

CAREERS

NUCLEAR FUSION How to manage a challenging reactor project **p.671**

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ISPEX PROJECT



Researchers measure atmospheric aerosols with iSPEX optical devices and smartphones.

TECHNOLOGY

Smartphone science

Researchers are learning how to convert devices into global laboratories.

BY JON CARTWRIGHT

A decade ago, Dutch astronomer Frans Snik invented a simple optical device to measure the density of dust, soot and other particles, or aerosols, in the atmosphere that affect human health and the climate. He hoped to launch it into orbit around Earth aboard a satellite. But one afternoon in 2011, Snik held up a demonstration version of his device to an iPhone camera. The smartphone's screen displayed a rainbow of colours: Snik's optical device was converting incoming light into a spectrum that contained polarization information and channelling it into the camera. Snik realized that he could pair smartphones with the optical device and make the same kind

of measurements that he and his colleagues planned to record from space.

An idea was born. "We thought, why not make use of a technology that millions of people carry around in their pockets anyway?"

By 2013, Snik and his colleagues at Leiden University in the Netherlands had given or sold a version of the optical device — called iSPEX — to more than 8,000 willing iPhone users across the country. The users followed instructions provided by an associated app to attach the optical devices to their iPhone cameras and photographed the sky in their local areas. Within a day, reams of crowdsourced spectra had stacked up in an online database, ready for analysis. It resulted in a Netherlands-wide map of atmospheric particles with unprecedented

resolution (F. Snik *et al. Geophys. Res. Lett.* **41**, 7351–7358; 2014) — several years before the proposed satellite launch and for a fraction of the original estimated cost. The team has since received funding from the European Union to repeat the project in 11 European cities.

CITIZEN SCIENCE

Many researchers are finding ways to exploit smartphones. Snik's project, and those of some geophysicists, astronomers and other scientists who need huge data sets, go one step further. They recruit citizen scientists who use their own smartphones to collect data that would be difficult — if not impossible — to obtain in conventional ways. The various internal sensors that smartphones carry, such as cameras, ►

► microphones, accelerometers and pressure gauges, coupled with user-friendly apps offer a way for the public to contribute high-quality data. “There are tons of possibilities for science,” says Travis Desell, a computer scientist at the University of North Dakota who designs research projects that run on smartphones.

Scientists who want to exploit the potential of smartphones first need to assess whether the devices can obtain the measurements they need. They must then decide which software platform will optimize the proposed use, before ironing out any errors or ‘bugs’ in the apps that will be used to collect data. Scientists should also determine how to screen out invalid data. And they need to find ways to recruit participants.

Although recruiting the public isn’t complicated, thanks to social media, it can still be time-consuming. Snik and his colleagues had a head start — the iSPEX project was covered by the Dutch media, which prompted a few thousand citizens to send in requests to participate. The team drummed up a similar number of contributors by collaborating with the charity Lung Foundation Netherlands in Amersfoort, which invited participation from supporters who were concerned about the effects of aerosols on health. Even so, the iSPEX researchers had to spend a year and a half on their crowdsourcing campaign, which involved uploading instruction manuals and video tutorials to a website, posting calls for support on social media and in

online publications, and answering questions. But their efforts paid off when they received more than 6,000 submissions of data.

The more technical aspects of crowdsourcing data can be trickier to master, and it helps to have some technological savvy. Scientists will find it useful to know how to write an app or how to manufacture an inexpensive hardware ‘add-on’ (see ‘How to create a hand-held research toolkit’). But if a researcher is not an adept programmer, help is available. Snik and his team turned to DDQ, a Netherlands-based company that creates apps that are tailored to citizen science. Researchers who lack funds for third-party support can learn to write an app themselves, thanks to a wealth of free online tutorials and discussion forums.

Researchers also need to decide which software platform to select. Snik and his colleagues chose the popular Apple iOS: the physical similarity between iPhone models made it easier to design a compatible add-on. But the leading platform, Google’s Android, has advantages, too. It is less strict about the nature of apps and presents fewer barriers to its instrumentation.

Remote-sensing scientist Liam Gumley at the University of Wisconsin–Madison has developed an app that aims to improve weather forecasting by comparing photos of the sky taken from smartphones with satellite imagery. He has advice for anyone who is interested in smartphone-aided science: “Just do it!” Gumley recommends drawing up a set of storyboards that describe exactly what the app will do, what each screen will look like and what will happen when the user touches an onscreen control or a button. It is also a good idea, he says, to determine whether any data processing will be performed by the app or by a server online. Depending on the type of processing that is required, one might be faster than the other.

BIG DATA

Researchers must also be ready with a database that can accommodate a deluge of data. “If you release the app globally, you may get more data than you expect within days,” warns Qingkai Kong, a PhD student in seismology at the University of California, Berkeley, who is working on MyShake, a seismology app. After extrapolating from a small group of users how much data he and his colleagues were likely to receive, they turned to Amazon Web Services to host their database. Other available cloud-computing services include the Google Cloud Platform and Microsoft Azure.

Once the data have been collected, it can be difficult to know whether they are reliable. Kong and his colleagues are refining MyShake so that it can distinguish between an actual seismic event and when a user is shaking a phone. A similar app, known as CSN-Droid and designed by scientists at the California Institute of Technology (Caltech) in Pasadena, was discontinued because it could not reliably make such distinctions. But Kong thinks that rigorous testing will

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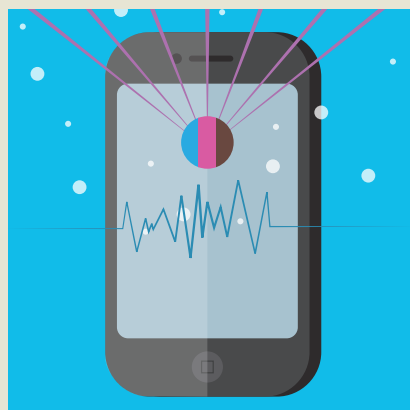
How to create a hand-held research toolkit

Converting smartphones into a tool for citizen science is likely to require an app, and could also involve designing and manufacturing hardware accessories, or ‘add-ons’. There is plenty of help available online for researchers who want to write their own app. Google’s Android, the world’s most popular mobile-device operating system, is supported by a development community (android.dev) that provides walk-through tutorials and guides to achieving specific functions.

The second-most popular mobile operating system, Apple’s iOS, has a similar community called the Apple Developer Forums (forums.developer.apple.com). And app developers for the Windows Phone can check in to the Microsoft Virtual Academy (academy.microsoft.com). Other websites offer free training, such as Alison (alison.academy), which takes novices through the app-writing process from start to finish.

The potential of apps for research has been recognized by Apple, which last year launched an online resource called ResearchKit (researchkit.apple.com). Developed with help from various universities and other research centres worldwide, ResearchKit is a set of tools and services that assist researchers to design and administer app-based studies for the iPhone (see *Nature* **531**, 422–423; 2016). The only catch is that ResearchKit is geared towards medicine. Apps that already benefit from it include mPower, which monitors people with Parkinson’s disease, and GlucoSuccess, which assesses how daily activities affect glucose levels.

Whatever the research goal, it is best to start with the basics. “I read a few tutorials and wrote a small do-nothing app,” says particle physicist Daniel Whiteson at the University of California, Irvine, who is



working on an app to record cosmic-ray events. “Then I slowly added functionality — such as accessing the camera and uploading data to another computer — until it was doing what I wanted.”

Creating add-ons for smartphones is a different challenge, but such devices need not be complex. In 2014, Steve Lee and his colleagues at the Australian National University in Canberra discovered that a smartphone camera could be given a magnification factor of up to 160 by attaching a single pea-sized lens. Costing less than an Australian cent (under US\$0.01), the lens is created by allowing a droplet of polymer to harden on a curved substrate. “It forms a basic low-powered microscope system,” says Lee.

Lee’s droplet lens builds on an existing smartphone instrument — its camera — but not all add-ons do. SCiO is a standalone near-infrared spectrometer developed by the start-up firm Consumer Physics in Israel. Due for release in July, the device will scan materials to provide molecular information and connect to a smartphone through Bluetooth wireless technology. **J.C.**

reveal ways to improve MyShake's accuracy.

Particle physicist Daniel Whiteson of the University of California, Irvine, is also tackling data reliability. He and his colleagues have developed an app called CRAYFIS (Cosmic Rays Found in Smartphones) that enables smartphone users to observe and record the particle debris that is generated when high-energy cosmic rays strike Earth's atmosphere (D. Whiteson *et al.* Preprint at <http://arxiv.org/abs/1410.2895>; 2014). If several hundred smartphones in a kilometre radius simultaneously detect a signal, or 'blip', the app registers the event as a cosmic-ray shower. The more blips that occur in a given radius, the greater the energy of the primary cosmic ray. But there is still the possibility that synchronous blips could originate from sources other than cosmic rays — including detector noise or ambient light.

Whiteson and his team hope to rule this out by recording the metadata that accompany blips, such as their time and location. If a smartphone is left in one place to record data, the researchers will be able to characterize sources of ambient light and noise so that genuine cosmic-ray signals become readily apparent. More than 150,000 people worldwide have already signed up to participate in the CRAYFIS study, but before

"Smartphones are very powerful and very flexible."

they release the app officially, the researchers want to make sure it is free of performance issues that

could drive contributors away. The team is currently running a test version of the app on 1,000 phones worldwide.

Despite the glitches, apps that crowd-source data are especially attractive for researchers because they can overcome issues that might prevent the collection of data. "The prospect that seismic data in large earthquakes can be obtained from consumer electronics is potentially transformative," says Tom Heaton, a seismologist at Caltech. "One major obstacle to acquiring seismic data in a building is that the building owners are frightened by the prospect that researchers will uncover a critical safety issue."

Just as smartphones have become indispensable for many scientists' day-to-day lives, they might also prove to be transformative vehicles for some experiments. "Gone are the days when governments would invest US\$10 billion to \$15 billion on new types of infrastructure, so it's important to think about the infrastructure that's already been built," Whiteson says. "Smartphones are very powerful and very flexible. It's an enormous platform that we're only now beginning to think about for science." ■

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TURNING POINT Reactor manager

Last December, plasma physicist Thomas Klinger saw almost 15 years of work come to life when the Wendelstein 7-X 'stellarator' — an experimental nuclear-fusion reactor — was turned on in Greifswald, Germany. The initiative had to overcome numerous challenges, but Klinger now thinks that the once-troubled project is on a solid footing.

How is plasma physics contributing to the promise of nuclear fusion?

Fusion needs a hot ionized gas known as a plasma, so basic research on high-temperature plasmas is needed for their application in fusion-based power plants. The fusion process that happens in the Sun is very difficult to realize on Earth. We must rely on magnetic fields to keep smaller fusion reactions under control.

What challenges has the Wendelstein 7-X (W7-X) stellarator faced?

When I joined the Max Planck Institute for Plasma Physics in Greifswald in 2001, the plan was to produce the first plasmas around 2007. By 2003, everybody realized that the W7-X project was in deep trouble, suffering from serious technical and management issues. The institute started to introduce reforms but they were not sufficient. So in 2005, I was put in charge of the construction project.

How did you move the W7-X project forward?

We hired an outstanding technical director and engineer, Rimmelt Haenge. For the first two weeks, we sat together and scratched our heads. We identified three areas to address: the most pressing technical problems; a reorganization that would involve hiring 100 engineers; and a review of the assembly plan. I got a crash course in fusion engineering. In September 2007, a new plan was accepted and a decision was made to continue the project. It was pivotal because we were in danger of being stopped.

Did you require any further skills to bring the W7-X into operation?

Our team had to learn about industrial professionalism. There are certain well-established principles, requirements and documentation practices that were not part of our management system at the institute. We had to completely reinvent ourselves.

Compare the stellarator and tokamak nuclear-fusion technologies.

Both use a magnetic field to isolate the plasma and to control its temperature. The fundamental shape of this magnetic field must be a doughnut,



or a ring. In a tokamak, such as the one being built for the ITER project near Cadarache, France, the magnetic field lines are twisted into shape by inducing a strong current in the plasma. But in a stellarator such as the W7-X, there is no current in the plasma. The twisting is done by the shape of the external coils of wire. Because it doesn't need a current, the stellarator is much more stable than the tokamak, and it can operate without interruptions — desirable for a power plant. The ITER and W7-X projects are very different. ITER is an international project with seven partners on a giant machine, so its management scheme is unusual and complex compared to that of the W7-X.

Will the W7-X be competitive with ITER?

The ITER tokamak is a fantastic machine, and it still delivers the best performance. The project is far ahead. But stellarators can catch up.

What are the next steps for the W7-X?

There will be two major shutdowns in which we will integrate large and complex components into the machine to enhance its performance. After 2020, we aim to produce high-performance plasmas. Our fundamental goal is to demonstrate that these plasmas can be created and kept stable for half an hour. That would be a breakthrough, and we hope to achieve this by 2025.

Why do humans need to harness fusion?

It's the only new primary source of energy that researchers are working on, and I'm convinced that it will be needed in the long run. The quest for energy will affect everything — from water to mobility. Sufficient energy means peace. ■

INTERVIEW BY VIRGINIA GEWIN

This interview has been edited for length and clarity.