Beam ME UP, SCOTTY

>> PREPARING FOR TELEPORTATION: THE GREEN TRACKING LASER ON LA PALMA KEEPS CONTACT WITH THE RECEIVER STATION ON TENERIFE. IN 2012, PHYSICISTS BEAMED PHOTONS BETWEEN THE TWO ISLANDS.

R Nino **Meese-Tamuri**

You probably know the feeling of early morning adrenaline flooding your system as you realize that that last snooze-button press was definitely a bad idea: as you groggily squint at the alarm clock, you slowly make sense of the combination of numbers telling you it's 8:55 a.m. Instantly, terror rushes through your body turning you into a frenzied headless chicken with an acute form of Tourettes as you remind yourself that you should be at work across town in less than five minutes! Well, what if even in such a dire situation you could calmly get dressed and have a quick bite to eat before going to work? What if you would not have to worry about traffic jams and parking spaces? What if you would only had to walk into a special room in your house, press a big red button and voilà...you are at work a few dozen miles away?

Ever since good old Scotty from Star Trek conveniently beamed crew members down to the surface of planets or onto other spaceships, teleportation has been the holy grail of transportation technologies. But it is all just a bunch of science fiction nonsense, right?

About two decades ago, teleportation only existed in the minds of science fiction authors and their loyal followers. Today, teleportation is reality. So much so in fact, that teleportation is at the root of a new space race. Who will be the first to beam up their photon into orbit?

As it turns out, that kind of 'get out of here' disbelief was precisely the overwhelming sentiment across the scientific community during the majority of the 20th century. However, in 1993, physicist Charles Bennett and his team (including Gilles Brassard from the University of Montreal and two other Canadian researchers) proved that teleportation is - at least in principle - scientifically sound. Since then, many experiments were able to teleport particles of light called photons across an increasingly large distance. The current speed of progress in teleportation technology has picked up so much in fact that the year 2012 saw the teleportation distance record smashed twice. In the late summer of 2012, the champagne from the celebrations of a distance record of 97 kilometres across a lake in China had not yet dried when an international team from Vienna stunned the scientific community by topping it with their own 143 kilometre teleportation through free space between the Canary Islands of La Palma and Tenerife.

"I remember it was quite exciting when my colleagues told me it finally worked out," said theoretical analyst Johannes Kofler from the Max Planck Institute of Quantum Optics in Germany. "They tried the experiment already a year earlier, but the weather conditions were just too bad. Even the second time, it took many days until the conditions were good enough. It still took over six hours to get the necessary 605 events to show that quantum teleportation really was achieved."

Space nations of the world, start your engines!

Motivated by these successes, researchers are now aiming for the stars...

"The goal is now to reach a satellite," said professor Thomas Jennewein from the Institute for Quantum Computing (IQC) in Waterloo, Ontario. Jennewein leads the Canadian effort to be the first nation to achieve a teleportation link beaming a photon to a satellite in Earth's orbit.

The pace of development, deployment speed and flexibility have been key parts of the Canadian team's philosophy.

> If you can make it there, you can make it **anywhere.**
> - Martin Laforest

"The main goal of the mission was always low cost and fast speed," said Jennewein. "Space experiments are generally complicated and require a lot of lead time. Our goal was to find a satellite for quantum communication that was as simple as possible."

This emphasis on simplicity also committed the team to teleport from the ground to the satellite rather than the other way around. The satellite will be equipped with the much simpler photon detector and receiver while the more complicated and expensive photon sources and emitters will stay on the ground. However, this configuration is far from a painful compromise.

"As it turns out, the quantum sources are also the more interesting part since they still undergo a lot of technical evolution at the moment. Almost every week, there is a new type of photon source discovered," said Jennewein.

This means the system remains easily upgradeable on the sender side making it more future-proof.

The satellite, which will be entirely Canadian built, is currently waiting for the final approval by the Canadian Space Agency, but could launch into orbit in as early as three to five years according to Jennewein.

The Canadians are not alone, though. Every major nation on Earth with even the most remote interest in space has - in one way or another - joined a real space race. The ranks of Canada's rivals swell quickly as teams from Europe, China, and even Singapore join the start line - all with their own satellite projects. With the exception of Canada, every other nation chose to put the quantum sources into space and teleport down to a ground station.

China appears particularly invested in a teleportation link to space.

"They are apparently putting a lot of emphasis in these kind of missions. I have heard that they are considering several generations of increasingly complex satellites," said Jennewein.

One notable absence from the starting grid so far, though, is the United States. However, the mere fact that the U.S. keeps a tight lid on its teleportation aspirations does not mean the "Stars and Stripes" nation is going to remain on the sidelines.

"The U.S. has been looking into a satellite for a long time. They have been talking about it for at least 15 years," said Jennewein. "They apparently have designed a system for quantum key distribution and have also done experiments outside in free space, but it is not clear when such a mission will go up or if it even will go up at all."

Other nations like Australia and Japan have also expressed great interest in the technology. While Japan may end up launching its own mission, Australia has been in talks with Canada to become a partner in its project.

"We see the satellite as a shared resource for the science community so that participating partners could use the satellite while it passes over their location," said Jennewein. "We have had a first informal round of discussion with Australia. This would be very interesting for us, because doing a quantum transmission from North America to Australia would be a truly global distance. It doesn't get much farther than that."

Beam my photon up, Scotty

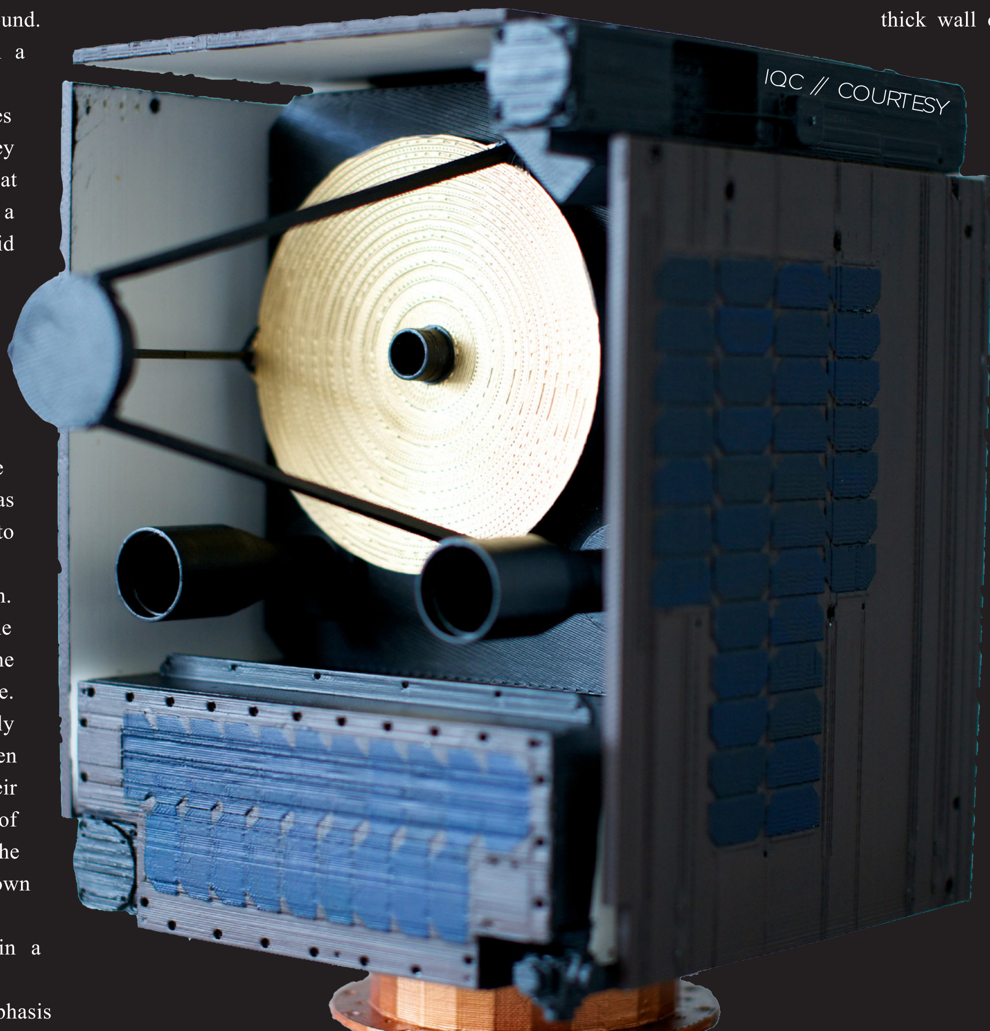
So, why is reaching space so attractive for the wannabe Scottys out there?

To say it in the words of Martin Laforest, Scientific Outreach Manager at IQC:

"If you can make it there, you can make it anywhere."

It is the emptiness of space that makes it a teleporter's dream.

At first glance, this seems ironic since the technology's biggest advantage is precisely that it really does not matter what lies in between point A and B. It could be a kilometre-thick wall of



>> MODEL OF THE CANADIAN TELEPORTATION SATELLLITE

solid steel or astronomical distances of millions of kilometers separating the two. A teleported object is not really travelling in the sense that it crosses a given distance at a given speed. To an outside observer, it just disappears on one end and instantaneously reappears on the other with no apparent connection in between.

It is important to note, though, that teleportation does not transport masses such as people or objects themselves. Instead, it transfers information about these bodies. In that regard, teleportation is like a next generation version of a fax machine. In the case of a fax machine, a document is first scanned and transformed into pure data. The data is then sent through the phone line to another fax machine which, based on the data, prints out a copy of the original document. The paper itself never travelled, but its content did.

Teleportation follows a similar approach. The entire process of scanning, transmitting and printing is taken care of through the exploitation of a weird, but very real quantum phenomenon: quantum entanglement. Einstein famously described this effect as a "spooky action at a distance". An entangled pair of particles will share a "magic connection" so that each twin will always know what state the other one is in. If one changes, the other will instantly do the same. This bond stays intact even as the two twins are separated over an arbitrary distance. Distance has no effect on the strength of this connection.

If we wanted to teleport a photon Carl from a lab on La Palma to a lab on Tenerife, we would need to introduce him to Alice, a photon which shares a "magic connection" with its entangled twin Barbara on Tenerife. This introduction, known as a Bell state measurement, transfers all of Carl's quantum information onto Alice. Since Barbara is entangled with Alice, she will instantly "feel" the change in Alice's state and will match the change herself. Barbara now contains all of Carl's initial quantum information and in quantum physics an object that has Carl's quantum information is the same as being Carl himself. To be sure we get Carl out on the other end rather than some rearranged version of him, it is also critical that La Palma gives Tenerife a call and tells the researchers the result of the original Bell state measurement. Using that additional information, the researchers can perform minor adjustments to the new Carl and complete the process. Carl has been successfully teleported to Tenerife.

So with Carl being on Tenerife who is left on La Palma? The short answer is: nobody. Quantum physics does not allow a copy of Carl to be left on La Palma. The so called "no cloning principle" demands that both Carl and Alice be destroyed in the process. Each teleportation run therefore uses up entanglement so that it has to be continuously replenished.

It is this set up process of sharing the entanglement that is vulnerable to interference from our atmosphere. If the lab on La Palma generates an entangled photon pair, it will need to keep one and shoot the other over to the lab on Tenerife where it is caught and prepped for teleportation. Storage of entangled photons is hard and the photons have to be used straight away before the entanglement becomes unstable. Researchers across the world are feverishly working to develop better quantum memory to stabilize the entanglement for longer periods of time. At the moment, though, these quantum memories barely last a second and entanglement has to be shared immediately before the experiment. Since particles of light are used to share the entanglement, they can be shot over at the speed of light using a weak laser. However, the photons will have to successfully avoid the swarm of particles in between which make up our atmosphere. The longer the distance, the more of the atmospheric soup will have to be avoided.

Encryption through quantum keys on the other hand is fundamentally uncrackable. Rather than just breaking a very difficult math problem, a spy trying to listen in to a quantum encrypted conversation would have to find a way to break the laws of physics instead.

"We lose many photons in the atmosphere," said IQC assistant professor Vadim Makarov. "In the Canary Islands, only about one in a thousand photons made it to Tenerife."

It is a relief to the physicists then that after the Canary Islands experiment, the worst seems behind them.

"In terms of loss, it will be easier than what we have done [in the Canary Islands] because the atmospheric layer is much thinner from the satellite to the ground station than from ground station to ground station," said quantum researcher Xiaosong Ma from Yale University.

However, switching the target from a stationary island to a fast moving satellite makes it much harder to accurately aim the laser over such large distances.

"The sender will have to be tracked by the receiver all the time. Otherwise, you will end up sending the beam to the wrong location and the loss will be infinite," said Ma. "For satellites, this will be much more difficult than for what we have done [at ground level]."

However, Ma is confident that existing tracking technology should be able to ensure that we don't just aimlessly spray the sky with salvos of entangled photons.

"This is a mature technology and will only have to be integrated into the quantum teleportation experiments," said Ma.

The different satellite projects differ in their approach, but all have the same goal: worldwide quantum key distribution via teleportation to enable global, perfectly secure communication.

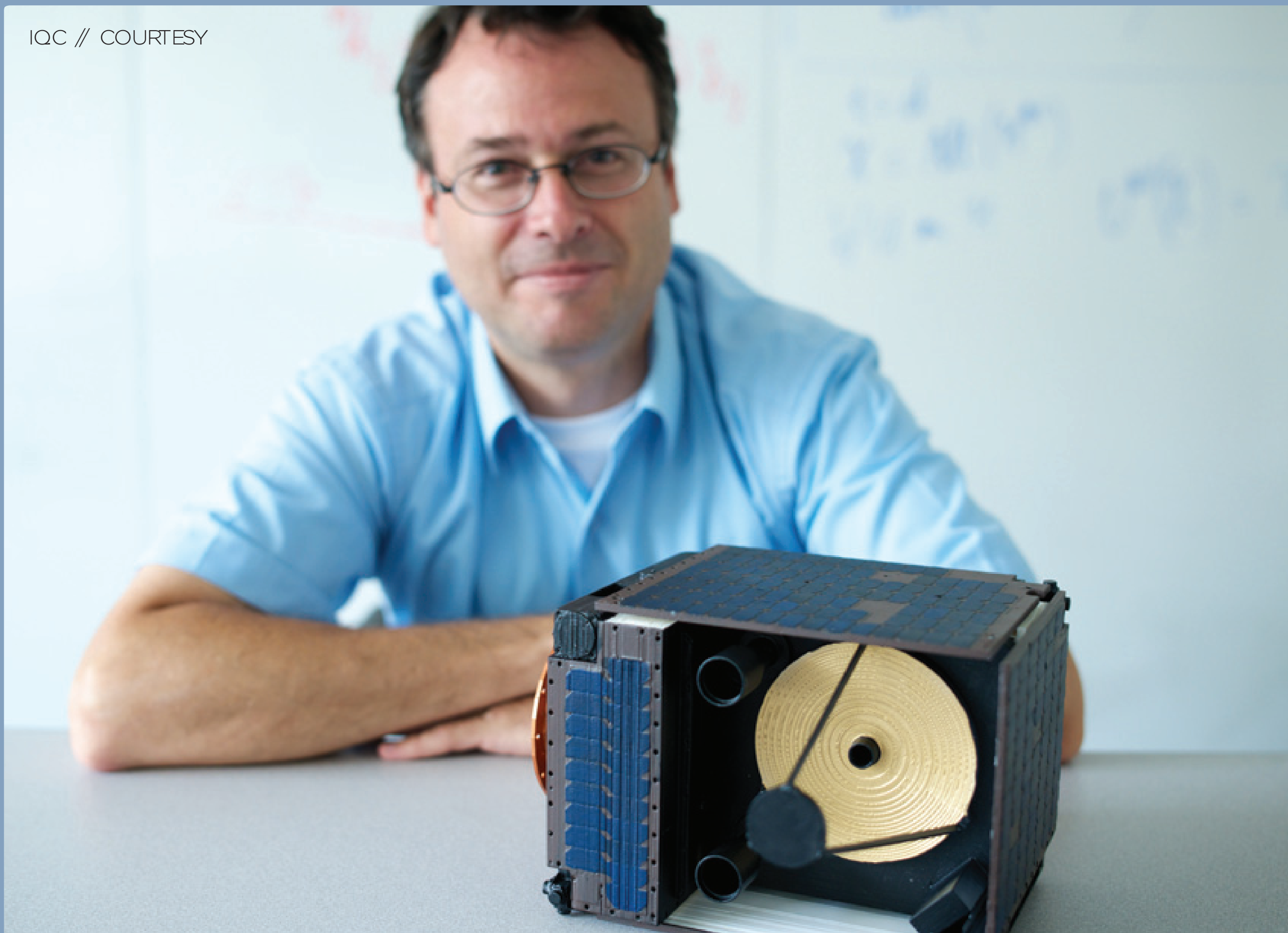
Traditional encryption relies on keys that are essentially very difficult mathematical problems that take even the fastest computers a long time to crack. But the point is that they can still be cracked allowing unauthorized third parties to eavesdrop on the conversation.

Encryption through quantum keys on the other hand is fundamentally uncrackable. Rather than just breaking a very difficult math problem, a spy trying to listen in to a quantum encrypted conversation would have to find a way to break the laws of physics instead.

Any attempt to spy on a conversation secured through entanglement would destroy the "magic connection" and expose the intrusion. Unless a way can be found to measure entanglement without "looking", quantum cryptography will be a nightmare for spy agencies worldwide.

Adding some meat to the equation

Now we have proven that we can teleport our photon Carl from one island to another and are working to teleport it to a satellite in Earth's orbit. But what about teleporting a real Carl made out of flesh and bones? Can teleportation be the solution to frustrating rush hour traffic jams?



>> SUPERVISOR DR. THOMAS JENNEWEIN POSES NEXT TO A MODEL OF THE CANADIAN TELEPORTATION SATELLITE.

Moving from relatively simple particles of light to much more complex objects or even living humans is a huge leap and bears some major technical difficulties – but surprisingly it is not impossible.

"Quantum mechanics as we know it today does not put any fundamental restrictions on this kind of technology," said Kofler. "But it is quite clear that teleporting such a complex thing as a human is still very far in the future."

This complexity is proving to be difficult to deal with at every step of the process. Just like a traditional fax machine, teleportation requires a compatible template to be already present at the start and finish line.

"We would have to create blobs of entangled matter at both locations and they would have to be made up of the same molecules or atoms that a person is made up of," said Jennewein. "In fact, the entangled blob would essentially be all possible persons at the same time."

Similarly to the photon teleportation, the real Carl would be absorbed in this blob of matter, transfer all his information onto it and die in the process. The result of the Bell state measurement, a huge amount of data, would then have to be sent via internet to the receiver where researchers can use that information to pick out the right person from the blob and let a new Carl pop out.

"This could work in principal, but we do not yet know how to create these entangled blobs of matter which could be used for teleportation," said Jennewein. "On the other hand, I must say that it is coming along. People have already teleported states of atoms and molecules from one place to another."

Kofler imagines that we may already have a good candidate for such a macroscopic template: a small diamond.

"A diamond has a perfect structure. If you put another diamond of same size and shape in the other lab, the template would be simple," said Kofler. "Then you only have to transmit the quantum information in the individual electrons and nuclei."

A possible next step could be that of a bacterium.

"A bacterium is already very complex. It has many molecules, a DNA ring, and should have at least 10^{10} atoms," said Kofler. "That's a huge jump."

Strangely, the fact that it is a living organism might not be a big problem.

"I don't think it will be an issue because it is living," said Kofler. "Living just means that the information is distributed in a special way with large complexity and dynamics, but there is no fundamental difference."

Since its first experimental success in 1997, teleportation research has focused on improving reliability, speed and distance for communication, but Kofler believes that "it is only a matter of time before people will attempt teleportation of more and more macroscopic objects."

While we wait for the technology to match our Star Trek spoiled expectations, there may only be one solution to a stressful morning: setting the alarm earlier.