Enlightening the End of the Cosmic Dark Ages with Brighter Simulations

Alessa I. Wiggins[1], Mia Sauda Bovill[1], Massimo Stiavelli[2]

[1]Department of Physics and Astronomy, Texas Christian University, Fort Worth, TX 76109, USA

[2]Space Telescope Science Institute, Baltimore, MD

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1. Introduction

The first stars in the universe, the metal free Population (Pop) III stars, play an essential role in cosmic evolution; their supernovae explosions enrich the interstellar medium and the inter galactic medium. This sets the stage for the enriched galaxies that follow them. Therefore, learning about the formation of this first light teaches us how subsequent, larger, and more complex structures formed.

While they are millions of times brighter than our Sun, distant, Pop III stars are too faint to be directly detected with JWST. Therefore, in order to learn more about their properties (e.g. mass), we need to use other avenues.

A subset of massive Pop III stars with a mass range of 140-260 $M_\odot$ (Heger et. al, 2003) end their lives as Pair Instability Supernovae (PISN). With energies of 100 times greater than core collapse supernova (CCSN), PISN are within reach of direct detection by JWST (Whalen et al, 2012). We present predictions for the dependence of the number of PISN on the slope of the Pop III Initial Mass Function (IMF).

3. Modelling the PISN Rates

Here, we present the details of the calculations we used to determine the PISN rates:

- We start by obtaining a heat map to show the number of halos with a given number of PISN throughout all redshifts in the simulation.
- We then determine the total number of PISN which occur in all halos at a given redshift
- We need to consider the NIRCam filters on JWST as they have a finite width. To approximate the rates seen for a given redshift with NIRCam we must smooth our PISN over δz. We choose $\delta z = 0.5$ to correspond to the wider NIRCam filters more suited to the deep and wide surveys required for PISN detection
- We then determine the number of PISN that would be visible in a single NIRCam pointing
- Finally, we convert the number of PISN to the rate of PISN per in a single year.
- The last step is to factor in the time dilation due to the expansion of space-time.
- We can now plot the number of PISN per year expected to be observed in a single NIRCam pointing

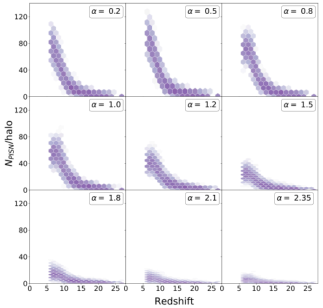


Figure 2: each of the above subfigures represents a heat map of the number of PISN in a Pop III forming halo, as a function of redshift at a certain slope of the IMF. The Pop III IMF of each halo is randomly populated 1000 times.

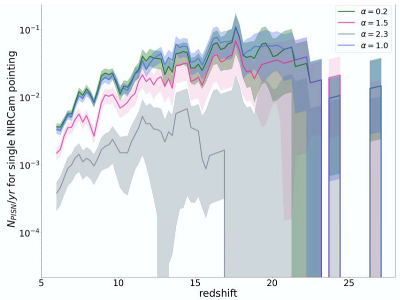


Figure 3: the rate of PISN per year for a single NIRCam pointing as a function of redshift. All curves show the median number of PISN after populating the IMF N=1000 times. The curves are plotted for a possible maximum mass of 1000 $M_\odot$.The shaded regions represented the standard deviation from the median for four slopes of the IMF (α= 0.2, 1.0, 1.5 and 2.35).

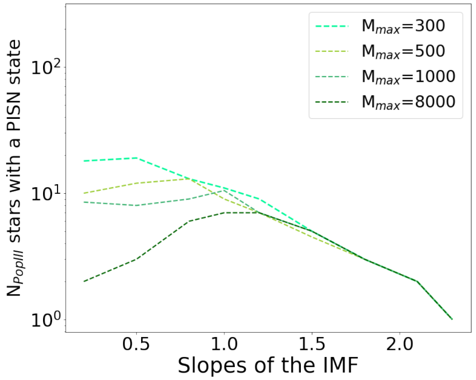
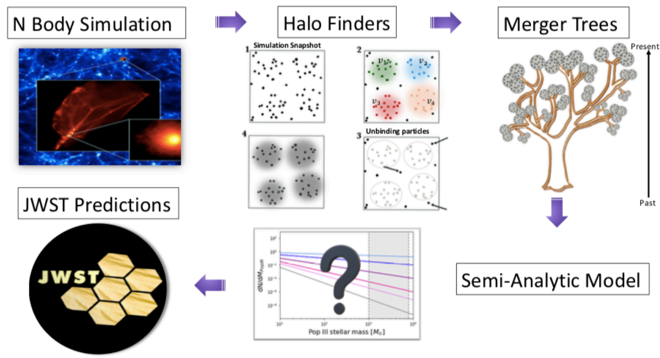


Figure 4: the number of Pop III stars that will explode as a PISN as a function of the IMF. Each curve is plotted for a different possible maximum mass of Pop III stars.

2. Modelling Population III Stars

1) We run an N-body simulation with sufficient resolution to resolve all possible sites of star formation, for the first billion years of cosmic evolution.
2) We identify the location of dark matter halos within the simulation, and link them through cosmic time into a merger tree.
3) We use a semi-analytic model to add the physics of gas cooling and Pop III star formation into the simulation.



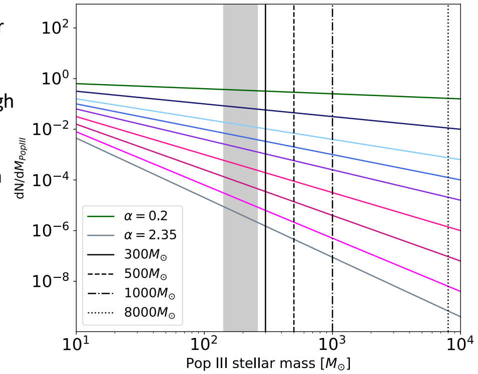


Figure 1: The number of Pop III stars at a given mass as a function of mass, starting at the accepted minimum mass required for forming a Pop III star of 10 $M_\odot$. The curves represent nine potential slopes of the Pop III IMF. The black curve $\alpha = 2.35$ is the Salpeter IMF. The grey area represents the mass range for stars exploding in a PISN.

4. Conclusions and Future Work

The rate of PISN changes by an order of magnitude when the slope IMF goes from bottom to top heavy. Thus, observations of the PISN rate from JWST and the Roman Space Telescope will provide a power probe of mass distribution of Pop III stars.

For moderately top-heavy IMFs (α < 1.0) the PISN rate is linearly dependent on the maximum possible mass of a Pop III star. If the Pop III IMF is independently determined, PISN rates become an unprecedented tool to constrain the maximum mass of Pop III stars.

Our next step is to determine the dependence of the PISN rate on the remaining parameter of the mass distribution, m_{min}, using a range of values drawn from recipes in hydrodynamic simulations.

5. SciCom

Population III stars are the first stars to be born in the universe, however much about them remains unknown. Since the first stars are more massive than stars today, they die in the most powerful supernovae explosions in the Universe. We can see these supernovae. This work provides the first predictions for supernova rates of the first stars for NASA's new James Webb Space Telescope.

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