PROJECT *MILESTONES*: TESTING CONSISTENT CHRONOLOGIES BETWEEN EXTINCT ^{53}Mn-^{53}Cr AND EXTANT U-Pb SYSTEMATICS IN THE EARLY SOLAR SYSTEM.

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Introduction: The accretion of the Solar System appears to have proceeded from a complex assembly of hot and cold domains, differentiating small planets and pristine dust, which coexisted and interacted for a few million years. Isotopic dating allows us to decipher chronological sequence of the events in assembling the Solar System, and thus to constrain the causal relations of physical processes.

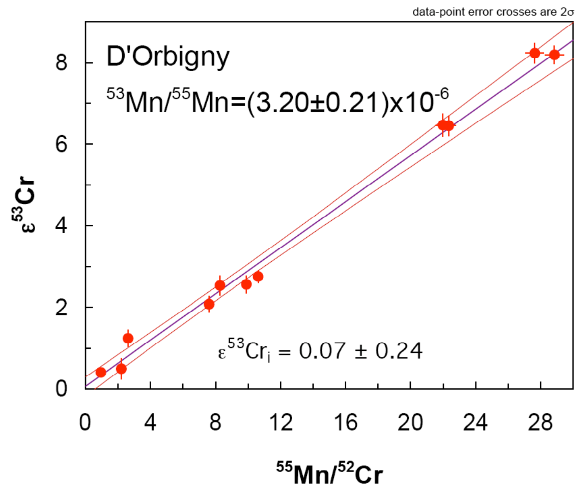
Using multiple isotopic chronometers, which date various processes (evaporation, condensation, magma differentiation, mineral growth etc.) that fractionate parent and daughter nuclides, greatly enhances the versatility of the timescale construction. We have to make sure, however, that the readings of chronometers are consistent. This can be done by dating select meteorites with relatively simple evolution history and suitable composition; about which we can be confident that fractionation of parent-daughter nuclide pairs of various chronometers occurred in the same event.

Angrites, and some eucrites, are the best candidates for this consistency test. Recently reported U-Pb [1,2] and ^{182}Hf-^{182}W [3,4] precise chronologies of angrites show excellent agreement between these chronometers. The ^{53}Mn-^{53}Cr chronometry of angrites [5-7] has been among the most extensively developed branches of cosmochronology, but the published data are no longer adequate, because the coverage of newly discovered angrites, dated with the U-Pb and ^{182}Hf-^{182}W methods, is lacking, and the discrepancies between the Mn-Cr dates for the same angrite determined with different techniques or by different researchers remain unexplained. Hence the ***Project Milestones***.

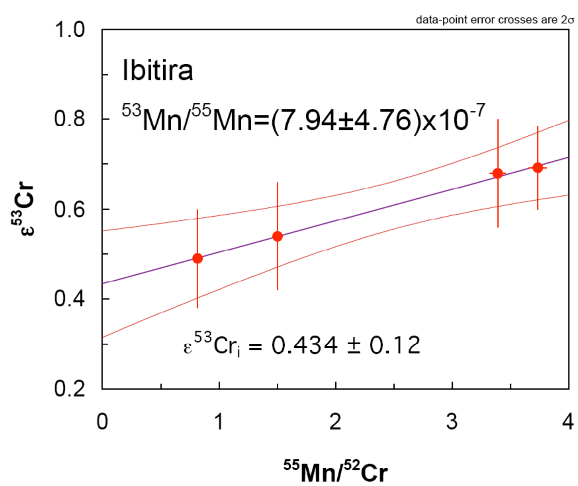
Methods: Minerals from three angrites and the eucrite Ibitira were prepared using magnetic separation followed by hand picking, or by hand picking only. Procedures for determination of the Mn/Cr ratios and Cr isotopic composition were adapted from [8].

Results: All four meteorites investigated contain resolvable excesses of ^{53}Cr that correlate with the Mn/Cr ratios. In all angrites, olivine has the highest Mn/Cr ratio and contains most radiogenic Cr.

D'Orbigny has several features that make it the best reference meteorite for constructing the early Solar System timescale. This large (16.5 kg) and therefore potentially more easily available meteorite yielded precise U-Pb [1], ^{182}Hf-^{182}W [3] and ^{26}Al-^{26}Mg [9] dates. ^{53}Mn-^{53}Cr isochron dates for D'Orbigny, obtained using TIMS [7,10] and ion microprobes [11,12] were reported previously, but these dates are discrepant. Our $^{53}Mn/^{55}Mn$ value for D'Orbigny is consistent with the higher of the two reported values [7,12].



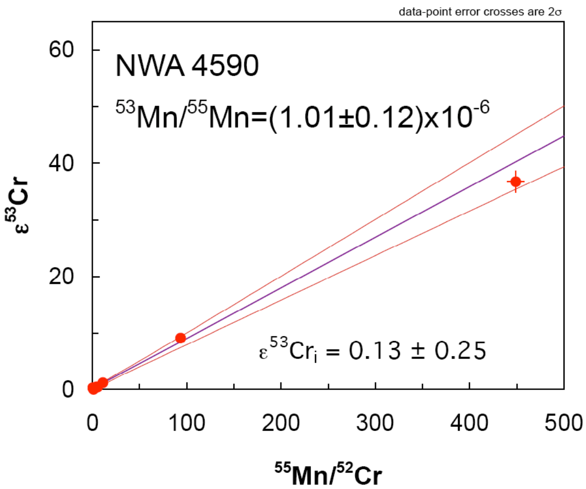
Ibitira is an unbrecciated monomict eucrite with an oxygen isotopic composition [13] and Fe/Mn ratio [14] different from most eucrites and probably originating from a different parent body. Our $^{53}Mn/^{55}Mn$ value for Ibitira is consistent with the published value of $(1.06\pm0.50)\times10^{-6}$ [6].

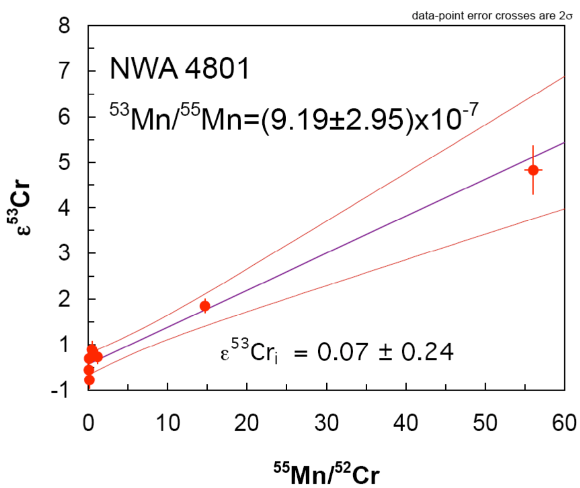


NWA 4590 and NWA 4801 are recently discovered plutonic angrites. No ^{53}Mn-^{53}Cr data for these meteorites were reported before. Our newly obtained results for these two meteorites are shown on the next page.

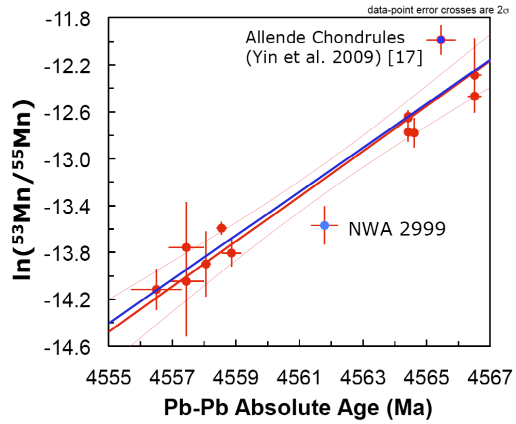
Consistent Chronology: Initial $^{53}Mn/^{55}Mn$ ratios, determined in this study, and published previously [6-7,10-11,15-17] are plotted against $^{207}Pb^*/^{206}Pb^*$ ages

[1-2, 18-19]. The red line with 95% error envelope is a regression line through the data. The blue line is a decay line of ^{53}Mn anchored to D'Orbigny. The lines coincide very closely, and most data points plot within the error limits, thereby confirming consistent performance of the U-Pb and ^{53}Mn-^{53}Cr chronometers.





The two notable deviations are the angrite NWA 2999 [2,15], and Allende chondrules [17, 19]. NWA 2999, a unique metal-rich plutonic angrite with a large chondritic component [20] proved exceedingly difficult to date due to pervasive coating of iron hydroxide on all mineral grains, which complicates mineral separation and picking, and ubiquitous inclusions of spinel in pyroxene crystals. Spinel, an abundant mineral in NWA 2999, is slightly soluble in HF under conditions of sample digestion, and contains non-radiogenic Pb that cannot be removed by leaching [2]. Due to these complications, the preliminary U-Pb date for NWA 2999 [2], and possibly the ^{53}Mn-^{53}Cr isochron [15] are not as reliable as the ages of the other angrites, and require verification.



Allende chondrules [17,19] plot above the decay curve, with ^{53}Mn-^{53}Cr age of 4567.91±0.76 Ma or 4567.42±0.83 Ma depending on age anchors used [17]. Pb-isotopic age of Allende chondrules may contain a systematic error exceeding the errors of isochron regressions [19,21] due to the presence of two or more non-radiogenic Pb components. More accurate age determination would require much more radiogenic data, similar to the recent data for angrites [1], which would make this source of error insignificant.

Alternative explanation for Allende chondrules is that solar nebula had a heterogeneous distribution of ^{53}Mn/^{55}Mn in the regions where chonrites, angrites and eucrites formed. This possibility can be tested by ^{53}Mn-^{53}Cr and U-Pb dating of chondrules spanning a range of ages of several million years (Milestones Stage 2), as has been done for angrites in this study. If our hypothesis were true, we expect to find chondrules of different ages define a decay line parallel to the line defined by differentiated meteorites.

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