Observations of a Freely Falling Observer into a Black Hole: No Divergent Blueshift Is Observed

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Mandatory Non-Ontological Disclaimer (Operational Scope)

All statements in this manuscript are operational and observer-local. No claim is made about horizon microphysics or any fundamental ontology of spacetime. All results are derived within standard classical General Relativity (GR), without invoking quantum assumptions. No observational fact is ignored to fit a preferred narrative.

Abstract

This paper analyzes what a freely falling observer actually measures near a strong gravitational field, and critically revisits the widespread claim that such an observer experiences a divergent or strongly blueshifted photon flux. Working strictly within classical GR and without appealing to event-horizon arguments or quantum assumptions, the analysis is anchored to the operational definition of measured photon frequency,

$$\omega_{\text{obs}} = -k_\mu u^\mu,$$

the unique local scalar corresponding to an ideal detector co-moving with the observer.

Photons are classified by their direction relative to the infalling observer into three families: co-directed, counter-directed, and angular (including lensed trajectories). We show that co-directed photons either do not lie in the observer's physical viewing cone or lead to redshift; counter-directed photons that are physically observable exhibit redshift due to increasing relative separation between source and observer; and angular photons—even with curved/lensed paths—remain bounded and well-behaved. Explicit supporting calculations and minimal numerical examples demonstrate that for all physically realizable configurations, the observed frequency remains finite; the only formal divergence channel is confined to the co-directed limit, which does not produce a physical divergent observational effect for the freely falling observer under the conditions relevant to this paper.

We further isolate the methodological root of many "strong blueshift" narratives: a confusion between local observable scalars and nonlocal reconstructed or coordinate-dependent quantities. The final result is that for a physical freely falling observer, no physically observable photon exhibits a divergent or strongly blueshifted signature. The statement "No divergent blueshift is observed" is therefore not a slogan but a necessary consequence of the operational definition of observation in GR.

1 1. Introduction: Why We Still Have to Ask "What Does the Infalling Observer See?"

In black hole physics, one of the most persistent mental images is that photons become strongly blueshifted as one approaches the horizon—often accompanied by coordinate plots, hypothetical stationary observers, and narratives of "energy blow-ups" near the horizon. In many presentations, this picture is implicitly transferred to a freely falling observer as well, without a complete specification of physical measurement conditions.

Despite decades of General Relativity, the question remains insufficiently clarified in operational terms: *What does a physical freely falling observer actually measure near a strong gravitational field?* Does the observer see photons with dramatically increasing frequency? Does any divergence appear in a physically realizable measurement? Or are such images the byproduct of combining nonlocal coordinate computations with nonphysical observer models?

This paper answers the question without introducing new structures or quantum interpretations. We return to the simplest physical definition of observation in GR: a *local* measurement of photon frequency as the contraction of the photon wave four-vector with the observer's four-velocity,

$$\omega_{\text{obs}} = -k_\mu u^\mu.$$

This definition intrinsically (i) enforces a physical observer model and (ii) forces photon directionality into the analysis—two ingredients that are frequently omitted or oversimplified in popular "blueshift" narratives.

This work does not compute quantum particle creation, but focuses exclusively on the operational meaning of local observations by freely falling detectors.

We show that when a freely falling observer is modeled correctly, and when photon directions and physically realizable intersections are treated explicitly, no strong or divergent blueshift appears in the observer's measurement. All physically observable photons are either redshifted, bounded, or not observable due to directional/physical constraints. The phrase "No divergent blueshift is observed" summarizes a conclusion derived from a complete local physical analysis, not from a coordinate slogan.

While the present analysis is strictly classical, it addresses a logically prior question: what constitutes an observational statement for a freely falling detector near a horizon. Any extension of the theory—classical or quantum—that claims to describe what such an observer 'sees' must reduce, at the level of local observables, to the frequency scalar $\omega_{\text{obs}} = -k_\mu u^\mu$.

2 2. Definition of a Physical Observer

Any claim about what is "observed" near a strong gravitational field depends first on *who* is observing. In GR, an observer is not merely a viewpoint: it is defined by a worldline and a timelike four-velocity. Only physically realizable observers can serve as a valid foundation for operational observational claims.

A primary source of confusion is the implicit use of a hypothetical observer "held at rest" at fixed radius near a black hole. Such a stationary observer requires an ever-increasing proper acceleration to remain fixed, and as one approaches the strong-field boundary of interest this acceleration grows without bound. The divergence of the required four-acceleration signals that this observer model is *not physically realizable* in that limit.

By contrast, a *freely falling observer*:

- has a timelike, finite four-velocity at all events along the worldline;
- experiences zero proper (local) acceleration;
- follows a physically natural trajectory determined by the spacetime geometry.

This is the only observer model relevant for answering what is physically measured near strong gravity. Many "strong blueshift" conclusions are, in fact, statements about nonphysical stationary observers or about nonlocal coordinate reconstructions. Transferring those conclusions to a freely falling observer without redefining the measurement process is an analytical error.

From this point forward, **the only observer considered as the primary physical observer is the freely falling observer**. Any mention of stationary constructions is solely comparative, to diagnose the origin of misconceptions, not to characterize physical experience.

3 3. Classification of Photon Directions Relative to the Freely Falling Observer

After defining the physical observer, the next step is to specify photon direction relative to the observer's motion. In GR, the observed frequency is not determined merely by position or "distance to a strong-field region"; it depends essentially on the relative orientation of the photon wave four-vector and the observer's four-velocity.

Neglecting this directional dependence is among the most common errors leading to incorrect blueshift conclusions. To remove ambiguity, photons that may reach the freely falling observer are classified into three distinct families.

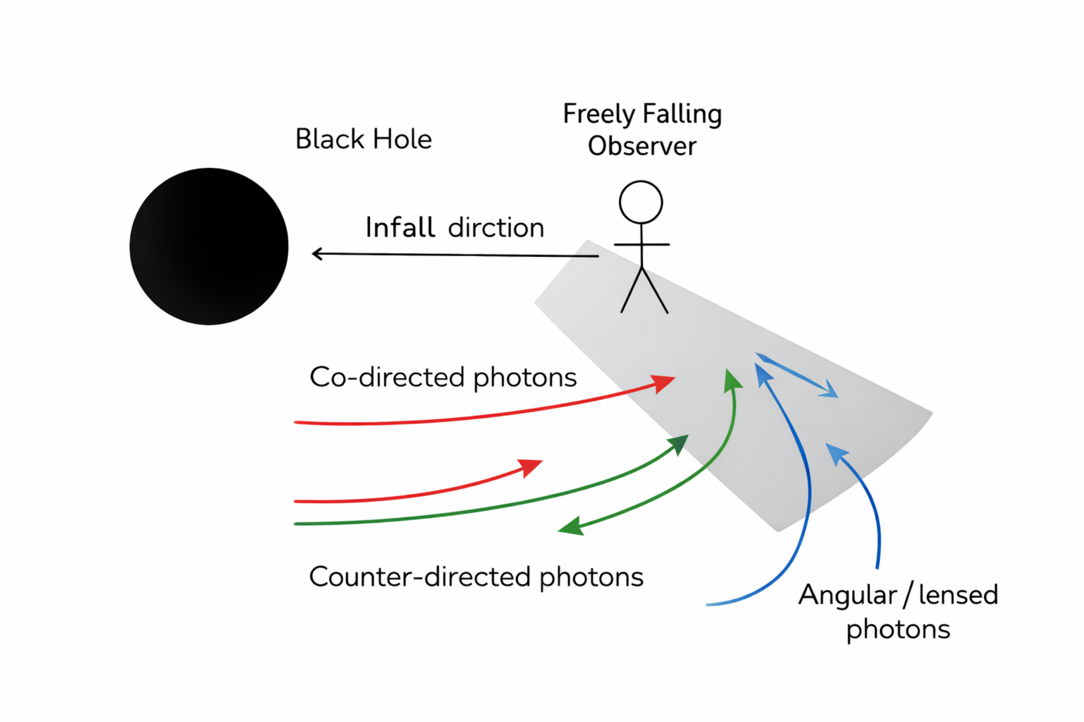

Figure 1: Illustrative schematic of the freely falling observer and representative photon families discussed in Section 3. All arrows are directed inward toward the black hole (left), emphasizing that the paper's claims concern local, observer-defined measurements, not radiation emitted by the horizon. This diagram is conceptual and not a numerical simulation.

A schematic overview of the observer–photon configuration discussed in this section is shown in Fig. 1.

3.1 3.1 Co-directed photons

These photons propagate in the same direction as the observer's infall; i.e., toward the interior direction of motion. Their sources may lie at larger radii, but their propagation direction is aligned with the observer's velocity.

In this configuration, the freely falling observer measures these photons as *redshifted.* This follows directly from the local operational definition of frequency as the scalar contraction $k_\mu u^\mu$, and the result does not depend on coordinate choices.

The key point is:

- there is no physical mechanism here for a divergent or strong blueshift;
- as the observer continues inward, such photons become more red, not more blue.

Thus, co-directed photons are not a source of blueshift; they indicate the opposite trend.

3.2 3.2 Counter-directed photons and forward sources

At first glance, photons arriving from the opposite direction to the observer's motion might seem able to produce blueshift, because the observer is moving toward the photon. Algebraically, the local contraction $k_\mu u^\mu$ can indeed yield a frequency increase in such a head-on configuration.

However, this conclusion is physically meaningful only if such a photon can *actually* reach the freely falling observer under physically realizable conditions. One must distinguish between a purely algebraic possibility and a real observable photon intersection.

First, external photons that are themselves falling inward co-directed with the observer propagate in a direction that, geometrically, does not lie in the observer's physical viewing cone. Such photons are typically *not observable* for the freely falling observer; the question of blueshift does not arise because the photon does not enter the observer's physical measurement channel. This conclusion does not require any event-horizon argument; it is a directional/geometric statement.

Second, consider a luminous source that is itself freely falling but slightly *ahead* of the observer (it started falling earlier and is deeper in the field). Such a source can emit photons outward (opposite to its own infall direction). Because the speed of light is invariant, these photons reach the trailing observer and are clearly observable.

In this forward-source configuration, the key operational fact is that the forward source typically accelerates faster (in stronger gravity), causing the source-observer separation to increase over time. This increasing separation yields an optical Doppler redshift in the measured signal. Crucially, this redshift conclusion does not depend on whether the source fell earlier or later; the relevant physical condition is that the relative separation increases, which generically drives a redshift.

Therefore, even when counter-directed photons are physically observable, the combined kinematics of relative motion and separation growth leads to *redshift*, not strong or divergent blueshift. No event-horizon appeal is required for this conclusion.

3.3 3.3 Angular photons and curved/lensed trajectories

The third family consists of photons that arrive at a nonzero angle relative to the observer's infall direction. These photons may follow curved paths due to gravitational lensing and can reach the observer from directions that would not arise in flat spacetime.

The crucial feature is that the photon direction includes a nonzero angular component relative to the observer's velocity. In GR, the observed frequency is defined locally and operationally by

$$\omega_{\text{obs}} = -k_\mu u^\mu.$$

In a local inertial frame at the measurement event, if the observer has instantaneous speed v and the photon arrives with angle θ relative to the observer's velocity, one obtains the explicit local relation

$$\omega_{\text{obs}} = \gamma\,\omega\,(1 - v\cos\theta), \qquad \gamma = \frac{1}{\sqrt{1-v^2}}.$$

This formula shows that frequency behavior depends not only on speed but also on the local arrival angle. For angular photons ($\theta \neq 0$), the factor $(1 - v\cos\theta)$ prevents any physically relevant strong or divergent blueshift in realizable measurements. A purely formal divergence channel is restricted to the co-directed limit $\theta \to 0$, which is precisely the co-directed configuration addressed in Section 3.1.

A minimal numerical illustration suffices. If $v = 0.9$, then $\gamma \approx 2.29$. For $\theta = 60^\circ$, $\cos\theta = 0.5$, so

$$\omega_{\text{obs}} = 2.29\,(1 - 0.9 \times 0.5)\,\omega = 2.29 \times 0.55\,\omega \approx 1.26\,\omega,$$

a modest, bounded amplification rather than a strong or divergent effect. Even for $\theta = 90^\circ$, one obtains $\omega_{\text{obs}} \approx \gamma\omega$, again bounded.

The curved history of the photon's path does not itself generate a new mechanism for strong blueshift. Observation is local: what matters is the instantaneous scalar contraction $k_\mu u^\mu$ at the detection event, not the full path history. Thus, angular/lensed photons remain well-behaved and do not produce strong or divergent blueshift for the freely falling observer.

This bounded behavior holds provided the photon and observer worldlines intersect within a classical spacetime region where the local inertial frame construction remains valid.

4 4. Local Frequency Measurement and the Nonlocal Reconstruction Error

After classifying photon configurations and analyzing frequency behavior in each class, we now address a more foundational question: *What is "measured frequency" in GR, and where is it defined?* The answer determines which results are physical and which are coordinate artifacts or nonlocal reconstructions.

In GR, an observational quantity is meaningful only when it is defined *locally* by a physical observer. For photons, the only unambiguous operational definition is the contraction of the photon wave four-vector with the observer's four-velocity:

$$\omega_{\text{obs}} = -k_\mu u^\mu.$$

This is a Lorentz scalar: it is coordinate-independent, local, and directly corresponds to the reading of an ideal detector co-moving with the observer. No alternative definition simultaneously preserves locality, coordinate-independence, and operational measurability.

4.1 Physical measurement vs. reconstructed quantities

Many claims of "strong" or "divergent" blueshift are not based on ω_{obs}, but rather on quantities obtained through *nonlocal reconstruction*:

- comparing photon frequencies at widely separated spacetime points;
- comparing quantities between hypothetical observers defined at different radii;
- interpreting coordinate components of k^μ directly as physical frequency.

These quantities can be mathematically useful, but they are not observational by themselves. A freely falling observer experiences only the local scalar $-k\cdot u$ at the measurement event. When nonlocal reconstructed quantities are mistakenly interpreted as what a real observer "sees," apparent divergences can arise that have no operational meaning.

4.2 Coordinate-independence and the diagnosis of apparent divergences

Because $\omega_{\text{obs}} = -k_\mu u^\mu$ is a scalar, it is invariant under coordinate transformations. If a calculation yields an apparent divergence in "frequency" near strong gravity, the first physical diagnostic is: *Is the computed object actually ω_{obs}, or is it a coordinate-dependent reconstruction?* In many standard presentations, the diverging quantity corresponds to a nonphysical stationary observer or a coordinate-dependent field reconstruction, not to an operational measurement by a freely falling observer.

Claims of divergence that arise from mode decompositions, coordinate frequencies, or nonlocal reconstructions do not by themselves constitute observational divergences unless reflected in the local scalar ω_{obs}.

4.3 Implication for the freely falling observer

For a freely falling observer with a finite timelike four-velocity, the operational definition guarantees that:

- no physically realizable measurement produces a divergent frequency;
- frequency changes depend continuously on relative velocity and photon direction;
- all observational results remain within standard relativistic kinematics.

This is why the three photon classes analyzed in Section 3 are bounded and well-behaved even in strong fields. The absence of strong/divergent blueshift is not a special assumption; it is a direct consequence of the operational definition of observation in GR.

4.4 Section summary

The key conclusion is:

- The only physical definition of observed photon frequency is $\omega_{\text{obs}} = -k\cdot u$.
- Any "frequency" not reducible to this local scalar is not an observational claim.
- Many strong-blueshift narratives arise from conflating local observables with nonlocal reconstructed quantities.

With this framework, the results of Section 3 become necessary consequences of GR's operational measurement structure, rather than isolated special cases.

5 5. Final Summary and Implications

This paper analyzed what a freely falling observer measures near a strong gravitational field, strictly within classical GR and anchored to operational local observation. The core strategy was to avoid conflating local measurable scalars with nonlocal reconstructed quantities, and to enforce physical realizability of the observer model.

5.1 Consolidated results

1. **Directional classification (Section 3).** Co-directed photons are not a source of strong blueshift; they are either not in the physical viewing channel or lead to redshift. Counter-directed photons that are physically observable exhibit redshift due to increasing relative separation between source and observer. Angular photons—even with curved/lensed trajectories—remain bounded and well-behaved.
2. **Local frequency measurement (Section 4).** The only valid observable frequency is $\omega_{\text{obs}} = -k_\mu u^\mu$, a local coordinate-independent scalar. Any alleged strong blueshift not reducible to this scalar is not an observational statement.
3. **Mathematical support (Appendix).** Explicit formulas and minimal numerical examples demonstrate bounded behavior for physically realizable configurations. The only formal divergence channel is confined to the co-directed limit, which does not yield a physically divergent experience for the freely falling observer under the conditions treated here.

5.2 Methodological implication

The main result is not an isolated claim but a necessary consequence of GR's operational definition of observation. When one (i) selects a physical freely falling observer, (ii) enforces locality, and (iii) specifies photon direction explicitly, there is no room for strong or divergent blueshift in the observer's measured experience.

5.3 Operational Consistency Condition for Any Extension Beyond Classical GR

This work establishes an operational baseline for interpreting observations by freely falling detectors near strong gravitational fields. The central tenet is that local detector readings, defined by the scalar contraction $\omega_{\text{obs}} = -k_\mu u^\mu$, constitute the primary observational content. Nonlocal constructs—such as coordinate frequencies, mode decompositions, or quantities reconstructed across different spacetime regions—may serve as useful computational or conceptual tools, but they do not by themselves constitute observational claims unless they reduce to local scalar measurements. This operational consistency condition provides a necessary requirement that any theoretical extension beyond classical GR, whether semiclassical or fully quantum, must respect when making statements about what a freely falling observer experiences near a horizon. It is a consistency requirement, not a refutation of existing frameworks, but rather a clarification of what constitutes an observational statement in this context.

5.4 Educational and interpretive implications

A clear boundary must be maintained between what can be computed and what can be observed. Nonphysical observer models and reconstructed nonlocal quantities should be labeled explicitly as computational tools, not as descriptions of freely falling experience. Narratives of an "energy wall" or "blueshift explosion" for the infalling observer require careful revision.

5.5 Final statement

> For a physical freely falling observer, no physically observable photon exhibits a divergent or strongly blueshifted signature near a strong gravitational field.

The present results clarify the operational content of observational statements for freely falling observers. They provide a consistency baseline that any further theoretical description—classical or quantum—must respect when interpreting near-horizon measurements.

Appendix A (3.1-A and 3.2-A): Mathematical + Numerical Support for Sections 3.1 and 3.2

A.1 Minimal operational starting point

Observed frequency:

$$\omega_{\text{obs}} = -k_\mu u^\mu.$$

In a local inertial frame (LIF), this reproduces the standard relativistic Doppler structure used below.

A.2 Support for Section 3.1 (co-directed photons)

In a LIF, for an observer moving with speed v and a photon arriving with angle θ relative to the velocity,

$$\omega_{\text{obs}} = \gamma(1 - v\cos\theta)\,\omega_{\text{local}}.$$

For co-directed photons, $\theta = 0$, hence

$$\omega_{\text{obs}} = \gamma(1-v)\,\omega_{\text{local}} = \omega_{\text{local}}\sqrt{\frac{1-v}{1+v}},$$

which is always $< \omega_{\text{local}}$ (redshift).

Minimal numerical example. Let $v = 0.8 \Rightarrow \gamma = 1/\sqrt{1-0.8^2} = 1.6667$. Then

$$\gamma(1-v) = 1.6667 \times 0.2 = 0.3333,$$

so $\omega_{\text{obs}} \approx 0.333\,\omega_{\text{local}}$. For $\omega_{\text{local}} = 600$ THz, $\omega_{\text{obs}} \approx 200$ THz (significant redshift).

A.3 Support for Section 3.2 (forward source emitting outward photons)

Consider a static Schwarzschild region strictly outside the strong-field boundary of interest (no event-horizon appeal). Let a freely falling source S at radius r_s emit an outward photon received by a freely falling observer O at radius $r_o > r_s$. A standard factorization yields

$$\frac{\omega_{\text{rec}}}{\omega_{\text{emit}}} = \left[\frac{\gamma_o(1+v_o)}{\gamma_s(1+v_s)}\right]\sqrt{\frac{1-2M/r_s}{1-2M/r_o}},$$

where v_s, v_o are local inward speeds measured by the local static frame at r_s, r_o, respectively.

For free fall from rest at infinity, a convenient local estimate is

$$v(r) = \sqrt{\frac{2M}{r}},$$

so deeper sources have larger v. The ratio $\gamma_o(1+v_o)/[\gamma_s(1+v_s)] < 1$ when $v_s > v_o$, and the gravitational factor is also < 1 for outward travel, thus producing net redshift.

Minimal numerical example (fully outside $r = 2M$). Choose $r_s = 4M$, $r_o = 6M$. Then

$$v_s = \sqrt{2M/4M} = \sqrt{0.5} = 0.7071, \quad v_o = \sqrt{2M/6M} = \sqrt{1/3} = 0.57735,$$

$$\gamma_s = \frac{1}{\sqrt{1-0.7071^2}} = \frac{1}{\sqrt{0.5}} = 1.4142, \quad \gamma_o = \frac{1}{\sqrt{1-0.57735^2}} = \frac{1}{\sqrt{2/3}} = 1.2247.$$

Compute the Doppler ratio:

$$\gamma_o(1+v_o) = 1.2247 \times 1.57735 = 1.9319, \quad \gamma_s(1+v_s) = 1.4142 \times 1.7071 = 2.4142,$$

$$\frac{\gamma_o(1+v_o)}{\gamma_s(1+v_s)} = \frac{1.9319}{2.4142} = 0.8000.$$

Compute the gravitational factor:

$$\sqrt{\frac{1-2M/4M}{1-2M/6M}} = \sqrt{\frac{1-0.5}{1-0.3333}} = \sqrt{\frac{0.5}{0.6667}} = \sqrt{0.75} = 0.8660.$$

Thus

$$\frac{\omega_{\text{rec}}}{\omega_{\text{emit}}} = 0.8000 \times 0.8660 = 0.6928,$$

a clear bounded redshift (about 31% reduction).

Appendix B (3.3-B): Mathematical Appendix for Section 3.3 (Angular Photons)

B.1 Purpose

This appendix provides an explicit local derivation supporting Section 3.3: angular photons ($\theta \neq 0$) measured by a freely falling observer remain bounded and well-behaved. No event-horizon argument is invoked; all statements are local and operational.

B.2 Operational definition

$$\omega_{\text{obs}} = -k_\mu u^\mu.$$

B.3 Local inertial frame (LIF) setup

At any event on the observer worldline, choose a LIF with metric $\eta_{\mu\nu} = \text{diag}(-1, 1, 1, 1)$. Let the observer velocity be along $+x$ with speed v (units $c = 1$):

$$u^\mu = \gamma(1, v, 0, 0), \qquad \gamma = \frac{1}{\sqrt{1-v^2}}.$$

Let a photon propagate in the x-y plane with angle θ relative to $+x$:

$$k^\mu = \omega(1, \cos\theta, \sin\theta, 0).$$

This is null:

$$k_\mu k^\mu = -\omega^2 + \omega^2(\cos^2\theta + \sin^2\theta) = 0.$$

B.4 Explicit evaluation of $\omega_{\text{obs}} = -k \cdot u$

In the LIF,

$$u_\mu = (-\gamma, \gamma v, 0, 0), \qquad k_\mu = (-\omega, \omega\cos\theta, \omega\sin\theta, 0).$$

Then

$$k_\mu u^\mu = (-\omega)\gamma + (\omega\cos\theta)(\gamma v) + (\omega\sin\theta)(0) = -\gamma\omega(1 - v\cos\theta),$$

so

$$\boxed{\omega_{\text{obs}} = \gamma\omega(1 - v\cos\theta)}.$$

B.5 Directional boundedness channel

Equation above shows directional dependence enters only through $\cos\theta$. A large amplification requires both $v \to 1$ and $\cos\theta \to 1$, i.e. $\theta \to 0$. Thus any formal divergence channel is confined to the co-directed limit $\theta \approx 0$. For angular photons with $\theta \neq 0$, the factor $1 - v\cos\theta$ does not collapse to the same scaling as $1 - v$ unless $\theta \to 0$. Hence angular photons do not open the divergence channel.

B.6 Minimal numerical checks

Take $v = 0.9 \Rightarrow \gamma \approx 2.294$.

- $\theta = 60^\circ \Rightarrow \cos\theta = 0.5$:

  $$D = \gamma(1 - v\cos\theta) = 2.294(1 - 0.45) = 2.294(0.55) = 1.262,$$

  so $\omega_{\text{obs}} \approx 1.262\,\omega$ (mild, bounded).

- $\theta = 90^\circ \Rightarrow \cos\theta = 0$:

  $$D = \gamma = 2.294, \quad \omega_{\text{obs}} \approx 2.294\,\omega,$$

  still bounded.

References

References

[1] R. M. Wald, *General Relativity*, University of Chicago Press (1984).

[2] C. W. Misner, K. S. Thorne, and J. A. Wheeler, *Gravitation*, W. H. Freeman (1973).

[3] E. Poisson, *A Relativist's Toolkit: The Mathematics of Black-Hole Mechanics*, Cambridge University Press (2004).

[4] S. M. Carroll, *Spacetime and Geometry: An Introduction to General Relativity*, Addison-Wesley (2004).

[5] B. F. Schutz, *A First Course in General Relativity*, 2nd ed., Cambridge University Press (2009).

[6] S. M. H. Emamifar and Z. Derakhshani, *A Critical Reassessment of the Theoretical Foundations of Hawking Radiation: From Mathematical Idealizations to Relativistic Inconsistencies*, Zenodo (2025), DOI: 10.5281/zenodo.18005185.

[7] S. M. H. Emamifar and Z. Derakhshani, *Photon Energy Exchange in Time-Dependent Gravitational Fields: On Blueshift, Redshift, and Black Hole Energy Accounting*, Zenodo (2025), DOI: 10.5281/zenodo.18005219.