

SPUTTERING OF PRESOLAR GRAINS VIA GALACTIC COSMIC RAYS IN INTERSTELLAR MEDIUM. A. Garg^{1,2}, K. K. Marhas¹ and V. Goyal¹ ¹Planetary Sciences Division, Physical Research Laboratory, Ahmedabad, Gujarat 380009, India Email: kkmarhas@prl.res.in, ²Dept. of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India Email: agarg@es.iitr.ac.in

Introduction: Circumstellar grains that condense in cooling circumstellar disk/ envelopes of stars are ejected into Interstellar Medium (ISM) during events like mass loss or death of stellar objects (supernova). Some of these grains are spewed into the ISM and reaches the proto-planetary disk where they survive the solar system formation. These Presolar grains are found in meteorites and are termed as Presolar grains. Spectroscopically they are mainly observed as carbides, nitrides, oxides and silicates. These grains travelling in low density and temperature region allow molecules to be adsorbed on the grain, forming an ice mantle on the grain. The composition of ice in a molecular cloud varies with the local conditions depending on various factors like shock waves, the collision of grains, absorption of photons etc.

Model calculations have been carried out for percentage sputtering of Presolar grains due to galactic cosmic rays (GCR) in ISM. Quantitative values for sputtering yield as well as the total sputtering and the percentage destruction of mantle due to the GCR.

GCRs are mainly composed of Hydrogen (90%) and rest is Helium with a small portion of heavy metals. The high abundance of light nuclei (H, He) doesn't really participate in sputtering as these nuclides are too small to generate a significant amount of recoils with a sufficient amount of energy for sputtering to occur. Heavy metals with very low abundance in GCR contribute to the sputtering of circumstellar dust. The energy density of GCR in ISM has been calculated as 1.8 eV /cm^{-3} [1]. The sputtering depends upon the surface binding energy of the elements present in the ice mantle and the core.

Lifetime and Growth of Presolar Grains: The estimated residence time of presolar grain in the interstellar medium is pretty difficult to calculate. Cosmogenic production of noble gases indicate lifetimes of the grains in the range of 3 Myr to 1070 My [2], whereas recoil loss corrected age, using cosmogenically produced Li, leads to a range of 40 Myr to 1 Gyr [3] which were further corrected to 40 Myr to 1572 Myr using cosmogenic Li [4]. However, according to observations on the lifetime estimates of large grains analyzed by Hirashita [5], SiC grains with radius $\geq 1 \mu\text{m}$ seems to survive for more than 1 Gyr.

The grains travelling in low density and temperature region allows molecules to be adsorbed on the grain, forming an ice mantle on the grain. For a grain

having radius $0.0104 \mu\text{m}$ with gas density 2×10^4 and a constant temperature of 10 K, around $0.0162 \mu\text{m}$ thick layer of ice accumulates [6]. Significant growth of ice layers begins around 10^4 years and ending around 3×10^5 years [6] and the grain growth, in general, tends to cease after 3×10^5 years, the chemistry remains dynamic and keeps on changing constantly with time [7,8]. The composition of ice in a molecular cloud varies with the local conditions [9, 10] depending on various factors like temperature, energy processing, temperature, density, diffusion rates etc.

We use the data obtained by Gibb (2004) [10] for four different types of environments. We pick one stellar region for each stellar environment (Elias 16 for the quiescent region, Elias 29 for Low Mass Young Stellar Object (YSO), R CrA IRS 1 for intermediate mass YSO, and Orion IRc2 for high mass YSO with weak processing).

Approach: We report calculations using sputtering fraction obtained from SDTrimSP (Version 5.07) for a given set of inputs.

Data obtained by Webber and Higbie [11] for the composition of galactic cosmic rays at several points has been considered in this work. The authors use two models, Monte Carlo Diffusion Model and Leaky Box Model to calculate the intensity of GCRs for different elements at various energies. The values obtained by Leaky Box Model match with the values obtained by the Voyager [12] for interstellar medium.

While using the SDTrimSP we ignore sputtering due to hydrogen and helium as due to their small radius and high energy their contribution in the grain and the ice mantle is pretty low and negligible. We ran SDTrimSP for the nh (no. of projectile for which programme was run) values between 100 and 10000 depending upon the computational power of Vikram 100 (HPC Supercomputing Facility at PRL, Ahmedabad). These values were then extrapolated for the total number of ions hitting the grain.

The ice mantle continues to grow until equilibrium is obtained between accretion and desorption processes. Some of the several desorption processes are thermal evaporation, cosmic ray induced photodesorption, direct cosmic ray heating desorption and many more which are given in detail by [8]. We extrapolate the data for the thickness of ice for $1 \mu\text{m}$ for at 8K. As mentioned before the ice accretion start after 10^4 years. Since this duration is negligible as compared to the

exposure age of the GCRs and the sputtering on the core is very less as compared to the ice layer, we neglect the sputtering for the duration before 10^4 years. Also, the surface is assumed to be a smooth sphere whereas in reality there are several pores in the mantle which increases the surface area [8] thus affecting the dynamics of ice accretion and processing. We obtained the value of $0.02\mu\text{m}$ as the thickness of the ice after it has reached a near equilibrium in its thickness at 8K.

Results: Results from SDTrimSP shows that the total sputtering increases with increase in the thickness of ice mantle. There is 0.9 to 2.5 % change in total sputtering for 50% increase in ice thickness and 1.6 to 6% increase in sputtering for 100% increase in ice thickness depending on the source. Also, there is a very little rise in temperature due to the collision of galactic cosmic rays (approximately 5-10 K in 1 Gyr). The back sputtering yield is directly proportional to the amount of oxygen and hydrogen in the mantle thus increases as we go from low quiescent to low mass YSO to intermediate mass YSO and decreases for high mass YSO with low energy processing (Fig. 1). The sputtering yield increases with increase in angle of incidence however as the angle approaches 70° , the slope for sputtering yield v/s angle becomes steeper with an increase in angle and becomes almost vertical as it approaches 90° (Fig. 2). Transmission sputtering contributes more to the total sputtering than back sputtering however, mean transmission sputtering does not decrease uniformly with increase in energy and shows a dip at 30 MeV mainly because as the ion having 30 MeV incident at angles greater than 70° loses so much of energy as it travels through the grain that the energy imparted to the surface atoms due to primary and secondary collisions is not as much as expected from the curve. Back sputtering, on the other hand, varies uniformly with a decrease in energy. In 1 Gyr, for $0.2\mu\text{m}$ ice mantle thickness, there is about 4% destruction of ice mantle for all sources due to the impact of GCRs having 10, 30, 100, 176, 316, 562, 1000 MeV energy per nucleon. For 100% destruction of ice mantle having thickness $0.015\mu\text{m}$, 2.8×10^{10} to 3.1×10^{10} GCRs (C, O, Fe) having energy per nucleon between 10 MeV and 1000 MeV are needed to strike the mantle uniformly from all directions. 34-44% of the total number of atoms getting sputtered are oxygen and 45-55% of the total number of atoms getting sputtered are hydrogen. Whereas, Si which is only present in the core of the grain (SiC) contributes only 4-5.6% of the total sputtering.

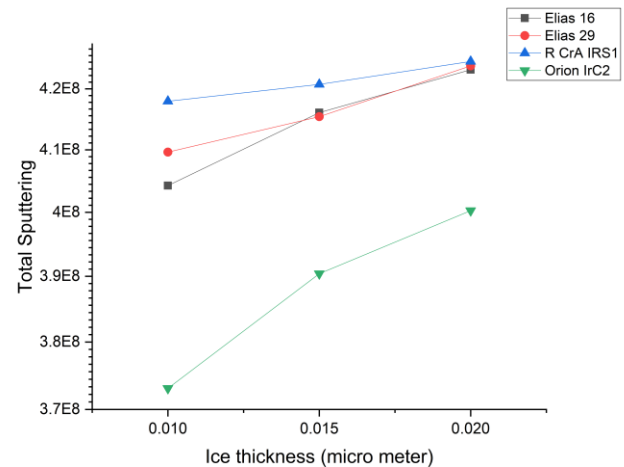


Fig. 1. Variation of total sputtering at different energies and ice mantle thickness for all four sources

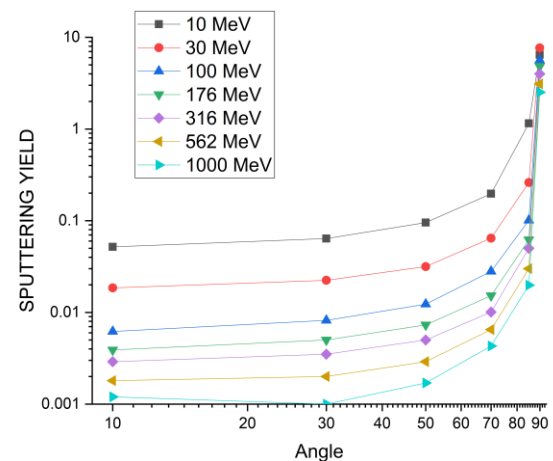


Fig. 2. Variation in Backward Sputtering Yield with the angle of incidence of GCRs

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