Spinning Einstein

If we want a theory of everything, we might have to break a few rules, says **Amanda Gefter**

IT'S not every day that respectable scientists challenge Einstein. But that's what Nobel prizewinner Sheldon Glashow and his colleague Andrew Cohen, both of Boston University in Massachusetts, have dared to do. They believe it is time to rewrite the rules of Einstein's special theory of relativity, our best description of the nature of space and time for over a century.

They call their theory very special relativity, or VSR. If Glashow and Cohen are

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and changes in velocity. If you were conducting a physics experiment, and your laboratory flipped upside down or began moving at a different speed, the fundamental laws of nature would not change, thanks to Lorentz symmetry.

Add to the Lorentz group the symmetry of space-time translations – meaning that you

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Glashow and Cohen realis
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Einstein's theory of spe
revolutionised our concep

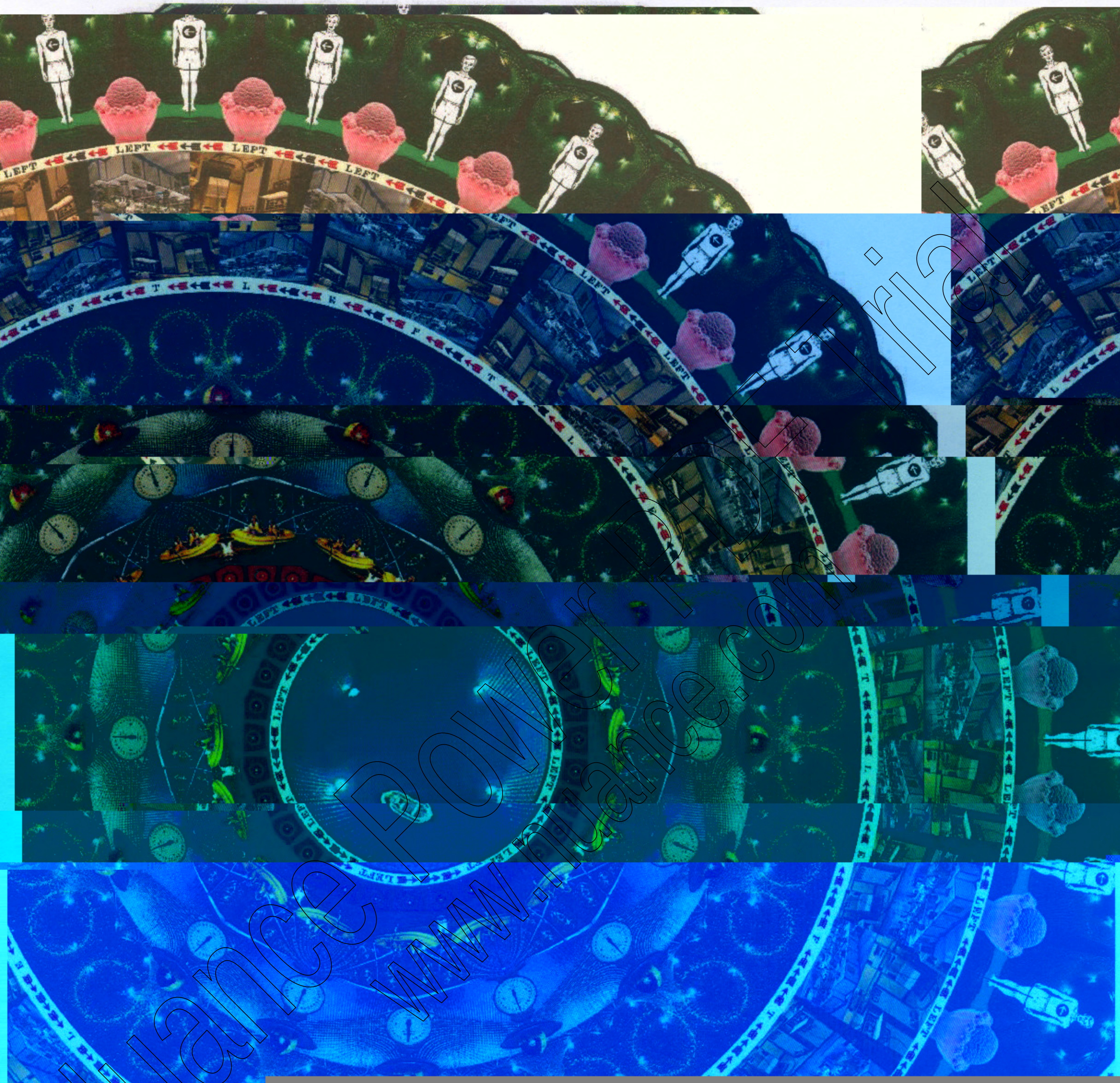
time by exposing the symmetries that underlie the reality we see around us. Symmetries are those aspects of the world that do not change when we view them from different perspectives. No matter how we rotate a circle, for instance, its geometry always looks the same, so we can say that a circle has 360-degree rotational symmetry.

Einstein began with two basic postulates from which the special theory of relativity

it implies: the speed of light remains the same no matter how fast the light source is moving, time slows and distances contract at near-light speeds, energy and mass are interchangeable, and events that appear simultaneous to one observer do not to another.

Today, however, many physicists wonder whether Lorentz symmetry is a true ▶

"Very special relativity... could tell us that space-time treats some directions differently"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symmetry, or if in fact it might be broken at extremely small distances or enormously high energies. They are motivated by the search for a theory of everything, something that can unite the seemingly incompatible theories of quantum mechanics – which describes the behaviour of subatomic particles – and general relativity, Einstein's extension of the theory to include gravity.

Various approaches to creating such a theory of everything have all suggested that Lorentz symmetry might be broken at the so-called Planck scale, around 10^{-35} metres, where both quantum mechanics and gravity come into play. Two such theories, string theory and loop quantum gravity, hint towards broken Lorentz symmetry. Another approach called non-commutative geometry explicitly ... for it. "If Lorentz violations are discovered they would provide an experimental handle on the underlying unified theory combining gravity and quantum physics – a handle that is sorely lacking to date," says Alan Kostelecký, a physicist at Indiana University in Bloomington.

Dozens of experiments looking for signs of broken Lorentz symmetry have been carried out. Not one has found any. That doesn't mean Lorentz symmetry is safe and sound, though. It just means that experiments have not been sensitive enough so far, or that physicists are looking in the wrong place.

Until now, physicists have searched for violations of Lorentz symmetry by picking away at well-tested consequences of special relativity such as the slowing of time or the constancy of the speed of light, which has led to experiments with light streaming in different directions or clocks flying at daredevil speeds.

Glashow and Cohen, however, have found a way to break Lorentz symmetry without disturbing any of those cherished relativistic effects. They modified the special theory of relativity to reduce the amount of symmetry and so formulated very special relativity.

In this new theory, Lorentz symmetry is not fully intact, yet the key effects of special relativity remain unaffected. "People are shocked," says Cohen. "I don't believe anyone ever contemplated that there could be Lorentz violation while one of the basic ideas of special relativity, the constancy of the speed of light, could still be preserved."

What is lost in VSR, however, is the full ... direction. But that's merely circumstantial – the underlying laws of physics see every direction as equal. Or so we thought. Cohen and Glashow are suggesting that maybe, even in the absence of a planet or anything else, space-time itself treats some directions differently from others.

According to VSR, the break in rotational symmetry should be extremely small and therefore unnoticeable at everyday scales. That's why, if such asymmetry exists, it has gone undetected for so long. "Rotational invariance is one of the additional postulates included in special relativity," Cohen says, "because people just have this intrinsic prejudice for it. What we said is, if you give up rotational invariance, there are these other possibilities." In other words, accept that space-time is even more counter-intuitive than we thought, and you might get a little closer to a theory of everything.

Although we have tested rotational invariance to a very high degree of accuracy, there is still wiggle room. "What's surprising is that if you give it up, these other possibilities nevertheless look very nearly rotationally invariant – just not exactly," Cohen says.

So at how small a scale would we find VSR's Lorentz violation? The answer lies with the neutrinos that are sailing through your body. Those ethereal little ghosts are hardly of this world, interacting with matter only through gravity, which barely notices them, and the so-called weak force, which exerts itself only in the cores of atomic nuclei. They are the least understood particles in the otherwise explicit framework of the standard model, our best description of the building blocks of matter and the forces that glue them together. Now, however, new explanations of the strange qualities of neutrinos are paving the way toward a deeper comprehension of the universe than the standard model offers.

Spinning neutrinos

It has been eight years since physicists first found conclusive evidence that neutrinos have mass, contrary to the predictions of the standard model. The 1998 discovery was made in Super-Kamiokande, a neutrino observatory located 1 kilometre below ground in a mine in Kamiokande, Japan. Neutrinos come in three distinct types or "flavours", but the Super-K experiment found that they were morphing from one flavour into another as they fell from the sky. It was as if you ordered a scoop of chocolate ice cream that transformed into strawberry on its way toward your lips and settled into vanilla upon your tongue.

The laws of quantum mechanics dictate that only particles with mass can change from one flavour to another. And so neutrinos, it seemed, must have a mass, albeit an incredibly tiny amount: a neutrino seems to be 100,000 million times lighter than a proton. The discovery was the first glimpse of physics beyond the standard model.

Physicists, however, still have no idea how neutrinos acquire mass. It is the way that neutrinos spin that is so puzzling. Researchers have observed that some particles are "ambidextrous" – they can spin either to the right or to the left – while others are strictly one-handed.

One-way universe

Every neutrino ever observed has been left-handed. Yet only massless particles can be one-handed, and here's why. Imagine you are watching a particle travelling along and spinning to the left. You start running and soon you are running faster than the particle. As you sprint ahead of it, you look over your shoulder and see the particle spinning the other way round (see Graphic).

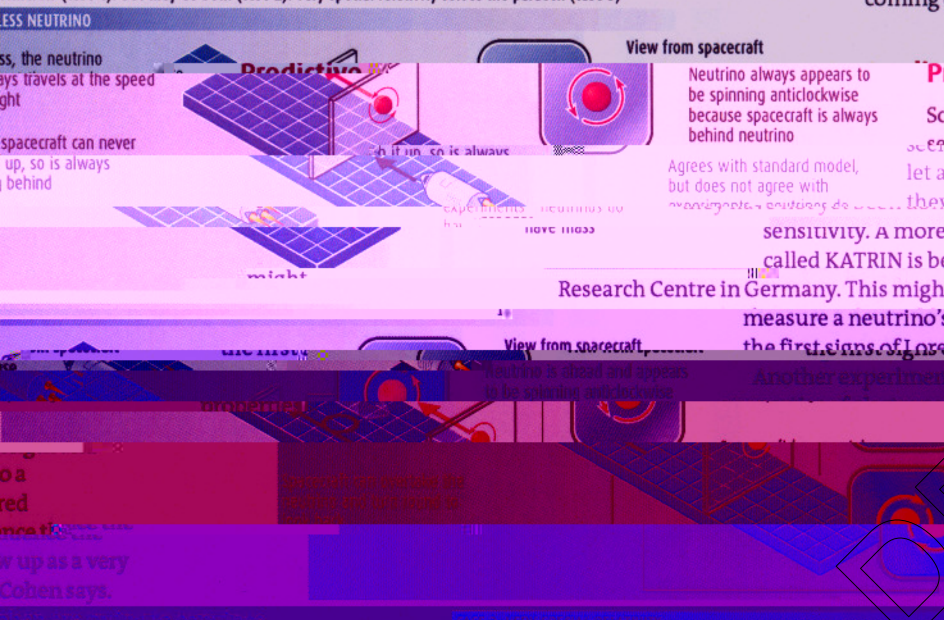
In other words, for any particle that spins to the left, there is some reference frame from which a faster-moving observer can look back and see the particle spinning to the right, making it ambidextrous. That is, unless the particle is moving at the speed of light, the ...

"Evidence for very special relativity may be right in front of your nose, or more accurately, passing right through it"

number of electrons versus energy. "You get a slightly different spectrum of the electrons coming out," says Cohen.

NEUTRINO PARADOX

According to standard theory, neutrinos cannot have mass and always spin in the same sense relative to their direction of travel, like a corkscrew (case 1). But they do both (case 2). Very special relativity solves the paradox (case 3)



Predictive power

So far, tritium decay experiments have not seen any evidence of a neutrino's mass, let alone VSR. However, Cohen points out that they have not yet been done at the necessary sensitivity. A more sensitive experiment called KATRIN is being built at the Karlsruhe Research Centre in Germany. This might measure a neutrino's mass and possibly spot the first signs of Lorentz violation.

Another experiment involves looking at properties of electrons such as the magnetic dipole moment, a measure of the strength and direction of the electron's response to a magnetic field. "If space has a preferred direction, as VSR claims, it will influence the electron in a way that should show up as a very peculiar time-dependent effect," Cohen says.

... the electromagnetic interaction (*New Scientist*, ...

... to determine whether it is possible to ... the electron's magnetic moment with ... sensitivity to look for the VSR effect. If it is, Glashow and Cohen's theory could be put to the test within a few years.

massless. Yet the Super-K results clearly showed that neutrinos have mass. How can a

proposed for the origin of neutrino mass. "They don't invoke ...

If VSR turns out to be right, it will mark a