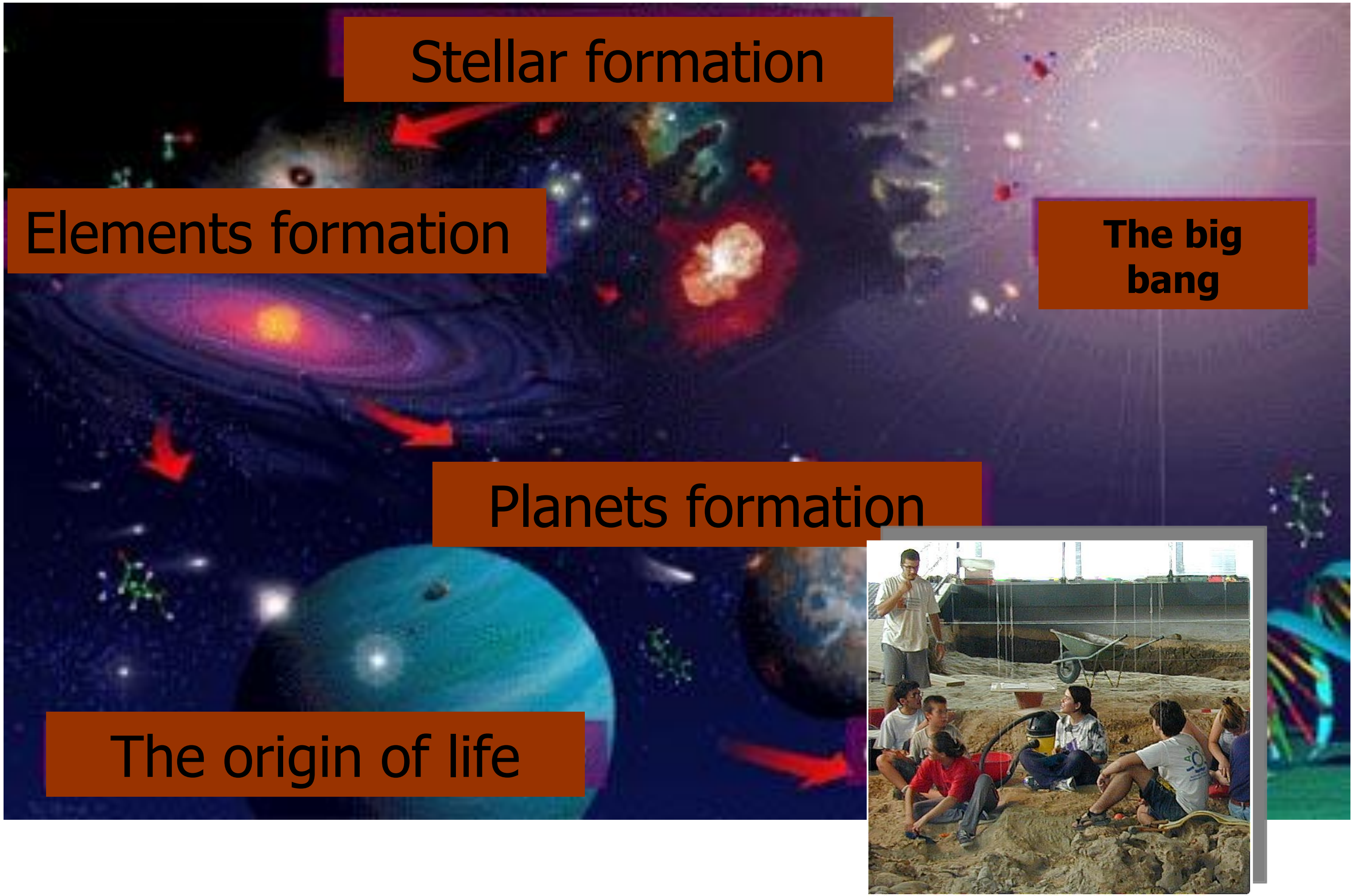
A time travel of 14 billion years



The big bang

- It occurred right here, nearly 14 billion years ago.

- All matter and energy of the Universe were concentrated in a very small space region.

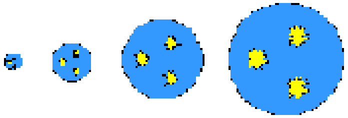
- At the beginning temperature was extremely high. Nuclei and atom constituents formed a primordial soup.

- Since that moment the Universe expanded and cooled down. Ordered structures were formed: nuclei, atoms, galaxies, planets…and human beings.

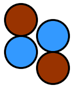
The big bang pillars

There are three strong evidences of the big bang theory:

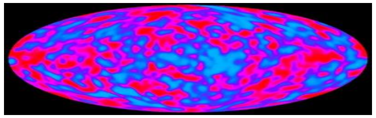
- Universe expansion



- Primordial nucleosynthesis



- Cosmic microwave background radiation



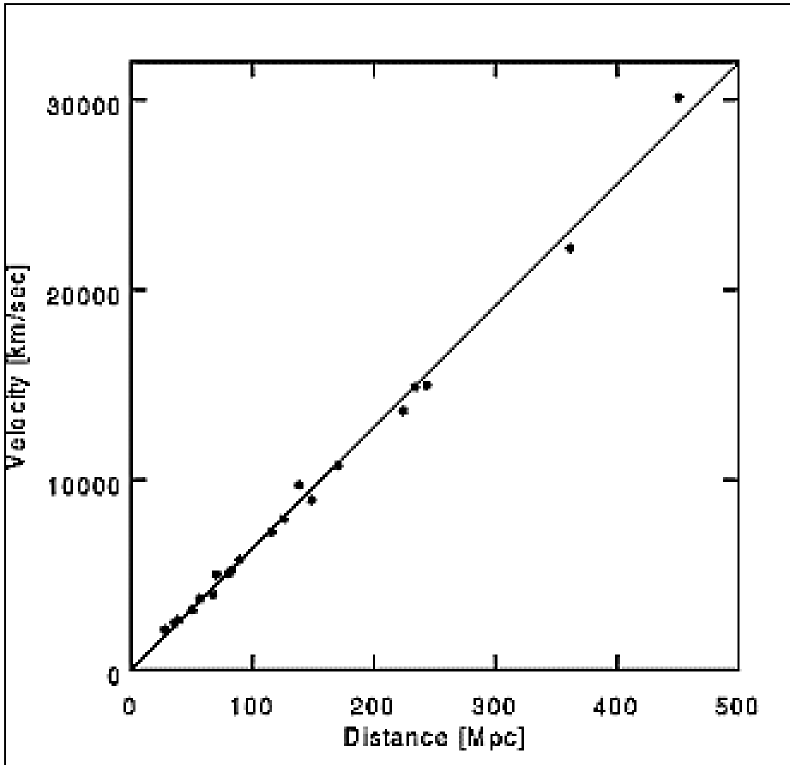
Universe expansion

• We see that galaxies receede from us, and that each of them is at a distance **D** proportional to its velocity **V** (Hubble's law):

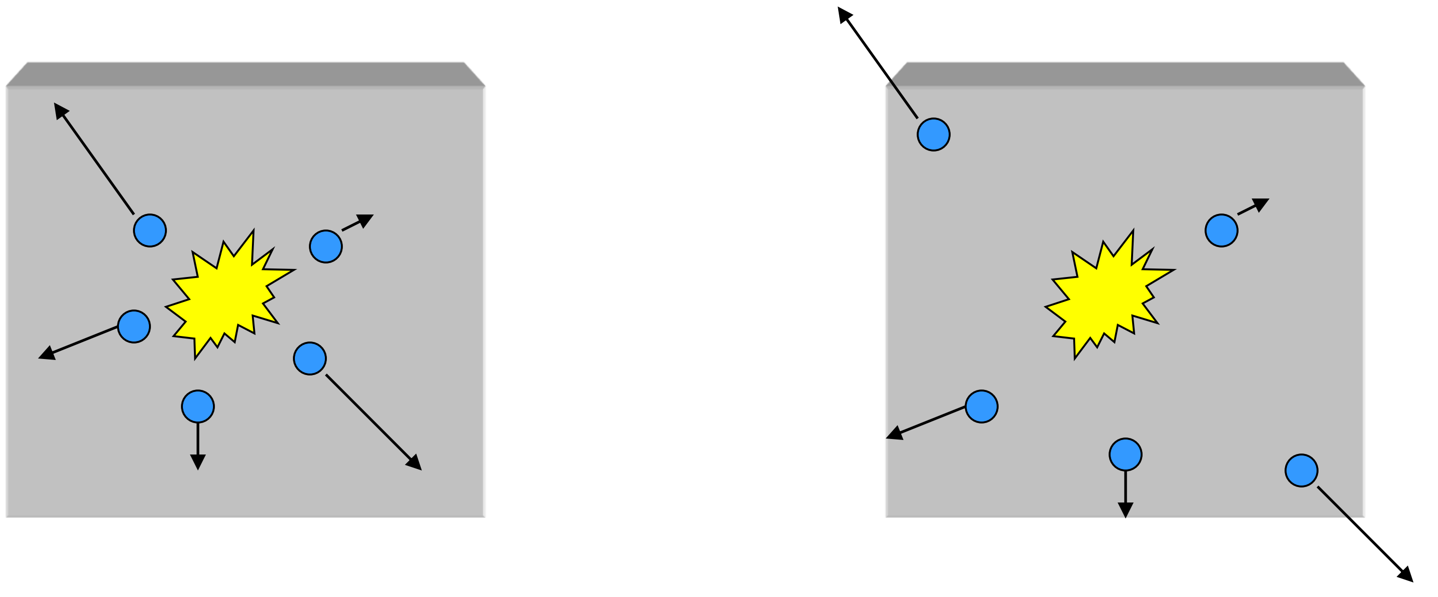
$$\mathbf{D= V\ t}$$

• If this law was valid also in the past, distances tend to zero when t=0, that means the universe reduced to a point.

• The present value, t= 14 Billion years, tells us how much time passed after the big bang occurred.



Universe explosion



• As in every explosion, objects with greater velocity travel longer distances.

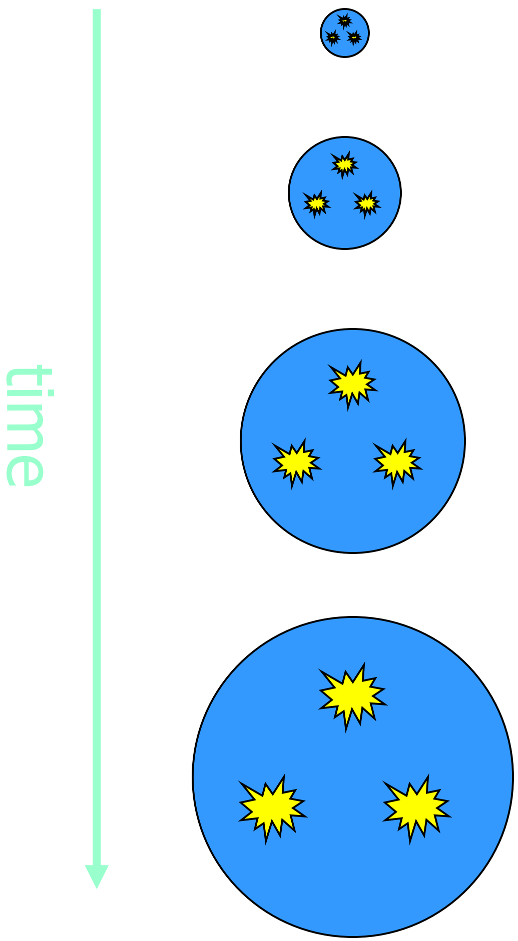
• But where did the explosion happen?

Why right here?

• Every point in the Universe is considered to be equivalent.

• When the Big Bang occurred the whole space was concentrated in a single point.

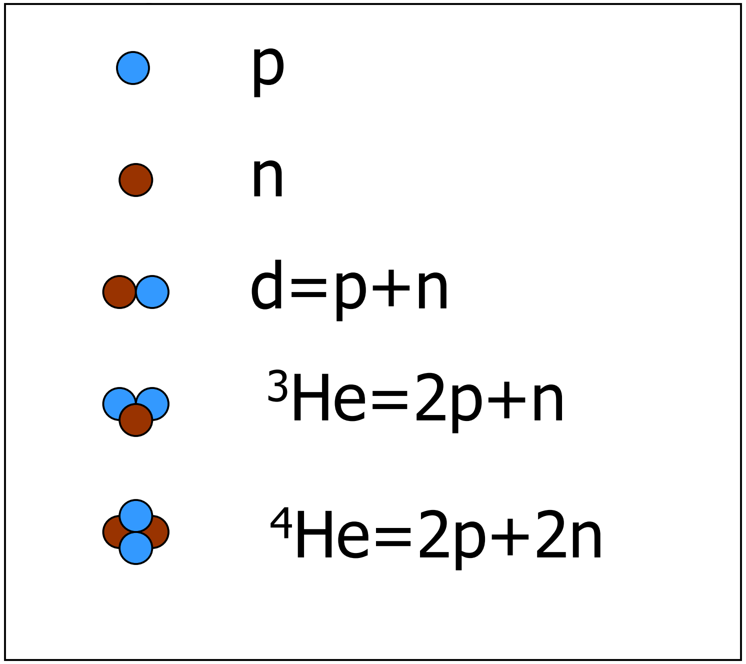
• Hence the Big Bang happened right here.

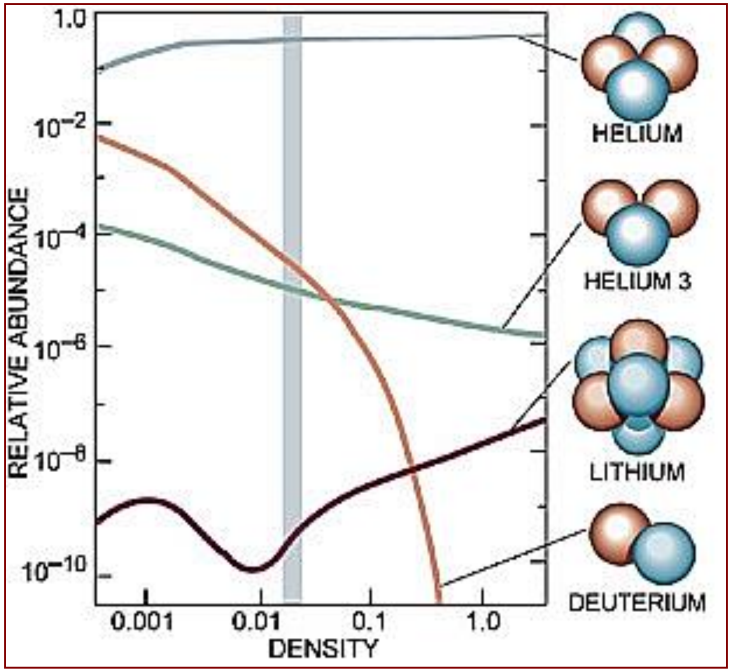


Three minutes of cooking

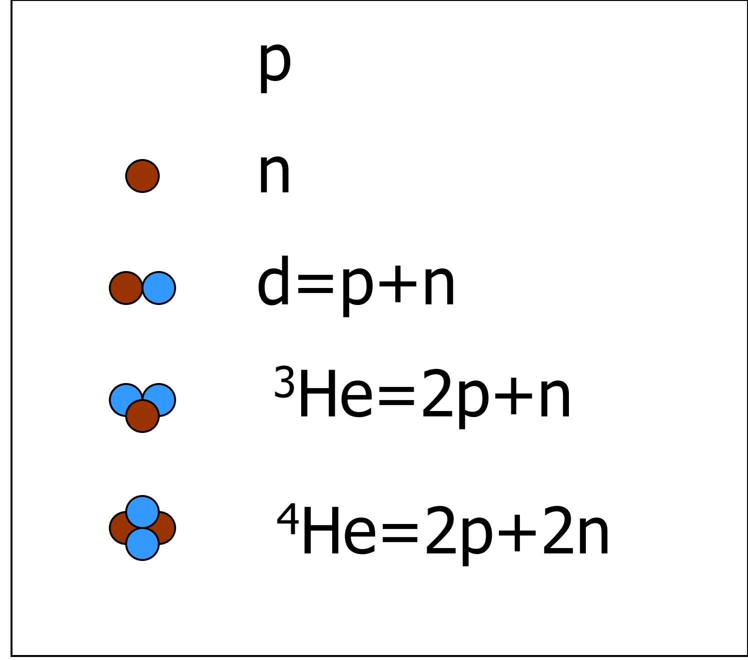
• In the first three minutes, when temperature was nearly 1 Billion degrees, protons and neutrons bound together giving origin to the nuclei of the lightest elements: deuterium and Helium (**He**).

• Abundance measurements of these elements, created in the primordial nucleosynthesis, are one of the confirmations of the big bang theory.





Just an appetizer..



• Be careful: during the big bang only the lightest nuclei were formed.

• Electrons could not firmly bind to nuclei because the temperature was too high.

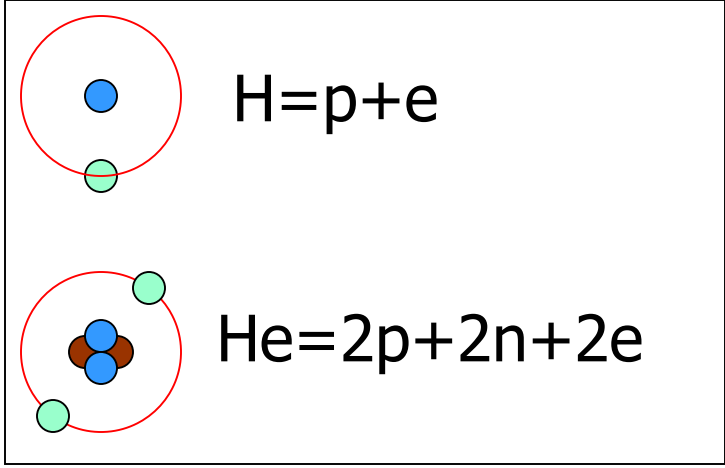
• The matter that we see is made of atoms, molecules and contains elements that are much heavier than helium. There must be other kitchens….

The first atoms

• 300.000 years after the big bang the temperature was nearly 1000 degrees and electrons can bind themselves to the nuclei giving origin to Hydrogen and Helium atoms.

• The Universe became transparent to light and heat.

• The background radiation permeated the whole universe giving us a trace of the big bang.



George Gamow

The cosmic background radiation

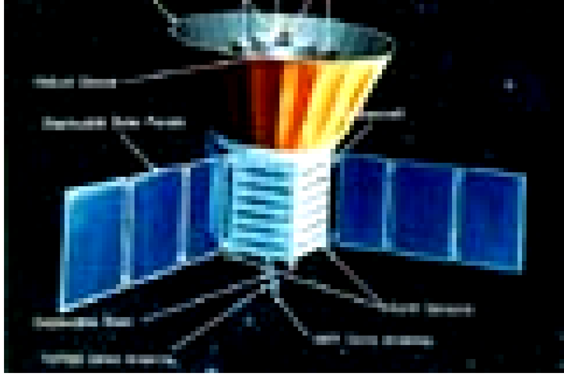
• The entire universe cooles like an expanding gas.

• The background radiation, that comes from interaction with matter at a temperature of nearly 1000 degrees, now has now a temperature of -270 degrees.

• This radiation was seen for the first time in 1964.

Penzias e Wilson

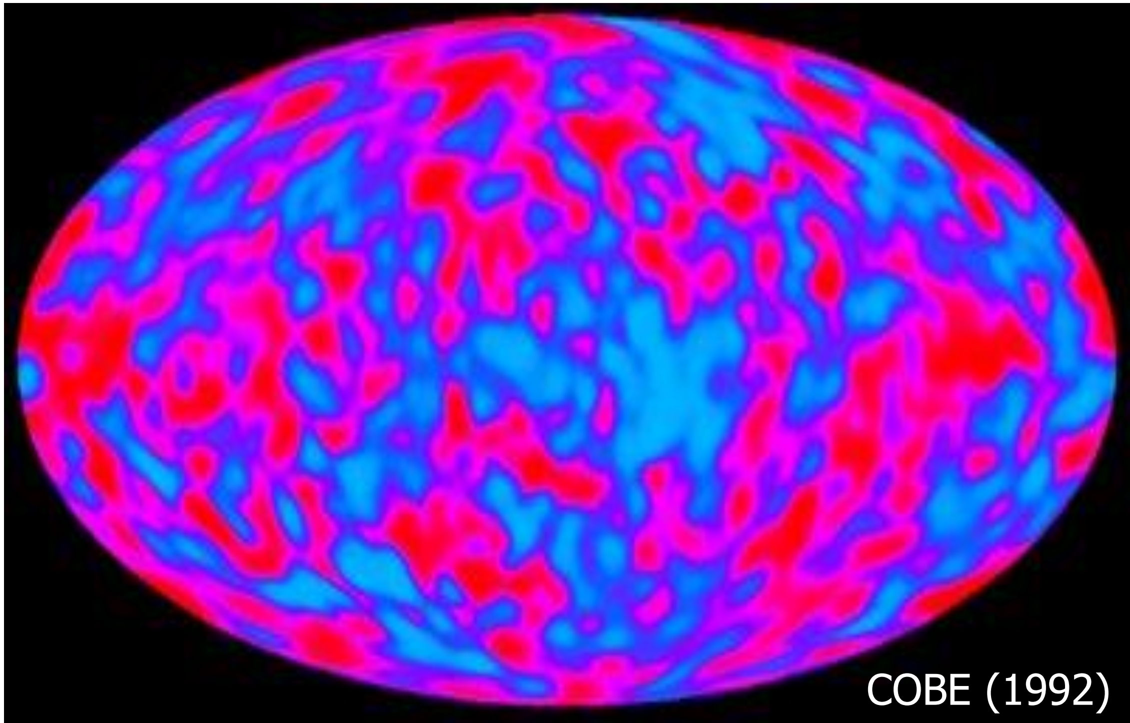
The primordial universe structure



- If we observe the cosmic background radiation we can observe the baby universe.

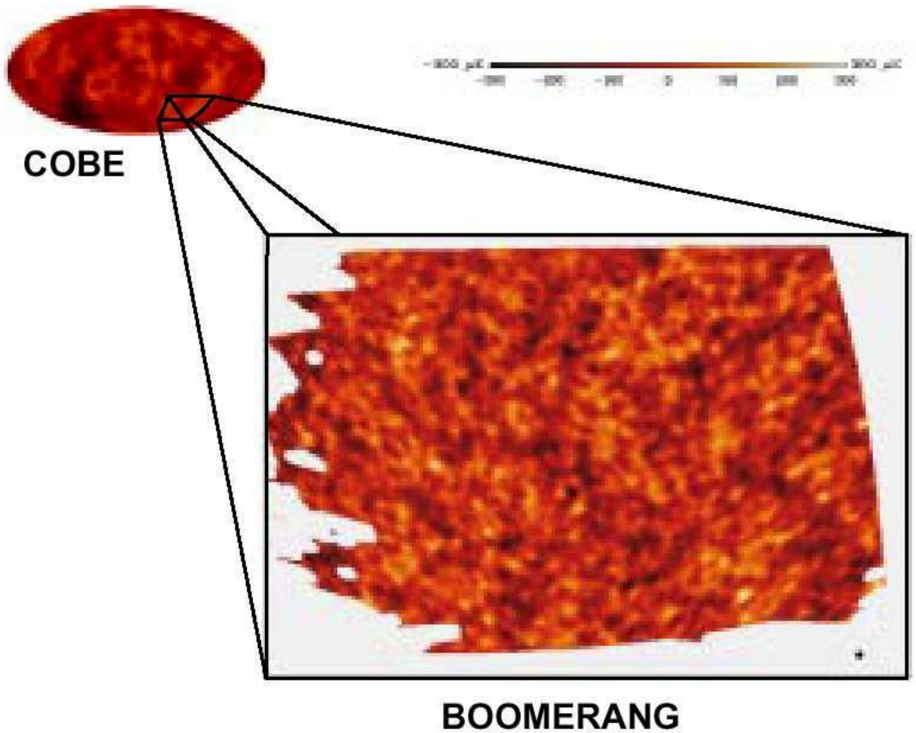
- If we look towards different directions in the sky, we see that the radiation has very small non uniformities.

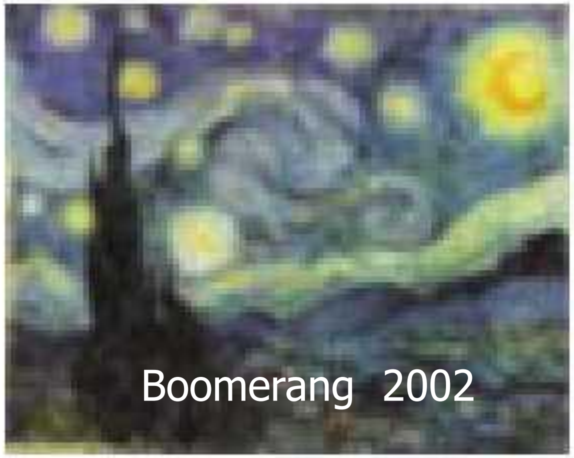
- These are the first signs of the formation of structures in the universe.

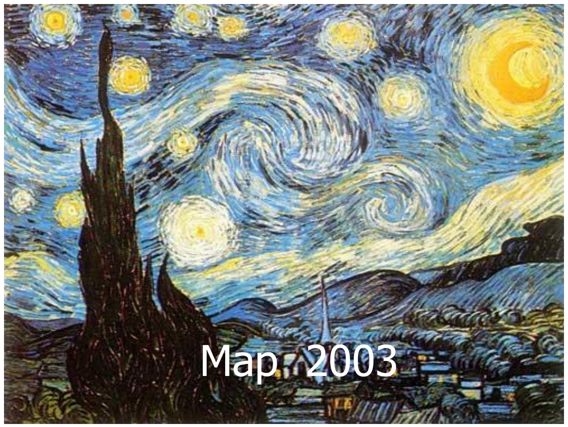


COBE (1992)

Twenty years of progress







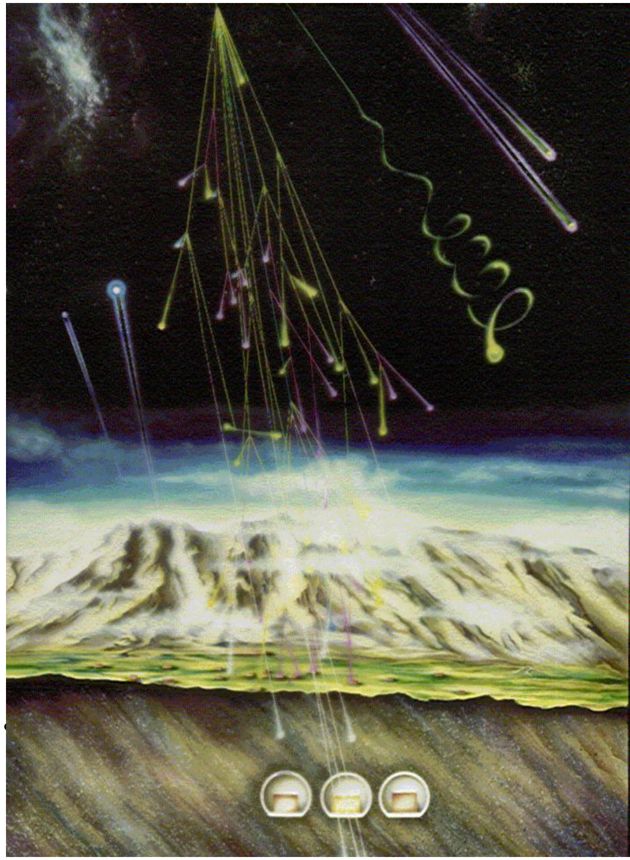
The resolution in the images of the cosmic microwave radiation is strongly increasing.

Other background radiations

• The cosmic microwave radiation takes a picture of the universe at an age of 300.000 years.

• There are other radiations in the cosmos, big bang's remainders that we are not (yet) able to detect:

-The background neutrinos that provide a picture of the universe a second after its birth.



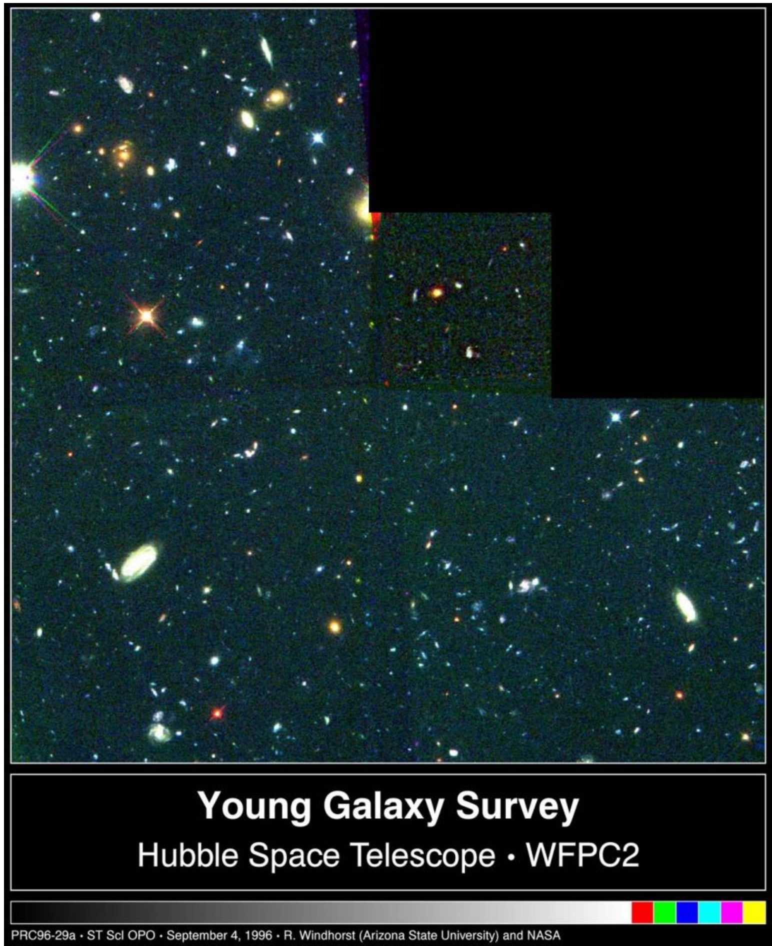
- The gravitational waves that provide a picture of the universe at 10^{-43} seconds after the Big Bang.

Galaxies origin

- Nearly after 1Billion years, matter started to gather in big stuctures under the effect of gravitational interaction.

- Galaxies clusters are considered to have initially formed.

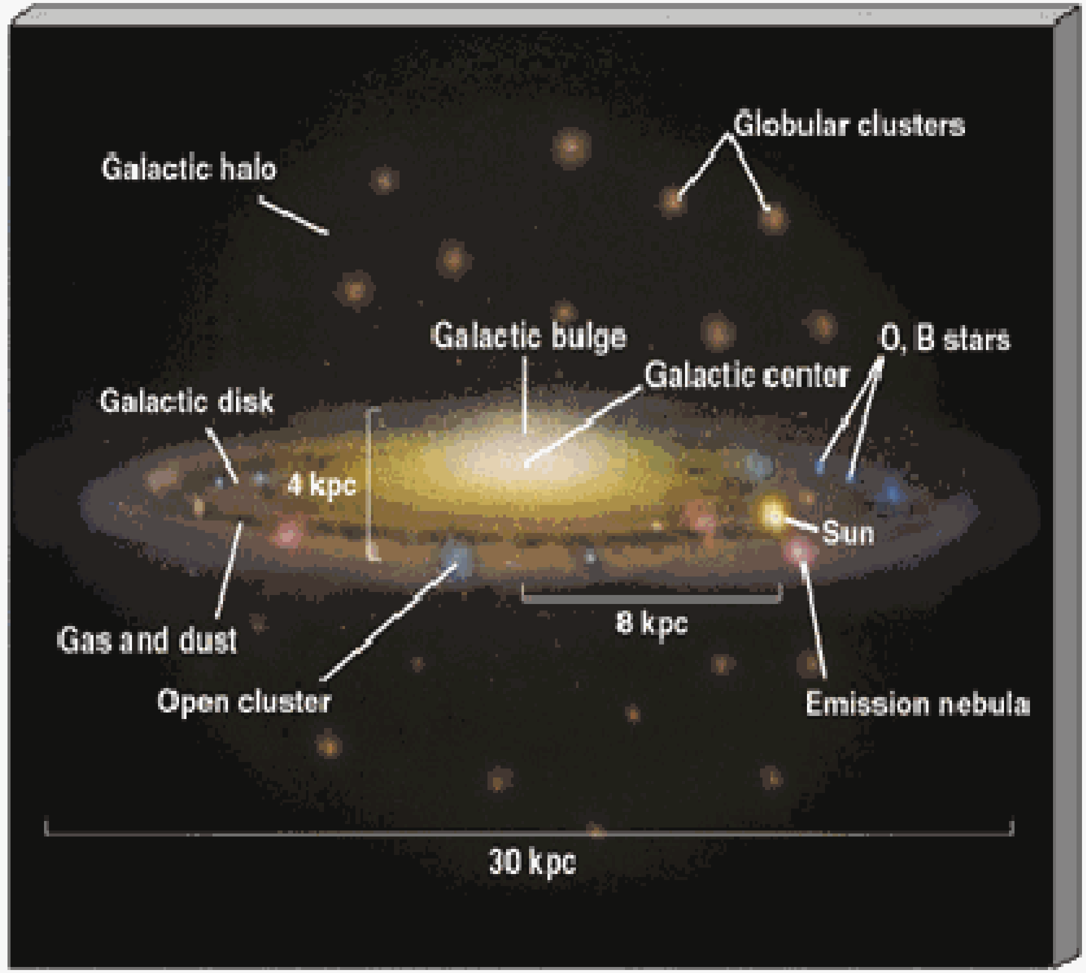
- Each of them would have been separated into galaxies.



The Galaxy

• In the Virgo cluster there's the Galaxy with capital G, that's the one in which we live.

• Light needs 100.000 years to go from an end of the Galaxy to another.



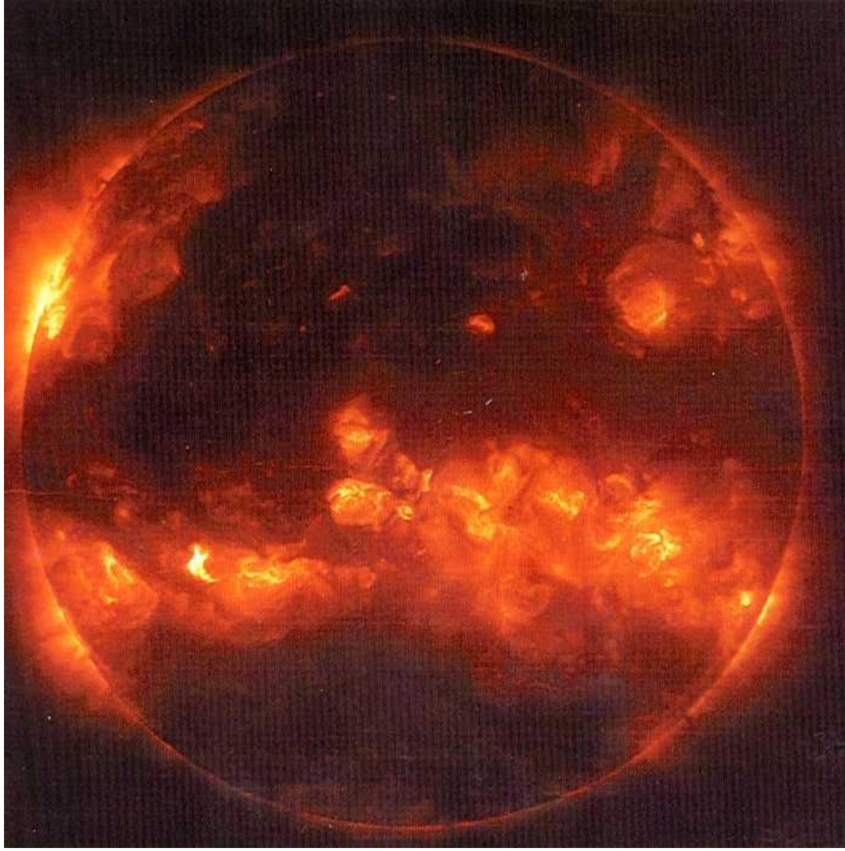
• The Galaxy contains nearly 100 billions stars: one of them, in the outskirts, is our Sun.

Stars birth

• The biggest galaxies inhabitants are giants clouds of gas, each of them containing the material that will form milions of stars.

• Due to gravity these clouds break into fragments around some gravitational accumulation centres, giving rise to the stars.

Stars energy source



•**Kelvin ≈1800**: Gravitational energy can sustain sun's luminosity for nearly 30.000.000 years.

• It's too short to justify the evolution of biological and geological processes.

• Understanding the stars energy source was the scientific problem of the XIX century.

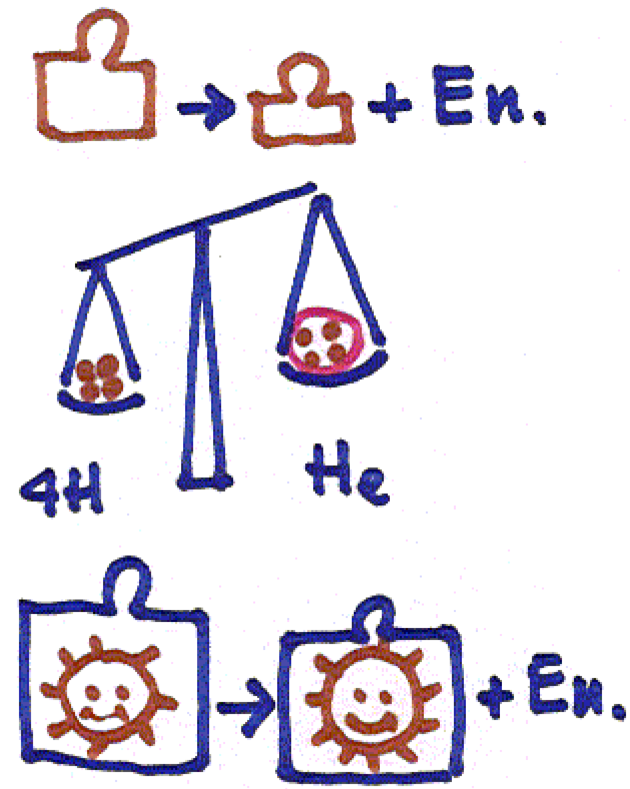
Which kind of energy source can sustain the sun for billion years?

Birth of nuclear astrophysics

Einstein (1905): $E=mc^2$

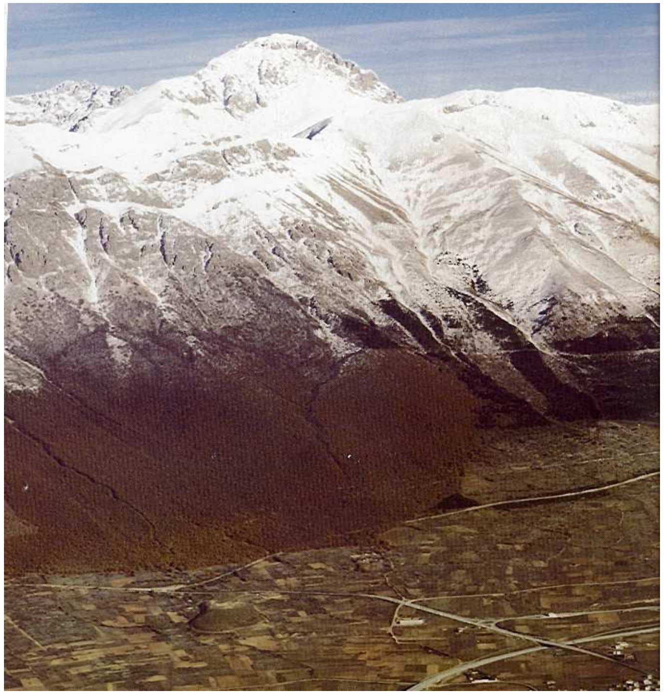
Aston (1918): m(He)<4 m(H)

Eddington (1920): If a star initially consists of hydrogen, that gradually is transformed into heavier elements, then we understand the energy source of stars…and…*



*...If this is true, then we are closer to the dream of controlling this latent power, to the benefit of the human race or for its suicide (1920)

The imprints of nuclear reactions in the sun



• Gallex experiment in the underground laboratories of Gran Sasso detected neutrinos coming from the nuclear fusions inside the sun.

•Gallex has demonstrated that the energy of the sun is produced by nuclear reactions taking place inside it.

Gallium Experiment at Gran Sasso

GALLEX

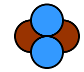
INTERNATIONAL
SOLAR NEUTRINO RESEARCH
COLLABORATION

The stars:
The nuclear kitchen

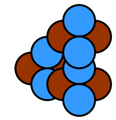
• Gravity leads a star to shrink towards its centre.

• The star balances gravity with the pressure originated from matter heated by nuclear reactions.

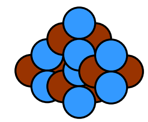
• These reactions tansform Hydrogen into Helium and, if the star is heavy enough, into Carbon and then Oxygen. In this way all chemical elements up to Iron are produced.



$^{4}He = 2p + 2n$



$^{12}C = {}^{4}He + {}^{4}He + {}^{4}He$



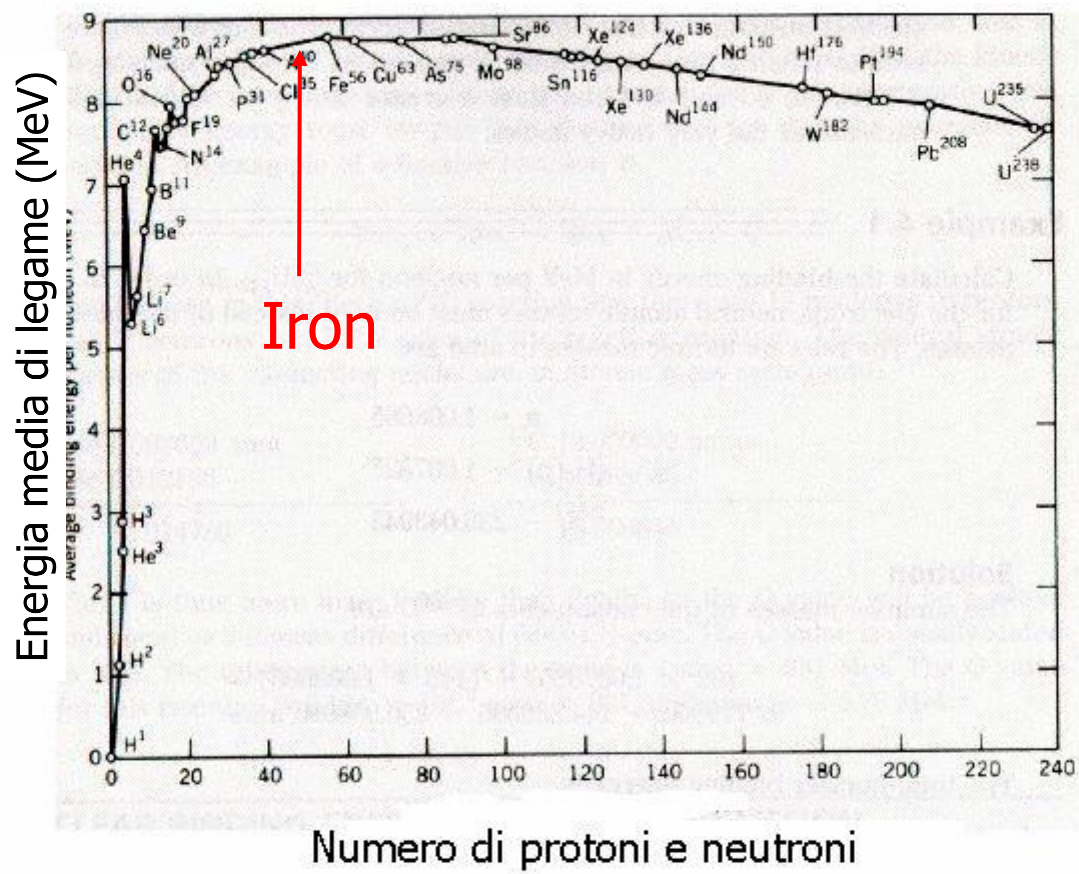
$^{16}O = {}^{12}C + {}^{4}He$

...

The first dish is ready

- Stars release energy by fusion of atomic nuclei.

- This process ends with the creation of Iron, that’s the most strongly bound nucleus.

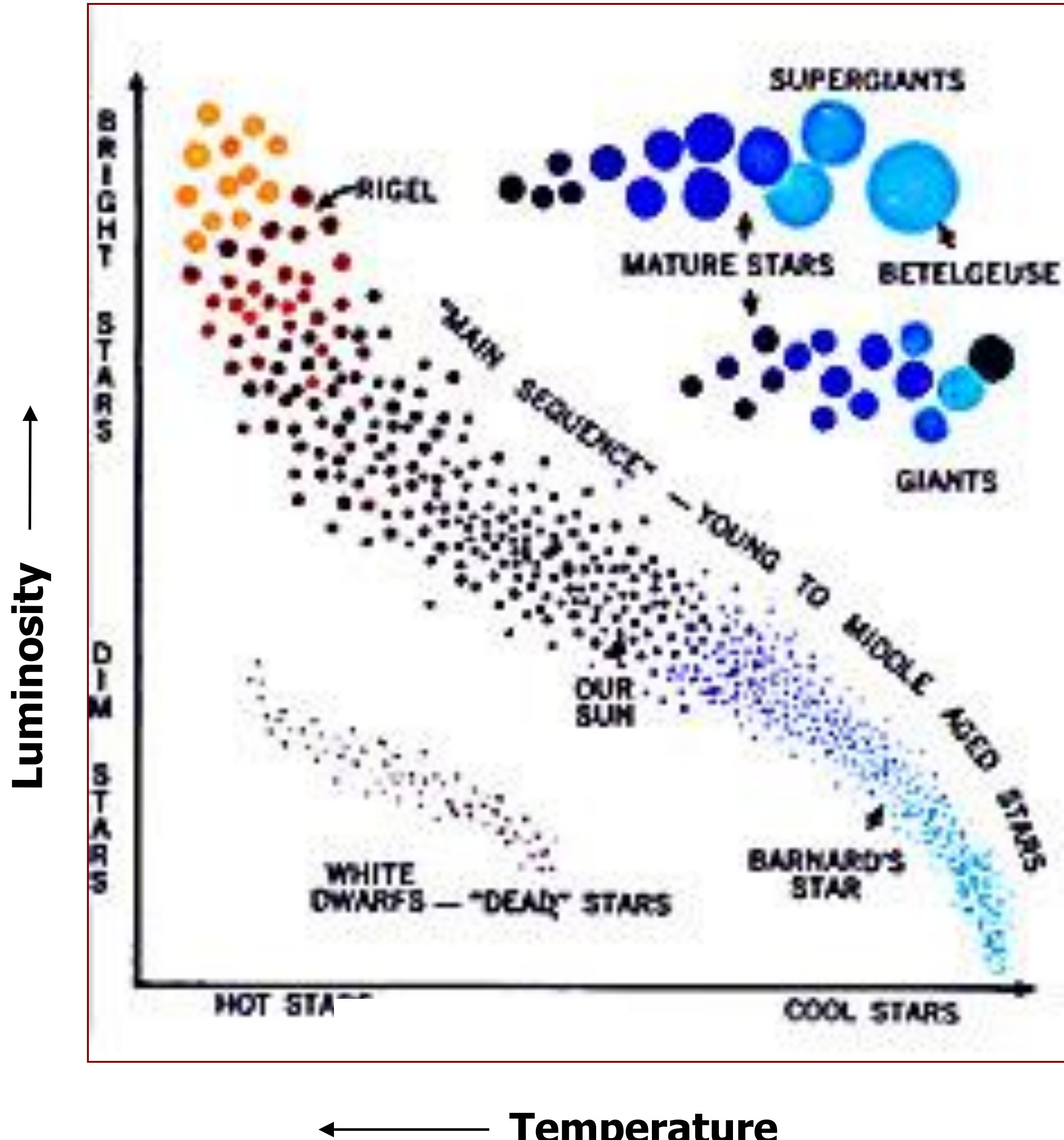


- The main meal is ready: nuclei up to Iron are produced by nuclear fusion. But where the heavier nuclei are formed?

Stars life

• Each star has its own history and its future.

• The life-time of a star and its destiny depends on its mass.



The end of stars

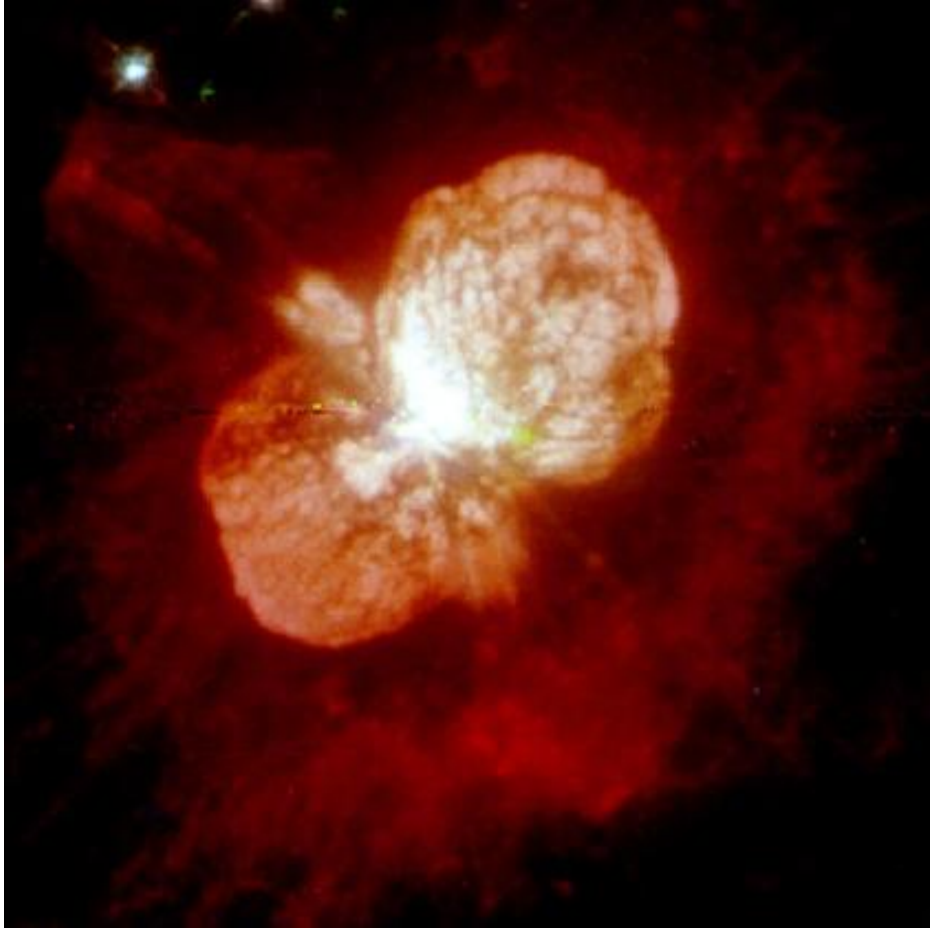
- Heavier stars have a violent end.

- When the nuclear fuel finishes gravitation shrinks the star which begins to implode.

- The outer parts bounce on the stellar core giving rise to an enormous explosion.

- This process gives life to a supernova, the most luminous objects in the galaxies.

Supernovae



- The nuclear kitchen completes with the formation of supernovae in which elements heavier than Iron are produced.

- The produced material is injected into the circumstant gas.

- The shockwave explosion triggers the formation of new stars.

- These stars contain the elements formed in the primordial Big Bang and in stars previously exploded.

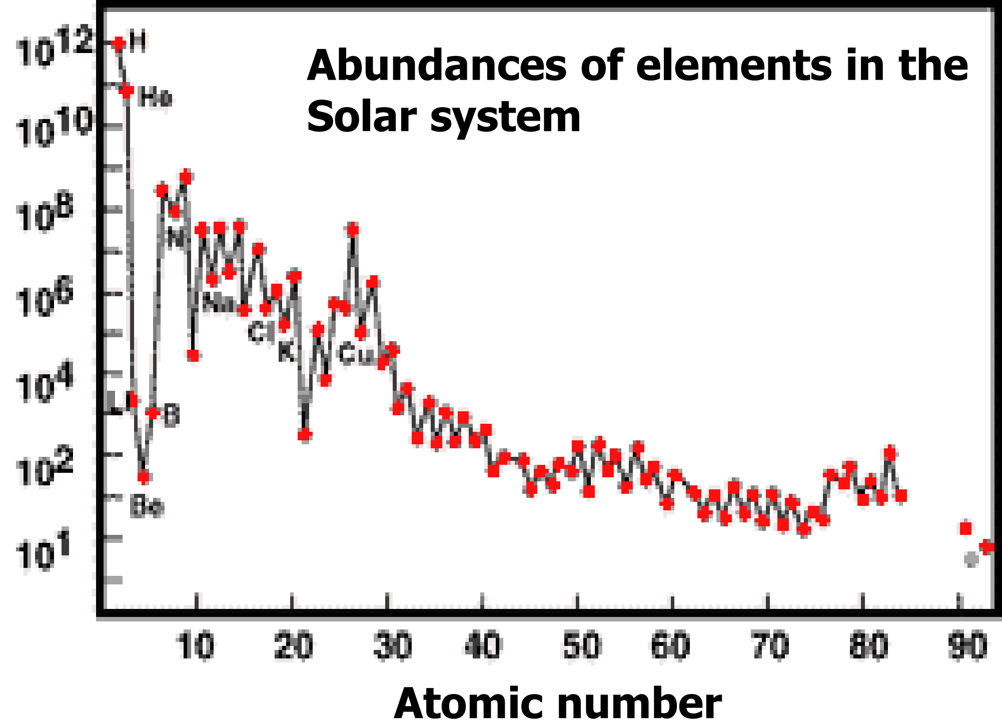
The Allende meteorite

• We believe that the solar system birth was preceded by the explosion of a near supernova, creating a shockwave which compressed the circumstant gas.

• The Allende meteorite contains inclusions coming from the radioactive decay of nuclei produced in a supernova with half life of milion years.

• This means that the explosion happened nearly 10 milion years before the formation of the solar system.

The solar system ingredients

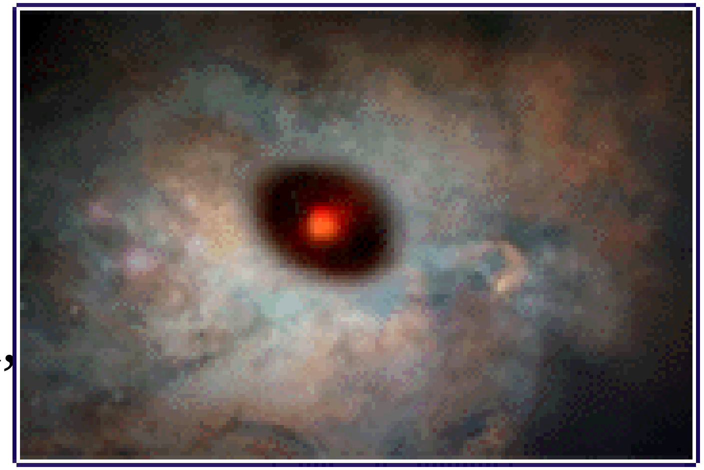


- At this point we have all the ingredients necessary to form the sun and the planets.

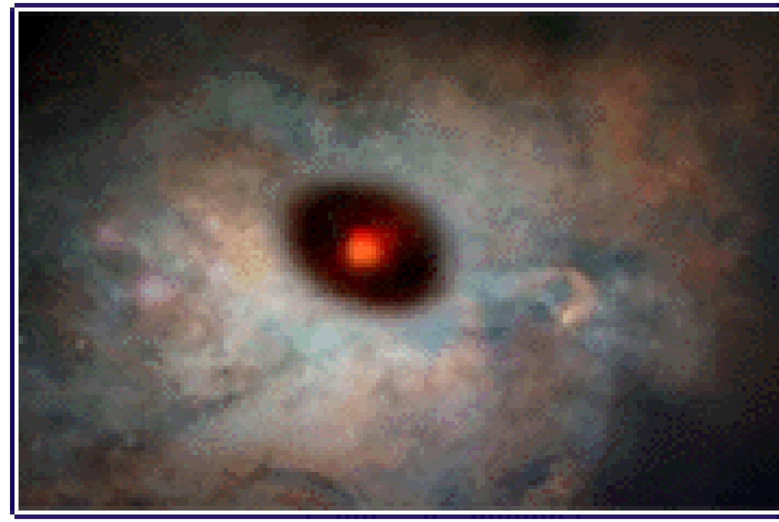
- 74 % of Hydrogen

- 24 % of Helium

- 2% of heavier elements, mainly Carbon, Nitrogen, Oxygen and Iron.

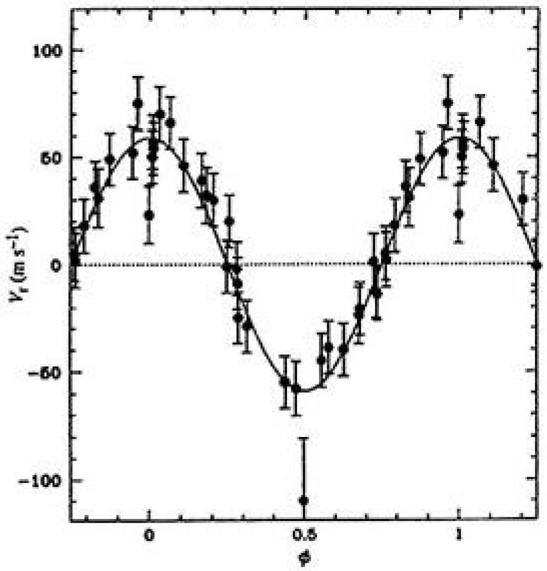


Birth of the solar system



- The cloud shrinks to form a star in its centre.
- The rotation of the cloud produces a disk.
- In the disk rocky planetesimals form near the star.
- Ice made planetisimals in the outer parts.
- Matter accumulates near these planetisimals while the solar wind sweeps the circumstant space.

Extrasolar planets



• Planets around other suns were discovered studying the perturbations of stellar orbits.

• Up to now we can observe planets big as Jupiter or Saturn.

• More sensitive instruments will allow us to observe planets of Earth size.

• The next step will be the research of life traces.

The travel steps