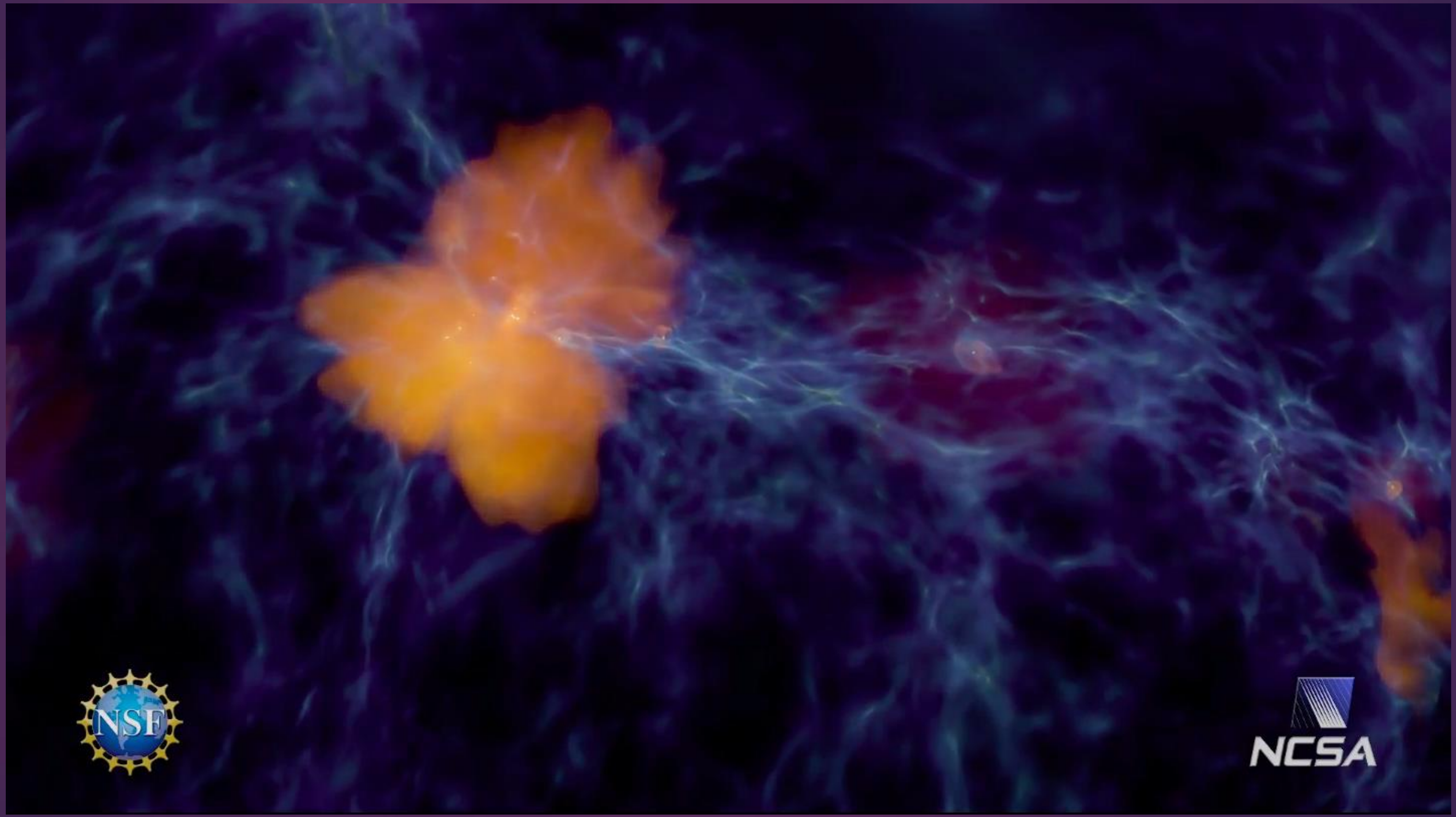
Cradles of the first stars: self-shielding, halo masses, and multiplicity



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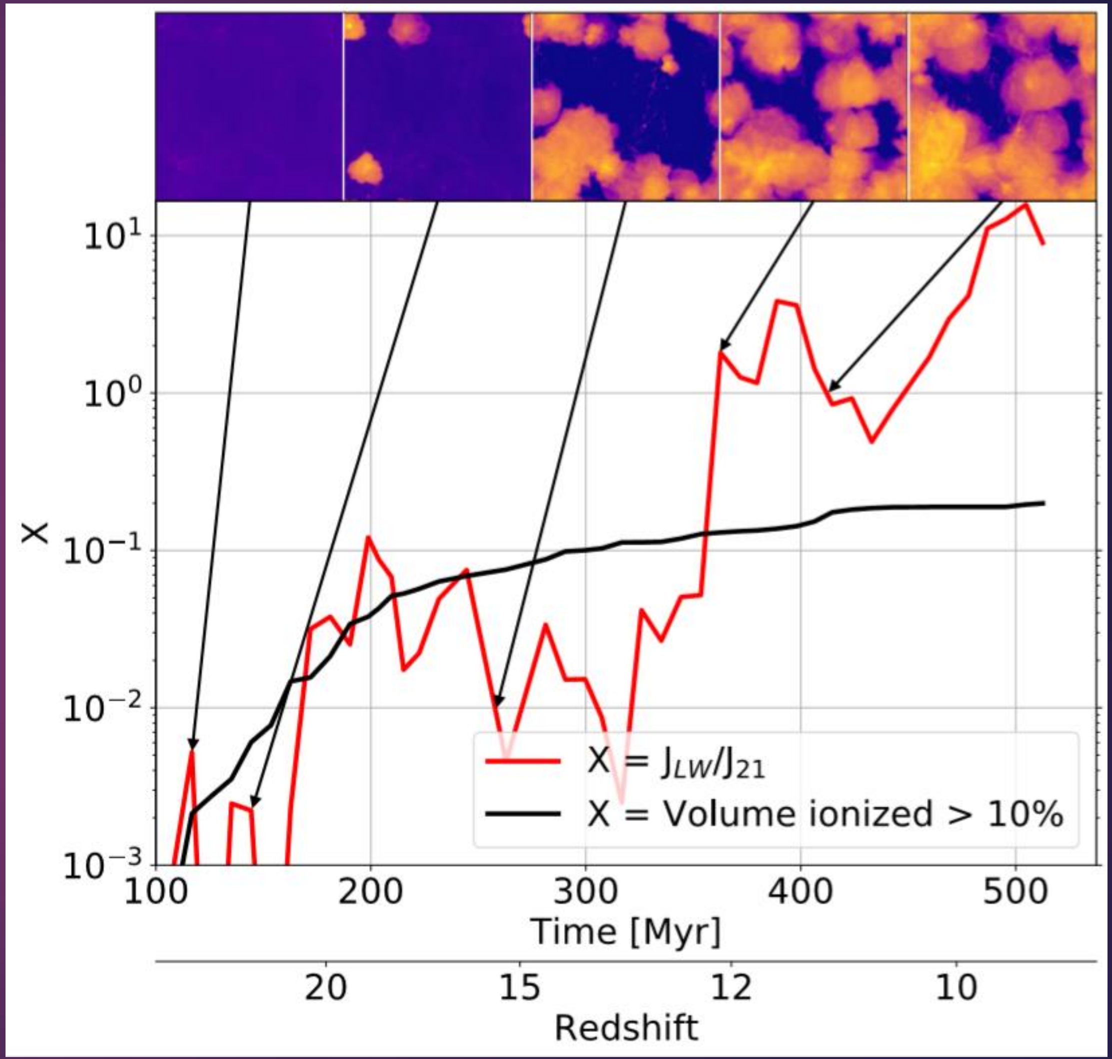
Introduction

- The first generation of stars (Population III; Pop III) are **metal-free** and unlike any star we see today. They have **never been observed**.
- Without the presence of metals, cooling occurs via H_2. **Cooling is crucial** for star formation.
- Once Pop III stars form, they produced **Lyman-Werner (LW) photons**, capable of photo-dissociating H_2 and therefore **suppressing further Pop III star formation**.
- Halos with enough H_2 can **self-shield** and allow for Pop III star formation even in large radiation fields.
- Traditional view:
  - Gas cloud cools via H_2, collapses and forms a Pop III star → Pop III star produces LW photons → LW photons destroy H_2 → Pop III star formation is suppressed
- What halos hosted Pop III stars? Does LW radiation affect which halos form stars? How significant is self-shielding?



Methods

- Cosmological simulation run with an adaptive mesh refinement code, Enzo
- Simulation details:
  - 1 Mpc^3 comoving volume
  - 256^3 base grid resolution
  - Maximal comoving resolution of 1pc
  - Planck 2013 cosmological parameters
  - Run until z=9
  - Time dependent LW background
  - H_2 self-shielding
- Run on Georgia Tech's HPC, PACE
  - 250k core-hours on 256 cores
  - Totaling about 6 weeks of run time and resulting in 12 Tb of data
- YT toolkit used for analysis

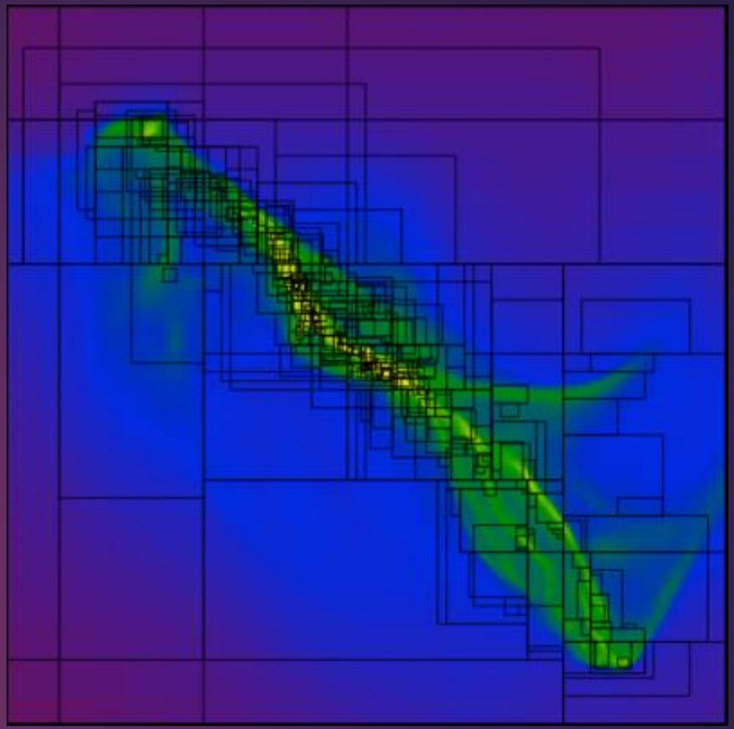
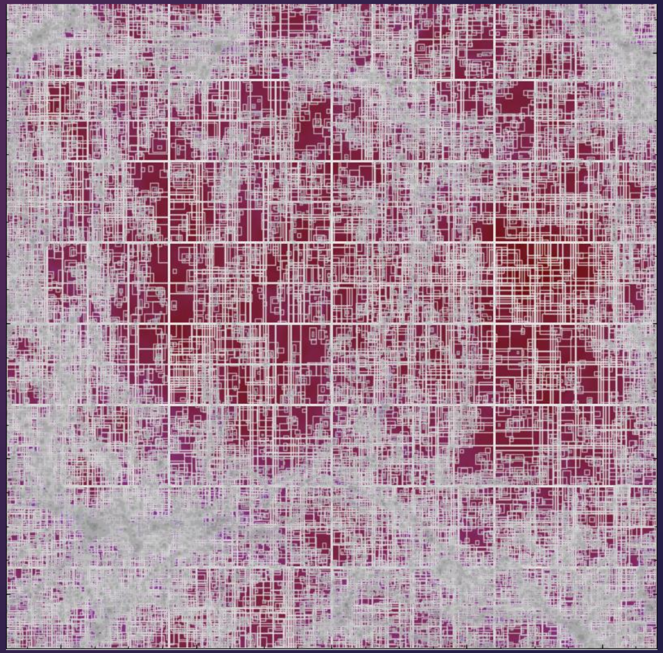


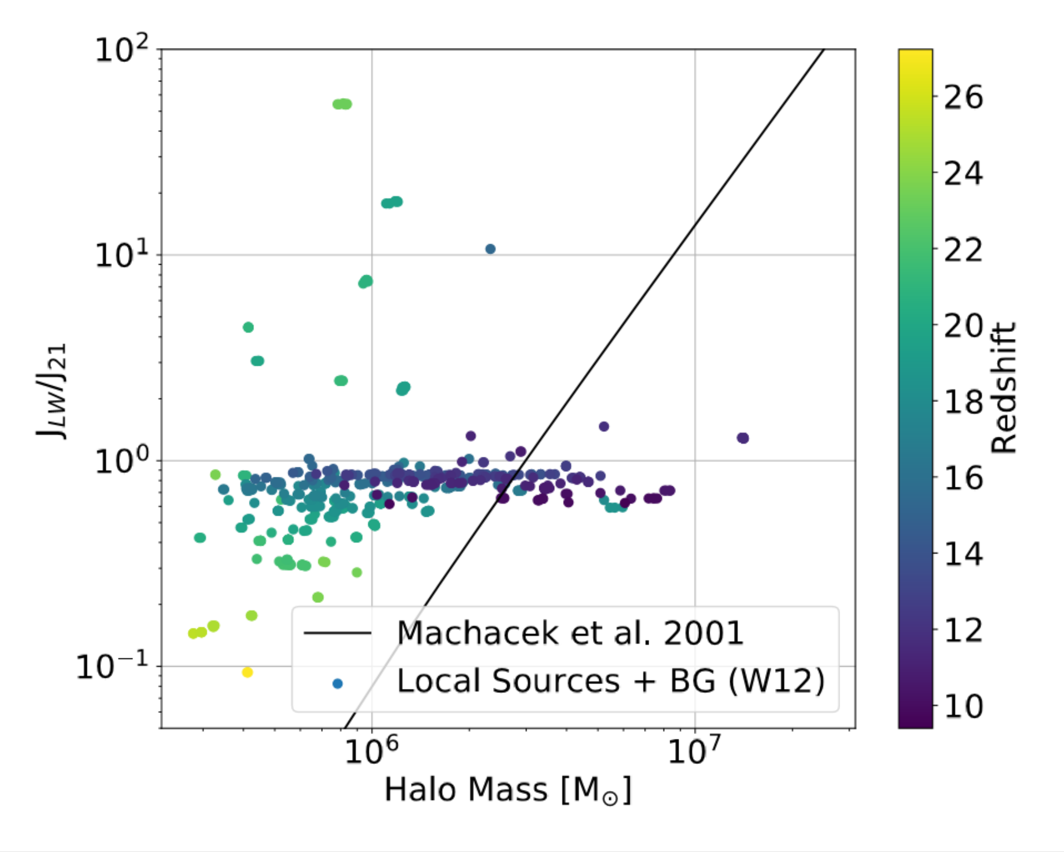
Image credit: Brian O'Shea, Enzo Workshop 2018

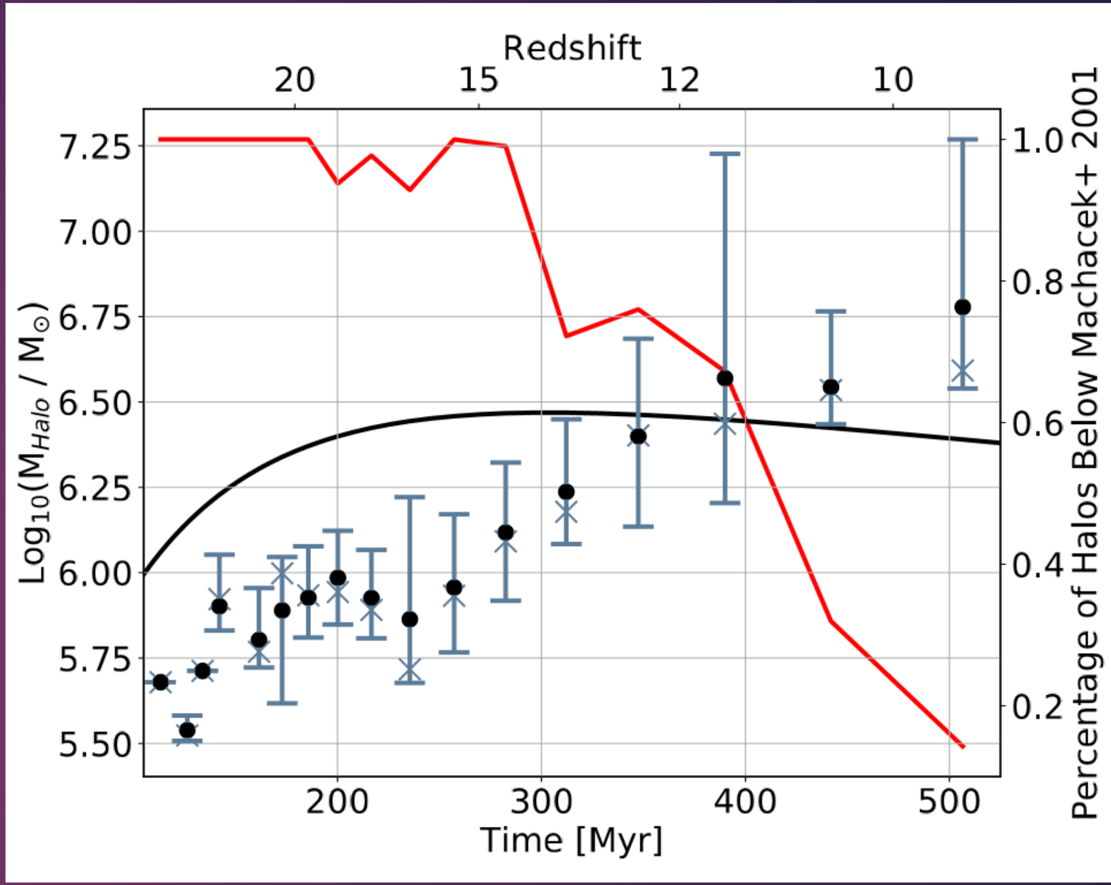
Examples of grid hierarchy



Results & Conclusions

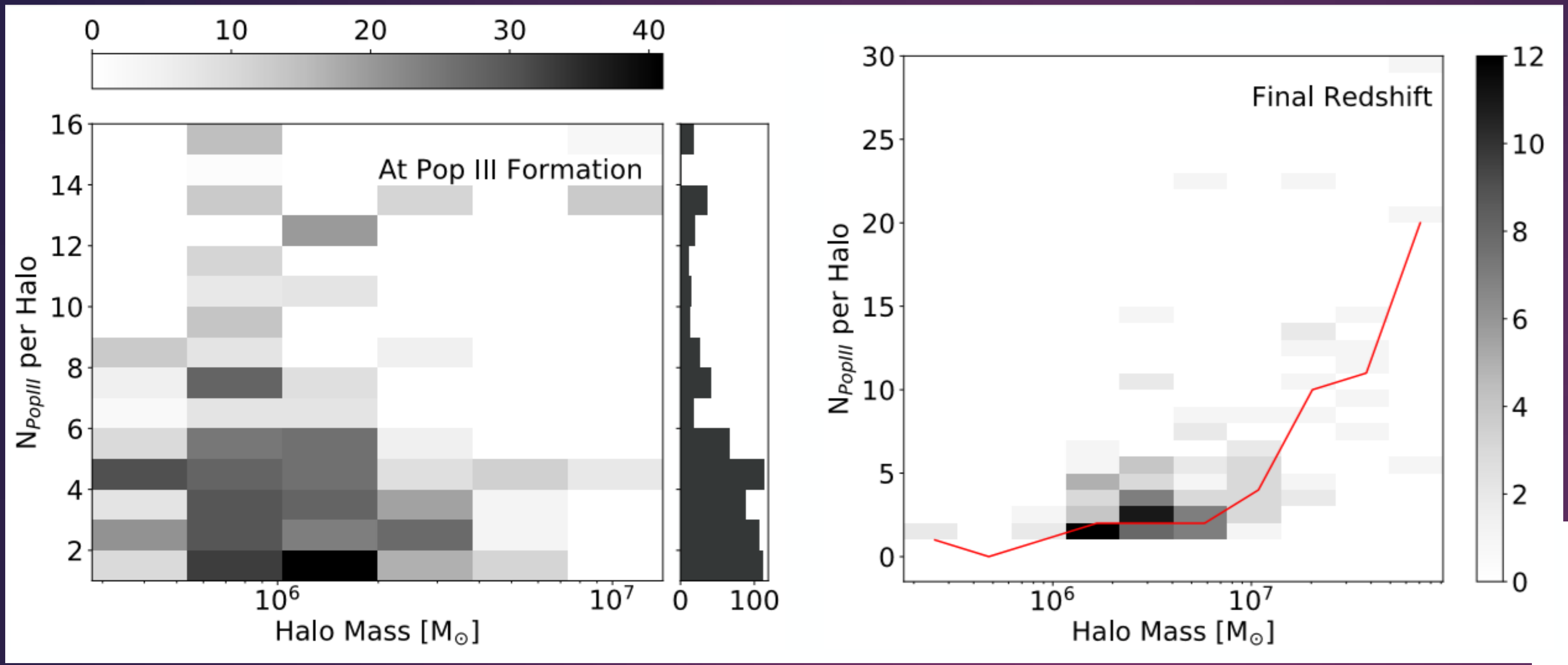
- Pop III stars form in lower mass halos with a mean mass below 10^6 Msun, lower than a commonly used mass threshold relationship, thanks to self-shielding.



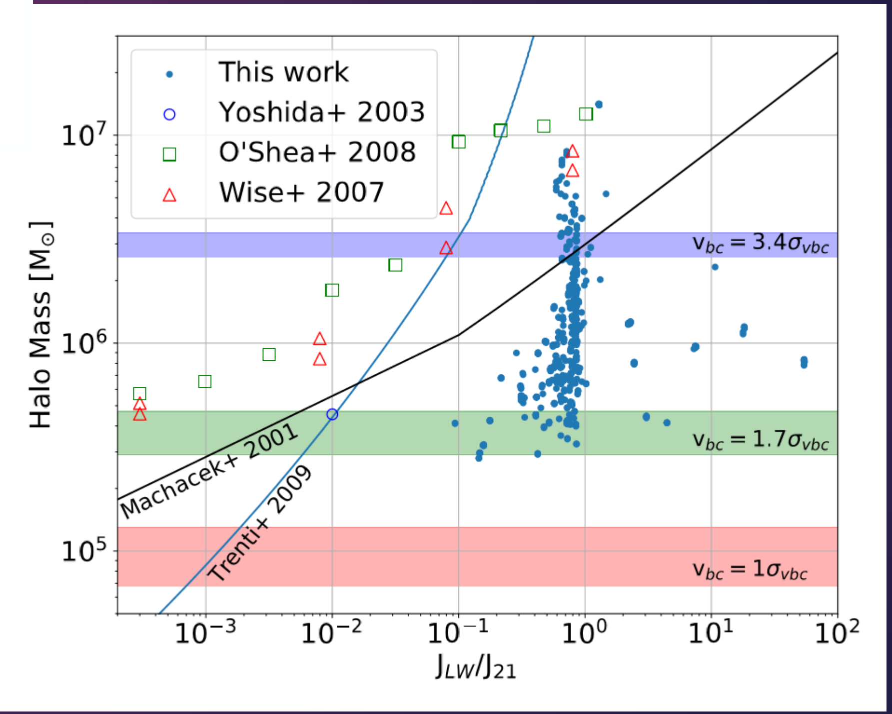


- Self-shielding creates a disconnect between the LW radiation background and collapse, resulting in a broad distribution of halo masses

Results & Conclusions



- Comparing with previous work which neglected self-shielding, we see halos forming Pop III stars at lower masses. Streaming velocities between dark matter and baryons also would not affect our results (figure below).



- Halos are likely to form multiple Pop III stars, contrary to the traditional understanding of the formation of these stars (left panel above).
- At the end of the simulation, halos with large masses acquire multiple Pop III stars due to mergers with smaller mass halos (right panel above).