Section A: Overview of the Research Project Proposal

1. Academic level:	MSc
2. Broad field of research:	Astronomy/Astrophysics
3. Title of the research project:	Quasar jet structures at ~300 micro-arcsecond angular resolution using Event Horizon Telescope imaging algorithms
4. Supervisors:	Prof Roger P. Deane / Dr Alet de Witt
5. Institutions:	University of Pretoria / HartRAO

Section B: Research Project Proposal

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.*

Very Long Baseline Interferometry (VLBI) is a technique where radio telescopes from different geographical locations simultaneously observe a source to provide the highest resolution imaging and precision astrometry (at sub-milli-arcsecond and tens of micro-arcsecond scales respectively). Geodetic and astrometric VLBI observations of extragalactic radio sources at 2.3 GHz (S-band) and 8.4 GHz (X-band) are used to define the International Celestial Reference Frame (ICRF), a quasi-inertial radio reference frame adopted by the International Astronomical Union (IAU) in 1997. In turn, geodetic VLBI observations of these reference sources are critical to many applications, for example, the realisation of the International Terrestrial Reference Frame (ITRF); calculating the orientation of the Earth in space; providing calibrator sources for parallax measurements, as well as for imaging faint sources in astronomy; studying the motion of tectonic plates; measurements of the sea level rise; and spacecraft navigation, to name but a few.

Bright extragalactic radio sources that are well suited to improve the high-accuracy reference framework must be compact or core-dominated on VLBI scales. However, at the standard S/X frequencies, many ICRF sources exhibit spatially extended intrinsic structures that may vary with time, frequency and baseline projection. Such structures can introduce significant errors in the VLBI measurements thereby degrading the accuracy of the estimated source positions. On VLBI scales, sources generally appear more compact at higher frequencies (see Fig 1). It may, therefore, be possible to reduce source structure effects by transitioning to higher frequency VLBI observations. However, while spatially-resolved sources are not desirable for astrometric purposes, they could be of great interest from an astrophysical standpoint, including rare objects such as binary, offset or recoiling supermassive black holes and complex relativistic jet structures that probe the physics of these central engines. **The identification and high-fidelity imaging of these resolved objects is therefore of key dual importance in this project.**

A K-band (24 GHz) celestial reference frame of 919 quasar sources covering the full sky has been constructed using over 0.5 million observations from 68 observing sessions from the Very Long Baseline Array (VLBA) and two radio telescopes in the South, the HartRAO 26 m telescope in

South Africa and the Hobart 26 m telescope in Tasmania. As previously outlined, observations at K-band are motivated by their access to more compact source morphology and reduced core shift relative to observations at the historically standard S/X-band (2.3/8.4 GHz). Some preliminary K-band imaging results from the VLBA strongly support this expectation. These have been produced with standard VLBI imaging software.

The aim of this proposed MSc project will be to produce images of sources observed in the K- band ICRF using the VLBA, to determine their suitability as reference sources, and identify sources of astrophysical interest. These higher frequency data should show more compact structure due to the lower brightness temperature sensitivity, which this project will verify. In addition, multi-epoch VLBA imaging can be used to compare the direction of radio-optical and radio-radio astrometric offsets with jet direction. We have ~40 sources that show > 5 sigma astrometric optical-radio offsets, that will be a priority for imaging.

The imaging using traditional software with be compared with the results of cutting-edge imaging algorithms developed for high-frequency VLBI by members of the Event Horizon Telescope (EHT) Consortium, of which co-supervisor Deane is a member. This software has been demonstrated to perform better than traditional methods if suitably tuned, as seen in VLBA 43 GHz observations of the is the one-sided jet of M87, as reported in Chael et al. 2016.

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.*

Calibration and imaging of a large number of VLBI datasets can be a computationally expensive process, however, the University of Pretoria is extremely well equipped to perform this, by virtue of its membership to the Inter-University Institute for Data-Intensive Astronomy (IDIA).

The datasets used have been successfully calibrated and imaged using traditional techniques, so there is no risk to the project from that perspective. All that remains is for the student to apply some of the sophisticated imaging and self-calibration algorithms developed as part of the EHT effort to this data suite.

All required VLBI data for this project is already in hand.

3. **Link the proposed project to one or more of the SARAO research priority areas for 2020** *(refer to Section 4 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).*

This project relates directly to VLBI Science as well as data processing and interferometric calibration.

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.

Some experience with interferometric calibration and imaging will be beneficial but not essential.