

The origin and evolution of the universe

Julieta Fierro, Susana Deustua, Beatriz García

International Astronomical Union,

Universidad Nacional Autónoma de México, México

Space Telescope Science Institute, USA

ITeDA and Universidad Tecnológica Nacional, Argentina



The universe is everything:

Space

Matter

Energy

The time



It is in continuous evolution.

Each object in the universe changes, as well as our ideas about them.

It's been less than one century since we have enough observations to quantify the universe and try to do the science on that subject.



The last few decades we have information about the universe and we can study it. Before there were only speculations.



Our intuitive appreciation of the universe is not the standard model of the Big Bang.

Historically, cultures attempt to explain the universe. For example, Babylonians thought that the Earth is flat, with certain elevations, and supported by elephants which, in turn, are placed on a tortoise surrounded by one snake. They were explaining the earthquakes with rearrangements of elephants.



Testing of the model:

The shadow of an elephant and a turtle, never looks like the shadow of the Earth on the Moon.

Only one sphere always has a circular shadow. Demonstration a Moon Eclipse



Advances in science

- Reflecting
- Thinking about questions we have about the nature
- Experimenting
- Thinking about the results
- Socializing the new knowledge through articles
- When other thinkers comment favorably our ideas, the knowledge is consolidated. Also when we learn from our mistakes.



Standard model of the Big Bang

■ This is the most simple one and explains the observations:

- Expansion
- Cosmic background radiation
- Chemical abundances
- Isotropy

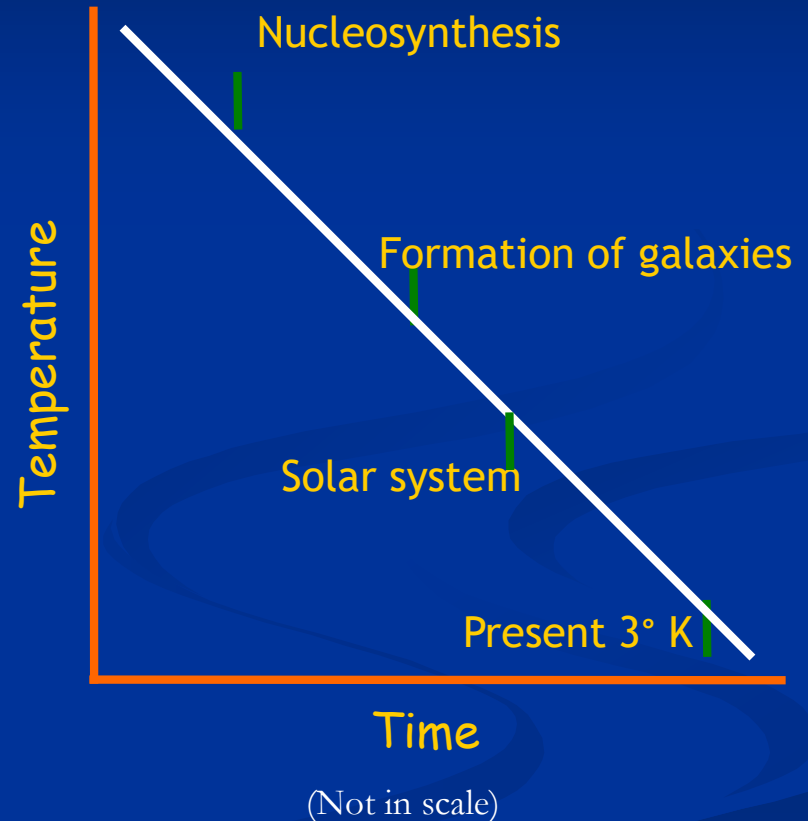
■ There are other models



□ Science does not claim to have the truth – it is unattainable.

Expansion of the Universe

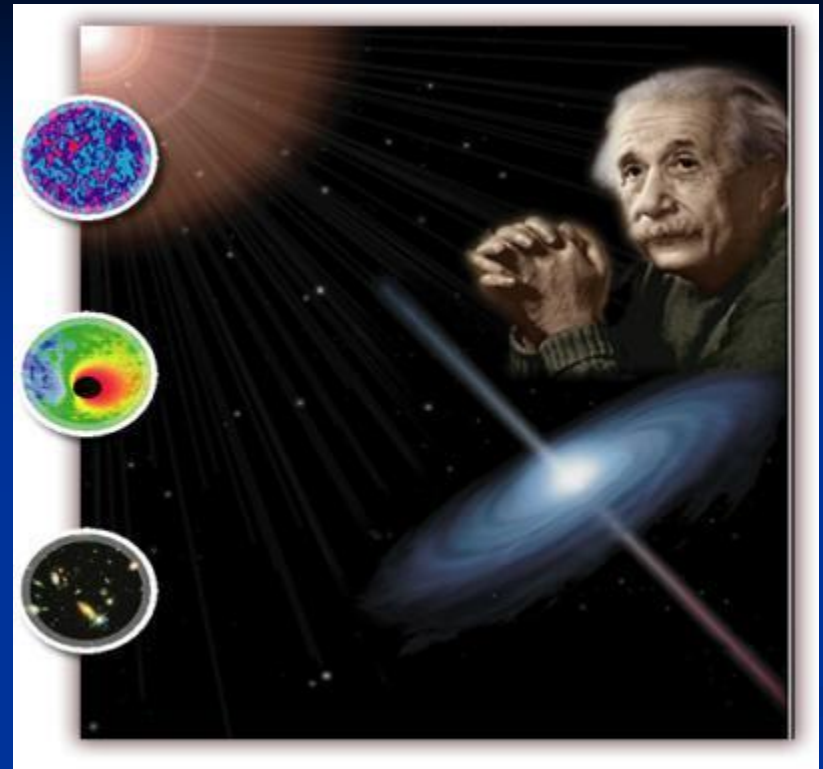
- ❑ The Universe was formed 14,000 million years ago.
- ❑ Everything started when energy was released from the vacuum
- ❑ This expanded and cooled in the process
- ❑ As a result, this energy was transformed into matter



Physics studied in the Earth and applied to the rest of the universe is Astrophysics.

Albert Einstein discovered that the energy can be converted into the matter and vice versa. At the beginning of the universe, the vacuum energy converted to matter.

Inside the stars the energy turns into matter, that's why they shine.



Equivalence between matter and energy

$$E = mc^2$$

quarks , leptons

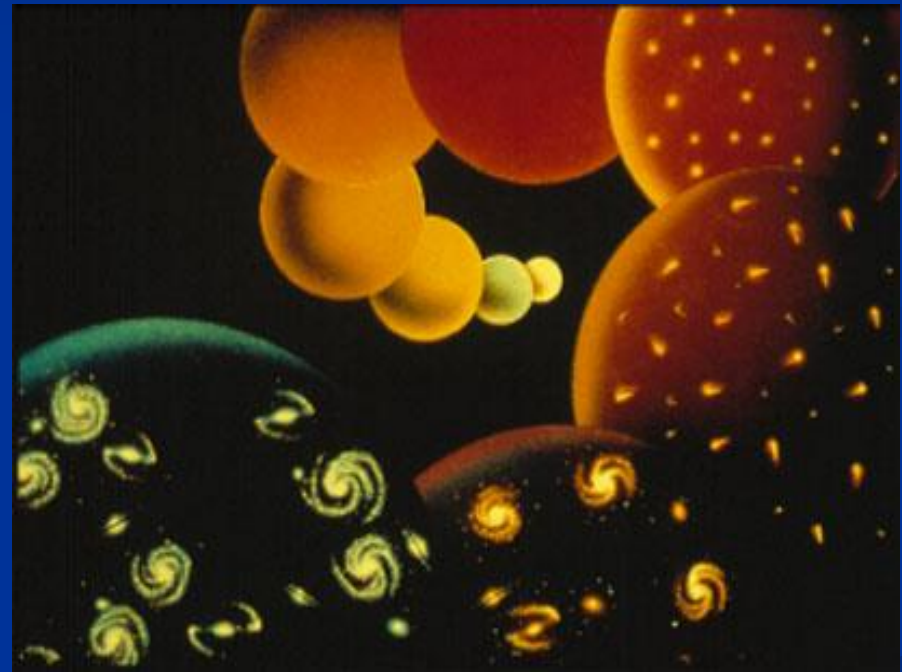
p^+ n e^-



At the beginning all matter was ionized

Later it recombined to
form neutral atoms

Atoms formed clouds,
and inside, the first
galaxies with the first
stars.



Later, the rocky planets (such as Earth)
were formed and the first life appeared.

Chemical evolution

Protons, neutrons and electrons formed in the first minute of the universe. They formed the simplest atoms, H and He.

$$E = mc^2$$

H - Formed by a proton p^+

4 H - Turns to He + 2ν + $2e^+$ + 2γ

- The rest of the elements formed inside the stars through thermonuclear reactions.
- The heaviest atoms, such as uranium, occurs when stars explode and eject particles that collide, forming new elements.
- Thousands of millions of years passed after the Big Bang, when elements other than hydrogen and helium were formed through stellar evolution.



Physics and cosmology

We can explain the daily life matter with quarks, constituents of protons, neutrons, and leptons (one of the best-known is the electron) and their interactions, such as electromagnetism.

Family			Interaction
lepton	electron	neutrino	Electromagnetic force
quarks	up	down	Strong force
baryon	proton	neutron	Weak force, strong force

This simplicity of the model helps to understand how was the early Universe, where energy was transforming into matter and matter into energy.



Through observations we learn about

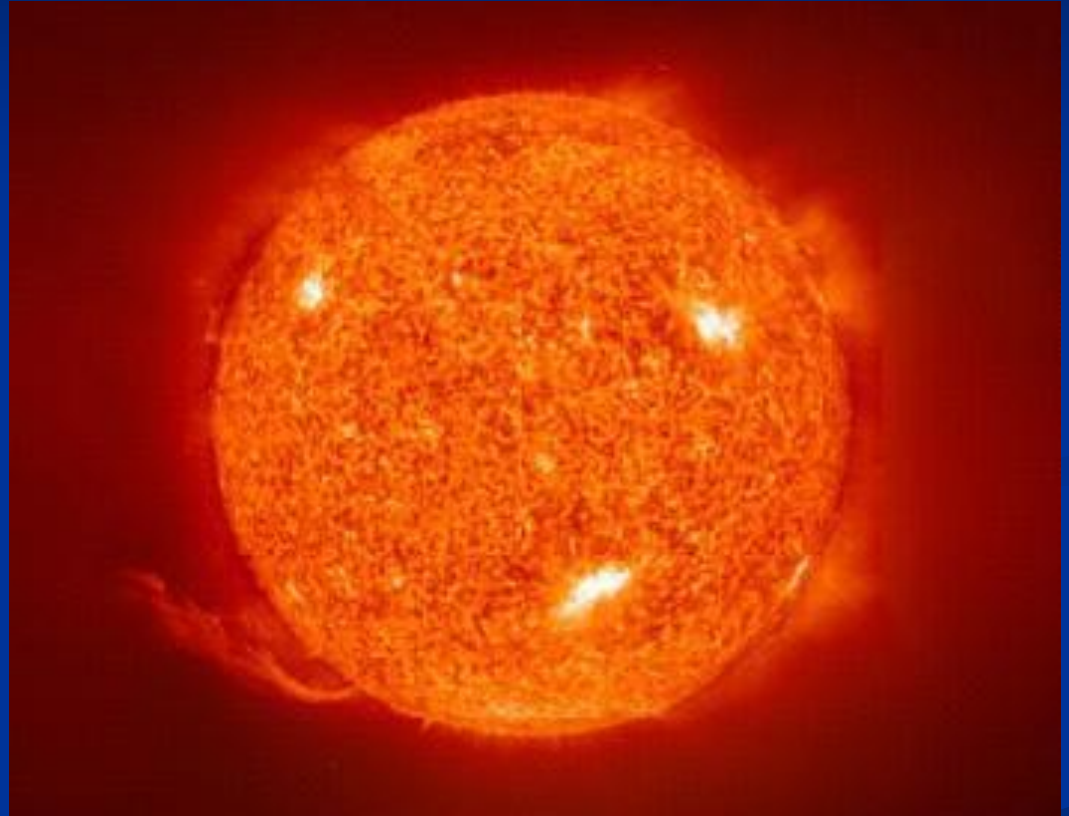
- The physical properties of the celestial objects
- Sizes and distances
- Times and ages
- Expansion rate of the universe
- Temperature of the background radiation
- Chemical composition
- Structure of the Universe
- Why the night is dark
- The existence of dark matter and dark energy



The Sun

The most studied objects are the brightest ones – easiest to do it.

The Sun and the rest of the stars are the most known objects.



Extra solar planets

In addition to stars, in the past few years a hundreds of planets have been discovered around other stars, not because they emit light, but because they disrupt the stellar orbits and light curves.



Life



Another property of the Universe is life. We have not yet discovered the life outside the Earth.

We believe that it requires water to flourish because it facilitates the exchange of substances and the formation of complex molecules.



Interstellar matter

The space between the stars is not empty, it is filled by interstellar matter. This is the material from which the new stars form.

The stars are born inside the clouds of gas and dust. The clouds are compressed forming new stars. They spend the biggest part of their life transforming in their core hydrogen into helium and energy.

Then later forming carbon, nitrogen and oxygen - the elements that we are made of.



Life cycle of Sun-like star



When stars exhaust their fuel, they eject into the surrounding space particles created inside of them. After each stellar generation, the interstellar medium - where new stars born – become more abundant with this elements.

Clusters

Many stars are agglomerated in clusters containing between 100 and 1,000,000 stars



Jewel Box, open
cluster



Omega Centauri,
globular cluster



Galaxies

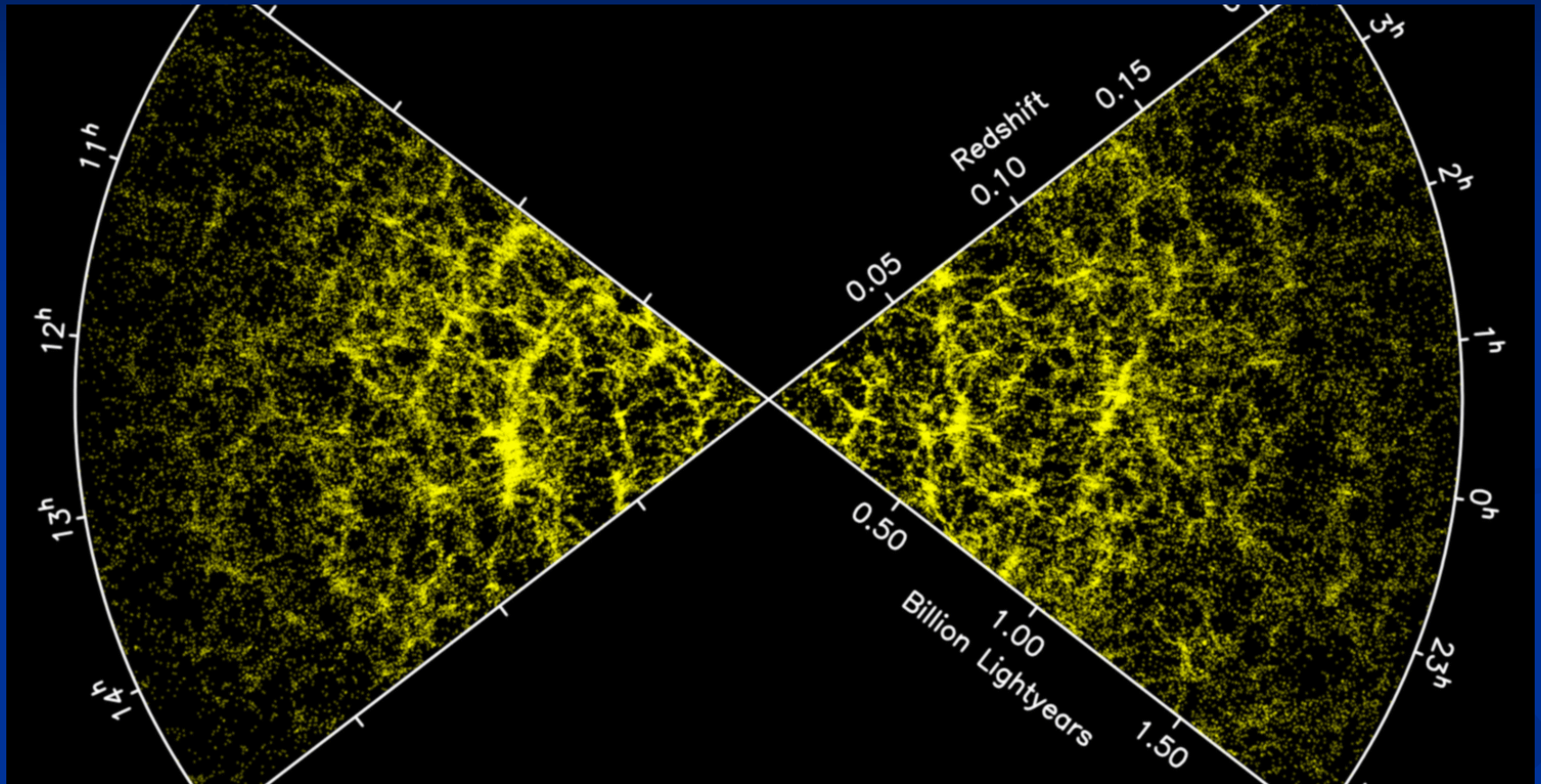
Conglomerates by excellence are the galaxies, the spiral one like ours, have >100 billion stars, each one with its planets, satellites and comets, gas, dust and most of the so-called dark matter



Whirlpool Spiral Galaxy
Source: Hubble Space Telescope



Filamentary universe



The groups of galaxies are arranged in what is called filamentary universe

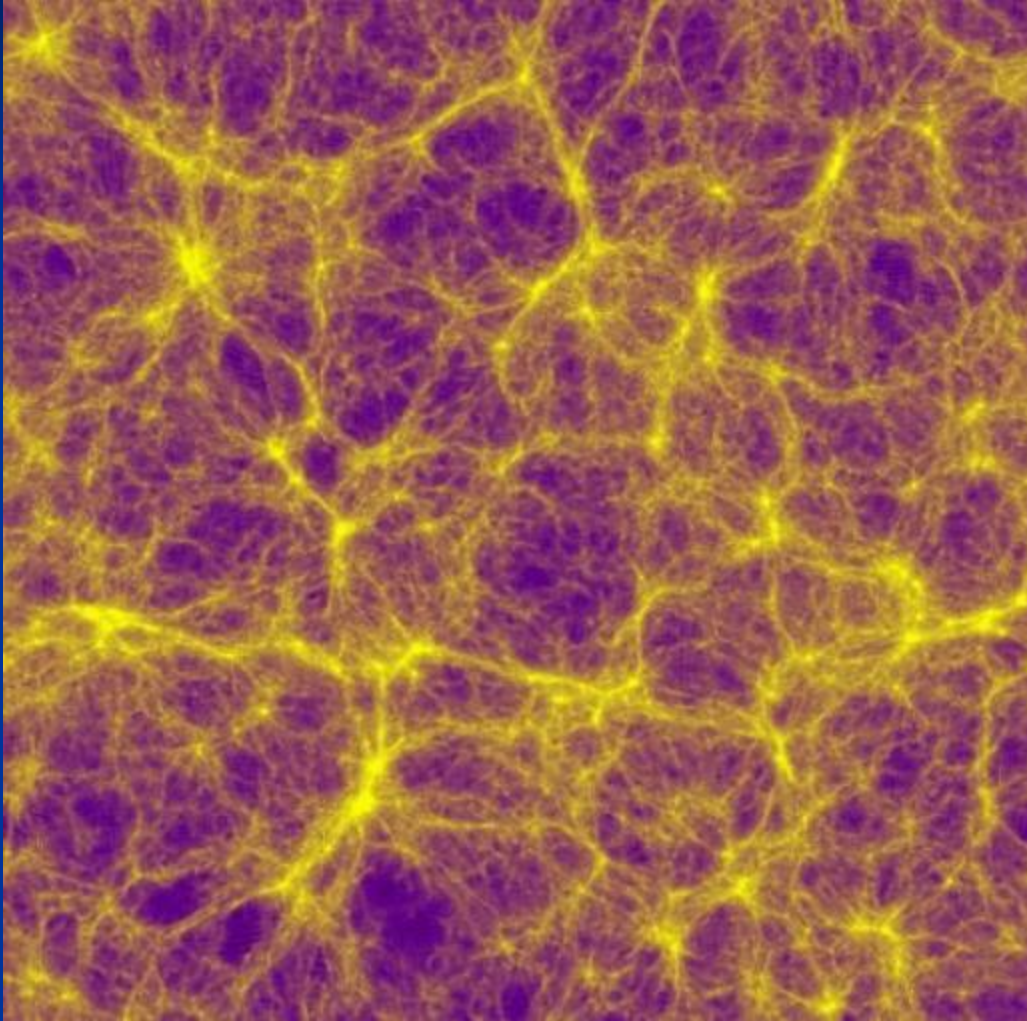


It's like the Universe is a bubble bath where the matter surrounds the space lacking with galaxies, and as the time passes the volume that lack with matter grows



As the Universe expands the space between clusters of galaxies increases and the universe dissolves more

Model of the filamentary universe



The clusters and superclusters of galaxies lie in the filaments, like on the surface of a bubble.

The model is coincident with the observations

Source: Millennium Project Max Planck Institute.



Structure of the universe: synthesis

- The stars are in clusters.
- The stellar clusters are inside the galaxies.
- The galaxies form clusters, made of few galaxies or thousands of them.
- The biggest structures in the universe are filaments, formed by clusters and super clusters of galaxies.



Sizes in the Cosmos

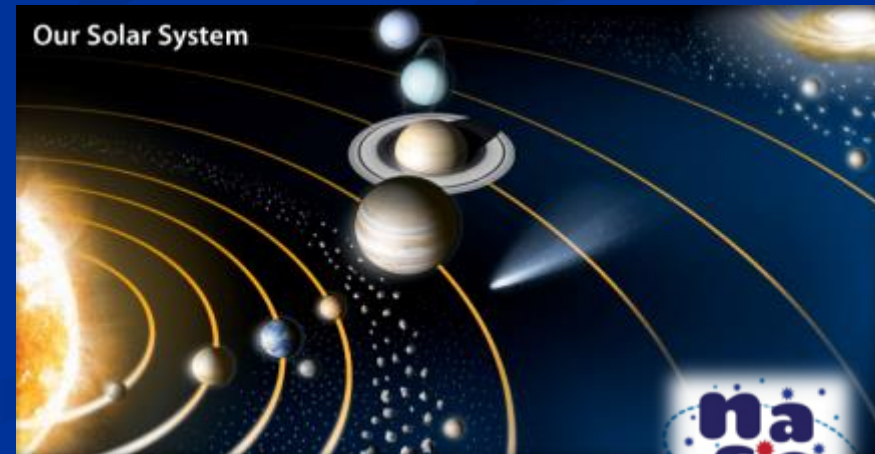
We can estimate the size of one meter, similar to the size of a child, and also a unit thousand times greater, one kilometer...



... distance thousand times greater, thousand kilometers, can be crossed by plane in couple of hours.

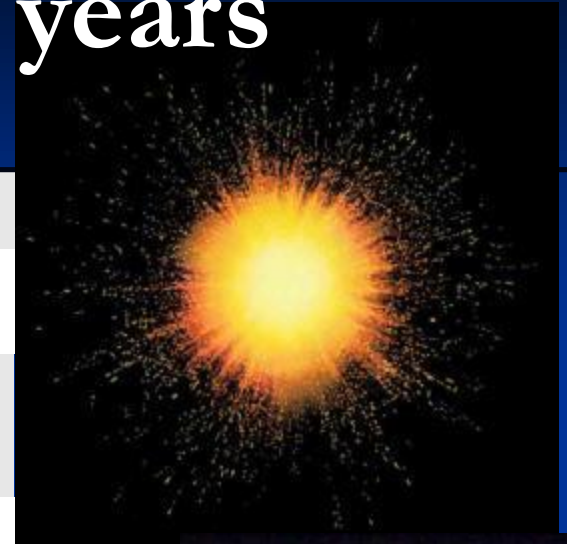
To get to the Moon we need three days and to cover the distance between the Sun and Jupiter several years.

The distance to nearby stars is thousand times higher



Time in the Cosmos in years

Big bang	14 000 000 000
Galaxy formation	13 000 000 000
Solar System formation	4 600 000 000
Appearance of life on Earth	3 800 000 000
Appearance of complex life	500 000 000
Appearance of dinosaurs	350 000 000
The Cretaceous extincion	65 000 000
Appearance of the modern man	120 000



The appearance of the man is very recent

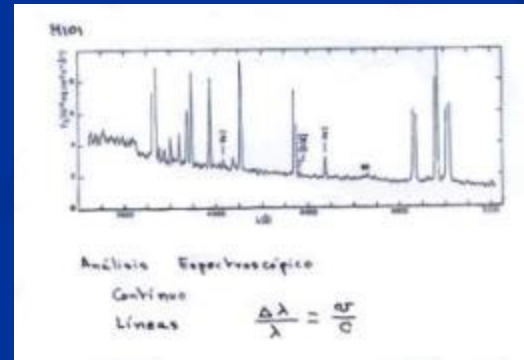
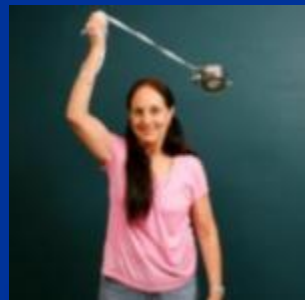
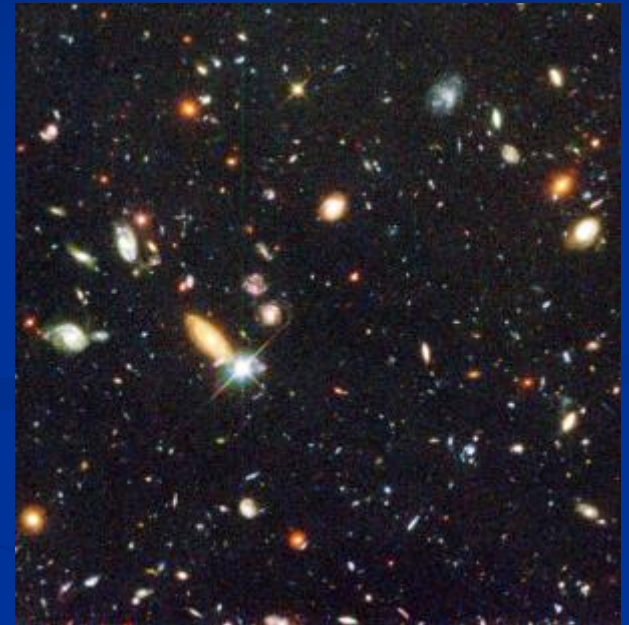
Observing the universe

You can take an image to determine the position or the appearance of a star, or the amount light emitted.

The spectra can determine the speed of the stars. This is what is known as the Doppler effect of light.

Analyzing the radiation that stars and galaxies emit, reflect or absorb, we learn about their nature.

(Doppler effect)



Pillars of the Standard Model

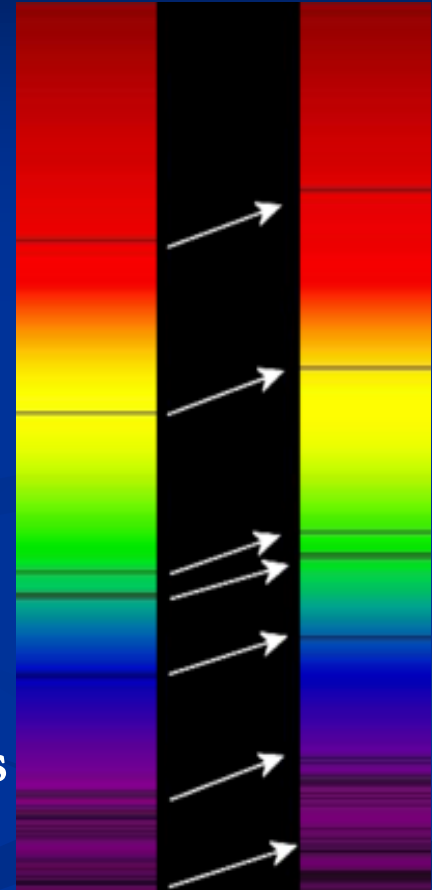
Expansion of the universe

Doppler shift to red demonstrates the expansion (If the stars are close to the observer the light is bluer and farther they are it is redder).

The groups of galaxies are moving away from each other and if they are further, they are moving away at faster rate

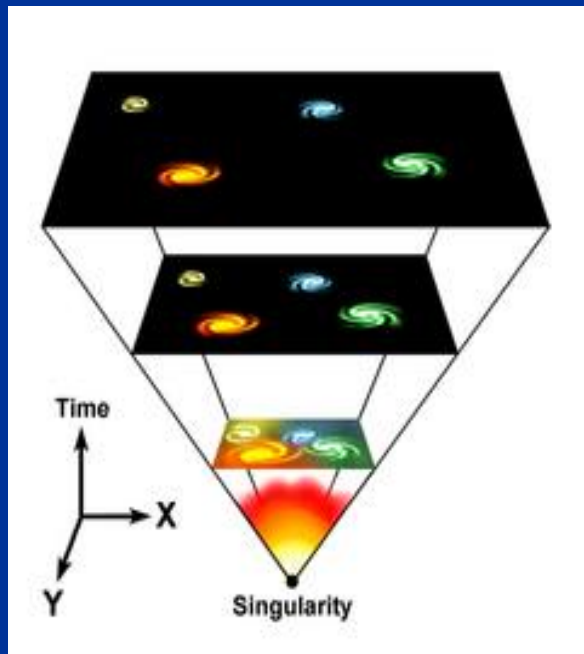
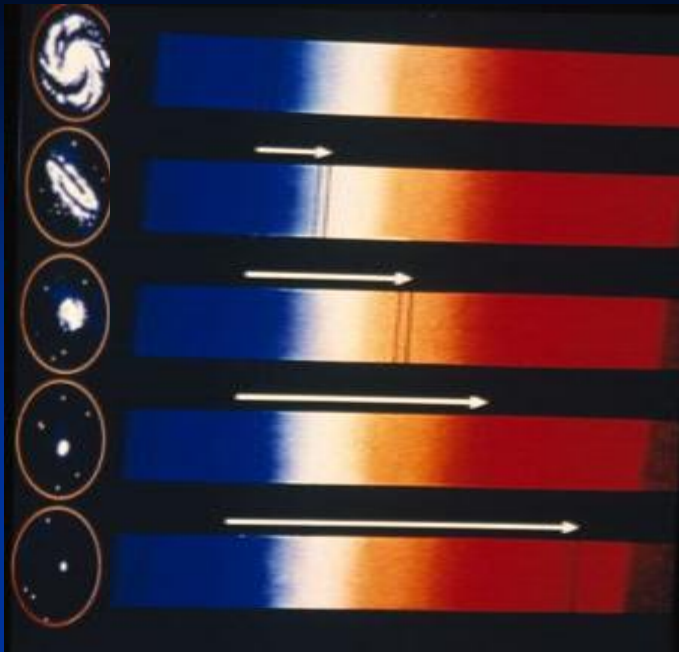
Chemical abundances in the universe

In the first minutes of the Cosmos, only H and He were formed; the expansion stopped the production: the radiation lost the energy and it was not possible any more to transform into protons and neutrons. C, N and O were created inside the stars and were mixed with the interstellar medium when the stars died.



Cosmic Expansion

The space expand, and also the photons of radiation are stretched. What in the past were tiny wavelength gamma rays, today we observe them as radio waves.

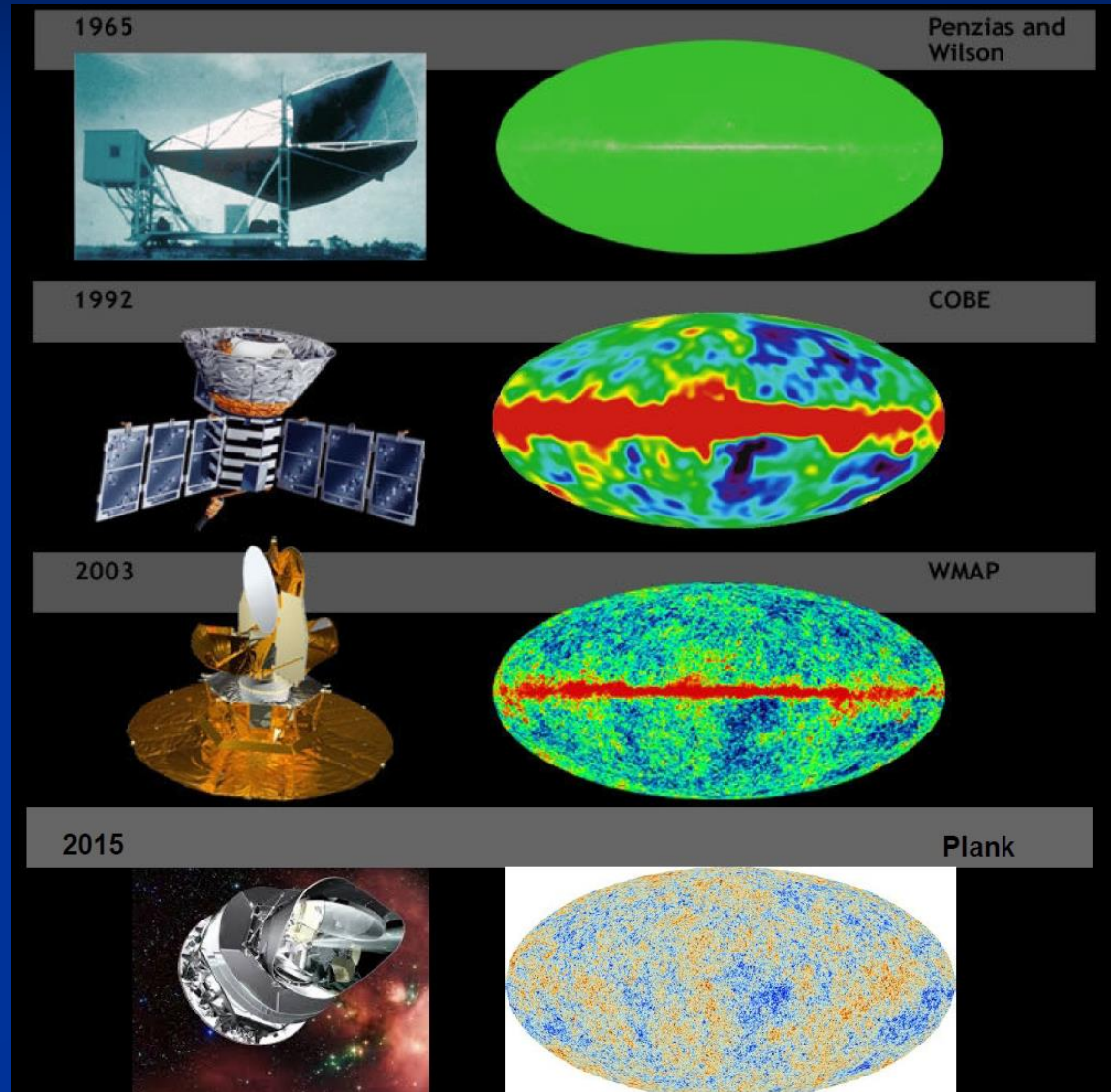


Measuring the cosmic expansion, we can calculate the age of the Universe, 14 billion years. This estimation is higher than the age measured for oldest stars



Cosmic Microwave Background (CMB) Radiation

- The COBE, WMAP and PLANCK missions made a map of the sky of CMB radiation, every time with more details, detecting small fluctuations: imprints of lumps of matter from which galaxies began to form



Is there the edge of the universe?



A necessary condition for the stability of the universe is that it is in continuous expansion. Otherwise, it would stop to exist as we see it now. The expansion of the universe is one of the pillars of the standard model of the Big Bang

but... there is no centre of the expansion



Does Gravity dominates the universe?



The Universe contains mass, so it has a huge gravitational force. Gravity attracts.

The expansion of the big bang compensates the gravity

The universe is accelerating and the source of energy responsible for that acceleration is unknown.



When observing distant galaxies, we look how they were in the past. Nearby galaxies are different from the distant galaxies



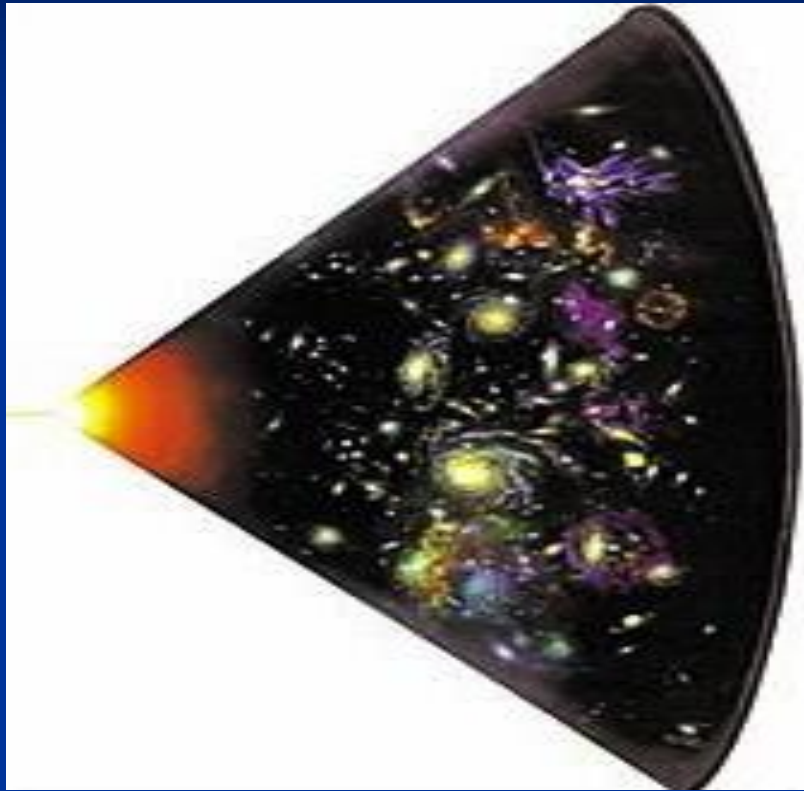
Nearby Spiral Galaxy



Distant galaxies are small and amorphous



Evolution



There is a limit beyond which we do not have information about the Cosmos.

We cannot observe the stars whose light takes more than fourteen billion years to reach us.

If our universe was small we would only have information about a small section, and if it was infinite this would be tiny



The INVISIBLE part of the universe,
95% dark matter and dark energy,
is detected due to its action on
VISIBLE objects.

We don't know the type of material that
it is made off



Sea surface



It's like we are marine biologists, but we can only see the surface of the sea

Bottom of the sea

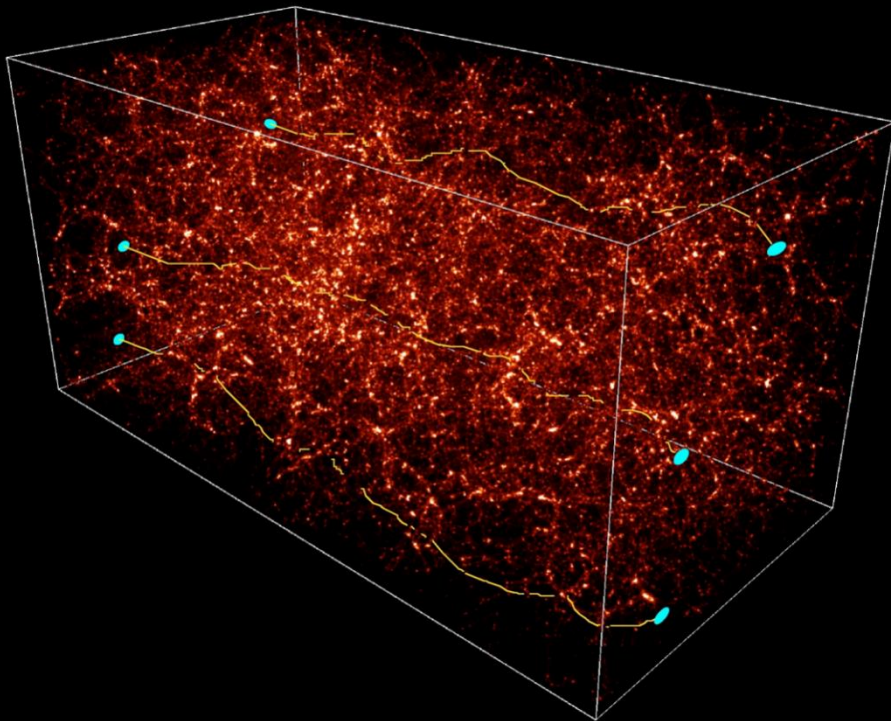


If we look from closer, we could discover a great diversity

The dark matter

We know that for every detected astronomical object there are thousand more which we have no information, only the mass containing. We do not know its shape and distribution

DEFLECTION OF LIGHT RAYS CROSSING THE UNIVERSE, EMITTED BY DISTANT GALAXIES



It is thought that dark matter is distributed filamentary. The blue shapes are distant galaxies.

The yellow lines are the paths of light emitted by galaxies.

Without dark matter they would be straight



The stars move around the galactic center because its mass attracts them. Clusters of galaxies remain bounded due to the gravitational force.

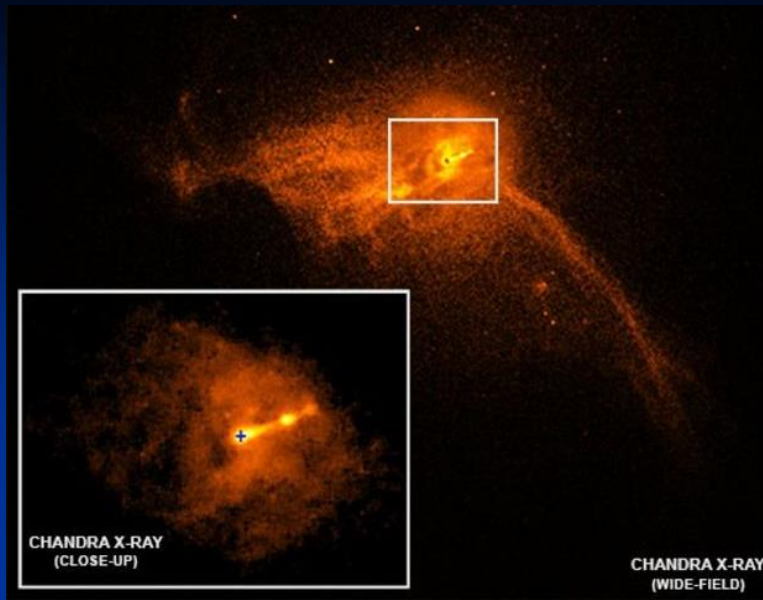


The dark matter is not visible, but can be detected through the gravity



There are objects that move around others that we can not see. For example, there are stars and groups of stars that move around the black holes in the center of the galaxies





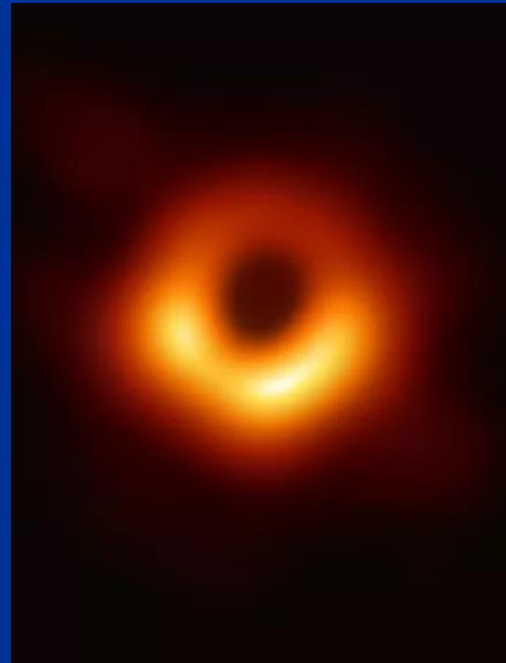
A consortium of more than 200 scientists and 60 institutions in 18 countries of 6 continents are part of the Event Horizon Telescope: 8 radio telescopes on all the Planet

Center of M87, distant 53.5 million l.y. from the Sun

(credit: NASA/CXC/Villanova University/J. Neilsen)

“Shadow” and the event horizon of the supermassive black hole in the center of M87, 6.5 billion times more massive than our Sun

(credit: Event Horizon Telescope)



The first image ever taken of a supermassive black hole, was presented at a press conference on April 10th 2019

Evolution of the universe

In the long timescales, the universe will continue to expand. The velocity of the expansion increases with time, it is accelerated. The energy responsible for this acceleration is still unknown. We call it dark energy.

After \sim trillions of years all interstellar matter will be consumed and stellar formation will stop.

The protons will disintegrate, and the black holes will evaporate.

The universe will be immense, populated with exotic matter and low-energy radio waves.



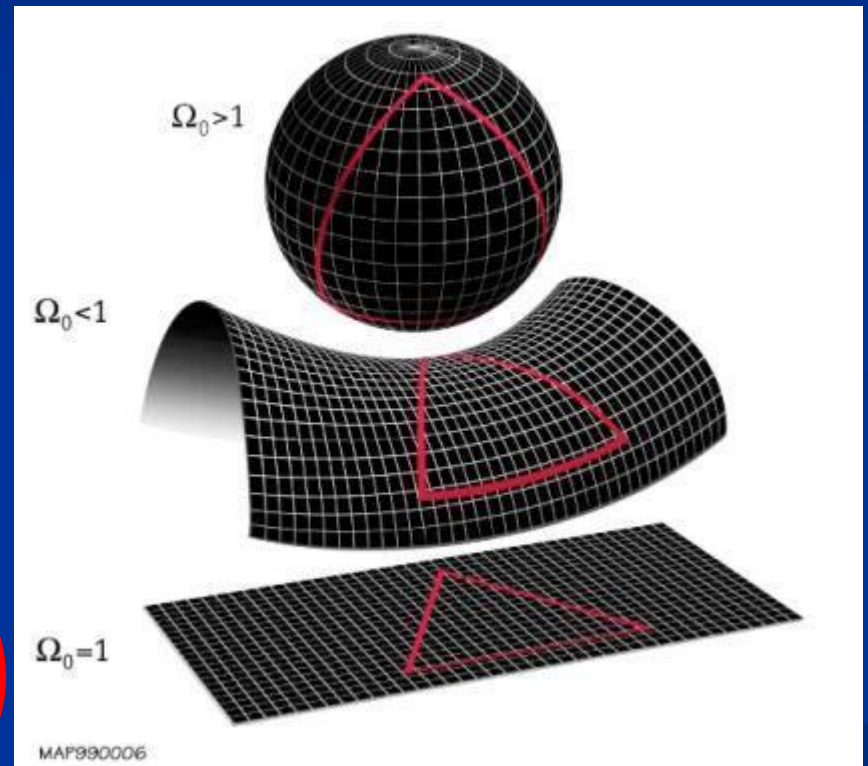
Geometry of the universe depending on the Cosmological constant

Close $\rightarrow \Omega > 1$

Open $\rightarrow \Omega < 1$

Flat $\rightarrow \Omega = 1$

(predicted by inflationary theory and coincident with observations)



The evolution depends of the content of the universe

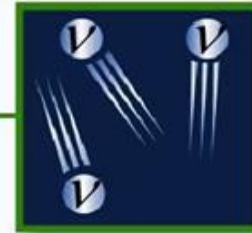
Cosmological constant

$$\Omega_{\text{total}}=1.0$$



Heavy elements

0.03%



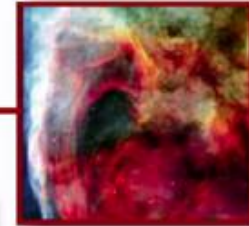
Neutrinos

0.47%



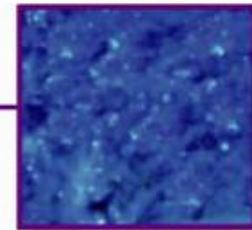
Stars

0.5%



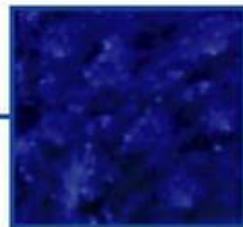
Free H
and He

4%



Dark matter

25%



Dark Energy:

70%

A Successful Model: The Big Bang (predictions-verifications)

- **Expansion:**
verified at the beginning of 20th century by E. Hubble.
- **Background Cosmic Radiation:**
discovered in 20th c. by A. Penzias and R. Wilson.
- **Abundance of the Chemical elements:**
demonstrated in 20th c.
- **Large Scale Structure:** discovered at the end of 20th c.



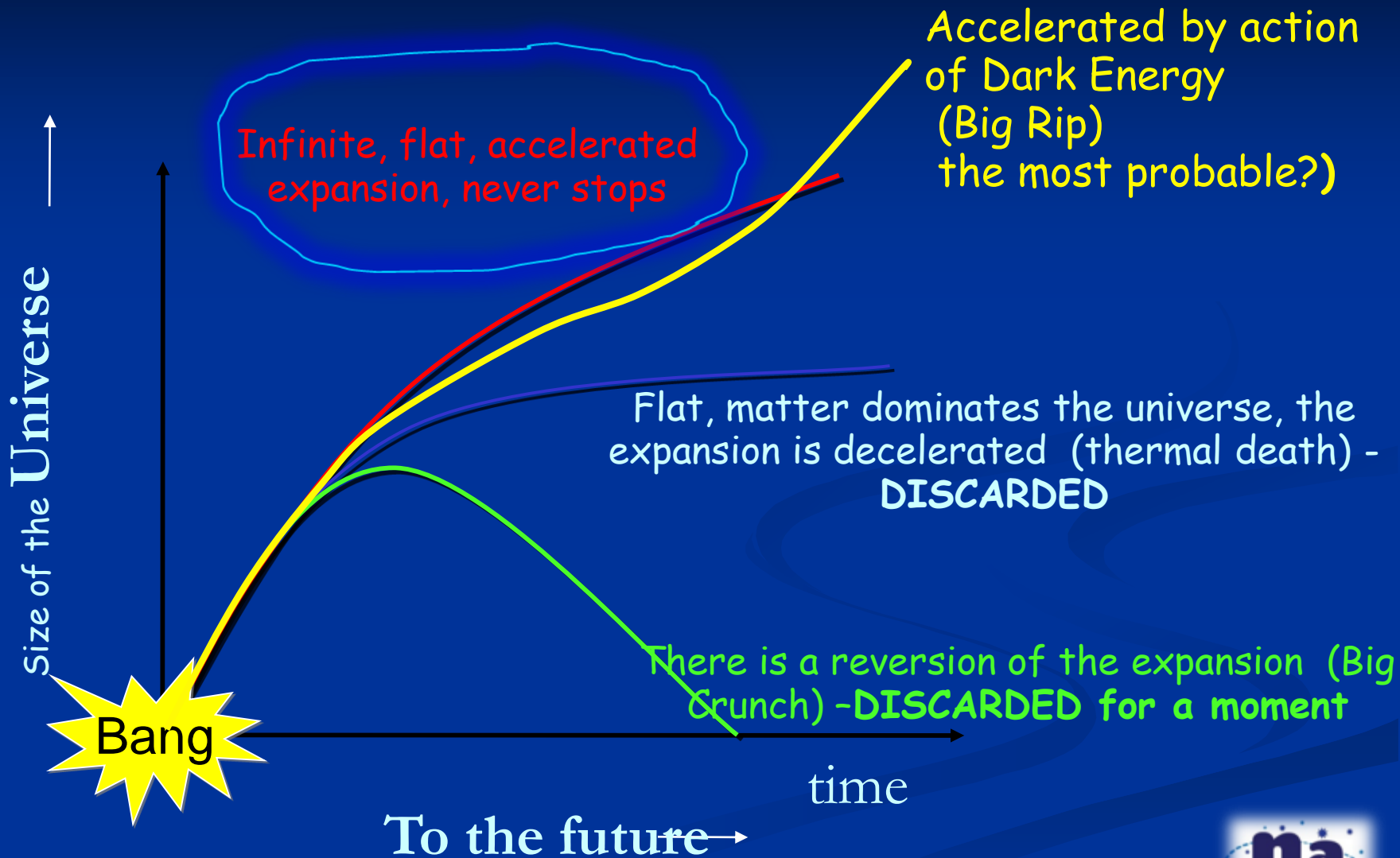
Final Destiny of the universe (possible scenarios)

- Big Crunch (reversion of expansion)
- Flat, thermal death (the expansion stops)
- **Infinite, flat, in permanent expansion
(this is the scenario now accepted)**
- Big Rip (accelerated expansion)

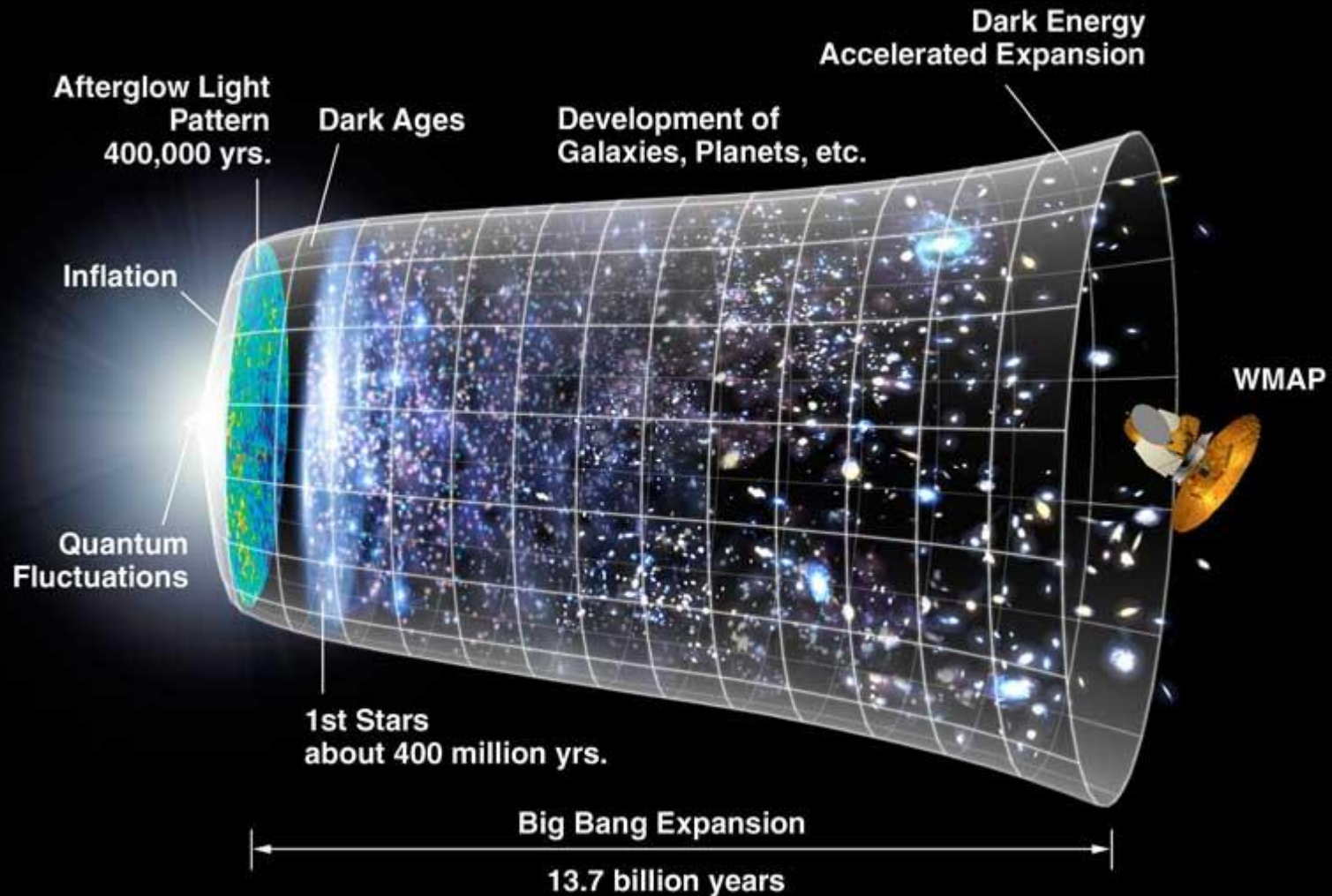
The Future depends on the content of the universe, on the critical density and on the existence of dark energy.



Shape and Destiny of the Universe

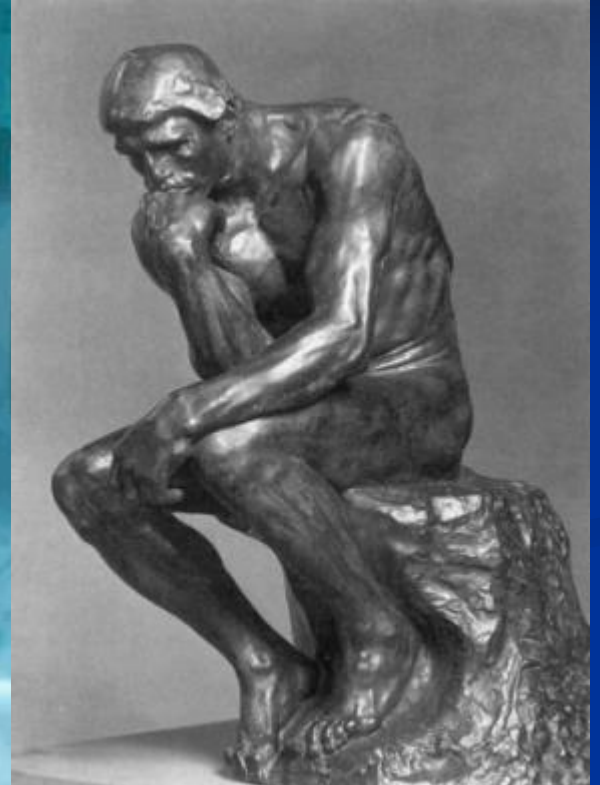


History of the universe



Epilog

We live in an extraordinary epoch in which we can think about the universe using the physical laws.



It is possible that with time our ideas change, but that's how is science

**Many thanks
for your attention!**