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Collaborative Research: Large Scale Intensity Mapping of Neutral Hydrogen with the Tianlai Pathfinders

Cooperative Research and Development Agreement Final Report

CRADA Number: FRA-2017-0007

Fermilab Technical Contact: Albert Stebbins

Summary Report
26 March 2021

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In accordance with Requirements set forth in Article X of the CRADA, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

CRADA number: FRA-2017-0007

CRADA Title: Collaborative Research: Large Scale Intensity Mapping of Neutral Hydrogen with the Tianlai Pathfinders

Parties to the Agreement: University of Wisconsin and Fermi Research Alliance, LLC

Abstract of CRADA work:

This program developed new analysis methods for current and upcoming cosmological hydrogen 21cm intensity mapping data from the Tianlai experiment, located in a radio quiet area of Western China. Such mapping provides important clues to the evolution of gas and galaxies in the early universe. The experiment measured the three-dimensional large-scale structure of the universe via hydrogen emission from distant galaxies. The primary goal was to develop ways to handle the large foreground signal, which has been previously quantified in a pathfinder 21cm program conducted on NSF's Green Bank Telescope.

Summary of Research Results:

From this grant we have:

- Setup computer infrastructure at Fermilab for analyzing data from the Tianlai Pathfinder Array. This was used not only by co-I Stebbins at Fermilab but by faculty, postdocs and graduate students at the University of Wisconsin at Madison and Brown University. It is still in use.
- Installed **tlpipe**, the Tianlai analysis pipeline; then extended and modified it for own needs.
- Received and installed ~200 days of raw interferometer data.
- Analyzed some of this data to characterize a large number of properties of the Array (beam, shape, correlated noise, RFI, instrumental drifts, ...) as well as to understand the radio sky in our band and field of view. This "sky" was previously unexplored territory.
- Developed novel methods for filtering data to remove foregrounds to any 21cm signal.
- Used these methods to set upper limits on signal beyond smooth spectrum foreground sources. These upper limits from 10 days of data may be the best published upper limits

October 2, 2016

- This work was done in collaboration with at least 7 graduate students and 1 postdoc providing a mentoring opportunity for these young scientists. 21cm cosmology is a growing field of research. We hope the hands-on experience gained by these students will be used to further develop this field.
- Details of the results obtained are given in the publications cited below. There are several more papers in progress.
- This results from this grant form a basis for further research with the Tianlai Array, which is still operating, and we expect will detect the 21cm signal with longer observations.
- We hope the analysis techniques will prove useful for parallel efforts around the world.

Related Reports, Publications, and Presentations:

Zuo, Pen, Wu, Stebbins, Wang, Chen “*An Eigenvector-Based Method of Radio Array Calibration and Its Application to the Tianlai Cylinder Pathfinder*” The Astronomical Journal **157** 14 (2019) FERMILAB-PUB-18-340-A

Zuo, Li, Li, Santanu, Stebbins, Masui, Shaw, Zhang, Wu, Chen “*Data Processing Pipeline for Tianlai Experiment*” Astronomy and Computing **34** 100439 (2021) FERMILAB-PUB-20-141-A

Li, Zuo, Wu, Wang, Zhang, Sun, Xu, Yu, Ansari, Li, Stebbins, Timbie, Cong, Geng, Hao, Huang, Li, Li, Liu, Liu, Liu, Marriner, Niu, Pen, Peterson, Shi, Shu, Song, Tian, Wang, Wang, Wang, Wang, Wang, Yu, Zhang, Zhu, Zhu, Chen “*The Tianlai Cylinder Pathfinder array: System functions and basic performance analysis*” Science China: Physics Mechanics Astronomy **63** 129862 (2020) FERMILAB-PUB-20-182-A

Li, Zuo, Chen, Das, Marriner, Oxholm, Phan, Stebbins, Timbie, Ansari, Campagne, Chen, Cong, Huang, Li, Liu, Liu, Niu, Osinga, Perdureau, Peterson, Shi, Siebert, Sun, Tian, Tucker, Wang, Wang, Wang, Wu, Xu, Yu, Yu, Zhang, Zhang, Zhu “*The Tianlai Dish Pathfinder Array: design, operation and performance of a prototype transit radio interferometer*” preliminarily accepted by Monthly Notices Royal of the Astronomical Society (2021)

Presentations (Stebbins)

2017-11-14 “*Tianlai Cosmic Vision*” Cosmic Visions Workshop, LBNL

2018-04-20 *Strategic Planning for 21cm Cosmology Astrophysics Mini-Retreat*, FNAL

2018-11-14 *Adventures in Hydrogen Intensity Mapping* Universitat de València, Spain

2018-11-30 *Adventures in Hydrogen Intensity Mapping* École Normale Supérieure, Paris

2019-01-15 *Adventures in Hydrogen Intensity Mapping* University of Melbourne: Physics

2019-02-21 *Finding 21cm Faster* Flatiron Institute: Center for Computational Astrophysics, NYC

2019-12-11 *Mapping the Observable universe with 21cm* CoSyne, Institut d’Astrophysique de Paris

2020-08-18 *Status of the Tianlai Pathfinder Arrays* PUMA Workshop

2020-12-10 *Tianlai Dish Array and Analysis* 21cm Science Mini-Workshop

2021-03-18 *Spectral Smoothness from Tianlai Dish Array* Precursor View of the SKA Sky

Subject Inventions listing:

None

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