21 cm intensity mapping: the Tianlai Project

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The Tianlai project is a 21-cm intensity mapping experiment which is aimed at surveying the large-scale structure and use its baryon acoustic oscillation features to constrain dark energy models. The pathfinder of the Tianlai array has been built, which includes three cylinders and sixteen dishes. In this talk, we will give a review of the Tianlai experiment.

1 Introduction

Baryon acoustic oscillations (BAO) are a feature imprinted on the cosmic microwave background and the large-scale structures in the late universe by acoustic waves traveling in the plasma prior to the recombination epoch. The comoving characteristic scale of the BAO is determined by the sound horizon at the last scattering surface. The BAO scale can be taken as a standard ruler to measure the angular diameter distance and the Hubble parameter $H(z)$, and hence to constrain the cosmological parameters. This technique has successfully been used to place cosmological constraints of dark energy parameters from optical surveys by using different tracers, such as the Luminous Red Galaxies [1], the main Galaxy sample [2], the quasar sample [3], the Lyα-Forests [4] et al.

In addition to the optical surveys, the radio observations of the 21cm line from the neutral hydrogen can also been used to detect the BAO signal. One direct way is to detect the 21cm signal from the signal galaxy in the low redshift, but it is difficult to resolve the single galaxy by using the small singe dishes, such as Green Bank Telescope (GBT) and the Parkes telescope. In the high redshift ($z > 10$) it is impossible to resolve the single even by using the Square Kilometer Array (SKA). Instead by observing the single galaxy one could observe the 21cm

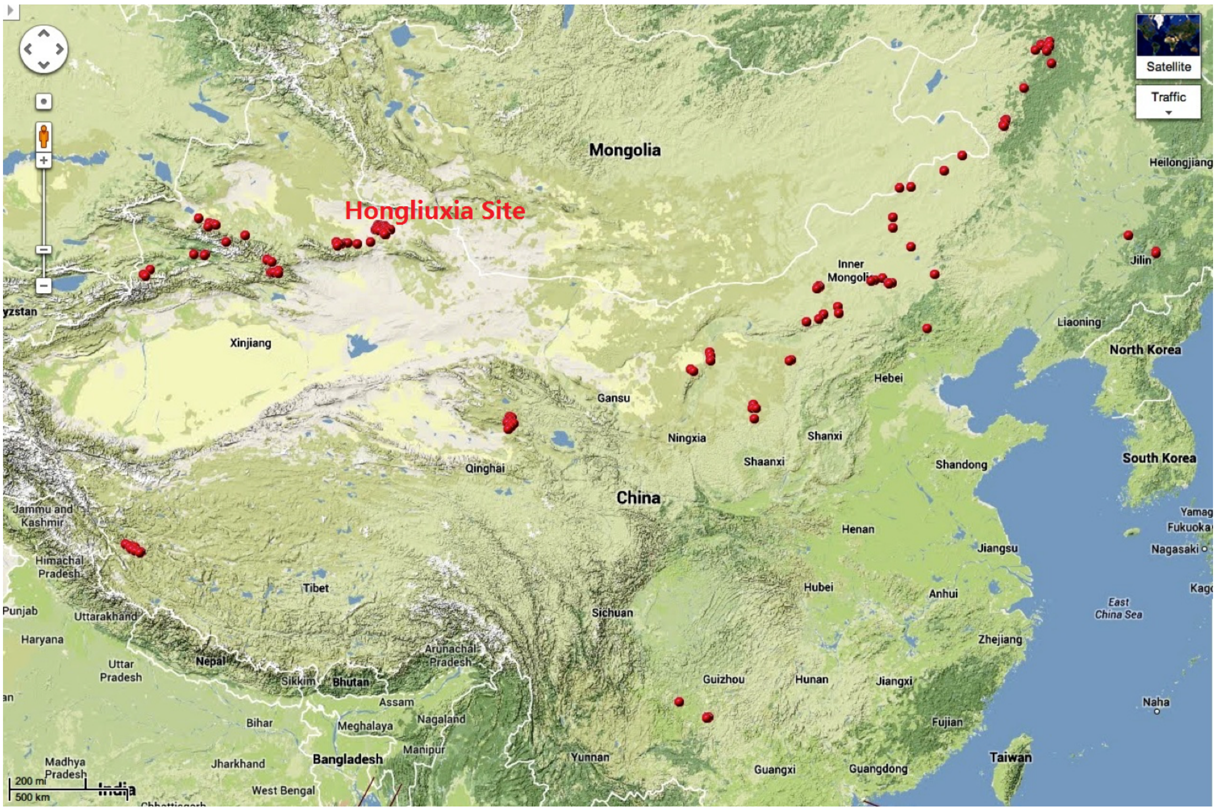

Figure 1 – The candidate sites for the Tianlai experiment. The Hongliuxia Site in the right top of the figure is the site for the Tianlai experiment.

signal in the intensity mapping mode, in which each pixel or voxel contains many galaxies. The method of the intensity mapping has been tested by the GBT and the Parkes telescope [5] [6] [7]. However, the time available and the survey speed are limited in these general purpose telescopes. The cylindrical reflector can be cheaply made and used to do the 21cm survey experiments [8].

The Tianlai 21 cm intensity mapping experiment is majorly aimed at surveying the northern sky 21cm intensity at mid-redshifts and use its BAO features to constrain dark energy models. The experiment is named “Tianlai” which means “heavenly sound” in classic Chinese. This phrase first appeared in the work of the ancient Chinese philosopher Chuang Tzu (369BC-286BC). In addition to the redshifted 21 cm intensity mapping, the Tianlai experiment can also be used for other observations, such as 21 cm absorber, fast radio burst, and electromagnetic counter part of gravitational wave events.

2 Site selection

Since the signal of the 21 cm in the sky is weak, a site with low radio frequency interference (RFI) is desired. Our primary aim is to observe the 21 cm signal from 400 MHz to 1.4 GHz, the main source of RFI at this frequency range is mobile phone signal and TV broadcasting. The RFIs can not be completely avoid, but if their strength is not too strong as to saturate or distort the output of the amplifier, it is possible to remove them with the post processing.

The ideal site for the Tianlai experiment is a terrain with mountain surrounding a $150m \times 150m$ flat land. Moreover, it is nice to have good logistic support, including road, electricity, communication networking and the geological structure is stable. We have measured the electromagnetic environment for more than 200 possible sites in Xijiang, Guizhou, inner Mongolia, Qinghai, Jilin, Tibet provinces in China. Figure 1 shows the candidate sites for the Tianlai experiment.

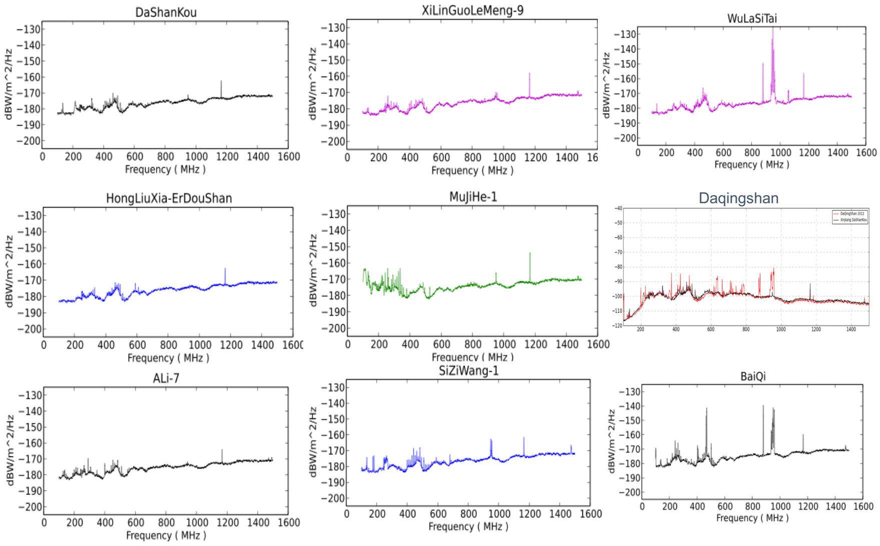

Figure 2 – The electromagnetic environment for nine possible sites. The blue line in the middle left panel is the result for the Hongliuxia site.

In Figure 2, we show the results electromagnetic environment of the nine possible sites. It is the seen that three sites (in left panels of this figure), Dashankou, Hongliuxia, and ALi-7 have the relative low RFI. Considering various factors, we have decided to take the Hongliuxia site as our experiment site.

In order to avoid to avoid the RFIs from the living area and from the receiver system itself, we put the living area and the antenna array in two different regions. The arrangement of the site can be found in Figure 3. The distance between the living area and the antenna array is ~ 7 km. There is a 10.2 km load which we can use to give round trip between two regions.

3 The pathfinder of the Tianlai experiment

To resolve the BAO peaks, compact inteferometer arrays with longest base line of about a hundred meter seems to be a good compromise. The fully-scale Tianlai experiment will consist of eight adjacent cylinder, each 15m wide and 120 m long, with a total of about 2000 dual polarization units covering the frequency range of 400-1420 MHz, corresponding to the redshift from 0 to 2.5. At present, a pathfinder experiment has been built in a radio quite site at Hongliuxia, Balikun County, Xinjiang Autonomous Region, China. The pathfinder experiment consists both of a cylinder array and a dish array (see Figure 4). The Tianlai pathfinder cylinder array (hereafter TPCA) is made of three adjacent cylindrical reflectors oriented in the North-South direction, each 15 m wide and 40 m long. The PCA has 96 dual polarization receives which do not cover the full length of the cylinders. In order to avoid the grating lobe problem, receivers are distributed irregularly in the array. Receiver numbers in three cylinder reflectors are 31, 32 and 33, respectively. The receivers occupy 12.4 m along North-South direction on each cylinder. We refer the interested reader to Zhang et al. (2015) [11] for more details about the arrangement of the receivers.

The Tianlai pathfinder dish array consists 16 dishes with 6 m diameter. These dishes are equipped with the electronically controlled motor drives in the altitude-azimuth mount, which allows the dishes to be pointed to almost any desirable directions above the horizon. The distribution of the Tianlai pathfinder dish array is shown in the bottom left of Figure 6.

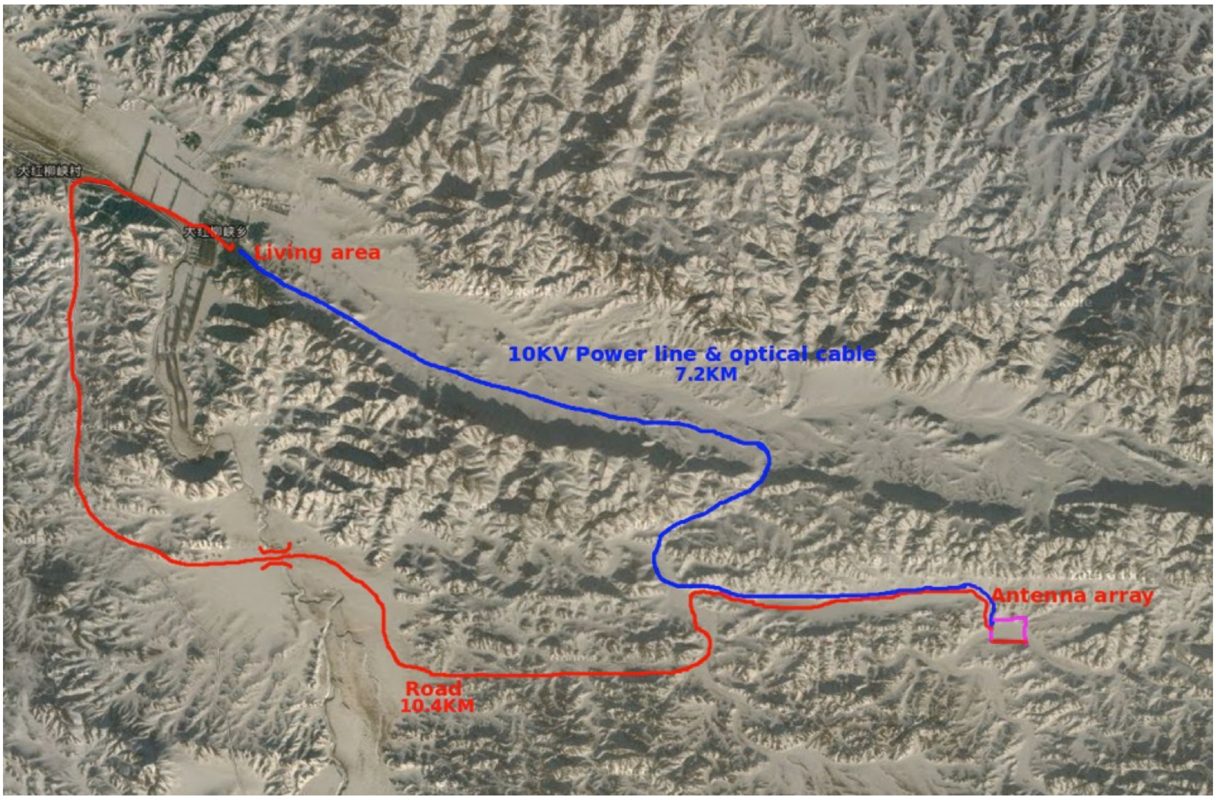

Figure 3 – The arrangement of the Tianlai site.

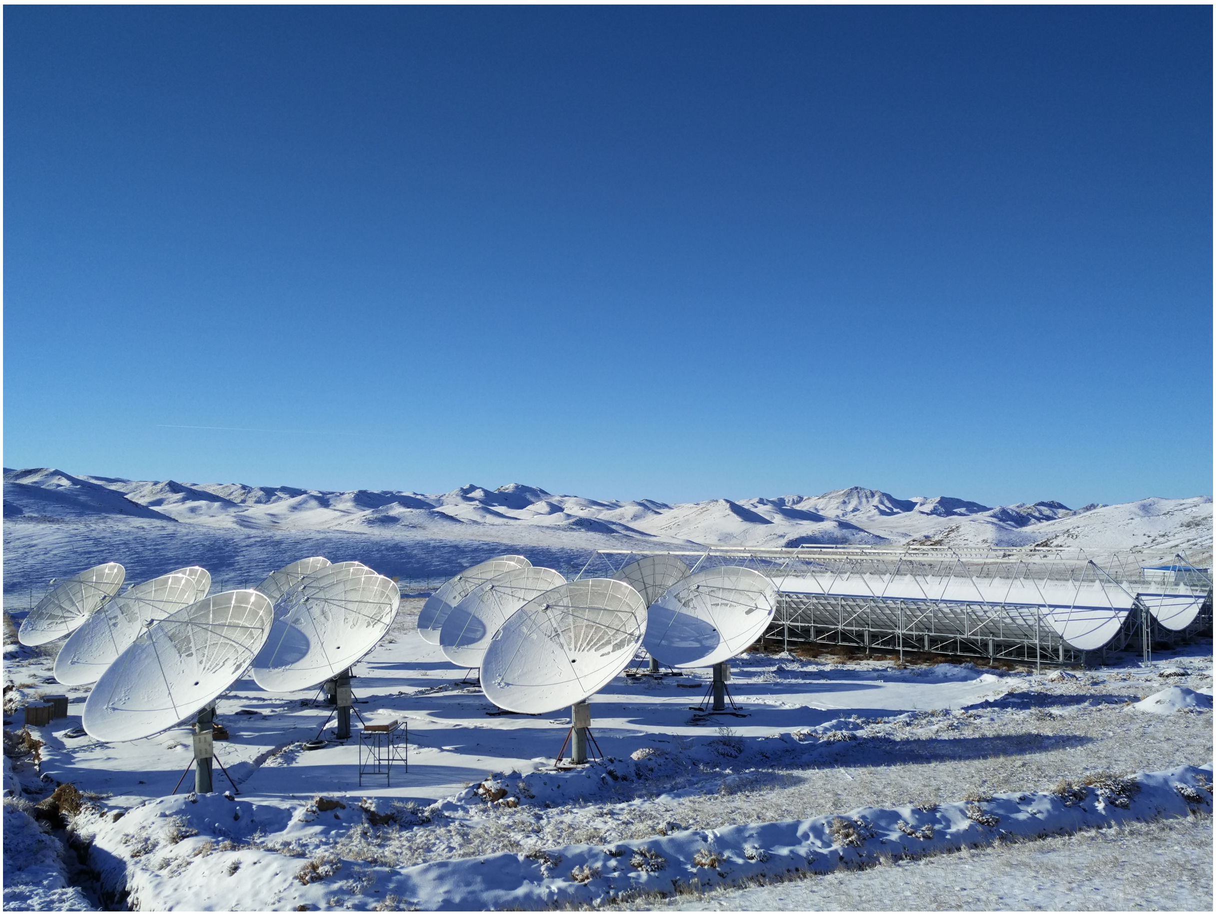

Figure 4 – The pathfinder of the Tianlai experiment

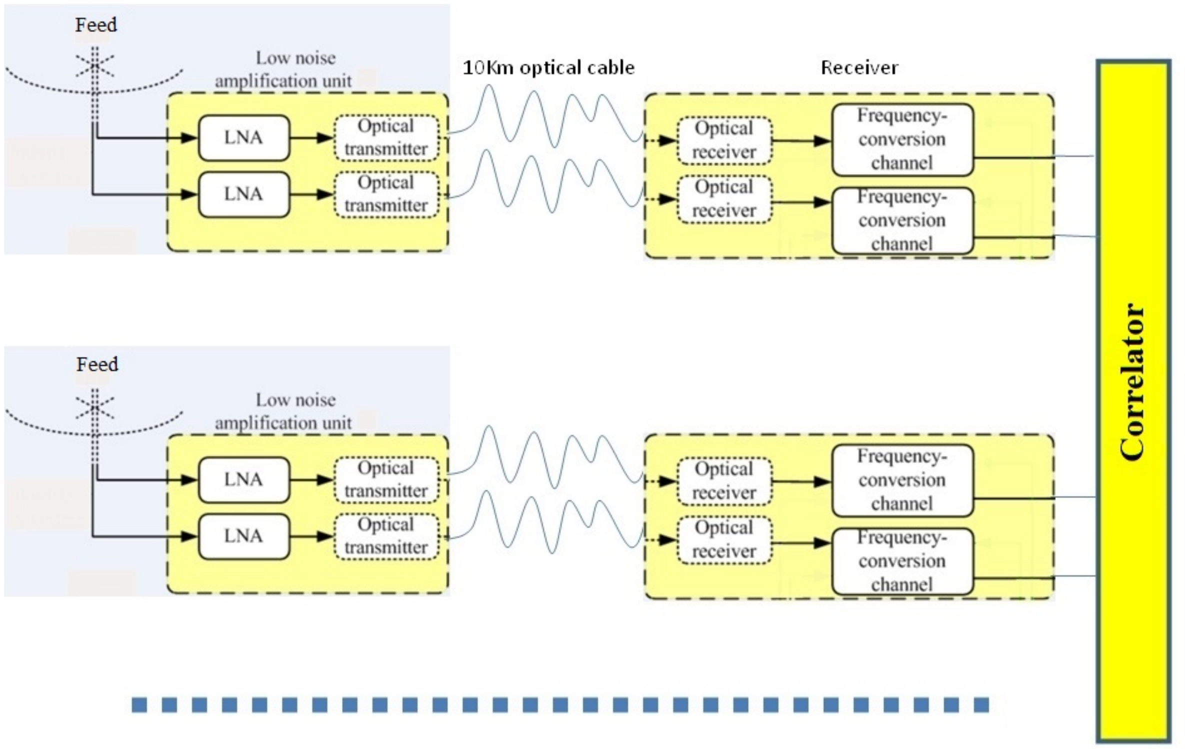

Figure 5 – The receiver chain for the Tianlai pathfinder experiment.

In Figure 5, we show a schematic of receiver chain for the Tianlai pathfinder experiment. The incoming radio wave is reflected by the reflector, picked by the feed, then amplified by the low noise amplifier (LAN). The signal then comes into the optical transmitter, and is transferred by the 7.2 km long optical cable to the optical receiver. Optical receiver is located in the station house, it transforms the optical signal back to RF signal, then RF signal is fed into the frequency downconverter and correlator, eventually correlator dumps the visibility data to storage.

4 Calibration

The strong radio sources Cygnus A, Cassiopeia A and Crab Nebula can be used to calibrate the amplitude and phase for the Tianlai pathfinder experiment. The method we used here is the principal component analysis (PCA) [12]. Since the PCA is fixed, these radio source locating in the file of the PCA are only several ten minutes. Therefore, we design a dedicated noise source calibration system to do relative phase and amplitude calibration. Noise source is thermostatic and supplied by high stable linear DC power to ensure the stability of amplitude. The on-off pace of noise source is controlled by the correlator 8-km away on station house through optical fiber. Schematic diagram for noise source calibration system could be found in Figure 6.

5 First light

On September 27, we get the first light of the TPCA. In the middle panel of Figure 7, we show the point source in the sky map in the TPCA observations from September 27 to 30, 2016. It is found that the positions of point sources in TPCA are consistent with those in the NASS surveys (left panel of Figure 7), which indicates our receiver system works well. We find that the Sun has strong effect on the sky map. If we only use the night data, then the bright tails in both left and right parts of the sky map from all day data (middle panel of Figure 7) disappear (see right panel of Figure 7). Even in the sky map of the night data, we still can see several bight

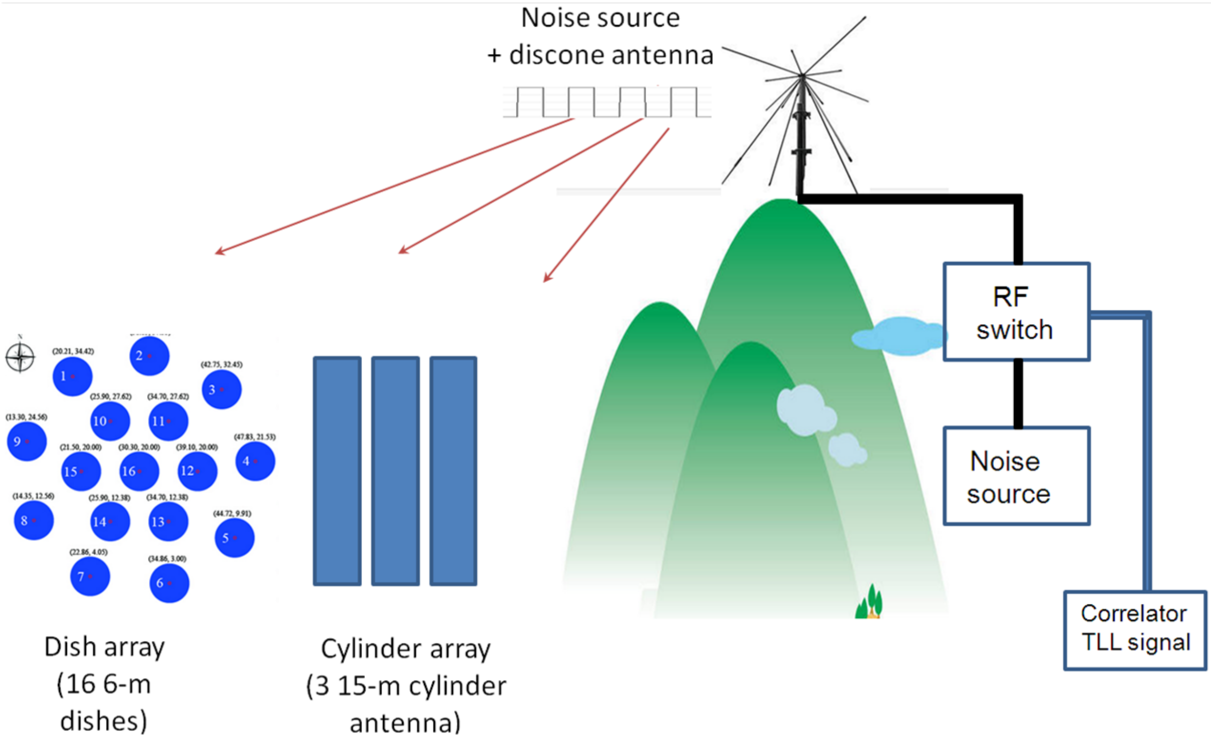

Figure 6 – Schematic diagram for noise source calibration system.

tails, they are the foreground from the Milky Way (MW). Therefore, removing the foreground of the MW is an import step to obtain the real 21 cm signals. We have used the Singular-Value-Decomposition method to remove the foreground in the GBT and Parkes intensity map data. We will try other methods and improve them in the foreground removing.

6 Future plan

At present, the Tianlai pathfinder experiment has acquired more than 400 Terabyte data. In the future, we will continue to obtain the data and improve the data analysis, with more careful analysis of the data quality and RFI removal. We will also do the polarization calibration.

The large field of view of Tianlai telescope make it an idea telescope to do FRB search. In 2018, we will start to make a 32-channels FRB search backend, and it will be extended to 192-channel FRB system in near future. FRB system will comprise three parts: acquisition system, beam forming system, and de-dispersion and storage system. Acquisition and beaming is realized by a FPGA base hardware, de-dispersion system is based on GPU and CPU system. The FRB search system is designed to reach a time resolution better than 1 milli-second.

7 Acknowledgments

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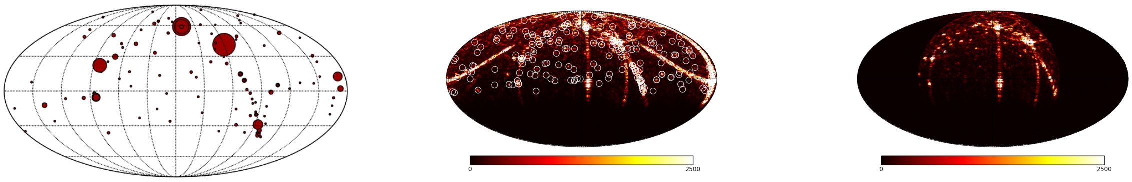

Figure 7 – NVSS (1.4 GHz) sources (>5Jy) (left), point source with all three day maps from TPCA and rotated (middle), and the sky map only from the night data in TPCA (right).

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