Precision measurements of intracluster light suggest possible link to dark matter

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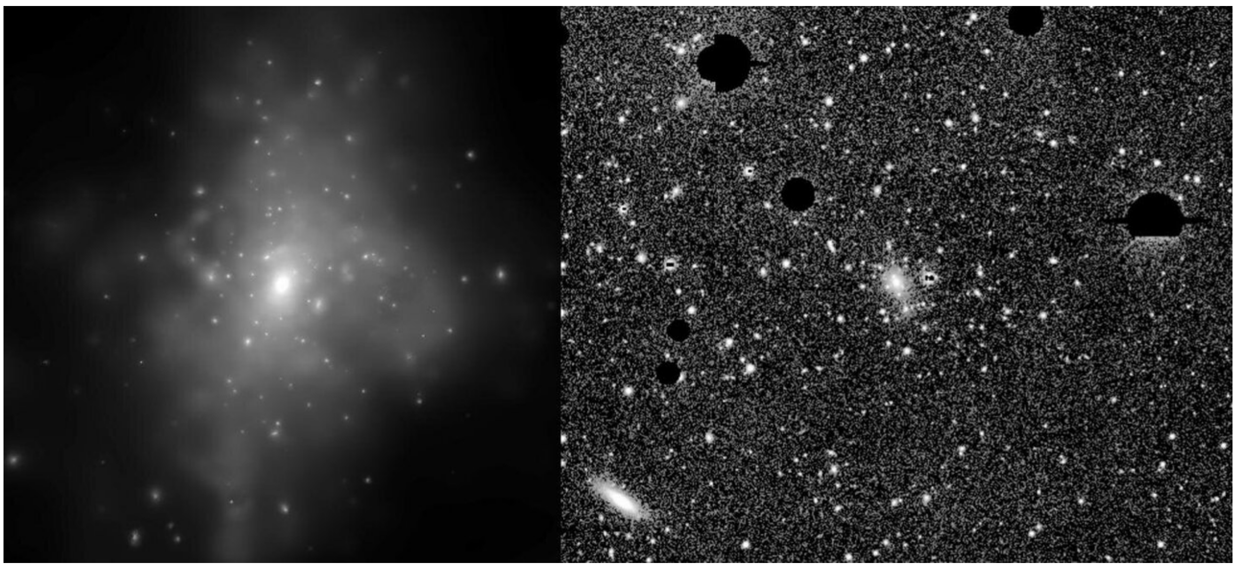

On the left is a simulated image in which intracluster light is visible as a diffuse haze between discrete peaks of brightness—the galaxies. In observations, as seen in the right, this intracluster light component is largely drowned in noise. Credit: Left image: Jesse Golden-Marx; simulation by The IllustrisTNG. Right image: Dark Energy Survey and Yuanyuan Zhang

A combination of observational data and sophisticated computer simulations have yielded advances in a field of astrophysics that has languished for half a century. The Dark Energy Survey, which is hosted by the U.S. Department of Energy's Fermi National Accelerator Laboratory, has published a burst of new results on what's called intracluster light, or ICL, a faint type of light found inside galaxy clusters.

The first burst of new, precision ICL measurements appeared in a paper published in *The Astrophysical Journal* in April 2019. Another appeared more recently in Monthly Notices of the Royal Astronomical Society. In a surprise finding of the latter, DES physicists discovered new evidence that ICL might provide a new way to measure a mysterious substance called dark matter.

The source of ICL appears to be rogue stars, those not gravitationally bound to any galaxy. The ICL has long been suspected of possibly being a significant component of clusters of galaxies, but its faintness makes it difficult to measure. No one knows how much there is or to what extent it has spread through galaxy clusters.

"Observationally we discovered that intracluster light is a pretty good radial tracer of dark matter. That means that where intracluster light is relatively bright, the dark matter is relatively dense," said Fermilab scientist Yuanyuan Zhang, who led both studies. "Just measuring the ICL itself is pretty exciting. The dark matter part is a serendipitous discovery. It's not what we expected."

Although invisible, dark matter accounts for most matter in the universe. What dark matter consists of stands as one of the major mysteries of modern cosmology. Scientists know only that it differs greatly from the normal matter consisting of the protons, neutrons and electrons that dominate everyday life.

But ICL, not dark matter, was initially on the research team's agenda. Most astrophysicists measure intracluster light at the center of a galaxy cluster, where it is brightest and most abundant.

"We went very far away from the centers of the galaxy clusters, where the light is really faint," Zhang said. "And the farther away from the center we went, the more difficult the measurement became."

Nevertheless, the DES collaborators managed to come away with the most radially extended measurement of ICL ever.

The team used weak gravitational lensing to compare the radial distribution of the ICL—how it changes over distance from the center of a cluster—to the radial distribution of the mass of a galaxy cluster. Weak lensing is a dark-matter-sensitive method of measuring the mass of a galaxy or cluster. It occurs when the gravity of a foreground star or cluster bends the light from a more distant galaxy, distorting its apparent shape.

It turned out observationally that ICL reflects the distribution of both the total visible mass of a galaxy cluster and, possibly, the distribution of the invisible dark matter.

"We did not expect to find such a tight connection between these radial distributions, but we did," said scientist Hillysson Sampaio-Santos, the lead author of the new paper.

Comparing observations with simulations

To gain more insight, the team used a sophisticated computer simulation to study the relationship between ICL and dark matter. They found that the radial profiles between the two phenomena in the simulation didn't agree with the observational data. In the simulation, "the ICL radial profile was not the best component to trace dark matter," said Sampaio-Santos, who is with the National Observatory in Rio de Janeiro, Brazil.

Zhang noted that it's too soon to tell exactly what caused the conflict between observation and simulation.

"If the simulation didn't get it right, it could mean that the simulated intracluster light is produced at a slightly different time than in observations. The simulated stars didn't have enough time to wander around and start to trace dark matter," she said.

Sampaio-Santos noted that further ICL studies could yield insights into the dynamics occurring inside galaxy clusters, including interactions that gravitationally release some of their stars, allowing them to wander around.

"I'm planning to study the intracluster light and the effects of relaxation," or spreading out, he said. For example, some clusters have merged together. These merged clusters should have different properties of ICL compared to clusters that are relaxed.

Enhancing signals in noisy data sets

The ICL that the team measured is about a hundred to a thousand times fainter than what DES scientists normally attempt. That means the team had to deal with a lot of noise and contamination in the signal.

The technical aspect of the feat was challenging, Zhang said, "but because we had quite a bit of data from the Dark Energy Survey, we were able to cancel out a lot of noise to do this kind of measurement. It's statistical averaging."

Astrophysicists typically make ICL measurements using a handful of galaxy clusters at a time.

"That's a great way to get information about the individual systems," Zhang said.

To get the bigger picture and to beat down the noise, the DES team statistically averaged about 300 galaxy clusters in the first study and more than 500 clusters in the second. All of them are a couple of billion light-years from Earth.

Teasing the signal from the noise of each cluster takes a lot of data, which is exactly what the DES has generated. In early 2019, DES completed its six-year mission of observing hundreds of millions of distant galaxies in the southern skies and publicly issued its second data release in mid-January.

The ICL measurements probe clusters that are up to 3.3 billion light-years from Earth. In future studies, Zhang would like to study the redshift evolution of ICL—how it changes with cosmic time.

"My dream is to go all the way to redshift one—10 billion light-years," Zhang said. "Studies say that's when the ICL has just started to evolve."

Going that far would enable scientists to see ICL building over time.

"But that's really hard because it's three times as far as the distance of our latest measurements, so everything is going to be extremely faint there," she said.

More information: Y. Zhang et al. Dark Energy Survey Year 1 Results: Detection of Intracluster Light at Redshift ~ 0.25, *The Astrophysical Journal* (2019). DOI: 10.3847/1538-4357/ab0dfd

Provided by Fermi National Accelerator Laboratory

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