Acausal Processes and Astrophysics: Case When Uncertainty is Non-Statistical (Fuzzy?)

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Abstract

In Newtonian physics, if we know the state of the world at some moment of time, then we can precisely predict the state of the world at all future times. In this sense, Newtonian physics is *deterministic*. In modern physics (starting with quantum mechanics), theories are usually *non-deterministic* in the sense that even if we know exactly the initial state of the world, we cannot uniquely predict the future state of the world. In quantum mechanics (and in most modern quantum-based physical theories), the best we can get is *probabilities* of different future states. In this sense, in the majority of modern physical theories, uncertainty is of statistical nature.

Lately, a new area of *acausal* (causality violating) processes has entered mainstream physics. This area has important astrophysical applications. In this paper, we show that acausal processes lead to *non-statistical* uncertainty.

The main purpose of this paper is to inform specialists in uncertainty representation about this situation, with a hope that formalisms for describing non-statistical uncertainty that have been developed to represent uncertainty of human knowledge (such as fuzzy logic) will help in formalizing physical non-statistical uncertainty as well.

1 Introduction

The main goal of this paper is to inform the specialists in physics and in uncertainty representation that they have one common problem in which their collaboration may be very fruitful: representation of non-statistical uncertainty that emerges in the analysis of acausal processes and their astrophysical applications.

Acausal processes and their astrophysical applications are hardly known to specialists in uncertainty and even to the majority of physicists. In view of that, we will describe the main ideas of acausal processes and their astrophysical applications in detail.

Before we describe them, let us briefly recall the history of uncertainty in physics.

1.1 Newtonian Physics was Deterministic

In Newtonian physics, if we know the state of the world at some moment of time, then we can precisely predict the state of the world at all future times. In this sense, Newtonian physics is *deterministic*.

1.2 In Modern Physics, There is Statistical Uncertainty

In modern physics (starting with quantum mechanics; see, e.g., [4])), theories are usually ***non-deterministic*** in the sense that even if we know exactly the initial state of the world, we cannot uniquely predict the future state of the world. In quantum mechanics (and in most modern quantum-based physical theories), the best we can get is ***probabilities*** of different future states. In this sense, in the majority of modern physical theories, uncertainty is of statistical nature.

1.3 New (Acausal) Processes Lead to Non-Statistical Uncertainty

Lately, a new area of ***acausal*** (causality violating) processes has entered mainstream physics. This area has important astrophysical applications.

In this paper, we show that acausal processes lead to ***non-statistical*** uncertainty. This non-statistical nature of uncertainty is a new result that has never been published before.

2 Acausal Processes

2.1 What Are Acausal Processes

Traditional physics is *causal* in the sense that future events are determined by the past state of the Universe. This dependence can be deterministic (as in classical, pre-quantum physics), or stochastic (as in quantum physics).

There have been for some time an idea of the possibility of *acausal* processes, in which the influence can go in the opposite direction: future can influence the past. Such processes are called *acausal*.

2.2 Acausal Processes Lead to Paradoxes

The idea of acausal processes was, for a long time, mainly part of science fiction, because this idea is paradoxical. The most well known *father* paradox is most convincingly described in terms of the actual *time travel* (travel to the past):

The time traveler paradox occurs when a time traveler goes to the past and shoots his own father to death before he himself was conceived. Then:

- On one hand, the time traveler *is* still *alive*, because he was alive before the killing, and he did not harm himself in any way.
- On the other hand, since his father has died, he could not have conceived the time traveler, and hence, the time traveler cannot be born. So, he is at the same time ***not alive***.

A similar paradox occurs if we cannot actually *travel* to the past, only *influence* it; also, it occurs even if we have no human beings at all, simply physical processes. The reason why we (and other authors) present this paradox in its time-traveler form rather that in the form of differential equations of physics is that when we have a problem with differential equations, there can be many reasons for that (wrong equations, wrong method of solution, etc.), while the *time-traveler* paradox reveals the paradoxical character of acausal processes themselves.

2.3 A Brief History of Acausal Processes in Physics

The idea that the speed of all particles cannot exceed the speed of light (and that, therefore, it is impossible to influence the past) was one of the main ideas of Einstein's Special Relativity Theory.

In quantum mechanics, due to its probabilistic character, many deterministic restrictions of pre-quantum physics become somewhat "blurred" in the sense that they are no longer prohibiting some events completely, but simply telling that these formerly prohibited events have small probability. For example, in classical physics, a particle cannot penetrate the potential barrier if the energy of this barrier exceeds the initial energy of the particle; in quantum physics, however, it is quite possible (although not highly probable) that a particle "tunnels" through this barrier and end up on the other side of it. This is not simply a theoretical conclusion, this "tunnel effect" is the basis of "tunnel diods" that are extensive used in nowadays electronics.

Uncovered possibility that quantum mechanics can make pre-quantum restrictions "soft" lead to a possibility that causality may also be violated in quantum processes. Such violations were first discovered by Einstein, Podolsky, and Rosen in their famous paradox (physicists call it EPR paradox for the first letters of the authors' names; for details, see [26]). Einstein, who was not a great fan of quantum mechanics, proposed this paradox as a way of disproving this theory. (It is worth noticing at this point that all experiments so far seem to confirm quantum mechanics.)

EPR paradox does not lead to a real time travel: it simply shows that in the resulting quantum formalism, the future state influences the past one; however, all attempts to extract a real time travel from it turned out to be futile because, crudely speaking, the resulting influence on the past is so small that, when we try to measure it, it "drowns" in the inevitable quantum uncertainty of measurements.

This fact does not mean that causality is true in quantum physics. In the last decade, several more sophisticated schemes have been proposed that, in principle, can lead to the actual time travel [27, 28, 29].

In addition to *physical* arguments in favor of possible causality violations, there exist *biological* motivations for such processes: Rosen [21] suggests that the living beings can use physical processes that influence the current events depending on the future ones (he calls such acausal processes *anticipatory*; see also [20, 22, 23, 24]).

Until 1988, these processes has been mainly considered as one the many possibilities, not the most probable possibility, and not part of the mainstream physics. In 1988, the situation radically changed.

2.4 Acausal Processes Become Mainstream Physics

Physicists' attitude to acausal processes changed when Kip S. Thorne, the world's leading astrophysicist, published several papers in the leading physical journal *Physical Reviews* in which he showed that within the existing quantum physics and cosmology, acausal processes are highly probable; these publications lead to several other serious research results [13, 14, 16, 5, 18, 25, 17, 1]. As a result of this research, three basic types of acausal processes have been discovered; these processes are summarizes in Thorne's recent monograph [26] (for more popular expositions, see, e.g., [10, 2, 9, 3, 19, 30, 15]).

2.5 How Are Paradoxes of Acausal Processes Resolved Now?

For clarity of exposition, we will describe the current solution of the paradoxes of acausality on the same time-traveler example as we described the paradox itself. Of course, similar to the fact that the paradox occurs even when there is no time traveler at all, the described solution is also applicable to the case of purely physical acausal processes.

This solution is described in [8, 7, 11, 12].

Since the time traveler is alive at the time when he starts the shooting, this means that he was conceived after all, and therefore, that his attempt to kill his father has failed. Why could it have failed? Well, the gun may have malfunctioned, or he might have missed, or a brick (or a meteorite) might have fallen on the time traveler's head at the very moment when he was ready to shoot, or a policeman of the past has stopped him, etc.

Some of these possibilities are quite realistic, some (like a meteorite) have an extremely low probability. The time traveler can prepare for some of these possibilities: he can check his gun before going to the past, use automatic weapons, wear a hard hat against falling bricks, a fake police uniform to prevent an interference of the past's police, etc. In principle, whatever possibility we describe, the time traveler can take care of it. However, he cannot take care of them all: for example, in principle, the gun can malfunction simply due to some unexpected (but probable) random Brownian motion of its molecules.

If the time traveler takes care of all possibilities with reasonable (sufficiently high) probability, this still leaves other possibilities, with extremely low probability, that normally do not occur, but that would have to occur because otherwise, we would have a paradox.

Summarizing: *if an acausal process is possible, then some events will take place, whose probability is normally extremely low to prevent this acausal influence from happening.* This conclusion is true not only for a time traveler, but for an arbitrary acausal process.

3 Possible Applications of Acausal Processes to Mainstream Astrophysics

3.1 A General Idea of These Applications

As we have mentioned, acausal processes lead to highly unprobable events. According to statistical physics, if Nature has a choice, it would rather prefer situations where these highly unprobable events do not occur. Therefore, if there is a random (statistical physics-type) process that can either lead to an acausal process or not, then, the *actual* probability of this process resulting in acausality is very low, *much lower* that it would have been if we did not take the possibility of acausal processes into consideration (practically, thermodynamically impossible).

In this paper, we only show this idea on two main possible applications, whose description enables us to avoid technical details; other applications are also possible (see, e.g., [8]).

3.2 The Isotropization of the Universe

One of the main problems of modern cosmology (see, e.g., [26]) is that the Universe is too isotropic. On large scale, in all directions in which we look, we see the same statistical distribution of matter. The initial state of the Universe was, according to the modern physical viewpoint, *random*, and therefore, far from being isotropic. Hence, the observable isotropization is due to some physical processes. Many physical processes shuffle matter around and thus, contribute to the isotropization, but calculations show that during the lifetime of our Universe, these processes are not sufficient to explain the current isotropy; to be more precise, for *random* initial conditions, the probability of the initial conditions that lead to the observed isotropy is very low.

The explanation of this phenomenon in acausal physics is as follows: Anisotropy means that different distant areas of the Universe will have radically different matter densities. For acausal processes, there is no speed restriction; therefore, since there is an excess of matter in one area and abundance in another area, acausal processes will re-shuffle the matter from the dense area to the area where matter is scarce. Such a process is, as we have mentioned, thermodynamically unprobable and therefore, it is much more possible that the random initial conditions are chosen in such a way that prevents these acausal re-shufflings, i.e., that the initial conditions lead to the observable isotropic Universe.

What this explanation does is shows that the probability of an initial state of the Universe leading to isotropization, the probability that is small if we do not take acausal processes into consideration, becomes much larger if we consider the possibility of acausal processes.

3.3 Separation of Particles and Anti-particles in the Early Universe

Equations of physics do not show any preference to particles (electron e^-, proton p, neutron n, etc.) or to their anti-particles (positron e^+, anti-proton $\tilde{p}$, anti-neutron $\tilde{n}$, etc.). So, if the initial condition is truly random, we would expect to see approximately as many particle as anti-particles. However, in the observed Universe, there are mainly particles, anti-particles are rare. Why?

The probability that a random initial condition leads to such a dis-balance is extremely small.

Acausal physics explains this visible asymmetry as follows. The exact formulation of the particle-anti-particle symmetry is made by the so-called *CPT theorem*, according to which physical equations remain invariant if we apply three transformations:

C: replacing particles with anti-particles and vice versa;

P: *parity* transformation: replacing coordinates $\vec{r}$ by $-\vec{r}$;

T: *time reversal*: $t \to -t$.

As a result, when we turn to anti-particles, in order to make the equations work, we need to change the orientation of time: when in normal particles, past events determine the future one, in the anti-particles, vice versa, future events influence the past ones.

Comment. This idea that, e.g., positron can be considered as an analogue of an electron that is going *back* in time was actively promoted by R. Feynman and was part of the motivating ideas behind *Feynman diagrams*, one of the major tools of modern theoretical physics (see, e.g., [4].

According to our general idea, if we take into consideration that the presence of anti-particles leads to acausal processes, the probability of *not* having anti-particles in a random initial state increases and thus, becomes quite reasonable.

4 Acausal Processes Lead to Non-Statistical Uncertainty

4.1 Uncertainty in Acausal Processes is Non-Statistical

So far, we have talked in terms of probabilities. At first glance, it may seem that the solution to the paradox (described above) is inside the statistical paradigm. Alas, we will see in a moment that the proposed solution is *not* exactly statistical.

Indeed, according to this solution, the "father"-type paradox is resolved by saying that in actuality, to avoid inconsistency, nature would choose some highly unprobable events to happen. If this paradox-causing situation happens repeatedly, the actual *frequencies* of these "highly unprobable" events will be much higher (closer to 1) than their "probabilities" (which are closer to 0).

Hence, in the presence of acausal processes, the "probabilities" computed by physical equations are *not* real *objective* probabilities (= frequencies) as in standard (mainstream) interpretations of statistical and quantum physics. In other words, in the presence of acausal processes, *uncertainty is non-statistical.*

4.2 Other Uncertainty Formalisms (Such as Fuzzy Logic) May Help

The main purpose of this paper is to inform specialists in physics and in uncertainty representation that there is an area of physics in which uncertainty is non-statistical.

We hope that formalisms for describing non-statistical uncertainty that have been developed to represent uncertainty of human knowledge (such as fuzzy logic [31, 6]) will help in formalizing physical non-statistical uncertainty as well.

4.3 In Particular, Fuzzy Logic May Be Helpful

4.3.1 Non-Frequency Probabilities are "Subjective Probabilities", Probably Describable by Fuzzy Logic

Formulas of traditional probability theory describes two types of probabilities:

- So-called *objective* probabilities. An objective probability of an event happening in a certain situation can be understood as a limit frequency of this event happening in a sequence of similar situations. For example, when we say that a coin has a probability 1/2 to fall heads, we mean that if we toss a coin sufficiently many time, then in approximately half of the cases, we will see heads, and as the number of experiments increases, the frequency of a head will tend to 0.5.
- So-called *subjective* probabilities (also known as *degrees of belief* or *degrees of confidence*) that do not describe any real frequencies, but describe the expert's degree of belief. For example, the subjective probability that a

certain student will get an A on a certain test is 80%. This student may be quite unusual, and there is no statistics possible about such students, so we cannot come up with any reasonable frequency or *objective* probability. However, we can describe a *subjective* probability, be it in terms of odds for betting or in some other way.

These "subjective probabilities" (degrees of belief) are, to a large extent, what fuzzy logic was designed to describe.

4.3.2 Which Version of Fuzzy Logic Should We Choose

"Fuzzy logic" is a generic term that includes several different possible pairs of &– and ∨–operations (see, e.g., [6]). Which pair should we choose?

Among these pairs, there is one pair that is the closest to normal logic in the sense that for this pair (and only for this pair), in accordance with our intuition, $A\&A$ is equivalent to A, and $A \vee A$ is equivalent to A: this pair consists of the operations $a\&b = \min(a, b)$ and $a \vee b = \max(a, b)$ originally proposed by Zadeh [31]. Since our only reason for using fuzzy logic (as opposed to classical two-valued one) is that we wanted to describe a paradox, and we have no reason to doubt the equivalence of $A\&A$ and A, we will therefore, try to use this pair $(\min, \max)$ in our description.

4.3.3 Fuzzy Logic Seems to Actually Help

Let us now show how this choice will affect the description of *very unprobable events* that are, according to the modern physical description, inevitable in the presence of acausal processes.

An event is usually highly unprobable if it is a combination of many sub-events that are, by themselves, quite possible: for example, it is quite possible that one gas molecule will go in a certain direction, but in order for the gun to malfunction due to a Brownian motion, *many* molecules must simultaneously go in the same (unintended) direction.

- In a *probabilistic* description, the probability p of such a rare combination of independent events is equal to the *product* $p_1 \cdot \ldots \cdot p_n$ of the probabilities $p_1, \ldots, p_n$ of these events. The probabilities p_i themselves are not so low, but when their number n is great, the resulting probability p becomes extremely small.

- In a *fuzzy* description, when we interpret the values p_i as degrees of belief, and use min as an & operation, the resulting degree of belief that all sub-events occur is equal to $p = \min(p_1, \ldots, p_n)$; in other words, this degree of belief is equal to the degree of belief of the *least* probable of the component sub-events. Since each sub-event (in particular, this *least probable* one) is considered to be quite probable, we can conclude that the entire combination of these sub-events is quite probable. Therefore, if acausal processes lead to fuzzy logic, then we get a reasonable degree of belief for these "highly unprobable" events, in good accordance with the physical conclusions that in the presence of acausal processes, such "highly unprobable" events actually occur.

This example makes us hope that in general, fuzzy logic will be helpful in the above-mentioned astrophysical applications of acausal physics.

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