Cosmic Dawn III recreates the Epoch of Reionization in unprecedented resolution

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Physicists have become keenly interested in the first billion years of the universe—the stretch between the Big Bang and the formation of the first stars during which galaxies began to form. During the last 600 million years or so of this period, the neutral interstellar galactic medium–and even pre-galactic medium–became ionized with ultraviolet radiation emitted by the first stars glowing in the earliest, growing galaxies. An understanding of the physics of this stretch, called the "Epoch of Reionization," or EoR, would connect the physics of the modern universe to the Big Bang.

"The Epoch of Reionization represents the last major transition of the universe in the story of cosmic evolution," says theoretical astrophysicist Paul Shapiro at the University of Texas at Austin, "from the phase when all of space was filled with a nearly featureless, homogeneous gas to the phase in which structure emerged, with the first galaxies forming and inside them, stars."

Observing the distant sources of reionization directly is challenging, and detections are so far limited to the brightest galaxies. Physicists use computer simulations to recreate the rich physics of the EoR. On April 10, during the APS April Meeting 2022, theoretical astrophysicist Paul Shapiro from the University of Texas at Austin will present highlights and observational predictions from the Cosmic Dawn III (CoDa) Project, the largest radiation-hydrodynamics simulation of the EoR to date.

Simulating the EoR with CoDa III required heavy computational lifting. With a trillion computational elements—8192^3 dark matter particles and 8192^3 gas and radiation cells in a region 300 million light-years across today—the model had a resolution high enough to follow all the newly forming galactic haloes that sourced reionization in that volume, well beyond the reach of ordinary computers. The simulation ran for 10 days on 131,072 processors coupled to 24,576 graphic processing units at the massively parallel supercomputer, Summit, located at Oak Ridge National Laboratory in Tennessee.

Size isn't the only remarkable feature of the CoDa III simulation, says Shapiro. Tracking the evolution of galaxy formation and reionization requires accounting for a mutual feedback process: ionizing radiation that leaked out of galaxies had to heat the intergalactic medium. That additional heat, in turn, pressurized gas enough to resist the gravitational pull of nearby galaxies. Since the gas would otherwise have fueled the formation of star formation, the net result of this process is to stymie new stars.

Previous models have separated these effects, but Shapiro says CoDa III can simulate the gravitational dynamics of gas and matter together while accounting for ionizing radiation and its effect on the gas. Without radiative transfer, time in the evolutionary model would have to be divided into steps small enough to represent the changing densities of gas and stars and dark matter. The addition of this feedback loop means the time steps must be hundreds of times smaller to capture the high speed of the "surfaces of ionization"—rapidly expanding ionizing bubbles racing outward from newly-formed galaxies and sweeping across the universe. The linked processors and GPUs at the Summit supercomputer, Shapiro says, made it possible to solve these equations almost as quickly as if the model did not include radiation.

Notably, Shapiro says, CoDa III solves a problem between theory and observational data that has emerged in EoR studies; namely, that the theoretical predictions of previous models don't line up with observations of quasar absorption spectra that probe the universe at the end of the EoR and after. This problem vanishes in CoDa III, as the simulation produces self-consistent predictions that agree with the latest observations.

Shapiro predicts that the study of the EoR is poised to undergo its own rapid expansion in coming years. Space-based observatories like the James Webb Space Telescope, which launched in December 2021, and the Nancy Grace Roman Space Telescope, which is scheduled to launch in 2027, along with ground-based projects like the Extremely Large Telescope, will improve astronomers' ability to observe the far flung drivers of reionization. Present and upcoming radio investigations could help researchers better constrain the clumpy, inhomogeneous way that the IGM became ionized.

Simulations like Cosmic Dawn, says Shapiro, provide a theoretical foundation for what these sophisticated telescopes will see. "Apart from matching the existing spectrum of observations and predicting new ones," he says, "it provides critical insight into the nature of the physical processes that took place."

More information: Conference: april.aps.org/

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