The 9 Biggest Unsolved Mysteries in Physics

by Natalie Wolchover | July 03, 2012 05:13pm ET

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Is there order in chaos?

Credit: Image via Shutterstock

Physicists can't exactly solve the set of equations that describes the behavior of fluids, from water to air to all other liquids and gases. In fact, it isn't known whether a general solution of the so-called Navier-Stokes equations even exists, or, if there is a solution, whether it describes fluids everywhere, or contains inherently unknowable points called singularities. As a consequence, the nature of chaos is not well understood. Physicists and mathematicians wonder, is the weather merely difficult to predict, or inherently unpredictable? Does turbulence transcend mathematical description, or does it all make sense when you tackle it with the right math?

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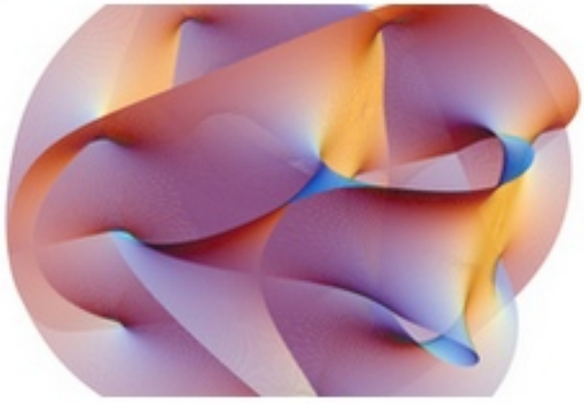

Is string theory correct?

Credit: Creative Commons | Lunch

When physicists assume all the elementary particles are actually one-dimensional loops, or "strings," each of which vibrates at a different frequency, physics gets much easier. String theory allows physicists to reconcile the laws governing particles, called quantum mechanics, with the laws governing space-time, called general relativity, and to unify the four fundamental forces of nature into a single framework. But the problem is, string theory can only work in a universe with 10 or 11 dimensions: three large spatial ones, six or seven compacted spatial ones, and a time dimension. The compacted spatial dimensions — as well as the vibrating strings themselves — are about a billionth of a trillionth of the size of an atomic nucleus. There's no conceivable way to detect anything that small, and so there's no known way to experimentally validate or invalidate string theory.

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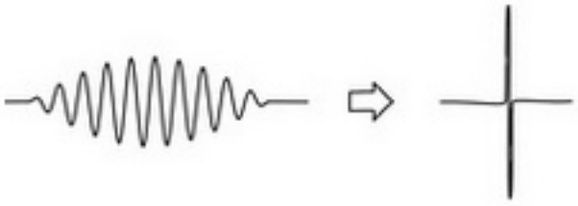

How do measurements collapse quantum wavefunctions?

Credit: John D. Norton

In the strange realm of electrons, photons and the other fundamental particles, quantum mechanics is law. Particles don't behave like tiny balls, but rather like waves that are spread over a large area. Each particle is described by a "wavefunction," or probability distribution, which tells what its location, velocity, and other properties are more likely to be, but not what those properties are. The particle actually has a range of values for all the properties, until you experimentally measure one of them — its location, for example — at which point the particle's wavefunction "collapses" and it adopts just one location. [Newborn Babies Understand Quantum Mechanics]

But how and why does measuring a particle make its wavefunction collapse, producing the concrete reality that we perceive to exist? The issue, known as the measurement problem, may seem esoteric, but our understanding of what reality is, or if it exists at all, hinges upon the answer.

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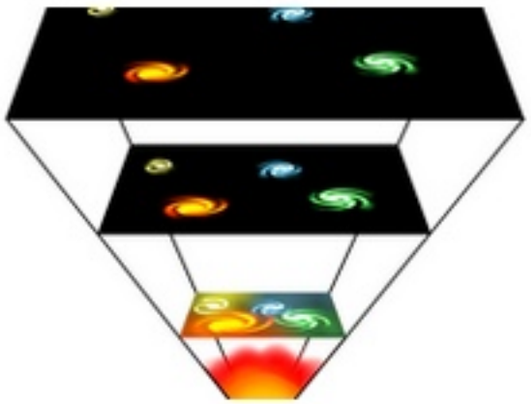

What is the fate of the universe?

Credit: Creative Commons Attribution-Share Alike 3.0 Unported | Bjarmason

The fate of the universe strongly depends on a factor of unknown value: Ω, a measure of the density of matter and energy throughout the cosmos. If Ω is greater than 1, then space-time would be "closed" like the surface of an enormous sphere. If there is no dark energy, such a universe would eventually stop expanding and would instead start contracting, eventually collapsing in on itself in an event dubbed the "Big Crunch." If the universe is closed but there *is* dark energy, the spherical universe would expand forever.

Alternatively, if Ω is less than 1, then the geometry of space would be "open" like the surface of a saddle. In this case, its ultimate fate is the "Big Freeze" followed by the "Big Rip": first, the universe's outward acceleration would tear galaxies and stars apart, leaving all matter frigid and alone. Next, the acceleration would grow so strong that it would overwhelm the effects of the forces that hold atoms together, and everything would be wrenched apart.

If Ω = 1, the universe would be flat, extending like an infinite plane in all directions. If there is no dark energy, such a planar universe would expand forever but at a continually decelerating rate, approaching a standstill. If there is dark energy, the flat universe ultimately would experience runaway expansion leading to the Big Rip.

Que sera, sera.

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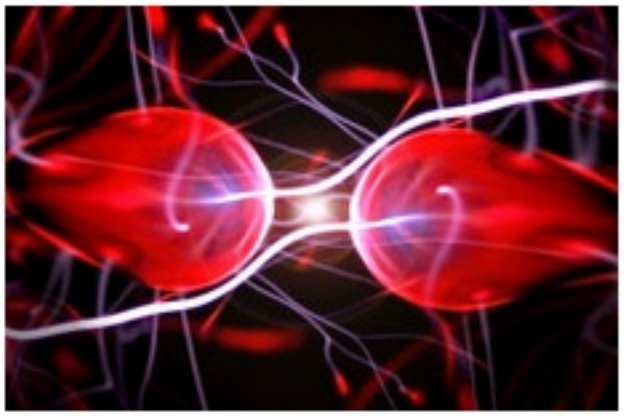

Why is there more matter than antimatter?

Credit: Image via Shutterstock

The question of why there is so much more matter than its oppositely-charged and oppositely-spinning twin, antimatter, is actually a question of why anything exists at all. One assumes the universe would treat matter and antimatter symmetrically, and thus that, at the moment of the Big Bang, equal amounts of matter and antimatter should have been produced. But if that had happened, there would have been a total annihilation of both: Protons would have canceled with antiprotons, electrons with anti-electrons (positrons), neutrons with antineutrons, and so on, leaving behind a dull sea of photons in a matterless expanse. For some reason, there was excess matter that didn't get annihilated, and here we are. For this, there is no accepted explanation.

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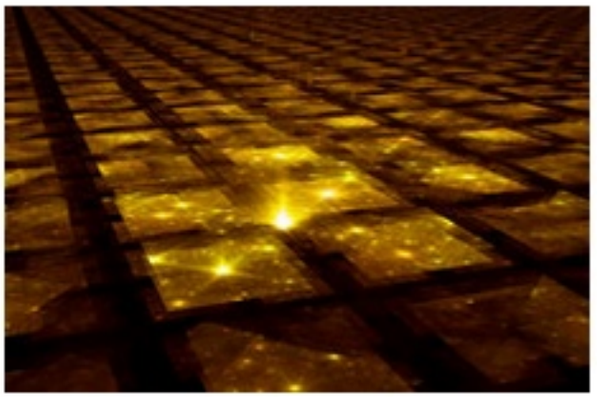

Are there parallel universes?

Credit: Image via Shutterstock

Astrophysical data suggests space-time might be "flat," rather than curved, and thus that it goes on forever. If so, then the region we can see (which we think of as "the universe") is just one patch in an infinitely large "quilted multiverse." At the same time, the laws of quantum mechanics dictate that there are only a finite number of possible particle configurations within each cosmic patch (10^10^122 distinct possibilities). So, with an infinite number of cosmic patches, the particle arrangements within them are forced to repeat — infinitely many times over. This means there are infinitely many parallel universes: cosmic patches exactly the same as ours (containing someone exactly like you), as well as patches that differ by just one particle's position, patches that differ by two particles' positions, and so on down to patches that are totally different from ours.

Is there something wrong with that logic, or is its bizarre outcome true? And if it is true, how might we ever detect the presence of parallel universes?

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Why is there an arrow of time?

Credit: Image via Shutterstock

Time moves forward because a property of the universe called "entropy," roughly defined as the level of disorder, only increases, and so there is no way to reverse a rise in entropy after it has occurred. The fact that entropy increases is a matter of logic: There are more disordered arrangements of particles than there are ordered arrangements, and so as things change, they tend to fall into disarray. But the underlying question here is, why was entropy so low in the past? Put differently, why was the universe so ordered at its beginning, when a huge amount of energy was crammed together in a small amount of space? [What's the Total Energy in the Universe?]

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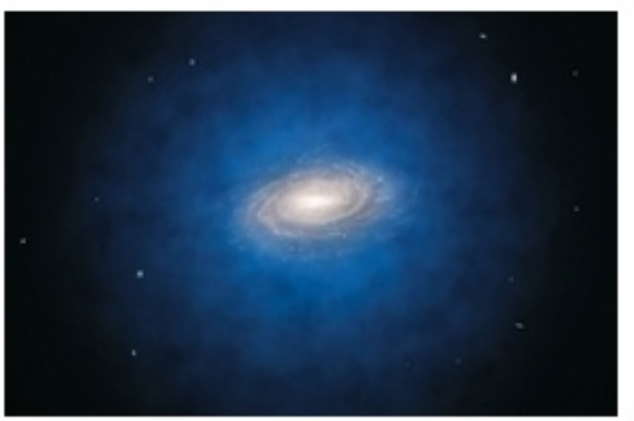

What is dark matter?

Credit: ESO/L. Calçada

Evidently, about 84 percent of the matter in the universe does not absorb or emit light. "Dark matter," as it is called, cannot be seen directly, and it hasn't yet been detected by indirect means, either. Instead, dark matter's existence and properties are inferred from its gravitational effects on visible matter, radiation and the structure of the universe. This shadowy substance is thought to pervade the outskirts of galaxies, and may be composed of "weakly interacting massive particles," or WIMPs. Worldwide, there are several detectors on the lookout for WIMPs, but so far, not one has been found. [If Not Dark Matter, then What?]

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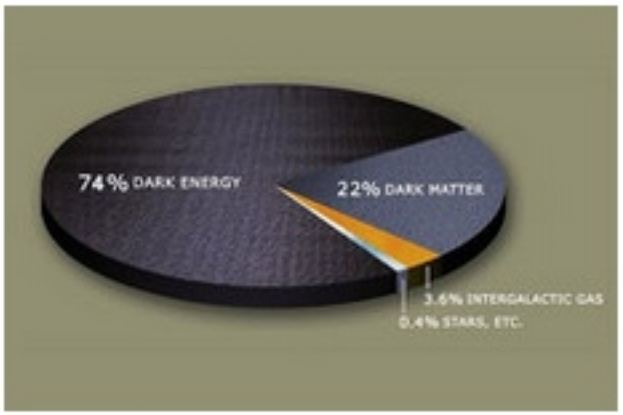

What is dark energy?

Credit: NASA

No matter how astrophysicists crunch the numbers, the universe simply doesn't add up. Even though gravity is pulling inward on space-time — the "fabric" of the cosmos — it keeps expanding outward faster and faster. To account for this, astrophysicists have proposed an invisible agent that counteracts gravity by pushing space-time apart. They call it dark energy. In the most widely accepted model of dark energy, it is a "cosmological constant": an inherent property of space itself, which has "negative pressure" driving space apart. As space expands, more space is created, and with it, more dark energy. Based on the observed rate of expansion, scientists know that the sum of all the dark energy must make up more than 70 percent of the total contents of the universe. But no one knows how to look for it.

If you hold up a grain of sand,
the patch of sky it covers
contains about 10,000 galaxies.