ELENA scientific performances test results

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Outline

• ELENA science performances requirement (SPR) and SERENA calibration plan
• IFSI activity in the frame of ELENA science requirement together with the experimental activity devoted to instrument verification
• ELENA crucial elements considerations
  - Experimental results of ELENA nano-shutters particle beam test: Open-Closed shutter validation
  - MCP calibration
• Conclusions
ELENA instrument

The neutral sensor ELENA for the ESA cornerstone BepiColombo mission to Mercury (in the SERENA instrument package) is a new kind of low energetic neutral atoms instrument, mostly devoted to sputtering emission from planetary surfaces, from $E \sim 20$ eV up to $E \sim 5$ keV, within 1-D (4.5°x76°).

ELENA is a Time-of-Flight (TOF) system, based on oscillating shutter (operated at frequencies up to a 100 kHz) and mechanical gratings: the incoming neutral particles directly impinge upon the entrance with a definite timing (START) and arrive to a STOP detector after a flight path. In this way the low-energy neutral particles are directly detected, without using elements of interaction.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>$&lt;0.02$-5 keV (mass dependent)</td>
</tr>
<tr>
<td>Velocity resolution $\Delta v/v$</td>
<td>Down to 10%</td>
</tr>
<tr>
<td>Viewing angle</td>
<td>4.5°x76°</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>4.5°x4.5° (actual)</td>
</tr>
<tr>
<td></td>
<td>4.5°x2.4° (nominal pixel)</td>
</tr>
<tr>
<td>Mass resolution $M/\Delta M$</td>
<td>H and heavy species</td>
</tr>
<tr>
<td>Optimal temporal resolution</td>
<td>40 s</td>
</tr>
<tr>
<td>Geometric factor $G$</td>
<td>$2 \times 10^{-5}$ cm$^2$ sr</td>
</tr>
<tr>
<td>Integral Geometric factor</td>
<td>$6 \times 10^{-4}$ cm$^2$ sr</td>
</tr>
</tbody>
</table>
2.1.1. ELENA calibration plan
The following ELENA elements will be independently tested and then assembled in the instrument.

2.1.1.1 Sub-unit test
- **The collimator ion rejection capability**
  Deflection plates are used to remove the charged particles from the neutrals direction in the ELENA instrument. Laboratory measurements are needed to define the real rejection capability of the system with respect to the simulated and calculated performances.

- **The ToF system**
  ToF system is realised with the START element consisting in an ultrasonic oscillating shutter and mechanical gratings (for the stop a MCP detectors is used). A preliminary test is necessary for the hi-frequency mechanical oscillator and the hi-resolution grating, in particular to verify the stability and performance in time of this START module.

- **Stop and Position detection with MCP detector.**
  Its efficiency at low energy and the discrete anode reading of the impinging position of the particles will be peculiar for the instrument to acquire the Stop of the particles and the incoming direction. Also the capability to distinguish the mass with its pulse-height will be verified.

2.1.1.2 Assembled instrument test
The instrument has to be verified in its functionality with all the modules assembled. The requested specifications will be tested and the calibration data set will be realised.

2.1.1.3 ELENA calibration test
The ELENA ground calibration activity will be performed at INAF/IFSI in Rome and at University of Bern.

The ELENA suite will be calibrated in its three peculiar objectives: capability of analysing the flow direction, the energy/mass resolution of the incoming particles, the ToF detection. The angular resolution has to be tested with a rotating system located into a vacuum chamber. The instrument will rotated with respect to the particle beam at several angles and a set of measurements will be developed to test the capability of analysing different directions of the incoming particles. The energy of the beam will be varied from few eV up to 5 keV and different masses have to be used to calibrate the Time of Flight system.
IFSI-INAF laboratory for ELENA particle beam test

IFSI-INAF ion beam laboratory at the research centre of Tor Vergata in Rome. At the moment one of the primary activity is the BepiColombo mission in the ELENA-SERENA unit and sub-unit testing and calibration.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum system</td>
<td>Pump system composed by a scroll, a turbopump or a cryopump reaches pressure up to 10-8 mbar.</td>
</tr>
<tr>
<td>Ion Beam</td>
<td>IQP 10/63 Penning discharge type ion source with energy range of 0-5 keV.</td>
</tr>
<tr>
<td>Residual Gas Analyser</td>
<td>Ametek-Dycor quadrupole mass spectrometer with AMU range 1-200.</td>
</tr>
<tr>
<td>Rotation, Translation</td>
<td>+/- 45 transverse axis rotation and 0-360 orthogonal axis rotation with 0.01 resolution Transverse Manipulator: translation 0-10cm</td>
</tr>
<tr>
<td>Detector</td>
<td>Custom Faraday Cup, MCP (Hamamatsu) chevron configuration</td>
</tr>
</tbody>
</table>

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Crucial ELENA elements to be tested with particle beam

• Crucial elements to reach the requested performances for TOF ELENA instrument are
  1. the **Start** element : Shutter System
  2. the **Stop** element : MCP detector (efficiency for low energy particles)

→ these two challenging items are the actual objects of our laboratory activity because they need to be tested with particle beam
1 - Shutter system
The crucial and innovative element of ELENA ToF system is the shut section consisting of a shutter system. The prototypes (realized by ISC-CNR and IFN-CNR) are tested at IFSI with particle beam.

The ELENA shutter prototype IIb characteristics
The shutter prototype consists of two bi-dimensional nano-gratings with slits of width of 400nm and 4µm pitch separated by about 5 µm. A piezoelectric ultrasonic actuator is used for oscillating the shutter.

<table>
<thead>
<tr>
<th>Shutter prototype IIb</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>Δx (ΔV)</td>
</tr>
<tr>
<td>ν</td>
</tr>
</tbody>
</table>

The gratings are Si3N4 laminas of 1µm thickness, with slits length of about 400nm X 2.4mm, respectively repeated every 4µm.
Shutter system: the alignment and motion control

- The **angular deviations** as well as the **distance** between the two ELENA gratings are to be finely regulated.

Shutter prototype IIb alignment *(by S.Selci-ISC)*

- The **angular deviations** are regulated by **Laser projection**.
  - Superposing the interference patterns coming out from the two gratings one can obtain a precision of about **1mrad** (1mm spotsize/1 meter projection).

  - A better precision will be provided by foreseen capacitive sensors.

  By IFN-CNR
• **Experimental set-up:**
  - Ion beam (IQP 10/63 Leybold/Specs source)
  - Position controller (IT6DCA Microcontrole and manual manipulator)
  - MCP detector in chevron configuration (Hamamatsu F2222)+HV(0-6kV) power supply ISEG-NHQ226L + Custom Charge Pre-amplifier-Shape amplifier SILENA 7611L
  - Frequency counter AGILENT 53131A /Oscilloscope HP 54645D
  - NANOTECH bipolar power ampl. 0- ±500V + Programmable 10MHz DDS function generator TTi TG1010
**Closed condition.** It was necessary to verify the opacity of membranes to the ion beam to allow the closed condition: a no-patterned membrane has been compared with closed shutter position → the beam is perfectly stopped.
Open-Closed shutter test-2 (linear displacement)

Open-Closed “Static” test (linear piezo voltage variation 0-110 V) at different He ion beam energy (500eV-1keV-2keV)

→ The open position, the pitch of ~4μm and the closed position are verified.
Open-Closed shutter test-3 (dynamic displacement variation)

Open-Closed ‘Dynamic test: (sinusoidal piezo voltage variation 0 - 95 V) test at low frequency shows good functionality of the open-closed shutter condition.

![Piezo Voltage](image.png)

<table>
<thead>
<tr>
<th>Piezo Voltage</th>
<th>0 - 95V</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \nu ) (frequency)</td>
<td>(~ 20 \text{ Hz})</td>
</tr>
<tr>
<td>Ion beam</td>
<td>Helium, ( E=1 \text{keV} )</td>
</tr>
</tbody>
</table>
State of the art for Start element at IFSI

- Prototype IIb experiment: validated
- Prototype IIc experiment (slit of 200nm): Test has been stopped to go forward for a different solution:
  → From scientific team different technological requirements are established to upgrade TOF resolution and the prototype has to be improved with a DLC coating on the membranes to realize a 0-distance condition in the shutter.
  → Membranes with DLC deposition are realized at Nanotech centre in Marghera (Italy) (see M. D’Alessandro-ISC presentation tomorrow morning 25 August)

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The MCP detection efficiency
The detection efficiency of a MCP is an important performance parameter. In the ELENA application it's crucial to understand the limit of this detector for very low impact energy.

The choice of the parameters:
several features can affect the detection efficiency: the Open Area Ratio (OAR), the Bias Angle, the coating that can efficiently enhance the secondary emission and consequently the detection efficiency. All these parameters can be accurately analysed to choose the better system.

In the past there have been many attempts to characterize and predict the detection efficiencies of MCP for electrons and ions. Less well studied is their detection efficiencies for low energy neutral species. This fact probably depends on the lack of facilities able to produce variable and well-controlled low energy beams of neutral atoms.

Stephen and Peko has procured some data about this argument for O and H species (Stephen et al, 2000; Peko et al., 2000) in the range 30eV-1000eV showing the dependence of efficiency with the energy and the charge state.

The new interest in this field is surely stimulated by the new attempts of the space science community to propose instruments to investigate phenomena with very low energetic ions and atoms to be detected. In our case for BepiColombo mission to Mercury, the ELENA instrument proposed is an application of these new line.

Fig. 1. Absolute detection efficiencies for $H^-$ (■), $H^+$ (○) and $H^+$ (▲) are presented in (a) as a function of impact energy. Efficiencies for $D^-$ (□), $D^+$ (○) and $D^+$ (▲) are given in (b).

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Our facility is not pointed to a very low energy range. Nevertheless in the past we tried to extrapolate some information about the MCP efficiency at facility in the ENEA Research Centre in Frascati at ENA facility. Using a retarding system we obtain the requested energies.

The measurement and the results

An *Absolute Detection Efficiency (ADE)* measurement needs to have the possibility to know the impinging particles and the detected ones. The ratio of these two data can be considered the ADE. The actually experimental apparatus doesn’t allow to do that.

So what we have done is to investigate the *Relative Detection Efficiency* respect to a known efficiency value at fixed high energy. We detect the particles signal at a fixed energy (in which the efficiency is considerate known) and then we slow down the impinging particles to measure the resulted detection particles at lower energies. We try to investigate an Hydrogen ion beam of H+ and H- to observe the relative efficiency behaviour.

→We obtain for H- specie a result in agreement with data of Stephen-Peko.
To evaluate the efficiency for ELENA we have used different fits of Stephen-Peko data:

Simulated Sputtered detected particles *(by A. Mura)*

Simulated Back-Scattered detected particles *(by A. Mura)*
Detection efficiency $Q_i$

$Q_i (\theta, \theta_B, E, Z_i, n, V_0, V_{\text{coll}}, L, h, D, A_{\text{open}})$

**Atom**: $E =$ energia cinetica (v), $Z_i =$ num. atomico, $n =$ carica elettronica  
$\theta =$ angolo di incidenza

**MCP**: $D =$ diametro, $L =$ lungh. Canale, $\theta_B =$ bias angle (inclinazione canale),  
$A_{\text{open}} =$ open area fraction

MCP electrodes: $h =$ channel penetration (or coating penetration depth)  
MCP voltage: $V_0 =$ pot. difference along the length of channels,  
$V_{\text{coll}} =$ pot. diff with metal mesh of transparency $T_m$

(from Fraser, 2002)
STATE of the art
for MCP detector efficiency

MCP efficiency calibration with neutrals

After preliminary test with ions and existing data analysis we have scheduled measurement of the detection efficiency for the selected ELENA type MCP in the energy range < 1keV

(Advance Performance Long-Life™ Microchannel Plate Detector APD 2 170X20/12/10/12 D 60:1 NR EDR CsI CUSTOM 01 - proposed by Photonis)

• ADE-RDE
• Low neutral beam (10-1000eV)

(Wieser and Wurz, 2005)

→ Facility: MEFISTO, UniBe
• Scheduled time: September/October 2010

MCP Characteristics

<table>
<thead>
<tr>
<th>Dim</th>
<th>170x20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias angle</td>
<td>12°</td>
</tr>
<tr>
<td>Pore size</td>
<td>10µm</td>
</tr>
<tr>
<td>C-C</td>
<td>12µm</td>
</tr>
<tr>
<td>Quality</td>
<td>1</td>
</tr>
<tr>
<td>L/D</td>
<td>60:1</td>
</tr>
<tr>
<td>Type</td>
<td>EDR</td>
</tr>
<tr>
<td>Coating</td>
<td>CsI</td>
</tr>
</tbody>
</table>

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Conclusions

The neutral sensor ELENA for the ESA cornerstone BepiColombo mission to Mercury (in the SERENA instrument package) is a new kind of low energetic neutral atoms instrument in particular for its Start section composed by a shuttering system:

- Collaboration of several institutions has allowed to realize prototype with manufacturing of nano-slits membranes (IFN-CNR), to apply the ultrasonic piezo actuator (ISC-CNR).

- Optical test have yet validate the propriety of this system with photons.

- Particle beam test at IFSI-INAF is the first validation of this new kind of Start section for a Time of Flight instrument devoted to low energy particle detection.

- ELENA MCP detection efficiency has to be calibrated at UniBe/MEFISTO facility.