

Observer-Dependent Rotation in Accelerated Motion: Philosophical Insights on Terrell-Penrose Rotation, Thomas Precession, and the Impossibility of Static Black Holes

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Abstract

This conceptual paper explores the subtle and intertwined phenomena of Terrell-Penrose rotation and Thomas precession in the context of accelerated motion toward black hole singularities. We argue that the apparent rotation induced by relativistic aberration (Terrell-Penrose rotation) couples with the intrinsic relativistic spin precession arising from non-collinear boosts (Thomas precession), yielding an effective rotational term that challenges the notion of perfectly static black holes. We propose heuristic formulas encapsulating this coupling and discuss profound implications for the ontology of spacetime, gravity, and observation. Finally, we suggest that rotation and angular momentum in black holes are fundamentally observer-dependent and emergent from relativistic effects, blurring the boundary between physical reality and perceptual illusion. While this work does not claim to present a definitive or formal theory, we argue that these ideas collectively suggest an intriguing consequence: static black holes may be incompatible with the full relativistic picture, particularly when visual and precessional effects such as Terrell-Penrose rotation are considered in conjunction with Thomas precession. By highlighting the ontological similarities between visual relativistic phenomena and geometric curvature, we explore how dynamic interpretation of spacetime may be more natural than a static one, and invite the reader to treat this as a speculative but motivated philosophical contribution.

1 Introduction

The study of relativistic phenomena such as length contraction and time dilation has long shaped our understanding of spacetime structure. Two related but often less emphasized effects — *Terrell-Penrose rotation* and *Thomas precession* — reveal that objects undergoing relativistic acceleration not only appear contracted but also exhibit rotational characteristics. This paper philosophically examines these effects and their potential physical consequences

in gravitational contexts, especially regarding black hole rotation and the existence (or non-existence) of static black holes.

2 Terrell-Penrose Rotation and Thomas Precession: Phenomena Overview

Terrell-Penrose rotation arises from relativistic aberration and light-travel-time effects, causing a moving object to appear rotated to a distant observer rather than simply contracted [1,2]. Although this rotation is traditionally considered an optical illusion in special relativity (SR), its interplay with the dynamics of accelerated observers invites reconsideration.

Thomas precession emerges when successive Lorentz boosts are non-collinear, inducing a real rotation of the spin vector of an accelerating particle [3, 4]. Unlike Terrell rotation, Thomas precession corresponds to an intrinsic precession in the rest frame of the particle.

3 Acceleration and Non-Collinearity of Velocity and Acceleration Vectors

When an object freely falls into a black hole, its velocity vector $\mathbf{v}(t)$ and acceleration vector $\mathbf{a}(t) = d\mathbf{v}/dt$ are generally *not parallel* due to spacetime curvature and the geometry of geodesics [5]. This non-collinearity implies that the object's motion can be decomposed into a series of non-collinear boosts, thereby producing Thomas precession.

Mathematically, the angular velocity of Thomas precession is given heuristically by

$$\boldsymbol{\Omega}_T = \frac{\gamma^2}{\gamma + 1} \mathbf{a} \times \mathbf{v} \quad , \quad (1)$$

where $\gamma = (1 - v^2)^{-1/2}$ is the Lorentz factor (with units $c = 1$).

4 Terrell Rotation as a Source of Minimal Spin

Terrell rotation, classically an observational effect, introduces an *apparent* rotation angle θ_{TP} approximated by

$$\theta_{TP} \sim \arcsin(v) \quad , \quad (2)$$

valid at subluminal speeds v . We propose that this *apparent* rotation provides the minimal initial spin necessary for Thomas precession to manifest, effectively making boosts \mathbf{a} and \mathbf{v} non-collinear.

5 Effective Rotational Dynamics and Geometry

We hypothesize an effective rotational 4-vector combining Thomas precession and the rate of change of Terrell rotation:

$$\Omega^\mu = \alpha \mathbf{\Omega}_T^\mu + \beta \frac{d\theta_{TP}}{d\tau} u^\mu \quad , \quad (3)$$

where u^μ is the four-velocity, τ is proper time, and α, β are phenomenological coupling constants.

This effective rotation modifies the usual covariant derivative of a vector V^μ by adding a torsion-like term:

$$\tilde{\nabla}_\nu V^\mu = \nabla_\nu V^\mu + \epsilon^\mu_{\rho\sigma\nu} \Omega^\rho V^\sigma \quad , \quad (4)$$

where $\epsilon^\mu_{\rho\sigma\nu}$ is the Levi-Civita tensor.

Such a modification suggests that acceleration-induced rotations introduce an *intrinsic twist* to spacetime, extending General Relativity (GR) beyond pure metric curvature to include rotational geometric effects.

6 Rotation Censorship and the Non-Existence of Singularities

In this section, we propose a novel mechanism to prevent the formation of physical singularities in black holes, based on the accumulation of relativistic precessional effects such as Thomas precession and Penrose–Terrell rotation. We argue that these effects transform apparent kinematic rotations into real angular momentum, saturating the rotational degrees of freedom of the black hole before a singularity can be physically realized.

6.1 Relativistic Precession in Infalling Matter

In General Relativity (GR), an infalling object undergoes acceleration due to spacetime curvature, and this acceleration is generally not parallel to the velocity vector as seen from a distant observer. This non-parallelism leads to relativistic precession effects. One key phenomenon is **Thomas precession**, which occurs when a particle experiences a sequence of non-collinear Lorentz boosts. The angular velocity of this precession is given by:

$$\mathbf{\Omega}_T = \frac{\gamma^2}{\gamma + 1} \frac{\mathbf{a} \times \mathbf{v}}{c^2}, \quad (5)$$

where γ is the Lorentz factor, \mathbf{a} is the 3-acceleration, and \mathbf{v} is the 3-velocity of the particle.

As an object falls toward the singularity of a black hole, both γ and $|\mathbf{a}|$ grow without bound. This causes the Thomas precession rate $\mathbf{\Omega}_T$ to diverge. The total accumulated precession angle is given by:

$$\Theta = \int \mathbf{\Omega}_T d\tau, \quad (6)$$

which may diverge as $\tau \rightarrow 0$ at the singularity, indicating an unbounded accumulation of rotational orientation.

6.2 Observer-Dependent Apparent Rotation

Additionally, the **Penrose–Terrell rotation** implies that relativistically moving objects appear rotated to distant observers due to the differential arrival times of light from different parts of the object. For infalling objects approaching the speed of light near the event horizon, this apparent rotation becomes significant and observationally indistinguishable from real rotation.

6.3 Angular Momentum Saturation and Black Hole Spin Limit

A Kerr black hole has a maximum possible spin given by:

$$J_{\max} = \frac{GM^2}{c}, \quad (7)$$

where J is the angular momentum and M is the mass of the black hole. If the accumulated Thomas precession and Penrose–Terrell rotation effectively convert into real angular momentum, then the black hole’s rotation parameter $a = J/M$ would approach its extremal limit.

We propose a **Rotation Censorship Principle**:

The total angular momentum resulting from infalling matter, due to both intrinsic and relativistic rotational effects, reaches a saturation point at or before the formation of a singularity, thus preventing the physical realization of a spacetime singularity.

6.4 Avoidance of the Singularity

As Ω_T diverges, physical mechanisms must intervene. Quantum gravity, minimal length hypotheses, or spacetime torsion theories (e.g., Einstein–Cartan) may provide the necessary corrections. In our framework, the dynamical accumulation of rotation imposes a lower bound on collapse radius:

$$\Omega_{\text{total}}(r_{\min}) = \Omega_{\max}^{\text{Kerr}}. \quad (8)$$

Thus, a finite minimal radius $r_{\min} > 0$ exists, preventing infinite curvature and density. Instead of a point-like singularity, a compact, rotating core (possibly a quantum torus or spin fluid) could remain.

6.5 Conclusion

The conversion of apparent relativistic precession into real angular momentum during gravitational collapse imposes a natural limit on rotation. This implies that *static, non-rotating black holes are physically unrealizable*, and that singularities are avoided via a kinematic censorship mechanism.

7 Illusions in Relativity: From Observation to Ontology

Special Relativity (SR) offers a framework in which space and time are observer-dependent constructs, shaped by the exchange of information at the finite speed of light. Observables such as length contraction and time dilation are not intrinsic properties of objects, but rather relational effects — projections from one inertial frame to another via Lorentz transformations. These phenomena, while measurable, can be interpreted as observational illusions: they reflect how information arrives to the observer, not what the object “is” in any absolute sense.

General Relativity (GR) extends this relational picture by encoding gravity not as a force, but as a manifestation of spacetime geometry. Locally, each patch of spacetime behaves as an SR frame, but globally, the metric tensor $g_{\mu\nu}(x)$ varies in response to the energy-momentum tensor $T_{\mu\nu}(x)$. Thus, GR can be seen as a field theory of local Lorentz frames glued together in a nontrivial way. The curvature of spacetime, then, is a geometric record of how inertial frames differ across regions. As such, GR may also be interpreted as a kind of large-scale illusion: gravity is not an external pull but a deviation in how observers measure intervals and parallel transport vectors due to metric variation.

A particularly subtle relativistic effect is the Terrell–Penrose rotation, where an object moving at relativistic speed appears rotated rather than contracted when visually observed. This effect arises from the different times it takes photons emitted from various points of the object to reach the observer. Though mathematically derivable from SR and optics, the apparent rotation is often mistaken for an intrinsic physical twist — it is in fact a perspectival illusion.

Yet, these illusions can have physical consequences. For instance, an object accelerating into a black hole experiences non-collinear velocity and acceleration vectors, leading to *Thomas precession*. If one includes the optical contributions from Terrell rotation — which pertain to the observer’s light cone structure — a composite effect emerges: the observed rotation implies an effective dynamical rotation of the falling body. This may be conceptualized as a relativistically induced torque, which is physically meaningful even if its origin lies in observation.

Philosophically, this framework suggests that:

General Relativity is Special Relativity with a radiative metric — a theory where geometry, not force, encodes interactions, and where curvature emerges as a dynamic illusion rooted in observational reciprocity.

Thus, all of relativity can be viewed as a network of *reciprocal illusions*: artifacts of how signals propagate and observers interpret measurements. While these illusions arise from appearances, they yield real equations, real dynamics, and real consequences.

“It looks like what it is, and it is like what it looks.” In relativity, the appearance is the ontology.

If length contraction and time dilation in SR are understood as *observer-dependent illusions*, then curvature in GR — which locally resembles SR at each spacetime point modulated by energy-momentum — is also a large-scale *relational illusion* shaped by observational frames [6, 7].

By analogy, Terrell-Penrose rotation, though traditionally called an optical illusion, contributes to *real physical rotation* when combined with Thomas precession in accelerated frames. This blurs the distinction between appearance and reality: *what looks like rotation* in the observer's frame *becomes* an effective angular momentum intrinsic to the system.

Hence, rotation of black holes and falling bodies cannot be fully disentangled from the observer's frame, implying that **static black holes cannot truly exist**, as any infalling matter will generate observer-dependent rotation via relativistic effects.

8 Conclusion

We conclude that:

- Thomas precession naturally arises for accelerated infalling objects due to non-collinear boosts.
- Terrell-Penrose rotation supplies the minimal apparent rotation to trigger Thomas precession.
- Their coupling introduces an effective rotational geometry correction that extends GR.
- Observed black hole rotation is at least partly observer-dependent and arises from relativistic acceleration effects.
- The notion of perfectly static black holes is, therefore, physically and philosophically problematic.

Future work should explore formal tensorial generalizations of this effective rotation term and its impact on black hole thermodynamics and quantum gravity.

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