Asteroid Material Shielding Potential Against High Energy Particles

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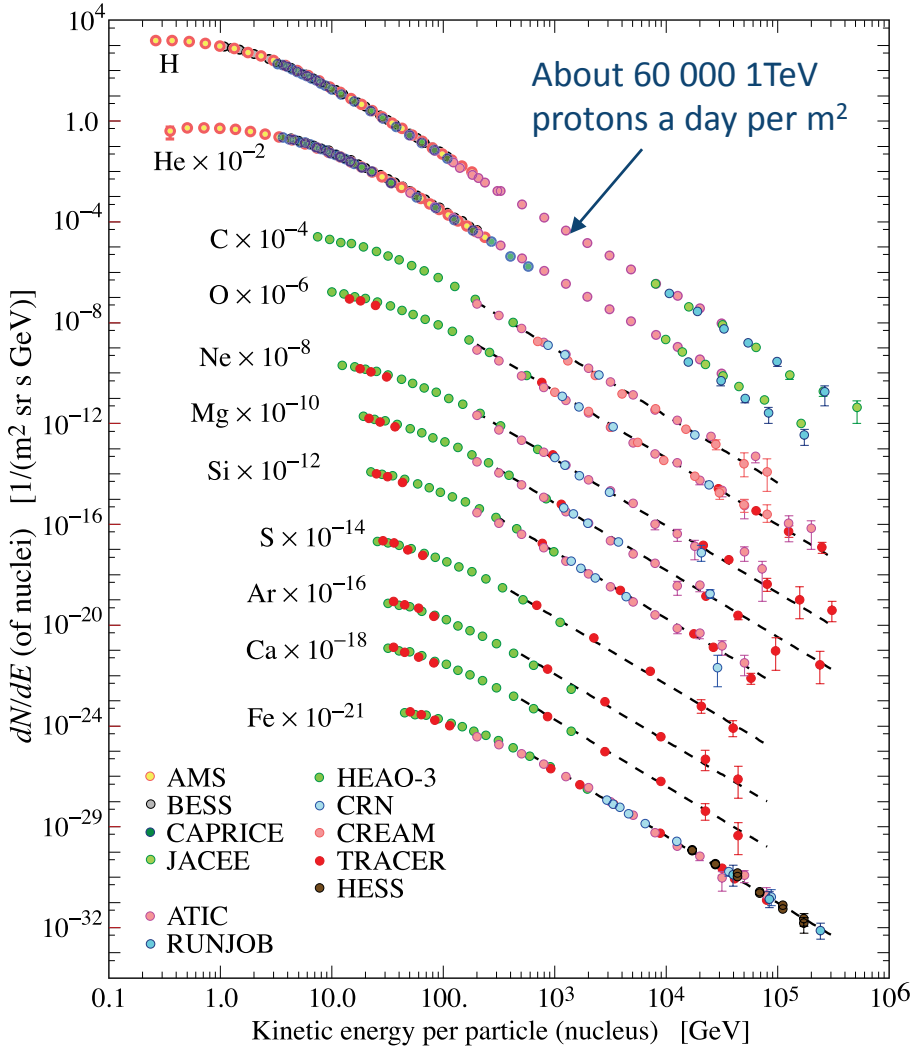
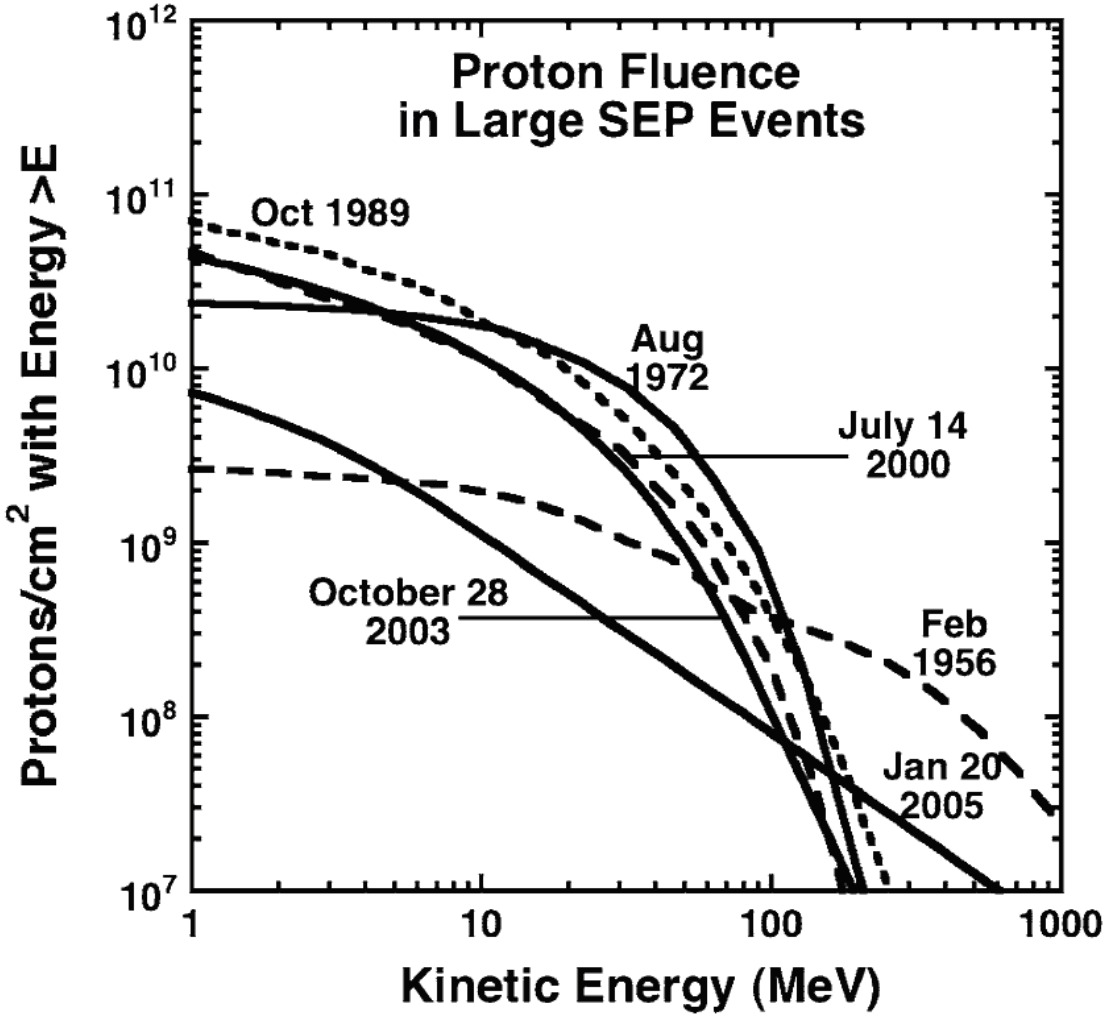
Components of space radiation

Galactic Cosmic Rays



Solar Energetic Particles



Radiation shielding

- Radiation risk
  - Space station crew receives about 80 mSv during a 6 month stay assuming solar maximum and about 160 mSv at solar minimum
  - Away from Earth's magnetic shield, radiation is a serious problem
- Attenuation → particles interact with matter
- 6 m × 4 m × 2 m living quarters, shielded by 0.5 m would require a prohibitive transport of ≈200 t of Al.
- If asteroid material can perform at least like Al in stopping energetic particles → in situ utilization can provide cost effective solution.
- Our work concerns the ability of asteroid material to remove energy from incident particles.

The concept of stopping power

- The ability to remove energy from incident particle = **stopping power**
- Energy lost per traversed unit length.
- How? Assuming charged particles:
  - Electromagnetic interaction with electrons
    - For $m_{\mathrm{i}} \gg m_{\mathrm{e}}$, removes the most significant portion E_{kinetic}
  - Electromagnetic interaction with nuclei
    - Mostly elastic scattering (for $m_{\mathrm{i}} \gg m_{\mathrm{e}}$)
  - Nuclear interactions
    - γ emissions, β decays, …

The assumptions

- Interaction assumed only electromagnetic with electrons:
  - Problem: Interactions with nuclei remove some energy as well. Secondary showers cannot be described.
  - Solution: Less than 0.1% energy is lost to the nuclei by velocity ions.
- $m_{\mathrm{i}} \gg m_{\mathrm{e}}$
- $v_{\mathrm{i}} \gg v_{\mathrm{e}}$
  - Problem: For $E_{\mathrm{k}} < 1\ \mathrm{MeV/amu}$ ions may capture electrons
- Individual atoms are independent
- Electrons in the target nucleus are uniformly distributed around motionless nucleus.
  - Problem: Charge of the incident particle pulls/pushes the electrons in the material → increased / decreased energy loss
  - Solution: For high velocity ions, this problem ceases as the electrons do not have enough time to move.

The limitations

- Low and high energy limits of usability
  - Mitigation: correction terms (SEP, GCR only high energy)
- Limitation to “pure” materials
  - Mitigation: Bragg additivity and experimental fitting
    - Approximation by layers of pure material and experimental fit of mean ionization energy for compounds
- No description of secondaries

Bethe theory of stopping power

Bethe (1932) & Fano (1963)

$$S = K\,\rho\,\frac{Z}{A}\,\frac{z^2}{\beta}\left[\frac{1}{2}\,\log\frac{2\,m_\mathrm{e}c^2\,\beta^2\,\gamma^2\,T_\mathrm{max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

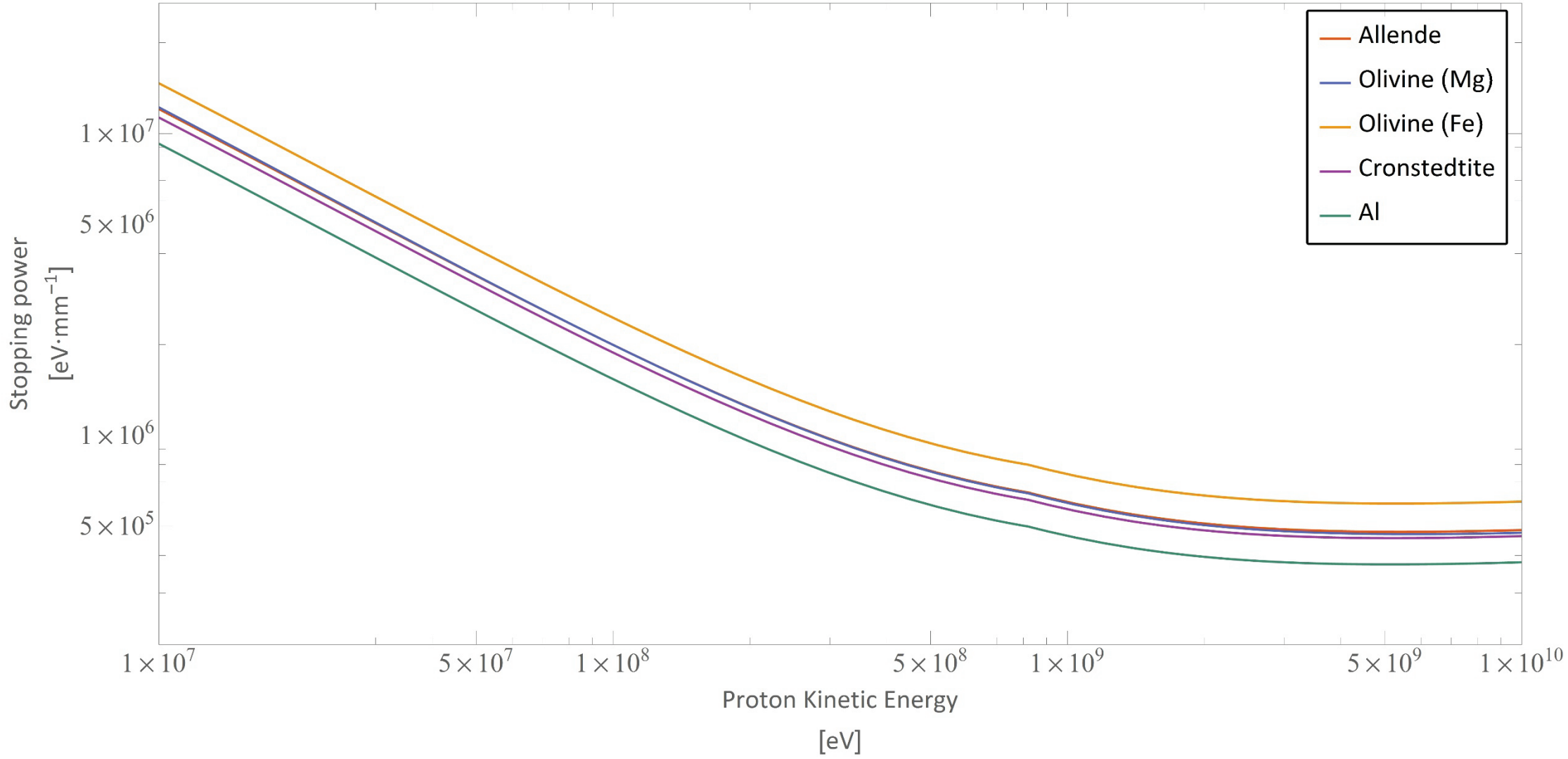
Where we have for the material:
ρ … mass volume density
A … atomic mass number
Z … atomic number
I … mean ionization potential

$$T_\mathrm{max} = \frac{2\,m_\mathrm{e}c^2\,\beta^2\,\gamma^2}{1 + 2\gamma\,\frac{m_\mathrm{e}}{m_\mathrm{i}} + \left(\frac{m_\mathrm{e}}{m_\mathrm{i}}\right)^2}$$

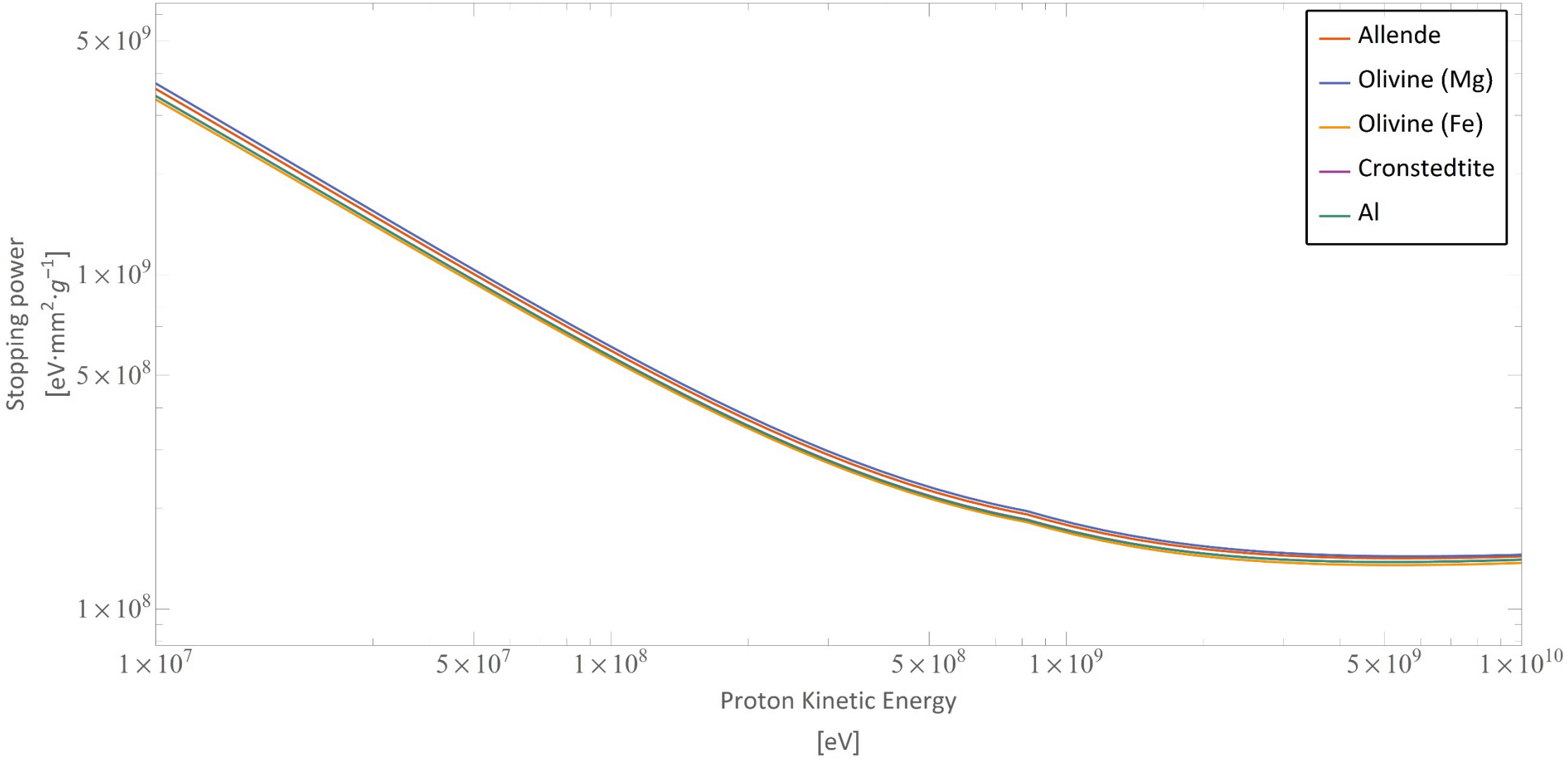
And for the incident particle:
β and γ … the standard relativistic factors,
z … the incident's particle charge
δ … density correction term
T_max … the maximum energy transfer to an electron in a single collision

$$K = 4\pi\,\mathrm{N_A}\,r_\mathrm{e}\,m_\mathrm{e}$$

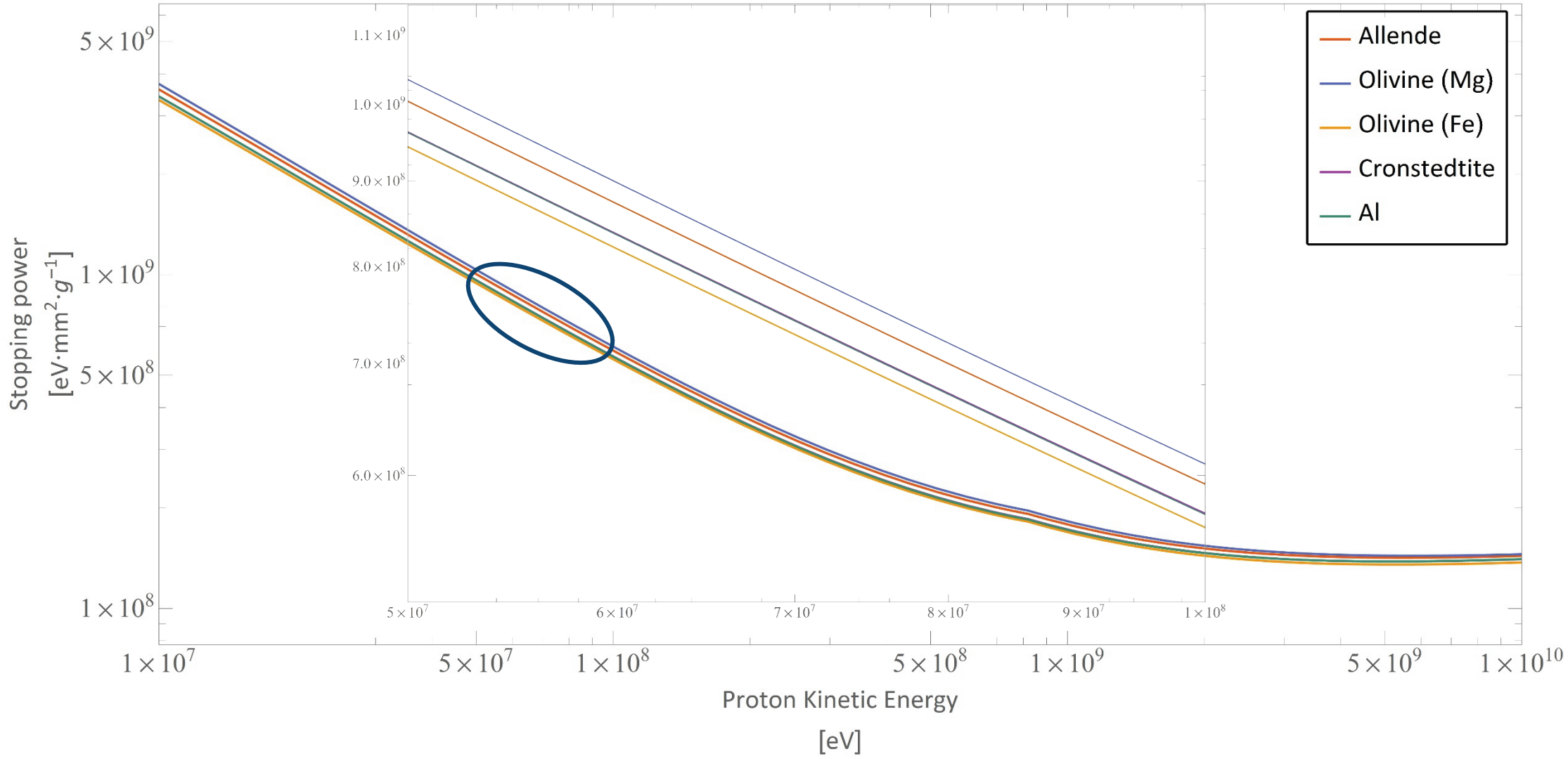
The results – analytical



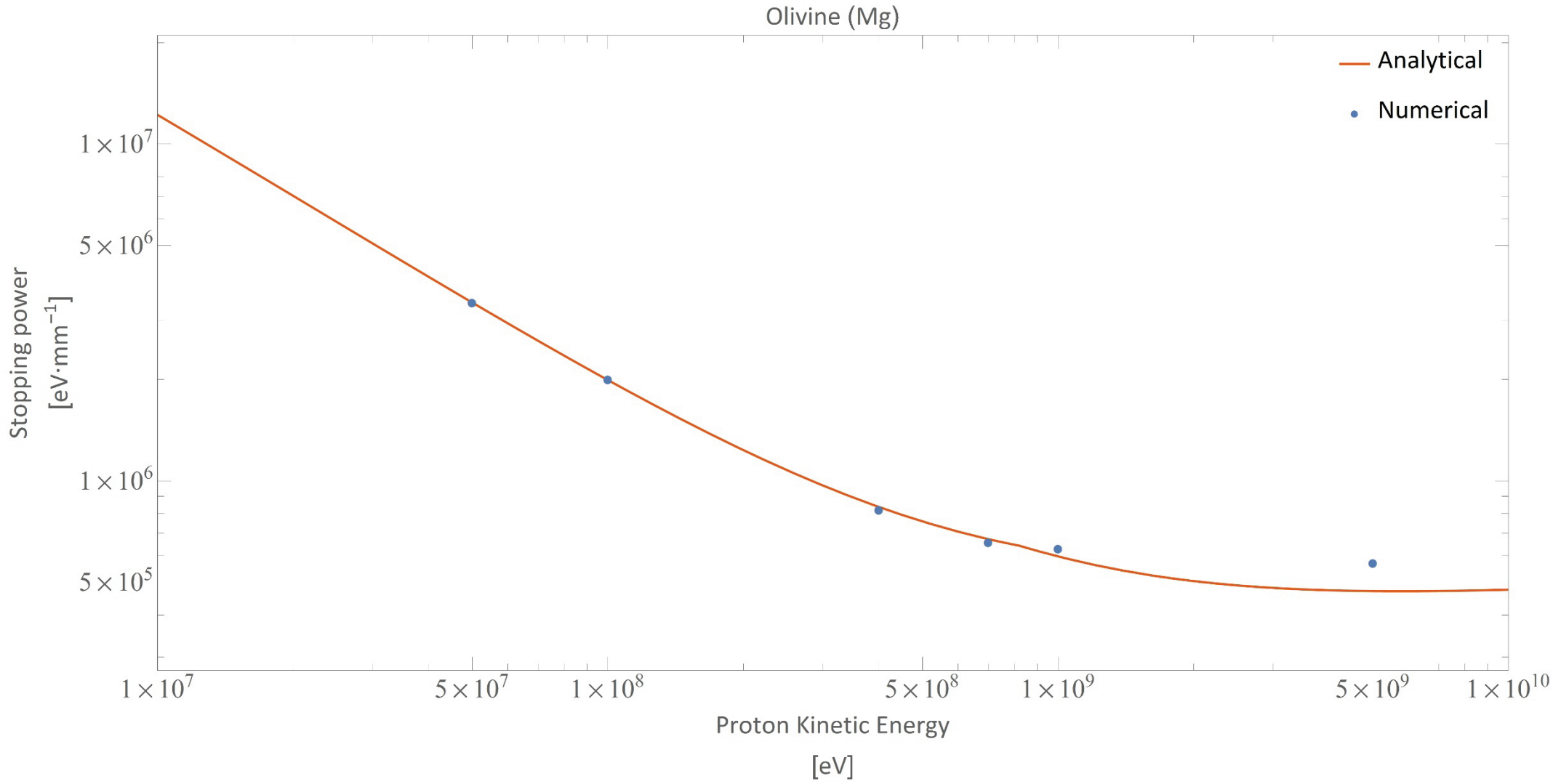
The results – analytical



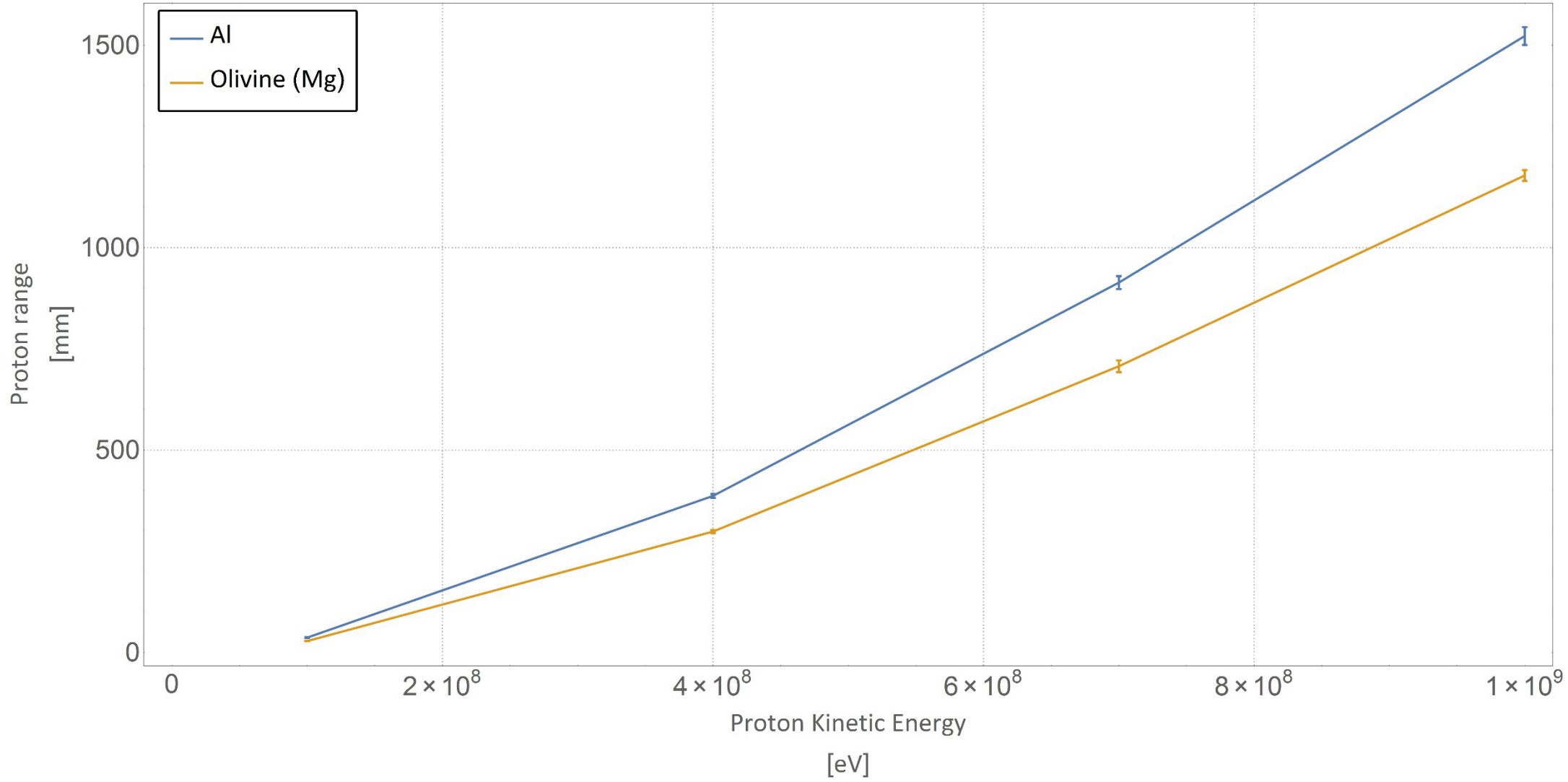
The results – analytical



The results - numerical



The results - range



Conclusions and Future work

- Asteroid material delivers about the same shielding result as Al.
- Separation of asteroid material into individual minerals is important for predictability of shielding properties.
- We plan to verify the theoretical results experimentally.
- We need to analyze secondary particle production, especially neutrons.
- Ultimately, numerical dosimetry to provide estimate radiation dose.