# Pulsar jackpot reveals globular cluster's inner structure

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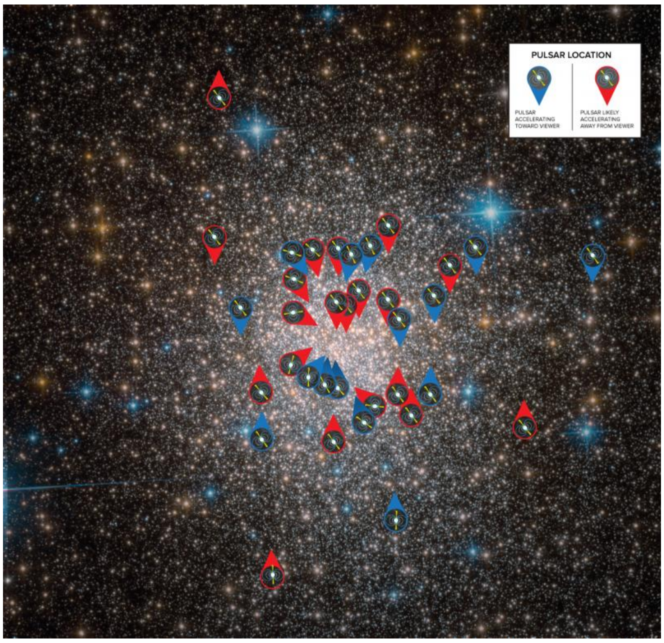


Graphic showing locations of millisecond pulsars inside the globular cluster Terzan 5 in an optical image taken by the Hubble space telescope. Pulsars represented in blue are accelerating toward observers on Earth; those in red are accelerating away. These relative accelerations were derived by measuring minute changes in the speed of rotation of the pulsars. Credit: B. Saxton (NRAO/AUI/NSF); GBO/AUI/NSF; NASA/ESA Hubble, F. Ferraro

The Milky Way is chock full of star clusters. Some contain just a few tens-to-hundreds of young stars. Others, known as globular clusters, are among the oldest objects in the Universe and contain up to a million ancient stars.

Some globular clusters are thought to be fragments of our galaxy, chiseled off when the Milky Way was in its infancy. Others may have started life as standalone dwarf galaxies before being captured by the Milky Way during its formative years.

Regardless of their origins, many globular clusters reside either in or behind the dusty regions of our galaxy. For ground- and space-based optical telescopes, however, this poses a challenge. Though it is possible to observe the cluster as a whole, the dust hinders astronomers' efforts to study the motions of individual stars. If astronomers could track the motions of individual stars, they could see how "lumpy" the globular cluster is or if it contains something really dense, like a giant black hole at its center.

Fortunately, radio waves—like those emitted by pulsars—are unhindered by galactic dust. So rather than tracing the motions of the stars, astronomers should be able to map the motions of pulsars instead. But, of course, things are never that simple. Though globular clusters are brimming with stars, they contain far fewer pulsars.

"That's what makes Terzan 5 such an important target of study; it has an unprecedented abundance of pulsars – a total of 37 detected so far, though only 36 were used in our study," said Brian Prager, a Ph.D. candidate at the University of Virginia in Charlottesville and lead author on a paper appearing in the *Astrophysical Journal*. "The more pulsars you can observe, the more complete your dataset and the more details you can discern about the interior of the cluster."

The Terzan 5 cluster is about 19,000 light-years from Earth, just outside the central bulge of our galaxy.

For their research, the astronomers used the National Science Foundation's (NSF) Green Bank Telescope (GBT) in West Virginia. The GBT is an amazingly efficient instrument for pulsar detection and observation. It has exquisitely sensitive electronics, some specifically optimized for this task, and a 100-meter dish, the largest of any fully steerable radio telescope.

Pulsars are neutron stars – the fantastically dense remains of supernovas—that emit beams of radio waves from their magnetic poles. As a pulsar rotates, its beams of radio light sweep across space in a cosmic version of a lighthouse. If the beams shine in the direction of Earth, astronomers can detect the exquisitely steady pulses from the star.

As the pulsars in Terzan 5 move in relation to Earth – drawn in different directions by the varying density of the cluster—the Doppler effect comes into play. This effect adds a tiny delay to the timing if the pulsar is moving away from Earth. It also shaves off the tiniest fraction of a millisecond if the pulsar is moving toward us.

In the case of Terzan 5, astronomers are particularly interested in a class of pulsars known as millisecond pulsars. These pulsars rotate hundreds of times each second with a regularity that rivals the precision of atomic clocks on Earth.

Pulsars achieve these remarkable speeds by siphoning off matter from a nearby companion star. The infalling matter hits the edge of the neutron star at an angle, increasing the pulsar's rate of spin in much the same way that a basketball balanced on the tip of a finger can be spun up by striking its side.

Millisecond pulsars are a particular boon to astronomers because they make it possible to detect almost infinitesimally small changes in the timing of the radio pulses.

"Pulsars are amazingly precise cosmic clocks," said Scott Ransom, an astronomer with the National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia, and coauthor on the paper. "With the GBT, our team was able to essentially measure how each of these clocks is falling through space toward regions of higher mass. Once we have that information, we can translate it into a very precise map of the density of the cluster, showing us where the bulk of the 'stuff' in the cluster resides."

Previously, astronomers thought that Terzan 5 might be either a warped dwarf galaxy gobbled up by the Milky Way or a fragment of the galactic bulge. If the cluster were a captured dwarf galaxy, it might also harbor a central supermassive black hole, which is one of the hallmarks of all large galaxies and can be found in many dwarf galaxies as well.

The new GBT data, however, show no obvious signs that a single, central black hole is lurking in Terzan 5. "However, we can't yet say for sure if a smaller, intermediate mass black hole resides there. The new observations also provide better evidence that Terzan 5 is a true globular cluster born in the Milky Way rather than the remains of a dwarf galaxy," said Ransom.

Future observations using more sophisticated acceleration models may better constrain the origin of Terzan 5.

**More information:** Brian J. Prager et al. Using Long-term Millisecond Pulsar Timing to Obtain Physical Characteristics of the Bulge Globular Cluster Terzan 5, *The Astrophysical Journal* (2017). DOI: 10.3847/1538-4357/aa7ed7

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