Section A. Overview of the Research Project

Title of the research project: Accretion and Outflows in Accreting Compact Binaries (ThunderKAT)

Broad area of research: Science

Academic level of research project: Masters

Abstract of research project:
This Masters project is focused on the study of accretion and outflows in accreting compact binaries and is linked to either the X-ray binary or the Cataclysmic Variable component of the MeerKAT large survey project ThunderKAT. You will have a choice of working on relativistic outflows in a black hole X-ray binary in outburst, or on a comparative MeerKAT study of the newly discovered radio-bright cataclysmic variable LAMOST J0240 and the unique magnetic propeller system AE Aqr.

Primary supervisor's details:
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University of Venda (Adjunct)

Co-supervisor's details:
Prof Rob Fender
University of Oxford

Please note that this project will be offered at **the University of Venda**, where Prof Woudt is an Adjunct Professor in the department of Physics.

Section B. Details of the Research Project

Scientific merit:

ThunderKAT is the approved and ongoing large survey project on MeerKAT for the study of X-ray binaries, Cataclysmic Variables, Type Ia Supernovae and short Gamma-Ray Bursts, as well as the commensal search for (image-plane) radio transients in all MeerKAT large survey project data. The goal of ThunderKAT is to identify and understand high energy astrophysical processes via their radio emission, often in concert with observations at other wavelengths (e.g. X-ray, optical, UV). For a detailed overview of the science case of ThunderKAT we refer the reader to Fender et al. (2017).

In this proposed Masters project you will work with the two co-PIs of ThunderKAT (Profs Woudt and Fender) to study the radio emission in accreting compact binaries. Depending on your scientific interest, this could either be the MeerKAT radio study of accreting black holes or neutron stars in compact binaries, also known as *low-mass X-ray binaries*, or, the MeerKAT radio study of accreting white dwarfs in compact binaries, also known as *Cataclysmic Variables*.

I. X-ray binaries

Over the past 2.5 years, the ThunderKAT project has used MeerKAT to study how varying accretion states in black hole X-ray binaries affect the power and type of kinetic feedback from the black hole via winds and jets. The best way to study the global connection between accretion and outflow in X-ray binaries is the radio/X-ray plane, where the variation in X-ray luminosity is a proxy for the varying accretion states and the radio luminosity a measure of the outflow. In Figure 1, we show the MeerKAT observations of the black hole X-ray binary H1743-322 against Swift (X-ray) observations in the radio/X-ray plane (Williams et al. 2020).

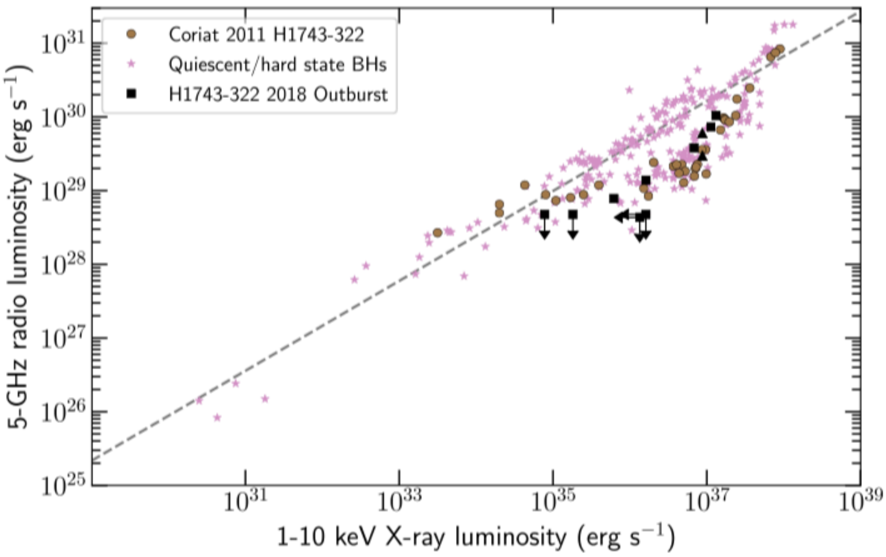

Figure 1. The radio/X-ray plane of the black hole X-ray binary H1743-322 during its 2018 outburst (black dots); the pink stars represent other black hole X-ray binaries, the brown circles represent previous outbursts of H1743-322 (from Williams et al. 2020).

When X-ray binaries transition into a high accretion state, they typically remain in outburst for weeks or months. With ThunderKAT we monitor X-ray binaries in outburst on a weekly basis. During any week, there are typically between 2 and 5 sources in outburst that we can observe with MeerKAT. There is one black hole X-ray binary (GX339-4) that we observe every week, regardless of its accretion state. Early results of MeerKAT observations in a low state in GX339-4 were presented by Tremou et al. (2020).

In some of the black hole X-ray binaries we can resolve the relativistic outflow (jets) from these systems with MeerKAT thanks to the excellent sensitivity of MeerKAT. A spectacular example of that is shown in Figure 2, where we see the outflow from MAXI J1820+070 as imaged by MeerKAT and other radio telescope arrays (Bright et al. 2020).

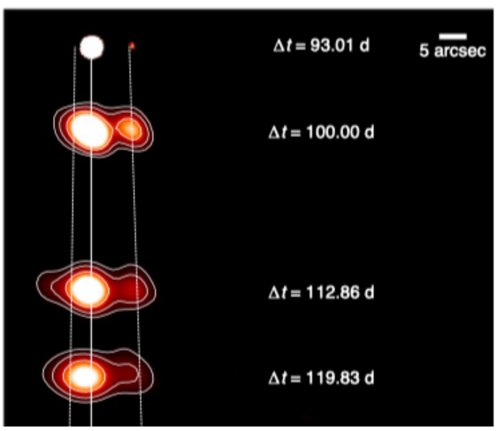

Figure 2. A few of the MeerKAT images of the core and the expanding ejecta of the black hole X-ray binary MAXI J1820+070 (from Bright et al. 2020).

To date, ThunderKAT observations have already led to seven publications of MeerKAT observations of black hole binaries, resulting in various new insights in the relation between the accretion state and the (relativistic) outflow in these systems: MAXI J1535-571 (Russell et al. 2019), GX339-4 (Tremou et al. 2020), MAXI J1820+070 (Bright et al. 2020, Espinasse et al. 2020), H1743-322 (Williams et al. 2020), MAXI J1348-630 (Chauvan et al. 2021), MAXI J1631-479 (Monageng et al. 2021), GRS 1915+105 (Motta et al. 2021).

If you were to choose a ThunderKAT Masters project on X-ray binaries, you would take ownership of a weekly monitoring data set of a new or previously known black hole X-ray binary in outburst which we have observed with MeerKAT. The data for this project will be ready for you at the start of your Masters. Simultaneous observations with the Swift X-ray telescope will be available to study the radio/X-ray behaviour. For some systems, simultaneous optical photometry from the MeerLICHT will be used to study the optical light curve during outburst.

II. Cataclysmic Variables

In a Cataclysmic Variable (CV), the accreting object is a white dwarf, accreting matter from a low-mass companion star. Recent studies (see Fender et al. 2017 for an overview) have shown that CVs are faint radio emitters. One of the better studied Cataclysmic Variables, the dwarf nova SS Cyg, shows many qualitative similarities to the radio properties of X-ray binaries. When it is in outburst, SS Cyg shows strong flares at the start and end of the outburst, and the flares are characterised by synchrotron emission, indicative of a jet outflow. The advantage of CVs over X-ray binaries is that they are more numerous (many thousands are known in the Milky Way), they are closer (distances of a few hundred parsec), and have more frequent (shorter-lived) outbursts (on time scales of days and weeks). They are great laboratories to study accretion physics.

ThunderKAT recently observed a volume-limited sample of nova-like CVs within 350 pc (Hewitt et al. 2020). Nova-likes are permanently in a high accretion state. From this sample, about 36% (4/11) were detected by MeerKAT using the L-band receiver. ThunderKAT also observed a twin system to the unique AE Aqr, namely LAMOST J0240, which turns out to be one of the most radio luminous CVs (Pretorius et al. 2021), see Figure 3. AE Aqr is unique in the sense that the white dwarf in this binary system is spinning with a period of 33 s, and part of the accretion flow is expelled from the binary system as the white dwarf acts as a propeller (Wynn, King & Horne 1997). LAMOST J0240 appears to be a similar system, a second of its kind.

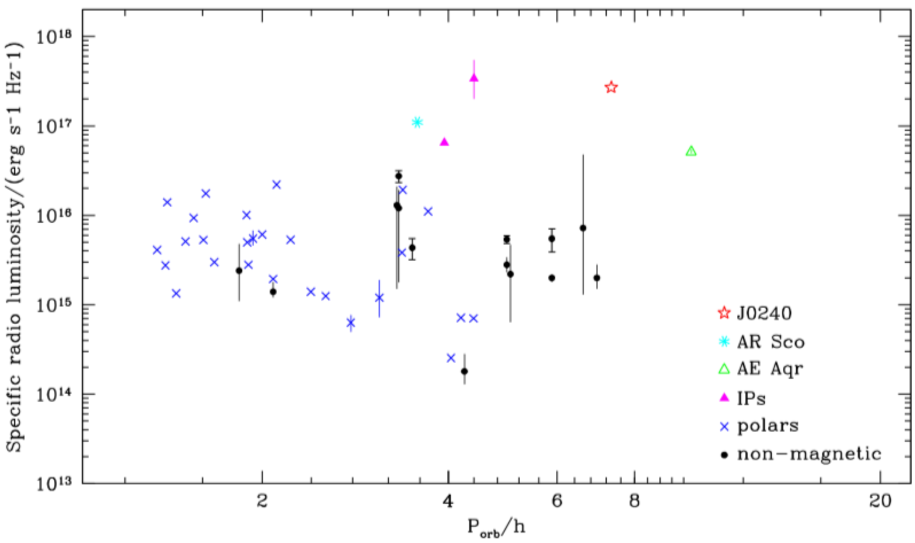

Figure 3. Radio luminosities as a function of orbital period. LAMOST J0240 is one of the most luminous CVs at radio frequencies (from Pretorius et al. 2021).

If you were to choose a ThunderKAT Masters project on Cataclysmic Variables, you would take ownership of a MeerKAT data set of both AE Aqr and LAMOST J0240, to perform a comparative analysis of these two CVs. The MeerKAT data will be complimented by higher frequency radio data from the AMI Large Array (UK), and by X-ray data from the Swift telescope.

References:

- Bright, J.S., et al., *An extremely powerful long-lived superluminal ejection from the black hole MAXI J1820+070*, 2020, Nature Astronomy, 4, 697-703
- Chauvan, J., et al., *Measuring the distance to the black hole X-ray binary MAXI J1348-630 using HI absorption*, 2021, MNRAS Letter, 501, L60-L64
- Espinasse, M., et al., *Relativistic X-ray jets from the black hole X-ray binary MAXI J1820+070*, 2020, ApJ, 895, L31
- Fender, R., et al., *ThunderKAT: The MeerKAT Large Survey Project for Image-Plane Radio Transients*, 2017, in MeerKAT Science: On the Pathway to the SKA, Proc. of Science, 277, id. 13
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- Monageng, I.M., et al., *Radio flaring and dual loud/quiet behaviour in the new candidate black hole X-ray binary MAXI J1631-479*, 2021, MNRAS, 501, 5776-5781
- Motta, S., et al., *Observations of a radio-bright, X-ray obscured GRS 1915+105*, 2021, MNRAS, in press (arXiv:2101.01187)
- Pretorius, M.L., et al., *Radio and optical observations of the possible AE Aqr twin, LAMOST J024048.51+195226.9*, 2021, MNRAS, in press [arXiv:2102.08800]
- Russell, T.D., et al., *Disk-jet coupling in the 2017/2018 outburst of the Galactic black hole candidate X-ray binary MAXI J1535-571*, 2019, ApJ, 883, id. 198
- Tremou, E., et al., *Radio & X-ray detections of GX 339-4 in quiescence using MeerKAT and Swift*, 2020, MNRAS, 493, L132-L137
- Williams, D.R.A., et al., *The 2018 outburst of the BHXB H1743-322 as seen with MeerKAT*, 2020, MNRAS, 491, L29-L33
- Wynn, G.A., King, A.R., Horne, K., *A magnetic propeller in the cataclysmic variable AE Aquarii,* 1997, MNRAS, 286, 436

Feasibility:

This project is offered as part of the ongoing ThunderKAT Large Survey Project on MeerKAT (2018-2023). Depending on the scientific interest of the candidate, this project can be offered either within the *Cataclysmic Variable component* of ThunderKAT, where we study accretion and outflows in compact white dwarf accreting systems, or within the *X-ray Binary component* of ThunderKAT, where we study accretion and outflows in compact neutron star or black hole accreting systems.

Both of these components on ThunderKAT are very active and have demonstrated their feasibility and impact on MeerKAT through numerous new high impact results and publications. The MeerKAT data will be available at the start of the Masters project. The data analysis will take place on the IDIA/Ilifu research cloud. The ThunderKAT collaboration has extensive experience in the use of the data pipeline on the IDIA/Ilifu cloud. The first three months will include a detailed background study into the nature of the compact binary, and training on the use of the IDIA/Ilifu cloud. The next 6 months will include the reduction and analysis of the MeerKAT data, followed by a 6-9 month period for a detailed multi-wavelength interpretation, and write up of the results.

SARAO Priority Area: MeerKAT Science

Pre-requisites: A BSc Hons degree in Astronomy or Physics. Good knowledge of Python will be advantageous.