UCSD Time-Dependent 3-D High-Resolution Reconstructions Providing Brightness and Polarization Brightness Ratio Analyses

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Abstract

UCSD's iterative time dependent three-dimensional (3-D) reconstruction program has characterized topology throughout the inner heliosphere based on interplanetary scintillation (IPS) and Thomson scattering brightness observations. We have tested these analyses using Solar Mass Ejection Imager (SMEI) brightness to learn how well the 3-D reconstructions perform to reproduce a known Coronal Mass Ejection (CME) simulation. From the density volumes generated using our volumetric data from these analyses, we have provided pseudo (or imitation) lines of sight (LoS) through the volume over time in both brightness (B) and polarization brightness (pB). This provides a means to establish how well the original 3-D reconstruction technique reproduces known solar wind features of both known CMEs and corotating structures. From these pseudo analyses we can then 3-D reconstruct densities from our iterative system that uses this type of imagery. In anticipation that PUNCH will provide both near-simultaneous brightness and polarization brightness data over time, *We announce that we now have used this pB/B ratio analysis from our pseudo data sets over time to accurately reproduce volumetric density structure using the UCSD iterative process* from SMEI data. The polarization brightness to brightness ratio of Thomson-scattered light has long been understood as a way to isolate small distinct features along the LoS in individual volumetric data sets due to the ratio difference. How well the UCSD iterative system will accurately work in practice to isolate whole volume density data sets depends on the quality of the data as well as its accurate measurement over time. Tests continue with these analyses to learn how well measurements of background density over time, and other sources of LoS noise including missing spatial data, affect the reconstruction of the density volumes for density structures of different scale sizes. In general, we expect that the ratio technique will lessen the flow requirement time needed to isolate different small-scale structures due to their outward flow.

URLS: https://stereo.ucsd.edu/PUNCH https://ips.ucsd.edu https://ashi.ucsd.edu https://LWS.ucsd.edu

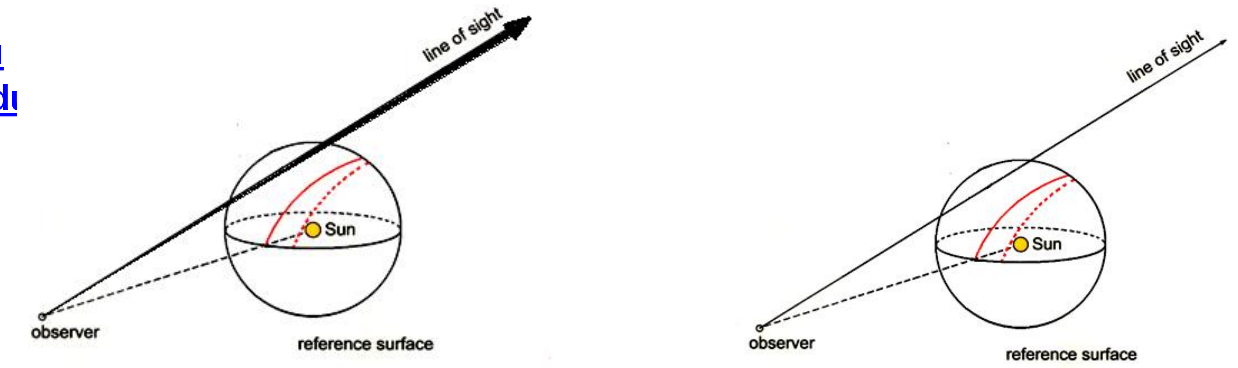
1. PUNCH

PUNCH Depiction in Earth Orbit

2. UCSD Heliosperic 3-D Reconstruction Analysis

The UCSD 3-D reconstruction technique uses carefully prepared images from heliospheric imagers to provide input for the 3-D reconstruction analyses. These images, as much as possible, are removed of stars, and any remnant of zodiacal light and high-pass filtered with an average baseline that extends over many days. This provides shorter-term variations from a mean value that are the electron Thomson scattering solar wind components showing the background solar wind, CMEs, corotating structures, and the time-variability of each.

Once prepared, these images are input to the UCSD 3-D reconstruction program that uses the line of sight (LoS) weighting of Thomson-scattering brightness (Billings, 1966), the outward flow, and the perspective view of each structure to provide the differentiation of features along the LoS. The 3-D reconstruction technique begins by assuming a constant density and velocity at lower latitude and longitude source surfaces that can vary over time and propagates these values outward until they can be viewed in the images as brightness and speed. At every step in the propagation, the location of each solar wind packet is preserved as a 4-D "traceback" matrix so that its onset location, density and velocity change from the source surface can be determined. The kinematic model used by UCSD conserves mass and mass flux at each outward step in the traceback and assumes radial solar wind outflow. Each observed LoS brightness from an image is compared with the initial model brightness, and changes relative to the initial model for each LoS location are then transferred back to the reference source surface. At the source surface each change is formally inverted and a new, better fitting set of source surface values are propagated outward. The procedure iterates to a converged set of lower boundary values. This technique was developed by Jackson *et al.* (1998; 2001). The mathematical description is found in Jackson *et al.* (2008) and is further elaborated in Jackson *et al.* (2006; 2020).

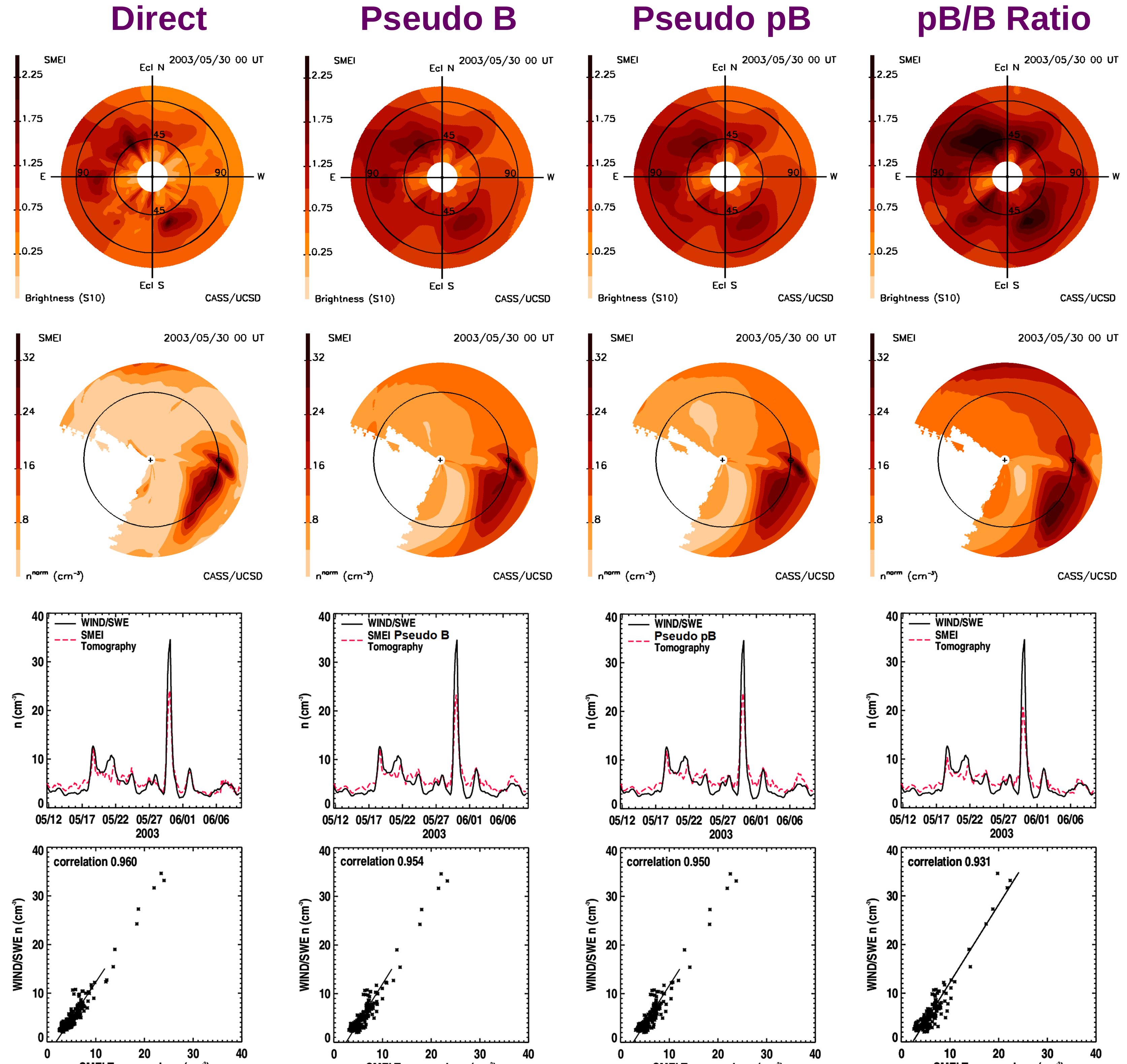


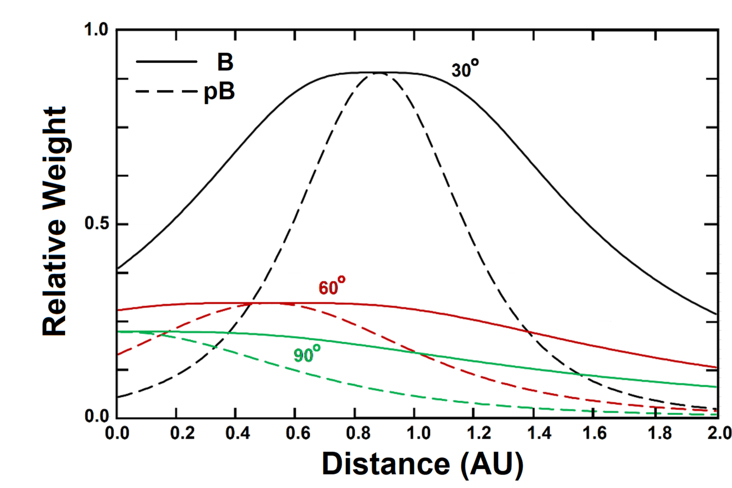
The reference (or source surface) is placed below all "lines of sight" (LoS) and the solar wind is traced outward from this inner surface using a time-dependent traceback matrix.

3. PUNCH B pB and pB/ Ratio Analyses

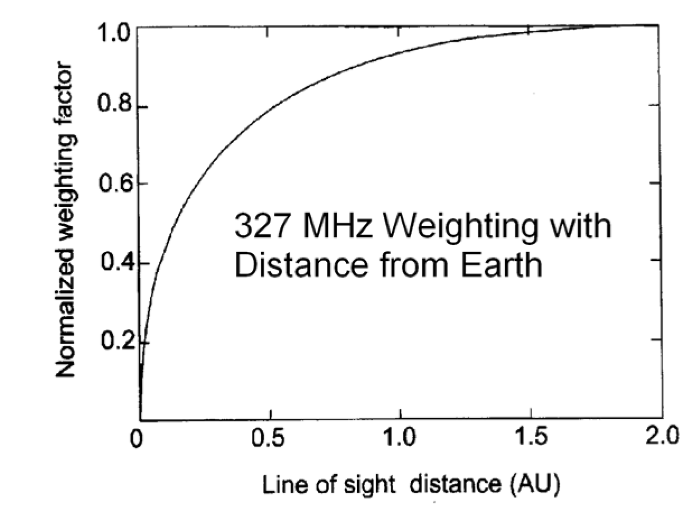
To test that the ratio analysis works to be expedient we have provided density from the SMEI analysis as a "direct" method of providing Brightness (B). LoS that provide B and polarization Brightness (pB) from these densities (pseudo values) are then used to create Brightness, ecliptic cuts, and Carrington time series.

May 27-30, 2003, halo CME complex (Low Resolution)





Thomson-scattering B and pB LoS weights

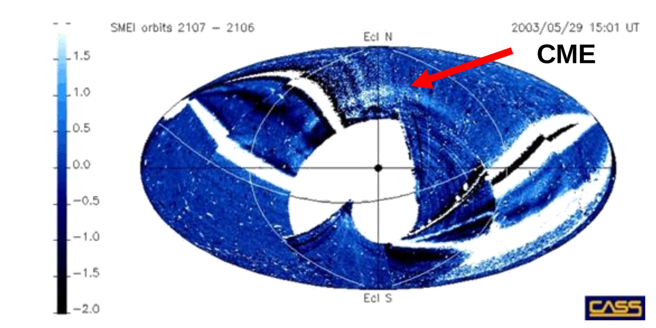


IPS LoS weighting

The only thing available to provide the 3-D analyses are 2-D images over time and the known scientific knowledge about the heliosphere. Polarization brightness (pB) and the Brightness (B) ratio can isolate simple structures, but when these structures are distributed along lines of sight (LoS), then the pB/B ratio must be used with outward flow to isolate them.

It is known that a LoS provides observations at each line segment from the same material and also known is the multiplicative factor or ratio needed to multiply pB by on each segment in order to make pB the same value as B at each line segment. In a first iteration, the model pB values multiplied by this ratio will not give a total to match the B values, but will give a total ratio that is different. Thus, to fix this difference and make the total model pB difference match that of the observed, the whole model line of sight must be multiplied by the total observed and modeled ratio differences times the ratio differences at each segment to fit the observed total ratio difference per LoS.
This is a linear fix and can be inverted using many LoS iteratively, and just like the B segment values or pB segment values can be inverted to deal with the outward flow.
This works as mode 1.
The multiplier required to make B values into pB LoS values and use the weights of the pB values to provide the inversion can be used in the same way.
This works as mode 2.
If these two modes work, one multiplier per LoS segment is just the inverted ratio of the other, so it is also possible to use one multiplier on a LoS and the other on the same LoS divide by 2 to get an average and invert with the B LoS totals as a set of B LoS. This works as mode 3. Mode 1 and mode 2 are not exactly the same because the line segments are digital representations of a LoS, and the two modes provide two chances to make a better average to a change that can be inverted.
The system converges using many LoS, does not care about one side or the other of the Thomson sphere since the flow is taken care of in the iterations by the different LoS when the difference is minimized for many observed and model ratios to provide density.

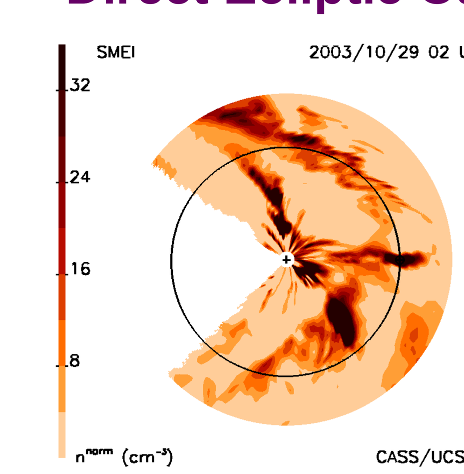
May 29, 2003, CME



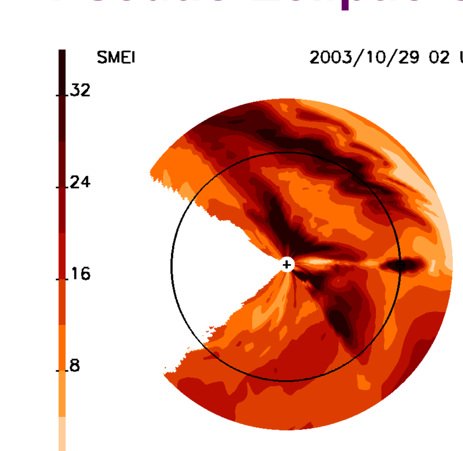
Raw SMEI Image

October 28-29, 2003, halo superstorm

High Resolution Direct Ecliptic Cut



High resolution Pseudo Ecliptic Cut



References:

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