SOLAR ION PROCESSING OF ITOKAWA GRAINS: CONSTRAINTS ON SURFACE EXPOSURE TIMES. R. Christoffersen[1] and L. P. Keller[2], [1]Jacobs, NASA Johnson Space Center, Mail Code XI, Houston, TX 77058, USA, roy.christoffersen-1@nasa.gov, [2]Mail Code XI, NASA Johnson Space Center, Houston, TX 77058, USA, lindsay.p.keller@nasa.gov.

Introduction: Analytical TEM observations obtained to date reveal that a significant sub-population of grains returned from the surface of asteroid Itokawa have had their outer 30-100 nm processed by space weathering effects [1,2,3]. Although the effects include some surface deposition of condensed impact vapor and isolated impact melt splashes, much of the width of the space weathered outer margins or "rims" on grains is derived from solar wind processing of the original host grain. Similar to what has long been reported for some lunar grains [4,5], the ion-processed rims on Itokawa grains exhibit varing degrees and depths of penetration of atomic-displacement ion damage, resulting in complete amorphization for some rims (particularly in plagioclase), or formation of highly defective but still crystalline structures in others (particularly in pyroxene and olivine) [1,2,3]. Possibly different from lunar grains, however, is the presence of isolated internal cavities or voids in Itokawa grain rims, which may be implantation "bubbles" due to accumulating implanted solar wind H and/or He. For a given mineral exposed at a particular set of long term solar wind conditions, the level of ion damage in a given grain rim, the depth of damage penetration represented by the rim width, and the formation or lack of formation of implantation bubbles can all be linked to the time spent by the grain in an uncovered state on the topmost, space-exposed, regolith surface. For the lunar case, we have previously shown that with reasonable assumptions about solar wind characteristics over time, a model can be developed to estimate this exposure time based on the width of amorphous rims on lunar grains [6]. Here we report on an expansion of the model to cover exposure time information contained in the array of solar ion-induced features in Itokawa grains.

Methods: Our previous use of the Monte Carlo ion-atom collision code SRIM [7] as a basis for modeling the ion damage versus depth relations in solar wind -exposed lunar grains is discussed in [6]. The approach takes experimental ion irradiation fluences measured for threshold structural changes such as amorphization, and converts them into the related, physically-linked, parameters of deposited collisional energy-per-(target)-atom (EPA), or atomic displacements-per-atom (DPA). As long as the calibrating experiments were performed with low-mass ions under stopping power conditions relatively similar to the solar wind, the experimental DPA-EPA values measured for a given ion-induced structural change can be assumed to be constant across the complete velocity (energy) spectrum of the H^+ and He^+ ions that comprise the bulk of the solar wind. The integrated fluence for a solar wind plasma to produce a given experimentally-calibrated structural change in a natural sample can then be modeled. This includes determining the depth inside a crystalline grain at which a structural change, such as amorphization, occurs for a given integrated solar wind fluence. An exposure time for the depth of amorphization (equal to the amorphous rim width) can then be obtained based on an assumed long-term solar wind flux/composition model. In addition to atomic displacement damage, SRIM also allows a corresponding relation to be obtained for the implanted concentration of solar wind ions as function of exposure time. The latter is useful for modeling implantation bubble formation.

The current study focused primarily on modeling solar wind atomic displacement (EPA/DPA) damage and implanted ion concentration as a function of time in Itokawa olivine grains. Olivine is an important phase in the Itokawa samples for which the experimental fluence both for critical amorphization, as well as implantation bubble formation, is better constrained for solar wind irradiation conditions compared to pyroxene and plagioclase (5.0×10^{16} He^+/cm^2 at 4 keV [8]). A notable feature of the Itokawa olivine grain rims, however, is that although they exhibit significant ion-induced structural strain and extended defect formation, they are not completely amorphous [1,2,3]. In-situ TEM ion irradiation experiments suggest that the fluence interval between formation of this defective structure and complete amorphization in olivine is between equivalent DPA values of 2.5 for partial amorphization and 3.8 for the complete amorphization fluence measured by [8]. These values were incorporated into our model calculations.

Results: Fig. 1 shows the separate and combined DPA damage versus depth curves for H^+ and He^+ in olivine after a 100 year exposure in a 1 AU solar wind plasma with a long-term normally-distributed velocity spectrum based on [10]. The model inputs include the effect of ion incidence angles varying over 2π steradians expected for a rotating asteroid. The curves show a notable cross-over point close to 20 nm where He^+ largely replaces H^+ in producing damage effects below this depth. For the typical ion-processed rim widths of

50-70 nm in Itokawa olivines, the last stages of rim widening are therefore controlled, and ultimately slowed down, by the lower He^+ fluxes in the solar wind [10]. This slowing is reflected in the semi-asymtotic shape of the overall rim width versus exposure time curves in Fig. 2. The model predicts that TEM-visible amorphous olivine rims should form initially very quickly in as little as 100 years, with a more or less steady-state width of 80-100 nm achieved in 5000-10,000 years. Incorporating additional model calculations for the implanted concentration of solar wind He^+, these exposure times also appear close to the upper limit before very extensive He implantation bubbles should form. Itokawa olivines possibly exhibit such bubbles but not in the extreme volume fractions predicted at 5000 years by our model combined with the experimental He^+ fluence for bubble formation in [8].

Discussion: Our model results present an interesting challenge in light of the fact that, although ~20 nm of complete rim amorphization is predicted in as little as 100 years, the Itokawa olivine rims are only partially ion-damaged and not amorphous at any depth. Even allowing for reasonable variation in the model input parameters, our predicted surface exposure times always come up at the extreme lowest end of times predicted by other methods such as solar flare track density (10^4-10^5 years [11]), and cosmic ray exposure ($1.5x10^6$ years [12]). The modeled limits for He^+ implantation bubble formation provide a separate line of support for the predicted short exposure ages for rim formation. This makes us prefer a recourse to a very dynamic regolith gardening model for Itokawa to explain our results, as opposed to large flaws in the model or its inputs. We are nevertheless currently testing for such flaws through additional ion irradiation experiments to improve the model inputs.

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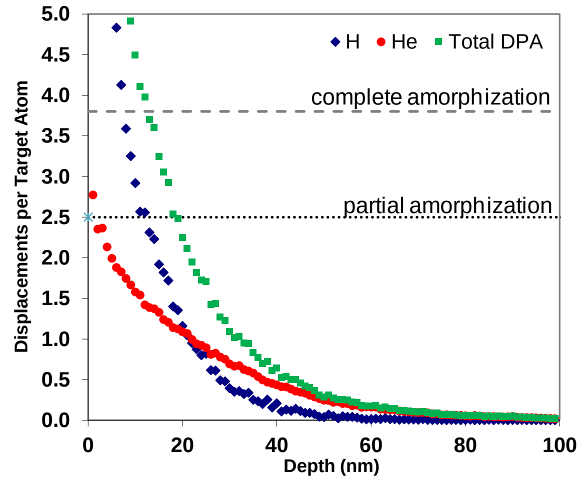

Fig. 1. Displacement-per-target-atom (DPA) ion damage induced by solar wind H^+ and He^+ as a function of depth in olivine for a 100 year asteroid surface exposure time at 1 AU.

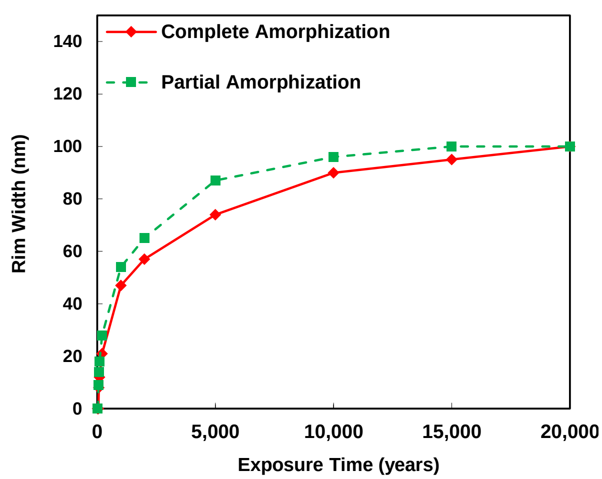

Fig. 2. Modeled width of partially and completely amorphous rims on olivine as a function of solar wind exposure time on the topmost regolith surface of a rotating asteroid at 1 AU.