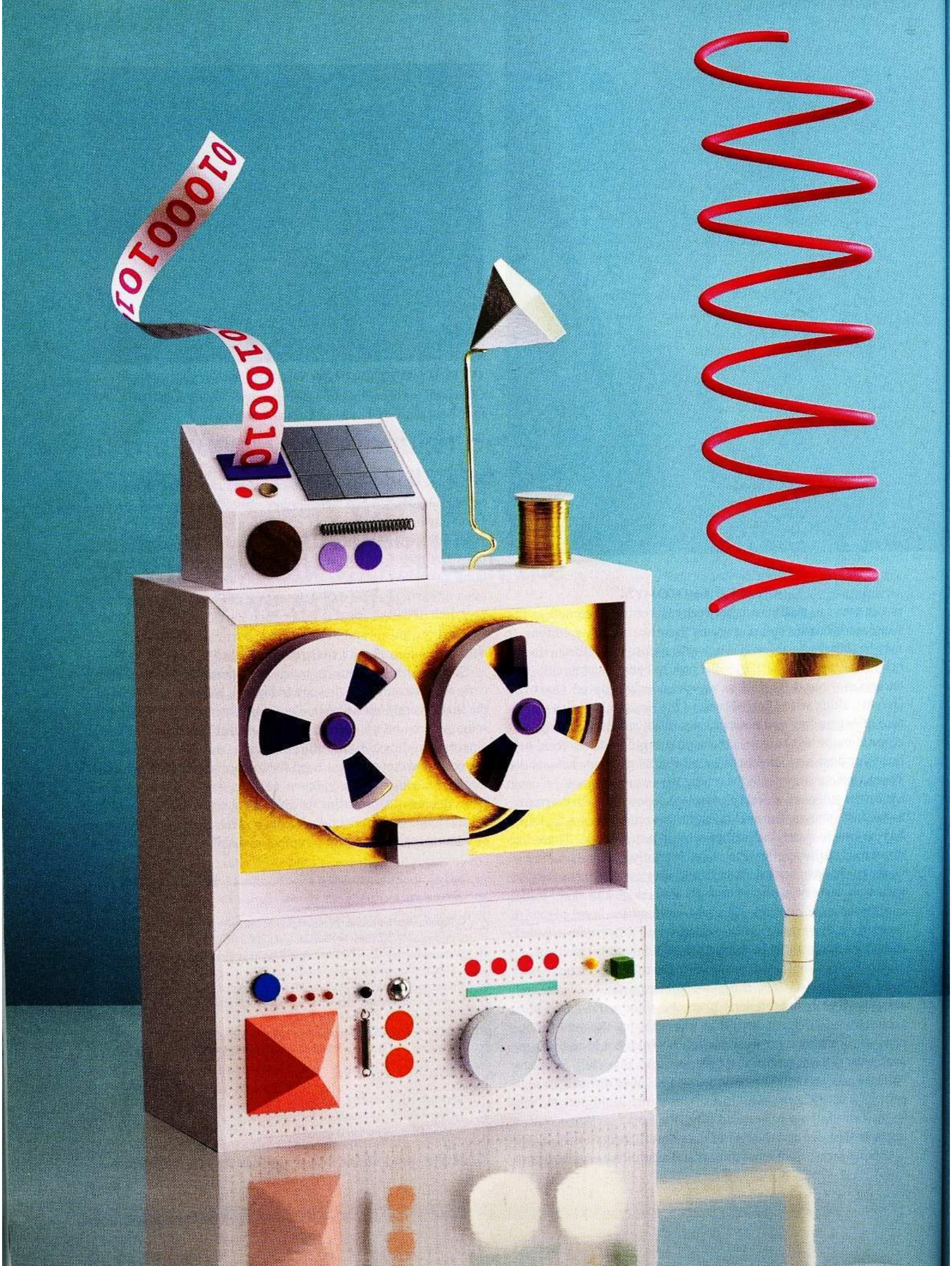

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TECHNOLOGY

SOUND BYTES

Ears are such terrific pattern finders that scientists are using audio data to detect cancer cells and particles from space

By Ron Cowen

Composer Robert L. Alexander was sitting in front of his laptop computer about three years ago, listening to a sound file that would have put most people to sleep: it was a faint flapping, like a distant flag waving in a stiff breeze, repeated over and over, sometimes a little louder, sometimes quieter.

Alexander is a patient man, however. Forty-five minutes into his listening session, the flapping stopped, replaced by a sound like a wind roaring through a forest. It was, he recalls, "the mother of all whooshes."

The sound did, in fact, represent something akin to the wind: the solar wind, a mad rush, across space, of charged particles belched by the sun at the rate of a million tons per second. In 2008 NASA's Wind spacecraft had measured the magnetic field created by these particles as they approached Earth. The field is utterly silent, but it does fluctuate in strength and direction. Alexander, who is also a graduate student at the University of Michigan working on solar data, applied his own algorithm to convert those variations into audible sounds.

This translation is more than a hobby. At 30, Alexander is part of a growing cadre of researchers devoted to the science of sonification: converting data that would ordinarily be displayed visually or numerically into sound. The ear, often more than the eye, has an exceptional ability to pick out subtle differences in a pattern, which is helpful in discovering phenomena not obvious in a visual display. Now it is helping to find hidden astronomical activity and to distinguish cancer cells from normal cells.

PHOTOGRAPH BY LYDIA WHITMORE

Our ears, says neuroscientist Andrew King of the University of Oxford, "can detect changes in a sound that occur after just a few milliseconds." By comparison, the eye's limit for detecting a flickering light is about 50 to 60 times a second. In addition to solar activity and cancer, sonification has been used to examine the eruptions of volcanoes and to discern patterns of changes in particles linked to the cosmic microwave background, the radiation left over from the big bang. Still, many researchers are not aware of the method's power. "I see it as a tool waiting to be exploited," says space scientist Aaron Roberts of the NASA Goddard Space Flight Center.

LISTEN TO THE DATA

TURNING DATA INTO SOUND is not a new idea. The Geiger counter, invented in 1908, emits clicks in the presence of energetic charged particles. And in the 1980s

Illustration by Chrissie Macdonald

physicist Donald A. Gurnett of the University of Iowa captivated audiences with recordings of a hailstorm near Saturn—he turned data from the Voyager 1 and 2 spacecraft into a "Ping! Ping!" made by bits of icy material striking the probes as they plowed through the planet's rings.

The ear can pick out subtle patterns, suggests neuroscientist Bechara Saab of the Neuroscience Center Zurich, because a mammal's auditory system is faster at transmitting neural signals than most other parts of the brain. This system holds the largest known connection between neurons, a giant synapse called the calyx of Held. This flower-shaped junction transforms sound waves into spikes in neuron activity; to do so, the calyx can release neurotransmitters—the brain's messengers—800 times a second. In contrast, the visual pathway does not have such a speedy neural connection, Saab notes: "In the end, these differences in mechanics mean that stimuli that would be 'invisible' to the eye could be easily picked up by the ear."

To create audio from silent data, scientists can take fluctuations in x-rays and gamma rays—or any other signal that is invisible to the eye—and assign a different sound to each frequency or change in intensity, bringing them within range of human hearing.

The trick is to figure out the meaning behind any changes that scientists hear. When Alexander heard the "whoosh" that day in 2012, he really had no idea what the sound might signify. Neither did space physicist Robert T. Wicks, a research fellow at Goddard, who had given Alexander the raw data.

But when Wicks started sifting through measurements recorded by other instruments on Wind during the same time period, he noticed an odd correlation with Alexander's recording. Nearly every time Alexander's file made a "whoosh" sound, Wick found an upswing in the density of certain charged particles—helium ions—in the solar wind. One possibility is that the influx of ions, which gyrate around the magnetic field lines, sends some of their energy back into the magnetic field, causing it to wiggle.

The interplay reveals one way that energy moves back and forth between the field and the particles. That finding, in turn, may offer new clues about one of the sun's deepest mysteries—why its outer atmosphere is hundreds of times hotter than its roiling surface.

The sound file "has been a revelation," Wicks says, thanks, in part, to audio's ability to compress information. The Wind spacecraft measures the magnetic field carried by the solar wind about 11 times a second. But the audio's CD-like sampling rate packs 44,100 measurements into a second of sound in the range of human hearing. A year's worth of field measurements, which would take months to analyze by eye, thus become just two hours of sound.

These nuanced changes have alerted scientists to important distinctions in the solar wind. Two years ago Alexander made an audio file from measurements of the sun's magnetic particle stream gathered by the Advanced Composition Explorer, another NASA satellite. He converted signals showing the relative abundance of two types of carbon ions in the wind—those stripped of four of their six electrons and others that were entirely denuded, with all six electrons gone—into audible sounds. While listening to the file, Alexander discerned a hum at a frequency of 137.5 cycles per second—a sound close to a C-sharp below middle C.

That there was a hum at all meant that the relative amounts of the two types of carbon ions fluctuated over time. The sounds assigned to the different ions were, every now and then, interfering with each other. Put more musically, they were creating harmony.

"I was digging into the data, listening to 20 to 30 parameters, and I realized that when I got to carbon, there was a very strong harmonic presence," Alexander says. "If I'm hearing carbon, and no one has noticed it, I thought, maybe this is something worth looking into."

The frequency of the hum held a further clue: it corresponded to a time interval in the original spacecraft data of nearly 27 days, the time it takes the sun to revolve once on its axis.

Alexander brought his discovery to University of Michigan space physicist Enrico Landi, who realized that the ratio of the two types of carbon ions changed in sync with the two types of wind produced by the sun. One type, a fast-moving wind, comes from dark, cooler regions in the sun's outer atmosphere (or corona) that are known as coronal holes. Magnetic field lines in these are not tightly packed together, so they let particles escape more quickly. The slow wind, on the other hand, comes from hotter regions, which have denser magnetic fields.

These higher-temperature regions, because they have more energy, strip more carbon atoms of all their electrons than the colder regions can. In 2012 Landi, Alexander and their colleagues published a paper in the *Astrophysical Journal* that argued that the carbon ion differences were the best way to tell the two types of solar wind apart. The method, they contended, should replace what has been the standard diagnostic tool, the ratio of oxygen ions. Advance warning of the type of wind heading toward Earth can be important because each type causes different kinds of space weather, and their magnetic properties can disrupt satellite communications in different ways.

"Just by listening to the data, you could determine the period [of the signal] to a higher accuracy than any other mathematical method," Landi says. That insight has inspired him to explore other features of the sun with audio. Although it is known that the sun's activity cycle, including the number of sunspots, solar flares and other eruptions, waxes and wanes every 11 years, some scientists have suggested that the cycle sometimes lasts longer—19 to 20 years. "We would like to apply auditory analysis to study the 'extended solar cycle' and its relation to the standard 11-year solar cycle," Landi says.

AN UNHEALTHY NOISE

EVEN MORE DOWN-TO-EARTH BENEFITS can be had from turning data into sound. Researchers in England have begun applying sonification to the problem of telling cancer cells from healthy

IN BRIEF

Ears are linked to very fast brain connections, making them excellent data pattern finders.

Signatures of the solar wind, as well as far-off stars, have been discovered by this process of sonification.

Quick diagnosis of cancer cells might also be done by turning their molecular fingerprints into sounds.

SCIENTIFIC AMERICAN ONLINE Listen to audio signals from cancer cells and healthy cells at ScientificAmerican.com/mar2015/science-sounds

cells while a pathologist is examining biopsy samples from a patient who needs an answer in a hurry.

"In the U.K. health system, there is a very long wait between taking a biopsy from a patient, sending it to a lab, and having it analyzed and sent back," says Ryan Stables, a musician and digital-media technologist at Birmingham City University. In conferring with a colleague, analytical chemist Graeme Clemens of the University of Central Lancashire, Stables got the idea of transforming a visual technique of identifying cancer cells into an audio method.

"We wanted to speed up the process and have someone either in the patient's room or a general practitioner's office" with the data in front of them, determining whether cells are cancerous, Stables says.

In the usual procedure, known as Raman spectroscopy, a pathologist shines infrared laser light on cells sitting on a slide, and the light's energy prompts molecules in the cells to vibrate. Different molecules vibrate in different ways, and the vibrations shift the frequency of photons scattered back from the sample. The spectrum of color in the scattered light coming back from them is a fingerprint that identifies the molecular properties. Some molecules, part of abnormal proteins in cancers, have different fingerprints than normal proteins do. The visual differences are subtle, however, and it takes time and expertise to determine if the cells are healthy or not.

Subtlety, of course, is an auditory specialty. "The human ear is naturally trained in spotting patterns and regularities and is much better than the eye in recognizing them," says Stables's collaborator Domenico Vicinanza, a physicist and musician at DANTE, a European consortium in Cambridge, England, that builds and operates high-speed networks for research and education. For instance, Vicinanza says, the eye cannot tell the difference between a light that blinks 30 and 60 times a second, but the ear can distinguish a source of sound that vibrates 30 and 60 times a second.

Working with Vicinanza, Stables sonified the data, focusing on those parts of the visual spectrum that show differences between cancerous and healthy cells and turning them into distinctive sounds. Stables says he was not surprised that there would be differences between the sonified spectrum of healthy and cancerous cells, but he remarks, "I was surprised by how well we could classify the differences."

In tests, about 150 clinicians were given 300 sound files, each representing a different tissue sample. According to Stables, the clinicians correctly discerned differences between the samples about 90 percent of the time. He and his colleagues reported this work last June at the 20th International Conference on Auditory Display in New York City. Within a year, Stables says, the team expects to begin testing its sonified spectra in doctors' offices.

Stables also believes this method could make its way into the operating room, giving physicians fast feedback during surgery about whether they have removed all cancer cells or whether some remain. To make this work, the spectroscopic analysis has to be done quickly, sonified and broadcast into the operating room. That means Stables and his colleagues not only have to choose tones, pitches and timbres that preserve the character of the original spectrum but also create sounds that are pleasant.

"If you're doing some kind of high-precision surgical procedure, you don't want have this distracting, constant ringing in your ears," Stables says. "It is very difficult to find a balance between making the signal nondistracting and yet preserving the quality of the data that are actually relevant to discerning the differences between two types of tissues or cells." But his tests with clinicians indicate that the sonifiers have found a good balance.

SOUND VS. SIGHT

ALTHOUGH SONIFICATION OFFERS advantages over visual display, Stables, Alexander and other sound specialists face a major hurdle: simply getting researchers to try this new way of exploring data. From elementary school onward, "we're surrounded by visual representations—bar graphs and pie charts," Alexander says. By the time someone becomes a scientist, he adds, "they have a syntax, they have an understanding of how these plots function and a sort of internal logic, whereas when you push 'play' and listen to the data for the first time, you don't have a vocabulary, so you don't really have a basis for comparison."

But recent popularization of some of the research could help highlight the value of the audio approach. An x-ray recording of the violent behavior of a pair of orbiting stars, for example, has been transformed into an album, available on iTunes, of music featuring Afro-Cuban rhythms.

The pair of stars, dubbed EX Hydrae, consists of a white dwarf—an elderly, ultracompact star—locked in a tight gravitational embrace with a puffy ordinary star. As the two stars circle each other, the white dwarf rips matter from its partner, spitting into space x-rays that have been recorded by NASA's Chandra X-ray Observatory. Astrophysicist Wanda Diaz-Merced, who is blind, used an open-source computer program, xSonify, to convert the fluctuating energies of the x-rays into audio. Some musically inclined colleagues saw some of these data printed out as music notes. They strongly resembled a rhythmic pattern, called a clave, found in Afro-Cuban and bossa nova music. German composer Volkmar Studtrucker, a cousin of one of the scientists, took the idea and ran with it, penning an x-ray bossa nova, a fugue, a waltz, a blues composition, a jazz ballad and several other pieces based on different sequences of notes derived from the x-rays. The album, featuring piano, bass and drums, is called *X-ray Hydra*.

The compositions have become quite popular in the astronomy community and among other scientists, and that is music to Alexander's ears: "Part of the challenge is really just getting the data out there, getting more people to listen." He thinks listening will lead to fresh discoveries. This kind of audio "is filled with short, nuanced sounds," Alexander says, "and each one is a physics puzzle waiting to be solved." ■

MORE TO EXPLORE

Assisted Differentiated Stem Cell Classification in Infrared Spectroscopy Using Auditory Feedback. Domenico Vicinanza et al. Presented at the 2014 International Conference on Auditory Display, June 23, 2014.

The Bird's Ear View of Space Physics: Audification as a Tool for the Spectral Analysis of Time Series Data. Robert L. Alexander et al. in *Journal of Geophysical Research: Space Physics*, Vol. 119, No. 7, pages 5259–5271; July 2014.

FROM OUR ARCHIVES

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