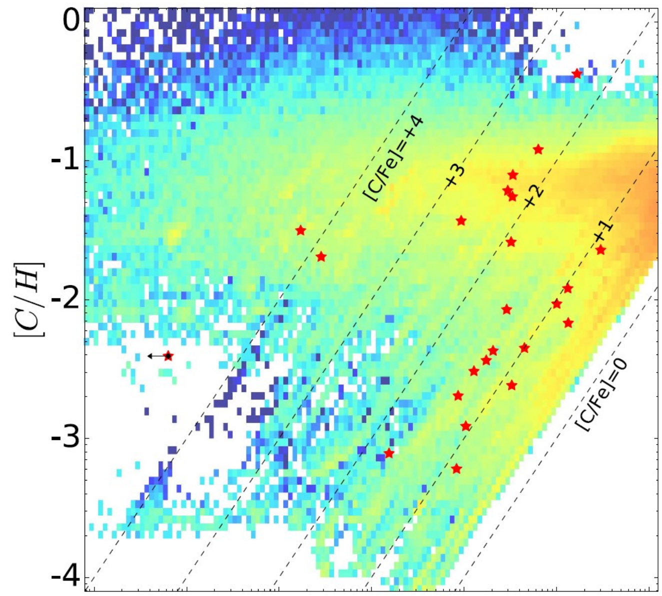
JINA: Center for the Evolution of the Elements

JINA-CEE

Following the Cosmic Evolution Of Pristine Gas

Understanding the role of the first stars, Population III (Pop III) stars, is central to understanding the evolution of the elements. These stars, composed purely of primordial hydrogen, helium and a tiny trace of lithium are responsible for generating the first metals in the universe. In turn, these metals were picked-up by the next generation of stars, the Pop II stars, that constitute some of the oldest stars observed in the Milky Way halo. These second-generation stars often display a carbon-enhanced yet iron-poor abundance signature that likely traces back to the supernova (SN) yields of the Pop III stars. Understanding the Pop III to Pop II transition is key to understanding these elemental abundance patterns, the nature of the first stars and the star formation history of the early universe.

No one has yet observed a Pop III star, so it falls to theory and simulation to model the evolution and SN yields of Pop III stars. Modeling these processes involves not only carrying out large-scale cosmological simulations but also simultaneously tracking the enrichment of material on the much smaller scales in which stars form since the overriding factor that determines the transition from Pop III to Pop II star formation is the metallicity of the gas. The key process governing the evolution of the metallicity of star-forming gas is the turbulent mixing of the heavy elements in SN ejecta. Until recently, modeling this mixing has been beyond the reach of cosmological simulations.



This joint probability plot depicts the mass-weighted probability for the chemical abundance of [C/H] as a function of [Fe/H] for all the stars in our simulation. Our results predict a bi-modal distribution of stars with a Carbon-to-Hydrogen ratio between 1/10 and 1/100 of the Sun's. We also predict a population of stars with a Carbon-to-Iron ratio of 10 ("+1 line"). These ratios are seen in observations of Milky Way halo stars, depicted by red stars (observational data from Keller et al. (2014)).

JINA-CEE researchers at ASU have developed a new model that allows them to statistically track the effects of turbulent mixing at subgrid scales in large-scale cosmological simulations. The method quantifies the pristine fraction of gas resulting in a more accurate model of Pop III star formation than was previously possible. The ASU researchers have also developed a computationally efficient model of tracking the unique metals generated by Pop III SN ejecta that allows them to evaluate any number of theoretical SN yield models in post-processing – without the need to re-run the computationally expensive simulation.

By convolving Pop III and Pop II SN ejecta yields the team has modeled the final metal content of simulated stars without the need to model more detailed, and costly, chemical synthesis networks. The approach allowed them to quickly explore some of the SN progenitor parameter space suggested by others, likely ruling out certain SN progenitor mass ranges and yield models. In their current work they have modeled Pop III SN metal abundances as the result of a $60M_{\odot}$ Pop III SN, demonstrating a possible origin for the metal levels seen in the sample of MW Halo CEMP-no stars that have been studied by several other JINA-CEE researchers (e.g. – T. Beers; A. Frebel and their teams). Going forward, the team plans to use these new tools to trace the evolution of, and derive observational characteristics for early galaxies.

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Further Reading:

R. Sarmento et al., Following The Cosmic Evolution Of Pristine Gas I: Implications For Milky Way Halo Stars, 2017, ApJ, 834, 23