

# Space Weathering on Near-Earth Objects investigated by Released Atoms MONitor



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and the RAMON Team

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# Outline

- RAMON scientific objectives
- Scientific requirements: expected neutral atom environment
  - The SPAWN Model
  - Results of the simulations
- RAMON basic concept

# Released Atoms MONitor key questions

- What processes can be identified as happening on the surface of the NEO as a result of exposure to the space environment and collisions? What is the erosion and the space weathering significance at the NEO surface?
- What is the efficiency of each process as a function of environment conditions?
- Is the efficiency of particle release processes uniform in the NEO surface?
- What is the composition of the escaping material and consequently, how it relates to the surface composition?
- What is the role of the surface release processes in the body evolution?

# Released Atoms MONitor scientific objectives

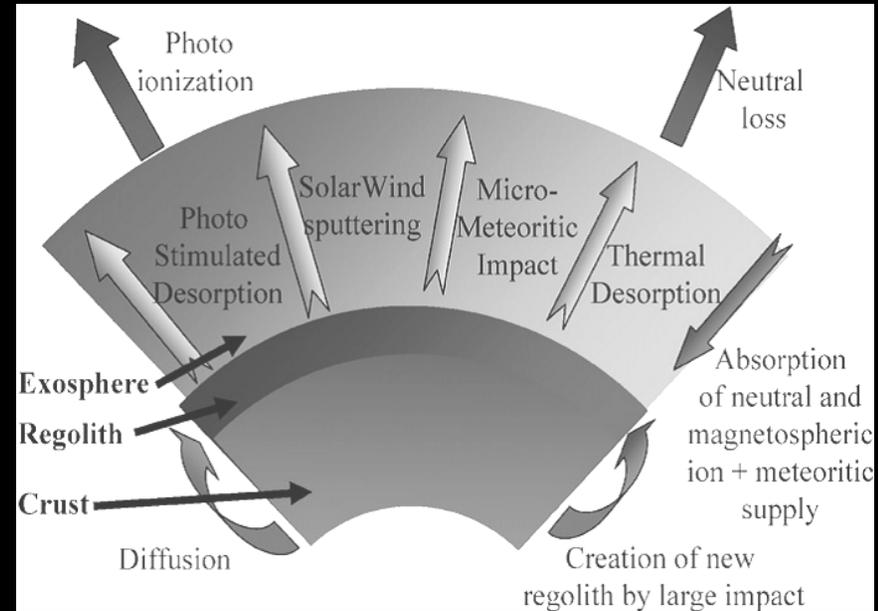
- To identify the particle release processes active on the NEO surface
- To evaluate the efficiency of each process as a function of environment conditions
- To evaluate the efficiency of each process as a function of surface properties
- To determine the composition of the escaping material
- To estimate the role of the surface release processes in the body evolution.

**Via RAMON the effect of space weathering on NEO will be investigated**



# What processes happen on the surface of a NEO

- **Ion Sputtering (IS)** : removal of a part of atoms or molecules from a solid surface, due to the interaction of a projectile ion with target electrons and nuclei, as well as secondary cascades of collisions between target atoms (Sigmund, 1981) → refractories (e.g. Si, Al, Mg) and volatiles, from 1 to > 100 eV)
- **Photon Stimulated Desorption (PSD)** : desorption of neutrals or ions as a result of direct excitation of surface atoms by photons (Hurych, 1988). → volatiles, < 1 eV (e.g. H, Na, K, C etc.)
- **Thermal Desorption (TD)** : exists when the thermal energy of an atom exceeds the surface binding energy → volatiles, < 1 eV (e.g. H, Na, K, C etc.)
- **Micrometeoroid Impact Vaporization (MIV)** : caused by micrometeorites hitting the surface of the asteroid



*Schematic view of the main mechanisms acting on a surface exposed to the solar system environment (Leblanc et al., 2007).*

# The SPAce Weathering on NEO (SPAWN) Model

intended to study space weathering effects taking place on the surface of an asteroid in the near-Earth interplanetary environment

## MODEL ASSUMPTIONS

### NEO surface composition :

- CI-chondrite type

### Surface processes : IS, PSD and TD.

*The most important exospheric process on the sunlit side of an asteroid at distances above 2 AU is the IS (Schläppi et al., 2008).*

*The **MIV contribution** is about one order of magnitude lower than the solar-wind sputtering at the subsolar point (Schläppi et al., 2008) and therefore it is not considered.*

Bulk element adapted from  
Brown et al. (2000)

Mass (amu)	Element	CI (atoms%)
1	H	38
12	C	11
24	Mg	15
27	Al	1
28	Si	14
32	S	6
40	Ca	1
56	Fe	13
59	Ni	1
	<b>Total</b>	<b>100</b>

IS occurs only on the dayside of the NEO.

# Contribution of TD and PSD

In the SPAWN Model TD and PSD are applied only to the **H-and-C** NEO populations (volatiles)

## Assumptions :

- energy distribution given by Wurz and Lammer (2003)
- photon flux in the orbit of Earth equal to  $3.31 \cdot 10^{19} \text{ m}^{-2}\text{s}^{-1}$  (Schläppi et al, 2008)
- PSD cross section equal to  $10^{-24} \text{ m}^2$  for the volatile components
- asteroid regolith surface density equal to  $7.5 \cdot 10^{18} \text{ m}^{-2}$  (Wurz and Lammer, 2003).

## Results :

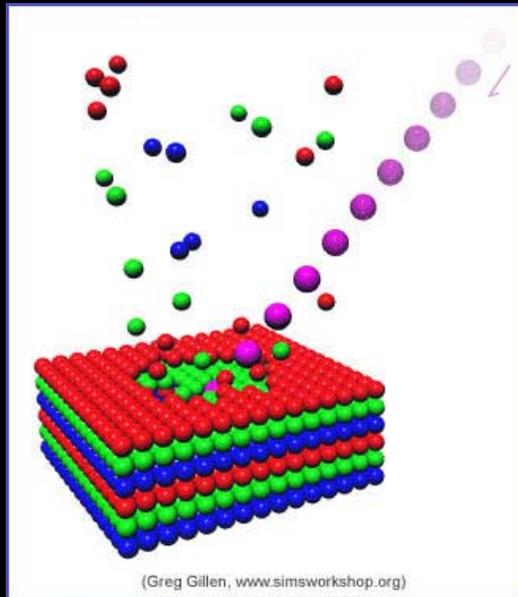
- The total density of the volatiles emerging from the NEO surface, via the **PSD** process, is  $\sim 1 \cdot 10^8 \text{ particles/m}^3$ .
- The released volatiles particle density, emerging from **TD**, varies from  $\sim 10^4 \text{ particles/m}^3$  (for  $T=400\text{K}$ ) to  $\sim 5 \cdot 10^8 \text{ particles/m}^3$  (for  $T=500\text{K}$ ).
- The erosion rate under PSD is estimated at  $\sim 10 \text{ \AA/year}$ . Since in the past NEO was located farther from the Sun and its temperature was lower, the erosion due to TD must have been negligible.
- Simulating both PSD and TD , we find that the total released particle density varies from  $\sim 1 \cdot 10^8 \text{ particles/m}^3$  to  $\sim 6 \cdot 10^8 \text{ particles/m}^3$ .
- The fluxes emerging via PSD and TD processes are 1.5-2 orders of magnitude more intense than those emerging via solar-wind sputtering.

Since in the past NEO was located farther from the Sun and its temperature was lower, the erosion due to TD must have been negligible.

All elements apart volatiles cannot be released from the surface via PSD and, thus, once H and C are removed the process comes to a standstill until material diffuses from the interior to the surface or fresh material is exposed by other processes (e.g. sputtering).

## Ion-sputtering

Production of Energetic Neutral Atoms (ENA) after the bombardment of a surface by energetic ionized plasma



The ion sputtering products depend on

- the composition and the chemical structure of the surface.
- the impinging plasma flux

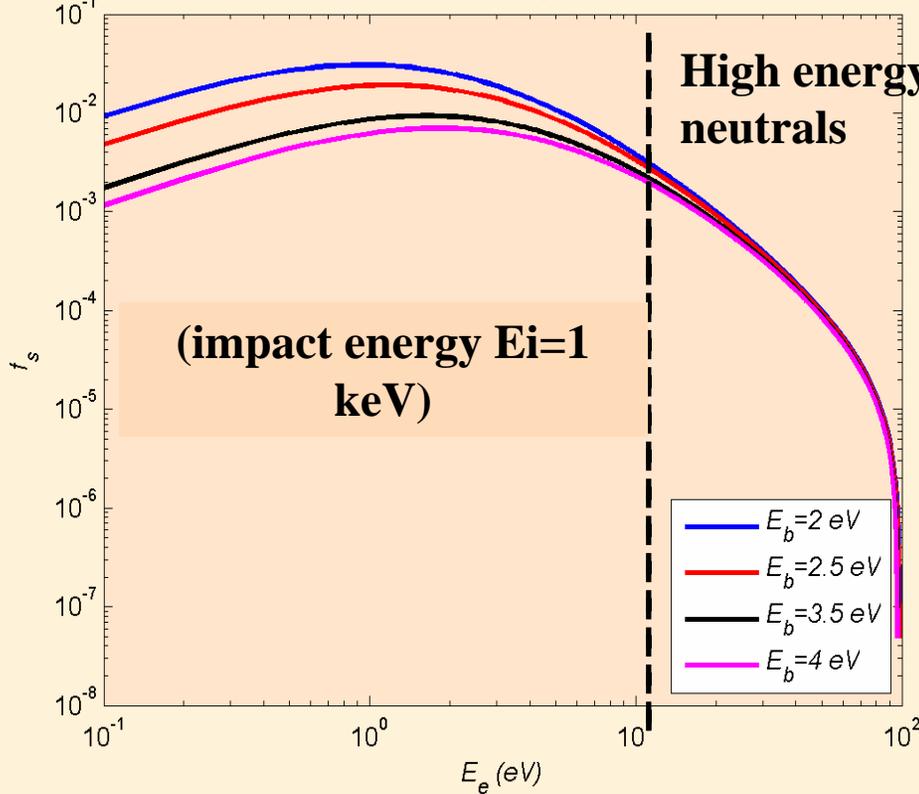
The basic quantities of interest are mainly two:

- the composition of the ejected particles
- the space flux distribution and the space density distribution of the sputtered particles

Examples of ion-sputtering process → Mercury, Moon, Europa, Saturn.

# Directional neutrals from the NEO surface

Energy distribution for sputtered particles using Sieveka and Johnson (1984) function



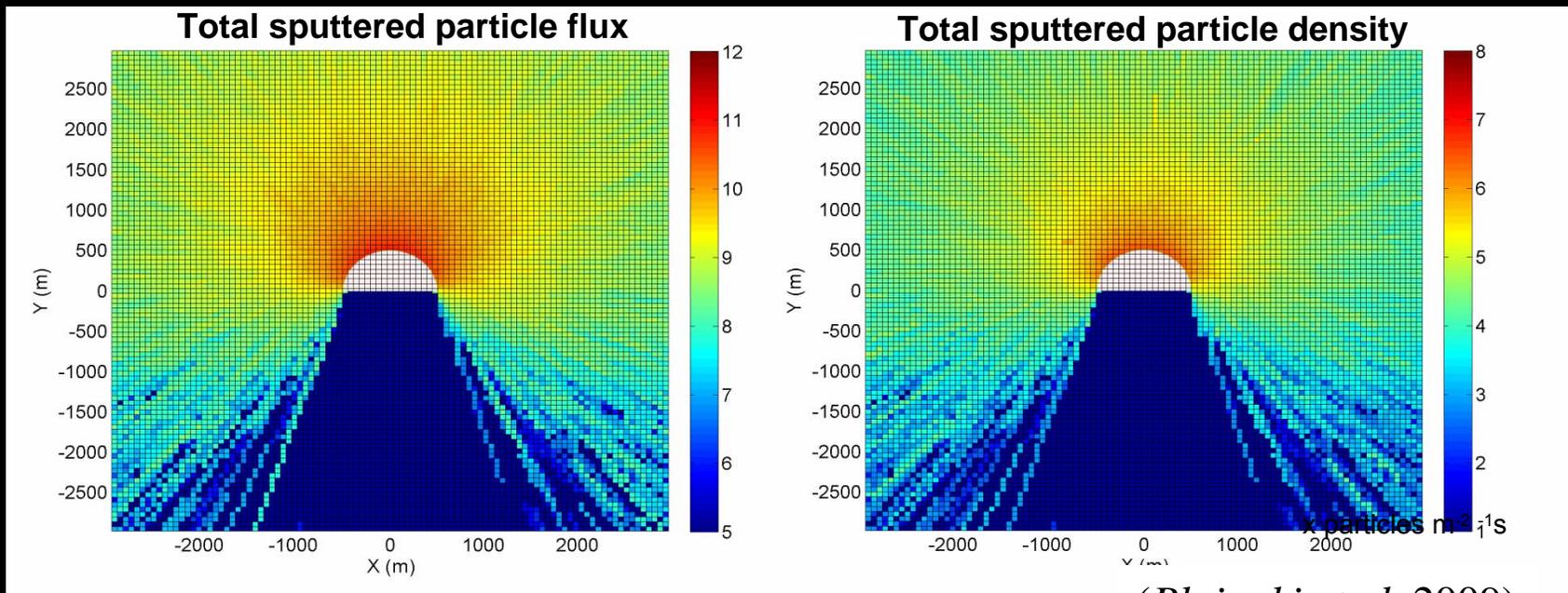
$$f_s(E_i, E_e) = \begin{cases} A \cdot \frac{E_e}{(E_e + E_b)^3} \left[ 1 - \left( \frac{E_e + E_b}{T_m} \right)^2 \right] & E_e \leq E_i - E_b \\ 0 & E_e > E_i - E_b \end{cases}$$

where  $E_e$  is the energy of the ejected particle,  $E_i$  is the energy of the incident particle and  $E_b$  is the binding energy

The detection of particles above 10 eVs (Sputtered High Energy Atoms - SHEA) is a method to identify the action of the ion-sputtering process on the NEO surface. In the energy range between 10 eV and a few keV particles released from all other processes are negligible.

- The mass identification is useful for determining properties of escaping material. For this goal the bulk of emitted particles must be detected.

# Results of the MC simulations for CI type NEO surfaces

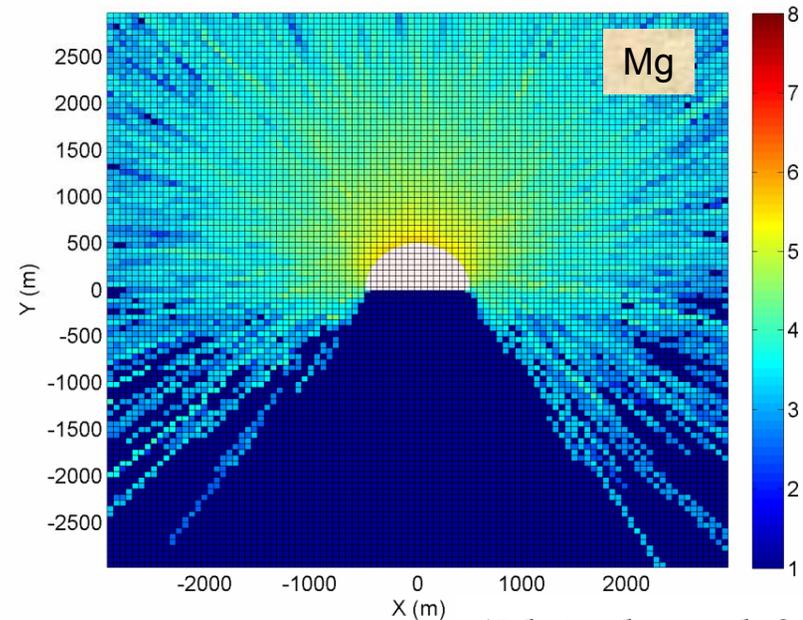
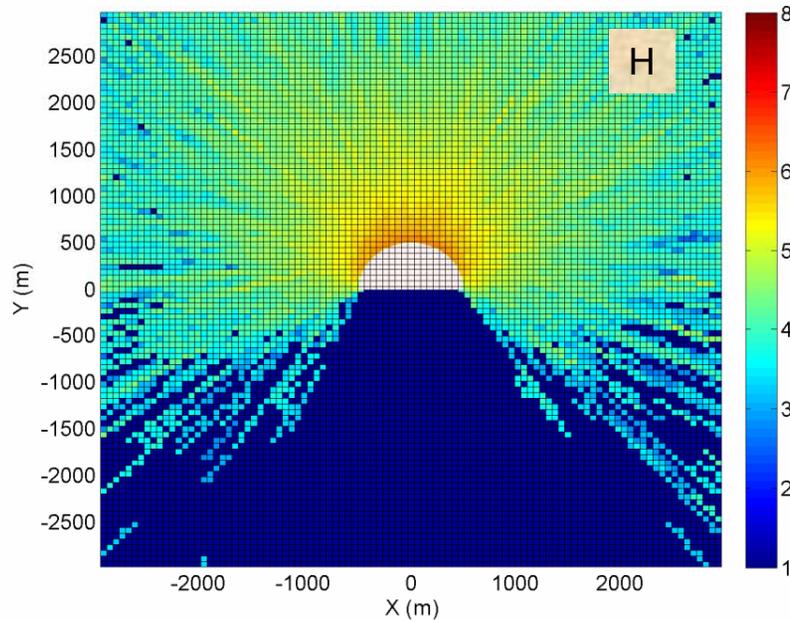


(Plainaki et al. 2009)

- Particles fluxes (up to  **$10^{11}$  particles  $m^{-2} s^{-1}$** ) appear in a region up to **1 km** above the NEO surface (in the solar wind direction).
- Maximum density is  $\sim$   **$3 \cdot 10^6$  particles  $m^{-3}$** .
- The global release rate from a NEO of radius **0.5 km** is estimated to be  **$3.14 \cdot 10^{17}$  particles/s**.

# Results of the MC simulations

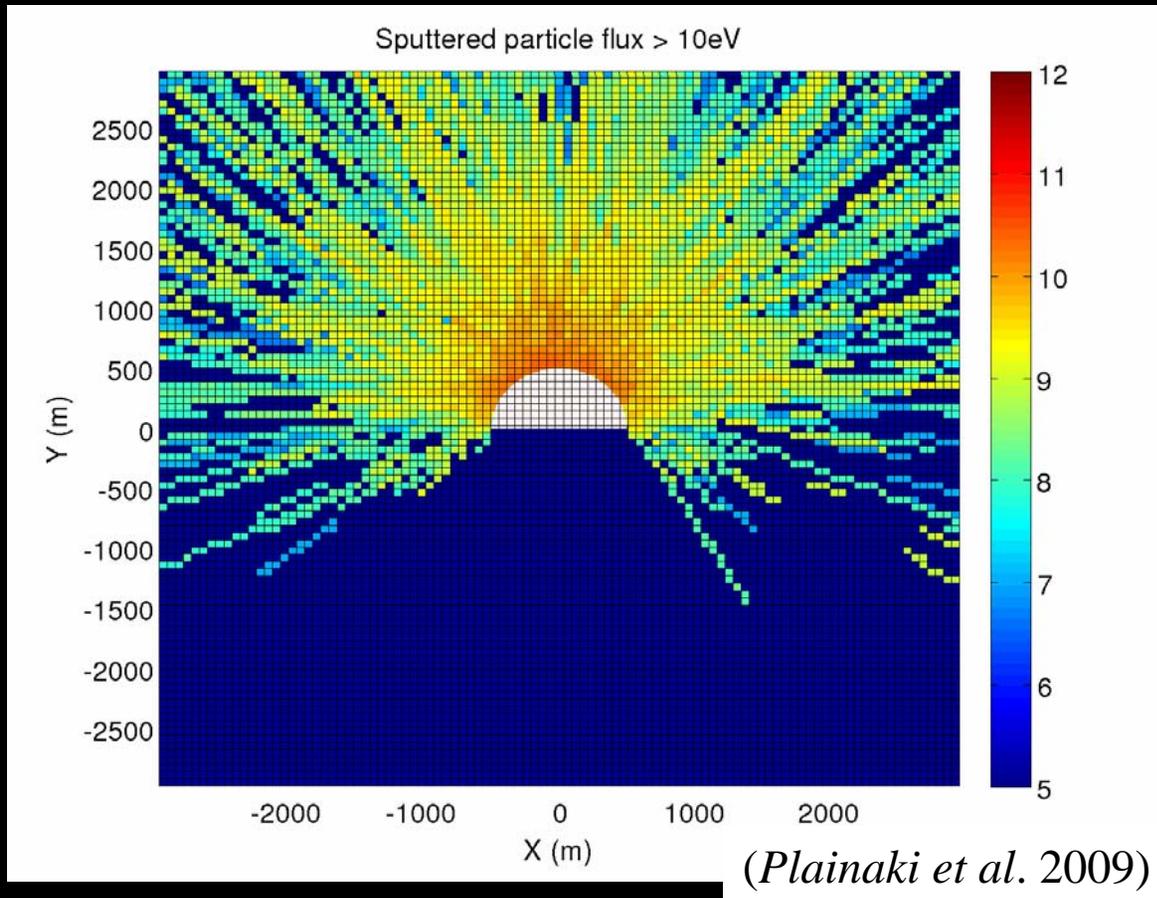
## Sputtered particle density of individual species



(Plainaki et al. 2009)

- The expected H density is bigger than that of Mg by a factor of  $\sim 10$ . This difference is related to the higher H abundance and to the higher H sputtering yield (Starukhina, 2003).
- The sputtered-H density constitutes  $\sim 90\%$  of the total one.

# Results of the MC simulations for SHEA



The SHEA flux (>10eV) derived by previous considerations is in the range  $10^9$  -  $10^{10}$  particles  $m^{-2} s^{-1}$ , which correspond to  $\sim 1$ -10 % of the total one.

# RAMON

It consists of two neutral atom sensors able to detect and characterize (in terms of Time of Flight (ToF), mass and direction) the neutral atoms released from the Near Earth Object (NEO) surface. In particular,

- **SHEAMON (Sputtered High-Energy Atoms MONitor)** will investigate the ion-sputtering process by detecting Sputtered High-Energy Atoms (SHEA) between  $\sim 10$  eV and  $\sim 3$  keV and determining their direction and ToF;
- **GASP (GAs SPectrometer)** will analyse the mass of the low-energy (below 10 eV) neutral atoms released by different surface processes.

# RAMON Concept

The composite radiation made by neutrals, ions and photons at the aperture.

Electrostatic lens (B) reject ions and electrons.

The neutral particles pass through an entrance of about 1 cm<sup>2</sup> divided for detecting low energies and higher energies.

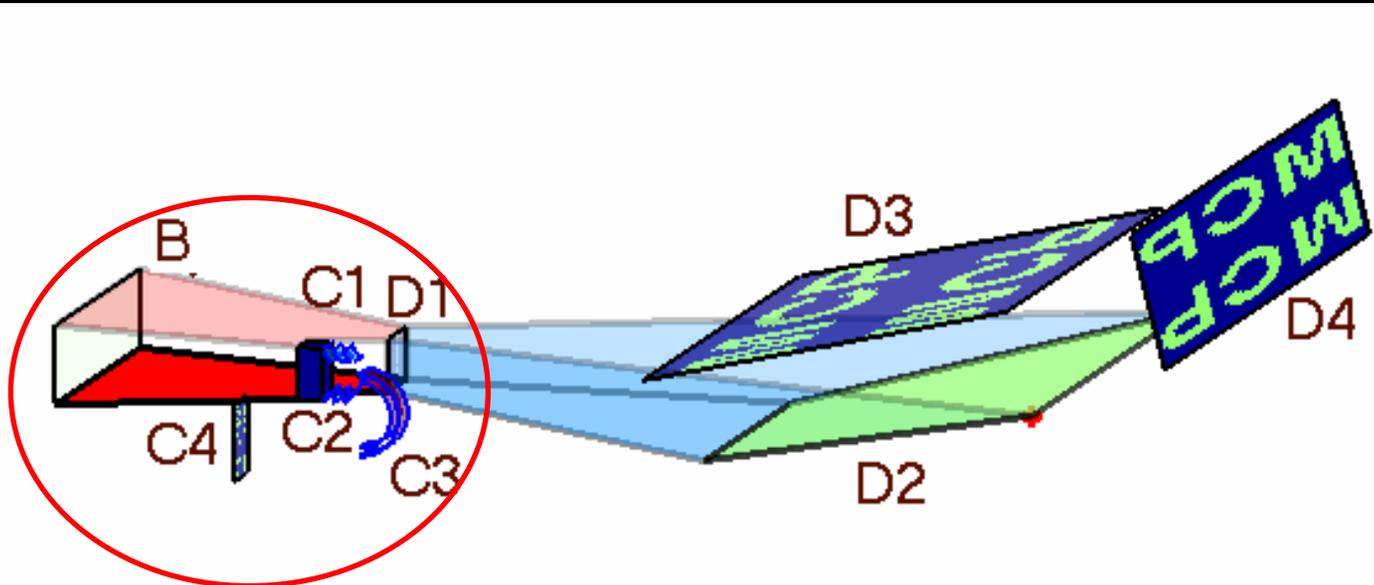
**GASP**: carbon nanotube system (C1).

electronic gate (C2) provides the START of the detection.

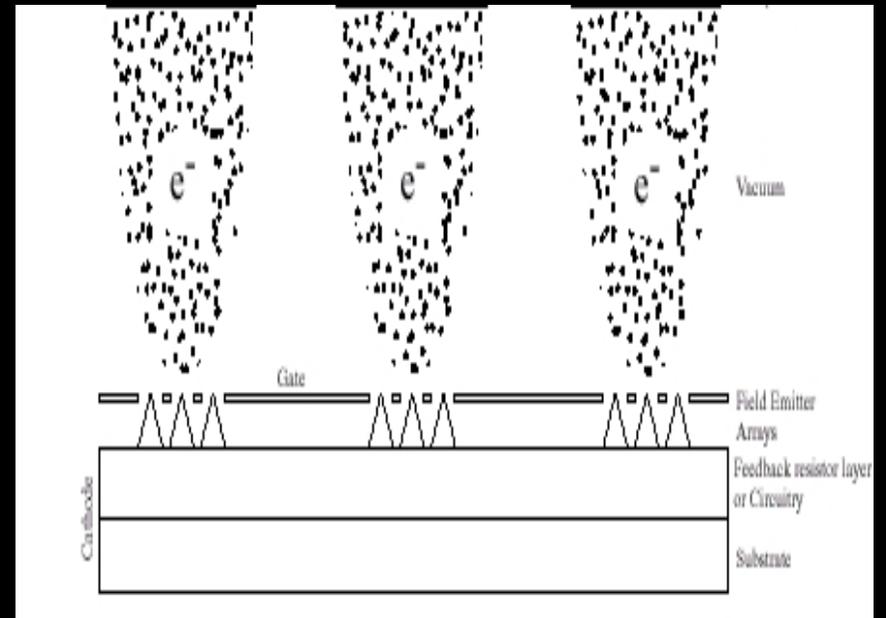
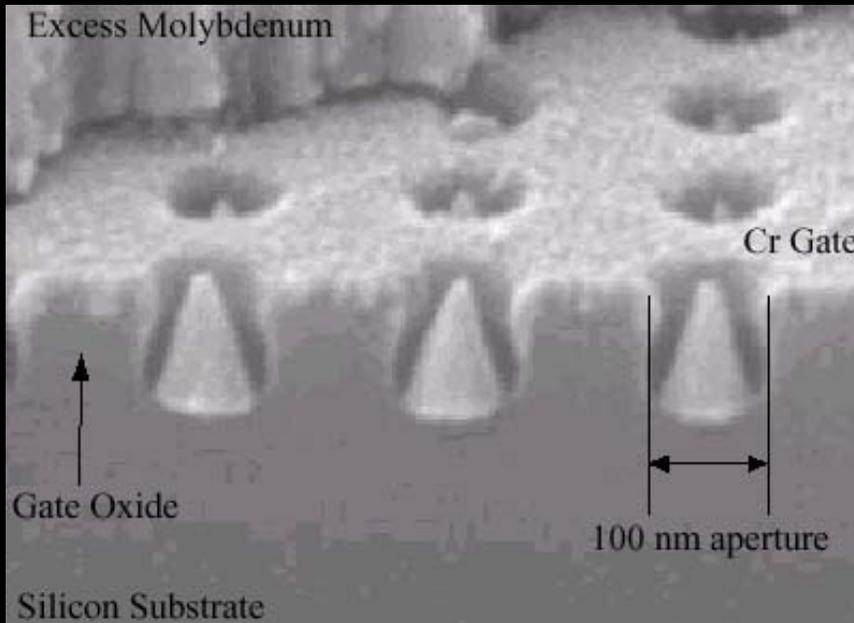
Particles are deviated and accelerated up to more than 1 keV by an electrostatic analyser (C3) and are detected by a MCP (C4). The time of flight provides **information about mass** (since the spread in energy is assumed negligible).

$\Delta m/m$  depends  
on mass  
~10% (H)  
~3% (50 amu)

GF= 0.14  
(Cnt/s)/cm<sup>-3</sup>



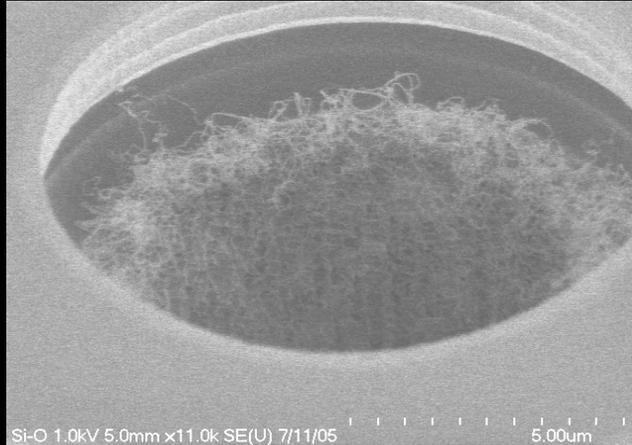
# e- emitter system



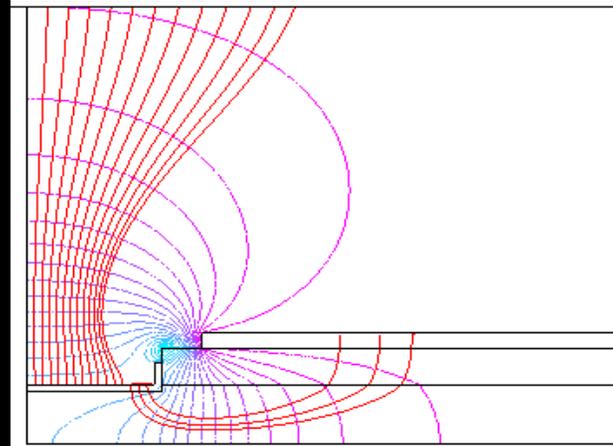
*(Courtesy of Space Nat. Laboratories -MIT)*  
**Field Emitter solution.**

# Carbon Nanotubes and Spindt cathodes

Successful growth of NT's



Relieved gate predictions direct emitted electrons to anode



*(Courtesy of SWRI – STROFIO team)*  
Nanotubes solution.

As power resources on spacecrafts are usually very limited, different approaches to the conventional hot filament to generate the electrons needed for the electron impact ionization process, have been investigated. The yield and linearity of the source and the lifetime characteristics can be experimentally investigated.

The carbon nanotube emitters are built on a Si Substrate, with 40 micron deep pits. A SiO<sub>2</sub> layer isolates the gate from the substrate. A new geometry with a relieved gate that is predicted through simulation to direct the emitted electrons to the anode is being investigated

# RAMON Concept

**SHEAMON**: double grating system (with slits of nanometric dimension) (D1) provides photon suppression. A shuttering system allows to move the two grids one with respect to the other to permit the neutrals to enter in the sensor only when the slits are aligned (open gate), which defines the START time.

Particles fly inside a ToF chamber

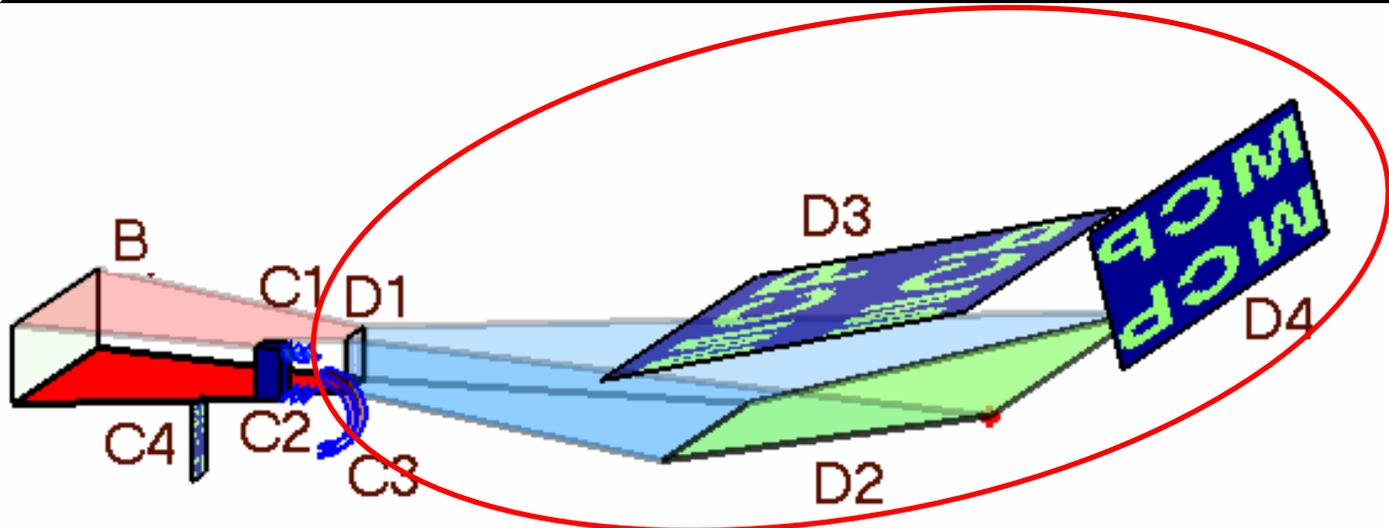
Ionization by using the technique of neutral-ion conversion surface (D2). During particle impact, electrons are released and collected toward the stop MCP detector, which also has position sensing capability (D3). The MCP will provide the STOP signal for the **ToF measurement as well as the angular direction of the velocity.**

The ion is accelerated and detected by an additional MCP (D4) that will provide an additional STOP signal.

angular res. =  
 $5^\circ \times 5^\circ$

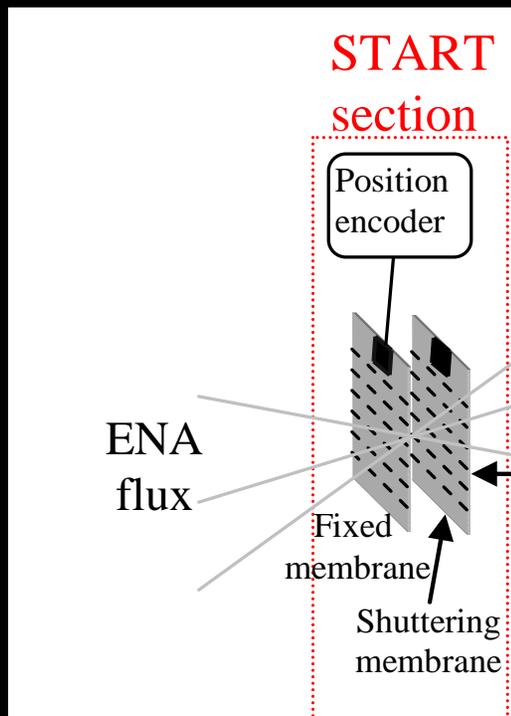
$\Delta v/v$  about 10%

GF =  $4 \cdot 10^{-4}$  or  
 $2 \cdot 10^{-5} \text{ cm}^2 \text{ sr}$



# BepiColombo/SERENA-ELENA shuttering elements

The mechanism of shuttering grids at the sensor entrance results in a un-substitutable device for ENA detection



Photons are completely suppressed when grids close. They are effectively reduced for diffraction also when grids are aligned.

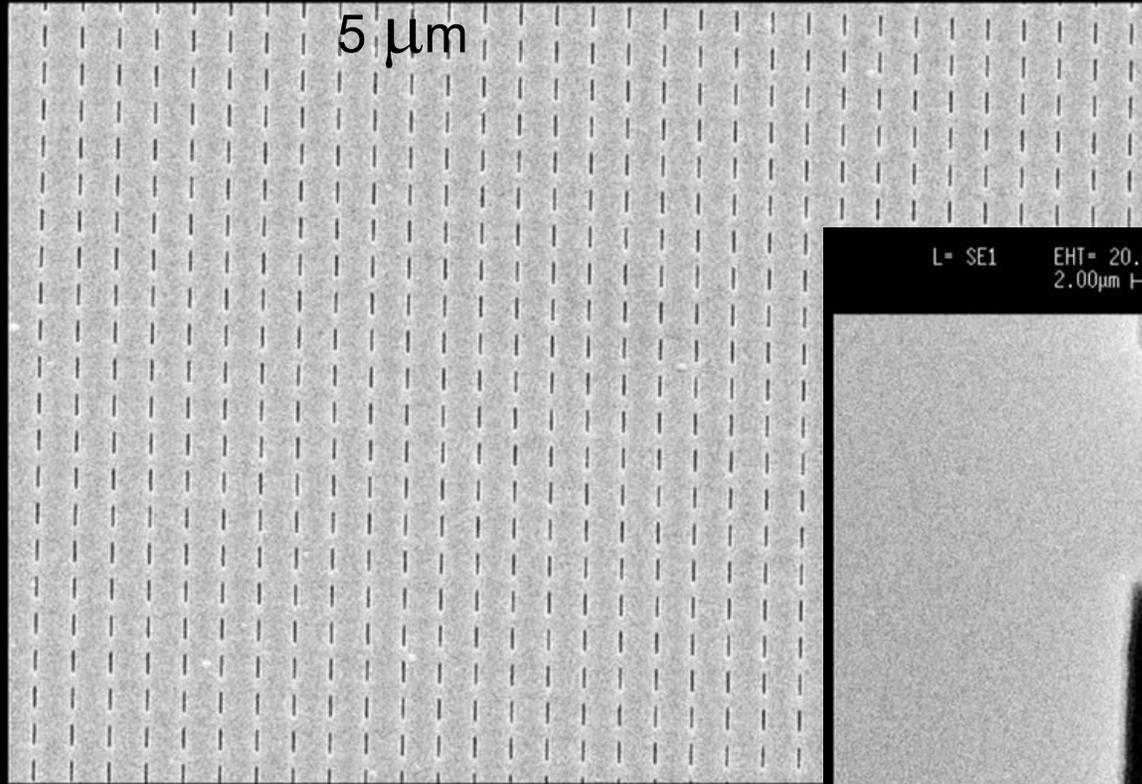
When the ToF signal will be analysed the first channel should be neglected.

Closed grids permit to measure the SHEA with very good angular resolution and ToF analysis.

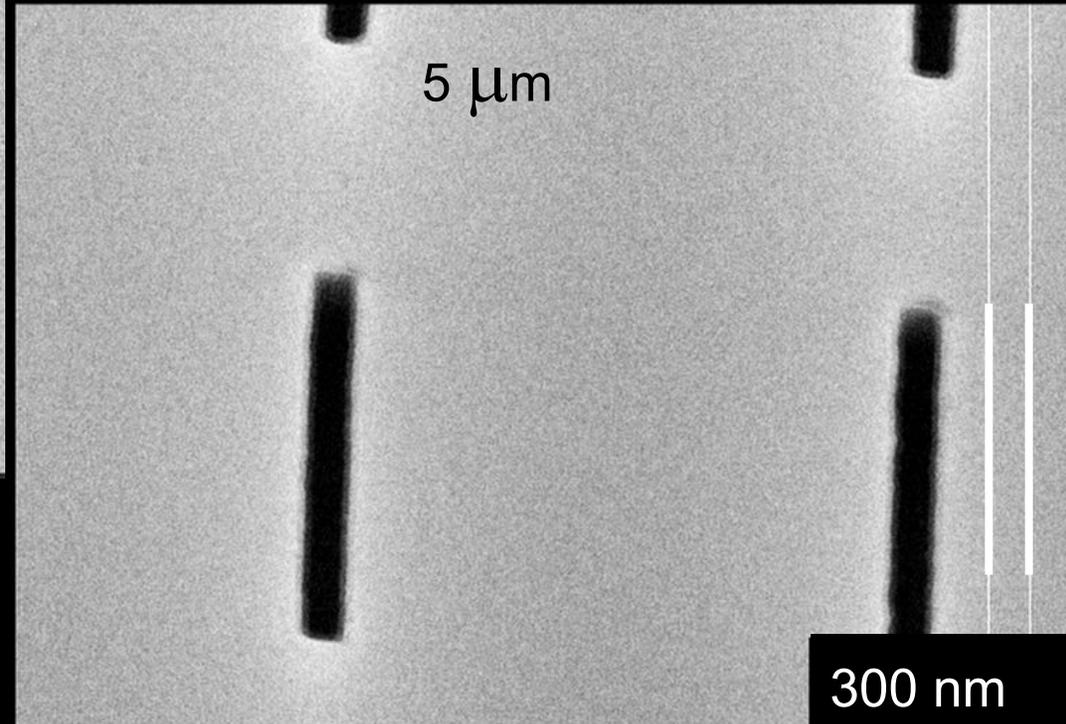
# Grid sample: prototypes-generation 5



L= SE1 EHT= 20.0 KV WD= 14 mm MAG= X 915. PHOTO= 0  
20.0µm



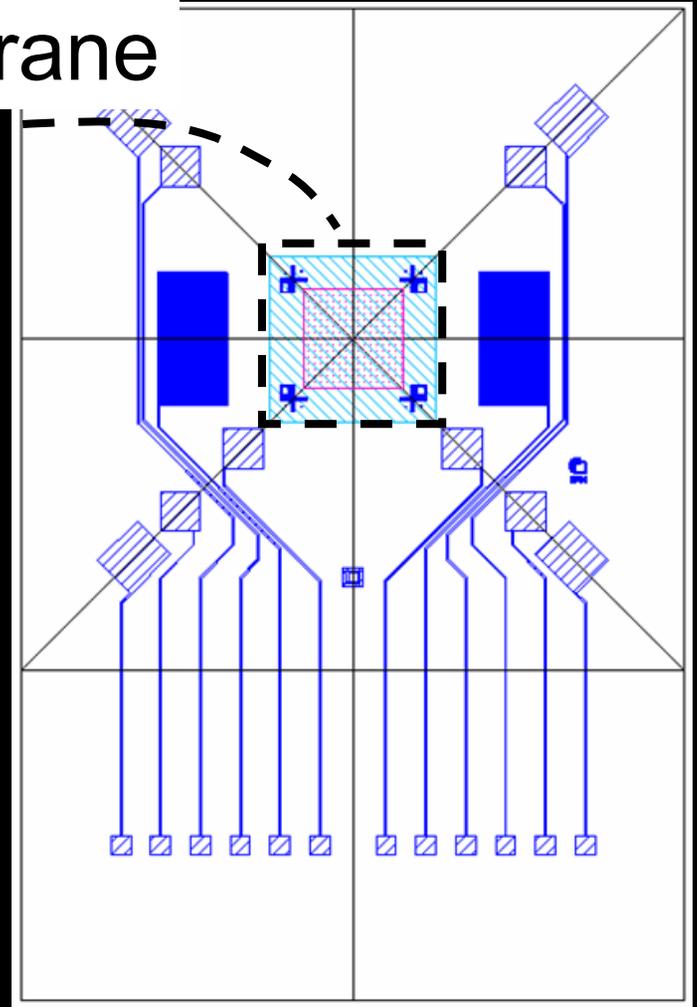
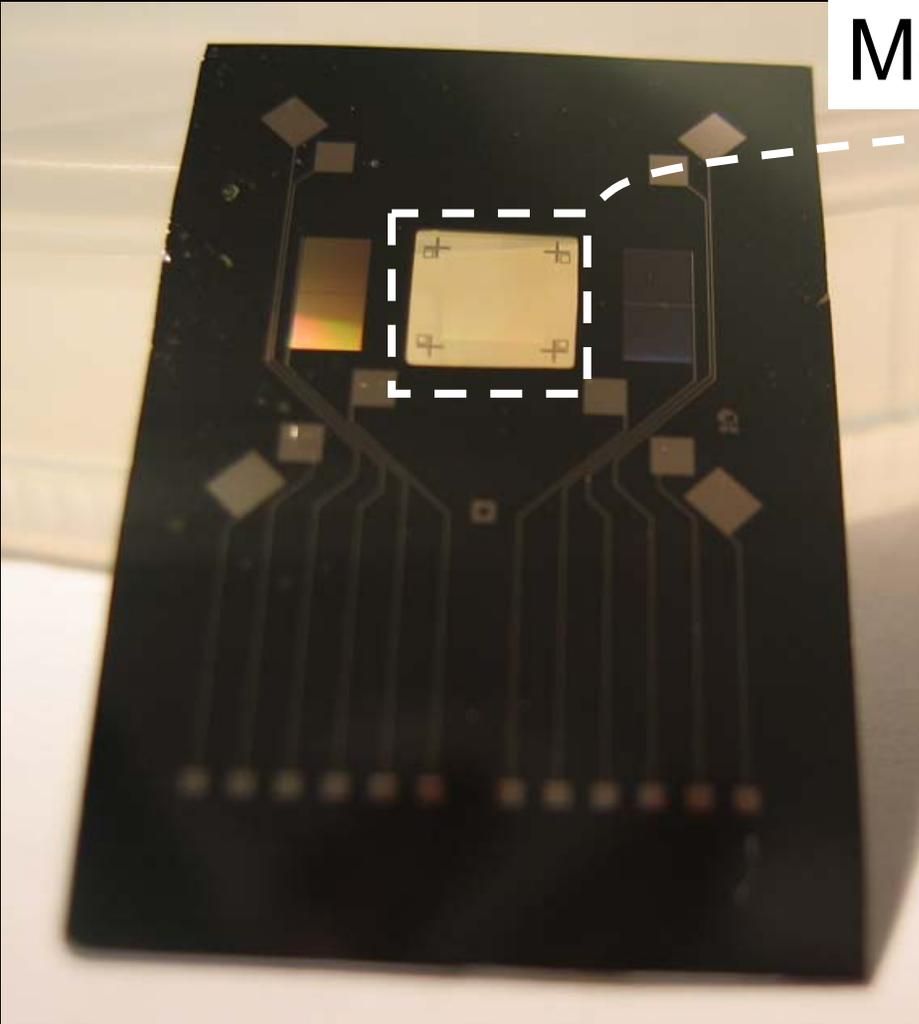
L= SE1 EHT= 20.0 KV WD= 13 mm MAG= X 16.4 K PHOTO= 0  
2.00µm



300 nm

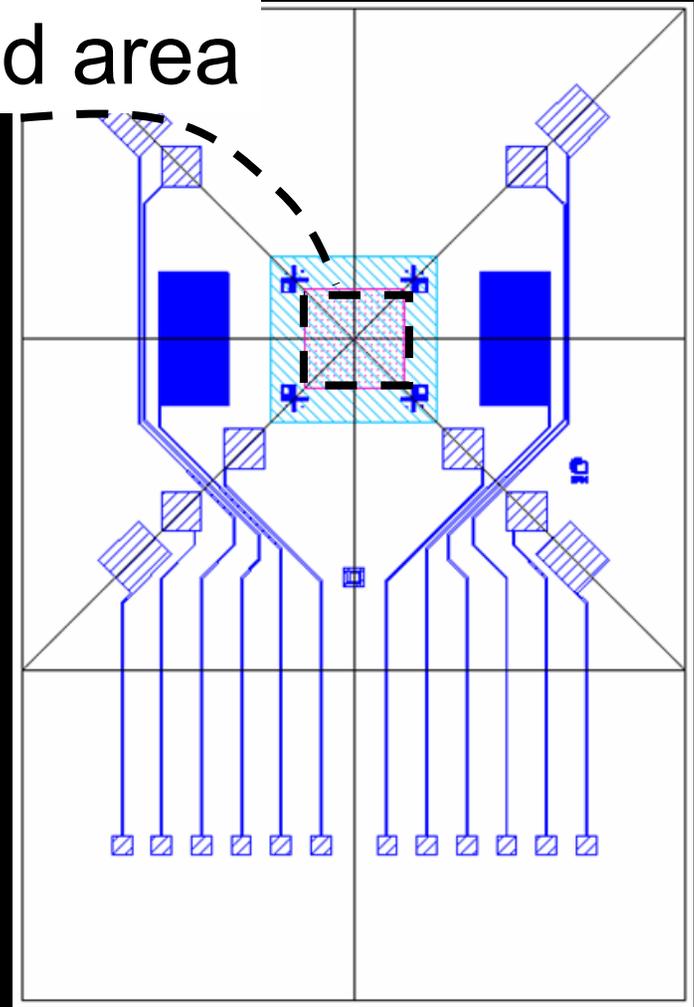
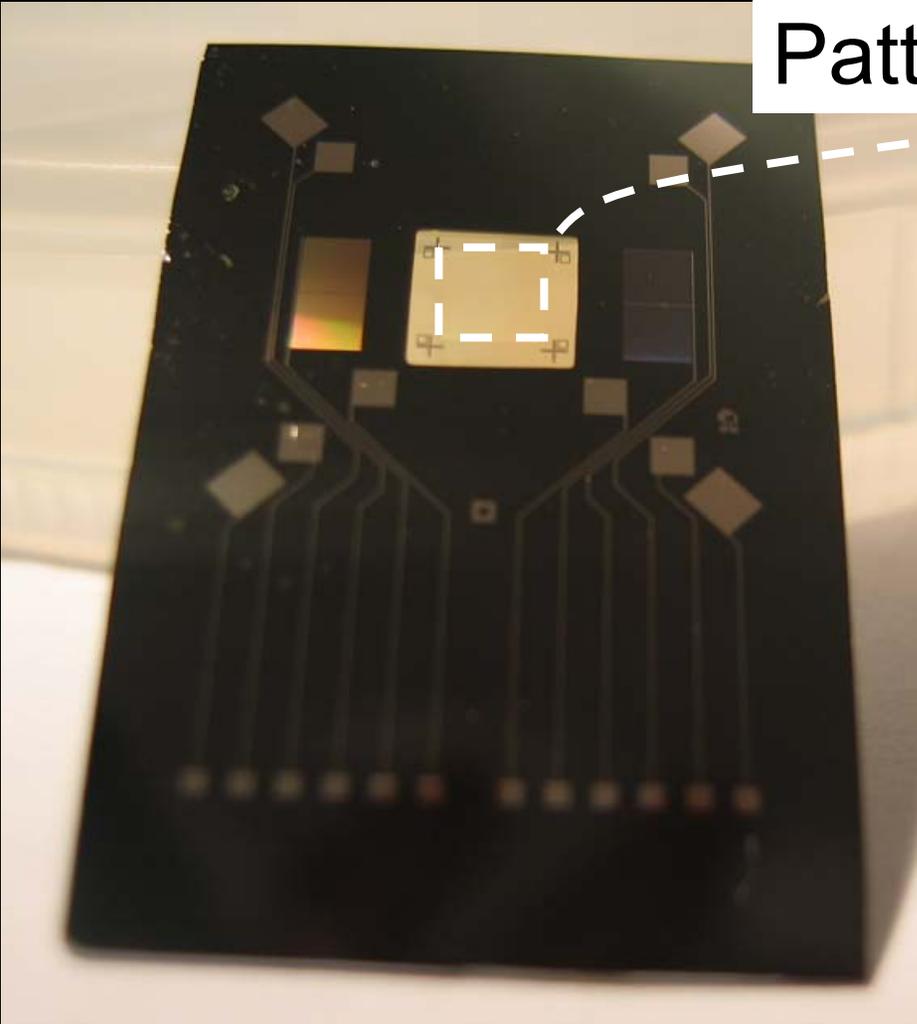
# Prototypes-generation 5

Membrane



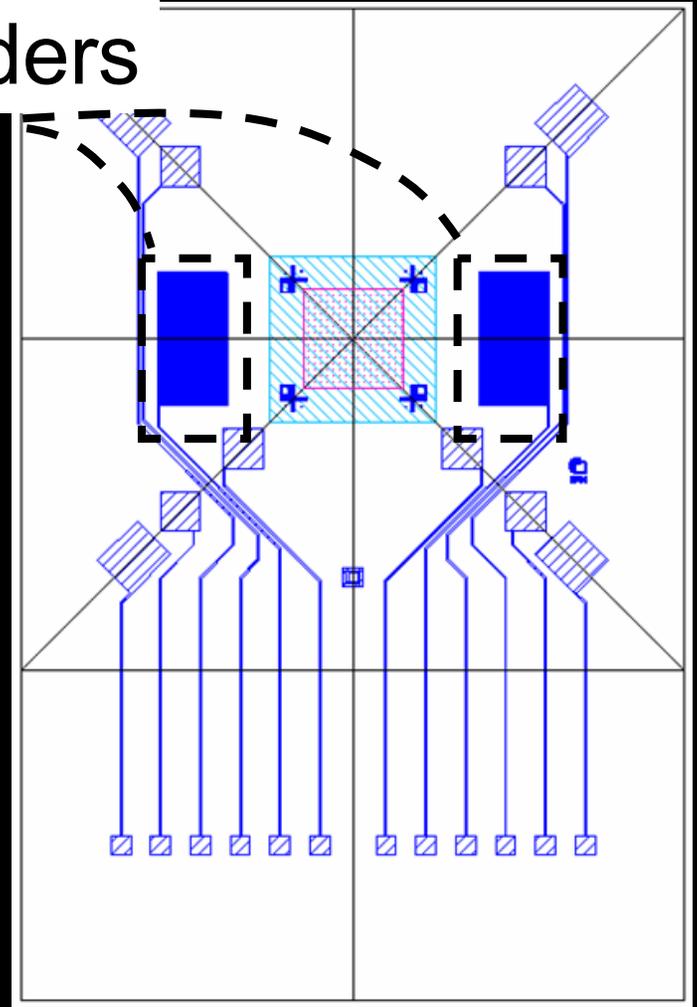
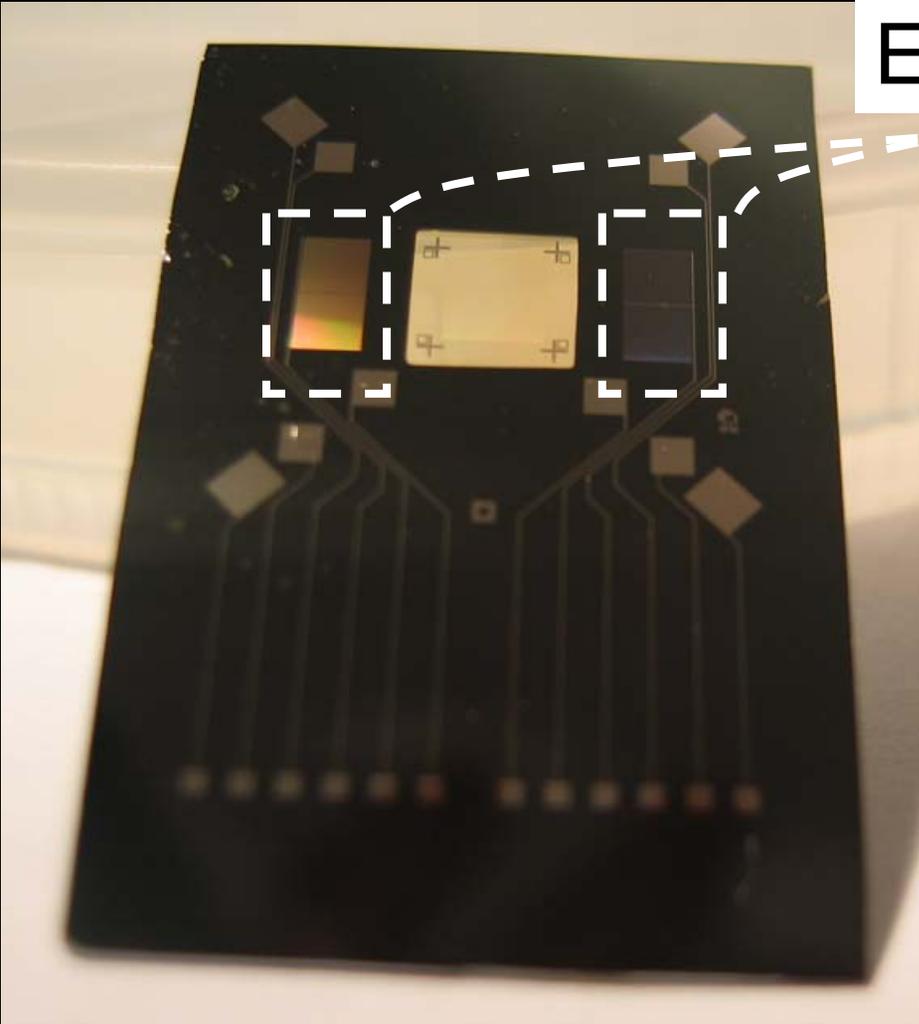
# Prototypes-generation 5

Patterned area



# Prototypes-generation 5

Encoders





# RAMON resources

	Mass (kg)	Power (W)	Volume (cm <sup>3</sup> )	Data rate (bit/s)
SHEAMON	1	7	20x10x10	40
GASP	1	1.5	15x10x10	15
SCU (Inside SHEAMON)	0.2	3	16x1x10	N/A
<b>RAMON TOT</b>	<b>2.2</b>	<b>11.5</b>	20x20x10	55

# Conclusions

- The **total density** of the volatiles emerging from the NEO surface is
  - via **PSD**  $\sim 1 \cdot 10^8$  **particles/m<sup>3</sup>**, mostly H, C
  - via **TD** from  $\sim 10^4$  **particles/m<sup>3</sup>** (T=400K) to  $\sim 5 \cdot 10^8$  **particles/m<sup>3</sup>** (T=500K), mostly H, C
  - via **IS**  $\sim 3 \cdot 10^6$  **particles/m<sup>3</sup>**, mostly H, C, Mg, Si, S, Fe.
- **The SHEA flux** (>10eV) is in the range  $10^9 - 10^{10}$  **particles m<sup>-2</sup> s<sup>-1</sup>**, which correspond to  $\sim 1-10$  % of the total one.
- RAMON will be able to detect and characterize these particles and relate them to solar wind and to surface remote sensing.  
Once the sample will be analyzed, a good feedback and comparison of space weathering investigation by remote sensing technique and by laboratory analysis, will be obtained.
- A more detailed study including MIV and back-scattering processes taking place on the NEO surface is going to be realized in the near future.
- The grating system is being characterizing in the frame of the SERENA project for BepiColombo.
- Carbon nanotube technologies are being evaluated together with SwRI and CNRS/IPSL.

# Thank you

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## Erosion rate because of IS

$$\rightarrow R = j \cdot \omega$$

$\omega = 10^{-29} \text{ m}^3$  > the atomic volume in a solid substance  
 $j$  = total sputtered particle flux leaving the NEO surface

**erosion rate ~ 0.3 Å/ye**

*similar to the estimation performed for the lunar surface, 0.2 Å/year, in case of solar-wind sputtering (Starukhina, 2003).*

- The upper limit of the rate of erosion under micrometeoritic bombardment is 0.13 Å/year (Starukhina, 2003; Lebedinets, 1981) → the contribution of IS to irreversible erosion possibly exceeds that of micrometeoritic bombardment.
- Since in the past NEO was located farther from the Sun and its temperature was lower, the erosion due to TD must have been negligible.
- All elements apart volatiles cannot be released from the surface via PSD and, thus, once H and C are removed the process comes to a standstill.