# Making Waves with Gravity

Xiao-Gang Wen thinks it's time physicists look outside of Schrödinger's Box for ways to unify gravity and quantum mechanics.

**by JEFF KANIPE**

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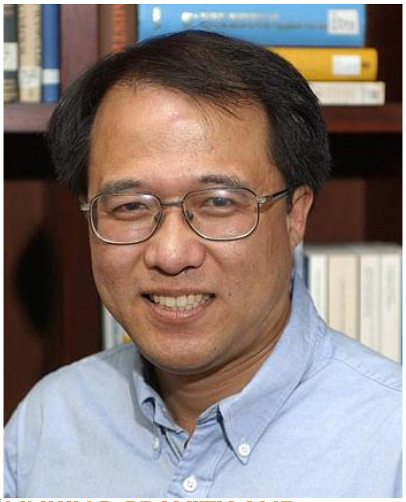
The realms of the very small and the very large are indisputably bound. Scientists know that both realities exist because galaxies, stars, and people can be reduced to molecules, atoms, and quarks.



**LINKING GRAVITY AND QUANTUM MECHANICS** **Xiao-Gang-Wen**

The problem is that somewhere at the extreme end of the microscopic level, the two realms not only go their separate ways, but also act as if the other doesn't exist. In the sub-microscopic domain — smaller than atoms — quantum theory is very successful at describing the behaviors and properties of atoms and elementary particles, but only when the law of gravity is ignored. At the very largest, or macroscopic, scales, gravity is very successful at describing the motions of planets, stars, and galaxies, but only if the principles governing the quantum world are assumed not to exist.

A unified framework is needed to include these two disparate realms, says Xiao-Gang Wen, a physicist at MIT. That is what he hopes to discover with his research project, "Microscopic Origin of Gravity and Light," sponsored by a grant worth $94,924 from The Foundational Questions Institute.

## Wave Machine

In simple terms, light – a sub-microscopic form of radiation – helps us visualize our world, while gravity – a macroscopic attractive force – keeps our world spinning around the Sun. But physicists note that light and gravity share an important quality: both can be represented as wave phenomena (at least theoretically for gravity). But what media gives rise to light and gravitational waves? In other words, muses Wen, what is waving?

In earlier work with Michael Levin, now a postdoctoral researcher in condensed matter theory at Harvard, Wen proposed that space might be formed by micro degrees of freedoms, like a magnet formed by quantum spins. With this picture of space, Levin and Wen described a unified understanding of light and electrons as the collective motions of properly organized "spins" forming the space. Wen now plans to do something similar for gravity, despite a formidable challenge: Einstein's General Theory of Relativity.

General Relativity reveals a definite link between gravity and light, indicating that, like light, gravity can also be in a wave form. In particular, both light waves and gravitational waves belong to a particular class of waves described by so-called "gauge theories." However, "despite our success in understanding light as collective motions of properly organized spins," says Wen, "we still do not know which organization of spins gives rise to gravitational waves. I hope to find a quantum spin model, similar to that of a magnet, where the wave-like collective modes satisfy the Einstein Equation and give rise to gravitons."

If such a spin system can be found, it would allow physicists to gain a deeper understanding of both gravity and light.

## Surfer Dude

Wen has long been noted for his research accomplishments and ability to question everything that everyone else accepts as fundamental. "He is a remarkably creative physicist whose ideas are so innovative that it typically takes 10 years before they are appreciated and understood by his colleagues," says Levin.

For instance, in 1989, Wen pointed out that spins in a spin liquid have a new kind of organization dubbed topological order, which opened a new field in condensed matter physics, Wen's specialty. In 2002, Wen introduced a mathematical notion, called projective symmetry group, to describe a novel class of even more general spin organizations known as quantum orders. And in 2005, Wen and Levin developed "string-net" theory for the new spin organizations, which unifies light and electrons. This theory can also be applied to his new project for FQXi.

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>
> *- Xiao-Gang-Wen*

One of the most basic and long-standing assumptions physicists make is that matter is best understood by subdividing it into smaller bits. However, Wen says this approach may be fundamentally flawed because it assumes that the vacuum of space is empty, and that particles placed in the vacuum are always divisible. Instead, matter and empty space may be two aspects of the same thing. Elementary particles may in fact arise from the collective behavior of some deeper structure that forms the space.

For example, according to quantum theory, sound waves propagating inside a crystal behave like particles called phonons. These particles cannot be understood by dividing them into smaller parts because phonons, as sound waves, arise from the collective motions of the atoms that form the entire crystal. In other words, phonons have no smaller parts.

Similarly, says Wen, photons and electrons may not be elementary at all but rather arise from the collective motions of degrees of freedom that form the space. Looked at this way, the vacuum is not a void but a dynamical medium formed by "spins" (or "qbits"). The collective motions of "spins" can give rise to both force-carrying elementary particles (such as photons, gluons, and the W and Z particles) and matter-forming elementary particles (such as electrons and quarks).

## String Nets

Supporting this notion is Wen and Levin's work, conducted in 2004, which described how spins should organize so that their collective motions behave like electromagnetic waves (light). The proper organization is called a "string-net liquid," where spin orientations form a pattern that looks like networks of strings that fill the entire space.

Such string-nets can fluctuate randomly to form a string-net liquid. (See http://dao.mit.edu/~wen/stringnet.html for a picture of a string-net.) This special organization satisfies the Maxwell Equations and behaves like a light wave.

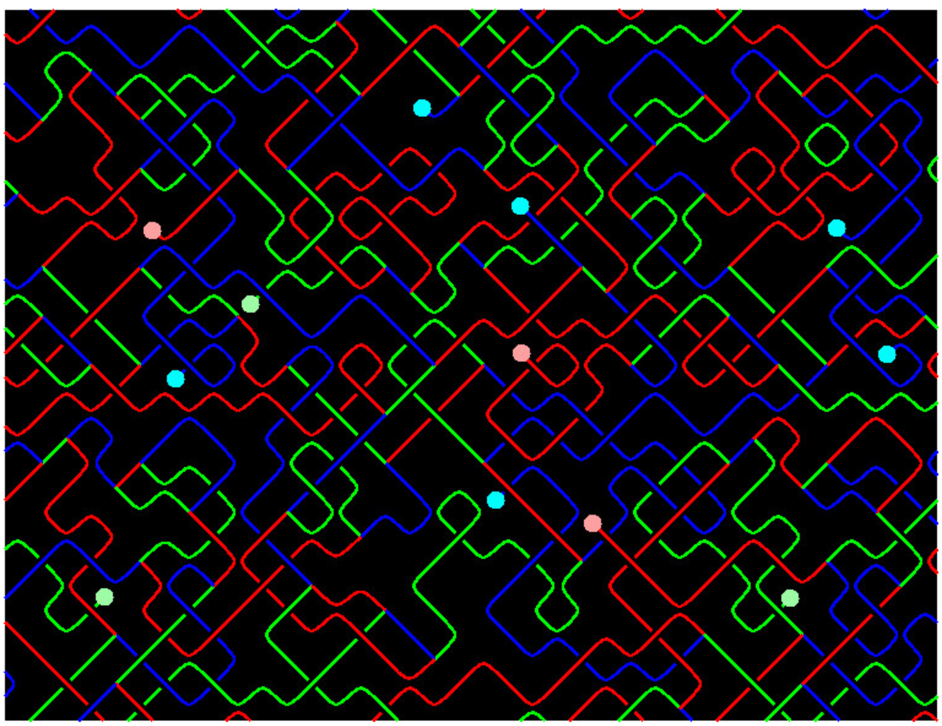
Normally, as the temperature decreases in a ferromagnetic material, spin orientations will eventually stop fluctuating, and point to a fixed direction. The waves in such organized spins satisfy a different equation, the Euler Equation, and do not correspond to light waves. However, if spins interact with each other in a certain way, even at temperatures approaching absolute zero, spin orientations can still fluctuate in a well-coordinated manner to form a string-net liquid. Materials with such spin interactions will contain waves that satisfy the Maxwell Equations and behave exactly like light.

Furthermore, string-net theory not only provides an origin of light, it also provides an origin of electrons. It turns out that in a string-net liquid, a single end of an open string moves around freely and behaves like an independent particle: that is, an electron. It interacts with light like an electron and even carries the Fermi statistics of electrons.

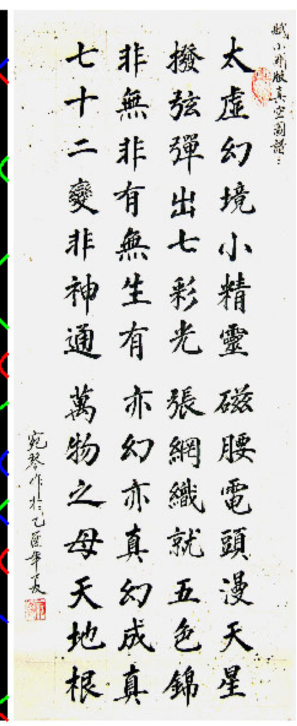
Other fermions (i.e., matter particles such as quarks) and other force-carrying particles (such as gluons) can arise in a similar fashion from different string-nets formed by different spins. So, string-net theory unifies light with electrons, or more generally, interactions with matter.

Still, gravity is not in this picture. With his new research project, says Wen, "we want to find a new organization of spins, something similar to but beyond the string-net organizations, that produces gravitational waves. If successful, the spin system will correspond to a quantum theory of gravity, thus solving the problem of linking gravity and quantum mechanics."

Wave on, string nets.



A picture of our vacuum




A string–net theory of light and electrons

**A PICTURE OF OUR VACUUM A string - net theory of Light and electrons.**