MOLYBDENUM AND RUTHENIUM ISOTOPIC COMPOSITIONS OF A METAL GRAIN IN A CALCIUM–ALUMINUM-RICH INCLUSION FROM THE EFREMOVKA CV3 CHONDRITE.

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Introduction: We have used the Chicago Instrument for Laser Ionization (CHILI) [1] to measure the Mo and Ru isotopic composition of a ~75 µm large metal grain within 27cE, a CAI from the Efremovka CV3 chondrite. Metal inclusions are typically ~10 µm across or smaller, making this one a rarity.

The goal of these measurements was to determine if there was any detectable variation from terrestrial ratios for Mo, Ru, and Ba isotopes that corresponded with the heterogeneity in elemental abundances in the metal grain. The only previous study of isotopic compositions of noble metal nuggets in CAIs found no isotopic anomalies in Mg, Fe, Mo, Ru, or W, although not all isotopes could be measured because of isobaric interferences in SIMS [2].

Materials and Methods: Efremovka 27cE is a coarse-grained CAI, transitional between Types A and B [3]. The polished CAI was imaged and X-ray mapped with a TESCAN LYRA3 focused ion beam scanning electron microscope (FIB-SEM) equipped with two Oxford XMax 80 mm^2 silicon drift X-ray detectors and Oxford AZtec software. From these images, twelve spots were selected for isotope analysis with CHILI due to their high Mo and/or Ru concentrations (Figure 1). Prior to each spot analysis, CHILI's desorption laser was used to remove the gold coating around the point of interest, in order to expose the sample surface.

CHILI is a resonance ionization mass spectrometer with six tunable Ti:sapphire lasers, allowing analysis of Mo, Ru, and Ba each with two-photon resonance schemes. CHILI's 351 nm desorption laser, focused to ~1 µm, liberates a cloud of atoms from the sample surface, which are then selectively ionized by the lasers tuned to element-specific electronic transitions.

The ionization lasers for Ru and Mo were fired on alternate shots from the desorption laser. While this reduces the useful yield by 50%, it enables the separation of the isobars (at 96 u, 98 u, and 100 u) shared between Mo and Ru. The Ba ionization lasers were fired together with the Ru lasers.

Results: The large metal grain is a multiphase grain with a bulk composition of 50.13 wt% Fe, 13.85% Os, 12.82% Ir, 8.21% Ni, 6.45% Mo, 5.00% Ru, 2.52% W, 0.50% Co, 0.41% Cr, 0.11% Pd, and <0.10% each of Pt and Re. X-ray mapping showed that some siderophile elements, including Mo and Ru, had increased abundances in localized areas within the grain, typically on the order of 1 µm^2 in size (Figure 1B and C). Analysis of the twelve spots in Figure 1A showed that the Mo isotopic composition is close to solar (Figure 2) and independent of Mo concentration. No Ba was found at any of the analyzed spots.

Not all spots shown in Figure 1A have been included in the Ru isotope analysis due to unresolved mass interferences in the measurements, including nonresonant ionization of Mo. However, all spots that were not affected by interferences have a Ru isotopic composition close to solar. Again, the measured isotopic compositions seem to be independent of the Ru concentrations.

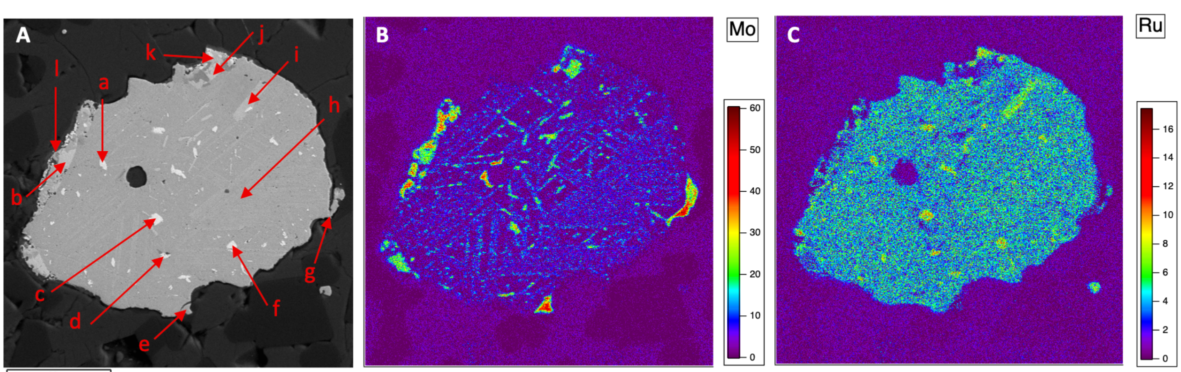

Figure 1. A) Backscattered electron image of large metal grain within Efremovka CAI 27cE. Spots of interest with respect to Mo and Ru are indicated with labeled arrows. SEM temperature map of elemental abundances for B) Mo and C) Ru on the grain in wt%.

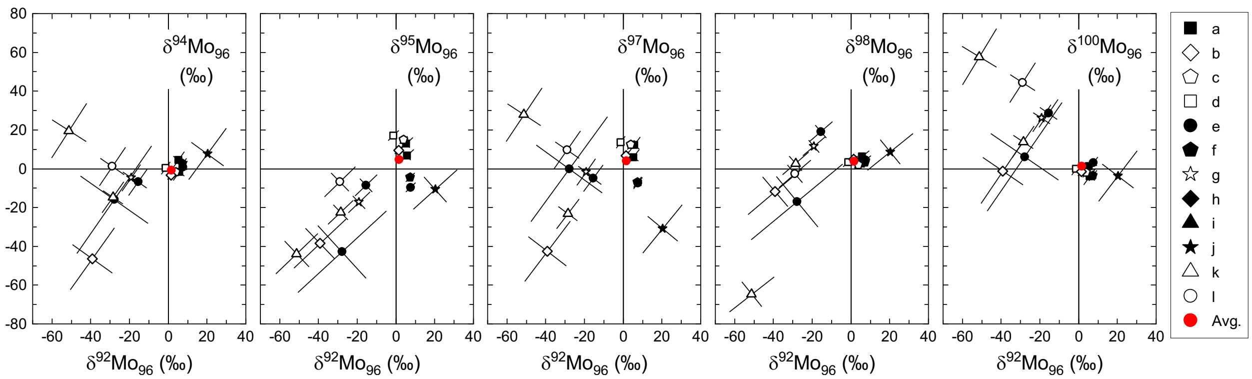

Figure 2. Mo isotope data for spots on the metal grain within Efremovka CAI 27cE measured by CHILI, normalized to the Mo standard. Error bars are 1σ counting statistic only.

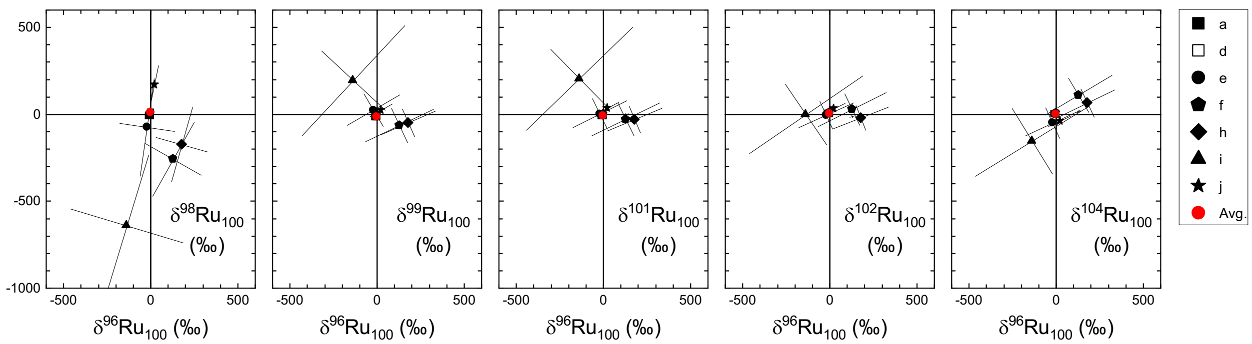

Figure 3. Ru isotope data for spots on the metal grain within Efremovka CAI 27cE measured by CHILI, normalized to the Ru standard. Spots with unresolved interferences to their Ru spectra are not included. Error bars are 1σ counting statistic only.

Discussion: Our measurements of the metal grain in Efremovka CAI 27cE show an overall solar Mo and Ru isotopic composition [4]. The average isotopic composition of the metal grain is as follows: $\delta^{92}Mo_{96}$ = 1.71, $\delta^{94}Mo_{96}$ = –0.82, $\delta^{95}Mo_{96}$ = 4.68, $\delta^{97}Mo_{96}$ = 3.95, $\delta^{98}Mo_{96}$ = 3.68, $\delta^{100}Mo_{96}$ = 1.16, $\delta^{96}Ru_{100}$ = –1.85, $\delta^{98}Ru_{100}$ = 11.78, $\delta^{99}Ru_{100}$ = –12.01, $\delta^{101}Ru_{100}$ = –7.53, $\delta^{102}Ru_{100}$ = 6.61, and $\delta^{104}Ru_{100}$ = –3.15. However, it is important to note that the systematic variation in mass–dependent fractionation for Mo and Ru standards is up to 26 ‰ and 16 ‰, respectively. Therefore, none of the analyses showed a significant deviation from solar isotope ratios.

The Ru/Mo elemental ratios for each spot on the metal grain are listed in Table 1. These ratios were calculated using a relative sensitivity factor (RSF) of 0.260, determined from Mo and Ru isotope measurements on iron meteorites using CHILI [5]. The Ru/Mo ratio of the bulk grain is 0.736, which is within the uncertainty of the solar ratio (0.696 ± 0.070) [6]. The Ru/Mo atomic ratios of the individual spots are not in good agreement with the solar ratio, but this is expected due to the variation in Mo and Ru elemental abundances shown in Figure 1B and C.

References: [1] Stephan T. et al. (2016) *Int. J. Mass Spectrom. 407*, 1–15. [2] Hutcheon I. D. et al. (1984) *GCA 51,* 3175–3192. [3] Ivanova M. A. et al. (2021) *GCA 296,* 97–116. [4] Meija J. et al. (2016) *Pure Appl. Chem. 88,* 293–306. [5] Regula A. et al. (2022) *LPS, 53, this conference.* [6] Lodders K. (2021) *Space Sci. Rev., 217,* 44.

Table 1. The Ru/Mo atomic ratio for each spot measured on the metal grain. Upper limits are given for spots that have unresolvable interferences in their Ru spectra. Errors are 1σ counting statistic only.

Spot	a	b	c	d	e	f	g	h	i	j	k
Ru/Mo	9.761	<0.261	<0.496	5.271	<0.206	3.126	<0.116	1.580	1.807	0.289	<0.221
Error	0.018	0.005	0.001	0.006	0.007	0.003	0.001	0.052	0.165	0.004	0.002