Section A: Overview of the Research Project Proposal

1. Academic level:	PhD
2. Broad field of research:	Astronomy/Astrophysics
3. Title of the research project:	Binary supermassive black holes in post-merger galaxies
4. Supervisor:	Prof Roger P. Deane
5. Institution:	University of Pretoria

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.*

The primary objective of this project is to search for binary AGN in a VLBA 5 GHz snapshot survey of 91 FIRST/SDSS-selected, visually-identified post-merger galaxies. Important ancillary science is to explore the radio-jet feedback mechanism at spatial scales unachievable at other wavelength for a comparable redshift range (z~0.1). The size of this targeted VLBA search in clearly disrupted host galaxies makes this a promising sample to identify low separation (<< 1 kpc) secondary companion SMBHs and attempt to constrain the binary AGN merger rate (although this will depend on the number of confirmed binaries).

To provide some contextual background, binary supermassive black hole (SMBH) systems have long been predicted to be common in the Universe (Begelman, Blandford & Rees, 1980), a natural consequence of most massive galaxies hosting nuclear black holes and hierarchical galaxy assembly through mergers (Kormendy & Richstone, 1995, Volonteri et al. 2003). Simulations suggest that they have a broad range of astrophysical impacts, including shallowing the inner density profiles of galactic halos as they eject stars via three-body interactions during in-spiral (e.g. Graham 2004, Merritt 2006); and an increase in bulge star formation and black hole accretion through disruption of cold gas angular momentum (e.g. van Wassenhove 2012). Furthermore, sub-parsec binary SMBHs are expected to dominate the stochastic gravitational wave background at nHz-μHz frequencies (Wyithe & Loeb 2003, Sesana 2013). Despite their forecasted ubiquity and importance to gravitational wave astronomy, our observations of these systems are very limited. The great challenge in understanding the late stages of binary SMBH orbital evolution is the extreme angular resolution required. A wide range of novel, yet mostly indirect attempts to make inferences on binary SMBH orbital evolution have been proposed and attempted with limited success. For example, high resolution optical/near-infrared imaging of nearby galactic nuclei has been used to attempt to measure the so-called `core deficits' or `missing mass' that results from a hardened binary inspiral ejecting stars through three-body interactions (Merritt 2006). Spatial offsets between AGN and their host galaxy photocentres have been measured to constrain the amplitude and rate of expected anisotropic gravitational-wave radiation that results from a binary SMBH merger, thereby displacing it from the host galaxy central potential. In addition, there have been velocity offset searches for recoiling black holes.

Clearly the above approaches illustrate that this is a challenging observational goal, requiring indirect methods with supreme quality data. To date there are very few strong binary/dual AGN candidates with spatially-resolved projected separations less than ~1 kpc, where the two lowest separation systems were both identified using VLBI. However, the inefficiency of VLBI surveys and limited time on global VLBI arrays prohibits large-scale searches of >>100 objects required to ensure an expected binary SMBH prevalence of >>1. Therefore, in order to maximise the discovery potential of VLBI, great emphasis must be placed on target selection.

VLBI imaging of a recently merged galaxies is clearly a comparatively easy and compelling approach to tackling this observational challenge. This PhD project will shed light on to what extent that is true, and make an estimate of the binary AGN merger rate based on this post-merger sample.

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.*

All required data (VLBA 5 GHz and SDSS value added catalogue data) is in hand and the supervisor of this project has already processed much of these data himself without any issues. The processing will be performed on the IDA Cloud.

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 links directly to VLBI science and to interferometric data processing and calibration, for obvious reasons. It also links indirectly to the MeerKAT MeerTime LSP, since the prevalence binary SMBHs is a key constraint in predicting or interpreting the detection of the stochastic gravitational wave background - hence it has indirect links to Science topics with MeerKAT.

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.

Experience in interferometric calibration and imaging will be beneficial but not essential. A strong physics and/or programming background will help significantly.