The astrophysics of the first galaxies

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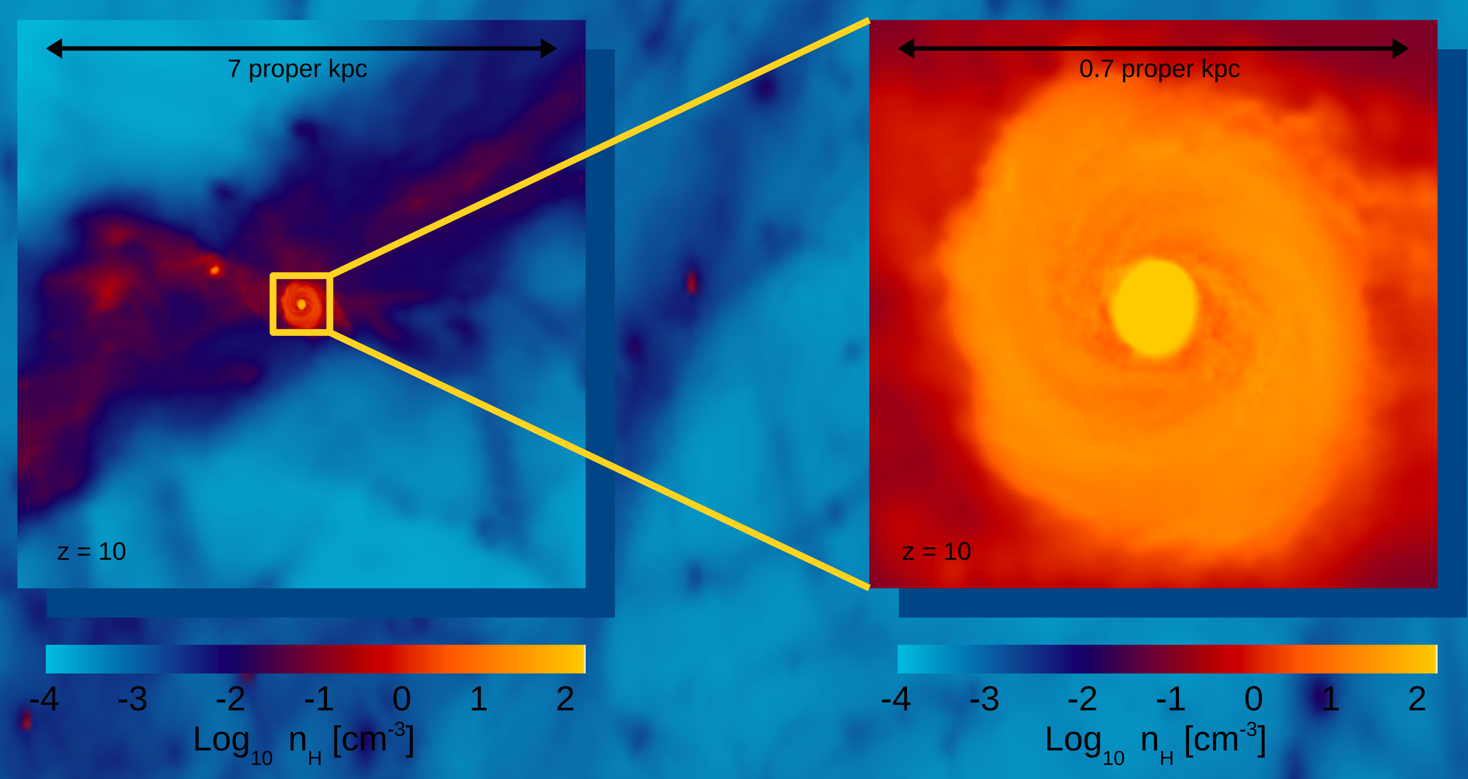
Introduction

Understanding the formation and evolution of the first stars and galaxies is crucial to the understanding of reionization. Detailed theoretical studies of the galaxies before and during reionization are now particularly urgent because of the wealth of observational data that will soon be provided by the next generation of telescopes, such as JWST, ALMA, LOFAR, MWA, and others. We simulate the formation of the first galaxies using cosmological smoothed particle hydrodynamics (SPH) simulations. Zooming in on individual galaxies, we explore how various physical processes affect their evolution. A highlight of our study will be the simulation of the radiation-hydrodynamics of galaxy assembly, which we will perform using our newly-developed multi-frequency radiative transfer method TRAPHIC. Feedback from radiation has long been suspected to play a decisive role in galaxy formation. We will investigate its implications for observable properties of the first galaxies.

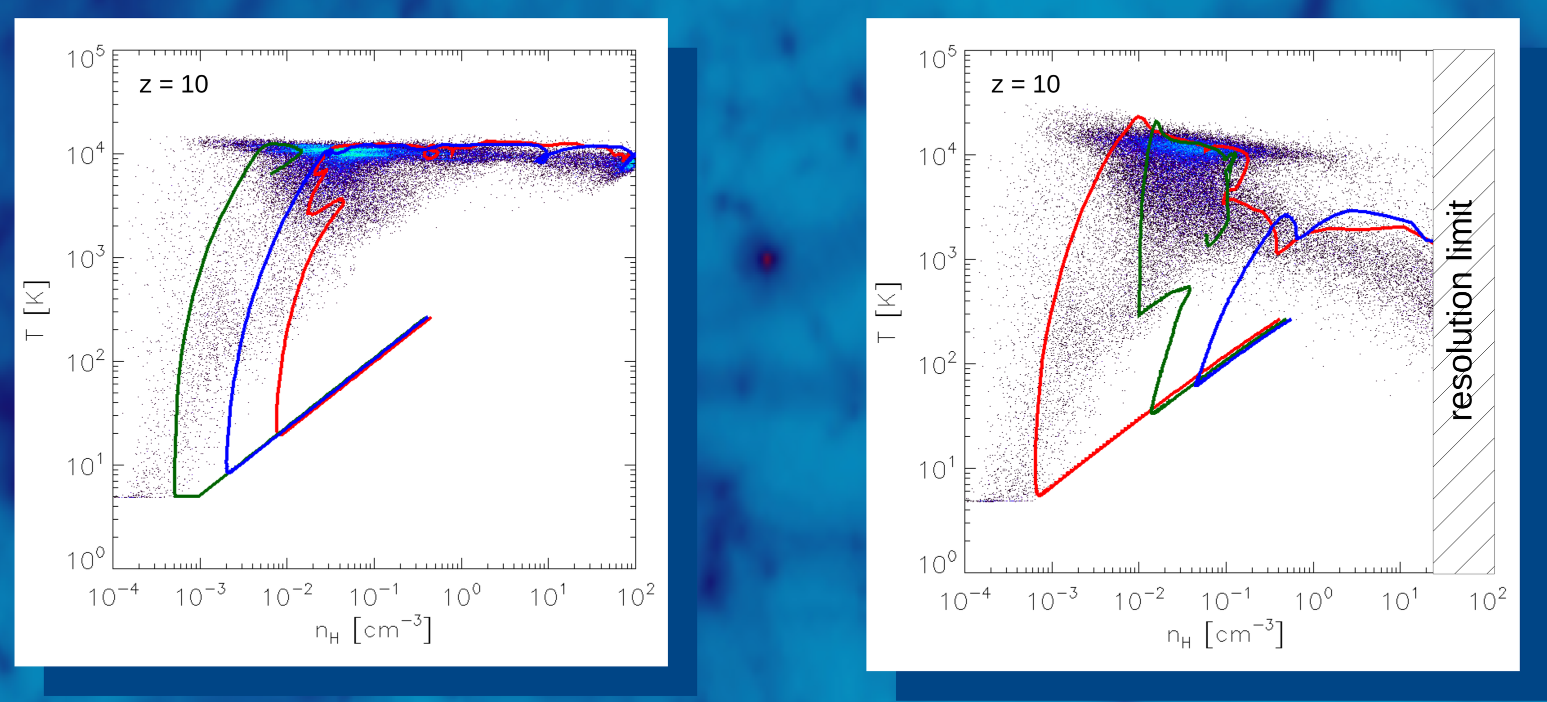
SPH simulations

We use a modified version of the N-body Tree-PM / SPH code P-Gadget-3-BG [1], a successor of Gadget-2 [2]. Starting from WMAP5 [3] LCDM cosmological initial conditions, we perform zoomed simulations of galaxies in halos reaching masses of 10^9 M_{sun} at redshift z = 10. This type of galaxies will be directly observed with JWST. The images show the gas densities in one of our simulations.



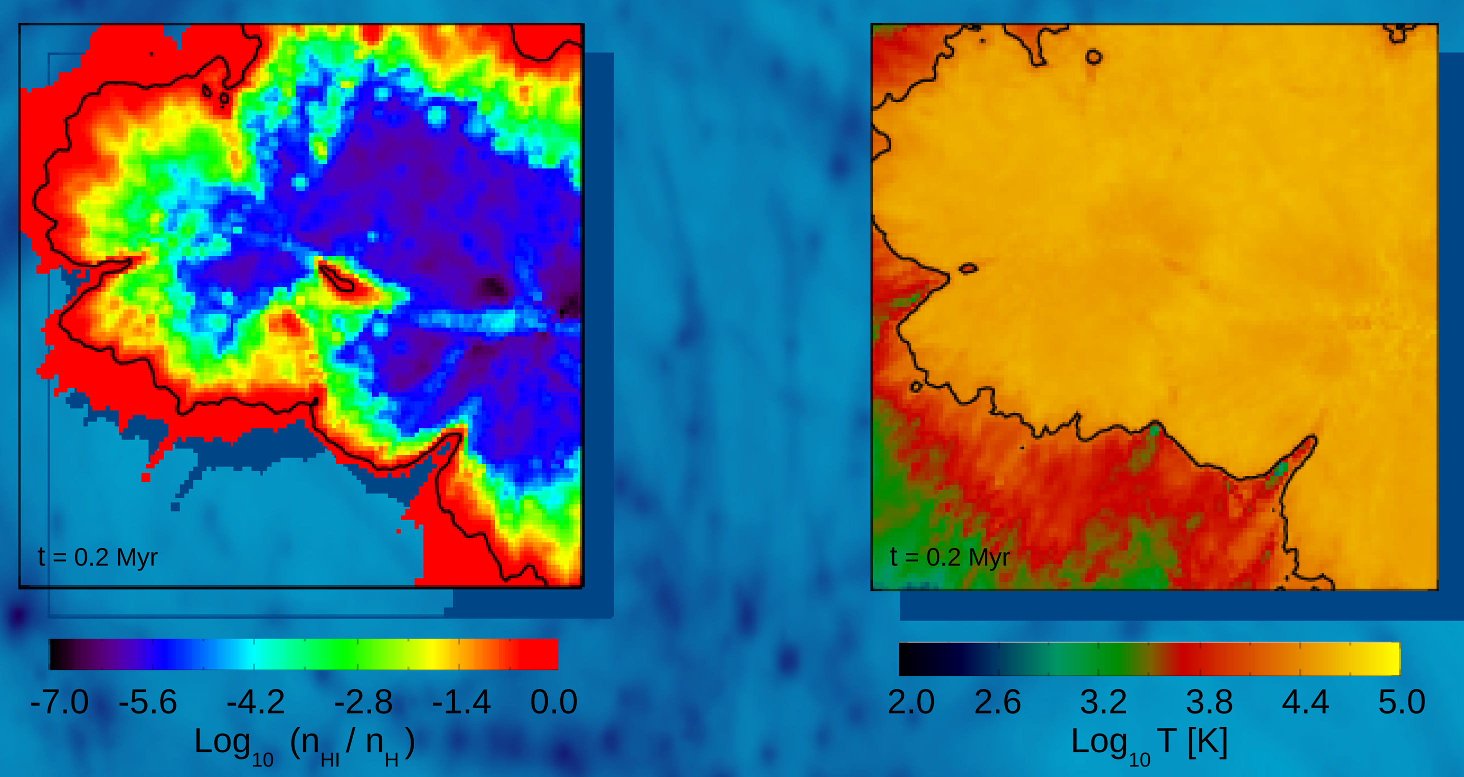
Chemistry & cooling

We follow the non-equilibrium H2+HD chemistry and cooling of primordial gas with the possibility to include a photo-ionizing / photo-dissociating background. The figures show a snapshot (at z = 10) of all particles contained in the galaxy displayed above in the temperature-density plane, assuming atomic equilibrium (left) and atomic+molecular non-equilibrium (right) cooling. Also shown are example particle histories.



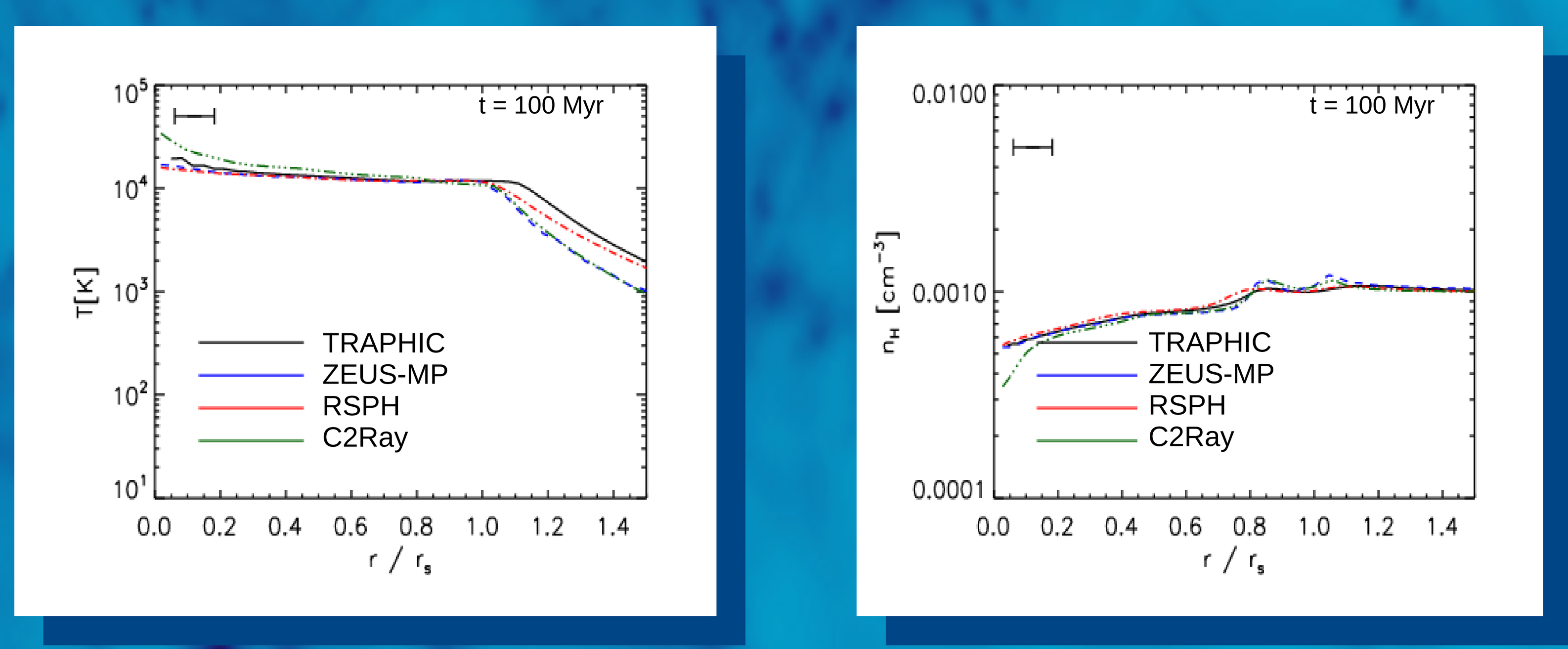
Radiative transfer

We use our novel multi-frequency radiative transfer method TRAPHIC [4,5] to solve the time-dependent radiative transfer problem in primordial gas (H+He). TRAPHIC's distinguishing features include that it is spatially adaptive, parallel on distributed memory and requires a computation time that does not scale with the number of sources. The images show its performance in Test 4 of the Code Comparison Project [6].



Radiation-hydrodynamical feedback

Photoheating increases the gas pressure, which initiates a gasdynamical response (e.g., shock). The figures show the performance of TRAPHIC/P-Gadget-3-BG in a radiation-hydrodynamical simulation of Test 5 of the Code Comparison Project [7]. The results obtained with TRAPHIC are in excellent agreement with the results obtained with state-of-the-art codes (ZEUS-MP [8], RSPH [9], C2Ray [10]).



Outlook

Simulating the first galaxies is a demanding task which requires to follow the non-equilibrium chemistry and cooling of primordial gas, to transport ionizing photons and to account for the radiation-hydrodynamical feedback in high-resolution cosmological runs. We have demonstrated that we are able to accomplish each of these parts in turn. The remaining quest is to combine them and to also include physics like star formation and associated feedback not considered above.

This research is supported by the NASA grant NNX09AJ33G. References: [1] Schaye et al. (2010); [2] Springel (2005); [3] Komatsu et al. (2008); [4] Pawlik & Schaye (2008); [5] Pawlik & Schaye (in prep); [6] Iliev et al. (2006); [7] Iliev et al. (2009); [8] Whalen & Norman (2008); [9] Susa (2006); [10] Mellema et al. (2006)