Research Project Proposal for Doctoral Research 2020

Project title: VLBI Exploration of the Spatio-kinematics of Masers in Massive Star-forming Regions

Section A: Overview of the Research Project Proposal
1. Academic level of research project: Doctoral
2. Broad field of research: Astronomy/Astrophysics
3. Title of the research project: VLBI Exploration of the Spatio-kinematics of Masers in Massive Star-forming Regions

4. Full names of supervisor and co-supervisor: Prof James Okwe CHIBUEZE
5. University where postgraduate student would be registered: North-West University

Section B: Research Project Proposal

1. Scientific merit:
Despite a large impact on astrophysics and astrochemistry, high-mass star formation remains poorly understood due to short evolutionary timescales, clustering, large distances, and heavy obscuration (Zinnecker & Yorke 2007). Statistical studies on quantitative properties of high-mass young stellar objects (HM-YSOs) and their evolution are usually examined by spectral energy distributions (SEDs). However, SED-based parameters highly depend on a model of circumstellar structures. Therefore, direct observations of detailed circumstellar structures are definitely essential for addressing the evolution of HM-YSOs and their feedback history. Furthermore, source-to-source diversities of jets/outflows, disks, and envelope structures also contain important suggestions both on initial condition and evolutionary process of high-mass star formation.

Various masers are known to be associated with a large number of HM-YSOs, and hence have been em- ployed in high-mass star formation studies. Water (H_2O) masers at 22 GHz trace shocked gas associated with various kinds of dynamical structures including jets, outflows, disks, and HII regions. Methanol (CH_3OH) masers are divided into two classes (Menten 1991); class I (e.g. 44 GHz) are usually located farther from HM-YSOs (Kurtz et al. 2004) while class II (e.g. 6.7 GHz) are located close to HM-YSOs (Fujisawa et al. 2014). Because of extremely high intensities, 22 GHz water masers and 6.7 GHz methanol masers (i.e. the strongest methanol maser) have been employed for very long baseline interferometry (VLBI) observations of HM-YSOs at ~1 milli-arcsecond (mas) resolution. In addition, we have reported the first VLBI imaging of the spatially extended 44 GHz methanol maser features (Matsumoto et al. 2014), demonstrating the unique capability of KaVA. These multiple masers are complementary with each other for investigating 3D structures and dynamics around HM-YSOs by well-planned multi-epoch high resolution VLBI studies, which are unique in the ALMA era.

Objectives of the HartRAO/EVN observations

This project aims conduct systematic monitoring observations of 22 GHz water and 6.7 GHz class II methanol masers. Our primary goal is to understand the dynamical evolution of HM-YSOs and their circumstellar structures by measuring the distributions and 3D velocity fields of the three different maser species including the 6.7 GHz class II methanol masers observed with European VLBI Network (EVN) and monitored by HartRAO.

Through this project, we will address key issues in high-mass star formation. First, we will establish an evolutionary sequence of different maser species with statistical samples. Although various maser species are known to be associated with HM-YSOs, their relationship is still unclear (e.g. Ellingsen 2007 vs Reid 2007). This is mainly due to a lack of high spatial resolution data to resolve HM-YSO clusters. We will investigate 3D velocity structures of three maser species at a resolution of ~1 mas to identify their possible powering sources at a scale of ~1000 AU (Fujisawa et al. 2014), by combining ancillary follow-up data.

In addition, this project will provide powerful tools to reveal driving mechanism of jets/outflows from HM- YSOs. Jets/outflows are one of the most important processes in star formation because of their significant roles to extract angular momentum (Hirota et al. 2017). Beuther & Shepherd (2005) proposed that initially well-collimated jets/outflows from HM-YSOs evolve into wide opening-angle outflows. However, Seifried et al. (2012) suggested an opposite scenario from their 3D MHD simulations, in which poorly-collimated outflows evolve into well-collimated developing Keplerian disks. Thus, it is worth establishing a scenario explaining when and how jets/outflows from HM-YSOs with different morphology are forming and evolving.

By combining HartRAO/EVN observations with VERA (distances), JVN/EAVN (6.7 GHz methanol masers), and ALMA cycles 3 and 6 (sub-mm continuum/thermal lines), we will provide novel information on physical properties (density, temperature, size, mass), 3D dynamical structures of disk/jet/outflow/infalling envelope, and relationship between maser species and evolutionary stages of HM-YSOs.

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.

Single-dish monitoring observation data (from HartRAO 26m telescope) is already available. The project will mine this data and propose follow-up observations where need be. Also there are existing EVN archival data that will be used for the purpose of this project and more observations will be done with the EVN (including HartRAO) if more observations are required.

We have a small cluster at the Centre for Space Research, North-West University that will be sufficient for the data processing and analysis.

It is expected that by the end of the first year, the student would have mastered AIPS/ CASA data reduction of the VLBI data.

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).

HartRAO constitute one of the research priorities of the SARAO. Granted, South African have contributed to scientific knowledge with the instrument especially in single-dish mode. However, most of the VLBI time of the HartRAO telescope as part of the EVN has benefited European scientist more. This is the first attempt at drawing large scale benefit from the HartRAO's EVN membership.

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.

MSc degree required for enrolment. Good data processing skill with AIPS/CASA and python. Ability to communicate properly in oral and written English is necessary.