Challenges in Panchromatic Modelling with
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Chemical enrichment of Pop III supernovae in the first galaxies

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Abstract. Understanding the formation of the first galaxies (FGs) is one of the most important topics in modern cosmology. In this proceeding, we briefly summarize the results of chemical enrichment from the Pop III supernovae during the assembly of the FGs. This early chemical enrichment plays an important role in triggering the Pop II star formation. Generally speaking, there are two major enrichment channels, inside-out (internal) and outside-in (external). Our results suggest that the external channel of chemical enrichment only works if the Pop III stars are very massive stars of 200–260 $M_\odot$, which produce strong enough radiative feedback and supernova to derive the external metal mixing down to the center of the nearby halo.

Keywords. The first stars, the first galaxies, supernovae, and early universe

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Discussions

The formation of Pop III stars transformed the simple early Universe into one of many complexes. One of the significant Pop III stellar feedback is by producing supernovae (SNe), which are extremely powerful explosions injecting a tremendous amount of energy into the interstellar medium. More critically, these SNe bring the first heavy elements to a primordial Universe only containing hydrogen and helium left from the Big Bang, and completely reshape the later stekkar and galaxy formation, see examples by Greif *et al.* (2010); Bromm & Yoshida (2011); Wise *et al.* (2012); Jeon *et al.* (2012). We show a schematic picture of how the dark matter, primordial gases, and feedback from the Pop III stars jointly formed into the FGs in Fig. 1.

One single SN can rapidly pollute the pristine intergalactic medium (IGM) of a size of 1 kpc with $10^{-4} - 10^{-3} Z_\odot$ as shown in Fig. 2. However, how these heavy elements mixing with the primordial gas to form the Pop II stars inside the FGs is still unclear. Previous studies by Smith *et al.* (2009, 2015); Chiaki *et al.* (2013) suggested external and internal channels for Pop III SNe to dispense the metals to the Pop II star-forming cloud. For an internal channel, the ejected metal eventually re-collapses to its host halo and triggers the consequent star formation in the FGs. For an external channel, the metal pollutes a nearby halo and mixes up the pristine gas to drive the later star formation. If these scenarios did happen in the cosmic dawn, one might ask which channel might be dominating and can it explain the origins of metal-poor stars?

We discuss the results of an external enrichment scenario based on Chen *et al.* (2017), that investigated how the first supernovae regulated the star formation in the nearby halos. Before the incoming metal, the pre-enriched minihalo is first photo-evaporation by the Pop III radiative feedback and the inputs of ionizing photons of hydrogen/helium are from the one-dimensional stellar evolution model. During the photo-heating process, the radiation pressure compresses the spherical halo into a bullet shape, and removes much gas out of the halo, that facilitates the following enrichment process. The massive Pop III star explodes as an SN after its short lifetime of several million years. SNe blow metal to

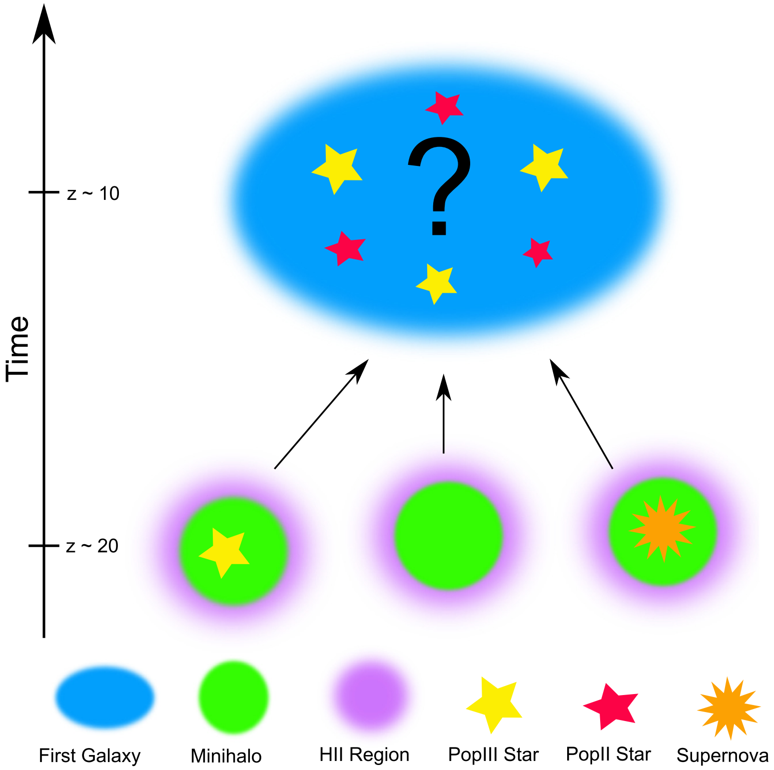

Figure 1. Formation of the FG. The FG contains a masses of about $10^8 M_\odot$ and forms at $z \sim 10$. Its assembly is determined by the Pop III stellar feedback, that builds up an extensive H II region of several kpc and forges the first heavy elements beyond the hydrogen and helium made, to be dispensed to the intergalactic medium through supernova explosions. The chemical enrichment would trigger the Pop II star formation in the FG.

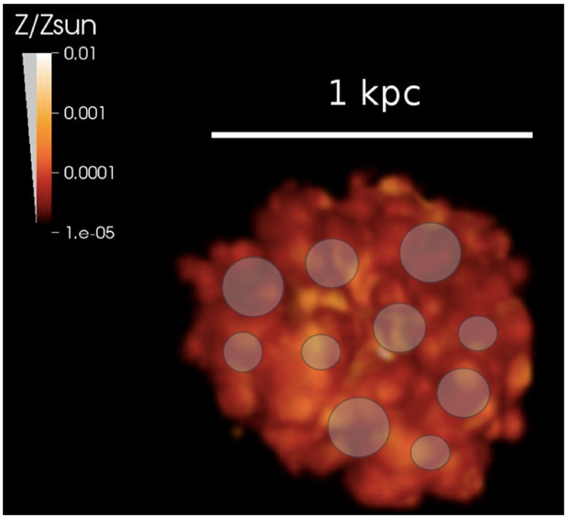

Figure 2. An extent metal region created by a Pop III SN. A Pop III SN can produce a big metal bubble of a size about 1 kpc with a metallicy of $10^{-3} - 10^{-4} Z_\odot$. There are several minihalos bathed inside this bubble. (reproduced from Chen *et al.* (2015))

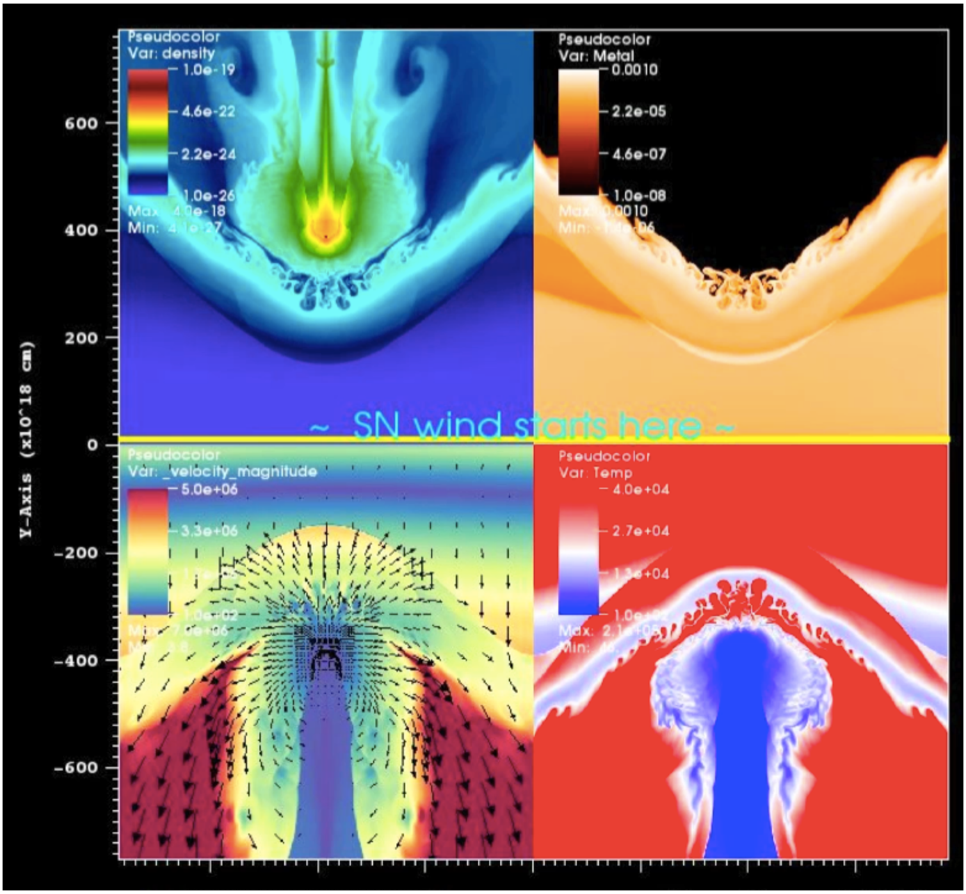

Figure 3. The external enrichment of SN metal. Panels show the physical quantities of; density, metallicity, velocity, temperature when the SN ejecta swipes through a nearby minihalo. The densest region indicates the center of minihalo and metal mixing only occurs around at outskirts without reaching to its center.

collide into the photo-heated halo and drive mixing at the outer shell of the halo. From five out of six models in Chen *et al.* (2017), most of the halos seem to be able to prevent from the enrichment of SN metals. If it were true for the real situation, the Pop III stars might have still formed in these nearby halos. Some mixing of metal appears at an outer skirt of the shell, even if the metal cooling acts effectively. However, the low gas density prevents the Pop II stars forming in this mixing region as shown in Fig. 3.

Based on the highly-resolved simulations of Chen *et al.* (2017), we conclude the external enrichment only work for very massive Pop III stars of 200 - 250 $M_\odot$, which have strong radiative feedback and die as powerful pair-instability supernovae (Chen *et al.* (2014)) to break out the dense shell of the nearby halo and mix metal deep into the center to initialize the Pop II star formation. Therefore, the external enrichment channel can be promising only if the Pop III IMF is very top-heavy.

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Questions:

1. How reliable can the cosmological simulations predict binary formation in population III stars?

Recent simulations of the first star formation have achieved a resolution of sub-solar mass scale and included many detailed micro-physics such as cooling, magnetic field, and radiation transfer. Their results suggested the fragmentation of star-forming disk and formation of binary stars. At least above 50% of the first stars may have formed into binaries.

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