Quantum-mechanically supported Galaxies

Galaxy Formation with Ultralight Axions

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In Short

- String theory predicts the existence of axion-like particles whose masses can be so low that their de Broglie wavelength can reach several kiloparsecs. They are a well motivated dark matter candidate.
- We investigate the impact dark matter consisting of ultra-light axion-like particles on galaxy formation, halo mergers and substructure in cosmological zoom-in simulations

Standard ΛCDM cosmology has proven extremely successful over the last decades. But cold dark matter (CDM) clusters on all scales. This leads to a number of small-scale problems like the missing satellites, the cusp-core or the too-big-to-fail problem. These problems have in common that numerical simulations using ΛCDM cosmology predict much larger DM over-densities on small scales than are inferred from experiments.

A variety of possible solutions like baryonic feedback or warm dark matter have been proposed to overcome these shortcomings. Another solution, which is considered in this project, is to postulate a non-interacting ultra-light scalar DM component, such as stringy axions, with masses in the order of m~10^{-22} eV [1–3]. This type of dark matter is commonly referred to as fuzzy dark matter (FDM). While lighter particles are in tension with constraints from the observed UV luminosity function at redshifts z~4-10 and from the re-ionization history, FDM masses of this order of magnitude are still consistent with observations. These particles have de Broglie wave lengths λ=h/mv~1 kpc of astrophysical scales. Consequently, the uncertainty principle can stabilize dark matter halo cores on small scales. FDM is treated as a classical complex scalar field whose evolution is governed by the comoving Schrödinger-Poisson system. For a comprehensive review on the topic see [4].

The Schrödinger-Poisson system can be integrated on a discretized grid or, can be approximately evolved using a particle method. On large scales the second method has the advantage of not needing to resolve the local de Broglie wave length, which is numerically not feasible. On the other hand, it cannot correctly capture interference patterns, resulting in a strongly oscillating matter density.

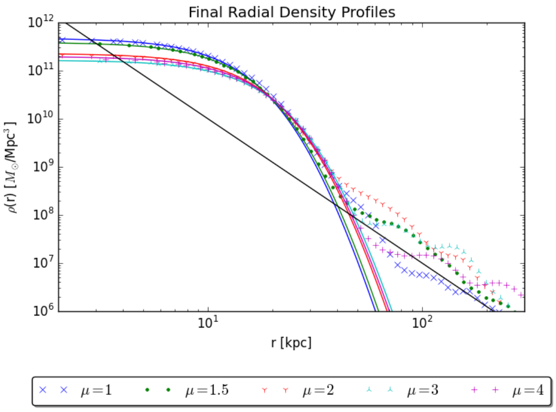

***Figure 1:** Final radial density profiles of binary mergers. Solid lines represent fitted core profiles. The black line corresponds to r^{-3} as expected for the outer parts of an NFW profile.*

In our paper [6] we used grid based three-dimensional simulations to study the dynamics and final structure of merging solitonic cores predicted to form in FDM halos. The necessary computational resources were provided by the HLRN within this project. We investigated mergers of ground state (boson star) configurations with varying mass ratios, relative phases, orbital angular momenta and initial separation with the primary goal to understand the mass loss of the emerging core by gravitational cooling. Previous results showing that the final density profiles have solitonic cores and NFW-like tails were confirmed (see Figure 1). We found that in binary mergers, the final core mass does not depend on initial phase difference or angular momentum and only depends on mass ratio, total initial mass, and total energy of the system. For non-zero angular momenta, the otherwise spherical cores become rotating ellipsoids. The results for mergers of multiple cores are qualitatively identical. Volume rendered images of two representative runs are shown in Figure 2.

The above method requires high spatial resolution. We were therefore restricted to galactic scales. In order to also model the structure formation on cosmological scale, in our paper [7], we followed the approach to use N-body simulations with an additional force term to the equations of motion of the particles. This accounts for the small scale effects of the scalar field which stems from the so-called quantum pressure in the Madelung representation of the Schrödinger equation. Our results show an enhanced power spectrum at small scales compared

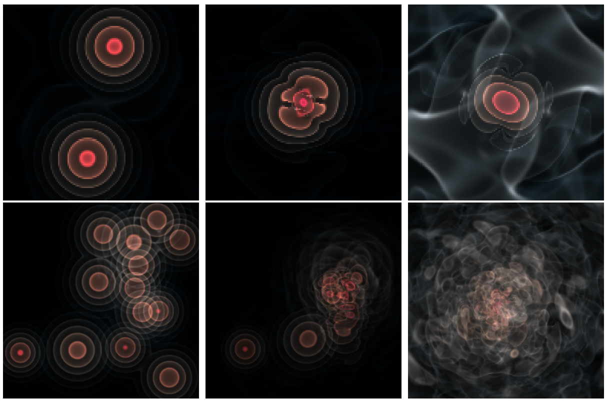

Figure 2: Volume rendered images of a binary merger (top) and the merging of 13 solitons. Shown is the central region of the computational domain at different times.

to standard N-body simulations.

In our recent paper [8], we combined the strengths of the above outlined algorithms. We conducted nested cosmological simulations using an extended version of the Enzo code. In contrast to previous entirely grid based simulations [5], we utilized a Particle-in-Cell method on coarse grids and used our grid based solver for the Schrödinger equation only on the finest levels. Since the Particle-in-Cell method is computationally much cheaper, this allowed us to well resolve a handful of pre-selected galaxies in a cosmological set-up (see Figure 3). We could thereby show that the solitonic cores exhibit strong quasi-normal oscillations that remain largely undamped on evolutionary timescales. On the other hand, no conclusive growth of the core mass by condensation or relaxation could be detected. In the incoherent halo surrounding the cores, the scalar field density profiles and velocity distributions showed no significant deviation from collisionless N-body simulations on scales larger than the coherence length. Our results are consistent with the core properties being determined mainly by the coherence length at the time of virialization, whereas the SchrÃ¶dinger-Vlasov correspondence explains the halo properties when averaged on scales greater than the coherence length.

Solving the equations of motion for baryonic matter (gas) simultaneously will enable us to consistently investigate hierarchical structure formation of FDM and its impact on halo substructure, baryonic physics, and the properties of the earliest generation of galaxies. We will be able to analyze the corresponding reionization history and the UV luminosity function in order to tighten the constraints on the FMD particle mass.

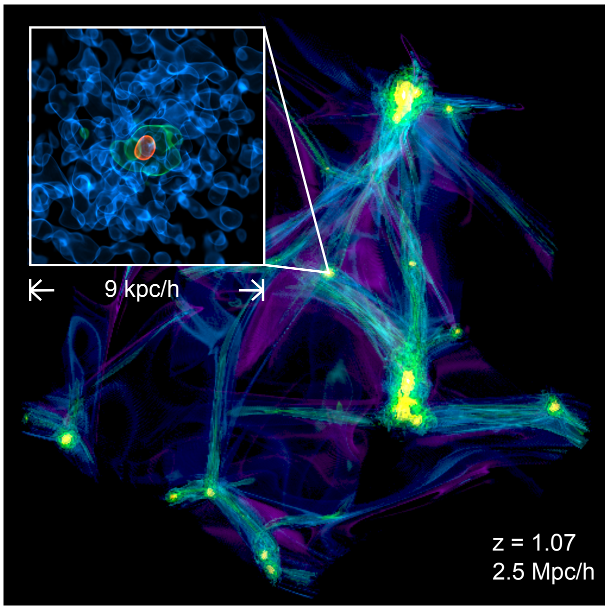

Figure 3: Simulated Fuzzy Dark Matter halo in a cosmological zoom-in simulation.

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http://www.uni-goettingen.de/de/axion+cosmology/541882.html

More Information

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