Coupling Dynamics and Chemistry in Accreting Protoplanetary Disks

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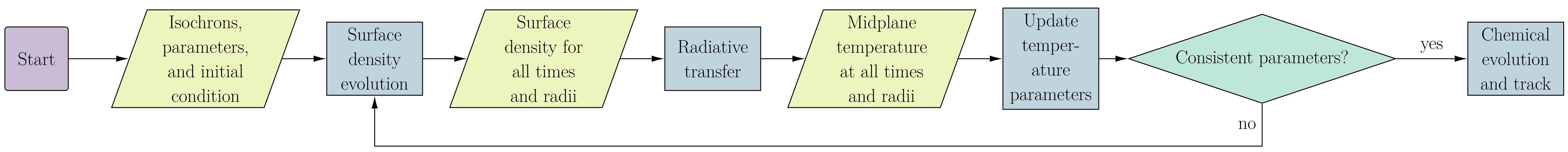
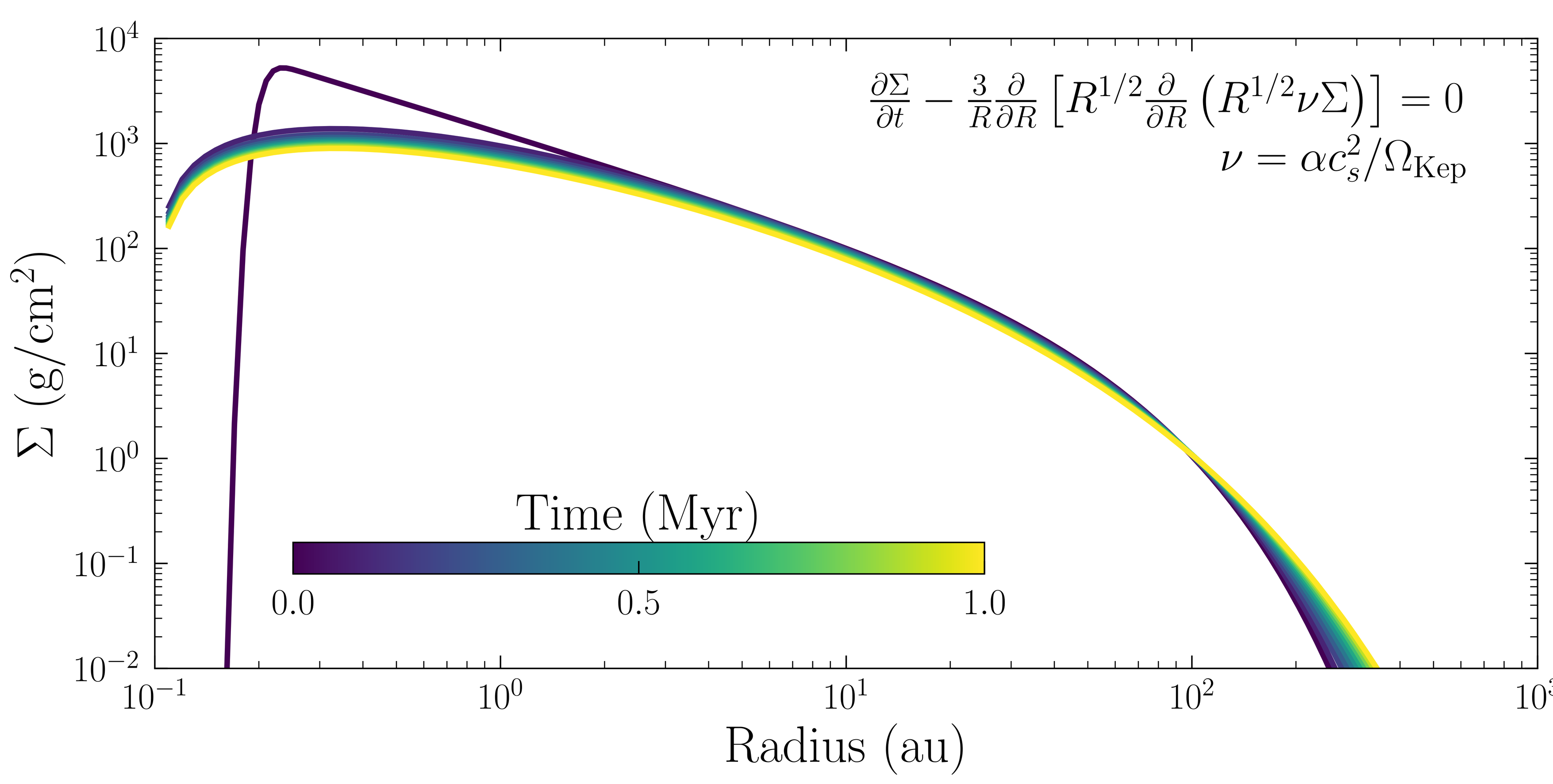
Background

Protoplanetary disks are complex systems of dust and gas orbiting young stars. Chemical reactions determine which species become abundant and, therefore, which species will contribute to the initial compositions of forming planetesimals. Changes in physical conditions affect which chemical reactions can take place and how the disk evolves at a given radius. Many existing disk chemistry codes compute time-varying chemistry as a function of radius in the disk but do not take into account the changing physical conditions. Codes which do couple chemistry and dynamics are frequently computationally expensive, preventing thorough exploration of parameter space. **We take a different approach by following local physical conditions in accretion streams of gas and small grains in the midplane,** which allows us to determine how disk parameters affect the underlying disk chemistry.

Methods



Disk Surface Density Evolution



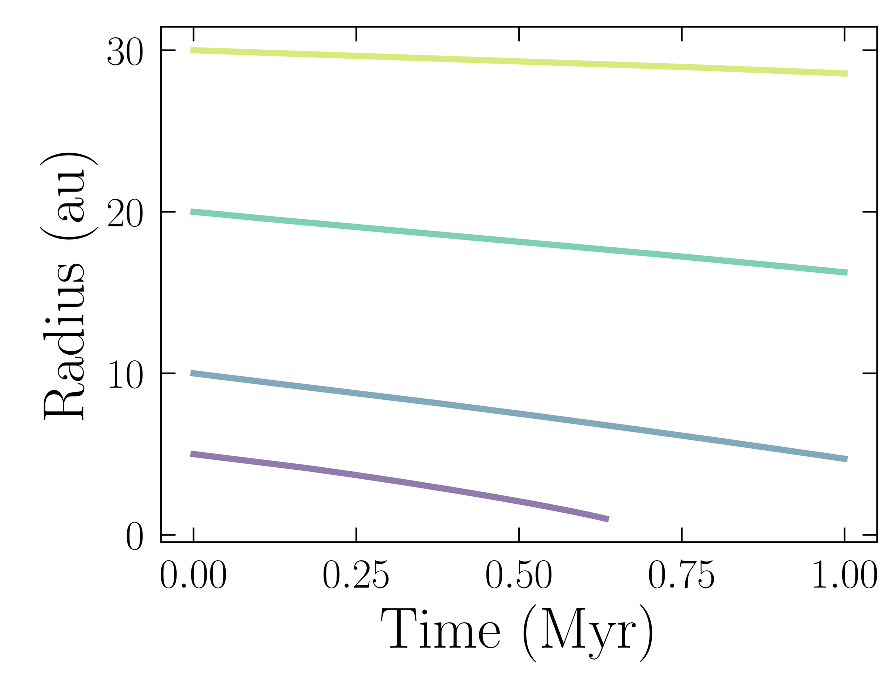
To compute the surface density at all times, we use an initial condition roughly consistent with the self-similar solution of Lynden-Bell & Pringle (1974) multiplied by a dimensionless factor $f(R)$ to impose the boundary condition $\Sigma(R = R_{\rm in}) = 0$,

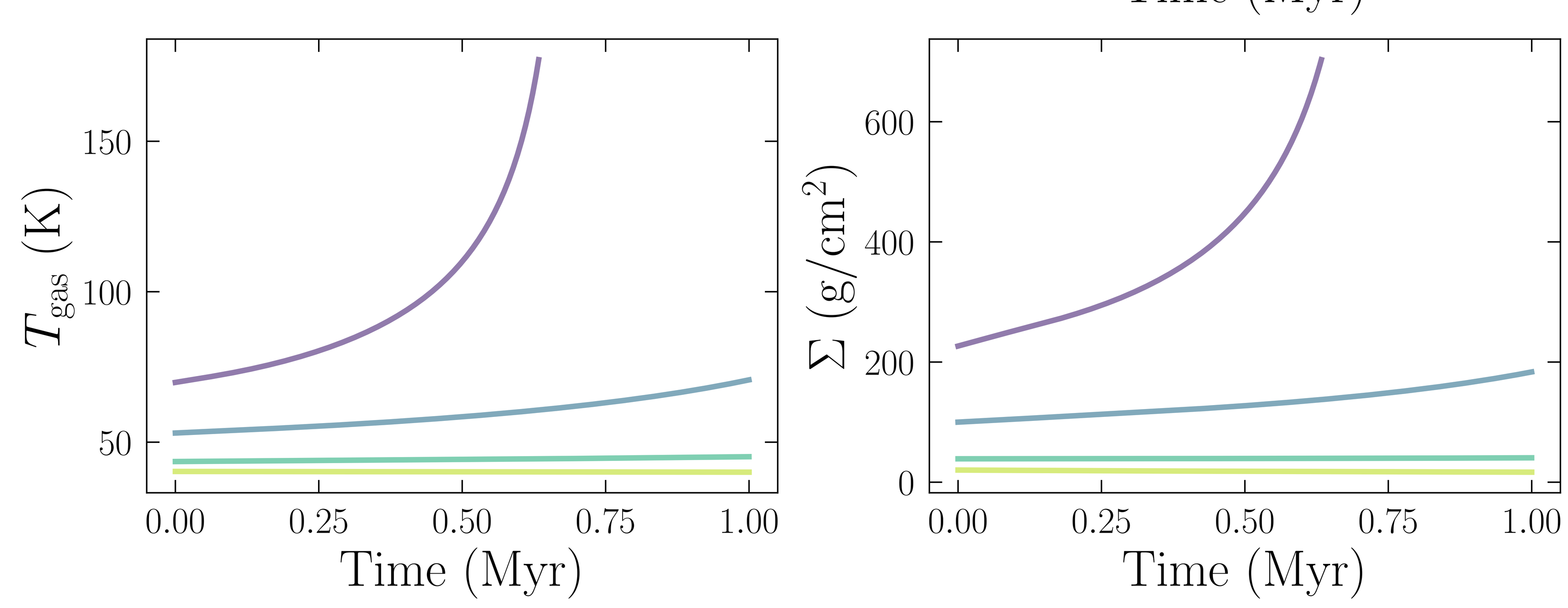
$$\Sigma(t=0) = \Sigma_0\, f(R) \left(\frac{R}{R_c}\right)^{-\gamma} \exp\left[-\left(\frac{R}{R_c}\right)^{2-\gamma}\right]$$

. where $\gamma = 1$ is motivated by observational fitting. Using a finite differences solver and Crank-Nicolson integrator, we recover the surface density profiles shown above.

Accreting Gas Parcel Trajectories

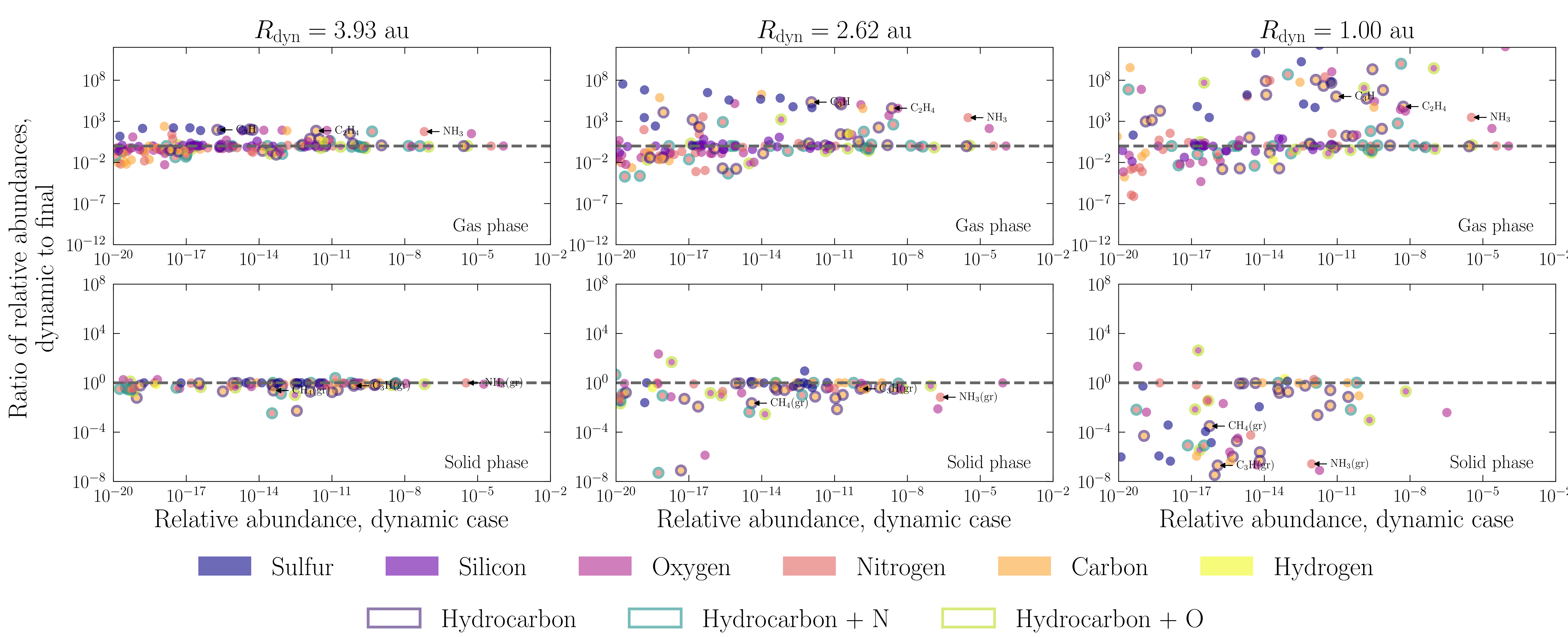
For tracks with various initial radii, indicated by each color, we show the evolution of the local physical parameters (gas temperature and surface density) as the parcel of gas follows the bulk motion of the gas and the star evolves.





Dynamic vs. Static Abundances for the Inner Disk

Below, we compare the chemical abundances of an accreting disk chemical model for a trajectory that begins at 5 au (with evolution) to a static chemical model with physical conditions fixed to the final point of the dynamic track. Species are colored by their heaviest atom, and interesting chemical families have been outlined as indicated in the key. The most "significant" species are those that are highly abundant (to the right of each panel) and either greatly enhanced or depleted (far from the dashed gray line).



Results

In the inner disk, the accretion history of the gas parcel enhances the abundances of many species by orders of magnitude; of particular interest are the hydrocarbons and sulfur-bearing species in the gas phase. **However, our main conclusion is that predicting whether a species will be enhanced or depleted by including accretion is not possible without running the full chemical model.**

Acknowledgements

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