Measuring the presence of magnetic fields in the circumgalactic medium and around HVCs using the POSSUM survey

Olivia Walters

Supervisors: Craig Anderson, Naomi McClure-Griffiths

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Except where otherwise indicated, this thesis is my own original work.

Olivia Walters
23 February 2024

Acknowledgments

Who do you want to thank?

Abstract

High Velocity Clouds (HVCs) are a proposed solution to how extragalactic gas enters into star-forming galaxies. However, the presence of magnetic fields is required to ensure that HVCs can travel through the halo without being torn apart by ram pressure. This report aims to measure the strength of the magnetic fields present within the Milky Way's halo and surrounding circumgalactic HVCs, to determine if they can support HVCs as they travel through the Galactic halo. This report uses data from the ASKAP Polarisation Sky Survey of the Universe's Magnetism (POSSUM) to pull a series of rotation measures (RMs) across the southern sky. These RMs are then converted into magnetic fields using an algorithm, using previously collected data from the Smith Cloud and Leading Arm. Statistical analysis tools are then applied to confirm if hypothesised magnetic fields can support HVCs. The report finds that [Summary of discussion and conclusion] . . .

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Chapter 1

Introduction

1.1 Motivation

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1.2 Literature Reviews

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1.3 Objectives, novelty, and expected outcomes

The objective of this honours thesis is to:

1. Investigate the presence of magnetic fields surrounding circumgalactic HVCs using RMs collected from the POSSUM survey

2. Determine if these magnetic fields, from a "rough estimation" (i.e. is the number big enough), can allow HVCs to travel through a halo relatively undisturbed

3. (if there is time) More in-depth modelling surrounding the specific structure of magnetic fields surrounding HVCs and if this structure is preventing the formation of Kelvin-Helmholtz instabilities

While previous reports exist that have measured magnetic fields surrounding circumgalactic HVCs, most of this data is from HVCs in the Smith Cloud or Leading Arm. There so far has not been a substantial analysis of magnetic fields throughout HVCs across the entire southern hemisphere. This is important, as it could be the case that the Smith Cloud and Leading Arm are exceptional compared to the relatively homogenous Galactic halo.

Novelty also comes in the scope of the analysis, as a broad measuring of HVCs in the southern hemisphere means a much larger data set for future researchers to pull on. This report takes advantage of the fact that only recently has the POSSUM survey catalogued enough data to perform this operation.

The RM Grid analysis is of a higher sensitivity with POSSUM, with 30 reliable measurements per square degree compared to previous surveys only having 1 measurement per square degree. This makes the HVC data significantly higher in resolution.

Of course, the report will rely heavily on previous data. Magnetic field measurements in Smith Cloud and Leading Arm HVCs, simply as a means of providing a test data set, from which it can be confirmed that the program is working as intended. Previous location and spectral analysis of HVCs, specifically in the measurement of HI emission and absorption spectra, is used to not only know where the HVCs are, but also to determine important factors like optical depth or internal ionisation.

[SOURCE?]

Because this report is one of the first to measure magnetic fields surrounding HVCs, there are a few potential outcomes that this report needs to anticipate:

- There are magnetic fields that are strong enough to support HVCs. This would mean that HVCs can act as a significant explanation for how galaxies take in external gas. Future research from this would involve more in-depth modelling on magnetic fields, the setup of a northern hemisphere equivalent to POSSUM, investigation of extragalactic HVCs, or determining if the gas content in HVCs can fully account for the fuel demands of star-forming galaxies.

- Magnetic fields exist surrounding HVCs in the halo, however they are only strong enough to partially explain HVC transport, meaning that this report would give a percentage estimation to how much is missing in the explanatory power of collected magnetic fields. Future research would involve investigating other possible sources of stability for HVCs or attempting to find a different method for how gas enters galactic disks.

- The magnetic fields are either non-existent or too weak to support HVCs i.e. a null result. This potentially eliminates HVCs as an explanation for gas infall, meaning that we are back at square one. Future research would involve checking to confirm if the null result of the report is correct, or if there is wiggle room in the data for other HVCs in the Milky Way. It may also involve completely abandoning HVCs as a candidate for gas infall after more careful analysis is done.

(Future) Methodology

2.1 Data analysis

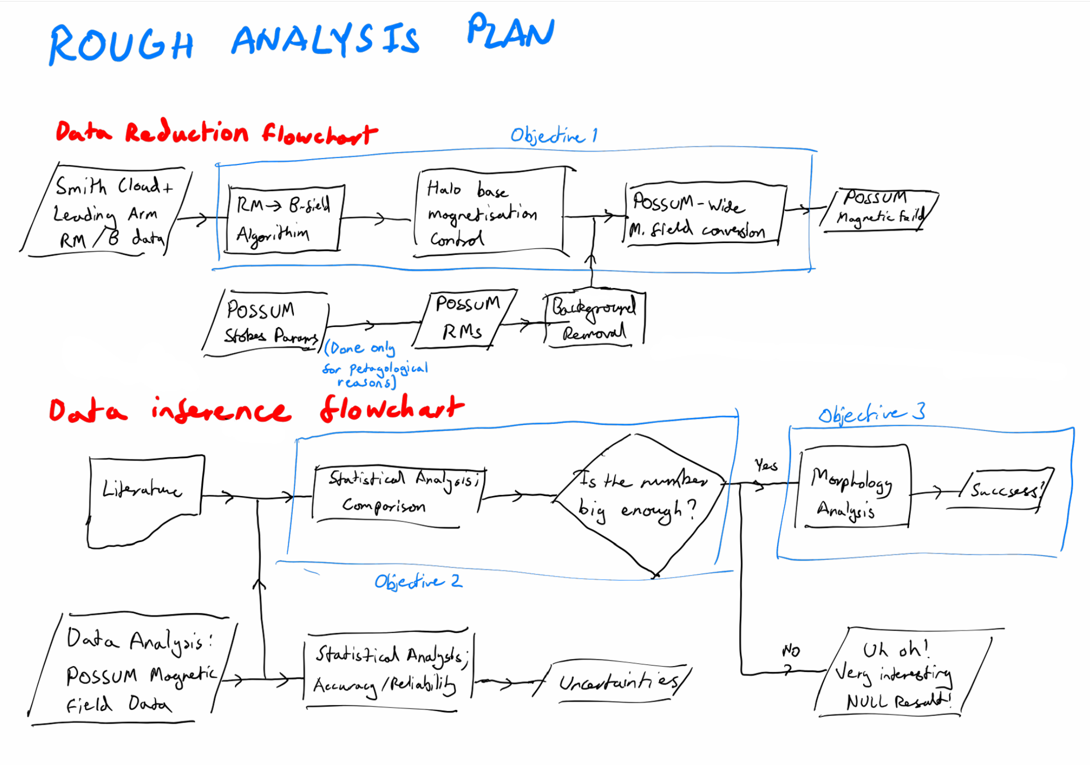

Figure 2.1: A rough flowchart of the data analysis method. A neater version of this flowchart will appear in future iterations of the report as a visual representation of the methodology.

Figure 2.1 represents the rough outline of the pipeline of data analysis as per the three objectives listed in 1.3.

The first point of data reduction is to convert the raw POSSUM data, i.e. stokes parameters in the field, to rotation measures. A component of research, revision, and programming will be dedicated to doing this. POSSUM as a survey has already condensed the stokes parameters into rotation measures. The purpose of doing it again is purely for pedagogical reasons - so that a better understanding about the nature of RMs is achieved. Purposefully, this part of the data reduction will only appear in perhaps a few sentences in the mid-term and final report, discussing how the POSSUM data was obtained.

Smith Cloud and Leading Arm HVC data will be obtained from a secondary source outside of POSSUM. The purpose of this data is to act as a testing set. Since past research has already determined the magnetic field strengths in HVCs in those regions, along with the base halo magnetisation. It is important that this data be used to confirm that the algorithm developed is working correctly.

After the program is developed to convert rotation measures into magnetic fields, data from the non-active components of the halo itself are then fed through the same algorithm. This will act as a control variable, providing a measure of base magnetisation for the Galactic Halo as well as pointing to a default ionisation state of the halo, which can support HVCs.

The halo control test will also help in the removal of background and foreground sources of Faraday rotation. The light used to measure polarisation comes from extragalactic synchrotron radiation, which is initially unpolarised. However, this radiation will have to travel a far distance before reaching us, at which point it can polarise from any sort of ionised gas in the Universe. HVCs will also be ionised in some manner, and it might be necessary to rely on spectroscopic observations of these HVCs to determine how much they will interfere with incoming light.

All these sources of interference can make it extremely difficult to determine the actual rotation measures in question. A background control run and analysis of the HVC can prevent this issue. RM interference is an active part of the process in radio astronomy, with aforementioned research that aims to tackle this problem. With a larger data set, however, there is more reliability simply because of the scope of data. In previous examples, as mentioned, HVCs in the leading arm can be obscured, which is a way HVCs in the halo can also experience faulty RMs. With more data comes more confidence and a better ability at eliminating outliers.

There are several methods by which one can convert rotation measures to magnetic fields, typically consisting of measuring kurtosis and skew. Other techniques for background removal include convolutional blurring, binned averages, signal whitening/bandpassing. Tools which will be investigated in literature while completing the implementation of objective 1.

Once all these processes are done, the algorithm should be fully capable of a simple pass-over across all HVCs in the entire southern sky. This step is the easiest, as it only involves repeatedly running an already completed script on several objects. After the program is developed, applied across all detected HVCs in the field, and the data is catalogued, the next step is to infer information from this data.

Most of the statistical analysis tools will be very basic, as objective 2 simply requires a rough estimate of the magnetic field strengths. Uncertainties will naturally arise from the program's mathematical evaluations. The K-S test will be used to compare magnetic field distributions to theoretical cases and example cases like the smith cloud. Simple averages, box plots, and other single-set analysis tools will be used to establish a characterisation of the sample. It Is expected, however, that HVCs that are further away from the Galactic disk will be more resolute as it is less contaminated by dust radio emission from the disk. This should be accounted for in the analysis of uncertainties.

Once these tests have been performed, it will be possible to assess if our results align with the initial alternative hypothesis. From there, either a tertiary objective is completed (if there is time), or further research is recommended in the conclusion of the report.

2.2 Timeline of honours project

Table 2.1 displays a rough timeline of both honours program milestones and self-assigned objectives.

As a general summary, the first half of the first semester will be focused on initialising the project and starting the process of research and planning. The second half will focus on primarily completing objective 1, in which 14 weeks sounds like a realistic timeframe. The midterm report will be worked on as the tasks of objective 1 start winding down, with all the new research discovered over those months being compiled into the incomplete skeleton of the report.

Objective 2 will require less time, and hence only will take the former half of the second semester. The latter half of the semester is dedicated to drafting and finalising the report and its results. As with any project, after the second semester exams, there will be a bit of time to clean up the project's code for future use, debriefing on the year, and if the research is of enough value, potentially publishing the report.

I do not actually know, according to the honours guidelines, if I am allowed to submit theses for formal publishing after the marking and reviewing of the report internally. At the very least, whether it happens or not, the potential for it to be published will act as a large personal motivator.

There will inevitably be disruptions to the timeline of planned events, in

Objective	**Task**	**Period**
Milestone 1 (Semester 1)	Initial Reading Research Period I Proposal	Weeks 0-1 Weeks 1-3 Weeks 1-4
Objective 1 (Semester 1)	Initial Analysis Stokes Parameters Development SC/LA Testing Halo Analysis Background Removal Full POSSUM Analysis	Weeks 3-5 Weeks 5-6 Weeks 6-7 Weeks MS2-7 Weeks 8-9 Weeks 10-11 Weeks 11-12 & Break
Milestone 2 (Semester 2)	Research Period II Compilation of Data Report Construction	Break Break & Weeks 0-1 Break & Weeks 0-1
Objective 2 (Semester 2)	Statistical Analysis Uncertainties Final Evaluation	Weeks 1-4 Weeks 4-6 Weeks 5-6
Milestones 4 & 5 (Semester 2)	Research Period III Final Compilation Seminar Preparation Drafting Finalisation	Weeks 6-7 Weeks 7-8 Weeks 7-9 Weeks 7-10 Weeks 10-12
Post-Submission (Oct-Dec 2024)	Cleanup/Debreif Publishing (Potential)	Week 12 After Semester 2

Table 2.1: A planned timeline of events.

order to account for these several contingency measures are employed:

1. Starting work on tasks 1-2 weeks before their allocated time
2. Spending a portion of the 20 hrs/week on non-focused tasks (i.e. reading for 3 hrs while working on objective 1)
3. Slightly overestimating the time it takes to complete each aspect of the project, to allow room for slow progress
4. Using a flowchart model of progression, so if one aspect of the project cannot be completed, only future contingencies are hindered
5. Regular and premature testing of programs

Chapter 3

Results

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Chapter 4

Discussion

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Chapter 5

Conclusion

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Chapter 6

Appendix

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