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Founding Physics on a Mathematical Background Reality

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Physics makes two questionable assumptions: (1) Distant galaxies are accelerating relative to Earth. (2) Entangled objects are spatially separated from each other. Why questionable? Acceleration relative to Earth has never been observed in a single galaxy. Observers perceive entangled objects as spatially separated, yet 3D space is relative. We show that physical realities are projections of a mathematical background reality: 4D Euclidean space (ES). In Euclidean relativity (ER), all objects move through ES at the speed C. There is no time coordinate in ES. All action is due to a monotonically increasing, absolute, external evolution parameter θ. An observer experiences two projections of ES as space and time. The axis of his current 4D motion is his proper time τ. Three orthogonal axes form his 3D space x_1, x_2, x_3. His physical reality is his spacetime $x_1(\vartheta), x_2(\vartheta), x_3(\vartheta), \tau(\vartheta)$, where τ is a natural time coordinate and θ converts to absolute parameter time ϑ. Without gravity, his spacetime is Minkowski-like. As in general relativity (GR), gravity in ER is the curvature of spacetime. Since coordinates in GR are merely labels, the Einstein field equations also hold in systems that use τ as the time coordinate. ER predicts time's arrow, relativistic effects, galactic motion, the Hubble tension, and entanglement. Remarkably, ER manages without cosmic inflation, expanding space, dark energy, and non-locality. ER tells us: (1) Distant galaxies maintain their recession speeds. (2) From their perspective, entangled objects have never been spatially separated, yet their proper time flows in opposite 4D directions.

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Clocks measure proper time τ. There are two ways to interpret τ: In special relativity (SR) [1] and general relativity (GR) [2], τ is frequently used to parameterize an object's worldline in spacetime. In Euclidean relativity (ER), τ is the time coordinate of spacetime. As in GR, gravity in ER is the curvature of spacetime. Unlike SR/GR, ER postulates a mathematical background reality, which provides information that is not available in SR/GR.

ER predicts (a) cosmic homogeneity without postulating cosmic inflation, (b) galactic motion without postulating expanding space and dark energy, and (c) entanglement without postulating non-locality. In all cases, a 4D vector "flow of proper time" $\boldsymbol{T}$ is required. For instance, distant galaxies maintain their recession speeds, but their 4D vector $\boldsymbol{T}'$ differs greatly from $\boldsymbol{T}$ of the Milky Way. *What is the key message of ER?* There is a mathematical reality beyond all physical realities. *Does ER make quantitative predictions?* Yes, ER predicts the ten percent discrepancy in the published values of the Hubble constant (see Sect. 5.10). This fact experimentally distinguishes ER-based from GR-based cosmology.

A request to all readers: Please take the following advice to heart. (1) *Do not apply the concepts of SR/GR to ER.* The only standards for a scientific theory are its own concepts and empirical facts. (2) *Do not reject ER because it extends beyond today's physics.* Reviewers of top journals rejected our theory. ER is a physical theory because it predicts what we observe. (3) *Do not reject ER because it does not yet reproduce all of GR's predictions.* If you do so anyway, you must also reject GR until it reproduces all of ER's predictions, such as the H_0 tension. The same standards apply to all theories! (4) *Be curious.* New coordinates can reveal new insights. In GR, coordinates are adjustable labels. In ER, coordinates are inherent properties of objects. They cannot be adjusted because they refer to absolute 4D Euclidean space. (5) *Be fair.* A single paper cannot cover all of physics, but it can serve as a guide.

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1. Introduction

Today's concepts of space and time were coined by Albert Einstein. In SR, the Minkowski metric describes a flat spacetime. The geometric framework is Minkowski spacetime [3]. The muon lifetime [4] is an often-cited example that supports SR. In GR, the metric tensor and the Einstein tensor describe a curved spacetime. 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.

Newburgh and Phipps [8] pioneer ER. Montanus [9, 10] adds a restriction: He considers a preferred reference frame in which a pure time interval is a pure time interval for all observers (see page 351 of [9]). By doing so, he deprives ER of its key feature: *full symmetry in all four axes.* Montanus claims (see page 17 of [11]): The preferred frame avoids "distant collisions" (without a physical contact) and a "character paradox" (confusion of photons, particles, antiparticles). Our formulation of ER does not prefer any reference frame. There are no distant collisions: Only three axes are experienced as spatial. There is no character paradox: "Photons", "particles", and "antiparticles" are physical terms. They refer to physical realities, but not to a mathematical reality. Montanus [10] uses a Euclidean metric to derive gravitational lensing and the precession of Mercury's perihelion. He even attempts to derive Maxwell's equations [11], but fails because of the SO(4) symmetry.

Almeida [12] analyses geodesics in 4D Euclidean space. Gersten [13] shows 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 [8–13] merely rearrange the metric of SR to give it a Euclidean appearance. Above all, they do not omit coordinate time t. We are taking a new path to make ER work: Physical realities are projections of a mathematical reality.

To this day, ER is rejected for various reasons: (a) Experiments have repeatedly confirmed GR. (b) There seem to be paradoxes in ER. (c) ER does not yet reproduce all of GR's predictions. We believe that physics is now at a turning point: (a) No theory is set in stone. (b) Our projections avoid paradoxes. (c) SR and GR have been tested for 100+ years. It takes time to accept a paradigm shift, but that does not rule out publishing on ER. We show that ER predicts the same relativistic effects as SR/GR (length contraction, time dilation, gravitational time dilation, gravitational redshift, gravitational lensing, and so on).

In *Newton's physics,* all objects move through 3D Euclidean space as a function of time. There is no speed limit. In *Einstein's physics,* all objects move through a 4D non-Euclidean spacetime as a function of an internal parameter. The speed limit is c. In *Euclidean relativity,* all objects move through 4D Euclidean space as a function of an external parameter. The 4D speed of everything is C. Einstein's physics reduces to Newton's physics when speeds are low and gravity is weak. *ER does not reduce to Einstein's physics.* ER uses a different time coordinate to predict the same effects as SR/GR plus some additional effects.

2. Coordinate Time and Its Shortcomings

In § 1 of SR [1], Einstein considers a reference frame "in which the equations of Newton's physics hold" (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 define time. Einstein gives an instruction on how to synchronize clocks at the points P and Q. At a coordinate time t_P, a light signal 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

$$t_Q - t_P = t_P^* - t_Q \,. \tag{1}$$

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

$$x_1' = \gamma\,(x_1 - v_1\,t)\ , \qquad x_2' = x_2\ , \qquad x_3' = x_3\ , \tag{2a}$$

$$t' = \gamma\,(t - v_1\,x_1/c^2)\ , \tag{2b}$$

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–b) transform the coordinates from K to K′. Covariant equations transform the coordinates from K′ to K. The metric of Minkowski spacetime is

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

where $\mathrm{d}\tau$ is an infinitesimal change in the invariant τ, and all $\mathrm{d}x_i$ $(i = 1, 2, 3)$ and $\mathrm{d}t$ are infinitesimal distances in 3D space x_1, x_2, x_3 and coordinate time t. Minkowski spacetime x_1, x_2, x_3, t is a construct because t is a *man-made* concept derived from Eq. (1): t is a label that is not inherent in clocks. In GR, t retains its function as a label. We identify four shortcomings of t: (1) SR/GR work for observers, but SR/GR do not provide diagrams that work for all observers. (2) GR-based cosmology fails to predict time's arrow and the H_0 tension. Other empirical facts can be predicted, but only by postulating highly speculative concepts (cosmic inflation, expanding space, dark energy). (3) t-based QM postulates another highly speculative concept (non-locality). (4) GR is probably incompatible with QM.

SR/GR provide *observer-specific diagrams* (spacetime diagrams): These diagrams do not work for all observers. There are coordinate-free formulations of SR [14] and GR [15], but they still lack absolute space and absolute time. In ER, physical realities remain relative, but they are embedded in absolute 4D Euclidean space and parameterized by absolute time. ER provides *observer-independent diagrams* (diagrams of 4D Euclidean space): These Master Diagrams work for all observers (see Sect. 3). Physics has paid an enormous price for sticking to coordinate time. ER predicts empirical facts (see Sect. 5) without postulating highly speculative concepts. ER even predicts time's arrow and the H_0 tension. Thus, the shortcomings of t are real. Michelson and Morley [16] refute absolute 3D space ("luminiferous ether"), but not absolute 4D space embedding countless relative 3D spaces.

Neither SR nor GR make false predictions. The shortcomings of t have much in common with the shortcomings of geocentrism: GR-based cosmology and t-based QM require concepts that are dispensable in ER. In the old days, it was believed that all celestial bodies orbited Earth. Only the astronomers wondered about the retrograde loops of planets and claimed: Earth orbits the sun! Nowadays, it is believed that the universe is expanding. It is our turn to wonder: *How could it be expanding?* The standard answer is this: The universe expands by creating new space within itself. Mathematically, the expansion is achieved by scaling the spatial components of the Friedmann–Lemaître–Robertson–Walker metric [17]. Physically, measured redshifts of galaxies seem to confirm the expansion.

The analogy between geocentrism and egocentrism in SR/GR is striking: (1) Diagrams of geocentrism are centered in Earth ("geo"). Spacetime diagrams of SR/GR are centered in observers ("ego"). (2) After centering another planet or after a transformation in SR/GR, the diagrams are still geocentric or else egocentric. (3) Retrograde loops make geocentrism work, but are dispensable in heliocentrism. Dark energy and non-locality make cosmology and QM work, but are dispensable in ER. (4) Heliocentrism breaks with geocentrism. ER breaks with egocentrism. (5) Geocentrism was a dogma in the old days. SR/GR are dogmata nowadays. *Has physics not learned from history? Is history repeating itself?*

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3. The Physics of Euclidean Relativity

ER is a new way to describe physical realities. Unlike SR/GR, ER postulates a mathematical background reality. Unlike SR/GR, ER uses a natural time coordinate and an absolute parameter time. Here is how we proceed: To determine an object's position in an observer's 3D space, we use the same rigid rods and the same 3D geometry (Euclidean geometry) as in SR. However, we will not use coordinate time t as the time coordinate, but the natural, proper time τ measured by clocks. That is, we do not construct time.

The postulates of ER: (1) *All objects move through 4D Euclidean space (ES) at the speed* C. There is no time coordinate in ES. All action is due to a monotonically increasing, absolute, external evolution parameter θ. (2) *An observer experiences two orthogonal projections of ES as space and time.* The axis of his current 4D motion is his proper time τ. Three orthogonal axes form his 3D space x_1, x_2, x_3. Without gravity, his 3D space is Euclidean and thus exactly the same as in SR. Orthogonal projections are described in various textbooks [18, 19]. (3) *The laws of physics take the same form in the physical realities of all observers.* An observer's physical reality is his spacetime x_1, x_2, x_3, τ. Without gravity, his spacetime is Minkowski-like (explained below). As in GR, gravity in ER is the curvature of spacetime (see Sect. 4). Our first postulate is stronger than the second postulate of SR: C is absolute and universal. Our second postulate is unique. Our third postulate does not apply to ES. Variational principles could be another way to derive ER. The metric of ES is

$$C^2\,\mathrm{d}\theta^2 \;=\; \mathrm{d}X_1^2 + \mathrm{d}X_2^2 + \mathrm{d}X_3^2 + \mathrm{d}X_4^2 \;, \tag{4}$$

where $\mathrm{d}\theta$ is an infinitesimal change in the invariant θ, and all $\mathrm{d}X_\mu$ ($\mu = 1, 2, 3, 4$) are infinitesimal distances in ES. We prefer the four indices 1–4 to 0–3 to emphasize the SO(4) symmetry of ES. We set the universal speed to $C = 1$. We define an object's 4D Euclidean vector "proper velocity" $\boldsymbol{U}$ in ES. We call its components $U_\mu = \mathrm{d}X_\mu/\mathrm{d}\theta$ "proper speed". According to these definitions, Eq. (4) is equivalent to our first postulate.

$$U_1^2 + U_2^2 + U_3^2 + U_4^2 \;=\; C^2 \;. \tag{5}$$

ES is a mathematical reality: θ, X_μ, C, U_μ are dimensionless. We consider two objects "r" (red) and "b" (blue) that move uniformly through ES. Every object is free to label the axes of its reference frame. We can thus assume that "r" (or "b") labels the axis of its *current* 4D motion as X_4 (or else X_4') and three orthogonal axes as X_1, X_2, X_3 (or else X_1', X_2', X_3'). According to our first postulate, "r" (or "b") always moves in the X_4 (or else X_4') axis at the speed C. Because of length contraction at the speed C (see Sect. 4), "r" does not experience X_4 as space, but as time. It experiences X_1, X_2, X_3 as space.

To accomplish the transition from ES to an observer's physical reality, we add units to X_1, X_2, X_3, X_4, obtaining x_1, x_2, x_3, x_4. We reassemble the four axes in the Minkowski way (space and time are given opposite signs in the metric) and call them "τ-based Minkowski-like spacetime" (τ-MS). The adjective "Minkowski-like" refers to the metric. The new coordinates are x_1, x_2, x_3, τ, where $\tau = x_4/c$ is a natural time coordinate and θ converts to absolute parameter time ϑ. An observer experiences τ-MS. The metric of τ-MS is

$$c^2\,\mathrm{d}\vartheta^2 \;=\; c^2\,\mathrm{d}\tau^2 - \mathrm{d}x_1^2 - \mathrm{d}x_2^2 - \mathrm{d}x_3^2 \;, \tag{6}$$

which differs from Eq. (3) only in that τ is replaced by ϑ, and t by τ. In τ-MS, the speed is $u_\mu = \mathrm{d}x_\mu/\mathrm{d}\vartheta$. The following conversions apply to the quantities in τ-MS.

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$$\vartheta \;=\; \theta \text{ in seconds (s)}, \tag{7a}$$

$$x_\mu \;=\; X_\mu \;\; (\mu = 1, 2, 3, 4) \text{ in light seconds (Ls)}, \tag{7b}$$

$$c \;=\; C \text{ in light seconds per second}, \tag{7c}$$

$$u_\mu \;=\; U_\mu \;\; (\mu = 1, 2, 3, 4) \text{ in light seconds per second}. \tag{7d}$$

Mathematically, Eq. (3) and Eq. (6)—and thus Minkowski spacetime and τ-MS—are identical. Physically, the time coordinate τ is not a label, but the proper time of a specific observer. In SR, observers experience a single manifold (Minkowski spacetime), but they do so in observer-specific reference frames. Inertial frames are related to each other by the Lorentz transformation. In ER, observers experience observer-specific projections of a single manifold (ES). The projections are reassembled to observer-specific spacetimes (τ-MS). The spacetimes are related to each other by a 4D Euclidean rotation (see Sect. 4). Maxwell's equations hold in τ-MS if the observer is at rest relative to the field source.

$$\nabla \boldsymbol{E} \;=\; 4\pi\rho \;, \qquad \nabla \times \boldsymbol{E} \;=\; -\,c^{-1}\,\partial \boldsymbol{B}/\partial\tau \;, \tag{8}$$

$$\nabla \boldsymbol{B} \;=\; 0 \;, \qquad \nabla \times \boldsymbol{B} \;=\; c^{-1}\,(4\pi \boldsymbol{j} \,+\, \partial \boldsymbol{E}/\partial\tau) \;, \tag{9}$$

where $\boldsymbol{E}$ is the electric field, $\boldsymbol{B}$ is the magnetic field, ρ is the electric charge density, and $\boldsymbol{j}$ is the current density. If the observer moves relative to the field source, τ' of the source differs from his τ. In this case, Eqs. (8) and (9) do not hold anymore. However, it is possible to reformulate Maxwell's equations using an "effective speed of light" [20].

ER describes two realities: a mathematical background reality (ES) and an observer's physical reality. Without gravity, the latter is τ-MS. The SO(4) symmetry of ES is not compatible with waves, while the SO(1,3) symmetry of τ-MS is. Waves exist in physical realities only. *How do we synchronize clocks in ER?* That is not necessary because θ is absolute. Clocks are naturally synchronized in the parameter θ. Thus, causality holds in ER: Events are causal with respect to θ. Since an object's τ flows in the direction of its 4D motion, it makes sense to introduce a 4D Euclidean vector "flow of proper time" $\boldsymbol{T}$.

$$\boldsymbol{T} \;=\; \boldsymbol{U} \;. \tag{10}$$

τ-MS is not a construct because τ is a *natural* concept: τ is inherent in clocks. Clocks measure nothing but proper time. In SR, the coordinates are $x_1(\tau), x_2(\tau), x_3(\tau), t(\tau)$, where t is a man-made concept and τ is an internal parameter. In ER, the coordinates of ES are $X_1(\theta), X_2(\theta), X_3(\theta), X_4(\theta)$ and the coordinates of τ-MS are $x_1(\vartheta), x_2(\vartheta), x_3(\vartheta), \tau(\vartheta)$, where τ is a natural concept. θ and ϑ are external parameters. ES is absolute. τ-MS is relative: An observer's time axis and thus his 3D space depend on his 4D vector $\boldsymbol{T}$.

It is instructive to compare θ, ϑ, and τ. The *evolution parameter* θ is the invariant in ES. In ES, clocks are odometers that display θ. Since θ does not depend on anything, it is absolute. *Parameter time* ϑ is the invariant in τ-MS. Because of Eq. (7a), ϑ is absolute too. *Proper time* τ is the time coordinate in τ-MS. An observer experiences projections: A clock measures its τ', but its time axis τ' is projected onto his time axis τ. It displays τ (not τ') in his τ-MS. *A clock can display different values in different realities because the projections affect both space and time.* For uniformly moving objects, Eqs. (3) and (6) hold. Thus,

$$\mathrm{d}\vartheta \;=\; \mathrm{d}t \qquad \text{(for uniformly moving objects)}. \tag{11}$$

Remarks: (1) Mathematically, ES is a 4D Euclidean manifold. Physically, three axes of ES are experienced as space and one axis as time. (2) ES and objects in ES are not observable. Our ES diagrams show objects (clock, rockets) to illustrate the projections. (3) Parameter time ϑ is not a fifth dimension. In SR, the parameter τ is not a fifth dimension either. (4) In the standard notation of SR, time is *always* the first (or fourth) coordinate. The same applies to τ-MS, yet *any* one axis of ES can be the preimage of the time axis in τ-MS. The variable preimage of the time axis justifies the 4D vector $\boldsymbol{T}$ (not available in SR and GR). (5) Do not confuse ER with a Wick rotation [21], where τ is the parameter.

We consider two clocks "r" and "b" that move uniformly through 3D space. In SR, "r" moves in the ct axis. "b" moves at the speed $v_1 = 0.6\,c$. Fig. 1 left shows that instant when both clocks moved 1.0 Ls in ct. "b" moved 0.8 Ls in ct'. Thus, "b" displays "0.8". In ER, "r" moves in the X_4 axis. "b" moves at the speed $U_1 = 0.6\,C$. Fig. 1 right shows that instant when 1.0 has elapsed in θ since both clocks left the origin. Thus, both clocks display "1.0" in ES. "r" moved 1.0 Ls in $c\tau$. Thus, "r" displays "1.0" in the reality of "r". "b" moved 0.8 Ls in $c\tau$ and 1.0 Ls in $c\tau'$. Thus, "b" displays "0.8" in the reality of "r" and "1.0" in the reality of "b" (not shown). Red digits on "b" indicate that it is read in the reality of "r".

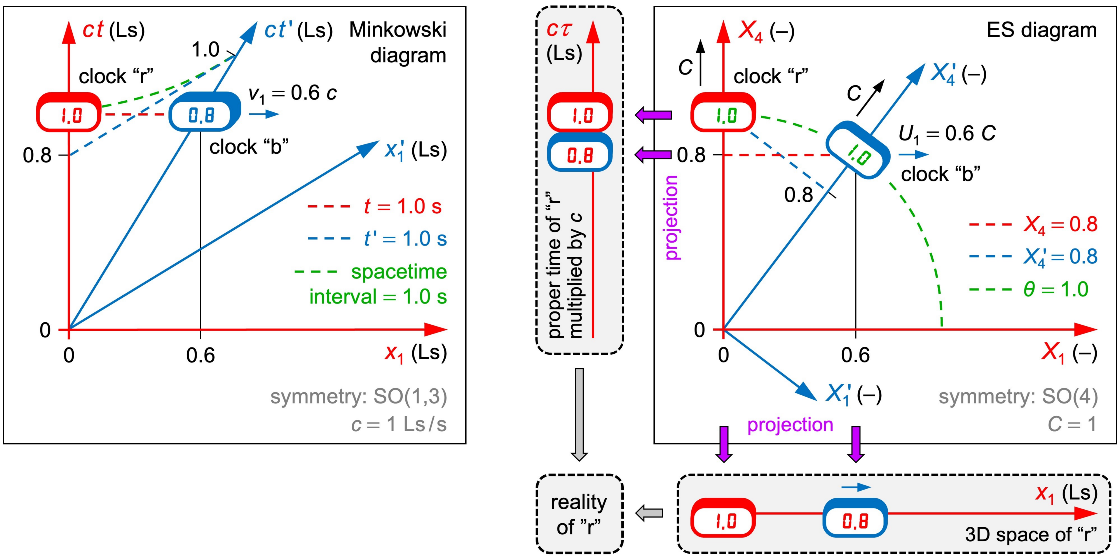

Fig. 1 Minkowski diagram and ES diagram of two uniformly moving clocks. **Left:** "b" is slow with respect to "r" in t'. Coordinate time is relative ("b" is at different positions in t and t'). **Right:** "b" is slow with respect to "r" in X_4. The evolution parameter is absolute (both clocks are at $\theta = 1.0$)

We assume that observer R (or B) moves with clock "r" (or else "b"). In SR and only for R ("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 $X_4 = 0.8$ when R is at $X_4 = 1.0$ (see Fig. 1 right). *Thus, "b" is slow with respect to "r" in* X_4. In SR and ER, "b" is slow with respect to "r", but time dilates in different axes. Experiments do not reveal in which axis a clock is slow. Clocks measure τ, not $\boldsymbol{T}$. If "b" reverses its x_1 motion at $x_1 = 0.6$ Ls, it collides with "r" at $x_1 = 0$. At this instant (not shown), both clocks display "2.0" in ES. In the reality of "r", however, "r" displays "2.0" and "b" displays "1.6". This is the ER analogy to the twin paradox in SR. It is not actually a paradox, but is resolved in the same way as in SR: "b" experiences a deceleration and an acceleration.

R and B experience different axes as time. This is why Fig. 1 left works for R only. A *second* Minkowski diagram is required for B, in which his axes x_1' and ct' are orthogonal. Minkowski diagrams are observer-specific. Most physicists do not care that two diagrams are required because there is no simultaneity (no "at once") for the two observers in SR. The ES diagram in Fig. 1 right works for R and for B "at once" (at the same $\theta = 1.0$). Not only are the two axes X_1 and X_4 orthogonal, but so are X_1' and X_4'. ES diagrams (not the spacetime diagrams) are observer-independent. They work for all observers. They show a mathematical Master Reality beyond all physical realities. *ES diagrams can be projected onto any observer's physical reality.* This is a huge advantage over SR/GR (see Sect. 5).

4. Relativistic Effects in Euclidean Relativity

We consider two rockets "r" and "b" that move uniformly through 3D space. R (or B) is in the rear end of "r" (or else "b"). R (or B) experiences X_1, X_2, X_3 (or else X_1', X_2', X_3') as his 3D space. R (or B) experiences X_4 (or else X_4') as his proper time. The two rockets start at the same point P and the same θ. They move relative to each other at the constant speed U_1. The ES diagrams in Fig. 2 must satisfy our three postulates and the two initial conditions (same P, same θ). 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 X_4 (or X_4') although its actual width is in X_2 and X_3 (or else X_2' and X_3').

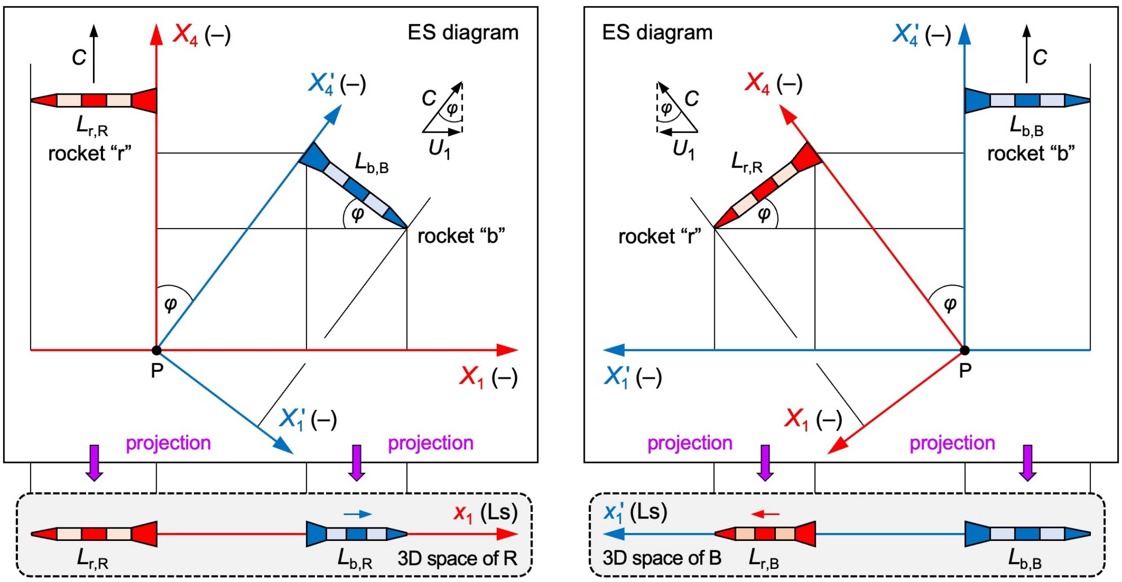

Fig. 2 ES diagrams of two uniformly moving rockets. "r" and "b" move in different 4D directions. The ES diagrams are identical. **Bottom left:** In the projection onto the 3D space of R, "b" contracts to $L_{\mathrm{b,R}}$. **Bottom right:** In the projection onto the 3D space of B, "r" contracts to $L_{\mathrm{r,B}}$

We now show: Projecting distances in ES onto the axes X_1 and X_4 causes length contraction and time dilation. Let $L_{\mathrm{b,R}}$ (or $L_{\mathrm{b,B}}$) be the length of "b" for observer R (or else B). In a first step, we project $L_{\mathrm{b,B}}$ onto the X_1 axis (see Fig. 2 left).

$$\sin^2\varphi \;+\; \cos^2\varphi \;=\; (U_1/C)^2 \;+\; (L_{\mathrm{b,R}}/L_{\mathrm{b,B}})^2 \;=\; 1\;, \tag{12}$$

$$L_{\mathrm{b,R}} \;=\; \gamma_{\mathrm{ER}}^{-1}\, L_{\mathrm{b,B}} \qquad \text{(length contraction)}, \tag{13}$$

where $\gamma_{\mathrm{ER}} = (1 - U_1^2/C^2)^{-0.5} = (1 - u_1^2/c^2)^{-0.5}$ has the same form as γ in SR. $\gamma_{\mathrm{ER}} = \gamma$ if $u_1 = v_1$. From $u_1 = \mathrm{d}x_1/\mathrm{d}\vartheta$ and $v_1 = \mathrm{d}x_1/\mathrm{d}t$, we derive: $u_1 = v_1$ if $\mathrm{d}\vartheta = \mathrm{d}t$. According to Eq. (11), $\mathrm{d}\vartheta = \mathrm{d}t$ for uniformly moving objects. Both rockets move uniformly. We conclude: *ER reproduces the Lorentz factor.* Since the projections are not injective, ES is the Master Reality. In a second step, we project B's motion through ES onto the X_4 axis.

$$\sin^2\varphi + \cos^2\varphi = (U_1/C)^2 + (X_{4,\mathrm{B}}/X'_{4,\mathrm{B}})^2 = 1 , \tag{14}$$

$$X_{4,\mathrm{B}} = \gamma_{\mathrm{ER}}^{-1}\, X'_{4,\mathrm{B}} , \tag{15}$$

where $X_{4,\mathrm{B}}$ (or $X'_{4,\mathrm{B}}$) is the distance that B traveled in X_4 (or else X'_4). With $X'_{4,\mathrm{B}} = X_{4,\mathrm{R}}$ (R and B travel the same distance in ES, but in different 4D directions), we calculate

$$X_{4,\mathrm{R}} = \gamma_{\mathrm{ER}}\, X_{4,\mathrm{B}} \qquad \text{(time dilation)}, \tag{16}$$

where $X_{4,\mathrm{R}}$ is the distance that R traveled in X_4. Eqs. (13) and (16) tell us: ER reproduces the relativistic effects of SR. *Can R observe distances in* X_4? We rotate "b" until it serves as a ruler in X_4. In the 3D space of R, this ruler contracts to zero length: The X_4 axis disappears because of length contraction at the speed C. The two rockets are just an example. To calculate the lifetime of a muon, we replace "b" with a muon and apply Eq. (16).

We now transform the 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. Fig. 2 right tells us how to calculate the 4D motion of R in the coordinates of B. The transformation is shown in Eqs. (17a–b). It is a 4D Euclidean rotation by the angle φ. Adding multiple rotations does not violate Einstein's relativistic addition of velocities. In SO(4), 4D rotations are additive. In SO(1,3), velocities are not additive.

$$X'_{1,\mathrm{R}}(\theta) = X_{4,\mathrm{R}}(\theta)\, \sin\varphi = X_{4,\mathrm{R}}(\theta)\; U_1/C , \tag{17a}$$

$$X'_{4,\mathrm{R}}(\theta) = X_{4,\mathrm{R}}(\theta)\, \cos\varphi = X_{4,\mathrm{R}}(\theta)\; \gamma_{\mathrm{ER}}^{-1} . \tag{17b}$$

Up next, we show: ER reproduces gravitational time dilation. Initially, our clocks "r" and "b" are far away from Earth and move in the X_4 axis at the speed C. Eventually, "b" falls freely toward Earth (see Fig. 3 left). If an object's worldline in ES is curved, its four axes continuously adapt to the current curvature (curvilinear coordinates [22], as also used in GR). Since the speed $U_{4,\mathrm{b}}$ of "b" in the X_4 axis is less than C, its distance to Earth in ES eventually increases. One may ask: *How can "b" then still experience the presence of Earth?* The answer is this: One axis of ES is always experienced as time. In the 3D space of "b", Earth accelerates toward "b" until they eventually collide (see Fig. 3 right).

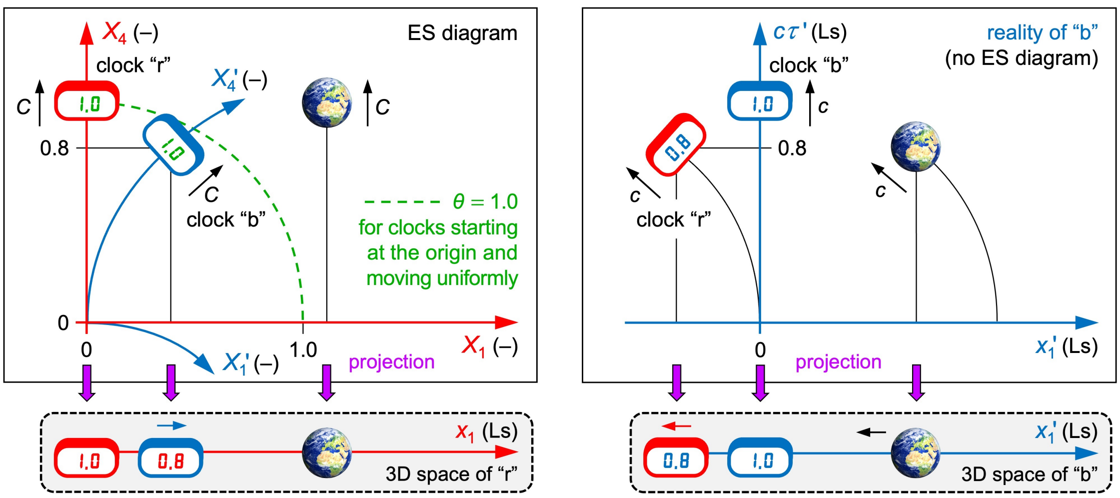

Fig. 3 Clock "b" falls freely toward Earth. **Left:** X'_4 indicates the current 4D motion of "b". In the 3D space of "r", "b" accelerates toward Earth. **Right:** This is not an ES diagram. "b" experiences gravity as an acceleration of everything else. In the 3D space of "b", Earth accelerates toward "b"

We make two assumptions: (1) *In the physical reality of "r", the kinetic energy of "b" and the potential energy of "b" take the same form as in Newton's physics.* (2) *In the physical reality of "r", energy is conserved.* Our first assumption is reasonable because we learned that relativistic effects in ER are caused by projecting ES. In particular, it is not necessary to consider a relativistic expression for kinetic energy. According to Eq. (7d), u_μ is essentially equal to $U_\mu = \mathrm{d}X_\mu/\mathrm{d}\theta$. Since u_μ can be expressed in the quantities of absolute ES, kinetic energy in ER cannot be subject to relativistic effects. Our second assumption is reasonable because the conservation of energy is a rigorously tested law of physics.

$$E_{\mathrm{kin}} \;=\; \tfrac{1}{2} m_{\mathrm{b}} u_{1,\mathrm{b}}^2 \;, \qquad E_{\mathrm{pot}} \;=\; -\,G m_{\mathrm{b}} m_{\mathrm{Earth}}/r \;, \tag{18}$$

$$\tfrac{1}{2} m_{\mathrm{b}} u_{1,\mathrm{b}}^2 \;=\; G m_{\mathrm{b}} m_{\mathrm{Earth}}/r \;, \tag{19}$$

where E_{kin} is the kinetic energy of "b" in the x_1 axis (see Fig. 3 left), m_{b} is the mass of "b", $u_{\mu,\mathrm{b}}$ is the speed of "b" in the x_μ axis ($\mu = 1, 2, 3, 4$), E_{pot} is the potential energy of "b", G is the gravitational constant, m_{Earth} is the mass of Earth, and r is the distance of "b" to the center of Earth in the x_1 axis. Our first postulate tells us: If an object accelerates in three axes of ES, it automatically decelerates in the fourth axis.

$$U_{4,\mathrm{b}}^2 \;=\; C^2 \;-\; U_{1,\mathrm{b}}^2 \;. \tag{20}$$

With the relation $U_{\mu,\mathrm{b}}/C = u_{\mu,\mathrm{b}}/c$, Eq. (20) turns into

$$u_{4,\mathrm{b}}^2 \;=\; c^2 \;-\; u_{1,\mathrm{b}}^2 \;. \tag{21}$$

By combining Eqs. (19) and (21), we calculate

$$u_{4,\mathrm{b}}^2 \;=\; c^2 \;-\; 2 G m_{\mathrm{Earth}}/r \;. \tag{22}$$

By inserting the speeds $u_{4,\mathrm{b}} = \mathrm{d}x_{4,\mathrm{b}}/\mathrm{d}\vartheta$ ("b" moves in the x_4 axis at the speed $u_{4,\mathrm{b}}$) and $c = \mathrm{d}x_{4,\mathrm{r}}/\mathrm{d}\vartheta$ ("r" moves in the x_4 axis at the speed c), Eq. (22) gives us

$$\mathrm{d}x_{4,\mathrm{b}}^2 \;=\; (c^2 \;-\; 2 G m_{\mathrm{Earth}}/r)\,(\mathrm{d}x_{4,\mathrm{r}}/c)^2 \;, \tag{23}$$

$$\mathrm{d}x_{4,\mathrm{r}} \;=\; \gamma_{\mathrm{grav}}\, \mathrm{d}x_{4,\mathrm{b}} \qquad \text{(gravitational time dilation)}, \tag{24}$$

where $\gamma_{\mathrm{grav}} = (1 - 2 G m_{\mathrm{Earth}}/(r c^2))^{-0.5}$ is the same dilation factor as in GR. We conclude: *ER reproduces gravitational time dilation.* Note that the axis of time dilation is different from that in GR. In ER, it is the observer's x_4 axis. We have shown that ER reproduces the factors γ and γ_{grav}. Thus, the Hafele–Keating experiment [23] supports not only SR/GR, but also ER. In particular, GPS devices [6] work in ER just as well as in SR/GR.

The Einstein field equations (EFE) in GR are tensor equations given by

$$G_{\mu\nu} + \Lambda g_{\mu\nu} \;=\; 8\pi G T_{\mu\nu}/c^4 \;, \tag{25}$$

where $G_{\mu\nu}$ is the Einstein tensor, Λ is the cosmological constant, $g_{\mu\nu}$ is the metric tensor, and $T_{\mu\nu}$ is the stress–energy tensor. The EFE are coordinate-invariant. Since coordinates in GR are merely labels, the EFE hold in any smooth and invertible coordinate system. In

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particular, the EFE also hold in systems that use proper time as the time coordinate. Whenever we replace t with τ, we switch from global coordinates to a locally co-moving frame, such as a falling observer. We conclude: *As in GR, gravity in ER is the curvature of spacetime.* An example of curved spacetime is the reference frame of clock "b" in Fig. 3 left. Note that the EFE do not hold in ES. The mathematical background reality remains flat.

Even in GR, τ is occasionally used as the time coordinate. Co-moving observers [24] and collapsing stars [25] are two examples. Whenever we use τ as a coordinate, the time-time component of the metric tensor is $g_{00} = +1$ or -1, depending on the signature. But there seems to be a catch: *τ is a local quantity*. In gravitational fields, clocks cannot be synchronized in the coordinate τ. We recall that we do not synchronize clocks in ER. They are naturally synchronized in the parameter θ. This renders the catch irrelevant.

We pause for a moment and summarize: SR/GR are background-free, but spacetime diagrams are observer-specific. ER provides observer-independent ES diagrams, but ER is not background-free. *Is a background-free approach an advantage? Or are observer-independent diagrams an advantage?* Sect. 5 will tell us: Observer-independent diagrams are indispensable. We will not discuss the EFE further, as we do not need them in Sect. 5.

ER also predicts gravitational waves [26]. In GR, a weak field allows us to decompose the metric into a flat Minkowski metric $\eta_{\mu\nu}$ plus a small perturbation $h_{\mu\nu}$ [15, 27].

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad (\text{with } |h_{\mu\nu}| \ll 1). \tag{26}$$

Since coordinate time is a label, we can again use τ as the time coordinate, but further studies are required. Lee and Zurek showed that τ is not just a parameter, but a physical observable of $h_{\mu\nu}$ in interferometer experiments [28]. ER supports the idea that gravity is carried by gravitons [29] and manifests itself in physical realities as waves.

ER teaches us that "observing" is synonymous with "projecting ES onto an observer's reality". Fig. 4 illustrates how to read an ES diagram correctly. Problem 1: A rocket moves along a guide wire. We assume that the guide wire moves in the X_4 axis at the speed C. Since the rocket moves in the two axes X_1 and X_4, its speed U_4 is less than C. *Doesn't the wire eventually escape from the rocket?* Problem 2: Earth orbits the sun. We assume that the sun moves in the X_4 axis at the speed C. Since Earth moves in the three axes X_1, X_2, and X_4, its speed U_4 is less than C. *Doesn't the sun eventually escape from Earth?*

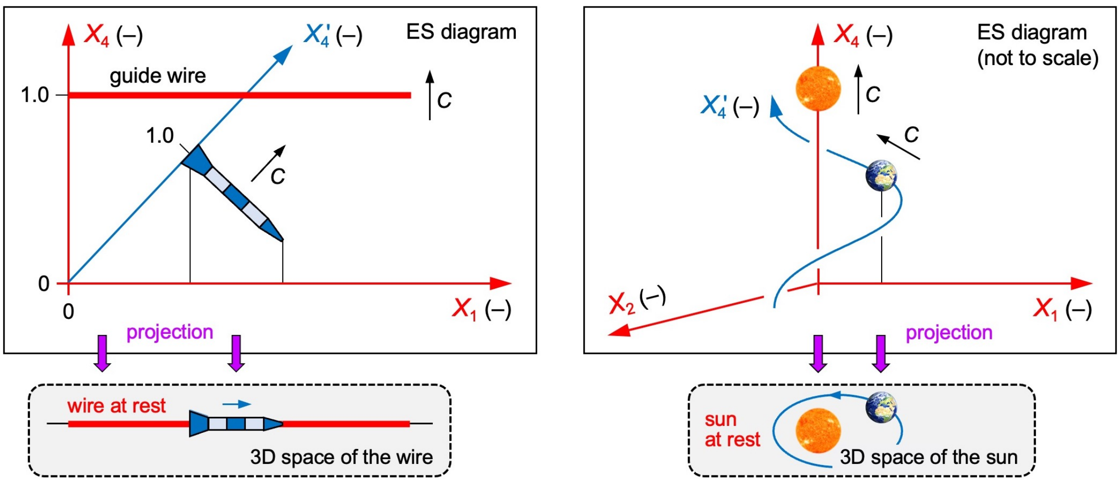

Fig. 4 Two instructive problems. **Left:** In the 3D space of a guide wire, a rocket moves along the wire. In ES, the wire escapes from the rocket. **Right:** In the 3D space of the sun, Earth orbits the sun. In ES, the sun escapes from Earth. We ignore the fact that the sun orbits the center of the Milky Way

The last paragraph seems to reveal paradoxes. The fallacy lies in assuming that all four axes of ES are experienced as spatial at once. We solve both problems by projecting ES onto the 3D space of that object which moves in the X_4 axis at the speed C. In Fig. 4 left, the guide wire does not spatially escape from the rocket. They age in different 4D directions! In 3D space, the only relevant quantities for guiding a rocket or for a collision of objects are x_1, x_2, x_3, ϑ. In the projection onto 3D space, the X_4 axis is "projected away". As in SR/GR, a coincidence in proper time is not required. Collisions in 3D space do not appear as collisions in ES because ϑ and θ are not coordinates, but parameters. In Fig. 4 right, the sun does not spatially escape from Earth. They age in different and in changing 4D directions! *ES diagrams do not show events, but an object's position and its 4D vector* $\boldsymbol{T}$.

5. Empirical Evidence for Euclidean Relativity

Here we show that ER predicts 12 empirical facts. In particular, ER passes those three tests that Albert Einstein himself proposes to validate GR (see § 22 of [2]): gravitational redshift, gravitational lensing, and the precession of Mercury's perihelion.

5.1. Time's Arrow

"Time's arrow" stands for time that flows only forward. *Why can't time flow backward?* Experienced time is the distance traveled in absolute ES divided by C. A distance traveled in absolute ES cannot be "untraveled" because θ is a monotonically increasing, absolute, external parameter. There is no such parameter in SR/GR.

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 predicts the same gravitational time dilation as GR (see Sect. 4), ER also predicts gravitational redshift.

5.3. Gravitational Lensing

Montanus [10] uses a Euclidean metric to derive the deflection of starlight by a spherical mass. On page 1387 of [10], he calculates the deflection angle ψ.

$$\psi \;=\; 4\mu/R \;, \tag{27}$$

where μ is half the Schwarzschild radius and R is the closest approach. Since [10] is published, we do not repeat the calculation. Montanus uses the parameter t (see page 1368 of [10]). For starlight deflected by the sun and observed on Earth, t is as good a parameter as ϑ: Because of their high speed C, the sun and Earth move almost uniformly through ES. Thus, $\mathrm{d}\vartheta \cong \mathrm{d}t$ according to Eq. (11). We conclude: *GR and ER predict the same* ψ.

5.4. Precession of Mercury's Perihelion

Montanus [10] uses a Euclidean metric to derive the precession of orbits. On page 1389 of [10], he calculates the additional orbital angle φ covered per revolution.

$$\varphi \;=\; 6\pi\mu/(L(1-e^2)) \;, \tag{28}$$

where L is the semimajor axis and e is the eccentricity. For Mercury, Montanus estimates $\varphi \cong 42.9''$ per century (see page 72 of [11]). Again, t is as good a parameter as ϑ: Mercury also moves almost uniformly through ES. Since [11] is not peer reviewed, further studies are required. Once [11] is confirmed, we may conclude: *GR and ER predict the same* φ.

5.5. Cosmic Microwave Background (CMB)

Today's standard model of cosmology, the inflationary Lambda-CDM model [30, 31], is based on GR. According to this model, the universe inflated from a singularity. The Big Bang occurred "everywhere". In Sects. 5.5 to 5.11, we outline an ER-based model of cosmology that localizes the Big Bang: A huge amount of energy was injected into a given ES at an origin O. *The Big Bang was a singularity in providing energy and radial momentum.* Ever since the Big Bang ($\theta = 0$), parameter time has been ticking uniformly and energy has been moving through ES at the speed C. Shortly after the Big Bang, all energy was highly concentrated. As it receded from O, it became less concentrated and created plasma particles. Today, we still observe the emitted recombination radiation as CMB [32].

The ER-based model must be able to answer several 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?* Here are some possible answers: (1) The CMB is scattered equally in the 3D space of Earth. (2) Plasma particles receded from O at very high speeds (Doppler redshift, see Sect. 5.11). (3) Some of the recombination radiation reaches Earth after traveling the same distance in X_1, X_2, X_3 (multiple scattering) as the Milky Way in X_4 (for the axes, see Fig. 5).

5.6. Hubble–Lemaître Law

A galaxy G and the Milky Way recede from O at the speed C (see Fig. 5 left). G recedes from Milky Way's X_4 axis at the speed U_1. D (or D_0) is the distance from G to the Milky Way in the 3D space of the Milky Way at a specific value θ (or else θ_0). *U_1 is to D as C is to the radius $C\theta$ of an expanding 3D hypersurface.* All energy is within the 4D hypersphere. Its radius $C\theta$ is parameterized by θ. Because of various effects (gravity, scattering, photon emission, pair production), some energy does not recede radially anymore.

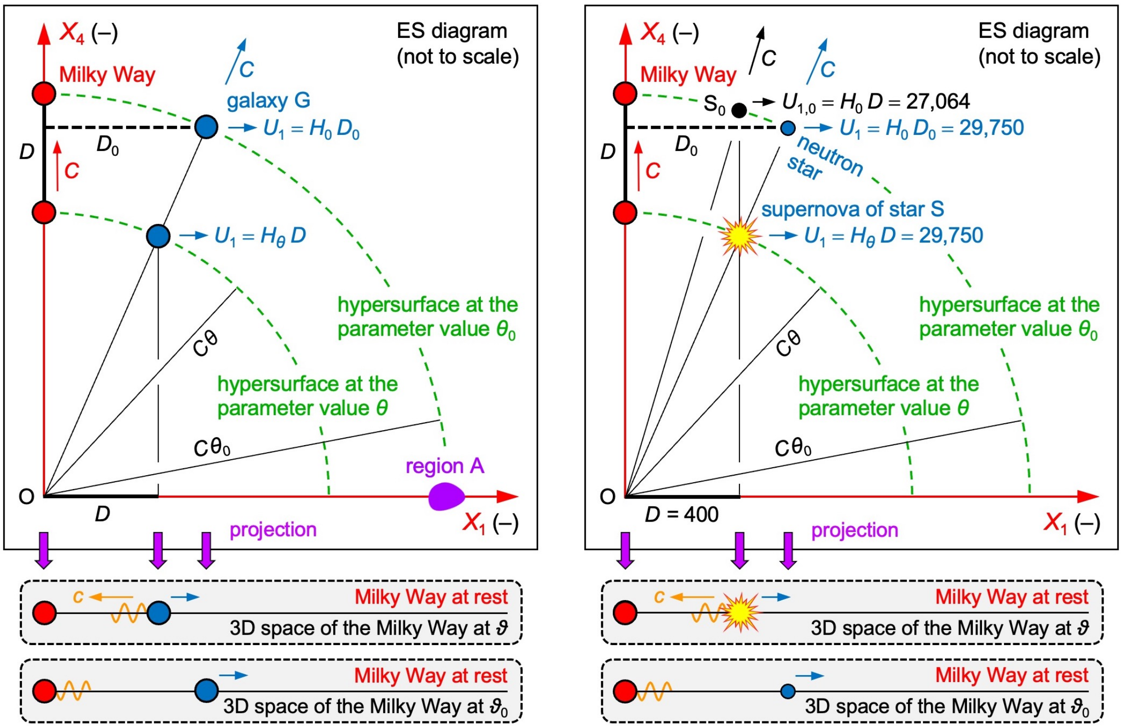

Fig. 5 ER-based model of cosmology. **Left:** A galaxy G recedes from O (location of the Big Bang) at the speed C and from the X_4 axis at the speed U_1. **Right:** If a star S_0 happens to be at the same distance D today at which the supernova of S occurred, S_0 recedes more slowly from X_4 than S

$$U_1 = DC/(C\theta) = D/\theta = H_\theta D \,, \tag{29}$$

where $H_\theta = 1/\theta$ is the ER-equivalent to the Hubble parameter. If we observe the galaxy G today (we denote "today" with the value θ_0 and thus with the parameter time ϑ_0), the two speeds U_1 and C remain unchanged. Thus, Eq. (29) turns into

$$U_1 = D_0 C/(C\theta_0) = D_0/\theta_0 = H_0 D_0 , \tag{30}$$

where $H_0 = 1/\theta_0$ is the ER-equivalent to the Hubble constant, $D_0 = D\theta_0/\theta$, and $C\theta_0$ is today's radius of the hypersurface. In the 3D space of the Milky Way, some light emitted by G at the time ϑ reaches the Milky Way at ϑ_0 (orange wave in Fig. 5 left). Eq. (30) is the Hubble–Lemaître law [33, 34]. Cosmologists are aware of the Hubble parameter. They are not yet aware that (a) the underlying 4D geometry is Euclidean, (b) space is not expanding, (c) ϑ is absolute, and (d) distant galaxies maintain their recession speeds. *Of two galaxies, the more distant one recedes faster, yet distant galaxies maintain their recession speeds.*

5.7. Flat Universe

An observer experiences neither flat ES nor the curved hypersurface. His "universe" (physical reality) is his spacetime x_1, x_2, x_3, τ. Mass and energy can locally curve his universe, but the overall spatial geometry is determined by ES and is thus flat.

5.8. Large-Scale Structures

Most cosmologists [35, 36] 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. We have shown that ER predicts the isotropic CMB and the flat universe. ER predicts large-scale structures if the fluctuations have been expanding with the hypersphere. **ER manages without cosmic inflation.**

5.9. Cosmic Homogeneity (Horizon Problem)

How can the universe be so homogeneous on large scales? In the Lambda-CDM model, two regions A and B at opposite sides of the universe are causally disconnected unless we postulate a "cosmic inflation". Otherwise, information could not have been transferred. In the ER-based model, A is at $X_1 = +C\theta_0$ (see Fig. 5 left) and B is at $X_1 = -C\theta_0$ (not shown). A and B experience the X_1' axis (equal to Milky Way's X_4 axis) as space. For A and B, the X_4' axis (equal to Milky Way's X_1 axis) disappears because of length contraction at the speed C. *From their perspective, A and B have never been spatially separated, yet their proper time flows in opposite 4D directions.* This is how A and B are causally connected. Their opposite 4D vectors $\boldsymbol{T}$ do not affect causal connectivity as long as A and B stay together spatially.

5.10. Hubble Tension (H_0 Tension)

Up next, we show: ER predicts the ten percent discrepancy in the published values of the Hubble constant. We consider CMB measurements and distance ladder measurements. The values do not match: 67.66 ± 0.42 km/s/Mpc (CMB and baryon acoustic oscillations) according to team A [37]. 73.04 ± 1.04 km/s/Mpc according to team B [38]. Team B made efforts to minimize the error margins in the distance measurements, but there is a systematic error in its calculation: Team B assumes an incorrect cause of the redshift.

We assume that team A's value is correct. We now simulate the supernova of a star S, which occurred at a distance of $D = 400$ (corresponding to 400 Mpc in the 3D space of the Milky Way) from the Milky Way (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 a wavelength

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of the supernova's light is either stretched by an expanding space (team B) or else Doppler-redshifted by receding objects (ER-based model). We assume that the supernova occurred at a specific value θ, but we observe it today at θ_0. While the supernova's light traveled the distance D in $-X_1$, the Milky Way traveled the same distance D in $+X_4$.

Team B calculates H_0 by plotting the distance modulus $\mu = m - M$ against the redshift (apparent magnitude m, absolute magnitude M). More precisely, it uses magnitudes of Type Ia supernovae that are calibrated in the B-band. Team B believes in the Lambda-CDM model. In particular, it believes that it is plotting *stretched* distances (stretched by an expanding space) against the redshift. In the ER-based model, distances are not stretched. Once we accept the ER-based model, team B is not plotting any stretched distances, but D of the past (when the supernova's light was emitted) against the redshift.

To a first approximation, our star S moves uniformly through ES. We ignore the fact that stars orbit the center of a galaxy. According to Eq. (11), $\mathrm{d}\vartheta \cong \mathrm{d}t$. Thus, $U_1/C = u_1/c$ is approximately equal to v_1/c. Since distances are not stretched in the ER-based model, $U_1/C \cong v_1/c$ is basically proportional to the redshift z. Thus, team B is basically plotting D against U_1. According to Eq. (29), the slope in such a plot is not H_0, but H_θ. In Fig. 6 (red points), we plot U_1 against D for distances from 0 to 500 in steps of 25. The slope of a straight-line fit through the origin is roughly ten percent higher than 67.66. According to Eq. (30), we must plot U_1 against D_0 to obtain a straight line. *Failure to account for the 4D Euclidean geometry leads to an increased value of* H_0. This explains the H_0 tension.

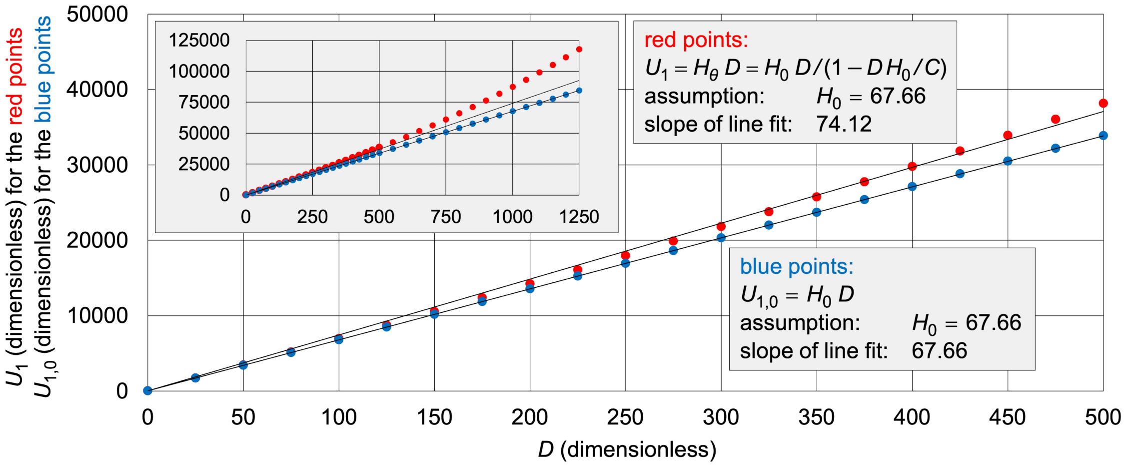

Fig. 6 Hubble diagram of simulated supernovae. According to Eqs. (29) and (32), the recession speed U_1 is equal to $H_0 D/(1 - DH_0/C)$. Thus, the red points do not form a straight line. According to Eq. (31), the recession speed $U_{1,0}$ is equal to $H_0 D$. Thus, the blue points do form a straight line

Eq. (30) requires the knowledge of D_0, but measurable magnitudes of supernovae are related to D. We solve this technical difficulty by rewriting Eq. (30) as

$$U_{1,0} = H_0 D \ , \tag{31}$$

where $U_{1,0}$ is the recession speed in X_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

$$H_\theta = C/(C\theta) = C/(C\theta_0 - D) = H_0/(1 - DH_0/C) \ . \tag{32}$$

We solve Eq. (29) for H_θ, we solve Eq. (31) for H_0, and we insert the resulting expressions and the above approximation $U_1/C \cong v_1/c$ into Eq. (32). This gives us

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$$U_{1,0} = U_1/(1 + U_1/C) \ , \tag{33}$$

$$U_{1,0} \cong v_1 C/(v_1 + c) \ . \tag{34}$$

We kindly ask team B to convert v_1 (obtained from z) to $U_{1,0}$ according to Eq. (34). We recall that $C = 1$ and $c = 1$ Ls/s. According to Eq. (31), plotting $U_{1,0}$ against D yields the correct value of H_0 (blue points in Fig. 6). It makes no difference whether we plot $U_{1,0}$ against D according to Eq. (31), or U_1 against D_0 according to Eq. (30). Fig. 6 also tells us: The more high-redshift data are taken into account, the greater the H_0 tension.

5.11. Cosmological Redshift

We now identify a second systematic error in cosmology. It concerns the supposedly accelerating expansion of the universe and cannot be resolved within the Lambda-CDM model unless we postulate a "dark energy". Most cosmologists [39, 40] believe in an accelerating expansion because recession speeds increasingly deviate from a straight line when plotted against distance. An accelerating expansion would redshift the supernova's light even more. In the Lambda-CDM model, space expands by creating new space within itself. However, acceleration relative to Earth has never been observed in a single galaxy. Moreover, the idea that space creates space is highly questionable from an ontological perspective. A non-expanding ES is far less speculative than an expanding 3D space.

In the ER-based model, there is no uniform expansion and no accelerating expansion of space. The supernova's light is redshifted by the *Doppler effect.* The older the supernova, 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 $D = 400$ today at which the supernova of S occurred, Eq. (33) tells us: S_0 recedes more slowly ($U_{1,0} = 27{,}064$, the shortest arrow in Fig. 5 right) from X_4 than S ($U_1 = 29{,}750$). *It does so because of the 4D Euclidean geometry.* The 4D vector $\boldsymbol{T}'$ of S_0 differs less from $\boldsymbol{T}$ of the Milky Way than $\boldsymbol{T}''$ of S differs from $\boldsymbol{T}$. "Dark energy" [41] was invented to explain an accelerating expansion of space. Dark energy is a stopgap solution for an effect that the Lambda-CDM model cannot explain. Earlier supernovae recede faster because of a greater value of H_θ, not because of dark energy.

The Hubble tension and puzzling redshifts have the same physical background: Any expansion of space—uniform or else accelerating—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 prize was awarded for an illusion. Most galaxies recede from the Milky Way, but they do so *uniformly* in a non-expanding ES. Dark energy, the driving force behind a supposedly accelerating expansion, is an illusion. Most energy recedes radially from the origin O because of the radial momentum provided by the Big Bang. **ER manages without expanding space and dark energy.**

The Hubble tension and cosmological redshift are very strong empirical evidence that challenges the Lambda-CDM model. They force us to take the 4D Euclidean geometry into account, and $\boldsymbol{T}$ in particular. GR works well if $\boldsymbol{T}$ is irrelevant, but $\boldsymbol{T}''$ of a high-redshift supernova differs greatly from $\boldsymbol{T}$ of the Milky Way. Space is not driven by dark energy. Every galaxy is driven by its momentum. Because of various effects (gravity, scattering, photon emission, pair production), some energy does not recede radially anymore. Gravity pulls nearby galaxies toward our galaxy. Table 1 compares two models of cosmology. ER predicts time's arrow, relativistic effects, galactic motion, and the Hubble tension. Remarkably, ER manages without cosmic inflation, expanding space, and dark energy. Thus, ER significantly improves cosmology. ER also improves QM (see Sect. 5.12).

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Inflationary Lambda-CDM model based on GR	ER-based model of cosmology
There is no absolute space.	4D Euclidean space is absolute.
There is no absolute time.	Parameter time is absolute.
The Big Bang was the beginning of everything.	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).
Shortly after the Big Bang, space was inflating.	There is no cosmic inflation.
Today, there is an accelerating expansion of space.	There is no expanding space.
Dark energy causes the accelerating expansion.	There is no dark energy.
Distant galaxies are accelerating relative to Earth.	Distant galaxies maintain their recession speeds.
This model does not predict the Hubble tension.	This model predicts the Hubble tension.

Table 1 Comparing two models of cosmology

5.12. *Quantum Entanglement*

Erwin Schrödinger coins the word “entanglement” in a comment [42] on the Einstein–Podolsky–Rosen paradox [43]. These three authors argue that QM does not provide a complete description of reality. Schrödinger’s neologism does not resolve the paradox, but it highlights our enormous difficulties in comprehending QM. John Bell [44] shows that QM is incompatible with local hidden-variable theories. Meanwhile, several experiments [45–47] have confirmed that entanglement violates locality in an observer’s 3D space. Quantum entanglement has been interpreted as a “non-local effect” ever since.

Up next, we show: ER “untangles” entanglement without the concept of non-locality. There is no violation of locality in 4D (!) space, where all four axes are fully symmetric. In Fig. 7, observer R moves in the X_4 axis at the speed C. We consider two pairs of objects. The first pair was created at the point P and moves in opposite directions $\pm X_4'$ (equal to $\pm X_1$ of R) at the speed C. The second pair was created at the point Q and moves in opposite directions $\pm X_4''$ at the speed C. Observer R perceives the first pair as entangled photons and the second pair as entangled material objects, such as electrons. In his 3D space, observer R perceives either pair as *spatially separated* objects. He has no idea how spatially separated objects are able to “communicate” with each other in no time.

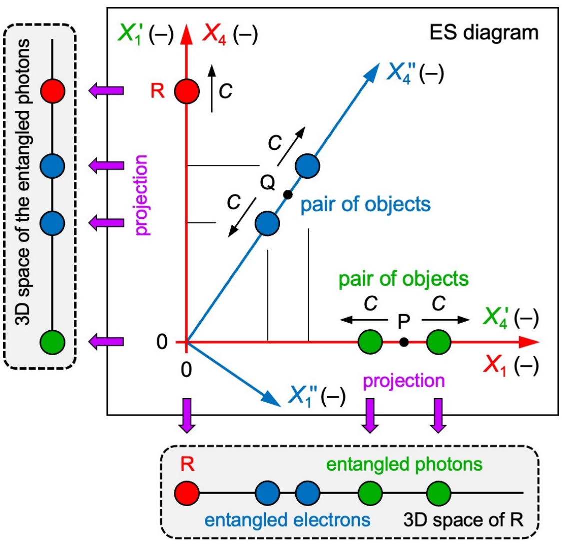

Fig. 7 Entanglement. R moves in the X_4 axis. He experiences the X_1 axis as space. In his 3D space, R perceives entangled objects as spatially separated objects. The photons (or electrons) experience the X_1' (or else X_1'') axis as space. In their 3D space, entangled objects stay together spatially

The photons (or electrons) experience the X_1' (or else X_1'') axis as space. For them, the X_4' (or else X_4'') axis disappears because of length contraction at the speed C. *From their perspective, entangled objects have never been spatially separated, yet their proper time flows in opposite 4D directions.* This is how they communicate with each other in no time. Their opposite 4D vectors $\boldsymbol{T}$ do not affect local communication as long as the twins stay together spatially. Only observers perceive Albert Einstein's "spooky action at a distance".

Cosmic homogeneity and entanglement have the same physical background: An observed object's (or region's) 4D vector $\boldsymbol{T}'$ and its 3D space may have rotated with respect to an observer's 4D vector $\boldsymbol{T}$ and his 3D space. This is only possible in ES, where all axes are fully symmetric. The SO(4) symmetry enables the entanglement of photons and other objects [48]. ER predicts that any two objects created in pair production are entangled. This gives us a chance to falsify ER. A measurement terminates one twin or rotates its 4D vector $\boldsymbol{T}$. The entanglement is destroyed. **ER manages without non-locality.**

6. Conclusions

ER is a new way to describe physical realities: (1) An observer experiences two projections of ES as space and time. Without gravity, his spacetime is Minkowski-like. As in GR, gravity in ER is the curvature of spacetime. (2) In ER, there is absolute space (ES), an absolute evolution parameter (θ), and a 4D vector "flow of proper time" ($\boldsymbol{T}$). Information hidden in ES, θ, and $\boldsymbol{T}$ is not available in SR/GR. ES is relevant for modeling an observer's physical reality. θ is relevant for modeling galactic motion. $\boldsymbol{T}$ is relevant for understanding cosmic homogeneity, cosmological redshift, and entanglement. (3) In ER, τ is replaced by ϑ, and man-made t by natural τ. There is a difference regarding the axis of time dilation. In SR and GR, an observed clock is slow with respect to an observer's clock in the observed clock's time axis. In ER, it is slow in the observer's time axis. Ultimately, this difference is irrelevant because experiments do not reveal in which axis a clock is slow.

ES is a background reality. GR is a background-free theory. ER refutes the widespread assumption that a background-free approach is an advantage. For instance, time is not an operator in the Schrödinger equation, but acts as an absolute, external parameter. θ and ϑ are such parameters. There are none in SR/GR. Thus, ER fits QM better than SR and GR. In summary, we propose (a) replacing Minkowski spacetime with τ-MS, (b) using ER in cosmology, and (c) using ER in QM. It is obvious that one paper cannot cover all of physics. It is also obvious that 12 predicted empirical facts in different (!) areas of physics are most likely not 12 coincidences. Some of these 12 facts can be predicted without ER, but only by postulating cosmic inflation, expanding space, dark energy, and non-locality. ER manages without these concepts. Occam's razor shaves them all off. No exceptions.

Einstein was awarded the Nobel Prize in Physics 1921 for his theory of the photoelectric effect [49], not for SR or GR. Our results show that ER penetrates to a "deeper level". Einstein, one of the most brilliant physicists ever, did not realize that nature's fundamental metric is Euclidean. He sacrificed absolute space and absolute time. ER reinstates absolute space (not 3D space, but 4D space) and absolute time (not a time coordinate, but parameter time). In retrospect, it was man-made coordinate time that delayed the formulation of ER. For the first time, humanity understands the nature of time: *Experienced time is the distance traveled in absolute ES divided by* C. The human brain is able to imagine that we move at the speed of light. Against this backdrop, human conflicts fade into insignificance.

Is ER a physical theory or a metaphysical theory? That is a very good question because we can access ES only in proper coordinates, but we cannot measure the proper time τ' ticking for another object. However, it is possible to calculate τ' from ES diagrams, $\tau' = x_4'/c$, and Eqs. (7b) and (17b). ES diagrams are observer-independent Master Diagrams of nature. Observing is our primary source of knowledge, but concepts can mislead us if they originate from observing. Physics is more than just observing. For instance, we cannot observe time. Coordinate time t works well in everyday life, but unfortunately t has also been applied to the very distant and the very small. For this reason, cosmology and QM benefit most from ER. ER is a physical theory because it predicts what we observe.

It seems as if Greek philosopher Plato anticipated ER in his famous *Cave Allegory* [50]: Humanity experiences projections, but it cannot observe the Master Reality beyond these projections. We have laid the foundation for ER and demonstrated its strength. Paradoxes are only virtual. One of the most important questions in science is this: *How can we describe nature without postulating highly speculative concepts?* The answer to this very question leads to the truth. Physics seeks one theory that fits all—from the very distant to the very small. ER is such a theory and thus indispensable for unifying physics. Everyone is invited to test and use ER. It is likely that the projections from ES will also deepen our understanding of wave functions in QM. Only in ER does Mother Nature reveal her secrets.

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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. (2) In ES, there are no singularities and thus no black holes. Again, this is no reason to reject ER. Singularities conflict with QM. Projections of highly concentrated energy could possibly be interpreted as "black holes". (3) It is often a good idea to match the symmetry. The symmetry of nature is SO(4). (4) Absolute time puts an end to all discussions about time travel. Does any other theory explain time's arrow as clearly as ER? (5) Physics does not ask: Why is my reality a projection? Projections are less speculative than postulating cosmic inflation *plus* expanding space *plus* dark energy *plus* non-locality.

It takes open-minded editors and reviewers to evaluate a new 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 valid arguments that would disprove ER. I was advised to consult experts or submit to other journals. Were the editors afraid of publishing against the mainstream? Did they underestimate the benefits of ER? I am told that predicting 12 empirical facts would be too much to be convincing. I disagree. A paradigm shift often leads to many new insights. Even good friends refused to support me. Every setback motivated me to formulate ER even better. Finally, I identified four shortcomings of coordinate time.

A well-known preprint archive suspended my submission privileges. I was penalized because I showed that GR is not as general as it seems. 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 reviewers. Several journals rejected ER because it was "neither innovative nor significant". I like to speak of ER as "holistic physics", but unfortunately the reviewers did not accept this term. I do not blame anyone. Paradigm shifts are hard to accept. In the long run, ER will prevail because it predicts what we observe. These comments shall encourage young scientists to stand up for good ideas even if it is challenging: "unscholarly research", "fake science", "equations from entry-level textbooks", "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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