An Accurate Solar Wind Electron Database in the Inner Heliosphere

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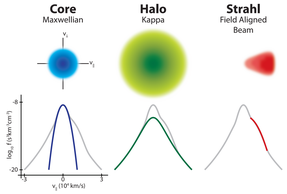
The solar wind electron distributions comprise several distinct populations, including the cold and dense core electrons, the hotter and more tenuous halo electrons, and the field-aligned strahl beam. We present a comprehensive analysis of electron distribution functions in the solar wind from the Wind 3DP experiment and from the Plasma experiment on Helios, generating an accurate database of core, halo and strahl electron parameters in the inner heliosphere, including temperature anisotropies, heat fluxes and spacecraft potential.

We are in the process of applying our analysis to the entire >15 year Wind and >10 year Helios electron data sets. This database is an important tool in probing electron thermodynamics and universal plasma processes observable in the solar wind. We provide a detailed description of our analysis technique, including descriptions of how we deal with crucial issues such as spacecraft potential and combining data from detectors covering different energy ranges. This technique leads to a precise characterization of both the thermal and suprathermal electron populations. We discuss their respective properties and variations in slow and fast wind flows and present some preliminary results.

Data

Wind: Great angular and energy resolution (88 angular bins, 15 energy bins for both high and low energy detector) at 1 AU.

Helios: Okay angular and energy resolution (8 angular bins aligned with ecliptic plane, 16 energy bins) from .3 to 1 AU.



Model Function

Wind: Fit to 2 components (core + halo), derive the strahl

Helios: Fit to 3 components (core + halo + strahl)

$$f_c(v_\parallel, v_\perp) = n_c\left(\frac{m}{2\pi}\right)^{3/2}\frac{1}{T_{c\perp}T_{c\parallel}}exp\left(-\frac{m}{2}\left(\frac{(v_\perp - v_{c\perp})^2}{T_{c\perp}} + \frac{(v_\parallel - v_{c\parallel})^2}{T_{c\parallel}}\right)\right)$$

$$f_h(v_\parallel, v_\perp) = n_h\left(\frac{m}{\pi(2\kappa_h - 3)}\right)^{3/2}\frac{1}{T_{h\perp}T_{h\parallel}}\frac{\Gamma(\kappa_h+1)}{\Gamma(\kappa_h - 1/2)}\left(1+\frac{m}{2\kappa_h - 3}\left(\frac{(v_\perp - v_{h\perp})^2}{T_{h\perp}} + \frac{(v_\parallel - v_{h\parallel})^2}{T_{h\parallel}}\right)\right)^{(-\kappa_h - 1)}$$

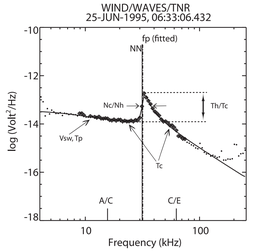
$$f_s(v_\parallel, v_\perp) = n_s\left(\frac{m}{\pi(2\kappa_s - 3)}\right)^{3/2}\frac{1}{T_{s\perp}T_{s\parallel}}\frac{\Gamma(\kappa_s+1)}{\Gamma(\kappa_s - 1/2)}\left(1+\frac{m}{2\kappa_s - 3}\left(\frac{(v_\perp - v_{s\perp})^2}{T_{s\perp}} + D\frac{(v_\parallel - v_{s\parallel})^2}{T_{s\parallel}}\right)\right)^{(-\kappa_s - 1)}$$

Correct for Spacecraft Potential

- A potential Φ arises from the balance between solar wind electrons impacting the surface of the spacecraft and photoelectrons being knocked off.
- A surefire way to estimate the spacecraft potential is to iteratively adjust our fit points by an isotropic potential until our fit density matches a known density.
- The spacecraft potential can also be determined theoretically. We derive the potential that must be present in order to ensure current balance between the electrons, protons, and alpha particles.

Wind: Two methods of determining S/C Φ. 1) Current balance, 2) iterative fitting using known density from TNR.

Helios: Only determine S/C Φ with iterative fitting, using density from ion instrument.



Above: A typical TNR spectrum, showing which electron parameters can be derived

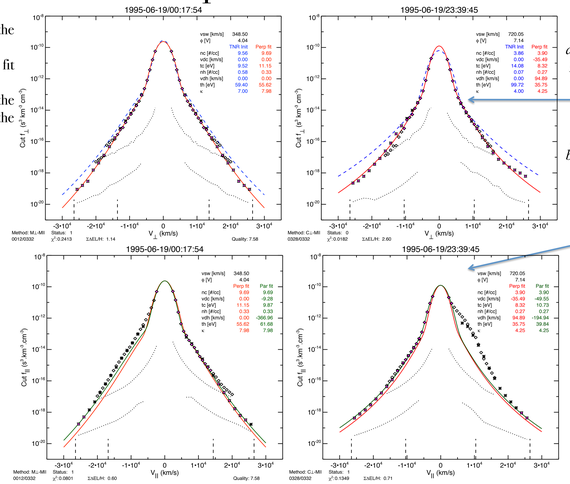
Method

Because electrons stream gyrotropically along magnetic field lines, the eVDFs (electron velocity distribution functions) are described only in terms of their components parallel and perpendicular to the magnetic field. We conduct nonlinear least-squares fitting to the eVDFs.

Wind: We fit 1 dimensional cuts along the || and ⊥ directions. We subtract the model from the data to obtain the strahl (see right)

Helios: Fit to the entire 2D distribution. The strahl is part of the model, but we still calculate the "delta strahl"

Example Fits from Wind

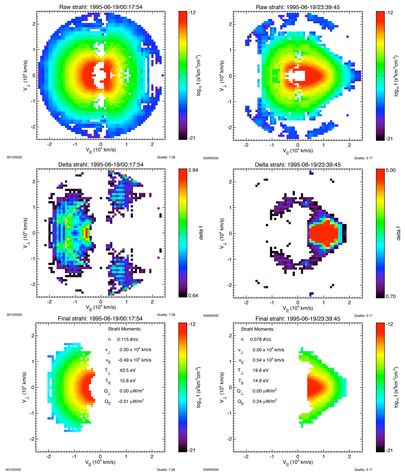


Shown at left are fits along the parallel and perpendicular cuts of a Wind eVDF. Note the symmetry of the perpendicular cut in velocity space. The parallel cut exhibits strong drifts and a prominent strahl. We take care not to fit to strahl points! The strahl distribution seems to be subsumed by the core at low energies and by the halo at high energies. The broad energy range of the Wind detectors EESA-H and EESA-L allows us to fit to the halo beyond the energy range of the strahl.

Plotted here are the parameters derived from the Wind fits over a period of one month. We include the solar wind speed and the status of the fit (whether or not it converged), which we will use in further analysis to help order our data

Extracting the Strahl

Step 1: subtract the model fit functions from the raw data

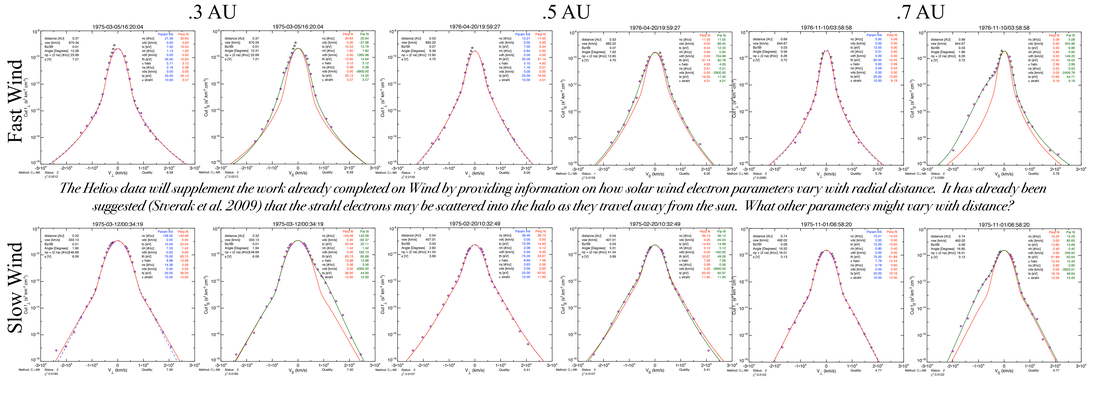


Step 2: we define a "delta" parameter $\delta = (f_{data} - f_{model})/f_{model}$. We define the strahl over the region where $\delta > 1$

Step 3: We define the strahl over the region where $\delta > 1$. The strahl moments are found by numerically integrating our final strahl distribution.

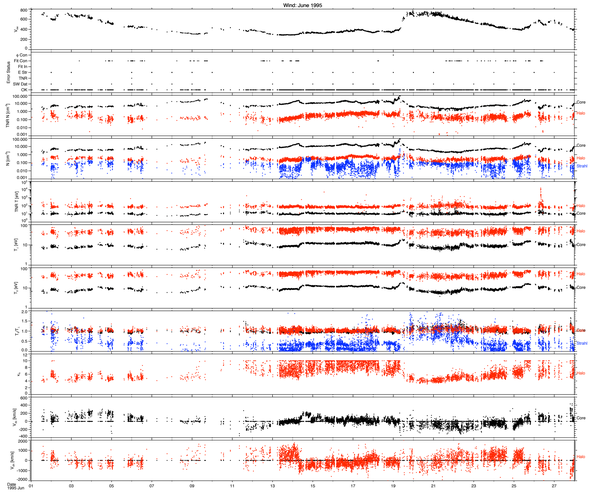
This work was funded by NASA grant NNX10AC03G and SHINE grant 0962726.

Example Fits from Helios



The Helios data will supplement the work already completed on Wind by providing information on how solar wind electron parameters vary with radial distance. It has already been suggested (Stverak et al. 2009) that the strahl electrons may be scattered into the halo as they travel away from the sun. What other parameters might vary with distance?

A Month of Wind Results



Our data set covers a wide range of solar wind regimes, and yields solar wind electron parameters with high accuracy. Further work will soon be done to with our data to look for evidence of physical processes, such as collisions and wave-particle interactions, that serve to regulate the solar wind electrons. See Marc Pulupa's SHINE poster for preliminary physical results.