Understanding the Dark Matter Distribution in our Galaxy

Michael S. Warren, Alexander Friedland, Daniel Holz, Alexia Schulz, Ian Shoemaker, T-2

The dark matter distribution in our galaxy strongly influences the signals from both direct and indirect dark matter detection experiments. Our aim is to understand the local density and velocity distribution of dark matter via large-scale numerical simulations. The intrinsic non-linearity of the gravitational evolution of matter limits analytic studies to small perturbations or restricted symmetries. The only way to obtain accurate 3D solutions is via numerical simulation. We have a long and distinguished history in the development of parallel numerical techniques to solve astrophysical and cosmological N-body problems. We have achieved superior performance on multiple generations of the fastest supercomputers in the world with our HOT code, spanning almost two decades and garnering multiple Gordon Bell Prizes for significant achievement in parallel processing.

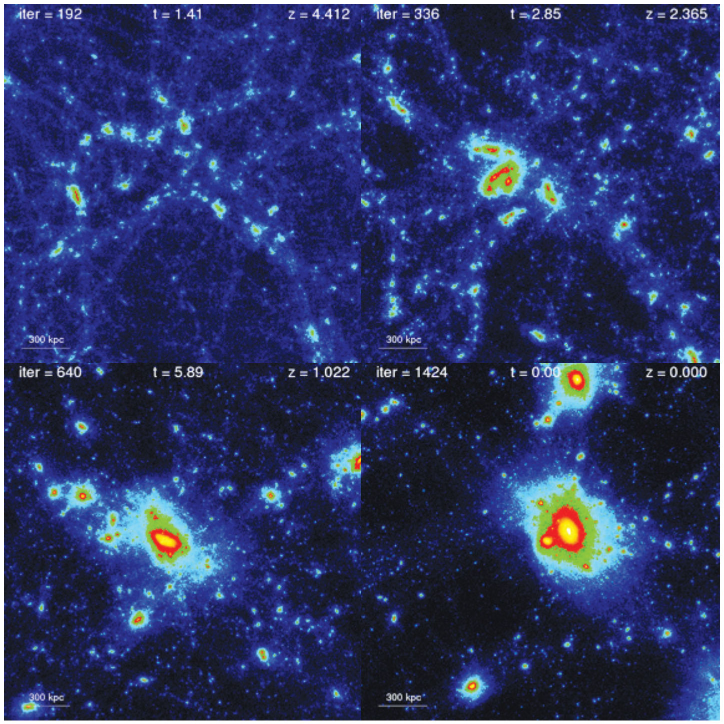

Fig. 1. We show the formation history of the largest galaxy halo in our simulation, which has a mass similar to the halo of our own galaxy. Colors represent the logarithm of projected density, with yellow being the most dense, and blue being the lowest density. Note the abundance of substructure throughout the evolution.

We have performed several high-resolution dark matter simulations to model the velocity distribution of dark matter under conditions similar to our own Milky Way galaxy. The most recent was of a spherical region of the universe, 12.5 Mpc in diameter, with cosmological parameters set to match the current best-fit results of the Wilkinson Microwave Anisotropy Probe (WMAP). Four snapshots of the largest dark matter halo forming over time are shown in Fig. 1. The dark matter particle mass was $5.3 \times 10^5\ M_\odot$. Evolving 70 million dark matter particles from a redshift of 64 to the present, we extracted 35 dark matter halos with total masses between 3×10^{11} and $2 \times 10^{12}\ M_\odot$. Initial results (see Fig. 2) confirm earlier work, which demonstrated that the velocity dispersion of the dark matter follows a Gaussian profile, with a width similar to the velocity of a test particle on a circular orbit (220 km/sec for the Milky Way). However, while the mean velocity distribution is well-described by a Gaussian, the density distribution of dark matter is clustered down to the scales resolved in the simulations, which may have consequences for the signal expected from direct dark matter detection experiments.

The clustering of substructure in a halo is explored in Fig. 3. An unresolved question is: "What is the smallest scale at which dark matter clusters?" If the density of dark matter varies substantially on scales of the solar system or smaller, we could be in an unusually dense or sparse region of dark matter. Answering this question requires careful consideration of the initial conditions of the dark matter in the universe, as well as posing a severe computational challenge,

For more information contact Michael S. Warren at mswarren@lanl.gov.

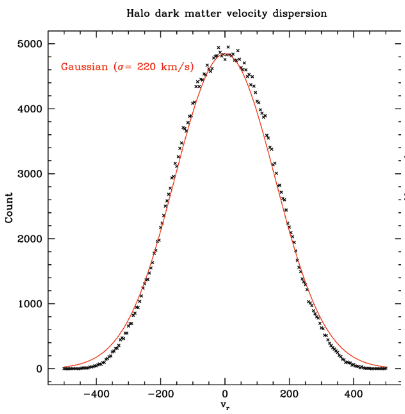

Fig. 2. We plot the 1D velocity dispersion of particles in a dark matter halo. At small velocities, the data is well-fit by a Gaussian with width 220 km/sec. The tails of the distribution deviate substantially, however, which will affect the constraints offered by the direct dark matter detection experiments that are most sensitive to high velocity dark matter particles.

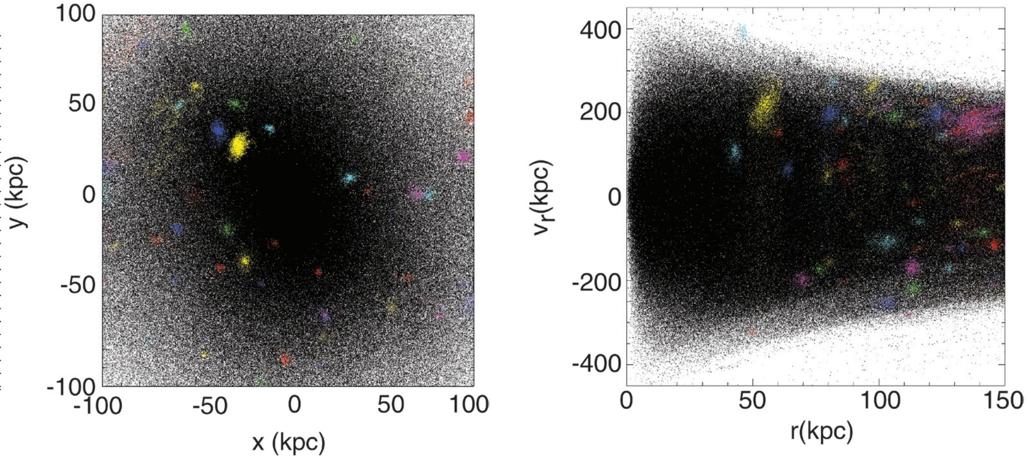

Fig. 3. On the left, we color code bound structures found within the larger halo. On the right, we plot the same data in position/velocity phase space. The need for higher-resolution simulations is demonstrated by the lack of resolved substructure within 40 kpc of the center.

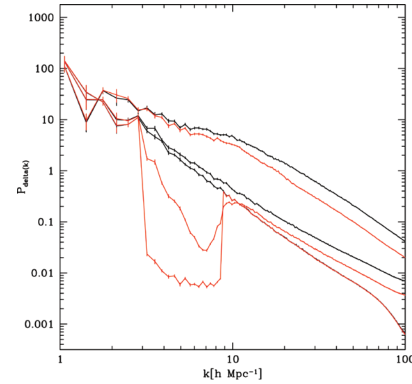

Fig. 4. We plot the evolving spectrum of density fluctuations for two models. The black lines show a -2.5 power law at three epochs. The red lines show an identical power spectrum, with a band of power removed from the initial conditions. The top two lines show the final power spectra, which are nearly identical at scales larger than the notch, but with structure significantly suppressed at all scales smaller than the notch. This implies that the normal techniques of performing simulations with periodic boundary conditions at scales approaching a single galaxy halo will artificially suppress the formation of structure due to the lack of perturbations from scales outside of the computational volume.

since a small computational volume cannot be considered in isolation from the rest of the universe. In order to assess the sensitivity of substructure to boundary conditions, we have performed simulations of "synthetic" initial conditions consisting of scale-free power laws, as well as combinations of power laws (i.e., "broken" power laws) and notch-filtered power laws. An example is show in Fig. 4.

Funding Acknowledgments
LANL Laboratory Direcrted Research and Development - Directed Research program; LANL Institutional Computing Program