The First Moments of the Universe: The Limits of Knowledge

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The contemporary astrophysicist today deals with questions that bear on the area known to traditional philosophy as "metaphysics." Consequently, it is tempting to cross the threshold. One can allow oneself to be tempted by the idea that science is in a position to provide solutions to ancient and venerable metaphysical quests. One can even imagine, according to the wish expressed two thousand years ago by Epicurus, that it can calm our "metaphysical anxieties."

Thus, it is of great importance to analyze the question with a critical eye. One can only proceed with the utmost caution into these territories, rife with obstacles. We must not forget that, in the course of similar inquiries, many researchers, blinded by their enthusiasm and their desire to make progress at last in this still unexplored terrain, have found themselves irremediably bogged down.

The fundamental question for metaphysics is that of being. It is perfectly well formulated in Leibniz's famous question: "Why is there something rather than nothing?" I see this question more as a "cry from the heart," as an expression of the intense emotion which arises from acquiring an awareness of our existence, than as a genuine question to which one might hope, one day, to supply some aspects of an answer, that, if it is not tautological to say so, would be philosophical as much as scientific.

However, certain scientific authors have given the impression that modern physics and contemporary astrophysics were in a position to put forward certain new propositions on the subject, even satisfactory explanations. What is the truth of the matter?

One can immediately point to a fundamental difficulty from which it is hard to escape. The normal scientific approach consists of seeking to explain "something" in terms of "something else."

Once it has been identified, it is natural to seek an explanation of this "something else" in terms of "something else again" and so on.

Scientific knowledge often appears in the form of a collection of embedded "whys." Take the classic example of falling apples. Apples fall because the Earth attracts them, Isaac Newton tells us. The Earth attracts the apple because the mass of the Earth changes the geometry of space, responds Albert Einstein. One does not yet really know "why mass modifies geometry." Currently, people are seeking to formulate a unified theory of physics in which this question will be given a "because" that, inevitably, will be expressed in terms of something else.

All this goes to show that it is unthinkable that something should be explained in terms of "nothing." Whereas, in fact, any attempt to explain "creation" in the true sense of the word leads us to this conclusion. It is nothing less than an attempt to give an account of the transition from nothingness to something which exists.

The fact that one can write down words somewhere or other can lead to the dangerous illusion that we know what we are talking about. The last sentence of the previous paragraph illustrates this illusion very well. It seems to make sense. But if one takes into account the fact that the word "nothingness" is, by definition, devoid of meaning, one has to conclude that the word "transition" can in no way be associated with it. It arises from an improper extension of the perfectly normal idea of "transition from one thing to another" to the idea that one of those things can be "nothing"...

The Original Myth

The cosmological theory known as the big bang has brought in its wake the idea that astrophysics now has something to say on the origin or beginning of the cosmos. We can now identify the creation of the world. This creation took place at "zero hour" on the cosmic clock that, today, gives us the age of the universe: fifteen billion years. Pope Pius XII did not hesitate to identify this event with the *fiat lux* of the Bible.

The temptation to "mythologize" is always present among human beings. It is natural to seek to attach familiar imagery to astonishing realities. It is easy to understand how the ever active imagination could attach to a theory of physics a myth that was timeless and, because of that, attractive (or perhaps it would be better to say "attractive and, because of that, timeless"). Hence, it is the duty of the physicist to cast a critical eye over the question and to be imbued with an uncomplacent rigorousness that characterizes well-conducted scientific reasoning and that has traditionally guaranteed its effectiveness. What remains of mythology and of metaphysical pretentions when the critical eye has been cast over them? Are we allowed to retain terms like "birth of the universe" or "the first moments of the universe"?

Exploring the Past

The problem with which we are dealing should be thought of as an exploration of the past. As usual, the main thing is to set out on the right foot, that is to say, from the right place. The best place from which to set out is the present moment. . . . Our "zero hour" is today. That is where our account in reverse begins.

The explorers of the last century entered unknown continents from their coasts. They advanced little by little into the interior, into regions colored white on the map and denoted by the words *terrae incognitae*, "unknown lands." Thanks to their efforts, the frontiers of explored territories advanced, year by year, into the still virgin zone. In letters that they sent to their families and the accounts sent to the academies that sponsored them they reported their discoveries: lakes, deserts, mountain ranges or, even, meetings with aboriginal peoples.

But if, by way of response, one had asked them, "What is *beyond* the land that you have explored up to now?," they would naturally have replied, "For the moment, we don't know. Be patient. Wait until we get there." Like them, when we leave the coast to explore the interior, we set out from the present to return to the past. It is important to mark the frontier of the region that has been explored, the point where the *terrae incognitae* of contemporary research begin.

We can also compare our approach with that of the specialist in prehistory who wishes to reconstruct the distant past of mankind. It is absolutely essential for him to have "fossils," that is to say, objects by means of which he is able to describe a state of existence that has disappeared, but that has left traces behind. Without objects from the past – sharpened flints, wall paintings, ashes from long extinct hearths, stones embedded in the ground – the special-

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ist in prehistory would not be able to say anything at all about, for example, Cro-Magnon man, who lived in Périgord eighteen thousand years ago. In the same way, without "cosmological fossils," the astrophysicist would not be able to go back in time toward the ancient universe. The credibility of his assertions is closely linked to the kind of fossils that he can extract and to his ability to interpret them correctly.

In recent decades, the astrophysicist's job has been to identify a number of fossils and to attempt to extract their message. In the context of astrophysics, a fossil is a piece of observed data whose physical size has been determined by events which were completed long ago. These data preserve, in some way or other, the record of these events and enable us to reconstruct them.

Thus, we have a small collection of fossils that, each in its own way, informs us about a particular epoch in the distant past of the universe. These are the landmarks in our great feat of exploration.

Did Time Have a Beginning?

The fact that galaxies are moving away from one another tells us that cosmic matter is becoming diluted. In other words, matter was more dense in the past.

We must have recourse to our knowledge of the laws of physics that govern matter in order to interpret this information. In doing this, we already encounter a very crucial problem. Our knowledge is based on laboratory experiments and is thereby constrained by the limitations of these experiments. Today, the most powerful accelerators can produce a billion billion (10^{12}) electron volts. Theory can extrapolate beyond this limit, but it becomes extremely speculative and must, therefore, be treated with caution. What is more, it itself becomes totally incoherent when we reach the Planck conditions (around 10^{32} degrees). In other words, we know nothing about the physical laws that govern the behavior of matter at such temperatures.

After this note of warning, let us now return to our fossils. Physics, with the theory of relativity, tells us that matter that was more dense in the past was also hotter. The relationship is a simple one: temperature is inversely proportional to the distance between the galaxies. When two given galaxies were twice as close to one another than they are today, the universe was twice as hot.

The rate of separation of galaxies allows us to calculate progres-

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sive rising temperature in the past. It is this that enables us to calculate that, fifteen billion years ago, the temperature must have been infinite. The same applies to the density of matter. In this context, this moment is called "zero hour." It is often identified with the "origin of the universe." It is scarcely necessary to add that the idea of an infinite temperature has made a powerful contribution to attracting fertile imaginations to the myth of the creation of the world.

The problem is that this calculation is based on an extremely bold extrapolation that, as we have seen, is completely unjustifiable. It is assumed that the laws of physics on which this reasoning is based, that apply at low temperatures, continue to be valid at any temperature, no matter how elevated. This is manifestly false.

A deeper knowledge of physics invites the researcher to call on Einstein's general theory of relativity. This theory can also provide a description of the earlier cosmos, suggested by the movement of galaxies away from one another. Following evolution in reverse, it appears, at very high densities, as a singularity. Under these conditions, the gravitational field would be so intense that nothing could escape from it, not even light. Matter is thus folded in upon itself, in another space-time, without any communication with the outside being possible.

The idea that the universe has been able to "emerge" from a singularity of space-time is certainly no less evocative than the idea of an infinite temperature. It is possibly even more amenable to the myth of a "creation of the universe." A good many authors have taken this up, particularly in the field of popular science.

In addition, the first models of the universe are located within the framework of a closed universe, that is to say, one possessing a density greater than critical density. These models have two extremely "mythogenic" properties. (I use this neologism to describe the ability of a mathematical model to stimulate active imaginations and to associate itself with one or other of the traditional myths of the human imagination.) The first is that it "appeared" at the moment of the big bang in the form of a confined mass whose volume went on to grow and reach the enormous dimensions of the universe observable today. This model evokes the myth of the cosmic egg in certain strands of Indian mythology. Having achieved its maximum size, the closed universe stops expanding and begins to contract until it is folded in upon itself as it was in its first confined state. In the process, it might then start again and why not indefinitely? In this form, it resembles the Indian myth of an eternal sequence of creation and destruction of the universe under the aegis of Shiva, successively taking the form of Great Creator and Great Exterminator of the cosmos.

But this leads on to a new complication. Epinal's new imagery is based on purely classical physics. It completely ignores the lessons of quantum physics. At present, no one knows how the yet-to-be-achieved incorporation of quantum theory would alter this scenario. What would remain of the Einsteinian singularity? Perhaps nothing. It would be like the black holes that ceased to be completely black when Hawking injected them with a little quantum physics.

Voyage to the Ends of Hell

The appropriate question should be: what temperature did the universe reach in the past? Do we have proofs, in the form of presentable documents, that it did reach a thousand, a million, a billion degrees, or more? Once again, the scientist must remain skeptical and require that any assertion should have solid and irreproachable justifications.

The discovery of fossil radiation at 3 degrees Kelvin by Penzias and Wilson in 1965 allows us to assert that the universe did reach a temperature of 3,000 degrees Kelvin. In the context of the cosmological model, this is the lowest temperature that would explain the thermalization of this radiation. In our chronology in reverse, this event is situated at around fifteen billion years before the present.

Measurements of the relative abundance of isotopes of hydrogen and helium, as well as the heavy isotope of lithium, also serve as cosmological fossils. One can show that a satisfactory explanation of these relationships of abundance implies that, in the past, the universe was at a temperature of at least ten billion degrees. It is only at such temperatures that cosmic matter can undergo a sequence of thermonuclear reactions capable of producing these isotopes. What is more, the study of this primordial nucleosynthesis allows us to predict correctly the number of families of elementary particles (three or four) and gives us an estimate of universal nucleonic density that is entirely compatible with astronomical data (around one nucleon per cubic meter today). This event is located around a million years prior to the emission of the fossil radiation.

We should note that these two fossils are compatible with very well known physical phenomena that can be reproduced in the laboratory: a few electron-volts for the fossil radiation, a few million electron-volts for the primordial nucleosynthesis. There is nothing of this kind for the fossils we are going to deal with next.

Scientists have always had something of the demographer about them. They love population statistics. We have seen how relative populations of light atoms – hydrogen, helium, lithium – have helped us to identify the period of primordial nucleosynthesis. One can also have a demography of photons. One can count around a billion photons for each nucleon (proton or neutron) in our universe. These photons belong almost entirely to the fossil radiation that has already been mentioned. All other photons, most of them born in radiation from the stars, only amount to around one thousandth of the photons that circulate in interstellar space.

Why are there a billion photons for each nucleon? Why not 36 or 0.12 for example? In science, all numbers conceal the question: why this number rather than another? In certain cases, this number becomes a fossil if it tells us something about the past of the universe.

Before responding to this question, it is necessary to ask another. The reply to both questions will be the same and it will become our oldest fossil. The question is: why don't we observe any antimatter in our universe?

The question takes on its full significance when one knows that, in the laboratory, there is a perfect symmetry between matter and antimatter. In other words, every time a nuclear collision produces a particle of matter – proton, neutron, or electron – it also produces a particle of antimatter – antiproton, antineutron, or antielectron (positron). There are no known exceptions to this rule. How, then, can we explain why our universe is so violently asymmetric? With the exception of extremely rare antiparticles of cosmic radiation, we do not observe any antimatter in its "natural" state, whether it be on the earth, in the solar system, anywhere in our galaxy, or even in neighboring galaxies. One cannot exclude the possibility that the most distant galaxies are made of antimatter, but there is no valid reason to think that they are.

One answer to the two questions – why are there a billion photons per nucleon, and why is there such an asymmetry in nature

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with respect to the two varieties of matter called matter and antimatter – may, according to the schemas of contemporary physics, require events to have taken place when the universe was at a temperature of around 10^{28} degrees, equivalent to an average thermic energy of 10^{24} electron-volts.

In the same spirit, one can say that the relative population of photons, together with the absence of antimatter, can be considered as a fossil that tells us that the universe reached a temperature of at least 10^{28} degrees. To continue our chronology in reverse, this must have taken place approximately a hundred seconds before the primordial nucleosynthesis.

At energies of this magnitude (10^{24} eV), one is well beyond the 10^{12} eV or so of our great contemporary accelerators. This means that theoretical extrapolation is long and, consequently, hazardous. In my own opinion, the ideas on which the replies to our two questions rest are probably correct, at least qualitatively, but they are far from having found their definitive form.

To sum up, we have identified three cosmological fossils that have allowed us to think that the universe was successively (in reverse order) at 3,000 degrees fifteen billion years ago, at 10 billion degrees one million years earlier and at 10^{28} degrees a few minutes before that. The reader will undoubtedly have noted the acute shrinking of the periods measured as one goes further back.

The Trap

Can we go even further back? For the time being we do not have any document, any "fossil" which allows to explore any further. In addition, we know that, if we persist, we will soon encounter a rather catastrophic situation. We are on the point of entering into the sphere of Planck conditions, which we will discuss now.

In physics we have two grand theories, each of which has worked wonders in its own sphere: quantum physics and Einstein's theory of generalized relativity.

The first is suited perfectly to the study of atoms and their interaction. These interactions show themselves in terms of "fields." In the most widespread version, contemporary physics appears as a collection of theories of fields applicable to each of the great interactions: electromagnetic, nuclear, weak, and gravitational. Its predictive power is extremely strong. However, its sphere of applica-

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tion is limited to situations in which the gravitational field is not too strong.

On the other hand, the second is eminently suited to calculating movements of matter in regions where gravity is at an arbitrarily high level. But it is incapable of absorbing the lessons of quantum physics, in particular that matter ultimately appears not in the form of massive particles indefinitely localizable in a space-time continuum, but in the form of quantum fields, subject to the Heisenberg uncertainty principles and with specific mathematical properties.

The fundamental problem of contemporary cosmology can be formulated in the following way. If we pursue our explorations of the past as far as temperatures of 10^{32} degrees, we have to deal with matter so dense that it requires both the techniques of general relativity (because of the extraordinarily high gravitational field) and the techniques of quantum mechanics (matter must be described in terms of quantum fields). And there lies the problem.

The difficulties are at the observational level. There are no experimental results at energies of this magnitude to disagree with the predictive calculation of the theory. It is at the level of internal coherence that the problems arise. In technical terms, one can say that current theories that can be applied in this context are "not renormalizable." That is to say that certain calculations, for example, the probability that a given event will occur, give a numerical value of infinity, whereas an acceptable response should be situated between zero and one. . . .

One can illustrate this situation by saying that, in certain conditions, there is a conflict between the relative delocalization implied by the uncertainties of quantum physics and the absolute confinement implied by the action of a very intense gravitational field, for example, in the vivid case of a black hole. The statistical fluctuations of the quantum field alter in an unpredictable manner the frame of space-time on which the phenomena described by general relativity are inscribed.

In other words, everything happens as though the traditional notions of time and space had become inappropriate to describe reality. The words "before" and "behind" or "future" and "past" can no longer be defined unambiguously.

In sum, at the present moment, there is no physical theory able to account for the behavior of matter at Planck's temperature (10^{28} degrees). This is not for lack of diligence on the part of theoreti-

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cians. Several avenues of research are being actively pursued to which are attached the words "supersymmetry," "supergravity," "superstrings," "composite models," and even "mini-universe." But all these are simply programs in which one can have some cautious hope.

The Limits of Knowledge

Planck temperature can be considered as the frontier of contemporary knowledge, both at the level of possible temperatures and at the level of our exploration of the past of the universe. No one knows if "temperature," "energies," "mass," "speed," "time," "space" – the cherished vocabulary of the physicist, without which he feels as naked as the Emperor of China in Hans Christian Andersen – still have any meaning. One can understand that the cursive question, "what was there before?," leaves him mute. He does not even know any longer what, under these circumstances, the word "before" could mean . . .

This is the distress of the physicist that one has to bear in mind when one wonders whether contemporary physics has anything to say about the "creation of the world" or the "first moments" of the universe.

Our fossils have led us to the conclusion that, in the past, the universe has been very hot: at least 10 billion degrees in order to explain primordial nucleosynthesis; perhaps 10^{24} degrees to explain the distribution of photons and the rarity of antimatter in our area. The present state of theoretical physics teaches us that, in any case, there is what one could call a "wall of ignorance" that is situated at around 10^{28} degrees. At this point, we reach not the limits of the world but the limits of our knowledge. We can say *nothing* about what is "beyond" in temperature or "before" in time. Pretentious attempts to explain creation or "why there is something rather than nothing" must be replaced by a pure and simple assertion of ignorance.

On the other hand, the words "the first moments" of the world take on a new meaning. If the concept of "time" becomes inapplicable in the neighborhood of Planck temperature, it is applicable to lower temperatures. One can thus use the expression "first moments" not in the groundless framework of something which follows a mythical "zero hour" but with the notion that the concept of time then becomes applicable. One would like to say "becomes applicable for the first time" if this expression is not itself somewhat contradictory.

Certainly, one cannot exclude the possibility that theoretical attempts currently being undertaken to penetrate the secrets of very high energy physics may return their conventional role to time and to space. In this way, they might give back some meaning to the question, "what was there before?" That would allow us to take another step forward toward, probably, new frontiers. Physics is a science which is constantly developing and what I have described here is the current state of progress (like the explorers of new continents). For the moment, we remain trapped in the swamps of internal incoherence. But it may well be that, sooner or later, we will find our way out.

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