Studies in History and Philosophy of Modern Physics 59 (2017) 21–29

Contents lists available at ScienceDirect

Studies in History and Philosophy of Modern Physics

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

String dualities and empirical equivalence

Richard Dawid

Stockholm University Department of Philosophy, 10691 Stockholm, Sweden

A R T I C L E I N F O

Article history:
Received 1 June 2015
Received in revised form
9 June 2016
Accepted 20 June 2016
Available online 12 July 2016

Keywords:
String theory
Duality
Conventionalism
Empirical equivalence

A B S T R A C T

String dualities establish empirical equivalence between theories that often look entirely different with respect to their basic ontology and physical structure. Therefore, they represent a particularly interesting example of empirical equivalence in physics. However, the status of duality relations in string physics differs substantially from the traditional understanding of the role played by empirical equivalence. The paper specifies three important differences and argues that they are related to a substantially altered view on the underdetermination of theory building.

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

1. Introduction

The abundance of duality relations constitutes one of the most important and conspicuous characteristics of string physics. Dual theories are empirically equivalent to each other. They typically share one parameter (like a coupling constant or the radius of a compact dimension) whose value is inverted when switching from a theory to its dual. The same spectrum of values for observables can be found in both theories, but those observables may be interpreted in very different ways in the theory and its dual. Two kinds of string dualities, T-duality and S-duality, play a crucial role in connecting the 5 consistent types of superstring theory, thereby turning the spectrum of possible types of superstring theories into one unique coherent web of ‘perspectives’ on the same theory. Another very important exemplification of duality is the AdS/CFT correspondence first suggested in Maldacena (1998). This correspondence reaches out beyond string theory proper by relating a string theory on anti-de Sitter spacetime to a conformal field theory on the boundary of that spacetime. Remarkably, this duality relation implies the empirical equivalence of a theory that contains gravity (the string theory) and a theory without gravity (the conformal field theory). In recent years, a lot of work has been invested into attempts to generalize AdS/CFT correspondence to other contexts and maybe eventually move towards a general gauge-gravity duality in physics. One effect of ideas in that direction was the emergence of a new understanding of the relation between string theory and quantum field theory. Both are now increasingly perceived as one overall of closely related concepts which may find a full understanding only when viewed in conjunction.

By constituting the most conspicuous form in which empirical equivalence between theoretical descriptions is found in high energy physics today, duality relations arguably have led to a new view on the phenomenon of empirical equivalence in physics. Identifying empirical equivalence in the form of duality relations has turned into a crucial method for acquiring a deeper and more complete understanding of a fundamental physical theory. The present paper will look at the nature of the change of perspective that takes place when empirical equivalence starts being understood primarily in terms of duality relations. The analysis will rely on a specific historical interpretation of the view on empirical equivalence that was prevalent throughout most of the 20th century (presented in general terms in Section 2). Section 3 will relate that view to Henry Poincaré's conventionalism. The comparison of this ‘traditional view’ with the picture that emerges in the context of string dualities will demonstrate what is new about the duality based point of view on empirical equivalence (Sections 4 and 5). The corresponding shift will then be argued to be exemplary of a general change of the perspective on theory building that has emerged in connection with the evolution of string theory.

E-mail address: richard.dawid@philosophy.su.se

http://dx.doi.org/10.1016/j.shpsb.2016.06.002
1355-2198/

2. Empirical equivalence in physics

The view on empirical equivalence that is characteristic of 20th century physics has been shaped to a considerable degree by the 19th century rise of abstract mathematics, which turned out far richer and more diverse than anyone would have imagined a century earlier and led to a novel view of the role of mathematics in the description of physical phenomena.

At the beginning of the 19th century, mathematics was understood to provide a tool for representing and analyzing the quantitative aspects of observations in a way that relied on human intuitions about the world.[1] It was further taken for granted that micro-physical objects adhered to those basic intuitions as well. Neither the need nor the possibility was acknowledged that mathematics or fundamental physics should or could lead beyond the basic intuitions on which human perception of the everyday world relied. Those intuitions grasped the physical world in terms of solid objects or continua that were exactly located in 3 dimensional flat space and moved along a universal time axis. Mathematics was the tool for representing and parameterizing the dynamics of those objects. I shall call this view the classical intuitive view of physics.

The notion of a ‘classical intuitive view’ will be helpful in the following for describing the role of abstract mathematics in 19th and 20th century physics. The reasons for using this concept will only become fully clear in Section 4, however, where it will play a crucial role in characterizing the specific status of duality relations in string physics.

Needless to say, already pre-19th century concepts relied on abstractions. Newtonian mechanics, or Aristotelian physics, for that matter, are abstract conceptions which do involve what one may call unintuitive elements. The notion of a “classical intuitive view” is not based on a fictitious point zero of abstraction. By stating the intuitions about physical objects at a given point in time (roughly the early 19th century), it rather introduces a backdrop against which the gradient towards the increasingly unintuitive conceptualizations of later periods can be defined.

The 19th century saw a fundamental shift in the understanding of mathematics. New mathematical conceptualizations like complex analysis and curved and higher dimensional spaces suggested that mathematics was not merely a discipline that could represent human intuitions but was capable of transcending them. The deployment of abstract mathematics made physics reach out beyond the classical intuitive view. New mathematics allowed for representations of observed data that did not rely on the classical intuitions about the spatial structure and ontology of objects. Eventually, physical theories such as special and general relativity or quantum mechanics were developed that reached dramatically beyond the physical posits of classical physics.[2]

The described shift from ‘old’ to ‘new’ physics had a substantial effect on the understanding of what was physically possible. ‘Old’ physics had been based on the understanding that the intuition-based and seemingly unquestionable basic understanding of what the objects of this world were like strictly implied what was a physically possible phenomenon. On that basis, to give one example, Newton could understand his development of scientific theory as a “deduction from the phenomena”: for Newton, the data available at the time uniquely implied the true theoretical description and, on its basis, the character of future observations.

Contrary to that view, the new understanding that emerged based on the increasing richness of abstract mathematics and its growing role in physics suggested that physics could come up with an adequate mathematical reconstruction whenever strange deviations from the classical empirical expectations showed up. Driving this point of view to its radical conclusion, it became plausible to expect that any observational regularity pattern imaginable could be represented by some physical theory based on a sufficiently inventive use of modern mathematics. By accounting for observation patterns that had appeared paradoxical from a classical intuitive view, special relativity and quantum mechanics both appeared as exemplifications of that process. If physical conceptualization based on modern mathematics seemed flexible enough to reproduce any sort of observational regularity, however, there was no reason to assume that just one empirically adequate physical conceptualization was possible. It seemed more natural to expect a systematic underdetermination of physical theory building by empirical data. In other words, it seemed plausible to expect that typically several or many empirically equivalent theories could be constructed which all could accurately describe a given observed phenomenon.[3]

At this point, it is important to make some clarificatory remarks on the relation between the underdetermination of theory building and empirical equivalence. The main focus of this paper lies on the issue of full empirical equivalence of scientific theories. Theories are empirically equivalent if they have identical empirical implications. Underdetermination of theory building in this strong sense means that not even all data that could be collected in principle could fully determine theory building. One might also consider a weaker form of underdetermination, however, underdetermination of theory building under the available data. Underdetermination in this sense has been called “transient” underdetermination by Sklar (1975) and Stanford (2006) and scientific underdetermination in Dawid (2006, 2013). Scientific underdetermination does not imply the existence of fully empirically equivalent theories. It merely implies that there are theories between which one cannot decide based on the available data.

Dawid (2006, 2013) makes the point that assessments of scientific underdetermination play a crucial role in motivating trust in string theory in the absence of empirical confirmation. The analysis of empirical equivalence cannot, on its own, provide such reasons. This paper therefore has a different focus. It analyses issues related to the evolution and conceptual understanding of string physics, irrespectively of the question as to whether or not one has good reasons for take the theory to be viable. Still, it is important to point out that the two forms of underdetermination are related. The general conceptual arguments for the existence of empirically equivalent theories that have been stated at the beginning of this section speak also in favour of scientific underdetermination: if the flexibility of theory building can be expected to allow for constructing empirically fully equivalent theories, it may be expected even more strongly that it allows for the construction of theories that are empirically indistinguishable based on the available data. Therefore, important characteristics of the view on empirical equivalence can be nicely illustrated already at

---

[1] At a philosophical level, this understanding is for example represented by Kant's view on the synthetic a priori character of space and time.

[2] Note that we are interested in what physicists took to be the physical characteristics of the world. Increased mathematical abstraction such as the deployment of the Hamiltonian or Lagrangian formalism in classical mechanics does not per se constitute a development away from the classical intuitive view as long as the more abstract formalism is taken to deal with the same old physical objects. The boundaries between physical characteristics of the world and mathematical formalism become increasingly blurred, however, with the deployment of higher mathematics. Nothing in our analysis hinges on keeping up a strict distinction between the two sides.

[3] This doesn't mean that ‘old’ physics knew no cases of empirically equivalent theory building. One may just think of the Ptolemaic and the Copernican systems of planetary motion. In the following, however, we shall be mostly interested in the connection between empirical equivalence and the unintuitive developments in modern physics based on advanced mathematics.