EXECUTIVE SUMMARY

Clusters of galaxies are both a useful probe of cosmology and a laboratory for understanding galactic feedback processes. However, modeling galactic-scale feedback processes in the context of a galaxy cluster presents a computational challenge because of the large dynamic range involved. Through the use of a highly scalable N-body/Smooth Particle Hydrodynamics code running on Blue Waters, our project is tackling this challenging problem. Preliminary results show that models that have successfully reproduced the morphology and number densities of isolated field galaxies can also produce realistic models of cluster galaxies. Large computational resources with high-performance networks are necessary for these calculations.

RESEARCH CHALLENGE

Groups and clusters of galaxies are the largest bound objects in the universe, containing more than a third of the warm–hot baryons and galaxies across the age of the universe. Furthermore, galaxy clusters are one of the few places where the majority of the baryons are visible via X-ray and microwave radiation. In contrast to field galaxies, where feedback from supernovae and AGN puts gas into a mostly invisible circumgalactic medium (ICM), feedback from cluster galaxies will impact the state of the ICM. Hence, clusters will provide very tight constraints on our understanding of galactic feedback processes. Clusters of galaxies are also key probes of cosmology and large-scale structure. Their size makes them visible across a wide range of redshifts, and their population statistics are sensitive to cosmological parameters such as the amplitude of the initial power spectrum and the evolution of the cosmic expansion rate. However, using clusters as cosmological probes requires understanding the physical processes that occur in group and cluster galaxy environments, including the interactions among the dark matter, hot diffuse gas, stars, and active galactic nuclei (AGN), is key to gaining insights into the evolution of baryons and galaxies across the age of the universe. Furthermore, galaxy clusters are one of the few places where we can access the full range of mass and space. We have demonstrated that we need mass resolutions of order $10^5$ solar masses to accurately follow star formation and galaxy morphology. Likewise, we need to model a galaxy cluster of order $10^9$ solar masses that is comparable to those observed over a range of redshifts. Hence, 10 billion particles are needed. Such a simulation can only be run on the largest computers available. Furthermore, the long-range nature of gravity requires a high-performance, low-latency network to perform the calculation.

RESULTS & IMPACT

We have completed the simulation of several smaller galaxy clusters in preparation for our flagship simulation. Even the completed smaller simulations are advancing the state of the art in the simulation of galaxy clusters. Of particular significance is that models based on energy injected from supernovae and active galactic nuclei in field galaxies are able to naturally explain the properties of clusters and the galaxies within them. In this way, the models become predictive of the growth of galaxies and the black holes that power the active galactic nuclei.

PUBLICATIONS & DATA SETS

