Ana-Maria Piso: Michigan Society of Fellows Research Proposal

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

Within the last two decades, more than one thousand exoplanets (planets outside the Solar system) have been discovered (http://www.exoplanet.eu). 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. Planets in our Solar System and elsewhere assemble from the dust and gas that surround stars during the first few million years of their lifetimes. The dust particles collide to form larger and larger bodies, which eventually become protoplanetary cores with masses and radii compared to our own Earth. The gas in the protoplanetary disk dissipates on sufficiently large timescales of a few million years; if there is still some gas left in the disk by the time a protoplanetary core has formed, this gas accumulates around the core and eventually forms a giant planet (e.g., Piso & Youdin 2014, Piso, Youdin, & Murray-Clay 2015), such as Jupiter or Saturn. It follows that the composition (both solid and gaseous) of giant planets is determined by and tightly linked to the structure and composition of the protoplanetary disk in which they form. **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 planets.**

1. Coupled Chemical and Dynamical Disk Evolution. Chemical and dynamical processes in a protoplanetary disk affect the disk structure and composition, and thus the composition of nascent planets. The dynamics of dust and gas in disks can have a large influence on the chemical structure of the disk (Piso, Öberg, et al. 2015). In my current research, I explore how two dynamical effects, specifically the movement of solids (radial drift) and gas (viscous gas accretion) towards the star, affect snowline locations, i.e. the distances from the star where the temperature is low enough for volatile species such as water, carbon dioxide and carbon monoxide to condense into solid ice grains (see Figure 1). **In this part of my research, I propose to expand this simple dynamical disk model in two directions: (1) I will add the slew of other dynamical processes that may affect the distribution of volatiles in disks, and (2) I will couple this model with a time-dependent chemistry. This will show how snowline locations, as well as the chemical composition of the disk gas and dust change with time, which has direct implications on the compositions of nascent planets.**

2. Planet and Planetesimal Migration. The model described above can predict the chemical composition of gas giants that have formed *in situ* and are no longer accreting solid material. In reality, 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 solid material (planetesimals) during the gas accretion phase, and therefore the final composition of a planet's atmosphere will depend on how much gas and solids are accreted in this stage. **In this part of my research, I will add dynamical effects such as planetary 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 that I will obtain from the research described in parts 1 and 2 will depend on the characteristics of the protoplanetary disk (such as temperature and surface density profile), the initial assumed chemical abundances, and the initial location of a nascent planet. **In this part of my research, I will vary these disk, chemical and planet properties. I will run a simulation to explore a wide parameter space of initial conditions, generate model planet**

populations and investigate potential planet formation locations. This will lead to achieving my ultimate two-fold goal: (1) to predict what kind of planet compositions result from planet formation in different parts of the disk, and (2) to back-track the planet formation location based on planet composition. This work provides essential context for characterizing the planets that instruments such as the James Webb Space Telescope and the Transiting Survey Exoplanet Satellite will one day discover.

Due to experts in both disk chemistry modeling and exoplanet characterization, such as Edwin Bergin, Emily Rauscher and Michael Meyer, the University of Michigan department of astronomy is an ideal place for me to pursue my postdoctoral research. I aim to lead a collaboration that connects the groups focused on characterization of protoplanetary disks and exoplanets. Through such collaboration, we could make some great scientific strides in understanding the complex connection between protoplanetary disks and the formation, evolution and composition of exoplanets.

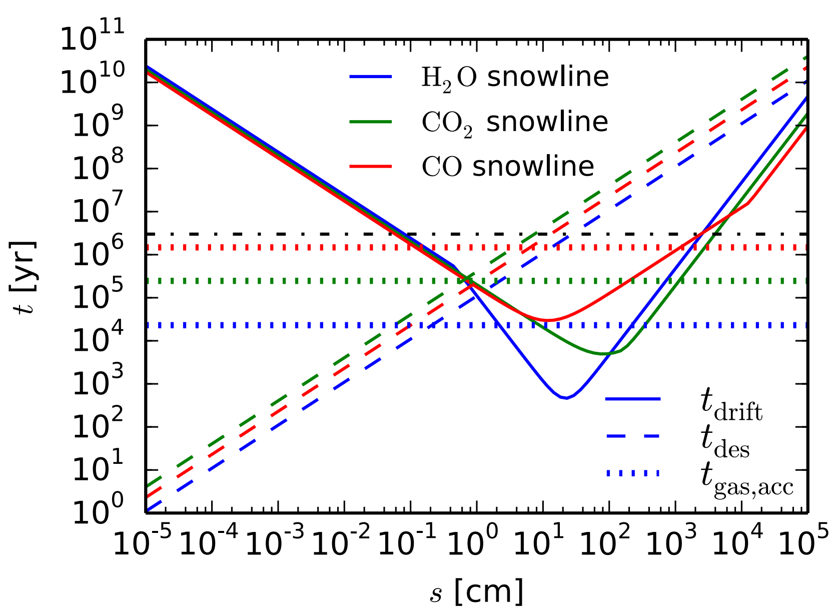

Figure 1: Relevant timescales for dynamical effects in the desorption process: drift timescale (solid lines), desorption timescale (dashed lines) and gas accretion timescale (dotted lines). The timescales are calculated at three representative locations, i.e. the H_2O, CO_2 and CO snowlines. The horizontal dot-dashed line represents a typical disk lifetime of 3 million years. Radial drift and gas accretion affect desorption in the regions where their respective timescales, i.e. t_{drift} and $_{tgas,acc}$, are comparable to the desorption timescale t_{des}.