Computational Cosmology at Extreme Scale with HACC

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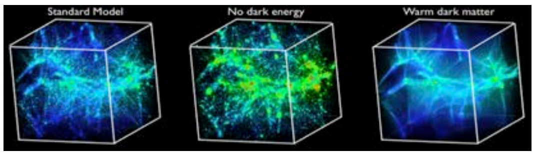
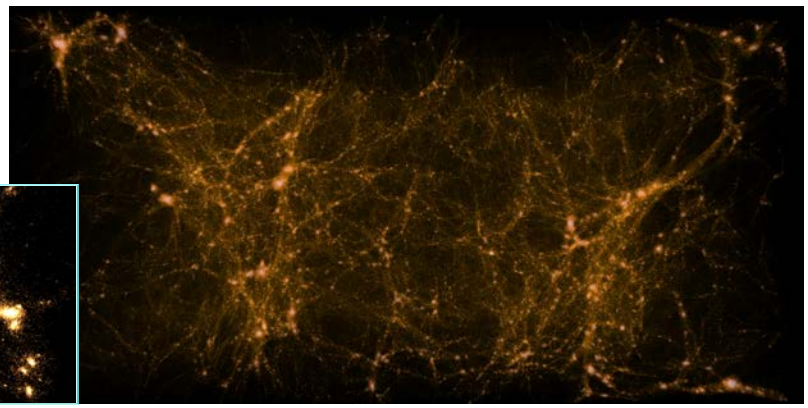
The Cosmic Frontier presents fundamental discovery opportunities related to dark energy, dark matter, the masses of neutrinos and their hierarchy, and unique probes of inflation and the early Universe. Large-scale sky surveys across multiple wavebands are collecting massive amounts of data that hold the key to a deeper understanding of the Universe. High performance computing is a powerful tool of discovery in extracting insights and making precision predictions for these observations. Our SciDAC project is building next generation computational cosmology prediction and analysis frameworks that are directly targeted to current and future observations. [S. Habib (Project Director), PIs: K. Heitmann (ANL), A. Slozar (BNL), S. Dodelson (FNAL), P. Nugent (LBNL), J. Ahrens (LANL), R. Wechsler (SLAC/ Stanford)]. HACC is one of the major codes contributing to this project.

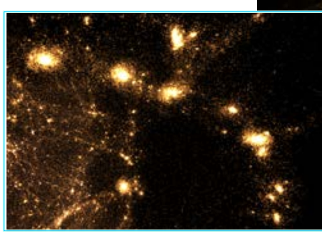


Simulated dark matter distribution for different cosmological models (colors represent velocity magnitudes), demonstrating the sensitivity of large scale structure to new physics.

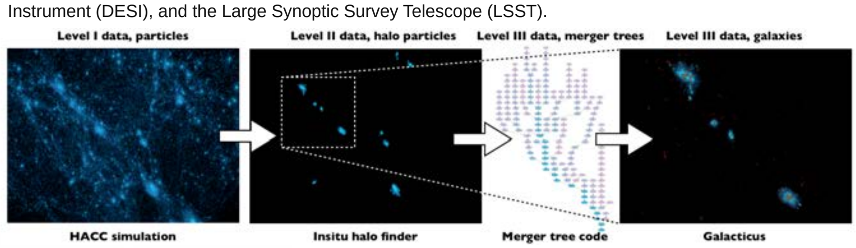
Next-Generation N-Body Code Framework and Tools:
- **HACC (Hardware/Hybrid Accelerated Cosmology Code)**
- **Associated CosmoTools analysis framework (in situ/offline)**
- **Runs at scale on all leadership-class platforms**
- **Designed for next-generation/exascale systems**
- **Large-volume, high resolution campaigns for sky surveys**

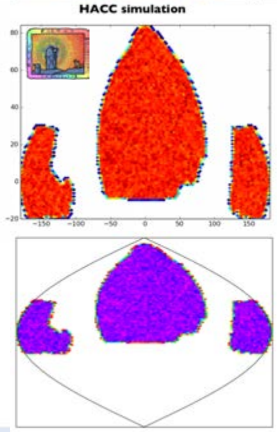


A small fraction (1/16384) of the total volume of a recently finished run on Titan at OLCF (right). This simulation is the world's largest high resolution cosmological simulation by a factor of more than 60. The small box (corner view) shows the details captured in the simulation, HACC has a dynamic range in excess of a million.

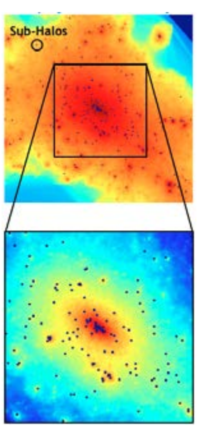


Halo merger tree (left) -- time runs from top to bottom -- illustrating the complexity of structure formation for a single clump in a simulation such as the one depicted above. Semi-analytic galaxy formation models can be run on these merger trees, using codes such as Galacticus (below). Synthetic sky catalogs are being generated using halo occupation distribution (HOD), subhalo abundance matching (SHAM) and semi-analytic modeling (SAM) methods for the Dark Energy Survey (DES), the Dark Energy Spectroscopic Instrument (DESI), and the Large Synoptic Survey Telescope (LSST).



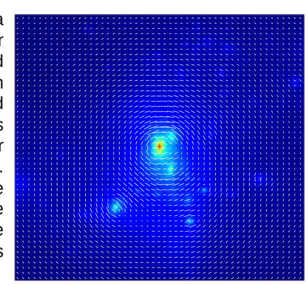


The areal density of emission line galaxies (ELGs) from synthetic catalogs produced for DESI (left). The catalogs are based on the 'Outer Rim' trillion-particle simulation run on Mira at ALCF. The catalogs are being used to test fiber assignment algorithms and to optimize the footprint and survey strategy for DESI. DESI is expected to go 'on sky' in 2018.



Subhalo tracking in a large halo from a simulation on Titan (left). Colors depict halo density. The detailed subhalo tracking is accomplished using the history of individual particles as they traverse a merger tree to their final end locations. Precision tracking of the subhalo structure is important for galaxy formation studies and for galaxy-galaxy lensing, an important cosmological probe, based on using stacked images for a large number of bright galaxies and analyzing the lensed images of background sources.

Weak lensing shear signal from a simulated massive galaxy cluster using a new tessellation-based density estimation algorithm (right). The. analysis of strong and weak gravitational lensing signals can help determine cluster masses and density profiles. Large numbers of clusters will be found in current and future surveys across multiple wavebands; cluster abundance is a major probe of cosmology.



Cosmic Frontier Computing