We are investigating the earliest stages of cosmological structure formation—namely, the transition of the universe from a dark, empty place to one filled with stars, galaxies, and the cosmic web. In investigating the “cosmic dark ages,” we focused on several specific topics: the transition between metal-free and metal-enriched star formation that marks a fundamental milestone in the early epochs of galaxy formation; and as the sites of formation and early growth of the first generations of galaxies in the early universe in different large-scale environments. We find that if these Population III stars form massive black hole/stellar binary systems, they are likely to be prodigious emitters of X-ray radiation. This radiation both heats and ionizes the intergalactic medium, in some cases to 10^7 Kelvin! This may be important for predicting the topology of the 21 cm neutral hydrogen signal, which will be detectable by low wavelength radio arrays in the coming years. We also show that radiation from early star formation can help suppress the collapse of gas in neighboring halos, delaying star formation and causing the galaxy luminosity function to be strongly suppressed at lower luminosities.

**METHODS & RESULTS**

Our simulation tool of choice is the Enzo code [1,2], an open-source, community-developed software platform for studying cosmological structure formation. Enzo allowed us to include all of 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—and to do so using a tool that can scale to large numbers of CPUs. All analysis was done with the YT code [3,4].

Using Blue Waters, we successfully modeled the formation of the first generation of metal-enriched stars in the universe and showed that there are several possible formation modes for these stars. These included self-enrichment of the halo where the first primordial star formed and pollution of neighboring halos by the supernova remnant. In addition, we showed that the presence of dust (which may form in the ejecta of the first supernova) can have a critical effect on metal-enriched star formation, directly resulting in additional cooling and the formation of additional molecular hydrogen. Extra hydrogen further increases cooling rates and may cause additional fragmentation and lower mass stars.

We have also modeled the evolution of large populations of galaxies in the early universe in several different large-scale environments. We find that the presence of dust (which may form in the ejecta of the first supernova) can have a critical effect on metal-enriched star formation, directly resulting in additional cooling and the formation of additional molecular hydrogen. Extra hydrogen further increases cooling rates and may cause additional fragmentation and lower mass stars. We find that the presence of dust (which may form in the ejecta of the first supernova) can have a critical effect on metal-enriched star formation, directly resulting in additional cooling and the formation of additional molecular hydrogen. Extra hydrogen further increases cooling rates and may cause additional fragmentation and lower mass stars.

**REFERENCES**


**FIGURE 1** (BACKGROUND) The gas ejected from the supernova created by the first star to form in a cosmological volume as it is leaving the dark matter halo where the star formed. The supernova remnant preferentially expands into the void regions near the halo rather than the filaments, since this is the path of least resistance and fills the intergalactic medium with metal-enriched gas. Simulations first published in Smith et al. (Astrophys. J., submitted).