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Appearance Under Relativistic Motion: A Quantitative Re-Examination Across Thermodynamic, Radiative, and Structural Channels

Rowan Brad Quni-Gudzin

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ABSTRACT

A recurring question in relativistic physics is whether a physical system "appears" the same, or in any sense invariant, to an observer moving at relativistic speed relative to it. We re-frame this question operationally: invariance of what quantity, under which measurement protocol? We analyze three concrete appearance channels — thermodynamic appearance (apparent temperature of a moving gas and of a blackbody radiation field), radiative appearance (Doppler factor, bolometric beaming, and radiation pressure on a moving mirror), and structural appearance (diffraction, jet morphology, and a modeled atmospheric re-entry event) — using only special-relativistic kinematics with fully shown arithmetic. For a representative speed $\beta_1 = 0.8$ we compute the Doppler factors $D_+ = 3$ and $D_- = 1/3$, the two candidate temperature-transformation outcomes $T_0/\gamma_1 = 0.6 T_0$ and $\gamma_1 T_0 = 1.666667 T_0$, and the solid-angle-averaged apparent temperature of an isotropic blackbody field, $\bar{T} = 0.8240 T_0$, i.e. a net cooling of 17.6%. [...]

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Abstract

A recurring question in relativistic physics is whether a physical system "appears" the same, or in any sense invariant, to an observer moving at relativistic speed relative to it. We re-frame this question operationally: invariance of *what* quantity, under *which* measurement protocol? We analyze three concrete appearance channels — thermodynamic appearance (apparent temperature of a moving gas and of a blackbody radiation field), radiative appearance (Doppler factor, bolometric beaming, and radiation pressure on a moving mirror), and structural appearance (diffraction, jet morphology, and a modeled atmospheric re-entry event) — using only special-relativistic kinematics with fully shown arithmetic. For a representative speed $\beta_1 = 0.8$ we compute the Doppler factors $D_+ = 3$ and $D_- = 1/3$, the two candidate temperature-transformation outcomes $T_0/\gamma_1 = 0.6 T_0$ and $\gamma_1 T_0 = 1.666667 T_0$, and the solid-angle-averaged apparent temperature of an isotropic blackbody field, $\bar{T} = 0.8240 T_0$, i.e. a net cooling of 17.6%. We also compute the idealized radiation pressure on a receding perfect mirror, $F_1/A = 0.1778 u_0$ versus the static value $2u_0$, a Jüttner tail suppression factor of 4.54×10^{-5} , and, for a modeled re-entry event at $\beta = 0.9$, an exact directional apparent-temperature ratio of 19 and a bolometric flux ratio of 130321. Our conclusion: appearance is generically *not* invariant; only properly defined rest-frame quantities are, and invariance where it exists is engineered, as in momentum-entangled Bell states.

1. Introduction

The question motivating this paper is whether a system can "appear invariant to an observer moving at relativistic speeds." The phrase "appear invariant" is ambiguous, and the ambiguity is the source of much confusion in discussions of relativistic thermodynamics and observation. An observer moving at speed $v_1 = \beta_1 c$ relative to a system receives

signals that are Doppler shifted, time-dilated, aberrated, and — for extended objects — distorted by light-travel-time effects. Whether the system "appears" invariant therefore depends on which observable the observer extracts: a photon frequency, a fitted temperature, a shape, an entanglement entropy, or an apparent velocity.

Special relativity guarantees invariance of scalar quantities defined in the rest frame of the measured system, such as the proper temperature T_0 that a comoving thermometer would read. It does *not* guarantee that the quantities an observer actually reconstructs from received signals equal those rest-frame values. Indeed, a substantial literature exists precisely because they do not: numeric simulations of relativistic gases conclude that a moving system appears cooler [1]; field-theoretic models have been built for thermal environments that are themselves moving [2]; drag forces arise on mirrors moving relative to blackbody radiation [3]; light-matter interaction calculations become challenging when the object moves relativistically relative to the source [4]; diffraction patterns of moving apertures change [5]; particle acceleration timescales depend on the flow frame in relativistic shear flows [6]; entanglement between spins can change under a boost unless momenta are appropriately entangled [7]; and the apparent velocity and Doppler factor of relativistic jets depend strongly on collimation and viewing geometry [8].

This paper makes a narrow, verifiable contribution: we state explicit measurement protocols, derive the apparent observables with every arithmetic step shown, and quantify the departure from invariance at fixed representative speeds. We do not claim new physics; we claim a clarified and quantified answer to the appearance-invariance question, assembled from standard kinematics and consistent with the cited literature. Three concrete scenarios are treated: a moving gas and blackbody field (Section 4, parts A–F), a modeled atmospheric re-entry event (Section 4, part H), and an idealized light-sail-like mirror (Section 4, part E).

2. Background and Related Work

We discuss the eight arXiv works in the supplied bibliography. Four QNFO entries [9], [10], [11], [12] are supplied with empty summary text; no substantive content from them can be used here, and we rely on them only as context labels for the broader corpus (competing ontological frameworks of spacetime, mass, and gravity [9]; relativistic topological superfluids [10]; self-proving theorem universes [11]; winding numbers and strange loops [12]).

[1] Numeric Experiments in Relativistic Thermodynamics: A Moving System Appears Cooler (arXiv:0804.3836v3). This work simulates a two-dimensional relativistic ideal gas using a relativistic elastic binary collision algorithm, shows that the simulated gas faithfully obeys Jüttner's speed distribution function, and — combining the simulation with the energy equipartition theorem for a relativistic gas — concludes that a moving system appears cooler. This is the closest existing answer to our motivating question on the thermodynamic channel: the appearance (fitted temperature) of a moving gas is *not* invariant but reduced. Our Section 4 derives the corresponding kinematic factors analytically for a blackbody field and shows the same sign of effect on angular average.

[2] Feynman-Vernon model of a moving thermal environment (arXiv:1803.10300v1). This paper reviews the Feynman-Vernon formulation of linear dissipative systems for a Brownian particle in an external potential $V(x, t)$ and introduces a generalized oscillator model of a Brownian particle coupled to a thermal environment moving with velocity v_{env} . The relevance to our question is structural: if the thermal environment itself must be assigned a velocity v_{env} in the dissipative dynamics, then the environment's state as seen by the particle is frame-dependent — the moving environment does not appear thermally identical to a resting one. The supplied summary is truncated and gives no quantitative results, so we use it only as evidence that moving-thermal-environment models are an active formulation problem.

[3] Blackbody radiation drag on a relativistically moving mirror (arXiv:0907.2311v1). The authors compute the drag force on a mirror moving at relativistic velocity relative to a blackbody radiation background. This establishes that even the mechanical response of a body to an isotropic thermal field is appearance-dependent: in the mirror's frame the radiation field is anisotropic and exerts a net retarding force. Our Section 4 computes an idealized unidirectional-beam version of this effect with full arithmetic, obtaining a pressure strongly reduced from the static value at $\beta_1 = 0.8$; we do not claim numerical equality with that work's result, which its summary does not state.

[4] Computing the interaction of light pulses with objects moving at relativistic speeds (arXiv:2404.05117v1). This work addresses polychromatic light–matter interaction when the object moves at constant relativistic speed relative to the light source, motivated by optical traps, optical tweezers, and light sails, where relative speeds should reach the relativistic regime. It confirms that the optical appearance of an object (its response to incident light) is velocity-dependent and computationally nontrivial; the supplied summary is truncated before quantitative results, so we cite it as motivation for the optical channel of our analysis.

[5] Rayleigh-Sommerfeld scalar diffraction by apertures moving at relativistic speeds (arXiv:2010.02547v2). The authors analytically obtain Rayleigh-Sommerfeld scalar diffraction results for single-slit, double-slit, grating, and circular apertures moving at relativistic speeds with velocity perpendicular to the direction of incidence, and also study an oscillatory-shutter single slit. This is direct evidence that the *structural* appearance of an object (its diffraction signature) is not invariant under transverse relativistic motion. The summary is truncated before specific formulas, so we do not attribute numerical results to it.

[6] Particle acceleration timescales in relativistic shear flows (arXiv:astro-ph/0506719v1). This review discusses acceleration of energetic particles in relativistic astrophysical jets with significant velocity shear, the possible formation of power-law momentum spectra, and typical acceleration timescales for parallel and azimuthal shear flows, with special attention to parallel shear. It shows that even the *effective particle spectrum* produced by a flow is frame- and profile-dependent: the appearance of an acceleration environment differs across frames. The summary is truncated, so we use it qualitatively only.

[7] Relativistic-invariant quantum entanglement between the spins of moving bodies (arXiv:quant-ph/0211159v2). Building on the observation (attributed in the entry to Gingrich and Adami, Phys. Rev. Lett. 89, 270402 (2002)) that spin-momentum mixing can change spin entanglement for a moving observer, this paper shows that if the momenta are appropriately entangled, the entanglement between the spins of Bell states can remain maximal when viewed by any moving observer. This is the one clear *positive* invariance result in our bibliography — and it is instructive: invariance is achieved not for free but by a specific preparation condition (momentum entanglement). Appearance invariance, where it exists, is engineered, not generic.

[8] The influence of collimation on the appearance of relativistic jets (arXiv:1010.5895v1). The authors numerically compute the apparent velocity and Doppler factor of a non-homokinetic jet under different velocity profiles to study the effect of collimation on jet appearance, arguing that if the motion is relativistic, the high- (summary truncated). Even truncated, the entry establishes that "appearance" quantities for relativistic motion (apparent velocity, Doppler factor) depend on the internal velocity distribution and collimation — i.e., appearance is a function of structure, not a frame-convention artifact alone. This is also the closest methodological template for our work: apparent observables computed as a function of viewing geometry.

Synthesis. Across thermodynamics [1], open quantum systems [2], mechanical drag [3], optical interaction [4], diffraction [5], astrophysical acceleration [6], quantum information [7], and jet astronomy [8], the consistent picture is: rest-frame quantities are invariant; received/reconstructed appearance quantities are not, except under special preparations [7]. Our contribution is to quantify the generic departure at fixed speeds with fully explicit arithmetic.

3. Methods

Protocol definition. We define an "appearance observable" X_{app} as any quantity an observer reconstructs from received signals (photon frequencies, fitted temperatures, pressures, diffraction patterns), and an "invariant observable" X_{inv} as a quantity defined in the system's rest frame (proper temperature T_0 , proper length L_0 , proper pressure). The invariance question is whether $X_{\text{app}} = X_{\text{inv}}$ for a moving observer.

Kinematic inputs. All derivations use only: (i) the Lorentz factor $\gamma(\beta) = (1 - \beta^2)^{-1/2}$; (ii) the relativistic Doppler factor for a line-of-sight velocity component $\beta_{\parallel}$, $D = 1/[\gamma(1 - \beta_{\parallel})]$; (iii) photon number/momentum conservation at a moving mirror; (iv) the Jüttner exponential weight $\exp[-(\gamma_p - 1)mc^2/(k_B T)]$ for a particle of Lorentz factor γ_p , which reference [1] reports their simulated gas obeys.

Representative speeds. We fix $\beta_1 = 0.8$ as the primary benchmark for the thermodynamic and radiative channels, and additionally compute the speed at which the forward Doppler factor reaches $D = 10$. For the re-entry scenario (part H) we adopt $\beta = 0.9$ as an assumed representative re-entry speed. As a cross-check at a more modest speed we also evaluate the equipartition cooling branch at $\beta = 0.6$.

Scope. We treat flat spacetime only, inertial frames only, and idealized objects (perfect mirror, isotropic blackbody field, unidirectional monochromatic beam, single-temperature re-entry sheath). All quantitative results in Section 5 are computed in Section 4; no simulation or experimental data are reported.

4. Analysis

All arithmetic is shown explicitly. No number is imported from an external measurement.

4.1 Thermodynamic and radiative channels at $\beta_1 = 0.8$

A. Lorentz factor.

$$\gamma_1 = \frac{1}{\sqrt{1 - \beta_1^2}} = \frac{1}{\sqrt{1 - 0.64}} = \frac{1}{\sqrt{0.36}} = \frac{1}{0.6} = \frac{5}{3} \approx 1.666667.$$

B. Doppler factors (longitudinal). For motion directly toward the observer ($\beta_{\parallel} = -\beta_1$, approaching):

$$D_+ = \frac{1}{\gamma_1(1 - \beta_1)} = \frac{1}{(5/3)(0.2)} = \frac{1}{1/3} = 3.$$

For receding motion ($\beta_{\parallel} = +\beta_1$):

$$D_- = \frac{1}{\gamma_1(1 + \beta_1)} = \frac{1}{(5/3)(1.8)} = \frac{1}{3}.$$

For transverse observation ($\beta_{\parallel} = 0$): $D_{\perp} = 1/\gamma_1 = 0.6$ (transverse Doppler redshift).

C. Candidate temperature transformations. Two candidate rules appear in the relativistic-thermodynamics literature; we compute both at $\beta_1 = 0.8$ for a rest temperature T_0 :

$$T_{\text{cool}} = \frac{T_0}{\gamma_1} = 0.6 T_0, \quad T_{\text{hot}} = \gamma_1 T_0 = 1.666667 T_0.$$

The ratio between the two candidates is $\gamma_1^2 = 25/9 \approx 2.777778$. Reference [1] concludes the cooler branch is realized for a moving gas; our blackbody calculation below independently yields a net-cooling result on angular average. As a cross-check at $\beta = 0.6$: $\gamma = 1/\sqrt{1 - 0.36} = 1/0.8 = 1.25$, and the cooler branch gives $T' = T_0/1.25 = 0.8 T_0$; for $T_0 = 300$ K (assumed laboratory rest temperature), $T' = 240$ K, a 20% reduction.

D. Apparent temperature of an isotropic blackbody field. An observer moving at β_1 through an isotropic blackbody field of rest temperature T_0 measures, in a direction making angle θ with the velocity (photons arriving from direction θ), an apparent temperature

$$T_{\text{app}}(\theta) = \frac{T_0}{\gamma_1(1 - \beta_1 \cos \theta)}.$$

Forward direction ($\theta = 0$): $T_{\text{app}} = T_0/[\gamma_1(1 - \beta_1)] = 3T_0$. Backward ($\theta = \pi$): $T_{\text{app}} = T_0/3$. The field therefore appears strongly anisotropic — not invariant.

Solid-angle average: with $\mu = \cos \theta$,

$$\langle D \rangle = \frac{1}{4\pi} \int \frac{d\Omega}{\gamma_1(1 - \beta_1 \mu)} = \frac{1}{\gamma_1} \cdot \frac{1}{2} \int_{-1}^1 \frac{d\mu}{1 - \beta_1 \mu}.$$

The integral: $\int_{-1}^1 \frac{d\mu}{1 - \beta_1 \mu} = \left[-\frac{1}{\beta_1} \ln(1 - \beta_1 \mu) \right]_{-1}^1 = \frac{1}{\beta_1} \ln \frac{1+\beta_1}{1-\beta_1} = \frac{2}{\beta_1} \text{atanh } \beta_1$. So $\langle D \rangle = \frac{\text{atanh } \beta_1}{\gamma_1 \beta_1}$ and

$$\bar{T} = \frac{T_0 \text{atanh } \beta_1}{\gamma_1 \beta_1}.$$

Numerically: $\text{atanh}(0.8) = \frac{1}{2} \ln \frac{1.8}{0.2} = \frac{1}{2} \ln 9 = 1.0986$; $\gamma_1 \beta_1 = (5/3)(0.8) = 4/3 \approx 1.3333$;

$$\bar{T} = T_0 \times \frac{1.0986}{1.3333} = 0.8240 T_0.$$

The angularly averaged appearance of the field is *cooler* by $1 - 0.8240 = 0.1760$, i.e. 17.6%, in qualitative agreement with the "moving system appears cooler" conclusion of [1].

E. Radiation pressure on a receding perfect mirror (idealized unidirectional beam). Let a beam of energy density u_0 (in the source frame) strike a perfect mirror receding at β_1 along the beam. Photon arrival rate per unit mirror area is reduced by $(1 - \beta_1)$; each photon of energy $h\nu$ reflects with frequency redshifted by the mirror Doppler factor $\nu_r/\nu = \frac{1-\beta_1}{1+\beta_1}$. Momentum transfer per photon:

$$\Delta p = \frac{h\nu}{c} \left(1 - \frac{\nu_r}{\nu}\right) = \frac{h\nu}{c} \left(1 - \frac{1 - \beta_1}{1 + \beta_1}\right) = \frac{h\nu}{c} \cdot \frac{2\beta_1}{1 + \beta_1}.$$

Force per area:

$$\frac{F}{A} = u_0(1 - \beta_1) \cdot \frac{2\beta_1}{1 + \beta_1} = u_0 \cdot \frac{2\beta_1(1 - \beta_1)}{1 + \beta_1}.$$

At $\beta_1 = 0.8$: numerator $2(0.8)(0.2) = 0.32$; denominator 1.8;

$$\frac{F_1}{A} = u_0 \times \frac{0.32}{1.8} = 0.1778 u_0.$$

For a static mirror ($\beta = 0$), $F_0/A = 2u_0$. The appearance of the beam's mechanical effect is therefore suppressed by a factor $0.1778/2 = 0.0889$ — an 89.1% reduction. This idealized calculation is consistent in spirit with the full blackbody-drag computation of [3] (drag exists and is velocity-dependent); we do not claim numerical equality with that work's result.

F. Jüttner tail suppression. Reference [1] reports that a relativistic gas obeys Jüttner's speed distribution, whose Boltzmann weight for a particle of Lorentz factor γ_p is $\exp[-(\gamma_p - 1)mc^2/(k_B T_0)]$. For a cold gas with $k_B T_0 = 0.1 mc^2$, the relative weight of particles at $\gamma_p = 2$ versus $\gamma_p = 1$ is

$$\frac{w(2)}{w(1)} = \exp \left[-\frac{(2-1)mc^2}{0.1 mc^2} \right] = e^{-10} = 4.5400 \times 10^{-5}.$$

A moving observer fitting a temperature from such a distribution samples Doppler-shifted energies; the fitted value inherits the frame dependence demonstrated in part D.

G. Speed for $D = 10$. For longitudinal approach, $D = \sqrt{\frac{1+\beta}{1-\beta}}$. Setting $D = 10$: $100 = \frac{1+\beta}{1-\beta} \Rightarrow 100 - 100\beta = 1 + \beta \Rightarrow \beta = \frac{99}{101} \approx 0.9802$.

4.2 Re-entry channel at $\beta = 0.9$

H. We model a re-entry event (a body entering a planetary atmosphere at high speed, dissipating kinetic energy as heat and radiation) in its rest frame S by three free model parameters: emitted temperature T_0 , proper duration $\Delta\tau$, and radiating area A . Inputs (all assumptions): $\beta = 0.9$, $T_0 = 2000$ K, $\Delta\tau = 100$ s.

Step 1: Lorentz factor.

$$\gamma = \frac{1}{\sqrt{1-0.9^2}} = \frac{1}{\sqrt{1-0.81}} = \frac{1}{\sqrt{0.19}} = \frac{1}{0.43589} \approx 2.2942.$$

Step 2: Doppler factor, approaching ($\theta = 0$).

$$D_{\text{app}} = \frac{1}{\gamma(1-\beta)} = \frac{1}{2.2942 \times 0.1} = \frac{1}{0.22942} \approx 4.3589.$$

Step 3: Doppler factor, receding ($\theta = \pi$).

$$D_{\text{rec}} = \frac{1}{\gamma(1+\beta)} = \frac{1}{2.2942 \times 1.9} = \frac{1}{4.3589} \approx 0.22942.$$

Note the exact duality $D_{\text{app}} = 1/D_{\text{rec}}$, which follows because $\gamma^2(1-\beta)(1+\beta) = \gamma^2(1-\beta^2) = 1$.

Step 4: Anisotropy ratio of apparent temperature.

$$\frac{T_{\text{app}}}{T_{\text{rec}}} = \frac{D_{\text{app}}}{D_{\text{rec}}} = \frac{1+\beta}{1-\beta} = \frac{1.9}{0.1} = 19.$$

This ratio is exact and independent of T_0 .

Step 5: Apparent temperatures. $T_{\text{app}} = 4.3589 \times 2000$ K = 8717.8 K; $T_{\text{rec}} = 0.22942 \times 2000$ K = 458.8 K; transverse ($\theta = \pi/2$): $D_{\perp} = 1/\gamma = 0.43589$, $T_{\perp} = 871.8$ K.

Step 6: Bolometric flux anisotropy. For an unresolved source, $F_{\text{obs}} = D^4 F_0$:

$$\frac{F_{\text{app}}}{F_{\text{rec}}} = \left(\frac{1+\beta}{1-\beta} \right)^4 = 19^4 = 130321,$$

since $19^2 = 361$ and $361^2 = 130321$. The absolute approaching beaming factor is $D_{\text{app}}^4 = 19.0000^2 = 361.00$ (exactly, since $D_{\text{app}}^2 = (1+\beta)/(1-\beta) = 19$); the receding factor is $0.22942^4 = 0.052634^2 \approx 2.77 \times 10^{-3}$.

Step 7: Duration dilation. $\Delta t_{\text{obs}} = \gamma \Delta\tau = 2.2942 \times 100$ s = 229.42 s.

Step 8: Invariance test. Since D ranges over $[0.22942, 4.3589]$, D^4 over $[2.77 \times 10^{-3}, 361.0]$, and $\gamma = 2.2942 \neq 1$, none of the three observables is independent of (β, θ) .

5. Results

All numbers below are computed in Section 4 from stated assumptions.

1. **Doppler appearance factors at $\beta_1 = 0.8$:** $D_+ = 3$ (approaching), $D_- = 1/3$ (receding), $D_\perp = 0.6$ (transverse). The forward/backward apparent-temperature ratio is 9.
2. **Temperature-transformation candidates:** $T_0/\gamma_1 = 0.6 T_0$ versus $\gamma_1 T_0 = 1.666667 T_0$; the candidates differ by a factor $\gamma_1^2 = 25/9 \approx 2.777778$. The literature simulation [1] supports the cooler branch. Cross-check at $\beta = 0.6$: $\gamma = 1.25$, $T' = 0.8 T_0$; for $T_0 = 300$ K, $T' = 240$ K (20% reduction).
3. **Angularly averaged apparent temperature of an isotropic blackbody field:** $\bar{T} = 0.8240 T_0$, a net cooling of 17.6%; locally, the field appears at $3T_0$ forward and $T_0/3$ backward.
4. **Idealized receding-mirror radiation pressure:** $F_1/A = 0.1778 u_0$, versus $F_0/A = 2u_0$ at rest — a suppression factor of 0.0889 (89.1% reduction).
5. **Jüttner tail suppression** for $k_B T_0 = 0.1 mc^2$ at $\gamma_p = 2$: 4.5400×10^{-5} .
6. **Speed for forward Doppler factor $D = 10$:** $\beta = 99/101 \approx 0.9802$.
7. **Re-entry channel at $\beta = 0.9$** (assumed $T_0 = 2000$ K, $\Delta\tau = 100$ s): $T_{\text{app}} = 8717.8$ K, $T_\perp = 871.8$ K, $T_{\text{rec}} = 458.8$ K; directional temperature ratio exactly 19; flux ratio $19^4 = 130321$; beaming factor span $[2.77 \times 10^{-3}, 361.0]$; duration $\Delta t_{\text{obs}} = 229.42$ s.

Projection (labeled as such). If the angular-average cooling factor $\bar{T}/T_0 = \text{atanh } \beta / (\gamma\beta)$ is taken as a proxy for thermodynamic appearance across speeds, then at $\beta = 0.5$ ($\gamma = 1.1547$, $\text{atanh } 0.5 = 0.5493$): $\bar{T} = 0.5493 / (1.1547 \times 0.5) T_0 = 0.9513 T_0$ (cooling 4.9%); at $\beta = 0.99$ ($\gamma = 7.0888$, $\text{atanh } 0.99 = 2.6467$): $\bar{T} = 2.6467 / (7.0888 \times 0.99) T_0 = 0.3771 T_0$ (cooling 62.3%). These are kinematic projections of the stated formula, not simulation results; their validity as thermodynamic appearance measures is an assumption, and the uncertainty is dominated by that assumption, not by arithmetic.

6. Discussion

Main claim. Appearance is generically not invariant under relativistic motion. Every channel examined — thermodynamic fit [1], dissipative environment response [2], mechanical radiation pressure [3], optical interaction [4], diffraction [5], acceleration environment [6], jet morphology [8], and the modeled re-entry event — is frame-dependent. The single positive invariance result in our corpus [7] required a special preparation (momentum entanglement), reinforcing that invariance is conditional, not generic.

Limitations and failure modes. (i) Our blackbody angular average (Result 3) is a specific protocol choice; a different weighting (e.g., energy-density-weighted rather than solid-angle-averaged temperature) gives a different number, so the "17.6% cooling" is protocol-relative. (ii) The mirror calculation (Result 4) uses a unidirectional monochromatic beam, not the isotropic blackbody background of [3]; the true drag on a mirror in an isotropic field involves angular integrals we did not perform, and our $0.1778 u_0$ should not be compared numerically to that work. (iii) The identification of $\bar{T}$ with the thermodynamic "appears cooler" statement of [1] is an interpretive bridge, not a derivation: [1] used a collision-algorithm simulation and equipartition, a different route, and its summary states the conclusion but not the transformation formula. If the thermodynamic and Doppler temperature transformations conflict for some observer configuration, our two-channel treatment would need reconciliation — this is an open question. (iv) The re-entry model (part H) treats the sheath as a single-temperature thermal emitter observed via a point-source Doppler factor; real re-entry plasmas are optically thick in places, spatially structured, and non-equilibrium, and no radiative transfer was performed. The scenario of an observer moving at $\beta = 0.9$ relative to a planet's atmosphere is physically extreme; we

retain it because the question posed is kinematic and the algebra is speed-independent in form. (v) We treated only inertial frames and flat spacetime; acceleration, gravity, and the ontological questions raised in the QNFO program [9], [10], [11], [12] (whose supplied summaries contain no usable content) are out of scope.

What would falsify the claims. A controlled simulation showing that a moving observer's fitted temperature of a relativistic gas equals T_0 to within statistical errors would falsify the cooling claim on the thermodynamic channel. A demonstration that the solid-angle-averaged Doppler factor equals unity at some $\beta > 0$ would falsify our formula — but the formula is elementary, so falsification would more plausibly target the *interpretation* (that the average is the relevant appearance observable). If the thermodynamic temperature transformation of [1] were found to exactly cancel the Doppler factor in all directions, the net apparent temperature could become invariant; our analysis shows the Doppler factor is strongly direction-dependent, so such an exact cancellation would itself be a remarkable directional result requiring proof. If entanglement-assisted invariance [7] generalized to thermodynamic quantities without special preparation, the framing of this paper would need revision.

Against ourselves. One might argue that "appearance invariance" should mean invariance of the underlying Lorentz-scalar description (four-momentum, invariant mass, proper time) — under that reading, every event is trivially "invariant." We reject this reading as vacuous for the question posed, which is about what a moving observer *sees*; but we acknowledge the terminological risk. Further, [7] shows that appropriate state preparation can protect a quantity (spin entanglement of Bell states) from all moving observers; no analogous protection mechanism is known for continuous thermodynamic observables, but we cannot rule out that a cleverly defined observable (e.g., a specific spectral-line ratio) could be constructed to be boost-invariant — we flag this as an open question rather than a claim.

Open questions. Which appearance observable, if any, is canonical? Does the cooling factor $\tanh \beta / (\gamma \beta)$ correspond to what an actual calorimetric measurement would yield? What is the exact transformation formula for the equipartition temperature derived in [1], and how does it compose with the Doppler factor? How do the diffraction results of [5] combine with the thermodynamic results of [1] for a moving, finite-temperature, structured object? The truncated summaries of [2], [4], [5], [6], and [8] prevent us from quoting their quantitative formulas, so our use of those works is limited to the qualitative roles their supplied entries state.

7. Conclusion

We asked whether a physical system appears invariant to an observer moving at relativistic speed, and answered operationally by fixing measurement protocols and computing appearance observables with fully shown arithmetic. Across the thermodynamic channel (candidate temperature transformations $T_0/\gamma_1 = 0.6 T_0$ versus $\gamma_1 T_0 = 1.666667 T_0$ at $\beta_1 = 0.8$; angularly averaged blackbody apparent temperature $\bar{T} = 0.8240 T_0$, a 17.6% cooling), the radiative channel (receding-mirror pressure $F_1/A = 0.1778 u_0$ versus $2u_0$ at rest; Jüttner tail suppression 4.5400×10^{-5}), and the structural channel (a modeled re-entry event at $\beta = 0.9$ with directional apparent-temperature ratio exactly 19 and bolometric flux ratio $19^4 = 130321$), no examined observable is invariant under boosts. The one positive invariance result in our corpus [7] holds only under a special preparation (momentum entanglement), supporting the conclusion that appearance invariance, where it exists, is engineered rather than generic. Rest-frame quantities remain the invariant content of the theory; what a moving observer reconstructs from received signals is generically frame-dependent, and the size of the departure is quantifiable at any stated speed by the elementary factors used here.

References

- [1] Numeric Experiments in Relativistic Thermodynamics: A Moving System Appears Cooler. arXiv:0804.3836v3. <https://arxiv.org/abs/0804.3836v3> [2] Feynman-Vernon model of a moving thermal environment. arXiv:1803.10300v1. <https://arxiv.org/abs/1803.10300v1> [3] Blackbody radiation drag on a relativistically moving mirror.

arXiv:0907.2311v1. <https://arxiv.org/abs/0907.2311v1> [4] Computing the interaction of light pulses with objects moving at relativistic speeds. arXiv:2404.05117v1. <https://arxiv.org/abs/2404.05117v1> [5] Rayleigh-Sommerfeld scalar diffraction by apertures moving at relativistic speeds. arXiv:2010.02547v2. <https://arxiv.org/abs/2010.02547v2> [6] Particle acceleration timescales in relativistic shear flows. arXiv:astro-ph/0506719v1. <https://arxiv.org/abs/astro-ph/0506719v1> [7] Relativistic-invariant quantum entanglement between the spins of moving bodies. arXiv:quant-ph/0211159v2. <https://arxiv.org/abs/quant-ph/0211159v2> [8] The influence of collimation on the appearance of relativistic jets. arXiv:1010.5895v1. <https://arxiv.org/abs/1010.5895v1> [9] QNFO: Critical Examination of Spacetime, Mass, and Gravity through Competing Ontological Frameworks [10] QNFO: Relativistic Topological Superfluid [11] QNFO: Universe as Self-Proving Theorem [12] QNFO: WINDING NUMBERS AND STRANGE LOOPS