Combining MeerKAT and ALMA Observations to Explore Environmental Influences on the Cold Gas Reservoirs of Dwarf Galaxies in the Virgo Cluster

1. **Research Category**: Science
2. **Academic Level**: Master's
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5. **Research Project Summary**:
   This project will combine MeerKAT HI data from the Virgo Cluster multi Telescope Observations in Radio of Interacting galaxies and AGN (ViCTORIA) project and CO(2-1) observations from the Atacama Large Millimeter/submillimeter Array (ALMA) Atacama Compact Array (ACA) to study the effects of the Virgo cluster environment on dwarf galaxies. The student will reduce and publish the ALMA observations for five such dwarf galaxies for the first time, and compare these resolved molecular gas maps to the resolved atomic gas maps from MeerKAT to study in detail how both gas phases are affected by environmental processes.

Details of the Research Project

1. **Scientific Merit**:

   Dense environments harbour a relatively large fraction of passive galaxies[1,2], suggesting that the star formation in galaxies residing in such environments is quenched more rapidly than that in more isolated galaxies in the "field". With almost half of the galaxies in the local Universe residing in groups or clusters[3], understanding environmentally driven galaxy evolution is key. Broadly, there are two categories of environmental processes: hydrodynamical interactions, such as the lack of gas accretion ("starvation") and the more violent removal of the interstellar medium (ISM) through ram pressure stripping (RPS)[4]; and galaxy-galaxy interactions, which are typically high-speed flybys[5]. A key question is which (combination of) processes is most effective at quenching star formation, and to what extent this varies between environments.

   Distributed in extended discs and relatively loosely bound, HI has long been an effective tracer of these processes[6–10]. With the introduction of the SKA precursors, however, these studies have become much more detailed, pushing the limits of sensitivity and resolution[11–13]. In fact, probing the atomic gas in galaxies in dense environment is one of MeerKAT's primary scientific objectives. One significant benefit is the ability to now trace HI in much lower-mass galaxies than previously possible[11]. Dwarf galaxies, which are plentiful in galaxy clusters, have historically been underrepresented in environmental studies, which have predominantly focused on more massive spiral galaxies.

   Because of their low gravitational potentials, the ISM of low-mass galaxies are easily affected by their environment, making them excellent probes of external quenching mechanisms in a variety of wavelengths. Furthermore, low-mass galaxies are the most common galaxies in the Universe (including in clusters, where dwarf ellipticals are especially abundant), and the building blocks of their more massive counterparts. Thus, if we aim to understand the formation history and evolution of galaxies, we need to include these objects in our studies. Optical photometry of dwarfs in clusters have revealed structures such as spiral arms, discs, bars, nuclei, and cores, suggesting that at least a fraction of them were originally (low-mass) spiral galaxies, that were transformed by the cluster environment[14,15].

   Additionally, while HI serves as a highly effective tracer of environmental processes, star formation ultimately occurs in molecular clouds. Therefore, to gain a comprehensive understanding of environmental quenching and the transformation of galaxies from active to passive states within the cluster environment, it is crucial to examine molecular gas in addition to HI, to cover this intermediate step.

   The proposed project will leverage data from the first blind MeerKAT survey of the Virgo cluster (ViCTORIA), combined with unpublished ALMA data that we have in hand, to investigate how environmental factors influence the evolution of dwarf galaxies in dense environments. While detailed studies of the cold interstellar medium (ISM) in galaxies within nearby clusters are a well-established research area, dwarf galaxies – abundant in such clusters – remain relatively underexplored. As a result, this project offers the student the opportunity to contribute a novel insight to one of MeerKAT's key research fields.

2. **Feasibility**:
   The ALMA data will be processed and imaged using CASA along with scripts provided by the ALMA support team. The resulting data cubes, in combination with the available MeerKAT data, will be analysed using software tools like CARTA and iDaVIE. Higher-level data products, including moment maps, position-velocity diagrams, and spectra, will be generated through custom `Python` scripts. To facilitate a meaningful comparison between the two datasets, post-processing techniques such as regridding and image smoothing will be applied. Standard mathematical methods will be employed to derive the necessary physical measurements.

3. **Skills Development**:
   This project will require the student to acquire a diverse range of skills. In addition to gaining an in-depth understanding of MeerKAT and familiarising themselves with the current status and literature on galaxy evolution in dense environments, the student will learn about interferometry and the process of interferometric data reduction. They will also enhance their `Python` programming skills, become proficient in using widely adopted software tools in the field, and develop their writing and communication abilities. The student will have exposure to international collaborations and gain insight into multi-wavelength astronomy. Furthermore, there will be ample opportunity to apply for follow-up observations, such as those with ALMA or SALT, allowing the student to gain experience in writing telescope proposals.

4. **Availability of Resources**:
   The necessary MeerKAT and ALMA data will be readily accessible to the student. They will have access to Ilifu for data processing and will be able to collaborate with researchers at UCT, SAAO, and international experts in the field, who will provide guidance and support throughout the project.

5. **Milestones and Time-frames**:
   In the first six months, the student will concentrate on familiarising themselves with the relevant literature and thoroughly exploring the MeerKAT and ALMA data. By the end of the first year, the data should be processed and imaged, with most high-level data products completed. In the first half of the second year, the student will focus on integrating and comparing the MeerKAT and ALMA datasets. The second half of the second year will be dedicated to data interpretation and writing up the results.

6. **Qualifications and Skills Required (if relevant)**:
   The student should possess a basic understanding of programming in Python, along with a background in galaxy evolution and interstellar medium (ISM) studies. Strong communication and writing skills, as well as effective time management abilities, will also be essential for success in the project.

References

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7 Alighieri et al., 2007, A&A, 474, 851
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10 Horellou et al., 1995, A&A, 303, 361
11 Serra et al., 2023, A&A, 673, A146
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