Probing magnetic fields with GALFACTS

Samuel J. George[1,2], Jeroen M. Stil[2], Mircea Andrecut[2] , A. Russ Taylor[2]

1. Astrophysics Group, University of Cambridge, UK; 2. Institute for Space Imaging Science, University of Calgary, Canada

email: sgeorge@mrao.cam.ac.uk

Abstract

The Galactic ALFA Continuum Survey (GALFACTS) is a large-area spectro-polarimetric survey on the Arecibo Radio telescope. It uses the seven-beam focal plane feed array receiver system (ALFA) to carry out an imaging survey project of the 12,700 square degrees of sky visible from Arecibo at 1.4 GHz with 8192 spectral channels over a bandwidth of 300 MHz sampled at 1 millisecond. The aggregate data rate is 875 MB/s. GALFACTS observations will create full-Stokes image cubes at an angular resolution of 3.5' with a band-averaged sensitivity of 90 μJy, allowing sensitive imaging of polarized radiation and Faraday Rotation Measure (RM) from both diffuse emission and extragalactic sources. GALFACTS is a scientific pathfinder to the Square Kilometre Array (SKA) in the area of cosmic magnetism. Key to magnetism science with the SKA is the technique of RM synthesis. The technique of RM synthesis is introduced and we discuss practical aspects of RM synthesis including efficient computational techniques and detection thresholds in the resulting Faraday spectrum. We illustrate the use of the technique by presenting the current development of the RM synthesis pipeline for GALFACTS and present early results.

GALFACTS

Linear polarization of radio sources contains information on magnetic fields in these sources, and Faraday rotation of the plane of polarization provides information on the direction and magnitude of the magnetic field along the line of sight. As such, observations of linear polarization of radio sources provide the most widely applicable probe of cosmic magnetic fields on scales from galaxies to clusters of galaxies. Finding polarized sources in survey images and fitting their parameters forms the basis of this analysis.

The GALFACTS Consortium is using the Arecibo telescope and ALFA to carry out a sensitive, high resolution, spectro-polarimetric survey of the region of the sky visible with the Arecibo telescope - the GALFA Continuum Transit Survey, GALFACTS [8]. A key observational objective of the GALFACTS is to image the polarized emission from both discrete objects and the diffuse interstellar medium of our Galaxy and to derive polarization properties, including Faraday Rotation Measures for a vast population of extragalactic sources.

For more take a look at `www.ucalgary.ca/ras/GALFACTS/`.

References

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Rotation Measure Synthesis

Polarimetric radio observations enable the study of synchrotron emission radiated by relativistic electrons as they are accelerated by magnetic fields. Multifrequency observations allow Rotation Measure (RM) Synthesis [1] to solve for the unknown Faraday depth, polarized intensity, and polarization angle simultaneously. The source is typically identified by the maximum value in the Faraday spectrum. The Faraday depth ϕ is defined as [2]

$$\phi\left(\vec{r}\right) = 0.81 \int_0^x \vec{B_{||}} n_e \cdot \mathrm{d}\vec{r} \text{ rad m}^{-2}, \tag{1}$$

where $\vec{B_{||}}$ is the line of sight magnetic field component, n_e is the thermal electron density, $\mathrm{d}\vec{r}$ is an infinitesimal path length, with the integral taken from the observer to the point x.
The complex polarized intensity $\mathcal{P}\left(\lambda^2\right) = Q + iU$ is the Fourier transform of the Faraday dispersion function $F(\phi)$,

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

The Faraday rotation measure RM is defined as the slope of a polarization angle Ψ versus λ^2:

$$RM\left(\lambda\right) = \frac{d\Psi}{d(\lambda^2)} \tag{3}$$

where

$$\Psi = \frac{1}{2} \tan^{-1} \frac{U}{Q}. \tag{4}$$

Once a polarized source has been detected, the observed polarized intensity $p = \sqrt{Q^2 + U^2}$ must be corrected for polarization bias. Since p is a positive-definite quantity, the noise in Stokes Q and U results in a positive value for p even if no signal is present. The statistics of p with a signal p_0 and noise σ_{QU} is given by the Rice distribution [6]. This matter is complicated by the uncertainty in the Faraday depth of the source. This introduces a stronger bias in the polarized intensity than the well known polarization bias but can be corrected for [3].

Application to GALFACTS

The first GALFACTS dataset is a cube of 5314 by 1074 pixels with 4096 spectral channels. The large number of pixels means that to do effective RM synthesis is computationally expensive. To solve this RM synthesis can be run in parallel on each pixel in the image plane with the results being combined to form one Faraday depth cube. This is currently not part of the main GALFACTS pipeline [4] but will be integrated as an application on `www.cyberska.org` [5]. For the N1 region RM synthesis was completed over a range of -1200 to 1200 rad.m^{-2} with an averaging of 0.4 MHz in the Q and U. To visualise the Faraday depth cube is difficult with such a large dataset and to over come this limitation a 1st moment map was created (Figure 1). Residual imaging artefacts dominate the compact sources but structure is seen in the diffuse emission (Figure 2).

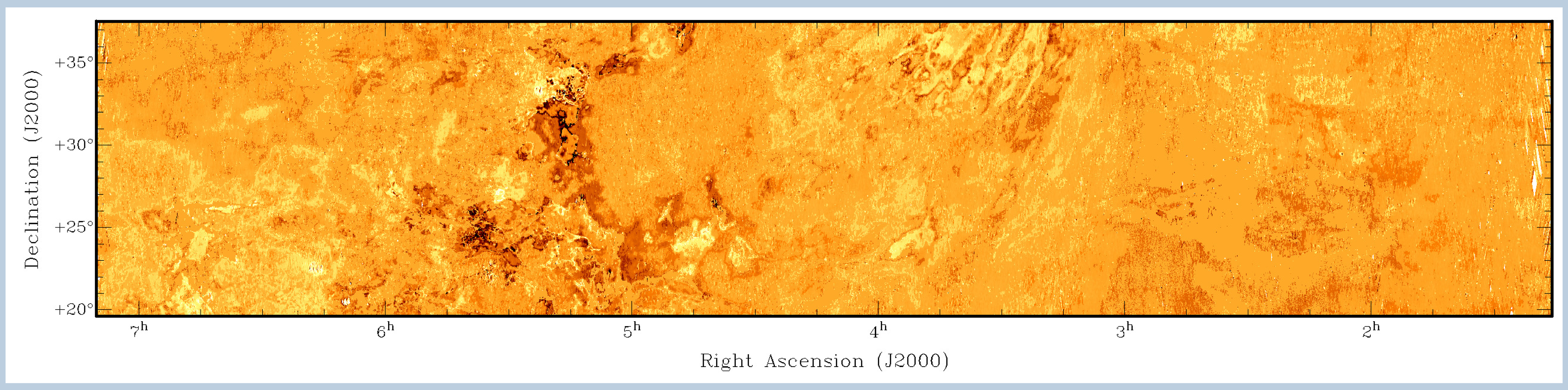

Figure 1: (top) A moment map of the N1 region showing structure in the Faraday spectrum; (bottom) a typical Faraday spectrum of a compact source in the preliminary data.

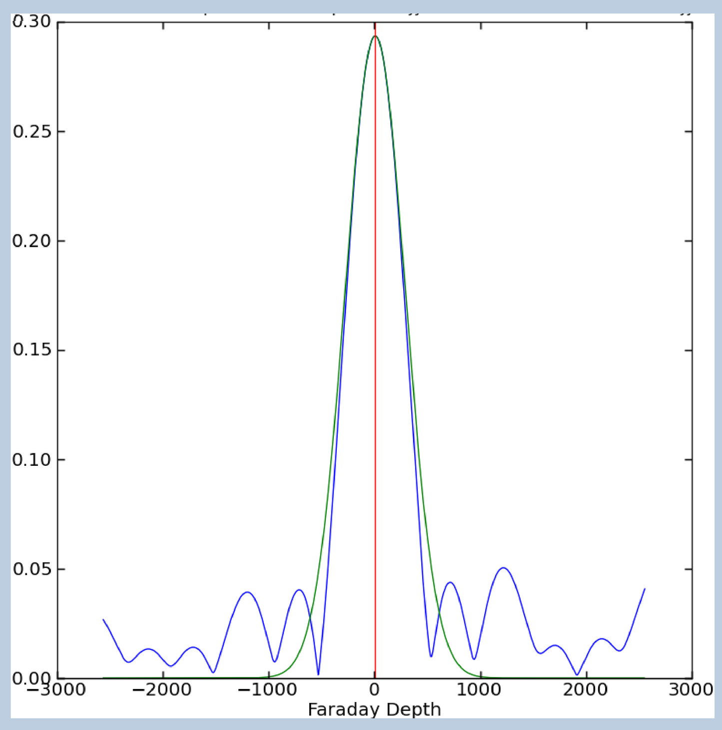

Figure 2: A typical Faraday spectrum of a compact source in the preliminary data.