

What Differs Between the Twins Is Not a Lagging Clock but the Length of a Worldline

— Time Dilation Read Through the Yamagishi Zero-Tension: the Null Hypothesis of Instrumental Lag Is
Rejected by the Muon — [Paper 123]

Yuuki YAMAGISHI (山岸 勇輝)
Yamagishi Complexity Torus Lab, Japan
August 2026

— *From thinking to syncing.* —

ABSTRACT

The popular line “a moving clock runs slow” invites a natural question in whoever hears it: **slow relative to what? and is the clock not simply going wrong?** This paper states that question as a **falsifiable null hypothesis** (Paper 89), writes down which data reject it, and then shows that **what invited the question was not the physics but the sentence. Null hypothesis H_0 : time dilation is an instrumental lag.** The mechanism of a moving clock is dulled by the motion, and recovers when the motion stops. **First, H_0 is rejected.** The decisive case is the muon, because **a muon is not a clock.** It is an unstable particle with no oscillator and no gears — there is nothing in it that could lag. Yet in the CERN storage ring (Bailey et al. 1977) the rest lifetime $\tau_0 = 2.1948 \pm 0.0010 \mu\text{s}$ became $\tau_+ = 64.419 \pm 0.058 \mu\text{s}$ in flight at $\gamma = 29.33$. The relativistic prediction $\gamma\tau_0 = 64.373 \mu\text{s}$ differs from the measurement by 0.71×10^{-3} (recomputed here). **Second, H_0 is rejected twice more.** (i) Clocks sharing no mechanism whatever — caesium, hydrogen maser, optical lattice, spectral lines, and decay — shift by **the same amount.** All they share is a worldline. (ii) A lag would be recovered at rest, and it is **not**: the Hafele--Keating clocks (1971) were brought home and compared at rest and kept their difference, and GPS requires a correction of **+38.6 μs /day** to this day (computed here from the orbital elements: SR **−7.2**, GR **+45.9**). **Third, what in the popular phrasing invited the question?** The word “slow” **d demands something to be slow relative to, and no universal clock exists.** This is the category error diagnosed in Paper 118: **a functional of a curve, $d\tau$, is being spoken of as though it were a coordinate, dt .** Put correctly, the question does not arise: **what differs between the twins is not a lagging clock but the length of a worldline.** Proper time is that length, exactly as two roads joining two cities may differ in length (Paper 108). **Fourth, an honest brake.** Every **process** tested — oscillators, decays, spectral lines — follows proper time, and none is known to disobey. **But no human has been carried at relativistic speed.** “A person would not age” is an **induction over processes**, not an observation. A strong induction, and still a different logical move.

Scope of this paper: this is not a paper that doubts relativity. Time dilation is real, and this paper marshals the data supporting it. **NO NEW PHYSICAL LAW AND NO NEW THEOREM** — every experiment used is established (Bailey et al. 1977, Hafele--Keating 1971, Ives--Stilwell 1938, GPS). What this paper does is (i) rewrite a common objection in a **falsifiable** form and locate its rejection, and (ii) diagnose **the popular phrasing that invited the objection** with the corpus's own tools. Section 6 (felt time) is quarantined as **Layer 3 (non-scientific)**.

1. Introduction: a question that was invited

“Fly near the speed of light and time slows down” is widely repeated. And most who hear it arrive at the same question.

If an atomic clock were flown and brought back, would it not simply be a clock gone out of step? Is nothing like the Urashima story really happening?

The question is not naive. It is a **testable hypothesis**, it has been tested, and it **has been rejected**. The first half of this paper writes that rejection.

But the second half matters more. There is a reason this question keeps arising: **the phrase “the clock runs slow” is shaped so as to invite it.** Put correctly, the question does not arise. **The physics is right and the sentence is wrong** — that is the diagnosis offered here.

2. Stating the null hypothesis

When testing a claim, this corpus first sets down a **falsifiable null hypothesis** (Paper 89, zero-tension). The opening question, rewritten in that form:

Null hypothesis H_0 : time dilation is an instrumental lag. A moving clock's mechanism is dulled so that its reading falls behind, and the reading regains its correctness once the clock is at rest.

This **H_0** is **not empty**: it has three testable consequences.

If H_0 were true	Test
(a) different mechanisms would lag differently	compare unlike clocks
(b) what is not a clock would not lag	look at a process that is not a clock
(c) the difference would vanish at rest	bring it home and compare at rest

For all three, the experiment exists.

3. Rejection (b): a muon is not a clock

Fact 3.1 (the CERN muon storage ring): Bailey et al. (1977) measured the lifetime of muons at $\gamma = 29.33$ in a storage ring. Against a rest lifetime $\tau_0 = 2.1948 \pm 0.0010 \mu s$, the lifetimes in flight were

$$\tau_+ = 64.419 \pm 0.058 \mu s, \quad \tau_- = 64.368 \pm 0.029 \mu s$$

Special relativity predicts $\gamma\tau_0 = 64.373 \mu s$, differing from the μ^+ measurement by 0.71×10^{-3} (recomputed here). The paper's own figure is that the time transformation holds to $(0.8 \pm 0.7) \times 10^{-3}$.

Observation 3.2 (this rejects $H_0(b)$): A muon is not a clock. It contains no oscillator, no spring, no gears. **There is no mechanism in it that could lag.** It is an unstable elementary particle whose whole behaviour is to decay.

And that decay ran slower by exactly γ . With no instrument to lag, “instrumental lag” cannot account for the fact. **H_0 is rejected here.**

Observation 3.3 (the size of the effect)

For cosmic-ray muons the effect is dramatic. With $\tau_0 = 2.1970 \mu s$ one has $c\tau_0 = 658.6$ m, so without dilation the fraction surviving 15 km of atmosphere would be $e^{-15000/658.6} = 1.29 \times 10^{-10}$. At $\gamma = 20$ the decay length becomes 13156 m and the survival fraction 0.32 — a factor of 2.5×10^9 (computed here).

That muons are observed at ground level is itself a direct consequence of time dilation. It is not a question of an instrument's reading but of **whether the particles are there at all.**

4. Rejections (a) and (c): the mechanism is irrelevant, and the difference does not return

Observation 4.1 (rejecting $H_0(a)$: clocks sharing no mechanism agree): Time dilation has been confirmed with instruments that share **no principle of operation.**

Instrument	What marks the time
Caesium clock (Hafele--Keating 1971)	a hyperfine transition
Hydrogen maser (Gravity Probe A 1976)	a different atom, a different transition
Optical lattice clock (2010s onward)	an optical transition, orders of magnitude apart
Spectral lines (Ives--Stilwell 1938)	not a clock at all
Muon decay (Bailey et al. 1977)	no oscillator

If the slowing were a dulling of a mechanism, unlike mechanisms would be dulled by unlike amounts. They are dulled by **the same** amount. What these share is not a mechanism but **a worldline**, which means **the agreement is on the worldline's side**.

Observation 4.2 (rejecting $H_0(c)$: the difference survives the return to rest): Hafele and Keating (1971) flew caesium clocks twice around the world, eastward and westward, and compared them **at rest** with the clocks of the U.S. Naval Observatory on their return.

Direction	Predicted (ns)	Observed (ns)
Eastward	-40 ± 23	-59 ± 10
Westward	$+275 \pm 21$	$+273 \pm 7$

The difference was not recovered. A lag would correct itself once the motion ceased; this did not. **What remains is not a wrong reading but a difference in the time that elapsed.**

Observation 4.3 (a refuting apparatus in continuous operation: GPS)

For a GPS satellite (orbital radius 2.656×10^7 m, speed 3874 m/s), special relativity gives $-7.2 \mu\text{s/day}$ and general relativity $+45.9 \mu\text{s/day}$, a net $+38.6 \mu\text{s/day}$ (computed here from the orbital elements). **Uncorrected, the ranging error grows by 11.6 km per day.**

This correction has been applied daily for decades. Were H_0 true the correction would be unnecessary, and GPS would have been useless from its first day.

5. So what invited the question?

H_0 has now been rejected three ways. **But that does not explain why the opening question keeps arising.** This section is the second core of the paper.

Observation 5.1 (“slow” demands something to be slow relative to)

The sentence “a moving clock runs slow” tacitly posits **something it is slow relative to**. But **no universal clock exists**. The most that can be posited is **another observer's coordinate time**, and from that observer's side the first clock is “slow” in return.

So the question “**which one is really slower?**” has **no answer**. And what makes people ask an unanswerable question is **the form of the sentence**. The one who asked did not err — **the sentence invited an ill-formed question**.

Observation 5.2 (this is the category error diagnosed in Paper 118)

Paper 118 showed that the one word “time” covers several logical types: the coordinate dt is a **label** pinned to the manifold, while proper time $d\tau$ is a **functional of a curve**.

“The clock runs slow” treats $d\tau$ as though it were dt : it speaks of a quantity **that may differ from curve to curve** as if it were **a scale everyone shares**. Hence the question “relative to what”, and hence its unanswerability. **Popular expositions keep reproducing the confusion not because the physics is unsettled but because they keep using a sentence with the categories crossed**.

Corollary 5.3 (the correct statement)

Since Minkowski (1908; Paper 108) the correct statement has been

$$d\tau^2 = dt^2 - \frac{dx^2 + dy^2 + dz^2}{c^2}, \quad \tau[\text{worldline}] = \int_{\text{worldline}} d\tau \quad (2)$$

Proper time is the length of a worldline. The two twins joined the same two events by two different paths. **The paths differ in length; that is all.**

Neither clock went wrong. Each measured the length of its own worldline **correctly and in full**. **What differs is what was measured, not the instrument that measured it.**

v/c	γ	proper time for 10 yr of coordinate time
0.5	1.1547	8.66 yr
0.8	1.6667	6.00 yr
0.9	2.2942	4.36 yr
0.99	7.0888	1.41 yr
0.99995	100.0	0.10 yr

Observation 5.4 (why the symmetry breaks)

The same restatement answers “if motion is relative, is the situation not symmetric?” **It is not symmetric**, because only one twin changes inertial frame. **This is not a matter of description**: give each twin an accelerometer and the readings differ.

In geometric terms: **the traveller's worldline is bent and the stay-at-home's is straight**, and in Minkowski geometry **the straight path maximises proper time** — the **opposite** of Euclidean geometry, where the straight path is shortest. **The bent path is shorter. That is the whole of it.**

6. On felt time — Layer 3 (non-scientific)

What follows is interpretation, not theorem, and is quarantined as Layer 3 (non-scientific). Nothing above uses any of it. The tale of Urashima Taro speaks not only of **a difference in elapsed time** but of **how that time felt to the one who lived it. The latter is not a quantity this paper has treated.** Paper 118 **explicitly refused** to enter felt time into the physics census: “the number belongs to the types on the physics side”. Paper 119 identified a fourth type (the flow parameter) and Paper 122 put those four through the dimensional tool, and **felt time is none of them. So the phrase “the Urashima effect” bundles two claims**: (i) that the proper time is shorter (established, and treated here), and (ii) that it felt shorter to the traveller (not treated here, and outside physics). **Spoken without separating them, doubts about (i) and doubts about (ii) become mixed.**

7. The one line not yet measured

Observation 7.1 (what has been measured and what has not)

The **processes** confirmed to follow time dilation are many: the caesium hyperfine transition, the hydrogen maser, optical lattice transitions, atomic spectral lines, and muon decay. **None is known to disobey.**

But no human has been carried at relativistic speed. The Hafele--Keating aircraft were subsonic, and the differences there were of order 10^{-7} s. **The statement “a person would not age” is an induction over processes.**

The induction is very strong. A living body is made of chemical reactions, chemical reactions are electromagnetic, and that electromagnetic processes follow proper time has been confirmed repeatedly since Ives--Stilwell. **To posit a physical process that does not follow proper time is to discard known physics.**

Even so, an induction is not an observation. Following the corpus's discipline, it is written as such: **what is established is that every process tested follows proper time; “a person would not age” is one step beyond that.** Not writing that step with the force of an observation is also **the honest reply to whoever raised the question.**

8. Scope

- **What this paper shows:** that the null hypothesis “time dilation is an instrumental lag” is **rejected three ways** — a muon, which is no clock, lives γ times longer (Fact 3.1); instruments sharing no mechanism shift by the same amount (Observation 4.1); the difference survives the return to rest (Observations 4.2, 4.3). And **where the popular phrasing's invitation comes from:** “slow” demands a comparison that does not exist, which is the category error of speaking of $d\tau$ as dt (Observations 5.1, 5.2). **The correct statement is the length of a worldline** (Corollary 5.3).
- **What this paper does not show:** (i) any new physical law — **there is none**; (ii) any doubt about relativity — **this paper is on the side of time dilation**; (iii) an **observation** that a person would not age — **that is an induction over processes** (Observation 7.1); (iv) anything about felt time — **it lies outside the physics census** (Section 6); (v) that acceleration is the “cause” — **acceleration breaks the symmetry, but what gives the difference in proper time is the shape of the worldline.**
- **What remains:** when a question keeps arising, suspect the sentence before the physics.

9. Conclusion

1. The objection “time dilation is only an instrument out of step” was formulated as a **falsifiable null hypothesis** (Paper 89), with three testable consequences — not an empty hypothesis.

2. **Rejection (b): a muon is not a clock.** Bailey et al. (1977) measured $\tau_+ = 64.419 \pm 0.058 \mu\text{s}$ at $\gamma = 29.33$ against the prediction $\gamma\tau_0 = 64.373 \mu\text{s}$, a difference of 0.71×10^{-3} (recomputed here). **In an object with no mechanism to lag, the decay itself ran slow.**
3. **Rejection (a): the mechanism is irrelevant.** Caesium, hydrogen maser, optical lattice, spectral lines, decay — all they share is a worldline, and the shift is the same.
4. **Rejection (c): the difference does not return.** The Hafele--Keating clocks kept their difference when compared at rest (eastward -59 ± 10 ns, westward $+273 \pm 7$ ns). GPS needs $+38.6 \mu\text{s/day}$, and uncorrected the ranging error grows by **11.6 km per day** (computed here).
5. **What invited the question was the phrasing** — “slow” demands a comparison that does not exist. This is the category error diagnosed in Paper 118: **$d\tau$, a functional of a curve, spoken of as dt , a coordinate** (Observations 5.1, 5.2).
6. **The correct statement: what differs between the twins is not a lagging clock but the length of a worldline** (Corollary 5.3). Neither clock went wrong; each measured its own path correctly. **The symmetry breaks because only one twin changes inertial frame, and in Minkowski geometry the straight path maximises proper time** (Observation 5.4).
7. **The line not yet measured:** every process tested follows proper time and none is known to disobey. **But no human has been carried at relativistic speed.** “A person would not age” is an **induction over processes**, not an observation (Observation 7.1).
8. **“The Urashima effect” bundles two claims** — that the proper time is shorter (established) and that it felt shorter (outside physics, Section 6). **Spoken together, doubts about the two become mixed.**

Closing: The question “is it not merely a clock out of step?” is neither naive nor unfair. **It is a testable hypothesis; it has been tested; it has been rejected.** And the reason it keeps arising is not that the physics is unsettled but that **the word “slow” tacitly erects a standard that does not exist.** **When a question keeps arising, suspect the sentence before the physics.**

References

1. Einstein, A. (1905). *Zur Elektrodynamik bewegter Körper*. *Annalen der Physik*, 322(10), 891--921.
2. Minkowski, H. (1909). *Raum und Zeit*. *Physikalische Zeitschrift*, 10, 104--111.
3. Ives, H. E., & Stilwell, G. R. (1938). *An experimental study of the rate of a moving atomic clock*. *Journal of the Optical Society of America*, 28(7), 215--226.
4. Hafele, J. C., & Keating, R. E. (1972). *Around-the-world atomic clocks: predicted relativistic time gains*. *Science*, 177(4044), 166--168.

5. Hafele, J. C., & Keating, R. E. (1972). *Around-the-world atomic clocks: observed relativistic time gains*. Science, 177(4044), 168-170.
6. Bailey, J., Borer, K., Combley, F., Drumm, H., Krienien, F., Lange, F., Picasso, E., von Ruden, W., Farley, F. J. M., Field, J. H., Flegel, W., & Hattersley, P. M. (1977). *Measurements of relativistic time dilatation for positive and negative muons in a circular orbit*. Nature, 268, 301--305.
7. Bailey, J. et al. (1979). *Final report on the CERN muon storage ring including the anomalous magnetic moment and the electric dipole moment of the muon, and a direct test of relativistic time dilation*. Nuclear Physics B, 150, 1--75.
8. Vessot, R. F. C., Levine, M. W., Mattison, E. M., Blomberg, E. L., Hoffman, T. E., Nystrom, G. U., Farrel, B. F., Decher, R., Eby, P. B., Baugher, C. R., Watts, J. W., Teuber, D. L., & Wills, F. D. (1980). *Test of relativistic gravitation with a space-borne hydrogen maser*. Physical Review Letters, 45(26), 2081--2084.
9. Ashby, N. (2003). *Relativity in the Global Positioning System*. Living Reviews in Relativity, 6, 1.
10. Yamagishi, Y. (2026). *Zero-Tension and the Inverse Problem* [Paper 89]. Zenodo. 10.5281/zenodo.21748664
11. Yamagishi, Y. (2026). *The Geometry Where the Invariant Lives* [Paper 108]. Zenodo. 10.5281/zenodo.21837313
12. Yamagishi, Y. (2026). *Two Clocks and One Scale* [Paper 118]. Zenodo. 10.5281/zenodo.22036237
13. Yamagishi, Y. (2026). *The Fourth Clock* [Paper 119]. Zenodo. 10.5281/zenodo.22036353
14. Yamagishi, Y. (2026). *How Much Do the Four Clocks Know About the Dimension They Are In* [Paper 122]. Zenodo. 10.5281/zenodo.22054748

— *From thinking to syncing.* —

Yuuki YAMAGISHI (山岸 勇輝)

© 2026 Yamagishi Complexity Torus Lab, Japan · Licensed under Creative Commons Attribution 4.0 International (CC BY 4.0)