A GRAIN TRANSPORT MODEL FOR THE ISOTOPIC EVOLUTION OF THE SOLAR SYSTEM: IMPLICATIONS FOR THE ORIGIN OF NUCLEOSYNTHETIC SIGNATURES IN METEORITES.

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Introduction: The isotopic evolution of proto-Solar nebula holds the key to understanding both early Solar System processes and how terrestrial planets formed. Nucleosynthetic anomalies have been identified in a wide range of meteorite groups for a wide range of elements [e.g. 1,2,3,4]. Anomalies in different elements broadly fit into two groups: one set come from supernovae (e-process, e.g. ε^{64}Ni [4], and the r-process, e.g. a contribution to ε^{95}Mo [1]) and the other group are formed by the s-process likely from AGB stars (e.g. ε^{100}Ru [5]). Isotopic compositions of meteorites show that different regions of the Solar System have characteristic isotopic signatures, likely due to long wavelength source changes through the proto-Solar nebula [e.g. 1,2,3,4]. These signatures can be used to fingerprint different proto-Solar regions for meteorite classification and tracing of mixing between different reservoirs. The creation of these characteristic signatures requires that different regions of the Solar system received different proportions of the carrier phases of nucleosynthetic anomalies, likely pre-Solar grains.

There are many models which attempt to explain these variations, but they broadly fit into two groups. Firstly, models where the isotopic heterogeneity is inherited from a stratified molecular cloud and the signatures are kept heterogeneously distributed by allowing only minor and selective mixing, for example by the early formation of Jupiter in the so-called isotopic dichotomy [e.g. 6]. Secondly, models in which the parent molecular cloud is homogeneous and pre-solar grain populations are unmixed, potentially by a range of processes (including: thermal processing, Poynting-Robertson drag, photopheresis and gas drag), to yield regions with distinct isotope compositions [e.g. 3,7]. An important phenomenon which occurs in proto-planetary disks and should have a significant effect on the differential concentrations of pre-Solar grains, due to their different sizes and densities, is the relative in-fall velocities resulting from aerodynamic gas drag [8]. Many previous studies have investigated the effect of gas drag on proto-Solar nebulae [e.g 9] but most have focused on mixing of chemical components, in particular volatile species, and not on the effects on nucleosynthetic isotope compositions.

Model: To investigate if aerodynamic gas drag on nebula grains can play a role in creating the nucleosynthetic anomalies observed in the Solar System I have modelled the movement of grains in a proto-planetary disk due to gas drag [following 8,9,10]. I simulate grain sizes and compositions both of known pre-Solar grain populations [e.g. 11], and grains which may have formed in different astrophysical environments [e.g. 12] but are not found in our collections due to sampling bias. Using these inputs I have calculated their net radial drift velocities. Starting with a homogenous molecular cloud populated with distinct grains, using the disk structure and the drift velocity, I have determined the effect of particle flux in different regions of the disk on the surface density (in gcm^{-2}) of different carrier phase populations. From these changes in surface density the isotopic compositions are then determined and the isotopic evolution of the disk tracked using the elements Ni, Ru and Mo [e.g. from 4, 5, 1] as examples.

Results:, The isotopic compositions which result from these models can reproduce the isotope anomalies observed in different regions of the early-Solar System as represented by meteorite samples. Testing of a variety of pre-Solar grain compositions, grains sizes and nebula conditions (nebula viscosity, power law exponents etc.) suggests that this is a relatively robust outcome. Indeed, a similar finding has recently been published using a different disk model [13] though the subsequent interpretation is rather different.

Discussion: The finding that the isotopic variations observed between early-Solar System materials can be produced by the evolution of pre-Solar grain populations due to gas drag alone from a homogenous molecular cloud has wide ranging and significant implications. Most importantly the isotopic composition of the CAI forming region can be reproduced in this model by the same processes responsible for forming the compositions of meteorites. This demonstrates that there is no requirement for keeping regions of the early-Solar System separated to maintain anomalies (though this may happen later). Instead, the meteorite isotope compositions are generated by large-scale transport and mixing of material between distant regions. Further, this link between the genesis of the isotopic composition of the meteorite and CAI forming regions suggests that the isotopic composition of meteorites, and the terrestrial planet forming regions, may have been largely set prior to the formation of CAIs.

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