RADIAL HETEROGENEITY OF $^{53}\text{Mn}$ IN THE EARLY SOLAR SYSTEM AND THE PLACE OF ORIGIN OF ORDINARY CHONDRITES. G. W. Lugmair, A. Shukolyukov, and Ch. MacIsaac, Scripps Inst. of Oceanography, Univ. of California, San Diego, La Jolla, CA 92093-0212.

The earlier results of our studies of $^{53}\text{Mn} - ^{53}\text{Cr}$ isotope systematics ($T_\gamma$ of $^{53}\text{Mn} = 3.7$ My) in angrites (LEW 86010, Angra dos Reis) and in some eucrites (Chervony Kut [CK], Juvinas [JUV]) have suggested that the resolution of small age differences between these differentiated objects is possible [1, 2, see Fig. 1] if the assumption is true that $^{53}\text{Mn}$ was homogeneously distributed at least in that region of the solar nebula where the meteorite parent bodies formed. The fact that the present day and the initial $^{53}\text{Cr}/^{52}\text{Cr}$ ratios in both meteorite classes are significantly higher than the terrestrial and lunar values led us to test the $^{53}\text{Mn} - ^{53}\text{Cr}$ systematics in several ordinary chondrites, the putative building blocks of planetesimals. We found that these chondrites possess uniform and higher than terrestrial bulk $^{53}\text{Cr}/^{52}\text{Cr}$ ratios ($0.5e; 1e = 1 \times 10^{-6}$) but more than a factor of two lower than the bulk eucrites. Thus, it became clear that the original assumption of $^{53}\text{Mn}$ homogeneity on a large scale may not be valid and that the low abundance on earth of the $^{53}\text{Mn}$ decay product may be the consequence of a solar system wide phenomenon rather than, say, simply depletion at 1 AU due to volatility. The idea of a radially heterogeneous $^{53}\text{Mn}$ distribution in the nebula was suggested and tests of this hypothesis were undertaken.

If the $^{53}\text{Mn}$ distribution in the late solar nebula had indeed a radial gradient which is now frozen into inner solar system bodies as characteristic and variable $^{53}\text{Cr}/^{52}\text{Cr}$ and if the measured ordinary chondrites originate from somewhere within the asteroid belt then samples from Mars should show an intrinsic $^{53}\text{Cr}/^{52}\text{Cr}$ ratio which is intermediate between that of the chondrites and of the earth-moon system. (We have shown previously [3] and have now confirmed that the bulk of the material which formed the moon must have originated in close proximity to the earth because of the identical $^{53}\text{Cr}/^{52}\text{Cr}$ signatures of both planets.)

We have studied the $^{53}\text{Mn} - ^{53}\text{Cr}$ systematics in samples from the pyroxinite ALH84001 and bulk Shergotty. All samples show excess $^{53}\text{Cr}$. As was expected, all mineral fractions from ALH84001 (Chromite, Px, bulk silicate) exhibit the same $^{53}\text{Cr}/^{52}\text{Cr}$ ratio (0.22e) and, thus, indicate total Cr isotopic equilibration after all $^{53}\text{Mn}$ had decayed. This same excess of 0.23e (typical error is 0.10e) was also found for Shergotty and appears to be the intrinsic $^{53}\text{Cr}/^{52}\text{Cr}$ excess for Mars (Fig 1). This excess is clearly intermediate between earth and the ordinary chondrites and satisfies the condition for a radial gradient as discussed above.

To visualize these findings in a simple and direct manner (i.e. no model assumptions) we plot in Fig. 2 the average intrinsic $^{53}\text{Cr}/^{52}\text{Cr}$ excesses vs. the heliocentric distance of the sample source where it is believed to be known: Earth at 1.0 AU with $^{53}\text{Cr}/^{52}\text{Cr} = 0e$, Mars at 1.51 AU with 0.23e, and Vesta, the likely source of the eucrites, at 2.36 AU with 1.15e (derived from the eucrite Caldera which was shown to have equilibrated Cr isotopes [4]). The curve through the data points is a 4th order polynomial fit. If we place the $^{53}\text{Cr}/^{52}\text{Cr}$ excess of 0.5e for the ordinary chondrites onto this curve a radial distance for the location of their parent bodies of -1.9 AU is indicated.

From this simple approach it becomes apparent that the place of origin for the ordinary chondrites is close to the inside edge of the asteroid belt. This heliocentric distance is tantalizingly close to the 2.04 AU resonance [5] through which the ordinary chondrites may have been ultimately ejected.

Of course, various refinements may be applied to this plain approach. For example, if one assumes that Mn/Cr was fractionated very early in the history of the mantle of the eucrite parent body so that the measured Mn/Cr ratio in the eucrites is higher than that of the basalt source then the average characteristic $^{53}\text{Cr}/^{52}\text{Cr}$ excess for this planetesimal may be somewhat lower than indicated by the eucrites. This would make the upper end of the curve in Fig. 2 flatter. As a consequence, the projected point of origin for the ordinary chondrites would move slightly outward and, thus, even closer to the 2.04 AU resonance. Overall, however, the picture would remain the same.
HETEROGENEITY OF $^{53}\text{Mn}$: G. W. Lugmair, A. Shukolyukov, and Ch. MacIsaac.

It is not known at present what type of mechanism is responsible for the observed radial heterogeneity of $^{53}\text{Mn}$. It could be due to an early radial Mn/Cr fractionation in the nebula where $^{53}\text{Mn}$ was originally homogeneously distributed. However, although poorly constrained, current chemical models infer a close to chondritic Mn/Cr ratio for both Mars and the eucrite parent body [6] which is consistent with an original $^{53}\text{Mn}$ heterogeneity. Thus, more probable in our view, this could be the result of a late heterogeneous $^{53}\text{Mn}$ injection into the nebula which most likely would also be true for other short-lived radionuclides. (It could even be due to direct production within the solar nebula although, as is well known, there are many problems such as the over-production of $^{26}\text{Al}$.)


Fig. 1: Summary of $^{53}\text{Cr}$ - $^{53}\text{Mn}$ systematics in some solar system bodies.

Fig. 2: $^{53}\text{Cr}$ excesses in solar system bodies as a function of their heliocentric distance. A radial heterogeneity of $^{53}\text{Mn}$ is clearly evident. The excess $^{53}\text{Cr}$ places the source of ordinary chondrites at $\sim 1.9$ AU and thus at the inner edge of the asteroid belt.