Entropy and an irreversible deterministic time-evolution coexist

Leonardo Pedro

May 15, 2023

Abstract

We show that a unitary quantum time-evolution defines the random sampling of an irreversible deterministic time-evolution. The coexistence of time-symmetric laws of physics and an arrow of time, is due to unitarity and not entropy. We also study the baryon asymmetry.

1. Introduction

The baryon asymmetry is often described as an observation that cannot be explained by the current laws of Physics. CP symmetry would imply baryon symmetry and despite that the Standard Model of Particle Physics is CP asymmetric, its small amount of CP asymmetry seems to clash with the small amount of anti-matter existing in the Universe.

Note that the quantum Hamiltonian of the Standard Model of Particle Physics has time reversal symmetry, in the sense that it has CPT reversal symmetry. The above reasoning is an obstacle to the main result our article, that the Standard Model in fact predicts an irreversible time-evolution, and would do so even if it would be CP symmetric. We conclude that the coexistence of time-symmetric laws of physics and an arrow of time, is due to unitarity and not entropy. In this article we will also show that the above reasoning is flawed, and that the baryon asymmetry problem can be merely an inconsistency of the existing cosmology models (with the present data, for instance it would be solved by a different age of the Universe) and it does not rise to the level of contradicting the predictions of the Standard Model of Particle Physics.

Note that the Cosmology models can and should be used to test the predictions of the Standard Model of Particle Physics as much as possible, since many alternatives to the Standard Model of Particle Physics make different predictions at sufficiently high-energy (as high as the energies in the beginning of time). But there is a huge uncertainty when we study what happened in the beginning of time itself using the present experimental data. Moreover, Quantum Gravity certainly plays a role in Cosmology, but no one knows exactly what role because Quantum Gravity is still very far from being a predictive theory, unfortunately it cannot yet be used to test the Standard Model of Particle Physics.

On the other hand, the conclusion that the Standard Model of Particle Physics predicts that the time-evolution is irreversible and deterministic is a solid conclusion, since all existing alternatives to the Standard Model make the same prediction (as far as we know). Note that as in any Quantum theory, there is random sampling, so it does not predict everything about the time-evolution.

Irreversible deterministic time-evolution

In a non-deterministic quantum time-evolution, the deterministic time-evolution is necessarily determined only after a random sampling. Consider the joint probability of an initial state and a final state after a time-evolution transformation. There is no uniform countable measure. Thus, the rationals are not enough for Probability Theory or Physics. A mixed standard probability space (which has countable and continuous measures) is unavoidable.

In the part of the probability space with a continuous measure, the step functions are dense in the Hilbert space. Thus, there is a part of the joint sample space which has a uniform probability measure up to an error as small as we want.

We rescale the square to $[0,1] \times [0,1]$. If we partition the square in n^2 smaller equal sized squares, then the probability of an invertible discrete function (whose domain and image is the index of an interval in the partition) is $\frac{n!}{n^n} \sim \sqrt{2\pi n}\ e^{-n}$ (as n goes to infinity, the ratio between the left and right sides approaches one in the limit). Thus it converges to 0 when $n \to +\infty$.

Moreover, the function almost surely maps sets of non-null measure into sets of non-null measure (that is, it is non-singular meaning it is injective), otherwise the random sampling would not follow a continuous probability measure. This follows from the fact that the conditional probability (conditioned on any set with non-null continuous measure) is always a continuous probability measure.

Thus, a function sampled randomly is almost surely a non-singular dissipative time-evolution (that is, non-singular dissipative dynamical system), in agreement with the uniform measure in the square $[0,1] \times [0,1]$.

A process with a dissipative time-evolution is irreversible: the deterministic time-evolution is not an invertible function (it is injective but not surjective). Then there is time asymmetry.

Baryon asymmetry

The quantum Hamiltonian of the Standard Model is not CP symmetric. Thus, given an initial state which is CP even, time-evolution may produce a state which breaks the CP symmetry. The problem lies in how much CP asymmetric is this final state.

One relevant ingredient is the fact that a small CP asymmetry at the level of the probabilities, can lead to a not so small measured CP asymmetry, because it is a random experiment. However, the bigger the difference between the two, the less likely it is. Note that Experimental Physics is based on probabilities, a ratio 0.1% is already considered evidence that something is not right. But the evolution of the Universe is not an experiment we can repeat, so this blurs the problem.

But the most relevant ingredient is that the expansion of the Universe increases the ratio of the energies in the matter vs. radiation contents, proportional to the scale of the Universe. So, in fact the CP asymmetry generated by Particle Physics was very small, but it was much amplified by the expansion of the Universe. But according to Cosmology, the age of the Universe would need to be significantly bigger for the CP asymmetry generated by the Standard Model of Particle Physics to be big enough.

Therefore, there is one more inconsistency in a Cosmology model, which can only convincingly explain 5% of the energy content of the Universe (the remaining being dark energy and dark matter). Moreover, Quantum Gravity (which it is not yet predictive) affects the age of the Universe.

From the point of view of Particle Physics, there is always room for surprises in high-energy processes. However, there does not seem to be a convincing contradiction between the predictions of the Standard Model of Particle Physics and the experimental observations: it predicts a very small CP asymmetry and the observation is consistent with a very small CP asymmetry which was amplified by the expansion of the Universe. There is still a mismatch, which can be due to the model of the expansion of the Universe, or due to Particle Physics (or both).