Chemistry of Gravitationally Unstable Disks: Using KROME as a post-process

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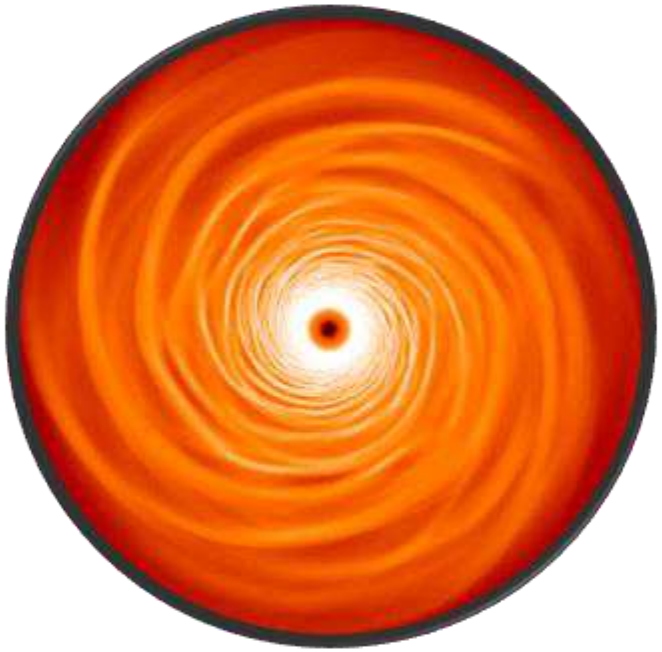
Background – Gravitational Unstable Disks

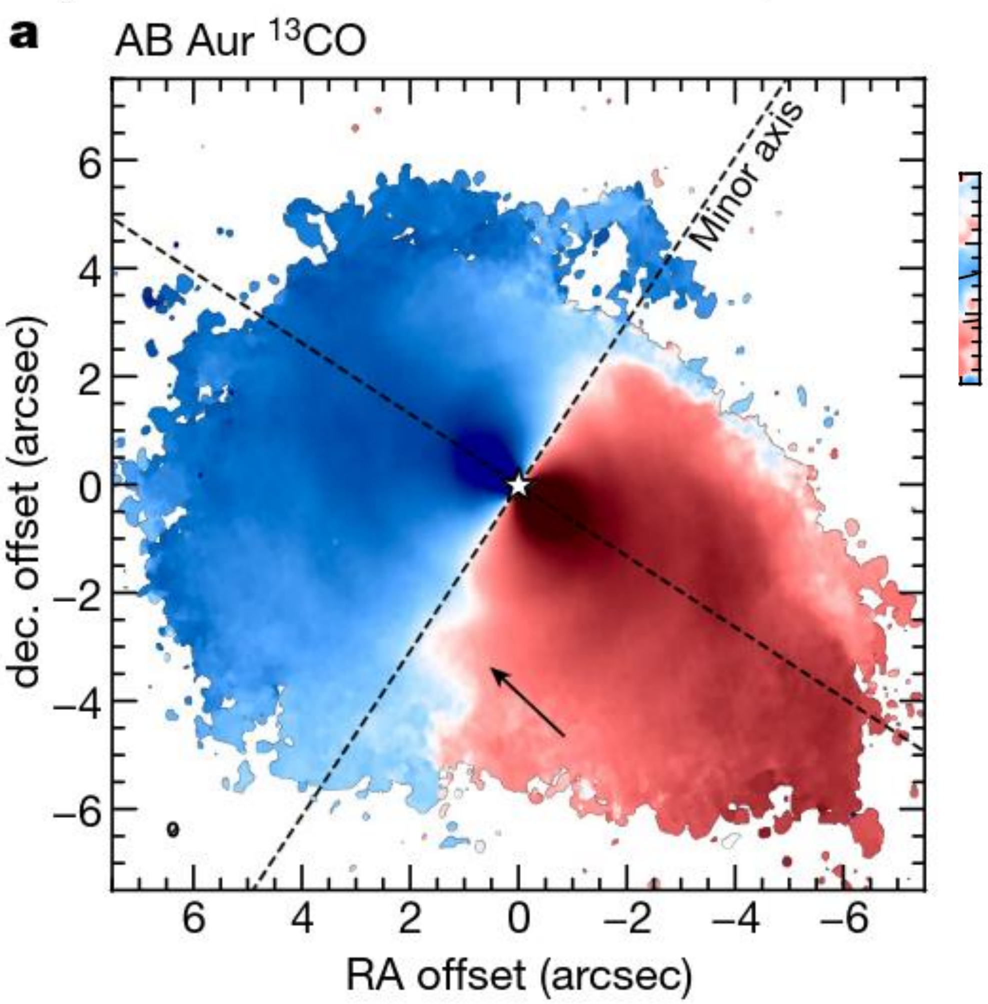


https://andthentheresphysics.wordpress.com/wp-content/uploads/2017/08/steadydisc_splash.png

$Q \lesssim Q_{Crit}$

$$Q = \frac{C_s\,\Omega_K}{G\,\pi\,\Sigma}$$

Toomre (1964)



Speedie + (2024)

Why do we need this theory?

- Explains rapid formation of giant planets (> 5 M_J) at distances ≥ 50 AU
- It may also be possible to rapidly form giant planets via core accretion (CA) in super-solar metallicity disks (Nguyen & Adibekyan (2024))

Rice + (2015); Terry + (2021)

Composition of Exoplanet Atmospheres

- Static model of exoplanetary composition – Comparing exoplanet atmospheric composition to host stars. Host stars composition acts as a proxy for the composition to host stars (Öberg + (2011))
- Used to infer that some hot Jupiters formed beyond water ice line (Brewer + (2016))

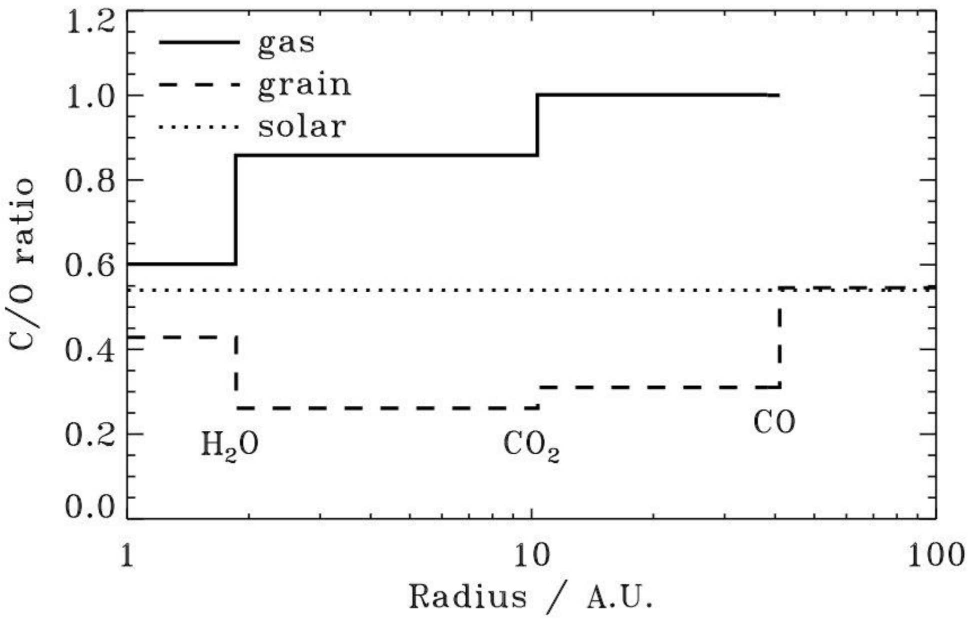
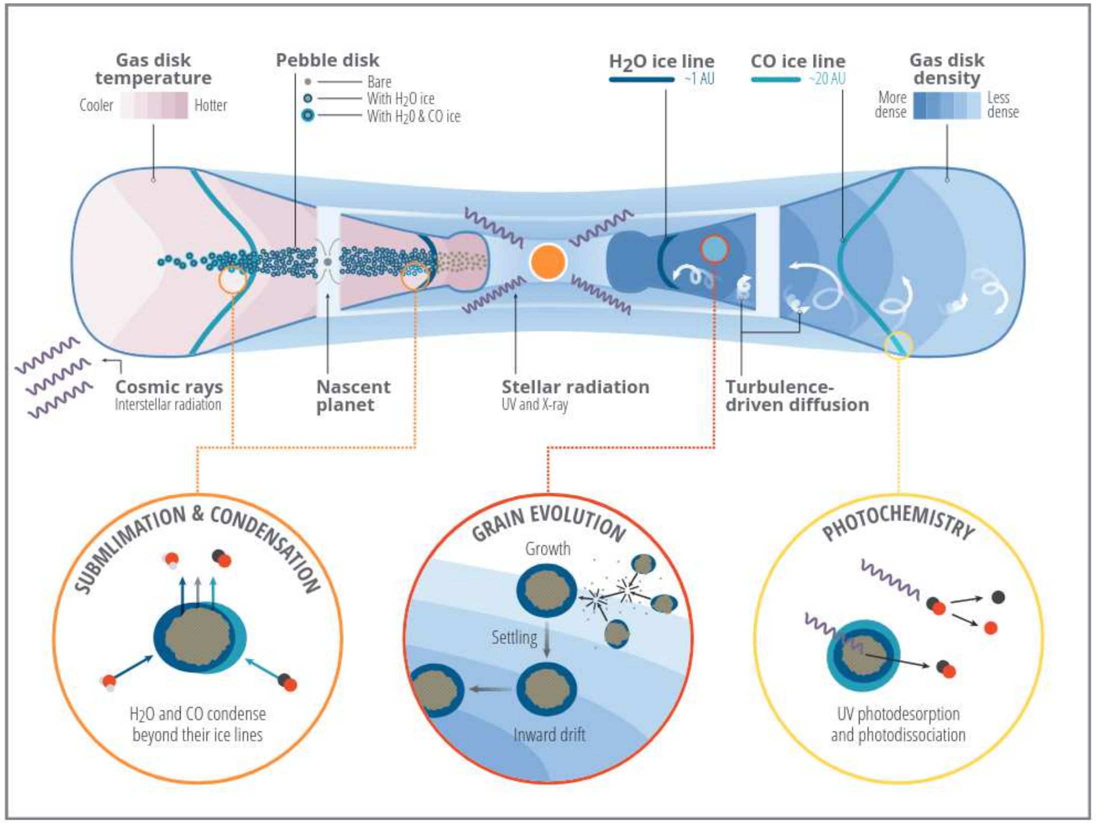


Fig. 1.— The C/O ratio in the gas and in grains, assuming the temperature structure of a 'typical' protoplanetary disk around a solar-type star (T_0 is 200 K, and $q = 0.62$). The H_2O, CO_2 and CO snow-lines are marked for reference.

Öberg + (2011)



Öberg & Bergin (2020)

GI differences

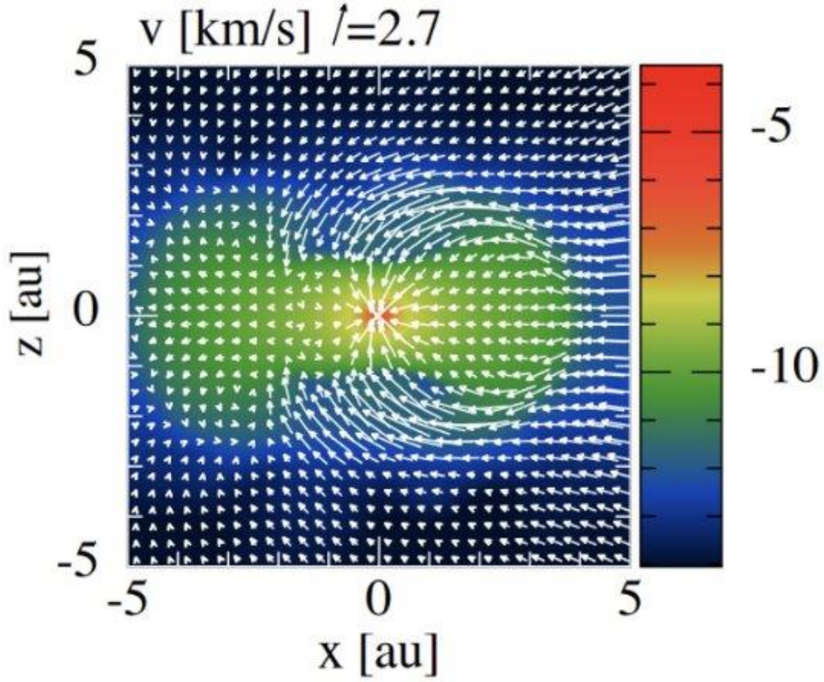
Hot/cold-start models (Spiegel & Burrows (2012))

GI giant exoplanets hotter and larger radii

GI planets appear to form as oblate spheroids (Fenton & Stamatellos (2024))

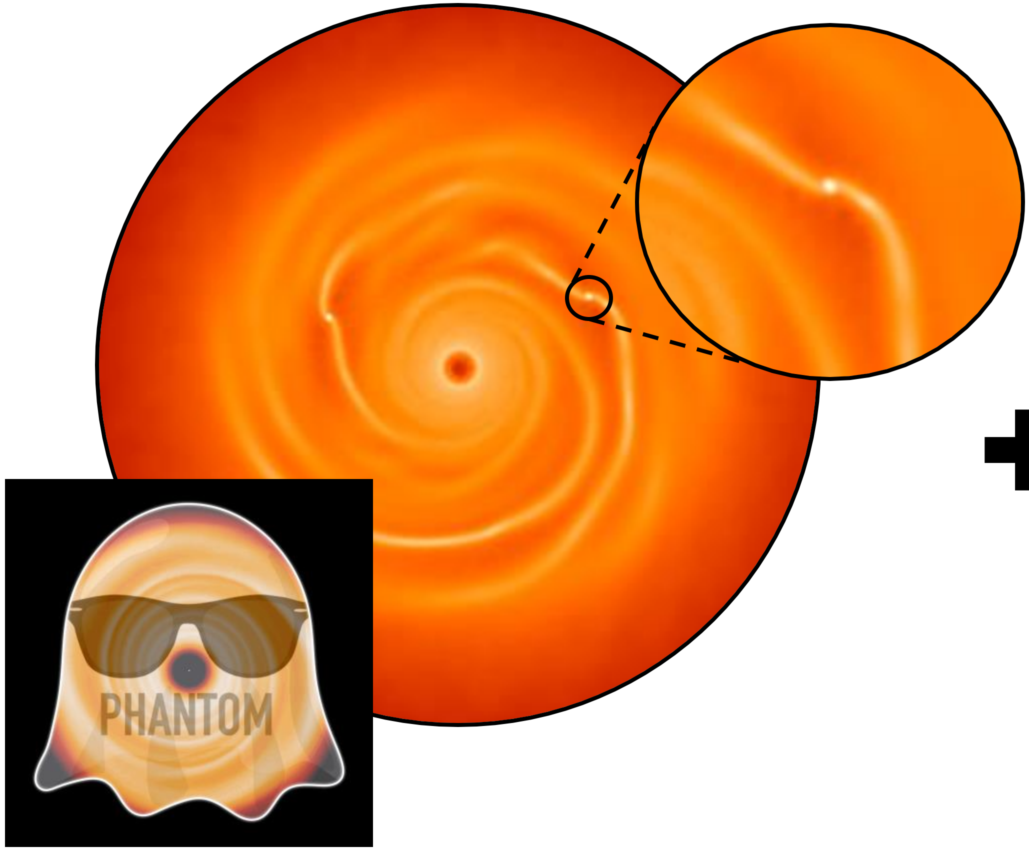
Inflow onto the poles of the forming planet will be of higher velocity (hotter)

More on this in the next talk.



Fenton & Stamatellos (2024)

Overview



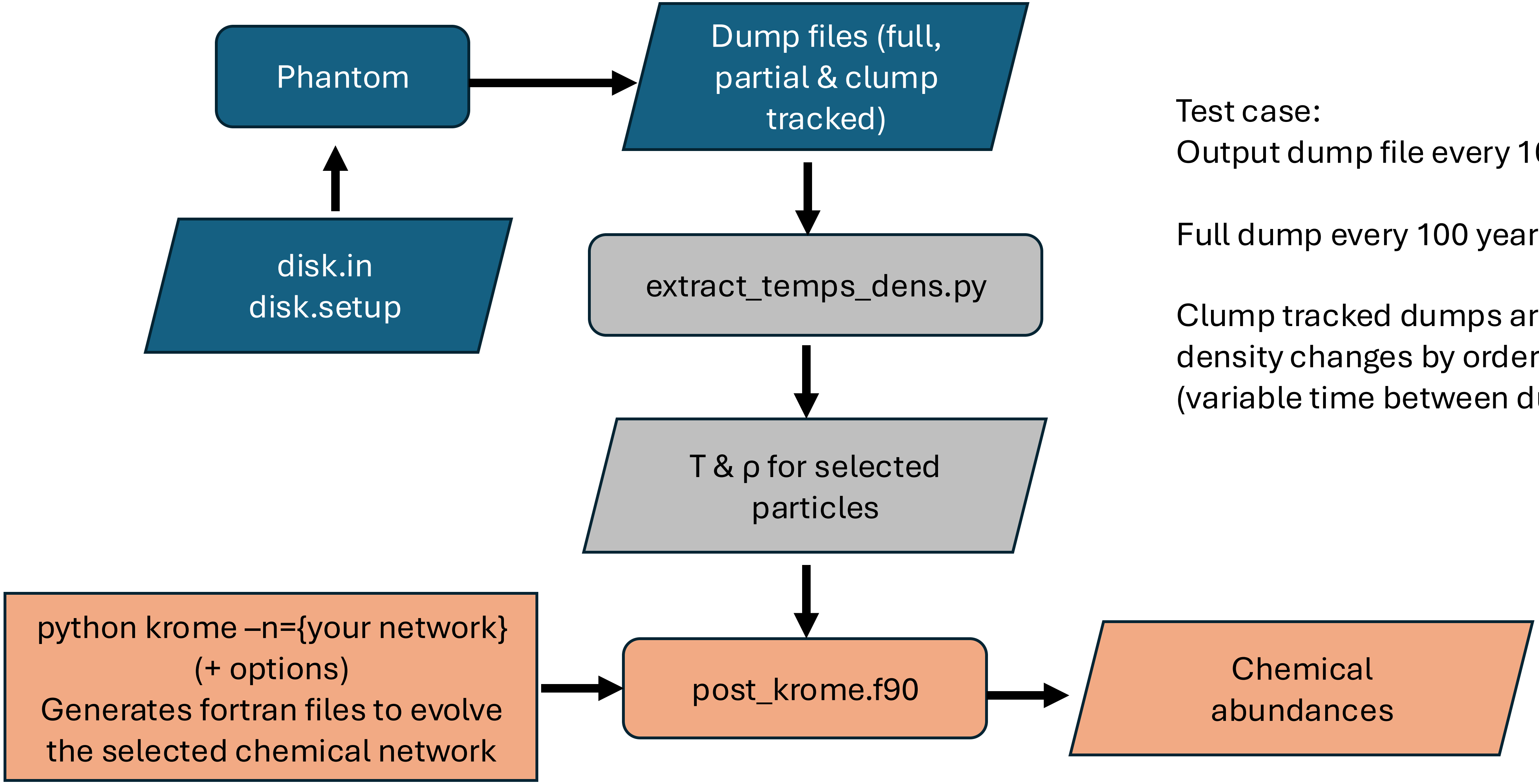
+

KROME

better science through chemistry

Price + (2018); Grassi + (2014)

Overview



Test case:
Output dump file every 10 years

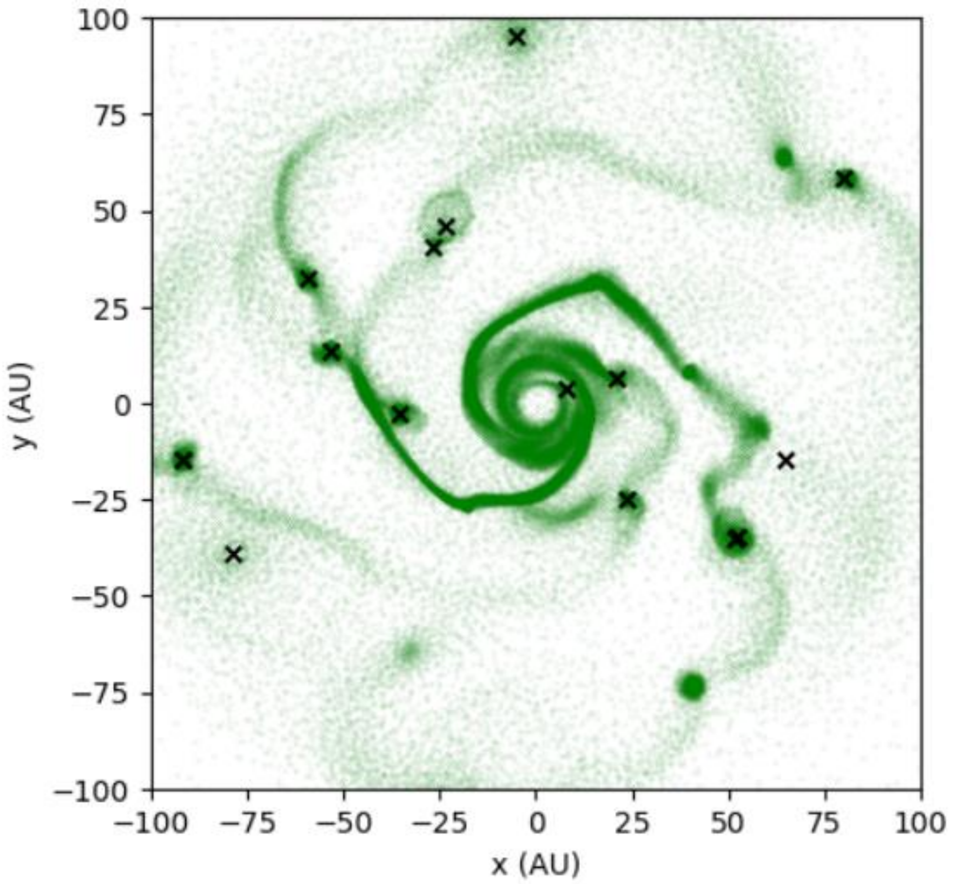
Full dump every 100 years

Clump tracked dumps are done when density changes by order of magnitude (variable time between dumps)

Test Case

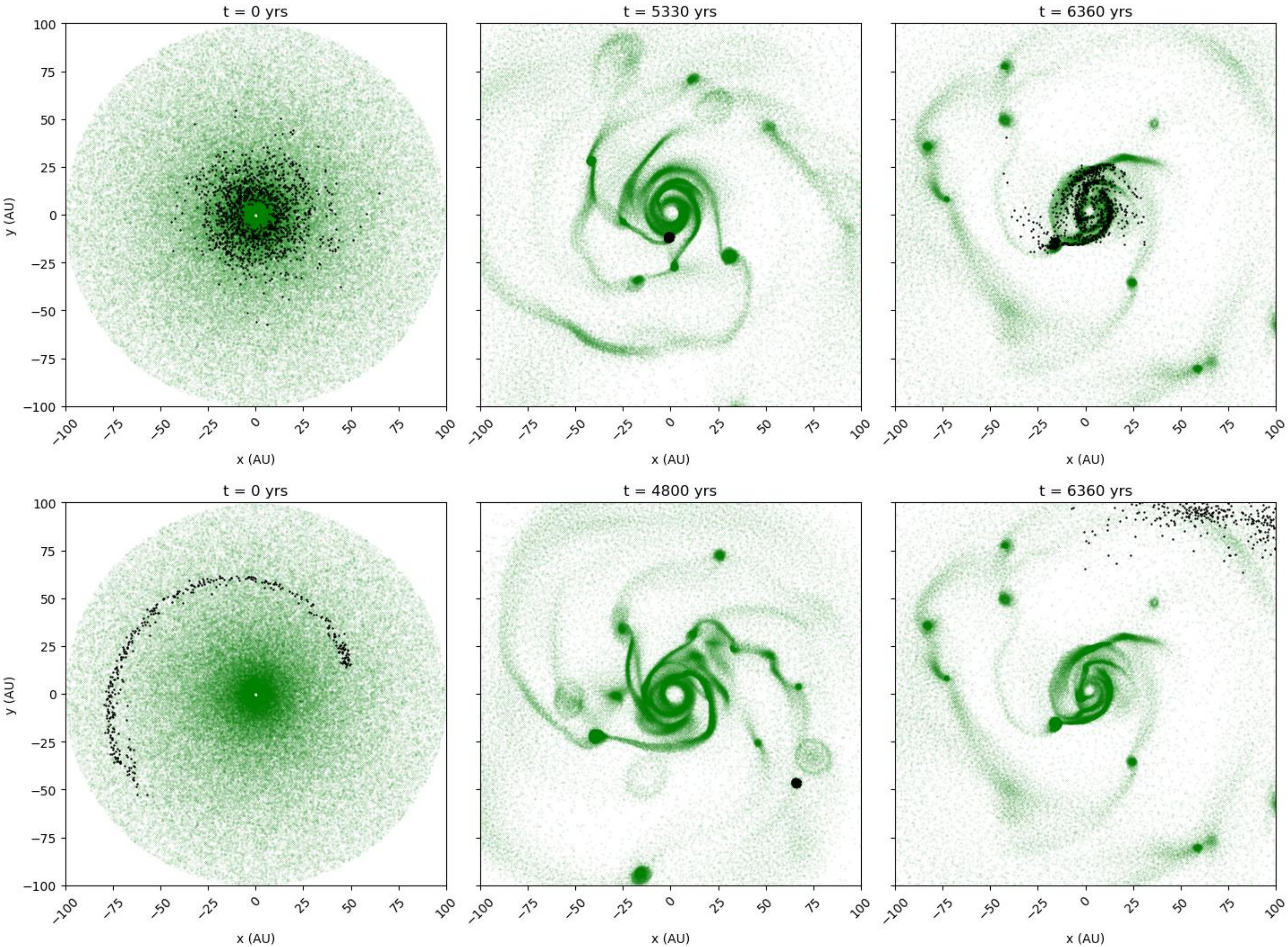
- 100,000 SPH particles, 100 AU disk.
- Using modified Lombardi method to model the cooling of the disk (Young + (2024))
- Using lumdisc=1, setting sound speed at R_{ref} using the luminosity of the star, which in turn sets H/R at R_{ref}
- Sinks created at 1×10^{-3} g cm^{-3}
- 0.7 $M_\odot$ Star, 0.4 $M_\odot$ disk, M_d/M_s = 0.57 (very unstable disk), L_{star} = 1.91 $L_\odot$ (Haworth + (2020))

x = sink particle



Sink 18

Sink 13



Reading the phantom binaries directly using Sarracen (Harris & Tricco 2023)

Temperatures are directly from the phantom dumps

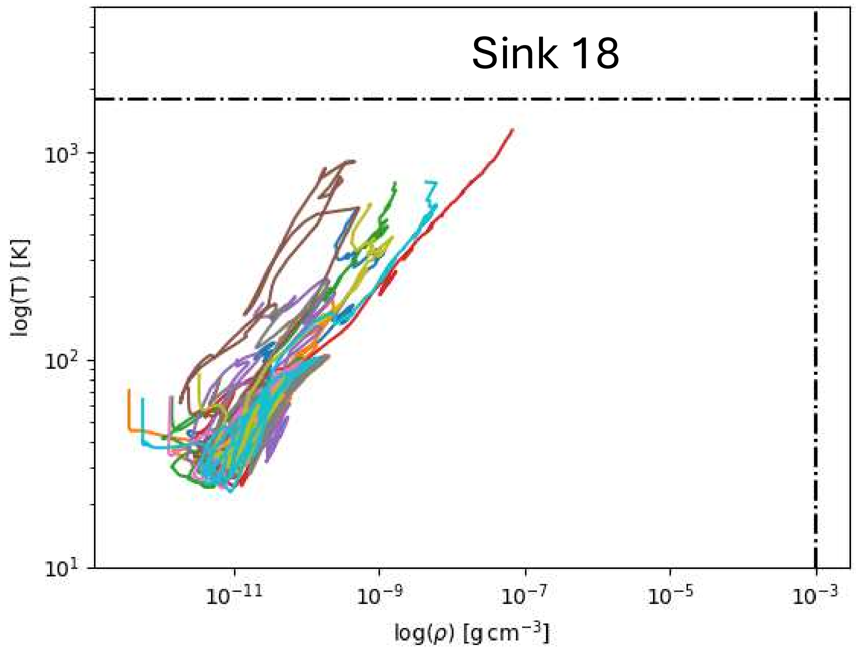
Density is calculated using Sarracen

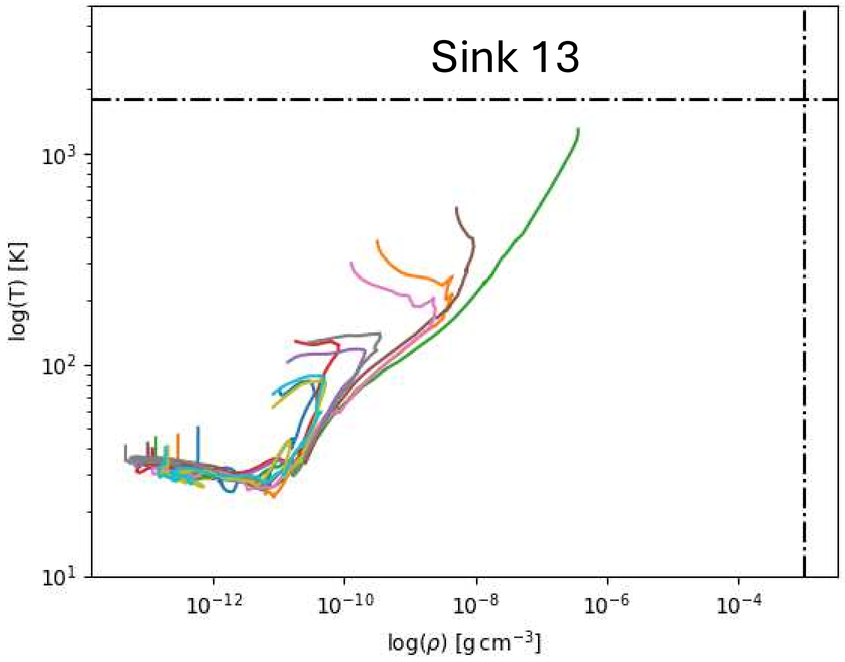
Stop tracking once sink is made

Variable time step based on the density of clumps, using clump_tracking

$$\rho = m \left(\frac{h_{\rm fact}}{h} \right)^{n_{\rm dim}}$$

https://sarracen.readthedocs.io/en/latest/api/
sarracen.SarracenDataFrame.calc_density.html
#sarracen.SarracenDataFrame.calc_density

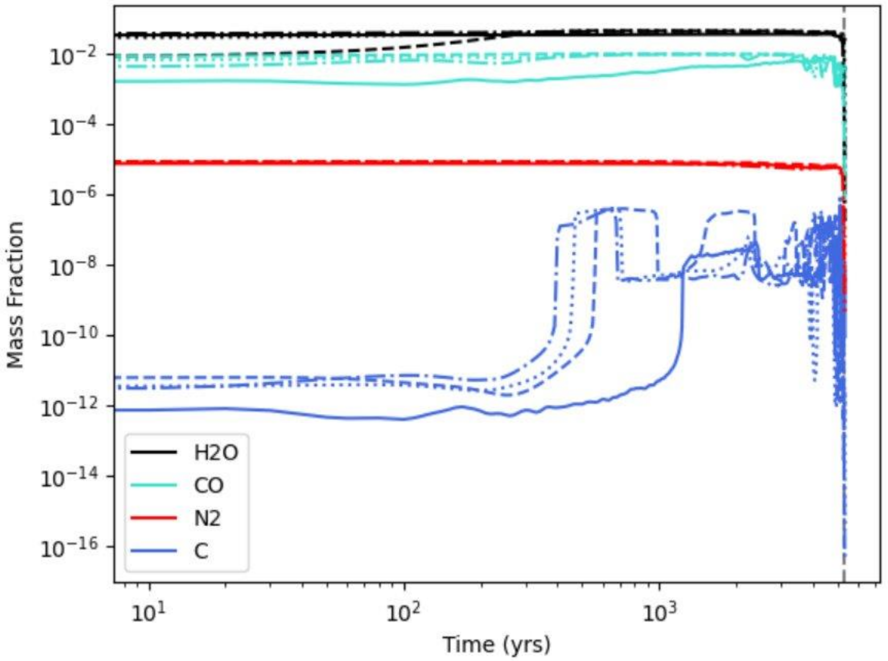


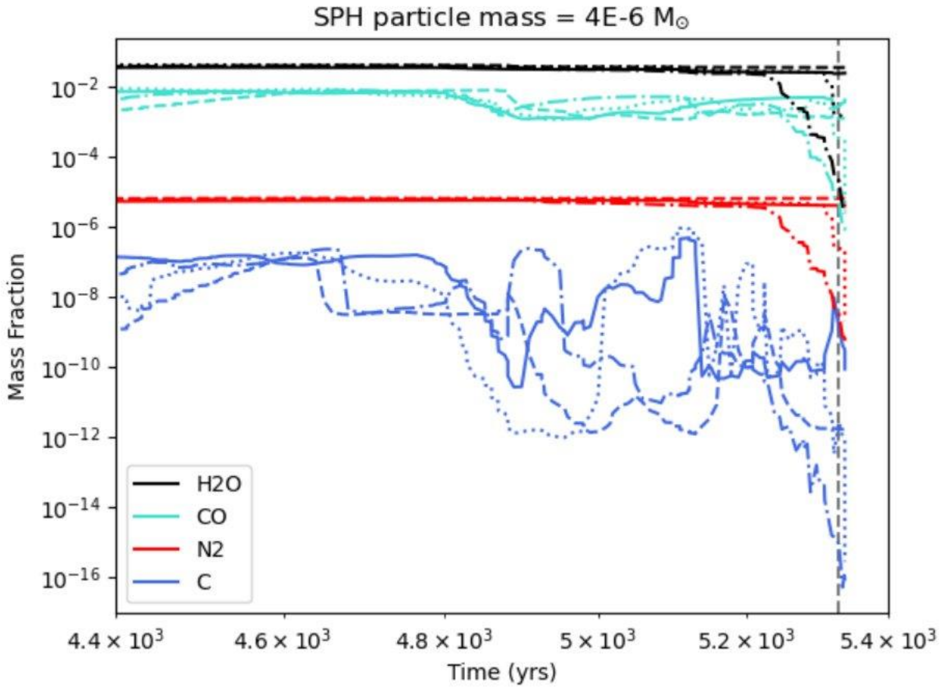


Sink 18

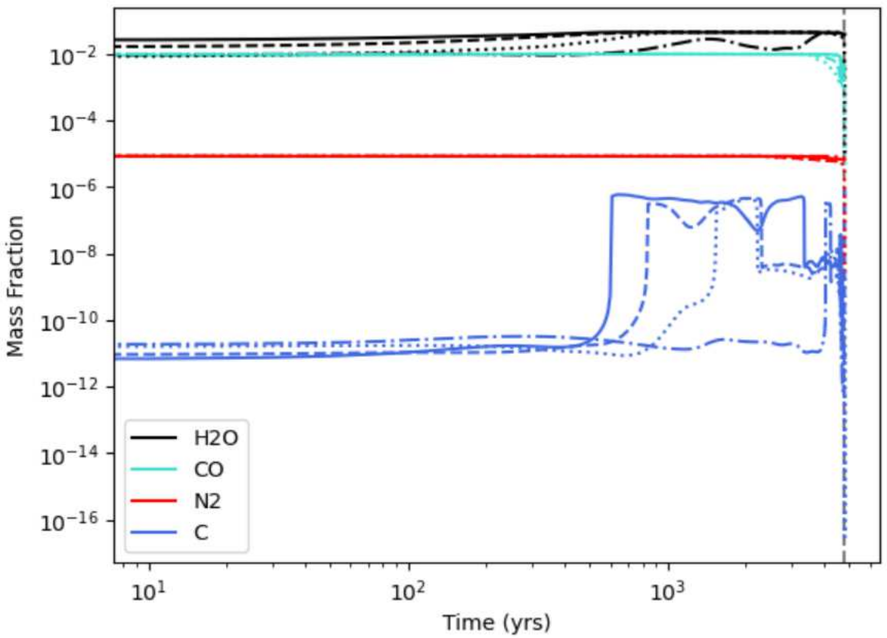
react_cloud network

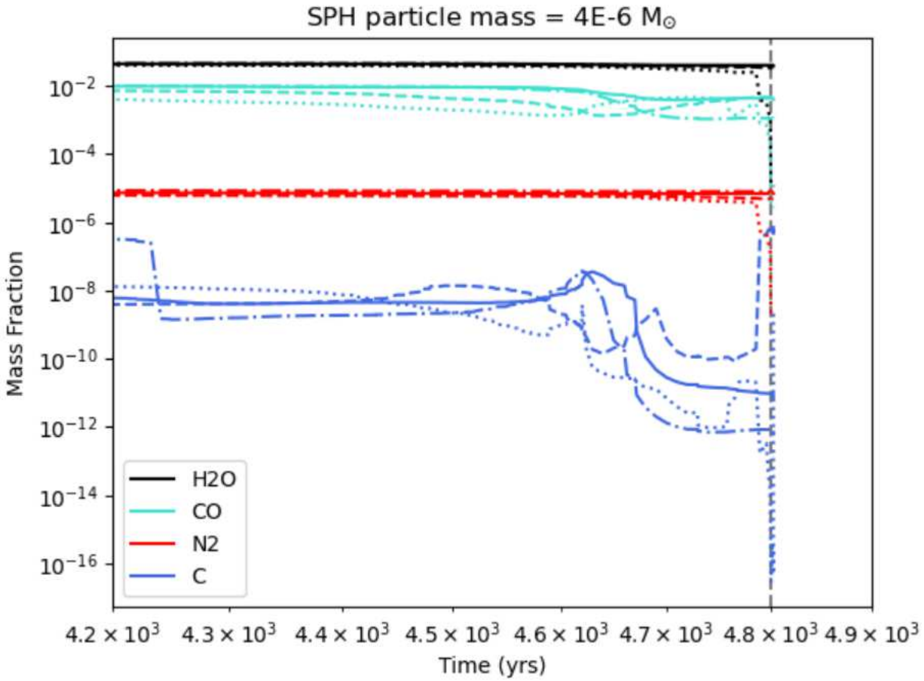
Initial abundances from Cridland + (2025)





Sink 13



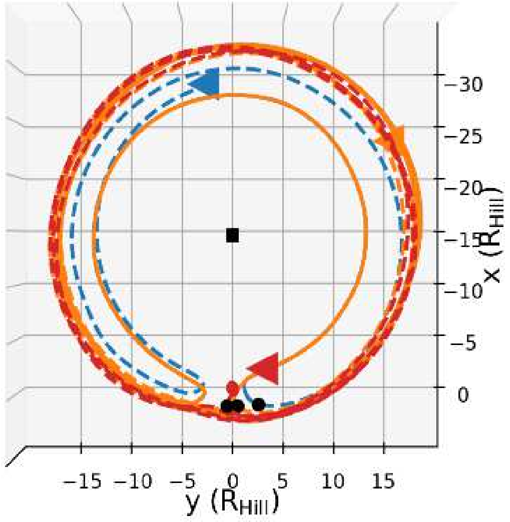


What's next?

The pipeline works, now to make it "right"

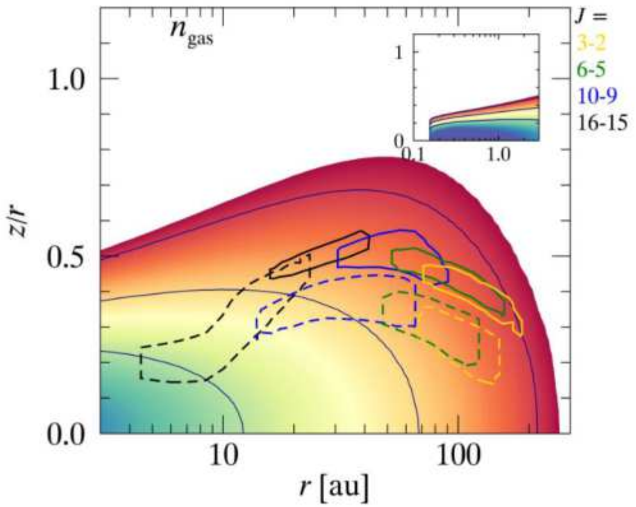
i.e. Realistic chemical network

Use APR to get better resolution around dense clumps of particles.



Cridland + (2025)

Compare to current work looking at the chemical processing around circumplanetary disks in CA formation.



Fedele + (2016)

Do the post_krome abundances agree with expected 2D structure of protoplanetary disks?

Thank you!