Artificial intelligence tool developed to predict the structure of the universe

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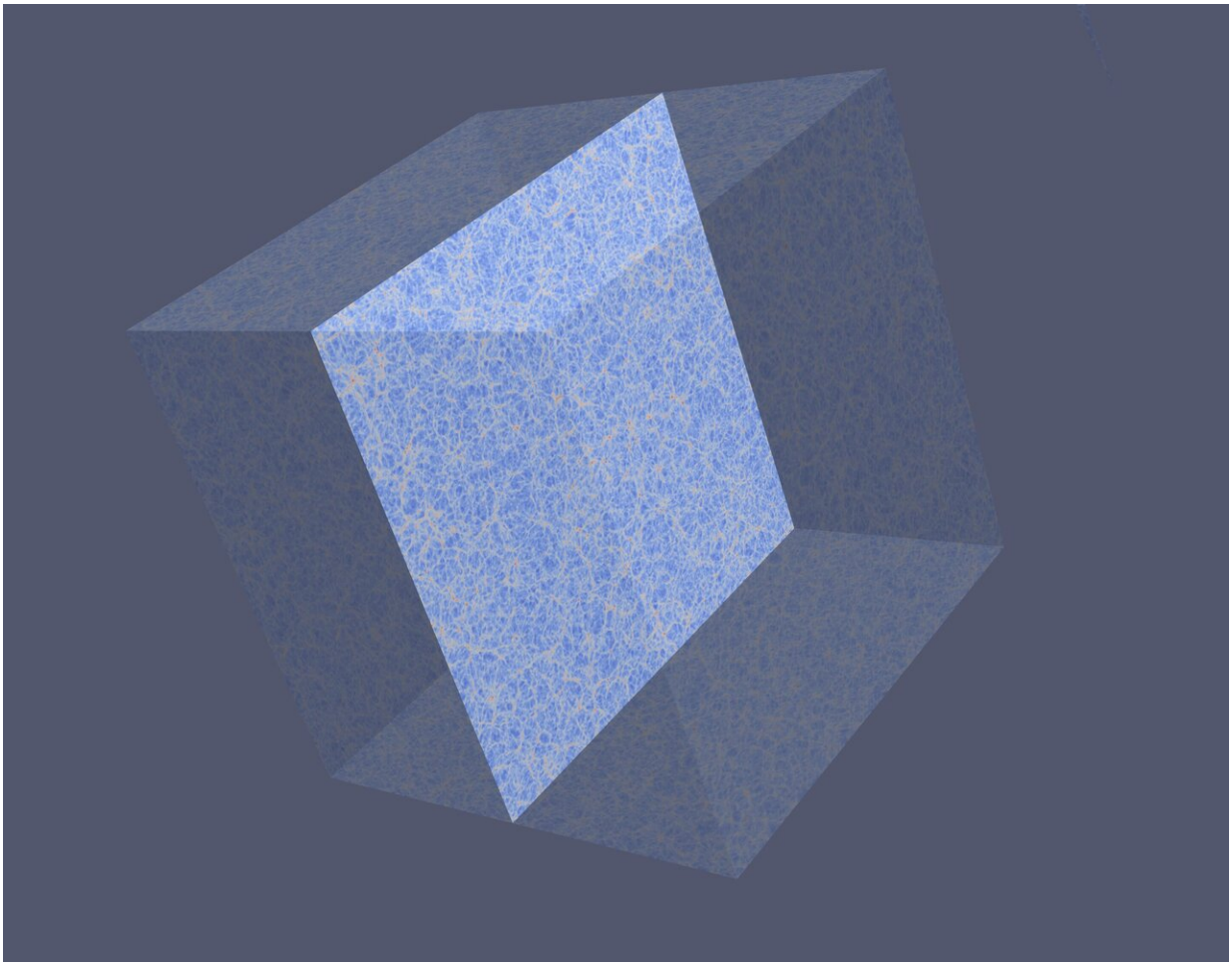

Figure 1:An example of the virtual universe created by ATERUI II supercomputer. It shows the distribution of about 10 billion particles in a volume encompassing about 4.9 billion light years evolved until today. It takes about two days using 800 CPU cores in ATERUI II. Credit: YITP

Advancements in telescopes have enabled researchers to study the universe with greater detail, and to establish a standard cosmological model that explains various observational facts simultaneously. But there are many things researchers still do not understand. Remarkably, the majority of the universe is made up of dark matter and dark energy of an unknown nature. A promising avenue to solving these mysteries is studying the structure of the universe. The universe is made up of filaments where galaxies cluster together. These filaments resemble threads from far away, surrounding voids where there appears to be nothing. The discovery of the cosmic microwave background has given researchers a snapshot of what the universe looked like close to its beginning; understanding how its structure evolved to what it is today would reveal valuable characteristics about dark matter and dark energy.

A team of researchers, including Kyoto University Yukawa Institute for Theoretical Physics Project Associate Professor Takahiro Nishimichi, and Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) Principal Investigator Masahiro Takada used the world's fastest astrophysical simulation supercomputers ATERUI and ATERUI II to develop the Dark Emulator. Using the emulator on data recorded by several of the world's largest observational surveys allows researchers to study possibilities concerning the origin of cosmic structures and how dark matter distribution could have changed over time.

"We built an extraordinarily large database using a supercomputer, which took us three years to finish, but now we can recreate it on a laptop in a matter of seconds. I feel like there is great potential in data science. Using this result, I hope we can work our way toward uncovering the greatest mystery of modern physics, which is to uncover what dark energy is. I also think this method we've developed will be useful in other fields such as natural sciences or social sciences," says lead author Nishimichi.

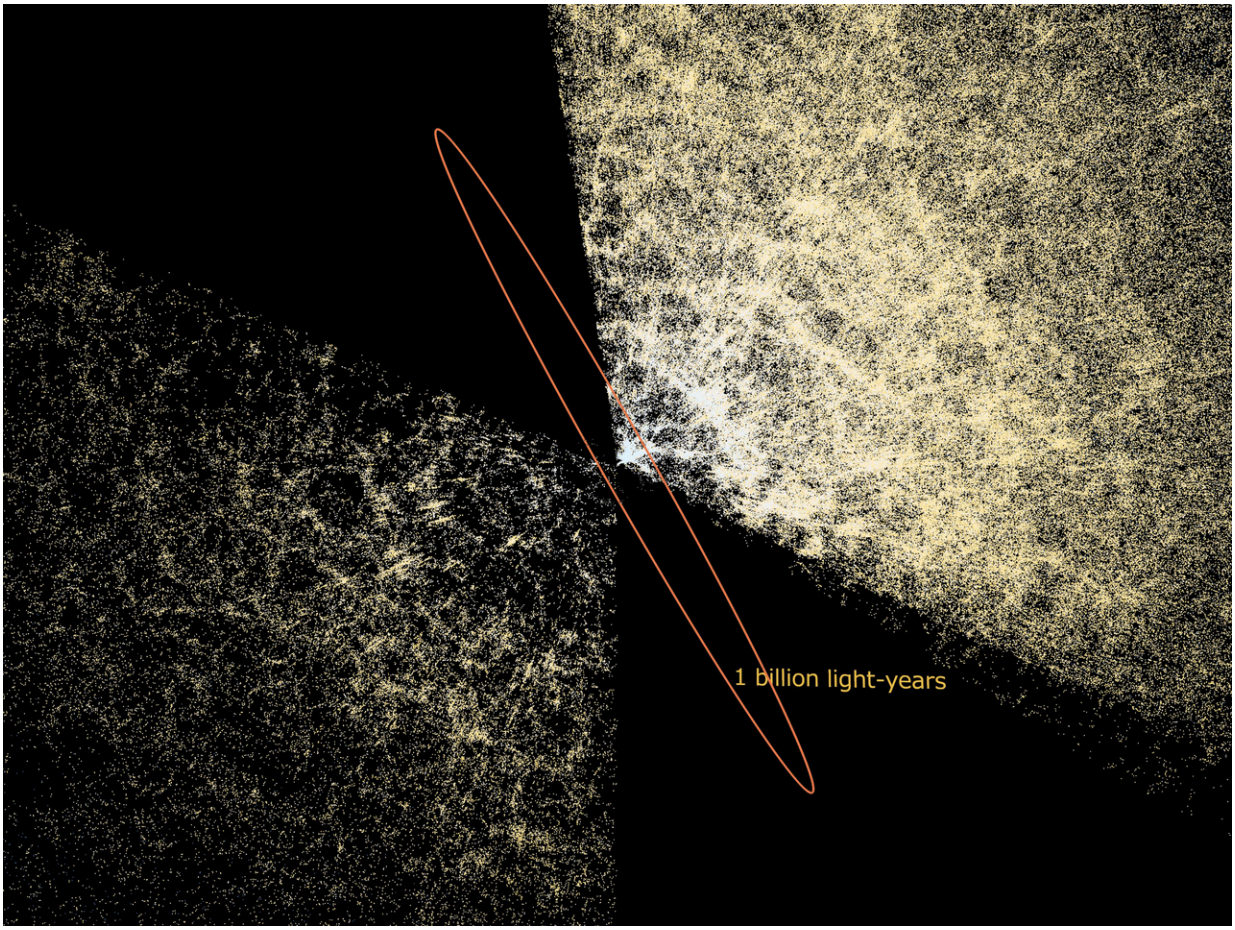

Figure 2: The way in which galaxies cluster together in the Universe is made clear in this image of the universe as observed by the Sloan Digital Sky Survey (SDSS). The yellow dots represent the position of individual galaxies, while the orange loop shows the area of the universe spanning 1 billion light-years. At the center is Earth, and around it is a three-dimensional map of where different galaxies are. The image reveals that galaxies are not uniformly spread out throughout the universe, and that they cluster together to create areas called filaments, or are completely absent in areas called voids. Credit: Tsunehiko Kato, ARC and SDSS, NAOJ Four-Dimensional Digital Universe Project

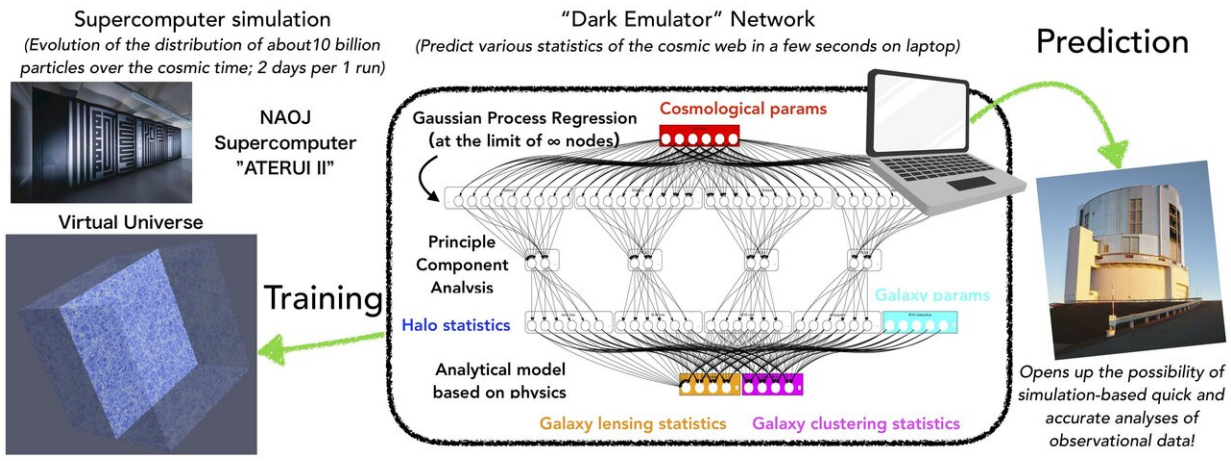

Figure 3:The conceptual design of Dark Emulator. Left: An example of the virtual universe created by ATERUI II supercomputer. Center: The architecture of Dark Emulator. It learns the correspondence between the fundamental cosmological parameters employed at the beginning of a simulation and its outcome based on a machine-learning architecture with hybrid implementation of multiple statistical methods. After training, the machine now immediately predicts accurately the expected observational signals for a new set of cosmological parameters without running a new simulation. This allows astronomers to drastically reduce the computational cost needed for the extraction of cosmological parameters from observational data Credit: YITP, NAOJ

This tool uses an aspect of artificial intelligence called machine learning. By changing several important characteristics of the universe, such as those of dark matter and dark energy, ATERUI and ATERUI II have created hundreds of virtual universes. Dark Emulator learns from the data, and guesses outcomes for new sets of characteristics without having to create entirely new simulations every time. When testing the resulting tool with real-life surveys, it successfully predicted weak gravitational lensing effects in the Hyper Suprime-Cam survey, along with the three-dimensional galaxy distribution patterns recorded in the

Sloan Digital Sky Survey to within 2 to 3% accuracy in a matter of seconds. In comparison, running simulations individually through a supercomputer without the AI, would take several days.

The researchers hope to apply their tool using data from upcoming surveys in the 2020s, enabling deeper studies of the origin on the universe.

More information: Takahiro Nishimichi et al. Dark Quest. I. Fast and Accurate Emulation of Halo Clustering Statistics and Its Application to Galaxy Clustering, *The Astrophysical Journal* (2019). DOI: 10.3847/1538-4357/ab3719

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