The SPHINX simulations of the first billion years of galaxy evolution and cosmic reionization

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Abstract

A few hundred million years after the Big Bang, the first stars and galaxies formed, ending the so-called dark ages and beginning the Epoch of Reionization. As the galaxies grew, the ultra-violet radiation emitted from their most massive stars warmed up the inter-galactic gas around them via photoionization. As these ionized bubbles grew and percolated, the whole Universe was transformed from a dark, cold, neutral state into a hot ionized one: reionization was completed, about 13 billion years ago. This last major transition of the Universe is a frontier research field in astronomy and the focus of the foremost upcoming telescopes, such as the James Webb Space Telescope and the Square Kilometre Array.

Yet, observations provide very limited data on the first galaxies, yielding only a very indirect picture of reionization. Comprehensive three-dimensional cosmological simulations performed with gravitational-radiation-hydrodynamics are necessary to understand this ancient epoch and interpret observational data. In addition to capturing the complex interplay of many physical processes, these simulations must encompass an extreme range of physical scales, from the deep interiors of galaxies where stars form out of collapsing gas and emit ionizing radiation, out to intergalactic space where this same radiation ionizes and warms up the entire Universe. Because such simulations are extremely demanding, we have so far only been able to understand fragments of the full picture.

In my talk I will present a new suite of simulations, called the SPHINX project (https://sphinx.univ-lyon1.fr), where new method developments and access to PRACE resources allow us to model cosmic reionization using a complex and unprecedented mix of physics and sub-grid models in cosmological volumes composed of several billion resolution elements. For the first time ever we can resolve the emission and escape of stellar radiation through the inter-stellar medium of thousands of galaxies, all evolving together in the same simulation, hence capturing the interplay of 'small' and large scales.

I will describe the simulations, their main components, and the key developments that made them possible. I will then show some of our key science results so far, on the effects of binary stellar systems on reionization, on the effect of reionization on inhibiting the growth of small galaxies, on the properties of the galaxies that mainly contribute to the photon budget of reionization, and on why we observe almost zero escape fractions of ionizing radiation from galaxies in the local Universe.

The simulations presented here were run on three tier-0 PRACE allocations (projects 2016153539, 2018184362, and 2019215124) of a total of about 97 million core-hours.