Astronomers offer possible explanation for elusive dark-matter-free galaxies

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Laura Sales (seated, left) with her research group of former and current students, including Jessica Doppel (seated, right). Credit: Stan Lim, UC Riverside

A team led by astronomers at the University of California, Riverside, has found that some dwarf galaxies may today appear to be dark-matter free even though they formed as galaxies dominated by dark matter in the past.

Galaxies that appear to have little to no dark matter—nonluminous material thought to constitute 85% of matter in the universe—complicate astronomers' understanding of the universe's dark matter content. Such galaxies, which have recently been found in observations, challenge a cosmological model used by astronomers called Lambda Cold Dark Matter, or LCDM, where all galaxies are surrounded by a massive and extended dark matter halo.

Dark-matter-free galaxies are not well understood in the astronomical community. One way to study the possible formation mechanisms for these elusive galaxies—the ultradiffuse DF2 and DF4 galaxies are examples—is to find similar objects in numerical simulations and study their time evolution and the circumstances that lead to their dark matter loss.

Jessica Doppel, a graduate student in the UC Riverside Department of Physics and Astronomy and the first author of research paper published in the *Monthly Notices of the Royal Astronomical Society*, explained that in a LCDM universe all galaxies should be dark matter dominated.

"That's the challenge," she said. "Finding analogs in simulations of what observers see is significant and not guaranteed. Beginning to pin down the origins of these types of objects and their often-anomalous globular cluster populations allows us to further solidify our theoretical framework of dark matter and galaxy formation and confirms that no alternative forms of dark matter are needed. We found cold dark matter performs well."

For the study, the researchers used cosmological and hydrodynamical simulation called Illustris, which offers a galaxy formation model that includes stellar evolution, supernova feedback, black hole growth, and mergers. The researchers found a couple of "dwarf galaxies" in clusters had similar stellar content, globular cluster numbers, and dark matter mass as DF2 and DF4. As its name suggests, a dwarf galaxy is small, comprising up to several billion stars. In contrast, the Milky Way, which has more than 20 known dwarf galaxies orbiting it, has 200 to 400 billion stars. Globular clusters are often used to estimate the dark matter content of galaxies, especially dwarfs.

The researchers used the Illustris simulation to investigate the origin of odd dwarf galaxies such as DF2 and DF4. They found simulated analogs to dark-matter-free dwarfs in the form of objects that had evolved within the galaxy clusters for a long time and lost more than 90% of their dark matter via tidal stripping—the stripping away of material by galactic tidal forces.

"Interestingly, the same mechanism of tidal stripping is able to explain other properties of dwarfs like DF2 and DF4—for example, the fact that they are 'ultradiffuse' galaxies," said co-author Laura Sales, an associate professor of physics and astronomy at UCR and Doppel's graduate advisor. "Our simulations suggest a combined solution to both the structure of these dwarfs and their low dark matter content. Possibly, extreme tidal mass loss in otherwise normal dwarf galaxies is how ultradiffuse objects are formed."

In collaboration with researchers at the Max Planck Institute for Astrophysics in Germany, Sales' group is currently working with improved simulations that feature more detailed physics and a numerical resolution about 16 times better than the Illustris simulation.

"With these data, we will be able to extend our study to even lower-mass dwarfs, which are more abundant in the universe and expected to be more dark matter dominated at their centers, making them more challenging to explain," Doppel said. "We will explore if tidal stripping could provide a path to deplete dwarfs of their inner dark matter content. We plan to make predictions about the dwarfs' stellar, globular cluster, and dark matter content, which we will then compare to future observations."

More information: Jessica E Doppel et al, Globular clusters as tracers of the dark matter content of dwarfs in galaxy clusters, *Monthly Notices of the Royal Astronomical Society*, Volume 502, Issue 2, April 2021, Pages 1661–1677, doi.org/10.1093/mnras/staa3915