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The Principle of Relativity as the Observable Signature of an Underlying Absolute

A simple, almost ironic paradox: the principle of relativity may be nothing more than the manifestation of an absolute subtly concealed within the very act of observation. The absolute frame of reference, which physics had set aside, seems to have faded in favour of laws that are invariant between observers in uniform relative motion. Yet what disappears from the equations does not necessarily disappear from reality.

The approach presented here suggests that this invariance may not be fundamental, but may instead emerge from the process of reconstructing observables. It would then constitute the missing piece that allows the energetic medium, identified here with the aether in its operational sense, to recover physical coherence, without contradicting the principle of relativity.

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Contents

1 Integration into the context of the dynamics of the energetic medium

This document is a direct extension of the theory of the energetic medium presented previously. It aims to explore a particular consequence of that theory: the emergence of the principle of relativity as an effective property of observations, rather than as a fundamental postulate.

Within the proposed framework, the energetic medium, analogous to an aether in the physical sense, defines an absolute frame of reference associated with its global state of motion. This absolute frame may be defined as the one in which an observer is locally co-moving with the energy flux of the medium, that is, in the absence of any relative velocity with respect to that flux.

However, the physical interactions accessible to experiment rest upon local exchanges within this medium, which do not allow direct access to this global state, nor do they permit an unambiguous determination of co-motion with the flux.

It follows that the usual laws, as reconstructed from these interactions, appear invariant for observers in uniform relative motion. The principle of relativity is then interpreted as an emergent manifestation of the structure of the medium, rather than as a primary symmetry imposed upon the laws of physics.

The analysis presented here aims to clarify this viewpoint by showing that an absolute frame of reference can coexist with an apparent invariance of the laws, and that this situation leads in particular to the effective constancy of the speed of light within ordinary experimental settings.

2 The apparent incompatibility between the principle of relativity and the existence of an absolute frame of reference

2.1 Background dynamics of the energetic medium

2.1.1 Limits of the isolated-body approximation

Until now, the fundamental mechanisms of the dynamics of the energetic medium have been introduced within the simplified framework of an isolated body. In this approximation, the Earth is regarded as the sole source of gravitational potential, and the flux of the medium is entirely determined by this contribution.

This yields a characteristic velocity corresponding to free fall from infinity to the Earth's surface:

$$11.2\,\mathrm{km\,s^{-1}} \tag{1}$$

This construction establishes a direct link between the local gravitational potential and the dynamics of the flux. However, it does not correspond to physical reality.

In practice, no system is isolated. The Earth is embedded within the gravitational field of the Sun, which is itself embedded within that of the Galaxy, which in turn has its own dynamics within the Universe.

The energetic medium therefore possesses a pre-existing dynamics, independent of the sole contribution of the Earth.

2.1.2 Superposition of potentials and energetic dynamics of the flux

Starting from the scale of celestial bodies such as the Earth, the dynamics of the medium is governed by the total gravitational potential.

In the presence of multiple sources, the individual contributions superpose and add linearly:

$$\Phi(\vec{r}) = \sum_i \Phi_i(\vec{r}) \tag{2}$$

The velocity of the flux follows from an energy relation along the flux lines:

$$\frac{v^2(\vec{r})}{2} + \Phi(\vec{r}) = \mathrm{const} \tag{3}$$

Setting a reference condition at large distance gives:

$$v^2(\vec{r}) = v_\infty^2 - 2\Phi(\vec{r}) \tag{4}$$

or, accounting for the superposition:

$$\boxed{v^2(\vec{r}) = v_\infty^2 - 2\sum_i \Phi_i(\vec{r})} \tag{5}$$

Thus, the composition of the velocity field does not result from a direct addition of velocities, but from a composition at the energetic level. This distinction is essential for understanding the actual structure of the flux.

2.1.3 Hierarchy of astrophysical contributions

In the real environment, several gravitational structures simultaneously contribute to the dynamics of the energetic medium.

The standard characteristic velocities are generally defined within the framework of an isolated body, and must be interpreted as local scales associated with each potential.

Terrestrial contribution:

$$v_{\mathrm{esc}\oplus}(R_\oplus) \simeq 11.2\,\mathrm{km\,s^{-1}} \tag{6}$$

At the scale of the solar system:

$$v_{\mathrm{orb}\oplus} \simeq 29.8\,\mathrm{km\,s^{-1}} \tag{7}$$

$$v_{\mathrm{esc}\odot}(1\,\mathrm{AU}) \simeq 42\,\mathrm{km\,s^{-1}} \tag{8}$$

At the galactic scale:

$$v_{\mathrm{orb,gal}} \simeq 220\,\mathrm{km\,s^{-1}} \tag{9}$$

$$v_{\mathrm{esc,gal}} \simeq 550 \text{ to } 600\,\mathrm{km\,s^{-1}} \tag{10}$$

This yields the following hierarchy of scales:

$$600,\ 220,\ 42,\ 30,\ 11\,\mathrm{km\,s^{-1}} \tag{11}$$

The actual velocity field of the medium is therefore a hierarchical structure. A quasi-uniform galactic flux constitutes a global background. The Sun imposes an intermediate modulation. The Earth introduces a local perturbation.

2.2 Inconsistency between the background flux and GPS system observations

2.2.1 Expected orbital modulation associated with a background flux

The presence of a significant global flux of the energetic medium raises, at first sight, an interpretational difficulty with regard to local experimental observations.

Indeed, if an absolute background velocity were to intervene directly in the slowing of clocks, then the rate of an on-board clock would depend not only on its local orbital dynamics around the Earth, but also on its instantaneous orientation with respect to this background flux.

Consider, for example, a galactic flux of the order of:

$$V_{\rm bg} \sim 220\,{\rm km\,s^{-1}} \tag{12}$$

and a typical orbital velocity of a GPS satellite:

$$u_{\rm GPS} \simeq 3.9\,{\rm km\,s^{-1}} \tag{13}$$

Over the course of the orbit, the direction of the satellite's velocity changes continuously. In a naive description where the relevant absolute velocity would be the vector sum of the orbital velocity and the background flux, the magnitude of the satellite's velocity with respect to the medium would vary periodically between two extreme values:

$$v_+ \simeq V_{\rm bg} + u_{\rm GPS} \tag{14}$$

and

$$v_- \simeq V_{\rm bg} - u_{\rm GPS} \tag{15}$$

The rate of the on-board clock would therefore also vary periodically between these two values. Using the standard form of the kinematic factor:

$$d\tau = dt\,\sqrt{1 - \frac{v^2}{c^2}} \tag{16}$$

the relative difference in rate between two diametrically opposite positions on the orbit is, retaining only the term linear in $u_{\rm GPS}/V_{\rm bg}$:

$$\Delta\left(\frac{d\tau}{dt}\right) \simeq \frac{v_-^2 - v_+^2}{2c^2} \tag{17}$$

since

$$v_+^2 - v_-^2 = (V_{\rm bg} + u_{\rm GPS})^2 - (V_{\rm bg} - u_{\rm GPS})^2 = 4V_{\rm bg}u_{\rm GPS} \tag{18}$$

hence

$$\left|\Delta\left(\frac{d\tau}{dt}\right)\right| \simeq \frac{2V_{\rm bg}u_{\rm GPS}}{c^2} \tag{19}$$

Numerically, with

$$V_{\rm bg} = 2.2 \times 10^5\,{\rm m\,s^{-1}} \tag{20}$$

and

$$u_{\rm GPS} = 3.9 \times 10^3\,{\rm m\,s^{-1}} \tag{21}$$

one obtains:

$$\frac{2V_{\rm bg}u_{\rm GPS}}{c^2} \simeq 1.9 \times 10^{-8} \tag{22}$$

This relative modulation is extraordinarily large on the scale of GPS clocks.

Over a half-orbit, of duration approximately:

$$T_{\frac{1}{2}} \simeq 4.3 \times 10^4\,{\rm s} \tag{23}$$

this would correspond to a temporal variation of the order of:

$$\Delta\tau_{\frac{1}{2}} \sim T_{\frac{1}{2}} \times 1.9 \times 10^{-8} \sim 8 \times 10^{-4}\,{\rm s} \tag{24}$$

that is, approximately:

$$\Delta\tau_{\frac{1}{2}} \sim 0.8\,{\rm ms} \tag{25}$$

The peak-to-peak amplitude of the modulation over a full orbit would therefore be of the order of:

$$\sim 1.6\,{\rm ms} \tag{26}$$

and would remain of the same order of magnitude even upon refining the geometric assumptions.

Taking not a galactic background velocity but simply the orbital velocity of the Earth around the Sun, namely:

$$V_{\rm bg} \simeq 29.8\,{\rm km\,s^{-1}} \tag{27}$$

the expected relative modulation becomes:

$$\left|\Delta\left(\frac{d\tau}{dt}\right)\right| \simeq \frac{2V_{\rm bg}u_{\rm GPS}}{c^2} \simeq 2.6\times 10^{-9} \tag{28}$$

Over a half GPS satellite orbit of typical duration:

$$T_{\frac{1}{2}} \simeq 4.3\times 10^{4}\,\mathrm{s} \tag{29}$$

this would correspond to a temporal variation of the order of:

$$\Delta\tau_{\frac{1}{2}} \sim T_{\frac{1}{2}} \times 2.6\times 10^{-9} \sim 1.1\times 10^{-4}\,\mathrm{s} \tag{30}$$

that is, approximately:

$$\Delta\tau_{\frac{1}{2}} \sim 0.11\,\mathrm{ms} \tag{31}$$

The peak-to-peak amplitude over a full orbit would therefore be of the order of:

$$\sim 0.22\,\mathrm{ms} \tag{32}$$

2.2.2 Experimental precision and local invariance

The estimates established above, in the cases of a galactic and then a solar background flux, both lead to the same conclusion.

In both situations, the expected orbital modulation of the clock rate is very large, reaching amplitudes of the order of a millisecond in the galactic case and hundreds of microseconds in the solar case.

Such an effect would be colossal for the GPS system. It would be immediately visible in clock comparisons and in navigation.

Even retaining a conservative hypothesis based on a simple solar background velocity, the expected effect would remain well above the experimental detection thresholds.

The performance of the GPS system allows a very precise estimation of the effects of variations in gravitational potential and velocity on the rate of on-board clocks.

In particular, the altitude variations of the satellites along their orbits, which are of the order of a few kilometres, induce measurable relativistic corrections at the level of a few nanoseconds per day.

These effects, linked to very small variations in the terrestrial gravitational potential and orbital velocity, are indeed observed and must be corrected with great precision to ensure the coherence of the navigation system.

This means that the GPS system is sensitive to relative rate variations of the order of:

$$\sim 10^{-14} \text{ to } 10^{-13} \tag{33}$$

corresponding to temporal offsets of the order of a nanosecond per day.

In this context, an orbital modulation of the order of:

$$\sim 10^{-4}\,\mathrm{s} \text{ to } 10^{-3}\,\mathrm{s} \tag{34}$$

such as that predicted in the presence of a background flux entering directly into local kinematics, would be gigantic.

Such an effect would exceed the system's detection thresholds by several orders of magnitude and would render its operation entirely incoherent.

Yet no modulation of this amplitude is observed experimentally.

One must therefore conclude that a large-scale uniform component of the flux of the energetic medium cannot intervene directly in local clock rate measurements. In other words, local phenomena must be invariant with respect to a uniform background flux shared by the entire Earth-satellite system.

This property is in agreement with the principle of relativity, according to which only the relative velocities between physical systems appear in observable laws, and no absolute velocity can be revealed by local experiments.

However, within the framework of the model considered, the existence of a structured energetic medium implies the existence of a privileged frame of reference, defined by the local state of that medium.

This model also rests upon the hypothesis of an absolute time, unique and common to the entire medium. This does not imply a uniformity in the rate of physical processes: their rate of evolution may be locally modulated by the state of the energetic medium, in particular by the gravitational potential and the structure of the flux. Clocks may thus slow down or speed up depending on their environment.

This slowing constitutes a local physical property of the medium, and not a consequence of the observer's state of motion. It does not reflect a relativity of time itself, but a modification of the processes used to measure it.

By contrast, special relativity introduces a proper time that depends on the observer's state of motion, leading to an explicit dependence of measured phenomena on the relative velocity.

A conceptual tension thus arises. On the one hand, the dynamics of the energetic medium seem to define an absolute structure of space and time, associated with a global flux and a universal temporality whose local manifestations may vary. On the other hand, experimental observations impose a local invariance that, under certain conditions, seems to prevent any direct detection of the background flux and confirms that only relative quantities enter into measurable phenomena.

How can one reconcile the existence of an absolute frame of reference and a universal time, whose local manifestations may be modulated, with the fact that, in certain experimental situations, such as in the GPS system, the observed phenomena exhibit an effective invariance in which only relative quantities seem to play a role?

It is precisely this question that must now be examined.

3 Kinematic reconstruction law in an absolute frame of reference

We place ourselves within a theoretical framework postulating the existence of an absolute frame of reference, identified with the aether. In this frame, the velocity of the observer $\vec{v}_o$ is assumed known and constitutes an intrinsic physical datum. Likewise, the velocity of the source $\vec{v}_s$ is defined relative to this aether.

However, the kinematic quantities accessible to the observer do not correspond directly to these absolute velocities. They result from a reconstruction process based on local measurements, themselves mediated by the propagation of signals within the energetic medium.

Thus, the observer never has direct access to $\vec{v}_s$, but reconstructs an apparent velocity $\vec{u}$ from observables such as propagation times and frequency shifts. This reconstruction process explicitly depends on the observer's own kinematic state within the absolute frame.

In other words, the velocity attributed to the source is a derived quantity, obtained from the processing of received signals, and not a primitive datum. It incorporates both the effect of the actual motion of the source and that of the observer's motion, as well as the propagation properties of the medium.

In this framework, the discrepancies between $\vec{u}$ and $\vec{v}_s$ do not reflect an actual modification of the source dynamics, but a systematic bias introduced by the process of measurement and reconstruction.

The objective of this section is to establish explicitly the relation connecting the true velocity of the source in the aether, $\vec{v}_s$, the absolute velocity of the observer, $\vec{v}_o$, and the apparent velocity $\vec{u}$ reconstructed by the observer, by identifying the physical mechanisms at the origin of this transformation.

3.1 Physical Methods of Positioning

Determining the position and velocity of an object relies, in practice, on indirect measurements based on local physical interactions. In all cases, these measurements involve either the use of material standards (rulers, clocks) or the analysis of signals propagated through the energetic medium.

In modern positioning systems such as GPS, distance measurement is explicitly based on the propagation of electromagnetic signals. A distance is then defined from a propagation time, assuming a propagation speed c. More precisely, the fundamental procedure is of the round-trip type: a signal is emitted, reflected, and received, and the distance is reconstructed via:

$$R = \frac{c}{2}\Delta t \tag{35}$$

where Δt is the measured round-trip time.

This point is essential: distance is not a directly measured quantity, but a quantity reconstructed from time and the propagation speed c. In other words, the operational length standard is derived from a temporal standard and the constant c.

Even when material standards are used, such as rulers or rigid structures, these do not constitute references independent of this mechanism. Their physical definition actually rests on internal electromagnetic processes, whose properties are themselves constrained by the finite-speed propagation of interactions at speed c.

Operational equivalence between material standards and radar measurement. This equivalence can be made explicit for a separation parallel to the observer's motion. Let L_{abs} be an absolute separation. If the observer moves at speed v_o, their material standards are contracted by a factor $1/\gamma_o$. The length expressed in proper units is then $L_{\mathrm{mes}} = \gamma_o L_{\mathrm{abs}}$.

The same separation, measured by a radar procedure based on a round-trip time and expressed using the observer's proper clocks, leads to the same result. Indeed, the total absolute time is:

$$t_{\mathrm{tot}} = \frac{L_{\mathrm{abs}}}{c - v_o} + \frac{L_{\mathrm{abs}}}{c + v_o} = \frac{2c\, L_{\mathrm{abs}}}{c^2 - v_o^2} \tag{36}$$

and the local time measured by the observer is $\tau_{\mathrm{tot}} = t_{\mathrm{tot}}/\gamma_o$. The reconstructed radar distance is therefore:

$$L_{\mathrm{radar}} = \frac{c}{2}\tau_{\mathrm{tot}} = \frac{c^2}{\gamma_o\,(c^2 - v_o^2)} L_{\mathrm{abs}} = \frac{1}{\gamma_o\left(1 - \dfrac{v_o^2}{c^2}\right)} L_{\mathrm{abs}} = \gamma_o L_{\mathrm{abs}} \tag{37}$$

which coincides with the length obtained using material standards. The two procedures are therefore operationally equivalent.

Thus, material standards implicitly incorporate the effects related to the propagation of interactions in the energetic medium. The length contraction and clock slowing induced by the state of motion in this medium modify these standards in such a way that they remain consistent with distances defined by radar-type measurements.

A fundamental point follows: the two approaches, based respectively on material standards and on propagation measurements, are not independent. They actually rest on the same underlying physical structure, governed by the propagation speed c.

The effects introduced by finite signal propagation in radar methods appear, in integrated form, in the very properties of material standards. Conversely, the deformations of these standards compensate for the biases arising from propagation in measurement procedures.

Consequently, the reconstructed quantities (distances, durations, velocities...) are identical regardless of the method employed. It is therefore legitimate, in what follows, to make no explicit distinction between procedures based on material standards and those based on radar measurements.

In other words, any result established within the framework of a reconstruction based on signal propagation remains valid in a framework where distances are measured using material standards, since the latter already incorporate the relevant physical effects.

In this context, the observer never has direct access to the actual position or velocity of an object. They measure intermediate observables, such as propagation times, phases, or frequency shifts, from which they reconstruct a kinematic state.

The quantities thus obtained are therefore not primitive data, but the result of a reconstruction process that depends both on the propagation medium and on the kinematic state of the observer.

3.2 Analogy with Human Perception

This reconstruction scheme has a direct analogy with human perception.

When an individual observes their environment, they do not have direct access to objects themselves, but to sensory signals — in particular light signals — that have been propagated to them.

The brain then reconstructs a representation of the world from these signals. Distance is estimated from binocular convergence and perspective, motion is inferred from temporal variations, and velocities are assessed from optical flow.

Thus, the perceived quantities are not raw data, but the result of processing based on an implicit assumption concerning the propagation of light signals.

Analogously, in positioning systems, radio and laser ranging methods, as well as GNSS systems such as GPS, reconstruct position and velocity from received signals. Propagation time is used to estimate distances, while Doppler shifts provide access to apparent velocities.

In both cases, this is a reconstruction process based on a propagation assumption. In humans, this assumption is integrated in a biological and unconscious manner. In measurement systems, it is explicitly encoded in the models used.

An essential point is that this reconstruction depends on the observer's state. In visual perception, the observer's motion modifies the optical flow and influences the estimation of trajectories. Likewise, in positioning systems, the observer's motion directly enters into the interpretation of signals.

Thus, within the framework of an absolute reference frame, the observer's velocity $\vec{v}_o$ constitutes a structuring parameter of the reconstruction process. It conditions the way in which signals are interpreted and, consequently, the apparent velocity $\vec{u}$ attributed to the source.

This analogy highlights a fundamental point: the kinematic quantities that are accessible are not intrinsic properties directly observed, but constructions arising from a reconstruction process.

It is precisely this dependence on the propagation medium and on the observer's state that the kinematic reconstruction law aims to formalise.

3.3 The kinematic reconstruction law

We seek to establish the apparent velocity $\vec{u}$ attributed by an observer to a source of true velocity $\vec{v}_s$ in the absolute aether frame, when the observer themselves possesses a known absolute velocity $\vec{v}_o$.

The guiding idea is as follows. The observer does not have direct access to the true trajectory of the source in the aether. They reconstruct this trajectory from received signals, using their own clocks and their own spatial standards. The apparent velocity therefore results from a ratio between a reconstructed distance and a reconstructed time.

3.3.1 Decomposition of the true velocity of the source

We introduce the unit vector aligned with the absolute velocity of the observer:

$$\hat{e}_o = \frac{\vec{v}_o}{v_o} \tag{38}$$

The true velocity of the source is then decomposed into a component parallel to $\vec{v}_o$ and a component perpendicular to it:

$$\vec{v}_s = \vec{v}_{s\parallel} + \vec{v}_{s\perp} \tag{39}$$

with

$$\vec{v}_{s\parallel} = (\vec{v}_s \cdot \hat{e}_o)\,\hat{e}_o \qquad \text{and} \qquad \vec{v}_{s\perp} = \vec{v}_s - \vec{v}_{s\parallel} \tag{40}$$

Over an infinitesimal interval of absolute time dt, the true displacement of the source in the aether is:

$$d\vec{r}_s = \vec{v}_s\,dt \tag{41}$$

and therefore

$$d\vec{r}_s = d\vec{r}_{s\parallel} + d\vec{r}_{s\perp} \tag{42}$$

with

$$d\vec{r}_{s\parallel} = \vec{v}_{s\parallel}\,dt \qquad \text{and} \qquad d\vec{r}_{s\perp} = \vec{v}_{s\perp}\,dt \tag{43}$$

3.3.2 Longitudinal relative displacement

During the same interval dt, the observer moves in the aether by:

$$d\vec{r}_o = \vec{v}_o\,dt \tag{44}$$

The true longitudinal separation between the source and the observer therefore evolves as:

$$\boxed{d\vec{r}_{\parallel}^{\,\mathrm{rel}} = d\vec{r}_{s\parallel} - d\vec{r}_o = (\vec{v}_{s\parallel} - \vec{v}_o)\,dt} \tag{45}$$

It is this true longitudinal displacement that forms the basis for the reconstruction of the parallel component.

3.3.3 Time reconstruction bias

The observer does not have direct access to the absolute time of events associated with the source. Dating relies on physical processes internal to the systems under consideration, which serve as effective clocks.

Within the framework of the energetic medium model, the propagation of interactions at finite speed c imposes a dynamical reorganisation of the electromagnetic field of moving systems. This redistribution alters the local conditions of equilibrium and propagation of the electromagnetic interactions that ensure, at the microscopic scale, the cohesion and functioning of material systems.

Consequently, the internal physical processes that serve as the basis for time measurement see their rate adjusted as a function of this field structure. The slowing of clocks thus appears as a dynamical consequence of the state of the energetic medium, and not as an intrinsic property of time itself.

As established, it follows that the observer's clocks, moving at velocity $\vec{v}_o$, do not measure the absolute time dt, but a local time:

$$\boxed{d\tau_o = \frac{dt}{\gamma_o} \qquad \text{with} \qquad \gamma_o = \frac{1}{\sqrt{1-\frac{v_o^2}{c^2}}}} \tag{46}$$

In other words, for the same interval of absolute time dt defined in the frame of the medium, the observer's clock accumulates a shorter local time interval $d\tau_o$. Its rate is therefore slowed relative to that of a clock co-moving with the medium.

To this intrinsic effect is added a second mechanism, linked to the reconstruction of distant events. The observer accesses these events only through signals propagated at finite speed in the medium. This reconstruction introduces a systematic bias of physical origin, distinct from the slowing of clocks.

Framework and notation. We place ourselves in the absolute rest frame of the medium, in which signals propagate isotropically at speed c. A source S moves at velocity $\vec{v}_s$ and an observer O at velocity $\vec{v}_o$.

The source emits two successive events:

$$E_1 = (t_1, \vec{r}_1) \qquad \text{and} \qquad E_2 = (t_1 + dt, \vec{r}_1 + d\vec{r}_s) \tag{47}$$

with

$$d\vec{r}_s = \vec{v}_s \, dt \tag{48}$$

The positions $\vec{r}_s$ and $\vec{r}_o$ denote coordinates in the absolute frame. The distance used in the dating procedure is a reconstructed radar distance, defined below.

Propagation asymmetry induced by motion. The observer O dates event E_1 via a round-trip procedure: he emits a signal toward the source, received at E_1, which is immediately re-emitted back toward him.

The closing speed denotes the relative speed between the signal and the observer projected onto the propagation direction $\hat{n}$. It equals $c - \vec{v}_o \cdot \hat{n}$ on the outward leg and $c + \vec{v}_o \cdot \hat{n}$ on the return leg.

To avoid any ambiguity, one must distinguish:

- the **simultaneous absolute distance** R_{abs} between source and observer in the absolute frame,
- the **reconstructed radar distance** R, defined operationally from the round-trip travel time measured by the observer.

In the absolute frame, if R_{abs} denotes the instantaneous separation projected along $\hat{n}$, the exact propagation times are:

$$t_{\text{out}} = \frac{R_{\text{abs}}}{c - \hat{n} \cdot \vec{v}_o} \tag{49}$$

$$t_{\text{ret}} = \frac{R_{\text{abs}}}{c + \hat{n} \cdot \vec{v}_o} \tag{50}$$

The exact asymmetry between the two legs is then:

$$\Delta t = t_{\text{out}} - t_{\text{ret}} = R_{\text{abs}} \frac{2\,\hat{n} \cdot \vec{v}_o}{c^2 - (\hat{n} \cdot \vec{v}_o)^2} \tag{51}$$

The reconstructed radar distance is now defined as:

$$\boxed{R = \frac{c}{2}\,(t_{\text{out}} + t_{\text{ret}})} \tag{52}$$

Substituting the exact expressions for t_{out} and t_{ret}:

$$R = \frac{c}{2} \left(\frac{R_{\text{abs}}}{c - \hat{n} \cdot \vec{v}_o} + \frac{R_{\text{abs}}}{c + \hat{n} \cdot \vec{v}_o} \right) = R_{\text{abs}} \frac{c^2}{c^2 - (\hat{n} \cdot \vec{v}_o)^2} \tag{53}$$

The asymmetry between the two legs can then be rewritten exactly as:

$$\boxed{\Delta t = \frac{2R\,(\hat{n} \cdot \vec{v}_o)}{c^2}} \tag{54}$$

where R denotes the radar distance reconstructed by the observer, not the simultaneous absolute distance in the rest frame of the medium.

If the observer applies the symmetric round-trip convention, he dates the event at the midpoint of the interval measured by his clock, implicitly assuming $t_{\text{out}} = t_{\text{ret}}$.

However, $t_{\text{out}} > t_{\text{ret}}$ whenever $\hat{n} \cdot \vec{v}_o > 0$. The signal therefore takes longer to reach the source than to return to the observer, which introduces an asymmetry in the propagation times and leads to an underestimation of the true time of the event.

The propagation times satisfy:

$$t_{\text{out}} = \frac{t_{\text{tot}}}{2} + \frac{\Delta t}{2} \qquad t_{\text{ret}} = \frac{t_{\text{tot}}}{2} - \frac{\Delta t}{2} \tag{55}$$

Since the event is dated at the midpoint of the round-trip interval, the error corresponds to the discrepancy between t_{out} and $\frac{t_{\text{tot}}}{2}$. The synchronisation error is then:

$$\boxed{\delta t_{\text{sync}} = \frac{\Delta t}{2} = \frac{R\,(\hat{n} \cdot \vec{v}_o)}{c^2}} \tag{56}$$

This error arises directly from the motion of the observer through the energetic medium, which constitutes the support for signal propagation. It cannot be eliminated by any local procedure relying solely on such signals.

The absolute time of the event is therefore greater than the time assigned by the observer. This positive bias must be subtracted from the absolute time in order to define the reconstructed time, which incorporates the dating error induced by the finite propagation of the signal and the motion of the observer.

Thus, accounting for the factor γ_o, which corrects for the time dilation of the observer's clocks as defined previously (46), the reconstructed time in the observer's frame is obtained from local measurements via:

$$\boxed{t_{\text{rec}} = \gamma_o\,(t - \delta t_{\text{sync}})} \tag{57}$$

Since the observer's clock runs slow by a factor $1/\gamma_o$, external processes appear accelerated when expressed in the observer's proper time units. This rescaling introduces a factor γ_o into the expression for the reconstructed time.

The factor γ_o therefore does not reflect a physical acceleration of phenomena, but rather a conversion between absolute time and the time reconstructed from a slowed clock.

Synchronisation bias along the source's displacement. Between events E_1 and E_2, the source moves by $d\vec{r}_s$. The reconstructed radar distance R and the direction $\hat{n}$ both vary during this motion, which induces a change in the synchronisation bias.

From (57), the expression for the reconstructed time over an infinitesimal interval follows:

$$\boxed{dt_{\text{rec}} = \gamma_o\,(dt - \delta t_{\text{bias}})} \tag{58}$$

with

$$\delta t_{\text{bias}} = d(\delta t_{\text{sync}}) \tag{59}$$

The synchronisation bias is written, as a function of the reconstructed position of the distant event:

$$\delta t_{\text{sync}} = \frac{\vec{v}_o \cdot \vec{R}}{c^2} \tag{60}$$

where $\vec{R} = R\hat{n}$ is the reconstructed radar position vector.

The variation of this bias is obtained by differentiation:

$$d(\delta t_{\text{sync}}) = \frac{\vec{v}_o \cdot d\vec{R}}{c^2} \tag{61}$$

Within the infinitesimal framework considered here, the variation of the reconstructed position coincides with the variation of the source event's position projected along the line of sight. For a fixed observer, one therefore identifies:

$$d\vec{R} = d\vec{r}_s \tag{62}$$

This gives:

$$d(\delta t_{\text{sync}}) = \frac{\vec{v}_o \cdot d\vec{r}_s}{c^2} \tag{63}$$

The differential reconstruction bias for time is finally identified as:

$$\boxed{\delta t_{\text{bias}} = d(\delta t_{\text{sync}}) = \frac{\vec{v}_o \cdot d\vec{r}_s}{c^2}} \tag{64}$$

This quantity represents the elementary change in the dating bias induced by the displacement of the source. It depends only on the scalar product between the observer's velocity and the source's displacement, which ensures the geometric consistency of the dating procedure.

This result is a scalar, independent of the choice of a preferred direction, which guarantees the geometric coherence of the dating procedure.

Expression of the reconstructed time. Starting from the expression (58) of the reconstructed time over an infinitesimal interval, and substituting (64), one has:

$$dt_{\text{rec}} = \gamma_o \left(dt - \frac{\vec{v}_o \cdot d\vec{r}_s}{c^2} \right) \tag{65}$$

Using $d\vec{r}_s = \vec{v}_s \, dt$, one finally obtains:

$$\boxed{dt_{\text{rec}} = \gamma_o \, dt \left(1 - \frac{\vec{v}_s \cdot \vec{v}_o}{c^2} \right)} \tag{66}$$

The time attributed to events, denoted dt_{rec}, corresponds to a reconstruction of the time of distant events from the observer's local measurements. It thus results from the combination of two distinct effects:

- the intrinsic slowing of material processes, which leads to a modification of the rate of the observer's clocks
- the reconstruction bias induced by the asymmetry of signal propagation for an observer in motion within that same medium

3.3.4 Spatial reconstruction bias

The spatial reconstruction differs depending on whether one considers the direction parallel or perpendicular to $\vec{v}_o$.

Parallel component. The reconstruction of the longitudinal component is based on the true relative displacement between the source and the observer, defined in the absolute frame of the energetic medium. As established previously in equation (45), this displacement is:

$$d\vec{r}_{\parallel}^{\,\text{rel}} = (\vec{v}_{s\parallel} - \vec{v}_o)\, dt \tag{67}$$

This quantity describes the effective evolution of the longitudinal separation in the medium's frame. It constitutes the basic physical quantity underpinning the reconstruction.

However, the observer does not have direct access to this true distance. Length measurements are performed using material standards whose properties depend on their absolute state of motion within the energetic medium.

The finite propagation of electromagnetic interactions imposes an anisotropic reorganisation of the cohesive fields of matter. This reorganisation modifies the internal equilibrium distances and leads to a contraction of lengths along the direction of absolute motion.

Thus, the observer's standards are longitudinally contracted by a factor of $1/\gamma_o$ in the frame of the medium. Consequently, the same true distance parallel to the motion corresponds to a greater number of the observer's own length units.

It follows that the true longitudinal displacement is reconstructed with a factor γ_o when expressed in the observer's own standards:

$$\boxed{d\vec{r}_{\parallel}^{\,\text{rec}} = \gamma_o\, d\vec{r}_{\parallel}^{\,\text{rel}} = \gamma_o(\vec{v}_{s\parallel} - \vec{v}_o)\, dt} \tag{68}$$

The factor γ_o thus appears as a direct consequence of the length contraction of the observer's standards in the direction of their absolute motion, and not as a geometric artefact introduced after the fact.

Perpendicular component. By construction, the perpendicular component is defined as being orthogonal to $\vec{v}_o$. The observer's displacement is:

$$d\vec{r}_o = \vec{v}_o\, dt \tag{69}$$

and is therefore strictly collinear with $\vec{v}_o$. It therefore has no component perpendicular to this direction:

$$d\vec{r}_{o\perp} = \vec{0} \tag{70}$$

It follows that, unlike the longitudinal case, there is no transverse relative displacement between the source and the observer linked to the latter's motion. The perpendicular component of the relative displacement therefore coincides directly with that of the source:

$$d\vec{r}_{\perp}^{\,\text{rel}} = d\vec{r}_{s\perp} \tag{71}$$

Furthermore, within the framework of the model, length contraction only affects the direction parallel to the absolute motion. Perpendicular dimensions remain unchanged, so the observer's standards undergo no modification in that direction.

There is therefore neither kinematic nor metric correction to the transverse component. One obtains directly:

$$\boxed{d\vec{r}_{\perp}^{\,\text{rec}} = d\vec{r}_{s\perp} = \vec{v}_{s\perp}\,dt} \tag{72}$$

3.3.5 Apparent velocity components

By definition, the reconstructed apparent velocity is the ratio of the reconstructed displacement to the reconstructed time.

For the parallel component, using (68) and (66), one obtains:

$$\vec{u}_{\parallel} = \frac{d\vec{r}_{\parallel}^{\,\text{rec}}}{dt_{\text{rec}}} = \frac{\gamma_o(\vec{v}_{s\parallel} - \vec{v}_o)\,dt}{\gamma_o\,dt\left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)} \tag{73}$$

hence

$$\boxed{\vec{u}_{\parallel} = \frac{\vec{v}_{s\parallel} - \vec{v}_o}{1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}}} \tag{74}$$

For the perpendicular component, using (72) and (66), one obtains:

$$\vec{u}_{\perp} = \frac{d\vec{r}_{\perp}^{\,\text{rec}}}{dt_{\text{rec}}} = \frac{\vec{v}_{s\perp}\,dt}{\gamma_o\,dt\left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)} \tag{75}$$

that is

$$\boxed{\vec{u}_\perp = \frac{\frac{1}{\gamma_o}\vec{v}_{s\perp}}{1 - \frac{\vec{v}_s \cdot \vec{v}_o}{c^2}}} \tag{76}$$

3.3.6 Final vector expression

The total apparent velocity is the sum of the parallel and perpendicular components:

$$\vec{u} = \vec{u}_\parallel + \vec{u}_\perp \tag{77}$$

Combining (74) and (76), one finally obtains:

$$\boxed{\vec{u} = \frac{\vec{v}_{s\parallel} - \vec{v}_o + \frac{1}{\gamma_o}\vec{v}_{s\perp}}{1 - \frac{\vec{v}_s \cdot \vec{v}_o}{c^2}}} \tag{78}$$

3.3.7 Immediate verifications

If the observer is at rest in the aether, $\vec{v}_o = \vec{0}$, then $\gamma_o = 1$ and the formula becomes:

$$\vec{u} = \vec{v}_s \tag{79}$$

which is consistent with the expected physical interpretation.

If the source is co-moving with the observer, $\vec{v}_s = \vec{v}_o$, then:

$$\vec{v}_{s\parallel} = \vec{v}_o \qquad \text{and} \qquad \vec{v}_{s\perp} = \vec{0} \tag{80}$$

hence

$$\vec{u} = \vec{0} \tag{81}$$

The observer therefore correctly reconstructs a stationary source when it shares the same absolute kinematic state.

Finally, if the source has only a component perpendicular to $\vec{v}_o$, one has $\vec{v}_{s\parallel} = \vec{0}$ and:

$$\vec{u} = \frac{-\vec{v}_o + \frac{1}{\gamma_o}\vec{v}_{s\perp}}{1} \tag{82}$$

which shows explicitly that the transverse component is reconstructed with a specific bias, governed by the factor $1/\gamma_o$, resulting from the coupling between temporal reconstruction and the decomposition of velocities.

3.3.8 Summary of kinematic reconstruction

This relation is not introduced as a primitive kinematic law. It results from the combination of several distinct physical mechanisms, all linked to the process of reconstruction from signals propagated through the medium:

1. the true longitudinal displacement between the source and the observer in the absolute frame, which fixes the structure of the parallel component
2. the contraction of lengths in the direction of absolute motion, which modifies the observer's spatial standards and introduces a correction factor into the reconstruction of the parallel component
3. the slowing of the observer's clocks, resulting from the internal dynamics of material systems in motion within the energetic medium
4. the temporal reconstruction bias, induced by the finite propagation of the signal and by the observer's motion during that propagation, which introduces a coupling between the source's displacement and the observer's kinematic state
5. the geometric dissymmetry between the directions parallel and perpendicular to $\vec{v}_o$, which reflects the fact that spatial reconstruction does not proceed isotropically in the observer's frame

The apparent velocity $\vec{u}$ is therefore not the true velocity of the source in the aether, but a reconstructed quantity. It does not constitute a primitive kinematic datum, but an effective relative velocity, emerging from the measurement process, which depends simultaneously on $\vec{v}_s$, $\vec{v}_o$, and the propagation properties of the medium.

In other words, $\vec{u}$ does not directly describe the motion of the source in the aether, but the motion as it is physically reconstructed by an observer immersed in that medium.

It incorporates:

- metric effects, linked to the modification of spatial standards through length contraction
- dynamical effects, linked to the slowing of the physical processes that define clocks
- propagation effects, linked to the finite speed of the signal and to the asymmetry of round-trip times

The final structure of the kinematic reconstruction law thus appears as the direct consequence of these physical mechanisms, and not as a fundamental geometric property of spacetime.

4 The invariance of observable laws as an emergent property of an absolute frame of reference

4.1 Time dilation as a differential reconstruction of rates

Within the framework of the energetic medium, time dilation, as it is termed in the geometric interpretation of relativity, corresponds here to a physical slowing of internal processes. It does not result from a measurement artefact, but from an actual modification of the internal dynamics of material systems induced by their motion within the medium.

More precisely, a clock does not measure an absolute time that is directly accessible, but the rate of an internal physical process. Comparing two clocks thus amounts to comparing two material dynamics, each being influenced by its kinematic state within the energetic medium.

The observer never has direct access to the rate of a distant clock. That rate is reconstructed from received signals, taking into account both the propagation time and the observer's kinematic state. It follows that the observed time dilation is not an absolute quantity, but a reconstructed one, dependent on the measurement process itself.

In this context, the difference in rate between a source and an observer manifests naturally as a frequency shift. The Doppler effect then appears as the direct expression of this rate asymmetry, combining both the kinematic effects of relative motion and the biases introduced by signal propagation.

Since frequency is defined as the inverse of a characteristic time interval, the ratio of frequencies can be interpreted directly as a ratio of temporal rates.

Denoting by $d\tau_s$ the local time interval separating two successive emissions in the source's frame, and by $d\tau_o$ the observer's local time interval between the reception of these same wavefronts, one has:

$$f_s = \frac{1}{d\tau_s} \qquad f_o = \frac{1}{d\tau_o} \tag{83}$$

One deduces immediately:

$$\frac{f_o}{f_s} = \frac{d\tau_s}{d\tau_o} \tag{84}$$

Thus, the ratio of observed frequencies directly measures the ratio of time intervals associated with the same physical process, as seen in the source's frame and in the observer's frame respectively.

4.2 The Doppler effect in the framework of the energetic medium

4.2.1 Identification of the observer's local time

Within the model, the observer does not directly measure absolute time, but reconstructs events from received signals. The reconstructed time dt_{rec}, defined in (66), is precisely the time expressed in the observer's own units, after correction for the slowing of their clocks and for the synchronisation bias induced by their motion in the medium.

It therefore constitutes the observer's effective measurement, and is identified directly with their local time:

$$d\tau_o = dt_{\mathrm{rec},o} \tag{85}$$

The emitted and received frequencies are thus:

$$f_s = \frac{1}{d\tau_s} = \frac{\gamma_s}{dt_s} \qquad \text{and} \qquad f_o = \frac{1}{d\tau_o} = \frac{1}{dt_{\mathrm{rec},o}} \tag{86}$$

4.2.2 Reconstructed interval between two emissions

Let $\hat{n}$ be the unit vector along the propagation direction of the wave, from the source toward the observer. The interval between two successive emissions in absolute time is dt_s. The observer reconstructs this interval via (66):

$$dt_{\mathrm{rec},s} = \gamma_o\, dt_s \left(1 - \frac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right) \tag{87}$$

This reconstructed time incorporates both the slowing of the observer's clocks and the synchronisation bias induced by the motion of the source in the medium.

4.2.3 Reconstructed interval between two receptions

Between the two successive emissions, the source has moved. From the observer's point of view, this displacement is described by the reconstructed velocity $\vec{u}$. Over the interval $dt_{\mathrm{rec},s}$, the source moves by $\vec{u}\, dt_{\mathrm{rec},s}$ in the observer's reconstructed frame.

The variation in distance along the propagation direction $\hat{n}$ is:

$$dR^{\mathrm{rec}} = -\vec{u} \cdot \hat{n}\; dt_{\mathrm{rec},s} \tag{88}$$

The negative sign reflects the fact that an approach of the source ($\vec{u} \cdot \hat{n} > 0$) shortens the distance and reduces the propagation time between two successive receptions.

The additional propagation time associated with this change in distance is dR^{rec}/c. The reconstructed interval between two receptions is therefore:

$$dt_{\mathrm{rec},o} = dt_{\mathrm{rec},s} + \frac{dR^{\mathrm{rec}}}{c} = dt_{\mathrm{rec},s} \left(1 - \frac{\vec{u} \cdot \hat{n}}{c}\right) \tag{89}$$

Substituting the expression for $dt_{\mathrm{rec},s}$:

$$dt_{\mathrm{rec},o} = \gamma_o\, dt_s \left(1 - \frac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right) \left(1 - \frac{\vec{u} \cdot \hat{n}}{c}\right) \tag{90}$$

4.2.4 Expression of the frequency ratio

The frequency ratio is:

$$\frac{f_o}{f_s} = \frac{d\tau_s}{d\tau_o} = \frac{d\tau_s}{dt_{\text{rec},o}} = \frac{dt_s/\gamma_s}{\gamma_o\, dt_s \left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)\left(1 - \dfrac{\vec{u} \cdot \hat{n}}{c}\right)} \tag{91}$$

that is:

$$\frac{f_o}{f_s} = \frac{1}{\gamma_s\, \gamma_o \left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)\left(1 - \dfrac{\vec{u} \cdot \hat{n}}{c}\right)} \tag{92}$$

It remains to simplify the factor $\gamma_s\, \gamma_o \left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)$. This factor can be expressed as a function of u starting from the norm of the reconstructed velocity. From the kinematic reconstruction law (74) and (76), one has:

$$u^2 = \frac{\left\|\vec{v}_{s\parallel} - \vec{v}_o\right\|^2 + \dfrac{1}{\gamma_o^2}\left\|\vec{v}_{s\perp}\right\|^2}{\left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)^2} \tag{93}$$

Expanding the numerator with $\left\|\vec{v}_{s\parallel} - \vec{v}_o\right\|^2 = v_{s\parallel}^2 + v_o^2 - 2\,\vec{v}_s \cdot \vec{v}_o$, $\dfrac{1}{\gamma_o^2} = 1 - \dfrac{v_o^2}{c^2}$, and grouping $v_{s\parallel}^2 + v_{s\perp}^2 = v_s^2$:

$$u^2 = \frac{v_s^2 + v_o^2 - 2\,\vec{v}_s \cdot \vec{v}_o - \dfrac{v_o^2\, v_{s\perp}^2}{c^2}}{\left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)^2} \tag{94}$$

One deduces:

$$1 - \frac{u^2}{c^2} = \frac{\left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)^2 - \dfrac{1}{c^2}\left(v_s^2 + v_o^2 - 2\,\vec{v}_s \cdot \vec{v}_o - \dfrac{v_o^2\, v_{s\perp}^2}{c^2}\right)}{\left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)^2} \tag{95}$$

Expanding the numerator and using $(\vec{v}_s \cdot \vec{v}_o)^2 = v_o^2\, v_{s\parallel}^2$, which gives $(\vec{v}_s \cdot \vec{v}_o)^2 + v_o^2\, v_{s\perp}^2 = v_o^2\, v_s^2$, one obtains:

$$1 - \frac{u^2}{c^2} = \frac{\left(1 - \dfrac{v_s^2}{c^2}\right)\left(1 - \dfrac{v_o^2}{c^2}\right)}{\left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)^2} = \frac{1}{\gamma_s^2\, \gamma_o^2 \left(1 - \dfrac{\vec{v}_s \cdot \vec{v}_o}{c^2}\right)^2} \tag{96}$$

Taking the square root:

$$\boxed{\gamma_s\,\gamma_o\left(1-\frac{\vec{v}_s\cdot\vec{v}_o}{c^2}\right)=\frac{1}{\sqrt{1-\dfrac{u^2}{c^2}}}} \tag{97}$$

Substituting into the expression for the frequency ratio:

$$\frac{f_o}{f_s}=\frac{1}{\gamma_s\,\gamma_o\left(1-\dfrac{\vec{v}_s\cdot\vec{v}_o}{c^2}\right)\left(1-\dfrac{\vec{u}\cdot\hat{n}}{c}\right)}=\frac{\sqrt{1-\dfrac{u^2}{c^2}}}{1-\dfrac{\vec{u}\cdot\hat{n}}{c}} \tag{98}$$

One finally obtains:

$$\boxed{\frac{f_o}{f_s}=\frac{\sqrt{1-\dfrac{u^2}{c^2}}}{1-\dfrac{\vec{u}\cdot\hat{n}}{c}}} \tag{99}$$

4.3 Analysis and physical scope of the result

4.3.1 Disappearance of absolute velocities

The result (99) is remarkable on several counts.

All dependences on $\vec{v}_s$, $\vec{v}_o$, and on any background velocity $\vec{V}_{\text{bg}}$ have disappeared. The observable depends only on the reconstructed apparent velocity $\vec{u}$, independently of any absolute frame of reference.

To understand this cancellation mechanism, recall that the absolute velocities of the source and observer may each be decomposed into a common contribution and a local contribution:

$$\vec{v}_s=\vec{V}_{\text{bg}}+\vec{v}_{s,\text{local}}\qquad \vec{v}_o=\vec{V}_{\text{bg}}+\vec{v}_{o,\text{local}} \tag{100}$$

The reconstructed velocity $\vec{u}$ is given by the kinematic reconstruction law:

$$\vec{u}=\frac{\vec{v}_{s\parallel}-\vec{v}_o+\dfrac{1}{\gamma_o}\vec{v}_{s\perp}}{1-\dfrac{\vec{v}_s\cdot\vec{v}_o}{c^2}} \tag{101}$$

where $\vec{v}_{s\parallel}$ and $\vec{v}_{s\perp}$ denote the components of $\vec{v}_s$ parallel and perpendicular to $\vec{v}_o$ respectively.

If source and observer share the same background velocity $\vec{V}_{\text{bg}}$, this velocity enters both $\vec{v}_s$ and $\vec{v}_o$ simultaneously, but cancels out in the reconstructed velocity $\vec{u}$. Indeed, as shown by the immediate verifications of the reconstruction law, if $\vec{v}_s=\vec{v}_o$, then $\vec{u}=\vec{0}$.

More generally, the structure of the reconstruction law guarantees that any component common to both systems disappears from the reconstructed quantity. The background velocity therefore leaves no signature in the final observable (99).

4.3.2 Special cases

Transverse case. If the relative velocity is perpendicular to the propagation direction, then $\vec{u} \cdot \hat{n} = 0$, and the law (99) becomes:

$$f_o = f_s \sqrt{1 - \frac{u^2}{c^2}} \tag{102}$$

The observed shift then arises solely from the relative slowing of rates, and depends exclusively on the relative velocity u, independently of any common background velocity.

Longitudinal case. If the relative velocity is collinear with the propagation direction, then $\vec{u} \cdot \hat{n} = \pm u$, and the law (99) becomes:

$$f_o = f_s \frac{\sqrt{1 - \frac{u^2}{c^2}}}{1 \mp \frac{u}{c}} = f_s \sqrt{\frac{1 \pm \frac{u}{c}}{1 \mp \frac{u}{c}}} \tag{103}$$

where the upper sign corresponds to approach and the lower sign to recession. One recovers the standard relativistic Doppler formula.

4.3.3 Coherence with the principle of relativity

The final form (99) is structurally identical to that obtained in special relativity. However, the two approaches differ fundamentally.

In special relativity, this expression is postulated as a direct consequence of Lorentz invariance and the constancy of the speed of light in all inertial frames.

In the framework presented here, it emerges as a consequence of the process of reconstructing kinematic quantities from signals propagated within a medium. The mechanisms at work are:

1. the slowing of the source's and observer's clocks, resulting from their absolute motion within the medium, which introduces the factors γ_s and γ_o
2. the synchronisation bias induced by the finite propagation of signals and the observer's motion, which introduces the factor $1 - \vec{v}_s \cdot \vec{v}_o / c^2$
3. the exact cancellation of these two contributions by the structure of the reconstruction law, which causes $\vec{u}$ to emerge as the sole relevant variable via (97)
4. the accounting of the source's displacement between two successive emissions, expressed in the observer's reconstructed frame, which introduces the geometric factor $1 - \vec{u} \cdot \hat{n} / c$

These four mechanisms operate simultaneously and combine so as to eliminate all traces of the individual absolute velocities. The result is a Doppler law that involves only the reconstructed relative velocity, in complete agreement with experimental observations.

4.4 Towards a reconciliation between absolute time and the dynamics of the medium

The framework developed in this work opens a new conceptual perspective: the compatibility between the existence of an absolute time, a privileged frame of reference, and the relativistic laws observed experimentally. This compatibility rests on a kinematic re-reading of phenomena, in which the effects traditionally interpreted as fundamental properties of spacetime emerge in reality from a dynamical interaction with a structuring energetic medium.

In this approach, relativistic transformations are no longer postulated as fundamental symmetries, but appear as effective consequences of the finite propagation of interactions within this medium. Clock retardation, length contraction, and generalised Doppler effects thus find a unified interpretation in terms of kinematic reconstruction of signals, dependent on the state of motion relative to the medium.

This reconstruction brings to light the existence of a systematic bias in the access to events, induced by the dynamics of the field and by the geometry of propagation. This bias masks the existence of an underlying absolute time, whilst producing laws that are invariant from the perspective of observers in relative motion. The result is a form of emergent invariance, not fundamental, but induced by the constraints of measurement.

This framework thus confers renewed credibility upon the hypothesis of an energetic medium, by giving it a precise operational role in the formation of observables. It is no longer a passive substrate, but a dynamic actor in the structuring of physical phenomena.

Furthermore, this approach opens a path for the exploration of new physical effects. In particular, kinematic reconstruction suggests the existence of fine corrections to the standard relativistic laws in regimes where the usual assumptions cease to be strictly valid. These potential deviations constitute accessible experimental signatures, allowing a direct test of the presence and properties of the medium.

To the best of my knowledge, such an approach, explicitly articulating absolute time, a privileged frame of reference, and apparent invariance via a mechanism of kinematic reconstruction, has not been developed in the literature in this form. It thus proposes an original conceptual framework, capable of renewing the analysis of the foundations of relativistic physics.

4.5 Cosmological evidence for a privileged frame of reference

A major observational element extends this analysis: the existence of the cosmic microwave background.

This fossil radiation, arising from the primordial universe, is observable today in all directions of space. Its most remarkable property is its near-perfect isotropy: the measured temperature is practically identical regardless of the direction of observation.

However, a dipole anisotropy of very small amplitude is observed with great precision. This anisotropy is naturally interpreted as a Doppler effect due to the motion of the observer relative to a frame in which the background radiation is isotropic.

This anisotropy corresponds to a relative temperature variation of the order of:

$$\frac{\Delta T}{T} \sim 10^{-3} \tag{104}$$

which, via the relativistic Doppler effect, indicates a velocity of the order of:

$$v \approx 370 \text{ km/s} \tag{105}$$

for the solar system relative to this cosmological frame.

There thus exists a particular frame satisfying:

$$T(\theta) = \text{constant} \tag{106}$$

in which the dipole component vanishes. This frame, defined operationally by the isotropy of the cosmic microwave background, constitutes a privileged frame of reference at the cosmological scale. It allows one to define an absolute velocity for astrophysical systems, including the Earth, the Sun, and the Galaxy.

This experimental finding introduces an element of global structure:

- it provides a physical definition of a state of rest at large scales
- it gives an operational meaning to the notion of absolute velocity within a cosmological setting
- it remains compatible with the local invariance of physical laws

The coexistence of these two aspects suggests a unified reading.

At the local scale, observables depend only on the reconstructed relative velocities, which guarantees the validity of the results of special relativity in all accessible experimental tests.

At the global scale, the existence of a propagation medium can define a privileged state of rest, accessible only through observations that integrate structures over very large scales.

In this perspective, the relativity of motion no longer corresponds to an absence of an absolute frame of reference, but to an intrinsic limitation of local measurement procedures. The mathematical structure of relativity, including the nonlinear composition of velocities and the Doppler law (99), then appears as a consequence of the interaction between:

- the finite propagation of signals in the medium
- the motion of the observer within this medium
- the mechanisms of reconstruction of physical quantities from received signals

Thus, the existence of an absolute frame of reference and the experimental validity of special relativity are no longer mutually exclusive, but are inscribed within a coherent description in which the observed laws emerge from the very conditions of their measurement.