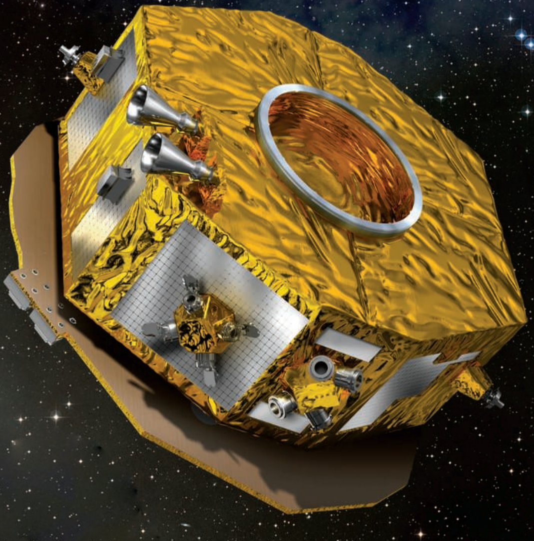


SPACE PHYSICS

LISA Pathfinder tests spacetime sensor

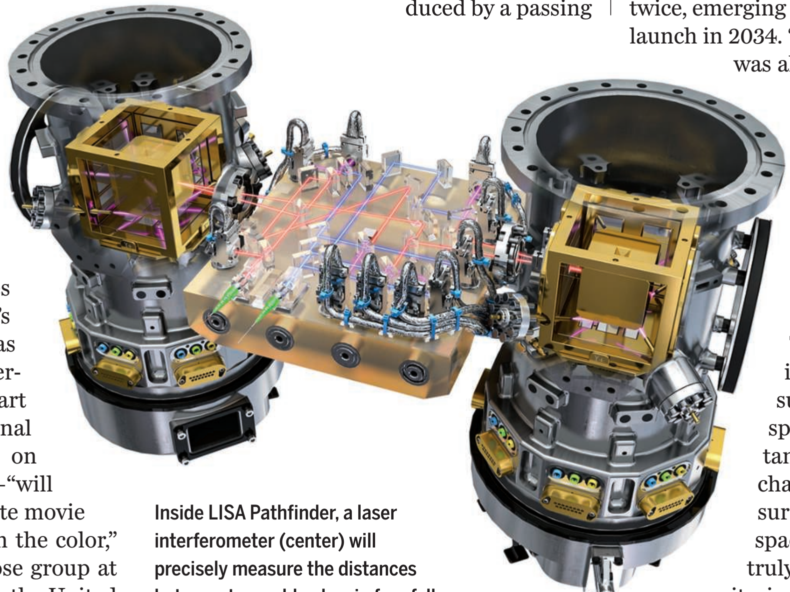
A European space probe is set to pave the way for measurements of gravitational waves

By **Daniel Clery**

In early December, the European Space Agency (ESA) will launch a spacecraft with a deceptively modest goal. It will not observe Earth or search space for quasars or exoplanets. Instead, it will set two cubes of gold-platinum alloy—each slightly larger than a golf ball—floating freely in weightlessness and attempt to measure their distance apart to the nearest trillionth of a meter. But if it succeeds, the €430 million Laser Interferometer Space Antenna (LISA) Pathfinder mission will open the way for major ambitions.

By making such precise measurements in space, the mission will prove the concept of the roughly €1 billion Evolved LISA (eLISA). To be launched in roughly 20 years if all goes well, eLISA aims to detect the gravitational waves emitted by some of the universe's most titanic processes, such as the death spiral of the supermassive black holes at the heart of galaxies. Detecting gravitational waves—a feat that detectors on Earth are also vying to achieve—"will be like going to a black-and-white movie and suddenly someone turns on the color," says physicist Mike Cruise, whose group at the University of Birmingham in the United Kingdom built part of the laser metrology equipment for LISA Pathfinder.

Physicists have been on the hunt for gravitational waves—one of the more striking predictions of Einstein's general relativity—since the 1960s. The biggest current effort, the $620 million Laser Interferometer Gravitational-Wave Observatory (LIGO) in Louisiana and Washington states, recently started up again after a major upgrade (*Science*, 6 March, p. 1084). In LIGO, physicists bounce laser beams along two 4-kilometer vacuum tubes, producing an interference pattern sensitive to the minuscule squeeze and stretch of space produced by a passing gravitational wave. The trouble is that a multitude of other vibrations can mimic that signal: everything from surf crashing on beaches to the churning of Earth's core.



Inside LISA Pathfinder, a laser interferometer (center) will precisely measure the distances between two gold cubes in free fall—a technique that future spacecraft will use to detect gravitational waves.

In space, the problem of vibrations disappears and real estate is cheap, allowing the arms to be far longer, monitored by free-flying spacecraft. A space-based detector was first proposed in the 1980s and coalesced into ESA's LISA. NASA joined the project, but it hasn't had an easy ride. In 2011 NASA pulled out because of budget problems and the mission was redesigned twice, emerging as eLISA and penciled in for launch in 2034. "In every review, the science was always rated as outstanding," says Paul McNamara, ESA project scientist for LISA Pathfinder. But when it came to selection, "it was always everyone's second favorite mission," he says.

eLISA's arms will be 5 million kilometers long. Three spacecraft will fly in formation around the sun, beaming lasers through space to measure their distances from one another. The challenge for eLISA is to ensure that the mirrors in each spacecraft are shielded and truly free-floating, so that gravity is the only force acting. "We have to make sure there are no interfering forces," Cruise says. Solar

IMAGES: (TOP TO BOTTOM) ESA–D. DUCROS, 2010; ESA/ATG MEDIALAB

The 2.9-meter-wide LISA Pathfinder will test technologies for a planned fleet of spacecraft that would orbit the sun 5 million kilometers apart.

wind and radiation or gravitational and magnetic forces from the spacecraft could all skew the results.

LISA Pathfinder replicates one arm of eLISA, but with 5 million kilometers shrunk down to 35 centimeters. The two alloy cubes are the mirrors; they will float inside the spacecraft while a laser interferometer measures the distance between them. “Almost all the technologies you need for eLISA are in LISA Pathfinder. Only the long arms are missing,” says Karsten Danzmann of the Albert Einstein Institute in Hannover, Germany, co–principal investigator for LISA Pathfinder.

Even if the prototype succeeds, astronomers will have to wait decades to look through their gravitational-wave telescope. It’s likely that LIGO or another instrument will be the first to detect spacetime ripples—perhaps in the next few years. But each detection technique is sensitive to waves with different frequencies and hence different astrophysical sources.

LIGO and similar detectors in Europe and Japan are sensitive to high-frequency waves from events such as the merger of binary neutron stars or black holes of a few times the mass of the sun. eLISA would pick up lower frequencies—about one beat every 1000 seconds—produced by much more massive, slower moving objects such as supermassive black holes. “When galaxies merge, their central black holes sink to the center and eventually merge [as they shed energy] by gravitational wave emission,” says theorist Jonathan Gair of the University of Edinburgh. “We’ll see the whole process.”

Other targets include small black holes falling into supermassive ones, and run-of-the-mill stars, such as white dwarfs, orbiting in binary pairs. eLISA will be able to take a census of such pairs across the Milky Way. And each measurement will be a test of general relativity itself, to see whether—after a century of stress testing—it still holds true in all circumstances. “If things deviate, even by a small amount, we can detect that,” Gair says.

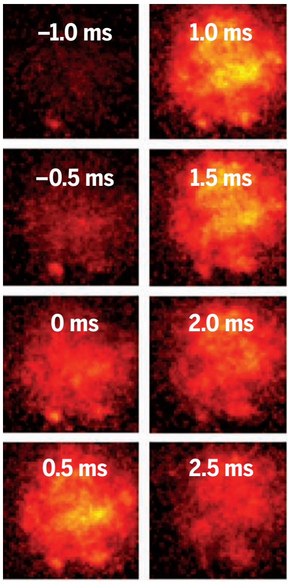
The first step will be LISA Pathfinder’s launch from the ESA spaceport in Kourou, French Guiana. A couple months later, when the spacecraft has reached its destination 1.5 million kilometers from Earth, the team will be on the edge of their seats, says principal investigator Stefano Vitale of the University of Trento in Italy. “The moment we release the test masses in free flight, [that will be] a first in space science.” ■

NEUROSCIENCE

A faster, brighter picture of brain cells in action

New voltage-sensor achieves submillisecond precision

By **Emily Underwood**



Voltage spreading through a fly neuron over several milliseconds.

IMAGE: GONG *ET AL.*/*SCIENCE*

At the heart of all brain activity—thoughts, perceptions, emotions, and memories—are rapid surges of electrical activity, called action potentials, that zip through neurons and transmit information throughout the brain. Capturing this play of activity across large numbers of neurons is essential to understanding cognition, but existing techniques for monitoring neurons are too slow, or their scope too limited, for scientists to really see the brain at work.

This week online in *Science*, a research team led by a physicist at Stanford University in Palo Alto, California, reports a new technique that renders spikes of electrical activity visible under a microscope as flashes of light with a temporal resolution of about 0.2 milliseconds. At that speed, scientists will be able to observe not just when cells fire a full-blown action potential, but more subtle electrical activity within individual neurons’ branches, says neuroscientist Van Wedeen of Harvard Medical School in Boston. “The field has been waiting for this for years.” Timing is everything in the brain, he notes, and witnessing such rapid dynamics “could reveal aspects of neural code we’ve never had experimental access to before.”

At present, scientists can record the aggregate electrical activity of large groups of cells with electrodes placed on the scalp or inserted into brain tissue. They can also record directly from individual neurons in a dish or animal using microelectrodes. But none of these techniques is well suited to recording details of a live brain’s electrical activity within individual neurons of a chosen genetic type, says Mark Schnitzer, the principal investigator of the new study.

So-called calcium imaging, in which neurons are coaxed to fluoresce in response to the surges of calcium ions that accompany action potentials, can track many individual neurons at once. But it is too slow to capture much of their electrical chatter, which unfolds within milliseconds or even fractions of a millisecond, Schnitzer says. In search of faster methods, his group and others have endowed neurons with genes for fluorescent proteins that brighten or dim when they sense changes in voltage in the cell membranes. But most voltage indicators fluoresce weakly, forcing researchers to use such powerful beams of light to reveal the sensors’ faint glow that it “barbecues anything living,” Wedeen says.

Yiyang Gong, formerly a postdoc in Schnitzer’s lab and now a professor at Duke University in Durham, North Carolina, has worked with the Stanford team to create a much brighter voltage sensor than those developed by other groups, while maintaining light levels that can be used in living animals. The group combined a fluorescent protein engineered by Nathan Shaner and colleagues at the Scintillion Institute with another, fungus-derived protein that responds five to six times more quickly to changes in voltage than the one used in their previous model. The new work is “the first demonstration that one can image action potentials optically in an awake mammalian brain,” Schnitzer says.

The new voltage sensors can also be expressed in just specific types of neurons, adding to the method’s usefulness. They can’t be used for extended periods, however, because the proteins lose their sensitivity to light after about 10 minutes of continuous exposure. But by using multiple short exposures, investigators should be able to observe neural activity for much longer periods, Schnitzer notes. “This should be the next big thing as the methods get refined and extended,” says Bruce Rosen, director of the Center for Biomedical Imaging at Harvard University, “I think this is pretty cool.” ■