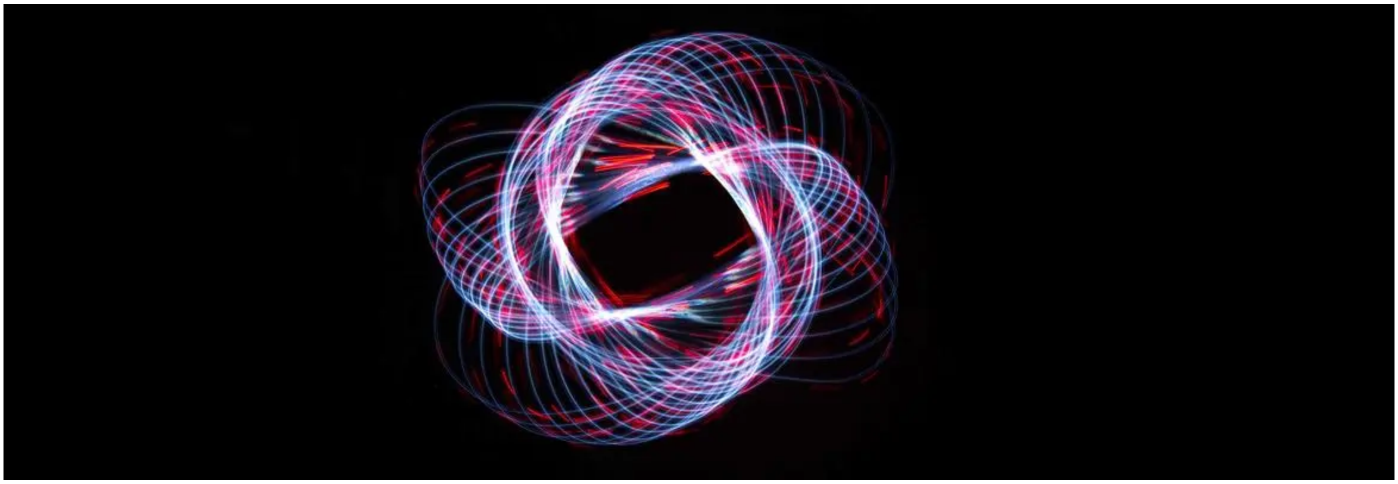
It's too soon to dump string theory

The truth of string theory



String theory’s unexpected and robust mathematical relationships may hold the key to understanding the universe, even if they don't neatly fit our current understanding of reality, writes Tasneem Zehra Husain.

Is string theory worth pursuing? This question, like the perennial Jack-in-the-Box, never stays down for long and - like said toy - creates a commotion every time it arises. Before calm is (temporarily) restored, it seems there are certain tunes that must be played. Typically, here’s how it goes:

Critics dismiss string theory on the charge that it’s not science. A successful scientific theory must incorporate known physical phenomena and make verifiable predictions about the natural world. String theory hasn’t, so it’s just a fantasy, they say; it should be abandoned. Proponents argue this assessment is superficial. They agree that concrete, testable, predictions are an essential feature of a mature theory - and remain an active goal of research - but string theory is still growing. It is not old enough to be oracular. More time is needed, they say; condemning it now would be premature.

You have had decades, the critics object. String theorists respond with a list of the many times this has happened before. From atoms (postulated two and a half millennia before being observed), to gravitational waves (detected a hundred years after prediction), the Higgs boson (found after a half-century long search), quantum entanglement (an empirically falsifiable prediction took three decades to formulate; verification took two more), and countless others. String theory would not be the first theory to ask for a bit of patience, and none has ever had better reason! Lest it be drowned out by the noise, string theorists reiterate the magnitude of the problem at hand. They are attempting to obtain the fundamental equations that encompass everything which unfolds in the universe - from the Big Bang to now, from light years to the Planck length - and then, they need to figure out how to test the implications of these equations.

Today's state-of-the-art technology can probe length scales up to 10^-17cm; the Planck length is ten million billion times smaller. Direct experimental verification is obviously not an option, but the complications of string theory are not limited to technology. Mathematically, too, the theory is immensely complex - more intricate than anything else we have chanced upon. It is any wonder that progress is slow, string theorists ask.

From here on, it plays out much as you might expect. Arguments and counterarguments weave back and forth until the landscape makes an appearance and - at the mention of these 10^500 (or so) possible universes the theory describes - we reach the crescendo.

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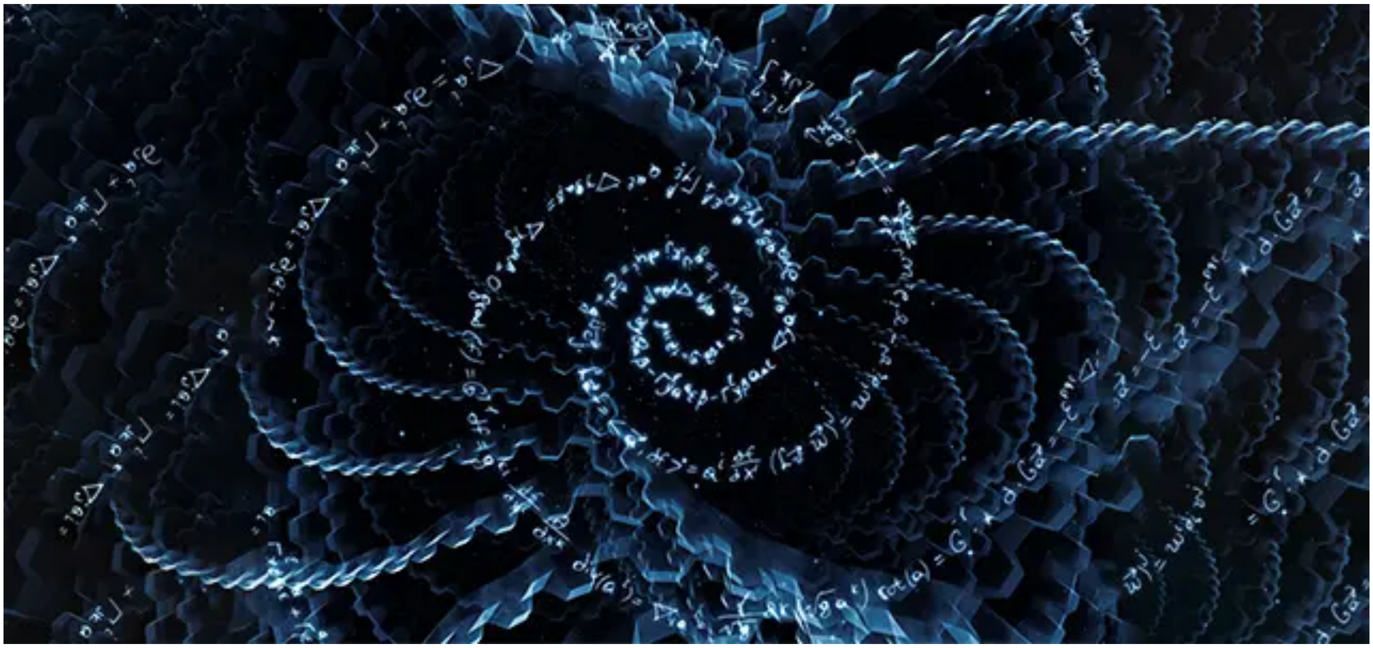
The discussion is so animated, so diverting, that it's easy to lose track of the fact that when we debate whether or not string theory is 'true', we limit ourselves to only one kind of truth. Most evaluations of string theory are based on how well it describes, explains, and predicts observations; in short, on physical truth. This is - as it should be - the central criterion. Physics is, after all, the study of what manifests, not a catalog of what could have been. The importance of physical truth is obvious and uncontested. What is mentioned far less often, is mathematical truth; this too, plays a role.

Just to be clear, physical and mathematical truths cannot - and should not - be conflated. They are neither equivalent nor interchangeable. Every mathematical equation need not be physically realized, but the converse does not hold. Every observable phenomenon is, simply by virtue of existing, a logically consistent system and therefore, mathematically expressible in principle.

But not yet in practice. Certain physical phenomena - black holes for instance - refuse to be rendered mathematically by the tools we currently have at our disposal. The equations evade us, but they exist. How do we know this? Because black holes do not cause the universe to implode. Had the laws of black holes been incompatible with the physics of the rest of the universe, one - or both - would collapse. But the universe exists, and black holes exist within it; so the equations governing black holes should exist also, as part of the mathematical framework that undergirds the universe. Neither quantum field theory nor general relativity rises to the challenge.



SUGGESTED VIEWING *The code to the cosmos* With Marika Taylor, Peter Woit, Arif Ahmed, David Malone

We know exactly what the problem is: quantum field theory and general relativity - each unprecedentedly successful in their own domains (the former rules the very small, the latter the very heavy) - are fundamentally incompatible. As long as we restrict ourselves to systems that are either very small or very heavy - which, arguably, covers most of the universe - everything works out beautifully. There are, however, a few exotic places where the theories overlap; places where so many secrets are squeezed into tiny spaces that the very small *becomes* the very heavy. Here, where the deepest structure of the universe is revealed - at the big bang, or inside black holes - where both theories should hold sway, neither utters anything remotely coherent.

It is clear that we need a new paradigm. What isn't nearly as clear, is how we should go about obtaining it. The attitudes and assumptions of our two reigning theories are so different, it is difficult to imagine how they could be reconciled. Here's the crux of the issue: Quantum field theory describes the interactions of fundamental particles against a fixed space-time; should all the world be a stage, elementary particles would be the players and quantum field theory the script. But in general relativity, spacetime - the stage - is responsive and continually reacts to what unfolds upon it. In the vast majority of situations, we can get away with applying either quantum field theory, or general relativity; we pick either a play enacted upon a static stage, or a graceful dance in an ever-changing arena.

Should we try to implement both theories together, we create an untenable situation - a true postmodern nightmare! Each step the actors take, every gesture they make, causes the sets and stage to morph. With the ground moving under their feet, actors scramble to adapt to this transforming environment; their actions are modified constantly to keep pace with the shifting context, and the script is perpetually rewritten to somehow make sense. It doesn't. No matter how artfully we construct their lines, all the actors end up screaming infinities.

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A simple mashup just does not work. If we are ever to achieve a coherent formulation of quantum gravity, we need an entirely novel approach. But where will this come from? If we insist on taking our cue only from that which we know – that which is physically realized - we are at a dead end. We have exhausted our intuition. In order to navigate the uncharted waters we now face, we will need to access an as yet untapped source of mathematical truths.

Or, we could just choose to stay on familiar land.

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One of the deep mysteries of mathematics is that, simply by requiring stability and consistency, we arrive at structures that seem imbued with an inner knowing. Time and again, we start to write, only to find our pens moving in invisible grooves, tracing figures we had not envisioned, uncovering consequences we could not have foreseen. Dirac set out to express the dynamics of an electron in a manner consistent with special relativity - but his equations held also the positron, paving the path for all of antimatter. The elegant equations of general relativity, so satisfyingly spare on the surface, hid black holes, left space for a cosmological constant, and prophesied gravitational waves - none of which was expected or even, initially, welcome. The annals of physics are full of such stories.

It feels like an incredible gift each time we are lifted to these foreign places we would never have reached on foot. Once we arrive, we chart the terrain, plot paths, add them to our maps, and work out ways to get there again. Future expeditions may be planned and purposeful, but that first time - when we have no idea where we will end up - there is a definite sense of being carried. In all our years of traveling by equation, string theory is by far the most extravagant structure we have encountered.

For an arrangement this intricate to be stable is an incredible feat in itself. Had it been nothing but a house of cards, the very fact that it stands would be commendable - but string theory has proved to be robust, even load-bearing. The architecture is unfamiliar but the design is remarkably self-consistent. The unexpected flourishes, the peculiar shapes which curve in on, and around, themselves - they all fit together seamlessly. Moreover, string theory displays a tensile strength we could not have anticipated. We have thrown problems at it, and it has grown to accommodate them; most equations would have simply collapsed under the weight. Such stability is only possible in a structure that is mathematically true.

It is an oft-told story, how strings were first uncovered by accident, on a dig for a theory of the strong interaction. They never quite belonged because no matter how you rubbed them, you just could not remove the peculiar glint from their surface … It took a while for people to recognize this glint as gravity, but once that happened, there was massive jubilation. String theory, it was thought, heralded the ultimate answer. It would show us a way to not only bridge quantum field theory and gravity, but unify them. It would lead us to a place from where all the matter and forces in the universe would appear to be notes played by a string; all we know, all we can know, arising from a vibrating strand of energy. At least, that was the idea.

Things didn't quite turn out that neatly.

Equations can be quite chatty if you let them, and to those who listened, string theory had plenty to say. It's true, what the critics allege - strings did not do what we asked of them; they did more. They enlarged the space of what we thought possible. Nestled in the nooks and crannies of string theory were problems we had not prepared for, elements we could not have expected - an entire menagerie of issues was unleased; the process of taming them is an ongoing education. But, amid all the creative chaos, there have also been answers - whispered answers to questions we didn't even know to ask.

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No one expected the theory to be 'correct' in its initial formulation. The name is merely historic. We always knew strings could not take us to a full-blown theory of quantum gravity on their own - but in a fascinating twist, they led us to the things that might. Until string theory came along, we had only a point-particle view of the universe, which - it turns out - was very restrictive. Strings had a whole new umwelt. They saw – and showed us - so much more than particles could. Open strings, probing space with mathematical tentacles, found their endpoints getting stuck in certain places; through their motion, they sketched the shapes of these invisible traps, thus revealing a whole family of higher dimensional membranes that until then, lay hidden.

String theory has offered up many revolutionary ideas - extra dimensions, large and small, and a possible explanation for black hole entropy among them - but one particular triumph is the discovery of duality. A duality is when two apparently unrelated theories - potentially containing different particles, different dynamics, operating in space-times of different shapes and dimensions - describe physically equivalent content. Or, to flip this around: duality says that the same physical situation can be modeled equally well in two unrecognizably different ways. What's more, the descriptions work in concert with each other. Questions asked of one theory may be answered by appealing to the other. It's as if the script of a play was equivalent to the score of a symphony, and by listening to the music, actors could learn their lines and take stage directions.

The insights obtained from string theory may have emerged in the 'unrealistic' contexts of AdS space (which we don't inhabit) or supersymmetric black holes (which cannot exist in our present universe), but the relationships they describe are not necessarily limited to those situations. At the very least, they tell us that certain arrangements and interdependencies are possible; ideally, they will turn out to be preliminary sketches - or even blueprints - for the physical world.

This may sound like wishful thinking, but in fact the history of physics is replete with such examples. Here's one of my favorites. Imaginary numbers do not, by definition, exist in the world around us. If the purpose of numbers is solely to quantify objects in the physical world, imaginary numbers make no sense at all - and yet, they are absolutely essential in formulating the equations of both quantum field theory *and* general relativity. Where *i* on its own may be dismissed as a flight of fancy, the abstract relationship it represents is enacted over and over again in the physical world.

A mathematically consistent framework is larger than, and independent of, the context from which it emerges. It is proof that a certain set of relationships, a particular pattern of evolution, is possible - that it is logically sound and structurally stable. The identities of those who enact these relationships is irrelevant. Symbols are roles anyone can step into, as long as the choreography of the equations is obeyed. It is, thus, entirely possible to extract mathematical truths from situations that are physically unrealized - even unrealistic - and store them as models, building up a library to consult when you encounter previously unmapped phenomena.

We stand today upon a cliff edge, facing what appears to be complete chaos. We are unable to identify any forms - not because they do not exist, but because we see only that which we have trained ourselves to see. What we behold now is completely new, and so we must learn to see again. If we are to articulate what lies ahead, we need a new lexicon of words to hold these amorphous realities. We need new patterns to connect what we find here, new templates to measure against, a new list of possible interactions.

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We need an entirely new set of models to contain this strangeness, but where, and how, do we look for something when we have no idea what it looks like? There is no prescribed path, no plan to follow, no way to mount a targeted search. Instead, we must wander, leaving ourselves open to serendipitous encounters, paying attention to whatever it is we find. If the romance of this quest does not appeal, it may help to remember that, while this may not be the most efficient way forward, we don’t know any other.

String theory has proved to be a veritable trove of mathematical treasure. Odd objects to be sure, but fascinating - and in the spirit of discovery, we study them. We may not know what purpose, if any, they will serve but we are in no rush to use them; they are stable, they will keep. Our mathematical cabinet of curiosities expands as, one by one, we place this motley assortment on our shelves, in the hope that one day in the future, sitting at our desk, turning over some unidentifiable phenomenon in our hands, we will hold it up to the light and find its contours eerily familiar. Perhaps there will be a moment of recognition. Perhaps we will spring to the cabinet, pull down a model from the shelves, dust it off - and see that we already have exactly what we need.