Application of the Regularized Optimization for Hyper-Spectral Analysis (ROHSA) Tool to Faraday Tomography Cubes

Artem Davydov

August 2021

Galactic magnetism plays an important role in dynamic processes like star formation. Constructing a three dimensional model of these magnetic fields is important to understanding the processes we observe in the Galaxy. Extracting magnetic field information from observables is a complicated task. Nevertheless, we are able to employ various techniques and leverage physical effects to inch towards a better understanding of these fields. My research project concentrated on the Faraday Effect by which a linearly polarized electromagnetic wave passing through a magneto-ionic medium has its polarization angle modified. The severeness of the modification of polarization angle depends on the strength and direction of magnetic fields parallel to the line of sight as well as the electron column density along the line of sight. These modifications can also be thought about as rotations of the polarization vector in the complex plane with angular velocity determined by an integral involving the magnetic field and electron density also called the Rotation Measure (RM) or more generically the Faraday Depth(FD). An important note is that the magnetic field information is degenerate with the electron density so to disentangle the two we need a complementary model of the column density along the line of sight. The observed polarization vectors are related to the Faraday Dispersion Function (FDF) through a Fourier transform like relation. The FDF encodes the Faraday Depth components encountered by the light as it travels to the observer. The functional form of these Faraday Depth components in the FDF appears to be closely Gaussian for low frequency narrow bandwidth data. As part of my research I synthesized low frequency narrow band polarization observations and fed them to a tool called RM synthesis, which applies the aforementioned Fourier transformation to obtain the FDF. The next step was to try and fit a model to the synthesized data however a naive Gaussian peak-finding model fitter is limited to the information along a single line of sight. We assume that the FD features be spatially smooth. The spectra line community created a tool called ROHSA, originally made to fit for diffuse structure in PPV cubes. Although the physics is different the problems solved by ROHSA are mathematically similar. I modified the ROHSA tool to work with my synthesized FDF cubes and started testing edge cases to assess the performance of ROHSA on Faraday tomography data.

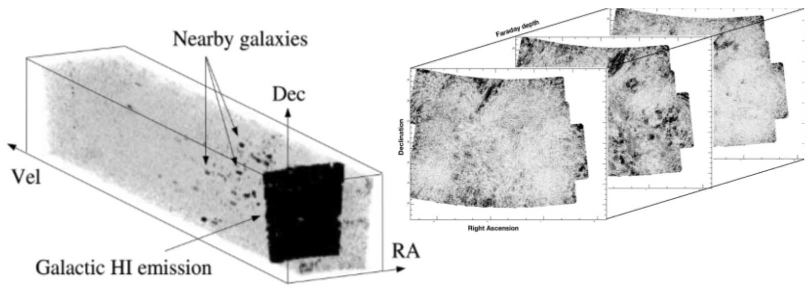

Figure 1: On the left is a cartoon of a 21cm PPV data cube (M. J. Meyer et al. 2004). On the right is cartoon of an RM cube PPF (Cameron Van Eck).

I focused my efforts on test involving polarized data with two input FD fields. For the case where the two components are well separated in the FD parameter space and the amplitude of the polarization is not swamped by noise ROHSA is successful at reconstructing the input FD fields. Another case that we looked into was the case of two intersecting planar FD fields. ROHSA failed to properly recover the two fields and it appears that the intersection of the two planes poses a challenge to algorithm. We also attempted to run ROHSA on FD fields simulated using fractal Brownian motion whose structure more closely resembles turbulent ISM. We found that as long as the two field are well separated in FD space ROHSA successfully recovers the fields.

The parameter space to explore remains vast. The next immediate step is to test the ROHSA toolkit on real world data. I applied the ROHSA tool on LOFAR IC342 data to assess how well it performs. A comparison with literature (Van Eck et al. 2017) revealed that ROHSA mixes FD components in a peculiar way. The interpretation of these results and work on this data set is still ongoing. Other next steps include coming up with more test cases that will challenge ROHSA and help us learn about its capabilities. I will also be documenting my simulator pipeline and will make it available on my GitHub for the community to use and run their own tests.