

Impacts of Low-Energy Pair-Instability Supernovae of the First Stars

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Introduction

The first stars were likely massive and may have exploded as pair-instability supernovae. Their high explosion energy can disrupt the host halo and enrich neighboring halos with metals. Previous work has shown that this occurs for pair-instability supernovae exploding with energies of up to 10^{53} erg. Here, we examine the impacts of pair-instability supernovae exploding with $5 \cdot 10^{51}$ erg in a hydrodynamical simulation with AREPO. This is the lower energy limit of pair-instability supernovae. Future simulations will explore the impacts of core-collapse supernovae.

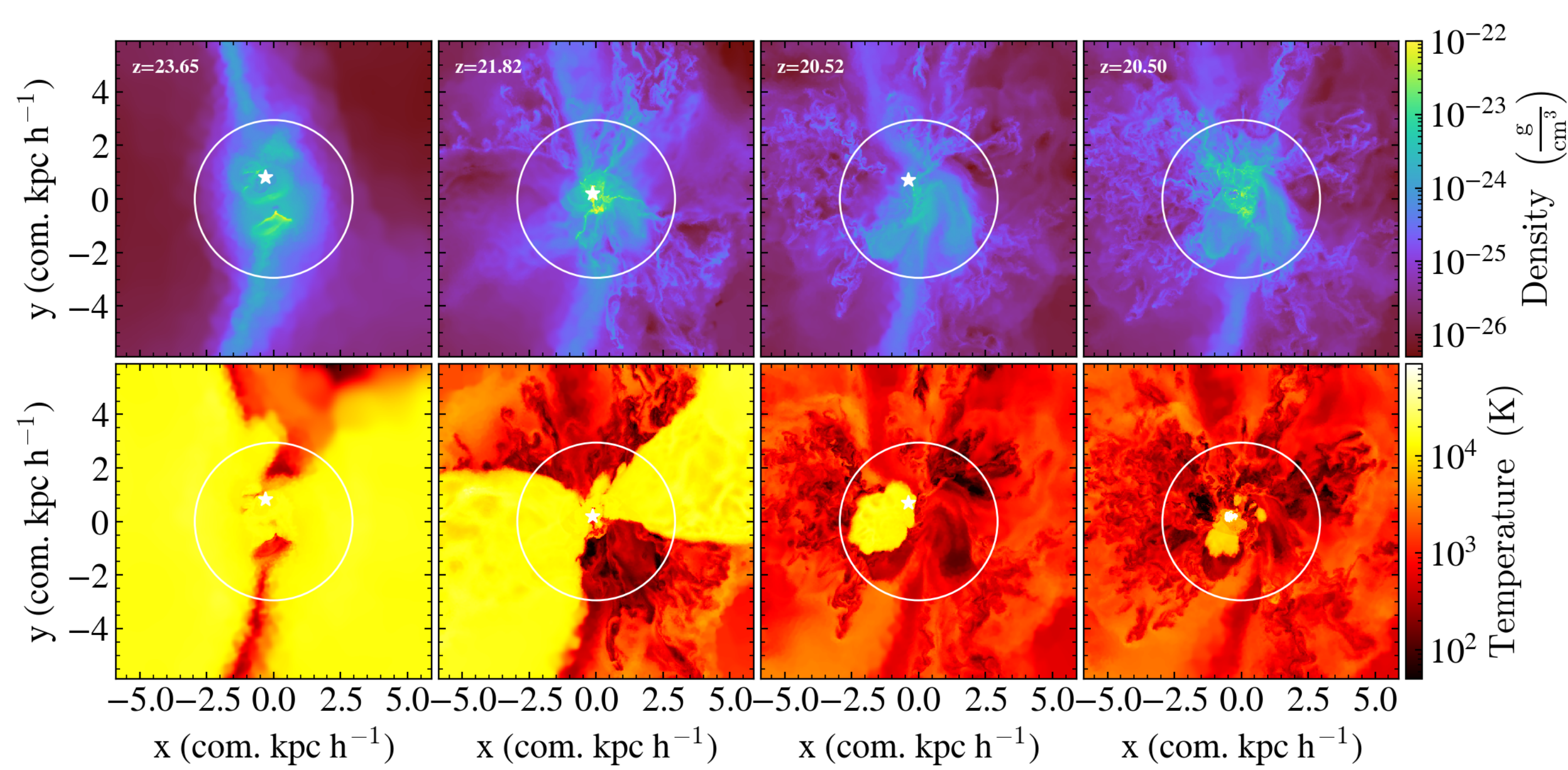


Fig. I: Slices of the gas density and temperature of one star-forming halo across time (blue line in the other figures). The top row shows a slice of the x-y-plane of the gas density centered at the minihalo. The bottom row shows a slice of the temperature at the same location. Sink (star) particles are indicated with a white star. The circle shows the dark matter virial radius of the minihalo. The first three columns are times just before the supernova explosion.

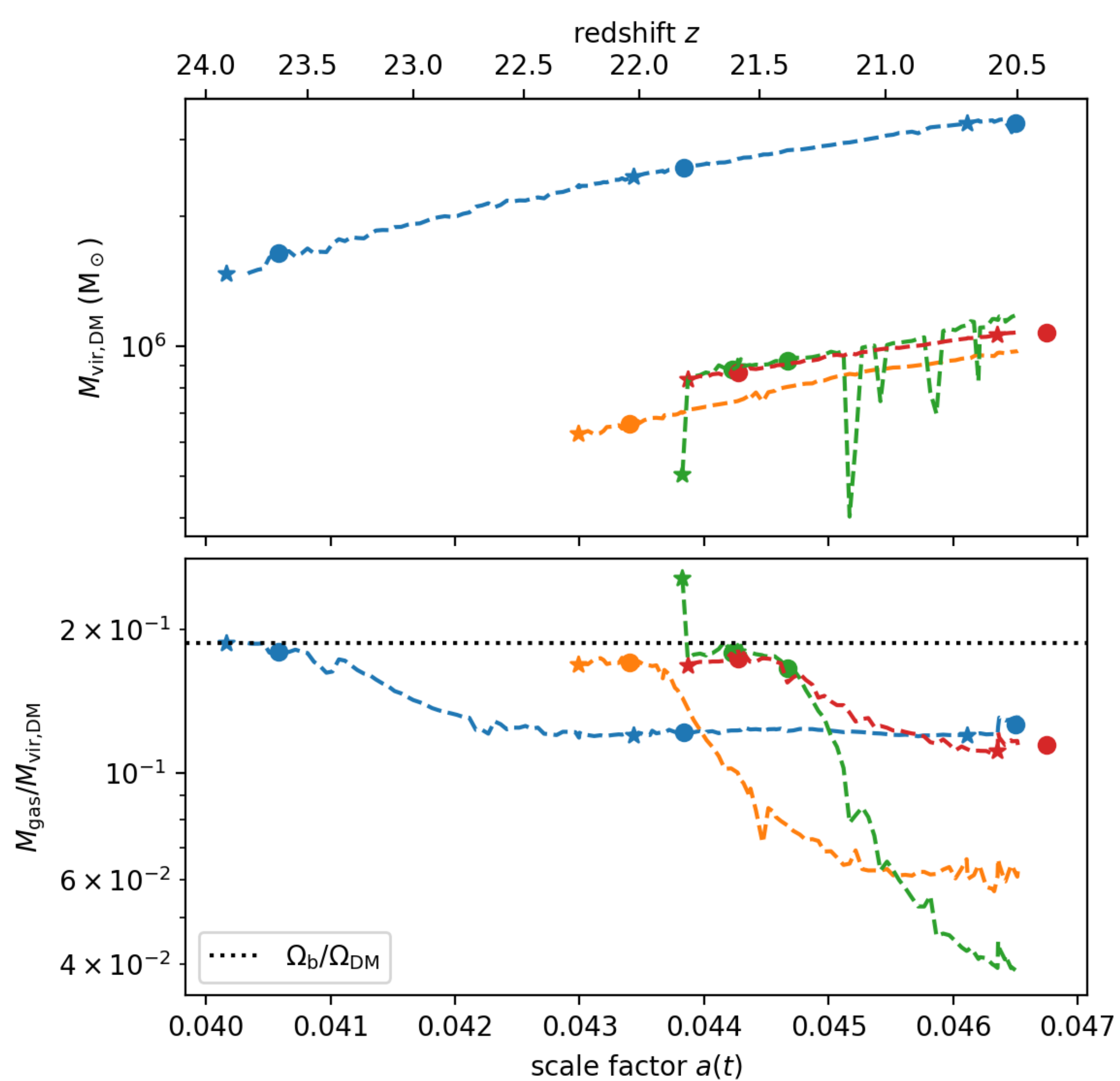


Fig. II (a) and (b): Evolution of the minihalo dark matter mass (top) and gas to dark matter fraction (bottom) as a function of the scale factor. The star-forming halos have masses of $\sim 10^6 M_\odot$, the most massive minihalo being the first one to form stars. The baryonic matter fraction is below the cosmic average and may decrease with time. The time of star formation is indicated by a star, the time of a supernova with a circle. Recollapse times are within 15 – 20 Myr.

Results (preliminary)

- Star-formation occurs in minihalos with a dark matter virial mass of $\sim 10^6 M_\odot$
- Recollapse time (until secondary star formation) are of 15 – 20 Myr
- Low-energy pair-instability supernovae enrich to $-5 \leq [\text{Fe}/\text{H}] \leq -4$ (halo average) consistent with extremely metal poor stars in second generation

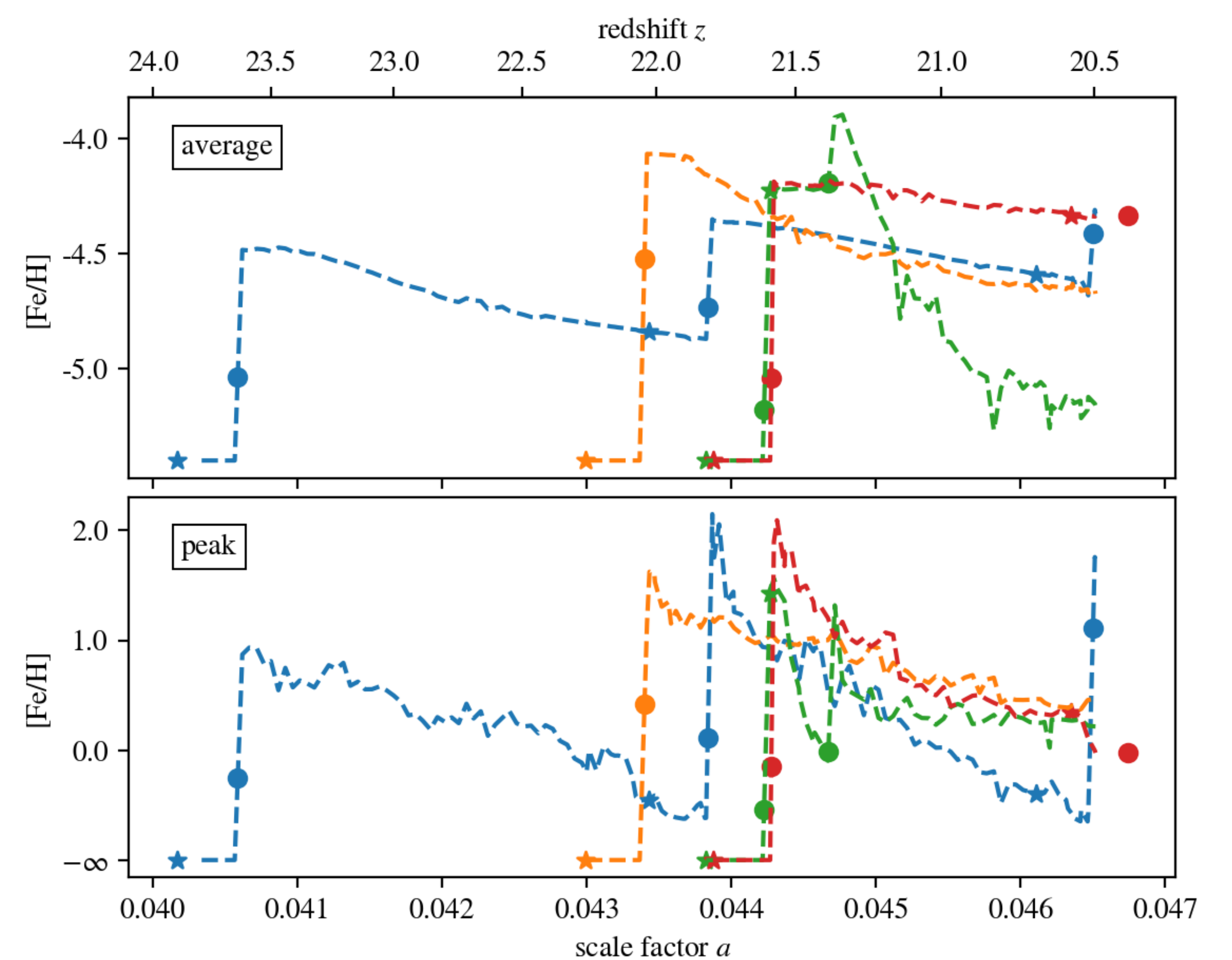


Fig. III (a) and (b): The halo average (top) and peak (bottom) $[\text{Fe}/\text{H}]$ abundance. Supernovae inject iron into the halo which then dilutes and may flow out of the halo beyond the virial radius. The halo average iron abundance during secondary star formation suggests the formation of extremely or ultra metal poor stars.

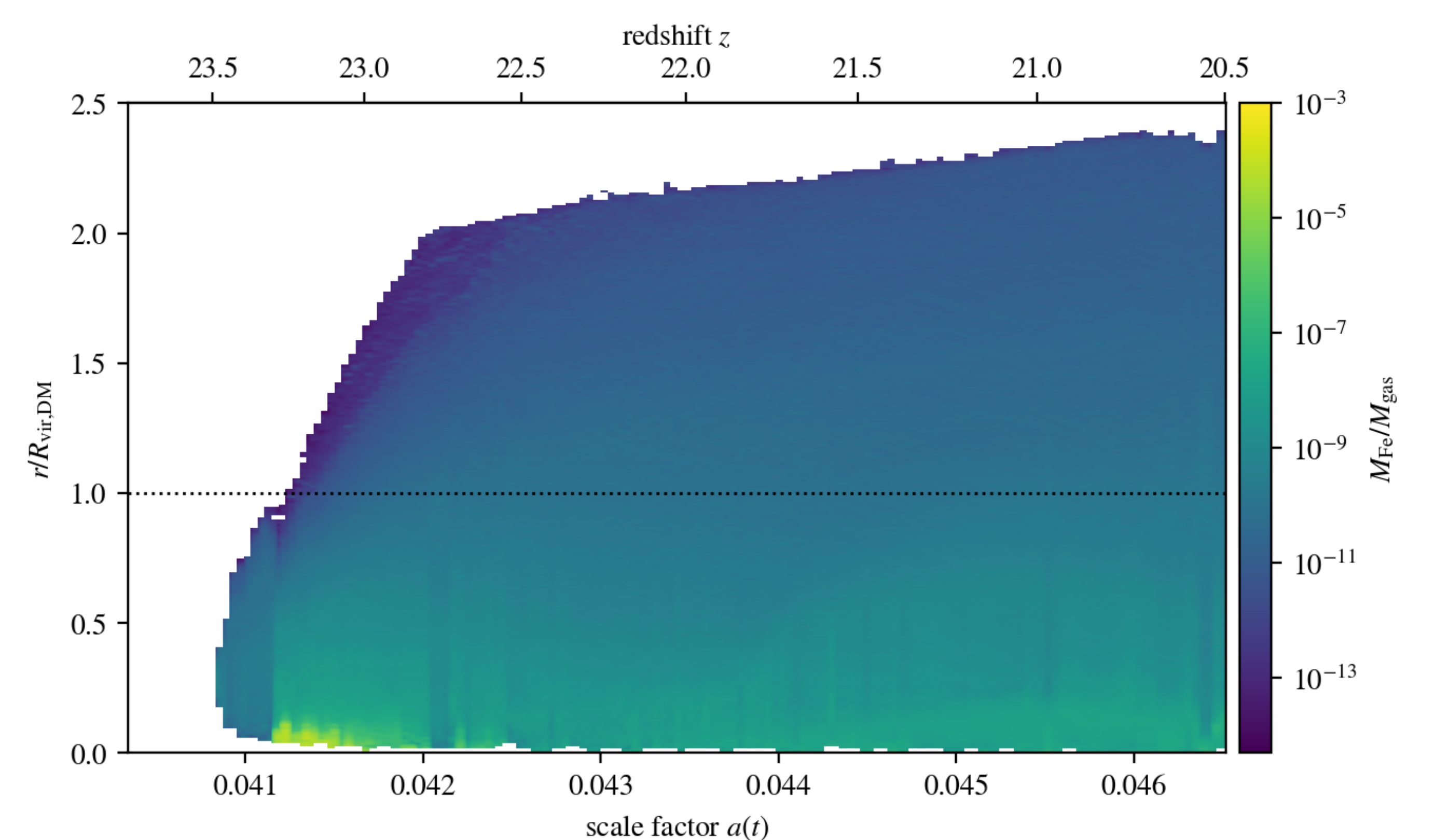


Fig. IV: Radial profiles of the iron mass fraction of one halo across time. For each snapshot, a radial profile of the iron mass fraction up to 2.5 times the dark matter virial radius. Metals slowly migrate out of the halo.

Simulation Setup

- Planck 2015 cosmology with baryonic streaming
- comoving $1 \text{ Mpc}^3 \text{ h}^{-3}$ box from $z = 200$
- 512^3 DM particles ($\sim 800 M_\odot$)
- Automatic refinement of gas cells (resolving Jeans mass and Strömgen sphere)
- Primordial chemistry of H, H_2 , D, HD, He (and ions) and radiative transfer
- Stars as sink particles ($M_* = 200 M_\odot$)
- Monte Carlo tracer particles for metal enrichment (100 000 per supernova)
- Simulation is based on Magg et al. (2022)