THE EFFECTS OF DISK BUILDING ON THE CHEMICAL EVOLUTION OF THE SOLAR NEBULA. Le Yang[1] and Fred J. Ciesla[1], [1]Department of the Geophysical Sciences, The University of Chicago, 5734 South Ellis Avenue, Chicago IL 60430, (leyang@uchicago.edu).

Introduction: Studies of chondritic meteorites and cometary materials reveal the important roles that mixing and transport played in defining the properties of planetesimals. Outward transport of hot, inner solar nebula products resulted in the delivery of high temperature materials, like CAIs, to the region where icy comets formed[1]. Mixing of fine-grained dust allowed pre-solar grains to become mixed with chondrules and CAIs, products of high temperature processing that would have destroyed the intersteallar signatures of pre-solar grains, on the sub-millimeter scale. Thus understanding how mixing and transport occurred is critical in order to fully develop our models of solar system formation.

Most models of mixing and transport in the solar nebula consider a disk that was fully formed as the starting point for a simulation, and that the subsequent dynamical evolution of the gas and solids determine the bulk properties of the planetesimals that eventually form. However, protoplanetary disks like our solar nebula are built as material from the parent molecular cloud rains down over a finite period of time. This material is then subjected to mass and angular momentum transport as it gets incorporated into the disk, some eventually being accreted by the central star, while some is pushed outwards to large distances. This dynamical evolution does not turn on the instant infall ceases, but rather is ongoing throughout the time of disk formation.

Here we consider the dynamical evolution of a solar nebula during and after the period when it is built from its parent molecular cloud. Specifically we investigate how the infall impacts the overall structure and dynamical evolution of the nebula and how materials that are added to the disk at different times are mixed throughout. This work has implications for the level of isotopic homogeneity that would be seen in primitive materials as well as the preservation of early formed solids.

Model Description: In simulating the evolution of a growing solar nebula, we follow the one-dimensional model of Hueso and Guillot [2]. We use the standard α-viscosity model to describe the mass and angular momentum transport within the disk. In our simulation, increased mass and angular momentum transport due to local gravitational instability is considered with expressions given in [3]. We account for disk building by adopting an analytic formula that describes the addition of mass to the central star and disk as a result of infall from the molecular cloud. The rate of infall depends on the initial temperature of the molecular cloud, while the physical distribution of this added mass depends on the initial angular momentum of the cloud. Infall takes place until the mass of the molecular cloud is completely incorporated into the star-disk system. The masses of each are tracked separately, and thus the star increases in mass as material is accreted from the disk.

Results: Figures 1-4 show the results of a typical model simulation. For this run we considered a isothermal one solar mass molecular cloud, with temperature set as 15K and rotational rate set as 1×10^{-14} s^{-1}. Under these conditions all the mass in the cloud falls inside of 10 AU from the central star at a rate of ~$3x10^{-6}$ $M_\odot$/yr. We use a base value of $\alpha=10^{-3}$ throughout the disk. Our model begins with a star of mass 0.5 $M_\odot$ and no mass in the disk (beyond 0.1 AU), meaning infall continues for another 0.16 Myr.

Figure 1 shows how the masses of the disk and star evolve with time. The disk's mass will grow to about 0.3 $M_\odot$ due to molecular material falling, then decrease as it is transported inward where it is finally accrete into the central star.

Figure 2 shows the surface density of the disk at different times. The disk grows more massive until infall caeases, after which it thins and grows in radial extent due to the continued mass and angular momentum transport associated with viscous evolution. Despite all molecular cloud material falling within 10 AU of the star, significant mass is carried outwards to beyond 100 AU over the course of our simulation.

Figure 3 shows the temperature distribution of the disk at different points of its evolution. During the earliest stages of evolution, the temperature increases everywhere as the disk grows in mass. After infall ceases, the disk cools with time as it becomes less massive. That is, the decrease in disk mass coincides with less internal viscous dissipation (heating) and greater ease for the disk to radiate away energy.

Figure 4 shows how the last 1 % material accreted from the molecular cloud is redistributed in the disk over time. After being accreted by the disk, that material is restricted to inside ~10 AU, making up 2-10% of the material present there. Over time, that material is redistributed via diffusion and the large-scale flows associated with disk evolution. The distribution of material flattens quickly, becoming uniformly distribted in the inner disk over a short period of time. Within

0.5 Myrs, the fraction is almost constant, making up a few percent of the remaining mass of the disk, except for the rapid drop off in the outermost region.

Discusion: With varying parameters, such as α or intial rotational rate of the molecular cloud, we find that the result that material is mixed well within the disk in <1 Myr is robust. This suggests materials formed immediately after the formation of solar nebula may record brief chemical or isotopic heterogeneities, but these will rapidly disappear over the course of disk evolution. Indeed, if there is any compositional heterogeneity in the parent molecular cloud at the time of collapse, either due to injection of material from a supernova [4] or from photochemical effects [e.g. 5], these may be reflected in the oldest solar system solids, such as the FUN CAIs [6]. Such issues are the subject of our current investigation.

While our dynamical model has thus far focused on gas or fine-dust within the nebula, the evolution outlined here may help explain the dynamical evolution of larger solids as well. In particular, the viscous spreading of a disk such as that modeled here will likely last longer than in models where the model begins with the disk at its largest mass. This increased viscous spreading may help offset the inward motions of larger particles due to gas drag, and in particular, explain how CAIs were preserved in the nebula for 1-2 million years prior to being incorporated into chondrite parent bodies [7].

References: [1] Brownlee, D. et al. (2006) *Science, 314,* 1711-1715. [2] Hueso, R. and Guillot, T. (2005) *A&A, 442,* 703–725. [3] Armitage, P. J. et al. (2001) *Mon. Not. R. Astron. Soc., 324,* 705-711. [4]Boss, A. P. et al. (2008) *ApJ, 686,* L119-L122. [5]Yurimoto, H., Kuramoto, K. (2004) Science 305, 1763–1766. [6]Macpherson, G.J (2003) Treatise on Geochemistry, vol. 1, 201-246. [7]Ciesla F. J. and Yang L. This conference.

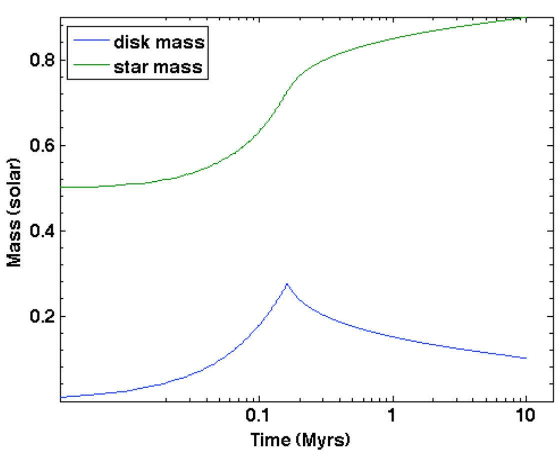

Figure 1: The mass evolution of the disk and star.

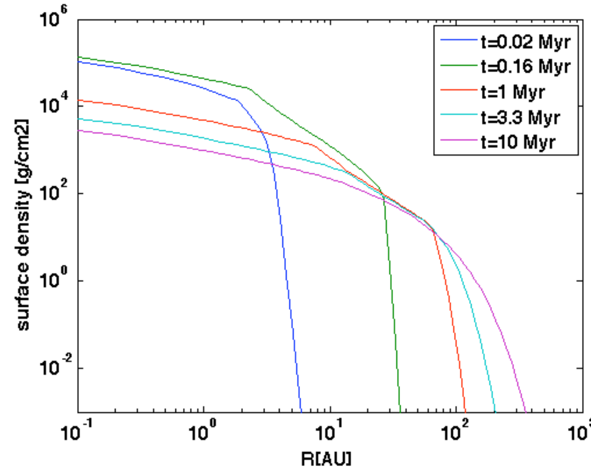

Figure 2: The (gas) surface density evolution of the disk.

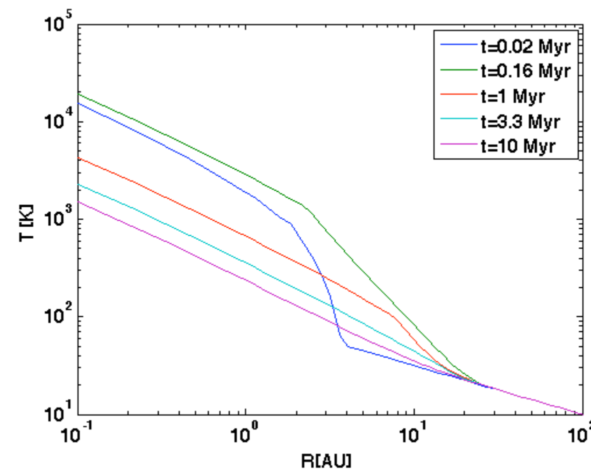

Figure 3: The thermal evolution of the disk.

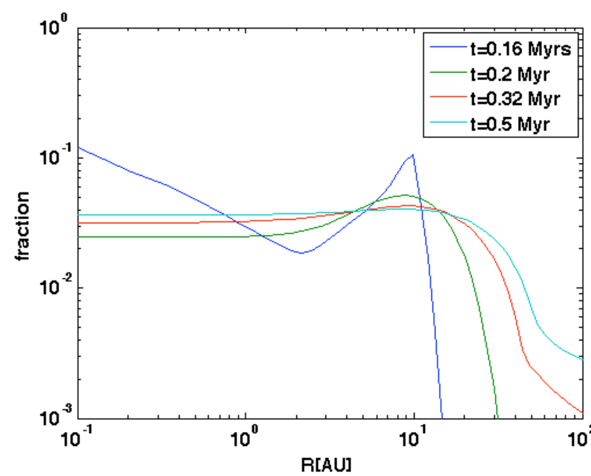

Figure 4: The fraction evolution of the last 1 % material.