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THE ANTHROPIC PRINCIPLE – PHYSICAL CONSTRAINTS FOR THE EVOLUTION OF INTELLIGENT LIFE – AN EPISTEMOLOGICAL ASSESSMENT

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I. FROM THE COPERNICAN TO THE ANTHROPIC PRINCIPLE

1. A Thousand Years on the Way to the Copernican Principle.

It was a long way from Greek geocentric cosmology to the modern centerless universe which is linked to the name of Copernicus.

Aristotle was the first to find a physical cosmology based on mathematical principles. His model of the universe was built out of the homocentric spheres of Eudoxos and Kallippos and was stongly devoted to a cosmic center. The geocentric picture of the Aristotelian world had its origin in dynamical foundations. He based his astronomical system on a dualistic physical ontology. The so-called sublunar sphere consisted of the four elements earth, water, air, and fire. The natural motion of these terrestrial elements was "up" and "down" and they had an intrinsic tendency to find their proper places according to their weight. On the contrary, the supralunar sphere was built entirely out of the fifth element, and its natural motion was the endless circular revolution around the center of the world occupied by the center of the earth.

More or less, this situation did not change even by the refinement of Ptolemaic astronomy, and during the medieval times the geocentric world picture with its natural place fitted very well into the cosmological ideas of Christianity. Thomas Aquinas showed how the Aristotelian universe could be adapted to the Christian thought by relatively slight modifications. Christian revelation was tightly connected with the conviction that mankind does indeed occupy the center of the universe. The displacement of the cosmic center could get on only step by step.

In 1543, Copernicus shifted it to the sun. Here it remained up to the times of William Herschel. At the end of the 18th Century, Herschel found that on astronomical reasons it should be removed to the core of our galaxy. But even that position was overthrown by Harlow Shapley in 1922, and at last Walter Baade discovered in 1952 that our milky way is a normal spiral galaxy not remarkably larger than the customary type. Hence, we can recognize in the history of cosmology the steadily growing conviction that mankind does not occupy the center of the universe.

Already at this point we should make an important distinction: cosmology may convince us that, from a global view-point, our kind of intelligent life has no special <u>location</u> in the universe, but in a local perspective we are surrounded by characteristic types of objects that might be unique. Our planetary system, the special location where the only known biological evolution took place, is perhaps distinguished in so far as peculiar constraints led to the building site of the biosphere. Current theories on the origin of life give no hint on the intrinsic properties of possible organisms that might be engendered by other planetary sites. The reason is, besides the low state of theoretical knowledge on the origin of life, that cosmology gives us only the main outline of the cosmic picture and ignores the irregularities of the local detail. Even a globally homogeneous universe without cosmic center and without outer edge can have a physically privileged place, where evolution took place. Cosmology makes spatiotemporal assertions, it is not concerned with estimations of complexity and a fortiori not with statements of value. Accordingly, it is possible that the human neural network is the system with the highest complexity in the entire universe and the only system that engenders values. This is fully compatible with our living in a typical location of the universe.

2. The Copernican Principle in Modern Cosmology.

Modern cosmology in the time of Einstein and Hubble brought about the idea of the isotropic and homogeneous universe. This is relevant to our purpose in the following sense: the location principle only makes a claim on the likelihood that <u>we</u> have a special location in the universe. Or, in the words of Hermann Bondi: The Earth is not in a central, specially favoured position."[1]

Such a principle leaves undecided the question whether or not a cosmic center does exist somewhere. The standard class of models (FRW) is quite explicit on this point. It takes into account only the subclass of spacetimes i.e. exact solutions of Einstein`s field equations, that comply with the boundary conditions of homogeneity and isotropy. But there is a snag in these restricting constraints. Observation leads unequivocally to an isotropic distribution of matter and radiation. Local irregularities set aside, beyond 100 Mpc galaxies are scattered evenly throughout 3-space up to the horizon. Radioastronomers have found that the very distant radio sources are distributed isotropically around us. The same is true for radiation, e.g. the X-ray background and foremost the cosmic microwave relic radiation, the remnant of the fireball state which today, after having expanded adiabatically for $15 \cdot 10^9$ years, is measured with a temperature of 2,9 K, show the same feature. Recent measurements reveal that the isotropy of the 3 K-radiation amounts to about 1 part in 10 000.[2]

Now comes the snag. It lies in the fact that humans are immobile observers. For obvious technical reasons we cannot explore the vastness of space in order to test the homogeneity of 3-space. But by looking around carefully we can only ascertain local isotropy. Local isotropy means rotational symmetry around our special point of observation. However, to establish homogeneity, we need global istropy, that means the same symmetry around any point whatever of the cosmological substratum.

It is a well-known theorem of differential geometry[3] that exact spherical symmetry around any point entails that the universe is spatially homogeneous. Such a spacetime admits a six-parameter group of isometries. Its surfaces of transitivity are spacelike three-surfaces of constant curvature.[4] In more colloquial terms: any point of 3-space in a homogeneous universe is physically equivalent to any other point on the same surface.

Hence, in order to fill the gap between local and global isotropy we need a bridging law. The lawful connection fulfilling this requirement is the Copernican principle. The name of this principle is clearly a misnomer, since Copernicus believed that the sun occupies the central place in the universe. Apparently, it perpetuates the belief that, indeed, a center does exist somewhere. Names, however, are of no importance, and we should pay more attention to the trend starting with Copernicus (with the ancient paragon Aristarchos). According to it we have to realize that we are living on a medium sized planet revolving round a normal main sequence star that is located on the rim of an average spiral galaxy which is in turn a member of a local group of galaxies. If we do so, we can make use of the term "Copernican Principle" in the sense that our position in space is not distinguished in any way.

Since we have to deal with counterarguments against the Copernican principle in due time, we should have in mind the many epistemological advantages of a homogeneous 3-space. This high symmetry makes cosmology a much easier task. A universe containing one or many special locations with physically distinct properties could not be dealt with in a comprehensive way. The customary inference from a cosmologically relevant sample to the whole spacetime (even beyond the event horizon and even if its global topology would be non-compact!) would be invalid.[5] In a hierarchical universe which is maximally inhomogeneous, no part, howsoever large, is significant for the universe as a whole.

Needless to stress that Einstein's field equations do not demand anything like homogeneity in the distribution of matter or radiation nor does this basic law require constant curvature for 3-space. Besides the simple Robertson-Walker spaces there is a large class of solutions in which the requirement of isotropy is dropped, but spatial homogeneity (in accordance with the Copernican principle) is retained. Even absolute rotation and shear could be included in the large-scale description, if astrophysical data would indicate such complications. The fact that no large-scale anisotropy of this kind has ever been detected indicates that we are living in a universe with very special initial conditions that are friendly to cosmologists.

So homogeneity is highly desirable from an epistemological point of view, and the Copernican principle - sometimes called the principle of cosmological democracy - has a clear-cut function if it can be rationally defended.

But the Copernican principle included an emotional component; it brought about an abdication of a cosmic privilege rooting in theology. It is on a par with the abdication physics and biology have remorselessly forced on us, when, by Darwin's evolutionary theory, the species of man was filed in the long range of living organisms. Maybe the Copernican movement evokes a feeling of injured vanity and is therefore feared and resented in some corners of the intellectual community up to the present time.

3. The Roots of the Anthropic Principle and its Ramifications

The origins of the countermovement against the Copernican principle are deeply rooted in 19^{th} Century's physics. Ludwig Boltzmann, the founder of statistical mechanics, was led to explain the direction of time by a natural line of arguments which comes close to the weak Anthropic Principle (WAP). His attempt to infer the thermodynamical arrow of time from mechanics forced him to assume either that the entire universe is at present in a highly improbable state or that our observable region is a tiny part of the whole universe which, globally, is in thermodynamic equilibrium.[6] Relatively small regions will deviate on account of the unavoidable fluctuations from thermodynamic equilibrium. The reason, why a living being finds himself in such a corner of the universe, for which a significant deviation from equilibrium defines an arrow of time, can be understood, if we remember that only on a slope of the entropy curve life, consciousness, and intelligence can evolve. Therefore, it does not come as a surprise that in our local cosmical environment time has the direction we actually observe, because open systems need thermodynamic unequilibrium as a necessary condition for the origin, evolution, and maintenance of their life.

For the moment it is worthwhile to notice that Boltzmann had to make his choice, either to accept very improbable initial conditions, for which in principle no furher experience could be given, or to include man and his thermodyamical suppositions in a physical argument. Even at that time Boltzmann's colleagues were reluctant to accept the anthropic fluctuation interpretation, and in modern times it was severely criticized by Karl Popper, who accused Boltzmann of having violated the objectivity of the direction of time.[7]

Even if reproaching Boltzmann with subjectivity is historically not entirely correct[8] - because Boltzmann defended a realistic and objectivistic theory of knowledge - we can recognize that already since their rise anthropic arguments ran great risk to be interpreted in the direction of an epistemological idealism.

In modern times, we can observe various roads to the AP. Science (not so much the humanities) can be regarded as the search for invariant aspects of the phenomena expressed in fundamental laws. Every law, however, contains constants the exact values of which remain more or less unexplained. Some of these constants of nature turn out to be tightly fixed by the necessary condition that they enable the existence of intelligent beings. This condition acts the part of a selection effect and characterizes the type of universe that can be inhabited and of which scientific knowledge is possible.

If we regard these constants that are inevitably contained in every law of nature, surprising coincidences show up which can be classified as follows:

i) absolutely senseless or chance coincidences. For an example we may consider the ratio of the mass of the nucleon to the mass of the electron. $\frac{m_N}{m_e}$ = 1836.1515. It resembles largely to the result of $6\pi^5$, which is 1836.118. Speculations on a hidden physical meaning of this coincidence lead nowhere.

ii) rather contrived numerical relations, the physical meaning of which can be assessed hardly today, like the mass of the nucleon, of the Λ, Σ and Ξ hadron which can be ordered progressively[9], or the so-called mass splitting coincidences[10] which connect the masses of some hadrons with the fine structure constant α.

They are not just a result of mysterious combinatorial juggling, but at the moment no deeper meaning can be grasped.

iii) very surprising coincidences of the type that, in 1937, caused Dirac to introduce his Large Number Hypothesis (LNH). Dirac was bewildered by a prevalence of dimensionless large numbers resulting from the ratio of atomic and cosmological quantities. More exactly, he felt that there was a need for an explanation of the chasm between the numbers built out of physical constants like $\frac{m_N}{m_e}$ and $\frac{e^2}{\hbar c}$ which are within a few magnitudes in the order of unity, and the really large numbers like

$$N_1 = \frac{\text{age of the universe}}{\text{atomic light crossing time}}$$ [11]

$$N_2 = \frac{\text{electric force between proton and electron}}{\text{gravitational force between proton and electron}}$$ [12]

on the other side.

To explain the surprising coincidence of the two large numbers N_1 and N_2, he put forward his famous LNH: "Any two of the very large dimensionless numbers occurring in nature are connected by a mathematical relation in which the coefficients are of the order of magnitude unity."[13]

It might be, of course, a matter of debate, whether the occurrence of two large numbers of that kind is <u>really</u> an item to be explained causally. Should we really regard it as an explanandum that points to a hidden nomological structure? Superficially, the two categories of numbers, the microphysical and the cosmological one, are quite unrelated according to current physics. If the hypothesis "N_1 = N_2 up to some trivial numerical factors of the order of unity" is taken seriously, we get dramatic consequences for gravitational theory in general and cosmology in particular. Since N_1 includes the Hubble age t_0, any number of the order of 10^{40} should be time-dependent and, accordingly, all numbers of the order of $(10^{40})^n \propto t^n$. The question as to why physics contains these large numbers at all is answered by referring to our cosmic age. When the universe was young, these numbers were small, but now they are large, and they are getting still larger in future.

Since $N_1 \propto N_2$, one of the constants of N_2 had to be time-dependent, too. With respect to well tested results of local quantum mechanics, Dirac chose the very consequence of the LNH that gravity must weaken with the passage of cosmic time, namely $G \propto t^{-1}$. Besides this novel non-Newtonian and non-Einsteinian gravitational theory, where $G = G(t)$, Dirac's approach led to the unusual prediction that the number of particles in the universe N (which is of the order of 10^{80} within the Hubble radius cH^{-1}) must increase with the square of t, $N \propto t^2$. This consequence, of course, leads to a head-on collision with energy conservation, if the universe is finite, a conflict that can only be avoided if the universe is infinite and N therefore not defined.[14]

Numerology of the Diracian type led many even renowned astrophysicists to delve into strange speculations. Pascual Jordan[15], e.g., extended violation of energy conservation to the realm of stellar masses[16]. From here, there is only a small step left to stars popping out of nothingness. Philosophers of science have always criticized the idea of continuous creation of matter[17] as an untestable process. The spontaneous genesis of entire stars ex nihilo is without doubt beyond the fringe.

On the other hand, varying G-theories act a part in a kind of subculture in physics up to the present. Many spatiotemporal variations of the fundamental "constants" were tried out, but physics is a strongly interrelated network, and every time one's proposal seemed to work another physicist could show up an unintended consequence which is contrary to the observed facts.

A devasting critique of the incorporation of Dirac's $G \alpha t^{-1}$ into stellar structure and planetary dynamics has been put forward by Edward Teller. He showed that on account of the sun's luminosity being higher in the distant past and the earth's orbit being smaller, the surface temperature of the earth would have been so high that in pre-Cambrian era the oceans must have been boiling. This argument already includes a kind of feed-back to the existence of life. Our knowledge of the very early microbiological form of life constrains the terrestrial surface temperature at that time. We urgently need research programs on a self-consistent set of variations of all fundamental parameters[18], including constants defining the strength of the known forces.

A new cosmological perspective came to the fore, when several scholars, included the famous J.B.S. Haldane, realized[19] that cosmological models in general and the variable G model in particular could have great importance for the origin and maintenance of life.

Of course, a cosmological model that is selfreferentially inconsistent in so far as it excludes man, the formulator of the problem, cannot be a viable scientific approach. Dirac's original model was of that kind. If N_1 equals permanently N_2, then G does vary in a way that eliminates the creatures, who observe the coincidence $N_1 = N_2$.

Therefore, a theory was strongly needed in which the gravitational constant G varies at a much lower rate. In this situation, the so-called scalar tensor theory of Carl Brans and Robert H. Dicke came to aid. Its construction was motivated by the endeavour of bringing Einstein's theory of gravitation into accordance with Mach's principle. The field equations[20], with an additional scalar field φ, hadn't any longer exact solutions for empty space, as Einstein's original equations did. A low variation of G, of course, can be brought into accordance with the original evolution of terrestrial life, but as the permanent validity of $N_1 = N_2$ is no longer upheld, the original intuition of Dirac is destroyed.

R.H. Dicke turned Dirac's approach upside down. For a rather long time, he was busy with a research program connecting biological factors and large number coincidences. Finally, he found the missing link between the apparent coincidences and the necessary pre-conditions for the existence of observers. When comparing N_1 with N_2, he argued, we should concentrate on the question why, today, we observe $N_1 = N_2$. In the early universe, when the world was young and hot, number N_1 was small, but there was nobody in the quad to notice this value. In the far future, when the universe will be old and the stars burnt out and partly collapsed to black holes, N_1 will be large and again nobody will be there to observe this value. Therefore, the discordance of N_1 and N_2 at very early and very late times is unobservable. Only within a limited epoch of cosmic time, when the astrophysical conditions are favourable to intelligent life, observers will exist and then be very suprised at the coincidence of N_1 and N_2.

Dicke realized later on that his argument in the above version was incomplete resp. contained many suppressed premisses.[21] In order to make the causal claim more explicit we remember that according to current biochemical knowledge life is built upon elements heavier than H and He. Heavy elements, however, are not primordial, as the standard hot big bang model tells us, they are "cooked" in massive stars and enrich interstellar material by supernova explosions. Carbon as the basic material for <u>our</u> kind of intelligent life cannot be produced in a universe that recollapses long before the first generation of stars have ended their life. So, surely, our carbon based life could not come into existence before the age of the universe is beyond the main sequence stellar age t_{ms}.

No wonder that t_o, the cosmic age of today, is α t_{ms} and as a consequence we observe $N_1 = N_2$ at present.

Important to stress that Dicke's argument does not presuppose, as Barrow and Tipler pointed out, that only carbon sustained life is physically possible. Even if many chemical bases for the origin of life reveal to be possible, "the fact remains that we are a carbon-based intelligent life-form which spontaneously evolved on an earthlike planet around a star of G 2 spectral type, and any observation we make is necessarily self-selected by this absolutely fundamental fact".[22]

It remains a matter of speculation, whether other material sites like interstellar clouds have enough inner complexity to bare living structures. Selection is a key word in this context, and Dicke's biological "explanation" of the coincidence $N_1 = N_2$ can be regarded as a reduction to an artificial selection effect. Whether it should be called a genuine explanation, this will be focussed in the following philosophical section. In any case, Dicke's turning Dirac's LNH around is the first modern use of the weak AP that establishes a link between a global property of the universe, namely its age, and certain necessary conditions for a special subsystem, i.e. a living organism. The stronger versions will be analysed in due time. Already now it should be stressed that the argument only yields a logical connection between the self-awareness of organic matter and a certain constellation of crucial parameters, namely if (but not iff) matter has begun to contemplate itself, then $N_1 = N_2$. Dicke's argument, however, cannot be constructed as a suffcient condition for the existence of life. Carbon, oxygen, silicon are presuppositions for the genesis not only of life, but also of anorganic complex structures like mountains. Physically possible are universes with many rocky planets in it, yet no intelligent life. Nobody looks around in this possible place for habitation to be aware that $N_1 = N_2$. The distinction between necessary and sufficient conditions is the characteristic difference between the strong AP and the weak AP (SAP and WAP). If the SAP holds, then the above situation of a mindless universe is impossible; the evolution of matter to higher states of complexity cannot stop at the anorganic chemical level. Every universe that is physically possible at all must be cognizable and in the formulation of Brandon Carter "admit the creation of observers within it at some stage".[23] In other words: a certain cosmic coincidence like $N_1 = N_2$ has to lead inevitably to life, mind, and consciousness.

It is, of course, a matter of debate, whether we really need the SAP to understand coincidences which otherwise, if we were restricted to the use of WAP, would escape our comprehension. It is philosophically important to realize that some authors make us believe that SAP can be interpreted semantically only as a design argument that means, in a teleological framework. Although we will be occupied with the epistemological evaluation of the various AP's later, it suffices at the moment to note that most scientists do not intend such a usage. To avoid idealistic and premature teleological interpretations, B. Carter has stressed in a recent paper that he regrets not having used the term "cognizability principle" instead of "anthropic principle".[24] Most scientists refuse to apply the SAP. So B.J. Carr has remarked that the AP is not to be used in the sense: "the universe does not exist, if we are not here to observe it", but only in the weaker sense "if we are here to observe it, the universe must be the way it is".[25] Here the task remains to clarify the notion "must"; we defer this point to a later chapter.

The WAP can be totally divorced from metaphysical or even teleological overtones if couched in the language of a world ensemble. The hypothesis of the plurality of worlds has been looked on with suspicion by many scientists, but if formulated properly, it neither contains logical inconsistency - it is erroneously argued that the universe must be unique by definition - nor does it lead into the mystical realm of unfathomable entities. Foremost we have to distinguish between an ensemble of possible worlds (in the sense of Gibbsian statistical mechanics) and a plurality of real worlds (in the sense of the Everett-Wheeler-Graham interpretation of quantum mechanics).

It is ontologically non-committal to examine an ensemble of possible worlds as to their structure of features enabling them to generate observers or not. This is nothing but to establish a subset relation of the cognizable set in the set of all physically possible worlds. It is, of course, a trivial analytical truth that we inhabit a member of the cognizable subset. However, it is a nontrivial task to establish a probability measure on the frequency of cognizable worlds. This relative frequency is a contingent fact on the whole ensemble. Such an estimation of a probability measure was put forward in connection with the problem of isotropy. Barry Collins and Stephen Hawking, who have analysed this problem in 1973, made use of the hypothesis of a world ensemble. To reduce an extreme unlikely coincidence, they introduced a real set of many worlds endowed with every kind of initial data.[26]

Before looking closer at this special application of the WAP, we should stress that it is not illegitimate to enlarge the pertaining ontology of a scientific hypothesis, if it can be justified via a higher explanation. In any case, it is better to trespass Occam's principle of ontological parsimony than to make an explanatory use of the AP which violates highly confirmed long-term fundamental rules of epistemology. To grasp the crucial point just look at the above- mentioned example of Robert H. Dicke. Taken as a genuine explanation, Dicke's argument would amount to the assertion: $N_1 = N_2$, because we are here, and that is preposterous, because it is back to front, that means, it violates our well-confirmed causal structure and asymmetry of time.

Metaphysical speculations on the plurality of worlds are as old as cosmology.[27] In modern science we find this hypothesis in the sense of the simultaneous existence of many spatiotemporal parts of an otherwise infinite universe, and we meet the hypothesis in form of a superspace of causally disjoint worlds spanning the range of all possible experimental results of a quantum mechanical measurement process.

Indeed, the notion of a plurality of worlds is not so an extravagant concept as it might seem at the first glance. It does not clash with the usual methodology of science. A world beyond our own is just a theoretical entity on a par with hypothesized, not directly observable elementary particles.

There is another conceptual distinction pertaining to the extension of the world ensemble.[28] Counterfactually, we can vary our known constants of nature like $\frac{e^2}{\hbar c}$, $\frac{m_N}{m_e}$, together with the dynamical traits of the universe like expansion rate, entropy content, matter and radiation density, to get the most comprehensive class of physically possible worlds. This is, of course, a subclass of the logically possible worlds which are defined so that contradiction is avoided.

It must be stressed that the general problem to assess the consequences of varying the dimensionless constants of nature is a difficult mathematical task, because we do not know the effect of compensatory changes in the values of other constants. One variation may exclude the existence of life, while another improves the situation. It is possible to estimate the consequences of a small change of say Sommerfeld's α, the strength of electromagnetic interaction, all other invariants of nature being fixed[29], but it is rather impossible to evaluate the consequences of variation in the whole network of constants pertaining to several fields of physics, although a few stability investigations have been made.

This indecisiveness also concerns Wheeler's reprocessing model of the universe according to which a finite universe will recollapse to a final singularity (big crunch). In every bounce, the fiery furnace of the cataclysmic singularity introduces a transmutation to the physical constants and the type of the expansion dynamics. It is difficult, however, to form an opinion on the measure of the cognizable combinations in the set of all combinations facing the infinite number of random oscillatory permutations of the constants.

If every physical basic feature - not just the particles, but also the fields and the geometry (including global topology) - are fossiles from the violent conditions encountered in the very early phase of the big bang[30], then it is difficult to estimate how often combinations favourable to life occur. One thing seems to be clear however: If topology change is included and if, one day, the compact spacetime turns into a non-compact connectivity, then such a universe is bound to expand in the indefinite future and the constants are frozen in the cosmic structure forever. If, in that case, expansion would be sufficiently violent, thereby preventing the formation of galaxies including planetary sites which are necessary for the origin of organisms, life would become extinct forever.

From a logical point of view, Jan Hacking has found a striking difference between the anthropic use of the reprocessing model of John Wheeler and Brandon Carter's many world hypothesis. We can regard the sequences of universes like the rolls of dice. If the universes divorced by singularities have no memory as to their precedent history, that means that a universe has effectively no trace of its predecessors, then the sequence of the worlds is like the rolls of a die. A fair die does not remember how it fell last time. If Wheeler's model of succession, where all physical constants are frozen in the first stage of the big bang and then molten and reprocessed to new values, is taken in the sense of statistical independence among the different classes of values, then an explanation of our present orderly universe based on this model is a matter of the inverse gambler's fallacy.[31]

Even a long chain of universes of every physical construction does not explain the present existence of our orderly life-supporting universe. Our habitable universe is not getting more probable, if many previous universes have been reprocessed by a genuine chance device. That would be to argue like a gambler coming into a room and seeing a double six just rolling on a chance device. If he thinks, "because the double six is seldom, there must have been many rolls this evening" he is committing the inverse gambler's fallacy.[32]

If we retain the actual values of the constants of nature, we get a restricted set of physical worlds, namely those which are ruled by Einstein's theory of gravitation. This smaller ensemble is generated by varying the initial and boundary conditions of the field equations.

The advantage of such a stricter definition is easily to be seen, when we have a look at the answer of Barry Collins and Stephen Hawking to the seemingly innocent question: "Why is the universe isotropic?" Their starting point was the now well established isotropy of the universe which manifests itself most overtly in the fact that the temperature of microwave background does not depend on the direction of measurement to the accuracy of $\frac{\Delta T}{T} \leqslant 10^{-5}$. The rotational symmetry of the 3 K background is even more baffling, when we realize that it extends beyond the cosmic event horizon. Parts of the sky that lie more than say 30° apart are equivalent in temperature $1:10^5$, although the time available since the origin of the universe is too short to make this conformity understandable by a causal process.

Isotropy confronts us with the paradox of causality: Why are all the causally disconnected regions of the universe so meticulously fine-tuned? Do we need the idea of a command or a conspiration coming out of the singularity itself to resolve the horizon puzzle, which is equivalent to the causality riddle?

To find an explanation of the high isotropy Collins and Hawking[33] studied the asymptotic stability of the open

FRW worlds under the action of spatially homogeneous anisotropy distortions. What happens if some deviation of anisotropy is put into the model at very early times? Do these worlds, more or less, approach regularity or are they becoming more irregular, as time goes on? The result of these highly technical investigations can be summarized as follows[34]:

If for the cosmological matter the two conditions[35] stating that negative pressures never dominate the energy density and that the sum of the principle pressures is non-negative are satisfied, then the set of cosmological initial data giving rise to models which approach isotropy as $t \to \infty$ is of measure zero in the metaspace of all spatially homogeneous initial data. Largely a corresponding assertion can be made for the closed homogeneous universes. They do not isotropize at large times, e.g. the spatial 3-curvature does not become isotropic at the time of R_{max}. Only in the limiting case of the flat (k=0) model, when the expansion dynamics lies in the borderline between the hyperbolic and the spherical curvature - in Newtonian terminology that would mean zero binding energy - isotropization occurs at large times. Since this spatially flat model of the Einstein-de Sitter type[36] is of zero measure in the metaspace of all cosmological Cauchy data sets, and the astronomical data show the universe to be very close to 3-flatness, Collins and Hawking were confronted with the question[37], why something occurs for which theory supplies an almost zero probability.

In this situation, Collins and Hawking made use of the WAP. Since a counterfactual analysis shows that matter condensations like galaxies can only grow in a universe in which the rate of expansion is just on the borderline to avoid recollapse[38] the two authors suscribe to the WAP in the following manner: "... the isotropy of the universe and our existence are both results of the fact that the Universe is expanding at just the critical rate. Since we could not observe the Universe to be different, if we were not here, one can say in a sense that the isotropy of the Universe is a consequence of our existence"[39]

As later investigations have shown, the conclusion of Collins and Hawking is not so straightforward as it looks at the first glance. It contains many hidden or suppressed astrophysical assumptions. Since we will be concerned more with the conceptual form of this novel type of argument, we shall take it in its original version.

4. Anthropocentricity, Teleology and Evolution

In modern science, teleological explanations had to give way to causal mechanistic explanations almost everywhere. Darwin's evolutionary theory expelled the question from the domain of science, whether the developmental trends of organic systems are goal-directed. Global teleology, the long-range purposeful development of nature, has been revealed as myth. Local teleological behaviour, e.g. planned action or free voluntary decision, has been restricted to a rather small subclass of higher mammals. Goal-directed actions of higher animals are, of course, not at variance with a causal description of these processes as certain activations of the central nervous system. They can be reconstructed properly as emergent qualities of a higher level of complex organizations.

Given this unmistaken historical trend of natural science, it is more than surprising that even amidst pure physics (e.g. cosmology and astrophysics) apparent teleological explanations came to the fore. Collins and Hawking have been rather silent on the correct interpretation of the last sentence of their seminal paper: "... the answer to the question, why is the universe isotropic, is, because we are here."[40]

Other authors like R. Dicke and P.J.E. Peebles[41] are more explicit on the logics of the relationship between man and the universe within anthropic arguments: "Could it be ... that it is the presence of observers that determines the nature of the universe?" Does it really make sense to interprete the verb "determines" as pointing to a goal-directed process? The case of Collins and Hawking argument suggests nothing like that.

It is a surprising fact that isotropy correlates strongly with the existence of intelligent life. That astonishment can be diminished, when the additional hypothesis is taken into account that reality consists not only of one universe, but of an infinite ensemble of universes with all possible initial conditions. Nearly each of these worlds becomes highly anisotropic at large times and therefore contains no observers. Hence, no teleological agens is needed (entelechia or Aristotelian steering tendency) to understand the amazing coincidence, it is just a selection effect.[42] It is not against but a part of customary scientific methodology to be aware of selection effects that can biase our observation. If an objective determination of all galaxies in a fixed interval of brightness is intended, allowance has to be made for the effect that brighter galaxies are more easily to be seen and therefore tend to adulterate the result. In the same way, cosmological observations are biased by the selection effect due to the existence of observers simply. It should, however, be made entirely clear that this selection effect of "carbonaceous astronomers" may indeed reduce the surprise on the a priori improbable feature of nature, but it cannot substitute a causal explanation, <u>why</u> these properties of the universe prevail and just yield the necessary conditions for carbon-based life.

II. FOUR TYPES OF THE ANTHROPIC PRINCIPLE

WAP used in the right way can be regarded as a blank to be filled in by a causal connection of the pertinent facts. Already in 1974, B. Carter[43] was convinced that some coincidences can be interpreted only involving the SAP: "The universe <u>must</u> be such as to admit the creation of observers within it at some stage". Here the term "must" is of crucial importance, it is open to a variety of meanings. Since "must" implies coercion and the latter points to an entity or agens that compels or forces the constants of nature, the teleological interpretation seems to be inescapable in order to get their values friendly to the observer. This is the meaning many have made out of the SAP: "In essence, it claims, that the universe is tailor-made for habitation and that both the laws of physics and the initial conditions obligingly arrange themselves in such a way that living organisms are subsequently assured of existence."[44] Of course, it is not a logical consequence in the sense of the entailment relation to take SAP in this way, as we stressed earlier, but within the framework of naturalistic science it is difficult to make sense out of Davies' claim. Why ought a material universe to be tailor-made for habitation, what does it mean that the initial conditions are obliged to arrange themselves in a goal-directed way which points to the evolution of man? These moral terms are undefined before the advent of intelligent beings. They are predications devoid of physical meaning within the context of a naturalistic ontology. Barrow and Tipler have rightly remarked that the design version of the SAP can only be understood if couched in a theological language that transcends the limits of science. This cannot be stated so easily if another twist is given to the SAP, namely the participatory version (PAP)[45]: "Observers are necessary to bring the universe into being." The PAP is motivated clearly by quantum mechanics and by an extreme epistemological idealism. Taken at the face value, it says more than customary phenomenalism of the Machian type. Phenomenalism claims that the only object of our investigations can be the world of sense experiences, but not the way they are brought about by physical reality behind the phenomena. A causal theory of sense experiences is impossible accordingly. Taken verbally, the PAP states even more than phenomenalism, namely the causal relation between observers and the universe. They seem to engender or produce physical reality. Needless to say that we don't have the slightest hint to such a kind of retrocausal activity of intelligent organisms. Cognition as it is understood today is an activity of the neural network and is in no way exempted from customary time asymmetric causality. No physical model could be established within current scientific theories to fill in the mechanism - responsible for a process of cognition - which, at cosmologically late times, arranges the constants and parameters of the early universe. That conjecture has trespassed the borderline between science and speculative metaphysics.

Barrow and Tipler have another version of the SAP on stock, the so-called "final AP" (FAP) stating that intelligence has to come one day in cosmological history, and once in existence, will never die out . Since the FAP is more related to information theory and computer science, a subject not intended to deal with here, we will skip its discussion.

III. ARE ANTHROPIC ARGUMENTS EXPLANATORY?

Given the four main varieties of the AP it is of central importance to realize which of them can be defended considering the approved rules of today's scientific methodology. Philosophers of science have uttered heavy criticism on the various APs foremost when they are put forward as explanations of a new anthropocentric type.[46] The patterns of explanation are thought to be well understood since C.G. Hempel analysed them as the deduction of an event E (explanandum) from a set of law statements together with some initial and boundary conditions. If we take the argument of Collins and Hawking as our main example, then the decisive boundary condition is that "intelligent life exists". Given the law of Einstein's gravitation theory, some additional astrophysical assumptions and some biological generalizations, we can construct a formally correct explanation of the isotropy of the universe. Nevertheless, its direction of explanation is wrong. The causal connection is one way, namely from the isotropy of the universe at late times to the existence of intelligent organisms, but not the other way round. The violation of the causal structure, a global property of spacetime, makes the anthropic explanation an illegitimate use of the AP. The methodological moral of this example is well-known, logic alone is not enough to analyse correct explanations. An explanatory argument has not only to be deductively correct, it needs to be supplemented by synthetic rules of a more general kind, pertaining to our concrete universe.

Anthropic arguments can, of course, point to novel hitherto unknown concatenations of organic systems with their cosmological embedding. If, however, answers to questions of the type

"Why is it that 3-space is flat, or
3 K radiation is isotropic, or
the universe is as old as a main sequence star (10^{10}y) or
the universe is roughly 10^{10} light yrs in extent?

are requested, then we have to take care of the direction of explanation, resp. we need certain additional premisses like the postulate of the world ensemble. If this enlargement of physical ontology has been accepted, an answer as to why we observe something that is of infinitesimal probability, can be given without inverting the causal structure of physical processes in any member of this ensemble. Therefore, I do not like to adopt the stance of D. Lewis, who argues[47] that the postulate of the world ensemble is a reason why we do not need an explanation at all. On the contrary, I hold that the ensemble hypothesis reduces the astonishment of improbability, but it cannot be taken as a substitute for the causal explanation why, in the individual worlds, the constants arange themselves in the way they do.[48]

Some philosophers have taken the point of view that even extremely rare coincidences do not need an explanation at all, so why bother with improbable chance events? Since unlikely events occur sometimes, we should not be disturbed by the above-mentioned cosmological coincidences. John Leslie has rightly criticized this kind of shrugging one's shoulders.[49] Take an example: If, on a lonely beach, you come across an inscription several square feet in extent "Coca Cola", you wouldn't argue that considering the long geological times and the many possible combinations of sandgrains one time even the improbable combination "Coca Cola" has formed. Given the existence of humans everybody would tend to a causal explanation: A stroller on the beach must have written these two words, maybe as a joke. If, however, no organism would be available for a dynamical explanation, a natural process has to be found to make this contrived order of sandgrains comprehensible. I will give a sketch of this solution in the last chapter. John Leslie's own philosophical approach which he calls "extreme axiarchism" and which contains a creative efficacy of ethical requiredness[50] appears to me of dubious ontological status. It seems far more difficult to vindicate philosophically a Platonic existence of values than the existence of many, even infinitely many, physical worlds.

IV. ANTHROPIC AND DYNAMIC EXPLANATIONS

Let us ask last, but not least: Is there a way out of the dead end in which cosmic coincidences seem to have led? Anthropocentric world views, ontological prodigality, activity of platonically existent values in themselves, teleological super naturalism - the whole limbo of metaphysical ideas seems to pop out. My hope for an explanation of the cosmic coincidences that constrain the existence of intelligent life comes from the development of the Grand Unified Theories. This approach has the great advantage that it operates within the well-corroborated paradigm of science, without taking refuge to exotic modes of explanation. How this conservative strategy may lead to a causal understanding of the a priori improbable combination of parameters and constants, this can be grasped in the so-called inflationary cosmology built on the unification of strong, weak, elektromagnetic and perhaps gravitational interaction.

The first step of this approach, the Glashow-Weinberg-Salam unification of the weak and the electromagnetic force, is now well-established by the discovery of the W^+, W^- and Z^0, the vector bosons that mediate, together with the photon, the electroweak interaction. Obviously, it is not surprising that optimists among the theoreticians are full of enthusiasm that fundamental physics will come soon to its final goal, the unification of all physical interactions.[51]

At present, different theoretical schemes rival as candidates for the final comprehensive description: supergravity including the Kaluza-Klein model of higher dimensional spacetime, and, as a newcomer, superstring theory in which the fundamental entities are not point particles, but one-dimensional entities susceptible to vibrations, the so-called <u>strings</u>.

If the unification procedure does exclude gravity, we move towards the so-called GUT scheme, a unification of the forces relevant for microphysics up to the energy level 10^{15}GeV. Even in the GUT realm we can observe, how cosmology and high energy physics work together and yield causal processes apt to explain mysterious coincidences.

The standard model for the evolution of the universe is the hot big bang scenario that starts with a primordial fireball stage and continues with subsequent cooling by adiabatic expansion of 3-space. The standard hot big bang model is now well confirmed, but it includes a few drawbacks. A bundle of urgent questions cannot be answered by this model, therefore it is not wrong or falsified, but it needs improvement. To mention just a few topics, where answers would be highly desirable:

i) the singularity problem

If general relativity is taken seriously up to extreme values of curvature, then the universe starts at a point which does not belong to the spacetime manifold. The initial singularity is an edge of Riemannian spacetime, but not a first event; it is not an event at all. What does it mean physically that spacetime does not exist at the origin of reality? Here something is missing.

ii) the horizon problem

If cognizance is taken of astrophysical observation, the spacetime of the universe is probably non-compact, in popular scientific diction called "open". How is it then possible that the many causal disconnected parts of the spatially infinite universe began by their expansion simultaneously at t=o? Is any hidden conspiration involved?

iii) the problem of homogeneity

Astrophysical fact and cosmological theory yield nearly perfect homogeneity of the observable part of 3-space; on a local scale, however, the universe contains irregular structures, from clusters of galaxies and large voids to planetary systems. The standard model handles homogeneity as a boundary condition which is fed in by hand into the model.Thereby the question of the origin of the overall homogeneity and of the germs of the local inhomogeneity is circumcumvented.

iv) the problems of contingency

All questions on the special value of the constants of nature, especially of the cosmological constant λ (= vacuum energy density), and the coupling constants (α, α_w, α_s, α_G) pertain to this group of problems. The reason for the 4-dimensionality of spacetime, totally ignored by physics up to recent times, belong to this category, too.

v) the flatness problem ($\Omega_o = \frac{\rho_o}{\rho_c} = 1$)

When talking on the isotropy, we realized that only a spacetime which is flat in the 3-spatial dimensions has the unique property of isotropizing at large times. If we look, however, at such a universe at early cosmic time, e.g. at the Planck time ($t = 10^{-43}$ sec), we have to note that the expansion rate had to be fine-tuned to the accuracy of $(\frac{\rho-\rho_c}{\rho_c})_{t_{Planck}} \leq 10^{-57}$, in order to fulfill the observational fact $\Omega_o = 1$ of today.[52]

This extremely balanced behavior of the universe is highly incredible.

There are much more features of the universe which cannot be explained within the standard hot big bang model, for instance the monopole problem and the matter -

antimatter asymmetry, but for our epistemological purpose it is sufficient to realize, how the gaps in the causal chain left by the AP can be filled in.

Within the last 8 years, a series of scenarios have been worked out with changing success. In 1980, Alan Guth started the inflationary paradigm with a theoretical model that works in the context of the GUT. In the meantime, it has been amended by Andreas Albrecht and Paul Steinhardt[53], and the recent seemingly simplest version, the so-called chaotic inflationary scenario, has been launched by Andrei Linde.[54]

For our pupose only the central traits of the new symbiosis of cosmology and high energy physics are relevant. Mainly all inflationary models assume the existence of some stage of evolution at which the universe expands exponentially ($R \alpha e^{Ht}$). In this rather short interval of cosmic time, the universe is kept in a vacuum-like state containing some homogeneous classical fields, but no particles. The rapid exponential expansion is called inflation. At the end of the inflationary epoch, the inital vacuum state decays into particles. The interaction of these particles establishes thermodynamical equilibrium and only at this stage the universe becomes hot and can then be coupled to the standard big bang model ($R \alpha t^{1/2}$ for a radiation-dominated FRW model).

The exponential expansion dominating the universe for a short period characterized by the de Sitter line element[55] is caused by the vacuum energy. It is the crucial ingredient of the inflationary paradigm.

We remember that the value $\Omega = 1$ is a strong constraint for the origin and the evolution of intelligent life. In the frame of the inflationary scenario the present proximity of the universe to the critical density, that is the flatness problem, gets a solution easily comprehensible by a causal process. The huge exponential expansion caused the curvature to become negligible, like the surface of a balloon which is heavily inflated. In the same way, the horizon or causality paradox can be tackled with. The exponential de Sitter expansion led to a rapid widening of the cosmological horizon within which signals can propagate in accord with special relativity.

There is a possible answer to a special case of the contingency problem that acted a main part in the discussion on the AP, namely the dimensionality of spacetime. Already before the advent of the APs in the sense of Carter, G.J. Whitrow tried to elucidate the 3-dimensionality of space in an anthropic manner. He argued by means of a counterfactual analysis. If the dimension of space n would be $n>3$, there couldn't exist stable orbits for planetary sites which are possible habitations for humans. The dimensions $n=1$ and $n=2$ are excluded, because in such spaces a large number of nerve cells cannot be concatenated to form a complex neural network that, alone, to our knowledge, is able to produce a mind generating ideas. It is no doubt that Whitrow uses the argument in an explanatory way, the existence of a "minding animal", among other premisses, acting the part of an explanans for the 3-dimensionality of space.

"... that the number of dimensions of space is necessarily three, no more and no less, because it is the unique natural concomitant of the higher forms of terrestrial life".[56] Rightly, J.J.C. Smart has criticized this back to front explanatory use of an anthropic argument as preposterous, but he is rather hesitating as to the feasability of the GUTs to fill in the bill, a strategy I have sustained recently.[57] However, there has been a move in recent unified theories to a renewal of an old idea of Th. Kaluza and O. Klein to introduce theories with spacetimes of more than four dimensions.[58] These extra dimensions of space - supergravity theories are favourably formulated in 10+1 dimensions, superstring theories in 9+1 dimensions - have been compactified, that means, shrunk into thin tubes of the order of the Planck length. According to such theories the universe had its full dimensionality, when $T \sim 10^{17}$GeV, but all except our well-known 3 spatial dimensions have been confined to experimentally unfathomable small regions already 10^{-40}s after the singularity. Here a road opens to a much deeper understanding of the old question as to why space has exactly three and spacetime accordingly four dimensions. It is because - and here we can use this term in the normal explanatory sense - today our universe is cold that the higher dimensions of space have been frozen up.

A possible critique of this approach might argue that the problems have only been deferred to the adjacent question, why the 11 or 10 dimensions of spacetime existed at that early time. But this point seems to me irrelevant. Every explanation has to start somewhere, nothing at all can be inferred from the zero set of presuppositions. Therefore the compactification process is a step to a deeper understanding. Beyond that there are good mathematical reasons[59] stemming from the symmetry group of the theories which give a rational defense as to why supergravity is properly defined in 11, and superstring theory in 10 dimensions.[60] On the other side, there are genuine questions on the Kaluza-Klein approach which cannot be put aside so easily.

One may wonder, why compactification stopped exactly with four dimensions of spacetime and not with any other number, and furthermore there should be a proof of uniqueness for a certain compactification scheme giving us the distinguished road from the full-dimensional high energy range down to our four dimensions and the low energy particle physics.

Even to these substantial questions a possible answer seems to have been found within the earlier mentioned scenario of chaotic inflation.[61] In this framework, the inflationary universe consists of many different smaller parts (mini-universes) in which all possible types of compactification produce every number of dimensionality. Our concrete four-dimensional realm and our special low energy particle spectrum are not in any way distinguished, but may be coupled to the preconditions of life. Although Linde may be right that there are certain distinguished compactification procedures that lead to kinds of mini-universes apt to contain life[62], he can dispense in no way with the specification of the causal mechanism that led to the pertinent contingent situation of our universe.

Most desirable, of course, would be a theory in which only one type of compactification can occur leading inevitably to our four dimensional inflationary universe together with the low energy physics we encounter in present experiments and observations.

To follow the path of dynamical explanations should not be taken as to devalue anthropic interconnections. The innumerable links that have been found between intelligent life and astrophysical and cosmological facts remind us, how strongly we are bound to our large-scale environment. Set in its proper stage, the APs are to be seen in the context of the unity of the universe.

It seems plausible to me to see the AP in an older tradition of ideas, namely the metaphysics of Leibniz' monadology which says roughly that every element of the universe contains in itself a mirror-like picture of the cosmic ground plan. A modern version of this microcosm-macrocosm speculation is G. Chew's bootstrap principle according to which "Nature is as it is because this is the only possible nature consistent with itself".[63] In the framework of the bootstrap picture the universe cannot contain purely accidental features. Since the APs connect the properties of organisms to certain traits of the cosmic environment, they can be called a partial realization of the bootstrap idea, or in the words of E. Harrison: "... the anthropic principle serves as a makeshift or poor man's bootstrap".[64]

However, since the holistic bootstrap idea is today far from yielding successful empirical physics - current elementary particle theories work more in the Newtonian-Cartesian idea of objects moving in a spacetime continuum - it is just a hope to be fulfilled by future research.[65]

The APs are not an invitation to turn the customary direction of explanation upside down, but to fill in the blank by dynamical considerations. Dynamical explanations built upon unified theories lead into deep philosophical waters. They contain surplus meaning in so far as they allow not only to deduce the anthropic constraints and numerical coincidences, but beyond that convey answers to questions physicists would have never imagined to bring into the domain of rational science. Therefore let us have at last a look on the singularity problem. Until quite recently, physicists have taken the stance that the genesis problem, that means the origin of physical reality itself, is beyond the grasp of scientific approach, because the creation of everything violates the logic of explanation. Paul Davies characterizes the former situation: "Because all physics breaks down there, the singularity does not belong to the physical universe, rather it marks the limits of the physical universe, it is the interface between the natural and the supernatural."[66] The inflationary scenario opens a perspective that would come to grips with the singularity problem and the old question of supernatural borderlines of reality. Two possible solutions show up, depending on the type of the inflationary scenario chosen. Within the scheme proposed by Alan Guth and improved by Albrecht and Steinhardt non-conservation of baryon number is most pertinent to this problem. The violation of that conservation law in the GUTs allows to deduce an important feature of our physical world, namely the ratio of the number of baryons to entropy, $\frac{n_B}{s}$ (which is about $10^{-10\pm1}$). In the absence of baryon number conservation, it becomes physically possible that our universe emerged from no prior substance, but from nothing at all. This situation in which a physical and entirely causal explanation of the origin of all the matter, energy and entropy would be feasible, seduced A. Guth to the striking remark:

"I have often heard it said that there is no such thing as a free lunch. It now appears possible that the universe is a free lunch."[67]

Another solution of the singularity problem comes in sight which lies more in the tradition of Lukrez' principle according to which nothing comes out of naught or goes into naught. If chaotic inflation is a correct scenario, then "it seems more likely that the universe is an eternally existing, self-producing entity, that it is divided into many mini-universes much larger than our observable portion and that the laws of low energy physics and even the dimensionality of spacetime may be different in each of these mini-universes".[68]

Of course, a perpetual existence of physical reality cuts off every question on its origin. It is the oldest answer in the history of philosophy of nature and perhaps the most rewarding for a scientist working in the rationalist paradigm.

foreign language = Alt + Shift together
Alt T B   type the number

NOTES:

[1] H. Bondi: *Cosmology*, Cambridge 2nd edition 1968, p. 13

[2] more exactly $\frac{\Delta T}{T} \leq 10^{-5}$

[3] A.G. Walker: Completely symmetric spaces. *Journ. Lond. Math. Soc.* 19 (1944) pp. 219-226

[4] S.W. Hawking & G.F.R. Ellis: *The large-scale structure of spacetime*. Cambridge 1973, p. 135

[5] This methodological point was a reason for E.P. Hubble to defend strongly the cosmological principle which expresses homogeneity and isotropy for 3-space.
Cf. N.S. Hetherington: Philosophical values and observations in Edwin Hubble's choice of a model of the universe. *Hist. Stud. Phys. Sci.* 13 (1983) pp. 41-67

[6] L. Boltzmann: Zu Herrn Zermelos Abhandlung: "Über die mechanische Erklärung irreversibler Vorgänge." *Wiedemannsche Annalen* 60 (1897) pp. 392-398

[7] K.R. Popper: Autobiography, in; P.A. Schilpp (ed.): *The Philosophy of Karl Popper*, LaSalle (Ill.) 1974, p. 126

[8] Cf. B. Kanitscheider: *Philosophie und moderne Physik*, Darmstadt 1979, p. 70

[9] $m_N : m_\Lambda : m_\Sigma : m_\Xi = 1:2^{1/4}:2^{1/3}:2^{1/2}$

[10] $\frac{m_n - m_N}{m_\Lambda - m_N} \simeq \alpha$

[11] $N_1 = \frac{t_o}{e^2/m_e c^3} \sim 6 \times 10^{39}$

[12] $N_2 = \frac{e^2}{G m_N m_e} \sim 2{,}3 \times 10^{39}$

[13] P.A.M. Dirac: The cosmological constants, *Nature* 139 (1937) p. 923

[14] This sounds more revolutionary than it is, because in relativistic cosmology, too, total energy is not conserved: it decreases in an expanding universe and increases in a contracting universe. Energy conservation is confined to regions that do not partake in the expansion of the universe.

[15] P. Jordan: Bemerkungen zur Kosmologie, *Ann. d. Phys.* 36 (1939) p. 64

[16] a typical main sequence star has a mass of roughly $M_\odot = 10^{60} m_N$, $M_\odot$ should therefore, according to Dirac's LNH, increase with $t^{3/2}$.

[17] M. Bunge: Cosmology and Magic, *The Monist* 47 (1962) pp. 116-141

[18] Time variations of coupling constants of electromagnetic, weak and strong interaction are constrained by

$$\frac{\dot{\alpha}}{\alpha} \lesssim 10^{-17}\,\mathrm{yr}^{-1} \quad \frac{\dot{\alpha}_w}{\alpha_w} \lesssim 2\cdot 10^{-12}\,\mathrm{yr}^{-1} \quad \frac{\dot{\alpha}_s}{\alpha_s} \lesssim 5\cdot 10^{-19}\,\mathrm{yr}^{-1}$$

Cf. A.J. Shlyakhter: Direct test of the constancy of fundamental nuclear constants. *Nature* 264 (1976) p. 340

The constancy of the gravitational constant has been checked by Reasenberg with the result G: $\left|\frac{\dot{G}}{G}\right| < 3 \cdot 10^{-11}\,\mathrm{yr}^{-1}$

Cf. R.D. Reasenberg: The constancy of G and other gravitational experiments. *Phil. Trans. R. Soc.* London A 310 (1983) pp. 227 -238

[19] J.B.S. Haldane: Comment on E.A. Milne's paper: On the Origin of Laws of Nature. *Nature* 139 (1937) Suppl. pp. 1003-4

[20]
$$G_{\alpha\beta} = \frac{8\pi}{\varphi} T_{\alpha\beta} + \frac{\omega}{\varphi^2}\left(\varphi_{,\alpha}\,\varphi_{,\beta} - \frac{1}{2} g_{\alpha\beta}\,\varphi_{,\mu}\varphi^{,\mu}\right) + \frac{1}{\varphi}\left(\varphi_{;\alpha\beta} - g_{\alpha\beta}\,\Box\varphi\right)$$

The first term on the right side corresponds to the matter part of Einstein's field equations.

[21] R.H. Dicke: Dirac's Cosmology and Mach's Principle, *Nature* 192 (1961) pp. 440-441

[22] J. Barrow/F. Tipler: *The Anthropic Cosmological Principle*, Cambridge 1986, p. 3

[23] B. Carter: Large Number Coincidences and the Anthropic Principle in Cosmology, in: M.S: Longair (ed.): *Confrontation of Cosmological Theories with Cosmological Data*, IAU Symp. 63, Dordrecht 1974, pp. 291-298

[24] B. Carter: The Anthropic Principle and its Implications for Biology, *Phil. Trans. Roy. Soc.* London A 310 (1983) pp. 347-363

[25] B.J. Carr: The Anthropic Principle, *Acta Cosmologica* 11 (1982) p. 143-151, esp. p. 150

[26] C.B. Collins/S.W. Hawking: Why the Universe is Isotropic? *Astrophys. Journ.* 180 (1973) pp. 317-334

[27] Cf. e.g. Bernard de Fontenelle: Entretiens sur la pluralité du monde. *Oeuvres de Fontenelle*, Tome deuxième, I[re] Partie, ' Paris 1818

[28] J.D. Barrow/F. Tipler: *The Anthropic Cosmological Principle*, loc. cit. p. 249

[29] This has been done by B. Carter: he could prove that one percent lowering or raising of α will cause all stars to turn into red stars, resp. blue stars. In neither case, a normal main sequence star as the sun would be possible. Since life is coupled to a long-time burning of main sequence stars, it would probably never occur in a world brought about by this counterfactual change. (Cf. Ch. Misner/K. Thorne/J.A. Wheeler: *Gravitation*, San Francisco 1973, Chapter 44)

[30] J.A. Wheeler: From relativity to mutability, in: J. Mehra (ed.): *The physicist's conception of nature*, Dordrecht 1973, pp. 202-247

[31] J. Hacking: The Inverse Gambler's Fallacy: the Argument from Design. The Anthropic Principle Applied to Wheeler Universes. *Mind* 1987, pp. 331-40

[32] Hacking's argument has been contested however. See e.g. P.J. McGrath: The Inverse Gambler's Fallacy and Cosmology - A Reply to Hacking. *Mind* 97, No. 386, April 1988, pp. 265-68

[33] B. Collins/S.W. Hawking: Why is the Universe Isotropic? loc. cit.

[34] For an updated version of the result cf. Barrow and Tipler, loc. cit. p. 425

[35] in technical terms $T^{oo} > |T^{\alpha\beta}|$ and $\sum_{k=0}^{3} T_{kk} \geq o$

[36] here the scale function is $(R \propto t^{2/3})$

[37] Here the alternative is disregarded that the time interval since the beginning was too short for the fact that anisotropy could show effects on the 3 K radiation

[38] - too strong an expansion, $\rho \ll \rho_c$, $\rho_c = \frac{3c^2 H^2}{8\pi G}$ destroys all germs of condensation, too weak an expansion $\rho \gg \rho_c$ yields early recollapse -

[39] B. Collins/S.W. Hawking: Why is the Universe Isotropic? loc. cit. p. 317

[40] loc. cit. p. 334

[41] R.H. Dicke/P.J.E. Peebles: The Big Bang Cosmology - Enigmas and Nostrums, in: S.W. Hawking/W. Israel (eds.): *General Relativity. An Einstein Centenary Survey.* Cambridge 1979, pp. 504-517

[42] The assumption that everything that can occur according to the laws of nature will occur has its historical origin in the principle of plenitude (Cf. A. Lovejoy: *The Great Chain of Being*, Cambridge (Mass.) 1948). Carter's supposition that all logically possible universes consistent with relativistic

cosmology actually coexist is a modern version of the principle of plenitude. Only causally sane deductive reasoning is involved therein. We as humans exist, because we are part of a possible universe, and all possible universes exist. Nothing is left to chance. The high state of orderliness of our universe is understood in such a way, that it is the only universe that supports our form of life. The principle of plenitude makes superfluous any resort to an intelligent designer. Carter's hypothesis is a piece of deductive reasoning within the realm of naturalistic ontology.

43 B. Carter: Large Number Coincidences, loc. cit. p. 294

44 P.C.W. Davies: *The accidental universe.* Cambridge UP 1982, p.12o

45 J.D. Barrow/F. Tipler: The Anthropic Cosmological Principle, loc. cit., p. 22

46 J.J.C. Smart: Philosophical Problems of Cosmology, *Revue Int. Phil.* 41, 160 (1987) pp. 112-126

47 D. Lewis: *On the plurality of worlds*, Oxford 1986, p. 132

48 For an evaluation of the many worlds hypothesis cf. Qu. Smith: The Anthropic Principle and Many Worlds Cosmology. *Australasian Journ. Phil.* 63, 3 (1985) pp. 336-348

49 J. Leslie: Anthropic Principles, world Ensemble, Design. *Am. Phil. Quat.* 19 (1982) pp. 141-151

50 J. Leslie: Cosmology, Probability and the Need to Explain Life, in: N. Rescher (ed.): *Scientific Explanation and Understanding.* UP of America 1983, pp. 53-82, esp. 56

51 St. Hawking: *Is the End in Sight for Theoretical Physics?* Cambridge 1980

52 A. Guth: Inflation Universes, a Possible Solution of the Horizon and Flatness Problem. *Phys. Rev.* D 23,2 (1981)

pp. 254-257

[53] A. Albrecht/P.J. Steinhardt: Cosmology for Grand Unified Theories with Radiatively Induced Symmetry Breaking, *Phys. Rev. Lett.* 48,17 (1982) pp. 1220-23

[54] A. Linde: Particle Physics and Inflationary Cosmology, *Physics Today*, Sept. 1987, pp. 61-68

[55] $ds^2 = -dt^2 + e^{2Ht}(dx^2+dy^2+dz^2)$

[56] G.J. Whitrow: Why Physical Space has Three Dimensions. *Brit. Journ. Phil. Sci.* 6 (1955) pp.13-31

[57] B. Kanitscheider: Explanation in Physical Cosmology, *Erkenntnis* 22 (1985) pp. 253-263

[58] Cf.P.G. Freund: Physics in 10 and 11 Dimensions. *Comments Nucl. Part. Phys*. 15,3 (1985) pp. 117-126

[59] B. Kanitscheider: Probleme und Grenzen einer geometrisierten Physik, in: Logic, Philosophy of Science and Epistemology, *Proc. 11th Intern. Wittgenstein-Symposium*, Wien 1987, pp. 129-144

[60] M.B. Green: Unification of forces and particles in superstring theories. *Nature* 314 (1985) pp. 409-414

[61] A. Linde: loc. cit. p. 68

[62] A. Linde: loc. cit. pp. 61-68

[63] G.F. Chew: 'Bootstrap': a scientific idea? *Science* 61 (1968) p. 762

[64] E. Harrison: *Cosmology*, Cambridge 1981, p. 115

[65] G.F. Chew: The Topological Bootstrap, in: A.H. Guth et al. (eds.): *Asymptotic Realms of Physics*, Cambridge 1983, pp. 49-49

[66] P.C.W. Davies: Quantum Gravity: A Unified Model of Existence? *Mitt. Astron. Ges*. Nr. 58, Hamburg 1983, p. 53

[67] A.H. Guth: Speculations on the Origin of the Matter, Energy and Entropy of the Universe, in: A.H. Guth (ed.): *Asymtpotic*

Realms of Physics, Cambridge MIT Press, Cambridge 1983, p. 215

[68] A. Linde: loc.cit., p. 68

GLOSSARY

m_N, m_e, m_Λ, m_Ξ = masses of the nucleon, electron, Λ and Ξ particles

$\alpha_e = \alpha = \frac{e^2}{\hbar c} = 137{,}036^{-1}$ = Sommerfeld's fine structure constant

$\frac{e^2}{m_e c^2} = 3 \cdot 10^{-13}$cm = classical radius of the electron

e = elementary charge

h = Planck's quantum of action

c = velocity of light

G = Gravitational constant

$t_\circ$ = present age of the universe

λ = Einstein's cosmological constant

$t_{Planck} = 10^{-43}$sec. after the initial singularity

α, α_W, α_S, α_G = dimensionless constants expressing the strength of the electromagnetic, weak, strong and gravitational forces respectively.

R(t) = scale function of an expanding spacetime

$\Omega = \frac{\rho}{\rho_c}$ ratio of the density of cosmic matter ρ to critical density ρ_c

FRW = Friedmann-Robertson-Walker models of cosmology

1 Mpc = 10^6pc = 3,26 X 10^6 light years

Isotropy = equivalence of all directions

Homogeneity = equivalence of all points in space

H(t) = Hubble parameter, $H(t)_{t=t_\circ} = H_\circ$

Singularity ="Point" where spacetime description breaks down

compact space = space with finite volume

topology = concerns the global connectivity of space

line element ds = distance between two infinitesimal events of spacetime

Baryon = fermionic matter particle that is governed by strong interaction

Entropy =thermodynamic magnitude that allows to order physical events in time