

Tiny antennas form vast radio telescope array

A grassroots telescope array is taking aim at a wide range of astronomy questions, with projects in geophysics and agriculture piggybacking on its infrastructure.

Dipole antennas dotting the Netherlands and several nearby countries together form a radio telescope that is sensitive in the relatively unexplored wavelength range of 1–10 m (roughly 10–250 MHz) and has an enormous field of view. About three-fourths of the telescope's 44 stations are functioning, and the rest are set to be completed by the end of the year.

The International LOFAR Telescope—known as both LOFAR (for Low Frequency Array) and ILT—bucks the decades-long trend toward ever larger dishes that see smaller portions of the sky in more depth. Instead, like today's optical-survey telescopes, LOFAR trades lower sensitivity for greater sky coverage. "Your chance of finding something unusual depends on how much of the sky you can see and how often you sweep across it," says UK LOFAR leader Rob Fender of Southampton University, who is heading up a project that will link LOFAR to other telescopes to get continuous all-sky coverage. The project, called 4 Pi Sky, will focus on finding transient events. "If our estimates are right," Fender says, "we may see hundreds of transients a day."

Studying transients is one of LOFAR's six key scientific projects. The others are conducting deep extragalactic surveys and studying ultrahigh-energy cosmic rays, the sun and space weather, cosmic magnetism, and the epoch of reionization—the transition from neutral to ionized gas in the universe, which is linked to fundamental questions about cosmology. "Each of these projects pushes LOFAR to be high quality in different ways," says the University of Amsterdam's Ralph Wijers. As examples, studying cosmic rays requires the ability to store large amounts of data; transients push high data rates; and picking up the weak signals of the epoch of reionization requires that the instrument "be exquisitely calibrated to take away all other radio signals," says Wijers. "We want LOFAR to be as all-around as possible. You never know what creative idea the next guy will have."

Partners in Germany, the UK, France, and Sweden have their own

Low-tech dipole antennas form the basis of the world's most advanced radio telescope, the International LOFAR Telescope in Europe. The array's longer-wavelength detectors are wire pyramids (below); shorter wavelengths are observed with packs of 16 dipoles (right) that are, in the field, encased in foam.



ASTRON

fields of dipole arrays. By far the largest number and tightest concentration of stations is in the Netherlands, but the international fields increase the baseline by a factor of 10, to 1500 km. "The collaboration increases the resolution and brings in enormous expertise," says Wijers. When the Square Kilometre Array (SKA) comes on the scene sometime in the next decade, says Fender, "it will supersede everything" in radio astronomy. Until then, both in terms of underlying principles and capabilities, LOFAR is the most advanced radio telescope around.

Simple, cheap, hearty

Each LOFAR station consists of adjacent fields of two types of dipole antennas. Operating from 10 to 90 MHz are 1.5-m-high polarization-sensitive wire pyramids, each with a receiver sitting at the apex and wires descending toward

the corners of a square. The second class of dipoles are sensitive from 110 to 250 MHz. Those smaller (50-cm-high) antennas are encased in polystyrene foam tiles in sets of 16. Fields consist of 96 low-band antennas and either the same number of or half as many high-band array tile sets—for a total of 1632 or 864 antennas per field.

"A lot of thought went into making sure the antennas meet the specifications and can be made as cheaply as possible. They have to be hard to break, easy to replace, and mass producible," Wijers says. The tab for a field of 96 low-band antennas is about €15 000 (some \$21 000), he adds. And the total construction cost of LOFAR is €150 million. The project is spearheaded by the Netherlands Institute for Radio Astronomy (ASTRON), with the Dutch government paying the lion's share. Dutch universities and

foreign partners are also contributing.

The antennas are arranged to maximize the number of independent baselines. With a regular pattern, the Fourier transform gives “some nasty results in separating nearby radio stars,” explains Wijers. “If you make the pattern random, the resolution becomes better behaved. It makes it easier to see a weak source that is close to a much brighter one.”

Each antenna sees the entire accessible sky. Pointing is achieved by introducing phase delays according to antenna position. That process is digital and is done in real time or, with saved data, up to a few minutes later.

A fish-eye lens and the Moon

For most fields, the data are combined before being sent to a central IBM Blue Gene P supercomputer located at the University of Groningen. If they weren’t combined, says Wijers, “one station would produce about 120 gigabits per second. But we can only send 3 gigabits per second.” The limiting factors, he notes, are the capacity of glass fibers and “how much you can stuff into the supercomputer.”

Summing the signals effectively shrinks the field of view to about 1000 times the area of the Moon. Since work on LOFAR began 10 years ago, computer power has improved. Wijers heads a project within LOFAR to retain the dipoles’ intrinsic all-sky capability for the telescope’s six central dipole fields, which occupy an area 350 m across. Dipoles in those fields are treated individually and the area, says Wijers, “has become the equivalent of a fish-eye lens.”

The price, he adds, is about an order of magnitude in instantaneous sensitivity. “We can catch the rarest and brightest objects.” The science goals of his project, called AARTFAAC for Amsterdam–ASTRON Radio Transients Facility and Analysis Centre, are to get at questions like How are black holes born? How can energy be expelled from black holes? What is the origin of magnetic fields and cosmic rays in jets and shocks?

Heino Falcke of the Netherlands’ Radboud University Nijmegen is using LOFAR to probe cosmic-ray particles. The radio signature of cosmic-ray particles hitting the atmosphere is a beam of radiation originating at an altitude of a few kilometers. “The nice thing about LOFAR,” Falcke says, “is that we can image the entire sky at all frequencies and all time scales. It doesn’t matter where the cosmic ray comes from, we can trace it back.” For atmospheric cos-

mic rays, LOFAR yields information similar to that from the Pierre Auger Observatory, says Falcke. (See PHYSICS TODAY, May 2010, page 15.) “You can get the height and evolution of a particle shower from looking with thousands of antennas. This should tell us something about the nature of the primary particle creating the shower.”

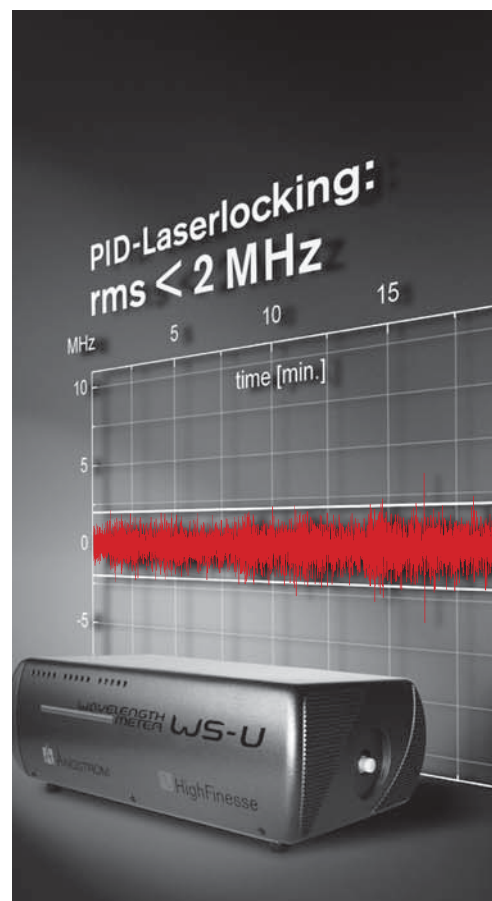
And for primaries with higher energies— 10^{22} eV and higher—possibly from topological defects in the early universe or accelerated by nearby black holes, Falcke says LOFAR has the advantage: “You would need millions of square kilometers, and that is nowhere to buy.” But by using the Moon as a detector, cosmic rays can be inferred from radio flashes produced when particles hit. “I think we will be able to rule out exotic models for neutrino production and probe the end of the ultrahigh-energy cosmic-ray spectrum,” he says.

Continuous, all-sky monitoring

“Ideally, we would like to find colliding neutron stars at redshift 10—right back to when stars and galaxies formed,” says Fender. “If we find something way back then, we would learn about rates of formation.” His 4 Pi Sky project involves collaborating with other observatories and automating data analysis to find “explosive and variable sources in real time without human intervention.” Software will identify, analyze, and make preliminary classifications. And it will send signals to partner telescopes. So far, Fender says, “we have the beginnings of things like decision trees. We know what [the software] should do, and how fast.” Like the projects led by Wijers and Falcke, 4 Pi Sky has funding on the order of €3 million over five years from the European Research Council.

The main partners for 4 Pi Sky are the Australian Square Kilometre Array Pathfinder (ASKAP) and the Karoo Array Telescope (MeerKAT) in South Africa—both being built for their own merit and in the hope of being selected next year as the SKA site. ASKAP and MeerKAT will both operate at higher frequencies than LOFAR. Between them, LOFAR and ASKAP will be able to sweep the whole sky daily, and MeerKAT can follow up on any transients identified by its fellow Southern Hemisphere array and about half of those spotted by LOFAR.

The 4 Pi Sky project also has agreements with the group that runs MAXI (Monitor of All-Sky X-Ray Image), a Japanese instrument aboard the International Space Station, and is seeking links to optical telescopes. In addition,



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Fender has hooked up with Advanced LIGO and Virgo, respectively the US- and European-led gravitational-wave detectors, to follow up on each other's observations. For example, says Fender, "if one object is spiraling into another, from the gravitational signal alone you can estimate the distance, assuming general relativity is right. Say LOFAR sees a flash, too. If the distances don't match, general relativity is wrong."

Besides astronomical research, LOFAR is serving as physical and software infrastructure for studies in agriculture and geophysics. The first agricultural project involved measuring temperature, humidity, and other parameters to help battle phytophthora, a fungal disease in potatoes. Among the geophysics projects in the works are seismic and infrasound studies to detect and characterize such events as earthquakes, nuclear detonations, vol-

canic eruptions, and sonic booms. Both sets of experiments involve attaching sensors to LOFAR's network. Delft University of Technology's Guy Drijkoningen, who heads the geophysics applications of LOFAR, says that for seismic and infrasound data, "the highly innovative aspect is the design and use of interferometry. It allows [us] to see sources in and above the Earth which have not been seen before."

Toni Feder

DOE looks again at inertial fusion as a potential clean-energy source

As ignition experiments get under way at the National Ignition Facility, an official says the Department of Energy should be preparing for a decision on whether laser-driven fusion energy can be harnessed.

Sometime during the next two years, physicists are expecting to achieve a long-sought milestone in fusion research: ignition and high energy gain. That breakthrough won't be happening at ITER, the international collaboration that is building a reactor in France, but at the National Ignition Facility (NIF) for nuclear weapons-related experiments that was completed two years ago at Lawrence Livermore National Laboratory (LLNL).

In the quest to develop nuclear fusion as a bountiful source of clean energy, the inertial confinement route, in which high-powered lasers implode tiny capsules of fuel to fuse heavy isotopes of hydrogen, has long been seen as the underdog. The magnetic confinement approach, in which powerful magnetic fields are used to bottle up plasmas of deuterium and tritium that are heated to more than 100 million K, has been pursued for decades by the US and other industrialized nations in the hope that it will become a practical and clean source of energy. Inertial confinement fusion (ICF) has been advanced primarily for its military applications, because it can simulate in the laboratory some of the processes that occur in the fusion stage of thermonuclear weapons.

But that landscape could be about to change as scientists begin to experiment in earnest toward their goal of achieving ignition and high gain at NIF. If they are successful, for the first time in more than 50 years of ICF research experimenters will get more energy from the fusion reaction than they put in to produce it. Already, scientists and engineers have begun to reexamine the possibility that ICF might offer a quicker path to fusion energy. At the request of Steven Koonin, DOE undersecretary for

science, a National Research Council (NRC) committee is looking at inertial fusion energy (IFE) and will advise how soon and at what cost the required technologies could be developed. Chaired by Ronald Davidson, former director of Princeton Plasma Physics Laboratory, and Gerald Kulcinski, a professor at the University of Wisconsin-Madison, the committee has met twice since December, and is expected to provide its interim findings to DOE in the summer.

In an interview, Koonin says he wants the NRC analysis in hand if and when ignition is achieved, so that he'll be prepared for the inevitable questions. Quoting hockey great Wayne Gretzky, Koonin says DOE should be "skating to where the puck will be" on IFE. Using that rationale, Koonin last year recruited David Crandall, the chief scientist in DOE's National Nuclear Security Administration (NNSA), to a new post that would administer DOE's IFE R&D, should LLNL experiments be successful.

The importance of ignition

Even proponents agree that the success of the experiments known as the national ignition campaign is critical to IFE's future. "You have to be able to show that a driver can compress a pellet enough to get at least as much fusion energy out of it as you are putting in," says Stephen Dean, president of Fusion Power Associates, an industry group. It's hoped that NIF will get 10–20 times the amount of energy out as went in. To become economical, a power plant might need to achieve a gain of 50–100, Dean says.

Koonin is no stranger to ICF. He has kept a close eye on the DOE program for the past two decades, during most of which he was a professor and

provost at Caltech. He is personally overseeing the ignition campaign, and has already visited LLNL twice to review the initial results. He has appointed a group of outside experts to provide their own takes on the experiments. Koonin has been a member of several external ICF review panels, including a 1992 committee that explored IFE's potential (see the article by William Hogan, Roger Bangerter, and Gerald Kulcinski in *PHYSICS TODAY*, September 1992, page 42). At least four other assessments of IFE, not counting the current one, have taken place, from 1978 to 2007. Each of them identified ignition as the required next milestone.

Koonin is well acquainted with NIF, having chaired a 1997 NRC committee that recommended DOE proceed with construction of the facility. At the time, the department estimated NIF would cost \$1.1 billion and be completed in 2002. In reality, the device was completed in 2009 for \$3.5 billion. But Koonin stands by his assertion in a December memo to other top agency officials that "the speed and efficiency with which the NIF was built and brought on line, in spite of unforeseen difficulties encountered along the way, are remarkable."

The NIF ignition campaign will be critical to IFE, Koonin says. While a failure to attain ignition within a few years could be a death sentence for IFE, its success would hardly assure its feasibility. For starters, NIF's lasers aren't capable of firing rapidly enough to produce meaningful amounts of energy. The laser optics must be cooled between shots. In weapons-physics experiments, that's not an issue, because one shot a day is more than enough. But LLNL already has proposed a different solid-state laser for IFE, where NIF's flashlamps are replaced by diodes, and new