Astrophysicists simulate a fuzzy dark matter galactic halo

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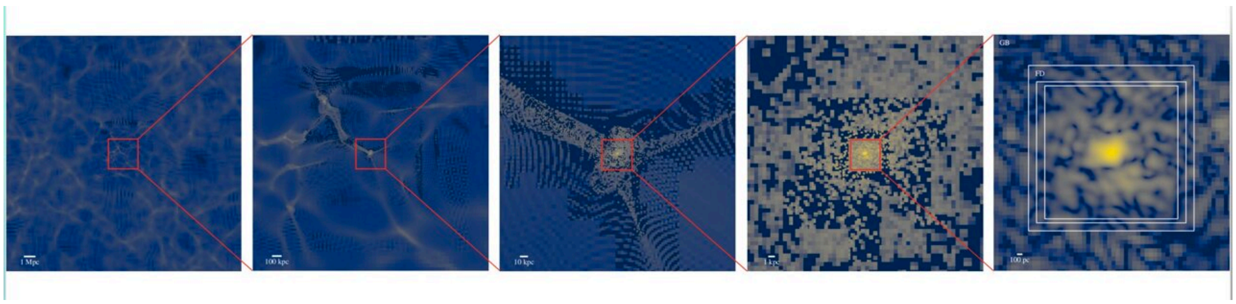

Density slices zooming into a fuzzy dark matter halo. The plot on the right shows the reconstructed fuzzy dark matter wave function with self-consistent interference pattern and central solitonic core using the newly presented Gaussian beam method in the innermost, highly resolved region of the halo. Credit: Schwabe & Niemeyer.

Dark matter is a type of matter in the universe that does not absorb, reflect or emit light, which makes it impossible to directly detect. In recent years, astrophysicists and cosmologists worldwide have been trying to indirectly detect this elusive type of matter, to better understand its unique features and composition.

One of the most promising candidates for dark matter is "fuzzy dark matter" a hypothetical form of dark matter that is thought to consist of extremely light scalar particles. This type of matter is known to be difficult to simulate, due to its unique characteristics.

Researchers at Universidad de Zaragoza in Spain and the Institute for Astrophysics in Germany have recently proposed a new method that could be used to simulate the fuzzy dark matter forming a galactic halo. This method, introduced in a paper published in *Physical Review Letters*, is based on the adaptation of an algorithm that the team introduced in their previous works.

"The numerical challenge for studies focusing on fuzzy dark matter is that its distinguishing features, the granular density fluctuations in collapsed halos and filaments, are orders of magnitude smaller than any cosmological simulation box large enough to accurately capture the dynamics of the cosmic web," Bodo Schwabe, one of the researchers who carried out the study, told Phys.org. "Thus, for years people have tried to combine efficient numerical methods capturing the large-scale dynamics with algorithms that are computationally demanding but can accurately evolve these density fluctuations."

As part of their recent study, Schwabe and his colleague Jens C. Niemeyer adapted and improved an algorithm that they had introduced in their previous work. So far, the method they developed is the only one that can be successfully used to conduct fuzzy dark matter cosmology simulations.

Using their adapted algorithm, the researchers were able to simulate the collapse of the cosmos web into filaments and halos. This was achieved using the so-called "n-body method," which divides the "initial density field" into small particles that freely evolve under the force of gravity.

"The n-body method is a very stable, well tested and efficient method, but it does not capture the density fluctuations of the interfering fuzzy dark matter field in filaments and halos," Schwabe explained. "In a tiny sub-volume of our simulation box tracing the center a pre-selected halo, we therefore switched to a different algorithm, known as the finite difference method, which directly evolves the fuzzy dark matter wave function and can thus capture its interfering modes yielding the characteristic granular density fluctuations."

While the n-body and the finite difference methods are widely used by astrophysics worldwide to perform cosmological simulations, they have rarely been used in conjunction. To perform their simulations, Schwabe and Niemeyer combined these two methods, relying on the moderation between them on the surface of the sub-volume.

More specifically, the method they used promotes the n-body particles to coherent wave packages known as "Gaussian beams." The superposition of these elements led to a fuzzy dark matter wave function at their intersection, which ultimately allowed to perform their simulations.

"Our successful combination of the n-body and finite difference methods paves the way for realistic cosmological fuzzy dark matter simulations," Schwabe added. "These simulations can include the collision of two or more fuzzy dark matter halos, the evolution of star clusters inside a halo, or their interaction with the central solitonic core whose random walk can potentially heat up or even disrupt the star cluster."

More information: Bodo Schwabe et al, Deep Zoom-In Simulation of a Fuzzy Dark Matter Galactic Halo, *Physical Review Letters* (2022). DOI: 10.1103/PhysRevLett.128.181301