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Space–time philosophy reconstructed *via* massive Nordström scalar gravities? Laws *vs.* geometry, conventionality, and underdetermination

J. Brian Pitts

Faculty of Philosophy, University of Cambridge, John Templeton Foundation grant #38761, United Kingdom

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ABSTRACT

What if gravity satisfied the Klein–Gordon equation? Both particle physics from the 1920–30s and the 1890s Neumann–Seeliger modification of Newtonian gravity with exponential decay suggest considering a "graviton mass term" for gravity, which is *algebraic* in the potential. Unlike Nordström's "massless" theory, massive scalar gravity is strictly special relativistic in the sense of being invariant under the Poincaré group but not the 15-parameter Bateman–Cunningham conformal group. It therefore exhibits the whole of Minkowski space–time structure, albeit only indirectly concerning volumes. Massive scalar gravity is plausible in terms of relativistic field theory, while violating most interesting versions of Einstein's principles of general covariance, general relativity, equivalence, and Mach. Geometry is a poor guide to understanding massive scalar gravity(s): matter sees a conformally flat metric due to universal coupling, but gravity also sees the rest of the flat metric (barely or on long distances) in the mass term. What is the 'true' geometry, one might wonder, in line with Poincaré's modal conventionality argument? Infinitely many theories exhibit this bimetric 'geometry,' all with the total stress–energy's trace as source; thus geometry does not explain the field equations. The irrelevance of the Ehlers–Pirani–Schild construction to a critique of conventionalism becomes evident when multi-geometry theories are contemplated. Much as Seeliger envisaged, the smooth massless limit indicates underdetermination of theories by data between massless and massive scalar gravities—indeed an unconceived alternative. At least one version easily could have been developed before General Relativity; it then would have motivated thinking of Einstein's equations along the lines of Einstein's newly re-appreciated "physical strategy" and particle physics and would have suggested a rivalry from massive spin 2 variants of General Relativity (massless spin 2, Pauli and Fierz found in 1939). The Putnam–Grünbaum debate on conventionality is revisited with an emphasis on the broad modal scope of conventionalist views. Massive scalar gravity thus contributes to a historically plausible rational reconstruction of much of 20th–21st century space–time philosophy in the light of particle physics. An appendix reconsiders the Malament–Weatherall–Manchak conformal restriction of conventionality and constructs the 'universal force' influencing the causal structure.

Subsequent works will discuss how massive gravity could have provided a template for a more Kant-friendly space–time theory that would have blocked Moritz Schlick's supposed refutation of synthetic *a priori* knowledge, and how Einstein's false analogy between the Neumann–Seeliger–Einstein modification of Newtonian gravity and the cosmological constant Λ generated lasting confusion that obscured massive gravity as a conceptual possibility.

1. Introduction

Plausibly, when one comes to recognize the historical contingency of hitherto apparently unavoidable ideas about the world, one can take a more critical attitude and rework one's beliefs to fit

E-mail address: jbp25@cam.ac.uk

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evidence and argument more fully. Mach's historical-critical investigations in physics exemplified that idea. More formally, it is plausible that the order in which one receives pieces of evidence ought not to affect one's final degrees of belief (Wagner, 2002), a criterion for avoiding one sort of historical accident. Failure of imagination can lead to our not entertaining theories that are comparably good to the ones that we did entertain; such unconceived alternatives undermine scientific realism (Stanford, 2006). In the interest of freeing ourselves from historical accidents regarding space–time theory, it is prudent, therefore, to employ whatever systematic means exist for generating plausible alternative theories.

Fortunately, there is a largely untapped source here, namely, the literature that studies all possible classical (*i.e.* not quantum) relativistic wave equations. That literature has gone untapped for a number of reasons, including a superficially quantum vocabulary. That literature is particle physics, of which Wigner's taxonomy of relativistic wave equations in terms of mass and spin (Wigner, 1939) is a prominent example. The terms "mass" and "spin," which misleadingly suggest concepts appropriate to quantum particles rather than relativistic waves, exemplify the vocabulary issue, on which more below. While space–time physics ought to be quantization-ready in the sense of recognizing that electrons and other fermions exist (though not much like light and gravity, the usual stars of space–time philosophy Pitts, 2012) and that classical theories are not the last word, this paper's use of particle physics literature will be entirely as a resource for classical relativistic fields and the space–time philosophy thereof.

In the 1910s Gunnar Nordström proposed a theory of gravity that met the strictures of Special Relativity (Bergmann, 1956; Norton, 1992; Renn & Schemmel, 2007; von Laue, 1917) in the sense of having, at least, Lorentz transformations as well as space- and time-translations as symmetries, and displaying retarded action through a field medium, as opposed to Newtonian instantaneous action at a distance. This use of the 10-parameter Poincaré symmetry group reflects a Kleinian subtractive strategy of gradually depriving coordinates of physical meaning *via* symmetries, as opposed to a Riemannian additive strategy (Norton, 1999b). There is a larger group of potential symmetries that one might contemplate, namely, the Bateman–Cunningham 15-parameter conformal group (Bateman, 1909, 1910; Cunningham, 1910); Nordström's theory, which is massless spin 0 in terms of particle physics, is invariant under that group, whereas massive theories are strictly Poincaré-invariant. Nordström's scalar gravity was a serious competitor to Einstein's program for some years during the middle 1910s. Neglecting time dependence and nonlinearity, it gives Poisson's equation just as Newton's theory does. Nordström's theory was eclipsed first by the theoretical brilliance of Einstein's much more daring project and the latter's better treatment of Mercury in 1915 (though a "dark matter" patch might have been possible), and then by the empirical success of Einstein's theory in the bending of light in 1919, a result manifestly inconsistent with Nordström's theory.

It is well known that Nordström's theory does not bend light (Kraichnan, 1955). That is an immediate consequence of the conformal flatness of the metric in Nordström's theory in geometrical form (Einstein & Fokker, 1914) and the conformal invariance of Maxwell's electromagnetism (Wald, 1984): space–time is flat in Nordström's theory except for the volume element, but light doesn't see the volume element in Maxwell's theory in 4 space–time dimensions.

While representing gravity primarily by a scalar field is no longer a viable physical proposal, there is a great deal that can be learned, surprisingly, by filling in a hole left by the premature abandonment of Nordström's scalar gravity theory due to Einstein's inventing General Relativity (GR) 'too soon.' While it is evident to particle physicists that Einstein's theory would have arisen eventually without Einstein (see, *e.g*, Feynman et al., 1995), Hans Ohanian, author of a General Relativity textbook (Ohanian & Ruffini, 1994) and not a particle physicist, has been prepared to offer, along with some vigorous opinions, even a fairly specific date:

> … [I]f Einstein had not introduced the mistaken Principle of Equivalence and approached the theory of general relativity via this twisted path, other physicists would have discovered the theory of general relativity some twenty years later, via a path originating in relativistic quantum mechanics. (Ohanian, 2008, p. 334).

Personally I can imagine it perhaps taking as long as 30 years, but one mustn't be too particular about dates in counterfactual history. In any case the task at hand is to learn what could have been learned in the intervening 20–30 years of that counterfactual history *before* Einstein's equations were found. Scalar gravity has the disadvantage of having been empirically falsified in 1919, but that isn't as bad as it sounds—witness the ongoing reflections on scalar gravity by physicists, often with no particular philosophical or historical interests (Alcántara Félix, Calogero, & Pankavich, 2014; Calogero, 2003; Calogero & Rein, 2004; Deruelle, 2011; Deruelle & Sasaki, 2011; Dowker, 1965; Garrett, 2011; Girelli, Liberati, & Sindoni, 2009; Gursey, 1953; Harvey, 1965; Littlewood, 1953; Manrique & Reuter, 2010; Pietenpol & Speiser, 1972; Romero, Fonseca-Neto, & Pucheu, 2012; Shapiro & Teukolsy, 1993; Sundrum, 2004; Watt & Misner, 1999; Wellner & Sandri, 1964; Yo, Baumgarte, & Shapiro, 2001).

Thinking seriously about scalar gravity helps one to separate the wheat from the chaff in Einstein's arguments. For example, as early as 1907 Einstein concluded that a relativistic field theory of gravity could not describe gravity with a scalar potential. In the common sympathetic Einstein historiography, this conclusion is often presented as a result, or at least isn't challenged. As it happens, Einstein's argument was wrong (Giulini, 2008):

> On his way to General Relativity, Einstein gave several arguments as to why a special-relativistic theory of gravity based on a massless scalar field could be ruled out merely on grounds of theoretical considerations. We re-investigate his two main arguments, which relate to energy conservation and some form of the principle of the universality of free fall. We find such a theory-based *a priori* abandonment not to be justified. Rather, the theory seems formally perfectly viable, though in clear contradiction with (later) experiments. (Giulini, 2008)

Einstein here seems to have made a lucky mistake, a habit to which Ohanian calls attention.

> HOW MUCH OF AN ADVANTAGE did Einstein gain over his colleagues by his mistakes? Typically, about ten or twenty years. (Ohanian, 2008, p. 334, *sic*)

There would have been much less reason to consider a tensor theory of gravity so early without erroneous arguments against scalar gravity.

Giulini illustrates two important themes: both the *a priori* plausibility of a graviton mass (to borrow quantum terms for a classical context) and the haste in which the idea is typically eliminated on narrowly empirical grounds, as though nothing conceptually interesting lay in the possibility of a small but nonzero graviton mass.

> In modern terminology, a natural way to proceed would be to consider fields according to mass and spin, [footnote suppressed] discuss their possible equations, the inner consistency of the mathematical schemes so obtained, and finally their