A Overview of the Research Project Proposal

1 Academic level of research project: PhD

2 Broad field of research: Engineering

3 Title of research project: HIRAX instrumentation

4 Research project abstract/summary:

A new frontier of radio astronomy is using the redshifted 21-cm emission line of neutral hydrogen to reconstruct a three-dimensional map of large-scale structure in the universe. These measurements 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. The Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX) is a new radio telescope array that has the goals of measuring BAOs, searching for pulsars, detecting fast radio bursts and other transients, finding neutral hydrogen absorbers, and other auxiliary science. HIRAX will be sited in South Africa and will map most of the southern sky (in a declination range of -60° to 0°) over a frequency range of 400–800 MHz. The array will consist of roughly 1000 6-m stationary dishes placed in a compact, redundant configuration. HIRAX is in its initial prototyping stages, and an eight-element pathfinder array is being commissioned at the Hartebeesthoek Radio Astronomy Observatory. The student who takes on this project will play an integral role in the pathfinder commissioning and deployment of the first science-grade HIRAX dishes at the SKA Karoo site. The student will additionally have opportunities to participate in the development of HIRAX outrigger stations for localizing fast radio bursts.

B Supervisor(s) Details

1 Primary supervisor's details

a Title and full name: Prof. Kavilan Moodley

b Name of South African or SKA Partner Country university at which the primary supervisor is a permanent academic staff member:
University of KwaZulu-Natal

c Email address and/or contact telephone number:
kavilan.moodley@gmail.com, 072 447 5499

d Supervision of postgraduate students – details of All the previous and Current postgraduate students Supervised, provided in the Table Format as shown In the Guidelines for the South African Radio Astronomy Observatory Research Project Proposals for Masters and Doctoral Research in 2019.

i Doctoral Students

Name of Student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Kenda Knowles	South Africa	Jan 2013	Dec 2015	Observational Probes Of Merging Galaxy Clusters	Matt Hilton Mathilde Jauzac
Susan Wilson	South Africa	Jan 2013	Aug 2017	Evolution of Galaxy Cluster Scaling Relations Over Half a Hubble Time	Matt Hilton (main supervisor) Nadeem Oozeer
Darell Moodley	South Africa	Jan 2010	Dec 2014	Optimisation Of The Population Monte Carlo Algorithm: Application To Cosmology	
Simon Muya Kasanda	Democratic Republic of Congo	Jan 2007	Dec 2011	Initial Conditions of the Universe: Signatures in the Cosmic Microwave Background and Baryon Acoustic Oscillations	
Ryan Warne	South Africa	Jan 2006	Dec 2010	The Thermal Sunyaev-Zel'dovich Effect as a Probe of Cluster Physics and Cosmology	
Angel Torres-Rodriguez	Spain	Jan 2007	Dec 2008	SKA simulations and cosmological constraints from large HI surveys	
Khadija El Bouchefry	Morocco	Jan 2004	Dec 2008	Multi-wavelength study of radio sources in the universe	Jon Rash (main supervisor)

ii Masters Students

Name of Student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Sinenhlanhla Sikhosana	South Africa	Jan 2015	Dec 2016	Giant Radio Halos and Relics in ACTPol Clusters	Sinenhlanhla Sikhosana
Heather Prince	South Africa	Jan 2014	Dec 2015	Gravitational Lensing Of The Cosmic Microwave Background: Techniques And Applications	Heather Prince
Jethro Ridl	South Africa	Jan 2010	Dec 2012	Weak Gravitational Lensing In The Cosmic Microwave Background: Reconstructing The Lensing Convergence	Jethro Ridl
Devin Crichton	South Africa	Jan 2010	Dec 2011	Probing Missing Baryons Using High Resolution Measurements Of The Cosmic Microwave Background	Devin Crichton
Darell Moodley	South Africa	Jan 2007	Dec 2010	Bayesian Analysis Of Cosmological Models	Darell Moodley
Mokhantso Phoolo	Lesotho	Jan 2006	Dec 2007	Optimal polarization measurements for constraining isocurvature modes	Mokhantso Phoolo
Simon Muya Kasanda	Democratic Republic of Congo	Jan 2005	Dec 2007	Cosmic Microwave Background Anisotropies in Neutrino Isocurvature Models	Simon Muya Kasanda
Ryan Warne	South Africa	Jan 2005	Dec 2005	Optical Observations Of Galaxy Clusters: Photometric Calibration Of Imaging Data From The Southern African Large Telescope	Ryan Warne

2 Co-supervisor / Research Supervisor's details

a Title and full name: Prof. Hsin Cynthia Chiang

b Name of South African or SKA Partner Country university at which the primary supervisor is a permanent academic staff member:
University of KwaZulu-Natal

c Email address and/or contact telephone number: chiang@ukzn.ac.za

d Supervision of postgraduate students – details of All the previous and Current postgraduate students Supervised, provided in the Table Format as shown In the Guidelines for the South African Radio Astronomy Observatory Research Project Proposals for Masters and Doctoral Research in 2019.

i Doctoral Students

Name of student	**Nationality**	**Date started Doctoral Degree (Month and Year)**	**Date completed / will complete Doctoral Degree (Month and Year)**	**Title of Research Project / Thesis**	**Co-Supervisor (if Relevant)**
Liju Philip	India	1/2016	12/2018	The Design, Construction and Deployment of PRIZM	Jonathan Sievers
Heiko Heilgendorff	RSA	9/2013	12/2017	The C-Band All Sky Survey Commissioning and Data Analysis	Jonathan Sievers

ii Masters Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if Relevant)
Bismark Kushiator	Ghana	7/2018	7/2020	HIRAX instrumentation and prototype characterisation	
Nivek Ghazi	RSA	1/2018	12/2019	Exploring cosmic dawn from the sub-Antarctic with PRIZM	
Austin Gumba	Kenya	1/2018	12/2019	Radio Astronomy Receiver Design and Commissioning	Jonathan Sievers
Kabelo Kesebonye	Botswana	1/2017	12/2018	HIRAX commissioning and instrument characterisation	
Johannes Allotey	Ghana	8/2014	12/2016	Commissioning and Characterisation of the C-Band All-Sky Survey Southern Telescope	

C Full Research Project Proposal, 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 seed funding, and an eight-element prototype array has been constructed and is being commissioned at HartRAO. The student who takes on this project will play a key role in the design and testing of HIRAX instrumentation. The work will focus on subsystem refinement and characterisation of the HartRAO prototype, in preparation for the deployment of a second stage 128-element prototype at the SKA Karoo site. These prototypes are critical milestones along the path to constructing the full science array, which will consist of 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 build expertise in radio interferometry, including antenna and array design, receiver technology, and readout/correlator electronics. The student will participate in the testing of the eight-element prototype, including subsystem development efforts for both hardware and analysis pipeline. 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. 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 128-element intermediate 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 seed funding for constructing a 128-element prototype, 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 Annexure 1 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, which is one of the SARAO research priority areas. This project will also address the priority area of radio astronomy antennas and receivers.

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.

D Signatures

1 Signature of the primary supervisor, with date

28 August 2018

2 If relevant, signature of the co-supervisor/research supervisor, with date

28 August 2018