PROBING MAGNETIC FIELDS ON THE LARGEST SCALES

1 Scientific Justification

Synchrotron radiation holds enormous promise for mapping the filamentary structure of the universe [11,17,14,10]. Although the densest regions are illuminated by galaxies and clusters, ≈30% of all baryons currently exist in the low-density shock heated 10^{5-7}K WHIM [7] where they are extremely difficult to detect [3]. These are the sites of critical evolutionary processes such as pre-heating, metal enrichment, ram pressure stripping, and relativistic particle acceleration. A key physical component in all of these processes is the presence of magnetic fields, though determining the properties of magnetic fields in filamentary large-scale structure (LSS) is extremely difficult. Only a handful of radio-detected filaments up to 4 Mpc in length have been found ([12] is a recent example), and none in polarization. The resolution of this problem has implications for key questions such as the origin of cosmic magnetic fields [16], and the origin and propagation environment of ultra-high-energy cosmic rays (UHECRs; e.g. [19]). Unfortunately, confusion from the diffuse synchrotron emission of the Milky Way can severely limit detection of structures greater than ∼30', depending on the details of the local Galactic foreground (see Fig. 4). The issue of Galactic foreground contamination is the major obstacle now facing the detection and study of low surface brightness extragalactic signals (e.g. WHIM, CMB polarization, & epoch of reionization).

In March of 2007, we conducted a pilot study on the GBT (coordinated with Westerbork rotation measure synthesis [4] observations) exploring the possibility of using polarization observations to push below the confusion limit in total intensity and detect synchrotron radiation associated with LSS. This study succeeded in confirming detections of a new class of large-scale polarized emission found through a reprocessing of the NVSS survey. Our observations yielded exciting new discoveries outlined in §2, with apparent LSS of sizes up to 5 Mpc, while also highlighting a need to better understand the detailed nature of the polarized Galactic contribution on the scales of interest.

We propose now to follow up the pilot study with additional observations of our most important new sources, and a survey of new targets selected based on the results of our previous findings. Our goals in this program are to: • Map the total extent of the new polarized regions, especially their relation to the galactic foreground and extragalactic optical/x-ray LSS; • Assess the energy densities and degree of magnetic field ordering in these extended regions; • Characterize the various scale-sizes of the Galactic polarized emission down to 9' resolution, critical to all future searches for extragalactic low surface brightness sources; • Search for a larger population of these sources, and in the process probe the surface brightness, angular scale parameter space that is optimal for a more complete survey.

2 Mpc Scale Polarized Structures

We report the 1.4 GHz detection of degree scale polarized emission likely associated with three superclusters of galaxies. The observations were conducted with the Green Bank Telescope, as part of our pilot project AGBT07A_048.

2.1 Coma Cluster

The Coma cluster is part of a well known supercluster of galaxies [1,6], and its radio relic is evidence of shock activity due to infall from a smaller cluster (e.g. [10]). We performed raster scans across the cluster and its relic at 1.4 GHz with the GBT Spectrometer. Fig.1 shows 1-d pseudo-continuum scans in Stokes Q and U which clearly show the relic source as expected, but it also shows a $\sim 2^o$ plateau of polarized continuum emission. This is an important confirmation of the 0.4 GHz total intensity emission seen by [12] (Fig. 1 top). [20] detected excess polarized power on the same scale in this region, but dismissed it as galactic based on its large angular size. Initial analysis of the polarization angle (not shown) across the scan suggests that the plateau was pre-existing, and the accretion shock amplified the transverse component of the magnetic field. A full map is needed in order to substantiate this. Our goals with this source are to confirm the coincidence of our polarized structure with that found in [12], and to explore/rule-out the possibility of a Galactic origin by examining the character of the polarized emission in the surrounding region at the appropriate resolution.

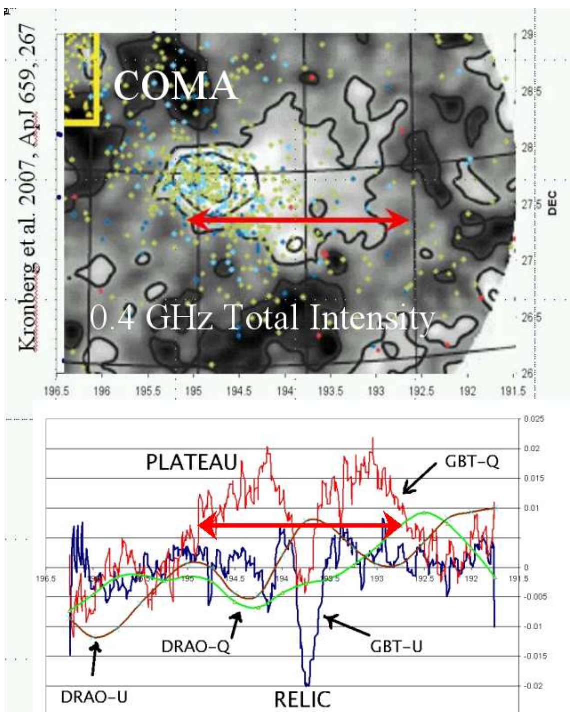

Figure 1: *Top: 0.4 GHz map of the Coma cluster from Kronberg et al. (2007). Bottom: Scans across the Coma relic Red: GBT Stokes Q; Blue: GBT Stokes U; Green: DRAO Stokes Q; Gold: DRAO Stokes U. The relic and 2^o plateau are visible in our GBT scans, but not in the lower resolution DRAO survey.*

2.2 Abell 907

Abell 907 is a rich cluster at $z \sim 0.153$ and is in close proximity and likely related to the Abell 901/902 supercluster [8,18]. We found evidence of large scale polarized emission near the periphery of A907 in the NVSS survey, and performed follow up scans with the GBT in March 2007. Figure 2 shows a clear confirmation of the NVSS detection, though its connection with A907 is still unclear. A full mapping of the cluster and the surrounding region is needed in order to sort out its true nature.

2.3 Abell 576

Abell 576 is a well studied cluster at the center of a rich concentration of 2MASS galaxies ($z \sim 0.039$, see Fig. 3). We have detected $> 1^o$ scale polarized emission surrounding the concentration, which appears to be the intersection of several filaments. [2] shows that A576 is a non-relaxed cluster, indicating active infall dynamics.

2.4 Galactic Foreground

Galactic synchrotron emission can be highly polarized, and has structure on many scales. The problem of differentiating between Galactic and extragalactic diffuse emission becomes more critical as we push our detections out toward the large-scale, low density WHIM. To this end, we will be particularly interested in the character of the Galactic emission near our sources. [21] presents absolutely calibrated polarization maps at 1.4 GHz (from DRAO) that illustrate the complexity of Galactic emission (Fig. 4; note that the sources described above are in relatively smooth Galactic regions). The resolution of this survey is ∼36'. Fig 1 shows a plot of our GBT scans across the Coma relic compared to the same cuts across the DRAO maps, and illustrates why going to GBT resolution is so critical. The Coma relic is clearly visible in our GBT scans, as is the 2^o plateau coincident with features seen in [12]; neither of these things is visible in DRAO polarization maps. This is the power of higher resolution. Due to the signed nature of Q and U, you "lose" a lot more quickly in terms of finding real structures as you lose resolution, compared to Stokes I, where you slowly dilute the structure. However, low resolution total intensity studies lack the polarization angle discriminant against Galactic structures, and also require extensive observations to remove the extragalactic confusion. The large area map proposed in §4.1 will not only allow us to distinguish extragalactic emission from the larger-scale Galactic environment, but also to characterize the angular power spectrum of the Galactic, polarized emission at higher resolution than any previous work at this galactic latitude [5,13].

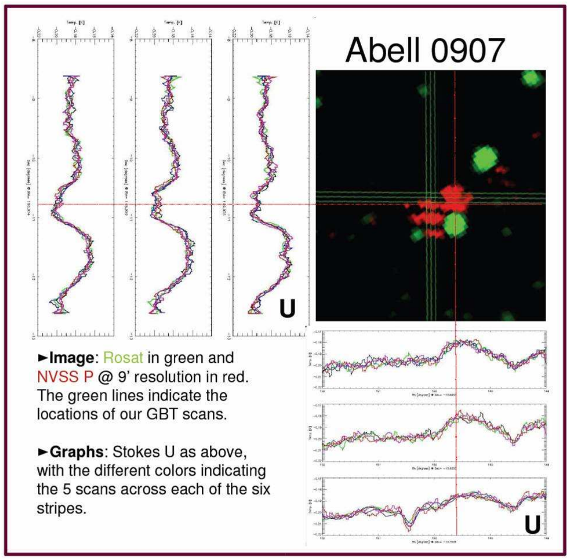

Figure 2: *Abell 907 (4^ox 4^o image): Red-NVSS polarized emission; Green-ROSAT X-ray; Colored plots-GBT Stokes U along 4^o green lines indicated on the map. Polarized emission is detected coincident with the NVSS emission, though Galactic structure is also present.*

3 Supercluster Survey

Our next critical step towards understanding the information gained from polarized supercluster emission is to observe a well-defined sample of superclusters. Our initial sample for GBT observations was based on our NVSS polarization work; however, we found that NVSS polarization was neither sufficient to guarantee a polarized synchrotron source (we found with the WSRT that some regions were Galactic Faraday screens), nor was NVSS necessary (the 2^o structure in Coma, which did not show up NVSS). With the likely detection of three supercluster regions, it is now important to begin a more systematic study of superclusters, to assess how common such extended supercluster scale synchrotron emission regions are, as well as how their presence, luminosity, and size are related to the depth of the local well (e.g., through comparison with X-ray derived masses). As an initial step toward a systematic study of superclusters, we propose an efficient 1-d survey of 28 supercluster regions. This sample was taken from the catalog of superclusters found in the 2dF survey [9], selected according to the following criteria: 1: $\delta > -10^o$. 2: $0.1 < z < 0.13$; 3: ROSAT detected X-rays in at least one member cluster. The redshift range was selected to ensure that we can resolve 1 Mpc with the 9' GBT L-band beam, and that 3 Mpc polarized structures similar to what we have seen so far will subtend less than $\sim 0.5^o$, and thus stand out from typical Galactic emission. The questions we need to answer are: Is large scale polarized emission typical of superclusters and related to other supercluster properties, or are our detections special cases? Is there a "sweet spot" in redshift at this resolution where we can clearly distinguish between Galactic and extra-galactic emission based on its scale size, thus informing the next generation of surveys.

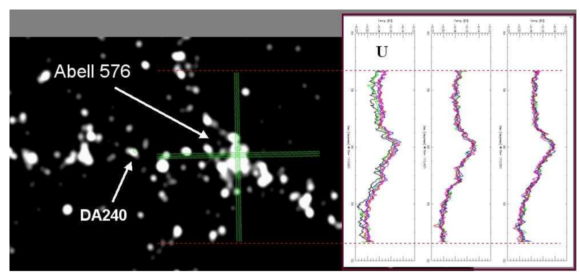

Figure 3: *Abell 576: The colored scans are GBT observations in Stokes U along the 3 vertical green lines indicated on the map of 2MASS galaxy concentration (smoothed).*

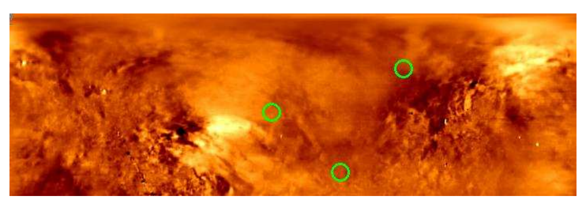

Figure 4: *Galactic Stokes Q at 1.4 GHz of the whole sky above -27^o declination from [21], illustrating the variety of structure confusing the detection of low surface brightness extragalactic emission. The green circles show the location of the three superclusters proposed here.*

4 Technical Justification

4.1 Observing Plan

We propose to conduct full 6^ox6^o mappings (basket weaving) of the three clusters using the L-band receiver and the Spectrometer backend. From our previous experience with pseudo-continuum observations with the Spectrometer, we plan to scan quickly across each region 5 times and use the repeatability of structures to edit out times when gain fluctuations/RFI dominates. We should note that gain fluctuations affect telescope Q more than Stokes U; we are in continuing conversation with scientific and engineering staff about handling this issue appropriately. Due to RFI, our previous GBT results utilized only 25 MHz of the 100 MHz available with a 2x50 MHz Spectrometer configuration. To avoid this problem, we intend to use a 4x12.5 MHz configuration, centering the 4 windows on RFI free regions. The large map sizes are essential to characterizing the Galactic emission in each region. From scan times in our detection program at the GBT, we calculate that each full map will take 19.3 hours. The calibrators will take another 0.7 hours per map. This means we need 60 hours to map the three clusters. The thermal noise will be 3.6 mK; however, our pilot study has shown that the limiting factor for these observations are the gain fluctuations, and with the proposed integration times we can achieve an rms of $\sim$11 mK, sufficient to detect structure at the Galactic confusion limit.

For our survey of supercluster regions, we propose to map only two long bands centered on each source (see green lines in Figs. 2,3). Each band will consist of three strips offset perpendicular to the scan by a full beamwidth. Though we will not be fully sampled, this will give us a rough characterization of the position and extent of any detected emission. The scan lengths will be $\approx 6^o$ to allow for adequate baseline subtraction and characterization of mottling due to local Galactic foregrounds. For the total times requested, we follow the observing manual and assume an overhead time of 15 min for slewing and focusing, 40 sec for each scan, and 5 min to switch between constant RA and constant Dec. observing. An additional 3 hours are needed for unpolarized and polarized source calibrations, which we will observe at a range of paralactic angles. Although the Mueller matrix for L-band appears well understood [15], we will conduct observations of 3C286 to tie it to our observing frequencies and analysis procedures.

4.2 Data Reduction and Analysis

We will edit/calibrate the data and produce maps using IDL. The spectral data will be edited for RFI, bandpass calibrated and averaged in frequency to create pseudo-continuum maps. We will apply the Mueller matrix of Robishaw & Heiles [12], modified as necessary, and produce I,Q,U maps for the three fields. We have hired an undergraduate student this summer to develop a visual RFI-flagging GUI in IDL, along with other data-manipulation routines tailored specifically for this project (GBT Spectrometer, full Stokes, pseudo-continuum mapping). We intend to consult with GBT staff as to how this effort can best be integrated with, and contribute to, current GBTIDL software.

5 References

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