The case for string theory

Several books criticizing string theory have been popular recently, while books supporting string theory have been rare. Nevertheless, I came across one recently: *Why String Theory?* by Joseph Conlon. This book is aimed at laymen and was actually recommended by Peter Woit, the most well-known string theory critic. Therefore, I recommend this book to anyone who is interested in string theory, not just to "the citizens and taxpayers of the United Kingdom, without whom this book could never have been written" to whom the author dedicated it. In this essay, I explain why I support string theory research, heavily citing this book and other sources.

To understand my explanation, you first need to know what string theory is and what string theory is about, even though you may not need to understand its details at the level of graduate students taking string theory courses. I already explained what string theory is and what string theory is about at layman's level in my article "A short introduction to the history of physics, and string theory as a "Theory of Everything"." I highly recommend you to read this article first. It gives you the context within which we can evaluate the importance of string theory if it turns out to be the real solution to the theory of everything and to quantum gravity (i.e., writing the theory of general relativity in a way compatible with quantum mechanics).

However, the importance of string theory doesn't only lie within its possibility as a solution to the theory of everything or the quantum theory of gravity. Actually, Joseph Conlon explains in great length how string theory affected its neighboring fields. He remarks,

> What then lies behind the success of string theory? A wise and wealthy entrepreneur once observed that the route to riches in a gold rush is not through discovering nuggets but instead through selling shovels and pans. In this analogy, the large nugget of pure gold corresponds to the true and experimentally validated theory of quantum gravity. The shovels and pans are calculational techniques, mathematical insights, and applications to other parts of theoretical physics. (p228)

He further notes,

> The enormous growth and professional success of string theory is because so many physicists with no a priori interest in it found that it had interesting things to say about topics that they cared about. (p228)

As one of such examples, Joseph Conlon explains the ADS/CFT correspondence. The ADS/CFT correspondence (also called "gauge/gravity duality") says that certain gauge theories (CFT, conformal field theories) are exactly the same theory as certain gravitational theories or string theories in anti-de Sitter (ADS) space background. What all these terminologies exactly mean is not important to laymen. The gist is that the ADS/CFT correspondence says that a certain quantity A in the gauge theory corresponds to a certain quantity B in the gravity (string) theory. In other words, A in the gauge theory is equal to B in the gravity (string) theory. The real power of the ADS/CFT correspondence is that it often happens that it is much easier to calculate a certain quantity in one side than the other. For example, if you do not know how to calculate A in the gauge theory, you can calculate B in the gravity (string) theory instead. Then, you will know what A is because you know that A must be equal to B according to the ADS/CFT correspondence.

Of course, such applications of the ADS/CFT correspondence are possible only when the ADS/CFT correspondence is true. So, is the ADS/CFT correspondence true? We have concrete physical arguments for why it should work, but no mathematical "proof." We also have much evidence for it, even though this is not proof either. To explain what such evidence looks like, Conlon gives a good example in his book:

$$\begin{aligned}\gamma_K(a) = 3a - 3a^2 + \frac{21}{4}a^3 - \left(\frac{39}{4} - \frac{9}{4}\zeta(3) + \frac{45}{8}\zeta(5)\right)a^4 \\ + \left(\frac{237}{16} + \frac{27}{4}\zeta(3) - \frac{81}{16}\zeta(3)^2 - \frac{135}{16}\zeta(5) + \frac{945}{32}\zeta(7)\right)a^5 \end{aligned} \tag{1}$$

This is a five-loop calculation in super Yang-Mills theory. Here ζ is the Riemann zeta function.[1] The above expression can be obtained in two different ways, by the ADS side (gauge theory) calculation, and by the CFT side (gravity theory) calculation. Even though the expression is horrendously complicated, the two calculations agree! Conlon notes that it is not possible to think that a term like $\frac{945}{32}\zeta(7)$ pops out in both calculations by chance. Actually, there are literally thousands of such examples that show complete agreement. (As of 2019, Juan Maldacena's ADS/CFT correspondence paper was cited more than 14,000 times.) It is not possible to believe that they are all coincidences.

However, there is no mathematical proof that the ADS/CFT correspondence must work. Even though a five-loop calculation in super Yang-Mills theory shows an agreement, who knows if a six-loop calculation doesn't agree? We know that it is quite unlikely that such disagreement happens considering that thousands of such agreements were found, but at the mathematician's standard, there is no guarantee that the six-loop calculation agrees.

Anyhow, as we briefly mentioned, physicists studying neighboring fields such as quantum field theory found novel ideas in string theory such as the ADS/CFT correspondence very useful in their research. Conlon wrote, "It is not that they [i.e., quantum field theorists] came to string theory; string theory came to them and explained that many interesting properties of

[1] The Riemann zeta function is defined by $\zeta(s) = \frac{1}{1^s} + \frac{1}{2^s} + \frac{1}{3^s} + \frac{1}{4^s} + \cdots$.

four-dimensional quantum field theories are best understood via higher-dimensional theories of gravity." (p229)

If string theory research had never been supported, the string theorist, Juan Maldacena would not have been able to propose the ADS/CFT correspondence which brought about many applications in neighboring fields in theoretical physics.

Furthermore, the very fact that the ADS/CFT correspondence works shows that string theorists are onto something. Even though this fact does not verify that string theory is correct, if string theory were an inconsistent theory there would be no such correspondence. Actually, there are numerous other similar evidence that show that string theory is consistent. This may not sound impressive to laymen who haven't done any actual string theory calculations, but they are remarkable like the example in Conlon's book. Complicated calculations, but the final results agree and are neat. Examples that I can explain the easiest would be the dualities among the five string theories. If you are interested, please read my article "M-theory and dualities" (`http://youngsubyoon.com/pdf/mtheoryduality.pdf`). The duality check is not as trivial as the examples that I made up in that article to explain the dualities to laymen, and it is indeed remarkable that they fit together so nicely. They are too neat to be wrong.

Let me digress a little bit. Actually, my work in loop quantum gravity which corrected the earlier loop quantum gravity could be first recognized because it had evidences. These evidences are not experimental ones, but mathematical ones, just like the ones that one can see in string theory.

Also, as I mentioned in my article on string theory, string theory research is valuable because it brought about many developments in mathematics. I would not elaborate more on it because I have already done it elsewhere. In this essay, let me just quote Conlon's book

> I can say with confidence that as mathematical results are eternal, the role of string theory in mathematics will never go away. It may wane or wax in fashion, but it will always be there. String theory is a consistent structure of something, and that consistent structure leads to interesting mathematics. These parts of mathematics are true in the same unqualified sense that the rest of mathematics is true, and they will always be true independent of what any experiment may ever say about the laws of physics. (p236)

In some cases, string theory corrected mathematicians' mistakes. In another interesting book that supports string research, I found an interesting anecdote.[2] In 1990, four string theorists, Philip Candelas, Xenia de la Ossa, Paul Green, and Linda Parkes devised a "string theoretic" method to calculate certain mathematical quantities. In most cases, their method yielded the results two Norwegian mathematicians, Geir Ellingsrud and Stein Arild Strømme obtained, but not all. As one mathematician recalled, mathematicians thought that the

[2] p140−141, *The Universe Speaks in Numbers: How Modern Math Reveals Nature's Deepest Secrets* by Graham Farmelo

physicists' methods were ridiculous. They were confident that the string theorists were wrong. In May 1991, many expert physicists and mathematicians met at the Mathematical Science Research Institute in Berkeley, California to discuss this matter. They talked to one another to try to understand others' methods. However, they couldn't resolve the disagreement. However, in July 1991, the Norwegian mathematicians found an error in the computer code. When they fixed it, they obtained string theorists' results. If string theorists were not there, mathematicians would not have noticed their mistakes.

Perhaps, we can also learn from history. When Sir Isaac Newton first came up with Newton's theory of gravity in the 17th century, the lack of a possible mechanism behind his theory was regarded by many as a serious defect. Newton's theory of gravity says that every object attracts one another. If every object attracts one another, why? However, such a criticism disappeared due to the numerous experimental evidences of Newton's theory, and such a question was completely set aside by physicists. No sensible physicists raised such a question anymore. Finally, in the 20th century, Einstein came up with Einstein's theory of gravity, and a satisfactory answer to such a question was found.

If physicists in the 17th century and the 18th century had totally abandoned Newton's theory because of its "defect," i.e., the lack of physical mechanism, despite its numerous experimental evidences, we would have never seen its full glory in the 19th century. Similarly, if physicists in the 21st century totally abandon string theory because of its "defect," i.e., the lack of experimental evidences, despite mathematical evidences and the presence of physical mechanism, we do not know what opportunities we will miss.

Some argue that string theory is not even science, because it does not make predictions that can be proven or falsified. Indeed, most predictions string theory currently makes are at the scale of 10^{-33} cm, which is currently out of reach. To such critics, the late string theorist Polchinski noted that it had taken 300 years to cross four orders of magnitude on the energy scale, from the optical scale to the atomic scale. Now, string theorists are working on the energy scale twenty-five orders of magnitude higher than the one currently accessible. Polchinski argued that demanding direct observation as a criterion of science is "too rigid"; restraining physics to scales that are currently reachable makes science "too weak." It would be "to decree that there are aspects of the natural world that are outside of its domain."[3] Polchinski says that string critics should be patient and open-minded.

Maybe, we can learn from history again. By the late 19th century, there were strong indirect evidences for atoms, but no direct ones. Many believed in atoms for these indirect evidences, but many others didn't, due to the lack of direct evidence. The renowned Austrian physicist and philosopher Ernst Mach was one of those who didn't. He had a belief that only the sensation was real, so he claimed that atoms did not exist, as it was a nonsense to talk about and postulate things one cannot detect.

In light of this, it is easy to see the fallacy of string critics who claim that string theory is "not even wrong," as it cannot be tested. I would argue that we cannot test it now, but

[3] J. Polchinski, "Why trust a theory? Some further remarks (part 1)," [arXiv:1601.06145 [hep-th]].

someday we may. I strongly suspect that these string critics are modern-day Machs. History teaches us that we should never overlook indirect evidences.

Of course, at this point, we can't be sure how string theory will turn out unless we are prophets, but a few centuries from now, string theory will perhaps have direct experimental evidences, as atomic theory did after a long waiting. Luckily, there are some working on string theory and others working on other things. This is good. String theory may turn out to be wrong, but there are also chances that it is correct. Moreover, even though it may turn out to be wrong, no one can deny that it is still very useful for mathematics and other fields of physics. What I can at least say for sure is that it would be a great loss if none works on string theory. If you think that string theory is not science because it doesn't suit your definition of science, that is fine; you may claim that it is neither physics nor math. However, if you argue that we should stop supporting string theory research for this reason, I will fiercely fight against you.