M2 internship
GREEN @IJCLab

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21 cm Intensity Mapping : Tianlai & PAON4/IDROGEN

Scientific context:

Mapping the universe in the radio band, through the observation of the 21 cm line emission of the atomic hydrogen (HI), is a complementary approach to optical surveys for the study of large scale structures (LSS), and baryonic acoustic oscillations (BAO) in particular. The challenge is to extract the cosmological signal in presence of foreground (mainly Galactic) emissions and receiver noise.

Foregrounds are in general about few thousand times higher than the HI emission, while the instantaneous receiver noise is still about ten times larger than the foreground emissions.

The reduction of instrumental noise is achieved through long integration time, a few hours for each direction of the sky and large collecting surfaces, in general made of several antennas forming dense interferometric arrays. This new approach to probe LSS probe has been proposed recently (~2007-2009) and has stimulated active R&D efforts, leading to the design and construction of pathfinder instruments like PAON4 and Tianlai or CHIME.

The IJCLab (formerly LAL) GREEN (https://bao.lal.in2p3.fr) team has initiated a pioneering effort to explore 21cm intensity mapping technic since the very beginning of this field, in 2007, which led to the creation of the BAORadio project, in collaboration with researchers from the IRFU (CEA) and the Observatoire de Paris (GEPI, LESIA, Station de Nançay). Our efforts have focused on the development of the PAON4 test interferometer and participation to the Tianlai project (China, USA) in the last few years. The possibilities to apply the 21cm 3D Intensity Mapping method has now been extended and is being considered for the SKA (Square Kilometer Array https://ska.org) and, large, dedicated instruments such as PUMA project (US) are being considered (https://arxiv.org/abs/1810.09572) .

Tianlai & PAON4 :
Two instruments have been built at the **Tianlai** (http://tianlai.bao.ac.cn/wiki/index.php/Main_Page) site in Hongliuxia, Xinjiang province (China): a 3-cylinder array (15m x 40m each), and a dense array of sixteen (16) D=6 meter parabolic antennae.
Observations have been carried out with these two instruments for nearly 4 years. The array of 16 antennae has the advantage of allowing observation toward different declinations, in the direction of the North Celestial Cap in particular. It is therefore possible to conduct a deep survey over a small area of the sky in order to achieve the sensitivities to extract the 21 cm extragalactic signal. A survey of the northern celestial cap (NCP) with the Tianlai dish array, has been under way for just over a year. It is planned to cover three redshift intervals, close to z~0, around z~0.15 and z~1.The low z surveys, should allow the detection of a few extragalactic HI clouds as well as the detection of LSS at 21 cm in cross-correlation with optical surveys.

PAON4 is a prototype interferometer deployed at the Nançay Observatory, 200 km south of Paris. It allows the study of some aspects related to the calibration and reconstruction of sky maps for interferometers observing in transit mode such as Tianlai or HIRAX. It will also serve as a qualification instrument for a new generation of digital electronics modules, the IDROGEN boards, which use the White Rabbit technology (https://white-rabbit.web.cern.ch), and are suitable for large interferometric radio arrays. This new electronics will be deployed on PAON4 in the first half of 2021, after final laboratory tests.

Internship:
The proposed internship's main objective is to use a set of simulation and sky map reconstruction tools and contribute to the work being carried to perform forecasts of the science reach of the Tianlai NCP surveys (publication in preparation).
Another more instrumental possible track for the internship would consist in contributing to the observations and the analysis with PAON4. Indeed, the analysis of the first observations with PAON4 equipped with the new IDROGEN boards in 2021 will provide a first evaluation of the performance of this advanced electronic system.

This internship may be a first step for a PhD work program, which will include both working on the simulation tools, with the goal of understanding finely Tianlai observations, as well as data analysis. The work is carried out in collaboration with US (Fermilab and University of Wisconsin) and Chinese colleagues, with the goal of reconstructing 3D radio maps of the sky from visibilities (correlation signals between antennas) before extracting the extragalactic 21cm signal. An additional analysis thread could be the evaluation of the benefits of cross-correlating brightness temperature maps from 21cm intensity mapping surveys with optical surveys, such as LSST (https://www.lsst.org). These cross-correlations could lead to improved photometric redshifts, and tighter constrains on cosmological models.