A Overview of the Research Project Proposal

1 Academic level of research project: MSc

2 Broad field of research: Astronomy/Astrophysics

3 Title of research project: HIRAX Quicklook

4 Research project abstract/summary:

The 21cm line of hydrogen is rapidly becoming one of the most powerful tools in our cosmological toolbox. A new generation of radio telescopes optimized for surveying large volumes of the universe will use the redshifted 21cm line to study the epoch of reionization through to the dark energy-dominated age in which we now live. The Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX) is a planned 1,024-element array of 6m dishes that has been approved for construction in the Karoo near the core MeerKAT site. It will map out the evolution of dark energy as it begins to drive the expansion of the universe, over the redshift range 2.5 to 0.8 (400-800 MHz). HIRAX will additionally be a premier instrument for finding fast radio bursts (FRBs). An 8-element prototype has been built at HartRAO, which has already taken more than a year's worth of data, with a second 8-element prototype planned in the near term for the Karoo, followed by a fully-funded 128-element pathfinder slated to break ground in the second half of 2019. Starting with the data already in-hand, the student will work closely with the instrumentation team to develop quick-look tools that will characterize the array behaviour and health.

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: Moodleyk41@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)
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	Democr atic 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

C Co-supervisor / Research Supervisor's details

a Title and full name: Prof. Jonathan Sievers

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: sieversj@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	Cynthia Chiang
Heiko Heilgendorff	RSA	9/2013	12/2017	The C-Band All Sky Survey Commissioning and Data Analysis	Cynthia Chiang
Onkabetse Sengate	Botswana	9/2016	9/2019	HIRAX Beamforming	
Tamirat Gogo	Ethiopia	3/2015	9/2019	Applications of Correlation Calibration to PAPER	

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
Austin Gumba	Kenya	1/2018	12/2019	Radio Astronomy Receiver Design and Commissioning
Onkabetse Sengate	Botswana	4/2014	9/2016	Removing CMB Foregrounds With JVLA
Ayanda Zungu	RSA	4/2014	4/2016	Studying the Evolution of Cold Gas in Galaxies: Large Absorption Line Survey with MeerKAT
Mthokozisi Mdlalose	RSA	3/2015	10/2017	Calibration Techniques for 21-cm Experiments with Application to HERA: Quasi-Redundant Calibration An

D 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 the Karoo about 20 km from the core MeerKAT site. HIRAX has been funded for 128 dishes with fundraising ongoing for the full array. An 8-element prototype began taking data at HartRAO in early 2017, with a second prototype using final science-grade dishes planned for the MeerKAT site in the near future. Construction for the 128-element array is planned to start in second-half 2019, with expansion to 512 and 1024 dishes one and two years later, respectively. An important part of any new array is characterizing performance and being able to monitor the health of the instrument. The student will work closely with the hardware team to develop a user-friendly pipeline so that different hardware configurations for the prototypes can be evaluated, and that array health can be monitored. These tools are an essential part of any large-scale, ongoing array. With a year of data from the HartRAO pathfinder in-hand, the student will be able to start working immediately.

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 and develop coding skills. The student will learn how to carry out rough but near-realtime calibration (greatly simplified by the fact that HIRAX observes the same sky every day), and to do preliminary RFI rejection. In the second year, with these tools in-hand, the student will then be able to monitor array health and characterize performance of antennas. This will be crucial in iterating on prototype performance as different hardware configurations are tested, and will indicate if any antennas/feeds/amplifiers have failed or if their gains/phases are wandering more than expected. The student will publish their work characterizing performance.

With over a year of data from the 8-element prototype the student will be able to start right away. Since HIRAX is fully funded for the 128-element pathfinder, the tools developed will be applied to an array that, though smaller than the final array, is a powerful instrument in its own right. Futher, the student will be able to carry out

intensive analysis on the UKZN 1,000-core hippo HPC cluster to verify algorithms and analysis techniques off-line.

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.

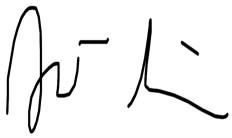
The student should either have or be willing to quickly develop familiarity with the python programming language. The student must also work closely with the hardware team to make sure that the pipeline developed accurately reports telescope health and performance.

E Signatures

1 Signature of the primary supervisor, with date

30 August 2018

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



30 August 2018