Researchers using pulsar measurements to probe dark matter find Milky Way galaxy is highly dynamic

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UAH Pei-Ling Chan Endowed Chair Dr. Sukanya Chakrabarti, professor in physics and astronomy. Credit: Michael Mercier | UAH

Dark matter comprises more than 80% of all matter in the cosmos but is invisible to conventional observation, because it seemingly does not interact with light or electromagnetic fields. Now Dr. Sukanya

Chakrabarti, the Pei-Ling Chan Endowed Chair in the College of Science at The University of Alabama in Huntsville (UAH), along with lead author Dr. Tom Donlon, a UAH postdoctoral associate, have written a paper to help illuminate just how much dark matter there is in our galaxy and where it resides by studying the gravitational acceleration of binary pulsars.

Chakrabarti gave a plenary talk on this work and other methods to measure galactic accelerations at the 243rd meeting of the American Astronomical Society in New Orleans in January. The findings are also posted on the *arXiv* preprint server.

Pulsars are rapidly rotating neutron stars that blast out pulses of radiation at regular intervals ranging from seconds to milliseconds. A binary pulsar is a pulsar with a companion that allows physicists to test general relativity because of the strong gravitational fields accompanying these objects. "Pulsars are fantastic galactic clocks that have a timing stability that rivals atomic clocks," Chakrabarti explains.

"Pulsars have been used for decades in precision tests of the theory of general relativity. We are using them to directly measure the tiny accelerations of stars that live in the gravitational potential of our galaxy. These accelerations are only about 10 centimeters per second over a decade, or about the speed of a crawling baby, which is why it's been difficult to measure these tiny changes previously. The pulsar timing data from facilities such as NANOGrav and other pulsar timing facilities made the measurements feasible."

NANOGrav, or the North American Nanohertz Observatory for Gravitational Waves, is a consortium of astronomers who detect gravitational waves using the Green Bank Telescope, Arecibo Observatory, the Very Large Array and the Canadian Hydrogen Intensity Mapping Experiment.

"By obtaining extreme-precision measurements of accelerations, we now have the most direct probe of the gravitational potential of the galaxy beyond what has been done in astronomy over the last century," Chakrabarti notes. "There are now many independent lines of evidence that show the galaxy has actually had a highly dynamic history. Tom's analysis of the larger pulsar timing sample shows directly for the first time that the galaxy has been disturbed by dynamical interactions, such as by passing dwarf galaxies."

Obtaining an accurate model of the galaxy's gravitational potential caused by dark matter is something like counting the ripples on a pond after the stone is thrown.

"We used every pulsar we could get, as long as it had all the measurements we need," lead author Donlon says. "In order to measure an acceleration from a pulsar, they need to be in a stable binary system. You also need to know how far away the pulsar is, its movement on the sky and details about its orbit; all these things require extremely precise measurements that take years of observations! As time goes on, we should have more pulsars we can use for future studies."

Donlon reports there are two main ways these accelerations help us learn about the universe. "The first, is that binary pulsars emit gravitational waves, which cause their orbits to get smaller over time, and eventually the two objects crash into each other. Because the gravitational field is very strong in this type of system, and the pulsar timing measurements are very precise, it's possible to test the predictions made by general relativity against the observed decay of the pulsar's orbit.

"The second way is through tests of dark matter. Dark matter can't be seen, but still interacts with regular matter through gravity, and that additional gravity causes accelerations on these pul-SARS. By comparing the accelerations we actually see with the accelerations we expect to get from just normal matter, we can figure out how much dark matter there is, and where it is."

Looking to the future of this research, Donlon concludes, "We can plan experiments that require many more pulsars, which will become possible as we get more pulsar timing measurements. As the number of data points grows, we will be able to map our galaxy's gravitational field with incredible precision, including things like any clumps of dark matter."

More information: Thomas Donlon et al, Galactic Structure From Binary Pulsar Accelerations: Beyond Smooth Models, *arXiv* (2024). DOI: 10.48550/arxiv.2401.15808

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