Chemical feedback of planet formation

Despite detections of over 6,000 planets orbiting other stars[1], what the composition of these planets may be, and what that means for the possibility of life, remains a mystery. My research addresses the pivotal question: *How do growing planets alter the chemical environment of planet formation?*

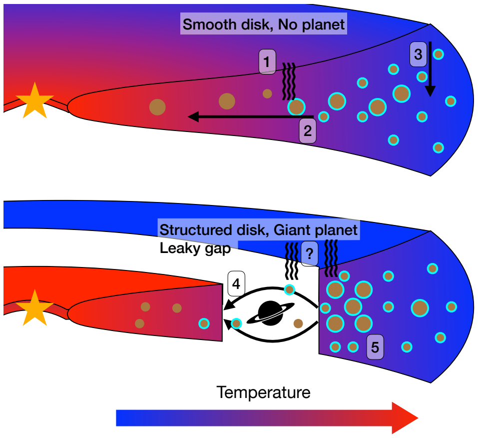

Figure 1: Example disks with and without a giant planet. In the absence of a planet, dust grains are expected to (1) sublimate ice, (2) drift radially inwards, (3) grow and settle. A giant planet however, may lead to (4) selective inward filtering of grains and (5) dust pile-ups in the disk.

Background

As gas and dust collapse from the interstellar medium to form a young protostar, a small fraction of the total mass creates a protoplanetary disk (PPD), a ring of gas and dust from which planets will form. While it has long been assumed that planets reflect the composition of the disk in which they form (e.g. [1]), recent observations of molecular line emission from protoplanetary disks have shown that not only are these disks highly dynamic [2], but also regions of active, and yet unexplained, chemistry [3]. One attractive explanation is the the presence of giant planets, similar to Jupiter in our solar system, which can have dramatic effects on the gas and dust distribution (Fig 1). **These dynamic effects may be altering not only their own birth environment, but also the subsequent formation of other planets around the same star.**

Despite recent advancements in our understanding of the chemical composition of PPDs, exoplanets, and bodies in our own solar system, we still lack a comprehensive theoretical framework connecting the chemical evolution PPDs to the planets that form within. Throughout my PhD, I have pioneered theoretical modeling techniques to examine the dynamic and chemical connections between the gas, dust, and planets withing a PPD [4,5]. As a Miller Fellow at Berkeley I will continue this work to model the dynamic chemical environments of the PPD and connect planetary compositions to their natal disk.

Research Approach

I will use a combination of **advanced 3D hydrodynamic models** with Monte Carlo particle integration to track the trajectories of ice covered grains through a PPD containing a giant planet. Not only do these small grains set the available temperature and UV radiation throughout the disk, but their surfaces provide important sites of grain-surface chemistry. Simple molecules present on the ice, such as water and carbon dioxide, can react with radiation from the host star creating complex carbohydrates [6]. Too much radiation, however, can sublimate ice or destroy these complex molecules all together. With my combined dynamic and chemical models I will be able to constrain this processing of volatile ices, and what this means for the possible delivery of life-relevant molecules to planets in our solar system and beyond.

Following on this, I will track both the dust and gas-phase chemistry together, modeling **coupled chemical evolution** in a self-consistent manner for the first time. Current disk models assume static disks, which cannot differentiate between chemical versus dynamical effects. My 3D dynamic models will inform the dust evolution in 2D chemical models, creating a new step forward for accurate disk chemical modeling and providing new insight for interpreting disk observations.

Finally, these combined chemistry and dynamic models for disks containing planets will allow me to **directly link planet compositions to disk conditions**. Even if these planets do not mirror the observed disk composition, the detection of tracer molecular species in the disk may tell us something about the planets forming inside. I will create the self-consistent modelling framework necessary to know the compositions of these yet undetected planets and if they are indeed hospitable for life.

References

[1] Öberg, K. I., Murray-Clay, R. & Bergin, E. A. 2011, *ApJ*, **743**, L16. [2] Andrews, S. M., Huang, J., Pérez, L. M., *et al.* 2018, *ApJ*, **869**, L41. [3] Öberg, K. I., Guzmán, V. V., Walsh, C., *et al.* 2021, *ApJS*, **257**, 1. [4] Van Clepper, E., Bergner, J. B., Bosman, A. D., *et al.* 2022, *ApJ*, **927**, 206. [5] Van Clepper, E., Price, E. & Ciesla, F. J. 2025, *ApJ*, **980**, 201. [6] Bergner, J. B. & Ciesla, F. 2021, *ApJ*, **919**, 45.

[1] https://exoplanetarchive.ipac.caltech.edu