Advances in Historical Studies, 2016, 5, 240-253
http://www.scirp.org/journal/ahs
ISSN Online: 2327-0446
ISSN Print: 2327-0438

Equivalence Principle and Ether: Two Revolutionary Kernels of Einstein's General Relativity

Salvo D'agostino

University "Sapienza", Rome, Italy
Email: saldagostino21@gmail.com

How to cite this paper: D'agostino, S. (2016). Equivalence Principle and Ether: Two Revolutionary Kernels of Einstein's General Relativity. *Advances in Historical Studies, 5,* 240-253.
http://dx.doi.org/10.4236/ahs.2016.55019

Received: July 26, 2016
Accepted: December 27, 2016
Published: December 30, 2016

Abstract

Einstein's discovery of the Equivalence Principle is to be considered as the most fundamental concept at the origin of his General Relativity. I highlight that the ether problem is related with Enstein's conception of gravitational waves as a perturbation of the space-time curvature, formalized as a specific space-time process, and not as the effect of a whatever supporting medium. Quite differently, the nineteenth century field theory of gravitation supported by physicists such as Maxwell, Heaviside, and Hertz, was based on a search for substantial ether, and on a parallelism with Maxwell's theory of electromagnetic waves. The negative results of their theories proved that parallelism was a wrong approach. Einstein's genius superseded their approach by considering that it was not a matter of the ether's constitution, but of a fundamental change in the role and nature of physics. In my paper I refer to Einstein's different approaches to ether since his 1905 Special Relativity up to his 1950' views. I argue that his different attempts were symptoms of the difficulty of his revolutionary innovation.

Keywords

Einstein, Maxwell, Heaviside, Hertz, Cassirer

1. Introduction

The celebrated Equivalence Principle, one of the kernels of Albert Einstein's General Relativity, affirmed that the gravitational force is locally eliminated by acceleration. No substantive reality is therefore to be attributed to ether as the supporter of gravitational effects, because of the contradiction implied by its elimination by a purely dynamical cause. In the eighteen century instead, Isaac Newton supported the idea of an absolute space as the "Sensorium Dei", and as the supporting medium of gravitation. The ether's role in Einstein's Relativity represents thus an important part of the revolutionary view of his General Relativity: gravitation is a space-time state. If it is true that in his fundamentally new approach, Einstein considered field theories the basis of General Relativity, his approach in his 1905 Special Relativity, was initially concerned with a theory of ether's constitution. The ether problem entered sideway in Einstein's theories since his 1907's contributions. In fact, since his 1907 so-called Tokio paper, he genially understood that it was not a matter of devising a theory of the ether's constitution, but that a new revolutionary idea of a physical theory (Renn, 2006) was implicitly embedded in his Equivalence Principle.

However, the doubt that the ether's constitution was a misleading premise for gravitational propagation, was one of Einstein's premises in his ten years long approach to GR and gravitation. He knew that in nineteenth century physicists such as Maxwell, Heaviside, and Hertz, had tried to construct a field gravitation theory founded on theories on the ether constitution, and on an analogy with the Electromagnetic waves propagation. Although almost ignored in the literature, I deem that the above theories deserve some attention. Their theory of the gravitational field based on a parallelism with the M.'s celebrated theory of electromagnetic waves led to wrong results, and many scientists between 1900 and 1905 were still trying to treat theories of gravitation as an electromagnetic type process. The negative results of their theories proved that *Parallelism* was a radically negative approach. Einstein's genius overturned the approach, by opposing that it was not a matter of different ether theories but of a fundamental change in the role and nature of physics (Renn, 2006: p. 320). In fact, the cultural import of his General Relativity overcame the altogether relevance of his particular contributions. Although parallelism was not the route that Einstein's great physics followed in his fundamental approach to General Relativity (Henseforth: GR), the parallelism approach was not altogether discredited by Einstein. It presented difficult problems to Einstein epistemology, as illustrated by the attempts to solve the gravitation problem on behalf of his contemporary scientist. A different approach to a theory of gravitation was in fact conceived in the twentieth century by Lo Less a scientist and mathematician than Hermann Minkowsky.

It is evident that a lot of physical and epistemological themes converged to complicate the physicist's work. On the level of an Einstenian historiography, a selection among the hundreds of pages that E. dedicated to explain and popularize Relativity poses some problem. In my paper I attributed the utmost significance to the remarkable essay "Physics and Reality", and to his 1949 conclusive pages in "Reply to Criticism". I also selected some paragraphs of contributions to the ether problem in his 1920 book, and his 1955 added Appendix. I argue that Einstein's views of the ether role in General Relativity implied fundamental epistemological problems. I interpret his wavering between opposite positions as a symptom of the difficulty of a definitive solution of the problem.

As my comment on the recent development of Einstein's historiography, I argue that one can efficiently summarize its situation, by selecting two different historiographical approaches. A) Either to privilege E.'s 1912-16 peculiar approach by Generally Covariant transformations. Or quite diversely, one could highlight B), the relevance of E.'s 1907 Equivalence Principle, and the local elimination of gravitation by the dynamical process of acceleration. Notice that this approach somehow conflicts with Einstein's subsequent attempts to attribute to ether a whatever reality. He solved initially the conflict by abolishing the traditional ether, but later on returned to an upsetting view of ether as a formal space-time equilibrium state. Let us consider that the most relevant historical reconstruction of E.'s Relativity, usually follow the first route. Let us quote as classical examples: John Norton (Norton, 1989), and John Stachel 1986 fundamental essays (Stachel, 1986). As examples of the second route, let us refer to Don Howard 1988 essay (Howard, 1988), to Arthur Miller's 1988 essay (Miller, 1988), and to Goldberg Essay (Goldberg, 1984). In my paper I adopted the second type historiography. I think that the ether problem is an important aspect of Einstein's General Relativity.

2. On the Pre-Einsteinian Field Theory of Gravitation

Although Maxwell's fundamental essay "A Dynamical Theory of the Electromagnetic Field" (Maxwell, 1865: pp. 526-597), was the contribution that mainly attracted the historians' attention, his "Note on the Attraction of Gravitation" (Maxwell, 1865a: pp. 570-571), a few pages in conclusion of his essay passed almost unnoticed in the historical literature. In his short Note, Maxwell remarks that gravitation arises from the action of the surrounding medium, and concerns therefore the problem of a gravitational field theory. He stated that the main difficulty with such a theory was the lack of the bipolar interaction of positive and negative charges, a feature of his electromagnetic theory as contrasting the unipolar gravitational attraction. However he assumed that when in a state of undisturbed equilibrium each part of the gravitational medium possessed an enormous intrinsic energy, whose density was accounted as greater than 1/8 R^2, $R^2 = a^2 + b^2 + c^2$, with a, b, c, the magnetic field components, and that the presence of the other bodies' gravitational attraction, would diminish that energy. But he admitted that a medium with such properties was for him unconceivable. He did not doubt however that the wrong approach concerned a Parallelism with ether, both the source and the transmitting medium of electromagnetic waves, the view he supported in his large essay "Ether", published on the Encyclopedia Britannica (Maxwell, Undated: Vol. 2, pp. 763-775).

It might seem amazing that the *Parallelism* approach with electromagnetic waves was more or less followed by Maxwell's heirs, and that Oliver Heaviside, the acknowledged heir of M.'s electromagnetic theory of light, was still convinced that Maxwell's field theory of electromagnetism still represented a natural precedent for a gravitational field theory (Heaviside, 1983: pp. 281-282; Jefimenko, 2001).

He proved that an extension of the electromagnetic potential to a potential of gravitational forces lead to an infinite velocity of their propagation. It was not true for him that the analogous of the bipolar magnetic force was absent in the gravitational analogy, since he stated that accounting for a gravitational field required to introduce a second vector potential (Heaviside, 1983: p. 200). He was inspired by the thought that it would be incredible that "the gravitational influence could be exerted without a medium", as it was believed in Newton's times. But in order to extend the analogy with electromagnetic waves he deemed necessary to admit that transversal motions propagated gravitation. Remarks "by the Editor and by Prof. Lodge" (sic) convinced Heaviside that an alteration of the intensity of the gravitational force in different direction around a moving body was a needed correction to Newton' s laws. But to carry out more fully the consequences of gravity propagation one should perhaps consider a change in the force "brought in by the finiteness of the velocity of light which is analogous to the magnetic force". If the variation of the force was too small to lead to observable perturbation of motion, then "the striking conclusion was that the speed of gravity could even be the same as that of light" (Heaviside, 1983).

Heinrich Hertz, the celebrated scientist and the discoverer of Maxwell's waves, believed that the utmost relevance of his discovery was the falsification of Newton's concept of action at a distance forces (Hertz, 1962). His approach was in fact advantaged by his original conception of ether as a primitive medium. He accounted for the ether's role by stating that two important ethereal constants in M.'s theory, the dielectric polarization and the magnetic inductivity, were to be considered as primitive ethereal constants, thus accomplishing the role of Maxwell's polarized dielectrics. He refuted Helmholtz's thesis that their transmission could be trusted to a Poisson type polarized medium different from ether. Let us notice that Hertz's view of the ether's independent role confirmed Faraday's belief of an independent existence of forces in space (D'Agostino, 1975).

He attributed to Faraday the merit of the new revolutionary concept of electromagnetic forces: "The most direct conclusion of the experiment on the finite velocity of propagation of electromagnetic forces, is the confirmation of Faraday's view, according to which the electric forces are polarizations existing independently in space."

Hertz's thesis of independent existence of electromagnetic waves, and especially his specific conception of electromagnetic waves, represented a progressive view with respect to the former Heaviside's distressing analogies with elastic-type propagation. Hertz's hope for a gravitational field theory is presented in one of his popular and important lectures. Hermann Minkowsky (Minkowsky, 1915) sought to formulate a relativistic mechanics on the basis of the basic equations for electromagnetic processes. In his 1915 posthumous Principle of Relativity (Pyenson, 1985: p. 80), he radically modified his point of view, and elaborated Hilbert's formulation of electricity and matter in terms of four dimensional space-time vectors (Minkowsky, 1915). Unlike many others mathematicians and physicists, Einstein remained unimpressed by Minkowsky's theory of matter as a four-dimensional space-time structure (Pyenson, 1985: p. 80).

3. Einstein's General Relativity: Equivalence Principle against a Substantive Ether. Gravitational Waves as a Formal Space-Time Process

In his Special Theory of Relativity, Einstein explained the absence of an ether wind by abolishing ether. He maintained that his abolition solved a contrast between the experimental symmetric features of Faraday's induction, and the asymmetry resulting from the theoretical inclusion of ether. But the success of his 1916 General Relativity (Henceforth: GR) implied some changes in his initial assumptions. He discussed the problem in many specialized and even popular essays, but I argue that his ideas on the ether's role in GR were sufficiently synthesized in his 1920 book (Einstein, 1994). He believed that the "far-reaching similarity, which subsists between the properties of light and those of elastic waves in ponderable bodies", represented "a fresh support" for an elastic type of ether as a medium for light's waves. The Einstein's "fresh support" might seem very close to the *Parallelism* mentioned approach, but he added that the support was also a source of great difficulties. In fact, "neither Maxwell nor his followers succeeded in elaborating a mechanical model for ether which might furnish a satisfactory mechanical interpretation of Maxwell's laws of electromagnetic field. *The laws were clear and simple*, *the mechanical interpretations clumsy and contradictory*" (my Italics). He thus decisively rejected a Parallelism between the properties of light and those of *mechanical* elastic waves in ponderable bodies. In order to avoid the clumsy and contradictory features of a mechanical interpretation, he underwent to change the justification of his 1905 approach, and assumed that ether consisted of particles whose motion was not observable in time:

> There may be supposed to be extended physical objects to which the idea of motion cannot be applied [...] the special theory of relativity abstracted from ether the last mechanical characteristic. But, a non mechanical ether might appear as a superfluous requirement in place of electromagnetic fields as ultimate, irreducible realities [...] If from the standpoint of ether this hypothesis appears at first to be an empty hypothesis, one should consider that in the electromagnetic processes in vacuo [...] the electromagnetic fields appear as ultimate, irreducible realities, and at first it seems superfluous to postulate a homogeneous, isotropic ether-medium, and to envisage electromagnetic fields as states of this medium…[but] the dualism still confronts us [...] in the theory of Hertz, where matter appears not only as the bearer of velocities, kinetic energy, and pressures, but also as the bearer of electromagnetic fields. (Einstein, 1994: p. 18)

Einstein brought in another "argument" that weighted in favor of ether: "to deny the ether is ultimately to assume that empty space has no physical qualities whatever. The fundamental facts of mechanics do not harmonize with this view". His criticism of Newton's mechanics is clearly commented in Mc Cormmach (Mc Cormmach, 1970). Another solution obtained by reducing the principles of mechanics to those of electricity, was also refuted by "responding to the general tendency to give conceptual priority to electromagnetic concepts". "A confidence in the strict validity of the equations of Newton's mechanics was shaken by the experiments with radioactive-rays and rapid cathode rays." But the electromagnetic reduction of mechanics was however objected by Einstein also because of his new understanding of Lorentz's electromagnetism. Einstein's approach to ether couldn't in fact neglect some attention to Lorentz, the authoritative supporter of an electrodynamics theory on the reality of ether: "according to Lorentz's theory, electromagnetic radiation, like ponderable matter, brings impulse and energy with it, and as both matter and radiation are but special forms of distributed energy, according to the special theory of relativity, ponderable mass is losing its isolation … appearing as a special form of energy." (Einstein, 1952: p. 147).

Although Lorentz's electromagnetic radiation could appear as a special form of distributed energy, and be partially accorded with the special theory of relativity, it could not be conceived as a field, the fundamental concept of Einstein's theory. In the following lines, Einstein defines his original view of a field:

> What is fundamentally new in the ether of the general theory of relativity as opposed to the ether of Lorentz consists in this, that the state of the former is at every place determined by connections with the matter and the state of the ether in neighboring places, which are amenable to law in the form of differential equations; *whereas the state of the Lorentzian ether in the absence of electromagnetic fields is conditioned by nothing outside itself, and is everywhere the same…* Thus we may also say, I think, that *the ether of the general theory of relativity is the outcome of the Lorentzian ether, through relativation* [my italics]. (Einstein, 1952: p. 147)

Einstein's ether is thus different from Lorentz's ether in as such as its connections with its matter and state in neighboring places are amenable to law in the form of differential equations. E.'s gravitation and gravitational ether are thus assimilated because of their essential formal nature: that of "substituting constants for the functions of space…disregarding the causes which condition its state" (Einstein, 1949c: p. 680). The kernel of Einstein's theory of gravitational waves can thus be formulated: *gravitational waves are wave-like without being substantive waves*, thus confirming the conceptual irrelevance of the earlier similarity theories of substantial ether, and affirming the new formal role of the ether properties.

4. Einstein's Self-Criticism of the Ether Role in General Relativity: The Upper Level Theories' Gain in Simplicity What They Lose in the Empirical Base

The almost general acceptance of [ ] General Relativity (Hence forth: G.R) did not exempt Einstein's theory from criticisms on behalf of his philosophers and physicists' entourage. As a special but significant detail, let me refer to Margenau's outspoken objections: "Einstein's position … contains features of rationalism and extreme empiricism" (Einstein, 1949c: p. 680). Notice Einstein's no less surprising reaction: "This remark is entirely correct. From whence comes this fluctuation? A logical conceptual system is physics insofar as its concepts and assertions are necessarily brought into relationship with the world of experiences. Whoever desires to set up such a system will find a dangerous obstacle in arbitrary choice (*Embarrass* de *riches*). *This is why he seeks to connect his concepts as directly and necessarily as possible with the world of experience. In* *this case his attitude is empirical. This path is often fruitful, but it is always open to doubt…*" (Einstein, 1949c: p. 680) (Italics S.D.).

In order to explain why the empirical approach is doubtful, one can refer to Einstein's idea of the connection between the concept and its empirical foundations: "… because the specific concept and the individual assertion can, after all, assert something confronted by the empirically given only in connection with the entire system. He [the physicist] then recognizes that there exists no logical path from the empirically given to that conceptual world…His attitude becomes then more nearly rationalistic, because he recognizes the logical independence of the system. *The danger in this attitude lies in the fact that in the search for the system one can lose every contact with the world of experience. A wavering between these extremes appears to me unavoidable*" (Einstein, 1936) (Italics S.D.). I consider his assertion on the physicist's wavering between two extreme positions a fundamental aspect of his epistemology, and I will devote to it a few comments in this paper. In his 1936 "Physics and Reality", he always dealt with the doubt that a theory represented physical reality (Howard, 1988). I note that in this essay, he returned to the problem of the empirical support for GR, but this time through a more general approach, founded on the concept of "Stratification of the Scientific System". 'Stratification implies various theoretical levels, starting from the lower level, the most primitive in a diachronic sense, that comprises concepts more directly related to perceptions (German: Empfindungen), and theorems that connect them (Einstein, 1936: p. 62). When passing to the upper level, a theory gains in simplicity, what it loses in the empirical base. However, in order to maintain contact with the empirical base, the upper level concepts need to be reduced to their "correspondents" in the lower level. The process is achieved by a mapping rule in the so-called Correspondence Area, by relating the upper level concepts to their lower level correspondents, but not vice versa. In this sense the correspondence relationship is a-symmetric, because it is univocal, not bi-univocal (D'Agostino, 1995). If the correspondence is established, the lower level concepts receive their physical meaning from their correspondents to the upper level concepts, not the reverse. The whole process is accounted for in Einstein's original metaphor: "*The relation is not analogous to that of a soup to a beef but rather of a cloakroom ticket to an overcoat*" (Einstein, 1936) [Italics S.D.].

As to my comment to the above rather intriguing Einstein statement, I argue that the metaphor of an a-symmetric correspondence between a cloakroom ticket and the empirical base express the risk of endangering the support that the GR formal relation should derive from the empirical bases of gravitation. Let us consider how in his survey article on relativity for the 1907 "Jaharbuch der Radioactivitaet und Elektronik", Einstein intended to eliminate the above risk. He elevated the experimental proof of the equality of inertia and gravitational force in the free fall of all bodies, to the status of an "Equivalence Principle". His attention to the empirical basis of the principle is documented by a passage in his 1907 letter to his friend Conrad Habicht, informing Habicht that he hoped to account for the "secular changes of the perihelion movement of Mercury" (Holton, 1973). In 1909 he began to argue that the only formalism that was capable of uniting physical theories was the continuous spatial functions and partial differential equations of a field theory (Einstein, 1949b: p. 57). But he expressed a different view of the relevance of the empirical basis of the Riemann's geometry in a 1954 letter to his dear friend Michele Besso (1873-1955), in response to Besso's point highlighting the relevance of the abstract role of E's theory (Einstein, 1972: p. 157).

I argue that his almost final answer in *Reply to Criticism*, can be interpreted as his choice between two grandiose alternative as requirements for an ideal theory: a) to accept a strongly axiomatic theory, but risking the contact with physical reality; b) to construct *under-determined theories*, gaining contact with phenomena, but losing the transcendental power of formalism as regard their purity (Pais, 1982: p. 189). Although controversial for some of its aspects, it can be reasonably argued that the fulfillment of the first requirement would correspond to Einstein's ideal of a purer theory (D'Agostino, 2009: pp. 89-98). I find very significant on this point Pais comment on the non-conformity of same of Einstein's statements on empiricism and on the contrasting possibility of a pure theory (Pais, 1982).

By Einstein's own admission, this ideal of a pure theory was not achieved in Einstein's lifetime (Einstein, 1949c: p. 686). He refers to Levi Civita, Hilbert, and Weyl's as examples of mathematical, not physical, pure theories. It is surprising, at least, that this important topic of E.'s philosophy was, to my present knowledge, ignored in the literature. Einstein's critical reaction to Weyl originated in Einstein's mentioned distrust for a total mathematization of theories. Notice that a total mathematization was supported by no less than Hilbert's authority. Einstein's views on the fundamental distinction between a physical and a mathematical theory are clearly formulated:

> One is struck that the theory [i.e., Einstein's GR] (except for the four-dimensional space) introduces two kinds of physical things, i.e., (1) measuring rods and clocks, (2) all other things, e.g., the electro-magnetic field, the material point, etc. This, in a certain sense is inconsistent; strictly speaking measuring rods and clocks would have to be represented as solutions of the basic equations (objects consisting of moving atomic configurations), not, as it were, as theoretically self-sufficient entities. However, the procedure justifies itself because it was clear from the very beginning that the postulates of the theory are not strong enough to deduce from them sufficiently complete equations for physical events sufficiently free from arbitrariness, in order to base upon such a foundation a theory of measuring rods and clocks (Einstein, 1949c: p. 686).

In the above passage Einstein criticizes the too early introduction into theory of measuring rods and clocks. He touches his I936 under-determination problem ("the postulates of the theory are not strong enough"). I interpret this fact as evidence that, in 1949, he matured the view that the determination of theories is part of the more general problem of the physical basis of GR and UFT. In fact, in his *Reply to Criticism*, he criticized the "current theory of relativity" (i.e., his GR) for not meeting the requirements for "a sufficiently complete equation for physical events: the postulates of the theory are not strong enough to deduce from them sufficiently complete equations for physical events sufficiently free from arbitrariness". The "physical events sufficiently free from arbitrariness" are clearly the measuring rods and clocks (Einstein, 1949c: p. 686). In his 1949 *Autobiographical Notes* he admitted that he had been incapable of doing a better work, and hoped that others could succeed. A complete theory Einstein's sense was never achieved in the span of Einstein's life, and it was considered hardly realizable by the majority of physicists in 1955, the more so after the approach to particles in Quantum Mechanics (Sigurdson, 1991).

Let us read Einstein's reaction to the criticism to his General Field Theory as his attempted generalization of GR: "to conceive physical reality a field, and moreover, one which is the generalization of the gravitational field, and in which the field law is a generalization of the law for the pure gravitational field, … is inclined to answer in negative by the present generation of physicists" (Einstein, 1949c: p. 686). It is thus clear that the "natural form of this generalization" is to be intended as a reference to Einstein's contemporary work on the Generalized Field Theories (GFT), and that he complains his contemporary physicists critical reaction to such a type of theory.

5. Weyl's Criticism to Einstein Relativity

Hermann Weyl wrote in 1918 his influent book *Raum*, *Zeit*, *Materie* (Weyl, Undated). *He* introduced as his generalization of Riemann's geometry his theory of the "Affine Field" and completed the Riemann axioms through the introduction of the so-called "Masstab-Invariance", which allowed him to deduce electricity and gravitation from a unique variation principle. Thus he avoided their deduction by "gluing" together two independent variation principles, an electromagnetic and a gravitational principle. Weyl believed that through his Affine Field Geometry he had improved on Riemann's local geometry, because this geometry—and consequently theories such as Einstein's—were not truly local. For they implied a strange effect-at-distance, due to the invariance of the space elements distance in parallel displacement. He was also convinced that his Geometry was the really truly local geometry of the world, and that the physics of the real world could be grasped just through the discovery of the axioms of a true geometry. Weyl's theory made a considerable impression upon theoreticians and initially on Einstein himself, who wrote that its depth and boldness must charm every reader (Vizgin, 1986: p. 303). However, in an Appendix to Weyl's 1918 essay (Weyl, 1918), Einstein objected that the theory contradicted his GR on some fundamental aspects. Whereas affine displacement implied a change in time and frequency scale, it contradicts the fact that chemical elements have spectral lines of definite frequency (Sigurdson, 1991: p. 165).

Weyl's response to Einstein's criticism dealt with the unsoundness of a space-time theory pretending to glue electromagnetism to gravitation as in Einstein 1922 approach to Unified Field Theory (UFT) (D'Agostino, 2009: pp. 89-98). Moreover, he taught that Einstein's approach was still sticking to the early Riemannian geometry. In 1928 he abandoned his research on Unified Field Theory for various reasons that he significantly condensed in his 1950 *Preface* to the First American Printing of the fourth 1920 edition of his 1918 *Raum*, *Zeit*, *Materie*. In 1950, he admitted that "the attempt described in his 1920 edition to obtain a unified field theory deriving all forces of nature from one common structure of the world and one uniquely determined law of action [...] by a new principle which I called gauge invariance (*Eichinvarianz*) [...] has failed" (Weyl, Undated). He added that the principle of general relativity [...] proved insufficient to reach the goal at which classical physics is aiming: a unified field theory deriving all forces of nature from one common structure of the world and one uniquely determined law of action. Initially, Einstein took Weyl's mathematics as an example of a "purer" theory, not committed to a more or less direct operational definition of the coordinates, hence more suitable for being transformed into an over-determined Complete theory. Exploring his various statement on Completeness, one is led to the following definition: a theory is said to be Complete if its postulates are strong enough to deduce from them sufficiently complete equations for physical events sufficiently free from arbitrariness. A complete physical theory of GR, would be a theory that affords to give physical meaning to the concepts of measuring rods and clocks by representing them as solutions of the basic equations, deduced from postulates of a stronger type. According to Einstein, a shortcoming of GR and UFT was the impossibility of deducing from the foundational postulates of GR a physical meaning of rod and clocks. He strongly opposed Weyl's pretention that his Geometry was the really true local world geometry, and that the physics of the real world could be grasped through the discovery of the axioms of a true geometry. Einstein's opposition was consistent with his 1921 "Geometrie und Erfahrung", where he had supported the view that Geometry alone is not capable of over-determining a physical theory, without a recourse to the physical counterpart. This request of "Empirie", as he labelled it in a letter to his friend Besso (Einstein, 1972: p. 138) has the sense of an indispensability of the empirical element expected to back up mathematics, not an empirical external support independently poured into a provisional theory, but introduced through the equations' over-determination (Einstein, 1949c: p. 686). He considered valid this request not only for the present provisional state of physics but also for his ideal (G+P) conception of the constructive process (Einstein, 1949c). In my thesis therefore, Einstein's conception of a complete theory fundamentally contrasted with Weyl's convictions. One has to agree that Einstein and Weyl's ideas inspired the researches in UFT in the thirties of the last century over the main European countries (D'Agostino, 2009). Although their approaches faded away from the physicists' interests after the Second World War, especially with the triumphal advent of quantum theories, it is an incontestable fact that the problems they met are still alive in physics. I argue that by forthrightly stating their methodological doubts, Einstein and Weyl made an important contribution to our understanding of the philosophical implications of theoretical physics (Holton, 1973: p. 246).

6. Cassirer's Interpretation of Einstein's Relativity

In his classic work (Cassirer, 1953) Ernst Cassirer clearly asserted that the second fundamental concept of Einstein's GR is the concept of ether:

> This evolution of GR is seen when we go from the concept of mass to the second fundamental concept o modern physics, to the concept of ether. The idea of ether as the bearer of optical and magnetic effects was at first conceived in the greatest possible analogy an affinity with our presentation of empirically given materials end things…either by comparing it now with a perfectly incompressible fluid, now with a perfectly elastic body. But … the more…more distinctly was it seen that they demanded the impossible of our faculty of presentation, …the unification of absolutely conflicting properties (Ibidem. Chapt. 4, 404).

Cassirer considered the true expression of Einstein's GR revolution, the analysis of the inner relation of measurements of the four dimensional space-time manifold with the ten components of gravitational potential: "for the ten functions g^{mn} that occur in the determination of the linear elements of the gravitation…represent also the ten components of the gravitational potential of E.'s theory". Although I consider Cassirer's synthesis one of the most significant definitions of Einstein's ether theory, I cannot miss to note that Einstein's wavering approach to ether represents for him an unresolvable conflict. Einstein's search for a substantive ether, or for an otherwise material support of gravitational waves, is in fact considered as that "of an impossible demand to our faculty of representation, i.e., the unification of absolutely conflicting properties: an alleged perennial antinomy between substance and function: the more … more distinctly was it seen that they *demanded the impossible of our faculty of presentation*, *… the unification of absolutely conflicting properties*" (Cassirer, 1953: p. 397). As a particular case he quotes: "the assumption of the Maxwell-Hertz differential equations for electrodynamics process in the pure ether excludes the possibility of their mechanical explanation".

Notice how he intended to generalize the alleged perennial antinomy between substance and function to the whole context of E.'s epistemology: "*while it destroys the thing-form of the finite and rigid reference body it would thereby only press forward to a higher form of object*, *to the true systematic form of nature and of its laws*" (Cassirer, 1953: p. 407) (Italics S.D.).

Although consistent with Cassirer's neo-Kantianism interpretation of Einstein's epistemology, I find that his generalization does not appear as the most relevant feature of an historical perspective of Einstein's epistemology. As my comment to Cassirer's analysis, let us confine our attention to Einstein's fifth Appendix, added in 1955, to his 1920 book (Einstein, 1952). The date of the contribution should by itself justify our reference, but our interest is increased by the additional remarks added to the 1920 comments of GR. If it was true that the negative results of Maxwell's and Hertz's theories were for Einstein a proof that *parallelism* was a wrong and negative approach, let us however remark that he met some difficulties in his view of an ether's total negation, and he returned on many occasions to the ether problem. Instead of agreeing with Cassirer about "the perennial conflict between the formal properties of gravitational waves, and the constitution of ether as a real thing", I prefer to support Einstein's conclusion: the physicist hard job is that of "*wavering between two extremes*".

7. A Mode of Conclusion

A highly positive frame of mind assimilates Einstein's thought to the scientific and philosophical tradition of great European physicists in the last two Centuries: the experimental success of their theories did not release them from thinking that they had to understand how and why theory and experiments were related, the *how and why of their success*. Their "ethos" was not only a discovery "ethos", but a cultural "ethos", which aimed to associate their science and philosophy in a single field of interest. Einstein represents an eminence of the European tradition. Max Planck, the first theoretical physicist, and Einstein's mentor, once expressed his anti-convectional view of science: "A science is never in a position completely and exhaustively to solve the problem it has to face. We must accept that as a hard and fast, irrefutable fact, and this fact cannot be removed by a theory which restricts the scope of science at its very start." (Planck, 1931).

Acknowledgements

To Don Howard, my appreciated History of Physics fan. To Gino Tarozzi for his appreciation of my welcome presence to the Cesena XXVIII Summer School in Philosophy and History of Science. To Giovanni D'Urso, for his encouragement to my historical work. To Arcangelo Rossi, and Vincenzo Bordoni, my best thanks and wishes for our hopeful further work. Last but not least, my thanks to Stefania Borgo for her suggestions on an initial draft of my paper.

References

Cassirer, E. (1953). *Substance and Function and Einstein's Theory of Relativity* (Unabridged Edition). Chicago: The Open Court Publ. Co.

D'Agostino, S. (1975). Hertz's Research on Electromagnetic Waves. *Historical Studies in the Physical Sciences, 6,* 261-323. https://doi.org/10.2307/27757343

D'Agostino, S. (2009). Einstein and Weyl on the epistemological Shortcomings of Unifies Field Theories. In C. Alumni, M. Castellana, D. Ria, & A. Rossi (Dir.), *Albert Einstein et Hermann Weyl 1995-2005, Questions épistemologiques ouvertes* (pp. 89-98). Manduria: Barbieri Selvaggi Editori.

D'Agostino, S. (1995). Einstein's Life Long Doubts on the Physical Foundations of General Relativity and Unified Field Theories. In C. Garola, & A. Rossi (Eds.), *The Foundations of Quantum Mechanics-Historical Analysis and Open Questions* (pp. 167-178). Dordrecht, Bostom, London: Kluwer Academic Publishers.

Goldberg, S. (1984). *Understanding Relativity. Origin and Impact of a Scientific Revolution. Exsp.: Chapt 8. Defending the Ether: The British Response.* Boston, Basel, Stuttgard: Birkhaeuser.

Einstein, A. (1936). Physics and Reality. *The Journal of the Franklin Institute, 221,* 349-382. https://doi.org/10.1016/S0016-0032(36)91047-5

Einstein, A. (1952). Appendix V. Added to A. Einstein (1994), *Relativity, the Special and the General Theory* (pp. 135-157).

Einstein, A. (1972). *Albert Einstein, Michele Besso, Correspondence, 1903-1955*. Paris: Hermann.

Einstein, A. (1994). *Relativity, the Special and General Theory* (pp. 1-138). di R. V. Lawson, & A. Einstein (Trans.) (1920) *Ueber die spezielle und die allgemeine Relativitaetstheorie* (*Gemeinverstaendlich*) Vieveg, Braouschweig of Methuen and Co. Ltd., London: Routlege.

Einstein, A. (1949b). Autobiographical Notes. In A. Einstein (Ed.), *Albert Einstein Philosopher Scientist* (Vol. 1, pp. 1-95). New York: Harper & Brothers Publ.

Einstein, A. (1949c). Reply to Criticism. In A. Einstein (Ed.), *Albert Einstein Philosopher Scientist* (pp. 665-688). New York: Harper & Brothers Publ.

Hertz, H. (1962). *Electric Waves, Being Researches on the Propagation of Electric Action with Finite Velocity through Space*. New York: Dover. English Translation of Hertz, H. (1892). *Untersuchungen ueber die Ausbreitung der elektrischen Kraft*. Leipzig: Johann Ambrosius Barth.

Heaviside, O. (1983). A Gravitational and Electromagnetic Analogy, Part I. *The Electrician,* 31, 281-282.

Holton, G. (1973). *Thematic Origin of Scientific Thought, Kepler to Einstein*. Oxford: Oxford University Press.

Howard, D. A. (1988). Einstein and Eindeutigkkeit: A Neglected Theme in the Philosophical Back-Ground to GR. In J. Eisenstaedt, & A. J. Kox (Eds.), *Studies in the History of General Relativity, Einstein Studies* (Vol. 3, pp. 154-243). Berlin, Birkhäuser.

Jefimenko, O. D. (2001). *Causality, Electromagnetic Induction, and Gravitation* (pp. 189-202.). Omsk: Omsk University.

Maxwell, J. C. (1865). A Dyanamical Theory of the Electromagnetic Field. In J. C. Maxwell (Undated), *The Scientific Papers of James Clerk Maxwell* (Vol. 1, pp. 526-597). Cambridge: Cambridge University Press. https://doi.org/10.5479/sil.423156.39088007130693

Maxwell, J. C. (1865a). A Note on the Attraction of Gravitation. In J. C. Maxwell (Undated), *The Scientific Papers of James Clerk Maxwell* (Vol. 1, pp. 570-571). Cambridge: Cambridge University Press.

Maxwell, J. C. (Undated). *The Scientific Papers of James Clerk Maxwell* (Vol. 2). Cambridge: Cambridge University Press.

Mc Cormmach, R. (1970). *Historical Studies in the Physical Sciences*.

Miller, A. (1988). *Albert Einstein's 1907 Jaharbuch Paper: The First Step from SRT to GRT*. Basel: Birkhaeuser.

Minkowsky, H. (1915). Das Relativitaetprinzip. *Annalen der Physik, 47,* 927-938. https://doi.org/10.1002/andp.19153521505

Norton, J. (1989). *What Was Einstein's Principle of Equivqlence?* Basel: Birkhaeuser.

Pais, A. (1982). *Subtle Is the Lord…The Science and Life of Albert Einstein*. Oxford: Oxford University Press.

Planck, M. (1931). Positivism and External Reality. *International Forum, 1,* 14-19.

Pyenson, L. (1985). *The Young Einstein. The Advent of Relativity*. Bristol: Adam Hilger Ltd.

Renn, J. (2006). *Auf den Schouldern von Riesen und Zwergen. Eintsein unwollendete Revolution*. Hoboken, NJ: Wiley.

Sigurdson, S. (1991). *Hermann Weyl, Mathematics and Physics, 1990-1927.* Cambridge, MA: Harvard University Press.

Stachel, J. (1986). Einstein's Search for General Covariance. In D. Howard, & J. Stakel (Eds.), *Einstein and the History of General Relativity*, *Einstein Studies* (Vol. 1). Berlin: Birkhäuser.

Vizgin, V. (1986). Einstein, Hilbert, and Weyl: The Genesis of the Geometrical Unified Field Theory Programm. In D. Howard, & J. Stakel (Eds.), *Einstein and the History of General Relativity*, *Einstein Studies* (Vol. 1). Berlin: Birkhäuser.

Weyl, H. (1918). Gravitation und Elektricität. *Sitzungsberichte der Königlich Preitssischen Ak. der Wissenschaften zu Berlin, 26,* 465-480.

Weyl, H. (Undated). *Space*, *Time*, *Matter*. New York: Dover.