APR15-2015-000425

Abstract for an Invited Paper
for the APR15 Meeting of
the American Physical Society

Cosmological N-body Simulation of Galaxy and Large-Scale Structure Formation: The Gravity Frontier

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One of the first N-body simulations done almost 50 years ago had only 200 self-gravitating particles. Even this first baby step made substantial impact on understanding how astronomical objects should form. Now powerful supercomputers and new algorithms allow astronomers produce N-body simulations that employ up to a trillion dark matter particles and produce vital theoretical predictions regarding formation, evolution, structure and statistics of objects ranging from dwarf galaxies to clusters and superclusters of galaxies. With only gravity involved in these theoretical models, one would naively expect that by now we should know everything we need about N-body dynamics of cosmological fluctuations. Not the case. It appears that the Universe was not cooperative and gave us divergencies in the initial conditions generated during the Inflation epoch and subsequent expansion of the Universe - the infinite phase-space density and divergent density fluctuations. Ever increasing observational demands on statistics and accuracy of theoretical predictions is another driving force for more realistic and larger N-body simulations. Large current and new planned observational projects such as BOSS, eBOSS, Euclid, LSST will bring information on spatial distribution, motion, and properties of millions of galaxies at different redshifts. Direct simulations of evolution of gas and formation of stars for millions of forming galaxies will not be available for years leaving astronomers with the only option - to develop methods to combine large N-body simulations with models of galaxy formation to produce accurate theoretical predictions. I will discuss the current status of the field and directions of its development.