NASA Goddard astrophysicist wins prize for pulsar work

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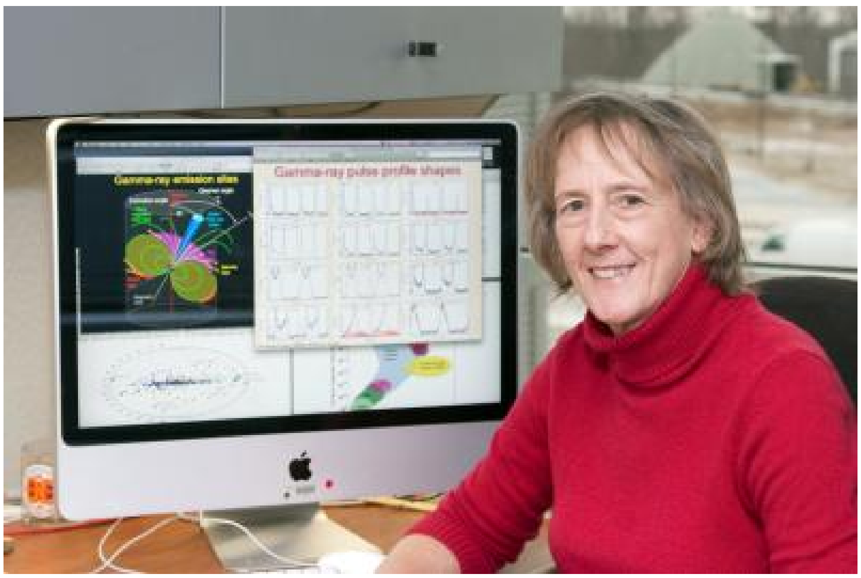

Alice Harding studies how gamma-ray pulsars work using observations from NASA's Fermi Gamma-Ray Space Telescope. For her contributions to understanding these objects, she shares the 2013 Bruno Rossi prize with Roger Romani of Stanford University. Credit: David Friedlander, NASA's Goddard Space Flight Center

To say that Alice Harding, an astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Md., has a passion for pulsars is a bit of an understatement. On Jan. 24, she was named a winner of the 2013 Bruno Rossi prize together with Roger Romani of Stanford University. The award recognizes their work in establishing a theoretical framework for understanding how pulsars emit gamma rays, the most powerful form of light.

"Roger and I have been arguing about how this works for 20 years," Harding said. "What's funny is that observations from NASA's Fermi Gamma-ray Space Telescope now show that we're both partly right."

Each year, the High Energy Astrophysics Division of the American Astronomical Society awards the prize for a significant contribution to high-energy astrophysics, with particular emphasis on recent, original work.

Pulsars are rapidly spinning neutron stars, superdense objects forged when a massive star collapses and explodes as a supernova. A neutron star is the closest thing to a black hole that astronomers can observe directly, crushing half a million times more mass than Earth into a sphere no larger than Manhattan Island or the District of Columbia.

Young neutron stars spin dozens of times a second and gradually slow with age. But if an aging pulsar is paired with a normal star in a binary system, their interaction may ramp up the neutron star's spin to hundreds of rotations each second, creating what astronomers call a millisecond pulsar.

"Pulsars are the only objects we know of with rigid surfaces spinning at up to 20 percent the speed of light, which is just one of the things I find so fascinating about them," Harding said.

Dizzying spin coupled with superstrong magnetic and electric fields make pulsars superb natural particle accelerators, nearly 1,000 times more powerful than any machine on Earth.

"In the vicinity of a pulsar's magnetic pole, the electric field near the surface is stronger than gravity," Harding explained. "It pulls out electrons and other particles and accelerates them upward along the star's magnetic field." The region around the pulsar teems with fast-moving charged particles interacting with the strong magnetic field, ultimately giving rise to emissions across the electromagnetic spectrum.

Originally discovered nearly 50 years ago by their radio emissions, more than 2,000 pulsars have been identified to date. Radio telescopes—and later, satellites with detectors sensitive to X-rays and gamma rays —detect a quick pulse whenever a pulsar's rotation sweeps its beam of emission across our field of view.

In the 1970s, a balloon experiment first detected gamma-ray pulsations from the pulsar in the Crab Nebula, and later NASA's SAS-2 satellite identified them from the pulsar in the Vela supernova remnant. NASA's Compton Gamma Ray Observatory, which operated throughout the 1990s, detected seven gamma-ray pulsars, including the Crab, Vela and the unusual Geminga (pronounced geh-MING-guh), a bright gamma-ray source with comparatively weak X-rays and no detectable radio emission.

"Of those seven, only the Crab, Vela and Geminga were best suited for attempting to model how these objects produced gamma rays," Harding recalls. "With such a small sample, our limited observations could not distinguish different theoretical approaches."

She and her colleagues initially predicted that the gamma rays were beamed from the pulsar's magnetic poles, where charged particles were being ripped from the surface and rapidly accelerated. A decade later, models by Romani and his team were predicting that the gamma rays arose at much higher altitudes from discrete sites in the outer region of the magnetosphere, an area surrounding the pulsar where its magnetic field controls the motion of charged particles.

Harding then developed an alternative model that produced gamma-ray emission from the poles to the outer magnetosphere. Because the outer magnetosphere rotates near the speed of light, narrow pulses form through the effects of Einstein's theory of special relativity. But with the existing data on gamma-ray pulsars, there was no way to confirm which of the three possible mechanisms—Harding's polar cap and "slot gap" models or Romani's "outer gap" theory—actually were at work.

One of the goals of NASA's Fermi Gamma-ray Space Telescope, the follow-up to Compton that launched in 2008, was to acquire enough data to enable scientists to decide between these competing ideas.

"With just two months of observations of the Vela pulsar, Fermi shot down the polar cap as the primary emission region, clearly showing that we weren't seeing gamma rays from the strong fields near the surface," Harding said. "This low-altitude emission is apparently either weaker than we had predicted or it does not sweep across our line of sight. I believe the emission must be there at some level and Fermi may eventually see it."

However, after Fermi's discovery of more than 100 gamma-ray pulsars, both the slot gap and outer gap theories survive. Each model seems to explain different subgroups of the gamma-ray pulsar population.

A characteristic of the slot gap theory is that the pulsar remains detectable in gamma rays throughout its entire rotation, and not just during the pulse peak emission. This behavior can be seen in the radio-quiet Geminga and Gamma Cygni pulsars. By contrast, the outer gap model predicts that pulsars remain undetectable outside the pulses, a pattern exhibited by the radio-loud Crab and Vela pulsars.

Yet even now, some pulsars stubbornly refuse to behave according to either model, so the quest to fully understand these incredible objects continues.

One aspect of Fermi's pulsar discoveries that seems to have surprised the astronomical community is the number of millisecond pulsars found to emit gamma rays. In a study published a year before Fermi's launch, Harding and her colleagues predicted that Fermi would find a few dozen millisecond pulsars as gamma-ray point sources in its first years—similar to what has been found—and recommended that radio observatories on the ground follow up to detect potential radio pulses, a strategy that has been quite successful.

"What does surprise me is the number of ancient millisecond gamma-ray pulsars whose pulses look just like those of young pulsars less than 10,000 years old," she said. "It was not expected from our theories and we're trying to understand why this is so."

Provided by NASA's Goddard Space Flight Center