Probing the quantum mechanics of ultra-light dark matter with strong gravitational lensing

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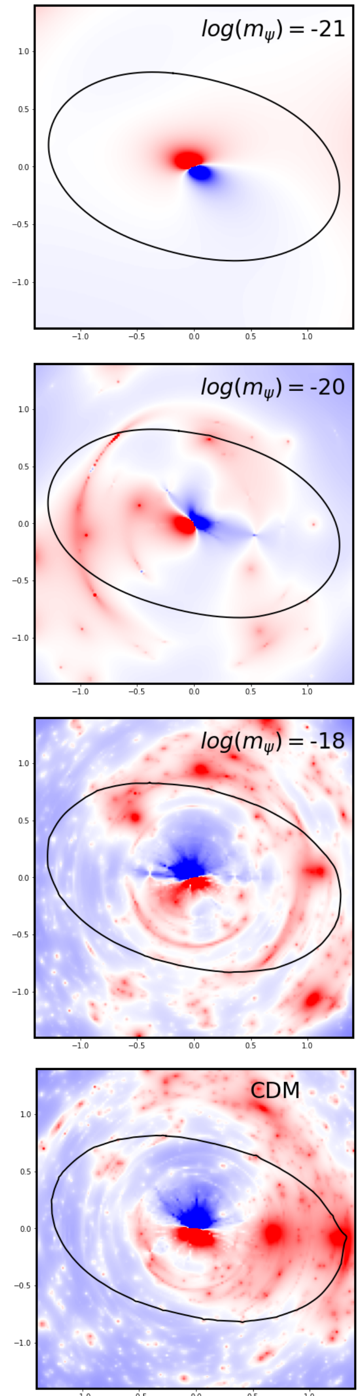

The nature of dark matter (DM), which is thought to compose roughly 85% of the matter in our universe, is currently unknown. Ultra-light dark matter (ULDM) is a proposed dark matter candidate made of ultra-light axions. These axions are so light that quantum mechanical effects manifest in ULDM on galactic scales. It is particularly challenging to study DM since it does not interact with ordinary matter. We can however study its gravitational impact, which makes strong gravitational lensing a promising tool to probe the composition of ULDM. Strong lensing occurs when light from a bright galaxy center, called a quasar, heads towards Earth and gets bent by the gravity field of a galaxy system into multiple images. The relative brightnesses of these images, called flux ratios, are sensitive to the dark matter structure along the entire line of sight which is deflecting the light from the quasar. We may use strong lensing to constrain the ultra-light axion mass since the shape and number of DM halos (DM clumps) change according to the axion mass.

We created a ULDM model which can generate populations of ULDM halos, for different axion masses, in a way that is consistent with theoretical predictions. The figures on the right show how the DM structure in a galaxy system changes for different axion masses. Two-dimensional projections of the DM distributions are shown, with red regions having higher mass densities than blue regions. Very light axions (top) strongly suppress the amount of structure relative to a cold dark matter (CDM) scenario (bottom), in which particles are collisionless and 10^{30} times heavier. This is in part due to lighter axion masses having more quantum pressure, which prohibits the formation of small halos. As the axion mass gets heavier (second from bottom), ULDM becomes increasingly indistinguishable from CDM. We can compare the data from observed strong lensing systems, i.e. the image locations and flux ratios, to ULDM simulations generated with our model and determine which axion mass is most likely.

Our model is currently neglecting the quantum fluctuations near the center ULDM halos. These are density fluctuations which are comparable in size to the average density of ULDM and manifest on small galactic scales corresponding to the de Broglie wavelength of the axion. They may significantly impact gravitational lensing and we plan to add these fluctuations in the near future. Once we have injected this component into our model, we will be able to use the current dataset of lensed quasars to constrain the axion mass.