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

Introduction: The ^{187}Re-^{187}Os isotope system (^{187}Re→^{187}Os + β; $t_{1/2}$ = 41.2 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}Os/^{188}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}Sm and excesses in r-process ^{135}Ba and ^{137}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}Ba and ^{137}Ba and deficits in ^{144}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., ^{54}Cr, ^{26}Mg, ^{62}Ni, ^{84}Sr, ^{92}Mo, ^{183}W), as well as for isotopes of a single element (^{46}Ti, ^{50}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]).

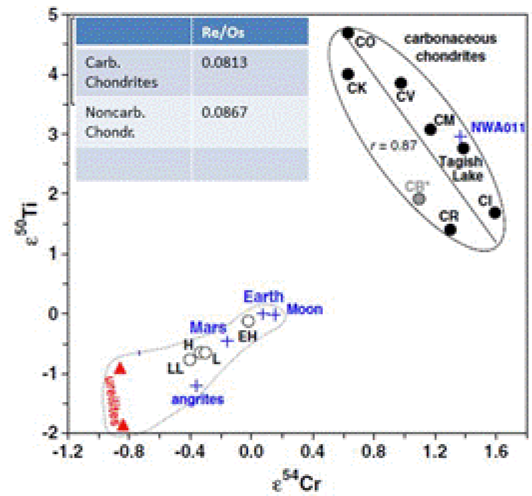

Fig. 1. *C- chondrites and O- chondrites (EH, H, L and LL) cluster in two groups in ε^{54}Cr-ε^{50}Ti space (modified from [13]). Their Re/Os ratios also display a bimodality (inset- Re/Os data from [14]).*

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}Os/^{188}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

(Fig. 1). Since mixing and thermal processing of pre-solar 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 (serpentinization 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 μg/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 it’s 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 1.3×10^6 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—a 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.

References: [1] Day J. et al. (2010), *EPSL*, *289*, 595-605.[2] Shirey S.B. and Walker R.J. (1998), *Ann.Rev Geol. Planet. Sci.*, *26*, 423-500.[3] Brandon A.D. et al. (2000), *GCA*, *64*, 4083-4095.[4] Andreasen R. and Sharma M. (2006), *Science*, *314*, 806-809.[5] Andreasen R. and Sharma M. (2007), *ApJ*, *665*, 874-883.[6] Carlson R.W. et al. (2007), *Science*, *316*, 1175-1178.[7] Brennecka G.A. et al. (2013), *PNAS*, *110*, 17241-17246. [8] Burkhardt C. et al. (2012), *EPSL*, *357*, 298-307.[9] Larsen K.K. et al. (2011), *ApJ Lett.*, *735*.[10] Paton C. et al. (2013), *ApJ Lett.*, *763*.[11] Regelous M. et al. (2008), *EPSL*, *272*, 330-338.[12] Trinquier A. et al. (2009), *Science*, *324*, 374-376.[13] Warren P.H. (2011), *EPSL*, *311*, 93-100.[14] Walker R.J. (2002), *GCA*, *66*, A818-A818.[15] Yokoyama T. et al. (2007), *EPSL*, *259*, 567-580.[16] Walker R.J. (2012), *EPSL*, *351–352*, 36–44.[17] Brandon A.D. et al. (2005), *GCA*, *69*, 1619-1631.[18] Walker R.J. (2009), *Chemie Der Erde*, *69*, 101-125.[19] Horan M.F. et al. (2003), *Chem Geol*, *196*, 5-20.[20] Stracke A. et al. (2012), *GCA*, *85*, 114-141.[21] Archer G.J. et al. (2014), *GCA*, *131*, 402-414.[22] Riciputi L.R. et al. (1994), *GCA*, *58*, 1343-1351.[23] Velbel M.A. et al. (2012), *GCA*, *87*, 117-135.[24] Zolensky M.E. et al. (2008), *Rev Mineral*, *68*, 429-462.[25] Le Guillou C. et al. (2014), *GCA*, *131*, 368-392.[26] Palguta J. et al. (2010), *EPSL*, *296*, 235-243.[27] Asplund M. et al. (2009), *Annu Rev Astron Astr*, *47*, 481-522.[28] Kwiatkowski M. et al. (1984), *Astron Astrophys.*, *135*, 59-60. [29] Quinet P. et al. (2006), *Astron Astrophys*, *448*, 1207-U93.[30] Swensson J.W. (1970), *Sol Phys*, *13*, 25-&.[31] Anders E. and Grevesse N. (1989), *GCA*, *53*, 197-214.[32] Burnett D.S. et al. (1989), *GCA*, *53*, 471-481.[33] Schmelz J.T. et al. (2012), *ApJ*, *755*.[34] Bochsler P. (2007), *Astron Astrophys Rev.*, *14*, 1-40. [35] Chen C. and Sharma M. (2009), *Anal Chem*, *81*, 5400-5406.