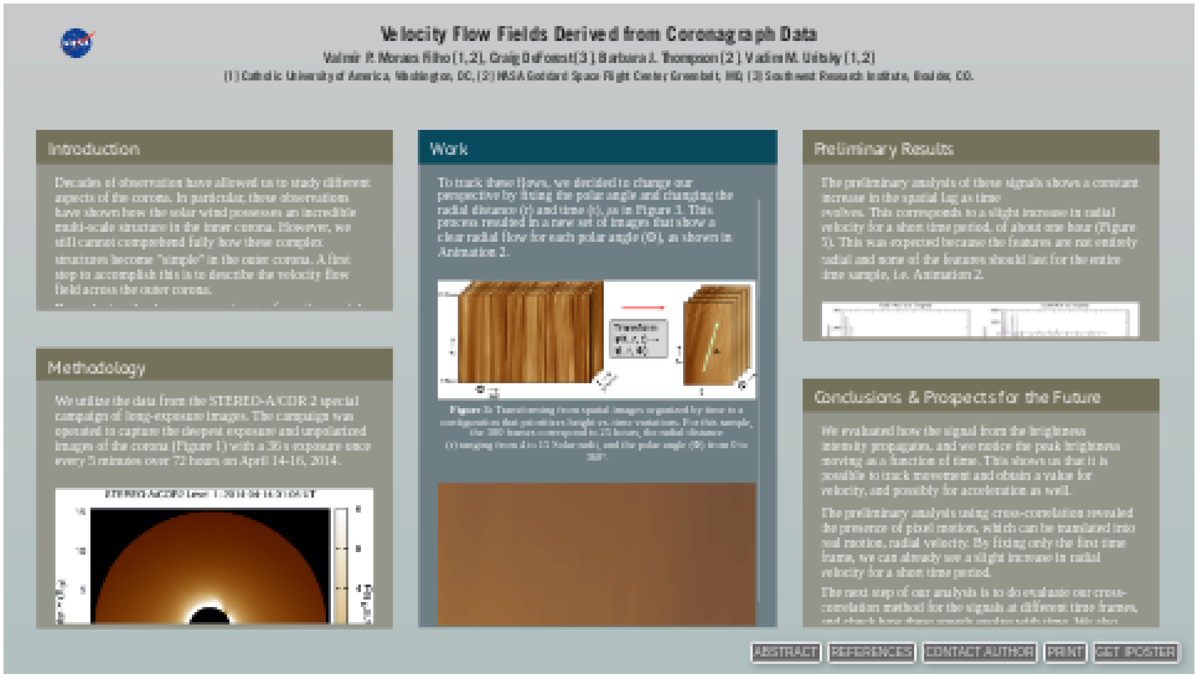
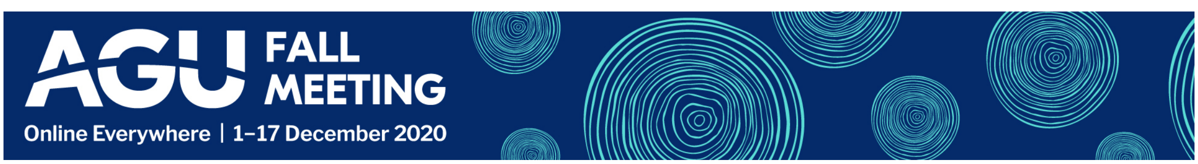
Velocity Flow Fields Derived from Coronagraph Data



Valmir P. Moraes Filho [1,2], Craig DeForest [3], Barbara J. Thompson [2], Vadim M. Uritsky [1,2]

[1] Catholic University of America, Washington, DC, [2] NASA Goddard Space Flight Center, Greenbelt, MD, [3] Southwest Research Institute, Boulder, CO.

PRESENTED AT:



INTRODUCTION

Decades of observation have allowed us to study different aspects of the corona. In particular, these observations have shown how the solar wind possesses an incredible multi-scale structure in the inner corona. However, we still cannot comprehend fully how these complex structures become "simple" in the outer corona. A first step to accomplish this is to describe the velocity flow field across the outer corona.

By analyzing the deep exposure images from the special campaign run by STEREO-A / COR-2 in 2014, we can track motion features in coronagraph images. By making the images "flow-friendly", we have developed a promising method to measure the velocity across the corona. Our preliminary analysis revealed a slight increase in radial velocity for a short range of time. This has also opened a possibility to determine an acceleration in the solar wind.

METHODOLOGY

We utilize the data from the STEREO-A/COR 2 special campaign of long-exposure images. The campaign was operated to capture the deepest exposure and unpolarized images of the corona (Figure 1) with a 36 s exposure once every 5 minutes over 72 hours on April 14-16, 2014.

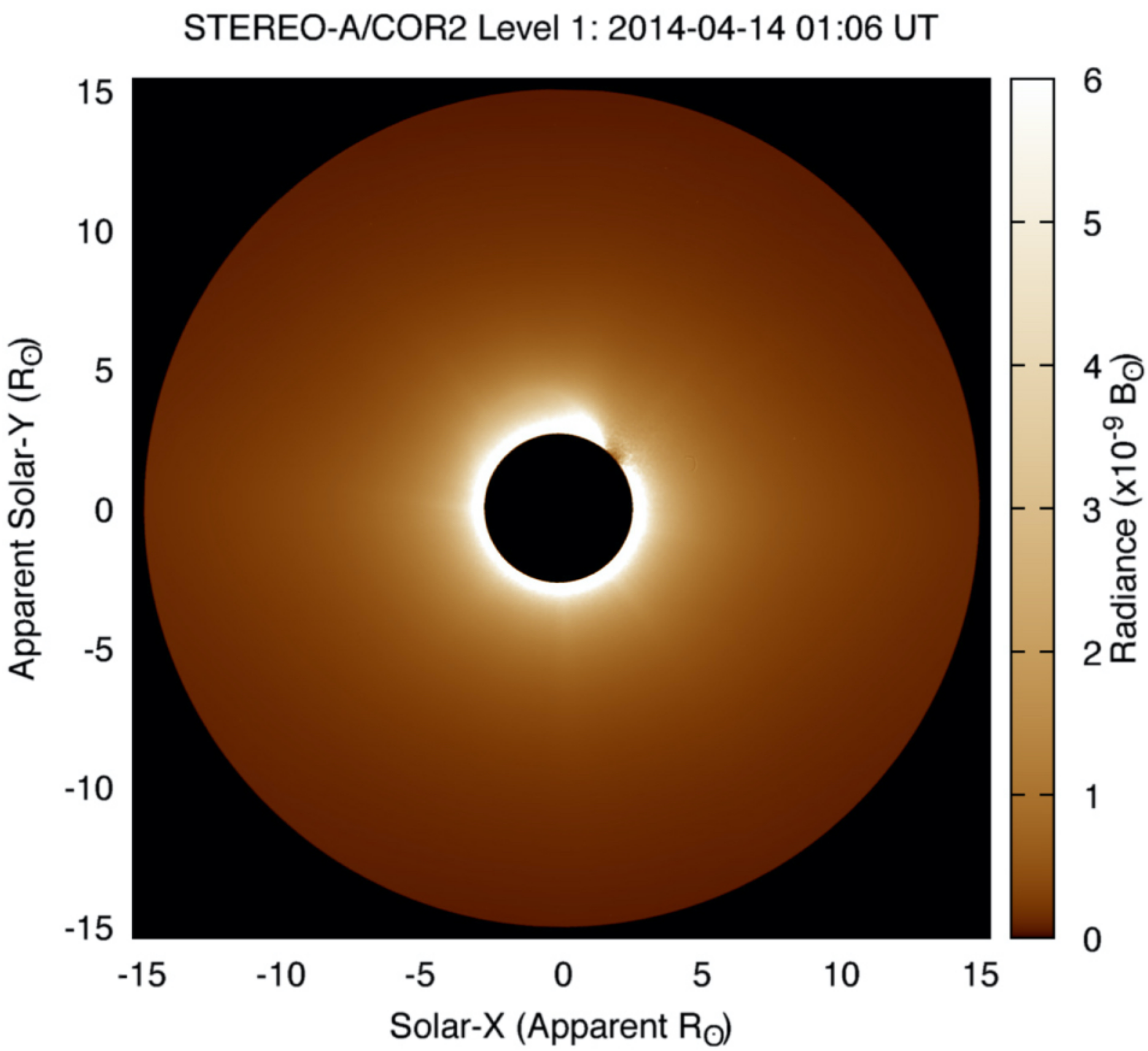


Figure 1: The frame represents the longest exposure data on its 1st level (L1) of preparation. They were prepared using SECCHI and resulted in a set of 2048 x 2048 pixels. The corona image is represented in terms of the radiance and the apparent radiance in the x- and y-components.

These images went through an intensive process of cleaning and enhancement. They had their coordinate system resampled from Cartesian (x,y) to polar (Φ,r) and had their background removed to standardize the average brightness as a function of the height r (Figure 2). For more details see DeForest et al. 2018.

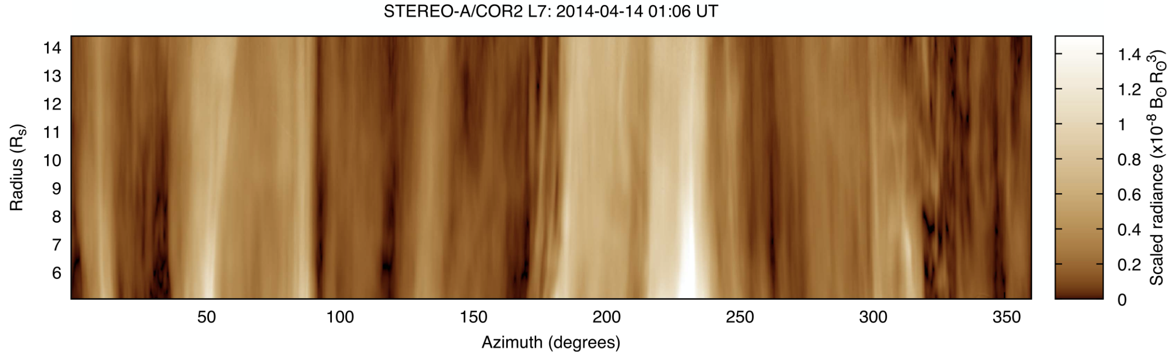


Figure 2: The frame represents one of the final levels (L7) of the data cleaning process. These had their background removed, coordinates resampled, and blur reduced and resulted in a true feature-excess brightness. The image represents the corona outflow in polar coordinates (Φ,r) with its radiance scales by r^3.

The biggest advantage of these images is that they show a clear flow across the corona. They represent a set of spatial images organized by time, i.e. a "stack" of photos in sequence, and in Animation 1 we can see a clear flow coming from all across the corona.

Animation 1: The animation shows the L7 data for different time frames. This sample contains 399 frames, with a total of 33 hours. This form of visualization makes the corona flows clear to the human eye. Note that the color table of this plot does not represent true feature-excess brightness.

WORK

To track these flows, we decided to change our perspective by fixing the polar angle and changing the radial distance (r) and time (t), as in Figure 3. This process resulted in a new set of images that show a clear radial flow for each polar angle (Φ), as shown in Animation 2.

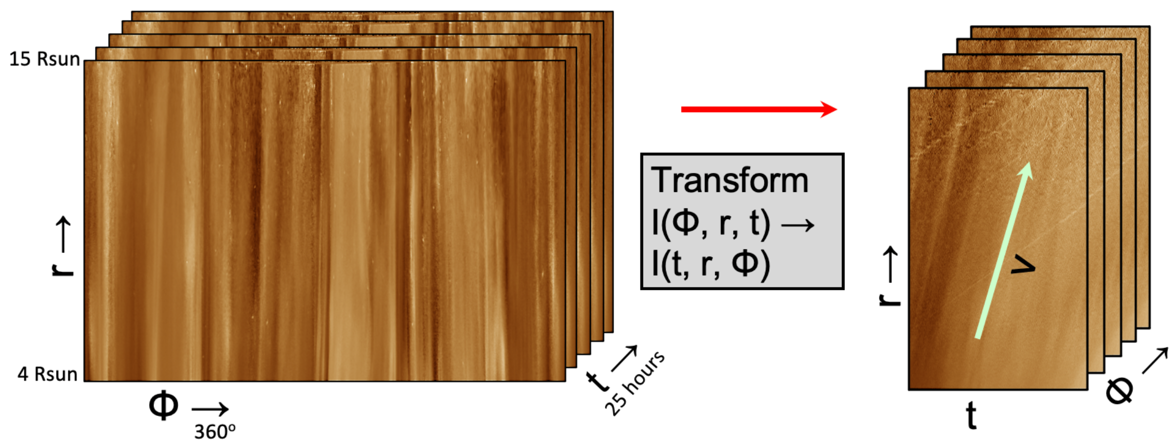
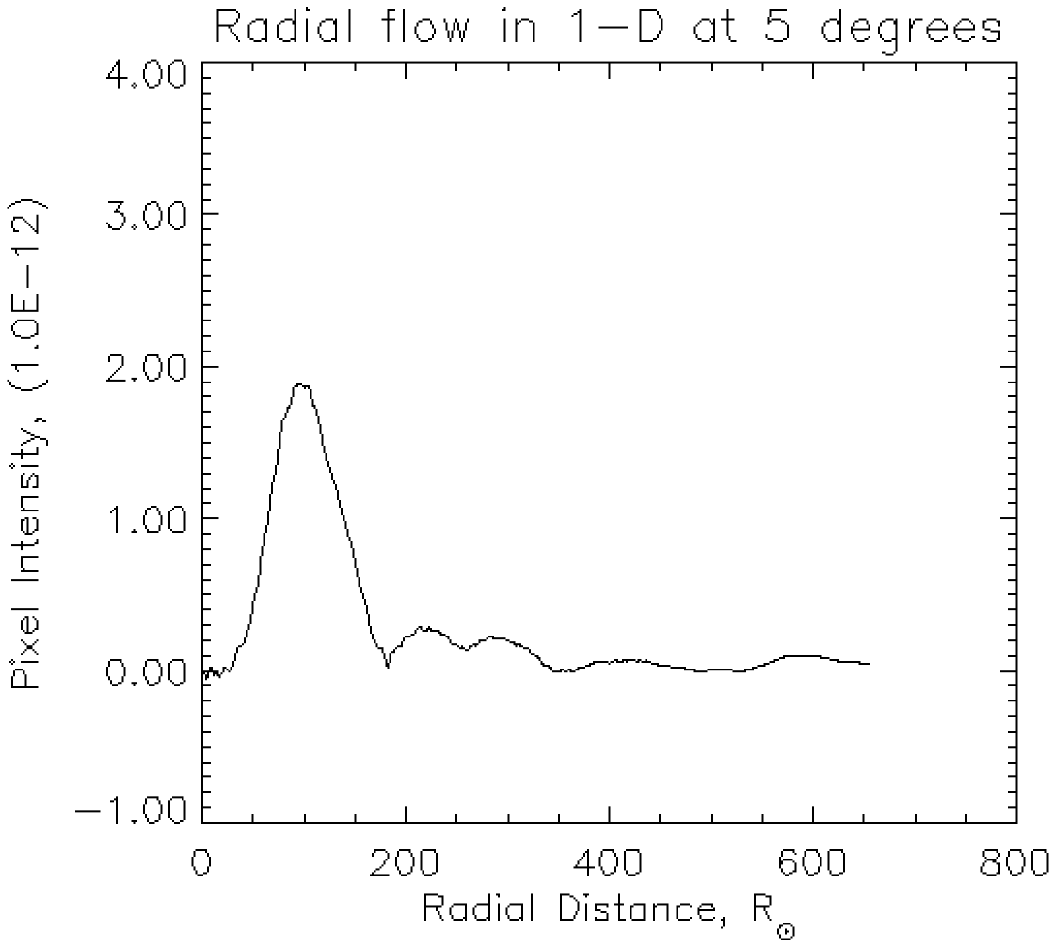


Figure 3: Transforming from spatial images organized by time to a configuration that prioritizes height vs. time variations. For this sample, the 300 frames correspond to 25 hours, the radial distance (r) ranging from 4 to 15 Solar radii, and the polar angle (Φ) from 0 to 360°.

Animation 2: The animation of the radial flows for each Φ. There is a total of 360 images, each image shows the variation in time (t) and radial distance (r) for a given polar angle (Φ).

For each time frame and a fixed polar angle, the radial flow images correspond to a collection of the brightness intensity at a distance r. As the signal propagates, its intensity decreases as a function of r^3 (Animation 3).



Animation 3: The animation of the peak intensity propagating over time for a fixed polar angle.

Figure 4 shows similarities for the different peaks and our hypothesis predicts that these should correlate. We believe that we can track how much these signals have propagated by measuring how much the peak of one signal has moved relative to the previous one. The propagation of the signal over time can provide us with a value of the velocity at the peak signal.

Our analysis evaluated the maximum cross-correlation of two signals and located its corresponding maximum spatial lag between the two signals. Furthermore, we obtained a value for maximum lag from cross-correlating of the first time frame with all time frames across all polar angles.

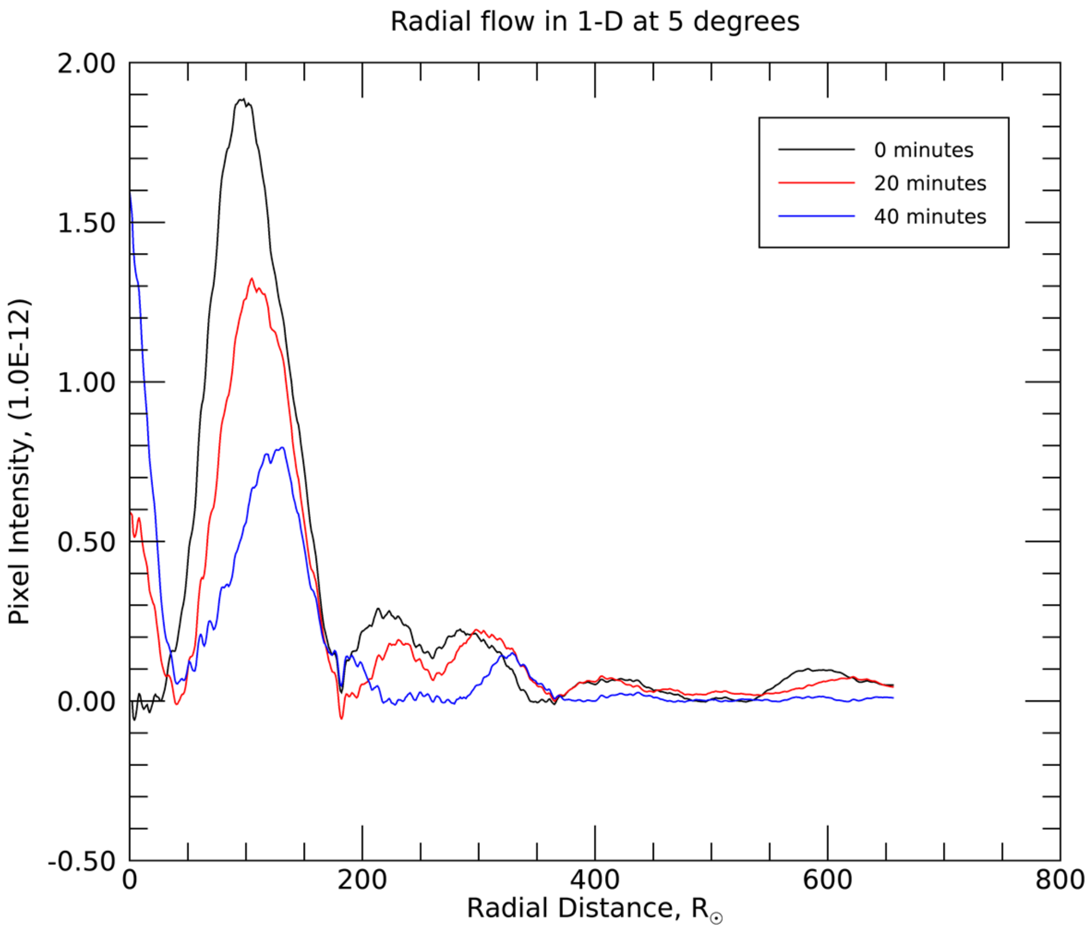


Figure 4: The plots show the radial flow from 3 frames, 20 minutes apart, for a given polar angle of 5°. The peak intensity of the different signals shows similarities across the frames. The slight increase before the peaks in the red and blue curves are probably artifacts due to the excessive brightness of the corona.

PRELIMINARY RESULTS

The preliminary analysis of these signals shows a constant increase in the spatial lag as time evolves. This corresponds to a slight increase in radial velocity for a short time period, of about one hour (Figure 5). This was expected because the features are not entirely radial and none of the features should last for the entire time sample, i.e. Animation 2.

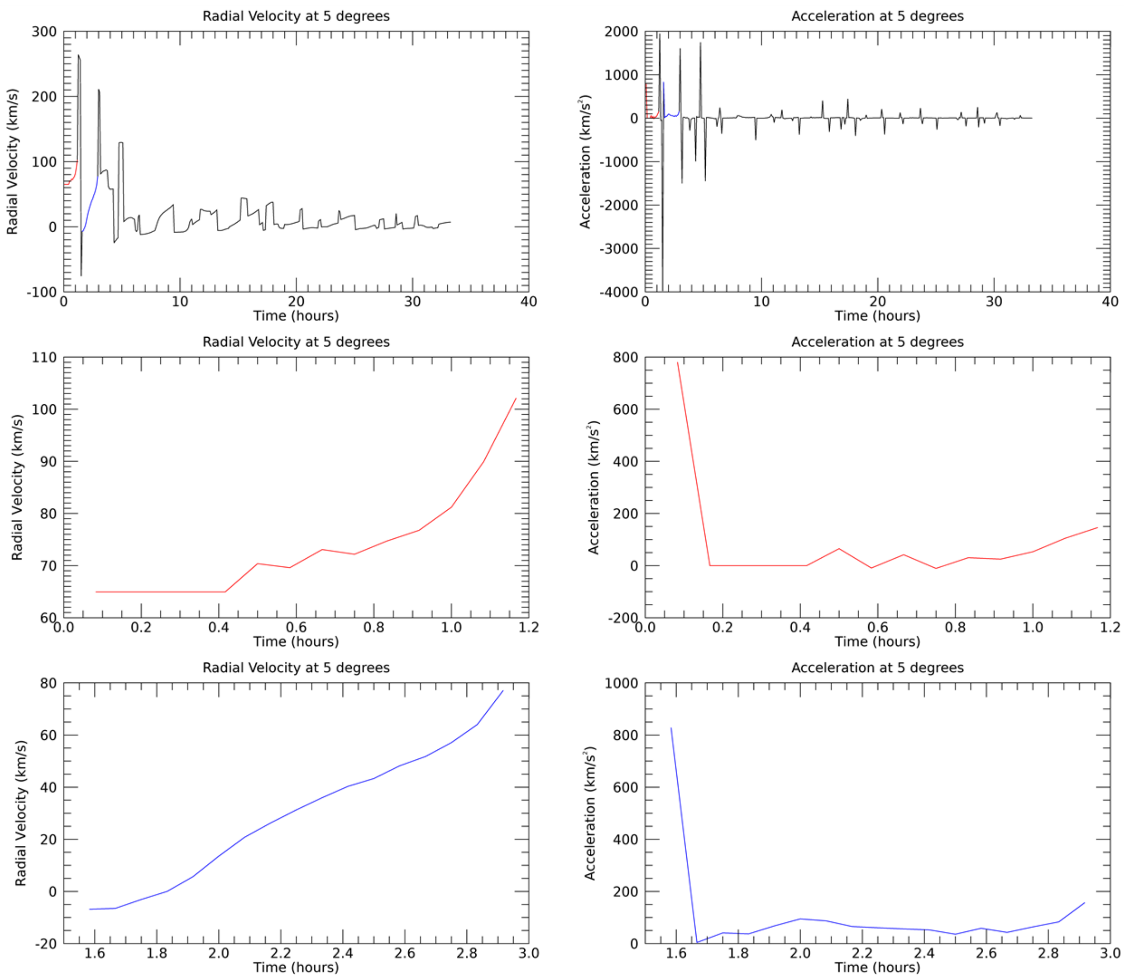


Figure 5: The radial velocity and acceleration plots for a given polar angle of 5°. (Top, right) The radial velocity plot for the entire sample reveals sudden speed changes, which is expected due to the radial flow structure. (Middle, right) The radial velocity for the first hour reveals an increasing behavior characteristic of an acceleration. (Top, left) The acceleration plot of the entire sample. (Middle, left) The acceleration of the first hour. (Bottom line) The velocity and acceleration for another hour with a promising increasing trend.

CONCLUSIONS & PROSPECTS FOR THE FUTURE

We evaluated how the signal from the brightness intensity propagates, and we notice the peak brightness moving as a function of time. This shows us that it is possible to track movement and obtain a value for velocity, and possibly for acceleration as well.

The preliminary analysis using cross-correlation revealed the presence of pixel motion, which can be translated into real motion, radial velocity. By fixing only the first time frame, we can already see a slight increase in radial velocity for a short time period.

The next step of our analysis is to do evaluate our cross-correlation method for the signals at different time frames, and check how these speeds evolve with time. We also want to implement this method to small patched of images, 2-D correlation.

AUTHOR INFORMATION

moraesfilho@cua.edu

ABSTRACT

In anticipation of the PUNCH mission, we examine the deep exposure data from the special campaign of the STEREO SECCHI COR2 instrument. Data was collected over April 14-16, 2014, representing altitudes of 4-15 solar radii, show clear flow structures throughout the field of view. We examine the variations in the derived flow as a function of altitude and polar angle, to present a picture of the solar wind velocities and acceleration through the corona and inner heliosphere.

REFERENCES

DeForest et al., “The Highly Structured Outer Solar Corona”, Astrophysical Journal, Vol. 862, 2018.

Thompson et al., “Tracking Flows and Disturbances in Coronograph Data”, AGU, 2018.