A Back-to-Back Model Validation of Inversions for Solar Coronal Magnetic Fields

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Abstract

Remote sensing the physical state of the hot solar corona is critical to addressing the source of its heat as well as the energy that it expels towards Earth, which has many negative terrestrial impacts.

In this work, we utilize state-of-the-art global coronal magnetohydrodynamic models provided by Predictive Sciences (PSImas) to study the emission from the corona and forward synthesize coronal observables applicable to the April 8th, 2024, total solar eclipse. Spectropolarimetry of forbidden coronal emission lines offers a wealth of information about solar density, temperature, and the coronal magnetic field, as compared to more routine intensity-only measurements.

We present key findings from our analysis, as well as insight gained while performing a back-to-back interpretation and validation of inversions using two newly developed open-source python packages, PyCELP and CLEDB.

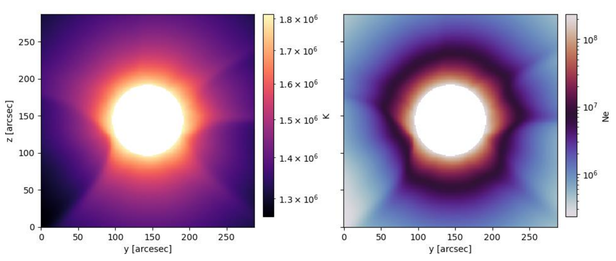
PSImas Models

We start by defining a "ground truth" by using PSImas global models of the corona.

We selected the models corresponding to the 2283 Carrington rotation, that includes inputs from the April 8th, 2024, total solar eclipse.

The models define physical state plasma parameters such as plasma temperature, plasma density, magnetic orientation, etc. which we utilize to forward synthesize coronal observations.

Plane of Sky Temperature and Electron Density



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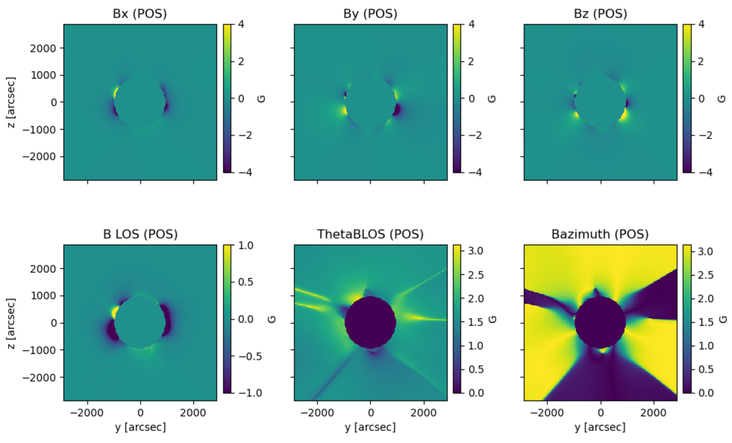
Magnetic Field in the Plane of the Sky from the Observer
Components are in the PSI model frame



Forward Synthesis and Inversion Tools

PyCELP (a Python package for Coronal Emission Line Polarization calculations) is used to calculate atomic density matrix elements for an ion (under coronal equilibrium conditions) using the CHIANTI atomic database, and then do a forward synthesis of polarized Stokes IQUV emissions for ions forming in the corona.

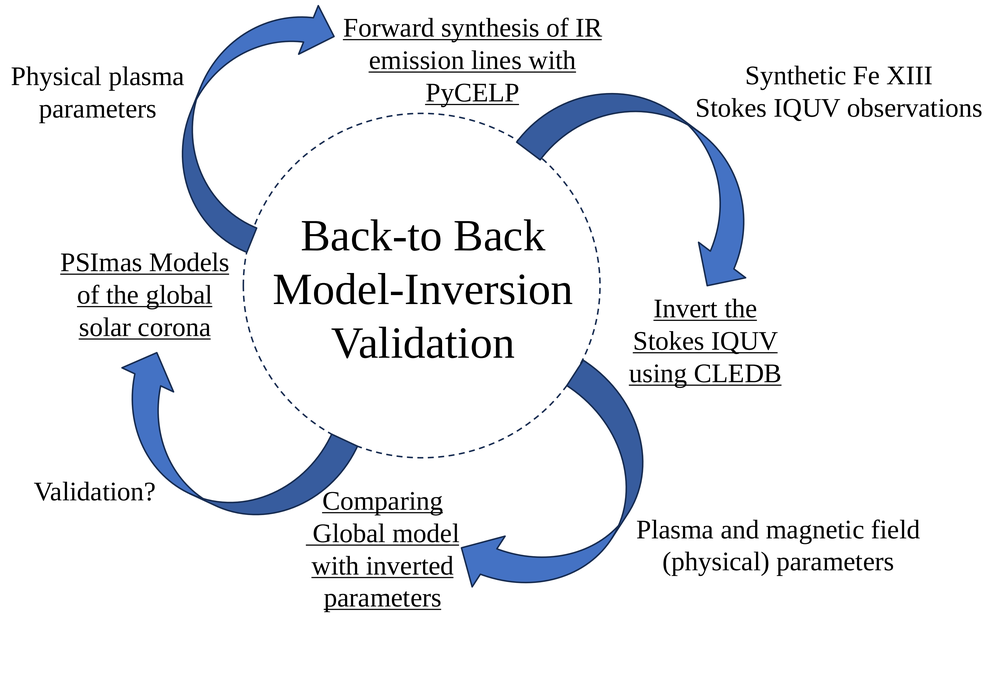
The package is open source and available at:

https://github.com/tschad/pycelp

CLEDB (Coronal Line Emission DataBase inversion) is inversion Python package that allows for the calculation of thermodynamic and magnetic field products when given the polarized Stokes IQUV.

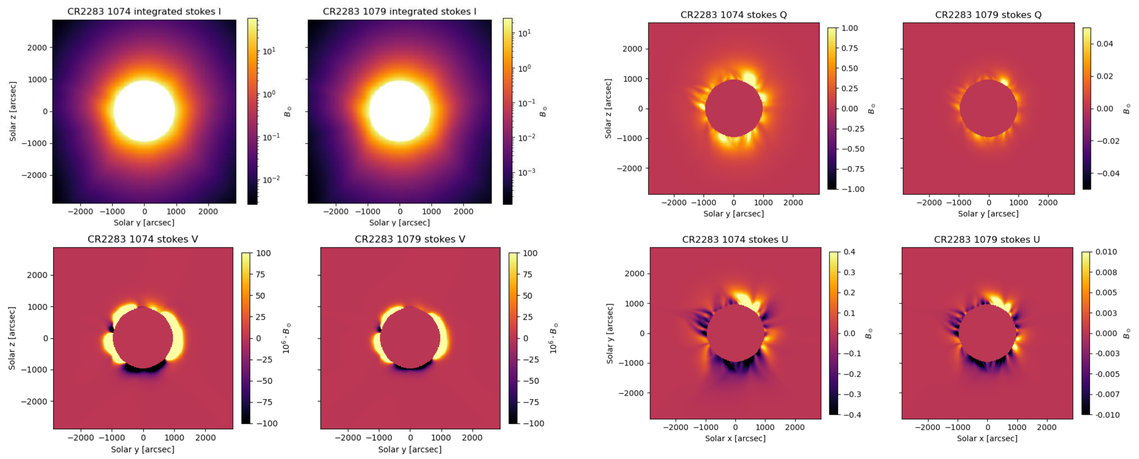
The package is open-source and available at:

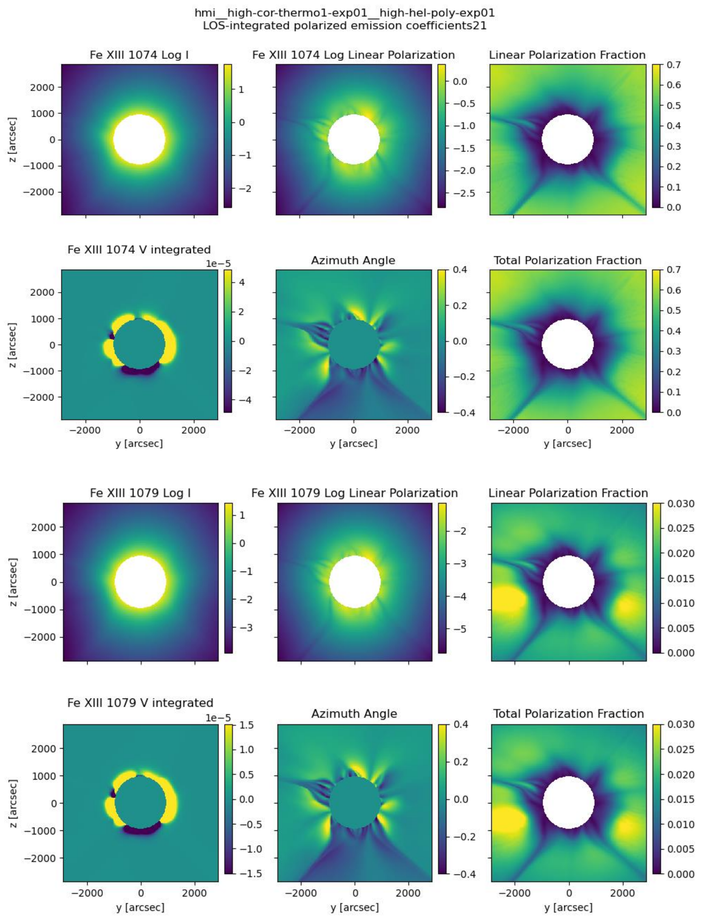
https://github.com/arparaschiv/solar-coronal-inversion



Forward Synthesis Results

PyCELP enabled us to start from physical state parameters and then compute Stokes polarization parameters respective to selected ions. Here we focus on the IR Fe XIII 1074.7 and 1079.8nm line pair. We thus integrated through a 3D cube containing physical information from the PSIMAS global coronal model and generated the synthetic IQUV observations.





Broader Impacts

- Validate and establish newly developed methodologies and tools for interpreting coronal plasma and magnetic fields.
- Help prepare for next-generation instruments and data like the DKIST.
- Understand and predict dynamic and/or eruptive solar phenomena.
- Gain a better understanding of coronal line formation and how plasma evolves in time.
- Learn how to invert and map the coronal magnetic field.

Further Goals

- Inversions with CLEDB: Inverting the Stokes back into physical parameters is the next step of this project.
- Validate the inversions against the Global models.
- Model-observation Comparisons: apply these forward synthesis and inversion techniques to spectropolarimetric data from DKIST Cryo-NIRSP.
- Continuously trying to improve forward synthesis and inversion methods.

ACKNOWLEDGMENTS

- This research was supported by the National Science Foundation REU program, Award #1950911
- CHIANTI is a collaborative project involving George Mason University, the University of Michigan (USA), University of Cambridge (UK) and NASA Goddard Space Flight Center (USA).
- This work includes PSImas models produced by Predictive Sciences Inc. available at https://www.predsci.com/corona/apr2024eclipse/home.php Coronal and heliospheric solutions provided by PSI were developed with the support of NASA, AFOSR and NSF.