The big bang's 'beginning of time' and the singular FLRW cosmological models

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Abstract

In this work it will be addressed the issue of singularities in space-time as described by Einstein's theory of gravitation in connection to issues related to cosmology; more specifically we will consider the singular FLRW space-time of contemporary cosmology in relation to the issue of the beginning of time in the so-called big bang.

1. Introduction

John Earman (1995) called the attention to singularities as an important foundational issue in space-time philosophy. While there are some high quality works devoted to this subject it is still not widely considered (see, e.g. Lam 2007, Curiel 2009, Manchak 2014). Part of the difficulty in dealing with singular space-times might be the lack of a general definition of what is a singularity. There is no unique definition. According to Earman the semiofficial definition of a singular space-time is made in terms of the so-called b-incompleteness (Earman 1995, 36). A curve $\gamma(t)$ in the manifold can be parametrized in terms of a so-called generalized affine parameter $\theta(t)$. If $\theta(t)$ is bounded then we call it b-incomplete and the space-time is considered singular. The b-incompleteness improves in relation to a tentative general all-encompassing definition of singularities in terms of geodesic incompleteness (Curiel 2009, 7).[1] However as Curiel mentions:

> the most damning fact about b-completeness is that, so far as I know, it is never used in the statement or demonstration of any result of physical interest. All the singularity theorems, for instance, demonstrate only the existence of null or timelike geodesics, and are formulated only in those terms. (Curiel 2009, 8)

For the purpose of this work it is enough to frame the singular space-time in terms of Earman's second and fourth 'tries' for tentative definitions (Earman 1995, 29-31): the blowup of curvature scalars (that Earman refers to as sufficient criterion, but not a necessary one)[2], and the incompleteness, in our case, of timelike geodesics.

As it is well-known, the contemporary general relativistic model of space-time in cosmology is based on the Friedmann-Lemaître-Robertson-Walker (FLRW) metrics and the Friedmann-Lemaître equations obtained from Einstein's equations with the FLRW line element and a stress-energy tensor treating matter as a perfect fluid (more exactly, in Friedmann's approach, as dust). This space-time is singular (see, e.g., Wald 1984 91-116; Rindler 2006, 347-416; Narlikar 2010, 245-273). In this way singularities are an aspect of our contemporary description of the Universe's evolution. Importantly the FLRW singularity is not due to the symmetries of the model (due to spatial homogeneity and isotropy); it is a generic feature of cosmological space-time models (including

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1 An inextensible geodesic is incomplete when the range of its affine parameter is not the whole real line (see, e.g., Ludvigsen 1999, 156).

2 Curiel (2009, 8-14) calls the attention to subtleties related to the blowup of curvature scalars (or the Riemann tensor) that led him to consider that “curvature pathology, as standardly quantified, is not in any physical sense a well defined property of a region of spacetime simpliciter” (Curiel 2009, 13). However in the case being considered in this work, that of Friedmann models, it is generally accepted that the density blowup (and corresponding blowup of the Ricci tensor) signal a singularity (see, e.g. Wald 1984, 99; Curiel 2009, 14 footnote 37)

less symmetrical models), as it is shown by the so-called singularity theorems (see, e.g., Wald 1984, 211-241; Earman 1995, 50-56).

In this work we will address the question of the beginning of time in the context of assuming a Friedmann model for space-time, i.e. a singular space-time, which corresponds in the standard cosmological model to the so-called big bang (see, e.g., Narlikar 2010, 223-331). This work will be developed around views and questions set forward by Henrik Zinkernagel and Erik Curiel.

On a paper on the concept of time in modern cosmology Svend Rugh and Henrik Zinkernagel address the issue of having or not a well defined concept of (cosmic) time in the early stages of the Universe (Rugh and Zinkernagel 2009). In a related work Zinkernagel addresses the question of the 'beginning of time' in a cosmological context (Zinkernagel 2008). According to Zinkernagel, "*if* the big bang model is a (roughly) correct description of our universe, then the best current answer to the question [did time have a beginning?] is that time did have a beginning" (Zinkernagel 2008, 237).

There is in our view an important insight in Curiel's work on singularities that provides a starting point to address, more thoroughly, the question and answer provided in Zinkernagel (2008) from the perspective of the study of space-time singularities. According to Curiel

> questions about what happened "before" the Big Bang, or why the universe "came into being", can come from their former nebulosity into sharper definition, for they become questions about the presence of certain global structure in the spacetime manifold, [(the singular structure)]. (Curiel 2009, 142)

From this perspective, the singular space-time itself would be our tool to provide an 'explanation', from within Einstein's theory of gravitation, of the 'beginning of time'. A criticism to Curiel's views might be, as he mentions, the apparent lack of 'explanation' involved in the reference to the singular structure. For example,

> since a [incomplete] timelike geodesic is the possible worldline of an observer or a particle, it is *prima facie* possible that an observer or particle could traverse such a singular curve, which seems to imply that a particle could pop in or out of existence *ex nihilo* or *ad nihilum* with no known physical process or mechanism capable of effecting such a thing dynamically (Curiel 2009b, 56).

In this work we will make the case that the singular structure of the FLRW model does in fact provided a sharper definition/characterization, in this case, of the issue of the beginning of time; and that the difficulty mentioned by Curiel when making reference to the space-time singularity is 'dissolved' when clarifying the content and implications of having a singular FLRW space-time.

2. On Curiel's proposition for considering questions like "did time have a beginning?" as questions about the presence of a global structure in space-time – the singular structure

Curiel distinguishes between what he calls local and global properties/structures of space-time. Accordingly, in an analogous way to topological properties, a local property must hold in arbitrarily small neighborhoods of every point of a manifold. If a property is not local then it is global (Curiel 2009, 22). Maximally incomplete time-like geodesics are according to Curiel a global property/structure of space-time (Curiel 2009, 22-3; Curiel 2009b 55-58). In this way

the incompleteness of the singular curve, however, as a property of the curve, does not exist in any localized sense in space-time. In general, one cannot even associate the incompleteness of an incomplete, inextendible curve with a bounded region of space-time. The existence of such an incomplete curve is, in a technical sense, a global feature of the space-time manifold and its metric. (Curiel 2009b, 58)

Characterizing the singular feature of a space-time in terms of incomplete curves leads to a view not of a singularity in space-time (a phrase that seems to indicate a local structure) but of singular space-times, i.e. space-times which have a global property/structure which we may call singularity while having in mind that this is not a local feature.

Curiel regards the (global) singular structure as a 'topological-like' global structure:

the non-localizability of incomplete, inextendible curves is no different from that of any other global topological structure, such as the spacetime manifold's paracompactness or the fact that it is Hausdorff separable or the value of its Euler characteristic. (Curiel 2009d, 58)

Curiel then thinks that the singular structure “would simply be one more type of global structure that all space-times necessarily had, along with, e.g., paracompactness” (Curiel 2009, 26). By adopting this view in terms of a topological-like global structure, Curiel considers that it is at this 'level' that we can address several issues. In this way

questions about what happened “before” the Big Bang, or why the universe “came into being”, can come from their former nebulosity into sharper definition, for they become questions about the presence of certain global structure in the space-time manifold, in principle no different from paracompactness, connectedness or the existence of an affine connection, and one can at least envisage possible forms of an answer to the (precise) question, “Are there any factors that necessitate space-time’s having such and such global structure?” And were we actually to observe particles popping in and out of existence, we could formulate and begin trying to answer the analogous questions. (Curiel 2009, 27-8)

Regarding the eventual phenomena of particles popping in and out of existence they seem to be a possibility when having a singular space-time, since curve incompleteness

seems to imply that particles could be “annihilated” or “created” right in the middle of space-time, with no known physical force or mechanism capable of performing such a virtuosic feat of prestidigitation (Curiel 2009, 26)

As already mentioned, Curiel recognizes that the approach in terms of the global structure might lead to problems in 'explaining' this type of phenomena. According to Curiel

a viewpoint [in terms of the singular structure] would seem to deny that certain types of potentially observable physical phenomena require explanation, when on their face they would look puzzling, to say the least. Were we to witness particles popping in and out of existence, the mettle of physics surely would demand an explanation. I would contend in such a case, however, that a perfectly adequate explanation was at hand: we would be observing singular structure (Curiel 2009, 27)

Without going into the details of what we might consider to be an 'explanation', simply referring to the singular structure does not provide much regarding,.e.g, the particular hypothetical phenomena of particles popping in and out of space-time. Curiel writes that if we observed this phenomena, somehow we might formulate it in terms of the singular structure (Curiel is not explicit how), and “begin trying to answer” (Curiel 2009, 28) whatever questions we might consider as related to it. Curiel envisages an approach in which issues might be address not, e.g., at a 'level' in which we make reference to the incomplete time-like geodesics, but at a more 'general' or 'abstract' level of a global structure “no different from that of any other global topological structure” (Curiel 2009d, 58). However Curiel arrives at a characterization of singularities as a global feature of space-time by considering incomplete time-like geodesics; and also, eventual explanatory difficulties arising by making reference to the global structure arise exactly by taking into account some of the phenomena that might be related to the incomplete time-like geodesics. In this way the existence of incomplete time-like geodesics is what makes 'singularities' into a global structure and eventually makes problematic any explanation made by reference to the global structure.

In this work we will be faithful to the spirit of Curiel's proposition but not to the letter. Instead of trying to develop an approach in terms of a mathematical 'topological-like' global structure of a manifold we will take the, for some, 'old-fashion' approach of considering directly the incomplete time-like geodesics in the context of a specific model that is a solution of Einstein's field equations. We think we are still being faithful to Curiel's predicate since it will be a detailed analysis of the physics of incomplete time-like geodesics (i.e. part of the physics of the singular structure) that will enable us to bring into a 'sharp definition' the question “did time have a beginning?” and address it more thoroughly.

3. The curvature blowup and geodesic incompleteness of the singular space-time of the Friedmann model

Let us consider the case of a Friedmann model in which we take galaxies to be represented by 'dust'. The stress-energy tensor of matter in the present epoch is given by the simple expression $T_{ab} = \rho_a u_a u_b$, where we can take ρ to be the observed average density of matter (see, e.g., Geroch 1972, 53-57). This simple matter distribution has the immediate implication that the universe cannot be static: the second derivative of the so-called scale factor $a(\tau)$ of the FLRW metric (or Friedmann equations) is negative, implying that the first derivative is positive or negative but not zero (see, e.g., Wald 1984, 96-98). We can interpret $a(\tau)$ physically as the rate of expansion of the Universe (see, e.g., Geroch 1972, 47-9). If $da(\tau)/d\tau > 0$ the Universe is expanding; in fact observation led us to think that the universe is in this epoch with an accelerated expansion (see, e.g., Schmidt 2012).

From the matter conservation equation it follows that when $t \to 0^+$ the scale factor $a(\tau)$ goes to zero and the density ρ goes to infinity (see, e.g., Ludvigsen 1999, 179). This is not a singularity in the matter field but a singularity in the space-time itself. That is, there is no $t = 0$ point of the space-time manifold. This can already be seen from the fact that the scalar curvature of space goes to infinity as ρ goes to infinity due to the relation between the Ricci tensor and the density (see, e.g., Geroch 1972, 51).

We can further check on the singular nature of space-time by considering the timelike geodesic equations (see, e.g., Fernández-Jambrina and Lazkov 2006). Expanding the scale factor as a series expansion around the (physically inexistent) time value of $t = 0$ conventionally taken to be the 'time' at the (mathematical) singularity, and retaining only the lowest order term we have $a(t) = c_0(t)t^{\eta_0}$, where $c_0 > 0$ and, due to the fact that we are considering an expanding universe, $\eta_0 > 0$ (see, e.g., Cattoën and Visser 2005; Fernández-Jambrina and Lazkov 2006). In this case while we obtain a finite proper time when integrating the equation for time from $t_0 = 0$ to the present epoch, the geodesic is singular at $t_0 = 0$ since $dt/d\tau$ is infinite there. We have an incomplete geodesic and a singularity at $t = 0$ (Fernández-Jambrina and Lazkov 2006). It is important to notice that mathematically $t = 0$ is not a 'point' of the manifold (as we immediately see from the singular nature of the geodesic). When we are determining the integral for the time between 0 and the time at the present epoch, we are in fact calculating an improper integral in which $t = 0$ is not part of the domain of integration.[3]

4. Obtaining the Friedmann solutions and the 'place' of the singularity in them

Modern cosmology is a combination of several physical theories with a particular tradition of observation, and related input from experimentation related to pertinent theories. The hot big bang model is not simply a model of general relativity but of general relativity plus a plethora of other

3 On the mathematical notion of improper integral see, e.g., Mattuck (1999, 290-9), Ross (2013, 331-6).

theories (see, e.g., Narlikar 2010, 275-304; Rugh and Zinkernagel 2009; Zinkernagel 2002). Part of the observational evidence for the hot big bang (in particular the prediction of light element abundances from nucleosynthesis and the cosmic microwave background radiation) are not related to general relativistic models of space-time. The main observation related to these models is the Hubble expansion.

If we look just into Einstein's theory of gravitation we do not have any 'initial' explosion. As Wald called the attention to "the big bang does not represent an explosion of matter concentrated at a point of a preexisting, nonsingular spacetime" (Wald 1984, 99). To see this clearly let us look, e.g., into Geroch's presentation of the Friedmann models (Geroch 1972). As mentioned the Friedmann equations are obtained by solving Einstein's equations by taking into account (explicitly or implicitly) the Robertson-Walker line element corresponding to a homogeneous and isotropic universe and a stress-energy tensor of matter corresponding to the simplifying assumption of a distribution of dust with a uniform density ρ. From this Geroch obtains two equations. According to Geroch the first equation

> has a simple physical interpretation. The da/dt is "the rate of charge with time of the rate of expansion of the Universe" and [the second equation] is also clear physically. It states that "the mass density of the dust decreases at a rate proportional to the rate of expansion of the Universe" – exactly what we would expect from conservation of dust particles. (Geroch 1972, 48)

The 'spatial geometry' of the Friedmann model can be characterized by the Ricci tensor $R_{ac} = h_{ac} [4\pi G\rho - da/dt - 3a^2]$. According to Geroch

> The fundamental quantities in the Friedmann solutions are a (the expansion rate), ρ (the mass density of galaxies), and R ($R^m{}_m$, the scalar curvature of space). These three quantities are not independent of each other, but satisfy a single identity; $R = 16\pi G\rho - ra^2$ … Thus, we may regard a and ρ as the independent quantities, with R expressed in terms of these by [the previous expression]. If, at any point of space-time, the values of a and ρ are given, then the values of a and ρ for all t are thereby determined by [the Friedmann equations]. Thus, these two quantities would have to be measured at the present Epoch of our Universe to determine in which Friedmann solution we live, and in what portion of that solution we are. (Geroch 1972, 51)

As we can see from this procedure to set up the model, we do not start with some sort of 'pre-manifold' with an asymptotically(?) high density from which dynamically emerges the space-time manifold of the Friedmann model. The parameters of the model are fixed by present time observations and one retrogrades backwards in time using the Friedmann equations arriving at an infinite density (see, e.g., Fernández-Jambrina and Lazkov 2010); or the geodesic equation (see, e.g., Fernández-Jambrina and Lazkov 2006) – corresponding to the Friedmann model –, arriving at a finite time but a singularity in the geodesic (implying both that we have an incomplete geodesic).

Importantly one does not reach the mathematical singularity: there is no 'initial' moment! It is correct that the proper time of an 'observer' going contrafactually backwards in time approaching the singularity is finite. However, as we have seen, we are dealing with an improper integral: $t = 0$ is not part of the domain of integration. We might say that as the observer approaches asymptotically the singularity the measured/calculated proper time converges to a finite value; but this convergence does not imply that the observer reaches the singularity. The singularity (thought as a mathematical point, not in the sense of the singular structure) is not part of space-time; it cannot be reached. In this way, there is no *initial* big bang in the FLRW cosmological models of the theory of general relativity, what we have is a 'singularity' in the past when retrograding in time the models.

5. Implications of the singular structure

Since we have a finite proper time associated to the incomplete timelike geodesics 'falling' into the singularity as we move backwards on time, the answer to the question “did time have a beginning?” seems to be yes; However from the previously seen in this paper, that does not seem to be the best way to answer the question. As Curiel expected, the reference to the singular structure of the space-time does enable a sharper definition/characterization of the issue at stake.

The singular space-time implies that the geodesics of possible observers going contrafactually backwards in time are incomplete and their proper times determined by improper integrals converge to finite values. As we have seen, we have no starting moment at the 'singularity'; our starting moment is the present time where we set the parameters of the model. The retrogression of the model does not reach the 'starting point' at the big bang. Under this conditions the use of the word 'beginning' to characterize the situation seems misleading. It might be more appropriate to say that the model implies that time is bounded, i.e. that we cannot consider that the model predicts that time can be meaningfully extended backwards into the past to infinity:

singular Friedmann space-time → bounded cosmic time.

Under these circumstances the received view (see, e.g., Hawking and Ellis 1973, 258) that the singular space-time makes it possible for matter to pop out or into existence without any 'dynamical' explanation does not apply. The general relativistic model does not bear on the issue of the 'beginning' of the universe or time or “what existed before the big bang?” and other similar questions. There is no beginning in the Friedmann space-time due to its singular structure. The most we can do is to analyze the behavior of matter in incomplete worldlines 'moving' contrafactually backwards in time. The model does predicts that an observer will measure a (converging) finite proper time in her/his backward motion along an incomplete geodesic – a geodesic without a final 'initial'-point; however the observer never 'falls' out of the Universe (the space-time manifold). In Einstein's theory of gravitation we have a description of the 'evolution' of the space-time manifold 'intertwined' with matter/electromagnetic fields. Nothing comes or goes out/in of existence.

6. As we go backwards in time towards the singularity

To address a question like “did time have a beginning?” it might be relevant to consider the domain of applicability of general relativity in the context of the backward retrograding towards the mathematical singularity. Basically what we want to know is if there are reasons to consider that the mathematical singularity is somewhat outside the domain of applicability of the theory from a physical point of view, i.e. if as we go backwards in time we reach a 'region' where we cannot consider the theory to be meaningfully applicable. We will consider three ways of addressing the issue:

a) breakdown of general relativity as we approach a time where quantum aspects must be taken into account.

b) limitation of the applicability of the theory when taking into account the input of other theories relevant in contemporary cosmology and the big bang model.

c) limitations of applicability due to the theory itself.

First approach: it is speculated that around the so-called Planck time t_p = sqrt($hG/2\pi c^5$) quantum effects must be taken into account and the classical general relativity cannot be applied 'below' the plank time. It is important to notice that as Rickles (2008) mentions quantum gravity is a 'work in progress'; there is no existing quantum theory of gravity (QTG). The Planck time is 'obtained' by dimensional analysis. It is the only constant obtained from a combination of G, c, and h so that $[t_p] = s$. It is not even clear if a 'full' quantum theory of gravity (QTG) will avoid the singularity. As Wüthrich considers:

> So do quantum effects generically wash out the initial singularity? There exists a plethora of further examples and counterexamples in the literature. This wealth of possibilities makes it impossible to draw any general conclusion. While some of the results discussed in this section can be taken as indication that quantum effects may generically smooth out classical singularities, at the bare minimum they induce the hope that a full QTG will be free of the singularities that so persistently plague the classical theory of general relativity. (Wüthrich 2006, 113)

Due to this state of affairs in QTG or other speculative high energy physical theories we will not consider this option to impose a limitation in the domain of applicability of general relativity that would exclude somehow the space-time singularity of the Friedmann model.

Second approach: according to Rugh and Zingernagel (2009) the interpretation of the manifold parameter as a physical time needs the existence of physical processes in space-time that can function as, what they call, core clocks. The authors' analysis of physical processes that are supposed to occur in the different epochs of the big bang model leads them to suggests that

> the necessary physical requirements for setting up a comoving coordinate system (the reference frame) for the FLRW model, and for making the t ←→ time interpretation, are no longer satisfied above the electroweak phase transition – unless speculative new physics is invoked. (Rugh and Zinkernagel 2009, 40)

One way of reading this suggestion is to say that around the time 10^{-11} of the electroweak transition we reach the limit of applicability of the theory. After all below 10^{-11} the mathematical time of the FLRW models would not be a physical time.[4] Nevertheless regarding the question "did time have a beginning?" in the context of the big bang model, Zinkernagel, while considering that "there are thus good reasons to doubt that the t ←→ time interpretation can be made all the way back to t = 0" (Zinkernagel 2008, 16), still affirms that "if the big bang model is a roughly correct description of our universe at large scales – the current best answer we have to the question of whether time had a beginning is affirmative" (Zinkernagel 2008, 19). It seems difficult to make compatible this conclusion with the view that 'below' 10^{-11} seconds we do not have a well defined conception of time. At least it seems necessary to make more precise what 'beginning' might mean in this context.

For the purpose of this work we just want to call the attention to the fact that these views are made by considering the cosmological model as a whole including different physical theories like the electroweak theory, quantum chromodynamics, nuclear physics, statistical mechanics, and others. The purpose of this work is to address the issue solely from general relativity. In this way we will not consider (eventual) 'external' limitations to the domain of applicability of general relativity.

4 Another related reading of Rugh and Zingernagel (2009) might be that it shows the inconsistency (at least at a conceptual level) of the 'package' of theories of cosmology below the time 10^{-11}. Due to the electroweak (Higgs) transition, at times earlier than ~ 10^{-11} seconds we cannot make the t ←→ time interpretation anymore. This can be read as implying that the time concept becomes 'insufficiently founded'; this then implies that quantum fields do not have a space-time 'background structure' necessary for their definition and application, i.e. there is a 'logical' breakdown in arguments using cosmology as a whole below 10^{-11}: we are considering a quantum field theory applicable below 10^{-11} to conclude that general relativity cannot be applied and thus that the quantum field theories we started with could not have been applied. This seems to imply that the 'package' of theories of cosmology is inconsistent for times below 10^{-11}.

Third approach: according to Brown (2005) we need the so-called clock hypothesis[5] to identify the parameter along a timelike worldline with proper time as the time gone by the material system in the worldline. We could expect that 'near' the singularity there could be no classical mechanical systems that could still behave as a clock. In this way we would loose any physical meaning of the parameter in terms of a time. We will not consider this possibility in this work on account of two things. One: even in a flat part of space-time we can imagine, e.g., a strong electromagnetic field that disturbs any mechanical physical system preventing it from functioning as a clock. If this is the case and we consider there to be a problem in identifying the proper time parameter as a time this would be an important foundational problem that goes well beyond the issue of singularities. It seems difficult to accept the view that we need a model of a mechanical clock to maintain an interpretation of proper time parameter as a time. In this case, an accelerated (classical) material particle might not have any time ascribed to it, only, possibly(?), indirectly through the coordinate time. While there is no prove to the contrary we will consider general relativity as innocent of such a drastic problem.[6] Second: there are alternatives to Brown's views. For example Arthur (2010) considers that the invariant Minkowski proper time is a physical magnitude implicitly defining an ideal clock. The clock hypothesis would be only a criterion to check when we might expect a particular physical system to behave (or not) as an ideal clock. In this view we can maintain an interpretation of proper time as a time all along a timelike worldline, independently that the worldline is complete or incomplete. This is the view adopted in this work.

7. Conclusions

In this paper we have tried to give an example where we apply Curiel's insight that there are questions related to the big bang model that "can come from their former nebulosity into sharper definition, for they become questions about the presence of certain global structure in the spacetime manifold, [(the singular structure)]" (Curiel 2009, 142).

The issue of "did time have a beginning?" is addressed by explicitly taking into account the singular structure of the space-time. We think this approach improves on Zinkernagel's, not only by answering the question by relying just on general relativity,[7] but, more importantly, by bringing into a sharper definition the physical situation that we have with Friedmann's singular space-time:

5 According to Brown, the clock hypothesis is "the claim that when a clock is accelerated, the effect of motion on the rate of the clock is no more than that associated with its instantaneous velocity – the acceleration adds nothing" (Brown 2005, 9). In Brown's view this is the case when "the external forces accelerating the clock are small in relation to the internal 'restoring' forces at work inside the clock" (Brown 2005, 115).

6 It might be possible to re-frame the issue of the clock hypothesis, specifically the breakdown of the identification of Minkowski's proper time parameter with a physical time, in terms of Rugh and Zinkernagel's time-clock relation and the consequences of its breakdown (Rugh and Zinkernagel 2009, 5). This might enable to consider this eventual foundational issue from the perspective of Rugh and Zinkernagel's approach. We will not address this possibility here.

7 From a methodological point of view we think it is a better option to consider the issue of the beginning of time first from general relativity and only after from cosmology, which is not done in Zinkernagel (2008). In the context of general relativity we arrive at a view of a bounded time: we cannot contrafactually go indefinitely into the past but there is no meaningful notion of $t = 0$ even if the proper time of a backwardly moving observer is finite. In this way the use of the term 'beginning' might be misleading or even inapplicable in this context. If we now take into account Rugh and Zingernagel (2009) 'result' that around the time 10^{-11} we might not have any meaningful concept of time (which we might interpret as having reached the 'limit' of the domain of applicability of general relativity in the context of cosmology), we might even consider that, in a cosmological context, the idea of a 'bounded cosmic time' does not provide a correct assessment of the situation. We cannot move backwards in time along an incomplete time-like geodesic below the electroweak phase transition around 10^{-11} since we loose a meaningful notion of time associated with the parameter of the curve. We cannot resort anymore to the idea that we still have a finite proper time even if $t = 0$ is not reached; it does not seem feasible in this situation to identify an improper integral between 0^+ and the present epoch with a physical proper time. In a cosmological context the argument for a bounded cosmic time seems to breakdown. In fact it might be the case that in the context of present day cosmology the question "did time have a beginning?" is not a well-posed one.

- there's no initial singular point.
- the geodesic of an observer moving backwards in time is incomplete – implying that it does not reach an 'initial' point in space-time.
- the finite proper time of a backwardly moving observer does not imply a beginning of time. The improper integral converges to a finite value as $t \rightarrow 0^+$ but the 'initial moment' is not reached.
- the cosmic time of the universe is bounded, but there is no meaningful notion of 'beginning' in the general relativistic model.

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