ZINC ISOTOPES IN METEORITES INDICATE A LOW-MASS CORE-COLLAPSE SUPERNOVA SOURCE TO OUR SOLAR SYSTEM

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Introduction: Iron-peak (IP) isotope anomalies in primitive meteorites point to a supernova-derived component in the pre-solar grain population of our proto-solar nebula [e.g. 1-3]. The main nucleosynthetic pathway for these anomalies is thought to be through explosive nucleosynthesis (NSE or QSE [4]), as the anomalies are generally in isotopes that have relatively high binding energies per nucleon. The strong linear covariation between different IP isotope anomalies in the same meteorites suggests that the simplest explanation for the anomalies is a single heterogeneously distributed phase in the solar nebula; however, it has been difficult to identify a single nucleosynthetic model that can satisfy the different anomalies for all IP isotope systems.

One anomalous IP isotope is ^{48}Ca [1]; explaining the (over)formation of this isotope is a long-standing problem [5]. Nevertheless, most workers agree that a low-entropy, n-rich environment is required to produce this isotope. One environment that satisfies these conditions is in Type Ia supernovae; however, such events are relatively rare. More recently, Wanajo and co-workers [6,7] suggested that electron-capture SN (ec-SN) or other low-mass (<10M$_\odot$) core-collapse supernovae (cc-SN) could also explain an overproduction of ^{48}Ca. These low-mass cc-SN models also predict relative over-production of some Zn isotopes – specifically ^{66}Zn, ^{68}Zn and ^{70}Zn. Here we apply Zn isotope anomaly data in primitive meteorites and a paired-anomaly mixing model to investigate if the Zn isotope heterogeneity in the solar system can be explained by a pre-solar phase formed in a low-mass cc-SN.

Methods: The Zn isotope anomaly data used in this work is taken from [8]; briefly, these data show positive ε^{66}Zn and (smaller but still positive) ε^{68}Zn anomalies (normalized to ^{67}Zn/^{64}Zn) in carbonaceous chondrites relative to Earth, with corresponding negative anomalies in these same isotopes in ordinary/enstatite chondrites; as with other IP isotope anomalies, this appears to reflect a "NC-CC dichotomy" [e.g., 9]. There is also good positive correlations seen between Zn isotope anomalies and other IP anomalies in the same meteorites [8]. Because there are two resolvable Zn anomalies when normalizing to the same ratio (^{67}Zn/^{64}Zn), we can follow the approach of [2] in modelling the array in ε^{66}Zn vs. ε^{68}Zn space as a mixture between "solar" and a small amount of isotopically exotic material. These potential exotic end-members can be calculated from a representative selection of nucleosynthetic reaction network yield models which take into account different initial stellar masses, supernova types and nucleosynthetic pathways – we have chosen a wide variety of models, including the yield data from [6-7]. In this way, our model can help to rule in or out specifical stellar progenitors for the Zn isotopes heterogeneity in primitive meteorites.

Results and discussion: The main result of our modelling is that very few extant nucleosynthetic yield models can explain the paired ^{66}Zn and ^{68}Zn anomalies in primitive meteorites. This includes the S-process, wherein these models predict an overproduction of ^{68}Zn (and ^{67}Zn) relative to ^{66}Zn, leading to higher ^{68}Zn anomalies relative to ε^{66}Zn. Equally, no Type 1a SN model can explain the relative magnitudes of the Zn anomalies (these models typically underproduce ^{68}Zn relative to ^{66}Zn). Finally, all high-mass cc-SN (i.e. Type 2 SN) models fail to explain the solar system Zn anomalies.

The models that are most in agreement with the measured Zn anomalies are those of the electron-capture SN (8.8M$_\odot$) and low mass core-collapse SN (9.6M$_\odot$) models of Wanajo et al. [6-7]. Both models imply formation of Zn isotopes in a low-entropy, high-n flux environment on a low-mass SN – this is in complete agreement with potential for formation of anomalously-rich ^{48}Ca material in the same environments. This same paper provides yields from the inner-most ejecta of larger cc-SN (11M$_\odot$, 15M$_\odot$ and 27M$_\odot$) – these models predict Zn anomalies that are extremely different to those measured in solar system materials, because although these are potential low-entropy environments, their slower rate of shock radii expansion leads to different (generally more proton-enriched) nucleosynthetic yields.

To summarise, it appears that the best match for the source of solar system Zn isotope anomalies is that of a low-mass, electron-capture SN (or ec-SN-"like") stellar environment. This stellar progenitor could explain ^{48}Ca meteorite anomalies, and we also find that the ec-SN yield data [6] can well explain measured solar system Ni isotope anomalies.

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