Section A: Overview of the Research Project Proposal

1. Academic level of research project (Masters or Doctoral)
   PhD
2. Broad field of research (Engineering or Astronomy/Astrophysics)
   Engineering
3. Title of the research project
   HIRAX Instrument Characterisation and Array Commissioning
4. Full names of supervisor and co-supervisor(s)
   Kavilan Moodley, Cynthia Chiang, Jon Sievers
5. University where postgraduate student would be registered
   University of KwaZulu-Natal

Section B: Full Research Project Proposal

Maximum of three A4 pages, written for a professional who is not necessarily an expert in the relevant subfield

1. Scientific merit: describe the objectives of the research project, placing them in the context of the current key questions and understanding of the field.

An exciting frontier of radio astronomy is using the redshifted 21-cm emission of neutral hydrogen to reconstruct a three-dimensional map of large-scale structure in the universe. These maps encode a faint imprint, known as baryon acoustic oscillations (BAOs), that correspond to remnant ripples left behind by sound waves echoing through the plasma of the early universe. Measurements from upcoming experiments will constrain BAOs with exquisite precision, opening new views into structure formation and the universe's expansion history, and shedding light on the mystery of dark energy.

We are in the initial stages of building a new radio telescope array called the Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX). HIRAX will measure BAOs by mapping the entire southern sky over a frequency range of 400–800 MHz, and the experiment will be sited in South Africa. The project is complementary to the Canadian Hydrogen Intensity Mapping Experiment (CHIME), which has recently begun surveying the northern sky. HIRAX has received funding to build a 256-element array, and an eight-element prototype array is already in place at HartRAO. The student who takes on this project will play a key role in the continued design and testing of HIRAX instrumentation. The work will include subsystem refinement and characterisation using the HartRAO prototype, in preparation for the deployment of a second stage 128-element pathfinder at the SKA Karoo site. These staged are critical milestones along the path to constructing the full science array, which at the first stage will consist of 256 funded elements but will eventually build up to 1024 elements. The student will work closely with local and international team members to characterize the prototypes, iterate on the experimental design, streamline the fabrication process, and analyze the initial data.

2. Feasibility: outline the methods that will be used to achieve the objectives. Provide details on the availability of required data / access to required equipment / availability of research facilities and other resources required. Include any relevant expected intermediate milestones and associated timeframes towards attaining the overall objectives of the project.

In the first year of this project, the student will participate in subsystem testing using the HartRAO eight-element prototype. The work will include refining the analog RF chain design (including active feeds, RF over fiber modules, second-stage architecture), developing expertise in the digital back end (ICE board readout system), and learning the basics of data analysis. In the second year of the project, the student's focus will shift toward the construction and integration of the first science-grade HIRAX elements at the SKA Karoo site. Calibration will be essential during this phase, and the student will be involved in multiple aspects of instrument characterisation: this includes taking specialised measurements (and possibly constructing ancillary calibration apparatus), analysing the instrument data, and using the measurements to guide improvements for the instrumentation. The student will focus on low-level characterization and will work in concert with other team members to ensure their characterizations flow into higher-level calibration pipelines. This work will carry on to year three, when the student will be involved in an extensive suite of end-to-end system tests with a subset of the 256-element array. The student will help refine the design for the final 1024-element array, and will publish a paper describing HIRAX instrumentation and projected performance.

The HIRAX project has been granted funding for constructing a 256-element array in its first phase, and the installation of the eight-element prototype is complete. We have a well established radio instrumentation laboratory with all the necessary equipment for subsystem development and characterization. Data analysis will be performed using UKZN's 1000-core HPC cluster.

3. Link the proposed project to at least one SARAO research priority areas (refer to Section 4 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).

HIRAX will target the BAO signal using intensity mapping -- analysis of data on early versions of the array forms one of the SARAO research priority areas.

This project will also address the priority area of "Radio astronomy antennas and receiver systems" associated with the guest instrument HIRAX (topic 6.2.1). HIRAX is one of the approved SARAO instruments specified in the call, and this work will directly contribute to its success, including work on front-end development and characterization.

Additionally by working closely with HIRAX's digital backend in the data pipeline, the student's work will also fall within topic 6.2.2: "Real-time digital signal processing instrumentation for radio astronomy, specifically using FPGA and GPU platforms."

The characterization and monitoring of instrument performance also falls under topic 6.2.4: "Hardware, software and data analytic systems associated with the control and monitoring of radio telescopes."

4. If relevant, describe any particular qualifications, academic abilities, skills and/or experience that a student should have in order to successfully deliver on the objectives of the research proposed.

The student must have sufficient patience and tenacity to withstand the inefficiencies and bureaucratic hurdles associated with hardware procurement.