NEW RECOIL MODEL FOR THE DETERMINATION OF INTERSTELLAR RESIDENT TIMES OF PRESOLAR GRAINS. R. Trappitsch[1,2,3,4], I. Leya[3], and P. R. Heck[1,4], [1]Chicago Center for Cosmochemistry, [2]Dept. of the Geophysical Sci., University of Chicago, IL 60637, USA, [3]Space Res. & Planetary Sci., University of Bern, 3012 Bern, Switzerland, [4]Robert A. Pritzker Center for Meteoritics and Polar Studies, Dept. of Geology, The Field Museum, Chicago, IL 60605, USA. (trappitsch@uchicago.edu)

Introduction: Presolar grains are found in unequilibrated meteorites. Due to their anomalous isotopic composition various types of stellar sources can be assigned [e.g., 1]. These grains travelled through the interstellar medium (ISM) until they were incorporated into larger solid bodies when the solar system formed. During their time in the ISM they were exposed to galactic cosmic rays (GCR) and cosmogenic nuclides were produced [e.g., 2]. In contrast to usual sized meteorites where reliable production rate models exist [cf., 3,4], two major problems exist for calculating cosmogenic production rates for presolar grains. First, some recoil energy is imparted to the cosmogenic nuclides after their production due to momentum conservation in the nuclear reaction, which depends, in part, on the energy of the projectile. Recoil causes the cosmogenic nuclide to travel a short distance in the presolar grain, the so-called recoil range. Due to the small size of presolar grains the recoil range can be larger than the grain itself, in which case the produced nuclide is lost into the ISM. Second, the GCR energy spectrum is relatively well known only within the solar system and within the last ~10 Ma. However, presolar grains were irradiated in the ISM prior to the formation of the solar system and we do not know the corresponding spectral shape of the GCR.

Recently Ott et al. [5] summarized the current state of solving the recoil loss problem. However, only selected primary particle energies are taken into account, e.g., for ^{21}Ne only recoil losses from the production by 200 MeV primary particles are considered. Here, we present the first data from our newly developed recoil loss model, which covers all relevant target-product combinations and projectile energies.

Model: To simulate nuclear reactions for a large number of target-product combinations we used the TALYS-1.2 [6] code for energies below 240 MeV and the INCL-ABLA 4.5 code [7] for energies between 240 MeV - 10 GeV. Using these codes we calculated the recoil spectrum for the production of residual nuclides from C, N, O, Na, Mg, Al, Si, Cl, K, Ca, Ti, Fe, Co, Ni, Rb, Sr, Y, Zr, Nb, Te, Ba, and La. The model can easily be extended to all possible target-product combinations.

Our recoil model requires an input file where the presolar grain properties are specified, namely the chemical composition, grain size, and density. Furthermore, the GCR spectrum for the incoming protons has to be specified and the cosmogenic nuclides of interest must be given. The recoil range of the specified nuclide within the grain is calculated using the PRAL algorithm [8], which is also part of the SRIM-2008 code [9]. The recoil loss for the nuclide is calculated geometrically assuming that the grain is spherical. The code loops over all isobars that decay to the nuclide of interest and over all energies in the GCR spectrum to yield the total recoil loss.

Our model has some advantages compared to earlier approaches [5,10]. (1) It uses a self-consistent dataset for all isotopes, especially for the isobaric decay. The earlier models use two completely different approaches to determine the recoil loss for ^{3}He and ^{21}Ne. (2) Our model considers production and recoil loss over the entire energy range of GCRs.

Results and Discussion: In order to test our model, we compare some of the predictions with the results from earlier approaches [5,10]. For the comparison, we modeled the retention of cosmogenic ^{21}Ne in SiC grains as a function of grain size using 200 MeV protons (Fig. 1).

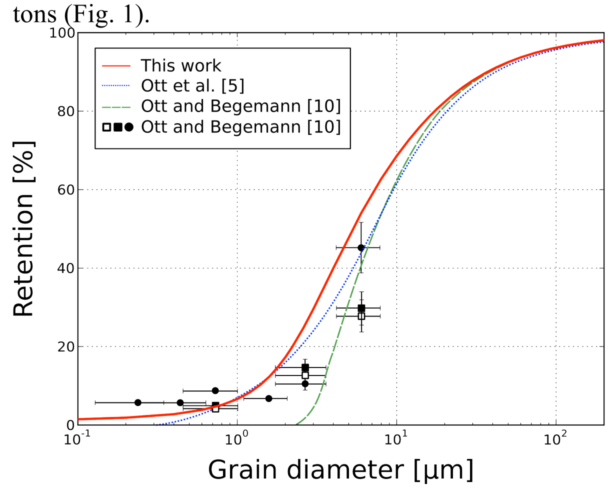

Figure 1 Comparison of our model with results by [5,10]. Plotted is the retention of cosmogenic ^{21}Ne produced in SiC grains for various grain sizes. As projectiles 200 MeV protons are assumed. The symbols are experimental data from [10].

The model used by Ott et al. [5] gives the retention of ^{21}Ne produced by protons with 200 MeV in SiC grains as a function of grain size (solid thin line). The dashed curve from Ott and Begemann [10] is calculated assuming a constant recoil range of 2.5 µm (thin dotted line).

Our model essentially confirms the trend predicted by the previous approaches. However, there are some notable differences. (1) Our model shows up to 10% higher retention for grains with diameters between 2 µm and 20 µm. (2) Compared to the earlier approaches, our model reaches a plateau for small grains (< 1 µm). The latter can be understood using basic nuclear physics. At 200 MeV some of the ^{21}Ne production is via pre-equilibrium reactions, i.e., some of the momentum of the incident particle is carried away by forward emitted ejectiles having relatively high energies. Consequently, this type of reaction leaves the residual ^{21}Ne with no or only little momentum (recoil range). Therefore, a plateau is expected for low grain sizes.

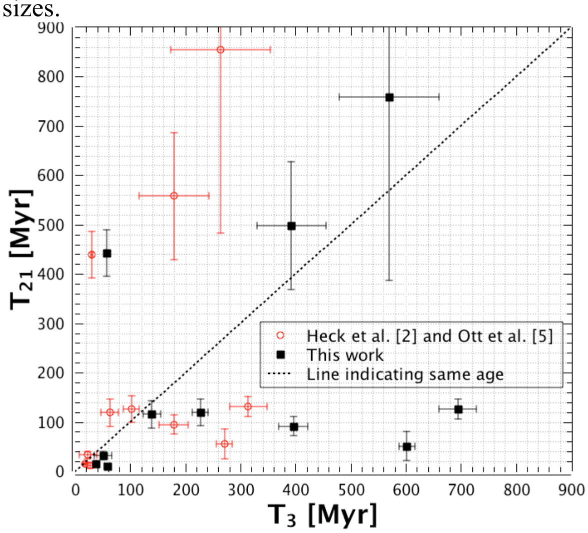

Figure 2 Comparison of the reported ages to the ages calculated with the new model. Plotted is the age calculated using the cosmogenic ^{21}Ne record against the age calculated using the cosmogenic ^{3}He record.

We apply our modeled recoil corrections to actual laboratory measurements of cosmogenic ^{3}He and ^{21}Ne in presolar Murchison SiC grains (LS+LU fraction) from [2]. Figure 2 shows the ages of the grains calculated with both cosmogenic nuclides, ^{3}He and ^{21}Ne. As a comparison, the ages from [2] corrected by [5] are plotted as well. Recoil corrections were calculated using a full GCR spectrum and assuming the solar modulation parameter to be 0. Fig. 2 does not include grains where upper or lower limits of either of the gas contents were reported [2]. Neither of the models shows consistent results for the ^{3}He and ^{21}Ne ages of the grains. There are 4 grains that show an older ^{3}He than ^{21}Ne age. This cannot be explained by diffusion losses because ^{3}He (and especially ^{3}H) gets lost more easily than ^{21}Ne. However, trapping of ^{3}He from GCR might be important, i.e., [5]. Another source of uncertainty, which could yield inconsistent ^{3}He and ^{21}Ne exposure ages, are the production rates [11]. In a next step we will calculate the production rates depending on the GCR spectrum using the cross section database already used by [3]. If we compare the results by the two approaches it can be seen that the ^{21}Ne ages are almost the same but that the ^{3}He ages differ substantially.

Implications: The presolar ^{21}Ne ages and implications discussed in [2] remain valid with the new recoil corrections: A small fraction (3 out of 12) of the grains have old presolar ages in the range of 400–800 Myr, while all other grains are much younger (<200 Myr) [2]. However, the nominal ^{3}He ages obtained with the new model are now significantly older than the ^{21}Ne ages, except for the three old grains. This is unexpected, since He is lost more readily from a grain than Ne, e.g., by diffusion. If the presolar grains were part of interstellar grain aggregates with several hundred microns in diameter they could have retained most of their cosmogenic He (see discussion in [2]). In this case our current correction would overestimate the recoil loss and would lead to incorrect T_3, [cf., 2].

Several alternative explanations for the apparent ^{3}He excess are ruled out [2]. (1) Recoil of cosmogenic ^{3}He from the host meteorite matrix into the grain results only in negligible ^{3}He contributions because of the short cosmic ray exposure age of Murchison. (2) Implantation of solar wind He is inconsistent with the measured ^{3}He/^{4}He ratios from all but one dated grain. Another explanation for the ^{3}He excess is trapping of low-energy GCR ^{3}He ions [5]: these ions have stopping ranges similar to large presolar grain sizes [5]. However, the GCR ^{3}He/^{4}He ratio [e.g., 13] is one to two orders of magnitude higher than the ratios measured by [2], and would require efficient removal of ^{4}He nuclei, which is difficult to imagine considering that ^{4}He is one of the most stable nucleus. Consequently, the ^{3}He excesses are not yet fully understood and further studies are needed.

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