Echoes of molecular cloud isotopic heterogeneity in primitive solar system materials

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The origins of short-lived radionuclides in the early solar system are coming into sharper focus. Studies of polluted white dwarf stars as well as the masses of ^{26}Al in star-forming regions indicate that the initial solar complement of ^{26}Al was typical of star-forming regions. A corollary is that solar ^{26}Al, ^{41}Ca, and ^{36}Cl were mainly the products of Wolf-Rayet stellar winds. This in turn leads to a robust theory for the relative abundances of the 13 radionuclides, from ^{36}Cl to ^{238}U, for which reliable estimates of both initial solar abundances and relative rates of production in the interstellar medium (ISM) are available. This emerging theory is validated by the recent discovery of the presence of ^{247}Cm in the early solar system at a level predicted by the theory.

The relative abundances of solar radionuclides indicate that they resided in dust grains for ~ 200 Myr *on average* prior to incorporation into the solar system. At first this timescale seems at odds with the much shorter mean lives of ^{41}Ca, ^{36}Cl, ^{26}Al, ^{60}Fe, ^{53}Mn, ^{182}Hf, and others. However, this is an *average* sequestration time that reflects large-scale masses and turnover timescales of reservoirs and not the ages of individual grains. Extreme heterogeneity in the isotopic compositions of individual ISM grains is implied.

It takes approximately 27 million ISM grains originating from the solar parental molecular cloud (MC) to construct a single hibonite grain in the solar protoplanetary disk. Similarly, it takes 2×10^{11} ISM grains to construct a typical CAI measuring 300 μm in diameter. Despite the implied efficacy of averaging, "echoes" of much greater heterogeneities among molecular cloud solids remain in these primitive constituents of carbonaceous chondrites.

Application of the central limit theorem shows that dispersion in ^{26}Mg*/^{24}Mg and ε^{50}Ti among CAIs and hibonite grains is the natural consequence of averaging and results neither from large-scale heterogeneities in reservoirs nor from diachronous additions of nuclides to the solar system. Primary evidence for the statistical effect comes from the decrease in dispersion in various isotope ratios with increasing mass. Extrapolation back to the dispersion in isotope ratios among MC grains suggests extreme grain-to-grain variability of many orders of magnitude.