Section A: Overview of the Research Project Proposal

1. Title of the research project: **Observations and simulation of the epoch of reionization with closure quantities: the HERA case**
2. Broad area of research: **Science**
3. Academic level of research project: **Masters**
4. Abstract: The Hydrogen Epoch of Reionization Array (HERA) is currently under construction at the Karoo site, with the goal of observing the birth of the first stars and galaxies through the (still undetected) 21 cm line from the intergalactic neutral Hydrogen. The candidate will analyze HERA observations using closure quantities in order to constrain the signal from cosmic reionization. As the 21 cm signal from reionization remains undetected to date, any improvement in current constraints (including a detection!) would represent a groundbreaking result.
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: One of the outstanding questions in modern cosmology is to understand how the first luminous structures (stars, galaxies) formed (likely at $z \sim 30$) and how they subsequently evolved and completely ionized the intergalactic medium ($z \sim 6$). These two epochs are generally known as Cosmic Dawn and Epoch of Reionization (EoR). One of their best observational probes is the redshifted 21 cm line emitted from neutral Hydrogen, observable in the 50-200 MHz radio window. The Hydrogen Epoch of Reionization Array (HERA, deBoer et al. 2017) is currently under construction at the Karoo site and its goal is to measure the evolution of the 21 cm emission from the Cosmic Dawn to the Epoch of Reionization. The candidate will analyze HERA observations using closure phase quantities, a recently proposed technique to detect the 21 cm signal from the EoR (Thyagarajan, Carilli & Nikolic 2018). The use of closure quantities may be more robust to systematic effects caused by strong foreground emission. The goal will be to detect (or place a stringent upper limit) to the 21 cm signal from the EoR using closure quantities in HERA observations. The candidate will also carry out simulations of the expected signal when observed using closure quantities in order to aid the interpretation of the results.

2. Feasibility: Observations of the redshifted 21 cm are difficult: its pursuit started fifteen years ago and a solid detection is still awaiting. 21 cm observations are one of the most challenging

goals of radio cosmology: the signal is faint and buried under foreground emission which is a few orders of magnitude brighter. Observations therefore require an exquisite interferometric calibration, often exploring novel techniques and approaches, and a careful control (and modeling) of systematic effects. Moreover, 21 cm cosmology requires knowledge of interferometry, cosmology, statistical and numerical methods.

Rhodes University hosts a small (but competitive) 21 cm group that works on the analysis of HERA data, coordinated by Prof. Smirnov and (visiting) Prof. Bernardi, including PhD student Ntsikelelo Charles and collaborating with Prof. Santos (University of Western Cape) and Dr. Landman Bester (SARAO). Over the last few years the group worked on the optimization of redundant calibration for HERA (Grobler et al., 2017), on the application of Gaussian Progress Regression to model and subtract foregrounds from HERA data (Ghosh et al., 2020), on the use of HERA closure phase quantities to detect the 21 cm signal (Charles et al., 2022).

The candidate will continue the work on closure phases carried out by the group and use them to analyze HERA observations. Closure phase is the sum of the visibility phase of a triad (i.e. the baselines formed by a group of three antennas) and is largely independent of interferometric calibration. This is the reason why closure phases are thought to be more robust to systematic effects arising by calibration imperfection and, therefore, promising to separate the feeble 21 cm signal from the EoR from bright foreground emission (Thyagarajan et al. 2018, 2021). Our work has shown that this property may still hold even when more realistic simulations of the interferometric array are used (Charles et al., 2022).

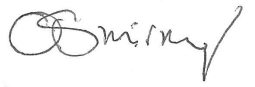
HERA is now in an advanced deployment stage, with more than 200 dishes built and the new wide-band (50-250 MHz) feeds installed in about 50 dishes. Deep integrations have already been carried out and the first 21 cm deep upper limits are published (Abdurashidova et al., 2022a; 2022b). The longest observing campaign has recently been completed and made available to the whole collaboration (internal data release 3.2). Even if such observations may not be sufficiently deep to detect the (still undetected) 21 cm signal, the student will process these observations using the closure phase technique aiming to derive the best upper limits to the 21 cm signal ever. In parallel the student will carry out simulations of the expected signal in order to help the interpretation of the observations, using the simulation framework already developed by our group (Charles et al., 2022).

We expect this work to become publishable at the end of the thesis. The candidate will be a member of the HERA collaboration, have full access to HERA data and computing and storage resources of the RATT cluster at Rhodes University, which have been used so far by the local HERA group.

3. Link to SARAO research priority areas for 2023: This is a science project that uses HERA data (focus area 5.1).

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 21 cm cosmology would be advantageous but not required. The candidate should be ready to undertake a cutting edge project.

Supervisor



Oleg Smirnov 22 February 2023