Preface

If superstring theory does turn out to be the TOE, historians of science will have a hard job explaining why it came into being.

Joel Shapiro

String theory seemingly has a very bizarre early history. In his recent book, on the so-called "monster sporadic group" and its relation to physics (including string theory), Terry Gannon writes of string theory that it "is still our best hope for a unified theory of everything, and in particular a consistent theory of quantum gravity," but, he continues, "[i]t goes through periods of boom and periods of bust, not unlike the breathing of a snoring drunk" ([6], p. 277). This book describes some of these periods of boom and bust: the snoring drunk. I aim to reveal aspects of string theory's development in what I hope are more honest terms that the accounts of a pristine, unique, ineluctable structure that form much of the current string theory literature (especially the popular presentations of the theory[1]). It tells the rather volatile story of string theory from just before its conception, toward the end of the 1960s, when it was bound to so-called "dual-resonance models" (themselves the high-point of Geoffrey Chew's 'bootstrap' approach to strong interaction physics), to the advent of *M*-theoretic ideas in the mid-1990s, where it isn't really clear that it is a theory of *strings* at all.

We do face something of a historiographical problem here: in a very real sense, **string theory**, in the very general sense of a physical framework grounded in a fundamental principle (which delivers the dynamics and physical degrees of freedom) along the lines of the equivalence principle of general relativity, say—**does not exist**! Instead, we have a strange inversion of the usual relationship between *principles* and *theories* according to which one derives the theory from the principles, rather than the other way around. So why write a history of string

[1] At the same time, it avoids the recent trend of engaging in 'string bashing,' presenting the history in such a way that stands aside from questions of the truth or falsity or the theory—though I do step down from the historian's podium, briefly, in the final chapter.

theory if there is no theory as such to speak of? There are several reasons why I think we should certainly proceed, despite this glaring incompleteness:

- String theory, though not an empirically well-confirmed theory (that is, beyond already known, "old evidence" such as the existence of gravity and various gauge symmetries), has been around for over 40 years. This is a fairly sizeable chunk of recent physics history—it could likely match more chronologically mature theories in physics in terms of the number of physicist-hours that have been devoted to it.
  However, as John Schwarz bemoaned in a recent talk on the early history of string theory [18], there appears to be a complete lack of interest in the subject from within the history of science community.[2] We can perhaps trace this to the unwillingness of historians to invest time (an awful lot of it, given string theory's technical demands) studying a theory that might well be "firing blanks". However, given both the length of time string theory has been on the scene, and, more crucially, given its importance and dominance in physics, and even in pure mathematics, I share Schwarz's belief that "there remains a need for a more scholarly study of the origins and history of string theory" (ibid., p. 1).[3] Even if string theory should prove to be an *empirical* dud,[4] its role in the development of the physical and mathematical sciences mark it out from many empirical duds of the past. It has, after all, been intimately entangled with various key episodes in

[2] There are a small handful of notable exceptions [3, 4, 11], though in each case string theory is dealt with only very briefly. This does not include the recent book *The Birth of String Theory* [1], which, strictly speaking, falls outside of 'professional' history of science (however, I have more to say about this below).

[3] This really ought to be expanded to a more general study of the development of quantum gravity research, for which see [15], for a first attempt (dealing, initially, with quantum gravity research up to 1957). This book is a *brief* history, intended to be read by nonspecialists (hopefully) without overwhelming them. As such, it does not aim to be exhaustive, sketching the broad outlines of development and seminal publications, rather than the most intricate details—there is such a wealth of primary literature spanning string theory's 40+ years that the task of writing its history will certainly require the contributions of many authors. Hence, though I do include enough detail to provide a coherent account of the evolution of the theory, it should be remembered, of course, that this involves much selection and filtering on my part that does not necessarily imply that what was filtered out was unworthy of inclusion.

[4] This is already highly unlikely as a general claim, since string theoretic models, and in particular duality symmetries present (or originating) in string theory, have led to several groundbreaking results that have experimental ramifications. In particular in the field of 'quark-gluon plasmas' which extremely difficult problems in particle physics are probed using what is essentially the study of black holes (see [12] for a good review; or [13] for a more elementary account). String theory has more recently found applications to the very difficult problem of explaining high-T_c superconductivity—this was carried out by Mihailo Cubrovic, Jan Zaanen, and Koenraad Schalm: [2, 9]. (This is not to mention certain early empirical successes of the hadronic string theory, such as a physically intuitive mechanism for quark confinement and Regge behaviour, which should not be underestimated.)

the wider history of physics, including the development of quantum chromodynamics, supersymmetry, supergravity, black holes, cosmology, statistical physics, and the anthropic principle. It is far richer in such connections than one might expect, given its esoteric reputation. To ignore it is to leave behind a notable gap in the historical record.

- Moreover, there is real value in looking at the earliest history of a subject and exposing it as it was originally presented (regardless of whether the subject can be considered "complete"). Reading the original work that paved the way to the creation of a field of research can prove to be very enlightening: not only can one gain more intuition for the field, but it is often very surprising how much has been *forgotten* in the intervening period, especially in terms of general guiding, physical principles. As Robert Woodhouse elegantly put it in his 1810 study of the early days of the calculus of variations: "the authors who write near the beginnings of science are, in general, the most instructive; they take the reader more along with them, show him the real difficulties and, which is the main point, teach him the subject, the way they themselves learned it" ([21], p. 1). Auguste Comte, in his *Positive Philosophy*, put it more strongly: "To understand a science it is necessary to know its history". Though this quotation is over-used, there is certainly some truth to it. Unless all one is doing is number-crunching, one will wish to know what the numbers and structure represent and why they have the form they have. But this is often exactly what is lost as a subject develops momentum, and such details are condensed into a misleading, simplified package. Problems of the theory are tackled for their own sake, as interesting puzzles independent from the fundamental *raison d'etre* of the theory—in fact, there appear to be several such *raisons d'etre* in string theory: it is far from being a unified endeavour. Of course, such puzzle solving often proves very fruitful, and can lead to expansions and generalisations of the theory. However, the point remains, through history comes a greater depth of understanding.[5]

This book is, then, intended to plug the string theoretic hole (or a decent portion of it) in the history of science literature, identified by Schwarz. For better or for worse, string theory is a central part of the landscape of science. Not only that, it is a science that has spread into the public domain because of its obvious popular appeal (theory of everything, the multiverse, colliding branes, hidden spatial dimensions, pre-big bang scenarios, etc.)—not to mention the spirited presentation in Brian Greene's PBS television series, *The Elegant Universe*. It is also a very

[5] I might add to this list (to echo the opening quote from Shapiro) the fact that string theory's history is, in many places, just downright strange and for that reason alone makes for an interesting book! However, I would take issue with Shapiro's comment: regardless or whether string theory is true or not has no bearing on how the history is written up to this point.

difficult subject for outsiders (and, I would guess, many insiders!) to understand. A study of this kind is clearly warranted and I think much needed.[6]

In fact, since Schwarz wrote of the dire lack of historical work on string theory, there has been some emerging interest, resulting in two collections of articles: [1] and [7] (though the latter is more of a *festschrift* for Gabriele Veneziano, who we will meet later: nonetheless, it contains some excellent chapters on the early history of string theory). These books have been enormously useful in providing clues as to the various stages of development of the subject (beyond the "internal" published literature), as has John Schwarz's own two volume collection of important papers from the early days of string theory, pre-1985 [16].[7] There remains, however, no monograph on the subject. One notable near-exception to this is James Cushing's masterly monograph (already cited), *Theory Construction and Selection in Modern Physics* [3], in which he treats the development of S-matrix theory from Heisenberg and Wheeler's early work to the emergence of the dual models that were forerunners of superstring theory. I am a great admirer of Cushing's book, and will take the baton from him, following the story from the dual models he concludes with to *M*-Theory.[8]

I take as my starting point, then, the birth of so-called "dual models" in the late 1960s, which have their origins in the attempt to capture patterns in the physics of hadrons. To make sense of this, however, it will be necessary to first say something about the state of particle physics in the 1960s in general, and about the developments in mathematical physics that paved the way for dual models, and ultimately string theory as we know it today. My ending point is the shift to the notion

[6] Copernicus wrote on the frontispiece to his *De Revolutionibus* that "mathematics is written for mathematicians". I think there is an element of this attitude in the string theory literature, making it very hard for non-string theorists to penetrate its labyrinthine structure. For example, one finds David Olive writing that "[a]n ideal introduction [to superstrings] could, with some justice, be subtitled 'The string theory prerequisites for mathematics'"([14], p. 1). John Schwarz (writing in 1986) predicted that "[t]he mathematical sophistication required to be a successful string theorist of the future is so much greater than what has been needed until now that there are sociological consequences worth considering" ([17], p. 200). He was quite right. Part of the purpose of this book is to attempt to expose the inner workings of string theory for the benefit of non-string theorists and those who do not possess the skills of a professional mathematician. A particularly good way of achieving this is to trace its 'life story' (again, following Woodhouse), as we shall attempt here.

[7] I must admit, however, encountering the former book, *The Birth of String Theory* [1], considerably slowed down the production of my own book, since it forced me to revisit and reassess very many parts of it in the light of the various 'from the horses mouth' reminiscences contained therein. I urge readers also to consult this book, as a companion, for more information on how the various architects of superstring theory think about the history of their subject, and their own roles in that history—though with the historian's warning that one must be careful, of course, to avoid what Jeff Hughes and Thomas Søderqvist label 'the living scientist syndrome': "memory and personal archives are notoriously selective" ([10], p. 1). However, Hughes and Søderqvist rightly admit that such recollections can be enormously fruitful in pointing out new lines of inquiry for historians to follow, and for cross-checking with other sources.

[8] However, I should point out, I am not grinding Cushing's methodological axe of 'contingency in physics' in this book—but see "Notes to the Philosopher of Science" below.

of *M*-Theory, signalled by the appearance of various non-perturbative clues brought to light by the discovery of duality symmetries linking together the various perturbative definitions of the several consistent superstring theories (and 11-dimensional supergravity). I leave it for other writers (mathematically better equipped) to follow the story further into this still rather *Mysterious* realm. I make no apologies for this somewhat early curtailment: unlike the period of string theory I cover (from around 1967 up until 1995), the development of *M*-Theory is incomplete in ways that make the historical study of the subject genuinely hard even to contemplate.[9] Despite this curtailment of the story at 1995, the biography of string theory between dual models and the beginnings of *M*-Theory provides very many interesting glimpses into the workings of both physics and pure mathematics, and their practitioners. Let me finish this preface by providing some bespoke reader's notes for the various audiences that I hope this book will attract.

Notes to the General Reader. Though this book is inevitably technical, I have tried to write with a wide readership in mind: there are elements that will interest philosophers, sociologists, and historians, in addition to physicists and mathematicians (the more obvious readership). However, given the nature of the subject matter, the book may appeal to a rather more general audience too. In view of this, I have made every attempt to keep this book self-contained, introducing and defining the necessary mathematical and physical concepts *en route*, integrating them within the general narrative. I encourage readers who fall within this domain to attempt the mathematical parts; but failing this, simply skip the formal details and press on. There is enough "informal" material in the text to provide sufficient information to follow the story to the end: the central focus is firmly on the evolution of *ideas*.

Notes to Historians and Sociologists of Science. Historians of science will most likely be disappointed with the strong whiff of Whiggishness in this book.[10] However, I have tried to make sure the book is not infused with too much presentism. The book is intended to be of some use to a wide variety of readers, so an overly vigilant eye on avoiding "future developments" of the theory as a guide to the selection of past sources would be likely to alienate non-

[9] I do provide a very brief review of some key aspects of string theory's development since 1995 in the concluding chapter, but this is less history and more a discussion of certain conceptual issues.

[10] Silvan Schweber defines Whiggish history as "the writing of history with the final, culminating event or set of events in focus, with all prior events selected and polarized so as to lead to that climax" ([19], p. 41). Though it can play an important role in the *pedagogy* of science, it ought really, in excessive quantities, to be given a wide berth in the history, philosophy, and sociology of science. However, in some ways, quantum gravity research programmes, such as string theory, provide an ideal laboratory where Whiggish footholds have not yet had time to fully form: quantum gravity is in many ways (despite the *problem's* relatively long life) a revolution still waiting to happen. The contingencies are often an open book, with loose, uncertain principles not yet fit to function as 'final, culminating events' (save, perhaps, in a local sense).

historians.[11] Rather than restrict myself to the published literature, I have aimed to use as many sources as possible: interviews, archives, reminiscences, correspondence, and so on. The aim was to put some flesh of the rather skeletal historical accounts that one finds thrown in the introductory chapters of textbooks on string theory, and also to deepen such accounts—and, if necessary, *correct* them. This is by no means intended to be a "definitive history" (whatever that might mean). Rather, it is simply this author's attempt at providing a coherent story of a very difficult field: a more objective perspective will, of course, require the patching together of many more such attempts.

Notes to Philosophers of Science. This book surveys the development of string theory from the early dual models that prefigured string theory to the more recent (non-perturbative) work on *M*-Theory. I am most concerned with the earliest work, and end with only a brief examination of *M*-Theory and related ideas. Though primarily a work of history, I am also deeply concerned with methodological issues and more general conceptual issues that emerge from this history. I think a good knowledge of the historical basis of their subject, along with the methodological and philosophical ramifications that go hand in hand with this, could prove invaluable to those string theorists who were not involved with string theory from its beginnings and perhaps have a different view of its status (clouded by the immutable appearance one finds in modern-day presentations of the subject). The present book might thus open up some new channels for dialog between philosophers and string theorists. Of more direct relevance to philosophers of science, string theory offers up some methodological novelties concerning "the way science works". Several of these novelties would make good case studies, and some might be generalizable to other areas of physics—I shall flag several of these explicitly as we proceed. Finally, though philosophers of physics (even those working on quantum gravity) have tended to shy away from string theory, I aim to show how string theory is rich with interesting philosophical projects, especially concerning the nature of spacetime.

Notes to Mathematicians. As Gomez and Ruiz-Altaba note in the opening of their review of string theory, "[t]here is much pretty mathematics in string theory" ([8], p. 2). There has, of course, been a close interaction between pure mathematics and string theory since its earliest days, and this book was written with mathematicians in mind as well as physicists. Indeed, string theory, especially in its formative years, is especially intriguing as a case-study in the "physics–mathematics" interaction. I know of no comparable episode in the history of science in which the flow of ideas between physics and mathematics is so prolific *in both directions*, with both mathematical physics and physical

[11] There is a wealth of published literature from the dual model and post-anomaly cancellation eras. I have naturally been forced to be very selective, as previously mentioned. Whenever possible my choices have been guided by citation analysis. However, often there are articles included purely for their historical interest, rather than their importance in the development of the theory.

mathematics.[12] The contents of the penultimate chapter will probably be of most relevance, containing discussions of the ubiquitous Calabi-Yau manifolds, as well as the links between string theory and such areas of mathematics as finite group theory—however, I should point out that groups theory and Calabi-Yau manifolds constitute just one small area of the overlap between string theory and pure mathematics.

Notes to Physicists. Finally, I address this book's most likely audience: physicists (still more likely: string theorists themselves). While I have striven for accuracy in terms of the formal presentation of the theory and the unfolding of events in its life story, errors will undoubtedly have crept in both cases: string theory's history is almost as complex as the theory itself. Note that, unlike Lee Smolin's recent book, *The Trouble with Physics* [20], and Peter Woit's book, *Not Even Wrong* [5], this book is *not* a critique of string theory (if anything, quite the opposite). I have nothing invested in any particular approach to quantum gravity, and am interested in it in a more general way, and more so in the *problem* itself rather than specific proposals to resolve it—in any case, string theory goes beyond the problem of quantum gravity, and initially had no connections with it at all. The book is instead an attempt to understand string theory, in numerous senses of "understand": to understand the theory and its claims; to understand its origins; to understand "influences" on its development, and, perhaps, to better understand its current dominant position in the research landscape. Whether this dominance is or is not deserved is, as mentioned above, not a concern of this book; though I do discuss the emergence of the controversy over string theory's status as one of many events in the life story of superstrings that have shaped its present appearance in the public eye.

Ultimately, however, I hope the richness of string theory's historical development, with its many and varied connections to other fields, will convince readers that it is a theory worth pursuing, whether as a practitioner, or in some other capacity (e.g., as an historian or philosopher of physics).

Sydney, October 2013 Dean Rickles

References

1. Cappelli, A., Castellani, E., Colomo, F., & Di Vecchia, P. (Eds.) (2012). *The birth of string theory*. Cambridge: Cambridge University Press.
2. Cubrovic, M., Zaanen, J., & Schalm, K. (2009). String theory, quantum phase transitions, and the emergent Fermi liquid. *Science*, *325*(5939), 439–444.
3. Cushing, J. T. (1990). *Theory construction and selection in modern physics: The S-matrix*. Cambridge: Cambridge University Press.

[12] It constitutes what Peter Galison calls "a trading zone" ([22], p. 24).

4. Galison, P. (1995). Theory bound and unbound: Superstrings and Experiments. In F. Weinert (Ed.), *Laws of nature: Essays on the philosophical, scientific, and historical dimensions* (pp. 369–408). Berlin: Walter de Gruyter.
5. Galison, P. (2004). Mirror symmetry: Persons, values, and objects, In M. Norton Wise (Ed.), *Growing explanations: Historical perspectives on recent science* (pp. 23–63). Durham: Duke University Press.
6. Gannon, T. (2006). *Moonshine beyond the monster: The bridge connecting algebra, modular forms and physics*. Cambridge: Cambridge University Press.
7. Gasperini, M. & Maharana, J. (Eds.) (2009). *String theory and fundamental interactions. Gabriele Veneziano and theoretical physics: Historical and contemporary perspectives*. Berlin: Springer.
8. Gomez, C., & Ruiz-Altaba, M. (1992). From dual amplitudes to non-critical strings: A brief review. *Rivista del Nuovo Cimento 16*(1), 1–124.
9. Hand, E. (2009). String theory hints at explanation for superconductivity. *Nature 25*(11), 114008–1140021.
10. Hughes, J., & Søderqvist, T. (1999). Why is it so difficult to write the history of contemporary Science? *Endeavour 23*(1), 1–2.
11. Kragh, H. (2011). *Higher speculations: Grand theories and failed revolutions in physics and cosmology.* Oxford: Oxford University Press.
12. Myers, R. C., & Vázquez, S. E. (2008). Quark soup *al dente*: Applied superstring theory. *Classical and Quantum Gravity 25*(11), 114008-11480021.
13. Natsuume, M. (2007). String theory and quark-gluon plasma. *Progress of Theoretical Physics, Supplement 168*, 372–380.
14. Olive, D. I. (1989). Introduction to string theory: Its structure and its uses. *Philosophical Transactions of the Royal Society of London A*, *329*(1605), 319–328.
15. Rickles, D. P. (forthcoming). *Covered in Deep Mist. The Development of Quantum Gravity: 1916–1956*. Oxford: Oxford University Press.
16. Schwarz, J. H. (1985). *Superstrings: The first fifteen years of superstring theory*. Singapore: World Scientific.
17. Schwarz, J. H. (1987). The future of string theory. In Brink, L. *et al.* (Eds.), *Unification of fundamental interactions* (pp. 197–201). *Physica Scripta*, The Royal Swedish Academy of Sciences. Singapore: World Scientific.
18. Schwarz, J. H. (2007). *The early history of string theory: A personal perspective*. arXiv:0708.1917v2 http://arxiv-web3.library.cornell.edu/abs/0708.1917v2.
19. Schweber, S. S. (1984). Some chapters for a history of quantum field theory. In B. DeWitt & R. Stora (Eds.), *Relativity, groups, and topology II* (pp. 40–220). Elsevier: North Holland.
20. Smolin, L. (2006). *The trouble with physics: The rise of string theory, the fall of science, and what comes next*. New York: Houghton Mifflin Books.
21. Woodhouse, R. (2004). *A history of the calculus of variations in the eighteenth century*. New York: American Mathematical Society.
22. Woit, P. (2006). *Not even wrong. The failure of string theory and the search for unity in physical law.* New York: Basic Books.

Springer

http://www.springer.com/978-3-642-45127-0

A Brief History of String Theory
From Dual Models to M-Theory
Rickles, D.
2014, XIX, 251 p. 39 illus., Hardcover
ISBN: 978-3-642-45127-0