

SERENA: a Novel Instrument Package on board BepiColombo-MPO to study Neutral and Ionized Particles in the Hermean Environment

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ABSTRACT

SERENA ('Search for Exospheric Refilling and Emitted Natural Abundances') is an instrument package that will fly on board the BepiColombo Mercury Planetary Orbiter (MPO); it will investigate the Mercury's complex particle environment that surrounds the planet. Such an environment is composed by thermal and directional neutral atoms (exosphere) originating via surface release and charge-exchange processes, and by ionized particles originated through photo-ionization and again by surface release processes. In order to accomplish the scientific goals, in-situ analysis of the environmental elements is necessary, and for such a purpose the SERENA instrument shall include four units: two Neutral Particle Analyzers (ELENA and STROFIO) and two Ion Spectrometers (MIPA and PICAM). The scientific merit of SERENA is presented, and the basic characteristics of the four units are described, with a focus on novel technological aspects.

SCIENCE MERITS

The Hermean Environment

The environment surrounding the planet Mercury is a complex system, generated by the coupling among solar wind, magnetosphere, exosphere and surface, so that a comprehensive description of its characteristics cannot avoid a detailed analysis of all these four 'elements' (e.g.: Milillo et al. 2005).

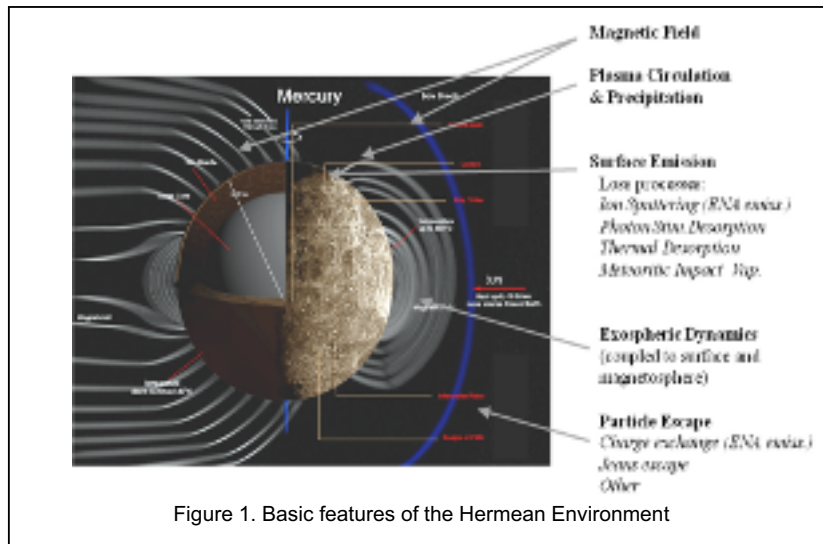


Figure 1 briefly describes the basic features of the Hermean environment. The planet has an intrinsic magnetic field, significantly weaker than the terrestrial one, so that the solar wind plasma and its frozen-in IMF can interact with it, generating a shock interface, very close to the planet surface. Inside this small-scale magnetosphere, plasma particles may circulate. Anyway, the ions have a big gyroradius compared to the planet scale length, so that in most of the inner regions no adiabatic approximation may be assumed. In large areas the solar wind impacts on the surface itself, generating neutral particle emission via ion-sputtering. This release process combines with others due to solar radiation and micrometeoroid impacts. The bulk of these escaping particles generate a tenuous collisionless gas cloud, typically defined as exosphere. The dynamical behaviour of this exospheric gas, strongly coupled with the planet surface and the Hermean magnetosphere, causes neutral particle precipitation onto the surface as well as escape towards space.

The Science Objectives

SERENA ('Search for Exospheric Refilling and Emitted Natural Abundances') is an instrument package that will fly on board the BepiColombo/Mercury Planetary Orbiter (MPO), able to provide information on the whole surface-exosphere-magnetosphere system, as well as on the processes involved in this system, subjected to strong interaction with the solar wind and the interplanetary medium. In the Hermean environment the interaction between energetic plasma particles, solar radiation and micrometeorites with the Hermean surface gives rise to both thermal and energetic neutral populations in the near-planet space. Such populations will be recorded by the SERENA Neutral Particle Analyzers, namely ELENA and STROFIO. The photo-ionized or charged component of the surface release processes as well as the precipitating and circulating plasma in the Hermean magnetosphere will be recorded by the SERENA Ion Spectrometers, namely PICAM and MIPA. In particular, ELENA investigates the neutral gas escaping from the surface of Mercury, and the related involved processes; STROFIO investigates the exospheric gas composition; PICAM investigates the exo-ionosphere extension and composition, and the close-to-planet magnetospheric dynamics; MIPA investigates the plasma precipitation toward the surface and ions energized and transported throughout the environment of Mercury.

Such scientific aspects will be addressed by SERENA according to the scientific goals of the experiment, as listed in the following.

Chemical and elemental composition of the exosphere

It is expected that the six observed elements (H, He, O, Na, K and Ca) may constitute only a small fraction of Mercury's exosphere (e.g., Milillo *et al.*, 2005; Killen and Ip, 1999). Radar-bright regions have been discovered at the poles, attributed to volatile deposits (water or sulphur) in permanently shadowed craters. The quantification of different exospheric components is crucial for the determination of the environment composition since the neutral component is the primary constituent of the Hermean environment. Determination of aggregation status of atoms and molecules in the exosphere is important for better understanding the occurring processes. The STROFIO sensor is unique in its capability to perform quantitative analysis and resolve exospheric gas chemical and elemental composition.

Exo-ionosphere composition and distribution

The ions of planetary origin not yet observed are likely present at Mercury, especially in the dayside hemisphere due to photoionisation and ion-sputtering processes (e.g., Milillo *et al.*, 2005). The MPO orbit, being close to the planet, and the good duty cycle provided by 3-axis stabilization will permit PICAM to obtain continuous measurements of these ions, enabling a detailed composition measurement. Along the MPO orbit at low altitude, PICAM will be able to detect ionized particles created in the nearby regions; hence, they maintain, at least partially, the information about their generation process. The quantification of the ion component will provide useful information for the unsolved problems of the presence of an exo-ionosphere at Mercury. The high sensitivity, the wide FOV and the mass resolution of PICAM will allow us to complete, together with the neutral component, the composition analysis of the Hermean envelope. Simultaneous measurement of the neutral (STROFIO) and ion (PICAM) densities around Mercury can be useful to provide experimental data (highly needed because still debated) for the photo-ionization rates of the neutral species at Mercury.

Surface emission rate and release processes

A central problem for understanding the evolution of solar system bodies is the role played by the solar wind (SW), solar radiation and micro-meteorite bombardment in controlling mass losses through surface release (Killen and Ip, 1999). The rate of surface ageing by thermal desorption (TD), photon stimulated desorption (PSD), and space weathering by ion-sputtering and micrometeoroid impact vaporisation is particularly relevant at Mercury.

Different release processes produce particles within different energy ranges (Wurz and Lammer, 2003). Observations of the gas evolving from the planet are of crucial importance to identify and to localize the different physical processes acting onto the surface as well as to estimate their relative efficiencies. Different release processes can have different efficiencies as a function of latitude and longitude at Mercury due to both surface compositions and external conditions, as solar irradiance or plasma precipitation. Hence, the detection of exospheric neutral particles over the whole energy range of each process, to be performed by STROFIO and ELENA, will allow us to identify the process responsible for their generation. Moreover, the correlation of the ELENA sputtered neutral flux and the MIPA plasma precipitation measurements will allow us to quantify the effectiveness of this process. The flow direction of the ion-sputtered neutrals detected through high spatial resolution measurements performed by ELENA will allow the determination of the surface area from which the particles are escaping; hence, it will be possible to map the location of the sputtering process on the surface and an imaging of the surface loss rate.

Plasma precipitation rate

The ions entering in the magnetosphere: a) partially reach the planet's surface and cause ion sputtering, hence producing neutral atoms and ions with energies up to hundreds of eV; b) partially are diffused toward closed field lines and circulate in the magnetosphere; c) partially exchange their charge with the thermal exospheric atoms, producing a Hydrogen-ENA signal in the keV range. The intense flux of SW protons toward the planet (Masetti et al. 2003; Kallio and Janhunen, 2004) will be monitored by MIPA. The precipitating planetary heavy ion fluxes are lower with respect to precipitating solar wind fluxes. Hence, they could be observable in the night side where the solar wind contribution is probably negligible. Simulations show that planetary Na^+ ions may convect to the night side, where they are subject to acceleration processes, and eventually they may hit the surface, causing a second generation of ion-sputtering process (Delcourt *et al.*, 2003; Seki et al., 2006). Anyway, the estimation of this signal is difficult to be quantified. Hence, both MIPA and PICAM could face this tricky detection. In summary, MIPA will measure the flux of loss-cone-precipitating particles at Mercury, which through ion-sputtering will be a source of neutral and ion emission. The identification of the composition and energy distribution of the planetary ion flux impacting the surface can be achieved by joint analysis of MIPA and PICAM.

Particle loss rate from Mercury's environment

The high-energy neutral products of the release processes as well as the charge-exchange ENA, are mainly created close to the surface and carried outward of the planetary environment due to their high velocity that exceeds the escape velocity. Directional neutral measurements are crucial for evaluating the mass loss from the Hermean environment. The ions produced at thermal energies are energized and become part of the magnetospheric ion populations, together with the SW plasma entering through the cusp regions. The magnetospheric plasma partially impacts on the surface (Ip, 1997; Delcourt *et al.*, 2003); hence, these particles are absorbed by the surface at specific latitudes (Delcourt *et al.* 2003; Leblanc *et al.* 2003) and are redistributed over the planetary surface (Killen *et al.*, 2004a). On the other hand, part of the magnetospheric plasma is eventually lost to the SW (Ip, 1997; Delcourt *et al.*, 2003). Ion measurements are important for the planetary global mass loss estimation and provide key information on the formation and on the erosion of Mercury's neutral exosphere. Such processes produce a global particle loss rate from the planet. The global loss rate can be derived from the measurements performed by ELENA and PICAM, thus providing crucial information for deriving the past and present evolution of the planet.

Gas density profile asymmetries

The measurements of the spatial distributions of the neutrals as well as ions are a possible way to understand the ejection processes that lead to these distributions and to have information about the history of the particles during their trajectories (e.g., dissociation, acceleration, etc...). Moreover, asymmetries, induced by strong thermal variations, between different latitudes, day/night, dawn/dusk sides and perihelion/aphelion are expected in the Hermean exospheric density (Potter *et al.*, 2006). STROFIO will be able to observe these asymmetries. It will be of particular interest to analyse the profiles for different species released via different release processes, for example it will be useful to compare the density profile of Na and Ca (Killen *et al.*, 2005) or Mg.

SERENA INSTRUMENT PACKAGE

The energy spectrum of neutral particles ranges from fractions of eV up to tens of keV. Such a large energy interval cannot be covered by a single detector (Wurz, 2000). The SERENA instrument is therefore based on a modular approach comprising four sensors: the STROFIO sensor measures the neutral particle composition at the

lowest energy range (~ 0 to a few eV) and the particle density in the exosphere; the ELENA sensor covers the < 20 eV – 5 keV energy spectrum;

The STROFIO sensor measures the neutral particles with low energies (exospheric particles) and has no imaging capability. The analysis of the exospheric released gases allows indirect reconstruction of the surface composition, by processing successive measurements over several orbits.

The ELENA sensor has a high angular resolution and a nadir pointing 1-D field-of-view (perpendicular to the S/C orbital plane). This configuration allows a subsequent collection of the ELENA observations along each single orbit for reconstructing the global image of the particle populations surrounding Mercury and its interaction with the surface.

The two ion spectrometers are complementary. MIPA geometrical factor is optimized for covering the very high fluxes (up to 10^9 part./(cm^2 s sr)) of the precipitating SW and magnetospheric ions, that may eventually induce ion-sputtering process. PICAM with its higher mass resolution is optimized for measuring lower fluxes of exo-ionosphere. PICAM with its more extended FOV is able to fully reconstruct hemispherical ion distributions, whereas MIPA is able to detect more energetic ions with better time resolution may respond more efficiently to abrupt and fast changes of the precipitating ion fluxes. In Table 1, the basic characteristics of the four units are listed.

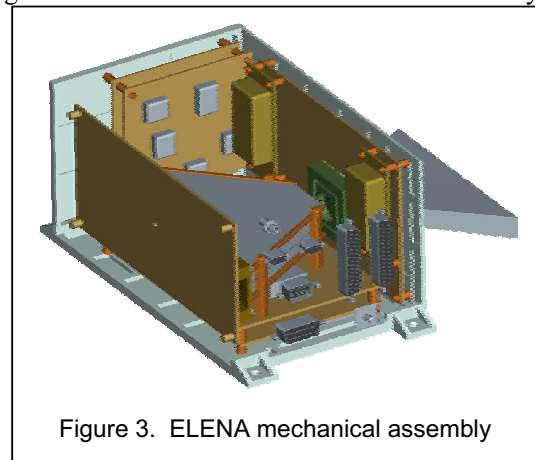
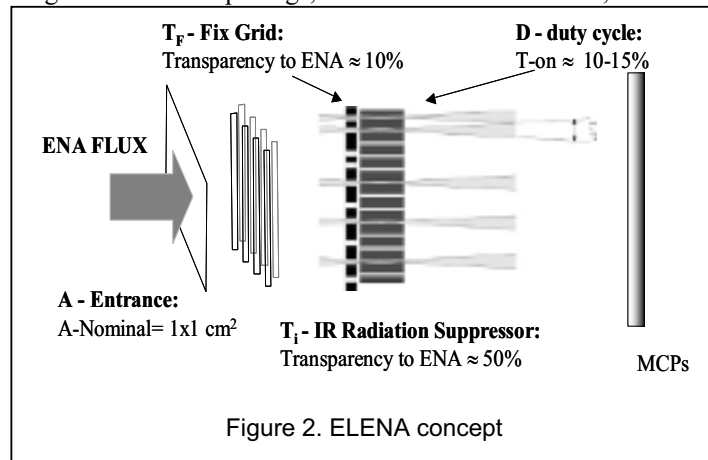
	STROFIO	ELENA	PICAM	MIPA
Energy range	< 1 eV	$< 0.02 - 5$ keV	$0.001 - 3$ keV	$0.01 - 15$ keV
Resolution	-	$\Delta v/v: \approx 15\%$	$\Delta E/E: 10\%$	$\Delta E/E: 7\%$
FOV, degrees	20×20	2×76	3D: hemisphere	2D: 9×180
Resolution, deg	-	2×2	22.5×22.5	4.5×22.5
Mass resolution	$M/\Delta M > 60$	H and heavy species	$M/\Delta M > 60$	$M/\Delta M \sim 5$
Geom. Factor (total)	0.14 (counts/s)/ (particles/ cm^3)	$\sim 4 \cdot 10^{-4}$ (cm^2 sr)	$\sim 3.4 \cdot 10^{-3}$ (cm^2 sr)	$\sim 1.8 \cdot 10^{-3}$ cm^2 sr eV/eV
Efficiency		ener. dep.: $\sim 5 \cdot 10^{-3} - 0.5$	energy dep.	1-10% (adjustable)

Table 1. SERENA units major characteristics

ELENA

ELENA (see Figure 2) is a Time-of-Flight (TOF) sensor, based on the state-of-the-art of ultra-sonic oscillating choppers (operated at frequencies above 20 kHz and up to 100 kHz), mechanical gratings and Micro-Channel Plate (MCP) detectors. The new development in this field allows unprecedented performance in timing discrimination against noise of low-flux neutral particles. The purpose of the chopping is to digitize space and time when tagging the incoming particles without introducing 'disturbing' detector elements, which may affect the particles trajectory or the energy. This is particularly important in this case, where neutrals of energies of a few tens of eVs must be detected.

The sensor concept is based on a mechanical nano-shuttering system, which releases the incoming neutral particles impinging on the detector entrance (with an instantaneous FOV of 2×76 deg) with a definite timing. The nano-shuttering element consists of two self standing silicon nitride (Si_3N_4) membranes, patterned with arrays of long and narrow openings, of the order of 100 nm, one facing the other. These nano-slits are fabricated by



electron beam lithography (EBL) and other techniques typically used for microelectronics. A piezoelectric ultrasonic actuator has been identified for oscillating the shutter, with frequency ranging up to 100 kHz. Particles passing through the openings (occurring when the slits of two oscillating membranes are aligned, thus identifying the START time) are then flown in a TOF chamber, and finally detected by a 1-dimensional array (based on MCP and discrete anode sets), allowing reconstructing of both velocity and direction of the incoming particles. The width of each cut opening provides the latitudinal 2° FOV resolution, whereas the 76° azimuthal FOV of the pinhole camera can be resolved into a series of $38\ 2^\circ \times 2^\circ$ -wide bins by means of discrete anode sets in the MCP back. In general, it is possible to have additional information from the pulse-height on the MCP, if it works in a proportional regime, so that it could be possible to discriminate a few mass channels.

The total moving assembly has a mass of a few grams. The composite radiation made by neutrals, ions and light fluxes impinges onto the ELENA sensor entrance through an equivalent aperture of about 1 cm^2 . The first IR stopping grid reflects unwished infrared (IR) radiation for minimizing the instrument heat loading. For the black body expected radiation at 434 K, IR is centred around $2800/434\ \mu\text{m}$, i.e.: $\lambda \approx 6.5\ \mu\text{m}$. For avoiding the IR transmission, metallic meshes of about $1 \times 4\ \mu\text{m}$ are used; transparency for the neutral particles is instead of the order of 50 %. Concerning Sunlight, the adopted $2\ \mu\text{m}$ - thick membranes with Si_3N_4 layers are almost completely opaque, so that generally, transparency is well below 10^{-28} . As far as the grid structure transmission is concerned, a specific simulation has been set-up for evaluating the leakage. It has been found that each cut drops the entrance intensity of a factor less than 10^{-8} . Ion deflecting plates are foreseen, located inside the TOF chamber. To observe the limb during apoherm passages, the linear array of ELENA angular pixels is shifted 8° in the perpendicular to the S/C orbital plane towards anti radiator direction. The ELENA main box (see Figure 3) houses all the sensor elements, the local proximity and event processing electronics, and the SERENA system control unit. Table 2 reviews the major ELENA characteristics. More details about ELENA are given in a dedicated paper inside this book (Orsini et al., 2007).

Energy range	<0.02- 5 keV (mass dependent)
Velocity resolution $\Delta v/v$	Down to 15%
Viewing angle	$2^\circ \times 76^\circ$
Nominal angular resolution	$2^\circ \times 2^\circ$
Mass resolution $M/\Delta M$	H and heavy species
Optimal temporal resolution	5 s ÷ 25 s
Geometric factor G	$\sim 1 \cdot 10^{-5}\text{ cm}^2\text{ sr}$
Integral Geometric factor	$\sim 4 \cdot 10^{-4}\text{ cm}^2\text{ sr}$

Table 2. ELENA major characteristics

ELENA signal simulation

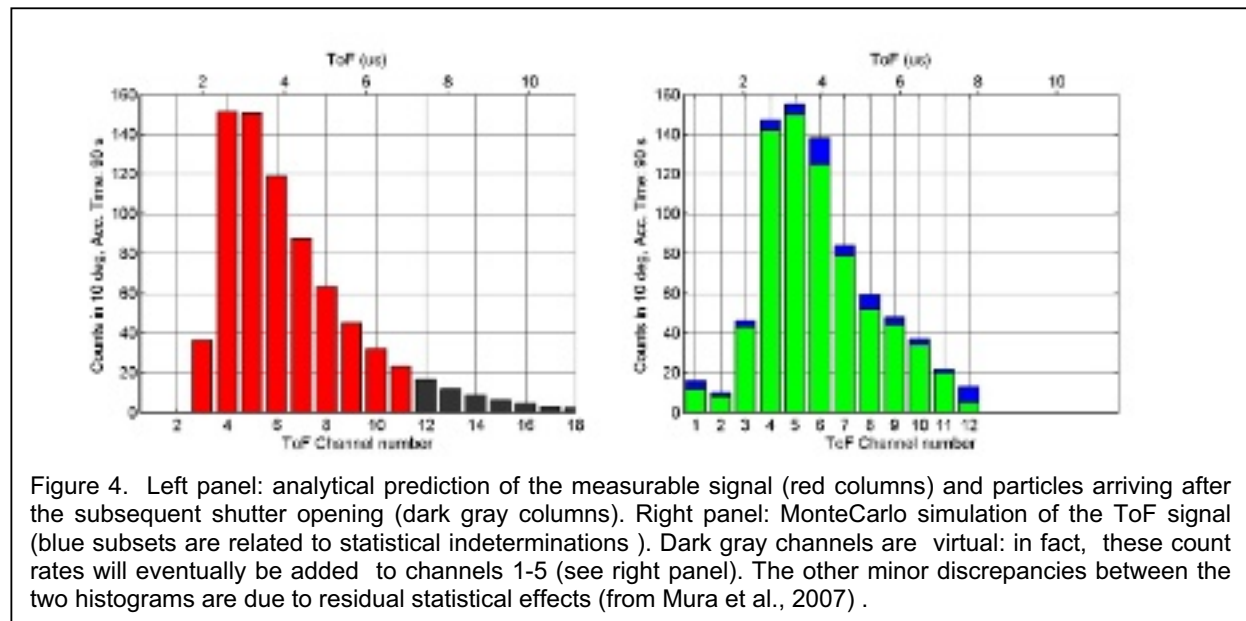


Figure 4. Left panel: analytical prediction of the measurable signal (red columns) and particles arriving after the subsequent shutter opening (dark gray columns). Right panel: MonteCarlo simulation of the ToF signal (blue subsets are related to statistical indeterminations). Dark gray channels are virtual: in fact, these count rates will eventually be added to channels 1-5 (see right panel). The other minor discrepancies between the two histograms are due to residual statistical effects (from Mura et al., 2007).

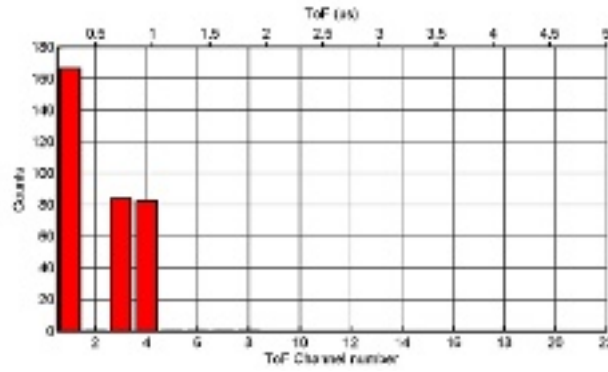


Figure 5. ELENA mass resolution capability based on ToF analysis. Simulation of two laboratory H- and O-ENA fluxes with similar energy distributions (~ 1 keV). The shutter frequency has been set to 100kHz. The peak in the first channel is H, whereas the peak in channels 3-4 is due to O (from Mura et al., 2007).

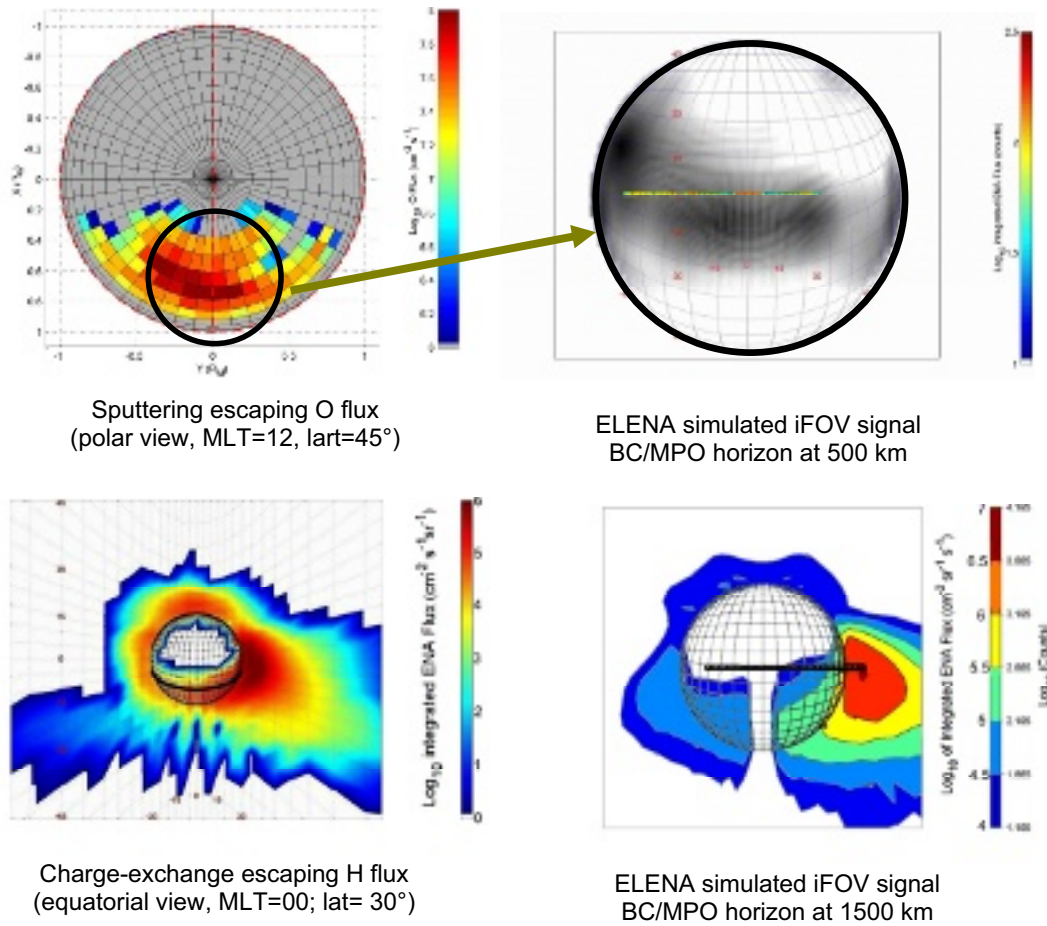


Figure 6. ELENA signal simulation: ion-sputtering (top panels) and charge exchange (bottom panels. Left column: theoretical predictions; right column: ELENA signal simulations (adapted from Mura et al., 2005)

Figure 4 shows an estimation of the count rates related to neutral fluxes that can be measured by ELENA instrument during an intense ion-sputtering event (i.e.: neutral fluxes of about $10^8 \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, where we consider

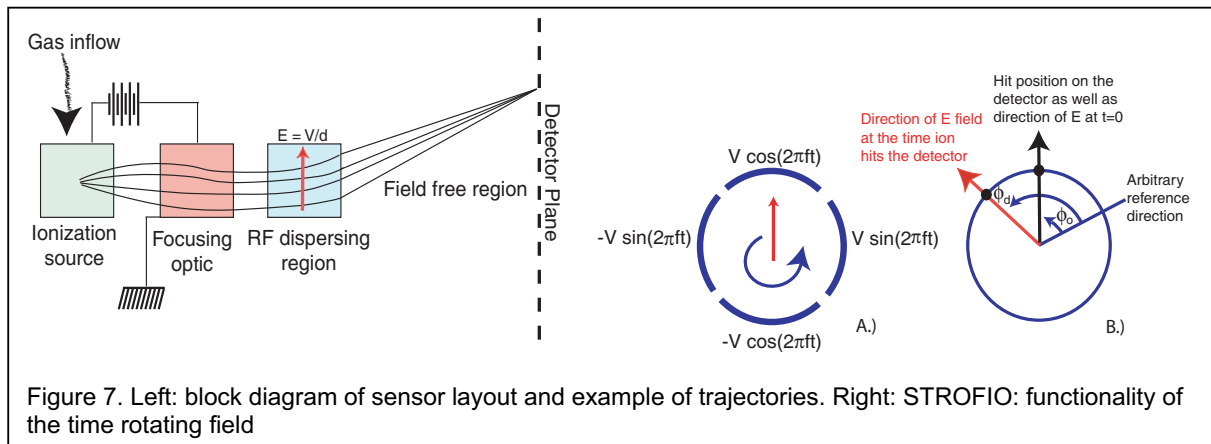
that all detectable particles are Na). The left panel shows the analytical prediction of the measurable signal (red columns) and particles arriving after the new opening (grey columns). We have estimated the count rates in the 11 useful TOF channels with a Monte Carlo model, simulating a sputtering distribution of a number of particles equal to $T_{int} G F n$, where T_{int} is the time window, G is the geometrical factor, F is the flux at instrument entrance, and n is the number of angular sectors. We have applied the proper STOP detection efficiency $\varepsilon(E)$ to the simulated signal for each event. The result is in the right panel (green columns). The good agreement between the two panels indicates that the count rates are high enough to permit a reconstruction of the incoming fluxes.

The ELENA ToF capability implies a limited possibility to discriminate light respect to heavy species. In Figure 5 we show a demonstrative simulation of such kind of analysis.

Since the real condition at Mercury is not known, ELENA will maintain the possibility to have a spatial resolution of $2^\circ \times 2^\circ$, allowing an imaging of the surface with resolution between 15 and 70 km (for peri- and apo-herm respectively). In Figure 6 (top panel) we show a simulation of the energy-integrated (between 20-1000 eV) sputtered O from vantage point close to the perihelion on the day-side. The instantaneous FOV of the linear array of the ELENA sensor is shown as a slice. The edge sectors of the array, which will observe the limb when the MPO spacecraft will approach the apoherm, will observe ENA from charge-exchange of SW with exospheric gas, providing insight into the SW circulation inside the Hermean magnetosphere (Mura et al., 2005). In Figure 6 (bottom panel) the energy-integrated H ENA signal from the night side apoherm is shown. The instantaneous FOV of the ELENA linear array is shown as a slice.

STROFIO

STROFIO (Start from a Rotating Field mass spectrometer) is a mass spectrograph that determines particle mass-per-charge (m/q) by a time-of-flight (TOF) technique. The name comes from the Greek word *Strofi*, which means “to rotate”: the phase of a rotating electric field “stamps” a start time on the particles’ trajectory, and the detector records the stop time. STROFIO is characterized by a high-sensitivity (0.14 counts/s when the density is



Energy range	< 1eV
Viewing angle [deg]	20 x 20
Mass resolution $M/\Delta M$	60
Mass range	1-64 dalton (AMU)
Sensitivity	0.14 (counts/s)/ (particles/cm ³)
Temporal resolution	10 s

Table 3. STROFIO major characteristics

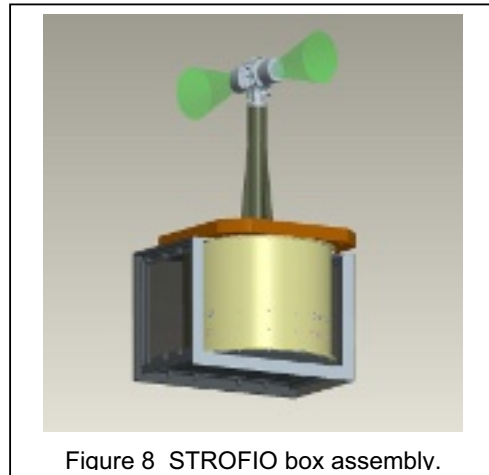


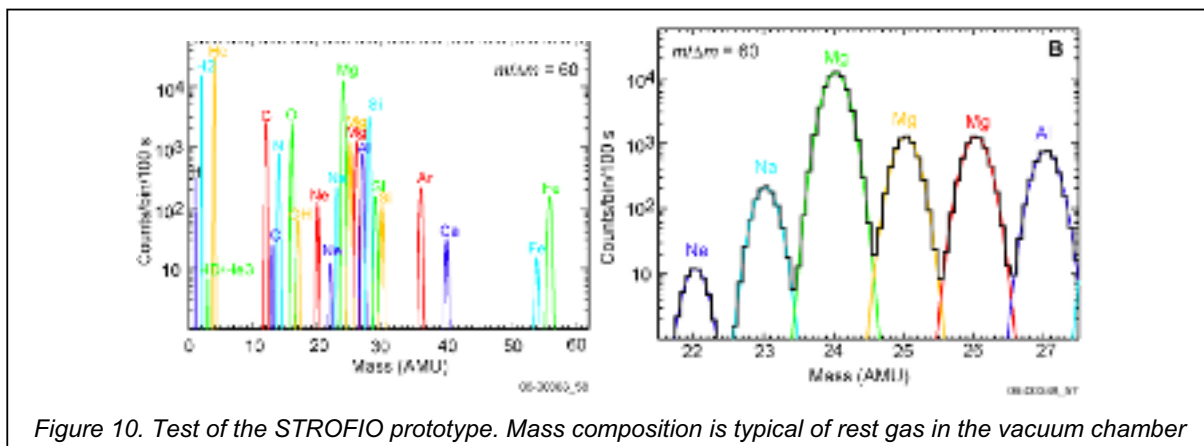
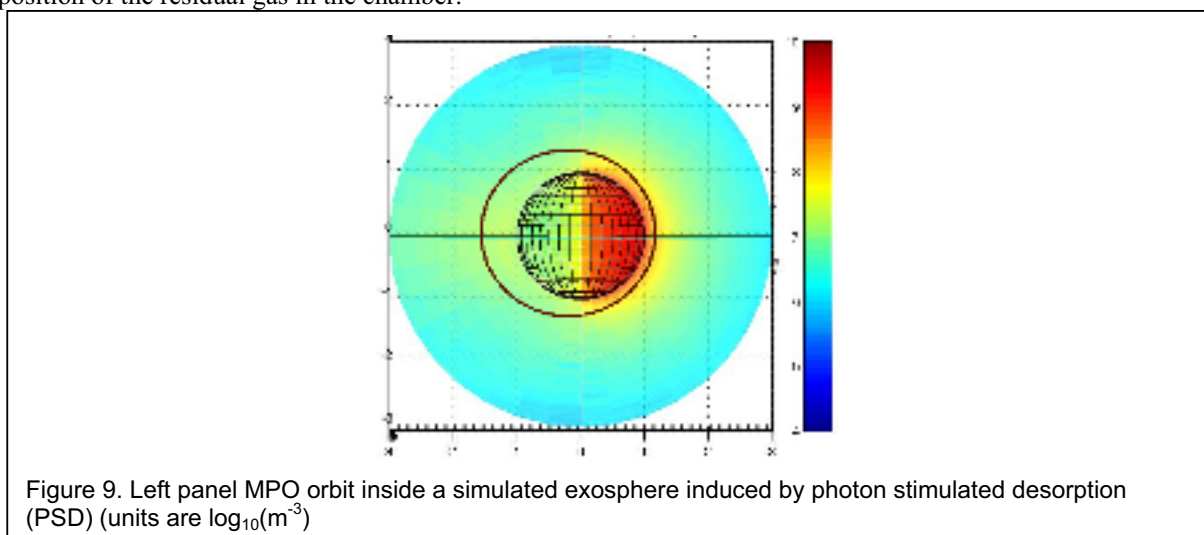
Figure 8 STROFIO box assembly.

1 particle/cm³). The mass resolution ($m/\Delta m = 60$) is achieved by fast electronics and does not require tight mechanical tolerances. STROFIO is a novel type of mass spectrometer: the start time is imprinted on the trajectory of the particle by a radio frequency electric field, that bends the trajectory in a given plane, and the stop time is the time when the particle reaches the detector. Every particle is analysed by the system, thus dramatically increasing the total sensitivity of the mass spectrometer. Moreover, its performances depends on fast electronics rather than on mechanical tolerances, making this type of sensors mechanical simple and easy to operate. In particular, the neutral particles enter into the ionization chamber through the entrance in the ram direction (see Figures 7-8). The neutral gas is ionized and accelerated into the mass analyzer. Here the ions experience the effects of an electric field, constant in magnitude, but with direction rotating uniformly in space, in a plane perpendicular to the initial ion velocity, at a frequency f . The trajectory of an ion can hit the detector only if the field points to the detector while the ion traverses the dispersing region. At other times, the ion will simply miss the detector. The time difference between the instant when the particle arrives at the detector and the time when the field was pointing in the appropriate direction is equal to the travel time through the field free region. In Table 3 the major STROFIO characteristics are summarized.

STROFIO signal simulation

In Figure 9 the MPO orbit is shown across an exospheric gas simulated release process induced by photon stimulated desorption. This is the major effect that causes exospheric refilling: in fact, the very low release energy does not allow any escape towards space. The particles flow along ballistic orbits, and then they may fall down on the planet surface. STROFIO will ‘capture’ these particles along the satellite ram direction, thus allowing a precise estimate of the mass composition.

Figure 10 shows a result obtained during a test of the STROFIO prototype. The spectrum shows the mass composition of the residual gas in the chamber.

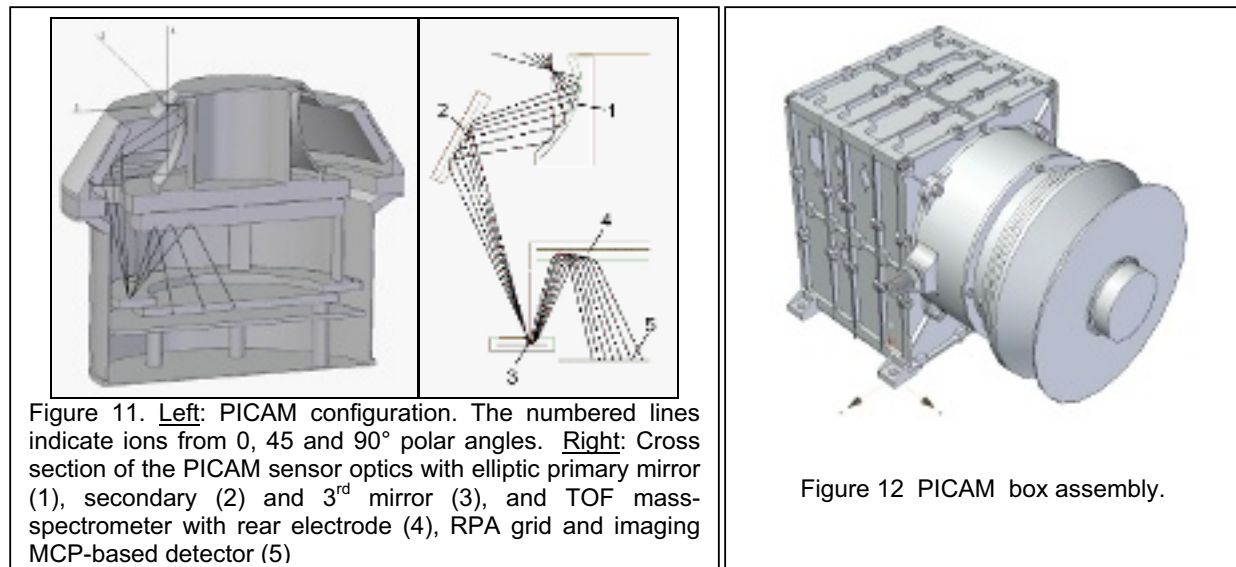


PICAM

PICAM (Planetary Ion CAMera) operates as an all-sky camera for charged particles (Vaisberg, 2001) allowing the determination of the 3D velocity distribution and mass spectrum for ions over a full 2π FOV, from thermal up to ~ 3 keV energies and in a mass range extending up to ~ 132 AMU (Xenon). The instantaneous 2π FOV coupled with this mass range and a mass resolution better than ~ 100 is a unique capability, which provides to PICAM superior performances in the frame of the MPO mission. Figure 11 shows a general layout of the sensor in order to obtain a 2π field of view. The ion optics is based on the principle of a modified pinhole camera. The sensor is symmetric along the Z-axis and its FOV is a hemisphere centred along this axis. Ions enter through an annular slit (Figure 11 left). After reflection on an ellipsoidal ion mirror the 90° polar angle distribution is folded into a 15° angular range. Here the ions pass a modulated wire gate which defines discrete packets of ions for analysis of the time-of-flight until the particles impact on the MCP. The modulation can be either single-shot or with a pseudo-random sequence which results in higher efficiency. After being reflected by a secondary, conical ion mirror, particles pass through a narrow, ring-shaped exit slit and are reflected by the third, planar mirror. Thereafter they enter the TOF and imaging section. A cross section of the ion optics is shown in Figure 11, right panel. UV rejection will be obtained by a striated primary mirror covered by a non-reflecting layer of Cu_2S , which decreases the UV reflection by a factor of 1000. Multiple reflections within the instrument, the small entrance slit and the narrow exit slit (3) in front of the mass analyzer provide very strong protection. PICAM is a single unit consisting of the sensor and an attached electronics box, which interfaces to the external electronics (see Figure 12). The outer part of the ion optics is designed for hot conditions. The lower part of the sensor containing the MCPs and the detector electronics is thermally decoupled. The specific PICAM electronics includes dedicated low and high voltage power supplies, detector, coordinate determination and gating electronics, and an FPGA-based controller. Table 4 summarizes the PICAM major characteristics.

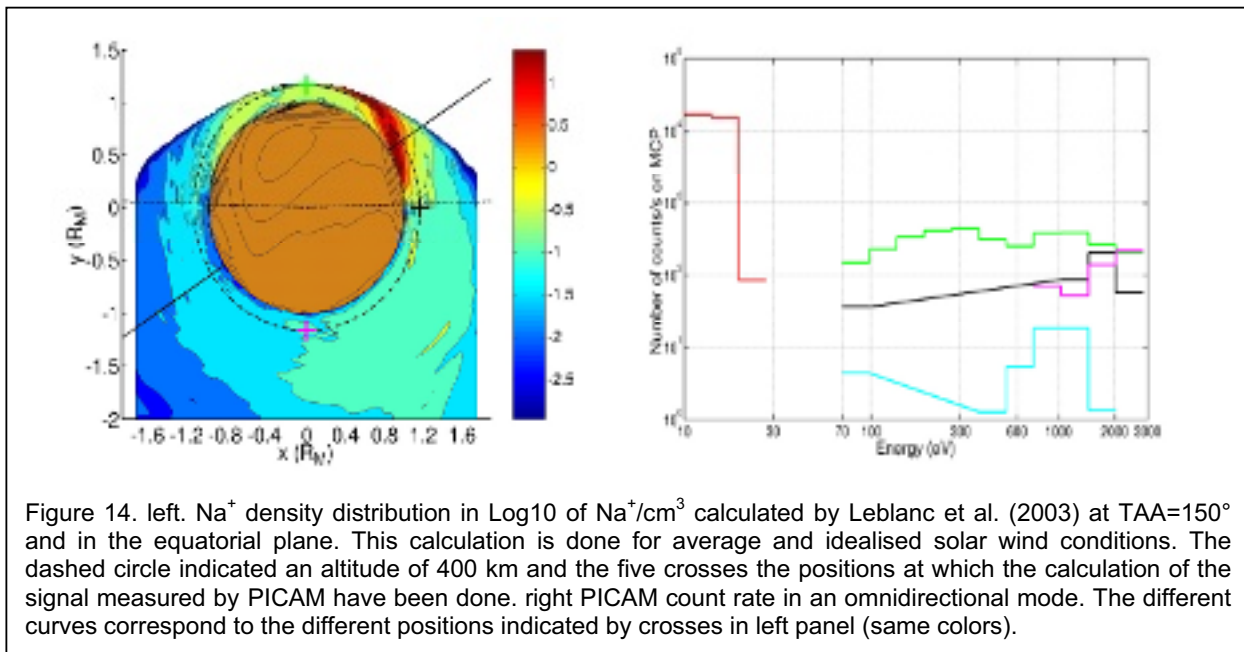
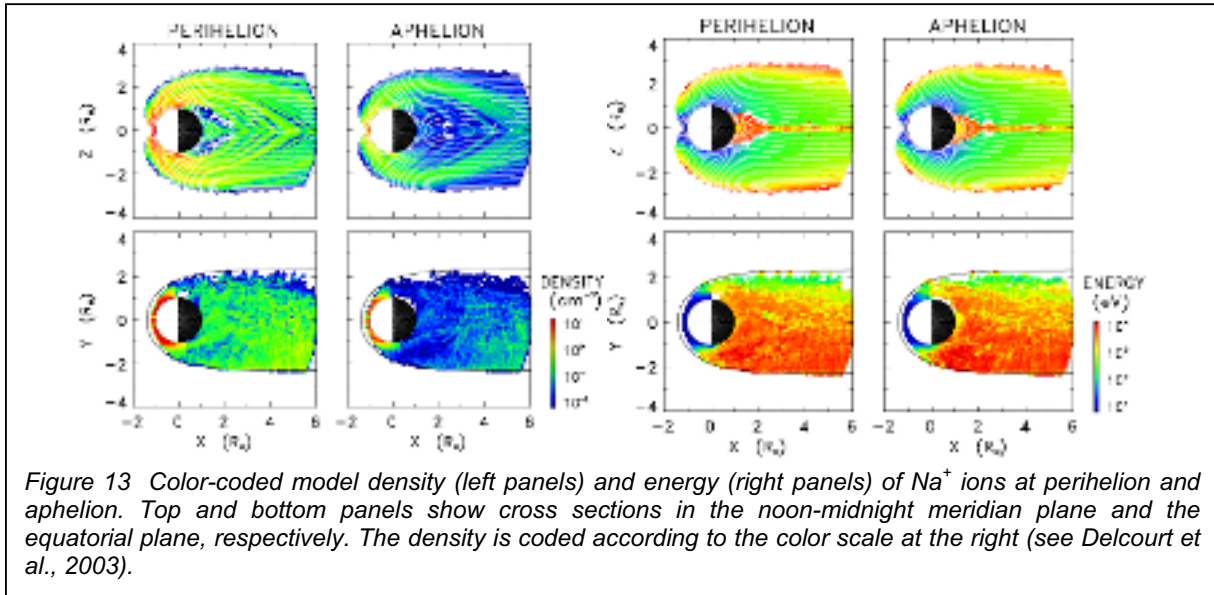
Energy range	1 eV - 3 keV
Energy resolution $\Delta E/E$	10%
Viewing angle	3-D, 2π
Angular resolution	$\sim 22.5^\circ$
Mass resolution $M/\Delta M$	>60
Mass range	1 ... ~ 132 AMU (Xe)
Time resolution	1 s ... 32 s
Geometric factor $G = S\Omega$	$3.4 \times 10^{-3} \text{ cm}^2 \text{ sr}$

Table 4. PICAM major characteristics



PICAM signal simulation

Delcourt *et al.* (2003) show that the ions trapped at low altitudes in the magnetic field of Mercury are drifting with velocities determined by the configuration of the magnetic and electric fields. The convection process results in localized ion populations, which may be accelerated to energies of several keV (see Figure 13). Using a 3D model describing the production and transport of neutral and ionised Na atoms around Mercury, Leblanc *et al.* (2003) derived the Na^+ distributions that can be expected at different positions around Mercury (Figure 14, right) from which PICAM count rates can be calculated (Figure 14, left). It is to be noted here that Na^+ ions are expected to be a relatively minor fraction of the ion population and therefore the count rates for most of the other ion species will be significantly higher. The estimates of the ion density are highly variable depending on assumptions. In Figure 15, the range of estimated densities at 400 km of altitude is shown for many species (Mg^+ , O^+ , C^+ , N^+ , Al^+ , Si^+ , S^+ , Fe^+ and Ni^+) (Leblanc *et al.*, 2004). The PICAM sensitivity is sufficient to perform significant measurements.



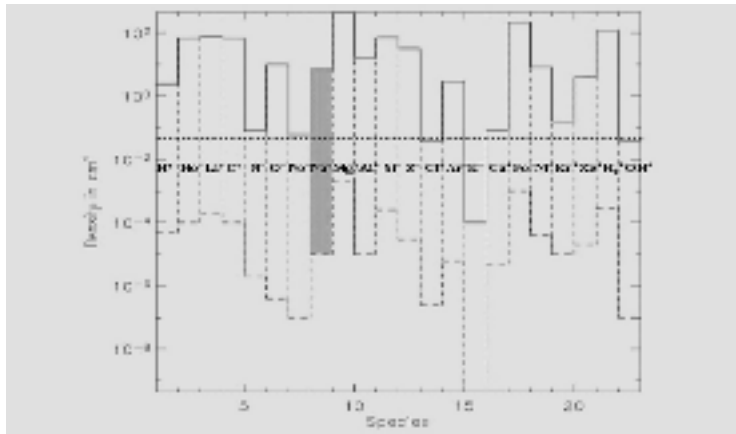


Figure 15. Range of expected densities at 400 km in altitude for the main ions thought to be present in Mercury's ion exosphere. Also indicated is the threshold of detection for PICAM at the satellite velocity (dashed black line). We underlined the case of the Na^+ , which has been discussed previously as a source of comparison to the other ions. The name of the ion is indicated. The solid line corresponds to the highest density expected and the dashed line for the lowest one. (from Leblanc et al., 2004)

MIPA

MIPA (Miniature Ion Precipitation Analyser) is a simple ion mass analyser optimised to provide monitoring of the precipitating ions using as little spacecraft resources as possible. The analyser is, yet, capable to measure all main groups of ions present in the magnetosphere. The energy range and mass range of the analyser was optimised to cover accelerated ionospheric ions. The ion flux arrival angle and energy are analysed by an electrostatic deflector, comprising of two 90° cylindrical electrodes, followed by an 128° double focusing cylinder electrostatic analyzer. The ions exiting the energy analyzer are post accelerated up to 1 keV energy by a voltage applied to a ToF cell. Inside the cell, ions hit START and STOP surfaces producing secondary electrons recorded by two ceramic channel electron multipliers giving respective timing. For energies above 4 keV, the post acceleration is switched off. The timing of the event gives the ion velocity and, in combination with known energy, the mass. Figure 16 shows the MIPA principle elements and the overall view. The MIPA total G-factor can be controlled/decreased by decreasing the post acceleration voltage resulting in lowering the impact energy and thus secondary electron yield from the START and STOP surfaces, and reducing the size of the aperture slits. The maximum possible geometrical factor given by optimization of all parameters is too high for the Mercury conditions (see simulated fluxes in Figure 16). The G-factor to be implemented in the sensor (base line) is to be lower than the maximum one. Table 5 lists the major MIPA characteristics.

Energy range	10 eV – 15 keV
Energy resolution $\Delta E/E$	7%
Viewing angle	$9^\circ \times 180^\circ$
Angular resolution	$4.5^\circ \times 22.5^\circ$
Mass range, amu	1 – 50
Mass resolution, $M/\Delta M$	~ 5
Time resolution, sec	8, Full Azimuth – Energy cycle (8A x 32E)
Efficiency,	1 – 10%
Geometrical factor	$1.8 \cdot 10^{-3} \text{ cm}^2 \text{ sr eV/eV w/o efficiency}$

Table 5. MIPA major characteristics

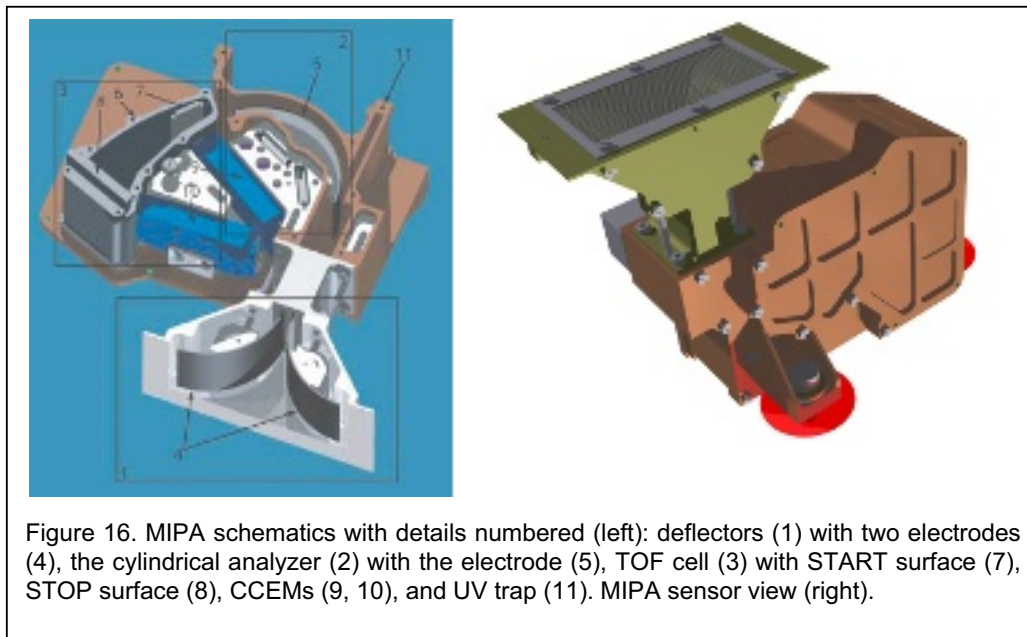


Figure 16. MIPA schematics with details numbered (left): deflectors (1) with two electrodes (4), the cylindrical analyzer (2) with the electrode (5), TOF cell (3) with START surface (7), STOP surface (8), CCEMs (9, 10), and UV trap (11). MIPA sensor view (right).

MIPA signal simulation

The SW plasma can enter the magnetosphere thanks to the magnetic reconnection of the IMF with planetary magnetic field. Massetti *et al.* (2003) notice that most of the energy of the precipitating magnetosheath particles (and flux estimated around $10^8 \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$) is deposited in a region that is narrow in latitude, but conversely extended in longitude (see Figure 17). A typical open field area of Mercury's cusps during moderate south-ward pointing IMF, under the assumption of a typical SW pressure of 16 nPa at 0.39 AU ranges between about 45° and 65° in latitude, and about -40° and 40° in longitude (see Figure 17). Different IMF orientations, SW conditions and electric field action cause the open area to shift in latitude and longitude, and to vary its extension (Sarantos *et al.*, 2001; Kallio and Janhunen, 2004; Mura *et al.*, 2005). This intense flux of SW protons toward the planet will be monitored by MIPA. The magnetic field configuration near Mercury is poorly known and the planetary

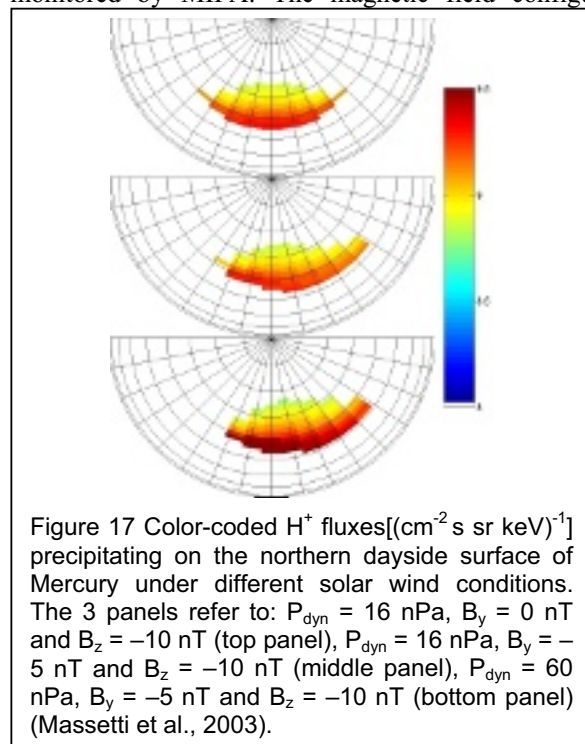


Figure 17 Color-coded H^+ fluxes $[(\text{cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ keV}^{-1})^{-1}]$ precipitating on the northern dayside surface of Mercury under different solar wind conditions. The 3 panels refer to: $P_{\text{dyn}} = 16 \text{ nPa}$, $B_y = 0 \text{ nT}$ and $B_z = -10 \text{ nT}$ (top panel), $P_{\text{dyn}} = 16 \text{ nPa}$, $B_y = -5 \text{ nT}$ and $B_z = -10 \text{ nT}$ (middle panel), $P_{\text{dyn}} = 60 \text{ nPa}$, $B_y = -5 \text{ nT}$ and $B_z = -10 \text{ nT}$ (bottom panel) (Massetti *et al.*, 2003).

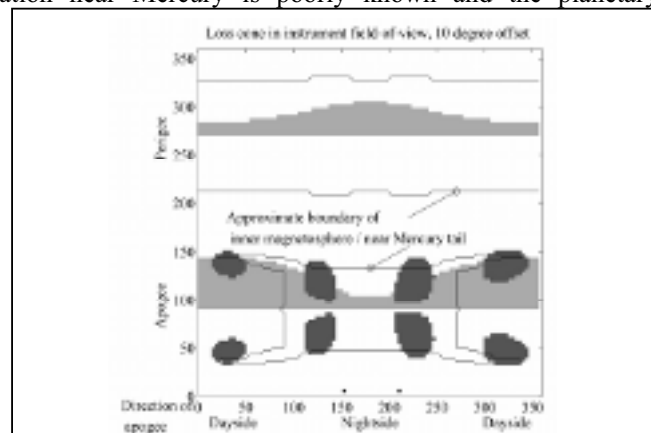


Figure 18. MIPA coverage of the loss cone as a function of the true anomaly angle and local time of the MPO orbital plane. Simulations for the real MPO orbit and the MIPA FOV is in the orbital plane with the bore-sight direction along the velocity vector. White regions: MIPA can observe particles within the loss cone. Light shaded regions: cases when all particles are coming from behind the sensor. Shaded regions: increasing likelihood that the entire loss-cone population is out of MIPA FOV (Nilsson *et al.*, 2003).

dipole field is highly deformed because of the solar wind interaction. Hence, the evaluation of the footprint of precipitating particles towards the surface is difficult. Because of the low-altitude orbit, MPO is the only platform useful for measuring and characterizing the amount of SW particles (Killen et al., 2004b, Massetti et al., 2003) as well as the heavier ions of planetary origin (Delcourt et al., 2003) that actually enter in the loss cone and, eventually, hit the planetary surface. In summary, MIPA will measure the flux of loss-cone-precipitating particles at Mercury (Figure 18), which through ion-sputtering will be a source of neutral and ion emission. The identification of the composition and energy distribution of the planetary ion flux impacting the surface can be achieved by joint analysis of MIPA and PICAM.

CONCLUSIONS

In order to successfully perform the observations, the SERENA units are based on novel concepts for particle instrumentation, potentially interesting for future planetary missions beyond BepiColombo. SERENA constitutes the only particle package on board the BepiColombo MPO. Thanks to the measurements provided by SERENA, a comparison with similar measurements taken on board the JAXA MMO satellite will be allowed. MMO is a spinning satellite that will elliptically orbit at higher altitudes; it will allocate instrumentation essentially devoted to the study of the Hermean Magnetosphere. The SERENA measurements will also complement other payload elements on board MPO devoted to environmental studies, like MERMAG (magnetic field), SIXS (solar radiation and energetic particles), and PHEBUS (UV exospheric emission).

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