The dynamics of the interstellar medium in galaxy groups

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Section A: Overview of the Research Project Proposal

1. Title of the research project:

The dynamics of the interstellar medium in common galaxy groups

2. Broad field of research:

Astrophysics

3. Academic level of the research project:

PhD

4. Research project abstract/summary:

The student will scrutinize the properties of the interstellar and intergalactic medium in one or more galaxy groups observed at L-band (20-cm) to an extreme depth using the MeerKAT radio telescope. We will make use of the complete range of information that the radio observations will provide, the neutral hydrogen line to characterise the kinematics and dynamics of the cool gas in the galaxies and the intergalactic medium, the radio continuum to study the unobscured star formation properties of the member galaxies, and the polarization properties to obtain information about the magnetic-field structure of the target group. The data will be complemented at other wavelengths. The goal is to characterize the evolutionary status of the galaxies and the group as an entity and to determine in this case-study how the group environment influences the evolution of the single galaxies and their surrounding medium.

5. Primary supervisor's details

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Section B: Details of Research Project

1. Scientific merit

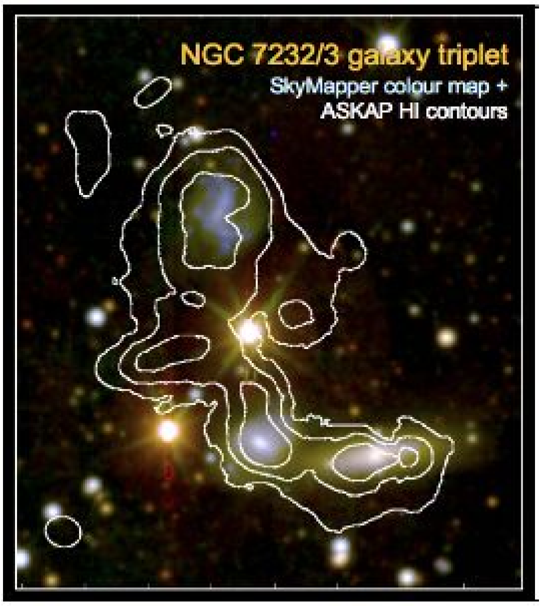
The pathway of galaxies transforming from star-forming disk galaxies into passively evolving elliptical or lenticular early-type galaxies is largely determined by their environment. On one hand galaxies accrete gas from the cosmic web, which allows them to actively form stars, on the other hand galaxies are depleted of their star forming material through interaction with other galaxies, groups, or clusters. Gas can be stripped from galaxies through tidal interactions, ram pressure stripping, and it can be ionized in the intergalactic UV field or simply be heated by gravitational interaction, making it inaccessible for star formation. Broadly speaking, galaxy evolution is hence understood, the shape and colour of a galaxy is determined by the (varying) surrounding galaxy density during its lifetime. It is the balance between the two processes that determine the current stage of a galaxy.

This picture is, however, an oversimplified one, and to truly understand galaxy formation one has to understand the details of these processes, where they occur, and how important the single paths of galaxy evolution are.

The field is the realm of late-type (spiral) galaxies, while early-type (elliptical and lenticular) galaxies mostly reside in galaxy clusters. Galaxy groups are an intermediate environment, where galaxies are often undergoing interaction and might change their morphology, before they enter, as a whole, into a cluster with its forces massively destructive to cold gas. A lot of evolution, however, happens in galaxy groups, the environment most galaxies are actually residing in. It is hence very important to get a detailed picture of this "galaxy pre-processing", which is so important for galaxy evolution in general.

In the scope of our radio imaging project, MeerKAT is gathering radio data of three

galaxy groups, which are in different evolutionary stages. The data allow us to study the motion and concentration of the neutral gas through the HI emission line, at an unrivalled depth, allowing us to see structures of the tenuous interstellar and intergalactic medium hitherto unseen. This neutral gas will, on one hand, reside in the galaxies themselves, on the other hand it will also be found in the intergalactic space between the galaxies, where it can be destroyed through heating, but also be re-accreted by the galaxies. The radio continuum data will also allow us to get an unbiased measure of the star formation rates in the galaxies, such that we can, using the radio data alone, get a picture whether the group galaxies form stars at an enhanced rate (and will hence will eventually lose it much faster than a normal galaxy), or whether their ability to replenish the young stellar population is already reduced. Using the polarisation of the radio continuum data, we will be able to study the magnetic fields inside the groups (and the galaxies), study where they arise and whether they play a role in the gas dynamics of the group and the galaxies.
In this project between the Australian research organization CSIRO, SARAO, and Rhodes university, the student will start with the analysis of one of the three groups, first studying the radio data themselves, but also combining them with observations of the group at other wavelengths. Those data either come from telescope archives or will be gathered during the PhD project.
The motion of the neutral atomic hydrogen of all group galaxies will be characterised in terms of rotation curves and more complex kinematics, contrasting observations with models, to find out how the neutral gas evolves in the group. Star formation properties will be derived from various indicators, to characterize the influence of the group environment on the single galaxies. Including the magnetic field structure in the group as traced through the radio continuum, we will attempt to create a complete picture of the galaxy group's past and future evolution and therefore contribute to a currently heavily disputed field.



Colour-composite of the NGC 7232 triplet (D = 24 Mpc), part of the NGC 7232 group. In contours: H I intensity map. This an example for tidal gas-stripping in an galaxy-galaxy interaction inside a galaxy group. Reference: Koribalski et al. (2020).

2. Feasibility and resources

The spectral line data needed for this Ph.D. project are being gathered as part of MeerKAT project SCI-20210212-BK-01. The NGC 3263, NGC 2434, and NGC 7232 galaxy groups will be observed with the maximum available integration time of 12h for high-velocity resolution data (32768 wideband channel mode). This will ensure that both the intergalactic HI and the continuum will be observed at very high sensitivity and resolution. Data from the Australian Telescope Compact Array are available for all three groups, giving us the possibility to compare results from both telescopes. The student will first concentrate on one galaxy group. We will decide later if more studies are possible in the scope of a PhD work. The student will search for archive data suitable to complement the study at other wavelengths. While the radio data alone and online data provide sufficient material for a PhD thesis, the student will apply for telescope time where appropriate. We have access to South African and Australian facilities.

RATT/RARG is in possession of several high-performance compute clusters and sufficient storage, such that there are sufficient resources to analyse the data. We will also make use of IDIA for data processing and creating smaller measurement sets, and CASS (Australia) where suitable HPC clusters exist. While a data cube as produced by MeerKAT can be very large, there are various techniques to reduce the data volume (it is e.g. not required to analyse the full bandwidth at full frequency resolution). Two types of 3D visualisation software developed by one of the scientific supervisors ("3Dvis", Koribalski) and within the broader group of collaborators ("iDaVIE", Jarrett) will aid the data analysis. We are using the very successful CARACal data reduction pipeline, partly developed by RATT, such that we can guarantee that the student will either be able to rapidly reduce the data or will have already reduced data at hand. The scientific supervisors and the broader scientific team connected to the project are firmly experienced and involved in software development for the techniques used to conduct the proposed analysis.

3. SARAO research priority areas

This project is addressing the following SARAO priority areas, ordered by relevance, from top to bottom:

- Data projected to be available by 2021-22 from key existing radio astronomy instruments located in South Africa, with MeerKAT having the highest priority: this is a MeerKAT project.

4. Student academic abilities / skills required

The student should have the ability to write Python scripts and be proficient in Physics. Some experience with the analysis of radio astronomical data, in particular data cubes is highly recommended. Experience in the kinematical and dynamical analysis of galaxies is welcome.