LOOP QUANTUM GRAVITY IN THE LIGHT OF NEO-KANTIAN PHILOSOPHY

La Gravità quantistica a Loop alla luce della filosofia neo-kantiana

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Abstract: The paper surveys the possibility of keeping a neo-Kantian approach in the face of Loop Quantum Gravity (LQG). Together with a preliminary analysis of Cassirer's re-interpretation of Kantian philosophy that allowed him to harmonize the *a priori* cognitions with the theory of relativity and quantum mechanics (QM), it will focus on the distinction between constitutive and regulative *a priori*. In this way, the paper will suggest that despite Rovelli's refutation of Kant's interpretation of space and time, he seems, at least implicitly, to hold to a couple of neo-Kantian assumptions: (i) the usage of constitutive *a priori* principles such as granularity, indeterminism and partially relation, (ii) and the claim for functionalism as a rule in ordering the 'appearances'.

Keywords: Kant; Cassirer; Kantianism; neo-Kantianism; Rovelli; Regulative and Constitutive A priori.

Riassunto: L'articolo si occupa di stabilire se sia possibile conservare un approccio neokantiano alla gravità quantistica a loop. Assieme ad un'analisi preliminare della reinterpretazione cassireriana della filosofia di Kant, la quale permise allo stesso Cassirer di conciliare quest'ultima con la teoria della relatività e la meccanica quantistica, l'articolo si concentrerà sulla distinzione fra *a priori* costitutivi e regolativi. In questo modo l'articolo intende suggerire che, nonostante il rigetto da parte di Rovelli della concezione kantiana dello spazio e del tempo, egli sembri, almeno implicitamente, attenersi a un paio di assunti neokantiani: (i) l'uso di *a priori* costitutivi quali la granularità, l'indeterminismo e, parzialmente, la relazione, (ii) così come la rivendicazione del funzionalismo come regola per ordinare i "fenomeni".

Parole chiave: Kant; Cassirer; Kantismo; Neokantismo; Rovelli; *A priori* costitutivo e regolativo.

> When one speaks of a scientific image of nature, this is not an image of nature but rather an image of our relation to it.
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> *Werner Heisenberg*[1]

1. Introduction

This paper investigates whether some recent developments of physics, in particular the so called Loop Quantum Gravity (LQG) defended by the Italian physicist Carlo Rovelli, have some assonance with the neo-Kantian adjustments of Kant's thought

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[1] Heisenberg (1984), my transl.

introduced to harmonize the critical philosophy with the developments of physics in the XX century, mainly General Relativity (GR) and Quantum Mechanics (QM). At first sight the very idea of speculating about possible assonances appears desperate, because Rovelli finds inspiration in philosophers very distant from Kant and explicitly rejects the thesis that space and time are pure intuitions (see sections 7 and 8)[2]. However, the efforts made by neo-Kantians in the past to conciliate transcendental philosophy with GR and QM appeared at the beginning equally desperate and yet produced results which proved vastly influential for the XX century epistemology[3]. Thus, a renewed attempt to compare, contrast and if possible couple the critical philosophy with the general picture of contemporary physics may be worth a try[4].

A good way to proceed is to introduce Cassirer's reconstruction of GR and QM in the light of Kantian philosophy (section 2). Indeed, LQG directly reacts to both theories. It is thus reasonable to expect that Cassirer's treatment may prove useful for our purposes. Cassirer's epistemology is centred upon the unveiling of the power of principles in the constitution of objectivity, to the point that a neo-Kantian version of the critique of knowledge should not ascertain whether there are *a priori* forms that, notwithstanding, can be applied to a given manifold[5]. On the contrary, it has to show that that happens

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[2] There are plenty of authors which Rovelli hints at, such as Aristotle, Democritus, Anaximander, Descartes and Leibniz. He seems to be interested in Aristotle's conception according to which space is somehow the limit of a place (*Phys*. 212a20), and he appreciates Descartes' notion of contiguity, though he admits that Descartes' physics is quite blundering; as far as Democritus is concerned, the focal point is of course atomism. But surprisingly, it is Anaximander who plays the central role. Rovelli, indeed, follows Heisenberg in stating that, in contemporary physics, one should rely on *apeiron* to explain the peculiar features of concepts such as matter, energy and even field. Leibniz is influential for his notion of space and time as order of relations. For an introduction to such predicaments, see Rovelli (2004a; 2014; 2015) and a series of lessons easily accessible on YouTube.

[3] Neo-Kantian scholars are used to distinguishing two strategies regarding the theory of relativity, namely "immunization" and, a step forward, "liberalisation", which corresponds to the broadening of conceptual synthesises. First, immunization preservers the 'transcendental ideality' of space and time in the face of the changes in their 'empiric reality'. Relativity deals with measurements, but not with their conditions – Natorp (1910, pp. 392-404). Natorp's stances were endorsed, almost unchanged, by other neo-Kantians such as Richard Hönigswald, Edward Sellien and Ilse Schneider, whereas Hermann Cohen highlighted that Einstein divorced from naïve substantivalism, to assume an "infinitesimal" and functional point of view on physical reality – Hentschel (1990, pp. 196-240); Ferrari (1996, pp. 113 and ff.). On the other hand, liberalization eradicates the primacy of pure intuition and allow us to endorse *a priori* forms as purely regulative invariants of experience – Friedman (2001). Hence no relevant argument to discern pure intuitions from pure concepts is provided. Space and time are as essentially conceptual as numbers and functions are in the construction of physical reality. Cassirer was so naturally receptive to the philosophical relevance of general covariance – Ryckman (1999).

[4] By the way, Cassirer (2001) upheld that if one were able to cut the link between the history of science and transcendental philosophy, the latter would become meaningless.

[5] The concept of 'manifold' has a specific place in geometry, but in this paper, I prevalently refer to its Kantian meaning. I will try to underscore when it will not be so.

following general principles of coordination – though giving up absolute stability in those principles –, which stem from the definition of function as the cornerstone within the formation of concepts. Accordingly, a theory that would radically emphasize a web of mathematical functions as its core might be still considered transcendental. That said, it will be worth your while to introduce the distinction between constitutive and regulative principles in section 3, to see which of them may align with LGQ (sections 5, 6, and 7). In the middle (section 4), I will provide the main historical takes that brought to LQG and its peculiar position in the field of quantum gravity.

2. Cassirer's Revision of Pure Intuition in the Light of Relativity Theory and Quantum Mechanics

It is indisputable that Cassirer's reinterpretation of pure intuition is profoundly liberal and that it entails a Leibnizian turn that partly sides with Kant's thought partly not[6]. However, Cassirer maintains that critical philosophy refers to some meta-levels of

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[6] I cannot discuss the comparison between Leibniz and Kant, but I can recall some fruitful topic for our endeavour. In general, their relation is made up partly of contrast and partly of an underestimated shared vision. The former is well expressed by Janiak (2016), when he states: "If we rigorously distinguish sensation from intuition *à la* Kant, then we open the possibility of objective representations that are akin to perceptions. We do not have a *sensation* of an infinite Euclidean magnitude (!), but we do have a singular and immediate representation of it. The Leibnizians lack room for this option". For the most part, Kant's critique of Leibniz is: one cannot avoid space when representing the distance between the objects, so their mutual relationship does not suffice to explain why space arises. Besides, it is not a concept, which means that one cannot subsume it as particular under a more general notion: the parts of space are still space. Indeed, no concept can contain "an infinite set of representations within itself" (*KrV*, A25/B40, Engl. tr. p. 175). It is not space that depends on how one defines the place, but it is the opposite: the definition of place presupposes space as intuition. However, it is to say that Kant's criticism is impulsive in some respect. In his *New Essays*, Leibniz explicitly refers to "common sense" as the source of the representation of space. He also pointed out that it binds with the external world, in a way that "the senses make us perceive", and this should suffice to provide both "definitions" and "demonstrations"; furthermore, space is for him not solely order of the "beings", but the "possibles", as though they were to exist – Leibniz (1981), II, V and XIII. Besides, Kant would agree with Leibniz that one must not reify absolute space: in the *Metaphysical Foundations*, it has a purely heuristic function, which one exploits to define all the possible relative motions (*MAN*, 4: 554 and ff.). In one of his letters to Clark – Leibniz (1890, 5, § 47, pp. 400-402) –, Leibniz similarly upheld that places are the relationships which one can settle between different objects sharing some order of coexistence, as they can change through motion: space is the name standing for the sum of such relative changes. In a few words, Kant seems to unveil the relativity of motion by focusing on the conditioning power of a given spatial frame of reference – though not inertial –, while Leibniz more strongly affirms that to allege the reality of space outside of the relationships originating from motions and places is nonsensical. As far as the relativity of motion is concerned, and despite Kant's research of a privileged "frame in which the centre of mass is at rest" – Friedman (2001), Pitts (2018) –, Friedman (2008) so highlights that Kant deals with "a definite sequence of rule-governed operations". This is the Kantian stance to which Cassirer will hold. A recent account of Cassirer's Leibnizian interpretation of Kant's space and time has been provided by Biagioli (2020) – but see also Ferrari (1996). According to Biagioli, the core of Cassirer's strategy is to highlight Kant's reference to Leibnizian terms and approaches to show that the Kantian position naturally develops from Leibniz.

knowledge that forerun and affect the determination of the empiric manifold. Cassirer aims to prove that despite the puzzling and sometimes dazed usage of the term, Kant's pure intuition points to establish purely conceptual and relational concepts that now replace the subjectivity once pivotal in Kant's definition of the 'transcendental ideality' of space and time[7]. Indeed, in Cassirer's philosophy, the Transcendental Aesthetic gives way to a functional program that culminates into the analysis of Klein's group theory. For the latter, space is the invariance of some definitions and properties, as well as the covariance of geometric transformations[8]. Transcendental philosophy so bends to an original sort of mathematical structuralism[9].

Since relativity theory widely relies on the concept of covariance, one may suppose that the coalescence of transcendentalism and mathematical structuralism radically emerges in the book that Cassirer devoted to Einstein's theory, i. e. *Zur Einsteinschen Relativitätstheorie. Erkenntnistheoretische Betrachtungen* (1921). If in SR a meta-definition of time is still required[10], the general relativity principle goes perhaps beyond a pure transcendental claim. Please consider an ideal space region with no gravitational influence, a box and an observer *K* situated in the box supplied with all the necessary measurement tools. In order not to float towards the top of the box, the observer

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[7] By the way, Kant's subjectivity is far from being merely perceptive. Indeed, such a subjectivity means the position of the observer in defining the relativity of motion, which is thus assumed as external (*KrV*, A23/B37, Engl. tr. pp. 174-178). In *Physics and Reality* (1936), Einstein even assumes it as the crucial and everlasting achievement of Kantian philosophy – Einstein (2003, pp. 23-24). In respect of Cassirer's deconstruction of transcendental subjectivity, see Ferrari (2015).

[8] Ryckman (2005) pointed out that there is some difference between 'invariance' and 'covariance'. The former is, as it were, merely relative to a passive change of coordinates physically associated "with the tangent space structure of spacetime", while the latter alludes to 'active' background independence. In this case, "diffeomorphisms can generate arbitrarily many solutions *S'* from *S* in the *same* coordinate system by differently spreading the values of the metric field functions $g_{\mu\nu}$ over the spacetime manifold of points" (p. 20). General active covariance so stands for applying *a priori* structures to any possible manifold. Cassirer's inclination for active covariance is clear since the analysis of Klein's program. Biagioli has conversely suggested that the triumph of function concepts in mathematics does not lie in the definition of the group and its invariance. Functionalism is actively related to "the discovery of a principle for the classification of a plurality of geometries" (2020, p. 37). So geometrical manifolds are not only to be shown as invariant against given transformations but shaped *a priori* moving from projective takes. Therefore, every possible manifold is conceivable by purely starting from theoretical principles. See at least Klein (1872); Ihmig (1996).

[9] See Schiemer (2018); Biagioli (2020); Reck (2020).

[10] Einstein's definition of time in SR is the following: "'The time' of an event is what is told to us by a motionless clock found at the place of the event simultaneously with the event, a clock which runs synchronously with a certain motionless clock and indeed synchronously with the latter at all times", Einstein (1905, p. 894, my transl.). As the reader may see, to synchronise his clock to the other one, the observer should know at least what *being in a place* means and look at the clock *when* an event is going to happen. These assumptions forerun the local time measurements. On the other hand, the application of causal laws presupposes the relativity of space and time – Ryckman (1999).

must tie himself to the floor with ropes. Through the box ceiling, in the middle, a hole is made and a hook, on which a constant force acts, moves the box up. Therefore, the observer is in equally accelerated motion with it. However, to another observer *K'*, situated in a not pulled by ropes frame of reference, the box will accelerate to reach an almost infinite speed in a very brief time – while to *K* acceleration can be exclusively transmitted by the reaction of the floor. If the observer in the box then drops an object from his hands, he notices that it falls to the floor. He consequently perceives and concludes that this is due to a uniform gravitational field, which acts upon every object:

> The observer will convince himself more and more that the acceleration of the body towards the floor of the box is always the same, whatever body he may use for the experiment. Moving from his knowledge of a gravitation field… the person in the box will conclude that he finds himself, together with the box, in a gravitational field which is quite constant against time[11].

One thus finds that (i) a free-falling body is locally equivalent to an inertial frame and that (ii) the gravitational force acting on the floor of the box corresponds with the acceleration -*g* of the box. While this seems to be far from intuition as a "a non-empiric, singular, immediate representation of space"[12], it still implies that there is nothing empiric in deciding *where* the observer is, whether within an inertial or a gravitational frame: "We have here no empiric proposition abstracted from particular observations, but a rule for our construction of physical concepts: a demand that we make, not directly of experience, but rather of our manner of intellectually representing it"[13].

Therefore, the liberalization in the mathematical structures leveraged by the relativists compels the transcendental philosopher to reshape his approach. The reference to a knowledge meta-level is maintained, but it is now not to consider how essentially stable *a priori* cognitions determine the manifold. On the contrary, one has to understand to what extent its variability falls under a system that, as it were, would anticipate variations through laws. In this respect, Cassirer hints at a vision according to which only the "*Eindeutigkeit der Zuordnung*" (1953, p. 415), namely the "uniqueness of coordination" that transforms subjective and contingent perceptions into physical and

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[11] Einstein (2009, p. 44, my transl.).
[12] Janiak (2016).
[13] Cassirer (1953, p. 428).

objective appearances, is under consideration[14]. This affects the canonical Kantian account since space and time now follow the rules of synthesis underlying them. As a consequence, Cassirer, by recalling the *Metaphysical Foundations*, points out that the "*logical universality*" of space cannot be mistaken for the "*physical universality* of real extension" (*MAN*, 4: 481-482) and concludes that: "All this finally demands that synthesis of the manifold, for which the term 'pure intuition' was formulated. The most general meaning of this term, which indeed was not always grasped by Kant with equal sharpness, since more special meanings and applications were substituted involuntarily in his case, is merely that of the serial form of coexistence and of succession"[15]. From Kant to Cassirer, we thus observe the rise of a new standpoint, in virtue of which pure intuition amounts to a purely functional account.

Pecere has noticed that Cassirer's reading that, in the formation of concepts, functions play the pivotal role is not wholly unveiled even in relativity theory since matter is still under consideration and not utterly surpassed by a unitary field theory (2007, pp. 474-478). That would happen solely within QM[16]. With the idealistic 'destruction' of matter claimed by the latter, we would be, however, beyond Kant. Therefore, to preserve a taste of Kantianism, Cassirer shifts from the epistemological to the "logical" analysis of physical judgements in *Determinismus und Indeterminismus* (1936). Such a task seems to be modest compared with other works, but it points to a way out from the intricacies of physical theory. Therefore, one implicitly suggests that transcendental philosophy can go ahead by canvassing and filing each sort of physical predicament in its 'formal' shape. In this respect, the critical philosopher aims to distinguish three levels that pertain to physics. In the first place, one faces metrical judgements since the empiric content of physical theory essentially consists of measurements. In the second place, they do not

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[14] "*Eindeutigkeit der Zuordung*" was a widespread expression in the epistemology of the early XX century. It generally meant the coordination of mathematical structures to empiric data – Ryckman (2005, pp. 28 and ff.; Howard, 1992). Nevertheless, Cassirer gave a nod to the old-fashioned Kantian approach. When he suggests that it is not a stretch to contend that Einstein's observer is to shape his assertions via some non-empiric preliminary considerations, he is relying on Kantian pure intuition. Indeed, such reference finally amount to the preliminary definition of "event": "The thought of space and time in their meaning as connecting forms of order is not first created by measurement but is only more closely defined and given a definite content. We must have grasped the concept of the 'event' as something spatio-temporal, we must have understood the meaning expressed in it, before we can ask as to the coincidence of events and seek to establish it by special methods of measurement", Cassirer (1953, p. 420).

[15] Cassirer (1953, p. 418).

[16] However, at least potentially, Cassirer's exposition is coherent with active general covariance, as widely recognised by Ryckman (2005, pp. 15 and ff., pp. 42-46). See footnote 8.

merely inhere in supposedly absolute objects for one addresses measures via laws, which are in turn relations between given variables. And finally, laws are not self-sufficient in explaining why some relations are more important than others. We gave the example of the equivalence principle in GR: without it, one can only provide instrumental reasons to justify the preference accorded to relativity theory. The latter works better than Newtonian celestial mechanics, and there would be nothing else to say. If no principles entered the first meta-level of physical knowledge, one would uniquely gather accidental connections between the appearances and laws would not frame any coherent account of the phenomena[17]. But significantly, Cassirer does not confine himself to such constitutive principles; he takes a step further towards a subsequent meta-level containing a reminder about the definition of physical laws. That is, a criterion to coordinate principles with laws and laws with measurements. It is so clear that such a take will never come into view since it is a mere "educated guess"[18] that illustrates a regulative principle: "*Looking* for some increasingly universal laws is a basic feature, a rule of our thought. The principle of causality is nothing but a regulative principle. In this respect, it is given *a priori* and is transcendental: it cannot be tested by experience"[19]. Cassirer could so relativize Heisenberg's attack to causality. Since Heisenberg (1927) abided by a sort of Machian turn, according to which physics should solely describe the formal connection of perceptions, Cassirer had free reign to interpret the uncertainty relations as merely metrical judgements. Indeed, once they are banished from the field of principles, they cannot affect causality because the latter is not an empiric concept. It is but a principle that guides physicists from principles to measures.

In conclusion, we noticed that a transcendental account discloses some knowledge meta-levels, which foreruns the empiric one. In the next section, we will see how to distinguish them from one another by more clearly parting constitutive from regulative *a priori*.

3. Constitutive and Regulative A priori

The liberalisation of pure intuition paralleled the conventionalist trend that, thanks to Poincaré and Duhem, appeared in the philosophy of science at the beginning of the XX

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[17] Friedman (2001, pp. 65-66).

[18] *Loc. cit.*

[19] Cassirer (2004, p. 67, my transl.).

century and showed to be very fruitful when Einstein leveraged it to draw the revolution in our representation of space and time according to relativity theory. Particularly in GR, one cannot shape any spatio-temporal manifold before having solved Einstein's field equations[20]. In this respect, Cassirer then noticed that semi-conventional principles are now at play in physics since geometry may change with the spacetime curvature[21]. However, a rigidly conventionalist approach seems to allude to a sort of choice – made by the observer – that is not what general covariance foresees. On the contrary, if we might refer to it via the Kantian lexicon, general covariance seeks to establish a synthesis of all subjective synthesises. For instance, in Eddington's differential geometry, objects are made up by synthesising all aspects for any conceivable observer to make the physical world such a world as seen "from the point of view of no one in particular"[22]. It is nothing else but Einstein's criterion of 'observer-independent' objectivity, and the idea expressed by Cassirer in this excerpt:

> Every assertorical affirmation of a reality, at the same time, implies an assertion concerning certain relations of law, i.e., implies the validity of universal rules of connection. When the phenomenon is brought to a fixed *numerical expression*, this logical relativity becomes most evident. The constant numerical values, by which we characterize a physical object or a physical event, indicate nothing but its introduction into a universal serial connection[23].

In fitting with these requirements, general covariance seems to be an analytic clarification about what one should intend as a physical law, as Cassirer himself points out[24]. The relativistic spatio-temporal measures in SR or the equivalence principle are approximate expressions of the "uniqueness of coordination", conceived as the model that should inspire every physical theory. Accordingly, in Cassirer's historical account,

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[20] As Ryckman has shown (2005, pp. 19 and ff.), this depends on the confutation of the 'hole argument', which culminated in GR's generally covariant equations. Since the metric field is an essential take to define the points-coincidence, the latter has to presuppose always more than (merely) topological space. It is the only way to ensure physical significance to GR's mathematical structures.

[21] Cassirer (1953, pp. 365-366).

[22] Ryckman (2005, p. 9 and ff.; pp. 177-234; see also 1999, pp. 608-612).

[23] Cassirer (1953, p. 140).

[24] *Loc. cit.*, pp. 383-384. Ibongu reported a private note in which Cassirer would have said that he was very close to the Vienna Circle (2011, p. 57). However, it is to say that Cassirer engaged a long epistolary dispute with Schlick that culminates in the explicit rejection of both the dualistic representation of the "uniqueness of coordination" and the predicament that coordinative principles are (utterly) conventional (see the letter to Schlick dated October 23, 1920, in Cassirer, 2009, pp. 50-51).

general covariance sets a regulative *a priori* to which physics must tend to eradicate anthropomorphism from its reign. Furthermore, it finally supports the defeat of substance in the struggle for the formation of concepts and the subordination of objects to laws.

In the recent neo-Kantian debate, there have been attempts at reducing the impact of such an analytic tendency by holding to intermediate meta-levels in the definition of scientific knowledge. That means that one has at least two meta-levels and cannot conflate the two into one analytic premise. It is one thing to presuppose that appearances obey lawful relations; it is another to provide given coordinative principles. Friedman's tripartite structure is then particularly striking and contrasts to some extent Cassirer's utterly idealisation[25]. According to Friedman, each physical theory consists of a mathematical, a mechanical and a properly empiric part[26]. Constitutive *a priori* belong to the second one since they serve to coordinate mathematics with empiric laws and facts; therefore, mathematical and constitutive principles together represent the empiric space of reasons that allows the passage from mere 'logical' to 'real' possibility. They are thus distinct from concerns about the ideal nature of laws[27]. While mathematics is never empirically testable, the coordination of mathematical structures to empirical laws and facts can, indeed, be called into question. The constitutive *a priori* are not subject to empirical proofs, but their application to empirical data is never fixed once and for all. This emerges by simply focusing on Friedman's examples. The constitutive *a priori* usually spring as empiric truths, though not well established, that are then 'elevated' to principles. The constancy of the speed of light in a vacuum or the equivalence principle, which are to some extent facts originating in electrodynamics and Newtonian mechanics, did not find clarity within them. An interesting consequence of

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[25] Cohen remarked it very early in a private comment to Cassirer. In a letter dated August 24, 1910, he addressed *Substance and Function*'s epistemology as a "complete idealisation of all matter" since Cassirer did not take the categorical character of 'relation' – see, among others, Giovanelli (2016).

[26] The comparison between Cassirer and Friedman may be hard to realize since the latter refers to a neo-empiricist approach with which the former did not side. Indeed, neo-empiricist theories of knowledge, such as that of Schlick or Reichenbach, dwelled on a rigid distinction between mathematical truths and empirical facts, while Cassirer could not accept such a dualistic standpoint. For this reason, he even locates what Friedman considers as constitutive and intermediate principles in the first meta-level not to give rise to substantial contraposition. Therefore, mathematical laws are lowered under the claim for increasingly general ways of finding and forging new lawful relations. However, I did not include such a take in the body of the text, for Friedman's position is not dualistic.

[27] A general appraisal of Friedman's relativised *a priori* is to be found in Ryckman (2005, pp. 245-249).

this model is that the constitutive *a priori* will be tested at a later stage once they have favoured the rise of a new theory[28].

It is thus clear that Friedman is trying to reduce the analytic impact of Cassirer's reading by more clearly outlining an intermediate level between laws and facts[29]. Friedman's and Cassirer's *a priori* cognitions are, nevertheless, equally embedded in the history of science and explain its 'progress'. Indeed, the constitutive *a priori* are provisory rules that ideally converge to the posterior scientific idealizations, which is also the point that Cassirer inherited from his Marburg masters and followed throughout his work[30]. Furthermore, both accounts elucidate that a proof for convergence is given within mathematics, where later principles and equations show to contain the earlier as limiting-cases, occurring when some particular conditions are at play. However, Cassirer more broadly points to the culmination of scientific theories, and his regulative principle[31] seems to eventuate somewhere in an unchangeable and universal truth, whilst Friedman maintains that the different stages of scientific progress pertain to the evolution of communicative rationalities[32] that are so, at least to some extent, incomparable to one another. The continuous development of physical concepts is not monotonic as that of

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[28] Friedman (2001, pp. 79-92).

[29] By the way, neither Einstein was foreign to such meta-levels. Despite his sympathetic judgement of empiristic philosophy, he refers to propositions that mediate between abstract (both logical and mathematical) notions and "primary concepts", which he intends as the intuitive reasons of sense experiences. He admits, nonetheless, the infinite proliferation of such propositions and a flexible distinction between them and physical laws – Einstein (2003).

[30] See Friedman (2001, pp. 65 and ff.).

[31] On the other hand, we saw (footnote 8) that general covariance does not remain (utterly) analytic since it provides the metric of the field. It is not by chance that Ryckman (2005) refers to Cassirer's usage as constitutive and not (merely) regulative, since it serves as a guide, but also points out *"what is a possible object of fundamental physical theory*" (p. 16).

[32] Friedman takes the concept of communicative rationality from Habermas to cope with Kuhn's incommensurability – Kuhn (2012, pp. 173 and ff.); Friedman (2001, pp. 47-68). Indeed, on the one hand, Friedman accepts that paradigms are non-intertranslatable, though he highlights that Kuhn's standpoint on discontinuity can only count for instrumental but not rational success. Kuhn seems to explain the change of paradigms by prevalently leveraging empiric reliability, and Friedman thinks that this does not fit with the intense commonality experienced throughout scientific research. On the other hand, Friedman seems afraid that a purely regulative conception of the *a priori* cognitions would discard the conditional character of scientific truths. To achieve his goal, Friedman so combines Cassirer's regulative *a priori* partly with the constitutive ones, as they are developed within logical empiricism, and partly with Habermas' account, which allows him to more strongly claim for the provisional character of scientific evolution (*loc. cit.*, p. 66, footnote).

mathematics[33] since constitutive principles within an earlier framework may shift to empiric laws in later ones[34].

In conclusion, Friedman (2001) upholds that principles such as simplicity or legality do not entertain the *a priori* moment of mathematical physics because they could not provide any coordination between theoretical frameworks and empiric data; they conversely resemble mere analytic truths abstracted from pure mathematics. Nevertheless, Friedman accepts that functionalism works as a necessary extension of Kant's original project. To Kant's eye, Euclidean geometry and Newtonian physics showed how to inject the *a priori* forms of the human mind into our experience of nature. On the other hand, non-Euclidean geometry and non-Newtonian physics free the Kantian theory of knowledge when confronted with the evolution and change of scientific theories. In this way, transcendental philosophy deals not only with a given manifold, but it is open to determine every possible manifold under laws that may change as well[35]. In this case, it might be that the first meta-level should display covariant equations that prescribe formal rules on how to shape laws and account in principle for any possible variation in the manifold. One should see whether LQG is compatible with both constitutive and regulative *a priori*, one or none of them. But before that, let me outline a short history of the general issue of quantising gravity.

4. Quantum Gravity: A Short Historical Prospect

The reader might know that QM and GR appeared to be soon incompatible. In short, the question is that GR is not consistent for spacetime at the Planck scale, and QM

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[33] In this respect, Heis (2015) forged the category of "developmentalism" to display the intrinsic logic according to which mathematical concepts evolve as 'realizations' of earlier stages of the same "logical structure".

[34] However, both Friedman (2001) and Ryckman (2005) realize, following Cassirer, that, to some extent, concepts intrinsically develop from themselves in physics too. For instance, general covariance sprang from the widening of the principle of locality that one so elevates from empirical evidence to an ideally constitutive/regulative principle.

[35] As a matter of fact, that is Einstein's peculiar endorsement of Kant in his later writings. Indeed, in his reply to the contributors of Schilpp's volume on his work, he pointed out that one leverages "categories" in addressing observations and empiric facts, but not as *a priori* forms conditioned by "the nature of thought" – Schilpp (1959, pp. 663-688). They are conversely "free conventions" – see Einstein (2003, pp. 22-25). A letter to Cassirer dated June 5, 1920, contained the same remarks: "I recognize that we have to approach experiences (*Erlebnisse*) starting from some conceptual functions, so that science may thereby be possible; but I am not persuaded that in our choice we are forced in virtue of the nature of our intellect", Cassirer (2009, p. 46, my transl.). See also Ryckman (1999, pp. 607 and ff.).

does not deal with curved spacetime[36]. Therefore, there is a need for accounting a whole field that refers to both relativistic and quantum assumptions, namely quantum gravity. There are essentially two different ways of surveying it, to wit, respectively, String Theory (ST) and LQG. The main difference is that ST does not quantise the metric tensor γ, which means that strings propagate within a fixed background (which is generally not 4-dimensional[37]), without directly impacting the concept of time. Hence, they explain the emergence of 2-dimensional surfaces that represent all the possible "stories" of the decay of a particle. LQG conversely tackles the fluctuations of spacetime and thus the quantisation of the gravitational field. Yet they both share the result of providing finite approaches to quantum gravity, although in ST one leans toward the unification with other forces in nature. They also conceive GR's spacetime as an emergent notion from a more fundamental theory (Rovelli 2004a, p. 7).

Of course, it is not the goal of a philosophical paper to establish which theory should be preferred or, even worse, which has the most reliable empiric potential; therefore, I deal with LQG because Rovelli's account openly leverages those philosophical questions which were focal to transcendental philosophy. Moreover, Rovelli himself considers philosophical clarification as a foundational aspect of the theory.

The roots of quantum gravity are in the work of the Soviet physicist Matvei Bronštejn, who vindicated the existence of a fundamental discrete length in a highly fascinating formula around 1936: $L_p = \sqrt{\frac{\hbar G}{c^3}}$ (1). Such a relation hints at a fundamental constant in nature about spacetime, which seemed to be lacking so far. The formula

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[36] In GR, the potential proliferation of different spacetimes is limited via the presence of a single metric tensor γ per model – so one metric and one causal structure at a time. To figure out all the intricacies of tying GR and QM, the reader can imagine facing the determination of the gravitational field in a single spot: if this spot is as big as the Planck scale is, then one is about to find the very renowned singularity foreseen by the theory of relativity. Hence, according to GR, spacetime at the Planck scale should vanish and, with it, all of our acquaintance with a supposedly empiric reality – Butterfield-Isham (2004).

[37] I note in passing that facing more than four dimensions may allow us to refer to some Kantian distinction between *phenomena and noumena* since there are sufficiently overlapped extra-dimensions that do not cause any perceivable effect – Butterfield-Isham (2004); Penrose (2004). More in general, there have been attempts in seeking Kantian-friendlier quantum gravity accounts in particle physics because it is possible to work here with a fixed background geometry, particularly with a flat spacetime indirectly observable at a large distance – Pitts (2018). Nonetheless, such approaches discard the relativised or liberalised neo-Kantian versions, which hinge on the constitutive/regulative role of principles that replace the primacy of pure intuition and are promptly consistent with historical changes (see section 3). I thus consider those attempts as maintaining an "immunising" strategy since they only focus on one of at least two alternate theories, while they reject the other that does not directly side with a transcendental standpoint.

combines the three and most important constants of nature, to wit, c, G and h: relativity, gravitation and quantum theory appear thus to merge into a single relation – Gorelik and Rotter (1995). Without referring to Bronštejn's ideas, Werner Heisenberg also upheld the urgency of finding a third constant of nature which dealt with length[38]. That would lead us to establish a unitary frame through which expressing relations between physical magnitudes. Say one is to address a 1 x 10^8 m/s speed: it is nothing but 1/3 c. Since the same is for h and L_p, it is not a stretch to contend that pure relationism – that is, functionalism – may be tied to a discontinuous account of spacetime. Bearing in mind the importance of the principle of continuity of Cassirer's philosophy of science, this might sound weird, but it is also true that QM provides, in Cassirer's parlance, strong evidence of the 'primacy' of laws over objects (2004). If one thus conceives of a theory capable of harmonizing general covariance with quantum field methods, one may perhaps expect to couple a regulative principle concerning how to formulate laws with such an ontological predicament.

But going with history, Wheeler-De Witt's equation originated a focal breakpoint in the subject: while physicists used to approach functions in the general form $x(t)$, this equation puts time aside. Time does not take part in it: $\hat{H}(x)|\psi\rangle = 0$ (2). $\hat{H}(x)$ is the Hamiltonian constraint from GR, which now does not address the evolution of the system, just as ψ, as the wave function of the universe, is not the probability cloud referring to a particle which can be located, after a given interaction, in a 3-dimensional space. It is, on the contrary, the probability cloud involving all possible configurations of spacetime.

That seems to be pure mathematics, but there was plenty of it that appeared to be merely theoretical before one came to show some application. However, when, in the 1950s, Penrose started working on spin-networks, the discreteness he thought of as crucial for spacetime yet implied the relational character of physical objects (or events). Accordingly, the quantization of the fields is promising for a relativized *a priori* since it puts aside the last 'vestiges' of objective reality, as already vindicated by the relativists[39]. Hence functions canvass relations between given variables, which in turn stands for the relations between events. This radical form of relationism is ensured via the introduction

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[38] To closer inspection, Einstein prefigured, around that time, the introduction of a fundamental length in physics as an alternative to the conception of rods and clocks as independent objects. He seemed aware, however, that would have implied the crash of his field theory (Ryckman, 2017).

[39] See among others Ryckman (1999, p. 610).

of some quanta of space, thereby relying on geometrical structures called graphs or spin-networks. A graph is made up of knots and links, and a whole and closed circuit is called a loop; moreover, as in QM, those graphs have to be endowed with a spin notion, which one must refer to via simple numbers. A peculiarly probabilistic calculation allows us to define the spacetime one is in, although in Penrose's original method it was confined to the unique case where three links merge into a knot.

The extension of such a program was reached in the 1980s when Ashtekar, Smolin and Rovelli succeeded in providing consistent solutions to the Wheeler-De Witt equation for the loops. At this point, one can compare the lines of the gravitation field with Faraday lines, except their quantisation. Hence, considering that the loops are solutions of the equation for every closed line of the field, one may say that the electric field vanishes outside the line[40]. It is also worth noticing that it is not possible to manipulate the wave function by assuming the pilot-wave hypothesis to have canonical spacetime; indeed, the states do not rely on "the configuration space of all 3-metrics"[41], and functions, once again, are not of the type $y=f(t)$. In conclusion, LQG arguably captures a functional approach that entails extreme relationism; thus, if a generally covariant formulation is reached, it will appear to be compatible only with a regulative *a priori* cognition. Is that true?

5. The Conceptual Presumptions of LQG

Essentially, LQG seems to assume no separation in the background spacetime, but it infers that the quantisation also affects the gravitational field. Therefore, LQG is a quantum theory: it interpolates general covariance with QM tools, basically a Hilbert space of states and the operators referring to the measurements of given quantities. As in QM, one will have transition amplitudes to determine the probability of such outcomes – although they now refer to spacetime. That said, it is sufficient to rely on 4-dimensional spacetime without implying supersymmetry.

The main consequence of such an approach is to reject both the idea that space(time) is the continuum upon which things are located and time the straight line along which events may happen. But no news is good news: we saw that transcendental

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[40] Rovelli (2004a).

[41] See Butterfield-Isham (2004).

philosophy survived such a naïve version of Kant's pure intuition to rather annihilate it. However, the fact that the concepts of space and time are related to information and probabilistic assumptions, as perhaps never before in the history of physics, is worth your while to deep consideration.

First, information appears in the characteristics which Rovelli thinks of as being the pinnacles of QM, i.e. "granularity", "indeterminism", and "relation". In particular, granularity elucidates that the information about a given system is finite for only certain possibilities will tend to become actual, while the others get lost or become irrelevant. That implies indeterminism and the (Kantian) reminder that our knowledge is limited. Finally, interactions, though they relate "physical facts" and not "mental concepts[42]", also encompass "the information we have about a given *system* as it follows from our past interactions with it; such information will allow us to foresee the effect on us of future interactions with the system itself"[43].

It is so clear that principles such as granularity, indeterminism and relation appear to be more than empiric truths provided by theory. For instance, in response to Oriti, Rovelli (2009) points out that granularity cannot stem from an algebra with related continuous observables; on the contrary, it relies on the computation of the spectra of a class of operators related to the geometry of spacetime. Therefore, he considers space granularity as constitutive for the quantum nature of the gravitational field[44]. Of course, Rovelli does not directly refer to neo-Kantian sources, but it sounds reasonable that if he had consistently read about constitutive *a priori*, he would have more willingly reconsidered the decision issued in many of his writings. Indeed, granularity especially fits with Friedman's demands: it emerges from QM and goes through Quantum Field Theory (QFT) to play the role of a non-empiric convention that later experiments might confirm. Accordingly, it will be empirically untestable until later developments surpass

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[42] Rovelli (2014, p. 221); Id. (2020, pp. 110 and ff.).

[43] Rovelli (2014, p. 214, my transl.). See also Rovelli (2017, p. 130). I thus find noteworthy that Rovelli seems to ignore a crucial result implied by Heisenberg's account of the wave function. Indeed, Heisenberg explicitly pointed out that the latter involves both objective and subjective statements since it refers to the relations between potential facts, just as to our relationship with a given physical system – Heisenberg (1958, p. 53). That brought Heisenberg to claim for the introduction of "a strange kind of physical reality" standing in the middle between possibility and reality, "the idea of an event" and "the actual event" (*loc. cit.*, p. 41). Since Rovelli also notices that Kant correctly holds that knowledge always depends on the correlation between the 'subject' and the 'object' (2014, p. 168), it is hard to explain why he so greatly emphasize that he is an anti-Kantian. In this respect, one may only say that Rovelli instinctively leans toward a putatively monistic process ontology – Whitehead (1929); Dorato (2015).

[44] See Rovelli (2004b, pp. 150-151).

it, but it will provide physical theory with enduring consistency as long as it takes. Indeterminism and relation conversely seem regulative principles because they tend to emphasize pure relational concerns. And, to some extent, it is so. However, since descending from granularity, they must have some constitutive impulse. Indeterminism recalls us that our experience selects only given portions of everything that will be possible in principle, while relation points to a given shape of interaction that involves us as actors in the determination of a supposedly external and objective reality. If one were not to charge Kantian philosophy with antiquity and narrowness in the philosophy of physics, one might conclude that Rovelli makes use at least of *a priori* constitutive principles.

6. Space(time) in LQG: a semi-Kantian Point of View

In our survey of the neo-Kantian tradition, we saw that the liberalisation of Kant brought to call the stability of *a priori* cognitions into question. In the first place, that meant to give up pure intuition and rigorously assess as *a priori* only the coordination between the intellect and the manifold and, consequently, the invariance or covariance criteria established as the goal of physical theory. In the second place, we saw that the shape of an intermediate meta-level between mathematics and empiric facts is crucial to establish some mixed principle that melts the fixity of categories but maintains their constitutive power. That said, it is clear that rejecting a supposedly Kantian representation of space and time is not enough to put transcendental philosophy aside. Nevertheless, it might be interesting to see how constitutive and regulative principles eventuate in a physical representation of space and time. Let us start from this excerpt:

> There is a crucial difference between the photons, quanta of the electromagnetic field, and the nodes of the graph, ‘quanta of space’. Photons do live in space, whereas the quanta of space are space themselves. Photons are characterized by ‘where they are’. On the contrary, the quanta of space have no place to be in, for they are ‘place’. They carry other crucial information, which characterizes them: the information about which other quanta of space are next to each other – what is next to what. This information is expressed by the links of the graph. Two nodes tied by a link are two close quanta of space. They are two grains of space touching each other. It is this ‘touching’ that builds the structure of space. These quanta of gravity represented by nodes and lines, I repeat, are not *in* space, *they are space*… The localisation of the single quanta of space is not defined to something, but it is only

> determined by links, and only according to the relationship that the one has to the other… And then there is the other novelty of quantum mechanics: we must not think of things as 'they are', but rather of as 'they interact with each other'. This means that we should not conceive of spin-networks as physical entities, as though they were a sheet upon which world is resting. We should think of them as the effect of space on things. Between two interactions, just as an electron does not stand in a place, but is diffused in a probability cloud over all places, space is not a specific spin-network, but a probability cloud over all possible spin-networks. At a very tiny scale, space is a floating pullulating of quanta of gravity acting on each other and all together they act on things, and they manifest themselves in these interactions as spin-networks, grains in relationship to each other. Physical space is the whole tissue deriving from the constant pullulating of these plots of relationships. Taken as they are, lines are nowhere nor in any place: they create, through their interactions, places. Space is made up of the interaction of the quanta of gravity[45].

After all of our endeavour, it would be unfair to address the "floating pullulating of quanta of gravity" as an anti-transcendental take. It might be so if a rigidly Kantian stance were under consideration. Indeed, constitutive principles come into play when one switches from the general discussion to the empiric determination of a given manifold. The latter depends on the structure and motion of graphs or spin-networks that emerge from the lines of the gravitational field, the links, which connect some nodes. The nodes are volumes, whereas the links are surfaces. Accordingly, considering that the lines are quantised, spacetime *in itself* is the probability cloud involving all the possible geometrical configurations of spacetime, but *to us*, it is the interaction that picks out a given possibility to become actual. Then spacetime is not conceivable without granularity and a relational assumption that actualises our interaction with it, thereby selecting such interaction as a limited perspective on a whole range of possible outcomes[46].

I am conversely afraid that when the closeness of the quanta outweighs their simple interaction, Rovelli did not correctly put his thoughts in words. Indeed, Rovelli clearly holds to the primacy of contiguity in assessing the emergence of spatial relations between the quanta of space; however, when he says that spin-networks are the "where" in respect of which something else (such as photons and matter) can be localised[47], he is

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[45] Rovelli (2014, pp. 150-52, my transl.).

[46] It is worth saying that spacetime is thus a sort of critical reminder, just as absolute space was in Kant's *Metaphysical Foundations* (see footnote 6).

[47] See Rovelli (2004a, p. 14).

only displaying a distinguishing property of the gravitational field. Other excerpts point in this direction[48].

Such an interpretation also has a physical counterpart. Penrose (2004) contended that it does not matter how ‘near’ a loop may be to another. That is, metrics is generated within the loops[49]. Accordingly, the spin-networks states are independent of coordinates, and it is difficult to interpret their *superposition*. The quanta of space are the appearances of “a quantum superposition of states whose geometry has discrete features, not a collection of elementary discrete objects”[50]. How should one thus think of their relative collocation? They are not localised indeed. In general, it is tough to think of two spacetime points as spacelike separated if one relies on probabilistic metrics[51]. Even though this seems to cast a shadow on the causal structure of relativity theory, the constitution of quantum space still follows from the quantisation of the volume; that is, contiguity hinges on the existence of “grains of space”[52]. Again, one holds to space granularity as a constitutive feature of quantum gravity and assumes it as a foundational aspect of the theory. That implies that when one is distancing oneself from Kant’s pure intuition, one might not have overcome neo-Kantianism.

Yet another question lurks just around the corner: what about time? We saw that it is not involved in the fundamental equations of LQG. What does it mean?

7. The Concept of Time in LQG and Functionalism

Let us start from QM, where time is not an operator. An operator, according to Born-Wiener, is a rule through which one can gain a given function $y(t)$ from $x(t)$. Operators entail the triumph of functional thought in physics since a physical object is not represented here as a thing in any sense, and the eigenvalues of an operator are not the same as the magnitude they stand for[53]. But that does not precisely apply to time, inasmuch as it is a background parameter like in classical physics. Accordingly, there

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[48] Just as a way of example, see: Rovelli (2004a, p. 55). But also consider this: “Things (the quanta) do not stand in space, they stand close to one another and space is the whole tissue of their contiguity relationships”, Rovelli (2014, p. 153, my transl.).

[49] I am thus doubtful, as Penrose (2004) claims, that through general covariance, one addresses (merely) topological relations – in this case, links and intersections (see section 4 and footnote 20).

[50] Rovelli (2004b, p. 110).

[51] See Butterfield-Isham (2004).

[52] Rovelli (2004a, p. 13).

[53] See Jammer (1966), p. 222; Prigogine-Stengers (1979).

could be still something evolving in time[54]. In LQG, time, on the contrary, seems to vanish and be replaced by processes. But processes are relational and it is thus striking that, like Einstein[55], Rovelli does not give up the dynamical representation to endorse the hypothesis of the block universe.

However, it is worth saying that a process is not solely a theoretical concept through which physicists try to communicate to folks what they are doing in their office, but rather a technical point. A process is a region of spacetime[56]. More specifically, what happens at the Planck scale depends on the interaction between the boundaries of different regions of spacetime. It follows that the very grounding geometrical idea of LQG is the study of the intersections between 2-dimensional surfaces and the loops; 2-dimensional surfaces of this sort are located in 3-dimensional spaces, which in turn intersect the loops in several points. One solely has the surface where the intersection is. Therefore, the assertion that the spin-networks are made up of the following items: 1) nodes, viz. the volumes; 2) links as generating surfaces, has obtained a physical basis. Accordingly, one can write the gravitational quantum state as follows: $|j_l v_n\rangle$, where j is a semi-integer number, l is the number of links and n that of nodes (v is the volume). Volumes (nodes) are connected through surfaces (links), but surfaces are quantised too, as shown by this equation:

$$A = 8\pi L_p^2 \sqrt{j(j+1)} \qquad (3).$$

Once again, time is not involved in the equations. Since it is unobservable, there is nothing like temporal information. Indeed, the evolution in time is replaced by the spinfoams emerging from the motion of the spin-networks. As a consequence, spinfoams do not happen within spacetime, but they stretch it at the Planck scale to produce reality in its becoming. It is anew clear that in this case, since no fields are lying on a given spacetime, physical reality is nothing but the interaction between the fields. Two other statements from Rovelli make clear what I just upheld:

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[54] Transition probabilities change in time, but there are of course the constraints due to the uncertainty relations, so that a real clock would, at least sometimes, run backwards – Butterfield-Isham (2004), Rovelli (2009). Please also bear in mind that, according to Heisenberg (1958), it is possible to follow up the wave function as evolving in time.

[55] See Weinert (2005).

[56] See Feynman (1997); Rovelli (2014).

> i) The central idea defended in this book is that in order to formulate the quantum theory of gravity we must abandon the idea that the flow of time is an ultimate aspect of reality. We must not describe the physical world in terms of time evolution of states and observables. Instead, we must describe it in terms of correlations between observables (2004a, p. 267).
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> ii) As far as we know, there is very little to be resembling with time from our experience. There is no 'time' variable, no difference between past and future, no spacetime. However, we can still write equations that describe the physical world. In these equations, variables *evolve the one in respect of the other*. It is neither a 'static' world nor a 'block universe', where change is illusory: it is conversely a world of events and not of things (2017, pp. 164-165, my transl. and italic mine).

As far as I can see, this is but an endorsement of Cassirer's functional account. Of course, Rovelli sides with a neo-Kantian position only accidentally, but that does not impinge on the importance of such an assumption. If physical reality consists of the relations between observables, the only logical structures that would reliably depict them eventuate in a web of mathematical functions: "What we need to do is simply confine ourselves to list variables *A, B, C…* which we observe, and then write the relations between such variables, to wit, the equations standing for the relations *A(B), B(C), C(A)…* which we observe; but not for the functions *A(t), B(t), C(t)…* which we do *not* observe"[57]. The link between functions and physical reality is ensured, on the one hand, by the fact, already recalled, that general covariance allows us, together with quantum methods in the calculation, to provide the gravitational field with a specific spacetime metric; on the other hand, by the restriction that variables that enter the functions correspond to observables. It is arguable that constitutive *a priori* interplay between these two horizons. If among them time does not emerge, that solely means that it does not partake in the reign of physical appearances, but in no way that these are merely chaotic semblances. It is the opposite: when the references to pure anthropomorphic representations are out of play, scientific knowledge has reached its pinnacle[58].

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[57] Rovelli (2014, p. 158, my transl.).

[58] Nevertheless, it is undeniable that Cassirer's later philosophy is a philosophy of man (broadly conceived). Ryckman has written beautiful pages on the topic (1999, pp. 613-614), though I have to address some divergence. Essentially, Ryckman correctly suggests that general covariance allows Cassirer to conceive of the relativity of scientific knowledge and to embed it in a whole philosophy of culture. Cassirer would intend, in practice, that since relativity theory taught us to firmly distinguish the physical conceptions of space and time from their 'everyday' versions, it also compels us to admit that space and time are in general relative to each domain of knowledge (myth, perception, language, science). In short, just as the principle of general covariance does not content with (merely) topological space, the philosophy of symbolic forms

8. Conclusive Remarks

In this paper, I presented the basic guidelines for a neo-Kantian reading of LQG. In the first place, I briefly outlined in section 2 how Cassirer answered to relativity theory and QM when they challenged Kantian philosophy. Since LQG combines relativistic with quantum assumptions, it is reasonable to expect that successful reinterpretations of transcendental philosophy may work for quantum gravity as well[59]. In short, I showed that Cassirer's strategy consisted of broadening that functional account he developed in his early writings; indeed, it perfectly coupled with theories that claimed for a full liberalization in the description of spacetime and an anti-substantivalist ontology. In the second place, the principle of general covariance and the equivalence principle came into play respectively as regulative and constitutive *a priori*. Although such a distinction is fluid to some extent, I tackled it in section 3 by relying on Friedman's *Dynamics of Reason*. We saw that constitutive principles require us to assume an intermediate meta-level that links mathematical laws to empiric data in order to avert analytic turns in the core of transcendental philosophy, as somewhat implied by Cassirer's "uniqueness of coordination" – which is a regulative *a priori*. Afterwards (section 4), I provided a short historical prospect of quantum gravity programs to shed light on the position taken by LQG. In sections 5 and 6, I dealt with Rovelli's usage of granularity, indeterminism and relation as constitutive principles to finally point out that they are particularly influential in the representation of space. In section 7, I illustrated that Rovelli's philosophy of science peaked with his functionalism, conceived as a consequence of the vanishing of time. That said, I concluded that Rovelli is, unknowingly though, putatively neo-Kantian.

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aims to provide a frame of how the 'topology' of spirit eventuates in 'locally' objective and symbolic forms. What I just upheld is precisely my point of divergence from Ryckman: in Cassirer, 'anthropomorphism' does not resurface in the philosophy of symbolic forms either since all anthropomorphic shifts are relative to a 'systematic philosophy' with its constitutive principles (basically "expression", "representation", and "symbolization"); that is, to a global phenomenology of culture. It is a philosophy of man but seen from the standpoint of no one in particular, as, I think, the usage of the "invariants of experience" (space, time, number and function) to approach the exposition of the forms may confirm.

[59] As far as I know, the first scholar to suggest some compatibility was incidentally Ryckman (1999, p. 608, footnote n. 40).

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