SOLAR WIND IN-SITU MEASUREMENTS OF COHERENT ELECTROSTATIC FLUCTUATIONS ON STEREO

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ABSTRACT

One of the striking results obtained in the recent years concerns the ***small-scale structure*** of the ***solar wind plasma***. Observations made by the **Time Domain Sampler**, an electric and magnetic *waveform analyzer* onboard **WIND**, have shed a new light on the ***nature*** of the "***ion acoustic***" ***electrostatic turbulence*** in the solar wind. This turbulence appears to consist of *small amplitude coherent waves* and *solitary structures*, many of which are ***weak double layers*** (WDL) with small potential drops of roughly 1 mV directed towards the Earth. It has been shown that those potential drops over a few tens of Debye lengths may be related to the ***large-scale interplanetary electric field*** needed to maintain the global charge neutrality in the solar wind.

The **STEREO/WAVES** experiment will have an improved, linear, waveform sampler experiment based on the WIND design. The **STEREO/TDS** instrument will sample from 3 orthogonal antennas ; a further improvement over WIND's 2-axis system. We will discuss the prospect of using data from the two STEREO spacecraft to measure and compare WDL structures along two solar wind trajectories.

The large-scale interplanetary electric field

- The **solar wind** is the outward extension of the million-degree hot solar corona. It is a **weakly collisional**, **strongly turbulent plasma** in a **supersonic spherical expansion**. Since the electrons are less gravitationally bounded by the Sun than the protons, they tend to be displaced outward with respect to the protons.

- To maintain the global charge neutrality of the solar wind plasma, an **interplanetary electrostatic potential difference** $\Delta\Phi_{IP}$ sets sets in between the solar corona and "infinity". The corresponding **electric field** $\boldsymbol{E_{IP}}$ is **directed antisunward** and plays a key role in the solar wind expansion.

- Values of $\Delta\Phi_{IP}$ can be obtained from different models for solar wind expansion, for example, in a **two-fluid model** (where E is related to the electron pressure) or in an **exospheric model** (where E is such as there is equality between the escaping electron and the proton fluxes). These models predict a **potential difference** $\Delta\Phi_{IP}$ of the order of 400 to 600 Volts between the solar corona and the Earth orbit. **Such large-scale potentials cannot be measured directly in-situ**.

The small-scale structure of the solar wind plasma

- Since the **solar wind** is a ***weakly collisional plasma***, it is usually argued that **wave-particle interactions** replace **binary collisions** in order to restore the fluid character of the flow by regulating the ***energy transport*** and ***dissipation***.

  [*Kellogg,* 2000 ; *Salem,* 2000]

- Among the waves that can play a role in this respect, **electrostatic waves** in the ***ion acoustic frequency range*** ($f_{pi} < f < f_{pe}$) have been observed by several spacecraft in the solar wind. This ***broadband ion acoustic activity*** is an ***intermittent*** but ***almost permanent*** feature of the solar wind.

  [*Gurnett,* 1991 ; *McDowall et al.,* 1996 ; *Mangeney et al.,* 1999]

- Neither the **wave mode** nor the **source** of these waves have yet been unambiguously identified [*Gurnett,* 1991].

- Recently, *high-time resolution data* from the WAVES experiment on **WIND** have led to a *major contribution* to our understanding of this **ion-acoustic-like wave activity** in the solar wind, by revealing for the first time its **highly coherent nature** [*Mangeney et al.,* 1999 ; *Salem et al.,* 1999].

<u>The WIND/WAVES experiment</u>

- Our observations were taken in the *ambient* solar wind, at the Lagrange point L1, from May 20 – June 26, 1995.

- **<u>The WAVES experiment on WIND</u>** [*Bougeret et al.*, 1995] :

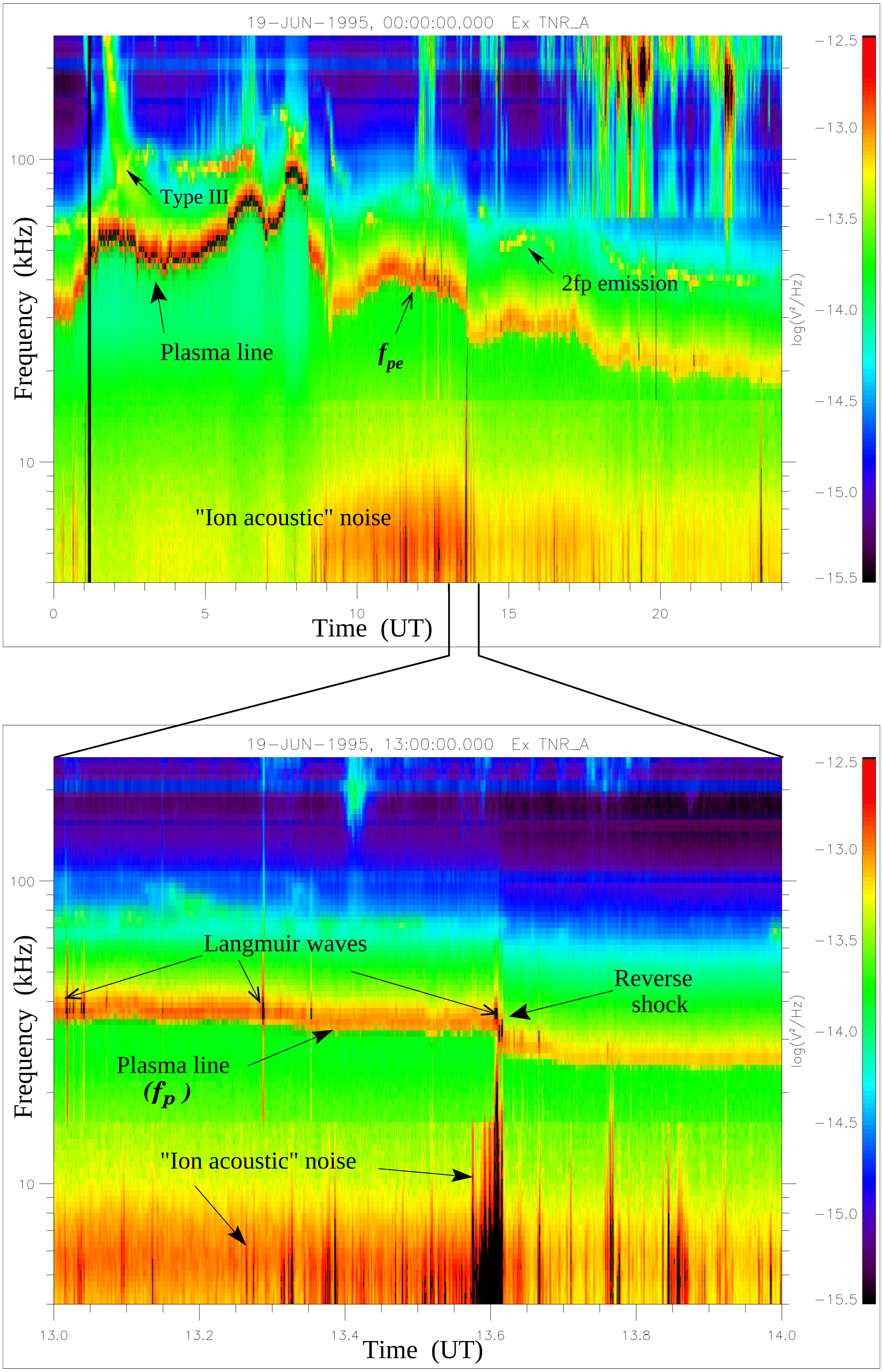
  The ***electric field fluctuations*** are measured by two different instruments, from 2 ***orthogonal dipole antennas*** (100 m and 15 m tip to tip) :

  - The **Thermal Noise Receiver** (**TNR**), a spectral analyzer, measure continuously electric field power spectra from 4 to 256 kHz every 4.5 s (with an integration time of 1.472 s).

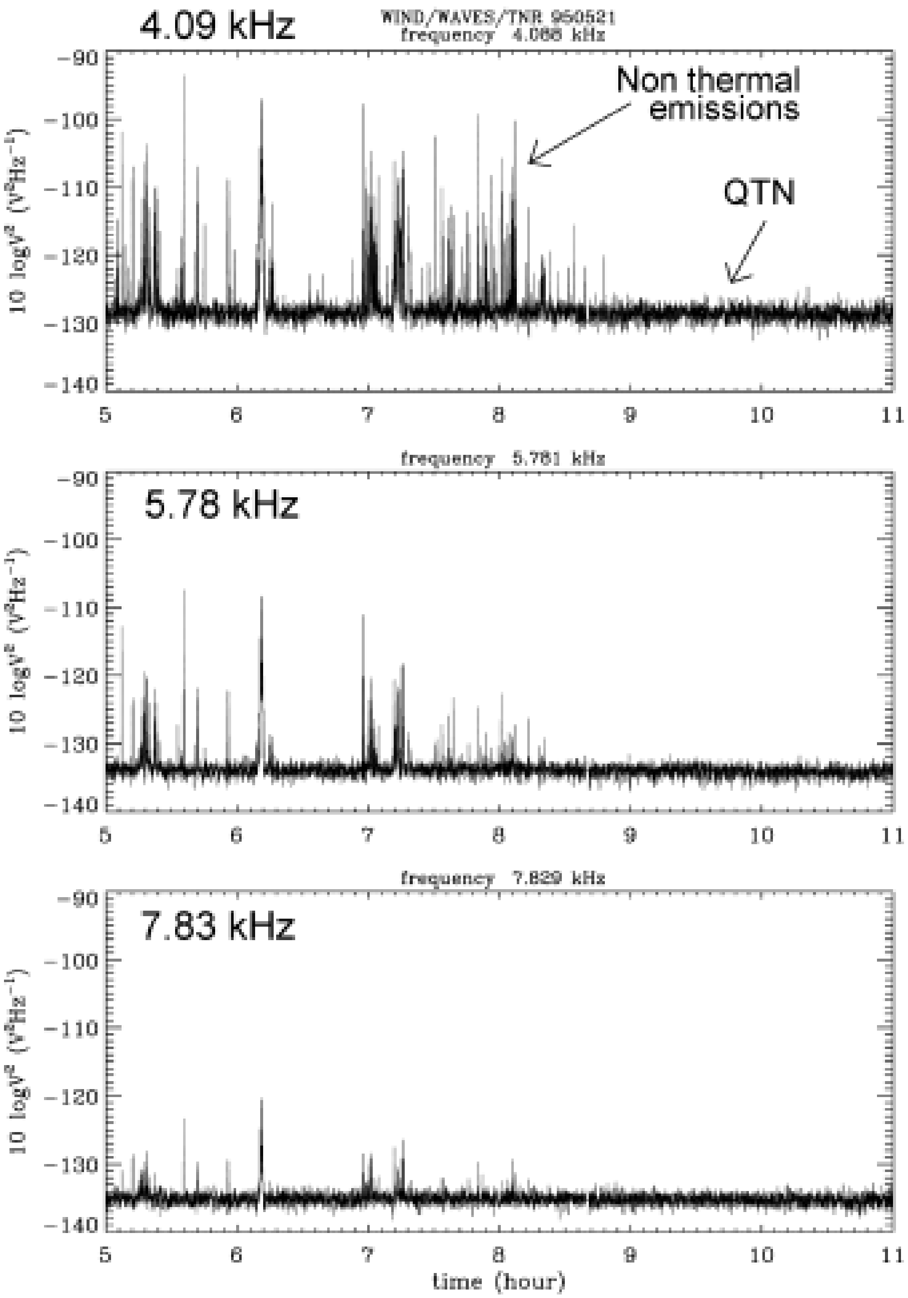
  - The **Time Domain Sampler** (**TDS**), an electric (& magnetic) waveform analyzer, detects all the electric signals above a programmable threshold of ~ 50 μV/m), but only a few waveforms are transmitted to the ground (roughly, one every 10 min).

    <u>Sampling rates</u> : 7500, 30000 and 120000 samples per second (time resolution up to 8 μs).
    <u>Samples</u> of 2048 data points ⇒ <u>event duration</u> = 270, 70 or 17 msec.

Electric fluctuations measured by TNR



Electric fluctuations on TNR at a given frequency

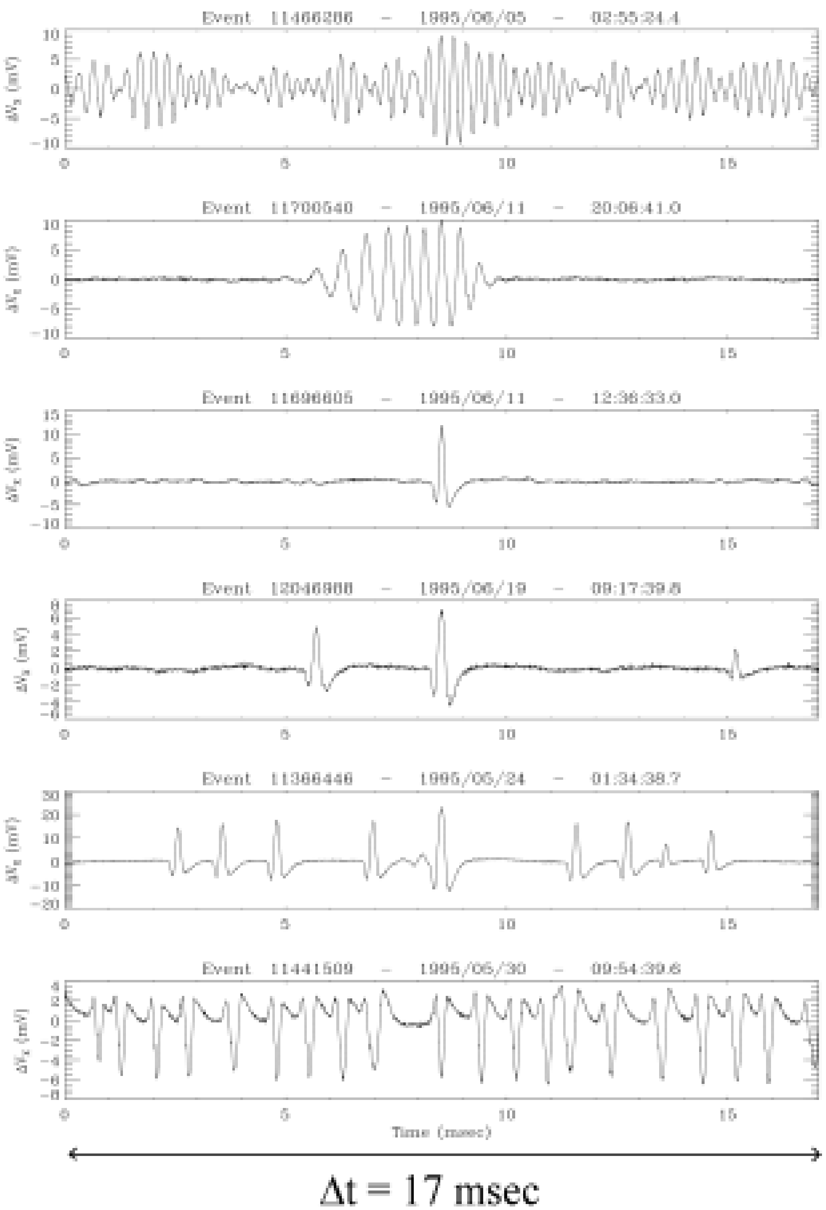


- **Quasi-thermal noise** (**QTN**) :
  [*Meyer-Vernet & Perche*, 1989 ; *Meyer-Vernet et al.*, 1998 ; *Issautier et al.*, 1999]
  at $E^2(f) \approx 10^{-13.5} - 10^{-13}\ V^2/Hz$
  with Gaussian statistics.

- **Intermittent non thermal emission**, with a power-law distribution.

- Above 7 kHz, these nonthermal emissions disappear.

Electric waveforms on TDS

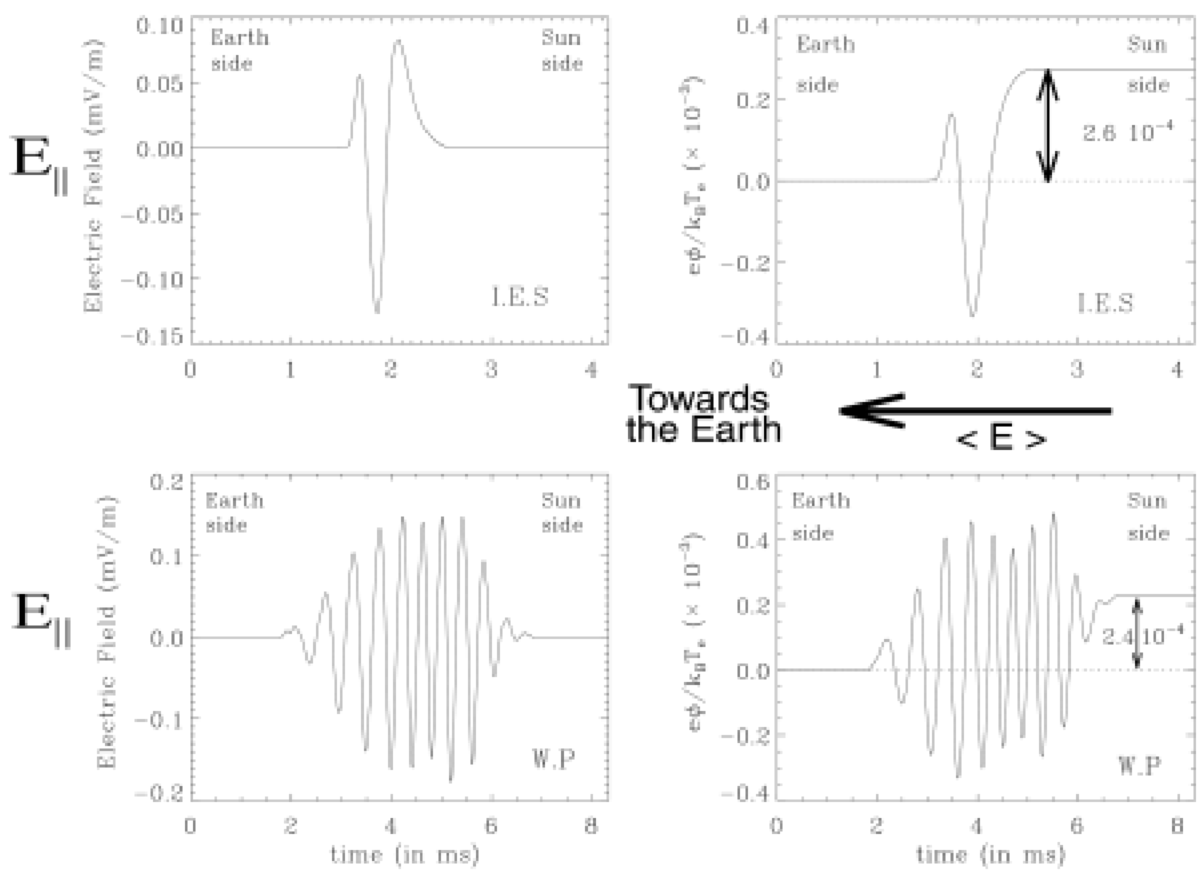


- In the "quiet" solar wind, all events detected by TDS are **coherent electrostatic waves** (**CEW**), with properties similar to those of ion acoustic waves
  [*Mangeney et al.*, 1999].

- The typical wavelengths are :
  - *10* < λ/λ_D < *50*, for the wave packets,
  - $\Delta x/\lambda_D \approx 25$, for the solitary structures.

- They are **parallel propagating waves**, with ***E // B***.

Weak Double Layers (WDL) in the solar wind



About 30% of these CEW are solitary structures with a measurable net potential drop :

$e\Delta\phi/k_BT_e \approx 10^{-4} - 10^{-3}$

or

$\Delta\phi \geq 10^{-3}$ Volts

The corresponding electric field is **almost always directed towards the Earth**

[*Mangeney et al.*, 1999]

Is $\Delta\Phi_{IP}$ the **result of a succession of small potential drops** in **weak double layers,** due to **small charge separations** ($\delta N/N_e \sim 10^{-5}$) between the protons and the escaping electrons ? [*Salem et al.*, 1999].

Occurrence of WDLs in the solar wind and estimation of $\Delta\Phi_{IP}$

[*Lacombe, Salem et al.*, 2002]

- Comparing the **average spectral energy densities** on TDS and on TNR, over a common frequency range (between 4 and 6 kHz) has allowed us to estimate the **frequency of occurrence of CEW in the solar wind** : $N_{CEW} \sim 0.5\ s^{-1}$.

- Since only 11% of the observed CEW's contribute to the frequency range above 4 kHz, and 30% have a measurable potential drop, we concluded that the **number of WDLs** drifting past WIND would be : $N_{WDL} \sim 1\text{-}1.5\ s^{-1}$.

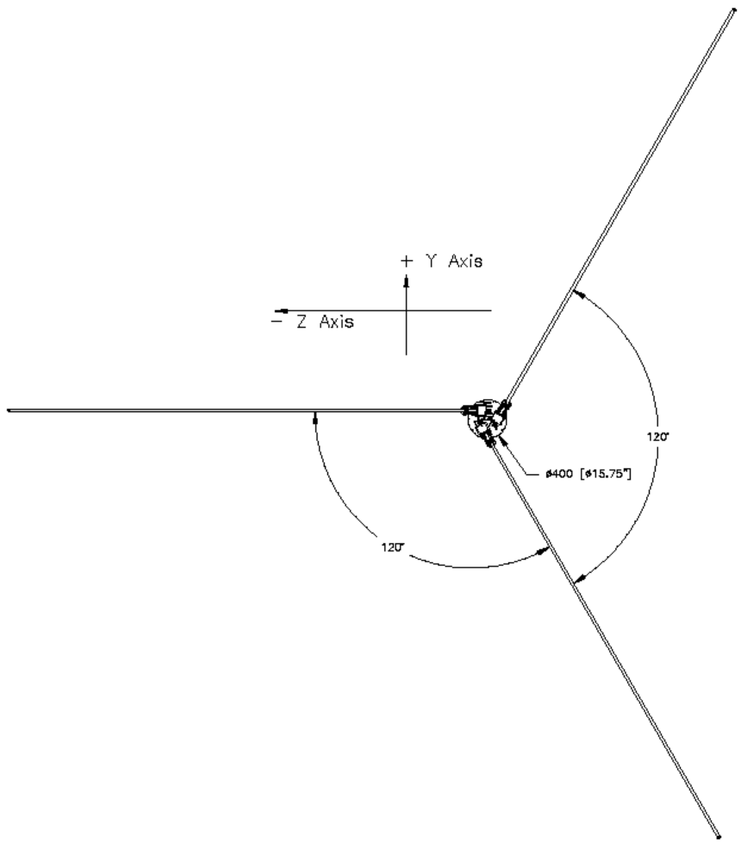
- **Extrapolating this result** and **assuming**,
  - an average travel time of 3 105 sec for a solar wind plasma element between the solar corona and the WIND orbit,
  - both NWDL and the average potential difference $\Delta\phi$ across a WDL remain constant,

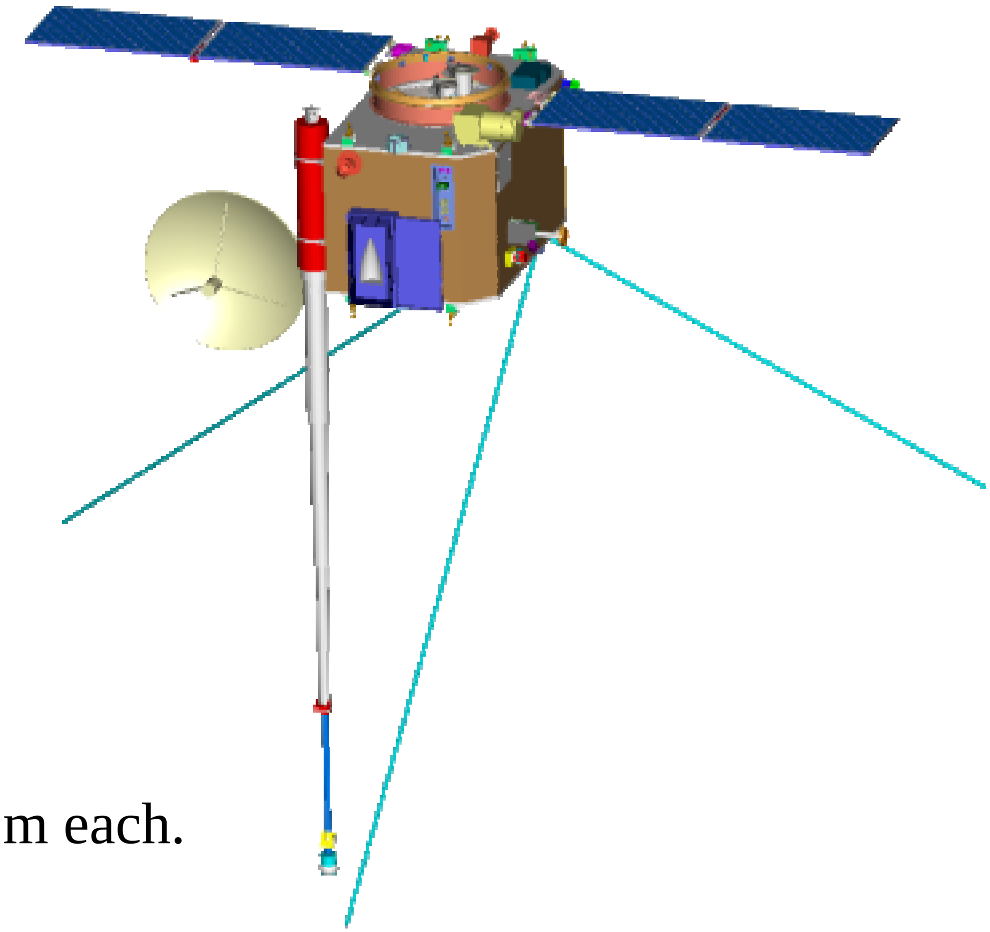
one may estimate the **total potential difference** (a lower estimate probably) :

$$(\Delta\Phi)_{1AU} \geq 400\ Volts$$

which is **in the range of values needed to maintain charge neutrality** in the solar wind [*Scudder and Olbert,* 1979].

<u>STEREO/WAVES Sensors</u>





- 3 orthogonal monopoles of 6 m each.
- magnetic loop antenna ?

STEREO/WAVES Time Domain Sampler (TDS)

- **TDS specifications** :
  - TDS on STEREO is a **16 bit** A/D converter.
  - TDS will sample from **3 orthogonal antennas**, measuring **3 components** of the AC electric field.
  - TDS has **programmable sampling rates** with events of maximum **length** of **16 ksamples**.
  - The **possible sampling rates** are : 250,000 samples/s, 125,000 samples/s, 31,250 samples/s, and 7,812.5 samples/s.

- **Measuring small amplitudes events with STEREO/TDS** :
  - On **WIND**, we actually measure the **logarithm of the potential difference** and **digitize to 8 bits**.
  - On **STEREO**, the use of a **16 bit linear A/D converter** provides **sufficient dynamic range** with **much better fidelity**. This will produce a **more accurate representation** of the **lowest amplitude WDL events** in the solar wind.

Advantages of STEREO/WAVES/TDS

- TDS on STEREO will provide a much **more accurate representation of the low amplitude signals** than on WIND.

- The use of **3 orthogonal antennas** on STEREO is a further improvement over **WIND's 2 axis system**. This will allow us to **determinate more accurately the wave properties** (wavevector and its direction, direction of the small-scale electric field associated to the WDLs, etc.).

- The event duration will be long enough to allow a **more accurate determination of the frequency of occurrence** of the coherent electrostatic wave as well as of the weak double layers in the solar solar. For example, a 16 ksample event, sampled at 31,250 samples/s will correspond to a half-second duration event.

- Finally, a **complete statistical study** of the **spatial distribution of weak double layers** along the magnetic field lines, and the corresponding estimate of the total potential difference between the solor corona and the Earth orbit, on **two different solar wind trajectories** could be achieved using **the two STEREO spacecrafts**.

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