Comment to the CPT-symmetic Universe: Two possible extensions

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In [1, 2] the antispacetime Universe was suggested as the analytic continuation of our Universe across the Big Bang singularity in conformal time. We consider two different scenarios of analytic continuation. In one of them the analytic continuation is extended to the temperature of the system. This extension suggests that if such analytic continuation is valid, then it is possible that the initial stage of the evolution of the Universe on our side of the Big Bang was characterized by the negative temperature. In the second scenario, the analytic continuation is considered in the proper time. In this scenario the Big Bang represents the bifurcation point at which the Z_2 symmetry between the spacetime and antispacetime is spontaneously broken.

The extension of the Universe beyond the Big Bang using the analytic continuation across the singularity has been considered for the radiation-dominated epoch [1, 2]. In this analytic continuation, at which the scale factor $a(\tau)$ changes sign at $\tau = 0$, the gravitational tetrads also change sign giving rise to what is called the antispacetime. This means that the Universe on the other side of the Big Bang is the mirror image of the Universe on our side of the Big Bang.

Different types of the antispacetime obtained by the space reversal P and time reversal T operations were considered ealier, including those where the determinant of the tetrads e changes sign [3–9]. Later the consideration has been extended to thermal states, where possible analytic continuation of the temperature across the transition from spacetime to antispacetime has been considered [10]. Here we discuss two scenarios of analytic contunuation across the Big Bang.

The CPT-symmetric Universe has been obtained in the conformal time frame [1], where the metric in the spatially flat radiation-dominated era is:

$$g_{\mu\nu} = a^2(\tau)\eta_{\mu\nu}, \tag{1}$$

where $\eta_{\mu\nu}$ is the flat Minkowski metric; $a(\tau)$ is the scale factor and τ is the conformal time. Since the scale factor $a(\tau) \propto \tau$, it was suggested that it can be analytically transformed to the region $\tau < 0$ before the Big Bang. Then the terad fields, which are proporional to $a(\tau)$, also change sign under this analytic continuation, $e_\mu^a(-\tau) = -e_\mu^a(\tau)$.

Now let us go further and extend the analytical continuation to the temperature of the system. In the spatially flat radiation-dominated era one has

$$T(\tau) \propto \frac{1}{N(\tau)} = \frac{1}{e_{00}(\tau)}, \quad \text{or} \quad \beta(\tau) \propto \tau. \tag{2}$$

The analytic continuation of $\beta(\tau)$ suggests that in the Universe at $\tau < 0$ the temperature is negative. The transition between the states with positive and negative temperatures occurs via the infinite T at $\tau = 0$ ($\beta(0) = 0$). The states with negative temperature are unstable thermodynamically. This means that if the analytic continuation is really valid, then one of the two states (before or after Big Bang) is thermodynamically unstable. It is more natural to assume, that the evolution of the system from $\tau = -\infty$ to $\tau = 0$ was equilibrium and corresponded to the positive temperature, $T(\tau < 0) > 0$. This is because the system had enough time to equilibrate before the collapse. So we should have the following analytic time dependence of temperature:

$$T(\tau) \propto -\frac{1}{e_{00}(\tau)}, \quad \text{or} \quad \beta(\tau) \propto -\tau, \tag{3}$$

and thus on our side of the Big Bang the temperature is negative, $T(\tau > 0) < 0$. Of course, this may happen

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only at the first stage of the evolution of our Universe, i.e. immediately after the Big Bang. After some time the equilibration occurs, and the system returns again to the evolution with the equilibrium positive temperature, $T(\tau > 0) > 0$. The proper justification of this suggestion is beyond this comment.

Let us consider the analytic continuation in terms of the physical proper time t. The metric for the radiation-dominated Universe is:

$$g_{\mu\nu} = dt^2 - a^2(t)d\mathbf{r}^2, \quad a^2(t) \propto t. \quad (4)$$

Let us now assume that the scale factor $a(t) \sim \sqrt{t}$ can be analytically extended around the singularity at $t = 0$. Then the spacetime (with positive spatial components of tetrads) and antispacetime (with negative spatial components of tetrads) can be connected by analytic continuation: by 2π rotation about $t = 0$. As distinct from scenario in [1], where the two Universes live together, in the proper time scenario the spacetime and antispacetime represent two different realizations of the Universe at $t > 0$, which exclude each other.

The Universe at $t > 0$ can be obtained by analytic continuation from the negative t region, where the metric has Euclidean signature. In this scenario, the Big Bang (at $t = 0$) represents the point of the phase transition from the Euclidean to Minkowski signature, which is similar to that, say, in [11–14] (an example of such transition in condensed matter can be found, e.g., in [15]). At the Big Bang, the state with Euclidean signature transforms either to the spacetime or to antispacetime (see Fig. 1), but not to the quantum superposition
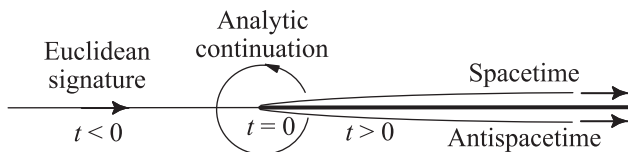

Fig. 1. Bifurcation at Big Bang. Analytic continuation in physical proper time t: the scale factor $a(t) \propto \sqrt{t}$ changes sign around the Big Bang point, transforming spacetime into antispacetime. At $t < 0$ the scale factor is imaginary, which corresponds to the metric with Euclidean signature. Crossing the Big Bang from the $t < 0$ semiaxis, the Universe approaches either spacetime or antispacetime. In this scenario, the Big Bang represents the bifurcation point at which the Z_2 symmetry between the spacetime and antispacetime is spontaneously broken. The quantum superposition of the two states is not allowed in the macroscopic system

of the two Universes. The latter is not allowed for the macroscopic systems, which experience the spontaneous symmetry breaking [16]. In principle, immediately after

the Big Bang the Universe may evolve as the quantum superposition of these two states, but due to rapid decoherence only one of the two states survives. Thus in this analytic continuation the Z_2 (CPT) symmetry is spontaneously broken, as distinct from the scenario in [1] describing creation of two Universes both evolving to the future with the conservation of the CPT symmetry.

In conclusion, we extended the analytic continuation across the Big Bang proposed in [1] in two different ways. The analytic continuation in the conformal time frame τ was extended to the temperature of the system. This extension suggests that if the analytic continuation of the terad is valid, then it is possible that the initial stage of the evolution of our Universe after the Big Bang was characterized by the negative temperature. The analytic continuation in the proper time t suggests that the Big Bang is the bifurcation point of the second order quantum transition from the Euclidean to Minkowski signature, where symmetry between spacetime and antispacetime is spontaneously broken.

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