CPBF-CS-004/08

The three-dimensionality of the Universe: a reason for the existence of chemists and beyond

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Abstract:

A general sketch of how the problem of space dimensionality depends on Anthropic arguments is presented. In particular, the influence of three-dimensionality on the stability of the solar system and on the origin of life on Earth is reviewed. A new constraint on space dimensionality and on its invariance in a very large time and spatial scales is proposed.

Keywords: Space; dimensionality; Anthropic principle

That space is three dimensional seems to be so obvious to laymen and even to scientists that one can easily disregard it as a scientific problem. Indeed, in almost all physical and chemical theories developed along centuries, dimensionality – an essential topological feature of space – is merely assumed as a given truth, as an unquestionable matter of fact. However, in this note it will be shown that things can go in a different way.

Whitrow, for example, in an important 1955 paper, asseverates that for trying "*to isolate three-dimensional space as the only possibility for the world in which we find ourselves, we must now invoke some argument for showing why the number of dimensions cannot be* less *than three*".[1] To do this, he adapted the well known topological result from knot theory, that we cannot make a knot in even-dimensional space, to the necessity of higher forms of animal life to have brains in which electrical pulse informations carried on by nerves could not interfere destructively, which excludes a twofold and other even-fold spaces. This argument automatically constrains space to have an odd dimensionality ≥ 3. Then, recognizing that the problem of space dimensionality was not yet solved – which is still true – Whitrow wrote:

> *"Despite various recent attempts to show that [space dimensionality] is either a necessary attribute of our conception of physical space or is partly conventional and partly contingent, the problem cannot be considered as finally solved. A new attempt to throw light on the question indicates that this fundamental topological property of the world may possibly be regarded as partly contingent and partly necessary, since it could be* inferred *as the unique natural concomitant of certain other contingent characteristics associated with the evolution of the higher forms of terrestrial life, in particular of Man,* the formulator of the problem*"*.[1]

Following a different approach, based on the *stability of atoms in high dimensional spaces*[2,3] and on the Uncertainty Principle, Barrow & Tipler[4] stressed that

> *"(...) it has been claimed that if we assume the structure of the laws of Physics to be independent of the dimension, stable atoms, chemistry and life can only exist in $N<4$ dimensions."*.

And therefore they conclude, perhaps inspired on the aforementioned Whitrow's ideas, that "*the dimensionality of the Universe is a reason for the existence of chemistry and therefore, most probably, for chemists also*".

So, chemists should be proud, since they exist and their existence should somehow be related to the comprehension of space dimensionality. This is not, however, a completely new idea and it is related to the so called "Anthropic Principle". To the best of our knowledge, this expression was coined, in 1973, by the astrophysicist Brandon Carter as a sort of reaction to the tremendous impact of Copernican Revolution on both Science and Society, which has taken Men out of the center of the Universe.[5] However, as Carter himself stresses, "*although our situation is not necessarily central, it is inevitably privileged to some extent*".

Nowadays, this expression hides many different meanings. What is now known as the "Weak Anthropic Principle" has it origins in an earlier Dicke's idea,[6] which was reformulated in 1979 by Carr & Rees,[7] and essentially tells us that the observed values of physical quantities are not

arbitrary but restrict to be compatible with the sustained evolution of life so far spatiality is concerned, and temporally consistent with biological and cosmological evolution of living beings and of their niches. There is also the "Strong Anthropic Principle" due to Carter,[8] which assumes that the Universe necessarily should contain life, and the "Participative Anthropic Principle" advocated by Wheeler who, taking into account the measurement problem in Quantum Mechanics, argued that Observers are necessary for the existence of the Universe.[9] In any case, of relevance to this note is the very fact that Anthropic arguments have been proposed, independently, by philosophers and scientists to explain why we perceive a three-dimensional Universe.[4] We could even say more: it seems unavoidable to make use – implicitly or explicitly – of some Anthropic argument when we try to justify and understand three-dimensionality. Some of these proposals will be briefly reviewed in this note and a possible relationship between methane structure, the origin of life and space dimensionality will be pointed out.

Kant's conjecture[10] that space three-dimensionality may, in some way, be related to Newton's inverse square law of Gravitation was the first step in the direction of a scientific explanation of dimensionality. Even though it has been shown[11] that Kant did not actually succeed in proving this conjecture – indeed, he just concluded that there should be a relationship between this law and *extension* –, his contribution has the very merit of suggesting that the problem of dimensionality can also be treated in the framework of Physics and does not belong exclusively to the domain of Mathematics, neither to that of pure philosophical speculation.

As a second step, one can quote the work of William Paley,[12] which can be considered the first attempt to shed light on the space dimensionality problem clearly from Anthropic arguments. In his work, Paley analyzes the consequences of changes in the form of Newton's gravitational law and of the stability of the solar system on human existence. Starting from a teleological thesis, his speculations take into account a number of mathematical arguments for an anthropocentric design of the World, which rest all upon the stability of the planetary orbits in our solar system and on a Newtonian mechanical *Weltanschauung*, as should be expected at that time.

In the twentieth century, the idea of how space dimensionality follows from the stability of planetary orbits in the solar system was revisited in Ehrenfest's seminal papers,[2] where several physical phenomena were discussed, trying to disclose any qualitative difference between three and other n-dimensional spaces. The existence of stable planetary orbits and the stability of atoms and molecules are just one point. These aspects depending on space dimensionality, which distinguish Physics from on kind of space to another, are called by him "singular aspects" and his works were aimed at stressing them. A crucial assumption is built in Ehrenfest's ideas, namely that it is possible to make the formal extension from three to n-dimensional space for a certain law of Physics and, then, one should find one or more principles that, in conjunction with this law, can be used to single out the proper dimensionality of space. The abrangence of this approach was noted by Tangherlini,[3] who proposed that for the Newton-Kepler problem, generalized to n-dimensional space, the principle to determine the spatial dimensionality could be summarized in the postulate that *there should be stable bound states orbits* – or "states" – for the equation of motion governing the interaction of bodies, treated as material points. This will be generically called, from now on, the *stability postulate*. In his paper of 1963, Tangherlini showed that the essential results of the Ehrenfest-Whitrow investigation are unchanged when Newton's gravitational theory is replaced by General Relativity, and so attributing a new scientific meaning for Paley's conjectures. Application of this same idea to the stability of hydrogen atom, described by a generalized Schrödinger equation, leads to the same kind of constraint in a very huge and different spatial scale.

In its essence, Ehrenfest's approach for planetary motion relies on two postulates: a) Poisson equation, which describes (at a Newtonian level) the planetary motion for any space

dimensionality, correctly explains the same phenomenon it describes in three dimensions; and b) the stability of the mechanical orbits should hold in the higher dimensional space. For him the former is the *causa formalis* and the later, the *causa efficiens* of space dimensionality. Actually, both are typical ingredients of any Anthropic constraint imposed on dimensionality. In spite of the fact that this kind of approach strongly reflects the recognition of our ignorance being complete and assumes a 'Principle of Similarity' – using the expression adopted elsewhere,[1] namely that alternative physical laws should mirror their actual form in three dimensions as closely as possible – it seems a very hard task to avoid it as long as dimensionality is to be understood in the realm of Physics. This briefly reviews how the *stability postulate* is used to cast some light on the problem of spatial dimensions, but we should point out that some epistemological and methodological aspects of this general approach based on the stability postulates were criticized twenty years ago.[13] New criticisms will be published elsewhere.[14]

Let us now try to present some remarks and some new conclusions about the time (and space) "scale" of the arguments previously discussed.

The first is related to Ehrenfest's stability argument which is typically valid for distances of the order of the solar system and in a time scale large enough to make the evolution of life possible on Earth, as mentioned by Whitrow.[1] However, his argument about this subject could be improved by stressing that it is not sufficient that the intensity of solar radiation on Earth's surface should not have fluctuated greatly for life still exist on Earth; actually, the fact that Sun's spectra of radiation did not fluctuate very much should also be required.[13]

By other side, Tangherlini's work about the stability of hydrogen atoms is often invoked to suggest the validity of Chemistry in the same time scale as a necessary, although not sufficient, condition – at least Chemical Thermodynamics of irreversible process should be also valid. Thus, *the presence of atomic spectra in remote stars may also indicate[s] that space has had the same dimensionality at cosmic scale*.[13] The existence of such a cosmic constraint on space dimensionality is a very interesting consideration and this subject was treated in elsewhere.[15]

The second one is also related to the general idea that among a large number of possible universes, the actual Universe is the one which contains intelligent life, or at least had some form of life in a very long time scale. We have quoted above what Withrow, Barrow and Tipler said about human life and how it imposes some constraints on the number of dimensions. Infallibly this query addresses us to Biochemistry. There is a nice chapter on this subject on Barrow and Tipler's book,[4] where several relevant topics are discussed in details, and so will not be treated here. Among them we can quote the unique properties of carbon, hydrogen, oxygen and nitrogen, or whether or not it is possible to base life on elements other than these ones, and finally that those unique properties are probably necessary to guarantee the ecological stability required by highly-evolved life, although not sufficient. Our aim here is to introduce a new argument in favor of a stable scenario for space dimensionality for a time scale longer than that required for the existence of human or another kind of highly-evolved life on Earth, remembering that the usually accepted scales are: 2 Millions years ago the *homo erectus* appeared, while the first *skeletons and easily recognizable fossils* range are of 600 Millions of years ago. This new argument is related to the methane structure as will be shown now.

Let us consider the famous experimental result published in 1959 by Harald C. Urey and Stanley Miller.[16] They showed to be possible, by means of an electrical discharge, to transform an admixture of gases consisting of methane, water, ammonia and hydrogen into a great number of organic compounds, among then some amino acids essential to life. Although it is not a *proof*, this result is widely considered as a strong evidence for the creation of life in a kind of primitive Earth atmosphere, quite different from that of the present days, composed of the four substances just

mentioned. Accepting this means to admit that, in certain sense, methane, which has the simpler formula among the organic compound (CH_4), is somehow related to the origin of amino acids that could build up primitive life. In addition, it is important to stress that it is implicit in this reasoning that the atomic structure and chemical properties of the elements have not changed in time.

Based on X-ray spectroscopy and on the empirical fact that an isomer of methane was never found, the tetrahedral structure of carbon was established. In other words, Nature seems to have chosen just one spatial disposal for methane atoms and also for all compounds of the type CH_3Y e CH_2YZ, with Y and Z being any group of atoms. This rules out any flat configuration for the simplest organic compound and requires, obviously, that the space in which it exists should be at least three dimensional.

So, to believe on Urey-Miller's experiment as a clue for the origin of amino acids essential to life, associated to an atmosphere possibly rich on methane, implicitly assumes that three is the minimum space dimensionality required by methane structure and for life to be developed this way. Putting this together with what was said above about the spectra of remote stars, a scenario where space dimensionality should be at least three for very large temporal and spatial scales seems plausible; much greater than that required by human life on Earth. Remember that some authors believe the origin of life occurs 3,500 Millions of years ago. Despite its speculative nature, this is a new constraint imposed not only on the number of dimensions but also on its stability throughout a very large space and time scale, obtained from a sort of modified strong Anthropic principle, namely, from the assumption that the early Universe should necessarily contain amino acids.

In conclusion, we would like to say that physicists and philosophers should still pay attention to many epistemological difficulties concerning the problem of space dimensionality, among which we could emphasize the incompleteness in the majority of approaches to this problem so far as they consider physical events taking place only in space, not in *space-time*. Thus, the problem of the number of space dimensions and that of time dimensions are probably not independent. Finally, whether or not a deeper comprehension on the problem of space dimensionality is to be reached and, in particular, if it could be possible to go on discussing this problem without taking into account any kind of Anthropic argument as some stage of a particular reasoning are still good questions without good answers.

Acknowledgments

The author would like to thank Gilvan Alves, Hélio da Motta and Mauro Velho de Castro Faria for fruitful discussions and for critical comments.

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