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
   Exploring cosmic dawn from the sub-Antarctic
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.

Observations of redshifted 21-cm emission of neutral hydrogen are a rapidly growing area of cosmology research. Measurements across a wide range of radio frequencies allow us to access redshifts all the way from cosmic dawn up to the formation of the first large-scale structures. At early times, about one hundred million years after the big bang, the formation of the first stars heated the intergalactic medium (IGM), imparting characteristic structure in the temperature of the globally averaged 21-cm sky signal as a function of frequency. As time progressed, the first luminous objects began to reionize the surrounding IGM, creating patchy, spatially varying structure in the 21-cm signal that can be characterized by a three-dimensional power spectrum. This era, known as reionization, took place over the course of several hundred million years, after which the universe became fully ionized. The first detection of the global 21-cm signal was reported in early 2018 by the EDGES team, and the reionization power spectrum is still undetected to date; many experiments are racing to make radio-frequency measurements of the universe in this slice of its history, an epoch that is ripe for new exploration.

Probing Radio Intensity at high-Z from Marion (PRIZM) is an experiment that aims to study cosmic dawn in the universe using low frequency (<150 MHz) observations of redshifted 21-cm emission from neutral hydrogen. The experiment comprises two small antennas that observe the 21-cm signal averaged over a large fraction of the visible sky. Measuring this global signal as a function of frequency/redshift opens a new window into a part of the universe's history that is very poorly understood.

One of the greatest challenges in probing cosmic dawn at low frequencies is terrestrial radio frequency interference (RFI), which swamps the cosmological signal even when the nearest RFI sources are hundreds of kilometres away. PRIZM has been funded by the South African National Antarctic Programme (SANAP) for deployments to Marion Island, which lies 2000 km from the nearest continental land masses and offers an exceptionally clean RFI environment. PRIZM was successfully installed on Marion Island during the April 2017 takeover voyage, and the instrument has been continuing to observe since then. The radio observing programme from Marion has been recently expanded to include the first pathfinder antennas for The Array of Long-Baseline Antennas for Taking Radio Observations from the Sub-antarctic (ALBATROS). ALBATROS complements PRIZM by aiming to image the radio sky at selected frequencies below 100 MHz, with the goal of laying the groundwork for future explorations of the cosmic dark ages. The array will ultimately consist of about 10 autonomous antenna stations, each writing precision timestamped raw data ("baseband") to disk, that will be subsequently correlated offline to image the sky. The first two ALBATROS pathfinder antennas were installed in 2018 (using direct correlation rather than writing baseband), and the first completely autonomous station was installed in 2019. Additional stations will be installed during the 2020 takeover voyage. The radio sky at these low frequencies represents one of the final frontiers in cosmology, with the state of the art dating from the 1960s, when Grote Reber caught brief glimpses of the ~2 MHz sky at low resolution. The combination of the unique RFI-clean environment of Marion Island, novel instrumentation techniques developed for the autonomous antenna stations, and the current solar minimum will enable us to see the low-frequency sky like never before.

Given the small scale of PRIZM and ALBATROS, the student who takes on this project will be able to contribute to a wide range of work spanning both instrumentation and analysis. The student will have the opportunity to participate in the April 2020 voyage to Marion Island, where we will perform continued on-site instrument characterisation and install new and improved ALBATROS stations. The student will also have opportunities to analyse data from the winter observations and develop hardware upgrades for future Marion deployments.

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 begin working with PRIZM and ALBATROS subsystems in the lab in preparation for the April 2020 takeover voyage to Marion Island. Much of the work will focus on developing hardware and firmware for the SNAP-based backend electronics system. Following the deployment, the student will perform lab tests of PRIZM and ALBATROS hardware in order to debug any potential instrumental issues and improve the system. The student will also analyse PRIZM and ALBATROS data retrieved during the takeover voyage. In year two, the student will continue lab tests of PRIZM and ALBATROS hardware, including instrumentation for possible future upgrades. The scope of work includes possible new antenna designs, improved power systems, and efficient on-site data storage techniques. In year three, the student will focus on data analysis. By this time, there will be data from multiple ALBATROS stations in hand, and the student will be able to produce at least rudimentary images of the radio sky. This project is expected to yield at least two papers for this particular student (one on instrumentation development, one on analysis, and most likely others as well).

PRIZM and ALBATROS are small-scale, self-contained experiments, and the observing programme has been funded through 2020. 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).

PRIZM/ALBATROS addresses nearly all of the SARAO engineering priorities. The student will be developing a full end-to-end radio astronomy system, including the antenna, receiver, and signal processing instrumentation (using the FPGA-based SNAP board) (area 6.2.2). Despite the clean RFI environment of Marion, this project will nevertheless require the student to build RFI identification expertise to search for, e.g., self-generated instrumental RFI at very low levels. ALBATROS additionally will require some RFI removal from shortwave reflections off the ionosphere (area 6.2.3). The PRIZM/ALBATROS monitoring software is all written in-house, and the student will continue developing and improving the software capabilities (area 6.2.4).

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.