Chapter 4 :

A stagnation which takes place at the same time in

The infinitely small and in the infinitely large.

Before considering this question, it is necessary to evoke in broad outline these "eighty glorious years". Eight decades along which theoretical works, experiments and observations have answered each other.

Let's start with the world of the infinitely small.

In 1905 Ernest Rutherford brings the confirmation of the corpuscular structure of the matter. At the beginning of this century, it was the electrons whose electrical charge was measured and we were able to weigh them. This is followed by a thorough dismantling of the material. To dismantle, we break, using particle gas pedals .

During these decades, there was no dead time, no latency. The discoveries are accumulating. While for the last five decades scientific journals focused on basic science have failed to fill their columns with credible and tangible work, at that time extraordinary discoveries were appearing, issue after issue, following one another at a frantic pace.

Sometimes these are experimental facts that challenge theorists, who are quick to integrate them into new facets of their models. On the contrary, as did the Englishman Dirac, the theorist proposed in 1931 the existence of new elements of the bestiary. In this case, it proposes to double this one, each particle having its double, of opposite charges, called antiparticle.

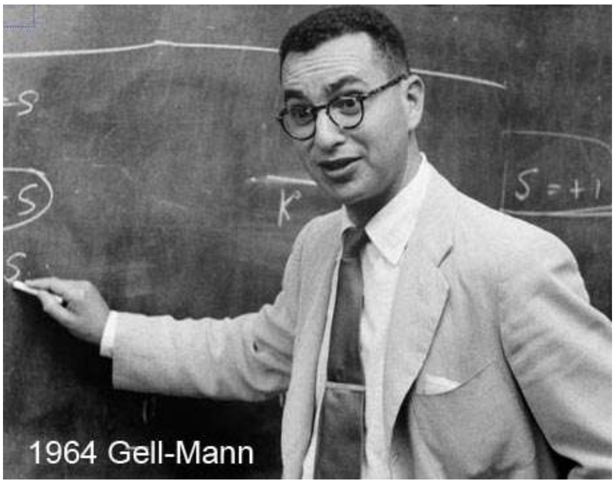
Paul Dirac

This proposal is not received with much warmth. Some, like Niels Bohr, do not hesitate to say:

- Dirac's theory seems to me to be an excellent way to capture elephants in Africa. Indeed, it is enough to hang the article on a tree. If an element passes by and reads it, it causes such a state of amazement in him that he can then be taken over without difficulty.

The creation of antimatter requires very high energies. Fortunately for Dirac these exist in cosmic rays. All kinds of particles are then created and the "Wilson chamber" [1] , which records their trajectory in a magnetic field, allows them to be identified. Soon enough a photograph reveals, next to the trajectory of an electron, that of its twin brother of opposite charge which turns in the opposite direction.

This physics of the particles, known as elementary, represents a rich bestiary. Their study is a new physics, which is also the physics of atomic nuclei. After having disassembled these theorists and experimenters undertake to try to disassemble the mixed constituents of the core. In 1964 a theorist, Gell-Mann, proposed a model where the proton is constituted by an assembly of three "quarks", linked by a force qualified as "strong interaction", where the particle conveying this force is the gluon [2] .



To break the proton into its components, a considerable amount of energy must be used. We are no longer trying to get these protons, these hydrogen nuclei, to hit a target. Two acceleration loops are involved, where packets of protons rotate in opposite directions. Then, when the acquired energy reaches the desired value, as with two railway lines, these flows are diverted to bring these photons to collide head-on. The assembly thus used takes the name of collider.

Physicists are confident. Quarks have fractional electric charges: minus 1/3 and plus 2/3. It has long been known to identify charged particles by recording their trajectories in bubble chambers. If the positive charges turn to the right, the negative exchanges turn to the left. The radius of gyration depends on the mass and charge of the electrically charged particles. The photon taken will thus make it possible to identify the quarks.

But it does not happen as planned. It should be noted that when such energies are used, they far exceed the basic energy of the proton, i.e. its mass, multiplied by the square of the speed of light. Based on the mass-energy equivalent, this energy can be transformed into

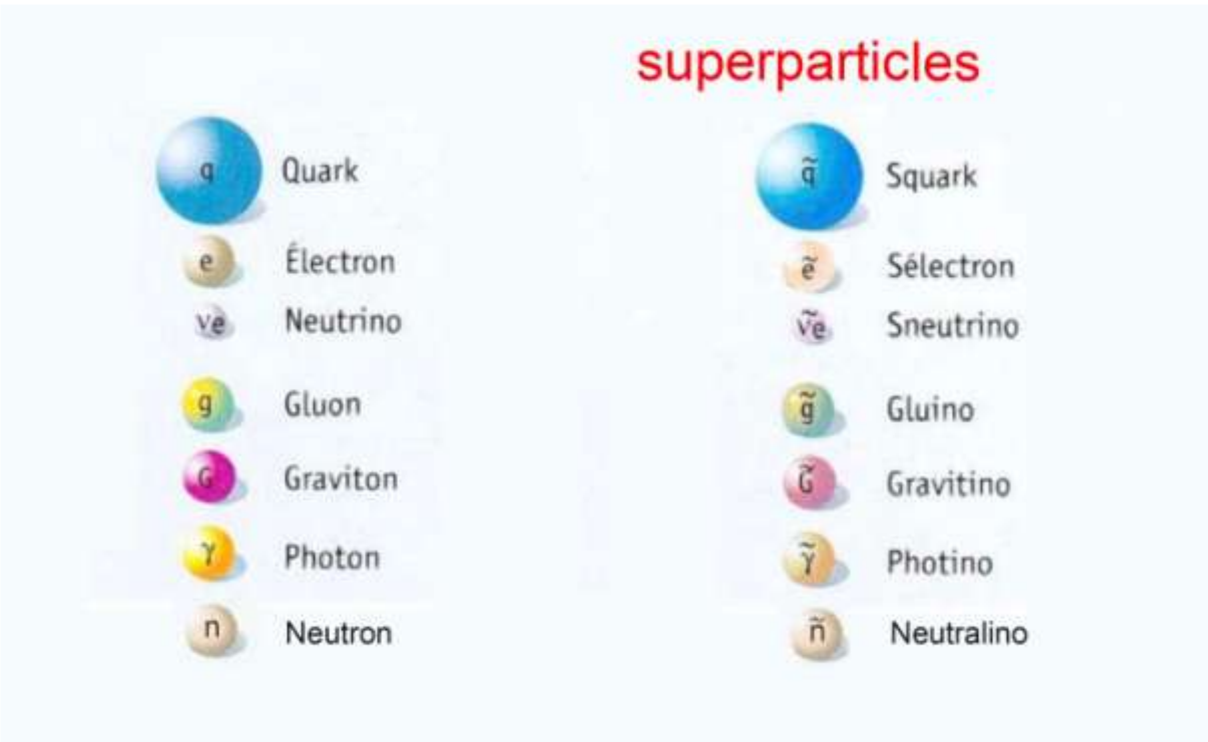
[1] Now replaced by the "bubble room".
[2] The particle carrying the electromagnetic force is the photon.

material particles, with variable lifetimes. The experimenter thus obtains a spray of particles, resulting from this conversion of kinetic energy of the proton into mass. No point of quarks [3] .

Nevertheless the quark model "works". It is now a fundamental part of what is referred to as the standard model. On this basis the theoretical physicists tried to envisage which particles would compose the "cosmic soup" by going further back in time, towards even higher temperatures. The colliders allowed access to the energies that were then supposed to give birth to these particles.

What are they?

They constitute a new bestiary to which one gave the name of "super particles". Thus each of the particles already identified was supposed to have a "double", including the photons, whose associated super particle had received the name of "photino".



The bestiary of super particles.

Note that even quarks are associated with "super quarks"! But none of this is observed, in debate of an increase of the implemented energies! The physics of the infinitely small has

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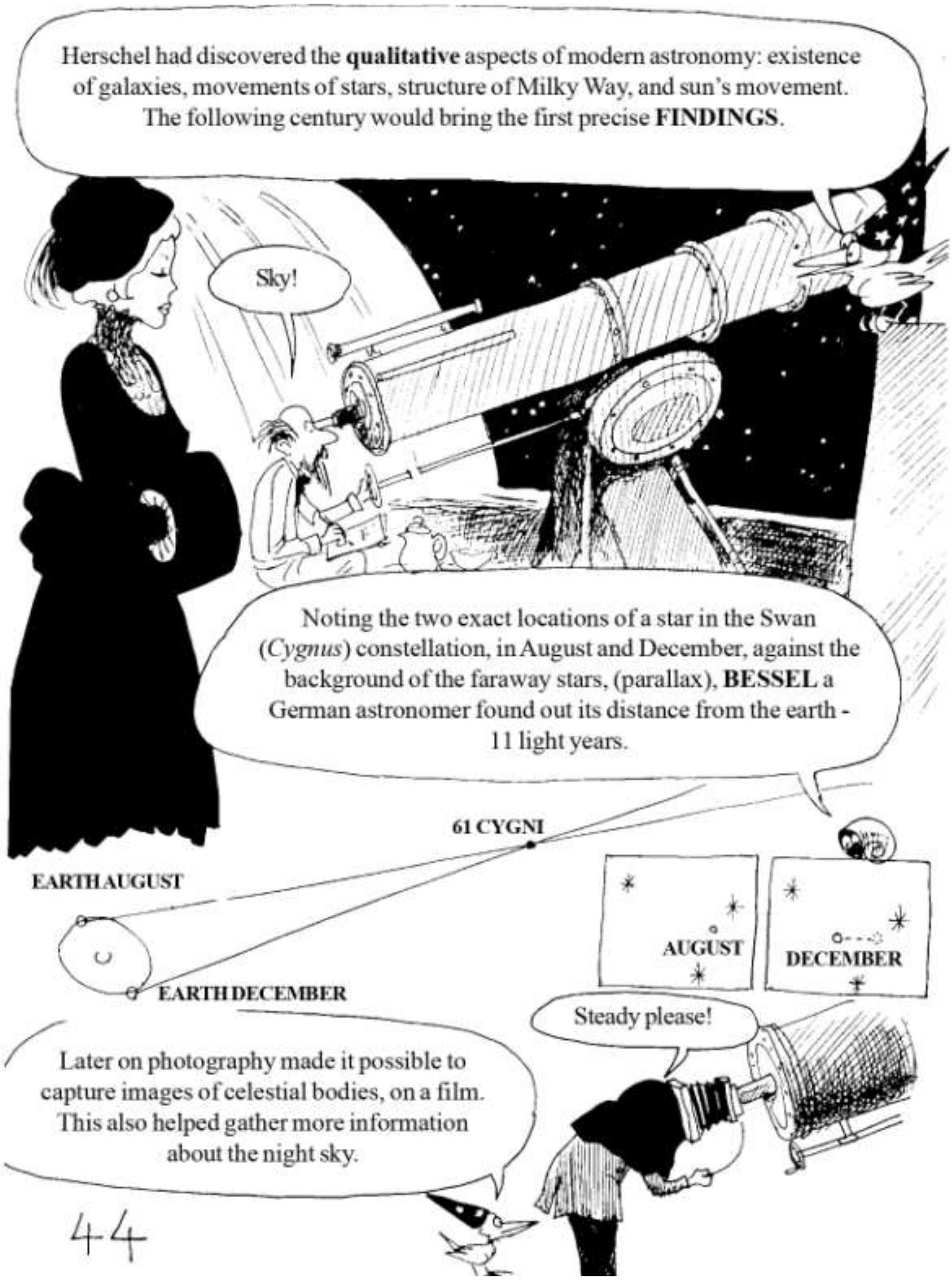
[3] Physicists use Greek words to classify particles. For example, 'leptos' means 'light', so the electron is a 'lepton'. The word 'baryos' means 'heavy', so the proton and neutron are 'baryons'. The meaning of the word "hadros" then tells us about the nature of "hadrons". They are then "numerous". Indeed, when the dislocation of nuclei on impact is supposed to create a "plasma of quarks and gluons", these immediately recombine to give these hadrons, as assemblies of quarks. This process is called "hadronisation". Unstable, these hadrons decay, giving rise to a cascade of decay products.

thus been undergoing a major, essential crisis for decades. Whereas the progress in this field had been entirely focused on the increase of the energy to the impact, with budgets more and more important, pharaonic, more and more scientists doubt that a new investment in this direction can generate new discoveries.

In this field it is not a question of a blue sky in which would remain some small gray clouds, to paraphrase the sentence of Lord Kelvin, but of the most opaque fog.

Let's move on to the world of the infinitely large.

The nineteenth century had opened the door, beyond the solar system, to a quantitative astronomy with the first measurements of distance.

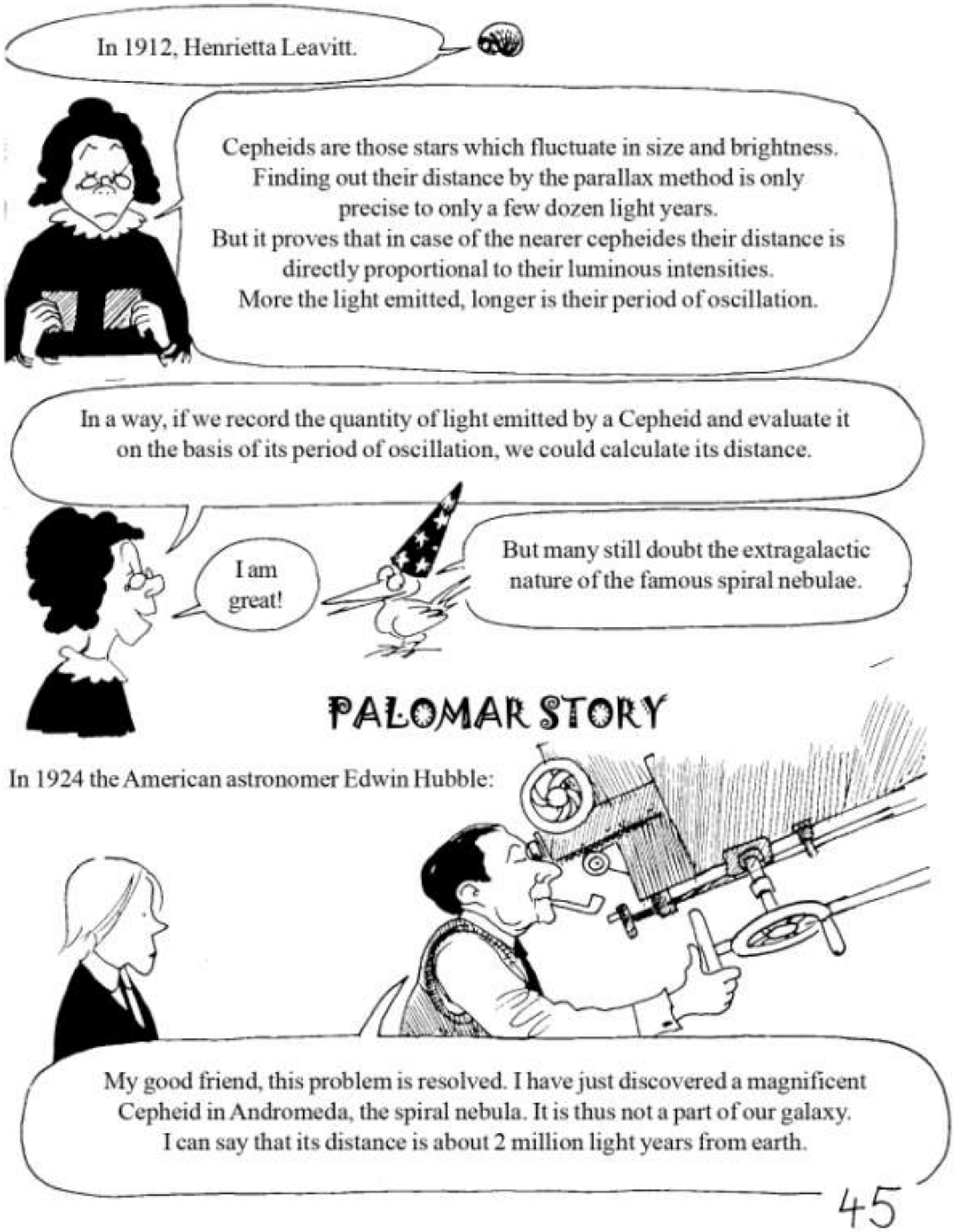


After 185, during the "eighty glorious years" associated with this domain, between nineteen hundred and fifteen and the middle of the seventies, as in particle physics, the observational and conceptual progresses answer each other.

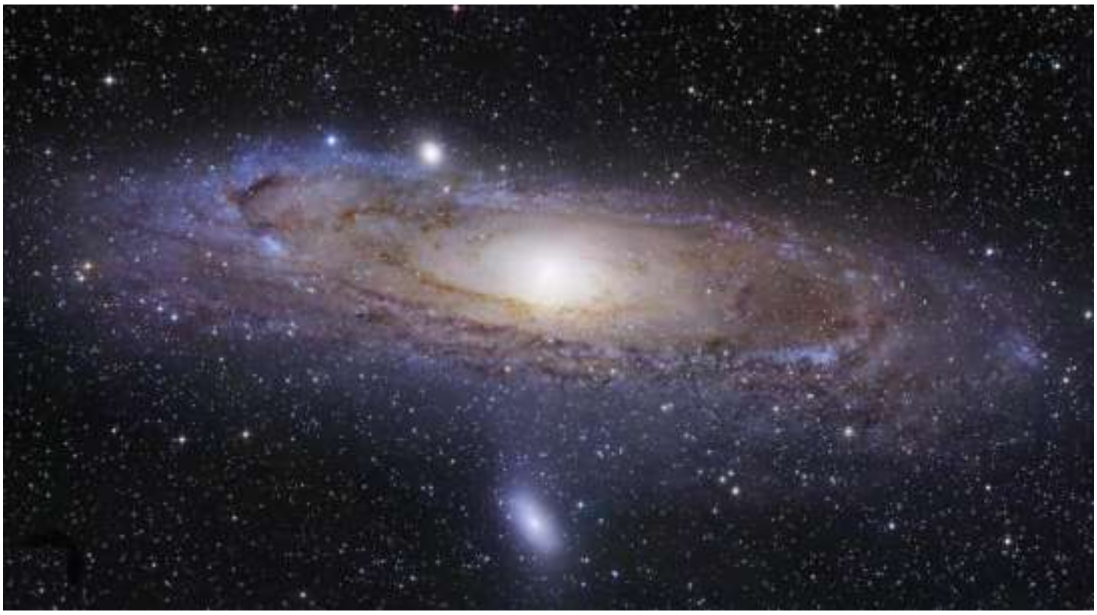
The first major advance was the publication, by Einstein, in 1915, of his field equation, with the first immediate application: the explanation of the advance of Mercury's perihelion.

Very quickly a second observational confirmation of the model is obtained: that of the deflection of light rays by the masses.

In 1912 a woman, Henrietta Leavitt, made a fantastic discovery, which will allow the measurement of large distances.



Thanks to this discovery, the galaxies, previously known as "nebulae", are identified with groups of stars, the closest, the Andromeda galaxy, being 2.5 million light-years away from ours.



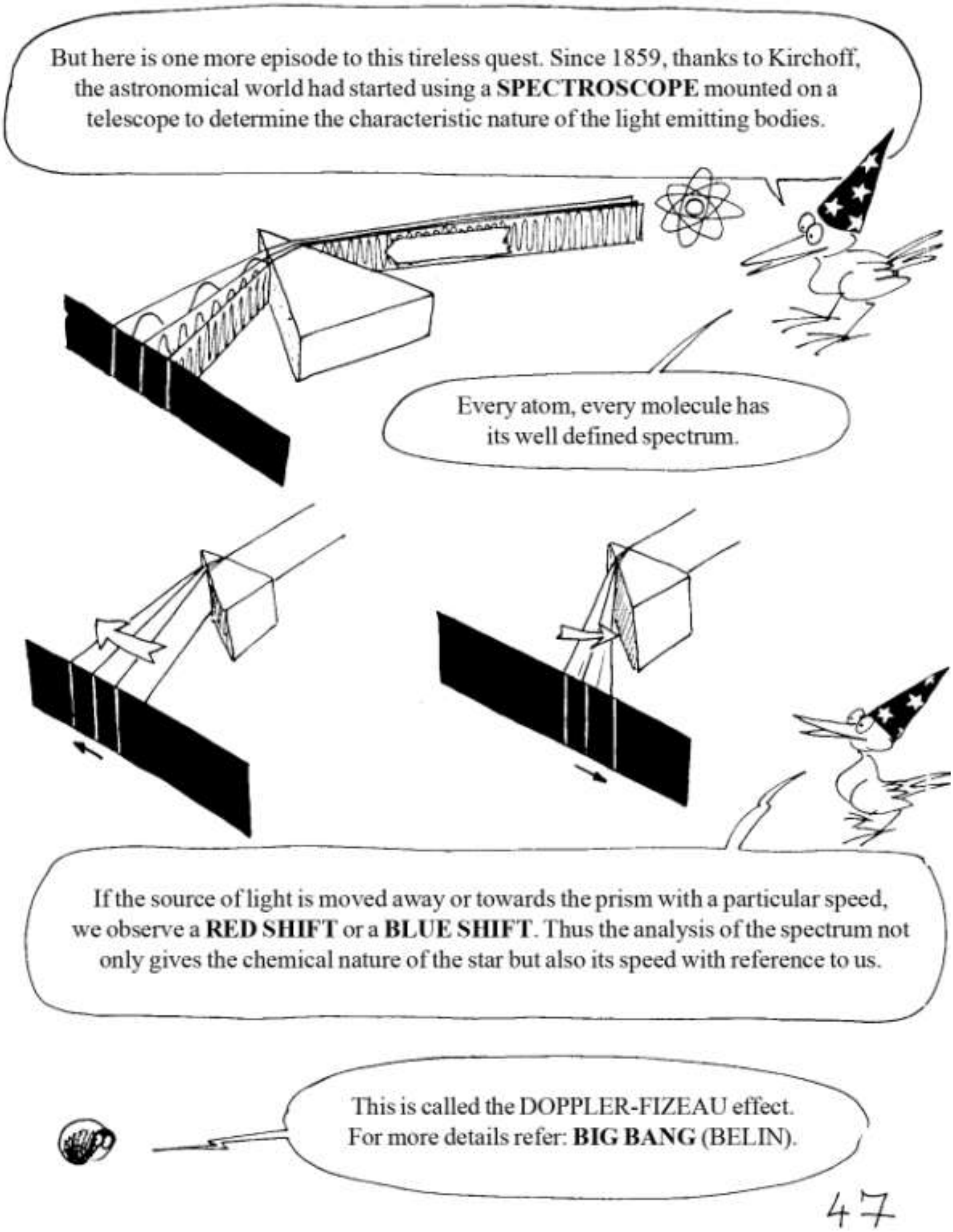
The Andromeda Galaxy.

On the observational level, the implementation of more and more powerful telescopes brings a harvest of discoveries.

Spectroscopy provides a wealth of information on the composition of stars. The measurements also allow us to evaluate the temperatures [4]. Combined with the progress of particle physics, the discovery of the energies released by the various fusion reactions, theorists conceive models of stars, classified according to their masses. The many images

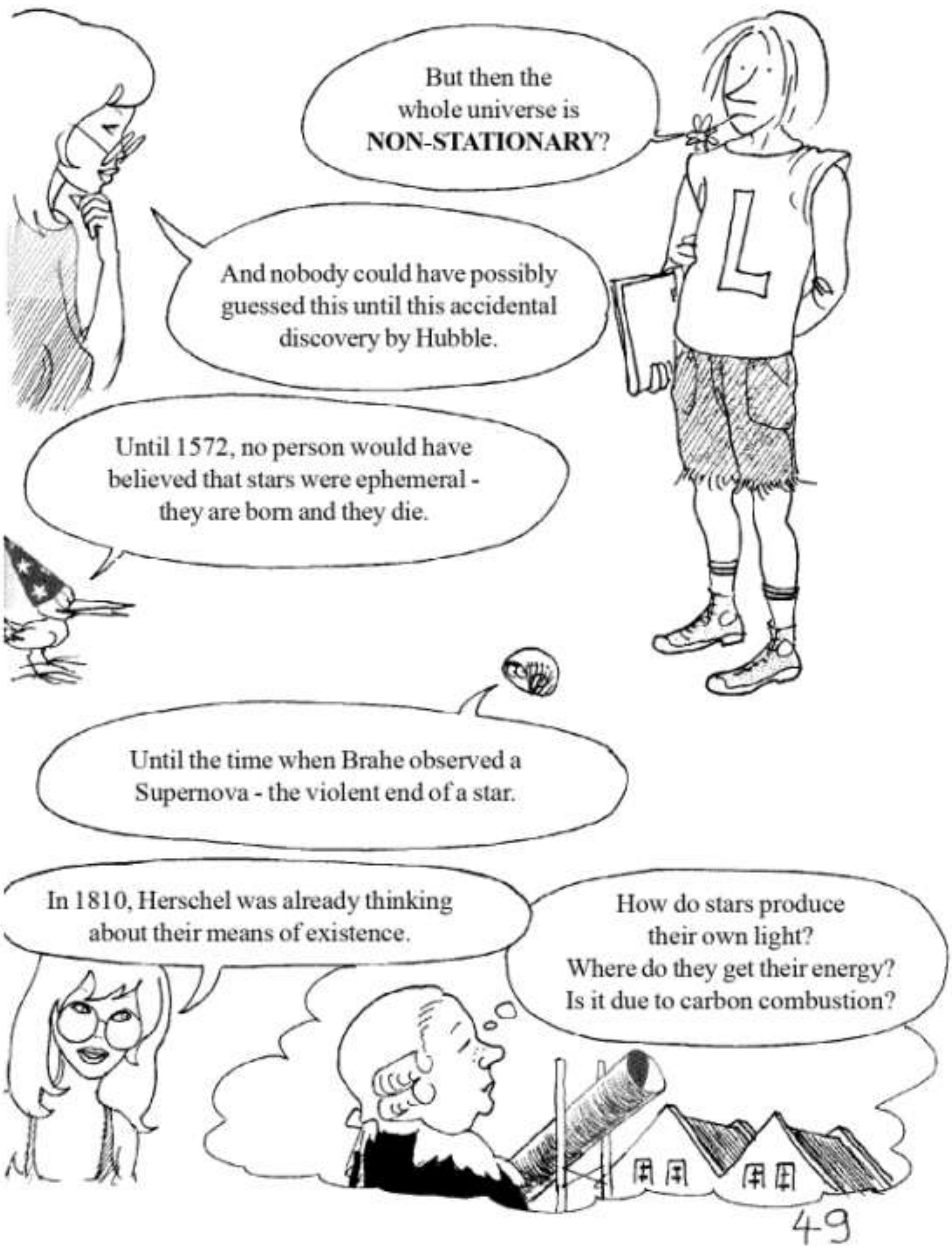
[4] By the broadening of the spectral lines, linked to the thermal agitation in the medium emitting this light.

available allow us to draw up scenarios of stellar evolution. Astronomers use the Doppler effect to estimate the speed of objects.



This will allow, in the twenties, Edwin Hubble and Milton Humason to discover the expansion of the universe;

What is quite extraordinary is that before the twenties, when the cosmic instationnarity was highlighted, nobody would have imagined that the universe could have existed otherwise than as it is currently observed.



This unawareness of a possible cosmic evolution is particularly visible when one examines carefully the article published by the mathematician David Hilbert in 1915. Since the text is only accessible by acquiring a book or by consulting it in a library in its English translation, it is relatively unknown, except to a handful of historians of science. Adding that they do not automatically have the mathematical background that allows them to grasp all the subtleties. Still, Hilbert, born in a protestant family, does not explicitly describe the birth of the universe. But, as the geometrical context is presented, there is an origin of time, which is then of a different nature from the space coordinates [5] . The cosmic contents are then simply "there", as they present themselves to our eyes.

This total unawareness of a possible cosmic evolution is also shared by Einstein, who will try to build a first stationary universe. The force of gravity then tends to cause the collapse of the universe. To prevent this, Einstein borrowed from David Hilbert a complement to his equation, the cosmological constant, which reflects the repulsive power of the vacuum.

Before David Hilbert's modification:

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} = \chi T_{\mu\nu}$$

Once this addition is made :

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda g_{\mu\nu} = \chi T_{\mu\nu}$$

But, very quickly, the observation highlights the phenomenon of cosmic expansion. The Russian Friedman modeled the phenomenon in 1922 by producing an unsteady solution of the Einstein equation.

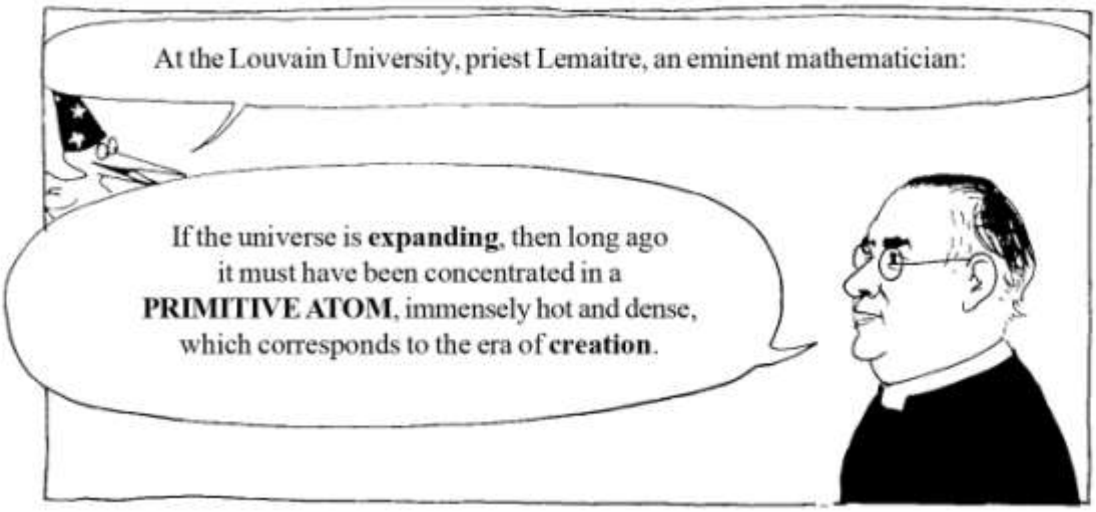
Quite depressed, this one would have declared:

[5] In David Hilbert's cosmological view time is a 'pure imaginary' quantity. This differs from Einstein's view that time is only one of the other coordinates of the space-time hyper-surface and could be measured in metres.

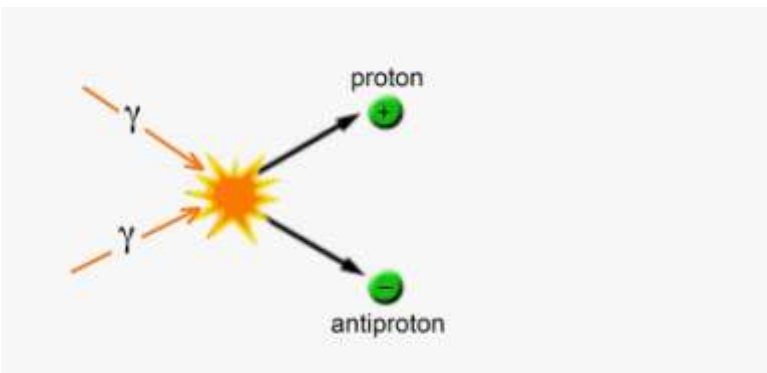
- If I had known that the universe was evolving I would have found this solution before Friedmann.

The cosmological constant does not seem to be necessary anymore to describe the evolution of the cosmos; this will make Einstein say that "its use was the greatest mistake of his career".

A Belgian priest, the abbot Lemaître, very aware of the works of general relativity, seizes this idea: If the universe is in expansion, then, going back in the past, we must reach an instant zero, that of the divine creation by God.

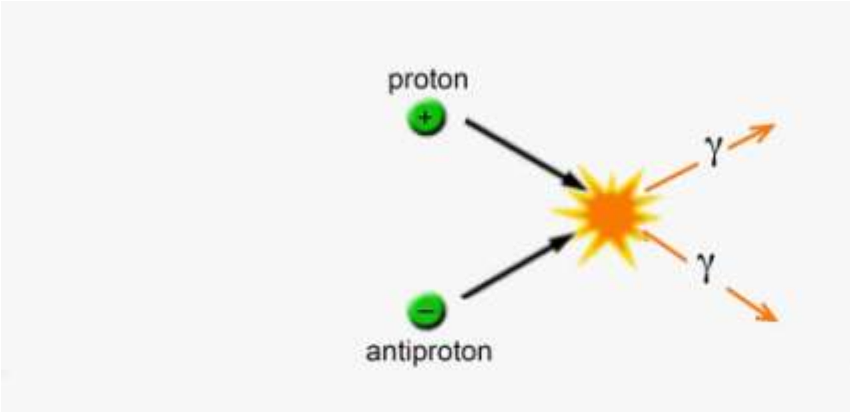


An English astrophysicist, Fred Hoyle, gave a name to this moment; the Big Bang. But what matters is the observational evidence. These will emerge in 1965. Indeed, by combining this idea of a very dense and very hot universe, in the distant past, with the theoretical data of particle physics we conclude that before the first hundredth of a second the universe must be the scene of two fundamental reactions, each being the inverse of the other. On the one hand, high energy photons, corresponding to gamma rays, give rise to particle-antiparticle pairs. For example to a couple formed by a proton and an antiproton.



Synthesis of a pair of particles from photons .

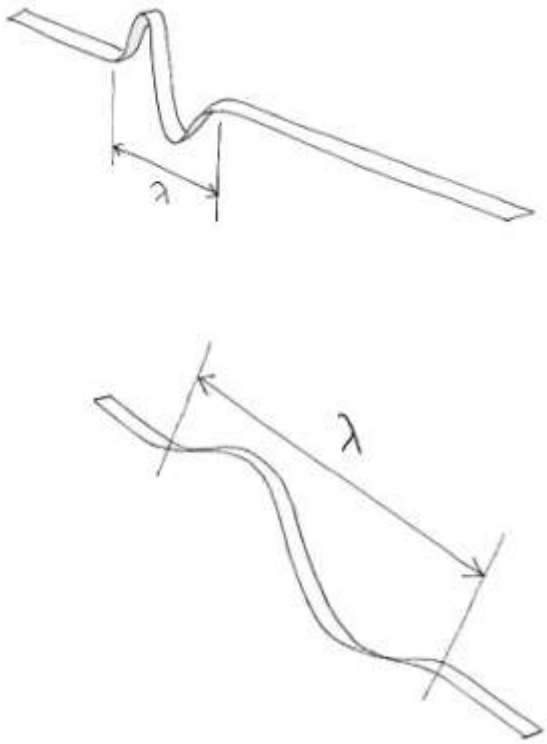
But these two particles, of opposite electric charges, attract each other and will go to annihilate a little further by giving again gamma photons:



Annihilation of a particle-anti-particle flow.

As in chemical systems a state of equilibrium is established, and in this state the universe, in the first thousandth of a second, is a mixture of matter, antimatter and photons, all these components spending their time changing nature at a frantic pace.

But the expansion plays its role by cooling the "photon gas". In fact, and we will come back to this bridge later, the wavelengths of photons cross at the same time as the universe itself. These photons do not travel in an expanding space, they are this space. We must imagine a kind of sheet crossed by undulations. As the sheet expands, the wavelengths follow this movement, as shown in the image below:



The extension of the wavelength of the photons which follows
the phenomenon of the cosmic expansion.

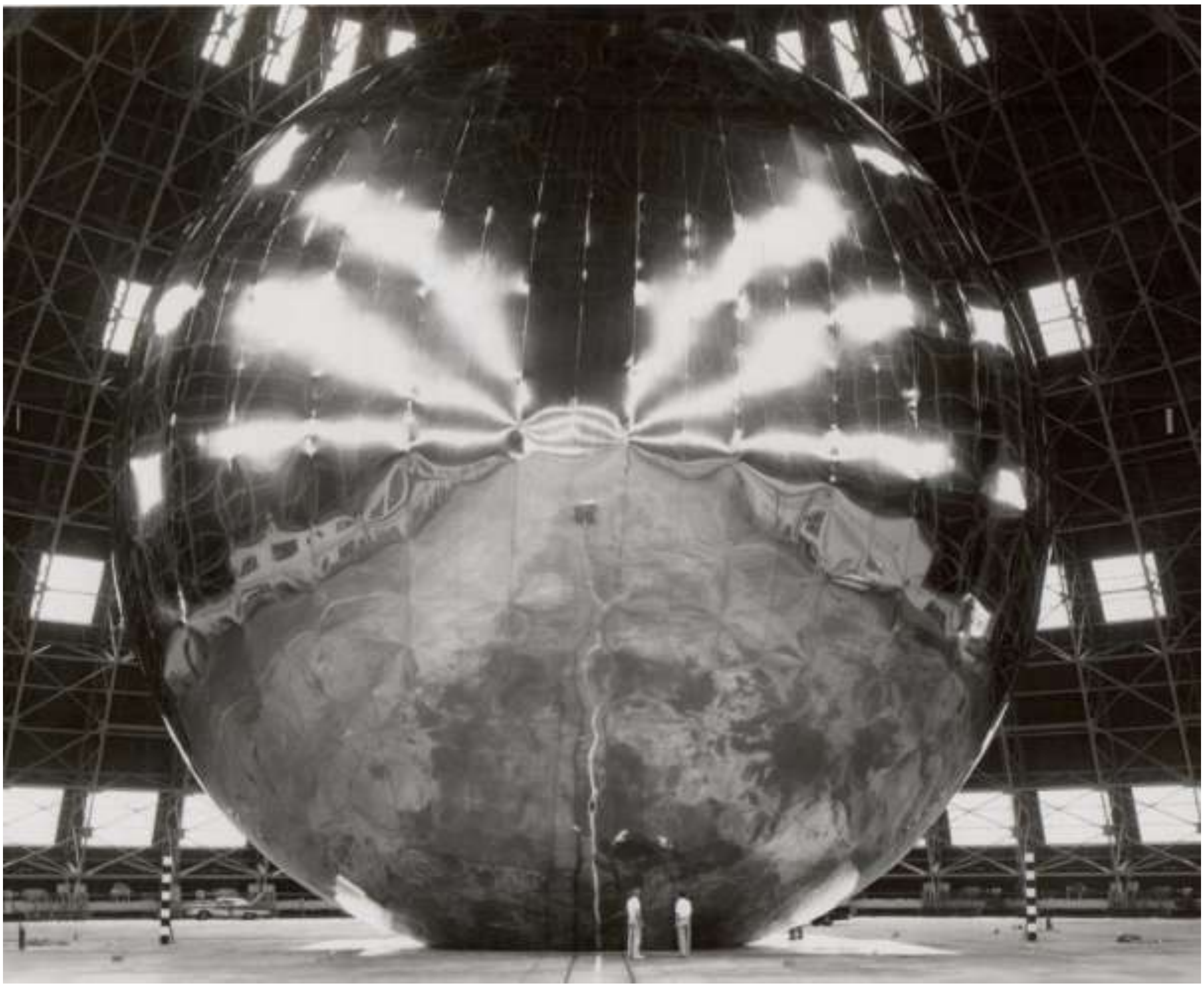
But the energy carried by the photons varies as the inverse of their wavelength. Therefore, after this first hundredth of a second, these photons are no longer able to compensate for the disappearance of particle-antiparticle pairs. These couples will then disappear by giving photons. These can be considered as the "ash" of this matter-antimatter annihilation reaction.

The expansion continuing its work the wavelengths of these photons will continue to stretch. At the present time their wavelength is measured in centimeters.

The visible light corresponds to wavelengths in microns, in fractions of thousandths of millimeters. Beyond, for shorter wavelengths, beyond that which is visible, that is to say the violet light, is the ultraviolet. Then, beyond that, X-rays. And pushing even further gamma radiation.

Conversely, for longer wavelengths, beyond the red, the last color of the visible spectrum, stands the infrared, plus the range of radio waves. The waves whose wavelengths are in centimeters, the centimetric waves, are radio waves.

In the sixties the Americans had joined the Russians in putting objects in orbit. They thought of placing a mylar balloon in orbit around the Earth, covered with a reflective metallized film. The idea was then to use this object as a reflector of radio waves, so as to facilitate communications at very great distance.

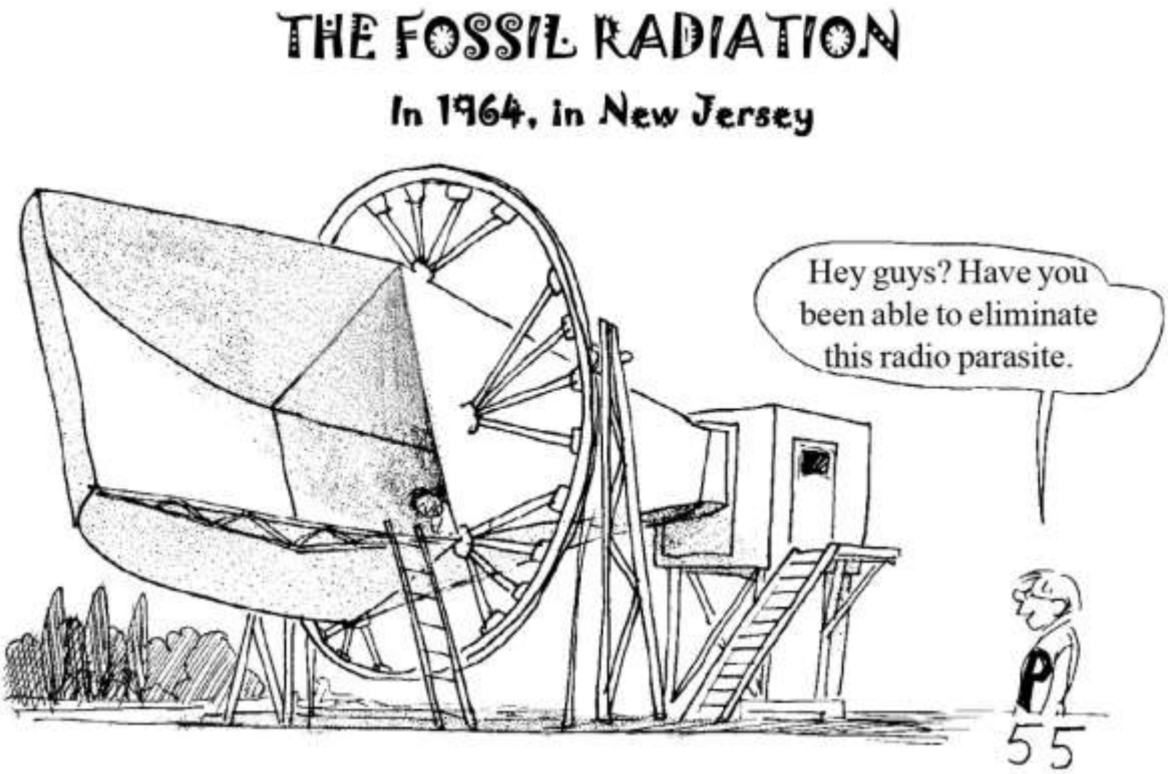


The Echo satellite balloon. Here in a hangar used to house airships.
The size of the characters gives the scale.

The receiver of the radio waves had the shape of a big acoustic horn, orientable and had been conceived by two American scientists, Robert Wilson and Arno Penzias, responsible for the whole project.

Project Echo Receiving Antenna

It is very common that important discoveries are made by chance. Indeed, neither Penzias nor Wilson were concerned with cosmology or high energy physics. They were very surprised to find that their antenna was picking up a very clear radio signal, while the echo balloon had not even been placed in its orbit. Everything was then considered, including that a couple of pigeons having established their nest in the antenna could be responsible for this phenomenon. The pigeons were therefore captured and released far from the antenna.



Not surprisingly, they immediately returned to what they considered their marital home. Penzias and Wilson then took action. The pigeons were killed and eaten.

But the reception of the parasite, in the range of the waves centimeters was maintained[6]. Even more, trying to locate the source of this emission, the two scientists pointed their antenna in all directions. But not only did the reception continue, but the intensity of the signal was the same, whatever the direction chosen. Finally the explanation was brought by a Princeton theorist, a certain Dicke, who told them:

- Congratulations guys. You have just made an extraordinary discovery. You have just brought the proof of the Big Bang theory.

[6] The emission of radiation from a "photon gas" at a radiation temperature T leads to a wavelength, expressed in metres = 0.0144/T. Today, precise measurements put this radiation temperature at 2.7 °K. This corresponds to a wavelength of 5.3 cm.

At the beginning of the seventies, when I was a researcher at the Marseille Observatory, the central problem of cosmology was to choose between the three possible solutions resulting from the construction of the unsteady solution found by Friedmann. The criterion is around the value of the average density of matter in the universe. I located this problem at the end of a comic book, the "Geometricon", and so I will illustrate this point in that form.

The critical value of the density is 10-29 grams per cubic centimeter. Another drawing helps to understand how the Friedmann model works. Let's imagine two roller skates each carrying a magnet. As they are initially placed, these magnets have opposite poles. So they attract each other and this attraction will represent the force of gravity. At the initial moment of this weighing experiment, a spring is placed between them which will give them an impulse by throwing them in opposite directions.

Roller skates equipped with magnets and a spring.

When the skates are released, they will receive a boost from the spring. Everything depends on the strength of the magnets. Too weak, their action will quickly become negligible and the skates (in the absence of any friction of course) will continue their course at constant speed. If, on the contrary, this force is important, after having moved away at a certain distance, they will fall back on each other at an accelerated speed, re-compressing the spring, which will project it again at a distance, etc. This will result in an oscillating system. 1

Between the two, an intermediate situation where the attractive action of the magnets is never negligible, but is not sufficient to cancel their speed and make them fall against each other.

Replace the force of magnets by that of gravity, during the density of matter generating an attraction and you will have the three Friedmann models. At the end of the sixties the search for the determination of the average density in the universe was at the heart of the concerns of cosmologists. At the same time consensus had appeared, the specialists of cosmology agreeing to think that the finding lambda, in the field equation, should be, if not zero, at least negligible. It will be seen that the following events were to lead them to seriously revise their position on this precise point.

Let's go back to the position of Lord Kelvin who, at the end of the nineteenth century, thought that the scientific panorama was a beautiful blue sky, where only a few small gray clouds remained. Let us return then to this discovery made by Penzias and Wilson, of this cosmic ash. How is it that this annihilation was not complete, leaving only a universe populated by photons? The fact remains that we are here. The observation leads to the conclusion that this matter which survived, forming the galaxies, the stars, the planets, us, represents only one particle of matter on a billion. But then, in these conditions, where is the equivalent amount of antimatter?

Everything was tried to discover where this primordial cosmological antimatter was hidden. One went so far as to consider that this separation took place, without specifying how, at the level of galaxies. So there must have been galaxies made of antimatter. These galaxies would contain anti-stars, made of anti-atoms of hydrogen, helium and other components. Around these anti-stars would orbit anti planet, etc..

These objects would not emit anti photons, but photons that our telescopes could then capture and that would not differ in any way from those that we have stars made of matter, and one of antimatter.1 Indeed the photon is the only component of the bestiary of the particles which does not have its complement. All particles are defined by a certain set of quantum numbers, which can take the values

(- 1 ; 0 ; + 1)

Its matter-antimatter symmetry consists in reversing all the quantum numbers. The photon has a particularity: all its quantum numbers are equal to zero. But plus zero is the same thing as minus zero.

Since antimatter has positive mass and is self-attracting, all this seemed scientifically possible.1 Knowing that if conscious anti-beings inhabited these anti-planets, any encounter between them and us would be forever impossible, on pain of immediate mutual annihilation.

But it turned out that collisions between galaxies were common phenomena. However, if a single encounter between a galaxy of matter and a galaxy of antimatter had occurred somewhere in the universe, the signal emitted in the form of gamma radiation would be perceived, with our instruments, even if it was emitted at the limits of the known universe.

Collision of two galaxies .

It was thus deduced that this cosmological antimatter was purely and simply beyond observation. Where had it gone? What had become of her? Nobody had a clue.

But this is where you need to be aware of a precept that is the precept of scientists. In all languages we find the equivalent of the proverb:

What I don't know doesn't warm me up[7] *.*

Transposing this into the world of astronomy and cosmology this becomes :

What I don't observe doesn't warm me up.

Indeed, do you see any trace of concern about this non-observation of primordial antimatter within the scientific community? Not really. The question is treated in a few lines in all the popular books, that's all.

No enlightening articles in specialized scientific journals either. No funding for research programs. When a laboratory or a university undertakes to create a conference on a given subject, everything starts with a "call for papers". Can we then imagine that a symposium is held on this question of primordial antimatter? There is none, simply because it is a "non-topic" [8] , that nobody has anything to say, nothing to propose, except the late Russian Andrei Sakharov, who will be mentioned later.

Let us continue this exploration of the discoveries that marked the pre-war and immediate post-war period.

The models of nuclear physics have driven the understanding of the functioning of stars. In the nineteenth century, people knew that the little twinkling lights that dotted the sky were other suns. The exploitation of the phenomenon of the parallax had allowed an estimation of the distance at which the closest stars were located, whose enormity had surprised many. As the Sun dispensed its energy on Earth, the question that haunted physicists was "how does it produce its energy? Some had even imagined that this energy could come from the combustion ... of coal!

On this subject, we recall a rather tasty anecdote:

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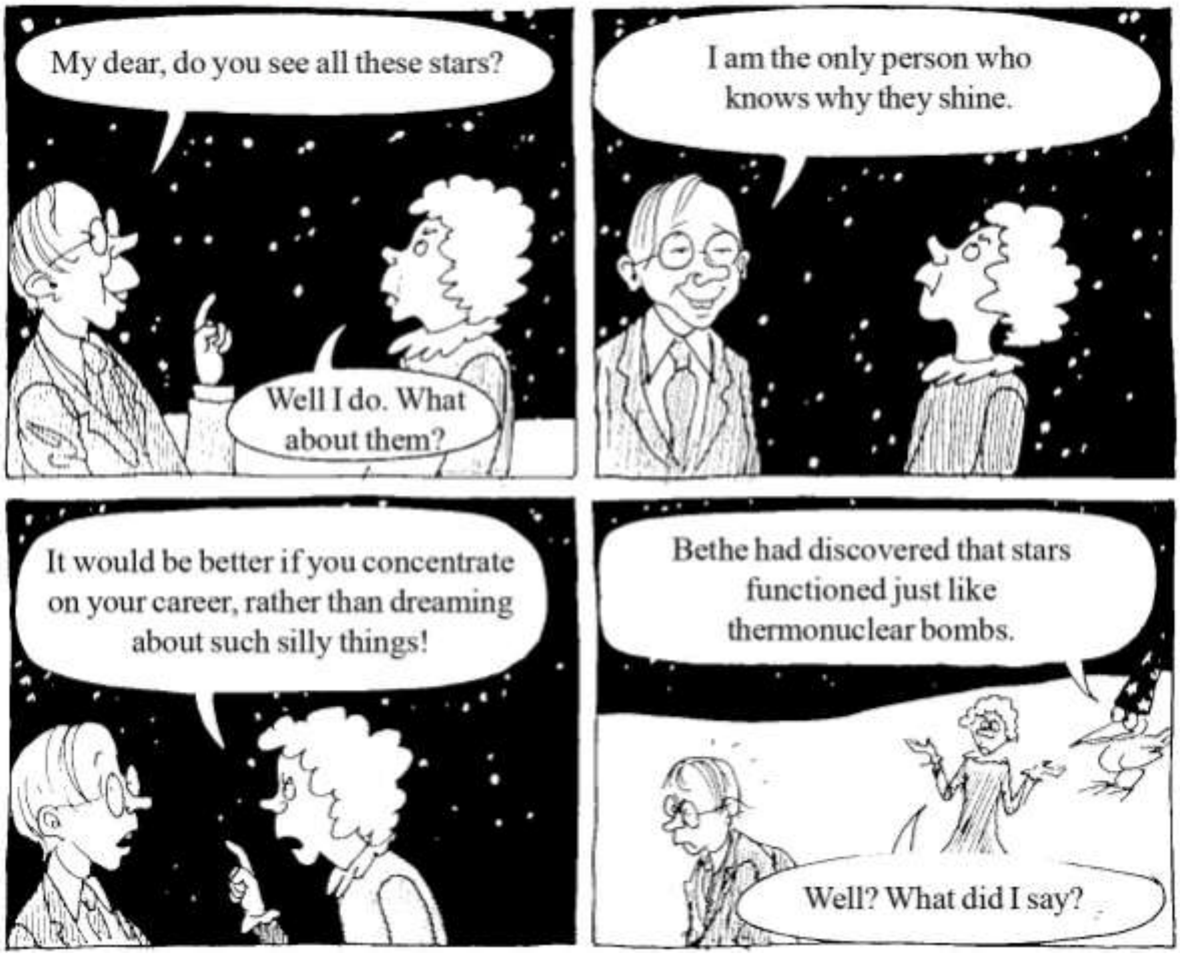
[7] The translator should look for the equivalent expression in the target language.
[8] We will see later that this is not the only issue. The issue of the Repeller Dipole has also been ignored by the scientific community, even though it is a major discovery.

A young German researcher: Frtiz Houtermans



Theoretical models were refined and astrophysicists understood that, according to their mass, stars had very different fates. At the beginning of the thirties an American of Swiss origin, Fritz Zwicky, predicted that beyond a certain mass [9] the stars should know catastrophic, explosive ends and he gave to this phenomenon the name of supernova. The idea was met with great skepticism. Stubbornly, Zwicky set out to track down the phenomenon, which gave these stars a luminosity so strong that they signaled their presence, fleeting (on cosmic time scales, that is. This excursion of luminosity is maintained during some months).

[9] More than 8 solar masses.

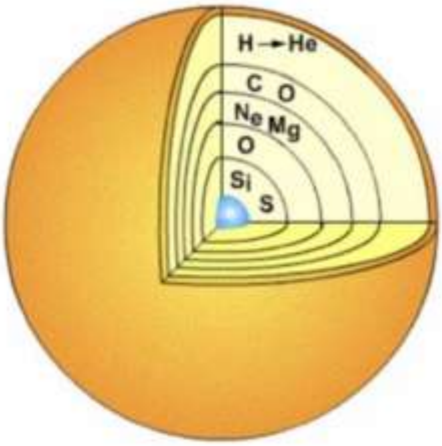
Fritz Zwicky in observation.

Zwicky compared a large number of photographs of galaxies until he detected a revealing light spot on one of them. Of course, at first, his colleagues laughed at him and told him that it was only a defect of the photographic medium. But the examples accumulated and it was necessary to contain that in a handful of galaxies, extremely powerful sources of light had suddenly appeared, which had then disappeared. The following photograph shows a picture of the galaxy NGC 4526, taken in 1994, on which we detect the presence of a supernova, on the left, a luminous spot which disappeared after a few months.

This supernova, below and left, appeared in 1994,
is part of one of the arms of this galaxy, not very visible.

Here we must note an essential point of astronomical observations. A galaxy like ours contains two hundred billion starts. And there are a huge number of galaxies in the universe. Thus, if such an object exists, or if the existence of such a phenomenon is conjectured by a scientist, it may be difficult to find a first example. But then, the number of objects or the number of these events, if they do exist, will grow exponentially. The phenomenon of supernovae is a typical example. When the first ones were discovered, they were given names. Today we have counted tens of thousands of them.

Zwicky was a visionary, who had a very fine perception of a great number of mechanisms at work in nature, which he knew how to combine. At the beginning of the thirties, during a memorable conference, he described the whole scenario of the supernova. When they run out of fusion fuel, these massive stars suddenly collapse on themselves in a few thousandths of a second. At the heart of the star is a sphere of iron. The fusion reactions follow one another, in massive stars, giving birth to heavier and heavier atoms, up to iron.

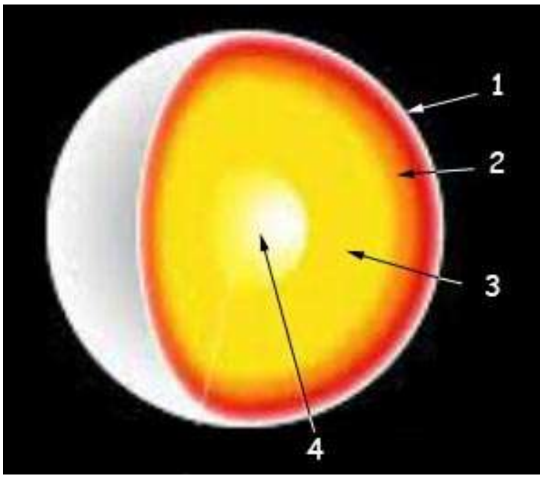


Internal structure of a massive star. In blue, its iron core.

The iron is the ash of the fusion reaction. Ash does not burn, which means that no energy can be extracted from it. Zwicky then calculates that this implosion of the star must result in a compression of this iron sphere, such that its atoms are dislocated into their components, protons, electrons and neutrons.

If Zwicky can envisage such a scenario it is because, precisely, neutrons have just been discovered, in 1932, by a certain James Chadwick, a British, student of Rutherford (discoverer of the first atomic nuclei in 1905). And then you come across something extraordinary: when an experimental discovery immediately boosts the progress of the theoretical model. Un phénomène qui est totalement absent dans le monde entier, depuis des années soixante-dix, où les découvertes expérimentales effondrent, l'une après l'autre, les certitudes de théoriciens.

It is indeed Zwicky who imagines that a singular star, the neutron star, could be formed after this fantastic compression.



Neutron star, internal structure :

1 - Iron
2 - Protons, neutrons, electrons.
3 - Neutrons, protons, mesons
4 - Neutrons

Here again the question of the existence of such objects in the universe arises. The confirmation did not occur until 1967. At that time the astrophysicist Anthony Hewish and his assistant Jocelyn Bell detected a pulsed radio signal with the help of the first radio telescope installed, listening to the cosmos.

Indeed this emission of radio waves comes from the extremely fast rotation of pulsars, which is usually of the order of a thousand revolutions per second. Their magnetic field is also extremely intense. And a rotating magnetic field generates radio waves.

We must now take stock, at the dawn of the seventies, of what, already, did not fit into the cosmological model.

In 1963 the phenomenon of quasars[10] was discovered. Their discovery was only possible because a researcher dared to consider something absurd: that the center of a galaxy can behave like a small source, which emits as much energy as the whole galaxy, that is to say hundreds of billions of times more emissive than the stars which compose it. A story that shows that for a discovery to be possible it is sometimes necessary for the scientist to put aside the barrier of his skepticism.

[10] A word derived from the contraction of "quasi stellar objects".

THE QUASARS

Observatory of Pasadena, Professor Jesse Greenstein has a new student Thomas Matthews.


I have been analyzing spectrums for years now, and I have never come across anything like this. No star emits light like this.
As it is completely in the red zone. Could it be because of the Doppler Effect? i.e. released from hydrogen and moving at a tremendous speed.
Thomas, according to Hubble's law the speed is proportional to the distance. So, if this star had such a terrific speed, it would be definitely far away. And in this case this minute particle which is 50,000 times smaller than the Milky Way, would emit 100 times more energy.
You may leave….
This is the price I have to pay...
What does he know about spectroscope? He is a radio astronomer.


ONE YEAR LATER.
Maarten Schmidt:
Hey, Jesse, did you see the spectrum emitted by these strange objects, "quasi stellar", these quasars which were detected one year back.
Yes Maarten.
This Dutchman is so calm....
Do you see this spectrum of hydrogen.
You superimpose it and slide it towards the red.
And they are now identical.
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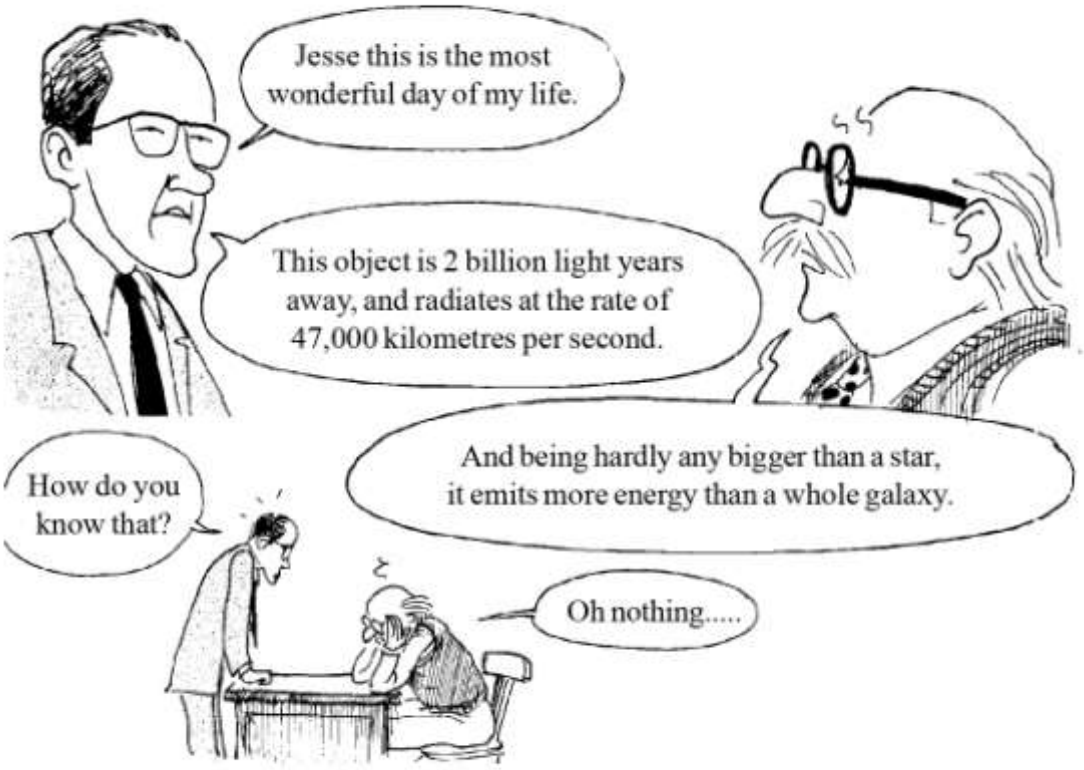
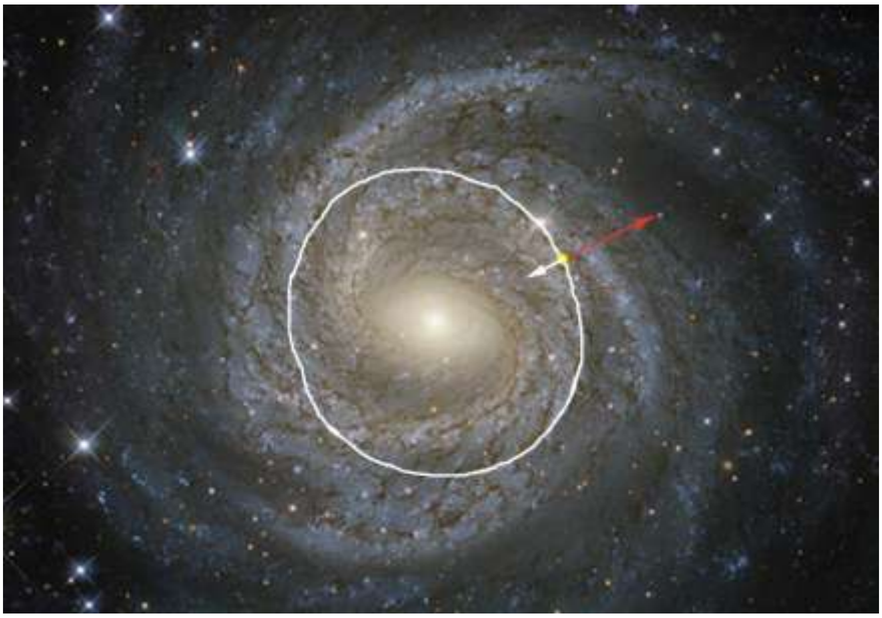


As I write these lines, more than sixty years have passed, and no one has the slightest hint of an explanation for such a phenomenon.

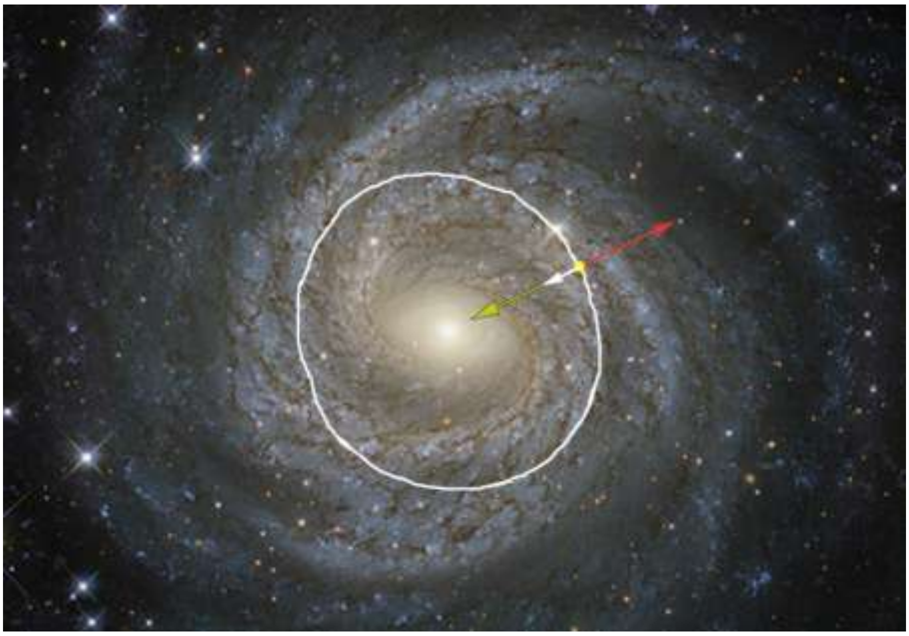
What else?

At the beginning of the seventies, more precise measurements of the orbital velocities of objects in galaxies began to arrive. The stars in the galaxies, have trajectories close to circles. The state of equilibrium is therefore deduced from the fact that the centrifugal force must be balanced by the gravitational force. This is far from being the case:



The force of gravity, deduced from the distribution of mass in the galaxy, white arrow, is 5 times weaker than the centrifugal force, red arrow, which exerts on the stars.

Astrophysicists have deduced that galaxies must contain a mass that escapes observation. Everything was tried to identify this missing mass, which was eventually designated under the name of dark matter.



The additional gravity force, green arrow, attributed
to a dark matter of unknown nature.

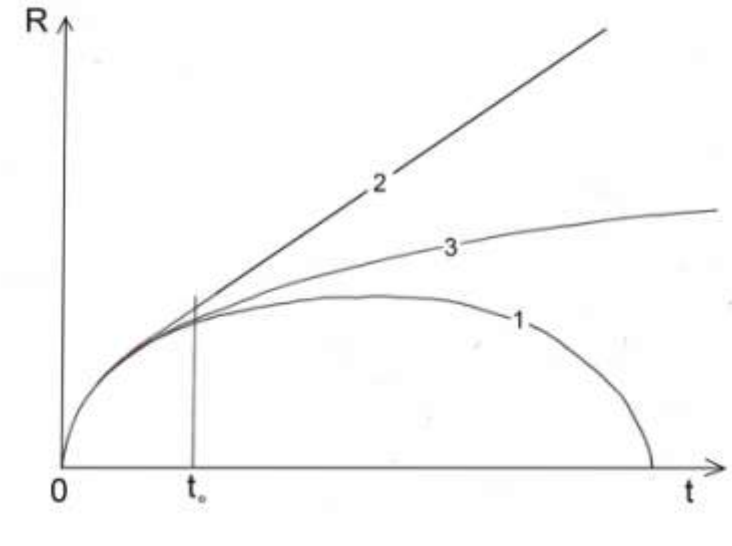
This totally modified the whole cosmological model, with a singularly degraded general content:

In blue: the percentage of dark matter.
In yellow: the percentage of observable matter.

This description of the contents of the universe would only be valid if this, or these invisible components could be identified. But to date there is no model of dark matter and no experiment to detect it has worked.

The panorama of scientific knowledge is beginning to become seriously obscured.

The solution of Einstein's equation, found by the Russian Friedman, led to three types of possible solutions, depending on whether the value of the average density of the universe was less than, equal to, or greater than a certain value[11]. Think of the spring-loaded roller skate model. They correspond to the following three curves.



Curve 1: after a maximum expansion, the universe collapses on itself.

[11] 10^{-29} gram per cubic centimeter.

Space is supposed to have a positive curvature.
Curve 2: Soon enough gravitation stops playing a role and the expansion of the universe then takes place linearly with respect to time. The curvature of space is then negative.

Curve 3: Intermediate situation of a parabolic expansion.
The curvature of space is zero. The space is "flat";

But these three solutions gave the same behavior, close to the origin of time. The fact that the tangent to the curve at the origin is vertical indicates that the particles at t = 0 are moving away from each other at an infinite speed. Thus higher than the speed of light.

to represents the current time. Only the parts of the curve on the left can be compared with observational data. The parts on the right are only speculative.

When it comes to data from the past, how far back can we go?

Given the time that light takes to reach us, the observations allow us to have access to a part of the past of the universe. As the universe is expanding, the Doppler effect causes a "red shift" of the captured light. The optical instruments we have can not operate in all wavelengths. Beyond the red, we first find what is called the near infrared. Our retinas cannot capture this light, but space telescopes like the Hubble telescope were equipped with instruments sensitive to this type of radiation[12].

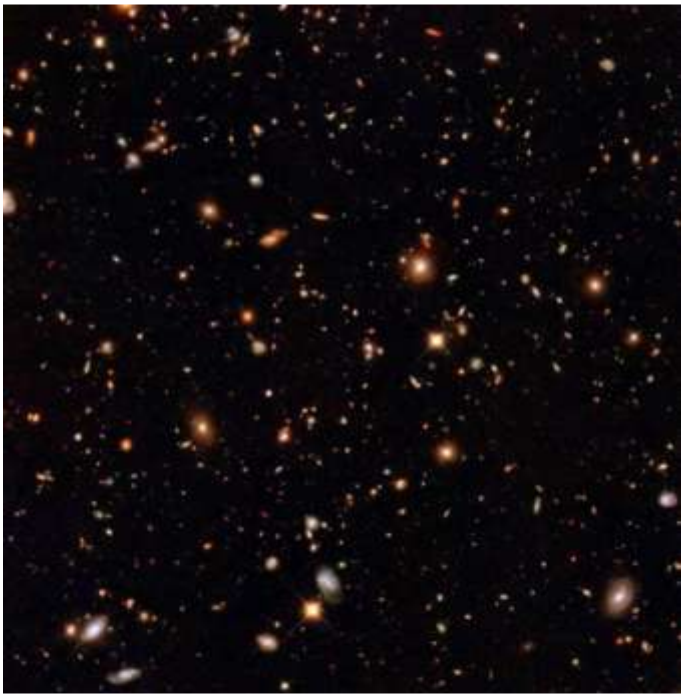
Hubble Space Telescope.

We then produced images "in false colors" by equipping these distant galaxies with a red color so that, on the pictures, we can see them.

[12] The longest wavelength that the human eye can perceive is 0.78 thousandths of a millimetre or microns. The Hubble Space Telescope is equipped with a camera capable of recording images at wavelengths up to 2.4 microns, the so-called near-infrared.

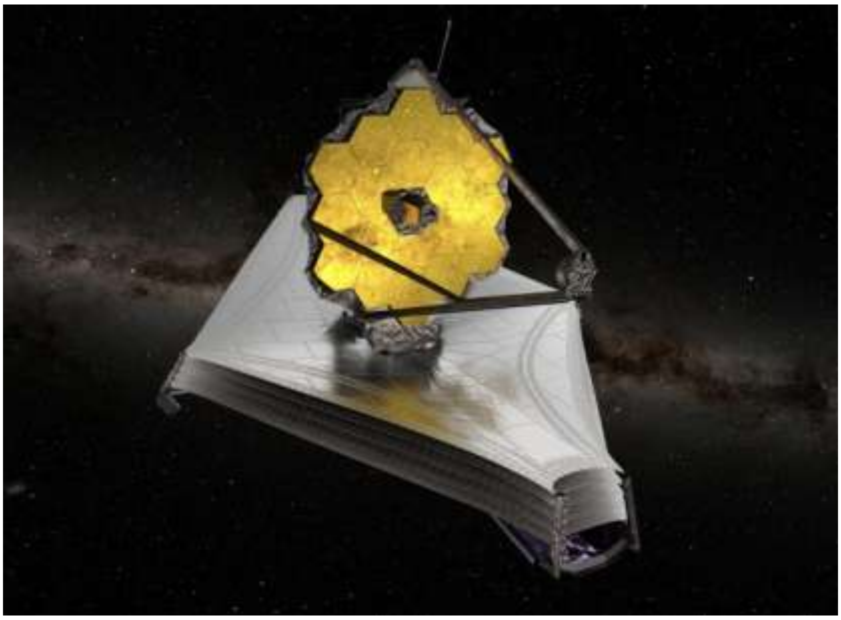
When we are in front of a beautiful picture of galaxies, we don't imagine that we had to capture photons during hours to constitute it. And, for terrestrial telescopes, these shooting times are limited to the night.

The further away the objects are, the weaker is the light we manage to capture. Thanks to its exceptional capacities it was possible to obtain, thanks to the Hubble space telescope to point it, in 1995, in a direction of the sky during 10 consecutive days. The image obtained combined the data of several "retinas" sensitive to wavelengths up to 0.8 microns, very little above the sensitivity of the human eye. . This after the image reworked so that the human eye can appreciate all the data. The field corresponds to a shirt button observed at 25 meters. The image shows 3000 galaxies.



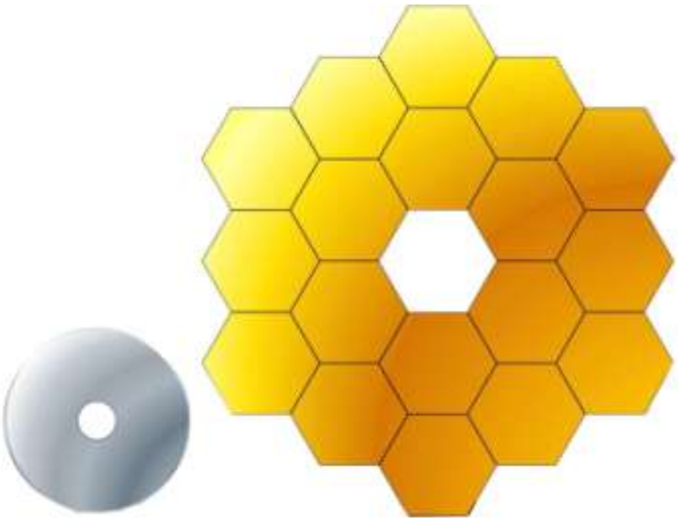
The "deep field", photographed by Hubble in 1995

But the optical exploration of the sky is limited by the possibility of space telescopes to observe in the infrared. this limitation is also that of "seeing in the past". This was the mission of the new James Webb Space Telescope, designed primarily for this purpose.



The James Webb Space Telescope

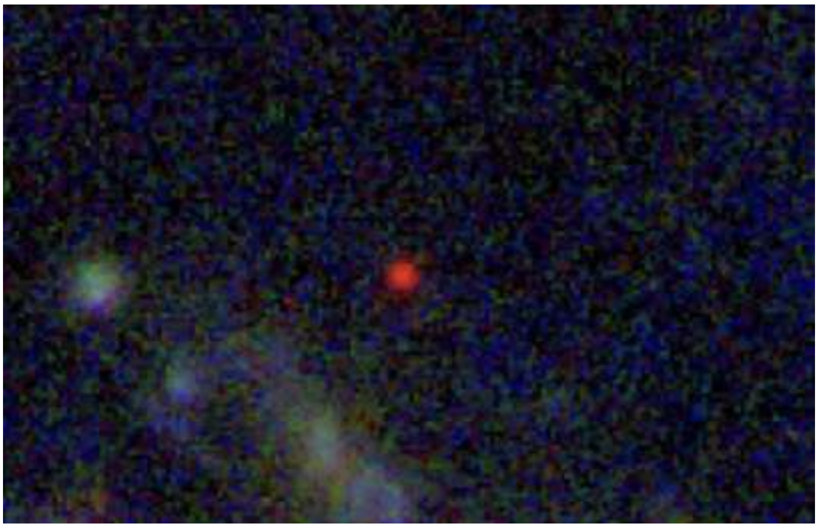
To extend its capacities of observation in the infrared it was necessary to equip it with a series of four protective screens to protect it, not only from the radiation emitted by the Earth, but from the radiation emitted by its own apparatuses, ensuring its operation, and laid out under these protective screens, not visible on this artist image. Its deployable mirror, made of 24 hexagonal mirrors, also offers a larger capture surface than the Hubble telescope.



Hubble and James Webb: mirror surface ratio: 6.2

The James Webb Telescope's protective shield could cover a tennis court.

These protections allow the James Webb Space Telescope to access infrared wavelengths up to 28.5 microns. These capabilities then allow this instrument to have access to light emitted 13.4 billion years ago, emanating from galaxies located 13.5 billion light years away, which are believed to have belonged to the universe when it was only 300 million years old[13].



Z13, the oldest galaxy, 13.4 billion light years away.

This red color is a "false color" because the real image is in the infrared. We will see later the surprises that emerged from this exploration of the adolescence of the universe.

Beyond that, it will be necessary to envisage even more powerful means of observation, to go even further in the long wavelengths, to try to capture images of galaxies in formation.

But there are strange "optical instruments" that are radio telescopes. They are finally not different from optical telescopes, with the difference that their mirrors are not made of glass but of a gridded surface, the size of the mesh corresponding to the considered wavelengths. They also converge the radiation thus captured, not on photographic plates, but on cells sensitive to these wavelengths.

[13] And this indeed corresponds to the image obtained of "Z13", the oldest galaxy whose image has reached us (in 2022), so named because Z corresponds to the ratio of the wavelengths.

Parabola of a radio telescope.

In fact, for a long time now, optical images have no longer been formed on the old photographic plates, but on CCD systems.

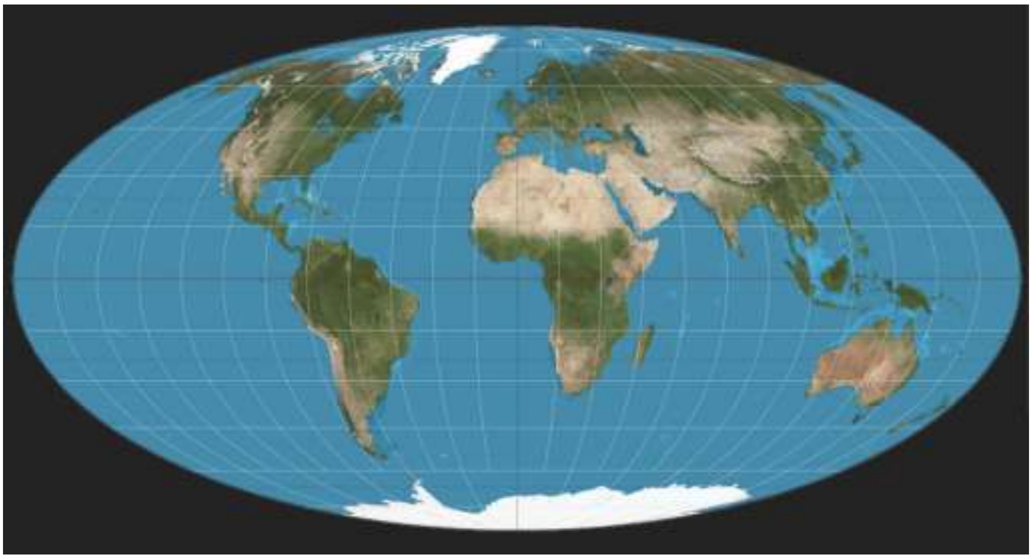
The interest of radio telescopes is that they plunge immediately into a more distant past, associated with longer wavelengths. Under these conditions, what is the limit? Wouldn't it be possible to imagine huge radio telescopes, with mesh sizes of one meter or more, allowing us to dive even further into the past?

The answer is no. There is a limit to how far back in time this can go, which corresponds to an age of the universe of 380,000 years. Before this time the temperature of the cosmic environment is higher than 3000°. So this one is totally ionized. If we manage to capture images of the universe, posterior to these 380.000 years it is because the universe, de-ionized, is then extraordinarily transparent. Indeed the photons can interact with the electrons bound to the atoms. On the other hand, when the medium is ionized, it is then rich in free electrons, which then interact strongly with the photons.

The medium is then not opaque, but translucent. The photons, captured by the free electrons are immediately re-emitted. But then the message is lost. Place a newspaper page behind the frosted glass of a shower stall. As soon as you move the page away from the glass, it stops being readable. Also we cannot receive any information from the universe, when it is less than 380.000 years old. The "face" it offers us is that of a plasma with a uniform temperature of 3000°K. As the expansion distends the universe by a factor of a thousand, this "face of the early universe" can then only be captured by radio telescopes working in a centimetric wavelength.

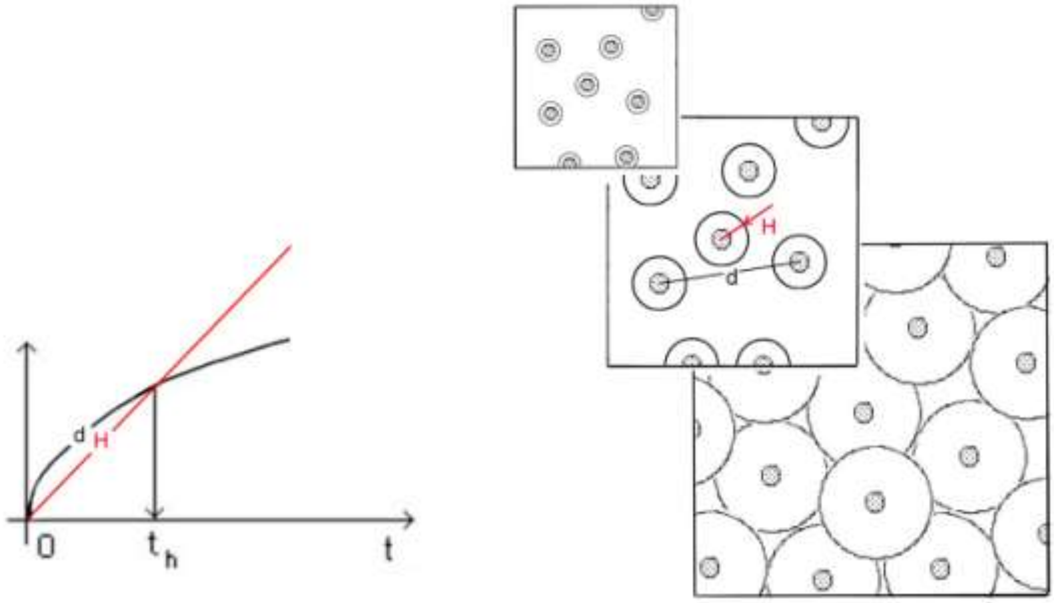
At the dawn of the nineties a satellite was launched, in order to know more about this state of the primitive universe.

It has been known for centuries that the complete surface of a sphere can be imaged using the so-called Mercator projection system:



The entire surface of the terrestrial sphere is inside an ellipse.

Let us now refer to the curves evoking, according to Friedmann's models, the behavior of the universe in its early childhood. The particles that compose it move away from each other at a speed greater than the speed of light. We represent around each of them a sphere, whose radius H, called "cosmological horizon", grows linearly with time. The drawing below shows that, under these conditions, the spheres interpenetrate only later in the past. There is a whole phase where the different regions of the universe cannot "communicate", i.e. exchange momentum and energy.

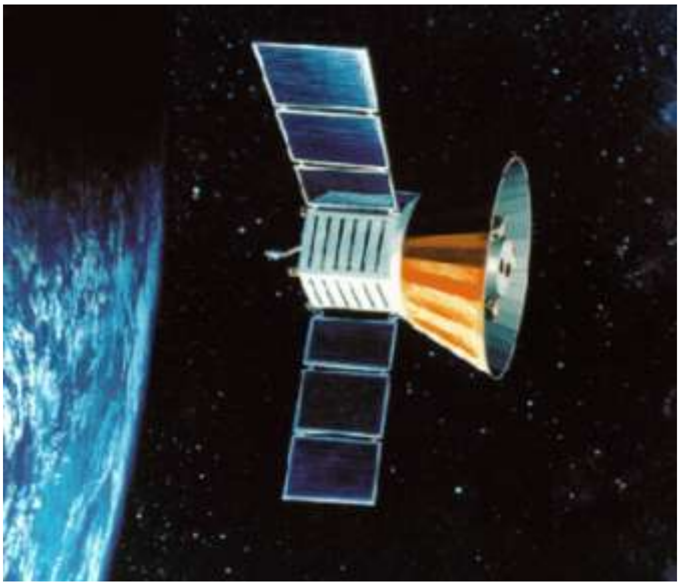


It is clear that during the whole period t < th
the "horizon-bubbles", of radius H, cannot interpenetrate.

It is because the air molecules in the room I am in are exchanging momentum and energy at a high rate, that the pressure and temperature in this volume are the same everywhere. These interactions between adjacent regions guarantee the homogeneity of the environment. 1

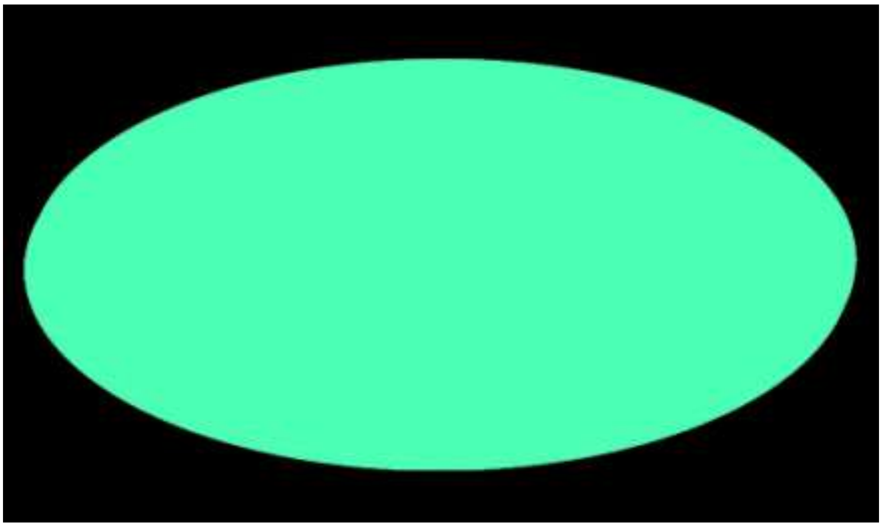
Now the image of the universe at time t = 380,000 years emerges from this period where no interaction could have occurred between adjacent regions. One thus expected, by capturing this "face" of the early universe in 1989, that of its CMB[14] with the help of a COBE[15] satellite, to find oneself facing a very inhomogeneous environment. This satellite has been equipped to capture only this type of radiation. It does not "see" stars or galaxies.

[14] CMB : Cosmic Microwave Background.
[15] COBE : Cosmic Background Explorer.



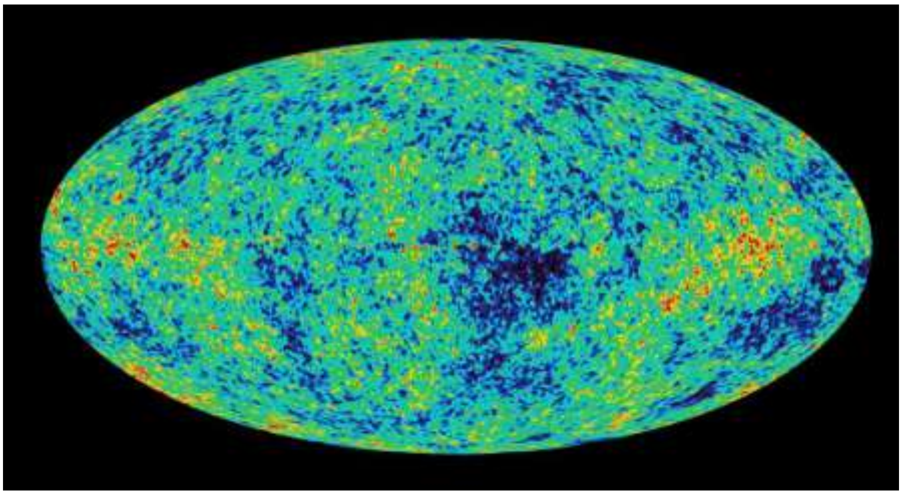
The COBE satellite, 1989.

The image obtained plunges the i in the perplexity. the universe, at t = 380 00 years appears homogeneous to the hundred thousandth:



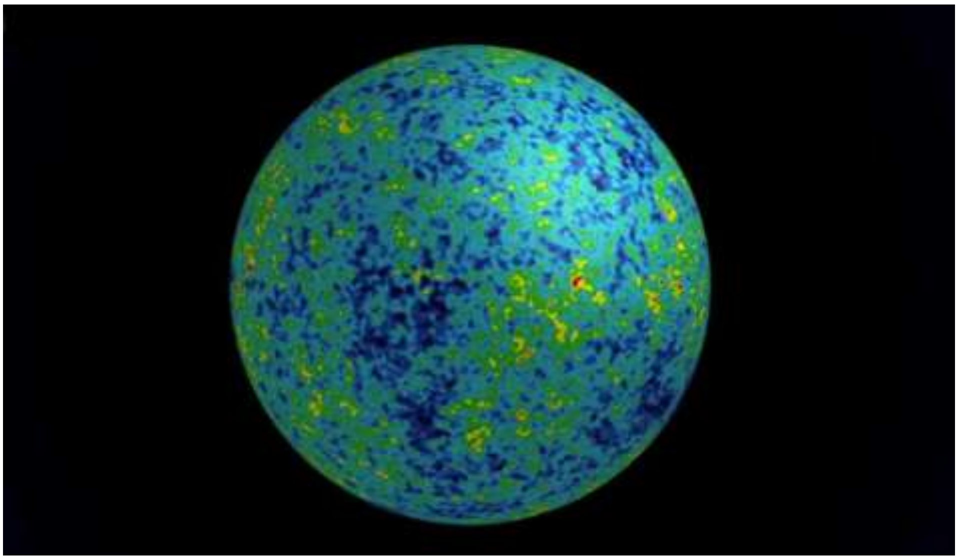
The remarkable homogeneity of the universe at t = 380,000 years

This is not exactly the image that the scientific media present. In fact this data is primarily recorded by a computer. It is therefore possible to implement a program that highlights the slightest of these inhomogeneities, indicated by a color coding: What follows is not the image obtained with the COBE satellite, but the one, much more precise, obtained in 2009 by the Planck satellite.



The image of the celestial sphere at t = 380,000 years, after accentuation of inhomogeneities by computer.

Remembering that this representation is the one that allows to present the whole surface of the sphere on a single image. Without it the aspect would be this:



The inhomogeneities, on the celestial sphere ;

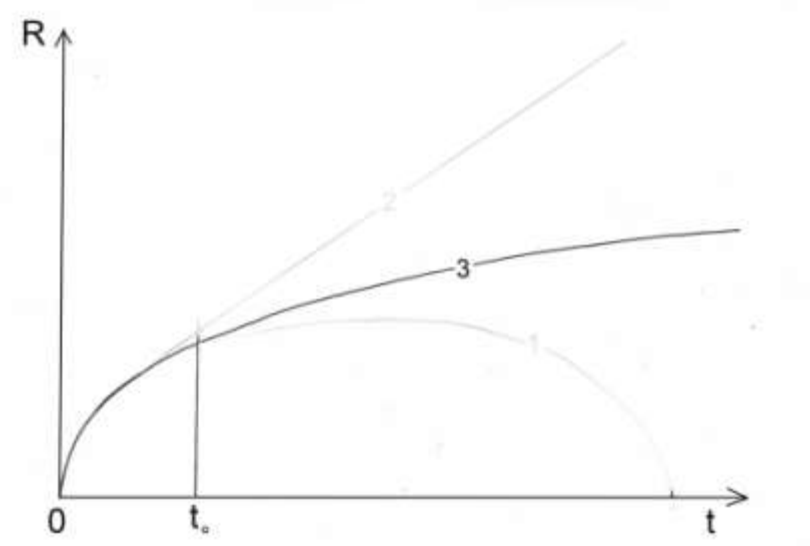
What we must remember is this extreme homogeneity of the universe at t = 380,000 years This constitutes a new cloud in the panorama of cosmology. To this we must try to provide an explanation. The Russian Andrei Linde provides his. According to him the universe would have known, at t = 10-33 second a fantastic dilation of a factor 1026.

The image of inflation, which has become established in all graphic representations of the of the evolution of the universe, with didactic aim.

This expansion would have had several effects.

- It would have flattened all the inhomogeneities that would have been present before this phenomenon occurred.

- It would annihilate all curves in the process. Thus the only cosmological model to consider is, within the three Friedmann models, the one where the curvature is zero and the expansion law corresponds to a parabola:



The parabolic expansion, "consequence" of the expansion process.

For this expansion to take place, the different particles must repel each other very violently. t is therefore necessary that a force field manifests itself, at this remote time, which will disappear immediately afterwards. But who says force field says particle carrying this interaction. We give it a name, it is the inflaton.

The best definition of inflaton, to date.

More than three decades have passed and there are as many models of inflatons as there are researchers who have tried to define them. We have been content to consider several patterns of inflation. This gave rise to the concept of baby universes or multiverse. According to their authors, this inflationary phenomenon could have given rise to an infinite number of universes, each with its own rate of expansion. Neighboring baby universes from which we could no longer capture the slightest information, the closest, adjacent, located beyond the cosmological horizon ct.

The "baby universes".

You got it. This represents a complete degradation of the scientific discourse, which is no longer conjugated in the conditional tense. Never has the expression "making people see the light at night" been more appropriate for this type of discourse.

But, as you have noticed, the discourse of cosmology and astrophysics specialists is of variable geometry. It adapts itself according to the data of the moment. The scientific community then produces a model that is called "standard". This means that it is considered the most credible, by the majority of scientists. At the beginning of the nineties, the image stabilized based on three main ideas:

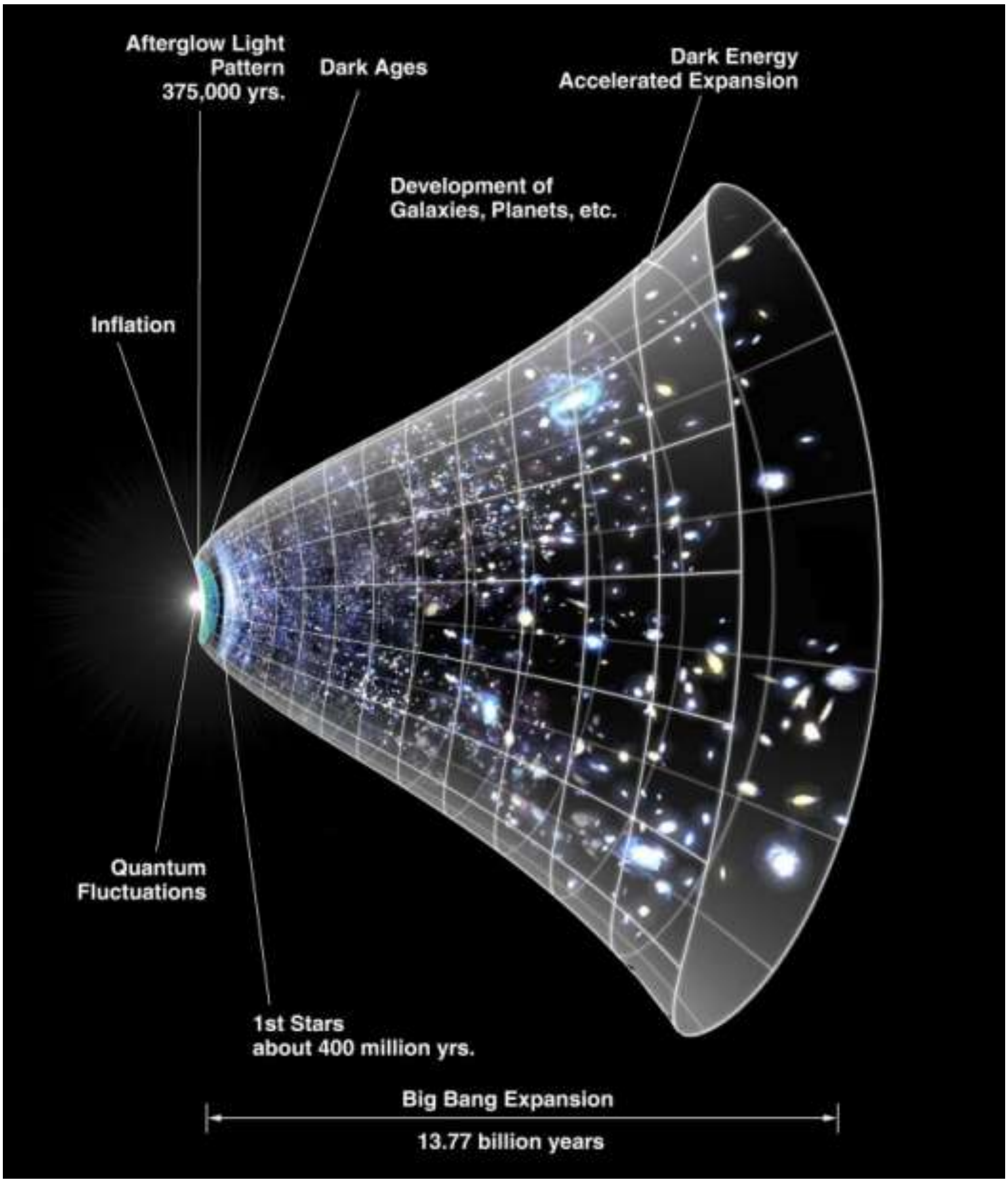
- The universe would have known in its very distant past a fantastic expansion, under the action of a hypothetical force of unknown nature.

- The universe would contain two types of matter. The one we observe and a second matter, quantitatively five times more important, but of which we ignore all of its nature.

- The evolution of the cosmos, mostly determined by its dark matter content, would correspond to a parabolic law, one of the three Friedmann solutions of Einstein's equation where the cosmological constant is, if not zero, negligible.

But since the beginning of the nineties, astronomers have been improving their measurements of the cosmic expansion phenomenon, at very great distances, by referring to objects whose magnitudes are close to a standard magnitude, the type IA supernovae.

After careful consideration, the scientific community decided to validate the work of three scientists, Saul Permutter, Brian Schmidt and Adam Riess, who were awarded a Nobel Prize in 2011. No matter what! The main scientific tool of today's cosmologists is Photoshop :



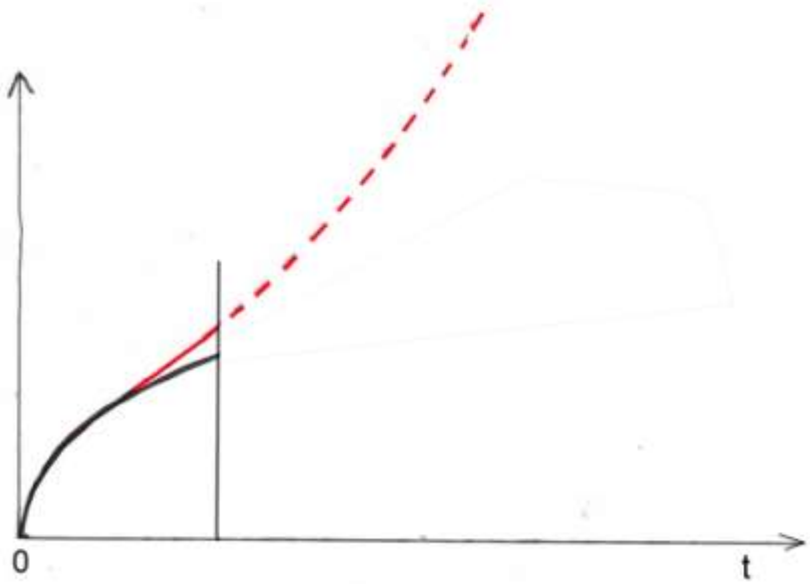
The universe, recreated thanks to Photoshop.

It will be noticed that some numbers have been improved, following what Lord Kelvin recommended: "add numbers after the decimal point". Thus the age of the universe is no longer 13 billion years, or 13.7 billion years, but 13.77. The last captured image of the universe is no longer 380,000 years old but 375,000 years old. We will see later how the first images captured by the James Webb Space Telescope have made these pseudo-precisions singularly illusory.

What then becomes of our cosmic expansion dynamics and to what could this phenomenon be attributed? Let's get the cosmological constant out of the attic where we had put it. By conferring a positive or negative value to it, we translate at will a "repulsive power of the void" as its attractive power. By choosing the right sign, Einstein's equation leads to a law of expansion that corresponds to an exponential function of time, extrapolating into the very distant future. Here is the equation from which everything follows, re-equipped with its cosmological constant, represented by the Greek letter lambda, of which it had been deprived for over half a century.

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda g_{\mu\nu} = \chi T_{\mu\nu}$$

Nous avons :



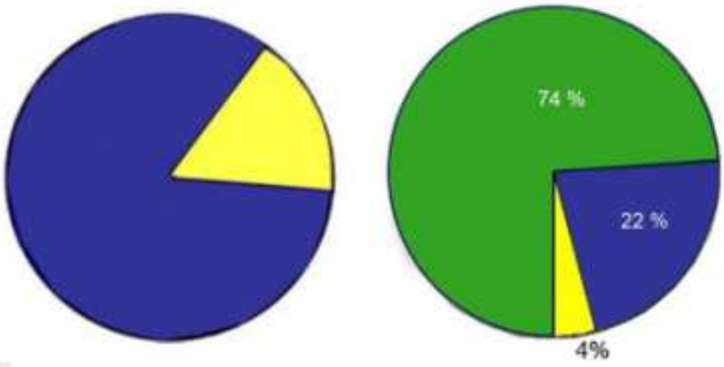
Driving the cosmic expansion by the cosmological constant :
An exponential expansion as a function of time.

The parabolic curve: disappeared, forgotten, in the dustbin of the history of science. The vertical line represents the present. To its left, the only thing that is accessible: the past. On the right, a dotted line, a conjectured future. As scientists are unable to say what this constant corresponds to, it is fashionable to talk about the future of the universe in a few hundred billion years. A future that only the gods will witness.

This cosmological constant represents an energy, of unknown nature. But we know one thing. To produce an acceleration, it must be negative. It was then sought to attach an equivalent using Einstein's relation:

E = mc2

We then obtain this:



We had used the yellow color for the ordinary matter, the blue color for the dark matter.
blue color for the dark matter. We will represent the content
of the dark energy by the green color.

But the public needs something to hold on to. For decades, if this sober matter is made of particles, one can think then a kind of gas, whose elements would agitate in all its with a speed of thermal agitation. Obviously, we think of giving them a positive mass. Under these conditions their average contribution to energy would be in the form of kinetic energy:

$$\frac{1}{2} m V^2$$

What is then the order of magnitude of this agitation velocity V? As the contribution in "mass equivalent" of this negative energy corresponds to mc2, where c is the speed of light, we conclude that for this contribution of a thermal agitation energy, positive, does not create us any problem, it is enough that this speed V is weak in front of c. We decide, before being able to say anything about its nature, to qualify this dark matter of "cold"[16]?

The new "standard model" then takes the name of :

ΛCDM Model[17]

[16] A "hot dark matter" is then endowed with a relativistic thermal agitation velocity.

[17] CDM stands for « Cold DarkMatter ».