FY23 Strategic Initiatives Research and Technology Development (SRTD)

Low-frequency foregrounds and the future of of polarized CMB measurements

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Strategic Focus Area: Developing tools for scientific optimization of missions | **Strategic Initiative Leader:** Charles Lawrence

Objectives:

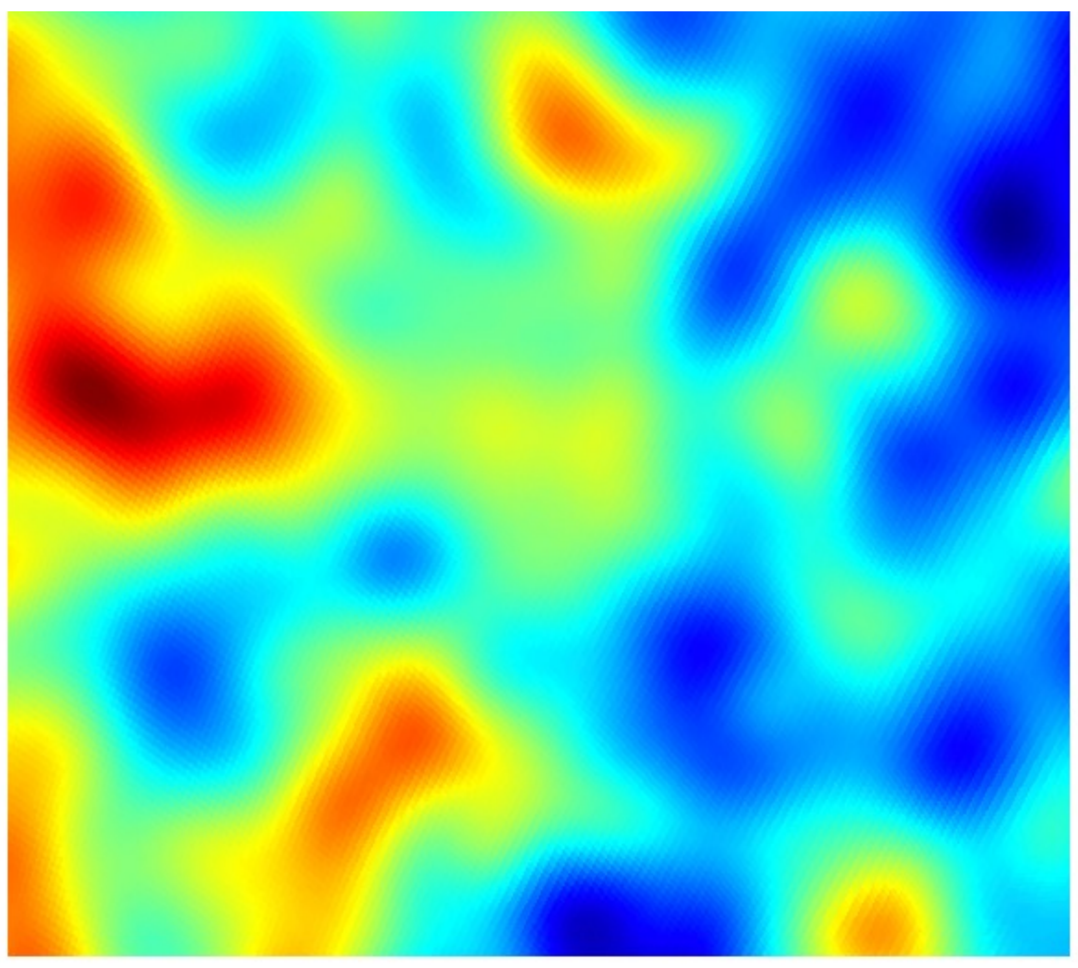
1) Develop low frequency polarized foreground models at the yet unobserved small angular scales (<1 deg).
2) Simulate phase correlated, i.e. filamented due to Galactic magnetic field, small angular scale polarized foreground signals at low frequency (~10 or ~20 GHz).
3) Implement frequency scaling for polarized synchrotron emission, ranging between constant spectral index to spatially variable spectral index models.
4) Assess performance of physical component separation methods applied to such low-freqeuncy, polarized emission models to – this is currently the “unknown-unknown” territory w.r.t. low-frequency polarized foregrounds.

Background: Multi-frequency measurements of CMB anisotropy must be “component separated” to reveal the primordial signals encoding physical effects of inflation in the early universe. The goal of the future high-precision CMB anisotropy measurements is to generate all sky maps of polarized CMB at angular resolution of a few arcmins. There are no quality measurements of the whole polarized microwave sky at low frequencies at resolution less than 2 deg - they may only be performed by the future satellite CMB mission. This is a hindrance for the future space mission design studies. This study aims at generating synthetic maps of polarized synchrotron emission including considerably smaller spatial scales than the existing measurements.The objective is to simulate small angular scale structure with high degree of spatial phase correlation and non-Gaussianity due to the filamentary structure of entangled magnetic fields, expected based on magnetohydrodynamic simulations of the galactic interstellar medium. Such simulations exist for small volumes (a few kpc), and they are not spatially scalable to support the full sky signal models. After this is demonstrated at, say, 23 GHz, the sky signals will be extrapolated to higher e-m frequencies involving modelling of synchrotron emission spectral index, eventually including its spatial variations.

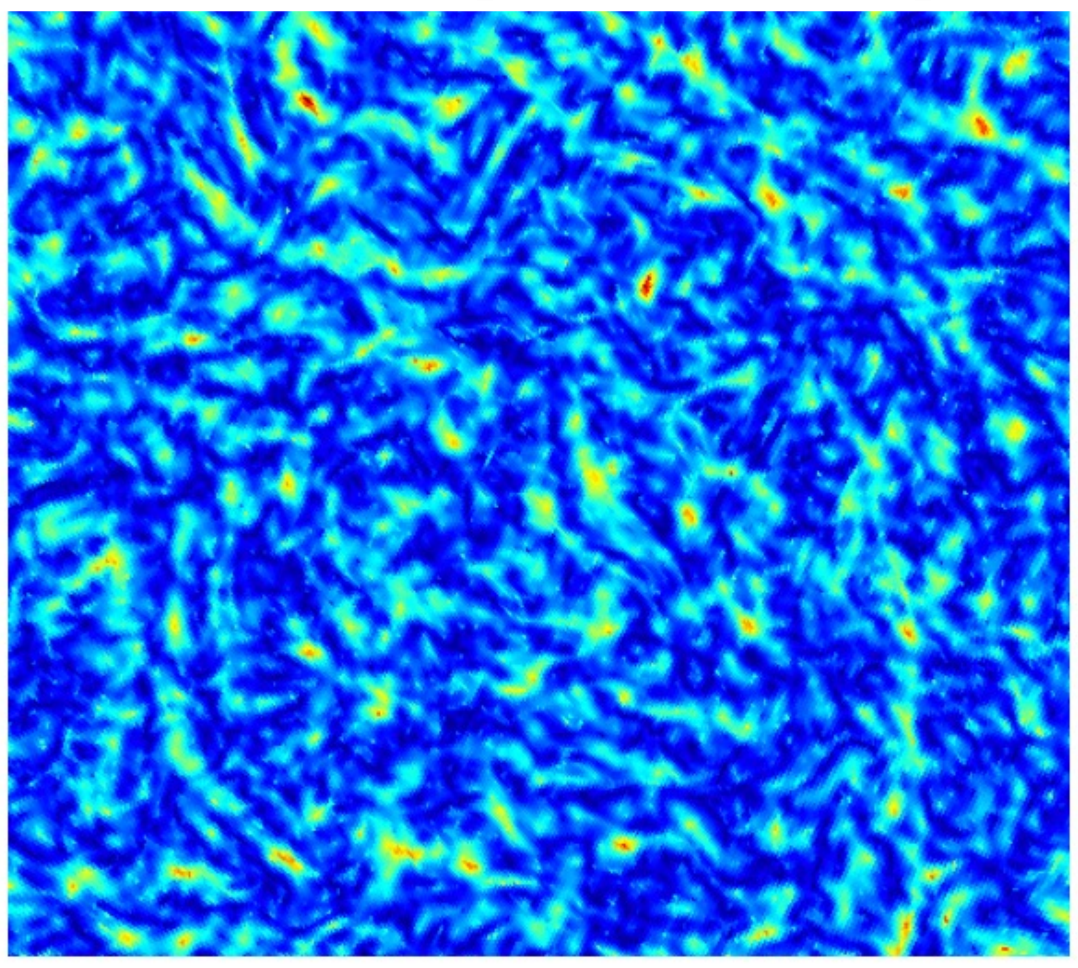
Approach and Results: Legacy WMAP K-band (~23 GHz) polarization maps are the lowest frequency full-sky data available for studies of polarized synchrotron emission. Lower frequency measurements are available on a fraction of the sky, but at frequencies affected severely by Faraday rotation of polarized signals, hence difficult to employ for component separation in the CMB range. Polarized synchrotron emission at K-band is bright (~(frequency)$^{-3}$ scaling), but these data are strongly noise dominated at small angular scales below FWHM=2 deg. Hence, we use the low-pass filtered K-band data for large angular scale synchrotron emission template. For the test approach to generating a synthetic map with small angular scale content, we use on input the spatially band-pass filtered 353 GHz Stokes Q, U polarization maps, corrected for the estimates of polarized CMB anisotropy by removal of the Indepent Linear Combination maps derived from the highest sensitivity polarized Planck sky maps at 100, 143, 217, and 353 GHz. The removed ILC CMB signal is so subdominant that visually this correction does not show at 10 arcmin resolution. This is not a physical synchrotron emission model proposal, as dust emission dominates the 353 GHz maps. However, we non-linearly modify the band-pass filtered signals, so that spatial phases, related to the same galactic magnetic field that affects both synchrotron and dust emission, are the feature of interest in this modeling exercise. In the future, this procedure will be generalized beyond direct use of 353 GHz data. The mentioned non-linear modification of the input, filtered 353 GHz q and U maps involves evaluation of their gradients, and second derivatives, contraction thereof (first non-liner step), normalization (second non-linear step), logarithmic transformation of the amplitude (third non-linear step), and rescaling for spectral match to the low-pass filtered K-band polarization map. The sum of the real and model data maps constitutes the hybrid synthetic template of synchrotron emission that is suitable for studies of effects of highly filamented small scale structure on component separation of multi-frequency microwave sky maps.
Nota bene: This FY23 study was completed in February ’23, with all funds expended at that time (on agreement with initiative lead at 7X) due to PI’s engaging in the 6-month SRS Research Leave.

Significance/Benefits to JPL and NASA: NAS Astro2020 report indicated that 2030s could be the timeframe for a Probe mission dedicated to the CMB polarization measurements, and that, prior to that, necessary developments of technology, including modeling and analysis techniques, should be demonstrated. JPL played important role in the space CMB research since in NASA’s COBE mission (1980s-90s) through ESA’s Planck mission (1990s-2020). Building on this legacy JPL will aim at participating in the next generation of CMB experimentation in space. Detailed design studies of a future CMB space mission were both conducted at JPL (e.g. EPIC), and participated in by the members of JPL CMB community (PICO). 7X supports studies on development of tools for scientific optimization of future missions, and, specifically, the polarized CMB anisotropy mission expected as Probe opportunity in the 2030s. The present effort focuses on one of the “Achilles heels” of the field, namely the marked asymmetry of phenomenological knowledge between the low- and high-frequency polarized foreground emission (mostly of our Galaxy) and its troublesome implications for the measurements of the cosmological signals in the polarized CMB anisotropies.

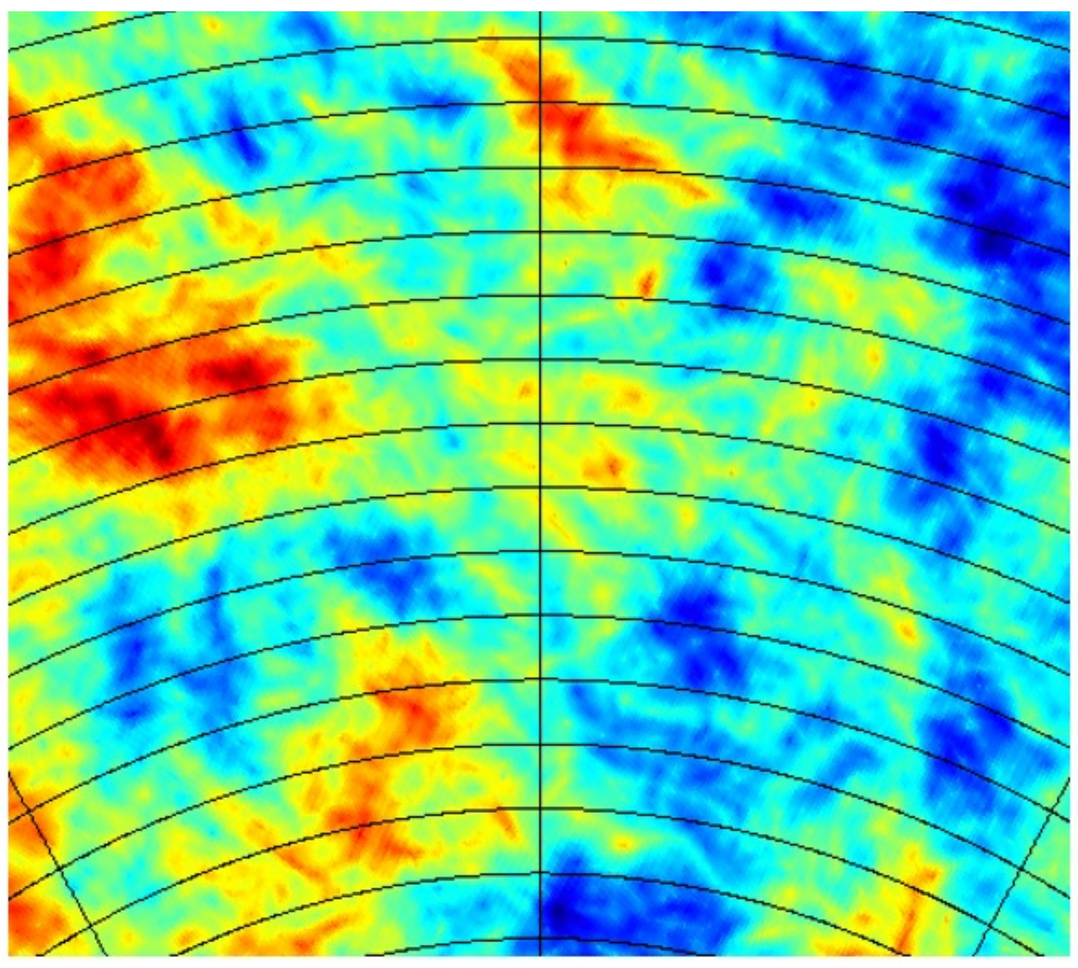
Illustration (polarization amplitude only) of construction of a template of polarized signal structure at 23 GHz by hybridization of real (low-resolution synchrotron emission measurements at K-band) and model (non-linear transformation of several power-bands of polarized emission at 353 GHz) data.



Real Data – K-band FWHM=2 deg



Model Data – non-linear transformation of 353 GHz power-bands at FWHM=20arcmin-2deg



Hybrid of Real Data and Model Data

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