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Computational Cosmology at the Bleeding Edge

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Large-area sky surveys are providing a wealth of cosmological information to address the mysteries of dark energy and dark matter. Observational probes based on tracking the formation of cosmic structure are essential to this effort, and rely crucially on N-body simulations that solve the Vlasov-Poisson equation in an expanding Universe. As statistical errors from survey observations continue to shrink, and cosmological probes increase in number and complexity, simulations are entering a new regime in their use as tools for scientific inference. Changes in supercomputer architectures provide another rationale for developing new parallel simulation and analysis capabilities that can scale to computational concurrency levels measured in the millions to billions. In this talk I will outline the motivations behind the development of the HACC (Hardware/Hybrid Accelerated Cosmology Code) extreme-scale cosmological simulation framework and describe its essential features. By exploiting a novel algorithmic structure that allows flexible tuning across diverse computer architectures, including accelerated and many-core systems, HACC has attained a performance of 14 PFlops on the IBM BG/Q Sequoia system at 69% of peak, using more than 1.5 million cores.