Ana-Maria Piso: Pappalardo Fellowship Application Statement

The Role of Disk Volatile Chemistry and Dynamics in Shaping the Compositions of Nascent Planets

Within the last two decades, more than one thousand extrasolar planets 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 composition is determined by and tightly linked to the structure and composition of the disk. As shown in my work on the minimum core mass of gas giants, planet formation depends sensitively on disk physics and chemistry**. I propose to develop a holistic chemo-dynamical framework to explore how disk dynamics and chemistry, as well as the dynamics of nascent planets and planetesimals, regulate the compositions of mature giant planets.** Such a model will enhance our understanding of planetary structures by enabling us to predict what kind of planet compositions result from planet formation in different parts of the disk. Furthermore, this work provides essential context for characterizing the planets that instruments such as the James Webb Space Telescope (JWST) and the Transiting Exoplanet Survey Satellite (TESS) will one day discover.

1. <u>Coupled Chemical and Dynamical Disk Evolution</u>. Chemical and dynamical processes in a protoplanetary disk affect the disk structure and composition, and thus the composition of nascent planets. Chemical abundances vary significantly across a typical disk, due to steep gradients in temperature, density and radiation. The complexity of disk chemistry means that coupling it with dynamical processes is non-trivial. Through analytical and numerical calculations, I will first explore a range of dynamical processes that may affect the distribution of volatiles in disks, expanding and generalizing the framework I developed during my dissertation research. I will couple this dynamical model with a simple chemical network, then use more complex chemical networks to develop a simplified time-dependent chemistry, informed by results from state-of-the-art disk chemistry models (that can only be run on static disks). This will show how the snowline locations of volatiles, as well as the chemical composition of the disk gas and dust evolve, which has direct implications on the compositions of young planets.

2. Planet and Planetesimal Migration. Giant planets can migrate through the disk while still accumulating gas, which will change their atmospheric composition since the disk chemical abundances are different at different disk locations. Additionally, giant planets may still accumulate planetesimals while accreting nebular gas. The final composition of a planet's atmosphere will thus depend on how much gas and solids are accreted in this stage. I will add planet dynamical effects such as migration and planetesimal accretion in the chemical and dynamical model developed in part 1, and quantify how these processes affect the chemical composition of gas giant envelopes.

3. Model Planet Populations. The results from parts 1 and 2 will feed into a large planet synthesis model, in which I will use a grid of different initial disk and planetary embryo conditions. For this computationally expensive step, I will only include the processes that I have identified to be the most important in the local simulations from steps 1 and 2. This will allow me to constrain a planet's formation location based on its chemical composition. Comparing my results with future JWST observations of atmospheric spectra will lead to great scientific strides in understanding the complex connection between protoplanetary disks and the formation, evolution and composition of exoplanets.

The MIT Physics Department is an ideal place for me to pursue my postdoctoral research, due to its vibrant community of experts in exoplanet atmospheres and dynamics. In particular, I would like to collaborate with Sara Seager, who is a co-investigator of the TESS mission and a world-leading theorist in atmospheric chemistry, as well as with members of her group, who specialize in a broad range of exoplanet theory and computational topics. I would also like to collaborate with Joshua Winn, who is an expert in discovering and characterizing exoplanets. Additionally, the MIT Physics Department is strongly connected to the Earth and Planetary Sciences Department, where I would love to work with Hilke Schlichting, a leader in planet formation theory and dynamics.