CORRELATED CA ISOTOPE ANOMALIES IN BULK SOLAR SYSTEM MATERIALS M. Schiller, C. Paton and M. Bizzarro, Centre for Star and Planet Formation, Natural History Museum of Denmark, University of Copenhagen, DK-1350 Copenhagen, Denmark; schiller@snm.ku.dk

Introduction: Nucleosynthetic anomalies have been found in various neutron-rich isotopes of iron-peak elements, most notably Cr, Ti, and Ni [1, 2, 3], but also in heavier elements such as Mo and Ru [4, 5] and the short-lived isotope ^{26}Al [6]. The existence of isotopic anomalies that are correlated for some elements and heterogeneously distributed throughout our solar system raises two important questions: firstly, what is the source of these enrichments (Type Ia or II supernovae) and secondly, what is the mechanism that resulted in a heterogeneous distribution of these isotopic anomalies between bulk solar system materials. Calcium is a prime target to address these questions because it has six isotopes that are produced by at least three different nucleosynthetic mechanisms. ^{40}Ca and ^{44}Ca are produced by α-capture. Neutron capture of the primary isotope ^{40}Ca produces ^{42}Ca, ^{43}Ca, ^{44}Ca, and ^{46}Ca, whereas ^{48}Ca, the isotope with the highest neutron excess among the major elements, requires a different mechanisms. Current thought is that it can only be efficiently produced in a low entropy environment most likely, but not exclusively, achieved in a type-Ia supernova [7]. Thus, high-precision Ca isotope measurements of meteorites and their components may allow for a better understanding of the nature of the various stellar sources that contributed matter to the nascent solar system. Most importantly, Ca allows us to investigate relative nucleosynthetic contributions within a single element, thus minimizing effects caused by, for example, differences in the chemical behavior of elements.

Methods: We established an improved chemical separation of Ca that effectively removes Ti and Sr, which are isobaric interferences on Ca isotopes. We measured the high mass range of Ca (42-48) by MC-ICPMS in high-resolution (m/Δm >5000) and at total beam intensities of >5000 V. This allowed the precise analysis of all Ca isotopes in this mass range. Repeated analyses of rock standards relative to the NIST SRM915b Ca-standard demonstrate that our approach enables us to measure ^{43}Ca/^{44}Ca, ^{46}Ca/^{44}Ca and ^{48}Ca/^{44}Ca to 2.5, 50 and 12 ppm (2 sd), respectively, when normalized to ^{42}Ca/^{44}Ca. This represents a 100-fold improvement over previous studies for the less abundant isotopes of Ca [8]. Using this improved resolution, we have re-investigated the extent of Ca-isotope heterogeneity in the solar protoplanetary disk by analyzing a suite of strategically selected inner solar system objects.

Results: We have analyzed bulk samples from ureilites, eucrites, angrites, CI chondrites and the anomalous achondrite NWA 2976. Data for all meteorites show correlated Ca isotope effects on ^{43}Ca, ^{46}Ca and ^{48}Ca (Fig. 1). Further, the anomalies in Ca isotopes are positively correlated with the isotopic anomalies reported for ^{54}Cr, ^{50}Ti and ^{26}Al for the same reservoirs (Fig. 1).

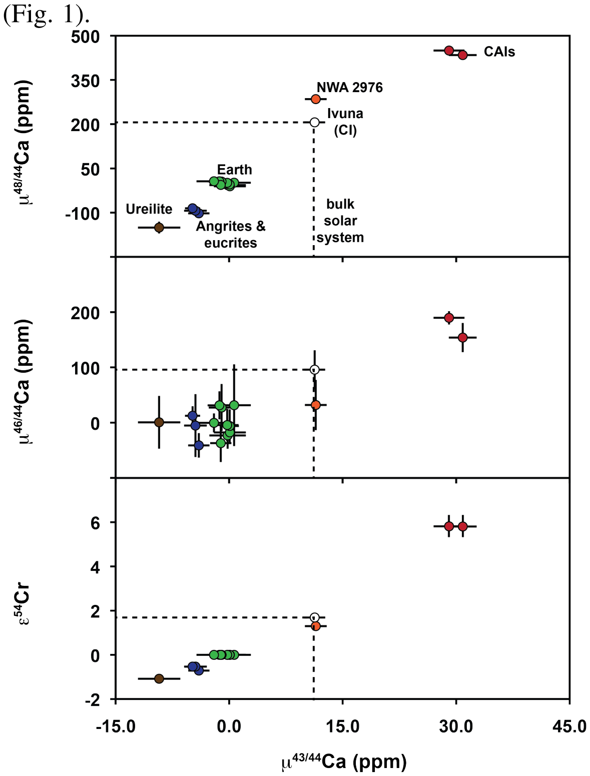

Figure 1: Ca isotope data for different bulk solar system materials and CAIs. Also shown is ^{54}Cr data from [1] for the same reservoirs.

Discussion: The observed Ca anomalies cannot be explained by analytical artifacts or interferences on the correcting isotope ratios, as the anomalies prevail whether corrected by ^{42}Ca/^{44}Ca, ^{43}Ca/^{44}Ca or ^{42}Ca/^{43}Ca. In addition, the ^{43}Ca and ^{48}Ca anomalies determined here in calcium-aluminum-rich inclusions (CAIs) are in perfect agreement with anomalies that have been measured by TIMS [9, 10]. The excellent correlation in anomalies of isotopes that are thought to be produced in very different environments requires that either our understanding of the production mechanism of especially ^{48}Ca is incomplete or, more likely, that multiple sources contributed to the molecular cloud from which our solar system consequently formed without completely erasing the memory of their original sources. The observed correlations of isotopes originating from multiple sources requires that mixing of their carrier material occurred prior to the mechanism which took place to produce the correlated Ca isotope anomalies observed in different bulk solar system reservoirs. In addition, the recent discovery of correlated ^{26}Al anomalies [6] requires these processes to have occurred before this short-lived nuclide had decayed. [2] suggested that thermal processing of a presolar carrier might explain correlated ^{54}Cr-^{50}Ti anomalies. Such a process could potentially also fulfill the requirement of preserving the memory of nucleosynthetic anomalies in physically different carrier grains as required by Ca isotopes, if the carriers were characterized by similar physical properties, such as their thermal stability. Speculatively, this could be achieved if the grains that carry the various isotopic signatures of their stellar origin share a similar young formation age and hence might have escaped extensive processing within the interstellar medium prior to solar system formation. Such grains might be more prone to sublimation during heating events in the protoplanetary disk compared to material that experienced long residence times within the interstellar medium. This could result in enrichment of the gas phase in the protoplanetary disk with isotopes that are now found to be heavily enriched in CAIs (which are thought to be condensates from a gas phase), while at the same time leaving the material from which planetary bodies formed variably depleted in the same isotopes.

References: [1] A. Trinquier, et al. (2007) *ApJ* 655:1179. [2] A. Trinquier, et al. (2009) *Science* 324:374. [3] M. Regelous, et al. (2008) *EPSL* 272:330. [4] C. Burkhardt, et al. (2011) *LPSC XLII* 2554. [5] J. H. Chen, et al. (2010) *GCA* 74:3851. [6] K. K. Larsen, et al. (2011) *ApJ* 735:L37. [7] B. Meyer (1993) *Phys. Rep.* 227:257. [8] F. Moynier, et al. (2010) *ApJ* 718:L7. [9] H. W. Chen, et al. (2010) *LPSC XLI* 2088. [10] T. Lee, et al. (2011) *LPSC XLII* 1828.