Chapter 2

PROBLEMS WITH THE ETERNITY OF THE UNIVERSE

1. THE ETERNITY AND INFINITY OF THE UNIVERSE

One of the simplest ways to explain the world is the attempt to convince oneself that there is nothing to explain. If the universe has always existed, then there is nothing to explain. Reality is simply "given us" and the problem is removed. No wonder that the doctrine of the "eternity of matter" has always constituted one of the pivotal claims of all manner of materialisms.

But such an explanation is only apparent. Already St. Augustine observed that if someone were to stand barefoot on the beach for all eternity, then his footmark on the sand would be eternal too, but nonetheless it would still have its cause – the foot making it. If we wanted to neutralise this argument as well, we could query the sense of asking about any kind of cause. This device was employed in the diverse forms of Positivism: it was claimed that experience can inform us only of the sequence in which phenomena occur, but not of their inner causal relations. This type of therapeutic manoeuvre has survived only within some of the more exotic trends in philosophy. Various sciences relating to the world are still searching for causal chains within those aspects of the world subject to their fields of study.

It is a historical fact that for a long time, more or less from the French Enlightenment onwards, the belief in the "world's eternity" has generally been regarded as something in the way of an ultimate explanation with no further questions asked relating to other "deeper causes of existence." Admittedly, the image of an eternal world has been consolidated by the progress made in classical physics. Newton himself was deeply convinced that his mechanics, when applied to the system of

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the universe, called for a Grand Architect to fix the initial conditions for the laws of mechanics, but his concept of absolute space and absolute time set the stage on which processes could take place without being influenced by space and time. True enough, the differential equations describing the laws of nature require initial conditions, but these may be selected for any arbitrary moment in time. Thus the word "initial" turns out to be established purely by consensus, and the initial (or boundary) conditions themselves serve only to enable us to select the right solution out of the entire class of possible solutions, therefore they do not appear to give rise to any serious problems from the philosophical point of view.

In the eighteenth and nineteenth centuries the image of an eternal universe extending out to infinity in a Euclidian space was one of those beliefs which are so obvious that they are not even discussed. This did not mean, however, that there were no problems pertaining to this image – generally accepted beliefs need not be unquestionable. Newton himself observed that his law of gravitation applied to an infinite universe containing an approximately homogeneous distribution of stars generated serious problems. How could the stability of such a system be ensured? An arbitrarily small disturbance in the density of the distribution of the stars would cause the collapse of the entire system into one gigantic body.[1] In 1895 the German astronomer Hugo von Seeliger said that this problem was so fundamental (and today it is called Seeliger's paradox) that he put forward an alternative. We should either query the infinity of the universe, or amend Newton's law of gravitation. And he decided on the latter option. A year later and absolutely independently, Carl Neumann, a mathematician, did the same. Both Seeliger and Neumann proposed that an additional constant be introduced to Newton's laws to stabilise the system of the universe.

2. THE THERMAL DEATH HYPOTHESIS

The belief in an eternal universe was well-nigh a dogma of the mechanistic worldview. The emergence of thermodynamics in the nineteenth century was hailed as yet another success for this philosophy. The theory of heat based on the concept of phlogiston, a "thermal fluid" flowing from warmer bodies to colder ones, was successfully replaced by statistical mechanics, in other words simply the Newtonian mechanics, in which the mean values of various magnitudes referred to large numbers of material molecules. However, this success cast a shadow over the doctrine of the eternal universe.

The first law of thermodynamics is the law of the conservation of energy applied to heat changes. So far there are no problems looming ahead. If we consider the universe as a single large thermodynamic system, the first law of thermodynamics may be regarded as an argument in favour of an eternal universe. If the energy of such a system is conserved, then it must have always been so, since energy can neither be lost not created.

The second law of thermodynamics was formulated in 1850 by Rudolf Clausius, who expressed it in the form of a theorem that no machine can be constructed which can transfer heat from a body at a lower temperature to a body at a higher temperature. Four years later he gave this principle a more mathematical form, introducing a function which he later named entropy. The principle expresses the tendency prevailing in an isolated thermodynamic system to equalise temperature, and it takes the form of a theorem which says that in such systems entropy increases (or remains constant in systems with reversible processes). Clausius himself did not refrain from drawing cosmological conclusions, observing that the entropy in the world was tending to a maximum, that is to the establishment of a uniform temperature throughout. Later Hermann Helmholtz called this state the heat death of the universe.

William Thomson drew further conclusions from the second law of thermodynamics. If heat death has not occurred yet, then the cooling down of the universe (viz. the equalising of temperatures to a uniform value throughout) must have started a finite time ago, in other words the process must have had a beginning. Thomson wrote of "some finite epoch [with] a state of matter derivable from no antecedent by natural laws."[2] This was too reminiscent of the notion of a beginning of the world not to evoke controversy and heated debate. They still recur even today in diverse publications.

Nonetheless most scientists did not treat all these cosmological discussions and speculations very seriously. The well-known Irish astronomer Agnes Mary Clerke expressed the prevailing opinion when she wrote in 1890 that whatever lay beyond the boundaries of the Milky Way was not the subject of scientific study, since "with the infinite possibilities beyond, science has no concern."[3] Cosmology would not become a respectable science until Albert Einstein and his general theory of relativity. The consolidation of the relativistic cosmology was a process which went on for several decades in the twentieth century, starting in 1917 with Einstein's first paper on cosmology.

3. EINSTEIN'S FIRST MODEL

Already at first glance Einstein's article is extremely pioneering, though otherwise it looks just like a standard scientific paper.[4] When he wrote it Einstein had the field equations available for the general theory of relativity, which show the gravitational field as a deformation of space-time caused by the distribution of all the sources of the field. In such a situation the cosmological question appears quite naturally. We simply have to answer the question in what way the mean distribution of the sources of the gravitational field deforms the space-time geometry. Of course in answering that question we have to resolve a whole series of conceptual and technical issues. The way in which Einstein accomplished this made his paper a breakthrough.

Above all, since Einstein's field equations are a set of differential equations there is the problem of boundary conditions, which is in turn connected with the distribution of the sources of the gravitational field (Einstein simply spoke of stars). The natural solution often applied in astronomical enquiries is to assume that we are dealing with an isolated system of bodies, on which the gravitational influence of other bodies is negligible enough to be ignored (the gravitational field disappears at the "boundary of the problem"). In cosmology this would correspond to one "island of stars" (e.g. the Milky Way) in the empty space surrounding it. Astronomers had been debating for quite a long time over "the island distribution of matter": some held that the spiral nebulae visible with a telescope were clouds of dust and gas in our own galaxy (the Milky Way), while others said that they were different galaxies, separate "island universes". The dispute continued, but for the time being neither side could put forward a clinching argument. Einstein probably did not know of the controversy, but in a sense he resolved it with one sweep of the pen. Considering the issue of boundary conditions, he observed that the assumption that the gravitational field disappeared at infinity could not hold in cosmology. A simple statistical approach convinced him that if we assumed just one "island of stars" in an otherwise empty space, then sooner or later the stars, agitated by random motion, would have to evaporate from the island. A solitary galaxy would be an unstable structure. Therefore we have to assume a statistically uniform distribution of stars (galaxies or clusters of galaxies, in the terminology used today) in space.

But then what boundary conditions should be applied? Somewhat earlier the Dutch astronomer Wilhelm de Sitter had hinted at a solution. In Einstein's theory we do not have to insist on a flat space: we know that gravitation distorts its geometry. So we may do away completely with the "boundary," and hence with the need to adopt any kind of boundary conditions. Such a situation would hold if space were spherical in shape, analogous to the surface of a sphere (if we move along it, nowhere do we encounter an edge). Einstein calculated that there was a solution to the field equations which had these properties.

There was just one remaining problem, the one that had troubled Newton – the question of gravitational instability: why would the stars in a spherical universe not collapse into a single point? To obviate the difficulty, Einstein did what von Seeliger and Neumann had proposed earlier with respect to Newton's theory of gravitation: he augmented his equations with a component entailing a constant the purpose of which was to stabilise the model. This constant – Einstein named it the cosmological constant – is an exact counterbalance of the attracting gravitational force. That is how the first cosmological model based on the theory of relativity was constructed. Today we call it Einstein's static model.

4. THE UNIVERSE AND PHILOSOPHY

Let's not be led astray by appearances, however. True enough, Einstein's paper is an example of a fine piece of research opening up new horizons while at the same time addressing the old problems. But his aim went much further: it was precisely to reach the ultimate explanation. Naturally, such intentions are not to be disclosed in a research paper submitted for publication in a scientific journal, although they may often inspire many an author. On the other hand we have to admit that Einstein cared far less about conventions than many of his colleagues. The attentive reader will quite readily identify a certain philosophical motif in his 1917 paper: "In a consistent theory of relativity," he wrote, "there can be no inertia relatively to 'space,' but only an inertia of masses relatively to one another."[5] Again this sounds technical, but it's fairly easy to decipher what Einstein was thinking of. The inertia of a particular body with respect to space, which would have to be something like Newton's absolute space, would mean that the body's mass, which is a measure of its inertia, would be its absolute property, something with which the body was endowed a priori. But the world should be a "closed system," all of its justifications should remain within it, not assumed a priori. The only sensible solution to this situation was to assume that the mass of a particular body was as it were induced in it by all the other bodies in the universe. Hence there would be no inertia with respect to space, only with respect to other masses. Einstein took this idea from the writings of the physicist and philosopher Ernst Mach, and in his honour called it Mach's principle. The intention to create a theory of physics incorporating Mach's principle was one of the main motives behind Einstein's efforts which eventually led to the emergence of the general theory of relativity. No wonder that this motive is clearly visible in his first paper on cosmology.

But Einstein's philosophical inspirations went even further. Ever since his young days he was interested in the life and work of Baruch Spinoza, a seventeenth-century philosopher. Spinoza was so fascinated with instances of rationality in the world that he identified the world with God. "By God," he wrote, "I understand a being absolutely infinite, that is, a substance consisting of an infinity of attributes, of which each one expresses an eternal and infinite essence."[6] Understood in this way, God is identical with the universe; hence God is the "substance" which exists "of itself" and is "self-explanatory." Einstein was quite open about his sympathy with pantheistic views of this kind. He, too, was fascinated by the "rationality of the universe" and often spoke of his "cosmic religion" in connection with this. No wonder, then, that the universe was "to explain itself"; the right cosmological theory should be the ultimate theory.[7]

Einstein immediately took up de Sitter's suggestion that troublesome boundary conditions could be evaded by assuming that the universe was spatially closed. The logical enclosure of the universe, that is the idea that all of its explanations should be enclosed within the universe, found its expression in the geometrical enclosure of the universe. On finishing his paper Einstein had every reason to feel pleased with himself. There was only one solution to the gravitational field equations which met all of his philosophical criteria. That solution presented an eternal universe, spatially closed and obeying Mach's principle.

Einstein thought that the "cosmological problem" had been solved. I wonder what research problems he was pondering about after that?

5. AN EXPANDING VACUUM

The "universe's rationality" is indeed one of its fascinating features. It certainly needn't have been so that our minds would be capable of fathoming the mysteries of its structure. For we have managed to fathom so much. Einstein's first paper on cosmology was undoubtedly a milestone on the road to understanding cosmic structure. As we think about this a disconcerting question comes to mind: are our brains advanced enough to allow us to completely solve the mystery of the universe? Or to put it in another way; does the structure of the universe have to correspond to our brain structure to such an extent as to allow us full access to discovering the way it works? On finishing his paper Einstein did not realise how far he still was from ultimate solutions. But he was soon to find out.

Still in 1917 de Sitter published a paper presenting a new cosmological solution to Einstein's equations (with the cosmological constant).[8] In this paper de Sitter embarked on a dispute with Einstein's understanding of Mach's principle and put forward his own interpretation. But this was not what proved fatal to the views of Einstein. The very existence of de Sitter's solution put them to a difficult test. In de Sitter's solution the density of matter is equal to zero. In other words de Sitter's model is empty, and in spite of this the structure of space-time is still well-defined. Therefore it is not defined by means of a distribution of "material sources" and Mach's principle (as Einstein understood it) is not obeyed in the general theory of relativity. Soon it turned out, thanks to the work of Georges Lemaître,[9] that although de Sitter's world was empty, his space was expanding: if we were to put into this world two particles the masses of which could be ignored as negligible, so as to still be able to consider the model as empty, then those masses would begin to move away from each other.

Meanwhile ever since 1912 Vesto Slipher had been measuring shifts in the spectra of galactic nebulae. In 1918, on the basis of his own and Slipher's observations, Carl Wirtz expressed an opinion that the prevalence of red shifts in the spectra of nebulae could mean that these nebulae were moving away from each other. In the same year Eddington wrote in a letter to Shapley that the spreading out of the nebulae had been predicted in de Sitter's model.[10] The recession of the nebulae came to be known as the de Sitter effect.

6. THE CRISIS OF EINSTEIN'S PHILOSOPHY

From the theoretical point of view the situation was paradoxical. Einstein's model had a non-zero density of matter but did not predict the moving away of the galaxies (spiral nebulae). De Sitter's model predicted the moving away of the galaxies but had a zero density of matter. Nonetheless the argument that the mean density of matter in the real world was smaller than the best vacuum we could obtain in laboratories on Earth, in other words that we could treat de Sitter's model as a close approximation to reality, was a dodge. And scientists knew it. After all, theoretical zero density is not the same as a very small density.

But the paradox was soon resolved. The Russian mathematician and meteorologist Aleksandr Aleksandrovich Friedman published two papers presenting his discovery of a whole class of spatially homogeneous and isotropic solutions to Einstein's equations of which Einstein's and de Sitter's solutions were special cases.[11] In this class there was only one static model (Einstein's); all the others were either expanding or shrinking. He also explained the apparently paradoxical status of de Sitter's solution: all the models expanding out to infinity (monotonically) tended to de Sitter's empty model as time tended to plus infinity. Thus de Sitter's state was effectively an asymptotic state for the expanding models, in which the density of matter tended to zero in outcome of the expansion.

Gradually the situation was starting to clear up. Einstein's proposition that there was only one unique, uniquely possible cosmological model concordant with all the philosophical expectations turned out not to hold. In cosmology, as in all the other branches of physics, many models can be constructed and only observation will tell which of them corresponds best to the reality in the world.

Cosmology would not become a fully experimental science until the last decades of the twentieth century, but it started to mature already by the 1920s. In 1929 Edwin Hubble collated about 40 results for the red shift measurements in the spectra of galaxies and published his famous law: the velocity at which a galaxy is moving away is directly proportional to its distance from us.[12] These results were already in circulation among scientists. In 1927 Georges Lemaître compared the results of measurements of the red shift with predictions for one of the solutions discovered by Friedman, which he had found independently of Friedman, and confirmed that there was no discrepancy between the theory and observations.[13]

In the 1930s the paradigm of an expanding universe became firmly established. Even Einstein, who for a long time would not accept it, finally had to concede in the face of facts. The reason for his opposition had been that an expanding universe suggested the idea that it must have had a beginning. Knowing the distance to a few galaxies and the velocities at which they were receding, on the basis of Hubble's law it is easy to estimate how long ago all the galaxies were situated "at one point." For Einstein this was a difficult conclusion to accept. A universe which was supposed to be self-explanatory should not have a beginning.

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