CORRELATED MOLYBDENUM AND RUTHENIUM ISOTOPES IN PRESOLAR SILICON CARBIDE.

T. Stephan[1,2], H. E. Bloom[1,2], A. M. Davis[1,2,3], P. Hoppe[4], J. M. Korsmeyer[2,5], M. J. Pellin[1,2,3,5], A. Regula[1,2], and S. Sheu[1,2]

[1]Department of the Geophysical Sciences, The University of Chicago, Chicago, IL 60637, USA, [2]Chicago Center for Cosmochemistry, [3]The Enrico Fermi Institute, The University of Chicago, Chicago, IL 60637, USA, [4]Max Planck Institute for Chemistry, 55128 Mainz, Germany, [5]Department of Chemistry, The University of Chicago, Chicago, IL 60637, USA, [5]Materials Science Division, Argonne National Laboratory, Argonne, IL 60439, USA. E-mail: tstephan@uchicago.edu.

Introduction: We have measured Mo, Ru, and Ba isotopes in presolar SiC grains with the Chicago Instrument for Laser Ionization (CHILI) [1]. These elements are important for understanding stellar nucleosynthesis. Here, we focus on results from Mo and Ru isotopes, as Ba concentrations are low and ^{134}Ba was affected by Cs implantation from prior NanoSIMS measurements. Previous studies on presolar SiC grains have allowed for quantification of the contributions from the various nucleosynthetic processes to the solar abundances of the seven stable Mo isotopes: ^{92}Mo is *p*-process-only; ^{94}Mo is mostly *p*-process with ~4 % *s*-process; ^{95}Mo, ^{97}Mo, and ^{98}Mo are from the *s*- and *r*-processes and are about 38 %, 47 %, and 74 % *s*-process, respectively; ^{96}Mo is *s*-process-only; and ^{100}Mo is mostly *r*-process with ~2 % *s*-process [2]. Ruthenium also has seven stable isotopes: ^{96}Ru and ^{98}Ru are purely *p*-process; ^{99}Ru, ^{101}Ru, and ^{102}Ru are *s*- and *r*-process; ^{100}Ru is *s*-process-only; and ^{104}Ru is mostly *r*-process. The goal of the present study is to quantify the contributions of the various processes to the Ru isotopes in the Solar System and to search for possible correlations between Mo and Ru isotope ratios in presolar grains.

Samples and Analytical Procedures: Twenty-five SiC grains from the Murchison (CM2) KJG (1.5–3 µm) size separate [3] were analyzed in this study. All grains were classified using C, N, and Si isotopic measurements with the CAMECA NanoSIMS 50 at the Max Planck Institute for Chemistry. Among the 25 grains were 16 mainstream (M), three Y, one Z, one X, and four AB (one AB1 and three AB2) grains. CHILI uses resonance ionization mass spectrometry (RIMS) to measure isotopic abundances from a cloud of atoms liberated from a sample via laser desorption, which are then selectively ionized with lasers tuned to element-specific electronic transitions. With its six tunable Ti:sapphire lasers, CHILI allows simultaneous analysis of three elements with independent two-photon resonance ionization schemes. Since Mo and Ru share isobars at masses 96 u, 98 u, and 100 u, we developed a pulsing scheme to fire the Mo and Ru ionization lasers separately on alternate desorption laser shots. This reduces the useful yield by 50 % but allows for clean separation of Mo and Ru isotopes. Barium lasers were fired together with the Ru lasers.

Results and Discussion: Molybdenum was detected in all 25 grains, confirming previously reported trends for SiC grain types [2, 4]. The only exception is the AB1 grain, which seems to show slight relative enrichments in *r*- and *p*- process Mo isotopes. Ruthenium was detected in 20 grains (12 M, 3 Y, 1 Z, and 4 AB). These are the first reported data for such grain types that include all stable Ru isotopes, as previous studies did not include data for ^{96}Ru and ^{98}Ru [5], except for data from two X grains with strong enrichments in those isotopes [4]. Ruthenium showed clear *s*-process-dominated isotope patterns for all grains except for the AB1 grain, which also has slight relative enrichments in *r*- and *p*-process Ru isotopes. The Ru and Mo *s*-process isotope enrichments for all other grains are strongly correlated. Contributions by the *s*-process to Solar System Ru isotopes (0 % ^{96}Ru, 4±2 % ^{98}Ru, 18±1 % ^{99}Ru, 100 % ^{100}Ru, 15±1 % ^{101}Ru, 44±1 % ^{102}Ru, and 1±1 % ^{104}Ru) were calculated from the intercepts of linear regressions through δ^{x}Ru vs. δ^{96}Ru and δ^{x}Ru vs. δ^{92}Mo data, showing identical intercepts within error but typically with smaller uncertainties for the latter due to higher count rates for ^{92}Mo than for ^{96}Ru. Of all correlations, only δ^{104}Ru vs. δ^{96}Ru (and vs. δ^{92}Mo) showed significant scatter beyond counting statistics.

Conclusions and Outlook: The strong correlation between Mo and Ru isotope anomalies for presolar grains of types M, Y, Z, and AB clearly indicate that *s*-process nucleosynthesis for these two elements happens simultaneously, that it is unlikely that the grains are significantly contaminated with Solar System Mo and Ru, and that the correlations are due to varying *s*-process contributions from grain to grain. Our current precision neither confirms nor rules out (beyond 2 σ) that 100 % of ^{98}Ru is made by the *p*-process, as would be expected. The only way to make ^{98}Ru by the *s*-process would be via ^{97}Ru (2.8 d half-life) with preexisting ^{96}Ru used as a seed. The significant scatter in ^{104}Ru indicates that there might be a minor contribution from the *s*-process to ^{104}Ru activating the branch point at ^{103}Ru (39 d half-life) in some parent stars. We plan to improve statistics by analyzing more SiC grains to ascertain possible *s*-process contributions to ^{98}Ru and ^{104}Ru.

References: [1] Stephan T. et al. (2016) *International Journal of Mass Spectrometry* 407:1–15. [2] Stephan T. et al. (2019) *The Astrophysical Journal* 887:101. [3] Amari S. et al. (1994) *Geochimica et Cosmochimica Acta* 58:459–470. [4] Pellin M. J. et al. (2006) *LPS XXXVII,* Abstract #2041. [5] Savina M. R. et al. (2004) *Science* 303:649–652.