PhD Thesis Proposal (Draft): Polarimetry and 21 cm HI as a Probe of Galactic Magnetism

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Abstract. The Galaxy contains a complex arrangement of interstellar media (ISM) that is magnetized and highly turbulent. While polarimetric studies are beginning to elucidate the magnetic properties of the ISM, the role that the Galactic magnetic field (GMF) plays in the cold neutral medium (CNM) remains poorly understood. The discovery of high-latitude magnetically aligned fibers in the CNM suggests that even their very low ionization fraction is sufficient to allow coupling with the GMF, potentially playing a crucial role in their formation. The additional discovery of filamentary-like structures in radio polarization gradients ($|\nabla \mathbf{P}|$) have led to the interpretation of structure in the warm ionized medium (WIM) being driven by magnetohydrodynamic turbulence. Investigating the spatial coherence between $|\nabla \mathbf{P}|$ and CNM fibers would help to elucidate the role that the GMF plays in CNM structure formation and its relation to the WIM. While obtaining a full three-dimensional picture of the GMF has proven to be considerably difficult, adopting the CNM as a part of this picture would impart valuable information on interpreting the GMF structure. Alongside various polarimetric methods, the CNM will provide another piece to the complex puzzle of understanding our Galaxy's elusive magnetic field.

1. Introduction

The interstellar medium (ISM) is a complex environment of gas and dust with varying degrees of ionization, densities, and spatial distributions (Ferrière, 2001). From the largest of scales in the diffuse ISM to smaller scales of dense molecular clouds, this tenuous plasma is threaded with magnetic fields and exhibits large degrees of turbulence, both of which are believed to be major driving forces in shaping the structure and dynamics of our Galaxy. The degree to which the galactic magnetic field (GMF) and magnetic turbulence influences the structure observed across different phases and spatial scales of the ISM, however, remains poorly understood.

Observations of the diffuse cold neutral medium (CNM) via 21 cm HI have identified long, slender structures deemed 'fibers' that appear to be very well aligned with the GMF (Clark et al., 2014, 2015). These studies were performed using a computational algorithm called the Rolling Hough Transform (RHT) which identifies linear features in the image plane by characterizing the probability that each image pixel is associated with a linear feature. This striking alignment suggests that even the very low ionization fraction of the CNM is sufficient enough to couple the magnetic field to the predominantly neutral gas, perhaps playing a fundamental role in CNM structure formation. So far, such an alignment has only been studied at high Galactic latitudes using starlight and dust polarization, leaving the low latitude Galactic plane and comparisons with other polarimetric measures incomplete. Narrow filamentary structures have also been discovered in radio polarization gradients ($|\nabla \mathbf{P}|$) of the warm ionized medium (WIM) believed to be driven by magnetohydrodynamic (MHD) turbulence (Gaensler et al., 2011). Decomposition techniques have very recently been applied to $|\nabla \mathbf{P}|$, characterizing how changes in the polarization angle and polarized intensity contribute to the observed structure (Herron et al., 2018a,b). As the magnetically-aligned HI fibers have yet to be compared to radio synchrotron emission, investigation of their alignment with $|\nabla \mathbf{P}|$ will help to elucidate the relationship between the WIM and the CNM.

Magnetic fields are not only a crucial aspect of the diffuse ISM, but they also play a fundamental role in the molecular ISM. One of the greatest outstanding questions in astrophysical magnetism is how magnetic fields regulate star formation within molecular clouds (McKee & Ostriker, 2007). On the scale of molecular clouds ($\sim 10 - 100\,\mathrm{pc}$), magnetic fields are believed to be the primary supporting agent against their own self-gravity (Shu et al., 1987). On the smallest scales of dense cores from which stars form ($\sim 0.1\,\mathrm{pc}$), magnetic fields are believed to control the star formation process via magnetic pressure while directing infalling material along magnetic field lines through ambipolar diffusion (Shu et al., 1987), and may be responsible for the extremely low observed star formation efficiencies (e.g., Myers et al., 1986). Studies have already begun investigating how magnetic fields influence the star formation process on the scale of molecular clouds and dense cores. The Balloon-borne Large Aperture Submillimeter Telescope for Polarimetry (BLASTPol) is a stratospheric balloon instrument specifically designed to map out the magnetic field of entire molecular clouds using far-infrared dust polarimetry (Galitzki et al., 2014). A Next-Generation BLAST Polarimeter (BLAST-TNG) is now underway to map magnetic fields of many more star forming regions at ten times higher resolution (Dober et al., 2014). However, magnetic fields within star forming regions have yet to be used to investigate their relationship with the surrounding GMF. Understanding the spatial coherence between the GMF and the magnetic structure within molecular clouds would provide a fundamental understanding of how the GMF influences molecular cloud structure formation and regulates the star formation process.

The GMF is difficult to understand since each polarimetric method probes a unique phase of the ISM with a limited spatial sampling of the magnetic field vector. Starlight and dust polarization trace the plane-of-sky magnetic field via the paramagnetic alignment of aspherical dust grains with the local GMF driven by radiative torques. Unpolarized optical starlight is selectively absorbed along the direction of the dust grains' long axis and is thermally re-emitted in the infrared (Lazarian, 2003, and references therein). Linearly polarized synchrotron emission is produced by relativistic electrons being trapped and accelerated by the local GMF (Rybicki & Lightman, 1986). As this radiation passes through the intervening magneto-ionic medium (MIM), birefringence induces a rotation of the polarization angle as a function of frequency characterized by the rotation measure (RM) which provides the line-of-sight magnetic field assuming a model of n_e (Burn, 1966). RM synthesis (i.e., Faraday tomography) has become an exceptionally transformative tool by providing the line-of-sight depth as a measure of Faraday rotation for an additional dimension of information previously unavailable with RM studies (Brentjens & de Bruyn, 2005). Using multiple polarimetric techniques in tandem alongside RM synthesis is now becoming the next advancement in magnetic field studies to gain a more complete understanding of the Galaxy's magnetic field.

2. Thesis Statement

This thesis aims to investigate how the GMF connects between different phases and spatial scales within the ISM as well as its three-dimensional geometry. As it has only been recently discovered that the ionization fraction of the CNM is sufficient enough to allow coupling with the magnetic field (Clark et al., 2014, 2015), the GMF of the predominantly neutral ISM and its relationship with the WIM remains poorly understood. Understanding the spatial coherence of the GMF between the CNM and the WIM will shed light on the relationship between the ionized and atomic phases of the ISM in addition to the role that the GMF plays in structure formation of the neutral ISM. Applying this to molecular clouds will also allow us to understand how the GMF aids in molecular cloud structure formation and the role it plays in subsequent star formation, a critical outstanding question in star formation theory (McKee & Ostriker, 2007). As a complete understanding of the GMF is substantially hampered by the difficulty in being able to interpret its three-dimensional structure, obtaining a method for reconstructing its full spatial geometry will serve as a useful proof-of-concept for more ambitious tasks of full-sky three-dimensional mapping of the GMF.

3. Approach and Proposed Thesis Structure

To carry out this thesis work, we propose using starlight polarization, dust polarization, radio synchrotron emission, and RM synthesis techniques accompanied by velocityresolved 21 cm HI. The following outlines the proposed approach and corresponding thesis structure.

3.1. A Comparison of the WIM and CNM Structure I. High Galactic Latitudes

Use private radio synchrotron data from the Galactic Arecibo L-band Feed Array Continuum Transit Survey (GALFACTS) and public HI data from GALFA-HI to investigate the spatial coherence between $|\nabla \mathbf{P}|$ and HI fibers at high Galactic latitudes. Regions with large $|\nabla \mathbf{P}|$ should probe structures with abrupt changes in the line-of-sight magnetic field driven by turbulence and an alignment with HI would suggest a fundamental role in CNM structure formation. Also explore this relationship using the radial and tangential components of $|\nabla \mathbf{P}|$; if a predominance of tangential polarization gradients probe a strong plane-of-sky magnetic field, HI fibers should be more prominent and well-aligned with the plane-of-sky field. Compare GALFACTS $|\nabla \mathbf{P}|$ and polarization angles via Planck dust polarization and GPIPS infrared starlight polarization; an alignment would suggest that magnetic turbulence influences the spatial distribution and alignment of dust in the ISM.

3.2. A Comparison of the WIM and CNM Structure II. Low Galactic Latitudes

Since the Aricebo telescope is limited to high Galactic latitudes, we aim to use numerous alternative HI surveys to investigate the spatial coherence between $|\nabla \mathbf{P}|$ and HI fibers at low Galactic latitudes. We will use VLA Galactic Plane Survey (VGPS), Canadian Galactic Plane Survey (CGPS), Southern Galactic Plane Survey (SGPS), The HI/OH/Recombination line survey of the Milky Way (THOR), and Galactic Australian SKA Pathfinder Survey (GASKAP) HI data to investigate the relationship between the CNM and WIM towards the Galactic plane and compare it to high Galactic latitudes.

3.3. A Three-Dimensional Picture of the GMF

We will locate well-behaved regions and caustics using the velocity coherence of GALFA-HI data to identify uniform plane-of-sky magnetic fields along the line-of-sight. Perform RM synthesis on these regions using GALFACTS synchrotron polarization and combine with polarization angles, extragalactic RMs, diffuse HI structure and starlight polarization to obtain a three-dimensional representation of the GMF along with its corresponding fully reconstructed Faraday depth function. This study will serve as proof-of-concept for more aspirational future methods of full-sky three-dimensional magnetic field mapping of the Galaxy and foreground removal for extragalactic studies.

3.4. Connecting the GMF to Magnetic Structure Within Star Forming Regions

Use RM synthesis to map out the large-scale GMF near the Gum Nebula using the Australia Telescope Compact Array (ATCA) and, in collaboration with Laura Fissell et al., combine with new data from The Next Generation Balloon-borne Large Aperture

Submillimeter Telescope for Polarimetry (BLASTpol-TNG) to see how it connects with the magnetic structure of star forming regions. Understanding the connection between the GMF and the magnetic field structure within molecular clouds will help to elucidate how magnetism influences molecular cloud structure and subsequent star formation.

4. Timeline

Dates	Goals
Second Year (2017 – 2018)	
April	Study for General Qualifying Exams.
April 27	Chat with Laura Fissel re: BLAST-TNG + ATCA project.
May 7 – 31	General Qualifying Exams.
June – Aug	Compare high-latitude polarization gradients and HI fibers.
June	Begin writing ATCA proposal; prepare for Thesis Qualifying Exam.
June 15	ATCA proposal deadline I.
July	Thesis Qualifying Exam.
Third Year (2018 – 2019)	
Sept – Dec	Write paper on high-latitude polarization gradients and HI fibers.
Oct	The Milky Way in the Age of Gaia Conference (Paris);
	PhD Supervisory Committee Meeting.
Jan – April	Compare high-latitude polarization gradients and HI fibers.
Dec 15	ATCA proposal deadline II.
Jan – Aug	Observe with ATCA (Australia)??
April	PhD Supervisory Committee Meeting.
May – Aug	Write paper on low-latitude polarization gradients and HI fibers.
Fourth Year (2019 – 2020)	
Sept – Aug	Conference (TBD)
Sept – Nov	Obtain three-dimensional magnetic field for well-behaved region.
Oct	PhD Supervisory Committee Meeting.
Dec – Feb	Write paper on three-dimensional magnetic field.
April	PhD Supervisory Committee Meeting.
March – May	Map magnetic field surrounding cloud towards Pyxis.
May	NRAO Synthesis Imaging Workshop (Socorro).
June – Aug	Write paper on magnetic field surrounding cloud towards Pyxis.
Fifth Year (2020 – 2021)	
Sept – Aug	Conference (TBD)
Sept	Begin job hunting and talk tours.
Oct	PhD Supervisory Committee Meeting.
Nov	Begin writing thesis.
April	PhD Supervisory Committee Meeting.
June	Thesis defence.
July – Aug	Thesis revisions.
Sept	Graduate!

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