THE STELLAR BUILDING BLOCKS OF THE SOLAR SYSTEM: NEW CONSTRAINTS FROM CORRELATED ISOTOPIC COMPOSITIONS IN METEORITES. K. R. Bermingham[1], B. S. Meyer[2], and K. Mezger[3,4], [1]Department of Earth and Planetary Sciences, Rutgers University USA (katherine.bermingham@rutgers.edu), [2]Physics and Astronomy, Clemson University USA; [3]Institut für Geologie, Universität Bern CH; [4]Center for Space and Habitability, Universität Bern CH.

Introduction: Characterization of the Solar System's stellar building blocks is required to reconstruct its compositional evolution in space and time. Stellar building blocks are predominately non-processed, isotopically diverse starting materials of the Solar System (e.g., presolar grains). The full complement of stellar events that contributed isotopically distinct matter to the Solar System could be identified by comparing the regional-scale distribution of presolar grains in the protoplanetary disk, as sampled by nucleosynthetic isotope anomalies, to stellar evolution models. Warren (2011) recognized that nucleosynthetic isotope anomalies divide parent bodies into a non-carbonaceous (NC) group or a carbonaceous chondrite (CC) group, which may reflect formation inboard and outboard of Jupiter, respectively [1]. The NC-CC dichotomy formed the basis for a variety of recent Solar System evolution models (for review see [2]).

To understand the significance of the NC-CC dichotomy and its role in constraining the chemical evolution of the Solar System, identification of the nucleosynthetic sources of presolar grains responsible for nucleosynthetic needs advancement. This would generate constraints on the timing, process of addition to the Solar System, and mixing history of presolar grains into the disk. A comprehensive multi-element isotopic dataset, however, has not yet been integrated with astrophysical models of the likely stellar events that contributed matter to the protoplanetary disk (e.g., AGB, SNIa, SNII, and neutron star merger events).

The present study synthesizes stellar nucleosynthesis models with a selection of high precision nucleosynthetic isotope data from bulk meteorites and CAIs [3]. The interelement isotopic relations between and within NC and CC groups compared with CAIs are assessed and interpreted in the context of new thermonuclear supernovae numerical models.

Methods and Results: Relations among μ^{48}Ca, μ^{46}Ti, μ^{50}Ti, μ^{54}Cr, μ^{54}Fe, μ^{58}Ni, μ^{62}Ni, μ^{84}Sr, and μ^{96}Zr are assessed using a compilation of published high precision bulk meteorite and CAI data (where $\mu = [{}^{x}R_{sample}/{}^{x}R_{standard} - 1] \times 10^{6}$).

The new isotope compilation indicates that CAIs exhibit the most anomalous isotopic compositions and the highest degree of group variability. Meteorites fall into either the NC or CC group. The NC group meteorites possess isotopic variations that are less pronounced than in CC meteorites (μNC < μCC). For some isotopes, e.g., μ^{46}Ti, μ^{54}Fe, μ^{84}Sr, μ^{96}Zr, the spread in the NC group is less than in the CC group. However, μ^{48}Ca, μ^{50}Ti, μ^{54}Cr show a similar range in isotopic variation among NC and CC meteorite groups. Some isotopes clearly delineate the NC and CC groups (e.g., μ^{48}Ca, μ^{46}Ti, μ^{50}Ti, μ^{54}Cr, μ^{84}Sr). Non-carbonaceous and CC groups overlap when comparing μ^{54}Fe, μ^{58}Ni or μ^{62}Ni, μ^{84}Sr, and μ^{96}Zr.

When contrasting μ^{46}Ti *vs.* μ^{50}Ti *vs.* μ^{48}Ca bulk meteorite compositions, high fit, linear, positive correlations persist between and within NC and CC groups. High fit, linear, positive correlations are also observed between μ^{50}Ti or μ^{46}Ti or μ^{48}Ca *vs.* μ^{54}Cr within NC, conversely high fit, linear, negative correlations persist between μ^{50}Ti or μ^{46}Ti or μ^{48}Ca *vs.* μ^{54}Cr within CC. Some of these updated and expanded data compilations extend earlier work first identifying the μ^{54}Cr *vs.* μ^{50}Ti relationship [1], μ^{46}Ti *vs.* μ^{50}Ti [4], and μ^{48}Ca *vs.* μ^{50}Ti [5].

High fit correlations persist between μ^{54}Fe *vs.* μ^{48}Ca or μ^{54}Cr or μ^{50}Ti in NC. The CC group, however, is low fit primarily due to the CI group which consistently is offset from the other CC groups. Moderately high fit, positive correlations are observed between μ^{84}Sr *vs.* μ^{96}Zr (although a high fit positive correlation is observed within the CC group), μ^{58}Ni or μ^{62}Ni *vs.* μ^{54}Cr, μ^{54}Fe *vs.* μ^{54}Cr or μ^{46}Ti, or μ^{50}Ti. Low fit correlations define the remaining inter-element isotope relations.

Discussion: The data compilation demonstrates that CAIs do not sample an isotopically homogeneous reservoir. Nor do they come from an isotopically distinct reservoir from NC and CC meteorites because the CAI compositional spread intersects with CC and/or NC meteorite groups in all isotopic systems. Given these characteristics CAIs, here designated the "CAI group", are a separate group to the NC and CC groups. An average composition for this group is not defined because doing so obscures compositional diversity of most CAI isotope compositions.

The persistence of high fit correlations between isotopes of several elements within and between NC and CC groups indicates that these relations are significant. A straightforward explanation of the cause of these nucleosynthetic isotope correlations is that the variable isotopes were housed in the same type of presolar grains that formed during the same type of stellar event. If so, the high fit correlations involving $\mu^{46}Ti$, $\mu^{50}Ti$, $\mu^{48}Ca$, $\mu^{54}Cr$, $\mu^{54}Fe$ may indicate these species were housed in the same type of presolar grains. The negative excursions may indicate there is an additional carrier phase. For example, one that is enriched in ^{48}Ca-^{46}Ti-^{50}Ti but does not vary in ^{54}Cr compositions, and another that is enriched in ^{54}Fe and does not vary in ^{54}Cr, ^{48}Ca, and ^{50}Ti.

Strontium and Zr are found in presolar silicon carbide grains (SiC), of which ~90 % have isotopic characteristics suggesting formation around asymptotic giant branch (AGB) stars [6,7]. If SiC grains from an AGB star were the sole presolar grain carrier phases responsible for producing Sr and Zr bulk meteorite sample isotope variations, high fit correlations between Sr and Zr are predicted (following Mo-Ru cosmic correlation, e.g., [8,9]). The interelement isotope variations exhibited between ^{84}Sr and ^{96}Zr, however, are weakly correlated within and between the NC and CC groups.

Thermonuclear models: Given the presence of neutron-rich isotopes (^{48}Ca, ^{50}Ti, and ^{54}Cr), a thermonuclear supernova is a possible stellar source for these species. To determine if addition of material from the same type of stellar event could explain the multi-element isotopic relations, we extended thermonuclear models (Neutron-Rich Low-Entropy matter Ejectors, NRLEEs) to include ^{54}Fe, Ni isotopes, ^{84}Sr, and ^{96}Zr [3].

Results indicate coupling of ^{48}Ca, ^{46}Ti, ^{50}Ti, ^{54}Cr, and ^{58}Ni in presolar grains originating from NRLEEs. In addition to *s*-process dominated presolar grains, an additional source of ^{84}Sr and ^{96}Zr is identified in NRLEEs. Notably, the significant abundance of ^{95}Zr that accompanies the ^{96}Zr could result in significant ^{95}Mo enrichments in oxide dust condensing in NRLEE ejecta. Molybdenum isotopes are not likely to be enriched in ^{95}Mo immediately after the explosion. Nevertheless, if NRLEE dust preferentially condensed Zr over Mo, the dust could be strongly enriched in ^{95}Mo. Such dust could give rise to the offset between $\mu^{94}Mo$-$\mu^{95}Mo$ correlation lines in NC and CC components (e.g., [10]).

Implications: Comparing NRLEE nuclides *vs.* *s*-process nuclides recorded by nucleosynthetic isotope data, an inverse relationship between the distribution of NRLEE and *s*-process components in the Solar System is evident [3]. This relationship supports the cause of nucleosynthetic isotope variations originating from incomplete mixing of presolar grains in the disk, rather than thermal processing of presolar phases. Preferential removal of NRLEE material from the NC region via loss of CAI or CAI-like material would leave a relative *s*-process enrichment and NRLEE depletion in the NC region compared to the CC region [3], thereby removing the requirement for in-fall of isotopically distinct molecular cloud material to the disk [e.g., 11].

In addition to the initial interstellar medium-processed dust (mostly non-anomalous) inherited by the Solar System, the predominately non-processed materials were likely from NRLEEs, AGB (*s*-process component), neutron star merger products (*r*-process component), and the stellar source of short-lived radioactive nuclides. Although grains from these astrophysical events were minor contributors to the Solar System's bulk inventory of initial building blocks, they played a key role in establishing the subtle nucleosynthetic isotopic anomalies recorded by planetary materials.

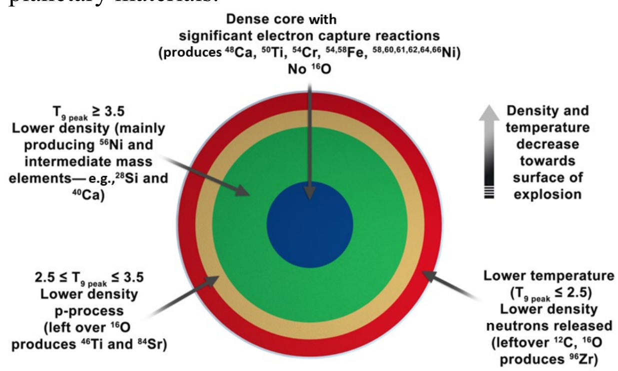

Fig. 1. *Schematic giving details of the nucleosynthetic yields in the different regions of the NRLEE immediately after the explosion.*

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