Tianlai project overview

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1 Introduction / executive summary

J. Peterson 10 lines

2 Science case : Dark energy/ BAO - 21 cm intensity mapping

Summarizes the following subsections in 1-2 pages (X. Chen & Peter Timbie

Our ultimate goal is to map cosmic structure over 1/2 of the sky out to $z = 3$. The scientific target are described below.

2.1 Distribution of Neutral Hydrogen

Critical to reaching the cosmological goals described below is first to improve our understanding of the distribution and evolution of hydrogen in the universe. At redshifts from $0 < z < 1$ the global neutral fraction of hydrogen has been determined using measurements of damped Lyman-alpha systems. These studies find $\Omega_{HI} \sim 1 - 2 \times 10^{-3}$ with little variation across this redshift range [?, ?]. The fact that substantial neutral gas is present at $z \sim 1$ is important, since the global star formation rate was then three to ten times higher than today. We know from these observations that neutral gas survives the high UV flux at $z \sim 1$ and that surveys using 21 cm emission are viable at redshifts up to 1, and presumably beyond that [?]. However, prior to our work at GBT, 21 cm emission had only been detected directly out to $z = 0.37$ [?]. Members of our team recently detected HI at $z \sim 0.8$ via cross-correlation of an HI map with optical galaxy surveys[?, ?]. Our intensity mapping technique detects widely distributed emission that previous surveys miss, allowing a more detailed understanding of the evolution of neutral gas density. HSA will provide the first all-sky intensity maps of 21 cm emission across a region that has also been surveyed optically.

2.2 Large Scale Structure

Observation of 21 cm fluctuations provides a tool for understanding structure formation in the post-reionization era. These HI regions presumably trace the dark matter and hence can be used to study the evolution of the matter power spectrum which in turn can be used to determine a variety of cosmological parameters. Loeb and Wyithe [?] emphasize that these surveys can sample an enormous volume - - a survey of the full sky out to $z = 6$ includes $\sim 20\%$ of the comoving volume of the observable universe. As a result, they can measure more than two orders of magnitude more independent modes than can present methods. A cosmic variance-limited measurement of the power spectrum from such a survey could detect the signature of neutrino mass at the 0.05 eV level.

2.3 Dark Energy

Multiple lines of observational evidence now indicate that dark energy accounts for $\sim 70\%$ of the energy density in the universe, but so far we have few clues to the physics underlying this phenomenon. To proceed, we need a new class of cosmological observations specifically designed to measure the equation of state of dark energy to distinguish between a host of dark energy models. The community, as represented by the Dark Energy Task Force, expects [?] four techniques to be particularly powerful: Baryon Acoustic Oscillations (BAO), Type Ia supernovae luminosities, cluster counts, and weak gravitational lensing.

Of these four techniques, BAO has emerged as the most robust against potential systematic effects. Acoustic oscillations in the early universe (when photons, electrons, and protons were tightly coupled) have been detected in the form of peaks and troughs in the spectrum of anisotropies in the cosmic microwave background [?]. The characteristic scale which defines the oscillations is the sound horizon at recombination: ~ 150 Mpc (comoving). Since we know the underlying physical scale, observing this feature in the correlation function of galaxies in both the radial and angular directions allows one to measure the angular diameter distance and the Hubble expansion rate. To date, the BAO feature has been detected [?] in the ground-based Sloan Digital Sky Survey (SDSS) in the Large Red Galaxy sample centered at $z \sim 0.35$ as well as with the 2df survey[?].

Our program will measure BAO features from the ground with a 21 cm intensity mapping instrument, and use this data to constrain the properties of dark energy. The recent report of the Dark Energy Task Force advising DOE/HEP [**?**] mentions 21 cm BAO observations as a promising technology, but 21 cm systems are not at a cost level that justifies DOE investment. The 21 cm technique will augment other dark energy experiments by providing a dark energy test with very different sources of systematic error. We can provide this at a small fraction of the cost of other proposed programs.

2.4 Intensity Mapping of 21 cm Emission

Intensity mapping provides a way to economically map huge cosmic volumes in three dimensions. Previously, the only known way to obtain a 3-D map of the structure in the universe was via galaxy redshift surveys, that is, by isolating millions of individual galaxies, recording spectra for each and determining each redshift. This has been done primarily using optical spectroscopy. Dedicated telescopes are being considered to extend such programs to larger volumes of the Universe (LSST, WFIRST). Members of this team, and others, have proposed a new strategy: measuring the collective emission of many unresolved galaxies in the 'cosmic web' without individual detections. We call this technique 'intensity mapping'[**?**]. Since the large scale structure and BAO features we wish to study are tens to hundreds of Mpc (comoving) across, the 21 cm telescope can be designed with the resolution to detect these structures, rather than to detect individual galaxies at high redshift. To carry out a 21 cm galaxy redshift survey, rather than an equivalent intensity mapping survey, would require roughly one hundred times as much telescope collecting area.

High sensitivity to three-dimensional specific intensity is achieved by using a telescope with a high aperture fill factor. Single dish telescopes offer this, as do compact arrays. However, most radio telescope arrays are designed for high angular resolution, at the expense of brightness sensitivity. Telescopes like VLA, GMRT and ATA are too dilute to offer the best possible intensity mapping sensitivity.

Members of our team have used intensity mapping to detect large-scale structure in neutral hydrogen at redshift ~ 0.8 [**?**, **?**]. Radio observations at the GBT were correlated with the DEEP2 optical galaxy redshift survey. More recently we have used the GBT to detect cosmic structure in the WiggleZ 15 hour field (Figs. **??** & **??**). We have applied for additional time on the GBT and are designing a focal plane array (4 - 9 elements) for it in the 700-950 MHz band with support from NRAO and ASIAA. With a significant investment of GBT observing time such a small array can measure the BAO signal near $z = 1$. However, to accurately measure the power spectrum to the limits of cosmic variance will require a dedicated interferometer like HSA.

3 Instrument concept & Array configurations

The instrument we plan to build is a radio interferometer array, operating in the GHz range. It will consist of a nearly filled array of $\sim 100 - 1000$ receiver elements, covering an area of few 1000 square meters. It will use full digital backend to process large bandwidth (>= 100 MHz) signals from the individual feeds. The main components of the instrument are

- Reflectors
- Feeds
- LNA and analog electronics
- Electronic calibration system
- Digitizers
- Signal processing hardware to perform frequency decomposition
- Dedicated electronic and specialized computer clusters to perform correlation computing
- On site data acquisition and storage

4 Data processing and science products

The collaboration has the formal responsability of processing the data and provide the reduced data sets to all members of the collaboration. Different levels and stages are foreseen for the data processing

- Level 1 : Data acquisition and on-line processing. This step should be performed on site and its output correspond the the raw science data (wave form or visibilities . . .)
- Level 2 : The level 1 data should go through the cleaning and calibration procedures, in order to produce the cleaned/calibrated science data (visibilities). This processing further reduces the data volume.
- The level 3 processing can be divided into two main steps:
    - Level 3.a : map making, which transforms the visibility data from level 2 into to 3D sky maps (data cubes)
    - Level 3.b : component separation (foreground removal) power spectrum computation . . .
- Level 4 : This represent the scientific analysis of the sky maps and power spectrum, to produce cosmological or astrophysical results.

5 Project plan & schedule

We plan to build the radio instrument in several stages

1. Stage 1 will consist of test interferometers, with a small number of feeds ($\sim 32 = 16$x2) to test and validate the technical concepts
2. Stage 2 will be the first instrument for science, with a $\sim 192 = 96$x2 elements
3. There might be some more ambitious (larger) instruments in future, which is beyond the scope of this document.

5.1 Site

A number of sistes have been considered and evaluated in China, but also in Morroco and Mexico. We currently consider a site (Dashankou), near Ulastai, in Xin Jiang province, west of China. The procedure for making the site available for building the instrument has started and the site preparation work might begin during summer 2013.

5.2 Construction schedule

- Summer 2013 : site preparation work
- Spring-summer 2014 : first construction work on the site
- 2014 : manufacture sub systems for stage 1 instrument
- Spring 2015 : installation of the stage 1 instrument on site
- Summer-fall 2015 : first light for stage 1 instrument
- Spring 2016 : installation of the stage 2 instrument on site
- Fall 2016 : first light for stage 2 instrument
- 2017-2018 : sky survey using the stage 2 instrument

6 Consortium and collaboration organization

A number of institutions from China, France, USA and Canada are currently involved in the project.

The project is led by the **NAOC** (National Astronomical Observatories of China), which has the formal responsability for building and operating the instrument. In China,

- CETC-54 Institute (China Electronic Technology Corporation)
- Institute of Automation, CAS (Chinese Academy of Sciences)

have contributed to the technological R&D effort in China. In addition,

- Xinjiang Observatory,
- Hangzhou Dianzi University,
- Peking University

are members of the collaboration.

The international partners include currently:

- Carnegie Mellon University (CMU), Pittburgh, USA
- University of Wisconsin Maddison, USA
- FNAL (Fermi National Laboratory), Chicago, USA
- LAL (CNRS-IN2P3) & Université Paris-Sud, Orsay, France
- IRFU (CEA), Saclay, France
- Observatoire de Paris, France
- CITA (Canadian Institute for Theoretical Astrophysics), Torronto, Canada

The scientific responsability is shared by the scientific members from the collaboration and the international partners may have technical constributions to the building of the instrument and data processing infrastructure. Detailed rules specifying collaboration membership, data rights and publication policies will have to be defined after discussion. A collaboration board will be setup which will formally approve the decisions.