THE PROBLEM WITH THE ESTIMATED Re/Os RATIO OF THE SOLAR NEBULA. M. Sharma1, A. Juriewicz1, and D. Burnett2. 1Department of Earth Sciences, 6105 Fairchild Hall, Dartmouth College, Hanover, NH 03755, 2Division of Geological & Planetary Sciences, MS 170-25, Caltech, Pasadena CA 91125.

Introduction: The \( ^{187}\text{Re} \rightarrow ^{187}\text{Os} + \beta; t_{1/2} = 41.2 \text{ billion years} \) has been extensively used in models of the evolution of the planetary mantles (e.g., [1-3]). These models assume that (1) the Os isotope composition of solar nebula was homogeneous and (2) the present-day chondritic \( ^{187}\text{Os} / ^{188}\text{Os} \) ratio is reflective of the time-integrated Re/Os ratio of the nebula. Whereas assumption (1) is supported by a number of well-constrained isochrones and by uniform stable Os isotope composition of different meteorites and terrestrial samples, we do not yet have a clear understanding of (2), the Re/Os ratio of the solar nebula. Since the abundances of a number of non-volatile elements match between solar photosphere and carbonaceous chondrites, of which CI appear least fractionated, cosmochemists have so far assumed that the Re/Os ratio of the solar nebula was identical to that of CI. Here we discuss that assumption (2) is not robust: a new, experimental determination using GENESIS samples is needed to validate the time-integrated Re/Os ratio of the solar system.

Re/Os ratio of the Solar Nebula: During the last ten years there has been a substantial improvement in our understanding of mixing and homogenization within solar nebula, the result of a number of studies searching for nucleosynthetic anomalies in meteorites and their components. For example, the discovery of deficits in p-process \( ^{144}\text{Sm} \) and excesses in r-process \( ^{135}\text{Ba} \) and \( ^{137}\text{Ba} \) in bulk samples of C-chondrites with respect to a variety of O-chondrites, an E-chondrite, a eucrite, and Earth [4-6] points to a large scale heterogeneity between the inner solar system and relatively outer regions of the solar nebula where C-chondrites formed. Second, the discovery that the most abundant CAIs found in C-chondrites display larger-magnitude excesses in \( ^{135}\text{Ba} \) and \( ^{137}\text{Ba} \) and deficits in \( ^{144}\text{Sm} \) than those in bulk samples [7] suggests that the incorporation of these objects in accreting C-chondrite parent bodies is the underlying cause of the observed heterogeneity. Finally, the discovery of correlated nucleosynthetic anomalies in different elements (e.g., \( ^{46}\text{Cr} \), \( ^{50}\text{Ti} \), \( ^{62}\text{Ni} \), \( ^{84}\text{Sr} \), \( ^{95}\text{Mo} \), \( ^{183}\text{W} \)), as well as for isotopes of a single element (\( ^{46}\text{Ti} \), \( ^{50}\text{Ti} \)) believed to originate from distinct stellar sources [8-12] in bulk-samples of chondrites and/or their leachates and residues, has required modification of the standard model which assumed that C-chondrites were the dominant building blocks for the terrestrial planets (Fig.1; [13]).

In comparison, the similarity of high-precision stable-isotope ratios for Os for Earth and different classes of meteorites indicates a rather homogeneous protosolar nebula for Os isotopes [15-17]. Synthesis of a large body of Re-Os data has shown, however, that the present-day \( ^{187}\text{Os} / ^{188}\text{Os} \) ratio of the terrestrial primitive upper mantle, Moon, Mars and Howardite-Eucrite-Diogenite parent body (asteroid 4 Vesta) are identical to that of O- chondrites/E- chondrites (= 0.129) and higher than C- chondrites (= 0.126) (c.f., [18] and references therein). This observation indicates that the time-integrated Re/Os ratios of the Earth, Moon, Mars and 4 Vesta are similar to that of O- chondrites/E- chondrites but not C-chondrites (Fig. 1). As the Earth, Moon, Mars and 4 Vesta have extremely different evolutionary histories, the above observation is remarkable! As Re and Os are amongst the most refractory elements [14, 19] the observed bimodality in Re/Os ratio cannot easily be explained as a consequence of volatility-based fractionations within the nebula. Variations in refractory element ratios in bulk chondrites could be related to the incorporation of CAI components with fractionated refractory element abundances [20]. This postulate is not supported by CAI data [21], suggesting CAIs could only play a subservient role in controlling the Re/Os ratio of chondrites.

Further, it is intriguing that the set of meteorite groups which differ in their Re/Os ratios is the same set distinguished by distinct nucleosynthetic anomalies.
Since mixing and thermal processing of presolar grains under nebular conditions likely did not impact the Re/Os ratio of the nebula, differential mobilization of Re over Os in the parent bodies of chondrites was likely responsible for the observed variation. For example, parent bodies of C-chondrites and especially CI chondrites underwent extensive aqueous alteration that involved dissolution/hydration of primary minerals (serpentinitization of olivine and pyroxenes), precipitation of secondary minerals (magnetite, sulfate, carbonates) (e.g., [22-24]) and formation/redistribution of organic matter [25]. Although water-rock interaction is considered static and isochemical, a recent study [26] suggests convective transport could also be possible in a large parent body being heated by decay of $^{26}$Al. If so, it is possible that the Re/Os in CI chondrites was modified from low temperature water-rock interaction. These observations suggest that the Re/Os ratio of CI chondrites cannot be assumed to be identical that of the solar nebula.

Re/Os ratio of the Solar Photosphere: Since solar photosphere has been isolated from the nuclear reactions taking place in the solar core, its Re/Os ratio should be the same as that of the solar nebula. The solar Re/Os ratio is not known. While direct measurements of solar Os abundance have been made [27-29], there is only one early attempt to provide an upper limit of Re abundance of 0.015 atoms/10$^6$ Si atoms (or 0.01042 $\mu$g/g) [30]. This limit appears to be consistent with the "smooth odd mass curve" criterion [31, 32] and taken at its face value and using the most recent Os abundance determination, we find that the solar Re/Os ratio is <0.0200. In comparison, the Re/Os ratio of CI chondrite Orgueil is 0.0797—at least a factor of four higher than the upper limit obtained by analysis of solar spectrum! A direct estimation of the solar Re/Os is therefore needed to provide a benchmark against which early alteration processes on meteorite parent bodies and planetary evolution scenarios could be evaluated.

Genesis returned solar wind (SW) provides a unique opportunity for determining the time integrated Re/Os ratio. No fractionation of Os or its isotopes during SW formation is predicted: first, the first ionization potential (FIP) of Os is 8.7 eV, which is less than the observed FIP threshold of ~10 eV beyond which elements are depleted in the corona relative to the photosphere by a factor of ~2 (e.g., [33]); second, calculations for inefficient coulomb drag in these uniformly-heavy isotopes indicate no measurable mass-dependent fractionation (cf. [34]). So, the Genesis SW Os concentration and isotope composition determination, which would also yield a SW Re abundance, will be a direct proxy for the photosphere.

The 2-year Genesis array Os fluence is 1.3 $\times$ 10$^6$ Os atoms/cm$^2$ (2.2cm$^2$/fg). At Dartmouth we have developed extremely sensitive measurement techniques for Os isotopes in water and routinely measure 100-200 fg Os (e.g., [35]). In our recent work on polar ice, we have successfully measured Os isotopes in samples containing a total of 30-50 fg of Os. The area of one Genesis array wafer is 50 cm$^2$. This would yield ~20 fg of Os. The experiment therefore requires an area equivalent to ~1 array wafer to make a measurement—technically challenging issue is therefore to find a) low background GENESIS material and b) develop ultraclean procedures to remove surface contaminants and obtain the Os fluence and $^{187}$Os/$^{188}$Os ratio of SW. We will present of initial assessment of materials and background contaminants.