NUCLEOSYNTHETIC Mo ISOTOPIC ANOMALIES IN PLANETARY MATERIALS AS TRACERS OF CIRCUMSTELLAR DISK PROCESSES.

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Introduction: Nucleosynthetic isotope anomalies in meteorites and their components provide key constraints regarding the early evolution of the solar nebula. In addition to the well established presence of isotopic anomalies among different components of chondritic meteorites [1], there is now evidence that large scale isotopic heterogeneities persisted in the solar nebula. The identification of such heterogeneities for some elements (e.g. Cr, Ti, Ni, Ru) contrasts with evidence for isotopic homogeneity in bulk samples for other elements (e.g. Hf, Os). The reasons for these contrasting results are yet not fully understood.

The investigation of Mo isotope anomalies is of particular interest in this regard. First, Mo has 7 about equally abundant isotopes that were produced by distinct nucleosynthetic processes such that a heterogeneous distribution of p-, s-, and r-process components can be readily determined. Second, as a refractory and moderately siderophile element Mo is found in measurable quantities in most meteorite classes. Third, the scale of Mo isotopic heterogeneities can be compared to that reported for other siderophile elements (Ni, Ru, Os). Finally, previous Mo isotopic studies on meteorites reported inconsistent results [2-5], such that the existence and extent of planetary-scale Mo isotope variations is yet not known. Here we present new Mo isotopic data for a comprehensive set of meteorites that reveal large-scale variations in the relative abundances of nucleosynthetic Mo components.

Samples and Analytical Methods: Samples from all major iron meteorite and chondrite groups, several Allende CAI, two pallasites, one angrite and two martian meteorites were investigated for this study. Chondrites, achondrites and CAI were dissolved in closed Savillex vials using HNO_3-HF-$HClO_4$, metal-rich meteorites were digested in HCl. To assess the effect of incomplete digestion of refractory minerals and presolar grains, powders of some chondrites and CAI samples were fused with a CO_2 laser [6] prior to digestion in HNO_3-HF-$HClO_4$. Mo was purified by ion exchange chromatography and Mo isotopic compositions were measured using the Nu Plasma 1700 MC-ICP-MS at ETH Zürich. Instrumental mass bias was corrected relative to ^{98}Mo/^{96}Mo, but internal normalization to other isotope pairs yields internally consistent results, demonstrating that analytical artifacts are absent.
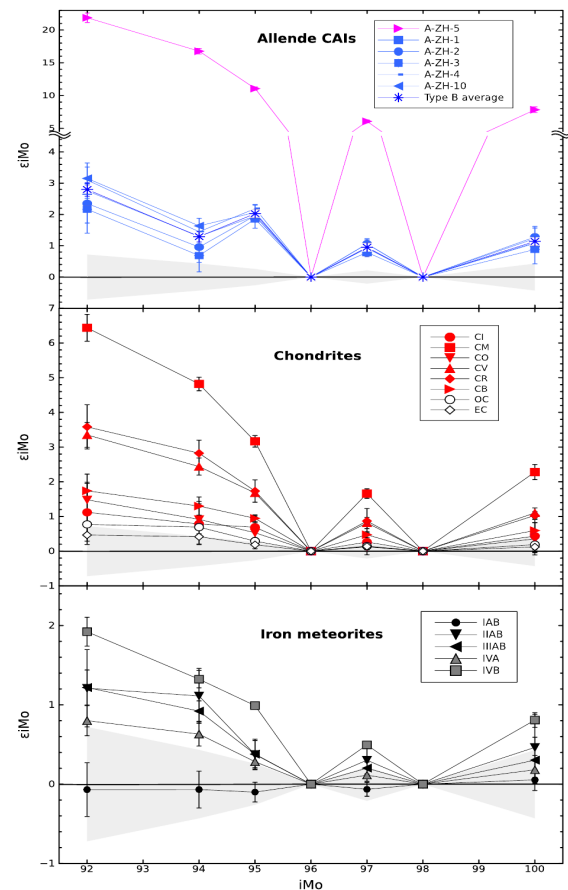

Figure 1: Mo isotopic composition of CAIs, chondrites and some iron meteorite groups normalized to ^{98}Mo/^{96}Mo in parts per 10,000 (ε) deviation from terrestrial Mo. The grey area represents the external reproducibility of the standard (2σ).

Results: Figure 1 shows results for CAI, chondrites and some iron meteorite groups in ^{i}Mo vs. $ε^{i}Mo$ plots.

CAIs: The 5 investigated type B CAIs have very similar Mo isotopic patterns (~2.8 ε in ^{92}Mo, kink in ^{94}Mo) that can be accounted for by an r-process excess relative to terrestrial Mo. In contrast, CAI A-ZH-5 exhibits a large s-process deficit ($ε^{92}Mo$ ~22, no kink in ^{94}Mo). No significant difference in the measured isotopic composition is observed between acid-digested (A-ZH-1 to -4) and laser-fused (A-ZH-10) CAIs.

Chondrites: The Mo isotopic compositions of all investigated chondrite groups are different from that of the Earth. While for most groups the anomalies are

well resolved, those of the enstatite, ordinary and CI chondrites are at the limit of our analytical resolution. However, these chondrites show Mo isotope patterns similar to those expected for an s-process deficit. Laser-fused and acid-digested samples show no significant differences in their measured Mo isotopic compositions, indicating that undigested refractory phases are not the cause for the measured Mo isotopic anomalies in chondrites. The anomalies thus reflect those of the bulk chondrites, demonstrating that different chondrites contain varying proportions of the various nucleosynthetic Mo components.

Iron meteorites: Except for the IAB and IIICD (not shown in Fig. 1) groups all iron meteorites exhibit Mo isotopic compositions different from that of the Earth. Different samples from one group of magmatic irons display identical Mo isotopic anomalies. The observed patterns are consistent with a variable s-process deficit. The IVB irons display the largest anomalies of up to ~2 ε in ^{92}Mo.

Pallasites, angrites and martian meteorites: The Main Group and Eagle Station pallasites have Mo isotopic compositions different from each other and the Earth. No resolvable anomalies were found for angrites and martian samples.

Discussion: Our results reveal planetary-scale nucleosynthetic Mo isotopic anomalies that require a heterogeneous distribution of s-process Mo carrier(s) in the solar nebula. The Mo isotopic anomalies correlate with those of Ru [7] exactly as predicted from nucleosynthetic theory for variable s-process deficits in different planetary bodies (Fig. 2). However no such correlations are found between nucleosynthetic anomalies in Mo and those for Ni [8] and other Fe-peak elements (Cr, Ti) [9]. Furthermore, the isotopic heterogeneity for Mo and some other elements contrasts with the lack of evidence for planetary-scale Os isotopic heterogeneity [10]. These observations indicate that Mo and Ru reside in the same s-process carrier(s), which are different from those of Os and the Fe-peak elements. To account for the lack of correlated anomalies between Mo, Ni and Os the distribution of these distinct carriers throughout the solar nebula must have been decoupled from each other [11]. While the carriers of Mo-Ru and the Fe-peak elements were heterogeneously distributed, the carriers of Os appear to have been well mixed.

The heterogeneous distribution of some presolar components either reflects inefficient mixing of star-derived dust in the solar nebula [12] or is the result of destruction of thermally unstable presolar components during thermal processing within the disk [9], or both. Accessing as to whether such process can account for the Mo and Os signatures requires additional work.
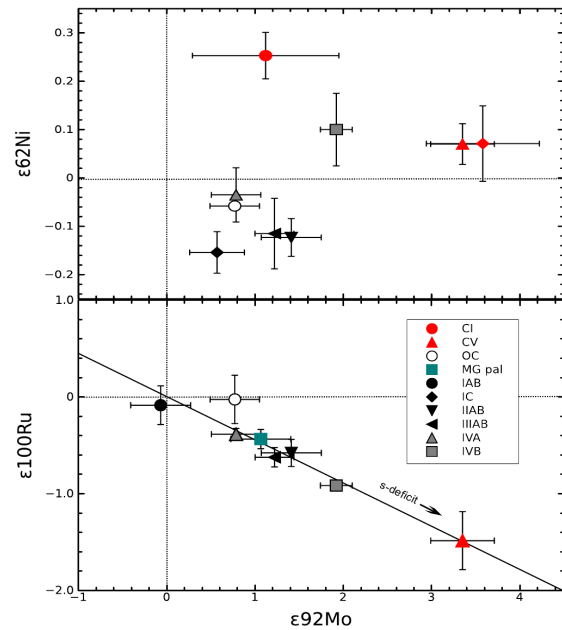

Figure 2: Nickel [8], Ru [7] and Mo isotopic compositions of bulk meteorites. While Ru and Mo anomalies correlate as expected for a s- process deficit, no such correlation is seen between Ni and Mo.

Whatever the cause that established the Mo anomalies in bulk meteorites in the first place they can be used as tracers of accretion and genetic relationships of planetary objects. Mainly based on O-isotopic measurements genetic relations between several meteorite groups were suggested: IAB-IIICD, IIE-H, IIIAB-MG pallasites, IVA-L-LL, CV-Eagle Station pallasites, CR-Taffassasset. Our data support the IAB-IIICD relation but disprove the CV-Eagle Station and CR-Taffassasset connection. They further imply that the Earth is not (only) made out of chondrites. All chondrite classes show a s-deficit. Therefore no combination of chondrites would produce the terrestrial Mo isotopic composition. It is noteworthy that so far no planetary material with negative Mo anomalies was found.

A model that relates the size of the anomalies to the age and size of the parent body will be presented at the conference.

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