Brownian Motion of Dark Matter

Scientists have revealed the fine structure and detailed motion of wavelike dark matter.

Dark matter comprises approximately 27% of the energy of the Universe and plays an indispensable role in galaxy formation and evolution. However, the nature of dark matter remains obscure; for example, what is its composition, particle mass, and temperature? Wave dark matter is an emerging dark matter candidate composed of ultralight, $\sim 10^{-22}$ eV, bosons in the Bose-Einstein condensation state. It exhibits a rich wavelike structure, including a soliton core within a surrounding halo that continuously self-interferes on the de Broglie scale (Fig. 1).

In a paper published in *Physical Review Letters* [1], Prof. Hsi-Yu Schive and Prof. Tzihong Chiueh of National Taiwan University (NTU), Taipei, Taiwan, in collaboration with Tom Broadhurst, an Ikerbasque researcher in Bilbao, Spain, have conducted unprecedentedly high-resolution simulations to study the detailed structure of wave dark matter. Using GAMER [2], a state-of-the-art multi-GPU accelerated code developed by the NTU team, their simulations achieved a resolution of 10^{-5} of the halo radius and revealed, for the first time, that the soliton undergoes a confined random walk at the base of the halo potential. "It is similar to the Brownian motion of a massive particle randomly colliding with a large set of smaller particles," said Prof. Schive.

This soliton random motion is significant for the fate of the ancient central star cluster in the ultrafaint dwarf galaxy Eridanus II, as the agitated soliton gravitationally shakes the star cluster in and out of the soliton, leading to complete tidal disruption of the star cluster.

The researchers also showed that this destructive effect can be mitigated if the halo of Eridanus II has been stripped away by the Milky Way tides, thereby reducing the agitation. Without the interplay between halo and soliton, the amplitude of soliton random motion would decline significantly, and so the star cluster and soliton could coexist.

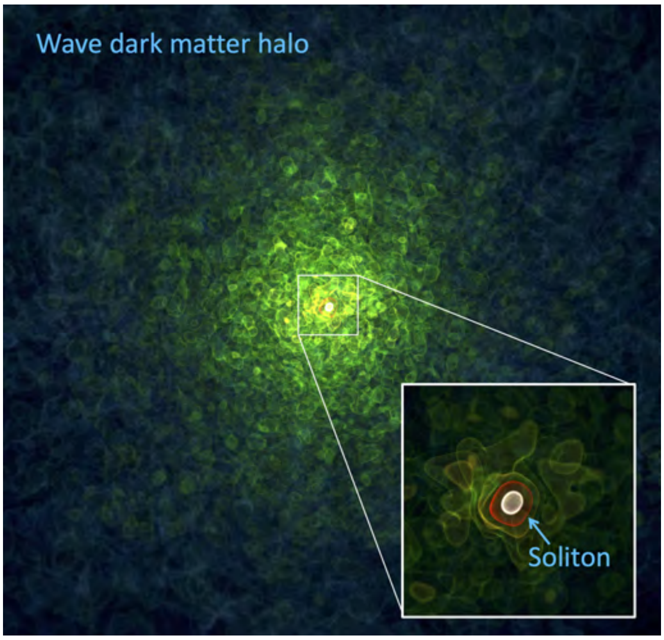

Fig 1: A halo-soliton pair in a state-of-the-art wave dark matter simulation. Image credit: Hsi-Yu Schive, National Taiwan University; visualized with the yt package.

According to Prof. Schive, "These exciting findings will allow scientists to explore the nature of dark matter in brand-new ways; for example, the soliton random motion may have a profound impact on the supermassive black hole at the galactic center." Prof. Chiueh stated, "Wave dark matter is a promising dark matter candidate that can originate from non-QCD axions and be one of the low-energy manifestations of string theory."

References

[1] "Soliton Random Walk and the Cluster-Stripping Problem in Ultralight Dark Matter", Hsi-Yu Schive, Tzihong Chiueh, and Tom Broadhurst, Phys. Rev. Lett., 124, 201301 (2020); https://doi.org/10.1103/PhysRevLett.124.201301

[2] "GAMER-2: a GPU-accelerated Adaptive Mesh Refinement Code – Accuracy, Performance, and Scalability", Schive et al., Mon. Not. R. Astron. Soc., 481, 4815 (2018); https://doi.org/10.1093/mnras/sty2586