BLUE WATERS
SUSTAINED PETASCALE COMPUTING

Allocation: NSF PRAC/8,100 Knh
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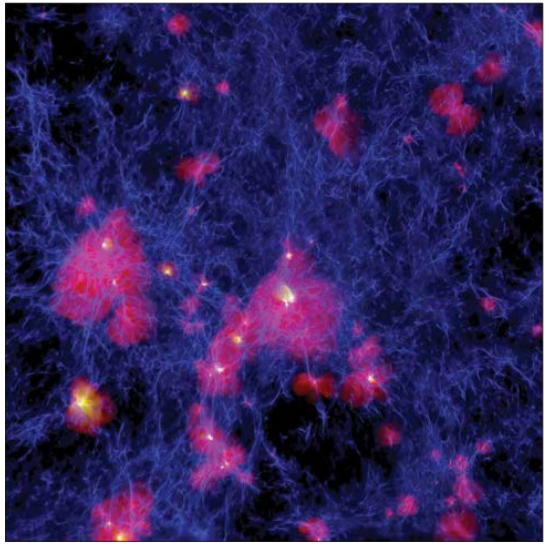
SIMULATING GALAXY FORMATION ACROSS COSMIC TIME



Composite volume rendering of several galaxies at z=8.6, approximately 590 million years after the Big Bang. The field of view is 250 kiloparsecs (approximately 800,000 light years) across. The blue color table shows density, red shows temperature, and green shows ionizing radiation.

Research Challenge

The goals are to understand *two critical issues in galaxy formation*: *the formation of the earliest generations of galaxies and their connections to the Milky Way* through hierarchical structure formation, and *how gas gets into and out of galaxies* and what it does while it is there. All of the calculations needed to study these problems require simulations with an extremely high dynamic range in space and time, complex physics (including radiation transport and non-equilibrium gas chemistry), and large simulation volumes.

Methods & Codes

Their simulation tool of choice is the *Enzo code*, an open-source and community-developed software platform for studying cosmological structure formation. Enzo allows them to include all the critical physical components needed to study galaxy formation—gravity, dark matter dynamics, fluid dynamics, the microphysics of plasmas, and prescriptions for star formation and feedback. *All analysis was done with the yt code*.

Results & Impacts

They find that *increasing the resolution by more than an order of magnitude results in the appearance of both spatial and chemical features that are seen in observations but not in previous models*. Similarly, they find in their idealized simulations that *galaxies can attain a dynamic equilibrium between cold gas condensing and falling into the galaxy, and the ejection of hot, metal-enriched gas into the circumgalactic medium*. This work changes understanding of the interface between the stellar and the diffuse plasma components.

Why Blue Waters

The simulations require extremely high spatial and temporal dynamic range, and also require complex physics; hence, in addition to *large simulation volumes* to model the many early galaxies, *huge numbers of cells* are required to accurately resolve the circumgalactic gas. Taken together, this requires the use of a supercomputer with *large memory and disk space, large computational resources, and an extremely high bandwidth, low- latency communication network* to enable significant scaling of the radiation transport code. *Blue Waters is the only machine available to the academic community that fits all of these requirements.*