RUTHENIUM ISOTOPE ANOMALIES IN METEORITES AND THE COSMIC Mo-Ru CORRELATION.

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Introduction: The presence of nucleosynthetic isotope anomalies in bulk meteorites indicate that different planetary bodies incorporated varying proportions of isotopically diverse presolar dust. Planetary-scale nucleosynthetic isotope heterogeneities have been documented for a number of elements (e.g., Cr, Ti, Ni, Ru, Mo) [1-5] but seem to be absent for other elements (e.g., Hf, Os) [6, 7]. Identifying isotope anomalies at the bulk meteorite scale provides important information regarding the extent and efficiency of mixing processes as well as pathways of material transport within the solar nebula. For instance, Mo isotope anomalies of meteorites and their components decrease over time, providing evidence for a progressive homogenization of the solar nebula. However, carbonaceous chondrites exhibit larger Mo anomalies than expected for their age, indicating that they may have received a greater portion of material from the outer solar system than other meteorite parent bodies and terrestrial planets [1, 8].

Ruthenium is a promising target for further investigation of isotope heterogeneities in bulk meteorite samples. Ru has seven isotopes, two of which were produced by the p-process (^{96}Ru, ^{98}Ru), one by the s-process (^{100}Ru), one by the r-process (^{104}Ru), and three by both, the s- and the r-processes (^{99,101,102}Ru). Precise Ru isotope measurements can thus be used to investigate the distribution of different nucleosynthetic components in the inner solar system. Chen et al. [2] reported the first evidence for nucleosynthetic Ru isotope anomalies in iron meteorites and bulk chondrites. The Ru anomalies correlate with those in Mo exactly as expected from s-process nucleosynthesis, providing strong evidence that the correlated Ru and Mo anomalies are caused by a heterogeneous distribution of one or more s-process carriers [1, 2, 9]. This cosmic Mo-Ru correlation, however, is currently mainly defined by iron meteorites. To further investigate the extent of Ru isotope variations in meteorites and to evaluate the significance of the Ru-Mo correlation we developed new analytical techniques for precise Ru isotope measurements by multicollector inductively coupled mass spectrometry (MC-ICPMS). Here we present new Ru isotope data for IVB iron meteorites, the ungrouped iron meteorite Chinga, and the CB chondrite Gujba.

Analytical Techniques: Iron meteorite specimens were first cleaned with metal-free abrasives and then dissolved in reverse aqua regia. A metal sample of Gujba was dissolved in 2M HCl and undissolved silicates were removed by centrifugation. Prior to purification of Ru by ion exchange chromatography, Os was removed from the samples by extraction into CCl_4 [10]. Ruthenium (together with remaining highly siderophile elements) was then separated from the sample matrix by cation exchange chromatography [11], and further purified by microdistillation [12].

Ruthenium isotope measurements were performed using the ThermoScientific Neptune *Plus* MC-ICPMS at the University of Münster, equipped with an APEX nebulizing system. Isobaric interferences of Mo and Pd on Ru masses 96, 98, 100, 102 and 104 were corrected by monitoring ^{97}Mo and ^{105}Pd. Measured Ru isotope ratios were corrected for mass bias by normalization to ^{99}Ru/^{100}Ru or ^{99}Ru/^{101}Ru using the exponential law. The Ru isotope data are reported in ε^{i}Ru units as the deviation in parts per 10,000 from the terrestrial Ru isotope composition (Alfa Aesar Specpure Ru standard solution).

Results: The new Ru isotope data for IVB iron meteorites, the ungrouped iron Chinga and the CB chondrite Gujba are displayed in Fig. 1. For mass bias correction relative to ^{99}Ru/^{101}Ru (Fig. 1a) all samples show a negative anomaly in ε^{100}Ru that is well resolved from the terrestrial standard. There are also hints for positive anomalies in ε^{96}Ru and ε^{98}Ru and a negative anomaly in ε^{102}Ru but these are yet not resolved from terrestrial Ru. When normalized to ^{99}Ru/^{100}Ru all samples show resolvable deficits in ε^{96}Ru and large enrichments in ε^{101}Ru, ε^{102}Ru and ε^{104}Ru (Fig. 1b). There also seem to be small deficits in ^{98}Ru but these are currently not well resolved from terrestrial Ru. In general, our new data are in excellent agreement with previously reported data for IVB irons by Chen et al. [2].

Discussion: In Fig. 1 the Ru isotope compositions of the samples are shown in comparison to those calculated for a deficit in s-process Ru isotopes using the stellar model of s-process nucleosynthesis of Arlandini et al. [13]. The excellent agreement between the calculated and observed patterns provides evidence that Ru isotope anomalies displayed by the IVB irons, Chinga and the CB chondrite Gujba are caused by a deficit in s-process isotopes, consistent with previous results and also with the correlated Ru and Mo isotope anomalies observed for bulk meteorites (Fig. 2).

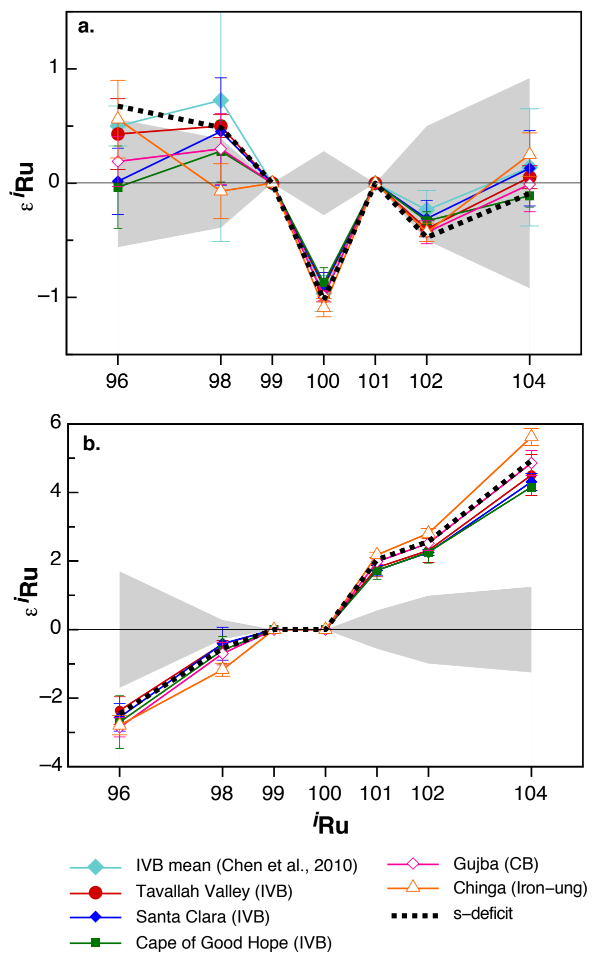

Fig. 1: Ruthenium isotope compositions for IVB iron meteorites, the ungrouped iron Chinga, and the CB chondrite Gujba normalized to ^{99}Ru/^{101}Ru (a.) and ^{99}Ru/^{100}Ru (b.). The grey area reflects the external reproducibility (2sd) of the Ru standard measurements.

An important observation from Fig. 2 is that our new Ru data for Gujba plot exactly on the Ru-Mo correlation line for a s-process deficit. Thus, the cosmic Mo-Ru correlation does not only apply to iron meteorites but also seems to extend to carbonaceous chondrites. Clearly, more data are needed for different groups of chondrites to examine the significance of the cosmic Mo-Ru correlation for chondrites in more detail.

It is noteworthy that a companion study of Pt isotopes on the same IVB iron meteorites investigated for the present study [14] does not find evidence for nucleosynthetic Pt isotope anomalies. This is consistent with the absence of Os isotope anomalies in bulk meteorites [6, 15, 16]. Thus, in contrast to the well-resolved Ru and Mo isotope anomalies observed for bulk meteorites, no such anomalies seem to exist for Os and Pt. This observation is surprising, because Ru, Pt and Os all are highly siderophile elements which most likely reside in similar carriers. The disparate isotope systematics of Ru, Pt and Os may thus be related to thermal processes within the solar nebula, rather than reflecting a primordial heterogeneity in the distribution of presolar dust within the protosolar accretion disk [5, 17]. However, more work is needed to firmly establish the processes responsible for generating nucleosynthetic isotope anomalies at the bulk meteorite scale.

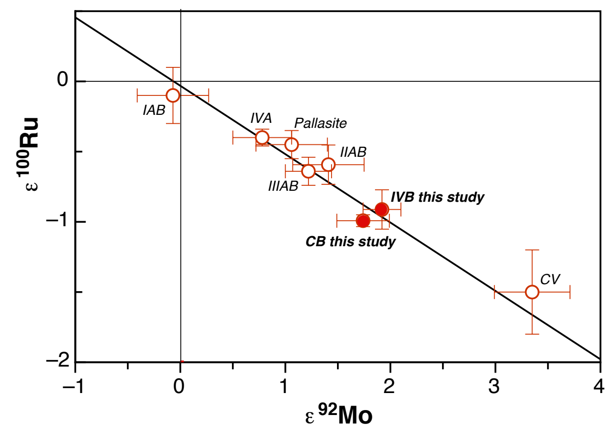

Fig. 2: ε^{92}Mo *vs.* ε^{100}Ru data for iron meteorites, carbonaceous chondrites and pallasites [this study, 1, 2]. A linear regression of the data yields a slope of -0.49 ± 0.09, in excellent agreement with the slope calculated for s-process abundances of Mo and Ru [9].

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