千葉大学
CHIBA UNIVERSITY

RESEARCH NEWS STORY

October 2, 2025
Chiba University

Could Dark Energy Change Over Time? Searching for Answers Through Computer Simulations

Researchers use Japan's Fugaku supercomputer to explore the effects of time-varying dark energy on cosmic evolution

Dark energy, which drives the accelerated expansion of the Universe, is assumed to be constant since the Universe began by today's leading model. Researchers from Japan, Spain, and the U.S. explored the possibility of time-varying dark energy by conducting one of the largest cosmological simulations to date. Their results show that while dark energy variations have modest effects alone, variations in other parameters like matter density significantly alter galaxy formation and cosmic structure, aligning closely with the latest observations.

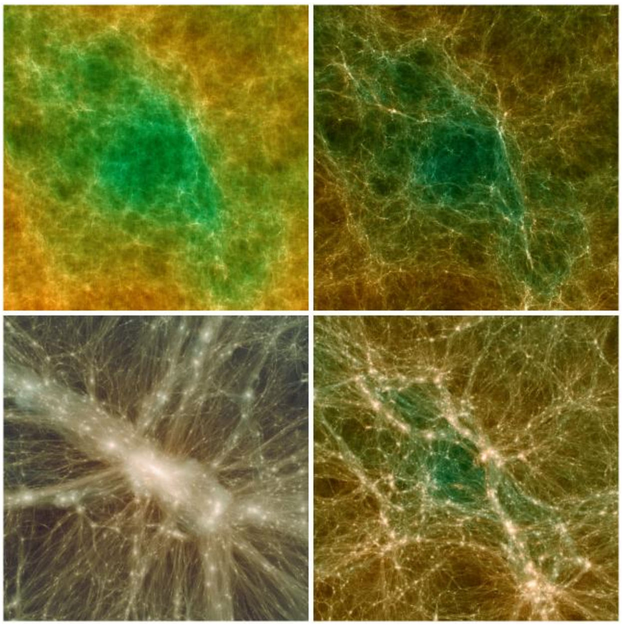

Image Title: The time evolution of dark matter structures in Uchuu.
Image Caption: Dark energy is responsible for the expansion of the Universe, but its true nature is still a subject of much debate. Computer simulations based on the latest astronomical data enable scientists to understand the effects of different values and behaviors of the dark energy parameter. This image shows the time evolution of dark matter structures revealed by one of the largest computational simulations, Uchuu, which is based on the standard cosmological model. The evolution is shown in the clockwise direction from the top-left panel.
Image credit: Drs Tomoaki Ishiyama and Hirotaka Nakayama, 4D2U Project, NAOJ
Source Link: https://www.youtube.com/watch?v=R7nV6JEMGAo
Image license: Original content
Usage Restrictions: Cannot be reused without permission.

Since the early 20^{th} century, scientists have gathered compelling evidence that the Universe is expanding at an accelerating rate. This acceleration is attributed to what is known as 'dark energy'— a fundamental property of spacetime that has a repulsive effect on galaxies. For decades, the leading cosmological model, known as the Lambda Cold Dark Matter (ΛCDM), has assumed that dark energy is a constant entity, unchanging throughout cosmic time. While this simple assumption has served as the bedrock of modern cosmology, it has left a fundamental question unanswered: what if dark energy is not constant, but instead a time-varying property of the Universe?

Recent groundbreaking observations have provided some of the first hints that the above-mentioned assumption may not be correct. The Dark Energy Spectroscopic Instrument (DESI), a sophisticated experiment for conducting astronomical surveys of distant galaxies, has produced data suggesting a preference for a dynamic dark energy (DDE) component. This finding represents a significant deviation from the standard ΛCDM model. Though this discovery implies a richer and more complex Universe's history, it also highlights an important knowledge gap: our understanding of how a time-varying dark energy component could influence the growth and evolution of large-scale structures in the Universe remains very limited.

Against this backdrop, a research team led by Associate Professor Tomoaki Ishiyama from the Digital Transformation Enhancement Council at Chiba University, Japan, has conducted one of the largest and most comprehensive cosmological simulations to date. The study was co-authored by Francisco Prada from the Instituto de Astrofísica de Andalucía, Spain, and Anatoly A. Klypin from New Mexico State University, USA, and was published in Volume 112, Issue 4 of the journal *Physical Review D* on August 4, 2025. Together, the researchers analyzed how time-varying dark energy would shape the cosmos and provide essential insights for interpreting observational data.

Using the Japanese flagship supercomputer Fugaku, the team ran three distinct, high-resolution N-body simulations, each with a volume eight times larger than the previous studies of this kind. One simulation modeled the standard Planck-2018 ΛCDM Universe, while the other two incorporated a DDE element. By comparing a DDE model with fixed cosmological parameters against the standard ΛCDM model, they were able to isolate the influence of the time-varying dark energy component itself. Then, they simulated a third model that included the best-fit DDE parameters derived from DESI Year-1 observations, allowing them to see the full effect of DDE on an 'updated' cosmological model.

The results show that the impact of the DDE component alone is surprisingly modest. However, when they adjusted cosmological parameters in the last DDE model based on DESI data (namely, a 10% higher matter density), the effects on the Universe's structure became much more pronounced. This is because a higher matter density creates stronger gravitational forces, leading to earlier and more efficient formation of massive clusters of galaxies, which are the cosmic 'scaffolding' where galaxies and galaxy clusters reside. The DESI-derived DDE model predicted up to 70% more massive clusters of galaxies in the Universe's early epochs.

The research team also analyzed baryonic acoustic oscillations (BAOs), a cosmological footprint left by ancient sound waves, now used as a cosmic ruler to measure cosmic distances with galaxy surveys like DESI. Their simulations showed that the BAO peak in the DESI-derived DDE model shifted by 3.71% toward smaller scales. This result from the simulation closely matched actual DESI observations, thus validating the model and confirming its predictive power.

Moreover, the researchers examined how galaxies are distributed and clustered throughout the Universe. The full DESI-derived DDE model exhibited significant and measurable differences in clustering compared to other models. More specifically, a higher matter density led to a stronger clustering signal, especially at smaller scales. By carefully studying the clustering patterns, the researchers confirmed that the DDE model's predictions aligned with the observational data from DESI.

Taken together, the results of the study provide key insights into the extent of the effects of DDE. "*Our large simulations demonstrate that variations in cosmological parameters, particularly the matter density in the Universe, have a greater influence on structure formation than the DDE component alone,"* explains Dr. Ishiyama.

With upcoming surveys expected to provide even more precise measurements, this research will be critical for understanding our Universe's evolution. "*In the near future, large-scale galaxy surveys from the Subaru Prime Focus Spectrograph and DESI are expected to significantly improve measurements of cosmological parameters. This study provides a theoretical basis for interpreting such upcoming data*," concludes Dr. Ishiyama.

To see more news from Chiba University, click here.

About Associate Professor Tomoaki Ishiyama from Chiba University, Japan
Dr. Tomoaki Ishiyama is an Associate Professor at the Digital Transformation Enhancement Council, Chiba University, Japan. His research focuses on elucidating the formation and evolution of various astronomical objects, such as galaxies and large-scale structures in the Universe, as well as on the study of dark matter structures within galaxies. He has published over 50 research papers on these topics.

Funding:
This work has been supported by IAAR Research Support Program in Chiba University, Japan, MEXT/JSPS KAKENHI (Grants No. JP19KK0344 and No. JP23H04002), MEXT as "Program for Promoting Researches on the Supercomputer Fugaku" (JPMXP1020230406), and JICFuS. Numerical computations were carried out on the supercomputer Fugaku provided by the RIKEN Center for Computational Science (Project ID: hp240184). Francisco Prada and Anatoly A. Klypin acknowledge support from the Spanish MICINN PID2021-126086NB-I00 funding grant. The data release used the Skies and Universes database, hosted at the skun@IAA computer and managed by the IAA-CSIC in Spain through MICINN EU-Feder Grant No. EQC2018-004366-P.

Reference:
Title of original paper: Evolution of clustering in cosmological models with time-varying dark energy
Authors: Tomoaki Ishiyama[1], Francisco Prada[2], and Anatoly A. Klypin[3,4]
Affiliations: (1) Digital Transformation Enhancement Council, Chiba University, Japan
(2) Instituto de Astrofísica de Andalucía (CSIC), Spain
(3) Astronomy Department, New Mexico State University, USA
(4) Department of Astronomy, University of Virginia, USA
Journal: *Physical Review D*
DOI: 10.1103/4k5f-gyrx

Contact: Tomoaki Ishiyama
Digital Transformation Enhancement Council, Chiba University, Japan
Email: ishiyama@chiba-u.jp

Academic Research & Innovation Management Organization (IMO), Chiba University
Address: 1-33 Yayoi, Inage, Chiba 263-8522 JAPAN
Email: cn-info@chiba-u.jp