UCI scientists discover how galaxies can exist without dark matter

In simulations, collisions cause smaller star groupings to lose material.

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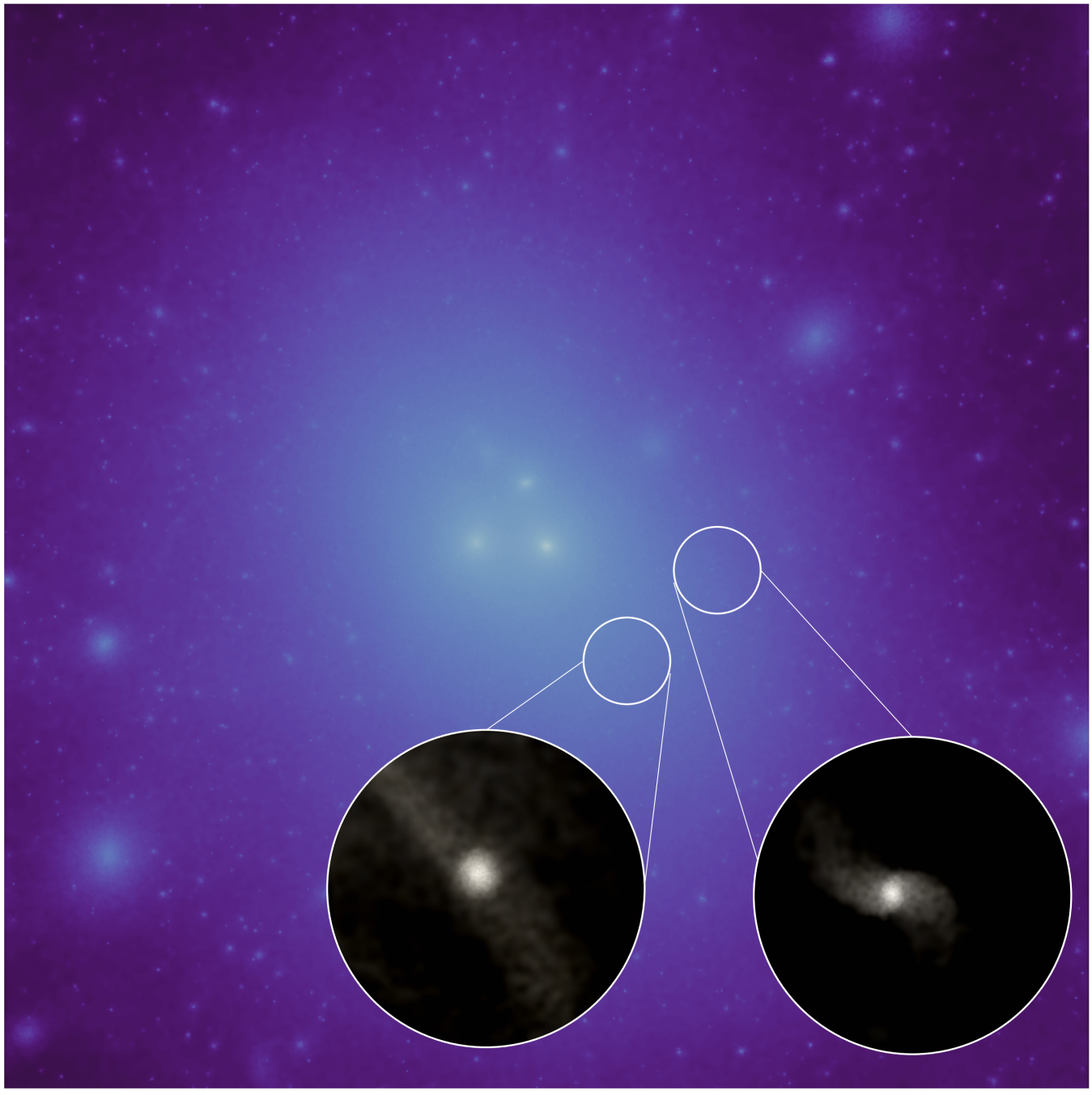

Dark matter distribution in a simulated galaxy group, with brighter areas showing higher concentrations of dark matter. Circles show close-up images of the stellar light associated with two galaxies lacking dark matter. If these galaxies had dark matter, they would appear as bright regions in the main image.

Picture Credit:
Morena et al.

Irvine, Calif., Feb. 14, 2022 — In a new *Nature Astronomy* study, an international team led by astrophysicists from the University of California, Irvine and Pomona College report how, when tiny galaxies collide with bigger ones, the bigger galaxies can strip the smaller galaxies of their dark matter — matter that we can't see directly, but which astrophysicists think must exist because, without its gravitational effects, they couldn't explain things like the motions of a galaxy's stars.

It's a mechanism that has the potential to explain how galaxies might be able to exist without dark matter – something once thought impossible.

It started in 2018 when astrophysicists Shany Danieli and Pieter van Dokkum of Princeton University and Yale University observed two galaxies that seemed to exist without most of their dark matter.

"We were expecting large fractions of dark matter," said Danieli, who's a co-author on the latest study. "It was quite surprising, and a lot of luck, honestly."

The lucky find, which van Dokkum and Danieli reported on in a *Nature* paper in 2018 and in an *Astrophysical Journal Letters* paper in 2020, threw the galaxies-need-dark-matter paradigm into turmoil, potentially upending what astrophysicists had come to see as a standard model for how galaxies work.

"It's been established for the last 40 years that galaxies have dark matter," said Jorge Moreno, an astronomy professor at Pomona College, who's the lead author of the new paper. "In particular, low-mass galaxies tend to have significantly higher dark matter fractions, making Danieli's finding quite surprising. For many of us, this meant that our current understanding of how dark matter helps galaxies grow needed an urgent revision."

The team ran computer models that simulated the evolution of a chunk of the universe – one about 60 million light years across – starting soon after the Big Bang

and running all the way to the present.

The team found seven galaxies devoid of dark matter. After several collisions with neighboring galaxies 1,000-times more massive, they were stripped of most of their material, leaving behind nothing but stars and some residual dark matter.

“It was pure serendipity,” said Moreno. “The moment I made the first images, I shared them immediately with Danieli, and invited her to collaborate.”

Robert Feldmann, a professor at the University of Zurich who designed the new simulation, said that “this theoretical work shows that dark matter-deficient galaxies should be very common, especially in the vicinity of massive galaxies.”

UCI’s James Bullock, an astrophysicist who’s a world-renowned expert on low-mass galaxies, described how he and the team didn’t build their model just so they could create galaxies without dark matter – something he said makes the model stronger, because it wasn’t designed in any way to create the collisions that they eventually found. “We don’t presuppose the interactions,” said Bullock.

Confirming that galaxies lacking dark matter can be explained in a universe where there’s lots of dark matter is a sigh of relief for researchers like Bullock, whose career and everything he’s discovered therein hinges on dark matter being the thing that makes galaxies behave the way they do.

“The observation that there are dark matter-free galaxies has been a little bit worrying to me.” said Bullock. “We have a successful model, developed over decades of hard work, where most of the matter in the cosmos is dark. There is always the possibility that nature has been fooling us.”

But, Moreno said, “you don’t have to get rid of the standard dark matter paradigm.”

Now that astrophysicists know how a galaxy might lose its dark matter, Moreno and his collaborators hope the findings inspire researchers who look at the night sky to look for real-world massive galaxies they might be in the process of stripping dark matter away from smaller ones.

“It still doesn’t mean this model is right,” Bullock said. “A real test will be to see if these things exist with the frequency and general characteristics that match our predictions.”

As part of this new work, Moreno, who has indigenous roots, received permission from Cherokee leaders to name the seven dark matter-free galaxies found in their simulations in honor of the seven Cherokee clans: Bird, Blue, Deer, Long Hair, Paint, Wild Potato and Wolf.

“I feel a personal connection to these galaxies,” said Moreno, who added that, just as the more massive galaxies robbed the smaller galaxies of their dark matter, “many people of indigenous ancestry were stripped of our culture. But our core remains, and we are still thriving.”

Funding for the work came from the National Science Foundation, sabbatical leave support for Moreno from Pomona College and the Harry and Grace Steele Foundation, and, for Danieli, from NASA through Hubble Fellowship grant HST-HF2-51454.001-A awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Incorporated, under NASA contract NAS5-26555. Other collaborators include Francisco Mercado, Courtney Klein and Zachary Hafen, all from UCI.

About the UCI’s Brilliant Future campaign: Publicly launched on October 4, 2019, the Brilliant Future campaign aims to raise awareness and support for UCI. By engaging 75,000 alumni and garnering $2 billion in philanthropic investment, UCI seeks to reach new heights of excellence in student success, health and wellness, research and more. The School of Physical Sciences plays a vital role in the success of the campaign. Learn more by visiting: https://brilliantfuture.uci.edu/uci-school-of-physical-sciences/.

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