RETENTION MODEL FOR RADIOGENIC LEAD ISOTOPES IN PRESOLAR GRAINS. R. Trappitsch[1,3] and A. M. Davis[1,2,3], [1]Department of the Geophysical Sciences, [2]Enrico Fermi Institute, [3]Chicago Center for Cosmochemistry, The University of Chicago, Chicago, IL 60637, USA (trappitsch@uchicago.edu).

Introduction: Presolar stardust grains are unique sources for probing stellar nucleosynthesis and galactic chemical evolution (GCE) [1]. Determining an absolute age of these grains would reveal valuable information on grain transport and destruction mechanisms in the interstellar medium. Dating techniques however are highly limited due to sample size, the largest grains being only tens of μm in diameter. Recent studies used cosmogenic nuclides [2,3] to determine exposure histories of presolar SiC grains, techniques that are highly dependent on modeled galactic cosmic-ray production rates. Recently, the first results for U-Th-Pb dating were presented [4]. While ^{235}U, ^{238}U, and ^{232}Th decay via several chains of α and β decays to ^{207}Pb, ^{206}Pb, and ^{208}Pb, respectively, each decay releases up to several MeV of energy. Since the energy in the system must be conserved, the remaining nucleus recoils with the same energy and travels a short distance within the presolar grain. Due to the small size of presolar grains, radioactive daughter products might be lost if this recoil distance is larger than the distance between the nucleus and the grain boundary. Here we model the effect of recoil losses and report simulation results for retention of radiogenic Pb in presolar SiC grains depending on grain size and geometry.

Methods: The radioactive decay path from U or Th to Pb goes through several radioactive daughter nuclides, each decay releasing a certain amount of energy. Furthermore, branched decays occur, e.g., ^{227}Ac (in the ^{235}U decay chain) decays in 98.62% of the cases to ^{227}Th and 1.38% to ^{223}Fr [5]. Energy conservation demands that the daughter nuclide recoils with the same energy as the α or β particle. We use this recoil energy [5] to calculate the recoil stopping distance using the SRIM program [6] in a given target chemistry – here SiC. If the nucleus happens to be at the edge of a sample or the sample is very small, the daughter nucleus can be lost due to recoil. We wrote a Monte Carlo (MC) routine to constrain retention of radioactive daughter products in presolar grains. We first define the geometry of the grain and then randomly place a U or Th atom within the sample. We then randomly choose a normalized direction vector in 4π and multiply it with the stopping range of the first decay. This value is added to the position vector and the routine checks if the nucleus is still in the sample or not. If not, the routine quits here and goes on to the next particle, otherwise the next decay is checked in the same way for retention. Branched decays are treated using a random number to decide which branch to follow, consistent with branch probabilities [5]. Finally, the number of retained nuclei was divided by the number of simulated ones to derive the retained fraction. This number ranges from 0 (all lost) to 1 (all retained).

Results: To test our MC model for convergence, we ran simulations with 10 to 10^6 particles ten times each and analyzed the scatter. In the case of 10 simulated particles, the scatter is between 0.14 and 0.18 for the three Pb isotopes of interest. For 10^5 and 10^6 particles, the scatter is around 0.005 and 0.002, respectively. The model therefore converges as expected. Simulations with 10^5 particles have less than 1% scatter. We expect that uncertainties in the geometry are higher. Therefore, subsequent simulations are all run with 10^5 particles.

Using this model, we determined retention values for presolar grains with radii between 1 μm and 50 μm. Figure 1 shows the results for retention of Pb isotopes in spherical and cylindrical grains. The radius of the sphere and cylinder are as indicated, the height of the cylinder was defined as 10% of its diameter. The chains for ^{206}Pb (^{238}U decay chain) and ^{207}Pb (^{235}U decay chain) are so similar that they plot on top of each other. ^{208}Pb is retained slightly more effectively (^{232}Th decay chain). For spherical grains, retention rises steeply up to about 10 μm in radius and flattens of thereafter. In the cylindrical case, the rise in retention starts later and is shallower than for spherical grains, because the thickness of the cylinder is only 5% of the radius. For cylinders up to about 5 μm radius, more than 95% of the Pb isotopes are

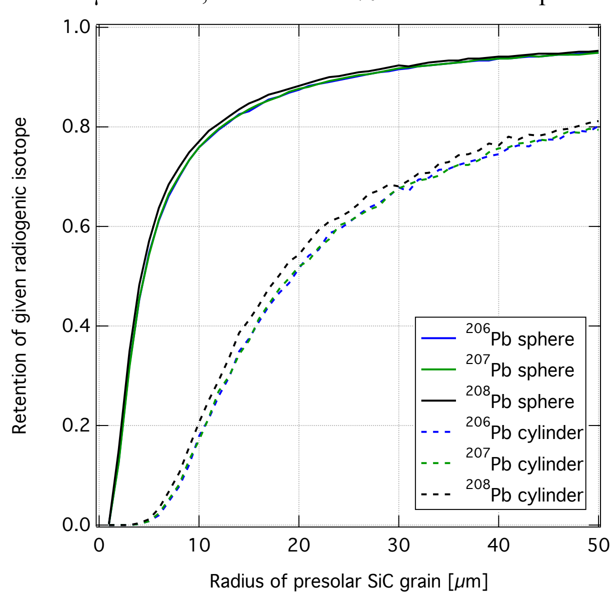

Figure 1: Retention of Pb isotopes for spherical and cylindrical grains.

expected to be lost by recoil. For large grains, retention asymptotically approaches one.

Discussion: Retention of radiogenic Pb is strongly controlled by sample geometry as shown in Fig. 1 and significant amounts of radiogenic Pb are lost in small grains. This biases ages towards incorrectly low values if not properly accounted for. Assuming a 5-µm spherical presolar SiC grain we can calculate the expected radiogenic Pb composition under certain assumptions. We assume that the solar system initial $^{235}U/^{238}U$ ratio of 0.32 represents a steady state value due to GCE. Since most presolar grains come from low-mass asymptotic giant branch stars, we consider stars of 2 and 3 solar masses. Their lifetime would be 1.8 Ga and 0.64 Ga, respectively. Using the assumed $^{235}U/^{238}U$ ratio due to GCE as input for the presolar grain's parent star, we calculate the ratio that goes into the grain by considering the star's lifetime. Assuming the U/Si ratio to be the same as in the solar system [7] and accounting for half the Si condensing into SiC (because of the stability of gaseous SiS [8]), we calculated the abundance of U isotopes in the presolar grain. Using the initial $^{235}U/^{238}U$ ratio and assuming that the *r*-process created the two isotopes equally (ratio 1), we can calculate when the *r*-process took place. This is important since [9] reported an *r*-process U/Th ratio of 0.571, which we can subsequently use to calculate the amount of Th that went into the presolar grain. We determine today's radiogenic Pb content for presolar grain ages between 4.6 Ga and 6 Ga. Figure 2 shows the range in compositions along with the average solar system composition and *s*-process predictions for a 2 and 3 $M_\odot$ star with solar metallicity based on [10]. Here, symbols are plotted for thermal pulses whenever the C/O ratio is larger than unity. The open triangles denote the measured composition, while the filled triangles denote the actual radiogenic Pb composition that would be present without recoil loss. The blue solid and dashed lines are mixing lines between the radiogenic Pb component of a presolar grain from a 2 solar mass star with an age of 4.6 Ga and the solar system composition. While the mixing is done for the non-recoil-corrected scenario (dashed line), the solid line represents the shift of the mixing line due to recoil loss. None or incorrect recoil correction can therefore shift the isotope ratios slightly along a mixing line where the *s*-process ratio is an end member. While *s*-process Pb is not expected to condense into presolar grains due to its low condensation temperature, incorrect recoil correction could invoke the presence of such a component. A thorough analysis considering measurements hence requires an appropriate recoil correction. Without the measurement of the actual U, Th, and Pb isotope abundances, no clear conclusion can be drawn in which directions recoil loss shifts the isotope ratios in grains.

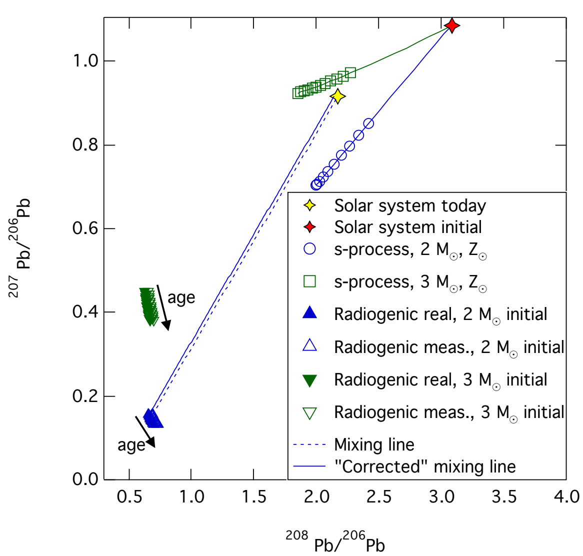

Figure 2: Possible presolar grain composition for a 2 and 3 $M_\odot$ star (described in the text), along with the today's, initial solar system and s-process (R. Gallino, pers. comm.) compositions. The mixing shows possible contamination in the laboratory and the shift that would have to be applied in order to correct for recoil losses.

Summary: We presented a MC model that constrains retention of Pb isotopes from U and Th decay in presolar SiC grains of spherical and cylindrical shapes in various sizes (Figure 1). Using feasible initial assumptions we showed the expected radiogenic record of a presolar SiC grain. Neglecting recoil correction will shift the measured value slightly in the direction of the *s*-process. This is due to the preferential retention of ^{208}Pb over ^{206}Pb and ^{207}Pb. Especially for small grains, retention values are small such that inferred ages from uncorrected measurements are too low. For direct age determination via one of the three systems, recoil loss corrections are essential. The comparison of spheres and cylinders also shows, that constraining the shape and size of the presolar grain prior to U-Th-Pb measurements is of utmost importance for an appropriate recoil correction.

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