Dark matter is likely 'cold,' not 'fuzzy,' scientists report after new simulations

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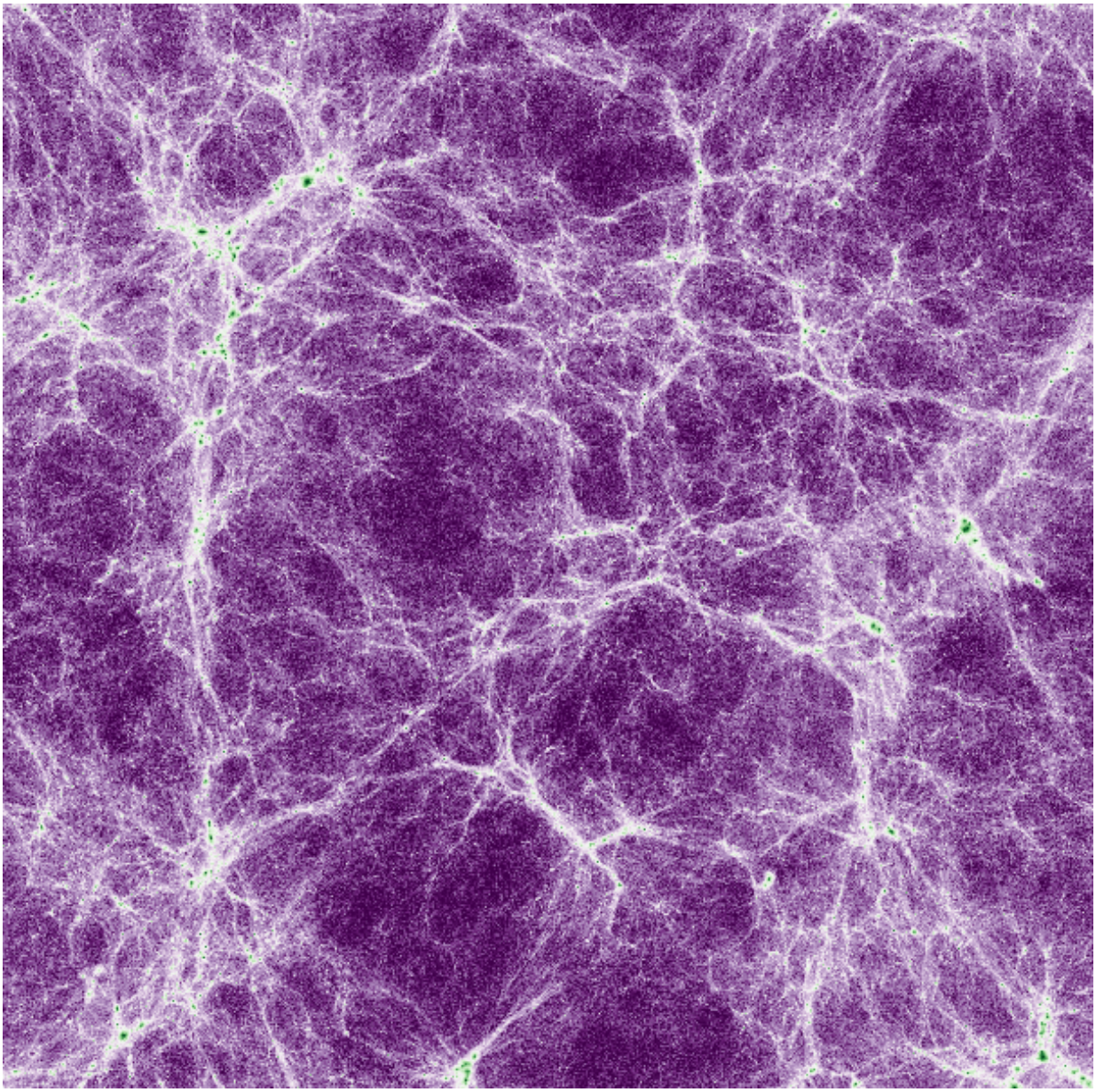


A depiction of hydrogen gas within the intergalactic medium, or IGM, with bright areas indicating high gas density. Credit: Vid Iršič

Dark matter is the aptly named unseen material that makes up the bulk of matter in our universe. But what dark matter is made of is a matter of debate.

Scientists have never directly detected dark matter. But over decades, they have proposed a variety of theories about what type of material—from new particles to primordial black holes—could comprise dark matter and explain its many effects on normal matter. In a paper published July 20 in the journal *Physical Review Letters*, an international team of cosmologists uses data from the intergalactic medium—the vast, largely empty space between galaxies—to narrow down what dark matter could be.

The team's findings cast doubt on a relatively new theory called "fuzzy dark matter," and instead lend credence to a different model called "cold dark matter." Their results could inform ongoing efforts to detect dark matter directly, especially if researchers have a clear idea of what sorts of properties they should be seeking.

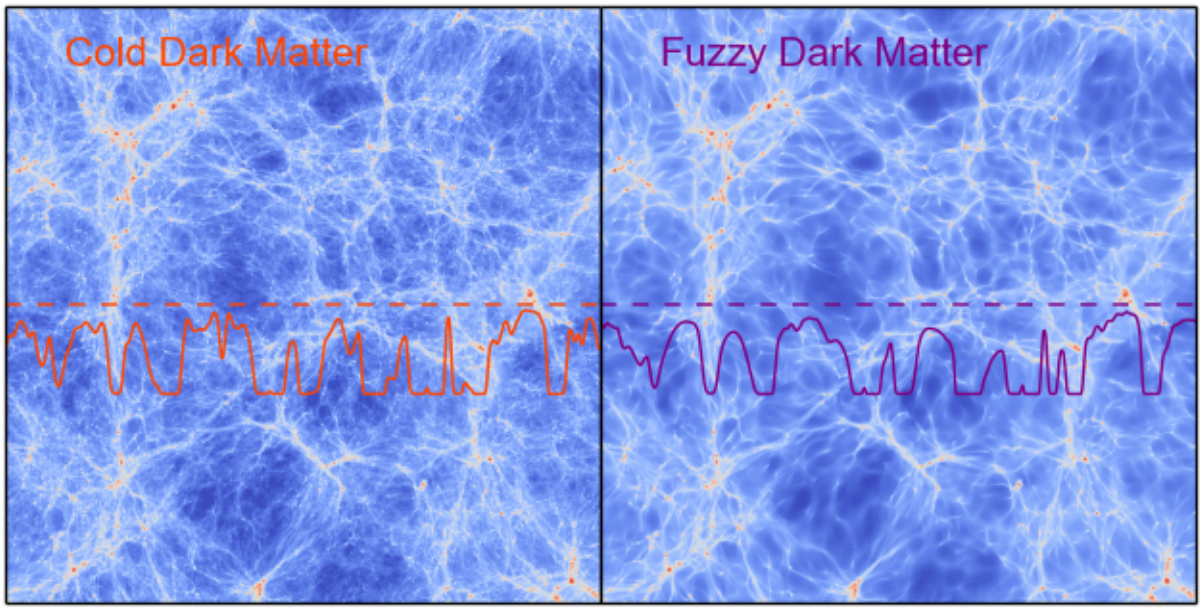
"For decades, theoretical physicists have tried to understand the properties of the particles and forces that must make up dark matter," said lead author Vid Iršič, a postdoctoral researcher in the Department of Astronomy at the University of Washington. "What we have done is place constraints on what dark matter could be—and 'fuzzy dark matter,' if it were to make up all of dark matter, is not consistent with our data."

Scientists had drawn up both the "fuzzy" and "cold" dark-matter theories to explain the effects that dark matter appears to have on galaxies and

the intergalactic medium between them.

Cold dark matter is the older of these two theories, dating back to the 1980s, and is currently the standard model for dark matter. It posits that dark matter is made up of a relatively massive, slow-moving type of particle with "weakly interacting" properties. It helps explain the unique, large-scale structure of the universe, such as why galaxies tend to cluster in larger groups.

But the cold dark matter theory also has some drawbacks and inconsistencies. For example, it predicts that our own Milky Way Galaxy should have hundreds of satellite galaxies nearby. Instead, we have only a few dozen small, close neighbors.



These images depict the absorption of light by hydrogen gas within the IGM, with bright areas indicating high gas density. The curves also show hydrogen absorption. On the left is a simulation based on the standard cold dark matter model. On the right is a simulation based on fuzzy dark matter. The left curve is

more consistent with data analyzed by Iršič and colleagues. Credit: Vid Iršič

The newer fuzzy dark matter theory addressed the deficiencies of the cold dark matter model. According to this theory, dark matter consists of an ultralight particle, rather than a heavy one, and also has a unique feature related to quantum mechanics. For many of the fundamental particles in our universe, their large-scale movements—traveling distances of meters, miles and beyond—can be explained using the principles of "classic" Newtonian physics. Explaining small-scale movements, such as at the subatomic level, requires the complex and often contradictory principles of quantum mechanics. But for the ultralight particle predicted in the fuzzy dark matter theory, movements at incredibly large scales—such as from one end of a galaxy to the other—also require quantum mechanics.

With these two theories of dark matter in mind, Iršič and his colleagues set out to model the hypothetical properties of dark matter based on relatively new observations of the intergalactic medium, or IGM. The IGM consists largely of dark matter—whatever that may be—along with hydrogen gas and a small amount of helium. The hydrogen within IGM absorbs light emitted from distant, bright objects, and astronomers have studied this absorption for decades using Earth-based instruments.

The team looked at how the IGM interacted with light emitted by quasars, which are distant, massive, starlike objects. One set of data came from a survey of 100 quasars by the European Southern Observatory in Chile. The team also included observations of 25 quasars by the Las Campanas Observatory in Chile and the W.M. Keck Observatory in Hawaii.

Using a supercomputer at the University of Cambridge, Iršič and co-authors simulated the IGM—and calculated what type of dark matter particle would be consistent with the quasar data. They discovered that a typical particle predicted by the fuzzy dark matter theory is simply too light to account for the hydrogen absorption patterns in the IGM. A heavier particle—similar to predictions of the traditional cold dark matter theory—is more consistent with their simulations.

"The mass of this particle has to be larger than what people had originally expected, based on the fuzzy dark matter solutions for issues surrounding our galaxy and others," said Iršič.

An ultralight "fuzzy" particle could still exist. But it cannot explain why galactic clusters form, or other questions like the paucity of satellite galaxies around the Milky Way, said Iršič. A heavier "cold" particle remains consistent with the astronomical observations and simulations of the IGM, he added.

The team's results do not address all of the longstanding drawbacks of the cold dark matter model. But Iršič believes that further mining of data from the IGM can help resolve the type—or types—of particles that make up dark matter. In addition, some scientists believe that there are no problems with the cold dark matter theory. Instead, scientists may simply not understand the complex forces at work in the IGM, Iršič added.

"Either way, the IGM remains a rich ground for understanding dark matter," said Iršič.

Co-authors on the paper are Matteo Viel of the International School for Advanced Studies in Italy, the Astronomical Observatory of Trieste and the National Institute for Nuclear Physics in Italy; Martin Haehnelt of the University of Cambridge; James Bolton of the University of

Nottingham; and George Becker of the University of California, Riverside. The work was funded by the National Science Foundation, the National Institute for Nuclear Physics in Italy, the European Research Council, the National Institute for Astrophysics in Italy, the Royal Society in the United Kingdom and the Kavli Foundation.

More information: Vid Iršič et al, First Constraints on Fuzzy Dark Matter from Lyman- α Forest Data and Hydrodynamical Simulations, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.119.031302 , arxiv.org/abs/1703.04683

Matteo Viel et al. Warm dark matter as a solution to the small scale crisis: New constraints from high redshift Lyman-αforest data, *Physical Review D* (2013). DOI: 10.1103/PhysRevD.88.043502

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