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

Planets form in protoplanetary disks, similarly to the way our own Solar system has formed from the Solar nebula. Protoplanetary disks are circumstellar disks composed of gas and dust that are rotating around a young star. 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 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, 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. Disks, in turn, undergo a multitude of chemical and dynamical processes. **I propose to understand how these disk processes connect to the eventual compositions of planets observed today.** My proposed research is outlined below as follows.

1. Coupled Chemical and Dynamical Disk Evolution. The chemistry in protoplanetary disks is incredibly complex and changes with time. There is a multitude of different chemical species that undergo several chemical reactions. Modeling the chemical evolution of a protoplanetary disk is therefore a non-trivial task. 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 for an example of the snowline locations of the volatile mentioned above and how they affect the carbon to oxygen ratio in a disk that does not take into account any dynamical processes). However, my current model does not take into account any chemical reactions between the three volatiles (H_2O, CO_2 and CO). **In this part of my research, I will develop a chemical network model and self-consistently incorporate in it the two dynamical effects outlined above. I will add more volatile compounds, such as nitrogen, ammonia and hydrocarbons. 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. Additional Dynamical Effects. 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 its rich and vibrant community of astronomers, The University of Michigan department of astronomy is an ideal place for me to pursue my postdoctoral research. In particular, collaborating with Professor Edwin Bergin, who is an expert in disk chemistry and tracing volatile species, would be an excellent opportunity. Through our collaboration we could make some great scientific strides in understanding the complex connection between protoplanetary disks and the formation, evolution and composition of exoplanets.

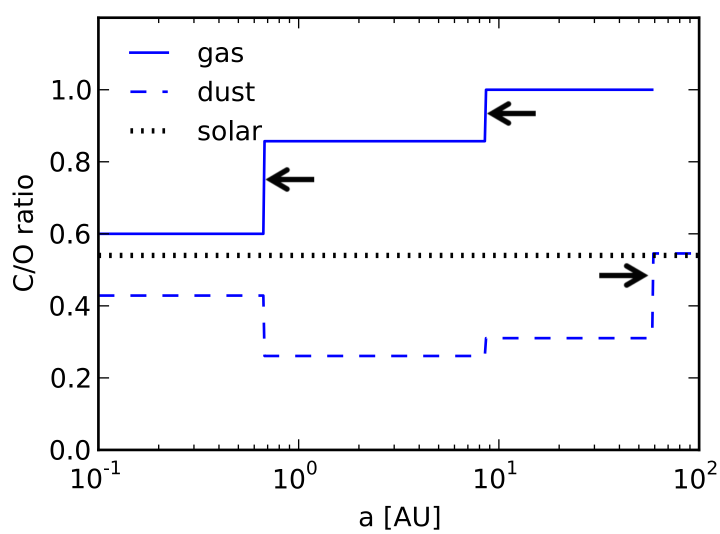

Figure 1. The C/O ratio in gas (solid lines) and dust (dashed lines) as a function of semimajor axis in a static disk. From left to right, the arrows (in other words, the vertical lines) mark the locations of the H_2O, CO_2 and CO snowlines, respectively. After Oberg, Murray-Clay & Bergin (2011)