Sputtering of Lunar Regolith by Solar Wind Protons and Heavy Ions

Samer Alnussirat

University of Alabama in Huntsville

M.S. Sabra, NASA-MSFC, Huntsville, AL 35805
A.F. Barghouty, NASA-MSFC, Huntsville, AL 35812
Douglas L. Rickman, NASA-MSFC, Huntsville AL 35812
Fred Meyer, Physics Division, ORNL, Oak Ridge, TN 37831

Outline

- Motivation
- Background
- Sputtering Mechanism
- Theory
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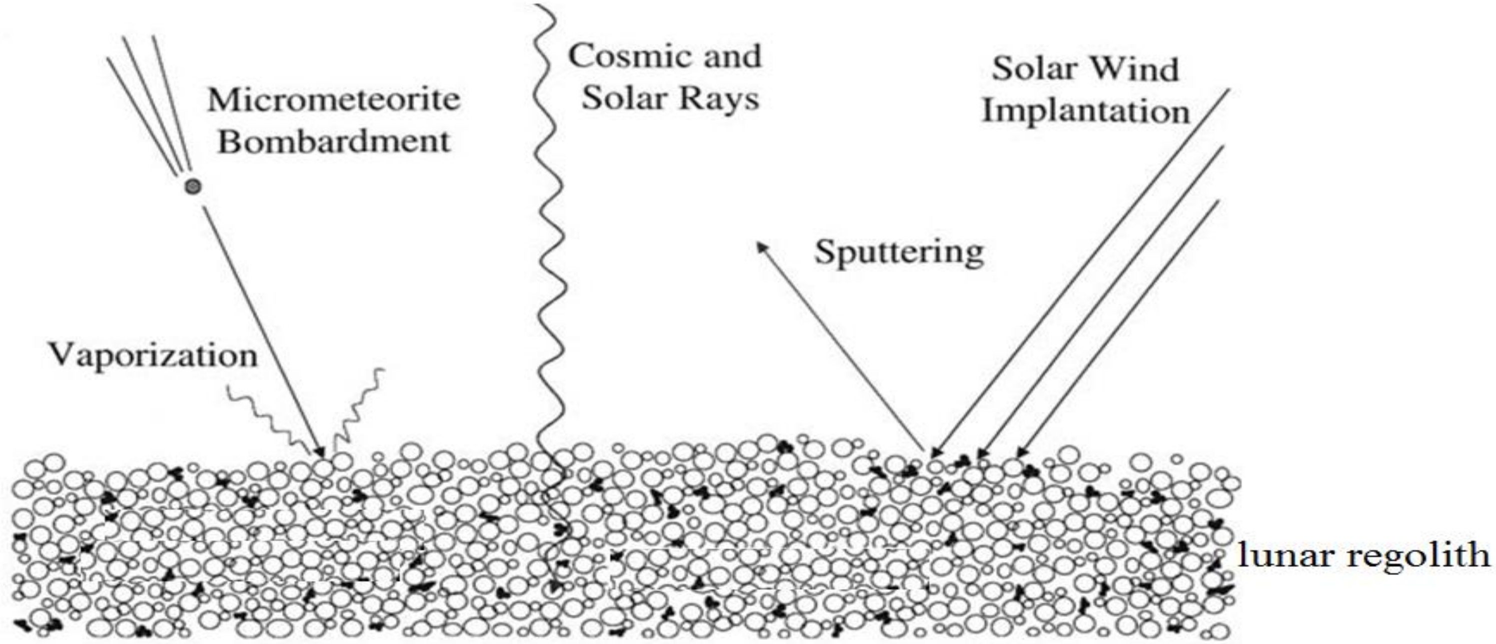
Motivation

- All previous simulations considered the kinetic sputtering and ignored the potential sputtering.
- Our motivation is include the potential sputtering in the simuation of lunar regolith by solar-wind protons and heavy ions.
- Our results showed that the potential sputtering has significant effects in:
  1. Changing the surface chemical composition
  2. Surface erosion rate
  3. Sputtering process timescale.

Background

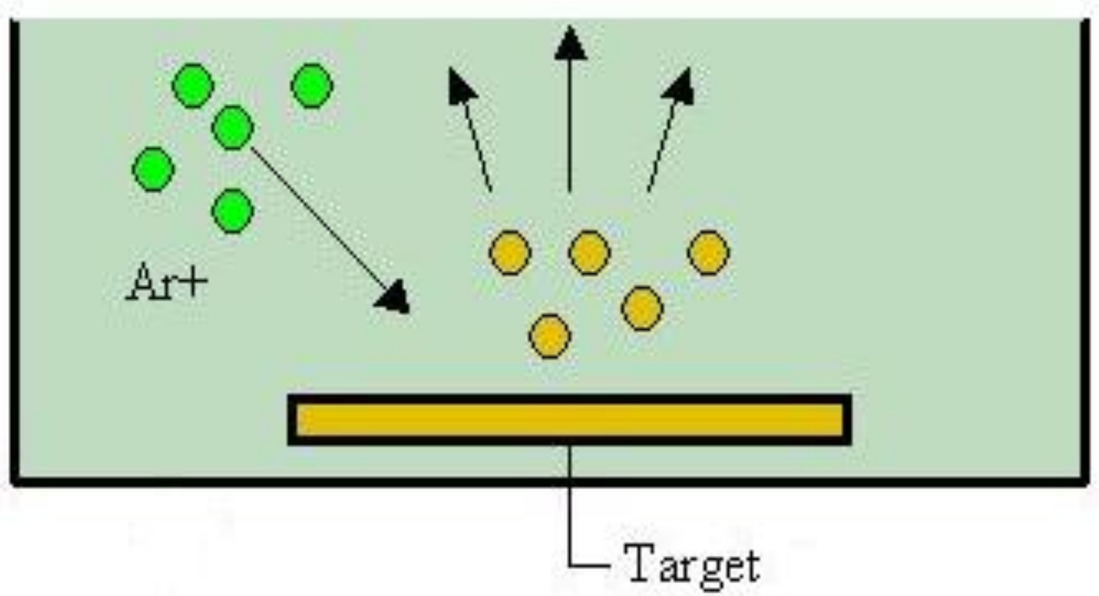
- Lunar surface material is accessible to the space weathering factors
- Solar wind protons and heavy ions with kinetic energies of about 1 keV/amu interact with the regolith



Sputtering Mechanism

When a target atom gains energy greater than the surface binding energy, then the atom may be sputtered

$$Y = \frac{Number\ of\ sputtered\ atoms}{Number\ of\ incident\ ions}$$



Sputtering

Kinetic Sputtering
(Singly charged ions)

Binary collisions

Radiation damage
and /or atom ejection

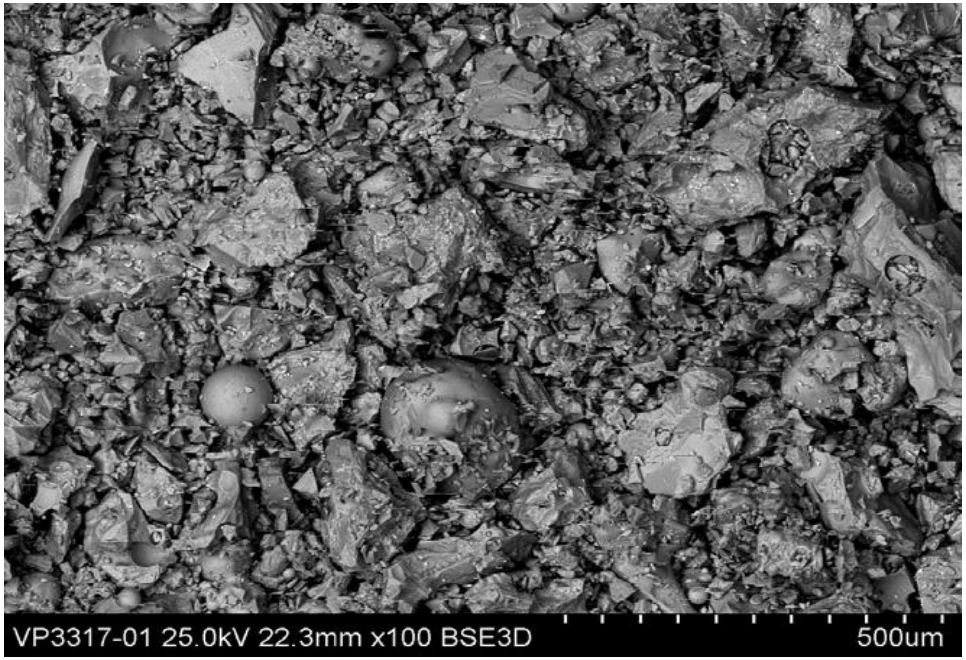
Potential Sputtering
(Multi-charged ions)

nonlinear electronic
excitation processes

Atom-hole formation
and atoms ejection

Lunar Regolith Simulant JSC-1A AGGL

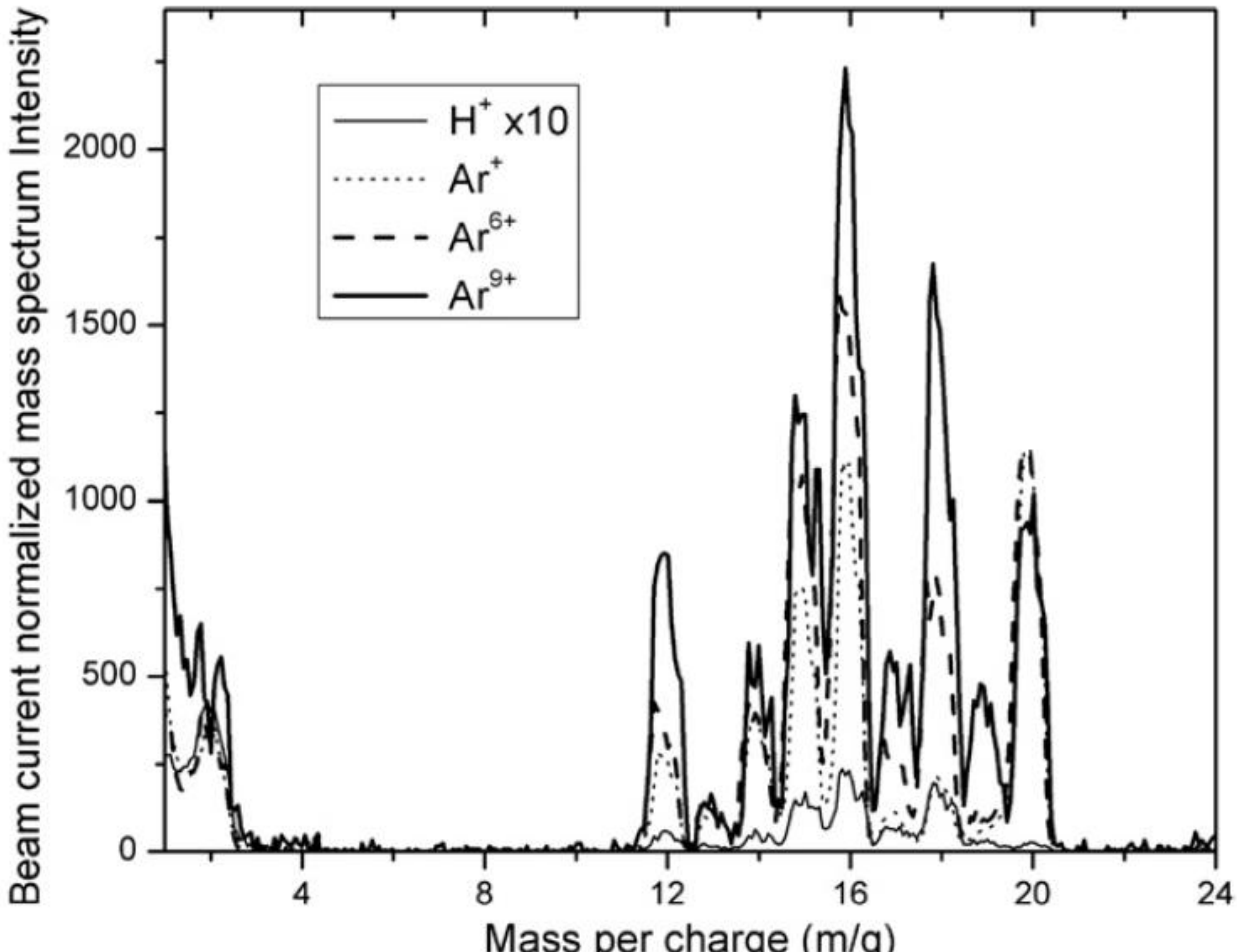
XPS: Surface of the simulant consists mostly of oxides



Experimental contamination

Element	C	O	Si	Al	Fe	Ca	Mg	Ti	Na	P	K	Cr	F
Atomic %	2.3	55.6	19.5	8.4	1.4	4.3	3.9	0.4	3.3	0.3	0.3	0.1	0.1

Mass distribution of sputtered species



Non-Equilibrium Model

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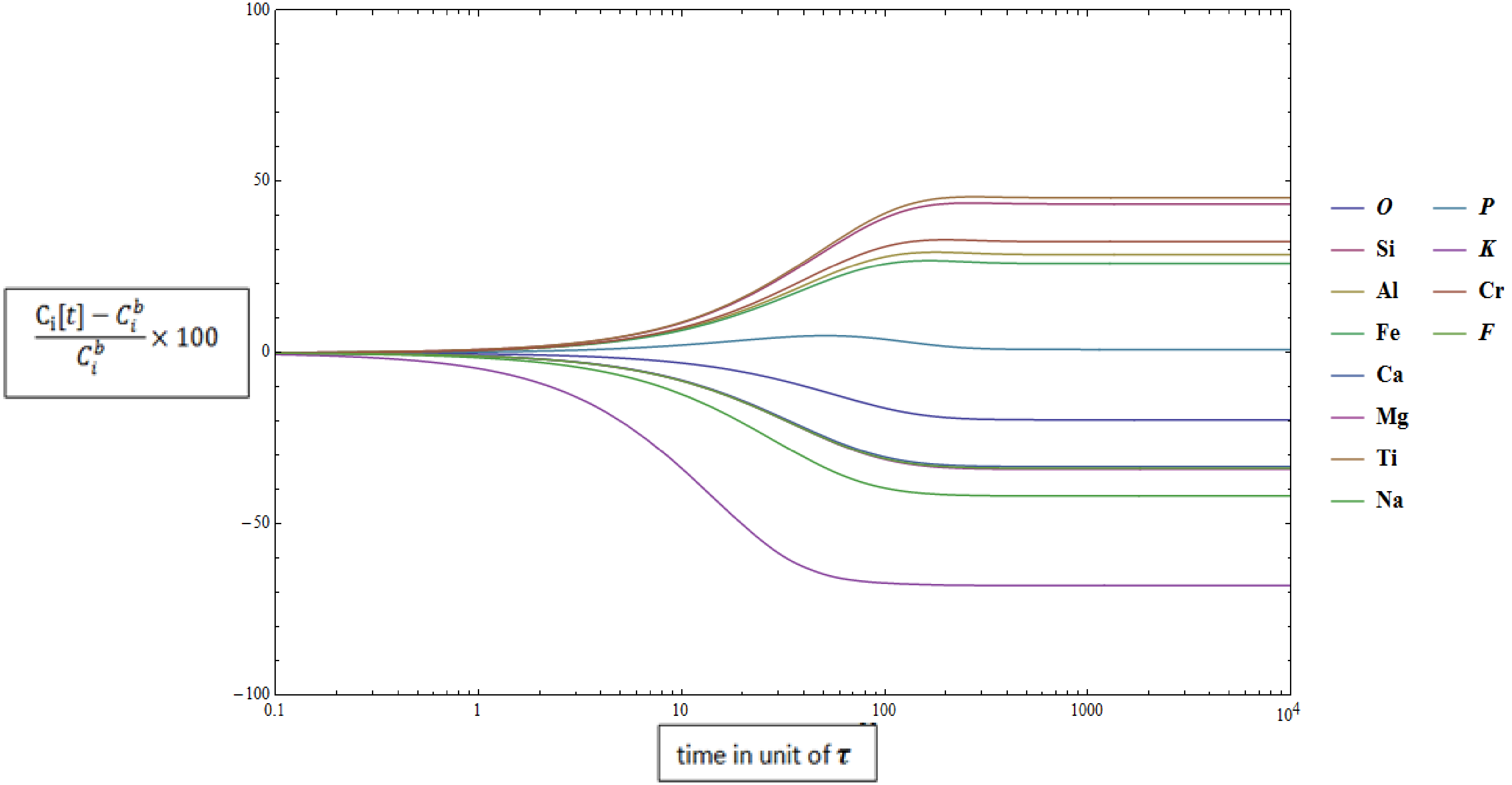
$$\frac{dC_i}{dt} = \frac{1}{\tau}\left[-C_i \sum_j Y_{ij} f_j + C_i^b \sum_k C_k Y_{kj} f_j\right]$$

- C_i is the abundant of element i in JSC
- $C^b{}_i$ is the fractional abundant of element i in the JSC bulk
- Y_{ij} is the yield of element i by solar wind ion j,
- F_j is the fraction of solar wind j in the solar wind flux
- Ƭ is a constant has dimension of time.
- A is the inter-atomic distance
- h is the penetration depth
- Y is the sputtering coefficient

$$\tau = \frac{h}{a^3 jY}$$

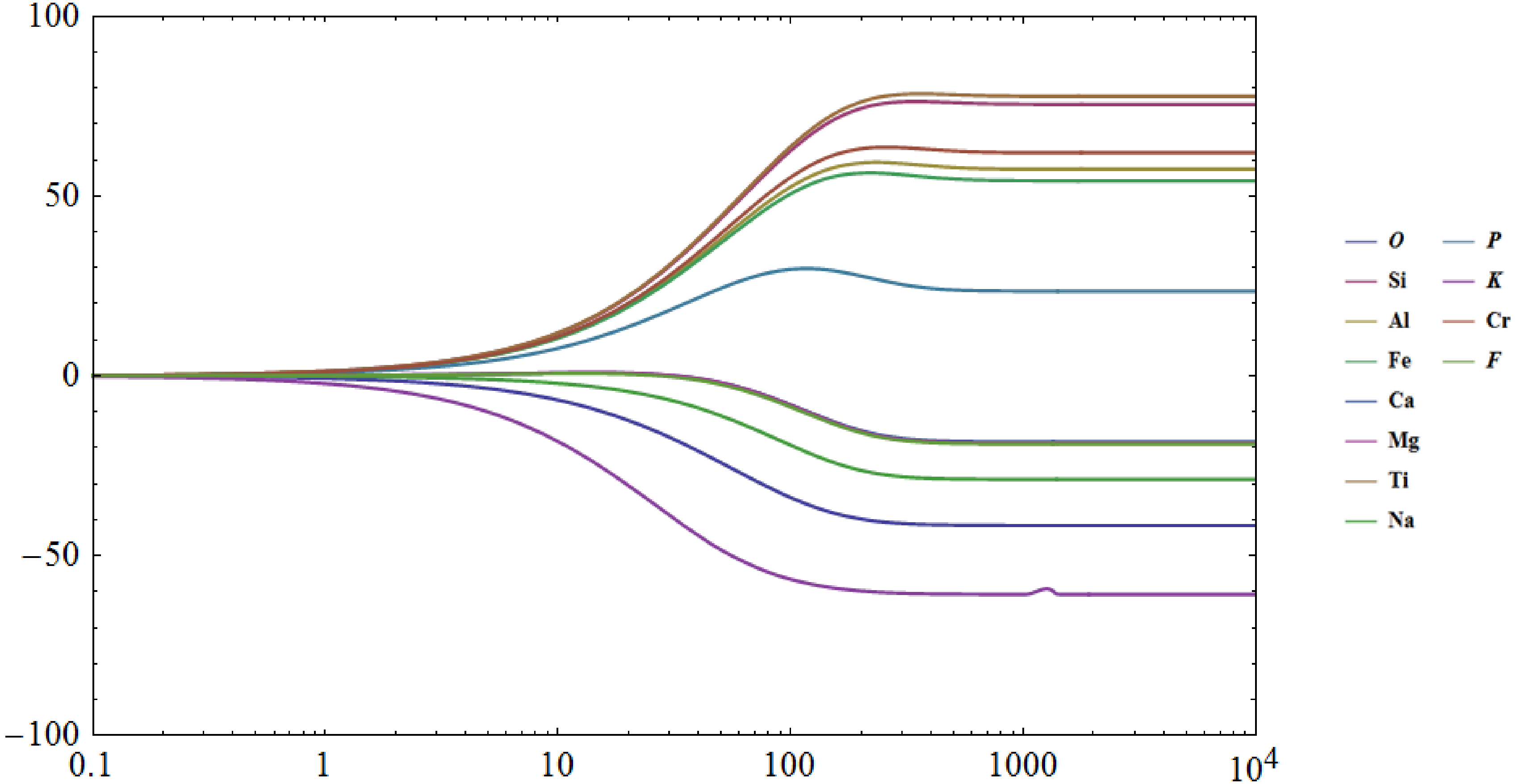
Calculated changes in the elemental composition of a JSC-1A AGGL surface as a function of time due to the **kinetic sputtering** of the solar-wind protons and heavy ions.



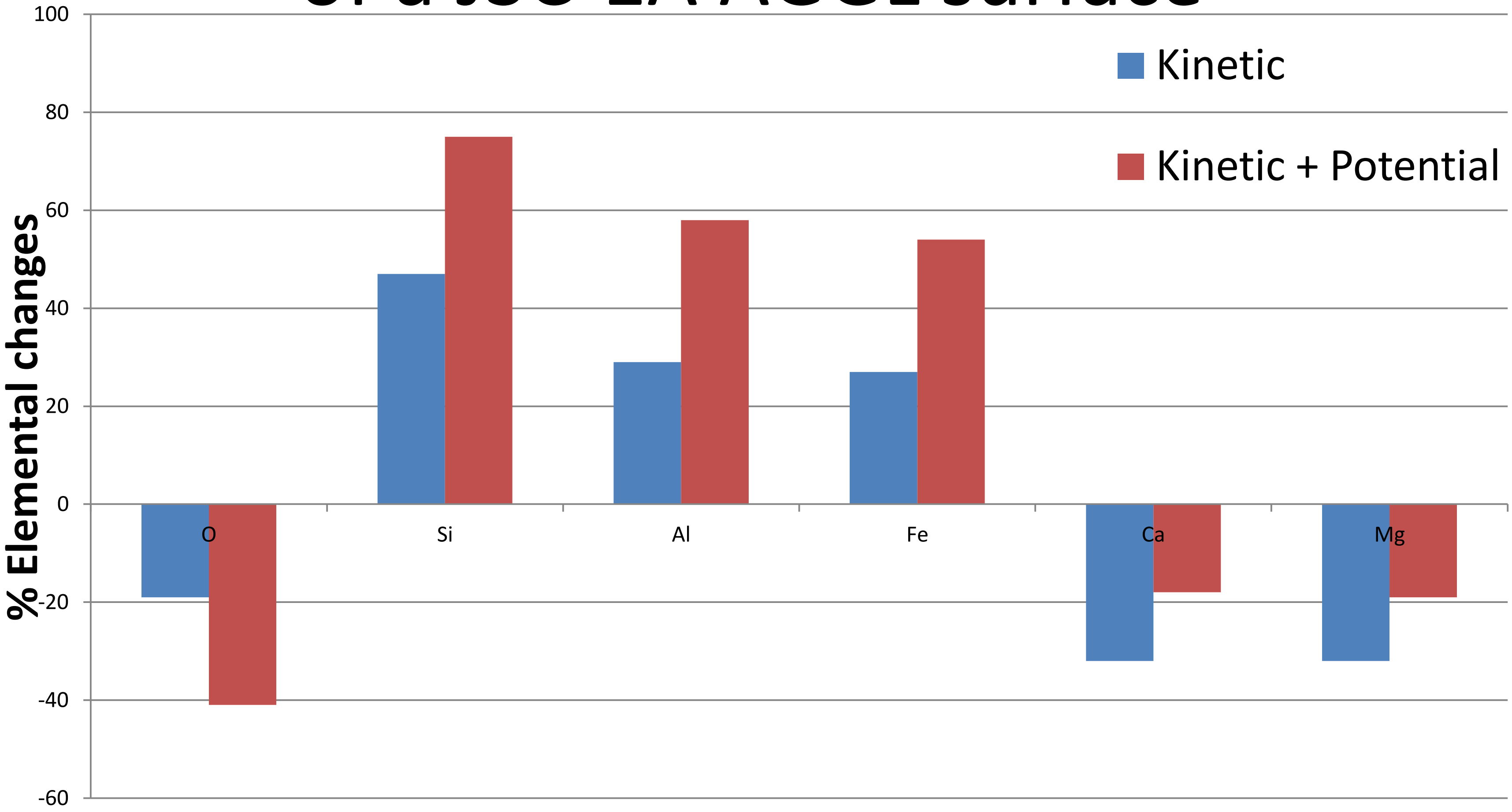
Potential Sputtering

$$Y_{ij}^{potential} = \alpha_i (\sum_n E_n - E_1)^{\beta_i}$$

$$\alpha_O = 3.12$$
$$\beta_O = 0.57$$



% changes in the elemental composition of a JSC-1A AGGL surface



Erosion Rate and Sputtering Time Scale:

- The erosion rate is given by: $$V_s = jY\,\delta_l\,\omega$$
- Sputtering process timescale $$\tau = \frac{h}{a^3\,jY}$$

Y	Time scale (Years)	Erosion rate (A^0/year)
0.12	724	0.224
0.14	621	0.261
0.15	543	0.298
0.18	434	0.335
0.20	395	0.373
0.23	362	0.447
0.28	310	0.522
0.31	271	0.597
0.35	241	0.671
0.40	214	0.746

Starukhina (Y = 0.14)

Our results (Kinetic) (Y = 0.20)

Our results (Kinetic and potential) (Y = 0.28)

Conclusions

- Potential sputtering is effective process in regolith-like materials (insulators).
- Solar wind heavy ions contribute about 52% of the proton yield.
- Potential sputtering decreases the sputtering time scale and increases the erosion rate by (33%).

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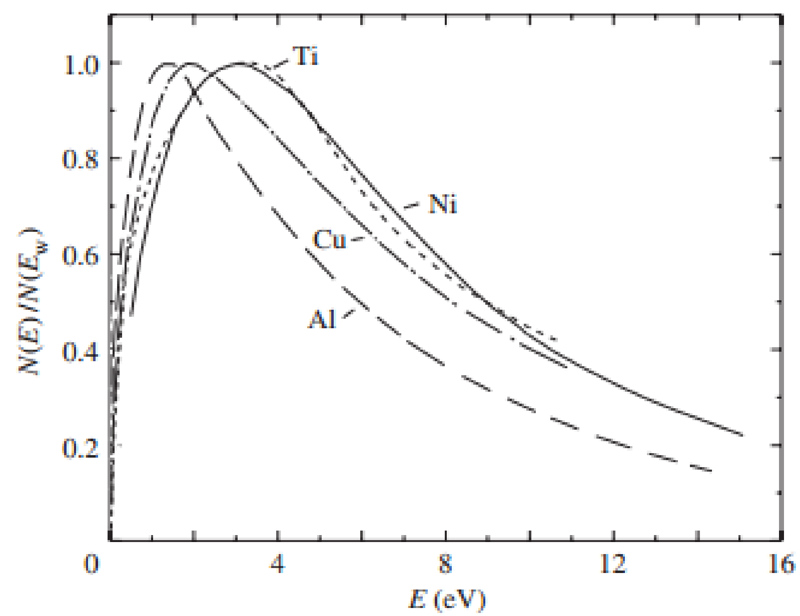
Thanks!

Questions?

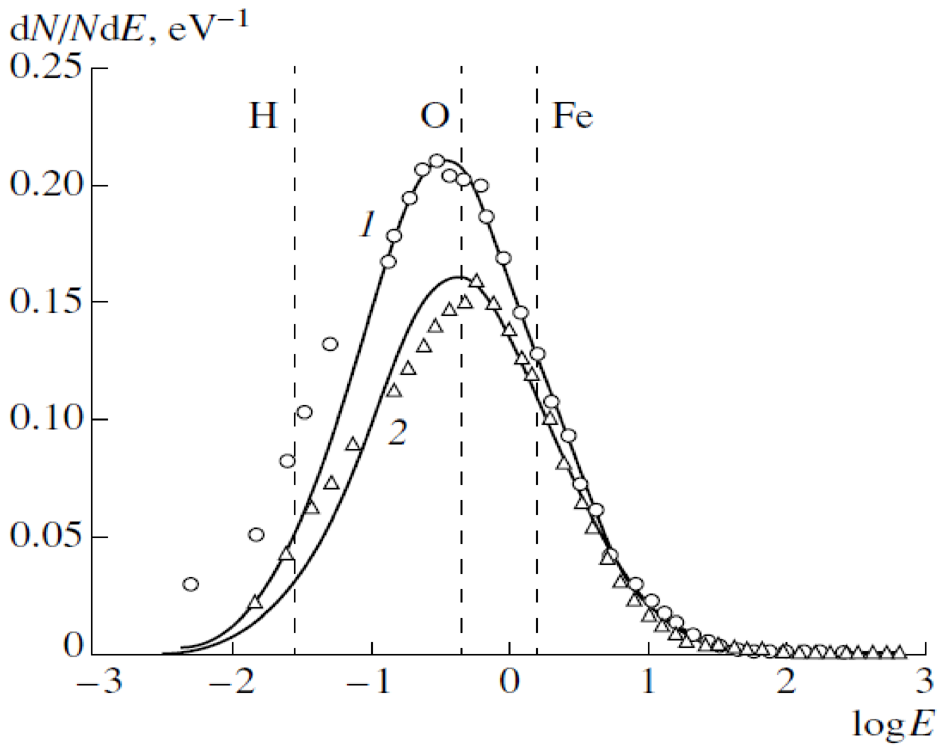
Energy distribution of sputtered atoms 1:

- Energy distributions of sputtered particles from several targets bombarded with 900 eV Ar^+ ions



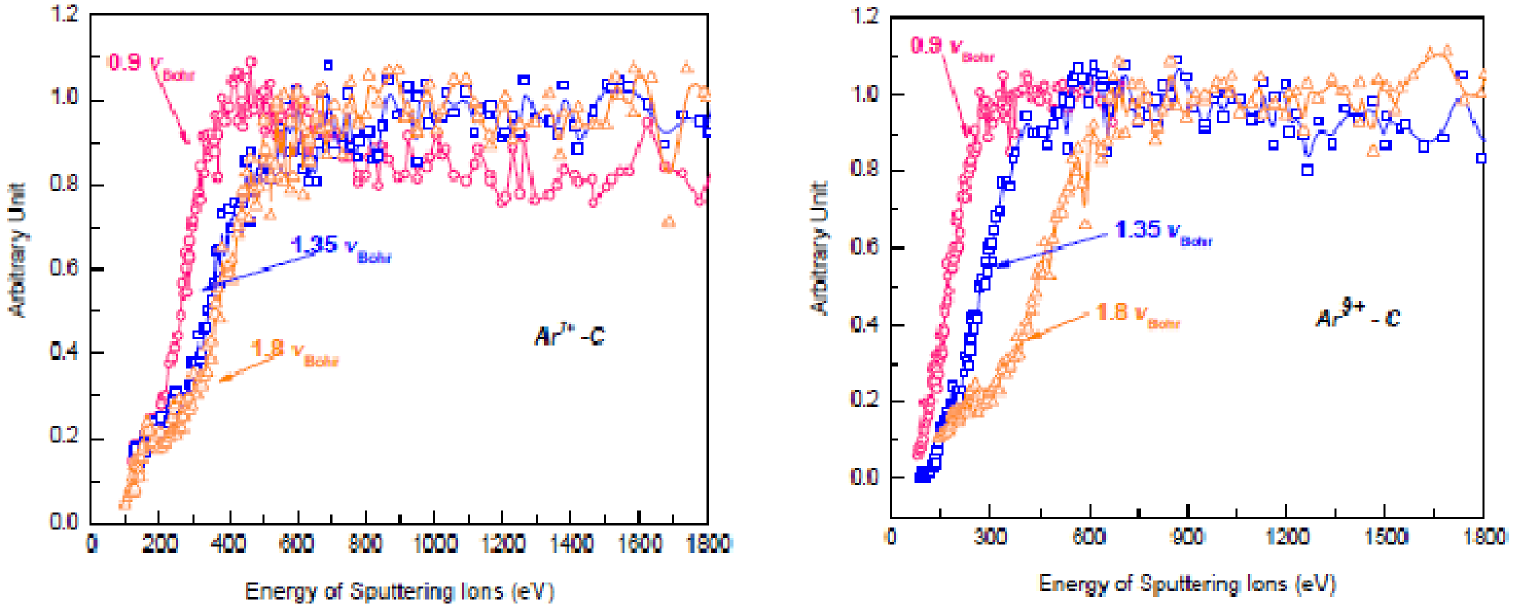
Energy distribution of sputtered atoms 2:

- Energy distribution of sputtered lunar regolith atoms due to kinetic sputtering by solar-wind **protons** (Starukhina 2003)



Energy distribution of sputtered atoms 3:

- For multi-charged ions (Ar^{7+} and of Ar^{9+}) and graphite target, experimental results show broad energy distribution



Energy distribution of sputtered atoms 4:

- Based on the previous observations and models and including potential sputtering we can suggest the following energy distribution :