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EXPLORE project: "The Life and Death of Dark Matter Halos"

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Dark matter halos are a fundamental unit of structure in the Universe: from the very first stars born in small mini-halos, all the way up to the supermassive halos that hold together clusters of thousands of galaxies. This research will study how dark matter's particle dynamics –its interactions and forces beyond gravity – can affect the time evolution of halos, potentially inducing a gravothermal catastrophe that causes runaway collapse. Performing a series of simplified numerical simulations, we will investigate the impact of several dark matter properties on halo dynamics: whether dark matter is one or more than one species of particle, whether different species can scatter elastically or inelastically into one another, and whether species have dissipative interactions that cause energy loss. Finally, we will consider these simulations in the context of the first stars to investigate whether collapsed mini-halos lead to the formation of supermassive early stars that ultimately seed supermassive black holes that form in the centers of galaxies. Our treatment for dark matter halo dynamics will be based on the so-called "fluid approximation" in which dark matter is treated as an ideal gas described by Euler's equations for a compressible fluid. We will review some basics of fluid dynamics and learn how dark matter's particle interactions are described (e.g. heat conduction and heat loss). Our approach for solving Euler's equations will be based on an elegant framework known as Smoothed Particle Hydrodynamics (SPH). SPH is the basis for any state-of-the-art numerical simulations for astrophysics (and beyond) that are run on supercomputers. Here, we will follow a much-simplified approach for SPH where spherical symmetry is assumed. Lastly, our numerical treatment of dark matter halo evolution has many interesting applications across the range of smallest to largest halos in the Universe. One such application is the formation of the first stars.

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