

# A computationally cheap trillion particle N-body simulation

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We present an augmented N-body simulation which is equivalent to a trillion particle simulation capable of resolving atomically cooled haloes between  $z \sim (20 - 5)$  that is ideal for Epoch of Reionisation studies.

## Background:

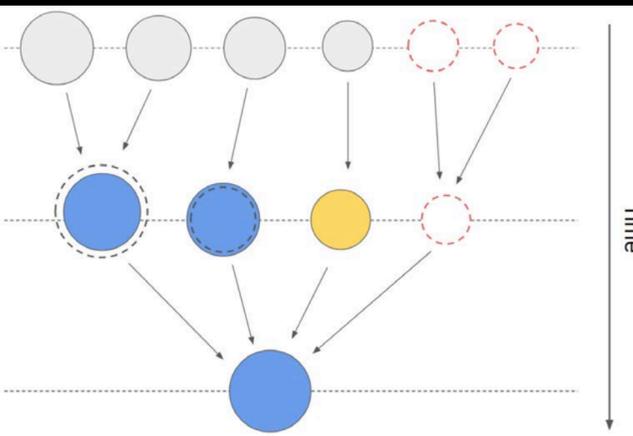
The Epoch of Reionisation (EoR) is the last major phase change of the Universe when the neutral hydrogen atoms were ionised by the photons from the first stars and galaxies. To study EoR, simulations with  $\sim 100$ s of Mpc in sidelength are needed to beat down sample variance while at the same time resolve all the galactic scale haloes.

## Why?:

The main driver of the computational cost of simulations is the number of particles. For a fixed number of particles we must compromise between volume and mass resolution (i.e. lowest mass object that can be resolved within our simulation). For example, if one needs to resolve all the atomically cooled haloes in a  $\sim 100 h^{-1}$  Mpc simulation one needs  $\sim 50$  billion particles and millions of CPU hours. Also, it has been shown that to properly study the effects of X-rays (one of the primary heating sources in the early Universe) on the EoR, simulation boxes of  $\sim 200 h^{-1}$  Mpc are required. (Kaur+2020, Katz+2020, Iliev+2014).

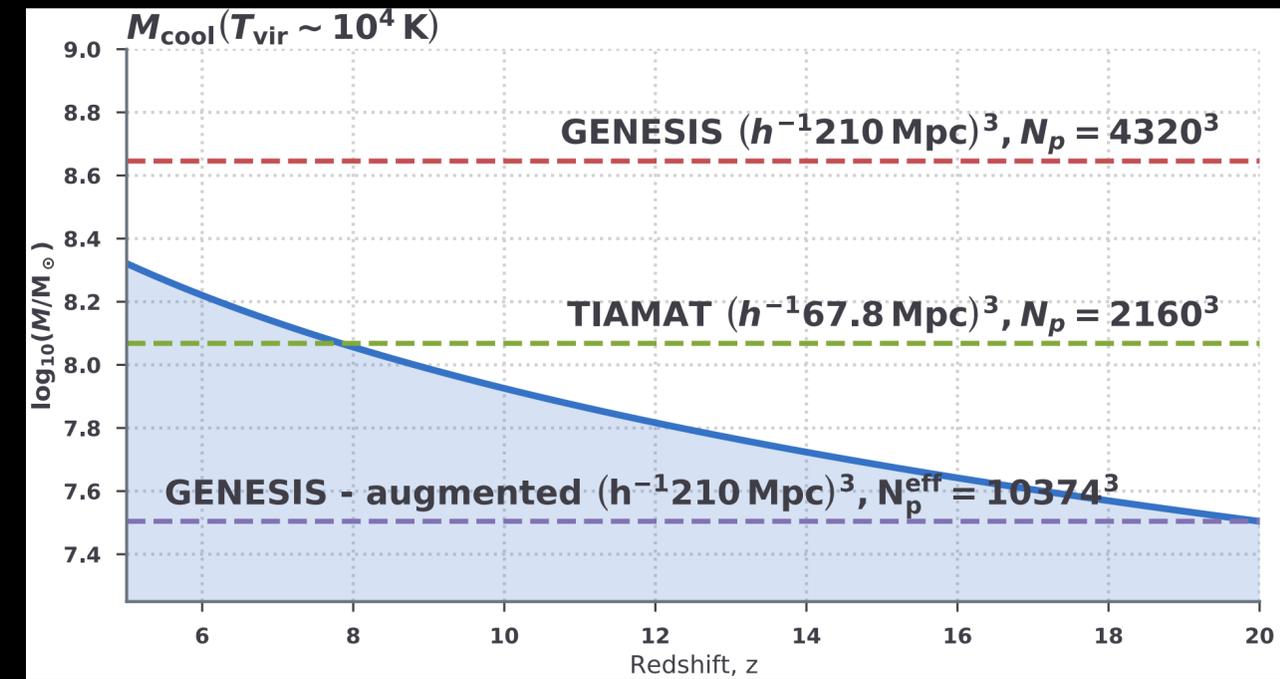
## How?:

*Darkforest* (Qiu+2020) uses an extended Press-Schechter formalism, which has been tuned with higher resolution N-Body simulations, to introduce new haloes into a simulation box via a Monte Carlo algorithm.

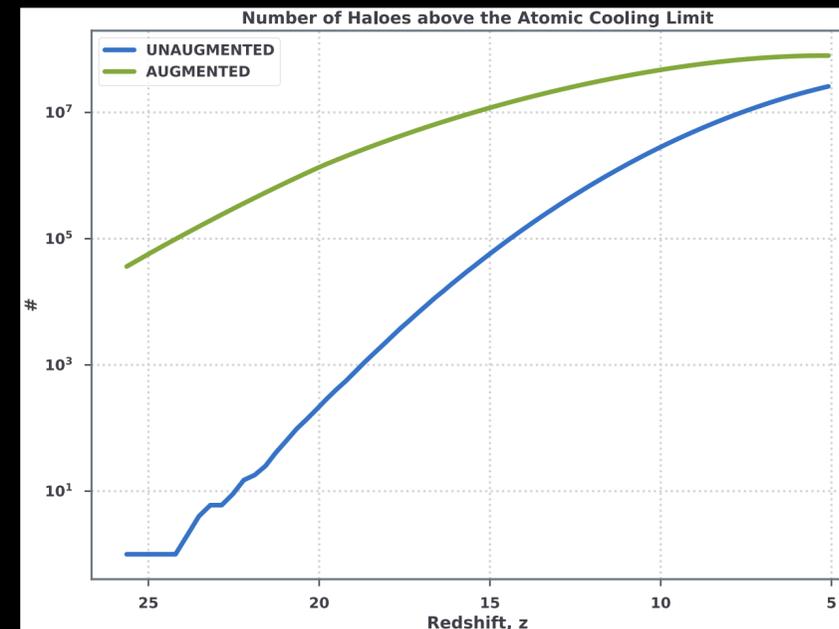


The schematic to the left shows the basic working of *Darkforest*. The algorithm removes some of the N-body haloes (yellow circle) from the simulation, but introduces numerous haloes that are less massive at the same time (red dotted circles).

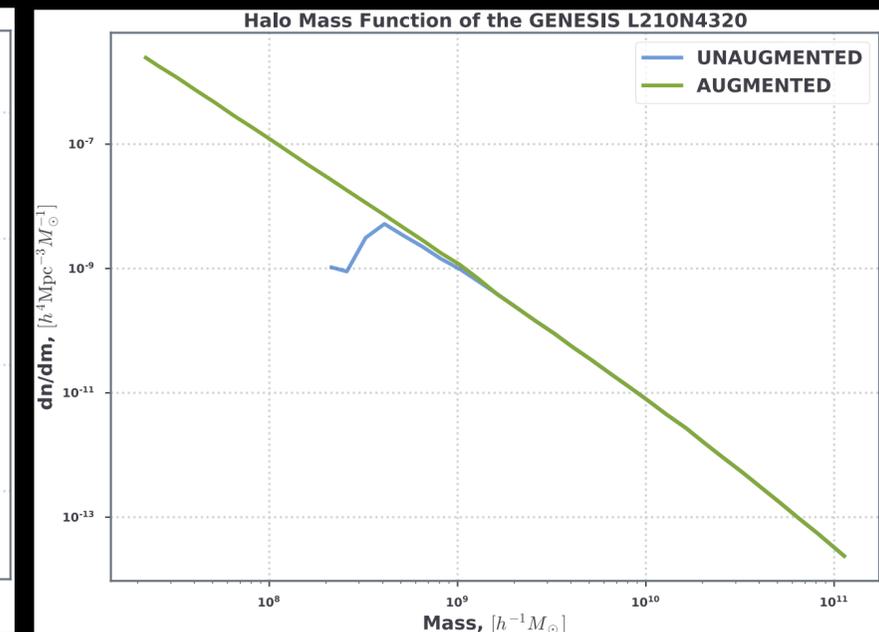
Here we augment the GENESIS L210N4320 box to a mass resolution of  $2.1 \times 10^7 h^{-1} M_{\odot}$  which is equivalent to having a simulation of  $\sim$ trillion particles.



Mass resolution of existing simulations along with our new augmented GENESIS simulation. The atomic cooling limit across the relevant redshifts is also shown.



Simulated number of haloes above the atomically cooling limit which contribute to reionisation



The Halo Mass Function at redshift 5, before and after augmentation