

SOLAR Rb/Sr: IS IT NON-CHONDRITIC?; Munir Humayun¹ and the Clayton Coffee Group^{1, 2, 3}. Departments of ¹the Geophysical Sciences, and ²Chemistry, and ³the Enrico Fermi Institute, University of Chicago, IL 60637.

The Rb/Sr ratio of the sun is an important quantity for the determination of relative chronology in the early solar nebula [1, 2]. This value, presently taken as 0.50, is larger than the C1 chondrite value, 0.30 [3]. This dichotomy is firmly entrenched in the cosmochemistry literature, and it is widely assumed that chondrites and component CAIs formed in (or differentiated from) this high Rb/Sr environment [1, 2, 4]. An examination of the solar abundances of Rb and Sr indicates that Sr is chondritic within error, but Rb is higher in the sun by about 60%. Is this evidence of a primordial differentiation or simply an inaccurate determination of the solar abundance of Rb? We examine this question and its consequences for early solar system chronology.

Because of the importance of the Rb/Sr ratio for geo- and cosmochemistry, Hauge [5, 6] determined the solar abundances and isotopic compositions of Rb and Sr from spectroscopic examination of the solar photosphere. The Rb isotopic composition is terrestrial within uncertainty, but the Rb abundance is significantly higher than the C1 chondrite value, while the Sr abundance closely agrees (2.90 ± 0.06 vs. 2.93 ± 0.03 dex). [All abundances will be given using the dex scale, $\log (N/N_H) + 12$, where N and N_H are the atomic abundances of the element and of hydrogen, respectively.] The Rb abundance of the sun is extremely hard to determine, since Rb has only two lines at 780.0 nm and 794.7 nm, and these suffer from blending with Si I (780 nm) and a terrestrial water vapour line (794.7 nm). The 780 nm line is easier to resolve, and has been used for the abundance determination of Rb, 2.60 ± 0.05 dex [5]. Anders and Grevesse [3] give the solar Rb abundance as 2.60 ± 0.15 dex. The lower error bound on this value is close to the chondritic value, 2.40 ± 0.03 dex [3]. Since the high Rb/Sr (0.5 ± 0.1) in the solar photosphere implies a high present day $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (≈ 0.80 vs. 0.76 for chondrites), a precise measurement of this quantity would be corroborative evidence for the Rb/Sr ratio. Unfortunately, this is beyond the precision generally obtained by spectroscopic methods, and only an upper limit to the solar $^{87}\text{Sr}/^{86}\text{Sr}$ has been set (≤ 3) [6]. We can conclude that the solar Rb determination is poor enough to allow the assignment of a chondritic Rb/Sr ratio (0.30) to the sun, and a chondritic abundance of Rb.

For the sake of argument, we will consider two other possibilities below: 1) The chondrites formed in a region of solar Rb/Sr (0.5), but failed to completely condense Rb [6] (volatile element fractionation), or perhaps less conceivably, 2) the solar nebula was grossly heterogeneous such that chondrites formed in a region of local Rb/Sr = 0.3, while the central part that formed the sun was enriched in Rb/Sr. We will take the latter case first. The sun comprises the dominant portion (50-90%) of the solar nebula mass, and is therefore regarded as the best representative of bulk primordial nebular composition. Eliminating only the most uncertain of the 63 elements (and Li, Be, B, which are depleted by nuclear reactions) in the compilation of [3] for which both solar and meteoritic data are available, the remaining 51 elements yield a mean difference (photospheric/meteoritic - 1) of +2% with a standard deviation of $\pm 22\%$. For the 29 well-determined elements, the agreement is $\pm 9\%$ [3]. This agreement can simply not be obtained if C1 chondrites were chemically dissimilar to the solar photosphere by as much as indicated by the Rb value (58.5%). The assumption of heterogeneity additionally implies that the solar Rb/Sr value is not applicable in the regions of cosmochemical interest: those where chondrite (CAI, chondrule, matrix) and planet formation took place. Further, this must be regarded as a rather unsatisfactory way of reconciling the solar and meteoritic Rb/Sr ratios.

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As concerns volatile element fractionation in C1 chondrites, this should affect the abundances of other elements of similar volatility by about the same factor, e.g. Na, S, K, Cu, and Zn. But these are chondritic (2-13%) in the sun within error. Elements of higher volatility (Cl, Cd, Tl) are likewise similar between the sun and C1 chondrites, but the analytical errors are greater for these [3]. As argued by [3, 7], hydrothermal alteration of C1 chondrites appears to have taken place in a closed system, and removal of Rb by either hydrothermal alteration or leaching would have a large effect on other elements, e.g. Mg, K, Br, Cs, Tl. We conclude: there does not appear to be any cosmochemically tenable mechanism for the selective depletion of Rb in C1 chondrites relative to solar abundances. Given that the solar abundances have relatively large uncertainties, including systematic errors, and that there are no unblended lines of Rb available for analysis, we reaffirm our statement above, and assign the apparent depletion to an inaccurate determination of solar Rb. It may be possible to redetermine the solar Rb abundance using space-borne telescopes that are free of the troublesome atmospheric H₂O blending.

Values of solar Rb/Sr of 0.65 and 0.50 have been widely used in the literature of early solar system chronology [1, 2]. The principal effect of the adoption of a chondritic Rb/Sr ratio is that relative time intervals are increased by a factor of 1.6-2, because of the slower reservoir evolution. Some workers have modelled chondrite isochron evolution in terms of differentiation from a nebula with high Rb/Sr ratios of 0.5-0.65. This is not justifiable if the nebular ratio is 0.3. Since H, LL, and E chondrites have Rb/Sr ratios different from C1 chondrites, due to volatile element fractionation in the nebular/early planetary stage, valid isochrons can still be obtained [4]. The relative time difference between BABI and the most primitive initial Sr ratio of [2] is about 15 m.y. using Rb/Sr = 0.3. The longer time-scales implied may be inconsistent with nebular processes, but can be interpreted in terms of large impacts accompanying planetary accretion [8]. Based on a comparison of Pb-Pb ages and initial Sr ratios for CAIs and achondrites, Tilton [8] has indicated that the chondritic Rb/Sr ratio is preferable. A final solution may yet be found by precise geochronological studies, or must await better determinations of the solar Rb abundance or Sr isotope ratio.

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