MASTERARBEIT / MASTER'S THESIS

Titel der Masterarbeit / Title of the Master's Thesis

A Theory of Types of Scientific Change and its Application to String Theory

verfasst von / submitted by

Nader Basafa

angestrebter akademischer Grad / in partial fulfilment of the requirements for the degree of

Master of Arts (MA)

Wien, 2016 / Vienna 2016

Studienkennzahl lt. Studienblatt / degree programme code as it appears on the student record sheet:	A 066944
Studienrichtung lt. Studienblatt / degree programme as it appears on the student record sheet:	Interdisziplinäres Masterstudium Wissenschaftsphilosophie und Wissenschaftsgeschichte UG2002
Betreut von / Supervisor:	Mag. Dr. Richard Dawid, Privatdoz.

Abstract:

I shall argue that the latest major theoretical construct in physics, the string theory, which has resulted in a powerful theoretico-logico-mathematical construct on the one hand, and theoretical constraints of empirical inaccessibility, predictive incapacity, as well as implicit underdetermination on the other, might quality as a paradigm shift in the spirit of the early Kuhn's thoughts on paradigms. Following Paul C. L. Tang I shall argue that the unit of scientific development is paradigm shift and not Kuhnian revolutions. "Paradigm shifts represent a genus, and scientific revolutions are species within that genus; and whereas all K-revolutions [Kuhnian revolutions] are paradigm shifts, the converse does not hold."[1]

Later Kuhn's thoughts on paradigms and revolutions, however, are somewhat different. For the later Kuhn, it is the "speciated" research community with a distinct incommensurable lexicon and taxonomic structure that becomes the epitome of the paradigm. Nevertheless, the idea of a paradigm shift or revolutionary change is still very useful in conceptualizing scientific change and progress in science. I shall approach the issue in two parts. The first part will consist of surveying the literature by Kuhn, and on Kuhn and his critics in search of support for the distinction outlined above. In the second part, I shall apply my findings in the first part and apply it to string theory and its development to determine if string theory satisfies the conditions of a paradigm shift or a revolution. In this context, I shall use popular texts written by contemporary physicists on the subject. The motivation to proceed in this

---

[1] Tang, P.C.L., *Paradigm Shifts, Scientific Revolutions, and the Unit of Scientific Change: Towards a Post-Kuhnian Theory of Types of Scientific Development*, Philosophy of Science Association 1984, Vol. 1, p.125

fashion is two folds: First, I believe on a meta level physicists argue for their case – free from formal constrainsts – using popular books to win not only the support of the general public, but also to use them as an informal means of exchange of relevant philosophical content and consequences of their work with their peers. Second, it is also the Kuhnian backdrop to this work that blends well into this fashion of exchange among the members of the scientific and philosophical community and their interested general public.

The context of the Kuhnian debate:

Larry Lauden writes that the Structure of Scientific Revolutions mattered "…because it posed in a particularly vivid form some direct challenges to the empiricism we were learning from the like of Hempel, Nagel, Popper, and Carnap….If Kuhn was right, all the then reigning methodological orthodoxies were simply wrong. It was a good deal less clear what Kuhn's positive message amounted to, and not entirely because many of Kuhn's philosophical readers were too shocked to read him carefully."[2]

Many philosophers of science have been puzzled by the vagueness of Kuhn's conceptions of the nature of scientific development in *the structure of scientific revolutions (SSR)*. There has been many attempts at interpretation to come to terms with aspects of the book that not only involves a conceptual challenge but also introduces a universe of new terms referring to revolutions, paradigms, incommensurability, and community to name a few. Ernan McMullin in asking "How deep, in short, do revolutions go?" brings it to the

[2] Laudan, L. (1984). *Science and values: The aim of science and their role in scientific debate*, p. 67 Berkeley and Los Angeles: University of California Press.

point: "There is an ambiguity in Kuhn's response to this question."[3] He then quotes the following paragraph from SSR, which relates closely to what is at issue: "Like the choice between competing political institutions, that between competing paradigms proves to be a choice between incompatible modes of community life. Because it has that character, the choice is not and cannot be determined merely by the evaluative procedures characteristic of normal science, for these depend in part upon a particular paradigm, and that paradigm is at issue. When paradigms enter, as they must, into a debate about paradigm choice, their role is necessarily circular. Each group uses its own paradigm to argue in that paradigm's defense."[4] As Laudan has put it: "Where Kuhn breaks, and breaks radically, with the tradition is in his insistence that rationaliy must be relativized to choices within a paradigm rather than choices between paradigms."[5]

McMullin then asks: "How important is this sort of 'Circularity' to Kuhn's

---

[3] McMullin, E. (1993). Rationality and paradigm change in science. In P. Horwich (Ed.), World *changes: Thomas Kuhn and the nature of science*, p. 58. Cambridge: MIT Press.

[4] Kuhn, T (1970). *The Structure of Scientific Revolutions*, p. 94.

[5] Laudan, L. (1984). *Science and values: The aim of science and their role in scientific debate*, p.68 Berkeley and Los Angeles: University of California Press.

account of the inability of either side in a paradigm debate to muster an entirely cogent argument in its own behalf?"[6] "One way to find out" he suggests "is to direct attention to the examples he gives of scientific revolutions and ask what paradigm change amounts to in each of these cases. When the question is put in this way, it is clear that there is a striking difference in the depth of the different changes classified by Kuhn as 'revolutions.'"[7] An attempt at explanation and an adequate answer to the question of 'difference' referred to above, has led a number of philosophers to draw more specific distinction among scientific revolutions and ultimately to a theory of types of scientific change. For example, McMullin has introduced the idea of shallow, intermediate, and deep revolutions;[8] or Paul C. L. Tang has proposed a theory of types.[9] Later, we shall explore the above proposals in detail and shall explain what justifies the distinctions proposed.

---

6 McMullin, E. (1993). Rationality and paradigm change in science. In P. Horwich (Ed.), World *changes: Thomas Kuhn and the nature of science*, p. 58. Cambridge: MIT Press.

7 Ibid., pp. 58-59.

8 Ibid., pp.59-61.

9 Tang, P.C.L., *Paradigm Shifts, Scientific Revolutions, and the Unit of Scientific Change: Towards a Post-Kuhnian Theory of Types of Scientific Development*, Philosophy of Science Association 1984, Vol. 1, p.125

For the time being, though, let us note that Kuhn did not provide his readers with a theory of types or specific criteria for the revolutions in question. Even though he referred to them in a general way, he never made his conceptualization of the ideas advanced in the SSR more readily accessible. This is the source of ambiguity referred to earlier. The elucidation of this point is a central aspect of this essay, but it shall be supplemented by a meta-level, namely the question of to what end? I believe that the answer was Kuhn's intuitive commitment to the *ineffable*! I shall develop this point by tracing the core of the development of Kuhn's thought. Kuhn originally attributed meaning change to revolutions but then meaning was replaced with incommensurability in his mind, which he in turn associated with the unlikelihood of translation. Kuhn admits: "In *Structure* I spoke of meaning change as a characteristic feature of scientific revolutions; later, as I increasingly identified incommensurability with difference of meaning, I repeatedly referred to the difficulties of translation….What I described, I now realize, was language learning, a process that need not, and ordinarily does not, make full translation possible."[10] Kuhn then applied this insight to

---

[10] Kuhn, T. (1993). Afterwords. In P. Horwich (Ed.), World *changes: Thomas Kuhn and the*

communication within the community of scientists: "The would-be communicants have encountered incommensurability, and communication breaks down in an especially frustrating way. But because what's involved is incommensurability, the missing prerequisite to communication -- …a 'lexical structure' for me -- can only be exhibited, not articulated."[11] This I believe is the essence of the ineffable in Kuhn's conception of paradigm change and revolutions. I also believe that the intuitive commitment to the ineffable, I referred to earlier, is in turn related to the vagueness inherent in the *Structure*. It turns out that Kuhn in outlining the conception in the *Structure* is not interested in enumerating the criteria of paradigm shifts and revolutions in a systematic fashion since he is first and foremost concerned with showing and not telling. The discussion of ambiguity can also find its parallel in a meta-level, namely, Kuhn's attempt to provide -- consciously or subconsciously -- the philosophy of science and the community of philosophers of science with problem-solutions or exemplars rather than placing the emphasis on a method or criteria of scientific change. These are

---

nature of science, p. 324. Cambridge: MIT Press.

[11] Ibid., p. 346

several aspects of the ambiguity that I have claimed stem from Kuhn's intuitive commitment to the ineffable, to what can at best be shown and not told. Perhaps another example provided by Kuhn himself drives this point home; Kuhn says that "There is, for example, no way, even in an enriched Newtonian vocabulary, to convey the Aristotelian propositions regularly misconstrued as asserting the proportionality of force and motion or the impossibility of void. Using our conceptual lexicon, these Aristotelian propositions cannot be expressed -- they are simply ineffable -- and we are barred by the no-overlap principle from access to the concepts required to express them."[12] Now, one of the aims of this essay is to go beyond Kuhn in putting the emphasis on the *criteria* of significant scientific change.

Towards a post-Kuhnian theory of types of scientific change:

Referring to the discussion of paradigms in the *Structure* and the ambiguity it had caused as to what exactly is a paradigm, Kuhn writes: "If I could, I would call these problem-solutions paradigms, for they are what led me to the choice

[12] Ibid., p. 330

of the term in the first place. Having lost control of the word, however, I shall henceforth describe them as exemplars."[13] In a footnote on the same page, Kuhn admits that the latter change deprived him "…of recourse to the phrases, 'pre-paradigm period' and 'post-paradigm period' when describing the maturation of a scientific specialty. In retrospect that seems to me all to the good, for, in both senses of the term, paradigms have throughout been possessed by any scientific community, including the schools of what I previously called the ‚pre-paradigm period'.[14] In this context, the motivation I shall be addressing in this section is the question of what are then our resources to account for scientific change? Can all the nuances of scientific change be subsumed solely under the umbrella of the community? A post-Kuhnian approach aimed in this essay is in the spirit of addressing these and similar questions.

The later Kuhn's thoughts on paradigms and revolutions are somewhat different than his early conceptions. For the later Kuhn, it is the "*specieated*" research community with a distinct *incommensurable* lexicon and lexical

[13] Kuhn, T., (1970). Reflections on my critics in Lakatos, I., and Musgrave, A.(eds.) *Criticism and the Growth of Knowledge*, p. 272, Cambridge University Press, London.

[14] Ibid., p. 272

structure that becomes the epitome of the paradigm. Nevertheless, the idea of a paradigm shift or revolutionary change is still very useful in conceptualizing scientific change and progress in science.

Before, we address this issue in any detail, the reader should be aware of Kuhn's position on such an analysis. In response to McMullin and his distinction of shallow and deep revolutions, Kuhn writes: "though revolutions do differ in size and difficulty, the epistemic problems they present are for me identical."[15] But what is Kuhn's sense of 'epistemic'? According to Kuhn "Michael Friedman's description of Reichenbach's distinction between two meanings of the Kantian a priori, one which 'involves unrevisability and …absolute fixity for all times, 'while the other means ‚constitutive of the concept of the object of knowledge'.…Though it is a more articulated source of constitutive categories, my structured lexicon resembles Kant's a priori when the latter is taken in its second, relativized sense. Both are constituents of *possible experience* of the world, but neither dictates what

[15] Kuhn, T. (1993). Afterword. In P. Horwich (Ed.), World *changes: Thomas Kuhn and the nature of science*, p. 337. Cambridge: MIT Press.

experience must be."[16] Kuhn's epistemic sense then seems part and parcel of his lexical structure and vice versa. "Both are stern teachers, firmly resisting the promulgation of beliefs unsuited to the form of life the lexicon permits. What results from respectful attention to them is knowledge of nature, and the criteria that serve to evaluate contributions to that knowledge are correspondingly, epistemic. The fact that experience within another form of life -- another time, place, or culture -- might have constituted knowledge differently is irrelevant to its status as knowledge."[17] So, to conclude, when Kuhn says that in the distinction between revolutions, the epistemic problem remains unchanged,[18] he seems to be saying that the dynamics of change governing the lexical structure in different types of revolutions remain the same. But what if the distinction is built on a different assumption namely that significant scientific change in the history of sciences have not necessarily resulted in revolutions requiring distinct lexical structures. Would Kuhn's objection to a distinction still hold?

The fact remains that others have also voiced concern over early Kuhn's lack of

---

[16] Ibid., p. 331

[17] Ibid., p. 332

[18] Ibid. p. 337

distinction among paradigm changes, which have led to accusation of relativism: "Kuhn's early view in SSR was that when paradigms change everything changes -- including the defining concepts, language and possible observation. While he developed different versions of his world change idea, he did not distinguish clearly between them."[19] In other words, critics of Kuhn have argued that "…for Kuhn, paradigm change is so profound as to result in an entire change of conceptual scheme, language and possible observations. As with methodological incommensurability, a strong relativism also leads to total communication failure between paradigms."[20] The point is that the distinction among Kuhnian revolutions – that some might only be paradigm shifts without being revolutions – is still not unessential on at least three grounds. First, it may guard againsta a type of relativism that methodologically incommensurable paradigms have been accused of. In other words, by distinquishing among revolutions, some scientific developments cease to be affected by the issue of incommensurability. Some paradigm developments, we shall see, as continuous, others as involving

19 Von Dietze, E. (2001). *Paradigms Explained*, Rethinking Thomas Kuhn's philosophy of science, p. 102-103, Praeger Publishers.

20 Ibid., p. 102

significant theoretical change while still others may comprise incommensurability in one form or another. Second, our endeavor at a distinction among paradigms, may at the same time, throw light on conceptualizing scientific change. Third, it might also assist us with the question at the center of this essay, namely, the type of change the development in string theory may represent.

The distinction I intend to elucidate in the following section is an old but relatively unnoticed distinction between paradigm shifts and revolutions, one that Kuhn himself does not address. The criteria I shall be using is Kuhnian comprising both the early and later Kuhn's ideas on the notion of paradigm. It is noteworthy that "While Kuhn no longer used the term 'paradigm,' many of the core concepts that were interwoven with the idea of paradigm continues to hold an important role in his thinking….One significant change is that he now understands the scientists as being able to participate in more than one lexical taxonomy at a time, in the same way as one might learn and understand more than one natural language. The emergent view is closely linked with Kuhn's attempts to overcome criticisms of his methodological incommensurability thesis, while not relinquishing incommensurability altogether."[21] Nevertheless, in illuminating the distinction in question, this essay attempts to reinstate the concept of paradigm shifts against the backdrop of K-revolutions through a theory of types. Within the problematic of the early and late Kuhn's ideas on paradigms, the distinction may serve as an indispensable tool in conceptualizing the dynamics of Kuhn's argumentation and that of scientific change.

A theory of types of scientific change:

Following Paul C. L. Tang, I shall argue that the unit of scientific development is paradigm shift and not Kuhnian revolutions. "Paradigm shifts represent a genus, and scientific revolutions are species within that genus; and whereas all K-revolutions [Kuhnian revolutions] are paradigm shifts, the converse does not hold."[22]

---

[21] Ibid., p. 89

[22] Tang, P.C.L., *Paradigm Shifts, Scientific Revolutions, and the Unit of Scientific Change: Towards a Post-Kuhnian Theory of Types of Scientific Development*, Philosophy of Science Association 1984, Vol. 1, p.125

I shall keep Tang's enumeration of what Kuhn identifies as a paradigm shift:

(i) a shift in problems solutions; (ii) a shift in methodologies; (iii) a shift of models; (iv) a shift in type of knowledge sought and attained; and (v) a shift of symbolic systems.[23]

Let us call this **set A**. However, a scientific revolution, which is a paradigm shift must satisfy the following additional criteria, which we shall call **set B**. Below, the paradigm has been represented as P and a respective paradigm shift as

P1 → P2:

(I) P1 → P2 is such that P2 is incompatible with P1;

(II) P1 → P2 commenced with an anomaly in P1;

(III) P1 → P2 was non-cumulative.[24]

I would like to expand the wording of Tang's set B and also to incorporate later Kuhn's view to comprise **set C**:

---

23 Ibid., p.126

24 Ibid., p. 126

I.	P1 → P2	P2 is semantically incommensurable with P1;
III.	P1 → P2	preceded by a crisis or anomaly in P1;
II.	P1 → P2	is non-cumulative;
IV.	P1 → P2	P1 is rejected or *degraded* by its revolutionary successor P2.

For the last item IV and allowing for later Kuhn's change of views relating to methodological incommensurability, I have added the term 'degraded' for the item. Where some have claimed that "Many older theories still continue to be utilized to form simple approximations for information that is far more complex to calculate in their successors. Newtonian physics, for instance, is a useful and widely used approximation of Einsteinian physics and is still commonly taught in science education. While such older theories have not been totally superseded, neither do they have any lingering adherents who claim loyalty to these rather than the newer theories."[25] In this context, let us also remember that Kuhn had strongly rejected the above assessment in SSR: "Though an out-of-date theory can always be viewed as a special case of its

[25] Von Dietze, E. (2001). *Paradigms Explained*, Rethinking Thomas Kuhn's philosophy of science, p. 102, Praeger Publishers.

up-to-date successor, it must be transformed for the purpose. And the transformation is one that can be undertaken only with the advantages of hindsight, the explicit guidance of the more recent theory. Furthermore, even if that transformation were a legitimate device to employ in interpreting the older theory, the result of its application would be a theory so restricted that it could only restate what was already known. Because of its economy, the restatement would have utility, but it could not suffice for the guidance of research."[26] In other words, that is an aspect of Kuhn's sense of rejection of an older paradigm and along this sense of rejection the resultant conclusion that "Without commitment to a paradigm there could be no normal science."[27]

So, one of Kuhn's major concerns when dealing with normal science and subsequent paradigm shifts and revolutions is the *possibility* of extraordinary science; according to Kuhn "If the existing theory binds the scientist only with respect to existing applications, then there can be no surprises, anomalies or crises…. If positivistic restrictions on the range of a theory's legitimate applicability are taken literally, the mechanism that tells the scientific

[26] Kuhn , T, 1970, *The Structure of Scientific Revolutions,* p. 103

[27] Ibid., p. 100

community what problems may lead to fundamental change must cease to function. And when that occurs, the community will inevitably return to something much like its pre-paradigm state, a condition in which all members practice science but in which their gross product scarcely resembles science at all. Is it really any wonder that the price of significant scientific advance is a commitment that runs the risk of being wrong?"[28]

What is implied here and I would like to underline is certainly the consequence of going beyond existing applications as a must for any type of paradigm. This also elucidates, I believe, an aspect of commitment to an untested paradigm, one that in the face of risks of being wrong must be pursued. But what are the differences, Kuhn asks between successive paradigms?[29] He himself responds "…paradigms differ in more than substance, for they are directed not only to nature but also back upon the science that produced them. They are the source of the methods, problem-field, and standards of solution accepted by any mature scientific

[28] Ibid., pp. 100-101

[29] Ibid., p. 103

community at any given time."[30]

Now, I would like us to return to the enumeration of the criteria relating to paradigm shifts and revolutions outlined at the beginning. I would like to pursue a thesis that claims that, first, revolutions in science, which are paradigm shifts are but species within the genus of paradigm shifts as markers of significant scientific developments. In other words, following Tang, I claim that the unit of scientific change is paradigm shift and not revolutions. I shall then use this as a springboard to further the cause of string theory in claiming that significant scientific change has already occurred on two accounts that qualify the theory both as paradigm shift and perhaps as revolution-in-the-making. The two accounts encompass, first, string theory's achievement of the unification of particles and forces "Thus -- at least on the level of the bosons…string theory unifies gravity with the other forces."[31] Second, the emergence of what I would like to call an outlook for a potential *revolution-in-the-making*, which implies that the already attained paradigm shift may or may not result in a complete revolution!

[30] Ibid., p. 103

[31] Smolin, L, 2008, *The Trouble with Physics*, p. 183

Let me back track briefly to the distinction discussed in the previous page. I believe the distinction among different types of scientific change, if tenable, amounts to something that the later Kuhn acknowledges as speciation: "With much reluctance I have increasingly come to feel that this process of specialization, with its consequent limitation on communication and community, is inescapable, a consequence of first principles….revolutions, which produce new divisions between fields in scientific development, are much like episodes of speciation in biological evolution. The biological parallel to revolutionary change is not mutation, as I thought for many years, but speciation."[32] If I undestand Kuhn correctly, Kuhn in making this analogy is moving away from revolutions as punctuated radical change (mutation) to diversification into distinct channels (speciation). It is the dynamics of these individuated channels or species that draw a close parallel to the distinctions among K-revolutions we are attempting to address. In other words, the later Kuhn seems to have recognized that revolutions as paradigm shifts are perhaps too flat of a structure to sustain the complexities of scientific change. Speciation implies distinction among what has changed, which is in turn the

[32] Kuhn, T, 1991, *The Road Since Structure*, Philosophy of Science Association, Vol. 2, p. 8

question at the heart of our inquiry. A theory of types of scientific change may indeed turn out to be the opposite side of the same coin, namely that of Kuhn's claim to speciation.

For the sake of clarity and in order to avert confusion, let us remember that in this context Reydon and Hoyningen-Huene have rightly suggested that in SSR and also in *The Road Since Structure* (RSS) "…Kuhn does not argue that the two mechanisms are instantiations of the same basic mechanism, nor does he argue that the two mechanisms operate in largely similar ways."[33] The point is of course made in reference to progress and does not stay in the way of our claim. Scientific development represented by revolutionary leaps was being replaced, for the later Kuhn, by "speciation" in community's specializations. In other words, paradigm shifts become the epitome of specialized scientific communities and since "speciation" here would imply a new community with unique new characteristics, then the unit of significant scientific change becomes the paradigm shift. I believe it would not be far-fetched to interprets

[33] Reydon, T.A.C. and Hoyningen-Huene 2010, *Kuhn's Evolutionary Analogy in The Structure of Scientific Revolutions and "The Road since Structure,"*Philosophy of Science, Vol. 77, No. 3, p. 472

the above in the following manner: A theory of types is an attempt at displaying "speciation" in scientific development.

Before we return to the first account, which involves string theory's achievement of the unification of particles and forces, let us first consider what Kuhn has to say about a similar phenomenon, which happens after revolutions: "Either a new branch has split off from the parent trunck…Or else a new specialty has been born at an area of apparent overlap between two preexisting specialties, as occurred for example, in the cases of physical chemistry and molecular biology. At the time of its occurrence this second sort of split is often hailed as a reunification of the sciences…As time goes on, however, one notices that the new shoot seldom or never gets assimilated to either of its parents. Instead it becomes one more separate specialty…."[34] Following the above as an analogy -- barring the minor difference of the overlap -- to our first account in string theory results in having to consider that a paradigm change and with it significant scientific development did occur at the point of unification of particles and forces, which may or may not have

[34] Ibid., p. 7

triggered a revolution-in-the-making. But, can we really tell if we are witnessing a paradigm shift or a revolution? Kuhn believes that "…the problems presented by speciation (e.g., the difficulty in identifying an episode of speciation until some time after it has occurred, and the impossibility, even then, of dating the time of its occurrence) are very similar to those presented by revolutionary change and by the emergence and individuation of new scientific specialties."[35] According to Kuhn then the answer is in the negative, and that is also the difficulty we face in string theory too.

We can now evaluate our criteria, first relating to paradigm shift and second in relation to a possible revolution or a revolution-in-the-making. _
Kuhn addresses the status of energy conservation within the context of a crisis in which the incompatibility of Newtonian dynamics and caloric theory of heat played a crucial role.[36] The context involves two interrelated points: First, that "only after the caloric theory had been rejected could energy conservation

[35] Ibid., p. 8

[36] Kuhn, T, 1970, *The Structure of Scientific Revolutions*, p. 98

become part of science;"[37] second, "And only after it had been part of science for some time could it come to seem a theory of a logically higher type, one not in conflict with its predecessors."[38] Kuhn also says that "Though logical inclusiveness remains a permissible view of the relation between successive scientific theories, it is a historical implausibility."[39] Nevertheless, I believe there have been shifts of this type having major scientific significance in the history of science. This is the shift from classical Mendelian genetics (MeG) to modern molecular genetics (MoG); "…MeG and MoG represent two distinct paradigms, and MeG → MoG represents a paradigm shift…

However, MeG → MoG did not commence with an anomaly and, moreover, MoG is not incompatible with MeG, nor was the paradigm shift non-cumulative."[40] This is obviously a different type of shift -- than those satisfying criteria of Kuhnian revolutions -- but nonetheless of great scientific significance.

Recently, others have used similar criteria to be applied to Kuhn's conception

---

[37] Ibid., p. 98

[38] Ibid., p. 98

[39] Kuhn, T., 1970, *The Structure of Scientific Revolutions*, p. 98

[40] Tang, P.C.L., *Philosophy of Science Association* 1984, Vol. 1, p.126

of scientific development. K. Brad Wray isolated three criteria and argued that "…Kuhn does provide us with a principle way to distinguish revolutionary changes from non-revolutionary changes in science."[41] Wray's criteria of scientific revolutions are changes in science that:

(1) involve taxonomic changes,

(2) are precipitated by disappointment with existing practices, and

(3) cannot be resolved by appealing to shared standards.[42]

He further argues that "an important and often overlooked dimension of the Kuhnian account of scientific change is the shift in focus from theories to research communities"[43] In other words, Wray is carrying on later Kuhn's emphasis on research communities; let us remember that Kuhn had emphasized that "In the scientific case, the unit [which undergoes speciation] is a community of intercommunicating specialists, a unit whose members share a lexicon that provides the basis for both the conduct and the evaluation of their research and which simultaneously, by barring full communication with those outside the group, maintain their isolation from practitioners of

---

[41] Wray, K.Brad, 2007, *Kuhnian Revolutions Revisited* in Synthese, Vol. 158, No. 1, p.61

[42] Ibid., p.61

[43] Ibid, p. 61

other specialties."[44] Wray also attributes to Kuhn's critics "four challenges to the distinction Kuhn draws between normal and revolutionary science:

(1) the changes that Kuhn regards as revolutionary changes are a diverse range of phenomena;

(2) the two types of changes, normal and revolutionary, are not *categorically* different;

(3) the two categories, normal and revolutionary, are not exhaustive; and, finally,

(4) the class of revolutionary changes is an empty class."[45] Note that Wray attributes the first two critiques to Ernan McMullin, the third to Alexander Bird, and the fourth to Larry Laudan.

Wray agrees with the critics' first concern: "The sorts of changes that Kuhn has grouped together under the label 'revolution' are not all the same type. Those scientific changes that deserve to be called revolutions involve the replacement of one lexicon or taxonomy by another."[46] In this context, I would like to refer back to my conception of criteria for Kuhnian revolutions in

---

[44] Kuhn, T, 1991, *The Road Since Structure*, Philosophy of Science Association, Vol. 2, p. 8

[45] Wray, K.Brad, 2007, *Kuhnian Revolutions Revisited* in Synthese, Vol. 158, No. 1, p.64

[46] Ibid., p. 68

science, namely, I (set C); here following Tang, I argued that the change from Mendelian genetics (MeG) to molecular genetics (MoG) represented by (MeG) → (MoG) was one that had not satisfied Tang's set B (the shift did not commence with an anomaly, MoG was not incompatible with its predecessor MeG, nor was the shift non-cumulative).

Wray uses the ideas the later Kuhn advanced on taxonomic change: "…I must revert briefly to my old distinction between normal and revolutionary development. In *Structure* it was the distinction between those developments that simply add to knowledge, and those which require giving up part of what's been believed before. In the new book it will emerge as the distinction between developments which do and developments which do not require local taxonomic change."[47] According to Kuhn "What I have been calling a lexical taxonomy might, that is, better be called a conceptual scheme, where the 'very notion' of a conceptual scheme is not that of a set of beliefs but of a particular operating mode of a mental module prerequisite to having beliefs, a mode that at once supplies and bounds the set of beliefs it is possible to

[47] Kuhn, T, 1991, *The Road Since Structure*, Philosophy of Science Association, Vol. 2, p. 7

conceive."[48]

Kuhn in fact admits that "the alteration permits a significantly more nuanced description of what goes on during revolutionary change than I've been able to provide before."[49] Wray also refers to examples of this sort namely to the discovery of X-rays and the discovery of Uranus. "Even though the discovery of X-rays had important implications for neighboring fields, it did not require the replacement of the taxonomies employed in neighboring fields. X-rays could be added to the inventory of possible entities by merely adding on to or extending the accepted taxonomy….The discovery of Uranus is also the sort of discovery that merely required the extension of an existing taxonomy. There was no need to replace the existing taxonomy with a new *incommensurable* one."[50] Going beyond Wray and briefly applying Tang's criteria of shifts to the above examples, we will end up with a type of paradigm with no shift in theoretical orientation. So far, I think that all are in agreement, including Kuhn himself, on the first point of the critique.

---

[48] Ibid., p. 5

[49] Ibid., p. 7

[50] Wray, K.Brad, 2007, *Kuhnian Revolutions Revisited* in Synthese, Vol. 158, No. 1, p.68

In this context, let us note that in an article entitle *Rationality and Paradigm Change in Science*, McMullin proposes shallow, intermediate, and deep revolutions. In such a system, X-rays would be a *shallow* revolution "…because so much was left untouched by it."[51] McMullin calls *intermediate* "…the replacement of phlogiston theory by the oxygen theory of combustion. It meant a reformulation of the entire field of chemistry, a new conceptual framework, a new set of problems."[52] In turn, in a *deep* revolution, "The shift in paradigm here meant a radical shift in the methodology of paradigm debate itself. Paradigm replacement means something much more thoroughgoing in such a case."[53] As examples of deep revolutions, he elaborates: "The Aristotelians and the Galileans totally disagreed as to how agreement itself should be brought about. So did the Cartesians and the Newtonians."[54]

As to the second critique point, namely, whether or not we should speak of a

---

[51] McMullin, E. (1993). Rationality and paradigm change in science. In P. Horwich (Ed.),, *World changes: Thomas Kuhn and the nature of science (p. 59).* Cambridge: MIT Press.

[52] Ibid., p. 60

[53] Ibid., p. 61

[54] Ibid., p. 61

continuum, McMullin says that "What we have here, I suspect, is a spectrum of different levels of intractability, not just a sharp dichotomy between revolutions and puzzle solutions. Nevertheless, Kuhn's dichotomy, though rather idealized did serve to bring out in a forceful and dramatic way how complex, and how far from a simple matter of demonstration, the choice between theoretical alternatives ordinarily is."[55]

Wray tells us that according to McMullin then: "…revolutionary discoveries are those rare discoveries laying at one end of a continuum of discoveries, a continuum that includes even the most routine discoveries of normal science."[56] Wray disagrees with McMullin on this point: "In normal science, scientists agree about the standards by which a contribution is to be evaluated, whereas in revolutionary science the parties involved do not agree about the standards by which their compelling claims should be judged. Consequently, revolutionary changes are resolved in a manner that resembles the resolution of political revolutions."[57]

I think here too, we are in agreement with our claim that revolutions are a

---

[55] Ibid., pp. 62-63

[56] Wray, K.Brad, 2007, *Kuhnian Revolutions Revisited* in Synthese, Vol. 158, No. 1, p.68

[57] Ibid, p. 68

different type of scientific change. The third point of critique advanced by Bird that Kuhn's taxonomy of scientific change is not exhaustive. Wray writes that "According to Bird, normal science and revolutionary science do not account for all of the types of changes in science. Bird is certainly correct about this. But the Kuhnian account of scientific change provides us with greater resources to account for the range of changes in science than Bird claims. Kuhn's account of the developmental cycle of scientific change explicitly recognizes at least two additional types of changes, *paradigm-creating* changes and *pre-paradigm* discoveries."[58] Wray relies back on taxonomy again to make his point; as for paradigm-creating changes: "A discovery that leads to the creation of the first paradigm in a field is neither a revolutionary change nor a normal change. Such a discovery neither applies a widely accepted taxonomy nor aims to replace a widely accepted taxonomy. The discovery of DNA seems to fit this description. The discovery of X-rays also fits this description….during the pre-pardigm stage of a field….For example, Kuhn cites a variety of discoveries made by those who studied electrical phenomena before a research community was formed with a widely accepted taxonomy

[58] Ibid, p. 68

(see Kuhn, 1996, pp.13-14)."[59] For our purposes, Wray, though agreeing with Bird, seems to be content by Kuhn's apparently different classes of scientific discoveries. Our aim, however, in this essay is to go post-Kuhnian so to speak and to put our theory of types to test of further critique in order to ascertain if it can provide us with a more clear overview of the problematic than what others have proposed. I believe that our theory of types here too can accommodate us best. We can continue to claim that the cases where no shift in theoretical orientation was determined, our analysis not only stands up to the face of competition and critique but is also a more focused explanation of the phenomenon of scientific change.

The fourth point of critique involves Lauden's suggestion "…that all changes in science are continuous enough with the traditions preceding them to make calling any of them 'revolutions' inappropriate. The only reason one would be led to believe otherwise, he claims, is if one fails to look at the process of change in sufficient detail."[60] In countering and rejecting this claim, Wray gives a detailed account of the Copernican discovery and concludes that "The

[59] Ibid, pp. 68-69

[60] Ibid, p. 64

Copernican Revolution, I have argued, is a paradigmatic case of a Kuhnian revolution."[61]

Wray takes a position opposite those of Cohen and Hidelberger in claiming "Cohen (1985), for example, suggest that if there was a revolution in 16th century astronomy it involved the *changes in practice* introduced by Tycho Brahe. As far as he is concerned, the 16th century witnessed no change in theory. And, Michael Heidelberger (1980) suggest that *‚with the emergence of Copernicus' theory, no paradigm-shift occurs but rather a coalescing of two traditional paradigms*, (p. 277)." Neither Cohen nor Heidelberger are correct, Wray claims"…for Copernicus' discovery involved a significant taxonomic change. The meaning of key terms in astronomy were altered, most notably 'planet. '"[62]

In conclusion, Wray emphasizes that "I have argued that an important and often overlooked dimension of the Kuhnian account of scientific change is the shift in focus from theories to research communities….Scientific revolutions are those changes in science that involve taxonomic changes, precipitated by disappointment with existing practices, that cannot be resolved by appealing

[61] Ibid, p. 72

[62] Ibid, p. 69

to shared standards."[63] As we can see, using later Kuhn's taxonomic conception, he reiterates Kuhn's emphasis on the community. But let us remember, that again for our purposes, this conclusion is very much in line with our criteria in Tang's set B or in my extension in set C. A closer look reveals, I believe, that Wray's reliance on Kuhn's emphasis on the research community is part and parcel of what we have claimed in our criteria; if for the later Kuhn, the unit of scientific change is the orientation by the new "specieated" community, then it simply implies a shift, which may nevertheless bring about significant scientific development without being or becoming a revolution. In other words, we can very well continue to speak of *paradigm shifts* and *revolutions* with our criteria in mind without necessarily appealing to taxonomy since the taxonomy is already implied in I (set A) or in I and IV (set C). But can we also speak of *revolutions-in-the-making*?

With his theory of types, Tang addresses "a global theory of scientific development that, in one sense, continues, and, in another sense, departs from, the philosophical theory advanced by Kuhn."[64] As his motivation for a global

63 Ibid, p. 72

64 Tang, P.C.L., *Philosophy of Science Association* 1984, Vol. 1, p.133

theory, which besides the natural sciences also includes the social sciences, he writes: "After all, it is certainly easier and more elegant to explain the development of significant episodes in science in terms of one basic, overall pattern, viz., K-revolutions. However, I think the price for this kind of elegance is too high to pay. That is why, I believe, we must pursue this more pluralistic, global theory of scientific development that I have begun here."[65] Let us now briefly look at Tang's global theory. Besides the example of shift from Mendelian genetics to molecular genetics, he gives two additional examples both in social sciences, namely cultural anthropology and the history of psychology. He argues as follows: "In each of the two cases from the social sciences, there was, from the 19th century to the 20th century, a shift in theoretical orientation/methodologies. In the case of anthropology, the shift was from evolutionism and arm-chair theorizing and *a priori* deduction from data provided by missionaries and travelers, to structuralism and a highly empirical, 'direct-observation' methodology, firmly grounded in field work, followed by statistical analysis of the data accumulated. For anthropologists, this shift in theoretical orientations/methodologies surely represented one of

[65] Ibid., pp. 133-134

the most significant episodes in the developmental history of their science. Concomitantly, there was a shift, or at least an expansion, of the problems to be addressed and the problem solutions that would be acceptable; a shift in models, and in the type of knowledge gained. And much the same could be said in considering the significant historical episodes in psychology -- again from the 19th century to the 20th century -- in terms of the shift from structuralism and its subjective, introspective methodology, to functionalism, with its highly empirical, observationally object-centered methodology."[66] In applying the above two fields to the criteria he proposes, Tang concludes that both fields satisfy set A but not set B "and hence both are *not* K-revolutions. They *differ* from MeG→MoG in that they both involve a shift in theoretical orientation/methodology, whereas MeG→MoG does not involve such a shift…."[67] In short, Tang shows that there are a number of paradigm shifts of different types -- and potentially many more represented by:

[66] Ibid., p. 130

[67] Ibid., p. 131

PS [paradigm shifts] = (T[type]1, T2, T3 … Tn) [68]

where the conditions of set A are satisfied and further display presence or absence of scientific theoretical orientation, whereas there are also other shifts of different type that satisfy both set A and set B -- these are the K-revolutions. One might argue that Tang's global theory of types cannot be applied to social sciences and that there is a huge gap between natural and social sciences. In addressing this type of critic, Tang askes: "In the two examples I gave above, the significant developmental espisodes do not conform to the pattern of K-revolutions. But does this fact in itself rule out these paradigm shifts as not significant?"[69]

The later Kuhn insists that the difference between natural and human sciences relates to hermeneutic: "The natural sciences, therefore, though they may require what I have called a hermeneutic base, are not themselves hermeneutic enterprise. The human sciences, on the other hand, often are, and they may have no alternative. Even if that's right, however, one may still reasonably

[68] Ibid., p. 133

[69] Ibid., p. 133

ask whether they are restricted to the hermeneutic, to interpretation. Isn't it possible that here and there, over time, an increasing number of specialties will find paradigms that can support normal, puzzle- solving research?"[70] In Kuhn's own assessment: "My impression is that in parts of economics and psychology, the case might already be made."[71] Therefore, in principle, there does not seem to be any arguments against a global assessment of scientific change.

[70] Kuhn, T, 2000, The Road Since Structure, p. 222

[71] Ibid., p. 223

Kvasz Assessment:

To round things off in this section, let us consider the contribution of Ladislav Kvasz in an article entitled *On Classification of Scientific Revolutions*. His approach is formal and his aim "…is to discriminate between the formal and the social aspects of the development of science and to compare them.[72]" In doing so, he introduces the concept of epistemic framework and *epistemic rupture*. In a nutshell, Kvasz says: "If we compare the changes of the theory's formal frame with the changes of its conceptual frame, we can see that the latter are neither conservative nor gradual. Thus if we take the conceptual frame, which is the categorical, explanatory and interpretative schemes, as a basis for the study of a scientific revolution, we shall arrive at a picture resembling Kuhn's. The history of science appears as a sequence of discrete paradigm shifts. Nevertheless it is important to realise that **this result is only the consequence of our choice** [Kvasz's emphasis]. If we took the formal and not the conceptual frame as the basis for our study, we would get a very different picture of the development of science….the resulting picture will be

[72] Kvasz, L., On Classification of Scientific Revolutions, *Journal of General Philosophy of Science* 30, p. 201

more patterned. We shall be able to recognise some regular patterns in the course of the development of science. For this reason we introduce the concept of the **epistemic rupture** as a discontinuity of the formal frame of a scientific theory in the course of its development."[73]

How is this to be done? Kvasz suggests that it can be done through the study of perturbation of the ruptures. For the purposes of this essay, I think it is important to emphasize that Kvasz's aim as he puts it "…is not to discuss the question whether they are or are not revolutions. We would rather look for formal similarities, which occur in the epistemic ruptures which accompany the revolutions….the formal frame of the new theory contains a fragment isomorphic to the formal frame of the old one. This circumstance is very important, because it makes it possible to employ the methods of the perturbation theory and to consider the new theory as a perturbation of the old one. In this way our analysis gets a solid mathematical basis."[74] Kvasz adds that he does not want to enter the technical details of perturbation theory; "Our aim is rather to present the global scope, leading from revolutions

[73] Ibid., p. 219

[74] Ibid, p. 219

through ruptures to perturbations. The main reason why we wish to connect the epistemic ruptures with the perturbation theory is that in this way we hope to obtain a definite answer as to how many different kinds of epistemic ruptures there are. We believe that the perturbation theory makes it possible to discriminate four kinds of ruptures, which are connected to four kinds of perturbations."[75] Kvasz defines four perturbations as follows[76]:

- **singular perturbation** -- that is a perturbation changing the leading term, and thus the degree of equations, enforcing in this way radical alterations upon the global structure of solutions.
- **regular perturbation of infinite degree** -- that is perturbations leaving the first (or leading) terms unchanged, what means that the solutions of the perturbed system (new theory) converge to the solutions of the no perturbed system. This convergence may however depend on infinitely many parameters, what many lead to some differences in the global properties of the solutions of the perturbed and the no perturbed system.

[75] Ibid., p. 220

[76] Ibid., p. 220

- **regular perturbations of finite degreee** -- that is perturbations similar to the previous case, with the exception, that the convergence of the solutions of the perturbed system depends now only from a small number of parameters (usually only one).
- **Direct extensions using only finitary methods, without any limits** -- here the solutions of both systems are exactly the same -- they are only expressed in different "coordinate systems", using different primitive notions, etc.

As to the examples of ruptures corresponding to the above perturbations, Kvasz cites a number of historical examples and in doing so, he also introduces four distinct types of ruptures, which he calles:

1. **idealisations:** "Examples of epistemic ruptures of the greatest magnitude (which correspond to singular perturbations) are the **Galilean rupture** in the 17th century, during which physics was turned into an experimental science and the **Pythagorean rupture** in the 5th century BC, during which mathematics was turned into a deductive science. This kind of rupture seperates Aristotelian physics from Newtonian ….The basic difference between Aristotelian and Newtonian physics lies in the way they idealise

motion."[77]

2. **re-presentations:** "Examples of epistemic ruptures of the next magnitude in mathematics (which correspond to regular perturbations of infinite degree) are the **Cartesian rupture** consisting of the birth of analytic geometry, the **Leibnizian rupture** consisting of the birth of the predicate calculus, the **Fregean rupture** consisting of the birth of the predicate calculus or the **Cantorian rupture** consisting of the birth of the set theory. Each of these ruptures changed the language, with the help of which mathematics constructs its objects. These changes are so deep that it seems as if in the course of these ruptures quite new universes were created….So what was qualitatively changed during this rupture was the scope of objects present in mathematics."[78]
3. **objectivisations:** "Examples of epistemic ruptures of the third magnitude in synthetic geometry (which correspond to regular perturbation of finite degree) are the **Desargean rupture** -- the birth of projective geometry, **Lobachevskyean rupture** -- the birth of the non-Euclidean geometrics,

[77] Ibid., p. 221

[78] Ibid., p. 221

Beltramian rupture -- the birth of models in geometry, **Cayleyan rupture** -- the birth of abstract approach to geometry or the **Kleinean rupture** -- the birth of group-theoretical representation in geometry. These ruptures do not change the way in which the geometrical objects are constructed (as opposed to the Cartesian rupture). In principle they use the Euclidean constructions with the compass and ruler. So they operate in the same universe of objects. But what they change radically is the ontological status of these objects."[79]

4. **re-formulations:** "The last, fourth kind encompasses epistemic ruptures of the smallest magnitudes (which correspond to direct extensions). We would like to include these ruptures into our theory for the same reason, that in physics we ascribe speed to a body which is in state of rest (qual to zero, but nevertheless, we speak about speed)….As an example of such re-formulation we can take the replacement of the Roman numerals by the Arabic ones. Each calculation fulfilled in one of them can also be executed in the other, and, of course, the results will be identical."[80]

[79] Ibid., p. 222

[80] Ibid., p. 222

In short, except re-formulations, which Kvasz considers as cumulative changes of the formal frame, “we can discriminate **three kinds of scientific revolutions**: idealisations, re-presentations and objectivisations.”[81]

It is important now to turn to two more points raised by Kvasz, one in connection with “fine structure” of revolutions and the other one in connection with Kvasz classification with the theory of Imre Lakatos.

According to Kvasz, Giulio Giorelleo in his paper *The ‘fine structure’ of mathematical revolutions: metaphysics, legitimacy, and rigour. The case of the calculus from Newton to Berkeley and Maclaurin* (Giorello, 1992) introduced the concept of the fine structure of scientific revolutions. It is an allusion to quantum mechanics. The basic idea is that a revolution is not an event, which happens in a moment, but rather a slow process, which has different phases. The classification of epistemic ruptures opens a possibility to study such fine structures.”[82] Kvasz points out that Planck‘s original formulation of the black body radiation and “the idea of quanta appeared as a formal trick, i.e., as a

[81] Ibid., p. 224

[82] Ibid., p. 226

re-formulation."[83] The next step according to Kvasz involves Einstein and the theory of photo-electrical effect in 1905. "There Einstein started to consider the quanta as if they really existed. Thus the rupture separating the quantum and the classical physics becomes an **objectivisation**….The whole 'old' quantum theory, including Bohr's theory of the atom or Debye's theory of capacity of solid bodies was developed on this basis."[84] "The revolutionary process" Kvasz tells us "reached the level of **re-presentation** in the work of de Broglie in 1923, when he formulated the idea that all particles, and not only light, have a dualistic nature…In this way the quantum hypothesis, which until then served only for the description of some objects (i.e., for the objectivisation of light), becomes a fundamental principle of representation of reality….It seems that [here] the concepts of re-formulation, objectivisation and re-presentation describe the succession of the ruptures and thus also the dynamics of the process rather well."[85]

I think the question to ponder is whether or not the 'fine structures' in question is anything close to original Kuhnian paradigm shifts. Kvasz speaks of

[83] Ibid., p. 226

[84] Ibid., p. 226

[85] Ibid., p. 226

revolutions in terms of 'process' or 'phase' in the development of major revolutions. Should this be the case, I believe we need to assume -- at least in some cases -- that such shifts or ruptures must be cumulative culminating in major revolutions since according to Kvass "… a scientific revolution is a rather complex process, consisting of several ruptures, the magnitudes of which are smaller than the magnitude of the greatest rupture, which determines the character of the revolution."[86] To compare the present situation with examples given earlier in this essay, i.e., by Tang, we find ourselves on the same grounds especially since Kvasz also acknowledges albeit in a different formulation what Tang had advanced namely that revolutions are pardigm shifts, but not all paradigm shifts are revolutions: "Each scientific revolution is accompanied by an epistemic rupture, which forms the formal aspect of the revolution. On the other hand, not to every rupture there is a corresponding scientific revolution. There are many ruptures, i.e., discontinuities in the formal frame of a theory, which has no parallel revolution."[87] In this connection though, Kvasz raises an interesting

[86] Ibid. p. 227

[87] Ibid., p. 227

epistemological question: "Which epistemic ruptures turn into revolutions? Thus the question is why [for instance] from the ten very similar or even identical epistemic ruptures in geometry only one is considered to be revolutionary. The fact that from the formal point of view all ten ruptures are nearly identical seems to indicate that in ascribing revolutionary character to a rupture many external factors play an important role."[88] But what are these external factors? Kvasz does not provide us with an answer here. He tells us however that when comparing Newtonian and Einsteinian revolutions: "As Einsteinian physics is a regular perturbation of the Newtonian, due to the regular character of this purturbation, learning Newtonian physics helps in understanding the Einsteinian laws. There are some changes in the differential equations, symmetries and invariants, but they don't change the global structure of the theory."[89] On the other hand, the case of the move from Aristotelian to Newtonian, according to Kvas "… is a singular perturbation, because it changes the first order Aristotelian dynamics into the second order Newtonian . So the rupture is more radical than it was in the case of the

[88] Ibid., p. 227

[89] Ibid., p. 228

Einsteinian revolution….That means that even if scientific revolutions may have some irrational aspects, there are also many rational motives, which can be analysed and understood."[90]

Perhaps the 'external factors' Kvasz is refering to is of the nature just outlined. If that is the case, can the external factors be determined only after the fact, that is after a revolution has been established, or are they principally predictable? Whatever the answer to such questions, we have now acquired additional tools and are better equipped to deal with questions at the heart of this essay -- albeit, at the level of confirmation of our initial intuition regarding a theory of types of scientific change.

Lakatos' distinction between the hard core of a research programm and its protective belt is also of interest to Kvasz in that he aims to apply his terminology and conceptualization to scientific research programs and associated anomalies: "If some anomolies appear, the scientific research programm defends itself by developing a protective belt. At first the re-formulations are examined….An even deeper anomaly represented the

[90] Ibid., p. 228

quantum phenomena, where the re-presentation was changed -- instead of motion of matter in space we have to deal with temporal evolution of probability densities. But even such a deep change was solved inside the belt, and so the hard core itself, based on idealisation of motion, could be saved. The revolutions, during which the type of dealities is changed, as it was during the Galilean and the Pythagorean revolutions, (for details see Kvasz, 1998a) represent the abandonment of the old programm and the birth of a new one."[91] For Kvasz, the ruptures in scientific language are of different magnitudes. For the greatest ones Kuhn's theory seems to be adequate, while for the smaller ones a Lakatosian account works better. The revolutions of the intermediate magnitude requires some combinatoin of the two approaches."[92] Let us recall though that here Kvasz seems to echo McMullin's proposal advanced earlier in this essay regarding the size of revolutions. Be that as it may, like others critical voices in this essay so far, Kvasz also refers to the vagueness of Kuhn's conceptualization and provides his own evaluation: "Our main point of criticism of Kuhn's theory was that in his concepts of

[91] Ibid., p. 229

[92] Ibid., p. 229

scientific revolution he included at least three qualitatively different kinds of revolutions….The Copernican revolution was (or led to) an idealisation, the development of the theory of electricity was a re-presentation, and the Einsteinian revolution was an objectivisation. Including all three kinds of revolution under the same concept caused his concepts of paradigm, anomaly, crisis, and incommensurability which were obtained from the analysis of such inhomogeneous material, to be defined only by rough and general features."[93] Kvasz concludes that "It is highly probable that the incommensurality of pardigms, which Kuhn described, has a different character in the three different cases. The incommensurability between Aristotelian and Newtonian physics, which lay on different paradigms of idealisation, might have a quite different nature than the incommensurability between the Newtonian and Einsteinian physics, which differ in the paradigm of objectivisation. Thus our classification opens the possibility to replace the qualitative and rather controversial question of whether two theories are or are not incommensurable, by the more specific question of what kind of

[93] Ibid., p. 229

incommensurability it is and what it consists of."[94]

Further, Kvasz emphasizes that "…the three different kinds of revolution have a different fine structure. An Idealisation might be accompanied by several re-formulations and objectivisations, a re-presentation might be accompanied by some objectivisation, while an objectivisation will probably have no specific fine structure. Thus the 'fine structure' of scientific revolutions is a phenomenon which is specific to science, and so it is an important supplement to Kuhn's rather sociological 'strucure' of scientific revolutions."[95]

The lingering question at least for the purpose of this essay is to what extent Giorello or Kvasz concept of 'fine structure' converges on the question of *revolution* in string theory or on perhaps even a new notion called a *paradigm-in-transition (Pit)*, which appears in the title of this essay. *Pit* I propose is a shift that may or may not redefine the future of a field. I shall return to this notion in 'Afterwords,' the final section of this essay. Whatever the case, in the course of our inquiry, we have indeed acquired additional tools using the intuitions of Tang and the formal approach of Kvasz with which I

[94] Ibid., p. 231

[95] Ibid., p. 231

intend to approach the case of string theory.

The Case of String Theory:

Solutions, Unanswered Questions and The Sense of Crisis

In this section I intend to take a novel or perhaps less traditional appraoch namely before addressing the question at hand of whether or not string theory can be considered a revolution in the Kuhnian sense, I am going to first look at some of the criticisms directed against the theory. The reason for such an approach is not to undermine the degree of plausibility of a potential revolution but to show what the physicists themselves see as the initial stumbling blocks on the way to the core of the question! I believe, it is through outlining the parameters of the investigation that central question re-emerges more vividly.

In *The Trouble with Physics*, Lee Smolin writes: " The events of 1984 did not follow Kuhn's structure. There never was an established theory addressing the problems that string theory addresses. There were no experimental anomolies; the standard model of particle physics and general relativity together sufficed to explain the results of all the experiments done until that time. Even so, how could one not call this a revolution? All of a sudden we had a good candidate for a final theory that could explain the universe and our place in it."[96] Smolin is speaking of the so called , First Superstring Revolution,' which occurred in the fall of 1984. But before we consider strings and supersting in detail, let me include other statements Smolin makes while making a case partly for but mainly against further pursuit of string theory as a worthwhile endeavor for modern physics. One of the points he makes is about a definite and pronounced divergence within the community of physicists. Towards the end of the book, he writes: "Despite a number of tantalizing conjectures, there is no evidence that string theory can solve several of the big problems in theoretical physics. Those who believe the conjectures find themselves in a very different intellectual universe from those who insist on believing only what the actual evidence supports. The very fact that such a vast divergence of views persists in a legitimate field of science is in itself an indication that something is badly amiss."[97] Smolin is not proposing to abandon string theory altogether; he believes that it may be pursued as perhaps one alley or even an avenue among others and points to a diversity of

[96] Smolin, Lee, 2008, *The Trouble with Physics*, p.116

[97] Ibid., p. 198

research programs as healthy for science.[98]

Perhaps one can begin to sense the frustration on the part of members of the community -- including Smolin. So, the question that arises here within the context of this essay is what are we to make of the current situation in the string theory. How do we make sense of seemingly contradictory lables of *The First Super String Revolution*, and practically an appeal for its abandonment three decades later! Would our theory of types of scientific change be of any help here? Before any attempt at applying a theory of types to string theory, we need to know about the achievments and failures of the theory within the context of the type of problems plaguing physics before string theory was born.

According to Smolin, there are five great problems in theoretical physics:

> *Problem 1: Combine general relativity and quantum theory into a single theory that can claim to be the complete theory of nature.*
>
> *Problem 2: Resolve the problems in the foundations of quantum mechanics, either by making sense of the theory as it stands or by inventing a new theory*

[98] Ibid., p. 198

> *that does make sense.*
>
> *Problem 3: Determine whether or not the various particles and forces can be unified in a theory that explains them all as manifestations of a single, fundamental entity.*
>
> *Problem 4: Explain how the values of the free constants in the standard model of particle physics are chosen in nature.*
>
> *Problem 5: Explain dark matter and dark energy. Or, if they don't exist, determine how and why gravity is modified on large scales. More generally, explain why the constants of the standard model of cosmology, including the dark energy, have the value they do.*[99]

Without elaborating the forementioned in detail, I'd like to move to the conclusions Smolin draws about the current state of affairs regarding the five major problems facing physics and in doing so I intend to roughly evaluate what string theory has so far been able to provide or has failed to provide as solutions to the above problems.

Let us look at the failures first: The failure, according to Smolin, involves

[99] Ibid., pp. 5-16

problems 2, 4, and 5 and gives respectively the following assessment: On *the foundational problems of quantum mechanics*, "String theory so far says nothing directly about the problems in the foundations of quantum theory."[100] On the fourth problem Smolin points out that since the evidence suggests that there are such vast numbers of consistent string theories, the theory will make few if any predictions.[101] The prospects for the fifth problem, he tells us, is also problematic: "String theories, since they typically include many more particles and forces than have been observed, do offer a number of candidates for the dark matter and energy. Some of the extra particles could be dark matter. Some of the extra forces could be dark energy. But string theory offers no *specific* predictions as to which of the many possible candidates are the dark matter or the dark energy."[102]

There remains problems 1 and 3. Problem 1 was *the quantum gravity* which in the case of string theory involves a major flaw that has to do with one of the greatest achievements of Einstein's general relativity, namely, *background independence* which simply means that the geometry of space is not fixed and

---

100 Ibid., p. 191

101 Ibid., p. 191

102 Ibid., p. 192

that it evolves dynamically as matter moves through it; "Until Einstein, the laws of Eucleadian geometry we learned in school were seen as eternal laws: It always was and always would be true that the angles of a triangle add up to 180 degrees. But in general relativity the angles of a triangle can add up to anything, because geometry of space can curve."[103] The concept of space is also dependent entirely on the notion of time -- any time so long as causality holds. In other words, geometry of space evolves in time. In this context, the question is: "Can we extend to quantum theory the principle that space has no fixed geometry? That is, can we make quantum theory background-independent, at least with regard to the geometry of space? If we can do that, we will automatically merge gravity and quantum theory, because gravity is already understood to be an aspect of dynamical spacetime geometry."[104] So, as for the problem 1 then, the point is that the background-independence is missing and in the light of the foregoing, this point is crucial when speaking of a solution to quantum gravity problem: "We understand string theory in terms of strings and other objects moving on fixed

[103] Ibid., p. 81

[104] Ibid., p. 83

classical background geometries of space and don't evolve in time." Further, according to Smolin, "the particles carrying the gravitational force come out of the vibrations of strings, as does the fact that the gravitational force exerted by a particle is proportional to its mass."[105] But in the absence of background-independence, he questions whether this alone suffices as the solution to the problem of quantum gravity. A word on branes and black holes may drive the point home: "Once we study ordinary black holes, or when we try to go inside to ask what happens to the singularity, we are unavoidably in the regime where the spacetime geometry evolves in time. Supersymmetry cannot work here, and neither do all the beautiful calculational tools that depend on it….We get marvelous results for very special cases, and we are unable to decide whether the results extend to the whole theory or are true only of the special cases where we can do the calucations."[106] Here, Smolin is questioning the resolution of the puzzles of black hole entropy, temperature, and information loss, which have been implied by Jackob Bekenstein and Stephen Hawking; "…calculations using the

[105] Ibid., p. 184

[106] Ibid., p. 190

model systems of branes do reproduce all the details of the formulas that describe the thermodynamics of the corresponding black holes. But these are nott black holes, they are just systems constrained by the requirements of having a large amount of supersymetry to have the thermal properties of black holes."[107]

Finally, we are left with problem 3 or the problem of the *unification of the particles and forces*, which is considered the achievment of the string theory. Here, where forces and particles are principally vibrations of strings, supersymetric string theories unify all the different kinds of particles. It is noteworthy that "…a string propagates so as to take up the least area in space-time. The beautiful simplicity of this is what excited us originally and what has kept many people so excited: a single kind of entitiy, satisfying a single simple law."[108]

So, what do string theorists mean when they speak of a revolution in string theory? Right at the very beginning of this section, I quoted Smolin

[107] Ibid., pp. 190-191

[108] Ibid., p. 184

expressing his bewilderment about the event of 1984 and his vague and cautious proclamation, 'how could one not call this a revolution?' Not only this but also other remarks, I believe, paint a certain picture. Consider the following: "Given that string theory promised so much, it is not surprising that Schwarz and his few collaborators were convinced it must be true. As far as the problem of unification was concerned, no other theory offered so much on the basis of a single simple idea. In the face of such promise, only two questions remained: Does it work? And what is the cost?"[109] Let me add a third question to Smolin's list -- perhaps the question he really wants to ask: Is it a revolution?

A short review of history is here in order. I intend to trace events spanning well over 30 years beginning with Veneziano's discoveries and extending into the theory of quantum chromodynamics (QCD), which was inherently related to the *strong interaction* of forces within the atomic neucleus (incorporating the actions of protons and neutrons and later discoveries of quarks). Within this context, first, Venzianos discoveries were to constitue a "revolutionary" step

[109] Ibid., p. 113

for a later coneption of string theroy and I shall close the above historial circle by references to Weinberg-Salam model and the electroweak force. Second, another "revolutionary" step can be conceived of as the evolution of the first namely that string theory is not just a theory of the strong force, but as Schwarz and Scherk pointed out in 1974, it is a quatum theory that includes gravity. In the words of Greene "…string theory offers a far fuller and more satisfying explanation than is found in the standard model….that string theory was well on its way to fulfilling its promise of being the ultimate unified theory."[110]We are perhaps closest at this second step to a Kuhnian revolution but we shall discuss this later.

For string theorists, the above two conceptual "revolutionary" steps heralds the so-called first string revolution only a decade later, and in fact, it is the birth of spacetime supersymmetry in the mid 1970s that led up to the paring of bosonic and fermionic vibrations in the string theory that strengthens the conviction to a new paradigm or a "revolution" in 1984. In the 1930s all the way to the 60s particle collision studies were on the rise. Among these

[110] Greene, Brian, The Elegant Universe, 2003, p. 138

studies and the data collected, one by Gabriele Veneziano showed interesting patterns. He proposed a formula that matched the pattern observed in the data remarkably well, which was in turn interpreted roughly a dacade later in terms of the physical world; this is perhaps the very moment of conception of a future string theory. Be that as it may, "Accoring to this picture, particles could not be seen as points, which is how they had always been seen before. Instead, they were ‚string like,' existing only in a single dimension, and they could be stretched; when they gave up energy, they contracted -- also just like rubber bands. And like rubber bands, they vibrated."[111]

In the early 1970s, enter Holger Nielsen, Kenneth Wilson, and Alexander Polyakov. Consider now how the story unfolds, which I believe is telling in many ways especially the way a new community forms, together with its creative impulse and convictions -- albeit literally out of worldy!

Just like Michael Faraday had thought of the *field lines* as real -- lines in and around two poles of a magnet, Nielsen thought of strings as or in terms of quantized lines of electric flux, while Polyakov conjured up further connections between gauge and string theory; "According to these visionaries,

[111] Smolin, Lee, 2008, *The Trouble with Physics*, p.103

the primary objects in a gauge theory are the field lines. They satisfy simple laws, which dictate how they stretch between charges. The fields themselves arise only as an alternative description. This way of thinking fits naturally into string theory, because the field lines can be taken to be strings."[112] This ingeniously suggests a duality of description of the point in case, which has aptly been called *the duality of strings and fields*; obviously, where there are dualities, there are common grounds. What is the nature of these commonalities? Symmetries. Here Smolin's entertaining example of what a symmetry is: "…suppose you take two groups of cats -- say, east-side cats and west-side cats -- and you test their abilities in jumping. If there is no difference in the average jump a cat can make, then we can say that cat-jumping is symmetric under the operation of trading all your east-side cats for west-side cats."[113] The idea that "…all the properties of a force can be determined by knowing *the symmetries* is one of the most important discoveries of twentieth-century physics. This idea is what is meant by the gauge

[112] Ibid., p. 110

[113] Ibid., p. 57

principle."[114] The commonalities, discovered by the gauge principle, a mathematical idea discovered by Herman Weyl, no doubt, paved the way to understanding not only laws of nature, but the dynamic and changing even *evolving nature of the laws themselves*; I strongly believe that this is what Smolin's description of the development of the string theory implies: "The laws describe only the space of what possibly may happen; the actual world governed by those laws a choice of one realization from many possibilites."[115] There are many examples one can conjure up from the real life situations, such as people meeting for the first time and then moving on to form smaller or larger groups and units; in other words, here the initial meeting is characterized as stable before the symmetry breaks giving rise to new groups or units where stability is restored again.

This turns out to become, according to Smolin, the second most important discovery in physics of the twentieth century, namely, *spontaneous symmetry breaking*, which eventually led in the 1960s to EBH phenomenon (Englert, Brout, Higgs) or popularly knows as Higgs phenomenon. They proposed

[114] Ibid., p. 57

[115] Ibid., p. 60

combining spontaneous symmetry breaking with the gauge theories. They showed that there is a particle whose existence is a consequence of spontaneous symmetry breaking. This is called the Higgs boson.[116]
As Smolin suggests, there is a departure from the reductionism in considering the properties of elementary particles as lasting and eternal and set by absolute law. "It opens up the possibility that many -- or even all -- properties of the elementary particles are contingent and depend on which solution of the laws is chosen in our region of the universe or in our particular era. They could be different in different regions. They could even change in time."[117] To close the historical circle, it is noteworthy to add Weinberg-Salam model, or the electroweak force, and *quantum chromodynamics*, or QCD; the former involved again combining the gauge principle and spontaneous symmetry breaking to unite electromagnetic and the weak nuclear forces, whereas the latter involved the gauge principle and its application to the strong nuclear force. Both these efforts form the foundation of the *standard model* of elementary particle physics.

[116] Ibid., p. 61
[117] Ibid. p. 62

We have now come very close to the question that directly hinges on the essay at hand, namely: Is this the junction where a paradigm changes, or are we observing a somewhat seamless progress in physics—a transition, for instance, from the readily available concept of field lines to more exotic string-like entities.

Let us remember now Venizanos pattern he had observed in data stemming from nuclear particle interaction, and later Nielsen, Wilson, and Polyakov's creative impulses to connect gauge with the string theory. In hindsight, it makes a lot of sense to attempt to bring together elements of a very successful standard model with that of a new theory. Recall, that this essay attempts to reinstate the concept of paradigm shifts against the backdrop of K-revolutions through a theory of types. Also recall from the first part of this essay that the later Kuhn believes that the scientist can now freely participate in different lexical taxonomy at a time, similar to speaking different languages -- without jeopardizing incommensurability altogether. Here too, it seems that the concept of paradigm change persists with a distinct lexicon and with a distinct hint of methodological incommensurability -- I am referring to the mathematical constructs in string theory. Consider for example the way

Holger Nielsen -- as discussed earlier -- imagined strings as lines of quantized electric flux. This is a change in persective with the consequence of eventual paradigmatic changes to the theory at hand, i.e, *first superstring revolution*. But was this revolution indeed a revolution in Kuhnian sense, or are we simply involved in exploring the consequences of a new paradigm?

Consider the following as I attempt to get at another physicist's frame of mind in estimating what could be conceived as a revolution in string theory, but I need to start with the idea of supersymmetry. In this connection, Brian Greene makes the following two points: First, "In the conext of string theory, spin -- just like mass and force charges -- is associated with the pattern of vibration that a string executes; and within this context, second, he writes that it was found that "…strings necessarily have a vibrational pattern in their repertoire that is *massless and has spin-2* -- the hallmark features of the graviton. Where there is a graviton there is also gravity."[118]

He then goes on to clarify: "…Just as ordinary rotational motion allows for

[118] Greene, Brian, The Elegant Universe, 2003, p. 172

the symmetry principle of rotational invariance … could it be that the more subtle rotational motion associated with spin leads to another possible symmetry of the laws of nature? …when spin is considered, there is precisely *one more symmetry of the laws of nature* that is mathematically possible. It is known as supersymmetry."[119] The analogy goes on to postulate that if universe is supersymmetric, nature's particles must come in pairs; "Such paris of particles -- regardless of whether they are thought of as point like (as in the standard model) or as tinly vibrating loops -- are called superpartners….supersymmetry appears to result in a paring -- a partnering -- of matter and force particles. As such, it seems like a wonderful unifying concept."[120]

The attempt at unification seems to rest at the boundries of the standad model. Greene then asks why haven't we then discovered any of the super partner particles? The answer he provides is that even for our best accelerators the energies involved are still out of reach. Greene refers to a discrepancy when discussing the strengths of the three nongravitational forces (strong, weak, and

[119] Ibid, p. 173

[120] Ibid, p. 173

electromagnetic) and the fact that they *almost agree, but not quite* at tiny intervals. However he tells us that the discrepancy vanishes once supersymmetry is applied.[121] Be that as it may, Greene tell us that after 1977 "The new string theory incorporated supersymmetry, and the observed paring of bosonic and fermionic vibrational patterns reflected this highly symmetric character. Supersymmetric string theory -- superstrings theory, that is -- had been born."[122]

The birth of superstrings heralds the revolution -- at least the way Greene presents his arguments: "String theory is the only way we know of to merge general relativity and quantum mechanics. But it's only the supersymmetric version of string theory that avoids the pernicious tachyon problem….Supersymmetry therefore comes hand-in-hand with string theory's proposal for a quantum theory of gravity, as well as with its grand claim of unifying all forces and all of the matter. If string theory is right, physicist expect that so is supersymmetry."[123]

Greene does not specifically use the word ‚revolution' -- Kuhnian or otherwise

[121] Ibid., p. 178

[122] Ibid., p. 181

[123] Ibid., pp. 181-182

– he instead uses descriptions such as 'significant departure from conventional wisdeom,'[124] or ‚…developments that carry forward the revolution in understanding of space and time initiated by Einstein's special and general theories of relativity,'[125] or ‚'…yet another radical revision.'[126] The foregoing refer to unification in higher dimensions.

Greene tells us that the story unfolds when Theodor Kaluza suggested in 1919 that after revising Einstein's formulas and applying them to 4 dimensions instead of 3, he realized that he had arrived at a formula written by Maxwell in 1880 for describing the electromagnetic force.[127] "By adding another space dimension, kaluza had untied Einstein's theory of gravity with Maxwell's theory of light….His [Kaluza's] theory argued that both gravity and electromagnetism are associated with ripples in the fabric of space. Gravity is carried by ripples in the familiar three space dimensioins, while electromagnetism is carried by ripples involving the new, curled-up

[124] Ibid., p. 183
[125] Ibid., p. 20
[126] Ibid., p. 184
[127] Ibid., p. 196

dimension."[128]

According to Greene, the idea was abandoned in the late 1920s but was called into service again in the early 80s. The standard model had achieved what it was made to achieve with the exception of resolving the conflict, or perhaps anomaly, between general relativity and quantum mechanics. "Having pursued numerous ideas that all ultimately failed, the mind-set of the community became more open to comparatively radical approaches."[129] I believe Greene here is refering to both string theorists and die-hard adherents of the standard model.

Are we observing both the community and the onset of scientific change in unison? Is this junction a real instance of communities parting ways? Perhaps or even likely! In the first section of this essay, I asked a similar question: Can all the nuances of scientific change be subsumed solely under the umbrella of the community? Is the concept of a Kuhnian pre-paradigm period mentioned earlier of any help? For the above two questions, I lean the other way and would answer in the negative. I have tried to show that up

128 Ibid., pp. 196-197

129 Ibid., p. 198

until this point string theoriests have been working and tweaking the theory at the boundaries of the traditional and accepted physics. Again, can one speak of a pre-paradigm? I believe that we can perhaps speak of pre-paradigm only after a paradigm has successfully established itself. Further, the results at this junction do not guaranttee or necessarily promise comprehensive solutions sought to the problems at hand -- let alone a full-fledged K-revolution. In short, we seem to be using new conceptualizations while the working paradigm, namely the standard model, continsues to stretch its boundaries.

Now, let us bring a central aspect of the so-called first revolution in the string theory to the fore; let me refer back to Lee Smolin according to whom: "The super symmetric string theory could be consistent only if the universe has nine dimenstions of space. There was no option for a theory that works in a three-dimensional space."[130] He points out: "Furthermore, the standard model was not completely reproduced. It is true that we can derive its general features, such as the existence of fermions and gauge fields. But the

130 Smolin, Lee, The Trouble with Physics, 2008, p. 119

exact combinations seen in nature did not come out of the equations."[131]

Let us now briefly examine the events in March 1995 that unleashed the second superstring revolution. "In his lecture at Strings'95, Witten gave evidence for a new, profound kind of duality….he suggested that the five string theories, although apparently different in their basic construction, are all just different ways of describing the same underlying physics. Rather than having five different string theories, then, we would simply have five different windows onto this single underlying theoretical framework."[132] This is known as the M-theory, which is comprised of Type I, Type IIB, Type IIA, Heterotic-E, and Heterotic-O. Later Edward Witten and Joe Polchinski confirmed an important aspect of the second superstring revolutions namely an aspect of *strong-weak duality*: "These strong coupling characteristics of Type I string theory exactly agree with known properties of Heterotic-O string theory, when the latter has a small value for its string coupling constant."[133] Greene compares the two as resembling water and ice, which at first seem

[131] Ibid, p. 121

[132] Greene, Brian, The Elegant Universe, 2003, p. 299

[133] Ibid., p. 304

totally different, but are actually dual.[134]

I have already mentioned the crucial roles of symmetry and duality in the elucidation of the first superstring revolution. Here, I would like to extend that understanding to a central utility of the so-called second supersting revolution, which I maintain lies in finding a gateway to the physics of special black holes. The instrumental scientists here, namely, Andrew Strominger, Cumrun Vafa, and Juan Maldacena are noteworthy. The connection involves two concepts of *extremal* and *branes* in connection with the limit to the amount of charge branes can have (*extremal*) and analogously to the maximal amount of electric charge black holes can have but continue to stay stable (*extremal black holes*). Now, the nuts and bolts of the so-called gateway are fermions and bosons; "This almost miraculous conincidence occurs because in both cases there are several different supersymmetry transformations relating fermions and bosons."[135]

Along these lines of thinking, let us now briefly examine another aspect of the

[134] Ibid., P. 304
[135] Smolin, Lee, The Trouble with Physics, 2008, p. 139

second superstring revolution namely the relation between string theory and quantum field theory.

In 1997 Madacena introduced a duality into the framework of string theory, which initiated a study of AdS/CFT (Anti-de Sitter/Conformal Field Theory Correspondence) also known as Maldecena's conjecture. "Madacena's revolutionary idea was that a string theory could have a dual description in terms of gauge theory. This is astonishing because string theory is a theory of gravity, on a fixed background spacetime. Moreover, the world described by the string theory has more dimensions than the gauge theory that represents it."[136] The latter,[137] I believe is pretty much a central component of the so-called second superstring revolution. I think it is important at this very important point to look at the nature of the mathematical structure that string theory suggest. Recall Polyakov and his assertion that in some cases strings require an additional dimension -- obviously not in our world -- if there were to be a connection to gauge theory; in this connection, Smolin asks: "How did

[136] Ibid., p. 141

[137] Note that only the perturbative approach uses a fixed background, but the duality is between a field theory and a full string theory, which is background independent.

Polyakov succeed in conjuring up an extra dimension for his strings to move in? "[138] Again, the answer to this question, I believe, throws light on the nature of the mathematics involved: "He found that when treated quantum-mechanically, the strings that arise from the gauge theory have an emergent property, which, it turns out, can be described by a number attached to each point on the string. A number can also be interpreted as a distance. In this case, Polyakov proposed that the number attached to each point of the string be interpreted as giving the position of that point in an additional dimension."[139] So, for Maldacena who refined Polyakov's original contribution "…our three dimensions of space host the *maximally super theory* -- the gauge theory with the maximal amount of super symmetry."[140] I think it is important to note that Smolin informs us that after many years of research there is at least an approximate correspondence between string theory and gauge theory -- even though not proved.[141] Let us make a mental signpost here before digesting what the foregoing developments often labled *revolutions*

---

[138] Smolin, Lee, The Trouble with Physics, 2008, p.141
[139] Ibid., p., 142
[140] Ibid., p. 142
[141] Smolin, Lee, The Trouble with Physics, 2008, p. 142

actually mean.

The key to Maldacen's conjecture is to see that in creating mathematical structures of the string theory, connection are sought literally at every corner, which are primarily inspired by *supersymmetry, duality* relations and the attempt at finding *correspondence with gauge theory*.

Brian Greene writes: "Nevertheless, the major initial impact of the work of Ramond, and also of Neveu and Schwarz, was not actually in string theory."[142] Greene is refering to a version of the string theory that introduced in 1971 worldsheet supersymmetric string theory[143]. "By 1973, the physicists Julius Wess and Bruno Zumino realized that super symmetry -- the new symmetry emerging from the reformulation of string theory -- was applicable even to theories based on point particles…..[which] has come to be called *supersymmetric quantum field theory*."[144]

Greene also calls the supersymmetric standard model one of the crowning

---

[142] Green, Brian, 2003, The Elegant Universe, p., 181

[143] It is important to distinguish supersymmetry on the worldsheet that was found in 1971 from spacetime supersymmetry that was formulated by Wess and Zumino for point particles in 1974 and then applied to string theory from the late 70s onwards, which eventually led to the superstring and to the first string revolution.

[144] Ibid, p. 181

theoretical achievements of those pursuits and that the point-paricle theory owes a great debt to string thery.[145] Consider another example, this one posed by Smolin in connection with Maldacena's conjecture, discussed earlier: "Remarkably, if Maldacena's conjecture proves true only at the lowest order of approximation, this has allowed us to calculate some properties of the corresponding gauge theory in our three-dimensional world. This in turn led to insights into the physics of the other gauge theories."[146]

In short and in order to put the foregoing in perspective, consider the following:

1. Veneziano's discoveries became inherently intertwined with the concept of *strong interaction*; this was a revolutionary step in the development of string theory.[147]
2. The second revolutionary step was the idea that string theory could be more than about the *strong interaction*; in fact, it was suspected that one

[145] Ibid, p. 181

[146] Smolin, Lee, The Trouble with Physics, 2006, p. 144

[147] Quantum Chromodynamics (QCD), which was later developed as an alternative approach to describe *strong interaction* was based on gauge field theory of point particles.

was dealing with a quatum theory that included gravity. This carried the promise of a theory that could unify everything.

3. First string revolution: The discovery of how consistent action of a string that includes fermions as oscillation modes can be formulated based on supersymmetry, began resembling a leap towards an all-encompassing change or a "revolution."
4. Second super string revolution: Already strengthend with symmetry, the theory now heralded *strong-weak* duality. Coupled with Maldacen's conjecture, more light was thrown on the nature of mathematics of the string theory. Again, The key to Maldacen's conjecture is to see that in creating mathematical structures of string theory, connection are sought literally at every corner, which are primarily inspired by *supersymmetry, duality* relations and the attempt at finding *correspondence with gauge theory*. As mentioned earlier , the new emerging supersymmetry was even applicable to point-like particles; this is known as *supersymmertic quantum field theory*.

In short:

A. Initially, the creative genius of Veneziano interpreted patterns in the available date in a novel fashion. The central tenets of the new theory was then further expanded (revolutionary step (1) leading to (2) as outlined above. This was no doubt revolutionary by any standard.

B. The so-called first and second revolutions further expanded what was achieved in (A).

In other words, (B) became the exploration of the consequences of (A). Now, to what extent can the contents of (B) be called "revolutions" is the subject of the conclusion of this essay.

CONCLUSION:

Let us now apply our findings in the previous sections to the case of string theory. Kvasz's assessment of the conept of *epistemic rupture*, the reader recalls, was a discontinuity of the formal frame of a theory in the course of its development. Obviously, due to limitations of scope of our endeavor in this essay, we shall not deal with string theory's formal frame and shall only direct our attention to its conceptual significance. From an alternative conceptual perspective then and following Kvasz's assessment, one can perhaps point to *regular perturbations of infinite degree* when discussing string theory's course of development, which means that the solutions of the new theory converge on the solutions of the not perturbed one. Roughly, it would mean that knowing contemporary physics (Einsteinian) helps in understanding string theory. In string theory, the rupture in scientific language is somewhat present, but remember Kvasz attests to the presence of different magnitudes of ruptures for different sizes of scientific change. Most importantly, not every rupture, formal or conceptual, constitutes a revolution. In string theory, the kind of move, process, or phase, or revolutionary step, e.g., from (1) to (2) outlined several pages earlier, qualifies as an example of a rupture in Kvasz sense. It can have different characters depending on *external factors* and can be cumulative or otherwise, some of the characteristics can only be determined after the fact meaning after a revolution has been completed.

Further, using Kvasz's assessment, one can see that string theory's revolutionary steps outlined earlier namely (1) to (2) beginning with Veneziano resembles Kvasz's *re-formulation*, which is something similar to the move from Roman numerals to Arabic numerals. Further, Kvasz considers *re-formulations* cumulative. Step (2) can pass for *objectivisation*; objectivisations for Kvasz are are the stuff of revolutions. Similar to envisioning quanta, vibrating strings postulates push the scientific endeavor beyound its current bouderies. Step (3) the so-called first string revolution, resembles a *re-presentation* understanding the previous move can be extended, i.e., in our case, to include all matter. This type of analysis may allow us to have a clearer picture – the fine structure – of the revolutionary process in the case at hand.

I started this essay by exploring a theory of types of scientific change and spent the bulk of the first section on voices for or critical of Kuhn's conception of scientific change. For the ease of reading, let me include the table I had presented at the beginning:

Set A. Below is Paul C.L. Tang's identification of Kuhn paradigm shift:

(i) a shift in problems solutions; (ii) a shift in methodologies; (iii) a shift of models; (iv) a shift in type of knowledge sought and attained; and (v) a shift of symbolic systems.

Set B. However, a scientific revolution, which is a paradigm shift must satisfy the following additional criteria:

(I)	P1 → P2	is such that P2 is incompatible with P1;
(II)	P1 → P2	commenced with an anomaly in P1;
(III)	P1 → P2	was non-cumulative.

Set C. Expanding Tang's set B and incorporating later Kuhn:

I.	P1 → P2	P2 is semantically incommensurable with P1;
II.	P1 → P2	preceded by a crisis or anomaly in P1;
III.	P1 → P2	is non-cumulative;
IV.	P1 → P2	P1 is rejected or *degraded* by its revolutionary Successor P2.

As mentioned at the beginning of the first section, the later Kuhn saw revolutions differently. He moved from radical change (mutation) to diversification (speciation) having realized that revolutions as paradigm shifts were perhaps too flat to sustain the complexities of scientific change. In a way, our theory of types has become an attempt at displaying "speciation" in scientific development. So far, our undertaking is very much in line even with the later Kuhn. However, at the end of the first section we argued for Tang's global theory of types of scientific change, which envisions a number of different types of paradigm shifts to include both the natural and the social sciences:

PS [paradigm shifts] = (T[type]1, T2, T3 … Tn)

This in no way stands in opposition to Kuhn's thoughts relating to a hermeneutic *base* of both the natural and the social sciences as elaborated earlier; in fact it agrees with it.

The point is that despite later Kuhn's views on *speciation*, which is more or less a watered down version of the original concept of revolutions, nothing stands in our way of continuing to speak of *paradigm shifts*, *revolutions*, and *types of scientific change*.

Therefore, if for later Kuhn, the unit of scientific change is the orientation by the new "speciated" community, then it would only imply a shift, which may nevertheless bring about significant scientific development without being or becoming a revolution. This general understanding may justify asking a related question of whether or not we can speak of a *revolution-in-the-making*? Specifically, could string theory be a *revolution-in-the-making*? Perhaps! That is obviously an open question at this point. The central point worth pursuing though remains the significance of the type of shift.

Here, Set A: (i) a shift in problems solutions; (ii) a shift in methodologies; (iii) a shift of models; (iv) a shift in type of knowledge sought and attained; and (v) a shift of symbolic systems.

In string theory, the above:

(i) relates to the exemplars, e.g., Hawking's puzzle and its solution (ii) in search for ultimate laws and explanations using priority of new mathematical means in, e.g., solving entrenched problems in cosmology and creating new further exemplars (iii) based on a model of vibrating strings and vibrating action (iv) towards a new understanding of form and components of (v) a multi-dimensional universe.

On the other hand, considering Set B, or expanded Set C to determine whether or not the conditions for a revolution are satisfied, we realize that none has been satisfied:

I. No distinct taxonomy or semantic incommensurability within – to use the words of Kuhn – a mental module prerequisite to having beliefs, II. No preceding crises as even Smolin admits to, III. Presence of cumulativeness indeed in relation to the traditional physics, therefore, no non-cumulativeness, IV. And there is no rejection or *degrading* of a predecessor theory.[148]

Even our reference to (1) and (2) as "revolutionary" steps is only in hindsight of further understanding or achievements in (3) and (4) of string theory. Veneziano's discovery, for instance, neither applied to a widely accepted taxonomy, nor aimed to replace one. This is consistent with Kuhn's *paradigm-creating* changes and *pre-paradigm* discoveries. (1) and (2) and later (3) and (4) outlined earlier, simply extended the accepted taxonomy and built upon it creatively.

In this context, let me also refer back to McMullin's suggestions to see if they

[148] It is true that with respect to general relativistic effects, general relativity does not replace Newton's theory, but it does as a theory of gravity. That is why I have added 'degrading' here to guard against the objection that the replacement of a theory is always a matter of perspective.

could shed more light on the issue. Recall that McMullin proposed that the discovery of X-rays for example was according to his scheme a *shallow* revolution, phlogiston giving way to oxygen an *intermediate*, and a *deep* revolution was one that required much more thorough debate. Well, McMullen's analysis, I am afraid, does not do much for us in string theory. Here the case of string theory is not clear-cut. It is not clear whether we are dealing with a *shallow* or an *intermediate* phenomenon – perhaps somewhere in between? The case of string theory escapes this analysis because here paradigm-creating and pre-paradigm discoveries did lead to unification at least on one level, so it cannot be labeled *shallow*. Second, *intermediate* is also not applicable here because string theory did not replace its predecessor! Our assessment gives the following picture:

Veneziano's discovery was a pre-paradigm discovery (1), leading to (2) paradigm-creating changes, which in turn led to (3) and (4) the so-called first and second revolutions where (3) and (4) are the achievements of (2). According to our analysis though, the story does not end here. In hindsight, we consider (2) a revolutionary paradigm-shift and (3) and (4) further developments of the shift. At no point, could we confirm the existence of a Kuhnian or any other revolution.

Further, in search of 'fine structures,' our analysis showed that string theory is perhaps a *regular perturbation of infinite degree*, which displays *reformulations*, *objectivisation*, and *re-presentations* in (1), (2), and (3) respectively leaving the outlook open for a revolution-in-the-making. This was to further elucidate that revolutions are paradigm shifts, but not all paradigm shifts are revolutions.

AFTERWORDS:

Paradigm-in-transition, *cross-theoretical calibration* and other theoretical goodies

Applying Kuhn's historical terminology to the problematic of string theory may throw some light on Kuhn's emphasis on the symbolic generalizations, models, and exemplars[149] as important elements of a community's shared disciplinary matrix; these elements can in turn be elucidated for string theory before we apply our theory of types to the case at hand.

According to Kuhn, after about 1630, and following the influential scientific works of Descartes, many assumed the microscopic and corpuscular composition of the universe:[150]

"That nest of commitments proved to be both metaphysical and methodological. As metaphysical, it told scientists what sort of entities the universe did and did not contain: there was only shaped matter in motion. As methodological, it told them what ultimate laws and fundamental explanations must be like: laws must specify corpuscular motion and

[149] Kuhn, T, 1977, *The Essential Tension*, p. 297

[150] Kuhn , T, 1970, *The Structure of Scientific Revolutions,* p. 41

interaction, and explanation must reduce any given natural phenomenon to corpuscular action under these laws. More important still, the corpuscular conception of the universe told scientists what many of their research problems should be. "[151]

The above though related to the disciplinary matrix of an older science, carries a message for string theory especially in relation to the third element of the matrix namely shared exemplars or paradigmatic problem solutions. Here, one might be able to argue that there have been exemplars or problem-solutions in string theory (recall that problem-solutions are among the fundamental components of the notion of a paradigm shift in Kuhnian sense and designated in the first part of this essay as (i) in set A).

The most paradigmatic problem-solution in string theory has been the unification of particles and forces as elucidated earlier. This achievement not only belongs within the standard model's paradigm but also to an integral aspect of a novel new theory— string theory; I had referred earlier to this by calling it *tweaking* the boundaries of the traditional and accepted physics. Nevertheless, the theory I suggest can also be seen as a legitimate paradigm in

151 Ibid., p. 41

transition, which is a construct with distinct features that make it go beyond widely discussed notions of paradigms – including paradigm shift.

Following an outline of a theory of types of paradigm shifts, we have arrived at a distinct *paradigm-in-transition (Pit)*, which we vaguely defined at the end of the first section as a shift that may or may not define the future of a field.

Lack of access to empirical data in string theory is part of the embodiment of the new paradigm, but there is no sense of Kuhnian crisis here since *Pit* embodies the nature of the new paradigm. One can imagine *Pit* as an alternative to, for example, a full-fledged Kuhnian paradigm shift that has in the course of its transformation both revolutionized a certain field and has in its course redefined the future of that field. *Pit* does not appear to be such a shift.

Earlier, we claimed that every shift that has led to a Kuhnian revolution has redefined that field and concluded that all revolutions were indeed full-fledged paradigm shifts, but the opposite did not hold. In string theory, we have acknowledged a shift of the latter kind. We can perhaps imagine *Pit* a new species of the above shift. Therefore, and according to this analysis string theory is neither a revolution, nor a full-fledged paradigm shift. It is a shift in transition!

Let us remember that relative to fundamental research, a non-trivial aspect of the novelty of *Pit* is its lack of access to normal research programs or normal science.

An underlying assumption here is not only lack but unliklihood of empirical testing – and that not simply because the paradigm in question is not empirically testable for the time being! It may never be testable. I think that is an important distinction because it allows string theory to lay claim to its unique status without having to contemplate at every turn, whether or not to make a dash for where it can do normal science. Should the critics of the theory continue to beat the drums of dissent, the theory can point to it acheivements within its unique status. Therefore, I believe it is important to see string theory from paradigm-in-transition perspective.

But what is the significance of the deficit of empirical testibility or, in other words, what are the costs of uniqueness of string theory and of *Pit* itself?

First, I think, the significance of this deficit is two-folds: On the one hand, it makes theoretical adjustment at least difficult and at most unlikely or even impossible, and on the other hand, as far as methodological issues in future problem-solutions are concerned, it is not clear what the anticipated results could or should be! Second, it also tells us that *Pit's* distinctive hope namely the final theory has in a sense the characteristic of a true scientific puzzle that could occupy scientists for some time to come. Kuhn writes that "If it is to classify as a puzzle, there must also be rules that limit both the nature of acceptable solutions and the steps by which they are to be obtained."[152] If we were to use Kuhn's insight or advice here, we see numerous examples in string theory that attest to the fact that such rules have been applied primarily in the application of mathematics of string theory within the bounds of known physical and cosmological discoveries – some of which have been broached in the second part of this essay. The point here is to emphasize the nature of challenges and the degree of the complexity of the puzzle implied by final theory claims *Pit* faces.

Now, how does *Pit* lend itself to puzzle solving? Usually, specific tools are created to solve specific problems as they arise within theories, but here the

152 Ibid, p. 38

opposite is the case, namely, the puzzles await being solved by application of the tools already created, e.g., mathematics dealing with a multi-dimentional universe. Here, I am genrally referring to myriad of ways string theory's mathematics can be applied to an unlimited range of puzzles (considering the current state of our knowledge, some of these problems or puzzles are either not availble to us, or do not constitute a puzzle yet). However, since we do not know what the fundamental explanations are like, we are back at the methodological impass arrived earlier.

Even though Hawking's Puzzle does to some extent satisfy an appeal to science's metaphysical commitments, it does not however address a clear-cut problem-solution for string theory, specifically the question of what ultimately is part and parcel of the structure of the universe; this shortcoming is mainly due to underdetermination cloaking potential explanation. [153] What it does address, I believe, is the contours or rough estimates of the methodological issues relating to fundamental laws and explanations. It thereby renders the problem-solution to some significant degree inderterminate and that is no doubt detrimental for *Pit* on the way to its maturity.

[153] Richard Dawid has explored the issue of underdetermination in string theory in great detail in his book *String Theory and the Scientific Method*.

Nevertheless, the powerful formalism generated by the string theory that has been applied to old and new areas of inquiry, e.g., solving problems in the standard model, or even the so-called "solution" to Hawking's Puzzle. This has involved the process of application of the mathematics of string theory to a cosmological question, which has in turn provided some degree of assurance as to problem-solving features of *Pit*. This crucial feature may provide one way out of the dilemma relating to methodological issues within the context of empirical inaccessibility, which is at the heart of *Pit*. With the examples of achievements of the string theory enumerated earlier, *cross-theoretical calibration* seems what *Pit* has done pretty well so long as it has *tweaked* the boundaries of the traditional and accepted physics. However, *cross-theoretical calibration* in the hope of finding the final theory shall prove at best tedious and at worst illusive. Why? The argument must again refer to underdetermination relating to *theoretical exuberance.*

In the absence of empirical results, does puzzle-solving on paper imply indirect confirmation? I believe we need to address this point and relate it to the problem as we go. I suppose, a quick answer is that we cannot exclude possibilities that could potentially include a different sense of confirmation such as corroborations or even encouraging results—albeit circumstantial. It seems though that theory adjustment or *cross-theoretical calibration* is all we have to work with. In the case of Hawking's puzzle, an untested *Pit* is at worst confronted with another unconfirmed theory with many unknowns. However, Hawking's puzzle is lodged within a more entrenched cosmological theory whereas *Pit* is not; this may need further clarification: Ideally, *cross-theoretical calibration* is active in both directions. T1 solves a puzzle of T2 and thereby at best gains an insight into its own workings. Assuming that the solution to the puzzle can be considered paradigmatic, this particular exemplar becomes incorporated into the community's disciplinary matrix, or it becomes the epitome of the community (according to our latest understanding of the definition of the paradigm shift by Kuhn). Since our aim is not merely to marvel at the formalism of the solution, we need to evaluate the consequences of the interaction of this particular problem solution with *Pit*, which is constrained by empirical inaccessibility, theory exuberance and the inherent underdetermination.[154]

---

[154] According to our analysis, the current status of string theory and its embodiment as *Pit* points to its

Let us now return to the issue of complexity of the problem situation and the question of implication of indirect confirmation we posed earlier. Suppose Hawking's Puzzle can qualify as an exemplar of *Pit*. One could imagine the interaction in the following way: The formalism of the theory solves the puzzle of a second, in this case entrenched theory – here a cosmological theory relating to black holes. The important point is that the latter is entrenched (rests figuratively against a more solid theoretical background hinging on at least some empirical and observational details). In other words, though unconfirmed it still enjoys a different status than *Pit*. Following the argument proposed earlier, by solving the puzzle and providing an explanation for an aspect of the more entrenched theory, *Pit* will not only acquire increased legitimacy within the so-called *web of belief*, but will also provides access to new definitions of the kind of problems it may be able to solve. Besides solving a problem of another theory, *Pit* gains insight into its own workings, limitations and its potential. Again, the process may prove tedious though involving scientists who shall at every turn face the prospect of ground-breaking or circumstantial solutions.

---

unique features as a paradigm, but it further does not represent a Kuhnian crisis.

Acknowledgement

Special thanks to Dr. Richard Dawid for his time and constructive remarks in streamlining this essay. In this vein, I also thank Dr. Elisabeth Nemeth and Dr. Friedrich Stadler. Further, I am greatly indebted to my former teacher Dr. Paul C. L. Tang whose ideas on a theory of types of scientific change sparked my interest in applying them to a new field of inquiry.