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The vacuum as a form of turbulent fluid: Motivations, experiments, implications

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HIGHLIGHTS

- A new reading of the stochastic signal in present ether-drift experiments.
- This paper can have substantial implications for the interpretation of relativity.
- This paper can also have implications for the whole approach to complexity.

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ABSTRACT

Basic foundational aspects of both quantum theory and relativity might induce one to represent the physical vacuum as an underlying highly turbulent fluid. By explicit numerical simulations, we show that a form of statistically isotropic and homogeneous vacuum turbulence is entirely consistent with the present ether-drift experiments. In particular, after subtracting known forms of disturbances, the observed stochastic signal requires velocity fluctuations whose absolute scale is well described by the average Earth's motion with respect to the Cosmic Microwave Background. We emphasize that the existence of a genuine stochastic ether-drift could be crucial for the emergence of forms of self-organization in matter and thus for the whole approach to complexity.

1. Introduction

According to the original Einstein view [1], the vacuum could be regarded as trivially empty since Lorentz symmetry is an exact symmetry of nature. In a Lorentzian approach [2–4], on the other hand, there is an underlying form of ether and Lorentz symmetry, rather than being postulated from scratch, should be considered as an 'emergent' phenomenon. In spite of these deep conceptual differences, however, it is far from obvious how to distinguish experimentally between these two points of view. This type of conclusion was, for instance, already clearly expressed by Ehrenfest in his lecture 'On the crisis of the light ether hypothesis' (Leyden, December 1912) as follows: "So, we see that the ether-less theory of Einstein demands exactly the same here as the ether theory of Lorentz. It is, in fact, because of this circumstance, that according to Einstein's theory an observer must observe exactly the same contractions, changes of rate, etc. in the measuring rods, clocks, etc. moving with respect to him as in the Lorentzian theory. And let it be said here right away and in all generality. As a matter of principle, there is no experimentum crucis between the two theories". This can be understood since, independently of all interpretative aspects, the basic quantitative ingredients, namely Lorentz transformations, are the same in both formulations.

To understand this crucial aspect, one can use a very simple argument. Suppose that the basic Lorentz transformations, rather than originating from the relative motion of a pair of observers S' and S'', as in Einstein's relativity, might instead be

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associated with their *individual* velocity parameters $\beta' = v'/c$ and $\beta'' = v''/c$ relative to some preferred frame Σ [5–7]. Still, due to the fundamental group properties, the two frames S' and S'' would also be mutually connected by a Lorentz transformation with relative velocity parameter

$$\beta_{\rm rel} = \frac{\beta' - \beta''}{1 - \beta'\beta''} \equiv \frac{v_{\rm rel}}{c} \tag{1}$$

(we restrict for simplicity to one-dimensional motion). This would produce a substantial quantitative equivalence with Einstein's formulation for most standard experimental tests, where one just compares the relative measurements of a pair of observers. Hence, the importance of the ether-drift experiments where one attempts to measure an absolute velocity.

At the same time, if the velocity of light c_γ propagating in the various interferometers coincides with the basic parameter c entering Lorentz transformations, relativistic effects conspire to make undetectable the individual β', β'', ... This means that a null result of the ether-drift experiments should *not* be automatically interpreted as a confirmation of Special Relativity. As stressed by Ehrenfest, the motion with respect to Σ might remain unobservable, yet one could interpret relativity 'à la Lorentz'. This could be crucial, for instance, to reconcile faster-than-light signals with causality [8] and thus provide a different view of the apparent non-local aspects of the quantum theory [9].

However, to a closer look, is it really impossible to detect the motion with respect to Σ? This possibility, which was implicit in Lorentz's words [4] "...it seems natural not to assume at starting that it can never make any difference whether a body moves through the ether or not..", may induce one to re-consider the various issues and go deeper into the analysis of the ether-drift experiments.

After this general premise, the scope of this paper is threefold. First, in Section 2, after comparing with basic foundational aspects of both quantum physics and relativity, we will argue that the physical vacuum could be represented as a random medium, similar to an underlying turbulent fluid. Second, through Sections 3–5, we will show, by explicit numerical simulations, that a form of statistically isotropic and homogeneous vacuum turbulence is entirely consistent with the type of stochastic signal observed in the present ether-drift experiments. In particular, after subtracting known forms of disturbances, the observed signal is consistent with velocity fluctuations whose absolute scale is fixed by the average Earth's motion with respect to the Cosmic Microwave Background. A definite confirmation (or refutation) of this result should be obtained with the next generation of cryogenic experiments. Finally, in Section 6, in the conclusions, we will emphasize that the detection of a genuine stochastic ether-drift could also be crucial to understand the emergence of forms of self-organization in matter and thus for the whole approach to complexity. In this sense, the ultimate implications of this analysis could go far beyond the mere interpretation of relativity.

2. The physical vacuum as a form of turbulent fluid

In this section, we will list several different motivations that might induce to represent the vacuum as a form of random medium which resembles a turbulent fluid.

(i) One could start by recalling that at the dawn of the 20th century Lorentz symmetry was believed to emerge from an underlying ether represented, by Thomson, Fitzgerald and others, as an incompressible turbulent fluid (a vortex 'sponge') [10]. More recently, the turbulent-ether model has been re-formulated by Troshkin [11] (see also Refs. [12,13]) in the framework of the Navier–Stokes equation and by Saul [14] by starting from Boltzmann's transport equation. The main point of these hydrodynamic derivations is that, due to the energy which is locally stored in the turbulent motion, on a coarse-grained scale, a fluid can start to behave as an elastic medium and thus support the propagation of transverse waves whose speed c_γ coincides with the average speed $c \equiv c_{\rm turbulence}$ of the chaotic internal motion of the elementary fluid constituents.

In this sense, the basic phenomenon of turbulence provides a conceptual transition from fluid dynamics to a different realm of physics, that of elasticity.[1] This conclusion is also supported by the formal correspondence [16,17] (velocity potential vs. displacement, velocity vs. distortion, vorticity vs. density of dislocations, . . .) that can be established between various systems of dislocations in an elastic solid and vortex fields in a liquid. With this transition the parameter c acquires also the meaning of a *limiting* speed for moving dislocations. This is due to the behavior of their elastic energy which increases proportionally to $(1-v^2/c^2)^{-1/2}$. For this reason, dislocations have been considered as a possible model for ordinary matter, see e.g. Refs. [18–21].

This perspective is similar to starting from the basic equation that determines the mutual variations of the energy E and the linear momentum $\mathbf{p} = M\mathbf{v}$ of a body

$$\frac{{\rm d}E}{{\rm d}t} = \mathbf{v} \cdot \frac{{\rm d}(M\mathbf{v})}{{\rm d}t} \tag{2}$$

and allowing for a v^2-dependence in M (see e.g. Ref. [22]). This gives

$${\rm d}E = \frac{1}{2}M{\rm d}v^2 + v^2{\rm d}M. \tag{3}$$

[1] The origin of this concept could probably be searched in Hertz's mechanics [15] with his idea of microscopic, hidden motions whose kinetic energy is actually the source of the forms of potential energy that we observe in nature.