GRADIENTS IN THE SPATIAL HETEROGENEITY OF THE SHORT-LIVED RADIOISOTOPES ⁶⁰Fe & ²⁶Al AND STABLE OXYGEN ISOTOPES IN THE SOLAR NEBULA

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Introduction: The short-lived radioisotope (SLRI) ⁶⁰Fe appears to have been synthesized in a supernova [1,2] and injected into the presolar cloud [3] from the same massive star that is likely to be the source of the bulk of the solar nebula’s ²⁶Al [4,5]. Given that the injection of SLRIs into the presolar cloud involved Rayleigh-Taylor fingers [3], it might be expected that the SLRIs would be initially highly spatially heterogeneous in their distribution in the solar nebula. However, the nearly identical Fe and Ni isotopic compositions of iron meteorites, chondrites, and the Earth require that the injected ⁶⁰Fe must have been mixed to less than 10% heterogeneity in the solar nebula [6]. A similar constraint arises from the need to preserve the use of ²⁶Al as an accurate nebular chronometer [7], while simultaneously allowing for the spread of stable oxygen isotope ratios [8,9]. Previous 3D models of the evolution of a marginally gravitationally unstable (MGU) solar nebula have shown that mixing of initially highly heterogeneous distributions of SLRIs can reduce the level of heterogeneity to ~10% or lower in less than 1000 yrs [10,11].

Results: A new set of 3D MGU disk models are underway that are similar to those studied previously [10,11], but with several variations. A color field is used to represent the evolution of SLRIs residing in solids small enough (~cm-size or less) to remain tied to the disk gas. Models 9S-16 and 9S-48 are identical to the previous model 9S [11] except for having the number of terms in the spherical harmonic expansion for the gravitational potential solver changed from 32 to either 16 or 48. Since MGU disks evolve solely as a result of gravitational torques, these changes have the effect of varying the numerical resolution. Models 9S-1.8 and 9S-1.9 are identical to model 9S [11] except for starting with a more gravitationally stable disk, as quantified by initial minimum Toomre Q values of 1.8 and 1.9, respectively, compared to 1.4 for 9S. All four of these new models evolve in much the same manner as model 9S: the initially high degree of heterogeneity is lowered by mixing within 1000 yrs to a dispersion of ~10% inside 5 AU and ~2% from 5 AU to 10 AU. Combined with previous results for disks extending to 20 AU [10], gradients in heterogeneity are to be expected in MGU disks.

Conclusions: 3D MGU disk models are consistent with rapid mixing of initially highly heterogeneous distributions of SLRIs to levels of ~10% or less in both the inner (< 5 AU) and outer (> 10 AU) nebula, and with even lower levels (~2%) in intermediate regions, where gravitational torques are most effective at mixing.