Is the Search for Immutable Laws of Nature a Wild-Goose Chase?

Four iconoclastic thinkers are challenging the assumption of scientists from Newton to Einstein: That there is one set of laws that perfectly describe the universe for all time.

By Adam Frank | August 3, 2010 5:00 AM

The Coma cluster is about 320 million light years away and stretches 20 million light-years across. Many of its galaxies are featureless ellipticals. ("fuzz balls") | Image: NASA/ESA/Hubble Heritage Team(STSCI/AURA)

If you want to build a star, start with the rules. That is the advice I give to my Ph.D. students at the **University of Rochester**. Using advanced supercomputers and programming, we simulate the complex interplay of gravity, radiation, and magnetic fields that constitutes the life of stars like the sun. Our goal is to better understand how stars are born, grow old, and die. Fundamentally, we start with the known laws of physics and take them wherever they lead us. The implicit understanding is that nature's rules are eternal, unbreakable, and all-controlling. As **Albert Einstein** once said, learning to read the laws of physics is like reading the mind of God.

Such thinking has animated much of the enterprise of physics ever since Isaac Newton formulated his laws of universal gravitation in 1687: one set of laws for both the heavens and the earth. The idea took full root a century ago, when Einstein developed his general theory of relativity. If we work hard enough, he suggested, we will eventually find the elegant and simple rules that undergird the entire universe. Physicists have taken it as an article of faith that the bedrock laws are there to be discovered, if only we are clever enough in looking for them. The dogged pursuit of that ultimate truth has led to many great discoveries, but recently it has begun to seem like a promise unkept.

The problem is that physics appears to be leading us not to resolution but into an Alice in Wonderland world of increasingly bizarre theories, each farther removed than the last from our experience of the everyday world. In recent years cosmologists have posited that our universe is just one among an untold number of universes that bubble up constantly from quantum foam. Theoretical physicists have looked to the exotic mathematics of string theory, which suggests the existence of seven extra dimensions beyond the four we already know about. Experimentalists have built the $10 billion **Large Hadron Collider** in part to understand why we can observe only a portion of what our theories of matter predict.

If scientists have to dream up dimensions that nobody has ever seen and universes that nobody may ever find, perhaps it is a sign that we are headed down a blind alley. If we are indeed getting closer to knowing nature's immutable laws, a few renegade physicists are now asking, why does each step we take only seem to send us deeper into the rabbit hole?

The mainstream response is that this is how science works. Each answer is supposed to yield new questions. Most physicists, to be sure, are still holding out for an elegant unifying vision—the long-promised "**theory of everything**"—and they are prepared to wait the 50 years or so it might take to arrive at one. The dissenters, though, are starting to wonder about this approach. If we have to take so much on faith, aren't we behaving more like priests than like scientists? Perhaps, argue the rebels, our basic assumptions are leading us astray. Perhaps those immutable laws that we have been pursuing all these years are not so immutable after all. Could it be that we have taken for granted the existence of something fundamental, the way early scientists took for granted the existence of God?

At present, those doubters are few. The four scientists profiled here represent idiosyncratic, minority views. But perhaps it is time to listen to what they have to say. They may very well be wrong—but if they are right, it would usher in the biggest disruption in physics since an apple fell on Newton's head.

THE MAN WHO KILLED TIME

Andreas Albrecht did not start out trying to buck the system. His father had been a chemist, and Andreas first became fascinated with physics at the breakfast table. He remembers reading a high school textbook about atoms and stumbling upon an appendix on quantum theory. “I just loved the idea that there were deeper laws behind what we see,” he says. He went on to study physics at Cornell University and the University of Pennsylvania, with a particular interest in the early universe. He had no problem with physics as a quest for the immutable laws of nature—until he ran into a paradox that he calls the clock ambiguity.

In our ordinary experience, we tend to take the passage of time for granted. If we want to know how long we have been procrastinating at work, we glance up at the clock and realize an hour has gone by. In the brief succession of moments immediately following the Big Bang, however, there were no walls and no clocks to hang on them: The universe was anything but ordinary. Albrecht, now a professor of physics at the University of California at Davis, was trying to understand what was going on in the infant universe when it had existed for only a million-billion-billion-billionth of a second. To get a handle on what was happening, he needed a clock or something that could serve as one—some regularly occurring phenomenon, like water dripping from a faucet, the swinging of a pendulum, or the oscillations of a quartz crystal.

Albrecht was not doing a real experiment, of course. It would take a collider 1,200 light-years around to reproduce the conditions of these first moments of creation. Rather, what he was attempting was an extrapolation of what my students and I do when we calculate the motion of a star. We plug time into the equation and let the forces acting on the star unfold in whatever way the laws of physics say they should. Because Albrecht was interested in a time when the entire universe was compressed into a space the size of a grapefruit, he was forced to rely heavily on the equations of quantum mechanics, which rule in matters of the very small. Those equations, though, become confusing when you are trying to tell a story that unfolds in a linear way, as Albrecht was attempting to do. The equations he had written out on paper described all possible futures of the early universe in terms of the probability that any one would actually happen. Without a clock, he realized, there was no unambiguous way to come up with a single, ticktock version of how events unfolded.

To get around this problem, Albrecht tried to manipulate the equations of quantum cosmology to isolate the dimension of time. That put him in the awkward position of having to undo the unification of time and space, a key achievement of Einstein’s general relativity. Peeling time from the equations appeared to make everything else unwind, and Albrecht found his model falling apart in his hands. Each time he tried to jury-rig a clock, the equations led him to a completely different kind of universe. In one universe, protons did not exist. In others, an action on one particle would have weird effects on neighboring particles. For instance, dropping a marble on the floor might cause an explosion on the scale of a supernova.

“I called it the clock ambiguity,” Albrecht says. “Basically, different choices of a clock lead to different kinds of physics. I got entirely different kinds of universes depending on the clock I chose.”

This is not what Albrecht was expecting or hoping for. He had expected quantum cosmology to tell him exactly why the universe we live in looks the way it does. The discovery of the clock ambiguity seemed to block that path. It looked to him as if quantum cosmology would never predict the course of history through the universe because the laws determining that history could never be specified beforehand. A few physicists have challenged this radical idea, but many share their colleague's befuddlement. "What I was finding seemed crazy," he says. "It meant that the fundamental physical laws were not fundamental."

Albrecht's frustration was understandable. The clock ambiguity goes against not just the Newtonian belief in universal law, but the even more deeply held faith in law itself—in the idea that nature is guided by timeless rules that can be described in mathematical terms. "All is number," **said Pythagoras** (he of the famous triangle theorem) 2,500 years ago. Plato believed in a realm of "ideal forms." When Newton wrote a single equation that described the fall of apples and the motion of planets, he was already tapping into an ancient tradition.

That tradition was threatened early in the 20th century when physicists realized that general relativity and quantum mechanics—the two leading ways of describing the world—were in key ways incompatible with each another. The theories break down most spectacularly in the early universe, when everything was compressed into a small space. Suddenly the domains of the very small (quantum mechanics) and the very large (relativity) overlap. You need to use quantum mechanics to describe the physics, but those equations do not encompass gravity.

The quest to reconcile the quantum and relativistic worldviews has occupied physics for decades. At the moment, string theory seems to be the most promising way forward. In this vision, matter is made up of incredibly minuscule vibrating strings that exist in an 11-dimensional space-time. With this formulation, many string theorists say, it may be possible to come up with one set of laws that describe the universe from the Big Bang onward. So far, though, no single version of string theory has yielded a consistent or complete answer.

With no established map, researchers must explore the terrain in bits and pieces. It was in exploring those interstitial domains that Albrecht stumbled on his clock ambiguity, which may have uncovered a fatal flaw: Even if string theory works, it is not clear how to use it to predict the kind of universe that would unfold from its rules. And that is far from the only objection being leveled against physicists' leading effort to craft a master theory of reality.

THE SLAYERS OF STRING THEORY

Like Albrecht, and like just about every other physicist, **Lee Smolin** of the **Perimeter Institute for Theoretical Physics** in Waterloo, Ontario, started as a true believer in timeless law. In the 1980s he did some work on string theory. He also developed his own version of a multiverse in which every black hole spawns a new universe at its center. This introduced Darwinian natural selection to his idea of the cosmos: Whether or not a particular kind of universe proliferates depends on its fitness. The universes that are good at creating black holes thrive; it is no coincidence, he concluded, that we live in just such a universe.

As Smolin was developing this notion, he began to have misgivings about string theory, which has come to dominate the orthodoxy of theoretical physics. His 2006 book, **The Trouble With Physics**, was a withering attack on this orthodoxy. His big complaint about string theory is that it could lead almost anywhere. Rather than converging on a single set of laws—namely, the ones we can observe—it opens up a vast new array of untestable possibilities. This struck Smolin as a dangerous departure from experimentally falsifiable physics. If we really want to understand the basic laws of the universe, he argues, we must look for deeper explanations that do not dismiss the near-at-hand. And to do that, we might have to abandon our attachment to the idea of timeless laws.

Smolin takes particular issue with two tenets of present-day physics: the claim that time as we know it emerges from some deeper set of laws, like the quantum cosmological equations Albrecht works with, and the belief that our universe is just one of many.

The so-called **multiverse theory** of the universe arose, like string theory, as a way to explain away some uncomfortable mysteries in cosmology. The troubles began when scientists began to accept inflation, a theory developed by American physicist **Alan Guth** and his Soviet counterpart, **Andrei Linde**, in the early 1980s. Inflation holds that shortly after the Big Bang, a small shard of space-time underwent extremely rapid expansion, ultimately to become what we see around us: a universe of galaxies receding from one another. That theory opened up the possibility that other chunks of space-time went through their own inflation, creating a tremendous number of “pocket universes.”

Eventually this idea grew into what is now known as the multiverse theory, the notion that our observable universe is just one of perhaps an infinite number of cosmic domains, each with its own version of the laws of physics. In this view there is no need to explain why our universe has a particular set of physical laws, since somewhere out there exists a pocket universe for each possible set.

Smolin does not like some of the metaphysical overtones of today’s physics and cosmology, but he primarily rejects hidden dimensions in physics and multiverse approaches in cosmology for technical reasons. He sees problems, for example, in the details of quantum cosmology—the type of problems Albrecht has also encountered. These technical objections have given Smolin the uneasy feeling that there is something rotten at the core of physics.

That feeling began to take on more concrete form when he met **Roberto Mangabeira Unger**, a professor at Harvard Law School. Smolin had been invited to a conference (on art and critical theory) and was trying to decide whether to go when he saw Unger’s name on the guest list. Smolin had known of Unger’s work, and he was intrigued. A mutual friend put them in touch, and during several phone conversations about multiverses and the nature of time, they realized that they were soul mates in skepticism. A few years later, at Unger’s suggestion, Smolin organized a workshop at the Perimeter Institute called **Evolving Laws** and invited Unger to come and talk things over with the group. Now the two scholars are collaborating on a book, *The Reality of Time and the Nature of Cosmological Laws*.

As a nonscientist, Unger approaches the problem from the standpoint of philosophy. The problem with theories that include hidden dimensions and alternate universes, he says, is that they are not theories at all but allegories. There is no way to test them with any experiments or observations. String theory cannot be made to work in a world of only four dimensions. In response, string theorists posited the existence of seven extra dimensions that are hidden from us. Of course, no one has observed these extra dimensions of space, and worse, it is not clear that such an observation is possible. The equations of string theory predict that there are an unimaginable number of different possibilities for how those dimensions are configured—on the order of 10 to the 500th power. It would take more time than has so far elapsed since the Big Bang just to count them all.

The experimental basis for a multiverse theory is equally shaky. None of the other universes that crop up could ever be seen because the space between us and them would be expanding at faster-than-light speed.

Neither string theory nor the multiverse theory explain nature's mysteries so much as explain them away, Unger concludes. "When we imagine our universe to be just one out of a multitude of possible worlds, we devalue this world, the one we see, the one we should be trying to explain," he says. "The scientist should treasure the riddles he can't solve, not explain them away at the outset."

Unger and Smolin want to shift the emphasis in physics away from these possible worlds and back to the one real world—our world, which is saturated with time. They urge their colleagues to abandon the search for timeless truths like string theory.

More broadly, they argue that physics should refrain from spinning any theories that require the existence of things that could never be disproved, such as multiverses. And it should recognize that there is no ideal realm of perfect, timeless mathematical forms that embody the laws of physics. Time is inherent in the universe, and nothing exists outside of time. Smolin thinks that Albrecht's clock ambiguity is a symptom of the larger problem with the current approach to physics.

Developing equations for a new kind of physics can come later, in Smolin and Unger's view. For now they want to open a frank conversation about the rationale for looking at those equations in the first place. With only one time-saturated universe, physicists will have to revise the way they think about nature's laws. If time is real, then everything in the universe is part of time and subject to it. The essence of time is change. What we call the laws of physics may also change with time. History will have to matter, even in this hardest of all sciences.

THE AGENT OF CHANGE

Theoretical biologist **Stuart Kauffman** has the advantage of never having been indoctrinated in the physicist's way of looking at the world. As a theoretician, though, he is used to tackling big ideas. Kauffman, a MacArthur "genius award" winner, pioneered the application of complexity theory to the life sciences. He honed those ideas during a 10-year residency at the famed **Santa Fe Institute** in New Mexico and most recently as a professor of biochemistry and mathematics at the University of Vermont. In the last couple of years Kauffman has turned his attention to physics, and like Smolin he has come to believe that the laws that underpin the cosmos are far from the immutable things we thought they were. But he plunges in where even Smolin does not dare to tread.

Kauffman has no qualms about abandoning an idea that has dominated the sciences since the days of Galileo: that a set of physical laws is all that is needed to predict the unfolding of reality. The name for this idea is reductionism—the belief that the whole can be understood by the predictable behavior of the parts. It is the philosophical underpinning of the physicist's conviction that timeless, eternal laws rule the universe from the bottom up. Understand quarks, the thinking goes, and everything else follows.

"The dream of reductionism," Kauffman says, "is that when all is said and done, science will provide us with a linked set of laws that begin with particle physics and take us through life all the way to social systems." Albrecht's clock ambiguity and Smolin's critiques of string theory expose chinks in the armor of reductionism. Kauffman has come to believe that reductionism can take us just so far. Only by moving beyond it will we be able to see the universe's hidden creativity.

That creativity is essentially Darwinian. Biological evolution, in Kauffman's view, offers a powerful model for how novelty, rather than timeless laws, could play an expanded role in cosmology and physics. If the laws of the biosphere have evolved over time, why can't the laws of the universe? Just as evolution in biology favors change from the simple to the more complex, perhaps evolution has taken the universe from the relative simplicity of its early moments to the full glory of our modern universe in all its dazzling complexity.

The game of chess is another useful metaphor for understanding how physical laws might have changed. Chess has its rules, and the way most people play, those rules are fixed, much like the laws of physics are assumed to be. But chess was a different kind of game when it was first played in India in the sixth century. When Europeans adopted the game in the 15th century, they renamed the pieces and modified the rules to suit themselves. Eventually chess settled on the intricate and complex game that we know now. In a similar way, the laws of space-time may have started off one way and changed over time, until the universe settled on what we know now.

We do not see change happening now—perhaps because the universe's laws have reached a point of stasis, or perhaps because they are changing very slowly. But the idea should, in theory, be testable. It should be possible to look back into the early universe and measure changes in physical laws. We may already have glimmers of such evidence. From measurements of the radiation given off by distant quasars, scientists have surmised that "alpha," the physical constant that defines how tightly electrons are held to an atom's nucleus, may have been slightly different in the early universe. The observations are tentative, partly because scientists have not been looking for signs of changing laws. At the very least, Kauffman suggests, we should be examining this possibility much more closely.

Extending evolutionary models to physics would mean exploring the notion that physical laws may have evolved for a time and then became fixed. Or they could still be evolving now. In biology there are constraints and rules that guide the behavior of the biosphere, rules that emerge in time and in the process set the stage for the next step in evolution. "In this way the biosphere builds the way it builds itself," Kauffman says. "Perhaps the universe acts in a similar way, sorting through all different kinds of laws to give us what we see today."

Physicists tend to recoil from Kauffman's notion of a universe that emerges from countless arbitrary laws because the universe we see seems to be remarkably regular in structure and behavior. But the laws we see now may simply be the ones that allowed us to be here looking, Kauffman notes. "Remember, in evolution we only see the winners," he says. "Everything else disappears." His idea has a kinship with Smolin's notion that universes can be spawned within other universes and evolve, with certain types of physical laws coming to dominate because they are more successful in producing a complex universe.

Kauffman's reasoning may sound like **the anthropic principle**—a controversial idea in cosmology that the only possible laws of physics are the ones that allow us to be here to observe them—but the two ideas differ in a fundamental way. The anthropic principle assumes a multitude of universes, each with its own immutable laws, and states that we lucked out by being in the one fine-tuned for life. Kauffman believes there is one universe, whose laws have evolved toward the complexity that allows for life. Rather than reasoning our way back to the beginning, we have to plumb the history of our universe to figure out how it evolved, step by step, into its present form.

From Kauffman's perspective, everyone from Newton to Einstein to the latest practitioners of string theory may have all been barking up the wrong tree, and the long-sought theory of everything may be nothing more than wishful thinking. "The whole point," he says, "is that there might not be eternal laws to reason backward to."

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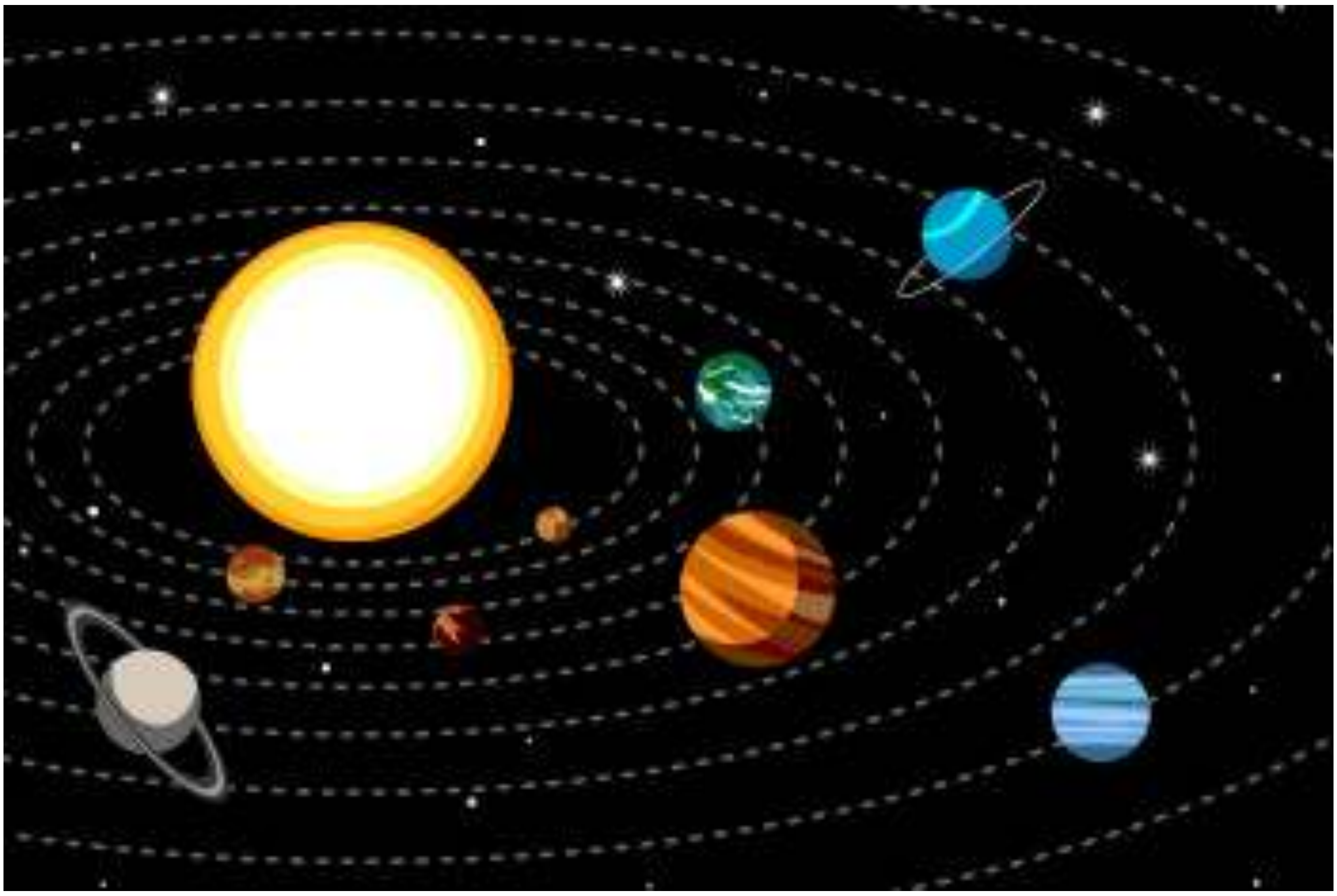

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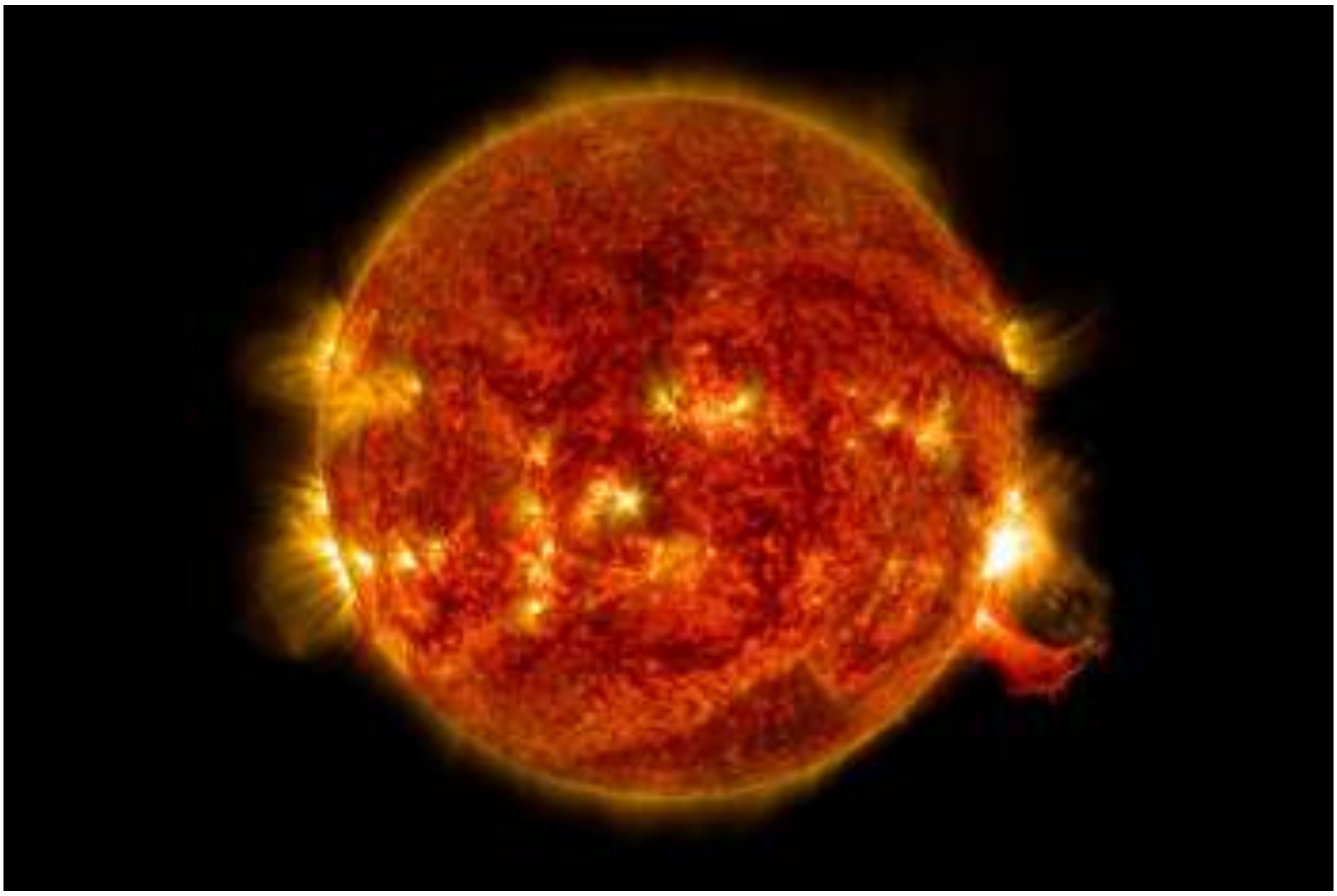

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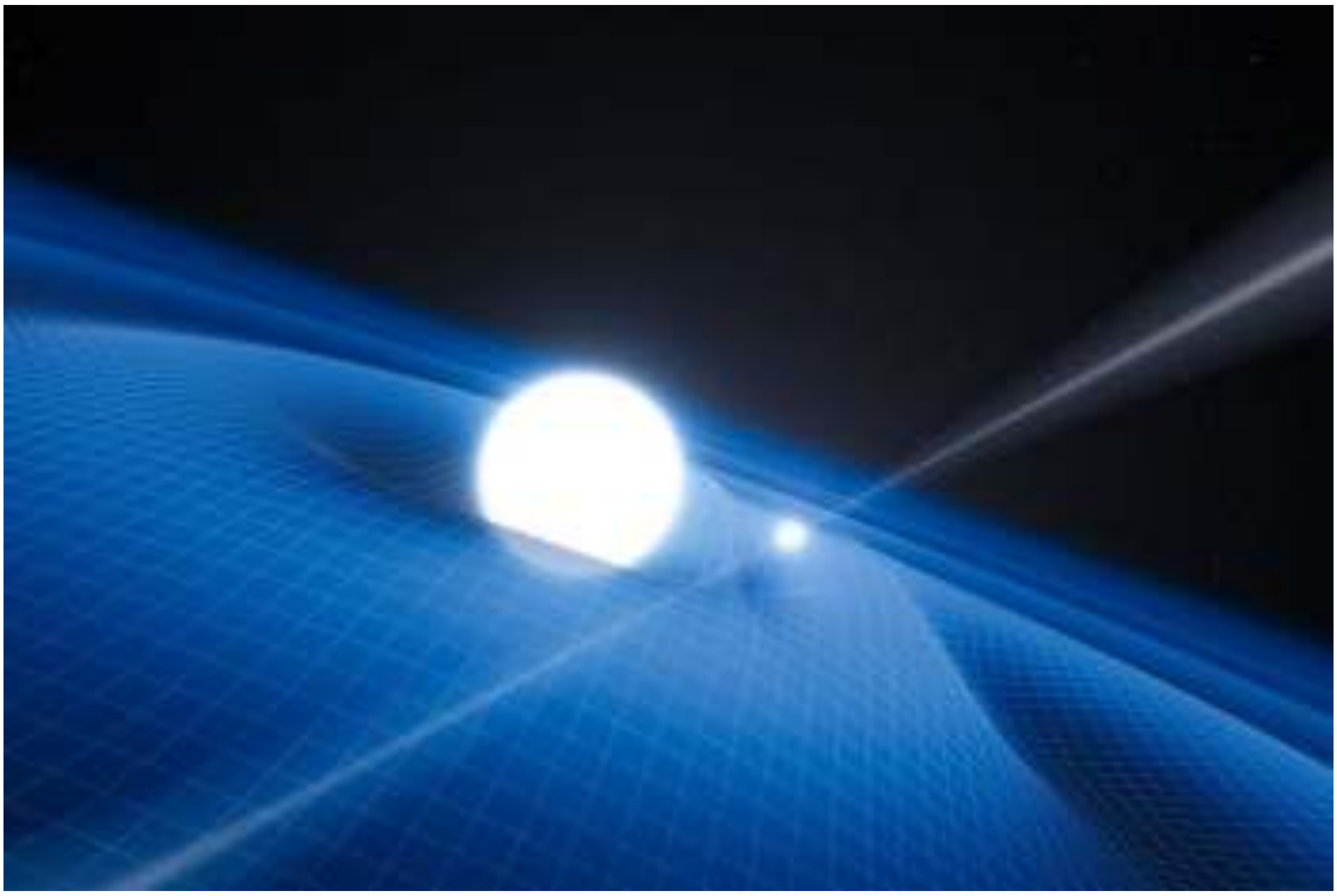

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