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Laboratory activity at INAF-IFSI in the framework of its participation to SWA onboard ESA-Solar Orbiter

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Abstract. The ESA-Solar Orbiter mission is devoted to solar and heliospheric physics and it has been recently redefined as part of a joint ESA-NASA programme called Heliophysical Explorers. This programme, which comprises ESA's Solar Orbiter and NASA's Solar Sentinels, will represent a quality leap in the understanding of plasma processes at the basis of energy and momentum transport in the solar wind. INAF-IFSI, as part of an international consortium, is deeply involved in the proposal for the Solar Wind Analyser (SWA). This proposal was recently submitted to ESA in response to the Announcement of Opportunity for Solar Orbiter as released by the Agency on October the 18th, 2007. SWA is a plasma suite made of 4 different instruments dedicated to reconstruct the full 3D velocity distribution function of protons, alphas, electrons and heavy ions. INAF-IFSI is one of the Lead Institutes within the consortium and its task will be the provision of the whole data processing unit for the entire suite, the onboard S/W and the EGSE. INAF-IFSI will also contribute to the design of the proton analyser (PAS). This paper aims to give a short overview of the main unsolved problems related to the study of solar wind plasma and of the SWA-Solar Orbiter related activities at IFSI.

Key words. Sun: solar wind, plasma

1. Introduction

ESA-Solar Orbiter is proposed as a space mission dedicated to study the solar surface, the corona and the solar wind by means of remote sensing and *in-situ* measurements, respectively. Consequently, the *s/c* will carry a heliospheric package primarily apt to measure ions and electrons of the solar wind, energetic

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particles, radio waves and magnetic fields. The space plasma group at IFSI, in collaboration with the universities of L'Aquila and Calabria and the AMDL s.r.l. company, is interested in developing instrumentation devoted to detect ions in the solar wind, toeing its traditional research line focused on the study of kinetic properties of space plasmas.

The importance of studying the kinetics of the solar wind is fundamental to fully understand the mechanisms acting within the micro scale, at the basis of the acceleration and heating of the wind itself. One of the major issues in space plasma physics is that, because of the inhomogeneity of interplanetary plasma, the complicated magnetic field topology and the radial gradient of fluid parameters, one would expect to find very strong deviations from Maxwellian distributions. In reality, although some clear deviations can be easily recognised (see review by Marsch 2006), they are much less dominant than it would be expected for a quasi-collisionless plasma. Thus, some dissipative mechanism must be at work favouring a partial isotropization of the distribution and a redistribution of kinetic energy among the different ion species, ensuring, at the same time, a fluid like behaviour to the solar wind as a whole. We know that the internal state of the wind at meso- and microscale undergoes a complicated evolution during the radial expansion into the interplanetary space (Marsch 2006). Energy stored in the stream structure is transferred to smaller and smaller scales via a relaxation process that takes place mostly within velocity shears to produce waves and turbulence (see review by Bruno and Carbone 2005). Plasma waves can also be excited by several other phenomena including currents, temperature anisotropies, ion beams and drifts via plasma instabilities (Marsch 2006). The action of these waves seems also to be at the basis of differential speed and temperature observed for atoms with different charge state. These phenomena need to be studied in detail since plasma waves act in the quasi-collisionless solar wind like collisions do in ordinary fluids.

Most of the present understanding of the processes at the basis of the above phenomena are essentially due to *in-situ* observations performed by Helios 1 and 2 between 0.3 and 1 AU, more than 25 years ago! Since then, no other spacecraft has ever sampled again the solar wind plasma so close to the Sun. Taking into account the enormous technological development experienced so far in the field of materials, sensors and electronics, a plasma instrument of new concept is promising of new and unexpected findings.

An international consortium established during 2007 and formed by MSSL-UCL (UK), SWRI (USA), University of Michigan (USA), CESR-Toulose (Fr) and INAF-IFSI (Rome), under the leadership of MSSL-UCL (UK), responded to the Solar Orbiter AO, released by ESA in October 2007, submitting its proposal for an instrument dedicated to the study of solar wind plasma called Solar Wind plasma Analyser (SWA). IFSI has a long experience in heliospheric instrumentation. The beginning of space activity at IFSI dates back to 1964 when ESA started its own space program in the field of satellites with terrestrial orbit apt to study the action exerted by the solar wind on the Earth's magnetic field and the complicated ionospheric-atmospheric system. Since then, IFSI participated to several international space projects dedicated to space plasma studies. Major successes since 1968 have been: HEOS 1, HEOS 2 to measure ions in the solar wind and to study the solar wind-magnetosphere interaction, ISEE 2 to measure the particles energy spectrum in the solar wind, at the bow-shock and in the magnetosphere, GIOTTO to measure the energy spectrum and ion composition of the gas emitted by comet Halley, CLUSTER 1 e 2 to measure the energy spectrum and ion composition in the magnetosphere and in the solar wind with 4 satellites and, finally, the equatorial *s/c* of Double Star mission, the European-Chinese magnetospheric mission.

2. The Solar Wind plasma Analyser

The SWA consists of a suite of 4 sensors that measure separately the $3-D$ velocity distribution functions of the most significant solar wind constituents. PAS (Proton Analyser

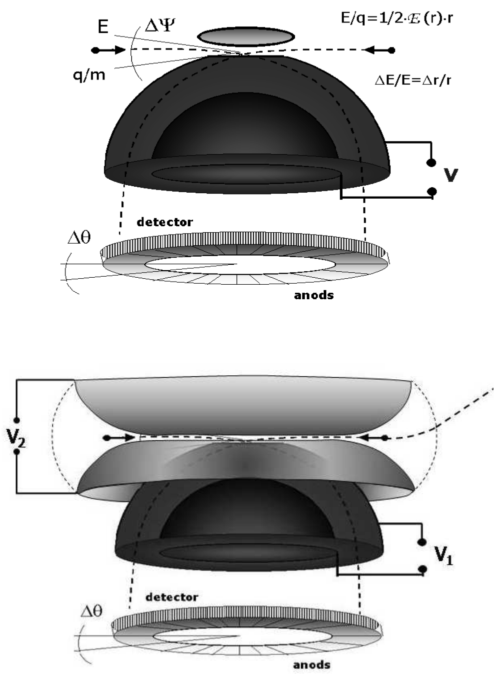

Fig. 1. Top panel: schematic of a quadrispherical top-hat analyser with a 2-D *FoV* perpendicular to its symmetry axis. Only ions with a given kinetic energy will reach the detectors. Bottom panel: the 2-D *FoV* can be transformed into a 3-D *FoV* simply by adding and polarising the toroidal section shown in the Figure.

Sensor) will measure protons and α-particles, HIS (Heavy Ion Sensor) will measure heavy ions and 2 EAS (Electron Analyser Sensor) will measure electrons. The SWA plasma suite is serviced by a common Data Processing Unit (DPU), which provides a single power, telemetry, and control interface to the spacecraft as well as power, switching, commanding, data handling and data compression functions for all of the sensors. This facilitates technical, programmatic and scientific sinergies, enables an integrated and coherent approach to correlative plasma measurements, and readily permits combining these measurements with theory and comprehensive modelling. It clearly offers advantages from the spacecraft resources point of view and potentially also in terms of inter-operation with other instrument suites on the spacecraft. The DPU will be equipped with an FPGA-based processor, namely a Leon 3 FT (Fault Tolerant) derived processor, able to provide instrument operations control and perform loss-less data compression. The DPU provision will be under direct responsibility of INAF-IFSI and will be built by the AMDL s.r.l. company.

Parallel to the study of the DPU, INAF-IFSI has been performing numerical studies to better define the Field of View (*FoV* hereafter) of PAS during the preparation of the proposal (D'Amicis et al. 2006). Following this line, laboratory activity is being set up in order to develop a full 3-D plasma analyser whose *FoV* is as close as possible to 4π (see Fig. 1) following an original idea developed at IFSI in the 90's (Di Lellis et al. 1992). This kind of sensors, based on a top-hat type (Carlson et al. 1983) similar to the one proposed for PAS, HIS and EAS, are particularly suited for 3-axis stabilised *s/c* like Solar Orbiter although a full *FoV* of 4π would be redundant for this particular *s/c* because the solar wind is observed within a limited solid angle. However, this kind of analysers can also be mounted on spinning *s/c* in order to increase the time resolution needed to reconstruct ion velocity distribution function and a possible use on the future ESA-Cross Scale programme can also be envisaged. This study is being funded by ASI in the framework of ASI contract n. $I/015/07/0$ dedicated to Solar System Exploration and it is both numerical and experimental. It is based on a logic scheme that can be summarized here below. We first determine the main features of particle velocity distribution, like bulk speed V_{sw}, proton density n_p and the perpendicular and parallel components of proton temperature with respect to the local magnetic field $T_\perp$ and $T_{//}$ using *in-situ* observations by previous *s/c* which operated in different plasma environments. Then we choose energy and angular resolution for our hypothetical analyser, simulate a bi-Maxwellian ion distribution and determine the expected count-rate in each energy channel and for each direction in phase space. Afterwards, using these count rates we can compute the moments of the measured Probability Distribution Function, like V_{sw}, n_p,

$T_\perp$ and $T_{//}$. At this point we compare these results to the exact moments corresponding to the simulated bi-Maxwellian. Obviously, we can change energy and angular resolution of our analyser and reiterate the process until this comparison is satisfied within certain limits. At this point we design an analyser which should have the desired energy resolution, *FoV* and geometrical factor (GF) and we simulate its response numerically, first solving the Poisson equation via finite differences method to obtain the electric potential and field and then shooting through its aperture a large number of particles belonging to a known distribution function. At the end of the process, if the design does not have to be modified because the analyser has the desired energy resolution, *FoV* and *GF* we build a mechanical prototype which will be tested in a vacuum chamber. INAF-IFSI has a small vacuum chamber of about 200 lt volume, equipped with an ion source Ar^+ of Penning type with energy ranging between 0 and 5 KeV. The highest vacuum level reachable is up to 10^{-8} mbar (10^{-8} with the ion source on). The chamber is also equipped with a two motorised stages which allow to orient the analyser with respect to the beam coming from the ion source. Microchannel Plates (MCP) or Ceramic Electron Multipliers (CEM) will be used to detect the incoming particles. INAF-IFSI has also a large plasma chamber 4.5m long with a diameter of 1.7 m where it is possible to recreate the ionospheric plasma environment with or without a magnetic field whose intensity can vary between 0 and 1Gauss and its direction is controlled by a 2-D coil system. The electrons have the typical temperature of the ionospheric F layer (1000 – 3000 K) whereas the ions inside the chamber flow at a speed of 8 km/s allowing to simulate the relative motion of a *s/c* in Earth orbit. In particular, the attitude of the magnetic field vector with respect to the direction of the ion beam can simulate polar and equatorial orbits.

3. Conclusions

The plasma group at INAF-IFSI has an important role within the international consortium that, at the beginning of this year, submitted a proposal for a plasma suite onboard ESA-Solar Orbiter. The main role of INAF-IFSI is that of providing a common centralised DPU for the whole suite which comprises four sensors, the flight S/W and the EGSE. However, INAF-IFSI is involved also in the definition of the final design of the proton electrostatic analyser PAS. This task is being performed within more general laboratory studies based on numerical simulations and experimental validations of plasma analysers. This activity is pointing to develop a full 3-D plasma analyser whose *FoV* is as close as possible to 4π. This kind of instrument besides being devoted to non-spinning *s/c* could also be used on spinning *s/c* in order to decrease the time needed for sampling the whole ion and/or electron velocity distribution function. A possible application of this kind of analyser also for ESA-Cross Scale programme is being studied.

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