High-Redshift Atomic Cooling Halos generally lead to Intermediate-Massive Black Hole Seeds

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INTRODUCTION

- Recent observations by JWST have revealed a population of high-z AGN hosting massive black holes with masses between $10^6 - 10^8 M_\odot$ (*Larson2023+; Greene2024+*).
- These observations hint at the need for heavy black hole seeds with predicted masses $\gtrsim 10^5 M_\odot$ formed by the first stars.
- We explore two theoretical pathways that can form supermassive Pop III stars and heavy black hole seeds:
  - A high Lyman-Werner background, J_{21}, that suppresses cooling by dissociating H_2.
  - High halo assembly rate, $\dot{M}$, on to the halo that delays star formation through dynamical heating.

OBJECTIVE

- Our goal is to determine how common it is expected to form heavy BH seeds by studying at high-resolution, the gas accretion rate on halos with varying J_{21} and accretion rate
- We explore a parameter space that spans a range of J_{21} and $\dot{M}$ for a large sample of halos and determine the impact on the ultimate predicted Pop III mass.

SIMULATION & RESULTS

- Hydrodynamical simulations were carried out using adaptive mesh refinement code *ENZO* (*Bryan2014+*) using a dark matter resolution of $\mathbf{7000}\ \boldsymbol{M_\odot}$ and a maximum level of refinement of $\mathbf{10^{-4}}$ **pc**. See top-center figure for an example.
- The average radial profiles (see bottom-middle figure) are generally similar for different J_{21}. A notable difference are the elevated average inflow rates for the $\boldsymbol{J_{21} \geq 10}$ simulations.
- We also find little correlation for different $\dot{M}$, with variations in J_{21} having a more dominant effect.

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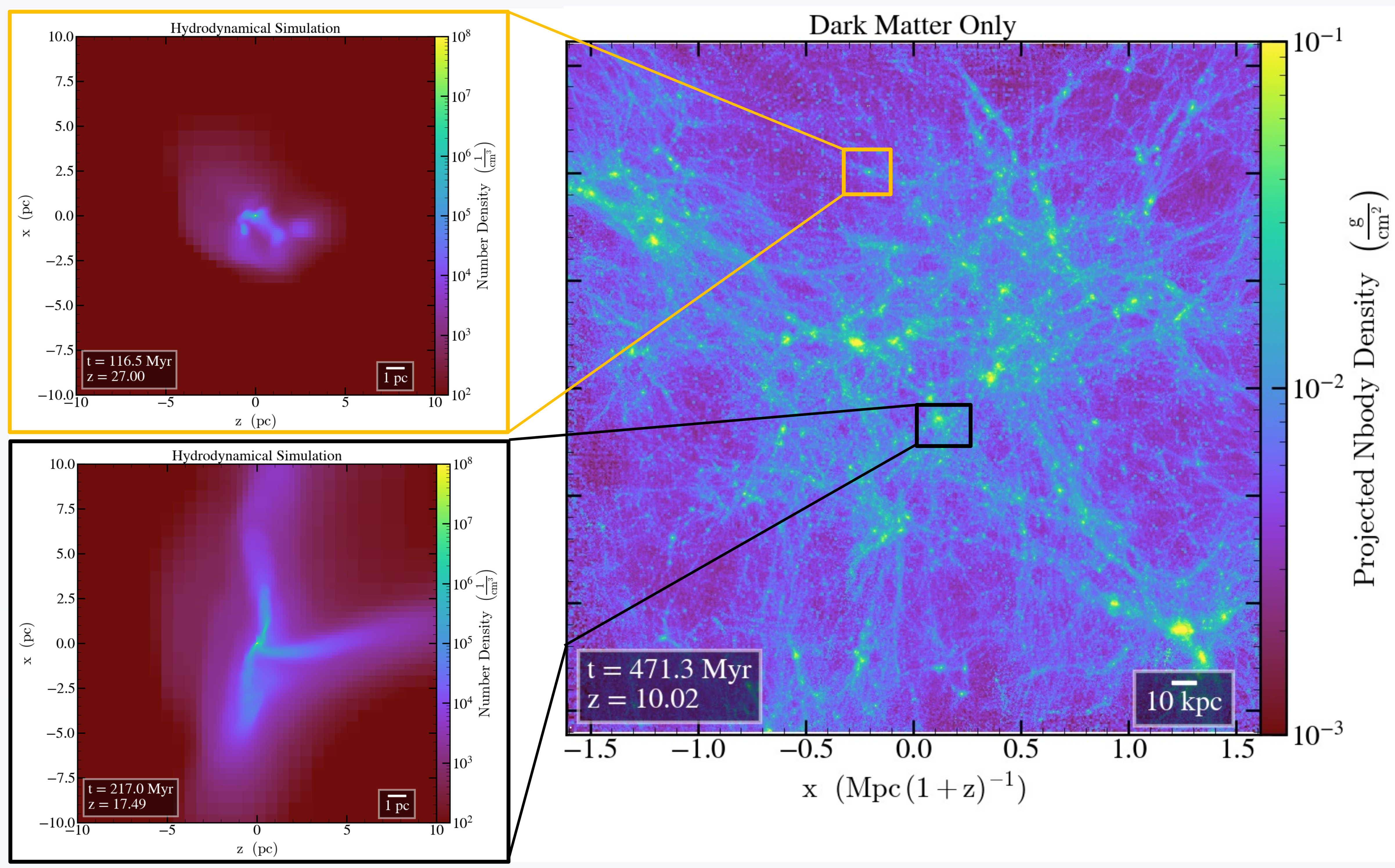
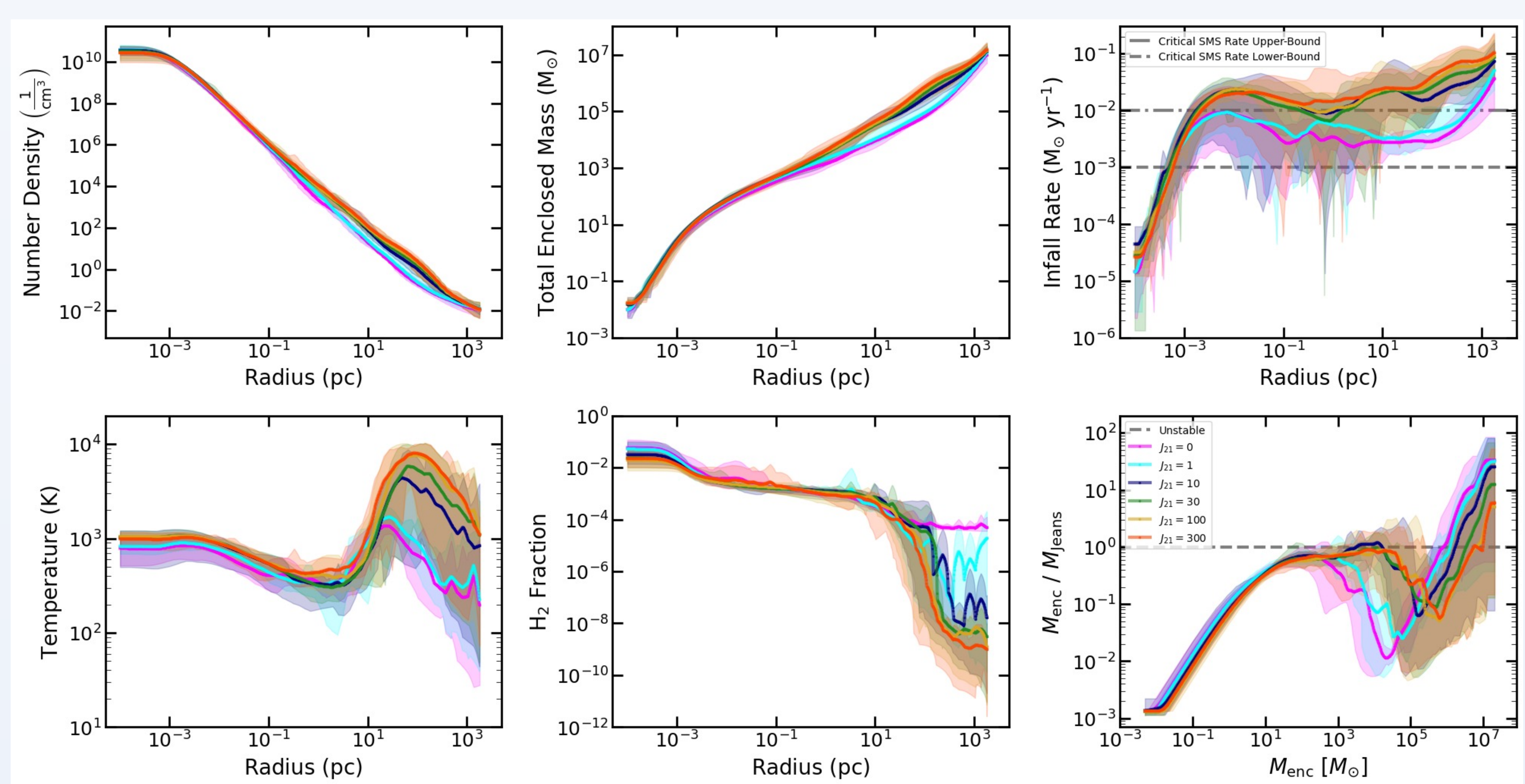
GAS DENSITY PROJECTIONS OF SIMULATIONS AT COLLAPSE



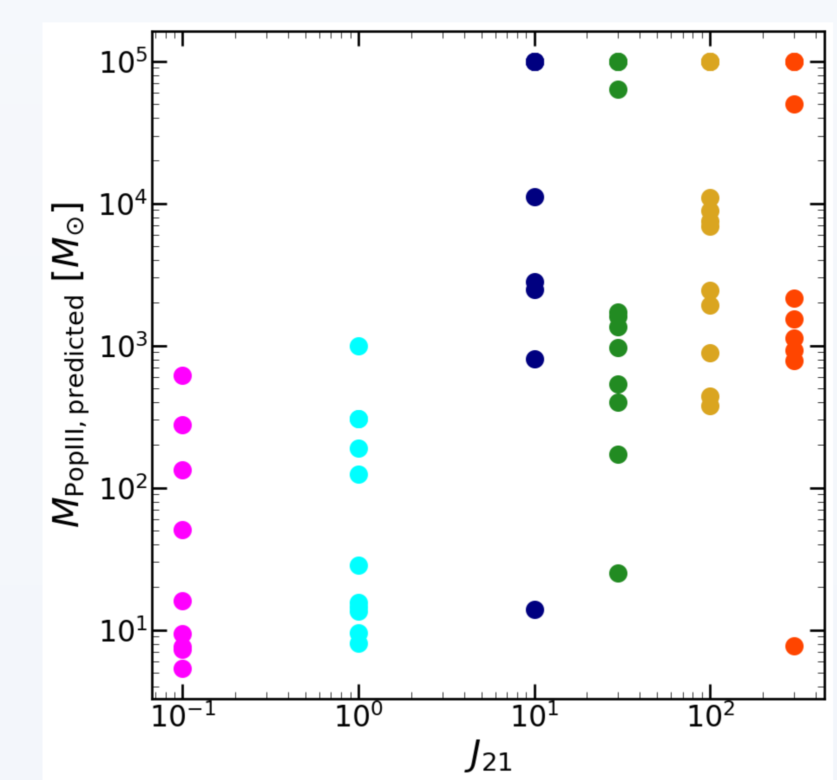
AVERAGE RADIAL PROFILES FROM ~50 SIMULATIONS WITH VARYING J_{21}



PREDICTING POP III STELLAR MASS

- Instead of modeling the accretion on to the protostar, we stop the simulation at collapse & predict the accretion using the radial profile for infall rate to estimate a final Pop III mass.
- We combine spherically averaged inward velocities, estimate inflow rates, & assume everything is accreted until the inflow rates falls below a critical supermassive star (SMS) accretion rate.
- We find agreement within a factor of ~3 with simulations using a sink particle approach (*Suazo2019+*) by using a critical SMS rate of $6.7{\times}10^{-3} M_\odot\ yr^{-1}$.

CONCLUSIONS



Note: $J_{21} = 1$ is set to 10^{-1} in this plot & J_{21} is $10^{-21}\ erg\ cm^{-2} s^{-1} Hz^{-1} sr^{-1}$

- We find that the inflow rates are above our critical SMS rate for $\boldsymbol{J_{21} \geq 10}$, if Jeans instability is not a factor, we would expect these halos to form massive BH seeds (see above figure).
- With Jeans instability, this generically results in fragments with BH seeds that are at least $\sim 10^3 M_\odot$. These fragments could potentially merge at later times.
- Whatever form the BH seeds take, they would be orders of magnitude more numerous than BH seeds produced by rare halos at $J_{crit} \sim 10^4\ J_{21}$. **These simulations point to more abundant massive BH seed formation than previously suggested.**

ACKNOWLEDGEMENTS

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