The Duration of The Epoch of Population III Stars

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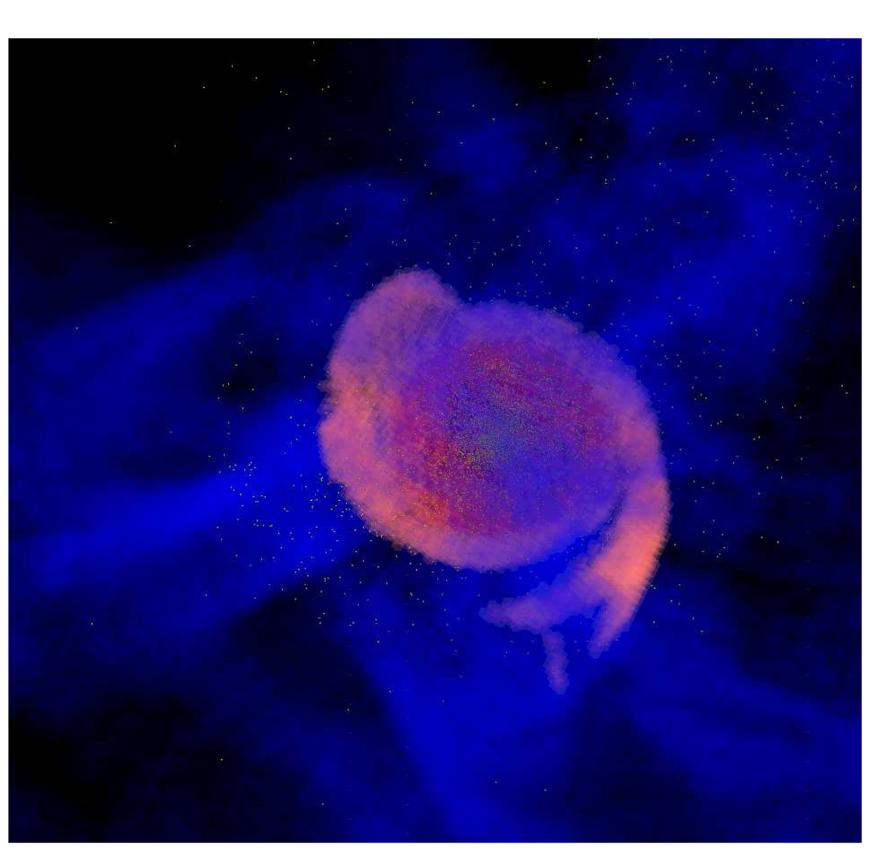
Abstract: We study the formation of the first galaxies using new hydrodynamic cosmological simulations with the ART code. Our simulations feature a recently developed model for dust-based formation of molecular gas . Here, we develop and implement a new recipe for the formation of metal-free Pop III stars. We reach a spatial resolution of 2 pc at *z=10* and resolve star-forming galaxies with the masses above 10^6 $M_\odot$. We find the epoch during which Pop III stars dominated the energy and metal budget of the universe to be short-lived. While these stars seed their host galaxies with metals, they cannot drive significant outflows to enrich the IGM in our simulations. This means that Pop III star formation can continue until *z~6* in different regions of the universe. Within any individual galaxy, Pop II stars overtake Pop III stars within ~50-150 Myr. Understanding the nature of the transition between Pop III and Pop II star formation is of key importance for studying the dawn of galaxy formation.

Simulations: We use the cosmological gasdynamics+N-body Adaptive Refinement Tree (ART) code with molecular gas formation on dust grains and star formation based on molecular gas (Gnedin, Tassis, & Kravtsov 2009). Our simulation boxes are typically 1 h^{-1} Mpc and use a 256^3 root grid and up to 8 additional levels of refinement. This affords a spatial resolution of 22 comoving pc and a DM particle mass of 5,500 $M_\odot$. To achieve even higher resolution, we also use 0.5 h^{-1} Mpc boxes with 256^3 root grid, giving up to 11 comoving pc spatial resolution and a DM particle mass of 690 $M_\odot$.

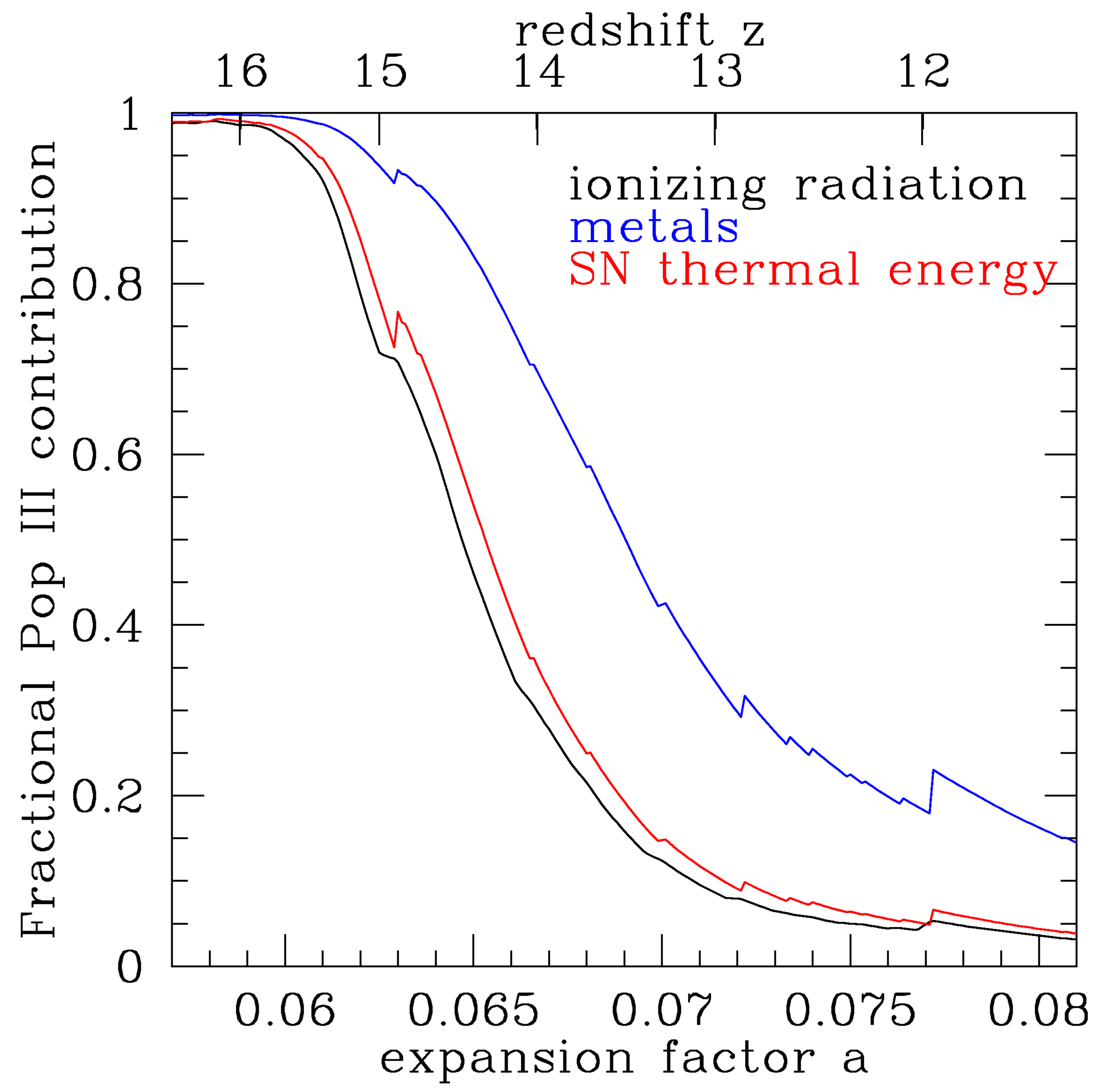
We test and implement a new recipe for Pop III star formation in metal-poor molecular gas ($\log Z/Z_\odot<-3.5$) at densities $n_H>10000$ cm^{-3}. All Pop III stars emit a factor of 10 times more ionizing photons per second per stellar mass than their Pop II counterparts. An assumed 50% fraction of Pop III stars explode in Pair Instability Supernovae (PISN), injecting 27 × 10^{51} ergs of thermal energy and 80 $M_\odot$ of metals into the ISM.

To test for the effects of cosmic variance, we use three different sets of initial conditions, sampling one overdense (OD) and two underdense (UD+, UD-) regions.

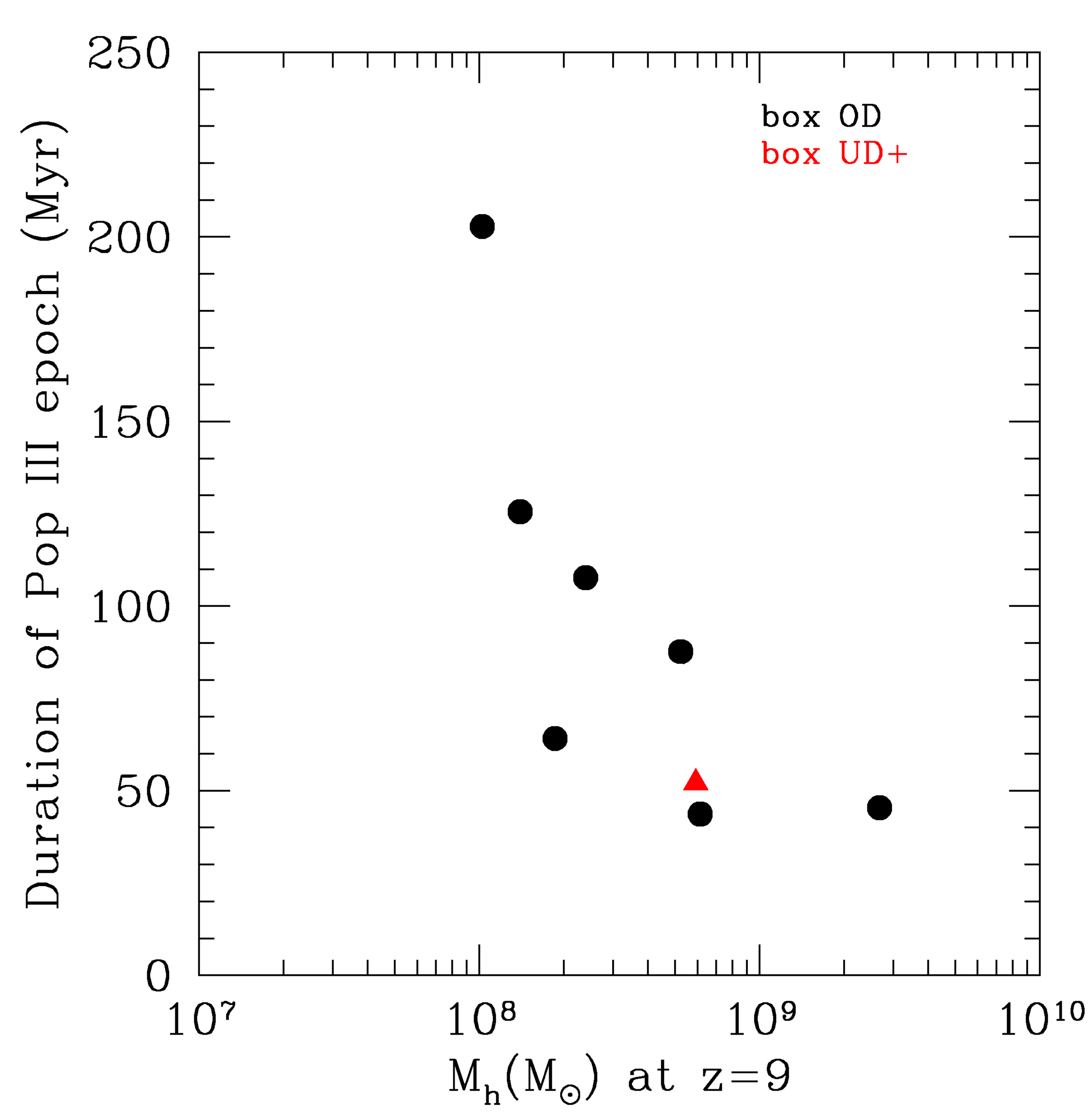
A paper describing the results of our study is currently in preparation.



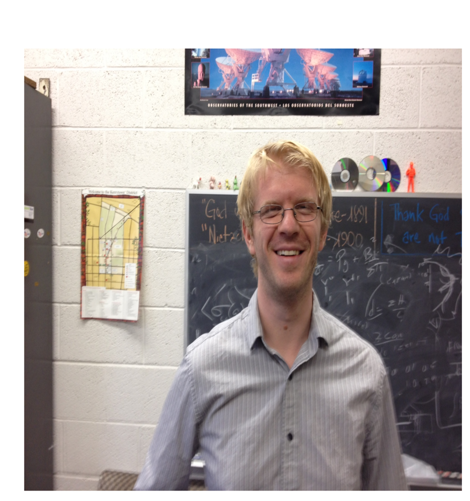
Projected 3D image of the inner kpc of the most active star-forming galaxy at *z=7*. Molecular gas is shown in red, atomic gas in blue, and stellar particles in yellow.



The epoch of Pop III stars: We determine the cumulative fractional contribution of Pop III stars relative to Pop II stars in terms of their total thermal energy, ionizing radiation, and metal production. By *a≈0.07 (z≈13)*, Pop III stars have already become sub-dominant to Pop II stars in every way, despite our assumption of very strong feedback. The brevity of the era is a result of the self-regulating nature of Pop III stars. The metals generated by the first supernovae quickly enrich the densest gas in their host galaxies, allowing for Pop II stars to take over.



The duration of the dominance of Pop III stars is here defined as the length of time between the beginning of star formation in a galaxy and the time at which the cumulative contribution of Pop II stars to the budget of ionizing photons matches Pop III. The duration is most brief in highly massive, highly biased galaxies. Less massive galaxies are slower to replenish their reservoir of dense gas needed for star formation after Pop III stars have heated it through ionizing radiation and PISNe thermal feedback. Pop III star formation does not constitute a long phase in the lifetime of any galaxy.



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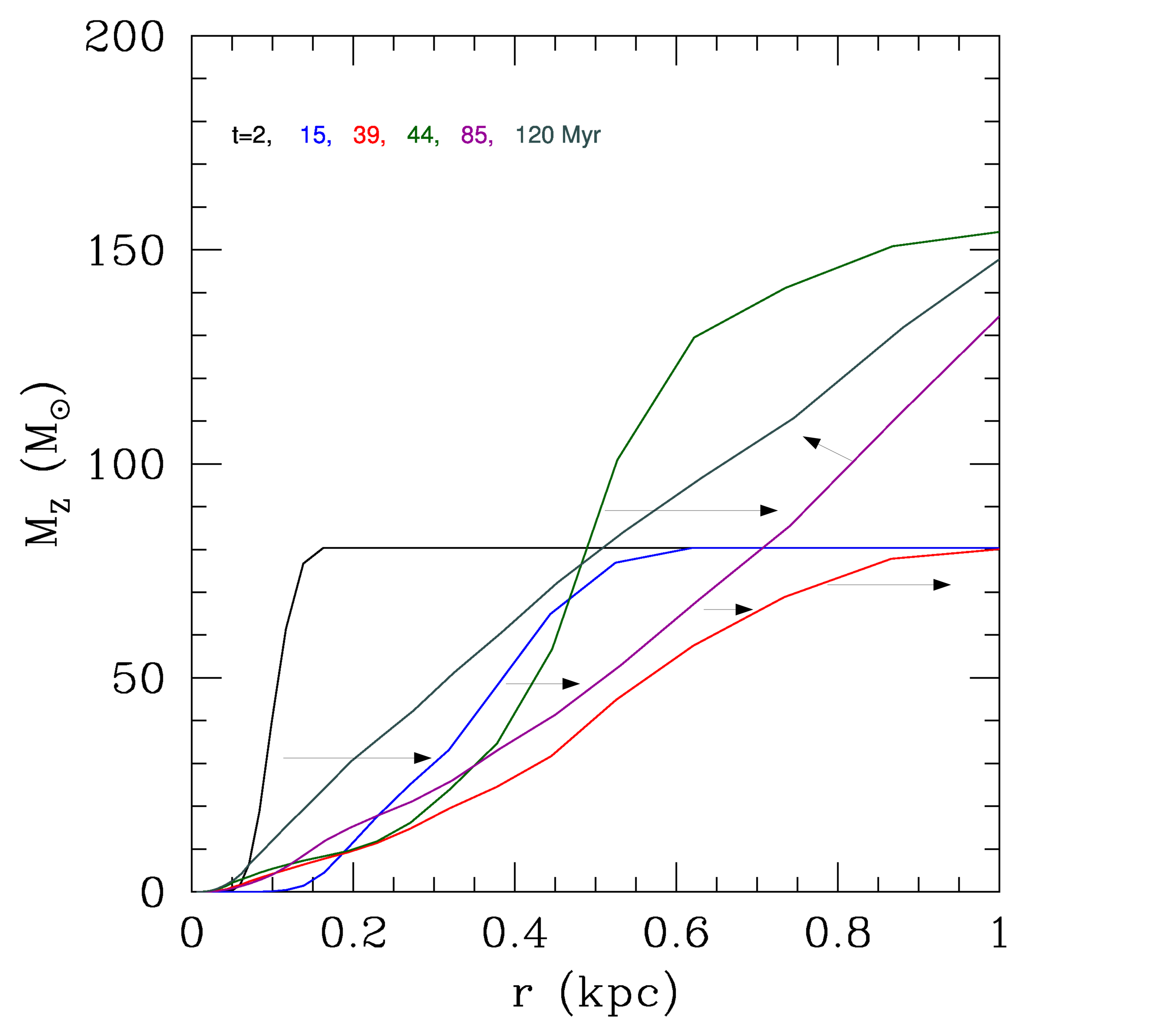
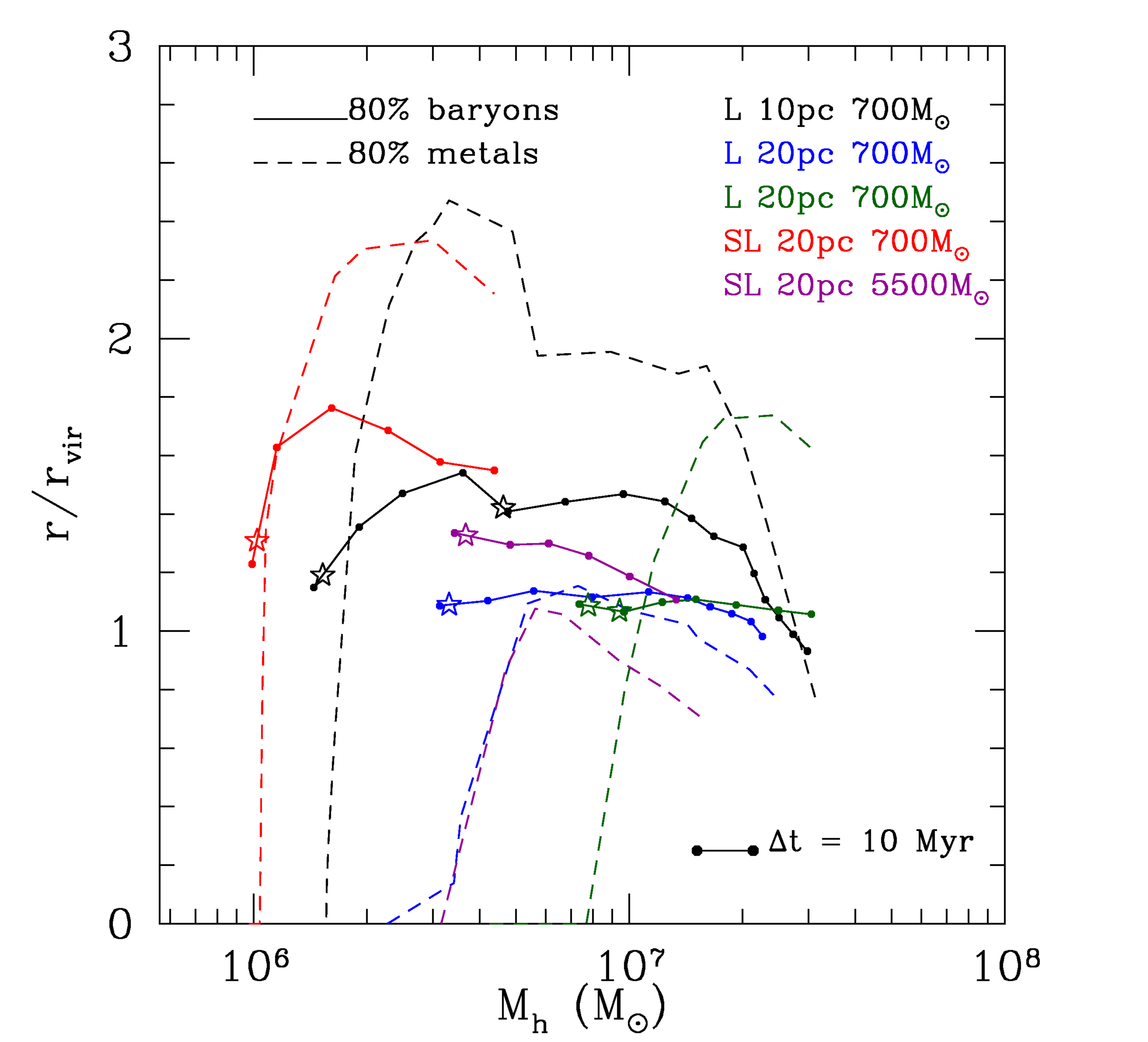


Pop III stars can enrich a volume of the IGM out to several kpc from where they form. Shown above is the enclosed mass of metals as a function of galactocentric distance for several epochs, tracing the outflow of PISNe ejecta. A second PISNe happens 40 Myr after the first, and drives a second outflow. However, 120 Myr after the first PISNe, the flow of metals points inwards, as the metal-rich ejecta have mixed with primordial gas accreting onto the galaxy.



The recollapse of metals: Though metals from PISNe are ejected past the virial radius, they do not stay there for long. Plotted here are the radii at which 80% of the metals produced in the galaxy are enclosed, as well as the radii where the mass of baryons enclosed divided by the virial mass equals 80% of the universal baryon fraction. Each line represents a galaxy as it evolves in time, beginning at the epoch when the first star is formed. Within 50 Myr of the PISNe (denoted by stars), most of the gas and metals have begun to recollapse. The radius of propagation is strongly regulated by halo mass.