A STUDY OF BROADBAND FARADAY ROTATION AND POLARIZATION BEHAVIOR OVER 1.3–10 GHz IN 36 DISCRETE RADIO SOURCES

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ABSTRACT

We present a broadband polarization analysis of 36 discrete polarized radio sources over a very broad, densely sampled frequency band. Our sample was selected on the basis of polarization behavior apparent in narrowband archival data at 1.4 GHz: half the sample shows complicated frequency-dependent polarization behavior (i.e., Faraday complexity) at these frequencies, while half shows comparatively simple behavior (i.e., they appear Faraday simple). We re-observed the sample using the Australia Telescope Compact Array in full polarization, with 6 GHz of densely sampled frequency coverage spanning 1.3–10 GHz. We have devised a general polarization modeling technique that allows us to identify multiple polarized emission components in a source, and to characterize their properties. We detect Faraday complex behavior in almost every source in our sample. Several sources exhibit particularly remarkable polarization behavior. By comparing our new and archival data, we have identified temporal variability in the broadband integrated polarization spectra of some sources. In a number of cases, the characteristics of the polarized emission components, including the range of Faraday depths over which they emit, their temporal variability, spectral index, and the linear extent of the source, allow us to argue that the spectropolarimetric data encode information about the magneto-ionic environment of active galactic nuclei themselves. Furthermore, the data place direct constraints on the geometry and magneto-ionic structure of this material. We discuss the consequences of restricted frequency bands on the detection and interpretation of polarization structures, and the implications for upcoming spectropolarimetric surveys.

Key words: galaxies: active – galaxies: magnetic fields – polarization – Sun: magnetic fields – techniques: polarimetric

Supporting material: machine-readable tables

1. INTRODUCTION

Radio-loud active galactic nuclei (AGNs) play a key role in driving the evolution and ecology of the universe by feeding energy and material into their broader environment. However, we still lack a clear picture of the exact physical processes involved, and indeed, of the detailed physical structure of AGNs, jets, and radio lobes more generally. Arguably, the main impediment to an improved understanding of these objects is the observational challenge of spatially resolving the structures of interest, which are small in physical extent and lie at great distances. Very long baseline interferometry (VLBI) observations represent one powerful method of approaching this problem, but at the current time, still provide limited survey capability and limited instantaneous frequency coverage, and key structures of interest still remain near or below the resolution limit (e.g., Taylor & Zavala 2010).

Often, the unresolved issues surrounding AGN fueling and feedback have, at their heart, a set of fundamental questions concerning the structure and dynamics of the magnetized plasma associated with AGNs. To address these questions, an alternative and complementary approach to VLBI-based studies is available: the frequency-dependant signal encoded in linearly polarized emission by Faraday rotation can be used to probe magneto-ionized structures toward radio sources on spatial scales below the observing resolution (e.g., Burn 1966; Gardner & Whiteoak 1966; Gaensler et al. 2015; Heald et al. 2015).

The way in which this information is encoded can be described mathematically as follows: first, the linear polarization state of radio emission is described by a complex vector $\mathbf{P}$. It is related to the Stokes parameters $Q$ and $U$, the polarization angle $\psi$, the fractional polarization $p$, and the total intensity $I$ as:

$$ \mathbf{P} = Q + iU = pIe^{i\psi}. $$

(1)

After being emitted at a distance $L$, linearly polarized radiation will be Faraday-rotated by magnetized plasma along the line of sight (LOS) to an observer by an amount equal to

$$ \Delta \psi = \phi \lambda^2 $$

(2)

where $\psi$ is the polarization angle, $\lambda$ is the observing wavelength, and $\phi$ is the Faraday depth, given by

$$ \phi = 0.812 \int_L^{\text{telescope}} n_e B \, ds \, \text{rad m}^{-2} $$

(3)

and, in turn, $n_e$ [cm$^{-3}$] and $B$ [$\mu$G] are the thermal electron density and magnetic field along the LOS, respectively.

The net observable polarization $P(\lambda^2)$ is obtained by summing the polarized emission emerging from all possible Faraday depths within the synthesized beam of the telescope:

$$ P(\lambda^2) = \int_{-\infty}^{\infty} F(\phi) e^{2i\phi\lambda^2} d\phi. $$

(4)

The function $F(\phi)$ (the so-called Faraday dispersion function (FDF)) specifies the distribution of polarized emission.
as a function of Faraday depth along the LOS, and possesses units of Jy m² rad⁻¹ for a source which is extended both in the plane of the sky and in Faraday depth. Based on the form of this function, two broad types of $P(\chi^2)$ behavior can result. When $F(\phi)$ is a δ-function (i.e., polarized emission emanates from a single Faraday depth), the polarization behavior is characterized by constant $p(\chi^2)$, linear $\psi(\chi^2)$ (modulo π radians), and a quantity known as the rotation measure (RM)—the gradient of $\psi(\chi^2)$. The RM parameterizes the magnitude of the Faraday-rotation effect, and can be related to magnetized structures along the LOS through a relation similar to Equation (3). Ultimately this Faraday simple behavior is an idealization, but one which individual polarized emission components from a source can closely approximate (e.g., O’Sullivan et al. 2012). Conversely, when polarized emission occurs over a range of Faraday depths, or if multiple polarized emission components are emitted from different Faraday depths, we refer to a source as being Faraday complex. In this case, Stokes $Q/I(\chi^2)$, $U/I(\chi^2)$, $p(\chi^2)$, and $\psi(\chi^2)$ can all show complicated behaviors which reveal magneto-ionized material along the LOS, and can be modeled to reveal the structure and properties of this material on scales smaller than the resolution of the observing instrument.

A number of authors have exploited Faraday complex behavior to study magneto-ionized structures toward unresolved radio sources. Early work by Slysh (1965) and Goldstein & Reid (1984) established the existence of Faraday complex behavior in discrete radio sources using narrowband polarization data. Observations over broad (but spuriously sampled) frequency bands (>10 GHz) appear to reveal the existence and properties of magnetized material in the vicinity of radio sources themselves (e.g., Conway et al. 1974, Farnes et al. 2014; Pasetto et al. 2016). Other studies have reached similar conclusions by studying narrower, ~GHz-wide bands with high sampling density (Law et al. 2011; O’Sullivan et al. 2012). In general, however, it remains unclear exactly which structures in radio sources are being studied, or indeed, whether other structures along the LOS also make a substantial contribution to the observed polarization behavior. For example, Anderson et al. (2015) recently analyzed ~160 polarized sources over 1.3–2 GHz and found evidence for a significant Galactic contribution to the Faraday complexity of background sources.

As a tool for studying the physics of unresolved magnetio-ionic structure in the radio source population, broadband spectropolarimetry will come of age in the approaching era of wide field, broadband surveys such as the Polarization Sky Survey of the Universe’s Magnetism (POSSUM; Gaensler 2009) and the Very Large Array Sky Survey (VLASS; VSSG 2015). However, even these surveys will have bandwidths which are narrow compared to what can be achieved with contemporary targeted observations of a (much) smaller sample. Currently, we lack a detailed survey of the near-continuously sampled, multi-GHz-bandwidth polarization properties of Faraday complex radio sources. What the broadband polarization spectra of AGNs look like remains a largely open question. The study we present here aims to address this issue by presenting a spectropolarimetric survey of confirmed Faraday complex sources over a very broad 1.3–10 GHz band. Specifically, we seek to address the following questions: to what extent and over what wavelength ranges do deviations from Faraday simple behavior occur?

What are the characteristic Faraday depths and dispersions of the emission components responsible for these deviations? Is it possible to model, in a simple way, polarization data over fractional bandwidths approaching 200%? To what extent can the properties of individual polarized emission components be distinguished and characterized? Where along the LOS are the emitting/rotating/Faraday dispersing medium/media located? In particular, are the Faraday effects generated in the sources themselves (thus providing a method for their study) or in the foreground? What are the implications and opportunities for upcoming broadband spectropolarimetric surveys? Finally, we note what our study is not, which is an in-depth investigation of the physics of individual sources. This would require complementary multiwavelength data which is not currently available for most objects in our sample.

Our paper is set out as follows. We describe the construction of a sample to address our questions in Section 2, our observations and their calibration in Section 3, and our spectropolarimetric analysis in Section 4, including imaging, modeling, and fitting the data. Ancillary non-spectropolarimetric analysis is described in Section 5. We present our results in Section 6 and our discussion in Section 7. A summary of our work and our conclusions are provided in Section 8.

2. SAMPLE CONSTRUCTION

The targets for our study were selected from among two archival polarization data sets (detailed in Table 1), which were observed and processed by several independent groups. Kim et al. (1998) conducted a 130 square degree survey of the Large Magellanic Cloud (LMC), during which polarization data were recorded commensally. Gaensler et al. (2005) reprocessed these data and imaged them in full polarization between 1.282 and 1.432 GHz. Feain et al. (2009) observed a 34 square degree region around the radio galaxy Centaurus A, imaging the data in full polarization between 1.296 and 1.480 GHz. For the combined total of 572 sources robustly detected in linear polarization in these data, Gaensler et al. (2005) and Feain et al. (2009) extracted Stokes $I$, $Q$, $U$, and $V$ flux densities at 8 MHz intervals through the respective bands. We applied RM synthesis (Brentjens & de Bruyn 2005) and rmclean (Heald et al. 2009) to these data, identifying Faraday complex sources using the second moment ($\sigma_{RF}$) of the rmclean component distribution $F_M$ (Brown et al. 2011, Anderson et al. 2015). This provides a measure of the spread of rmclean components in $\phi$ space, and is given by:

$$\sigma_{RF} = K^{-1} \sum_{i=1}^{n} (\phi_i - \mu_\phi^2) |F_M(\phi_i)|$$ (5)

where the normalization constant $K$ is given by

$$K = \sum_{i=0}^{n} |F_M(\phi_i)|$$ (6)

and $\mu_\phi$, the first moment of the distribution, is given by

$$\mu_\phi = K^{-1} \sum_{i=0}^{n} \phi_i |F_M(\phi_i)|$$ (7)

where $n$ is the number of channels $i$ possessing non-zero values in the rmclean model and $\phi_i$ is the Faraday depth of channel $i$. We identified sources for which $\sigma_{RF} > 10$ rad m⁻² as candidates for our Faraday complex sample (e.g., see Anderson et al. 2015), and sources with $\sigma_{RF} = 0$ rad m⁻² (i.e., Faraday simple
Table 1
Summary of Observational Data used in This Work

| (1) Observations      | (2) ν span (GHz) | (3) Epoch            | (4) ATCA config. | (5) Beam (°) | (6) δφ (rad m⁻²) | (7) φmax-scale (rad m⁻²) | (8) | | \(\phi_{\text{max}}\) | \(|\phi_{\text{max}}|\) |
|-----------------------|------------------|----------------------|------------------|--------------|------------------|--------------------------|-----| | |
| LMC (Archival)        | 1.328–1.432      | 1994 Oct 26–Nov 9    | 750D             | 60 × 60      | 490              | 72                       | 3200 |
| "                     | "                | "                    | 750A             | "            | "                | "                        | "   |
| "                     | "                | 1995 Feb 23–Mar 11   | 750B             | "            | "                | "                        | "   |
| "                     | "                | 1995 Jun 2–7         | 750B             | "            | "                | "                        | "   |
| "                     | "                | 1995 Oct 15–31       | 750B             | "            | "                | "                        | "   |
| "                     | "                | 1996 Jan 27–Feb 8    | 750C             | "            | "                | "                        | "   |
| Cen A (Archival)      | 1.296–1.480      | 2006 Dec 20–2007 Jan | 750A             | 66 × 33      | 280              | 77                       | 3300 |
| "                     | "                | "                    | 750D             | "            | "                | "                        | "   |
| "                     | "                | 2007 Feb 23–Mar 13   | 750C             | "            | "                | "                        | "   |
| "                     | "                | 2007 Dec 7–30        | 750B             | "            | "                | "                        | "   |
| "                     | "                | 2008 Feb 16–Mar 13   | 750B             | "            | "                | "                        | "   |
| This paper            | 1.350–9.900      | 2012 Feb 10–12       | 6A               | 15 × 15–1 × 1| 70               | 3400                     | 7900 |
| "                     | "                | "                    | 6D               | "            | "                | "                        | "   |
| "                     | "                | 2012 Jun 22–24       | 6A               | "            | "                | "                        | "   |
| "                     | "                | 2012 Aug 17–19       | 6A               | "            | "                | "                        | "   |

Note. For the current observations, the quoted range in synthesized beam size (Column 5) corresponds to the change between 1.3 and 9.9 GHz, \(\delta\phi\) (Column 6), max-scale (Column 7), and \(\phi_{\text{max}}\) (Column 8) are the resolution in \(\phi\)-space, the maximum detectable emission scale in \(\phi\)-space, and the maximum detectable Faraday depth of emission, respectively. Note that the current observations have \(\phi_{\text{max-scale}} \gg \delta\phi\), while the opposite is true for the archival observations.

Figure 1. The positions of sources in our sample in relation to the LMC (left panel) and Centaurus A radio lobes (right panel). The grayscale for the LMC shows the emission measure (see Gaensler et al. 2005), while the grayscale for the Centaurus radio lobes is a combined ATCA/Parkes radio image at 1.4 GHz (see Feain et al. 2011). The contour levels for the Centaurus radio lobes have been chosen to approximately delineate the extent of the bright middle and faint outer lobes.

sources) as a control sample. In addition, we only selected sources where the chance of foreground contamination from the LMC and Centaurus A radio lobes was minimal. In the former case, we selected only sources which fell outside the boundaries of the LMC, and in regions with an emission measure consistent with zero (i.e., with a low column density of free electrons—see the left-hand panel of Figure 1). In the latter case, we generally selected sources which sat outside the Centaurus A radio lobes, although we chose to include several sources which do not meet this criterion (see the right-hand panel of Figure 1). We note that our choice of array configurations and \(uv\) weighting scheme (see Section 4.1) results in the diffuse emission from the lobes being completely resolved out. As such, the only way that the lobes could affect the level of Faraday complexity in our polarization data is if RM variations within the lobes act as a depolarizing foreground screen. However, Feain et al. (2009) showed that the lobes do not appear to show RM structure on angular scales below 0°2, which all of our sources are considerably smaller than.

In total, 7 (13) complex and 7 (13) simple sources were selected from the LMC (Centaurus) data sets, with band-averaged, undebiased (see Simmons & Stewart 1985) polarized signal-to-noise ratios (S/N) of between 4 and 350. In this paper, we use source designations that begin with either "cena" or "lmc" to specify the data set that each source was selected from, followed by a "c" or "s" to specify whether the source was selected because it was Faraday complex or simple, and which end with a sequential numerical designation—e.g., lmc_c04. In addition, we have added our two phase calibrators...
to the sample (named 0515-674 and 1315-46 in this work; see Section 3). All of these sources are listed in Column 1 of Table 2 along with their corresponding R.A. and decl. (Columns 2 and 3, respectively).

3. OBSERVATIONS AND CALIBRATION

We observed the 40 sample sources using the Australia Telescope Compact Array (ATCA; Wilson et al. 2011) over 1.1–3.1 GHz, 4.5–6.5 GHz, and 8.0–10.0 GHz in full polarization with a nominal 1 MHz channel resolution. At each end of each of these bands, 100 channels were flagged due to diminished sensitivity in these regions, resulting in an effective frequency coverage of 1.2–3.0 GHz, 4.6–6.4 GHz, and 8.1–9.9 GHz. Henceforth, we refer to these as the 16 cm, 6 cm, and 3 cm bands, respectively.

Each source was observed on-axis over a full 12 hr synthesis, receiving a total integration time of 23 minutes split over 15 uv cuts for the 16 cm observations, and 50 minutes split over 33 uv cuts for the 6 and 3 cm band observations. We used 6 km array configurations to achieve high spatial resolution and to maximize overlap in uv coverage between bands (see Figure 2) for sources that became resolved toward higher frequencies. We provide images of these sources in Appendix A. The minimum uv scales in the 16 cm, 6 cm, and 3 cm bands are 1.4 kλ, 4.8 kλ, and 8 kλ, respectively, corresponding to a maximum angular scale sensitivity of approximately 130″, 40″, and 10″.
Figure 2. The frequency-averaged conjugate $uv$ coverage of our observations for a typical source (lmc_s11). The red, blue, and black data points correspond to the 16, 6, and 3 cm bands, respectively. Each data point represents an average $uv$ coordinate, corresponding to the mean frequency of the lower, middle, or upper third of frequencies in each band for a single visit of the telescope to the source.

and 22”. Important details of our observations are summarized in Table 1.

The data were reduced and calibrated using standard procedures for centimeter-band ATCA data. Radio-frequency interference (RFI) was flagged iteratively throughout the calibration process using the SUMTHRESHOLD algorithm (Offringa et al. 2010). RFI was so severe below 1.3 GHz that all data below this frequency were discarded. Daily observations of either PKS B1934-638 or PKS B0823-500 were used to calibrate the bandpass response and primary flux scale. The time-dependent complex antenna gains and on-axis polarization leakage were calibrated using PKS B0515-674 and MRC B1315-460 for the LMC and Centaurus sources, respectively, observed half-hourly for the 16 cm band observations and every 20 minutes for the 6 and 3 cm band observations. Independent calibration solutions were derived at 128 MHz intervals in each band then interpolated to account for the frequency dependence of the complex gain and leakage (Schnitzeler et al. 2011). We have included these two calibrators as sources in our sample; their properties are discussed alongside those of the other sample sources in the relevant sections of our paper.

We phase and amplitude self-calibrated the data for all sources in our sample for bands where adequate signal was present. To handle the large fractional bandwidths involved, we split the data for self-calibration into sixteen 128 MHz sub-bands for the 16 cm data, eight 256 MHz sub-bands for the 6 cm data, and four 512 MHz sub-bands for the 3 cm data, then derived separate self-calibration solutions in each sub-band. The calibration solutions were interpolated and applied continuously across each of the 2 GHz bands. For sources and bands in which good phase and amplitude self-calibration solutions were found, we compared the data extracted from images made both before and after the procedure. We found that for the pre-self-calibration images, the source flux densities were systematically lower (by up to 20%), and the noise levels higher by a factor of up to ten, than for the post-self-calibrated images. This effect was particularly evident for the 3 cm band data. As such, we chose to discard data for sources in bands where both the phase and amplitude self-calibration were unsuccessful. We list the frequency bands in which self-calibration was successful for each source in Column 4 of Table 2.

For the archival data extracted from mosaiced images, the estimated maximum polarization leakage in the mosaiced images is $\sim$0.1% of Stokes $I$ (e.g., Feain et al. 2009). For the current on-axis observations, the frequency-dependent leakage is no greater than $\sim$0.05% of Stokes $I$ (e.g., Schnitzeler et al. 2011), and as low as 0.002% of Stokes $I$ when averaged over the full available bandwidth (see the results for 0515-674 presented in Section 6.2.1).

4. SPECTROPOLARIMETRIC ANALYSIS

4.1. Imaging and Polarized Signal Extraction

We imaged each source in Stokes $I$, $Q$, and $U$ at 20 MHz intervals through the 16 and 6 cm bands, and at a substantially coarser resolution of 200 MHz in the 3 cm band after verifying that no components with extreme Faraday depth were present in the calibrated $uv$ data. We used robust = 0 weighting (Briggs 1995) to moderately down-weight data in sparsely populated regions of the $uv$ plane. The higher spatial resolution of the new versus archival data (Table 1) meant that several sources are resolved at all frequencies, some become resolved above some frequency $v_{\text{res}}$, while the rest are fully unresolved. We convey this information by recording either “$*$”, “$\sim$”, or “$-$”, respectively, in Column 5 of Table 2. For the sources which became resolved above a frequency $v_{\text{res}}$, we applied a taper to the $uv$ data above this frequency to match the resolution of the observations at $v_{\text{res}}$. For the fully resolved sources, we tapered the $uv$ data to match the scale-size sensitivity at 1.3 GHz. Of the 40 sources originally selected for our new observations, six subsequently proved so faint and/or heavily resolved that we discarded them from the study. Including the two calibrators, our final sample thus consists of the 36 sources listed in Table 2.

For our spectropolarimetric analysis, we extracted the integrated-frequency-dependent Stokes $I$, $Q$, and $U$ flux densities for each source. These quantities were measured at the location of the peak pixel in Stokes $I$ for the fully unresolved and partially resolved sources (in the latter case, after convolving the images at $v > v_{\text{res}}$ to match the resolution at $v_{\text{res}}$). To extract the integrated polarization of the fully resolved sources, we applied a mask to the source at its 10% flux density radio contour and extracted the integrated flux densities from the unmasked region. The uncertainty in each Stokes parameter was estimated via direct measurement of the rms noise adjacent to the source, modified appropriately for the number of independent beams sampled in the unmasked regions for “$*$” sources.

Our spectropolarimetric analysis was conducted on the fractional Stokes parameters $q(v)$ and $u(v)$, which were obtained by fitting a polynomial to log($I$) versus log($v$), transforming this model into linear space then dividing it out of Stokes $Q$ and $U$. The 1.4 GHz Stokes $I$ flux density predicted by the model, the degree of the polynomial fit required, and the
spectral index of the model at 1.4 GHz are presented in columns 6, 7, and 8 of Table 2, respectively.

4.2. Modeling Stokes q(λ^2) and u(λ^2)

A key goal of our work is to identify and characterize Faraday-thick components. This has traditionally been achieved by fitting \( P(\lambda^2) \) with a depolarization model derived for a specific physical arrangement of magneto-ionic material (e.g., O’Sullivan et al. 2012). However, this approach involves making assumptions about the structure of the magneto-ionic material under investigation. Moreover, we found that existing models were incapable of reproducing the detailed polarization behavior of several of our high S/N sources.

Instead, we modeled our data in a general way that allowed us to quantify the number of dominant emission components in each source, their width and shape in \( \phi \) space, and their initial polarization angle. We did this by constructing model FDFs from elementary basis functions. For each model, \( n \) polarized emission components \( p(\phi) \) (which could be Faraday thick or thin) are combined in \( \phi \) space as:

\[
F_\phi = p_1(\phi) + p_2(\phi) + \ldots + p_n(\phi)
\]

then transformed into \( \lambda^2 \) space (see Section 4.3) using

\[
P(\lambda^2) = \sum_\phi F_\phi e^{2i\omega\lambda^2}
\]

The goodness of fit of the \( P(\lambda^2) \) model to the measured polarization data can then be assessed.

We modeled Faraday-thin FDF components as complex-valued \( \delta \) functions of modulus \( p \) with polarization angle \( \psi_0 \) at a Faraday depth of \( \phi \). For Faraday-thick components, we used a parametric function capable of generating a variety of \( P(\lambda^2) \) behaviors—a super-Gaussian (e.g., Decker 1994) which takes on complex values, defined by:

\[
p(\phi) = -\frac{A}{\sqrt{2\pi}\sigma_0} \exp\left(\frac{-(\phi - \phi_{\text{peak}})^{2N}}{2\sigma_0^2}\right)
\]

where \( A \) is an amplitude parameter, \( \psi_0 \) is the emitted polarization angle, \( \phi_{\text{peak}} \) is the mean Faraday depth of the emission component, \( N \) is a shape parameter, and \( \sigma_0 \) is a width parameter which is related to the traditional FWHM of the Gaussian \( \sigma \) parameter as:

\[
\sigma \approx \sigma_0 (\pi/2)^{1/N-1}
\]

With reasonably few parameters, the super-Gaussian function provides a generic Faraday-thick FDF component capable of modeling emission from an assortment of magneto-ionic arrangements. For example, when \( N = 2 \), Equation (10) reduces to a normal Gaussian function and can be used to model depolarization from a large number of independent magneto-ionicized cells covering the source in a foreground Faraday-rotating medium (i.e., the Burn foreground screen; Burn 1966). As \( N \) increases, the Gaussian becomes progressively “squared” (see Figure 3) until at \( N \approx 30 \), \( p(\phi) \) becomes a reasonable approximation to a top hat function, which can be used to model a region of mixed emitting and Faraday-rotating plasma (i.e., the “Burn slab”; Burn 1966), linear RM gradients, or specific types of foreground depolarization screen (Schnitzeler et al. 2015). Other values of \( N \) provide the flexibility to approximate the polarization behaviors expected from non-uniform gradients in the RM of a foreground Faraday-rotating medium or an illuminating background source, and multiple layers of 2D turbulent foregrounds (Schnitzeler et al. 2015), among other possible structures. While a lone super-Gaussian cannot describe magneto-ionic structures that have a skewed distribution in \( \phi \) space, different parametric curves could in principle be used for this purpose. In general, we found that this was not necessary to achieve reasonably good fits to our data (but see Section 6.2.1).

We point out that our method avoids the deconvolution ambiguities that afflict the so-called open-ended spectropolarimetric analysis algorithms (see Sun et al. 2015), while at the same time, it avoids making significant a priori assumptions about the magneto-ionic structure of the source under study. It therefore combines some of the benefits of open-ended methods with those of \( QU \)-fitting, however, with the drawback that using Monte Carlo methods (see Section 4.3 below), the fitting process can be quite time-consuming.

In this work, we refer to FDF models which contain a specific combination of thick and/or thin components as a “model type.” We denote the model type with character strings in which each “S” (“T”) indicates the presence of a thin (thick) component (the characters S and T were chosen in reference to “simple” and “thick”, respectively). For example, a model consisting of two thin components and a thick component is denoted by the string “SST.” We refer to a specific realization of a model type—i.e., when all parameters in the model have
4.3. Fitting The Models and Selecting The Best-fit Model(s)

We fit our models using Monte Carlo methods. The posterior probability $\Pr(\theta|D, M)$ for a set of model parameters $\theta$ given some data $D$ and a model type $(M)$ can be calculated using Bayes theorem:

$$\Pr(\theta|D, M) = \frac{\Pr(D|\theta, M) \times \Pr(\theta|M)}{\Pr(D|M)}$$

(12)

The likelihood $\Pr(D|\theta, M) = \mathcal{L}$ for polarization data $(q_i, u_i)$ and a model $(q_{mod,i}, u_{mod,i})$ can be quantified as:

$$\mathcal{L} = \frac{1}{\pi \sigma_{q_i} \sigma_{u_i}} \exp \left( -\frac{(q_i - q_{mod,i})^2}{2\sigma_{q_i}^2} - \frac{(u_i - u_{mod,i})^2}{2\sigma_{u_i}^2} \right)$$

(13)

For $\Pr(\theta|M)$—the prior belief that the model parameters should take on a set of values—we used a uniform probability distribution function (PDF) in ranges where these values were physically acceptable: $[-\pi/2, \pi/2]$ rad for $\psi_0$ (the initial polarization angle), $[0, 0.7]$ for $p$ (the fractional polarized amplitude), $[-3000, 3000]$ rad$^{-2}$ for $\phi_{peak}$, and $[0, 1500]$ rad$^{-2}$ for $\sigma_\theta$. The PDF was set to zero outside these ranges. Note that the prior ranges for $\phi_{peak}$ and $\sigma_\theta$ do not probe the full range of parameter space allowed by our data (see Table 1). We imposed these limits to aid the computational tractability of our fitting procedure.

Finally, since we are only interested in relative probabilities for the purpose of model comparison, we set the normalization factor $\Pr(D|M) = 1$.

We used the affine-invariant Markov chain Monte Carlo sampler Emcee (Foreman-Mackey et al. 2013) to sample $\Pr(\theta|D, M)$, deeming the parameter values which maximized $\Pr(\theta|D, M)$ to specify the best fit capable of being achieved with a given model type. The 1\(\sigma\) uncertainties for each fitted parameter were measured directly from the posterior probability distribution (marginalized over all other model parameters). These values are only meaningful when a good fit to the data has been achieved.

Initially, we fit models of type S, T, SS, ST, TT, and SSS to every source in our sample. Several sources required more complicated model types to achieve a good fit (Imc_c03, Imc_c04, and Imc_s11; described in Section 6.2.1). We constructed these models manually on a case-by-case basis, by adding additional S and T components to the models until a good fit was achieved. For the best fit obtained for each model type, we quantified the absolute goodness of fit using the reduced chi-squared ($\chi^2$) statistic.

We compared the relative merit of each fitted model type using the Akaike information criterion (AIC; Akaike 1974). Formally, for a model $M$ the AIC$_M$ is calculated as

$$\text{AIC}_M = 2k - 2\ln(\mathcal{L}_{\text{max}})$$

(14)

where $k$ = no. of fitted model parameters, and $\mathcal{L}_{\text{max}}$ is the maximum of the likelihood distribution for model $M$. For two models $M_1$ and $M_2$ with AIC values of AIC$_1$ and AIC$_2$, respectively, $M_2$ is then $\exp[(\text{AIC}_1 - \text{AIC}_2)/2]$ times as likely as $M_1$ to minimize the information lost by over or under fitting the data. We consider a model to be substantially favored by the AIC when AIC$_1 + 10 < \text{AIC}_2$ (i.e., $>99\%$ confidence). We refer to the model with the lowest AIC value for a given source as the overall best-fit model.

5. ANCILLARY ANALYSIS

5.1. RM Synthesis and rmclean

RM synthesis (Brentjens & de Bruyn 2005) is a technique for directly calculating $P(\phi)$ (also called the Faraday dispersion spectrum (FDS)) from observations of $P(\lambda^2)$ using a Fourier transform (see also Burn 1966). A procedure called rmclean (Heald et al. 2009) is usually then applied to the FDS to remove artifacts caused by imperfect sampling of $\lambda^2$. We applied RM synthesis and rmclean to each source in our sample so that the resulting FDS could be directly compared to our FDF models.

5.2. Morphological Constraints

We crossmatched our sources with the AT20G high angular resolution catalog (Chhetri et al. 2013) to provide morphological constraints on $\sim 0^\circ.15$ angular scales. This catalog contains ratios of scalar-averaged visibilities measured on 6 km and 4.5 km baselines for $\sim 5000$ sources observed by ATCA at 20 GHz. We record the visibility ratios for matched sources in Column 9 of Table 2.

6. RESULTS

6.1. Spectropolarimetric Data

We begin by presenting our spectropolarimetric data, and by pointing out several obvious and noteworthy features found therein. Our data (and our best-fit polarization models—discussed in the next section) are plotted on separate panels in Figures 4–38. The sources are presented in order such that the $\chi^2$ value of the best-fit S model decreases—i.e., roughly in order of decreasing Faraday complexity. In panels (a), (d), and (e) of these figures, we plot $(q, u)$, $p$, and $\psi$, respectively, against $\lambda^2$. The $\chi^2$ coverage is dominated the 16 cm band data which span 0.01 < $\lambda^2$ < 0.05 m$^{-2}$, while the 6 cm and 3 cm data correspond to $\lambda^2$ < 0.005 m$^{-2}$ and $\lambda^2$ < 0.0015 m$^{-2}$, respectively. The uncertainty in the plotted quantities is larger at frequencies where our sources are resolved (see Column 5 of Table 2), reflecting the the loss of information brought about by the image convolution procedure described in Section 4.1. Panel (b) plots Stokes $u$ versus $q$, while panel (c) plots the magnitude of the FDS and rmclean components, along with the rmclean cutoff (see Section 5.1; also Heald et al. 2009). Panel (f) plots the overall best-fit model FDF; the magnitude of each model component is plotted on the main axes, while the intrinsic polarization angle of each component is plotted on the inset polar axes. Panel (g) plots the total intensity spectrum and a polynomial model fit to these data (see Section 4.1, also Column 7 of Table 2). We also plot the instantaneous spectral index associated with the polynomial model, calculated as $\partial \log(I_{\text{model}}(\nu))/\partial \log(\nu)$. Panels (a), (d), (e), and (g) additionally contain inset axes below the main axes, on which we plot the standardized residual (SR) between the data and the model fit, where $\text{SR} = (d_i - M_i)/\sigma_i$ and $d_i$, $M_i$, and $\sigma_i$ are the values of the data, model, and standard uncertainty, respectively, in channel $i$. For panels (a) and (g), these data should be Gaussian distributed about $\text{SR} = 0$ with a standard deviation of 1.
The plots described above immediately reveal the existence of substantial variety in the spectropolarimetric behavior of the sample. Particular features of note include:

1. The presence of Faraday-thick structures: these are both obvious and resolved in the FDS for several sources in our sample (see panel (c) of relevant figures, noting that our observations have $\phi_{\text{max-scale}} = 3400 \text{ rad m}^{-2}$ but $b \phi = 70 \text{ rad m}^{-2}$—see Table 1). lmc_s11 (Figure 4), lmc_c04 (Figure 5), lmc_c03 (Figure 6), and 1315-46 (Figure 10) provide further examples.

2. Varied $p(\lambda^2)$ behavior: $p(\lambda^2)$, panel (d), decreases monotonically to zero for some sources (e.g., cen_c1827; Figure 11), apparently to finite limiting values for others (e.g., cen_c1466; Figure 8), and oscillates for still others (e.g., lmc_c15; Figure 16). lmc_s13 (Figure 7) repolarizes (i.e., $\partial \psi / \partial \phi$ is positive) over the full $\lambda^2$ band.

3. Behavioral transitions in $(q,u)/p/\psi$ (panels (a), (d), and (e)): several sources show abrupt changes in spectropolarimetric behavior which occur over comparatively small $\lambda^2$ ranges, particularly at short wavelengths—e.g., lmc_s11 (Figure 4) at $\lambda^2 \approx 0.005 \text{ m}^2$, lmc_c02 (Figure 9) at both $\lambda^2 \approx 0.005 \text{ m}^2$ and $\lambda^2 \approx 0.01 \text{ m}^2$, and lmc_c03 (Figure 6) at $\lambda^2 < 0.003 \text{ m}^2$.

4. Linearity (or lack thereof) of $\psi(\lambda^2)$; for some sources, near-linearity of $\psi(\lambda^2)$, panel (e), is maintained over broad $\lambda^2$ ranges despite strong concurrent depolarization—e.g., lmc_s11 (Figure 4), lmc_c03 (Figure 6), lmc_c02 (Figure 9), cen_c1827 (Figure 11), cen_c1972 (Figure 12), and lmc_c01 (Figure 14). For other sources, $\psi(\lambda^2)$ is strongly frequency-dependent (and so therefore is the RM)—e.g., lmc_c15 (Figure 16) and lmc_c04 (Figure 5).

5. Structure in the total intensity spectra (panel (g)); $\partial \log I$ versus $\partial \log (\nu)$ is rarely well-described by a pure power law, but rather, often shows substantial structure. Concave (e.g cen_c1972; Figure 12) and convex (e.g lmc_c04; Figure 5) features are apparent—often in the same spectrum (e.g lmc_s11; Figure 4). Several sources such as lmc_c02 (Figure 9) and lmc_s13 (Figure 7) possess particularly complicated Stokes $I$ spectra.

We interpret these behaviors in light of our polarimetric models in Section 7.1.
Figure 5. As for Figure 4. Source: lmc_c04.

Figure 6. As for Figure 4. Source: lmc_c03.
Figure 7. As for Figure 4. Source: lmc_s13.

Figure 8. As for Figure 4. Source: cen_c1466.
Figure 9. As for Figure 4. Source: lmc_c02.

Figure 10. As for Figure 4. Source: 1315-46 (Centaurus A data set phase calibrator).
6.2. 1.3–10 GHz Spectropolarimetric Modeling

We now report on the results of fitting the 1.3–10 GHz polarization data presented in Section 6.1, using the modeling techniques described in Sections 4.2 and 4.3. Table 3 contains a summary of the fitting results. The sources are ordered in the table by the $\tilde{\chi}^2$ value of the best-fitting S model, from highest to lowest (i.e., most to least Faraday complex). We include results for the best-fitting S model for each source by default, but only include results for Faraday complex models if they have a better (i.e., lower) AIC value than the best-fitting S model, and are either (a) the best-fitting model over all, or (b) indistinguishable from the overall best-fit model on the basis of our AIC criteria (i.e., $-10 < \text{AIC}_{\text{best fit}} - \text{AIC}_C < 0$).

The results for each source occupy several rows in the table and are arranged as follows. The source names in Column 1 indicate where the fitting data for each source begin and end. In the first row entry for each source, the figure number displaying the source data, the polarized S/N of the source, the overall best-fit model type, and the corresponding $\tilde{\chi}^2$ and AIC values are listed in Columns 2, 3, 4, 5, and 6, respectively. For the first component in the best-fit model, we list its type in Column 7, contribution to fractional polarization as $\lambda \rightarrow 0$ in Column 8, and best-fit parameter values $P_1$–$P_5$ in Columns 9–13. This is repeated for each of the $n$ remaining best-fit model components in Columns 9–13 $n$ subsequent rows of the table. Further complex models warranting inclusion are presented in subsequent rows in the same way, followed by the best-fit S model for each source. In all cases, the first row entry for a given model is indicated in Column 4 by listing its model type.

For all quantities, the uncertainties are indicated using standard parenthesis notation. Note that for one source only in our sample (0515-674), a model with zero polarized emission provides an excellent fit to the data. We have entered “Unp” as the model type in this isolated case.

6.2.1. Overall Best-Fit Models: Goodness of Fit and Model Type

The overall best-fit model for 30/36 sources has $\tilde{\chi}^2 < 2.1$ (Column 5, Table 3), with an average $\tilde{\chi}^2$ value of 1.49. We used a Komogorov–Smirnov test to compare the distribution of the standardized $(q,u)$ residuals (defined in Section 6.1, see also inset axes in panel (a) of Figures 4–38) to the standard normal distribution, and found no statistically significant difference for any of these sources. The remaining four sources—lmc_s11 (Figure 4), lmc_c04 (Figure 5), lmc_c03 (Figure 6), and cen_c1466 (Figure 8)—had higher $\tilde{\chi}^2$ values of 3.7, 4.4, 7.8, and 4.2, respectively, but each has a high polarized S/N and the fractional data–model residual values are low.

With the exception of a single source (0515-674), the overall best-fit model improves on the AIC value of the best-fitting S model by between 10 and $\sim 23,000$. Thus, we positively detect Faraday complex polarization structure in almost our entire sample, including those sources selected to be part of our Faraday simple control group (Section 2). The bright calibrator source 0515-674 represents the sole, remarkable exception (Figure 39). The best-fit S model has a fractional polarization of less than $2 \times 10^{-5}$, although an unpolarized model is also consistent with the data across the entire band.
Figure 12. As for Figure 4. Source: cen_c1972.

Figure 13. As for Figure 4. Source: cen_c1573.
The best-fit model type is unambiguous for 23 sources, while the remaining thirteen sources—which are generally faint or heavily resolved—have multiple best-fit candidates. The overall best-fit model for each source contains between one and four emission components. Only in three cases were the polarization data well-described by a model with a single component (0515-674 (Figure 39), cen_c1764 (Figure 35), and cen_c1435 (Figure 36)). Twenty nine sources required two model components, while five sources required either three or four model components. Three of the sources in this latter group (lmc_s11 (Figure 4), lmc_c04 (Figure 5), lmc_c03 (Figure 6)) also had larger $\chi^2$ values for the overall best-fit models, suggesting that an even greater number of model components might be required to adequately describe their polarization behavior. However, we were unsuccessful in identifying any such model. Alternatively, it may indicate that a more sophisticated functional form for T model components is required to fit the subtle $P(\lambda^2)$ behavior in the data with high S/N.

Of the T, SS, ST, TT, and SSS model types fit to the entire sample, each provided the best fit for at least one source. TT models were most commonly selected by the AIC (19 sources), followed by the ST and SS models (six and four sources, respectively), SSS models (two sources), and a T model (one source). The custom models required for lmc_c04, lmc_s11, and lmc_c03 were of types STT, SSTT, and SSTT, respectively. In general then, both S and T components were required to model our data, with 14 (28) of the 36 sources requiring at least one S (T) component.

6.2.2. Spectropolarimetric Structure of Resolved Sources

In Appendix A, we provide images of the resolved sources in our sample in both total and linearly polarized intensity. A range of morphological types are present. In both quantities, there are sources which resolve cleanly into multiple sub-components which are themselves unresolved, sources which resolve into one or more extended components, and various other combinations of these possibilities.

It is interesting to consider whether the number and type of spectropolarimetric model components fit to these sources (remembering that our spectropolarimetric analysis is performed on the integrated flux for each source) shows any clear relationship with the morphological components present in images of the sources. In general, we do not find this to be the case. Sources with two FDF model components (either S or T type) often show two spatial components in the appendix images (e.g., Lmc_c16—Figures 17 and 46; lmc_s14—Figures 33 and 48; lmc_c06—Figures 15 and 49; cen_c1832—Figures 32 and 55; cen_c1573—Figures 13 and 56). However, there are also sources which require a greater number of components in the FDF model than there are visible morphological components (e.g., Lmc_c15—Figures 16 and 47; lmc_s11—Figures 4 and 50; lmc_c03—Figures 6 and 51; cen_s1681—Figures 28 and 53; cen_c1972—Figures 12 and 54), and vice versa (e.g., Cen_c1764—Figures 35 and 59; cen_c1827—Figures 11 and 58). Furthermore, we are unable to identify any clear relationship between the presence or absence of unresolved/extended sub-components in the images, and the presence or absence of S or T components in the best-fit FDF models. For example, spatially unresolved components in the
Figure 15. As for Figure 4. Source: lmc_c06.

Figure 16. As for Figure 4. Source: lmc_c15.
source images give rise to both S components (e.g., Lmc_c15—Figures 16 and 47) and T components (e.g., Lmc_c16—Figures 17 and 46), while extended components in the source images can do likewise (e.g., Cen_s1803—Figures 38 and 63, and lmc_c06—Figures 15 and 49, for S and T components, respectively).

However, it is likely that this analysis is significantly hampered by a lack of spatial resolution and the range of source brightnesses present in our sample.

6.2.3. Requirement for Broad Components in The Best-fit FDF Models

A primary motivation for our study was to search for emission components with large peak Faraday depths and dispersions, since this can place strong constraints on the physical origin of the emission. Such components are required to fit the polarization data in the FDF models of 1315-46, lmc_s11, lmc_c02, lmc_c03, and lmc_c04. We now describe the characteristics of these components.

The phase calibrator source 1315-46 shows very strong depolarization in the 3 and 6 cm bands. Its FDF model (panel (f) of Figure 10) possesses two broad emission components, centered on $\phi_{\text{peak}} = -70 \pm 30$ and $+420 \pm 40$ rad m$^{-2}$ with $\sigma_0 = 470 \pm 15$ and $300 \pm 15$ rad m$^{-2}$, respectively. The super-Gaussian shape parameter is strongly constrained for the dominant T component with a value of $N = 2.5 \pm 0.2$. Thus, this T component depolarizes in a manner close to that expected for the Burn (1966) foreground screen until $\lambda^2 \approx 0.01$ m$^2$, by which point their contribution to the integrated polarization is negligible.

The FDF model for lmc_s11 (panel (f) of Figure 4) possesses two components with large Faraday depth/dispersion, centered on $\phi_{\text{peak}} = +109 \pm 7$ and $-133 \pm 5$ rad m$^{-2}$ with $\sigma_0 = 98 \pm 5$ and $132 \pm 3$ rad m$^{-2}$, respectively. This model achieves an excellent fit to the data with the exception of Stokes $u$ in the 3 cm band, which deviates from our model significantly (see the inset axis in panel (a) of Figure 4). While we could broadly reproduce this behavior using models containing components with similar Faraday depths and dispersions, the goodness of fit at 6 cm was compromised and the result was strongly disfavored by the AIC. The super-Gaussian shape parameter is strongly constrained for both T components in the best-fit model with $N = 2.1 \pm 0.1$ and $2.13 \pm 0.02$. Thus, each T component essentially depolarizes $\propto \exp(-k\lambda^2)$ (where $k$ is some constant) until $\lambda^2 \approx 0.01$ m$^2$, beyond which the polarized signal is effectively undetectable.

For lmc_c03 (Figure 6), two T components successfully reproduce most aspects of the $(q,u)$ behavior at 6 cm and 3 cm, although minor discrepancies are also evident (see the inset axis in panel (a) of Figure 6). The components have $\sigma_0 = 1439 \pm 4$ and $503 \pm 3$ rad m$^{-2}$—by far the the most highly Faraday dispersed emission components detected in our data—centered on $\phi_{\text{peak}} = +287 \pm 20$ and $+269 \pm 10$ rad m$^{-2}$, respectively. Both components are mostly depolarized by $\lambda^2 \approx 0.003$ m$^2$, but since $N > 2$ for each, small oscillations persist in $q$ and $u$ out to $\lambda^2 \approx 0.02$ m$^2$ (see panel (b)). For $\lambda^2 < 0.0009$ m$^2$ and $0.0014 < \lambda^2 < 0.0021$ m$^2$ where we have no data, the model predicts pronounced structure which is likely an artifact of the unconstrained fit in these regions.
The model for lmc_c02 (Figure 9) contains two T components. The component with the smaller amplitude has \( \sigma_0 = 71 \pm 6 \text{ rad m}^{-2} \), \( \phi_{\text{peak}} = +147 \pm 8 \text{ rad m}^{-2} \), and \( N = 2.0 \pm 0.1 \). As with lmc_s11, this component depolarizes smoothly and monotonically \( \propto \exp(-kx^2) \) for \( 0 < x^2 < 0.012 \text{ m}^2 \).

lmc_c04 (Figure 5) shows arguably the most spectacular \( P(\lambda^2) \) behavior, which is primarily caused by a dominant T component possessing \( \sigma_0 \approx 67 \pm 1 \), centered on \( \phi_{\text{peak}} = +124 \pm 2 \text{ rad m}^{-2} \) with \( N \approx 6.4 \pm 0.4 \) (panel (f)). The \( \sigma_0 \) and \( N \) values combine to produce strong oscillatory depolarization in \( P(\lambda^2) \), with a deep null at \( \lambda^2 \approx 0.022 \text{ m}^2 \) and several local maxima and minima evident (panel (d)). While this behavior is reminiscent of that associated with the Burn (1966) slab, our model differs in its detailed behavior (e.g., see Figure 3, which shows the subtle effect which the \( N \) parameter has on depolarization behavior).

6.2.4. Detection and Characteristics of Bright Emission Components with Low Faraday Dispersion

The overall best-fit models for the sources lmc_s13 (Figure 7), cen_c1466 (Figure 8), lmc_s11 (Figure 4), and lmc_c15 (Figure 16) contain at least one bright S component (with a band-averaged S/N of between 20 and 160). Although components which are truly Faraday-thin will never be generated in Nature, the emission modeled by these S components must nevertheless approach this ideal, otherwise T components would have been selected over S components by the AIC criteria. At the same time, \(|\phi_{\text{peak}}|\) values of 10–120 rad m\(^{-2}\) indicate that substantial Faraday rotation has occurred along the LOS. Together, this suggests that the Faraday-rotating plasmas lying along the LOS possess comparatively uniform \( n_e \) and \( B \) structure. In this section, we derive upper limits on the Faraday dispersion of these components to more fully explore this possibility.

To derive these limits, we refit our data over \( \lambda^2 \) ranges where the low-Faraday-dispersion components dominate \( P(\lambda^2) \) (i.e., \( \lambda^2 > 0.01 \text{ m}^2 \) for lmc_s13, cen_c1466, and lmc_s11, and the entire band for lmc_c15) using models consisting solely of T components. We present the results in Table 4. They show that emission components which contribute substantially to the fractional polarization of these sources (Column 5) typically possess very low Faraday dispersions—the upper limits are generally a few rad m\(^{-2}\), while the lower limits are in some cases consistent with 0 rad m\(^{-2}\) (Column 7). We discuss these results further in Section 7.3.

6.3. Spectropolarimetric Variability Over 1.3–1.5 GHz

Law et al. (2011) and O’Sullivan et al. (2012) detected multiple components in the broadband polarization spectra of a number of radio sources, and argued that these emission components likely arise in the inner parsec-scale regions of the associated AGN. Given that parsec-scale magneto-ionic structure in AGNs is observed to evolve over timescales of months to years (e.g., Zavala & Taylor 2001; Hovatta et al. 2012), these authors predict that the integrated polarization spectra of core-dominated radio sources may also vary with time. If this behavior is commonplace, time domain broadband

![Figure 18. As for Figure 4. Source: cen_s1290.](image-url)
Figure 19. As for Figure 4. Source: cen_c1636.

Figure 20. As for Figure 4. Source: cen_s1437.
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Source | Figure no. | Polarized S/N | Model Type | $\chi^2$ | AIC | Component Type | $P_{l=0}$ | $P_1$ $[\text{f}^1]$ | $P_2$ $[\text{f}^1]$ | $P_3$ $[\text{f}^1]$ | $P_4$ $[\text{f}^1]$ | $P_5$ $[\text{f}^1]$ |
| lmc_s11 | 4 | 157.1 | SSTT | 4.4 | –2807.2 | S | 0.031 | 0.0313(7) | 53.7(6) | ... | ... | −0.46(2) |
| lmc_s11 | 5 | 24.8 | S | 315.8 | >50000 | S | 0.004 | 0.0040(8) | 0(3) | ... | ... | −0.3(1) |
| lmc_c04 | 6 | 334.1 | S | 259.5 | >50000 | S | 0.007 | 0.0123(8) | 109(7) | 98(5) | 2.1(1) | −0.94(4) |
| lmc_c03 | 7 | 54.5 | ST | 2.1 | –3204.9 | S | 0.025 | 0.0246(3) | −135(3) | 132(3) | 2.1(2) | 0.65(1) |
| lmc_c04 | 8 | 160.9 | SS | 2.5 | –1756.7 | S | 0.004 | 0.0053(4) | 124(2) | 167(1) | 6.4(4) | −1.42(2) |
| lmc_c02 | 9 | 40.4 | TT | 2.1 | –2520.1 | T | 0.010 | 0.01673(5) | 193.7(2) | ... | ... | 1.443(2) |
| lmc_c02 | 10 | 3.1 | TT | 0.8 | –4144.3 | S | 0.028 | 0.0162(6) | 45.1(1) | ... | ... | −1.15(1) |
| lmc_c02 | 11 | 20.4 | TT | 0.5 | –1787.5 | S | 0.010 | 0.0162(5) | 41.9(3) | 6.6(5) | 2(8) | 0.21(2) |
| lmc_s13 | 12 | 100.0 | TT | 1.2 | –1488.5 | S | 0.004 | 0.0058(4) | 3(1) | ... | ... | 0.01(8) |
| lmc_s13 | 13 | 31.1 | ST | 1.6 | –1624.9 | S | 0.003 | 0.0065(5) | 70(30) | 470(15) | 2.5(2) | 1.16(5) |
| lmc_s13 | 14 | 20.4 | TT | 0.5 | –1787.5 | S | 0.003 | 0.0065(8) | 40(20) | 30(6) | 3.0(9) | 0.08(0.2) |
| lmc_s13 | 15 | 22.6 | SSS | 1.5 | –1584.4 | S | 0.002 | 0.0283(6) | 98(1) | ... | ... | −0.359(3) |

Table 3
Results for Model Fitting Described in Sections 4.2 and 4.3
Table 3 (Continued)

| Source      | Figure no. | Polarized S/N | Model Type | $\chi^2$ | AIC | Component Type | $p_A = 0$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ |
|-------------|------------|---------------|------------|---------|-----|----------------|----------|-------|-------|-------|-------|-------|
| lmc_c16     | 17         | 118.0         | TT         | 1.6     | T   | S              | 0.026    | 0.0257(8) | −50(4) | ... | ... | 0.38(3) |
| cena_s1290  | 18         | 13.8          | ST         | 2.1     | S   | 0.046          | 0.0463(6) | 115.1(8) | ... | ... | −0.09(2) |
| cena_c1636  | 19         | 32.8          | TT         | 1.8     | S   | 0.022          | 0.0223(4) | 47.3(6) | ... | ... | 0.89(3) |
| cena_s1437  | 20         | 15.9          | S          | 6.0     | 1411.4 | 0.025          | 0.0252(5) | −290(10) | 89(40) | 23(7) | −0.01(2) |
| lmc_c07     | 21         | 12.6          | TT         | 1.1     | S   | 0.257          | 0.263(3) | −110(1) | 11.6(8) | 20(10) | 1.00(6) |
| cena_s1443  | 22         | 10.3          | S          | 5.4     | −1331.0 | 0.16          | 0.16(1) | −24(0) | 0.08(2) | ... | 0.56(2) |
| cena_c1640  | 23         | 5.5           | TT         | 1.6     | S   | 0.026          | 0.0261(5) | −24(0) | 60(10) | 28(8) | 0.41(4) |
| cena_s1031  | 24         | 10.0          | TT         | 1.6     | S   | 0.010          | 0.0101(2) | 58.4(8) | ... | ... | 0.56(2) |
| cena_c1093  | 25         | 15.5          | TT         | 1.5     | S   | 0.079          | 0.079(6) | −18(3) | ... | ... | 0.35(9) |
| cena_s1605  | 26         | 10.3          | TT         | 1.5     | S   | 0.094          | 0.12(4) | 120(40) | 23(9) | 0.05(2) |
| cena_s1568  | 27         | 4.5           | TT         | 1.5     | S   | 0.091          | 0.09(1) | −59(9) | 11(2) | 26(4) | −0.56(1) |
| cena_s1681  | 28         | 11.4          | TT         | 1.3     | S   | 0.053          | 0.07(3) | −32(2) | 60.0(70) | 28(7) | −1(1) |
| cena_s1568  | 29         | 4.5           | TT         | 1.4     | S   | 0.035          | 0.035(5) | −48(8) | ... | ... | 0.13(4) |

Note: $P_1$, $P_2$, $P_3$, $P_4$, and $P_5$ are best-fit parameters for different model components.
### Table 3
(Continued)

| Source      | Figure no. | Polarized S/N | Model Type | Component Type | $\chi^2$ | AIC | $p_{\lambda} = 0$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ |
|-------------|------------|---------------|------------|----------------|---------|-----|------------------|-------|-------|-------|-------|-------|-------|
| cena_c1748  | 29         | S             | TT         | S              | 3.7     | 447.0 | 0.099            | 0.099(2) | −79.9(7) | ... | ... | 0.73(2) |
| cena_s1382  | 30         | 11.1          | TT         | T              | 1.3     | −320.9 | 0.069            | 0.11(1) | −2(2) | 65(40) | 6.0(6.0) | 0.3(1.0) |
| cena_c1152  | 31         | 10.4          | TT         | T              | 1.2     | −503.8 | 0.080            | 0.10(1) | −4(6) | 13(4) | 12(9) | 0.4(3) |
| cena_c1832  | 32         | 5.7           | TT         | T              | 1.2     | −1202.6 | 0.024            | 0.03(1) | −60(100.0) | 30(40) | 4(8) | −0.7(6) |
| lmc_s14     | 33         | 44.9          | TT         | T              | 1.0     | −580.4 | 0.065            | 0.08(3) | −90(20) | 60(30) | 25(5) | 0.1(1) |
| cena_s1014  | 34         | 4.1           | SSS        | S              | 3.1     | −391.1 | 0.168            | 0.168(2) | 48.3(6) | ... | ... | 0.12(2) |
| cena_c1764  | 35         | 15.3          | T          | S              | 2.2     | −240.5 | 0.042            | 0.042(5) | −90(10) | ... | ... | 0.05(0.3) |
| cena_c1435  | 36         | 14.2          | SS         | T              | 1.4     | −1397.3 | 0.021            | 0.021(3) | −72(9) | ... | ... | −0.2(1) |
| cena_s1349  | 37         | 9.2           | SS         | S              | 1.6     | −1342.7 | 0.025            | 0.025(7) | −66(1) | ... | ... | −0.2(4) |
| cena_s1803  | 38         | 12.5          | SS         | T              | 1.1     | −1284.5 | 0.042            | 0.042(10) | −27(5) | ... | ... | 0.6(2) |
Table 3
(Continued)

| Source     | Figure no. | Polarized S/N | Model Type | $\chi^2$ | AIC | Component Type | $P_{\lambda - 0}$ | Best-fit Parameters for Model Component |
|------------|------------|---------------|------------|----------|-----|----------------|-------------------|----------------------------------------|
|            |            |               | S          |          |     |                |                   | $P_1$ [\mathrm{\mu rad m}^{-2}]$ | $P_2$ [\mathrm{\mu rad m}^{-2}]$ | $P_3$ [\mathrm{\mu rad m}^{-2}]$ | $P_4$ [\mathrm{\mu rad m}^{-2}]$ | $P_5$ [\mathrm{\mu rad m}^{-2}]$ |
| 0515-674   | 39         | 3.5           | S          | -1273.8  |     |                | 0.029             | 0.029(9) | -17(7)         | ...                             | ...                             | 1.06(4)                       |
| Unp        |            |               | S          | -4957.5  |     |                | 0.023             | 0.023(1) | -32(2)         | ...                             | ...                             | ...                           |
|            |            |               | S          |          |     |                | 0.00002           | 0.00002(2) | -100(700)      | ...                             | ...                             | 0(1)                          |
|            |            |               | S          | -4956.4  |     |                | $2 \times 10^{-5}$| $2(2) \times 10^{-5}$ | -100(700)      | ...                             | ...                             | 0(1)                          |

Note.

The fitted model parameters $P_1$–$P_5$ refer to different quantities possessing different units for S (Faraday simple/thin) and T (Faraday-thick) model components. For T model components, $P_1$, $P_2$, $P_3$, $P_4$, and $P_5$ correspond to $A$ [non-dim], $\phi$ [rad m$^{-2}$], $\sigma_0$ [rad m$^{-2}$], N [non-dim], and $\psi_0$ [rad] in Equation (10), respectively. For S model components, $P_1$, $P_2$, and $P_5$ correspond to $p$ [non-dim], RM [rad m$^{-2}$], and $\psi_0$ [rad], respectively. The column positions for S components are chosen such that similar quantities align between S and T components. $P_3$ and $P_4$ are therefore left blank. Note that a model with zero polarization provides an excellent fit to 0515-674. In this table for this isolated case, we designate this model type as “Unp” (unpolarized).
Figure 21. As for Figure 4. Source: lmc_c07.

Figure 22. As for Figure 4. Source: cen_s1443.
Figure 23. As for Figure 4. Source: cen_c1640.

Figure 24. As for Figure 4. Source: cen_s1031.
Figure 25. As for Figure 4. Source: cen_c1093.

Figure 26. As for Figure 4. Source: cen_s1605.
Figure 27. As for Figure 4. Source: cen_s1568.

Figure 28. As for Figure 4. Source: cen_s1681.
Figure 29. As for Figure 4. Source: cen_c1748.

Figure 30. As for Figure 4. Source: cen_s1382.
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spectropolarimetry could become a powerful tool for studying magneto-ionic structure in the immediate vicinity of AGNs using non-VLBI radio telescopes.

We searched for the predicted variability by fitting polarization models to both the archival and 2012 data (for the non-calibrator sample sources only) over the 1.3–1.5 GHz band common to both epochs. We used models consisting of a single T component to account for the small amount of depolarization apparent in some sources over this narrow band. However, the σ₀ and N parameters (Equation 10) were poorly constrained by the narrowband data, so we ignore them in the subsequent analysis. We identified variability in the remaining parameters—A, φ_peak, and ψ₀ (see Equation 10)—by calculating the standardized difference ξ between the best-fit model parameter values for each epoch, defined by

\[
ξ = \frac{|μ_1 - μ_2|}{\sqrt{σ_1^2 + σ_2^2}}
\]

where μ₁ and μ₂ represent the best-fit parameters values for A, φ_peak, and ψ₀ in the archival and 2012 epochs, respectively, and σ₁ and σ₂ are the standard uncertainties on those parameter values. We flagged sources as potentially variable when ξ > 3 (i.e., the best-fit model parameter values differ between epochs with >99% confidence) for one or more of the best-fit model parameters.

Thirty-one of the 34 sources either have ξ ≤ 3 for all model parameters and thus show no evidence of spectropolarimetric variability, or show significant changes which are nevertheless more readily attributed to other factors. An example of the latter case is cen_c1972. Its Stokes I, (q,u), and (Q,U) data are plotted in row 1 of Figure 40, while the fitted parameter values and uncertainties are listed in row 1 of Table 5. The polarization data and models are evidently similar between epochs. ξ ≈ 1 for both φ_peak and ψ₀, indicating no substantial change in either polarization property. At first, the 13% increase in A appears significant with ξ_A ≈ 9.8. However, the total intensity decreases by a similar amount over the same period, meaning the changes are probably unrelated to the polarization structure of the source. The Stokes (Q,U) data show no statistically significant differences between epochs.

The remaining three sources—lmc_c03, lmc_s11, and lmc_s13—vary in one or more of the fitted model parameters. lmc_s11 shows the biggest changes (fourth row of Table 5 and Figure 40), with ξ_A ≈ 108, ξ_φ̂_peak ≈ 10, and ξ_ψ̂₀ ≈ 8. Between the archival and 2012 epochs, the fractional polarization (i.e., A) increases by 2.23(3)%, φ̂_peak increases by ~29(3) rad m⁻², and ψ₀ by ~1.1(1) rad. The total intensity changes during the same period, but the polarization changes are evident in both (q,u) and (Q,U), and cannot be explained by total intensity variation. lmc_s13 (third row of Table 5 and Figure 40) shows highly significant change in A with ξ_A ≈ 28, with moderately significant accompanying changes in φ̂_peak (ξ_φ̂_peak = 2.9) and ψ₀ (ξ_ψ̂₀ = 2.6). From the archival to 2012 epochs, the fractional polarization has increased by 2.9(1)%, φ̂_peak by 27(11) rad m⁻², an ψ₀ by 1.3(9) rad. Finally, for lmc_c03 (second row of Table 5 and Figure 40), Stokes I changes by ~25% between epochs and the Stokes (Q,U) data differ more between epochs than the (q,u) data. Nonetheless, moderately

Figure 31. As for Figure 4. Source: cen_c1152.
Figure 32. As for Figure 4. Source: cen_c1832.

Figure 33. As for Figure 4. Source: lmc_s14.
Figure 34. As for Figure 4. Source: cen_s1014.

Figure 35. As for Figure 4. Source: cen_c1764.
Figure 36. As for Figure 4. Source: cen_c1435.

Figure 37. As for Figure 4. Source: cen_s1349.
Figure 38. As for Figure 4. Source: cen_s1803.

Figure 39. As for Figure 4. Source: 0515-674 (LMC data set phase calibrator).
significant differences remain in the \((q,u)\) data. The source shows small but significant changes of 6.4 \((2.5)\) \(\text{rad m}^{-2}\) in \(\phi_{\text{peak}}\) \((\xi_{\phi_{\text{peak}}} = 3.1)\) and 0.5(1) \(\text{rad}\) in \(\psi_{\phi}\) \((\xi_{\psi_{\phi}} = 4.7)\), with a tiny, marginal change of 0.16(7)% in \(A\) \((\xi_{A} = 2.8)\).

### Table 4

| Source   | Model | \(\xi^2\) | Comp. | \(A\) | \(\phi_{\text{peak}}\) | \(\alpha_{\phi}\) |
|----------|-------|-----------|-------|------|-----------------|-----------------|
| lmc_s13  | TT    | 1.3       | T     | 0.038| 75(5)           | 35(4)           |
|          |       |           |       |      |                 |                 |
| cen_c1466| TT    | 2.8       | T     | 0.058| -39(2)          | 0.84(18)        |
|          |       |           |       |      |                 |                 |
| lmc_s11  | TT    | 2.5       | T     | 0.032| 54.5(6)        | 0.31(10)        |
|          |       |           |       |      |                 |                 |
| lmc_c15  | TTT   | 1.9       | T     | 0.045| 119.3(8)       | 0.77(10)        |
|          |       |           |       |      |                 |                 |
|          |       |           |       |      |                 |                 |

Note. This table is formatted similarly to Table 3—see Section 6.2 for a detailed description of the layout. The superscript and subscript values quoted in column 7 are the \(1\sigma\) standard errors on the fitted model parameters.

### 7. DISCUSSION

#### 7.1. Interpreting Complex \(P(\lambda^2)\) Behavior using Model FDFs

The FDF models derived using our method can often assist in interpreting \(P(\lambda^2)\) behavior which might otherwise remain cryptic. In this section we briefly illustrate this point by considering examples of the notable polarization behaviors described in Section 6.1.

In Section 6.1, we noted the existence of transitions in \((q,u)\), \(p\), or \(\psi\) behavior for the sources lmc_s11 (Figure 4) at \(\lambda^2 \approx 0.005 \text{m}^2\), lmc_c02 (Figure 9) at both \(\lambda^2 \approx 0.005 \text{m}^2\) and \(\lambda^2 \approx 0.01 \text{m}^2\), and lmc_c03 (Figure 6) at \(\lambda^2 < 0.003 \text{m}^2\). This behavior is invariably caused by a transition in the emission component(s) dominating the net polarization as a function of \(\lambda^2\). Typically, one or more strongly depolarizing T components dominate at small \(\lambda^2\) values, transitioning to dominance by fainter component(s) with lower Faraday dispersion(s) at larger \(\lambda^2\) values. The resulting \(P(\lambda^2)\) behavior can be counter-intuitive: in the case of lmc_c02, over the \(\lambda^2\) range \(0-0.01 \text{m}^2\), two depolarizing T components (panel (f) of Figure 9) interfere to produce a pronounced increase in the integrated fractional polarization (panel (d)), before the thicker of the two components depolarizes completely at \(\lambda^2 \approx 0.01 \text{m}^2\) and net depolarization associated with the remaining component ensues.

The linearity of \(\psi(\lambda^2)\) depends on the relative symmetry of the FDF (Burn 1966), after depolarization effects are accounted for. Sources with asymmetric FDFs exhibit nonlinearity in \(\psi(\lambda^2)\) (e.g., lmc_c15; Figure 16) and vice versa (e.g., cen_s1349; Figure 37), lmc_s11 (Figure 4) provides an example of more complicated behavior: its FDF model is asymmetric at high frequencies due to the presence of two broad T components, but these depolarize by \(\lambda^2 \approx 0.01 \text{m}^2\). Two S components remain, providing comparative symmetry in the FDF and approximately linear \(\psi(\lambda^2)\) behavior.

The observed \(p(\lambda^2)\) behavior depends on the number, shape, and type of components in the model FDF. If the source contains T components, their shape in \(\phi\) space strongly affects whether they depolarize monotonically to \(p = 0\) (e.g., cen_c1827; Figure 11) or repolarize (e.g., lmc_c04; Figure 5). The presence of an additional S component is associated with depolarization to a finite limiting value (e.g., cen_s1681; Figure 28).

#### 7.2. The Origin of Broad Components in The FDF Models

In Section 6.2.3, we described how broad FDF model components were required to model the polarization data for several of our sources. There are two possible sources for these polarization behaviors: the first is associated with Faraday rotation, while the second, which may apply to flat-spectrum core-dominated source, is associated with optical depth effects, whereby different parts of the radio core are observed at different frequencies. In the following, we assume that Faraday effects are responsible for the observed polarization properties, while acknowledging that the latter effect may indeed be acting to some extent (most plausibly in the flat-spectrum source lmc_c02). Disentangling the relative contribution of these effects in typical sources will require broadband polarimetric studies of sources at high spatial resolution, and is beyond the scope of this paper.

#### 7.2.1. The Location of The Dispersive Medium Along The LOS

The Faraday-thick emission components detected in 1315-46 (Figure 10), lmc_s11 (Figure 4), lmc_c02 (Figure 9), lmc_c03 (Figure 6), and lmc_c04 (Figure 5) have \(\theta_{\phi}\) in the range \(65-1450 \text{ rad m}^{-2}\) and \(|\phi_{\text{peak}}|\) in the range \(40-420 \text{ rad m}^{-2}\). These values are lower limits—they must multiplied by a factor of \((1 + z)^2\) to obtain the values in the rest frame of a Faraday-rotating medium at redshift \(z\). In this section we discuss the origin of these components, the information they convey about magneto-ionic structure along the LOS, and the nature of the associated radio sources.

Other than the Faraday-rotating medium associated with the host galaxy, the most plausible origin of the large Faraday dispersions observed in 1315-46, lmc_s11, lmc_c02, lmc_c03, and lmc_c04 is variation in the RM across each source, caused by the hot thermal plasma associated with the intracluster medium (ICM) of galaxy clusters. Typically, RM variations across radio sources embedded in ICMs are observed to be \(\sim\) a few hundred \(\text{rad m}^{-2}\) in the emitting frame (e.g., Murgia et al. 2004; Bonafede et al. 2010; Govoni et al. 2010), but can exceed thousands of \(\text{rad m}^{-2}\) for the inner-most regions of cooling core clusters (Perley & Taylor 1991; Vogt & Enßlin 2006). However, lmc_s11, lmc_c02, and lmc_c04 are completely spatially unresolved over 1.3–10 GHz, while lmc_c03 is dominated by an unresolved component in the 6 cm and 3 cm bands (see Figure 51). The corresponding upper limit on physical extent is \(\sim\) a few kpc regardless of redshift. Moreover, the visibility ratios from the AT20G high angular resolution catalog (Column 9, Table 2) indicate that lmc_s11 and lmc_c04 are compact on angular scales of \(0\text{'15} \sim (1 \text{kpc}) maximum. The auto-correlation length for the magnetic field in cooling core clusters is typically estimated to be \(\sim\) 5 kpc, with minimum fluctuation scales of \(\sim\) 0.7–2 kpc (e.g., Bonafede et al. 2010; Vacca et al. 2012). Thus, even if these sources were deeply embedded in such a cluster, their small physical extent means
they are unlikely to intercept a sufficient number of depolarizing cells to account for their Faraday dispersion. Independent evidence against the ICM-based origin is provided by the spectral index of the sources: sources embedded in dense cluster environments typically have \( \alpha \lesssim -1.0 \) (e.g., Slee et al. 1983; Klamer et al. 2006), whereas lmc_s11, lmc_c04, and lmc_c02 have \( \langle \alpha_0 \rangle > -0.55 \), and lmc_c03 has \( \langle \alpha_0 \rangle = -0.83 \) (Table 2, Column 8). The observed values of \( \sigma_\phi \) and \( \phi_{\text{peak}} \) are generally lower than seen at parsec-scales in AGN jets (with the exception of lmc_c03), but are broadly consistent with structures seen at kpc scales (e.g., Algaba et al. 2016). Thus, for the sources lmc_s11, lmc_c02, lmc_c03, and lmc_c04, we claim that the Faraday dispersion of the broad T components detected in our modeling is generated either inside, or in the immediate vicinity of, AGN jets on \( \sim \)kpc scales or below.

The source 1315-46 is somewhat different to the other four discussed above. Although it is also unresolved over 1.3–10 GHz, it possesses a steep spectral index of \( \alpha = -1.0 \), and two emission components with large Faraday dispersion (\( \sim \)several hundred rad m\(^{-2} \)). The brightest of these has an \( N \) value consistent with depolarization by a turbulent foreground screen (see Section 6.2.3). Thus, we suggest that 1315-46 is most plausibly a young, compact source embedded

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**Table 5**

Best-Fit Model Parameters, Uncertainties, and Standardized Differences in Parameter Values Between Epochs (\( \xi; \) Defined in the Main Text) for S Model Fits to The Archival and 2012 Data

| Source | \( A \) (2012) | \( A \) (Archival) | \( \phi_{\text{peak}} \) (2012) \( \text{rad m}^{-2} \) | \( \phi_{\text{peak}} \) (Archival) \( \text{rad m}^{-2} \) | \( \psi_0 \) (2012) \( \text{rad} \) | \( \psi_0 \) (Archival) \( \text{rad} \) | \( \xi_A \) | \( \xi_{\phi_{\text{peak}}} \) | \( \xi_{\psi_0} \) |
|--------|--------------|-----------------|-----------------|-----------------|----------------|----------------|---------|----------------|---------|
| cen_c1972 | \( 7.94(7) \times 10^{-2} \) | \( 6.89(8) \times 10^{-2} \) | \( -76(1) \) | \( -74(2) \) | \( 1.30(5) \) | \( 1.36(8) \) | \( 9.8 \) | \( 3.1 \) | \( 4.7 \) |
| lmc_c03 | \( 5.71(2) \times 10^{-2} \) | \( 5.87(5) \times 10^{-2} \) | \( 40.6(6) \) | \( 47(2) \) | \( 1.34(4) \) | \( 0.8(1) \) | \( 0.8 \) | \( 2.8 \) | \( 3.1 \) |
| lmc_s13 | \( 5.00(7) \times 10^{-2} \) | \( 2.12(9) \times 10^{-2} \) | \( 66(2) \) | \( 39(9) \) | \( -0.4(1) \) | \( 0.9(8) \) | \( 0.9 \) | \( 2.9 \) | \( 2.6 \) |
| lmc_c11 | \( 2.81(2) \times 10^{-2} \) | \( 5.8(1) \times 10^{-3} \) | \( 45.5(1) \) | \( 17(3) \) | \( -0.11(4) \) | \( 1.0(1) \) | \( 1.0 \) | \( 9.5 \) | \( 7.9 \) |

Note. The line ruled under the first row of the table distinguishes sources in which we detect temporal variability (sources below the line) from cen_c1972—an example of a source which we argue shows temporal change but not true polarization variability (see the main text).
in a strong depolarizing medium, possibly a cluster environment.

Finally, we note that Anderson et al. (2015) implicated the Galactic interstellar medium in causing depolarization among sources which were partially resolved at an ~arcminute resolution between 1.3 and 2 GHz. We reject a Galactic origin for the depolarization associated with the emission components discussed in this section. Given their angular size, the sources intercept structures no larger than a tiny fraction of a parsec. We reject a Galactic origin for depolarization (in a strong depolarizing medium, possibly a cluster

7.2.2. Use in Characterizing Magneto-ionized Structure in AGNs

If the Faraday-thick components do originate due to a Faraday-rotating medium in the vicinity of AGNs, our FDF model fits place direct constraints on the magneto-ionized structure of these regions. In this section we explain which structures are ruled out by our data, and speculate on some remaining possibilities.

For 1315-46, lmc_s11, and lmc_c02, the dominant T components in the FDF model have \( N \approx 2 \) (Section 6.2.3; panel (f) of Figures 4, 9, and 10), depolarizing proportional to \( \exp(-k\lambda^2) \). This strongly suggests depolarization by numerous independent "cells" in a random, turbulent Faraday-rotating plasma (Burn 1966), which must be separated from the synchrotron emitting source, but could be located in close proximity to it. In contrast, lmc_c04 shows oscillatory \( p(\lambda^2) \) depolarization (Figure 5, panel (d)) produced by a dominant T component with \( N = 6.4 \pm 0.3 \) (described in Section 7.2.1). This immediately rules out magneto-ionic structures that cause monotonic depolarization, such as those described by Burn (1966), Tribble (1992), Rossetti et al. (2008), Bernet et al. (2012), and Farnes et al. (2014). While the behavior is reminiscent of that expected for a cubic volume of mixed emitting and rotating plasma (i.e., the Burn slab 1966), the precise location, spacing, and amplitude of maxima and minima in \( p(\lambda^2) \) for the two T components are not consistent with the Burn slab model. The data are also inconsistent with a spherical volume of mixed emitting and rotating plasma (Burn 1966), linear RM gradients across a uniform background source, or a single layer of depolarizing turbulent cells in front of a background source (Schnitzeler et al. 2015). Similar arguments apply to the T components with \( N = 3.4 \) and 4.6 for lmc_c03 (Figure 6) described in the Section 6.2.3.

In spite of this, numerous plausible magneto-ionic configurations remain consistent with the lmc_c03 and lmc_c04 data. It is not our intention to explore these possibilities exhaustively. Rather, we choose to outline one intriguing possibility, which is that the Faraday dispersions are associated with nonlinear, monotonic RM gradients across AGN jets. Let us assume for simplicity that an emission component in a jet provides uniform illumination of a magnetized plasma in the immediate foreground. We depict this scenario in Figure 41. We designate \( x \) and \( y \) to be the transverse and longitudinal coordinates (relative to the jet axis) over this illuminating component. We also assume that \( \partial\phi/\partial x \) is positive definite and that \( \partial\phi/\partial y = 0 \). We then pose the question: how must \( \phi(x) \) vary across the jet (i.e., from point A to point B in Figure 41) to produce a T component with the functional form of a super-Gaussian in the source FDF? The answer is plotted in Figure 42 for super-Gaussian FDF components possessing \( N=2 \) and \( 6 \) and two different (arbitrary) values of \( \sigma_\phi \). These curves are comparable in qualitative form to the RM gradients observed across jets in VLBI observations (e.g., Gabuzda et al. 2015, cf. Figure 1; Mahmud et al. 2013, cf. Figures 3 and 4) and which are predicted by theoretical models (e.g., Broderick & McKinney 2010, cf. Figures 4–10). RM gradients, particularly those where the sign of the RM changes from negative to positive or vice versa, are invoked as evidence of helical \( B \) fields in jets—an important part of the theory of jet launching and propagation. We suggest that by using broadband
polarimetric analysis, these structures could be identified in unresolved sources by searching for broad T components which emit over both positive and negative Faraday depths (e.g., for lmc_c03; see panel (f) of Figure 6). Sources suspected of having RM gradients could then be re-observed with targeted high resolution observations.

Of course, since jets generally propagate from regions of higher to lower average plasma density, RM gradients may also occur along jets (i.e., $\partial \phi / \partial y = 0$ in the scenario above). For individual unresolved sources, this may be impossible to unambiguously distinguish from gradients across jets. However, we suggest that that on average, the character of the resulting Faraday-thick components will differ. In the former scenario for example, the symmetry of an RM gradient about the jet axis is more likely to produce a T component spanning both positive and negative Faraday depths (e.g., lmc_c03; see panel (f) of Figure 6), while in the latter scenario, the T component will perhaps be more likely to span only positive or negative Faraday depths (e.g., lmc_c02; see panel (f) of Figure 9). In addition, the specific shape of the T component in $\phi$-space may also differ on average between the scenarios, although we make no attempt to calculate the nature of that difference here.

Since magnetic fields in AGN jets are highly structured, we also searched for relationships between the initial polarization angles of model components within a single source. No relationship was found when S components were compared to one another or between S and T components. Intriguingly, however, the difference in $\psi_0$ between the two T components detected in each of lmc_c03, lmc_c04, lmc_c11, and lmc_c02—the sources where we attributed the polarized emission to jets directly above—is 0.05 ± 0.1, 0.09(15), 1.59(5), and 1.73(8) radians, respectively. This is consistent with a difference in angle of either $\sim 0$ or $\pi/2$ radians (the $\psi_0$ values for these sources are plotted on the inset polar axes in panel (f) of Figures 4–6 and 9, respectively). Components with parallel and orthogonal Faraday-rotated polarization angles are commonly observed in AGN jets (e.g., Attridge et al. 1999; Lyutikov et al. 2005; Pushkarev et al. 2005). Thus, we suggest that we have been able to discern the initial polarization angles of multiple components in unresolved AGN jets spectropolarimetrically.

If magneto-ionic structure in AGNs, including RM gradients and the polarization angles of components in jets, can be detected and constrained with broadband spectropolarimetric data, this will have major applications in upcoming broadband spectropolarimetric surveys such as POSSUM and VLASS. However, the correspondence between magnetized structure inferred from low resolution spectropolarimetric data and data with VLBI-scale resolution is yet to be robustly explored. We intend to undertake such an analysis in future work.

7.2.3. Stokes I Spectral Energy Distributions and The Nature of The AGN

Of the five sources possessing highly Faraday dispersed emission components, lmc_c02 (Figure 9, panel (g)), lmc_s11 (Figure 4), and lmc_c03 (Figure 6) each show multiple oscillations in spectral index through the band, while lmc_c04 (Figure 5) possesses a convex spectrum which flattens from $\alpha = -0.7$ to $\alpha = -0.3$ at 10 GHz. These results are consistent with the recent findings of Pasetto et al. (2016), who found that compact sources which possess high RMs often show substantial structure in their Stokes I spectrum. The observed Stokes I structures imply that contributions are made by multiple populations of synchrotron emitting particles. This may suggest that the sources have undergone episodic periods of AGN activity, or recent re-triggering. In future, broadband spectropolarimetry may therefore provide a unique and powerful avenue for studying magnetized plasmas intimately associated with AGNs, possibly extending to, we speculate, material which will eventually fuel the AGN, or which is closely associated with AGN feedback processes. However, the multiple emitting regions implied by the Stokes I data also mean that our $(q,u)$ spectra must be interpreted cautiously. This is because the polarized emission properties of each emitting region will likely differ, and dividing Stokes $Q$ and $U$ by Stokes $I$ to form Stokes $q$ and $u$ introduces inaccuracies. This remains a fundamental ambiguity with the interpretation of low angular resolution spectropolarimetric analysis.

7.3. The Nature of Bright Emission Components with Low-Faraday Dispersion

In Section 6.2.4 we placed upper limits on the Faraday dispersion of emission components from lmc_s13, cen_c1466, lmc_s11, and lmc_c15 of order $\sim 1$ rad m$^{-2}$. Each of these sources is either bright and unresolved at all frequencies (Table 2), or is otherwise dominated by such components at 10 GHz (lmc_c15). Furthermore, lmc_s13 and cen_c1466 both have inverted spectra (see Table 2 and panel (g) of Figures 7 and 8) while lmc_s13 and lmc_s11 show spectropolarimetric variability (Section 6.3). Thus, each source shows evidence of being dominated by sub-kpc or pc-scale emission regions, which typically have comparatively high Faraday dispersions (e.g., Zavala & Taylor 2004; Algaba et al. 2012). However, Hovatta et al. (2012) found that the Faraday rotation and depolarization of pc-scale jet components was best explained by interception of fewer than ten depolarizing cells in a random foreground Faraday-rotating plasma structure in the host galaxy. We suggest that our low-Faraday dispersion components are either shining through comparatively uniform "gaps" in such structures in these AGNs, or are otherwise sufficiently compact that they do not intercept multiple depolarizing cells in these screens.
7.4. Prospects for Studying Magnetized Structure in AGNs with Time Domain Broadband Spectropolarimetry

For the time-variable sources discussed in Section 6.3, we can consider whether the narrowband archival data can be fit by making minor changes to the model parameters for our 2012 1.3–10 GHz broadband data (Section 6.2.1). We find that this is indeed the case for each source. For example, consider the 2012 best-fit FDF model for lmc_s13 (panel f) of Figure 7. If the difference in $\phi_{\text{peak}}$ between the two dominant emission components is either 5 rad m$^{-2}$ or 70 rad m$^{-2}$, rather than our measured value of 16(3) rad m$^{-2}$, the 1996 $(q, u)$ data are well fit. Alternatively, the 1996 data are well-modeled if one emission component is switched off completely, leaving the parameter values of the other component unchanged. For lmc_s11 the archival data can be fit by changing $p$ and $\psi_0$ by 1% and 0.2 rad, respectively, for one of the S components in the best-fit SSTT model (panel f) of Figure 4. The archival data can, for example, be fit by a 1% change to $p$ and a 0.3 rad change to $\psi_0$ for one of the Faraday-thin components in the full band 2012 model (panel f) of Figure 6.

Thus, only minor changes in the polarization structure of each source are required to explain the changes in the spectropolarimetric data. Since all three of the variable sources are unresolved at 0.3' (Column 9, Table 2) with corresponding ~kpc upper size limits on the emitting regions, and have $\langle \alpha_{\phi,13} \rangle > -0.5$ (Column 8, Table 2), it is tempting to attribute the observed spectropolarimetric variability to changes in pc-scale polarization structure, as suggested by Law et al. (2011) and O’Sullivan et al. (2012). While the narrow bandwidth of our current archival data set prevents us from discerning the precise nature of the changes, broadband polarization data would provide much more stringent constraints. If our claim in Section 7.3 is correct—namely, that components possessing low-Faraday dispersion represent highly compact emitting regions in AGN jets—tracking the temporal evolution of the polarization angle, Faraday depth and dispersion of these components spectropolarimetrically may provide an extremely fine probe of the magneto-ionic properties of material in AGNs at sub-pc scales.

Based on our data alone, it is difficult to say how common such “spectropolarimetric variables” might be. While we have obtained only three detections from 34 sources, we note that all of the detections are associated with bright and unresolved objects, and that for the most part, the signal level was only just sufficient to allow for statistically significant detections of changes in their polarization properties. If we consider only the unresolved, flat-spectrum (i.e., core-dominated) sources in our sample, which are not much fainter than those for which we achieve detections ($\sim$100 mJy), then variability is detected in about half of the viable candidates (see Table 2). Sources of this type might therefore be common, and high cadence, broadband polarization monitoring of numerous such sources using survey telescopes such as the Australian Square Kilometre Array Pathfinder (Johnston et al. 2007) might be possible.

7.5. The Impact of Attenuated Bandwidth and Implications for Upcoming Spectropolarimetric Surveys

While upcoming spectropolarimetric surveys will have broad $\lambda^2$ coverage by historical standards—e.g., POSSUM [1.1–1.4 GHz], POSSUM early science [approximately 0.7–1.8 GHz], and VLASS [2–4 GHz]—the 1.3–10 GHz coverage explored in this work will not be achieved in survey-style observations for the foreseeable future. In this section, we comment on the impact that limited $\lambda^2$ coverage has on the detection and characterization of Faraday complex polarization structure in our sources.

First, we consider the degree of deviation from Faraday simple behavior shown by our sources as a function of frequency over 1.3–10 GHz. Figure 43 plots a measure of this deviation. To generate this plot, we first fit the following Faraday simple model to each source over the narrow 1.3–1.5 GHz band:

$$p(\chi^2) = p_0 e^{2(\psi_0 + \text{RM} \chi^2)}$$

(16)

where $p_0$ is a constant and all other parameters have been previously defined. For each source, we then calculated $\chi^2$ for the best-fit simple model and the polarization data between 1.3 GHz and an upper frequency limit $\nu_{\text{upper}}$, GHz, then plotted $\chi^2$ versus $\nu_{\text{upper}}$. The resulting curves show the increase in $\chi^2$ from a simple model fit as a function of the upper bound on the considered frequency band for each source. The curves are colored according to the logarithm of $\partial \chi^2/\partial \nu_{\text{upper}}$. The plot shows the following:

1. Several sources show a strong increase in $\chi^2$ with $\nu_{\text{upper}}$ in each of the 16, 6, and 3 cm bands. This, data from each band are necessary to fully characterize the Faraday complex polarization behavior of these sources. Furthermore, it demonstrates that polarization data at $\nu < 1$ GHz and $\nu > 10$ GHz will be necessary for characterizing the polarization structure of at least some types of sources. Given the way in which our sample was selected, it is difficult to say how common such sources might be.

2. Strong increases in $\chi^2$ versus $\nu_{\text{upper}}$ ($\partial \chi^2/\partial \nu_{\text{upper}} > 10$) are most common in the 16 cm band, and least common in the 3 cm band. This is unsurprising given the way in which our sample was selected. However, a Spearman rank comparison of the $\chi^2$ values obtained for the sample at $\nu_{\text{upper}} = 2$ and 10 GHz yields a coefficient of 0.75, indicating that the $\chi^2$ value calculated for $\nu_{\text{upper}} = 2$ GHz is a reasonably good predictor of relative Faraday complexity over the full 1.3–10 GHz band.
3. The four sources with the highest $\chi^2$ values at $\nu_{\text{upper}} = 10$ GHz all reach $\partial^2\chi^2/\partial \nu_{\text{upper}} > 100$ GHz$^{-1}$ at $\nu_{\text{upper}} < 2$ GHz. Despite the small sample, this suggests that a strong increase in $\chi^2$ with $\nu_{\text{upper}}$ at low frequencies might be a useful predictor of the presence of Faraday-thick components at higher frequencies, which would otherwise be unobservable in frequency-limited observations.

In summary, both 6 and 3 cm band observations are crucial for characterizing the Faraday structure of some sources. Conversely, indications of complex behavior in the 6 and 3 cm bands can, at least sometimes, be identified at frequencies as low as 2 GHz.

Deviations from the Faraday simple model in the 6 and 3 cm bands can generally be attributed to the presence of Faraday-thick emission components. To gauge the extent to which these components would manifest in data possessing the $\chi^2$ coverage of upcoming surveys, we plot the fractional depolarization of each of the T components detected in our FDF models in Figure 44. We include upper and lower $\chi^2$ limits for the surveys mentioned above (see the caption). It shows that:

1. Oscillatory depolarization continues to $\chi^2$ values that are substantially higher than $\lambda_{1/2}$—i.e., the wavelength at which the fractional depolarization first drops below 0.5. This is caused by T components with $N \approx 2$. For low S/N data at low frequencies, these oscillations could be misconstrued as bandpass, calibration, or deconvolution errors. In high S/N data, such structure can be used to infer the presence of high $\sigma_{\theta}$ T components which would otherwise be completely depolarized for $N \approx 2$.

2. Over 1.1–1.4 GHz (i.e., the POSSUM survey band), oscillatory ringing from T components is generally not of sufficiently high frequency to result in multiple maxima and minima in the band. For components with initial minima at frequencies just above 1.4 GHz ($\chi^2 \approx 0.045$ m$^2$), the resulting $p(\chi^2)$ essentially mimics the behavior expected from interfering Faraday-thin components—completely analogous to the equivalent situation in aperture synthesis imaging where, for example, an extended circular source will appear as a ring when short baseline information is not present. Care must be taken in interpreting such data.

3. In combination, POSSUM (both the full survey and early science) and VLASS will cover almost the full range of depolarization behavior caused by Faraday-thick components in our sample (lmc_c03 is an exception). Thus we anticipate that the types of sources and behaviors we have detected will be prevalent in these surveys, and that the type of analysis we have conducted will represent powerful methods for studying magnetized structure in AGNs.

For sources possessing multiple S components, the primary issue for interpretation of the polarization data is degeneracy of the fitted polarization models over narrow bands (O’Sullivan et al. 2012; Sun et al. 2015). The frequency-dependent instantaneous RM values (i.e., $\partial \psi / \partial \lambda^2$) of many of our sources can deviate from the RM value determined from a Faraday simple model fit to low frequency, narrowband data by 10 s–100 s of rad m$^{-2}$. Such large deviations typically occur over small $\lambda^2$ ranges, but inaccuracies and biases can persist when fitting to larger bands, especially at higher frequencies. As an example, in Figure 45 we plot the 1.3–10 GHz data for lmc_c15, including the best-fit models resulting from fits to the data over the restricted bands $\nu < 1.5$ GHz and $2 < \nu < 4$ GHz. Good fits to the data are achieved in each individual band. However, the number of interfering components in the source, their RMSs, and the fractional polarizations are mischaracterized for both sub-bands. Note that this is true even when observed using 2 GHz of continuous bandwidth in the case of the 2–4 GHz band. For this particular source, the addition of 4–6 GHz data is required to obtain the “correct” RMSs, although there is no guarantee that additional low frequency data would not modify the RMSs or even the number of polarization components required even further.
Figure 46. Source: lmc_c16. Central image frequencies: 1.4, 2.8, 4.8, 6.1, 8.3, and 9.6 GHz (left to right). The source is somewhat resolved at all frequencies from 1.3 to 10 GHz. The best-fit polarization model is of type TT.

Figure 47. Source: lmc_c15. Central image frequencies: 1.4, 2.8, 4.8, 6.1, 8.3, and 9.6 GHz (left to right). The spectropolarimetric data represent the integrated Stokes I, Q, and U flux densities over both components visible in the images above (which are themselves marginally resolved), as described in Section 4.1. The best-fit polarization model is of type SSS.

Figure 48. Source: lmc_s14. Central image frequencies: 1.4, 2.8, 4.8, and 6.1 GHz (left to right). The spectropolarimetric data represent the integrated Stokes I, Q, and U flux densities over the entire extended source, as described in Section 4.1. The best-fit polarization model is of type TT.
8. SUMMARY AND CONCLUSIONS

We have obtained polarization data for 36 discrete, mostly unresolved radio sources spanning a total frequency range of 1.3–10 GHz with 6 GHz of the spectral range densely sampled. The polarization data show remarkable structure and variety, with complicated frequency-dependent changes in Stokes $q$ and $u$.
observed in a number of sources. After finding that we were unable to reproduce these behaviors with existing depolarization models, we developed an alternative spectropolarimetric modeling method. This involves constructing model FDFs in Faraday depth space from simple parametric basis functions, which can then be Fourier-transformed and assessed for goodness of fit to Stokes q(\lambda^2) and u(\lambda^2) polarization data. Our main findings are as follows:

i. Using our modeling technique, we were able to achieve good fits to complex frequency-dependent polarization behavior over three densely sampled 2 GHz bands which, in total, spanned nearly 9 GHz (a fractional bandwidth of ~200%). Subtle discrepancies between the data and best-fit models remained for the very brightest sources in our sample. However even in these cases, we were able to broadly reproduce the observed polarization behavior. The resulting FDF models can greatly aid in interpreting (q, u), p, and \psi versus \lambda^2 behaviors.

ii. Only one source in our sample is best fit by a Faraday-rotation-only polarization model over the 1.3–10 GHz band (although a zero-polarization model does almost as well in this case). All other sources show some level of deviation from idealized, Faraday-rotation-only behavior (i.e., show Faraday complexity).

iii. The presence of multiple individual emission components in spatially unresolved radio sources can be discerned, and their individual Faraday depth distributions and initial polarization angles can be measured, using broadband polarization data. These measurements can place strong constraints on the structure of magnetized material in the radio sources.

iv. For five sources in our sample, we detect Faraday-thick emission components at high S/N, which emit over a Faraday depth range of between ~130 and 2890 rad m^{-2}. In contrast to our previous work, where we attributed the Faraday complex behavior observed in extended sources at low frequencies to the Galactic interstellar medium (Anderson et al. 2015), constraints supplied by the linear size and spectral index of four of these sources, coupled with their large measured Faraday dispersions, strongly implicate a Faraday dispersive medium which is intrinsic to the source. We believe the most satisfactory explanation of these observations is that the Faraday-thick emission components are generated by magnetized material in the vicinity of kpc-scale AGN jets.

v. Three sources show variability in their broadband polarization data on ~15 year timescales. This represents a detection rate of about 50% among viable candidate sources (i.e., sufficiently bright, core-dominated sources). As such, broadband polarization variability might be commonly observed in the future. Only small changes in the physical polarization structure of each source were required to account for these changes, although the limited bandwidth of the archival observations prevented us from uniquely determining their nature. Multi-epoch comparison of ~GHz bandwidth data would allow the nature of the changes to be determined far more precisely.

vi. Observations at wavelengths as short as 3 cm are crucial for characterizing the full polarization behavior of some sources. Conversely, complex behavior in the 6 and 3 cm bands can sometimes be inferred from polarization behavior at frequencies as low as 2 GHz. In particular, oscillatory depolarization from Faraday-thick components “rings” down to substantially lower frequencies than might be expected under the assumption of monotonic depolarization, even for components with \sigma_0 \gg 100 rad m^{-2}. This has important implications for upcoming polarization surveys such as POSSUM and VLASS.

In future work, we intend to obtain broadband radio polarization data and observations at other wavelengths for a sample of sources, in order to facilitate a deeper investigation of the physics of magnetized structures in AGNs. We intend to compare magnetized structure observed at VLBI-scale resolution with that inferred through broadband spectropolarimetry, to ascertain the reliability of these inferences. Finally, we plan to undertake multi-epoch broadband polarimetric observations of core-dominated AGNs, in order to explore the utility of broadband polarization variability for studying magnetized structure in the vicinity of AGN jets.

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Figure 53. Source: cen_s1681. Central image frequencies: 1.4, 2.8, 4.8, and 6.1 GHz (left to right). The source is somewhat resolved at all frequencies from 1.3 to 6.4 GHz. The best-fit polarization model is of type TT.

Figure 54. Source: cen_c1972. Central image frequencies: 1.4, 2.8, 4.8, 6.1, 8.3, and 9.6 GHz (left to right). The spectropolarimetric data for this source was extracted from the left-most component of the double source visible in the images above. This component becomes resolved itself at a frequency of $\sim$6 GHz (see Table 2). The best-fit polarization model is of type TT.

Figure 55. Source: cen_c1832. Central image frequencies: 1.4, 2.8, 4.8, and 6.1 GHz (left to right). The spectropolarimetric data represent the integrated Stokes $I$, $Q$, and $U$ flux densities over the entire extended source, as described in Section 4.1. The best-fit polarization model is of type ST.
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APPENDIX A
IMAGES OF RESOLVED SOURCES

In Figures 46–63 we provide images of our resolved sample sources at both the low and high frequency ends of each CABB band. The sources are presented in the order that they are listed in Table 2—i.e., in order of increasing R.A. We only include images that span the frequency range used in the spectropolarimetric analysis of each source (see Section 3). Each image represents a cleaned and restored multi-frequency synthesis image of a 100 MHz band centered on (for image positions running from left to right) 1.4, 2.8, 4.8, 6.1, 8.3, or 9.6 GHz. For each source, the top row contains total intensity images, for which the saturation points for the grayscale are set to −3 and 15 mJy. The bottom row contains images of linearly polarized intensity, for which the saturation points for the grayscale are set to −1 and 5 mJy. The source name is provided in the top left-hand corner of the lowest frequency Stokes I image of each source, while the maximum flux density, noise...
Figure 58. Source: cen_c1827. Central image frequencies: 1.4, 2.8, 4.8, 6.1, 8.3, and 9.6 GHz (left to right). The spectropolarimetric data represent the integrated Stokes I, Q, and U flux densities over the entire extended source, as described in Section 4.1. The best-fit polarization model is of type TT.

Figure 59. Source: cen_c1764. Central image frequencies: 1.4, 2.8, 4.8, and 6.1 GHz (left to right). The spectropolarimetric data represent the integrated Stokes I, Q, and U flux densities over the entire extended source, as described in Section 4.1. Note that the data were extracted for the bright triple component source only—the nearby double-component radio source that is visible at low frequencies was excluded. The best-fit polarization model is of type T.

Figure 60. Source: cen_s1605. Central image frequencies: 1.4, 2.8, 4.8, and 6.1 GHz (left to right). The source is somewhat resolved at all frequencies from 1.3 to 6.4 GHz. The best-fit polarization model is of type TT.
Figure 61. Source: cen_c1435. Central image frequencies: 1.4, 2.8, 4.8, and 6.1 GHz (left to right). The spectropolarimetric data represent the integrated Stokes I, Q, and U flux densities over the entire extended source, as described in Section 4.1. The best-fit polarization model is of type SS.

Figure 62. Source: cen_c1636. Central image frequencies: 1.4, 2.8, 4.8, and 6.1 GHz (left to right). The source is somewhat resolved at all frequencies from 1.3 to 6.4 GHz. The best-fit polarization model is of type TT.

Figure 63. Source: cen_s1803. Central image frequencies: 1.4, 2.8, 4.8, 6.1, 8.3, and 9.6 GHz (left to right). The spectropolarimetric data represent the integrated Stokes I, Q, and U flux densities over the entire extended source, as described in Section 4.1. The best-fit polarization model is of type SS.
level, beam, and angular scale are provided in all images. Note that the coordinate labels on the 1.4 GHz images apply to these images only—all images at frequencies greater than 1.4 GHz have different spatial scales, which can be judged using the scale bar at the bottom right of each image. For the Stokes I images only, we have drawn green contours at 50% of the peak measured flux density, in order to facilitate comparison of source morphology with the primary beam. Brief notes on measured images only, we have drawn green contours at 50% of the peak scale bar at the bottom right of each image. For the Stokes I images only, we have drawn green contours at 50% of the peak measured flux density, in order to facilitate comparison of source morphology with the primary beam. Brief notes on measured images only, we have drawn green contours at 50% of the peak scale bar at the bottom right of each image.

**APPENDIX B**

**SPECTROPOLARIMETRIC DATA**

We consider that our data might be useful for future research—e.g., as standard cases for comparing and testing new polarimetric analysis algorithms, or for monitoring these sources for temporal changes in their broadband polarization properties. As such, we provide the raw frequency-dependent Stokes I, Q, U, and V data, along with their uncertainties, for each source in our sample (i.e., those sources listed in Table 2) as named in the table caption. An example is presented below to provide an indication of format; the full set of tables can be found at VizieR. The data for each source have been calibrated, imaged, and processed as described in the main text.

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