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*FROM SCIENTIFIC STRUCTURALISM TO TRANSCENDENTAL STRUCTURALISM**

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RESUMO *No debate atual entre realismo científico e empirismo, ambos os lados parecem abraçar algum tipo de estruturalismo como um componente importante de suas descrições sobre a ciência. O realismo estrutural é geralmente apresentado em duas versões: uma ôntica e outra epistêmica. Tem-se argumentado que o* realismo estrutural epistêmico *(ESR), por sua vez, é próximo, se não idêntico, a uma abordagem kantiana. Nosso objetivo neste artigo é mostrar que esse não é o caso. Sendo o ESR fundamentalmente uma posição realista, queremos defender que ele não pode ser totalmente compatível com uma abordagem transcendental. Uma posição kantiana mais coerente é aqui defendida sob o nome de* estruturalismo transcendental *(TS). Neste artigo, partiremos da interpretação de Henry Allison do idealismo transcendental para estabelecer as devidas distinções entre ESR e TS.*

Palavras-chave *Realismo estrutural ôntico, realismo estrutural epistêmico, estruturalismo transcendental.*

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ABSTRACT *In the current debate between scientific realism and empiricism, both sides seem to embrace some sort of structuralism as an important component of their descriptions of science. The structural realism is generally presented in two versions: one ontic and the other epistemic. It has been argued that that* epistemic structural realism *(ESR) is close, if not identical, to a Kantian approach. We aim to show that this is not the case, since ESR, being fundamentally a realist position, cannot be fully consistent with a transcendental approach. Such a position is better called* transcendental structuralism *(TS), an alternative that we believe is worth being investigated on its own. In this paper, we will take Henry Allison's interpretation of transcendental idealism as a starting point to establish the distinctions between ESR and TS.*

Keywords *Ontic structural realism, epistemic structural realism, transcendental structuralism.*

> Einstein's use of non-Euclidean geometry presents no obstacle at all to our purified and generalized form of (neo-) Kantianism. For we no longer require that any particular mathematical structure be fixed for all time, but only that the historical-developmental sequence of such structures continuously converge. (M. Friedman, 2011)

1 Introduction

In a seminal paper, John Worrall (1989) presented *structural realism* (SR) as a way to retain the "best of two worlds": retaining scientific realism, while at the same time avoiding its main deficiencies. Worrall claimed that SR could be viewed as a development of the conventionalist positions adopted by Poincaré and Duhem. The basic idea of SR is that, although scientific theories change in the course of history, therefore not allowing us to accept naively ontological claims about unobservable entities, there is however a continuity in the structural content between successive theories. This preservation of structure explains how science can progress and achieve better approximations to the truth (which entails a realist position), discarding older ontological views along the way. Structural realism, then, is the view that we can rationally believe only in the natural or physical structures represented by our scientific theories.

Almost ten years after Worrall's paper, James Ladyman (1998) made a distinction between two ways of construing structural realism. The first way contains the view that science tells us solely about the structure of the world because that is all there is. In this case the fundamental ontology of reality is natural or physical structure *per se*, or in-itself. This view is called *ontic structural realism* (OSR). In the second way, limits are imposed on our knowledge of the world: we can know (albeit approximately) only its apparent or manifest structure, not the hidden entities-in-themselves underlying the structure or somehow embedded in the structure. This is an epistemic view, referred to as *epistemic structural realism* (ESR). ESR divides the external unobservable world into two parts: (i) the knowable structures (the apparent or manifest structures) and (ii) the unknowable reality that lies beyond them (the noumenal world, or world-in-itself). For OSR, however, there is only one level of external reality, the noumenal structure-in-itself. French and Ladyman (2003) defend OSR by means of a thesis of quantum underdetermination between individuals and non-individuals. In view of this underdetermination, they then propose a consistent structuralist view of the unobservable world that directly postulates a noumenal ontology of relations.

There is no necessity, however, for structuralism to be developed only as a *realist* position. In fact, an *empiricist* approach to structuralism is an alternative that has been pursued by Bas van Fraassen (2006, 2008). He accepts the possible continuity of structure from one scientific theory to another, but rejects a realist interpretation of it.

It is striking, nevertheless, that a polarization between realism (whether ontic or epistemic) and empiricism has dominated the debate on structuralism, with no room, so far, for the important third possibility of a properly *transcendental* approach. Indeed, this dialectical development within recent and contemporary scientific structuralism should fully remind us of the classical dialectical opposition between either platonist or indirect realist rationalism on the one hand, and empiricism on the other hand, that confronted Kant in the mid-to-late 18th century.

It is commonly argued–e.g., by Ladyman (2009)–that ESR corresponds to a Kantian position, merely because it makes basic reference to the inherent limitations of human knowledge. But precisely the same view about our inherent perceptual or otherwise cognitive limitations is made by empiricists and other anti-realists, including Locke, Berkeley, Hume, and the Logical Empiricists, so this expresses a naïve and in effect *subjective idealist*, *phenomenalist*, or *constructive empiricist* approach to Kant that is widely rejected by contemporary Kant-scholars and Kantians alike. So far, then, little effort has been made to

distinguish ESR from a more careful reformulation of Kant's own ideas, that could incorporate a specifically *transcendental* view of the structures. Moreover, it has largely gone unnoticed that some recent Kant-scholars and contemporary Kantians have also explicitly adopted a structuralist interpretation of Kant's transcendental metaphysics of nature and his philosophy of mathematics.[1]

The word 'transcendental' is here taken in its original sense given by Kant, as picking out the a priori forms by means of which, in rational human cognition, we constitute or disclose the objectivity of human experience, under the famous Kantian "Copernican hypothesis" to the effect that, necessarily, the basic structures of the apparent or manifest world of experience conform to our a priori forms, as opposed to holding that our cognition conforms to the objects. It is from this perspective that, e.g., an important neo-Kantian thinker like Ernst Cassirer should be understood. It is misleading to acknowledge his contributions to structuralism if we disregard the transcendental context in which they were made. In view of this, we will adopt the expression *transcendental structuralism* (TS), proposed by Thomas Ryckman,[2] to characterize a position about science that should not be taken as identical to ESR. TS attempts to be faithful to Kant's fundamental insights while also incorporating the fundamental insights of structuralism. And if, as Robert Hanna (2006, 2010) has argued, Kant himself is a metaphysical and mathematical structuralist *avant la lettre*, then the fusion of Kantianism and structuralism is not only fully consistent and coherent but in a sense philosophically inevitable, since in that case, modern structuralism itself ultimately flows from Kantian philosophy.

In this paper, we will describe TS in more detail and compare and contrast it with both versions of structural realism, OSR and ESR, as well as with structural empiricism. In doing so,we hope to break the polarization between structuralist realism and empiricism that has become fashionable, and in effect recapitulates the classical 17th and 18th century rationalist-empiricist polarization. In the rest of the paper, then, following Kant, Ryckman (2005), and Michel Bitbol (2010), we argue that a transcendental and neo-Kantian approach can provide a more penetrating and robust version of scientific structuralism than either the standard realist (whether ontic or epistemic) or empiricist approaches. Our aim is to present and defend a specifically *transcendental and epistemic Kantian* version of structuralism, in relation to contemporary philosophy of science.

1 See, e.g., Hanna (2006, chs. 3-4, 6, and 8); Hanna (2010); and Chapman et al. (2013, part 2, VIII).
2 Ryckman used this expression during a talk at the colloquium *Structuralism in physics*, on March 7, 2005, in Paris. See also Ladyman (2009).

2 One World is World Enough

The supposedly Kantian aspect of ESR is premised on ESR's thesis that the noumenal world of quantum individual entities is not cognizable. In this sense, apparent or manifest formal structures and their empirical counterparts are all we can scientifically know about the world. As Ladyman (2009) points out, there are several ways to express the ESR approach. But in all of them, two ontological levels are presupposed: (i) the first-order level of individuals with their intrinsic non-relational properties, which we cannot know, and (ii) the structural second-order level of their relational properties. In particular, Poincaré's structuralism seems at the very least a version of Kantianism. And thus there is at least one version of ESR that can be identified as a Kantian position due to its claims that we can never know more than the apparent or manifest structure of the noumenal world or world-in-itself, whose constitutive entities or individuals and their intrinsic non-relational properties are cognitively inaccessible tous: as if the unobservable entities postulated by scientific theories were the Kantian things in themselves us.

In this version, the essential nature of the world of things-in-themselves remains hidden to human cognizers. Nevertheless, we *can* know its a priori mathematical structures, which in turn, together with natural laws, explain empirical-phenomenal relations between objects of experience. In this connection, Ladyman (2009) says that

> while Worrall never directly endorses the Kantian aspect of Poincaré's thought, [Elie] Zahar's structural realism is explicitly a form of Kantian transcendental idealism according to which science can never tell us more than the structure of the noumenal world; the nature of the entities and properties of which it consists are epistemically inaccessible to us.

This basic claim of Kantian ESR seems to assert or at least imply the controversial thesis ascribed to transcendental idealism that "the mind is affected by transcendental objects that provide the content (material) of all our cognitive representations, while those transcendental objects are in themselves not cognizable" (Ladyman, 2009).

This allegedly Kantian claim is nevertheless a classical source of controversy and also a recent and contemporary flashpoint for many sharply divergent interpretations of transcendental idealism. For example, in recent Kant-interpretation, the very idea of a non-sensible cause as a source of our sensible representations famously or notoriously led Peter Strawson (1966) to claim that Kant's doctrine of things-in-themselves is disastrously incoherent. Strawson's analysis can be supported by certain passages in the "Critique of Pure Reason"

where sensibility is characterized as a faculty of intuition, which is affected in a purely receptive way by external noumenal objects. Kant writes:

> The sensible faculty of intuition is really only a receptivity for being affected in a certain way with representations [...]. The non-sensible cause of these representations is entirely unknown to us [...]. Meanwhile we can call the merely intelligible cause of appearances in general the transcendental object, merely so that we may have something corresponding to sensibility as a receptivity (KrV, A494/B523).

Other texts in the first *Critique* also support the thesis of transcendental *affection*, whereby things-in-themselves are non-spatiotemporal, mind-independent objects, constituted by their intrinsic non-relational properties, that somehow act on us in a causal way. These non-sensible entities, which purportedly affect the subject, cannot be objects of human cognition (*Erkenntnis*) or knowing (*Wissen*), because that they do not correspond to any object of human sensible intuition. Kant thereby seems to fuse, on the one hand, a noumenally realistic ontological thesis that asserts the existence of transcendent objects, things-in-themselves, as causes of our representations, with, on the other hand, a non-noumenally-realistic epistemic thesis, in which our cognitive representations of perceptual or experiential objects are really possible only by reference to the intrinsic spatiotemporal structure of our specifically human kind of sensibility.

Many seemingly intractable philosophical difficulties flow from this apparent fusion of theses. Strawson, e.g., argues that this doctrine is flat-out conceptually incoherent, because, according to him, it is only by reference to a spatiotemporal framework that one can talk intelligibly about causal affection. This incoherence is made even more evident when Kant explicitly asserts that all human intuitions or *Anschaaungen* (i.e., directly referential, object-dependent cognitions) are sensible intuitions, as opposed to concepts or *Begriffe* whose inherently descriptive, general reference to objects is necessarily mediated by sensible intuitions.

The primary difficulty flows from the problematic conjunction of two independently intelligible and defensible theses. **First**, there is the inherently "immediate" (= directly referential, object-dependent, non-conceptual) character of sensible intuitions, which, it is claimed, stand in a veridical relationship with the transcendent, noumenal, uncognizable, and unknowable objects. And **second**, there is the inherently mediated and "restricted" character of synthetic a priori necessary truths about causality, flowing from the objectively valid category of causality, whose applicability is necessarily limited to all and only actual and possible spatiotemporal objects of experience, which seems to flat-out contradict the noumenal externalist doctrine of the knowable existence and

efficacious causal powers of a non-conceptually-accessed transcendent cause of human sensible intuitions, i.e., the thing-in-itself.

What looks odd in all of this is the alliance created by transcendental idealism between an internalist doctrine – which states that our empirical knowledge is framed by internal mental structures, where the spatiotemporal intuition and the causal category present themselves as transcendental conditions of the possibility of experience – and an externalist doctrine – which assumes that our mental representations are caused by non-cognitive, non-spatiotemporal and extra-sensible entities, introducing a kind of transcendent causality.

Accordingly, transcendental idealism seems to postulate two classes of objects: (i) the noumena or things-in-themselves and (ii) the phenomena or appearances. Objects of the first class do not depend on human cognition. However, objects of the second class do depend, on the one hand, on the cognitive apparatus of the subject, and on the other hand, on the existence of objects of the first class. This "two- world" or "two-object" view of transcendental idealism is thereby based on an ontological dichotomy between the noumenal world and the phenomenal world, or between two essentially different and mutually exclusive objects, the transcendent object and the representational object.

In his influential book "Kant's Transcendental Idealism", Henry Allison (2004) reacts strongly against those interpreters (especially Strawson) who, in Allison's words, try to save Kant from himself. Given the two-world or two-object interpretation, transcendental idealism transforms itself into a classical rationalist-style metaphysical doctrine that claims the non-cognizability of the things-in-themselves, and correspondingly places phenomenal cognition in the purely subjective realm of representations. For Allison, on this view the notion of phenomena is a mixture of a typical Berkeleyan approach, in which, what is cognized is what is now consciously experienced by the mind, with an additional postulation of a set of metaphysical entities that are non-cognizable. The inaccessible noumenal world in-itself, which lies behind the directly perceived phenomenal world, is the affective or triggering cause of phenomena and the phenomenal world–even if it is not a sufficient cause, due to the spontaneous constructive activity of the mind that is jointly required, along with noumenal causal affection/triggering, for the constitution of appearances and the apparent world.

In this way, Kantian ESR seems to embody and recapitulate all the problematic aspects of the classical rationalist-style metaphysics of transcendental idealism. Moreover, it introduces an *additional* level of reality between the phenomenal and the noumenal worlds: the structural level. Instead of the two-world or two-object view of transcendental idealism, the ESR approach postuates three

distinct "worlds" or kinds of objects: (i) the phenomenal, (ii) the structural, and (iii) the noumenal. The first level of reality is causally determined by the second level together with the third level. The first two levels are known to us through their physical and mathematical relational properties, while the third level with its intrinsic properties remains absolutely unknown.

It seems to us that the metaphysical position assumed by Kantian ESR is clearly distinguishable from a *philosophically defensible* Kantian position, which takes a non-noumenal-realistic view much more seriously. In characterizing a transcendental structuralism, which does not share the noumenal-realistic thesis assumed by ESR, we will initially utilize Allison's well-known *epistemic* one-world interpretation of Kant's idealism along with the neo-Kantian approach to transcendental structuralism. But in the next two sections, we will switch from Allison's well-known epistemic interpretation to Hanna's less well-known *cognitive-semantic* one-world interpretation, which specifically emphasizes Kant's *empirical realism* and his *non-conceptualism*, and then develop what we call a *cognitive-semantic Kantian* transcendental structuralism.

Allison's interpretation exhibits what he calls a "meta-epistemological" as opposed to a "metaphysical" approach to transcendental idealism. He introduces the concept of an "epistemic condition" as a key to understanding not only transcendental idealism, but also the argument of the "Critique of Pure Reason" as a whole. Epistemic conditions are distinct from merely subjective psychological conditions and from the objective ontological ones. Epistemic conditions are conditions of the possibility of objectivity and can share both properties, i.e., the subjective-psychological ones, and the objective ones.

As against the traditional two-object or two-world view, Allison proposes an *epistemic two-aspect* view, which holds that the distinction between noumena/things-in-themselves and phenomena/appearances is not a distinction between two types of world or object. Instead, the distinction between noumena/things-in-themselves and phenomena/appearances is a distinction between two ways in which things (empirical objects) can be considered or taken: (i) things considered or taken as they might be or would be in themselves, or as they would be independently of the human standpoint, and (ii) things considered or taken as they appear, that is, as they are in relation to the subjective conditions of human cognition. Since things *considered or taken as they might be or would be in themselves* does not entail the existence of a corresponding in-itself world or in-itself objects, according to Allison's interpretation of transcendental idealism (building on earlier work by Gerrold Prauss) there is no claim that a separate world of uncognizable, unknowable entities exists. There is only one world of things, considered or taken in two epistemically different ways.

For Allison, it is only the concept of an epistemic condition that makes transcendental idealism into a philosophically viable doctrine. Such an epistemic condition implies the revitalization of the concept of the object as a relational concept relative to human cognition and to the conditions of its representation. According to Allison's epistemic two-aspect view of transcendental idealism, then, noumena or things-in-themselves need not count as "really real" objects for us, which somehow mysteriously cause phenomena or appearances. Rather, they can be construed strictly as a priori ideas of reason applicable to objects of our experience. The noumena or things-in-themselves, not as really real objects, but as representations of human reason, must in turn be understood in light of Kant's fundamental distinction between *constitutive* and *regulative* principles. Constitutive principles entail the objective reality of that which they refer to, whereas regulative principles do not: instead, regulative principles entail only the *representation* of that which they refer to, and can then be used hypothetically or instrumentally as guides for rational acts or practices of various kinds, whether cognitive-theoretical or volitional-practical. In the specific case of the practice of natural science, the regulative use of the ideas of pure reason does not represent metaphysical entities but rather merely projects a goal or ideal that leads the practice of natural science to expand coherently and smoothly over the domain of its investigation, even beyond what is empirically confirmable. As Kant puts it:

> [the transcendental ideas] have an excellent and indispensably necessary regulative use, namely that of directing the understanding to a certain goal respecting which the lines of direction of all its rules converge at one point, which, although it is only an idea (*focus imaginarius*) – i.e., a point from which the concepts of the understanding do not really proceed, since it lies entirely outside the bounds of possible experience – nonetheless still serves to obtain for these concepts the greatest unity alongside the greatest extension (KrV, A644/B672).

Or in Allison's words:

> expressions such as 'things as they are in themselves', 'noumena', the 'transcendental object', and their correlates, are to be understood as technical terms within this metalanguage rather than as terms referring to transcendentally real entities. (Allison, 2004, p. 73)[3]

3 For a remarkably sophisticated discussion of the many functions of Kant's concept of a "thing," see Cassirer (1922, pp. 733-762).

As a result, from this epistemic two-aspect perspective, the notion of objectivity cannot be understood separated from the way we, human beings, represent worldly objects, as empirical objects. Nevertheless, it is also necessary, according to Allison, to interpret the epistemic condition so as to imply the thesis that human cognition is *necessarily discursive, thought-generating, or conceptual*. This means that no independent or autonomous intuitive human cognition is possible: neither sensible intuitive cognition, as an independent and autonomous human cognition of material things, nor intellectual intuitive cognition, as might be possible for a divine being. A specifically human cognition requires the synthesis of both concepts and specifically human sensible intuition. To be sure, on Kant's view, in a way sharply different from empiricism, the receptivity of human sensible intuition is essentially related to the a priori forms of human sensible intuition, i.e., the pure intuitional representations of space and time. Nevertheless, according to Allison, sensible intuition is not a sufficient condition for the cognition of empirical objects. In order to determine cognitions understood as objectively valid judgments of experience, two cognitive capacities come into play, performing radically distinct and never interchangeable functions: one is an intuitional cognitive capacity, essentially non-conceptual in nature, and the other is a conceptual cognitive capacity, inherently discursive in nature. The first is characteristic of the receptivity of the sensibility and the second of the spontaneity of the understanding. At the same time, Kant clearly assumes that there are non-conceptual contents and they play an essential role in cognition. On the level of sensibility, the phenomena are characterized as undetermined objects of an empirical intuition, only spatiotemporally organized, but with no conceptual determination. The conceptual activity of the understanding applied to intuitive representations produces conceptually-determined objective representational contents and–given Kant's conformity thesis, which says that necessarily, the apparent world we perceive conforms to the transcendental structures of the mind, rather than conversely–also worldly objectivity in the form of synthetic cognition and knowledge of the empirically real apparent world, a mode of cognition and knowledge that is necessarily discursive.

3 The Role of Structures in Transcendental Philosophy

From the transcendental perspective, every intuitive representation contains a reference to space and time, as the two a priori forms of sensibility and as preconditions of all objectively valid cognition and knowledge. In the Transcendental Aesthetic Kant claims that the representations of space and time are not concepts but instead pure intuitions. Nevertheless, in his "Metaphysical

Foundations of Natural Science", he also allows for the construction of *physical concepts* based on these pure non-conceptual contents, both in an empirical and in a non-empirical sense. What enables the construction is the addition of the empirical concept of *matter* to the pure intuitional representations of space and time, where matter is that which *fills* or *occupies* space and time. Thus the physical concepts of space and time in the "Phoronomy" section of the *Metaphysical Foundations* presuppose not only the pure a priori intuitions of space and time of the Transcendental Aesthetic, as well as the mathematical (i.e., arithmetical and geometrical) and a priori concepts of space and time. As an empirical concept, the concept of physical space is always relative. However it is inherently related to a non-empirical concept of absolute physical space. Kant (2004) does not accept the Newtonian notion of absolute space in its ontological sense, but considers it as a mere regulative idea (MAN, AA 04: 481, 559).[4] Nevertheless, even taking into account the absolute notions of space and time as regulative ideas, Kant shares the classical conception that these notions provide a fixed background in reference to which objects and their motion are described.

However, this absolute character of space and time was challenged and ultimately refuted by Einstein's work, which utilized the new concept of spacetime. Einstein's spacetime is different from Newton's space and time in two important ways. **First**, it rejects the notion that space and time are independent from each other; rather it binds them together in a single conceptual unity. **Second**, and more importantly, according to the general theory of relativity (GR), spacetime itself has dynamical properties. This means that it is not just a background for the description of objects and their motion, but changes its own form in connection with surrounding densities of matter and energy.

A very controversial issue in the philosophy of GR is whether or not relativistic spacetime is a substance.[5] In a way that mirrors the classical opposition between Newton's absolutist conception of space and time and Leibniz's relational conception of space and time, there are correspondingly two opposed views about relativistic spacetime: substantivalism and relationalism. On the substantivalist side, although GR rules the absolutist conception of space and time, as per Newton's approach, one can, nevertheless, defend a view according to which spacetime exists independently of matter and field as a substance-like absolute continuum of four dimensions.

4 See Friedman (1992, p. 143).
5 See, e.g., Earman (1989).

Nevertheless, according to Earman (1989), the relationalist conception of spacetime is a more coherent and plausible view. For our purposes, in any case, relationalism coheres perfectly with a transcendental approach. This entails that if spacetime is to have a role in contemporary transcendental philosophy similar to that of classical space and time for Kant, then it cannot be based on an absolutist conception. Such a role has to be based on some fundamental property of spacetime that is essentially relational. The metric field has little meaning when not describing relations between objects. According to the relationalist view spacetime is a geometric ideal structure realized by physical matter, such that the spatiotemporal relations between material events are taken as primitive, and in this way spacetime provides *intrinsic relational properties* of material things.[6]

Ernst Cassirer (1923), the influential neo-Kantian, was one of the first philosophers to realize that Einstein's dynamical spacetime does not necessarily contradict transcendental idealism, the non-absolute character of spacetime notwithstanding. In Cassirer's view, if we take the structure of spacetime as a precondition of experience, we can still have a coherent transcendental position. The crucial point from a neo-Kantian point of view is that the structural character of spacetime is conceptually constructed by the subject, rather than derived from the mind-independent world. This was recognized by Cassirer and also by Hermann Weyl and Arthur Eddington, as Ryckman pointed out in his analysis of the philosophy of spacetime in the early years of general relativity.[7] Given this structural character of spacetime, we then realize that structures play a fundamental role in the transcendental construction of objectivity. In this neo-Kantian structuralist perspective, we perceive phenomena as structured because we project our ideal structures onto them. Structures are preconditions of the possibility of experience in general and at the same time preconditions of the possibility of objects of experience. It is not the case that physical theories reveal the mathematical structure of reality but rather they express the scientific construction of reality. Instead of trying to explain the remarkable success of GR in describing objective experience by looking through the theory towards the noumenal or in-itself structure of the world, adopting the transcendental perspective provides a now-familiar Kantian Copernican revolution: we look

6 "Intrinsic" in this context means "necessary, inherent or immanent, and constituting a proper part", not "necessary, inherent, and non-relational," as it does in a Leibnizian and David-Lewisian context. Hence "intrinsic properties" in the sense in which we are using this term can be either relational or non-relational. For more on intrinsic relational properties in a specifically Kantian but also in more general contemporary metaphysical setting, see Hanna (2006), and Hanna & Maiese (2009).

7 See Ryckman (2005, pp. 242-243).

through the theory towards the structural a priori conditions of possibility of our cognition and knowledge of the world.

Part of Kant's motivation in promoting this Copernican turn is of course a direct response to Hume's empiricist critical analysis of the idea of necessary connexion. As Hume says in the "Treatise":

> necessity is something, that exists in the mind, not in objects; nor is it possible for us ever to form the most distant idea of it, considered as a quality in bodies. [...] Thus as the necessity, which makes two times two equal to four, or three angles of a triangle equal to two right ones, lies only in the act of the understanding, by which we consider and compare these ideas; in like manner the necessity or power, which unites causes and effects, lies in the determination of the mind to pass from the one to the other (Hume, 1978, pp. 165-166).

But as we will see in section IV below, an equally important Kantian motivation is the need to explain the real possibility of a priori cognition and knowledge, as applied to transcendental structures. Kant modifies Hume's idea of necessity, which according to Hume, would be applicable only in the sciences of geometry, algebra, and arithmetic, to explain the mathematical nature of empirical theories. In the same way, we can consider in GR the spatiotemporal relations between the material events, expressed by the mathematical formalism, as necessarily conforming to the a priori structures of our cognition of the physical world. This transcendental turn, consequently, aligns beautifully with Einstein's general thesis that "space-time does not claim existence in its own right, but only as a structural quality of the field" (Einstein, 2001, p. 157). This neo-Kantian revision of Kant's transcendental idealism, proposed by Cassirer, whereby the notion of structure plays a fundamental role, is what we call *transcendental structuralism* (TS).

According to Cassirer (1923), Einstein's general theory of relativity and its corresponding mathematical theory fully supports Cassirer's own neo-Kantian conception of functional and relational structures in contrast with the classical substantialist theory of the concept.[8] Cassirer's analysis of GR allows us to see that, even with the introduction of non-Euclidian geometry and with the recognition of the relational and dynamic character of spacetime, mathematical structure plays a transcendental function both within the classical context of Newtonian physics and also within the relativistic context of Einstein's theory. As Michael Friedman (2011) rightly notes in his essay about Cassirer, which we have already cited as one of the epigraphs of this paper:

8 See Massimi (2011), who characterizes Cassirer's approach as a version of scientific realism.

> Einstein's use of non-Euclidean geometry presents no obstacle at all to our purified and generalized form of (neo-)Kantianism. For we no longer require that any particular mathematical structure be fixed for all time, but only that the historical-developmental sequence of such structures continuously converge.

Cassirer's position regarding this convergence, as interpreted by Friedman, seems to undermine the Kuhnian incommensurability thesis in an essential way. On the one hand, Cassirer recognizes a deep change of meaning in the terms and concepts of the two competing theories and in some cases a complete change in their mathematical structures. In this sense, there is no commensurability between them. But on the other hand, he acknowledges a functional convergence of their mathematical structures that allows them to be compared and contrasted with one another. If there is convergence, we can talk about continuity of the functional structures of successive theories.

The transcendental ideality of space and time asserted by Kant expresses the epistemic idea that the objectivity of physics is inherently mathematically structured.[9] This in part explains the a priori character of mathematical physics. However, it is problematic to assume that the representation of space and time, and, as a consequence, the representation of objects in space and time, is not in any sense discursive, and does not involve a certain logical complexity that is not present in the representations of pure intuition. Kant can be correctly and most charitably interpreted, therefore, only if we claim that conceptual spontaneity and intuitional receptivity are not two separate and non-integrated moments of rational human cognitive processing, but dynamically combined with and molded by one another in the representation of material objects or physical systems embedded in spacetime. According to another famous neo-Kantian, Hermann Cohen, Kant shrewdly realized that the differential equations governing a physical system's behavior in its evolution through time is a predictive structure that has an a priori nature. Kant's principle of the Anticipations of Perception, as Cohen (1871) insightfully noted, seeks to express in philosophical language the role that the differential calculus plays in the continuous constitution of the states of physical objects.

It is interesting and relevant to note that the central category or pure concept of the understanding corresponding to the principle of the Anticipationsof Perception is the pure concept or category of "reality". In this way, Kant emphasizes that the reality corresponding to sensation is comprised of what Hanna calls *authentic appearances* (as opposed to "mere" or "illusory" appearances).[10]

9 See Friedman (2008).
10 See Hanna (2006, esp. part 1).

Therefore, they are not *noumena* or things-in-themselves that mysteriously correspond to sensation. Indeed, in the crucial text describing the basic conditions for applying the Anticipations of Perception to objective reality, noumena or things-in themselves are *not* presented as the causal sources of perceptions. Many other passages from the first *Critique* rule out the identification of noumena or things-in-themselves with the affective/triggering cause of perceptions. This is part and parcel of Kant's *empirical realism*. The Critical notion of an object of experience is limited to representations that pick out apparent items that are "connected and determinable in [their] relations (in space and time) according to laws of the unity of experience" (KrV, A494/B522).

This emphasis on empirical realism is picked up by Allison's one-world-two-aspect analysis, which tries to dissipate the mystery surrounding the transcendent concept of cause, thereby eliminating any type of mysterious noumenal-realist explanation of the given fact of causal affection/triggering. Allison holds that the category of cause, as a transcendental condition of causal affection/triggering, is permitted only if understood in its epistemic sense, suggesting that the relation to a transcendental object can only be thought, but neither objectively validly cognized, nor known. Thus Kant makes the concept of a noumenon or a thing-in-itself a *limiting concept* that sets essential restrictions on our capacity to know.

As we can now see, according to the epistemic transcendental approach to structuralism, structures are epistemic conditions in the sense presented by Allison's interpretation of Kant's transcendental idealism. This also shows the fundamental difference between TS and ESR: while, according to the latter (=ESR), structures are necessarily part of the objective world and exist independently of us, as being exactly the part of the world that we can know about, by contrast, according to the former (=TS), structures are necessarily part of us, and therefore it is not surprising that we can cognize and know the world only through them. The two-world view of transcendental idealism blurs this distinction to an important extent, and therefore is naturally associable with ESR. Therefore, it seems reasonable to follow Allison and reject this thesis, hence defining TS in a more consistent transcendental way, along one-world-two-aspect lines.

Before closing this sub-section, here is an important caveat: In the context of this section, we aim neither to provide a transcendental deduction of the *a priori* structures nor to take into account any new mathematical structures different from those presented by the realistic views. Rather, our aim is just to focus like a laser beam on the epistemic transcendental status of the mathematical structures of physical theories, by contrast with the other structuralist approaches.

4 Contrasting TS with Structural Realism

As we mentioned earlier, ESR and OSR are intended to retain scientific realism's main successes, while avoiding its major deficiencies. Both versions assert that there is structural continuity between scientific theories even in the absence of ontological continuity. This explains why ontological discontinuity is not a problem for the progress of science, which in turn is explained by the structural content of scientific theories gradually approaching closer to the true structure of the world, which is assumed to be independent of us. We will now contrast TS with structural realism, in relation to these issues about the ontological discontinuity and structural continuity between theories.

Since TS is a non-noumenal-realist position, the discontinuity in ontology is not a problem. In a transcendental approach, we are not dealing with the ontology of objects in-themselves, but only with objects as cognized or known, i.e., as constituted. According to this view, objectivity is conceptually constructed by the a priori cognitive capacities of the rational subject, in accordance with its a priori forms or structures. Therefore, continuity in the ontology of scientific theories would not be expected to begin with.

On the other hand, there is good (even if not overwhelming) evidence for continuity between theories at the structural level. One example, among many, is the caloric theory (a theory that treats heat as a substance), which became obsolete with the rise of thermodynamics, although its mathematical structure survived. From a TS point of view, such preservation of structures occurs due to their transcendental a priori source. Attempts at creating a new theory that agrees with new data while also not contradicting the successes of an older theory, naturally lead to some degree of structural similarity, although it is quite possible that a radical structural change is needed. An example of this is quantum mechanics, which, despite having classical mechanics as a limiting case, introduces a whole new structure based on the use of operators in a Hilbert space. From a Kantian point of view, one can ascribe a transcendental role in the preservation of structures between theories to the principle of the Anticipations of Perception. This because it is the fundamental principle indicating how the mathematical structure of differential calculus enables us to constitute the objects of experience as qualitatively determined.[11] In turn, they are qualitatively determined because they are subjected to a synthesis whereby they are generated in accordance with the principle of intensive magnitude.[12] In this way, the strong

11 See Cohen (1871).
12 For more details, see Kauark-Leite (2009, 2012).

link between prediction and anticipation of a perception in scientific practices is justified. The success of a theory is to a large extent a function of its predictive power, and so viable structures are those that lead to good predictions. Again, the Anticipations of Perception is an a priori principle, and thus, according to TS, there is no mind-independent external structure guiding the success of science.[13]

It should be clear that the lack of a commitment to the external character of the structural content of theories is a basic feature that differentiates TS from all forms of structural realism. We will now see in a little more detail the specific differences between TS and the two interpretations of structural realism – the ontic and the epistemic versions.

4.1 Contrasting TS with Ontic Structural Realism

French and Ladyman argue in favor of OSR, the version of structural realism according to which structure is all there is.[14] Their main support for this position is that individual particles of the same kind in quantum mechanics are indistinguishable, so that, according to the principle of the Identity of the Indiscernibles, formulated by Leibniz (1989, pp. 41-42) in his "Discourse on Metaphysics", they should not be regarded as different individuals. A different view about the indistinguishability of quantum particles was given by Simon Saunders (2006), who considered both classical and quantum particles as distinguishable or indistinguishable depending on the conditions of permutability. As he puts it, "our conclusion is rather that indistinguishability has nothing at all to do with the quantum and classical divide" (Saunders, 2006, p. 62). Even indistinguishable quantum particles exhibit a weak (relational) discernibility. Nevertheless, given the demands of quantum mechanics, if what counts as an individual is that it is absolutely discernible the problem of individualization remains. French and Ladyman must reconstruct the whole foundation of our ontology without basing it on individual entities. This approach then leads to a notion of structure as the fundamental ontological level, in terms of which the concept of an object should be derived.

From the perspective of TS, cognition or knowledge of the world necessarily has a structural character. This is because structure is at the basis of how we know, not because it is outside us in the external world. Whether our representations of appearances take the form of objects or networks of relations, they are always our representations. The very notion of object, in an epistemic transcendental approach, is a conceptual construction. In this respect, it is not really important

13 See Bitbol (2005, 2010).
14 See French (1998) and French and Ladyman (2003).

whether our representations are formulated in terms of individual objects or of networks of relations only. TS does not deal with ontology. Whatever our representations might be of, they have a structural character, which is an a priori condition of possibility of any experience. So, even if it can be said that we perceive objects, this very perception is constituted in a way that requires the activity of structures. Hence, for an epistemic transcendental structuralism, OSR's specific claim that structure is all there is, is equivalent to making a claim about noumena or things-in-themselves.

4.2 Contrasting TS with Epistemic Structural Realism

Matteo Morganti (2004) criticizes the arguments for OSR, stressing two points. **First**, French and Ladyman's analysis of the individuality of particles is based on a particular interpretation of quantum mechanics. There are other interpretations that do not lead to the same conclusion. Specifically, the de Broglie-Bohm formulation of quantum mechanics assumes from the start the existence of individual particles, thereby achieving empirical equivalence to the more usual formulation in terms of hidden variables. These hidden variables point to an epistemic restriction on knowledge about quantum particles, not necessarily to an ontological thesis about them.

This leads to Morganti's **second** point: the burden of proof is on OSR. It is up to its defenders to establish that structure is all there is. The ESR supporters, on the other hand, can hold an agnostic position regarding the ontology of things beyond structure. According to Morganti, in order to endorse ESR, there is no need to claim that there are things beyond structure. Since ESR is a position according to which we can know only the structure of the world and not what lies beyond it, it is enough to stop there and accept that something may exist beyond the knowable structure. We cannot be sure if it really exists or not. He proposes, therefore, a weak version of ESR in this agnostic way, avoiding a metaphysical commitment to a thesis as strong as that of OSR. He does not trade "structure is all there is" for "structure is not all there is".

From the point of view of TS, however, ESR is already committed to a metaphysical noumenal-realist claim: namely, the one about the world having a knowable structure in itself, that is wholly independent of us. As argued above, this should not be confused with the epistemic *transcendental* approach, according to which we cognize or know the world through a structured representation because structures play a fundamental role in how we constitute objectivity. Thus, ESR, even in the agnostic stance proposed by Morganti, is not transcendental and certainly cannot be called Kantian merely because it acknowledges limitations on what is knowable. ESR is still a realist position and should be regarded as such.

5 Contrasting TS with Structural Empiricism

Broadly speaking, empiricism is the view that experience is the essential source of cognition and the only reliable source of knowledge. Van Fraassen (1980) has for a long time consistently advocated a version of empiricism according to which scientific theories are only empirically adequate and nothing more, thus combining a realist view of directly observable objects with an anti-realist view of the unobservable objects that appear in the theoretical construction of scientific theories. He calls this position *constructive empiricism*. More recently, van Fraassen (2006, 2008) has also developed his ideas into a new position he calls *empiricist structuralism*, thereby aiming to incorporate the role of structures in the empiricist picture of science.[15] According to him, the structures preserved across theory-change are little more than the structures of our ordinary empirical observations. Insofar as they constitute a common core of how the world appears to us, these structures should be preserved through different theories, because otherwise, science would be of little use to us.

Anti-realism runs deeper in TS than in van Fraassen's empiricism, since he accepts a realist view of what is directly observed, thus being anti-realist only in regard to what is unobservable, while the epistemictranscendental approach considers all experience to be constituted by the subject. The sources of structures for the two positions are also different; in empiricist structuralism, structures are given to us as properties of empirical observations, being preserved through different theories as a result of their empirical adequacy, while in TS they are preconditions of any experience, being preserved because of the predictive character of the a priori structures. Therefore, although empiricist structuralism and TS agree in not giving an ontological status to unobservable objects, they differ greatly in most other respects.

6 Conclusion

The realization of the crucial role played by structures in scientific theories, which has its roots in the works of thinkers like Poincaré and Cassirer, grew throughout the twentieth century, becoming a predominant view about how we are to understand theory-change in science. In the current debate between realists and empiricists, both sides, for the most part, have embraced some sort of structuralism, despite their radical differences in other regards. We tried to

15 See also Bueno (1999).

show that a transcendental approach could also incorporate a structuralist view of science, a third way that seems to have been overlooked so far.

We proposed following Thomas Ryckman in using the term *transcendental structuralism* to capture a Kantian position. For us, TS is essentially a reformulation of Kant's transcendental idealism that takes structures as being the fundamental aspect of the subject's constitution of objectivity. Following Allison, we argued that this transcendental structuralism is more coherently defined in conjunction with a rejection of the two-world interpretation of Kant's ideas. We then focused our analysis on contrasting transcendental structuralism, so defined, with both the ontic and the epistemic versions of structural realism, as well as with structural empiricism. We have shown how TS differs from all these positions. Following Michel Bitbol, we agree that TS can provide a robust version of scientific structuralism that deserves serious attention.

Of special importance is the difference between TS and the epistemic version of structural realism, ESR. The latter is frequently associated with a Kantian view, because it posits fundamental limits to our knowledge of the world. However, it should not be forgotten that ESR is fundamentally a noumenal realist position, not a transcendental one. The crucial difference between the two views lies in the source of the knowable structure of the world: for ESR, it is part of the world itself, being independent of us, while, for TS, it comes from us, as a priori formal preconditions of experience in the broadest sense.

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