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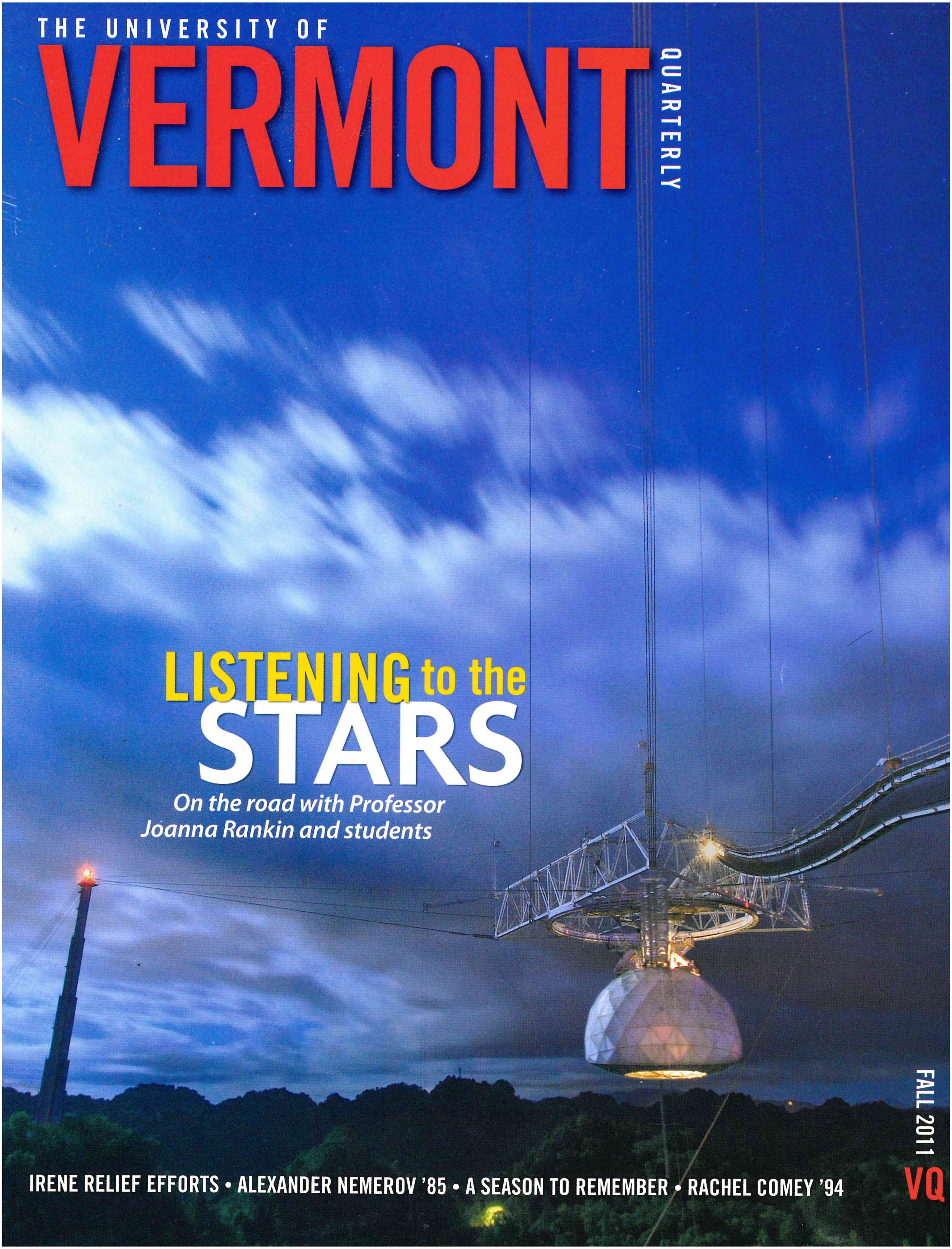

LISTENING to the STARS

On the road with Professor Joanna Rankin and students

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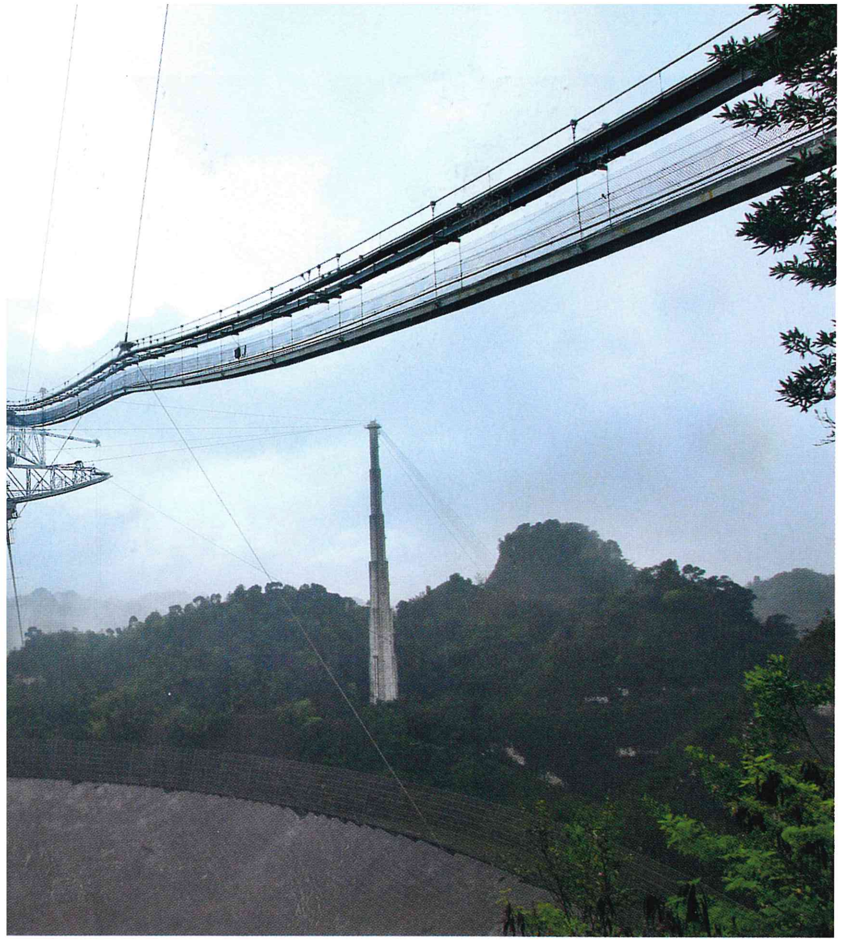
LISTENING to the STARS

story & photography by Joshua Brown

IT IS ALMOST NIGHT on the island of Puerto Rico. Astronomer Joanna Rankin raises her head toward the sky. A few of the brightest stars shine through blue cracks in a ragged dome of gray clouds. To her back, a jungle throbs with the insistent call of frogs. In front of her, a giant bowl made of perforated metal dips steeply and rises on the other side of the valley, a thousand feet away. It looks like a colossal contact lens dropped from outer space.

This is the reflecting dish of the Arecibo Observatory: the largest radio telescope in the world, located in Puerto Rico due to ideal natural conditions, a sinkhole in the limestone hills over which to suspend the dish. Rankin has been coming here to study stars since she was a graduate student in the 1960s. Now she brings her own students here to, as she says, "get their hands on the wheel." Tonight, she stands next to one of the three concrete towers that surround the dish, chatting amiably in the fading pink light with her partner, Mary Fillmore, and three undergraduates from the UVM physics department: Isabel Kloumann '10, Mateus Teixeira '11, and Stephanie Young '11.

Above them, 450 feet over the center of the reflecting dish, floats an impossible-looking metal lattice triangle. Suspended by cables from the three towers, it looks like some child's fantasy airship made from an erector set—except it weighs nine-hundred tons. From the underbelly of this contraption dangles a huge antenna and a flattened silver ball sixty feet across, the telescope's Gregorian dome.



"I've never lost sight of my privilege in using this instrument," Rankin says, again turning her head skyward, "to come here and have a kind of one-way conversation with nature that almost no one else can."

What Rankin listens for in this conversation are the sounds of pulsars—one of nature's strangest objects. And what she hears from these unlikely stars may help to prove one of Albert Einstein's most outlandish theories: the existence of waves in the fabric of space itself. But even if the sky were perfectly clear tonight, the pulsars Rankin has come here to study would not be visible. Instead, she relies on the staggering sensitivity of this telescope to gather infinitesimal drops of radio-wave energy from them, which she then teases apart looking for sidereal meaning, the language of stars.

At first, astronomers thought pulsars might be aliens. In 1967, an enterprising graduate student at Cambridge University named Jocelyn Bell was baffled by the extreme regularity of highly focused radio wave bursts she accidentally discovered coming in from one point in the Milky Way. On then off—every 1.3 seconds. Nothing like this had ever been observed in the heavens; nothing like it had even been imagined. She dubbed the source LGM-1, for "little green men." Had she made contact? The extraterrestrial messages turned out to be radio bursts from a pulsar.

No bright glowing ball of gas like our home-star, pulsars are the burned-out core of a moderately large star that has consumed all its fuel. With no more outward pressure from the burning hydrogen, the star suddenly collapses on itself and then rebounds, blowing off its outer layer in a spectacularly violent explosion. Compressed by the explosion and gravity, what remains is a sphere so dense that its atoms degenerate into naked neutrons and exotic particles smashed on top of each other in unearthly layers that contain about a billion tons per square centimeter.

"Pulsars are about the size of a small city, like Burlington—maybe ten miles across," Rankin says, "with mass comparable to or somewhat greater than the sun." Compared to a black hole, a pulsar is a kind of scrawny cousin not quite massive enough to fall into complete light-sucking density. Still, a sugar cube of this star-stuff would weigh more than all the people on Earth.

And, like a twirling figure skater who suddenly pulls her arms in and starts spinning much faster, this tremendous compression of mass during the formation of a pulsar sets it spinning so fast it challenges our Earth-bound conception of speed. A "regular" pulsar will spin several times per second, but another family of pulsars gathers additional speed by pulling in gas from another star nearby. These so-called millisecond pulsars can spin as fast as seven hundred times a second, nearly one-quarter the speed of light.

"Pulsar" is a contraction for "pulsating star"—but they're actually more like a lighthouse. As a pulsar spins—or more accurately because a pulsar spins, like the universe's most powerful electrical generator—it shoots out two cones of radio emissions from several hundred miles above its bogglingly powerful magnetic poles. Then this dual beam sweeps across the cosmos for hundreds or thousands of years, until it happens to shine on Earth, and a few of its photons chance to fall on a reflector in a limestone sinkhole in a Puerto Rican forest—where this radio energy appears as a methodical flash in a telescope tuned to the right frequencies.

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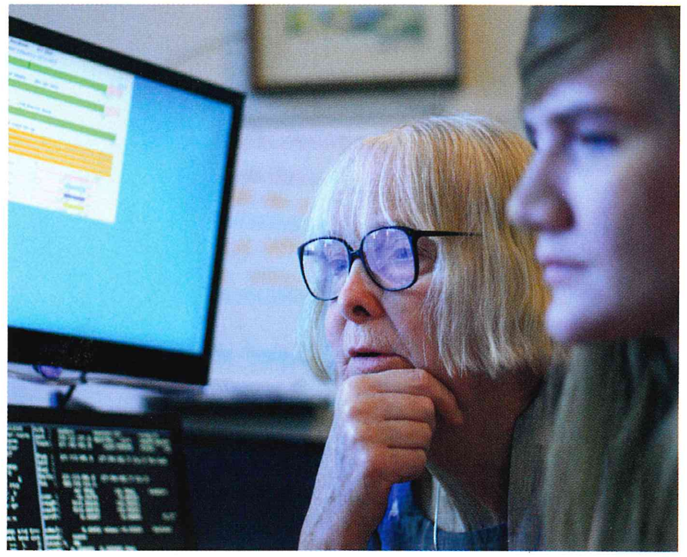
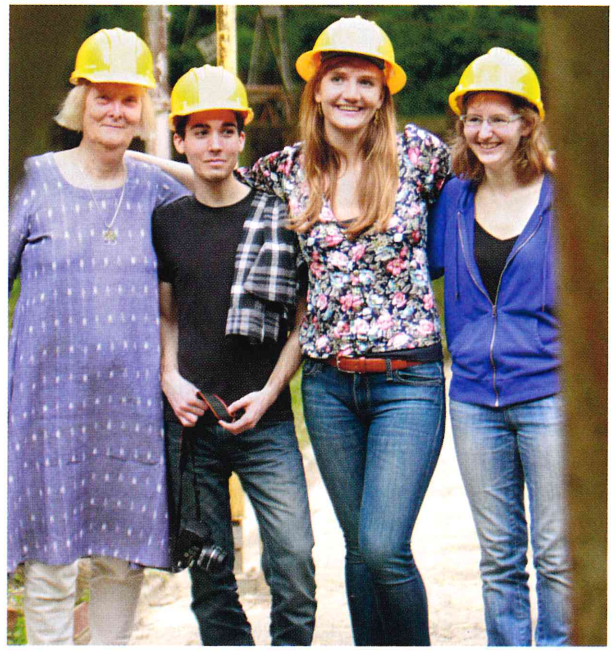
—*Joanna Rankin*

Two days later, Rankin and one of her students, Isabel Kloumann, are in the Arecibo Observatory's control room, tuning in pulsars. They've been allotted about three hours to run the telescope. The place looks like a cross between the bridge from Star Trek and the nurse's station in an intensive care unit. Behind a curving bank of double-stacked computer screens—filled with pulsing graphs and long rows of numbers—a two-story window looks out on the telescope. From speakers





"Joanna is a pulsar goddess," Isabel Kloumann and the other physics students say several times during the Arecibo visit. "She's a fantastic mentor who is there when you need her and leaves you alone when you don't."

on the wall, a soft repetitive beeping fills the air, sounding a bit like Arecibo's nighttime frogs. It's the noise of motors and gears on the telescope's platform, moving overhead to follow a star.

Rankin and Kloumann have almost finished a forty-minute run of having the telescope track a faint pulsar named, without even a whiff of poetry, B2044+15. "So, we should make a move to a new star," Rankin says, and then looks through the top of her glasses with a smile. "Do you want to drive?"

"I'd love to, yes," says Kloumann and Rankin pushes back her chair so that her student can get to the keyboard.

Rankin points to one of the flat-screen monitors glowing blue in the strange half-light. "If you go over to the left-most panel you can bring up pointing control," Rankin instructs. "And let's go to pulsar 2110+27," she says.

Kloumann begins to enter instructions into the computer and soon the massive telescope outside starts moving to her commands, the Gregorian dome ponderously sliding along its curving track as the whole circular base rotates. Soon radio waves from B2110+27 will begin bouncing off the reflecting dish up to helium-cooled receivers in the Gregorian dome. Then, as improbably as picking out a mosquito's heartbeat in a roaring stadium, the star's pulses begin thump, thump, thumping across the screen.

In these pulses is the raw material for months of future analysis by Rankin and her students. And much of what has been learned about pulsars in the last four decades has been from radio data gathered, just like what Rankin and Kloumann are doing, here at the Arecibo Observatory, a facility of the National Science Foundation.

"But there is much that remains mysterious," Rankin says. "We have a very good cartoon," she says, "we know that pulsars tap their rotational energy—somehow—and turn it into radio waves."

"But we don't exactly understand the emissions processes," she says, "is it more like a laser or clouds of particles?"

To even get to the cartoon stage of understanding, astrophysicists like Rankin have tried to decipher the language of emissions that different kinds of pulsars produce. And her students do the same.

"The flash is not just a flash," Kloumann says, "it has structure to it."

When you shine a flashlight on the wall, some parts are bright, some are dim. Ditto for pulsar emissions. The radio beam surges and shifts like a rotating carousel of lights. "The devil is in those details of the pulse's variations and geometry," says Rankin.

Or consider pulsar B1944+17 that Kloumann has been studying on her own for several years. She will be presenting a scientific paper on this star here at the observatory in a few days—in a conference dubbed the "Fab Five Fest," to honor five astronomers, including Rankin, who have been the leading pulsar scientists at Arecibo over the years. Kloumann will tell them how B1944+17 sometimes just turns off. And no one is exactly sure why.

"All of us in Joanna's group, we're looking at these really unusual stars that don't fit the perfect model," Kloumann says. "They test the bounds of the theory—which is what you always should do in science: push the limits of the theory."

Night has fallen again and Joanna Rankin, Mary Fillmore, and Isabel Kloumann are sitting on the porch of one of the small plywood huts that dot the steep hillside about the telescope, mixing drinks with pineapple juice. Again the darkness is laced with the sound of frogs, a hint of salt air from the nearby ocean, and thin bands of stars through the thick vegetation.

Over the years, with funding from the National Science Foundation, Rankin has brought many crews of students to Arecibo. "They're my pulsar mafia," she says with a deadpan look and then laughs, "watch out for astronomers." Some of the students do go on in astronomy. Isaac Backus ’11 came back for a summer internship at the observatory and then onto another post at a telescope in India. He's about to begin a doctorate in physics at the University of Washington. Megan Force ’09 G’11 came to Arecibo with Rankin and is now enrolled in a doctoral program in astrophysics at Dartmouth. And this is Kloumann's second trip to the telescope. She has leveraged her training in astronomy and applied mathematics into a slot as a doctoral student at Cornell.

Rankin, and several of Kloumann's other professors, describe her as one of the finest students they've taught. Winner of a Goldwater Scholarship and other awards, she's first author on a publication in the *Monthly Notices* of the Royal Astronomical Society and is a co-author on a forthcoming article in the journal *PLoS One*.

In her turn, Kloumann raves about Rankin. "Joanna is a pulsar goddess," Kloumann and the other physics students say several times during the Arecibo visit. "She's a fantastic mentor who is there when you need her and leaves you alone when you don't."

Tonight, Rankin and Kloumann are tutoring a somewhat more plodding student of physics. They're explaining to me, for a second time, how a better theory of pulsars may, in turn, help confirm one of Albert Einstein's most intriguing predictions: the existence of gravitational waves.

In 1916, Einstein put forth his general theory of relativity and that was the end of Western science's two-hundred-year trip on Isaac Newton's leaking boat. In the first great scientific revolution of the twentieth century, Einstein demonstrated that space and time flow together—that they are, really, as physicists now say, "spacetime." Equally strange, Einstein demonstrated that this spacetime, "like a vast sheet of rubber," says Kloumann, can be bent by matter and energy.

And it's this bending, these dimples and depressions in this substanceless sheet, that are responsible for gravity. In Isaac Newton's universe, the moon and Earth simply attract each other. In Albert Einstein's universe, the moon falls into the depression the Earth has made in the fabric of spacetime. And the flow of time, too, slows down as spacetime is warped near massive objects, like Earth, or, far more so, stars.

From this general theory, Einstein conjectured that when two massive objects, say two black holes, "go spinning around each other like a whirling dumbbell," says Kloumann, they should make waves in the fabric of spacetime. "A bit like ripples from a pebble tossed into a pond," she says.

> **"To detect gravitational waves is in some sense the missing link of Einstein's theory of general relativity."**
>
> *—Astronomer Joanna Rankin*

These waves, physicists now are confident, travel through the universe, passing through Earth, you, this magazine—at the speed of light.

"To detect gravitational waves is in some sense the missing link of Einstein's theory of general relativity," says Rankin. Problem is, gravitational waves are small. "Exceedingly tiny, tiny, tiny," says Kloumann. So small that a passing gravitational wave would stretch this magazine by only a fraction of the width of an atom. Which is why, though they were indirectly confirmed in 1993, they have never been directly observed.

Here's where pulsars may help. To understand how, consider another freakish aspect of these stars: they are the universe's best clocks. In 1967, Jocelyn Bell discovered that her little green men didn't flash every 1.3 seconds, they flashed exactly every 1.337 seconds. No, every 1.33728 seconds... and when she and her professor were done calculating they realized that the finest human-made clocks of the day were not accurate enough to time this strange signal.

Because of their extreme density and enormous speed, pulsars turn out to be a nearly perfect flywheel—and this stability makes the arrival of each pulse so regular that some pulsars rival or exceed the precision of human-made atomic clocks. Scientists can now show that, about five hundred light-years away, the pulsar J0437-4715 spins on its axis every 5.7574451831072007 milliseconds—give or take a pinch.

And that accuracy—and more—will be necessary to surf the trough of a gravitational wave. Which is what a consortium of U.S. and international astrophysicists, including Rankin, aims to do. The group, NANOGrav, is assembling a selection of highly precise pulsars in many parts of the sky and is timing the arrival of their pulses for years.

These dozens of pulsars, working as far-off clocks, will allow the team to sift out when a gravitational wave has passed by. They'll be looking for a distinctive pattern in the arrival time of emissions from pulsars in opposite sides of the sky. And this requires developing enough precision to distinguish the wave's faint but unmistakable signature from many other disturbances to the incoming radio waves.

"Pulsars are highly precise, but they're not perfectly precise," Kloumann says. Sometimes pulsars appear to have starquakes. These kinds of glitches and the variations within single pulses that Rankin studies are one form of noise that need to be accounted for in the NANOGrav models—so the team can pick out the puny voice of gravity from the roaring din of the cosmos.

If gravitational waves can be detected, then the location and strength of their sources can be calculated. And that, Rankin thinks, could be as revolutionary as Galileo's invention of the optical telescope. "Being able to detect gravitational waves opens up a whole new equivalent spectrum," she says. "We'll be able to study gravitational radiation as well as electromagnetic radiation."

Some astronomers anticipate the invention of gravity telescopes that will be able to look at spinning black holes, cracks in the universe called cosmic strings, and deeper into space than the most-distant quasars now visible. Some speculate about revealing new galaxies of invisible stars made from exotic dark matter. Perhaps some member of Joanna Rankin's pulsar mafia will, like Jocelyn Bell in 1967, make the next unexpected discovery. "Who knows what we'll find out there," says Kloumann. "It's like never having seen light before." **VQ**