Section A: Overview of the Research Project Proposal

1. Title: **Calibration of Epoch of Reionization observations with the Hydrogen Epoch of Reionization Array**
2. Broad field of research: **Science**
3. Academic level of research project: **Masters**
4. Abstract: One of the frontiers of modern cosmology is to understand when and how first luminous structures formed in our Universe (Cosmic Dawn) and how these first galaxies subsequently reionized the intergalactic neutral medium (Epoch of Reionization). Direct observations of the intergalactic medium with the 21 cm neutral Hydrogen line emitted by the intergalactic medium is the most promising way to study these epochs and has motivated the construction of the Hydrogen Epoch of Reionization Array (HERA). The detection of the redshifted 21 cm line requires an exquisite spectral calibration that prevents the cosmological signal from being jeopardized by bright foregrounds. The candidate will use newly developed calibration algorithms (CubiCal, SageCal) in order to improve the spectral calibration of HERA observations and detect the redshifted 21 cm line.
5. Primary supervisor: **Prof Oleg Smirnov,** o.smirnov@ru.ac.za, Rhodes University
6. Research supervisor: **Dr Gianni Bernardi,** INAF-IRA (Italy) & Rhodes University

Section B: Details of Research Project

1. Scientific merit: The study of cosmic reionization is one of the frontiers in modern cosmology and low-frequency radio astronomy. Despite two decades of intense theoretical and observational studies, we only have limited knowledge of how the first stars and galaxies formed (Cosmic Dawn) and when their intense star-formation driven UV radiation completely ionized the surrounding intergalactic medium (Epoch of Reionization, EoR). The 21 cm line emitted from the neutral Hydrogen in the Intergalactic Medium (IGM) is considered to be the best probe of the Cosmic Dawn and the Epoch of Reionization and has been the driver behind the construction of the Hydrogen Epoch of Reionization Array (HERA). Once completed, HERA will include 331 dishes in a compact, highly redundant hexagonal configuration, providing the best sensitivity for 21 cm observations in the $6 < z < 30$ range.
HERA observations have been routinely carried out with 47 dishes, with a total of a few hundreds of hours collected and under analysis (internal data release 2.1, or IDR2.1). By the beginning of this project, HERA will comprise more than 100 correlated antennas, most of them equipped with new feeds that will enable observations with a simultaneous 50-200 MHz bandwidth.

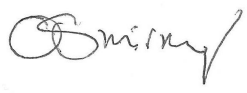
HERA takes advantage of the so-called “redundant” calibration, i.e. baselines of the same length and orientation must measure the same sky brightness. Redundant calibration does not, therefore, need a model of the sky brightness distribution. Redundant calibration is not sufficient, however, to correct for the instrumental bandpass, i.e. the frequency-dependent response of the instrument that corrupts the intrinsic sky spectrum. Accurate calibration is, however, required as the only way to separate foregrounds and the 21 cm signal is through their different spectral properties. This project is focused on improving the accuracy of spectral calibration in order to improve the foreground separation.

2. Feasibility: The student will be using newly developed calibration algorithms like Cubical (Kenyon et al., 2019) or SageCal (Yatawatta et al., 2013) to iteratively self calibrate IDR2.1 (and the upcoming data releases). The student will derive sky models from HERA data and combine them with existing catalogues in order to improve self-calibration. The final goal will be to quantify the impact of the different calibration strategies and, through sky-based self-calibration, to improve the foreground separation and, ultimately, the 21 cm power spectrum (or its best upper limits).
The student will be joining the HERA group at Rhodes University (currently comprised of one MSc student and two PhD students) and will be expected to closely collaborate with them. The candidate will be in a position to publish a first author paper as the outcome of the thesis work. The candidate will have full access to HERA data and to computing and storage resources at the RATT centre at Rhodes University, which have been used so far by the local HERA group.

3. Link to SARAO research priority areas for 2021: This is a science project that uses HERA data. If the candidate is interested, he will have the opportunity to be involved in the analysis of the 21 cm global signal REACH, which will be deployed in 2020 at the Karoo site.

4. **Qualifications, academic abilities, skills and/or experience that a student should have in order to successfully deliver on the objectives of the research proposed:**
Familiarity with interferometry and good programming skills would be advantageous but not required.

Supervisor



Oleg Smirnov 7 February 2020