ENDEMIC Mo ISOTOPIC ANOMALIES IN IRON AND CARBONACEOUS METEORITES. J. H. Chen[1], D. A. Papanastassiou[1,2,3], G. J. Wasserburg[3], and H. H. Ngo[1], [1]Earth and Space Sciences Division, M/S 183-601 ([2]M/S 183-335), Jet Propulsion Laboratory, Caltech, 4800 Oak Grove Dr., Pasadena, CA 91109. [3]The Lunatic Asylum, Division of Geological and Planetary Sciences, M/C 170-25, Caltech, Pasadena, CA 91125.

Mo in refractory interstellar grains shows large isotope anomalies [1-3]. Recent Mo studies showed isotope effects in Allende and Murchison, and in iron meteorites, mesosiderites, and pallasites [4-6]. Excesses of *p*- and *r*-process isotopes (or depletion of *s*-process isotopes) of up to 3.5 ε units (εu=parts in 10^4) were reported. We have reported on endemic isotope anomalies in Ru [7, 8]. Other workers have resolved *no* isotope anomalies for Mo [9-11] or Ru [12] and have claimed that the work by [4-7] is incorrect. Because Ru isotopes can interfere at ^{96,98,100}Mo, we improved the chemical separations and eliminated interferences. For Mo work, we used the same solutions from which we separated and analyzed Ru [7,8]. Three of the iron meteorites (Coahuila, Cape York, and Cape of Good Hope) were chosen for their large Mo isotopic effects [4]. Mo was loaded on outgassed Re filaments, and then reduced; we used $Ba(OH)_2$-NaOH as emitter, and measured Mo in static mode, as MoO_3^-. We used ^{98}Mo/^{96}Mo for the mass fractionation correction (exponential law). No interferences from Ru or Zr isotopes were detected using the electron multiplier and no corrections were needed. For results on Mo standards we show 2σ (*not* $2\sigma_{mean}$) external precision better than: 0.7εu for ^{94}Mo/ ^{96}Mo and ^{95}Mo/^{96}Mo; 1.0εu for ^{92}Mo/^{96}Mo and ^{97}Mo/ ^{96}Mo; 1.4εu for ^{100}Mo/^{96}Mo. Reproducibility for Mo standards is shown as contours (blue lines) in Fig. 1a-d.

Iron meteorites. Two analyses on Bennett Co. (IIA) yield normal Mo isotopic composition. Coahuila (IIA) shows an excess in ^{92}Mo (1.7±0.5εu), while Cape York shows shifts in both ^{92}Mo (2.1±1.2εu) and ^{95}Mo (1.6± 0.5εu). Two group IIIB irons (Acuna, Tres Castillos) and a group IVB iron (Cape of Good Hope), show hints of possible shifts in ^{92}Mo and ^{95}Mo. Hoba (IVB) yields normal values, despite its ^{100}Ru deficit [7]. Direct comparison of our results with [4] shows: a) Coahuila: agreement for ^{92,94,95}Mo; but, we report no resolved effects for ^{97,100}Mo; b) Cape York: agreement for ^{92,94}Mo; excess ^{95}Mo which is larger than the excess in [4]; no effects in ^{97,100}Mo, where [4] reported a marginal excess in ^{97}Mo and no effect in ^{100}Mo; c) Cape of Good Hope: agreement for ^{92}Mo; disagreement for ^{94}Mo, where we find no effect; agreement for excess in ^{95}Mo; agreement for ^{97,100}Mo which show no resolved effects either here or in [4]. For this meteorite, no effect was found in ^{94,95,97}Mo by [6].

Pallasites and Ordinary Chondrites. A pallasite (Spring Water) and two OCs (Olivenza and Ransom) show no shifts in Mo isotopic compositions.

Carbonaceous Chondrites and CAI. Murchison (CM2) and two samples of Allende (CV3) show clearly resolvable shifts in ^{92}Mo (up to 2.6±0.5εu) and ^{95}Mo (up to 1.9±0.3εu). Three Allende coarse-grained CAI (Egg-3, Egg-6, Big-Al) also show relatively large shifts in ^{92}Mo (1.5±1.0, 1.7±1.0, 2.8±0.3εu) and ^{95}Mo (1.5± 0.7, 1.7±0.3 2.1±0.3εu). These "whole rocks" and coarse CAI show no resolved effects for ^{94,97,100}Mo. A fine-grained spinel-rich Allende CAI (Pink Angel [13]) shows a distinct pattern, with well-resolved deficits in ^{92}Mo (-1.6±0.5εu), ^{97}Mo (-2.6 ±0.6εu) and ^{100}Mo (-1.7 ±0.7εu). This pattern is similar to the pattern observed for a Murchison mainstream SiC grain [1] and consistent with both the classical and stellar *s*-processes [14]. Overall, the new Mo data on IIA, IIIAB, IVB iron meteorites, on carbonaceous chondrites and on 3 coarse-grained Allende CAI clearly show enrichments of ^{92}Mo (pure *p*-process) and ^{95}Mo (*s*- and *r*-process), but no resolvable shifts in other Mo isotopes. The absence of effects in ^{97}Mo can be ascertained with high precision from our data. An *s*-process pattern is observed for the spinel-rich, fine-grained CAI Pink Angel. We confirm the presence of clear isotope anomalies for Mo, including the presence of large anomalies for carbonaceous meteorites [4-6] and Allende CAI. The effects that we are reporting are different from the general "Mo-W" pattern reported previously [4-6]. In particular, within the resolution of our data, we do not identify excesses in ^{94,97,100}Mo/^{96}Mo. We also observe that effects in the *p*-process isotope ^{92}Mo are not accompanied by similar effects in the 2nd *p*-process isotope, ^{94}Mo. This indicates that the observed *p*-process effects in Mo for this study are distinct from the average *p*-process represented by the Solar System "normal" Mo composition. The pattern for the *p*-process isotopes suggests that production of ^{92}Mo is enhanced over production of ^{94}Mo, in the exotic component (or components). We note that the high abundances for *p*-process isotopes both for Mo and Ru have long been a key puzzle for nucleosynthesis. The observation of no detectable enrichment in ^{100}Mo, an *r*-only isotope, indicates that *p*- and *r*- process contributions are decoupled, as was observed also for Sm and Nd isotope anomalies for FUN Allende CAI C-1 [15, 16]. A correlation of ^{100}Ru/^{101}Ru (from [7]) and ^{92}Mo/^{96}Mo (from [4]), presented by [18] is due to a mixture of *s*-process and of the potentially distinct *p*-process which produced the

^{92}Mo in preference to ^{94}Mo. In comparison, our Ru data [7,8] on iron meteorites, pallasites, carbonaceous chondrites and Allende CAI suggest up to –1.7 εu depletion in a pure *s*-process nuclide, ^{100}Ru, relative to other Ru isotopes. The absence of ^{97}Mo and ^{100}Mo effects in our data, removes the clear resolution of an *r*-process contribution and leaves the effects in ^{95}Mo harder to interpret. Mo in Allende CAI A44A [6] does show an *r*-process component (decoupled also from *p*-process [6]). We conclude, along with [6, 18], that there is evidence for multiple *r*-process components to address the observed Mo isotope anomalies. Our data show no hint of excess in ^{97}Mo and no evidence from decay of extinct ^{97}Tc ($t_{1/2}$=3.8 Ma). In conclusion, our new Mo results show enrichments of ^{92}Mo and ^{95}Mo in some IIA, IIIAB, IVB meteorites, carbonaceous chondrites and Allende CAIs, but absence of Mo isotopic anomalies in some other iron meteorites, in pallasites, and in ordinary chondrites. Our new results confirm the presence of isotope anomalies for Mo and Ru not only in primitive meteorites, but preserved also in planetary differentiates. The results we have presented are in disagreement with the general conclusions of [9,10, and 11] on the ostensible absence of Ru and/or Mo anomalies even in carbonaceous meteorites. Similarly the conclusions reached in a news commentary by [19] are in disagreement with our Mo and Ru data and with reports of small isotope anomalies by many groups. The disagreements in the Mo data reflect probably technical issues associated with mass interference corrections, which are absent in the data presented here.

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