The first billion years of cosmic evolution remain one of the last largely uncharted territories in astrophysics. During this key period the cosmic web of structures we see today first took shape and the very first stars and galaxies formed. The radiation from these first galaxies started the process of cosmic reionization, which eventually ionized and heated the entire universe. This inherently multi-scale process, mostly driven by stellar radiation from low-mass galaxies, had profound effects on the cosmic structures, leaving a lasting impression. The star formation inside such galaxies is strongly affected by complex radiative and hydrodynamic feedback effects, including ionizing and non-ionizing UV radiation, shock waves, gas cooling and heating, stellar winds and enrichment by heavy elements.

We will present the latest results from our current and recent PRACE Tier-0 and Tier-1 projects lead by Prof. Ilian Iliev. Our project relies on massively-parallel N-body, radiative transfer and radiative-hydrodynamics simulations covering the full, vast range of relevant scales, from pc to hundreds of Mpc (dynamic range of more than one million), using a variety of advanced numerical techniques, including Adaptive Mesh Refinement (AMR), artificial neural networks and GPU acceleration. Some of the key questions we are aiming to address are:

1) how does the radiative feedback from the First Stars hosted in cosmological minihaloes and dwarf galaxies affect the formation of early structures and subsequent star formation? 2) how much does high-redshift galaxy formation differ from the one at the present day? What are the observational signatures of the first galaxies? 3) how important is the recently pointed out effect of local modulation of the star formation in minihaloes due to differential supersonic drift velocities between baryons and dark matter? 4) how are these feedback effects imprinted on large-scale observational features? 5) how small-scale (often unresolved) structures affect the reionization progress and observables.

In particular, the latter point is often ignored or poorly modelled in current simulations. We have recently developed detailed sub-grid models for both sources and sinks of radiation based on the local density, including the significant scatter around the mean relations of the source numbers, collapsed fractions and gas clumping their time evolution due to both cosmological structure formation and feedback effects. Large and complex projects like these require millions to tens of millions of core-hours per run and can produce up to Petabytes of data, and thus can only be performed on Petascale HPC systems.