Dark Sky Simulations Collaboration

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The Dark Sky Simulations are an ongoing series of cosmological N-body simulations designed to provide a quantitative and accessible model of the evolution of the large-scale Universe. Cosmological simulations are the cornerstone of theoretical analysis of structure in the Universe from scales of kiloparsecs to gigaparsecs. Predictions from numerical models are critical to almost every aspect of the studies of dark matter and dark energy, due to the intrinsically non-linear gravitational evolution of matter. During the next few years, projects such as Pan-STARRS, the South Pole Telescope (SPT) and the Dark Energy Survey (DES) will measure the spatial distribution of large-scale structure in enormous volumes of space across billions of years of cosmic evolution. At the other extreme (sub-galactic and galactic scales from 100 parsecs to a megaparsec) understanding the distribution of dark matter within Milky Way type halos is necessary to interpret the results of Earth-based dark matter detection experiments. The revolutionary transformation of cosmology from a qualitative to a quantitative science has occurred over just the last twenty years. Driven by a diverse suite of observations, the parameters describing the large-scale Universe are now known to near 1% precision. Yet, the precise nature of dark matter and dark energy remain a mystery, and are unquestionably among the most important unsolved problems in physics. Advances in modeling must keep pace with observational advances if we are to understand the Universe which led to these observations.

We have achieved superior performance on multiple generations of the fastest supercomputers in the world with our hashed oct-tree N-body code (`HOT`), spanning two decades and garnering multiple Gordon Bell Prizes for significant achievement in parallel processing. Using several new integrated and innovative algorithmic and computational science advances embodied in version 2 of the code (`2HOT`), combined with a unified data analysis effort based on the widely-adopted `yt` project, we propose a far-reaching set of scientific goals. We additionally aim to advance the state-of-the-art in domain decomposition and hierarchical tree-based computational techniques relevant to many simulation and data analysis problems. We will address a wide range of scientifically relevant tests of the standard cosmological model, including measurements of cluster abundance, void statistics, baryon acoustic oscillations, redshift-space distortions, velocity statistics and gravitational lensing. At small scales, we will test the abundance and central kinematics of the dwarf spheroidal galaxy satellites and related small-scale gravitational physics which determine the expected signal for dark matter detection experiments. Our simulations will produce an unprecedented suite of accurate and reliable halo, sub-halo and mock galaxy catalogs, which we will make publicly available.