Impacting Atmospheres: Linking Solid Accretion During Formation to Exoplanet Composition

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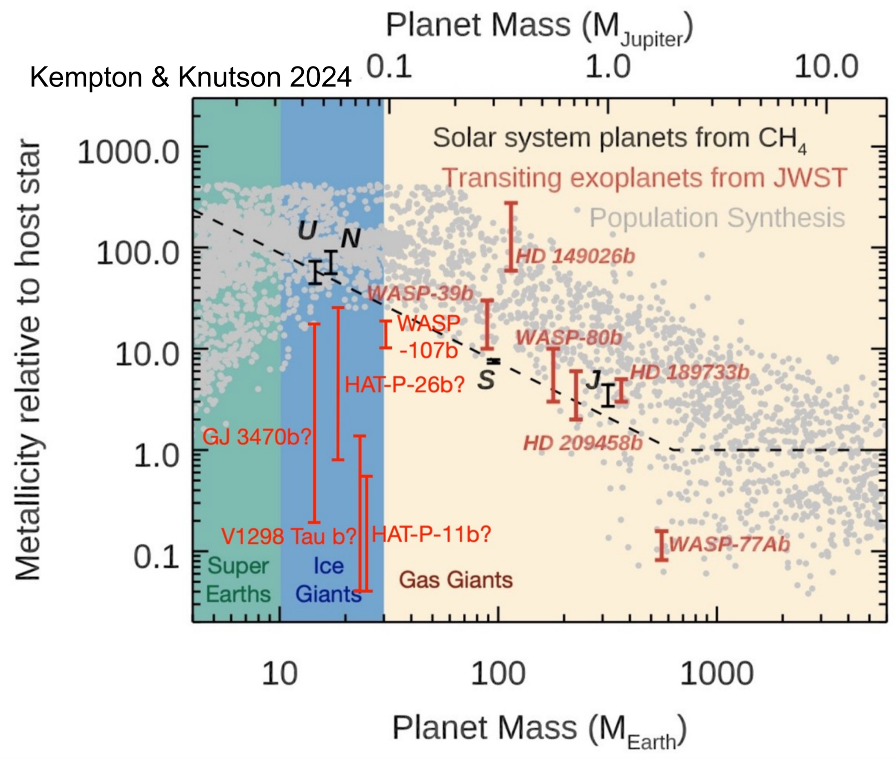
How Can the Scatter be Interpreted?

Atmospheric metallicities of lower mass exoplanets scatter around the population synthesis model.

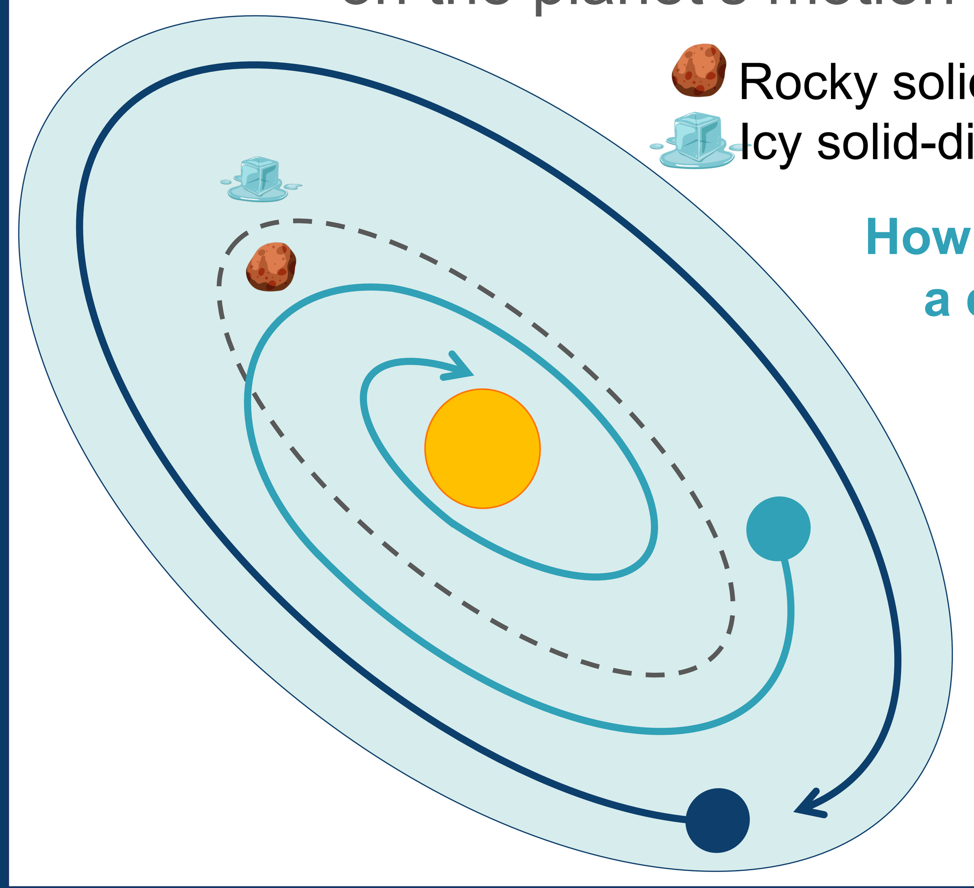
- Young planets within the circumstellar disk frequently accrete solid materials into their atmospheres.
- These materials evaporate, polluting the atmospheres with heavy elements.



How does post formation pollution give rise to the metallicity scatter?

Solid Accretion Within the Disk

The amount and type(s) of material accreted depends on the planet's motion through the disk.



How much mass will be accreted over a disk lifetime of 1 million years?

Solid Surface Density: determines the amount solid that can be accreted.

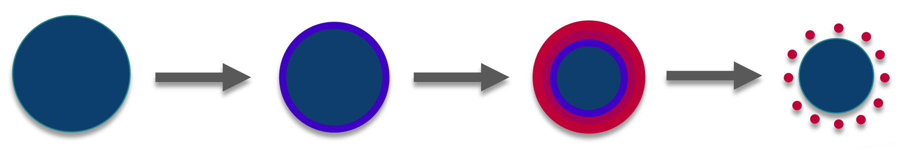
$$\Sigma_s = 6.2 \times 10^3 \left(\frac{a}{0.2\text{au}}\right)^{-1.6}$$

Planetesimal Accretion Rate: the mass flux through the area of the core's cross section.

$$\dot{M} = \Sigma_s \Omega_k R_{core}^2$$

Impactor Ablation

The amount of material deposited in the atmosphere depends on the **trajectory** and **vaporization** of solid impactors within in the envelope:



$$P_{fric} + P_{rad} + P_{vap} = 0$$

$$\frac{dm}{dt} = -4\pi r^2 P_v \sqrt{\frac{m_g}{2\pi k_b T_s}}$$

Thermal Evolution: The impactors surface temperature is set by balancing **friction**, **thermal radiation**, and **vaporization**.

Vaporization Rate: The mass loss rate is set Knudsen Langmuir equation and depends primarily on surface temperature.

Shock Treatment

At high velocities, the imapctor's motion becomes **supersonic:**

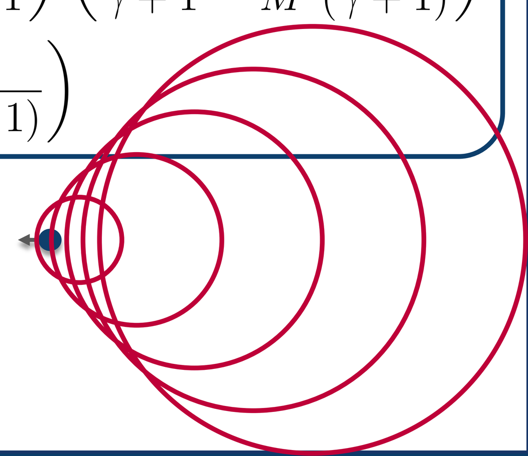
- The shock is **adiabatic**; the infall time is much smaller than the thermal diffusion timescale.
- Impactors undergo increased **radiative** (T_g) and **frictional** (ρ_g) heating.

$$T_g^{shocked} = T_g \cdot \left(\frac{2\gamma}{\gamma+1}M^2 - \frac{\gamma-1}{\gamma+1}\right)\left(\frac{\gamma-1}{\gamma+1} + \frac{2}{M^2(\gamma+1)}\right)$$

$$\rho_g^{shocked} = \rho_g \cdot \left(\frac{\gamma-1}{\gamma+1} + \frac{2}{M^2(\gamma+1)}\right)$$

→ $\gamma \sim 1.4$

→ $M \sim 1.5 - 2.5$



Envelope Enrichment

Evaporated materials remain in the atmospheric layer into which they are deposited.

Number of impactors **×** Mass deposited by one impactor **=** Atmospheric metallicity

Metallicity is limited by saturation…

$$f_{sat} = \frac{P_{vap}(T_g)}{P_g}$$

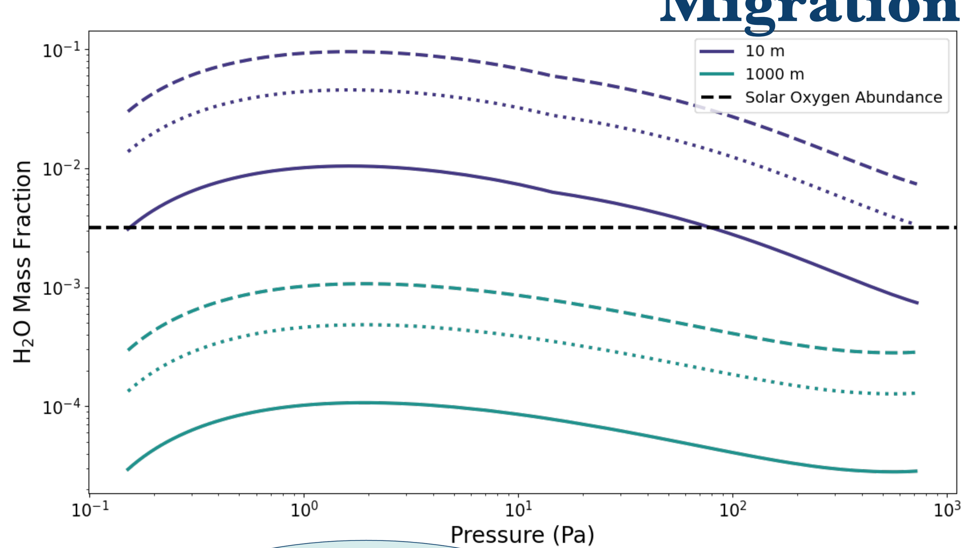
… beyond which metals are assumed to condense out and rain into the inner atmosphere.

Atmospheric Metallicities

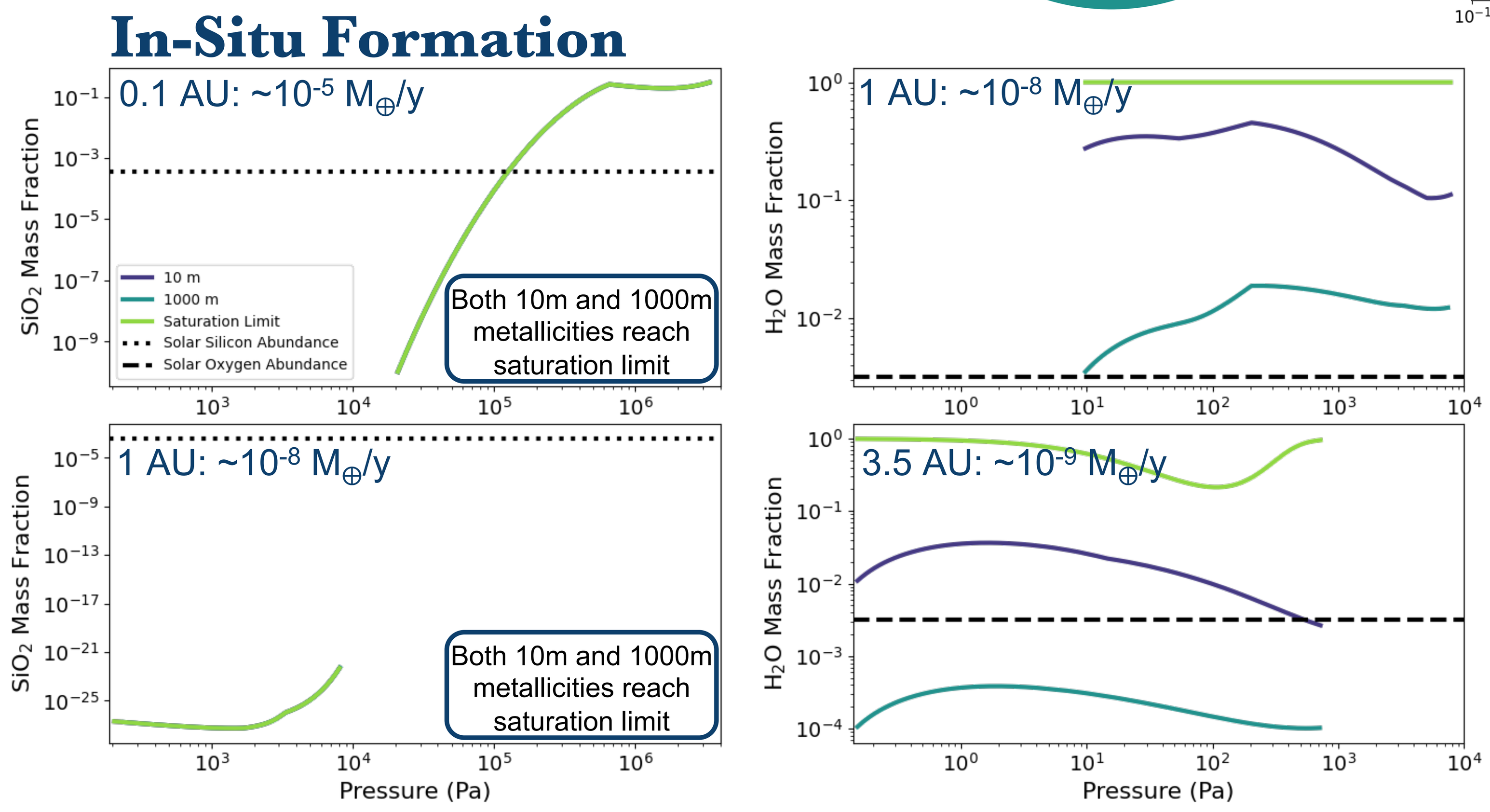
Profiles are evaluated for **5 $M_\oplus$** protoplanets with a **6% gas to core ratio**.

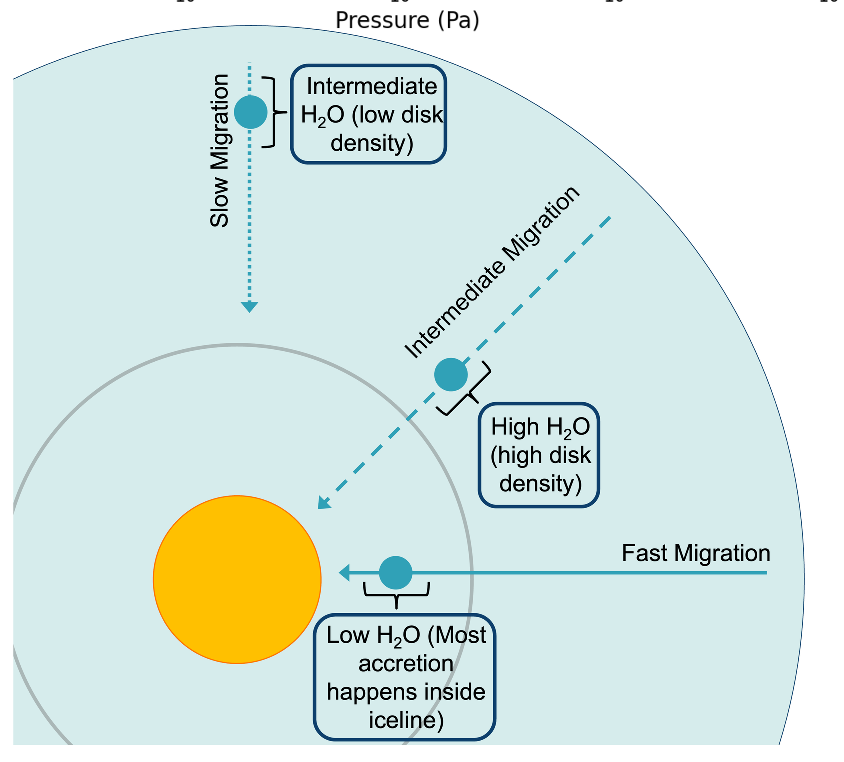
Small impactors are most efficient at enriching the atmosphere than **large impactors** because they evaporate away a higher fraction of their mass.

Migration



In-Situ Formation

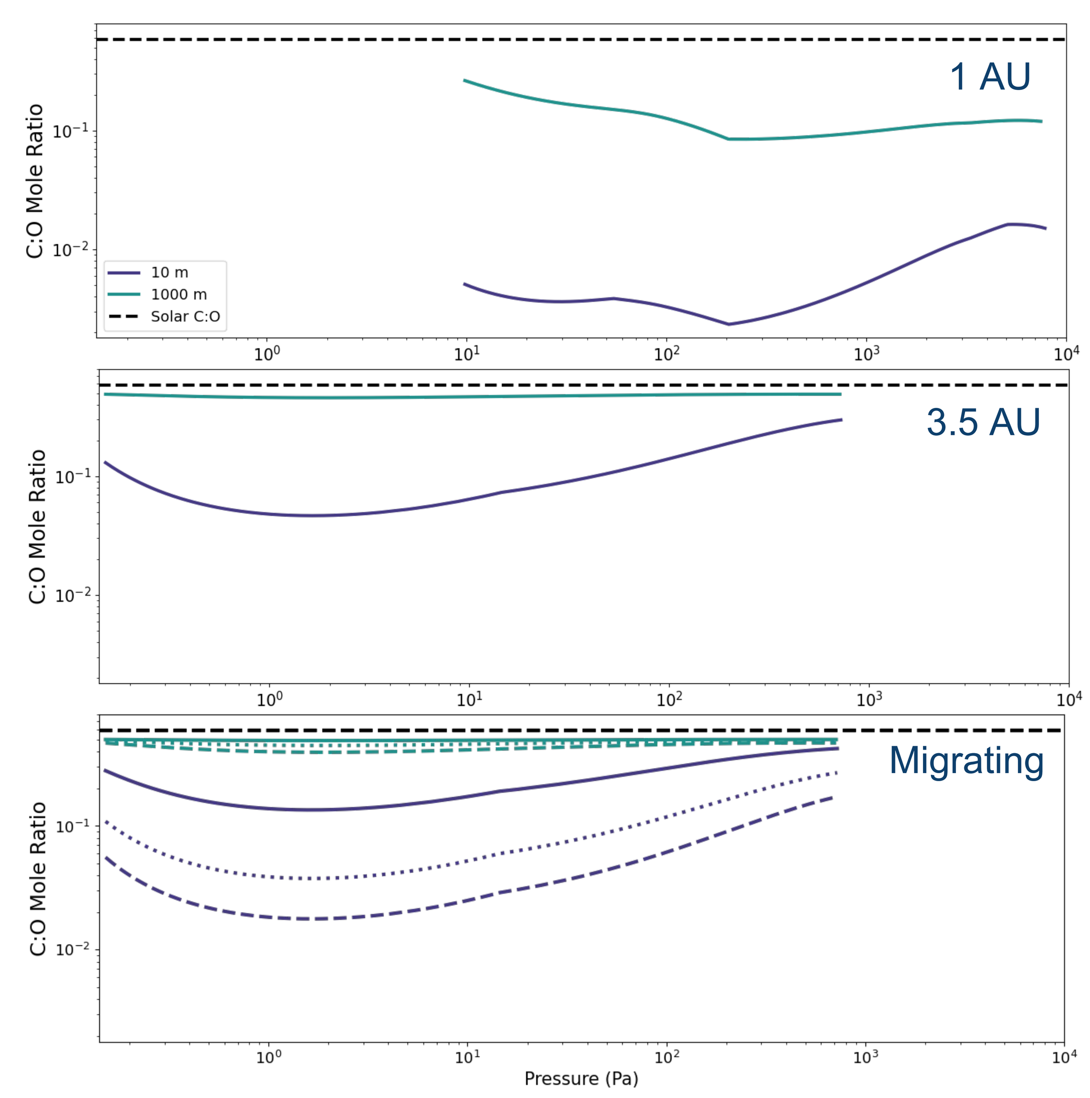




Planets migrate inwards from **3.5 AU**

C : O Ratios

Estimated from H_2O abundances assuming an initial atmosphere of solar metallicity:



The deposition of H_2O lowers the C:O ratio.

- **High H_2O abundance**: C:O << solar
- **Low H_2O abundance**: C:O → solar

The accretion of solids post-formation can yield a wide spread in atmospheric metallicities for planets of the same mass.