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A Powerful Alternative to Einstein's Concepts of Time

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There are two concepts of time in special relativity (SR): The invariant evolution parameter is natural, but object-related, proper time τ. The time coordinate is man-made, coordinate time t. We present a novel, *all-natural* formulation of Euclidean relativity (ER): The invariant evolution parameter is natural, cosmic time $\theta = 1/H_\theta$ (Hubble parameter H_θ). The time coordinate is natural τ measured by clocks. All objects move through 4D Euclidean space (ES) at the speed of light c. Each object experiences two orthogonal projections from absolute ES as a relative, Euclidean spacetime: the axis of its current 4D motion as proper time and the other three axes as proper space. ER and SR describe the same cosmos, but in different metrics. ER confirms the Lorentz factor of SR and—only locally—the gravitational time dilation of general relativity (GR). Thus, the predictions made by SR are exact, while either GR or ER is an approximation. GR is probably that approximation because absolute θ suits quantum mechanics better than relative t. τ is the length of a 4D Euclidean vector $\boldsymbol{\tau}$. *ES diagrams do not show events, but* $\boldsymbol{\tau}$. Gravity makes a comeback as a force. Any acceleration rotates an object's $\boldsymbol{\tau}$ and curves its worldline in ES. Information hidden in θ or $\boldsymbol{\tau}$ is not available in SR/GR, but enables ER to predict time's arrow, galactic motion, the Hubble tension, entanglement, the baryon asymmetry, and more. Remarkably, ER requires neither dark energy nor non-locality. Is ER the key to unifying physics?

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Clocks measure proper time τ. There are two options of how we can conceive of τ: either as the invariant evolution parameter or else as the time coordinate of spacetime. In special relativity (SR) [1] and general relativity (GR) [2], τ can be used to parameterize worldlines in spacetime. In Euclidean relativity (ER), τ is the time coordinate of spacetime, whereas cosmic time θ (ticking uniformly since the Big Bang) is the parameter.

A new theory of spacetime must either refute SR/GR or else not conflict with SR/GR. Because of different concepts, there is no conflict. However, ER tells us that the scope of SR/GR is limited: We must apply ER (a) to the very early cosmos, (b) to very distant objects (high-redshift supernovae), and (c) to entangled objects (they move in opposite 4D directions at the speed of light c). In such extreme situations, a 4D vector "flow of proper time" must be taken into account. *Does ER make quantitative predictions?* ER predicts the 10 percent discrepancy in the published values of the Hubble constant. *What is the key message of ER?* Physicists should strive for an all-natural description of nature.

Request to all readers: Avoid the following pitfalls. Several reviewers at top journals have fallen into them. (1) *Do not apply the concepts of SR/GR to ER.* The only standards for a new theory are its own concepts and measurement data. (2) *Note that I do not refute SR/GR.* I show that the scope of SR/GR is limited. (3) *Note that my formulation of ER is unique in its definition of concepts.* Cosmic time θ is neither equal to coordinate time t nor equal to $i\tau$. (4) *Note that new coordinates can provide new insights.* In SR/GR, coordinates are only labels that can be freely adjusted to simplify computations. In ER, coordinates are inherent properties of objects that cannot be adjusted because they refer to absolute, 4D Euclidean space. (5) *Note that a paper cannot cover all of physics.* New concepts deserve to be published if they are consistent and helpful! Time will tell whether ER will replace SR/GR.

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1. Introduction

Today's concepts of space and time were coined by Albert Einstein. In SR, space and time are merged into a flat spacetime described by the Minkowski metric. SR is often presented in Minkowski spacetime [3]. The lifetime of muons [4] is one example that supports SR. In GR, a curved spacetime is described by the Einstein tensor. The deflection of starlight [5] and the accuracy of GPS [6] are two examples that support GR. Quantum field theory [7] unifies classical field theory, SR, and quantum mechanics (QM), but not GR.

In 1969, Newburgh and Phipps [8] pioneered ER. Montanus [9] added a constraint: A pure time interval must be a pure time interval for all observers. According to Montanus [10], this constraint is required to avoid "distant collisions" (without physical contact) and a "character paradox" (confusion of photons, particles, antiparticles). I show that the constraint is not required. There are no "distant collisions" if we take projections into account. There is no "character paradox" if we take the 4D vector "flow of proper time" of ER into account. Montanus used a Euclidean metric to calculate the deflection of starlight and the precession of Mercury's perihelion [10, 11], but failed to derive Maxwell's equations [10]. His constraint deprives ER of its most important feature: full symmetry in all four axes. His parameter is not cosmic time, but coordinate time (see page 13 of [10]). Montanus did not realize that Maxwell's equations hold in ER (see Sect. 3).

Almeida [12] studied geodesics in 4D Euclidean space. Gersten [13] showed that the Lorentz transformation is an SO(4) rotation in a mixed space x_1, x_2, x_3, t', where t' is the Lorentz transform of t. There is also a website about ER: https://euclideanrelativity.com. Previous formulations of ER merely swapped coordinate time t of SR with proper time τ of SR. Here we present a novel formulation of ER that takes three steps to make ER work: (1) The invariant evolution parameter is $\theta = 1/H_\theta$ (Hubble parameter H_θ). (2) The time coordinate is proper time τ. (3) Each object experiences two orthogonal projections from absolute, 4D Euclidean space as a relative, Euclidean spacetime.

Today, most physicists still reject ER because (a) they believe that there is no causality in ER, (b) they believe that ER is incompatible with waves, (c) they believe that there are paradoxes in ER, and (d) they expect ER to describe events. *This paper marks a turning point.* I show: (a) Causality also holds in ER, but it manifests itself in the parameter θ and not in the time coordinate τ. (b) ER is compatible with waves. (c) Orthogonal projections avoid paradoxes in ER. (d) Spacetime in ER is not an event spacetime.

It is instructive to contrast Newton's physics, Einstein's physics, and ER. In Newton's physics, all objects move through 3D Euclidean space as a function of independent time. There is no speed limit for matter. In Einstein's physics, all objects move through a non-Euclidean spacetime. The 3D speed of matter is $v < c$. In ER, all objects move through 4D Euclidean space. The 4D speed of everything is c. For better readability, an observer is referred to as "he". To compensate, Mother Nature is referred to as "she".

2. Identifying an Issue in Special and General Relativity

In § 1 of SR [1], Einstein considers a reference frame "in which the equations of Newton's physics apply" (to a first approximation). If an object is at rest in this frame, its position in 3D space is determined using rigid rods and a 3D Euclidean geometry. If we also want to describe an object's motion, we have to express its space coordinates as a function of time. Einstein points out the need to define time and gives an instruction on how to synchronize clocks at two points P and Q in 3D space. At a time t_P, a light signal is sent from P to Q. At t_Q, the signal is reflected at Q. At t_P^*, it is back at P. The clocks synchronize if

$$t_Q - t_P = t_P^* - t_Q \ . \quad (1)$$

In § 3 of SR, Einstein derives the Lorentz transformation. The coordinates x_1, x_2, x_3, t of an event in a system K are transformed to the coordinates x_1', x_2', x_3', t' in K′ by

$$x_1' = \gamma\,(x_1 - v_1\,t) \ , \quad (2a)$$

$$x_2' = x_2 \ , \qquad x_3' = x_3 \ , \quad (2b)$$

$$t' = \gamma\,(t - v_1\,x_1/c^2) \ , \quad (2c)$$

where K′ moves relative to K in x_1 at the constant speed v_1 and $\gamma = (1 - v_1^2/c^2)^{-0.5}$ is the Lorentz factor. Eqs. (2a–c) transform the coordinates from K to K′. There are covariant equations that transform the coordinates from K′ to K. The metric in SR is given by

$$c^2\,\mathrm{d}\tau^2 = c^2\,\mathrm{d}t^2 - \mathrm{d}x_1^2 - \mathrm{d}x_2^2 - \mathrm{d}x_3^2 \ , \quad (3)$$

where $\mathrm{d}\tau$ is an infinitesimal distance in proper time τ, whereas all $\mathrm{d}x_i$ $(i = 1, 2, 3)$ and $\mathrm{d}t$ are infinitesimal distances in coordinate space x_1, x_2, x_3 and coordinate time t. Coordinate spacetime x_1, x_2, x_3, t is a construct because t is a man-made concept: t is not inherent in clocks. Rather, t is a label that can be freely adjusted to simplify computations. Mathematically, SR is correct. Physically, there is a momentous issue in both SR and GR: *Einstein's concepts of time fail to predict time's arrow, the Hubble tension, and the baryon asymmetry; other observations (see Sect. 5) are predicted, but only by adding highly speculative concepts (cosmic inflation, expanding space, dark energy, non-locality).* There are coordinate-free formulations of SR/GR [14–16], but there is no absolute space and absolute time in these theories. SR/GR lack a "holistic view" (definition: nature is described as an absolute manifold). Only a holistic view provides Master Diagrams of Nature (see Sect. 3).

The view in SR and GR is "multi-egocentric" (definition: nature is described as a relative manifold). SR/GR have been very successful because they work well for all observers. What is not yet known: There is more than describing nature for observers. All observers' perspectives taken together do not give us a holistic view because they still lack absolute space and absolute time. Physics paid a high price for giving up absolute space and absolute time: *ER predicts time's arrow, the Hubble tension, and the baryon asymmetry; other observations are predicted without adding highly speculative concepts.* Thus, the issue is real. There is relevant information beyond SR/GR. Michelson and Morley [17] refuted the "ether" (absolute 3D space), but not 3D space with a relative orientation in absolute 4D space.

The issue in SR/GR is not about wrong predictions, but about fewer predictions and unnecessary concepts. It has much in common with the issue in geocentrism, which is the egocentric view of humanity. In the old days, it was tempting to believe that all celestial bodies would orbit Earth. Only astronomers wondered about the retrograde loops of some planets and claimed: Earth orbits the sun, so we better get rid of geocentrism! Meanwhile, physicists have "invented" coordinate time. Nowadays, it is tempting to believe that this man-made concept would enable us to calculate the time ticking for other objects. Now it is my turn to wonder and claim: Coordinate time omits relevant information. Clocks measure proper time and nothing else, so we better get rid of coordinate time! The human brain is smart, but it often considers itself the center/measure of everything.

The analogy of geocentrism to SR/GR is not perfect, but fits well: (1) After designating another planet as the center (or after a transformation in SR/GR), the view is still geocentric (or else egocentric). (2) Retrograde loops make geocentrism work, but are not required in heliocentrism. Dark energy and non-locality make today's cosmology and QM work, but are not required in ER. (3) Heliocentrism places Earth on the level of all planets. ER places the observer on the level of all objects. (4) Heliocentrism overcomes geocentrism. ER overcomes multi-egocentrism. (5) Geocentrism was a dogma in the old days. SR/GR are dogmata nowadays. *Have physicists not learned from history? Does history repeat itself?*

3. The Physics of Euclidean Relativity

SR tells us that merging 3D Euclidean space and coordinate time into a *Euclidean* spacetime is problematic, especially when the rigid rods used by Einstein move at relativistic speeds. In this case, length contraction shortens them in the direction of motion. Einstein becomes aware of this problem and therefore merges 3D Euclidean space and coordinate time not into a Euclidean spacetime, but into a *non-Euclidean* spacetime. This step has far-reaching consequences because it also affects GR. We can avoid this unfortunate step by replacing the concepts of time. So, here is how we will proceed: To determine an object's position in 3D space, we use the same 3D Euclidean geometry as Einstein in SR. However, instead of describing nature in man-made, coordinate time t, we work directly with natural, proper time τ measured by clocks. That is, we do not construct time.

The postulates of ER: (1) *All objects move as "wavematters" through 4D Euclidean space (ES) at the speed of light* c. Wavematters (see Sect. 5.10) are a generalization of the de Broglie hypothesis. Louis de Broglie claimed that all matter also exhibits wave-like behavior [18]. (2) *The laws of physics have the same form in the "realities" of objects that move uniformly through ES.* An object's reality is made up by its proper space and its proper time (two orthogonal projections from ES). Throughout this paper, we use "proper space" and "3D space" as synonyms. My first postulate is stronger than the second postulate of SR: In ER, the speed c is both absolute and universal. My second postulate refers only to projections from ES, but not to ES itself. The metric in ER is Euclidean and given by

$$c^2\,\mathrm{d}\theta^2 \;=\; \mathrm{d}d_1^2 + \mathrm{d}d_2^2 + \mathrm{d}d_3^2 + \mathrm{d}d_4^2\ , \tag{4}$$

where $\mathrm{d}\theta$ is an infinitesimal distance in the parameter θ (to be given a meaning later on), whereas all $\mathrm{d}d_\mu$ ($\mu = 1, 2, 3, 4$) are infinitesimal "pure distances" (neither spatial nor temporal) in ES. I prefer the indices 1–4 to 0–3 to emphasize the SO(4) symmetry. Each object is free to label the axes of its reference frame in ES. Observers are objects too. We consider two objects "r" and "b". We assume: "r" (or "b") labels the axis of its *current* 4D motion as d_4 (or else d'_4) and the other three axes as d_1, d_2, d_3 (or else d'_1, d'_2, d'_3). According to my first postulate, "r" (or "b") always moves in d_4 (or else d'_4) at the speed c. This axis is experienced as time because of length contraction at the speed c (see Sect. 4).

We can also put it this way: Each object experiences *two orthogonal projections* [19, 20] from absolute ES as a relative, Euclidean spacetime (EST): the axis of its current 4D motion as proper time τ and the other three axes as proper space d_1, d_2, d_3. If an object's worldline is curved in ES, the two orthogonal projections continuously adapt to the curvature. The object's reference frame adapts accordingly. $d_i = x_i$ ($i = 1, 2, 3$) because we use the same 3D Euclidean geometry as in SR to determine an object's position in 3D space. Only the time coordinate is different. In EST, an object's τ is the time coordinate of its reference frame. In ES, τ is the length of a 4D Euclidean vector "flow of proper time" $\boldsymbol{\tau}$.

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$$\tau \;=\; d_4/c \;, \qquad \tau' \;=\; d_4'/c \;, \tag{5}$$

$$\boldsymbol{\tau} \;=\; d_4\,\boldsymbol{u}/c^2 \;, \qquad \boldsymbol{\tau}' \;=\; d_4'\,\boldsymbol{u}'/c^2 \;, \tag{6}$$

where $\boldsymbol{u}$ is an object's 4D Euclidean vector "proper velocity" in ES. We call the four components $u_\mu = \mathrm{d}d_\mu/\mathrm{d}\theta$ ($\mu = 1, 2, 3, 4$) of $\boldsymbol{u}$ "proper speed". We call the three components $v_i = \mathrm{d}x_i/\mathrm{d}t$ ($i = 1, 2, 3$) "coordinate speed". Thus, Eq. (4) is my first postulate.

$$u_1^2 \;+\; u_2^2 \;+\; u_3^2 \;+\; u_4^2 \;=\; c^2 \;. \tag{7}$$

"Proper spacetime" d_1, d_2, d_3, τ is not a construct because τ is a natural concept: τ is inherent in all clocks. Even the internal clocks of objects, such as biological clocks, measure τ. Since τ and θ are natural, but t is man-made, $\tau \neq t$ and $\theta \neq t$. The inequality $\theta \neq t$ underlines that ER provides a unique description of nature even if τ is the same in both SR and ER. SR describes nature in man-made spacetime $x_1(\tau), x_2(\tau), x_3(\tau), t(\tau)$, where t is man-made and τ is natural, but object-related. ER describes nature in natural spacetime $d_1(\theta), d_2(\theta), d_3(\theta), \tau(\theta)$, where τ is natural and θ is natural and universal. This is why I call θ "cosmic time" and define it as $\theta = 1/H_\theta$ (Hubble parameter H_θ).

Remarks: (1) Mathematically, ES is a 4D Euclidean manifold. Physically, only three axes of ES are experienced as spatial and one as temporal. This is why it is not possible to observe all four axes at once. (2) Clocks measure neither θ nor t, but τ. However, natural θ is more general than man-made t. (3) Montanus [9–11] did not distinguish between θ and t. He merely swapped t with τ in Eq. (3) to enforce a Euclidean metric. I show that, despite $\theta \neq t$, $\mathrm{d}\theta = \mathrm{d}t$ holds for uniformly moving objects. (4) Montanus [9–11] rejected four fully symmetric axes. I show that an observer's τ can be proper time or one axis of proper space or a combination of both for someone else. (5) Do not confuse ER with a Wick rotation [21], which retains τ as the parameter. In ER, $\theta \neq i\tau$ and $\tau \neq it$.

It is instructive to contrast three concepts of time. Coordinate time t is a subjective measure of time: t simplifies computations, but it omits relevant information. Proper time τ is an objective measure of time: Clocks measure τ independently of observers. Cosmic time θ is an object's total distance traveled in ES (the length of its worldline) divided by c. According to Eq. (4), we must add the distances traveled in all four axes to calculate the length of a worldline. Since θ is the invariant and universal, it represents absolute time. The "twin paradox" is not a paradox: Each twin reads his biological time as τ on his clock. In Sect. 4, we discuss clocks that experience different gravitational fields.

We consider two identical clocks "r" (red clock) and "b" (blue clock). In SR, "r" moves in the ct axis. "b" starts at $x_1 = 0$ and moves at the constant speed $v_1 = 0.6\,c$. Fig. 1 left shows that instant when either clock moved 1.0 Ls (light seconds) in ct. "b" moved 0.8 Ls in ct'. Thus, it displays "0.8". In ER, the two clocks move as wavematters (see Sect. 5.10) through ES. Fig. 1 right shows ES and two orthogonal projections. "r" moves in the d_4 axis. "b" starts at $d_1 = 0$ and moves at the constant speed $u_1 = 0.6\,c$. Fig. 1 right shows that instant when 1.0 s have elapsed in θ since "r" and "b" left the origin. "r" moved 1.0 Ls in d_4. Thus, it displays "1.0" in the reality of "r". "b" moved 0.8 Ls in d_4 and 1.0 Ls in d_4'. Thus, it displays "0.8" in the reality of "r" and "1.0" in the reality of "b" (not shown). Red digits on clock "b" indicate that "b" is read in the reality of "r". Since one projection axis is time, the time displayed by a clock depends on the respective reality. Clock "r" remains at $d_1 = 0$. Clock "b" remains at $d_1' = 0$. Thus, according to Eqs. (4) and (5), $\mathrm{d}\theta = \mathrm{d}\tau$ and $\mathrm{d}\theta = \mathrm{d}\tau'$. *In its reality, a uniformly moving clock always displays both its τ and θ.*

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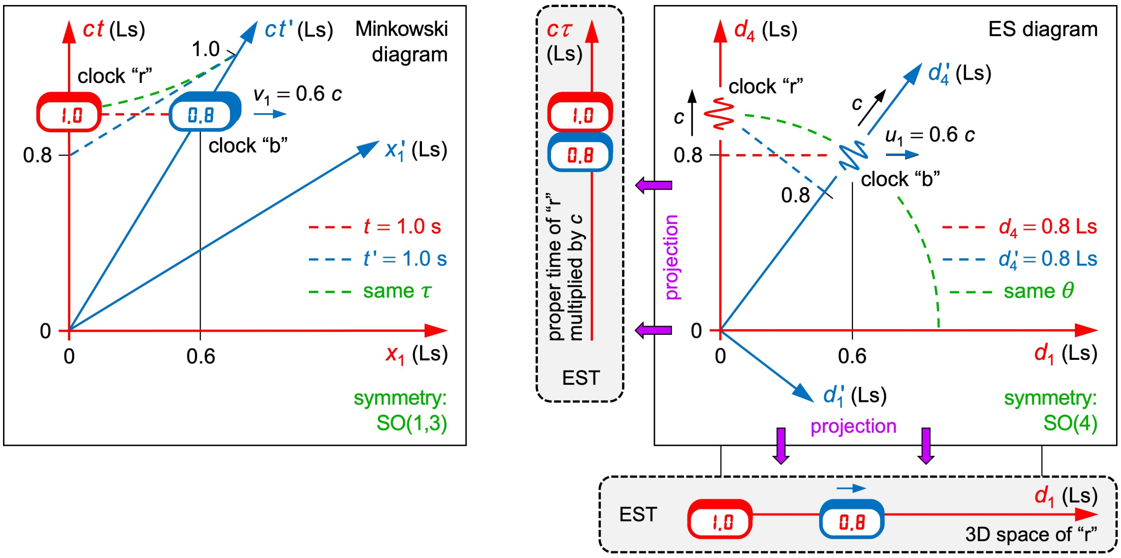

Fig. 1 Minkowski diagram and ES diagram of two uniformly moving clocks. **Left:** "b" is slow with respect to "r" in t'. Coordinate time is relative ("b" is at different positions in t and t'). **Right:** "b" is slow with respect to "r" in d_4. Cosmic time is absolute ("r" and "b" are at the same position in θ)

We assume that observer R (or B) moves with clock "r" (or else "b"). In SR and only for R (because "b" measures τ' and not t'!), B is at $ct' = 0.8$ Ls when R is at $ct = 1.0$ Ls (see Fig. 1 left). *Thus, "b" is slow with respect to "r" in* t'. In ER and independently of observers, B is at $d_4 = 0.8$ Ls when R is at $d_4 = 1.0$ Ls (see Fig. 1 right). *Thus, "b" is slow with respect to "r" in* d_4. In SR and ER, "b" is slow with respect to "r", but time dilation occurs in different axes. Experiments do not reveal in which axis a clock is slow. Thus, both SR and ER describe time dilation correctly if they yield the same Lorentz factor, which will be shown in Sect. 4. If "b" reverses its motion in the d_1 axis at $d_1 = 0.6$ Ls, it meets "r" again at $d_1 = 0$. Now both clocks stand side by side in the proper space of "r" (not in the proper space of "b"), and "r" displays "2.0" when "b" displays "1.6" (not shown).

ES is absolute. So, according to my definition in Sect. 2, the view in ER is holistic. Why is it beneficial? R and B experience different axes as temporal. This is why Fig. 1 left works for R only. For B, a second Minkowski diagram is required, in which the two axes x_1' and ct' are orthogonal. *Here the view is multi-egocentric.* Most physicists don't care that two Minkowski diagrams are required. They circumvent this problem by saying that simultaneity is not absolute. In ER, Master Diagrams of Nature (that is, ES diagrams) solve the problem: Fig. 1 right works for R and for B "at once" (at the same cosmic time θ). Not only are d_1 and d_4 orthogonal, but also d_1' and d_4'. *Here the view is holistic.* Master Diagrams can be projected onto any object's/observer's reality. This is a huge benefit!

Regarding waves, I was misled by editors who claimed that ER is incompatible with waves. ER is compatible with waves because Eq. (4) can be rewritten as

$$c^2\,\mathrm{d}\tau^2 \;=\; c^2\,\mathrm{d}\theta^2 - \mathrm{d}d_1^2 - \mathrm{d}d_2^2 - \mathrm{d}d_3^2\;, \tag{8}$$

which has the same form as the metric in SR. From Eqs. (3), (4), (5), and $d_i = x_i$, we calculate $\mathrm{d}\theta = \mathrm{d}t$ for uniformly moving objects. Only in this case does Eq. (8) turn into Eq. (3). Thus, Maxwell's equations and the wave equation hold in ER, but $\mathrm{d}\theta$ replaces $\mathrm{d}t$. Clocks do not measure θ in Eq. (8). This is fine because clocks do not measure t in Eq. (3) either. Clocks measure τ. Since ER is compatible with waves, wavematters can reduce to wave packets that propagate and oscillate as a function of θ.

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4. Geometric Effects in Euclidean Relativity

We consider two identical rockets "r" (red rocket) and "b" (blue rocket). Let observer R (or B) be in the rear end of "r" (or else "b"). The 3D space of R (or B) is spanned by d_1, d_2, d_3 (or else d_1', d_2', d_3'). The proper time ticking for R (or B) is d_4/c (or else d_4'/c). Both rockets start at the same point P and at the same time θ_0. They move relative to each other at the constant speed u_1. The ES diagrams in Fig. 2 must satisfy my two postulates and the two initial conditions (same P, same θ_0). This is achieved by rotating the red and blue frames against each other. In ES diagrams, objects retain proper length. For better readability, a rocket's width is drawn in d_4 (or d_4') instead of d_2 and d_3 (or else d_2' and d_3').

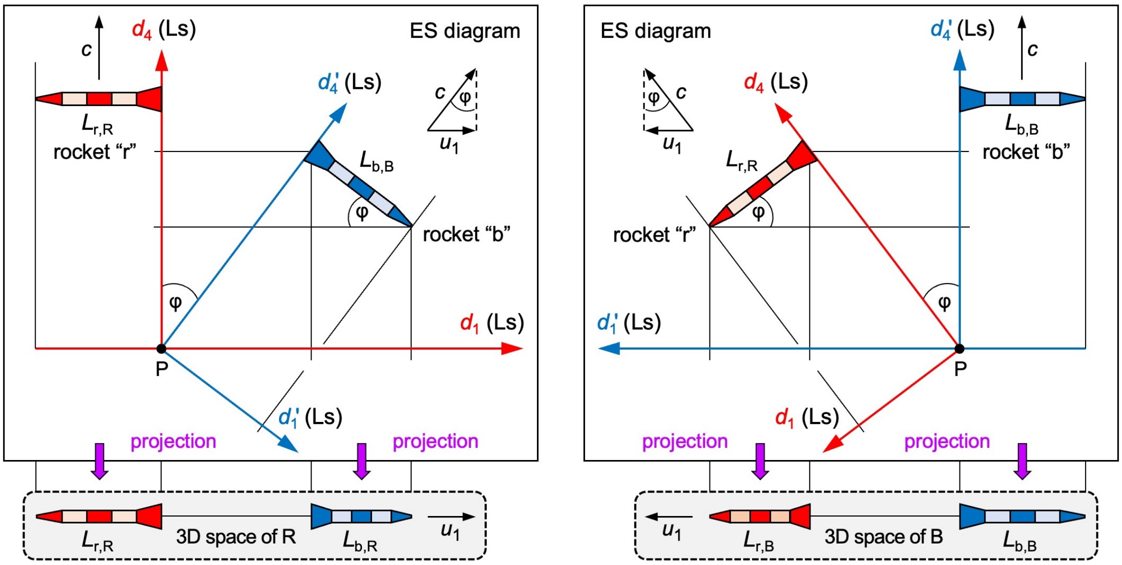

Fig. 2 ES diagrams of two uniformly moving rockets. Observer R (or B) is in the rear end of "r" (or else "b"). **Top left and top right:** "r" and "b" move at the speed c, but in different 4D directions. Their relative speed is u_1. The ES diagrams are identical. **Bottom left:** In the projection onto the 3D space of R, "b" contracts to $L_{b,R}$. **Right:** In the projection onto the 3D space of B, "r" contracts to $L_{r,B}$

Up next, we verify: Projecting distances in ES onto the axes d_1 and d_4 of an observer causes length contraction and time dilation. Let $L_{b,R}$ (or $L_{b,B}$) be the length of rocket "b" for R (or else B). In a first step, we project $L_{b,B}$ onto the d_1 axis (see Fig. 2 left).

$$\sin^2\varphi + \cos^2\varphi = (u_1/c)^2 + (L_{b,R}/L_{b,B})^2 = 1 , \tag{9}$$

$$L_{b,R} = \gamma_{ER}^{-1}\, L_{b,B} \qquad \text{(length contraction)} , \tag{10}$$

where $\gamma_{ER} = (1 - u_1^2/c^2)^{-0.5}$ is the same Lorentz factor as in SR if and only if $u_1 = v_1$. We recall from Sect. 3 that $d_i = x_i$ $(i = 1, 2, 3)$. Thus, $u_1 = \mathrm{d}d_1/\mathrm{d}\theta$ and $v_1 = \mathrm{d}x_1/\mathrm{d}t$ are equal if and only if $\mathrm{d}\theta = \mathrm{d}t$. As already shown in Sect. 3, $\mathrm{d}\theta = \mathrm{d}t$ for uniformly moving objects. The combination of a 4D rotation and a projection to the d_1 axis yields the Lorentz factor of SR. We conclude: ***ER confirms the Lorentz factor of SR.*** In a second step, we project the distance that observer B moved in d_4' onto the d_4 axis (see Fig. 2 left).

$$\sin^2\varphi + \cos^2\varphi = (u_1/c)^2 + (d_{4,B}/d_{4,B}')^2 = 1 , \tag{11}$$

$$d_{4,B} = \gamma_{ER}^{-1}\, d_{4,B}' , \tag{12}$$

where $d_{4,\mathrm{B}}$ (or $d'_{4,\mathrm{B}}$) is the distance that B moved in d_4 (or else d'_4). With $d'_{4,\mathrm{B}} = d_{4,\mathrm{R}}$ (R and B travel the same distance in ES, but in different 4D directions), we calculate

$$d_{4,\mathrm{R}} \;=\; \gamma_{\mathrm{ER}}\, d_{4,\mathrm{B}} \qquad \text{(time dilation)}\,, \tag{13}$$

where $d_{4,\mathrm{R}}$ is the distance that R moved in d_4. Eqs. (10) and (13) tell us that ER confirms the relativistic effects of SR: length contraction and time dilation. We now ask: Which distances does R observe in the d_4 axis? We rotate rocket "b" until it serves as a ruler in d_4. In the 3D space of R, this ruler contracts to zero length. *For R, the d_4 axis disappears because of length contraction at the speed c.* Our rockets serve only as an example. To calculate the lifetime of a muon in ER, we simply replace rocket "b" with a muon.

We now transform the proper coordinates of R (unprimed) to the ones of B (primed). R cannot measure the proper time τ' ticking for B, and vice versa, but we can calculate τ' from ES diagrams and Eq. (5). Fig. 2 right tells us how to calculate the 4D motion of R in the proper coordinates of B. The transformation is shown in Eqs. (14a–b). It is a 4D rotation by the angle φ. Note that adding multiple rotations in ER does not violate Einstein's relativistic addition of velocities in SR because EST is not the same as Minkowski spacetime. In SO(4), rotations are additive. In SO(1,3), velocities are not additive.

$$d'_{1,\mathrm{R}}(\theta) \;=\; d_{4,\mathrm{R}}(\theta)\,\sin\varphi \;=\; d_{4,\mathrm{R}}(\theta)\; u_1/c\;. \tag{14a}$$

$$d'_{4,\mathrm{R}}(\theta) \;=\; d_{4,\mathrm{R}}(\theta)\,\cos\varphi \;=\; d_{4,\mathrm{R}}(\theta)\; \gamma_{\mathrm{ER}}^{-1}\;. \tag{14b}$$

Up next, I show that ER also confirms gravitational time dilation. Initially, our clocks "r" and "b" are very far away from Earth (see Fig. 3 left). Eventually, "b" falls freely toward Earth. Clock "r" and Earth keep on moving in the d_4 axis at the speed c.

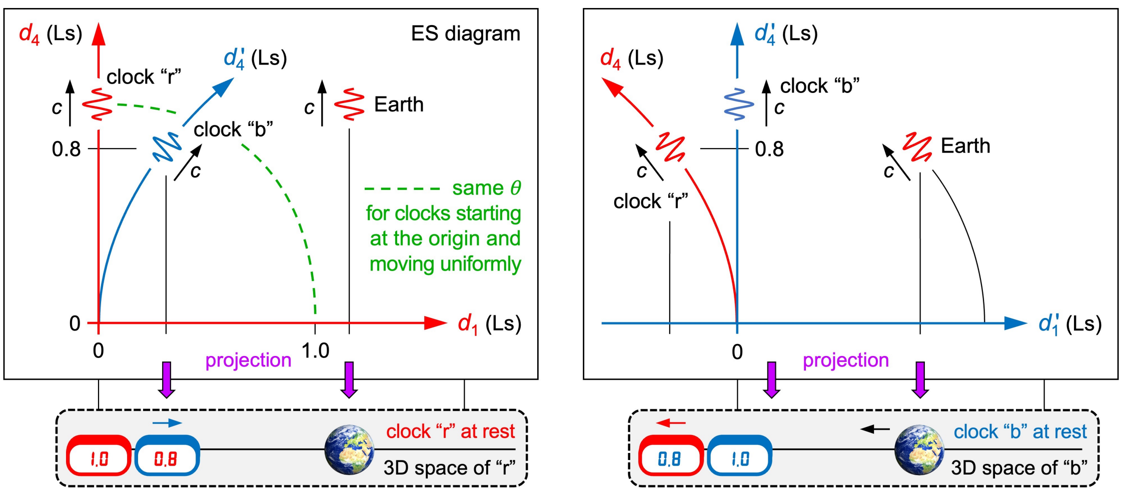

Fig. 3 Two clocks and Earth move through ES. "b" accelerates toward Earth. **Left:** This is an ES diagram because "r" moves uniformly through ES. The d'_4 axis is drawn curved because it indicates the current 4D motion of "b". **Right:** This diagram shows the same objects as in the left figure, but in the EST of "b". This is not (!) an ES diagram because "b" accelerates with respect to ES

Because of Eq. (7), all accelerations in ES are transversal. In particular, Eq. (7) tells us: *If an object accelerates in an observer's proper space, it automatically decelerates in his proper time.* The speed $u_{1,\mathrm{b}}$ of "b" in d_1 increases at the expense of its speed $u_{4,\mathrm{b}}$ in d_4. We assume that $u_{1,\mathrm{b}} = v_{1,\mathrm{b}}$. In this case, the kinetic energy of "b" (mass m) in d_1 is

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$$\tfrac{1}{2} m u_{1,\mathrm{b}}^2 \;=\; GMm/R \;, \tag{15}$$

where G is the gravitational constant, M is the mass of Earth, and $R = d_{1,\mathrm{Earth}} - d_{1,\mathrm{b}}$ is the distance of "b" to the center of Earth in d_1. Eqs. (7) and (15) give us

$$u_{4,\mathrm{b}}^2 \;=\; c^2 \;-\; u_{1,\mathrm{b}}^2 \;=\; c^2 \;-\; 2GM/R \;. \tag{16}$$

With $u_{4,\mathrm{b}} = \mathrm{d}d_{4,\mathrm{b}}/\mathrm{d}\theta$ ("b" moves in the d_4 axis at the speed $u_{4,\mathrm{b}}$) and $c = \mathrm{d}d_{4,\mathrm{r}}/\mathrm{d}\theta$ ("r" moves in the d_4 axis at the speed c), we calculate

$$\mathrm{d}d_{4,\mathrm{b}}^2 \;=\; (c^2 \;-\; 2GM/R)\,(\mathrm{d}d_{4,\mathrm{r}}/c)^2 \;, \tag{17}$$

$$\mathrm{d}d_{4,\mathrm{r}} \;=\; \gamma_{\mathrm{grav}}\,\mathrm{d}d_{4,\mathrm{b}} \qquad \text{(gravitational time dilation)}\;, \tag{18}$$

where $\gamma_{\mathrm{grav}} = (1 - 2GM/(Rc^2))^{-0.5}$ is the same dilation factor as in GR. We recall that we assumed $u_{1,\mathrm{b}} = v_{1,\mathrm{b}}$ in Eq. (15). Thus, the very same argument applies as for the Lorentz factor: $u_{1,\mathrm{b}} = v_{1,\mathrm{b}}$ if and only if $\mathrm{d}\theta = \mathrm{d}t$. Since spacetime in GR is locally Minkowskian, thus locally $\mathrm{d}\theta = \mathrm{d}t$ (see the end of Sect. 3), we conclude: ***ER confirms—only locally—the gravitational time dilation of GR.*** Thus, ER tells us that either GR or ER is an approximation. In my Conclusions, I give an argument for why GR is probably that approximation. Physically, there is another major difference: In GR, gravity is the curvature of spacetime. In ER, gravity makes a comeback as a force. Because of Eq. (7), any acceleration rotates an object's $\boldsymbol{\tau}$ and curves its worldline in ES. The law of gravity retains its $1/R^2$ form because ES is projected onto (reduced to) an observer's 3D space.

In its reality, the uniformly moving clock "r" always displays both its τ and θ. "b" is slow with respect to "r" in d_4. Thus, "b" is slow even with respect to absolute time θ. This is shown in Fig. 3 left, where "b" has not yet reached the green arc (θ = 1.0 s). *In its reality, an accelerated clock always displays its τ, but not θ.* This is why two clocks placed next to each other display different times after being exposed to different gravitational fields. There is no device that measures θ under acceleration. I invite theorists to show: (1) Variational principles [22] are another option to derive ER. (2) Gravitational waves [23] are also predicted by ER. If they are the carriers of gravity moving at the speed c, there is no action at a distance in ER either. I showed: ER confirms γ and γ_{grav}.

Résumé of time dilation: In SR, a uniformly moving clock "b" is slow with respect to a clock "r" at rest in the time axis of "b". In GR, an accelerated clock "b" or a clock "b" in a more curved spacetime is slow with respect to a clock "r" at rest in the time axis of "b". In ER, a clock "b"—uniformly moving or accelerated—is slow with respect to a uniformly moving clock "r" in the time axis of "r" (!). This is because the 4D vector $\boldsymbol{\tau}'$ of "b" differs from $\boldsymbol{\tau}$ of "r". The Hafele–Keating experiment [24] also supports ER because ER confirms both γ and γ_{grav}. Thus, GPS works in ER just as well as in SR/GR.

Fig. 4 teaches us how to read ES diagrams. Problem 1: Two objects move through ES. "r" moves in d_4. "b" emits a radio signal at d_4' = 1.0 Ls. The signal recedes radially from "b" in all axes as a function of θ, but cannot catch up with "r" in d_4. *Can the signal and "r" collide in the 3D space of "r" if they do not collide in ES?* Problem 2: A rocket moves along a guide wire. The wire moves in d_4. The rocket's speed in d_4 is less than c. *Doesn't the guide wire eventually escape from the rocket?* Problem 3: Earth orbits the sun. The sun moves in d_4. Earth's speed in d_4 is less than c. *Doesn't the sun eventually escape from Earth?*

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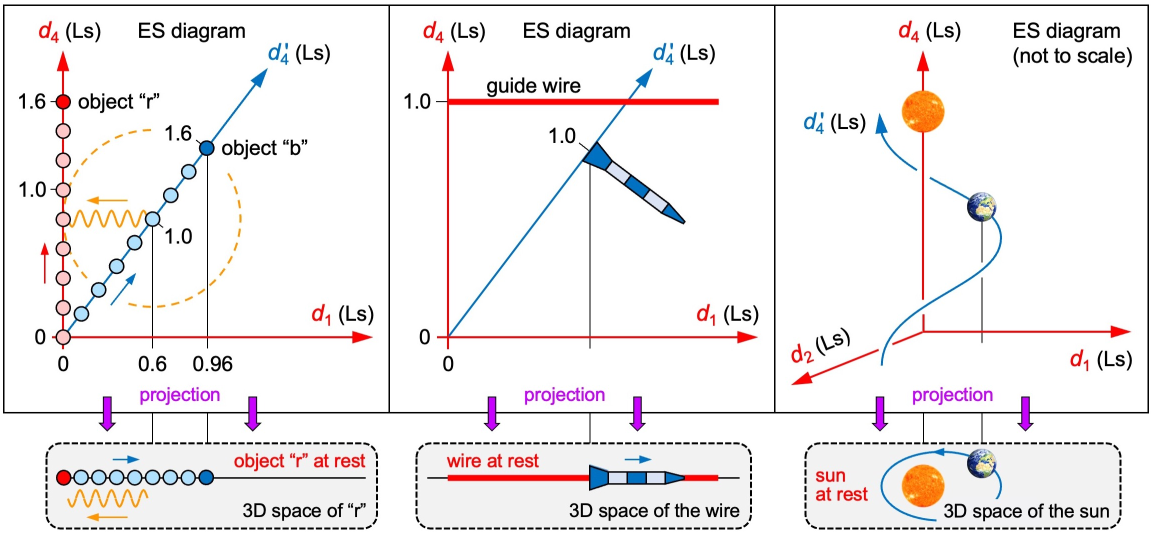

Fig. 4 Three problems. **Left:** Two objects move through ES. The circle shows where a signal emitted by "b" at $d'_4 = 1.0$ Ls is when another 0.6 s have elapsed in θ. In ES, the signal and "r" do not collide. In the 3D space of "r", they do. **Center:** In ES, the wire escapes from the rocket. In the 3D space of the wire, it does not. **Right:** In ES, the sun escapes from Earth. In the 3D space of the sun, it does not

The last paragraph seems to reveal paradoxes. The fallacy lies in assuming that all four axes of ES are experienced as spatial. We solve all problems by projecting ES onto the 3D space of that object which moves in d_4 at the speed c. In Fig. 4 left, the signal collides with "r" in the 3D space of "r" when their positions in d_1, d_2, d_3, θ coincide. In the projection to 3D space, d_4 is projected away. As in SR, collisions do not require the same position in τ. The collision occurs when 1.6 s have elapsed in θ since "r" and "b" left the origin. The collision also occurs in the 3D space of the signal (not shown), where "r" reverses its motion at $\theta = 1.0$ s. *Events and thus causality manifest themselves in θ and not in τ*. Collisions in 3D space do not show up as collisions in ES because θ is not a coordinate. In Fig. 4 right, sun and Earth age in different and changing 4D directions. This information is not available in SR/GR. ***ES diagrams do not show events, but the flow of proper time.***

5. Experimental Evidence for Euclidean Relativity

In § 22 of GR [2], Einstein mentions three tests for GR: gravitational redshift (see Sect. 5.2), deflection of starlight, and the precession of Mercury's perihelion. Montanus [10] showed that a Euclidean metric predicts the same deflection and the same precession as GR. He did not use θ as the parameter, but t (see page 13 of [10]). Since spacetime in GR is locally Minkowskian, thus locally $d\theta = dt$ (see the end of Sect. 3), we conclude: For objects of a local group on cosmic scales (sun, Mercury, Earth), t is as good a parameter as θ. Thus, ER passes the latter two tests. On top, ER predicts the following observations.

5.1. Time's Arrow

"Time's arrow" stands for time that flows only forward. Why can't it flow backward? θ is an object's total distance traveled in ES divided by c. τ is an object's current distance traveled in d_4 divided by c. "Distance traveled" can increase, but never decrease.

5.2. Gravitational Redshift

Gravitational redshift is the decrease in frequency of radiation emerging from a gravitational well. Frequency is related to time. Since ER locally confirms the gravitational time dilation of GR (see Sect. 4), ER locally predicts the same gravitational redshift as GR.

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5.3. Cosmic Microwave Background (CMB)

In Sects. 5.3 to 5.9, I outline an "ER-based model of cosmology", in which the Big Bang can be localized: It injected a huge amount of energy into ES at an origin O. Cosmic time θ has been ticking uniformly since the Big Bang. *The Big Bang was a singularity in providing energy and radial momentum.* Ever since the Big Bang ($\theta = 0$), this energy has been moving through ES at the speed c. Shortly after $\theta = 0$, all energy was highly concentrated. While it receded from O, it became less concentrated and reduced to plasma particles in 3D space. Recombination radiation was emitted that we observe as CMB today [25].

The ER-based model must be able to answer these questions: (1) Why is the CMB so isotropic? (2) Why is the CMB temperature so low? (3) Why do we still observe the CMB today? Some possible answers: (1) The CMB is scattered equally in d_1, d_2, d_3, the 3D space of Earth. (2) The plasma particles receded at a very high speed in d_1, d_2, d_3 (Doppler red-shift, see Sect. 5.9). (3) Some of the recombination radiation hits Earth after having traveled the same distance in d_1, d_2, d_3 (multiple scattering) as Earth in d_4.

5.4. Hubble–Lemaître Law

Earth and a galaxy G recede from the origin O of ES at the speed c (see Fig. 5 left). G also recedes from Earth's d_4 axis at the speed u_1. Distance D (or D_0) is the distance of G to Earth in the 3D space of Earth at the time θ (or else θ_0). Because of the 4D Euclidean geometry, u_1 is to D as c is to the radius r of an expanding 4D hypersphere. All injected energy is within this 4D hypersphere. Most energy is in its 3D hypersurface. An object can change its direction of 4D motion continuously because of a transversal acceleration (scattering, gravitational field) or discontinuously (photon emission, pair production).

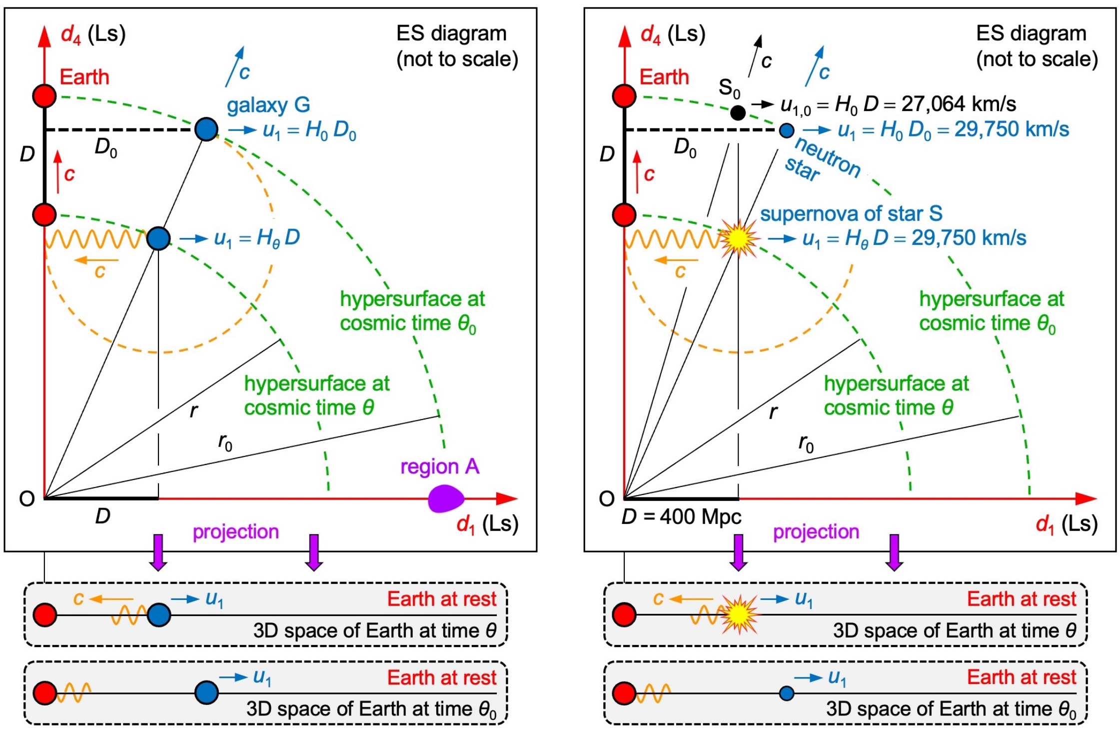

Fig. 5 ER-based model of cosmology. The orange circles show where most of the energy emitted by G or S at the time θ is today at θ_0. The green arcs show parts of a 3D hypersurface. **Left:** G recedes from O at the speed c and from the d_4 axis at the speed u_1. **Right:** If S_0 happens to be at the same distance D today at which the supernova of S occurred, S_0 recedes more slowly from d_4 than S

$$u_1 \;=\; D\,c/r \;=\; H_\theta\, D\;, \tag{19}$$

where $H_\theta = c/r = 1/\theta$ is the Hubble parameter. If we observe G today at the cosmic time θ_0, the recession speed u_1 and c remain unchanged. Thus, Eq. (19) turns into

$$u_1 = D_0\, c/r_0 = H_0\, D_0 \; , \tag{20}$$

where $H_0 = c/r_0 = 1/\theta_0$ is the Hubble constant, $D_0 = D\, r_0/r$, and r_0 is today's radius of the 4D hypersphere. Eq. (20) is an improved Hubble–Lemaître law [26, 27]. Cosmologists are well aware of θ and H_θ. They are not yet aware (a) that the 4D geometry is Euclidean, (b) that θ is absolute, and (c) that Eq. (20) relates proper speed u_1 to D_0. Eq. (19) relates u_1 to D, but H_θ is not a constant. *Of two galaxies, the one farther away recedes faster, but each galaxy maintains its recession speed.* G moves in d_1 at the speed u_1. Thus, it moves in d_4 at the speed $(c^2 - u_1^2)^{0.5}$. Thus, a clock in G is slow with respect to a clock on Earth in d_4 by $c/(c^2 - u_1^2)^{0.5} = \gamma_{\mathrm{ER}}$. The d_4 values of Earth and ΔE (energy emitted by G at the time θ) never match. *Can ΔE and Earth collide in the 3D space of Earth if they do not collide in ES?* As in Fig. 4 left, collisions in 3D space do not show up as collisions in ES. ΔE collides with Earth when ΔE has traveled the same distance in $-d_1$ as Earth in $+d_4$.

5.5. Flat Universe

An object's reality is made up by two orthogonal projections from ES. Thus, it experiences two independent structures: a flat "universe" (its proper space) and its proper time. This is true even if an object's worldline in ES is curved, as for clock "b" in Fig. 3. We use "universe" as another synonym of "proper space" and "3D space".

5.6. Large-Scale Structures

Most cosmologists [28, 29] believe that an inflation of space shortly after the Big Bang is responsible for the isotropic CMB, the flat universe, and large-scale structures. The latter are said to have inflated from quantum fluctuations. I showed that ER predicts the isotropic CMB and the flat universe. ER predicts large-scale structures if the quantum fluctuations expand together with the 3D hypersurface. ***ER does not require cosmic inflation.***

5.7. Cosmic Homogeneity (Horizon Problem)

How can the universe be so homogeneous if there are causally disconnected regions? In the Lambda-CDM model, region A at $x_1 = +r_0$ and region B at $x_1 = -r_0$ are causally disconnected unless we postulate cosmic inflation. Otherwise, an exchange of information would not have been possible. In the ER-based model, A is at $d_1 = +r_0$ (see Fig. 5 left) and B is at $d_1 = -r_0$ (not shown). A and B experience d_1 (equal to their d_4') as their time axis. For A and for B, the d_4' axis disappears because of length contraction at the speed c. *From their perspective, A and B have never been separated spatially, but their proper time flows in opposite 4D directions.* This is how A and B are causally connected. Their opposite 4D vectors $\boldsymbol{\tau}$ do not affect causal connectivity as long as A and B stay together spatially.

5.8. Hubble Tension

Up next, I show that ER predicts the 10 percent discrepancy in the published values of H_0 (known as the "Hubble tension"). We consider CMB measurements and distance ladder measurements. The values do not match: $H_0 = 67.66 \pm 0.42$ km/s/Mpc according to team A [30], and $H_0 = 73.04 \pm 1.04$ km/s/Mpc according to team B [31]. Team B made efforts to minimize the error margins in the distance measurements, but there is a systematic error in its calculation. The error lies in assuming a wrong cause of the redshifts.

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We assume that team A's value of H_0 is correct. We simulate the supernova of a star S that occurred at a distance of $D = 400$ Mpc from Earth (see Fig. 5 right). The recession speed of S is calculated from the measured redshift. The redshift parameter $z = \Delta\lambda/\lambda$ tells us how each wavelength λ of the supernova's light is either stretched by an "expanding space" (team B) or else Doppler-redshifted by receding objects (ER-based model). The supernova occurred at the time θ, but we observe it today at the time θ_0. While the supernova's light moved the distance D in $-d_1$, Earth moved the same distance D, but in $+d_4$. This is because the light and Earth move at the same speed through ES.

According to Eq. (19), we now plot u_1 versus D for distances from 0 Mpc to 500 Mpc in steps of 25 Mpc (red points in Fig. 6). The slope of a straight-line fit through the origin is roughly 10 percent higher than H_0. This is because H_θ is not a constant. The red points tell us: If we compare the supernovae of two stars S and S′, the star farther away from Earth recedes at a higher speed. And yet, each star maintains its recession speed. As shown in Sect. 4, $u_1 = v_1$ for uniformly moving objects. Thus, u_1 in our plot is equal to v_1 calculated from the measured redshift. According to Eq. (20), we have to plot u_1 versus D_0 to get a straight line (blue points). Since team B does not take Eq. (20) into account, its value of H_0 is roughly 10 percent too high. *Ignoring the 4D Euclidean geometry in the distance ladder measurements overestimates the value of* H_0. This explains the Hubble tension.

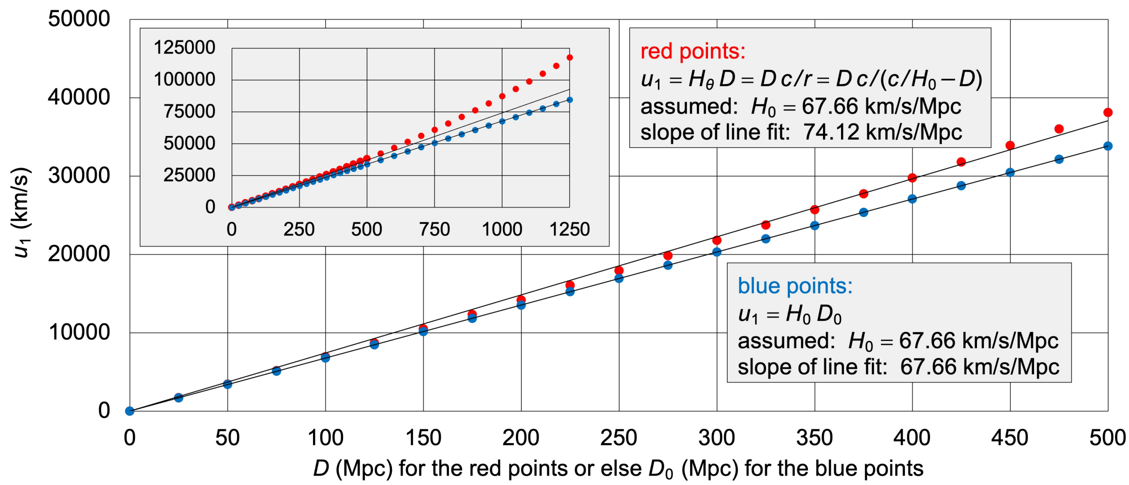

Fig. 6 Hubble diagram of simulated supernovae. The red points, calculated from Eq. (19), do not yield a straight line because u_1 is not proportional to D, but to $D/(c/H_0 - D)$. The blue points, calculated from Eq. (20), yield a straight line because u_1 is proportional to D_0

Eq. (20) requires the knowledge of D_0, but measurable magnitudes of supernovae are related to D. We solve this technical difficulty by rewriting Eq. (20) as

$$u_{1,0} \;=\; D\,c/r_0 \;=\; H_0\,D \;, \tag{21}$$

where $u_{1,0}$ is the recession speed in d_1 of a star S_0 that happens to be at the same distance D today at which the supernova of S occurred (see Fig. 5 right). We calculate

$$H_\theta \;=\; c/r \;=\; c/(r_0 - D) \;=\; H_0/(1 - H_0\,D/c) \;. \tag{22}$$

By inserting Eqs. (19) and (21) into Eq. (22), we obtain

$$u_{1,0} \;=\; u_1/(1 + u_1/c) \;=\; v_1/(1 + v_1/c) \;. \tag{23}$$

We kindly ask team B to recalculate its value of H_0 after converting all calculated v_1 to $u_{1,0}$ according to Eq. (23). Because of Eq. (21), team B gets a straight line and the correct value of H_0 when plotting $u_{1,0}$ versus D. Fig. 6 also tells us: The more high-redshift data are included in team B's calculation, the more the Hubble tension increases.

5.9. Cosmological Redshift

I now identify a second systematic error. This error is even more serious than the one in team B's value of H_0. It concerns the supposedly "accelerating expansion of space" and cannot be resolved within the Lambda-CDM model unless we postulate dark energy. Most cosmologists [32, 33] believe in an accelerating expansion of space because the recession speeds increasingly deviate from a straight line when plotted versus distance D. Indeed, an accelerating expansion of space would stretch each wavelength further, thus causing these deviations. In the Lambda-CDM model, the moment of the supernova is irrelevant. All that matters is the duration of the light's journey to Earth.

In the ER-based model, all that matters is the moment of the supernova. Its light is redshifted by the Doppler effect. The longer ago a supernova occurred, the more H_θ deviates from H_0, and thus the more u_1 deviates from $u_{1,0}$. If a star S_0 happens to be at the same distance of $D = 400$ Mpc today at which the supernova of S occurred, Eq. (23) tells us: S_0 recedes more slowly (27,064 km/s, shortest arrow in Fig. 5 right) from d_4 than S (29,750 km/s). *It does so because of the 4D Euclidean geometry.* The 4D vector $\boldsymbol{\tau}'$ of S_0 deviates less from $\boldsymbol{\tau}$ of Earth than $\boldsymbol{\tau}''$ of S deviates from $\boldsymbol{\tau}$. Dark energy [34] is held responsible for an accelerating expansion of space, but this is a stopgap solution for an effect that the Lambda-CDM model cannot explain. Supernovae occurring earlier in θ recede faster because of a greater value of H_θ in Eq. (19) and not because of a dark energy.

Cosmological redshift and the Hubble tension have the same physical background: In Eq. (20), we must not confuse D_0 with D. Because of Eq. (19) and $H_\theta = c/(r_0 - D)$, u_1 is not proportional to D, but to $D/(c/H_0 - D)$. This is why the red points in Fig. 6 deviate from a straight line. Any expansion of space—uniform or accelerating expansion—is only virtual even if the Nobel Prize in Physics 2011 was awarded "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae". This particular prize was awarded for an illusion that stems from man-made, coordinate time. Most galaxies recede from Earth, but they do so uniformly in a non-expanding space. I can imagine that this insight will provoke controversy, but ER clearly identifies dark energy, the driving force behind a supposedly accelerating expansion, as an illusion. Space cannot expand. With respect to what could space expand? Energy recedes from the location of the Big Bang in ES. ***ER requires neither expanding space nor dark energy.***

Cosmological redshift and the Hubble tension are strong experimental evidence that challenges the Lambda-CDM model. They force us to take the 4D Euclidean geometry into account, and $\boldsymbol{\tau}$ in particular. GR works well as long as $\boldsymbol{\tau}$ is irrelevant, but $\boldsymbol{\tau}$ is relevant for high-redshift supernovae: Their $\boldsymbol{\tau}'$ deviates significantly from $\boldsymbol{\tau}$ of Earth. Space is not driven by dark energy. Each galaxy is driven by its momentum and maintains its recession speed u_1 with respect to Earth. Because of various effects (scattering, gravitational field, photon emission, pair production), the 4D motion of some energy deviates from receding radially from the origin O of ES. Gravitational attraction enables near-by galaxies to move toward our galaxy. Table 1 compares two models of cosmology. The ER-based model does not require cosmic inflation, expanding space, and dark energy. Thus, cosmology benefits greatly from ER. Up next, I show that QM also benefits greatly from ER.

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Inflationary Lambda-CDM model based on GR	ER-based model of cosmology
The Big Bang was the beginning of the Universe.	The Big Bang was an injection of energy into ES.
The Big Bang occurred "everywhere".	The Big Bang can be localized (origin O of ES).
There are competing values of H_0.	H_0 is approximately 67–68 km/s/Mpc.
Spacetime is non-Euclidean.	Spacetime is Euclidean.
Gravity is the curvature of spacetime.	Gravity is a force.
There is no absolute time.	Cosmic time is absolute.
Shortly after the Big Bang, space was inflating.	There is no inflation of space.
Today, there is an accelerating expansion of space.	There is no expansion of space.
Dark energy causes the accelerating expansion.	There is no dark energy.

Table 1 Comparing two models of cosmology

5.10. Wave–Particle Duality

The wave–particle duality was first discussed by Niels Bohr and Werner Heisenberg [35]. It has bothered physicists ever since. In some experiments, objects behave like waves. In others, the same objects behave like particles (known as the "wave–particle duality"). One object cannot be both because waves are distributed in 3D space and capable of interference, while particles are localized in 3D space and incapable of interference. To resolve the duality, we need ER and the concept of wavematter. In ER, different 3D spaces—and thus *different projections* of a particular wavematter—can be observed. In an observer's 3D space, a wavematter reduces to a wave packet if not tracked or else to a particle if tracked. In its own 3D space, a wavematter always reduces to a particle.

In Fig. 7, observer R moves in the d_4 axis at the speed c. Three wavematters WM_1, WM_2, and WM_3 move in different 4D directions at the speed c. WM_1 does not move relative to R. It is automatically tracked and reduces to a particle (P_1). In the 3D space of R, WM_2 and WM_3 reduce to wave packets ($\mathrm{W}_2, \mathrm{W}_3$) if not tracked or else to particles ($\mathrm{P}_2, \mathrm{P}_3$) if tracked. In the 3D space of R, W_2 moves at a speed less than c. W_2 is what Louis de Broglie called "matter wave" [18]. Erwin Schrödinger initially understood his equation as a description of matter waves [36]. In the 3D space of R, W_3 and P_3 move at the speed c. WM_3 is the only wavematter that reduces to an electromagnetic wave packet (W_3) or else to a photon (P_3). Light gives us an idea of what wavematters are like.

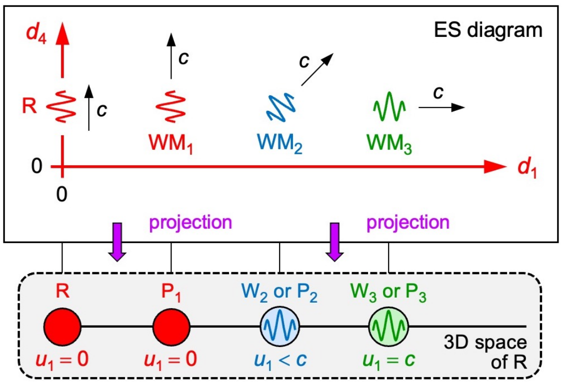

Fig. 7 Wavematters. Observer R moves in the d_4 axis. In his 3D space, WM_2 and WM_3 reduce to wave packets ($\mathrm{W}_2, \mathrm{W}_3$) if not tracked or else to particles ($\mathrm{P}_2, \mathrm{P}_3$) if tracked. P_1: possibly an atom of R. W_2: matter wave. P_2: possibly a moving atom. W_3: electromagnetic wave packet. P_3: photon

Remarks: (1) "Wavematter" is not just a new word for the duality. It is a new concept, which tells us where the duality comes from and that it is experienced by observers only. (2) In SR/GR, we cannot assign a reference frame to a photon. Only in ER can we assign a

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proper space and a proper time to each object. The new concept of wavematter enables us to treat all objects equally. Isn't it enriching to learn that particles, matter waves, photons, and electromagnetic waves all originate from a common concept? (3) Einstein taught that energy and mass are equivalent [37]. The concept of wavematter stands for precisely this equivalence: the equivalence of a wave's energy and a particle's mass.

In double-slit experiments, light creates an interference pattern on a screen if one does not track which slit discrete portions of energy pass through. The same applies to material objects, such as electrons [38]. *Here wavematters behave like waves.* In the photoelectric effect, an electron is released from a metal surface when the energy of an incident photon exceeds the binding energy of that electron. The photon–electron interaction reveals their current position. Thus, both photon and electron are tracked. *Here wavematters behave like particles.* Since an observer automatically tracks all objects that are slow in his 3D space, he classifies slow objects—and thus macroscopic objects—as matter. For better readability, some of my ES diagrams do not show wavematters, but how they appear to observers.

5.11. Quantum Entanglement

It was Erwin Schrödinger who coined the word "entanglement" in his comment [39] on the Einstein–Podolsky–Rosen paradox [40]. The three authors argued that QM would not provide a complete description of reality. Schrödinger's neologism does not resolve the paradox, but it demonstrates our difficulties in comprehending QM. John Bell [41] showed that QM is incompatible with local hidden-variable theories. Meanwhile, it has been confirmed in several experiments [42–44] that entanglement violates locality in an observer's *3D space.* Entanglement has been interpreted as a non-local effect ever since.

Up next, I show that ER untangles entanglement without the concept of non-locality. There is no violation of locality in a *4D manifold,* where all four axes are fully symmetric. In Fig. 8, observer R moves in the d_4 axis at the speed c. There are two pairs of wavematters. One pair was created at the point P and moves in opposite directions $\pm d_4'$ (equal to $\pm d_1$ of R) at the speed c. The other pair was created at the point Q and moves in opposite directions $\pm d_4''$ at the speed c. In the 3D space of R, one pair reduces to entangled photons. The other pair reduces to entangled material objects, such as electrons. R has no idea how entangled objects are able to "communicate" with each other in no time.

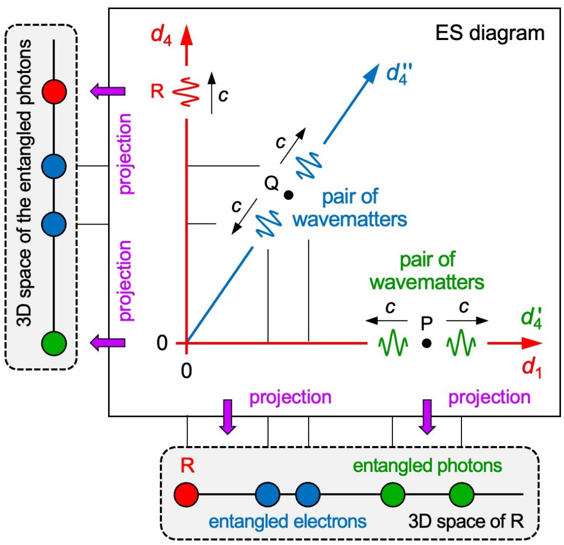

Fig. 8 Entanglement. Observer R moves in the d_4 axis. In the 3D space of R, one pair of wavematters reduces to entangled photons. The other pair reduces to entangled electrons. In the photons' 3D space (or electrons' 3D space, not shown), the photons (or else electrons) stay together

For the two photons (or the two electrons), the d_4' (or else d_4'') axis disappears because of length contraction at the speed c. For each pair, we can say: The twins stay together in their common 3D space. *From their perspective, entangled objects have never been separated spatially, but their proper time flows in opposite 4D directions.* This is how entangled objects are able to communicate with each other in no time. Their opposite 4D vectors $\boldsymbol{\tau}$ do not affect local communication as long as the twins stay together spatially. There is a "spooky action at a distance" (a phrase attributed to Albert Einstein) for observers only.

Entanglement and the horizon problem have the same physical background: An observed object's (or region's) 4D vector $\boldsymbol{\tau}'$ and its 3D space can differ from the observer's 4D vector $\boldsymbol{\tau}$ and his 3D space. This is possible, but only in ES, where all four axes are fully symmetric. The SO(4) symmetry of ES predicts the entanglement of photons and material objects [45]. Any measurement terminates the existence of one twin or tilts the axis of its 4D motion. The entanglement is destroyed. ***ER does not require non-locality.***

5.12. Baryon Asymmetry

In the Lambda-CDM model, almost all matter was created shortly after $\theta = 0$ when the high temperature enabled pair production. This process creates equal amounts of particles and antiparticles. Annihilation destroys equal amounts of particles and antiparticles. Why do we observe more baryons than antibaryons (known as the "baryon asymmetry")? In the ER-based model, wavematters reduce to wave packets or else to particles in an observer's 3D space. Pair production creates particles and antiparticles that annihilate each other very soon. Thus, there is one source of *long-lived particles* (reduction of wavematters), one source of *short-lived particles* (pair production), but only one source of *short-lived antiparticles* (pair production). This explains the baryon asymmetry. Why don't wavematters reduce to antiparticles? Obviously, this was not intended by nature.

ER also tells us why an antiparticle's proper time seems "to flow backward": Proper time flows in opposite 4D directions for any two wavematters created in pair production. ER predicts that these two wavematters are entangled. This gives us a chance to falsify ER. Scientific theories must be falsifiable [46]. Note that objects moving in $-d_4$ are not necessarily antiparticles. Their 4D vector $\boldsymbol{\tau}'$ is reversed with respect to $\boldsymbol{\tau}$ of an observer moving in $+d_4$, but their physical charges are not necessarily reversed.

6. Conclusions

Today's physics lacks two qualities of time: absolute and vectorial. In ER, there is absolute time θ separating absolute past, present, and future. There is also a 4D vector "flow of proper time" $\boldsymbol{\tau}$. In SR/GR, there is no absolute time θ and no 4D vector $\boldsymbol{\tau}$. Information hidden in θ or $\boldsymbol{\tau}$ is not available in SR/GR. In ER, the reference frame of a uniformly moving object is rotated with respect to an observer's frame (see Fig. 1 right). In SR, it is sheared (see Fig. 1 left). Causality manifests itself in θ (ER) or else in t (SR).

ER confirms the Lorentz factor of SR and—only locally—the gravitational time dilation of GR. Thus, the predictions made by SR are exact, while either GR or ER is an approximation. GR is probably that approximation because absolute θ suits QM better than relative t. For instance, time is not an operator in the Schrödinger equation, but acts as an external, universal parameter. In ER, θ is this parameter. In GR, there is no such parameter. I doubt that 12 predicted observations in *different* areas of physics (cosmology, QM, particle physics) are 12 coincidences. Some observations can be predicted without ER, but only by adding highly speculative concepts (cosmic inflation, expanding space, dark energy, non-locality). ER requires none of them. Occam's razor shaves them all off. No exceptions.

It was a wise decision to award Einstein the Nobel Prize for his theory of the photoelectric effect [47] and not for SR/GR. ER penetrates to a deeper level. Einstein, one of the most brilliant physicists ever, did not realize that nature's fundamental metric is Euclidean. Einstein sacrificed absolute space and absolute time. ER reinstates absolute space (not 3D space, but 4D space) and absolute time (not coordinate time, but parameter time). Yet ER sacrifices the absoluteness of particles, matter waves, photons, electromagnetic waves. In retrospect, man-made, coordinate time delayed the formulation of ER. For the first time ever, humanity understands the nature of time: *Cosmic time is an object's total distance traveled in ES divided by the speed of light* c*.* The human brain is able to imagine that we all move at the speed c. With that said, conflicts of humanity become all so small.

Is ER a physical or a metaphysical theory? That is a very good question because only in proper coordinates can we access ES, but the proper time ticking for another object cannot be measured. And yet, it can be calculated from ES diagrams, as I showed in Eq. (14b). The problem with coordinate time is persistent: t is incompatible with Master Diagrams. These diagrams display a mathematical reality beyond all observers' realities. Observing wavematters or measuring their coordinates is equivalent to projecting them from ES. In an observer's 3D space, they reduce to wave packets or else to particles. This reminds me of collapsing wave functions. Observing is our primary source of knowledge, but concepts derived from observing can be deficient. Physics is not all about observing. For instance, we cannot observe time. t works well in everyday life, but unfortunately t has also been applied to the very distant and the very small. This is why cosmology and QM benefit most from ER. *ER is a physical theory because it predicts what we observe.*

It seems as if Plato had anticipated ER in his *Cave Allegory* [48]: Humanity experiences projections and cannot observe a reality beyond. I laid the groundwork for ER and showed how powerful it is. Paradoxes are only virtual. The key question in science is this: How do we describe nature without adding highly speculative concepts? The answer leads to the truth. The pillars of physics are ER, SR/GR (for observers), and QM. Together, they describe nature from the very distant to the very small. Everyone is welcome to test the natural concepts of ER. For an experimental physicist like me, it makes perfect sense to work directly with natural, proper time measured by clocks. *Only in natural concepts does Mother Nature reveal her secrets.* Isn't it natural that she rewards an all-natural description?

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Comments: (1) Further studies on gravity are required, but this is no reason to reject ER. GR seems to explain gravity, but GR is incompatible with QM unless we add quantum gravity. I have not discussed the carriers of gravity. Gravitational waves could be these carriers. If not, postulating "dark carriers" would in no way be inferior to postulating "dark energy". (2) In ES, there are no singularities and thus no black holes. This is also no reason to reject ER. Singularities conflict with QM. Black holes could be projections of highly concentrated energy. (3) It often helps to match the symmetry. The symmetry of nature is SO(4). (4) Absolute time ends all discussions about time travel. Which theory explains time's arrow as beautifully as ER? (5) Physics does not ask: Why is reality a projection? Projections are far less speculative than cosmic inflation *plus* expanding space *plus* dark energy *plus* non-locality.

It takes open-minded editors and reviewers to evaluate a theory that heralds a paradigm shift. Taking SR and GR for granted paralyzes progress. I apologize for my numerous preprint versions, but

I received little support only. The preprints document my path. The final version is all that is needed. I did not surrender when top journals rejected ER. Interestingly, I was never given any solid arguments that would disprove ER. Instead, I was advised to consult experts or to submit to a different journal. Were the editors afraid of publishing against the mainstream? Did they underestimate the benefits of ER? I was told that predicting 12 observations all at once were too many to be trustworthy. I disagree. Paradigm shifts often yield several insights. Even good friends refused to support me. Every setback motivated me to formulate ER even better. Finally, I identified an issue in SR and GR.

A well-known preprint archive suspended my submission privileges. I was penalized because I showed that GR is not as general as it seems. I was told that I may only submit articles that have already appeared in a mainstream conventional journal. The editor-in-chief of a top journal replied: "Publishing is for experts only." One editor rejected ER because it would "demand too much" from his experts. Several journals rejected ER because it was "neither innovative nor significant". I do not blame anyone. Paradigm shifts are hard to accept. In the long run, ER will prevail simply because it predicts what we observe. These comments shall encourage young physicists to stand up for promising ideas even if it is hard work to oppose the mainstream: "unscholarly research", "fake science", "too simple to be true". *Simplicity and truth are not mutually exclusive. Beauty is when they go hand in hand together.*

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References

1. Einstein, A.: Zur Elektrodynamik bewegter Körper. Ann. Phys. **322,** 891–921 (1905)
2. Einstein, A.: Die Grundlage der allgemeinen Relativitätstheorie. Ann. Phys. **354,** 769–822 (1905)
3. Minkowski, H.: Die Grundgleichungen für die elektromagnetischen Vorgänge in bewegten Körpern. Math. Ann. **68,** 472–525 (1910)
4. Rossi B., Hall, D.B.: Variation of the rate of decay of mesotrons with momentum. Phys. Rev. **59,** 223–228 (1941)
5. Dyson, F.W., Eddington, A.S., Davidson, C.: A determination of the deflection of light by the sun's gravitational field, from observations made at the total eclipse of May 29, 1919. Phil. Trans. R. Soc. A **220,** 291–333 (1920)
6. Ashby, N.: Relativity in the global positioning system. Living Rev. Relativ. **6,** 1–42 (2003)
7. Ryder, L.H.: Quantum Field Theory. Cambridge University Press, Cambridge (1985)
8. Newburgh, R.G., Phipps Jr., T.E.: Physical Sciences Research Papers no. 401. United States Air Force (1969)
9. Montanus, H.: Special relativity in an absolute Euclidean space-time. Phys. Essays **4,** 350–356 (1991)
10. Montanus, H.: Proper Time as Fourth Coordinate. ISBN 978-90-829889-4-9 (2023). https://greenbluemath.nl/proper-time-as-fourth-coordinate/ (accessed 19 Oct 2025)
11. Montanus, J.M.C.: Proper-time formulation of relativistic dynamics. Found. Phys. **31,** 1357–1400 (2001)
12. Almeida, J.B.: An alternative to Minkowski space-time. arXiv:gr-qc/0104029 (2001)
13. Gersten, A.: Euclidean special relativity. Found. Phys. **33,** 1237–1251 (2003)
14. Hudgin, R.H.: Coordinate-free relativity. Synthese **24,** 281–297 (1972)
15. Misner, C.W., Thorne, K.S., Wheeler, A.: Gravitation. W. H. Freeman and Company, San Francisco (1973)
16. Sasane, A.: A Mathematical Introduction to General Relativity. World Scientific, Singapore (2022)
17. Michelson, A.A., Morley, E.W.: On the relative motion of the Earth and the luminiferous ether. Am J. Sci. **34,** 333–345 (1887)
18. de Broglie, L.: The reinterpretation of wave mechanics. Found. Phys. **1,** 5–15 (1970)
19. Church, A.E., Bartlett, G.M.: Elements of Descriptive Geometry. Part I. Orthographic Projections. American Book Company, New York (1911)
20. Nowinski, J.L.: Applications of Functional Analysis in Engineering. Plenum Press, New York (1981)
21. Wick, G.C.: Properties of Bethe-Salpeter wave functions. Phys. Rev. **96,** 1124–1134 (1954)

22. Wald, R.M.: General Relativity. The University of Chicago Press, Chicago (1984)
23. Abbott, B.P. *et al.*: Observation of gravitational waves from a binary black hole merger. Phys. Rev. Lett. **116,** 061102 (2016)
24. Hafele, J.C., Keating, R.E.: Around-the-world atomic clocks: predicted relativistic time gains. Science **177,** 166–168 (1972)
25. Penzias, A.A., Wilson, R.W.: A measurement of excess antenna temperature at 4080 Mc/s. Astrophys. J. **142,** 419–421 (1965)
26. Hubble, E.: A relation between distance and radial velocity among extra-galactic nebulae. Proc. Natl. Acad. Sci. U.S.A. **15,** 168–173 (1965)
27. Lemaître, G.: Un univers homogène de masse constante et de rayon croissant, rendant compte de la vitesse radiale des nébuleuses extra-galactiques. Ann. Soc. Sci. Bruxelles A **47,** 49–59 (1927)
28. Linde, A.: Inflation and Quantum Cosmology. Academic Press, Boston (1990)
29. Guth, A.H.: The Inflationary Universe. Perseus Books, New York (1997)
30. Aghanim, N. *et al.*: Planck 2018 results. VI. Cosmological parameters. Astron. Astrophys. **641,** A6 (2020)
31. Riess, A.G. *et al.*: A comprehensive measurement of the local value of the Hubble constant with 1 km s^{-1} Mpc^{-1} uncertainty from the Hubble Space Telescope and the SH0ES team. Astrophys. J. Lett. **934,** L7 (2022)
32. Perlmutter, S. *et al.*: Measurements of Ω and Λ from 42 high-redshift supernovae. Astrophys. J. **517,** 565–586 (1999)
33. Riess, A.G. *et al.*: Observational evidence from supernovae for an accelerating universe and a cosmological constant. Astron. J. **116,** 1009–1038 (1998)
34. Turner, M.S.: Dark matter and dark energy in the universe. arXiv:astro-ph/9811454 (1998)
35. Heisenberg, W.: Die physikalischen Prinzipien der Quantentheorie. Hirzel, Leipzig (1930)
36. Schrödinger, E.: An undulatory theory of the mechanics of atoms and molecules. Phys. Rev. **28,** 1049–1070 (1926)
37. Einstein, A.: Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig? Ann. Phys. **323,** 639–641 (1905)
38. Jönsson, C.: Elektroneninterferenzen an mehreren künstlich hergestellten Feinspalten. Z. Phys. **161,** 454–474 (1961)
39. Schrödinger, E.: Die gegenwärtige Situation in der Quantenmechanik. Naturwissenschaften **23,** 807–812 (1935)
40. Einstein, A., Podolsky, B., Rosen, N.: Can quantum-mechanical description of physical reality be considered complete? Phys. Rev. **47,** 777–780 (1935)
41. Bell, J.S.: On the Einstein Podolsky Rosen paradox. Physics **1,** 195–200 (1964)
42. Freedman, S.J., Clauser, J.F.: Experimental test of local hidden-variable theories. Phys. Rev. Lett. **28,** 938–941 (1972)
43. Aspect, A., Dalibard, J., Roger, G.: Experimental test of Bell's inequalities using time-varying analyzers. Phys. Rev. Lett. **49,** 1804–1807 (1982)
44. Bouwmeester, D. *et al.*: Experimental quantum teleportation. Nature **390,** 575–579 (1997)
45. Hensen, B. *et al.*: Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres. Nature **526,** 682–686 (2015)
46. Popper, K.: Logik der Forschung. Julius Springer, Vienna (1935)
47. Einstein, A.: Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt. Ann. Phys. **322,** 132–148 (1905)
48. Plato: Politeia, 514a