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Imaging Simulations of the Tianlai Cylinder Pathfinder Array

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The Tianlai cylinder array is a pathfinder for developing and testing 21cm intensity mapping techniques. It consists three parallel and adjacent cylinder reflectors, each 40 meter long and 15 meter wide, with the long axis oriented in the North-South direction. The three cylinders are equipped with 31, 32 and 33 dual linear-polarization receiver feeds in the center section. The instantaneous field of view is a long strip of sky along the meridian. As the Earth rotates, the sky is surveyed with drift scan. The telescope is located at 91° 48' E, 44° 09' N, near Hongliuxia, Balikun County in Xinjiang, China. The observation is at present carried out in the 700-800 MHz band [1].

In this paper, we use numerical simulation to assess how its imaging is affected by thermal noise, calibration errors, and the error in map-making process. The beam is modelled by fitting to the electromagnetic simulation of the antenna, and the variations of the complex gains of the array elements are modelled by Gaussian processes. We generate mock visibility data and run it through our data processing pipeline. We find that the error of the current calibration is dominated by the absolute calibration, coming mainly from the approximation of a single dominating point source [2].

We then studied the m-mode map-making process, considering both the Moore-Penrose inverse, and regularization methods such as the Tikhonov regularization [3]. The former generates visible artifacts in the map when modes with singular values smaller than a threshold are discarded. The angular power spectrum of the reconstructed map show that the current Tianlai cylinder pathfinder, which has a shorter maximum baseline length in the North-South direction, can measure modes up to $l \lesssim 200$ very well, but would lose a significant fraction of higher angular modes when noise is present. These results help us to identify the main limiting factors in our current array configuration and data analysis procedure, and suggest that the performance can be improved by reconfiguration of the array feed positions.

Finally, we also discuss briefly the cross-couplings and its mitigation in the Tianlai array.

1. Li, J., Zuo, S., Wu, F., et al. 2020, Science China Physics, Mechanics, and Astronomy, 63, 129862

2. Kaifeng Yu, Fengquan Wu, Shifan Zuo, Jixia Li, Shijie Sun, Yougang Wang, Xuelei Chen, 2023, Research in Astronomy and Astrophysics, 23, 105008, arXiv:2308.04931

3. Kaifeng Yu, Shifan Zuo, Fengquan Wu, Yougang Wang, Xuelei Chen, 2023, "Application of Regularization Methods in the Sky Map Reconstruction of the Tianlai Cylinder Pathfinder Array", RAA accepted, arxiv:2312.01064