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THE FINITE SPACE-TIME OF THE MICROCOSM
EXPLAINS THE PARADOX OF ACHILLE AND THE TURTLE

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Let's move to Greece in the fourth century B.C. . Among the olive trees and on the Aegean coast you can breathe the magnificence of the thought that, embracing the south of Italy, would have forged the European character over the centuries. Science and art, in the highest form, would have soon invaded the world and like a beneficial virus they would have infected the minds.

It is in this wonderful atmosphere that Aristotle reports the content of four apparently extravagant paradoxes devised by Zeno of Elea, the inventor of the famous dialectic, the Greek philosopher whose work was so important that it was used as a textbook in the Academy of Plato.

Proclus, philosopher and mathematician of the fifth century A.C. , says that Zeno's paradoxes were even forty, but the work that contained them was stolen. Therefore it is thanks to the sensible and precious testimony of Aristotle that today we know four of them, one of which, the most famous, that of Achilles and the turtle, is truly an invaluable jewel produced by the mind of man.

Evidently Aristotle understands that Zeno's thesis is an affirmation that obeys to the scientific rigor dominant in the mathematical thought of the epoch, an extremely profound reflection on the true nature of space, anything but a ridiculous logical sophism that someone urges to abandon, because useless.Instead someone has been so superficial as to think that the Achilles paradox was even a brake on the development of the mathematical understanding of what was infinite and continuous.

But, as demonstrating its importance, many famous minds have written about it, in two thousand five hundred years, minds who have ventured to solve this fascinating and inviolable enigma, so impenetrable as to soon renounce to take it seriously, setting it aside. Enigmaso impenetrable as to circumvent it as a useless obstacle, to arrive directly at incontrovertible conclusions, which however renounce to face the phenomenological problem, hitherto completely wrapped in mystery.

The absurd conclusion to which the Achilles paradox leads is obviously disconcerting, so much it appears real and at the same time clearly contrary to reality.

This enigma urges the solution of a problem hitherto unsolved by science, which still after many centuries wonders if space-time is continuous or a set of units.

Solving the absurd truth of Zeno's most famous paradox therefore means taking a big step for science.

This step is possible if we investigate the true nature of the space-time in which we live.

Achille and the turtle

Zeno narrates that a hilarious race takes place in Greece a long time agobetween Achilles, famous for the speed of his race, and a young and athletic turtle.The gap between the speeds of the two legendary athletes is really embarrassing. Achilles runs at a v_A speed of 10 km per hour. The turtle is panting at a v_T speed of 1 km per hour.

Therefore Achilles, sure of himself, decides to offer the vigorous tortoise a considerable advantage. The starting line of the turtle is thus engraved on the dusty ground 9 km after the one already drawn for Achilles.

So the race starts. After 54 minutes Achilles finally reaches the turtle's starting line, but this has obviously moved by 0, 9 km, since its speed is one tenth of that of the athlete. So when Achilles is 9 km from his starting line, the turtle is 9 + 0.9, that is 9.9 km from it. The two are now 0.9 km apart.

The race goes on. Achilles continues to run for 0.9 km, but the turtle has moved another tenth of the stretch covered by Achilles and precisely is now at 9 + 0.9 + 0.09, that is, 9.99 Km from the line of Achilles departure. The gap between the two runners is now 0.09 km.

As expected, the gap decreases considerably.

Precisely, those who attend the race, note that the second gap is one tenth of the first, the third is one tenth of the second, the fourth is one tenth of the third. There is no doubt! But if the race proceeds in this way what will be the foreseeable conclusion?

The continuous reduction of detachment leads to a consequence that leaves the spectators, and the poor Achilles, stunned, because completely unexpected and unacceptable. The series of detachments is endless. The turtle is always leading the race, because there is always an interval, however small, between itself and Achilles.

After the first detachment, the turtle is 9.9 km from Achilles starting line, after the second it is 9.99 km, after the third it is 9.999 km. So the number of digits 9 to the right of the comma is equal to the number of detachments made by the turtle,

measured at time intervals which are each one tenth of the previous one. Then for n detachments we will have n digits 9 to the right of the comma.

But what would happen if the number of detachments had no end?

Many centuries after the extravagant event narrated by Zeno, the absurd conclusion was still animatedly discussed and no longer in Greece.

In the seventeenth century the story is known in full Europe. These are the years of Newton and Leibniz and finally the mathematical thought seems to seize the fearsome concept of infinity.

In truth, mathematicians have takenadifferent approachin research from that taken in Aristotle's time, different from Euclid's rigorous reasoning, from his firm theoretical development made of iron proofs derived from solid axioms.

Minds like those of Bernoulli, Euler, d'Alembert rely on their intuitions, freeing themselves from the rigor of Greek mathematicians in searching the infinitely large and the infinitely small. It is in this atmosphere that Newton and Leibniz simultaneously discover the infinitesimal calculus, sometimes without the rigid support of Greek logic (1).

According to the infinitesimal calculus, the number 9, 999 ... with infinite digits 9 placed to the right of the comma is equal to number 10.

But even the infinitesimal calculation, which hoped to be able to unravel the mystery contained in the ancient paradox, proves to be impotent, because the fact remains that the distance between the two athletes is not annulled.

It is undeniable that poor Achilles, based on Zeno's calculation, never reaches the courageous competitor and both never reach the end of the tenth kilometer.

Not even infinitesimal calculus therefore solves the extraordinary and far from extravagant paradox with which Zeno still involves us after so many centuries.

What is this extraordinary enigma of science hiding?

The paradox appears even more insidious and irritating because we are able to immediately calculate the point and time in which the two athletes find themselves side by side.It is enough to equalize the space $s_a$covered by Achilles to the space $s_t$covered by the turtle, spaces expressed as product of speed for time.

We'll have:

$s_a = v_a \cdot t = 10 \cdot t$ $\quad$ $s_t = 9 + v_t \cdot t = 9 + t$

$10 \cdot t = 9 +$ tand therefore $\quad t = 1$ hour

So Achilles appears side by side with the turtle an hour after departure. Precisely, being $s_a = 10t$, the two runners stand side by side at 10 km from the starting line. This result is unexceptionable, but it does not resolve the paradox, rather it accentuates it.

Incredibly we are faced with two contrasting mathematical truths. On the one hand, the successive detachments between Achilles and the turtle prevent Achilles from winning. On the other hand, the two are next to each other, and we witness Achille's overtaking, an hour after the start of the race.

How is all this possible?

At this point we can assume that the Achilles paradox hides something really important, a hitherto unknown conformation of the extension of space and therefore of its mathematical description. This idea is not surprising if we think of the revolution of the concept of space and time that occurred about a century ago with the theory of general relativity by A. Einstein

Space-time is a physical entity and takes the place of Euclid's inert space, indeed incorporates it, as an acceptable approximate description, limited to the medium-cosmos, that is, to the stage of the spatial extension most familiar to us men.

The middle-cosmos lies between the microcosm of elementary particles and the macrocosm of clusters of galaxies, both spaces that we cannot deeply know by relying only on our senses, that is, without the use of appropriate tools.

Euclid's space and time, separate, independent, absolute, have held human knowledge for millennia, but at a certain moment they have shown their limits. . The space and time of Einstein, united, dependent, relative, allowed instead to start a great expansion of our knowledge.

The space-time of relativity becomes the main physical entity, because by incurving itself, it expresses all the fundamental forces hitherto known in nature.This is the basic great discovery that is allowing us to greatly expand our knowledge of the world. What does it reserve for understanding the concept of continuous and infinite space-time?

The revolution of space

In the early years of the twentieth century A. Einstein upset the idea of space, demonstrating that this, fused with time, deforms, curves. Geometry becomes overwhelmingly adherent to empirical reality, so much so that it merges with physics (2).

In fact, it is shown that the space described by geometry is a physical entity, not at all homogeneous, nor isotropic. The shape of the space is not what has been believed for centuries, although the representation based on Euclid's axioms is still sufficient for all human activities that do not concern macrocosm and microcosm.

Since space-time is a physical entity, it can and must be represented by a geometry conforming to experience, capable of explaining the known phenomena and

anticipating those still unknown. The role of geometry is confirmed as the original one of studying the real dimensions of space in accordance with experience.

Space-time curves. This is the sensational affirmation demonstrated by the theory of general relativity. However, Einstein does not clarify some important geometric consequences of the space-time curving proved by his theory. Let us now examine them carefully.

The first immediate consequence of the space-time curving is the impossibility of the existence of the straight line. Any entity of space must in fact always be, and in any way, incurvable.

But it is immediate to understand, even without resorting to theorems (3), that the straight line, (open entity, the extremes of which, by definition, do not coincide), cannot curve, cannot assume constant curvature, because it would become a circumference, closed entity.

The straight line is actually the maximum circumference visible to the human observer. The straight line concept arises from the alignment of point light sources that have coincident images on the retina. Infact, an observer cannot evaluate the curvature if he belongs to the curve, that is, if he has only the size of the curve.

This makes us understand how the rectilinear appearance of the circumference, to which the aforementioned sources belong, is a relative phenomenon, because this circumference which appears maximum to one observer, does not appear maximum to another.

To deal with the reality of curved space-time, we must then simply replace the circumference to the straight line.

Another important consequence of the curvature of space-time is the existence of other real dimensions besides the three which, as we have known for a century, are inseparable from time.

Recall that as early as 1919, a few years after the birth of the theory of general relativity, the mathematician T. Kaluza thinks that, if Einstein described the force of gravity in terms of the curvature of space-time, then it is possible to use the same idea with the other known force, the electromagnetic force.

If three-dimensional space expresses gravity, then what space exists to express electromagnetic force? Kaluza therefore thinks of the need for other dimensions beyond the known three. But where are these dimensions?

This is how many scientists, including Einstein himself, seek in vain, like Kaluza, a theory based on unknown dimensions, a theory capable of describing, through dimensions, all the forces of nature, even nuclear forces, with a single set of ideas, a theory of everything.

Yet it is precisely the theory of general relativity, which, demonstrating the curvature of space-time, indicates the way to go to discover the unknown dimensions.

The fourth real dimension of space-time

Let's describe the first three dimensions of space-time, giving straight line its true nature of circumference.

1-dimensional space-time s_1 is that of maximum circumference with respect to human observer.

2-dimensional space-time s_2 is that of maximum spherical surface with respect to human observer.

3-dimensional space-time s_3 is that of maximum spherical volume with respect to human observer.

Maximum circumference s_1, changing curvature, occupies maximum spherical surface s_2.

Maximum spherical surface s_2, changing curvature, occupies maximum spherical volume s_3.

Maximum spherical volume s_3, changing curvature, occupies maximum 4-dimensional space s_4.

This is equivalent to saying that:

2-dimensional space allows curving 1-dimensional space,
3-dimensional space allows curving 2-dimensional space,
4-dimensional spaceallows curving3-dimensional space.

Curving 3-dimensional space-time then means expanding or contracting it, because in this way the curvature of the circumferences, of the spherical surfaces, of the spherical volumes that belong to it, changes.

The fourth dimension allows expansion and contraction of space-time.

On the other hand, the fourthdimension appears familiar to us if we evaluate that the magnification of the microscope or telescope simulates the reality seen by an observer who contracts in the fourth dimension. Even our visual system simulatesthe fourth dimension when we approach or move away from an object.

Bipolarity of space-time

We know that 3-dimensional space-time expresses gravitational force.

In this curved space-time, if the length of the radii of a circumference c increases without limits, the curvature of c is reduced, until itself is inverted from convex to concave, because also the radii are curved (F. 1).Then the magnification of the c is reversed in reduction.

Therefore the spherical surface of the three-dimensional space-time, which, by enlarging itself and rotating (5), describes the field of gravitational attraction of a celestial body, invert itself in a spherical surface which, reducing itself and rotating, describes a gravitational repulsion field.

It is thus shown that a gravitational repulsor point must correspond to a gravitational attractor point.

This bipolarity of space-time is an inevitable consequence of its curvature.

The curvature of space-time then shows that the attractor center of mass of each celestial body corresponds a repulsor center of the same.

As in a fabric, the texture of space-time, consisting of the circumferences and therefore of the spheres existing between the minimum and the maximum, is linked to the warp, consisting of the rays existing between the minimum and the maximum.

This fabric is present in every place of space-time, but the curvature must obey the attractor and repulsor points.

This bipolarity, being caused by the general curved nature of space-time, must be present in allthe dimensions, therefore also in the fourth (5).

Then, how does the fourth dimension manifest itself in the reality in which we live? What force field is associated with the 4-dimensional space-time?

Due to the bipolarity of curved space-time, a spherical volume that expands into the fourth dimension inverts its curvature from convex to concave, becoming a spherical volume that contracts in the fourth dimension.

Therefore the spherical volume, which, by expanding itself, describes a positive force field, is inverted into a spherical volume which, by contracting, describes a negative force field.

However, according to the third principle of the dynamics, the principle of action and reaction, inside the expanding spherical volume, which describes a positive force field, there must be a contracting spherical volume, which describes a negative force field.

Conversely, inside the contracting spherical volume, which describes a negative force field, there must be an expanding spherical volume, which describes a positive force field.

There are only two types of volumes, of particles, in nature corresponding to this prediction: the electron and the positron. The opposition of the verses of the fourth dimension, that is the opposition of the verses of the electric field, allows the concreteness of reality, the matter.

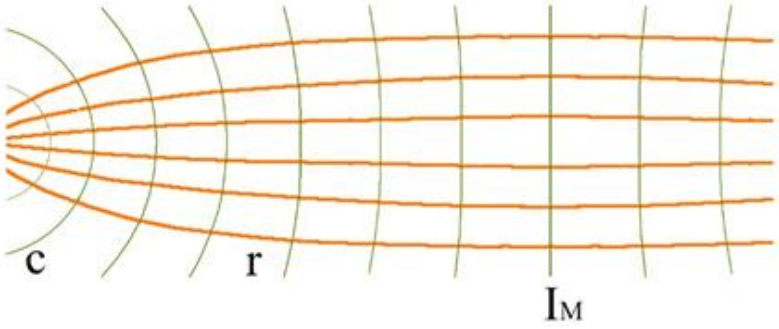

Figure 1
In three-dimensional space-time, if the length of the rays of a circumference c increases without limits, the curvature of c is reduced until itself is inverted from convex to concave, because the rays are also curved.

Then the spherical particle of matter and that of antimatter would be the unattainable limits between the two opposite verses of the fourth dimension.

The balance between the two opposite verses of the electric field, present outside and inside the electron, would also be in accordance with the predictionions of the model of the electron described by P. Dirac in 1962 (4).

There are other dimensions besides the fourth (5), but we are now anxious to answer the question we asked ourselves at the beginning.

How much is the concept of continuous and infinite space-time affected by the extraordinary revolution brought about by the discovery of its curvature, which determines the existence of the fundamental forces of nature?

To answer this question we must open ourselves to a new description of space-time based on the trend of its curvature in the macrocosm and in the microcosm.

We cross the four-dimensional space-time in the direction of expansion.

The observer, enlarging himself (F. 2), would see that the circumference is forced to invert its curvature, varying the magnification in shrinking, in correspondence with I_M, until it becomes the circumference -c extended as the + c and having center -C. In I_M there would be a maximum circumference (5).

The observer, shrinking, would see that the circumference is still forced to reverse its curvature, changing the shrinking into enlargement, in correspondence with Im, until the circumference –c coincides with + c. In Im there would be a minimum circumference.

In the transition from macrocosm to microcosm the expansion in fourth dimension inverts the curvature of the radii r of the c(F. 3).Due to this inversion, c decreases despite expansion in the fourth dimension, until reduction reverses to enlargement.

The annulment of the curvature in the maximum circumference I_M is, as it has been shown, relative to the observer, when he is unable to evaluate the curvature of the circumference. Therefore the circumference that appears maximum to one observer does not appear maximum to another.

Similarly, the annulment of the radius in the minimum circumference I_m is relative to the observer, when he is unable to evaluate the curvature of the circumference. Therefore the circumference that appears minimal to one observer does not appear minimal to another.

The inversion of the extension in the macrocosm and in the microcosm causes that the space extends from every point of the Universe more and more up to a maximum after which it extends less and less until it is reduced to the starting point..

So the enlargement and the reduction of the Euclidean space to infinity don’t exist, but the inversion of the enlargement into reduction and vice versa exist.

This inversion, we described thanks to the fourth dimension, manifests itself in the electrical field that is three-dimensional finite, that is, in quadridimensional space-

time referred to the greatness of the particles of the mediocosm, electron and positron, which also we observers are made of.

Nothing is stationary

The knowledge of nature, in macrocosm and in microcosm, shows that nothing is stationary in universe. When the objects around us appear to be stationary, we are obviously faced with an illusion, because their particles, which we do not distinguish, are in continuous reciprocal movement and together with our planet they move with respect to all celestial bodies.The appearance of an apparently stationary body actually changes continuously.

Space-time moves continuously, that is all dimensions and the relative fields of force extend continuously.

In the curved space-time, an increasingly large spherical surface changes with continuity its curvature from convex to concave.

Therefore all bodies move with continuity, based on the continuity of the force fields that cause it.

Therefore we, observers, are able to grasp only the movement, in general the change, because only this exists.Our machine of knowledge, that is the eye-brain system, is necessarily made in order to grasp the continuity of reality, that is, the continuous passage of an object from the previous position to the following one, from the previous aspect to the following one.

Time, intimately fused with space, is the continuous change of all that exists, the movement of force fields and therefore of the bodies, the continuous passage of the consciousness from a previous state to a subsequent one.

This passage is the instant. If the instant weren't a passage, the flow of the consciousness and the movement of all that exists would not be continuous.

A photon moves with continuity and therefore with continuity invests the retina.

When a body, huge set of elementary particles, appears to us to be stationary, for example a book on a table top, we continuously receive the photon reflected by the same moving particle, but compared to our eye-brain system the smallness of such particle and of its displacement is such as to superimpose the waves of the photon on the retinal cell itself.

The process is the same if a body ismoving relative to us, if for example someone moves the book. We receive with continuity the photon reflected by the same moving particle, but this time the continuous movement of the body is added to the continuous movement of the particle and the movement of it is such as not to overlap the waves of the photon on the same retinal cell.

Why did we focus on the continuity of space-time and motion?

Because the continuous or discreet, that is corpuscular, nature of reality is the current fundamental problem of physics and geometry, problem which Zeno highlighted 2400 years ago.

For the theory of relativity, the space-time of the Universe, which generates the gravitational field, is continuous.

For quantum theory, the mass or energy that generates the electromagnetic field, the field of the strong nuclear force and the field of the weak nuclear force, is corpuscular.

Therefore the quantum theory does not describe the gravitational force, but only the electromagnetic force, the strong nuclear force and the weak nuclear force.

Until now it was believed that continuity implied the division of space-time to infinity.We have found that the reality of the curved space-time does not allow for an infinite division.

The continuous reduction of space-time reverses itself in magnification and vice versa.Therefore the space-time of the Universe is continuous, but cannot be divided to infinity.

Its curvature leads to the inversion of the forces expressed by space-time, that is to the bipolarity.

This happens for the gravitational force expressed by the first triad of dimensions, 1,2,3, for the electromagnetic force (5) expressed by the second triad of dimensions, 4,5,6, as well as for the nuclear forces expressed by the third triad of dimensions, 7,8,9.

The bipolarity in the second triad is that of the electron-positron pair.

The corpuscular nature of these particles is due, as it has been shown, to the opposition of the verses of the electric field, that is, to the opposition of two continuous extensions of space-time.

The bipolarity in the third triad is that of the neutron-antineutron pair.The corpuscular nature of these particles is due to the opposition of the verses of the nuclear field, that is, to the opposition of the two continuous extensions of the positron-electron pair (5).

Then we understand that the quantization, that is the existence of the particles, is the result of the opposition between continuities. It is always the same continuous space-time which, curving into subsequent dimensions, determines the formation of elementary particles.

Bipolarity, immediate consequence of the curvature of space-time, is necessarily present in all three triads that nature manifests.

The Overtaking of Achilles

Now we have the theoretical principles that allow us to solve the Zeno's paradox.

Let's go back to the race. The turtle is at the head and is struggling to maintain a constant speed. Achilles is distraught and cannot give himself peace because of the impossibility of overcoming the opponent. This is the fun scenario, yet rigorously correct in Euclidean geometry.

But what does the curved geometry of space-time dictate? It requires that any space-time always undergoes a continuous curvature which reverses magnification into diminution and vice versa.

Even the gap between the two athletes must necessarily follow the conformation of space-time, because it is part of space-time.

By enlarging the microcosm in the fourth dimension, it has been shown that, due to the curvature, space-time reduces until the reduction reverses in magnification (F. 3).

The reversal point I_m is precisely the overtaking point.

So the gap between Achilles and the turtle is continually reduces until to overtaking, to grow progressively, allowing the famous athlete to win the race.

Achille's overtaking makes me think of the extraordinary overtaking that the discovery of the curvature of space-time, made physically by the theory of relativity and geometrically by the theory of dimensions (3), has allowed our science, compared to the representation of the world that we have maintained for many centuries.

The latter is a representation, a model, to which, however, we remain firmly tied, a model which we owe the development of our civilization, of humanistic and scientific progress. But the Euclidean model proved to be limited. It does not describe the real nature of space, except in an approximate way in the mediocosm.

Zeno's greatness is that of having highlighted, in the poverty of knowledge of his time, but together, in the refinement of Greek thought, the limits of the representation of space that would have been ordered and rigorously demonstrated in the most famous work of Euclid a century later.

The inexplicable paradox was and remained for many centuries the signal that indicated to science a remoteness from the correct representation of space and therefore from the correct physical knowledge of time, matter, energy and motion.

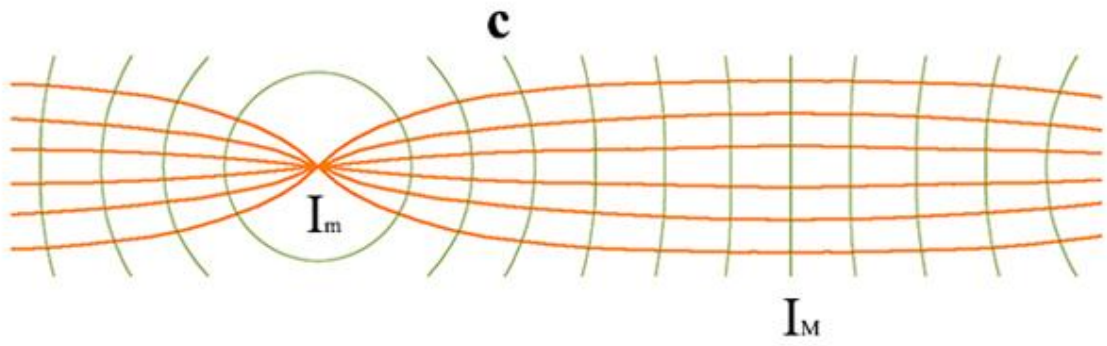

Figure 2

The observer, shrinking (Fig. 2), would see the length of the rays of a generic circumference c increasing without limits in the macrocosm and the magnification of it inverting in reduction in correspondence of IM, because the rays of it are curved. In IM there would be a maximum circumference (5).

The observer, would also see (Fig. 3) the length of the rays of a generic circumference c reducing without limits in the microcosm and its shrinking inverting in magnification at Im, because the rays are curved. In Im there would be a minimum circumference.

Note

1Josef Mazur, *Achilles and the turtle*, Il Saggiatore, Milano 2019, pp. 122-142.

2 Of Albert Einstein, who made the first great act in the revolution of the concept of space, it is nice to remember these brief reflections:
"A complete system of theoretical physics is composed of ideas, of fundamental laws that must be applicable to these ideas, and of consequent propositions that derive from them by logical deduction. It is these propositions that must correspond to our individual experiences; their deduction necessarily occupies, in a work of theory, almost all the pages.
Basically, it is exactly the same in Euclid's geometry, except that in this the fundamental principles are called axioms and the question is not raised that the consequent propositions must correspond to any experience. But if Euclidean geometry is conceived as the doctrine of the possibilities of the reciprocal position of practically rigid bodies and, consequently, if it is interpreted as a physical science without abstracting from its initial empirical background, the logical identity of geometry and theoretical physics is complete ".

3 The curvature of space theorem proves that space cannot be represented by lines. Giuseppe Maria Catalano, The dimensions of the space-time, International Institute for Advanced Studies of Space Representation Sciences, Palermo 2008, pp. 4-6.

4 P. A. M. Dirac, *An extensible model of the electron*, Journal article , Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 268, No. 1332 (Jun. 19, 1962), pp. 57-67.

5 Giuseppe Maria Catalano,*Ninereal dimensions of the space-time diiscovered*, International Institute for Advanced Studies of Space Representation Sciences, Palermo 2019.

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