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Relevance, not Invariance, Explanatoriness, not Manipulability: Discussion of Woodward on Explanatory Relevance.

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Abstract

In Woodward's causal model of explanation, explanatory information is information that is relevant to manipulation and control and that affords to change the value of some target *explanandum* variable by intervening on some other. Accordingly, the depth of an explanation is evaluated through the size of the domain of invariance of the generalization involved.

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1. Introduction

The question of explanatory relevance has been for long a challenge for theorists of explanation. It is well-known for example that Hempel's DN model, Salmon's SR model or Salmon's causal models fail to characterize philosophically what type of information is relevant to the explanation of some fact *F* and should therefore figure in its explanation.

In the last two decades, James Woodward has developed a manipulationist model of explanation, which seems to fare better than its predecessors about explanatory relevance, if not to solve the issue, and that accounts for many of the usual tricky cases. In this model, explanatory information is information that is relevant to manipulation or control and that affords to change the value of some target *explanandum* variable by intervening on some other. Accordingly, the depth of an explanation is evaluated through the size of the domain of invariance of the generalization involved.

In this paper, I argue that Woodward's treatment of relevance in terms of invariant causal relations is still subtly but unavoidably wanting because it forces one to include within the explanation of a fact F much information that may be relevant to account for other facts of a same physical type but may be irrelevant to F. I further suggest to evaluate the depth of an explanation through the size of the domain of circumstances it describes as leaving the *explanandum* phenomenon unchanged.

In section 2, I briefly present Woodward's account of explanation and his notion of explanatory depth. I develop at length in section 3 a test case example dealing with the explanation of the law of Areas and describe two ways to explain this physical regularity. I show in section 4 that, whereas the first explanation includes clearly irrelevant facts, according to Woodward's account, it cannot be said to be less explanatory than the second. I further analyze why satisfying the manipulability requirement may imply to include irrelevant facts in explanations in order to make them deeper (in Woodward's sense). I further describe in section 5 a new criterion for judging explanatory depth and argue that this criterion and Woodward's criterion are incompatible. I finally emphasize in section 6 that manipulability is still a virtue, even if not an essential virtue of explanations and that, depending on the circumstances, one may be interested in developing explanations that are less explanatory (because they contain irrelevant facts) but that afford to control physical systems.

2. Woodward's manipulationist account of explanation

It may seem weird to challenge Woodward (and Hitchcock) on the question of explanatory relevance for they have themselves showed much acumen in diagnosing where existing accounts fail and offered new answers to the problem. Indeed, in his 1995 article, Hitchcock elegantly shows that the problem of explanatory relevance is still a worry for Salmon's causal model because identifying all the intermingled spatio-temporal causal processes running in some physical circumstances falls short of indicating why exactly some phenomenon takes place in these circumstances. As Woodward further notes, even if the right causal processes are identified, "features of a process *P* in virtue of which it qualifies as a causal process (ability to transmit mark *M*) may not be the features of *P* that are causally or explanatorily relevant to the outcome *E* that we want to explain" (Woodward, 2003, 353).

In this context, it comes as no surprise that Woodward tries to answer the above worries by means of his causal model. Doing justice to all aspects of Woodward's rich treatment of explanatory relevance and explanation would take much longer than can be done within this short paper. The next paragraphs are therefore merely devoted to reminding the reader some important aspects of Woodward's account so that what it amounts to when it comes to the analysis of the coming example appears clearly.

For Woodward, "explanation is a matter of exhibiting systematic patterns of counterfactual dependence" (2003, 191). Explanatory generalization used in an explanation must indicate that the *explanandum* was to be expected *and* how it would change, were some changes made in the circumstances that obtained; said differently, good explanations "are such that they can be used to answer a range of counterfactual questions about the conditions under which their *explananda* would have been different" (ibidem).

In this perspective, "explanatory relevant information is information that is potentially relevant to manipulation and control" (2003, 10). In other words, something is relevant information if it essentially figures in an explanation describing how the *explanandum* was to happen and how it would change, were the properties described in the *explanans* modified. This requirement also discards irrelevant circumstances through the identification of irrelevant variables: "an *explanans* variable *S* is explanatorily irrelevant to the value of an *explanandum* variable *M* if *M* would have this value for any value of *S* produced by an intervention" (2003, 200).

Woodward further defines the notion of invariance of a generalization. A generalization can be stable under many changes of conditions not mentioned in it. For example, Coulomb's law holds under changes in the weather. By contrast, a generalization that "continues to hold or is stable in this way under some class of interventions that change the conditions described in its antecedent and that tells us how the conditions described in its consequent would change in response to these interventions is invariant under such interventions" (1997, S.31)[1].

It is then clear that invariance is a gradual notion because a generalization can hold under more or less interventions. Accordingly, depending on the degree of invariance of the generalization they rely upon, explanations provide patterns for answering more or less what-if explanatory requests about these counterfactual circumstances and therefore for controlling the corresponding systems.

Woodward further claims that the concept of invariance provides a means for evaluating the goodness of explanations – what he calls "explanatory depth": "We can thus make comparative judgments about the size of domains of invariance and this is all that is required to motivate comparative judgments of explanatory depth of the sort we have been making" (1997, S.39). To put things briefly, the more invariant, the more explanatory, or to use Woodward's own words: "generalizations that are invariant under a larger and more important set of changes often can be used to provide better explanations and are valued in science for just this reason" (2003, 257).

At this step, my claim can be precisely formulated: even if they are valued in science, more invariant explanations are not always more explanatory because the request for invariance may run contrary to the fundamental request for relevance that explanations should primarily satisfy.

3. The law of Areas and its explanations

[1] More precisely, invariance is defined by means of the notion of "testing intervention". See (2003, 250) for more details.

The test case I now want to investigate is the explanation of the law of Areas (also called "Kepler's second law"), which states that, "for planets in our solar system, a line joining a planet and the sun sweeps out equal areas during equal intervals of time". I shall describe two explanations of it and compare them with respects to invariance and relevance.

As we shall see, the first explanation (hereafter explanation 1) relies upon the general angular momentum theorem. Let us go deeper into it. Let us assume a Galilean reference frame, a fixed axis M' with position given by vector **r'** and a moving material point with position given by vector **r**, having mass *m* and momentum **p** (bold characters denote vectors). The angular momentum of M about M' is defined by: $\mathbf{L}_{\mathbf{r}'} = (\mathbf{r}'-\mathbf{r}) \times \mathbf{p} = m\,(\mathbf{r}'-\mathbf{r}) \times \mathbf{v}$, where the symbol "×" stands for the usual external product. Let **F** denotes the sum of forces applied to M. The momentum of **F** about axis M' or torque is defined as $\boldsymbol{\mu}_{\mathbf{F/M'}} = (\mathbf{r}'-\mathbf{r}) \times \mathbf{F}$. Then, deriving the angular momentum yields

$$\frac{d\mathbf{L}_{\mathbf{r}'}}{dt} = \frac{d((\mathbf{r}-\mathbf{r}')\times\mathbf{p})}{dt} = (\mathbf{r}-\mathbf{r}')\times\frac{d\mathbf{p}}{dt} + \frac{d(\mathbf{r}-\mathbf{r}')}{dt}\times\mathbf{p}$$

Because the momentum **p** is collinear to the speed of M, the second term in the right-hand part of the equation is null. So far no physics has been used. Newton's second law says that $d\mathbf{p}/dt = d(m\mathbf{v}) / dt = m\mathbf{a} = \mathbf{F}$. So finally, one gets

$$(1)\ \frac{d\mathbf{L}_{\mathbf{r}'}}{dt} = (\mathbf{r}-\mathbf{r}')\times\mathbf{F} = \mu_{\mathbf{F/M'}}$$

For a collection of particles, one can also define the total torque $\mu = \Sigma\, \mu_i$, which is the sum of the torques on each particle, as well as the total angular momentum **L**, which is the sum of momentum of each particle and one gets

$$(1.5)\ \mu = \Sigma\, \mu_i = d\mathbf{L}/dt.$$

The total torque is the sum of the momentum of all forces, internal and external. But, because of Newton's law of action and reaction, the torques on two reacting objects compensate and therefore, the internal torques balance out pair by pair. In conclusion, "the rate of change of the total angular momentum about any axis is equal to the external torque about that axis". This is the general angular momentum theorem, which is true for any collection of objects, whether they form a rigid body or not.

If one wants to explain the law of Areas, one should finally note that, in the case of the Earth/Sun two-body system, if $\mathbf{v_E}$ denotes the speed of the Earth, $\mathbf{r_E}$ its position, $\mathbf{F_G}$ the gravitational force, $\mathbf{L_E}$ the Earth momentum about the Sun, α the angle between $\mathbf{r_E}$ and $\mathbf{v_E}$, and A_E (t) the swept area in function of time, in virtue of the definition of the outer product,

$$(2)\ \frac{\|\mathbf{L_E}\|}{m_E} = \frac{\|\mathbf{r_E} \times \mathbf{v_E}\|}{m_E} = \|\mathbf{r}_E\|.\|\mathbf{v}_E\|\sin(\alpha) = 2.\frac{dA_E(t)}{dt}.$$

Because this relation holds for each mass point, the relation $\mu=\Sigma\ \mu_i = d\mathbf{L}/dt$ can now be seen as describing the variation of the variation of the sum of the areas swept by each point of a system about an axis, be it a rigid body or a set of independent mass points.

In the case of the Earth-Sun system, it should further be noted that the momentum of the gravitational force $\mathbf{F_G}$ about the Sun is zero (because the force and the vector $\mathbf{r}$ are collinear). Therefore, because of (1.5), the angular momentum of the Earth about the Sun is constant and because of (2), A(t) grows linearly with time, which demonstrates that the law of Areas obtains.

This explanation perfectly fits Woodward's account of explanation and one can repeat what he says about his paradigmatic case of the theoretical explanation in terms of Coulomb's law of the electrostatic relation $E=\lambda/(2\pi\varepsilon_0 r)$ (203,196-204). The explanation does exhibit the features emphasized by DN theorists: it is a deductively valid argument in terms of Newton's second law and the description of the system (positions, speeds and masses of the points, forces). But in addition, it does exhibit a systematic pattern of counterfactual dependence, which can be summarized by combining (1.5) and (2) into the general relation (3) $\mu=\Sigma\ \mu_i = dL/dt=2\ \Sigma\ m_i\ d/dt\ (dA_i(t)/dt)$, which the law of Areas is a special case when the right variables are assigned the right values (two bodies, one central gravitational force, etc.). The derivation describes how the *explanandum* law of Areas would change according to (3) and how it systematically depends on Newton's second law, the forces and the particular conditions cited in the *explanans*. More specifically, the explanation makes clear how the total swept area would vary were the mass, speed, position of the Earth different, were additional forces at play but also were additional bodies included in the system. In short, (3) and the explanation including it also indicate how to answer a range of what-if questions about counterfactual circumstances in which the *explanandum* would have changed. Regarding the range of these questions and the invariance of the explanation, it is difficult to do better, because Newton's law and (3) cover all situations in classical physics and therefore all classical changes that can be brought about to the two-body system case.

Let us now turn to the second explanation (hereafter explanation 2). In order to give the reader a clearer feeling of why it is better, I shall give two versions of it, one of which more pictorial. Let us start with the vectorial derivation. Because of relation (2), the law of Areas obtains if the intensity $\|\mathbf{L_E}\|$ of the angular momentum $\mathbf{L_E}$ of the Earth about the Sun is constant. In virtue of relation (1), this happens when $(\mathbf{r'}\text{-}\mathbf{r}) \times d\mathbf{p}/dt = 0$, which is the case if $d\mathbf{p}/dt$ and $(\mathbf{r'}\text{-}\mathbf{r})$ are collinear. This is so because the only force at play is radial and the variation of momentum of a particle is along the direction of the force exerted upon it, that is $d\mathbf{p}/dt = \alpha\,\mathbf{F}$, where α is real, not necessarily constant and not specified. Newton provides a more geometrical way to see the explanation:

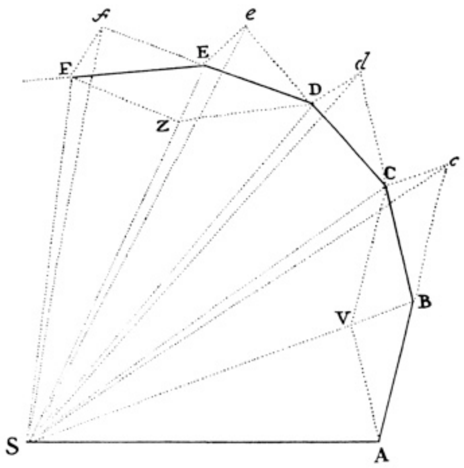

Figure 1: Geometrical demonstration of the Law of Areas by Newton (1726/1972)

The Earth's trajectory goes through A, B, C, etc. and the law of Areas obtains if the area of SAB, SBC, etc. are numerically equal. The explanation of each trajectory step is decomposed in two parts. On the one hand, if no force was at play, in virtue of the inertia principle, the Earth would go straight from B to c in one time interval with AB=Bc. This implies that the area of SAB and SBc are numerically equal. On the other hand, if the Earth was motionless in B, because of the central gravitational force, it would go somewhere on (SB), say in V. By combining the two moves, the Earth finally goes to C, with **BV**=**cC**. Because (Cc) and (SB) are parallel, the area of SAC and SBc are also numerically equal. By combining the two equalities, one gets that that the area of SAB and SAC are numerically equal. The law of Areas finally obtains by taking smaller and smaller time intervals. The important point is that the numerical equality between the area of SBc and SBC obtains whatever the position of V on (SB): in other words, it obtains provided that the change of momentum due to a force is along the force direction, that is, provided d**p**/dt = α **F**.

How good is this second explanation? First, it also exhibits the features emphasized by DN theorists: it is a deductively valid argument in which some nomological component is essentially needed (as well as the description of some particular circumstances). It shows in addition that the whole content of Newton's second law is not required within the explanation. More precisely, the quantitative part of Newton's second law, which relates the values of forces and acceleration, can be removed for the premises without altering the validity of the argument. Better, from a physical point of view, this removal brings some important piece of explanatory information because it indicates more specifically what in the physics is essential for the law of Areas to obtain. The quantitative aspect of the momentum variation is shown to be explanatorily irrelevant, which indicates that the law of Areas does obtain for all worlds with a dynamical law such that the variation of momentum is along the force direction – and this is a piece of explanatory information that explanation 1 does not provide because it includes the described irrelevant information.

Accordingly, explanation 2 is also instrumental to answer what-if questions about what would happen should the intensity of the force be different, time be discrete or the gravitational constant change with time. So, the corresponding explanatory generalization is also invariant under a large range of interventions.

4. Comparison between the two explanations regarding depth and diagnosis about the inadequacy of Woodward's account

Let us now see how the two explanations comparatively fare according to Woodward's criterion of explanatory depth. As just mentioned, both explanations are invariant under a large range of interventions. As we saw, Woodward suggests assessing explanatory depth by comparing domains of invariance. In the present case, none of the two explanations can then be said to be deeper than the other because none of the two sets is a subset of the other. Indeed, explanation 1 directly yields answers to what-if questions about how the total swept area quantitatively changes when, say, non radial forces are at play or more bodies involved, which explanation 2 does not (because it omits the quantitative part of Newton's second law).

Conversely, explanation 2 explicitly indicates that the law of Areas would still obtain in circumstances in which Newton's second law would be violated, which explanation 1 does not, because it designs as explanatory relevant the whole law with its quantitative aspect. Overall, from Woodward's perspective, we have a situation with two good explanations which explanatory depth cannot be compared because their domains of invariance only partly overlap. And this is a case that is accommodated by Woodward when he notes that the comparison of the domains of invariance of explanations "obviously yields only a partial ordering" because "for many pairs of generalizations, neither will have a range of invariance that is a proper subset of the other" (2003, 262-64).

My point is that this woodwardian conclusion is not satisfactory: if one focuses upon the relevance of the explanatory material regarding the *explanandum*, explanation 2 is better than explanatory 1. It is indeed commonly agreed that an explanation of A should merely include explanatory information that is relevant to the occurrence of A (at least if one's epistemic goal is to provide an explanation of A that is as explanatory as possible (see section 6 for more comments about this restriction). As mentioned earlier, explanation 2 omits explanatory material that is irrelevant to the occurrence of the law of Areas, which explanation 1 does not. It is then no surprise that explanation 1 provides an answer to many what-if questions which answer depends on this irrelevant material and cannot therefore be given by explanation 1. However, while these additional answerable questions contribute to extend the invariance of explanation 1, the ability to answer them should not be seen as a sign of the greater goodness of explanation 1 (quite the contrary!) because, as the Newtonian investigation described above shows, answering them requires some causal information that is here explanatorily irrelevant[2].

Let us now try to see more clearly why Woodward's account leads to include irrelevant features in explanations to make them deeper. The reason seems to be that he requires that an explanation should account for many counterfactual cases that belong to a same physical type, defined in terms of the *explanandum* variable appearing in the explanatory generalization, and which the *explanandum* fact is an instantiation of. But this compels him to include in the explanatory material not only the facts that are explanatorily relevant to the target *explanandum* but also the facts that are explanatory relevant to all the values the *explanandum* variable may take. But as the example shows, the explanatorily relevant facts for the latter and the former need not coincide. The moral to draw is that facts belonging to an identical type do not always have the same explanations nor explanations of the same type.

Here, it is important to note that the *explanandum* type that requires to draw this moral (the variation of the swept area) is not the product of some gerrymandering artificially associating pears and apples. So the moral should be rephrased more precisely and strongly like this: facts belonging to an identical *bona fide physical* type (corresponding to the *explanandum* variable of a genuine physical generality) do not always have the same set of explanatory relevant facts nor explanations of the same type.

This conclusion has a counterpart in terms of whether domains of invariance are appropriate to assess the depth of an explanation and which what-if erotetic requests are *appropriate* for this task (to use a notion Woodward often relies upon). Requiring that an explanation of a

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[2] Of course, these irrelevant features belong to a fundamental causal law, which is true in all models described by classical physics. But this does not imply that they should pop up in all our explanations of physical phenomena.

target *explanandum* fact F should allow one to answer what-if questions about counterfactual circumstances corresponding to the invariance domain of some general and functionally described regularity, which the *explanandum* case is an instance of, may imply to include in the explanatory material physical information that is relevant for these circumstances but not for F. Accordingly, even if these explanatory requests are by themselves scientifically legitimate, it may be illegitimate to judge the goodness or depth of an explanation of F by the ability it provides to answer these requests because the physical information necessary for this task may be explanatory irrelevant regarding *F* - and this information should therefore not be included in a good explanation E of F, which removes the possibility of answering these requests on the basis of E. In short, being a what-if question about some circumstances in the domain of invariance of the explanatory generalization that one uses in the explanation E is not a sufficient condition for being an appropriate question for testing the depth of E because this criterion is incompatible with a satisfactory treatment of the problem of relevance for explanations.

The conclusion regarding the evaluation of explanatory depth in terms of domain of invariance comes naturally. It is not legitimate to evaluate the depth of an explanation by assessing the domain of invariance of the generalization used in it. Performing well on the invariance criterion leads to promote explanations of individual facts that are special cases of general explanatory patterns built on generalizations that are invariant on large domains… but it potentially also leads to violate the requirement of relevance for the explanations of these individual facts.

5. Another criterion for explanatory depth

Still, as can be inferred from the discussion of the example, it seems that a good explanation (which satisfies the criterion of explanatory relevance) does provide answers to many *appropriate* what-if questions. Explanation 2 shows that the law of Areas would still obtain in many circumstances in which the quantitative part of Newton's second law or the intensity of the gravitational law would be different. It thereby enables one to answer in the affirmative the corresponding "would-the-explanandum-still-be-the-case" (in short "would-still" questions). For a derivative explanation, this set of circumstances in which the *explanandum* is shown by an explanatory argument to be left unchanged corresponds to the set of situations in which the premises of the explanatory argument are true. Further, the more irrelevant information is removed from the premises, the weaker these explanatory premises and the wider the class of situations to which they apply. Let us call this class of situations the domain of strict invariance of the explanation (by contrasts with Woodward's notion of domain of (large) invariance of the generalization employed in the explanation, hereafter "large invariance"). Then, the above discussion leads to the following suggestion:

(S) The wider the domain of strict invariance of an explanation, the deeper the explanation.

It would take much more that can be said here to develop this suggestion into a fully-fledged proposal about the nature of explanation. In particular, a critical comparison with notions discussed by Reichenbach or Salmon in different contexts such as the notions of *broadest homogeneous reference class*, *maximal class of maximal specificity* or *exhaustiveness* (Salmon, 1989, 69, 104, 193) would be helpful. Nevertheless, the following remarks are in order. First, (S) indicates how an explanation can be turned into a better one by expurgating its premises from irrelevant information; but it does not however indicates in general what type of information can be present in the premises for something to count as a potential explanation. Therefore, it should not be seen as something standing on its own (otherwise, the best explanation would be the self-explanation of one fact by itself). Second, the domain that is here described should be distinguished from the scope of the laws or the domain of invariance of the generalization present in the premises, which characterize statements: strict invariance characterizes the explanation itself. Alternatively it can be seen as the domain of the explanatory generalization saying that when the premises hold (in this or different worlds), so does the *explanandum*. Third, just as for Woodward's account, this criterion is likely to describe only a partial order over explanations. Finally, it should be noted that the criteria of having a large domain of large invariance and of having a large domain of strict invariance go into two opposite directions. Indeed, explanations with large domains of general invariance require generalization with much physical information packed in it; whereas explanations with large domains of strict invariance require premises with as little physical information as possible in their premises. So it does not seem possible to try to conciliate both criteria about the nature of explanatory depth.

6. Concluding remarks: generality and manipulability *versus* specificity and relevance or the contextual choice of epistemic virtues in scientific practice

I have criticized in this article the use of the size of the domains of invariance of the generalizations used in explanation to describe the depth of these explanations. I have argued that this characterization of the goodness of explanations fares badly by the requirement of relevance, which explanatory explanations should primarily satisfy. To describe the goodness of explanations I have proposed a different criterion based on the notion of strict invariance and the ability to answer "would-still" questions offered by explanations. And I have emphasized that satisfying one criterion may run contra the satisfaction of the other.

One final word of caution is needed here. The above analysis dealt with the explanatory character of explanations of specific individual facts, which relevance is a clear component of. Now, like all other things, explanations may also have unspecific additional virtues, which may be philosophically unessential to them but practically crucial to their use. In the present case, having a wide large invariance is no doubt such an unessential virtue. Indeed, an explanation with wide large invariance, even if it is of average quality regarding explanatory relevance, does provide a functional pattern for a family of similar explanations: it offers the opportunity to explain many similar phenomena with the same pattern of reasoning, which yields some significant economy of scientific and cognitive means. As any versatile tool, because it is general, such an explanation may prove useful, even if it is not optimal for specific explanatory tasks. Finding such explanations is therefore a scientifically legitimate (and difficult) task.

So should scientists favor in practice specific relevant explanations with wide domains of strict invariance over general explanations with wide domains of large invariance? I think there is no general answer to this question. *Pace* the philosophical interest for essential epistemic virtues, contextual interests are to prevail depending on what scientific needs are. Suppose that you are interested in controlling optical rays within optical fibers or the trajectory of a car in various circumstances; then there is little doubt that you will be interested in finding explanations with wide domains of large invariance so that you can determine how the rays or the cars will behave in a wide range of circumstances with one single functional relation and control them by adopting the external forcing. For some of these covered circumstances, it is likely that this single functional relation will contain unnecessary (irrelevant) information and for some specific cases you may even be using a sledgehammer to crack a nut; but why should you care? For control purposes, it may be more convenient to use one single relation covering all cases than a cumbersome wealth of them, each specifically targeted at some subset of circumstances.

Suppose now that you are interested is observing a green flash effect (some optical phenomena occurring after sunset or before sunrise, when a green spot is visible above the sun). Then, what you want to learn about the circumstances in which you stand a good choice to observe a green flash effect and you want to know a set of circumstances that is as large as possible. Therefore, knowing which circumstances will not alter the phenomenon (because they are irrelevant to the mechanism involved) is crucial. In this case, you will be interested in discarding from the explanation any irrelevant information that restricts your knowledge of this set, even if it comes at the price of leaving out of the *explanans* physical information that may be useful to answer questions about what would happen in close circumstances (in which no green flash effect is observed). So you may end up with an explanation that is not useful for manipulationist purposes because it is specifically targeted at the green flash effect; perhaps this explanation will not even have a functional form (like above the explanation 2 of the law of Areas); but, because its *explanans* only describes the physical facts that are crucial for the green flash effect to happen and discards the other, it will be more explanatory and therefore more informative about the whole range of circumstances in which the observation can be made.

In conclusion, Woodward's criterion for explanatory depth seems more appropriate to characterize explanations that are useful for control than the ones that are deeply explanatory.

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