Studies in History and Philosophy of Modern Physics 55 (2016) 1–12

Contents lists available at ScienceDirect

Studies in History and Philosophy of Modern Physics

journal homepage: www.elsevier.com/locate/shpsb

Minkowski spacetime and Lorentz invariance: The cart and the horse or two sides of a single coin?

Pablo Acuña

Instituto de Filosofía, Pontificia Universidad Católica de Valparaíso, Avenida El Bosque 1290, 2530388 Viña del Mar, Chile

ARTICLE INFO

Article history:
Received 3 February 2016
Accepted 30 April 2016
Available online 3 June 2016

Keywords:
Lorentz invariance
Minkowski spacetime
Explanation
Theories of principle
Constructive theories
Spacetime ontology

ABSTRACT

Michel Janssen and Harvey Brown have driven a prominent recent debate concerning the direction of an alleged arrow of explanation between Minkowski spacetime and Lorentz invariance of dynamical laws in special relativity. In this article, I critically assess this controversy with the aim of clarifying the explanatory foundations of the theory. First, I show that two assumptions shared by the parties—that the dispute is independent of issues concerning spacetime ontology, and that there is an urgent need for a constructive interpretation of special relativity—are problematic and negatively affect the debate. Second, I argue that the whole discussion relies on a misleading conception of the link between Minkowski spacetime structure and Lorentz invariance, a misconception that in turn sheds more shadows than light on our understanding of the explanatory nature and power of Einstein's theory. I state that the arrow connecting Lorentz invariance and Minkowski spacetime is not explanatory and unidirectional, but analytic and bidirectional, and that this analytic arrow grounds the chronogeometric explanations of physical phenomena that special relativity offers.

When citing this paper, please use the full journal title *Studies in History and Philosophy of Modern Physics*

1. Introduction

Over the last decade, an interpretive debate about the explanatory nature of Einstein's special theory of relativity has developed. Janssen and Brown have driven it (Balashov & Janssen, 2003; Brown, 2003, 2005a, 2005b; Brown & Pooley, 2001, 2006; Janssen, 1995, 2002a, 2002b, 2009), and it has become a much-discussed issue in the philosophy of physics literature (e.g., Dorato & Felline, 2010, Felline, 2011, Frisch, 2011, Norton, 2008, Van Camp, 2011). The point in dispute concerns the direction of an alleged arrow of explanation between Minkowski spacetime structure and Lorentz invariance of physical laws: they argue about which is the cart and which is the horse. Harvey Brown affirms that Lorentz invariance explains the Minkowski structure of spacetime, whereas Janssen claims that the arrow of explanation points in the opposite direction, i.e., from Minkowski structure to Lorentz invariance:

> Our central disagreement [. . .] is a dispute about the direction of the arrow of explanation connecting the symmetries of Minkowski spacetime and the Lorentz-invariance of the dynamical laws governing systems in Minkowski spacetime. I argue that the spacetime symmetries are the *explanans* and that the Lorentz invariance of the various laws is the *explanandum*. Brown argues that it is the other way around (Janssen, 2009, 29).

The first goal of this article is to show that the dispute relies on a misleading overinterpretation of the relation between Minkowski structure and Lorentz invariance in special relativity, which in turn results in a misconception of the explanatory nature of Einstein's theory. I point out two problematic issues underlying the debate that have a significant negative import on its overall evaluation. More precisely, despite the authors' explicit comments to the contrary, I show that the discussion is knotted with the question of the ontology of spacetime: Janssen's view is connected to a form of substantivalism, whereas Brown's view assumes a form of relationism. I also show that the urgent demand for a constructive interpretation of special relativity that Janssen and Brown argue for is unjustified and unnecessary, and that it actually obscures our understanding of the explanatory nature and power of the theory.

E-mail address: pablo.acuna.l@pucv.cl

http://dx.doi.org/10.1016/j.shpsb.2016.04.002
1355-2198/

Second, I argue that rather than a debate about what is the cart and what is the horse, the discussion between Brown and Janssen is an instance of the dispute about what was first, the egg or the chicken. I claim that Minkowski structure and Lorentz invariance need not be conceived in such a way that one must explain the other. Instead, they are better understood as the two sides of a single coin: the arrow between them is not explanatory, but *analytic* (in a sense that I explain below). Furthermore, I argue that this conception of the link between Lorentz invariance and Minkowski chronogeometry, unlike the conception that motivates the Janssen-Brown debate, sheds light on our understanding of the explanatory nature and power of special relativity. I claim that the aforementioned analytic connection between Minkowski structure and Lorentz grounds the explanatory foundations of Einstein's theory.

The structure of this article is the following. In Section 2, I provide an overview of the debate, paying special attention to the aspects that are most relevant for my critical assessment. In Section 3, I underscore two crucial assumptions endorsed by Brown and Janssen—that the discussion is independent of questions about spacetime ontology, and that the arrow of explanation at stake must be constructive—and I ponder about the justification that the authors offer (and implicitly assume) for them. In Section 4, I show that both these assumptions are problematic and unjustified, thus tainting the whole debate. In Section 5, I argue that Minkowski structure and Lorentz invariance are analytically linked, and that this link—that is not itself explanatory—clarifies the source of the chronogeometric explanations of physical phenomena that special relativity provides. In Section 6, I conclude and value the lessons that we can draw from Janssen's and Brown's arguments in the light of my present proposal.

2. The Janssen–Brown debate

The debate at issue concerns the direction of an alleged arrow of explanation between the structure of Minkowski spacetime and the Lorentz invariance of physical laws. Brown states that the latter explains the former, whereas Janssen asserts that the explanatory arrow goes from Minkowski structure to Lorentz invariance. In this section, I analyze both stances in turn.

2.1. Brown's interpretation

According to Harvey Brown, it is a widespread view in foundational studies on special relativity that dynamical aspects of the theory are explained by the structure of Minkowski spacetime. As an example, Brown (2005a, 24) quotes a passage in which Graham Nerlich provides an explanation of inertial motion given by the shape of Minkowski spacetime. Nerlich states that since a particle cannot be 'aware' of how all the rest of the objects behave, the fact that when the particle moves freely it follows a characteristic trajectory cannot be explained in relational terms. Thus, Nerlich argues, the physical underpinning of inertial motion must rely on the affine structure of Minkowski spacetime:

> Without the affine structure there is nothing to determine how the [free] particle trajectory should lie. It has no antennae to tell it where other objects are, even if there were other objects [. . .]. *It is because spacetime has a certain shape that world lines lie as they do* (Nerlich, 1976, 264).

Brown proposes two arguments against this view. First, he states that this line of thought is highly problematic from an ontological standpoint. Even if we take for granted that there is a self-standing spacetime endowed with a specific structure, it is deeply mysterious how physical objects can get to 'know' this structure, so that they can behave accordingly. Brown claims that Nerlich's view amounts to state that freely moving objects follow the ruts and grooves of spacetime, just as an iron ball follows the groove of an inclined plane. However, since spacetime is not a physical object like an inclined plane, there cannot be any guiding friction, so it is not comprehensible how spacetime can determine the trajectory of a freely moving object.[1]

Brown's second argument against the standard view is of a more logical vein. Even if we assume that there is a self-standing spacetime with a specific structure, it does not follow from this assumption that the dynamical symmetries of physical laws mirror such a structure:

> As a matter of logic alone, if one postulates spacetime structure as a self-standing, autonomous element in one's theory, it need have no constraining role on the form of the laws governing the rest of the theory's models. So how is its influence supposed to work? Unless this question is answered, spacetime cannot be taken to explain the Lorentz covariance of the dynamical laws (Brown & Pooley, 2006, 84).

Brown & Pooley are certainly right in this point. There is a historical example that illustrates that there is no guaranteed correspondence between spacetime structure and dynamical symmetries, namely, Lorentz's ether theory. The spacetime structure postulated by this theory is Newtonian, whereas the dynamical symmetries of physical laws are given by the Lorentz transformations (see Acuña, 2014; Janssen, 1995, chapter 3).

Considering the ontological and logical difficulties of the 'standard' view, Brown asserts that it is much more natural and plausible to conceive the link between Minkowski spacetime structure and Lorentz invariance in such a way that the latter explains the former. That is, Brown asserts that special relativistic spacetime has the structure it has because the symmetries of the dynamical laws that govern physical systems are the Lorentz transformations: "the appropriate structure is Minkowski geometry *precisely because* the laws of physics [. . .] are Lorentz covariant" (Brown & Pooley, 2006, 80).

A very important feature in Brown's interpretation, usually overlooked in the related literature, is that it is, in a sense, provisional. The physical underpinning of Lorentz invariance is not explicitly accounted for—in the current state of science—by a fundamental theory of matter. The most natural candidate to fulfill this task is quantum theory. However, in quantum field theory the Lorentz invariance of fundamental dynamical laws is written in by hand, it is not a *result* (cf. Hagar & Hemmo, 2013). Thus, quantum theory, in its current state of development, does not provide an explanation of Lorentz invariance at a fundamental level. This is why Brown describes his interpretation as *truncated*: although we

[1] Nerlich (2010) replies that Brown's is a parodical misrepresentation of his views. He openly rejects that spacetime causally explains inertial motion. Rather, Nerlich states that the kind of explanation involved is geometrical. He points out that straight trajectories, defined by the affine structure of Newtonian spacetime, constitute the default (force-free, zero acceleration) trajectories in classical physics. Thus, he argues, that a particle follows such a trajectory does not need a causal account in terms of forces or 'spacetime friction'—inertial motion is not caused. Nerlich's geometrical explanation relies on an identification: inertial motion *is* motion along a straight trajectory. The same explanation can be extrapolated to special and general relativity: default force-free trajectories *are* geodesic trajectories. Although this view is certainly much more nuanced than Brown's construal, it is still open to criticism from Brown's point of view. Nerlich's proposal assumes spacetime substantivalism, for he argues that the identification on which the geometric explanation relies is possible only by assuming that spacetime is real: "to parody Quine—no identities without entities. Only a realist can tell this story" (Nerlich, 2010, 186). Now, if spacetime with a particular structure stands in and by itself, one may wonder why the dynamics that governs the behavior of physical systems corresponds to such a structure (see Sections 3.1 and 4.1).