ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

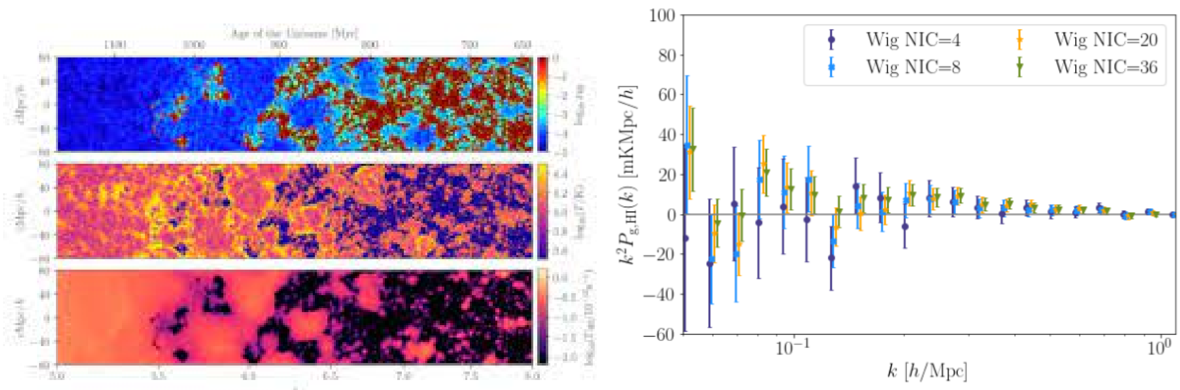
DIPARTIMENTO DI FISICA E ASTRONOMIA
Department of Physics and Astronomy - DIFA

PhD project in ASTROPHYSICS

Title of the Project: 21 cm cosmology

Supervisor : Dr. Gianni Bernardi
Co-Supervisors : Prof. Lauro Moscardni, Dr. Marta Spinelli

Scientific Case: 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).

The two following projects are available for the candidate.

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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PhD project in ASTROPHYSICS

Title of the Project:
The Interstellar Medium as a tool for exploring galaxy evolution

Supervisors:
Viviana Casasola (INAF-IRA), Francesca Pozzi (UniBo)

Abstract:
Observations of the interstellar medium (ISM) are key to deciphering the physical processes regulating star formation in galaxies, one of the main drivers of galaxy evolution. The ISM is composed of gas, dust, and the so-called 'metals' (helium and heavier elements).
This PhD project aims at characterizing all components of the ISM in the galaxies of the Local Universe, where the proximity allows us to deeply explore the physics, the composition, and the distribution of the ISM. This information on ISM will be combined with those on other important galaxy properties such as stellar mass and star-formation rate. The project is based on multi-wavelength (from UV to radio) images coming from big archives (e.g, DustPedia) and proprietary spectroscopic (Integral Field Units) data (e.g., Metal-THINGS Survey of Nearby Galaxies). This data comes from both ground-based and spatial telescopes (e.g., ALMA, Herschel, JVLA). Thanks to the holistic analysis of multi-wavelength data, this Thesis will draw a complete picture of how internal and external mechanisms can influence and affect galaxy evolution in nearby objects.
The Thesis is in close collaboration with Prof. Jacopo Fritz of the Instituto de Radioastronomia y Astrofisica in Morelia, Mexico. Viviana Casasola and Jacopo Fritz are members of the DustPedia collaboration, and Jacopo Fritz is a member of the Metal-THINGS survey.

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PhD Thesis Proposal

Title: Development of techniques and tools to process radar signals for the observation of Near Earth Asteroids

Supervisors:
Prof. Daniele Dallacasa, DIFA – Università di Bologna
Dr. Giuseppe Pupillo, INAF - Istituto di Radioastronomia

Scientific Case: Radar experiments have been successfully used in the exploration of the Solar System, both from orbit and from ground. Radar echoes can be processed to achieve a variety of information on the target, such as astrometric measurements for orbital refinement, images for the characterization and the geological study of the surface and subsurface of Solar System bodies, etc.
Ground-based radars are frequently used to perform such experiments on Near Earth Objects (NEOs) with a detail that cannot be achieved using optical telescopes. The currently existing facilities for radar observations of NEOs are located in the United States; there are plans to develop such capability also in Europe, for both scientific and planetary defense aims.

Outline of the Project: The candidate will learn the basics of radar signal processing techniques, developing and specialising them to the case of NEO observations, and testing them on past data available in public or proprietary archives. He/she will help in the definition of a European ground-based planetary radar system, through modelling of the performance and simulation of observations. He/she will also analyse data from currently-available test observations performed using receiving facilities in Europe and help planning and executing future measurement campaigns using the antennas available in INAF, with the final goal to enable such observations to produce both astrometric and imaging results. The candidate should be interested in the study and modelling of electromagnetic propagation, in the implementation of numerical simulations and methods for radar observations and radio signal analysis. He/she should possess at least basic skills in high-level programming languages (Matlab, Python, etc.).

These activities will be performed in collaboration with ESA, NASA/JPL and radar imaging experts at the University of Helsinki.

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