TIME TRAVEL?!

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SUMMARY

The *Large Hadron Collider* (LHC) has been successfully switched on recently. According to a pair of noted Russian mathematicians — Irina *Aref'eva* and Igor *Volovich* — it might turn out to be the Earth's first time machine [1]. If the two experts are correct, the LHC debut at CERN could yield a landmark in history.

To systematically review the state of our knowledge on time travel is therefore highly actual. In the following, we'll discuss the pros and cons of time travel, including its history, conditions and inferences.

INTRODUCTION

The origins of time travel can be found within legends and fairytales. The first depiction of time-travel may have been in the Sanskrit-Indian classic *Mahābhārata*, written roughly 2,400 to 2,800 years ago, in which a character journeys to heaven and then returns to Earth, only to discover he has jumped ahead centuries into the future.

An illustrative selection in the literature of modern times (no overall consensus of who wrote the first time travel story):

- Samuel Madden: Memoirs of the 20th Century (1733),
- Lewis Caroll: Alice in Wonderland (1865),
- Mark Twain: A Connecticut Yankee in King Arthur's Court (1889),
- H. G. Wells: The Time Machine (1895).

The „golden medal" belongs to Wells for writing a novel entirely focused on intentional time travel — accomplished not by gods, demons or wizards, but by science and a human being.

TIME TRAVEL IN CLASSICAL PHYSICS

Do the laws of physics allow time travel? Well, we all travel in time at 60 seconds per minute and according to *Newtonian physics* the time is flowing uniformly at a constant rate everywhere at all times and under any conditions in the whole universe.

As the propagation velocity of light is 300 000 km/s, we see a 1 km distant tower as it was 1/300 00 seconds ago, we see light that left the sun some eight minutes ago, a 1 light-year distant star as it beamed one year ago, a 1 billion light-year far-away galaxy as it existed one billion years ago. Extra individual time travel is not possible.

But Albert *Einstein's Special* (1905) and *General* (1915) *Theory of Relativity* changed the Newtonian picture radically. According to the former one if we travel at velocity v, then our proper time (T) passes for us at a slower rate relative to the time (t) of a stationary observer. This effect is known as *time dilation*, and the numerical relationship is given by:

$$T = t/(1- v^2/c^2)^{½} \qquad (1)$$

COSMIC TIME TRAVEL

In special relativity, time dilation is most simply described in circumstances where relative velocity is unchanging (see equation 1). Nevertheless, the Lorentz equations allow one to calculate proper time and movement in space for the case of a spaceship whose acceleration — relative to some stationary object — is uniform throughout the period of measurement.

In our cosmic round-trip (figure 1), we will travel in a spaceship to a distant destination and back with constant 2g acceleration. We accelerate towards our destination over the first-half of the distance, and decelerate over the second one, so that our spaceship reaches its highest speed half-way between the ends and is at rest at our destination. The spaceship will then make the return trip to Earth in the same way. At the end of the trip, we compare the clock carried by the spacecraft to a clock left at Earth. What we find is that substantially more time has passed for Earth than for the travelers on our spacecraft (see figure 2).

The equation for the time at Earth (t) versus the time in the spaceship for a round trip is given by

$$t= 4\ c\ \sinh(aT/4c)/a \qquad (2)$$

where *c* is the speed of light, *a* is the acceleration (in our case 2g), and *T* is the proper time of the spacecraft. The time dilation — as a function of T — is illustrated on figure 2.

We can observe extreme time dilation in the Universe. Some cosmic ray particles travel at a velocity of 0.999999999999999c (15 decimal places)! These are free neutrons which have a half-life around 10 minutes (in proper time). They were emitted at the Big Bang and they are still travelling today. They feel the Universe is only 10 minutes old!!! (Another good example: Cosmic particles entering the atmosphere of the Earth when collide with the air particles at a height of ~10 km produce the short living (2 micro seconds) muon particles. In spite of their short life they reach the Earth's surface due to the dilation of their proper time.)

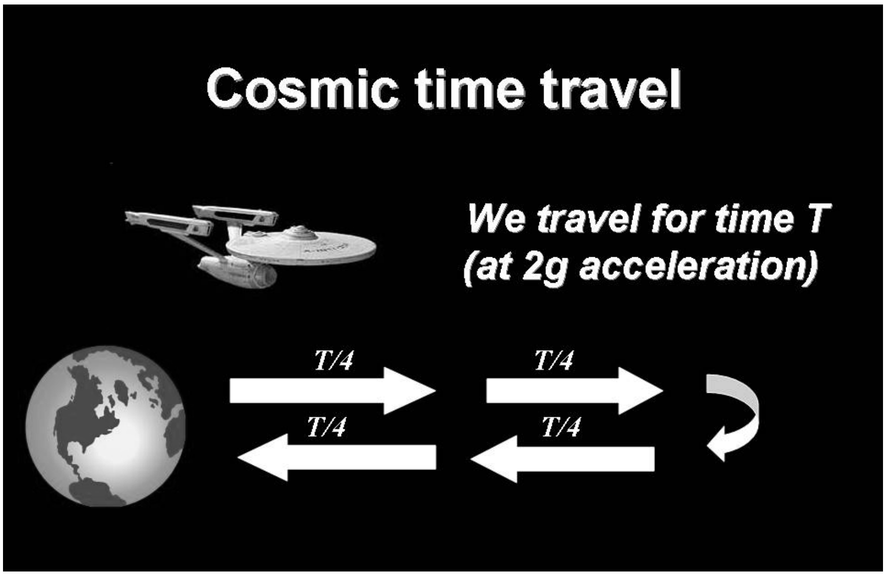

Figure 1.
Let's make a space-travel with 2g acceleration. We speed up for the first quarter of the trip, speed down for the second one, speed up for the third one and speed down again for the final one. The time-gain — as a function of T — is illustrated on figure 2.

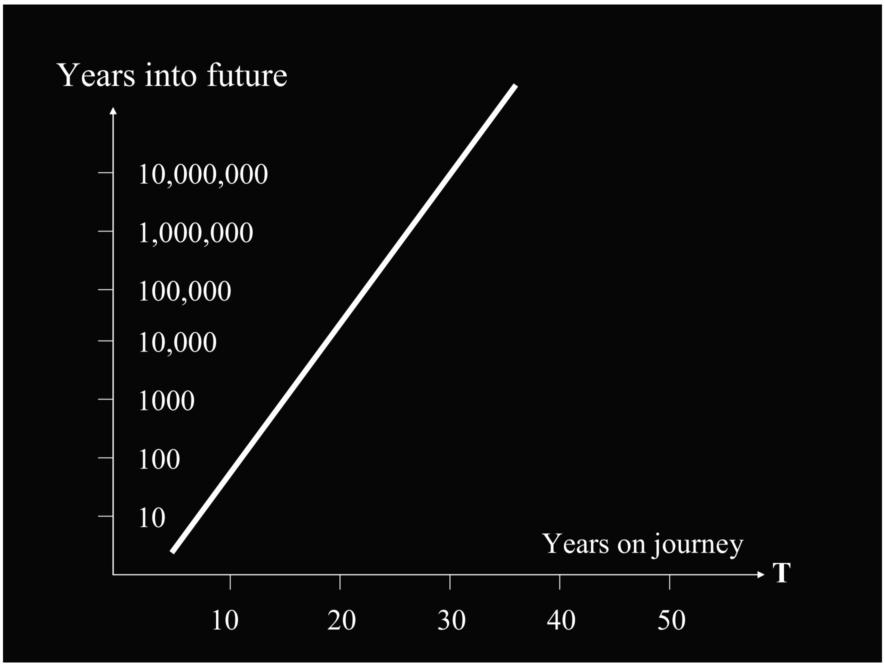

Figure 2.
Time dilation during the cosmic travel illustrated in figure 1 as a function of the proper time (T) of the spacecraft.

TIME TRAVEL INTO THE PAST

Using the phenomenon of time dilation an object made of normal matter can not travel into the past (figure 3). (However — according to Nobel Laureate Richard *Feynman* — antiparticles can be regarded as particles going backwards in time.)

Fortunately, because otherwise we would run in a number of time paradoxes; e.g.:

- What if I travel back in time and kill my grandfather when he's still a baby?
- What if I travel back in time and kill myself?!
- What if I travel back in time and give myself non-contemporary information?

An ingenious escape from this trap is the many-worlds hypothesis of Hugh *Everett* [2, 3]. The sequence of thought of the author is the following one:

- When a quantum process occurs, the outcome is determined by probability.
- For every possible outcome a new universe is created and branches off. (The wave function never collapses; it splits into new wave functions. The split off wave functions reside in physically distinguishable "worlds").
- Our world is bifurcating endlessly like branches and twigs of an infinite tree.

According to this theory, when a time-traveler changes the past, a new universe is immediately created and branches off from the original one. Thus *history in the original universe cannot be changed*. Instead, a new history is created in the new universe. This provides a possible solution to the above paradoxes, but one wonders whether the price is not too high?

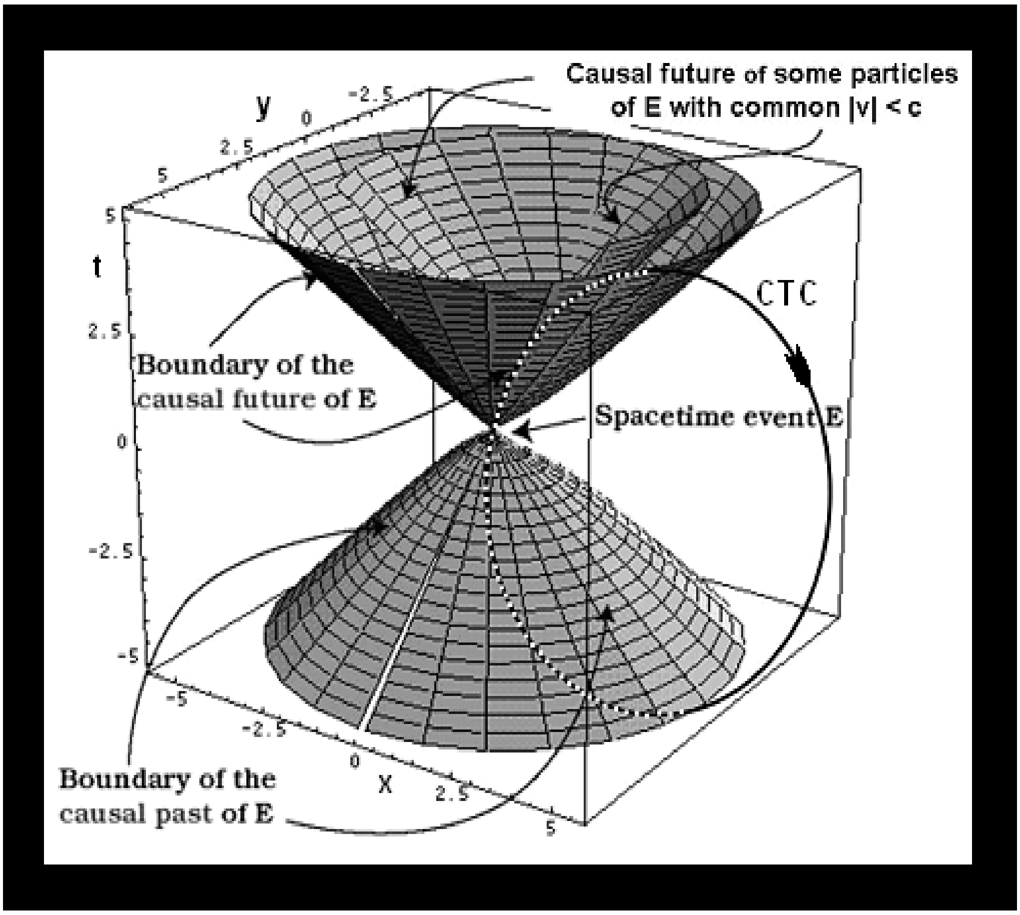

Figure 3.
Time is the fourth dimension. In this graph, time is vertical and space is horizontal. The z-axis has been suppressed. Every particle traces out a worldline in space-time. The set of all light rays passing through the point of some event E forms the light cone. A closed timelike curve (CTC) is a worldline that loops back onto itself. A traveler using such a curve has to travel faster than light at some stage. But faster- than-light-travel is not possible in the framework of special relativity.

TIME TRAVEL IN CURVED SPACE

According to Einstein's General Relativity — which is based on the geometric revolution of *Bolyai, Lobacsevszkij* and *Riemann* — the metric of the universe is not Euclidean everywhere. Matter, energy and motion deform the space-time and the geodetic line between two locations is not always a straight line (figure 4).

Henceforth, let's recapitulate the basic scientific literature of time travel:

- 1905, Einstein's Special Relativity: time travel into the future is absolutely possible.
- 1616, Einstein's General Relativity opens new perspectives for the topic about time travel.
- 1949, Kurt *Gödel* shows that even backwards time travel is possible in a rotating universe ([4], figure 5).
- 1974, Frank *Tipler* shows that backwards time travel is also possible around a massive rotating cylinder [5]. Taking advantage of the phenomenon of *frame dragging* — in the environment of such an object with proper mass, density, length and speed — reverse time travel can be achieved without having to travel faster than light.
- 1988, Kip *Thorne* suggests that *wormholes* can be made to function as time-machines ([6], figure 6).
- 1991, Richard *Gott* points out that *cosmic strings* can be used to allow backward time travel [7]. Gott's solution depends upon the antigravitational tension of the strings to deform space without attracting nearby objects. Two atomwidth super-dense strings would have to travel parallel to one another in opposite directions. They would create severly curved space-time, in which a closed timelike curve would open up. A hypothetic time traveler might be able to exploit these conditions at just the right moment and fly his space-ship along the CTC right there created by the strings.

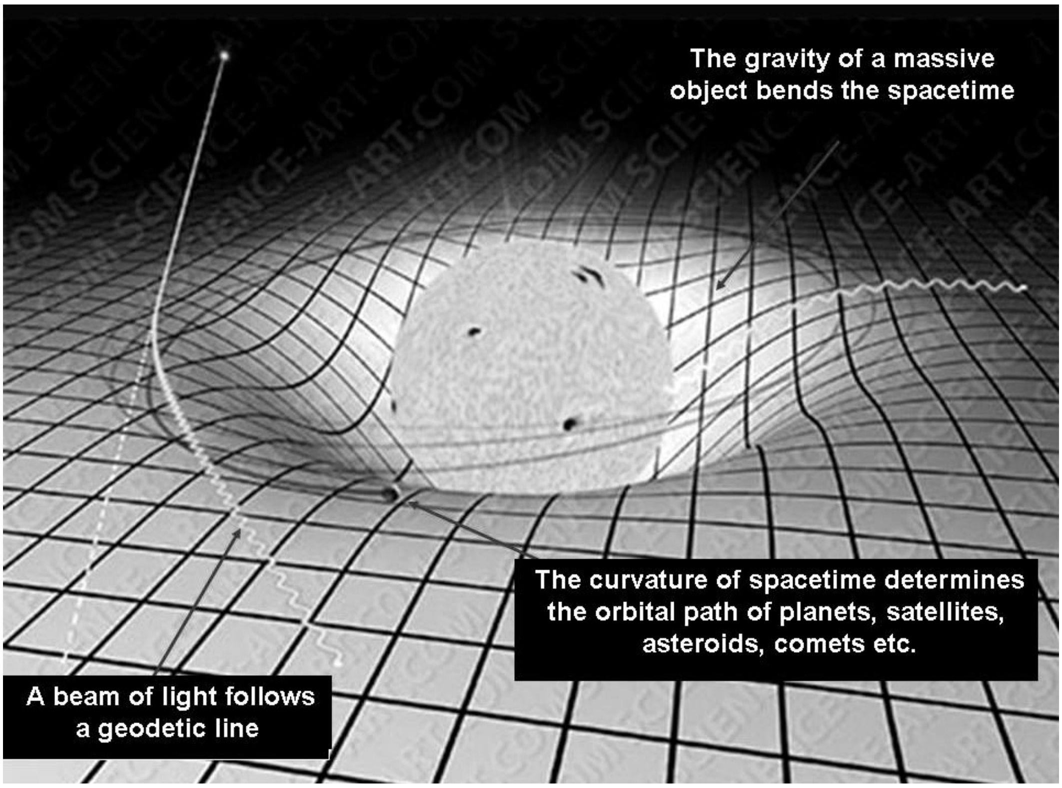

Figure 4.
Illustration of curved space-time around a massive object.

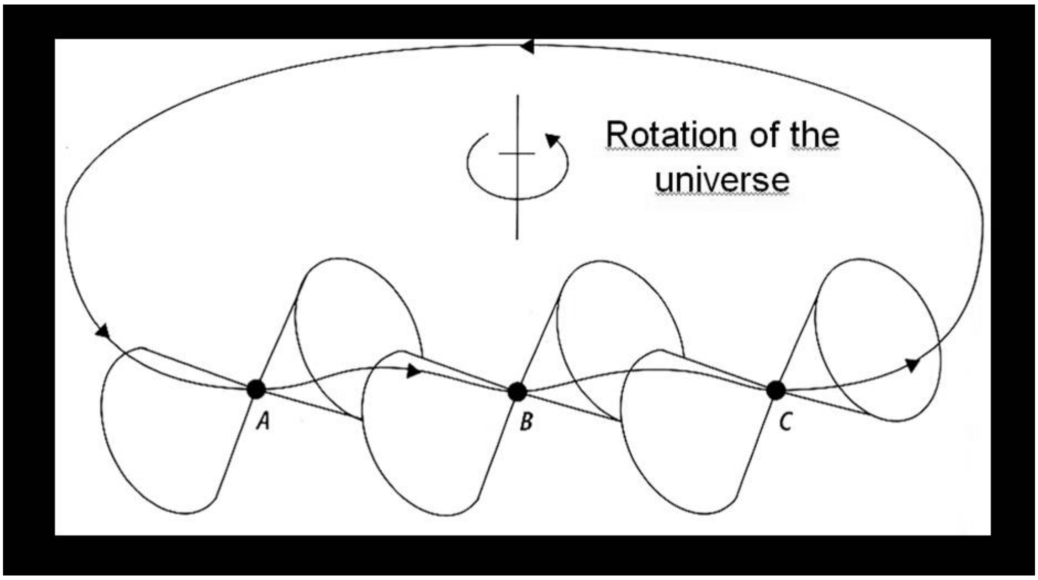

Figure 5.
Light cones may tip over to form a CTC in a rotating universe. It is not considered a proper solution for backwards time travel since the universe is expanding, not rotating.

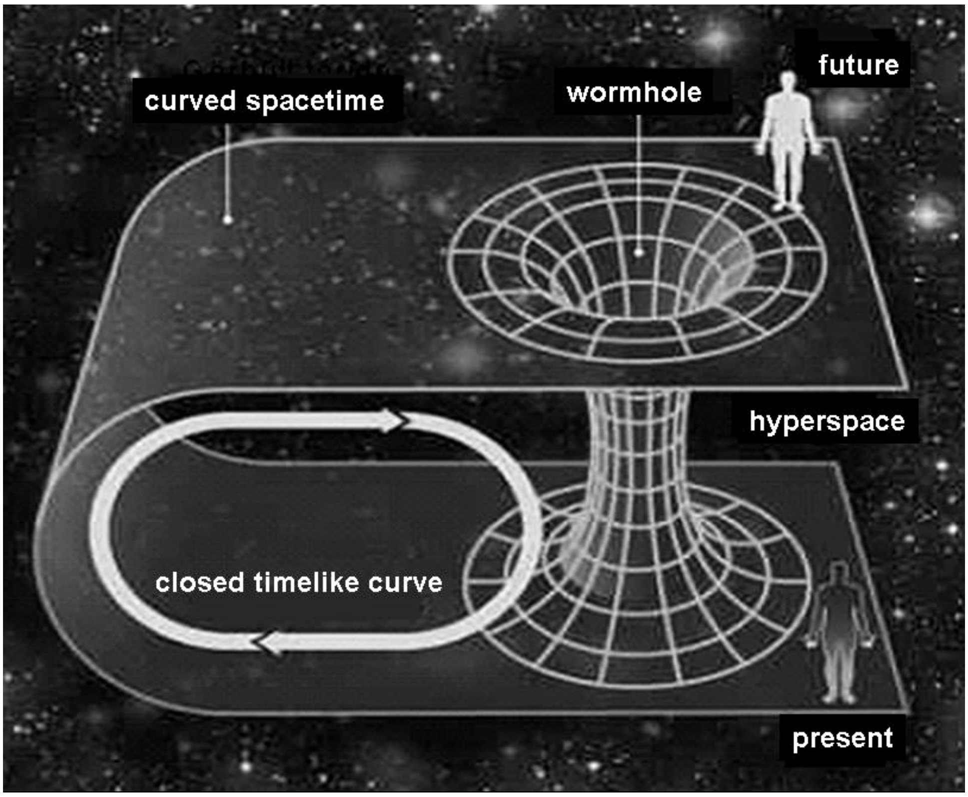

Figure 6.
The wormhole connects two distant points of the curved space-time and creates a closed timelike curve, which allows objects to travel into the future, or from the future to the present.

TRAVERSABLE WORMHOLES AS TIME MACHINES

Wormholes arise as solutions to the equations of Einstein's general theory of relativity. They are connecting two different points in space-time in such a way that a trip through the wormhole could take much less time than a journey between the same starting and ending points in normal space (figure 6). The ends of a wormhole could, in theory, be *intra-universe* (i.e. both exist in the same universe) or *inter-universe* (exist in different universes in a multiverse, and thus serve as a connecting passage between the two).

Formerly, one used to think that they are highly unstable and would probably collapse instantly if even the tiniest amount of matter, such as a single photon, attempted to pass through them. But S. V. *Krasnikov* had recently shown that some wormholes can be suitable for time travel [8]. The wormholes of this class are static and have arbitrarily wide throats, which makes them traversable even for persons. The matter necessary for these configurations consists of two exotic components. *Exotic matter* [9] violates one or more energy conditions or is not made of known baryonic particles. This hypothetical kind of matter has both a negative energy density and a negative pressure. Such materials would possess qualities like negative mass or being repelled rather than attracted by gravity.

According to Aref'eva and Volovich, extreme conditions at the Large Hadron Collider where colliding gravitational waves from highly accelerated protons – at an energy level of 14 TeV concentrated into a tiny space range of about 10^{-15}m – may produce wormholes in space-time. An advanced civilization might be able to manipulate one of these to create a traversable "tunnel" back to the point in time, when the wormhole was first created!

THE MAIN PARADOXES OF BACKWARDS TIME TRAVEL

Aside from the actual construction of a time machine the most challenging part would be the result of changing the past. Stephen *Hawking* proposed a simple solution to this problem called the *Chronology Protection Hypothesis*. It states that nature would always find a way of preventing wormholes and other ways of changing the past. But the proof is still missing!

The basic types of time travel paradoxes are the following ones:

- **Causality paradox:** A hypothetical effect that would result if an individual were to travel back in time and cause changes to the circumstances that led to his or her current actions. Open type: Going back in time and killing your own father before you were conceived. Closed type: One goes back in time and saves his own life. Solution: Multiverse?
- **Multiplication paradox:** Rendezvous with our earlier ourselves. The main problem is the violation of the fundamental principle of conservation of matter-energy. Solution: Multiverse?
- **Information paradox:** It is a paradox that questions the originality of information that travel in time. In simpler terms, some information is brought back in time, and it becomes the input that was initially brought back in time in the first place. Specific example: a time traveler is going to Homer's time with a scroll of paper containing the whole Odyssey. Homer — pressed for time — simply copies the information from the future. The consequence is that actually *no one* really writes the heroic poem! Or a more practical one: It would be easy for a time traveler to find out next week's winning Lotto numbers and an original draw would be impossible. Solution: not known for the author.

CONCLUSION

This paper is an enquiry into the physical possibility of time travel. Modern space-time theories such as general relativity seem to permit models that feature closed timelike curves. We sketchily reviewed the recent literature on so-called time machines, i.e. of devices that produce closed traversable worldlines. Finally, we argued that none of the purported paradoxes unequivocally ruled out time travel.

Epilogue: The entities of the past, present and future are coexisting. Right now I am just a transient spatio-temporal part of the whole that is me throughout 4-dimensional space-time!

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