Ca-43 ISOTOPIC ANOMALY IN CAI AND THE ASTROPHYSICAL ORIGIN OF Ca ISOTOPES.

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The Making of Ca Isotopes: The six stable isotopes of Calcium (Ca-40, 42, 43, 44, 46, and 48) were made by at least three nucleosynthetic processes. Moreover, Ca-41 is an extinct radio-nuclide with a interesting half life of 100 kyr. The first process is the s-process to slowly capture neutrons (about one every few years, in the hydrostatic core He burning or in the AGB phase. Capturing neutrons will deplete the dominant Ca-40 while increase the minor Ca isotopes all the way to Ca-44 including Ca-41. It may reach Ca- 46 with a substantially weakened branch due to β decay at Ca-45 whose half life is only 0.5 year. The second process is nuclear statistical equilibrium (NSE) which is at essentially thermal equilibrium (i.e. everything is governed by temperature and density except the weak interaction is too slow to equilibrate n and p). Thus we need another parameter to describe the weak interaction (e.g. neutron excess: η = (n-p)/(n+p). η increases toward the center as the density rises. It eventually reaches the limit of 1 (i.e. a neutronized core). At each radius in an NSE zone, the production of nuclides with the same η as the zone is favored. For this reason Ca-48 is thought to have come from an n-rich zone since it has an η of 0.167 the highest among major elements. The third process is α-rich freeze-out that takes place when a shock-heated region begins to cool again. As temperature drops the nucleons would be driven into the nucleus reduce the total number density. Since α particle is also a doubly magic nuclide, it became abundant so that nuclides that can be produced by a series of α-captures are enriched. Note that Ca-40 and Ti-44 are α nuclides and the latter decays into Sc-44 and finally Ca-44. So this process produces both Ca-40 and Ca-44 but not Ca-48 since α capture on Ti-44 makes Cr-58 that decays to Ti-48 while adding α to Ca-44 produces Ti-48.

Detection of Ca-43 Anomaly in CAI:

We have recently developed a method to run about 2 micro-gram of Ca in our TIMS (Triton) at an intensity of 2 nano-ampere (200 volt Ca-40 signal) for an hour to measure Ca-43, Ca-46 and Ca-48 relative to Ca-44 after fractionation correction using Ca-42 as normalization. The large signal means that even 0.004% Ca-46 can be measured using a Faraday cup to avoid complication from using multiplier. From a total of 70 runs of our NBS 915a standard, we binned the four consecutive runs in order to estimate the long term reproducibility for each sample binned the same way. The two standard deviation (s.d.) is calculated from the 18 means to be 0.13 ε for Ca-43. We have carefully checked the possible interference of AlO with multiplier. The limit of 1 count per min is not high enough to account for the size of the effect found here. We have analyzed 5 CAIs (4 type B and 1 type A) from the Allende C3V meteorite. Each CAI was sampled once and it was chemically separated using conventional ion exchange technique. The Ca was loaded onto 4 filaments and analyzed. The 4 results were binned to increase our precision by a factor of 2. We found that all five CAIs have an almost constant shift of 0.3 ε. Admittedly this is a small effect in the absolute sense. However, the precision we achieved for this second smallest Ca isotope is high with a s.d.= 0.13/2. Therefore we have so far detected a five s.d. effect for five samples.

Conclusion: The production of the six Ca isotopes involve many different epochs and sites in the late stage evolution of massive stars. Potentially, we can learn a lot if correlated effects in multiple isotopes can be found. There may be additional production mechanisms other than the three discussed above. For instance, it would be important to find out whether neutrino induced processes are involved. The existence of Ca-43 effects in samples that already show Ca-48 anomaly seems to be a challenging initial step to fulfill this dream.

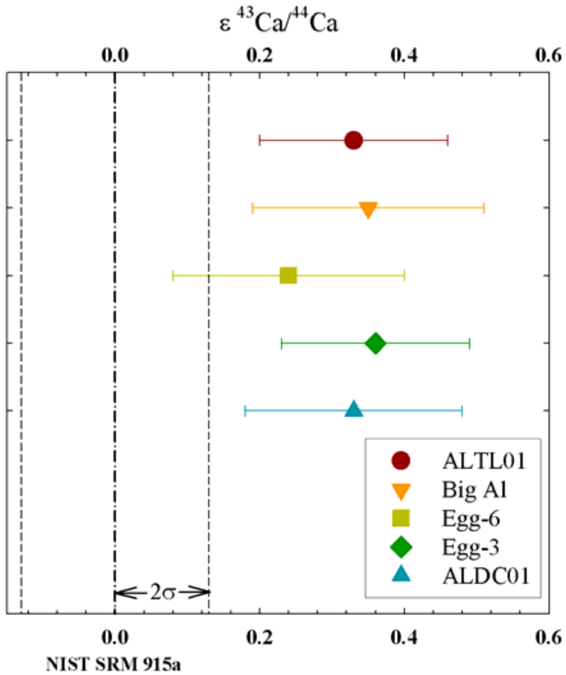

Fig. Detection of Ca-43 anomaly in five CAI. Only ALDC01 is type A and the rest are all type B. Four different loadings were run and the results were averaged for each sample. Error bar for each sample represents either the long term reproducibility or the two standard deviations from the four runs, whichever is larger.