SPINE Meeting

Solar Orbiter and Solar Probe Plus: problems of wake and electromagnetic perturbations

Vladimir Krasnoselskikh (LPC2E) with the assistance of « Fields » and « RPW » teams

Plan

- SO and SPP
- Wave measurements: search coil sensors
- Instruments onboard satellite and sources of contamination
- Physical mechanisms invoked
- Information available: Helios
- Recent simulations: Ergun et al. and Lipatov et al.
- What can we do to avoid troubles?

« Solar Probe Plus » : scientific objectifs

- **Determine the Structure and Dynamics of the Magnetic Fields at the Source of the Fast and Slow Solar Wind ("Sources")**

- **Trace the Flow of Energy that Heats the Solar Corona and Accelerates the Solar Wind ("Heating")**

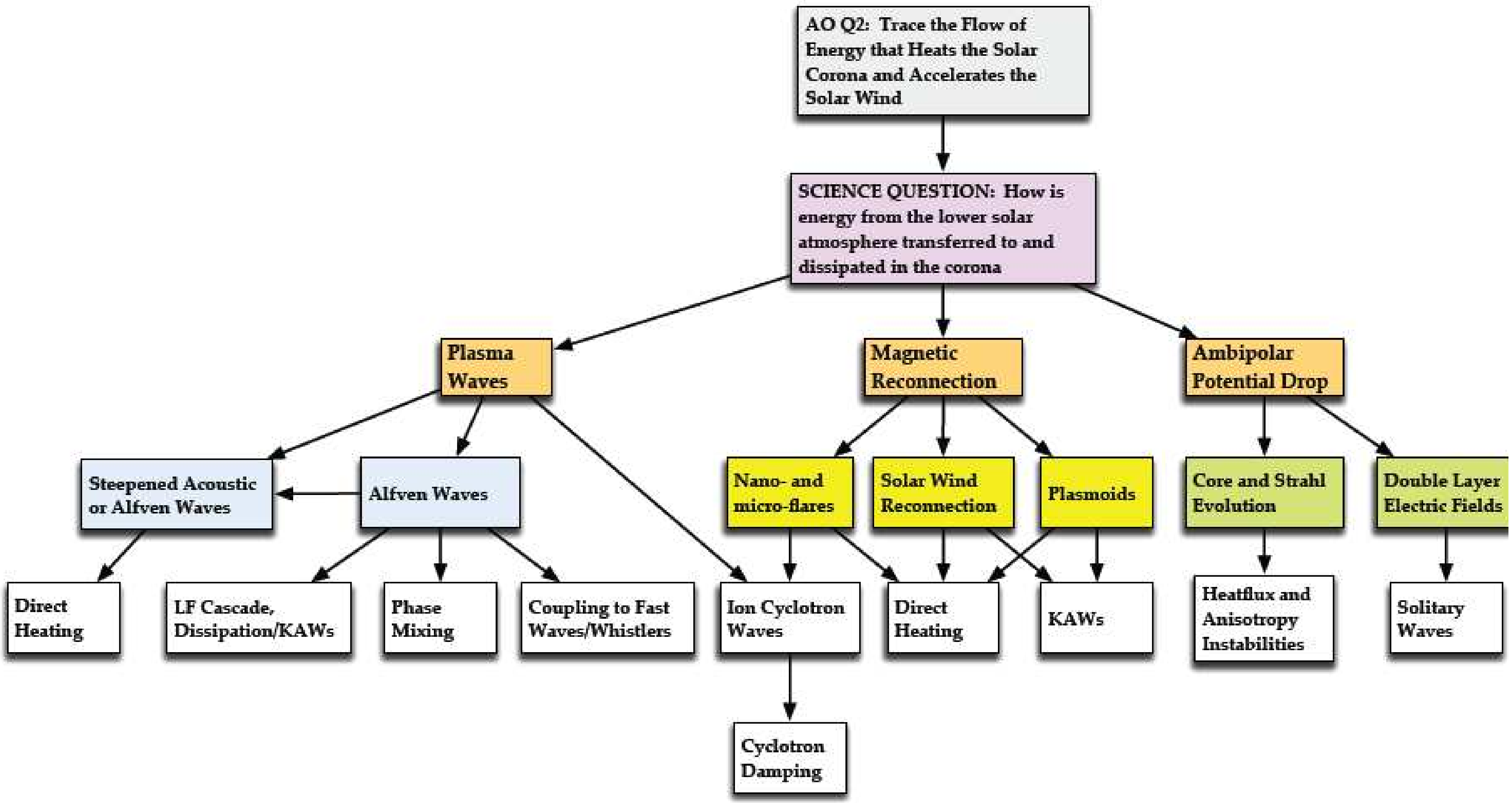
- **Explore Mechanisms that Accelerate**
- **and Transport Energetic Particles ("SEPs'")**

- **Explore Dusty Plasma Phenomena in**
- **the near-Sun Environment and their influence**
- **on the Solar Wind and Energetic Particle Formation**
- **("Dust")**

RPW scientific objectives

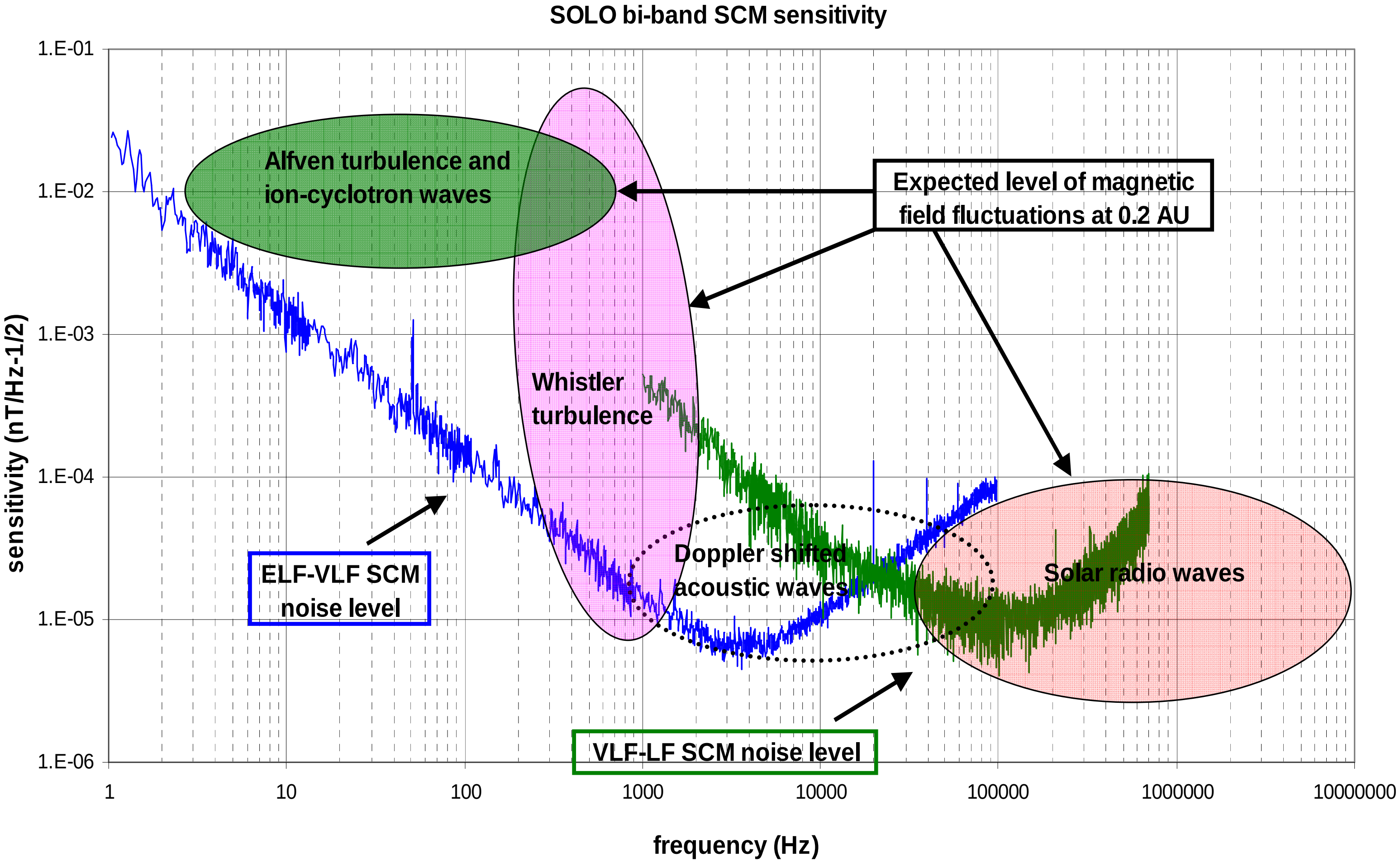
- **RPW will allow to determine the properties, dynamics and interactions of plasma, fields and particles in the near-Sun heliosphere.**
- **RPW will participate in the investigation of the links between the solar surface, corona and inner heliosphere.**
- **RPW will explore, at all latitudes, the energetics, dynamics and fine-scale structure of the Sun's magnetized atmosphere.**
- More specifically, RPW will measure magnetic and electric fields at high time resolution using a number of sensors, to determine the characteristics of electromagnetic and electrostatic waves in the solar wind from almost DC to 20 MHz.
- **The design and performance of the RPW experiment will allow for the first time high quality measurements of low frequency/DC electric fields in the inner heliosphere, at shocks, current sheets and in the ambient solar wind. Therefore, among the numerous science objectives described in section 3 of this document, the main target objectives of the investigation are:**
- **shock electric fields in the inner heliosphere (shock acceleration)**
- **dissipation/dispersion of turbulence at short wavelengths**
- **role of electromagnetic instabilities in regulating the anisotropy and heat conduction of the solar wind.**

Role of « Waves » in SPP



Scientific Objectives

- **To mesure AC magnétic fields in the range ELF/VLF et VLF/LF**



« Waves » and « Search Coil » caractéristics

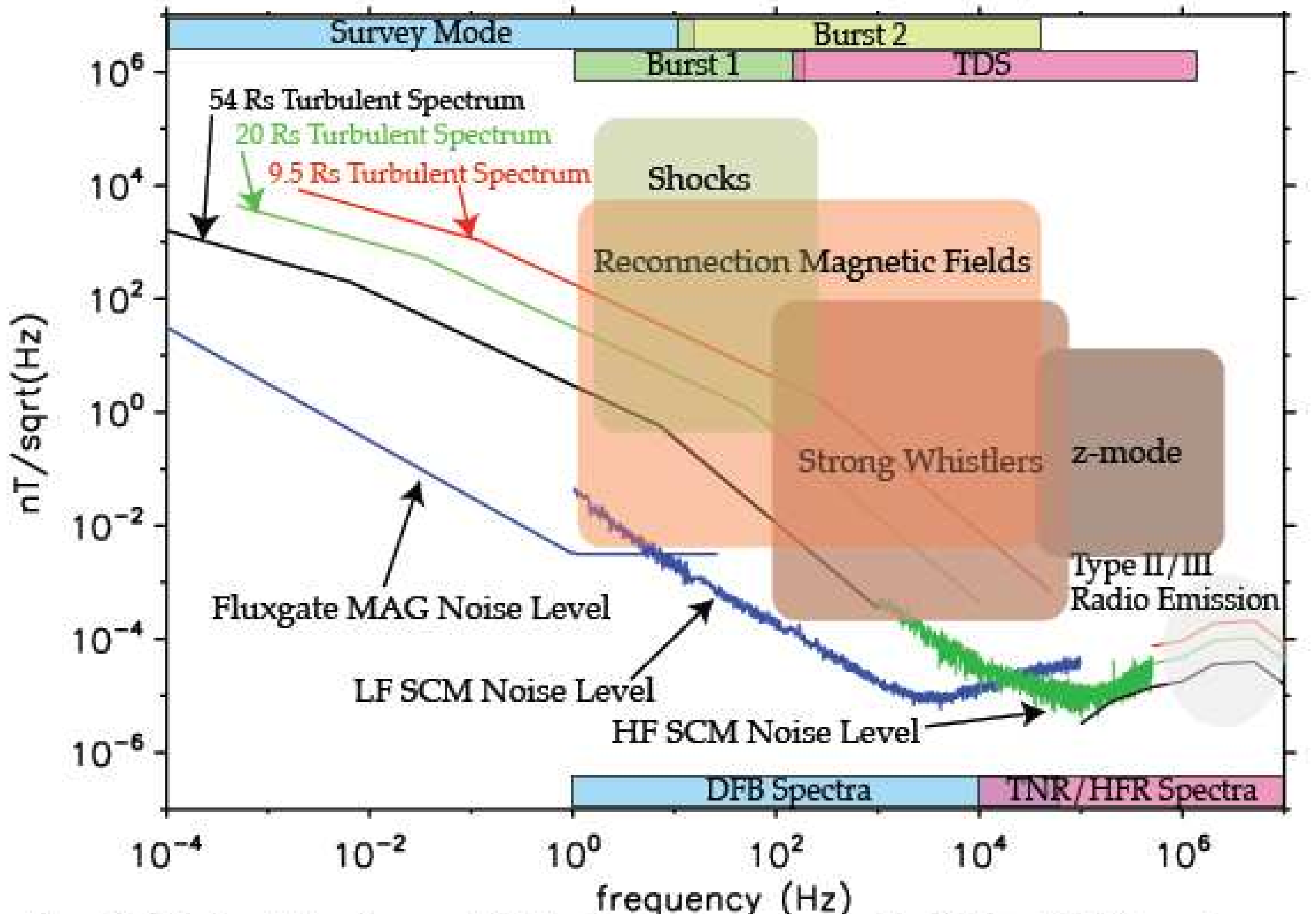
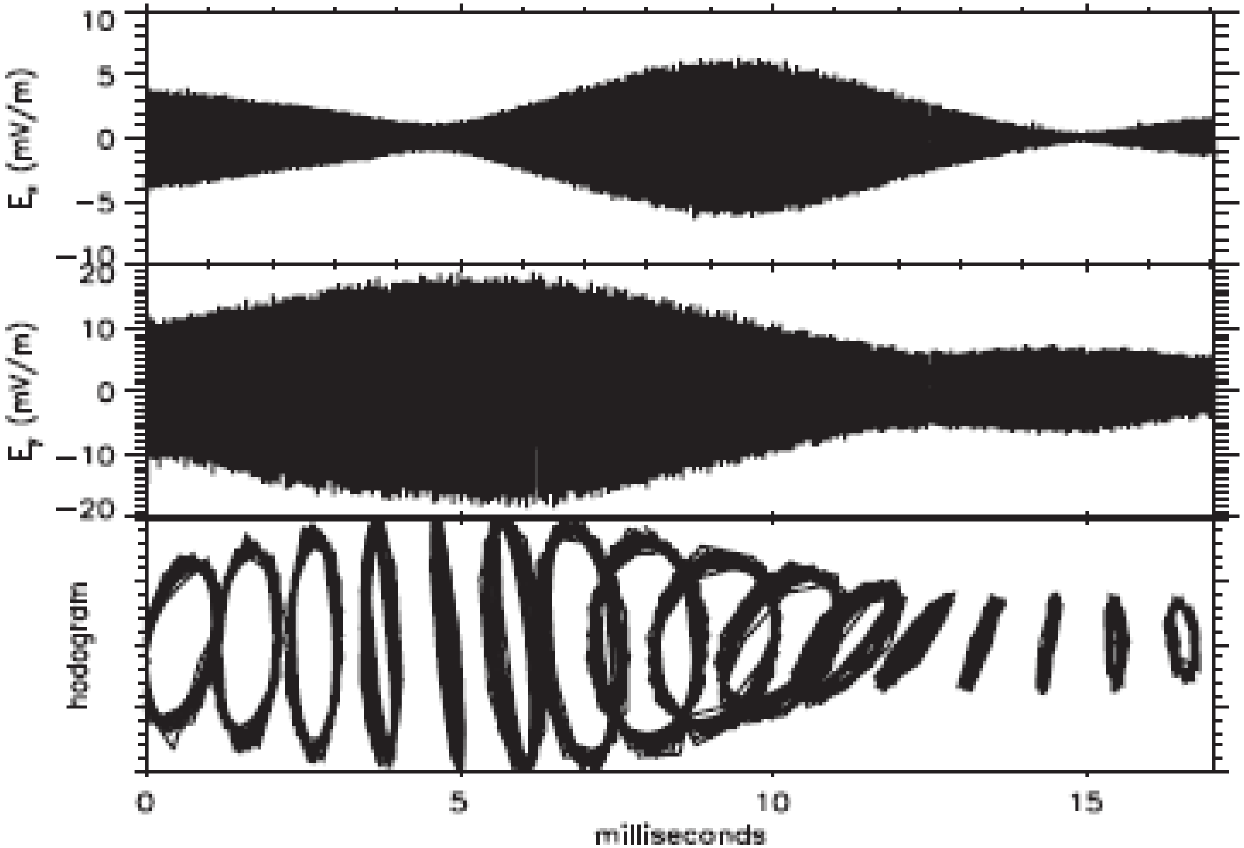


Figure D.2-6. Sensitivity of magnetic field and waves measurements. The SCM and MAG together cover the full range of required measurements. SCM becomes more sensitive than MAG at ~10 Hz. The HF SCM measures z-mode, very intense radio bursts, and very fast solitary waves.

Why to mesure magnetic fluctuations?
« Wind » data



Electric field waveform events at 1 AU

Wind + observations radio sol
IZMIRAN radio telescope

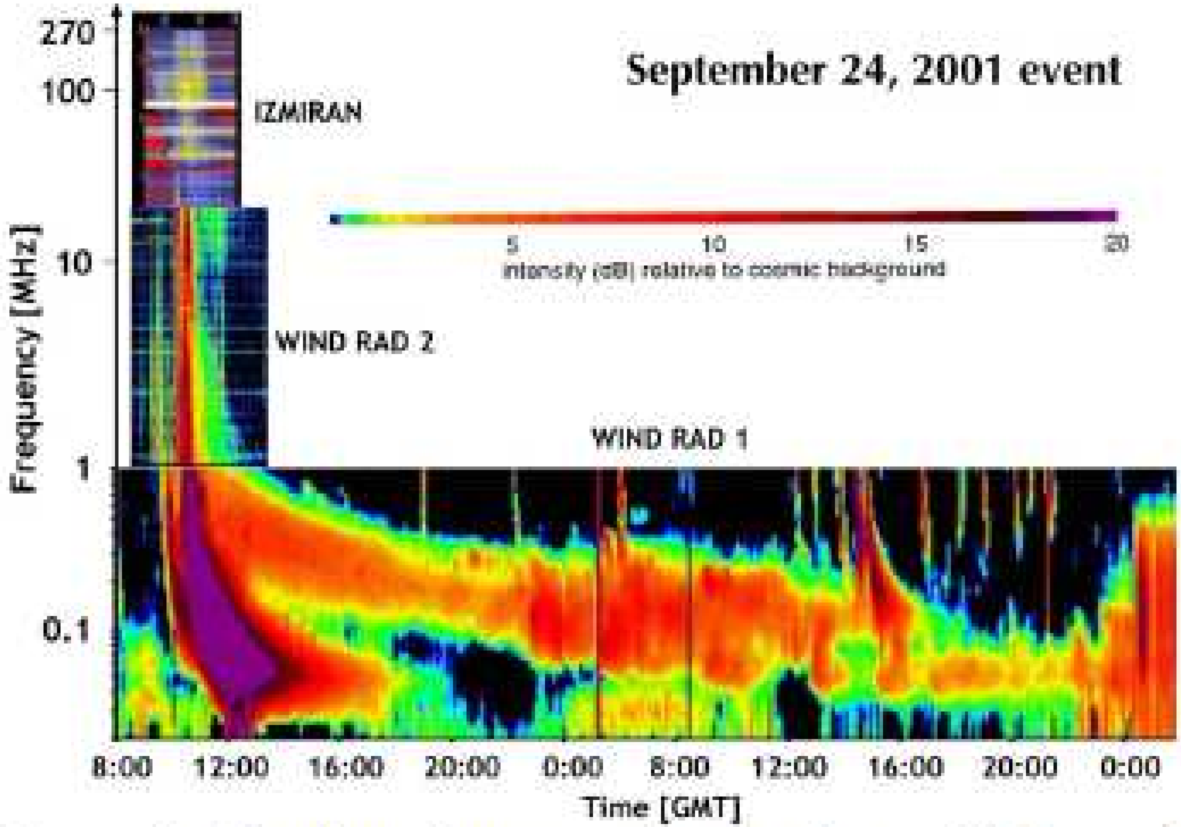


Figure 1. Combined measurements of type III / type II bursts observed onboard Wind satellite (RAD 1 and RAD 2 instruments) and by IZMIRAN radio-telescope

Search Coil Magnetometer

- **Overall Description: To achieve the scientific objectives of Solar Orbiter, the three components of the fluctuating magnetic field need to be measured within the ELF/VLF frequency range, and only one component within the VLF/LF frequency range.**
- **Hardware Description: The measurements can be performed with the required sensitivity using a 3-axial bi-band search coil magnetometer (3 magnetic antennas arranged in a compact configuration) mounted on a short boom. The tri-axial search coil we propose for Solar Orbiter will be derived from the DEMETER and Bepi Colombo search coils (see figure 1) but it will be based on a smaller sensor (L=104mm and Ø=20mm) associated with a highly miniaturized preamplifier. The total mass of the bi-band ELF/VLF-VLF/LF tri-axial search coil including the preamplifier is estimated to be 330g+100g=430g.**

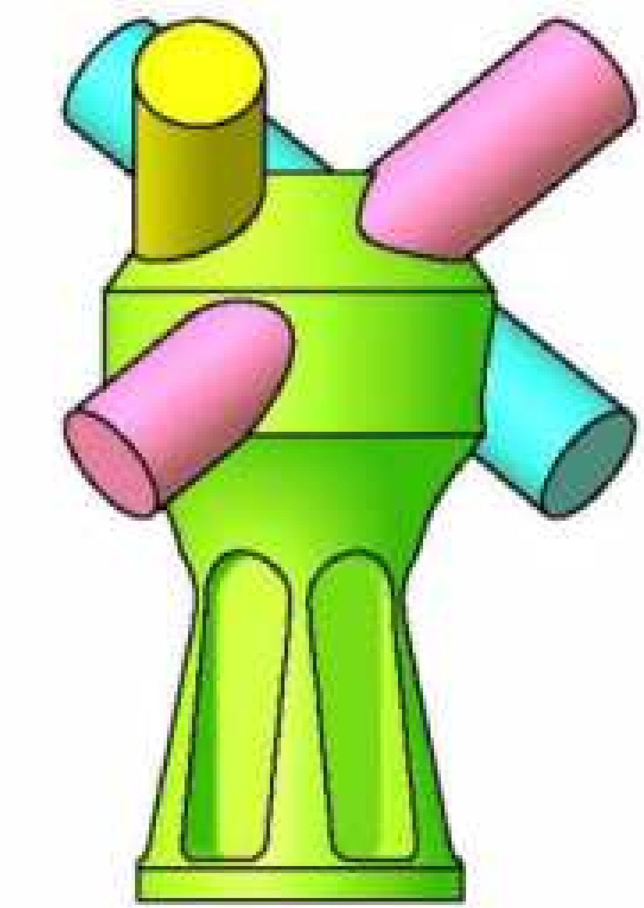
Search Coil Magnetometer

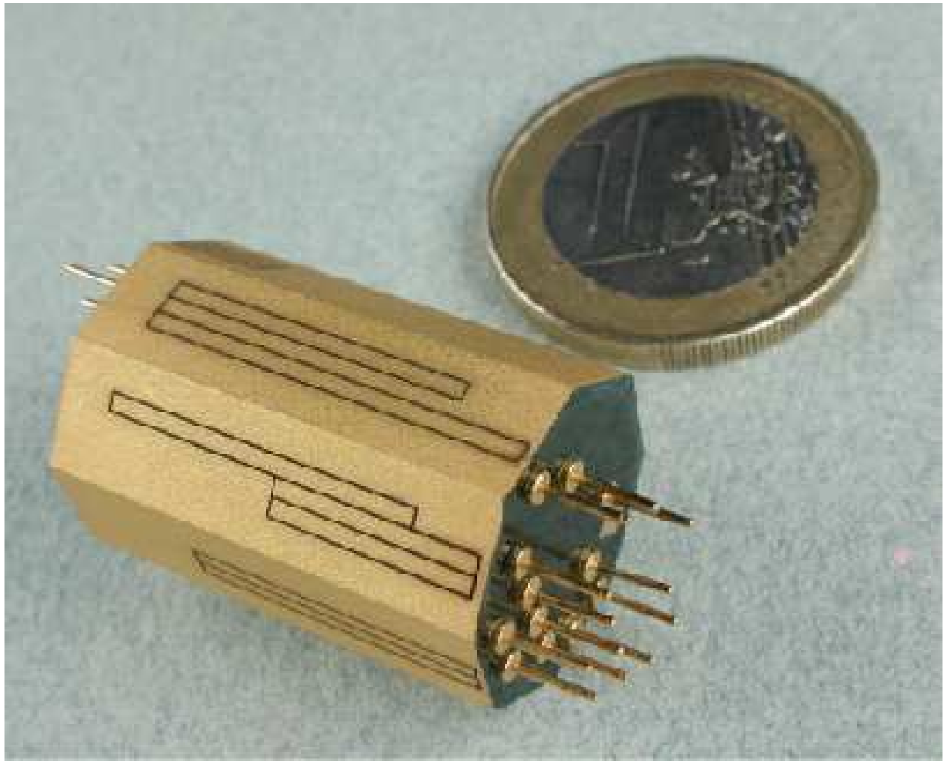
- **For Solar Orbiter mission, the magnetometer is carried out with bi-band antennas, each antenna is composed of 2 couples of coils (primary and secondary coil previously described). One couple is for ELF/VLF frequency range (1Hz to 10kHz) and the other one is for VLF/VF frequency range (10kHz to 400kHz).**

- **An electrostatic screen (comb shaped flexible printed circuit) connected to the signal ground maintains a uniform potential around the windings. The rod, the windings, the electrostatic screen, and the output cable are potted inside an epoxy tube (104 mm long, external diameter 20 mm).**

- **The antennas are assembled orthogonally in the most compact way as possible by the body of the sensor. This mechanical support is made in a nonmagnetic material (PEEK KETRON) and stands for the interface with the satellite**

Search Coil Magnetometer





SCM sensor and its miniaturized preamplifier

ELF/VLF-VLF/LF 3-axial bi-band search coil

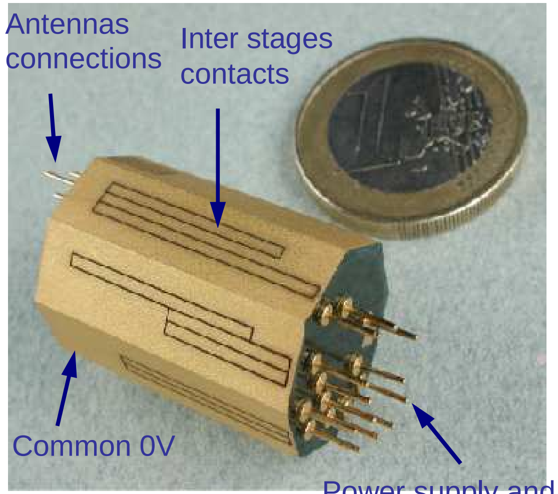
- Bandwidth ELF/VLF1 Hz – 10 kHz
- Sensitivity 2.10^{-3} nT/(Hz)^{½} at 10Hz
- 5.10^{-5} nT/(Hz)½ at 2kHz
- Bandwidth VLF/LF 10 kHz – 400 kHz
- Sensitivity 10^{-5} nT/(Hz)^{½} at 20kHz
- 9.10^{-6} – 10^{-5} nT/(Hz)^{½} at 100kHz
- Dimensions antenna: L=100mm; Ø=20 mm
- Volume of the whole sensor :
- cylinder Ø=120mm; height=150mm
- Mass bi-band antennas: 3×55g
- boom interface: 150g; connector: 15g
- Total: 330 g + 100 g preamplifier = 430 g

Preamplifier design

- 3 LF and 1 MF amplification channels
- Preamplifier build in 3D technology integrated in the sensor's foot (nominal solution)
- Possibility to integrate it in a separate box on the satellite plateform (backup) in case of too important thermal stresses
- Power consumption :

Voltage	Current	Power
+12 V	11.4 mA	137 mW
-12 V	11.1 mA	133 mW
TOTAL		**270 mW**

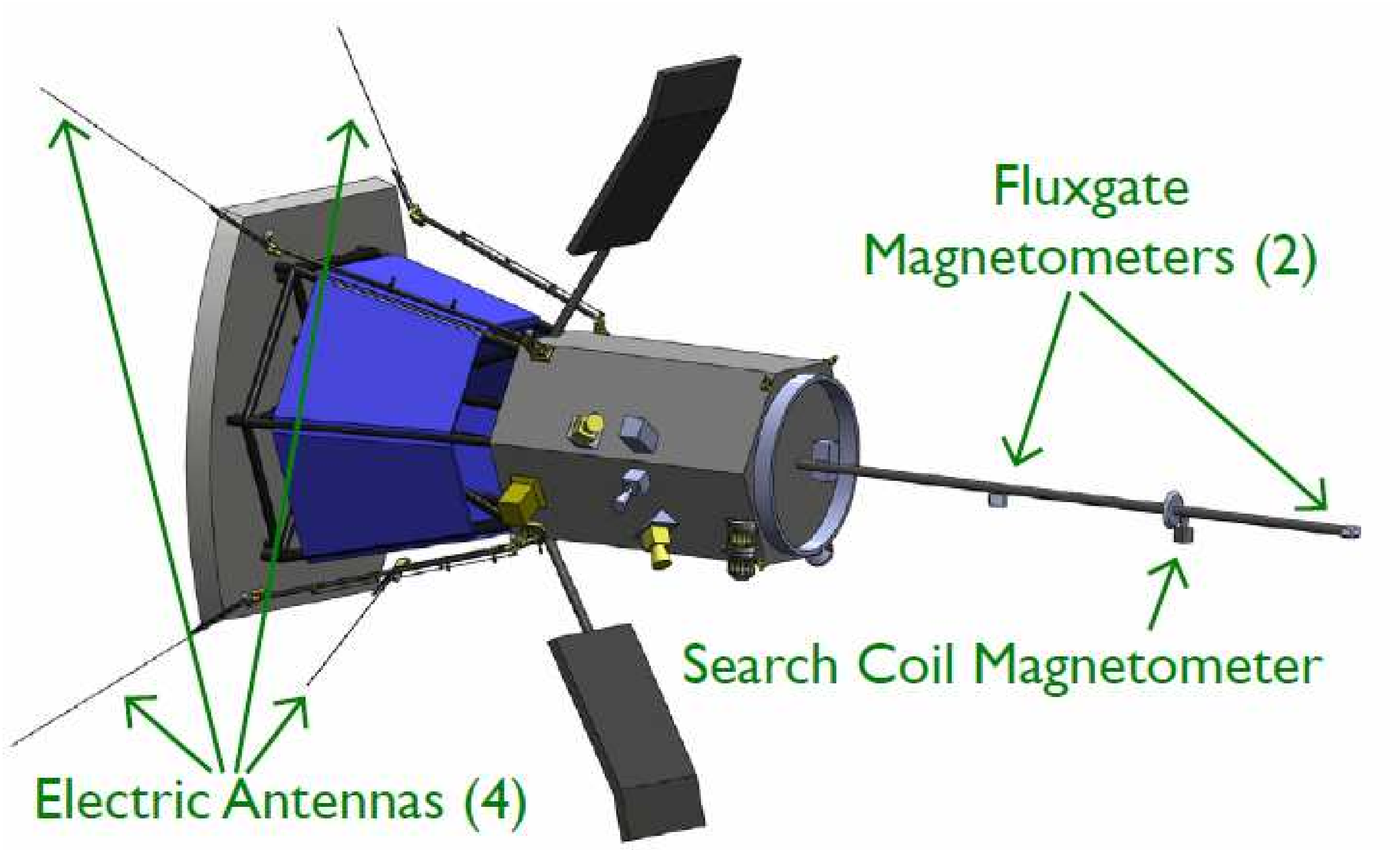
- Adjustable radiations protection with tantalum layers or cylinder



Search Coil Magnetometer: Accomodation

- **Accommodation:** **To minimize noise interference from the spacecraft and other instrument subsystems, the SCM needs to be mounted on a boom extended away from the Solar Orbiter spacecraft and in the shade. The SCM should be mounted at least 1m from any other sensors that include active electronics or magnetic materials.**
- **Heritage:** **The SCM sensor is based on designs for the DEMETER and BepiColombo sensors and similar to designs flown on Cluster and several sounding rocket missions**

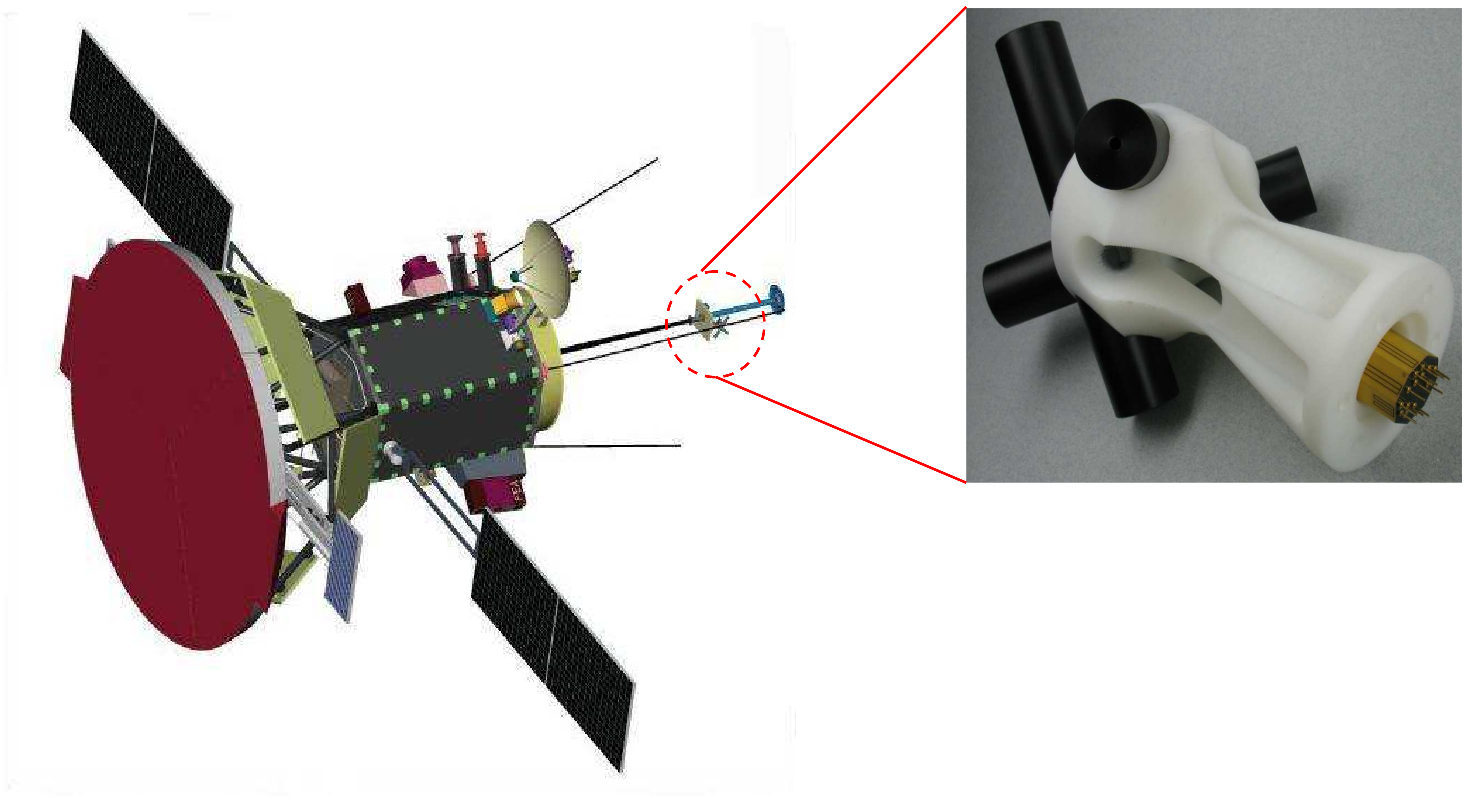
Satellite configuration Solar Probe +



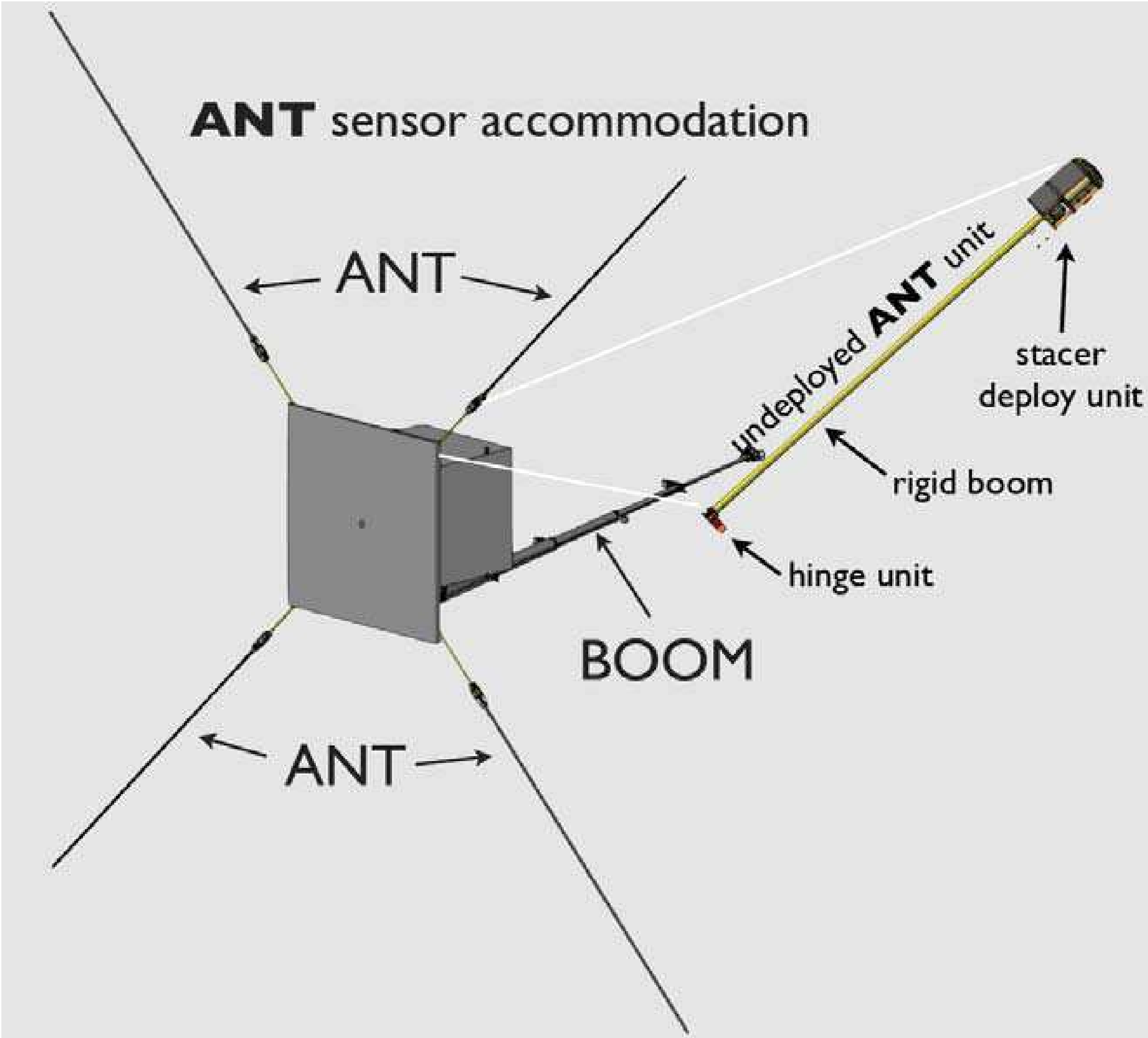
Consortium FIELDS

➢ FIELDS est un consortium d’instruments « ondes » dirigé par l’université de Berkeley

➢ La contribution instrumentale du LPC2E est la fourniture d’un magnétomètre alternatif de type Search Coil triaxial similaire à celui qui sera développé pour la mission Solar Orbiter



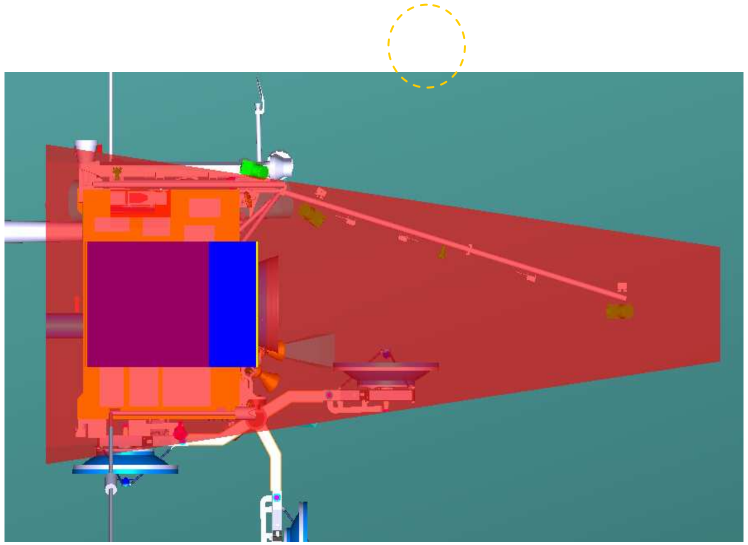
Search coil accomodation on the boom onboard « Solar Orbiter »



Thermal design : de-pointing phases

- De-pointing phase at 0.8AU in all directions for indefinite duration
  - Require external protection to withstand direct sun exposure at 0.8AU (high temperature resistive material)

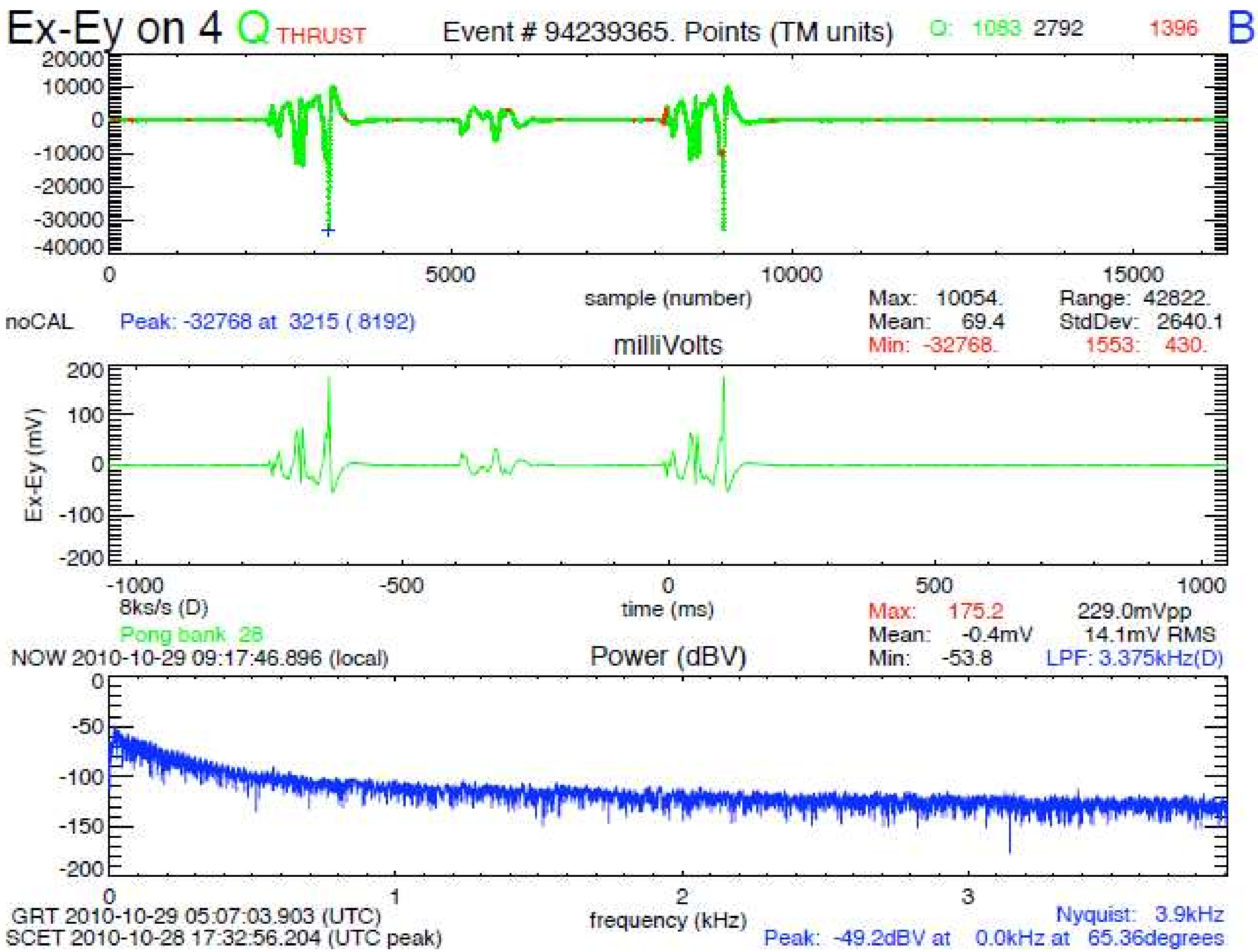
- 15° de-pointing at perihelion (0.28AU) : SCM remains in the shadow cone



Problems for measurements

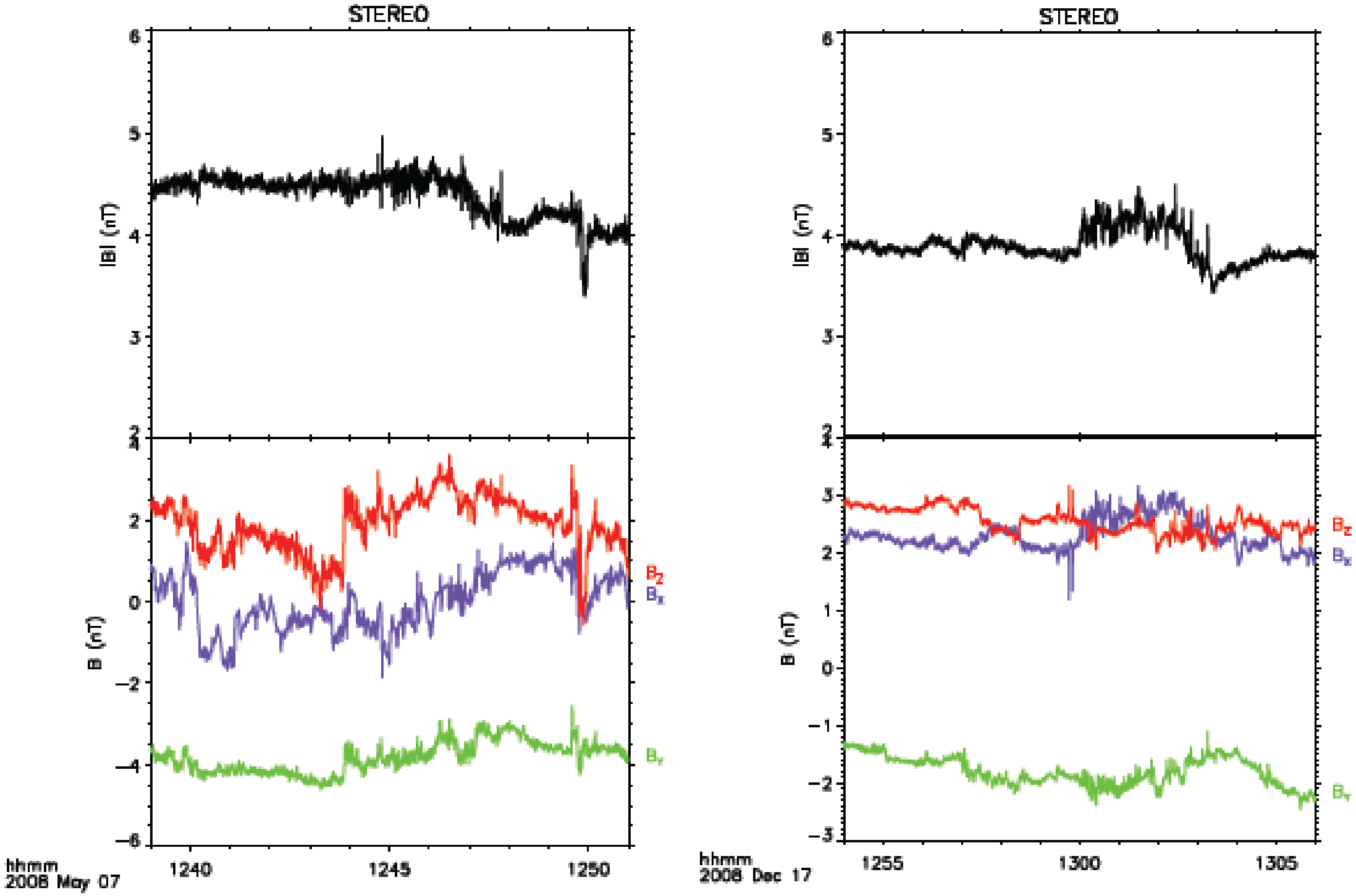
- Satellite EMC: distance from the satellite 2m (SO) and 3m (SPP)
- Shielding degasing
- Thruster operations
- Accomodation with other instruments on the same boom
- Satellite charging and wake: what is known and recent modelling results

Thruster operations (Stereo)



Thruster operations

STEREO fluxgate magnetometer



FIELDS concerns about thrusters

On STEREO, thrusters corrupt S/WAVES electric field measurements

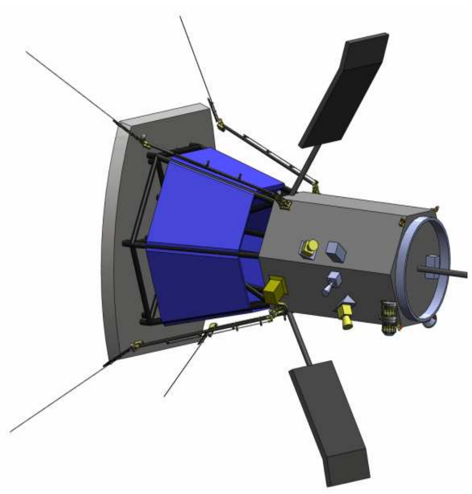
On STEREO, thrusters corrupt fluxgate magnetic field measurements

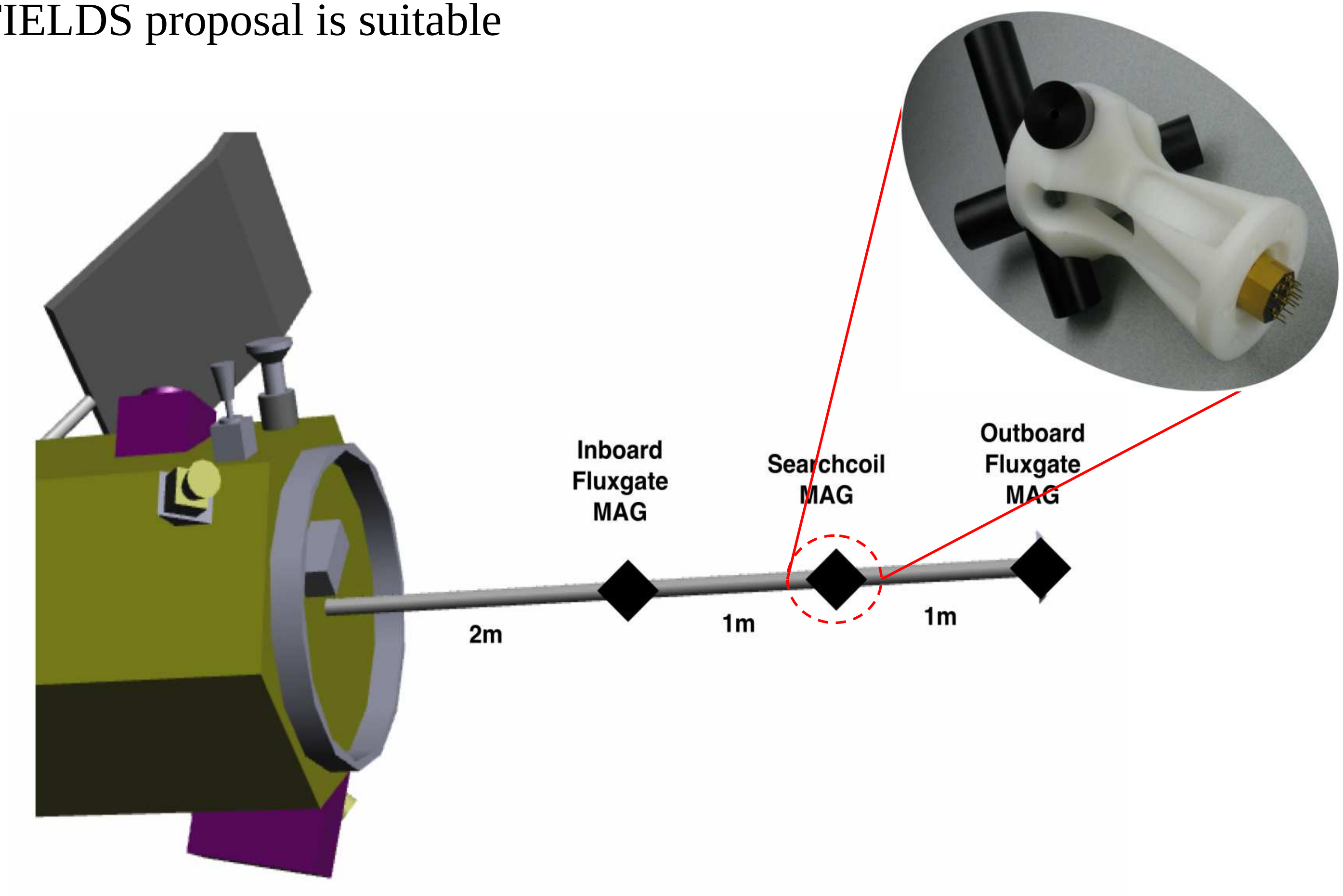
On STEREO, thrusters corrupt thermal electron measurements

On Polar, thrusters corrupt DC electric field measurements

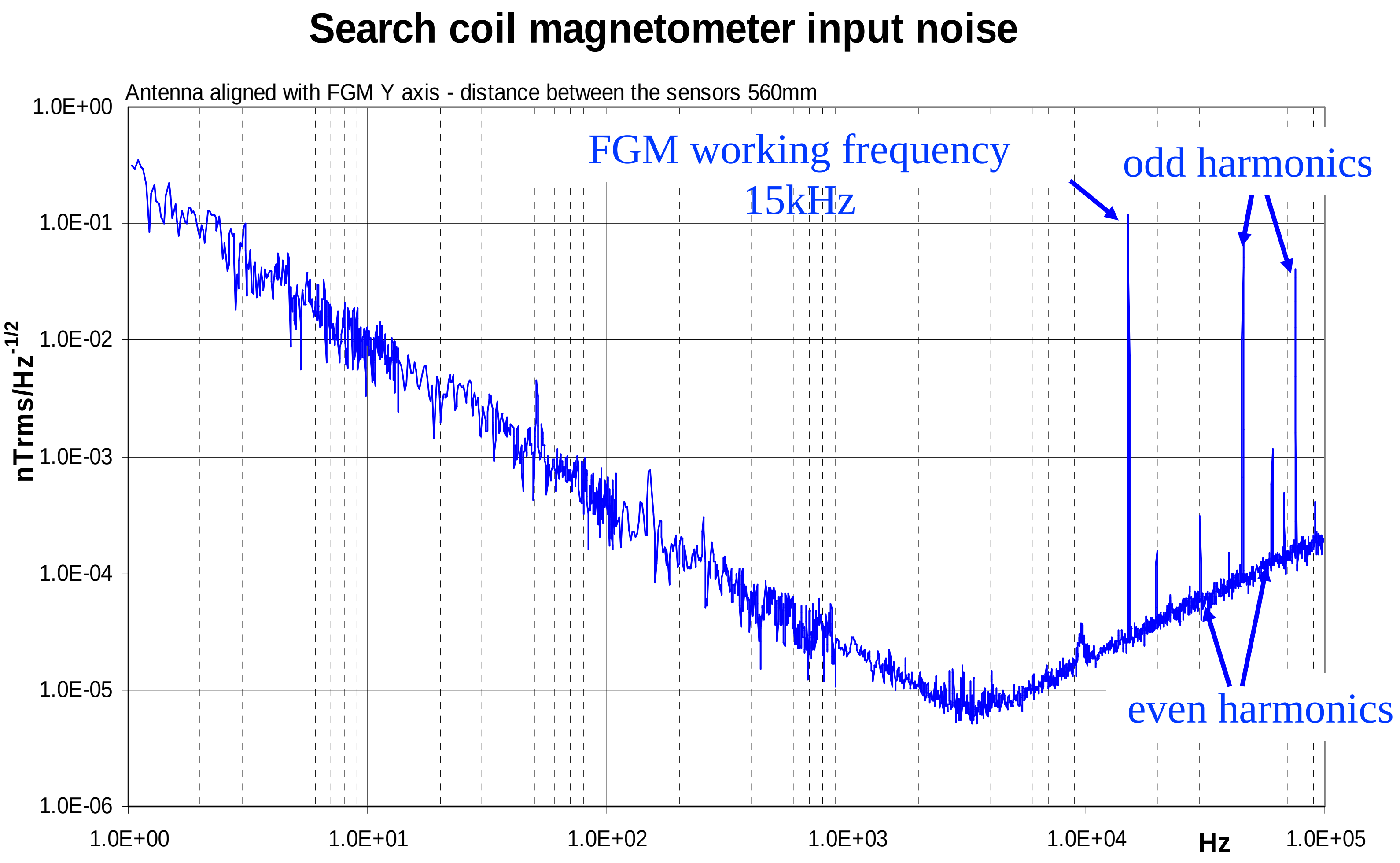
Accommodation

- ➢ Feedback experience of previous missions or interference measurements
    - SCM at 2m from the spacecraft
    - SCM at 1m from other boom borne instrument (MAG)
- ➢ Accommodation in FIELDS proposal is suitable



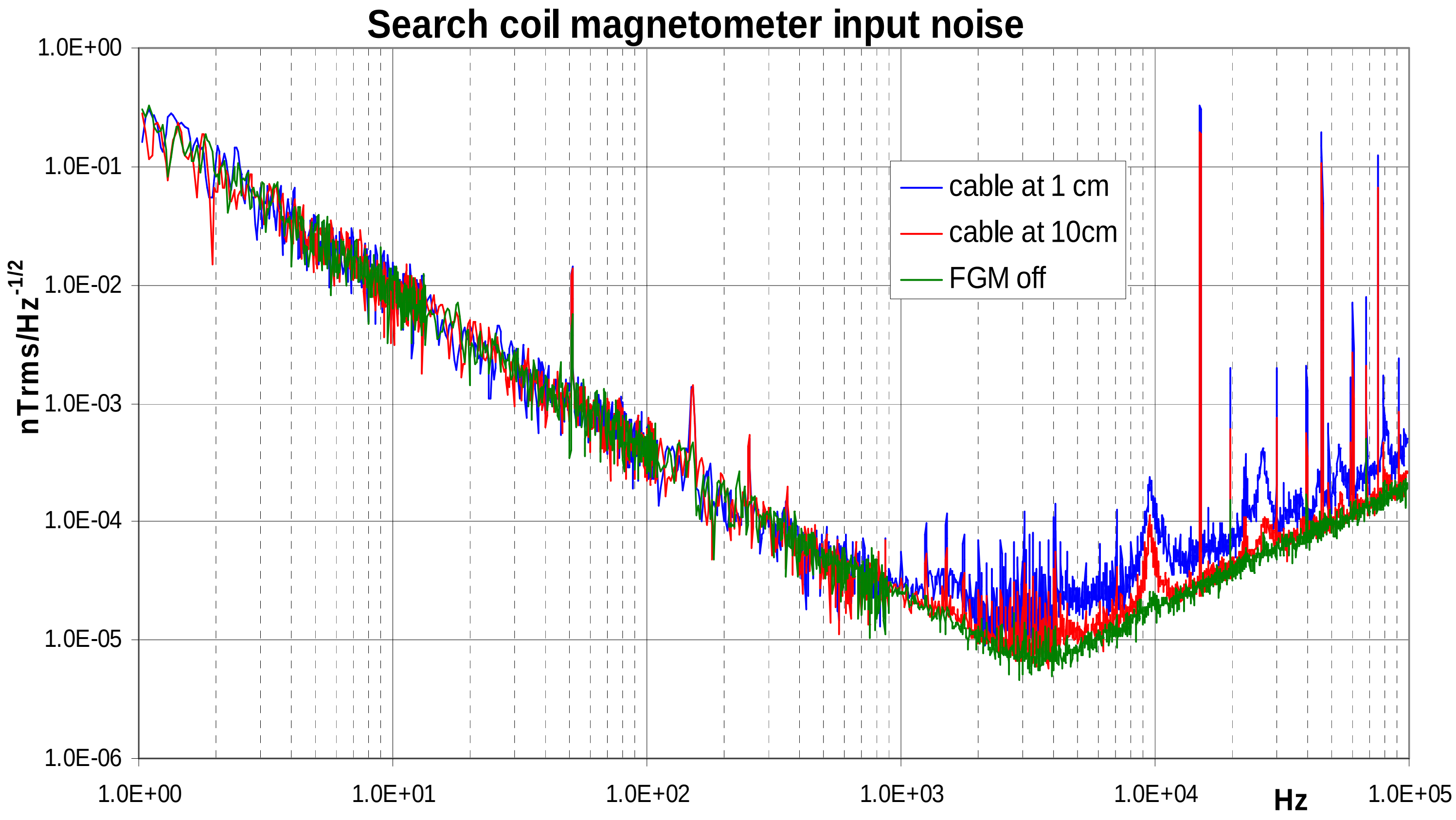


Effects of FGM working frequency



Effects of FGM cable on SCM: problem of heaters

- At 10cm the effect of the cable is only visible in the most sensitive frequency range of the sensor but not enough to be visible after the digitizing.



Charging problem: wake effects

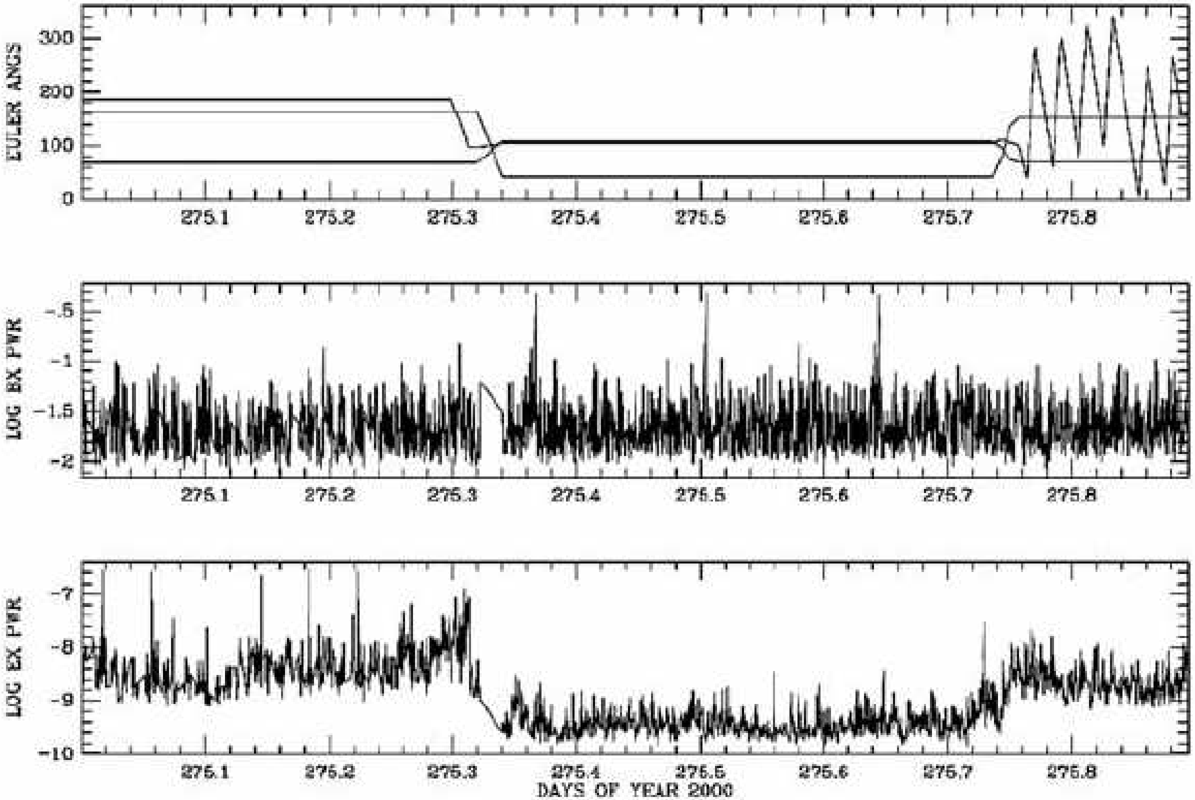


Figure 2. RPWS observations on 1 October 2000 showing electric and magnetic fields and how they change as the orientation of Cassini is changed. The upper panel shows the Euler angles of the attitude without designation to show when the attitude changed. N and E refer to a view from the north ecliptic pole and from the ecliptic east, and 1 and 2 refer to the different periods of Figure 2. See text.

The effect of the probe position

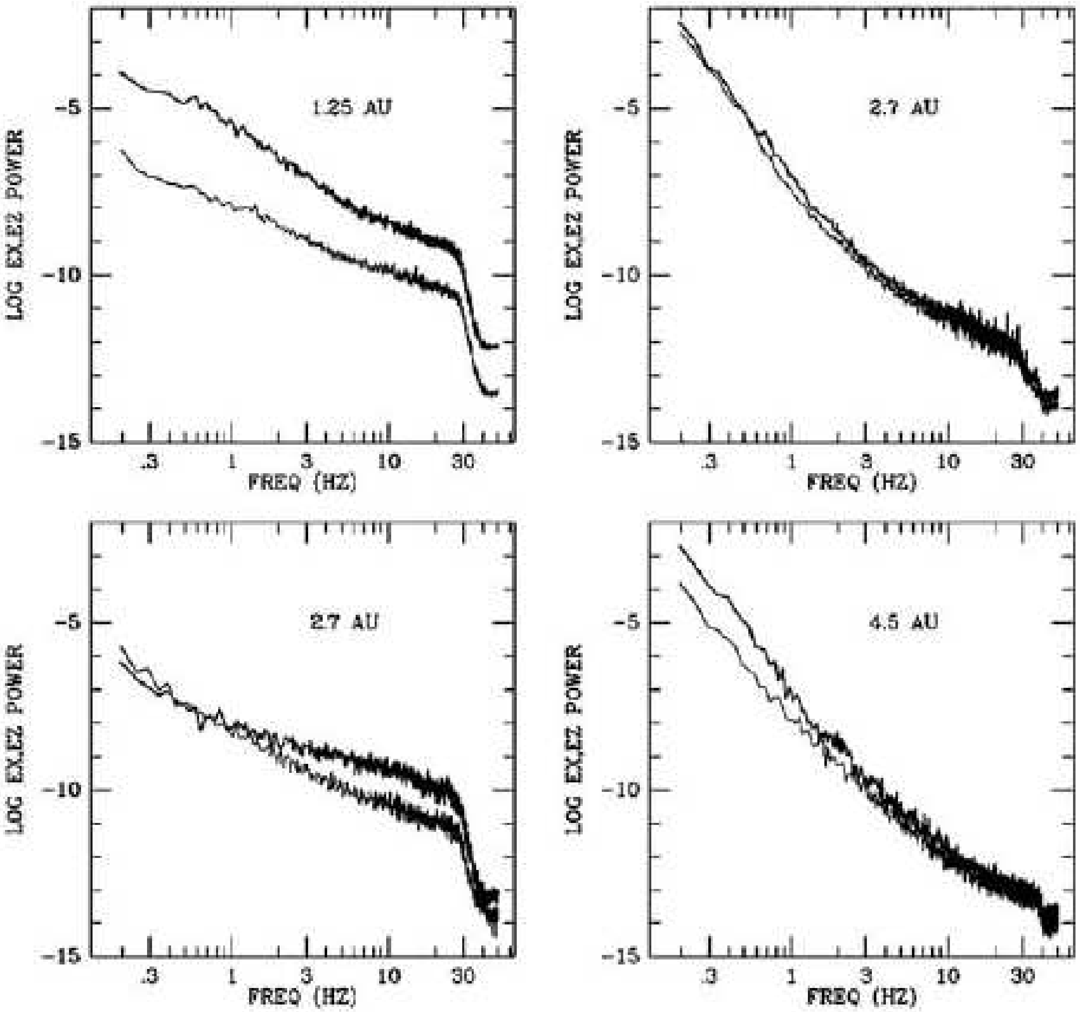


Figure 3. Averaged signal power on the Ex dipole (light line) and on the Ew monopole (dark line) for several distances from the Sun.

Photoionisation influence on wave measurements (Lin et al., 2003)

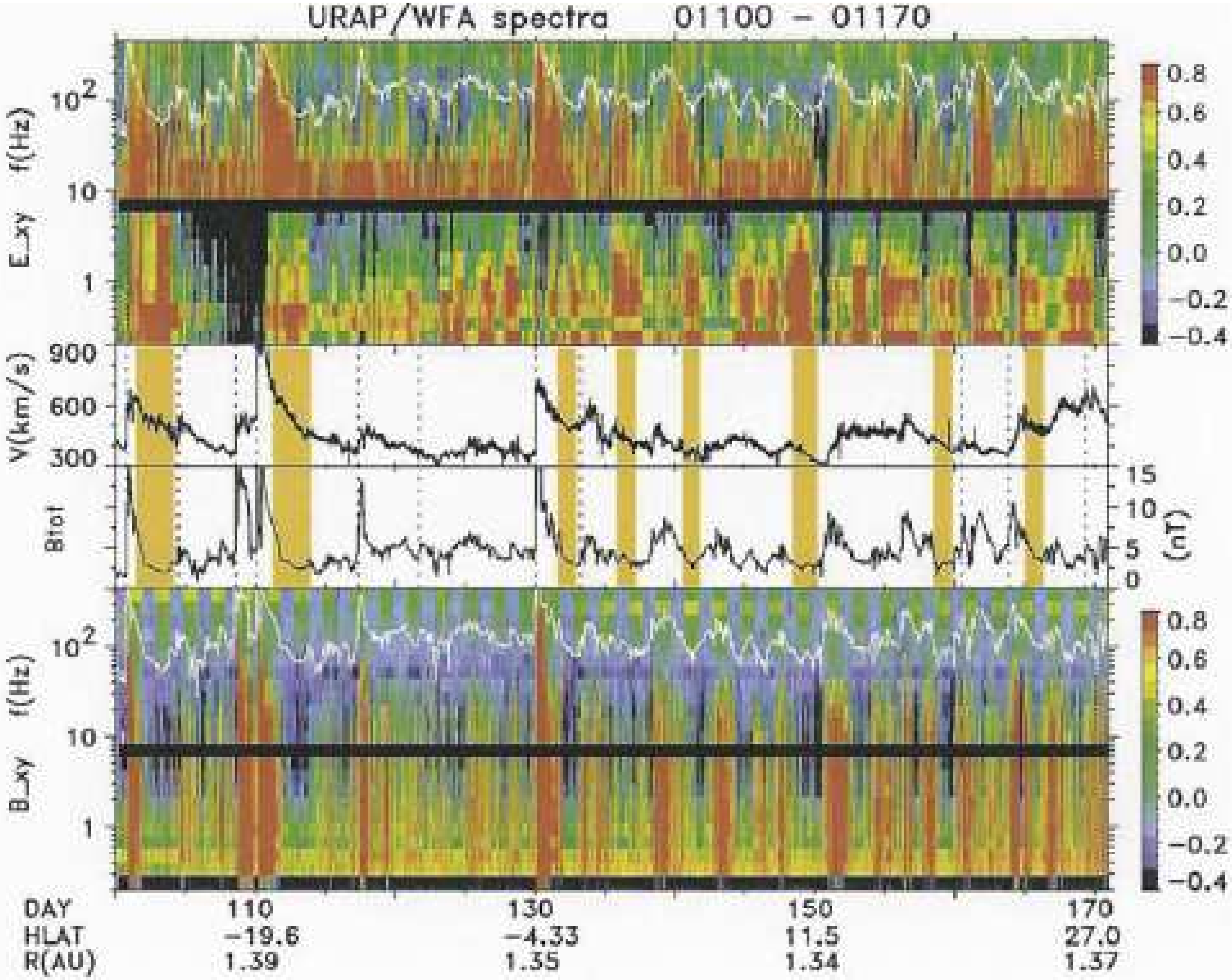


Figure 1. From top to bottom: Spectra of 15-min averaged relative intensity of spin plane electric wave power for the period from day 100 to day 170 of 2001 (the local f_{ce} is overplotted as a white line); the solar wind velocity in km/s; the electron density; and the magnetic wave power in the same format as that of the electric field spectra. The vertical dotted lines mark IP shock crossings. The vertical yellow stripes in the two middle panels indicate periods of low-density level. The horizontal black bars in the middle of E and B spectra mark the frequency gaps between the low band and high band

Photoionisation effect on wave activity (Lin et al., 2003)

LIN ET AL.: VLF WAVES IN THE SOLAR WIND ULY 3 - 3

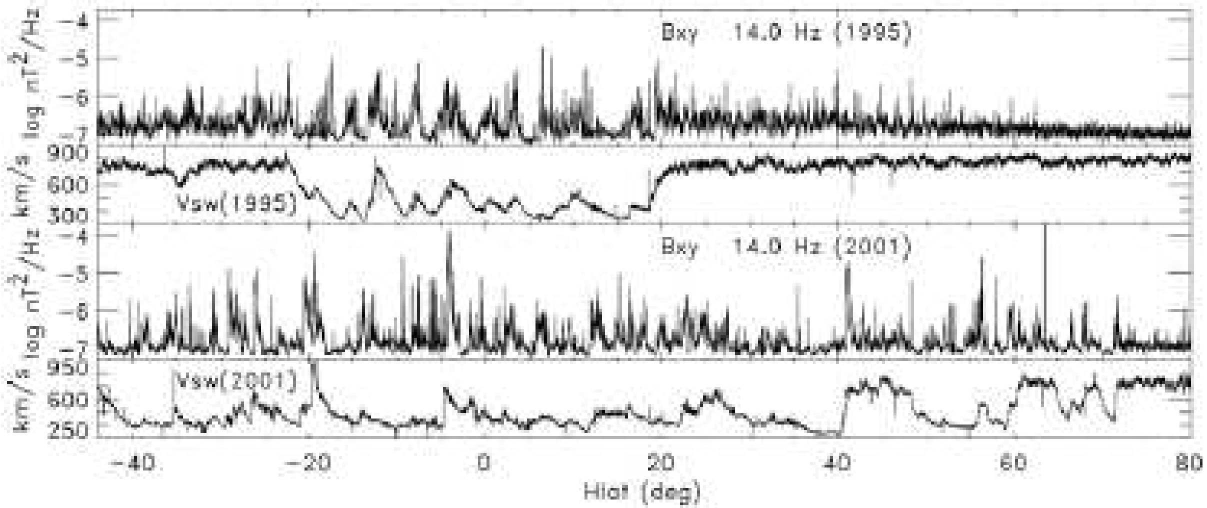


Figure 2. The 30-min-averaged power density of spin plane magnetic field waves (in the log scale) at 14.0 Hz and the solar wind velocity plotted vs. heliographic latitude. The first two panels are for days 1–207 of 1995 when Ulysses traveled from −44° to +80° heliographic latitude. The lower two panels are for days 73–279 of 2001 for the same latitude range.

Photoionisation influence on waves

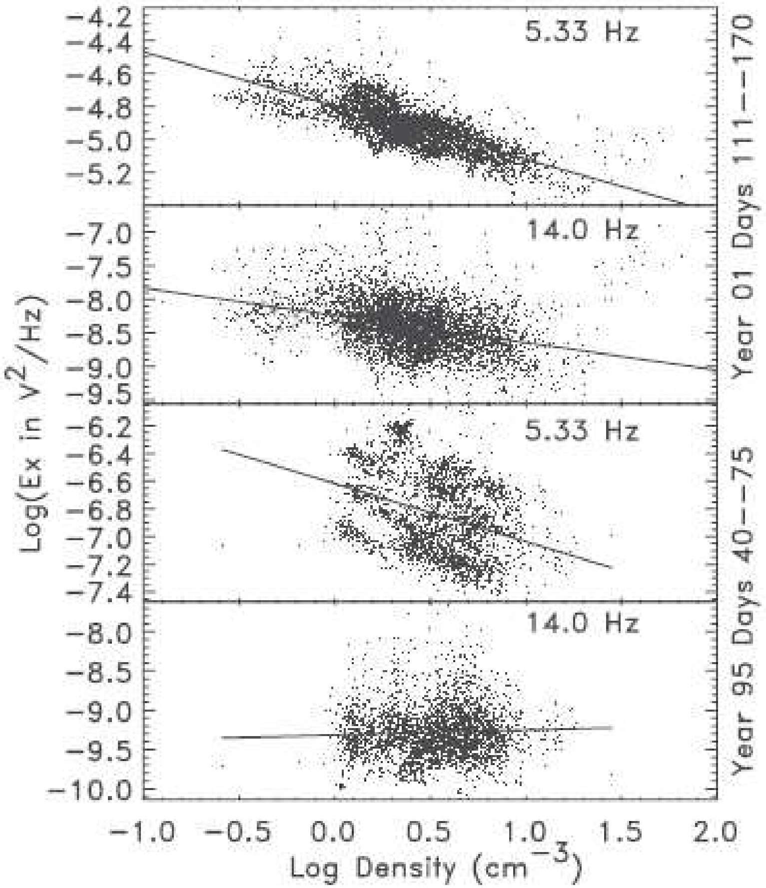


Figure 3. The 15-min-averaged power density of spin plane electric field waves (in the log scale) detected in two channels with central frequencies of 5.33 Hz and 14.0 Hz for periods marked on the left hand side, plotted vs. electron density (in the log scale).

Helios related studies (Isensee et al., 1975, 1977, 1981)

- Energy flow of ions (1keV) is weakly perturbed
- Photoionisation: electron production rate dependent upon potential, born electrons have an energy 1 eV
- Electrons are described by the method similar to PIC
- Poisson equation is solved and replaced by some procedure relating currents with the potential of the body
- Satellite body is conductive

Helios related studies

Minimum in front of satellite due to photoionisation U = -1.4 V,

wake U = -4.5 V

satellite body U = 2.9 V

584

U. Isensee

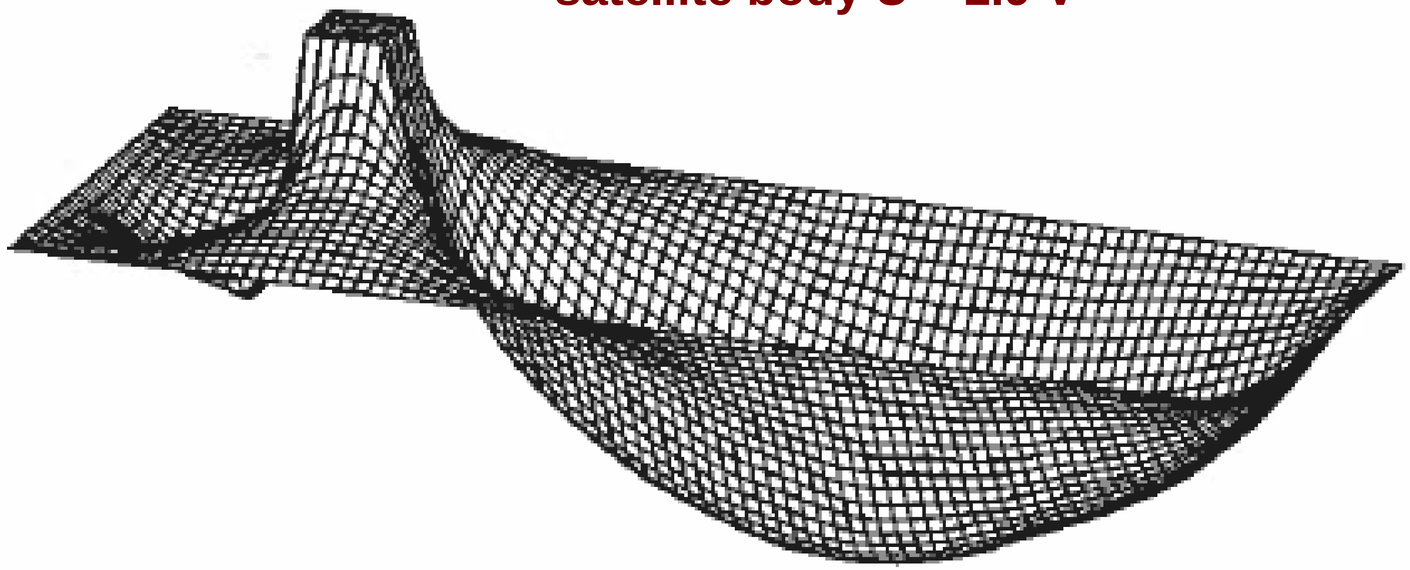


Fig. 1. The potential $\phi(x)$ for solar wind conditions at 0.2 AU distance from the sun. The solar wind flows from the left to the right. The spacecraft is represented by the square with a surface potential of 2.9 V. The minimum in front of the probe (−1.4 V) is due to the photo electron cloud. The minimum in the wake has a depth of −4.5 V

Isensee and Maassberg, 1981

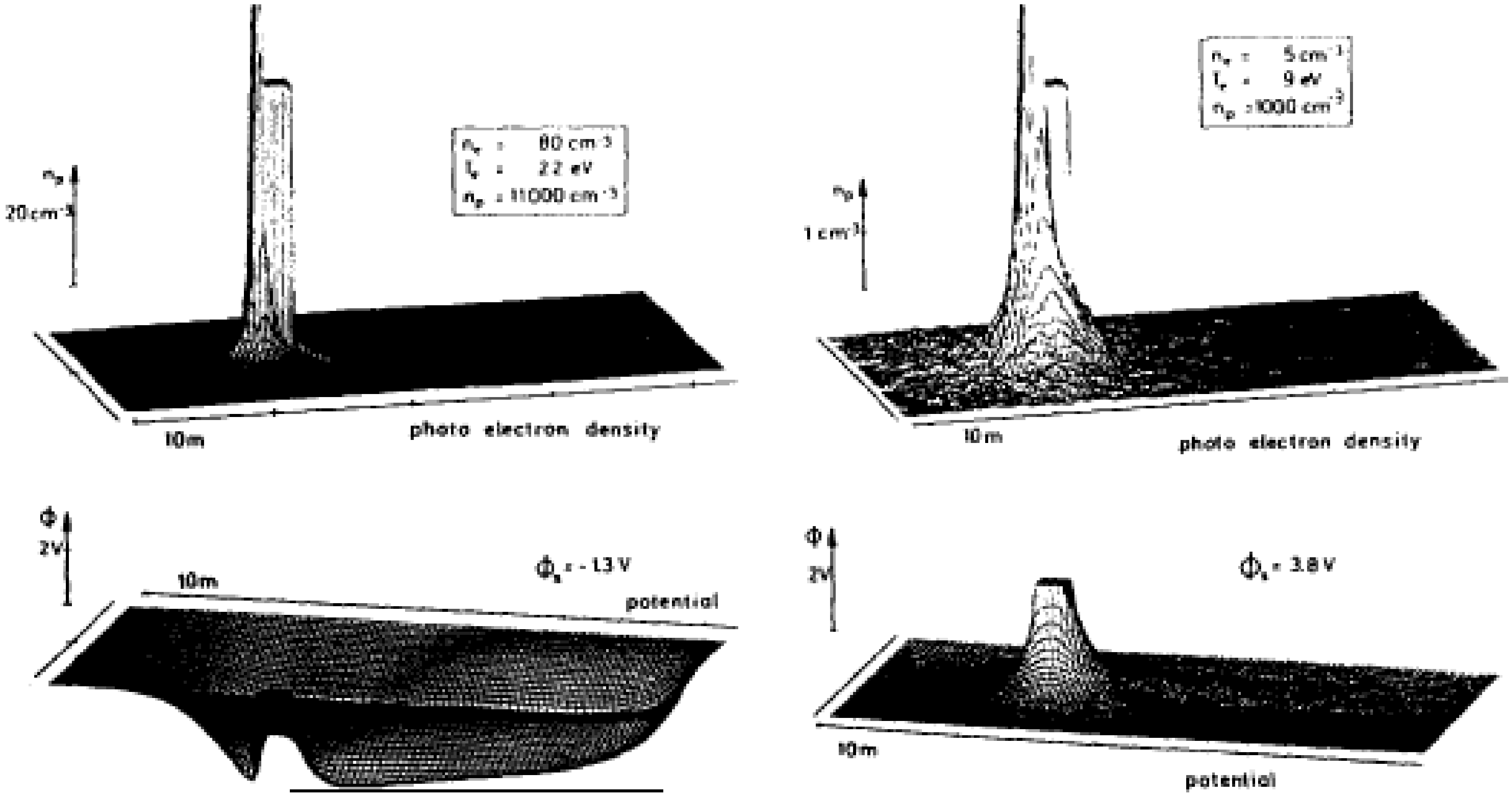


Fig. 1 (0.3 AU) Fig. 2 (1.0 AU)

Results from the numerical simulation. The probe with potential ϕ_S is shown by the squares in the middle of the perspective representations. The solar wind is streaming from the left.

Characteristic parameters of simulations

- **Undisturbed electron and ion plasma density**
- **at 0.2 AU 175 cm^{-3} at 0.3 AU 80 cm^{-3}**
- **Background electron temperature**
- **at 0.2 AU $3*10^5$ at 0.3 AU $2.5*10^5$**
- **Background ion temperature**
- **at 0.2 AU $3*10^5$ at 0.3 AU $2.0*10^5$**
- **Density of photoelectrons**
- **at 0.2 AU $2.5*10^4$ cm^{-3} at 0.3 AU 10^4**
- **Solar wind velocity 4 – 8 * 10^5 m/sec**
- **Energy of photoionized electrons 1eV**

- **Debye length comparable with the size of the satellite**
- **Important ratio $N_{ph} / N_b \sim 100$**

Supposed parameters

Source	Parameter	Units	1 AU	0.25 AU	35 R_S	20 R_S	9.5 R_S
Helios (MM)	electron density	cm^{-3}	6.93	116.1	281.3	880.8	4022.0
Helios (Freeman)	electron temperature	eV	8.0	30.72	39.9	55.82	87.25
Helios (MM)	ion temperature	eV	8.14	22.95	31.8	48.33	84.47
Helios (CS)	magnetic field intensity	nT	5.80	67.0	156.8	475.9	2102.0
Helios (SDB)	convection electric field	mV/m	1.32	5.88	9.38	17.2	38.38
Helios (SDB)	solar wind speed	km/sec	363.0	307.5	291.9	273.0	249.65
	Debye length	m	8.02	3.29	2.49	1.73	1.07
	electron skin depth	m	2015	492.3	316.3	178.8	83.65
	ion skin depth	km	86.65	21.17	13.6	7.69	3.60
	electron gyroradius	m	1660	241.2	121.3	49.3	14.75
	ion gyroradius	km	70.25	11.9	5.80	2.26	0.64

Recent simulations (Lipatov et al., 2011

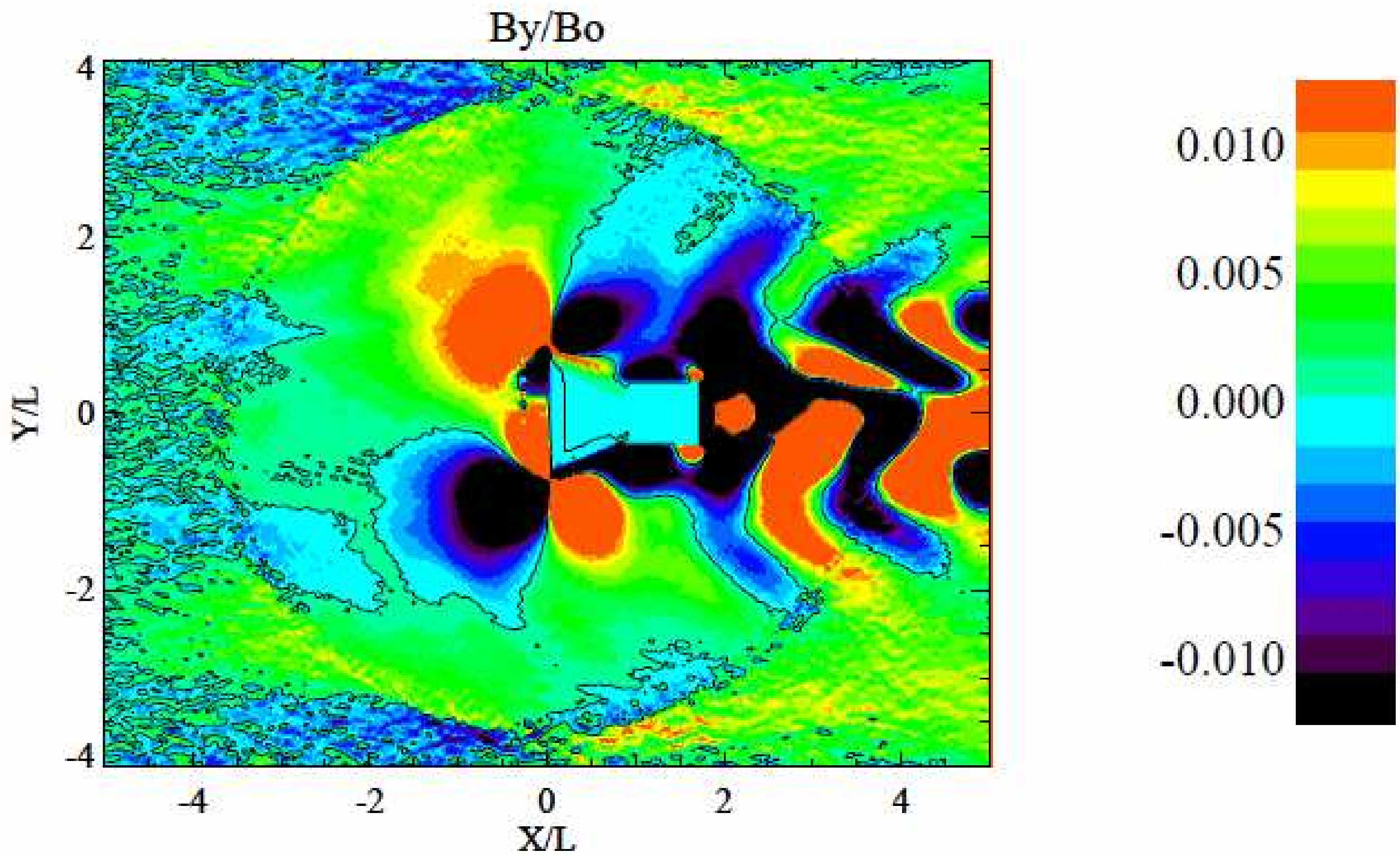
- (a) Standard hybrid simulation (ion in kinetic approximation, electron in fluid approach) on the large scale;
-
- (b) Fully kinetic implicit simulation with kinetic model for electrons and ions incorporated in the large scale hybrid model.

- The last simulation will take into account charge separation near the surface of the spacecraft and finite electron gyroradius
- effects. We will take into account the realistic distribution of the spacecraft surface’s conductivity.

- Our simulation will serve as an expert system for design of the ”Solar Probe+” spacecraft. The present model of the interaction of the solar wind with the SP+ does not take into account several effects in plasma environment near thespacecraft.

- Future simulation will take into account the charging of the spacecraft, charge separation effects, outgassing from heat shield, photoionization and electron impact ionization effects near the spacecraft.

Recent NASA simulations (Lipatov et al., 2011)



Recent simulations

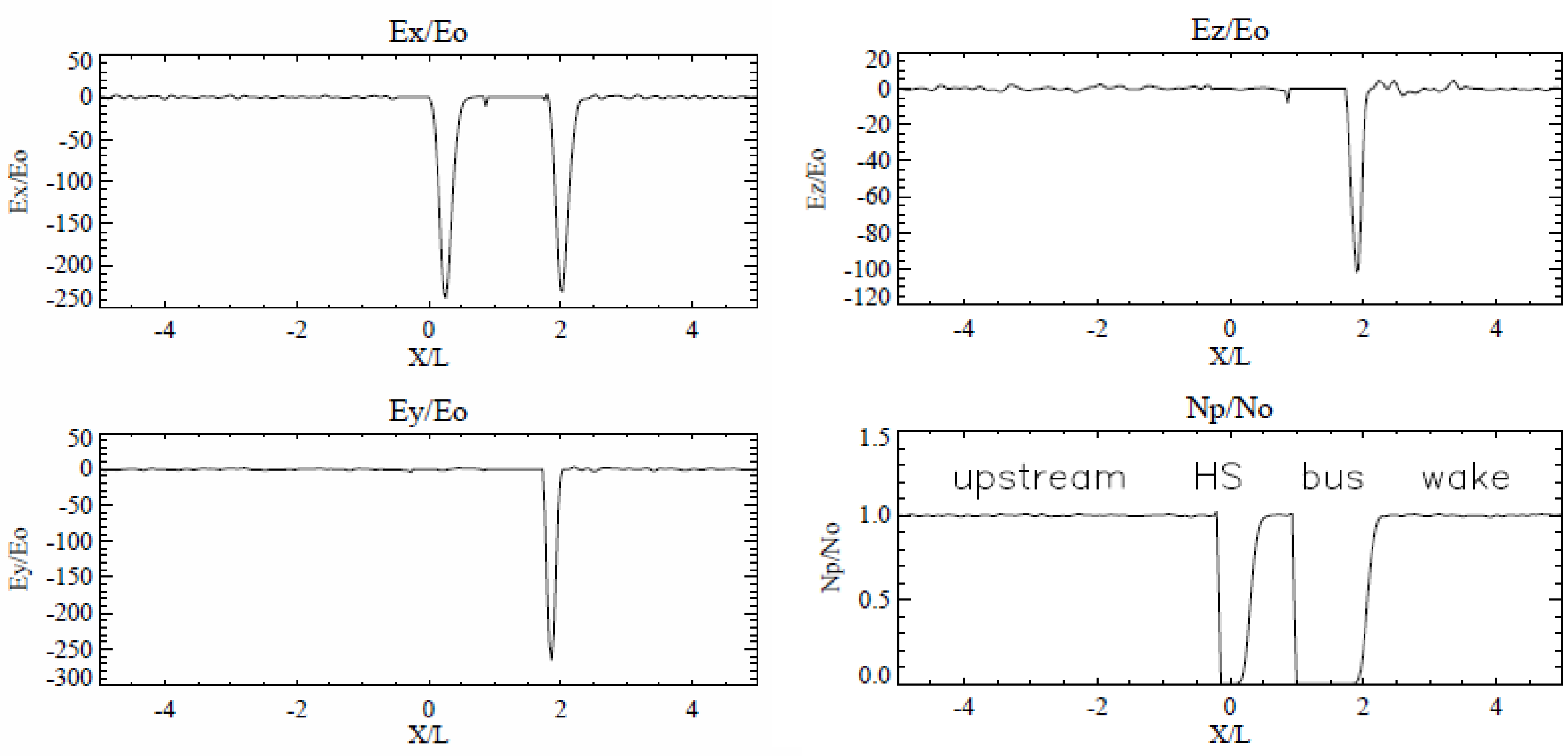


Figure 36. 1-D cuts for the electric field component $E_x(E_0)$, $E_y(E_0)$ and $E_z(E_0)$ ($y = 0$, $z = 0$). $U_0 = 200\,\mathrm{km/s}$, $M_A = 1.5$, $B_0 = 1500\,\mathrm{nT}$, $n = 5 \times 10^3\,\mathrm{cm}^{-3}$, $\beta_p = 0.1$, $\beta_e = 0.1$, $\theta_{bu} = 11^o$. Nonlinear saturation of the perturbations at $t = 0.29\,T_{ce}(0.04\,T_{transit})$ (case c).

- **It is very interesting and desirable to perform SPIS simulations of the solar wind plasma interaction with the satellite for Solar Orbiter and Solar Probe projects**