@21cm cosmology workshop (2023/7/16-7/22)



21cm cosmology with machine learning



Hayato Shimabukuro(島袋隼士) (Yunnan university, Nagoya university)

21cm line emission

F

Years after the Big Bang



Brightness temperature (21cm signal)

$$\delta T_b = \frac{T_{\rm S} - T_{\gamma}}{1+z} (1 - \exp(\tau_{\nu}))$$

$$\sim 27 x_{\rm H} (1 + \delta_m) \left(\frac{H}{dv_r/dr + H}\right) \left(1 - \frac{T_{\gamma}}{T_{\rm S}}\right) \left(\frac{1+z}{10} \frac{0.15}{\Omega_m h^2}\right)^{1/2} \left(\frac{\Omega_b h^2}{0.023}\right) [\rm mK]$$

21cm line emission

We can map the distribution of HI in the IGM with 21cm line.



To describe 21cm signal statistically...

21cm global signal: Sky-averaged 21cm line signal

21cm line emission

We can map the distribution of HI in the IGM with 21cm line.



21cm line power spectrum

To describe 21cm signal statistically...

$$\langle \delta T_b(\mathbf{k}) \delta T_b(\mathbf{k}') \rangle = (2\pi)^3 \delta(\mathbf{k} + \mathbf{k}') P_{21}$$

Statistical challenge in 21cm cosmology



Astrophysics from 21cm upper limits



Shimabukuro+ (2023)

Applications of machine learning(ML)

Application of ML to 21cm studies

Hey, *ChatGPT*, Please tell me how we can apply ML to 21cm studies.

Please tell me the application of machine learning in 21cm studies

- Machine learning has various applications in 21cm studies, particularly in the field of cosmology and astrophysics. The 21cm line refers to the spectral line emitted by neutral hydrogen atoms at a wavelength of 21 centimeters, and it is used to study the early universe, galaxy formation, and large-scale structure. Here are some specific applications of machine learning in 21cm studies:
 - Image Reconstruction: The detection of the 21cm signal requires highly sensitive radio interferometers. Machine learning algorithms can be used to improve the quality of the reconstructed images from interferometric data. Neural networks, for example, can help in enhancing the resolution and reducing the noise in the reconstructed 21cm images.
 - 2. Signal Detection and Characterization: Identifying the faint 21cm signal amidst noise and foreground contamination is a challenging task. Machine learning techniques such as convolutional neural networks (CNNs) and support vector machines (SVMs) can be employed to develop automated algorithms for signal detection, classification, and characterization. These algorithms can aid in extracting valuable cosmological information from the data.
 - Data Analysis and Feature Extraction: Machine learning algorithms can assist in extracting relevant features from large datasets, including 21cm observations. By automatically identifying patterns and correlations in the data, machine learning techniques can help uncover hidden information and improve the efficiency of data analysis pipelines.
 - 4. Simulation and Modeling: Simulating the complex astrophysical processes involved in 21cm studies requires computational models. Machine learning can be used to enhance these simulations by training models on existing data and incorporating learned behaviors into the simulations. This approach can speed up the simulation process and provide more accurate predictions for different cosmological scenarios.
 - 5. Foreground Subtraction: One of the major challenges in 21cm observations is the presence of bright foreground emissions, which can mask the faint 21cm signal. Machine learning algorithms can be utilized to separate the foreground emissions from the desired signal, allowing for a cleaner extraction of the cosmological information encoded in the 21cm data.

S Regenerate response

1. Image reconstruction

2.Signal detection and characterization

3. Data analysis and feature extraction

4.Simulation and modeling

5. Foreground subtraction





Artificial Neural Network (ANN)



https://www.snexplores.org/article/explainer-what-is-a-neuron

21cm study + ML

•Emulator + MCMC -> parameter estimate

(e.g.) Kern+ (2017), Schmit+ (2018), Aviad+ (2020), Bevins+ (2021), Yoshiura+ (2023)

•Direct parameter estimate

(e.g.) **Shimabukuro&Semelin (2017)**, Gilet+ (2018), Nicolas+ (2019), Doussot+ (2019), Choudhury+(2020,2021,2022), Zhao+ (2022a,b), Vivekanand+ (2023)

•Distinguish EoR sources

(e.g) Hassan+ (2019)

•Others

(e.g.) Mertens+ (2017), Li+ (2019), Chardin+ (2019), **Yoshiura**+ (**2020**), **Shimabukuro**+ (**2022**), Bianco+ (2021,2023)

Parameter estimate (inverse problem)



Image > Parameters





(Gillet +2018)

21cm study + ML

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•Parameter estimate

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•Distinguish EoR sources

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•Others

(e.g.) Mertens+ (2017), Li+ (2019), Chardin+ (2019), **Yoshiura**+ (**2020**), **Shimabukuro**+ (**2022**), Bianco+ (2021,2023)

Recovering statistics from another statistics

•We can associate statistics with other statistics by the ANN. Can we recover statistics from anothe



Recovering statistics from another statistics



(Note) It does not mean 21cm PS contains beyond Gaussian information. Training enables us to connect a data space to another data space.

Bubble size distribution(BSD)

•Bubble size distribution(BSD) tells us the information on EoR sources, ionizing efficiency, radiative feedback, etc. We can measure BSD from 21cm image map.



Bubble size distribution(BSD)

We can directly compute 21cm power spectrum from visibility **without Inverse Fourier Transformation**.



Can we recover BSD from 21cm PS?

Recovering BSD from 21cm PS



Recovering BSD from 21cm PS



HS, Mao, Tan (2022)

Including thermal noise



Reconstruction of HI distribution from LAE

Output :

Yoshiura, HS +2021



Recovering statistics from another statistics

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HS and Mao, *preliminary*

Xin Zhang's talk

Our review paper

PASJ

Exploring the cosmic dawn and epoch of reionization with 21cm line

Hayato Shimabukuro¹*, Kenji HASEGAWA², Akira KUCHINOMACHI³, Hidenobu YAJIMA⁴ and Shintaro YOSHIURA⁵⁶



- ¹Yunnan university,SWIFAR,No. 2 North Green Lake Road, Kunming, Yunnan Province 650500, China
- ²Department of Physics and Astrophysics, Nagoya University Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8602, Japan
- ³Kumamoto University, Faculty of Advanced Science and Technology, Kumamoto, Kumamoto 860-8555, Japan
- ⁴Center for Computational Sciences, University of Tsukuba, Ten-nodai, 1-1-1 Tsukuba, Ibaraki 305-8577, Japan
- ⁵Mizusawa VLBI Observatory, National Astronomical Observatory Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan
- ⁶The University of Melbourne, School of Physics, Parkville, VIC 3010, Australia

Shimabukuro+(2023)



21cm cosmology + machine learning has big potential!



