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IS THE UNIVERSE CHANGING?

I. INTRODUCTION

Today we know, and this will be the subject of this article, that the universe is in continuous evolution, even revolution. This observation has been possible only quite recently. It was necessary to wait for the observations of distant galaxies, undertaken between 1930 and 1950 by Edwin P. Hubble, the astronomer who was the first to show that the universe as a whole is presently expanding. We know now also that the form of the constellations closest to us, such as the Great Bear, has been modified over the last millennia. Ancient astronomers, and with them the rest of humanity, imagined at that time that the universe was eternal and unchangeable. Astrophysicists today are convinced, in the large majority, that twenty billion years ago the universe went through a unique phase during which it was very hot and very dense. To this phenomenon they have given the name of the original or primordial explosion.[1] As will be seen later, certain people believe that the universe will once again experience this great "heat",

Translated by R. Scott Walker

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[1] In English-language scientific literature, we find reference to this phase under the heading "big bang". As one of my colleagues, Michel Cassé, has noted, this "sonorous" expression has no meaning, for it was not an explosion that occurred but a rapid expansion.

which will be generated during future contractions. Others foresee an increasingly frozen and empty future for the universe. Between this glorious past and this uncertain future, the universe each day reveals more of its splendor thanks to the arrival of modern techniques of observation and the beginning of the conquest of space. The purpose of this article is to give a brief survey of the manner in which astronomers see the universe today; working from the position of man in the universe, his relation to it begins to be understood better.

Science and technology in general, and astronomy in particular, have undergone considerable development in the later part of this century. Our vision of the heavens and what is contained in them has been modified and enriched continuously thanks to human intelligence, which invented more sensitive light receivers or effected more autonomous space probes. This "revolution" in the observable world is thus a result of the remarkable progress made by modern techniques of observation, that is the important ground instruments, both optical and radio-astronomical, and the arrival of the space age. Astronomy, which is perhaps one of the most ancient human sciences, today benefits from the great progress made in physics and in particular from the physics of the infinitely small. As we will be seeing, the universe is the greatest possible laboratory; the universe provides us with physical conditions that we cannot achieve on earth: super-dense matter, for example, such as that making up neutron stars better known as pulsars, very hot matter during the original phase, explosive matter such as that making up especially brilliant stars like the supernovae.

Since the beginning of the twentieth century, using Planck's quantum theory, then Bohr's atomic theory and finally Einstein's theory of relativity, man began to master the physics of the infinitely large, dominated by gravity. On the other hand, thanks to atomic physics, we are beginning to understand the structure of the atom, made up of a nucleus and of electrons revolving around it; thanks to nuclear physics the structure of the nuclei of atoms and their possible transmutation; and now the physics of elementary particles posits that the world is full of particles forming the matter of which we are made and even more numerous ones that fill the universe. This very recent understanding of the infinitely small makes it possible for us to grasp the history and the structure of the universe as a whole.

This view of the universe using these new techniques of observation and this understanding of its most tenuous constituents make it possible for us to follow the evolution of the universe. We can now know the age of this universe from its beginning thanks to three different techniques: the expansion of the universe, the age of the oldest stars and the age of chemical elements with long life, such as uranium. We are capable of describing the history of every constituent part of the universe: clusters of galaxies, galaxies (our Milky Way), stars, clusters of stars, solar system(s).

The universe is around twenty billion years old. One billion years after its birth, the galaxies were formed, and the sun is 4.6 billion years old. We know that in five billion years the sun will expand and engulf the earth, becoming what is called a giant red star. At that point our earth will be made one with the sun. A billion years later the sun will lose its superficial layers and become a magnificent planetary nebula, then it will become a white dwarf star. It will then be extremely condensed since its diameter will equal that of the earth, and it will have a surface temperature greater than 50,000 K. As it cools off from a white dwarf to a black dwarf, the sun will fossilize completely and will no longer be able to manifest itself other than through the effects of gravity that it will be able to exercise on surrounding matter.

We can also attempt to predict the future of our universe. Either the universe will have a new very hot phase, that is a phase of contraction that will occur in one hundred billion years, or else it will have a glacial phase. In either case we can form rather clear ideas about these tomorrows, whether they be very hot or very cold. Thus, with regard to our universe we can adopt the viewpoint of answer, of physicist and historian. These different points of view will be examined in each part of this article. We will conclude by recalling that the universe is the ultimate laboratory and that we are the dust of stars. Humanity is inseparable from the total universe; we can only understand the universe if we know ourselves well.

II. THE OBSERVATION OF THE UNIVERSE

Man has been observing the heavens since Antiquity. In the writing of the Babylonians and of every other ancient civilization, we find traces of this fascination. The specific nature of the planets was recognized by Greek and Roman civilizations as well as by the Egyptians and the Chinese. However. until the beginning of the seventeenth century, man disposed of but one instrument: his own eyes. In fact, as my colleague Alfred Vidal-Madjar noted in the *Grand Atlas d'astronomie* (1983), man's true instrument of observation is his brain. All the observation techniques, both on earth and in space, that we are going to look at are merely adjuncts to the eyes and brain of man.

Observation from the earth is conditioned by the existence of our atmosphere, which (and fortunately so for the development of life) absorbs ultra-violet radiation thanks to its layer of ozone (the triatomic molecule of oxygen) contained in the stratosphere. The terrestrial atmosphere allows only visible radiation [whose length is between 0.4 and 0.8 micron (one-thousandth of a mm)] and radio waves [whose wave lengths fall between 1 mm and 100 m] coming from beyond the earth to pass. Certain infra-red radiation is also visible from earth. To have access to ultra-violet radiation and to more energetic radiation (x-rays such as those used in radiography) and gamma rays or to examine the full range of infra-red rays, it is necessary to use space techniques to ovecome the effects of atmospheric absorption.

Astronomic observation did not really begin until the seventeenth century with Galileo's invention of the first telescope, which bears his name. Then telescopes began to be developed by Cassegrain and Newton. And it is thanks to such telescopes that an eighteenth century astronomer such as Herschel was able to discover, for example, the planet Uranus. In the nineteenth century, two fundamental instruments appeared. The first was the photographic plate, which has two advantages: conservation of the astronomic image and the ability to cover a very large area of the sky with a single shot. The second invention is linked to the development of atomic physics, which led to the invention of spectrographs making it possible to analyze light in simple radiation, observing the rays, either in emission or in absorption, emitted or absorbed by various chemical elements. Through the work of Fraunhofer and Kirchoff it was possible to determine the composition of the surface of the sun. This analysis was extremely important because it led to the discovery of helium, almost absent from the surface of the earth, despite the fact that it is the most abundant chemical element after hydrogen. This represents an understanding of the principal features of the total chemical composition of the universe.

In the twentieth century scientific and technical progress were of extraordinary benefit to astronomers and astrophysicists. Large optical telescopes were constructed in the 1920's. Radio-astronomy came into being after Jansky's initial efforts, around 1935, and especially after World War II, which had accelerated the development of radars, the forerunners of large radio-telescopes. Access to space dates from the beginning of the century when the Austrian V. Ness ascended in a balloon in 1913 with electroscopes and discovered the extraterrestrial nature of cosmic radiation. After balloons, rockets were developed that carried devices sensitive to ultra-violet radiation. But it was the early artificial satellites, Sputnik in October, 1957, followed by numerous American, Soviet, European, Japanese, Indian and Chinese satellites that opened up the path to a new era of exploration of the heavens. Today we have been able to marvel at the success of the Apollo missions, which allowed man to walk on the moon, and especially Voyager I and II, which made it possible for us to see Jupiter with its very different rings and satellites, Saturn and its myriad rings, and now Uranus, barely visible with a telescope. In around two years an optical telescope will be launched into orbit around the earth at an average altitude of 500 km, allowing it to overcome the handicaps imposed by the terrestrial atmosphere, extending its viewing capacity to stars one hundred times less brilliant than those at the limits of observation with the largest of telescopes. The ingenuity of scientists, engineers and technicians is so great that radio-telescopes, some set in Europe and others in the United States, can observe the same source at the same time with an extremely acute angular resolution (one hundred to one thousand times better than what can be achieved with visual astronomy). This technique is called very long-base interferometry.

With regard to detectors, astronomers are no longer limited to classical methods of photography or to prism or network spectrography. Instruments derived from television cameras make it possible to count grains of light, photons, one by one. Moreover, their requirements for collection and processing of images result in the fact that astronomy can have almost immediate practical applications. The scanner used in medical radiography is an instrument derived from radio-astronomy. The television receivers of tomorrow already exist in the form of prototypes developed in laboratories and observatories.

To summarize, astrophysicists can now pick up any extra-terrestrial electromagnetic radiation from whatever frequency (or wave length) with receivers that are increasingly large, increasingly precise and increasingly sensitive.

Every frequency, every wave length provides unique information about the universe. In the visible realm it is possible to see planets, stars and galaxies and to determine their chemical composition since the radiation absorbed or emitted by these various chemical substances can be found in the domain of the wave length. And with regard to stars, we know that it is not possible to achieve angular resolution from the earth. A French astronomer, Antoine Labeyrie, has invented a very ingenious method, interferometry of spots, which is the first step toward direct determination of the diameter of the stars.

Short wave length radiation (ultra-violet, x-rays and gamma rays) are emitted by hot or energetic objects. Ultra-violet radiation is characteristic of very hot stars and the ionized inter-stellar environment. X-rays are emitted by the extremely hot gas that fills clusters of galaxies, explosive stars (novae and supernovae) and by matter before it is attracted by stars as massive as black holes. Gamma radiation comes from the interaction between cosmic radiation and the inter-stellar environment as well as from supernovae.

Long wave length radiation (infra-red, millimetric and radio waves) is obviously emitted by cold objects or those with low energy levels. Infra-red radiation characterizes cold stars and inter-stellar dust. Radio-astronomy is dominated by the 21 cm atomic hydrogen line making it possible to map the inter-stellar environment. Most inter-stellar molecules were discovered in the realms of millimetric and centimetric wave lengths. Galaxies and quasars are also powerful radio transmitters, just like pulsars, that are nothing other than very dense stars, called neutron stars.

Luminous or more generally electromagnetic radiation is not the only source of information available to the astrophysicist. We have already referred to the cosmic radiation made up of the nuclei of very high energy atoms. Some particles of this type are so energetic that they give birth to showers of secondary particles in the atmosphere. To measure the composition of these cosmic radiations, astrophysicists build detectors, exactly like those used in nuclear physics, which they then place in satellites. Physicists also try to trace other manifestations of particles or of energy in the universe, such as the flow of neutrinos by the sun or gravitational waves emitted by particularly dense stars. Neutrinos are particles with no or very low mass in the family of electrons emitted during the transformation of protons into neutrons (and *vice versa* for anti-neutrinos). During the fusion of hydrogen into helium, which makes up the principal source of energy from the sun, it gives off this energy not in the form of photons but also in the form of neutrinos. The problem is that these neutrinos only rarely and difficultly react with ordinary matter. This is why American colleagues have installed a reservoir containing four hundred thousand liters of carbon tetrachloride in an abandoned North Dakota gold mine, and a European consortium is planning to store thirty tonnes of gallium (equivalent to three years production worldwide) in the Gran Sasso tunnel in order to detect these particles. The detection of solar neutrinos is important, for it will reveal the internal structure of the sun that is inaccessible through direct observation, and it will refine our knowledge of neutrinos themselves, particles that are as numerous in the universe as photons. Likewise, several groups in the world are seeking to construct devices sensitive to the emission of gravitational waves whose existence has now been proven since the observation of the double system of neutron stars.

Other experiments, such as research into the lifespan of the proton, which is perhaps the most important consequence of the unification of the forces of nature or the discovery of W and Z bosons through the C.E.R.N. experiment, have major implications with regard to the structure and evolution of the universe. Without wanting to seem absurd, perhaps it is from laboratories buried in mines or under mountains to detect imperceptible particles that we will at last be able to understand the universe properly.

III. THE UNIVERSE OF THE PHYSICIST: THE RELATION BETWEEN THE WORLD OF THE INFINITELY LARGE AND THE INFINITELY SMALL

The fundamental role of elementary particles with regard to the evolution of the universe as a whole is a consequence of the power of the laws of physics over the universe. The most recent developments in physics—the physics of the infinitely small, in other words atomic physics, nuclear physics and the physics of particles, all three derived from quantum mechanics; and the physics of the infinitely large, general relativity—find their immediate applications in the structure of the universe as a whole.

Four fundamental interactions are the tangible manifestation of the action of physics on the universe. Two of these—gravity, described first by Newton's law and now by Einstein's relations in the cases in which the speeds are elevated and the bodies quite massive, and electromagnetism, described by the law of Coulomb—are long range interactions. The inter-reacting bodies can be at a great distance from one another, like a planet rotating around the sun. These are the two physical effects to which we are most accustomed and which condition our lives (lighting, communications, etc.). The world of the infinitely small (atom, nucleus, proton or neutron, or even more elementary particles such as a quark) do not escape from these interactions. Elementary particles have an electrical charge and mass. But it is subject to two other forces that have a very short range (10^{-13} cm for a strong force and 10^{-16} cm for a weak force). The strong force is so called because it is the most powerful interaction on the four. It is one thousand times stronger than the weak force and 10^{39} times stronger than gravity. The strong force can only function between particles called hadrons which are nucleons (protons and neutrons) and π mesons. The typical example of the strong force is a thermonuclear reaction such as: proton + carbon 12 yields nitrogen 13, or a neutron absorption reaction such as: carbon 13 + neutron yields carbon 14.

The weak force necessarily involves particles called leptons, which are electrons, muons and neutrinos. The typical example of a weak interaction is the disintegration of the neutron into proton + electron + antineutrino, a process that requires on the average about ten minutes. The weak force is much more probable, which explains in particular why solar neutrinos are so difficult to detect.

These four forces give off waves: electrical waves or electromagnetic radiation (particularly light) for electromagnetism, gravitational waves for gravity, and gamma radiation for the two microscopic nuclear forces. They are produced by an exchange of specific particles that can exist in an indeterminate number and that are called exchange bosons. The name "bosons" comes from the fact that these particles obey the Bose-Einstein statistical laws. An indeterminate number can exist in the same place in the same state of energy. Electromagnetism bosons are photons; gravity bosons are gravitons, whose existence has not yet been proven experimentally. Those from a weak interaction are the W and Z particles, discovered in 1983 at the C.E.R.N. by Rubbia and Van Der Meersch, 1984 Nobel Prize winners in physics, and their collaborators. As for the strong interaction, until recently it was thought that it was caused by an exchange of π mesons. Now it is presumed that the vector role of the strong interaction falls back on gluons, which are particles that "cover" quarks and make them stay together. In particle physics it is said that gluons "confine" quarks. Quarks are particles with a charge of $\pm$ 1/3 or $\pm$ 2/3 that exist in the same number as the known leptons (the electron, the muon, the tau and their three neutrinos), that is six. With three quarks a proton or a neutron can be made, whereas only two are necessary to produce a π meson. Quarks are not simply products of the wild imaginations of mad physicists. Five of them have been detected experimentally, the first one on the linear accelerator at Stanford University in the United States.

These four forces are sufficient for understanding all physical interactions known in the universe. The sun draws its energy from strong nuclear interactions (weak interactions by neutrinos represent an energy loss for the sun); life is a succession of chemical and biological reactions, governed primarily by electromagnetism and secondarily by gravity.

One of the greatest discoveries of modern physics is that these four forces, at first glance very dissimilar, are apparently the consequences or the branches of one and the same force in which they can all four be united provided that the available energy is sufficient. This adventure of the unification of interactions began with the theory of Glashow, Weinberg and Salam, who imagined that electromagnetic force and the weak force are capable of uniting if the average energy of each particle is 100 GeV or one hundred times the mass of the proton or else corresponding to a temperature of 10^{15}K. The experimental demonstration of the unification of these two forces was provided by the discovery of W and Z.

Physicists call the theory of the physics of particles liable to unify the strong force with the electro-weak force the grand unification theory. In these theories, particles liable to be exchanged during the unification of these three forces must have a mass of at least 10^{15} GeV, one million billion times that of the proton corresponding to a temperature of around 10^{28} K. These particles are called X and Y by particle physicists. Their existence implies that the proton, which is one of the bricks from which the visible universe is formed (and ourselves in particular), has a finite lifespan of around 10^{31} years. To make this correspond in some way to our own scale, for a man weighing 70 kilograms, there are three chances in ten that a single one of his protons might disintegrate during his estimated life of 75 years. This extremely rare incident (fortunately for us) is actively being researched by around ten groups of physicists who, all over the world, have used immense detectors, which are huge cubes filled with water thousands of meters under ground. The result of these experiences is important for the particle physicist and, as we will see, for the astrophysicist. The proton today seems more resistant to disintegration than the unified theories claim. This is why (and for many other reasons that are beyond the scope of this article), physicists, never at a lack for imagination, invented the theories of "supersymmetry" capable of unifying not only the two microscopic forces with the electromagnetic force, but likewise the force of gravity with the other three. The price that must be paid (for in physics, just as in life in general there is always a price!) is that today we are required to suppose the existence of a great number of new elementary particles. This situation would not be serious if the chances of detecting these particles were important. Unfortunately this is not the case, which makes these developments undemonstrable and thus incomplete from the scientific point of view.

Even the patient reader will be asking himself at this point why the astrophysicist (since the issue here is the universe as a whole) is so interested in these developments in microscopic physics, certain ones of which can seem quite esoteric. There are two reasons for this interest. The first comes from the fact that all these particles play a predominant role in numerous astrophysical situations. A very dense star becomes a neutron star (pulsar) because at extremely high density of around the order of nuclear density, protons combine with electrons to yield neutrons, which then become stable, and neutrinos. The beginning of the universe, or, if we prefer, its primordial phase, should be marked, as we are about to see, by successive "disunifications" of the fundamental forces; the dynamics of galaxies and clusters of galaxies is apparently due to the presence in the universe of many particles, generally of modest mass, which are by nature quite different relative to the matter of which we are formed. With these four forces and the particles they put into play, we have available for us the agents and the motives for the action that results in the evolution and the history of the universe.

IV. THE ASTROPHYSICIST IS AN HISTORIAN, AN ARCHAEOLOGIST AND A DETECTIVE

We are now going to retrace in very broad strokes the history of the universe as a whole, mentioning at the proper moment the history of a galaxy, of a star, or even the history of the solar system. Here we are placing ourselves in the framework of the cosmological theory adopted by most astrophysicists, the so-called Big Bang theory, discovered by A. Penzias and R. Wilson in 1965 from the radiation diffused at 3 K that entirely fills the universe and that gave full credibility to this theory. The primordial event must have occurred, as we said, twenty billion years ago. The history of the universe can be subdivided into six periods. The first only lasted but a second, but it was extremely rich in events because of the extremely high temperature of the universe at that period, which went from 10^{32} K to 10^{10} K. The second period lasted around three minutes; it was during this period, which provided the title for S. Weinberg's book *The First Three Minutes*, that the universe saw the formation of the lightest elements, such as deuterium, which is the heavy isotope of hydrogen, the two isotopes of helium (atomic mass 3 and 4), and lithium (atomic mass 7). The temperature of the universe was then between 10^{10} and 10^{8} K. The third phase lasted one million years and came to an end when the universe reached a temperature of around 10,000 K. At this temperature protons began to combine with electrons to give birth to atoms of hydrogen; the universe ceased being opaque,[2] and the photons emitted at the moment hydrogen was formed are those that would cool off because of the expansion of the universe and give the diffuse 3 K radiation, the maximum of which is found in the domain of millimetric waves. In every cubic centimeter of the universe there are 300 photons of diffuse background that came from this formation of hydrogen. The first million years also thus marked the end of the radiative era in which radiation dominated matter, and which preceded the so-called stellar era, in which we are presently living. This stellar era can itself be divided up into three phases as primordial era: the first billion years that saw the birth of the galaxies and the clusters of galaxies; the era in which we are presently living, marked by the birth, life and death of stars; and finally the distant future of the universe, linked either to the death of the proton or to that of black holes that will finally be the only form of fossil matter.

The first second of the universe

This first second of the universe was characterized by immense heat and density that should have made it possible for the many particles mentioned earlier to be born, in particular those predicted by the unification theories, and for certain ones of them to

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[2] When we look far away, we see the stars at extremely remote time. The big bang theory postulates that we can never observe any further than this period in which the universe was opaque, which forms what is called the cosmological horizon.

disappear. Because of Heisenberg's principle of incertitude, which derived directly from quantum mechanics, the product of the incertitude about time multiplied by the energy contained in the universe cannot be less than Planck's constant. Consequently we cannot define time at less than 10^{-43} seconds, to which we give the name Planck's universe time.

In this respect let us recall that the question "what was there before the birth of the universe?" has no meaning. There is no before because time can only have a real definition when matter is present.

The critical moments in this first second are located, then, at 10^{-35} second, where the force of gravity and the strong force cease being unified with the electro-weak force. This moment, dominated by the X and Y particles, ceased when quarks and leptons appeared. During the time between 10^{-32} and 10^{-10} second, the electro-weak force remained unified, the quarks were no longer confined by gluons; they were free and coexisted with the W and Z particles.

The two moments in which the forces ceased being unified at 10^{-39} second for all the 4 or 3 forces (the problem of gravity still remains quite mysterious) and at 10^{-10} second for the electro-weak force correspond to what physicists call phase transitions, analogous to the transformation of water as a liquid into ice or steam. Several cosmologists, such as A. Guth, P. Steinhardt, M. Turner and A. Linde, think that at the time of 10^{-35} second the universe underwent a very rapid acceleration in its expansion because of this transition of phase, and they give this phenomenon the name "inflation of the universe". This hypothesis of a brutal expansion has the advantage of dismissing the conceptual difficulty that consists in imagining a universe without rays at this particular era since this inflation erased the past (if there was one) of the universe.

It made the universe causal since the classic model of the big bang theory is incapable of explaining why two quite distant regions of the universe have the same physical properties.

At the time of 10^{-10} second another phase transition occurred, to which particle physicists give the esoteric name of quantum chromodynamics; this phase brought about the confinement of the quarks and their combination in π mesons and in nucleons, protons and neutrons. At this time, and until the end of the first second, leptons, electrons and positrons dominated physics and not photons, which had to wait until the end of the first second.

We owe to the Russian physicist Andrei Sakharov, well known to the world but for other reasons, the discovery that the universe very quickly became asymmetrical, meaning that from the very first seconds of the universe, it ceased having the same amount of anti-matter as matter. At the end of the first second, which marked the beginning of the radiative era, the universe was made up of ten billion times more photons than nucleons (protons and neutrons).

The first three minutes of the universe

When the first second was over, the balance that had been established between protons, neutrons, negative and positive electrons and their neutrinos ceased and the primordial neutrons began to disintegrate. However, the temperature then became favorable for the formation of lighter elements. The temperature was sufficiently warm (greater than 10^8 K) so that after the absorption of neutrons by protons, deutrium could be formed, which engendered helium 3, helium 4 and lithium 7, and the temperature was not so high (less than 10^{10} K) that photons would destroy what the fusion reactions had created.

Without going into the technical details that have no place here, we can "prove" that to explain the values observed for deuterium and helium 4, which were formed at this time, the density of the universe in the form of ordinary matter must have been less than that from which the universe, under the effect of its own gravity, contracted after having dilated.[3] On the other hand, we have observed for the moment three different types of leptons (the electron, the muon and the tau) with their associated neutrinos (that the unification theory places in close relation to the six types of quarks). There is no room for a new family of leptons which, if

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[3] The universe can either dilate continuously, if its own gravity is not too elevated, or contract in a later phase in the same manner in which a satellite is able to overcome earthly gravity to a large extent, which is not the case for an artillery shell, for example.

it existed, would accelerate the expansion of the universe and would lead to an overproduction of helium 4. From this we can measure the full value of these processes of primordial nucleosynthesis that lead to "falsifiable" consequences. If we find other families of leptons, this overly simple big bang theory, with or without "inflation", will have to be replaced by another theory that takes into account the existence of these new leptons.

The first million years

There is little to be said about the first million years, once we know that they were dominated by photons and that it was certainly during this period that the fluctuations in density that would give birth to the galaxies and to the clusters of galaxies must have been formed. The shift from the radiative era to the stellar era through the combination of protons and electrons and the liberation of "cosmological" photons has already been mentioned.

The first billion years

During this period all the galaxies must have been formed (including the Milky Way, which is our galaxy), which then formed into clusters of galaxies from these primordial fluctuations. There are still two competing theories: the Soviet theory, called the "pancake" theory (or perhaps the blini theory!) supposes that first there were created very large structures, much larger than the clusters of galaxies, which then broke up into clusters of galaxies and then into galaxies. The Anglo-Saxon theory postulates that these fluctuations increased with the passage of time and that we move from clusters of stars to galaxies and then to clusters of galaxies. Today it would seem that the Anglo-Saxon theory takes into consideration a little better the observations of the dynamics of large structures.

We can recall that the formation of very light elements sets an upper limit to the density of the universe in the form of ordinary matter. This limit is roughly equal to 10-20 per cent of the critical density beyond which the universe would recontract in the future.

Is the Universe Changing?

By studying the dynamics of large structures (clusters of galaxies, for example), it is apparent that the total density of the universe should be around 60 per cent of the critical density. It is, therefore, premature to think that the universe can contract once again. On the other hand, there must be invisible matter made up of particles completely different from the nucleons (protons and neutrons) out of which we are formed. These are perhaps low mass particles (one ten-thousandth of the mass of electrons), or rather low mass particles but which are also animated at low speeds (which is not the case for neutrinos!). The fervent imaginations of particle physicists do not lack for suggestions: cords, supercords, axions, quark nuggets, etc.

During this era certain galaxies at the very active center (nucleus), thus much more brilliant than their outer regions, must have become quasars, which are nothing other than galaxies with a very active, energetic and brilliant nucleus.

The Present

We are now living in an era in which ordinary matter dominates the physics of the universe and which is marked by the life, evolution and death of stars. Galaxies are thus composed of several hundred billion stars. One of these, the sun, has played an important role for us since it is around this start that the earth rotates, and we draw our energy from its radiation.

Through isotopic dating of meteorites, we know the age of the sun with a precision that goes much beyond that with which we can determine other astronomical factors. The sun was born of an interstellar cloud 4.555 billion years ago. After having contracted from the effect of its own gravity for some ten million years, it must have had a relatively constant luminosity and surface temperature throughout this period, as the early appearance of life on earth proves. During its contraction it abandoned a small part of its mass, which gave birth to the solar system. While the sun itself rotates very slowly on its axis, with a 28 day cycle, rotation of the solar system is practically concentrated on Jupiter and Saturn. The sun draws its energy from the transformation of hydrogen into helium at its center, where there are temperatures of around ten million degrees. In approximately five billion years, the amount of hydrogen at the center of the sun will no longer be sufficient. At this time a very dramatic event will occur. There will be a contraction of the central regions until they attain a temperature of 100 million degrees, sufficient to transform helium into carbon, and expansion of the outer regions. In five billion years the earth will once again be a part of the sun. There will then remain around one billion years of "life" left to the sun. It will end its evolution as a planetary nebula and then a white dwarf, a very high density fossil star (10^9 grams per cm^3) and consequently with weak rays, that will become an invisible black dwarf in several million years.[4]

Stars more massive than the sun will not last as long because they are much more luminous (their luminosity increases as the cube of their mass while their available energy is proportional to the mass). They will end their lives in a magnificent supernova explosion, a very rare event (once every fifty years for a galaxy) but so energetic that it conditions the physics of the inter-stellar matter of a galaxy. The rest of the supernova, that is what remains at the center, is a neutron star or pulsar.

The future of the universe

Two possibilities have already been foreseen. First, if the density is greater than the critical density, which is not as impossible as the preceding developments might make it seem, the universe will experience a new contraction phase in around fifty billion years, which will bring about another very hot phase, and so on. On the other hand, if the proton is mortal, in approximately 10^{32} years there will be only electrons and radiation left in the universe.

If the density of the universe is less than the critical density and if the proton resists better than particle physicists make it seem, it will continue, then, to dilate, that is, to cool off. Radiation at 3 K will become 2 K and then 1 K (absolute zero is an unattainable limit just like a time of 10^{-43} second). Two physicists, F. Dyson and

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[4] A white dwarf has a ray practically equal to that of earth (1/100 of a solar ray) for a mass analogous to that of the sun.

J. N. Islam, thought that in the universe there would remain only black holes, that is objects so dense that they imprison their own radiation.[5] There are good reasons for thinking that there is a black hole at the center of most galaxies (especially quasars). These black holes attract the rest of galactic matter, which they "swallow" while heating it up, helping to activate the nucleus of the galaxy.

In very remote times only black holes will be left, which will "evaporate" through radiation by interacting with particle-antiparticle pairs created by quantum fluctuations of the vacuum. J. N. Islam thought it would take $10^{10^{76}}$ years for these black holes to disappear completely from the effects of this slow evaporation. Such time is inconceivable for us. However, it is not infinite. In the same manner that the universe was born of unique events, it will disappear through radiation over a relatively long time).

V. A VIEW OF THE EVOLUTION OF THE UNIVERSE AND OF HUMANITY

All that has just been said about the observations of the universe and the laws of physics that govern its evolution and its history is obviously fragmentary given the format of this article. However, we see how our vision and our understanding of the universe has developed very recently. Most of the theories of micro-physics developed here are only a few years old. In the same manner we only knew of three rings around Saturn until 1981, when the Voyager probe revealed the complex beauty emanating from the system of numerous rings orbiting around this planet. Our vision of the world evolves and becomes richer very quickly, both through ever more refined and precise observations and also through our better knowledge of the infinitely small.

One inevitable conclusion of this schematic analysis of the evolution of the universe is that the infinitely small governs the evolution of the infinitely large. Depending on the existence or not of relativist particles, we must modify our ideas about the structure

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[5] These stars, whose physical properties are a direct consequence of general relativity, were imagined a very long time ago by Laplace. There are many candidates in the heavens to become stellar and galactic black holes.

and the dynamics of clusters of galaxies. The study of the first second of the universe is in itself an almost pure problem of particle physics (except for the question of quantum gravity). Now it is evident that the universe is the best possible laboratory and that we understand the growing attraction it can exercise over colleagues specialized in fields that do not spend their time admiring the heavens.

Another consideration that we have not been able to develop in this article is the fact that we ourselves are intimately part of the universe, which we cannot consider independently from our own destinies. It is well known that the chemical elements of which we are formed come from generations of stars prior to the birth of the sun. The youngest of the nuclei of our atoms are five billion years old, our hydrogen atoms are twenty billion years old. According to a now banal image, we are made of star dust; and our existence has depended on a great number of very fortunate circumstances, most of them involving once again the world of microphysics. To limit ourselves only to the most classic examples, the emergence of life on earth comes from the fact that the fusion of hydrogen into helium is very slow. This slow pace itself comes from the fact that nuclei with the atomic mass 5 and 8 are very unstable. The fusion of helium into carbon is only possible because the system of the three helium nuclei corresponds in terms of energy to an excited level of carbon. We could multiply the examples of nuclear "coincidences" favorable to the emergence of nuclei such as carbon, nitrogen and oxygen, themselves apt to create biological molecules.

The universe is not an object isolated from us. It remains mysterious, and will always remain so, but every passing day allows us to understand it better and to appreciate it more.

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