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String Theory and the Anthropic Principle

L. Consoli
Heyendaal Program on Theology and Science
Faculty of Religious Studies, Radboud University Nijmegen
The Netherlands

Abstract

String theory is a promising approach to achieve unification of all known fundamental interactions. It has been touted as a way to reconcile (and supersede) the two most successful (but mutually incompatible) theories in modern physics, General Relativity and the Standard Model. It provides a way to avoid infinities in the treatment of gravity and it was thought to produce a limited number of interrelated consistent theories, the low-energy limit of which would give the known particles and masses of our physical world. Research in the last years, though, has shown that string theory possesses a huge number of false vacua (the string landscape). In the absence of a mechanism to select which one of these vacua corresponds to the real world, the theory seems to lose any predictive capability and even its scientific status, reducing to a bright mathematical game. A heated scientific debate is ongoing as to the actual status of string theory in the light of these developments. We concentrate in this paper on the so-called anthropic landscape scenario. This approach seems to reinterpret the role and function of scientific knowledge in a quite radical way. Its proponents not only claim that the lack of predictability of string theory is not a shortcoming. There is also the related claim that the selection criteria for the low-energy limit must not come from the model, but by realizing that the fundamental constants may have the values they have not for fundamental physical reasons, but rather because such values are necessary for life. This new self-understanding of at least a part of the scientific community about scientific knowledge raises some questions, which I will analyze in this paper: Is the application of the (weak) anthropic principle to string theory a justified move? Does this understanding of science lead to a renewal of a teleological picture of the world? What are the possible consequences of this move for the science and theology dialogue?

Keywords: modern physics, string theory, anthropic principle, scientific knowledge, scientific method, nature of reality, science-theology relationship.

Introduction

Scientific knowledge derives its epistemological robustness from the criteria used to produce it, a set of principles commonly called “scientific methodology”. This is true of all scientific disciplines, and even if the criteria for reliable biological knowledge may partially differ from the ones for reliable physical knowledge, modern science shares a common paradigm. Recent developments in the field of theoretical physics seem to challenge some basic tenets of this methodology, by calling into question the very definition of what constitutes a scientific theory. If successful, this move could amount to no less than a paradigm shift and have obvious far-reaching consequences for the status of scientific knowledge as well as its relationship with other forms of knowledge. In this paper I will sketch the contours of this development and discuss its possible implications for our understanding of science and its relationship with theology. The structure of the paper is as follows: in the following section I will introduce the basic ideas behind unification theories, and shortly present one of the most promising candidates, string theory. The main problem with the latter theory will then be presented, together with its possible implications for our understanding of what constitutes a scientific theory. Subsequently, one possible way of dealing with this situation (the anthropic landscape) will be presented and discussed, highlighting the
conceptual confusion in the way the discussion is carried out. The potential implications of the use of the anthropic landscape argument and of anthropic reasoning in general will be then discussed, and the paper will be concluded by some final remarks.

**A paradigm war in theoretical physics?**

One of the basic problems in the field of theoretical physics stems almost paradoxically from its huge success in describing physical reality. Two models are currently accepted as being our best description of Nature. On one hand, we have General Relativity, which gives a (classical) description of gravitational interaction in terms of curvature of space and time. This theory describes the large-scale features of the Universe, and has shown striking predictive power. Two well-known examples are the existence of black holes and gravitational lensing (the latter predicted by Einstein in 1936 and not observed until 1979, the former predicted in 1915 and indirectly observed in 1971).

On the other hand, we have the Standard Model, in which electromagnetic and nuclear interactions are described by a quantum field theory consistent with both quantum mechanics and special relativity. The Standard Model has been extremely successful in describing the small-scale features of the Universe. Also in this case, predictions about the existence of particles have been invariably confirmed, with almost miraculous agreement between the theoretical and experimental values.

The great mystery of modern theoretical physics is that these two highly successful theories are incompatible. In other words: it is not (yet) possible to write the two theories with a common formalism. The standard procedure followed to achieve such a common description is to try and quantize gravity, but extensive research has shown than this produces physically absurd results. Technically, a quantum theory of gravity is not-renormalizable. This means that the standard procedure to get finite quantities for physical values by applying a cut-off (i.e. not considering terms after a certain order in the perturbative expansion) does not work in the case of quantum gravity, and quantities diverge (see Kreimer 2008 for a technical discussion on this point).

This situation in which our two most successful theories can not be brought together has been perceived by many scientists as a sign that our knowledge of the physical world is fundamentally incomplete.

This dissatisfaction has led to search for a way to succeed in the task of producing a new theory, a “unification theory”, which describes all fundamental interactions within one framework. At this point, one could take a step back and argue that the whole idea of unification is at least problematic, as there does not seem to be a necessary reason why Nature should be described by one consistent theory, besides some Platonic longings (for another problem regarding the metaphysical status of mathematical entities in physics and how this could affect the idea of unification, see Kfia 1993). In this paper we will not further analyze this question.

Among many approaches that have been tried, string theory seemed to be up to recently one of the most successful of all.

The basic idea of string theory is deceptively simple: substitute the building block of our physical world (the 0-dimensional particle) with an extended object, a 1-dimensional “string”. These strings are embedded into manifolds, on which they describe not trajectories, but “worldsheets” (for a general introduction to string theory, see Zwiebach 2004). Very coarsely put, this property solves the not-renormalizability problem. A graphical way to illustrate this is by making use of Feynman diagrams (see fig. 1).

![Fig. 1: left, the Feynman diagram of a particle.](image-url)
The particles of our everyday (low-energy) experience are then obtained as “vibration modes” of the strings.

This approach provides an elegant method to obtain a unified description of the four known fundamental interactions (the three already unified in the Standard Model and gravity as described by General Relativity Theory). Until recently, it also seemed that there were a limited number of consistent string theories, which were interrelated by so-called dualities. This had led to the speculation about the existence of an underlying, even more fundamental theory, the 11-dimensional M-theory, which would be the “true” Theory of Everything (literature is vast, see e.g. Witten 1996).

These hopes have been at least severely damped in the last years, when developments in theoretical physics have pointed out that, far from being a nice and tidy world of 5-6 theories with nice and clear relationships, string theory has a huge a number of possible false vacua, caused by the possibility of choosing different Calabi-Yau manifolds and different values of generalized magnetic fluxes over different homologies. These vacua create what has been called a “string landscape” (Smolin 1992). The thought is that in some portions of this landscape the laws of physics as we know them should be found. The landscape seems to pose a fundamental problem for the physical character of string theory, for a crucial question immediately arises: how can we select the portion of the landscape in which the theory reduces to our physical world? The theory does not give guiding principles for how and where to look. This would seem to imply that all we are left with is a theory that has no true predictive power. Why should string theory then be considered as a plausible scientific theory? The capacity of producing predictions about the physical world independently of arbitrary factor seems a minimal requirement to ask of a model that purports to be the “Theory of Everything”. Even worse: Why should string theory be considered a scientific theory at all? Predictive power is one of the properties we require tout court of a scientific theory. Things do not look good for string theory: or do they?

Enter the anthropic landscape: a possible way out?

Some leading string theorists have proposed in recent years an approach to the selection problem sketched out in the previous section (Susskind 2003 and 2004, Polchinski 2005). This approach involves an appeal to the anthropic principle and has sparked a very intense controversy within the field of physics as to its admissibility as a scientific criterion and as to how its application should be precisely understood. Before detailing this (in many ways surprising) move, let us review the other possible alternatives to get out of the “selection impasse”.

Science usually proceeds by selecting the best working theories and models at a given moment and using and refining them until stagnation occurs and progress is not possible any more. Within a Lakatosian perspective, a Research Program is valid until it starts to degenerate and when the hard-core can not be defended any more by the protective belt (Lakatos 1978). Is this the situation for string theory?

A first answer can be: the research program is indeed stagnating, at least from the perspective of physics (mathematically, it still produces a lot of beautiful and powerful results), but it is not degenerating yet, and there is hope of solving the landscape problem without stepping out of the accepted methodology of physics. Prominent physicists who endorse this position (explicitly or implicitly) are for example David Gross (Nobel Prize winner for physics in 2004 and one of the formulators of the theory of the heterotic string) and Ed Witten (one of world leading theoretical physicists, and the one who coined the idea of the M-theory).

A second answer can be: the program is indeed degenerating, we should not waste time and energy on the model any more, and look for viable alternatives. A prominent
proponent of this answer is Lee Smolin, who champions a very different approach called Loop Quantum Gravity (see e.g. Smolin 2005). These first two possible answers are both “traditional”, in the sense that they do not question the validity of current scientific methodology in physics and search within the paradigm for alternatives in order to carry on.

A third position is not only possible but, as we mentioned above, has been already explicitly put forward by some major string theorists. The basic idea is: if the way we are understanding the theory does not allow solving the selection problem, the solution has to be found in a different way to understand the theory; more specifically, in an application of the anthropic principle.

How should we understand this position? In the words of one of the proponents:

“Mostly physicists have hated the idea of the anthropic principle; they all hoped that the constants of nature could be derived from the beautiful symmetry of some mathematical theory. And now what people like Joe Polchinski and I are telling them is that it's contingent on the environment. It's different over there, it's different over there, and you will never derive the fact that there's an electron, a proton, a neutron, whatever, with exactly the right properties. You will never derive it because it’s not true in other parts of the universe.”¹

There are at least two important points mentioned and/or implied in this quotation. Firstly: physics can not in principle give answers as to why the fundamental constants of nature have the value they have, because they are not the same everywhere. Secondly: the only criterion of choice relies in the fact that we humans are in a part of universe where they have these values.

The second point is where the anthropic principle is applied to solve the “selection impasse” of string theory. It is not mentioned explicitly (there is only a reference to the environment), but it follows rather clearly: since we do not have a a priori (from first principles) way to select the right vacuum from the huge amount of metastable states produced by string theory, the fact that we observe the universe means that we live in a “pocket” of the universe where they have “just” the right values for observers to be there. In other words, the presence of observers is the selection criterion.

Before proceeding, we should observe that appeals to the anthropic principle in modern physics to tackle problems, in particular the observed value of the cosmological constant, are not completely new; Steven Weinberg wrote an (in)famous paper in 1987 in which he proposed that the emergence of organic life puts a lower bound to the value of the constant (Weinberg 1987). Weinberg's paper was and is controversial; but the position of Susskind, Polchinski, and other physicists goes much further than Weinberg's claims. Is an appeal to the anthropic principle a feasible and adequate solution for the selection impasse? Does it imply that string theory is indeed the best way to proceed in the search for a “theory of everything”, in spite of its predictive shortcomings? Does this way of using the anthropic principle brings back (though unwillingly) teleology in science? It seems that the introduction of the anthropic principle raises fundamental questions of which the proponents themselves are not aware.

In the next sections, we will first show that it is not at all clear which anthropic principle is meant by the proponents of this option, and after that we will discuss whether the implications of such a choice (once this is clear) are indeed positive and desired for scientific knowledge and its relationship with other forms of knowledge.

Which anthropic principle(s)?

The notion of “anthropic principle” was introduced by astrophysicist Brandon Carter (Carter 1974), but has been popularized in particular by the book of Barrow and Tipler

¹  L. Susskind, quoted at: http://www.edge.org/3rd_culture/susskind03/susskind_index.html
The Anthropic Cosmological Principle (Barrow and Tipler 1986). We will indicate them in this context as CAP (Carter's Anthropic Principle) and BAC (Barrow's Anthropic Principle) respectively. CAP and BAC are actually rather different, but they are often used as synonymous, causing a good deal of confusion. The situation is compounded by the fact that both CAP and BAC exist in two versions, the weak one (WCAP and WBAC) and the strong one (SCAP and SBAC).

WCAP is the rather tautological statement that “we must be prepared to take account of the fact that our location in the universe is...privileged to the extent of being compatible with our existence as observers” (Carter 1974). Stated in this form, the principle is not particularly controversial and is not undermining in any way current scientific methodology. It can be used to explain away some “cosmic coincidences” in the values of some parameters (Penrose 1989). WBAC goes much further, though, and actually includes the value of the fundamental physical constants, which were explicitly reserved in the Carter version for SCAP. It states: “The observed values of all physical and cosmological quantities are not equally probable but they take on values restricted by the requirement that there exist sites where carbon-based life can evolve and by the requirements that the Universe be old enough for it to have already done so” (Barrow and Tipler 1986: 16). SCAP affirms: “the Universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers within it at some stage. To paraphrase Descartes, 'cogito ergo mundus talis est’” (Carter 1974). SBAC is the “strongest” version of all, stating that “The Universe must have those properties which allow life to develop within it at some stage in its history” (Barrow and Tipler 1986), where the “must” seems to be an imperative. SCAP seems to rely on deductive reasoning, but it still allow for a teleological view. SBAC is the most controversial version at least from a scientific point of view, in that its teleological character seems undisputable, implying some purpose for the physical Universe and its creation (and the necessity for human beings to appear in order for the Universe to be brought into being). We can say in general that weak versions of the principle are tautological and strong versions can imply a teleological vision.

Since different versions of the principle imply very different consequences about teleology, the status of science and the role of human beings, the crucial point is: which of these (if any) versions of the anthropic principle is meant by the proponents of its application to string theory?

We can in any case exclude SBAC. Nowhere in the discussion within the theoretical physics community about the use of the anthropic principle in string theory is a mention to be found of some inherent necessity for us to be here or to some kind of purpose. This is not surprising, since the discussion is not about the meaning of the Universe, but rather about how to keep a promising theory from being dismissed. WCAP seems also not to be implied, since it does not involve the values of the fundamental constants, which are one of the points of contention in the debate. We have therefore excluded the weakest and the strongest version of the anthropic principle.

Further analysis of statements made by the pre-eminent proponents of anthropic reasoning in string theory seems to point to something in between SCAP and WBAC. On one hand, the use of the principle is explicitly invoked as only way to explain why the fundamental constants of nature have the value they have (which fits both SCAP and WBAC), but on the other hand any teleological implications are at least not mentioned and even flatly rejected (see for example Weinberg 2007). Let us take an example in which the discussion focuses on the small non-zero positive value of the cosmological constant (Polchinski 2005). This discussion is directly related to the string landscape question, in that if one of the vacua of the theory is indeed our Universe, then it must have the right value for the cosmological constant. Polchinski (one of the top physicists advocating the use of anthropic reasoning) states flatly: “of course, the anthropic principle is in some sense a tautology: we must live where we can live” (Polchinski 2005: 12). This comes very close to WBAC. Polchinski adds further that if this principle alone can be used, there is no reason to look for alternative explanations. In particular, he makes the following crucial statement, discussing why many scientists are against it and in favour of sticking to predictive models: “we wish fundamental theory to be as
predictive as we have long assumed it would be” (Polchinski 2005: 13). Polchinski then makes another interesting move, in lending to what he describes a tautological principle predictive power! In particular, he states the fact that the cosmological constant is not zero was not something physicists were looking for, but it is something that does follow from the use of the anthropic principle, and therefore it can be considered a true prediction. We will come back to this important point in the following section.

Nowhere in the example we took is the “carbon-based” aspect of WBAC mentioned, in spite of being a fundamental aspect of the latter (Barrow and Tipler 1986). In general, physicists discussing these issues stay with the term “observers” (Vilenkin 2007). In that sense, WBAC does not fit completely and we get something that looks more like SCAP. It is interesting for us to note that, in the cited paper, Vilenkin (another high-profile proponent of anthropic reasoning) does not distinguish between Carter and Barrow and Tipler, citing them both as supporting the idea that “anthropic selection” explains why “a narrow range of...the parameters we call constants of Nature...is consistent with the existence of life” (Vilenkin 2007: 1). This shows that even among the top-rated physicists advocating anthropic reasoning there is some conceptual confusion as to what this way of thinking assumes and implies.

Concluding, we can state that the way in which the anthropic principle is used in the discussion about the status of string theory (and the related issue of the value of the cosmological constant) is rather confused and confusing, in that different definitions seem to be used at the same time.

One could dismiss such conclusion as being of little relevance for broader philosophical and theological issues. I contend that this would be an oversimplification: if science accepts anthropic reasoning as part of its methodological toolbox, the implications are far-reaching.

A new epistemology is born?

In spite of its unclear application, the use of (a form of) the anthropic principle in science could lead to a radical revision of what constitutes a good scientific theory. This switch could also have consequences for how scientific knowledge is assessed and compared to other kinds of knowledge, consequences I argue are largely unanticipated and unwanted by its proponents.

The first consequence that an endorsement of anthropic reasoning as a way to establish valid scientific knowledge has, is that the requirement of predictability ceases to be necessary. Moreover, testability seems also to become less relevant. While it is true that in the latter case one could argue that partial lack of testability is already a feature of scientific theories (Livio and Rees 2005), the former requirement seems to weaken in a substantial way the criteria for scientific knowledge.

As far as the former point is concerned, we have seen that Polchinski seems to disagree with it, and considers anthropic reasoning capable of making predictive statements. This position is further argued by Vilenkin (2007). He claims that arguments about the unpredictive character of anthropic reasoning no longer apply to the way it is used in modern science, and in particular in cosmology. His argument is twofold: on one side, he distinguishes between “anthropic bounds” and “anthropic predictions”, arguing that the former has indeed no predictive power. How to obtain anthropic predictions then? He contends that “these predictions are of a statistical nature, but they still allow models to be confirmed or falsified at a specific confidence level” (Vilenkin 2007: 1-2).

The argument of Vilenkin (and the related ones of Polchinski) seems to rely on a different notion of predictability that the one usually used in science. They use a kind of “circular argument” for prediction. In fact: it is indeed true that anthropic reasoning leads to the conclusion that the cosmological constant must be not zero, but there is no necessary reason to begin with to introduce anthropic reasoning in the model, besides the fact that the model is not giving the correct predictions! In other words, this kind of “predictions” look more like the ad hoc hypotheses that, in a Kuhnian framework, are added to a
theory to save it when anomalies start to pile up. In that respect, they are not predictions at all.

In this sense, thus, sticking to anthropic reasoning substantially modifies the established notion of predictability. This seems to be recognized also by Vilenkin, when he states that, because of their probabilistic character, "in anthropic reasoning...predictions...have an intrinsic variance which cannot be further reduced" (Vilenkin 2007: 12).

What he does not seem aware of is the fact that this redefinition is far-reaching and leads to radical epistemological consequences, because it changes the very meaning of scientific knowledge. In particular, it seems to reverse the theory-experiment relationship. Where (in the “traditional” approach) theory has always to answer to empiry (underdetermination arguments notwithstanding), in this vision theory actually dominates empiry, in that it can always resort to anthropic reasoning, without the need to modify its tenets. Popper would likely condemn this move as relegating the theory into the realm of non-science.

The second consequence I want to stress here has to do with possible teleological implications. When discussing the various versions of the anthropic principle, we have seen that weak versions of it are usually considered tautological, but that strong versions can be seen as teleological. We have also concluded that the way anthropic reasoning is used in the debate about the status of modern theoretical physics is not conceptually clear, and actually leaves space for at least the strong version as formulated by Carter. (Re)-introducing the notion of purpose in the scientific way of studying the physical world is absolutely not what the proponents of anthropic reasoning for string theory want or desire. It could be an unanticipated consequence, though, and surely an unwanted one. This is made clear by Weinberg, when he claims that anthropic reasoning is a weapon against what he calls "flavours of religion": “the string landscape may explain how the constants of nature that we observe can take values suitable for life without being fine-tuned by a benevolent creator” (Weinberg 2007). The only argument he actually gives for this position is a reference to the famous and highly controversial statement by Christoph Cardinal Schönborn that the multiverse hypothesis (which makes use of anthropic reasoning), along with Neo-Darwinism, is a way to avoid recognising design and purpose in the Universe (Schönborn 2005). I contend that anthropic reasoning does open (at least potentially) the doors to teleology and purpose within science, as soon as it does not strictly adhere to a tautological version. This is because the issue of the necessity of the observers will come up at some stage, and when this is the case, Ockham’s razor dictates that chance is a much less simple explanation than fine-tuning and purpose. Also in this sense, thus, the introduction of anthropic reasoning profoundly affects the very notion of science.

The question at this point is: is anthropic reasoning worth this radical revision of our notion of scientific knowledge? Based on what I have described in this paper, I take the position that it is not at all clear which advantages such a profound revision would bring about, besides avoiding to reject string theory as a viable avenue for unification. Saving a theory (as popular as it may be) seems hardly a good reason to embark on such a journey.

Final remarks

If scientific knowledge would undergo the kind of deep transformation which I argued is required by the introduction of anthropic reasoning, this would also affect its relationship with other forms of knowledge. In particular, the relationship science-theology would have to be rethought, in the light of the new epistemological status of science. I have argued that this redefinition of science does not seem justified and, therefore, that

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2 This point was made also at the recent international conference Strings 2008 by David Gross (http://ph-dep-th.web.cern.ch/ph-dep-th/content2/workshops/strings2008/?site=content/welcome.html), where he noticed that most talks did not mention the anthropic principle at all.
anthropic reasoning in science is undesirable. These conclusions hold also for the
dialogue between science and theology. Modern science does provide very interesting
starting points for rethinking theological issues. In particular, unification theories like
string theory reinterpret and redefine concepts like determinism and time, and this can
be used to formulate a new, scientifically informed, theory of God’s action in the world
(Consoli, in preparation). But for this dialogue to be fruitful and inspiring we do not need
radical revisions of the concept of science, surely not one based on confused and
confusing notions.

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**Short CV**

L. (Luca) Consoli (1971) got his PhD in theoretical physics in 2002. He is currently Assistant Professor of Science and Society at the Faculty of Science, Radboud University Nijmegen, and Senior Researcher in Theology and Physics in the Heyendaal Program on Theology and Science at the same University. His research interests are the possible consequences for theological discourse of modern physical unification theories.