A PUBLICATION OF THE UNIVERSITY OF VERMONT DEPARTMENT OF PHYSICS SUMMER 2012

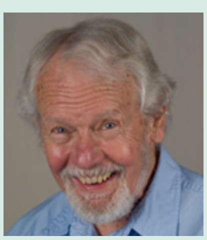
Physics@UVM

Faculty Notes

Dr. Randall L. Headrick was promoted to Professor of Physics. Dr. Headrick's research broadly concerns the study of the properties and structure of materials. He makes frequent use of x-ray diffraction to characterize surfaces and interfaces of materials. Dr. Headrick is widely recognized for his important contributions to the use of surface x-ray techniques.

Dr. Madalina Furis was promoted to Associate Professor of Physics with tenure. Dr. Furis's research program focuses on electronic and magnetic properties of semiconductor nanostructures. During her time at UVM, she has established a state-of-the-art ultrafast magneto-spectroscopy facility that has attracted the attention of condensed matter physicists at a variety of universities and institutions across the country.

Dr. Malcolm Sanders was reappointed as Senior Lecturer of Physics. Dr. Sanders teaches an array of core introductory courses in physics. He has also created a number of popular electives in physics, including the Physics of Music and Musical Instruments (PHYS 044) and Energy and the Environment (PHYS 009).



Mr. Don Manley was promoted to Lecturer III. Mr. Manley has played a key role in the growth in the astronomy program. Don created our very popular introductory astronomy laboratory course Measuring the Sky (ASTR 023). He has also developed several astronomy elective courses, including Moons and Planets (ASTR 053) and the Big Bang (ASTR 055).

Dr. Adrian Del Maestro, Assistant Professor of Physics, was an invited lecturer at the international summer school on new trends in computational approaches for many-body systems, held May 28-June 8, 2012 in Magog, Quebec.

Dr. Valeri Kotov, Assistant Professor of Physics, was an invited member of the Kavli Institute for Theoretical Physics in Santa Barbara, California during the month of January 2012. He served as a participant on the KITP program on the physics of graphene.

Dr. Jun-ru Wu, Professor of Physics, was recently awarded a patent titled "Piezoelectric vibrational energy harvesting systems incorporating parametric bending mode energy harvesting," with his co-inventor Dr. Robert Andosca.

In memoriam

By Junru Wu and Elsa Mondou

Dr. Wesley Nyborg, Physics Professor Emeritus at the University of Vermont, passed away on September 24, 2011 after a full and wonderful life of 94 years. Wesley was born in Ruthven, Iowa in 1917 as the youngest of Isaac Nyborg and Alma Larson's 6 children. Wesley's childhood was spent on a rural farm in a time and place before electricity and cars were widely available. In his youth, he attended a one-room schoolhouse, and greatly enjoyed family sing-a-longs at the piano. After high school, he studied at Luther College where he was introduced to physics, which became his lifelong intellectual pursuit. He earned his Ph.D. from Pennsylvania State University in 1947, and served as an Assistant and Associate Professor of Physics at Brown University prior to joining the UVM Physics Department in 1960. He loved physics passionately and authored numerous peer reviewed articles and book chapters with a focus on ultrasound, particularly its clinical application and biophysical effects. He developed fundamental theory on microstreaming, acoustic radiation pressure and thermal effects of ultrasound, and he was considered one of the most influential pioneers by the international biomedical ultrasound community.

He was a member of the National Academy of Engineering, and a fellow of the Acoustical Society of America, the American Institute of Ultrasound in Medicine (AIUM), and the American Association for the Advancement of Sciences. He was also an honorary member of National Council on Radiation Protection and Measurements and served as a consultant to the WHO and FDA. He was presented with many honors and awards including the prestigious Silver Medal of Acoustic Society of America, the Joseph H. Homes Pioneer Award, the W. J. Fry Memorial Lecture Award, and the Lauriston S. Taylor Lecture Award.

He was a venerable, gentle man with a fine sweetness of character and humility. He loved the UVM Physics Department, and worked there more than 50 years. He donated generously to the department, making possible the establishment of a physics colloquium, a new faculty startup fund and a students' summer research scholarship. Wes was also a deeply religious man. He was active in his local Community Lutheran church and the community, and gave freely and generously to many charities. He loved to sing, and was in a barber shop quartet as a young man and in church choirs for many years thereafter.

Wes deeply loved and cherished his wife Beth who died in 1989 after 44 years of marriage. He is survived by his daughter, Elsa Mondou, of Raleigh, North Carolina, four grandchildren, Christine, Michael, Julie, and Martin, and additional family and friends. He was an exceptional man with a profoundly good temperament, whose gift of unconditional love, and qualities of determination and independent spirit will provide inspiration for young scientists for a long time to come.

Awards and Honors

Two departmental awards were presented to physics undergraduates at the College of Arts and Sciences' Honors ceremony held in Ira Allen Chapel on May 18, 2012. Cody J. Lamarche and Mateus M. Teixeira were the co-recipients of the Albert D. Crowell Award for experimental physics.

Cody Lamarche (left) and Mateus Teixeira with Professor Clougherty at CAS Honors Day in Ira Allen Chapel. (Photo courtesy of Sally McCay.)

The David W. Juenker Prize for outstanding scholarship in physics was awarded to Roy A. Anderson, pictured above with Stephanie Young, President of the UVM chapter of the Society of Physics Students and Professor Clougherty.

2012 Sigma Pi Sigma Inductees

Five undergraduates were inducted in the UVM chapter of Sigma Pi Sigma in May 2012: Daniel L. Abrams; Roy A. Anderson; Thomas J. Howard; Richard W. Kenyon; and Evan W. Laird. Founded in 1921, Sigma Pi Sigma is the national physics honor society. Sigma Pi Sigma honors outstanding scholarship and service in physics, encouraging and stimulating members in their scientific pursuits.

Professor Spartalian with Lisa Carpenter, Physics Graduate Teaching Fellow of the Year at the physics reception on May 3, 2012.

Lisa Carpenter named GTF of Year

Lisa Carpenter, a physics M.S. student, was named Graduate Teaching Fellow of the Year in the Department of Physics. Lisa received a certificate of achievement and a membership to the American Association of Physics Teachers at the physics department awards reception on May 3, 2012.

Nota Bene

We would enjoy hearing from all UVM physics alums and friends. Send your email to physics@uvm.edu.

Undergraduate Honors Theses in Physics

Evan Border, "Quantum Monte Carlo Measurements of the Superfluid Density in Helium-4." Adviser: Adrian G. Del Maestro, Ph.D.

Steven Philbin, "Tau Isoform-Specific Effect on the Mechanical Rigidity of Microtubules." Advisers: Christopher Berger, Ph.D. and Kelvin Chu, Ph.D.

Emily Smith, "Dynamic Analysis of Radio Pulsar B1237+25's Emission and Polarization Modes." Adviser: Joanna M. Rankin, Ph.D.

Mateus Teixeira, "Development of Geometric Models for Four-Component Pulsars J0815+0939 and J0631+1036." Adviser: Joanna M. Rankin, Ph.D.

Jacob Wahlen-Strothman, "Low-Temperature Magnetic Studies of Meso-tetraphenylporphyrin Crystalline Films." Adviser: Kelvin Chu, Ph.D.

Stephanie Young, "Core Emission and Nulling Phenomenon in Pulsars." Adviser: Joanna M. Rankin, Ph.D

Professor Spartalian with Dr. Milton Cole, Distinguished Professor of Physics at Penn State during the physics reception May 3, 2012. Professor Cole gave a colloquium titled "Adsorption on a Fullerene: Controlled Manipulation of Electrical Transport."

Phi Beta Kappa

Senior Physics majors Mateus M. Teixeira, Emily Smith and Stephanie Young were inducted as new members into Phi Beta Kappa honor society. Phi Beta Kappa is the oldest honor society in the country, and among the most prestigious. From the society's website: "The ideal Phi Beta Kappan has demonstrated intellectual integrity, tolerance for other views, and a broad range of academic interests. Each year, about one college senior in a hundred, nationwide, is invited to join Phi Beta Kappa." The Alpha Chapter of Vermont was chartered in 1848. In 1875, it became the first chapter in the nation to admit women to its membership.

From left to right: Emily Smith, Professor Robert Arns and Stephanie Young at the Phi Beta Kappa initiation on May 19, 2012. (Photo courtesy of Prof. Furis.)

2012 Graduates

Bachelor of Science degree recipients

Daniel Abrams
Evan Border
Christopher Libby
Steven Philbin
Emily Smith*
Mateus Teixeira*
Jacob Wahlen-Strothman*
Stephanie Young
*cum laude

Jacob Wahlen-Strothman and Stephanie Young, with Professor Clougherty at 2012 Commencement on May 20, 2012. (Photo courtesy of Prof. Furis.)

Master of Science degree recipients

Ian Goyette
Benjamin Knight

Ph.D. Materials Science recipients

Dr. Robert Andosca
Dr. Yanting Zhang

Dr. Yanting Zhang, Dr. Robert Andosca and Professor Clougherty (right to left) at the Graduate College Commencement ceremony on May 19, 2012. (Photo courtesy of Prof. Furis.)

Congratulations graduates!

Evan Border, Emily Smith, Jacob Wahlen-Strothman, Professor Clougherty, Stephanie Young, Daniel Abrams, Steven Philbin and Chris Libby (left to right) at UVM Commencement 2012.

NanoDays 2012

The UVM chapters of the Society of Physics Students and Sigma Pi Sigma organized a series of events for NanoDays 2012, an annual national celebration of nanoscale science, technology and engineering that includes hands-on activities, demonstrations and lectures for the general public. The ECHO Science Center was the site for all events.

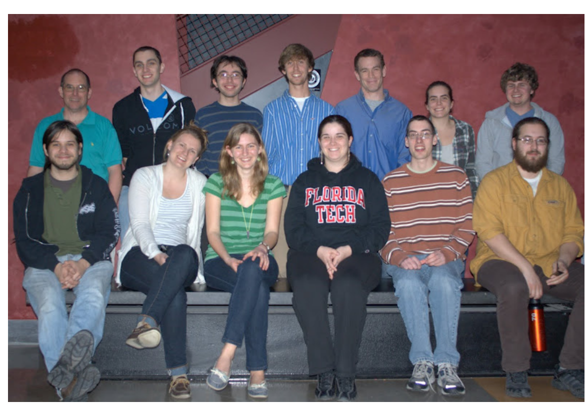
Physics majors Richard Kenyon and T.J. Howard give instruction during NanoDays 2012. (Photo courtesy of Prof. Furis.)

Physics major Cody Lamarche with future scientists at ECHO Science Center. (Photo courtesy of Prof. Furis)

Fun with carbon nanostructures at ECHO. (Photo courtesy of Prof. Furis)

Faraday's Law elicits fear, wonder and joy. (NanoDays 2012)

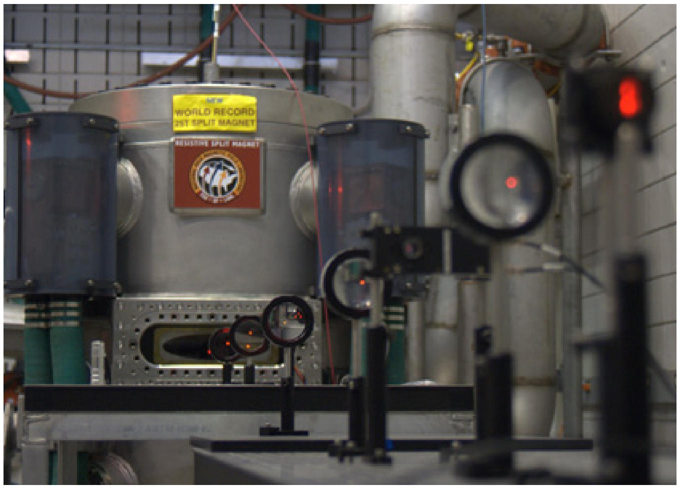
Physics graduate student Max Graves and Amanda Roffman at ECHO Science Center during NanoDays 2012. (Photo courtesy of Prof. Furis)



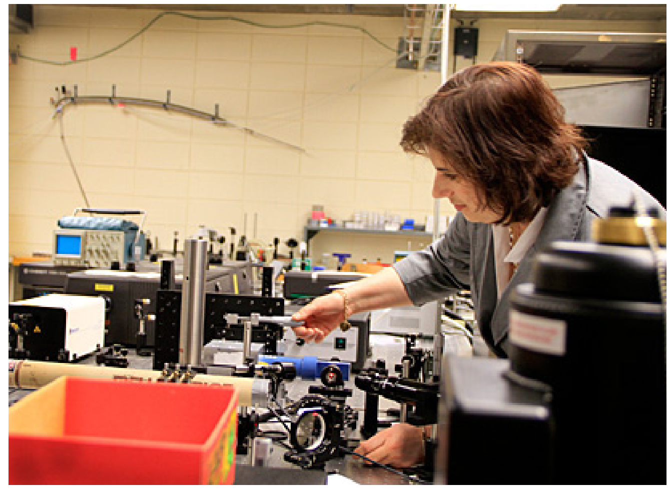
David Hammond (top right) led the team of UVM physics students in NanoDays 2012. David Hammond, Cody Duquette, Joshuah Heath, TJ Howard, Owen Myers, Amanda Roffman, Max Graves (top, left to right); Dan Abrams, Kasey Hulvey, Stephanie Young, Crystal Latham, Cody Lamarche and Evan Laird (bottom, left to right).

Into the Magnetic Blue Yonder

By Joshua Brown



The orbital momentum and spin of electrons makes a magnet stick to your refrigerator. Physicist Madalina Furis, winner of a National Science Foundation CAREER grant, demonstrates how she uses lasers and a powerful magnet in her laboratory to look at how electrons do this trick. (Photo: Joshua Brown)



A UVM physics team launched a first-of-its-kind experiment on this new machine at the National High Magnetic Field Laboratory in Florida – the most powerful "split magnet" ever built.

Probing the quantum mechanics of magnetism is not for the faint of heart. Literally. The door to Madalina Furis' laboratory on the fifth floor of the Cook Building has a sign that reads "Stop! No pacemakers beyond this point."

On the other side of the door, Furis, an assistant professor of physics, and her students, run a powerful magnet that could wreak havoc on such devices. "Sorry, but if you get a pacemaker you cannot be a high-magnetic-field researcher," she says, with a cheerful laugh in her rich Romanian accent.

But her magnet research may help bring to life a whole new generation of devices, like computer screens that could roll up like a piece of paper.

"Making cheap, flexible electronics — that's the ultimate goal of this work," she says.

Electron behaviors

Furis' research is several steps removed from manufacturing or even from materials engineering. Instead, she seeks to peek deep inside the molecular structure of strange organic compounds – called metal phthalocyanines – and, with a combination of light and extreme magnetic fields, catch a glimpse of certain spinning electrons.

"What we do here is probe electrons in materials," she says. "Our field of research is to look at how electrons behave in different materials, because electrons are what makes your computer work, what makes your solid-state lighting."

And how the electrons are arranged and flow in phthalocyanines give these materials their gorgeous blue colors (they were originally used as dyes in the early twentieth century) but also the rare property of being organic compounds that are, sometimes, magnetic.

And materials like these raise the possibility of creating semiconductors — the basis of modern electronics, from hard drives to telephones — that are made from inexpensive, flexible organic molecules. The hope is that these could be precisely engineered — "tuned," as physicists say — to have particular combinations of magnetism and conductivity, for applications like switches and data storage.

But in order to do this, the specific families of electrons that control the degree of magnetism need to be pinpointed. Which is where very big magnets and lasers come in handy.

Magnetism has been observed since ancient times, but only in the last century have physicists exposed the underlying cause. "It's actually the quantum mechanical properties of the electron — called spin — that is the origin of magnetization," explains Furis.

Typically, measurements of magnetization are done in the realm of classical physics. This is the familiar, macro-scale world where, for some spooky reason, chunks of metal will stick to your refrigerator. This magnetism is measured by taking an indirect reading of an ensemble of many of these quantum-scale effects.

But that macro effect in no way points to its micro cause. "If electrons are involved in mediating this interaction, in arranging the spins, which ones of them are doing that?" asks Furis. "That's a very big

Into the Magnetic Blue Yonder, continued

question. And that cannot be answered with a classical measurement of the net magnetization."

Polarized probe

Getting a view of these electrons is not easy. But it turns out that photons of light — of carefully selected wavelengths and with a special twist called circular polarization — shining onto these organic materials lets Furis and her team identify and select certain electrons — some are free and some are bound to the nucleus of atoms; some are at higher energy states and others at lower ones; some line up parallel to the magnetic field, others antiparallel. And how the photons are absorbed and bounced back allows the researchers to find out which electrons are the underlying engine of that material's magnetism.

But this probing with polarized light — for materials of relatively low magnetic power like phthalocyanines — only works in the presence of a magnetic field. A very strong magnetic field.

Which is why Furis and her students place samples in the magnet here in her laboratory. Rated to five tesla (a tesla is a unit of magnetic field strength), and purchased with support from the National Science Foundation, this machine is far stronger than a typical hospital MRI machine, thousands of times stronger than the Earth's magnetic field.

"See this?" says Lane Manning '08, now a doctoral student in Furis' lab. He holds up a small threaded disc with a tiny wafer of blue-green material affixed at center. It's a sample of phthalocyanine.

"This sample is mounted on this probe here, and we'll put the sample right in the center," he says, screwing the disc into a large blue ring with tubes and wires sticking out in many directions. This is the UVM team's magnet. "Now we have the sample in the magnet," he says, "then we can bring in light to probe it."

"And see this?" he says pointing to the opening through the middle of the magnet. "We can see through this magnet, and that is key," he says. Instead of having to use fiber optics, this direct path "allows us to have an incredibly precise control of the polarization of the light going to the sample." And that precision is what lets them detect the relatively weak magnetic interactions in these organic materials.

To 25 tesla

But this magnet is really just a pre-testing site, and stepping stone, to a much more powerful one that Furis and her students helped inaugurate this past summer. The new twenty-five telsa magnet at the National High Magnetic Field Laboratory at Florida State University in Tallahassee is the strongest so-called "split-magnet" in the world.

It's hard to create a powerful magnet, but ever so much more difficult to make a window into it. But that is what this new machine does; it's split into two halves, with a direct sightline in, which allows Furis' team to shine polarized light at samples within, unlike other magnets of similar strength.

"Optics in high-magnetic fields were always the Cinderella of high-magnetic fields despite the huge amount of information one can get out of this," says Furis, "because they are so hard to do." But this machine may be ushering in a new era, she thinks.

In a first-of-its-kind experiment, with support from the National Science Foundation, Furis and several of her students, including doctoral student Zhenwen Pan and undergraduate Cody Lamarche, tested a copper-based phthalocyanine on the new Florida magnet — to see if they could identify which electrons were responsible for its magnetism.

It worked. Though the whole experiment won't be complete until the team can return to the magnet this spring to do additional tests at extremely low temperatures, the initial results at room and fairly low temperatures were promising.

"We basically identified which electronic states are responsible for mediating this interaction," says Furis.

Spintronics

And this kind of knowledge opens the possibility for chemists and materials engineers to "reverse engineer" desired properties into different forms of these organic semiconductors. For example, by changing the metal atom at the heart of the organic ring that forms phthalocyanines — perhaps changing it from copper to manganese — produces different numbers and densities of free electrons in the material, which, in turn, creates different magnetic strengths. Or arranging the molecules like plates in a dishrack, instead of like a vertical stack of plates, creates different patterns of electrons too.

"Almost every single device we have works because we understand the quantum mechanic properties of electrons," says Furis.

Furis is helping lead an emerging field of physics called "spintronics" which is looking at the potential of using spin — the quantum mechanical property of electrons — instead of traditional electric charge, as means of moving and storing information.

"This work is of interest not only for organic semiconductors; there has been an effort in the world of silicon for almost twenty years to make a device where we control electron spin in the same way we control charge in transistors," says Furis, "and having an all-organic version of that, where you could have control of charge as well as spin, would be very attractive."

Story and photograph 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

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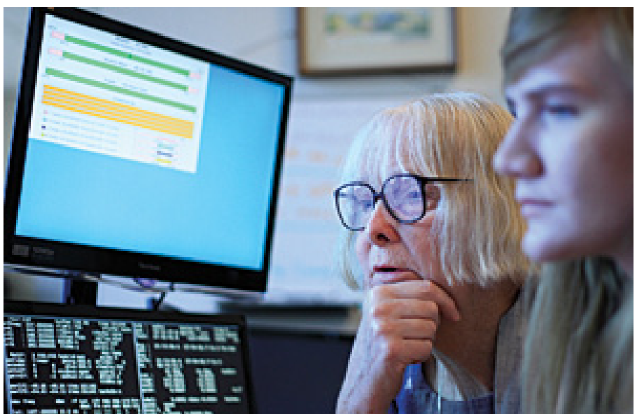
Listening to the Stars.... *continued*

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.



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 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

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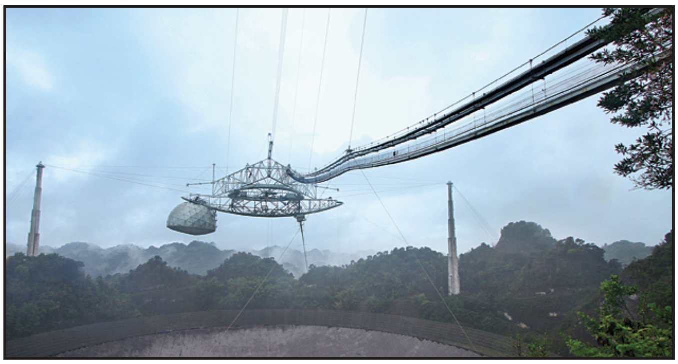
Listening to the Stars.... *continued*

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."



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

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.

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.

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Listening to the Stars.... continued

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.

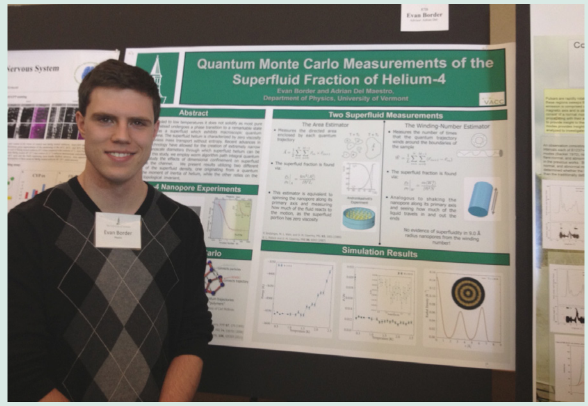
These dozens of pulsars, working as far-off clocks, will allow the team to sift out when a gravitational wave has passed by. They'll be looking for a distinctive pattern in the arrival time of emissions from pulsars in opposite sides of the sky. And this requires developing enough precision to distinguish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

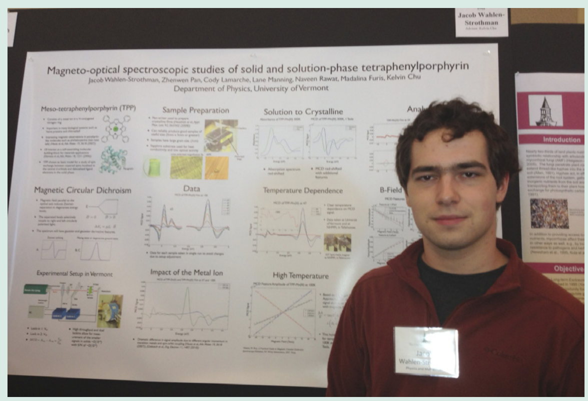
If gravitational waves can be detected, then the location and strength of their sources can be calculated. And that, Rankin thinks, could be as revolutionary as Galileo's invention of the optical telescope. "Being able to detect gravitational waves opens up a whole new equivalent spectrum," she says.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

Student Research



Evan Border '12 presents a poster of his Honor's thesis research as part of UVM Student Research Day at the Davis Center on April 19, 2012. His project titled "Quantum Monte Carlo Measurements of the Superfluid Density of Helium-4" was supervised by Professor Del Maestro.



Jacob Wahlen-Strothman '12 presents a poster of his Honor's thesis research as part of UVM Student Research Day at the Davis Center on April 19, 2012. His project titled "Magneto-optical spectroscopic studies of solid and solution-phase tetra-phenyl porphyrin" was supervised by Professor Chu.

Yanting Zhang, Ph. D. '12, presented her research at the American Physical Society March meeting in Boston, Massachusetts on March 2, 2012. The title of her talk was "Orthogonality Catastrophe in Quantum Sticking."

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