Can long-range forces can be mediated by continuous spin particles?

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Perimeter researchers Natalia Toro and Philip Schuster are investigating whether long-range forces can be mediated by continuous spin particles. They've found more than they bargained for.

Perimeter Faculty members Philip Schuster and Natalia Toro ventured down a dark alley expecting to reach a dead end.

Instead, they found a wide-open field.

The figurative dark alley was the study of continuous spin particles – a study Schuster and Toro believed was headed nowhere. "Our goal in the beginning was to prove that continuous spin particles don't make sense," says Toro.

"We wanted to write a paper entitled 'We Can Stop Thinking About Continuous Spin,'" adds Schuster. "We tried, but so far we've failed." What they discovered, in fact, made them think it's time to start taking continuous spin more seriously.

Continuous spin particles require a bit of backstory. There are four known forces in nature. Two, the weak nuclear force and the strong nuclear force, work only over very short distances – we mostly see them inside atomic nuclei. The other two forces, electromagnetism and gravity, can reach across galaxies. This is because they're mediated by massless particles – the photon for electromagnetism, the as-yet-unobserved graviton for gravity.

Photons and gravitons (and many other particles) have an intrinsic quality called spin. It's an imperfect analogy, but you can think of spin as nature's smallest bar magnet: it gives the particles something like a north and a south pole, which can point in any direction.

In 1939, Eugene Wigner identified two distinct types of massless particle: those whose spin points straight along their direction of motion and those whose spin can be misaligned. When spin is aligned with momentum, it is also called helicity. Spin can have various magnitudes, and so helicity can too: particles can be helicity-1, helicity-2, helicity-3, and so on. They cannot be helicity-⅓ (for instance) because helicity is quantized.

The interesting bit is that the nature of forces mediated by massless particles is determined by the helicity of those particles. For instance, the fact that electric charges also feel magnetic forces falls naturally out of modelling it with helicity-1 particles. Gravity, meanwhile, is modelled using helicity-2, which predicts certain properties of gravity.

In the 1960s, Steven Weinberg showed that particles with higher helicities (helicity-3 and up) cannot mediate forces. Weinberg's work, however, left open the possibility that continuous spin particles could also mediate long-range forces.

So what are continuous spin particles? You can think of them either as particles whose spin is misaligned or particles whose helicity can have any (quantized) magnitude. These two approaches to continuous spin particles are mathematically related, but let's consider the second one for now.

Photons are now modelled as if they were all helicity-1. If photons were in fact continuous spin particles, then most would be helicity-1, but some would be helicity-2, and more rarely helicity-3, and -4, etc. These states would mix.

"Continuous spin is a terrible name for particles like that," says Schuster. "But we seem to be stuck with it." Researchers call them CSPs for short.

The possibility that CSPs could mediate long-range forces, while technically open, has never seemed very likely. Having these extra possibilities – these helicity-2 and -3 and -4 and -5 photons and gravitons – was thought to introduce all kinds of problems. Scattering amplitudes (the basic quantities that predict what happens when two particles interact) would diverge, giving nonsensical predictions. Stray high-helicity photons would carry off heat, causing hot things, including the sun, to cool rapidly. Since we don't observe such effects, it's been widely assumed that CSPs don't mediate long-range forces.

However well-founded an assumption that appears, though, it's still an assumption. Testing that assumption – peering into that dark alleyway – is where Toro and Schuster come in.

Starting from scratch – using only Lorentz invariance and unitarity as inputs – the pair began to develop a model of long-range forces mediated by CSPs. They hoped to quickly prove that CSPs made no sense as force carriers. Instead, the model began to produce results that, in Schuster's words, "felt like a series of miracles."

The scattering amplitudes turned out not only to exist, but to produce sensible predictions. The foreseen problems with thermodynamics didn't materialize. The new model began producing predictions that looked a lot like the physics we know, with only a few small differences.

These are initial results and they can only be applied to particular types of reactions involving CSPs. Toro and Schuster are working on developing a theory that would let them predict the results of any process involving CSPs.

"That's such a big step into the dark that it might turn up new inconsistencies," says Toro. "But if the similarity with known physics persists in this wider setting, it will raise an exciting possibility – that forces we think we understand might actually be mediated by continuous spin particles."

This would be a true breakthrough in our understanding of long-range forces. For instance, Toro and Schuster's research shows that if gravity were mediated by a continuous spin graviton, it would get weaker at large distances. Gravity, of course, is already weaker at large distances – two masses that are far apart feel less gravitational attraction than two that are close together. But a CSP model for gravity predicts that this effect would be more pronounced, and that the gravitational force would weaken faster than the famous inverse square law (1/r2) predicts.

This is a theory in its infancy and, like any infant, it's been challenging. But Toro and Schuster are pushing ahead. Schuster is passionate as he explains why: "The basic point is that the behaviour of long-range forces is determined by the spin of the particles that mediate them. There are solid theoretical descriptions for most possible spins, but we are only now scratching the surface for CSPs." It's a gap he's determined to fill.

"CSPs are the only potential force mediator that's not understood – and understanding things like that is written into our job descriptions as physicists. It's on line one."

More information: Read "A Gauge Field Theory of Continuous Spin Particles" on arXiv: arxiv.org/pdf/1302.3225.pdf

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