Tianlai: a 21cm radio telescope array for BAO and dark energy, status and progress

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The Tianlai project is a 21cm intensity mapping experiment dedicated to the survey of the neutral hydrogen in the Universe below redshift 3. Through this survey, one could probe the large-scale structure and detect baryon acoustic oscillation (BAO) features to constrain dark energy models. The construction of the Tianlai cylinder and dish pathfinder arrays have been completed at the end of 2015, the two arrays are now undergoing the commissioning process.

1 Introduction

The 21cm radio emission comes from the transition between the two levels of the hydrogen 1s ground state, slightly split by the interaction between the electron spin and the nuclear spin. The splitting is known as hyperfine structure. As the neutral hydrogen constitutes about 3/4 of the baryonic matter in the Universe, these 21cm emissions provide a very useful tool to probe the universe. Radio observations usually suffer the problem of low angular resolution, but it has been proposed that the large-scale structure of the universe can be surveyed without resolving individual galaxies[1,2]. The hydrogen distribution follows cosmic density field on large scales, so the 21cm intensity fluctuations can be used to measure the power spectrum of matter fluctuations. From the power spectrum of matter fluctuations, one could detect the baryon acoustic oscillation (BAO) wiggles. The BAO wiggles could provide a "standard ruler" for distance measurement in cosmology and help us to understand the acceleration of the Universe and the nature of dark energy which causes such acceleration.

The Tianlai project is a pathfinder for testing the basic principles and key technologies of 21cm intensity mapping[3,4]. The project is an international effort with participants from China, France, the USA and Canada. Telescopes are built in a radio very quiet site in Balikun, Xinjiang, China[5], consist of 3 cylinders(15m wide and 40 m long) and 16 dishes(6m diameter) at present. A forecast for the capability of the cylinder array in constraining dark energy parameters and primordial non-Gaussianity can be found in Xu et al. (2015) [6].

2 Status and Progress

The construction of the Tianlai cylinder and dish pathfinder arrays (see Fig.1: left panel) have been completed at the end of 2015, the two arrays are now undergoing the commissioning process. The cylinder array includes three adjacent 15m long 40m wide cylindrical reflectors oriented in the North-South direction, equipped with 96 dual linear-polarization feeds(see Fig.1: right panel). These feeds could be moved freely along the guide rail. This allows people to

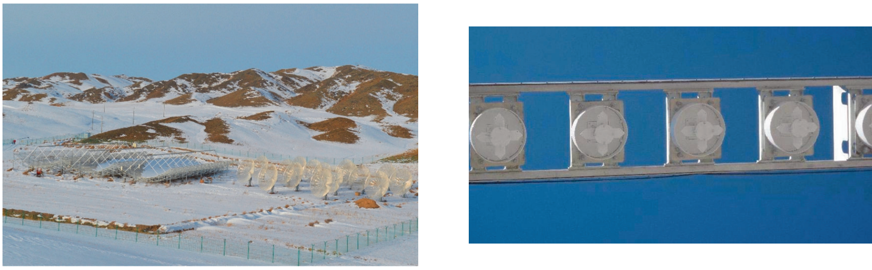

Figure 1 – Left: Tianlai cylinder array and dish array. Right: feeds on cylinder antenna.

change the separation between the feeds flexibly. Next to the cylinder array, there is also a dish pathfinder array, with 16 dishes of 6m diameter, each equipped with a dual linear-polarization feed. These dishes are equipped with electronically controlled motor drives in the altitude-azimuth mount, which allow us to steer the dishes to point to almost any desirable directions above the horizon.

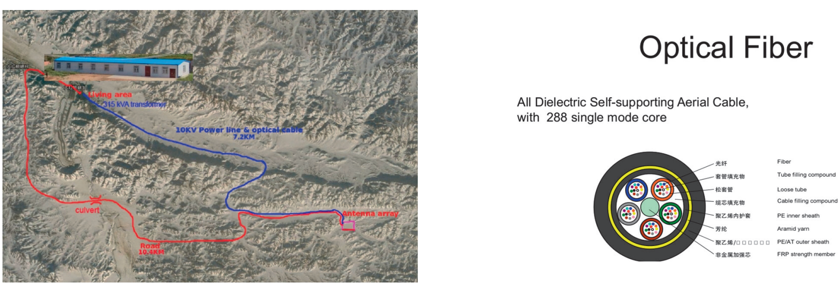

Figure 2 – Left:map of living area and antenna site. Right: sketch of optical fiber with 288 cores.

The antenna arrays are located in a sparsely populated area, shielded by hills and accessible only through a dirt trail. To avoid self-inflicted radio frequency interferences (RFI), the station house is built at the Hongliuxia village, which is about 8 km away as the crow flies. The array are connected with the station house by a 288-core optical fibre cable for signal transportation and a 10kV power line for electricity. (see Fig.2).

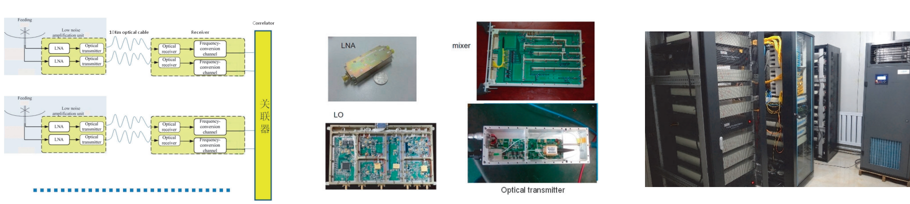

Figure 3 – RF analog system. Left: schematic of analog system. Center: LNA, mixer, LO and optical transmitter. Right: analog-system room.

The density evolution of the Universe is very sensitive to the dark energy below redshift 2.5. This redshift range corresponds to frequency of 400-1420MHz for 21cm emission. Therefore, the Tianlai array receivers are designed to have broad band response (400-1500MHz), and there is a replaceable bandpass filter in front of receiver which has 100 MHz bandwidth and very high rectangle coefficient(30dB:3dB <2). This enables us to switch the observation frequency easily. A schematic of the RF analog system is shown in Fig.3. The incoming radio wave is focused by the cylinder reflector, picked up by the feed, and amplified by the low noise amplifier (LNA) mounted on the back of the feed can. The LNA is design to have low noise temperature (about 35K at room temperature) and wide operating frequency range(400-1500MHz). Then through the 3-layer shielded radio frequency (RF) cable, RF signal is sent to the optical transmitter under the antenna. Via optical transmitter, RF signal is converted to optical signal, which is then transmitted to the station house via optical fiber. In the RF analog system room in the station house, the optical signal is converted back to the RF electric signal, then in the mixer the RF signal is converted to the intermediate frequency (IF) band. Finally, the IF signal is sent to digital system in the next room through bulkhead connectors between the analog and digital systems (Fig.4 Right panel).

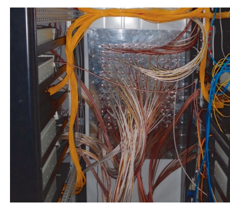

Figure 4 – Digital system(Left) and bulkhead connectors between analog and digital system(Right).

The digital backend system (Fig.4) has 200 signal channels, and it consists of three subsystems: (1) the analog to digital converter (ADC) and FPGA, which perform an fast Fourier transform (FFT) of the time series data and send the frequency domain data to a switch board; (2) the switch board system, with a rapidIO switch which connects the FPGA acquisition system and the DSP correlation system, the data of the same frequency but from different input channels are collected in the same unit for cross-correlation computation; (3) the DSP computing boards which computes the correlations. The sampling rate of the system is 250MSPS, with 14 bits sampling length.

The calibration system is very important, especially for the phase difference induced in the transmission of the data. The absolute calibration could be done by celestial calibration sources. We develop a set of relative calibration system by using the noise source controlled by the correlator. A schematic diagram for the noise source calibration system could be found in Fig.5.

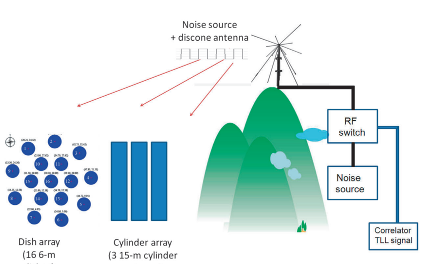

Figure 5 – Schematic diagram for noise source calibration system(Left) and calibration antenna on the hill beside the antenna array(Right).

3 Conclusion

The Tianlai pathfinder has both a cylinder array, with 3 north-south oriented cylinders of 15m wide, 40m long, and also a 16 dish array, with 6m dishes, which are dedicated to study new technique for 21cm intensity mapping. In the future the cylinder array may be expanded to $100m^2$ and thousands of receiver units. The construction of the Tianlai cylinder and dish pathfinder arrays have been completed by the end of 2015, the two arrays are now undergoing the commissioning process. A lot of adjustments and tests will be made during this year. Formal observation will probably start at the end of 2016, and may last a few years while we try to collect and analyse the data. By running this small experiment, we will be able to identify possible problems, make improvements, and try various methods of data analysis. Hopefully, the results of this experiment will pave the way for precision measurement of dark energy using radio observations.

Acknowledgments

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References

1. T. Chang, U. Pen, J. B. Peterson, P. McDonald, Baryon Acoustic Oscillation Intensity Mapping of Dark Energy, Physical Review Letters 100, 1303(2008)
2. J.B. Peterson, et al., 2009, 21 cm Intensity Mapping, White Paper for the Astro2010 Astronomy Decadal Review, arxiv:0902.3091
3. Xuelei Chen., 2012, 090008The Tianlai project: a 21cm cosmology experiment090009, International Journal of Physics Conference Series, 12, 256, proceeding of the 2nd Galileo-Xu Guangqi Meeting (2009)070302 arxiv:1212.6278
4. Xuelei Chen at. al. Tianlai: A 21cm intensity Mapping Experiment, Proceedings of the XXXIst URSI General Assembly and Scientific Symposium
5. Fengquan Wu at. al. Site Selection for the Tianlai experiment, Proceedings of the XXXIst URSI General Assembly and Scientific Symposium
6. Xu Y., Wang X., Chen X., Forecasts on the Dark Energy and Primordial Non-Gaussianity Observations with the Tianlai Cylinder Array, ApJ, 798, 40 (2015)