Section A: Overview of the Research Project

1. Title of the research Project:
   Precipitable water vapour measurements for the Africa Millimetre Telescope, a prospective telescope for the AVN

2. Broad area of research:
   Engineering

3. Academic level of research project:
   Masters

4. Abstract of research project:
   The Africa Millimetre Telescope (AMT) shall be an African addition to the Event Horizon Telescope (EHT) at millimetre wavelength and at the same time (one of) the next additions to the African VLBI Network (AVN) at centimetre wavelengths. Before the establishment of the AMT in the area around Mt Gamsberg and the H.E.S.S. site in Namibia, thorough site characterization is needed. The amount of precipitable water vapour (PWV) is one of the most crucial atmospheric characteristics for establishing mm-wave radio telescopes. The recent refurbishment of the dual-frequency HartRAO Water Vapour Radiometer will for the first time enable direct and in-situ measurements of the PWV at the sites and, hence, supply crucial information for the establishment of the AMT.

5. Primary supervisor's details:
   a. Full name: Michael Backes
   b. Email address: mbackes@unam.na
   c. University where employed: University of Namibia (& North-West University)

6. Co-supervisor's details:
   a. Full name: Tinus Stander
   b. Email address: tinus.stander@up.ac.za
   c. University where employed: University of Pretoria

Section B: Details of Research Project

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.

Precipitable Water Vapour (PWV) is the amount of water vapour in the atmospheric column above a location. Water vapour is the main source of opacity in the Earth's atmosphere at infrared and millimetre to sub-millimetre wavelengths. The Africa Millimetre Telescope (AMT) is planned to be built on Mt Gamsberg in Namibia and aims to complement international VLBI networks like the Event Horizon Telescope (EHT) and the Global Millimeter VLBI Array (GMVA) at millimetre wavelengths, as well as the Africa VLBI Network (AVN) at cm wavelengths (Backes et al. 2017), with further possibilities to also be used for space geodesy.

Preliminary studies by Frans (2019, 2020) of the PWV at Mt Gamsberg and at the H.E.S.S. site were conducted, determining the PWV indirectly from IR-sky temperature data at the H.E.S.S. site. The PWV at Mt Gamsberg was determined by scaling the PWV from the H.E.S.S. site to what it would be at the height of Mt Gamsberg. Those studies indicate that Mt Gamsberg is a suitable site for millimetre wave astronomy, however it was recommended that direct PWV measurements should be taken to confirm the result of this study.

Meanwhile, research and development is undertaken to improve the state of water vapour radiometry in South Africa (Stander et al. 2020). Besides the long-term plan of developing low-cost site surveying instruments, also an existing dual-band 22/31 GHz radiometer was successfully refurbished, including substantial upgrades with most control function now embedded on a Rasberry-PI (Ferrusca et al. 2020).

With this newly refurbished instrument, first direct and in-situ measurements of the PWV will be conducted at the H.E.S.S. site and on Mt. Gamsberg, leading to conclusive results, supporting or disproving previous indirect measurements.

References:

Backes, M. *et al.*, The Africa Millimetre Telescope, Proc. 4th Annual Conf. on High Energy Astrophysics in Southern Africa (HEASA 2016), Cape Town, id.29 (23 June 2017); https://doi.org/10.22323/1.275.0029.

Ferrusca, D., *et al.* (*incl.* Stander, T.), *Embedded system upgrade based on Raspberry Pi computer for a 23/31 GHz dual-channel water vapor radiometer*, Proc. SPIE 11445, Ground-based and Airborne Telescopes VIII, 1144586 (13 December 2020); https://doi.org/10.1117/12.2561733

Frans, L.N., Evans, R., Backes, M., *Determination of the suitability of Mt Gamsberg in Namibia for millimetre wave astronomy by measurements of the precipitable water vapour*, 7th Annual Science Research Conference, Windhoek (November 2019).

Frans, L.N., *Determination of the suitability of Mt Gamsberg in Namibia for millimetre wave astronomy by measurements of the precipitable water vapour*, Master's thesis, University of Namibia (July 2020); http://hdl.handle.net/11070/2766.

Stander, T., *et al.*, *Progress toward improved water vapour radiometry: an overview of the South Africa-Mexico bilateral programme*, Proc. SPIE 11445, Ground-based and Airborne Telescopes VIII, 114451B (13 December 2020); https://doi.org/10.1117/12.2562017.

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.

The group at the University of Namibia has longstanding experience in site testing for astronomical instrumentation, including preliminary investigations of precipitable water vapour in the Mt Gamsberg / H.E.S.S. area. The newly refurbished 23/31 GHz dual-channel water vapour radiometer of HartRAO is readily available at the University of Pretoria with the Co-supervisor being the main expert in data retrieval from the instrument. Site access will be facilitated.

In addition to those local resources, the student is to benefit from the good relations of the supervisors to the group of Prof G. Cotter at the University of Oxford. We have a close, established working relationship, with Dr Backes being an Academic Visitor at Oxford and Prof Cotter being awarded a Visiting Professorship at UNAM. Prof Cotter will host the student for up to 3 months from the 3rd quarter of the first year where they will benefit from the broad research environment, especially in high-energy astrophysics and the SKA, as well as specialist graduate courses.

Potential objectives for this project would be:

Year 1: Coursework[1], including *Research Methodology and Project Proposal*. For the development of the Research Proposal also literature review on mm-radio wave attenuation by water vapour and water vapour radiometry.

Year 2: Installation and calibration of the instrument, data-taking, data-analysis, cross-calibration with other available instruments, and interpretation.

3. Link to priority SARAO areas 2021:

Link the proposed project to one or more of the SARAO research priority areas for 2022 (refer to Section 5 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).

This project on atmospheric site characterization lies at the interface between Science and Engineering and is, hence, ideally suited to be co-supervised by a scientists and an (electronics) engineer. As for the setting up of SARAO research priorities, this project is classified as engineering project, relating to the priorities

[1] Following the rigorous processes of registering programmes on the National Qualifications Framework (NQF) of the Namibian National Qualifications Authority (NQA) and subsequent accreditation of such programmes by the National Council of Higher Education (NCHE), the Department of Physics at the University of Namibia offers a 2-year Master of Science in Physics programme, which is comprised of 1 year of coursework and a 1 year thesis, see https://www.unam.edu.na/faculty-of-science/physics/postgraduate-qualifications?qualificationid=3456. Please note that no Masters programme in Physics is offered based solely on a research project.

5.2.1 “Radio astronomy antennas and receiver systems (including digitisation) associated with supported and hosted instruments”, with the AMT, particularly within the AVN, being since early planning phases a SARAO supported instrument.

4. Student background:

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 preferred candidate would have a firm undergraduate background in data analysis and handling/readout of electronics equipment, having completed (preferably) a related final year B.Sc.(Hons)[2] project in Astrophysics.

[2] B.Eng.(Hons) graduates would be suited for the project as well but as outlined in footnote 1, UNAM may only offer MSc by coursework and thesis, where the compulsory coursework includes e.g. modules on *Advanced Quantum Mechanics* and *Advanced Classical Mechanics* which require sound foundation in those subjects, being unlikely for B.Eng.(Hons) graduates.