"New developments in AI through study of evolution of the Milky Way from initial quantum fluctuations to its assembly"

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In this project we use an AI-assisted method to understand how cosmic structures, including our Milky Way Galaxy, have grown from the seed fluctuations, which originated from the quantum fluctuations in the inflationary era, from cosmological data including those from the 8.2m Subaru Telescope.

One of the most powerful cosmological methods is to use the map of the universe obtained from the distribution of galaxies that are observed by telescopes including the Subaru Telescope. By comparing cosmological observables obtained from the universe map with the predictions obtained from the standard model of the universe, we can measure the physical quantities of the universe such as the amount of dark matter. Cosmological simulations using supercomputers make it possible to accurately calculate the time evolution of the distribution of dark matter (the inhomogeneities of matter distribution) starting from the seed fluctuations in the early universe as the initial conditions. However, even with a supercomputer, it takes a few days to run a high-precision simulation for a single cosmological model.

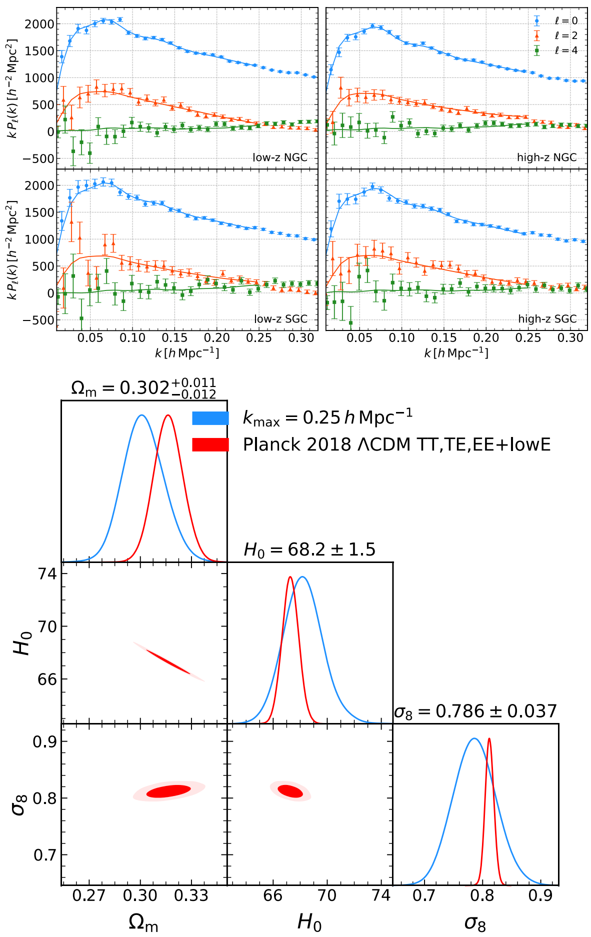

Fig.1 Upper panel: The data points are the measurement of galaxy power spectra measured from the Sloan Digital Sky Survey data. The solid lines in each panel show the best-fit model computed from the Dark Emulator. Lower panel: The posterior distribution of cosmological parameters obtained from the comparison of the SDSS data with the Dark Emulator predictions.

In this project, we performed high-precision cosmological simulations for each of the 100 cosmological models using the supercomputer. By using a deep learning method to learn the simulation data, we were able to build "Dark Emulator," a machine that can predict the properties of structure formation with the same degree of accuracy as a high-precision simulation, even for an input cosmological model for which no simulation has been run. Dark Emulator can perform calculations in only about 0.1 second, which are equivalent to simulations that would take a few days to complete on a supercomputer. In other words, we were able to speed up the computation by a factor of 1 million. By comparing the theoretical predictions computed by Dark Emulator with the cosmological statistics observed from the universe map data, we were able to measure cosmological parameters such as the total amount of dark matter (Fig. 1). This method is equivalent to comparing the universe map with the universe computed by a supercomputer using different cosmological models.

Recently, we presented the cosmology results using the data obtained from the Hyper Suprime-Cam (HSC) on the Subaru Telescope in Hawaii. We measured the weak gravitational lensing effect, the prediction of the Einstein's theory of gravity, from the Subaru HSC data and then compared the measurement with the predictions computed by Dark Emulator to measure the cosmological parameters.

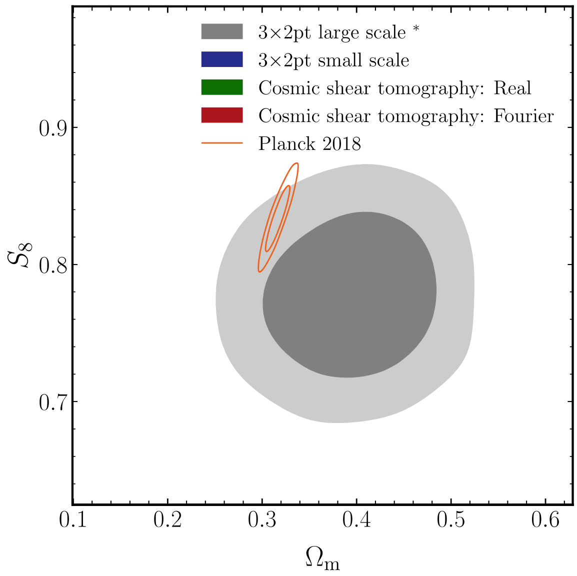

Fig.2 The cosmological parameters measured by comparing the model predictions with the weak lensing measurements from the Subaru HSC data. For comparison, we also show the result obtained from the Planck cosmic microwave background data.

Both of our cosmological parameter measurements mentioned above show some discrepancies with the independent results obtained from the cosmic microwave background data. This discrepancy is currently one of the hottest topics in the cosmology field. It may indicate new physics of the universe, and further research is underway. There is no doubt that AI/machine learning methods will be used more and more in cosmology, taking advantage of upcoming big data such as that from the Subaru Telescope.

As a separate project independently from the cosmology project above, we used the

Subaru Telescope's large data set to measure the proper motions of stars, which can tell us how the Milky Way evolved and formed through the assembly history of smaller building blocks. We also measured the proper motion of the Sextans dwarf galaxy that is one of the most famous classical dwarf galaxies in the outer region of the Milky Way halo.

We were able to advance our understanding of the structure formation in the universe, from the Milky Way to large-scale structure. Here we would like to thank the beyond AI for the support for the past three years.

Selected Publications

1. "Hyper Suprime-Cam Year 3 results: Cosmology from galaxy clustering and weak lensing with HSC and SDSS using the minimal bias model", S. Sugiyama, et al. including M. Takada and H. Murayama, Phys. Rev. D 12, 123521 (2023)
2. "Hyper Suprime-Cam Year 3 Results: Cosmology from Cosmic Shear Power Spectra", R. Dalal, et al. including M. Takada and H. Murayama, Phys. Rev. D 108, 1235219 (2023)
3. "Hyper Suprime-Cam Year 3 Results: Cosmology from Cosmic Shear Two-point Correlation Functions1", X. Li, et al. including M. Takada and H. Murayama, Phys. Rev. D 108, 1235218 (2023)
4. "Hyper Suprime-Cam Year 3 results: Cosmology from galaxy clustering and weak lensing with HSC and SDSS using the emulator based halo model", H. Miyatake, S. Sugiyama, M. Takada et al. including H. Murayama, Phys. Rev. D 108, 1235217 (2023)
5. "Study of structural parameters and systemic proper motion of Sextans dwarf spheroidal galaxy with Subaru Hyper Suprime-Cam data", A. Tokiwa, M. Takada et al., MNRAS 526, 1310 (2023)
6. "Galaxy clustering from the bottom up: a streaming model emulator I", C. Cuesta-Lazaro et al. including M. Takada, MRAS 523, 3219 (2023)
7. "Cosmological inference from an emulator based halo model. II. Joint analysis of galaxy-galaxy weak lensing and galaxy clustering from HSC-Y1 and SDSS", H. Miyatake, S. Sugiyama, M. Takada et al. including H. Murayama, Phys. Rev. D 106, 083520 (2022)
8. "Full-shape cosmology analysis of the SDSS-III BOSS galaxy power spectrum using an emulator-based halo model: A 5% determination of σ8", Y. Kobayashi, T. Nishimichi, M. Takada, H. Miyatake, Phys. Rev. D 105, 083517 (2022)
9. "Proper motion measurements for stars up to 100 kpc with Subaru HSC and SDSS Stripe 82", T. Qiu, M. Takada, et al., MNRAS 501, 5149 (2021)