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Author Q&A: Carlo Rovelli on the physics of time

The theoretical physicist explains why the idea of the present may not be as simple as our brains would have us believe.

Melinda Baldwin

rovelli.carlo@gmail.com

Theoretical physicist Carlo Rovelli is best known among physicists for his work on loop quantum gravity, a mathematical theory that quantizes spacetime (see the article by Martin Bojowald, *Physics Today*, March 2013, page 35). His broader appeal comes from his book *Seven Brief Lessons on Physics*, which introduced general audiences to the physics of black holes, general relativity, and quantum mechanics.

In his latest book, *The Order of Time*, Rovelli explores what he calls "perhaps the greatest remaining mystery" in physics: the nature of time. "Why do we remember the past and not the future?" he asks. "What does it really mean to say that time 'passes'? . . . What am I listening to when I listen to the passing of time?"

To answer those questions, Rovelli takes readers on a tour of what physicists know—and what they don't know—about time. In the February issue of *Physics Today*, cosmologist Anthony Aguirre calls the book "lovely,

thoughtful, and poetic” and says it “will give all readers a taste of the mysteries of time.”

PT: What inspired you to write a book about time?

ROVELLI: To work in quantum gravity, one must face questions about the nature of time. So… especially TIME is the least studied "thing" of all the "things" in the world, it is the least studied physical quantity. ((Professors like Kulhánek know about it, only that it runs - nothing more)). First: "what is time"? Time is a physical phenomenon of this world, the Universe, which is even more than a physical quantity - see: http://www.hypothesis-of-universe.com/docs/c/c_300.jpg . Time - a phenomenon / quantity also has three basic dimensions as space, so we will say: "time" - 3D and "space" - 3D. The universe would not make sense without space-time…, which is a statement exactly the opposite of what prof. Kulhánek: without matter there is no space-time, matter is said to produce space-time. Using the phenomenon "Time" and Length ", the Universe builds a basic 3 + 3 grid-web-web ŕ, ie 3 + 3D space-time, in which our Universe will" float ". (To date, no one has examined whether Time-quantity also has dimensions, or why it must not have them !!). This basic state of space-time "stands indifferently" (as the state before the Bang), there is no matter in it, it is inert, infinite in everything, time does not flow here, longitudinal dimensions do not expand here. Time passes only after Třesko, after which the state of it before Třesk changes to the state of čp after Třesk. The state 3 + 3D flat (before Třesko) changes (according to the principle of alternating symmetries with asymmetries) to the state after Třeskem, ie there is a change in the infinite flat state of space-time "in the final locality" (recently called singularity) and in this locality to "maximum curvature of dimensions" 3 + 3D spatiotemporal; we will perceive this locality (in the middle of the infinite flatness of the Bang) as "our Universe" and the first state will be the foam of dimensions, the state of boiling vacuum = plasma. Only from this moment-position does time begin to pass, because the "time dimension" "expands", the curvature of all three time dimensions expands! ! !, each differently, exceptionally each, just like on Earth in the stop-state "today" it is said that new points were created = intervals of space in the "spatial grid" by "blowing" (but no new intervals were created on time dimensions… ?!) The curved locality 3 + 3D finite (our Universe) "floats" in a non-curved network-grid 3 + 3D infinite, then here begins the expansion of time dimensions and we perceive it as a flow-flow of time. In the stop states from Třesk, the ratio of expanded longitudinal to temporal dimensions is not the same everywhere. This means that the "point" shifts in space-time expanding v <c, ie v3 <c3 = 13/13 The point from the curved cp shifts in the non-curved raster cp. So it can also be said that time does not pass to us, but to the material we flow the object to it, we flow = we move over time - along the time dimension a… and thus cut the time intervals to the "standing" dimension of time… No one has yet proved that the pace of time is still the same from Bang to today, that it is universal for every place in space. No one has proved that t1 = t2 = t3 holds on Earth and that t1 = t2 <t3 can also hold on Earth, which is commonly reported in STR when time dilates only in the direction

of the body's motion from us. (by the way: the curvature of the time dimensions x / (t1. t2) then manifests itself as gravity). *3 + 3D space-time network (before and after Bang) is flat and endless. Then, after the Bang, floating curves of 3 + 3D ŕ fields and any assemblies of matter float in it and interact as "intertwined" packages from tangled dimensions no. , by the time dimension, by the longitudinal dimension ... etc. etc. Further descriptions are elsewhere.*

General relativity tells us that the amount of time between two events is determined by gravity, and here on Earth. I'm not sure whether also in interstellar space or intergalactic space, the time-interval between two events is determined by gravity ???! In every historical time since the Bang, global gravity was different and that such a statement would also apply that time = the pace of the passage of time is determined by gravity ?? ? and therefore time is affected by the quantum behavior of gravity. There can be quantum superpositions of different temporal states. A clock can be in a quantum superposition of two different times. ?? what-what "time states" are something independent of matter and gravity and others? .. shouldn't there be talk of a "pace of time"? in different states of curvature of space-time and different density of mass-field distribution ?? The clock can be in a quantum superposition of two different times. The clock is not - the clock is not "time", the clock is a mechanism that MUST tick some of the same selected time intervals So I have been thinking about the nature of time (and I, Mr Rovelli) and the many problems it raises all through my scientific life. I thought that the moment had arrived to try to connect the dots and write down what I think we do and do not understand about time.

PT: In the introduction to your book, you argue that “the growth of our knowledge has led to a slow disintegration of our notion of time.” What are some of the advances or revelations that challenge the idea that time flows neatly from past to present to future? There are no revelations that time flows in this sector / quadrant of the Universe with one arrow of time "there" other than from the past to the future! But the passage of time in the opposite exists in the anti-world, ie in the second quadrant of this Universe (only in my HDV is the vision and "curvature" of the dimensions (packing) of time shown once "in the direction of the time arrow and once the other way around.")

ROVELLI: I cover several in the first part of the book. We have learned that time passes at different (The word "speed" is inappropriate. Use the "tempo" of the passage of time) rates depending on altitude and on speed. We have learned that the fundamental equations of physics do not distinguish the past from the future. And we have learned that our very strong intuition about the present is valid only in a relatively small bubble around us; there is no objectively defined *present* in the large universe. Those are not speculations. They are established physics.

Then there is the speculative research in quantum gravity that further questions the nature of time. In loop quantum gravity, for example, there

is no time variable in the fundamental equations of the theory. The theory describes the relative evolution of physical variables rather than their evolution in time. I can't comment, I don't understand "quantum gravity". (In my opinion, this is probably "straightening the nonlinearity of gravity by" quantizing "it - but that would be a scam on the PRINCIPLE!)

PT: If the universe is fundamentally atemporal, what do you think explains the phenomenon that humans experience as time? Is time an illusion?

ROVELLI: I do not think that the universe is fundamentally atemporal. The position of the Observer is basically a "stop-state", both in the position and in the flow of time... .; and basically in the "expanding space and the expanding flow of time" it is possible to declare "" "relatively" "" that "we stand and time flows around us, or even that time stands (it is a dimension in a standing grid -before the web of 3 + 3D Euclidean space-time and we flow to it, we move along the "standing dimension of time and by our shift we cut intervals into the time dimension - we then perceive it as" our time, our flow of time ". The main point of the book is that there isn't a single notion of time that is either true or false. What we call *time* is a rich, stratified concept; it has many layers. Some of time's layers apply only at limited scales within limited domains. This does not make them illusions.

For instance, the distinction between up and down is not an illusion, but it has no meaning away from Earth. There is no up and down for astronauts during interplanetary travel. Many properties of time are similar. In particular, there are aspects of our own human experience of time that are very much tied to the specific way our brain works: the fact that we have memories, that we anticipate the future, and so on. It is the human It is the human brain, not the basic physics that determines what we call the passage of time and the sense-direction of the speed-pace that flows. (*)

PT: What is your next project?

ROVELLI: I always have too many projects going on at the same time. I am mostly focused on white holes right now. A white hole, like a black hole, is a solution of the Einstein field equations but reversed in time. I am studying the possibility that black holes end their lives by becoming white holes.

The time from the formation of the black hole to its evaporation, transformation into a white hole, and final dissipation can be extremely long as observed from the outside but extremely short as measured from inside the hole. It's an intriguing scenario that I developed with Eugenio Bianchi and colleagues in a recent paper. If that scenario is correct, the black holes we see in the sky are stars that are collapsing and then bouncing out, but we see that in extremely slow motion because of gravitational time dilation.

PT: Can white holes be observed?

ROVELLI: Yes, perhaps. One hypothesis is that their formation is the cause of fast radio bursts, mysterious super-violent signals captured by radio telescopes. Francesca Vidotto and I recently suggested another possibility that I find intriguing: that small white holes left over by black holes at the end of evaporation could be stable, and they could form an important component of dark matter.

PT: What are you reading right now?

ROVELLI: An extraordinary book by Alexander Bogdanov, *Tectology*. Bogdanov was a great Russian intellectual at the beginning of the 20th century. His ideas anticipated aspects of cybernetics, system theory, and contemporary structural realism.

JN, comment in red from 04.06. to 29.06.2021