Astrophysics research: Pulsar physics at UVM

Pulsars: some are 10 miles wide and heavier than the sun. Undergraduate researchers Isaac Backus and Isabel Kloumann are helping to draw a portrait of the "rotating carousel" of radio waves that shines forth from these strange stars.

(Photo: Joshua Brown)

To the Cosmic Lighthouse (By Joshua Brown)

And you thought the remote for your TV was tricky? Isabel Kloumann and Isaac Backus, both undergraduate students, sit in a cinderblock office on the fifth floor in the Cook Building entering coordinates into an iMac computer. One-thousand-eight-hundred-forty-seven miles away — in a limestone sinkhole on a mountaintop in Arecibo, Puerto Rico — the world's largest telescope moves to their commands.

"It's like playing a slow video game," says Kloumann.

Far stranger are the objects they are pointing the telescope toward: pulsars many light years away.

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, these strange objects are staggeringly dense, holding about a billion tons per square centimeter. Imagine a teaspoon of sugar that weighed as much as three thousand Empire State Buildings.

"Pulsars are about the size of Burlington with mass comparable or greater than the sun," says UVM astrophysicist Joanna Rankin, who has employed Kloumann and Backus as independent researchers. "What we're observing this morning are city-sized remnants of medium-massed stars."

Contact?

This observing depends on the Arecibo telescope that Rankin and her students use several times each year through funding from the National Science Foundation. With a reflecting dish a thousand feet across and a colossal cable system to carry the receiver hither and yon overtop, the telescope gathers radio waves pouring in from clouds of cold gas throughout the Milky Way and beyond, like the famed Andromeda galaxy.

But the telescope also records the compact, highly regular, on/off bursts of radio energy that come from pulsars. ("Pulsar" is a contraction of pulsating star.). As these spheres of hyper-dense neutrons spin — some rotating once every few seconds, some hundreds of times per second — they shoot out two cones of radio emissions from above their bogglingly powerful magnetic poles.

"It's just like a lighthouse," says Kloumann, "every time it sweeps past, you get a flash." But, in 1967, when the first pulsar was discovered by an enterprising graduate student named Jocelyn Bell, nothing like it had ever been observed in the heavens. Nothing like it was even imagined.

"How could it be that we have a compact natural radio transmitter sending signals across the galaxy?" says Rankin, "it was completely unexpected."

"They were originally thought to be aliens," says Kloumann and so the first pulsar was dubbed LGM-1.

"The little green men turned out to be pulsars," says Backus.

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Flashy, with substance

Forty years later, more is known about pulsars, but their extreme physics are still mysterious. "We have a cartoon that is probably right," says Rankin, "they tap their rotational energy — somehow — and turn it into radio waves."

"A pulsar is highly conductive," she says "as it rotates, it acts like a dynamo and you get huge electrical potentials across the star."

"Those potentials appear in a narrow column of magnetic field above the star's magnetic poles," she says, and serve as the power source for the radio transmissions. Or something like that.

"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 signature of emissions that different kinds of pulsars produce. And her students do the same.

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

"If you shine a flashlight at the wall, some parts are bright, some are dim," says Backus. Ditto for pulsar emissions. The radio beam surges and shifts like a rotating carousel of lights. Or consider pulsar B1944 + 17 that Kloumann has been studying on her own for the past year. Sometimes it just turns off. And no one is exactly sure why.

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

Both Kloumann and Backus are publishing scientific papers as the first author. Or at least they're optimistic. Backus has submitted his paper comparing two unusual pulsars to the well-regarded astronomy journal, the Monthly Notices of the Royal Astronomical Society. The journal's referees, "liked it," he says. "The comments were mostly about grammar. Well, with a few other things."

Kloumann — an Honors College student, Goldwater Scholar, and "one of UVM's stars in physics and mathematics," says Rankin — will be submitting her study of pulsar B1944 + 17 to the same publication.

"My freshman year I wanted to be involved in research, so I went and found Joanna," Kloumann says.

"I worked one-on-one with her every week and she would tell me about pulsars for three hours!" Kloumann says. "She's a great mentor. She's given us a lot of freedom and flexibility. And she's there when you need her."

Kloumann, Backus, and graduate student Megan Force have worked closely together, and each has had a chance to travel to Arecibo with Rankin to see the telescope in action.

"You feel like Galileo," says Force, "right there next to the machine."

The pulsar is in the details

For her part, Rankin calls herself a pulsar sociologist. "I make exploratory observations of a large number of pulsars looking for common features and then I am able to identify a set that would be interesting to study," she says.

"Most of physical science is confirmation of theoretical expectations. That's not quite what we do in some parts of astronomy — including pulsar work — because we don't know enough," she says.

"You can think of what I do as phenomenology, which isn't quite theory. It's observationally based efforts to identify what are the important physical principles," she says. "What I hope my work will do is to stimulate theorists to do a better job with the mathematical theory, using Maxwell's equations and quantum mechanics, to figure out, in detail, why pulsars work the way they to. And that's a very complex problem."

"The early theories were heroic, but they were wrong," she says, and then turns back to her computer to adjust some power levels on the telescope in Puerto Rico. "You can't study pulsars in general; you have to deal with the specifics."

Undergraduate News:

Isabel Kloumann, a junior physics major, was named a 2009 Goldwater Scholar. Goldwater Scholars are selected on the basis of academic merit from a field of typically over one thousand mathematics, science, and engineering students who were nominated by the faculties of colleges and universities nationwide. Goldwater Scholars have very impressive academic qualifications that have garnered the attention of prestigious post-graduate fellowship programs. Recent Goldwater Scholars have been awarded 73 Rhodes Scholarships, 102 Marshall Awards (7 of the 40 awarded in the United States in 2009), and numerous other distinguished fellowships.

Kameron Harris, a 2009 UVM physics graduate, was named a 2009 Fulbright Scholar. Kameron will begin work on his project entitled "Traffic Modeling for a Busier World" in March 2010 in Valparaiso Chile. There, he will work with Andres Moreira, a computer scientist with the Universidad Tecnica Federico Santa Maria (UTFSM), as his advisor, and Eric Goles, mathematician and director of the Instituto de Sistemas Complcjos de Valparaiso, with whom both will collaborate. In addition to his research, Kam will enter the computer science master's program at UTFSM. Kam will use his Fulbright fellowship to study current issues related to mass traffic associated with Transantiago, the new bus system in Santiago, Chile.