Ana-Maria Piso: Statement of Research

Origins of Gas Giant Compositions: The Role of Disk Location, Dynamics and Chemistry

Within the last two decades, more than one thousand extrasolar planets (exoplanets) have been discovered. Their diversity in terms of mass, radius, location and composition provides an exciting field of research, with the eventual goal of finding planets that are similar to our own Earth and may sustain life. For this purpose, it is thus crucial to explore and understand how planets obtain their compositions. Both terrestrial and giant planets are born in protoplanetary disks, which implies that their compositions are determined by and tightly linked to the structure and composition of the disk. The chemical and dynamical evolution of disks, as well the formation of giant planets have both been previously investigated in isolation. However, the coupled chemo-dynamical disk evolution, planet compositions, and most importantly the disk-planet connection have not yet been considered in detail. In my research, I uncover some of the answers to this issue from two standpoints: (1) by looking at the role of disk location in setting the conditions for the formation of wide-separation gas giants, and (2) by investigating how the structure and chemical composition of the protoplanetary disk at different radii affects the composition of nascent giant planets.

To answer the first issue, I study giant planet formation through core accretion. I show how the minimum core mass required to form a giant planet during the lifetime of the protoplanetary disk depends on the location in the disk, the equation of state of the nebular gas and dust opacity. This minimum applies when planetesimal accretion does not substantially heat the core's atmosphere. The minimum core mass decreases with semimajor axis, and may be significantly lower than the typically quoted value of 10 Earth masses, thus challenging previous studies that core accretion cannot operate in the outer disk.

To investigate the second issue, I explore how the composition and evolution of protoplanetary disks may affect the formation and chemical composition of giant planets. Volatile snowlines are highly important in the planet formation process. I thus show how the snowline locations of the main carbon, oxygen and nitrogen carriers, as well as the C/N/O ratios, are affected by disk dynamics and ice morphology. Compared to a static disk, disk dynamics and ice morphology combined may change the CO and N2 snowline locations by a factor of 7. Moreover, the gas-phase N/O ratio is highly enhanced throughout most of the disk, meaning that wide-separation giants should have an excess of nitrogen in their atmospheres which may be used to trace their origins. The large range of possible CO and N2 snowline locations, and hence of regions with highly enhanced N/O ratios, implies that snowline observations at various stages of planet formation are crucial in order to use C/N/O ratios as beacons for planet formation zones.

I am currently expanding the work described above by considering the effect of diffusion on the C/N/O ratios in viscous steady-state disks. I am developing a simplified method to estimate the abundance of different volatiles at various disk locations, and thus their effect on the C/N/O ratio both in static and dynamic disks. The complexity of disk chemistry means that coupling it with dynamical processes, while necessary, is non-trivial. As a next step I will thus couple the dynamical framework outlined above with time-dependent chemical models of increasing complexity, informed by results from state-of-the-art disk chemistry models (that can only be run on static disks). By having a better understudying on how disk chemistry and dynamics affect the composition of nascent, and eventually mature planets, my work may provide essential context for characterizing the gas giants that instruments such as JWST and TESS will one day discover.