Statistical Analysis of Random Fields in Cosmology

Report of Contributions

https://conference-indico.kek.jp/e/250

Contribution ID: **1** Type: **not specified**

Opening

Monday, 4 March 2024 10:50 (10 minutes)

Contribution ID: **3** Type: **not specified**

Minkowski functionals for isotropic random fields in the Euclidean space and the sphere

Monday, 4 March 2024 13:20 (40 minutes)

We first introduce the expected Minkowski functional (MF) formulas for the excursion sets of a weakly non-Gaussian smooth isotropic random field. Here, the random field is defined on a bounded index set T in the Euclidean space. The MF formulas contain the boundary correction terms unless the MFs of the index set T vanish. In applications in cosmology, only their leading terms proportional to the volume of the index set T are often used, and the boundary effects are ignored. We numerically evaluate the effects of boundaries in typical settings and demonstrate the importance of boundary corrections.
Next, we discuss the isotropic (orthogonally invariant) random field on the sphere. We show that modifying the Euclidean case obtains the corresponding MF formulas. The resulting formulas are almost the same as the Euclidean case, and we see that the curvature information cannot be detected from the observed MFs.
(joint work with T. Matsubara and C. Hikage)

Presenter: KURIKI, Satoshi

Session Classification: Chair: Dan Cheng

Contribution ID: **4** Type: **not specified**

Application of Minkowski functional to high energy physics and deep learning

Monday, 4 March 2024 14:00 (40 minutes)

Presenter: NOJIRI, Mihoko

Session Classification: Chair: Dan Cheng

Contribution ID: **5** Type: **not specified**

Minkowski Tensors in Cosmology

Monday, 4 March 2024 15:00 (1 hour)

The tensor Minkowski functionals or Minkowski tensors (MTs) are generalizations of the usual Minkowski Functionals, which are scalar quantities. The MTs are a set of statistics defined as integrals over the boundary of an excursion set, with integrands related to symmetric tensor products of position vectors and normals to the boundary. They provide directional or anisotropy information that is not present in the scalar Minkowski functionals. Since 2017, the MTs have been used in cosmology. Efficient and accurate algorithms have been developed for calculation of MTs for analyses of cosmic microwave background radiation anisotropy on the surface of the celestial sphere, and matter and galaxy density fluctuations in 3D space or in 2D slice. Extensive studies have been made to examine the impacts of the nonlinear gravitational evolution, galaxy bias, and redshift space distortion on the MTs of large-scale structures in the universe. The recent developments in the application of the MTs in cosmology are reviewed.

Presenter: PARK, Changbom

Session Classification: Chair: Chiaki Hikage

Contribution ID: **6** Type: **not specified**

Precision cosmology with big data

Monday, 4 March 2024 16:10 (40 minutes)

Presenter: TAKADA, Masahiro

Session Classification: Chair: Yuji Chinone

Contribution ID: **7** Type: **not specified**

Weak lensing analysis

Monday, 4 March 2024 16:50 (40 minutes)

I'll describe the basics of weak lensing analysis.

Presenter: OGURI, Masamune

Session Classification: Chair: Yuji Chinone

Contribution ID: **8** Type: **not specified**

Data analysis methods for the Cosmic Microwave Background (CMB) polarization

Tuesday, 5 March 2024 09:30 (40 minutes)

Presenter: CHINONE, Yuji

Session Classification: Chair: Takahiro Nishimichi

Contribution ID: **9** Type: **not specified**

21cm cosmology with machine learning

Tuesday, 5 March 2024 16:50 (40 minutes)

Presenter: SHIMABUKURO, Hayato

Session Classification: Chair: Tsutomu Takeuchi

Contribution ID: **10** Type: **not specified**

Learning from Topology: Cosmological Parameter Inference from the Large-scale Structure

Tuesday, 5 March 2024 11:00 (1 hour)

A challenge common to different scientific areas is to effectively infer from big, complex, higher-dimensional datasets the underlying theory. Persistent homology is a tool in computational topology developed for recognizing the "shape"of data. Such topological measures have the advantages that 1) they are stable against experimental noise, 2) they probe multiscale, non-local characteristics of a dataset, 3) they provide interpretable statistics that encode information of all higher-point correlations. In this talk, I will focus on the applications of persistent homology to cosmological inference. I'll show how the constraints on primordial non-Gaussianities and cosmological parameters derived from persistent homologies are generally tighter than those from the redshift-space power spectrum and bispectrum combined. I'll also present a recent work in which we proposed a neural network model to map persistence images to cosmological parameters. Through a parameter recovery test, we demonstrate that our model makes accurate and precise estimates, considerably outperforming conventional Bayesian inference approaches. This provides a proof-of-concept that topological data analysis (via persistent homology) and machine learning can be combined for cosmological inference.

Presenter: SHIU, Gary

Session Classification: Chair: Takahiro Nishimichi

Contribution ID: **11** Type: **not specified**

Astronomy and Data Science

Tuesday, 5 March 2024 10:10 (40 minutes)

The importance of data science is increasing in various fields, and this trend is also evident in the natural sciences. For the past decade, I have been engaged in research applying data science methods to astronomy. One of the highlights of the work is the imaging of a black hole shadow by the Event Horizon Telescope Collaboration. In the presentation, I will provide an overview of my researches in astronomical data analysis, including the results of the EHT collaboration.

Presenter: IKEDA, Shiro

Session Classification: Chair: Takahiro Nishimichi

Contribution ID: **12** Type: **not specified**

Data Scientific Approach to the Large-Scale Structure in the Universe

Tuesday, 5 March 2024 14:00 (40 minutes)

Presenter: TAKEUCHI, Tsutomu

Session Classification: Chair: Atsushi J. Nishizawa

Contribution ID: **13** Type: **not specified**

Exploring the Potential of 3D Scene Reconstruction Techniques in Astronomy

Tuesday, 5 March 2024 15:00 (1 hour)

In recent years, technologies for reconstructing 3D scenes from limited 2D image data, such as Neural Radiance Fields (NeRF) and 3D Gaussian Splatting, have been actively developed. These technologies have gained attention in a wide range of applications, including VR/AR and Simultaneous Localization and Mapping (SLAM). This study explores the potential application of these technologies in the field of astronomy. Specifically, we focus on the possibility of reconstructing 3D dark matter distributions from 2D gravitational lensing data, discussing the feasibility and challenges of this approach. Our research presents new possibilities in the analysis of astronomical data and is expected to contribute to the advancement of related technologies.

Presenter: HIKAGE, Chiaki

Session Classification: Chair: Hayato Shimabukuro

Contribution ID: **14** Type: **not specified**

image based cosmology on the large-scale structure

Tuesday, 5 March 2024 16:10 (40 minutes)

After the great success of the perturbation theory of the large-scale structure, we definitely need more accurate and robust tools to expand the analysis to utilize more and more information embedded in the large-scale structure.
One possible approach which has already got great success is to extent the order of expansion to higher order or to use the interpolation method calibrated based on the set of numerical simulations.
Another approach recently proposed is not based on the summary statistics but on the field level inference, that is based on the "image".
In this talk, I will revisit the recent works based on the image of the large-scale structure, and discuss our recent cosmological analysis based on the machine learning methods.

Presenter: NICHIZAWA, Atsushi J.

Session Classification: Chair: Tsutomu Takeuchi

Contribution ID: **16** Type: **not specified**

Symmetry breaking in the large scale distribution of spin vector of galaxies?

Wednesday, 6 March 2024 15:40 (40 minutes)

We are compiling spin catalogs of galaxies from PanStarrs, SDSS, DES and HSC surveys to make statistical studies to search for any symmetry breaking in the large scale distribution of spin vectors of galaxies. The method and some tentative results of analyses will be reported.

Presenter: IYE, Masanori

Session Classification: Chair: Ken Osato

Contribution ID: **17** Type: **not specified**

Galaxy shape/alignment statistics as a novel cosmological probe

Wednesday, 6 March 2024 15:00 (40 minutes)

Mapping the large-scale structure of the universe with galaxy surveys is one of the main science drivers for cosmology. So far, most of the analysis has been made wth the galaxy positional information, ignoring the individual shapes and orientations. In this talk, we consider the galaxy intrinsic orientation (intrinsic alignment, IA) as a novel probe, and show that the spatial correlation of the IAs is beneficial to tighten cosmological constraints. Precision modeling of the IA statistics is thus very important, and we will present an improved model of the IA power spectrum, which properly takes into account the nonlinear effects of gravity and redshift-space distortions based on perturbation theory.

Presenter: TARUYA, Atsushi

Session Classification: Chair: Ken Osato

Contribution ID: **18** Type: **not specified**

Interpretable reduced modeling of large-scale pattern dynamics - from materials science to astrophysics -

Wednesday, 6 March 2024 11:00 (1 hour)

Presenter: MOTOTAKE, Yoh-ichi

Session Classification: Chair: Satoshi Kuriki

Contribution ID: **20** Type: **not specified**

How much information is left in galaxy clustering beyond the power spectrum?

Wednesday, 6 March 2024 13:20 (40 minutes)

Presenter: AKITSU, Kazuyuki

Session Classification: Chair: Atsushi Taruya

Contribution ID: **21** Type: **not specified**

Field-level inference with differentiable GridSPT

Wednesday, 6 March 2024 14:00 (40 minutes)

In galaxy clustering measurements, summary statistics, e.g., 2-pt correlation functions and power spectra, have been widely used to extract cosmological information. These statistics summarise the information of the observed galaxy number density field and theoretical models such as perturbation theory can accurately predict the statistics up to mildly non-linear regime. On the other hand, the statistics do not contain the full information of the observed field and, especially for non-linear fields, a large fraction of the information is not accessible solely from the statistics. In this work, we focus on the field-level approach that directly compares the observed field itself with the non-linear density field calculated by the forward modelling. To this end, we develop differentiable GridSPT, which is a forward modelling method based on standard perturbation theory and utilizes accelerated Fourier transforms and automatic differentiation with GPUs. This functionaltiy makes statistical inference more efficient and convergent. We discuss the validity of the field-level inference through reconstruction of the initial density field and cosmological parameters from non-linear density fields from N-body simulations.

Presenter: OSATO, Ken

Session Classification: Chair: Atsushi Taruya

Contribution ID: **22** Type: **not specified**

Consistency relations of the kurtosis in large scale structure and modified gravity

Wednesday, 6 March 2024 09:30 (40 minutes)

Skewness and kurtosis parameters are the quantities to probe non-Gaussianities of density fluctuations.
By introducing some spatial derivatives, we can define multiple skewness and kurtosis parameters.
We argue that the consistency relations among observables of the skewness and kurtosis parameters can be derived, particularly focusing on the kurtosis parameters in this talk.
The consistency relations can serve as a test of gravity theories.

Presenter: YAMASHITA, Sora

Session Classification: Chair: Kazuyuki Akitsu

Contribution ID: **24** Type: **not specified**

Banquet

Tuesday, 5 March 2024 18:00 (3 hours)

https://andryu.owst.jp/

Contribution ID: **25** Type: **not specified**

Photo

Tuesday, 5 March 2024 12:00 (5 minutes)

Contribution ID: **26** Type: **not specified**

Emulators for cosmological inference

Wednesday, 6 March 2024 10:10 (40 minutes)

Cosmological large-scale structure is a nonlinear stochastic process governed mainly by gravity. Its statistical properties depend on the initial conditions and the energy components that constitute the universe. Therefore, extracting information on these fundamental cosmological problems from observational data is an inverse problem. The computational cost of numerical simulations is a bottleneck in this problem setting. We discuss the use of emulators as a working example to replace simulations and alleviate this issue.

Presenter: NISHIMICHI, Takahiro

Session Classification: Chair: Kazuyuki Akitsu

Contribution ID: **27** Type: **not specified**

Non-Gaussian Statistics for Non-Gaussian Fields

Tuesday, 5 March 2024 13:20 (40 minutes)

I will present our recent results analyzing HSC weak lensing data using non-Gaussian statistics, where 30% improvement in cosmological parameter constraints was achieved. I will also summarize our ongoing effort in preparing for future non-Gaussian statistics analysis with Rubin LSST.

Presenter: LIU, Jia

Session Classification: Chair: Atsushi J. Nishizawa

Contribution ID: **28** Type: **not specified**

Peak height distributions of Gaussian random fields and their statistical applications

Monday, 4 March 2024 11:00 (1 hour)

Motivated by computing p-values for multiple testing of local maxima in signal and change point detections, we study the height distribution of local maxima of smooth isotropic Gaussian random fields parameterized on Euclidean space or spheres. The obtained formulae hold in general in the sense that there are no restrictions on the covariance function of the field except for smoothness and isotropy. The results are based on a characterization of the distribution of the Hessian of the Gaussian field by means of the family of Gaussian orthogonally invariant (GOI) matrices, of which the Gaussian orthogonal ensemble (GOE) is a special case. I will also present related statistical applications such as peak/signal detection in cosmology and change point detection.

Presenter: CHENG, Dan

Session Classification: Chair: Satoshi Kuriki

Contribution ID: **29** Type: **not specified**

Registration

Monday, 4 March 2024 10:20 (30 minutes)