Physics 761 Presentation: "Population III stars: hidden or disappeared?"

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1 Background: Metallicity & Stellar Populations

As we know, the post-recombination universe was filled with a isotropic, homogeneous mixture of mostly hydrogen and helium, with 23% of the mass in He, and the rest in hydrogen and trace lithium. While the universe today is also mostly hydrogen, it is also suffused with heavier elements (metals) from the generations of stars that have gone through their full life cycle before the present. As they reach the end of their lifespans, they eject their envelopes into the ISM through either type II supernovae or in their planetary nebulae. This spreads the metals generated in the stellar core out into the ISM, where it "pollutes" the ISM with metals. These metals play a key role in cooling and radiative transfer in the gas of the ISM, increasing its opacity. The fraction of an object's atoms that are metals (elements beyond helium) is called the metallicity, and is defined in equation 1.

$$Z = 1 - \frac{N_H + N_{He}}{N_{total}} \tag{1}$$

The conditions in which the first stars form were totally devoid of all metals but for trace amounts of lithium. The higher gas fragmentation scale (due both to higher density and a "calmer" environment), along with the low opacity of the ISM is hypothesized to have been an ideal environment for the formation of very massive stars. These are the *Population III* stars. Formed from gas with metallicity at or below $Z_{cr} = 10^{-}5Z_{\odot}$, these stars burned very quickly, with peak temperatures in the $10^5 + K$ range. These death of these stars raised the total metallicity of the ISM, and allowed the low-metallicity modern Population II stars we see in the galactic halo, as well as the metal rich Population I stars such as our sun. Most models predict a rapid shutdown of Population III star formation as the metallicity of the universe increased, and the evidence for the existence of any Population III stars at redshifts above 9 is tenuous. However, the redshifts predicted for the end of Population III star formation have been as low as 5. This raises the question: are Population III stars available to observers, but simply hidden by their low density at low redshifts, or has the universe evolved to a state where they can no longer form whatsoever?

2 The Paper's Methodology

This paper tried to answer the question of how late could Population III stars could still form using a series of numerical simulations. The authors used smoothed particle hydrodynamics (SPH) to simulate a comoving volume of 13.89^3 Mpc^3. This volume was filled with $2 * 256^3$ dark matter and baryonic particles (256^3 of each). The dark matter particles had a mass of $5.03 * 10^6 M_{\odot}$, and the baryonic matter particles each a mass of $9.49 * 10^5 M_{\odot}$. The simulation was run from a redshift of 99 to a redshift of 2.5. The author's also ran two smaller simulations, at 1/8th of the original density, at the same density, and at 1/8th the density as a comparison set. In addition to the n-body hydrodynamics, the authors also incorporated radiative transfer and cooling, along with chemical enrichment to track the production and transport of C, O, Mg, Si, S, and Fe.

3 The Paper's Results

The simulation results were used to examine the Population II and III star formation rates in the volume, and track the flow of metals throughout the gas. A single Population III star was found to be able to enrich a large amount of surrounding gas, to the point where Population III star formation drops to 1% by $z = 14$, and down to $\approx 10^{-4}$ by $z = 6$. Despite this, they did find that Population III stars were forming at non-negligible rates even when the average ISM metallicity was above Z_{cr}. The integrated SFR at $z = 5$ was found to yield a small but significant Population III density $\Omega_{III} \approx 2 * 10^{-6}\Omega_b$. The second interesting finding was that photoheating was a significant factor in preventing Population III star formation. The increased temperature of the ISM increased the Jeans mass for collapsing haloes, preventing smaller pristine pockets of gas from collapsing. As the attached figure shows, the spread of metals through the ISM occurs in patches and lumps, with areas of low-metallicity present even at the the lowest redshift. The migration of Population III star formation from the enriched gas clouds, where Population II stars now dominate, to uncontaminated regions produces the opposite situation predicted by the age-metallicity relation. Rather than having the oldest stars being the most metal poor, this simulation produced metal-free stars younger than the enriched Population II stars.

4 Conclusions

The ultimate finding the authors present is that Population III stars continue to form, albeit in low densities around the outskirts of collapsing structures. These findings of late Population III star formation is at odds with previous semi-analytic models, which 04 Population III stars in much higher densities early on in the universe's evolution. They plan to do a more detailed comparison of why this discrepancy exists in a future paper.

The implications of this paper are significant: the authors found Population III star formation continuing down to the moderate redshift of $z = 2.5$. This opens up the possibility of detecting evidence for Population III evolution using existing surveys and telescopes (the SDSS for example contains quasar spectra down to $z = 6$). As the primary tool that astronomers planned to use to examine Population III evolution, the James Webb Space Telescope, is in political jeopardy, the existence of hidden Population III stars at lower redshifts may be the key to examining these objects in the coming decades.

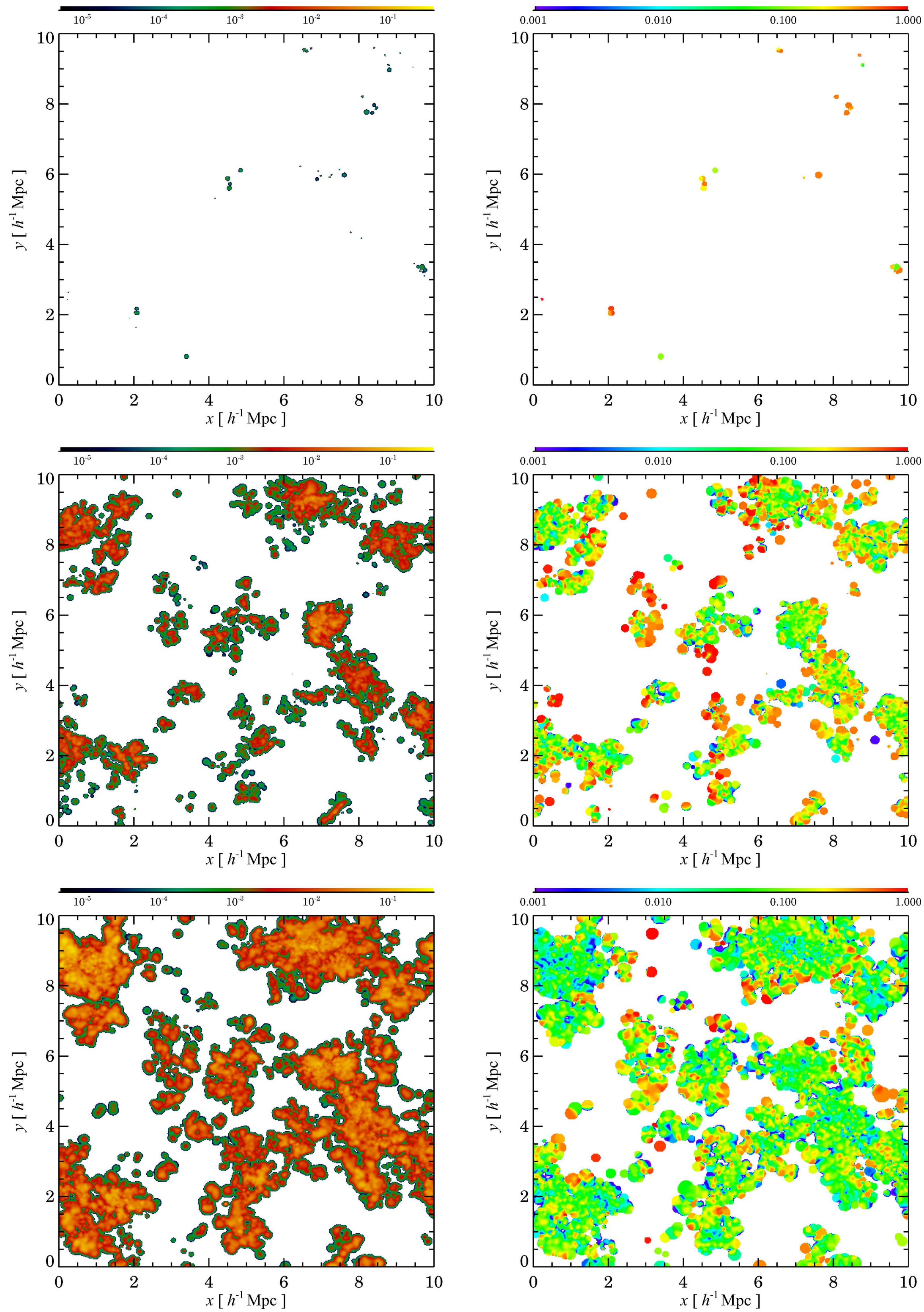

Figure 1: Metallicity in a 500 kpc slice of the simulation. The left frames show metals contributed just by Population III stars, while the right frames show the total metallicity. The redshifts, from the top row, are 10, 5, and 3.