**Mario Bunge and Gustavo Romero on Gravitational Waves and Reality of Space: Towards Neo-Bungean Space(time) Structuralism**

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**Abstract:**

Since the detection of the gravitational waves by LIGO (Abbott, 2016), scientific and philosophical debates were stimulated. Among these was the discussion on the nature of space(time): Emphasizing that space cannot exist in absence of matter (i.e., when Tμν = 0), Mario Bunge (2018a; 2018b, pp. 119-123) was on the ‘relationalist’ camp. Gustavo Romero in his rebuttal (2018a) on the other hand, advanced a substantivalist position: space is a substance, a material entity that persists in the absence of other material things. In this paper I will summarize the exchange and try to propose a relationalist alternative for the Bungean position, which will be dubbed Neo-Bungean Structuralism.

**A Summary of the Exchange:**

Mario Bunge presents his argument for the materiality of space into two linked syllogisms (Bunge 2018a; 2018b, p. 122):

First syllogism:

**P1.** Gravitational waves activate their detectors.

**P2.** Detectors react only to specific material stimuli.

**P3.** LIGO has detected gravitational waves.

**C.** Gravitational waves are material.

Second syllogism:

**P'1.** Gravitational waves are ripples in spacetime as well as fields spreading out.

**P’2.** Whatever is changeable is material and vice versa.

**C’.** Spacetime is material.

The two syllogisms are clearly valid. A defense, however, of **P’1** is offered by Bunge:

**P’1** is based upon the two different readings of Einstein’s equations:

*Gik* ≔ *− κTik,* where *i, k* = 0, 1, 2, 3. (1)

*The lefthand side* is Einstein’s tensor which describes the curvature of spacetime. This tensor is defined as:

*Gik = Rik − ½ Rgik,*

Where *gik* is the metric tensor, *Rik* is the Ricci tensor formed with second order derivatives of *gik*, and *R* is the Ricci scalar formed by contraction of *Rik*.

In the *righthand side* of equation (1), *Tik* is the stress–energy–momentum tensor which describes the energy and momentum of the material source of the gravitational field (i.e. the curvature). As for *κ*, it is a universal constant proportional to Newton’s universal gravitational constant G (*κ* = 8πG/c4).

These tensors are defined over a 4-dimensional, real and differentiable pseudo-Riemannian manifold. The manifold along with the metric tensor describes the spacetime. Solving equation (1) will yield the metric tensor *gik*. The affine connection Γlik can be calculated from the first-order derivatives of *gik*. Then, the equations of motion for test particles can be obtained.

**P’1**, then, is justified by the two different readings of Equation (1):

*Left to Right* Spacetime curvature affects matter.

*Right to Left* Matter curves spacetime.

Both readings[[1]](#footnote-2) supply us with reciprocal interaction between space(time) and the distribution of energy density and momentum through the curvature. Since gravitational field produced by matter is identified with the space(time) curvature, it follows that the oscillations of the field are ripples of space(time). And “Since the LIGO folks have shown that spacetime is changeable, they have unwittingly proved also that spacetime is material” (Bunge, 2017, p. 128).

But Bunge, as Romero (2018a) noted, does not stop here. He relates Einstein’s equations to Poisson’s equation of electrostatics[[2]](#footnote-3):

Δφ = 4πρ

Where φ is the electric potential, ρ is the charge density, and the Laplacian Δ = ∇2 is the slope of the slope.

Bunge will draw parallels between the two equations:

“In the case of gravitation, the metric tensor *gik* is analogous to the electric potential φ, whereas the stress-energy tensor *T* is parallel to the charge density ρ. For propagating fields, whether gravitational or electromagnetic, the operator Δ is generalized to the four-dimensional d'Alembertian operator ☐ = Δ - (1/c2) ∂2/∂t2, the signature of a wave traveling at the speed c of light in vacuo” (Bunge, 2018a; 2018b, p. 120)

“According to Bunge,” Romero explains, “this limit implies that the coefficients of the metric can be interpreted as the potential of the gravitational field (a view already expressed in Bunge 1967). So, Einstein’s equations can be read alternatively as referring to a gravitational field or to spacetime” (Romero, 2018a).

Since gravitational fields, according to Bunge, are identified with space(time) curvature produced by matter, it follows that there is no gravitational field when matter vanishes. But what happens to space with *T* = 0?

“Commonsense adds that only spacetime, or at least space, remains. Further, this space would be flat, for wherever *T* vanishes so does *G*, and *G* = 0 is the signature of a Minkowski or pseudo-Euclidean spacetime” (Bunge, 2018a; 2018b, p. 122). But Bunge’s stance is more radical: “Since there is nothing real between two geometric points in that hole, their physical distance should be null according to any relational conception of space” (ibid.). Bunge also invokes Einstein, who “stated explicitly that there would be no metric tensor *gik* anywhere if the matter tensor *Tik* were to vanish everywhere” (ibid.).

Bunge, then, holds a hybrid between substantivalism (space is a thing) and relationalism (space is somehow contingent upon the existence of [other] material thing). Thus, the vacuum solutions, as Bunge had stated in his earlier writings, are not physically possible (Bunge, 1977, p. 295) nor physically meaningful (Bunge, 1985, pp. 163-165).

Romero agrees with Bunge on the validity of the two-linked syllogisms and the soundness of the premises (and by entailment, the conclusions). He disagrees, however, on the analogy stated by Bunge between Einstein’s equations and Poisson’s equation. Romero believes that the reference of each theory is different, for “what we call ‘‘gravitational effects’’ are due to spacetime when its curvature is different from zero” (Romero, 2018a). Romero continues: “The gravitational field is alien to general relativity in a similar way as classical concepts such as intrinsic angular momentum are alien to quantum mechanics” (ibid.). It is true that “Einstein originally was inspired by Maxwell’s and Lorentz’s concepts of field” (ibid.), but “the final theory that resulted from his endeavours was not completely akin to Maxwell’s” (ibid.). “Spacetime”, says Romero, “has a unique ontological status in general relativity: it is an entity, which can exist by itself and, as LIGO detectors have shown, act upon matter. But spacetime can also exist in the absence of any other material entity” (ibid.). Romero went on to quote from Einstein’s Leiden lecture:

“Recapitulating, we may say that according to general relativity space is endowed with physical qualities”. (Einstein, 1920).

Romero believes that Bunge’s proposal to identify gravitational field with spacetime through the analogy between the two sets of equations has led him to the false conclusion of denying the existence of empty space. Romero then, defends the “commonsense” that Bunge rejected, i.e., substantivalism (“spacetime realism” as he calls it). “Bunge” says Romero “is not taking seriously enough his own conclusion enunciated above: spacetime is material. And as a material entity, spacetime can exist in absence of matter—just as gravitational waves show us it is the case” (Romero, 2018a).

**The assessment:**

In his earlier writings (Bunge & Máynez 1976, Bunge 1977, pp. 276-296; 2006, p. 244-247), Mario Bunge expressed strict relationalism. “Physical space”, said Bunge, “is the collection of changing things together with the relation of betweenness” (Bunge, 2003, p. 274). This Paleo-Bungean characterization was updated when the gravitational waves were detected by LIGO. Space according to the later Bunge (2017, pp. 128-129; 2018a; 2018b, pp. 119-123) has a substantial existence as well. Space is a thing whose existence is predicated upon the existence of other material things. It is this contingency that allowed Bunge to describe new account of space as relationalist. In other words, the relationalist aspect in the new characterization is constituted by the simple formula: *when there is nothing, there is no space*.

But even if this kind of ‘substanti-relationalism’ that Bunge advocated is internally consistent[[3]](#footnote-4), it seems arbitrary to exclude coherent solutions of Einstein’s equations (i.e., vacuum solutions) that the regular substantivalism[[4]](#footnote-5) allows. At best, substanti-relationalism is unnecessary restrictive.

Romero considers substantivalism to be identical to spacetime realism (see also, Romero, 2018b, p. 133). But a strict relationalist could counter by stating that certain relations between things are also objective and real[[5]](#footnote-6). “Ordinary space, then, is just as real as any other real relation” (Bunge, 1977, p. 296), for “space is rooted in the separation between things, and time in the separation between events (relative to the same reference frame). So, spatiality and temporality are vicariously just as material, and therefore just as real, as the properties of the material objects that generate them; only, they have no independent existence. But then, things and the changes in their properties have no independent existence either: there are only mutually spaced things and successive changes in things” (Bunge 2006, p. 245). Space and time “are real, though not in themselves but as features of matter” (ibid, p. 247).

Romero believes, as stated earlier, that the analogy between Einstein’s and Poisson’s equations is what lead Bunge to such a stance. I believe the issue runs deeper: Besides stating the analogy, Bunge invokes the Machian Einstein in order to revert to semi-relational stance. What lead Bunge to this position, I believe, is the implicit adherence to the source hypothesis: that gravitational field is produced by other material entities (i.e., Mach’s Principle[[6]](#footnote-7)), discussed next.

The Source Hypothesis and Einstein’s mature position on space(time)[[7]](#footnote-8)

Einstein’s view of space(time) went through lengthy process to reach maturity. One can summarize the journey into three phases:

1. The Machian Einstein: which resembles the early Bungean relationalism and, to a lesser degree, the latter Bungean substanti-relationalism.
2. The Post-Machian Pre-Unified Field Theory (UFT) Einstein: which resembles the Romerian substantivalism.
3. The Mature Post-UFT Einstein: which resembles the Neo-Bungean structuralism advocated by the author.

The first phase was explicitly endorsed by Einstein in his "*On the Foundations of the General Theory of Relativity*" published in 1918. In this paper, Einstein mentions the three fundamental principles upon which his understanding of the General Theory of Relativity back then was based, one of which was:

“c. Mach's Principle. “The G-field[[8]](#footnote-9) is completely determined by the masses of the bodies. Since mass and energy are—according to the results of the special theory of relativity—the same, and since energy is formally described by the symmetric energy tensor (*Tμν*), it follows that the G-field is caused and determined by the energy tensor of matter.” (Einstein, 1918).

He elaborates:

“Mach's principle (c) is a different story. The necessity to uphold it is by no means shared by all colleagues; but I myself feel it is absolutely necessary to satisfy it. With (c), according to the field equations of gravitation, there can be no G-field without matter. Obviously, postulate (c) is closely connected to the spacetime structure of the world as a whole, because all masses in the universe will partake in the generation of the G-field.” (ibid.)

Einstein, however, noticed that the original field equations do not satisfy Mach’s principle, for vacuum solution (where g*μν* = const. and *Tμν* = 0) is possible. In other words, the equations “allow for a G-field without any generating matter” (ibid.). To satisfy Mach’s principle, Einstein amends the original equations by adding the λ-term[[9]](#footnote-10).

Einstein, primarily after his famous debate with de Sitter, began to depart from his earlier convictions. The departure began with his Leiden Lecture, the one Romero quoted from. However, in the same Lecture, Einstein stated:

“There can be no space nor any part of space without gravitational potentials; for these confer upon space its metrical qualities, without which it cannot be imagined at all. The existence of the gravitational field is inseparably bound up with the existence of space.” (Einstein, 1920)

“Since according to our present conceptions the elementary particles of matter are also, in their essence, nothing else than condensations of the electromagnetic field, our present view of the universe presents two realities which are completely separated from each other conceptually, although connected causally, namely, gravitational ether and electromagnetic field, or—as they might also be called—space and matter.” (ibid.)

“Recapitulating, we may say that according to the general theory of relativity space is endowed with physical qualities; in this sense, therefore, there exists an ether. According to the general theory of relativity space without ether is unthinkable; for in such space there not only would be no propagation of light, but also no possibility of existence for standards of space and time (measuring-rods and clocks), nor therefore any spacetime intervals in the physical sense.” (ibid.)

It is evident then that Einstein, contra Romero, did not believe in a space(time) devoid of gravitational field/ether. Yet, the relationship between these two “entities” was not fully developed by Einstein at that time. The “subtle change” as noted by Cao, “occurred in the mid-1920s, apparently concomitant with his pursuing a Unified Field Theory (UFT) starting in 1923” (Cao, 2019, p. 81). Einstein mature stance was asserted in the 15th edition of his *Relativity: The Special and The General*. In the preface, he states:

“In this edition I have added, as a fifth appendix, a presentation of my views on the problem of space in general and on the gradual modifications of our ideas on space resulting from the influence of the relativistic view-point. I wished to show that space-time is not necessarily something to which one can ascribe a separate existence, independently of the actual objects of physical reality. Physical objects are not in space, but these objects are spatially extended. In this way the concept “empty space” loses its meaning.” (Einstein, 1952a).

What was the idea Einstein presented in the appendix?

“In accordance with classical mechanics and according to the special theory of relativity, space (space-time) has an existence independent of matter or field. In order to be able to describe at all that which fills up space and is dependent on the co-ordinates, space-time or the inertial system with its metrical properties must be thought of at once as existing, for otherwise the description of “that which fills up space” would have no meaning. On the basis of the general theory of relativity, on the other hand, space as opposed to “what fills space”, which is dependent on the co-ordinates, has no separate existence. Thus a pure gravitational field might have been described in terms of the *gik* (as functions of the co-ordinates), by solution of the gravitational equations. If we imagine the gravitational field, i.e. the functions *gik*, to be removed, there does not remain a space of the type (1)[[10]](#footnote-11), but absolutely nothing, and also no “topological space”[[11]](#footnote-12). For the functions *gik* describe not only the field, but at the same time also the topological and metrical structural properties of the manifold. A space of the type (1), judged from the standpoint of the general theory of relativity, is not a space without field, but a special case of the *gik* field, for which—for the co-ordinate system used, which in itself has no objective significance—the functions *gik* have values that do not depend on the co-ordinates. There is no such thing as an empty space, i.e. a space without field. Space-time does not claim existence on its own, but only as a structural quality of the field.

Thus Descartes was not so far from the truth when he believed he must exclude the existence of an empty space. The notion indeed appears absurd, as long as physical reality is seen exclusively in ponderable bodies. It requires the idea of the field as the representative of reality, in combination with the general principle of relativity, to show the true kernel of Descartes’ idea; there exists no space “empty of field”.” (Einstein, 1952b, pp. 154-156)

The same idea was expressed in Einstein’s forward to Jammer’s *Concepts of Space*:

“It required a severe struggle to arrive at the concept of independent and absolute space, indispensable for the development of theory. It has required no less strenuous exertions subsequently to overcome this concept–a process which is by no means as yet completed.” (Einstein, 1953).

“That which constitutes the spatial character of reality is then simply the four-dimensionality of the field. There is then no “empty” space, that is, there is no space without a field.” (ibid.)

One can see the difference between Romero’s and Einstein’s conceptions of space(time); Romero believes that space(time) is a material entity that can exist in the absence of any other material things, while Einstein considered space(time) to be a relational property of the gravitational field. This, in fact, reflects a deeper conflict between the two in understanding the general theory of relativity; Romero believes that the gravitational field is alien to the theory, while Einstein held that “as far as we are able to judge at the present, the general theory of relativity can be conceived only as a field theory” (Einstein, 1954, p. 140). Indeed, for “it is clear that the theory of relativity presupposes the independence of the field concept” (ibid.)[[12]](#footnote-13).

It is clear then that what Einstein held in his later years was not the reciprocal interaction between space(time) and matter, but between the gravitational field and other material things. Based on this conclusion, the premises of the first syllogism proposed by Bunge are sound. Those of the second, on the other hand, are not, for its first premise commits reification, that is “the treatment or a property, relation, process, or idea as if it were a thing” (Bunge, 2003, p. 274). Space(time) is a structural quality of the gravitational field, not an independent entity. And, “not being a thing, physical space has no causal efficacy… That is, just as things do not act upon space (since space is not a thing), so space does not react back on things” (Bunge, 1977, p. 296).

So Close, Yet So Far? The “Source” of All Evil

What prevented Bunge from reaching the same conclusion established by Einstein was his adherence to the source hypothesis. If such hypothesis is abandoned, a more rigorous conceptualization of the vacuum solutions can be attained. Such vacuum is not absolute nothing, the inside of the hollow sphere is not void; The gravitational field persists, even when the other kinds of matter are absent. To put it in Bunge's words: There is something real between two geometric points in the hole. Hence, space(time) exists in an empty shell, being a structural quality of the field.

Incidentally, Bunge was already aware of the fact that the source hypothesis is not a part of classical electromagnetism (CEM) nor is it a part of general relativity (GR). In his *Foundations of Physics*, published in 1967, Bunge states regarding CEM:

“the source hypothesis is an extra assumption: as our axiom systems show, fields and currents are conjoined but not causally associated: Only field changes are causally associated with charged bodies in case there are any in the region considered.” (Bunge, 1967, p. 173)

“Both in CEM and in GR the “source”-free field equations have infinitely many nontrivial solutions, in particular waves. In short, the source hypothesis is an extra assumption that may but need not be made – not any more than its converse, the sink hypothesis. Consequently there is no reason to discard the “advanced” *F*’s, particularly as they need not be interpreted as advanced fields.

For example, j(x’, t+) might be interpreted as the current at x’, t+ associated with the field *F*+; i.e., *F*+ might be regarded as the part of the field that reacts on the current and influences its value at a later instant. Consequently the total solution (4.18)[[13]](#footnote-14) could be interpreted as describing both the action of the currents on the field and the latter’s reaction on the former. Whether or not this interpretation holds water is here immaterial: the point is that some of the difficulties of CEM are of a semantic nature and some of them are caused by tacit and controvertible assumptions such as that the charges produce fields but not conversely – a hypothesis that is clearly absent from the axiom basis of CEM” (ibid, p. 174)

And regarding GR, he says:

“It is also said that the field equations show that matter determines the structure of space, which is one of the versions of the highly ambiguous “Mach principle” (EINSTEIN, 1918). This is not quite so: matter only codetermines the structure of space, as shown by setting *T* = 0… this theory states only that matter and gravitation are associated. This association is as loose as the one between charged bodies and e. m. fields: in fact although whenever there is matter there is a field (because the metric deviates then from the flat form), the converse is as false in GR as in CEM… Indeed, on setting *T* = 0 we still get an infinite set of gravitational fields, because *G* = 0 does not entail the vanishing of the affinity (only the converse being true). Not even the vanishing of the full curvature tensor corresponds to a zero field but refers to a constant homogeneous field. In short *T* codetermines the metric; the boundary and initial conditions on the metric, which are independent of *T*, are as important as *T*. Finally GR provides no mechanism for the matter-field association.” (ibid, p. 226)

Romero is also aware of this fact. In his *Physics and Philosophy of Physics in the Work of Mario Bunge*, Romero notes:

“Bunge’s analysis of the electromagnetic field is remarkably lucid. Among other Issues, he points out that theory does not properly contain the hypothesis that charges are the sources of the field. Strictly speaking, electromagnetic theory is a theory of the interactions between fields and charged particles. The hypothesis that charges are sources of the field must be added to the Maxwell equations in order to discard the advanced contributions (determined by future events) to the solutions of the inhomogeneous Dalambertian equation. This is done by means of the application of the principle of causality. This hypothesis is logical [*sic*], ontological [*sic*] and epistemologically independent from the rest of the theory.

Something similar happens with the general theory of relativity: the hypothesis that matter is the cause of the curvature of spacetime (gravitational field) is *a posteriori*.” (Romero, 2019).

It does not stop here. Bunge noticed that “Since the coefficients g*μν* of the metric are functions of space and time, they seem to be interpretable as the components of a physical field” (Bunge, 1967, p. 224). He also admitted that the red shift formula would seem to reinforce such interpretation (ibid.). Yet he discarded all of that saying: “if *g* were taken as the gravitational field representative, it could not be locally transformed away as required by the equivalence "principle"; on the other hand the vanishing of the affinity in one frame does not entail its vanishing in every other frame, because ***Γ*** is not a tensor.” (ibid.). Surprisingly, Einstein did in fact touch upon this objection in an exchange with Max von Laue, where he said:

“Now to the gravitational field. Here, one has to properly distinguish between different concepts. In Newtonian theory, everything that is built from the potential counts as the gravitational field. In particular, we would understand the first derivative of the potential as the field strength. In the relativistic theory of gravity, the gravitational field is everything built from the symmetric *gik*. Now, it is clear that we cannot do justice to the interpretation of the relativistic gravitational field by appeal to Newtonian theory. Of course, the interpretation of the field of a system that is accelerated and moving parallel to an inertial system (equivalence principle) was of the utmost heuristic importance, because such a field is equivalent to a Newtonian gravitational field with parallel force lines. In this case, the Newtonian field strength is equal to the spatial derivative of g44. One can thus, if one wants to, speak of the first derivatives of the *gik*, i.e. of the affine connection Γ, as the gravitational field strength. Of course, these quantities are not tensorial. With this manner of speaking, it is indeed the case that introducing cylinder coordinates in a Galilean space [i.e. Minkowski spacetime] would bring with it the appearance of field strengths. This is only a manner of speaking. But what is essential is that also in the case of a Galilean, i.e. Minkowskian, space there is, according to the general theory of relativity, a gravitational field, even if its field strengths vanish in the sense defined above. For in the theory of relativity the dimensionality of the field is the only thing that remains from the earlier, physically independent, (absolute) space. I think that most have not understood this main achievement of the theory.” (Einstein, 1951 as cited in Lehmkuhl, 2022; see also Norton, 1985).

In other words, the metric tensor represents the gravitational field while the affine connection represents its ‘effects’. A vanishing Γ therefore does not refer to the absence of the field but only to its ‘strength’, a clear consequence of the Equivalence Principle. Simply put, Minkowski spacetime is not devoid of gravitational field, it is the very same conclusion stated by Einstein in the fifth appendix to his *Relativity: The Special and The General*, quoted above. Yet, if one insists on considering Minkowski spacetime to be gravitation-free, then the physical field represented by the metric can be dubbed ‘inertio-gravitational field’ while the affine connection represents the locally-transformable gravitational ‘manifestation’ of the field. Accordingly, in Minkowski space the field does not vanish with local transformation, its gravitational ‘effects’ do while a purely inertial field persists.

It is worth noting that the discovery of quantum vacuum state, celebrated by Bunge, may present a good case for the independence of the source hypothesis from the field theory. “Quantum electrodynamics” says Bunge “discovered that, even when a container is thoroughly vacuumed, and all the electromagnetic fields are switched off, something remains in addition to the gravitational field: namely, the fluctuating quantum vacuum. This field may be regarded as the residual field that remains after all the electric charges have been removed.” (Bunge, 2010, p. 47), i.e., the vacuum state of electromagnetic field. “The electromagnetic field that remains in a region of space after all the electric charges have been neutralized, and all the electric currents have been switched off, is a concrete though tenuous thing.” (Bunge, 2010, p.66; 2012, p. 136). So, Bunge’s suggestion to “step down to the level of the fluctuating vacuum of quantum electrodynamics, with its small but measurable Lamb shift and Casimir force” (Bunge 2018a, 2018b, p. 123) is truly illuminating.

**A possibility for Neo-Bungean Space(time) Structuralism**

Based upon the late Einsteinian remarks on the nature of space(time), one could update the Bungean relationalism. Brief notes will be given, upon which one can build and expand.

What is a structure?

A structure is a set of certain relations within and/or among things. Bunge differentiates between two types of relations: binding and non-binding relations. Binding (or bonding) relations are links that couple two (or) more things together in a system. These relations “make difference” to the relata, think of physical forces, chemical bonds, friendship, business relation, etc. (Bunge, 2003, p. 33). Spatiotemporal relations, on the other hand, are not bonds. True, “they may render bonds possible or impossible” (ibid.), but they in themselves do not affect the relata.

Another dichotomy that Bunge (Mahner & Bunge, 1997, p. 27; Bunge, 2001, p. 42; 2006, p. 36; 2013, p. 45; see also Mahner 2017, p. 188-189) proposes is that of internal structure (*endostructure*) and external structure (*exostructure*). The endostructure is the set of bonding and nonbonding relations internal to the thing (among the components of a system). The exostructure then, is defined as the set of bonding and nonbonding relations held externally among a thing (or some of its parts) and the items in its environment. The superset that includes the endo- and the exostructure will be dubbed *holostructure* in this paper.

Spatial structure, then, is the set of all nonbinding spatial relations held among material things. According to GR, the gravitational field plays a central role, for space(time) is a structural quality of the field. The spatial relations within the gravitational field constitute the endostructure of space and those among the field (or some of its parts) and other material entities constitute the exostructure. The union of these two sets makes up the holostructure of space.

Space(time) structur(al)ism, then, is synonymous with relation(al)ism, or yet a better description for the Bungean position, for “space is not a relation but a set of related things or, if preferred, a relational structure” (Bunge, 1977, p. 296).

But what defines spatial relations? One could adopt the notions of interposition and separation that Bunge and Máynez (1976; see also Bunge 1977, pp. 276-333) proposed or the updated version by Pérez-Bergliaffa, Romero and Vucetich (1998) and start from there.

Beyond Syntax and Semantics

One might argue that the whole debate is nothing but a semantic dispute: one party calls the entity ‘space(time)’ while the other calls it ‘gravitational field’. A superficial glance might push to such conclusion, yet on deeper analysis one cannot but notice the different foundations each position is built upon, and the consequences each stance entails:

1. The ‘Neo-Bungean’ stance is already indebted to Bunge for its axiomatization. Romero (2018b) nonetheless proposed his own sets of axioms. He adopts the position that the Lorentzian metric tensor “represents both the geometrical properties of spacetime and the potential of gravity” (Romero, 2018, p. 150). Thus, “the ten coefficients of the metric do not represent a physical field, but a class of properties of a substantival entity: spacetime” (ibid, p. 151)[[14]](#footnote-15). Yet, this puts the Romerian position under the same light of criticism as the Paleo-Bungean: the components of the coefficients of the metric can be interpreted as components of a physical field, which is reinforced by the red shift formula. The Neo-Bungean position solves the problem by ditching the source hypothesis and admitting that the metric tensor does in fact represent the (inertio)gravitational field. Indeed, without such field the manifold losses its meaning. The manifold depends on the metric tensor because space(time), in GR, is dependent upon the field, i.e., it is a structural property of the (inertio)gravitational field. After all, GR, à la Einstein and pace Romero, is a field theory.
2. As a consequence of the first point, the Neo-Bungean position renders the field represented by the metric tensor, i.e., the (inertio)gravitational field, similar to other physical fields. This provides a solid philosophical ground for scientific research regarding quantum gravity and the possibility for uniting field theories into a grand theory. This advantage is absent from the Romerian stance, for he admits that his axioms entail that “the metric field is not akin other physical fields; it represents the geometrical properties of spacetime and does not have independent existence” (ibid, p. 152).
3. On a philosophical note, substantivalism is an unnecessary postulate at best, for if all kinds of motion can be accounted for by relations only (either in relation to the (inertio)gravitational field or to matter in general), then the substantivality of space(time) would become an extra assumption. Plus, such relations within the substance of space(time) (i.e. the spatial endostructure) is not accounted for by a superspace(time), but rather by the mere spatial relations within it, rendering substantivalism (or at least the settling for a single spacetime) arbitrary and rather demanding.
4. Finally, to insist on calling “spacetime” the gravitational field in GR with the above-mentioned properties “is a very weakened substantivalist position. One is free to call “spacetime” anything with respect to which we define position. But to what extent is spacetime different from any arbitrary continuum of objects used to define position? Newton’s acute formulation of his substantivalism... contains a precise characterization of “space”:

…so it is necessary that the definition of places, and hence of local motion, be referred to some motionless thing such as extension alone or “space,” *in so far as space is seen to be truly distinct from moving bodies.*

The characterizing feature of space is that of being truly distinct from moving bodies,that is, in modern terms and after the Faraday–Maxwell conceptual revolution, that of being truly distinct from dynamical entities such as particles or fields. This is clearlynot the case for the spacetime of GR. If the modern substantivalist is happy to give upNewton’s strong substantivalism and identify the thesis that “spacetime is an entity”with the thesis that “spacetime is the gravitational field, which is a dynamical entity,” then the distinction between substantivalism and relationalism is completely reducedto one of semantics” (Rovelli, 2010, pp. 77-87, emphasis in original).

**Conclusion:**

Scientific discoveries are of great importance for scientific-oriented philosophy, an example of this was the detection of the gravitational waves as predicted by general relativity and the subsequent debate regarding the nature of space. The Neo-Bungean structuralism advanced in this paper is nothing but the Paleo-Bungean relationalism, just without the source hypothesis that is alien to the general theory of relativity, as Bunge (1967) himself argued. The (inertio)gravitational field (represented by metric tensor) has space(time) as a structural quality (represented by the manifold). Other material entities (represented by the stress–energy–momentum tensor), by acting on the (inertio)gravitational field, distorts the latter and alters its structure. The (inertio)gravitational field reacts to matter, determining the latter’s trajectory.

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1. While Bunge (2018b, p. 120) considers both readings legitimate, he believes that the dualistic formula: “Geometry tells matter how to move, and matter tells geometry how to bend” is puzzling; Geometry involves abstract entities (i.e., fictions) that don’t have causal power on their own. What have causal powers are material things, including the material space, not the mathematical abstraction. [↑](#footnote-ref-2)
2. Romero (2018a) ‘steelmanned’ the argument by directly mentioning the Poisson’s equation of Newtonian gravitation instead:

   ∇2 = 4πGρ [↑](#footnote-ref-3)
3. The substantivalist reality and the relational contingency of space are separate non-contradictory propositions. To put it bluntly, humans are material things yet they are contingent upon oxygen, water, food, etc. Hence, Romero’s objection that the materiality of space entails its existence in absence of matter does not appear to be accurate. [↑](#footnote-ref-4)
4. Bunge might have noticed the arbitrariness of such position. In an update published in *From a Scientific Point of View* he suggests “suspending our final judgment for the time being” (Bunge,2018b, p. 123), since both stances on the reality of empty space are currently untestable. [↑](#footnote-ref-5)
5. Romero (2018b, p. 31) also maintains that things have properties which can be intrinsic (like electric charge) or relational (like velocity of massive bodies). [↑](#footnote-ref-6)
6. The Mach’s Principle I refer to is the original formulation which states that bodies are the sole physical reality, and therefore the sole determinants of space(time). [↑](#footnote-ref-7)
7. For a detailed account, the reader is referred to Cao (2019). [↑](#footnote-ref-8)
8. “B. Principle of Equivalence. Inertia and gravity are phenomena identical in nature. From this and from the special theory of relativity it follows necessarily that the symmetric “fundamental tensor” (g*μν*) determines the metric properties of space, the inertial behavior of bodies in this space, as well as the gravitational effects. We shall call the state of space which is described by this fundamental tensor the “G-field”.” (Einstein, 1918). [↑](#footnote-ref-9)
9. The cosmological constant, also known as “Einstein’s biggest blunder” at the time. [↑](#footnote-ref-10)
10. Minkowski space. [↑](#footnote-ref-11)
11. The manifold/continuum. [↑](#footnote-ref-12)
12. The same idea was expressed by Einstein in a letter to Felix Pirani, written in 1954 and translated by Lehmkuhl (2011): “[Proponents of Mach’s principle] think that the field should be completely determined by matter. But this is tricky, for the *Tik*, which are supposed to represent ‘matter’, always presuppose the *gik* field. [...] [O]ne should not speak of Mach’s principle anymore.” [↑](#footnote-ref-13)
13. Aμ(x, t) = kμ*−*Aμ*−*(x, t) + kμ+Aμ+(x, t) [↑](#footnote-ref-14)
14. Romero, in fact, argues in similar lines with Bunge: by adhering to the source hypothesis and appealing to the Equivalence Principle. [↑](#footnote-ref-15)