Visualization tool for radiative magnetohydrodynamic numerical simulations of the solar atmosphere

Carmel Baharav*, Juan Martínez-Sykora†

*Palo Alto Unified School District, 25 Churchill Avenue, Palo Alto, CA, 94306

†Lockheed Martin Solar and Astrophysics Laboratory, 3251 Hanover Street, Palo Alto, CA, 94304

Abstract

The complexity of spectropolarimetric imaging observations of the solar atmosphere require models to interpret them. The example in Figure 1 shows the interface region between the surface of the Sun and the million degree corona, i.e., the chromosphere, using **NASA's Interface Region Imaging Spectrograph** (IRIS, De Pontieu et al 2014). To interpret these observations we use **radiative magnetohydrodynamic numerical simulations**. These numerical simulations generate **4D data sets** comprised of space and time of many vector (e.g. velocity, or magnetic field) and scalar (e.g. density, or energy) variables. These data sets could also include variables with possible interdependencies such as temperature. Exploration of relations among variables in the simulations requires visualization tools. **In this work, we describe a tool written in Python that allows for both scripted investigation of the data as well as interactive user guided manipulation**. The tool allows the user to plot contours, magnetic field lines, stream lines, vectors, and save movies and visual representation features.

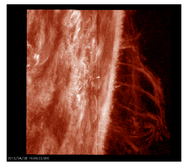


Fig 1. IRIS observation of a solar prominence at the limb on April 28, 2015

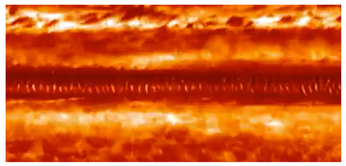
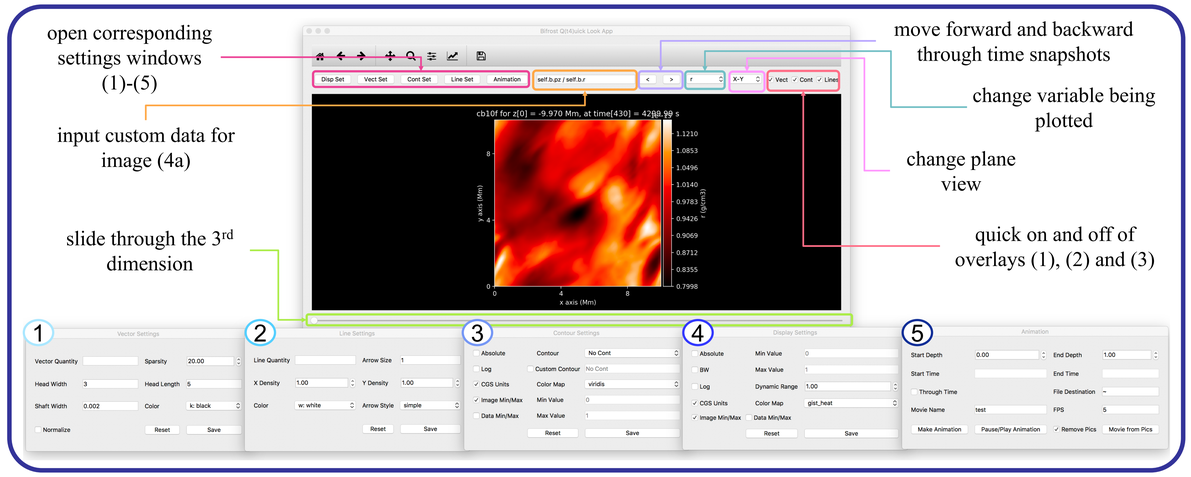


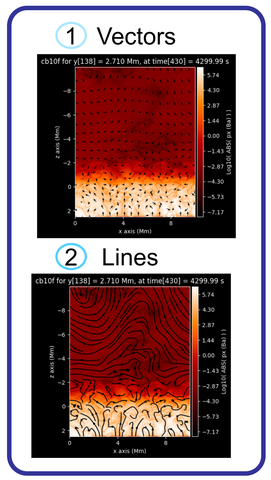
Fig 2. IRIS Spectral observation at the line core of Mg II demonstrating the presence of waves inside a sunspot. The waves can be seen as the periodic intensity variation along the horizontal row of small vertical lines in the center.

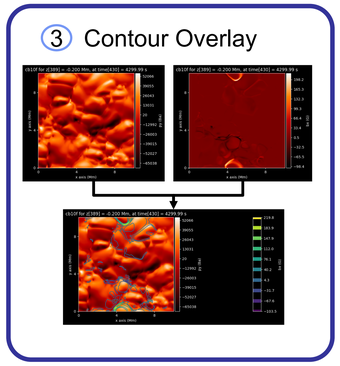
Introduction

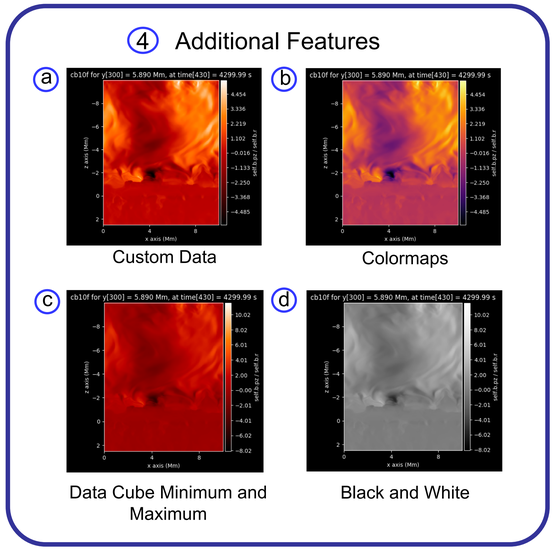
The IRIS satellite was launched on June 27, 2013. It is equipped with an ultraviolet telescope (Fig 1) as well as an imaging spectrograph (Fig 2), and is used to study the chromosphere to better understand how heat is transferred to the corona. IRIS observations require advanced models of the Sun to interpret them. **One of the most suited codes to model the chromosphere is the Bifrost code** (Gudiksen et al 2011). Bifrost simulations describe several quantities of the plasma in the chromosphere over space and time. The complex nature of the produced data set makes it challenging to analyze the models. **The goal of this project is to implement the functionality of previous visualization tools using a modern platform, such as Python.** This will enable a broader usage base in the future, and make this tool more accessible.

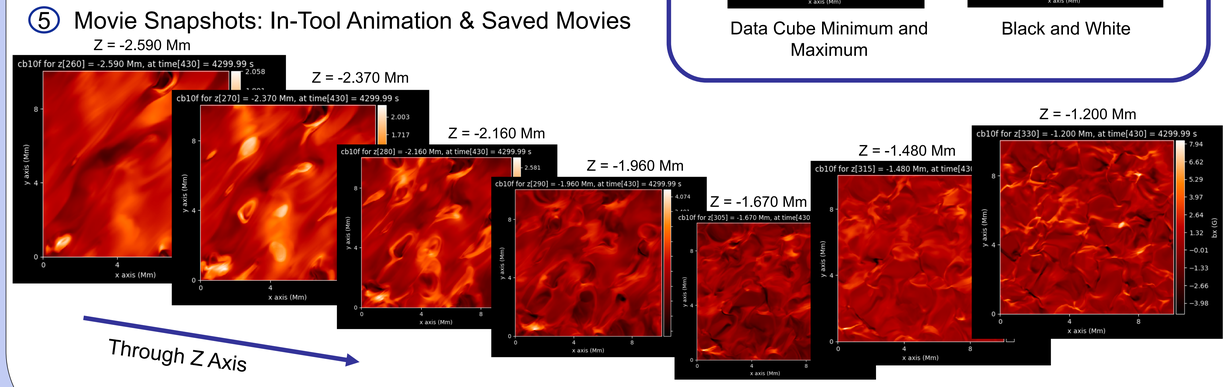
Project Description & Results











Tools Used

- Python
- Numpy
- Matplotlib
- PyQt5
- Bifrost code
- Helita

Future Directions

IRIS observations reveal the presence of **Alfvénic and acoustic waves** (e.g. Fig 2) in the solar atmosphere. The models recreate some of these, so in the future we will **include wave analysis through Fourier transforms in our tool**. The Alfvénic waves (including Alfvén waves, sausage modes, kink waves, rotational waves, etc.) are transverse waves caused by the Lorentz Force, among other forces, that cause plasma movement perpendicular to the magnetic field. The acoustic waves are caused by gas pressure perturbations and lead to plasma movement parallel to the magnetic field. In order to accelerate the calculations, we will take advantage of graphics processing units (GPUs).

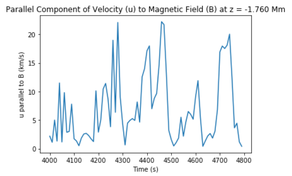


Fig 3. Movements of plasma along the magnetic field at a specific location in the chromosphere

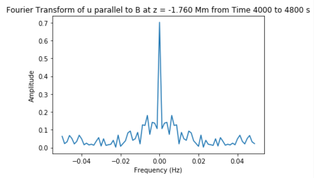


Fig 4. Fourier transform of the values in Figure 3

Figures 3 and 4 illustrates our current wave analysis visualization capabilities. Our future projects include:

- Creating graphical representations of wave analysis
- Integrating wave graphs with current tool

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References

Gudiksen et al 2011 A&A 531, 154

De Pontieu et al 2014, Sol. Phys. 289, 2733