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The Diversity of Extrasolar Terrestrial Planets: adding migration into the mix.

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Abstract

Extrasolar terrestrial planets are likely to have compositions unlike anything previously observed. Previous work on this issue has not examined the impact giant planet migration may have on these planetary compositions beyond looking at possible water content. We present 12 simulations incorporating planetary migration. In all cases, migration was found to dramatically alter the planetary composition, acting to broaden the feeding zones and decrease radial variations in composition. Furthermore, migration was found to assist in the delivery of water-rich material to accreting planets.

1. Introduction

Extrasolar planetary systems have long been known to be chemical distinct from field stars without known planetary companions. Enrichments in a wide variety of essential terrestrial planet forming elements (such as Fe, Mg and Si (e.g. [3])) have been repeatedly observed. Additionally, significant variations in the key planet formation ratios such as Mg/Si and C/O have been seen [2]. These variations have significant implications on the composition and nature of terrestrial planets possibly forming within these systems [1]. Also of importance is the relatively large degree of giant planet migration believed to have occurred within many of these systems. Such migration will ultimately act to redistribute solid material throughout the disk, thus altering the composition of the feeding zones for any terrestrial planets present within the system.

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.

2. Methodology

As in previous work [1,2], 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 accreted by the final planets, 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.

2.1 Migration Models

A suite of four simulations incorporating the effects of both giant planet migration and gas drag were run for hypothetical extrasolar planetary systems. All simulations assumed a 1 Jupiter-mass planet migrating from 5AU to 1AU on a 0.1Myr timescale. Each simulation consisted of ~80 Mars-mass planetary embryos and ~2700 planetesimals that initially span the region from 0.3 to 9 AU. Additionally, we also consider eight of the simulations of [4] wherein a Jupiter mass body migrates from 5.2AU to 0.25AU during terrestrial accretion. Four simulations were run with a Jupiter mass planet alone while an additional four were also run with a stationary Saturn mass planet at 9.5AU. For comparison, a series of four in-situ terrestrial planet formation simulations (where the giant planet was initially located at 1AU and did not migrate) were also run.

2.2 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. 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 five known planetary host stars: solar, Gl777 (average host star Mg/Si and C/O values), HD213240 (high Mg/Si value), HD 19994 and HD4203 (high C/O values).

3. Results

The inclusion of giant planet migration and gas drag acted to drastically alter the composition of the simulated terrestrial planets produced. In the simulations with giant planet migration, significant amounts (up to ~30%) of final planetary mass originates from beyond 2AU compared to none in the in-situ simulations. This material is largely composed of Mg-silicate material (olivine and pyroxene) and metallic Iron with hydrous species (water ice and serpentine) present in the more distant regions of the disk.

As such, the planets produced in the simulations incorporating giant planet migration and gas drag produced planets containing larger amounts of O, Si, Fe and Mg than those that did not consider these effects. Furthermore, migration saw the delivery of hydrous material to the terrestrial planets during accretion, in direct contrast to the ‘dry’ planets produced under the assumption of in-situ formation.

Radial variations in the composition of solid material present within a given system were often in effect ‘smoothed out’ by the inclusion of migration and gas drag. This produced some significant differences in planetary composition between the in-situ and migration simulations. For example, for HD4203, the inclusion of migration and gas drag decreased the C present in the simulated planet by more than 50% and increased the relative abundance of Mg present by a factor of 3.5 times and O by a factor 4.5 (see Fig. 1).

4. Summary and Conclusions

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, while also serving to deliver water-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. We are exploring other planetary configurations including terrestrial planet formation around M dwarf host stars and incorporating a larger variety of clathrates and volatiles into our simulations in order to more fully examine the delivery of hydrous species to an accreting planet.

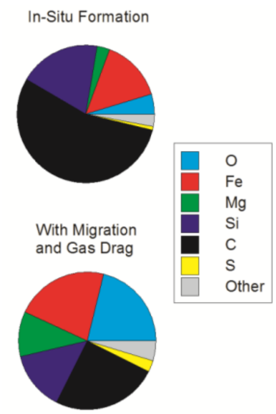

Figure 1: Diagram of the bulk composition of a terrestrial planet produced by simulations of in-situ planet formation (top) and simulations with giant planet migration and gas drag (bottom) for the abundances of HD4203. The planets are otherwise similar in mass and orbital semi-major axis.

Acknowledgements

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