In the Key of Symmetry

When it comes to the smallest scales, perhaps things aren't as smooth as they seem. John Donoghue seeks a new tune in the key of symmetry.

fq(x) News

by MIKE PERRICONE

FQXi Awardee: John Donoghue, University of Massachusetts, Amherst — November 2, 2007

John Donoghue's Irish-American heritage seeps into many corners of his life. Donoghue attended Notre Dame University, as did his son, father and two uncles – including Uncle Dick, a 1929 All-American under legendary football coach Knute Rockne.

Donoghue also plays guitar, lute, and tenor banjo in Tir Na Nog, a six-member band of Celtic-style musicians around Amherst, Massachusetts. Music, Donoghue says, offers a break from his research on theoretical physics at the University of Massachusetts, as well as a unique perspective.

"I see many others with such clear talent in music, compared to my very pedestrian abilities in this area," he says. "Music has taught me about the special and individual nature of talent."

While his musical talent may be modest, Donoghue's professional talent is not. Yale University theorist Thomas Appelquist says Donoghue has the skills and knowledge necessary to rethink the physical concept of symmetry. "It's important that some people continue to tackle very difficult and off-the-beaten-track problems," as Donoghue is doing, says Appelquist.

For when it comes to the timeworn physical concept of symmetry, Donoghue would like to play a new tune on the old banjo.

Symmetry Emerges

In physics, the long-established concept of symmetry requires that the same rules apply throughout a system, all the time, to all components, under any given condition. A circle is a perfect example. It has no inherent "up" or "down," and rotating it will cause no changes. Nothing about a circle, and no operation performed on a circle, will break its symmetry of "circleness."

Likewise, the fundamental physical law of conservation of energy is another powerful example of symmetry: energy must be equivalent on both sides of the equation for any interaction. No exceptions.

Still, symmetry isn't present everywhere, and many important phenomena originate in symmetries being broken. The evolution of the universe, for example, has depended on several broken

TIR NA NOG Donoghue is at upper left, with banjo

symmetries. One is the separation of the four fundamental forces (gravity, electromagnetism, the weak force, and the strong force) from a single super-force present in the nascent cosmos, as temperature and pressure changed.

Another is the difference in behavior between matter and antimatter. This asymmetry, increasingly demonstrated in the field of particle physics, produced our universe of matter but virtually no observed antimatter.

So how does symmetry arise? While the Big Bang and Grand Unification theories regard symmetry as the universe's initial condition, Donoghue thinks there might be prior circumstances that allow symmetries to evolve, or "emerge." Donoghue has received a grant of more than US$64,000 from The Foundational Questions Institute to study this possibility.

Emergent Symmetry Emerges

"The basic idea of emergent properties is actually pretty familiar," Donoghue says. Think of water waves, he says, such as those created by a stone dropped into a pond. These waves may be mathematically described by a wave equation. At the microscopic level, however, water is made of atoms; waves result when the atoms collide. Yet the wave equation does not apply at this tiny scale. In other words, water waves are a macroscopic, emergent property of non-waving atomic motions.

"Somehow, the water waves have emerged as the right description over large distances, even though the fundamental description is something else at very small scales," says Donoghue. In the same way, Donoghue thinks that certain physical properties may appear symmetric on one scale, but actually be asymmetric at a smaller, perhaps currently unobservable scale.

In the standard paradigm, however, more and more symmetry appears to be revealed with ever-tinier distances. Symmetry breaking is thus currently seen as a macroscopic, "low energy" phenomenon – but if that view were to change, the results would be dramatic.

Playing a New Tune

The field of emergent symmetry originated about 25 years ago in work by Holger Nielsen of Denmark's Niels Bohr Institute. Other theorists have worked on this theory since then, but Appelquist sees a need to put "more flesh on the bones" of the basic idea.

The basic idea goes like this. In laws or theories where symmetry is present, exchanging two particles in an equation will not create a different result. Many physical laws allow this type of transformation without changing the laws themselves.

But often, the rules of a theory require making the particle exchange everywhere in the universe in the same way. This is called a global symmetry. Donoghue's focus is gauge symmetry, in which particle exchanges are allowed separately, at different places.

"Someone in a different galaxy could make the transformation," Donoghue says, "but we here on Earth do not have to do the same thing, and still there is no change in form to the laws themselves. So a gauge symmetry refers to a higher symmetry – one which exists separately at every place in space, without regard to other places."

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>
> *- John Donoghue*

Among other results, gauge theories imply that waves propagating from one point to another that are similar to light waves. "The theory of light is the original gauge symmetry," Donoghue says.

As a rule, gauge symmetries involve massless waves, like light, which are plentiful and easier to produce than more massive particles. So, Neilson's original suggestion was that gauge symmetries might be particularly likely to emerge at low energy.

That's where Donoghue's work comes in.

"This framework [of physics being symmetric at small scales] has worked beautifully through many decades of research," Appelquist says, "and it strongly shapes our expectations about the next energy frontier." However, Appelquist points to a few theorists who say that future experiments, at now-impossible energy scales, may reveal an asymmetric physics.

"The underlying physics could have very little symmetry, with larger symmetry appearing as the emergent phenomenon below this new frontier," says Appelquist. "It could even be that gauge symmetry itself, seeming to underlie all of fundamental physics, could be an emergent phenomenon."

If so, then Donoghue will be playing that tune.