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ABSTRACT OF PHD DISSERTATION

With over 6,000 confirmed exoplanets, numerous high angular resolution protoplanetary disk surveys, and multiple sample return missions from meteorites, the field of planet formation has an excess of data on different stages of planet formation, yet still no clear pathway to fully connect these observations. Perhaps the most consequential discovery of the past decade is a ubiquity of substructures in protoplanetary disks. These substructures include rings, gaps, spiral arms, and azimuthal asymmetries in the dust emission from the disks, with some such substructures directly linked to the forming planets embedded in the disk. While it has become clear that planets sculpt their formation environment, it is not yet clear how the creation of these planet-induced disk substructures influence the composition of the growing planet, nor how they may affect the formation of subsequent planets.

In this thesis, I examine the feedback of planet formation on the protoplanetary disk, and how the composition of both the disk and the planets that grow there influence one another over the disk lifetime. I explore these feedback mechanisms — including planet-induced disk substructures, grain growth and fragmentation, and planetary heating — using a variety of computational techniques to constrain the effects on the composition of embedded planets in self-consistent ways. I compare the results of these computational models with meteorite compositions to place constraints on the Solar Nebula, but also more broadly with detected disks and exoplanets.

First, I present the results of a newly developed chemical model that simultaneously solves the chemical composition of the ice and gas in a protoplanetary disk while accounting for grain growth and ice sequestration. I show that while depleting small grains from the disk by growing larger pebbles accelerates photon-driven chemistry throughout the disk, the bulk of solids in the midplane retain their inherited composition from the protostellar cloud. As such, the earliest forming solids, including meteorite parent bodies in our solar system, likely do not record much of the chemical processing that occurs in the disk.

Second, I examine the extent of radial mixing in a protoplanetary disk containing a growing giant planet. These results are presented within the context of the observed meteoritic dichotomy, for which it has been proposed that Jupiter acted as a physical barrier between the inner and outer solar nebula, preventing mixing of carbonaceous and non-carbonaceous material. While a massive giant planet is capable of halting the inward drift of large pebbles in the disk, I show that small dust is capable of passing past the embedded planet at later stages of growth. As such, the extent of radial mixing in the solar nebula evolves over time, with large grains drifting inward initially, while small dust is transported both inwards and outwards once the jovian core reaches sufficient mass.

Finally, I examine how the stirring of small dust may act to enrich the atmospheres of giant planets with volatile ices after the planets have reached their pebble isolation mass. As giant planets accrete gas from the disk, they stir small dust to upper layers of the disk where temperatures are higher than the disk midplane. If these small grains are abundant as a result of particle fragmentation outside the disk gap carved by the planet, then this may be a promising mechanism to enrich these atmospheres in carbon, oxygen, and nitrogen, explaining observed enrichments in both Jupiter and directly imaged giant exoplanets.