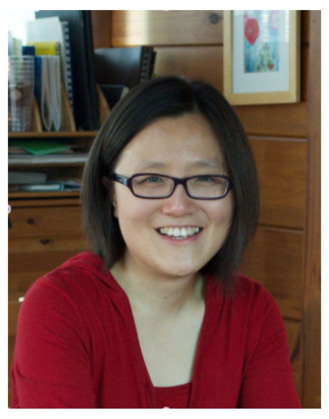

Wide-band Jansky Very Large Array Polarization Observations of M51

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Summary: We present new L band (1-2 GHz) multi-configuration Jansky Very Large Array polarization observations of M51. For the first time, we perform direct fits to Stokes Q and U of the diffuse polarized emission from an external galaxy as a function of wavelength to various Faraday rotation models. The measured polarized emission as a function of wavelength at L band is consistent with polarized emission from the top layer of the synchrotron disk being Faraday rotated in an external screen in M51's near-side halo. The distribution of rotation measure across M51 can be explained by the presence of a halo magnetic field which has a bisymmetric plane-parallel component and a coherent perpendicular component. Future wide-band observations of M51 above 2 GHz will enable one to model its disk and halo fields simultaneously.

Introduction

Faraday rotation is a powerful probe of the magneto-ionic medium. The plane of polarization gets modified when radiation travels through a magnetized medium. Faraday depth is defined as

$$\Phi = 0.812 \int_{\text{source}}^{\text{observer}} n_e(l) B_{\parallel}(l)\, dl \quad \text{rad m}^{-2},$$

where $n_e(l)$ (in cm^{-3}) is the thermal electron density, $B_{\parallel}(l)$ (in μG) is the line-of-sight magnetic field strength and dl (in pc) is a line element along the line of sight. In the case where the background radiation experiences a single-component Faraday rotation in a foreground uniform screen, the rotation measure (RM) and the Faraday depth are equivalent.

The Degree of polarization can also be modified when background polarized radiation propagates through a magnetized medium. For example, if the medium is a turbulent screen, then beam depolarization would reduce the intrinsic polarization by a factor of $\exp(-2\sigma_{RM}^2\lambda^4)$, where σ_{RM} is the RM fluctuation within the beam (Burn 1966).

M51, the first external galaxy detected in radio polarization (Mathewson et al. 1972), is an excellent target to study the nature of the polarized emission. Although previous polarization observations were conducted at a number of frequencies (Horrellou et al. 1992, Berkhuijsen et al. 1997, Fletcher et al. 2011, Heald et al. 2009), they consist of relatively narrow bandwidths. *Thus, wide-band polarization observations of M51 are long overdue.*

New Jansky VLA Observations

M51 was observed as part of the science demonstration of the Expanded Very Large Array project. Observations were carried out in D, C and B configurations at L band (971 MHz – 1995 MHz) in 512 2-MHz channels. The total time on source is approximately 7 hours. Calibration, reduction and imaging were carried out using the CASA package. After flagging, approximately 400 MHz of the 1 GHz bandwidth remains usable. The Stokes Q and U channel maps were then used to perform RM synthesis (Brentjens & de Bruyn 2005) to obtain the Faraday depth and the intrinsic polarization angle distribution across M51.

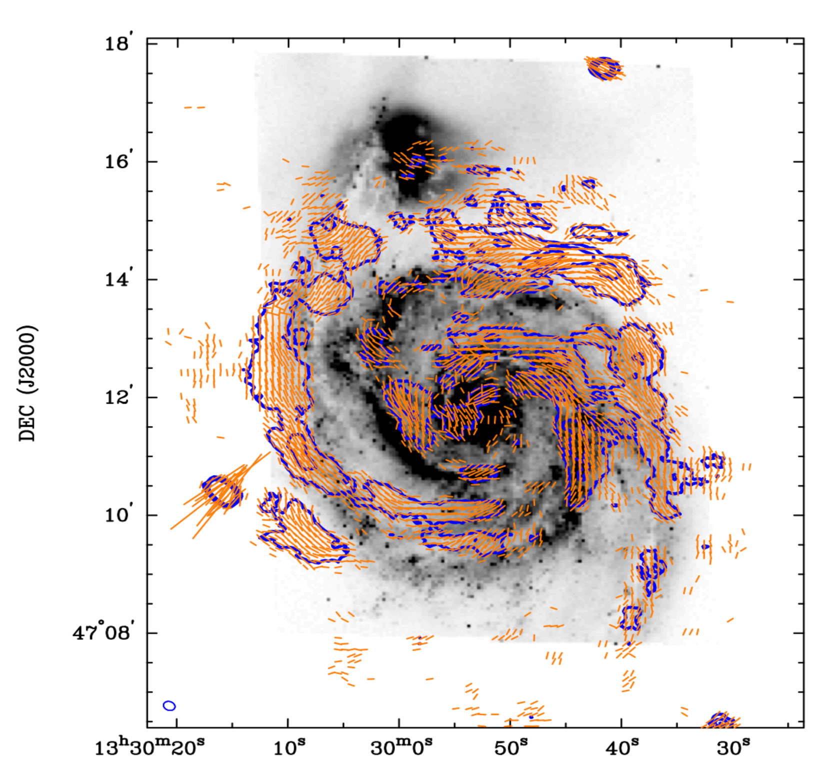

Figure 1: Intrinsic B field orientations (orange) superposed on a DSS image of M51. Only sightlines with polarization SNR > 7 are shown. The blue contour is at a polarized intensity of 60 μJy/beam.

Fit directly to $Q(\lambda^2)$ and $U(\lambda^2)$

Though RM synthesis is an excellent tool to visualize polarized emission at different Faraday depths, it may yield erroneous Faraday structures in the presence of multiple interfering components (Farnsworth et al. 2011). Therefore, *we have performed a pixel-by-pixel maximum likelihood fit of the measured Stokes Q, U vs λ^2* (O'Sullivan et al. 2012) *to various internal and external depolarization models*. Models with more free parameters are considered superior only if the f-test significance level exceeds 5 σ.

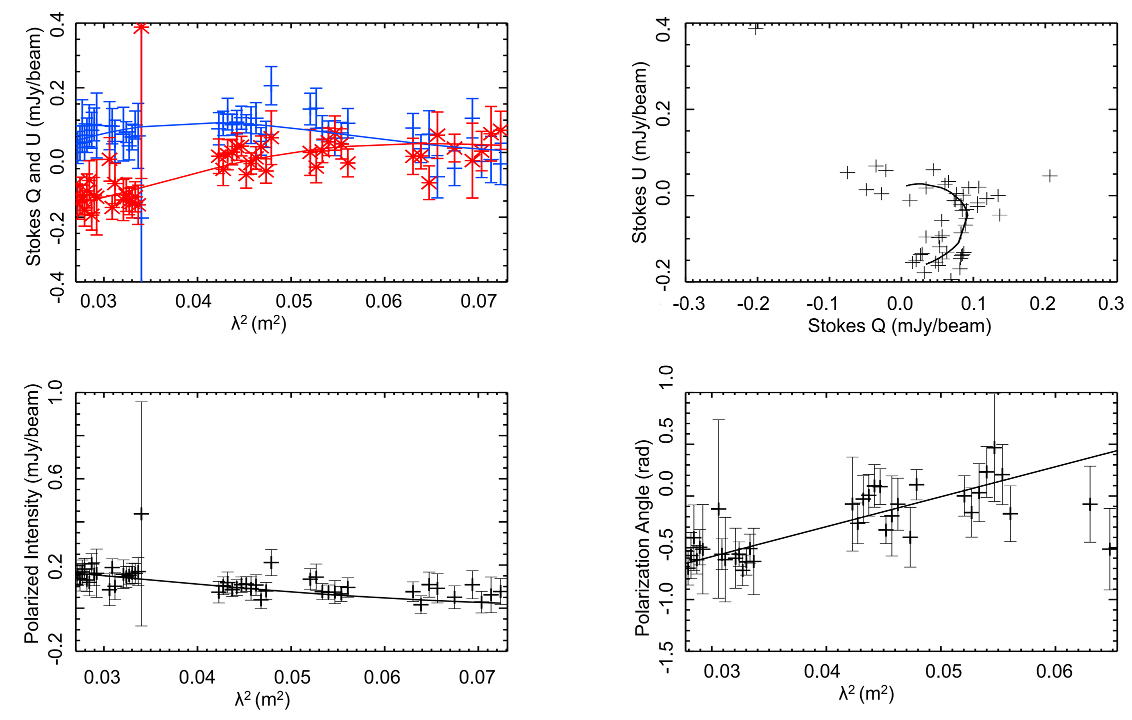

Figure 2: An example fit of the observed complex polarization along a sightline best fitted by Faraday rotation in a turbulent external screen.

Nature of the Polarized Emission

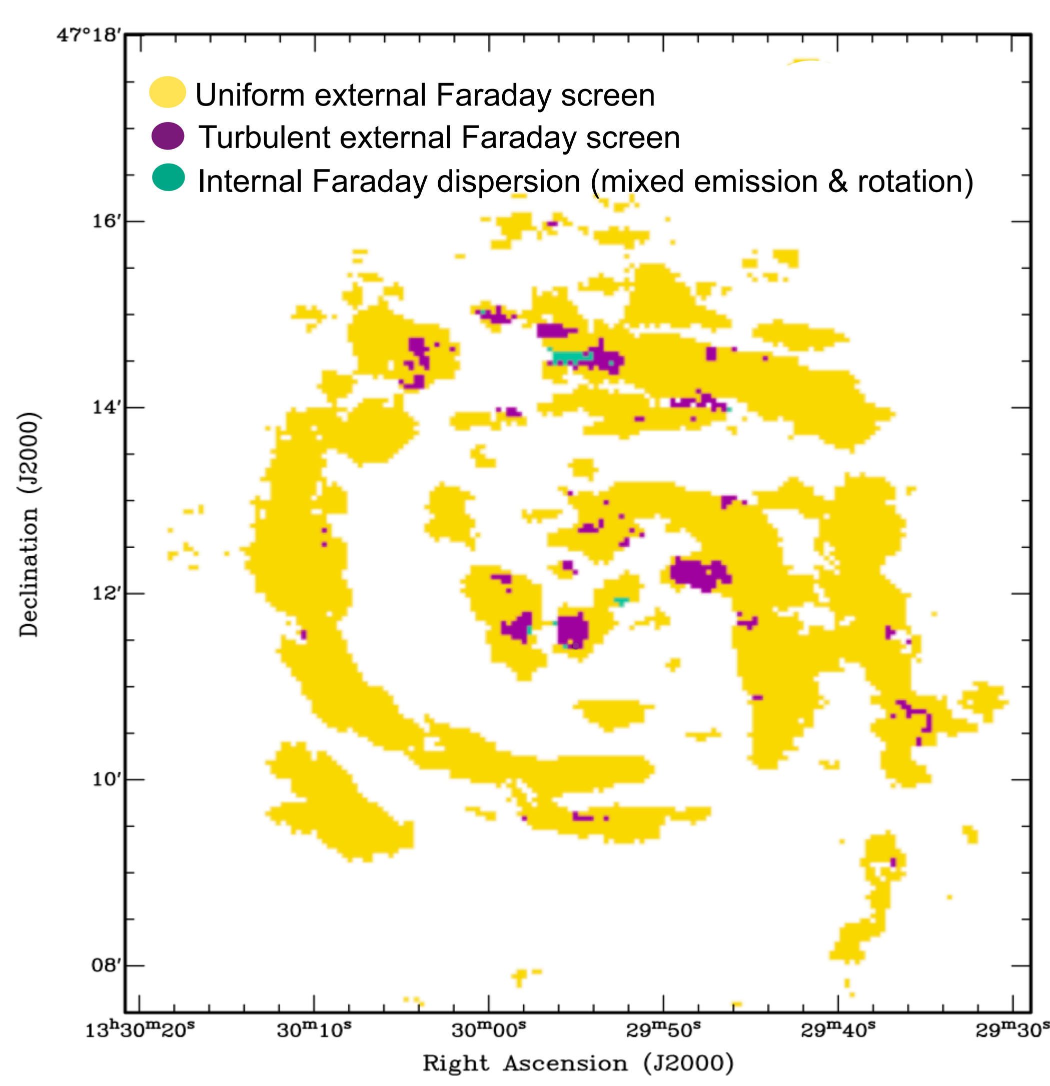

Figure 3: The structure of the Faraday rotating medium in M51 at 1.4 GHz. Most sightlines toward M51 are consistent with the scenario where polarized emission from the top layer of the synchrotron emitting disk is Faraday rotated in a foreground screen in the near-side halo. This implies that the scale height of thermal electrons is larger than that of the synchrotron emitting disk at 1.4 GHz. Regions close to the nucleus of M51 and NGC 5195 are consistent with Faraday rotation occurring in a turbulent foreground screen which could be due to the more turbulent conditions in these regions. We note that this result remains valid if we correct for the spectral index effect by assuming a constant non-thermal α of -0.7.

References: Berkhuijsen et al. 1997 A&A, 318, 70 ❖Braun et al. 2010 A&A 514, 42❖Brentjens & de Bruyn 2005 A&A, 441, 1217❖Burn 1966 MNRAS, 133, 67❖Farnsworth et al. 2011 AJ 141, 191❖Fletcher et al. 2011 MNRAS, 412, 2396❖Heald et al. 2009 A&A 503, 409❖Horrellou et al. 1992 A&A, 265, 417❖Mathewson et al. 1972 A&A, 17, 468❖O'Sullivan et al. 2012 MNRAS, 421, 3300❖

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Large-Scale B Field in M51

We can compare the observed Faraday depth distribution towards M51 with the predicted L band Faraday depths from the Fletcher et al. (2011) M51 magnetic field model that consists of a bisymmetric halo magnetic field. Our data and the Fletcher model are consistent with each other if we include an additional vertical field in the halo of M51 which produces a Faraday rotation of ~ -15 rad m^{-2}.

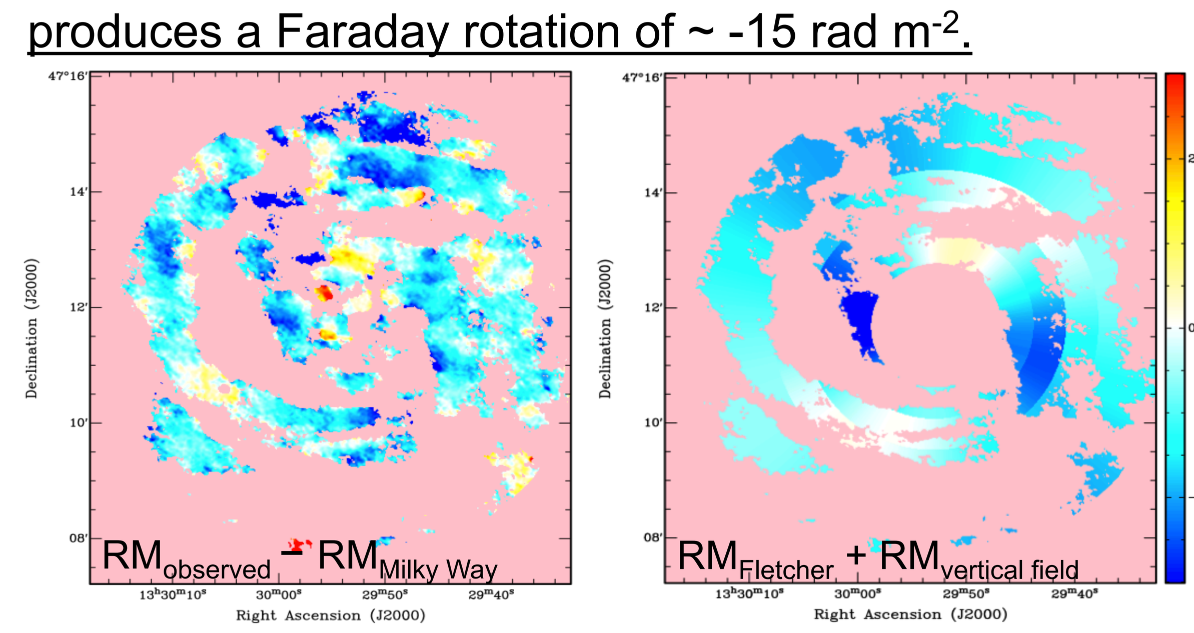

Figure 4: Left: The observed Faraday depth distribution of M51 after removing the Galactic foreground rotation measure. Right: Predicted Faraday depths of M51 at 1.4 GHz of the Fletcher et al. (2011) model with an additional RM contribution from a vertical field in the halo.

Search for the Far-side Halo

Braun et al. (2010) suggested that polarized emission from the far-side halo of M51 would suffer from depolarization and additional Faraday rotation through its turbulent mid-plane, producing weak polarized emission at Faraday depths ~±200 rad m^{-2}. We can better address this question because of the improved λ^2 coverage of the new VLA data.

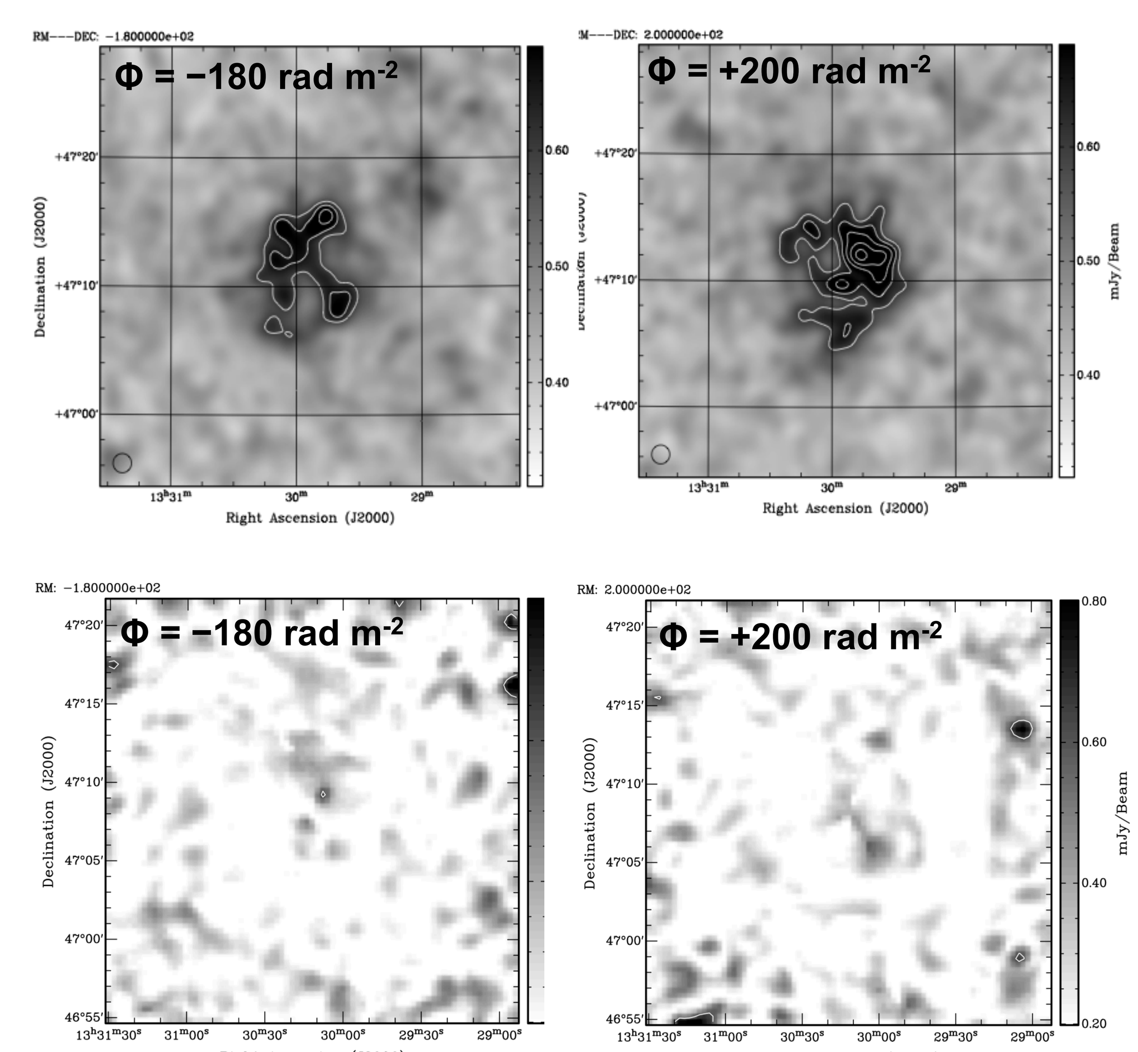

Figure 5: Polarized emission towards M51 at 1.4 GHz from the Braun et al. (2010) study (top panels) and our new VLA observations (bottom panels) at a Faraday depth of -180 rad m^{-2} (left) and +200 rad m^{-2} (right). We do not detect any significant emission associated with the far-side halo. This suggests that the far-side halo, if exists, is more severely depolarized than predicted in Braun et al. (2010) (> a factor of 4-5). The detection of the far-side halo reported in Braun et al. (2010) is likely to be an artifact rather than real emission.