Literal versus Careful Interpretations of Scientific Theories: The Vacuum Approach to the Problem of Motion in General Relativity

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The problem of motion in general relativity is about how exactly the gravitational field equations, the Einstein equations, are related to the equations of motion of material bodies subject to gravitational fields. This article compares two approaches to derive the geodesic motion of (test) matter from the field equations: the 'T approach' and the 'vacuum approach'. The latter approach has been dismissed by philosophers of physics because it apparently represents material bodies by singularities. I argue that a careful interpretation of the approach shows that it does not depend on introducing singularities at all and that it holds at least as much promise as the T approach.

1. Introduction. It is a bit ironic that one of the most widely embraced definitions of what it means to be a scientific realist is due to the arch-anti-realist Bas van Fraassen. His definition starts by stating that "Science aims to give us, in its theories, a literally true story of what the world is like" (van Fraassen 1980, 8). And indeed, scientific realists often see themselves as com-

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mitted to 'taking scientific theories at face value': if the best theories of particle physics say that quarks exist, then we should believe that they exist; if general relativity tells us that gravity is really just an aspect of space-time structure, then we should believe it; if quantum mechanics tells us that the world is at its core nondeterministic, then we should believe that too.

The problem is that scientific theories, or at least the theories of modern physics, are not that straightforward with us. They may seem so at first, but if you listen to the details of their respective stories, if you take your time to look under the surface, what exactly we should take them to tell us about the world is far from clear. Murray Gell-Mann, the inventor of the concept of quarks, for a long time did not think that quarks should be interpreted as literally existing; neither did Richard Feynman. Albert Einstein passionately resisted the interpretation of general relativity that says that the gravitational force field of Newtonian theory is ontologically reduced to the geometry of space-time in general relativity. And of course, there is a long-standing battle in foundations of physics about whether quantum mechanics really does tell us that the world is nondeterministic.[1]

In this article I introduce a new case study that provides further evidence for the position that, whether you are a realist or not, the *literal interpretation* of a scientific theory, especially in physics, can be rather misleading. I will argue that what we should aim for is a *careful interpretation*; an interpretation of the theory or model or formalism that engages both with the details of its mathematical structure and with how it is applied to the natural world. Philosophy of science must be willing to look under the hood.

The case study I want to look at is the so-called problem of motion in the general theory of relativity (GR). It asks about the precise relationship between the two sets of equations that are at the very heart of GR. On the one hand, there are the Einstein field equations, which give us the dynamics of the gravitational potential (the metric tensor) $g_{\mu\nu}$:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \kappa_E T_{\mu\nu}. \tag{1}$$

On the other hand, we have the geodesic equation that determines which paths through space-time are geodesics of the connection $\Gamma^{\nu}_{\mu\sigma}$ compatible with the metric $g_{\mu\nu}$:

$$\frac{d^2 x_\tau}{ds^2} + \Gamma^{\tau}_{\mu\nu} \frac{dx_\mu}{ds} \frac{dx_\nu}{ds} = 0. \tag{2}$$

1. For a discussion of different interpretations of the quark concept, see Pickering (1999); for Einstein's opposition to interpreting general relativity as a geometrization of gravity, see Lehmkuhl (2014); and for debate on whether quantum mechanics is really indeterministic, see, e.g., Saunders et al. (2010).

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In GR, material bodies subject only to gravitational fields are supposed to move on the geodesics determined by equation (2). The problem of motion in GR is the question of whether the equations of motion of matter subject to gravitational fields (2) can be derived from the gravitational field equations (1).

Einstein himself, in his first publication on the topic, a paper cowritten with Jakob Grommer and published in 1927, compares different classes of attempts to give such a derivation. In particular, Einstein and Grommer distinguish between two classes of attempts at deriving the geodesic motion of matter from the gravitational field equations, which I will term the *T approach* and the *vacuum approach*, respectively. The T approach starts from the realization that the field equations (1) imply the conservation condition, namely, that the covariant divergence of the energy-momentum tensor $T_{\mu\nu}$ vanishes:

$$\nabla^{\mu} T_{\mu\nu} = 0. \tag{3}$$

From this, together with certain conditions on the energy-momentum tensor $T_{\mu\nu}$, the T approach derives that material particles move on time-like geodesics. It is this kind of approach to the problem of motion that philosophers have engaged with almost exclusively up to now.[2]

Einstein and Grommer end up dismissing the T approach and suggest an alternative path to deriving geodesic motion instead. It is a particular version of a *vacuum approach to the problem of motion*. Einstein and Grommer start from the vacuum form of the Einstein field equations,

$$R_{\mu\nu} = 0, \tag{4}$$

and attempt to derive that the equations (4) imply that material particles move on geodesics.

To the extent that philosophers have engaged with this approach at all, they have quickly dismissed it because it seems to model material bodies by singularities in space-time, while singularities, by definition, are not even part of space-time. However, in this article I argue that this dismissal was far too fast and that indeed the vacuum approach deserves at least as much attention by philosophers as the T approach. The vacuum approach, despite first appearances, engages more closely with some of the most major predictions of GR: both the prediction of the perihelion of Mercury and the prediction of light bending by the Sun use the vacuum approach to the derivation of motion of material systems. Indeed, even the prediction of gravitational

2. For a comprehensive review of the early history of this approach, see Havas (1989) and Kennefick (2005); for two particularly beautiful exemplars from within this class of proofs, see Geroch and Jang (1975) and Ehlers and Geroch (2004), which are investigated by Brown (2007), Weatherall (2011, 2017), and Malament (2012).

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waves resulting from a binary black hole merger that was recently confirmed rests on the vacuum field equations, for black holes are described by vacuum solutions.[3]

My argument in this article proceeds in three steps. First, I argue that the vacuum approach to the problem of motion promises certain advantages that the T approach lacks. Second, I argue that the problems of the vacuum approach for which it has been dismissed are artifacts of a too-literal interpretation of the formalism and its application to the problem at hand. Third, I argue that a careful interpretation makes the problems disappear; I argue that the approach does not need to interpret singularities as representing material bodies.

2. A Critical Comparison of the Two Research Programs. I said above that the T approach to the problem of motion proceeds via the fact that the Einstein field equations (1) imply the conservation condition (3), which in turn implies the geodesic motion of matter. However, as Malament (2012) pointed out, the conservation condition by itself is not sufficient to prove that the geodesic equation is the equation of motion of material particles. One of the most general proofs from within the T approach, proposed by Geroch and Jang (1975) and further generalized by Ehlers and Geroch (2004), rests not only on the conservation condition (3) but also on the strengthened dominant energy condition (SDEC), which states:

> Given any time-like covector ξ_μ at any point in M, $T^{\mu\nu}\xi_\mu\xi_\nu \geq 0$, and either $T^{\mu\nu} = 0$ or $T^{\mu\nu}\xi_\mu$ is time-like.

The first clause is effectively the weak energy condition, which states that the mass-energy-momentum density associated with the body in question is always nonnegative. The second clause states that every observer will judge the mass energy momentum of the body to propagate along time-like curves only.[4]

It would be rather attractive if we did not have to presume that material particles move on time-like curves to then show that these curves are actually time-like geodesics, and if we did not have to presume that matter cannot have nonnegative mass energy. These are weak assumptions about the nature of matter, but they are assumptions.

The vacuum approach to the problem of motion, however, aims to make no assumptions about the nature of matter and its properties at all and to still derive that matter moves on geodesics. It starts from the question of whether

3. See Abbott et al. (2016) and references therein.

4. For more on the interpretation of the SDEC, see Weatherall (2011, 2017) and esp. Curiel (2017).

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just knowing the exterior gravitational field of a material body, and how this gravitational field interacts with the gravitational field of its surroundings, is enough to derive that the body will move on a geodesic of the metric surrounding it. Arguably, this program is far more ambitious than the T approach, for it starts with fewer assumptions.[5] And yet, if successful, it would really fit much better the virtues that philosophers have associated with the geodesic theorem(s) in the first place: deriving the inertial motion of matter from knowledge of the dynamics of gravitational fields alone (cf. Brown 2007, 141 and 163).

Einstein was deeply skeptical of the role of the energy-momentum tensor in GR. Throughout the decades, he emphasized that $T_{\mu\nu}$ provides only a "phenomenological representation of matter."[6] Einstein's aim is then to instead start with the vacuum field equations (4), treat material particles as singularities in the metric field, and derive that they move on geodesics of a metric $g_{\mu\nu}$ that solves the vacuum field equations (4) in the region through which the particle moves.

To the extent that philosophers have engaged with this approach at all, they have already dismissed it at this point. The main criticism is that the very idea of the approach is flawed: a singularity is not even part of space-time. How should it be possible to describe its motion in said space-time?

Both Torretti and Earman essentially answer that this is not possible and that the whole program is ill conceived. Earman (1995, 12), writes: "Singularities in the spacetime metric cannot be regarded as taking place at points of the spacetime manifold M. Thus, to speak of singularities in $g_{\mu\nu}$ as geodesics of the spacetime is to speak in oxymorons."[7] The most detailed discussion of the Einstein-Grommer paper in the philosophical literature is due to Tamir (2012). After quoting the above statement by Earman, Tamir goes on to write (142): "The proponent of such a 'vacuum-cum-singularity' technique is faced with the rather paradoxical challenge of explaining in what sense we can say that a singular curve (ostensibly constituted by the *missing* points in the manifold) is actually a geodesic of the spacetime from which it

5. One might be tempted to argue that despite first appearances the vacuum approach starts with more demanding assumptions than the T approach. For the vacuum Einstein eqq. (4) logically imply that the SDEC holds for the Ricci tensor $R_{\mu\nu}$. The opposite is not true, so that demanding Ricci flatness is clearly a stronger constraint on the Ricci tensor than demanding that it obeys the SDEC. But the T approach assumes (i) the full Einstein field eqq. (1) and (ii) that the energy-momentum tensor (and thus the Einstein tensor) adheres to the SDEC. The vacuum approach only assumes the vacuum Einstein eq. (4), and thus starts with weaker assumptions than the T approach.

6. See, e.g., Einstein (1922), Einstein to Michele Besso, August 11, 1926 (EA-7-361); and Einstein (1936).

7. For similar statements, see Torretti (1996), sec. 5.8.

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is absent. Not only is no metric defined at the singularity, but also technically there are not even spacetime points there: the geodesic does not exist."

I will argue that by looking at the details of the Einstein-Grommer approach we come to a different interpretation of it, one that sheds a completely different light on the alleged presence of singularities. We will see that a careful (rather than literal) interpretation of the vacuum approach, and the Einstein-Grommer paper in particular, does not actually depend on introducing singularities at all.

3. The Vacuum Approach to the Problem of Motion

3.1. Two Ways of Looking at Einstein's Model of the Sun-Mercury System. In a way, the story of the vacuum approach to the problem of motion starts in 1915, with Einstein's treatment of the orbit of Mercury around the Sun in the context of GR. It is a two-body problem: a small body (Mercury) with a comparatively small mass orbits a large body (the Sun). Einstein seems to postulate (more on the 'seems' below) that the Sun be represented by what would soon be recognized as an approximation to the Schwarzschild metric. He definitely postulates that Mercury moves on a geodesic of said metric.[8] In a way, the problem of motion in GR is about the question of whether this second postulate is really necessary.

If we now look at Einstein's Mercury paper and recall the kind of criticism that was launched against the vacuum approach to the problem of motion, we may find ourselves puzzled. After all, the Schwarzschild metric is a solution to the vacuum field equations, and it has a singularity at its center.[9] If representing material bodies by singular metrics is so problematic, how does it come about that Einstein (1915) successfully predicted the perihelion motion of Mercury? Why is it not problematic to represent the Sun by the singular Schwarzschild metric?

The answer lies in denying the premise of the question. Einstein's treatment of the Sun-Mercury system should not be interpreted as involving him representing the Sun by (an approximation of) the Schwarzschild metric. We know that the Sun is a material body with nonvanishing mass energy and that it does not have a space-time singularity at its center. What Einstein really does is to convert the two-body problem Sun-Mercury into a one-body problem, where one body (Mercury) is subject to an external gravitational field. It is the exterior gravitational field of the Sun, not the Sun itself,

8. For a careful analysis of Einstein's Mercury paper and how it rests on the Einstein-Besso manuscript, see Earman and Janssen (1993) and Janssen's editorial note on the Einstein-Besso manuscript in vol. 4 of the *Collected Papers of Albert Einstein*.

9. For the history and interpretation of the Schwarzschild metric and its analytic extensions, see Eisenstaedt (1989) and Bonnor (1992).

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that is represented by the Schwarzschild metric. And that is enough to predict the perihelion of Mercury: we do not need to know what the Sun is made of or what happens in its interior; all that matters is the exterior gravitational field that Mercury is subject to.

Thus, worrying about the singularity at the center of the Schwarzschild metric just misses the point: we do not have to interpret the interior part of the Schwarzschild metric literally, at least not in this application.

In what follows, I argue that we should interpret the appearance of singularities in the Einstein-Grommer vacuum approach to the problem of motion in a similar vein.

3.2. The Einstein-Grommer Vacuum Approach to the Problem of Motion. The general scheme of the Einstein-Grommer approach proceeds as follows.

1. Reformulate the vacuum Einstein equations in terms of a surface integral over a three-dimensional hypersurface such that we can ask whether gravitational energy-momentum represented by the pseudotensor t_α^τ passes through the surface.
2. Pick a curve that is supposed to represent the path of a material particle.
3. Impose the linear approximation according to which $g_{\mu\nu} = \eta_{\mu\nu} + \gamma_{\mu\nu}$; that is, assume that, at least close to the curve, the metric deviates from Minkowski space-time $\eta_{\mu\nu}$ only slightly.
4. Realize that not all solutions to the linearized field equations will correspond to solutions of the nonlinear field equations that the linearized field equations approximate. Argue that in the case in which an 'equilibrium condition' for the energy pseudotensor of the gravitational field holds, the $\gamma_{\mu\nu}$ of the linearized field equations will solve the full nonlinear equations reformulated as a surface integral.[10]
5. Now, split the $\gamma_{\mu\nu}$ in the immediate neighborhood of the particle into the 'inner metric' $\bar{\gamma}_{\mu\nu}$ that the particle itself gives rise to and the 'outer metric' $\bar{\bar{\gamma}}_{\mu\nu}$ that is due to other sources (or lack thereof). Observe that the 'outer metric' is entirely regular, even if extended to the point at which the material particle is supposed to be located.
6. Integrate the surface integral that is equivalent to the vacuum field equations 'around' the curve that is supposed to represent the path of a material particle. For the case in which the integration surface is a sphere, the equilibrium condition for t_α^τ simplifies to $\partial\bar{\bar{\gamma}}_{44}/\partial x_\sigma = 0$.

10. This step is very intricate, and it would take me a few pages to do it justice; I will have to do so elsewhere.

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7. Conclude that the curve that represents the path of a material particle is a geodesic of the outer metric $\bar{\bar{\gamma}}_{\mu\nu}$.

4. Interpreting the Einstein-Grommer Approach to the Problem of Motion. The reader might think that the argument presented in the last section cannot be a faithful representation of the Einstein-Grommer approach; after all, where is the claim that the material particle is represented by a singularity, the reason the approach was dismissed by Earman and Tamir? Indeed, I have omitted that after step 5 of the argument Einstein and Grommer do say that one could assume that the inner metric $\bar{\gamma}_{\mu\nu}$ is given by what is effectively the Schwarzschild metric: it is spherically symmetric and has a singularity at the center. And yet, Einstein and Grommer never use this assumption in their argument. They call the material particle 'the singularity' all the time, but their argument does not depend on assuming any particular form for the inner metric, let alone one that is necessarily singular. As a matter of fact, they do not even mention a concrete candidate metric for the outer metric $\bar{\bar{\gamma}}_{\mu\nu}$; all they need is that $\gamma_{\mu\nu}$ is split into the inner metric $\bar{\gamma}_{\mu\nu}$ and the outer metric $\bar{\bar{\gamma}}_{\mu\nu}$ in such a way that $\bar{\bar{\gamma}}_{\mu\nu}$ is nonsingular everywhere.

Note that this does not mean that we know that the inner metric $\bar{\gamma}_{\mu\nu}$ is nonsingular. We do not know anything about the inner metric, for the argument is independent of $\bar{\gamma}_{\mu\nu}$ having any particular form, just like the derivation of Mercury's perihelion was independent of whether there is a singularity at the center of the Schwarzschild metric that represented the exterior field of the Sun.

With regard to the Sun-Mercury system I argued that we should not interpret the Schwarzschild metric as representing the Sun but as representing its exterior gravitational field. The part of the Sun that is within the event horizon, including the singularity at the center, should not be taken as a representation of the actual interior of the Sun but as a placeholder or a blind spot within the current description of the Sun-Mercury system: a docking station for a theoretical model of the Sun not included in Einstein's Sun-Mercury model.[11]

Likewise, we should interpret the inner metric $\bar{\gamma}_{\mu\nu}$ in the Einstein-Grommer approach as a placeholder for a representation of matter not included in the current theoretical approach. Sure, you can set $\bar{\gamma}_{\mu\nu}$ to be a Schwarzschild-like metric with a singularity at the center. But you do not have to do that to make the Einstein-Grommer argument work, and even if you do make that assumption, you should still take this particular inner metric with a singularity at its center as a placeholder for a representation or the-

11. Note that there are interior extensions of the Schwarzschild metric that model the interior of the Sun by solutions of the nonvacuum field eqq. (1), e.g., by an incompressible perfect fluid. See Bonnor (1992), sec. 5.

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ory of matter not yet provided. But now wait a minute. You might have disliked the occurrence of singularities as representations of particles, but at least the singularity (in lieu of a nonvanishing energy-momentum tensor) gave you an idea of where in space-time the particle was supposed to be. True, Earman and Tamir rightly pointed out that the singularity is not actually part of space-time, and so it can hardly serve to localize the particle in space-time. Still, you might think that we are throwing the baby out with the bath water by not choosing any inner metric. After all, is it not the case then that the curve we have been focusing on is just any curve, without any reason to think of this curve as the curve of a material particle?[12]

Again, I think we can counter this criticism by comparing the Einstein-Grommer approach to Einstein's (1915) treatment of the Sun-Mercury system. What Einstein did there was to assume that Mercury would move on some geodesic of the exterior gravitational field produced by the Sun. He calculated an approximation to the external gravitational field of a static, spherically symmetric body, whose metric is asymptotically flat; this gravitational field he saw as represented by the connection components $\Gamma^{\nu}_{\mu\sigma}$ of a metric $g_{\mu\nu}$, which deviated only slightly from the flat Minkowski metric. He then inserted these gravitational field components $\Gamma^{\nu}_{\mu\sigma}$ into the geodesic equation (2). He showed that this law contained Newton's first law and Newton's second law with a gravitational potential giving rise to a force as a limiting case, and he showed how the resulting Keplerian laws for orbits differ in his theory as compared to its Newtonian limit. In the end, he obtained that according to the new theory the perihelion ε of any geodesic orbit around the Sun is given by

$$\varepsilon = 24\pi^3 \frac{a^2}{T^2 c^2 (1 - e^2)}. \tag{5}$$

Here a denotes the length of the semimajor axis of the orbit in question, e its eccentricity, c the speed of light, and T the orbital period of the planet in question. Einstein then takes the astronomically known values for Mercury, plugs them into equation (5), and thereby predicts that Mercury's perihelion changes by 43" per century.

Note that there is nothing in the theoretical description that singles out any particular path as that of Mercury. There is no theoretical representation of Mercury, no model. All that is there is the assumption that Mercury will move on one of the geodesics of the affine connection determined by the spherically symmetric field of the Sun. A general equation that all possible geodesic orbits have to fulfill is derived. And then external knowledge is used to single out one of these orbits as that of Mercury. Einstein trusts that the astronomers have measured the orbital period, the semimajor axis, and the

12. I thank Jim Weatherall for putting this question to me.

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eccentricity of Mercury correctly. It is this external knowledge, plugged into his theoretical model, which does not in itself contain a representation of Mercury or its path, that produces the prediction.

In many ways, the whole vacuum approach to the problem of motion is about the question whether in this kind of scenario we really have to assume the geodesic equation as the equation of motion of matter over and above the gravitational field equations. Indeed, let us look at the Sun-Mercury system within the 1927 Einstein-Grommer approach. The problem of motion, then, is the question whether Einstein really had to introduce the gravitational field equations (to describe the exterior gravitational field of the Sun) and the geodesic equation (to describe the path of Mercury subject to this gravitational field) as separate assumptions.[13] Could he have only assumed the gravitational field equations and derived that Mercury moves on a geodesic of the exterior field of the Sun? My point is that, just like in Einstein's 1915 treatment, the 1927 Einstein-Grommer approach does not need to commit to a theoretical model that allows us to localize Mercury internally. It is fine to ask whether the exterior gravitational field around a given curve 'forces' that curve to be a geodesic. Just like in the 1915 treatment, Einstein and Grommer could then use external knowledge about whether that particular curve is actually the curve of a material object, or of Mercury in particular. No inner metric, no singularity to represent the material body, is actually needed.

Let us take a step back though, for there is an important difference between the structure of Einstein's 1915 treatment of Mercury on the one hand and the 1927 Einstein-Grommer approach on the other. In the Mercury case, Einstein had assumed that Mercury moves on a geodesic (i.e., a special kind of curve), and model-external knowledge about the period, eccentricity, and semimajor axis of Mercury could then be used to determine which of the many geodesics of the Schwarzschild metric corresponded to the path of Mercury. But in the case of the Einstein-Grommer argument, what is in question is whether we can prove that the path of Mercury, say, is a geodesic. Thus, at first sight it looks as if while the 1915 argument only needed external knowledge to determine which geodesic is that of Mercury, appeal to external knowledge in the Einstein-Grommer case would have to determine (*a*) that this curve is a geodesic and (*b*) that it is the curve of a material body.

Einstein and Grommer did not aim to derive both *a* and *b*. Instead, while Einstein in 1915 used external knowledge at the end of his argument, Einstein and Grommer in 1927 use it at the beginning. They start out by assum-

13. Interestingly, Einstein did not yet have the final gravitational field equations in the Mercury paper; he found them a week later, in his fourth paper of November 1915. However, the approximation of the Schwarzschild metric that he uses in the Mercury paper is an approximative solution of both the field equations from the Mercury paper and the final Einstein field equations.

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ing that a given curve is the curve of a material particle and then ask whether having a regular outer metric (which solves the vacuum field equations) around the curve means that the curve of this material particle, given the further conditions summarized in section 3.2, must be a geodesic. Rather than finishing the argument by appeal to external knowledge (as in Einstein 1915), the Einstein-Grommer argument starts with an appeal to external knowledge, which singles out a particular curve as that of a material body.

Either way, both in Einstein's 1915 treatment and in the Einstein-Grommer approach there is no reason to interpret the singularity (appearing in the Schwarzschild metric or the inner metric, respectively) literally. In both cases, the singularity should be interpreted to signify a placeholder or a blind spot of the theoretical treatment, rather than something that should be interpreted literally, as referring and approximately true. Indeed, both Einstein's 1915 treatment of the Sun-Mercury system and Einstein and Grommer's treatment of an arbitrary material particle subject to an external gravitational field work just as well if, in the former case, no interior metric (to describe the interior of the Sun) or, in the latter case, no inner metric (to represent the location of the particle on the curve) is ever specified.

5. Conclusion. I started out by saying that whether we are realists or antirealists, we should aim for a careful interpretation, rather than a literal interpretation, of the scientific theory that we want to be realists or antirealists about. Using a case study, I argued that the vacuum approach to the problem of motion in GR, and the Einstein-Grommer approach in particular, is far more sensible and promising if we interpret the singularities not as representing material bodies but as placeholders for a representation of material bodies that is not included in the model. Indeed, I argued that the approach does not even need the introduction of singularities to represent material bodies; their introduction does not do any work in answering the question at hand.[14]

14. The argument that we should thus not see a realist as committed to being a realist about the singularities appearing in the Einstein-Grommer paper resonates well with selective or posit realism as introduced by Vickers (2013). The idea there is that we should only be realists with respect to components of a prediction that 'fuel the success' of the prediction, i.e., that are indispensable in the derivation of what is predicted. Using Vickers's distinction, the introduction of a singular inner metric in the Einstein-Grommer approach is an idle rather than a working posit. However, note that the call for careful rather than literal interpretations with which I started is independent of/complementary to aiming for identification of the idle posits in a derivation. For *even if* we had found that the introduction of the singular inner metric did do work in the derivation of geodesic motion, could we have argued (with less force) that the singularity should be interpreted as a placeholder for a future theory of matter, as a temporary measure within an effective theory, and thus not as something that we should interpret as possessing as much 'reality' or 'referring power' as the regular outer metric governed by the field equations.

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Given that in their paper Einstein and Grommer seem to take the singularities as representing material bodies, one might wonder whether this allegedly more careful interpretation does not fall prey to the criticism that the careful interpreter presumes to understand the theory/formalism in question better than its originators. This might seem at odds with the realist tenet of taking scientists and science 'seriously'. I do indeed think that putting the Einstein-Grommer paper into its proper historical context by analyzing Einstein's correspondence leading up to the paper and by relating it to his overarching research project at the time would convincingly show that he subscribed to something very much like the 'placeholder interpretation' I defended above. Showing this in detail will have to wait for a much longer paper, and I do not ask the reader to just take my word for it. So let us say, for the sake of the argument, that Einstein and Grommer did indeed intend the singularities as representatives of material objects in a rather straightforward way. I believe that we should not take their word for it either. And neither did Einstein. Just a few years after the Einstein-Grommer paper, in his famed 1933 Spencer lectures at the University of Oxford, Einstein (1934, 163) told us in his opening words: "If you wish to learn from the theoretical physicist anything about the methods which he uses, I would give you the following advice: Do not listen to his words, examine his achievements."[15]

In philosophy of science, I believe there is no better way of examining a scientist's achievements than by looking for the best possible interpretation of his or her theories. To do that, we have to not just listen to the words of the scientist who created or discovered it; we have to see what the theory does in practice, how it is used, which of its parts really do the work.

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15. See Einstein (1934) and van Dongen (2010) for a detailed analysis of the text.

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