Section A: Overview of the Research Project Proposal

1. Title: **Observations of the Universe first (radio) light with HERA (and REACH)**
2. Broad field of research: **Science**
3. Academic level of research project: **Doctoral**
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 become part of the HERA collaboration, with the goal of analyzing data with the closure phase technique - that holds promises in terms of mitigating the foreground contamination. In the best case scenario, the candidate will be one of the relevant players of the 21 cm detection; in the worst case scenario, they will place constraints on the physics of reionization.
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/Engineering 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. 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 with the goal to make the first detection of the 21 cm signal.

2. Feasibility: Observations of the redshifted 21 cm are difficult: its pursue 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 knit up) 21 cm group that works on the analysis of HERA data, coordinated by Prof. Smirnov and visiting Prof. Bernardi, and often collaborating with Prof. Santos (University of Western Cape). 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., submitted), on the use of HERA closure phase quantities to detect the 21 cm signal (Matika, PhD thesis; Charles, MSc thesis) and on foreground modeling from HERA data using an advanced, DDFacet algorithm (Chanka, PhD thesis).

The candidate will become part of the aforementioned group and their specific project will be to use closure quantities to analyse HERA data and use them as a tool for signal detection. Closure phases are particularly appealing as they are insensitive to antenna gains and, therefore, mitigate the requirements for accurate interferometric calibration needed by the presence of bright foregrounds (Carilli et al., 2018; Thyagarajan et al, 2018; Thyagarajan et al., submitted). HERA is now in an advanced deployment stage, with close to 200 dishes built and the new wide-band (50-250 MHz) feeds installed in ~50 dishes. Deep integrations have already been carried out and are being analyzed (Kern et al., 2019; Kern et al., submitted). At this stage of development, the candidate will have a real chance to contribute to a detection or place a meaningful upper limits that, with an adequate modeling effort, will turn into the first constraints on the physics of cosmic reionization.

Depending upon their background, the candidate may spend their first year mastering interferometry and 21 cm cosmology. A pipeline to analyse HERA data with closure quantities has largely been developed and the candidate will use it and complement with the new requirements in terms of data quality assessment, analysis of systematic effects, modeling and interpretation of the signal. The candidate will publish collaboration papers, but we expect that their work will result in, at least, one first author paper throughout the thesis period.

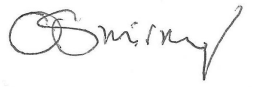
The candidate will have full access to HERA data and to computing and storage resources at the RATT centre at Rhodes University, which have been used so far by the local HERA group.

Finally, we would like to underline that the project is suited to the exploration of the other aforementioned research lines too, including synergies with the 21 cm global signal REACH, a single dipole experiment currently under deployment at the Karoo site and that attempts to measure the sky-averaged 21 cm signal in the $6 < z < 30$ redshift range.

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

Supervisor



Oleg Smirnov 7 February 2020