THE END OF THE UNIVERSE AND THEN WHAT ?

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General Seminar,
Verão Quantico workshop.
Ubu-Anchieta, Brazil,
April, 2023

Universe, Cosmology's central concept

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- **The subject of Cosmology's concern is the Universe, defined as the set of all that is accessible to our observation, directly or indirectly.**
- **Although we certainly are a part of this subject of study, our influence upon the overall development of Universe as a whole is minimal; to tell the truth - it can be safely said non existent at all.**

Cosmology is not an experimental science, but a purely observational one.

We observe the Universe...

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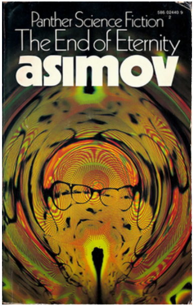
- **Can Universe die of a sudden death? ?**
- **Could the Universe be different from what it is ?**

The end of Eternity ?



Isaac Asimov and his novel “The end of Eternity”

Another paradox...quasi eternal. According to Woody Allen,
“Eternity must be extremely dull. Especially towards the end”...

Essential question - four possible scenarios

The essential question to which the Mankind seeked to find the answer since times immemorial is to know its fate, collective and individual alike.

As soon as we evoke the concepts of "beginning" and the "end" of the Universe, we are automatically confronted with four possible types of history of the Universe as a whole:

1) No beginning and no end: ————————————————

2) No beginning but with an end: —————————————-]

3) With beginning but endless: [—————————————-

4) With both beginning and end: [—————————————]

Ancient Chinese views

In early Chinese views on cosmology, the creation of the universe is thought as multiplicity that has arisen from unity. In order for space to come into existence, unity must disperse into multiplicity, or duality of two essential, but opposite principles "yin" and "yang".

Some ancient Chinese texts describe the birth of our universe as order coming from chaos, like in ancient Greek mythology.

The basic stuff out of which all things are made is called "qi". Everything that ever existed or does exist, is made of qi, including inanimate matter, humans and animals, the sky, ideas and emotions, demons and ghosts.

Ancient Indian views

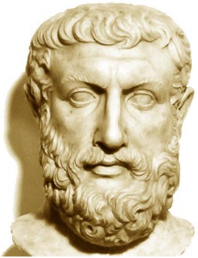
According to Vedic cosmology, the universe is eternal and has no beginning or end.

The universe goes through cycles of creation and destruction, each lasting billions of years.

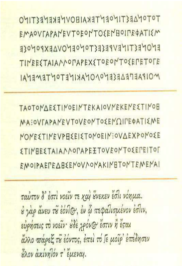
The Vedic texts describe the universe as created and sustained by the cosmic being known as Brahman, and the ultimate goal of existence is to realise the unity of the individual self with Brahman.

Is the Universe unique ?

First of all, what do we mean by “Universe” ?



Parmenides of Elea



ταὐτὸν δ' ἐστὶ νοεῖν τε καὶ οὕνεκέν ἐστι νόημα.
οὐ γὰρ ἄνευ τοῦ ἐόντος, ἐν ᾧ πεφατισμένον ἐστίν,
εὑρήσεις τὸ νοεῖν· οὐδὲ χρόνος ἐστὶν ἢ ἔσται
ἄλλο πάρεξ τοῦ ἐόντος, ἐπεὶ τό γε μοῖρ' ἐπέδησεν
οὖλον ἀκίνητόν τ' ἔμεναι.

A page of his Poem

Parmenides of Elea (515 (?) - 440 (?) B.C.E.was probably the first to use the concept of Universe defined as the realm of things that exist.

Here are Parmenides' words:

- **"...the only two ways of search that can be thought of. The first, namely, that It is, and that it is impossible for anything not to be, is the way of. conviction, for truth is its companion..**

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- **The other, namely, that It is not, and that something must needs not be, - that, I tell thee, is a wholly untrustworthy path. For you cannot know what is not - that is impossible - nor utter it;**
  (Fragments II, lines 3 to 8 of Parmenides' Poem, translated by John Burnet (1892))

Proofs of uniqueness and eternity

- **Were there two distinct Beings, there should be a separation between the two. But if separation does exist, it is, by definition, a part of Being; therefore the two Beings should be separated by a Non-Being. But Non-Being does not exist, whence the conclusion: Universe is one. CQFD**

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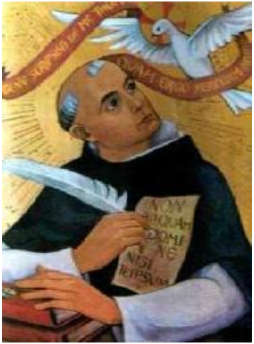
- **In a similar manner, one proves that Universe is eternal - because if it stopped to exist, it would have been replaced by a Non-Being. But the latter does not exist, whence the conclusion CQFD**

Is the vacuum possible ?

Aristotle followed Parmenides' ideas declaring that VACUUM cannot exist in Nature.

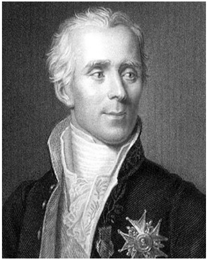
"Nothingness" is the most difficult to imagine...

The eternal Universe



For St. Thomas Aquinas, the Universe must be eternal, because
"If even one sole grain of dust could be annihilated,
the entire Universe would crumble down".

Modern Cosmogony

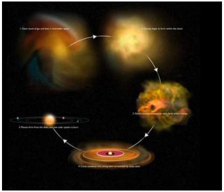


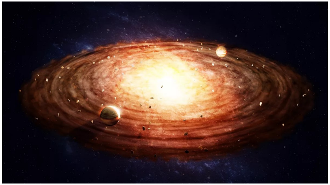
Immanuel Kant   Pierre-Simon de Laplace

Kant produced the first model of Solar System's birth.

Laplace gave it more physical and mathematical substance

For both these thinkers space and time were given a priori.



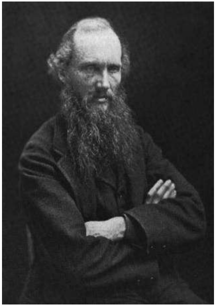


According to Kant's hypothesis published in 1755 in his book "*Universal Natural History and Theory of the Heavens*", gaseous clouds (nebulae) slowly rotate, gradually collapse and flatten due to gravity, eventally forming stars and planets.

- **In** 1796 **Laplace independently proposed and developed a similar model, in his "***Exposition du système du monde***". The Sun was supposed to have initially a hot atmosphere extending throughout the Solar System. It flattened and spun more rapidly, shedding a series of rings, from which the panets were formed.**

- **In 1796 Laplace independently proposed and developed a similar model, in his "*Exposition du système du monde*". The Sun was supposed to have initially a hot atmosphere extending throughout the Solar System. It flattened and spun more rapidly, shedding a series of rings, from which the panets were formed.**
- **Although very popular in XIX^{th} century, this model encountered a number of difficulties, the main one being the angular momentum distribution. The Sun contains 99.98% of the total mass, while the planets carry the 99% of total angular momentum. This could not be explained by Kant-Laplace's nebular model.**

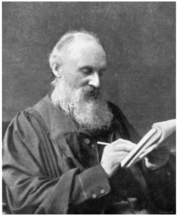
The first caretakers



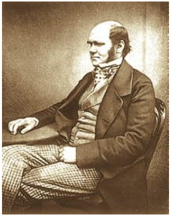
Lord Kelvin Rudolf Clausius

They foresaw "the thermal death" of Universe resulting from temperatures' uniformization, the end of thermal exchanges and motion.

A lesson of scientific humility



Lord Kelvin

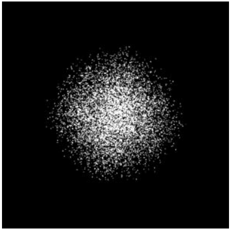


Charles Darwin.

Having concluded that dinosaurs' skeletons were dozens of millions years old, Darwin hesitated to publish his finding. He went to ask the renowned physicist Lord Kelvin, whether it could be true. The categorical answer was: "certainly not, because we have proven that the Sun can not last more than $1,000.000$ years."

Newtonian Cosmology

The fundamental equation of modern cosmology could have been formulated in the framework of Newton's gravity theory



According to Newton's universal gravity law, no static configuration of massive bodies can remain in equilibrium, because the force of gravity will make them fall towards their common center of mass.

The Universe cannot be static

- **In order not to fall on each other, masses must have enough energy enabling them to leave the gravitating sphere that attracts them.**

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- **In order not to fall on each other, masses must have enough energy enabling them to leave the gravitating sphere that attracts them.**
- **The “escape velocity” (or the “second cosmic velocity”) is given by the following formula:**

$$\frac{m}{2}\left(\frac{dr}{dt}\right)^2 = \frac{GMm}{r}.$$

Newtonian Cosmology

The same formula can be generalized: the sum of kinetic and potential energies per unit of mass m can be positive, negative or null:

$$\frac{m}{2}\left(\frac{dr}{dt}\right)^2 - \frac{GmM}{r} = mE$$

For a uniform density ρ we get:

$$M = \frac{4\pi r^3}{3}\,\rho \quad \text{therefore} \quad \frac{1}{r^2}\left(\frac{dr}{dt}\right)^2 = \frac{8\pi G}{3}\,\rho + \frac{2E}{r^2}$$

The quantity $H = \frac{1}{r}\frac{dr}{dt}$ **is called** *the Hubble's constant*.

Hubble's law

Supposing the density ρ constant and in perfect equilibrium, which means the equality between kinetic and potential energies, we get from

$$\frac{1}{r^2}\left(\frac{dr}{dt}\right)^2 = \frac{8\pi G}{3}\,\rho$$

Hubble's law

$$\frac{dr}{dt} = r\,\sqrt{\frac{8\pi G}{3}\,\rho} = H_0\, r,$$

telling that the escape velocity is proportional to the distance to the center. With actual value of H_O equal to $72 \pm 5 km/sec \cdot Mpc$ one finds the *critical density*

$$\rho_{cr} = \frac{3H_0^2}{8\pi G} = 9,47{\cdot}10^{-27} kg/m^3 \simeq 5,7 \text{ protons}/m^3. \;\; \text{we set } \Omega = \frac{\rho}{\rho_{cr}}.$$

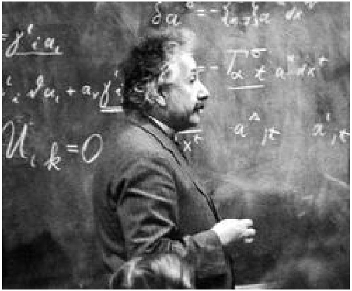
Einsteinian Cosmology

The equations of General Relativity to which Einstein added the so-called cosmological constant Λ in order to make stationary solutions possible:

$$R_{ik} - \frac{1}{2} g_{ik} R = - \frac{8\pi G}{c^4} T_{ik} + \Lambda g_{ik},$$

Here R_{ik} is the Ricci tensor, g_{ik} the metric tensor, and R is the curvature scalar; the combination appearing in the equation is the Einstein tensor, measuring the effect of space-time curvature, while T_{ik} is the energy-momentum tensor and Λ the cosmological constant.

Einstein et Friedmann

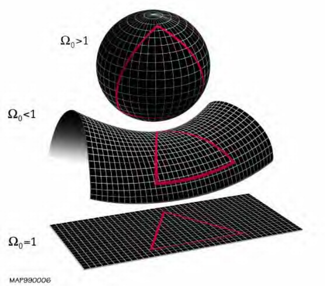


Albert Einstein Alexandre Friedmann

The Einstein equations lead to the same result as the Newtonian cosmological model, but their interpretation is radically different.

Three possible geometries of space

$$\left(\frac{1}{R}\frac{dR}{dt}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{R^2}$$



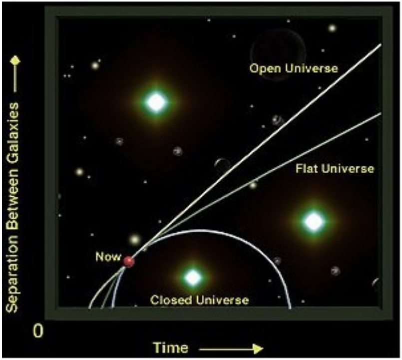
The Einstein-Friedmann equations

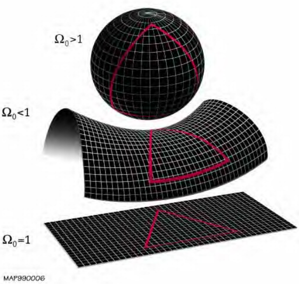
$$\left(\frac{dR}{dt}\right)^2 = \frac{8\pi G R^2}{3}(\epsilon + \Lambda) - k$$

$$\boxed{H^2 = \frac{8\,\pi\,G}{3}\,\rho - \frac{k\,c^2}{a^2}}$$

Here the scale factor $a(t)$ replaces $R(t)$ (the radius of the Universe).

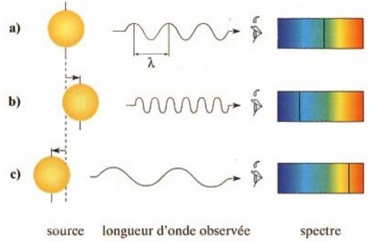
The Universe according to Relativistic Cosmology

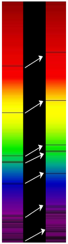




Possible scenarios of Universe's history

The Doppler effect and the red shift





The Doppler effect **Spectral shift**

Here is the spectral shift formula: $z = \frac{\lambda_{obs} - \lambda_0}{\lambda_0}$

The Doppler effect in our Universe

The relativistic Doppler effect produces a spectral shift due to the Hubble recession velocity:

$$\frac{\lambda_{obs}}{\lambda_0} = \sqrt{\frac{c+v}{c-v}}.$$

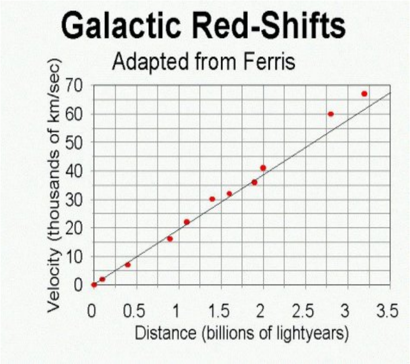
The Doppler effect applied to the Friedmann model gives:

$$1 + z = \frac{\lambda_{obs}}{\lambda_0} = \frac{a(0)}{a(t)}$$

where $a(0)$ is the scale factor at present, and $a(t)$ is the scale factor at time t when the photon was emitted.

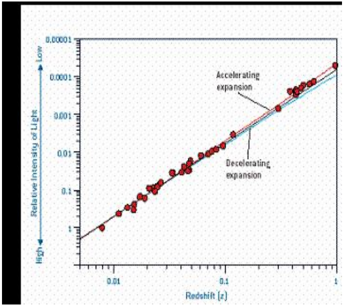
Hubble and the recession of galaxies

Edwin Hubble



Recession velocity of Galaxies

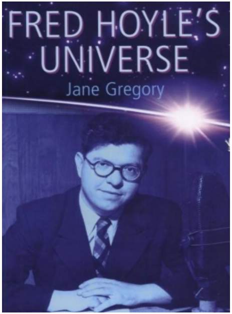
Hubble's law



$$3\left(\frac{H^2}{c^2}+\frac{K}{a^2}\right)=\frac{8\pi G}{c^4}\rho$$

Recent data **Friedmann's equation**

Unbounded optimism: Fred Hoyle, “The Steady State”



A follower of Parmenides, Fred Hoyle (1915-2001) is the author of the “Steady State” theory, an eternal and infinite Universe, whose expansion would be due to constant extra matter creation.

Infinite space-time with matter creation

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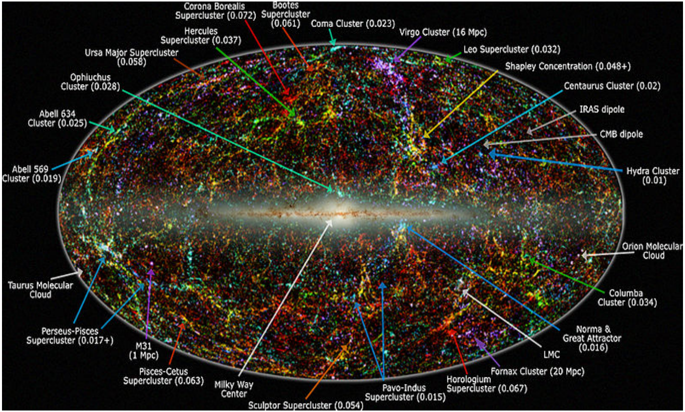
- Our Universe is so vast, and its expansion so slow, that it would suffice to create a single hydrogene atom per one cubic kilometer a year in order to ensure maintaining constant density.
- Following the discovery in 1965 of the relict background radiation by Penzias and Wilson, Hoyle's model could not withstand against the "Big Bang" model.

Inventory



Stellar clusters and galaxies in our local Super-Cluster.
Synthetic image obtained using the 2MASS programme.
It shows the vicinity of our Milky Way up to the 380 000 000 L.Y. distance.

The visible content of the Universe

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- **in each galaxy, about 100 to 400 billion stars and at 50 billion planets;**
- **plus a huge amount of gas and dust, and an unknown number of black holes.**

The estimated Universe's total mass

An estimated total mass of observable Universe:

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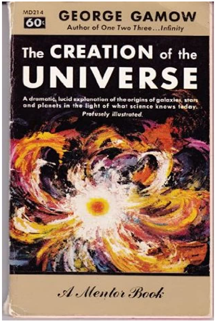
- **Masse of the proton:** $1.67 \cdot 10^{-27}$ kg.

Creation of Modern Cosmology

George Gamow (1904, Odessa - 1968, Boulder), was the first to set the foundations of modern cosmology - foreseeing the initial ultra-hot and ultra-dense state which he named "Ilem", and the cosmic background radiation whose temperature he evaluaated to be 4.2K.

George Gamow



Gamow's book.

Where do we come from ?

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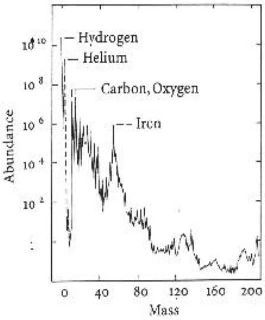
- **The most precise answer was given by Hans Bethe who explained the mechanism of energy production in stars.**
- **As a matter of fact, all the elements we are made of, except the hydrogen, are being produced in the Supernovae explosions - when stellar energy cycle comes to an end.**

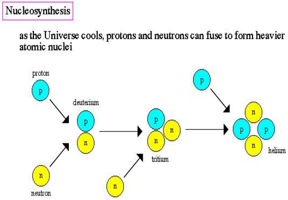
What are we made of ?

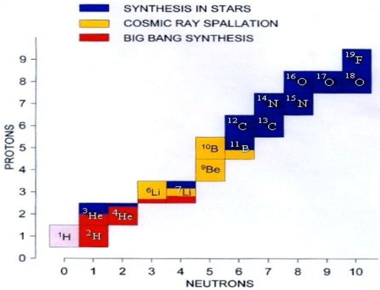


Hydrogène	92,1 %
Hélium	7,8 %
Oxygène	0,061 %
Carbone	0,030 %
Nitrogène	0,0084 %
Néon	0,0076 %
Fer	0,0037 %
Silicium	0,0031 %
Magnésium	0,0024 %
Sulfure	0,0015 %
Autres	0,0015 %

The chemical composition of our Sun $\simeq$ and of actual Universe.

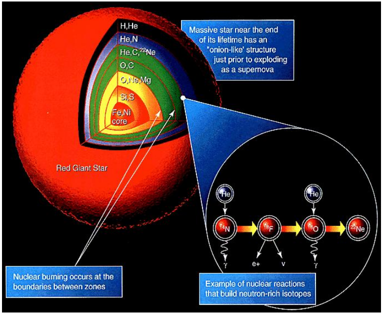
The synthesis of chemical elements





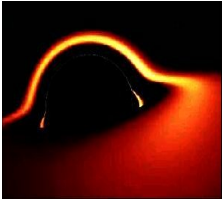
Primordial nucleosynthesis.
versus nucleosynthesis in stars
of the first generation.

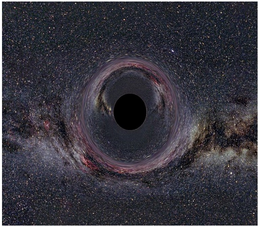
The source of heavier elements



A Supernova **The Crab nebula**

A black hole is probably situated at the center of this nebula





Two artistic visions of a Black Hole

Matter swallowed by a BH emits intense radiation before disappearing forever

The second "portrait" depicts the hypothetical BH at the center of our Galaxy

If G is Newton's gravitational constant and **M** the mass of a spherical body with radius R, then the liberation velocity at its surface is equal to $v = \sqrt{\frac{2GM}{R}}$. In the case of a Black Hole, this velocity equals c, the velocity of light. This defines the Schwarzschild radius $R_S = \frac{2GM}{c^2}$.

Towards our Universe's origins

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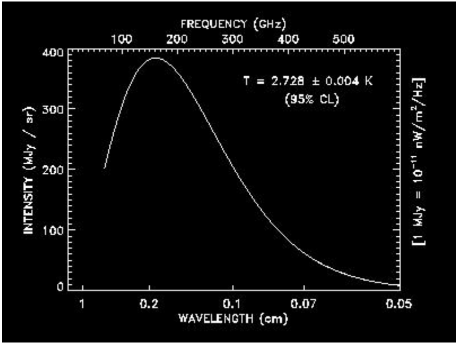
- **In primordial Universe Hydrogen and Helium are being formed due to recombination of protons, electrons and neutrons**
- **Recombination becomes possible when the temperature decreases below** 3000 **K, and the energy of photons is no more sufficient to ionise the H and He atoms.**

The primordial background radiation



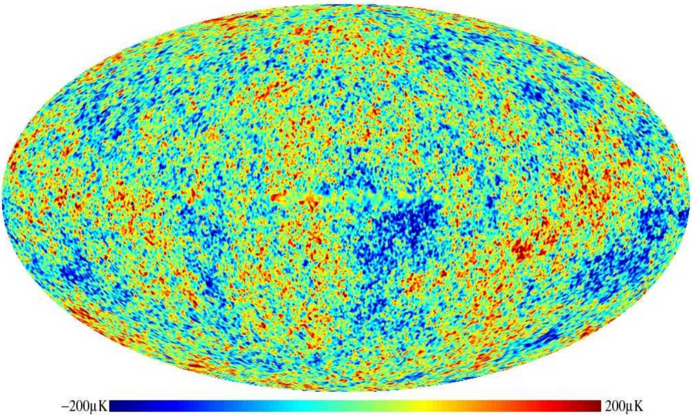
The spectrum of relic radiation discovered by Penzias and Wilson.

It coincides perfectly with the theoretical curve

corresponding to the black body radiation at

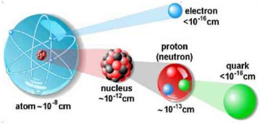
2.73 K

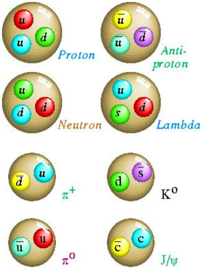
The Universe becomes transparent



The ultimate frontier: cosmic background radiation

Before the decoupling of photons





The baryons (hadrons) are composed of quarks,

which cannot be observed in an unbound freely propagating) state.

It is supposed that at ultra-high eneries $\geq 10^{22}$ eV,

quarks can become free and form a mixed quark-gluon-photon plasma .

The Big Bang theory

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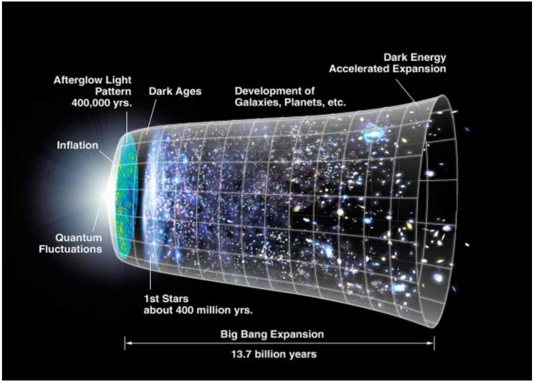
- Nevertheless a number of questions remains without answer, in particular what is the origin of the galaxies?
- We should not forget that the “Big Bang” is only a model which the physicists try to bring as close to the observation as possible.
- But it still remains a model, non deprived of faults.

The “Big Bang”



An artistic representation of Universe’s evolution,

since the “Big Bang” until our time.

Parameter	Symbol	Value $\pm\Delta$
Hubble's constant	H_0	72 ± 5 km/s/Mpc
Critical density	ρ_c	$0.974 \times 10^{-26}\,\mathrm{kg\,m^{-3}}$
Reduced total density	Ω_{tot}	1.02 ± 0.02
Curvature reduced density	Ω_k	0.02 ± 0.02
Density of Λ	Ω_Λ	0.70 ± 0.10
Reduced matter density	Ω_m	0.29 ± 0.07

Table I : **Essential cosmological parameters.**

Parameter	Symbol	Value et $\pm\Delta$
Reduced baryon density	Ω_b	0.0470 ± 0.0006
Reduced photon density	Ω_{ph}	$4.76 \pm 0.30 \times 10^{-5}$
Ratio baryons/photons	η	$6.5 \pm 0.4 \times 10^{-10}$
Numerical baryon density	n_b	$0.27 \pm 0.01\,\mathrm{m}^{-3}$
Numerical photon density	n_γ	$410.4 \pm 0.9 \times 10^6\,\mathrm{m}^{-3}$
Luminous baryonic matter	Ω_{lum}	0.010 ± 0.005
Reduced neutrino density	Ω_ν	$10^{-4} - 1.4 \times 10^{-2}$

Table II : **Essential cosmological parameters**

Parameter	Symbol	Value $\pm\Delta$
Age of the Universe	t_0	$13.4 \pm 0.3\,\mathrm{Gan}$
Age of the oldest star	t_E	$13.2 \pm 0.2\,\mathrm{Gan}$
Redshift of photon decoupling	z_{dec}	1088 ± 2
Redshift of matter-radiation equality	z_{eq}	3454 ± 390

Table III : **Essential cosmological parameters.**

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- Quantum Physics is valid for the phenomena comparable in scale set by Planck's constant $\hbar$; it also takes into account the speed of light c; the relativistic theory of gravitation contains c as well, along with the universal gravitational constant G
- From those three constants one can produce several universal standard quantities

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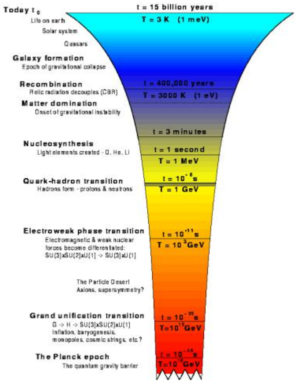
- **The Planck density,** $\rho_{Pl} = m_{Pl} \cdot l_{Pl}^{-3} = 5,1 \cdot 10^{96}\ kg/m^3$.
- **Recalling that the total mass of Universe accessible to our observation is about** $1,6 \cdot 10^{55}$ **kg, we find that in order to reach the Planck density, the entire Universe should be compressed to a volume of a proton, with diameter** 10^{-13} m. **Is it just a coincidence?**

Matter before time and space



Extrapolating backwards, we get to totally unknown conditions and at unimaginable times and distances: 10^{-43} **second.**

Can we still speak pof time and space in such circumstances ?

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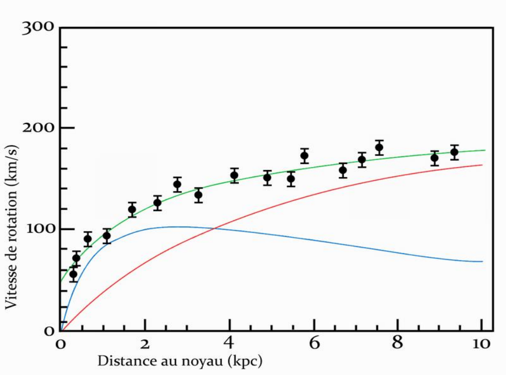
- **The first problem is posed by the velocity distribution of stars observed practically in all known galaxies.**
- **Taking into account the estimated total mass of typical galaxy, its gravitational force is apparently far too weak to keep stars endowed with such velocities orbiting around the galactic center.**
- **Conclusion: we must admit the presence of some extra mass, enormous but invisible, either in the form of black holes, or in another, yet unknown type of gravitating "Dark Matter"**



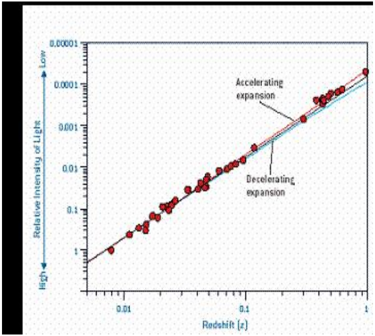
Rotation curves in a typical spiral galaxy.

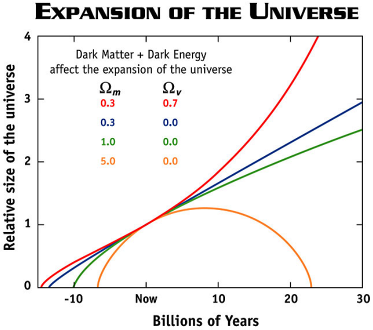
black curve: observational date, with error bars displayed

blue curve: a solid disc rotation velocity

red curve: with a halo of invisible matter justifying observation.

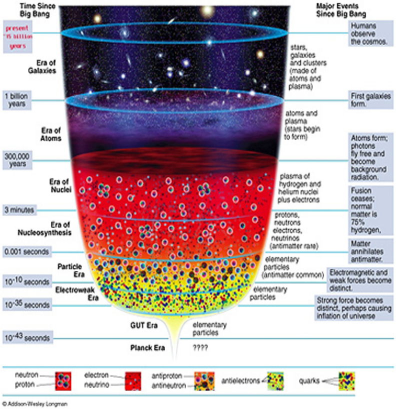
The second problem: Dark Energy





The accelerated expansion of the Universe cannot be explained without a negative pressure produced by the hypothetical "Dark Energy" permeating the entire Universe.

The “Big Bang”



The evolution of the Universe since the Big Bang

The third problem

Extrapolating backwards in time, we arrive to the stage when photons' energy was great enough to create proton-antiproton pairs. The actual number of photons is about 10^9 versus ONE proton, suggesting that initially there must have been as much matter as anti-matter present in the primordial Universe.
Consequently, what we observe at present is the remnant of a small fluctuation, a little excess of matter over anti-matter, of the order of 10^{-9}. But if it is true, that fluctuation could have produced a few times more or a few times less baryons than now, and the actual total mass of the Universe cannot be explained by principle - just a random quantity.
Such a stance is far from being satisfactory, both scientifically and philosophically.

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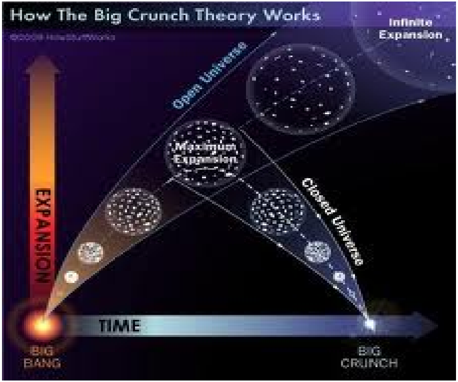
- **either the contraction ("big crunch") if the combined matter-energy density is higher than the critical density** $10^{-29}\ \frac{g}{cm^3}$,
- **or an eternal limitless expansion if the density is lower or equal to the critical one**

An infinite expansion or a closed cycle ?



If matter density of the Universe is above the critical value

The "Big Crunch" is inevitable.

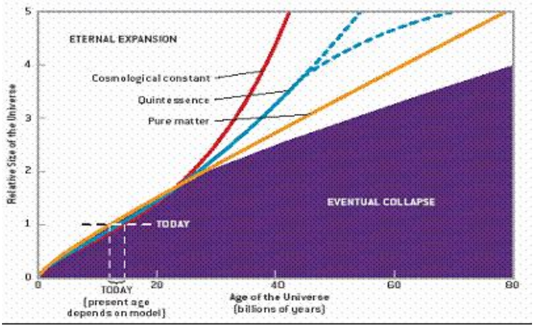
The closed cycle

In the case when the density of matter happened to be higher than the critical density,

$$\rho > \rho_{cr}, \quad \Omega = \frac{\rho}{\rho_{cr}} > 1,$$

Contraction will follow the initial expansion period,
and all stages of Universe's evolution
will follow the inverse scenario.

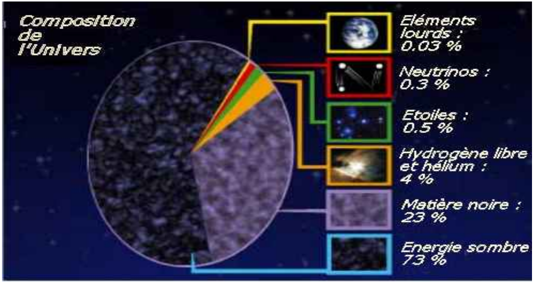
Eternal expansion ?



Various scenarios of Universe's history

according to most of the presently accepted theories.

What our Universe is made of.



Partition into different forms of matter (energy) in Universe

according to the most recent hypotheses.

Continuous creation of space and time

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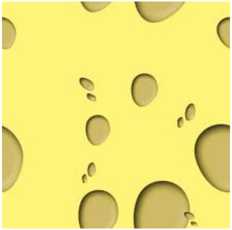
- It seems plausible, in the light of what we just said, that the existence of matter could be prior to the existence of space and time themselves as such.
- In a way, it is an inverse "Steady State" model: the quantity of matter (or its energy equivalent) remains the same, but the space-time is continously created.

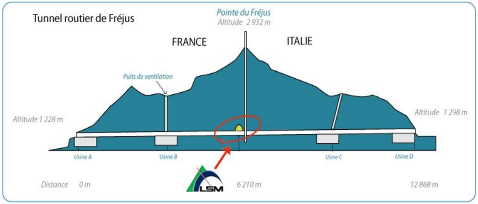
Another nightmare: the "Big Rift"



If acceleration goes on forever, the expansion will rip everything,

including the elementary particles. The end of the space-time?

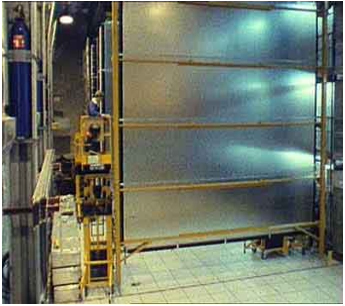
The Fréjus Tunnel experiment



An outstanding experiment which lasted almost 10 years (1980 – 1988).

The goal was to determine the lifetime span of a proton.

The Fréjus tunnel experiment

Partial views of Fréjus experimental setting

in the tunnel more than 2000 meters under the granite rocks.

Besides the neutrinos, only about 4 cosmic μ-mesons per day could penetrate.

The extraordinary longevity of proton

- **A total mass of more than** 600 **tons of iron,** **equivalent of more than** 5×10^{32} **protons,** **stuffed with spark detectors was under scrutiny** 24 **hours round o'clock.**

The extraordinary longevity of proton

- **A total mass of more than 600 tons of iron, equivalent of more than 5×10^{32} protons, stuffed with spark detectors was under scrutiny 24 hours round o'clock.**
- **Not a single event of proton disintegration was observed during all these years. Conslusion: The life time of a proton is longer than 10^{33} years !**

A very unusual warranty

- **The life span of a proton (or of a quark, for that matter) is 10^{23} times longer that the estimated age of our Universe, which is, as of today, about $1,5 \cdot 10^{10}$ years long**

A very unusual warranty

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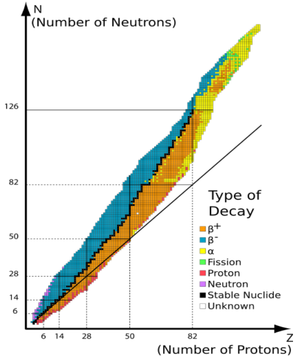
- **To compare, taking the life span of human beings limited by 10^2 years, imagine, when you buy a car, a warranty proposal for 10^{25} years**

  - which would seem totally senseless...

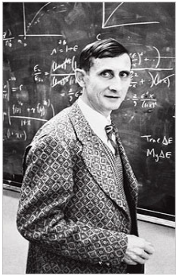
The extraordinary stability of matter



Nuclei of all the isotopes of existing chemical elements.

The isotope of Iron 56 is the most stable of all.

The bright future prophecy: Freeman Dyson



Freeman Dyson.

According to Dyson, the future of our Universe is bright, because after long enough time, all the matter content of the Universe will trasform into photons. ("Time without end: Physics and Biology in an open universe", *Rev. Mod. Phys* . Vol. 51 (3), 1979)

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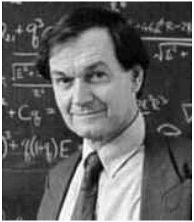
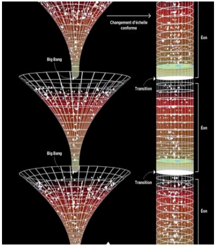
- **All the stars transformed into Black Holes: $10^{10^{26}}$ ans.**
- **Evaporation of Black Holes: $10^{10^{76}}$ ans.**

Eternal Conformal Re-Birth?





Left: Roger Penrose; Right: Conformal Cycles.

From Roger Penrose's perspective, conformal infinity is another sinularity, from which the new Big Bang is initiated. An infinite series of conformal cycles, reproducing themselves.

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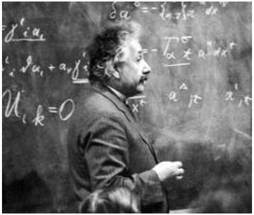
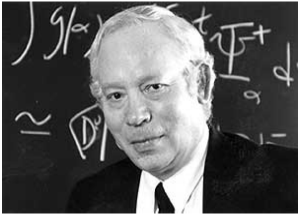
- **Hopefully, there is still a lot of time left for more learning.**

Two points of view on the Universe



Albert Einstein



Steven Weinberg.

Einstein expressed his bewilderment as follows:
"The most incomprehensible thing about the Universe is that it is comprehensible" **while another famous physicist, Steven Weinberg, expressed a rather pessimistic view:**
"The more the Universe seems comprehensible, the more it also seems pointless",

- **However, we should not let ourselves to be discouraged by such pessimistic statements. After all, if the Universe, our existence and all our actions were really pointless, this would ipso facto apply to Weinberg's remark as well.**

- However, we should not let ourselves to be discouraged by such pessimistic statements. After all, if the Universe, our existence and all our actions were really pointless, this would ipso facto apply to Weinberg's remark as well.
- Yes, one can but feel similar disappointment after realizing that not only we and our beautiful planet, but even the majestuous Solar System, represent nothing more than a tiny peripheral speck in our Galaxy hosting billions of suns, which itself is a tiny lump of matter lost among billions of galaxies forming large clusters filling space with gigantic filament-like structures.

Conclusion

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- **Although we still don't understand the goal, it does not mean that there is no purpose at all. It might be that we don't even know how to formulate such questions properly.**

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- Other intelligent beings may exist somewhere, and may be superior to us, as suggested in Fred Hoyle's science-fiction novel "The Black Cloud".

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- **We are still at the beginning of a road full of discoveries. Perhaps the search for a purpose is the ultimate goal?**
- **The Universe could have existed without us, but we could not be there without the Universe.**
- **So, if we find the meaning of our own existence, the entire Universe will acquire meaning and purpose in our eyes, too.**