THE DIVERSITY OF EXTRASOLAR TERRESTRIAL PLANET COMPOSITIONS: ADDING MIGRATION INTO THE MIX. J. C. Bond[1], D. P. O'Brien[1] and D. S. Lauretta[2], [1]Planetary Science Institute, Tucson AZ 85719. jbond@psi.edu [2]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721.

Introduction: Extrasolar planetary systems are known to be chemical distinct from field stars without known planetary companions. They display enrichments in a variety of essential terrestrial planet forming elements such as Fe, Mg and Si (e.g. [1]). Furthermore, they display large variation in the key planet formation ratios of Mg/Si and C/O [2]. These variations have drastic implications on the composition and nature of terrestrial planets possibly forming within these systems [2].

At the same time, extrasolar planetary systems are believed to have encountered relatively large amounts of giant planet migration (e.g. [3]). Such migration will ultimately act to redistribute solid material throughout the disk, thus altering the final composition of any terrestrial planets present within the system. However, no study to date has considered both terrestrial planet formation during the epoch of giant planet migration and the bulk chemical composition of the resulting planets. Such a study is necessary to better determine the full range of terrestrial palnet compositions possible within known planetary systems. Here we present the results of our ongoing study to combine N-body dynamical simulations incorporating giant planet migration with equilibrium condensation models in protoplanetary disks.

Methodology: As in our recent studies [2,4], we determine the bulk composition of our simulated planets by assuming that each planetary embryo and planetesimal in our dynamical simulations retains the equilibrium chemical composition of the area of the nebula in which it first formed, and contributes that composition to the final planet. As such, by tracing the origin of each embryo and planetesimal in our dynamical simulations, and calculating the chemical composition of those bodies based on their original locations, we are able to constrain the bulk composition of the final terrestrial planets.

Dynamical Models. A suite of 16 simulations were run for a hypothetical extrasolar planetary system. These simulations incorporate the effects of both giant panet migration and gas drag. All simulations assumed a 1 Jupiter-mass planet migrating from 5AU to 1AU. Two different migration timescales were adopted: 1 Myr and 0.1 Myr. Simulations were run with both with and without gas drag included. Each simulation consisted of ~80 Mars-mass planetary embryos and ~2000 planetesimals that initially span the region from 0.3 to 4 AU. For comparison, a series of 4 in-situ terrestrial planet formation simulations (where the giant planet was initially located at 1AU and did not migrate) were also run.

Chemical Models. The equilibrium composition of solids condensed in the nebula, and hence the initial compositions of the planetesimals and embryos, was determined by using the HSC Chemistry (v. 5.1) software package. In order to fully explore the possible chemical diversity of extrasolar terrestrial planets, simulations were run with 16 different elements (H, He, C, N, O, Na, Mg, Al, Si, P, S, Ca, Ti, Cr, Fe and Ni) using the abundances of four known planetary host stars: solar, HD27442 (similar to solar), Gl777 (average host star Mg/Si and C/O values) and HD4203 (high C/O value). Pressure and temperature conditions in the disc were adopted from [6] at 5.0×10^5 yr based on the results of [4].

Results: As one would intuitively expect, the inclusion of both giant planet migration and gas drag acted to drastically alter the composition of the simulated terrestrial planets produced, more so than with just the inclusion of giant planet migration alone. In these simulations, significant amounts (~30%) of final planetary mass originates from beyond 2AU compared to none in the in-situ simulations and limited amounts in the outermost planets formed in the simulations including giant planet migration alone. Material in this region (i.e. beyond 2AU) is predominately composed of Mg-silicate material (olivine and pyroxene) and metallic Iron with hydrous species (water ice and serpentine) present in the outer regions of the disk.

As such, the planets produced in the simulations incorporating both giant planet migration and gas drag produced planets containing larger amounts of O, Si, Fe and Mg than those without either effect. Additionally, hydrous material is also delivered to the terrestrial planets during accretion while little to none is accreted in either the in-situ or no gas drag simulations.

The changes in bulk planetary composition produced by the inclusion of gas drag and migration are most pronounced for those systems with highly radially zoned chemical profiles such as HD4203. This system has an inner zone dominated by carbide phases before transitioning to a broad silicate-dominated region and finally a region containing hydrous species. The inclusion of migration and gas drag decreased the

C present in the simulated planet by more than 50% while also increasing the amount of Mg present by 3.5 times and the amunt of O by 4.5 times (see Fig. 1). Similar effects (although less drastic) were also observed for the refractory elements of other systems (e.g. HD27442) (see Fig. 2).

In the case where multiple terrestrial planets are produced, the inclusion of giant planet migration and gas drag acts to reduce the radial variation in composition between planets. Some variation remains between the simulated planets but it is drastically reduced from the in-situ formation case.

Conclusions: We have found that the inclusion of the effects of both giant planet migration and gas drag can drastically alter the composition of simulated terrestrial planets. Generally the inclusion of these effects acts to increase the amount of Mg-silicate material and metallic Iron present in the simulated planet. It also serves to deliver hyrdous-rich material to the planets during the accretion process. As such, the inclusion of these effects in both dynamical and chemical studies of terrestrial planet formation are essential in order to better understand full range of planetary compositions possible within extrasolar planetary systems. With this in mind, we are currently beginning to explore other planetary configurations including a larger disk (extending our simuations out to 9AU) and an extended range of planet migration (in to 0.3AU instead of the 1AU barrier considered here)

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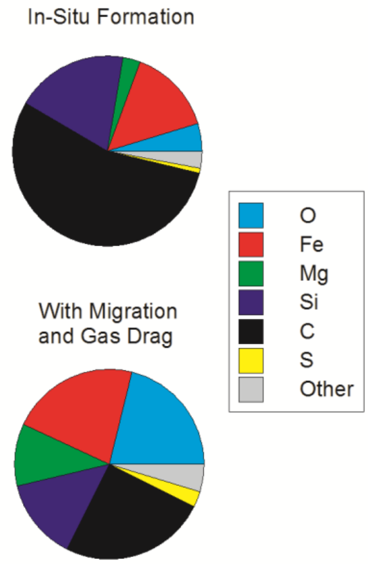

Figure 1: Diagram of the bulk composition of a terrestrial planet produced by simulations of in-situ planet formation (top) and simulations incorporating the effects of giant planet migration and gas drag (bottom) for the abundnaces of HD4203. The planets are otherwise similar in both mass ($M_{in\text{-}situ}$ = 1.26 M_{Earth} vs. $M_{migration + drag}$ = 1.32 M_{Earth}) and orbital semi-major axis ($a_{in\text{-}situ}$ = 0.40AU vs. $a_{migration + drag}$ = 0.45AU).

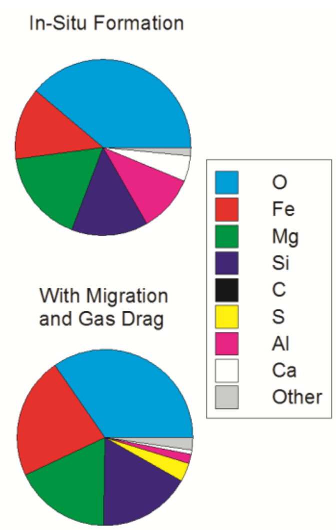

Figure 2: Diagram of the bulk composition of a terrestrial planet produced by simulations of in-situ planet formation (top) and simulations incorporating the effects of giant planet migration and gas drag (bottom) for the abundnaces of HD27442. The planets are otherwise similar in both mass ($M_{in\text{-}situ}$ = 1.26 M_{Earth} vs. $M_{migration + drag}$ = 1.32 M_{Earth}) and orbital semi-major axis ($a_{in\text{-}situ}$ = 0.40AU vs. $a_{migration + drag}$ = 0.45AU).