PARTICLE RESIDENCE TIMES IN SOLAR NEBULAR ENVIRONMENTS: VERTICAL MOTIONS

F. J. Ciesla. Department of the Geophysical Sciences, University of Chicago, 5734 South Ellis Avenue, Chicago IL 60637 E-mail: fciesla@uchicago.edu.

Introduction: One of the leading candidates for explaining the mixing and transport recorded by primitive materials is turbulence in the solar nebula. Turbulence has long been invoked as the source of the viscosity needed to drive mass and angular momentum transport within protoplanetary disks [1]. Many properties of chondritic meteorites can be understood in the context of a turbulent solar nebula [2,3] and the delivery of high-temperature materials to the comet formation region has also been explained in this setting [4,5]. In fact, planetesimal formation itself may rely on turbulence within a disk [6,7]. Thus, while the level of turbulence in protoplanetary disks is still the subject of ongoing study [8,9], the overall impact it has on the evolution of primitive materials must be understood.

Turbulence in the solar nebula would have led to random displacements of solids and gas molecules over time. In terms of vertical motions, particles would move up and down throughout the height of the disk. As the pressure, temperature, and radiation intensity would all vary with height, individual particles would be exposed to a range of physical and chemical environments over their lifetime in the solar nebula. Primitive materials would be altered to various levels depending on the paths that they took through the nebula, with the integrated paths of the particles determining the chemical and physical properties that they would add to the planetesimal into which they were incorporated.

Methods: I have developed a Monte Carlo model to track the paths that individual particles take as they diffuse vertically within the solar nebula [10]. This model allows for constant diffusivity with height, as is generally assumed in standard α-disk models, as well as diffusivities that vary with height as might be expected in MRI-layered disks [8,9]. By following the individual trajectories of a large number of grains in the nebula and tracking the pressure, temperature, and photon intensities to which they are exposed, we can quantify the impact that diffusive transport had on the chemical evolution of primitive materials.

Discussion: The long-term dynamical evolution of small particles and gaseous molecules is independent of the specific form of the diffusivity in that they spend comparable fractions of their lifetimes at different heights in the disk. However, the paths that the particles and molecules take depend strongly on the form of the diffusivity. In particular, low levels of diffusivity result in materials moving slowly from one location to the other, and thus being exposed to a given environment continuously for long periods of time. Highly diffusive disks quickly cycle materials through different locations, exposing them to a large number of environments, but each one only briefly at any given time. The implications these paths have on the thermal evolution of solids and gas-solid and photochemical reactions will be discussed.

References: [1] Lynden-Bell D. and Pringle J. E. 1974. *MNRAS* 168:603-637. [2] Cuzzi J. N. et al. 2005. *Chondrites and the Protoplanetary Disk* 732-762. [3] Ciesla F. J. and Cuzzi J. N. 2006. *Icarus* 181:178-204. [4] Bockelee-Morvan D. et al. 2002. *A&A* 384:1107-1118. [5] Ciesla F. J. 2009. *Icarus* 200:655-671. [6] Johansen A. et al. 2007. *Nature* 448:1022-1025. [7] Cuzzi J. N. 2008. *ApJ* 687:1432-1447. [8] Gammie C. 1996. *ApJ* 457:355-362. [9] Oishi J. S. et al. 2007. *ApJ* 670:805-819. [10] Ciesla F. J. 2010. *ApJ Submitted.*