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An Accurate Solar Wind Electron Database From the 3DP Experiment Onboard the Wind Spacecraft

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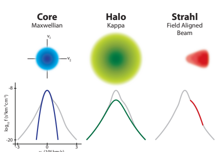
For more information on our science objectives, see Chadi Salem's talk SH54B-09 at 5:49 today in Moscone South 307.

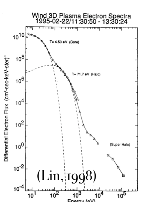
The solar wind electron distribution functions (eVDFs) comprise several distinct populations, including the cold and dense core electrons, the hotter and more tenuous halo electrons, and the field-aligned strahl beam. In this work, we have analyzed several years of eVDFs from the Wind 3DP instrument, generating an *accurate database of core, halo and strahl electron parameters*, including temperature anisotropies and heat fluxes.

We present here a detailed summary 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 populations.

Introduction

- Solar wind electrons are not in thermodynamic equilibrium. Their eVDFs display non-equilibrium features such as temperature anisotropies, suprathermal tails, and heat fluxes along B). How to accurately model them?
- These non-thermal properties are driven (expansion) but regulated (collisions, turbulence, wave-particle interactions).
- They are of great importance for addressing outstanding questions about, for instance, *heat conduction*, *plasma micro-instabilities*, *wave growth*, and *transport in a weakly collisional plasma*, as well as in the scenario at *the origin of the solar wind.*





(Lin, 1998)

Modeling of the eVDF typically divides the solar wind into three distinct populations: a thermal core, a tenuous and hot suprathermal halo, and a suprathermal field-aligned strahl. We model the core with a bi-Maxwellian distribution, and the halo with a bi-kappa distribution, which is like the bi-Maxwellian at low energies but exhibits power law behavior at higher energies. The value of kappa measures the strength of the suprathermal tail of the halo. We do not assume an explicit functional form for the strahl (see "Method" section).

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

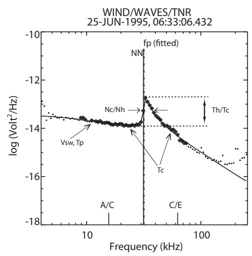
$$\text{HALO} \longrightarrow \; + n_h \left(\frac{m}{\pi(2\kappa-3)}\right)^{3/2} \frac{1}{T_{h\perp}\sqrt{T_{h\parallel}}} \frac{\Gamma(\kappa+1)}{\Gamma(\kappa-1/2)} \left(1 + \frac{m}{2\kappa-3}\left(\frac{(v_\perp - v_{h\perp})^2}{T_{h\perp}} + \frac{(v_\parallel - v_{h\parallel})^2}{T_{h\parallel}}\right)\right)^{(-\kappa-1)}$$

Maxwellian core plus kappa halo model for the distribution function

Data

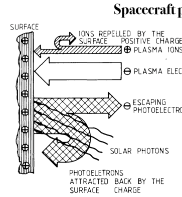
- Data from 3DP and Wind/WAVES TNR.
- eVDFs are measured by EESA-H and EESA-L.
- EESA-L energy range: 15 bins from a few eV to 1.1 keV
- EESA-H energy range: 15 bins from ~100 eV to 30 keV
- EESA-L and EESA-H: 88 angular bins, providing full 4π angular coverage.
- eVDFs transmitted every 99 seconds, which over our 10-year data set gives roughly a million solar wind measurements

TNR Measurements



- TNR measures the electron thermal noise spectrum
- Shape of the spectrum depends on electron core and halo densities and temperatures
- These measurements are independent of the effects of spacecraft potential, and are used to initialize our fits.

Spacecraft potential



(Grard, 1983)

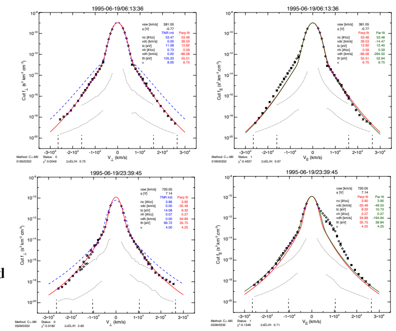
- Due to photoemission, the spacecraft usually charges a few volts positive. This increases the energy of electrons as measured by 3DP, affecting moments of the eVDF.
- We can use the accurate densities measured by TNR to correct for this spacecraft potential effect.

Method

Once we have transformed our eVDFs into the magnetic field frame, we fit our core+halo model along 1-dimensional cuts. We conduct initial fits to determine the value of the spacecraft potential, adjusting the potential (and thus the distribution function) until the fit is able to conform to the TNR density measurement. Then we correct the 3DP measured energies by subtracting eΦ, and fit simultaneously to the core and halo. We first fit along the perpendicular direction to find n_c, n_h, $T_{c,\perp}$, $T_{h,\perp}$, and κ. We then fit along the the parallel direction to find $T_{c,||}$ and $T_{h,||}$, keeping n_c, n_h, and κ fixed.

Slow wind

Fast wind

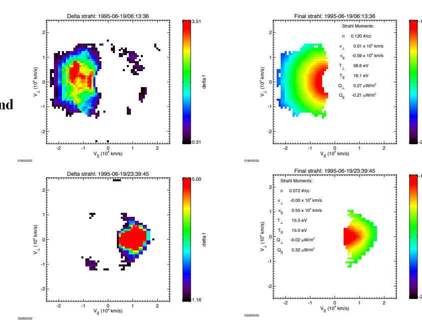


Above: Fits along perpendicular (left) and parallel (right) directions of the eVDF. In the perpendicular plot, the blue dashed line represents our guess function (core + halo) constructed from the fit-initializing TNR parameters. The 1D eVDF cuts are represented by the stars (EESA-H) and diamonds (EESA-L).

We can use our fitted parameters to construct a 2D map of the core + halo eVDF. Subtracting this model from the measured eVDF gives the strahl. To avoid contamination from error in our fit, we define a "delta" parameter $\delta = (f_{data} - f_{model})/f_{model}$. We define the strahl over the region where $\delta > 1$.

Slow wind

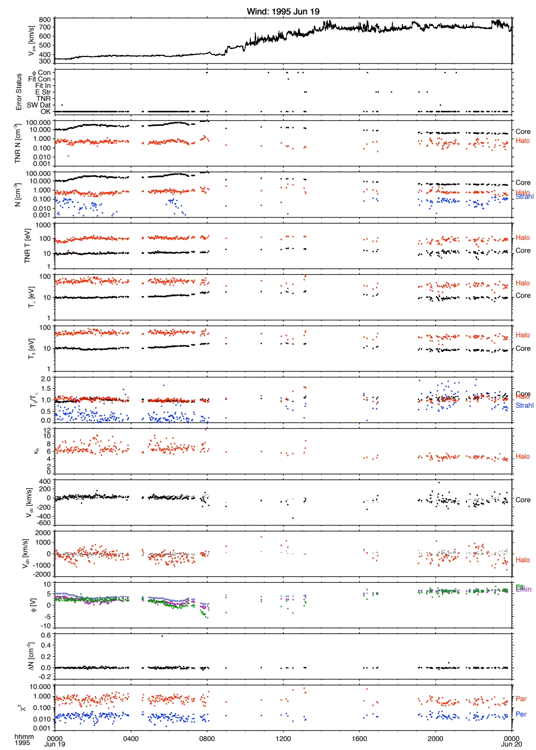
Fast wind



The "delta" and "final" strahl. The top row displays an eVDF measured in the slow solar wind (v_{drift} < 450 km/sec). The bottom row displays the fast wind strahl (v_{drift} > 600 km/sec), in which the strahl beam width is typically narrower. The raw strahl was obtained by subtracting our fitted model from the actual eVDF. Establishing a cutoff in the delta parameter allows us to to define the extent of our final strahl, whose raw moments we calculate from its eVDF.

Results

We are currently applying this fitting procedure to the entire Wind data set in the ambient solar wind to generate a comprensive database of electron core, halo, and strahl paramters at 1 AU, including densities, temperatures, drift speeds, temperature anisotropies, and heat flux.



Above: The results of our fitting procedure over the course of June 19th, 1995.

The resulting database is a promising tool for probing the role of plasma instabilities in regulating electron temperature anisotropy, electron heat flux, and the evolution of the electron strahl.

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