C/N/O Ratios & Ice Lines

in protoplanetary disks

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

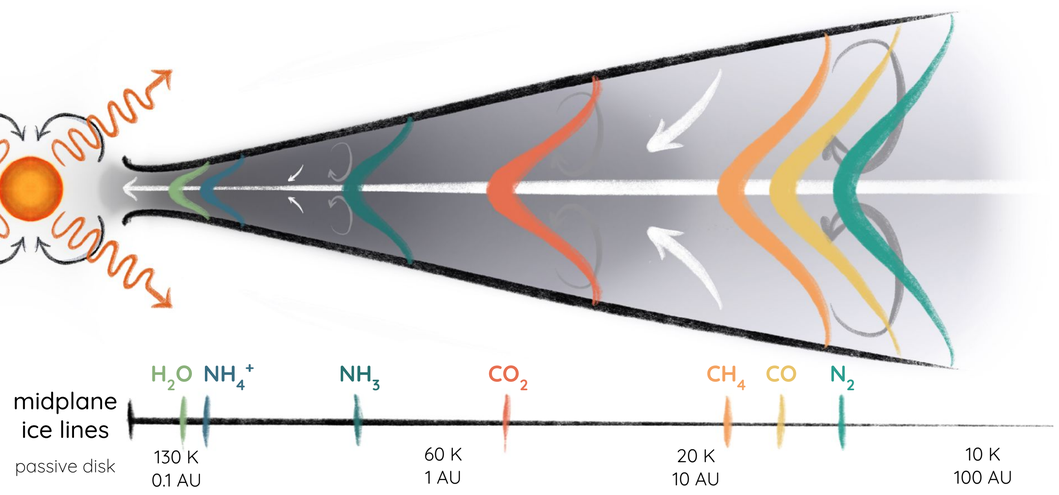
Elizabeth Yunerman[1], Ellen Price[2], Karin Öberg[1]
1. Center for Astrophysics | Harvard & Smithsonian
2. University of Chicago

Protoplanetary disk ice lines influence a multitude of planet formation mechanisms, and shape the elemental abundance ratios that set the compositions of planetary cores and atmospheres.

We aim to understand the impact of this feedback (between dynamical processes and chemistry) on the abundance, distribution, and evolution, of major volatiles (H_2O NH_4^+ NH_3 CO_2 CH_4 CO N_2) in disks.

We use numerical efforts and expand on the model put forth in Price et. al (2021) to calculate spatially and temporally evolving gas and solid surface densities.

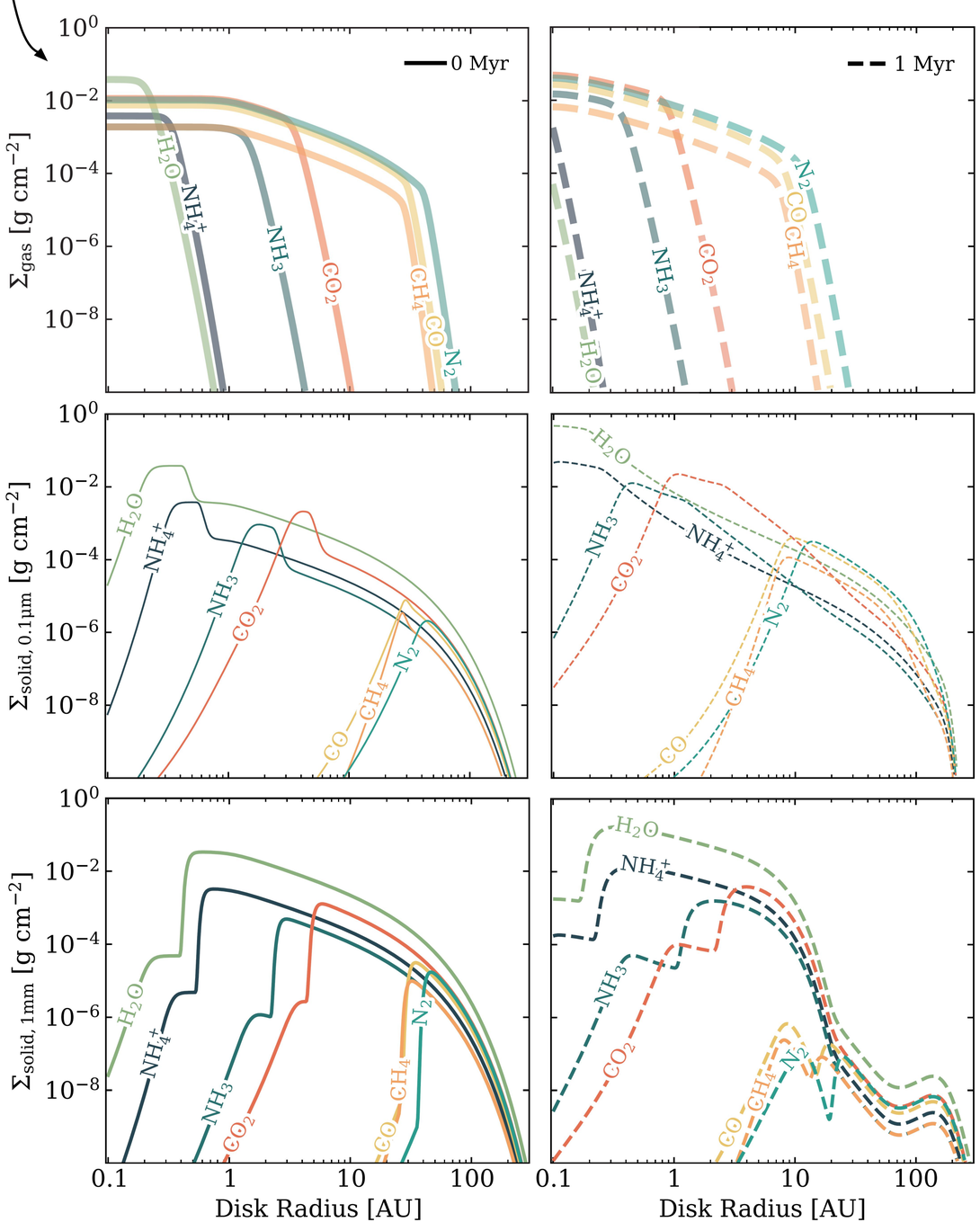
How do disk **physical + chemical** processes interact to shape **ice lines** and **elemental ratios**?



1. Surface Density, $\Sigma(r,t)$ (model output)

Calculated surface densities over 1 Myr for gas, small solids (micron-sized), and larger solids (mm-sized) in a cold passive disk.

Small particles stay well coupled to the gas while larger particles begin to decouple and rapidly drift inward. Larger icy particles will also interact with their respective ice line and will desorb or potentially re-adsorb if advected back outwards.



PHYSICAL

included in our model

inward solid particle drift

vertical settling onto midplane...

solid particle growth

fragmentation, erosion, bouncing barriers....

gas disk turbulence

fluid instabilities...
dust traps...

passive irradiative heating

active viscous accretion heating....

decreasing luminosity as protostar evolves...

initial abundances...

grain surface chemistry

material properties...

binding energy & attempt frequency

photochemistry

adsorption/desorption around ice lines

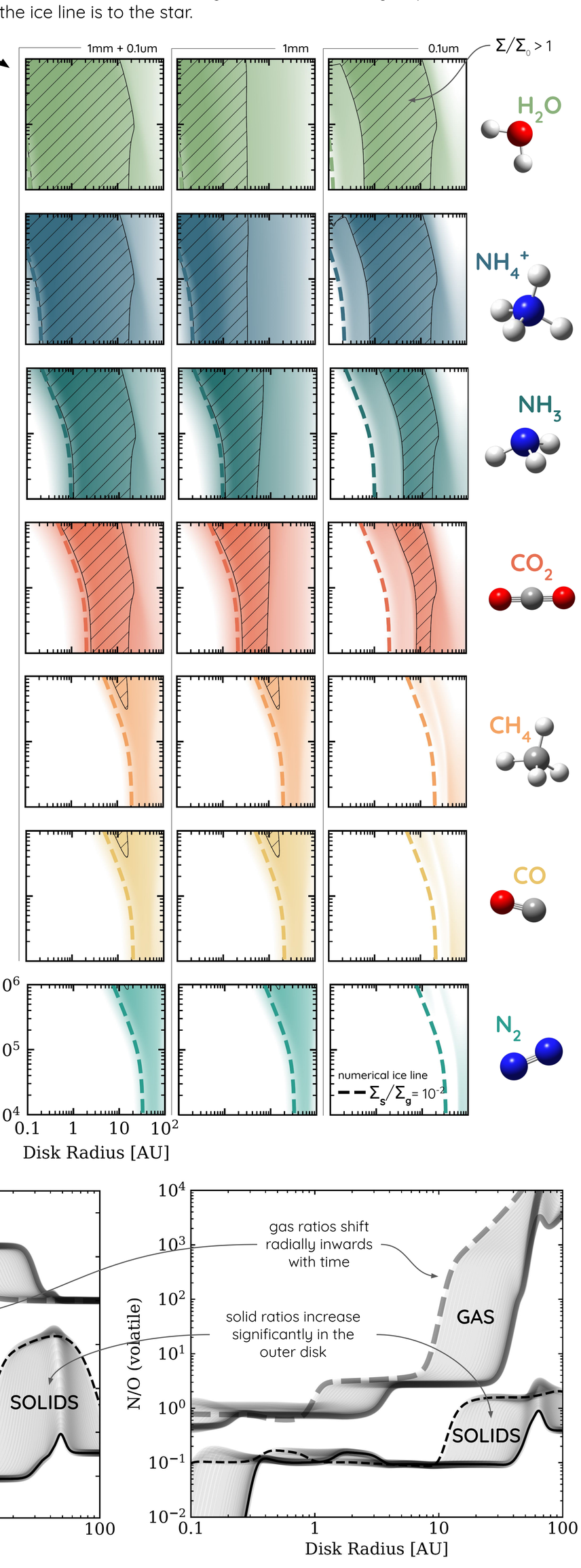
bond formation/destruction

CHEMICAL

2. Relative Solid (ice) Enhancement, Σ/Σ_0

Grid of micron and millimeter-sized solid surface densities relative to initial abundances for each volatile throughout the disk and with time.

Regions just beyond an ice line become more enhanced with time, and enhancement is stronger and more radially dispersed the closer the ice line is to the star.



3. Elemental Abundance Ratios for C/O & N/O

The gas ratios (& surface densities) decrease with time, linearly shifting inwards, as the the star's luminosity decreases.

Interplay between inward drift of solids and adsorption/desorption causes an increase in solid elemental ratios in the outer disk.

We find consistent icy enhancements near all ice lines. Which results in high solid C/O & N/O ratios developing after 1 Myr in the outer disk.

How could this result change (next steps) ?

- inner disk solid particle evolution
- different disk temperature profiles
- distribution of particle sizes
- particle size evolution
- chemical reactions

eyunerman@cfa.harvard.edu