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Making Sense of Non-Refuting Anomalies

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Abstract:	Abstract As emphasized by Larry Laudan in developing the notion of non-refuting anomalies (1977, 2000), traditional analyses of empirical adequacy have not paid enough attention to the fact that the latter does not only depend on a theory's empirical consequences being true but also on them corresponding to the most salient phenomena in its domain of application. The purpose of this paper is to elucidate the notion of non-refuting anomaly. To this end, I critically examine Laudan's account and provide a criterion to determine when a non-refuting anomaly can be ascribed to the applicative domain of a theory. Unless this latter issue is clarified, no proper sense can be made of non-refuting anomalies, and no argument could be opposed to those cases where an arbitrary restriction in a theory's domain of application dramatically reduces the possibilities for its empirical scrutiny. In arguing for the importance of this notion, I show how several semanticist resources can help to reveal its crucial implications, not only for theory evaluation, but also for understanding the nature of a theory's applicative domain.
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Making Sense of Non-Refuting Anomalies

1. Introduction

According to the prevailing view of empirical adequacy, refuting anomalies constitute the main challenge a theory must face. In contrast to this, Larry Laudan has argued that non-refuting anomalies should also count against the empirical validity of a theory. As he emphasizes, the empirical shortcomings of a theory are not only related to its false empirical consequences, but also to its incapacity to cope with phenomena within its applicative domain. The plausibility of Laudan's view, however, essentially depends on whether non-refuting anomalies can be legitimately ascribed to the domain of specific theories. This problem, which has remained overlooked both in traditional and non-traditional philosophy of science, is the focus of the present paper. Unless this issue is clarified, no proper sense can be made of non-refuting anomalies, and no argument could be opposed to those cases where an arbitrary restriction in a theory's domain of application dramatically reduce the possibilities for its empirical scrutiny.

In the next section, I show the great significance of Laudan's notion of non-refuting anomalies for theory evaluation and critically examine some aspects of his view, like the requirement that, in order to regard some phenomenon as a non-refuting anomaly for a theory, another theory should have been able to successfully explain it. Instead of this merely contingent requirement, I put forward some conceptual conditions that better accommodate the strong intuition that a theory's domain of application, and therefore its empirical adequacy, is not contingent on any arbitrary decisions scientists could make as to what to exclude from that domain. The third section provides some technical structuralist resources that prove useful in avoiding both the questionable aspects of Laudan’s approach and the main weaknesses in the standard conception of empirical adequacy. There it is explainehow the structuralist notion of partial potential model enables us to characterize the domain of application of a theory without assuming some questionable consequentialist and observational restrictions.

The two historical cases dealt with in section forth illustrate how non-refuting anomalies play a crucial role in theory development and theory change. Both examples were initially mentioned by Laudan in arguing for the significance of this kind of anomaly (1977, 29 and 2000, 167, respectively). The first one is Laplace’s introduction of the nebular hypothesis in order to account for the fact that all the planets move in the same direction and nearly in the same plane, something unexplained from Newton’s theory (Laplace, 1796/1930, 361-363). The second example concerns the phenomenon of continental fit, which remained unexplained by the theory of Earth’s contraction and could only be later explained by Wegener’s theory of continental drift (Thagard, 1992, chapter 7).

Finally, in the last section, I summarize the main consequences that the present discussion on non-refuting anomalies has for two closely intertwined issues, viz., a theory’s empirical adequacy and its applicative domain.

2. Non-Refuting Anomalies, Empirical Adequacy, and Domain Ascription

The notion of non-refuting anomaly is introduced by Laudan in *Progress and its Problems* (1977), where he characterizes anomalies in general as “empirical problems which raise reasonable doubts about the empirical adequacy of a theory" once another theory has solved them (1977, 28, 30). According to him, non-refuting anomalies, in contrast to refuting ones, do not involve any logical incompatibility between empirical consequences of the theory on the one hand and verified statements regarding empirical facts on the other (1977, 27-29). They rather entail a theory's incapability to account for certain kind of salient empirical phenomena whose description is consistent with everything established by the theory (1981, p. 618).[1]

The problem, then, is not a disagreement between theory and phenomena, but rather the insufficiency of the theory's informative resources to account for certain important phenomena in its domain. In arguing for the importance of completeness as a theoretical virtue, Laudan initially mentions two cases in point: the incapability of pre-Galilean kinematics to explain the mathematical features of pendular motion, i.e., the absence of predictions for the geometry of the moving weight, and Newtonian mechanics' lack of explanation for the coplanarity and common direction of the planets' orbits, which had been accommodated in Keplerian and Cartesian astronomies (1977, 29). Some other examples are added in his 2000 paper:

> "For instance, stable-continent theories of geology offered no explanation as to why the continents fit together so neatly. (…) Steady state cosmology offered no explanation for residual background radiation. (…) Ptolemaic astronomy did not explain why – even within Ptolemy's own theory – all the

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[1] It must be pointed out that there is a close connection between Laudan's notion of non-refuting anomaly and T. Kuipers' notion of a neutral individual fact for a theory (Kuipers, 2000, 115-117). In putting forward his comparative HD-evaluation of theories, the second distinguishes between positive (confirmatory) facts, negative (disconfirmatory) facts, and neutral facts, that is, neither positive nor negative ones. Although including this third kind of fact makes his account of theory success more fine-grained than the traditional ones, no further implications are examined regarding the philosophical significance of such notion.

> planets have a solar component to their motion. Phlogistic chemistry is wholly silent about why gaseous elements combine only in integral multiples by volume. Theories of terrestrial causes of dinosaur extinction leave unexplained the worldwide iridium spike that occurred towards the end of the Cretaceous. Geostatic models of the Earth cannot explain the Coriolis effects associated with large bodies of wind and water” (p. 167).

Laudan’s conception of anomalies, strongly inspired by Kuhn’s (1962/1970, 52-65),[2] includes several independent theses about scientific methodology, some of which, even if deemed correct, are not central to the issue considered here, and others, which do seem central, are nevertheless not endorsed in the present approach. Among the first, we can mention Laudan’s insight that the refutation of a theory does not entail its rejection, since, as he emphasizes, a refuted theory may still prove more theoretically virtuous than its rivals. The occurrence of a refuting anomaly would thus not constitute definite grounds for abandoning a theory. Despite its interest and the controversy surrounding it (Musgrave, 1979, 448-9), this aspect of the subject goes beyond the scope of the present discussion. There is, however, a different aspect that does deserve attention for our present purposes, to wit, the idea that anomalies can only be so regarded when another

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[2] It may be worthwhile to briefly recall Kuhn’s notion of anomaly, since some of Laudan’s points were already suggested by the former, who nevertheless failed to fully realize about their consequences for the traditional conception of evidential support. The general notion of anomaly introduced by Kuhn corresponds to those problems or phenomena that a theory cannot accommodate and that do not fit the theoretical expectations (1962/1970, 58). Both refuting and non-refuting anomalies fall under the above general notion. Finally, Kuhn, as opposed to Laudan, does not regard it as necessary, for an anomaly to be recognized as such, that some rival has been able to solve it. On the contrary, he argues that it is the previous awareness of anomaly what initiates the process of theory modification or theory change (1962/1970, 62).

theory has been capable of solving them.[3] Here I resist this restricted notion of anomaly and favor instead a wider characterization according to which anomalies (of either kind) consist in empirical problems that raise rational doubts about the empirical credentials of a theory regardless of whether another theory has succeeded in solving them. Without denying the interest that a comparative assessment of rival theories' evidential support has, it may still be useful to set some conditions for evidential support that are applicable to separate theories. Here I sympathize with A. Musgrave's objections to Laudan's comparative view of theory evaluation. The former notes some counterintuitive consequences of the latter's view that "unsolved problems are not genuine problems", the precession of Mercury's perihelion being mentioned as a historical counterexample (Musgrave, 448). The same kind of objection holds for non-refuting anomalies which remain unsolved, hence the recognition of a theory's non-refuting anomalies does not imply the recognition of a contrast class of alternative theories capable of solving such anomalies. It is worth noticing, though, that not all non-refuting anomalies are immediately assignable to the domain of a particular theory, since there are cases where the nature of the striking phenomenon is so unfamiliar, that an explanation for it can initially be sought from different theories and even from different disciplines. The phenomenon of Brownian motion clearly illustrates this point (Laudan, 1977, 19-20), since over the 19th century different disciplines like biology, chemistry and several fields within physics were approaching such phenomenon in search of an explanation. Here, again, I disagree with Laudan's suggestion that this (domain-)ambiguity about non-

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[3] Cf. Laudan, 1977, 29 (also n. 15). Consequently, Laudan equates what has been called "Kuhn's losses" (Kuhn, 1962/1970, 107-108) with certain instances of non-refuting anomalies, namely, those in which the successor theory provides no explanation for phenomena that the previous theory successfully covered.

refuting anomalies is most generally the case. And it is precisely the implications regarding this issue that have been most frequently overlooked by philosophers of science. Both A. Musgrave (1979, 445-9) and H. Krips (1980, 600-7), for example, acknowledge that non-refuting anomalies constitute real empirical problems for scientific theories, merely pointing out that, in rejecting traditional philosophy of science, Laudan ignores how the latter can successfully account for such problems. Krips shows how classical disconfirmation models can be applied to the case of non-refuting anomalies by invoking abductive inferences of Bayesian probabilities, and, as already mentioned, Musgrave objects to Laudan's comparative restrictions. Without denying the usefulness of these criticisms, what I would like to emphasize here is that they all depend on a quite controversial assumption, viz., that non-refuting anomalies can legitimately be regarded as belonging to the domain of specific theories. It is this problem that points to some shortcomings in the traditional philosophy of science, in particular to some weaknesses in the classical conception of a theory's applicative domain.

Let us note that, after all, if an empirical problem is not ascribable to any particular applicative domain, then it can just be discarded or kept for future research without detriment to a theory's empirical adequacy. By contrast, if an anomaly is indeed ascribable to a particular domain, then it does have an impact in the empirical adequacy of a theory, whether or not scientists acknowledge it. C. A. Chinn's and W. F. Brewer's report on how scientist and children similarly react to anomalies shows that there are seven basic responses: ignore, reject, exclude, hold in abeyance, reinterpret the data while retaining the theory, reinterpret the data making peripheral changes to the theory, accept the data and change the theory in favor of another (Chinn & Brewer 1993, Brewer &

Chinn 1994). Here as well as in the historical cases discussed below, I will just focus on well-established anomalies, putting aside those cases where rejection would be an option. So when anomalies are regarded as alien to the applicative domain of a theory, ignoring or excluding them may seem as the appropriate response. Both holding in abeyance and changing the theory either partially or completely, would rather amount to a tacit recognition of those anomalies falling into its domain. Yet, neither in these empirical studies, nor in the philosophical discussion on the subject, do we find any explanation based on a criterion for non-refuting anomalies to fall inside the domain of a theory. In fact, without such criterion, the exclusion of a non-refuting anomaly from the domain of a theory seems to be something completely hinging on scientists' decisions, however arbitrary, rather than on any objective criteria for domain ascription. Here we arrive at two extreme conflicting possibilities: either non-refuting anomalies are just relative to theories by virtue of the latter's content and regardless of scientists' intentions, or they are just relative to the intentions expressed by scientists.

In Willard Humphreys' enlightening discussion on anomalies–one previous to Laudan's-, we can find a non-pragmatic account of them, where purposes, desires or intentions are not acknowledged any important role (1968, 81-85). Nevertheless, as emphasized by Kuhn in introducing the notion of exemplar (1962/1970, 180-9) and later with the structuralist concept of intended application **(**Balzer, Moulines, & Sneed, 1987, 86-90), it is only by providing paradigmatic examples of how a theory is to be applied that the latter acquires a specific empirical interpretation, however partial and approximate. Humphreys restricts his account to deal with just cases of refuting anomalies, which obviously makes it easier to leave the pragmatic elements aside and put forward a logical criterion for anomalies based on the contradiction between their description and some consequences of an accepted theory. When dealing with non-refuting anomalies, pragmatic aspects may prove even more relevant as a means to reduce a theory's indefinitely open domain of application. Yet once that some paradigmatic applications of a theory have been established pragmatically **(**Balzer, Moulines, & Sneed, 1987, 88-89), similarity and/or close causal connection to these applications, together with the descriptive resources of a theory's empirical framework, should be relevant to determine whether an empirical fact constitutes a non-refuting anomaly for such theory. So, even if there is a pragmatic side to it, in determining what makes a non-refuting empirical fact an anomalous fact for a theory, it is ultimately the empirical content of a theory, and not some arbitrary decisions by scientists, what ultimately makes a difference.

I can already give an idea of what distinguishes non-refuting anomalies from cases where some phenomena remain unexplained by a theory either due to the fact that they fall outside its domain of application or because, despite being included in the domain, it is foreseeable that the theory, as it stands, will be able to account for them in the future. Unlike the first kind of case, non-refuting anomalies very often bear a close similarity or causal connection to paradigmatic exemplars of a theory's intended applications; as opposed to the second kind of case, these anomalies are doomed to remain recalcitrant given their disconnection from the theoretical content of the theory. Overall, this suggests that, in order for non-refuting anomalies to be solved, the theory affected by them will need substantial modifications, additions or even a replacement. Against this, and favoring Laudan's view, it could be argued that unless there is a contrast class of alternative theories capable of solving certain non-refuting empirical problems, we do not have grounds for regarding the latter as anomalies rather than just mere problems of adjustment between theory and data, or, alternatively, mere empirical findings related to contingent phenomena and not targeted for explanation.[4] In reply to the first option, it must be emphasized that non-refuting anomalies do not point to those cases in which a theory speaks only very approximately but to those cases where a theory, despite possible efforts to the contrary, remains silent with respect to certain phenomena. As for the second possibility, it is important to note that anomalies consist in salient or striking phenomena (most often empirical regularities) that a theory should be able to accommodate, given their similarity and/or close causal connection to its paradigmatic applications. Such causal relation is pointed to by the kind of question that scientists are impelled to ask when addressing non-refuting anomalies, or analogously by the kind of explanatory inference they are impelled to make. Their questions are of the following kind: what could have caused *e* other than something involving *i*? (‘*e*’ stands for the description of the non-refuting anomaly and ‘*i*’ for the description of an intended application). Similarly, their explanatory inferences from *e* fit the following abductive pattern: any highly probable causal explanation of *e* would involve *i*. To use one of Laudan’s most illustrative examples, the common direction of planetary orbits is a phenomenon similar to other mechanical phenomena included among the intended applications of Newtonian mechanics like comets’ trajectories or planets’ deviations from

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[4] Just to be clear, the argument here is not that every phenomenon should count as a problem or be eventually explained. Some phenomena may indeed be regarded as merely contingent and therefore remain unexplained even in a novel theoretical framework. Furthermore, the contingent nature of some phenomena may be found out after some attempts have been made at explaining them. For example, Kepler explained the ratio between the radii of the planets in terms of Platonic bodies, while today we believe those values to be contingent. Again, it is important to notice that, unlike non-refuting anomalies, these contingent phenomena usually lack the features of similarity and/or close causal connection to paradigmatic applications of the theory.

their orbits -all of which involve direction as an essential element to be accounted for in terms of forces acting on the bodies. Moreover, the co-directionality of planets is causally connected to the mechanical phenomena that Newtonian mechanics is intended to explain, for any highly probable causal explanation of such anomaly would require positing a mechanical phenomenon (or a sequence of them) taking place as a result of some acting force/s.[5]

The example from geology that is examined below also meets the above conditions. The jig-saw puzzle fit of continental coasts can be considered as a non-refuting anomaly for the theory of Earth's contraction, since is both similar to the latter's intended applications and causally connected to them. The contraction theory was primarily focused on those phenomena that could be perceived as deformations of the Earth's crust, especially on mountain building and boundaries between continents and ocean basins (Oreskes 2003, 4-5). The fit between continental edges can be easily perceived the same way to the extent that it naturally entails a former break apart of the continents. But again, even leaving similarity aside, the causal connection between continental fit and crust deformation seems unquestionable. By applying the previous criterion for salience, we can ask: what could have caused continental fit other than something involving crust deformation? Indeed, any highly probable causal explanation

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[5] Interestingly, these ideas concerning salience, as well as the corresponding constraints on non-refuting anomalies, are in tune with Krips' traditionalist view on how to explain the cognitive relevance of such anomalies. After analyzing the very same example discussed above, he concludes that their cognitive relevance could be determined by applying the following abductive pattern of argument: "(P_1): The only way to explain e, given B, is by assuming/rejecting h. (P_2): B is the total relevant "background knowledge," and includes e. (C): (probably) $h/\neg h$" (Krips 1980, 604). Thus, according to Krips, non-refuting anomalies prompt the formulation of new hypotheses that would confer high probability to the former and, conversely, diminish the probability of those hypotheses incompatible with the new ones. In a similar abductive vein, I have argued for the possibility of establishing when an event e represents a non-refuting anomaly for a theory T. Regardless of whether e resembles T's intended applications, there should be a causal connection between e and such intended applications, so that any highly probable causal explanation of e would involve the latter. Sometimes, the new hypothesis would be compatible with T, sometimes otherwise.

of the first (like continental break-up) would involve the second. It is important to note that even in cases where the similarity between paradigmatic applications and non-refuting anomalies is low, the close causal connection between them provides a criterion to determine the latter.

Laudan's vindication of the role played by non-refuting anomalies entails the rejection of what he calls the "consequentialist theory of evidence or plausibility". Non-refuting anomalies decrease the evidential support of a theory even though they are consistent with the theory. By the same token, the warrant conditions of a statement should not be equated with its truth conditions, since poor explanatory power would raise doubts about the epistemic virtue of a theory regardless of whether the latter's truth conditions are widely satisfied (1995, 33).[6] The challenge, then, is to characterize the kind of information that, even if logically disconnected from what a theory entails, nonetheless provides crucial evidence for the theory and falls inside its domain of application. Van Fraassen's notion of empirical adequacy, for instance, cannot successfully account for the significance of non-refuting anomalies, since it still retains the main consequestialist restrictions.

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[6] In his 1988 paper, T. Nickles argues that the consequentialist model of scientific justification should be combined with Laudan's generative model, since the second points to theoretical changes that fall outside the standard conditionalization, the latter depending on background knowledge remaining fixed (1988, 10). Although in a different context such as the field of mathematics, I. Lakatos introduces a notion similar to Laudan's non-refuting anomalies, namely, that of *heuristic* falsifiers. He explains that, unlike logical falsifiers, which show that a theory as such is false (inconsistent), heuristic falsifiers merely show that a theory does not *explain* properly what it set out to explain—it is a false theory of the informal domain in question. Still, when Lakatos claims that "*the crucial role of heuristic refutations is to shift problems to more important ones*, to stimulate the development of theoretical frameworks with more content" (Lakatos, 1967/1978, 40), he is emphasizing only one side of the issue, leaving completely out of the discussion the questions the question as to how to ascribe a certain domain of application to a theory.

In the next section I will develop some ideas that may be helpful to overcome the two main shortcomings in van Fraassen's conception of the empirical adequacy, namely, its consequentalist restrictions and its definition of a theory's empirical basis (or applicative domain) in purely observational terms.

3. A Wider Characterization of a Theory's Domain of Application

In order to respond to the challenge that non-refuting anomalies pose for understanding of empirical adequacy, the nature of a theory's applicative domain should be carefully examined. The notion of applicative domain usually remains extremely ambiguous in current philosophical discussion on scientific theories. In fact, there are at least four senses in which philosophers use such expression: first, they may refer to the domain of successful application of a theory, second, to the domain of actual (either successful or unsuccessful) application, third, to the domain of intended (not necessarily actual) application, and fourth, to the domain of corresponding (not necessarily intended) application. The above senses have been enumerated from the narrowest to the widest. In the first case, the focus is on the domain where the theory proves empirically adequate. The second case has to do with the domain involved in actual applications of a theory, regardless of whether the latter proves empirically adequate or inadequate. The third sense embraces all applications intended by upholders of a theory, even those for which the theory has no actual application yet. Finally, the last case concerns the domain of all possible applications ascribable to a theory, with no restrictions related to the intentions of its upholders. Now, the first two senses seem too narrow, for non-refuting anomalies cannot be accommodated as part of the applicative domain in neither case. On the other hand, the last case would render the notion of non-refuting anomaly too coarse-grained for purposes of theory assessment, as any striking phenomenon falling within the potential scope of a theory could then be considered as part of its expected applicative domain. As already emphasized, in the philosophical literature the notion of applicative domain has received little attention, and consequently no serious attempt at disentangling the above issue has been made. There are seldom cases in which this problem is approached at all, and when that happens, like in M. Suárez (2005, 56-61), the discussion is often only partial. His argument to distinguish between a theory's domain of empirical adequacy and its domain of application, amounts to a distinction between the first two senses sorted out above. Again, in previous approaches we usually find no room for the notion of non-refuting anomalies. Part of the problem lies on the absence of a distinction between the empirical conceptual framework of a theory and its empirical content. Usually only the second is recognized as relevant for the evaluation of a theory's empirical adequacy (even if just implicitly) and, ultimately, for the determination of a theory's applicative domain. However, the descriptive resources of a theory should be neatly distinguished from its claims about those phenomena described by applying such resources. In what follows, I will carefully separate both notions, so that the importance of non-refuting anomalies for the question of empirical adequacy can be established on that basis.

In particular, what is required is an analytical approach that makes it possible to ascertain how a theory represents those empirical phenomena that, neither confirming nor disconfirming its laws, are nevertheless describable in terms of its empirical concepts – and, for this reason, are plausibly included into the theory's domain of application. An adequate characterization of a theory's domain of application, therefore, should account for two possible and not mutually exclusive kinds of relations between the descriptions of empirical phenomena included in a theory and its theoretical apparatus, one logical, the other conceptual. In the one case, the empirical descriptions bear a logical relation (either implication or inconsistency) with the laws of the theory. In the other case, they bear no logical relation with the theoretical laws (apart from consistency), but rather a conceptual relation of embedment in the conceptual apparatus of a theory. The corresponding distinction between empirical phenomena whose description is related to the laws of a theory and empirical phenomena whose description is not related to the laws of a theory, but only to its conceptual apparatus, helps to clarify that between refuting and non-refuting anomalies. Refuting anomalies bear a logical relation of inconsistency with theoretical laws; non-refuting anomalies, by contrast, bear a conceptual relation of embedment in a theory's conceptual apparatus.

Now, the above clarification hinges on an underlying distinction between frame conditions (i.e., conceptual apparatus) and substantial laws of a theory, and more precisely, between the latter and the empirical frame conditions (i.e., empirical conceptual apparatus). The crucial point here is to find a way to carefully differentiate the above components or "layers" of a theory, so that concrete historical examples of non-refuting anomalies can be accurately analyzed. Within the semantic view of theories, structuralism provides some useful tools to this end. The most relevant structuralist notions for our present purposes will be explained next.

From the structuralist standpoint, a scientific theory is not just constituted by a class of models (i.e., sequences of set-theoretical entities) satisfying a set-theoretical predicate, but by different classes of models, hierarchically organized according to the level of complexity, and satisfying a correspondingly complex set-theoretical predicate (Moulines 2002, 4-5). Two main classes of models are distinguished: on the one hand, the class of potential models (‘Mp’, from now on), which just satisfy the theory’s frame conditions, and, on the other hand, the actual models (‘M’ in what follows), which satisfy both the frame conditions and the substantial or theoretical laws (Balzer, Moulines, Sneed 1987, 2-6). Frame conditions just supply the conceptual machinery of a theory, that is, they set the formal properties of the scientific concepts employed in a theory. The conceptual framework of a theory determines its descriptive resources, it does not however say anything about the world. The axioms or conditions satisfied by Mp are non-lawlike axiomatic statements which just specify the type or structure of each concept (i.e. of each domain or relation included in the theory). This kind of axioms thus establish what structure each of the fundamental concepts of a theory must have so that the tupla formed by the corresponding set-theoretical entities may be regarded as a possible candidate for an actual model of the theory. Substantial laws, on the contrary, do say something about the world, and they do this by means of the concepts determined by the frame conditions. A first important consequence of the above distinction is that potential models may or may not be also actual models. In the second case, the models would satisfy only the frame conditions, and not the substantial laws.

Since the focus of this study is the nature of non-refuting anomalies, I am primarily concerned with the empirical models of a theory, that is, with those substructures that constitute its empirical basis or applicative domain. From a standard semanticist approach, like van Fraassen's structural empiricism, the empirical models are understood as empirical substructures obtained by cutting the theoretical components off from the theoretical models. The latter are, in turn, characterized as those structures that satisfy the substantial laws of the theory. If we make use now of the structuralist distinction mentioned earlier, it is easy to realize that, according to van Fraassen's view, the empirical substructures would be obtained by cutting the theoretical components off from the actual models, not from the potential models. A theory's empirical adequacy would require that (in at least one of its models) all its empirical substructures are isomorphic to the corresponding phenomena (van Fraassen, 1976). If, for a given empirical substructure, no isomorphic phenomenon is found, then the theory would fail to be empirically adequate. Laudan's criticism against such consequentialist conception of empirical adequacy draws attention to the fact that, even if a theory is empirically adequate in the consequentialist sense, there may be phenomena that are not isomorphic to any empirical substructure of a theory (understood in van Fraassen's sense), and which, nevertheless, should also be covered by the theory. In order to account for this sort of case, which is the one related to the problem of non-refuting anomalies, it is important to introduce the structuralist notion of partial potential model.

The class of a theory's partial potential models ('Mpp' from now on) contains the empirical substructures of Mp. Such substructures constitute the "outside world" of T, whereas the structures corresponding to Mp can be conceived as the specific apparatus of T for "seeing the world" (Balzer, Moulines, Sneed 1987, 277). Partial potential models play a decisive role in the empirical interpretation and application of the potential models in which they are included. Since usually a theory is primarily directed towards a certain subset of Mpp, within the structuralist approach such specially relevant subset has been differentiated from the rest of empirical substructures and characterized as T's "intended applications" ('I', in what follows). As this very label suggests, I has a predominantly pragmatic nature, for it includes those empirical substructures that are targeted by the scientific comunity endorsing the theory. Given that non-refuting anomalies make evident a theory's limitations in scope and informative resources, the former are most likely not directly targeted by the theory and thus not explicitly included into I. Laudan's point, however, is that because of their empirical significance, as well as their salient and striking nature, they should be targeted by the theory.

The important point to be clarified next is how the empirical phenomena in general, and the salient empirical phenomena in particular, are here understood. This general issue about the empirical basis will be answered with the help of another useful distinction coming from structuralism - the one between T-theoretical concepts and T-non-theoretical concepts-, as well as relying on O. Bueno's account of observational practices (2014, 11-19).[7] The more concrete issue regarding salience has been already discussed in section 2, where I emphasized the role of similarity or close causal connection between the phenomena outside I and those included in I. With respect to the first issue, it should be noticed that van Fraassen's very narrow conception of an empirical domain (as the domain of the observable) poses serious problems for the applicability of his account. Most scientific theories have very sophisticated and theoretically dependent data as their empirical basis. The structuralist conception of an empirical domain is meant to be sensitive enough to this fact. For this reason, the distinction between Mp (theoretical structures) and Mpp (empirical substructures) is drawn on the basis of another distinction, that between T-theoretical concepts and T-non-theoretical concepts. T-theoretical concepts can only be determined by taking into account T's actual models (corresponding to the substantial laws), T-non-theoretical models, on the other hand, are determined by models coming from outside of T, typically by the actual models of other underlying (presupposed) theories (Balzer, Moulines, Sneed 1987, 62-67, 73-77, Moulines 2002, 7-8).

It must be noted that, since the empirical domain of a theory is usually determined through instrumentally obtained data, the presupposed theories providing the empirical concepts are precisely those necessarily involved in the use of the relevant instruments. This suggests that, even if rejecting van Fraassen's narrow conception of an empirical domain, there is a way to retain some of the features typically ascribed to the second. Such features concern those epistemic properties shared by both instrumental and observational practices: robustness, refinement, couterfactual dependency, tracking (Bueno, 2014, 12). The robustness of an instrumental practices stems from the fact that

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[7] Bueno's account of observational practices is in turn based on works by Azzouni and Lewis.

the results are dependent neither on our own making nor on the beliefs concerning the focus of the instrumental practice. The possibility of improving the discrimination power of such practices accounts for their refined nature. As for the counterfactual dependence and tracking of instrumental practice, they become clear whenever the result changes according to changes in the object of such practice.

The above discussion suggests that non-refuting anomalies consist in what could be called “potential intended applications” of a theory, that is, empirical phenomena that:

- are neither excluded by its theoretical models nor necessarily included in its actual intended applications;
- bear a similarity relation to its actual intended applications or are at least causally closely connected to them;
- can be represented through its partial potential models or describable by means of borrowed conceptual resources.

4. Discussion of Some Historical Examples

In illustrating historical cases of theory development where non-refuting anomalies played a crucial role, I am going to focus on two of the examples mentioned by Laudan (1977, 29 and 2000, 167). Our first example is Laplace’s introduction of the nebular hypothesis in order to account for the fact that all the planets move in the same direction and nearly in the same plane (Laplace 1796/1930, 361-363). This fact constituted at the time a non-refuting anomaly for Newtonian Mechanics. Laplace, however, managed to explain such anomaly without discarding Newtonian Mechanics, just by making an informative addition to it (viz., the *nebulae* hypothesis).[8] The second example concerns one of the non-refuting anomalies involved in the geological revolution towards the middle of the twentieth century (Thagard, 1992, chapter 7, Oreskes 2013). Geological anomalies like that of continental fit remained unexplained by the theory of Earth's contraction and could only be later explained by Wegener's theory of continental drift, which is turn embedded into plate tectonics (the author XXXX).

4.1. Case in Which the Theory Facing a Non-Refuting Anomaly Is Supplemented by a New One: The Addition of Laplace's Nebulae Hypothesis to Newtonian Mechanics

Some historical remarks are in order before presenting a structural analysis of Laplace's hypothesis and its relation to both Newtonian mechanics and the latter's applicative domain.

4.1.1. <u>Historical background</u>

The so called "nebulae hypothesis" was first presented by Laplace in his popular exposition from 1796 entitled *The System of the World*. There he completed the

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[8] This point is noted by A. Grobler as he discusses the transient nature of Kuhn's losses: "What I mean is that Kuhn's losses" can be regained just like something pawned. There was nothing in the oxygen theory which precluded a future explanation of the metallic luster of metals within a more developed version of the theory or within some other theory which would be compatible with the oxygen theory. A similar pattern can be observed in connection with the replacement of Cartesian physics with Newtonian physics. There were "losses" of the vortex theory's explanation of the coplanarity of the planet's orbits, which was regained by the theory of the evolution of the solar system added to Newton's theory" (2000, pp. 65-66).

Newtonian revolution by showing that Newton's laws were sufficient to account for the stability of the Solar System as well as for the three apparent "secular inequalities" –long-term deviations from Keplerian motion- widely discussed by astronomers during the 18th century.[9] Laplace introduced his monistic cosmogonical theory of the Solar System as an alternative to Buffon's dualistic one, which also accounted for the stability of planetary motions on the basis of a single physical cause or process in the distant past without including any theological assumptions. In contrast to the monistic account, which implies that the Solar System developed autonomously along with the Sun itself, the dualistic account involves that this system came into existence because of the action of outside entities (Brush, 1996, p. 3). Laplace begins his abovementioned work by pointing out that Buffon's rival cosmogony, which postulates that a comet falling upon the sun and removing matter from it originated the Solar System, can only explain the first of the five phenomena characteristic of planetary motions -as opposed to Laplace's own cosmogony, which could explain all of them. These five empirical regularities are mentioned in the initial paragraph of his presentation:

> "We have five phenomena, as follows, from which to ascend to the cause of the primitive motions of the planetary system: The motions of the planets are in the same direction and almost in the same plane; the motions of the satellites are in the same direction as the planets; the motions of rotation of these several bodies and of the sun are in the same direction as their motions of translation, and in planes only slightly inclined to each other; the eccentricity of the orbits of the

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[9] These three inequalities are the acceleration of the Moon, the long inequality of Jupiter and Saturn, and the decrease in the obliquity of the ecliptic (Brush, 1996, 17). In showing their cyclical rather than secular character, Laplace strengthens the view that the Solar System constitutes a highly stable system.

> planets and of the satellites is very small; and, lastly, the eccentricity of the orbits of the comets is large, although the inclinations of these bodies may have been the result of chance" (Laplace, 1796/1930, p. 354)

It is worth noting that Newton himself did recognize the puzzling nature of this phenomenon, emphasizing how unlikely it would be that it had happened just randomly. Newton's laws of motion and gravitation were clearly intended to explain terrestrial as well as celestial mechanical phenomena, including the main mechanical features of planetary orbits, like distances covered and eccentricities. Since direction undoubtedly constitutes an essential feature of mechanical systems -one often regarded as an effect of forces causing mechanical phenomena-, a common direction of orbital motion within the same planetary system seems to call for an explanation of such kind. His acknowledgment of these phenomena as deserving some explanation becomes clear from Query 28:

"To what end are Comets, and whence is it the Planets move all one and the same way in Orbs concentrick, while Comets move all manner of ways in Orbs very excentrick; and what hinders the fix'd Stars from falling upon one another? (1704/1730, 344-5).[10]

As it is frequently noted, Laplace's explanation of such stability in terms of known forces makes him more Newtonian than Newton himself, who had rather appealed to divine intervention in famous Query 31 of *Opticks* (1730). In "ascending" to the physical cause of these striking regularities, Laplace makes use of the Newtonian laws of

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[10] Grammatical peculiarities have been kept from the original source.

motion and the principles of conservation of momentum and angular momentum. At the time it was widely accepted that such laws and principles governed processes like the following: the gravitational contraction of a diffuse system, the transfer of heat from high to low temperatures, the impact of solid bodies, the rotational flattening and the tidal distortion and dissipation, all of them being highly relevant for explaining the origin and main mechanical features of the Solar System (Brush, 1996, p. 5). Laplace developed his nebulae hypothesis based, on the one hand, solely on Newtonian principles together with the recognition of certain processes governed by them, and, on the other hand, based on the postulation of a Sun's rotating atmosphere initially covering the entire domain of the present Solar System.[11] His theory is mainly aimed at explaining the fact that all then known planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn) revolved around the Sun in the one direction and in orbits nearly the same plane. This fact could be understood as the result of an initial state and of several subsequent processes, which were qualitatively described by Laplace in *The System of the World*, and that can be summarized as follows.

Originally the sun was a giant rotating nebula, a cloud of gas as extensive as the space of the Solar System. The giant cloud contracted due to cooling and gravity, and this contraction, in turn, increased the speed of the nebulae. As a consequence, a rim of gas detached from the cloud and eventually became a planet after having undergone the same process of cooling and contraction previously affecting the undivided nebulae. The same chain of processes – cooling-contraction-faster rotation-rim detachment-planet formation – repeated several times to produce all the planets. The remaining gas cloud in the middle

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[11] The very fact that Laplace' solution depends on using the conceptual resources of Newton's theory suggests that the former amounts to a specialized version of the latter. In structuralist terms: Laplace's conception can be understood as a specialized theory element of the corresponding net of Newtonian Mechanics.

became the sun. Satellites formed in the same fashion as planets, as the result of the cooling and contraction of the rotating gaseous atmosphere surrounding each planet. Asteroids like the ones that had been observed between Mars and Jupiter, on the other hand, were caused by rims which failed to contract properly.

As emphasized by Brush (1996, 3-4), even if twentieth century planetogony fluctuated between “monistic” and “dualistic “ (or catastrophist) approaches, the first kind of approach is currently the prevalent one, and Laplace’s hypothesis is still widely accepted today.

4.1.2. Laplace’s Cosmogonical Theory of the Solar System and the Resolution of a Newtonian non-refuting anomaly

Let us focus now on Laplace’s *Nebulae Hypothesis* (‘NEB’ in what follows) and its conceptual resources to deal with one striking anomaly faced by Newtonian mechanics.

NEB’s Conceptual Framework

Let us first consider **NEB**’s basic domains and relations, those determining its basic conceptual framework and therefore its class of potential models.

If we begin by characterizing the basic domains, we have that B is a set of celestial bodies, A is a set of volumes corresponding to different nebulae, and T is a set of temporal intervals. The three domains are finite, non-empty sets.

Moving to the non-basic domains or subsets of B, P is interpreted as being a set of planets, and E as a set of satellites, it being the case that $P \cap S = \varnothing$. The concept of Sun is represented by h, which is an element of B.

The derived concept of volume of nebula surrounding a celestial body is defined accordingly by combining the primitive concepts of volume of nebula and celestial body. The expression 'a_b' thus stands for 'the nebula a surrounding the celestial body b'.

Turning now to **NEB**'s relations and functions, we find that function r determines the temperature by assigning a real number to each celestial body: $r: A \rightarrow \mathrm{R}$.

c is the function that determines the contraction of volumes of nebulae, assigning to the volume of each nebula a in t_1 a smaller volume in t_2: $c: (A \times \{\mathrm{t_i}\}) \rightarrow (A \times \{\mathrm{t_{i+1}}\})$.

μ is the function that determines the standard gravitational parameter for each volume of nebula: $\mu: A \rightarrow \mathrm{R}^+$.

ω is the function that determines de rotational speed or angular movement of each volume of nebula ($\omega: A \rightarrow \mathrm{R}^3$), and v the one that defines the orbital movement between celestial bodies: $v: (B \times B) \rightarrow \mathrm{R}^3$.

Finally, M is the mereological relation of parthood between volumes of nebula: $M \subseteq A \times A$, and M determines a partial, non-strict order.

NEB's class of potential models thus contains structures of the following kind:

$< B, A, h, P, E, T, \mathbb{R}, \mathrm{c}, r, \mu, \omega, v, M >$, all of them satisfying the above typifications and characterizations.

NEB's Laws

After having depicted **NEB** class of potential models or conceptual framework, let us focus on its fundamental laws, that is, those which specify some conditions which the potential models must satisfy in order to be acknowledged also as actual models of **NEB**.

(1) A first axiom or law simply states that actual models of **NEB** are systems formed by the domains and relations included in the tuple provided by the potential models, that is, $x \in$ **M(NEB)**) iff there exist $x = < B, A, h, P, E, T, \mathrm{R}^{+}, c, r, \mu, \omega, v, M >$ such that $x \in$ **Mp(NEB)**.

(2) The second axiom says the nebula from which the Sun originated had a rotary motion. Stated formally:

$a_h \in \mathrm{Dom}\ (\omega)$ at t_1 and $\omega(a_h) = \mathrm{i}$ at t_1

(3) The third law establishes that as temperature decreases the nebula contracts itself thereby increasing its gravitational force:

$r(a_h)$ at $t_1 > r(a_h)$ at t_2 and $c^{1}(\mathrm{a_h})$ at $t_2 < \mathrm{a_h}$ at t_1

(4) The fourth law specifies the consequence of the latter processes, viz. that both the nebula’s gravitational force and its rotary motion increase. That is:

$\mu(a_h)$ at $t_1 < \mu(a_h)$ at t_2 and $\omega(a_h)$ at $t_2 > \omega\ (a_h)$ at t_1

(5) In the fifth axiom the following three conditions are established. First, a portion of the initial volume of nebula detaches from it, that is, such portion is not part of the initial substance at t_2. This can be formally put as follows:

(5i) There are some $a \in A$ such that: aMa_h at t_1 it is not the case that aMa_h at t_2

Second, the detached volume of atmosphere cools down and contracts itself.

(5ii) There are some $a \in A$ such that: $r(a)$ at $t_2 > r(a)$ at t_3 and $c^1(a) < a$

Third, the above process results in an increase of both the nebula's gravitational force and its rotary motion, a process which brings with it the formation of a planet orbiting around the original atmosphere. Put formally:

(5iii) There are some $a \in A$ such that for all $p \in P$:

$\mu(a)$ at $t_2 < \mu(a)$ at t_3 and $\omega(a)$ at $t_3 > \omega(a)$ at t_2 so that there is a $<p,a_h> \in \mathrm{Dom}(v)$ at t_4 and it is not the case that $<p,a_h> \in \mathrm{Dom}(v)$ at t_3

Similarly, the sixth axiom sets forth three analogous conditions for the ulterior formation of satellites orbiting around planets. Formally expressed:

(6) there are some $a \in A$ such that for all $e \in E$:

(6i) aMa_p at t_4 and it is not the case that aMa_p at t_5

(6ii) $r(a)$ at $t_4 > r(a)$ at t_5 and $c^1(a)$ at $t_5 < a$ t_4

(6iii) $\mu(a)$ at $t_4 < \mu(a)$ at t_5 and $\omega(a)$ at $t_5 > \omega(a)$ at t_4 so that there is a $<e,p> \in \mathrm{Dom}(v)$ at t_6 and it is not the case that $<e,p> \in \mathrm{Dom}(v)$ at t_5

NEB's Empirical Framework

Let us now define **NEB**'s class of empirical or partial potential models by removing, from the tuple representing potential models, those elements whose determination necessarily involves applying **NEB**'s fundamental laws. Therefore:

y is a partial potential model of the nebulae hypothesis ($y \in$ **Mpp(NEB)** iff there exists an x such that $x = < B, A, h, P, E, T, c, r, \mu, \omega, v, M > \in$ **Mp(NEB)** and $y = < B, h, P, E, T, r, \mu, v, M >$

NEB-theoretical concepts are those of contraction (c) and rotational speed (w) of volumes of nebulae, together with the derived ones of nebula surrounding the Sun (a_h) and nebula surrounding other celestial bodies (a_b). In all these cases, concept determination requires **NEB**'s theoretical assumptions regarding the existence of particular nebulae surrounding certain celestial bodies, as well as of contraction processes and angular movement ascribable to such nebulae. On the other hand, the very concept of volume of nebula is **NEB**-non-theoretical, as it was originally equated with diffuse, cloud-like astronomical bodies satisfying Archimedes' principle. The other **NEB**-non-theoretical entities and relations are most of them determined by assuming Copernican astronomy (like in the case of planets and satellites), Kepler's theory of planetary motion (as it occurs with the concept of orbital movement v) and Newtonian mechanics (as it happens with the standard gravitational parameter μ).[12] Other concepts, however, like

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[12] If we regard **NEB** as a specialized theory element within the net of Newtonian mechanics, and also assume the structuralist view that the distinction between theoretical and non-theoretical concepts refers to entire theory-nets, then every Newtonian-theoretical concept would be also **NEB**-theoretical. This, however, does not alter the main point that is being emphasized, viz., that without **NEB**'s conceptual additions to the Newtonian framework, the latter had the necessary Newtonian non-theoretical concepts to describe the anomalies, but not the necessary Newtonian theoretical ones to explain them.

that of temporal instant, $t \in T$, depend on different theories -in this case a chronometric one.

Since Kepler's theory relies on the Copernican system, and Kepler's theory was in turn proven approximately reducible to Newtonian mechanics (Balzer, W., Moulines, C. U., and Sneed, J. D, 1987, 374-383), the above considerations imply that Newtonian mechanics already had the necessary conceptual resources to depict empirical facts such as the direction and relative motions of celestial bodies within the solar system. Indeed, Newtonian mechanics not only had those resources but also some paradigmatic intentional applications very closely connected to such kinds of phenomena, like (changes of) directionality due to collisions or to proximity of massive bodies, and (changes of) shape due to tidal distortion. In fact, Laplace's theory only added some postulated initial conditions to Newton's laws, as well as a hypothesis about a continuous contraction process. It is worth emphasizing again that, in pursuing a physical explanation of the above mechanical characteristics of the Solar System, Laplace managed to apply Newtonian laws to a domain where Newton himself did not think them applicable. Where the latter saw an extraordinarily harmonious regularity calling for a theological explanation -something made explicit in his famous Query 31-, the former found another striking regularity addressable on the basis of Newtonian mechanics.

4.2. Case Where the Theory Facing the Non-Refuting Anomaly Is Discarded: The Rivalry between the Contraction Theory and Wegener's Theory of Continental Drift

If the above discussion illustrated how a single non-refuting anomaly may prompt further additions to a theory; now I am going to examine a case in which another non-refuting anomaly is directly involved in the replacement of one theory with another. Before presenting a structural analysis of Wegener's theory and its relation to both contraction theory and the latter's applicative domain, I will make a few historical remarks concerning the two theories.

4.2.1. Historical background

According to standard literature on the subject (Laudan, 1978, Cohen, 1985/2001, Thagard, 1992, Marvin 2001, Oreskes 2003), before Alfred Wegener presented his conjecture regarding continental drift in 1915, the predominant view was that the solid Earth had a stable nature and that actual geological accidents like mountains had been caused by terrestrial contraction due to the globe's decrease in temperature. Terrestrial contraction was postulated as the main causal force behind surface deformation. At the turn of the 20th century, Edward Suess assumed that most of the Earth's surface was initially covered by a giant supercontinent that broke apart due to contraction forming ocean basins and continents. Continuous contraction over geological history resulted in a periodic interchange of land and sea floors. A different version of the contraction theory, one put forward by James D. Dana towards the end of the 19th century, presented continents and ocean basins as permanent features, always in the same relative positions. According to his theory, contraction would create more pressure in the boundaries between continents and sea floors, thereby prompting mountain formation along continental margins. This version of the contraction theory was closely related to James Hall's theory of geosynclines, which established that sedimentary materials eroded off the continents accumulating along their edges and finally forming mountains (Oreskes 2003 4-8).

Yet, the jigsaw-puzzle fit of the continental edges was a well known fact already since the 16th century, and such fact, together with others established in the 19th century from paleontological and paleoenvironmental research, seriously challenged the contraction theory, leading Wegener to develop the theory of continental drift. More precisely, he relied on observations regarding: 1) the fit of the continents' edges, 2) the correlation of fossil plants and animals as well as of rock strata across oceans, and 3) the presence of cold climate indicators (such as ancient glacial deposits) near the equator, and the presence of warm climate indicators (such as limestones, laterites and coals) near the poles. Wegener explained all these facts by supposing that, originally, all continents were together forming a single supercontinent (Pangaea) and that, through time, they moved away from each other thereby shifting their position. According to his theory, mountain formation is caused by the resistance of cool oceanic crust to continental movement.

As frequently emphasized by historians and philosophers dealing with the geological revolution, Wegener's theory faced a strong opposition by most geologists of that period, and it was never fully accepted by the scientific community (Frankel 1979, 49-52, Ruse 1981-1989, 73-74, 85-87, Cohen, 1985/2001, 446, 464-465, Marvin 2001, 213-215, Oreskes 2013, 13-27). The overthrown of the contraction theory did not happen until the 60s, when plate tectonics developed, mainly from oceanographic, paleomagnetic, and seismic evidence originally collected by geophysicists who were not involved in the development of this theory. These kinds of evidence would make it possible to develop an empirically sound account of continental movement, one that covered an important gap in the previous account, namely, the causal mechanism of such motion.[13] All this combined evidence supported the conjecture that both continents and sea floors stand on moving plates whose dynamics manifests itself in the phenomena of sea floor spreading and destruction. Such conjecture was independently developed by several geologists, like J. Tuzo Wilson, Daniel P. McKenzie together with Robert L. Parker, and Jason Morgan, providing a synthetic picture of crustal motions as rigid body rotations on a sphere (Oreskes 2003, 25-27). Mountains, on the other hand, were now understood as geological formations resulting in some cases from the pressure and friction between colliding plates and, in some other cases, from collision between continents and island arcs, oceanic plateaus and microcontinents (Frisch *et. al.* 2011, 149-158). In all these cases, a very gradual process of subduction of continental or oceanic crust originated the later collisions.

Despite the interest of plate tectonics for purposes of illustrating the crucial role played by non-refuting anomalies, I will simplify the present analysis by focusing just on the role played by a single non-refuting anomaly – viz. the jigsaw-puzzle fit of the

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[13] By stressing the importance of evidence quality as the driving force in the career of geological theories, Laudan opposes the popular view put forward by Stephen Jay Gould (1977), which implied that the initial rejection of drift theory was due to a lack of an adequate mechanism to move continents through a static ocean floor (Laudan 1978, 229-232).

continental edges- in the competition between the theory of Earth's contraction and the theory of continental drift.

4.2.2. Continental drift and the resolution of a main non-refuting anomaly affecting the contraction theory

Let us examine now Wegener's theory ('DRIFT' in what follows) and the conceptual resources it provides to resolve a main non-refuting anomaly faced by the contraction theory ('CON' in what follows).

CON's Conceptual Framework

Let us start by examining those basic domains and relations that determine **CON**'s class of potential models, thereby constituting its basic conceptual framework.

CON's basic domains are represented by U, which is a set of volumes of earth's crust, and T, which is interpreted as a set of temporal instants. Both domains are finite, non-empty sets, and $T = \{t_1, t_2\}$.

As for the non-basic domains or subsets of U, we have C, which is interpreted as being a set of volumes corresponding to continents, M, interpreted as a set of volumes corresponding to mountains, and F, equated with a set of volumes corresponding to sea floors. All of them are non-empty subsets of U, and $F \cap C = \varnothing$.

Passing now to **CON**'s relational concepts, we find that function c determines the contraction of the Earth, by assigning to the volume of each portion of crust u in t_1 a smaller volume in t_2: $c: (U \times \{t_1\}) \rightarrow (U \times \{t_2\})$

The other relational concept is P, which is the mereological relation of parthood between volumes of crust, and does not have a functional character: $P \subseteq U \times U$, and it determines a partial, non-strict order.

Each $<U, T, C, M, F, \mathrm{R}^{+}, c, P>$ that satisfies the above typifications and characterizations therefore belongs to **CON**’s class of potential models.

CON’s Laws

Let us move now to **CON**’s fundamental laws, i.e., to those axioms specifying some conditions which **CON**’s potential models must satisfy in order to be recognized also as its actual models.

(1) The first axiom merely states that **CON**’s actual models are systems formed by the domains and relations included in the tuple provided by the potential models, namely, $< U, T, C, M, F, \mathrm{R}^{+}, c, P >$.

(2) The second law establishes that continents contract through time, so that they occupy a smaller spatial region after the contraction. Formally put:

For all $u \in \mathrm{Dom}(c)$: $c^{1}(\mathrm{u})$ at $t_2 < \mathrm{u}$ at t_1

(3) According to the third law, mountains form either in continents or seafloors due to contraction. That is:

For all c, $f \in$ Dom(c): if $<c, t_1> \in$ Dom(c) y $<f, t_1> \in$ Dom(c) then there exist m, $m' \in M$ such that it is not the case that mPc at t_1 nor that $m'Pf$ at t_1 and it is the case that mPc at t_2 and that $m'Pf$ at t_2

CON's Empirical Framework

Turning now to **CON**'s class of partial potential models, let us see what elements of the tuple representing the potential models should be removed given the fact that their determination necessarily involves **CON**'s fundamental laws. Such removal leads to the following kind of structure:

y is a partial potential model of the contraction theory ($y \in$ **Mpp(CON)**) iff there exists an x such that $x = <U, T, C, M, F, \mathbb{R}^+, c, P> \in$ **Mp(CON)** and $y = <U, T, C, M, F, \mathbb{R}^+, P>$

The matter of theoreticity concerns U, T, C, M, F, c, P. The two basic sets, along with the two derived ones and the (non-functional) relation P are **CON**-non-theoretical, given that they may all be determined without resorting to the notion of geological contraction and ignoring **CON**'s fundamental laws. c, on the contrary, must be considered as **CON**-theoretical given its dependence of these laws. In particular, the determination of c requires the assumption of the laws affirming the existence of a contraction process affecting continents and causing mountain formation. These laws appear in the formal definition of **M(CON)** as axioms (3) and (4).

I shall now go on to examine the criteria for determining the functions and/or notions expressed by **CON**-non-theoretical terms. U, C, M and F are determined (during the historical period in which **CON** prevailed) by principally applying pre-scientific notions. The notions of crust, continent, mountain and seafloor could only be determined on the basis of a disjunction of descriptions or predicates that express different properties: location, surroundings, material constitution, shape, etc. Continent and mountain formation are the principal phenomena dealt with by **CON**, and given that the corresponding notions can be characterized within the **CON**-non-theoretical language (more specifically, in ordinary language), it follows that the determination of C and M is governed by the same criteria as that of **Mpp**. The determination of T presupposes some type of chronometric theory. Lastly, some mereological theory is required for determining P.

DRIFT's Conceptual Framework

Let us examine those basic domains and relations that determine **DRIFT**'s class of potential models.

DRIFT's basic domains are represented by L, which is a set of volumes of lithosphere, T, which is interpreted as a set of temporal instants, and S, which represents a set of spatial regions. These three domains are finite, non-empty sets, and $T = \{t_1, t_2\}$.

As for the non-basic domains or subsets of L, we have U, which is a set of volumes of earth's crust, C, which is interpreted as being a set of volumes corresponding to continents, M, interpreted as a set of volumes corresponding to mountains, and F, equated with a set of volumes corresponding to sea floors. All of them are non-empty subsets of U, and $F \cap C = \varnothing$.

Passing now to **DRIFT**'s relational concepts, we find P, which is the mereological relation of parthood between volumes of crust, and does not have a functional character. $P \subseteq U \times U$, and it determines a partial, non-strict order. The movement of the continents is represented by means of the function d, under which each volume corresponding to a continent and a certain spatial region in t_1 have assigned the volume of a continent and a different spatial region in t_2:

$d: (C \times S \times \{t_1\}) \rightarrow (C \times S \times \{t_2\})$

The function k determines the kinetic friction between volumes of continents and volumes of sea floors, by assigning to each couple of neighbouring continent and sea floor at a given time a friction coefficient: $k: C \times F \times T \rightarrow \mathbb{R}^+$

I is the fit relation between volumes of continents and its character is not functional: $I \subseteq C \times C$

The structures contained in **DRIFT**'s class of potential models are tuples of the following kind: $<L, U, T, S, C, M, F, \mathbb{R}^+, d, k, P, I>$, which satisfy the above typifications and characterizations.

DRIFT's Laws

Apart from the axiom (1) stating that **DRIFT**'s class of actual models is a subset of its class of potential models, there are four fundamental laws unfolding **DRIFT**'s specific content.

Axiom (2) establishes that all continents existing today were part of the same continent at t_1. That is:

There is a $c' \in C$ at t_1 such that for all $c \in C$ at t_2: cPc' at t_1

In axiom (3), continents’ outline fit occurring at present is explained on the basis of a previous continental separation. Formally expressed:

There are some c, c',c'' $\in C$ such that: if cPc'' and $c'Pc''$ at t_1 and it is not the case that cPc'' nor that $c'Pc''$ at t_2, then cIc' at t_2

Axiom (4) states that the location of continents changes along time, which means that continents move with respect to each other. That is:

For all $c \in C$: there is some $<c, \mathrm{s}, t_1> \in \mathrm{Dom}(d)$ such that: $d(<c, \mathrm{s}, t_1>) = <c, \mathrm{s}', t_2>$ and $\mathrm{s} \neq \mathrm{s}'$

Finally, the last law asserts that mountain formation depends on some kinetic friction taking place between continents and sea floors. Put formally:

Axiom (5) For all $m \in M$, $c \in C$ and $f \in F$:

there is some $f \in F$ such that if $k(<c, f, t_1>) = i \neq 0$ and $k(<c, f, t_2>) = i'$ with $i' > i$, then mPc or mPf at t_2

DRIFT’s Empirical Framework

Turning now to **DRIFT**’s class of partial potential models, let us see what elements of the tuple representing the potential models should be removed given the fact that their determination necessarily involves **DRIFT**’s fundamental laws. Such removal leads to the following kind of structure:

y is a partial potential model of the continental drift theory ($y \in$ $\mathbf{M_{pp}(DRIF)}$) iff there exists an x such that $x = <L, U, T, \mathrm{S}, C, M, F, \mathbb{R}^+, d, k, P, I> \in$ $\mathbf{M_p(DRIFT)}$ and $y = < L, U, T, S, C, M, F, \mathbb{R}^+, P, I >$.

The matter of theoreticity concerns *L, U, T, S, C, M, F, d, k, P, I.* The three basic sets, along with the four non-basic ones, and the (non-functional) relations *P* and *I* are **DRIFT**-non-theoretical, as they may all be determined without relying on **DRIFT**'s fundamental laws. *d* and *k*, by contrast, must be considered as **DRIFT**-theoretical given its dependence on these laws, more specifically on axioms (4) and (5). The notions of continental movement and kinetic friction between continents and sea floors can only be defined on the basis of **DRIFT**'s postulation of such functions.

I shall now go on to examine the criteria for determining the functions and/or notions expressed by **DRIFT**-non-theoretical terms. The notion of lithosphere (*L*) was first introduced by Joseph Barrell in 1914, with the publication of his article "The Strength of the Earth's Crust", and more than two decades later developed by Reginald Aldworth Daly in his *Strength and Structure of the Earth* (1940). The term ´lithosphere' referred to the Earth's strong outer layer, which was thought to surround a weaker, floating layer called 'asthenosphere'. Several striking gravity anomalies over continental crust were explained on the basis of these two notions. **CON** and **DRIFT** share the concepts of earth's crust (*U*), temporal instant (*T*), continent (*C*), mountain (*M*), sea floor (*F*), and parthood between volumes of crust (*P*). All of them are not theoretical with respect to both theories. The determination of *S* and *I* respectively requires some topological and cartographic theory. In addition to the relation of fit between volumes of continents (*I*), *C* and *M* are the main **DRIFT**-non-theoretical domains whose formation the theory was intended to explain.

In addition to the abovementioned ones, **CON** and **DRIFT** share some other empirical concepts that are presupposed in one theory and explicitly included in another, as in the case of spatial region and fit between volumes of continents. **CON** presupposes a change in the spatial region occupied by a portion of crust as it contracts and decreases in volume. By the same token, changes in volume due to contraction involve changes in shape, which in turn implies a possible determination of fit between volumes of continents. Therefore, even if **DRIFT**-non-theoretical concept of spatial region is not explicitly included in **CON**, it is presupposed as an empirical concept. Similarly, despite the fact that **DRIFT**-non-theoretical concept of fit between volumes of continents is not explicitly included in **CON**, it is presupposed as an empirical concept, given the presupposition of the concept of volume and the inclusion of the concept of continent. The concept of fit between volumes of continents can clearly be characterized independently of both theories, just by taking into account the relevant cartographic studies. The phenomenon captured by this concept constitutes one of the main phenomena to be explained by **DRIFT**. The concepts that **DRIFT** do not share with **CON** are those of continental (lateral) drift and kinetic friction between continents and seafloors, which are precisely the **DRIFT**-theoretical ones. They can only be determined by presupposing **DRIFT**’s laws, more in particular, axioms (3) and (4).

On the conceptual side, thus, **CON** and **DRIFT** share all the necessary resources to commonly determine the empirical phenomenon of continental fit. On the pragmatic or intentional side, the close causal connection between **DRIFT** and **CON**'s paradigmatic applications also guarantees a common acknowledgment of continental fit as an anomaly. Taking into account that shape, together with material composition and location, has always been widely regarded as a revealing feature of geological accidents, the shape fitting of continents can hardly be excluded from the applicative domain of a general geological theory. After all, **CON**'s main intentional application, i.e. mountain formation, is determined mainly by features related to shape. Hence, here again we find an essential feature connecting the intentional applications of two successive theories, which despite its striking peculiarities, is only included among the intended applications of one of the theories. To put it in a nutshell, either the jigsaw-puzzle fit of the continental edges is discarded as a random event –something that seems highly implausible, or it must be acknowledged as part of the domain of application of a general geological theory.

5. Conclusion

The previous analysis is intended to clarify the role played by non-refuting anomalies in theory development and theory change, a role that can only be understood once the nature of a theory's applicative domain has been reconsidered. It has been shown that some empirical phenomena can be legitimately regarded as belonging to a theory's applicative domain, even if they are not commonly acknowledged as targeted by its upholders. Successive or competing theories such as, respectively, Newtonian mechanics and Laplace's nebulae hypothesis, or the two rival geological theories preceding tectonic plates, shared the necessary conceptual resources to commonly characterize these empirical phenomena. The latter would amount to non-refuting anomalies for one of the theories and to successfully explained phenomena for the other. Hence, non-refuting anomalies can be perfectly expressed by means of a theory's "inherited" conceptual resources, despite the fact that the empirical substructures corresponding to its actual models do not point to those anomalies. Contrary to the traditional view, the empirical implications of a theory (i.e., its empirical content) do not determine what empirical phenomena can be acknowledged from a theory. The latter depends on the empirical substructures of the potential (not the actual) models, what has been called here the "partial potential models", following the structuralist tradition. The fit between continental edges is a non-refuting anomaly for the contraction theory that could have been perfectly representable within such theory if its advocates would have decided to target such phenomenon. This situation is analogous to the one affecting Newtonian mechanics–where the non-refuting anomaly of all planets orbiting in the same direction could have been recognized as open to scientific explanation, instead of it being attributed to divine intervention.

From a normative point of view, and concerning scientific progress, intentional exclusions of non-refuting anomalies should count against the empirical justification of the theory affected by them, since these anomalies are ascribable to its domain of application. As for the resolution of such anomalies, there are two possible cases, both of them illustrated by the historical cases which have been discussed above. One possibility is that a theory can be appropriately extended to cover those anomalies –like in Laplace's extension of Newtonian mechanics. The other possibility is that the new theoretical content needed to cover such phenomena proves incompatible with the previous theory –

as in the case of continental drift theory and its resolution of one of the main non-refuting anomalies affecting the contraction theory.

Non-refuting anomalies represent a clear indicator of a theory’s limited scope. They make evident that the content of a theory does not include what it should in order to account for certain empirical phenomena that, nevertheless, are describable within the empirical framework of the theory and similar or closely connected to other phenomena explained by it. The intentional aspect often invoked to determine the domain of application of a theory should not be the only one taken into consideration, since otherwise the domain of application would be subject to any arbitrary restriction that scientists decided to establish. The analysis developed in this paper, while acknowledging the intentional aspect, introduces some objective conditions to ascertain a theory’s domain of application. These conditions are related, on the one hand, to the conceptual or descriptive resources available from the theory facing the anomaly, rather than to its explanatory ones –as it would be expected from the traditional, consequentialist view. On the other hand, they concern the causal connection between non-refuting anomalies faced by a theory and its paradigmatic applications. Thus, regardless of what theorists decide to include within the intentional applications of a theory once that its paradigmatic applications have being established, the conceptual resources of the theory affected by non-refuting anomalies suffice to characterize its applicative domain.

References

Balzer, W., Moulines, C. U., Sneed, J. D. 1987. *An Architectonic for Science. The Structuralist Program*, Dordrecht: Reidel.

Barrell, J. 1914. "The strength of the Earth's crust", *Journal of Geology* 22, 4: 289–314.

Brewer, W. F., Chinn, C. A. 1994. “Scientists’ Responses to Anomalous Data: Evidence from Psychology, History and Philosophy of Science”, *Philosophy of Science Association*, Vol. 1, 304-313.

Brush, S. G. 1996. *Nebulous Earth: The Origin of the Solar System an the Core of the Earth from Laplace to Jeffreys*, Cambridge: Cambridge University Press.

Bueno, O. 2014. “Scientific Instruments, Domains of Application, and Incommensurability”, forthcoming in *Studies in History and Philosophy of Science*, accessed March 14, 2016, http://www.as.miami.edu/personal/obueno/Site/Online_Papers_files/Incomm%26DomOfApplic2_DRAFT.pdf

Chinn, C. A., Brewer, W. F. 1993. “The Role of Anomalous Data in Knowledge Acquisition: A Theoretical Framework and Implications for Science Instruction”, *Technical Report n. 583,* Urbana-Champaign: University of Illinois.

Cohen, I. B. 1985/2001. “Continental Drift and Plate Tectonics: A Revolution in the Earth Science”, *Revolution in Science*, Cambridge, MA: Harvard University Press, ch. 29: 446-466.

Daly, R. A. 1940. *Strength and structure of the Earth,* New York: Prentice-Hall.

Frankel, H. 1979. “The Career Of Continental Drift Theory: An Application of Imre Lakatos’ Analysis of Scientific Growth to the Rise of Drift Theory”, *Studies in History and Philosophy of Science*, 10, 1: 21-66.

Frisch, W., Meschede, M. & Blakey, R. (2011). *Plate Tectonics: Continental Drift and Mountain Building*. (Heidelberg: Springer-Verlag Berlin).

Gould, S. J. 1977. “The Validation of Continental Drift”, *Ever Since Darwin: Reflections in Natural History*, New York: Norton, chapter 5, section 20: 160-167.

Grobler, A. 2000. “Explanation and Epistemic Virtue”, in Adam Jonkisz & Leon Koj (eds.), *On Comparing and Evaluating Scientific Theories*, *Poznan Studies in the Philosophy of the Sciences and the Humanities*, 72: 61-88.

Humphreys, W. 1968. *Anomalies and Scientific Theories*, San Francisco: Freeman, Cooper & Company.

Kuhn, T. S. 1962/1970. *The Structure of Scientific Revolutions*, Chicago: The University of Chicago Press.

Krips, H. 1980. “Problems for “Progress and Its Problems””, *Philosophy of Science*, vol. 47, n. 4, Dec.: 601-616.

Kuipers, T. 2000. *From Instrumentalism to Constructive Realism*, Dordrecht: Kluwer Academic Publishers.

Lakatos, I., 1967/1978. *Mathematics, Science and Epistemology* (Philosophical Papers Vol. II), ed. J. Worrall and G. Currie, Cambridge: Cambridge University Press.

Laplace, P. S. 1796/1930. *The System of the World*, University Press for Longmans, Rees, Orme, Brown and Green Dublin, Volume 2, Book, V, Chapter VI: 354-375.

Laudan, L. 1977. *Progress and its problems*, Berkeley: University of California Press.

Laudan, L. 1981. “Anomalous Anomalies”, *Philosophy of Science*, vol. 48, n. 4, Dec.: 618-619.

Laudan, L. 1995. “Damn the Consequences!”, *Proceedings and Addresses of the APA*, 69: 27-34.

Laudan, L. 2000. “Is Epistemology Adequate to the Task of Rational Theory Evaluation?”, in R. Nola & H. Sankey (ed.), *After Popper, Kuhn and Feyerabend. Recent Issues in Theories of Scientific Method*, Kluwer Academic Publishers, Dordrecht: 165-175.

Laudan, R. 1978. “The Recent Revolution in Geology and Kuhn's Theory of Scientific Change”, *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association*, vol. 2, Symposia and Invited Papers: 227-239.

Marvin, U. B. 2001. “Reflections on the American Rejection of continental Drift”, *Metascience*, 10: 208–217.

Moulines, C. U. 2002. “Introduction: Structuralism as a Program for Modelling Theoretical Science”, *Synthese*, 130: 1-11.

Musgrave, A. 1979. “Problems with Progress”, *Synthese*, 42: 443-464.

Newton, I. 1704/1730. *Opticks: or, a Treatise of the Reflections, Refractions, Inflections and Colors of Light*, London: William Innys, 4th edition.

Nickles, T. 1988. “Truth or Consequences? Generative versus Consequential Justification in Science”, *PSA: Proceeding of the Biennial Meeting of the Philosophy of Science Association*, vol. 2: 393-405.

Oreskes, N. (2003). “From Continental Drift to Plate Tectonics”. (In Naomi Oreskes & Homer Le Grand (eds.) *Plate Tectonics: An Insiders’ History of the Modern Theory of the Earth*, Boulder: Westview Press, chapter 1: 3-27).

Ruse, M. 1981/1989. “What Kind of Revolution Occurred in Geology”, *The Darwinian Paradigm, Essays on Its History, Philosophy and Religious Implications*, London: Routledge, ch. 3: 55-89.

Suárez, M. 2005. “The Semantic View, Empirical Adequacy, and Application”, *Crítica. Revista Hispanoamericana de Filosofía*, vol. 37, n. 109, April: 29-63.

Thagard, P. 1992. *Conceptual Revolutions*, Princeton: Princeton University Press.

Van Fraassen, B. 1976/1992. “To Save the Phenomena”, in R. Boyd, P. Gasper, and J. D. Trout (eds.)**,** *The Philosophy of Science*, Cambridge: Massachusetts Institute of Technology: 187-194.

Van Fraassen, B. 1977/1992. “The Pragmatics of Explanation”, in R. Boyd, P. Gasper, and J. D. Trout (eds.)**,** *The Philosophy of Science*, Cambridge: Massachusetts Institute of Technology: 317-327.

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Abstract

As emphasized by Larry Laudan in developing the notion of non-refuting anomalies (1977, 2000), traditional analyses of empirical adequacy have not paid enough attention to the fact that the latter does not only depend on a theory's empirical consequences being true but also on them corresponding to the most salient phenomena in its domain of application. The purpose of this paper is to elucidate the notion of non-refuting anomaly. To this end, I critically examine Laudan's account and provide a criterion to determine when a non-refuting anomaly can be ascribed to the applicative domain of a theory. Unless this latter issue is clarified, no proper sense can be made of non-refuting anomalies, and no argument could be opposed to those cases where an arbitrary restriction in a theory's domain of application dramatically reduces the possibilities for its empirical scrutiny. In arguing for the importance of this notion, I show how several semanticist resources can help to reveal its crucial implications, not only for theory evaluation, but also for understanding the nature of a theory's applicative domain.

Keywords: non-refuting anomaly, applicative domain, partial potential model.

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