Star-by-star simulations of galaxy formation on Fugaku

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How galaxies are formed has been one of the most important problems in modern astronomy or modern cosmology, for many different reasons. First of all, stars are formed in galaxies. Thus, to understand how stars are formed, it is necessary to understand how the environment of star formation evolves, and that means we need to understand how galaxies are formed. From the viewpoint of the observational cosmology, we use galaxies as the tracers of the structure formation of the universe through the gravitational instabilities of dark matter. At the beginning of the universe, there are only several light elements such as H, He, and Li, and other heavier elements are synthesized during stellar evolution and proceeding energize events such as supernovae and neutron star mergers. Hence, the origins of rocky planets and life are linked with the origin of galaxies.

Galaxy formation is a very challenging issue because of its multi-scale/multi-physics properties. It involves wide scales such as the cosmic web (10 Mpc scale), the dark matter halo (100 kpc scale), and the star formation (1 pc scale) simultaneously and a variety of physics such as gravity, hydrodynamics, radiation processes, etc. Thus, computational simulation plays a crucial role to study it. The current computational power, even at the most powerful computers in the world, is, however, insufficient to handle individual stars in a galaxy because of the lack of their power. A typical number of particles used in a galaxy is at most 10^7, which means that it is impossible to resolve individual stars while Gaia, the space astrometry satellite, now provides the five-dimensional phase space data of more than 10^8 nearby stars. It requires 2-3 orders of magnitudes larger number of particles for numerical simulation to resolve individual stars and to archive direct comparison of models and observations.

The computational performance of the Japanese national supercomputer Fugaku is high enough to resolve individual stars in galaxy formation simulation. We are now developing a simulation code that can handle Fugaku's 1M CPU cores well. In my talk, I first show the current status of high-resolution galaxy formation simulations. I, then, describe our approach to archive galaxy formation simulations using an extremely large number of cores. I finalize my talk by showing some performance results on the Fugaku test environment.

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