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Rethinking Our Concepts of Time

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In special relativity (SR) and general relativity (GR), there are two concepts of time: coordinate time t and proper time τ. Two facts deserve reflection: (1) Clocks measure τ, but τ is assigned a much smaller role in the equations of physics than t. (2) Cosmologists are aware of the Hubble parameter H_θ, but when parameterizing worldlines in spacetime, the parameter τ is preferred over $\theta = 1/H_\theta$. **Here we show:** There is a different description of nature that does not conflict with SR/GR. Euclidean relativity (ER) uses τ as a coordinate, θ as the "cosmic evolution parameter", and a Euclidean metric. All energy moves through 4D Euclidean space (ES) at the speed c. The laws of physics have the same form in each object's reference frame. An object's reference frame is spanned by its proper space and proper time. Each object experiences its 4D motion as proper time τ, which is the length of a 4D Euclidean vector "flow of proper time" $\boldsymbol{\tau}$. Any acceleration rotates an object's $\boldsymbol{\tau}$ and curves its worldline in flat ES. $\boldsymbol{\tau}$ proves crucial for objects that are very far away or entangled. Information hidden in θ and $\boldsymbol{\tau}$ is not available in SR/GR. ER solves 15 fundamental mysteries, such as the nature of time, the Hubble tension, the wave–particle duality, and the baryon asymmetry. On top, ER declares cosmic inflation, expanding space, dark energy, and non-locality obsolete.

Keywords: spacetime; cosmology; Hubble tension; dark energy; quantum mechanics; non-locality

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There are two approaches to describing nature: either in "empirical concepts" (based on observing) or else in "natural concepts" (inherent in all objects). Observing implies that the description may not be complete or that some of the applied concepts are obsolete. Special and general relativity (SR/GR) take the first approach [1, 2], but there is no absolute time in SR/GR and thus no "holistic view" (universal for all objects at the *same* instant in time). Euclidean relativity (ER) takes the second approach and provides a holistic view. In this paper, I show that natural concepts improve our understanding of nature. For a better readability, I refer to an observer as "he". To compensate, I refer to nature as "she".

A new theory of spacetime must either disprove SR/GR or else not conflict with SR/GR. Because of different concepts, ER does not conflict with SR/GR. However, ER tells us that the scope of SR/GR is limited: We must apply ER to objects that are very far away (such as high-redshift supernovae) or entangled (moving in opposite 4D directions at the speed c). In such extreme situations, the 4D vector "flow of proper time" of ER is crucial. ER raises questions: (1) *Does ER predict the same relativistic effects as SR/GR?* Yes, the Lorentz factor and gravitational time dilation are recovered in ER. (2) *What are the benefits of ER?* It solves mysteries of cosmology and quantum mechanics (QM). (3) *Does ER also make quantitative predictions?* Yes, it predicts the 10 percent deviation in the published values of H_0.

Request to editors/reviewers: (1) *Please read carefully.* I do not disprove SR/GR. I show that the scope of SR/GR is limited. (2) *Do not reject ER without disproving ER.* A new theory deserves full consideration unless it can be disproven. (3) *Do not apply the concepts of SR/GR to ER.* One reviewer argued that spacetime cannot be Euclidean because it is non-Euclidean in SR/GR. According to this logic, Earth cannot orbit the sun because it does not orbit the sun in the geocentric model. (4) *Appreciate illustrations.* As a geometric theory, ER complies with the stringency of math. (5) *Be fair.* One paper cannot cover all of physics. Despite some unanswered questions, ER is very promising because it solves 15 mysteries.

1. Introduction

Today's concepts of space and time were coined by Albert Einstein. In SR, space and time are fused into a flat spacetime described by the Minkowski metric. SR is often presented in Minkowski spacetime [3]. Predicting 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 high accuracy of GPS [6] are two examples that support GR. Quantum field theory [7] unifies classical field theory, SR, and QM, but not GR.

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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). The constraint is obsolete. Whatever is proper time to me, it can be one axis of proper space for you. There are no distant collisions once we take projections into account. There is no character paradox once we take the 4D vector "flow of proper time" (see Sect. 3) into account. Not only the proper time of an antiparticle can flow backward, but also that of a particle (see Sect. 5.15). Montanus verified the precession of Mercury's perihelion in ER [10] and other effects [11], but he failed to derive Maxwell's equations because of a wrong sign [10]. Montanus used coordinate time as the parameter. The correct parameter in ER is cosmic time.

Almeida [12] studied geodesics in ER. Gersten [13] showed that the Lorentz transformation is an SO(4) rotation. There is a website about ER: https://euclideanrelativity.com/. Here is why theorists reject ER: (1) Dark energy and non-locality make cosmology and QM work. (2) The SO(4) symmetry in ER seems to exclude waves. (3) Paradoxes seem to arise. This paper marks a turning point. It shows that dark energy and non-locality are obsolete concepts, SO(4) is compatible with waves, and projections avoid paradoxes.

The two postulates of ER: (1) All energy moves through 4D Euclidean space (ES) at the speed of light c. (2) The laws of physics have the same form in each object's reference frame. An object's reference frame is spanned by its proper space and proper time. Unlike coordinate space and coordinate time in SR, proper space and proper time are assembled to a Euclidean spacetime. My first postulate is stronger than the second SR postulate: c is absolute and universal. My second postulate is not limited to inertial frames. The order of the postulates is reversed. Absoluteness comes first. Relativity comes second.

Fig. 1 left illustrates the reference frames of two objects in ES. Each object experiences that axis in which it moves at the speed c as its proper time. It experiences the other three axes as its proper space. Proper space and proper time make up its "reality". There are as many realities as there are objects. Mathematically, ES is 4D Euclidean space, and proper space/proper time are two orthogonal projections from ES. *Physically, only three axes of ES are experienced as spatial, one as temporal, and measuring an object's coordinates is equivalent to projecting it from ES to an observer's reality.* Fig. 1 right illustrates two approaches to describing nature. We must not play SR/GR and ER off against each other. The concepts of SR/GR do not apply to ER, and vice versa. ER solves mysteries that are rooted in ES.

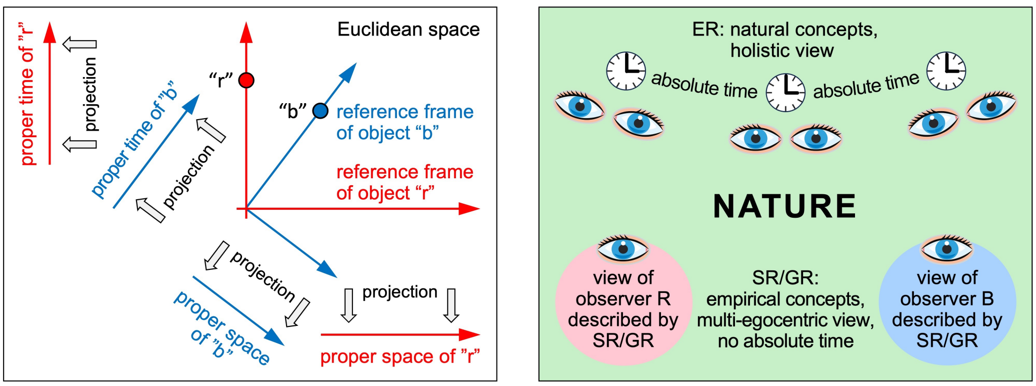

Fig. 1 Orthogonal projections and two approaches to describing nature. **Left:** How to project ES to an object's reality. **Right:** ER and SR/GR describe nature in different concepts

It is instructive to contrast Newton's physics, Einstein's physics, and ER. In Newton's physics, all energy moves through 3D Euclidean space as a function of independent time. There is no speed limit for matter. In Einstein's physics, all energy moves through a non-Euclidean spacetime. The 3D speed of matter is $v_{3D} < c$. In ER, all energy moves through ES. The 4D speed of all energy is c. Newton's physics [14] influenced many philosophers. I am convinced that ER will reform both physics and philosophy.

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2. Identifying an Issue in Special and General Relativity

The fourth coordinate in SR is an observer's coordinate time t. In § 1 of SR, Einstein gives an instruction for synchronizing clocks at the points P and Q. At t_{P}, a light pulse is sent from P to Q. At t_{Q}, it is reflected at Q. At t_{P}^*, it is back at P. The clocks synchronize if

$$t_{\mathrm{Q}} - t_{\mathrm{P}} = t_{\mathrm{P}}^* - t_{\mathrm{Q}} . \tag{1}$$

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

$$x_1' = \gamma\,(x_1 - v_{\mathrm{3D}}\,t) , \tag{2a}$$

$$x_2' = x_2 , \qquad x_3' = x_3 , \tag{2b}$$

$$t' = \gamma\,(t - v_{\mathrm{3D}}\,x_1/c^2) , \tag{2c}$$

where K′ moves relative to K in x_1 at the constant speed v_{3D} and $\gamma = (1 - v_{\mathrm{3D}}^2/c^2)^{-0.5}$ is the Lorentz factor. Mathematically, Eqs. (2a–c) are correct: They transform the coordinates from K to K′. There are covariant equations that transform the coordinates from K′ to K. Physically, there is an issue in SR and also in GR: *The empirical concepts of SR/GR fail to solve fundamental mysteries.* There are coordinate-free formulations of both SR and GR [15, 16], but there is no absolute time in SR/GR and thus no "holistic view" (I repeat the important definition: universal for all objects at the *same* instant in time). The view in SR/GR is "multi-egocentric": SR/GR work for all observers, but each observer's view is egocentric. All observers' views taken together do not make a holistic view because they still do not provide absolute time. Without absolute time, observers will not always agree on what is past and what is future. Physics paid a high price for dismissing absolute time: ER restores absolute time (see Sect. 3) and solves 15 mysteries (see Sect. 5). Thus, the issue is real.

The issue in SR/GR is not about making wrong predictions. It has much in common with the issue in the geocentric model: In either case, there is no holistic view. Geocentrism is the egocentric view of mankind. In the old days, it was natural to believe that all celestial bodies would orbit Earth. Only astronomers wondered about the retrograde loops of some planets and claimed that Earth orbits the sun. In modern times, engineers have improved rulers and clocks. Today, it is natural to believe that it would be fine to describe nature as accurately as possible, but in the empirical concepts of one or more observers. The human brain is smart, but it often takes itself as the center/measure of everything.

The analogy of the geocentric model to SR/GR is not perfect: Heliocentrism and geocentrism exclude each other. ER does not conflict with SR/GR. Nevertheless, the analogy is close: (1) After taking some other planet as the center of the Universe (or after a transformation in SR/GR), the view is still geocentric (or else egocentric). (2) Retrograde loops are obsolete in heliocentrism, but they make geocentrism work. Dark energy and non-locality are obsolete in ER, but they make cosmology and QM work. (3) Heliocentrism overcomes the limited perspective from Earth. ER overcomes the limited perspectives of observing. (4) The geocentric model was a dogma in the old days. SR and GR are dogmata nowadays. *Have physicists not learned from history? Does history repeat itself?*

3. The Physics of Euclidean Relativity

ER cannot be derived from measurement instructions because the proper coordinates of other objects cannot be measured. We start with the Minkowski metric of SR

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

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 an observer's coordinate space x_1, x_2, x_3 and coordinate time t. Coordinate spacetime x_1, x_2, x_3, t is an *empirical spacetime* because its coordinates

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are construed by an observer and thus not inherent in rulers and clocks. Rulers measure proper length. Clocks measure proper time. We introduce ER by its metric

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

where $\mathrm{d}\theta$ is an infinitesimal distance in the parameter θ, whereas all $\mathrm{d}d_i$ $(i = 1, 2, 3)$ and $\mathrm{d}d_4 = c\,\mathrm{d}\tau$ are infinitesimal distances in an object's (!) proper space d_1, d_2, d_3 and proper time τ. Observers are objects too. The fourth coordinate is τ. The invariant is θ. The metric tensor is the identity matrix. I prefer the indices 1–4 to 0–3 to stress the SO(4) symmetry. An object's proper space d_1, d_2, d_3 and proper time τ span its reference frame d_1, d_2, d_3, d_4 in 4D Euclidean space (ES), where $d_4 = c\tau$. The orientation of its reference frame in absolute ES can change. ES is experienced as a Euclidean spacetime (EST). EST is a *natural spacetime* because its coordinates are measured by and thus inherent in rulers and clocks. Intrinsic rulers and clocks of all objects measure distances in EST and not in coordinate spacetime! Do not confuse ER with a Wick rotation [17], which keeps τ invariant.

Montanus [9] distinguished "absolute Euclidean spacetime" (AEST) from a "relative Euclidean spacetime" (REST). His AEST is my ES. His REST is my EST. Montanus [9–11] promoted AEST, but he unnecessarily disqualified REST. He rejected the idea of four fully symmetric axes. I show: Whatever is proper time to me, it can be one axis of proper space (or a mix of proper space and proper time) for you. Montanus merely rearranged Eq. (3) to make the metric look Euclidean. He did not distinguish between t and θ.

Each object is free to label the axes of its reference frame. We assume: It labels the axis of its *current* 4D motion as d_4. Because of my first postulate, it thus always moves in the d_4 axis at the speed c. If the object moves along a curved worldline in ES, the orientation of its reference frame always adapts to the curvature as if the frame were gimbal-mounted to the origin of ES. Because of length contraction at the speed c (see Sect. 4), the d_4 axis disappears for itself and is experienced as proper time. Objects moving in the d_4' axis at the speed c experience the d_4' axis as proper time. Each object experiences its 4D motion as proper time τ, which is the length of a 4D Euclidean vector "flow of proper time" $\boldsymbol{\tau}$. Information hidden in θ and $\boldsymbol{\tau}$ is not available in SR/GR.

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

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

where $\boldsymbol{u}$ is an object's 4D velocity. In ER, speed is not defined as $v_i = \mathrm{d}x_i/\mathrm{d}t$ $(i = 1, 2, 3)$, but as $u_\mu = \mathrm{d}d_\mu/\mathrm{d}\theta$ $(\mu = 1, 2, 3, 4)$. Thus, Eq. (4) is nothing but my first postulate

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

Because of $t \neq \theta$, there is no continuous transition between Eqs. (3) and (4) nor between SR/GR and ER. This fact underlines that ER provides a unique description of nature. SR describes nature in empirical concepts $x_1(\tau), x_2(\tau), x_3(\tau), t(\tau)$, where τ is some object-related parameter. GR is locally equivalent to SR. ER describes nature in natural concepts $d_1(\theta), d_2(\theta), d_3(\theta), d_4(\theta)$, where θ is what I call the "cosmic evolution parameter". When parameterizing worldlines in spacetime, the parameter θ proves more powerful than τ. Only in proper coordinates can we access ES, but the proper coordinates of other objects cannot be measured. In my Conclusions, I will explain why this is fine.

It is instructive to contrast three concepts of time. t is a subjective measure of time: An observer uses his clock as the master clock. τ is an objective measure of time: Clocks measure τ independently of observers. θ is the total distance covered in ES (length of a worldline) divided by c. As the invariant in Eq. (4), θ is a concept of absolute time. This is why I also call it "cosmic time". By referring to θ, observers can agree on what is past and what is future. Regarding causality, a finite c is incompatible with a coordinate "absolute time". However, it is compatible with a parameter "absolute time".

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We consider two identical clocks "r" (red clock) and "b" (blue clock). In SR, "r" moves in the ct axis. Clock "b" starts at $x_1 = 0$ and moves in the x_1 axis at a constant speed of $v_{3D} = 0.6\,c$. Fig. 2 left shows the instant when either clock moved 1.0 Ls (light seconds) in ct. Clock "b" moved 0.6 Ls in x_1 and 0.8 Ls in ct'. It displays "0.8". In ER, "r" moves in the d_4 axis. Fig. 2 right shows the instant when either clock moved 1.0 s in its proper time. Both clocks display "1.0". Since "r" remains at $d_1 = 0$ and "b" remains at $d_1' = 0$, there is $\tau = \theta$ for "r" and $\tau' = \theta$ for "b" according to Eq. (4). *A uniformly moving clock always displays both its* τ *and* θ. However, τ is not invariant in ER. Thus, d_4 of "r" is not equal to d_4 of "b". In ER, θ is invariant. Thus, d_4 of "r" is equal to d_4' of "b".

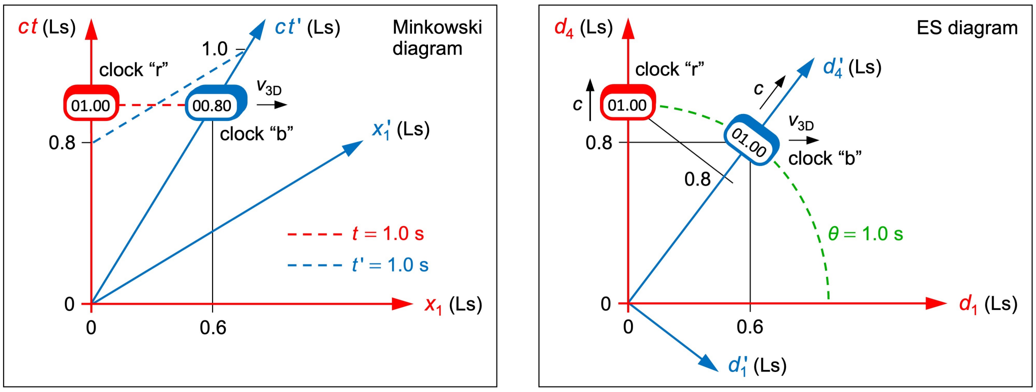

Fig. 2 Minkowski diagram and ES diagram of two clocks "r" and "b". **Left:** "b" is slow with respect to "r" in t'. Coordinate time is relative ("b" is at different positions in t and t'). **Right:** "b" is slow with respect to "r" in d_4. Cosmic time is absolute ("r" is in d_4 at the same position as "b" in d_4')

We now assume that an observer R (or B) moves with clock "r" (or else "b"). In SR and only from the perspective of R, clock "b" is at $ct' = 0.8$ Ls when "r" is at $ct = 1.0$ Ls (see Fig. 2 left). Thus, "b" is slow with respect to "r" in t' (of B). In ER and independently of observers, clock "b" is at $d_4 = 0.8$ Ls when "r" is at $d_4 = 1.0$ Ls (see Fig. 2 right). Thus, "b" is slow with respect to "r" in d_4 (of R). In SR and ER, "b" is slow with respect to "r", but time dilation occurs in different axes. Experiments do not disclose that axis in which a clock is slow. Thus, both SR and ER describe time dilation correctly if ER yields the same Lorentz factor as SR. In Sect. 4, I will show that this is the case.

Note that the Michelson–Morley experiment [18] refutes a 3D ether, but not absolute ES and its projections to an object's proper space and proper time. Note also that "relativity" has different connotations in SR and ER. In SR, spatial/temporal distances are relative: They depend on an observer's frame of reference. In ES, there are no spatial/temporal distances. All d_μ are "pure distances". Only objects/observers experience three axes of ES as spatial and one as temporal. However, the orientation of a frame of reference in ES is relative: It depends on an object's/observer's 4D vector $\boldsymbol{\tau}$. There is also a difference regarding clock synchronization: In SR, R synchronizes clock "b" to his clock "r" (same value of ct in Fig. 2 left). If he does, the clocks are not synchronized for B. In ER and independently of observers, clocks with the same $\boldsymbol{\tau}$ are naturally synchronized, while clocks with different $\boldsymbol{\tau}$ and $\boldsymbol{\tau}'$ are never synchronized (different values of d_4 in Fig. 2 right).

But why does ER provide a holistic view? Eq. (4) is symmetric in all d_μ ($\mu = 1, 2, 3, 4$). R and B experience different axes as temporal. This is why Fig. 2 left works for R, but not for B: A second Minkowski diagram is required, where x_1' and ct' are orthogonal. *Here the view is multi-egocentric.* In contrast, Fig. 2 right works for R and for B at once (at the same cosmic time): Not only are d_1 and d_4 orthogonal, but also d_1' and d_4'. ES is independent of observers and thus absolute. *Here the view is universal and thus holistic.*

Regarding waves, I was misled by editors who insisted that the SO(4) symmetry of ES is incompatible with waves. SO(4) is incompatible with waves that propagate as a function of a coordinate time t, but compatible with waves that propagate as a function of the cosmic evolution parameter θ. This is because Eq. (4) can be rewritten as

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$$c^2\,\mathrm{d}\tau^2 \;=\; c^2\,\mathrm{d}\theta^2 - \mathrm{d}d_1^2 - \mathrm{d}d_2^2 - \mathrm{d}d_3^2 \;, \tag{4*}$$

which is of the same form as Eq. (3). A big advantage of mathematics is that it remains the same when we replace the variables. Maxwell's equations thus have the same form in ER as in today's physics except that θ replaces t and waves can propagate in one out of four axes. I claim: *All objects are "wavematters" (pure energy) that propagate through and oscillate in ES as a function of the parameter* θ. I will give evidence of my claim in Sect. 5.13.

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'). *We use "3D space" as a synonym of proper space.* The proper time of R (or B) relates to d_4 (or else d_4') according to Eq. (5). Both rockets start at the same point P and at the same cosmic time θ_0. They move relative to each other at the constant speed v_{3D}. R and B are free to label the axis of relative motion in 3D space. R (or B) labels it as d_1 (or else d_1'). The ES diagrams in Fig. 3 must fulfill my two postulates and the initial conditions (same P, same θ_0). This is achieved by rotating the red and the blue frame with respect to each other. Do not confuse ES diagrams with Minkowski diagrams. *In ES diagrams, objects maintain proper length and clocks display proper time.* For a better readability, a rocket's width is drawn in d_4 (or d_4'), although its width is in d_2, d_3 (or else d_2', d_3').

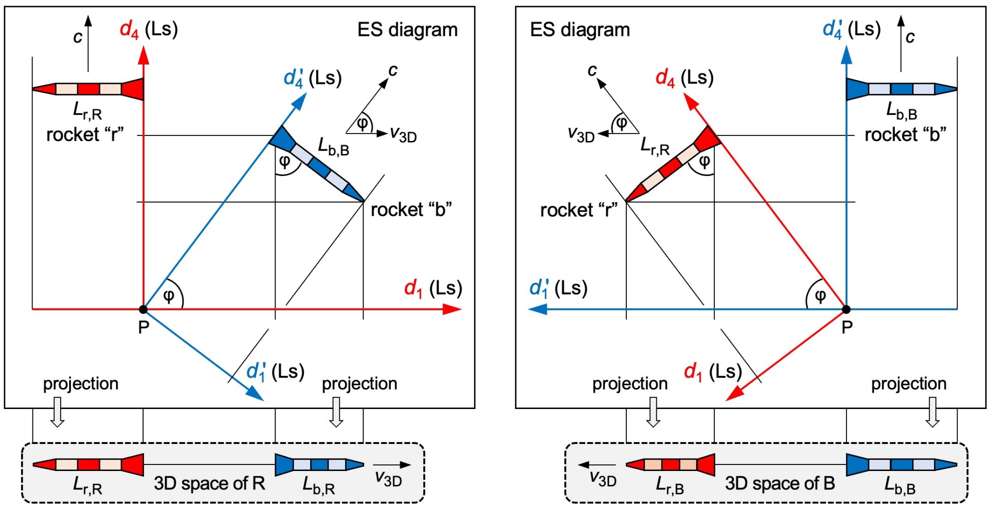

Fig. 3 ES diagrams of two rockets "r" and "b". Observer R (or B) is in the rear end of "r" (or else "b"). **Left:** "r" moves in the d_4 axis. "b" moves in the d_4' axis. In the 3D space of R, "b" contracts to $L_{\mathrm{b,R}}$. **Right:** The ES diagram has been rotated only. In the 3D space of B, "r" contracts to $L_{\mathrm{r,B}}$

Up next, we verify: Projecting distances in ES to the axes d_1 and d_4 of an observer causes length contraction and time dilation. Let $L_{\mathrm{b,R}}$ (or $L_{\mathrm{b,B}}$) be the length of rocket "b" for observer R (or else B). In a first step, we project "b" in Fig. 3 left to the d_1 axis.

$$\sin^2\varphi + \cos^2\varphi \;=\; (L_{\mathrm{b,R}}/L_{\mathrm{b,B}})^2 + (v_{3D}/c)^2 \;=\; 1 \;, \tag{8}$$

$$L_{\mathrm{b,R}} \;=\; \gamma^{-1}\, L_{\mathrm{b,B}} \qquad \text{(length contraction)}, \tag{9}$$

where $\gamma = (1 - v_{3D}^2/c^2)^{-0.5}$ is the same Lorentz factor as in SR. For observer R, rocket "b" contracts to $L_{\mathrm{b,R}}$. Despite the Euclidean metric, we calculate the same Lorentz factor as in SR. We now ask: Which distances will R observe in the d_4 axis? We rotate rocket "b" until it serves as a ruler for R in the d_4 axis. In his 3D space, this ruler contracts to zero length. In other words: The d_4 axis disappears for R because of length contraction at the speed c. In a second step, we project "b" in Fig. 3 left to the d_4 axis.

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$$\sin^2\varphi \;+\; \cos^2\varphi \;=\; (d_{4,\mathrm{B}}/d'_{4,\mathrm{B}})^2 \;+\; (v_{3\mathrm{D}}/c)^2 \;=\; 1\;, \tag{10}$$

$$d_{4,\mathrm{B}} \;=\; \gamma^{-1}\, d'_{4,\mathrm{B}}\;, \tag{11}$$

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 cover the same distance in ES, but in different 4D directions), we calculate

$$d_{4,\mathrm{R}} \;=\; \gamma\, d_{4,\mathrm{B}} \qquad \text{(time dilation)}, \tag{12}$$

where $d_{4,\mathrm{R}}$ is the distance that R moved in d_4. Eqs. (9) and (12) tell us: γ is recovered in ER if we project ES to the axes d_1 and d_4 of an observer. This result is significant: **It tells us that ER predicts the same relativistic effects as SR.** The rockets serve as an example. Other objects are projected the same way. For orthogonal projections, the reader is referred to geometry textbooks [19, 20]. For instance, γ and the lifetime of a muon are recovered in ER when R is kept as the observer and the blue rocket is replaced by a muon.

We now transform the proper coordinates of observer R (unprimed) to the ones of B (primed). R cannot measure the proper coordinates of B, and vice versa, but we can always calculate them from ES diagrams. Fig. 3 right tells us how to calculate the 4D motion of R in the proper coordinates of B. The transformation is a 4D rotation by the angle φ.

$$d'_{1,\mathrm{R}}(\theta) \;=\; d_{4,\mathrm{R}}(\theta)\,\cos\varphi \;=\; d_{4,\mathrm{R}}(\theta)\; v_{3\mathrm{D}}/c\;, \tag{13a}$$

$$d'_{2,\mathrm{R}}(\theta) \;=\; d_{2,\mathrm{R}}(\theta)\;, \qquad d'_{3,\mathrm{R}}(\theta) \;=\; d_{3,\mathrm{R}}(\theta)\;, \tag{13b}$$

$$d'_{4,\mathrm{R}}(\theta) \;=\; d_{4,\mathrm{R}}(\theta)\,\sin\varphi \;=\; d_{4,\mathrm{R}}(\theta)\;\gamma^{-1}\;. \tag{13c}$$

Up next, I show that not only the Lorentz factor is recovered in ER, but also gravitational time dilation. Clock "r" and Earth move in the d_4 axis at the speed c (see Fig. 4). Clock "b" accelerates toward Earth while maintaining the speed c in ES. Because of Eq. (7), there are only transversal accelerations in ES. 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. Thus, "b" is slow with respect to "r" in d_4.

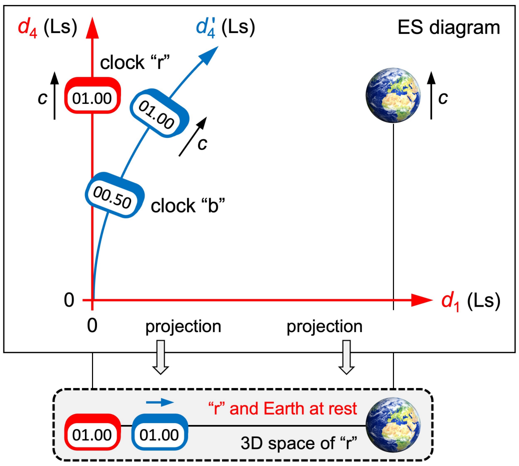

Fig. 4 ES diagram of two clocks "r" and "b" and Earth. Clock "b" accelerates toward Earth. The d'_4 axis is drawn curved because it indicates the current 4D motion of "b"

Initially, our two clocks shall be very far away from Earth. Eventually, clock "b" falls freely toward Earth. The kinetic energy of "b" (mass m) in the d_1 axis of "r" is

$$\tfrac{1}{2} m u_{1,\mathrm{b}}^2 \;=\; GMm/R\;, \tag{14}$$

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 Earth in the 3D space of "r". By applying Eq. (7), we get

$$u_{4,\mathrm{b}}^2 \;=\; c^2 - u_{1,\mathrm{b}}^2 \;=\; c^2 - 2GM/R \;. \tag{15}$$

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

$$\mathrm{d}d_{4,\mathrm{b}}^2 \;=\; (c^2 - 2GM/R)\,(\mathrm{d}d_{4,\mathrm{r}}/c)^2 \;, \tag{16}$$

$$\mathrm{d}d_{4,\mathrm{r}} \;=\; \gamma_{\mathrm{gr}}\,\mathrm{d}d_{4,\mathrm{b}} \qquad \text{(gravitational time dilation)}, \tag{17}$$

where $\gamma_{\mathrm{gr}} = (1 - 2GM/(Rc^2))^{-0.5}$ is the same dilation factor as in GR. Eq. (17) tells us: γ_{gr} is recovered in ER if we project ES to the d_4 axis of an observer. This result is significant: **It tells us that ER predicts the same gravitational time dilation as GR.** However, curved spacetime in GR replaces gravitational fields. In ER, gravitational fields celebrate a comeback. Any acceleration rotates an object's $\boldsymbol{\tau}$ and curves its worldline in flat ES.

Clock "b" is slow with respect to "r" in d_4. Since "r" displays both its τ and θ, "b" is slow even with respect to θ, although θ is absolute time. *An accelerated clock displays its τ, but not θ.* For this reason, clocks placed next to each other display different times after being exposed to different gravitational fields. Since γ_{gr} does not depend on $u_{1,\mathrm{b}}$, "b" is slow with respect to θ whether or not it keeps on moving relative to Earth. Action at a distance is not an issue if variations in field strength also spread at the speed c. I invite theorists to show: (1) Gravitational waves [21] are compatible with ER. (2) Variational principles [22] are an alternative to derive ER. I showed that γ and γ_{gr} are recovered in ER.

Summary of time dilation: In SR, a uniformly moving clock "b" is slow with respect to "r" in the time axis of "b". In GR, an accelerated clock "b" or else a clock "b" in a more curved spacetime is slow with respect to "r" in the time axis of "b". In ER, a clock "b" is slow with respect to "r" in the time axis of "r" (!) if the 4D vector $\boldsymbol{\tau}'$ of "b" differs from the 4D vector $\boldsymbol{\tau}$ of "r". Since both γ and γ_{gr} are recovered in ER, the Hafele–Keating experiment [23] supports ER too. GPS works in ER just as well as in SR/GR.

Fig. 5 illustrates 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 the d_4 axis. *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 wire 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 escape from Earth's orbit?*

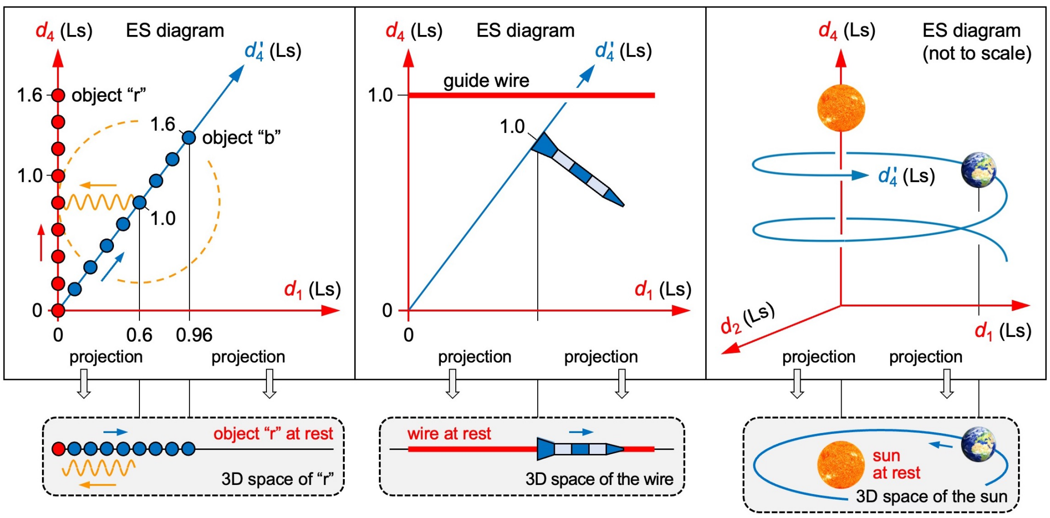

Fig. 5 Three instructive problems. **Left:** Two objects move through ES. The orange circle shows where a signal emitted by "b" at $\theta = 1.0$ s is at $\theta = 1.6$ s. In ES, the objects do not collide. In the 3D space of "r", they do. **Center:** In ES, the wire escapes from the rocket. In the 3D space of the wire, it does not. **Right:** In ES, the sun escapes from Earth's orbit. In the 3D space of the sun, it does not

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The last paragraph seems to reveal paradoxes in ER. The fallacy lies in the assumption that all four axes d_μ would be spatial at once. This is not the case. Only three axes of ES are experienced as spatial and one as temporal. We solve all problems by projecting ES to the 3D space of that object which moves in d_4 at the speed c. In its 3D space, it is always at rest. The radio signal collides with "r" in the 3D space of "r" if $d_{i,\mathrm{r}} = d_{i,\mathrm{signal}}$ $(i = 1, 2, 3)$ at one instant in cosmic time θ. Thus, a collision is possible even if there is $d_{4,\mathrm{r}} \neq d_{4,\mathrm{signal}}$. Two objects collide when their positions in d_1, d_2, d_3, θ coincide. In Fig. 5 left, the signal collides with "r" once $\theta = 1.6$ s has elapsed since "r" started from the origin. Collisions in 3D space do not show up as collisions in ES. In ER, events are not a function of t, but a function of the parameter θ. This parameter is not an axis in ES diagrams. **ES diagrams do not show events, but each object's flow of proper time.** The sun does not *spatially* escape from Earth's orbit. Rather, the sun and Earth are aging in different 4D directions.

5. Outlining the Solutions to 15 Fundamental Mysteries

In Sects. 5.1 through 5.15, ER solves 15 mysteries and declares four concepts obsolete.

5.1. The Nature of Time

Clocks measure proper time τ. This fact is true even under acceleration. Cosmic time θ is the total distance covered in ES divided by c. A uniformly moving clock always displays both its τ and θ. An accelerated clock displays its τ, but not θ. An observed clock's 4D vector $\boldsymbol{\tau}'$ can differ from the observer's 4D vector $\boldsymbol{\tau}$. If it does, the observed clock is slow with respect to the observer's clock in his time axis.

5.2. Time's Arrow

"Time's arrow" is a synonym of time flowing forward only. Why does time flow forward only? Here is the answer: Covered distance cannot decrease, but only increase.

5.3. The Factor c^2 in the Energy Term mc^2

In SR, the total energy E of an object (mass m) in the absence of forces is given by

$$E = \gamma mc^2 = E_{\mathrm{kin,3D}} + mc^2 , \tag{18}$$

where $E_{\mathrm{kin,3D}}$ is its kinetic energy in an observer's coordinate space and mc^2 is its energy at rest. The term mc^2 can be derived from SR, but SR does not tell us why there is a factor c^2 in the energy of objects that move at a speed less than c. ER is eye-opening: An object is never "at rest". From its perspective, $E_{\mathrm{kin,3D}}$ is zero and mc^2 is its kinetic energy in d_4'. The factor c^2 is a hint that it moves through ES at the speed c. In SR, there is also

$$E^2 = p^2\, c^2 = p_{\mathrm{3D}}^2\, c^2 + m^2\, c^4 , \tag{19}$$

where p is the total momentum of an object and p_{3D} is its momentum in an observer's coordinate space. Again, ER is eye-opening: From its perspective, p_{3D} is zero and mc is its momentum in d_4'. The factor c is a hint that it moves through ES at the speed c.

5.4. Length Contraction and Time Dilation

In SR, length contraction and time dilation can be traced back to Einstein's instruction for synchronizing clocks. In ER, these relativistic effects are natural effects: They stem from projecting distances in ES to the axes d_1 and d_4 of an observer.

5.5. Gravitational Time Dilation

In GR, gravitational time dilation stems from curved spacetime. In ER, this relativistic effect stems from projecting curved worldlines in ES to the d_4 axis of an observer. Eq. (7) tells us: *If an object accelerates in his proper space, it automatically decelerates in his proper time.* More studies are required to understand other gravitational effects in ER.

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5.6. The Cosmic Microwave Background (CMB)

In the inflationary Lambda-CDM model, the Big Bang occurred "everywhere" (space inflated from a singularity). In Sects. 5.6 through 5.12, 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 is the total time that has elapsed since the Big Bang. At $\theta = 0$, all energy started moving radially away from O. *The Big Bang was a singularity in providing energy and radial momentum.* Ever since the Big Bang, this energy has been moving through ES at the speed c. Shortly after $\theta = 0$, energy was highly concentrated. While it became less concentrated, plasma particles were created in the projection to any 3D space. Recombination radiation was emitted that we still observe as CMB today [24].

The ER-based model must be able to answer these questions: (1) Why is the CMB so isotropic? (2) Why is the temperature of the CMB so low? (3) Why do we still observe the CMB today? Here are some possible answers: (1) The CMB is so isotropic because it has been scattered equally in the 3D space d_1, d_2, d_3 of Earth. (2) The temperature of the CMB is so low because the plasma particles receded at a very high speed v_{3D} (Doppler redshift, see Sect. 5.11). (3) We still observe the CMB today because the radiation reaches Earth after having covered the same distance in d_1, d_2, d_3 (multiple scattering) as Earth in d_4.

5.7. The Hubble–Lemaître Law

Earth and a galaxy G recede from the origin O of ES at the speed c (see Fig. 6 left). While doing so, G recedes from the d_4 axis at the speed v_{3D}. 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, v_{3D} relates to D as c relates to the radius r of an expanding 4D hypersphere. All energy is within this hypersphere. Some energy is in its 3D hypersurface. The 4D motion of energy can change continuously by a transversal acceleration (scattering, gravitational field) or discontinuously (photon emission, pair production).

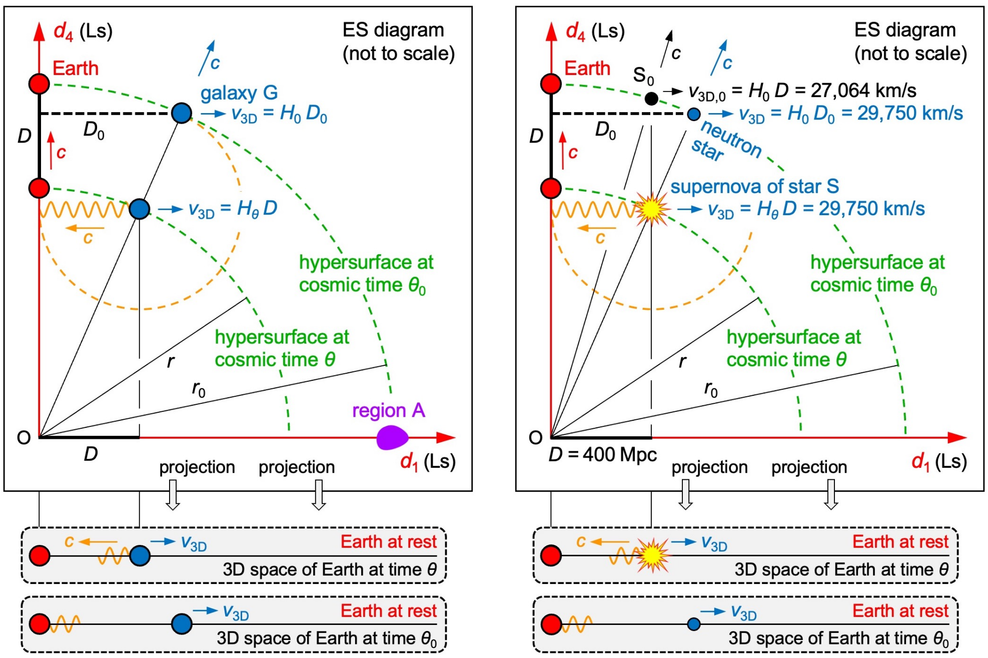

Fig. 6 ER-based model of cosmology. The green arcs show parts of a 3D hypersurface. The orange circles show where most of the energy emitted by G or S at the time θ is today. **Left:** G recedes from O at the speed c and from the d_4 axis at the speed v_{3D}. **Right:** If a star S_0 happens to be at the same distance D today at which the supernova of S occurred, S_0 recedes more slowly from d_4 than S

$$v_{3D} \;=\; D\,c/r \;=\; H_\theta\, D\ , \tag{20}$$

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 v_{3D} and c remain unchanged. Thus, Eq. (20) turns into

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$$v_{3D} = D_0\, c/r_0 = H_0\, D_0 \;, \tag{21}$$

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. (21) is an improved Hubble–Lemaître law [25, 26]. Cosmologists are aware of θ and H_θ. They are not yet aware that the 4D geometry is Euclidean, that θ is absolute, and that v_{3D} is equal to $H_0\, D_0$ (not to $H_0\, D$). *Out of two galaxies, the one farther away recedes faster, but each galaxy maintains its recession speed* v_{3D}. Time dilation results from Eq. (7): Since G moves in d_1 at the speed v_{3D}, it moves in d_4 at the speed $(c^2 - v_{3D}^2)^{0.5}$. Thus, a clock in G is slow with respect to a clock on Earth in the axis d_4 and by the factor $c/(c^2 - v_{3D}^2)^{0.5} = \gamma$. The d_4 values of Earth and an energy ΔE (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. 5 left, collisions in 3D space do not show up as collisions in ES. ΔE collides with Earth once ΔE has covered the same distance in d_1 as Earth in d_4.

5.8. The Flat Universe

Two orthogonal projections from flat ES make up an observer's reality. This is why he experiences two independent structures: flat 3D space and time.

5.9. Cosmic Inflation

Most cosmologists [27, 28] believe that an inflation of space shortly after the Big Bang explains the isotropic CMB, the flat universe, and large-scale structures. The latter inflated from quantum fluctuations. I just showed that ER explains the first two effects. ER even explains large-scale structures if the impacts of quantum fluctuations have been expanding like the 3D hypersurface. ***In ER, cosmic inflation is an obsolete concept.***

5.10. 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. Without inflation, information could not have covered $2r_0$ since the Big Bang. The ER-based model applies natural concepts: Region A is at $d_1 = +r_0$ (see Fig. 6 left). Region B is at $d_1 = -r_0$ (not shown in Fig. 6 left). For A and for B, their d_4' axis (equal to Earth's d_1 axis) disappears because of length contraction at the speed c. Since A and B overlap spatially in their 3D space, they are causally connected. Note that their opposite 4D vectors "flow of proper time" do not affect causal connectivity as long as A and B overlap spatially.

5.11. The Hubble Tension

Up next, I show that ER predicts the 10 percent deviation in the published values of H_0 (known as the "Hubble tension"). We consider CMB measurements and distance ladder measurements. According to team A [29], there is $H_0 = 67.66 \pm 0.42$ km/s/Mpc. According to team B [30], there is $H_0 = 73.04 \pm 1.04$ km/s/Mpc. Team B made efforts to minimize the error margins in the distance measurements, but there is a systematic error in team B's value of H_0. The error stems from assuming a wrong cause of the redshifts.

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. 6 right). The recession speed v_{3D} of S is calculated from measured redshifts. 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 cosmic time θ, but we observe it today at the cosmic time θ_0 (see Fig. 6 right). While the supernova's light moved the distance D in the d_1 axis, Earth moved the same distance D, but in the d_4 axis (first postulate). There is

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

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For a short distance of $D = 400$ kpc, Eq. (22) tells us that H_θ deviates from H_0 by only 0.009 percent. When plotting v_{3D} versus D for distances from 0 Mpc to 500 Mpc in steps of 25 Mpc (red points in Fig. 7), the slope of a straight-line fit through the origin is roughly 10 percent greater than H_0. Since team B calculates H_0 from z versus magnitude, which is like plotting v_{3D} versus D, its value of H_0 is roughly 10 percent too high. Team B's value of H_0 is not correct because Eq. (21) tells us: We must plot v_{3D} versus D_0 to get a straight line (blue points in Fig. 7). *Ignoring the 4D Euclidean geometry in distance ladder measurements leads to an overestimation of* H_0 *by 10 percent.* This solves the Hubble tension.

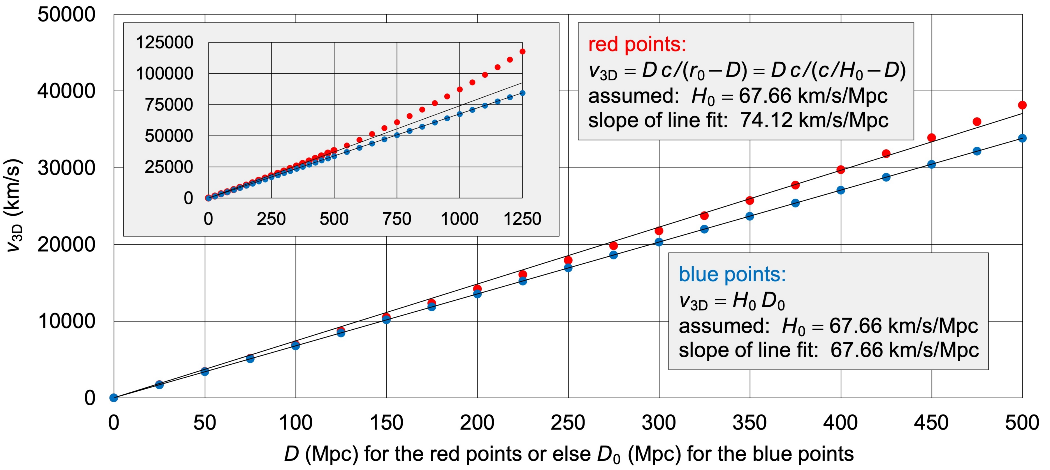

Fig. 7 Hubble diagram of simulated supernovae. The horizontal axis is D for the red points or else D_0 for the blue points. The red points, calculated from Eq. (20), do not yield a straight line because H_θ is not a constant. The blue points, calculated from Eq. (21), yield a straight line

We cannot measure D_0. Observable magnitudes relate to D and not to D_0. Thus, the easiest way to fix the calculation of team B is to rewrite Eq. (21) as

$$v_{3D,0} \;=\; D\,c/r_0 \;=\; H_0\,D\;, \tag{23}$$

where $v_{3D,0}$ is today's 3D speed of a star S_0 that happens to be at the same distance D today at which the supernova of S occurred (see Fig. 6 right). I kindly ask team B to recalculate H_0 after converting all v_{3D} to $v_{3D,0}$ by combining Eqs. (22), (23), and (20) to

$$H_\theta \;=\; H_0\,c/(c - H_0\,D) \;=\; H_0/(1 - v_{3D,0}/c)\;, \tag{24}$$

$$v_{3D,0} \;=\; v_{3D}/(1 + v_{3D}/c)\;. \tag{25}$$

Because of Eq. (23), we also get a straight line by applying Eq. (25) and plotting $v_{3D,0}$ versus D. In addition, Fig. 7 tells us: The more high-redshift data are included in team B's calculation, the more the Hubble tension increases. The moment of the supernova is irrelevant to team B's calculation. In the Lambda-CDM model, all that counts is the duration of the light's journey to Earth (z increases during the journey). In the ER-based model, all that counts is the moment of the supernova. Wavelengths are redshifted by the Doppler effect (z is constant during the journey). Space is not expanding. Energy recedes from the location of the Big Bang in ES. ***In ER, expanding space is an obsolete concept.***

5.12. Dark Energy

I now identify another systematic error, but it is inherent in the Lambda-CDM model. It stems from assuming an accelerating expansion of space and is only solved by switching to the ER-based model unless we postulate dark energy. Most cosmologists [31, 32] believe in an accelerating expansion because the recession speeds v_{3D} increasingly deviate from a straight line when v_{3D} is plotted versus D. An accelerating expansion of space would indeed stretch each wavelength even further and explain the deviations.

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In ER, the cause of the deviations is far less speculative: The longer ago a supernova occurred, the more H_θ deviates from H_0, and thus the more v_{3D} deviates from $v_{3D,0}$. 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. (25) tells us: S_0 recedes more slowly (27,064 km/s, the shortest arrow in Fig. 6 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 $\boldsymbol{\tau}$. As of today, cosmologists hold dark energy [33] responsible for an accelerating expansion of space. Dark energy has not been confirmed. It is a stopgap solution for an effect that the Lambda-CDM model cannot explain. Supernovae occurring earlier in cosmic time recede faster because of a larger H_θ in Eq. (20) and not because of dark energy.

The Hubble tension and dark energy are solved exactly the same way: *In Eq. (21), we must not confuse D_0 with D.* Because of Eq. (20) and because of $H_\theta = c/(r_0 - D)$, the recession speed v_{3D} is not proportional to D, but to $D/(r_0 - D)$. This is why the red points in Fig. 7 run away from a straight line. Any expansion of space (uniform or else accelerating) is only virtual even if the Nobel Prize in Physics 2011 was given "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae". This particular prize was given for an illusion that stems from interpreting astronomical observations in the wrong concepts. Most galaxies recede from Earth, but they do so uniformly in a non-expanding space. ***In ER, dark energy is an obsolete concept.***

The Hubble tension and dark energy are solved by taking the 4D Euclidean geometry into account, and the 4D vector $\boldsymbol{\tau}$ in particular. These results cast doubt on the Lambda-CDM model. GR works well as long as $\boldsymbol{\tau}$ is not crucial, but it is crucial for high-redshift supernovae. Space is not driven by dark energy. Galaxies are driven by their momentum and maintain their recession speed v_{3D} with respect to Earth. Because of various effects (scattering, gravitational field, photon emission, pair production), some energy deviates from a radial motion in ES while maintaining the speed c. Gravitational attraction enables near-by galaxies to move toward our galaxy. Table 1 compares two models of cosmology. Note that "the Universe" (Lambda-CDM model) and "universe" (ER-based model) are not the same thing. *Each observer experiences three axes of ES as his universe.* Cosmology benefits from ER. In Sects. 5.13 and 5.14, I show that QM also benefits from ER.

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 two competing values of H_0.	H_0 is approximately 67–68 km/s/Mpc.
The Universe: spacetime and all energy.	Synonyms of universe: proper space, 3D space.
Spacetime is non-Euclidean.	Spacetime is Euclidean.
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.
Space is driven by dark energy.	Galaxies are driven by their momentum.
Dark energy has not been confirmed.	There is no dark energy.

Table 1 Comparing two models of cosmology

5.13. The Wave–Particle Duality

The wave–particle duality was first discussed by Niels Bohr and Werner Heisenberg [34]. 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 a wave's energy spreads out in space, whereas a particle's energy is always localized in space. We overcome the duality by introducing another natural concept: All objects are "wavematters" (pure energy) that propagate through and oscillate in ES as a function of the parameter θ. In an observer's view, wavematters reduce to wave packets if not tracked or else to particles if tracked.

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In Fig. 8, 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. For a better readability, a wavematter's oscillation is drawn in the d_1, d_4 plane, although it can oscillate in any axis that is orthogonal to its propagation axis. WM_1 does not move relative to R. Thus, 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 (W_2, W_3) if not tracked or else to particles (P_2, P_3) if tracked. In the 3D space of R, W_2 moves at a speed less than c. Thus, W_2 is what Louis de Broglie called a "matter wave" [35]. Erwin Schrödinger formulated his Schrödinger equation to describe matter waves [36]. In the 3D space of R, both W_3 and P_3 move at the speed c. Thus, WM_3 is the only wavematter that reduces for R to an electromagnetic wave packet or else to a photon. Light gives us a good idea of how wavematters move through ES.

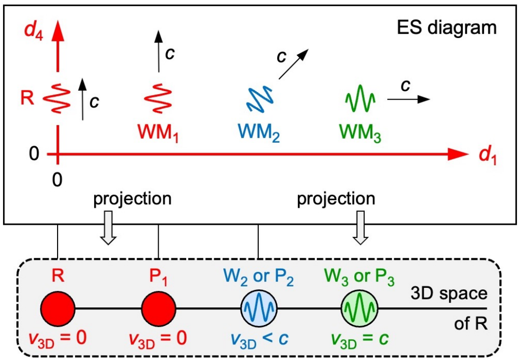

Fig. 8 Wavematters. Observer R moves in the d_4 axis. In his 3D space, WM_2 and WM_3 reduce to wave packets (W_2, W_3) if not tracked or else to particles (P_2, P_3) if tracked. P_1: possibly an atom of R. W_2: matter wave. P_2: moving particle. W_3: electromagnetic wave packet. P_3: photon

Remarks: (1) "Wavematter" is not just a new word for the duality. It is a new concept, which tells us where the duality stems from and that it is experienced by observers only. Isn't it enriching to learn that particles, matter waves, photons, and electromagnetic waves all stem from a common concept? (2) In today's physics, there is no "photon's view". In ER, we can assign a 3D space and a proper time to each wavematter. In its view, its 4D motion disappears because of length contraction at the speed c. In its 3D space, it is always at rest and reduces to a particle. (3) In a particle, a wavematter's energy condenses to mass. Albert Einstein taught that energy and mass are equivalent [37]. Wavematters suggest that, likewise, a wave's polarization and a particle's spin are equivalent.

In double-slit experiments, light creates an interference pattern on a screen if it is not tracked through which slit single portions of energy are passing. The same applies if material objects, such as electrons, are sent through the double-slit [38]. *Here light and matter behave like waves.* In experiments on the photoelectric effect, an electron is released from a metal surface only if the energy of an incoming photon exceeds the binding energy of that electron. The photon must interact with that electron to release it. The interaction discloses their current position. They are tracked. *Here light and matter behave like particles.* Since an observer automatically tracks all objects that are slow in his 3D space, he classifies all slow objects—and thus all macroscopic objects—as matter. For a better readability, most of my ES diagrams do not show wavematters, but how they appear to observers.

5.14. Non-Locality

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 solve 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.

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Up next, I show that ER is able to “untangle” entanglement. There is no violation of locality in ES, where all four axes are fully symmetric. In Fig. 9, observer R moves in the d_4 axis at the speed c. There are two pairs of entangled wavematters. One pair was created at the point P and moves in opposite directions $\pm d_4'$ (equal to the axes $\pm d_1$ 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, the first pair (green) reduces to two entangled photons. The second pair (blue) reduces to two entangled material objects (for instance, electrons). R has no idea how two entangled objects are able to “communicate” in no time.

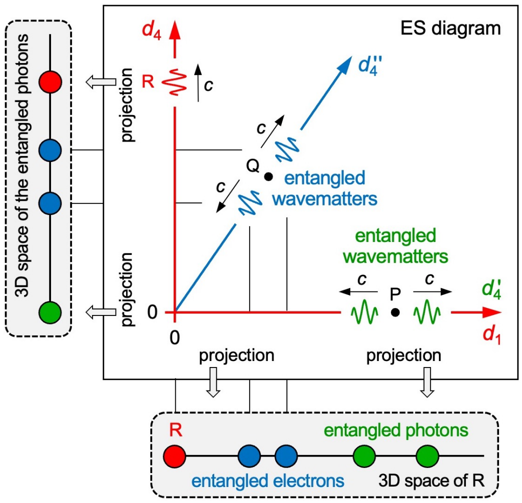

Fig. 9 Entanglement. Observer R moves in the d_4 axis at the speed c. Two entangled wavematters (green) reduce to photons. Two entangled wavematters (blue) reduce to electrons. In the photons’ 3D space (or electrons’ 3D space, not shown), the photons (or else electrons) stay together

In the photons’ view (or electrons’ view), the d_4' axis (or else the d_4'' axis) disappears because of length contraction at the speed c. Thus, each pair stays together in its respective 3D space. Entangled objects have never been spatially separated in their view, but their proper time flows in opposite 4D directions. This is how two entangled objects are able to communicate in no time. Note that their opposite 4D vectors “flow of proper time” do not affect local communication as long as the twins stay together spatially. There is a “spooky action at a distance” (attributed to Einstein) in an observer’s view only.

The horizon problem and entanglement are solved exactly the same way: *An observed region’s (or an observed object’s) 4D vector* $\boldsymbol{\tau}'$ *and its 3D space can differ from the observer’s 4D vector* $\boldsymbol{\tau}$ *and his 3D space.* All of this is possible, but only in ES, where all four axes are fully symmetric. The SO(4) symmetry of ES solves entanglement. It explains the entanglement of photons just as well as the entanglement of material objects, such as atoms or electrons [45]. Any measurement on one entangled twin will terminate its existence or tilt the axis of its 4D motion. In either case, the twins will not move in opposite 4D directions anymore. The entanglement is destroyed. ***In ER, non-locality is an obsolete concept.***

5.15. The Baryon Asymmetry

In the Lambda-CDM model, almost all matter was created shortly after $\theta = 0$, when the temperature was high enough to enable pair production. But this process creates equal amounts of particles and antiparticles, and the process of annihilation annihilates equal amounts of particles and antiparticles. So, why do we observe more baryons than antibaryons (known as the “baryon asymmetry”)? In an observer’s view, wavematters reduce to wave packets or else to particles. Pair production creates particles and antiparticles, which 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 solves the baryon asymmetry.

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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. The antiparticle's 4D vector $\boldsymbol{\tau}''$ is reversed with respect to the particle's 4D vector $\boldsymbol{\tau}'$. In the antiparticle's view, its proper time flows forward. ER predicts that any two wavematters created in pair production are entangled. This gives us a chance to falsify ER. Scientific theories must be falsifiable [46]. Note that galaxies moving in $-d_4$ (not shown in Fig. 6 left) are not made up of antimatter. Only their flow of proper time is reversed with respect to galaxies moving in $+d_4$. Their physical charges are not reversed.

6. Conclusions

Modern physics lacks two qualities of time: absolute and vectorial. On the one hand, there is the cosmic evolution parameter θ (absolute time), which separates absolute past, present, and future. There is no absolute time in SR/GR. On the other hand, proper time τ is the length of a 4D Euclidean vector "flow of proper time" $\boldsymbol{\tau}$. There is no $\boldsymbol{\tau}$ in SR/GR. While SR/GR work for all observers, the 15 mysteries solved in Sect. 5 show that the scope of SR/GR is limited. The 4D vector $\boldsymbol{\tau}$ is crucial for objects that are very far away or entangled. Information hidden in θ and $\boldsymbol{\tau}$ is not available in SR/GR. It is very unlikely that 15 solutions in different (!) areas of physics are 15 coincidences. Some of the 15 mysteries had been solved without ER, but with concepts that now prove obsolete. ER declares cosmic inflation, expanding space, dark energy, and non-locality obsolete. They are all subject to Occam's razor. Occam shaves off obsolete concepts. 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 the metric of nature is Euclidean. In fact, his instruction for synchronizing clocks blocks access to ER. He sacrificed absolute space and time. ER restores absolute time, but sacrifices the absolute nature of particles, matter waves, photons, and electromagnetic waves. In retrospect, two unfortunate practices of physicists delayed the formulation of ER: (1) Clocks measure τ, but τ is assigned a much smaller role in the equations of physics than t. (2) Cosmologists are aware of H_θ, but when parameterizing worldlines in spacetime, the parameter τ is preferred over $\theta = 1/H_\theta$. For the first time ever, mankind now understands the nature of time: Cosmic time is the total distance covered in ES divided by c. The human brain is able to imagine that we move at the speed c. With that said, conflicts of mankind become all so small.

Is ER a physical or a metaphysical theory? This is a very good question because only in proper coordinates can we access ES, but the proper coordinates of other objects cannot be measured. I now explain why this is fine: We can always calculate these proper coordinates from ES diagrams as I showed in Eqs. (13a–c). Measuring is an observer's source of knowledge, but ER tells us not to interpret too much into whatever we measure. Measurements are wedded to observers, whose concepts can be obsolete. I was often told that physics is all about observing. I disagree. We cannot observe quarks, can we? Regrettably, physicists have applied empirical concepts—which work well in our everyday life—to the very distant and the very small. This is why cosmology and QM benefit the most from ER. *ER is a physical theory because it solves fundamental mysteries of physics.*

Final remarks: (1) I only touched on gravity. We must not reject ER because gravity is still an issue. GR seems to solve gravity, but GR is incompatible with QM unless we add quantum gravity. Since ER solves mysteries of QM, quantum gravity is probably another obsolete concept. More studies are required to understand gravitational effects in ER. (2) Mysteries often disappear once the symmetry is matched. The symmetry group of natural spacetime is SO(4). (3) The parameter θ puts an end to all discussions about time travel. Does any other theory solve the mystery of time's arrow as beautifully as ER? (4) Physics does not ask: Why is my reality a projection? Nor does it ask: Why is it a wave function? Projections are far less speculative than cosmic inflation plus expanding space plus dark energy plus non-locality. (5) It seems as if Plato had anticipated ER in his *Allegory of the Cave* [48]: Mankind experiences projections and cannot observe any reality beyond.

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The key question in science is this: How does all of our insight into nature fit together without adding highly speculative concepts? It is this very question that leads to the truth. I laid the groundwork for ER and showed how powerful it is. Paradoxes are only virtual. The true pillars of physics are ER, SR/GR (for observers), and QM. Together they describe Mother Nature from the very distant down to the very small. Whenever we use empirical concepts, we must apply SR/GR. Whenever we use natural concepts, we must apply ER. Introducing a holistic view to physics is probably the most significant achievement of this paper. I demonstrated that SR/GR do not provide a holistic view. All observers' views taken together do not make a holistic view because they still do not provide absolute time. Physics got stuck in its own concepts. Empirical concepts block our view of nature as a whole. Only in natural concepts does Mother Nature reveal her secrets. Everyone is welcome to solve even more mysteries by describing her in natural concepts.

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Comments: It takes open-minded editors and reviewers to evaluate a theory that heralds a paradigm shift. Taking SR/GR for granted paralyzes progress. I apologize for 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 my theory. Interestingly, I was never given any solid arguments that would disprove my theory. Rather, I was asked to try a different journal. Were the editors afraid of publishing a theory that is off the mainstream? Did they underestimate the benefits of ER? I was told that 15 solved mysteries are too much to be trustworthy. I disagree. Paradigm shifts often solve many mysteries at once. Even good friends refused to support me. Anyway, each setback motivated me to work out the benefits of ER even better. Finally, I succeeded in identifying an issue in SR/GR, which shows that Einstein's general relativity is not as general as it seems.

Some physicists are not ready to accept ER because the SO(4) symmetry of ES seems to exclude waves. ER does not exclude waves. SO(4) is compatible with waves that propagate as a function of the parameter θ. A well-known preprint archive suspended my submission privileges. I was penalized because I identified an issue in Einstein's SR and GR. The editor-in-chief of a top journal replied: "Publishing is for experts only." One editor rejected my paper because it would "demand too much" from the reviewers. One editor could not imagine that the Hubble tension is solved without GR and called me a "pesky irritation". I don't blame anyone. Paradigm shifts are hard to accept. These comments shall encourage young scientists to stand up for good ideas even if it is hard work to oppose the mainstream. I was told that ER is "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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