GOD, CAUSALITY, AND THE CREATION OF THE UNIVERSE

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RESUMEN: *Dios, causalidad y la creación del universo*
El argumento cosmológico de Kalam es quizás el más sólido y difundido de los argumentos para justificar la idea de que el universo ha sido creado. Las objeciones usuales a este argumento se han centrado en la segunda premisa. En el presente trabajo se discute la dependencia de la primera premisa de la estructura topológica de la variedad espacio-temporal que corresponde al modelo cosmológico subyacente. Se muestra que en espacio-tiempos con violación cronológica la primera premisa es también violada. La violación cronológica requiere, a su vez, una violación masiva de las llamadas 'condiciones de energía', lo que puede tener consecuencias observables. De aquí que existan observaciones astronómicas relevantes para la validez del argumento, que tradicionalmente ha sido considerado metafísico. En este sentido, podemos hablar de una 'teología observacional'.

ABSTRACT: The Kalam Cosmological Argument is perhaps the most solid and widely discussed argument for a caused creation of the universe. The usual objections to the argument mainly focus on the second premise. In this paper we discuss the dependency of the first premise on the topological structure of the space-time manifold adopted for the underlying cosmological model. It is shown that in chronology-violating space-times the first premise can also be violated. The chronology-violation, in turn, requires a massive violation of the so-called energy conditions which might have observational effects that are briefly discussed here. Hence, astronomical observations could be relevant for the validity of the metaphysical argument. In this sense, it is possible to talk of "observational theology".

Introduction

The so-called Kalam Cosmological Argument (e.g. Craig 1979) is a version of the classical cosmological argument based on some medieval Islamic arguments against the infinitude of the past. It was originally proposed by the Islamic theologian, jurist, philosopher, and mystic Abu Hāmid Muhammad ibn Tā'ūs Ahmad al- Tūsi al-Shāfi'i (1058-1111, known as Algazel in the West) in 1095. 'Kalam' is the Arabic word for 'speech' but it means also 'philosophical theology'. Nowadays it is used to designate the movement in the Arabic thought

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that can be described as Arabic scholasticism. In modern syllogistic form the Kalam Cosmological Argument can be formulated as follows:

1. Whatever begins to exist has a cause of its existence.
2. The universe began to exist.
3. Therefore, the universe has a cause of its existence.

It has been argued that the first premise is a fundamental metaphysical principle which cannot be intelligibly denied and that the second premise is supported by modern cosmology, in such a way that the conclusion of the argument is true (Craig 1979, Craig & Smith 1993). These contentions have been discussed in recent years by several philosophers, notably Adolf Günbaum, who argued that the Big Bang model does not support the second premise (e.g. Grünbaum 1989, 1990, 1991, 2000, and some replies in Craig 1991 and 1992). The first premise, on the contrary, has not been considered controversial except from the point of view of quantum mechanics (see the discussions in Craig & Smith 1993).

In this paper we shall argue that the validity of the first premise depends on the topology of the space-time manifold adopted for the underlying cosmological model. Multiple connected space-times can be compatible with objects that obey all physical laws but violate the first premise of the Kalam Cosmological Argument. Some semantic comments are in order first to clarify the meaning of the expression "to begin to exist".

A semantical note

Craig (1992) attributes to Grünbaum the implicit use of the following definition:

> *"x begins to exist"=def. "x exists at time t and there are instants of time immediately prior to t at which x does not exist".*

This definition is objected because it is difficult to accept that the existence of x at t can entail the existence of temporal instants prior to t. Admittedly, in the context of a relational theory of space-time (e.g. Perez-Bergliaffa, Romero & Vucetich 1998) the requirement of the existence of moments prior to t is nothing else than the requirement of the existence of objects other than x before x. Such a definition, then, is not adequate to the discussion of the origin of the system formed by all things, i.e. the universe. Craig, in turn, proposes:

> *"x begins to exist"=def. "x exists at time t and there are no instants of time immediately prior to t at which x exists".*

This allows for a beginning of time itself and is apparently apt for a discussion on the beginning of the universe. But it has the problem of demanding a sharp edge for the existence of x. Anything created by an evolutionary process lasting a finite time interval is excluded. Let us consider, for example, the Mankind. It certainly exists now and it certainly did not exist 50 million years ago, but can we point out an instant t at which it did existed and an immediately prior instant at which it did not? Not only biological counterexamples are possible, but we can also think in most physical systems, like a star or a molecular cloud, which are formed by a slow transition from a previous state.

In order to remove this problem we propose:

"x begins to exist"=def. "x exists at time t and there is a time interval $\Delta t \geq 0$ such that there are no instants of time immediately prior to $t - \Delta t$ at which x exists".

For $\Delta t = 0$ we recover Craig's definition. In what follows we shall understand "to begin to exist" in the sense of this latter definition.

Chronology-violating space-times and self-existent objects

A relativistic space-time is represented by a four-dimensional manifold *M* equipped with a Lorentzian metric g_{ab}. The General Theory of Relativity requires the manifold to be continuous and differentiable but not specific constraints are imposed on the details of its topology. Usually, simply connected manifolds are considered, but multiply connected ones cannot be ruled out only on a priori grounds.

In recent years there has been a sustained interest in multiple connected space-times, also called wormhole space-times, originated in the fact that close timelike curves (CTCs) naturally appear in them (e.g. Morris, Thorne & Yurtsever 1988, Thorne 1992). These curves represent the world lines of any physical system in a temporally orientable space-time that, moving always in the future direction, ends arriving back at some point of its own past. Any space-time with CTCs is called a chronology-violating space-time. Objections to the formation of CTCs in the real universe had been formulated by a number of scientists, most notably by Hawking (1992), but in the absence of a complete theory of quantum gravity the possibility of wormholes in space-time cannot be ruled out (see the discussions and references in Earman 1995a, Romero & Torres 2001, and Nahin 1999).

One of the most strange implications of chronology-violating space-times is the possibility of an ontology with self-existent objects. These are physical systems "trapped" in CTCs. Romero & Torres (2001), who have discussed these systems in depth, give the following toy-example to illustrate the nature of such objects:

> *Suppose that, in a space-time where CTCs exist, a time traveler takes a ride on a time machine carrying a book with her. She goes back to the past, forgets the book in –what will be– her laboratory, and returns to the future. The book remains then hidden until the time traveler finds it just before starting her time trip, carrying the book with her.*

The book in question is a self-existent object: it exists at a given *t*, there exists $\Delta t \geq 0$ such that the object does not exist at $t\text{-}\Delta t$, but, however, there is not an external cause of its existence. The self-existent object *is just a feature of space-time itself*, it is not either created or destroyed in space-time. Such objects clearly violate the first premise of the Kalam Cosmological Argument.

It is very important to emphasize that, despite that the self-existent objects have not a cause of their existence, they do not violate causality. In fact, since their space-time history is a continuous closed curve, *their physical state at every time t is casually linked to a previous state*. In this way, these objects are not causally created, but they have a finite existence in the sense that they exist during a finite time interval, and their existence does not violate strict causality.

Romero & Torres (2001) have argued against an ontology of self-existent objects invoking a full Principle of Self-Consistency for all laws of nature. This principle, which is used to dissolve the so-called "paradoxes" of time travel (Earman 1995b, Nahin 1999), can be stated as:

The laws of nature are such that any local solution of their equations that represents a feature of the real universe must be extensible to a global solution.

Romero and Torres suggest that this principle is a metanomological statement (see Bunge 1961) that enforces the harmony between local and global affairs in space-time. By including thermodynamics in the consistency analysis of the motion of macroscopic systems through wormhole space-times, they have shown that non-interacting self-existent objects are not possible in the real universe because energy degradation along the CTC results in non-consistent histories.

Notwithstanding these objections, the development of consistent histories remains an open possibility for isolated systems where entropy cannot be defined (e.g. single particles) and for interacting systems where their energy degradation is exactly compensated by external work made upon them (Lossev & Novikov 1992). Hence, if CTCs actually occur in the universe, there seems to be no form to avoid the possibility of at least some types of self-existent objects.

Very recently, J. Richard Gott III and Li-Xin Li (1998) have even proposed that the universe itself could be a self-existent object. From a philosophical point of view, this would be a violation of both premises of the Kalam Cosmological Argument with a single counterexample. As far as it can be seen, the work by Gott and Li is consistent with the Big Bang paradigm. They only require the existence of a multiply connected space-time with a CTC region beyond the original inflationary state. There is no creation in such model. The universe is just a back-reaction to its own future state.

A key point for the validity of the first premise of the Kalam Cosmological Argument is that the space-time in the real universe must be described by a simply connected manifold, with no CTCs[1]. Otherwise, the presence of objects that have "began to exist" without external cause but notwithstanding are subject to causality cannot be excluded. We have, then, two possibilities in order to explore the validity of the first premise in the context of its dependency on the underlying topology of space-time: 1) we can try to prove, from basic physical laws, that CTCs cannot be formed in the real universe (i.e. we can try to find out a mechanism to enforce chronology protection), or 2) we can inquire about the observational signatures of wormhole structures in space-time and try to test through observations the hypothesis that natural wormholes actually do exist. The first option requires a full theory of Quantum Gravity, something that is beyond our present knowledge. The second approach is being already explored by some scientists.

Observational signatures of WEC-violating matter

Macroscopic and static wormhole structures as those necessary to allow the formation of CTCs require that the average null energy condition (ANEC) be violated in the wormhole throat (see Appendix 2). This condition is part of the so-called energy conditions of Einstein gravity, which are very general hypothesis designed to provide as much information as possible on a wide variety of physical systems without specifying a particular equation of state. These conditions are not proved from basic principles; they are just conjectures, which can be very useful in some contexts. However, many violating systems are known, including the universe itself (see Visser 1996).

The energy conditions violated by a traversable wormhole can be put in terms of the stress-energy tensor of the matter threading the wormhole as $\rho + p \geq 0$, where ρ is the energy density and p is the total pressure. This implies also a violation of the so-called weak energy condition –WEC– ($\rho \geq 0 \wedge \rho + p \geq 0$; see Visser 1996 for details, also Morris and Thorne 1988. Plainly stated, all this means that the matter threading the wormhole must exert gravitational repulsion in order to stay stable against collapse. If natural wormholes exist in the universe (e.g. if the original topology after the Big-Bang was multiply connected), then there should be observable signatures of the interactions between matter with negative energy density with the normal matter.

At astronomical level the most important observational consequence of the existence of natural wormholes is gravitational lensing of background sources (Cramer et al. 1995, Torres et al. 1998; Eiroa et al. 2001, Safonova et al. 2001). There are very specific features produced by chromaticity effects in lensing of extended sources that could be used to differentiate events produced by wormholes from those of other objects (Eiroa et al. 2001). In the wormhole microlensing case there are two intensity peaks in the light curve during each event separated by an umbra region. On the contrary, in the normal case there is a single, time-symmetric peak. In addition, in the wormhole case it can be shown that there is a spectral break that is not observed in the usual case (Eiroa et al. 2001 for details).

Also, the macrolensing effects upon a background field of galaxies produced by large-scale violations of the energy conditions are observationally distinguishable from the normal macrolensing by either dark or luminous matter concentrations (see Safonova et al. 2001 for complete numerical simulations of macrolensed galaxy fields). In particular, it can be shown that for positive mass we see concentric arcs, whereas for negative energy densities we have filamentary features radially projected from the center.

The above examples are enough to illustrate the kind of observational effects that can be expected in an universe with multiple connected topology. Whether such space-time wormholes actually exist in our universe is something that has to be found yet.

The mere existence of a multiple connected topology for space-time does not warrant, by itself, the violation of the first premise of the Kalam Cosmological Argument. But it makes possible the formation of CTCs and non-cronal situations in that space-time, hence opening the possibility of an ontology with self-existent objects. This implies that the universality of the premise can be objected even at a macroscopic level, without resorting to quantum considerations.

Conclusions: Theology meets experiment

The first premise of the Kalam Cosmological Argument, namely that "whatever that begins to exist has a cause of its existence", is not a self-evident, universally valid statement as it is usually accepted. We have shown that the truth value of the premise is dependent on some basic characteristics of the space-time manifold that represents the real universe. In particular, multiple connected space-times can accommodate objects that exist by themselves, without external cause, but also without any local violation of causality. These objects "begin to exist" in accordance to even the most restrictive definitions given in Section 2.

Since the connectivity of space-time can be probed through astronomical observations (see Anchordoqui et al. 1999 for an example of these observational studies), the validity of the Kalam Cosmological Argument can be tested by the scientific method. Not only the second premise, which uses to be discussed in the light of the Big Bang cosmology, but also the first premise of the argument is susceptible to experimental test. It is in this more extended sense that in the Kalam Cosmological Argument we can say that theology meets experiment.

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Appendix 1: Aquinas on the Cosmological Argument

The so-called Cosmological Argument is actually a family of arguments for the existence of God that are usually considered as *a posteriori*, i.e. they start with some very general feature of the world known by the experience and then they proceed to derive the conclusion of God existence with the help of some additional premise of metaphysical nature. Because of its logical structure, the Cosmological Argument is a deductive argument. It was introduced by Plato and Aristotle, and developed by Algazel, Aquinas, Duns Scotus, Leibniz, and Samuel Clarke, among others. In some of its well-known versions (e.g. those due to Aquinas and Leibniz) is has been strongly criticized by Hume, Kant, Russel, Ayer, and others. Most of these criticisms do not affect the Kalam form of the Argument.

Let us compare the form of the Argument given by Aquinas, in his second way, with the Kalam form expressed in Section 1. Aquinas's second way may be stated as follows:

1. Some things exist and their existence is caused.
2. Whatever is caused to exist is caused to exist by something else.
3. An infinite regress of causes resulting in the existence of a particular thing is impo-s ssible.
4. Therefore, there is a first cause of existence.

This particular form (due to William L. Rowe) avoids some problems of the more popular forms that start the first premise with an universal quantification. We can argue that the first two premises are general features learned from our experience of the world. But the third premise is a metaphysical statement that should be either self-evident or deducible from self-evident first principles. Certainly, this is matter of controversy. In comparison, the Kalam version of the Argument has only two premises and, as we have shown in this paper, both of them are falsifiable by experiment. Hence, contrary to Aquinas's version, the Kalam Cosmological Argument is a truly *a posteriori* argument.

But there is another important point related to the current ideas on the nature of causality. The casual relation, according to modern science, is not a relation between things or states of things, but a relation between events. An event is a change in the state of a given thing. An event in thing A causes an event, or a series of events (i.e. a process) in thing B. Causation is just a mode of energy transfer (e.g. Bunge 1977). What is caused is not the universe (a thing), but the beginning of the universe (an event). The cause of the beginning of the universe is not God, but the act of creation (an event). God is the agent of creation, which is a different thing. In this way, the Kalam Cosmological Argument seems to say that God injected the energy of the universe at the Big Bang, triggering the whole chain of cosmic evolution.

Appendix 2: Wormhole space-times

A wormhole is a region of space-time with non-trivial topology. It has two mouths connected by a throat. The mouths are not hidden by event horizons, as in the case of black holes, and, in addition, there is no singularity that could avoid the passage of particles, or travelers, from one side to the other.

We review here the basic properties that a space-time needs to obey in order to display wormhole-like features. We begin by introducing the static spherically symmetric line element,

$$ds^2 = - e^{2\Phi(l)} dt^2 + dl^2 + r(l)^2 d\,\Omega_2^2 \qquad (1)$$

where l is a proper radial distance that covers the entire possible range (-8,ˀ). In order to have a wormhole which is traversable in principle, we need to demand that:

1. $\Phi(l)$ be finite everywhere, to be consistent with the absence of event horizons.
2. In order for the spatial geometry to tend to an appropriate asymptotically flat limit, it must happen that

$$\lim_{r□ˀ} r(l)/l = 1$$

and

$$\lim_{r''ˀ} ø(l) = ø_0 < ˀ.$$

The radius of the wormhole is defined by $r_0 = \min r(l)$, where we can set $l = 0$.

To consider wormholes which can be traversable in practice, we should introduce additional engineering constraints (see Visser 1996). Notice that for simplicity we have considered both asymptotic regions as interchangeable. This is the best choice of coordinates for the study of wormhole geometries because calculations result considerably simplified. However, as it is usually easy to also derive solutions of the field equations working with Schwarzschild coordinates, we shall mention the necessary conditions in this case too. In general, two patches are needed to cover the whole range of *l*, but this is not noticed if both asymptotic regions are assumed similar. The static line element is,

$$ds^2 = -e^{2\Phi(r)}dt^2 + e^{2\Lambda(r)}dr^2 + r^2\, d\,\Omega_2^2 \qquad (2)$$

where the redshift function Φ and the shape-like function $e^{2\Lambda}$ characterize the wormhole topology. They must satisfy:

1. $e^{2\Lambda}$. 0 throughout the space-time. This is required to ensure the finiteness of the proper radial distance defined by $dl = \pm e^{\Lambda}\, dr$. The ± signs refer to the two asymptotically flat regions which are connected by the wormhole throat.

2. The precise definition of the wormhole's throat (minimum radius) entails a vertical slope of the embedding surface

$$\lim_{r\to r_{th}^+} \frac{dz}{dr} = \lim_{r\to r_{th}^+} \pm\sqrt{e^{2\Lambda}-1} = \infty \qquad (3)$$

3. As *l* ″ ±˜ (or equivalently, *r* ″ ˜), $e^{2\Lambda}$ ″ 1 and $e^{2\Phi}$ ″ 1. This is the asymptotic flatness condition on the wormhole space-time.

4. $\Phi(r)$ needs to be finite throughout the space-time to ensure the absence of event horizons and singularities.

5. Finally, the *flaring out* condition, that asserts that the inverse of the embedding function $r(z)$ must satisfy $d^2r/dz^2 > 0$ at or near the throat. Stated mathematically,

$$\frac{\Lambda' e^{-2\Lambda}}{\left(1-e^{-2\Lambda}\right)^2} > 0. \qquad (4)$$

This is equivalent to state that $r(l)$ has a minimum.

Static wormhole structures as those described by the above metric require that the average null energy condition must be violated in the wormhole throat. To see why let us consider the metric in the proper coordinate *l*. The Einstein tensor for this metric is,

$$G_{tt} = -\frac{2r''}{r} + \frac{1-(r')^2}{r^2}, \tag{5}$$

$$G_{rr} = \frac{2r'\Phi'}{r} - \frac{1-(r')^2}{r^2}, \tag{6}$$

$$G_{\theta\theta} = G_{\varphi\varphi} = \Phi'' + (\Phi')^2 + \frac{\Phi' r' + r''}{r}. \tag{7}$$

In particular,

$$G_{tt} + G_{rr} = -\frac{2r''}{r} + \frac{2r'\Phi'}{r}. \tag{8}$$

Because of its own definition, r´ = 0 at the throat. Then, due to the flaring out condition, two open regions *l* Î (0, l_*^+) and *l* Q (- l_*^-, 0) should exist such that r˝(*l*) > 0.

This implies that ς*l* Q (- l_*^-, 0) ∪ (0, l_*^+)

$$G_{tt} + G_{rr} < 0. \tag{9}$$

This constraint can be put in terms of the stress-energy tensor of the matter threading the wormhole. Using the field equations, it reads

$$T_{tt} + T_{rr} < 0, \tag{10}$$

which represents a violation of the null energy condition. This implies also a violation of the weak energy condition (see Visser 1996 for details). Plainly stated, it means that the matter threading the wormhole must exert gravitational repulsion in order to stay stable against collapse. Although there are known violations to the energy conditions (e.g. the Casimir effect), it is far from clear at present whether large macroscopic amounts of "exotic matter" exist in nature.

Repetition studies on the entire gamma ray burst sample can be used to constrain the total number of wormholes that may exist in the universe. Currently, the observational data allow to establish an upper bound on the total amount of exotic matter under the form of wormholes of ˆ 10^{-36} g cm^{-3} (Torres et al. 1998).

Finally, we mention that a wormhole can be immediately transformed into a time machine inducing a time-shift between the two mouths. This can be made through relativistic motion of the mouths (a special relativity effect) or by exposing one of them to an intense gravitational field (see Morris, Thorne and Yurtsever 1988 and Frolov & Novikov 1990 for further details).

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NOTE

[1] Formally, CTCs are possible even in simply connected space-times, but these kind of solutions of Einstein field equations, like the classical Gödel (1949) rotating universe, are thought to be not applicable to the real world.

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