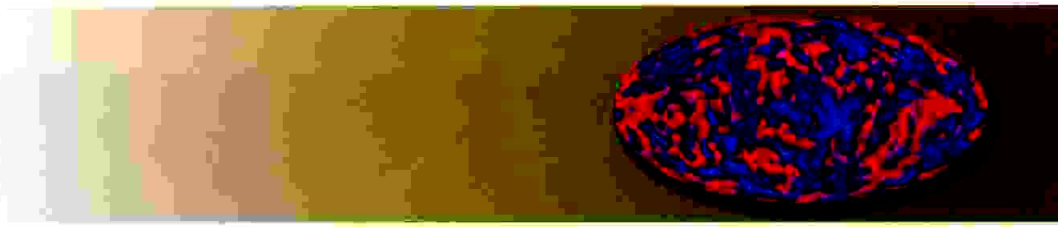

I GOT THE UNIVERSE ON A STRING

What is the mass (or size) of the strings from which the entire material world is composed? The answer may be found in the universe – the largest laboratory of all. To that end, the fundamentals of string theory must be revised to take modern cosmology into account and to find the essential connection between the potential that describes the strings, and measurements of cosmic radiation and the cosmological constant

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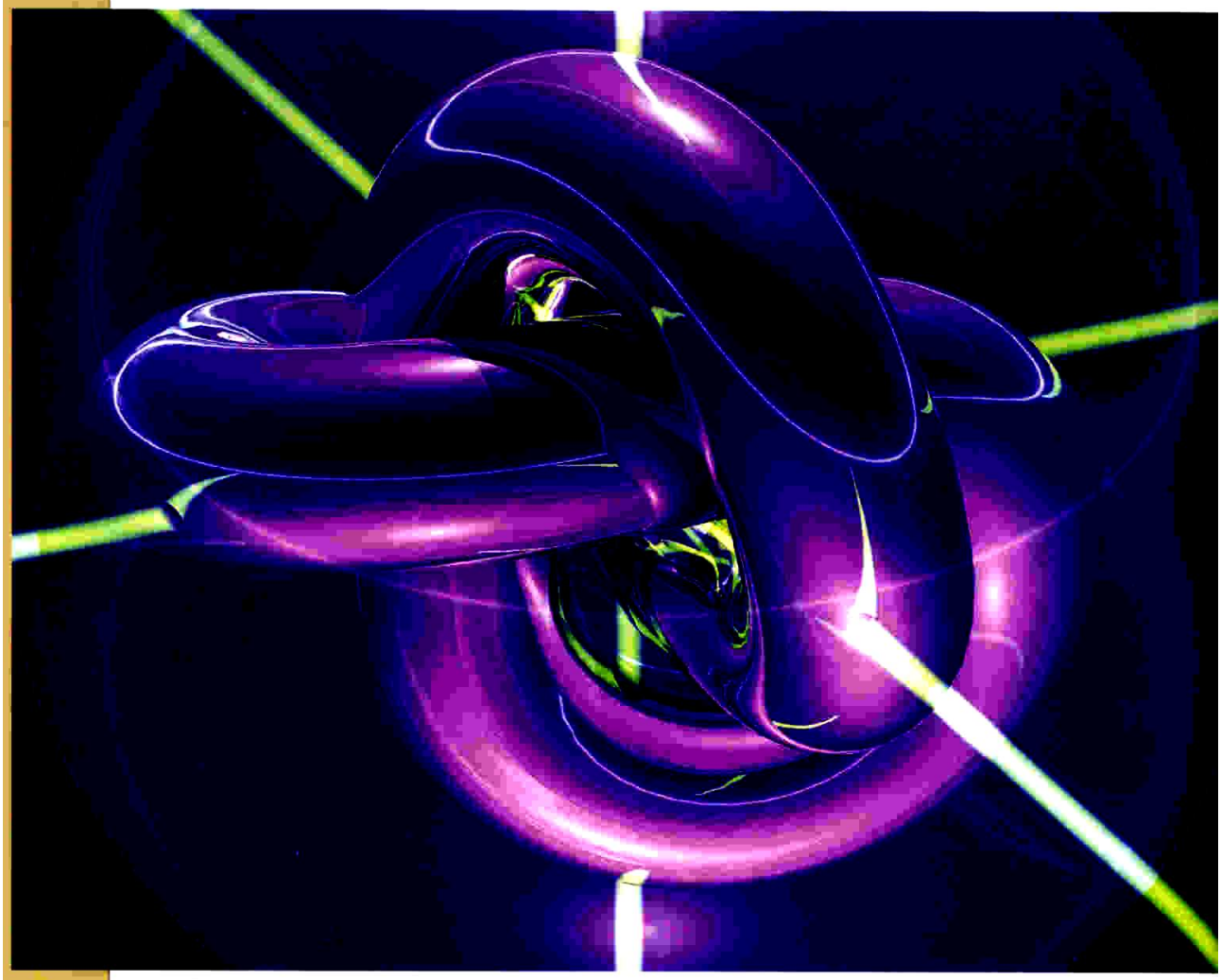
The elixir for physicists is the "Theory of Everything," which will succinctly and faithfully describe all the known aspects of the various particles found in nature, and the interaction between them. However, when this theory is formulated, how will we be able to judge its validity? How will we know whether the theory holds water, or whether it's full of mistakes and merely describes our limited knowledge of the material world around us?

The Theory of Everything

The physics of the 20th century advanced in measured steps towards its target. First, all of the familiar forces in nature were isolated – gravity, electro-magnetic force, and strong and weak nuclear forces. Simultaneously, physicists identified the various particles from which human beings, planets, stars and everything in between are made. While providing detailed identification of these objects, physicists were already trying to discover the secret links between particles and forces – which particle breaks down into which particles, which force is a manifestation in the unified group of forces.

During the 20th century, physicists succeeded in demonstrating that electro-magnetic force (which holds atoms together) and the weak nuclear force (which prevents the neutron from breaking apart) are essentially two sides of the same coin – the electro-weak force. Then, in a theory called the "Standard

Picture at top: Temperature map of the cosmic microwave background, as measured by the COBE satellite. Analysis of the temperature fluctuations may yield hints about "M-theory" (Orig. NASA)



"The super strings," by Hanazato Sugahiko, Studio Gradation, Japan

Model," physicists succeeded in setting up a lavish mathematical structure in which the strong nuclear force was added to the two united forces. Standard though it may be, this model lacked many bricks, the most important of which is the Higgs particle, which physicists in every research lab in the world are still trying to find.

But the Standard Model still leaves the force of gravity on its own, unable to be paired up with any of the other forces. Unlike the other forces, gravity determines the arena in which particles exist, and in which other forces are expressed in nature. As opposed to electrical force, for example, which is only felt by electrically charged particles, every particle in the world feels the force of gravity. However, the smaller the particles we study, the more difficult it becomes to attribute a defined physical size to them. The method for dealing with their behavior is quantum theory, not the Newtonian mechanics we prefer to use for describing falling spheres and sliding bodies.

Many attempts have been made to unify gravitational force – as described by Einstein's General Theory of Relativity – with the other three forces, but all have failed. A turning point was reached when physicists gave up on describing basic particles as point particles and began to describe them at first as string-like (one-dimensional), and then as membranes, or

manifolds, with multiple dimensions. Current string theories are described as theories that reside in an expanse comprising more dimensions than the three with which we are familiar in everyday life – x, y and z (as well as the dimension of time). Six other dimensions were enlisted in order to create what physicists call "maintaining symmetry," an approach positing that the laws of physics are also valid in other reference systems, and that all particles are simply different expressions of the same exact strings/membranes.

If we wish to represent all existing forces as projections, as reflections of a single force, it is critical that this force resides in a multi-dimensional space. To settle our daily, spatial, three-dimensional experience with the ten dimensions, we have to cast away the additional dimensions. This trick is accomplished by declaring that the additional dimensions are "compactified" – they exist in much smaller scales than the everyday scales, they are closed up, curled in on themselves, and we have no access to them. This could be likened to a thin wire that from a distance seems one-dimensional, but only from very close up can be seen to have circumference, as well: a compactified dimension.

By 1995, physicists had come up with five different string theories that met these requirements. The profusion of theories was not at all to the liking of the physics community. The inability to decide between the correctness of one theory and the miscalculations of another was a source of frustration to anyone engaged in the attempt to formulate string theory. Succor arrived when it developed that the five theories were merely different faces of a single comprehensive theory known as M-theory – whose name apparently derives from the multi-dimensional membranes that replaced the slender strings. Naturally, since the known particles are thought to be a reflection of the strings, the size of the strings themselves is smaller than the size of the particles. Scientists are still struggling to determine how small strings are. In an attempt to find the answer to this question, Brustein and de Alwis, with the assistance of the United States-Israel Binational Science Foundation (BSF), went to what seemed to be the most unexpected place, although in retrospect it turns out to have been the most appropriate choice of all.

From small to big

To try to either confirm or refute the string theories, one must find an experimentation environment that can handle much smaller particles than those tested in particle accelerators. As strange as it may sound, this arena is the largest scale laboratory known to us – cosmology – the physical doctrine that attempts to describe the entire universe. Cosmology is well suited to the examination of the new membrane theories for two reasons.

One has to do with the parallels between the particle size and energy. As one delves deeper into the basic particles of matter, additional energy is required. The intensity of the bonds between particles at the smallest scale is immense; to break a strong bond, abundant energy must be expended. This energy can be expressed, for example, in the velocity of particles, or in the agent of these velocities in aggregated particles: temperature. The higher the temperature, the greater the energy per particle; this energy can also break up the bonds between it and other particles. Since the cosmological Big Bang theory states that the universe was once much smaller and hotter than it is today, this means there was a point in time when the temperature of the universe was high enough that the strings did not yet form other elementary particles, but remained free and unbonded. If the character of the strings from that era left an impression on the form of the universe in our time, then it should be possible to search for these traces and draw conclusions from them about the character of the strings.

The second reason why cosmology can help test the validity of string theories is the large space stored within it by the universe. This space is predominantly, almost totally empty - except that "empty" in string theory (as in every other particle theory) does not necessarily mean it is empty of energy. It is very possible, according to these theories, that even a vacuum contains energy. The energy of the vacuum can be infinitesimal (as measured per unit volume), and we must therefore "gather" a very large volume until its effect can be felt.

The universe is a natural laboratory containing the large volume that is required. Since the dynamics of the universe are determined by the energy and mass contained within it, a universe in which emptiness has energy will behave and develop very differently from a universe in which emptiness has no energy. Cosmological measurements provide an indication of the way the universe is developing, determining the possible values of the energy of the vacuum (or in its cosmological name, the "cosmological constant"). As such, they pose a challenge to string theories. Any theory that purports to explain all natural phenomena will have to contend with the measured values of the cosmological constant and predict them, or at least not reject them. Nevertheless, the connection between the string theories, which are measured to explain much tinier scales than the scale of the universe, and the cosmological values that are predicted from them, is complex and not at all simple to infer.

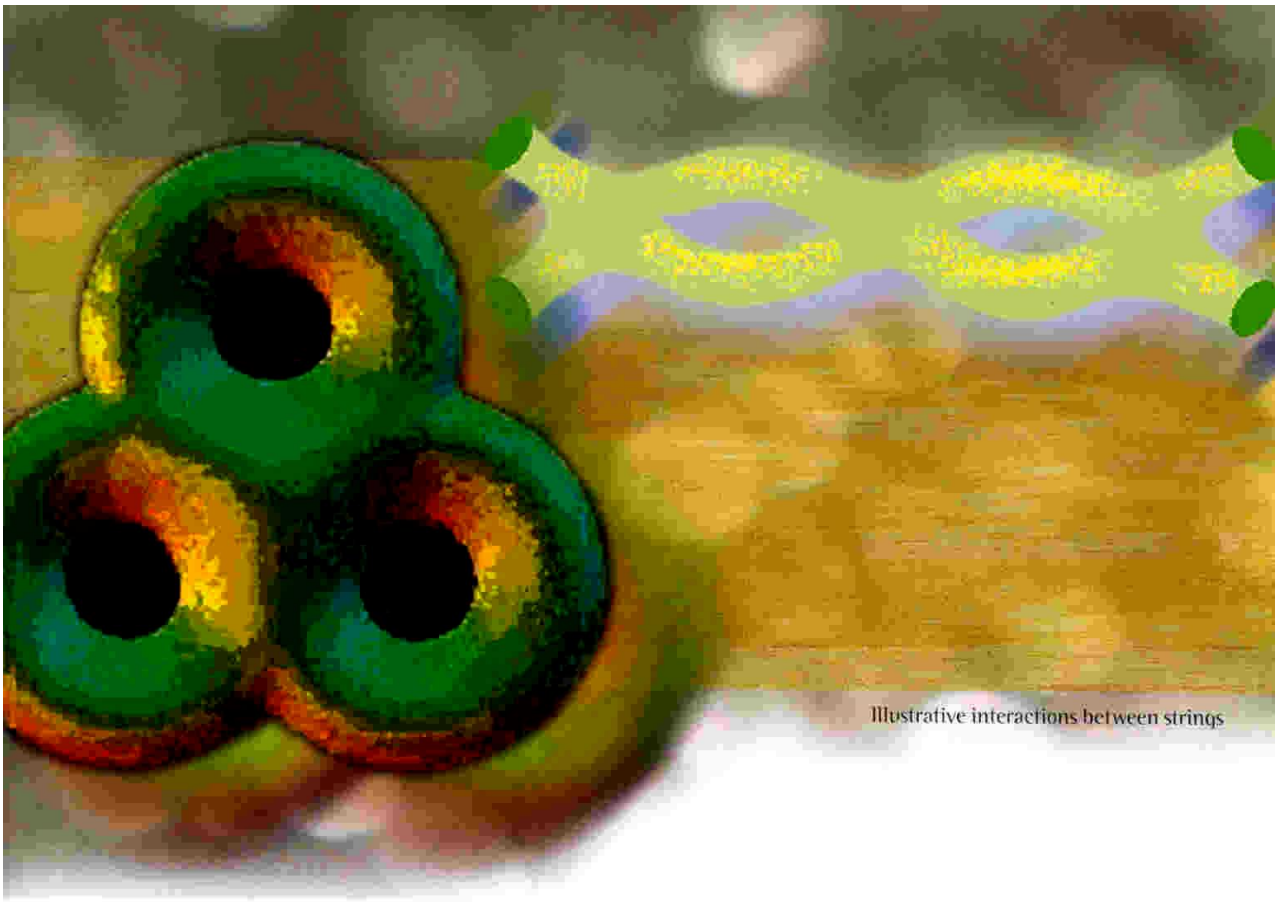
Variable constants

"We realized that to discover the hidden links between the various string theory proposals and cosmology, we first had to formulate very precisely the questions to ask," says Brustein. "Several obstacles stood in our way. The first was the proliferation of string theories (five); even though it turned out that all of them were different faces of the same theory, in order to link them to the physical world, we had to work with one of them. To sidestep this obstacle, we found a way through which we could disregard the slight variations in each string theory version, focusing only on that which is common to all of them – namely, the big picture described by M-theory. That is string universality. We have to sort them out and decide what should stay in the big picture and what is superfluous to the issues at hand."

The second obstacle faced by Brustein and de Alwis was the difference between gravity as we know it from Einstein and his General Theory of Relativity, and gravity as expressed in string theory. The Theory of Gravity must comply with a few criteria to enable physicists to accept it as reasonable. One criterion is that it will be possible to move from any reference frame to another frame that moves at a constant speed, or even accelerated relative to the first system. For this criterion to be met, the ordinary theory of gravity has to be slightly modified. From this modification, it derives that Newton's constant – the famous G that determines the strength of attraction between two massive bodies placed a constant distance from one another – ceased to be constant!

This situation is not at all desirable. After all, based on measurements, we know that the theories of Newton and Einstein accurately describe gravity, as it is found in small scale (the laboratory), in the solar system, and between galaxies and the entire universe. We are therefore hoping to find an area within string theory in which Newton's constant is indeed constant. Similar considerations lead to the same demands regarding the fine structure constant, which determines the electromagnetic force of the bond between atoms.

"We ask the following question: How can we take string theory, ignore its details, find the field theory that describes them in a general fashion, and then tailor the criteria this theory must meet so that the physical constants deriving from it are in fact constant, as required," says Brustein. "We presented the answer to this question in a series of articles."



Illustrative interactions between strings

Strings and cosmic radiation

After having precisely formulated the problem, Brustein and de Alwis moved ahead and succeeded in linking these theories to familiar, well-known events in cosmology, and more importantly, to the predictions generated by these events. The predictions can easily be contrasted with existing observed data, or data that will become available in the very near future.

How do we associate smallness of the strings to the observation of heavenly bodies?

In modern physics, the era in which the sub-atomic reality was presented as an accumulation of particles is over. Instead of describing it this way, we calculate a "field" for every point in space and time. From this field, we can calculate the chances of a particle being found at a specific time and place, when the values of all the other fields (that is, the remaining types of particles, and the interactions between them) are known.

This formulation rightly bears a certain similarity to the good old electrical field, or the gravity field. In the same way that they can be described in terms of "potential energy," so too are all existing particles, including strings, described in modern physics. Therefore, instead of asking what is the mass, or the size, of the string, or in which interactions it takes part, you may very succinctly ask, "What is the field description of the string?" In this context, any description will require a mathematical function.

In modern cosmology, you take the fields, position them in the expanding space of the universe, and ask how they will develop over time. Early on in its existence, the universe was smaller and hotter, meaning that it had higher-energy fields. Simply put, we ask how the strings behaved as the temperature of the universe dropped – into what (and at what rate) did they break down, what was the chance of finding a concentration of strings in one place and an area relatively devoid of strings in another place, and so on.

These questions about strings are not purely academic; rather, they are closely related to the continued development of structures in the universe. The universe, as it is now being revealed to us, is a reinforced reflection of the original "arrangement" of the strings. In a (large enough) place where many strings had been concentrated, we would expect to find a galaxy or a cluster of galaxies. The problem is that this reflection of the original arrangement of strings in the present arrangement of the galaxies is being increasingly blurred as time passes; after all, the galaxies around us were formed billions of years after the Big Bang. It is therefore much easier to compare the arrangement of the strings to a picture that was formed only half a million years or so after the strings ceased to be free particles. Such a picture provides a record of the cosmic background radiation in its hotter and cooler areas. The background radiation temperature is immediately translated into gravitational potential, and the potential is affected by the concentration of the strings, which explains how the ends are tied together. "For any given potential of the strings, we extrapolated what picture would result – n the sky – from cosmic background radiation," says Brustein.

In the past two decades, we have begun to receive detailed measurements of cosmic background radiation, and in the decade to come, even more accurate measurements can be expected; clearly, this is no longer a mere theory. The correlation between cosmic radiation temperatures in adjacent areas of the sky is evidence of a "spectrum of radiation" that is closely linked to the fluctuations and perturbations in the initial arrangement of the strings, that is, in their fields. As stated above, the field serves as a repository of information on the mass of the strings, and the interactions in which they take part.

The method by which the cosmological constant is linked to string theory is similar, and Brustein and de Alwis, with the support of the BSF, are now applying it, as part of the broadening of their research study. There is cosmological evidence from the astrophysics field that the cosmological constant – the energy level that can be found even in complete emptiness – is non-zero. On the other hand, various string theory versions predict a zero cosmological constant, or a constant that is much higher than its observed value. "The method we used to identify the relevant string theories that provide natural constants that are in fact constant, applies here, as well. The expanse of the various versions of string theory must be mapped out, so as to work out which of them offers the opportunity to fine tune the cosmological constant, thus making it possible to accept the observed value," says Brustein.

The linkage between string theory and cosmology may turn out to be equally effective for both sides. Cosmology will try to understand how the universe develops in its initial moments of existence, development that in large part also determines the face of the universe today. And string theory will surely be offering predictions and forecasts that can be refuted by observation or experiment. This would elevate the status of string theory, which would cease to be a mathematical stepchild in the world of physics, and ascend to full membership in the fraternity. ■

By Tsafrir Kolatt