# AN ESTIMATED ALL SKY ROTATION MEASURE MAP

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## ABSTRACT

We have produced an all sky Rotation Measure (RM) map by interpolating from a set of over 800 extra-galactic objects with published RM's. The resultant map provides both a useful tool for assessing the extent and magnitude of the RM contamination by the galaxy of other astronomical objects and provides some clues to the field structure associated with the spiral arms.

## INTRODUCTION

In recent years the rôle of magnetic fields in both galactic and extragalactic regimes has gained increased attention across many astrophysical disciplines. For example, the magnetic field is a key factor in studies of large-scale structure formation, galaxy and star formation, and cosmic ray generation. Cosmic magnetic fields on all scales have been studied since the late seventies with varying degrees of success. While it is clear that magnetic field research has progressed considerably in this time, the mostly indirect measurement techniques have meant that it has been difficult to address many basic issues. Questions as to how strong magnetic fields are, how uniform they are, what the seeding and amplification mechanisms are, and, most importantly, what their contribution is to the energy density of the intergalactic medium, remain topics of animated debate.

One of the standard ways to obtain estimates of the magnetic field is through the use of a population of background radio galaxies as probes of the Faraday rotation along the line of sight. Faraday rotation was first proposed for astronomical sources to explain the observed wavelength dependence of the polarization position angle seen in Centaurus A [1]. If linearly polarized light is passed through a magnetized plasma, the electric vector will be rotated through an angle $\theta$ which depends on the net component of the magnetic field along the line of sight The phenomenon can be described by:

$$\theta = \theta_{in} + (\mathrm{RM})\lambda^2,$$

where $\theta_{in}$ is the intrinsic position angle of the radiation and A is the wavelength. The degree of rotation is given by the rotation measure, RM, where

$$\mathrm{RM} = 8.1 \times 10^5 \int_0^L B_l n_e . dl \qquad \mathrm{rad\ m^{-2}},$$

$B_l$ is the line-of-sight component of the magnetic field in gauss, $n_e$ is the electron density in $cm^{-3}$ and L is the path length in pc. By obtaining RM values along many lines of sight through foreground structures and analysing these data in conjunction with X-ray derived electron densities, it is possible to obtain estimates of mean magnetic fields.

To date several studies have employed Rotation Measures (RM) in order to investigate the nature of magnetic fields both within our own and other spiral galaxies [2]. Reference [3] and references therein demonstrate the correlation of an ordered magnetic field component with the arms of nearby spiral galaxies, while several attempts have been made using both RM's from extra-galactic and galactic sources to unravel the internal structure of the Milky way [4], [5], [6], [7]. With the completion or near completion of major polarimetric surveys such as the Southern Galactic Plane Survey [8], and the Canadian Galactic Plane Survey, a wealth of new information on the magnetic field structure of our galaxy will soon become available. The expected boost in available data for this work is a factor of 5-10. Tantalizing preliminary results have recent1y appeared, giving new insight into both the RM structure of the sky as seen through the Galaxy and the rôle of the magnetic field in diffuse galactic plasma [9], [10]. As these new data become available better modeling and subtraction of the effect of the local field, which has heretofore been difficult due to the paucity of available RM data, will be possible.

**THIS STUDY**

This work was motivated primarily by the need to determine the physical extent and strength to which the magnetic field of the Milky way interferes with obtaining accurate line of sight RM's for distant objects such as clusters of galaxies. It has been shown that the distribution of RM's obtained for distant objects will have a statistical broadening, therefore implying an enhancement of the magnetic field in these objects [11]. However, such measurements must account for an intrinsic background probe source RM, the object RM and a galactic contribution. Previous work of this type has assumed the probe source RM to be negligible and then attempted to account for the galactic component by averaging RM's of extragalactic background sources in some arbitrary radius on the sky around the object of interest to give a Residual Rotation Measure (RRM) [11], [12]. While this approach may in some cases give a good approximation to the actual galactic RM contribution it suffers from two major problems, being the arbitrarily sized averaging radius and the loss of spatial information on the galactic distribution provided by the background sources. Applying this technique can result in single large intrinsic RM's sources dominating the averaging, which will result in an over-subtraction. References [13], [14] made an attempt to correct for the first problem by calculating the source distribution in their averaging interval and removing those sources with RM's of more than 3 sigma from the mean modulus RM. However due to the paucity of available extra galactic RM's at that time this technique suffered from poor statistics.

In order to provide a better solution we sought a method which gave greater weighting to nearby points but that prevented single large points from dominating the calculated value. Presented here is an interpolated all sky Rotation Measure map which is not subject to an arbitrarily chosen averaging scale and preserves the source spatial information. After investigating several interpolation algorithms, the 2-Dimensional solution for Poisson's equations in combination with a statistical culling algorithm was chosen.

Unlike other common 2-dimensional averaging techniques the 2-Dimensional solutions of Poisson's equations allow a convergent interpolated solution for the Rotation Measure to be computed whilst retaining the physical information provided by the source spatial distribution on the sky. It also uses all RM data over the entire sky, weighted against distance from the point of interest to determine an interpolated value. This provides the maximum number of points in any calculation and allows the points closest to the region of interest to provide the majority of information. The use of the statistical culling algorithm reduces the effect of spurious data from probe source with an assumed high intrinsic RM component.

**INTERPOLATION**

Over 900 extra-galactic RM's taken from several catalogues [13],[15], [16], [17], [18], [19], were initially examined. Only those with a reliable RM fit over at least three wavelength were selected. In the case of sources appearing in more than one reference, the more reliable fit was used. This produced a final catalogue of 855 sources which were utilized in the two stage process. First a culling algorithm removed sources for which there was a 3 sigma deviation from the local median modulus RM. This was similar to previous techniques [13], [14] but rather than using a defined radius about an individual point the code tests the population of the nine nearest neighbors. The interpolation was performed by obtaining a convergent solution to the 2 -Dimensional Poisson's equations. Figure 1 shows the resultant estimated RM map, with the source density across the sky marked as crosses.

The source density of this dataset is approximately 0.013 per square degree on average, while density of sources in the plane of the galaxy, as defined by $|b| < 30$ degrees is 0.01 per square degree. As the source density is quite low, particularly in the region of the galactic plane, only large-scale features from the data may be reliably inferred. However, with the imminent release of new galactic plane survey data and the advent of better instruments such at the SKA, it is expected that this situation will be greatly improved.

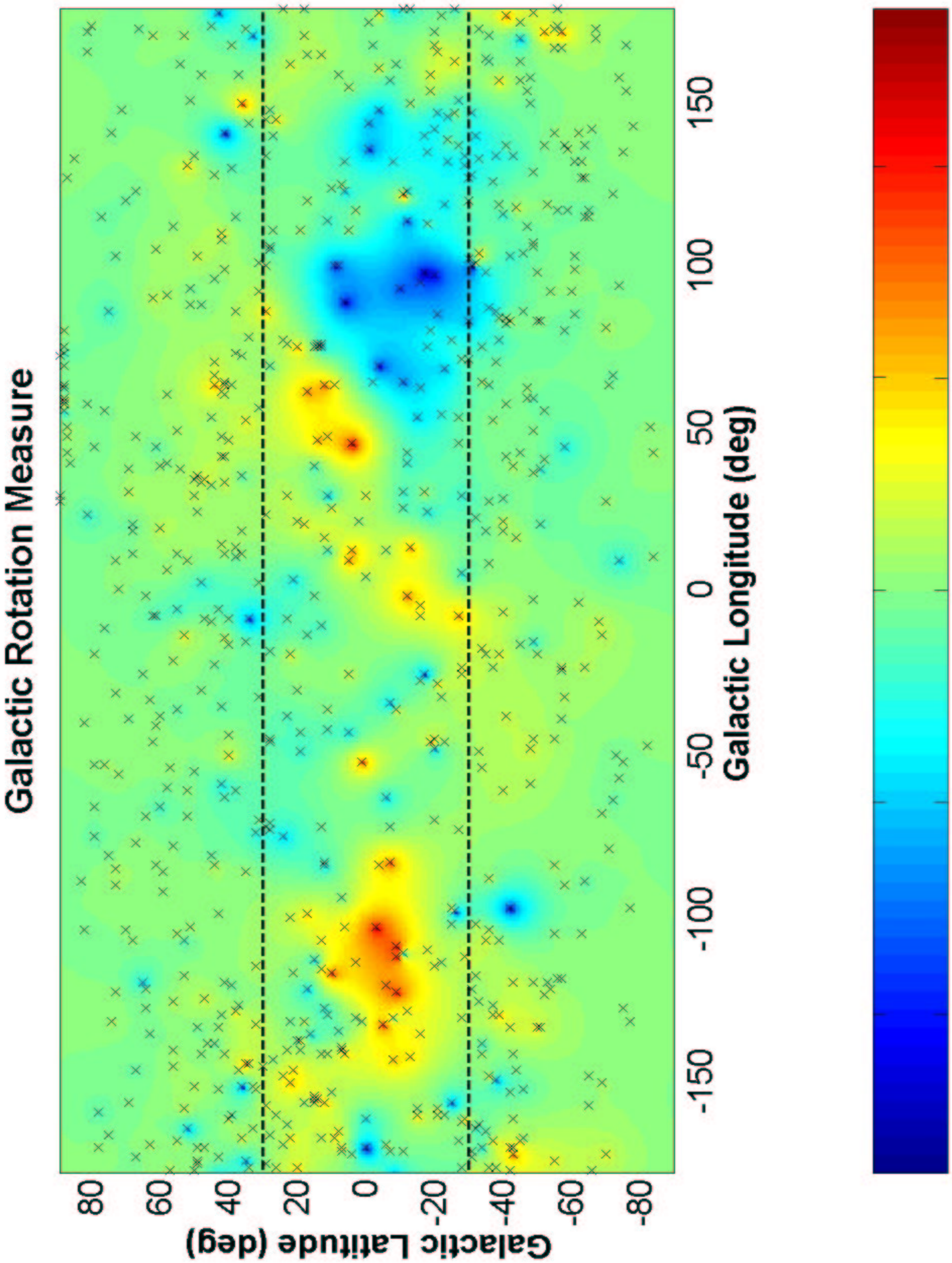


Fig. 1. The Rotation Measure Sky as interpolated from over 800 extra-galactic RM values. The crosses give the location of the data that were used while the dashed lines are marked at 30 degrees from the galactic plane.

## DISCUSSION

With such a dataset it is possible to determine statically the extent to which our galaxy significantly affects Rotation Measure values. Though this is only an approximation to the magnetic field influence of our galaxy we find two key results. Firstly it can be seen that the influence of our galaxy on RM values extends to roughly 30 degrees either side of the galactic plane, (perhaps slightly more in the southern hemisphere). Secondly we confirm the large-scale positive and negative RM regions associate with the local spiral arm found in the contemporary wavelet analysis study [20].

Ironically, the property that makes radio galaxies suitable for such a study, i.e., they emit polarized synchrotron radio emission, may also introduce a bias into the dataset. Since the high degree of polarization suggests ordered internal magnetic fields in the probe source, there will be an internal rotation measure component which will be added into the final result in spite of any culling we perform. Only by understanding the contribution of this internal component and accounting for it statistically can a true insight into the validity and robustness of such maps be obtained. This will be the focus of future work.

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