Electrostatic Environment of Ion Emitting Spacecraft study
Preliminary User Requirements

A. Retinò with contributions from THOR team & ONERA
SPINE Meeting, ESTEC, 23/10/2017

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Modelling of the Electrostatic Environment of Ion Emitting Spacecraft

- ESA/EXPRO+ project. KO September 2017.

- LPP tasks
  - SPIS User Requirements for spacecraft having active potential control (ASPOC)
  - Validation of SPIS simulation runs with Cluster data
  - Close collaboration with IRF-U (Sweden)

SPIS User Requirements

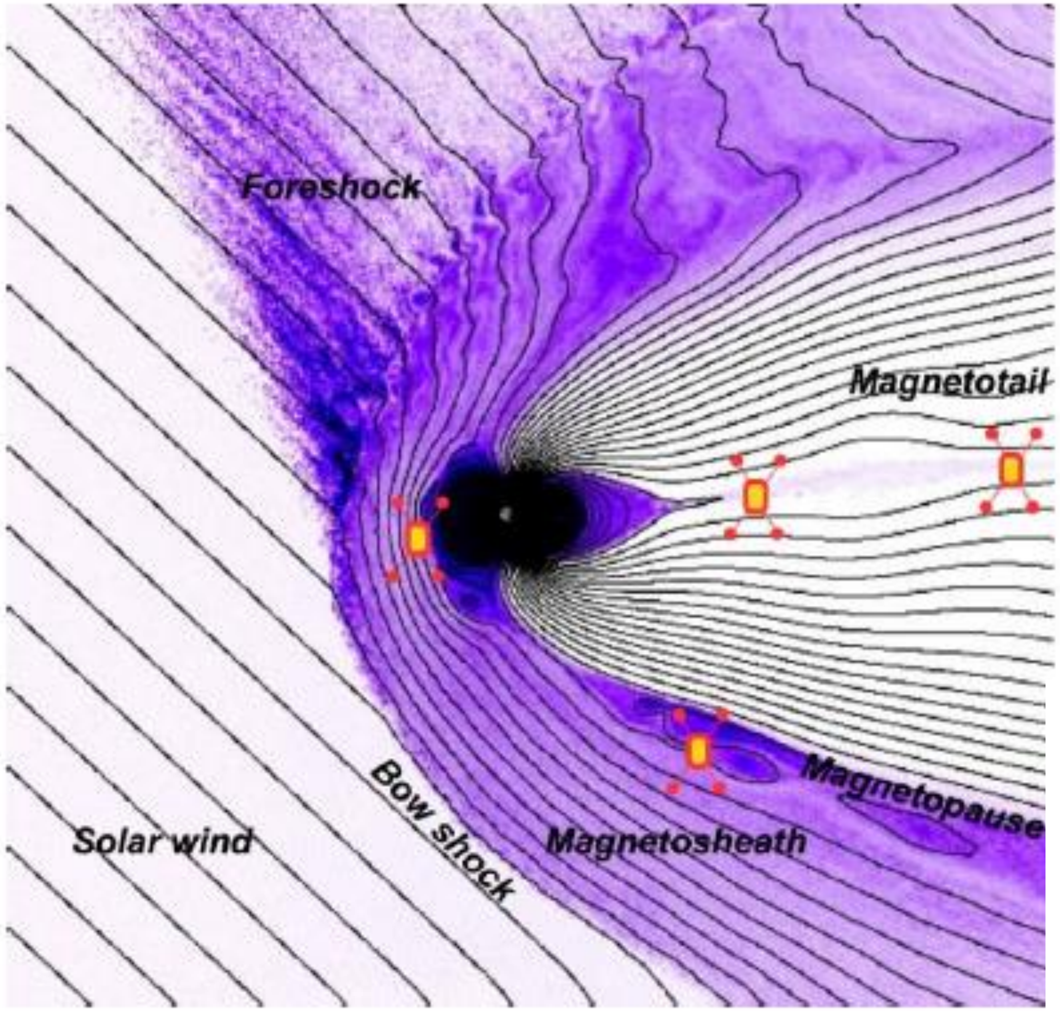
- Formulation of SPIS User Requirements coming from scientific needs regarding the effects to be modelled using SPIS as well as the required modelling accuracy, for the case of solar wind/magnetosphere spacecraft having active potential control (ASPOC)
- Collect input from the science community, e.g. users of Cluster, DoubleStar, MMS data and THOR’s science and payload community

Tools

- Cluster, DoubleStar, MMS data (with focus on Cluster from CSA archive)

- THOR science requirements
  - THOR proposal
  - Assesment Study Report (Yellow Book)
  - SciReqDoc
  - EMC requirements

Near-Earth plasma environment



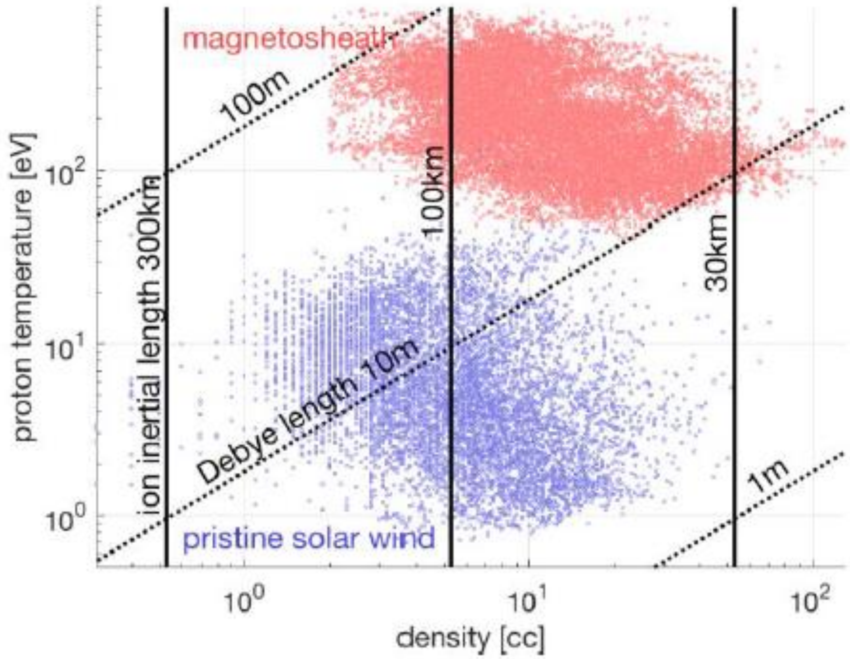
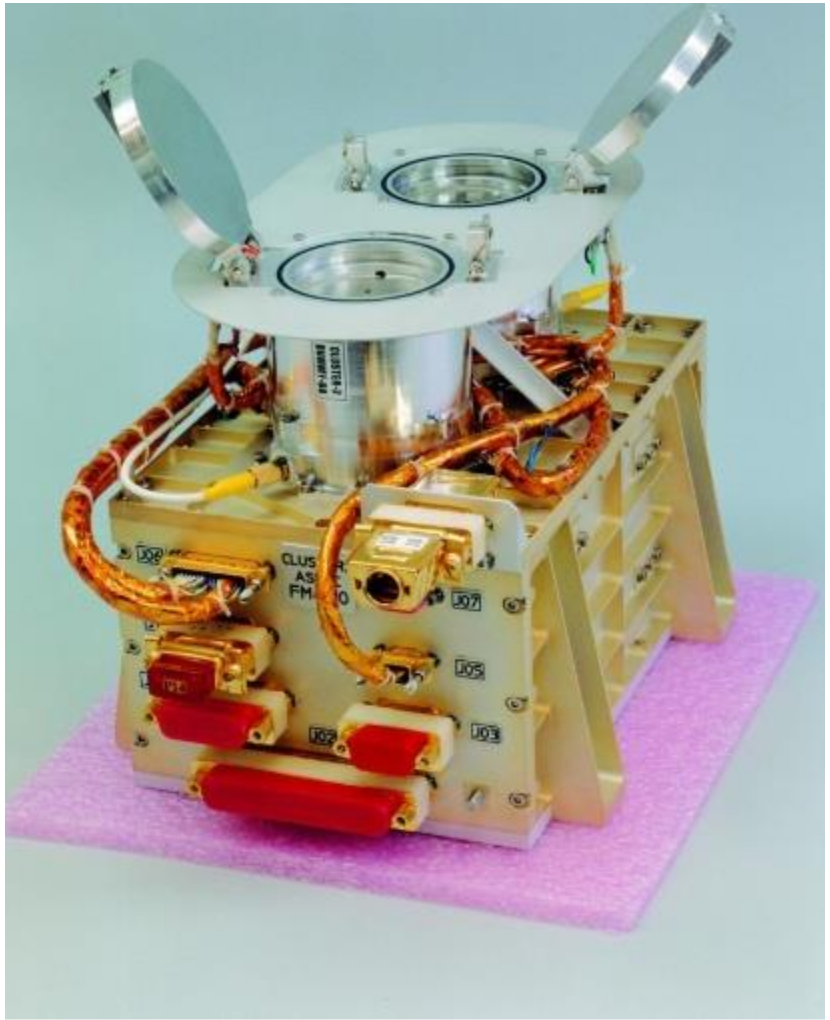


Table 6: Typical values of several solar wind parameters as measured by Helios 2 at 1 AU.

Wind Parameter	Slow wind	Fast wind
number density	$\sim 15\ \mathrm{cm}^{-3}$	$\sim 4\ \mathrm{cm}^{-3}$
bulk velocity	$\sim 350\ \mathrm{km\ s}^{-1}$	$\sim 600\ \mathrm{km\ s}^{-1}$
proton temperature	$\sim 5 \cdot 10^4$ K	$\sim 2 \cdot 10^5$ K
electron temperature	$\sim 2 \cdot 10^5$ K	$\sim 1 \cdot 10^5$ K
α-particles temperature	$\sim 2 \cdot 10^5$ K	$\sim 8 \cdot 10^5$ K
magnetic field	~ 6 nT	~ 6 nT

ASPOC instrument

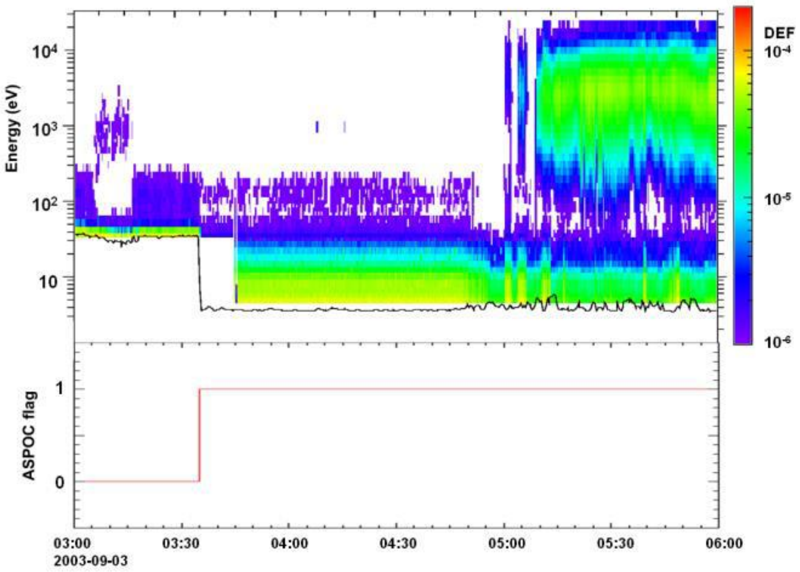
- Active SPacecraft POtential Control
- It controls the electric potential of the spacecraft by means of a beam of positive indium ions (115 amu) at energies of about 6 to 9 keV and currents up to about 30 μA. Typical currents applied in the mission were between 10 and 20 μA (Cluster mission)
- Beneficial for electric field measurements and low-energy electron and ion measurements
- Recent near-Earth missions: Cluster, DoubleStar, MMS



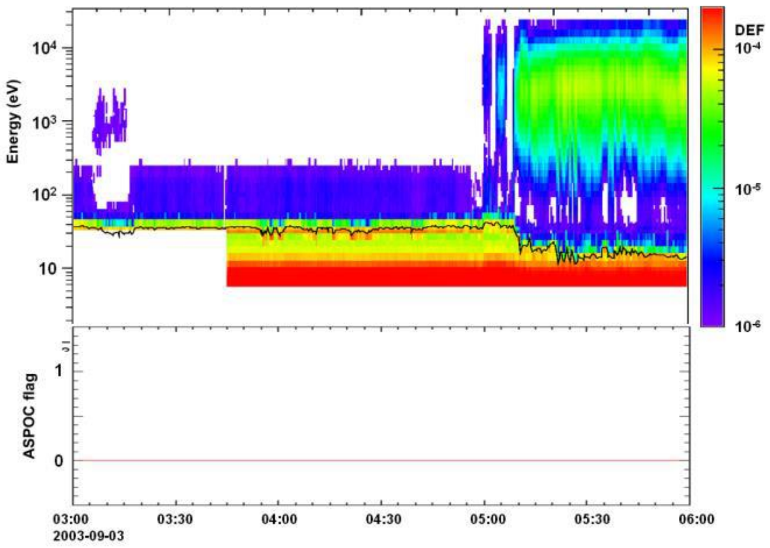
ASPOC on ESA/Cluster

Effects of ASPOC on electron measurements

ON



OFF



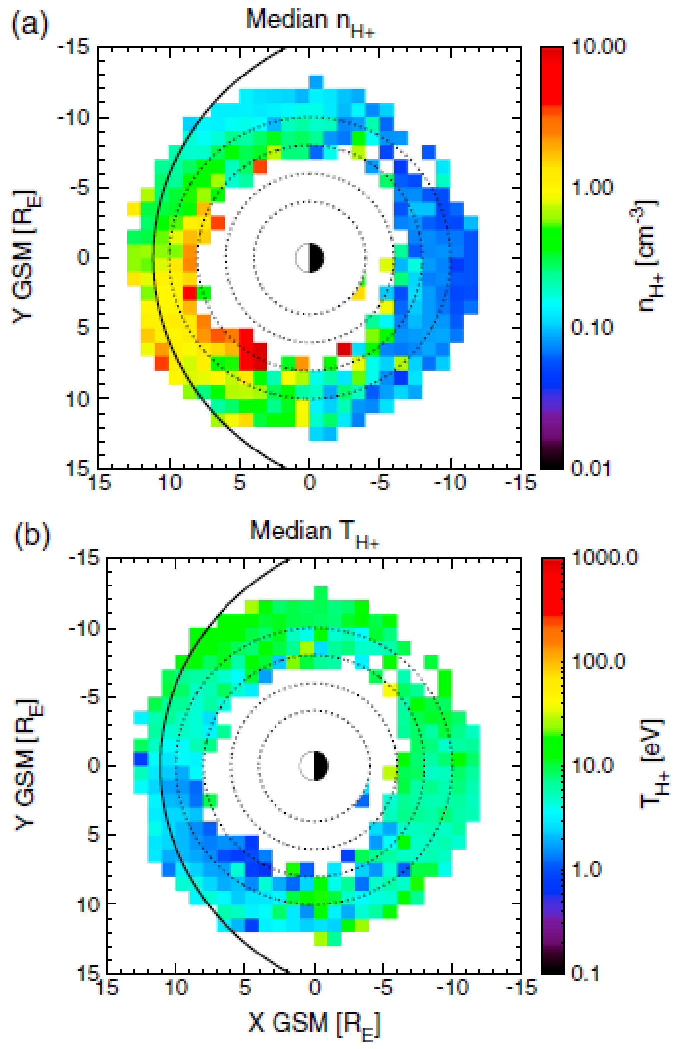
Cluster crossing from cold magnetotail lobe to hotter plasmasheet. Black trace shows spacecraft potential from EFW. Orange line under the black trace are EFW probe photoelectrons. Low energy electrons (measured energies between ~5 and 30 eV) in the lobe are revealed on C3 and the persistence of a low energy electron population in the plasmasheet is also evident.

- ASPOC can improve measurements of electron moments for relatively cold electrons (from few to 100s eV) which can be contaminated by spacecraft photoelectrons. Importance for lobes and pristine solar wind.
- ASPOC can perturb trajectories of electrons close to electron instruments' entrance thus affecting accuracy of moments

Effects of ASPOC on ion measurements

- ASPOC is necessary to detect ions with energy smaller than uncontrolled Vsc (e.g. in magnetosheath and magnetopshere). This affects accuracy of moments.

- ASPOC can perturb ion measurements depending on the distribution of the plume (energy of beam ions+ low-frequency B perturbations due to the beam)

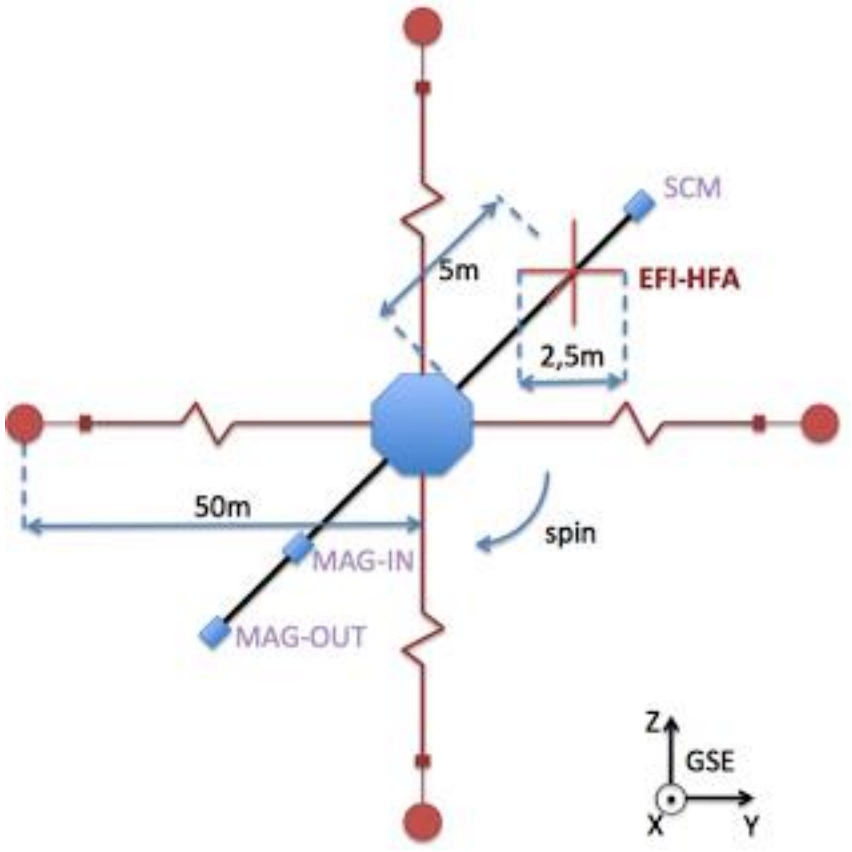


Adopted from Lee et al. JGR, 2014

Effects of ASPOC on electric field measurements

- ASPOC helps to reduce the wake due to cold ion flows. This can affect the accuracy of electric field measurements in case of magnetospheric cold ions.

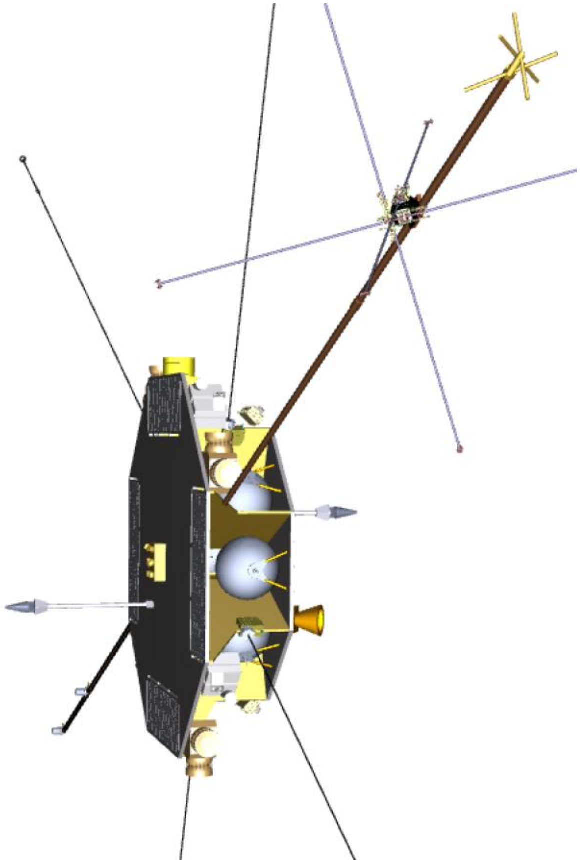
- Note that too low spacecraft potential may lead to an increased photoelectron cloud and thus less accurate electric field measurements.



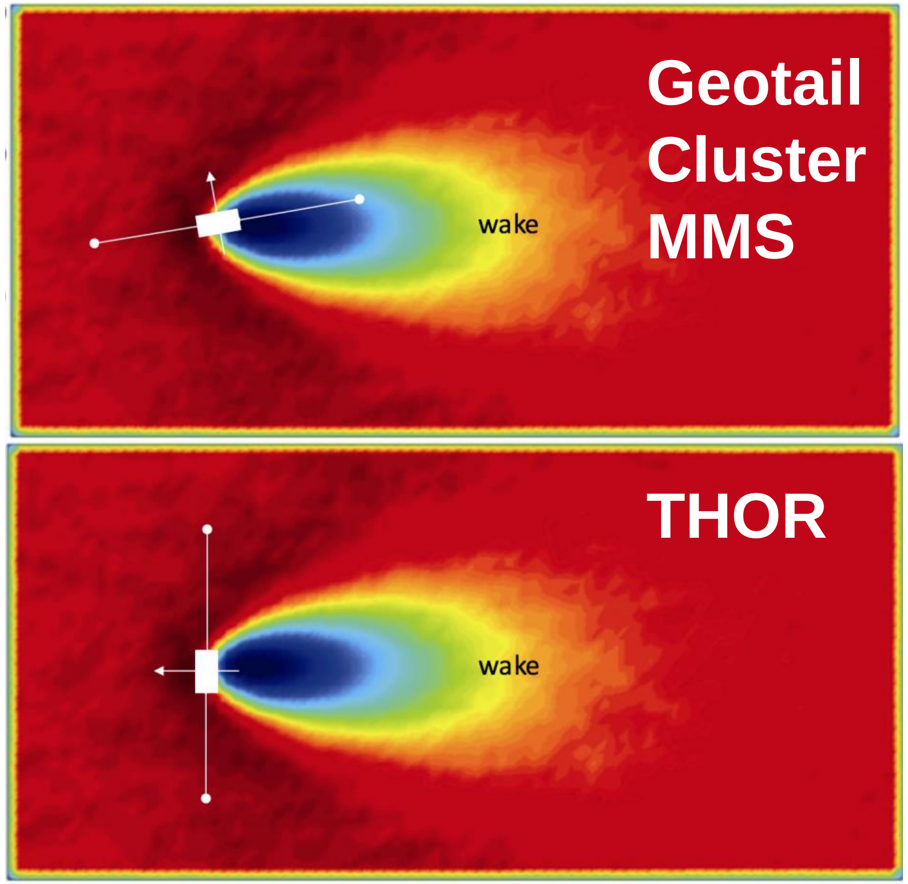
Schematics of THOR/EFI instruument (adopted from THOR Yellow Book)

ESA/THOR spacecraft

- Payload 170kg
- Sun-pointer
- Apogee in solar wind 45 RE
- Slow spinner (2 rpm)
- Long (>6m) booms for magnetometers
- Launch 2026 (Ariane 6.2)



http://thor.irfu.se/spacecraft



SPIS simulation of ion density around a spacecraft immersed in solar wind plasma

Examples of THOR science requirements (L2)

PAY_5: It shall be possible to measure background B with accuracy better than 0.2 nT in pristine solar wind and 0.5 nT in magnetosheath

PAY_6: Measure at least two components of **E** with absolute accuracy better than 0.1 mV/m for |E|<1 mV/m, and with relative accuracy better than 10% for |E|>1 mV/m.

PAY_13: It shall be possible to measure the 3D ion distribution function in the regions specified below in energy range E_range, with maximum resolutions in: energy dE/E, time dT, angle dα. These maximum resolutions are not required simultaneously.

Magnetosheath:
2a) H+: E_range< 5 keV, dT=150 ms, dE/E=15%, dα=11.25°
2b) He++: E_range< 5 keV, dT=300 ms, dE/E=15%, dα=11.25°

PAY_14: It shall be possible to measure the 3D electron distribution function in the regions specified below in energy range E_range, with maximum resolutions in: energy dE/E, time dT, angle dα. These maximum resolutions are not required simultaneously.

Pristine solar wind:
E_range< 100 eV, dT=5 ms, dE/E=17%, dα=11.25°

Examples of THOR EMC requirements

EMC-010: The voltage between any two points on spacecraft surface shall be at most 1 V.

EMC-060-090: AC magnetc field emissions

EMC-120-185: AC electric field emissions

EMC-210: The magnetic field due to spacecraft and payload perpendicular to all lines of sight of individual sensors and integrated along these lines shall not exceed 290 nTm (most stringent case for electrons)

EMC-220: The potential of the spacecraft surface relative to the surrounding plasma environment must be positive.

EMC-230: In the regions of interest it shall be possible to limit the potential of the spacecraft surface relative to the surrounding plasma environment to a value of less than 10V.

Preliminary SPIS User Requirements (1)

SPIS shall be able to provide accurate (<0.01-0.1 V depending on field amplitudeTBC) maps of the electrostatic potential when ASPOC is ON/OFF in different plasma regions (e.g.pristine solar wind, magnetosheath)

Required to:

- quantify the perturbations on the potential at the end of the wire booms w and w/o ion beam
- quantify error in E field measurements (< 0.1-1 mV/m TBC)

Preliminary SPIS User Requirements (2)

SPIS shall be able to provide of trajectory of charged particles (electrons, protons, alphas, oxygen) having energy ~ several eV in the vicinity of the ion and electron instruments' entrance when ASPOC is ON/OFF

Required to:

- quantify the perturbation on particle trajectories due to the spacecraft potential when ASPOC is ON/OFF
- quantify the error on moments when ASPOC is ON/OFF

(< few % TBC)

Preliminary SPIS User Requirements (3)

SPIS shall be able to provide of trajectory of charged particles (electrons, protons, alphas, oxygen) having energy ~ several eV in the vicinity of the ion and electron instruments' entrance when ASPOC is ON/OFF

Required to:

- quantify the perturbation on particle trajectories due to the low-frequency integrated magnetic field (due to spacecraft and payload) along the line of sight of particle instruments when ASPOC is ON/OFF (see THOR EMC requirement EMC-210: 145 nTm)
- quantify the error on moments due to integrated B when ASPOC is ON/OFF (< few % TBC)

Preliminary SPIS User Requirements (4)

SPIS shall be able to produce maps of the amplitude of electric and magnetic field perturbations due to low-frequency (TBC) waves produced by the interaction of the ASPOC ion beam with ambient plasma when ASPOC is ON

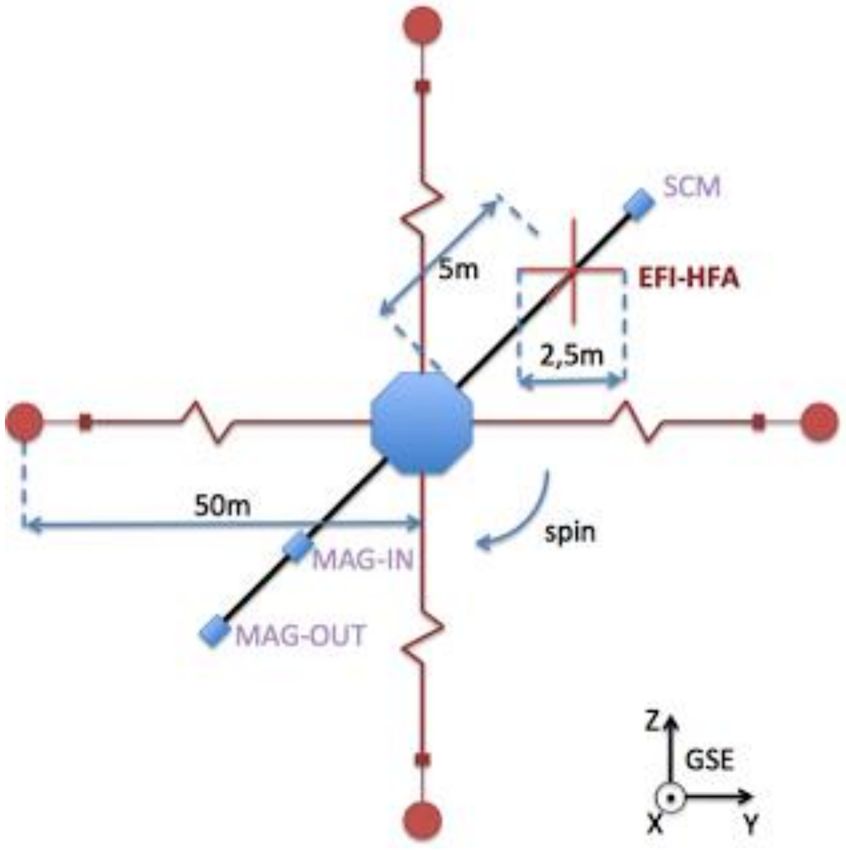
Required to:

- quantify the perturbation on δE and δB fields measurements at at the location of E and B sensors. See THOR EMC requirements EMC-020 to EMC-185.
- quantify the error on δE and δB when ASPOC is ON (< few % TBC)

Other needs (electric field instruments)

SPIS simulations with ASPOC ON/OFF for THOR-like spacecraft to:

- Verify the optimal accommodation of electric dipoles on the search-coil magnetometer solid boom
- Understanding the impact of asymmetric accommodation of spin double-probe relative to the solid booms on the electric dipoles and spin double-probe performance



THOR EFI/SDP & EFI/HFA

Example of validation with Cluster data

- Choose a specific region e.g. magnetosheath
- Choose in the Archive cases with different settings of ASPOC: OFF, ON, different values of current on different spacecraft (e.g. OFF on C1, ON with I1 on C2, ON with I2 on C3 etc.)
- For each value of the ASPOC current, calculate electron moments from PEACE by using the actual value of spacecraft potential provided by EFW (to remove photoelectrons). Compare with SPIS to evaluate the error on the moments that one makes depending on how ASPOC affects the value of the potential at each sphere (current balance and therefore potential of the spheres can be different; which value of spacecraft potential one takes? Normally we use the average from four probes)
- For each value of the ASPOC current, calculate ion moments from CIS/HIA. Compare with SPIS to evaluate the error on moments depending on (1) how the trajectory of cold ions is affected by the spacecraft potential close to HIA and how many ions can actually reach HIA (2) how much ASPOC perturbs the density of the ambient ions close to HIA sensor (6-9 keV)
- Evaluate from SPIS simulations the effect of the low-frequency magnetic field induced by the ions emitted by ASPOC current on the total magnetic field and how this impacts the accuracy of the ion moments
- Compare these results for different orientation of the spin axis for the period where one spacecraft was inclined by 45° (May 2008)