ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

DIPARTIMENTO DI FISICA E ASTRONOMIA
Department of Physics and Astronomy - DIFA

PhD project in ASTROPHYSICS

Title of the Project: 21 cm cosmology
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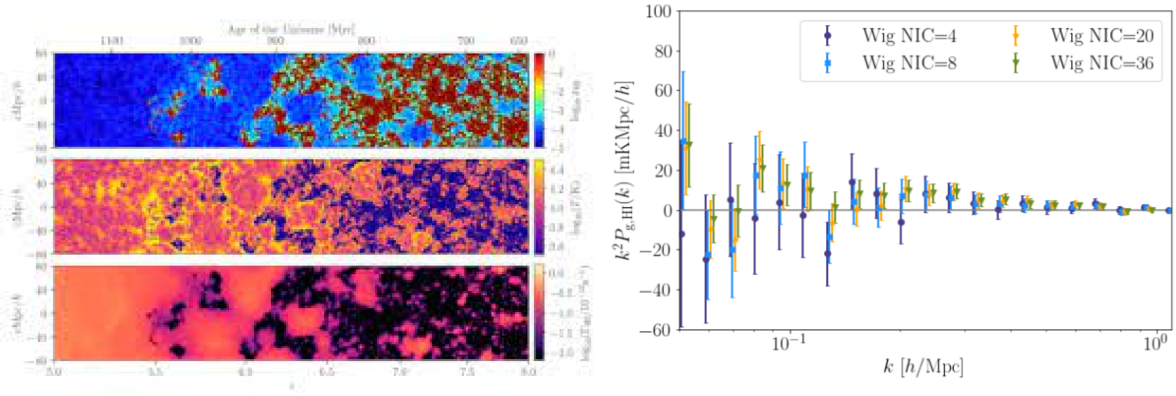
Observations of the redshifted 21 cm line from neutral Hydrogen (HI) is one of the most powerful cosmological probes. At high redshift ($6 < z < 35$) the 21cm line allows to study cosmic reionization and the birth of the first stars and galaxies. At lower redshifts ($z < 6$) observations trace the cosmological distribution of dark matter web and, eventually, dark energy.



(*Left*): Example of a cosmological 21 cm simulation: evolution of the neutral hydrogen fraction (top), temperature of the intergalactic medium (middle) and photo-ionization rate emitted by galaxies (bottom). (Right): The detection of the HI signal using the cross-correlation of foreground cleaned GBT 21cm maps and WiggleZ galaxy survey (Wolz et al. 2021).

This project can therefore take two flavors:

1. Characterization of the Cosmic Dawn and Epoch of Reionization.

This project is focused on observations of the 21 cm emission to constrain the thermal and ionization evolution of the intergalactic medium (IGM) in the $6 < z < 30$ range. The student will analyze state of the art observations taken with dedicated telescopes (HERA, LEDA, REACH) in order to detect (or place the most stringent upper limits on) the (so far undetected) signal. A detection will open up a new window on the first billion years of the Universe's history, allowing us to derive the properties of stars and galaxies in the first billion years (their mass, luminosity, dark matter halo function), their evolution and the timing of reionization.

Project outline:
- analysis of observations using existing pipelines, initial power spectra, assessment of systematic limitations due to systematic effects;
- development of techniques for improved foreground subtraction/modeling systematic effects;

- re-analysis to obtain improved power spectra and parameter constraints evolution (in particular in the $12 < z < 30$ range): evolution of the temperature and ionization of the IGM, constraints on the heating mechanism of the early IGM, measurement of the DM halo mass function.

2. Unveiling the large scale structures using 21cm Intensity Mapping.

Large cosmological volumes can be probed within reasonable amounts of telescope time by exploiting the technique of Intensity Mapping (IM): the signal is integrated in large sky pixels without resolving individual HI galaxies, too faint for a direct detection. The measurement and interpretation of the HI IM signal is the next frontier of cosmology and one of the main observational programmes at the MeerKAT telescope, located in the Karoo outback in South Africa. MeerKAT has recently started its observing campaign that will eventually lead to exquisite measurements of the growth of structures, the angular diameter distance and the Hubble rate. The success of HI IM observations heavily relies on the ability to separate the cosmological signal from the strong foreground emission. The student will work on the foreground separation and will carry out simulations to test the accuracy of the subtraction. The candidate will also explore the cross-correlation with optical galaxy surveys in order to enhance the detection significance by suppressing systematic effects.

Project outline:

- construction on MeerKAT specific mock 21cm intensity maps and use of existing mock galaxy catalogues for cross-correlation;
- exploitation of existing foreground sky models to be adapted to IM frequencies and application of state-of-the art cleaning techniques on simulations;
- cosmological parameters forecasts;
- application of cleaning techniques on 21cm data: power spectra and detection/upper limits.

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