How quantum physicists are looking for life on exoplanets

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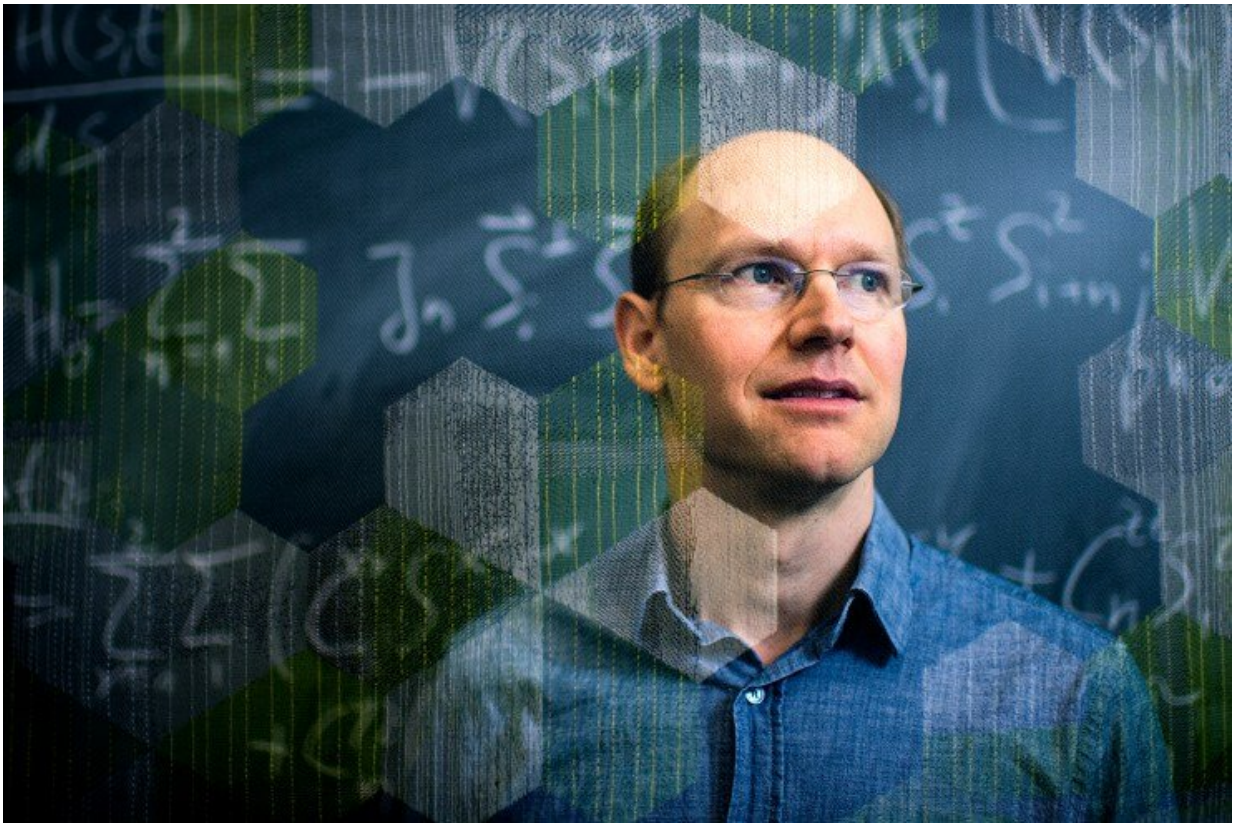

Credit: Northeastern University

The world that quantum physicists study with a trained eye is the very same world that we non-scientists navigate every day. The only difference is that it's been magnified to scales incomprehensibly small

and large.

Still, quantum physics remains largely a murky subject—even for scientifically astute readers. News@Northeastern spoke to Gregory Fiete, a physics professor at Northeastern, about some of the broad applications of quantum research, from developing renewable energy sources and building more powerful computers, to advancing humanity's quest to discover life beyond the solar system. Fiete's comments have been edited for brevity and clarity.

To start off, let's give our audience some insight into the nature of your work, looking down into the world of the infinitesimally small. What are some misconceptions about the work quantum physicists such as yourself are engaged in—and why is it important?

You mentioned quantum and the world of the small. That's what most people think of when they think of quantum mechanics and the way that some of the early foundations of quantum theory developed, which considered the hydrogen atom and how it has discrete energy levels, which you can observe experimentally by looking at the spectra, or how it absorbs and emits light, for example.

[The hydrogen atom] absorbs and emits at particular frequencies, and we now understand that it's because of the quantum nature of the atom—how there are only specific allowed orbits of an electron around the nucleus. So we tend to think of quantum mechanics in terms of this very important early example of a hydrogen atom, and therefore we're biased into thinking that quantum is about the small. But in fact it's not at all about the small.

Take the sun, for example. The sun is very large—it's the biggest object in our solar system; our planets are revolving around it in orbits because of its gravitational pull.

The way the sun functions is it's burning hydrogen. Its gravitational pull is so great that it's combining hydrogen into helium, and then helium into other elements. It's fusing atoms together and that fusion process is a quantum phenomenon, and it's behind one of the great energy challenges being undertaken here on Earth, known as sustained fusion. That's just taking hydrogen and combining it into helium—if we can do that on Earth within a magnetic confinement, then we'll have a clean and renewable energy source.

There's essentially unlimited amounts of hydrogen that can be combined, and helium is not radioactive. So we could produce a lot of energy from things that are more or less infinitely abundant without producing waste in the form of radioactive material. This is a dream that physicists are working toward. So, some of the biggest things in the universe are certainly quantum mechanical, including supermassive blackholes which can lose energy through a quantum phenomenon known as Hawking radiation.

The second point is one often thinks quantum deals with very low temperatures. Again, to take our sun as an example—it's very hot, but that's quantum mechanical. Low temperature doesn't serve as a requirement for quantum. This example of a star and the quantumness of the fusion process and the high temperatures associated with that—I just want to broaden the view of what quantum mechanics is and how ubiquitous it is.

When we write about the work you and your colleagues are doing, there are always real-world

applications. Can you talk about some of the ways quantum physicists are spurring technological advancements beyond their field?

I'll name a few of my favorite technologies. One of the things that really excites me about quantum physics is its use for what I think of as "forensics," or quantum forensics, if you will.

Because things like atoms have discrete energy levels associated with them, it turns out that that can be used to identify atoms. If you compare the energy levels allowed for hydrogen and the energy levels allowed for helium, or any other element, they're different. If you had a gas of anything, then you could determine what atoms are in the gas by looking at how it absorbs and emits light. This is of great practical value if you're interested in something far away, such as a planet that's revolving around a star that is not our own.

There's a fantastic field of exoplanets we're discovering using powerful telescopes, detecting these planets moving in between stars and our Earth. Our telescopes—some of them are in space attached to satellites with incredible frequency resolution and sensitivity—are so powerful that we can look at the thin layer of the atmosphere around these planets, and how the light from the star is passing through it. Then we use the technique of spectroscopy and see how the light from the star behind is being absorbed by the atmosphere of this planet, which could be thousands of light years away. So we can detect what atoms are in the atmosphere.

That's quite interesting. But it goes further. We can detect what molecules are there as well. For example, are there two atoms of hydrogen attached to one atom of oxygen? In other words, is there water in the atmosphere? Molecules have their own spectroscopic signature. So

we can actually detect if there's water in the atmosphere of some of these planets, and that's really exciting.

Yet, we can take it a step further. When there are temperatures involved, then these spectral lines, as they are called, these specific frequencies get broadened out. There's kind of like a range of frequencies where you see the absorption and emission. And the amount that it's broadened out tells you about a molecule's temperature—in other words, the temperature of the atmosphere of these planets.

It's quite amazing that we can determine what is in these planets' atmospheres—planets that would be impossible for humans to ever visit. That, and we can look for signatures of life, like, are there molecules that we associate with life floating around in these planets, at least if it's Earth-like life; then we might be able to determine with some probability that some planet way out there that no human could ever visit, harbors life. Or maybe we could discover other candidate forms of life. That's an example that's quite inspiring, and it ultimately relies on quantum physics and the technique of spectroscopy.

One other example that I think is also of wide interest is that quantum physics is producing energy sources that are beyond the reach of solar energy. So when you send a deep space probe to look at the outer planets of our solar system, let's say Pluto (technically no longer considered a planet). If you want to look at Pluto, you send a deep space probe—it takes years to get there. You might ask, what kind of power source can you have for the computers on this probe so you can send back the beautiful pictures that we see? Well, you can put a battery on there. It's going to take years to get there, space has a lot of radiation and the batteries can get damaged; they may not function properly when they're launched through all of the heat variations getting out of the atmosphere, and the cold of space, etc. That's not very practical. There's not enough light from the sun you can collect with solar panels to run the computer

systems and send images back.

So how do they power the computers on these deep space probes? What they use is radiation. They use a radioactive material, and radioactivity is again another quantum process, where heavy elements decay into lighter elements; when they do, they eject parts of their nucleus. But these ejected parts of the nucleus carry energy that can be captured.

There are materials, some of which are very close to things that I work on, which are called thermoelectric materials. They take high temperature regions and they link them with low temperature regions, converting this high-low temperature difference into a voltage, which is then acting like a battery. Once you have a voltage in an electrical system, now you can move currents around and operate a computer or electrical circuits in more or less the normal way.

It's all very interesting. It sounds like quantum physics really is the foundational work that goes into transforming our energy infrastructure, among other technologies. Is that the right way to think about it?

Yes, that's right. That's a great point—to think about climate change and renewable energies and also technologies that don't pollute our environment.

If we just think about energy for a moment, like when we discussed the example of fusion, which is a green technology—assuming we can get it to work. If we step away from fusion, there are other technologies in place right now that are green. Take wind turbines. What do wind turbines have to do with quantum physics? The way that wind turbines work is that they have a magnet in them attached to the propellers as the wind turns them, and turning a magnet generates an electric current.

That's how you generate electricity: you twist a magnet inside a coil of wires.

But the question is: which magnet should you use? So this is where fundamental research—in fact research that I'm involved in to some extent at Northeastern—comes in: thinking about magnetic systems that would have desirable properties for applications like wind turbines.

You need to have a very robust magnet that needs to survive high temperatures, meaning much above room temperature, because it can get hot up there with the sun shining on it. It must also have properties that are robust enough to survive whatever strains and stresses as it's twisted about in this turbine system. Those are so-called hard magnets. So how do you develop better magnets? That's a quantum question.

As a final thought, I'm wondering what your great hopes are for your research and for the field. What would you like to see happen during your lifetime, and are there any advancements that we're on the cusp of?

That's a hard question that everyone in the field is asking: what are the advancements that we're truly on the cusp of? A well-cited example is quantum computing. Having a quantum computer is not going to solve every computing problem that anyone can dream of. It turns out that quantum computers are particularly adept at certain classes of problems, where they can provide what's called a "quantum advantage." There are some specific problems for which quantum computers are more useful; but other problems might be better solved by conventional supercomputers.

So one of the questions in the field is trying to provide a little bit of a

sharper resolution on what are the specific problems that quantum computers will help us with. It's an evolving area, like what is the true niche problem for a quantum computer. I think all of us who work in the field feel that there will be some specific applications, where quantum computers really just outperform everything else—and everyone wants to be involved in this; everyone meaning each developed nation. Everyone wants to be a part of this next quantum revolution, which is not about just developing quantum mechanics as a new science, but transitioning quantum mechanics into very wide applications. And computing is just one area at the forefront.

Provided by Northeastern University

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