

The Interpretation Dilemma of Special Relativity: A Critique of a Pure Inertial Thought Experiment Based on Falsifiability

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Abstract

This paper constructs a pure inertial frame thought experiment with uniform linear motion throughout, free of acceleration, turnaround, and gravitational interference. Strictly following the core principles of special relativity and eliminating all interfering physical variables, it analyzes the interpretive contradictions of time dilation layer by layer in a minimalist spacetime observation scenario. Based on the equivalence of inertial frames and the deduction of time dilation, the experiment yields the result that between equivalent inertial frames, mutual observation shows each other's time flow is slowed down. To resolve this contradiction, special relativity uses the relativity of simultaneity to attribute bilateral time dilation to a reference frame measurement artifact, yet recognizes time dilation as an objective physical reality in comparable experimental scenarios. The core stance of this paper is: special relativity does not provide a consistent and unified physical picture of spacetime; mere conceptual distinctions cannot resolve the intuitive contradictions at the observational level. Moreover, experiments such as particle lifetime extension manifest real physical effects that cannot be fully explained by the theoretical division between proper time and coordinate time. Further, from the perspective of scientific falsifiability, bilateral time dilation in a never-meeting pure inertial scenario can be neither experimentally verified nor falsified. Relativity achieves self-consistency by artificially defining *clock-comparable* = *real* and *non-clock-comparable* = *apparent*, rather than relying on objective physical evidence. This paper fully presents this two-level progressive core conflict, reveals the inherent tension and double standard in the interpretation of spacetime reality in special relativity, and provides a powerful critical framework for reflecting on the theoretical foundation of relativity based on principles of scientific philosophy.

Key words: Special Relativity; Pure Inertial Frame; Time Dilation; Physical Reality; Relativity of Simultaneity; Falsifiability

1. Introduction

Since its establishment in 1905, special relativity has reconstructed human basic understanding of spacetime based on the principle of relativity and the constancy of the speed of light. Its mathematical framework is highly self-consistent and verified by numerous physical experiments, becoming an important foundation of modern physics. As a core deduction, the time dilation effect has been clearly confirmed in experiments such as muon lifetime extension, atomic clock timing deviations, and slowed decay of high-energy particles, where the retardation of physical processes is a directly observable objective result.

However, at the level of theoretical interpretation, the essential attribute of time dilation and the logical consistency of spacetime observations have long been controversial. Most previous relevant thought experiments introduce non-inertial processes such as acceleration, turnaround, and circular motion, which can easily be evaded by special relativity on the grounds of non-equivalent reference frames, failing to touch the underlying logic of the theory. More crucially, special relativity has never provided a clear and self-consistent physical picture of spacetime. Relying solely on mathematical transformations and conceptual definitions cannot resolve the intuitive contradictions arising in actual observations. To completely eliminate controversial premises, this paper designs a fully idealized pure inertial frame thought experiment with uniform linear motion throughout, no external forces or changes in motion state, and only vertical observation to eliminate spatial scale and optical signal timing interference. It deduces contradictions in the cleanest theoretical scenario, focuses on the actual conflicts at the observational level and the essential connection with experimental facts, further points out the non-empirical problems of special relativity in the division of reality, and fully presents its interpretation dilemma.

2. Construction of the Pure Inertial Frame Thought Experiment and Observation Scenario

2.1 Ideal Experimental Conditions

A flat spacetime in deep space without gravity, medium, or rotation is selected. Two fully equivalent inertial reference frames are set: one is a stationary inertial frame equipped with an observation display and recording equipment; the other is a moving inertial frame moving at a near-light speed in constant uniform linear motion, with no acceleration, deceleration, steering, or turnaround throughout, maintaining a pure inertial state at all times.

The two inertial frames conduct continuous bilateral observations perpendicular to the direction of relative motion. This observation method does not produce length contraction or introduce timing reversal caused by aberration, allowing direct recording of the rate of physical processes within the opposite reference frame and presenting the purest observation picture. The experiment does not dwell on the definition of time itself, but only focuses on the changes in physical processes intuitively captured by observation equipment and observers.

2.2 Bilateral Observation Results of the Experiment

According to the equivalence of inertial frames and the time dilation effect in special relativity, the experiment presents a completely symmetric and irreconcilable intuitive observational contradiction.

From the perspective of the stationary inertial frame, all physical processes and object change rates in the high-speed moving inertial frame are significantly slowed down, and the observation display clearly shows the time dilation of the moving reference frame. From the perspective of the moving inertial frame, according to the principle of relativity, it can be regarded as stationary, while the stationary inertial frame moves in the reverse direction at high speed relative to it. Its observation equipment also records that the time flow of the stationary inertial frame is comprehensively slowed down.

The entire experiment strictly conforms to the premises of special relativity without any physical loopholes or additional assumptions. The final result is: two equivalent inertial frames observe each other through observation equipment, both intuitively seeing the other's time flow significantly slowed down, forming a direct and irreconcilable pictorial contradiction at the observational level. Special relativity does not provide a reasonable physical picture explanation for this conflict, but only evades it with theoretical concepts.

3. Intrinsic Logical Contradiction: Bilateral Observation Conflict in Inertial Frames and the Absence of Physical Picture

This pure inertial experiment directly exposes the core flaw of special relativity: the theory can neither resolve the observational contradiction caused by bilateral time dilation nor construct a unified and self-consistent physical picture of spacetime.

From the logic of actual observation, two inertial frames with completely equal status and no superiority or inferiority obtain completely opposite observation results based on the same physical theory—the stationary frame sees the moving frame slowed down, and the moving frame sees the stationary frame slowed down. Both observation pictures hold simultaneously and are mutually exclusive. Special relativity does not provide any concretizable, logically consistent physical picture of spacetime to resolve this intuitive conflict at the observational level. It only explains it through the relativity of simultaneity, failing to respond to the contradictoriness of the observation picture itself.

More crucially, the two inertial frames maintain uniform inertial motion throughout, never meet, and cannot directly compare clocks. There is no objective node to verify which is true or false. This contradiction does not stem from flaws in experimental conditions, but is a direct manifestation of the absence of physical picture and observational logical contradiction in special relativity under pure inertial scenarios.

4. Methodological Dilemma: Double Standard in Interpretation and Disconnection from Experimental Facts

Faced with the observational contradiction of bilateral time dilation, special relativity introduces the relativity of simultaneity and classifies it as a reference frame measurement artifact rather than an objective physical process. However, in experiments such as muon decay and atomic clock flights, it explicitly acknowledges time dilation as a real physical effect. This interpretive approach forms an irreconcilable double standard and is essentially disconnected from experimental facts.

On the one hand, muon lifetime extension is an indisputable objective physical result: high-speed muons fly farther and have longer decay periods, which are directly measurable and repeatable real physical changes that cannot be explained by the mere theoretical distinction between proper time and coordinate time. In such experiments, time dilation is by no means an observational artifact, but a real change in physical processes—an objective fact independent of reference frame observation.

On the other hand, in pure inertial, never-meeting observation scenarios, special relativity forcibly defines the fully homologous bilateral time dilation effect as a measurement artifact. This definition has no empirical basis: there are neither experimental data to distinguish "real dilation" from "apparent dilation", nor a physical mechanism to explain the essential difference between the two. The only division criterion is whether clock comparison can be achieved. This division is entirely a subjective choice to maintain theoretical self-consistency, not based on objective physical laws, further highlighting the fragmentation in the physical interpretation of special relativity—emphasizing the reality of the effect when facing verifiable experiments, and downgrading it to an observational artifact when facing theoretical logical contradictions, failing to form a unified interpretive logic.

5. Conclusion: The Interpretation Dilemma and Theoretical Limitations of Special Relativity

Based on the above arguments, special relativity falls into an irreconcilable dilemma in three aspects: physical picture of spacetime, resolution of observational contradictions, and interpretation of experimental facts, with undeniable theoretical limitations.

The theory has high precision in its mathematical system and experimental predictions, and can adapt to existing verifiable physical experiments. However, it always lacks a consistent and unified physical picture of spacetime and cannot explain the intuitive contradiction of bilateral observation in pure inertial scenarios. Meanwhile, it adopts a double standard in the interpretation of the time dilation effect: on the one hand, it recognizes experiments such as muon lifetime extension as real physical effects and refuses to deny experimental facts with the conceptual

distinction between proper time and coordinate time; on the other hand, it uses similar conceptual definitions to evade theoretical contradictions in pure inertial scenarios, completely deviating from the principle of scientific empiricism.

Special relativity has never solved the boundary problem between "observational artifact" and "physical reality". Its two characterizations of the time dilation effect are unsupported by objective physical evidence, but only ad hoc hypotheses for theoretical self-consistency. Ultimately, it can only achieve a closed loop in mathematical form, remaining in a split state in physical interpretation and interpretation of the essence of spacetime.

In summary, special relativity has extremely high practical value, but has fundamental limitations in interpreting the essence of spacetime, logical self-consistency of physics, and resolving observational contradictions. The pure inertial thought experiment constructed in this paper directly hits the core problems of the theory's lack of physical picture and double standard in interpretation, providing a solid basis for re-examining the theoretical foundation of special relativity and breaking through the existing interpretation framework of spacetime. The future development of fundamental spacetime theory must face this dilemma and construct a new spacetime theory system that is compatible with experimental facts, has a unified physical picture, and is logically self-consistent.

References

- [1] Einstein A. On the Electrodynamics of Moving Bodies[J]. Annalen der Physik, 1905, 322(10): 891-922.
- [2] Zhang Y Z. Experimental Foundations of Special Relativity[M]. Beijing: Science Press, 1994.
- [3] Zhao K H, Luo W Y. New Concept Physics Course: Mechanics[M]. Beijing: Higher Education Press, 2018.
- [4] French A P. Special Relativity[M]. New York: W.W. Norton & Company, 1968.
- [5] Hu Z J. Logical Examination of the Time Dilation Effect in Special Relativity[J]. Physics and Engineering, 2020, 30(2): 7-12.