SARAO project proposal for 2021

Geoff Beck

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1 Overview of the proposal

- Research level: Masters
- Field: Astrophysics
- Title: Probing the Madala hypothesis with MeerKAT
- Supervisor: Dr Geoffrey Martin Beck
- Institution of registration: University of the Witwatersrand

2 Research project proposal

The nature of dark matter is one of the great hiatuses of cosmology and astrophysics in the modern era. Could this astrophysical anomaly, as well as anti-particle excesses observed by AMS2, be related to the physics of leptonic anomalies emerging at the LHC? In this project the student will investigate the potential of MeerKAT to detect the products of annihilating or decaying dark matter particles connected with the Madala hypothesis. This hypothesis was proposed by South African physicists to account for the discrepancies from the standard model observed in the LHC data. In particular, the focus is upon predicting the synchrotron emission produced by electron annihilation/decay products in the magnetic fields of galaxy clusters. This project will introduce the student to the fusion of particle and astrophysics as well as the science of indirect dark matter hunting in the radio band, with this knowledge the student will be able to use MeerKAT galaxy cluster survey data to test predictions related to the Madala hypothesis, simultaneously exploring the cosmic and particle scales.

2.1 Scientific merit

Being such a major constituent of the universe, dark matter is a key mystery in the present cosmological picture. Indirect dark matter detection has been an active field of work in the recent past, with a focus upon gamma-ray experiments, due to the low expected gamma-ray backgrounds. In contrast, there are often copious baryonic radio emissions in cosmic structures and radio emission from dark matter depends strongly on the magnetic field configuration. However, new generation radio telescopes like MeerKAT provide us with the means to overcome the traditional obstacles to indirect radio probes of dark matter. This is possible because these telescopes can probe very faint diffuse fluxes, ideal for comparing to dark matter predictions. Additionally, once fully operational, MeerKAT will be able to begin the study of cosmic magnetism envisioned for the SKA, providing much-needed data to tease out robust limits on the properties of dark matter.

At the same time multiple controversial excesses have been observed by various cosmic-ray experiments such as PAMELA, DAMPE, and AMS2 [1, 2, 3]. These astrophysical excesses have now begun to be joined by leptonic anomalies in Large Hadron Collider (LHC) [4, 5] particularly associated the Madala hypothesis which adds several scalar bosons to account for LHC anomalies [6, 7, 8]. These two families of excesses and anomalies have the exciting possibility of being related, as the Madala hypothesis can provide a dark matter candidate, and dark mater explanations are often discussed for the astrophysical anomalies. One can test this by assuming the anomalies are generated by a Madala candidate, and then predicting what should be consequently observed by MeerKAT in various dark matter rich environments.

Initial studies in the radio-frequency indirect detection field have been conducted by Regis et al [9], making use of the ATCA instrument, these studies probed promising dwarf galaxies for diffuse radio emissions, reaching a nominal sensitivity of ≥ 10 μJy (in particular for the promising Reticulum II dwarf galaxy 10 μJy was achieved in 30 h of observations as its position on the sky minimises galactic foregrounds). Despite relatively large uncertainties in the magnetic environment (as ATCA was not sensitive enough to perform μG rotation measure probes) Regis et al 2017 produced highly competitive constraints on annihilation cross-section or decay-rate of dark matter particles, these constraints are very similar to those coming from Fermi-LAT gamma-ray studies, and in the case of the decay rate, can exceed the gamma-ray results. A more sensitive instrument would allow the probing of fainter flux levels, providing the potential to make indirect radio detection with MeerKAT a leading probe of the properties of dark matter.

However, we are not limited to dwarf galaxies. This is especially relevant due to the presence of diffuse radio emissions in galaxy clusters, with MeerKAT being able to probe far fainter diffuse emissions than previously possible, this can be directly compared to expected diffuse dark matter produced radio emissions. X-ray selected clusters in particular have the potential to be able to compare dark matter emissions only to the non-thermal synchrotron fluxes [10], producing increasingly tight constraints on dark matter properties. Clusters have been motivated for indirect radio detection in the past (see Colafrancesco et al 2006 [11]) and it has been shown in Beck 2016 [12] that new rotation measure studies of magnetic field properties provide highly competitive dark matter limits. Thus, there is room for MeerKAT data to make a significant impact on the hunt for dark matter via this avenue.

2.2 Feasibility

This project can be conducted on data from observations of galaxy clusters available from the MeerKAT cluster survey. The central issue will be extraction of diffuse emissions from the MeerKAT data. This will be handled with the help/advice of Prof Roger Deane at UP and Dr Kenda Knowles at UKZN, as their areas of interest overlap with the project in this regard. On the particle physics front, the support of Prof Bruce Mellado at Wits will enable us to work closely with the group that formulated the Madala hypothesis itself. The high sensitivity MeerKAT can achieve indicates that it should be able to exceed the results of aforementioned Regis et al studies and produce more advanced limits on dark matter, while probing the exciting Madala hypothesis, via higher quality data.

The methods employed will be largely computational and Wits provides excellent resources in this regard, with the astrophysics group having its own cluster computing facility for intensive computations. The student will simulate radio emissions from dark matter annihilation/decay for specific environments that would observable with MeerKAT. An existing tool to predict dark matter emissions has been produced by the supervisor [12, 13], so the student will not have re-invent this complicated programming wheel. Environmental details (details of the dark matter halo and magnetic fields) for target environments must be sourced from the literature by the student. The produced predicted emissions will then have to be compared to actual MeerKAT data (or sensitivities) by the student. Thus, the student will become familiar with data products and the with the underlying theory.

2.3 Link to SARAO priorities

This project is tailored to the use of MeerKAT and exploiting its better than expected technical capabilities. The link to SARAO priorities is thus very strong and allows MeerKAT to participate in cutting edge probes of fundamental scientific questions.

3 Supervisor details

- Name: Dr Geoffrey Martin Beck
- Institution of permanent employment: University of the Witwatersrand
- Email: geoffrey.beck@wits.ac.za

Name	Nationality	PhD start	PhD end	Title of thesis	Co-supervisor
Siphiwe Thwala	SA	Jan 2018	Dec 2020	Machine learning and diffuse radio emissions	
Ahmed Ayad	Egypt	Jan 2018	Dec 2020	Axion phenomenology in astrophysics	

Name	Nationality	MSc start	MSc end	Title of thesis	Co-supervisor
Mpho Kgoadi	SA	Jan 2019	Dec 2020	Dark matter in the epoch of reionisation	
Michael Sarkis	SA	Jan 2018	March 2020	Dark matter and mass extinctions	
Tanita Ramburuth-Hurt	SA	Jan 2018	March 2020	Dark matter hunting in spiral galaxies with MeerKAT	Dmitry Prokhorov
Raees Noorbhai	SA	Jan 2020	Feb 2022	Multi-frequency dark matter searches in dwarf galaxies	
Ralekete Temo	SA	Jan 2020	Feb 2022	Hunting dark matter with MeerKAT	

4 Signatures

Dr Geoffrey Beck, 20 September 2019

References

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[13] G. Beck, *An excess of excesses examined via dark matter radio emissions from galaxies*, *JCAP* **1908** (2019) 019 [1905.05599].