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0:00:06.0 Sarah Crespi: Welcome to the Science Podcast for February 26, 2021. I'm Sarah Crespi. Each week, we feature the most interesting news and research published in Science and the sister journals. First up, freelance science writer, Julia Rosen, talks about a growing fleet of radar satellites that will soon be able to detect centimeter-size changes anywhere on Earth's surface daily. Then I talk with researcher, Hui Cao, about a new way to generate enormous streams of random numbers faster than ever using a tiny laser that can fit on a computer chip.

0:00:46.5 SC: Now we have science writer, Julia Rosen. We're gonna talk about a growing fleet of radar satellites that can image tiny shifts in the Earth's surface surface. Hi, Julia.

0:00:58.7 Julia Rosen: Hi.

0:01:00.2 SC: The technology behind these satellites, the way these observations are being made is with something called Synthetic Aperture Radar. How does that work?

0:01:08.6 JR: So the idea is that these satellites are orbiting the Earth and they're sending out little microwave pulses, and then they are collecting the echoes that come back off the surface of the Earth. The length of the antenna is called the aperture, and the more of those pulses you record, the better of an image you get. And the reason it's called synthetic is that, instead of building a really, really long antenna to collect all of those, they basically take a small antenna and collect all the returns as it moves through space, so it acts like a much bigger antenna, and that allows it to create these really high resolution images of the surface down to meters or centimeters, in terms of the pixel resolution.

0:01:50.0 SC: And this is Synthetic Aperture Radar, SAR. Now let's take SAR and turn it into InSAR.

0:01:56.5 JR: Right.

0:01:58.2 SC: This is the way you can get changes over time?

0:02:00.8 JR: Yes, that's right. That's one of the uses of InSAR, and that's the one we talk about in the story. So, the way that it works is those microwave signals, they're waves, so they have a sinusoidal path, and the antenna records where in that path the signal returns to the antenna. It's called the phase. And if you have two SAR images that are taken from the same location at different times, if there is any change in the phase of that signal, it tells you that that signal traveled a slightly different distance, and so you can use it to look at movements of the surface that are very, very small. Sometimes, with InSAR, you can detect movements of just a few millimeters from space over a really large area.

0:02:42.2 SC: Wow. Well, GPS can kind of do the same thing, right? It can tell you a location, and if that location is different.

0:02:51.3 JR: Right, the difference is that, with GPS, you need a station on the surface, so it can very precisely measure changes in the service at that location where the station is, but with InSAR, you're looking at a swath of the planet that is, in some cases, 200 or more kilometers wide, and you're measuring these changes across this vast area. And you don't need anything on the ground. You're just looking at it from space.

0:03:13.1 SC: Well, SAR has been around for a few decades, but there were some issues, it wasn't easy to process the images, the devices, where they were being used, were often turned on and off for different experiments, but we still saw some cool stuff in the early days. Can you talk a little bit about the early things that InSAR was able to show?

0:03:30.9 JR: Yeah. So the technology, originally, it originated for... In the military, and was used from the 1950s on for that purpose, and then, in the 70s, scientists started to get their hands on it, and about a decade later, people started to develop the math behind InSAR. And so some of the first applications, really, the first sort of proof of concept was using some data that was collected by this short-lived Ocean Observing satellite called CSAT, and the researchers used InSAR to compare several images that were taken of the Imperial Valley in California over just the course of a few weeks, and what they could see was the subtle swelling of fields due to irrigation. So, again, just really, really tiny movements. The big study that really got a lot of people's attention came a few years later. It was after there was a big earthquake in Landers, California, and researchers used InSAR to look at the deformation that that earthquake caused. And that study was really groundbreaking for several reasons. One is that they were able to sort of see the impact of the earthquake from afar, without having to do this detailed fieldwork. So they were able to see how much the fault slipped, all the things that you normally want to know about an earthquake.

0:04:38.9 JR: In addition to that, it showed how the surface deformed for miles and miles around the earthquake. So it was really a picture of how the earthquake affected the surface, that wasn't possible with any other technique.

0:04:51.3 SC: And now more and more of these satellites are coming online, some of them dedicated solely to just imaging the Earth in this way. What kinds of science can be done, now that we have these dedicated satellites and much more of this data coming back?

0:05:06.6 JR: One of the big breakthroughs, as you said, was that scientists and also governments, people who have reasons to want to monitor the Earth, they really needed a regular, reliable source of data, and now the European Space Agency Sentinel-1 mission has been doing that for several years. And there will be... NASA and the Indian Space Research Organization are launching a similar mission in a few years. So those, they provide data all the time, it's very regular, and it allows people to sort of watch the planet change in real-time. So you can look at subsidence due to groundwater pumping. You can look at how volcanoes are inflating, which can be a sign that they are becoming more active. You can look at... If dams are moving a little bit in a way that means they might not be stable. You can monitor buildings, railroad tracks. You can look at natural disasters. There's all sorts of applications that this sort of regular data allows people to do.

0:06:04.7 SC: There's kind of two different uses for this data. There is science, saying, "Well, what can we find out about how things are working down there?" And then there's also monitoring, saying, "Oh, can we keep an eye on crops? Can we keep an eye on ice packs? Can we keep an eye on flood damage?" Like that kind of thing.

0:06:21.6 JR: Right. Yeah, there's a whole bunch of scientific applications where the more regularly you can observe things, the more you can... Instead of saying like, "Hey, there was an earthquake. What happened?" You can actually look at processes and start to understand what's going on at faults? What's going on at glaciers and volcanoes? And then, on the monitoring side, yeah, as you said, it's just this remote observation that allows people to make sure that infrastructure is stable or catch it before something bad happens, monitor water resources, yeah, respond to natural disasters. And that's really where a lot of the growth is coming from, is more in that application side. People are just... As the technology is maturing and as the data analysis gets easier because of computing advances, there's rapidly expanding number of applications beyond science.

0:07:06.7 SC: You open your story with this anecdote of using satellite data to look at volcanoes. So what can you learn from space about a volcano, that you can't from little monitors on the ground or living near one and feeling the rumbles?

0:07:22.4 JR: There are a lot of volcanoes on Earth and many are not really monitored. It takes a lot of resources to go and put seismometers and various instruments on a volcano to see what it's doing. The example that I open the story with is in the East African rift zone, and there are something like 78 volcanoes in this area, most of which have not historically been monitored, and so some researchers used InSAR to look at these volcanoes from space and see what they were doing, and they found that, most recently, about 14 of them have been either subtly inflating or deflating over the last five years, and basically, that's a clue that either magma or hydrothermal fluids are moving. It doesn't necessarily mean they're gonna erupt, but it means the volcanoes are active, people need to probably pay attention to what's going on, it's worthy of more investigation, and that type of a survey just really isn't possible with any other technology, where you're just looking at an area hundreds of kilometers long and wide, and being able to detect millimeter movements of the surface.

0:08:31.1 SC: I like this other example that you mention about working on a railway station somewhere, and they notice that it's sinking a little bit.

0:08:38.1 JR: Yeah. So, Norway, European Space Agency's Sentinel-1 program, one of the things that sets that program apart is their data is totally free. They have the same policy as NASA, so all the data is free and open. So Norway took that data and they made a national deformation map. So you can go on the web and you can look it up, and there's probably millions of points, and you can look at every place in Norway, whether it's staying the same or sinking or rising. So one of the things that they found in this map was that parts of the main train station in Oslo were sinking. So that's good to know. [chuckle] And this is a very easy way to monitor those changes in buildings and infrastructure, not to mention one of the main motivations for the map was to look for rock slide hazards. Norway's really mountainous and rugged, and so that was one of the reasons, and they found a ton more rock slide hazards after they did the map than they knew about going into it.

0:09:29.3 SC: So let's talk about how fast and often we can scan the Earth for millimeter changes.

One of these companies that you talk about is looking to put 100 satellites in orbit. How often are they gonna take a picture, basically, of the Earth and its entire surface?

0:09:43.8 JR: This is a Finnish company called ICEYE, and their motto is "Every Square Meter, Every Hour." Talking to them, I think that's really an aspirational goal, and they've told me that it sort of depends on what their clients actually need, whether they go all the way to that, but they are hoping this year to at least reach daily revisits, so they would be revisiting most places on Earth at least once a day. They hope, very soon, to do that multiple times a day, which, again, opens up all sorts of applications, like looking at how a building expands in the heat of the day and contracts at night. All sorts of things where you're operating on human timescales, as they put it.

0:10:19.6 SC: I feel like there are gonna be a lot of applications we haven't even thought of once we start to see a steady stream of this data.

0:10:25.9 JR: One of the founders of ICEYE, he compares it to GPS, like when the military first admitted GPS, nobody had any idea that it would lead to Uber or DoorDash, something like that. These are completely unanticipated applications, and he believes that the first step for that is really creating this reliable data that people can actually integrate into those sorts of applications. So, yeah, who knows where it's gonna go. Already, the number of applications has increased dramatically from the early days.

0:10:53.7 SC: There's already probably so much data banked from these passes that there's a million research projects that could be just done out of those.

0:11:02.0 JR: Yeah, exactly. And that's a whole other side of this, the data analysis side. There's way more data already, that's been collected, than people have time to look through, and historically, it's been very laborious, especially to do InSAR. As those microwaves pass through the atmosphere, they are slowed down a little bit by water vapor, and obviously, the amount of water vapor changes with the weather, and so that creates some sources of noise that people have to deal with when they're looking at these data. And so there's a whole bunch of advances using artificial intelligence and deep learning techniques to automate some of that process and help people sort through this data more quickly, because there's just a ton of stuff out there that people haven't even had the chance to look at.

0:11:43.4 SC: Alright. Thank you so much, Julia.

0:11:44.8 JR: You're welcome. Thanks for having me.

0:11:46.2 SC: Julia Rosen is a freelance science writer based in Portland, Oregon. You can find a link to the story we discussed and some great images at sciencemag.org/podcast.

From encryption to scientific models, we need random numbers more than ever. Stay tuned for my interview with Hui Cao on how we can use lasers to get them.

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0:12:13.1 SC: Random numbers underlie so much of what we do these days, but it's hard to get them fast enough. Hui Cao is a Professor of Applied Physics at Yale University, and she's here to talk about her science paper that describes a new way to generate huge amounts of random numbers very quickly. Hi, Hui.

0:12:31.6 Hui Cao: Hi, Sarah.

0:12:32.9 SC: Alright, let's start with why we need all these random numbers these days.

0:12:38.0 HC: Random numbers are widely used for secure communication and cryptography. For example, when we do online purchase or online banking, we need random numbers. Also, our society becomes more and more connected in the internet, so the ability to generate a lot of high-quality random numbers at high speed will be very important and also urgent for cybersecurity.

0:13:04.6 SC: There's also scientific reasons that you wanna generate random...

0:13:07.4 HC: Yes. In addition, these random numbers are used for stochastic modeling, for example, the spreading of viruses, the fluctuations in the stock market, and also quantum simulation to understand the collective behaviors of a large number of atoms and molecules to design new materials.

0:13:28.9 SC: We're gonna use a laser to make random numbers. I know, in the past, we've used radiation, you observe the radiation decay, and that's a way of getting random numbers from physical phenomenon, but why can't we just make an algorithm, use a computer to make random numbers for us?

0:13:45.6 HC: Most random numbers we are using today, they are generated by computers, but they are not true random numbers, they are actually pseudo-random numbers generated by computer algorithms. For example, taking a short random seed and then expanding it into a random-like bitstream using some deterministic algorithms. Such scheme is easy to implement and cost-effective, that's why it has been used widely. However, it is vulnerable to attacks because the future sequence can be computed if one discovers the seed or the algorithm. And also, even in modeling and content simulation where the security is not important, the pseudo-random numbers can produce inaccurate or even incorrect results.

0:14:37.5 SC: It turns out that it's necessary to capture randomness from a physical process like radiation, but you wanna do it much faster than waiting for something to decay, and in your research, you're using a laser and a specially-shaped cavity. How can you get randomness from that?

0:14:56.5 HC: So, yes, typically, to generate true random numbers, we need to sample real physical phenomenon that are stochastic, unpredictable and unreproducible, but for most schemes that have been developed so far, the random number generation rates are low and then the cost is high. So that's why we tried using a laser. So, as you know, a laser contains a gain medium that creates light, and a cavity that reflects light for amplification, so we tailor our laser cavity shape to resemble an hourglass in order to have many modes resonate in a cavity.

0:15:35.5 SC: When you say it has multiple modes, what does that mean?

0:15:38.1 HC: Let me make a simple analogy. So let's compare our laser to a violin. The body of a violin has a shape of an hourglass, and it amplifies the sound generated by the strings, and so this hollow wooden body serves as an acoustic wave resonator and its shape is tailored to resonate with many acoustic frequencies in order to make the violin sound rich. Similarly, our laser cavity serves as a resonator for optical waves, so we design the cavity shape to resonate with many optical waves that have different spatial profiles and temporal frequencies, so we call them optical modes. These modes will then be amplified in the laser cavity, so they will beat to generate random intensive fluctuations in space and time.

0:16:33.2 SC: So you're able to observe those fluctuations and that is the randomness that you're capturing?

0:16:37.9 HC: Exactly, we actually measure the output emission intensity from the laser, we observe this random intensive fluctuations in space and time, then we digitize these fluctuations at different spatial locations to generate many random bitstreams in parallel.

0:16:56.2 SC: Right, many bitstreams in parallel. Let's talk about how much you're capturing here. This is one of the big points of the paper, a lot more random numbers are being generated per second with this process than the fastest technology currently available, and part of this is parallel processing, the many bitstreams being produced in parallel, but it's also how much you get per stream.

0:17:21.5 HC: Exactly. Previously, many physical phenomenon has been explored for random number generation, and the faster scheme is using semiconductor lasers.

0:17:32.0 SC: A semiconductor laser?

0:17:33.2 HC: Yeah, semiconductor laser, like a laser made of semiconductor it's pretty small, like a laser diode, we have been using for laser scanning for many things. Typically, for calculating dynamics people used before, the timescale is 10 to minus nine seconds. Now, for this kind of beating, we can go to 10 to minus 12 seconds, which is much faster. That allow us to really use this very fast process of intensive fluctuation for high-speed, random number generation.

0:18:03.7 SC: And so, when you add up across all the channels that you're monitoring here, all of these picosecond changes, you're ending up with terabytes per second of random numbers?

0:18:14.6 HC: Yes, terabyte is 10 to the twelfth bit per second. So, for any channel, we already reach the random number generation rate of two terabit per second, and we have 127 channels, so the total rate goes to 450 terabit per second.

0:18:34.0 SC: And that's orders of magnitude larger than earlier versions.

0:18:38.2 HC: Yeah, that is actually 100 times faster or two orders of magnitude larger than the existing record.

0:18:47.1 SC: One thing that I thought of as I was reading this is that, for some reason, I kept thinking about Bitcoin and mining Bitcoin, how energy intensive that is. Is this an energy-intensive process?

0:19:00.0 HC: No. Actually, our laser is energy efficient. Typically, we inject electrical current about one ampere, and the total power of laser emission is about 800 milliwatt, so it's very efficient, and that's not using much power.

0:19:15.2 SC: Well, so this is a small laser that doesn't use a lot of power and it uses kind of standard processing techniques to get your final output. Is this something that you see as scalable, that a lot of researchers or people who need to encode things on the internet are gonna be able to use in the future?

0:19:32.6 HC: Yes, I hope it will be someday. Our laser is very small, the dimension is less than one millimeter. So, first of all, we can integrate a large number of lasers in a single chip, and this can be widely distributed. So I hope this will be widely used someday.

0:19:50.1 SC: What kind of improvements do you see that could be made to get even more random numbers, more terabytes, even a larger number of bytes per second out of this kind of system?

0:20:02.5 HC: Actually, our laser, our current laser, can generate the random bit up to the rate of two petabits per second, which means ten times more.

0:20:13.6 SC: Can you say that again? What is it? A petabit?

0:20:15.9 HC: Yeah, a petabit is 10 to the 15.

0:20:18.8 SC: I've never even heard of that before.

0:20:20.2 HC: Yeah, I know. It's too high, right? So, actually, our... We are still... Our demonstration is to do it ten times below than what can be achieved from our laser because we are limited by our photo detection systems. So I think that just by improve our photo detection systems, we should be able to increase the random number generation rate by another order of magnitude.

0:20:47.4 SC: Wow, and then do you think changing the shape of the chamber, making it some other shape, some other instrument...

0:20:53.1 HC: Yes, we can definitely further improve our laser cavity design to further enhance the number of modes, and another important improvement is that, right now, the photodetection of the laser emission is done off the chip. So, in the future, the fast photodetectors can been integrated with the laser in a single chip. This will make a compact parallel random bit generation system.

0:21:20.0 SC: I could just put it in my computer.

0:21:21.4 HC: Yes, I hope someday you will just directly sending the random number to your computer memory.

0:21:27.2 SC: That's really interesting. Thank you, Hui.

0:21:30.1 HC: Thank you.

0:21:30.8 SC: Hui Cao is the John C. Malone Professor of Applied Physics at Yale University. You can find a link to her paper on the episode page for this episode at sciencemag.org/podcast.

0:21:43.5 SC: And that concludes this edition of the Science Podcast. If you have any comments or suggestions for the show, write to us at sciencepodcast@aaas.org. You can listen to the show on the Science website at sciencemag.org/podcast. On the site, you'll find links to the research and news discussed in the episode, and of course, you can subscribe anywhere you get your podcast. This show was edited and produced by Sarah Crespi with production help from Podigy, Meagan Cantwell and Joel Goldberg. Transcripts are via Scribie and Jeffrey Cook composed the music. On behalf of Science Magazine and its publisher, AAAS, thanks for joining us.